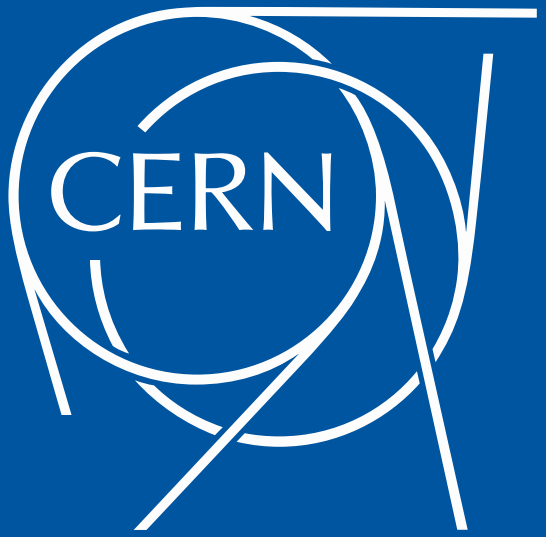

CERN

Engineering of Critical-Safety Systems at CERN

Testing of Safety Functions

ICALEPCS - 06-11 October 2013

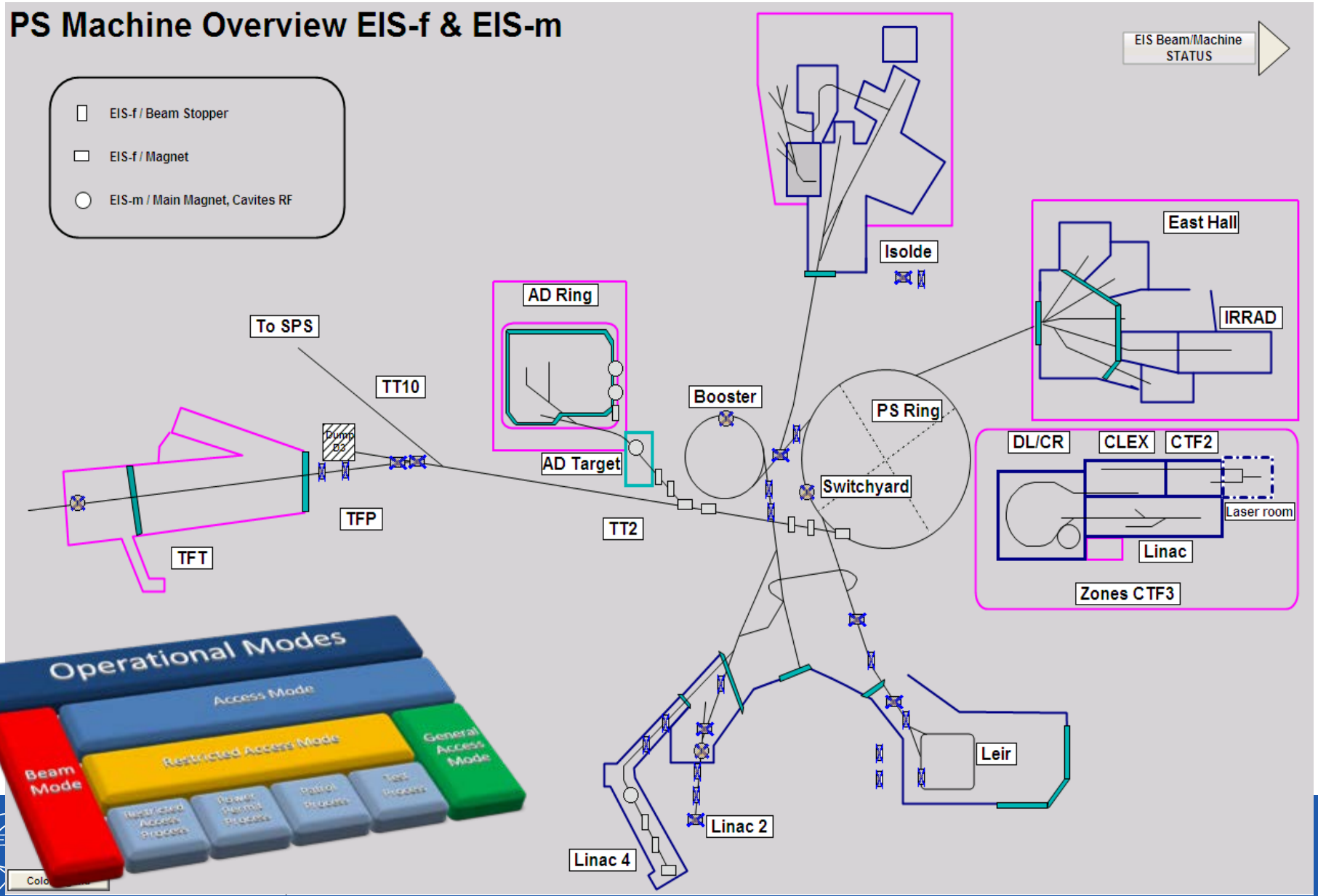
Authors: P. Ninin, F. Valentini

Outline

The return of experience of CERN in the development and validation of Safety Personnel Protection Systems showed us that the realization of a performing Test Platform is essential to ensure the quality of the Verification and Validation activities. However the adoption of a Formal Language for the specification of the Safety Functions in another essential Key.

- PS-PPS Project Scope
- Safety Test Bench Conception
- Safety Functions – Formal Definition Language
- Model-Based Testing Approach for Validation
- Conclusions

PS-PPS Project Scope



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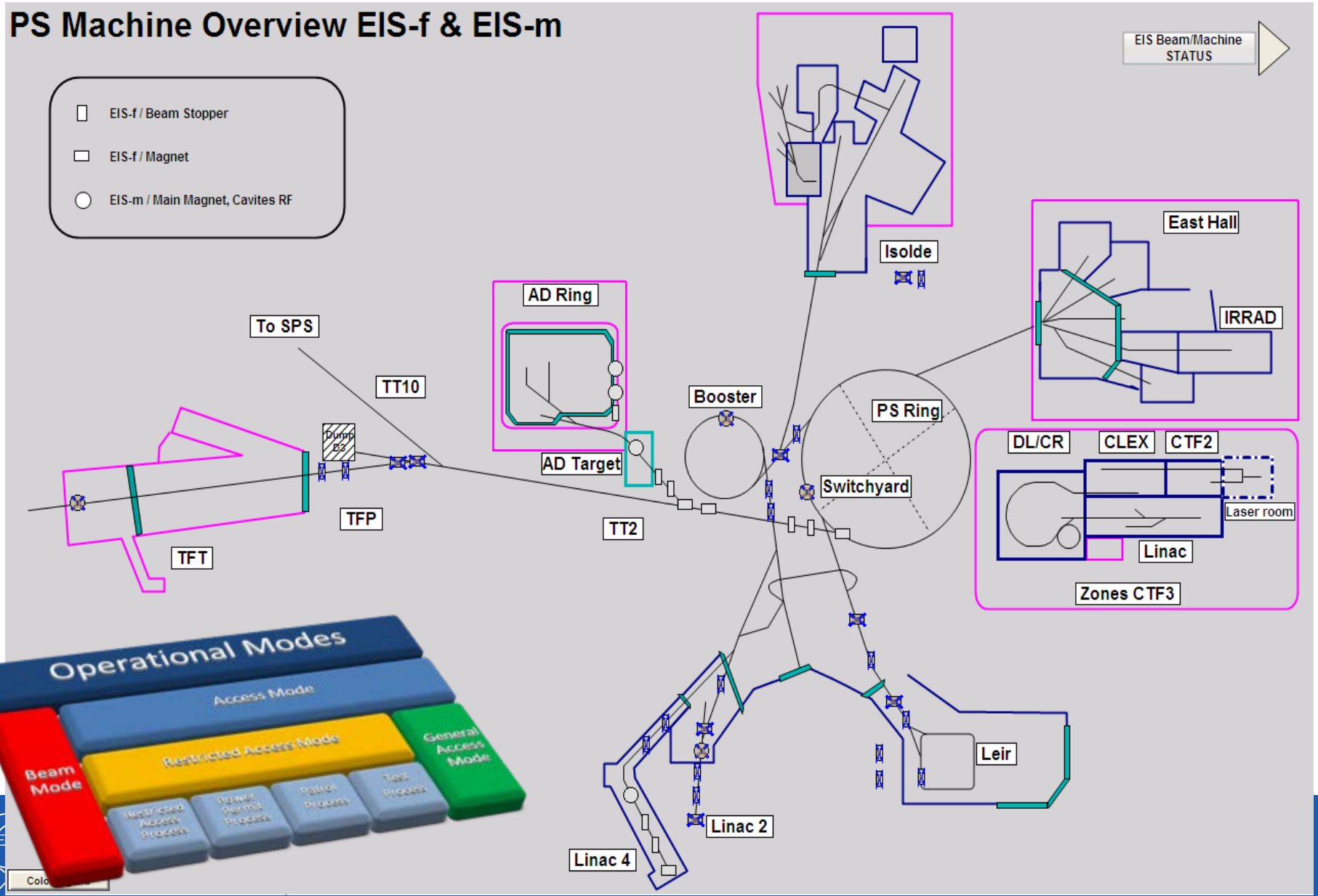

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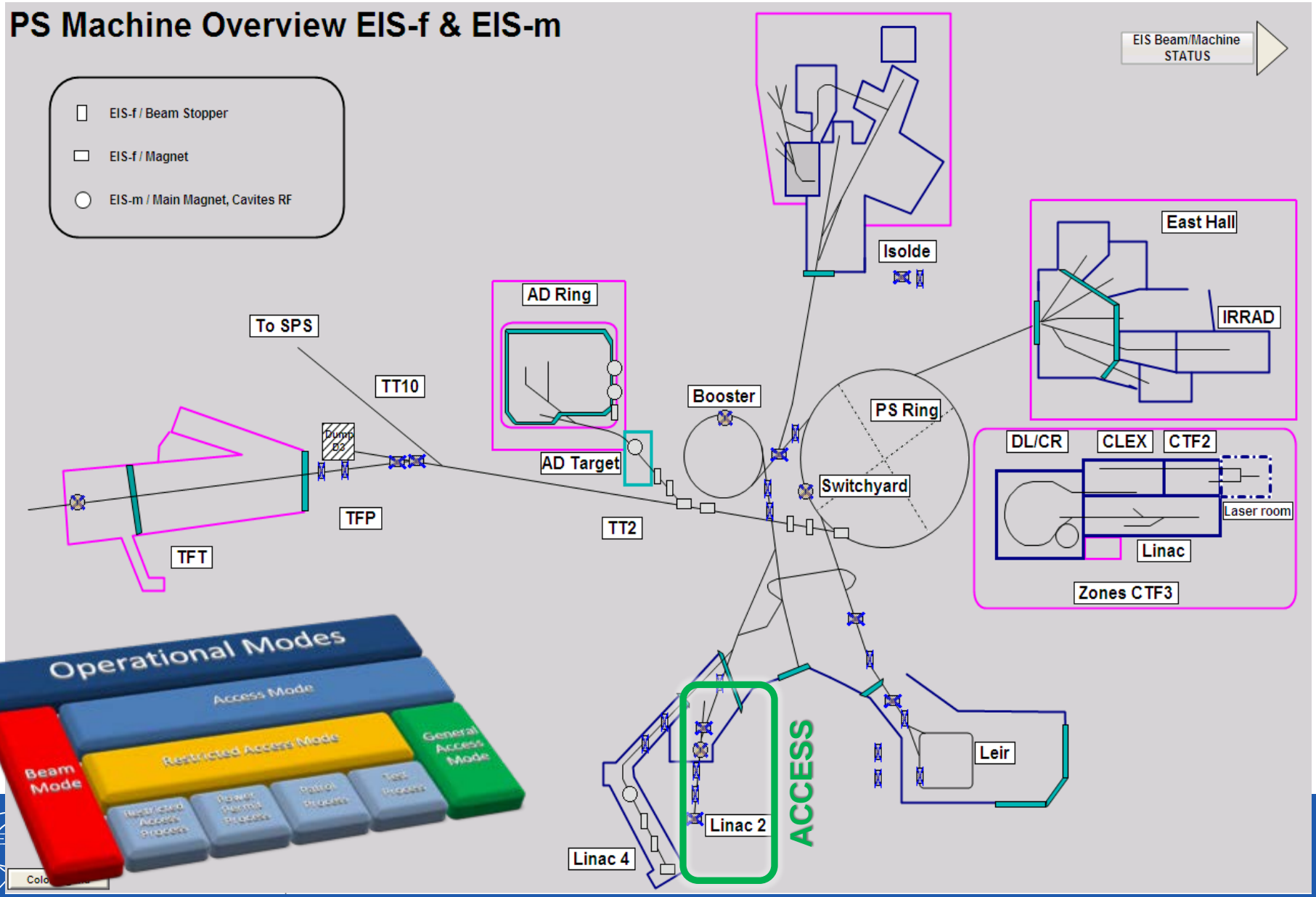

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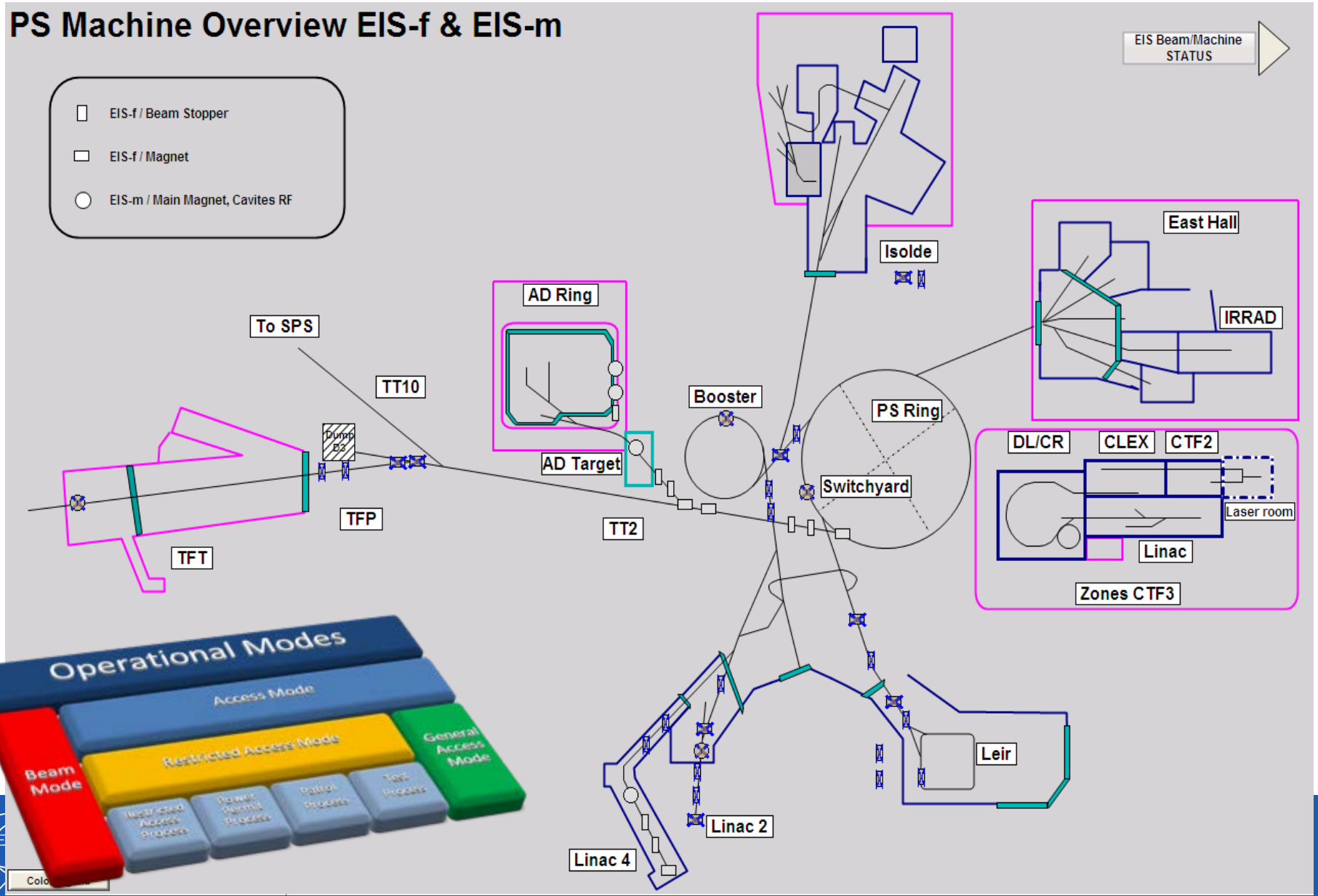

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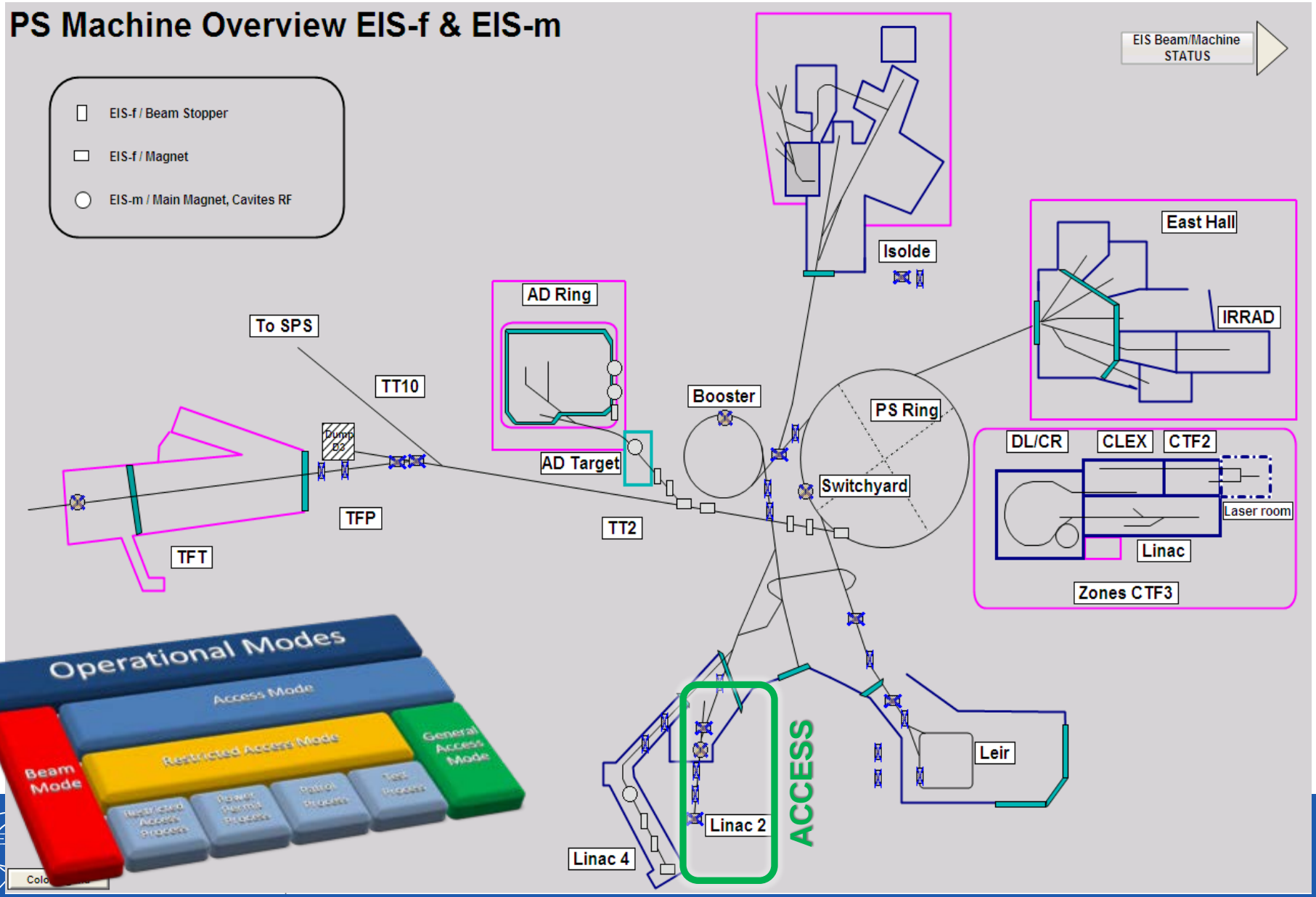

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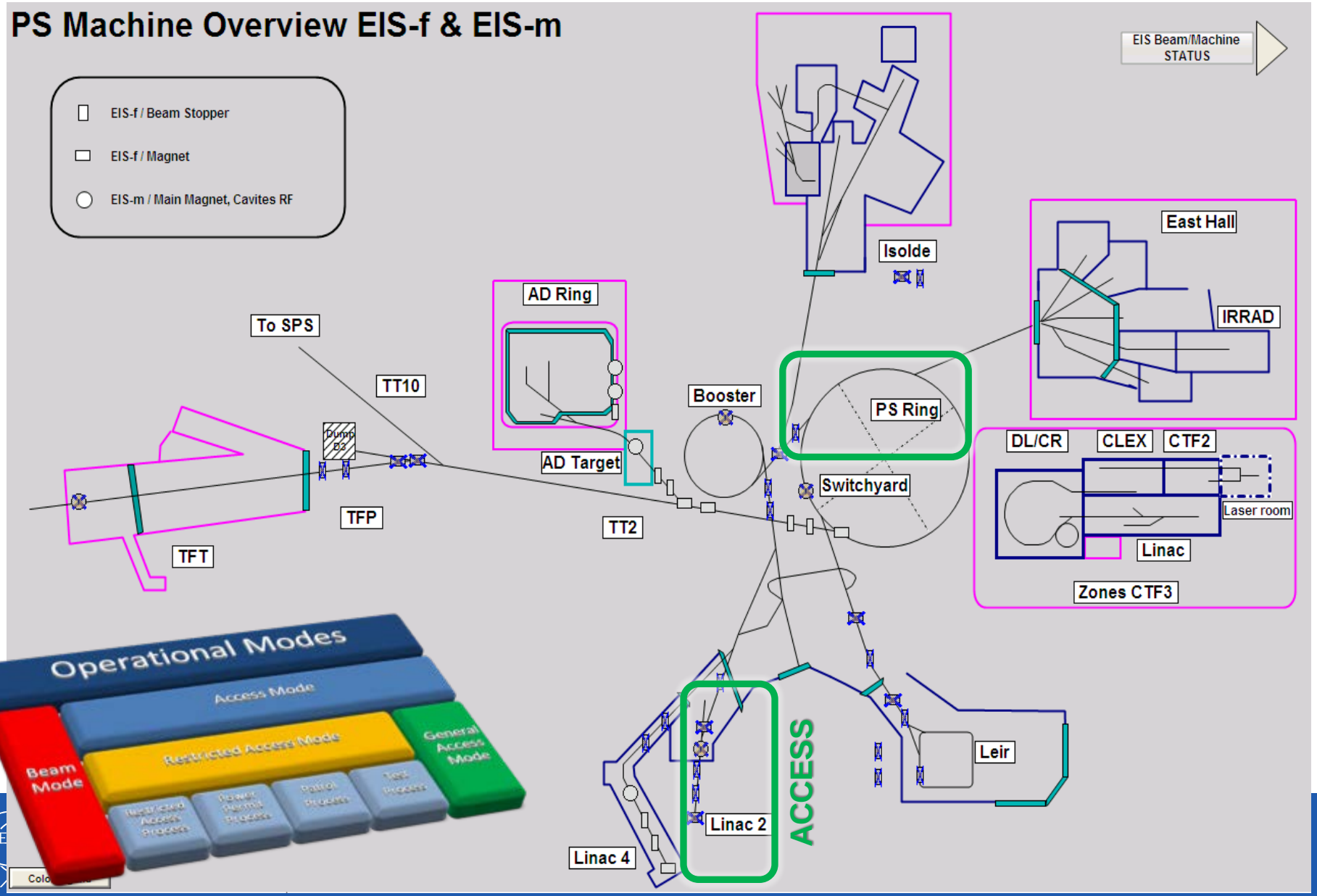

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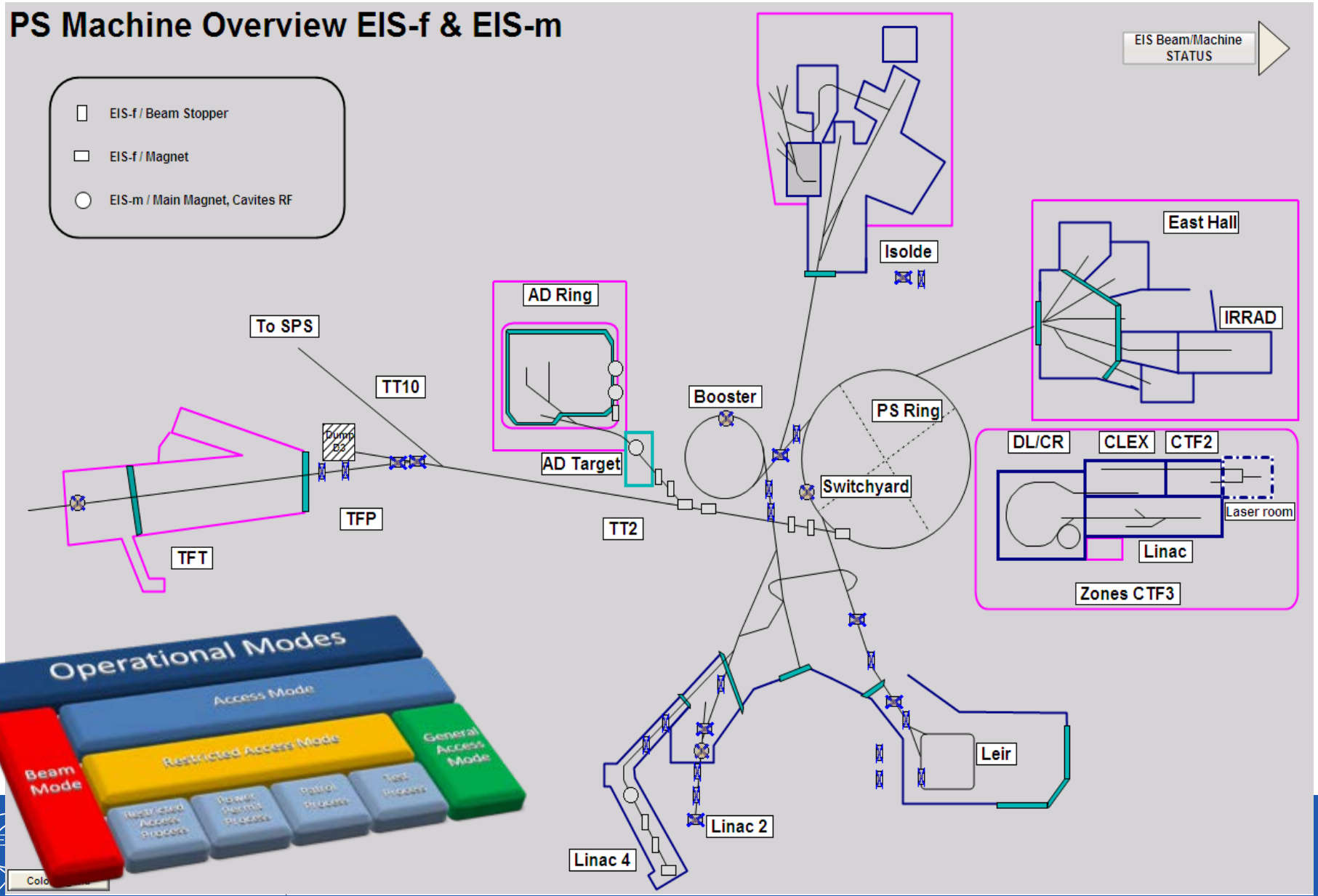

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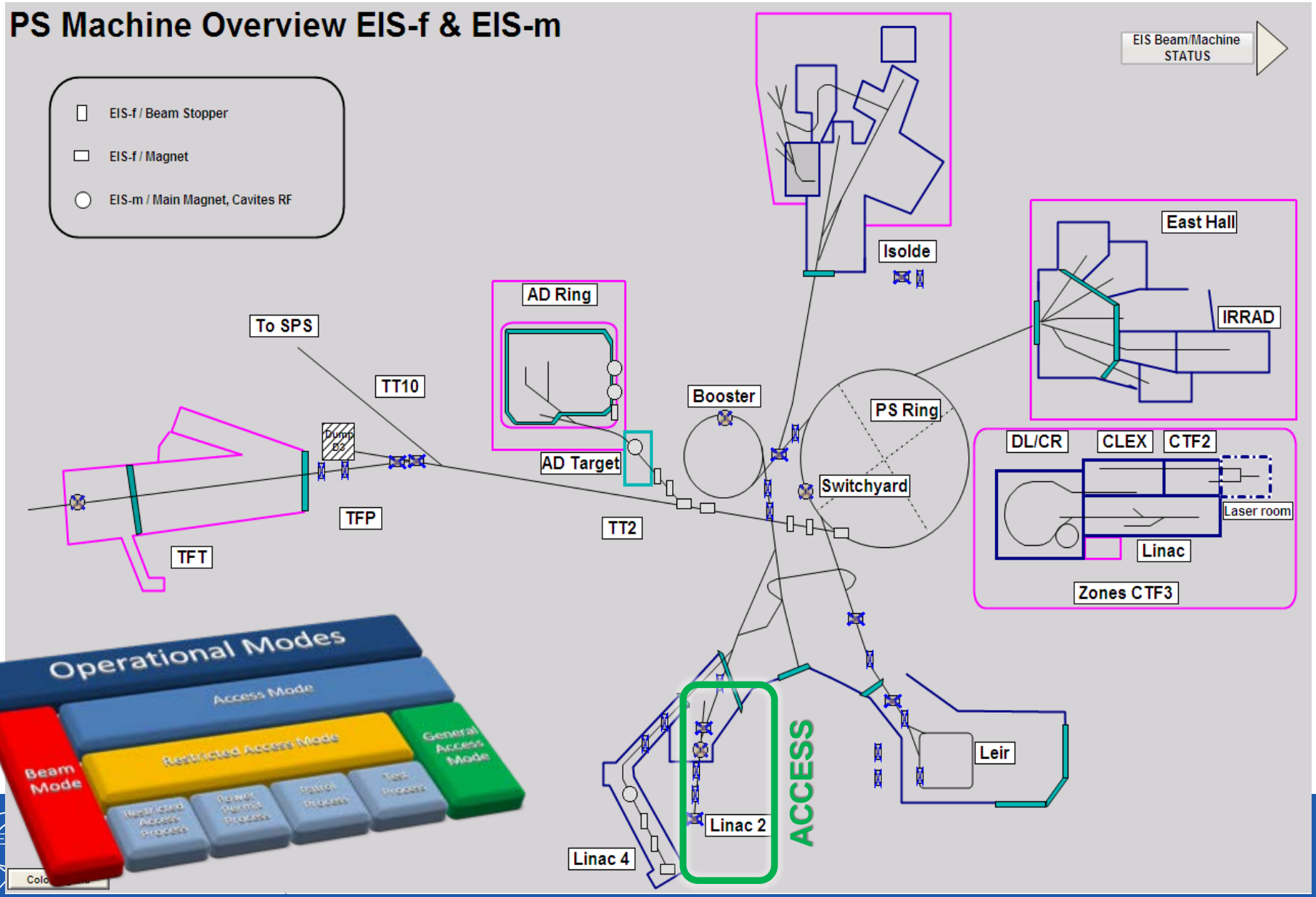

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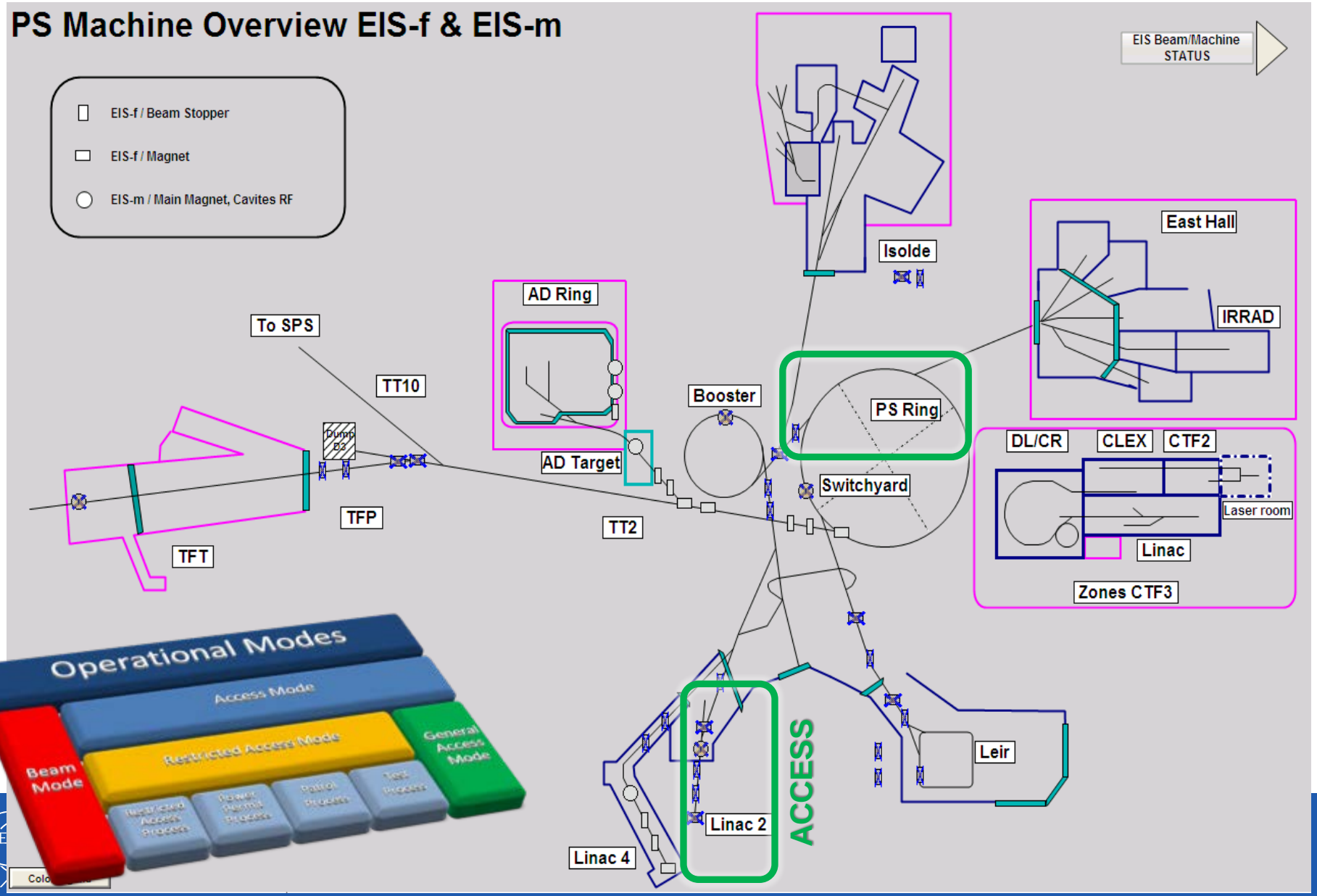

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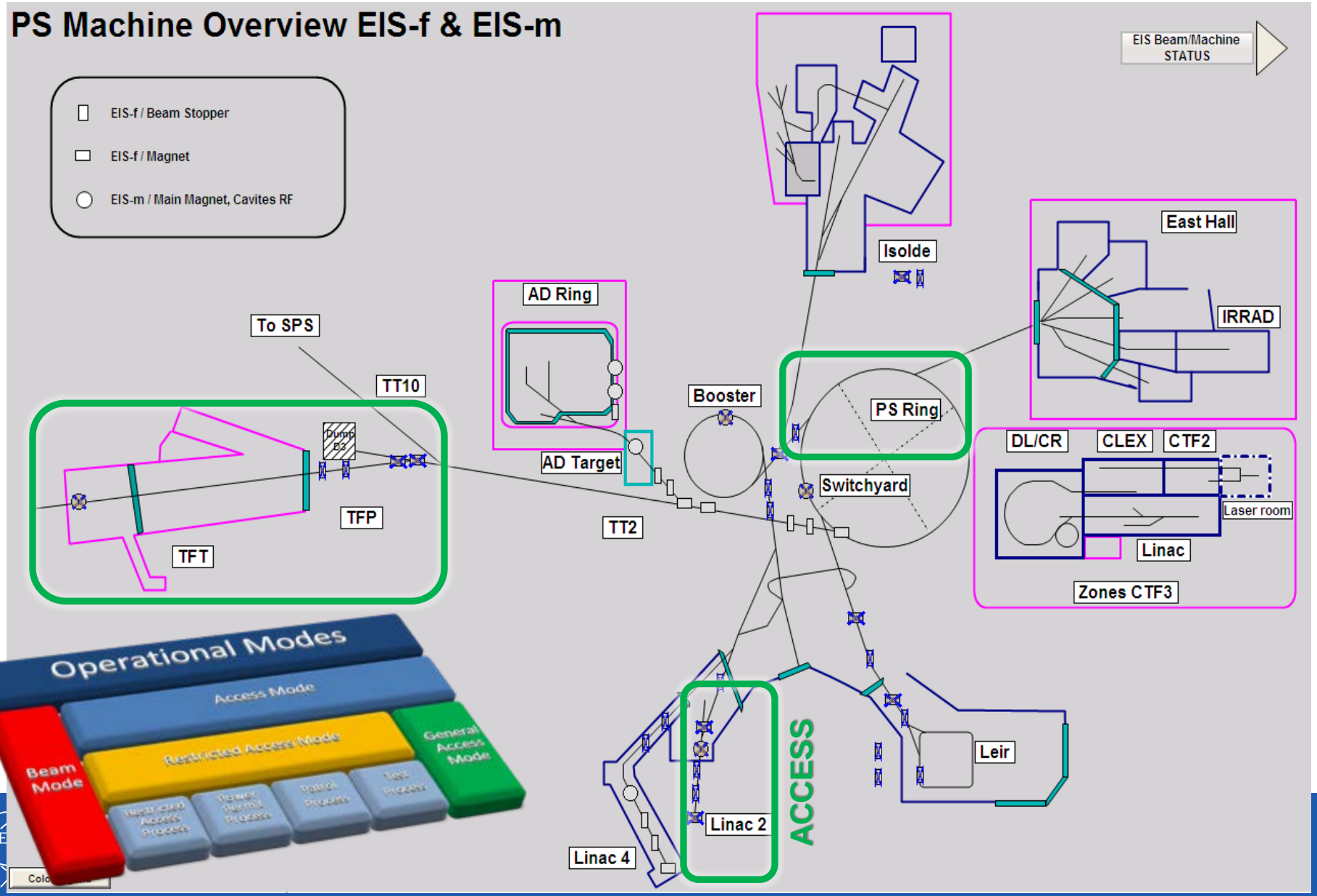

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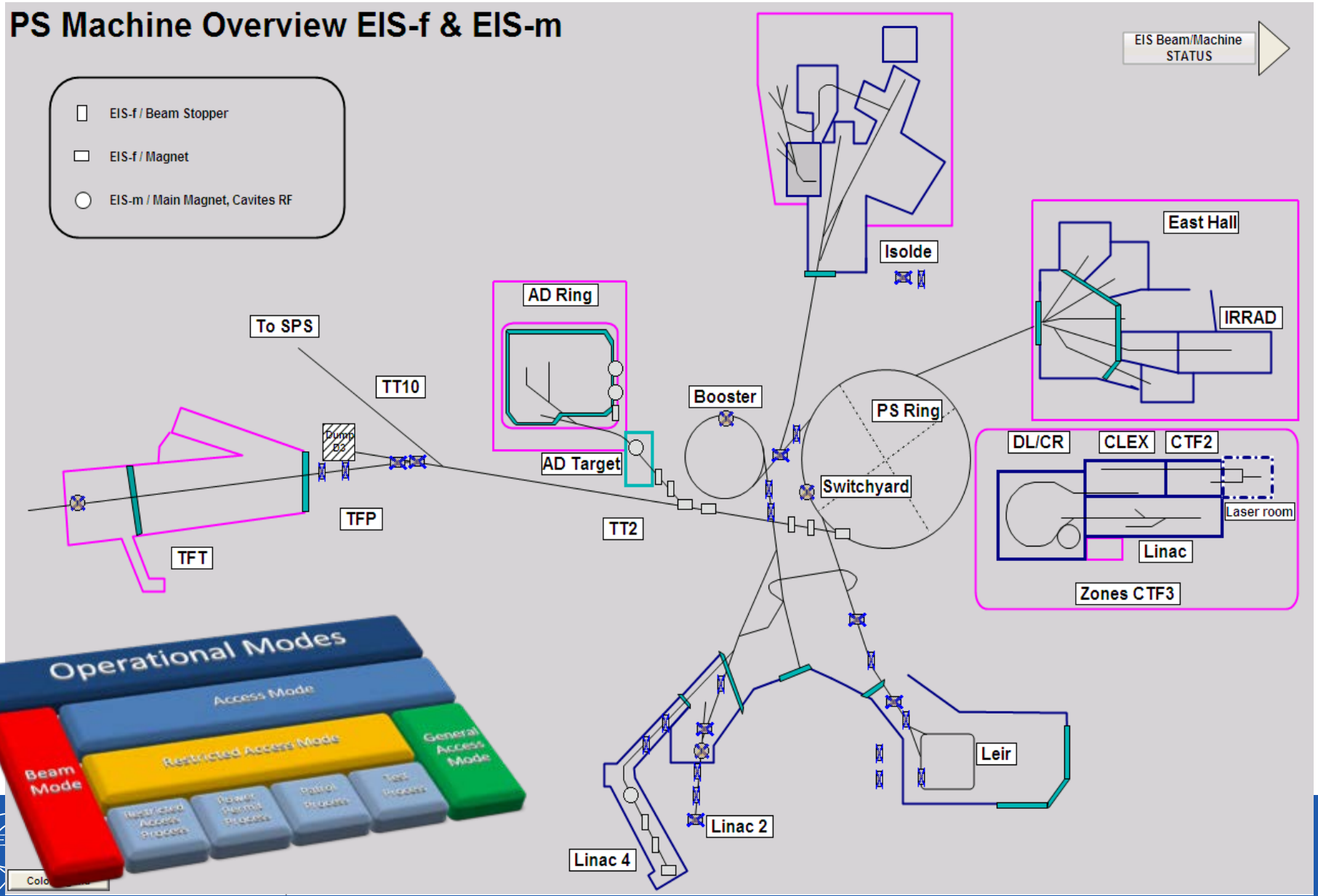

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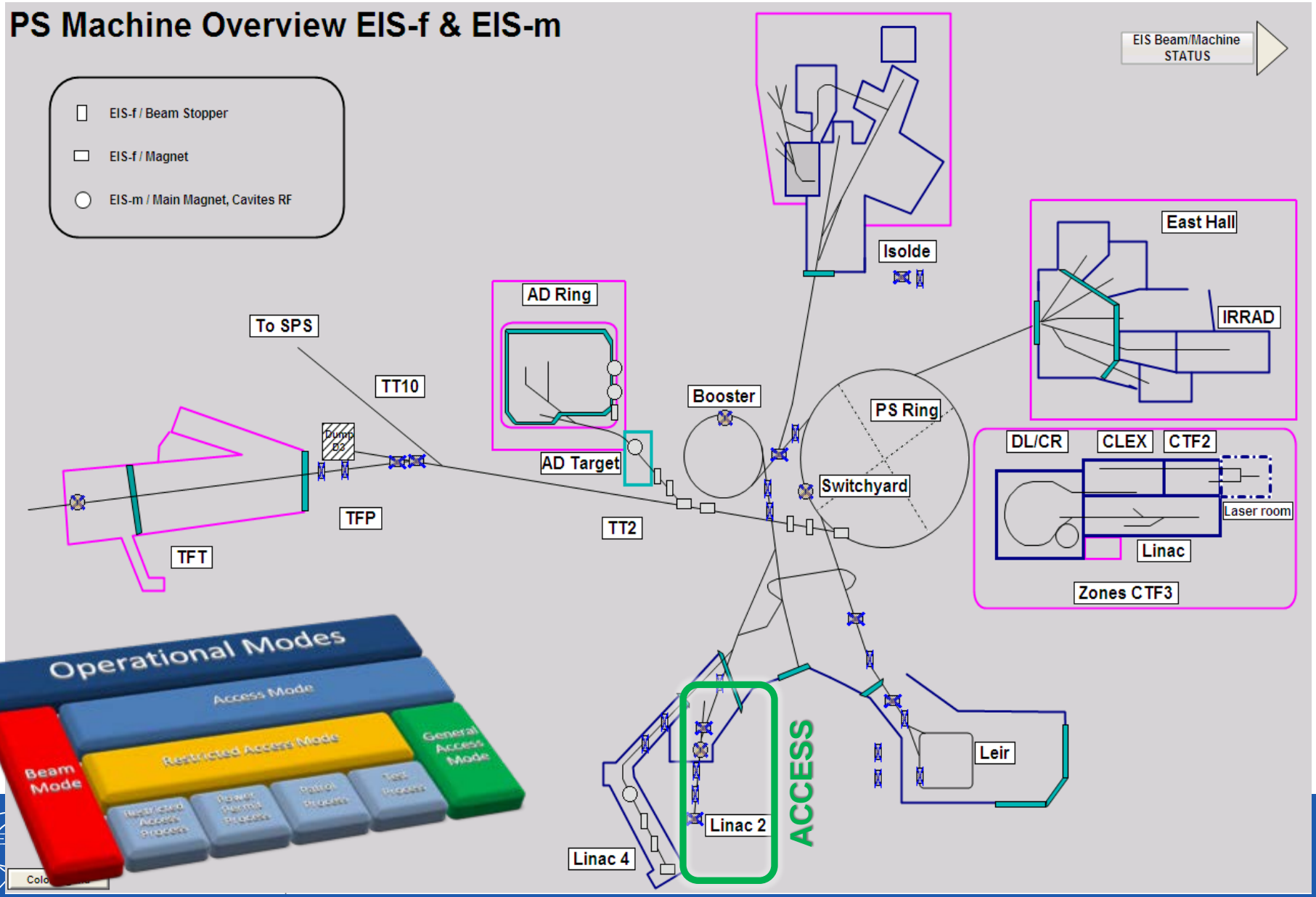

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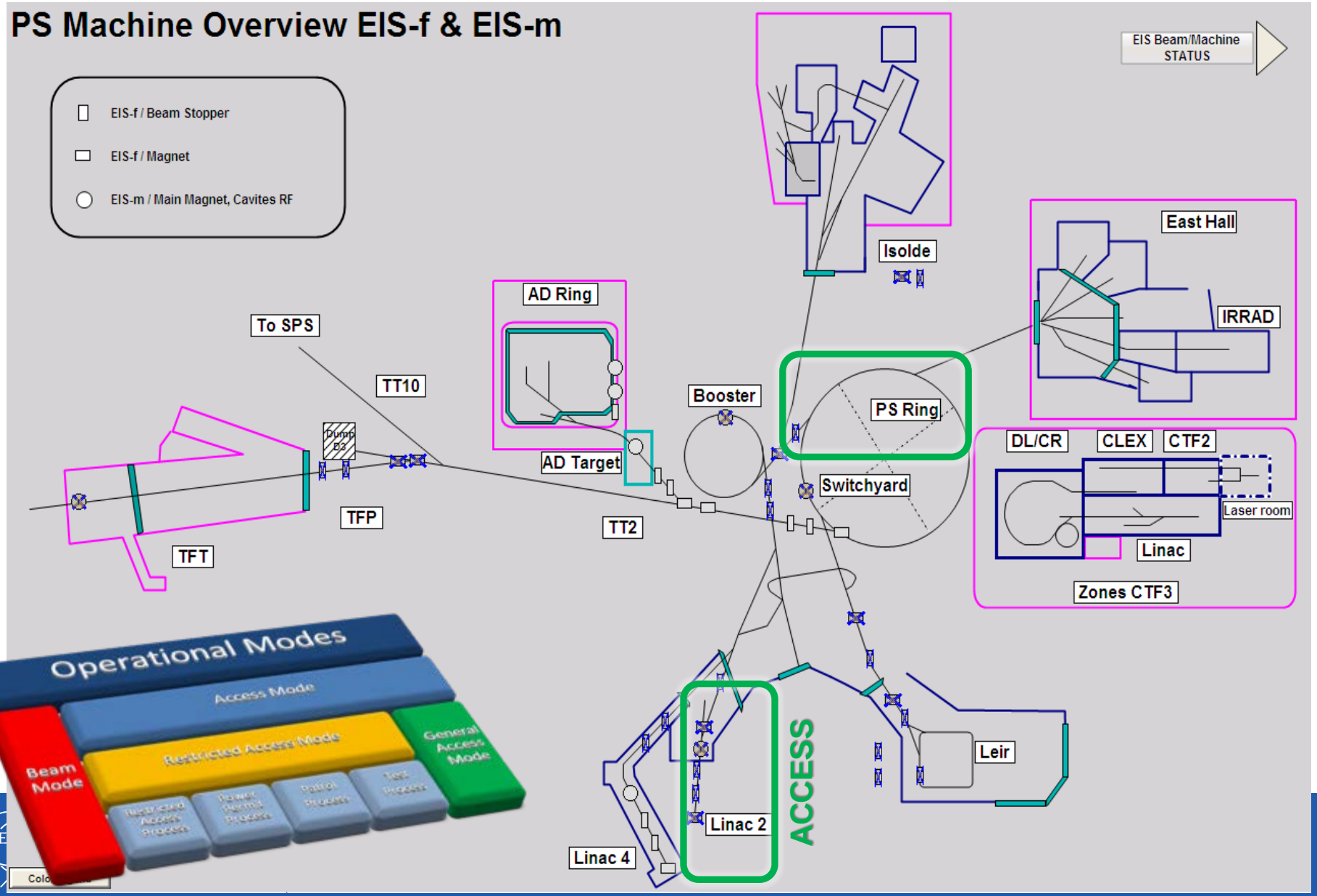

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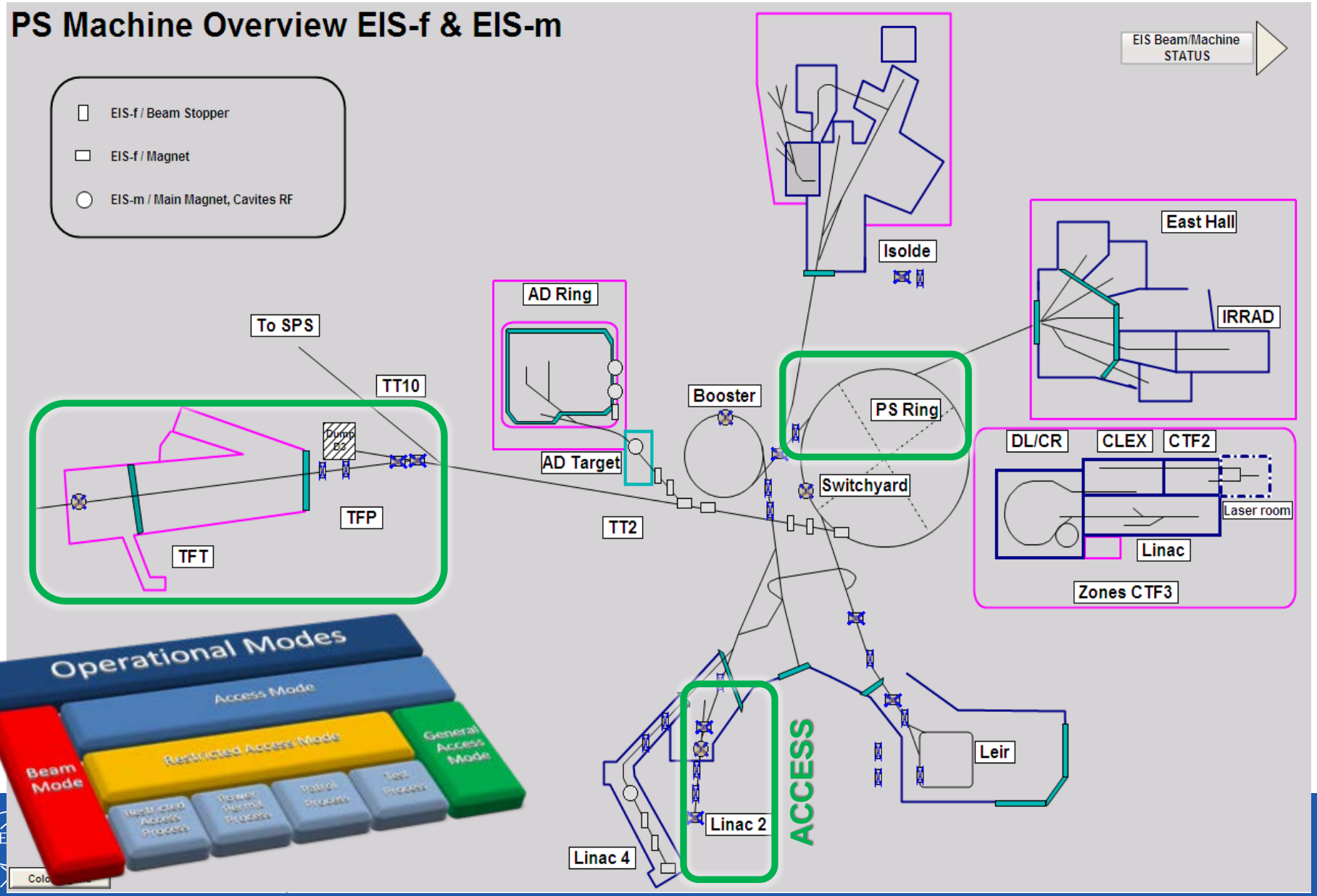

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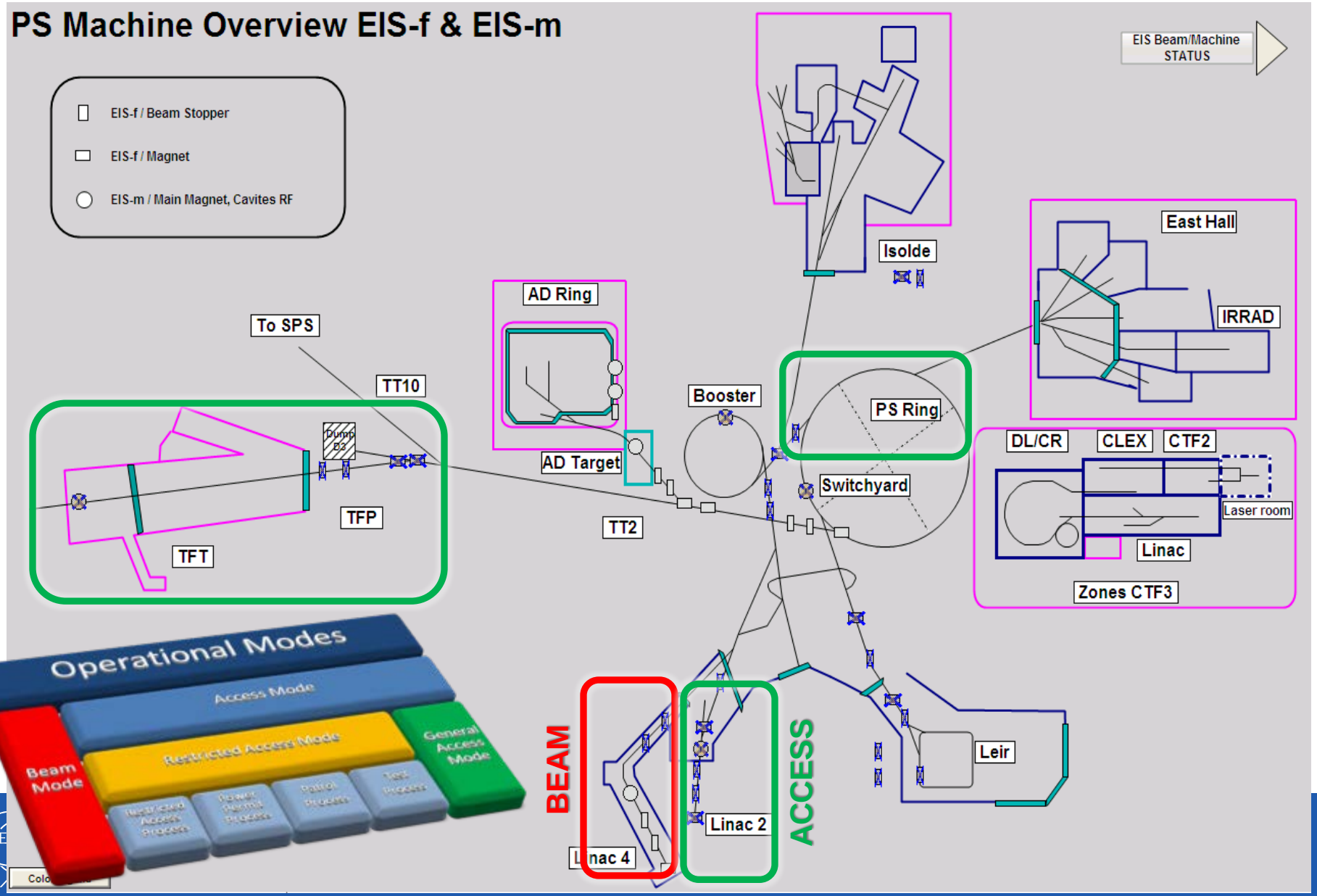

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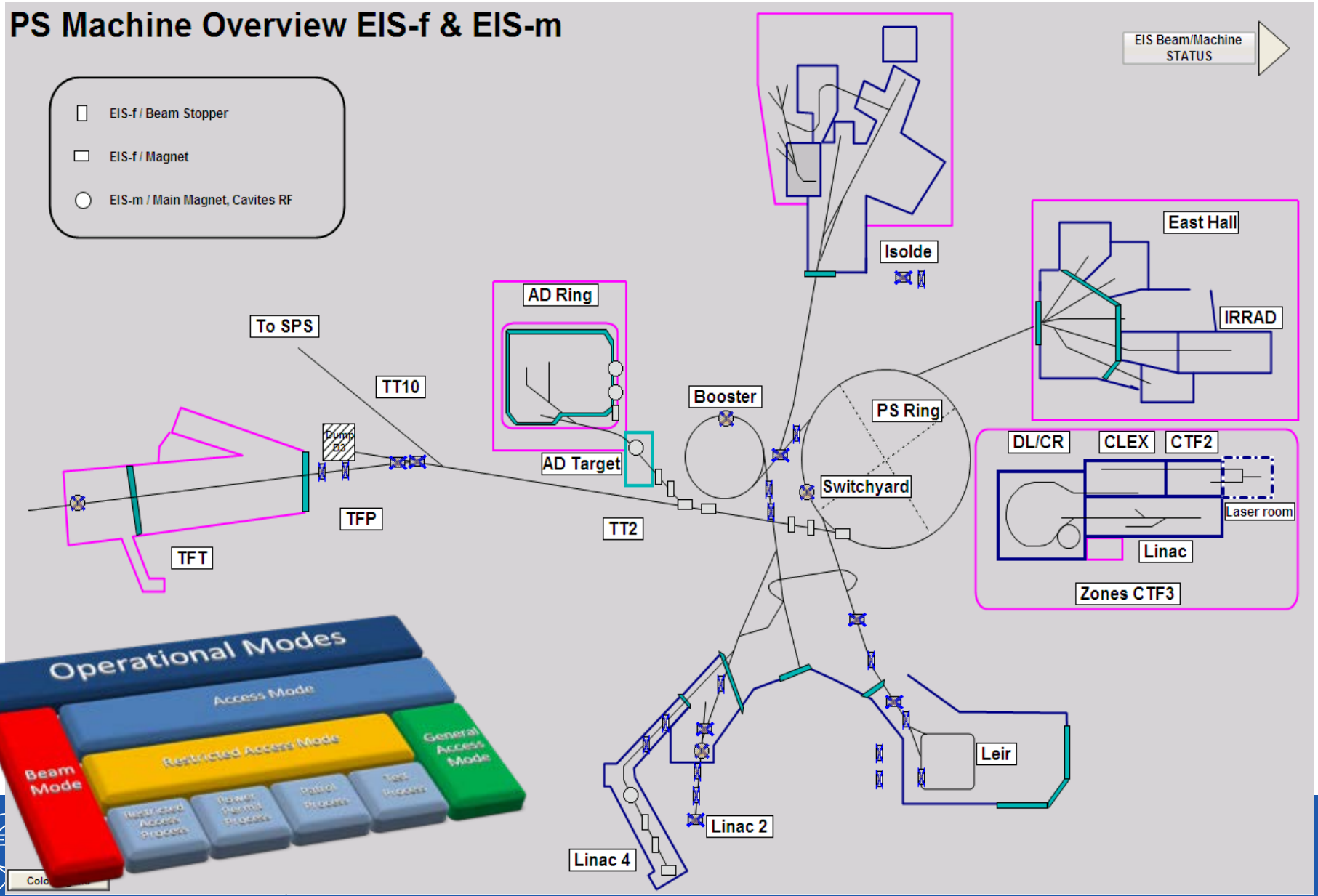

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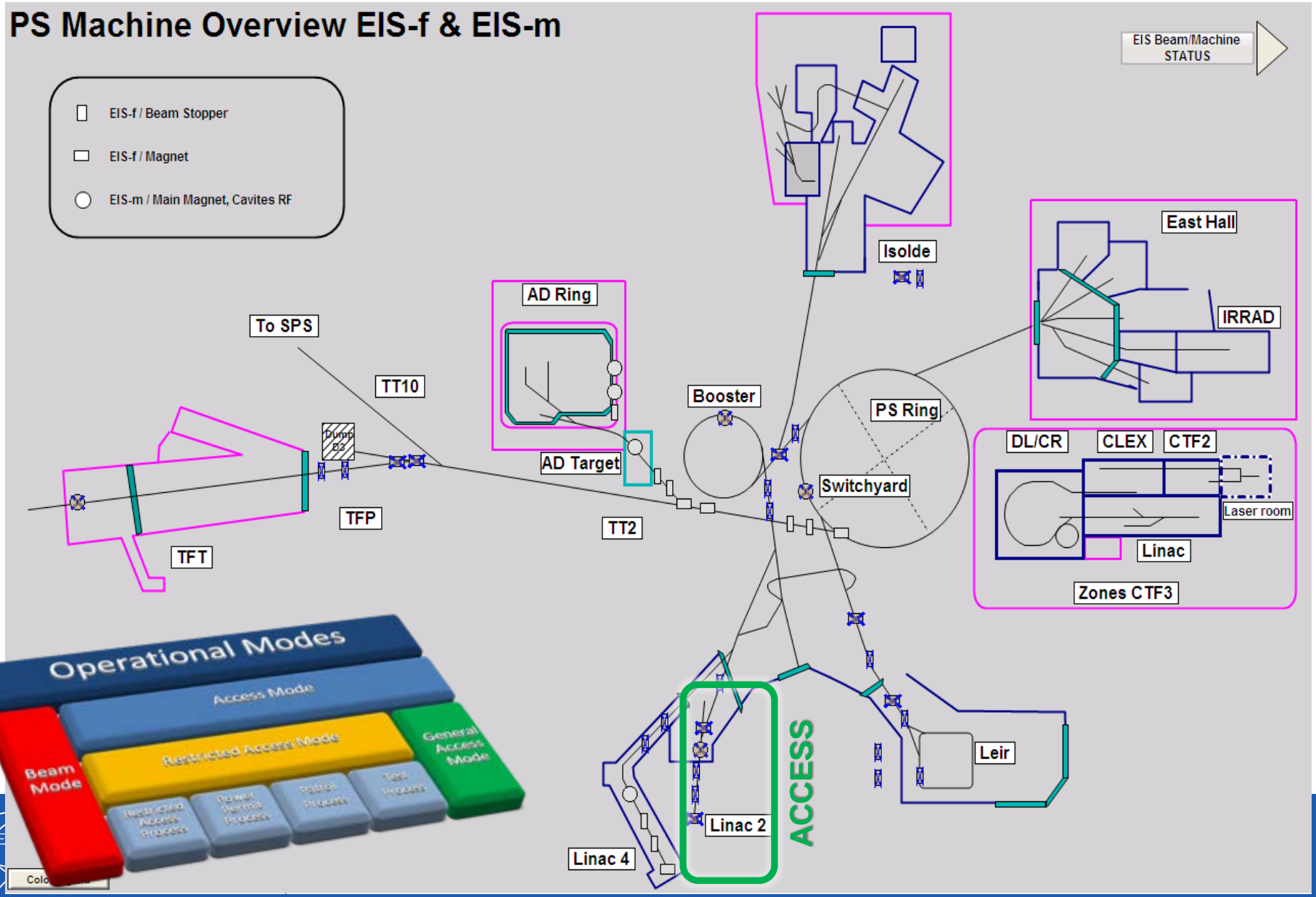

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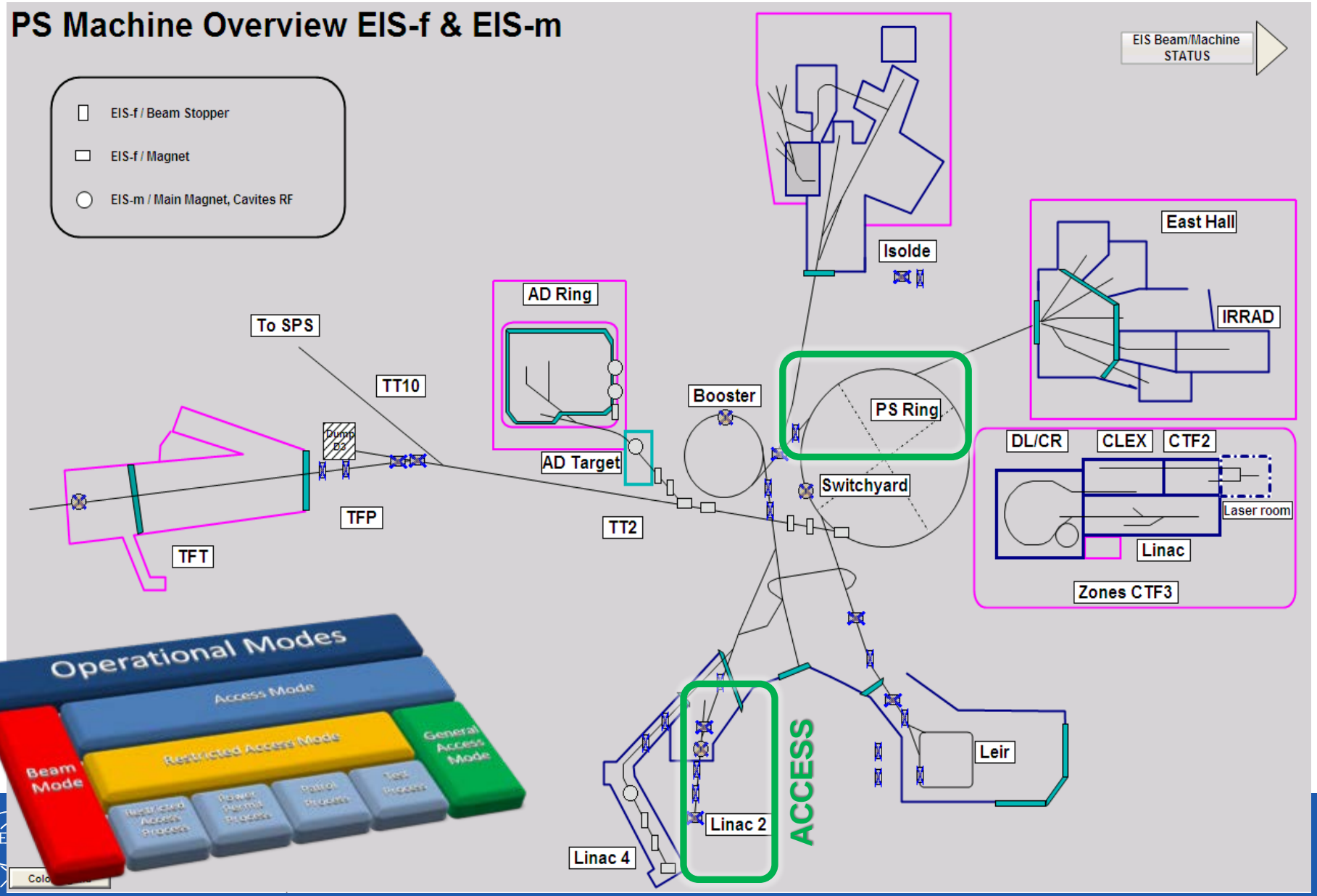

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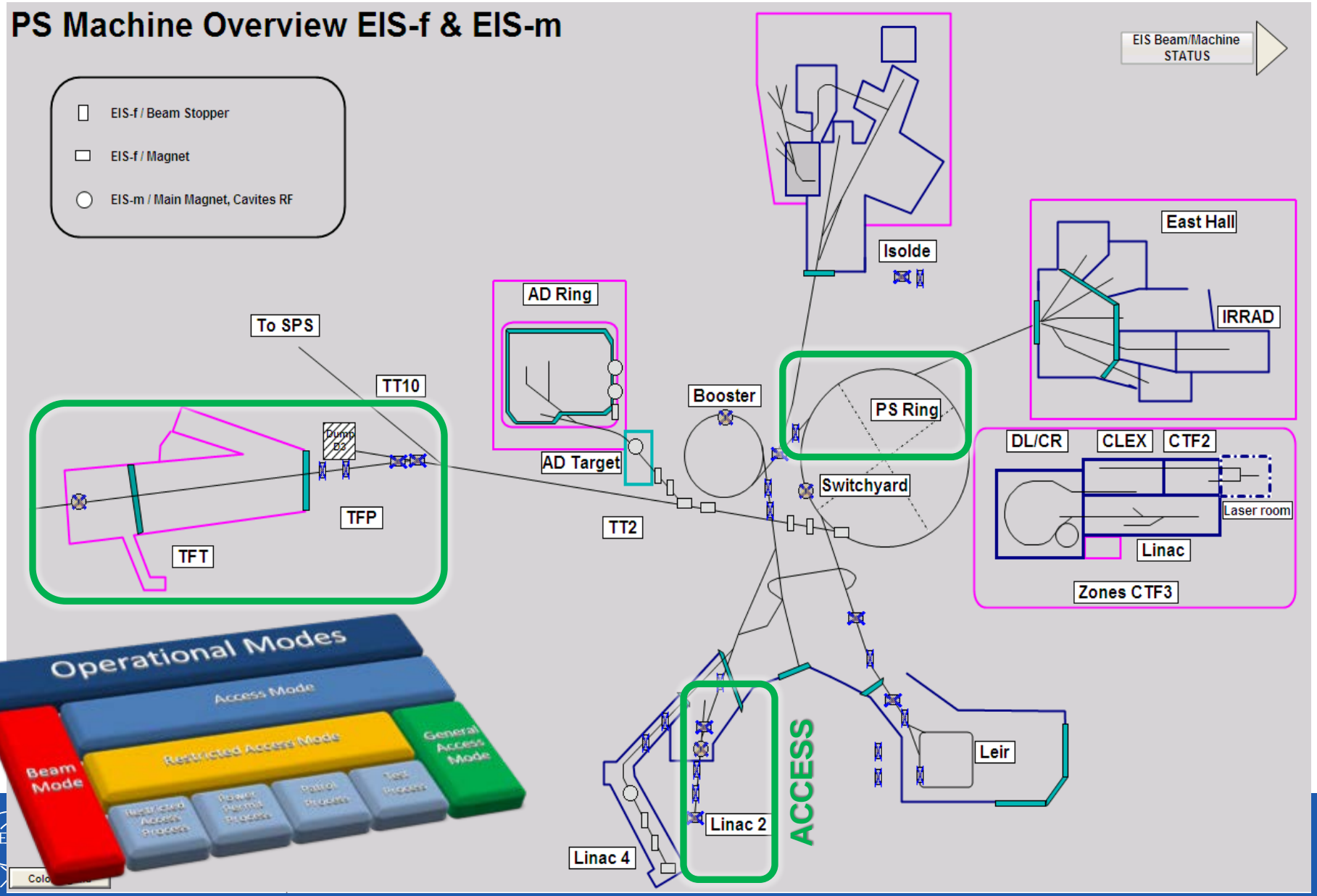

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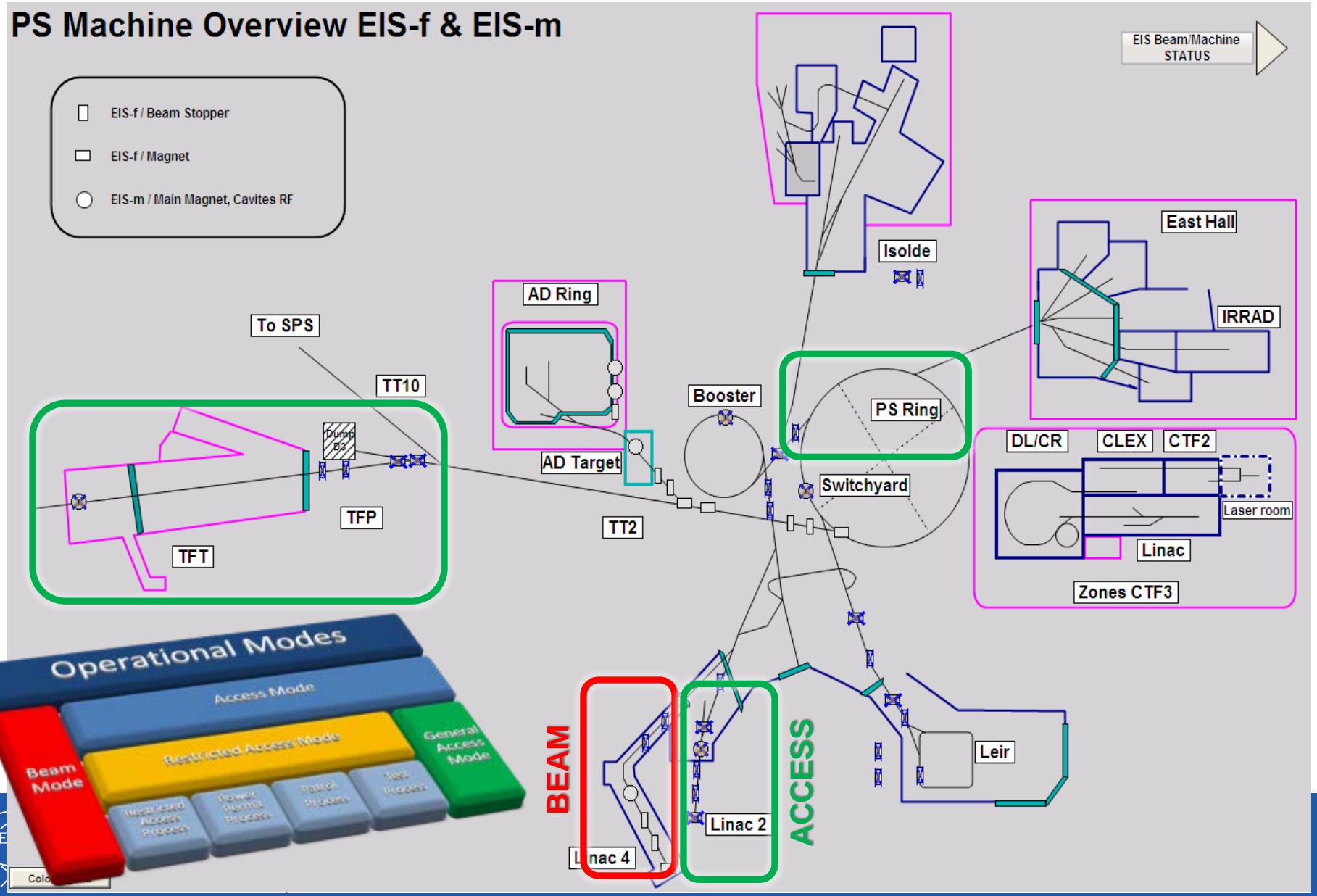

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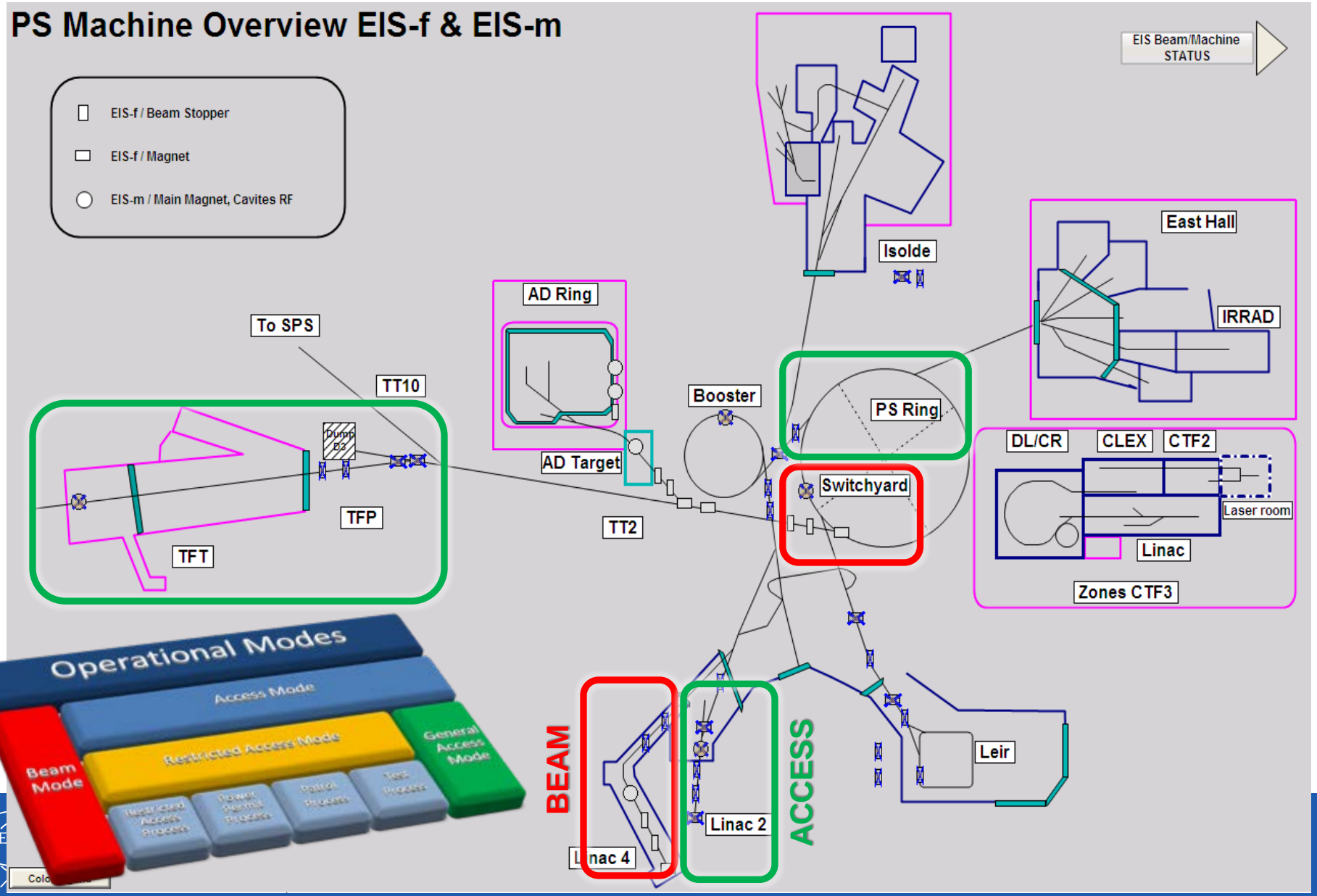

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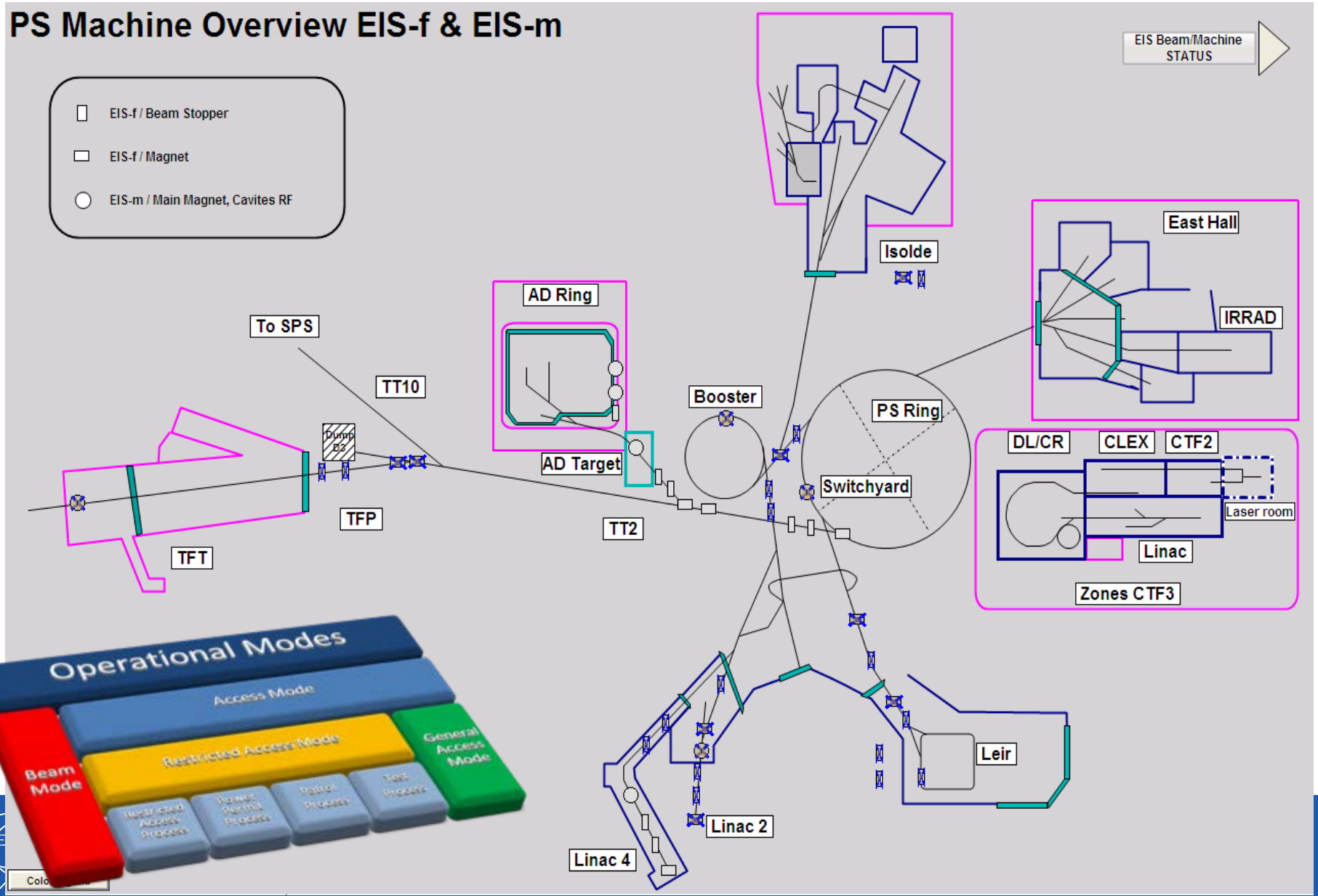

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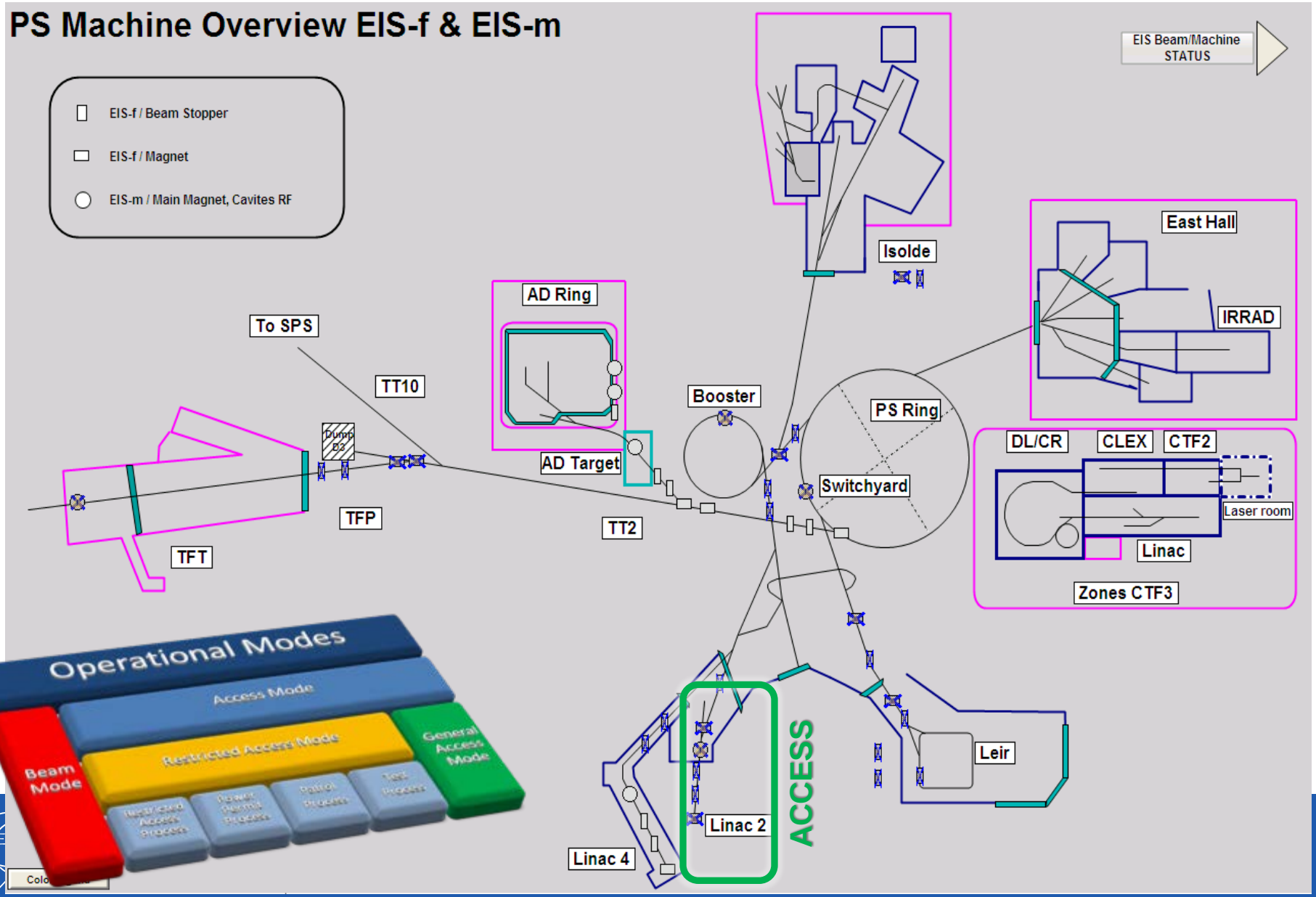

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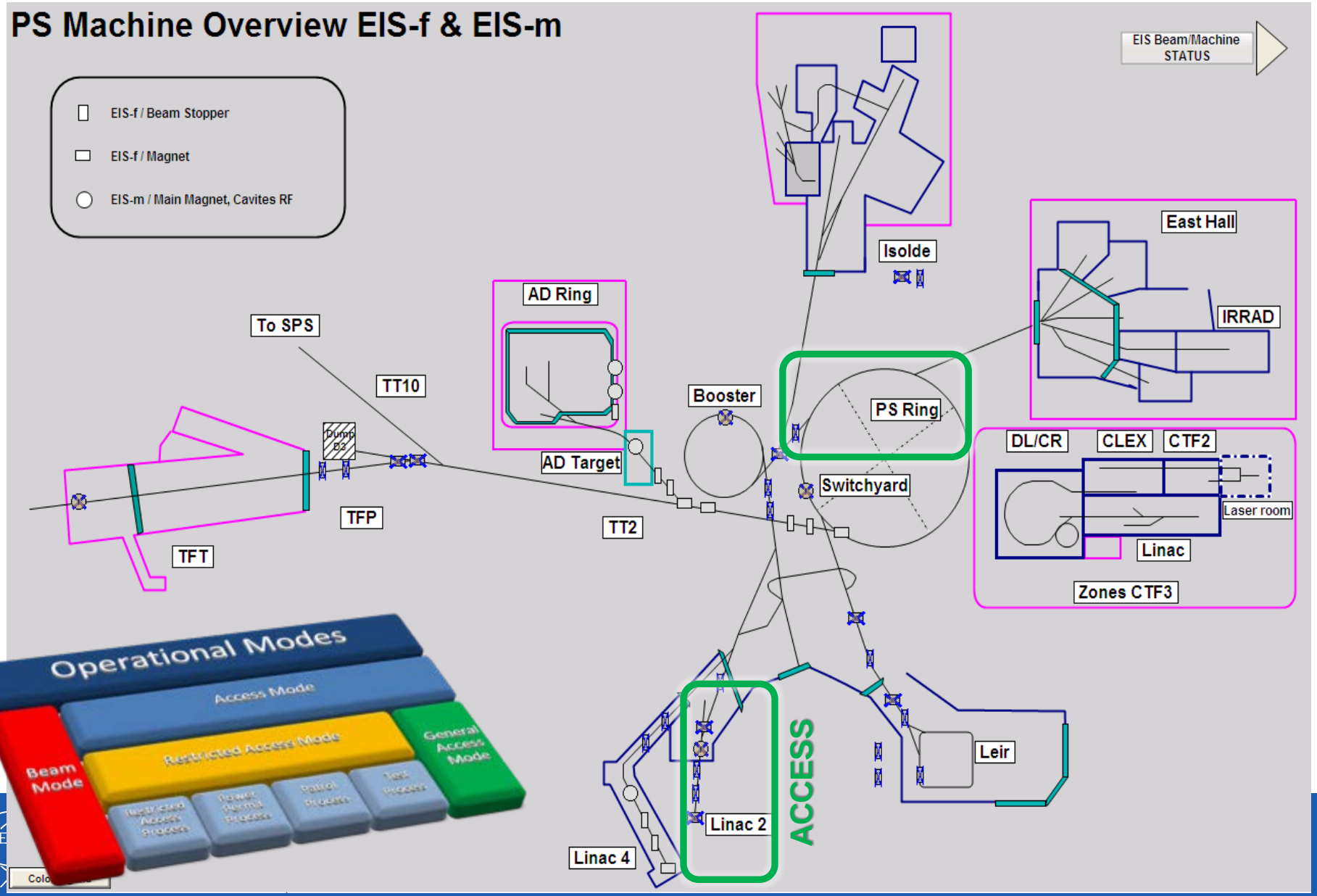

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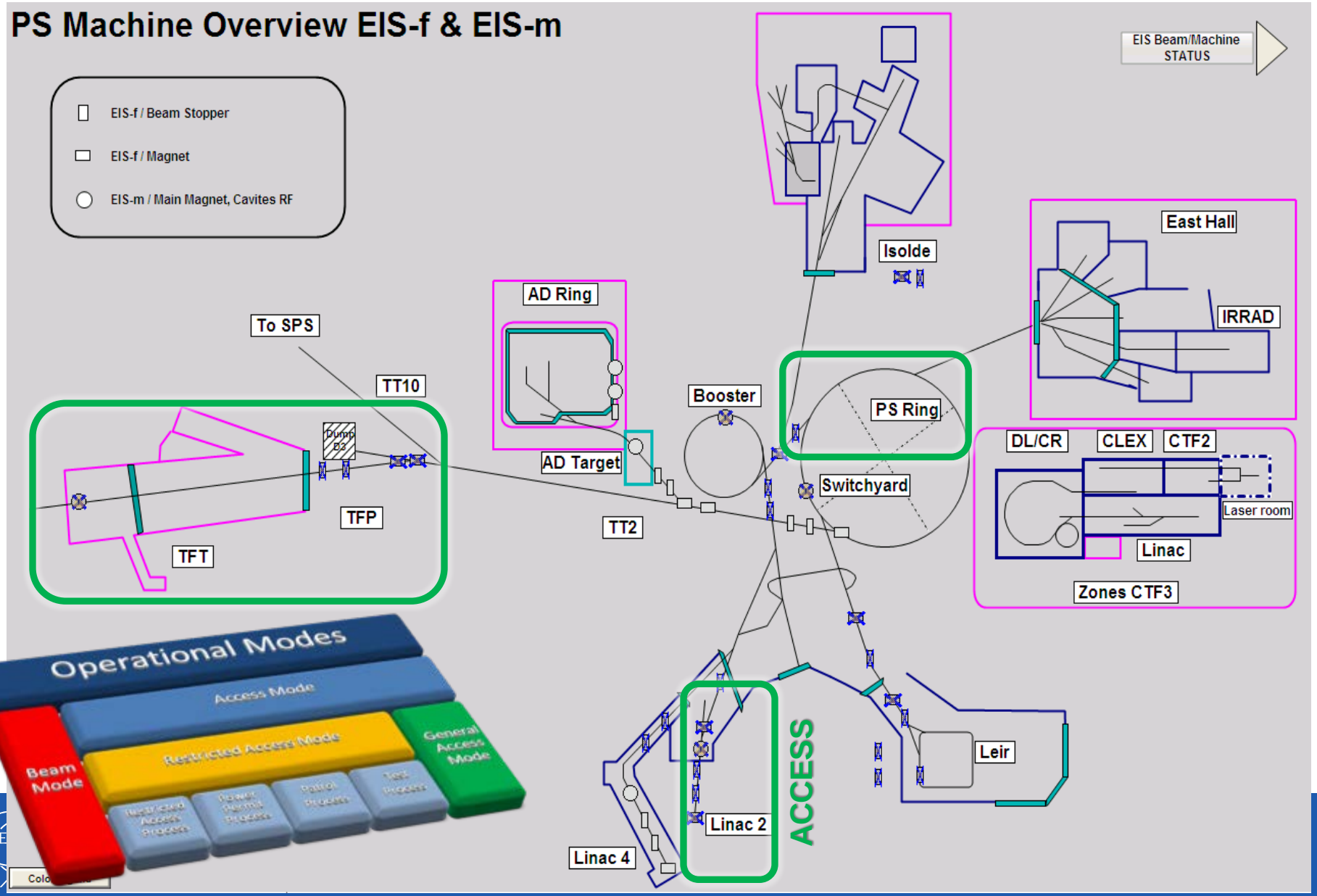

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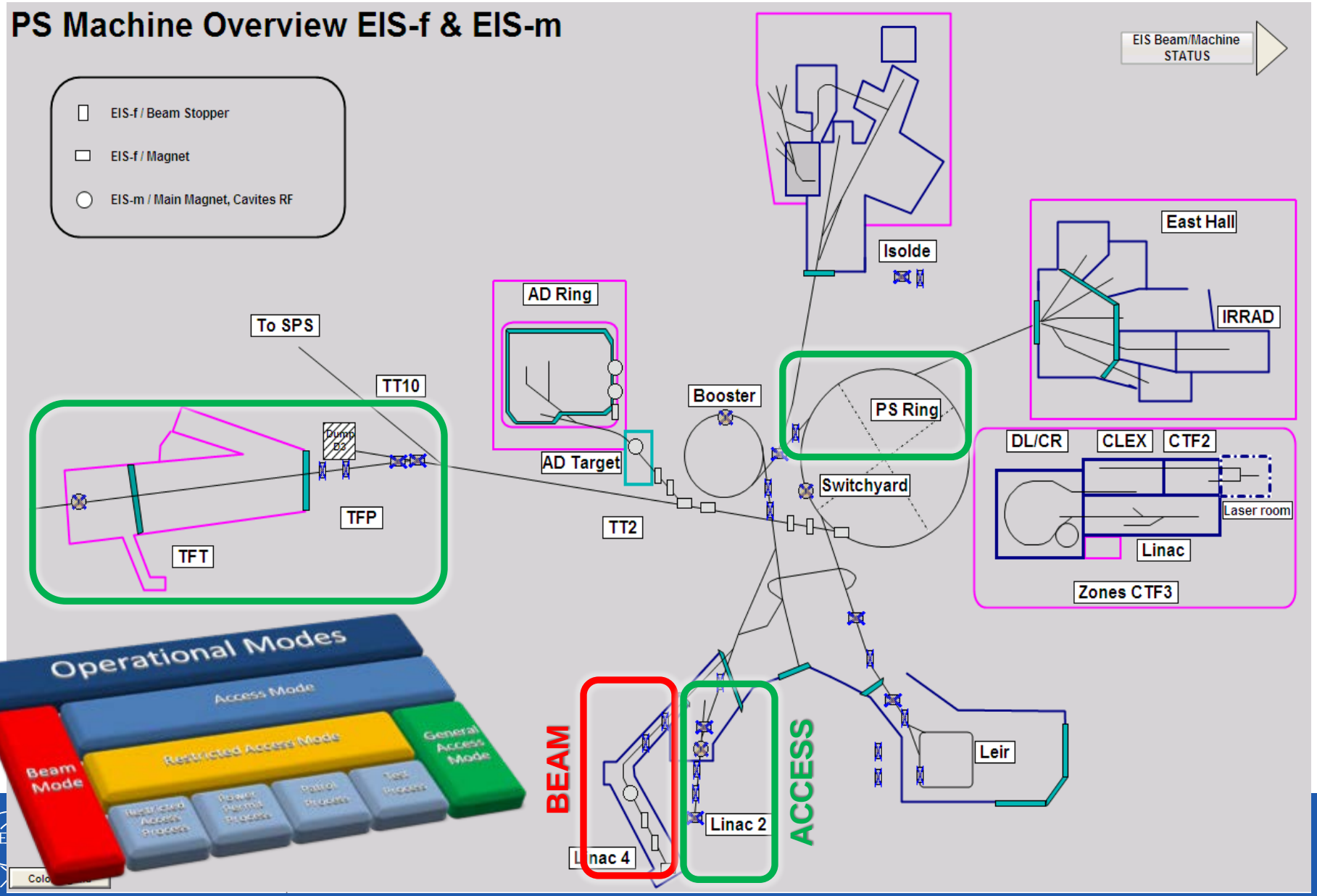

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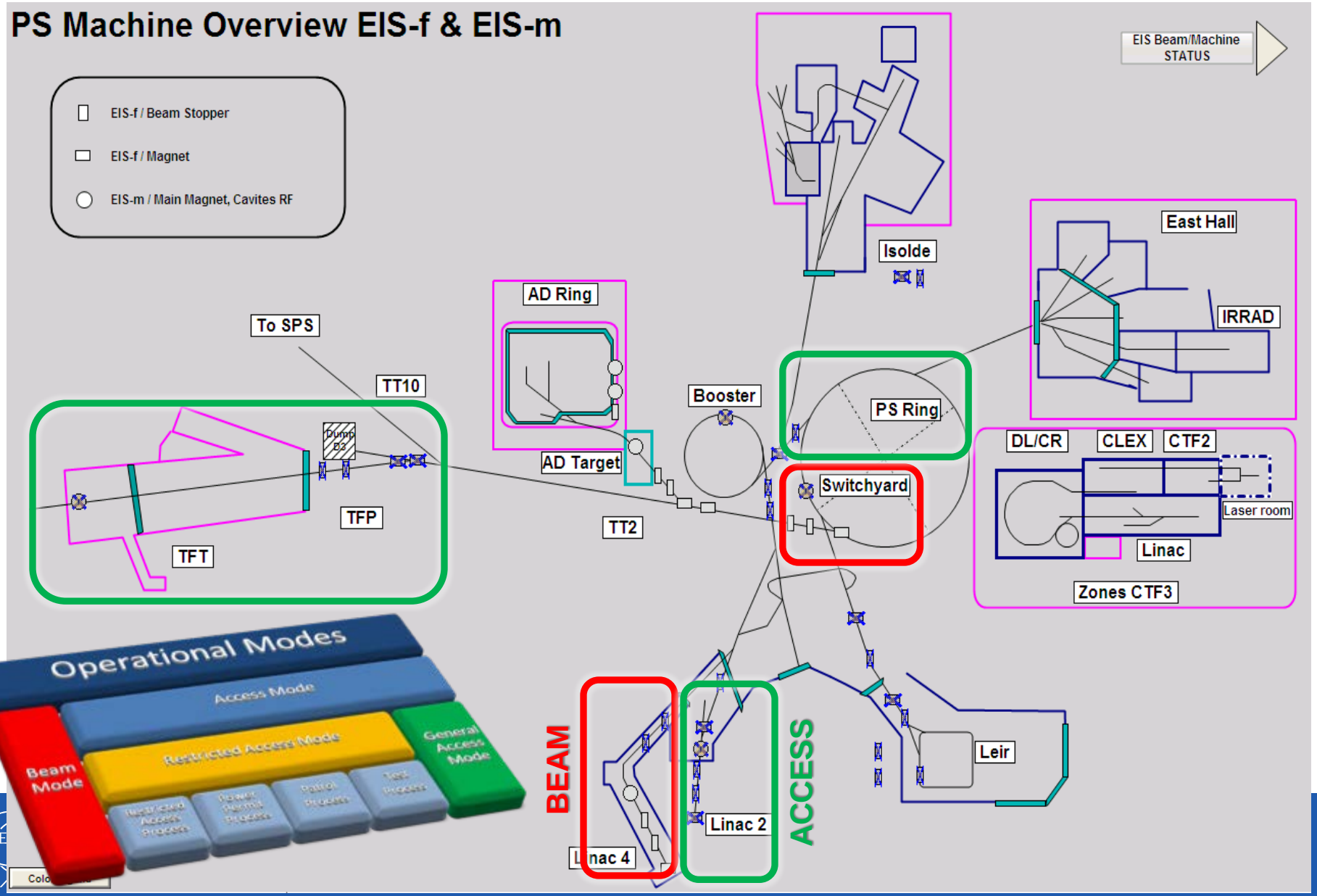

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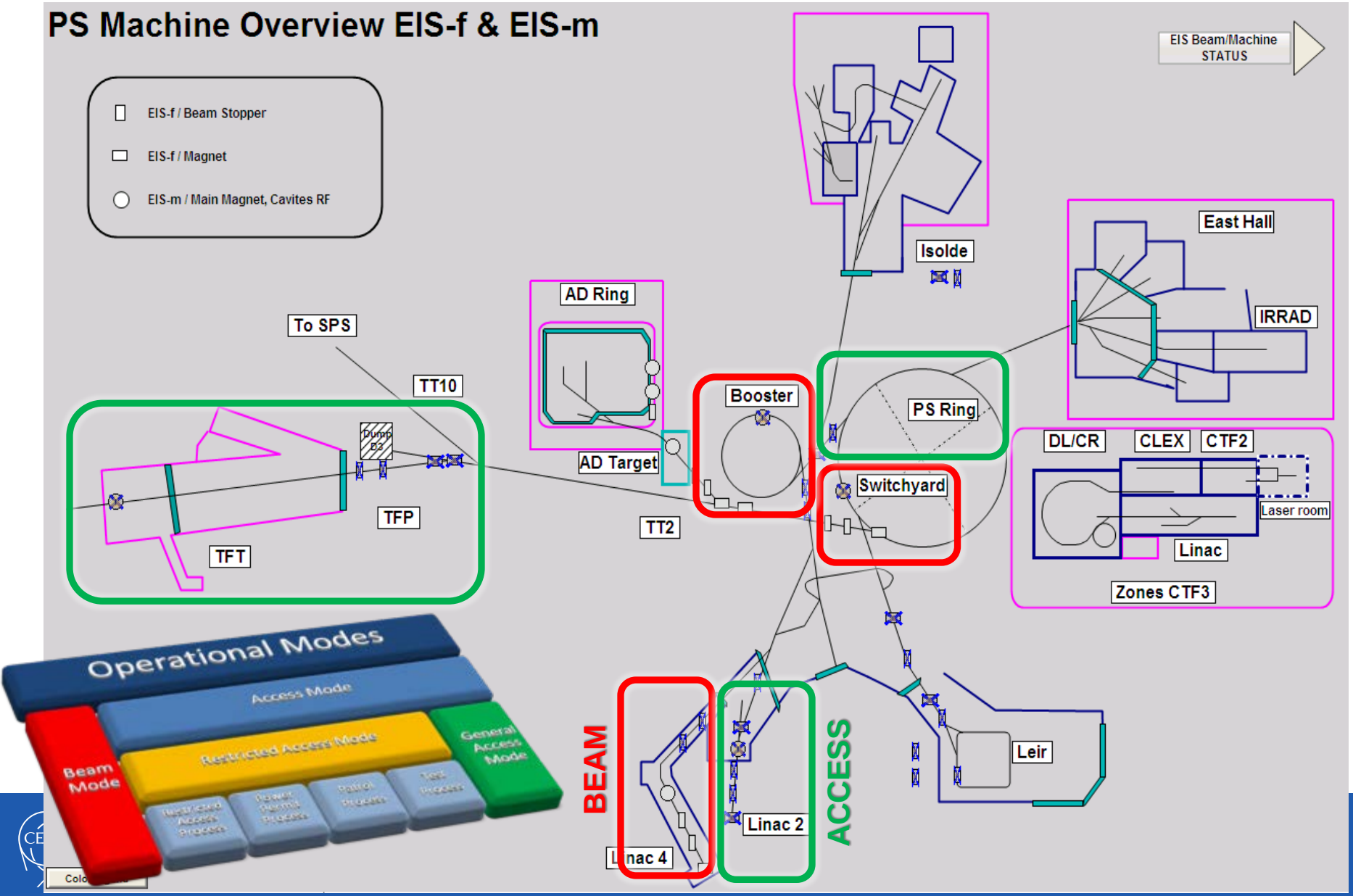

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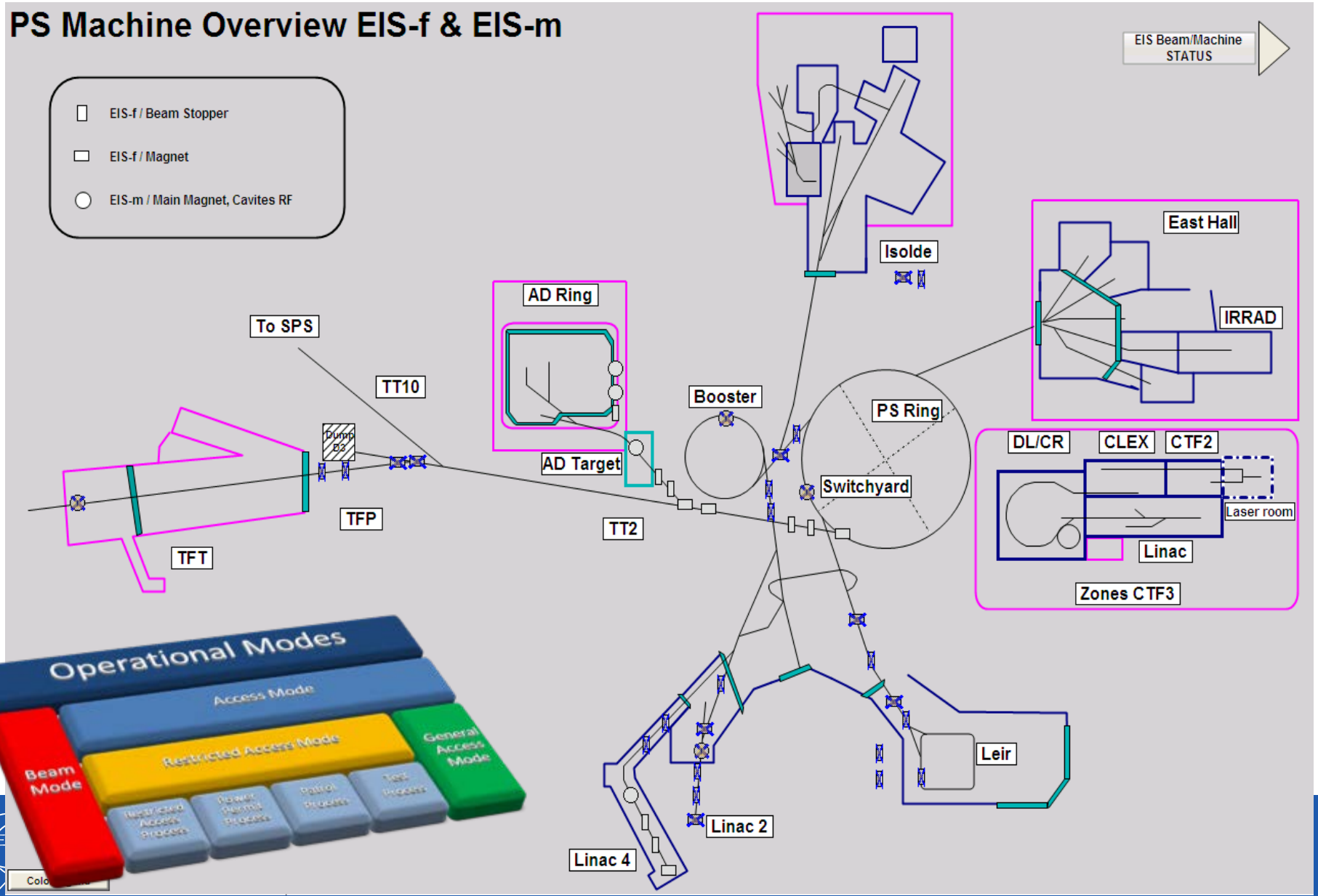

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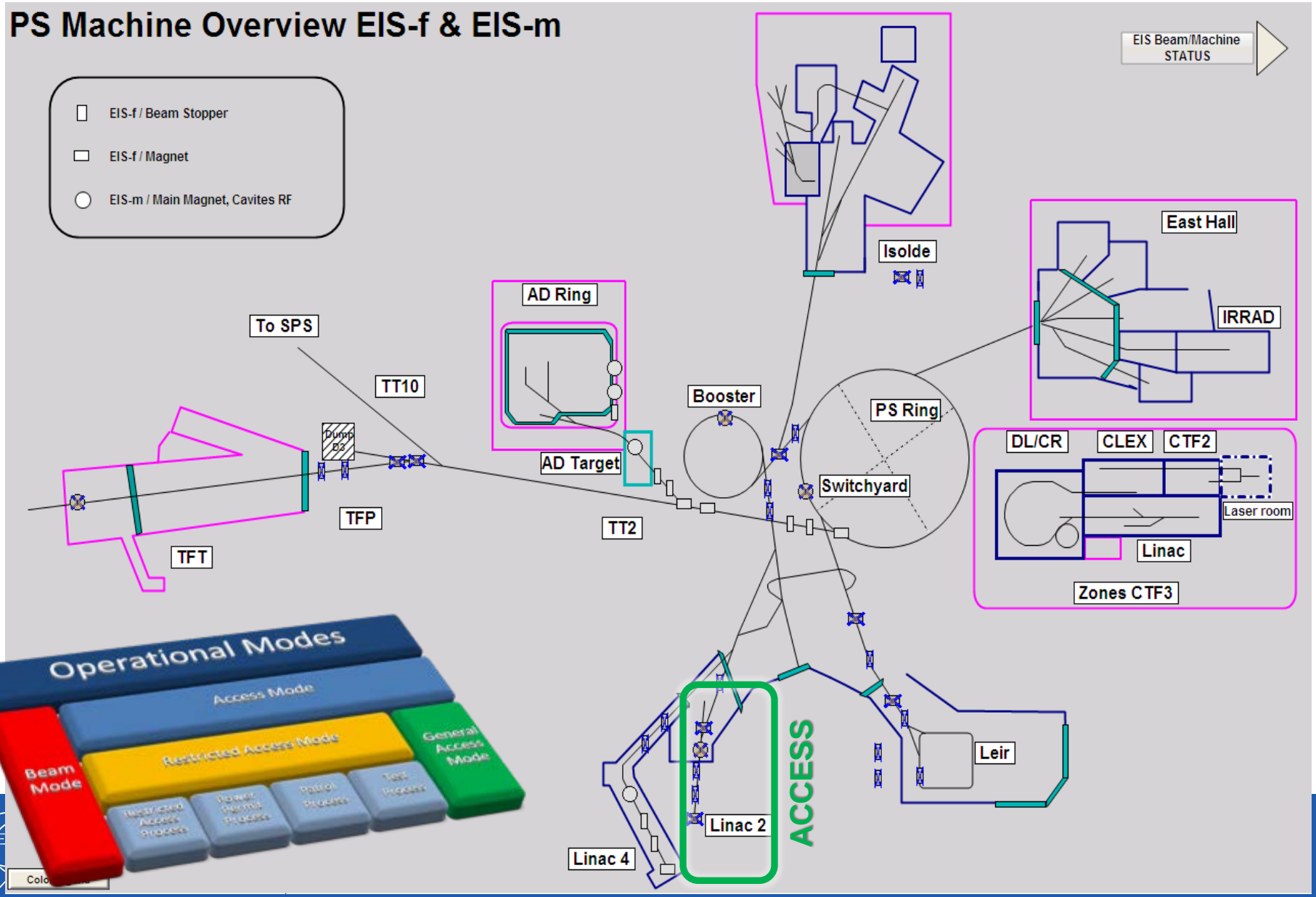

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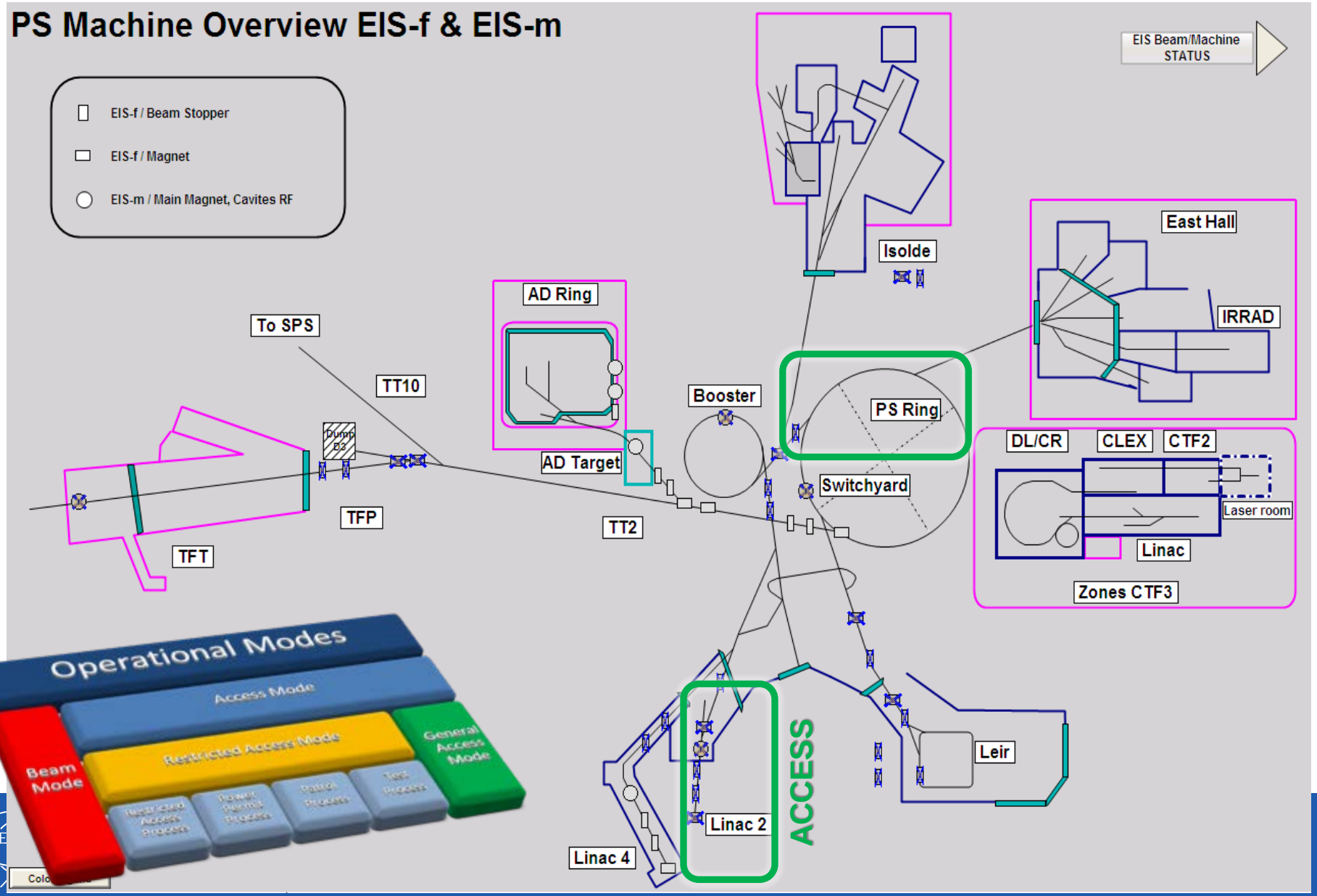

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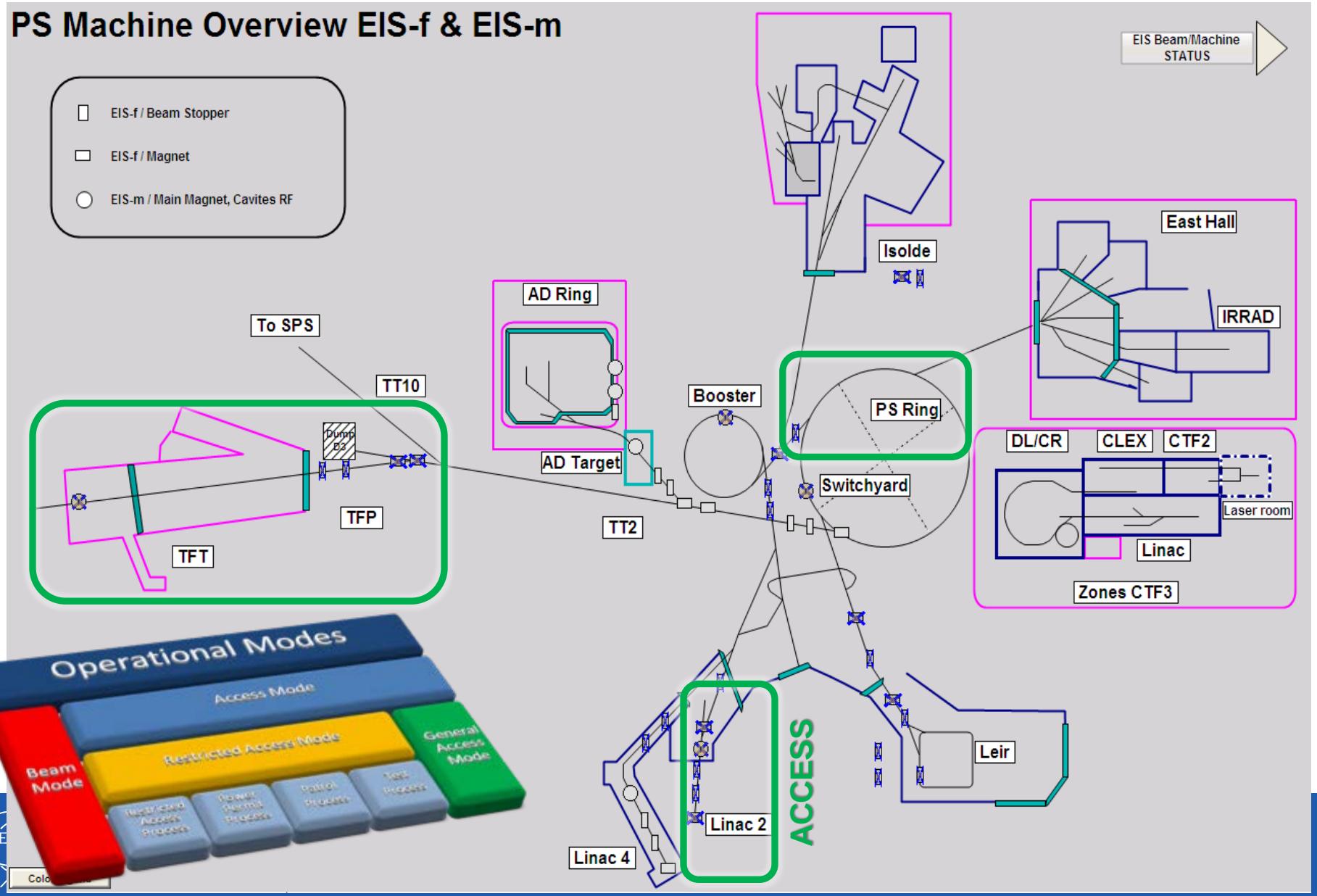

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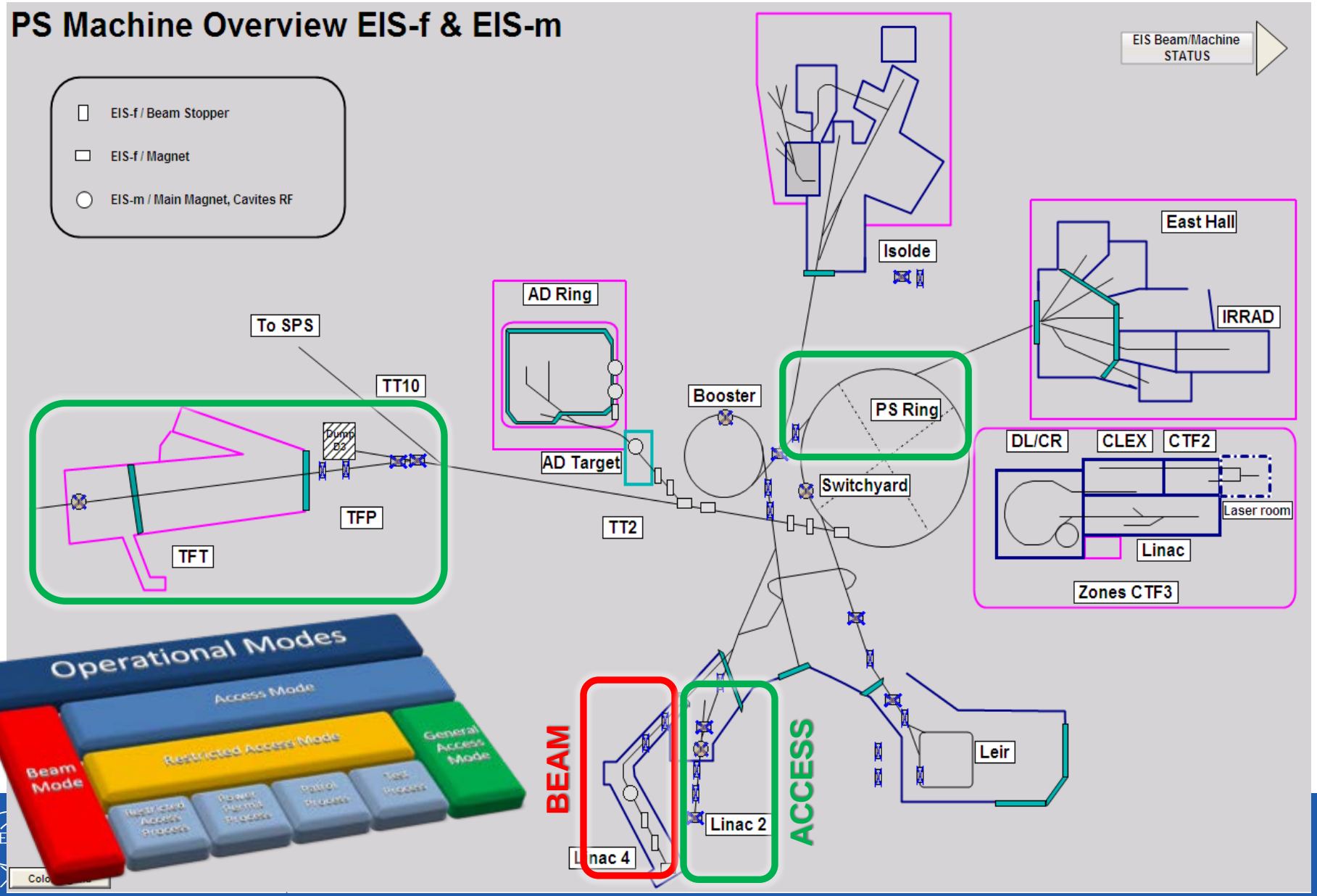

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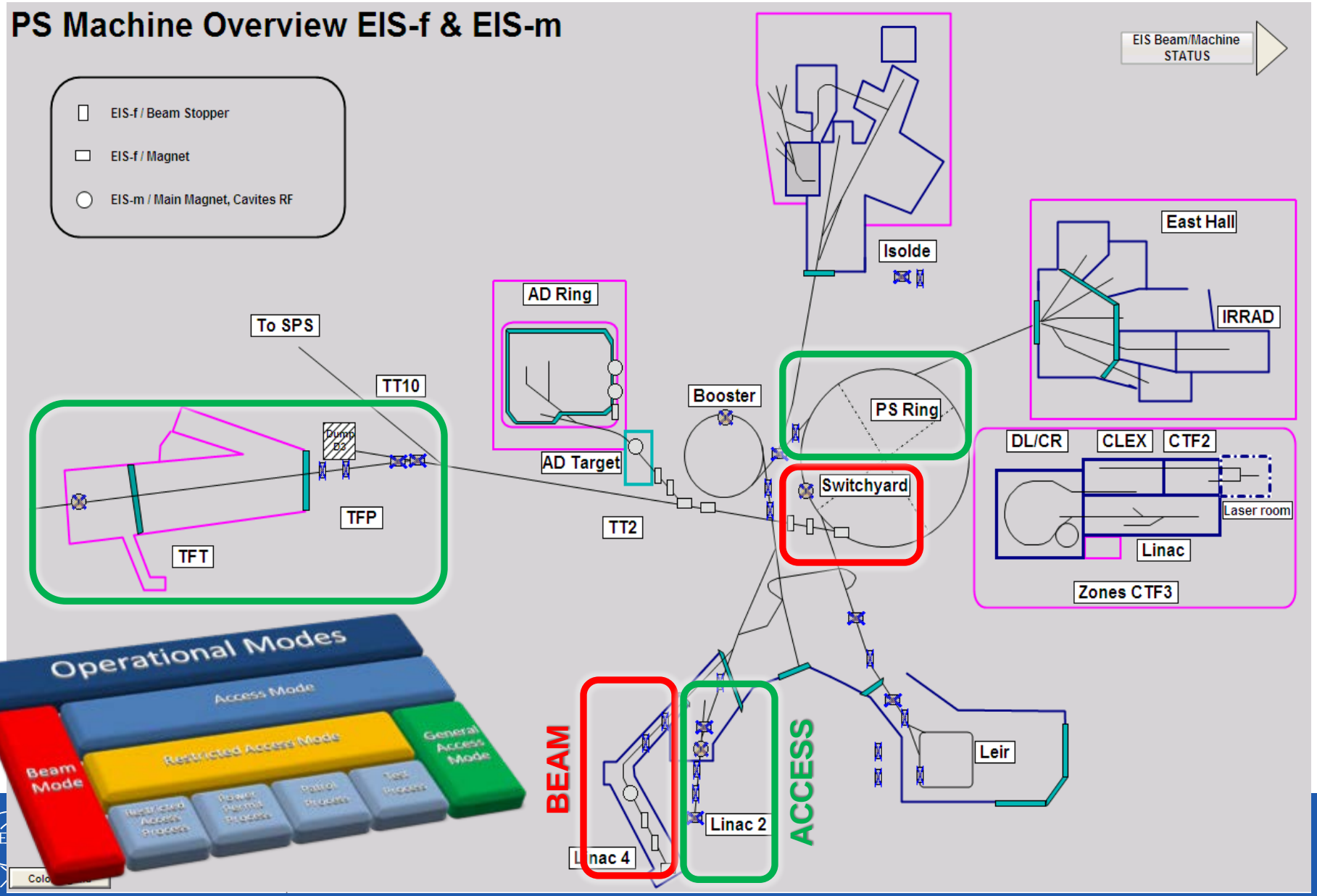

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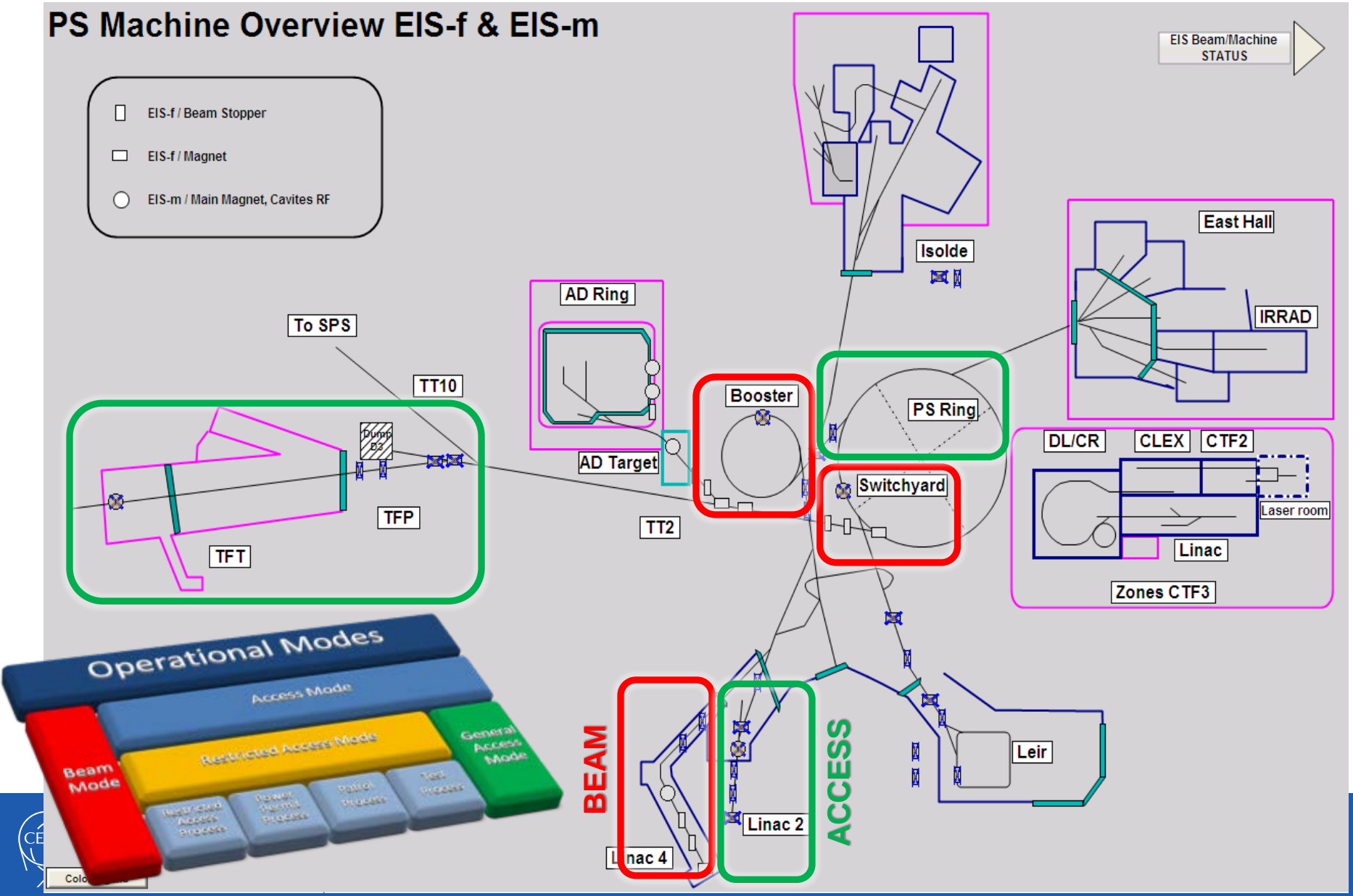

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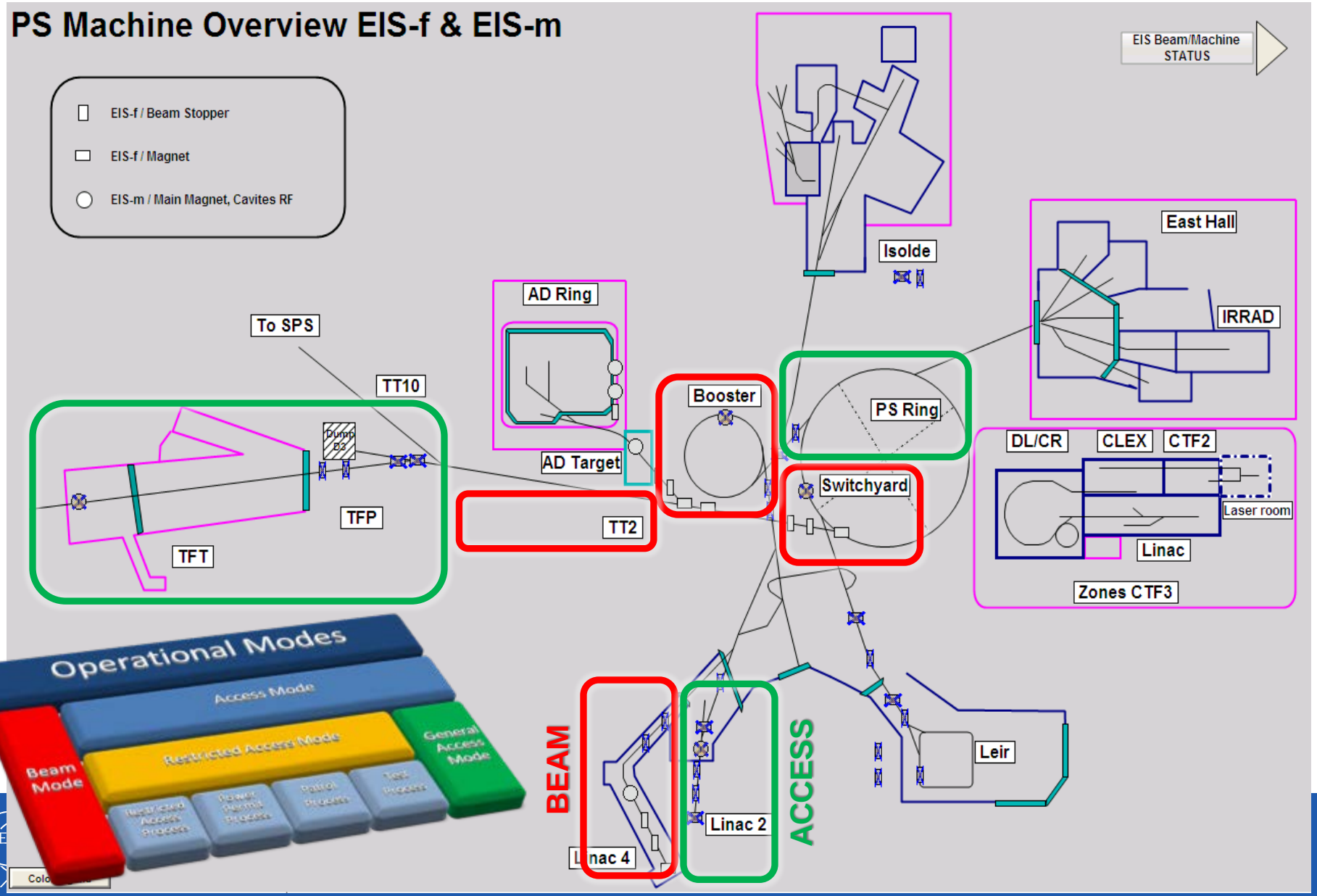

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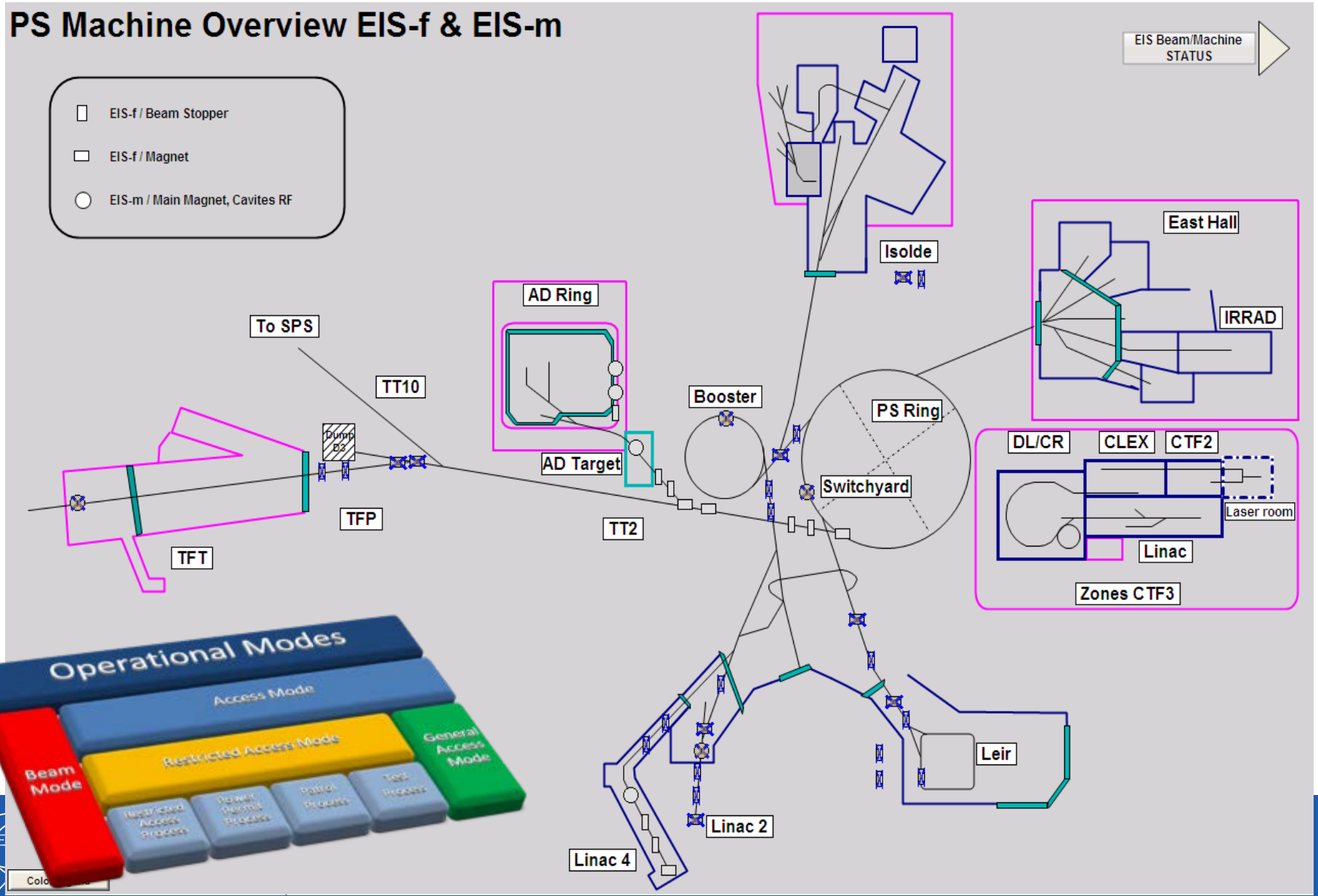

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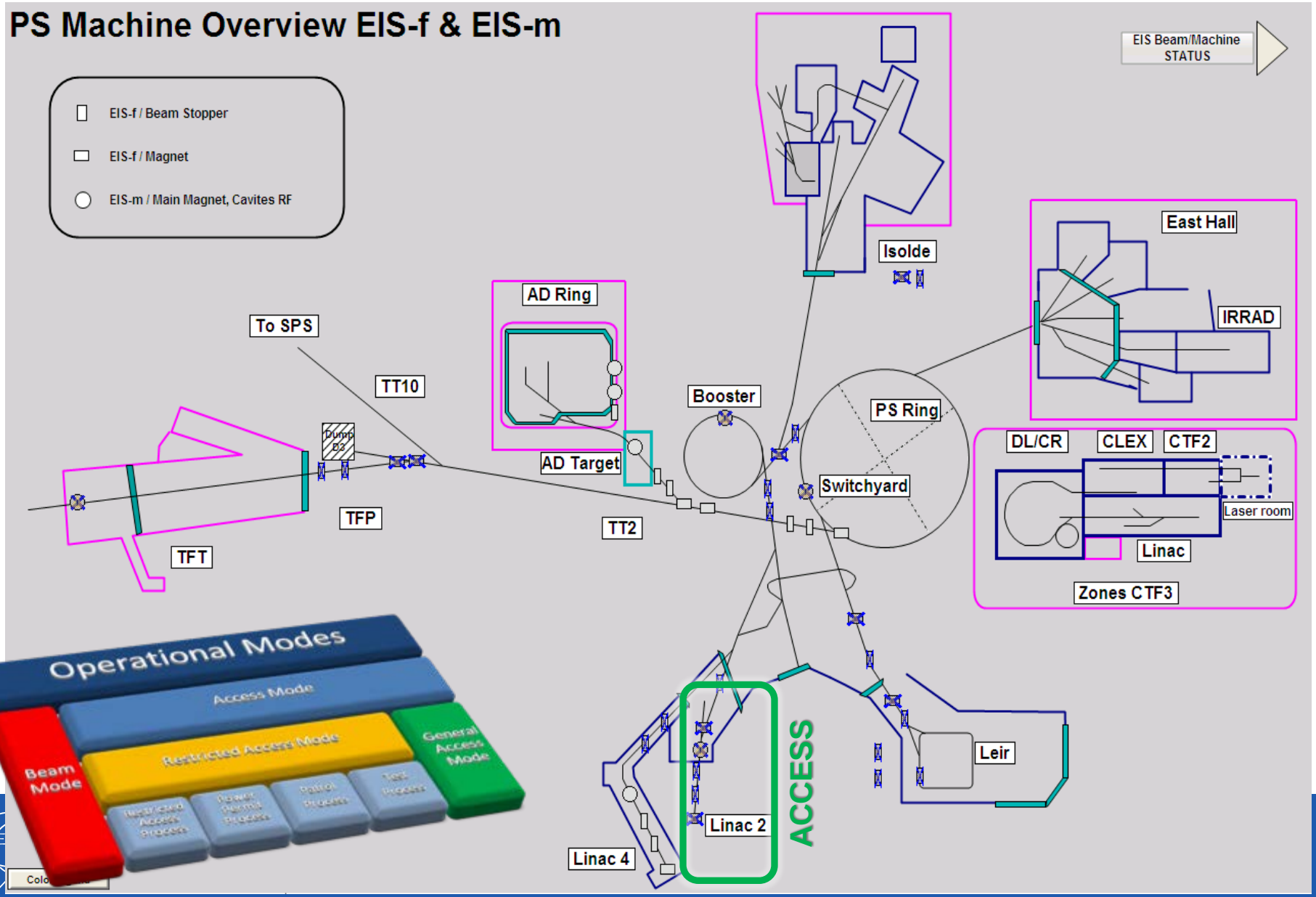

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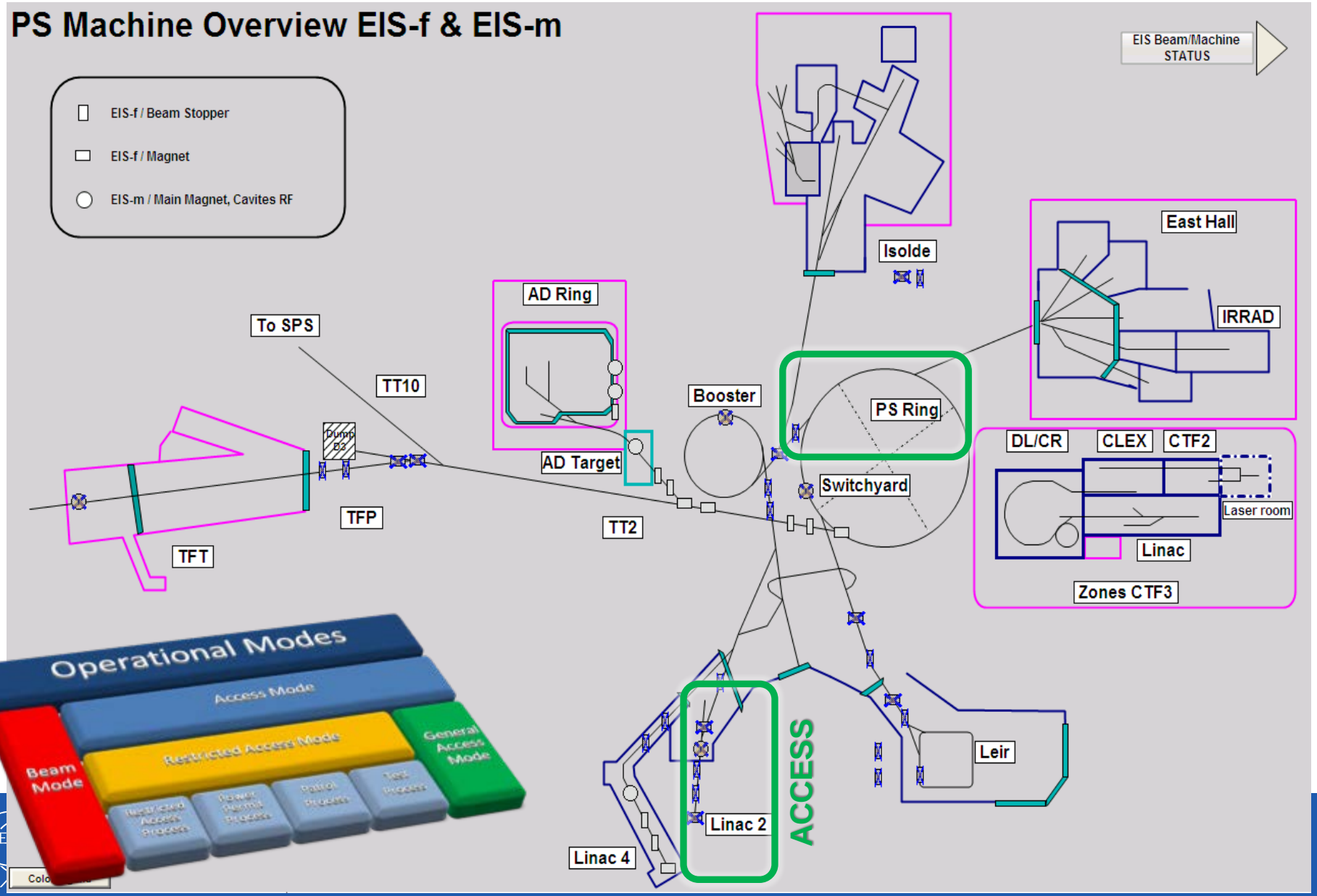

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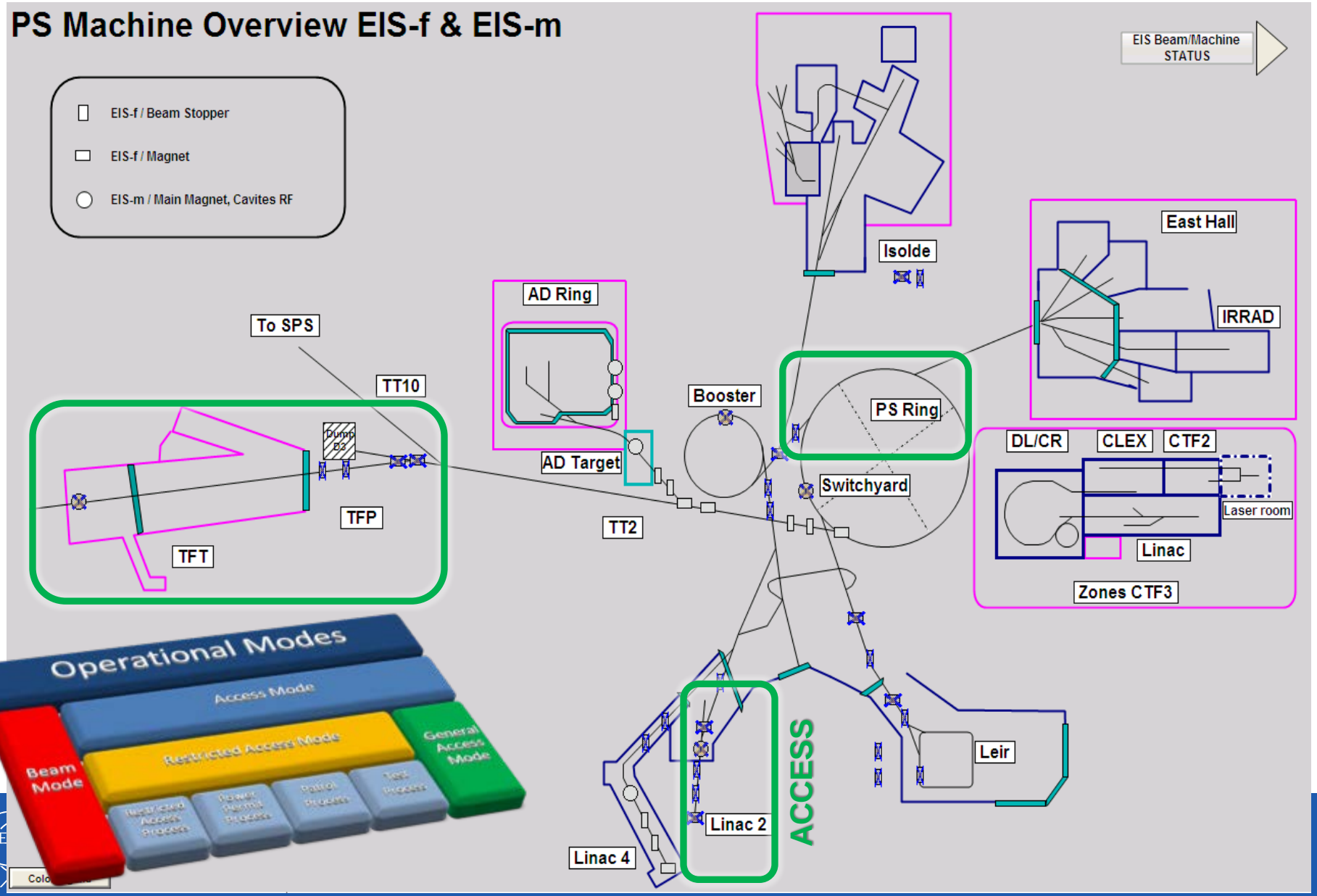

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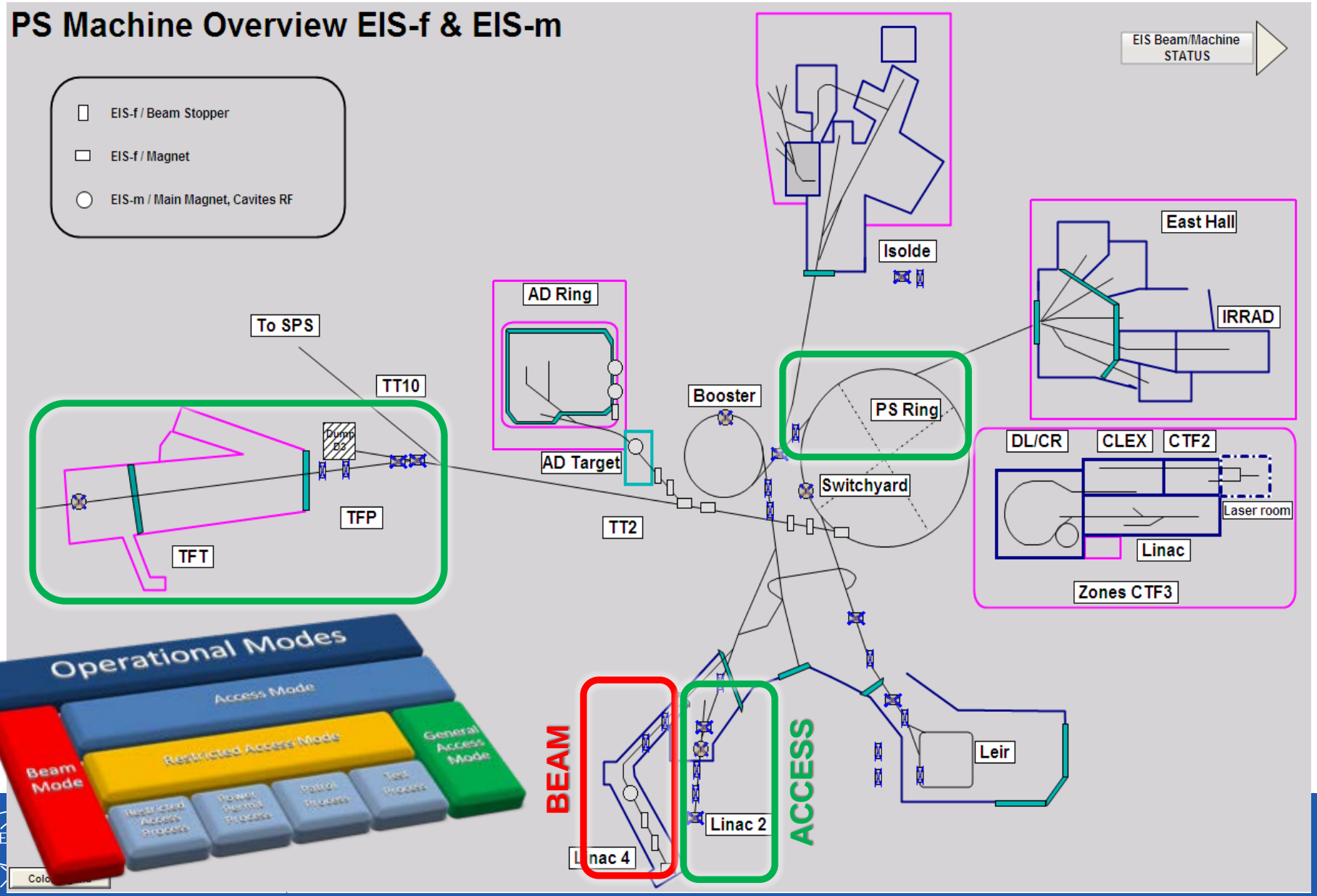

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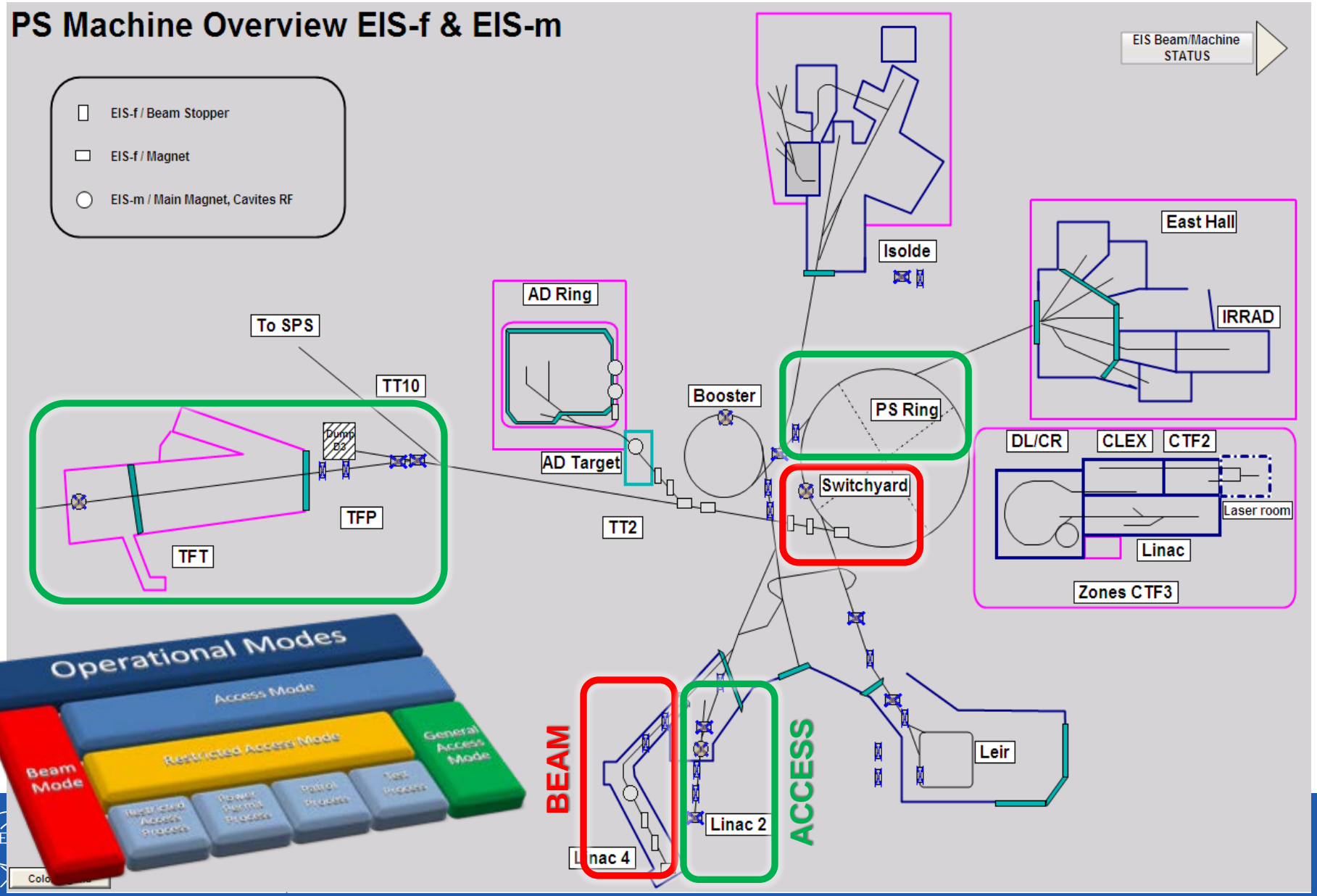

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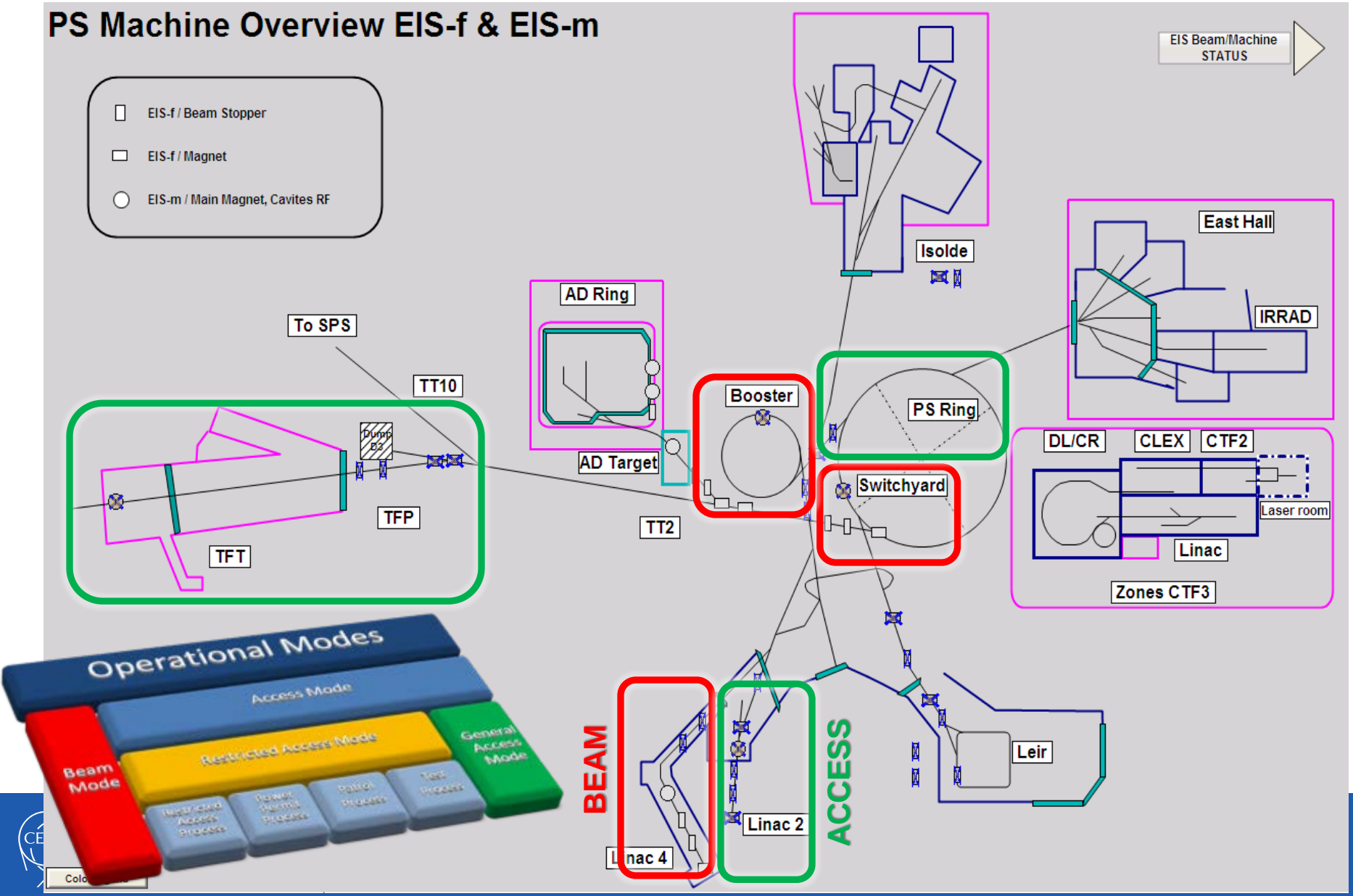

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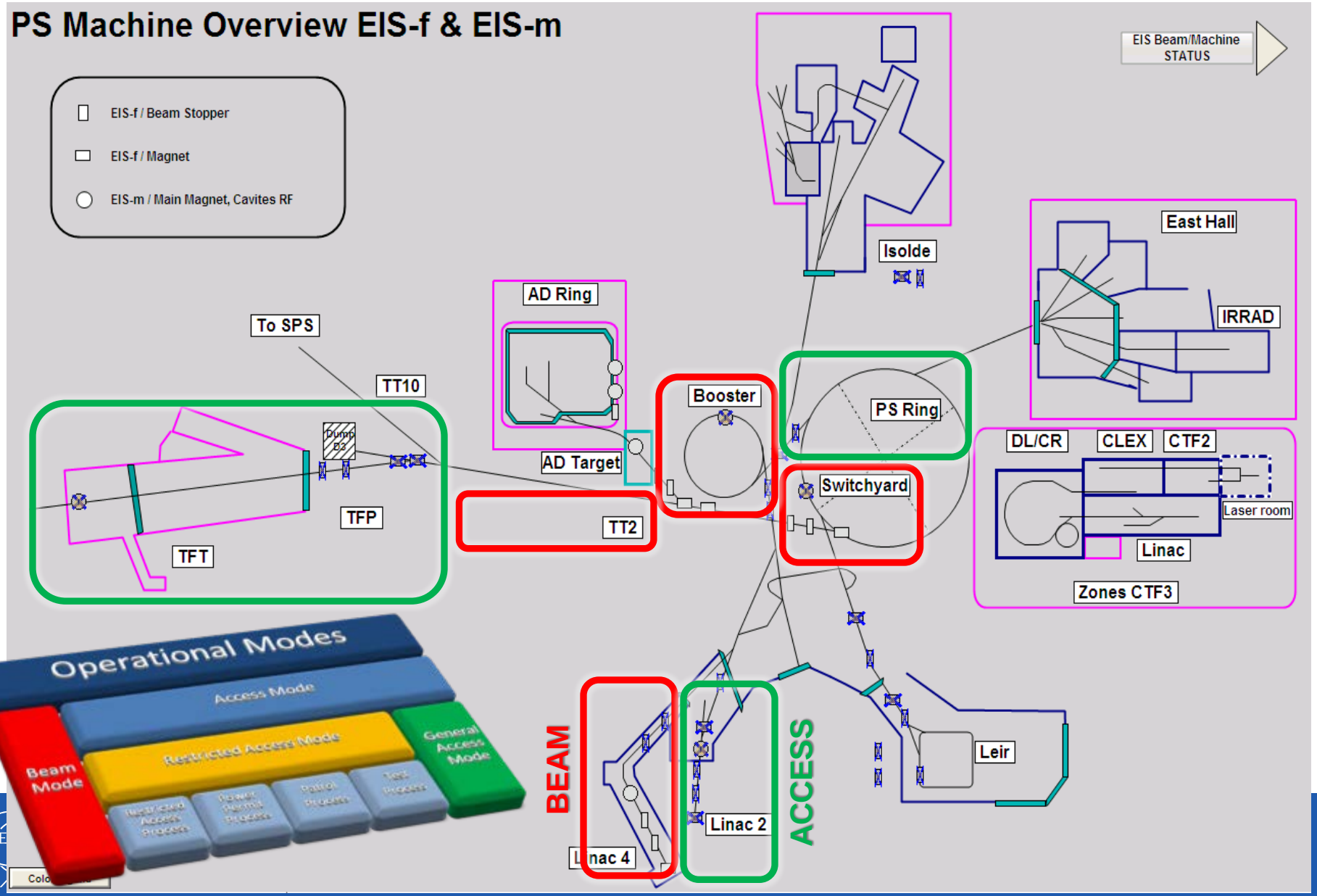

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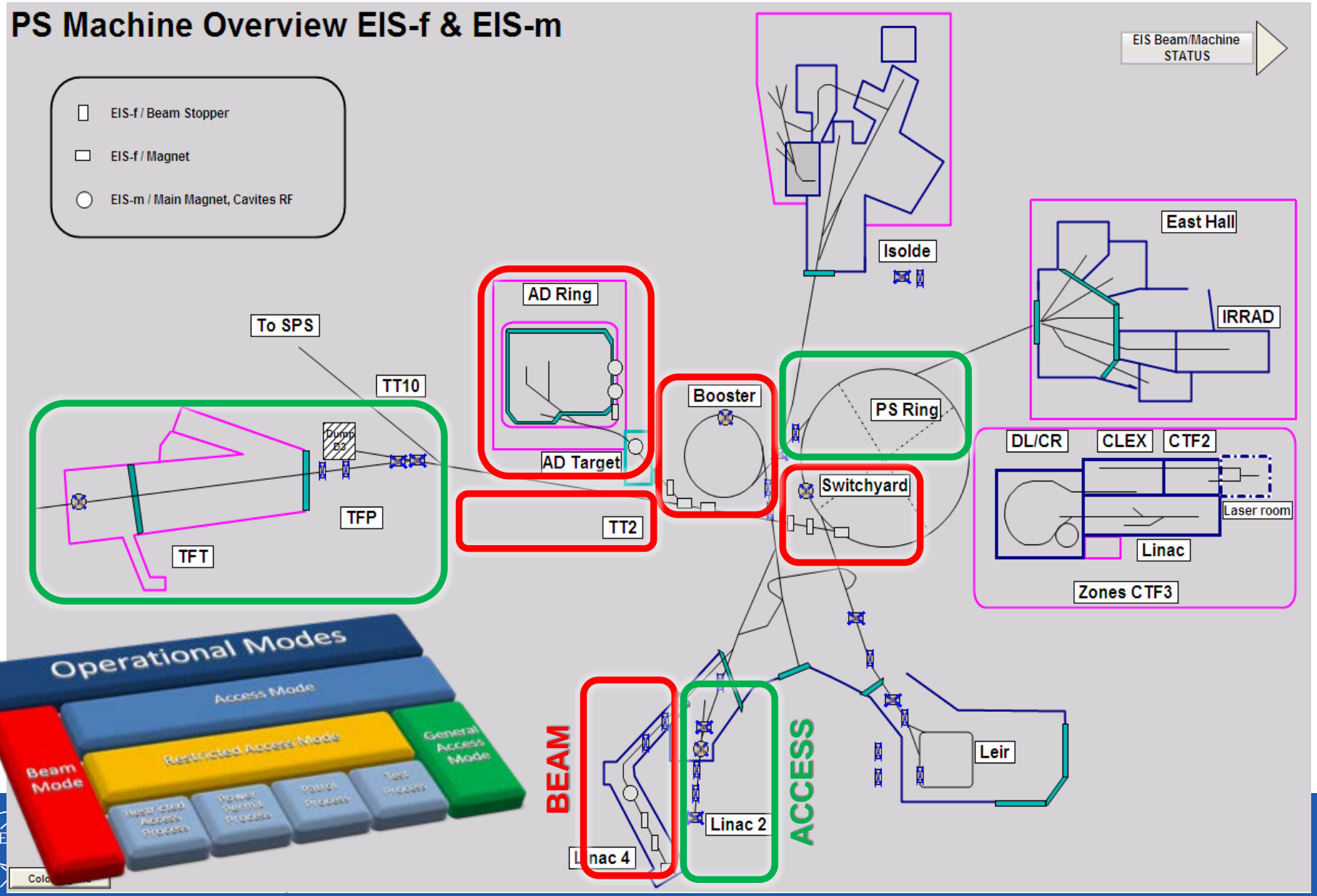

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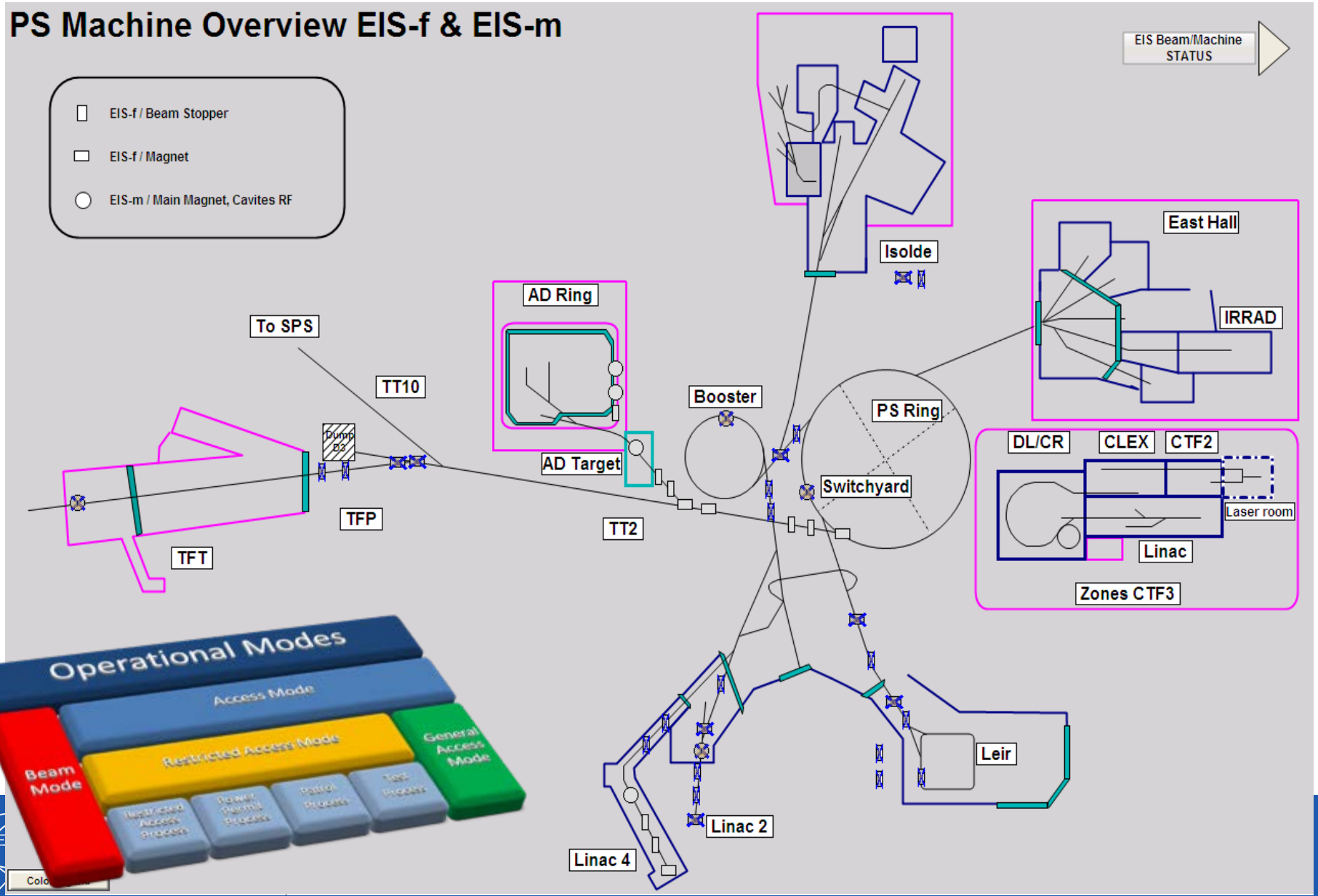

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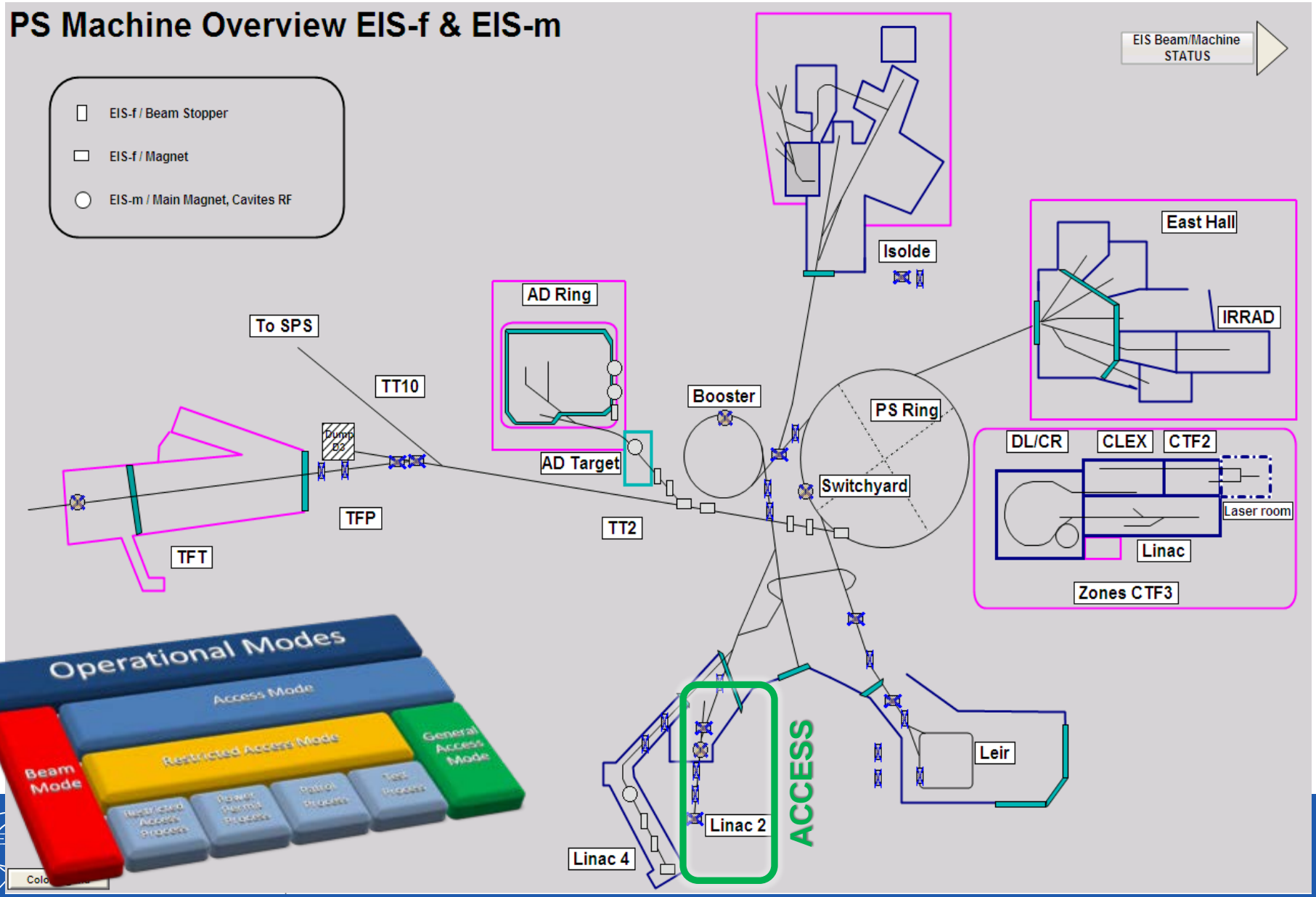

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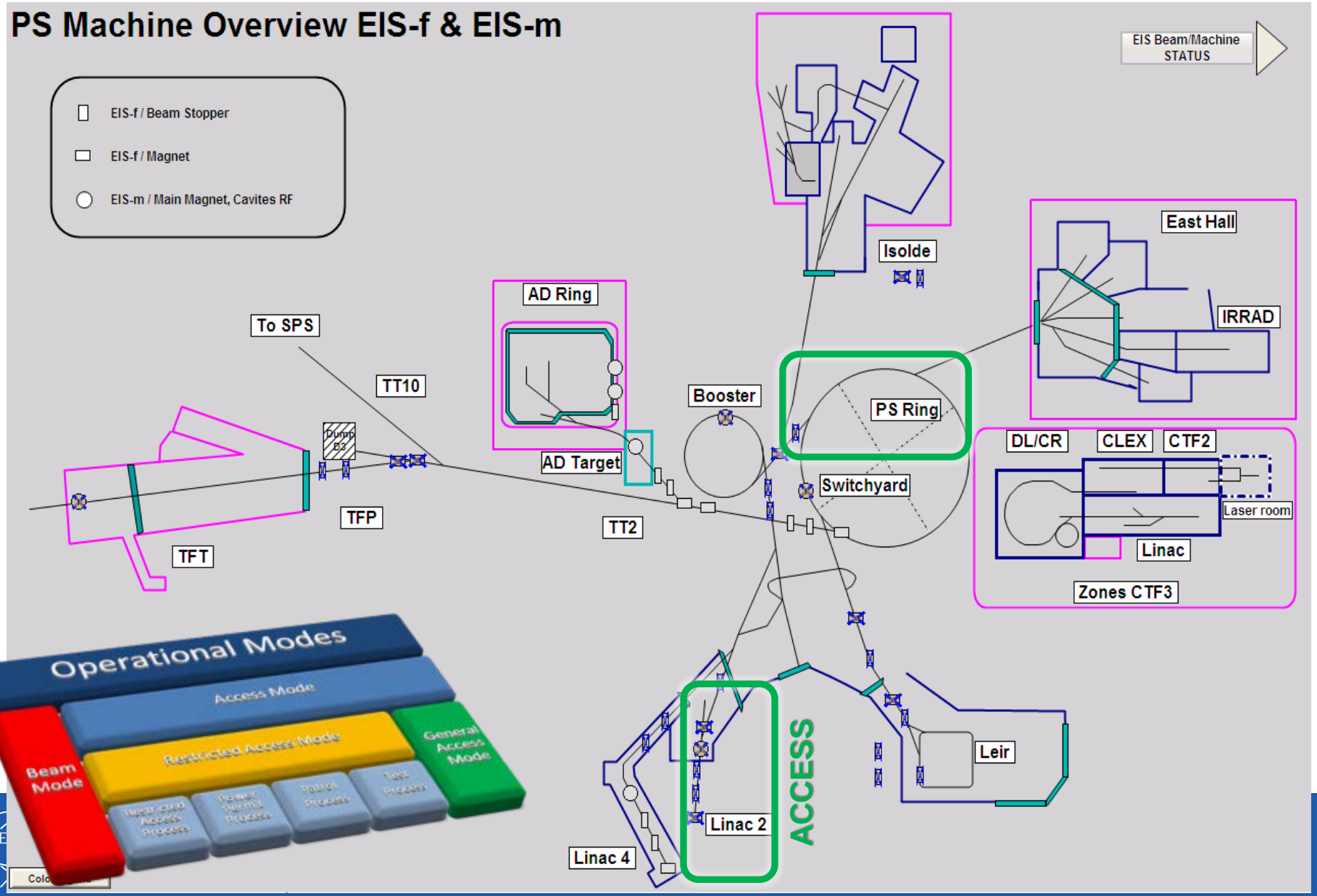

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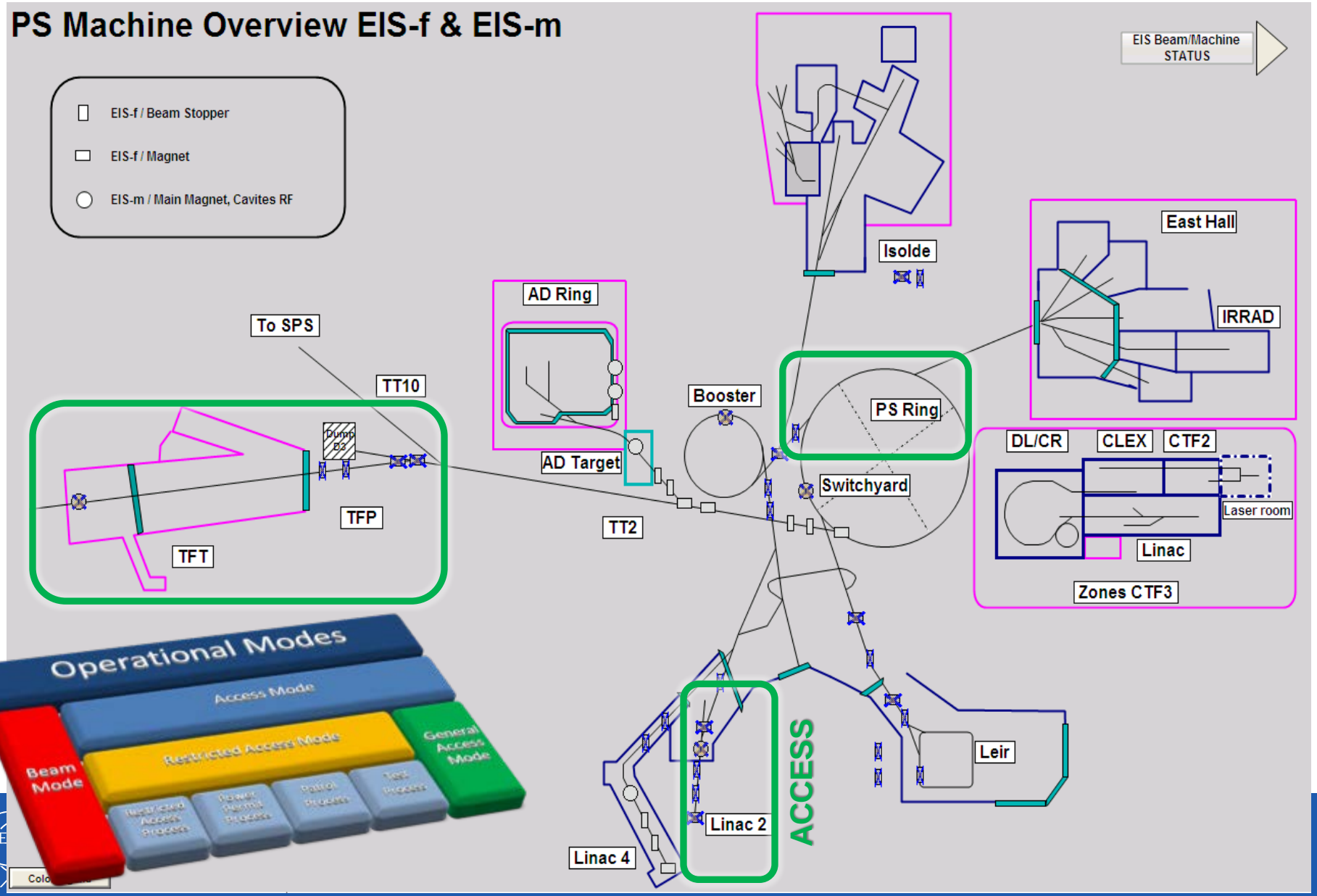

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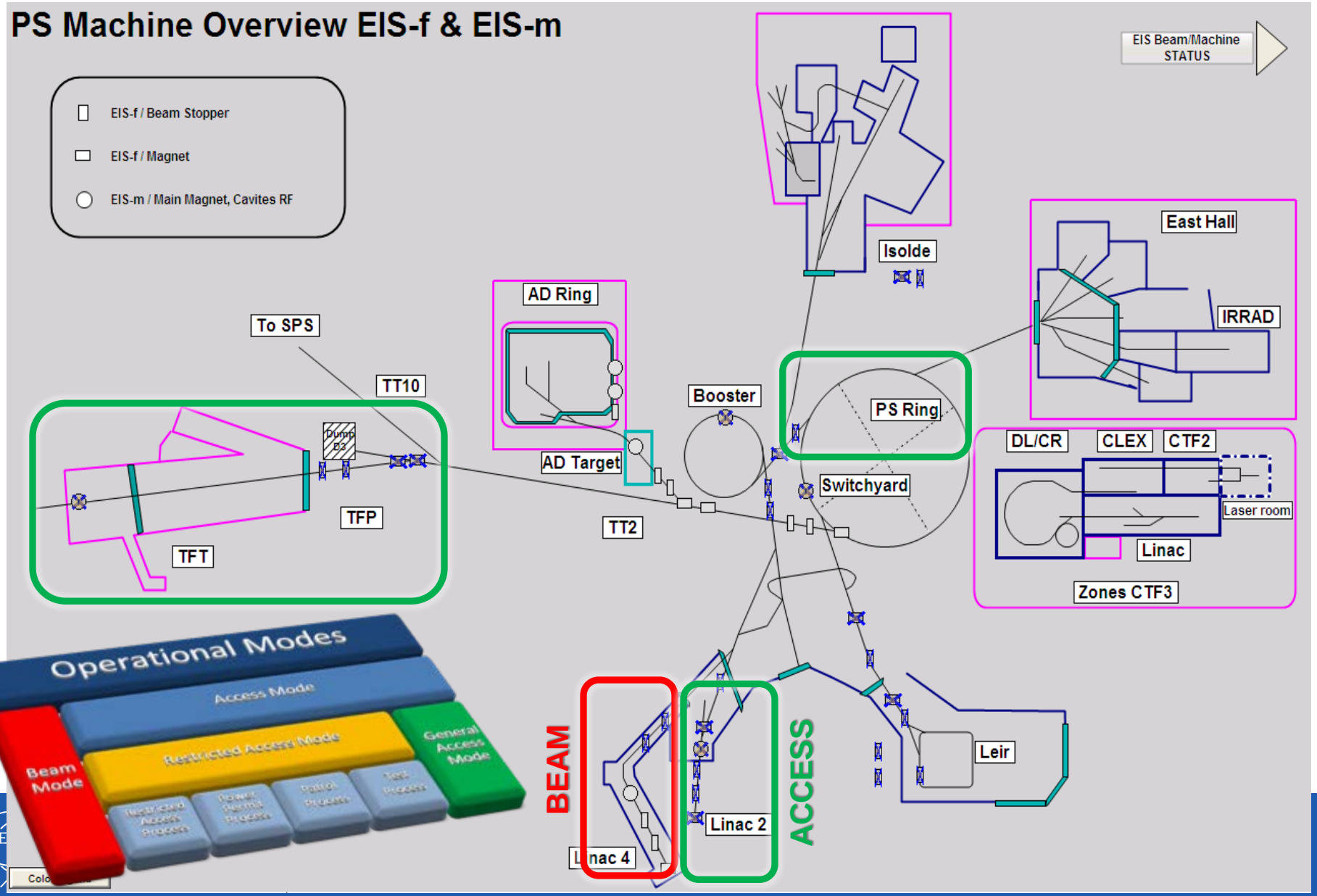

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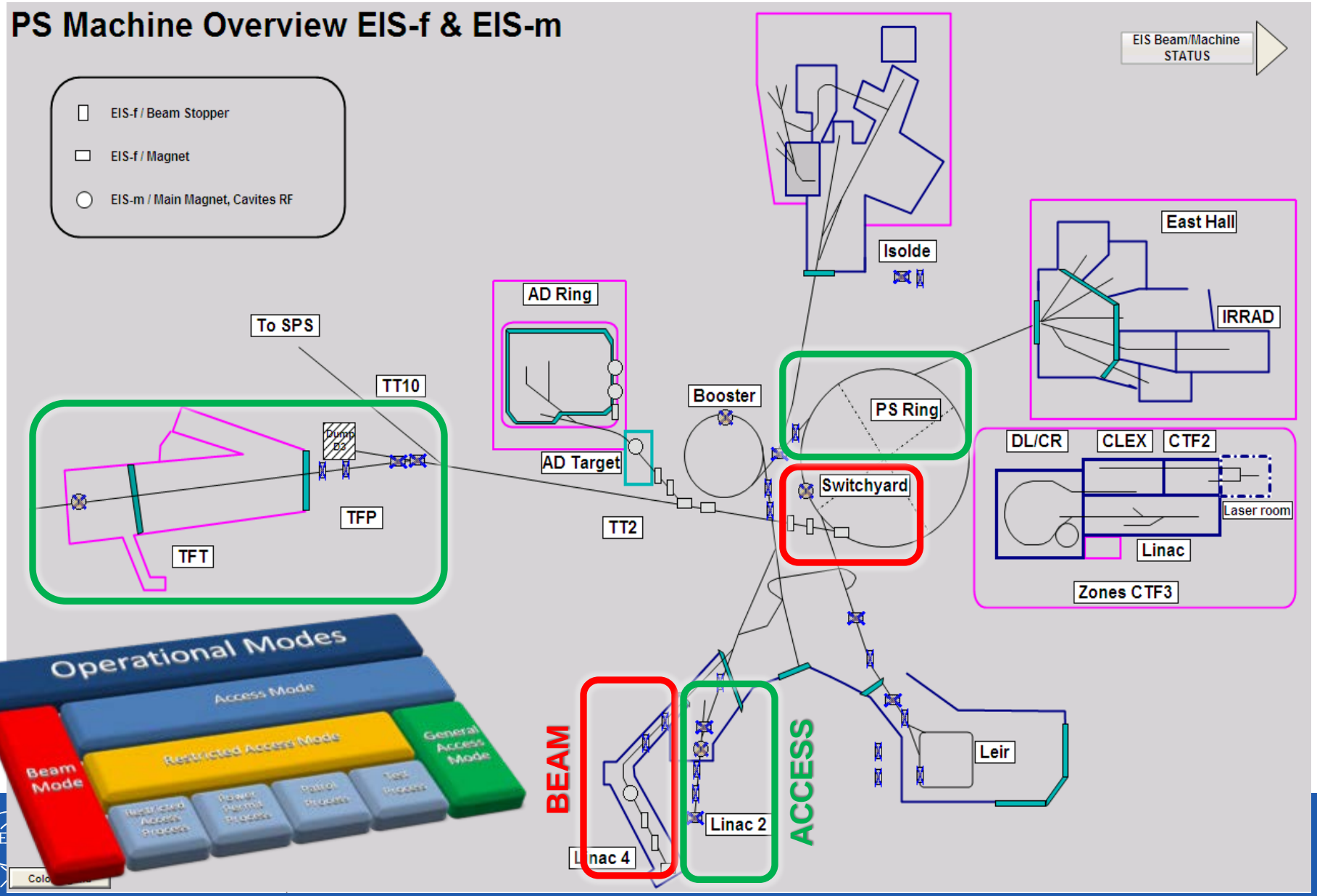

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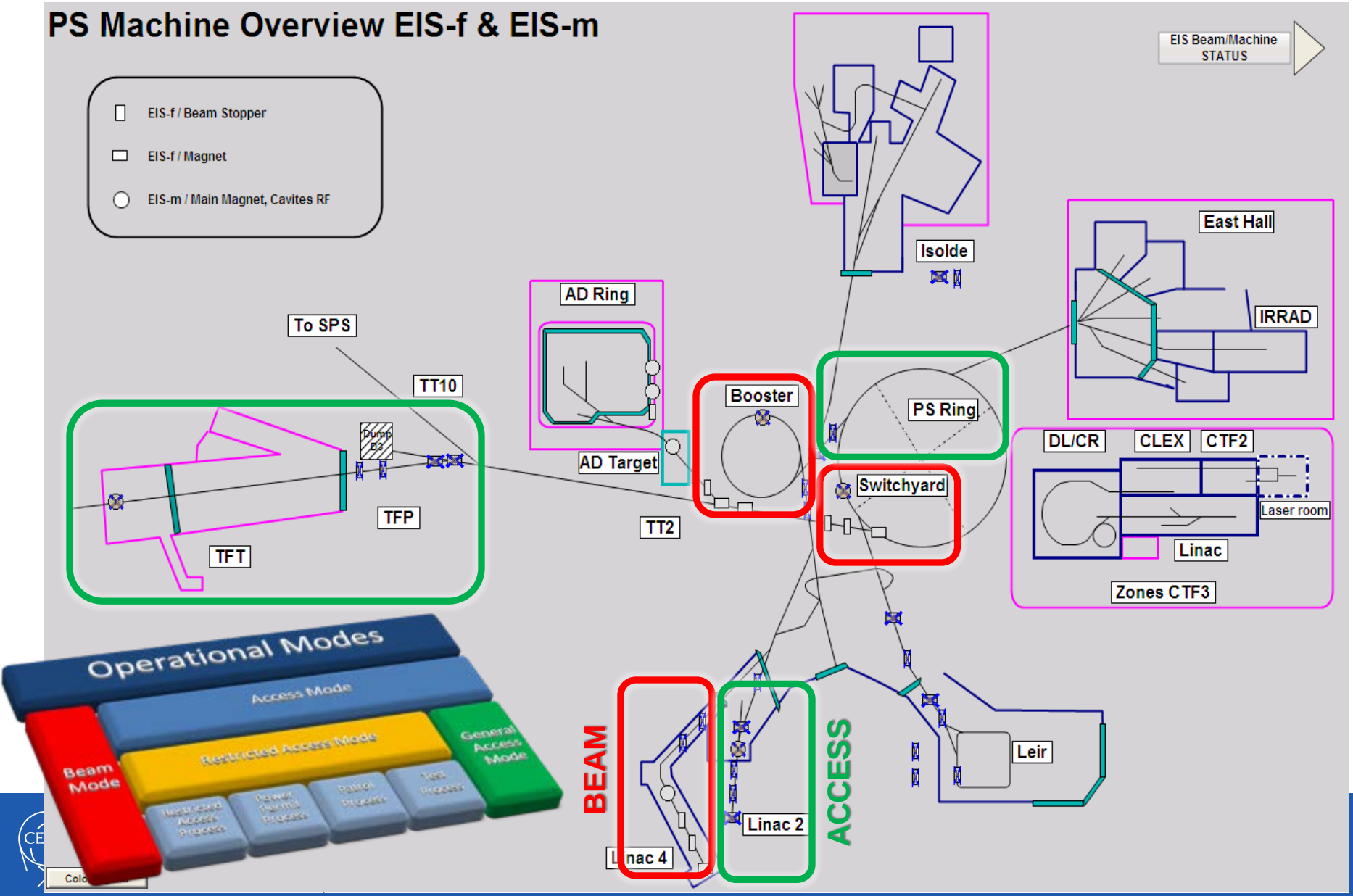

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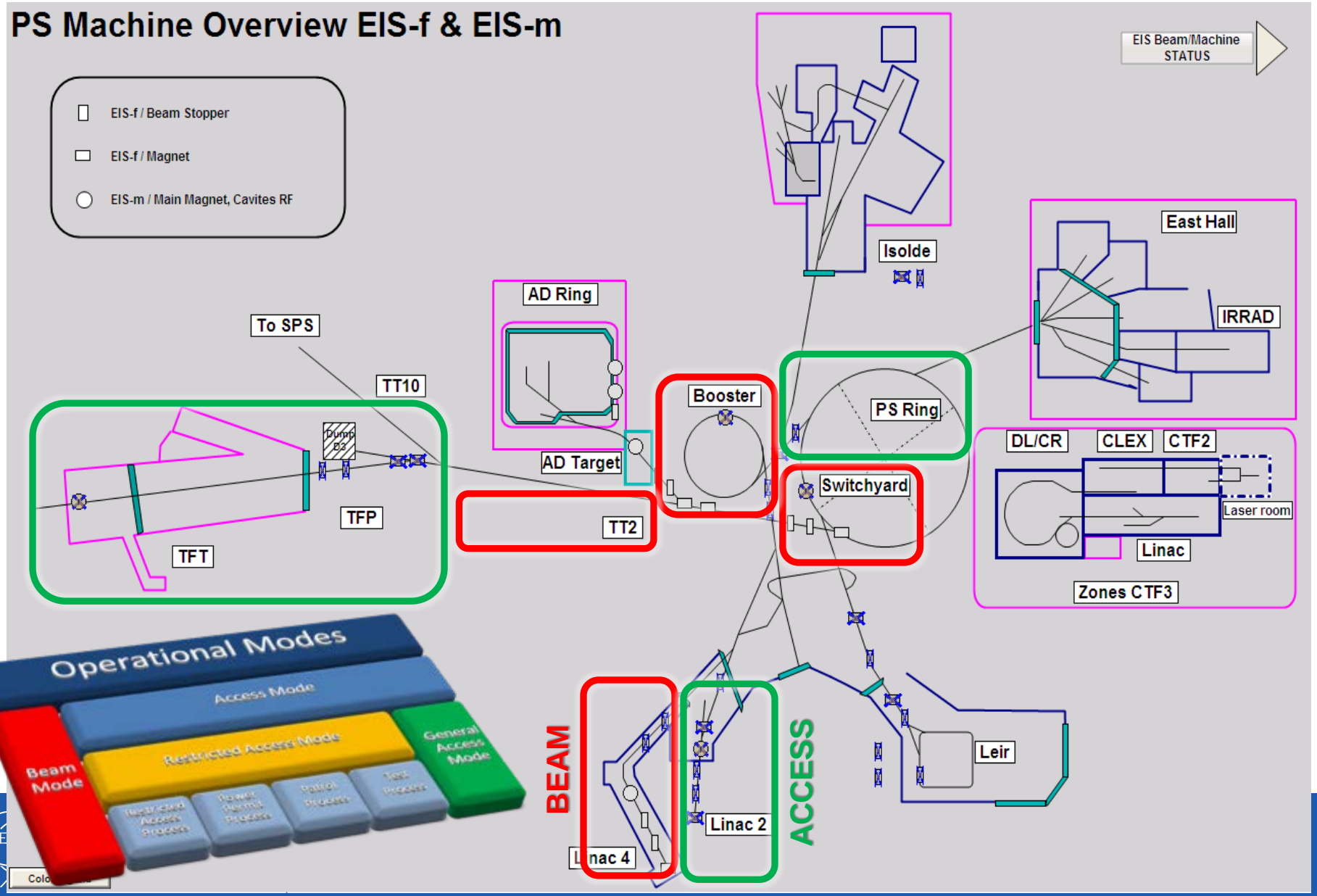

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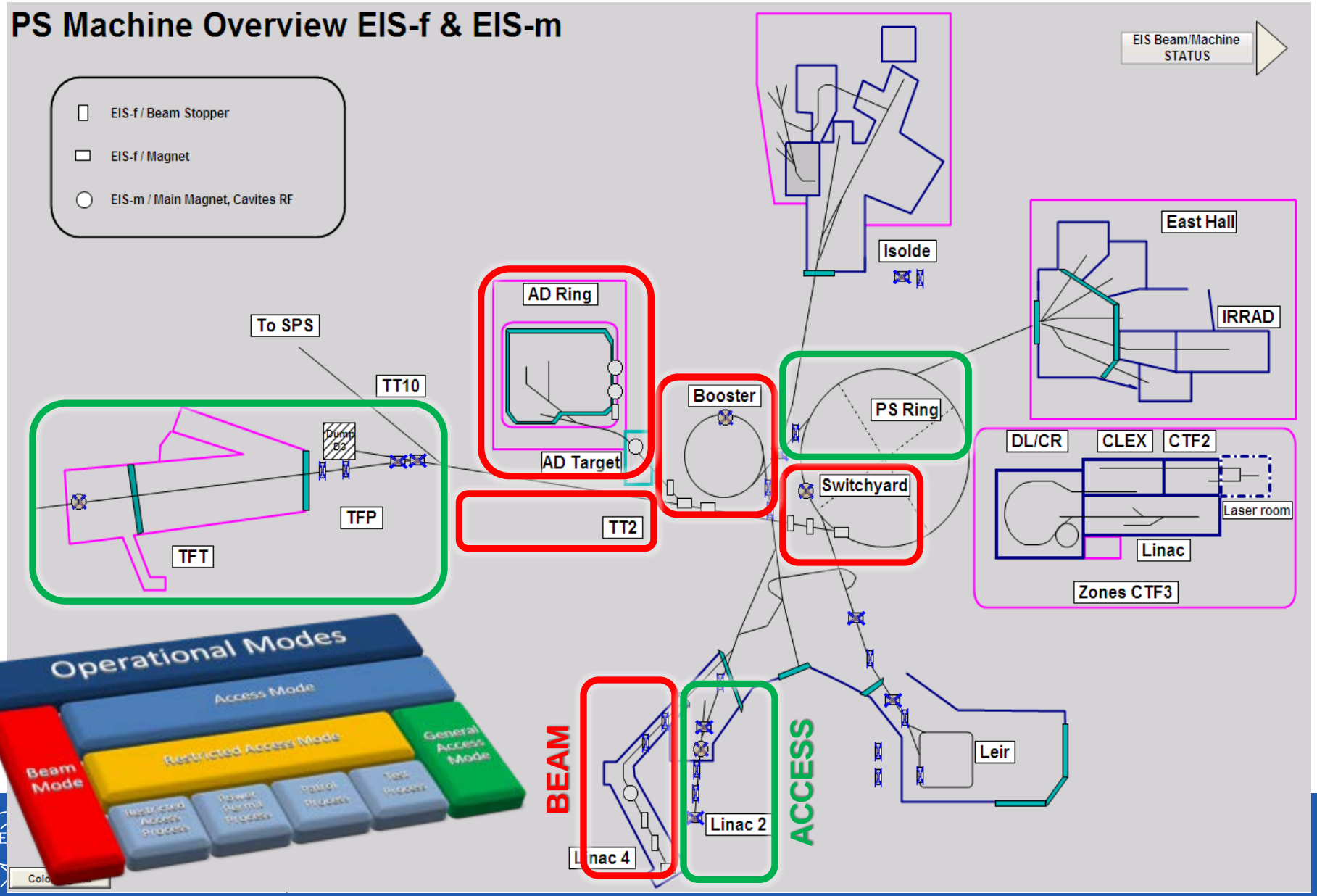

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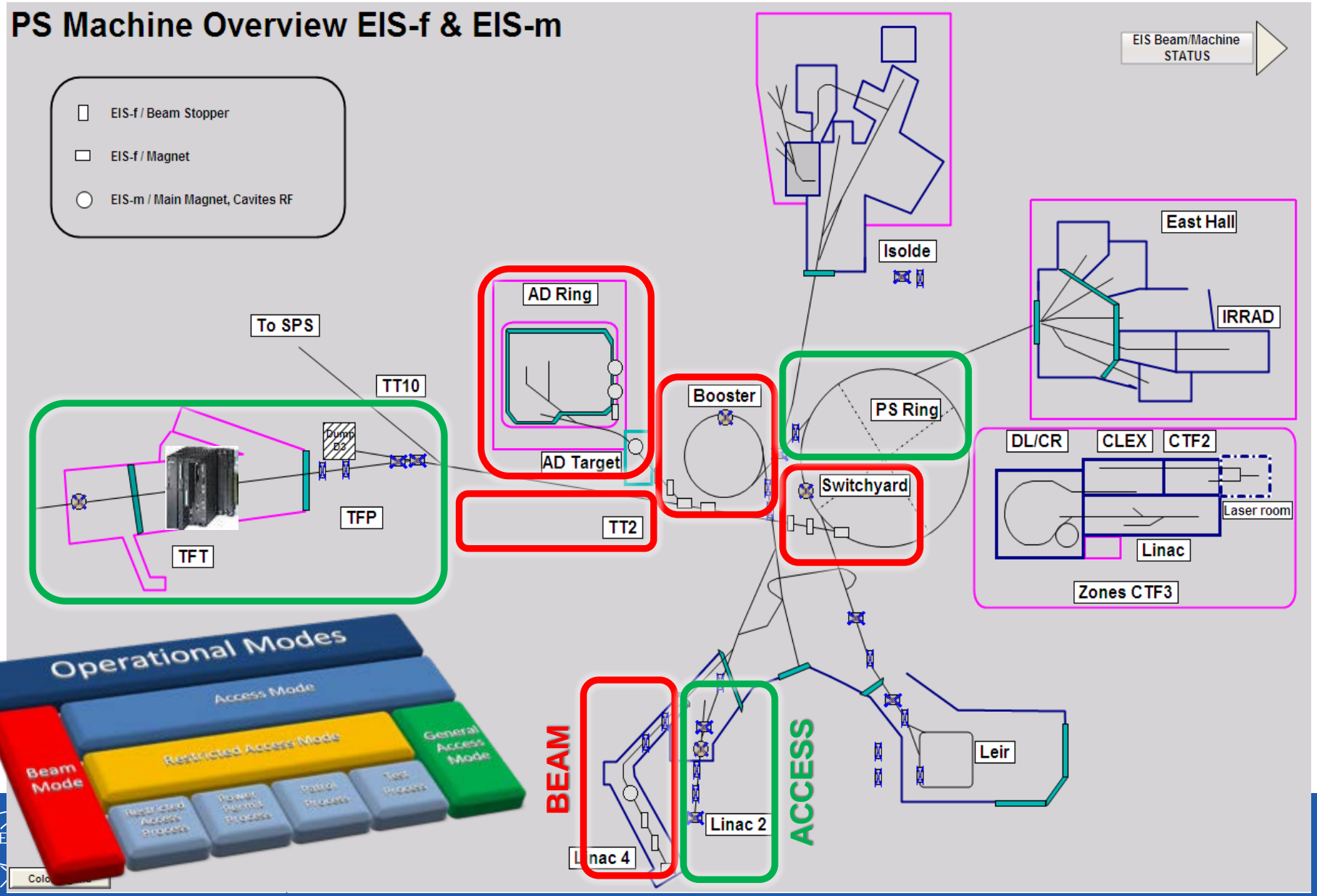

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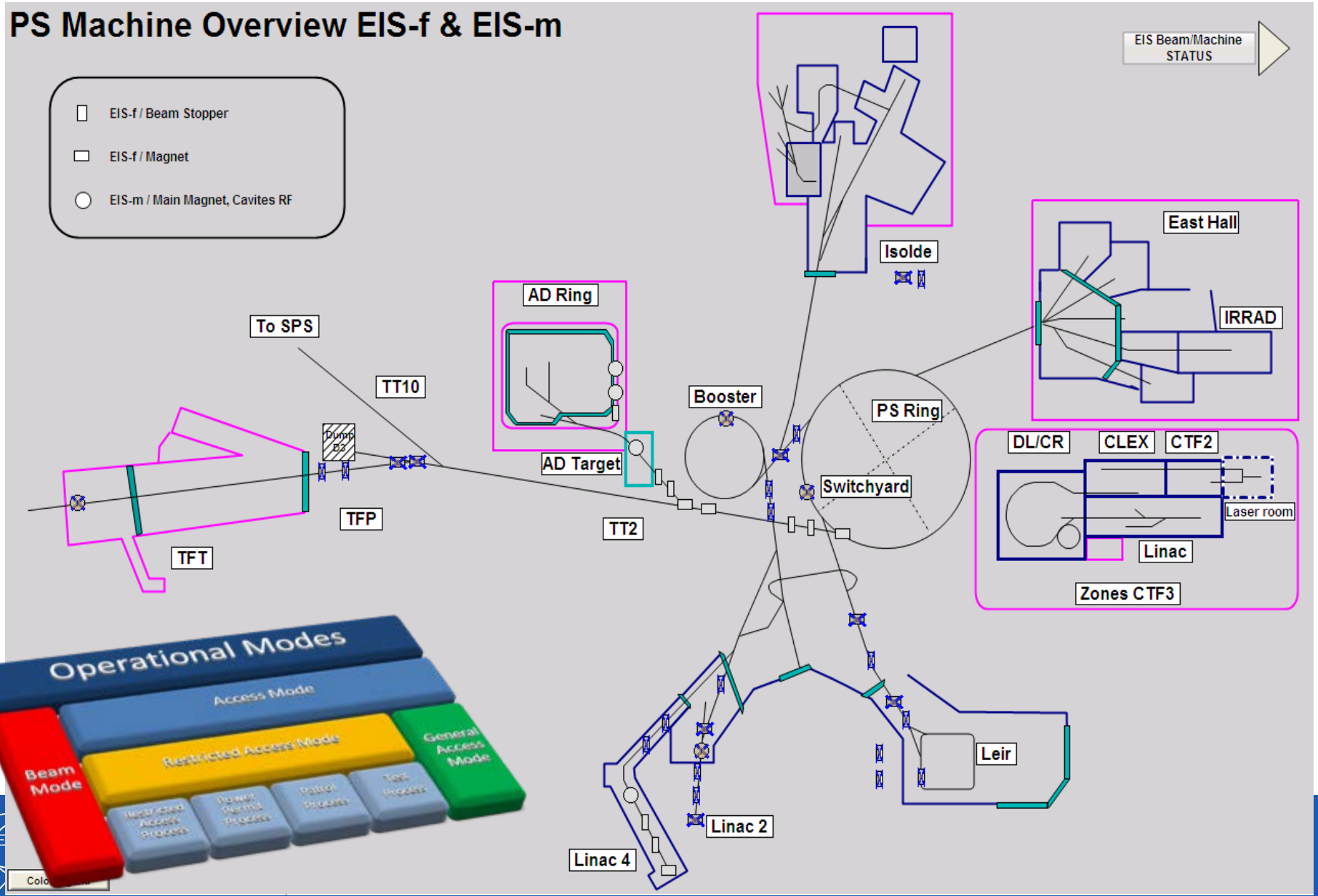

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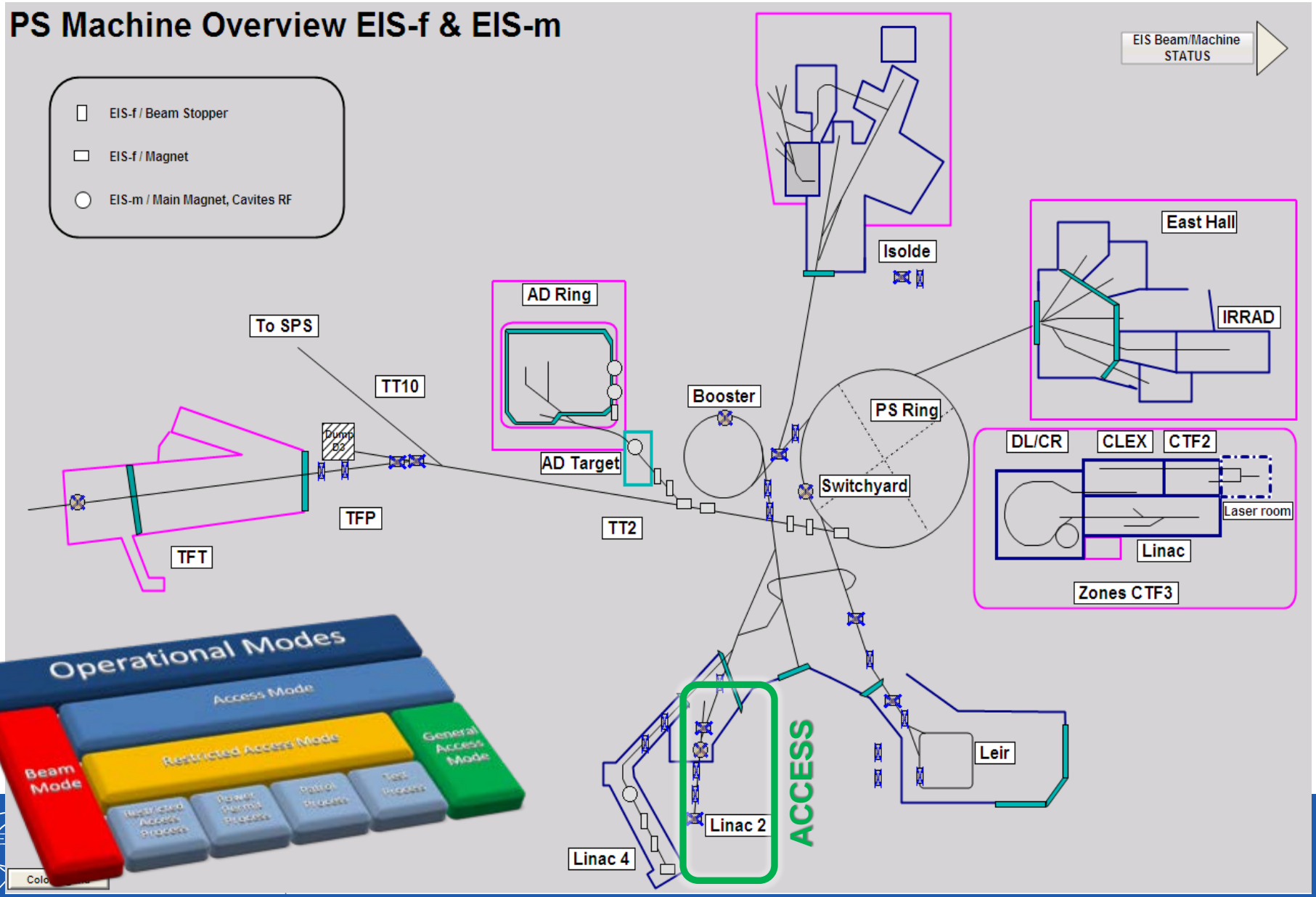

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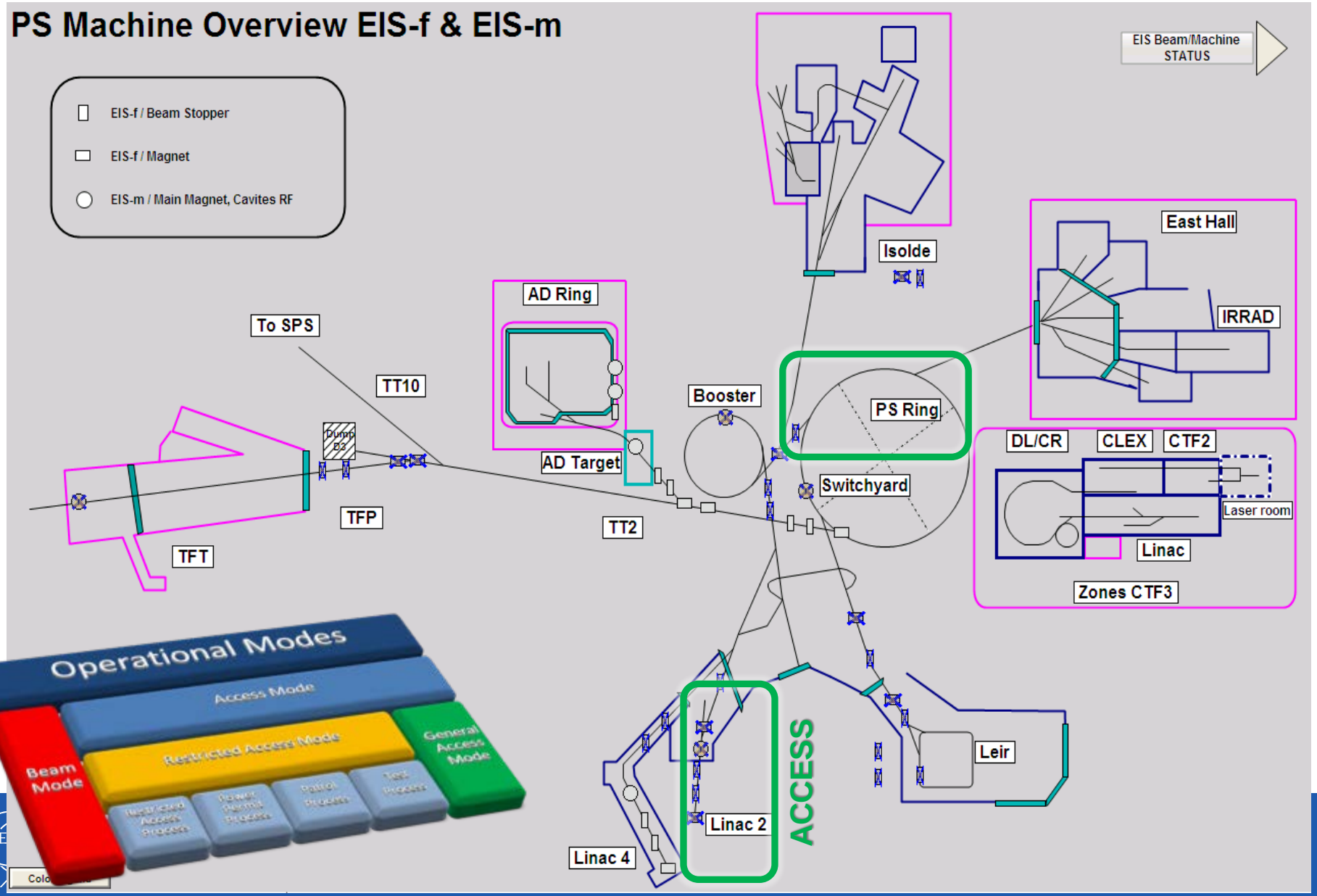

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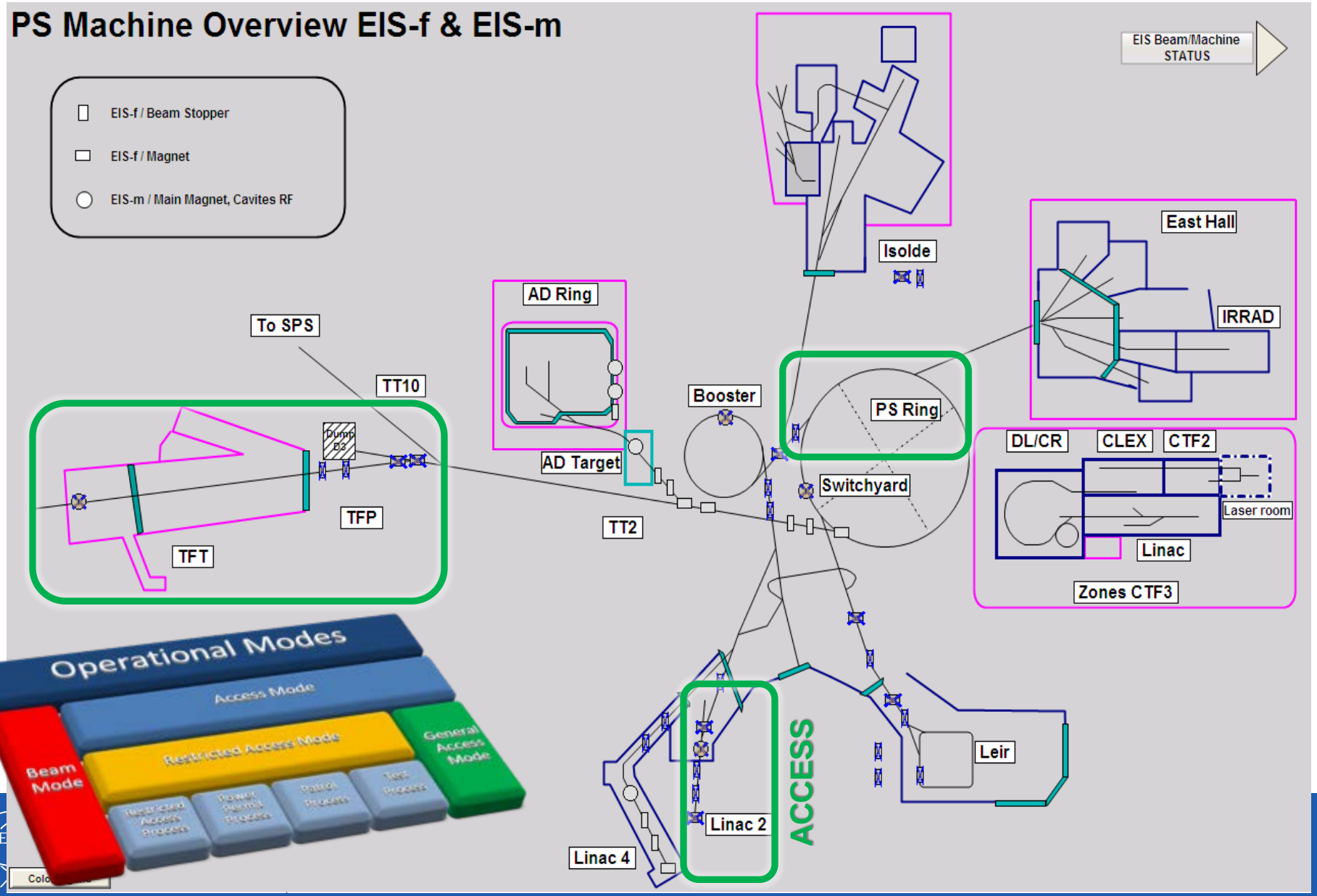

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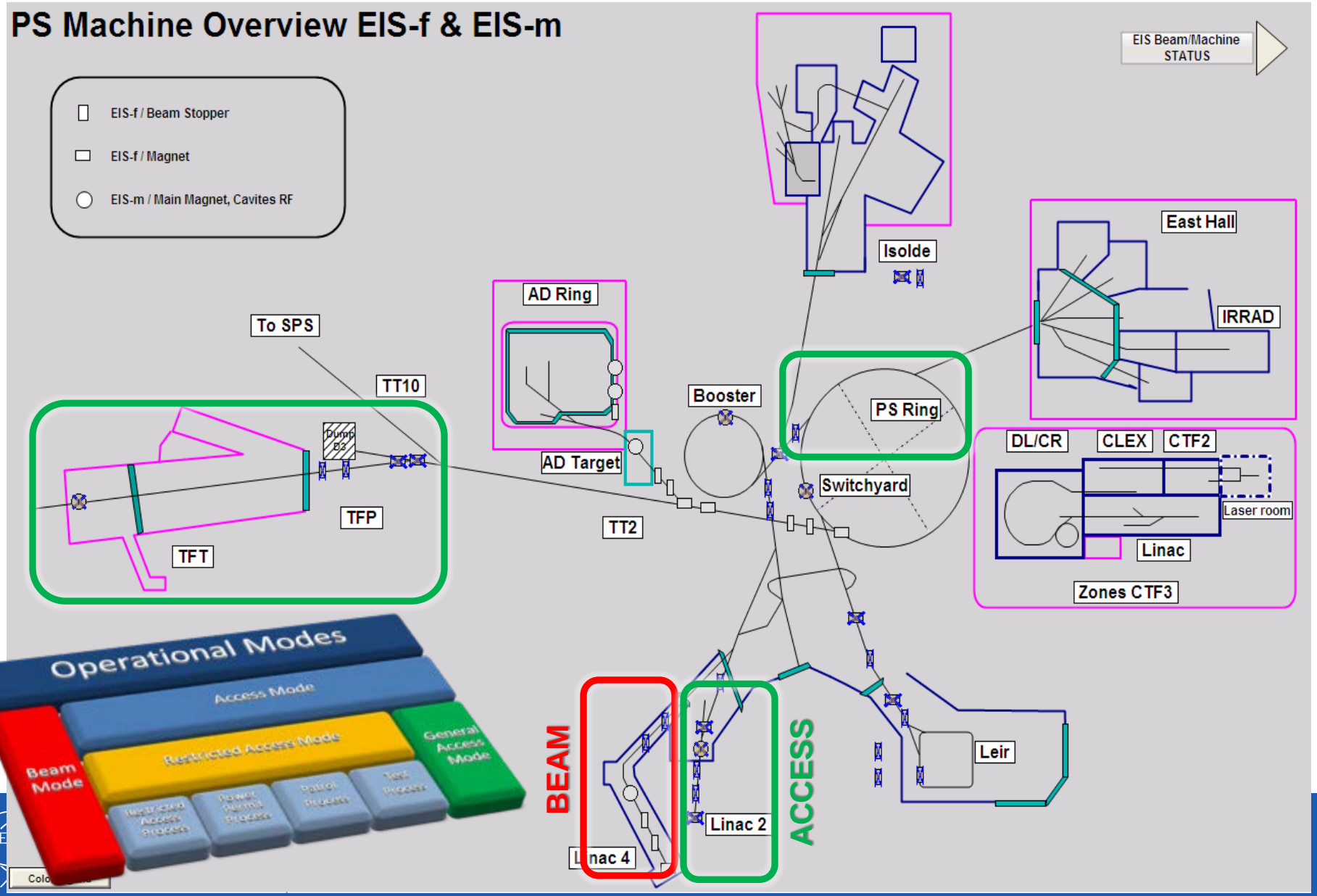

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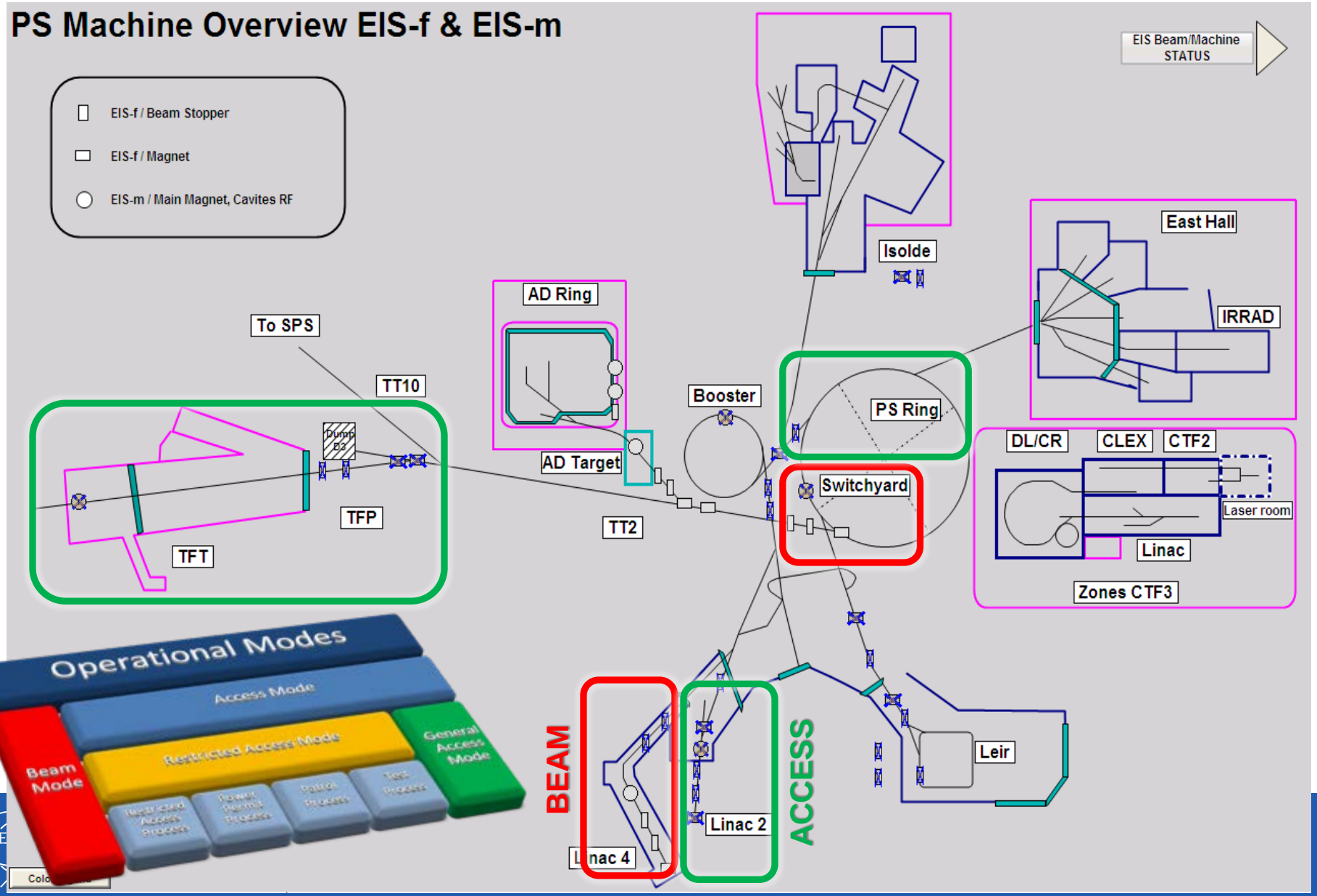

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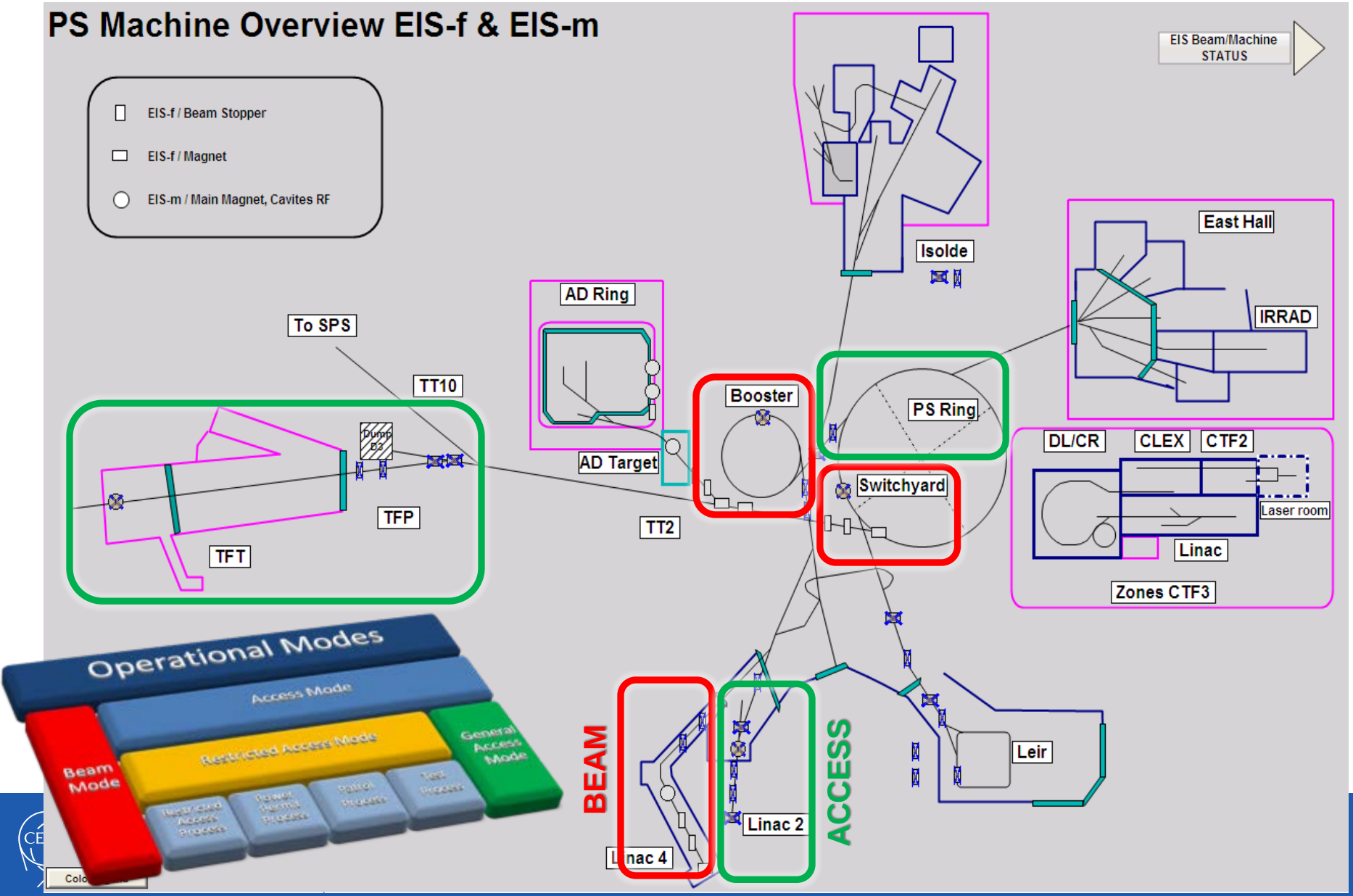

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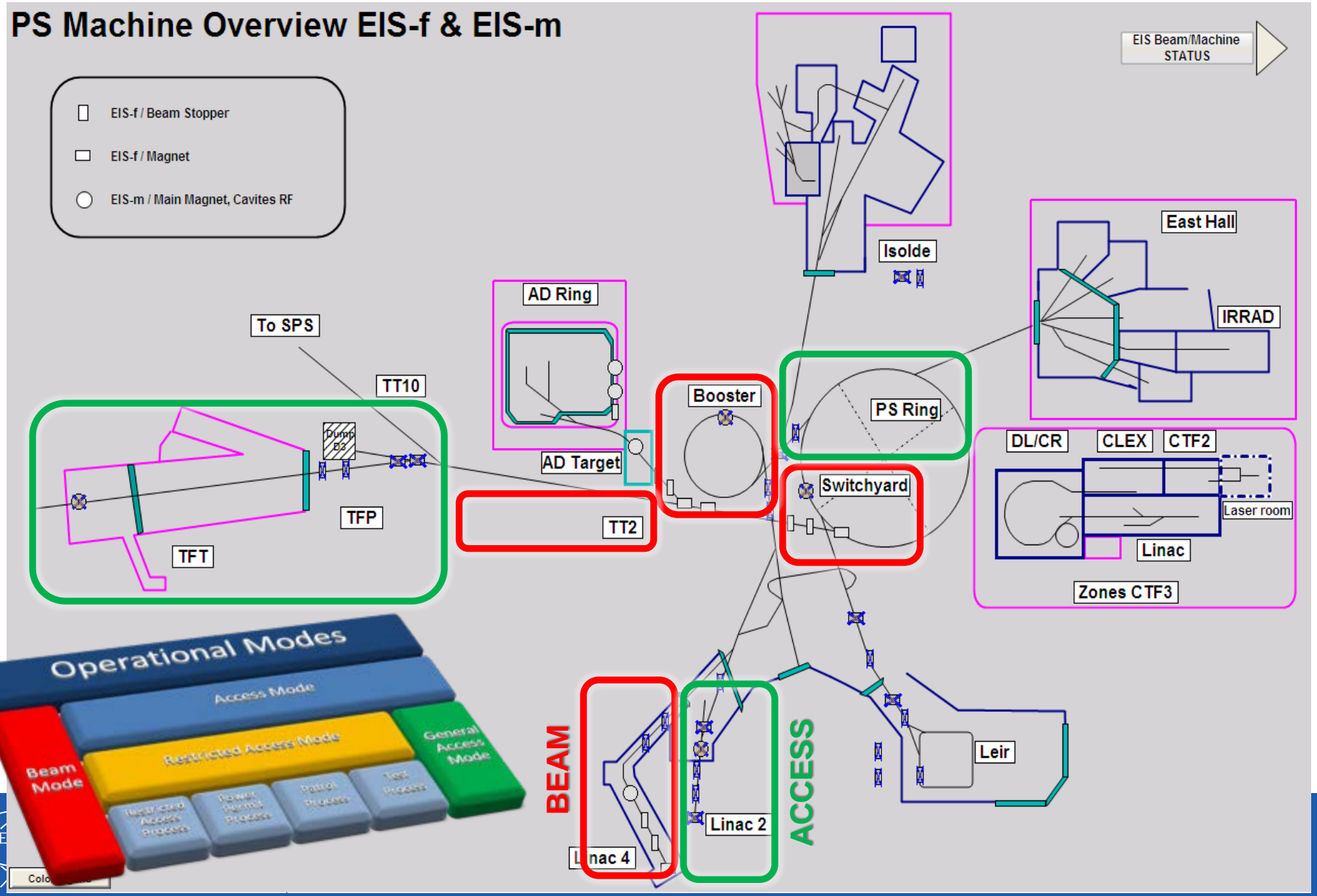

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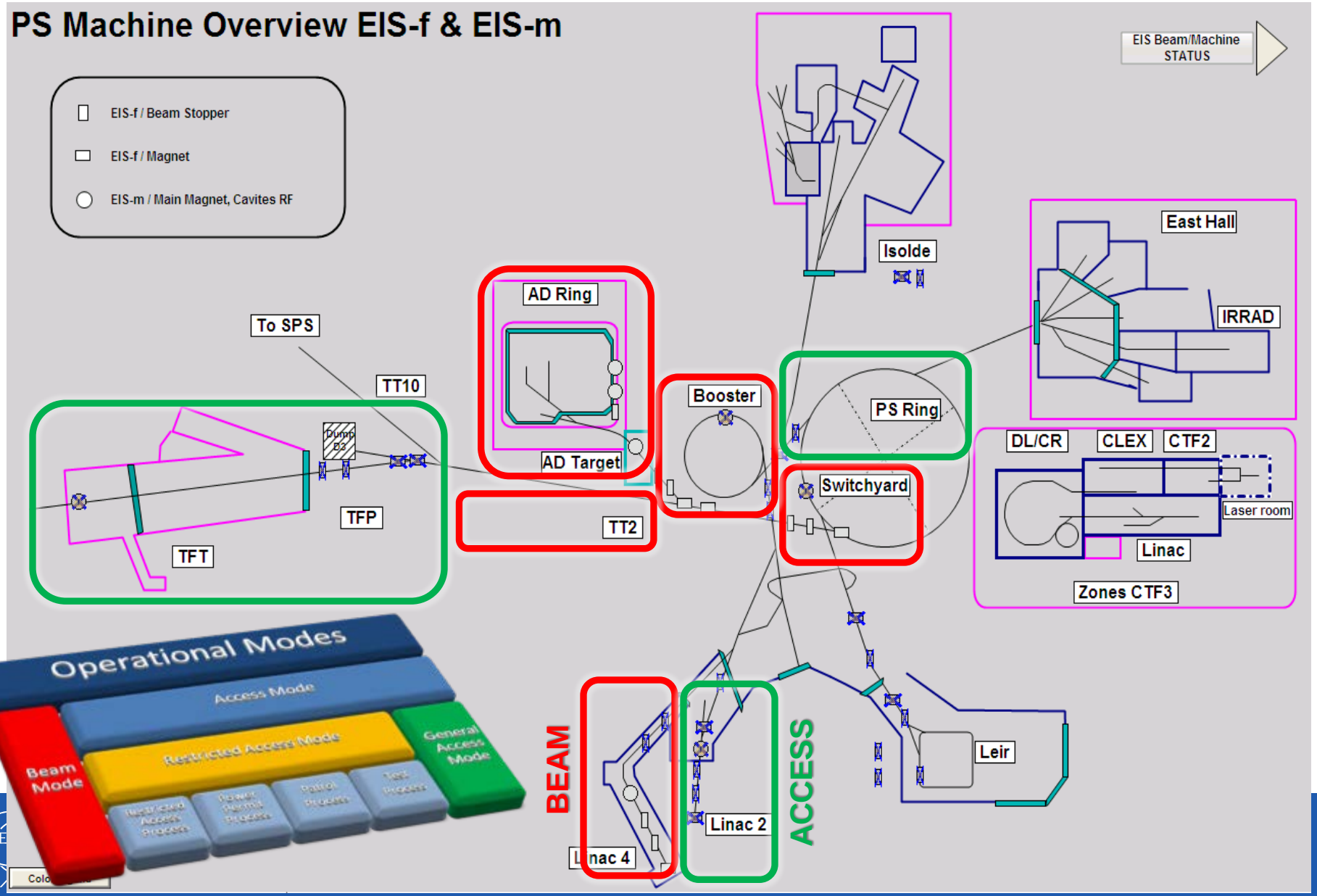

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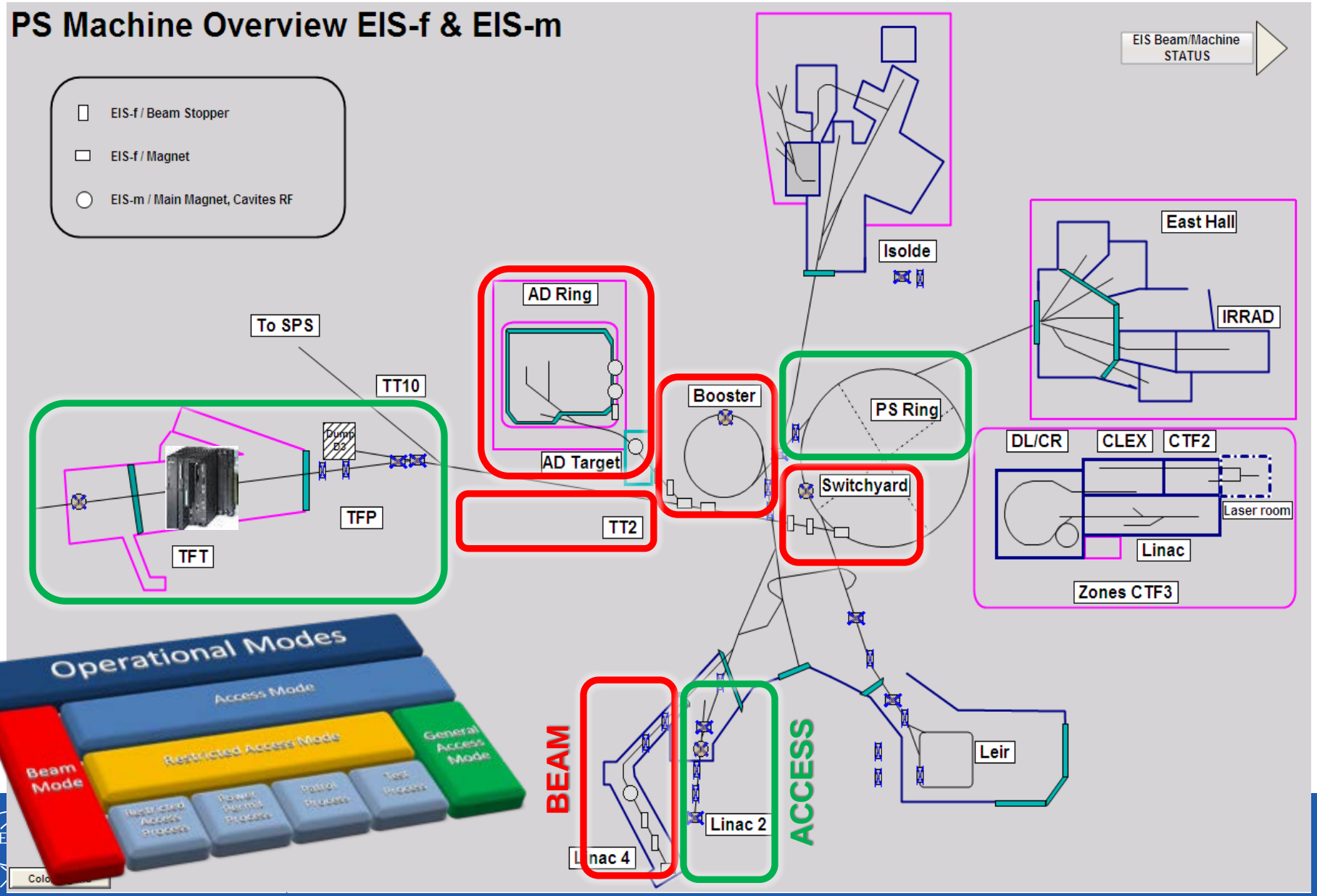

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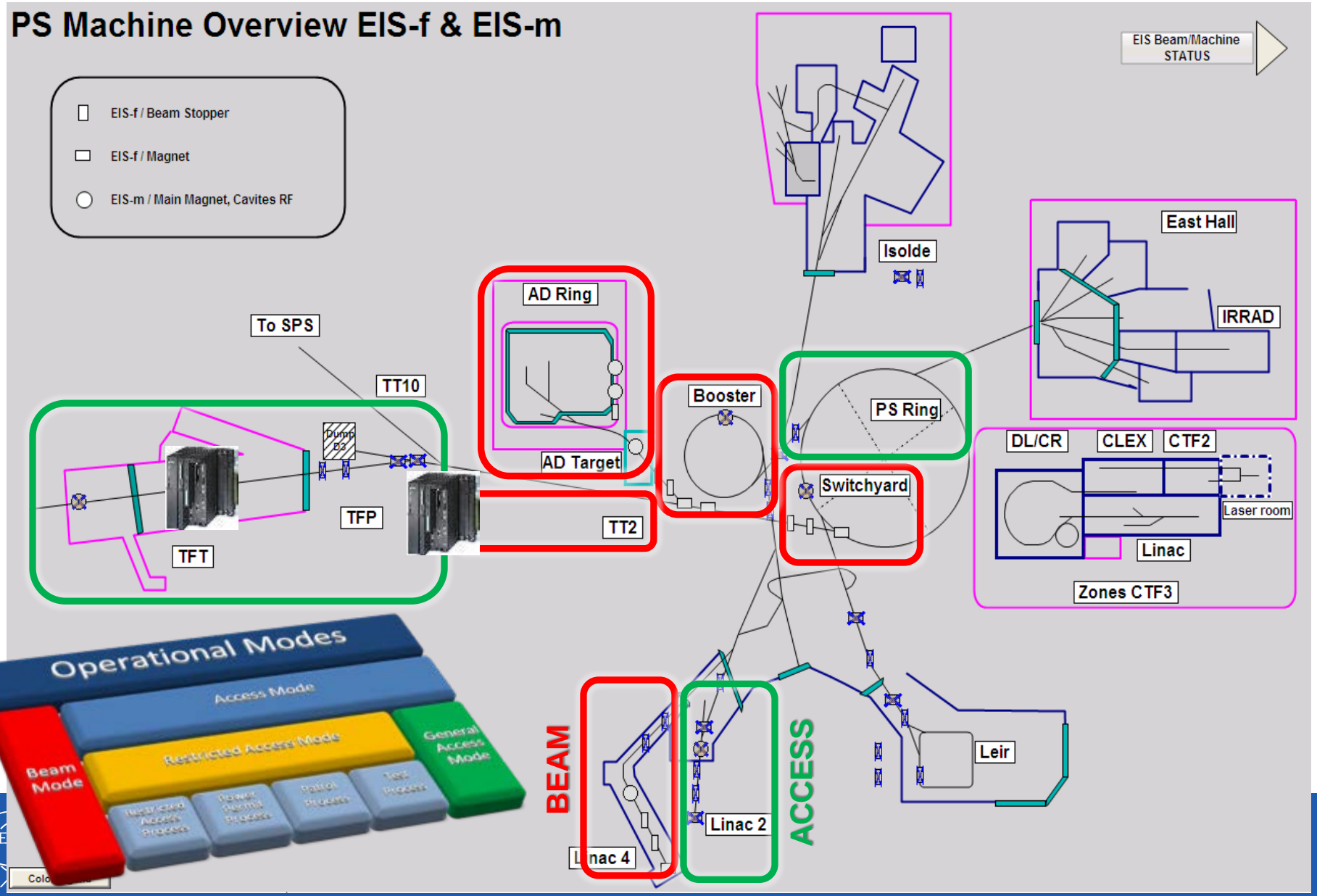

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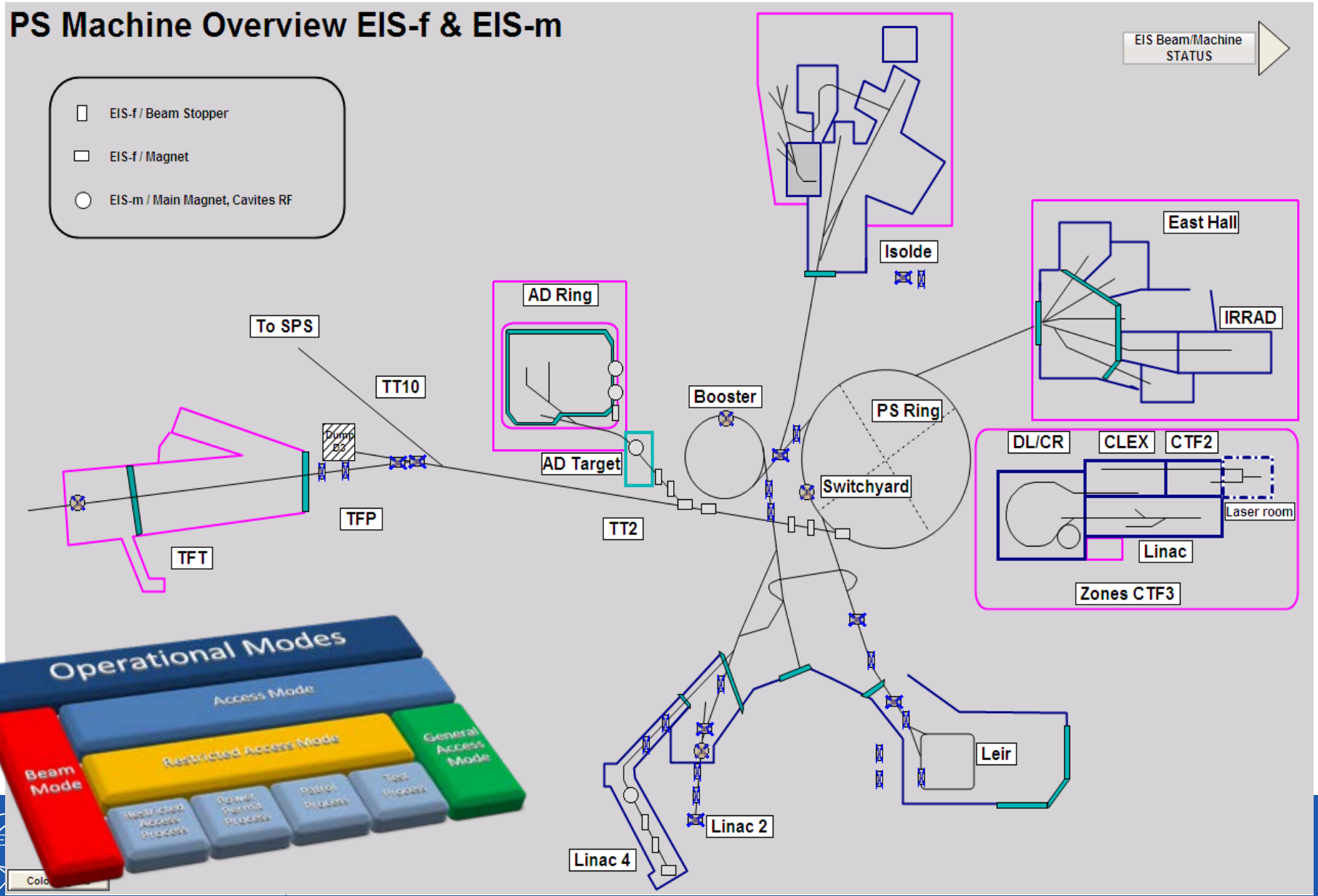

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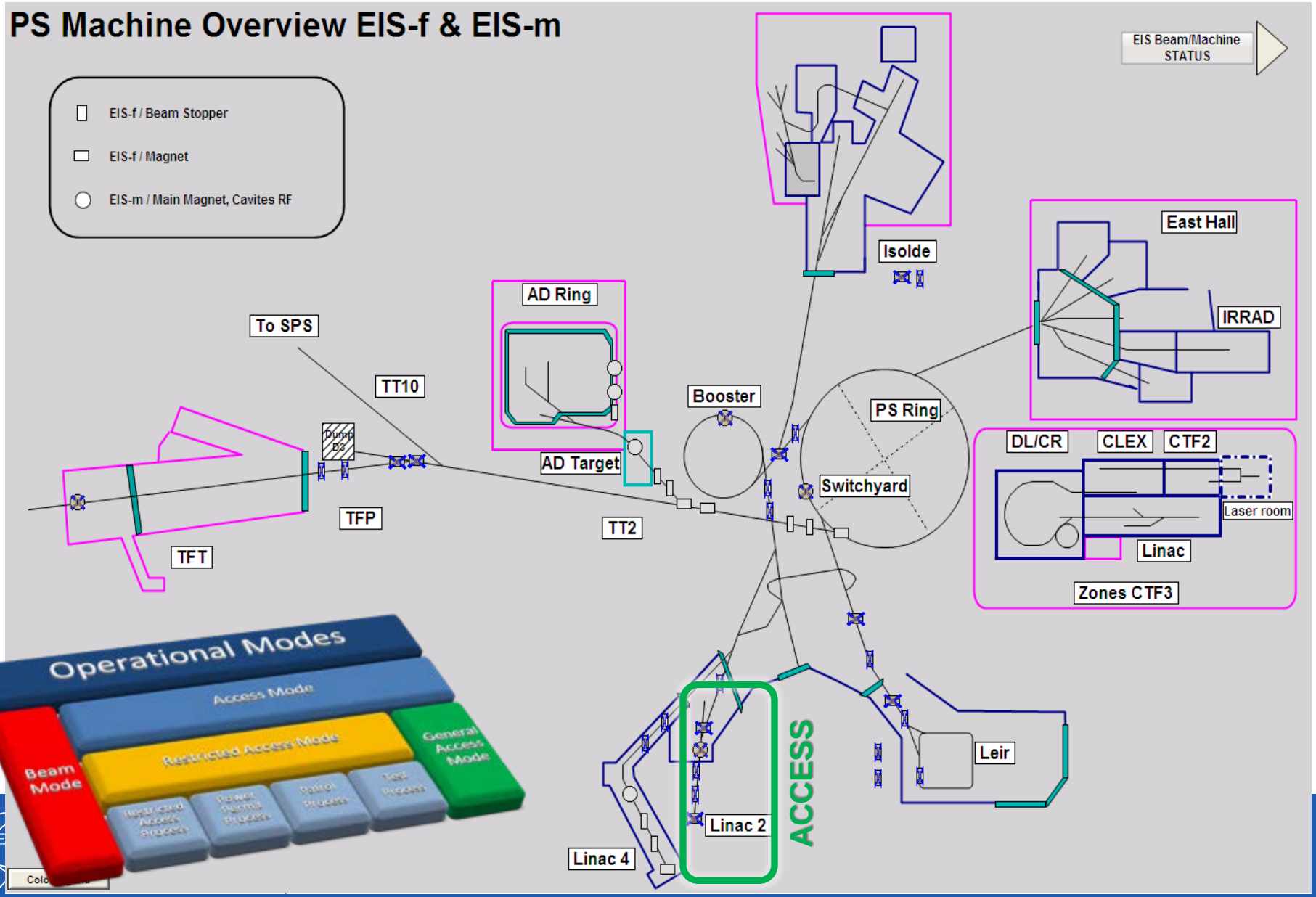

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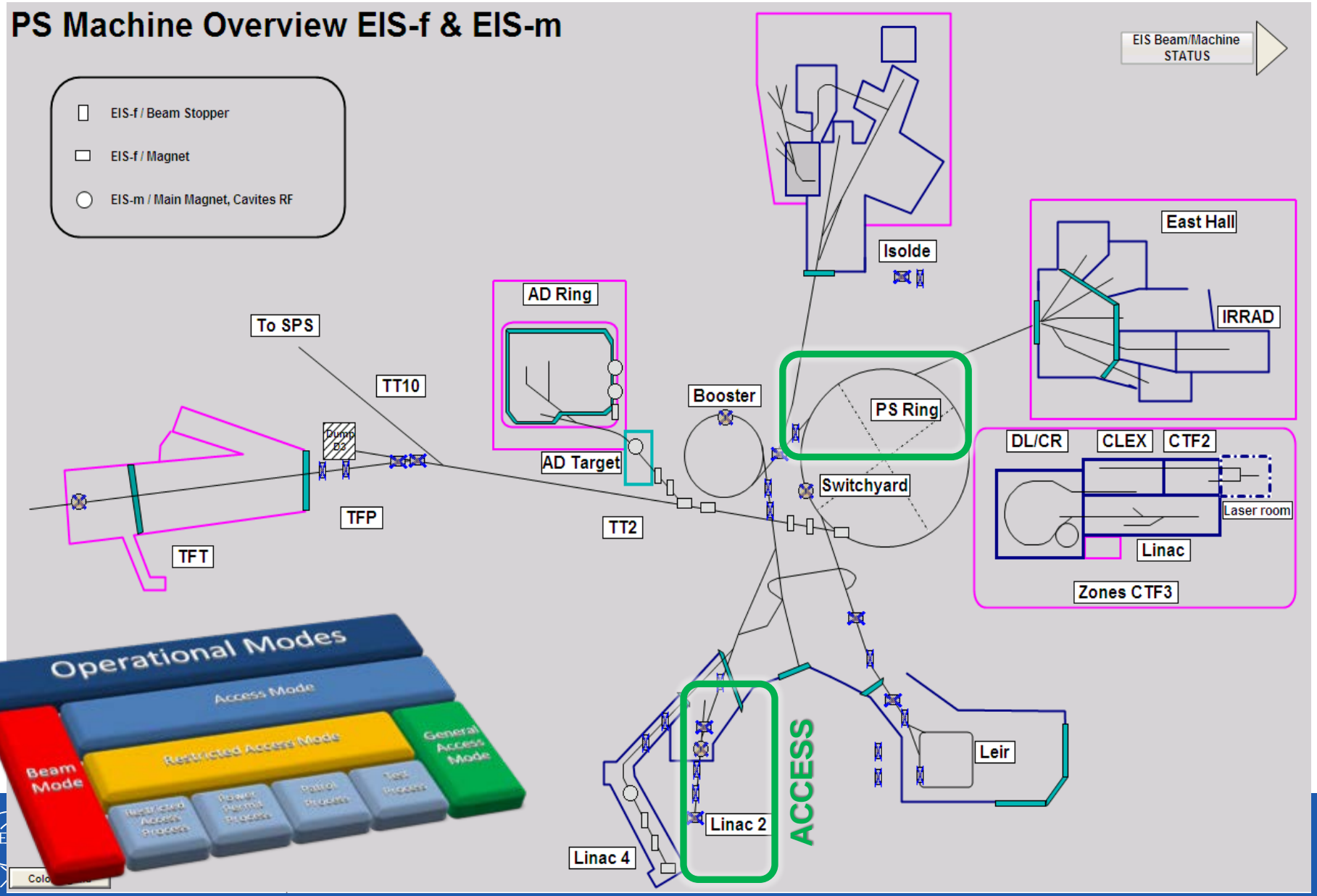

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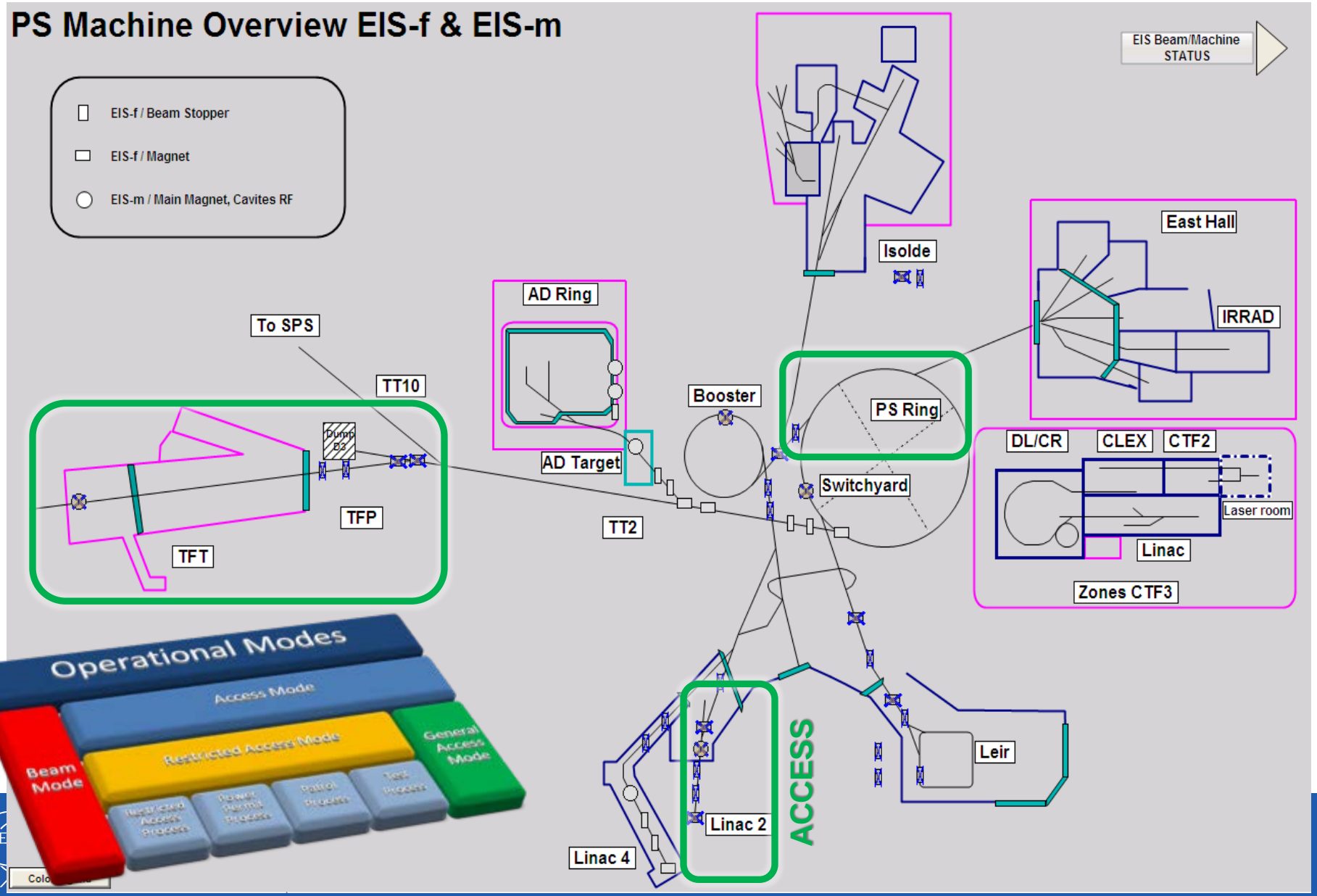

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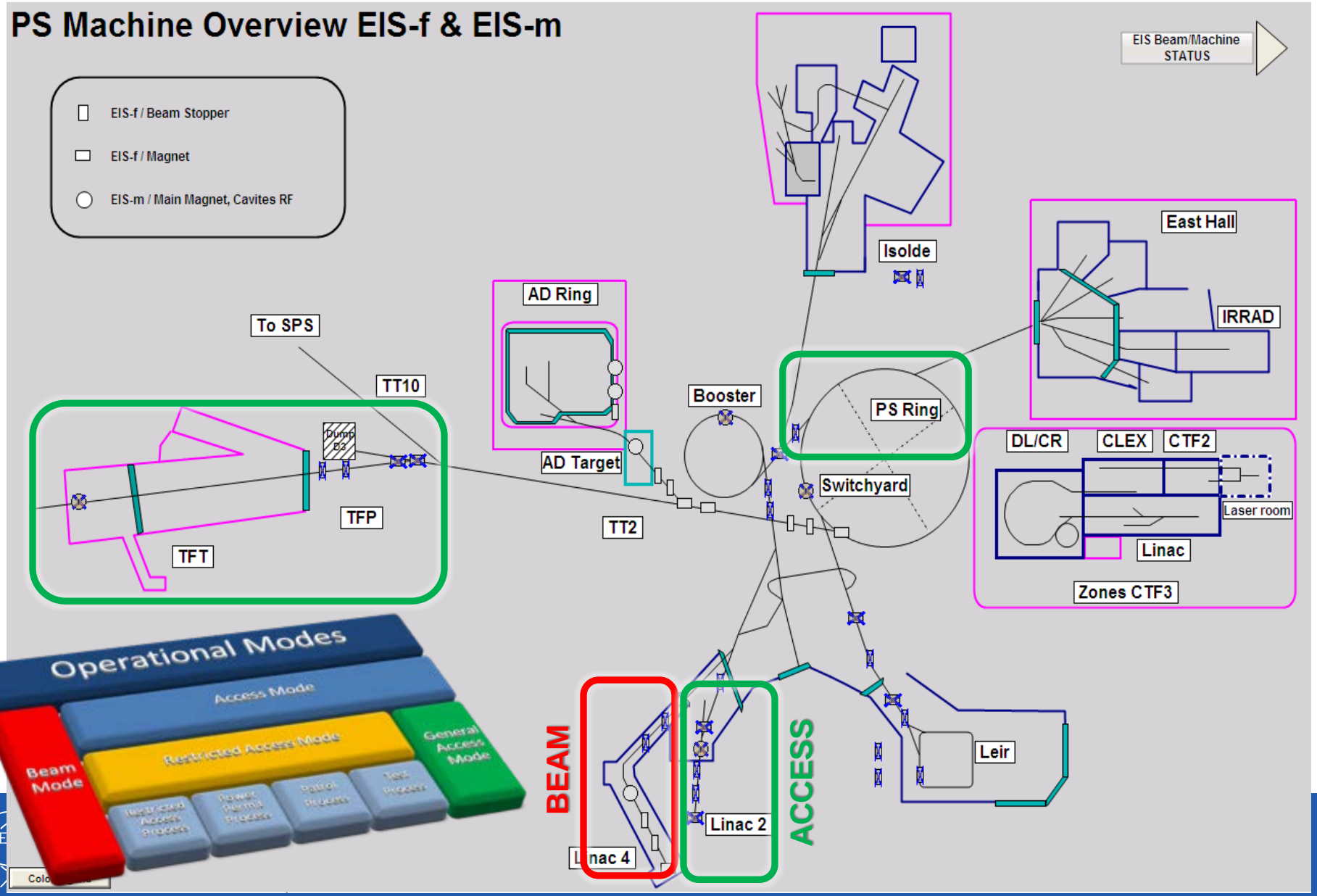

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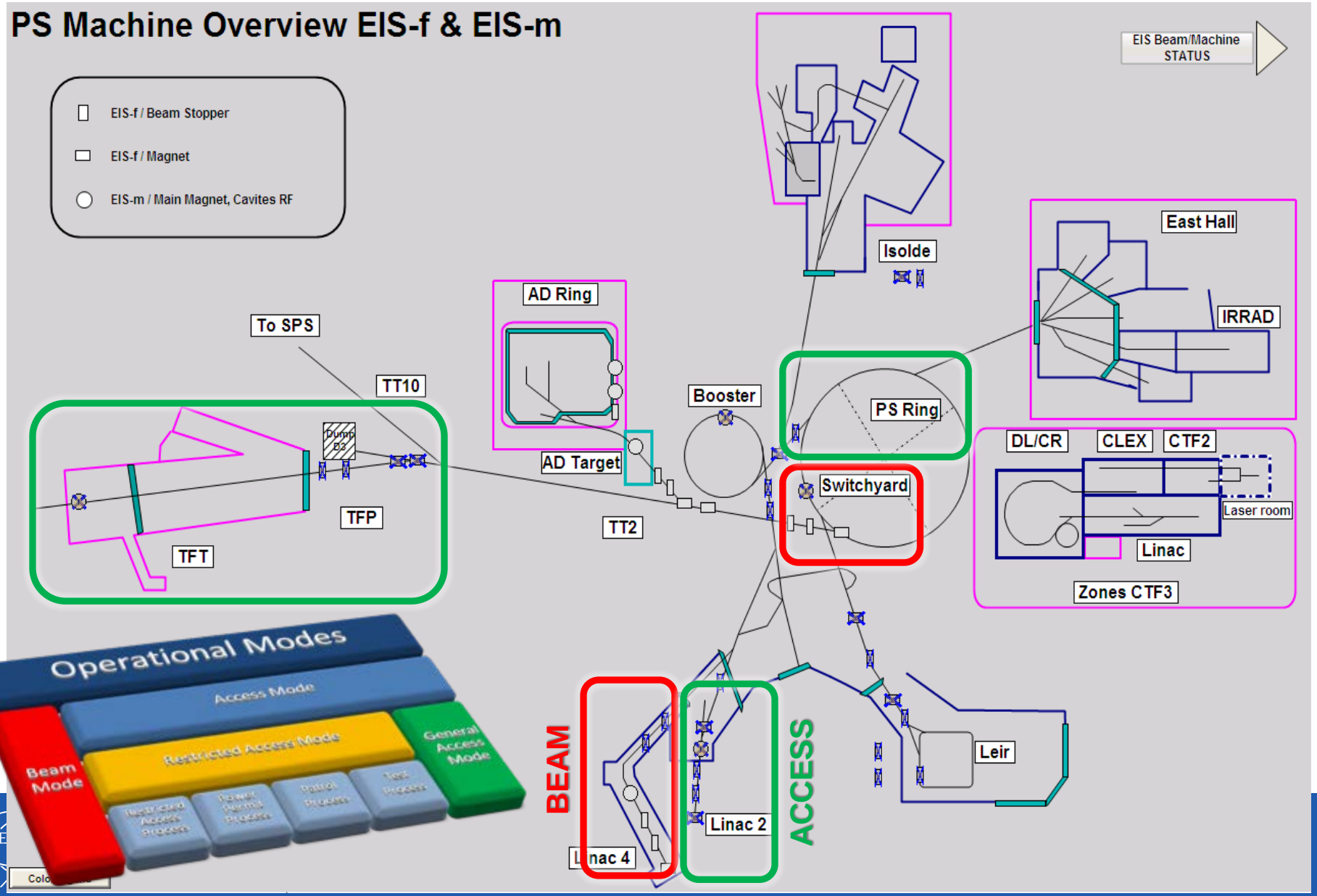

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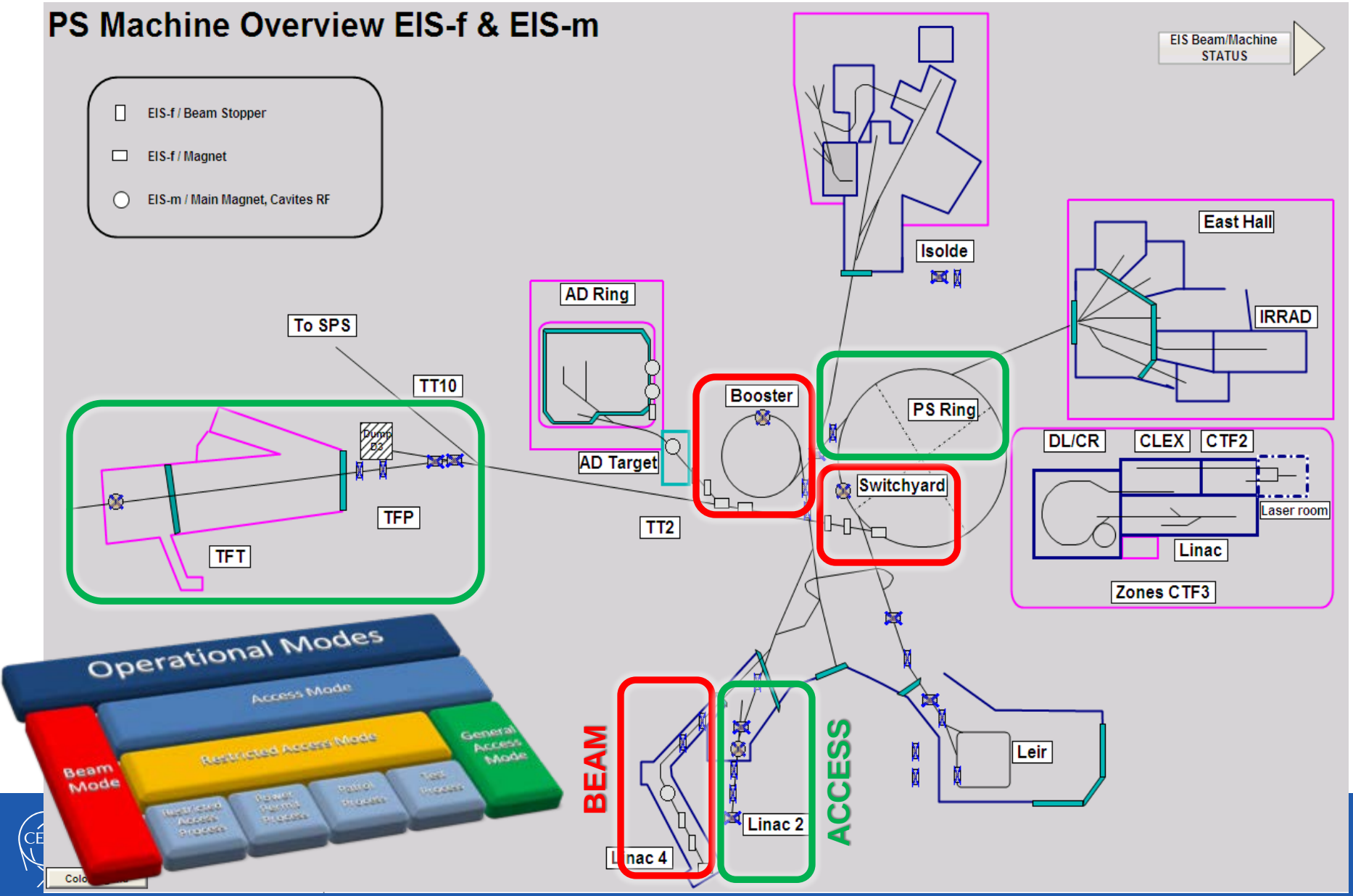

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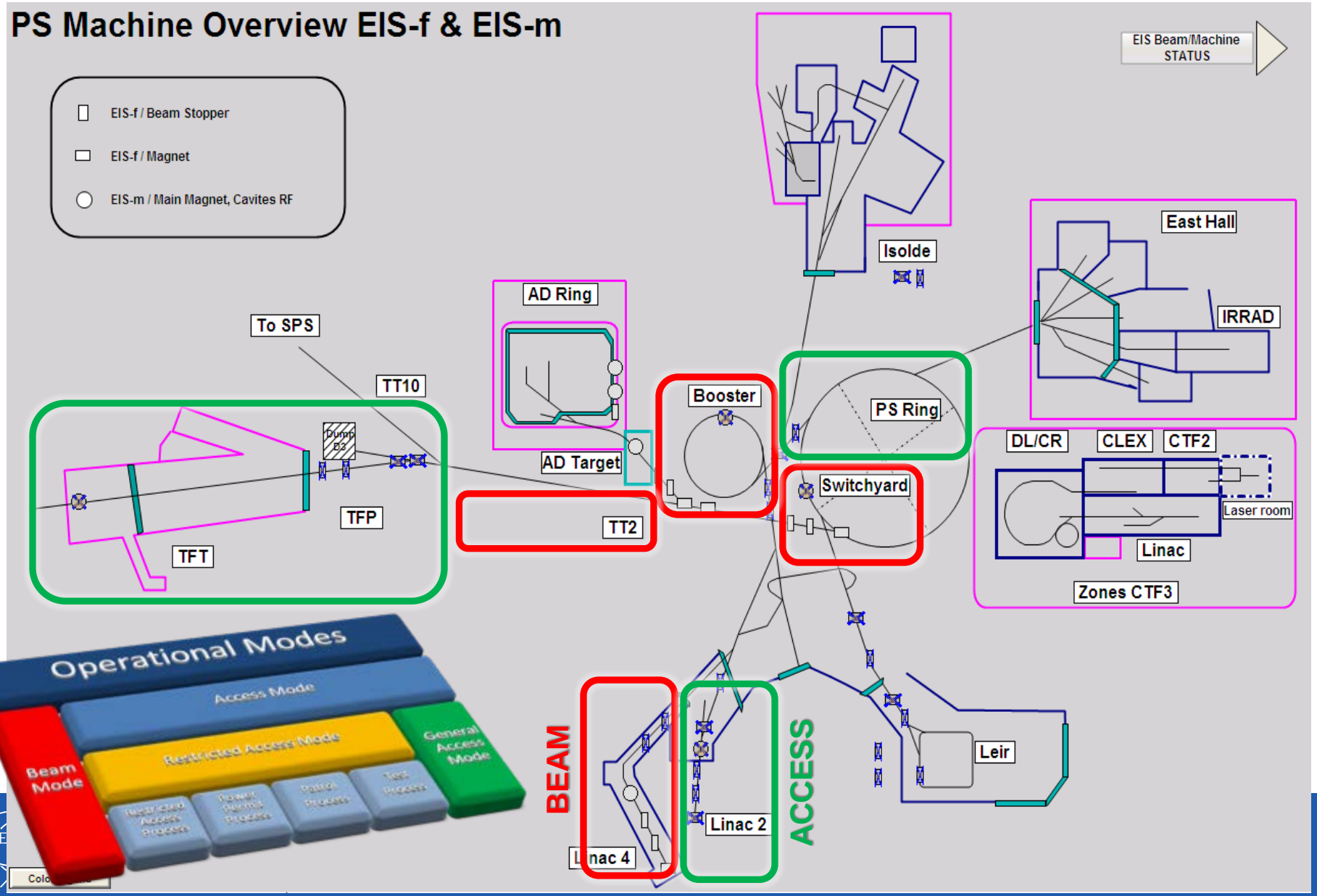

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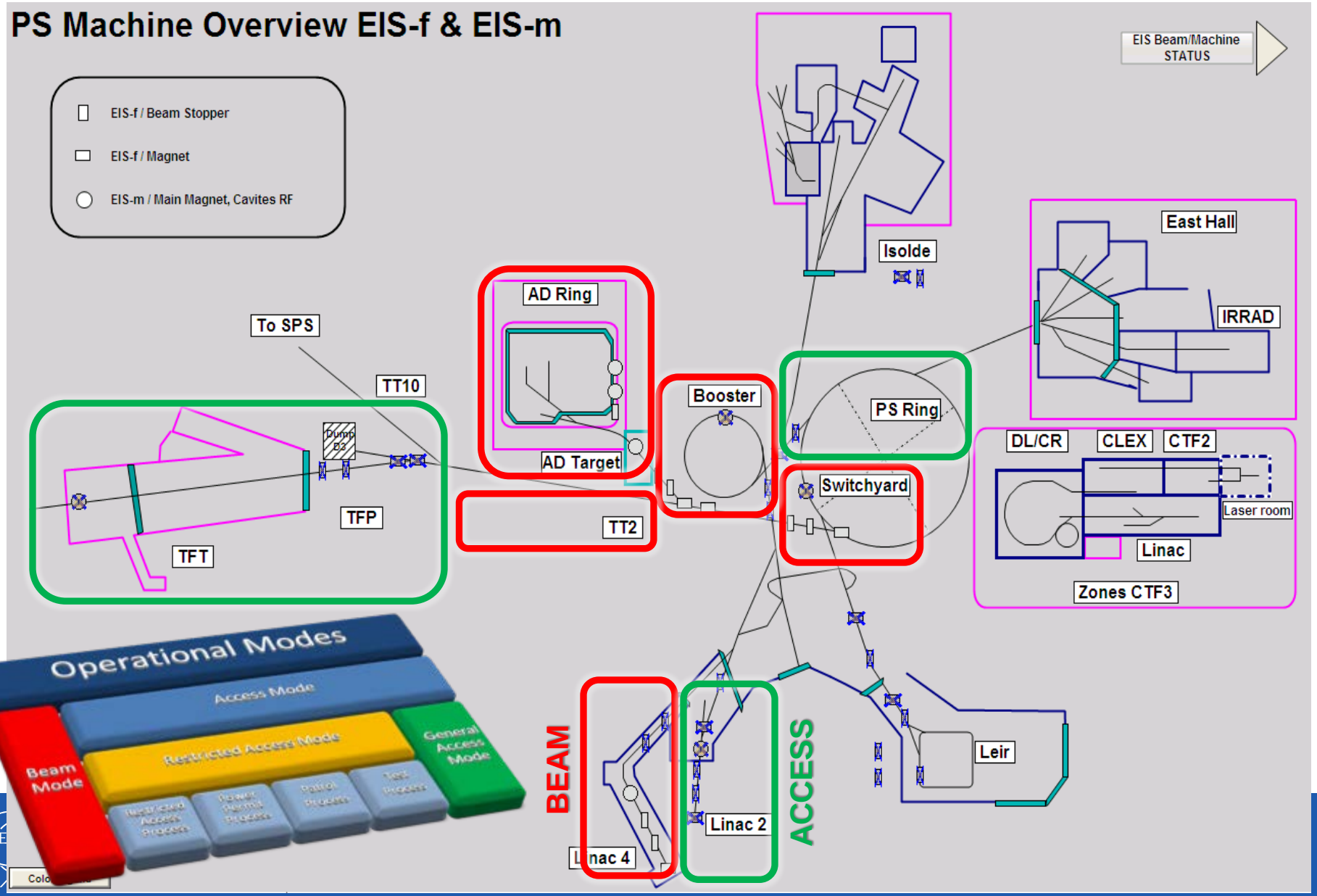

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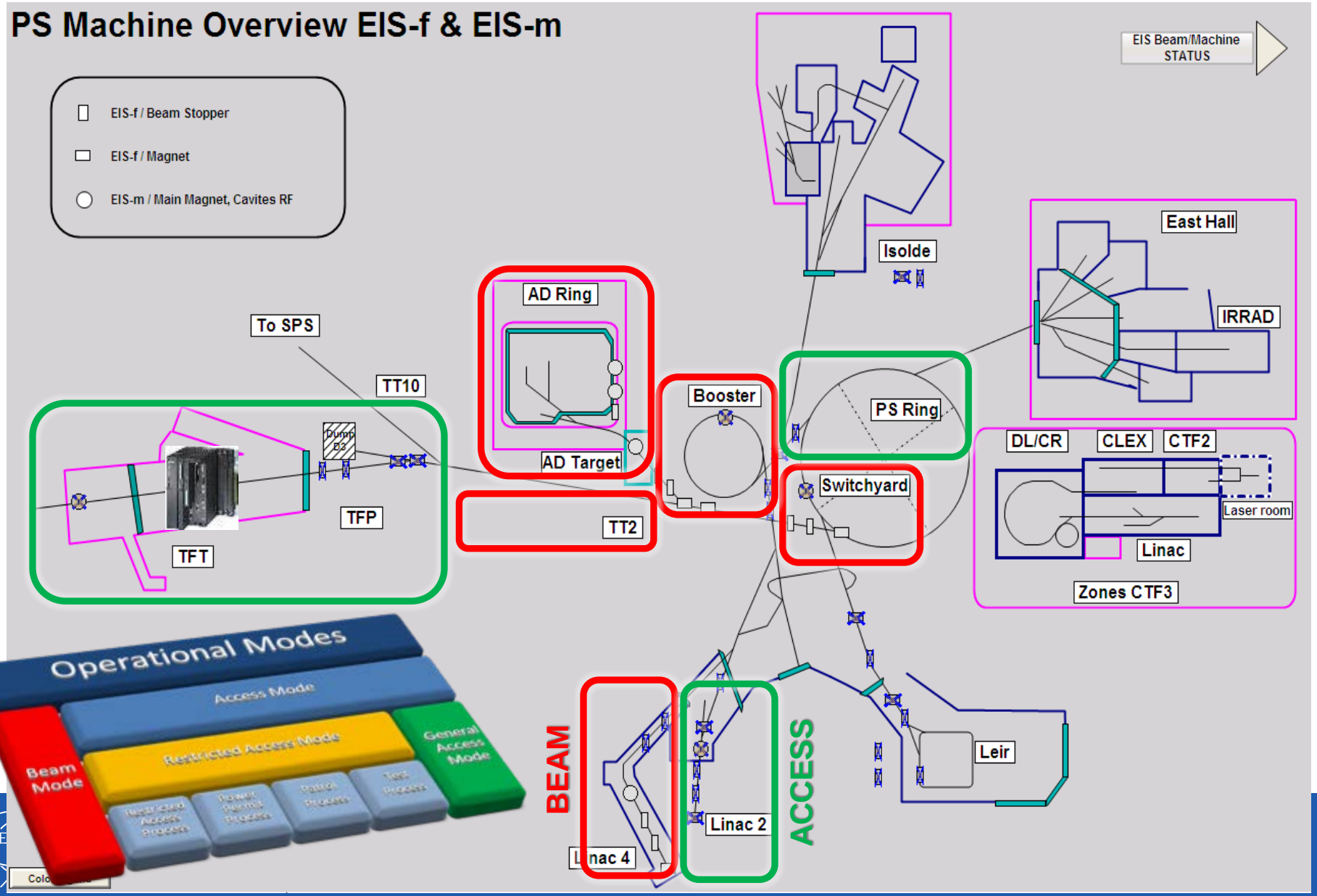

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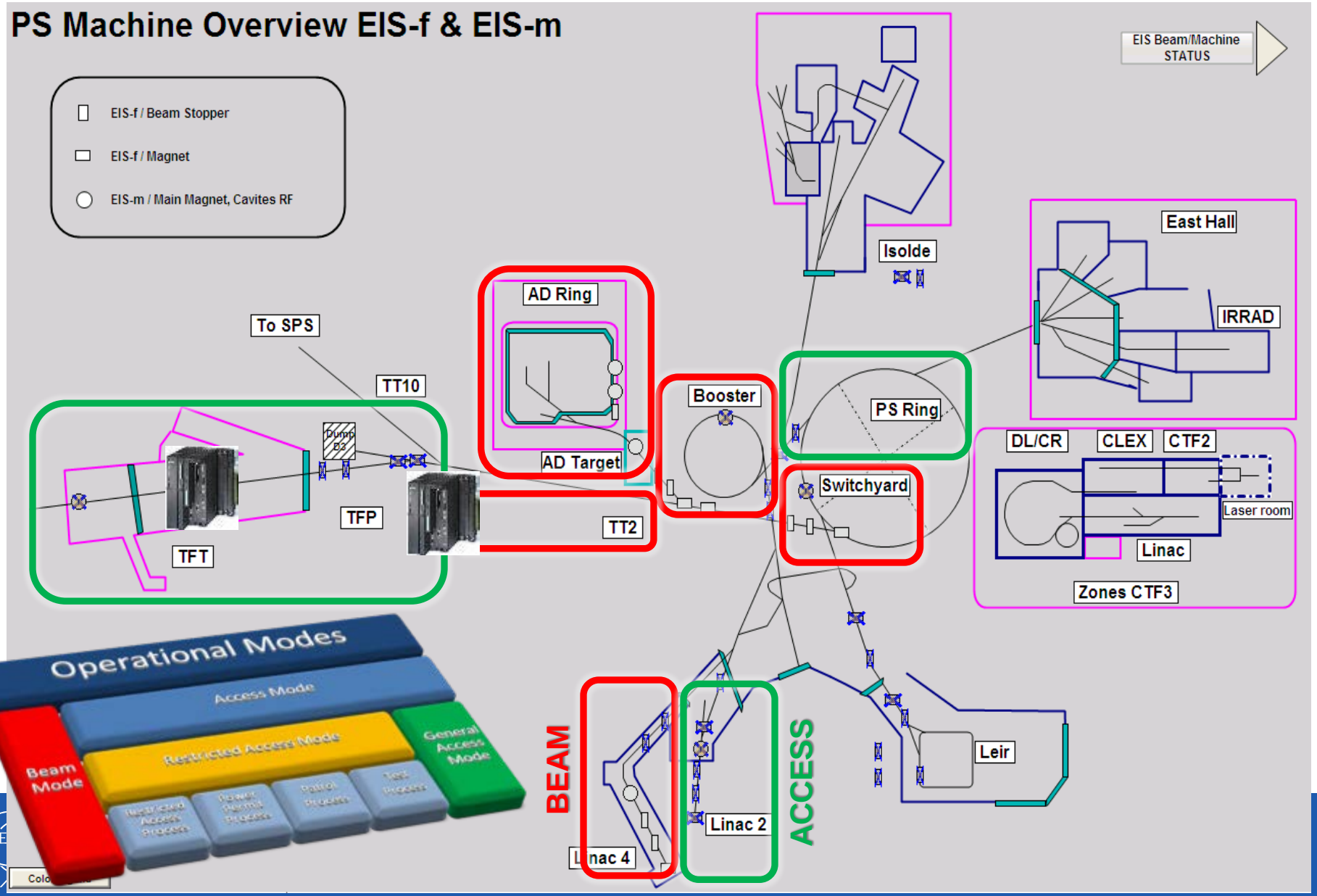

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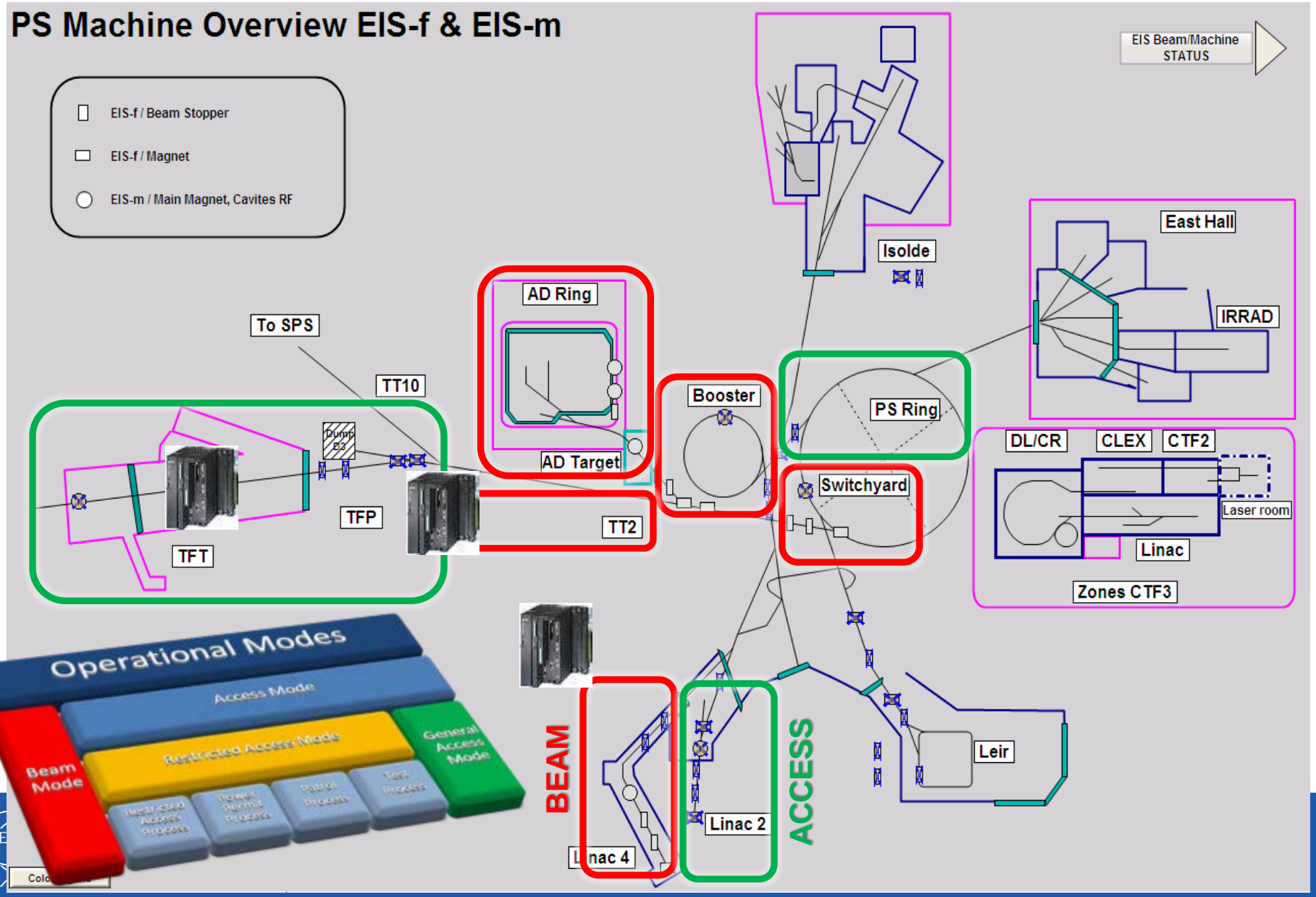

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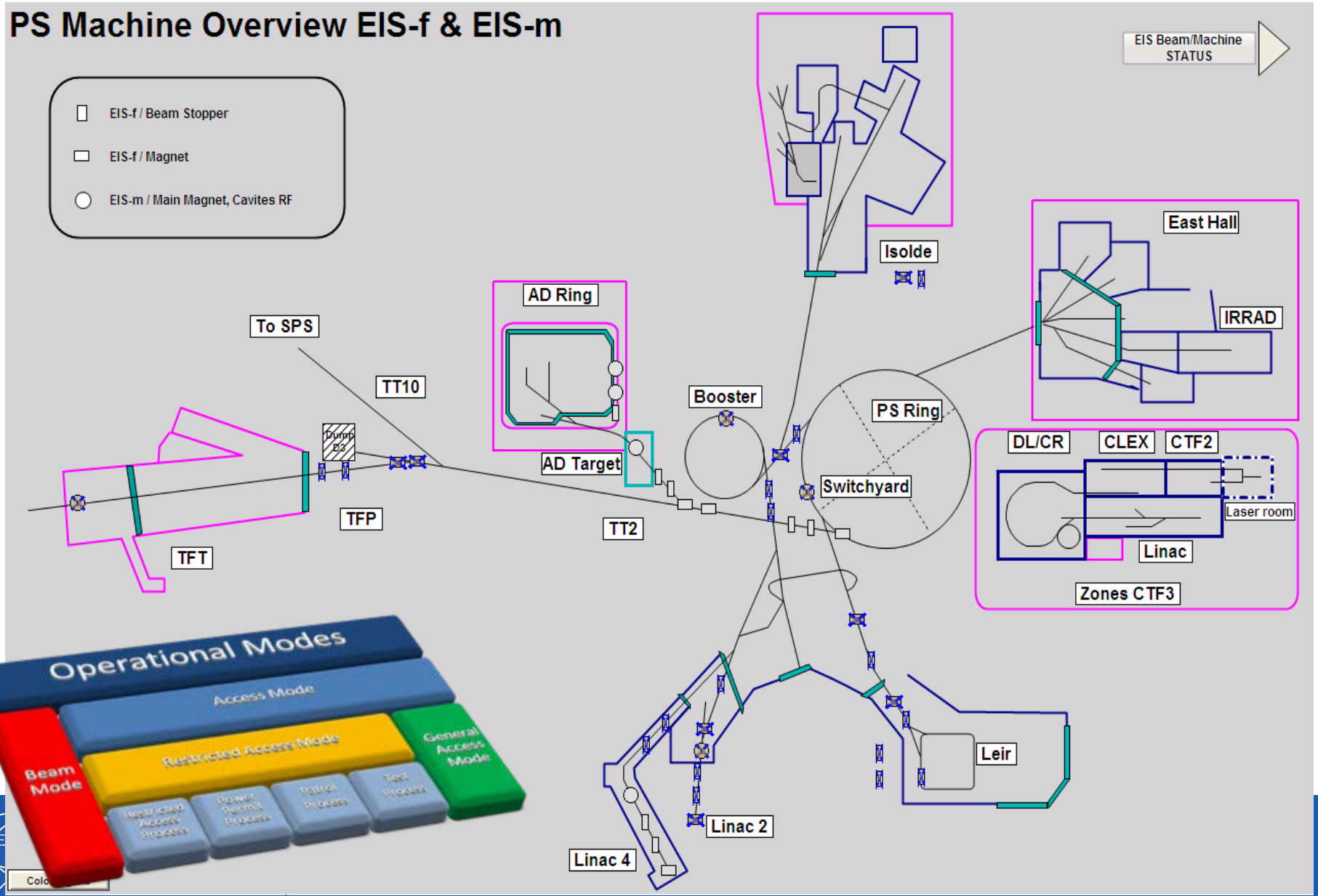

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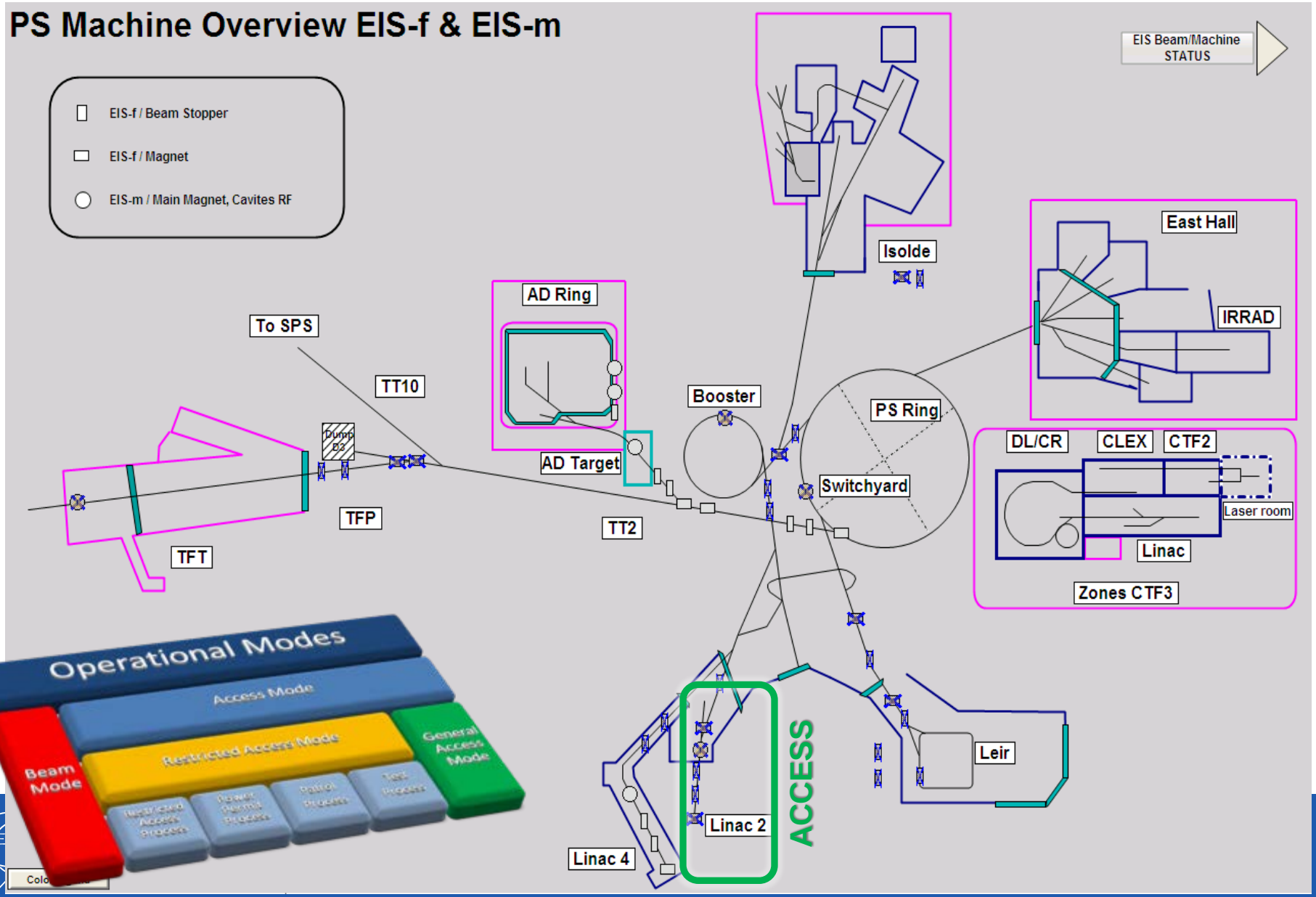

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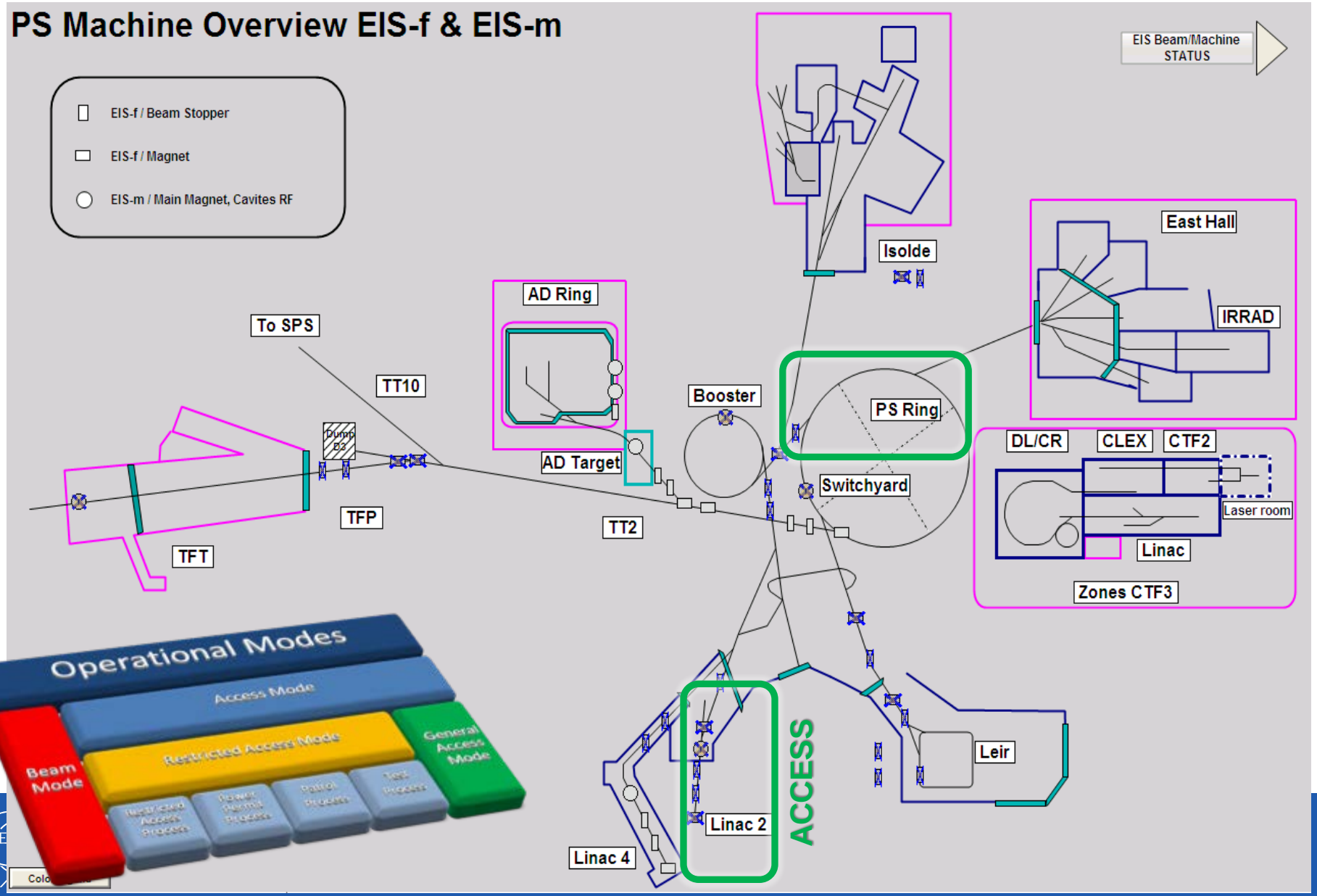

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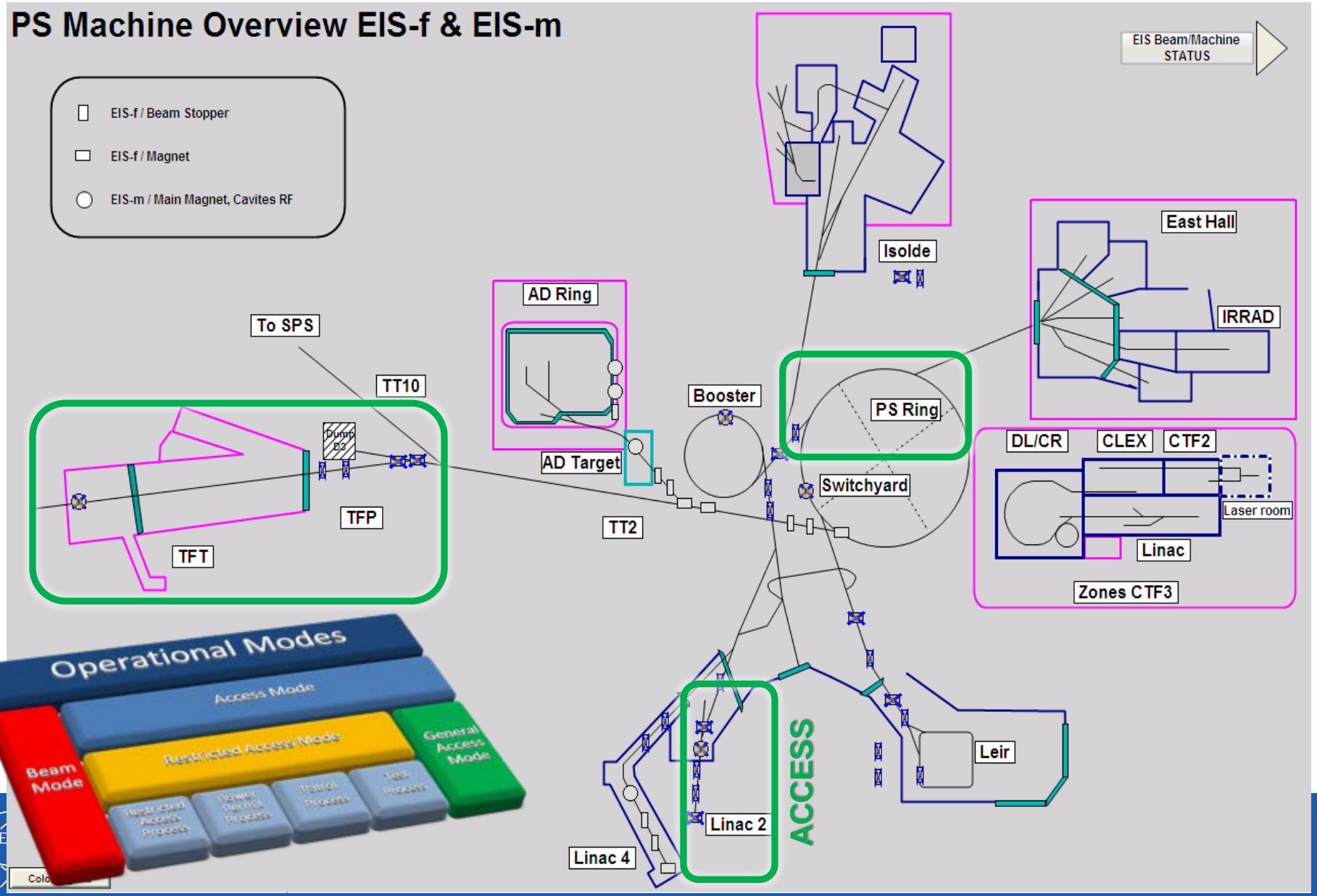

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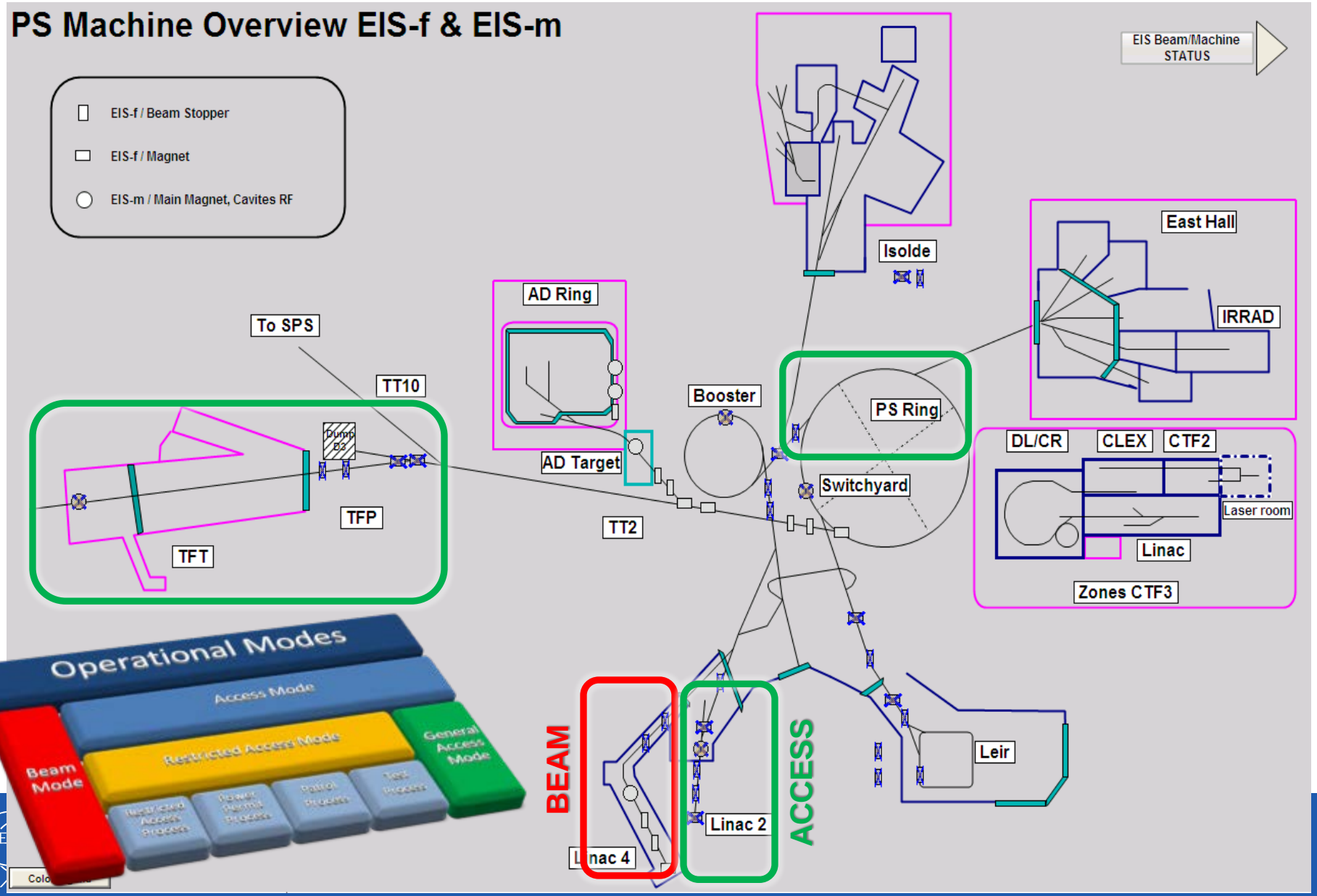

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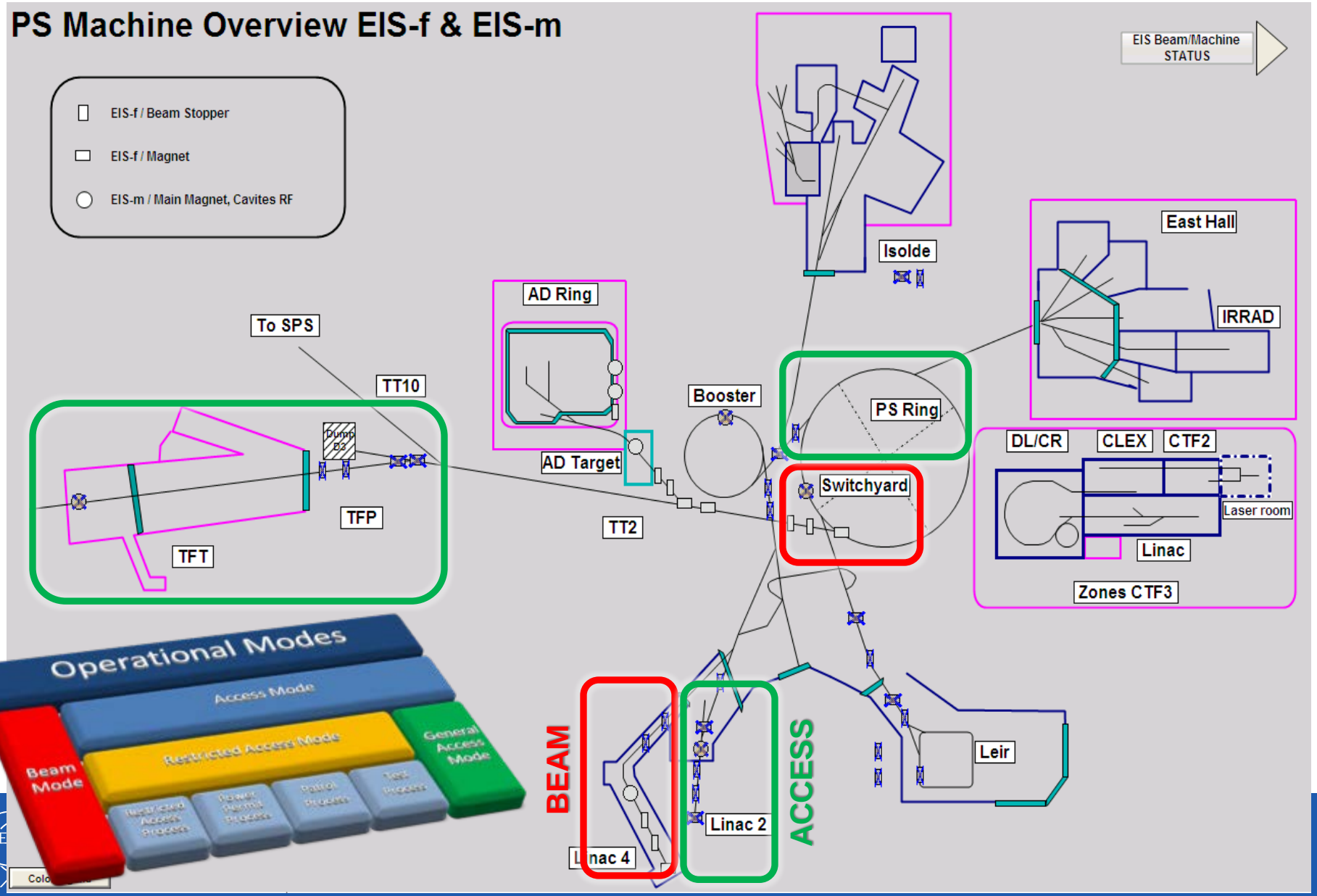

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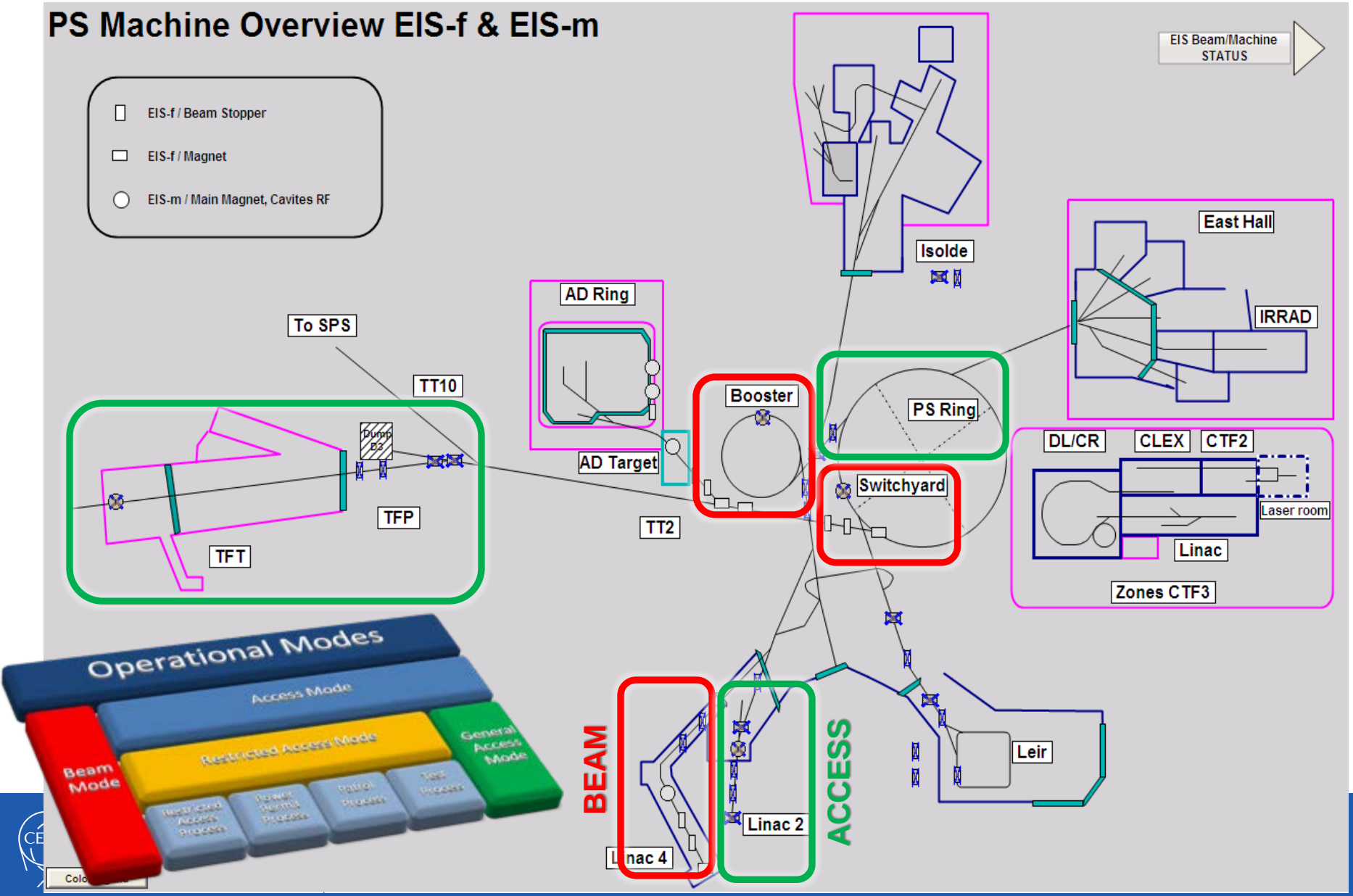

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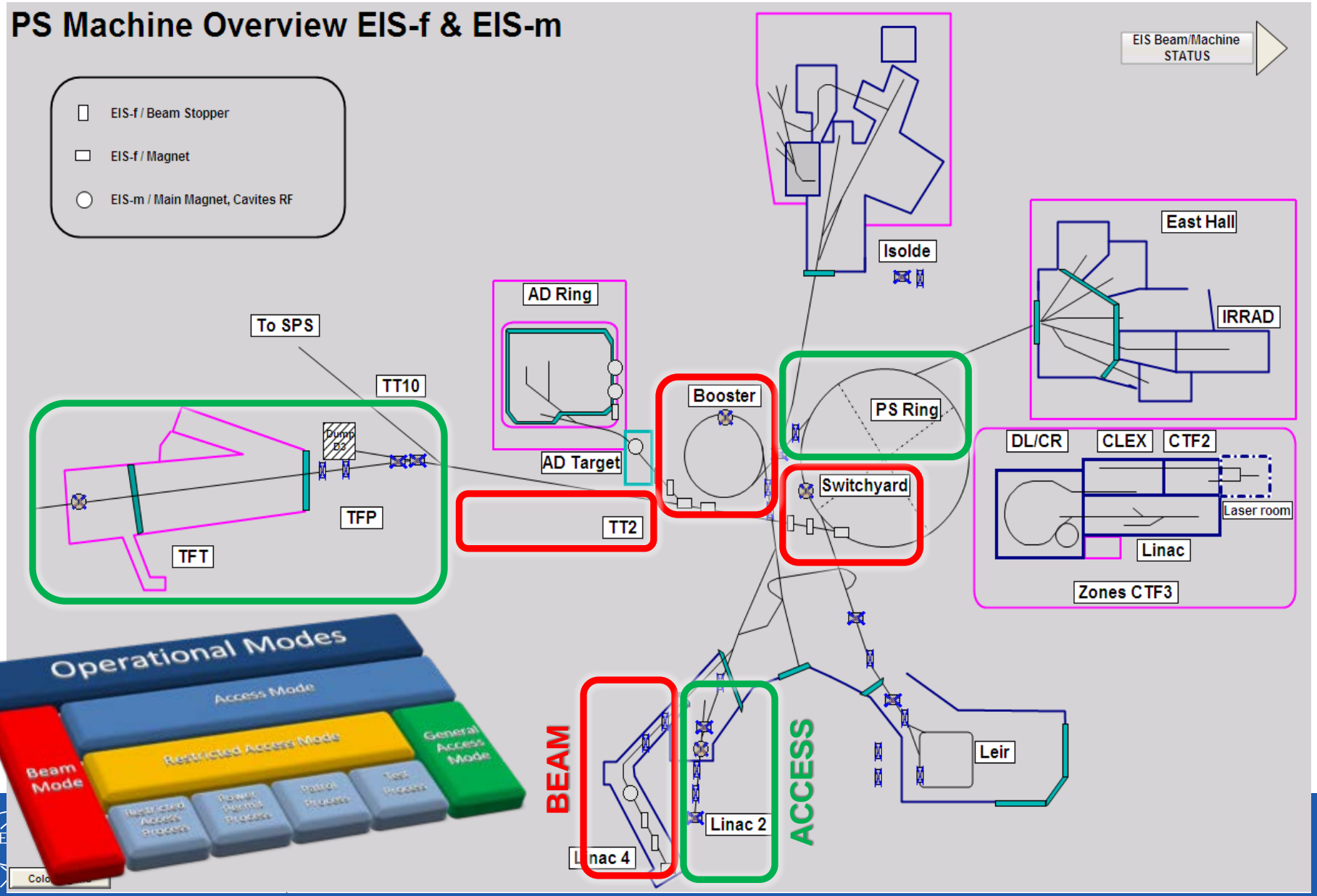

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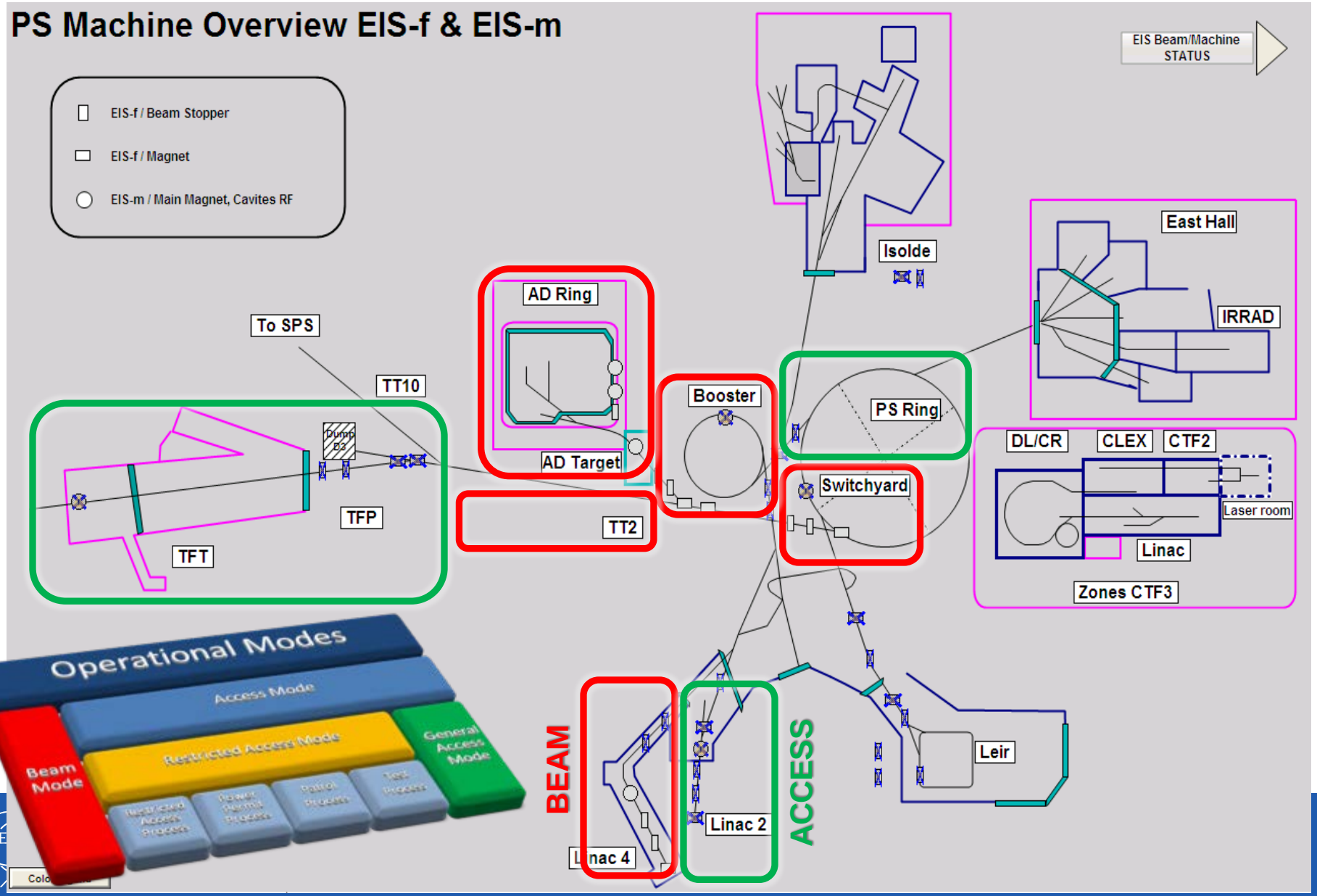

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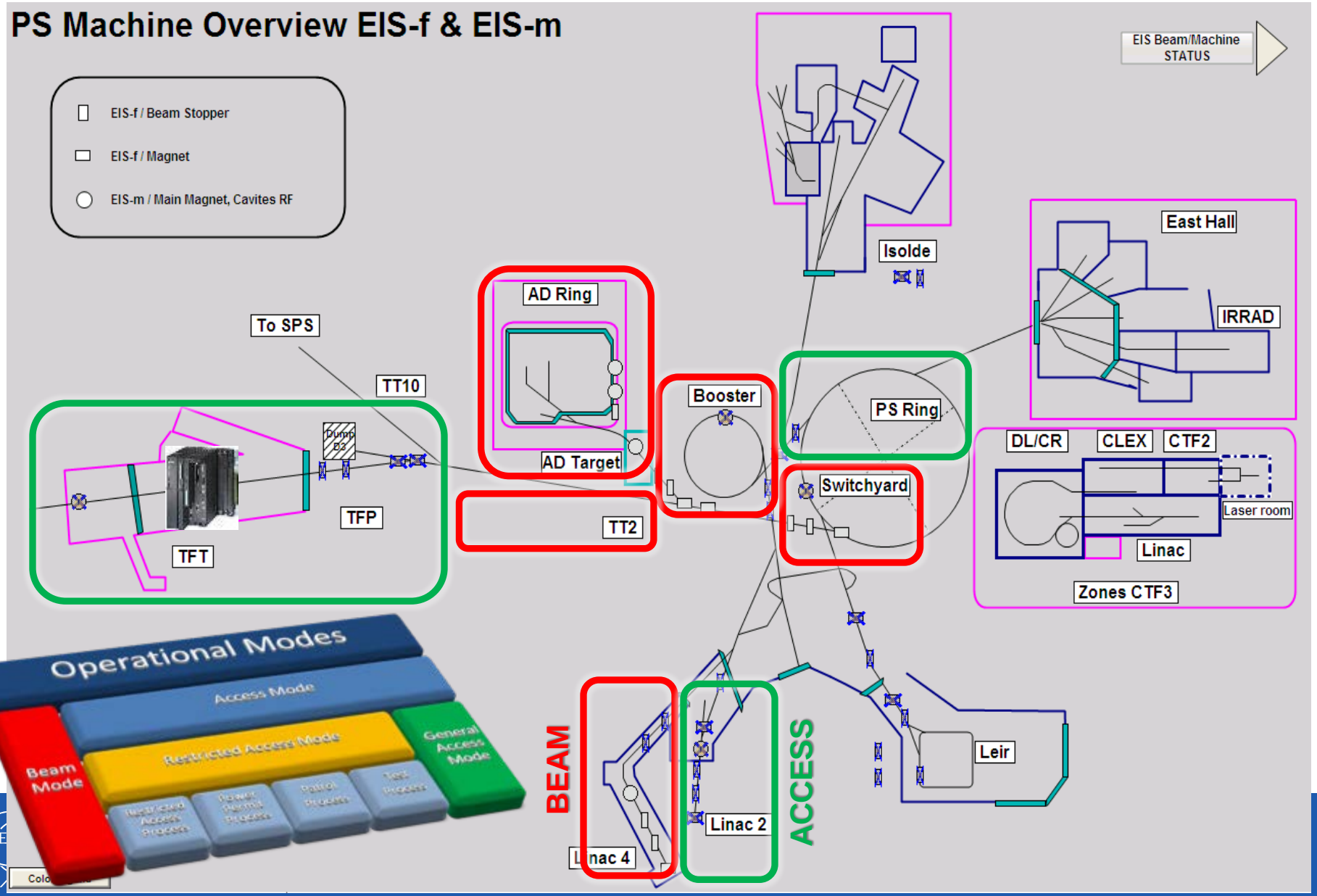

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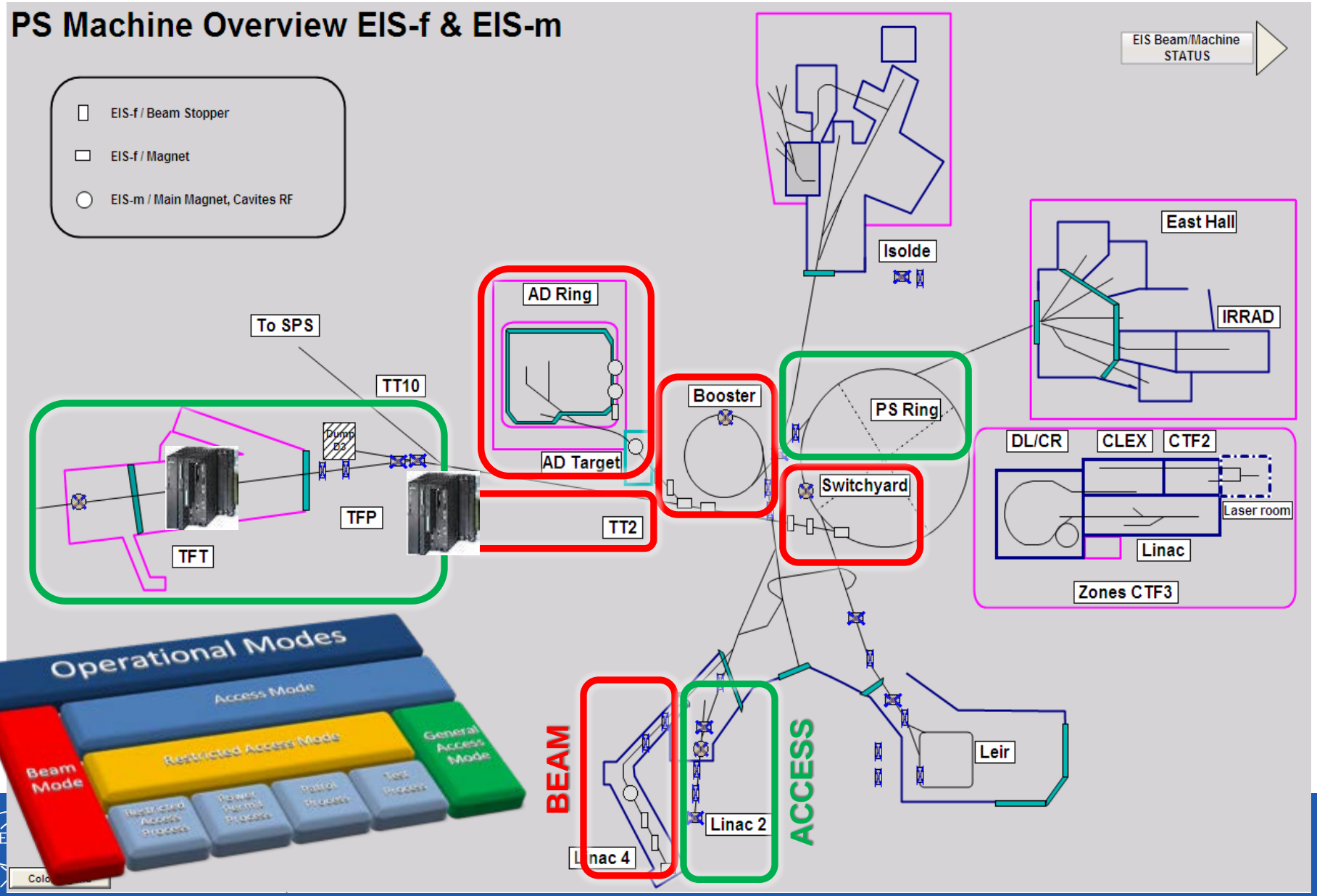

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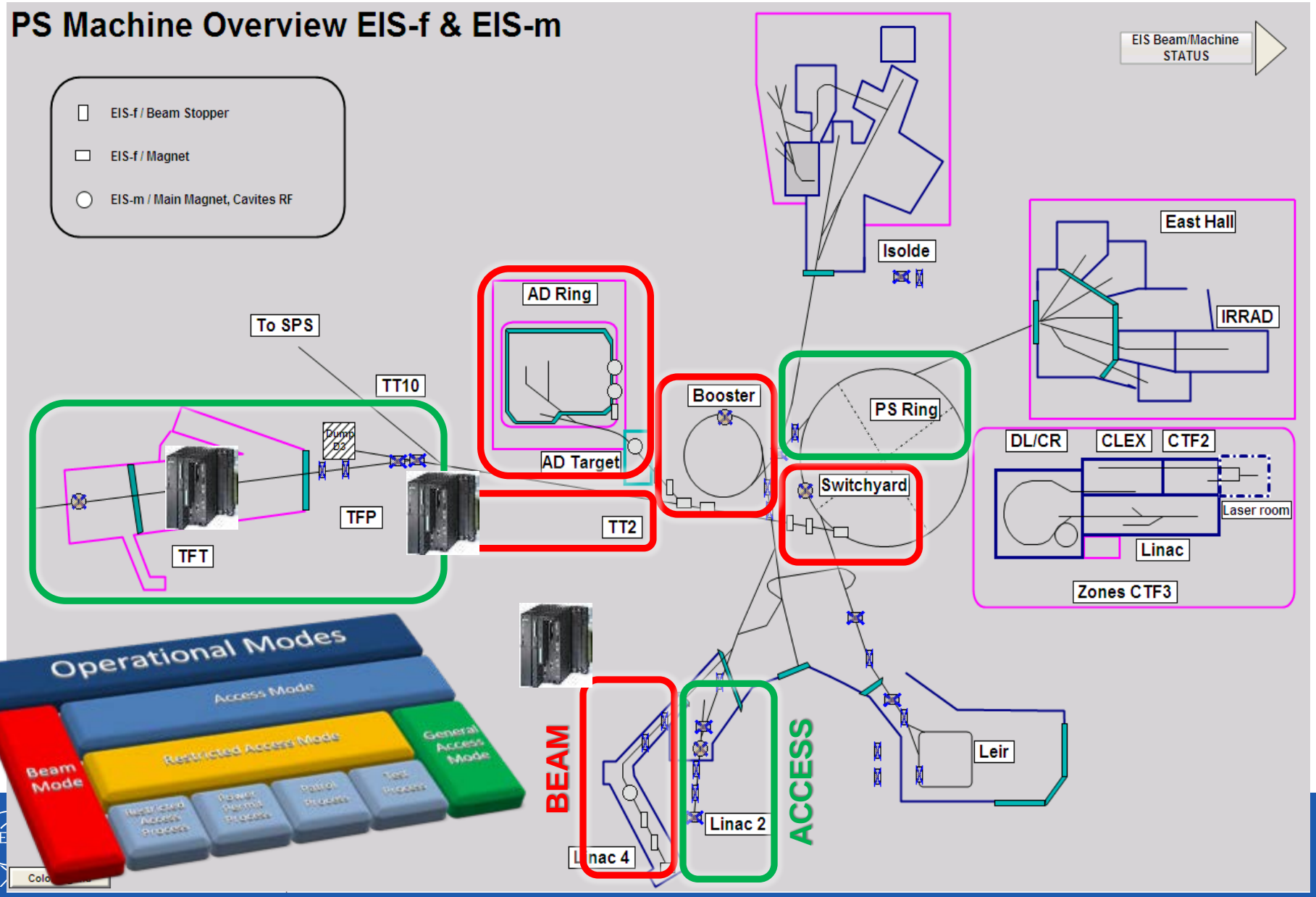

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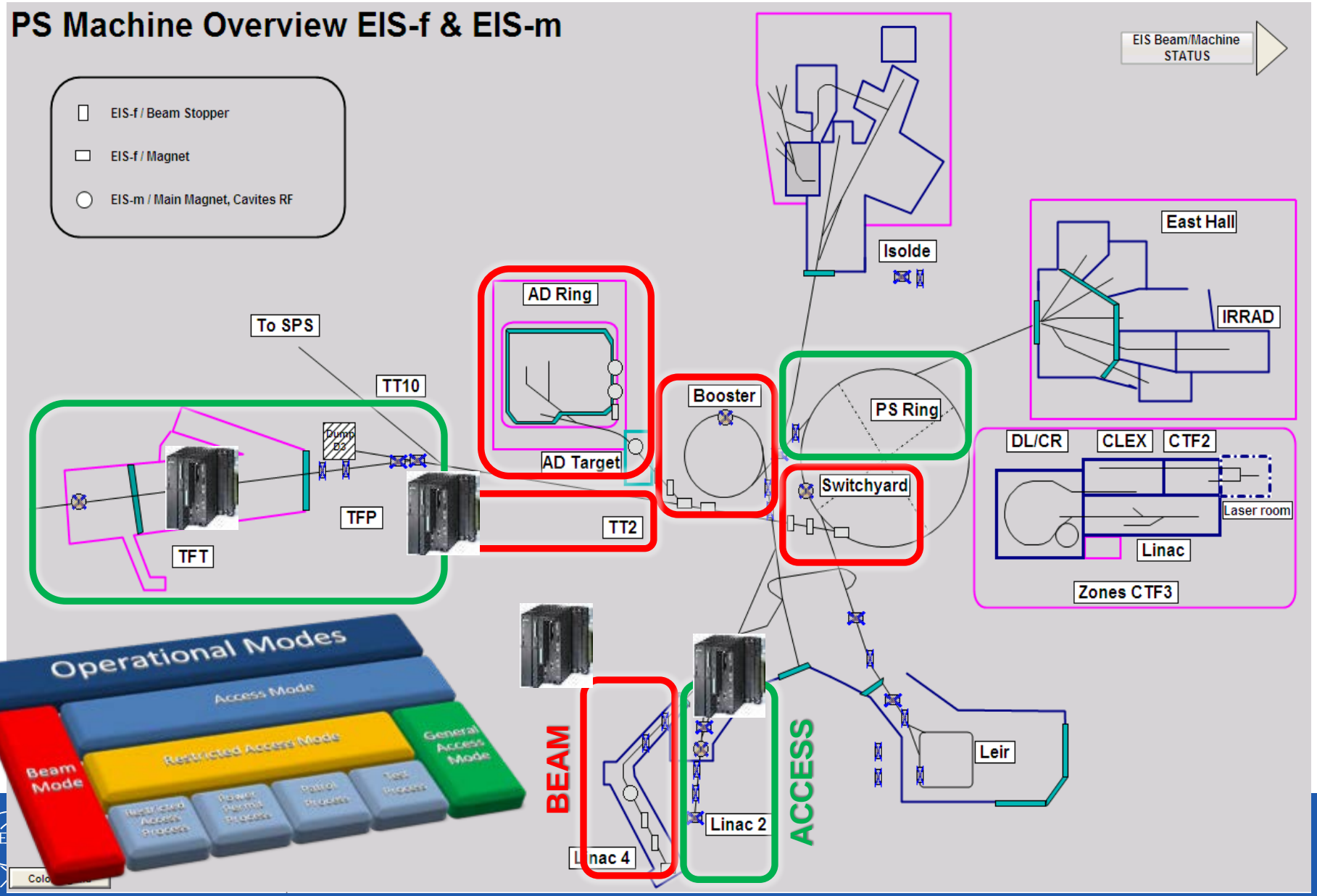

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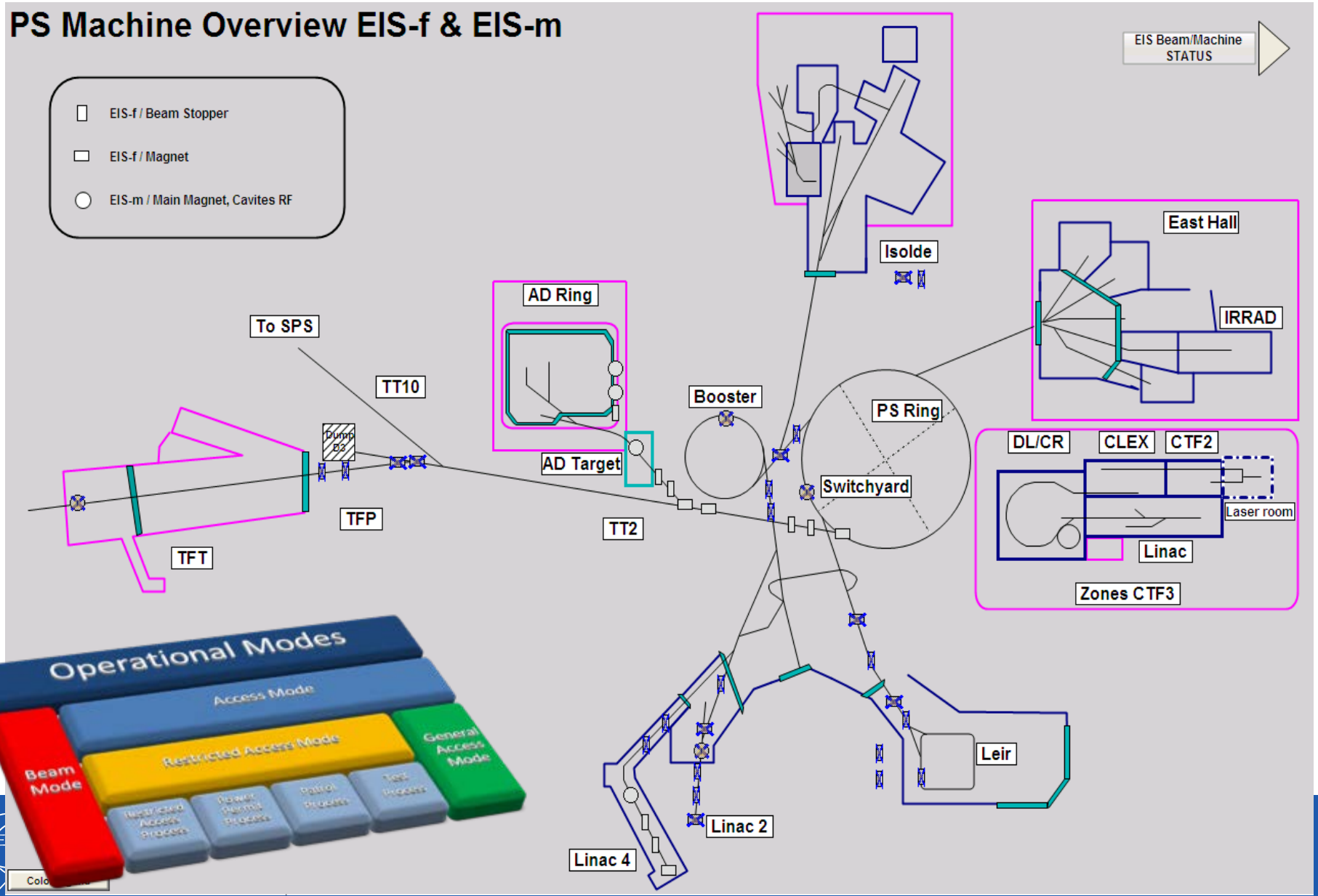

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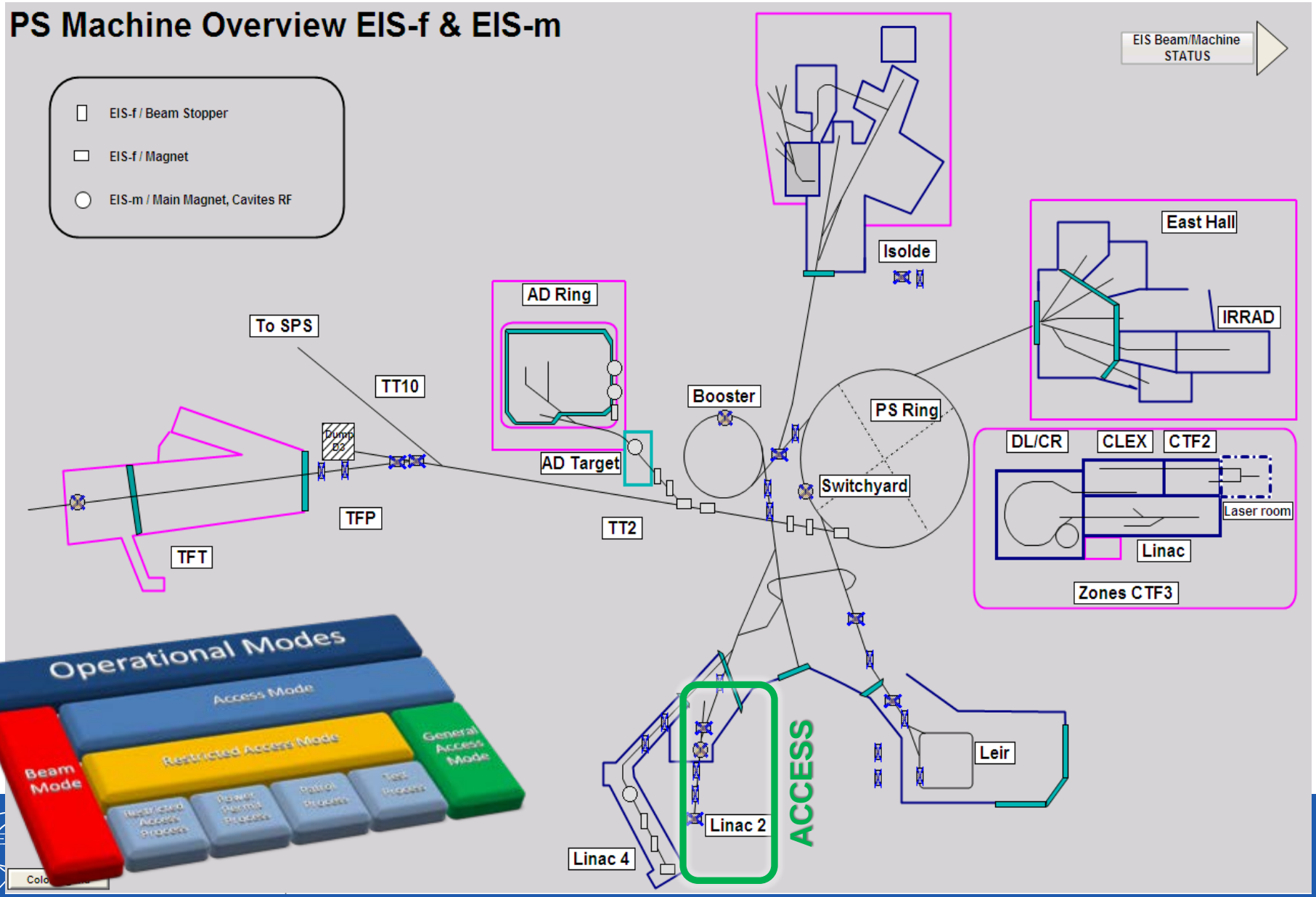

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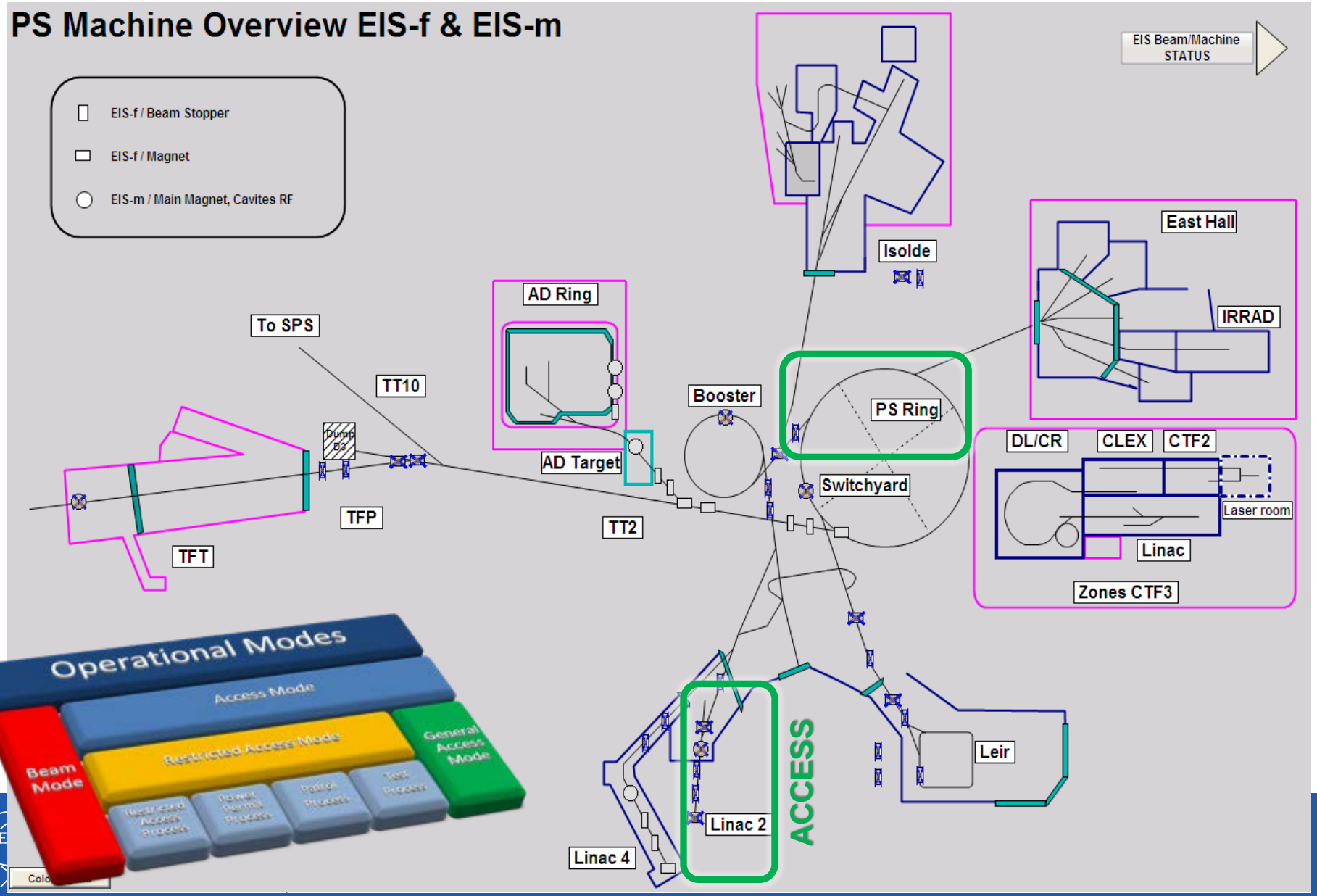

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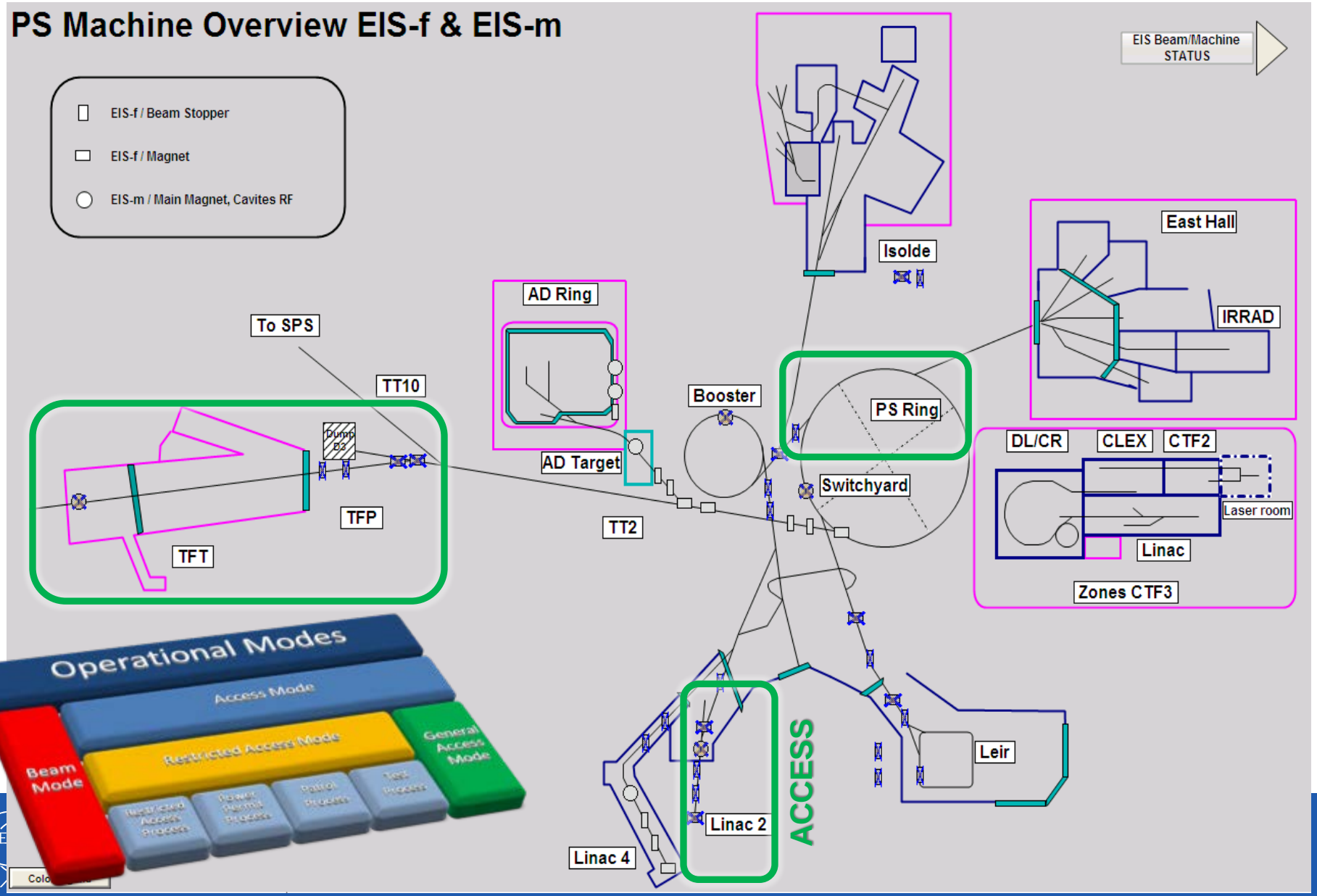

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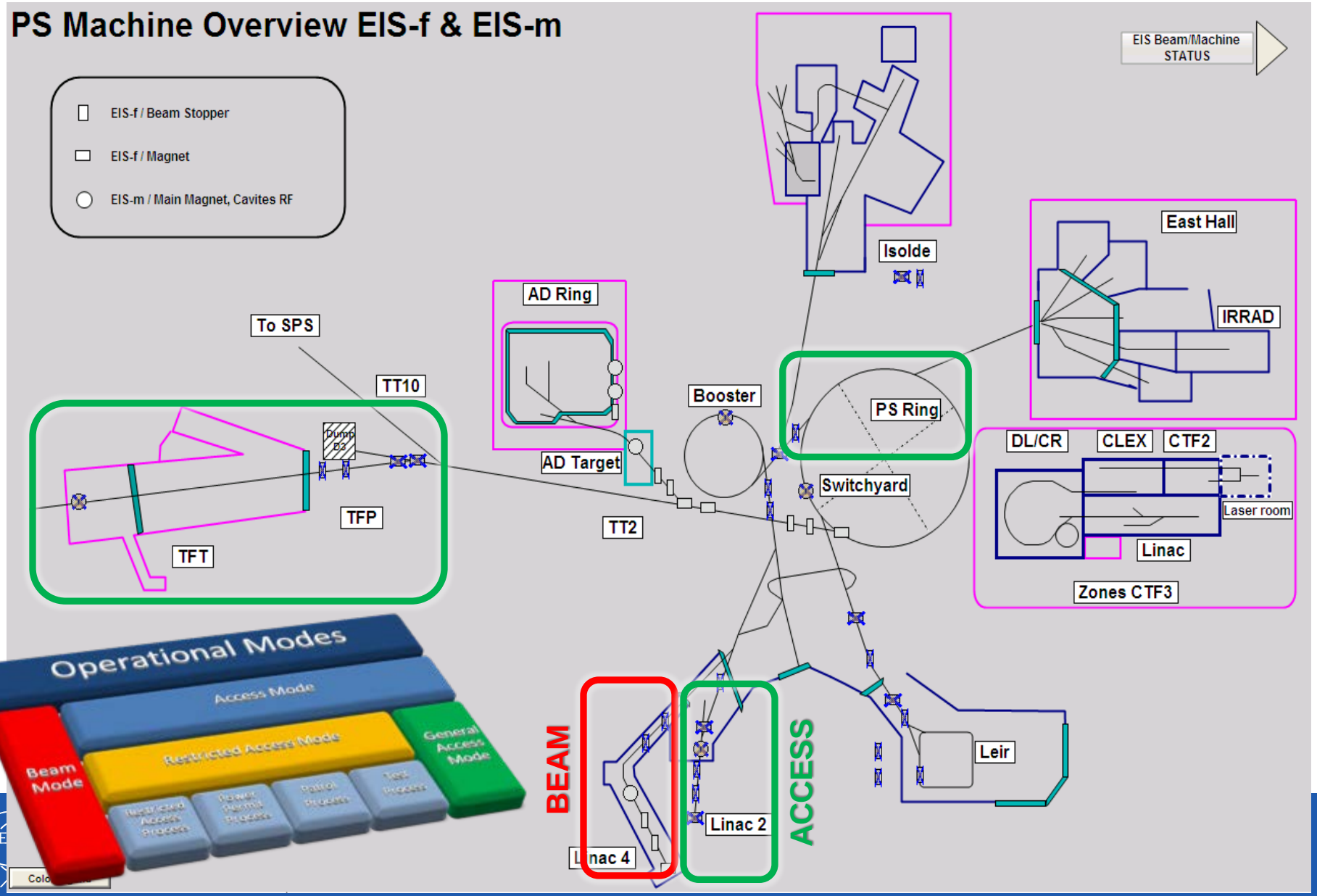

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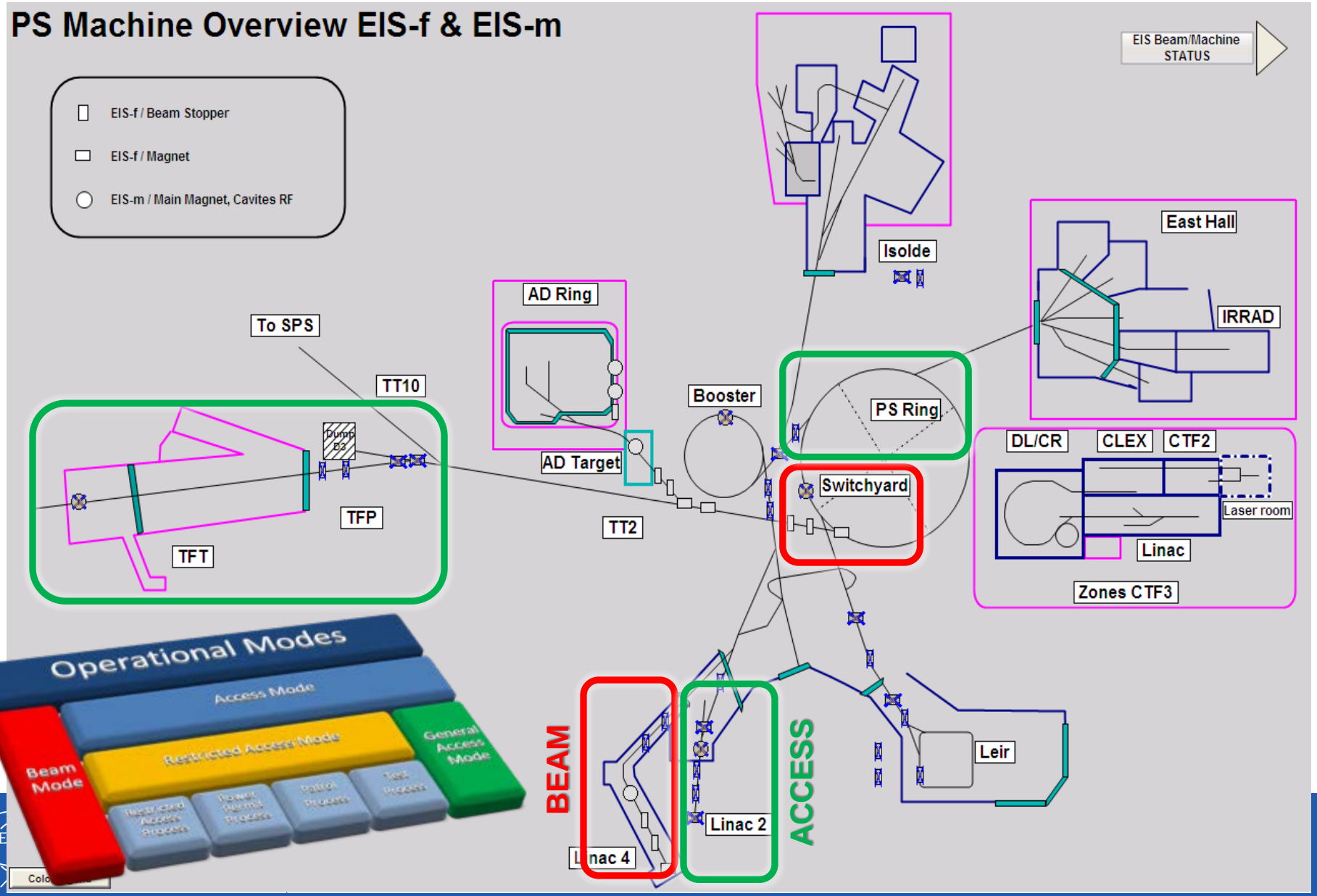

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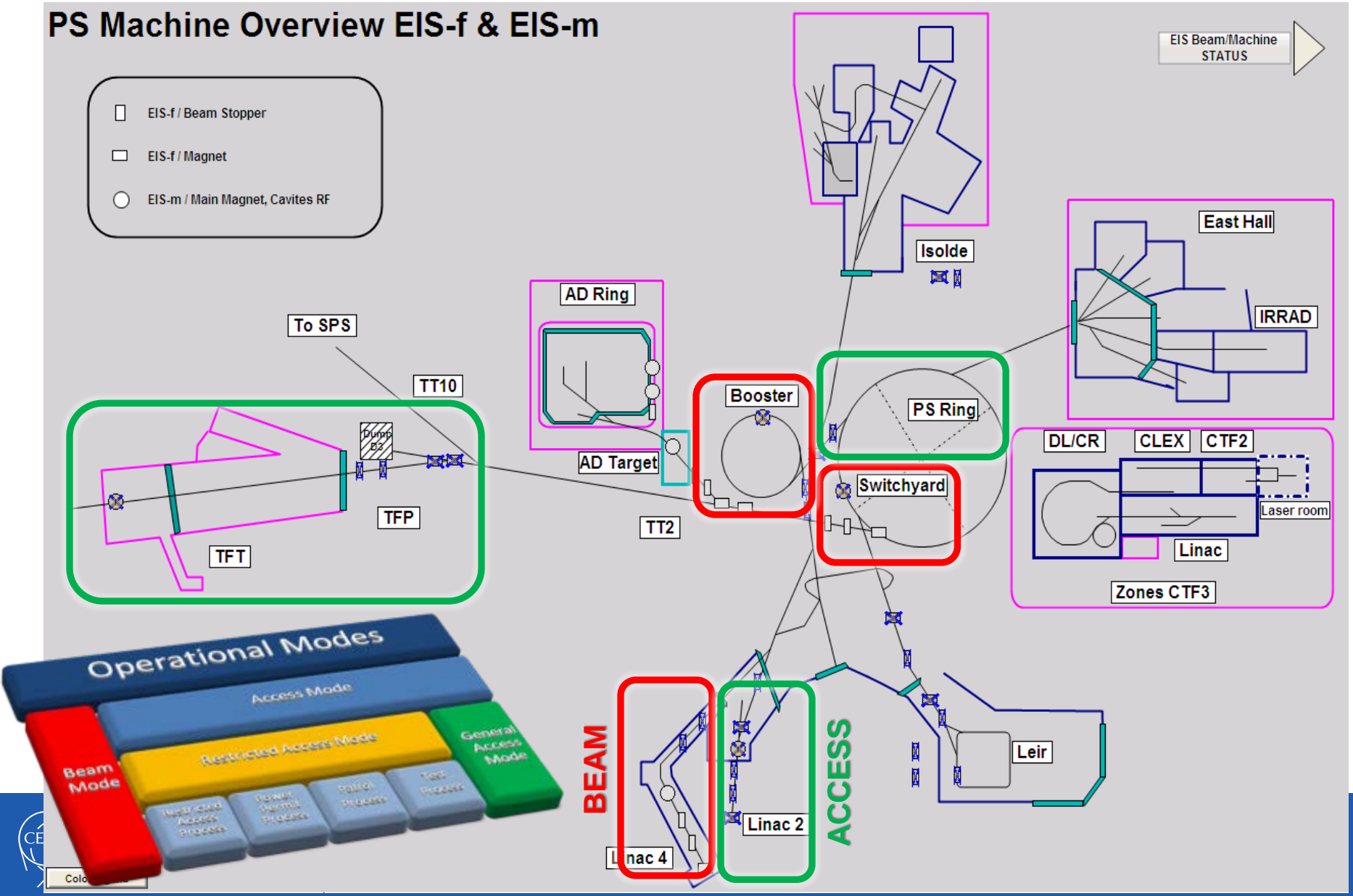

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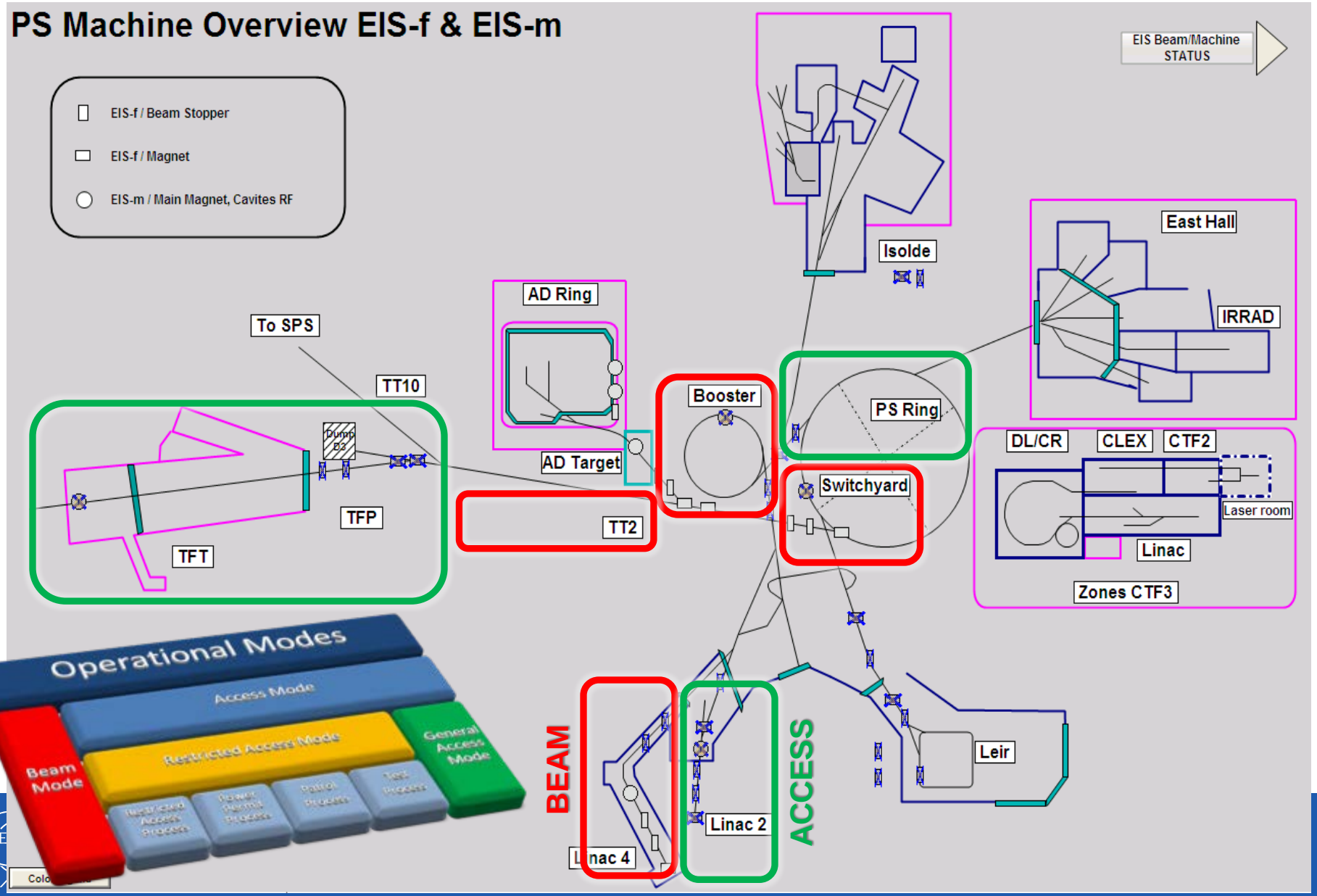

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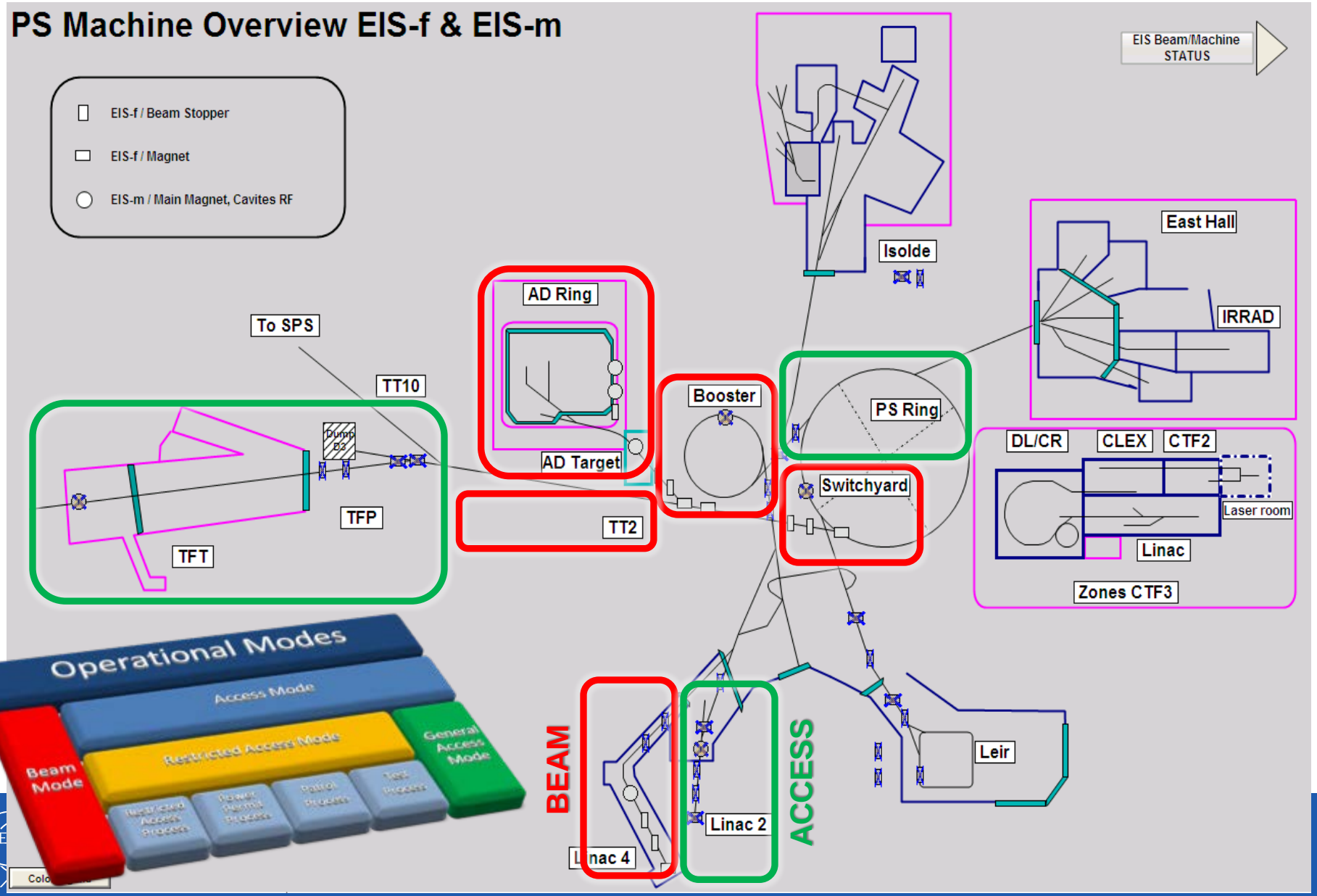

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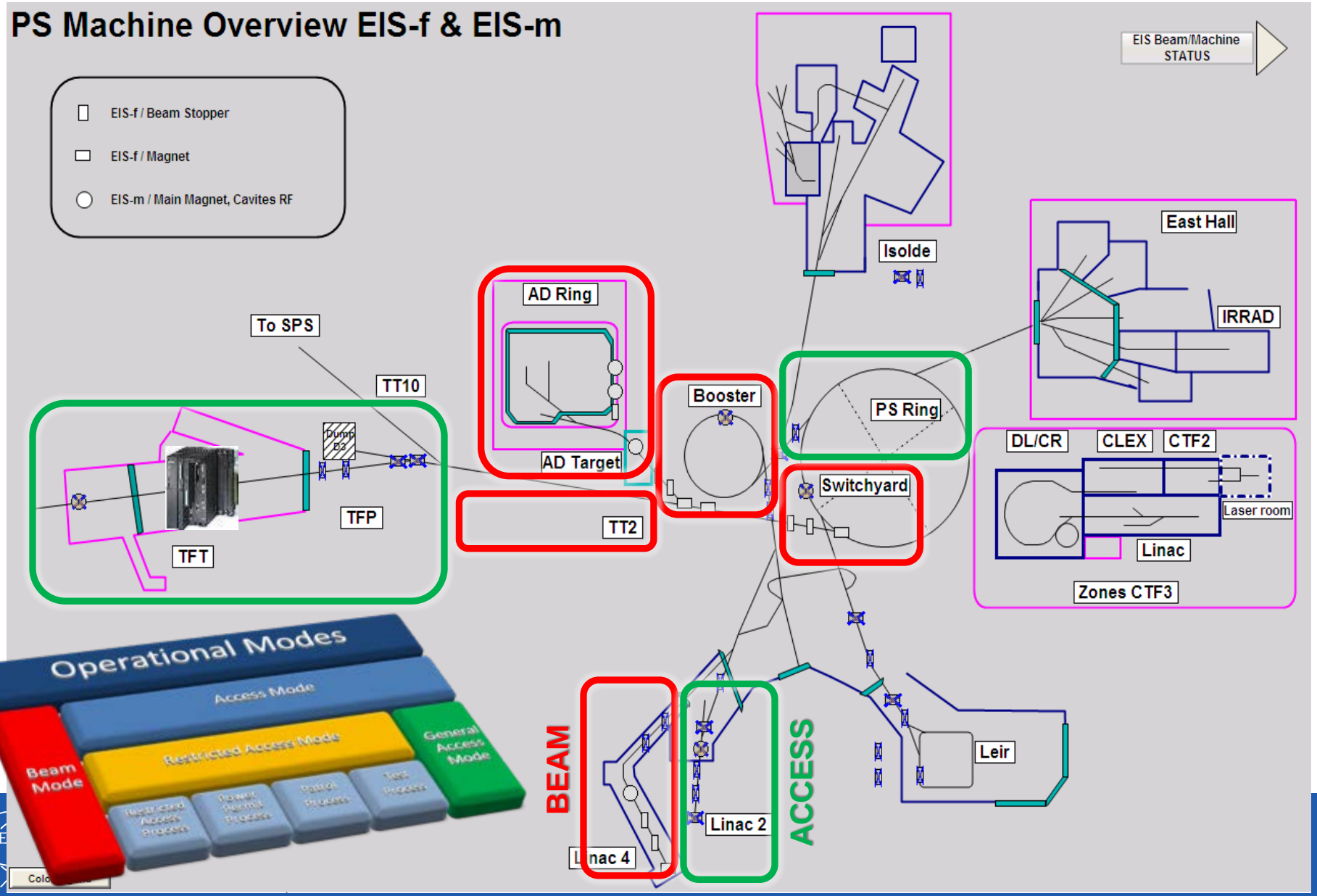

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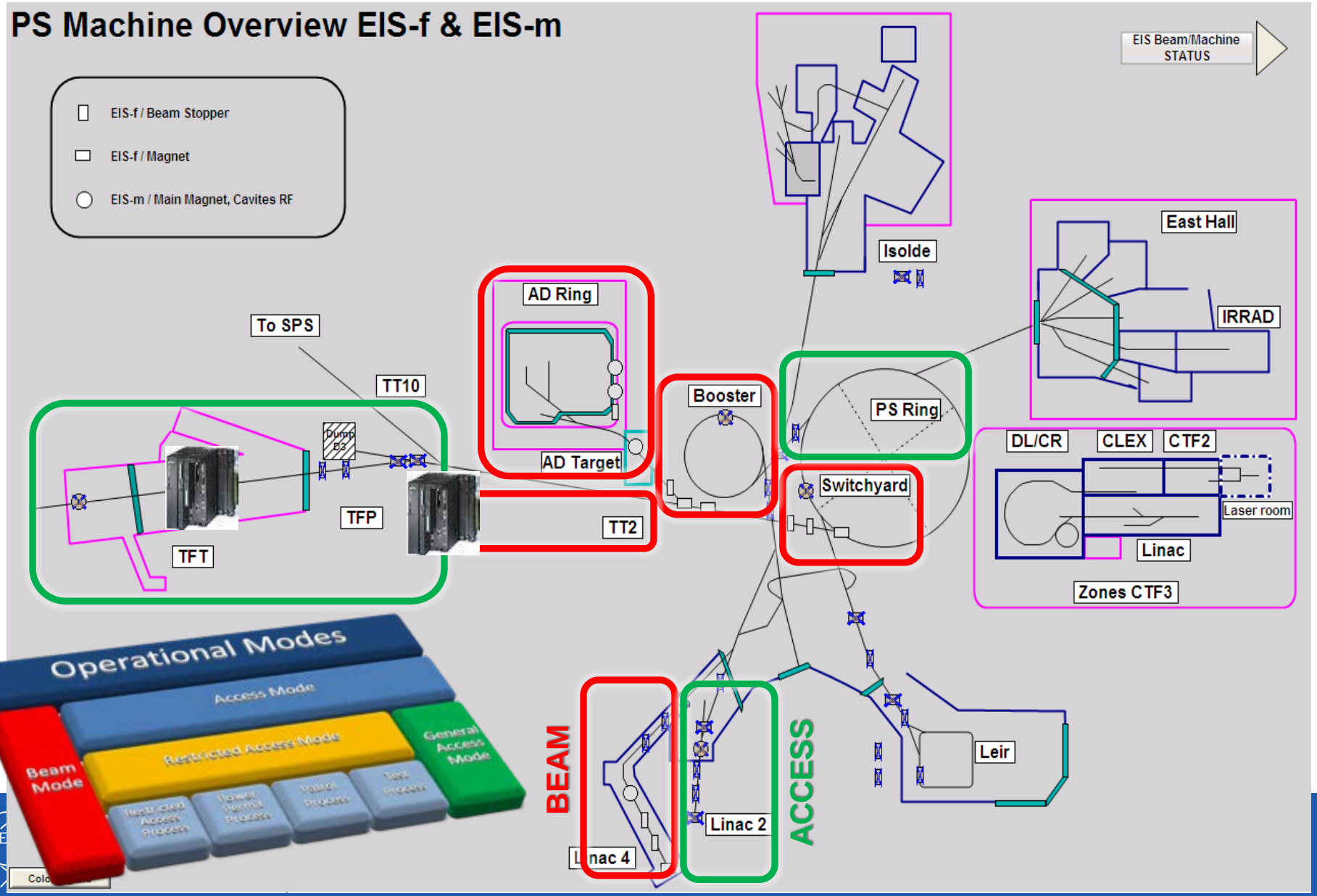

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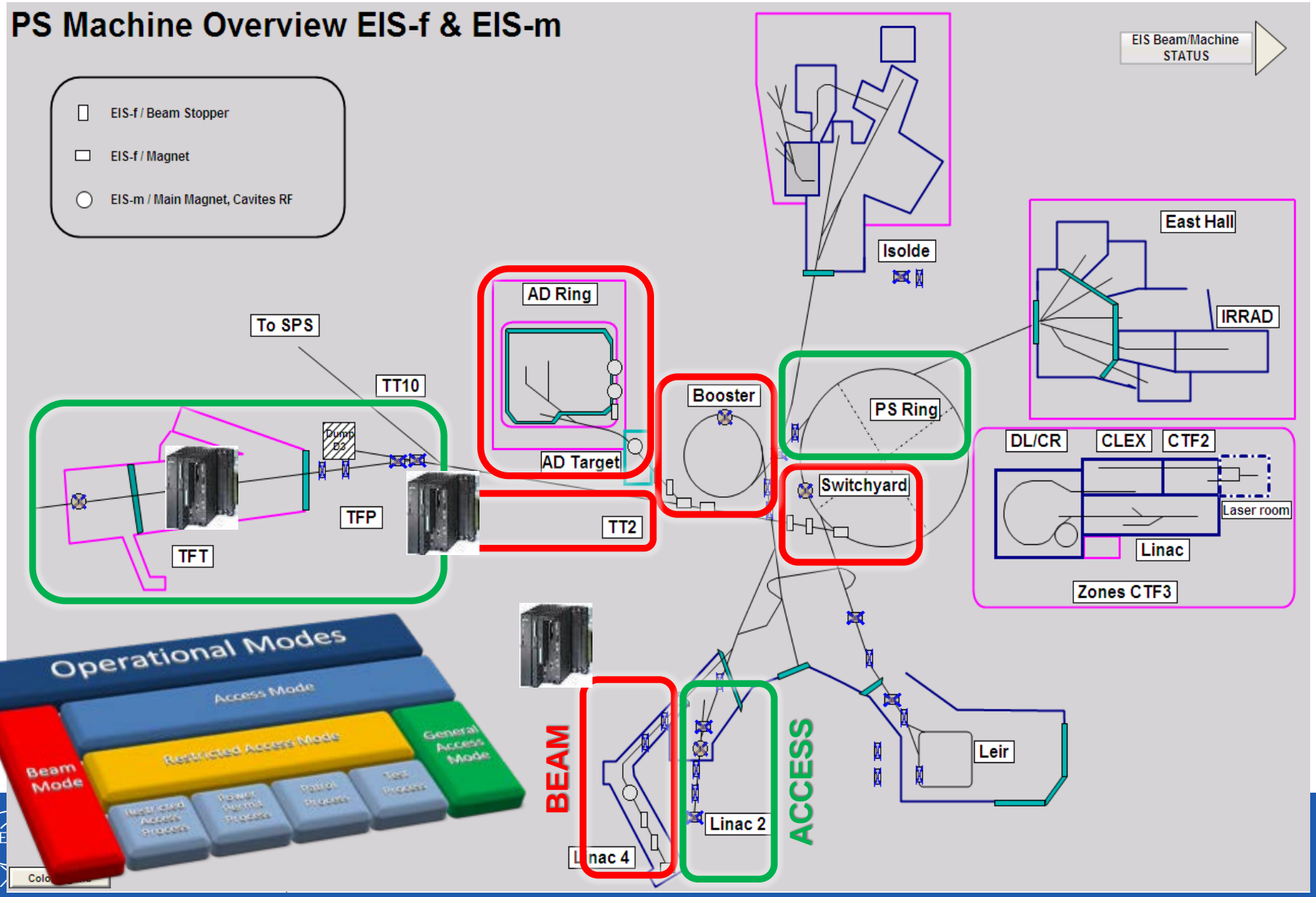

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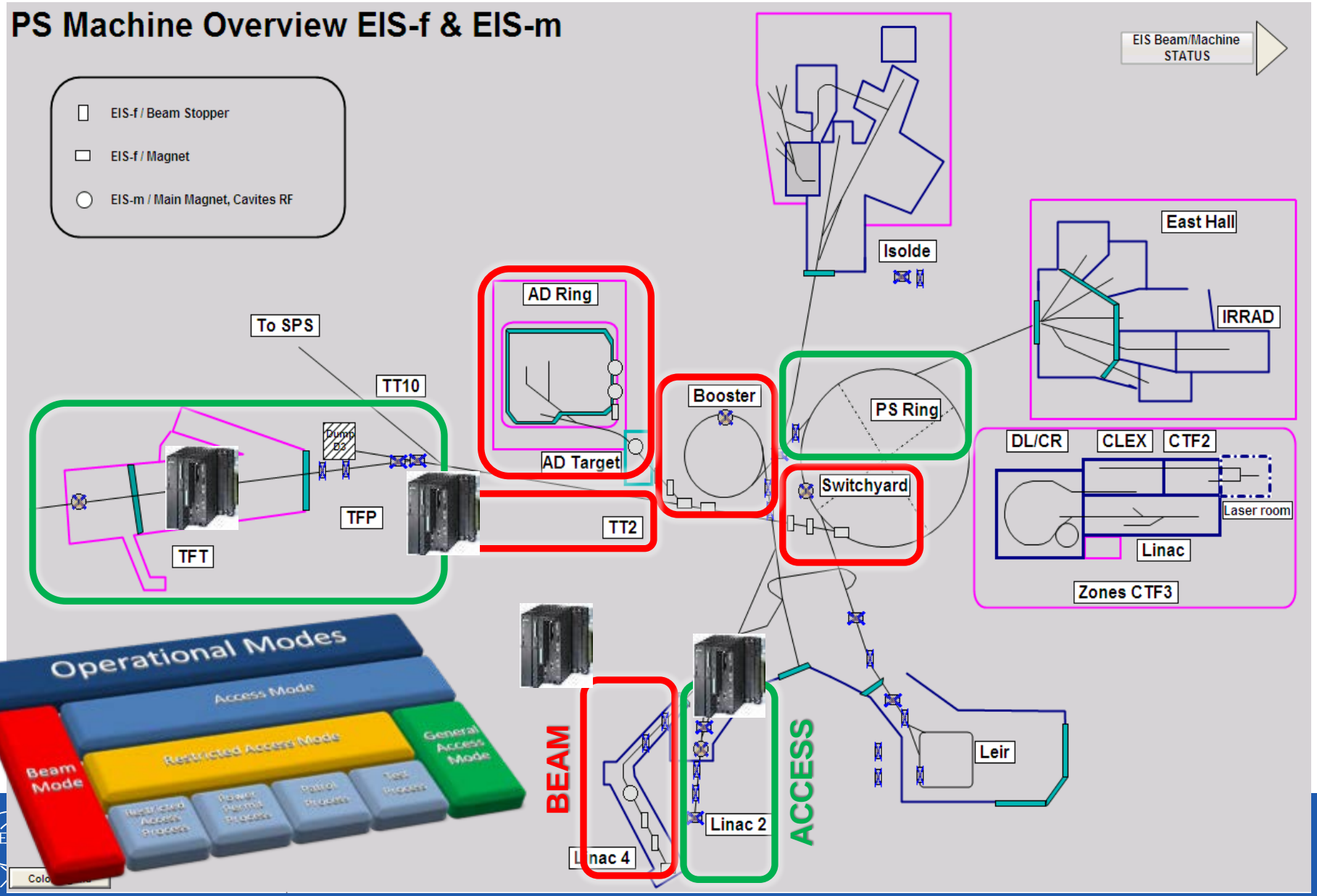

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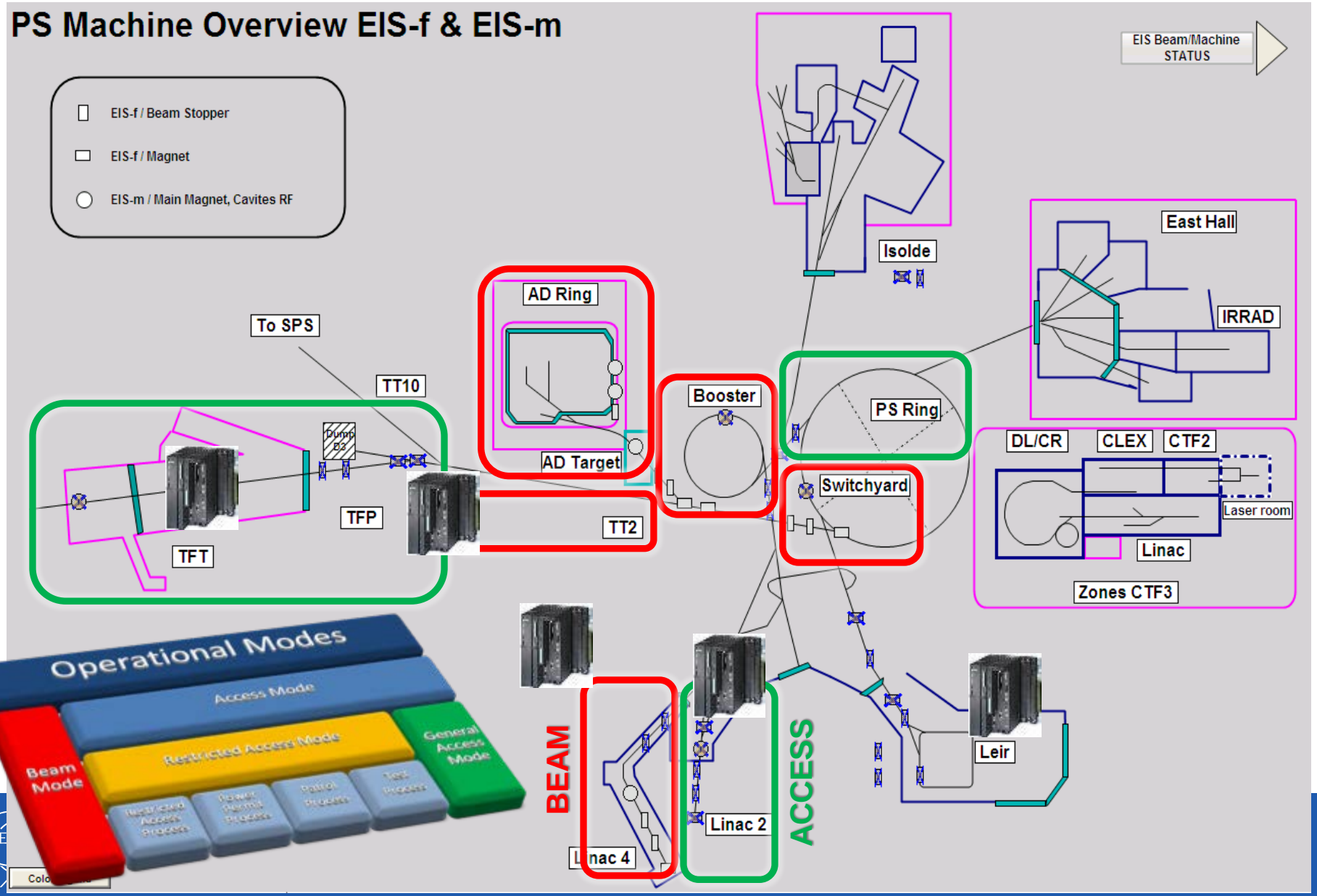

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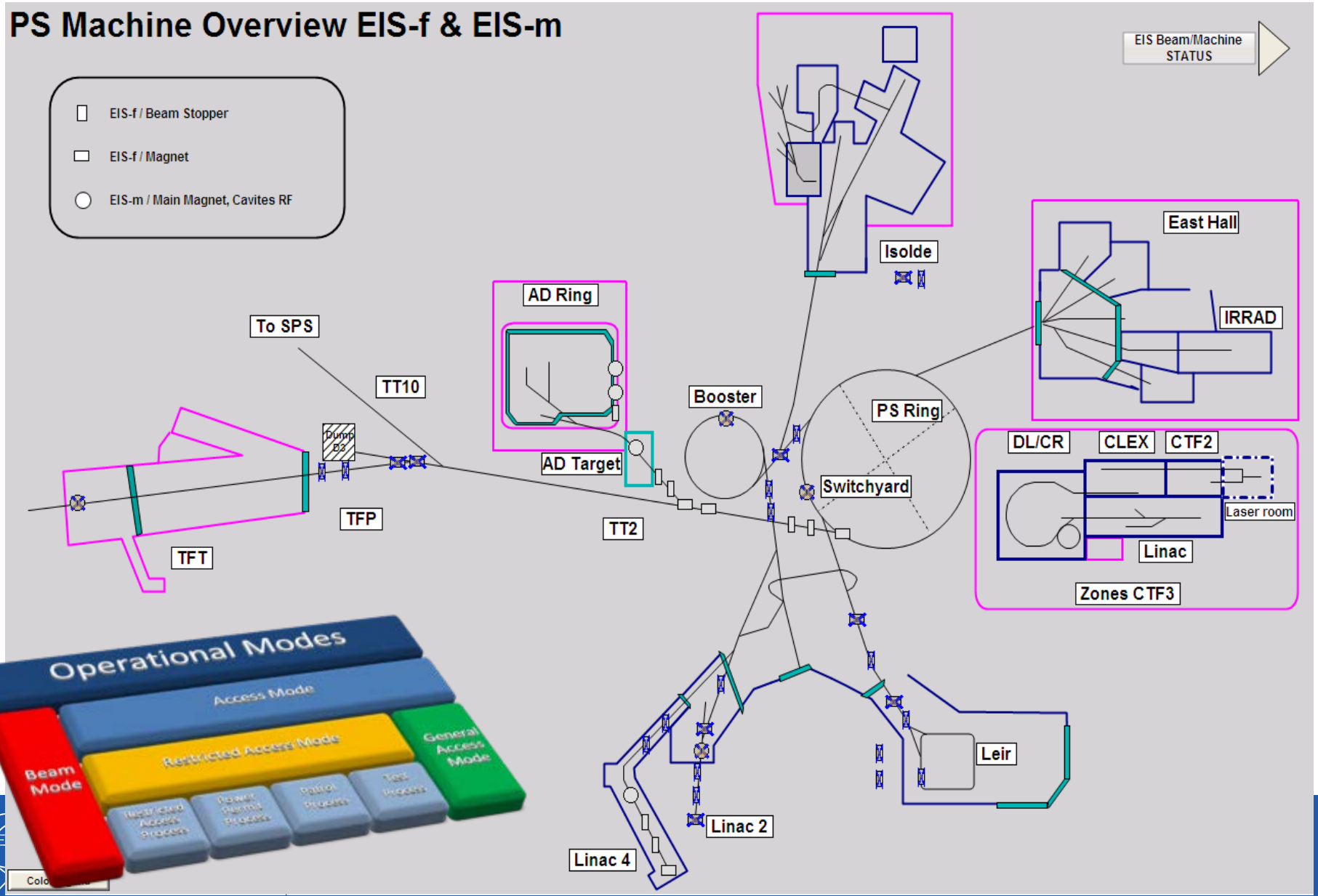

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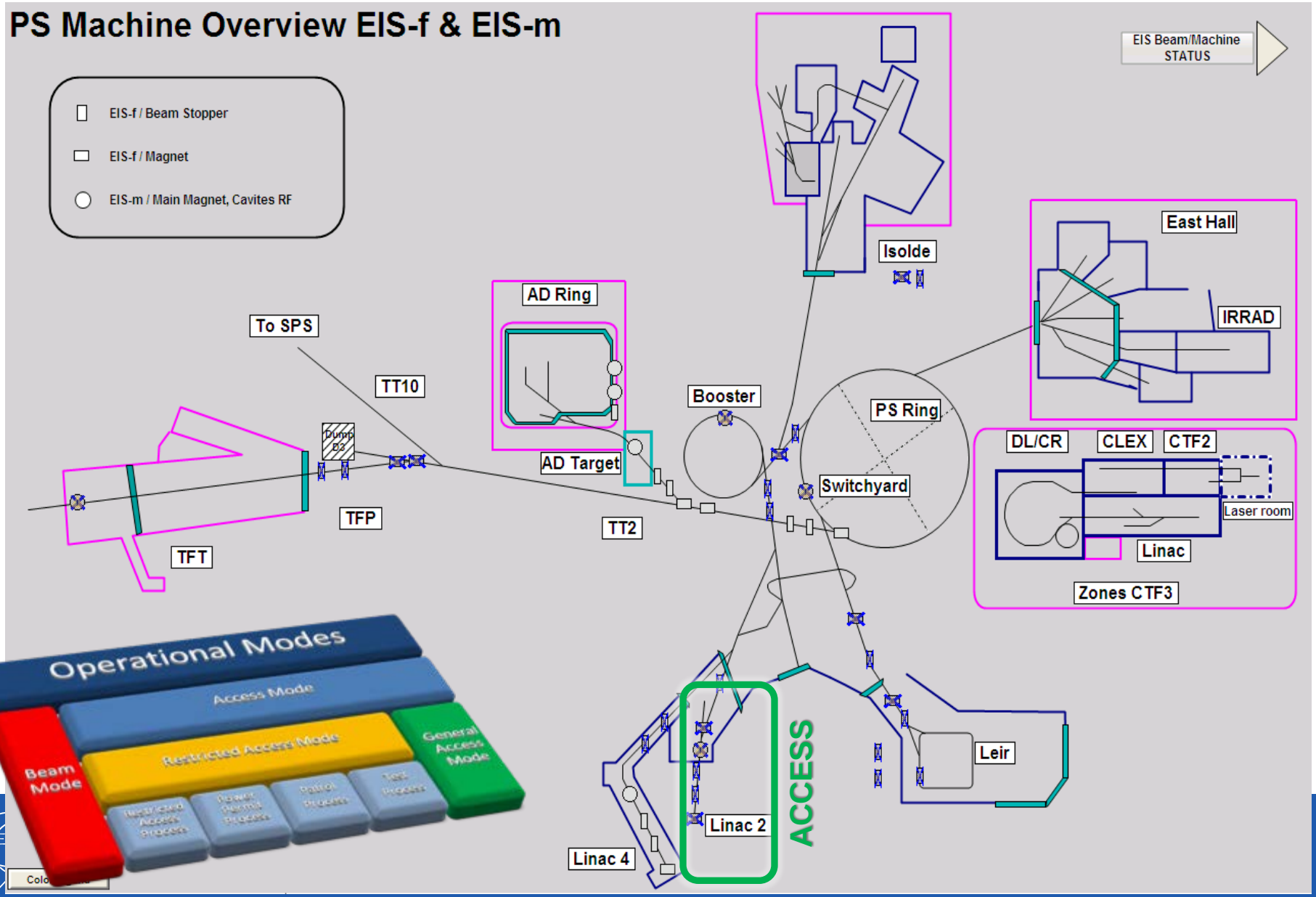

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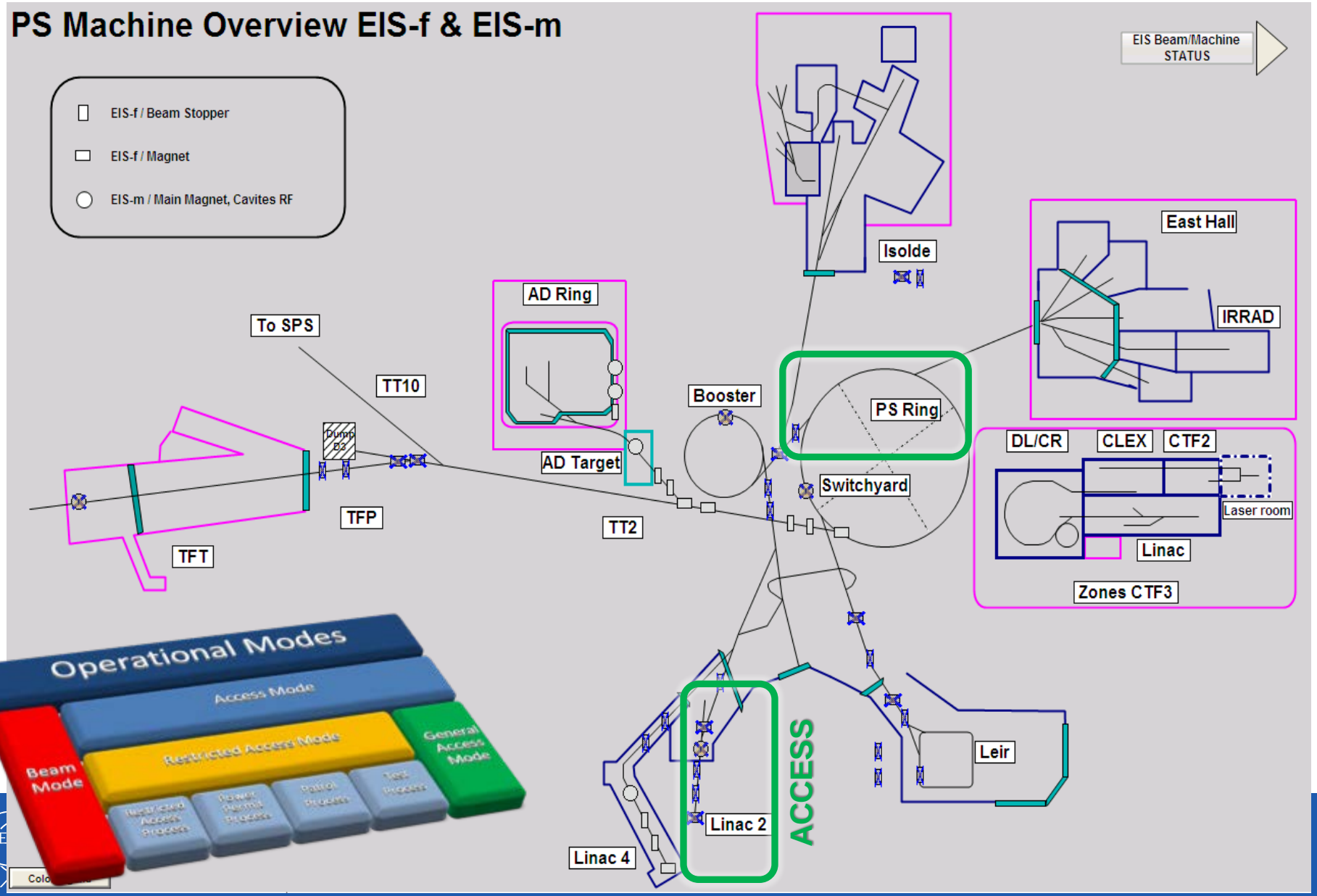

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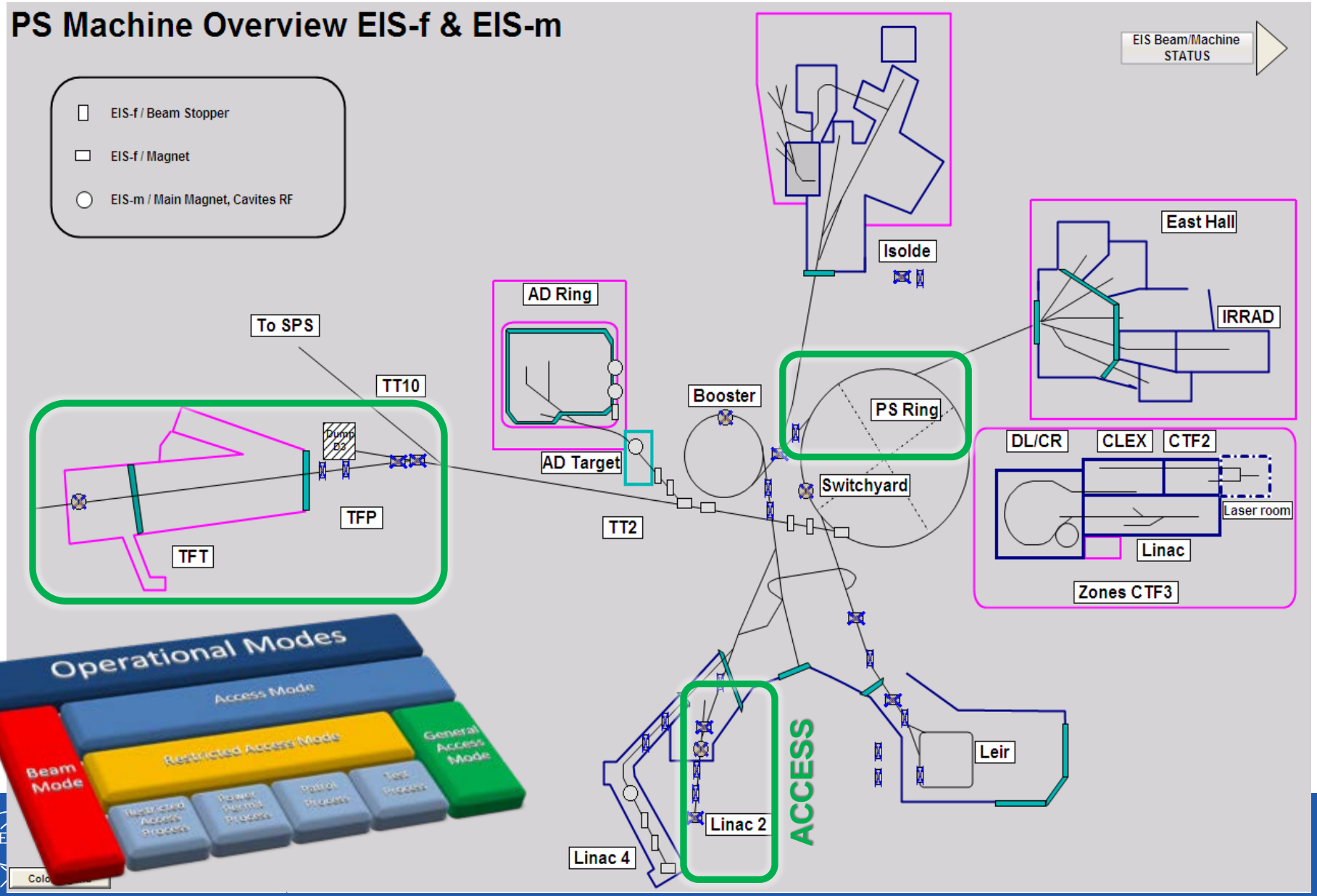

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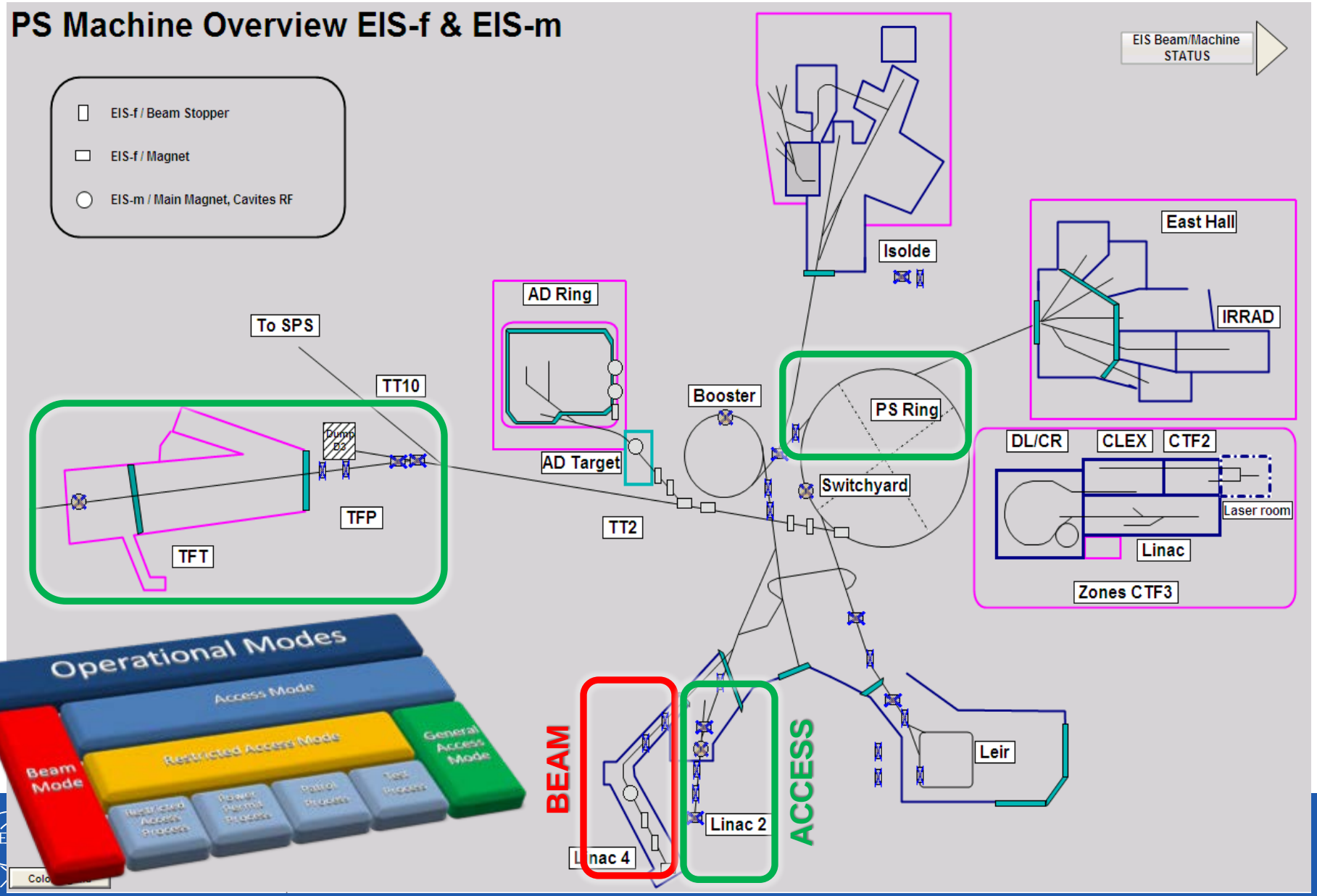

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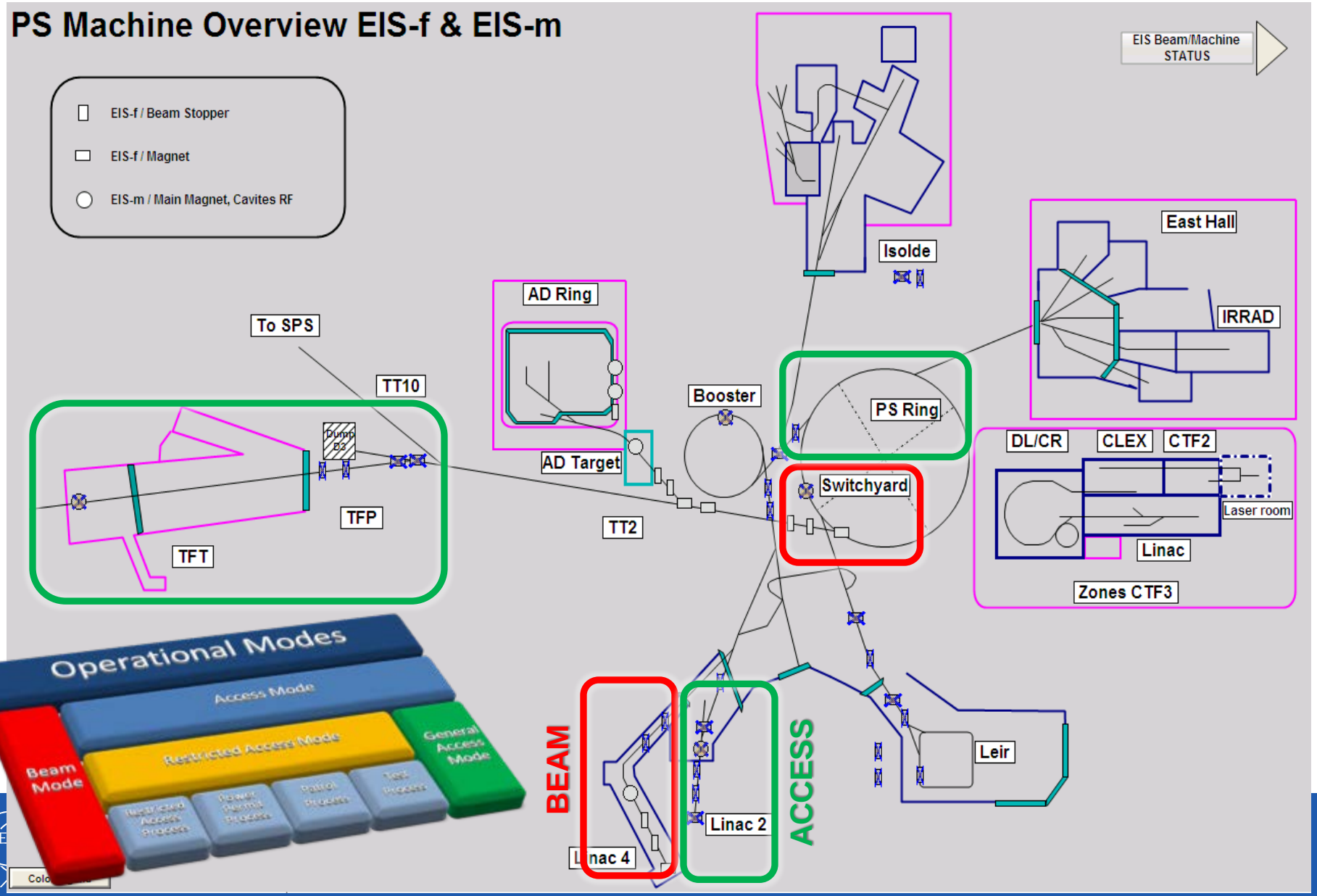

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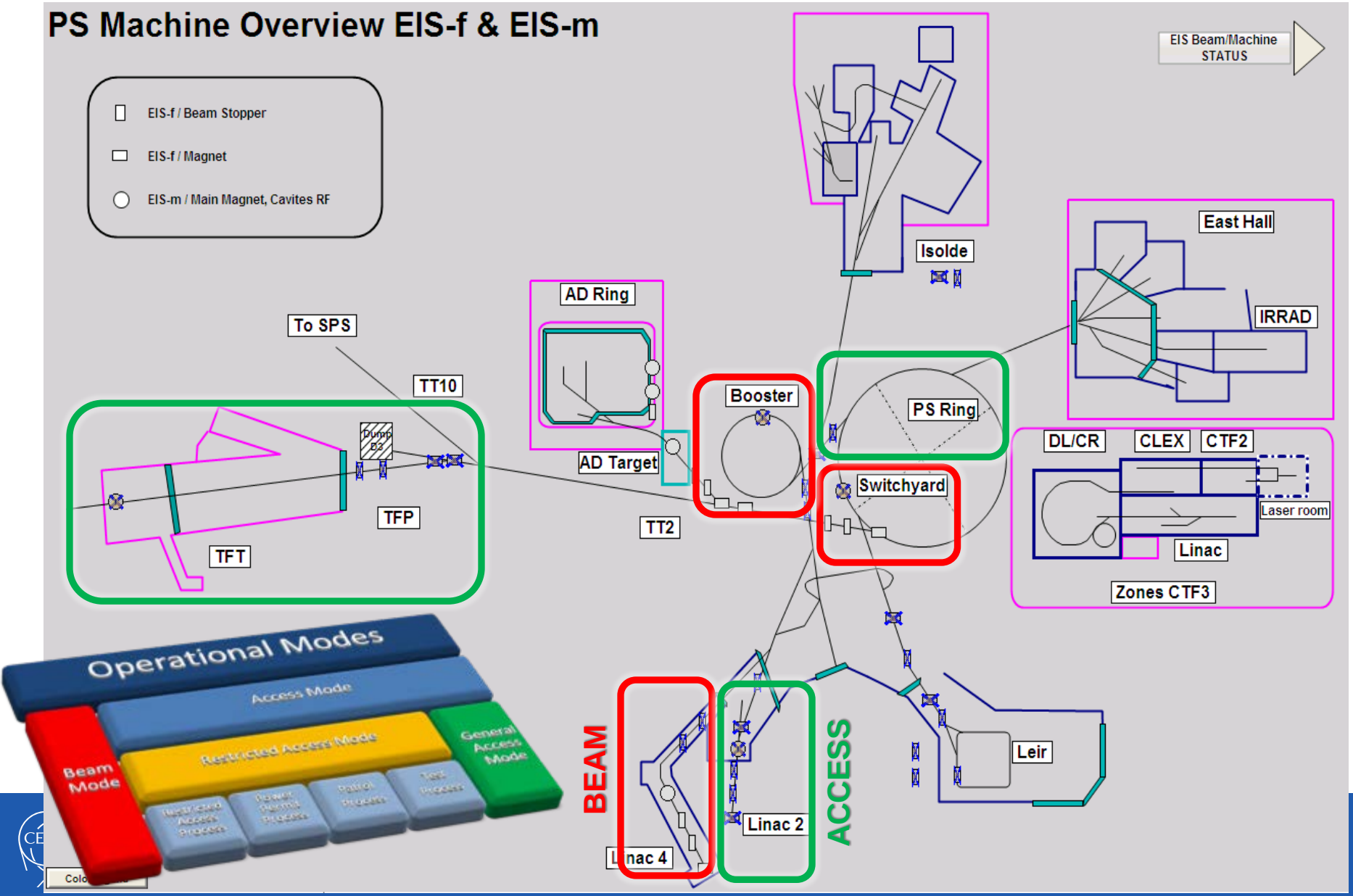

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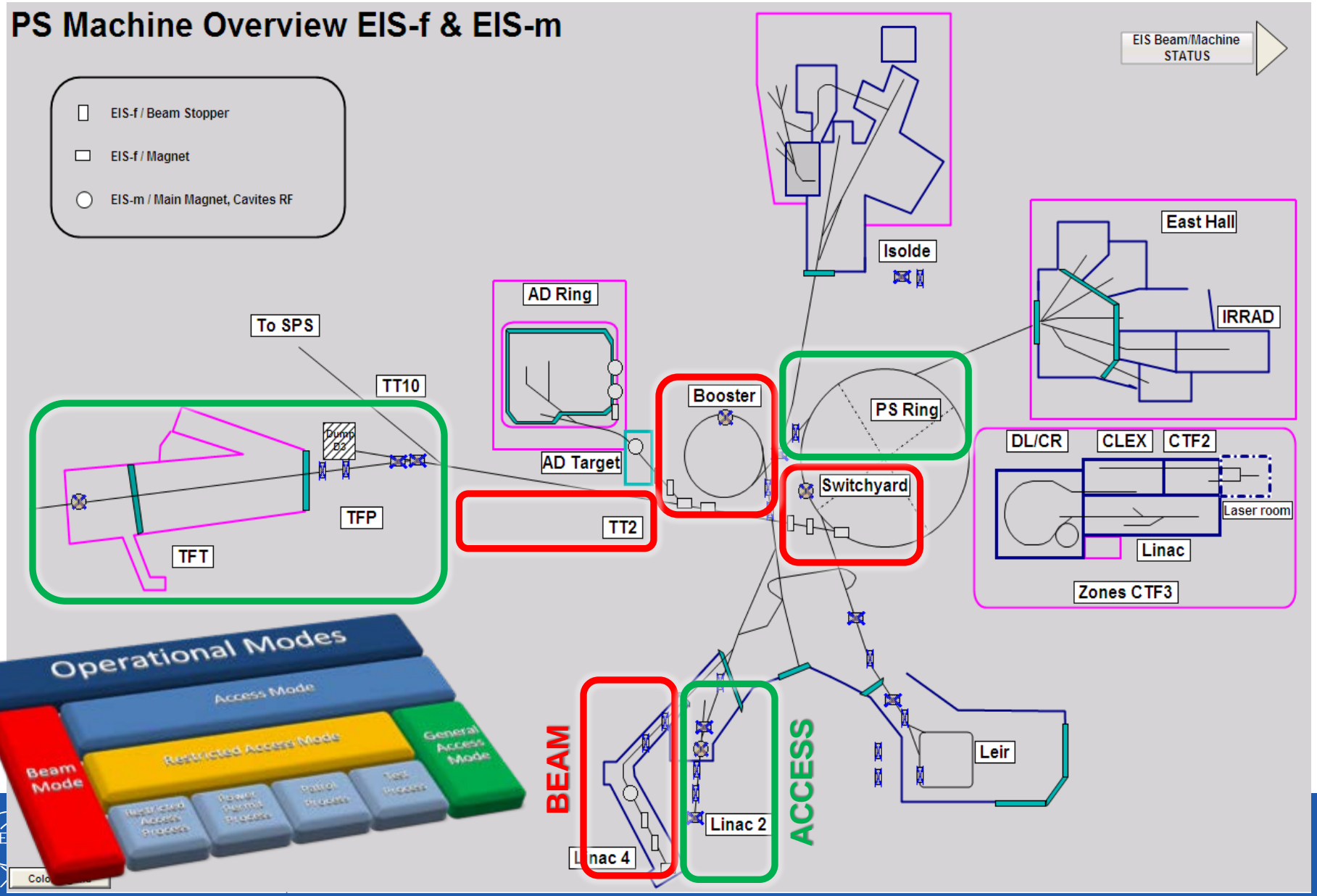

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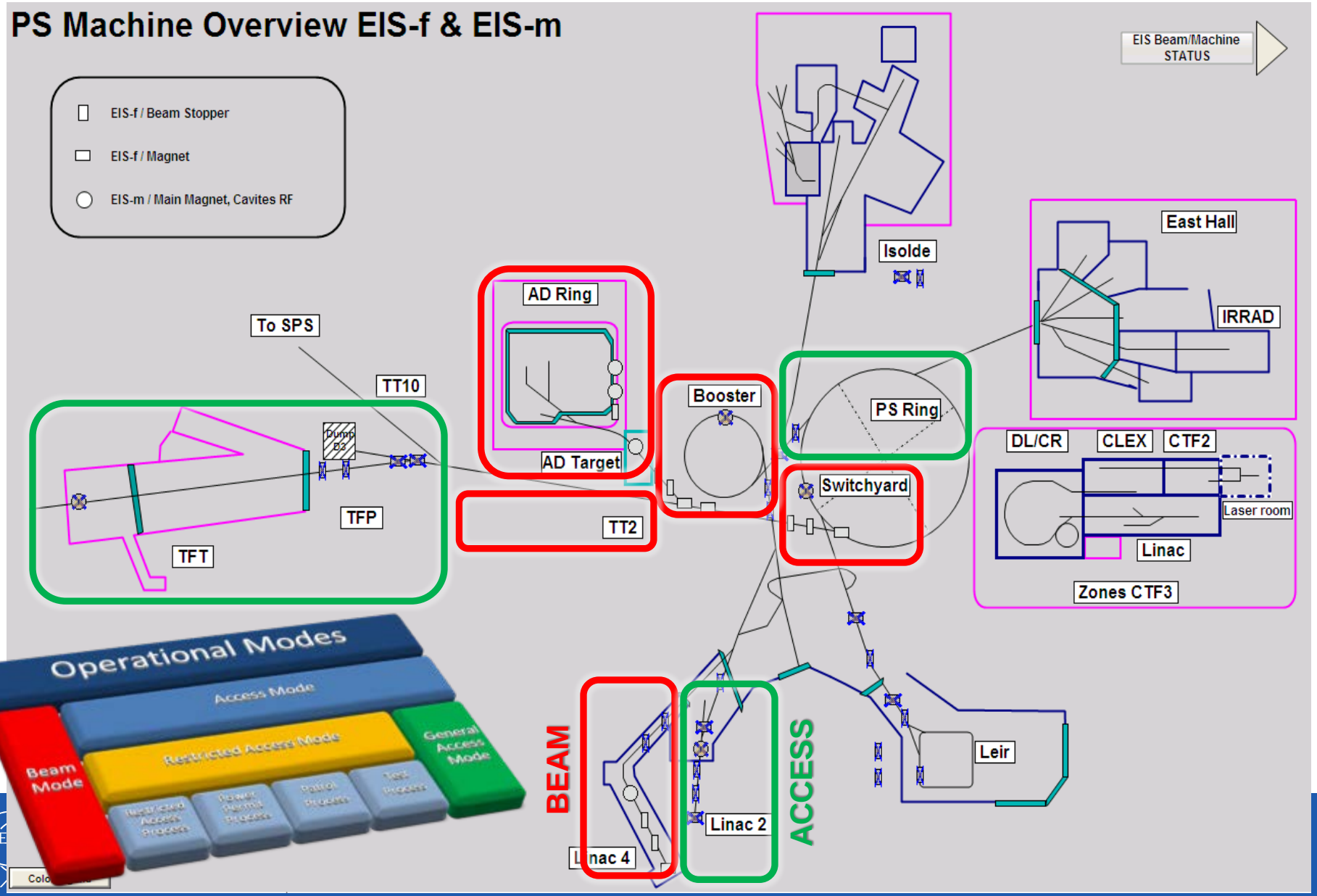

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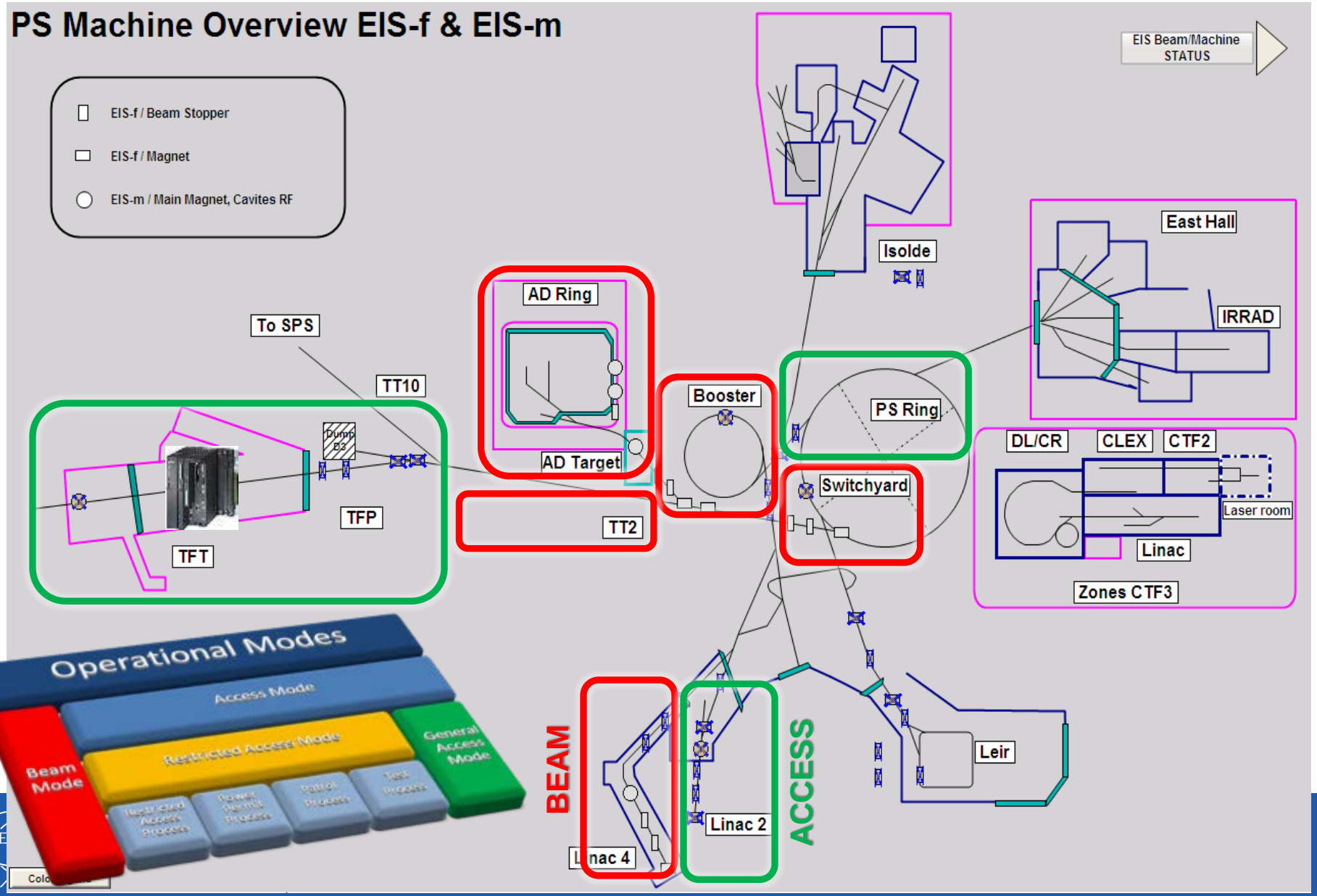

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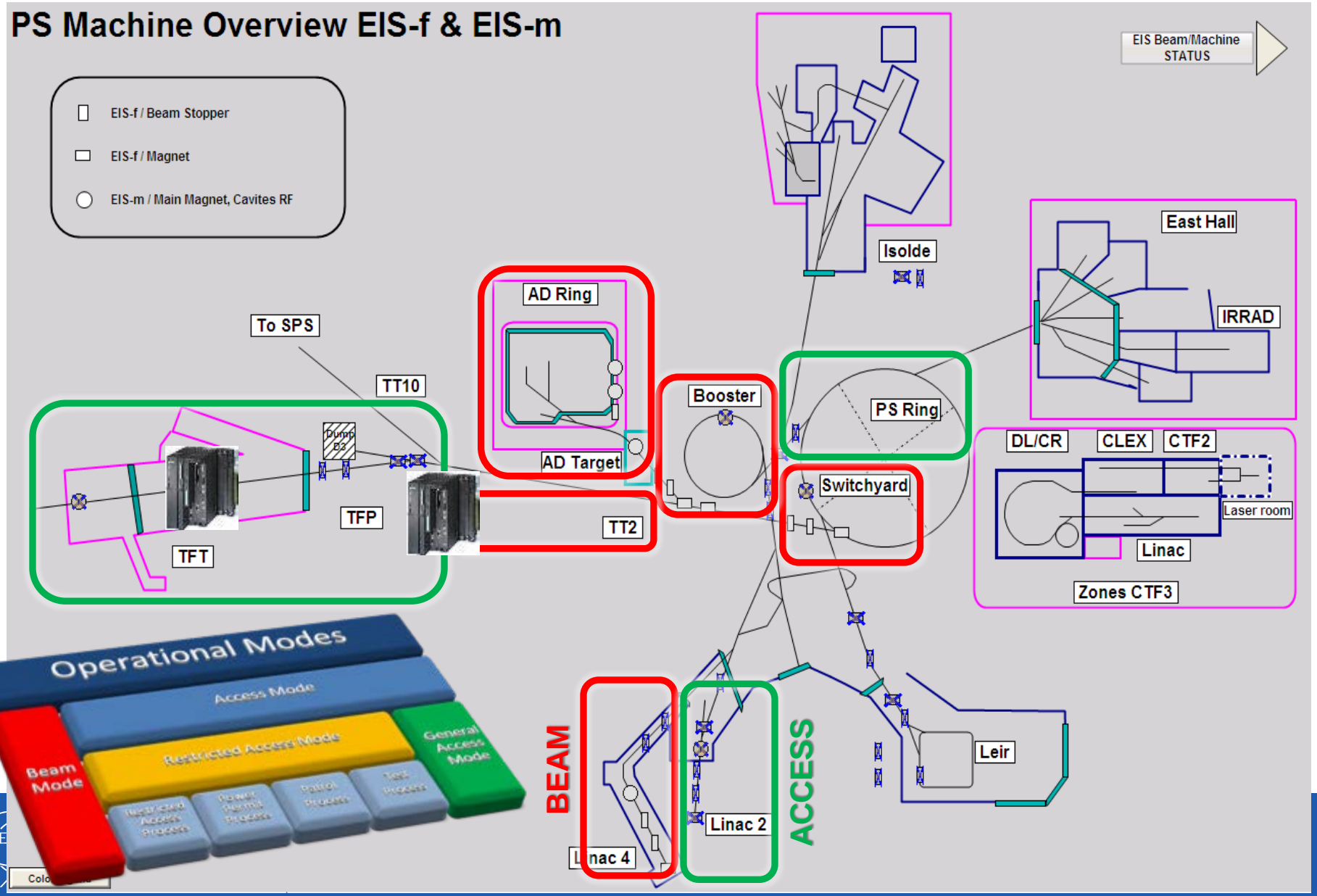

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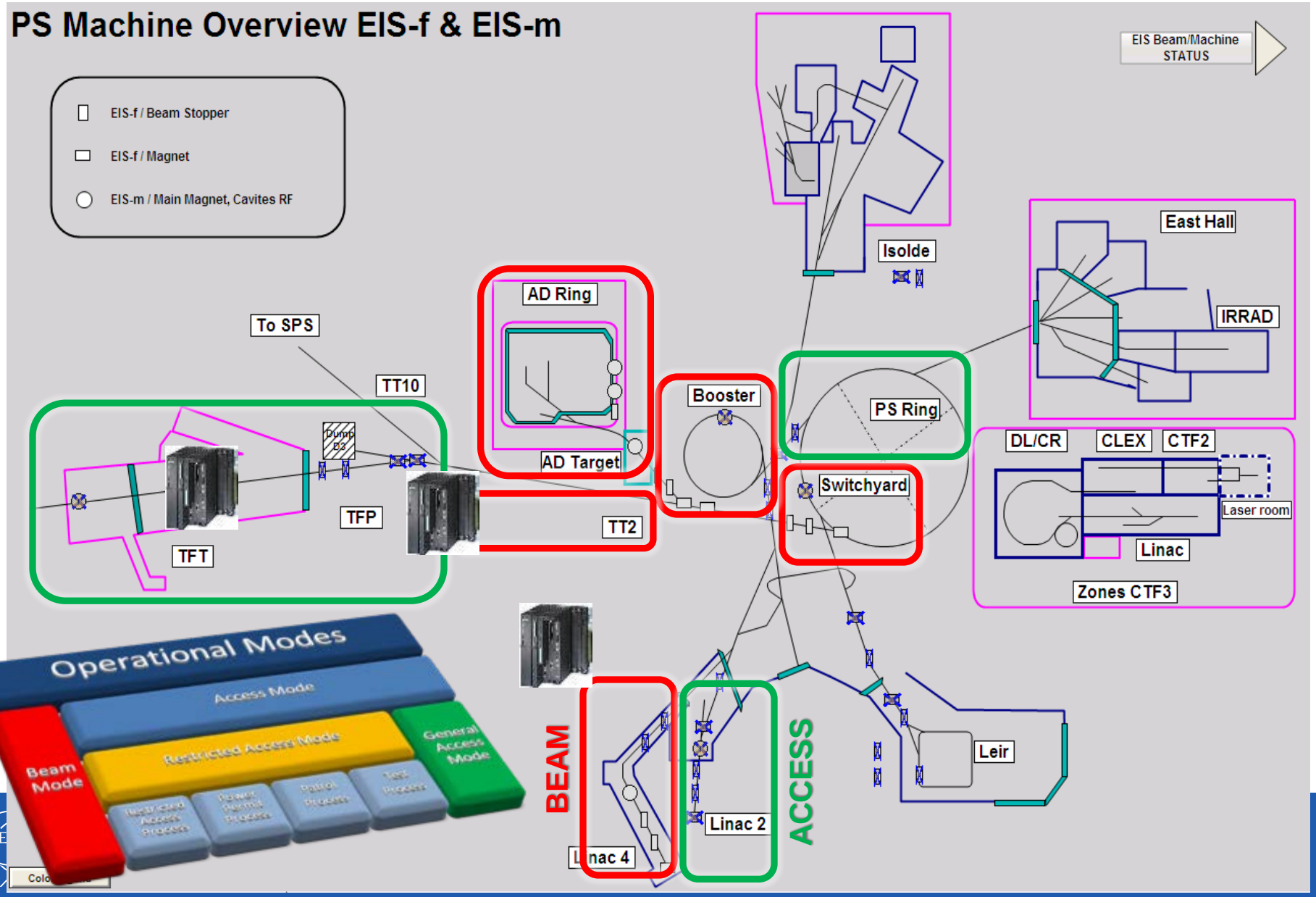

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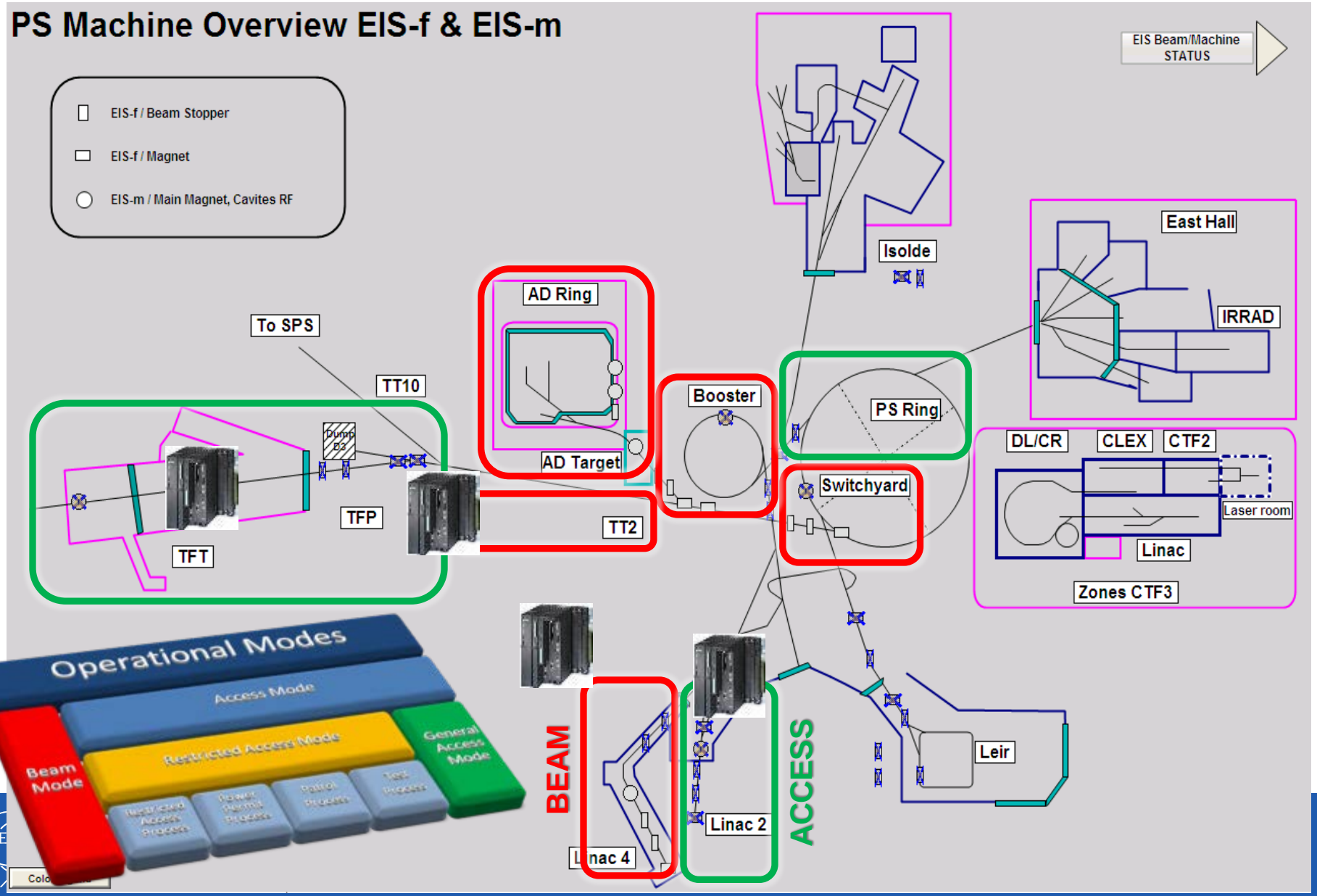

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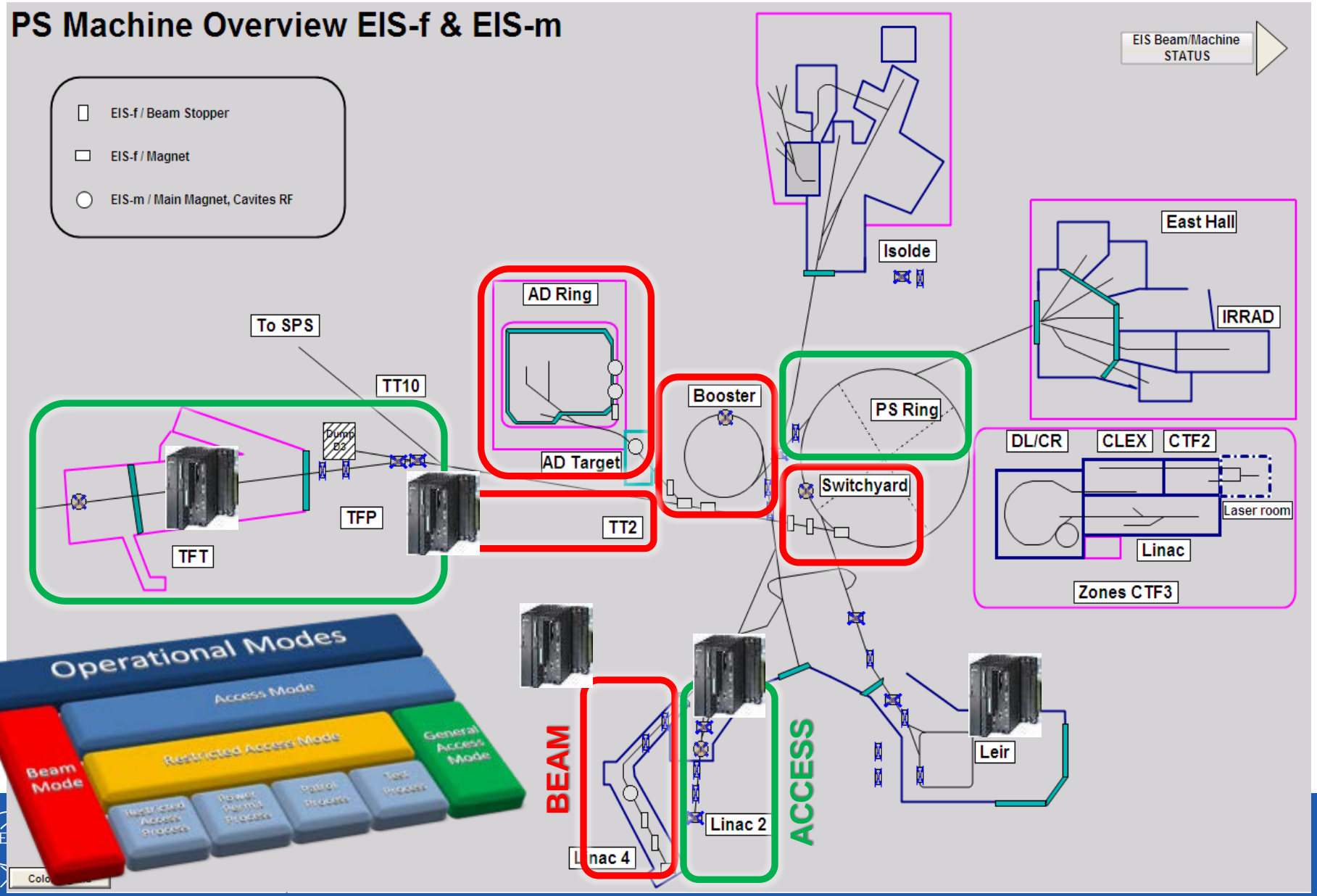

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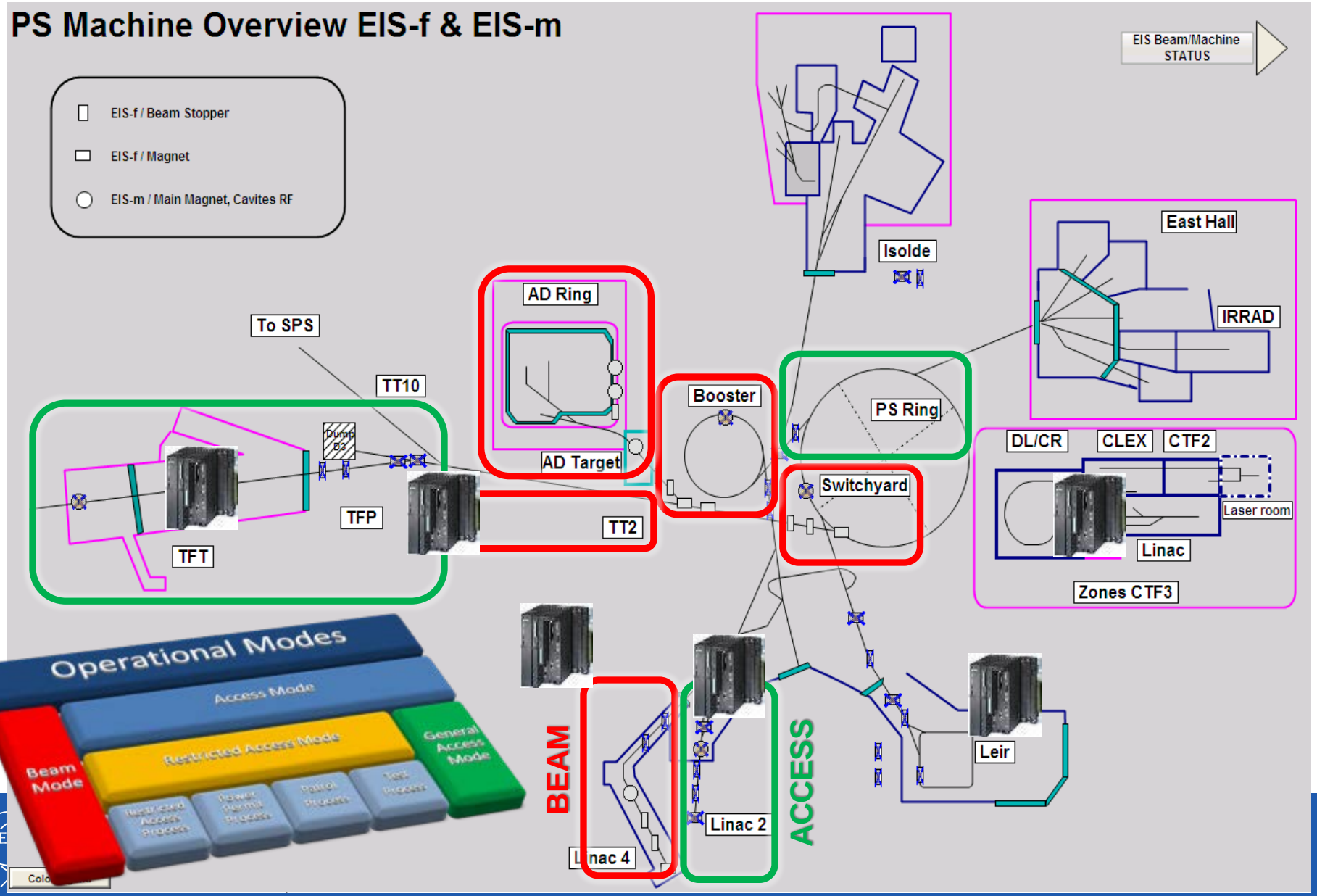

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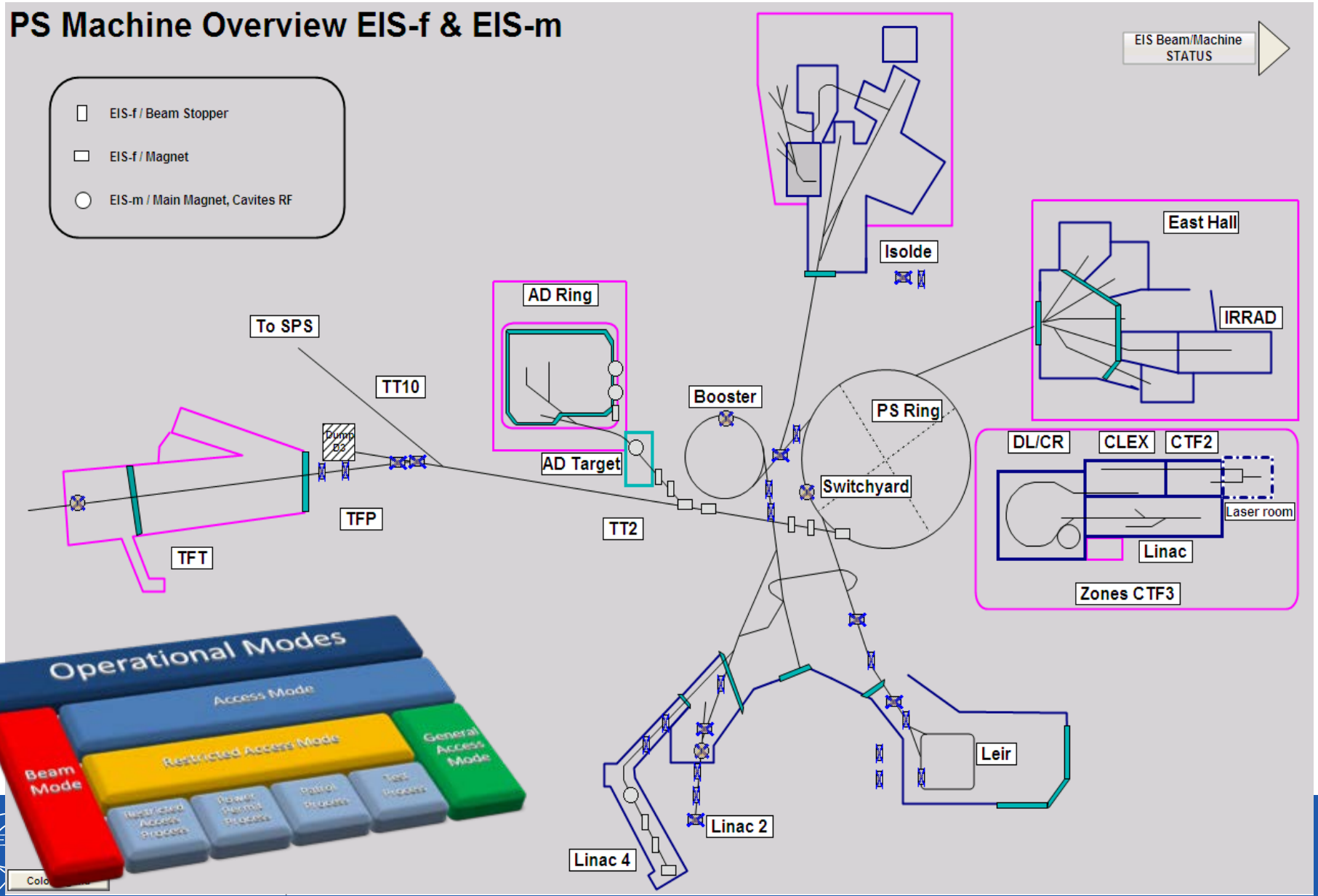

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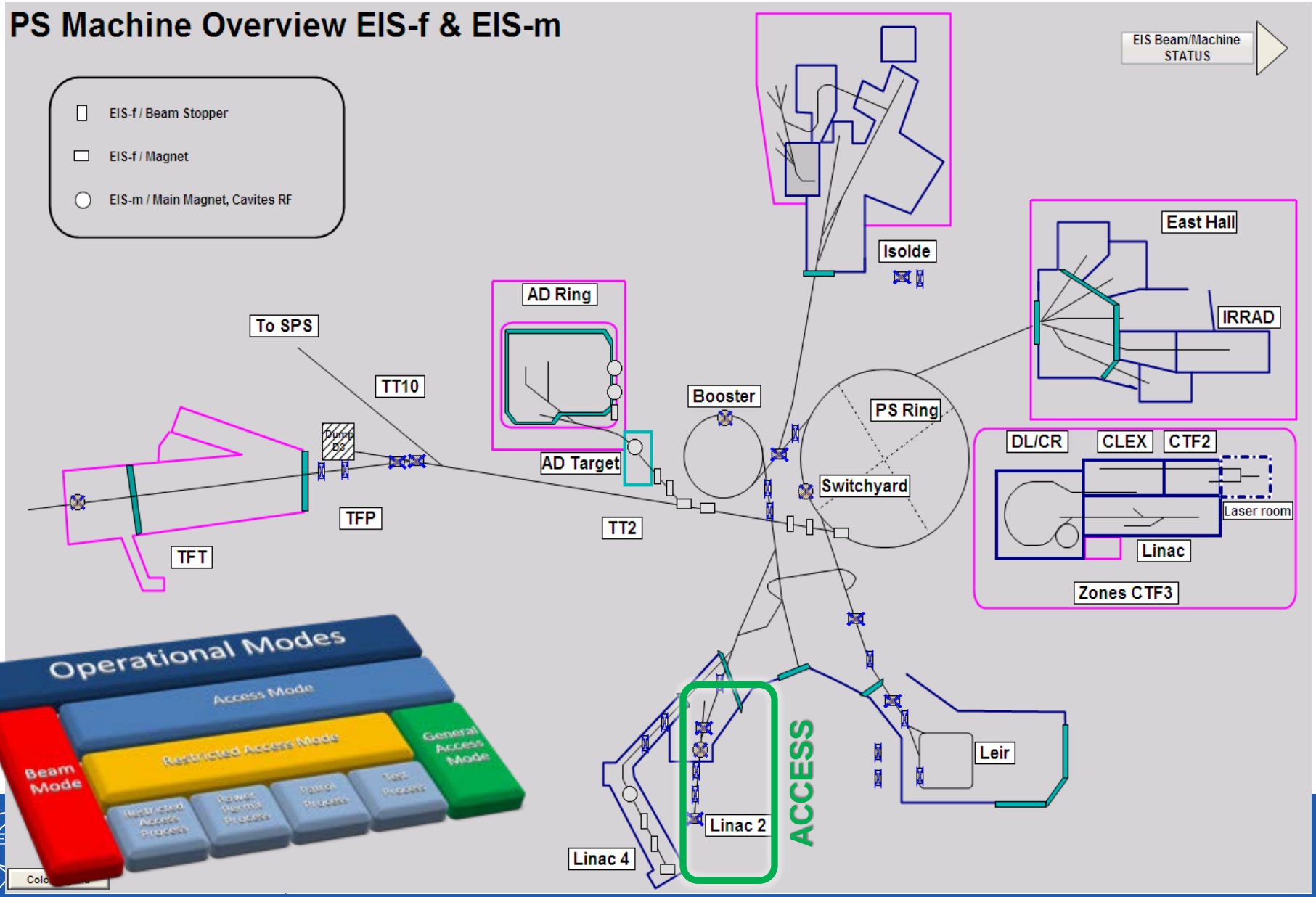

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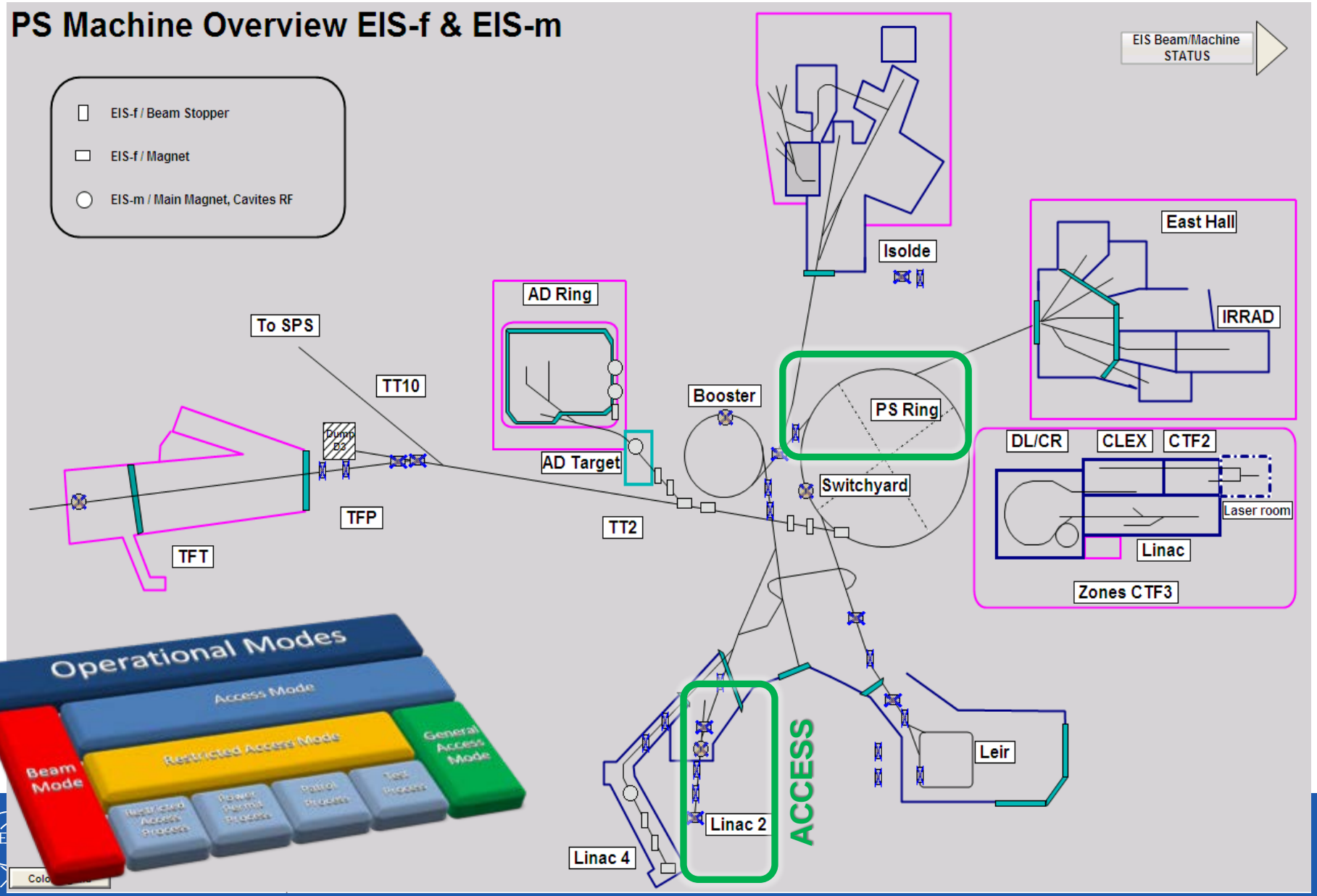

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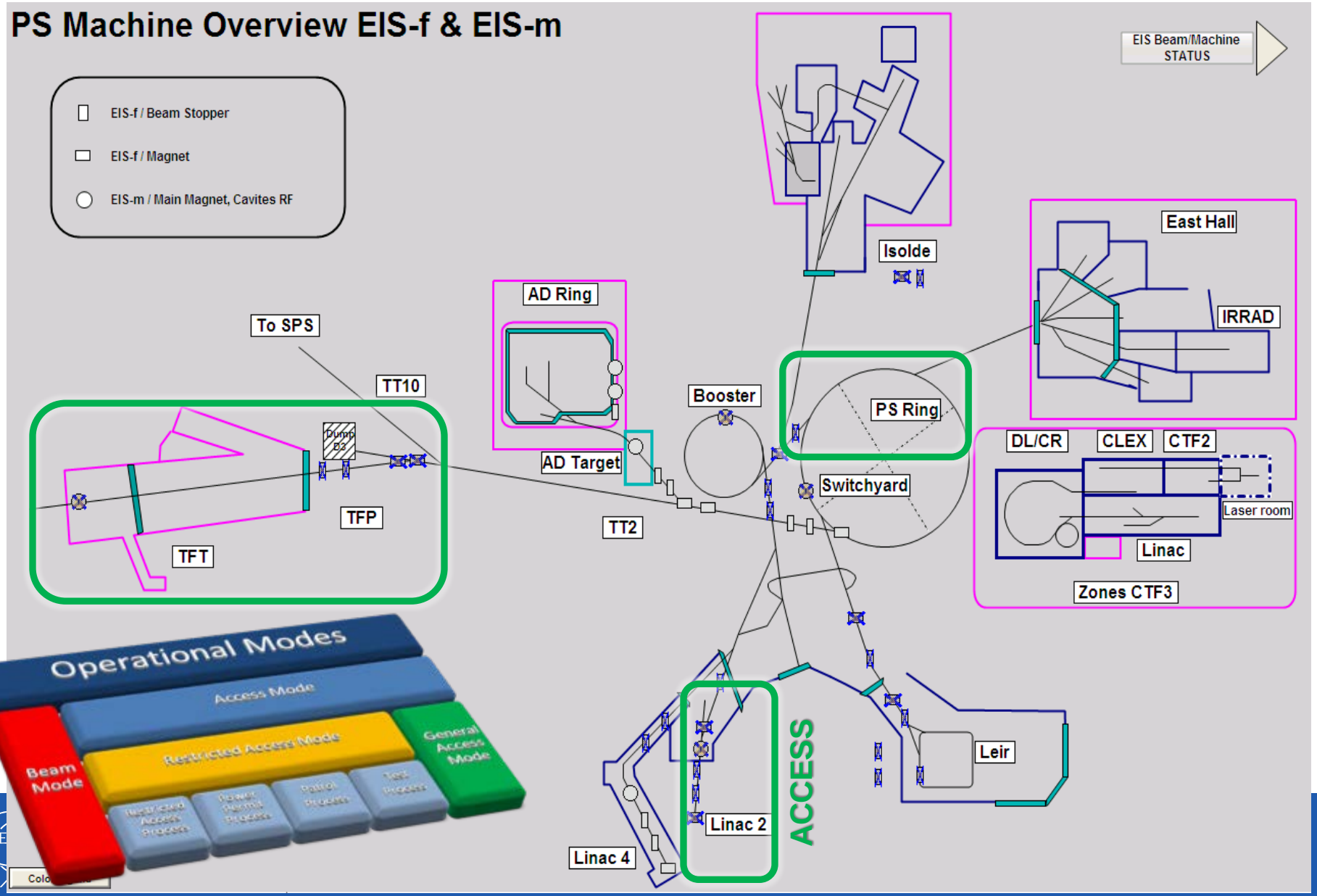

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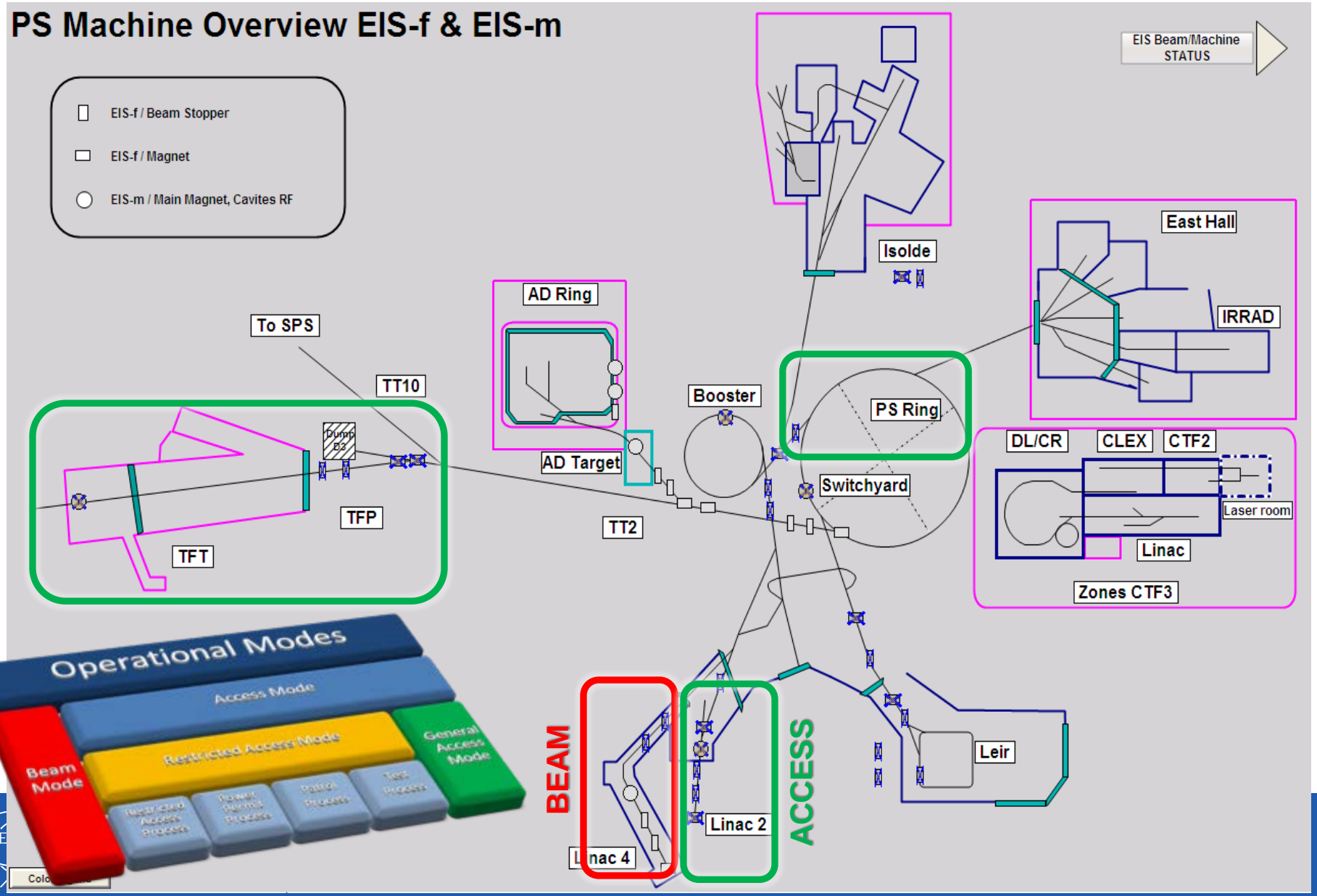

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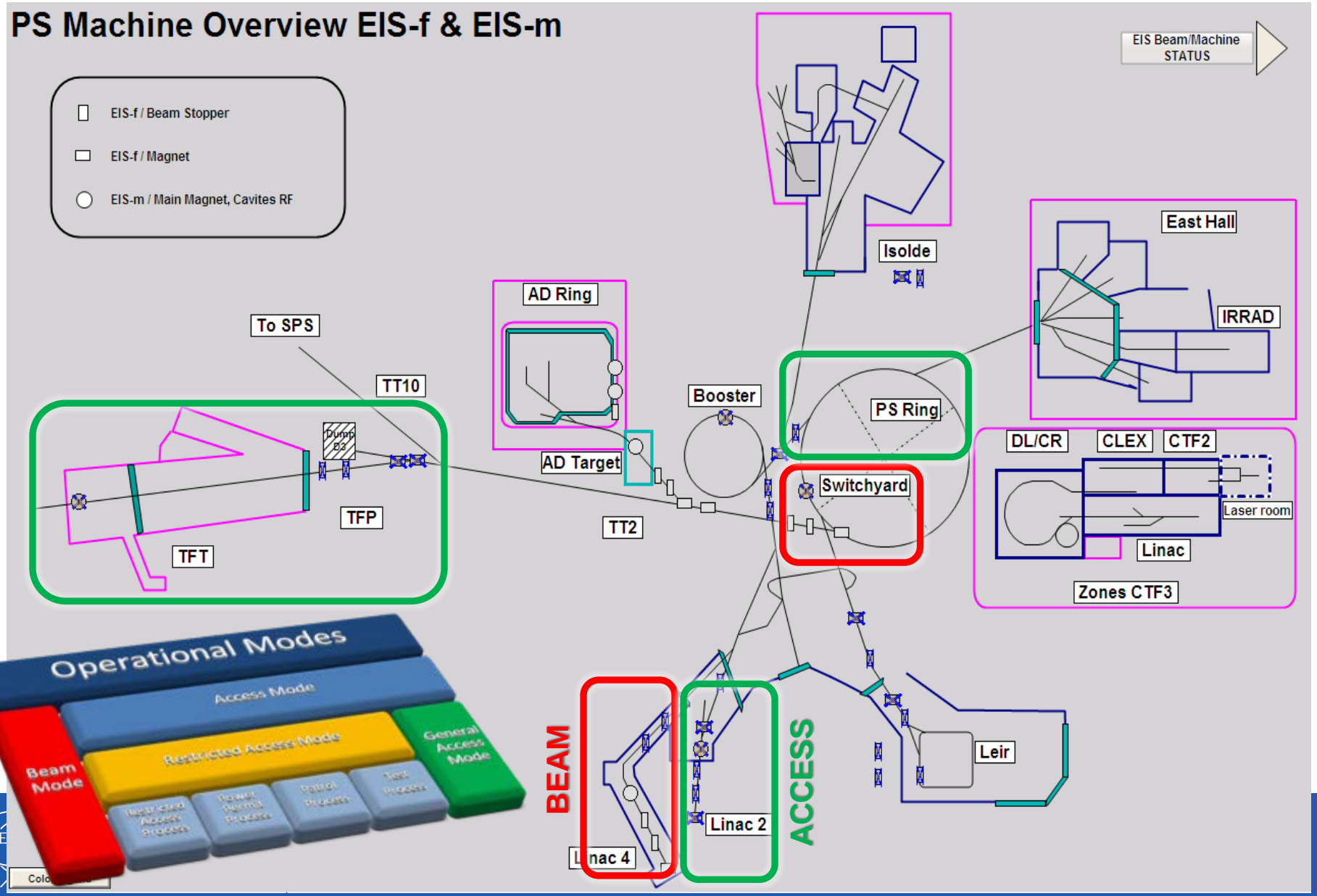

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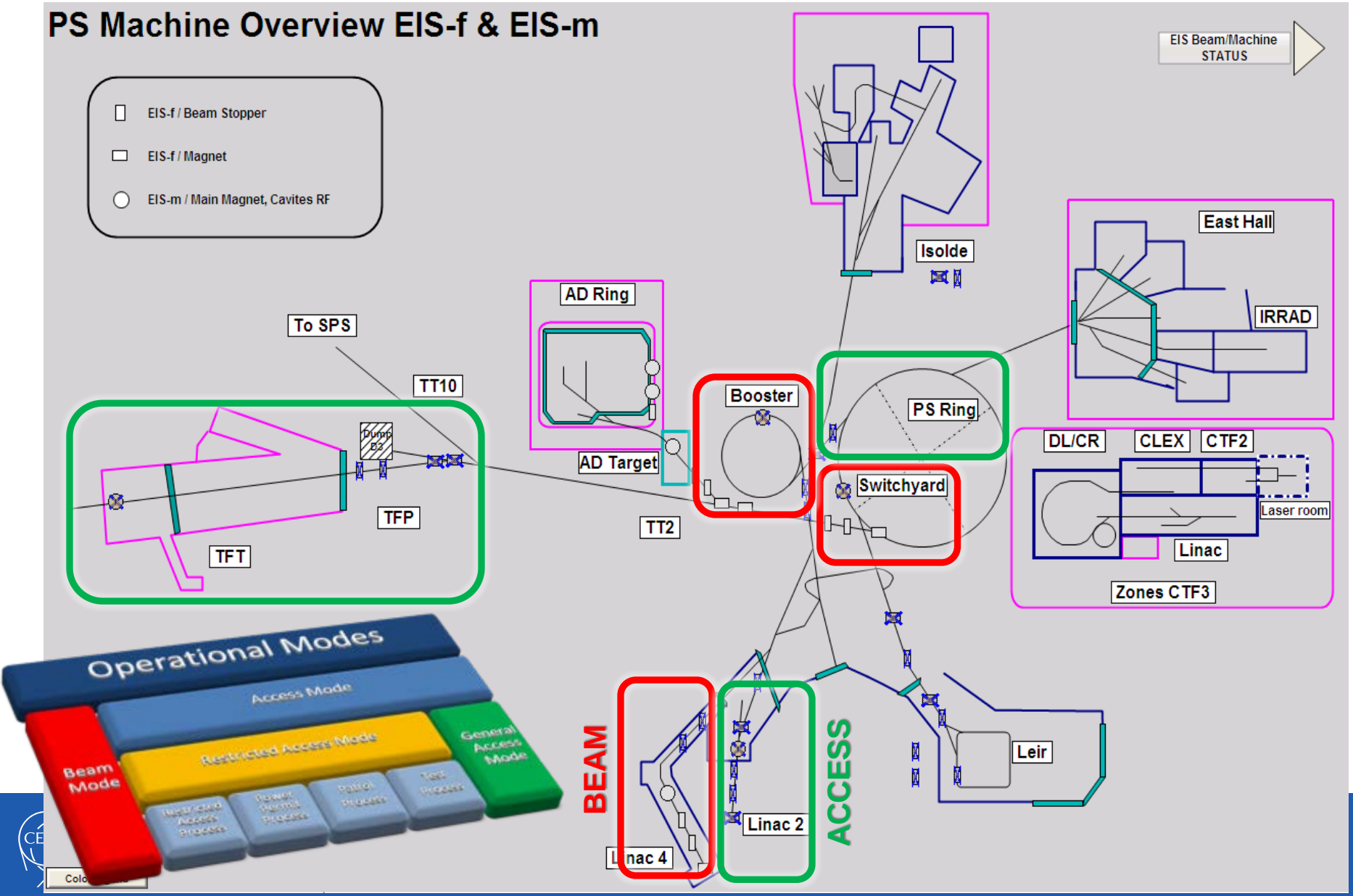

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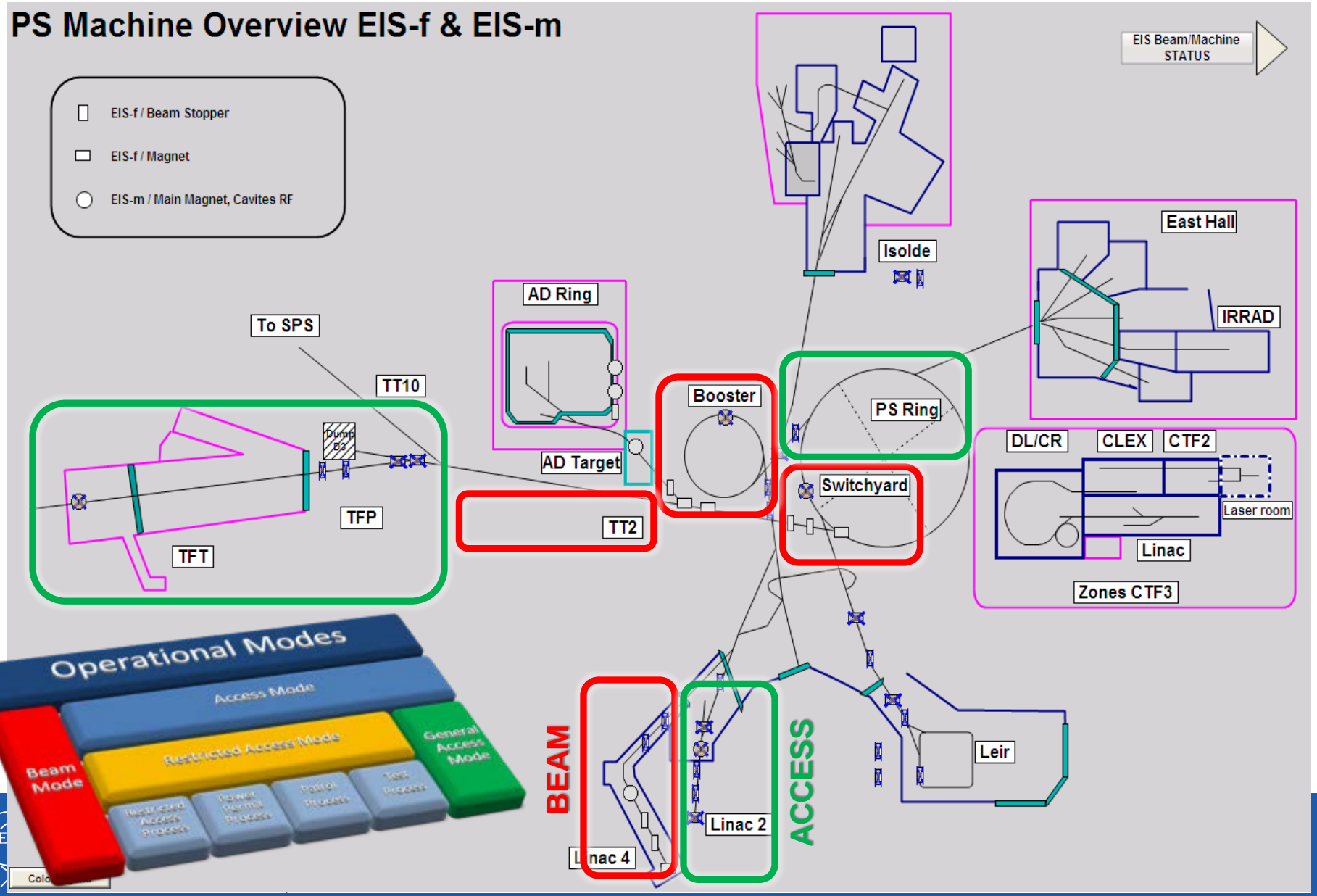

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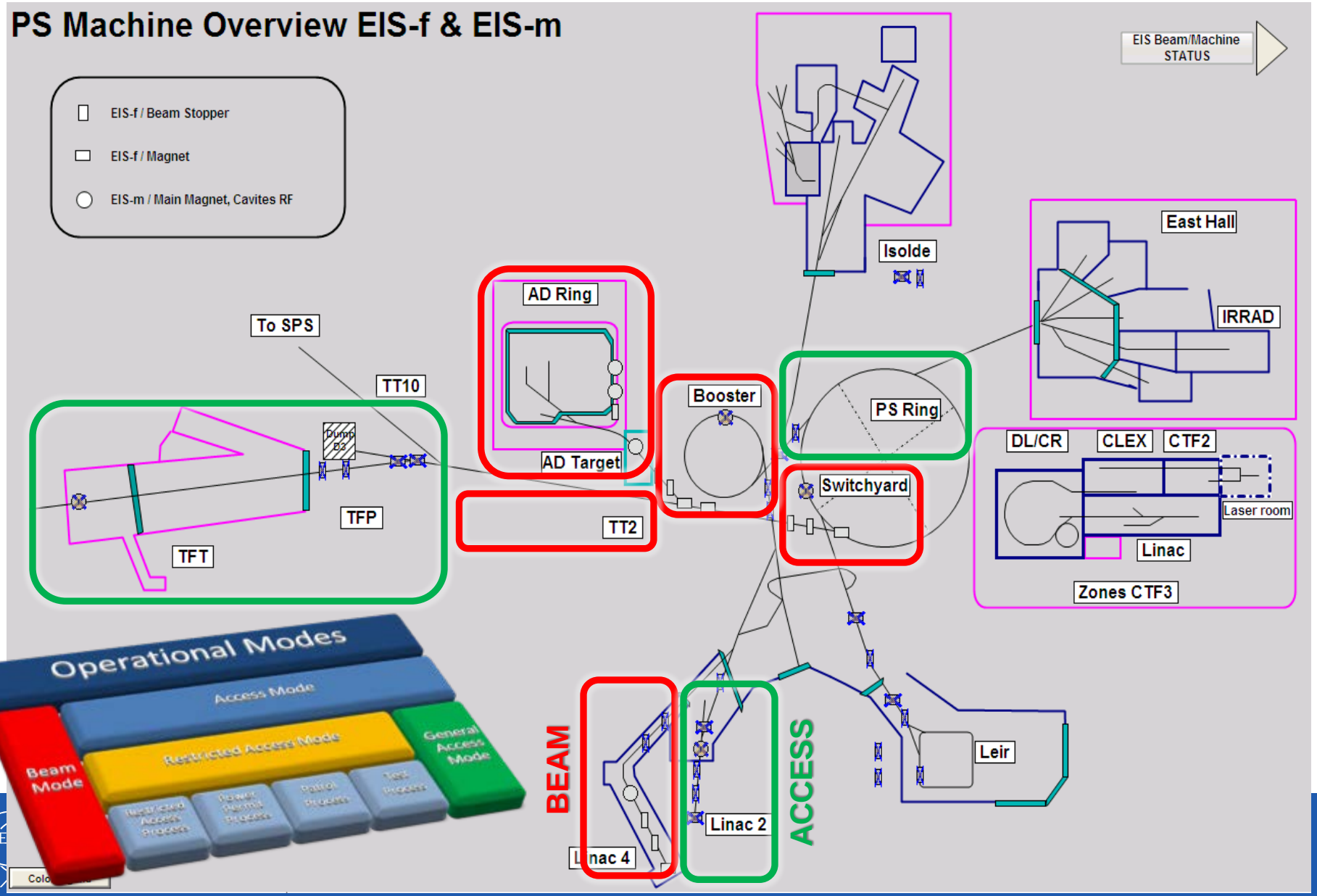

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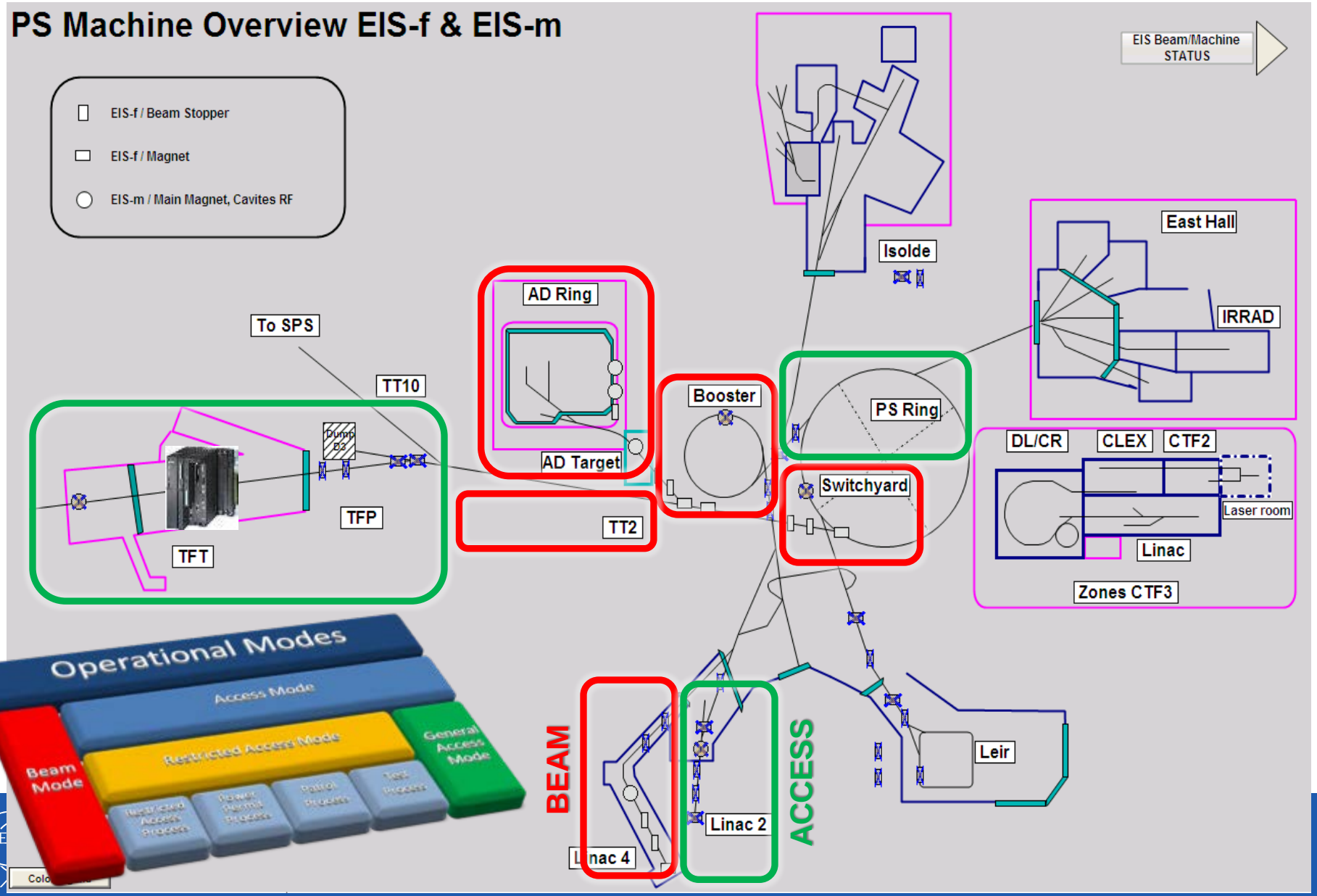

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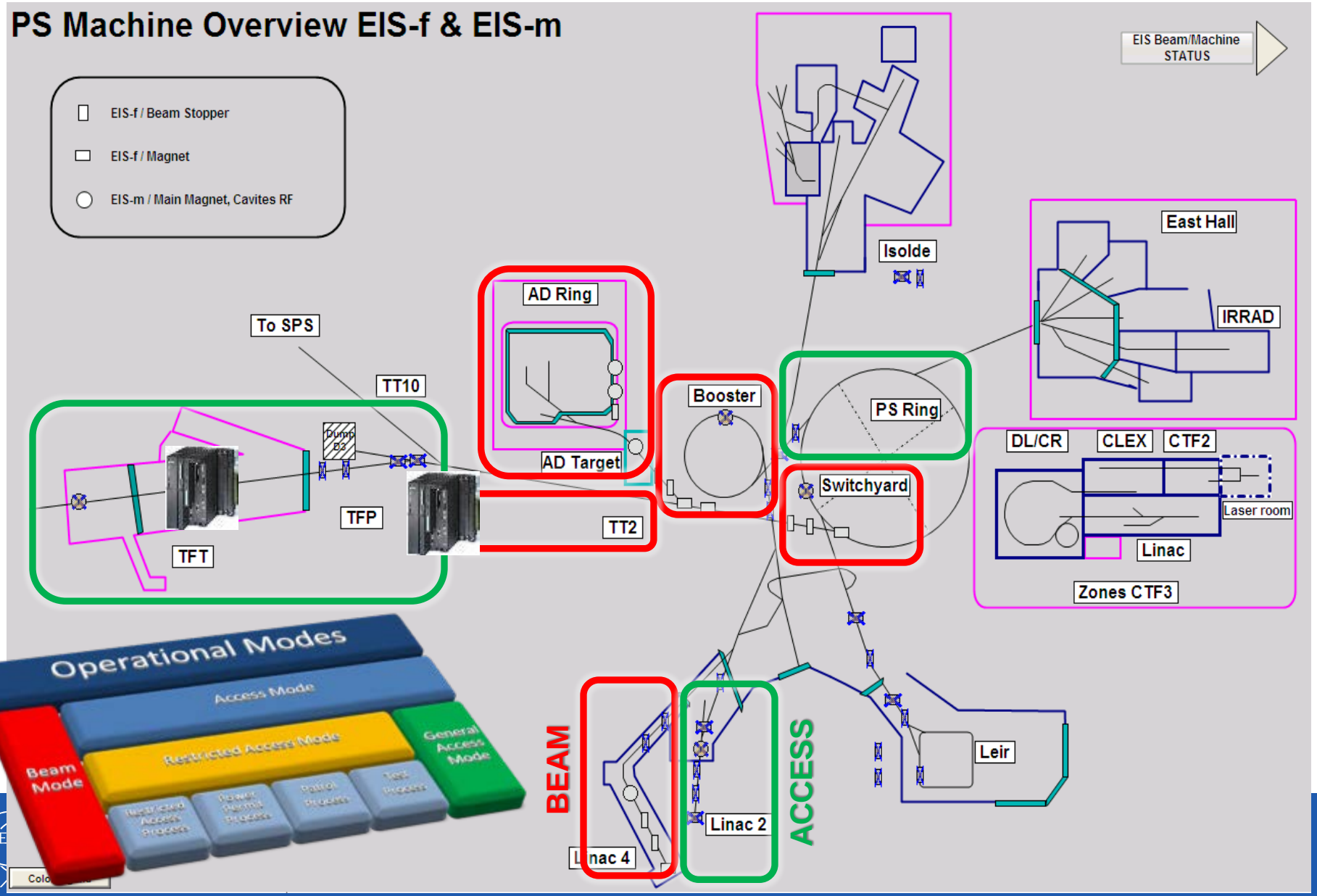

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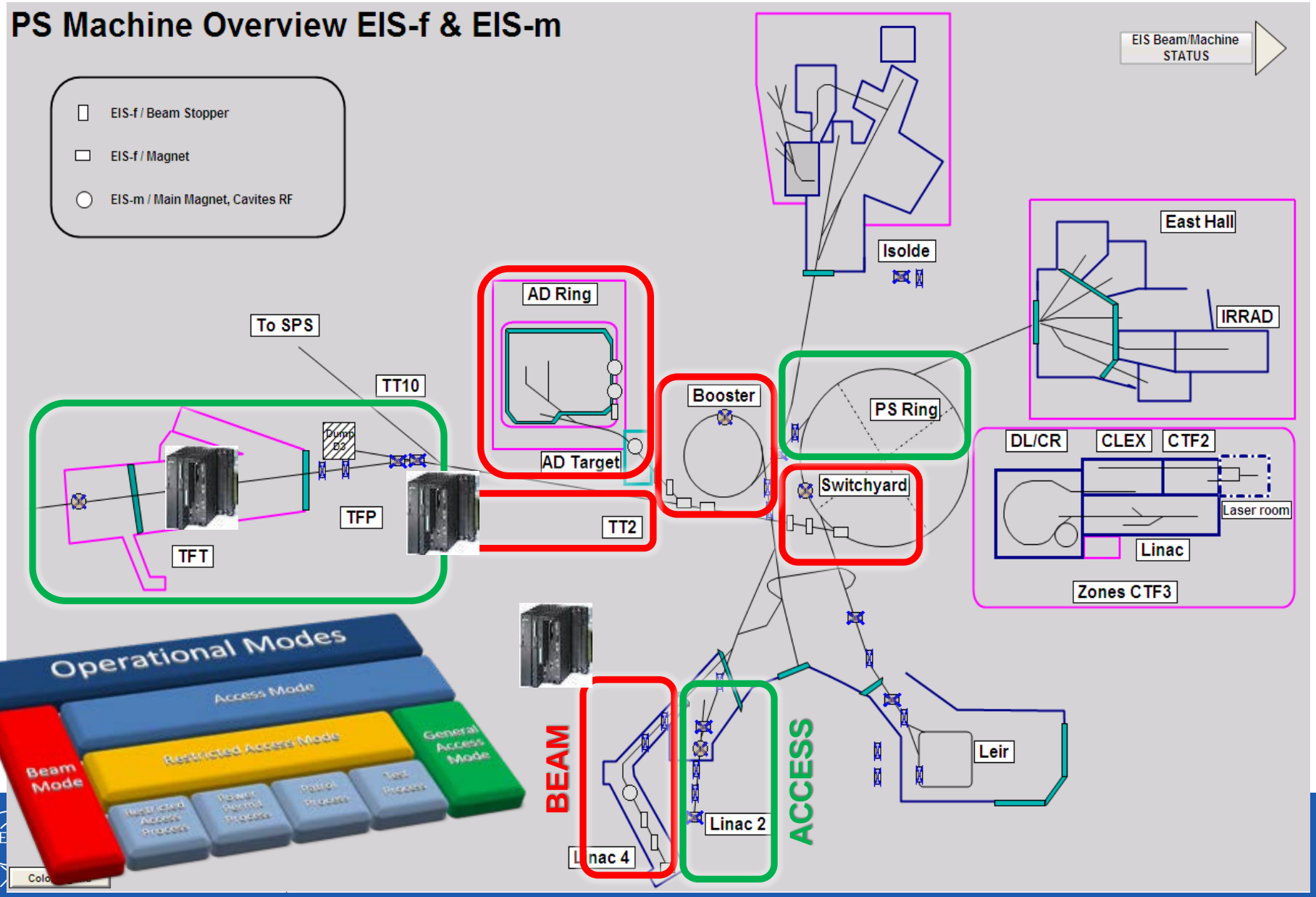

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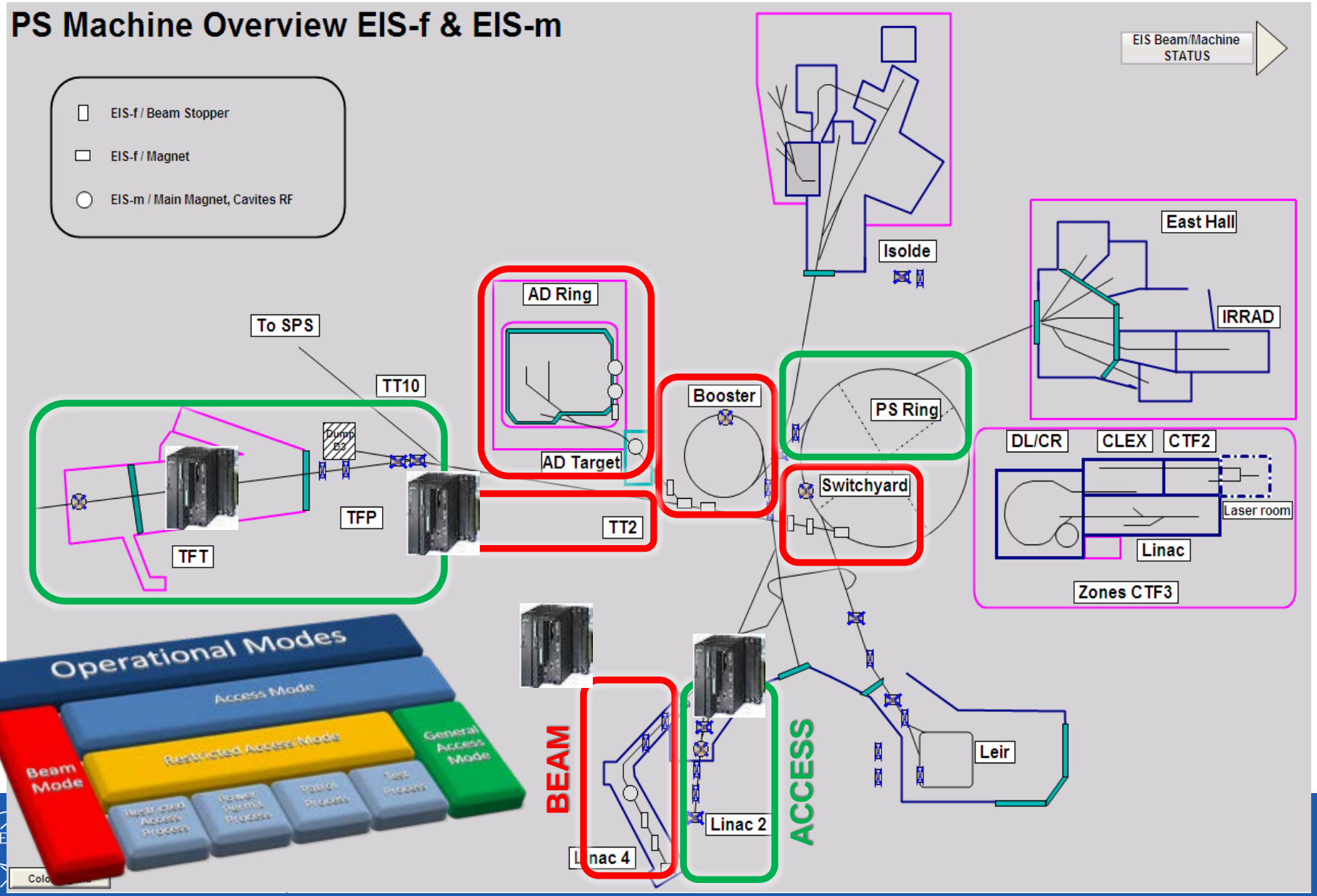

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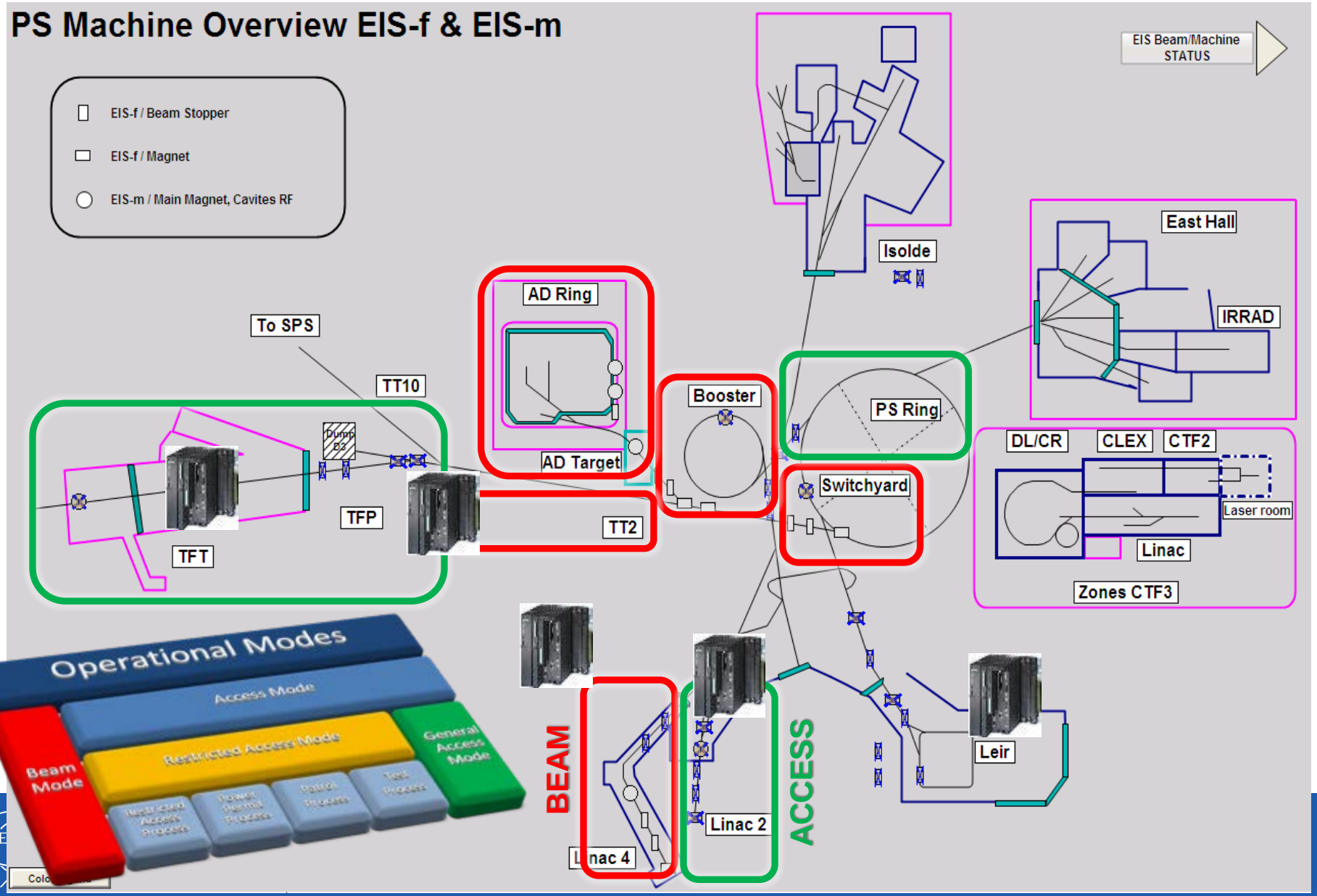

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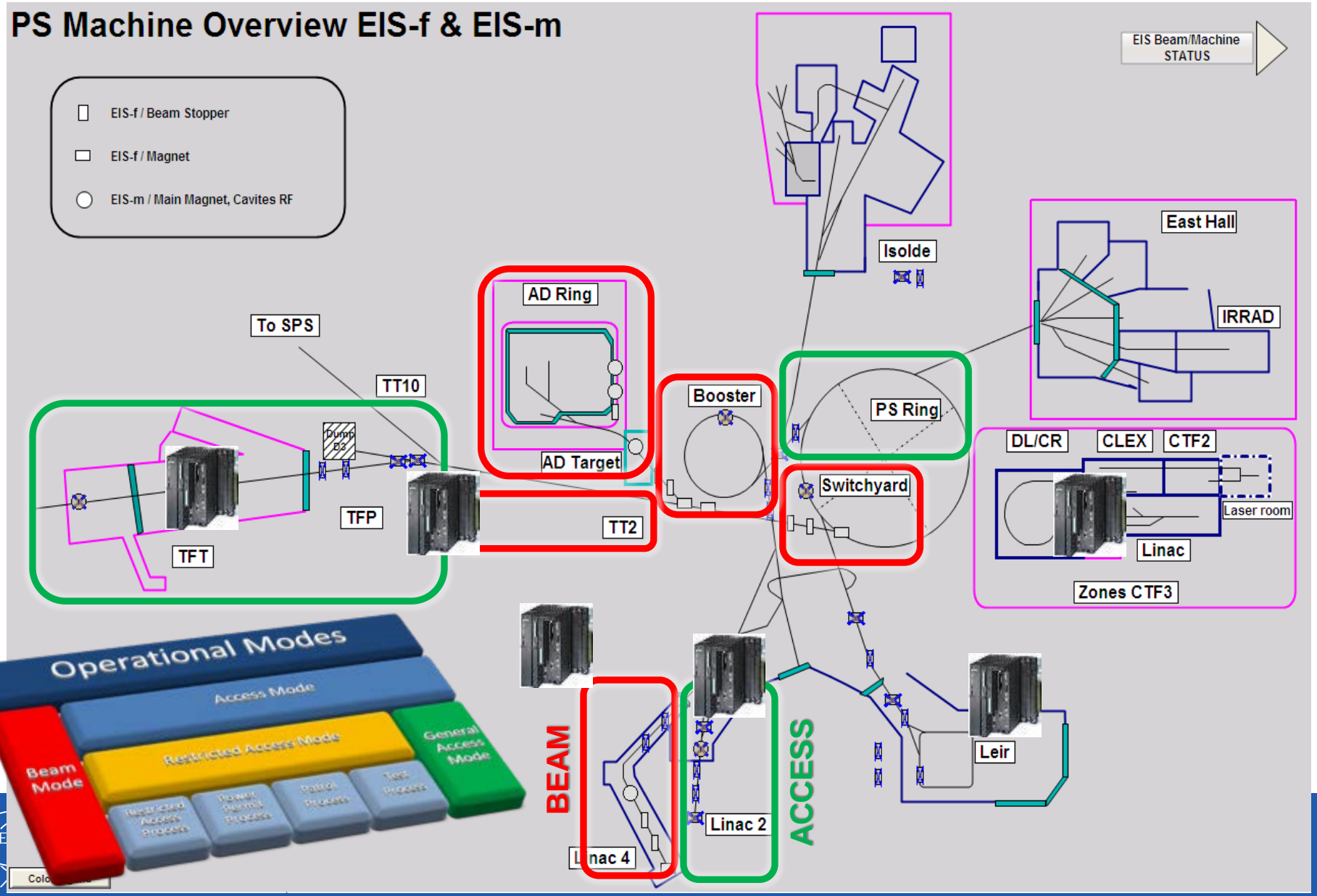

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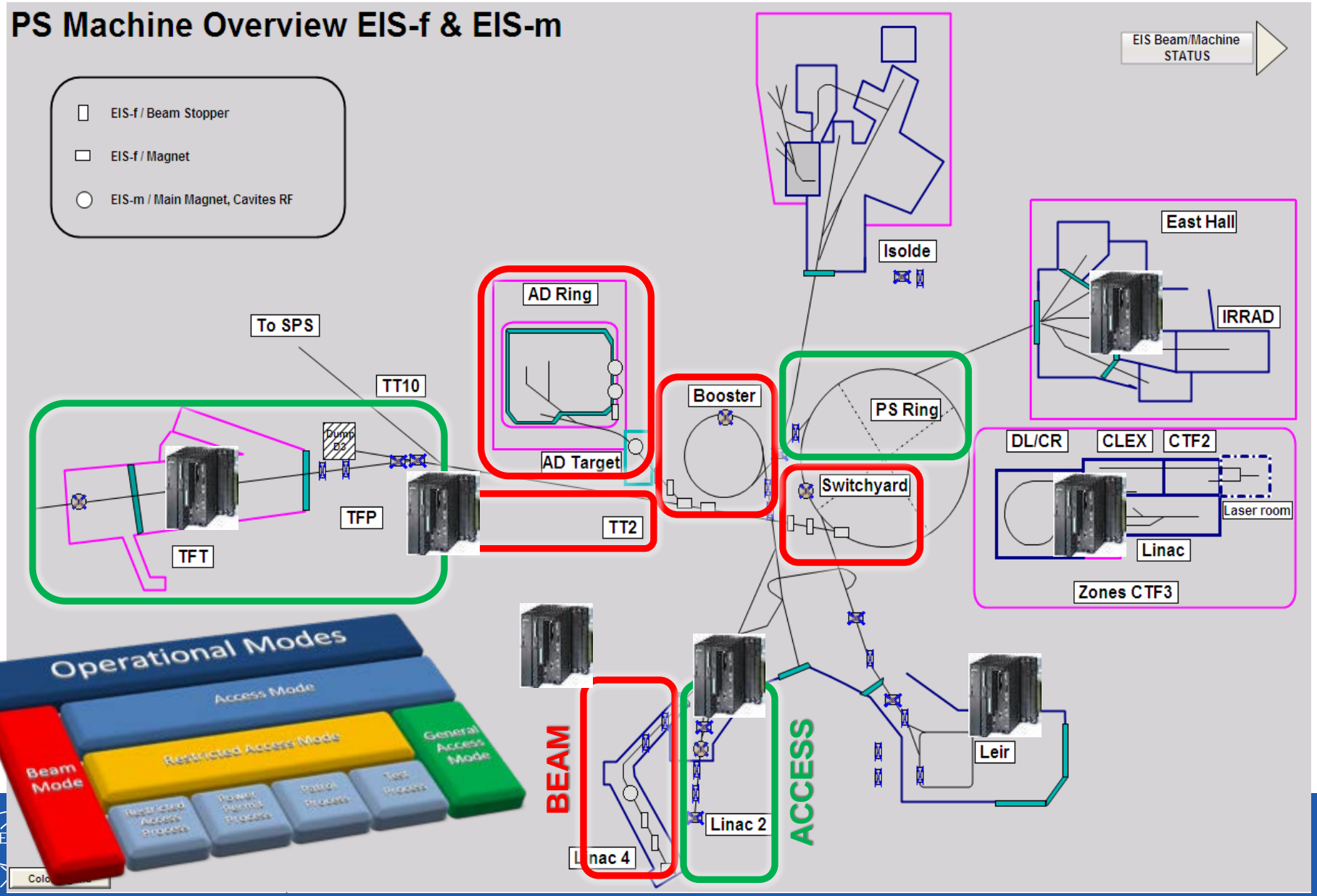

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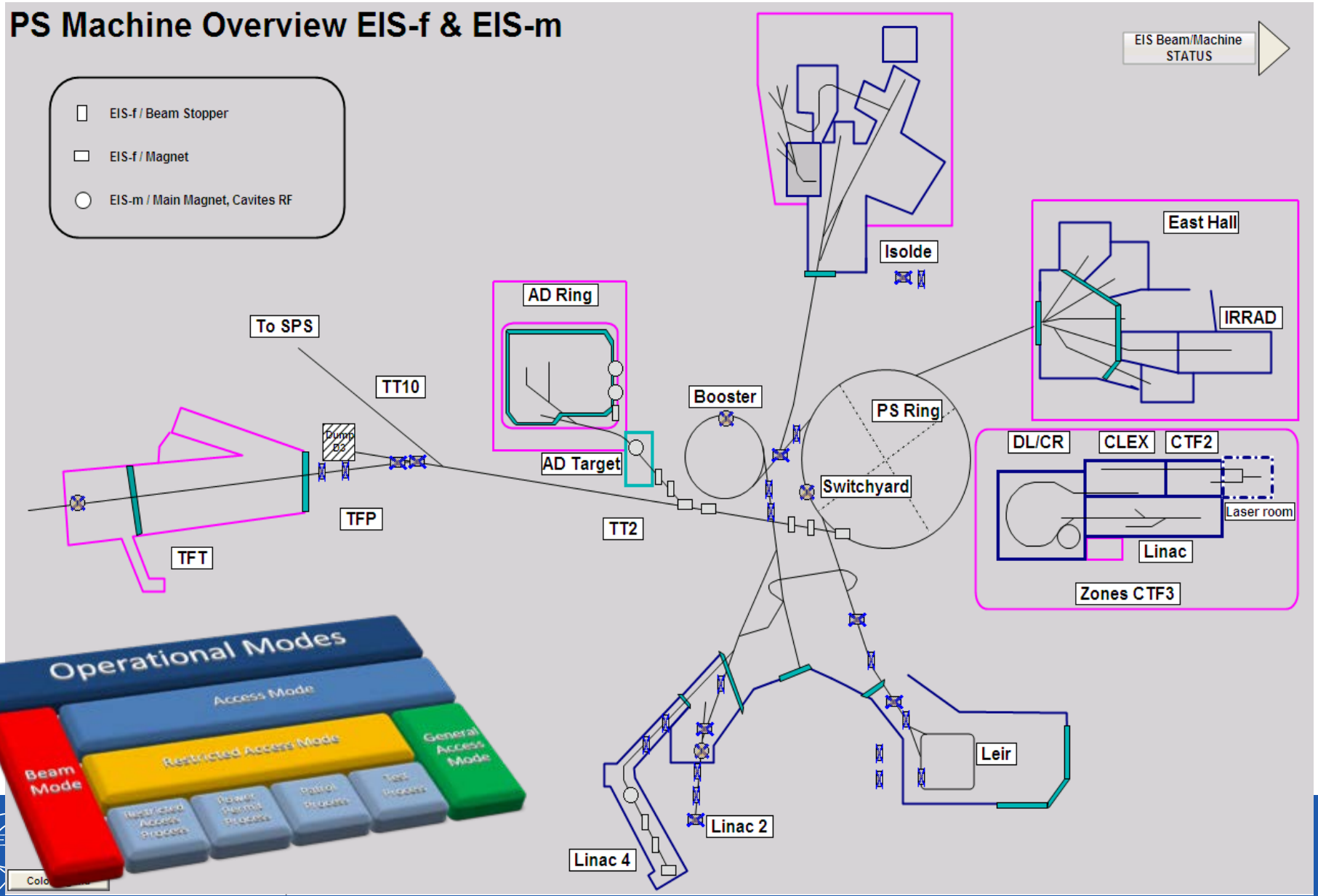

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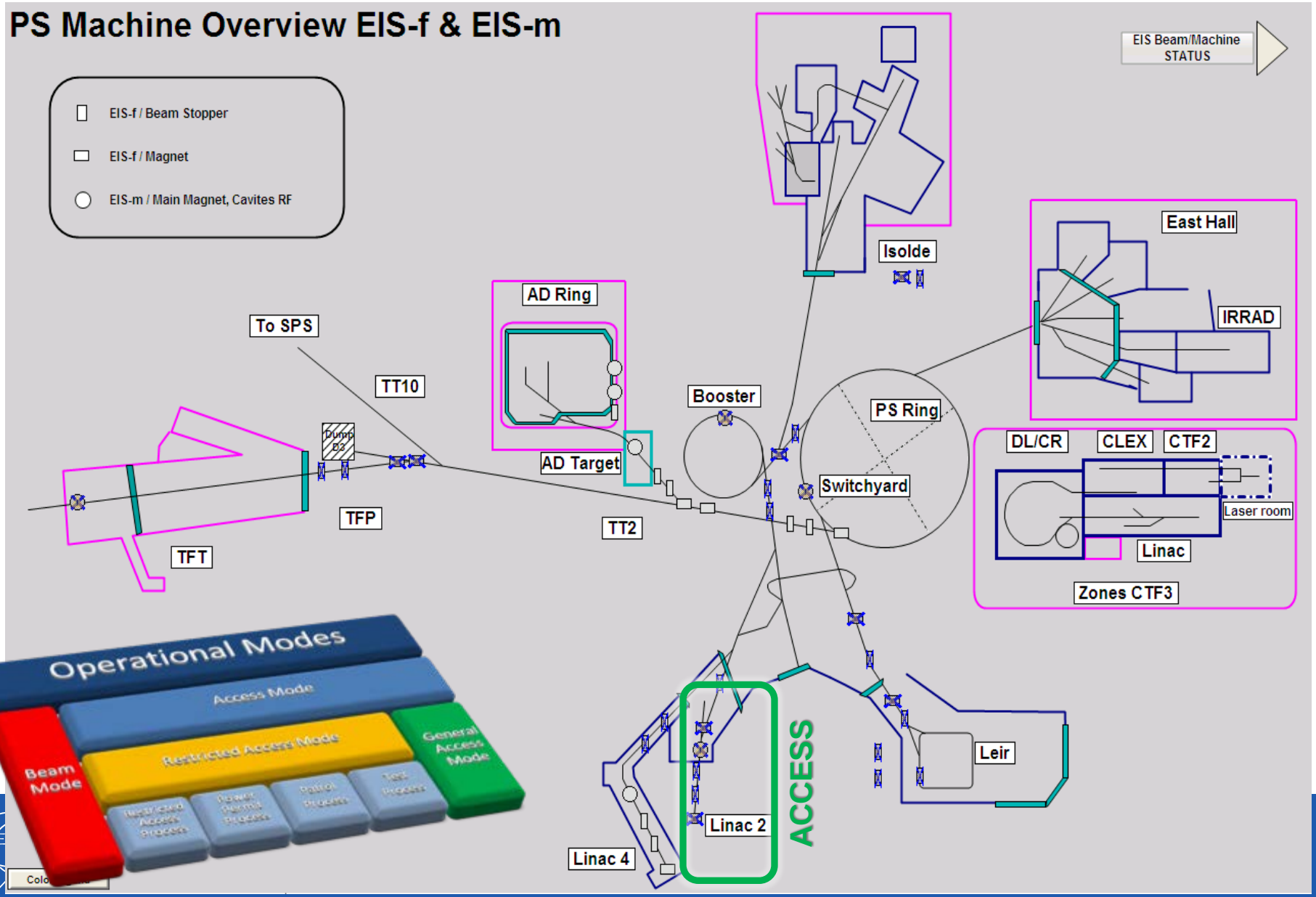

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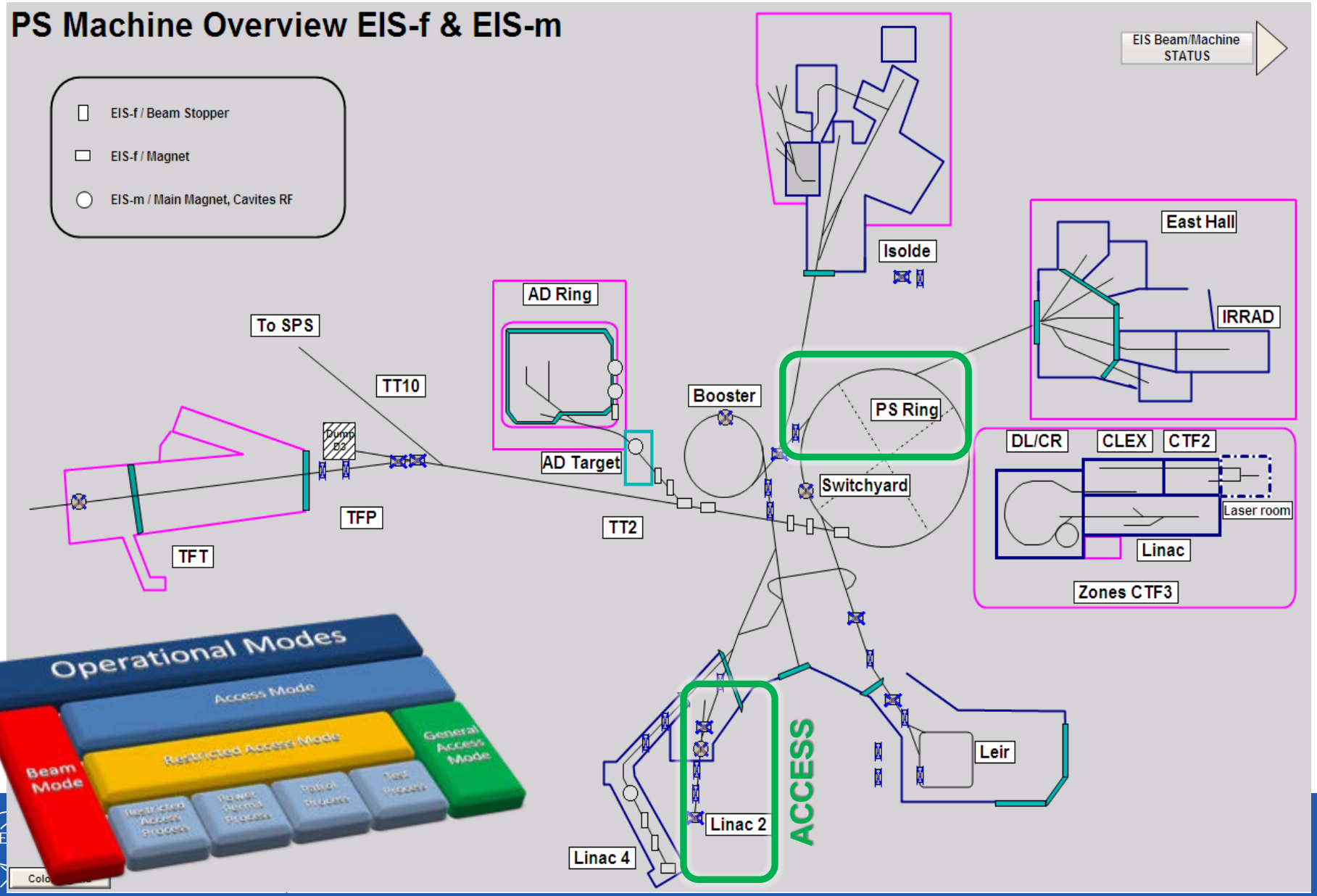

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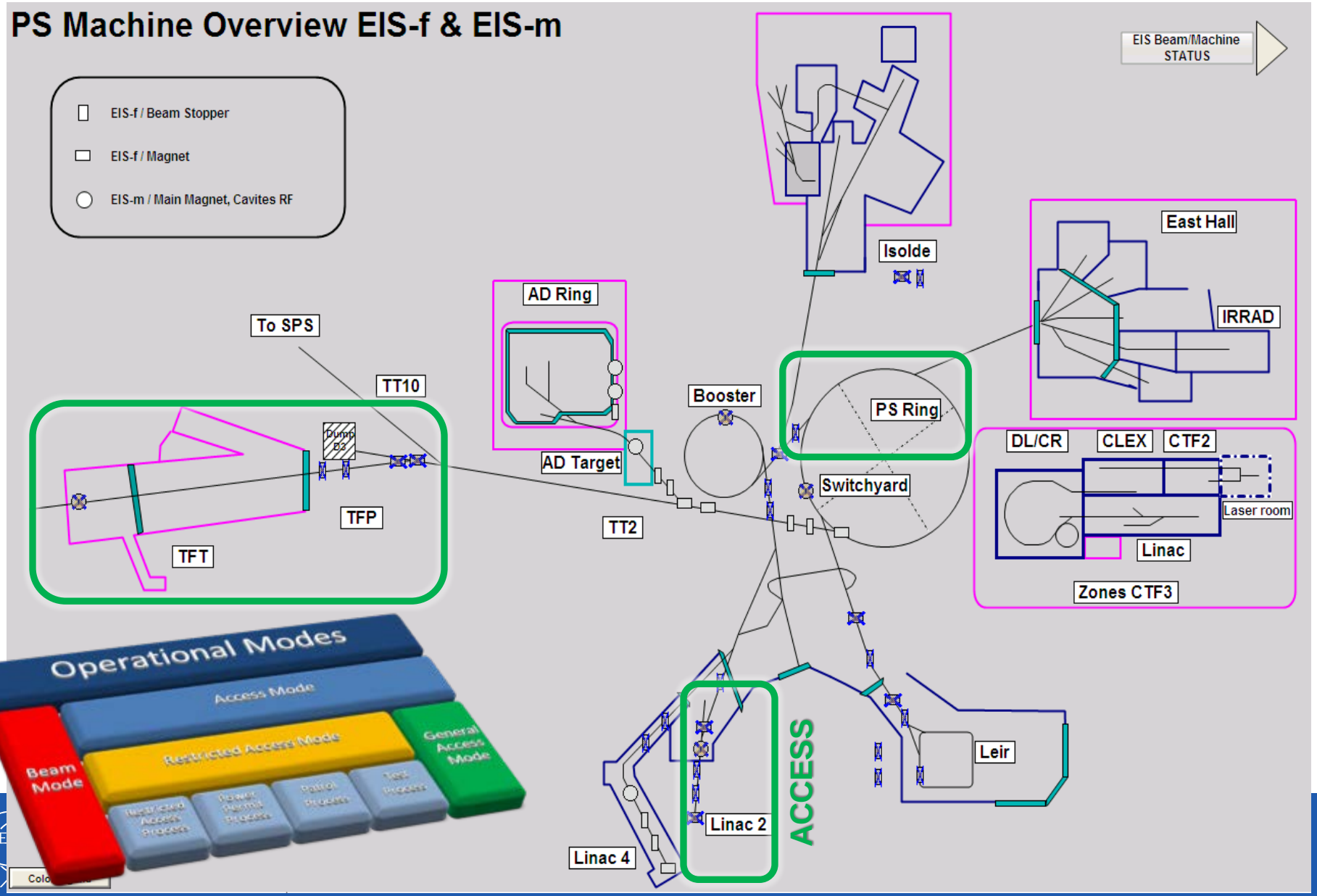

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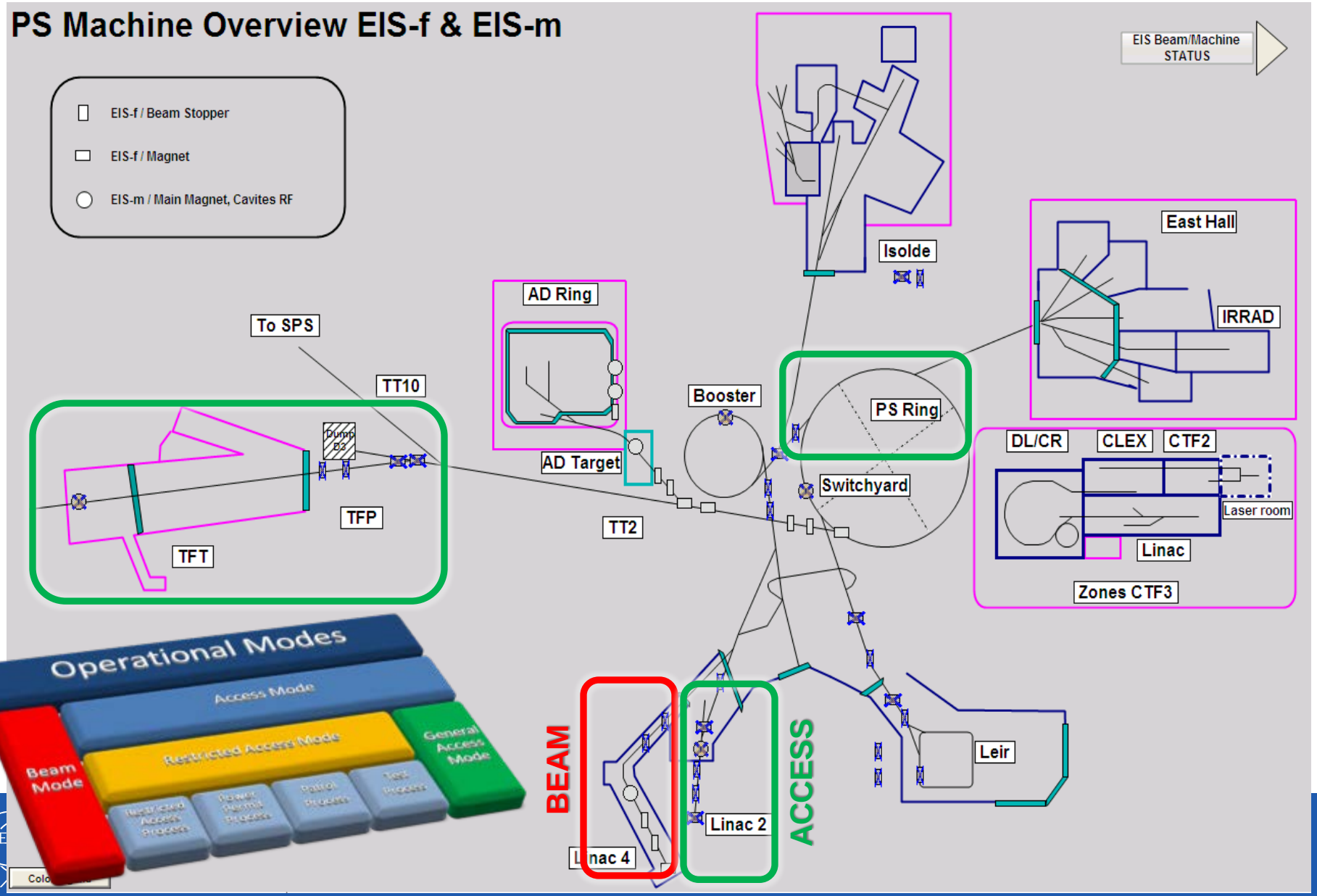

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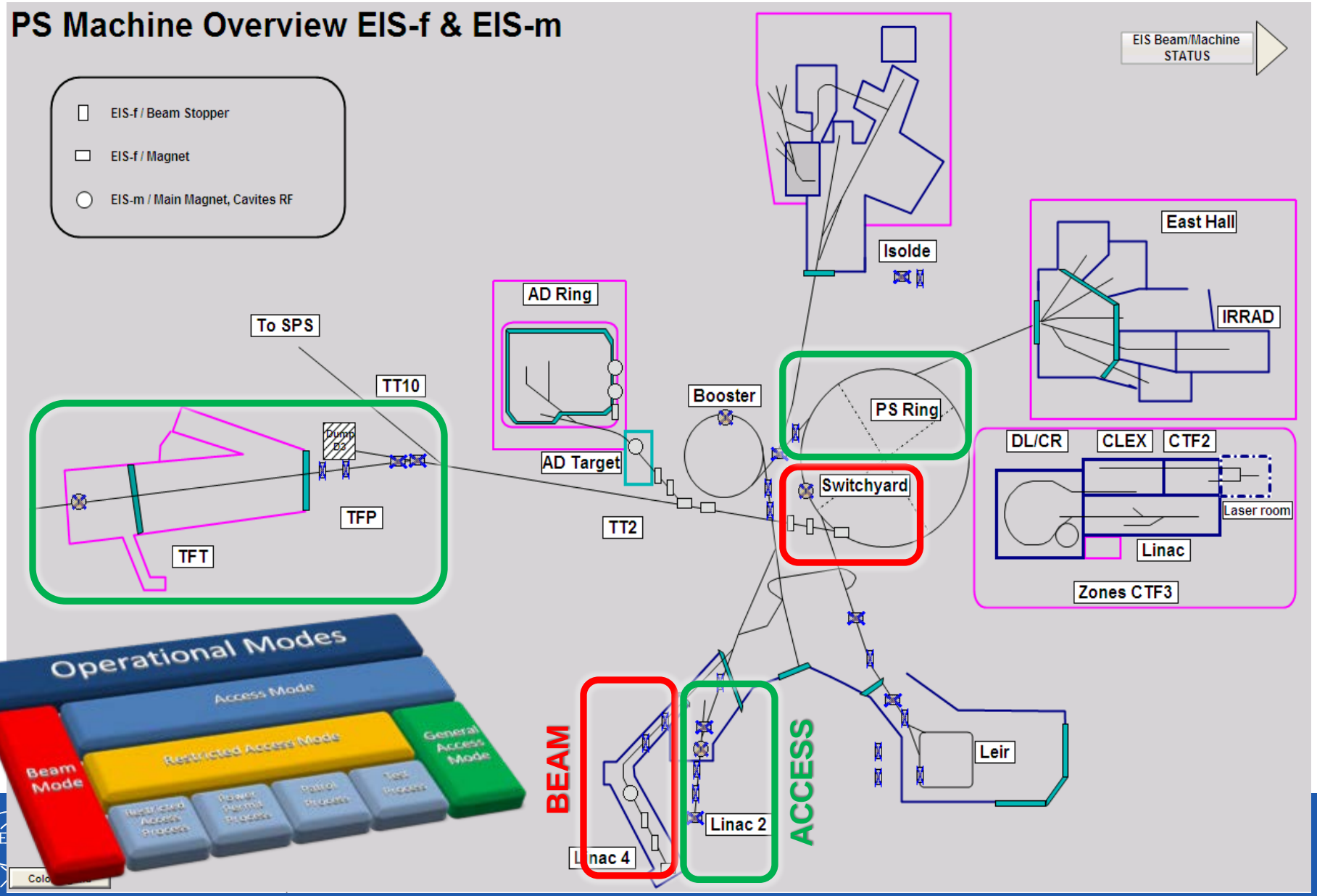

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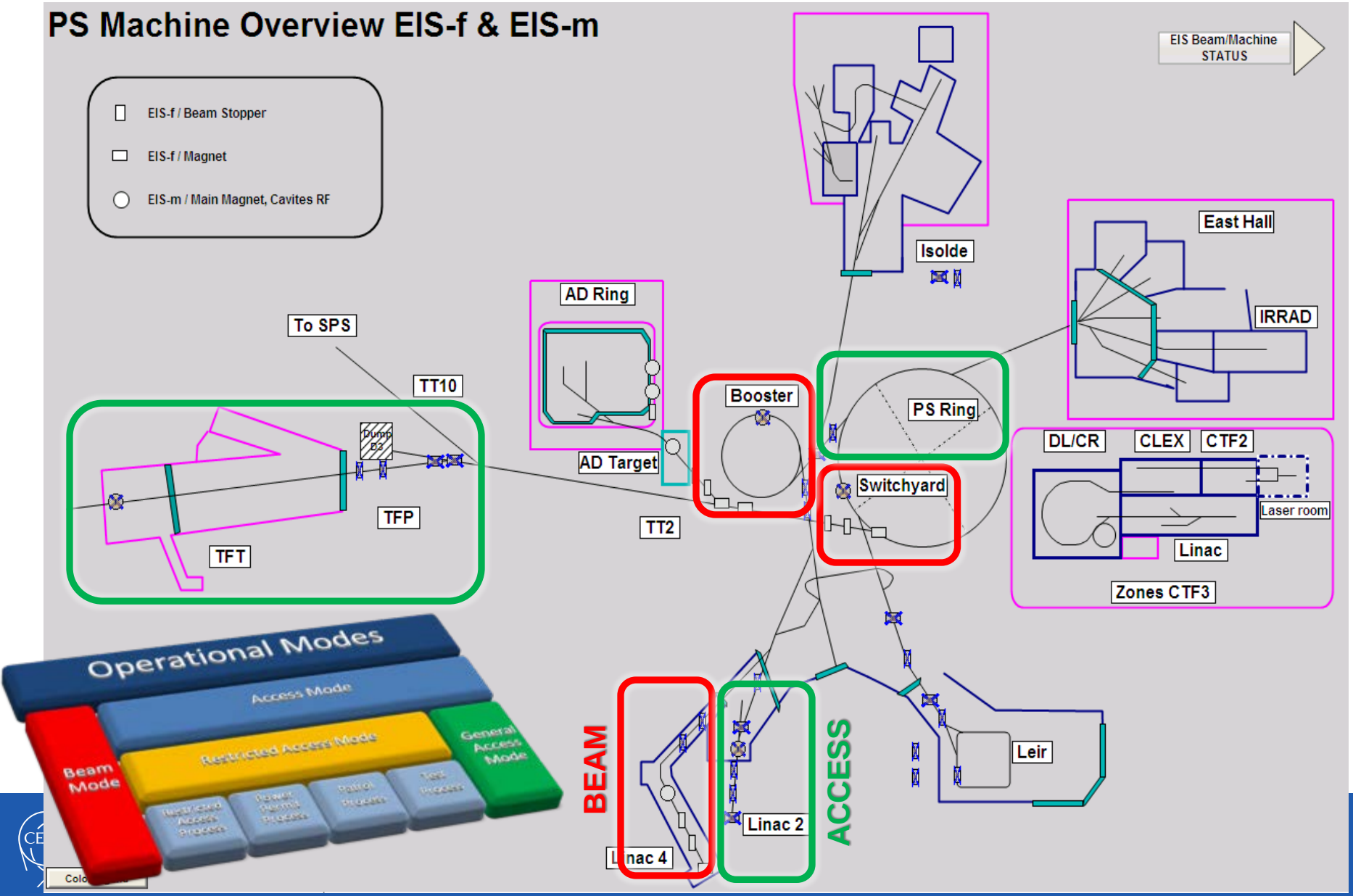

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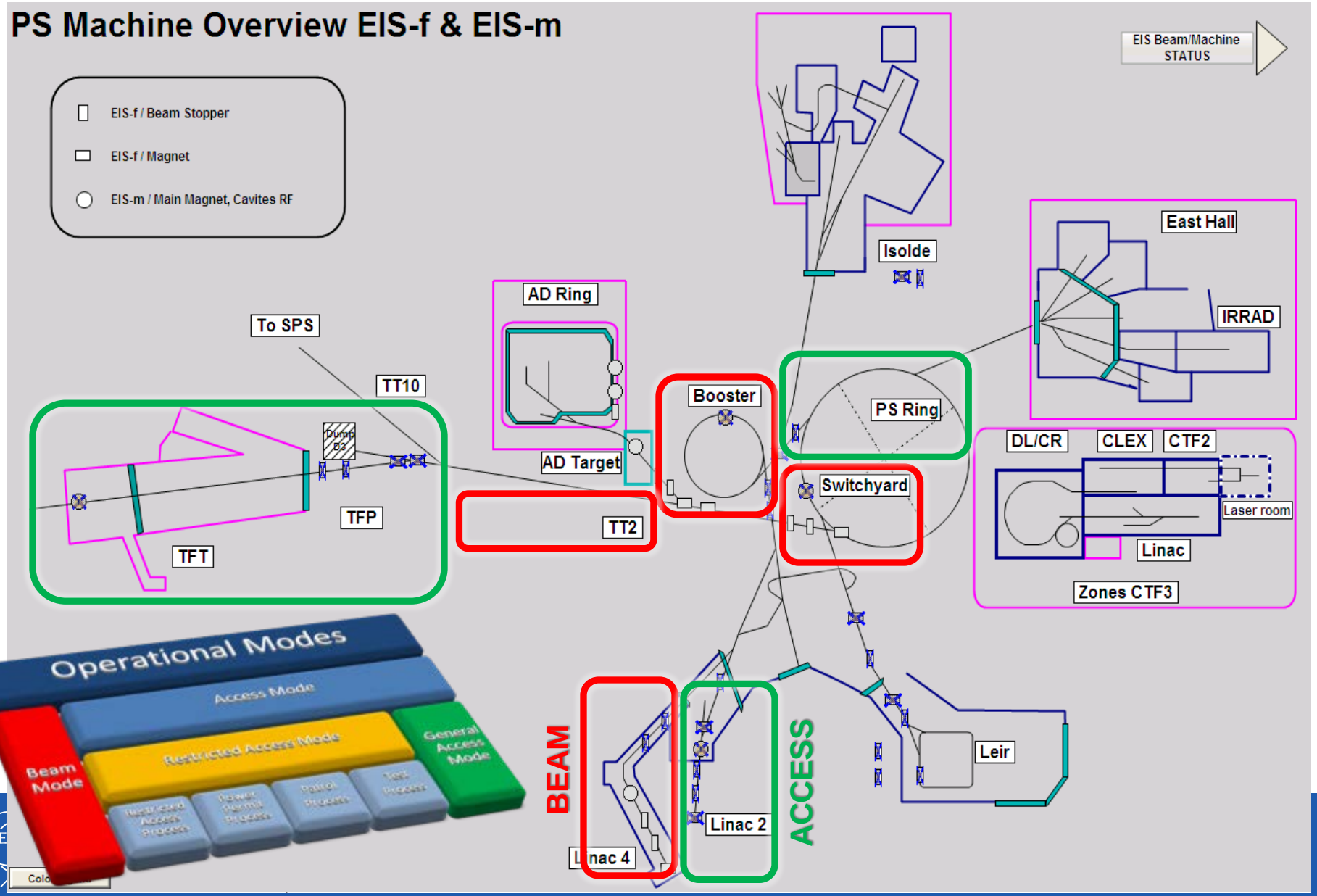

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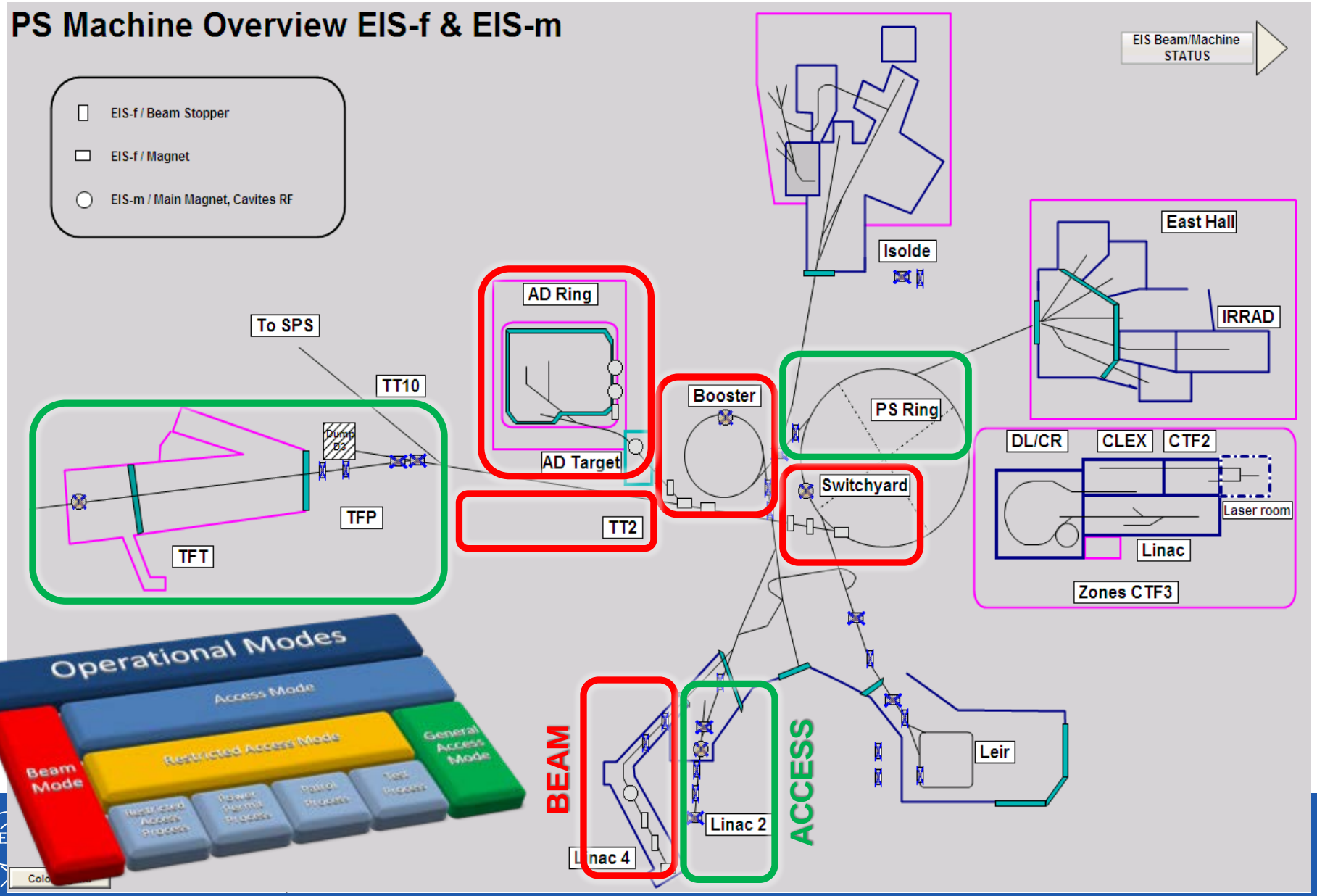

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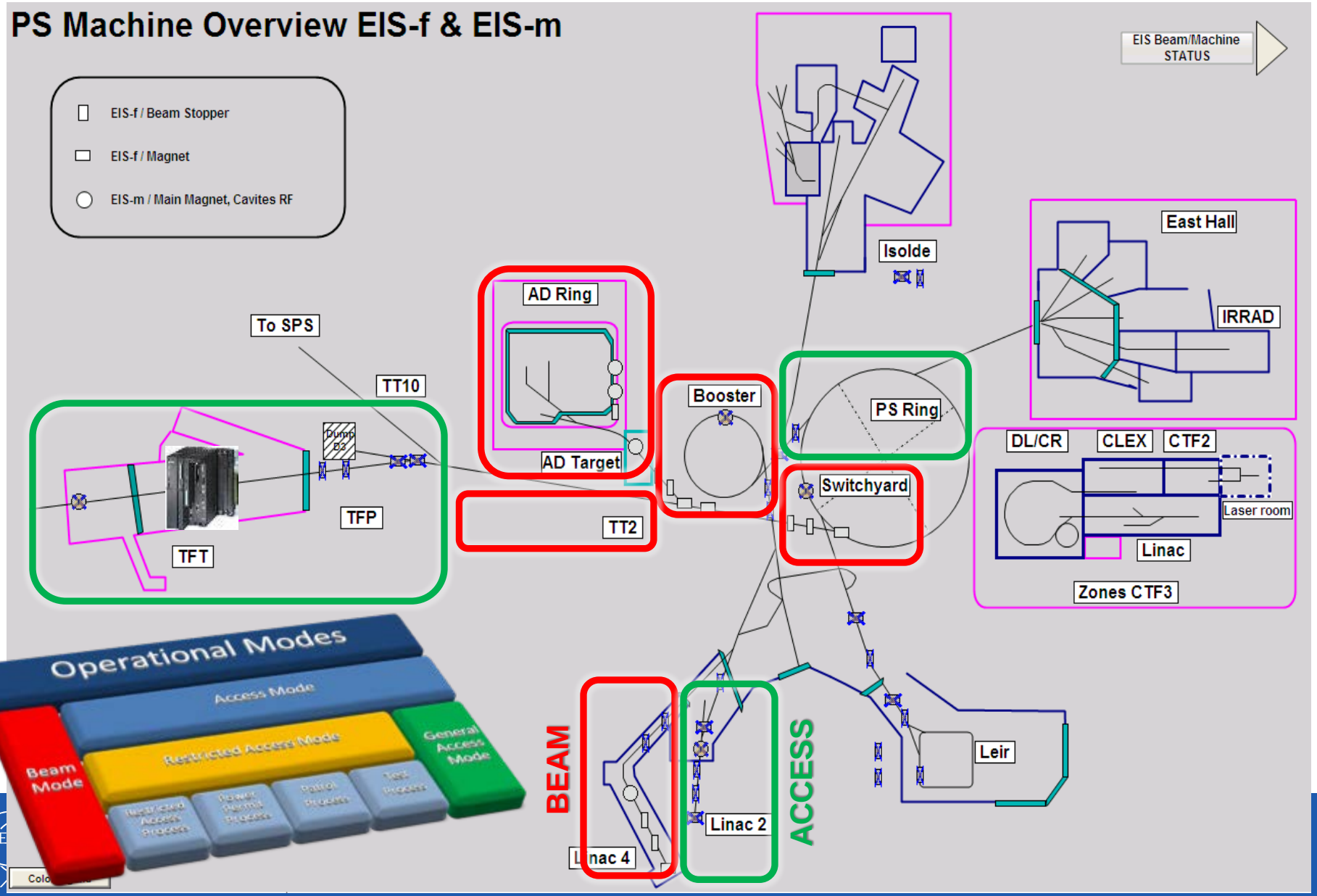

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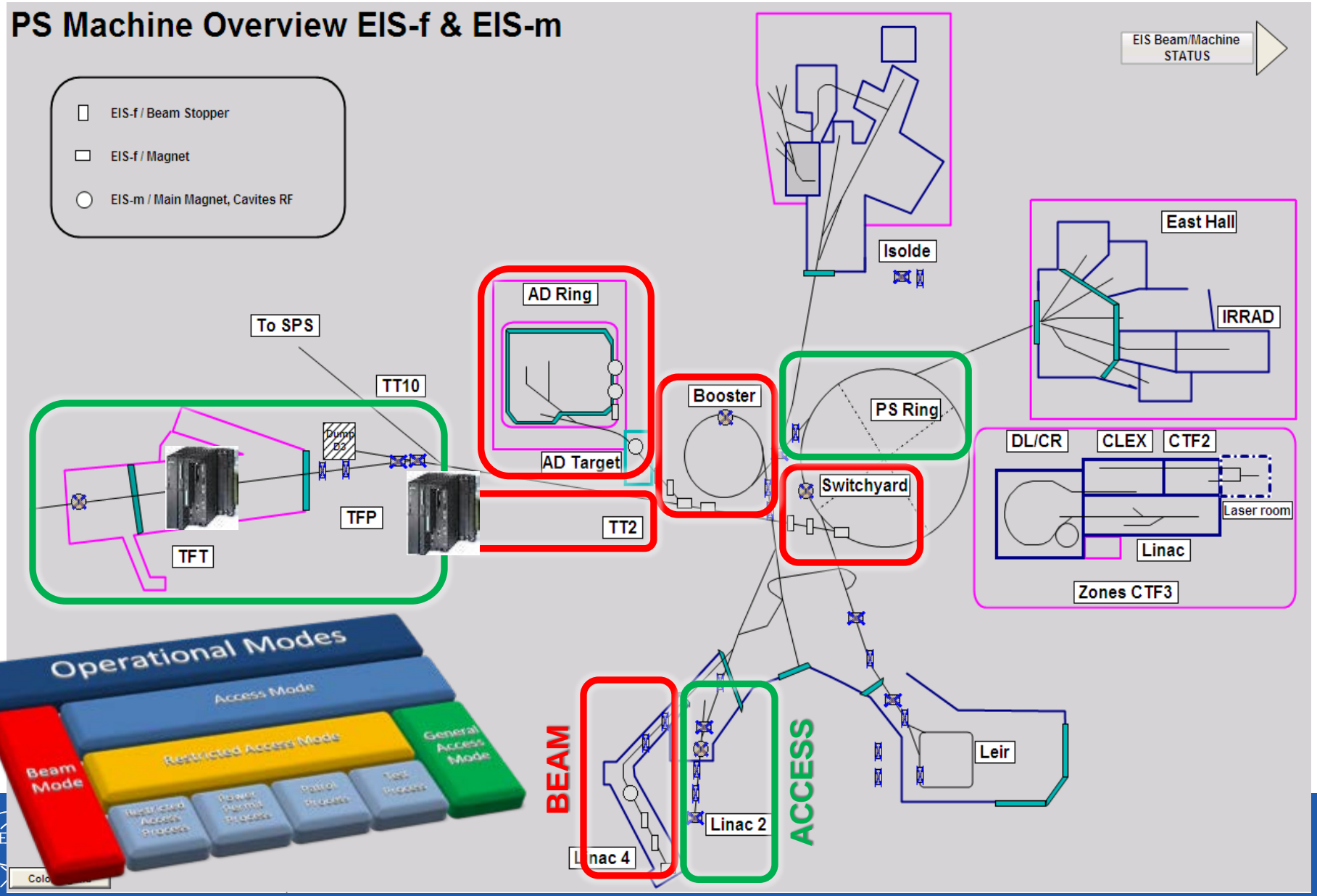

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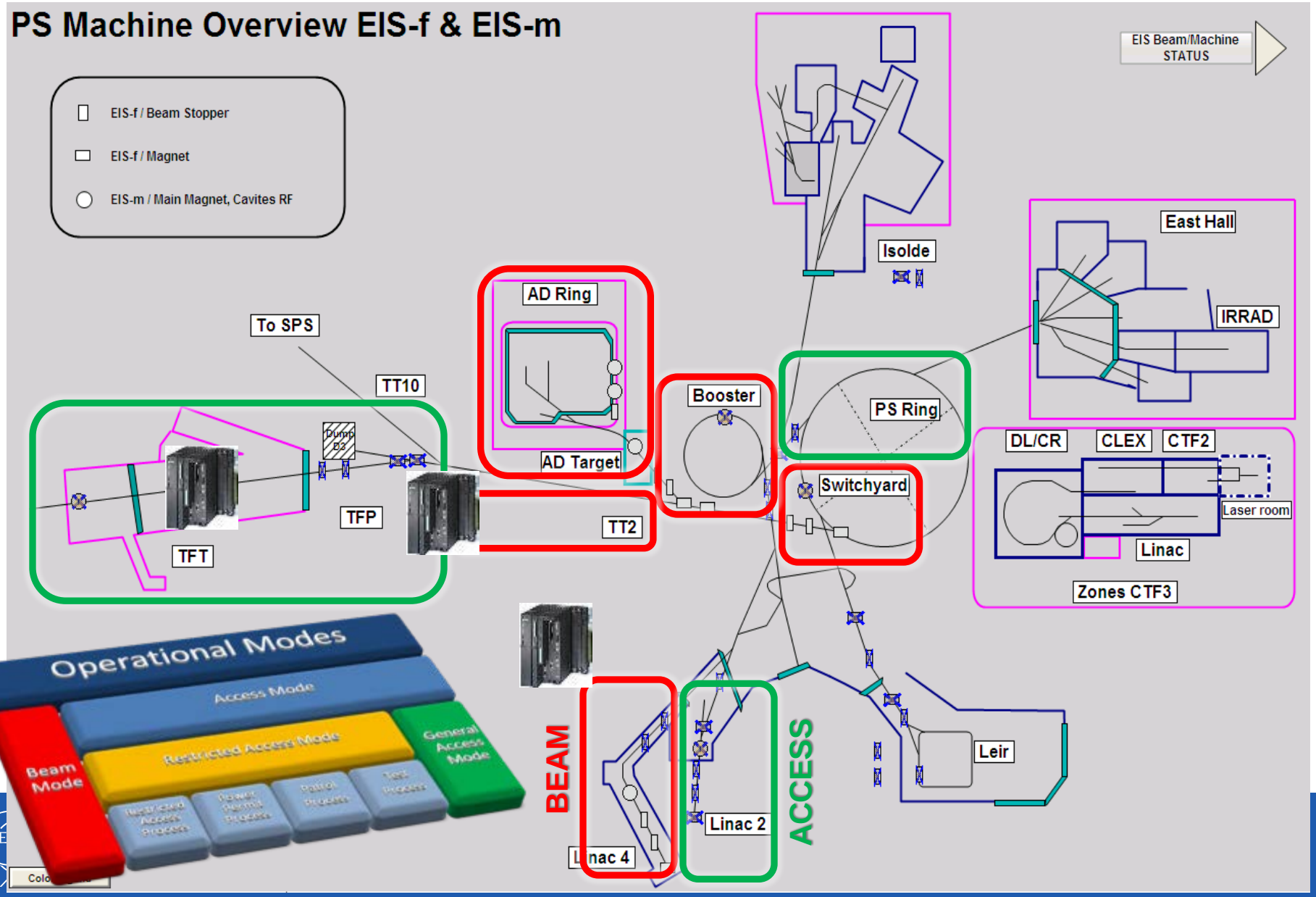

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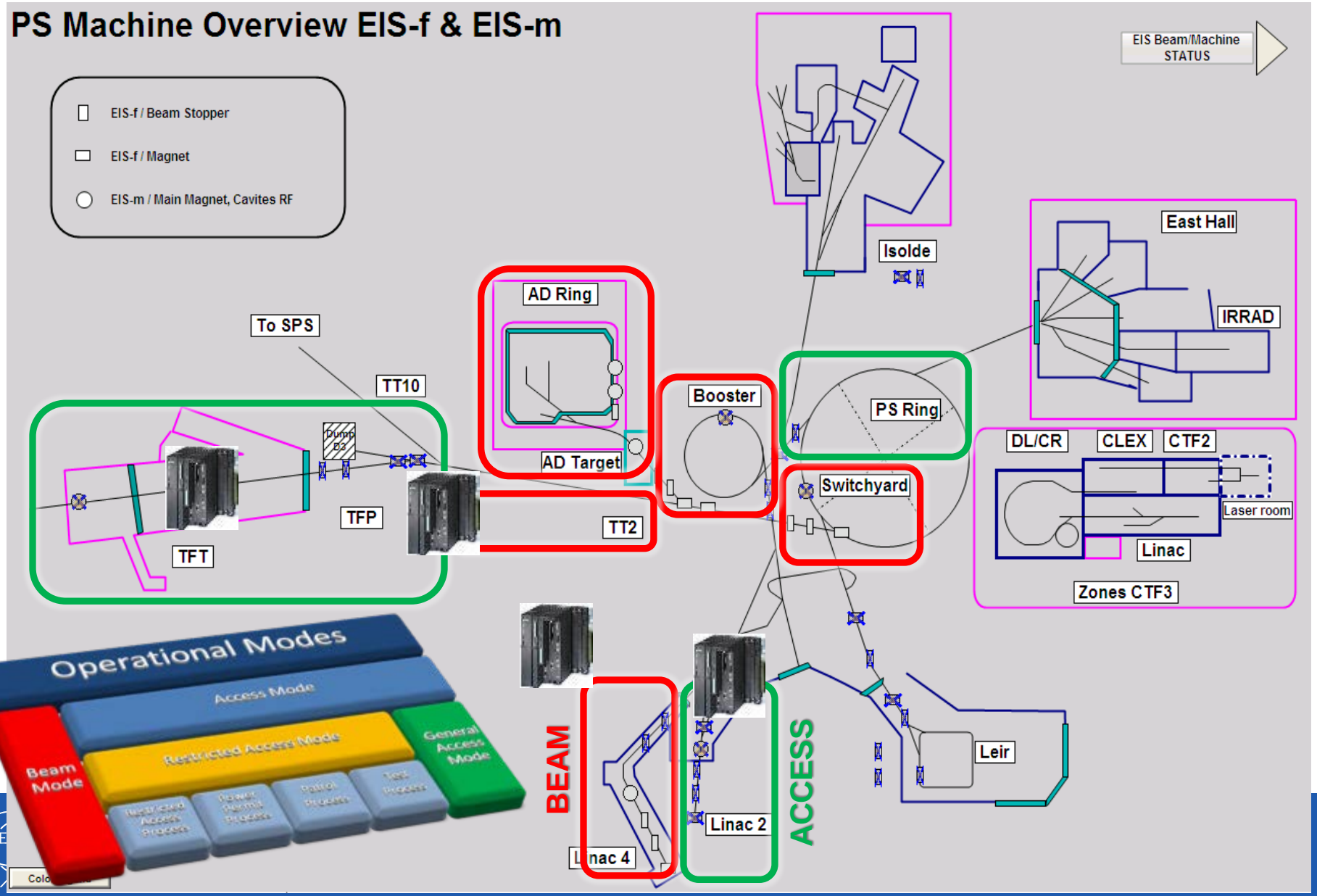

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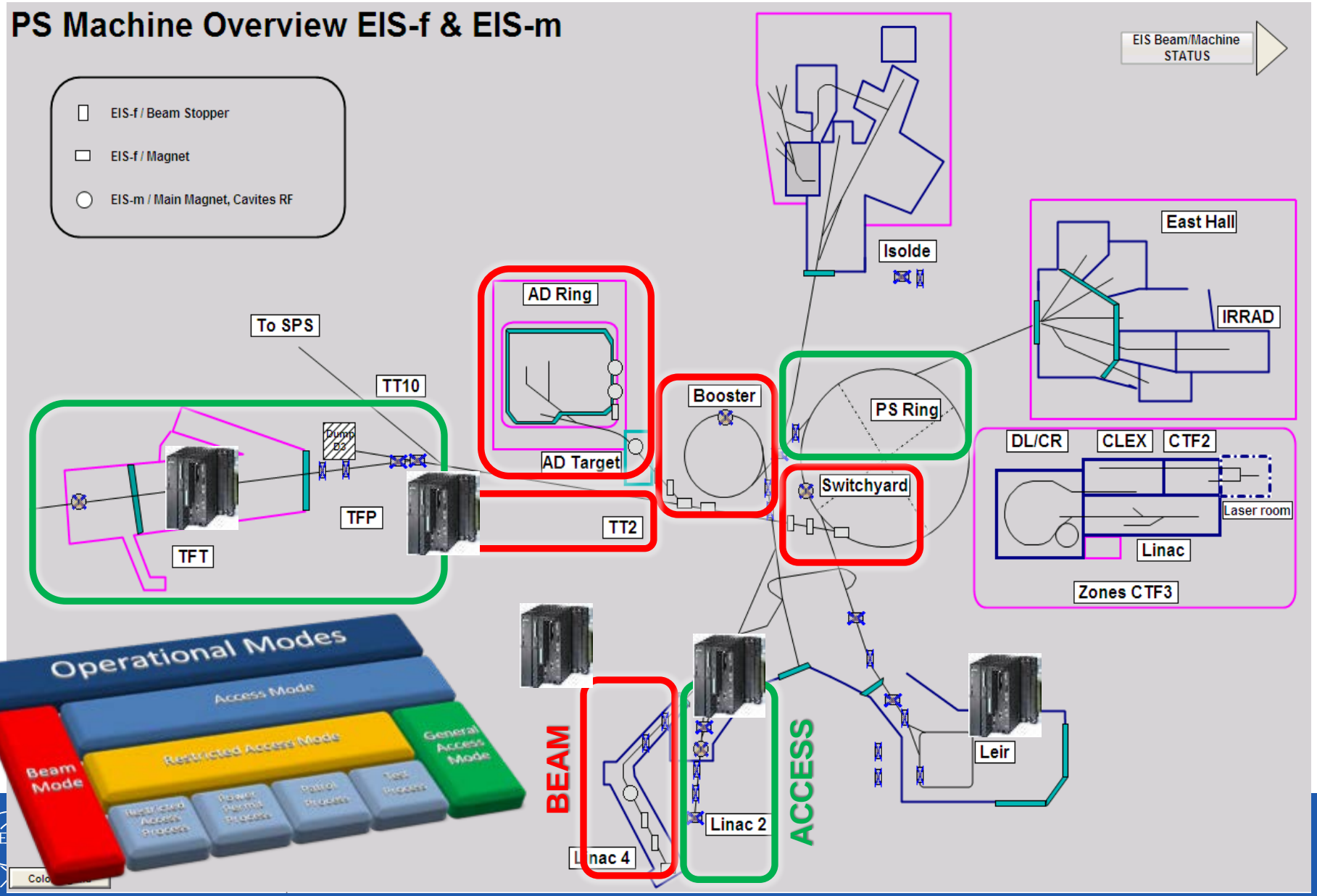

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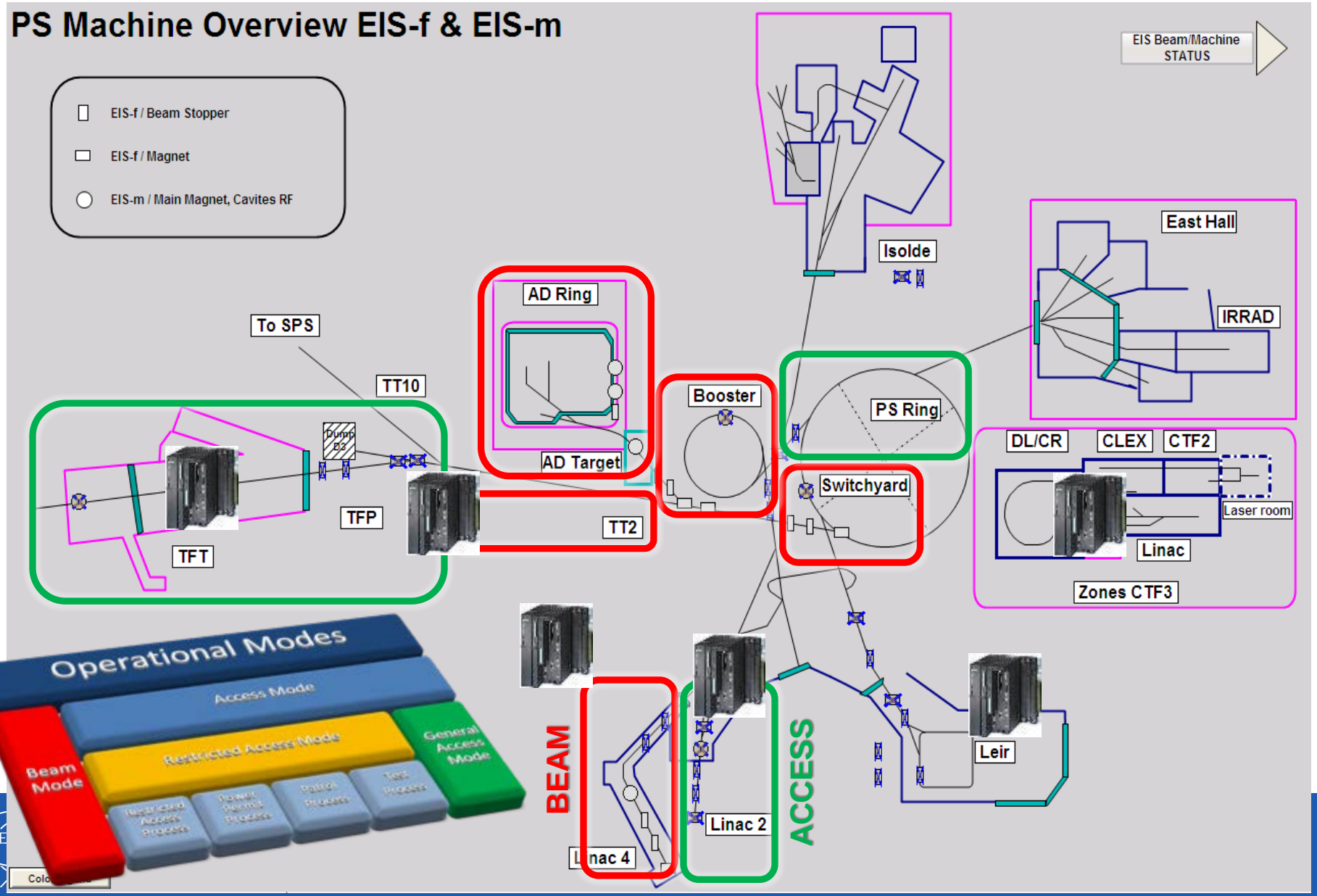

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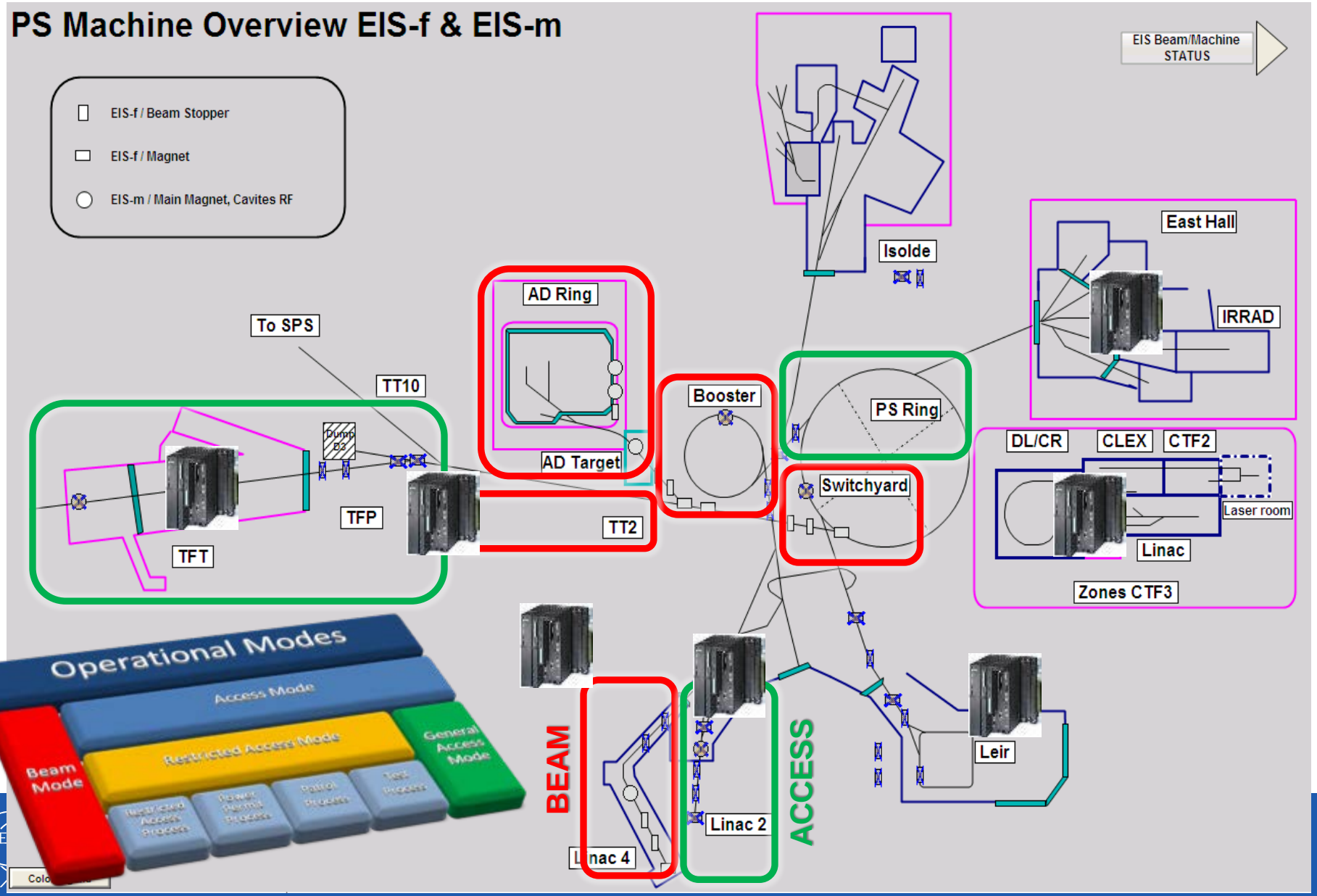

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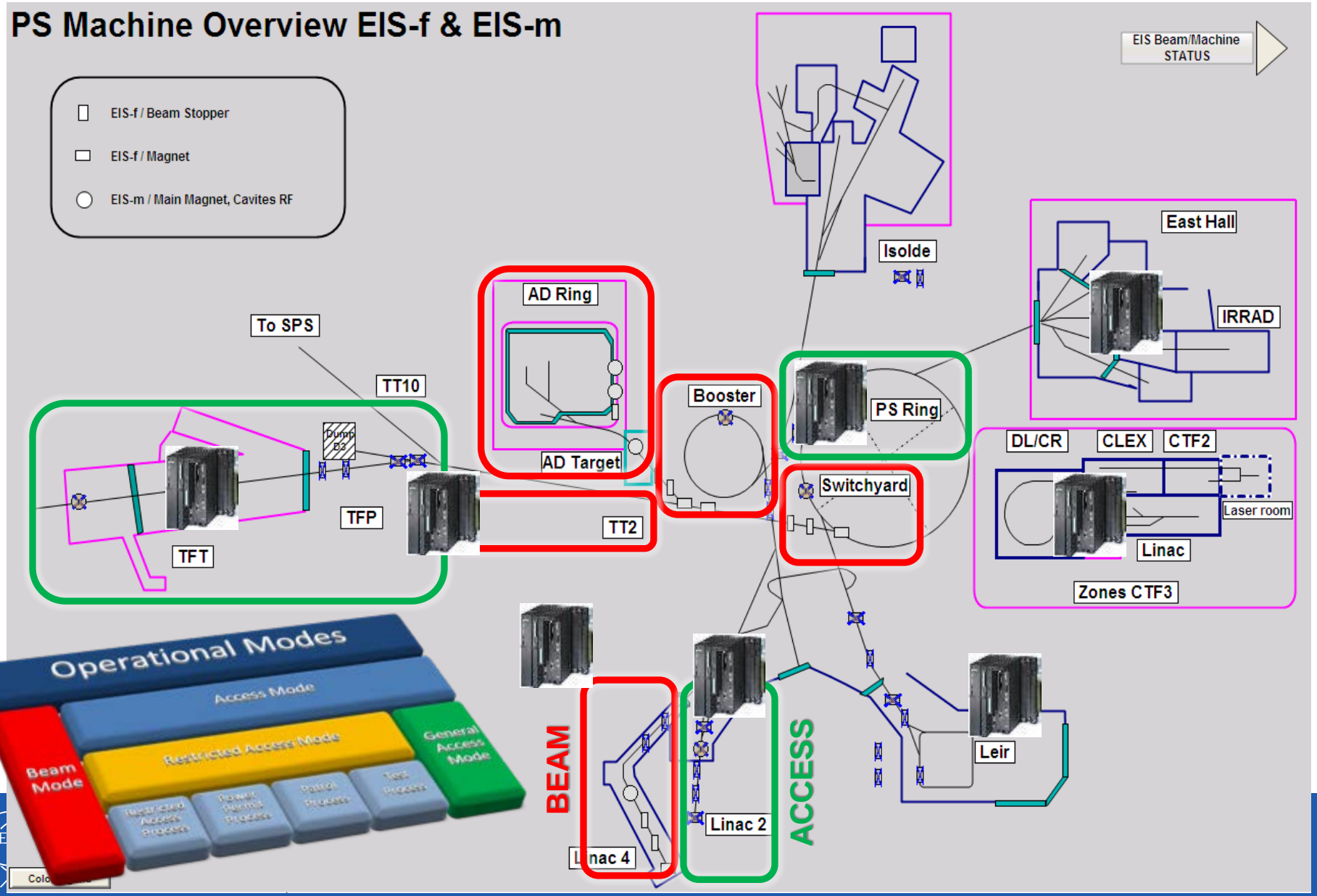

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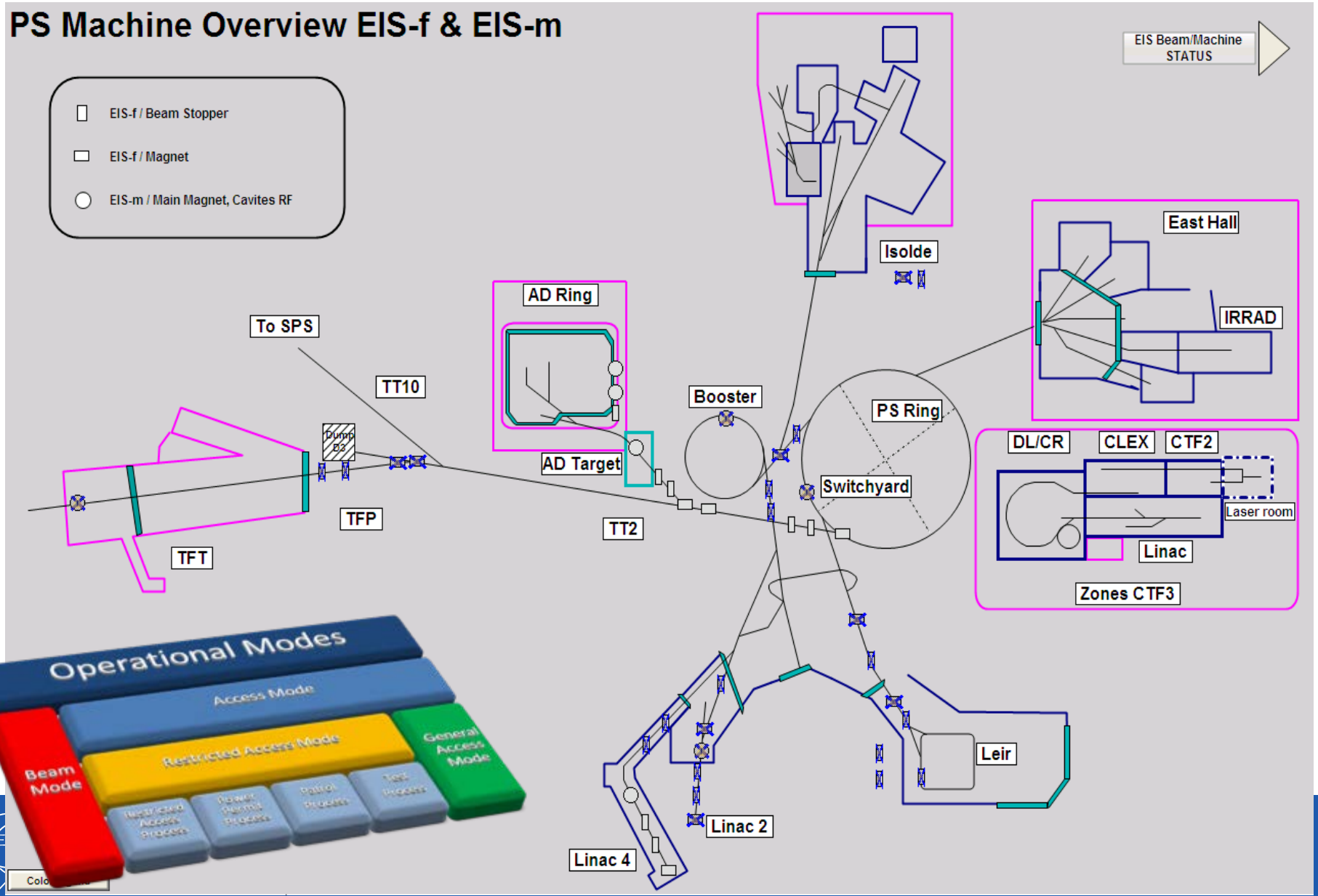

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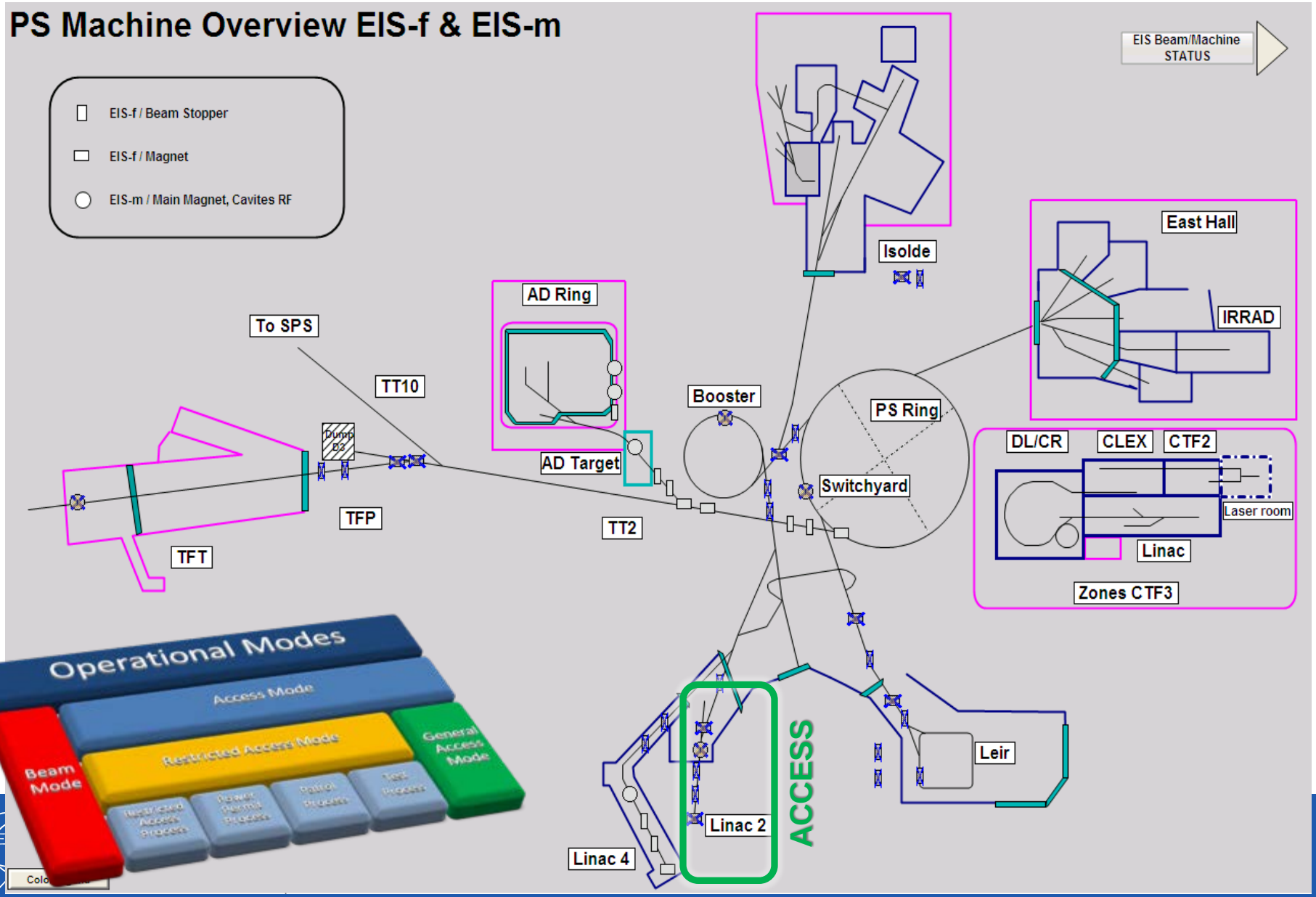

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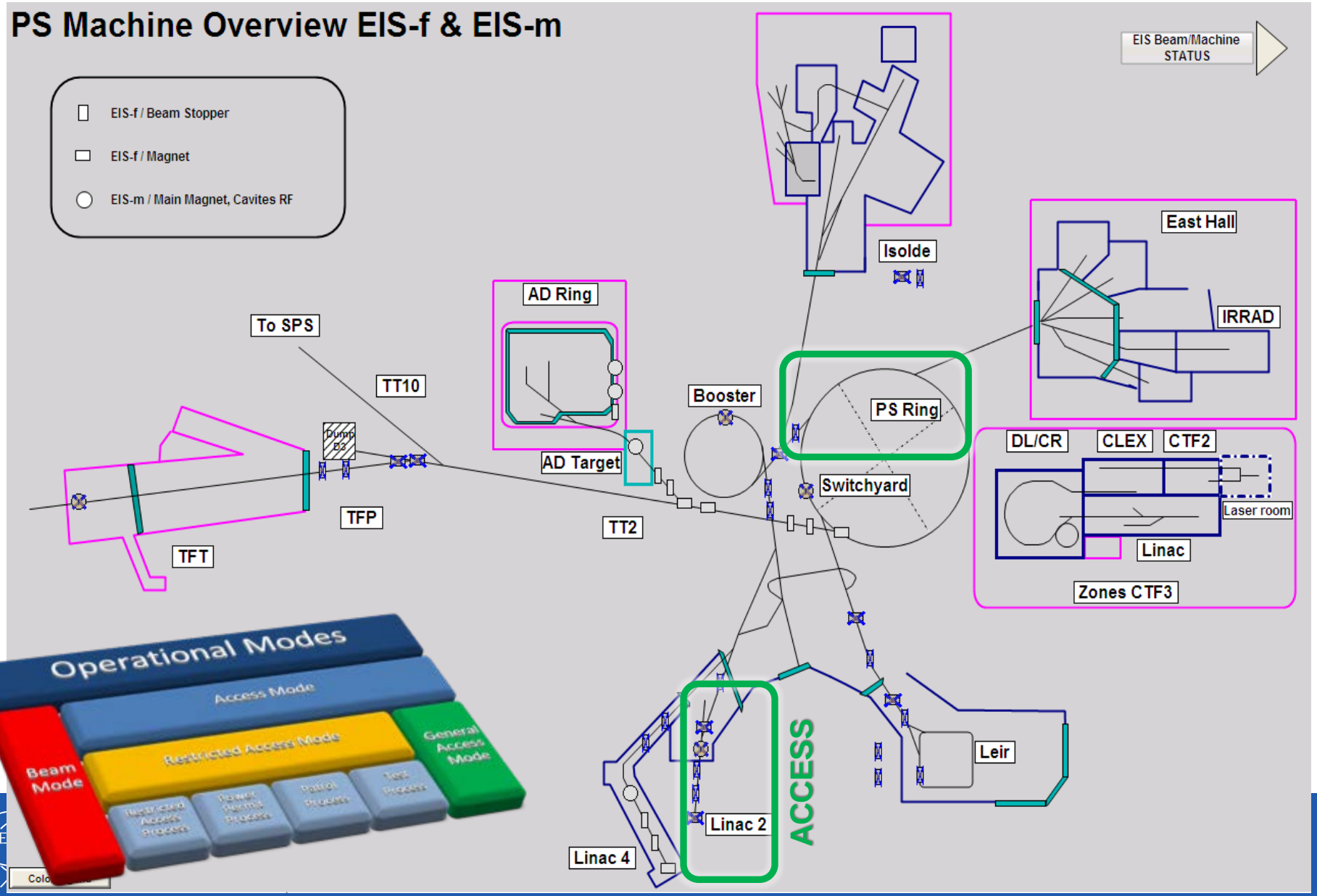

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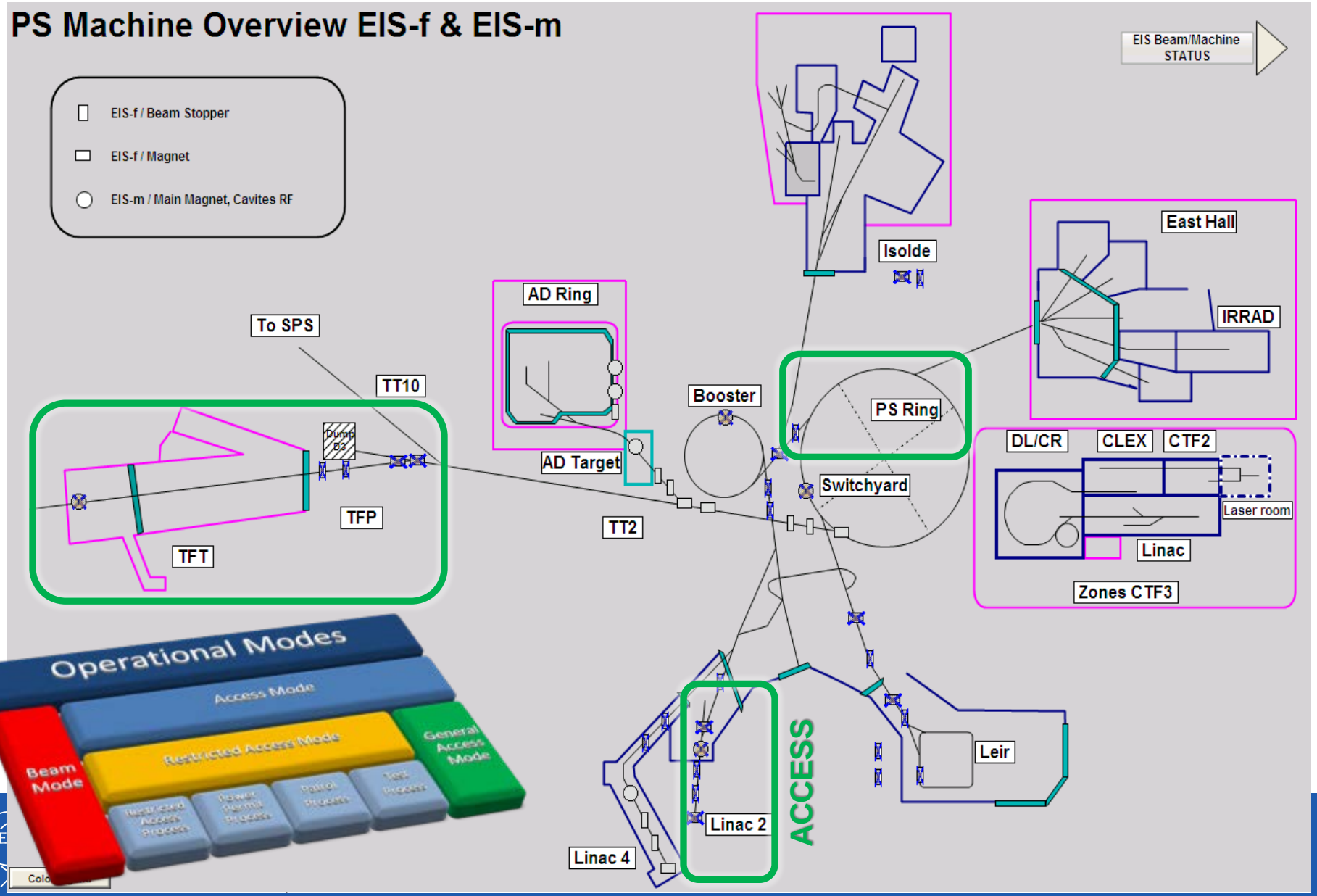

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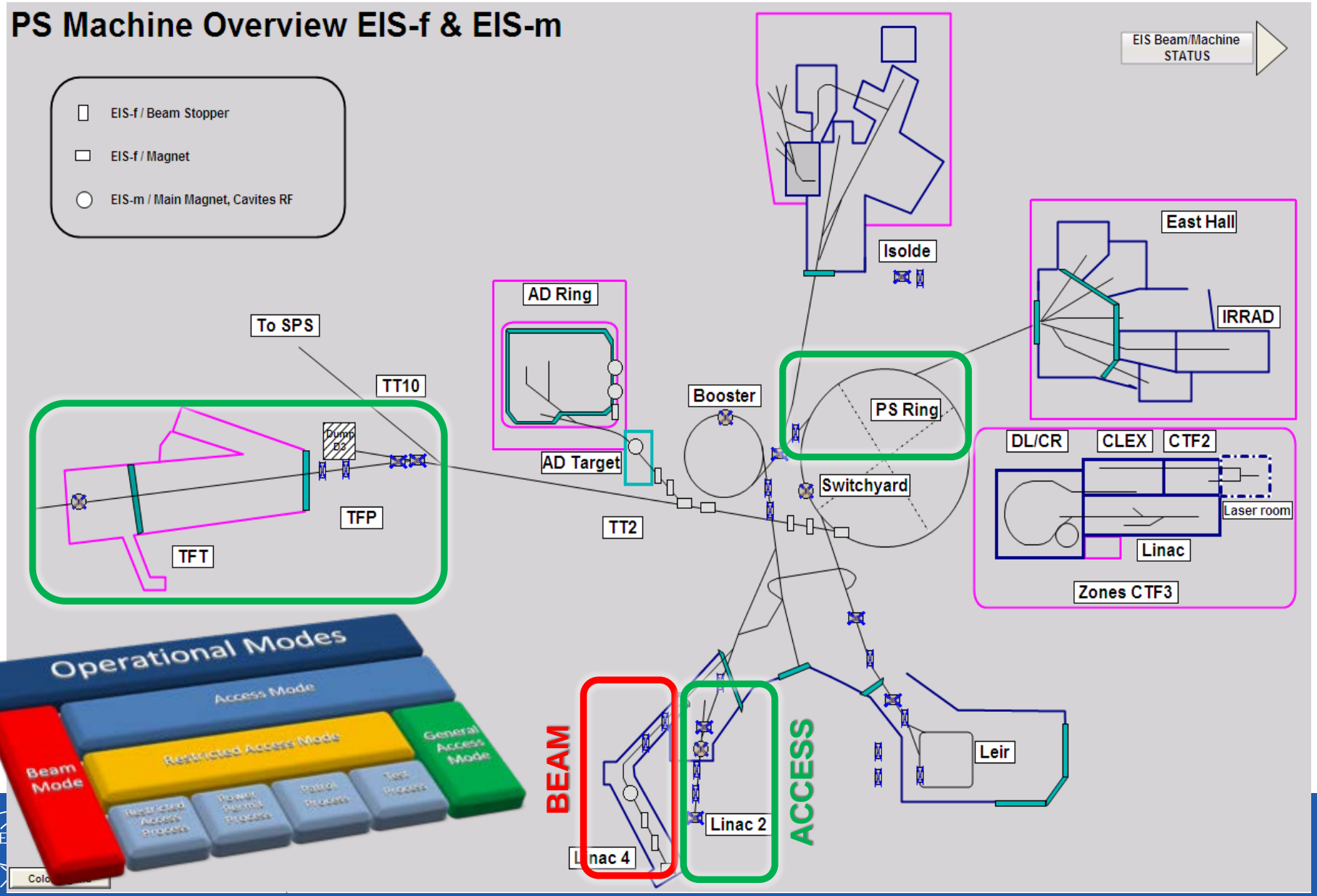

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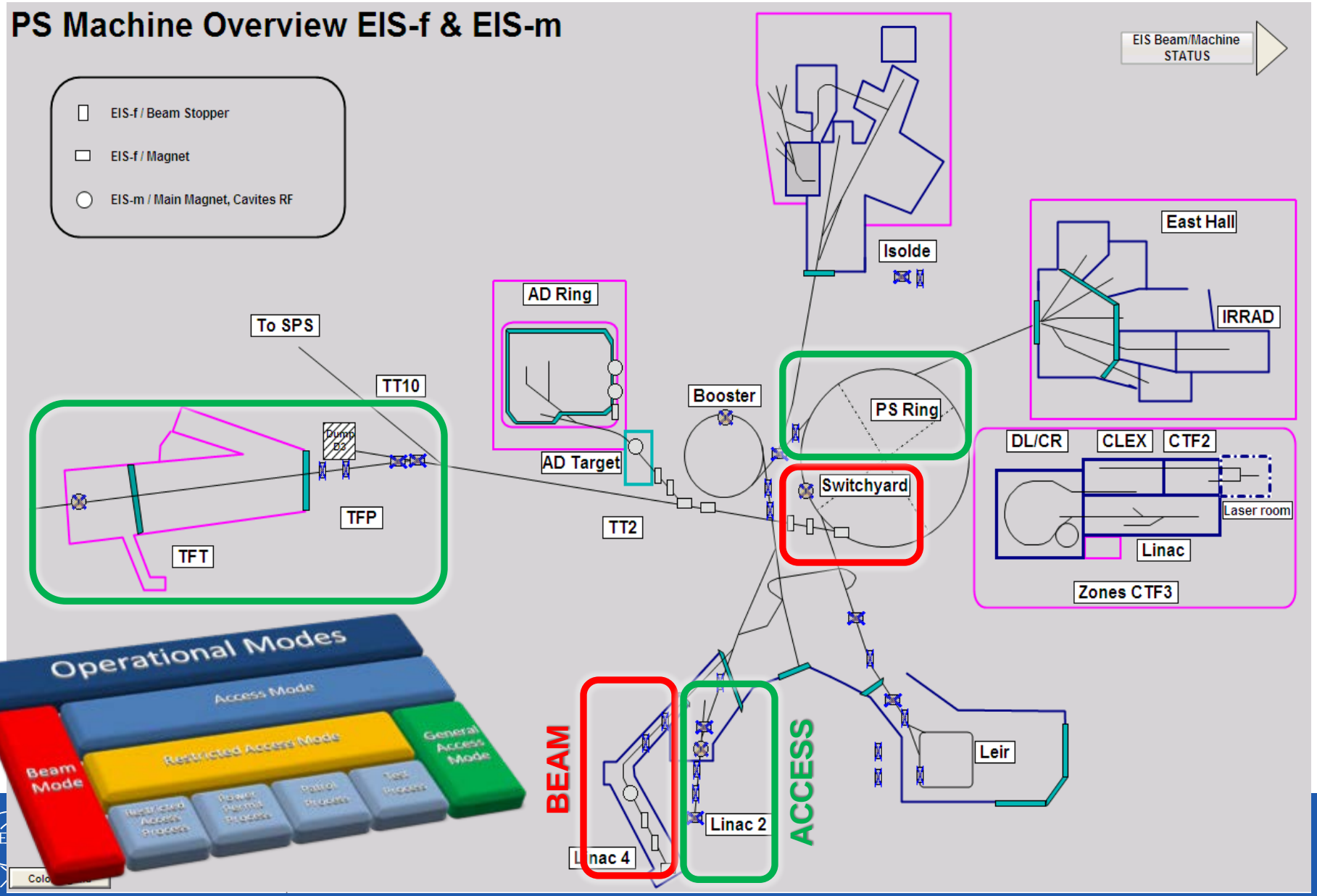

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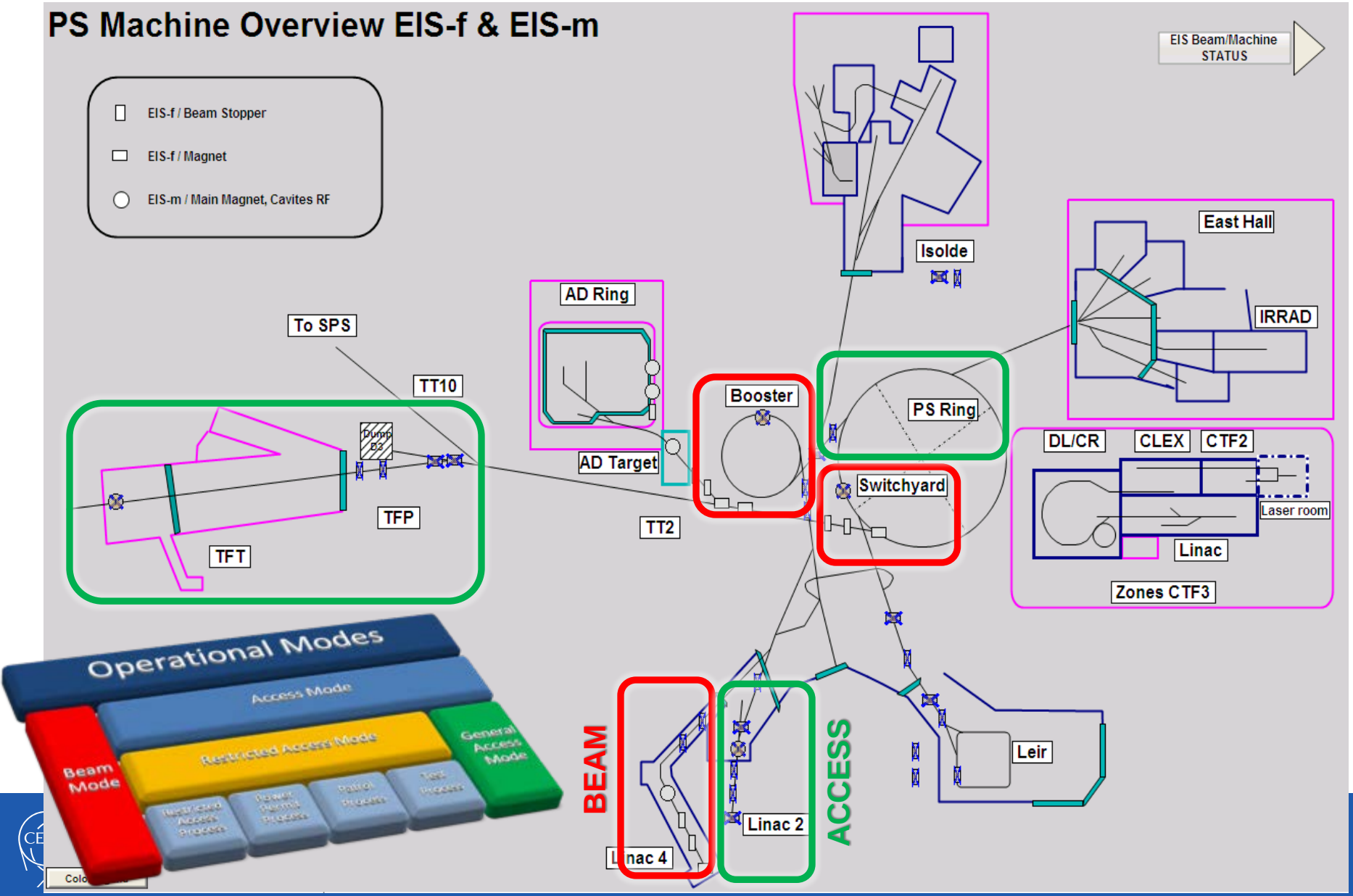

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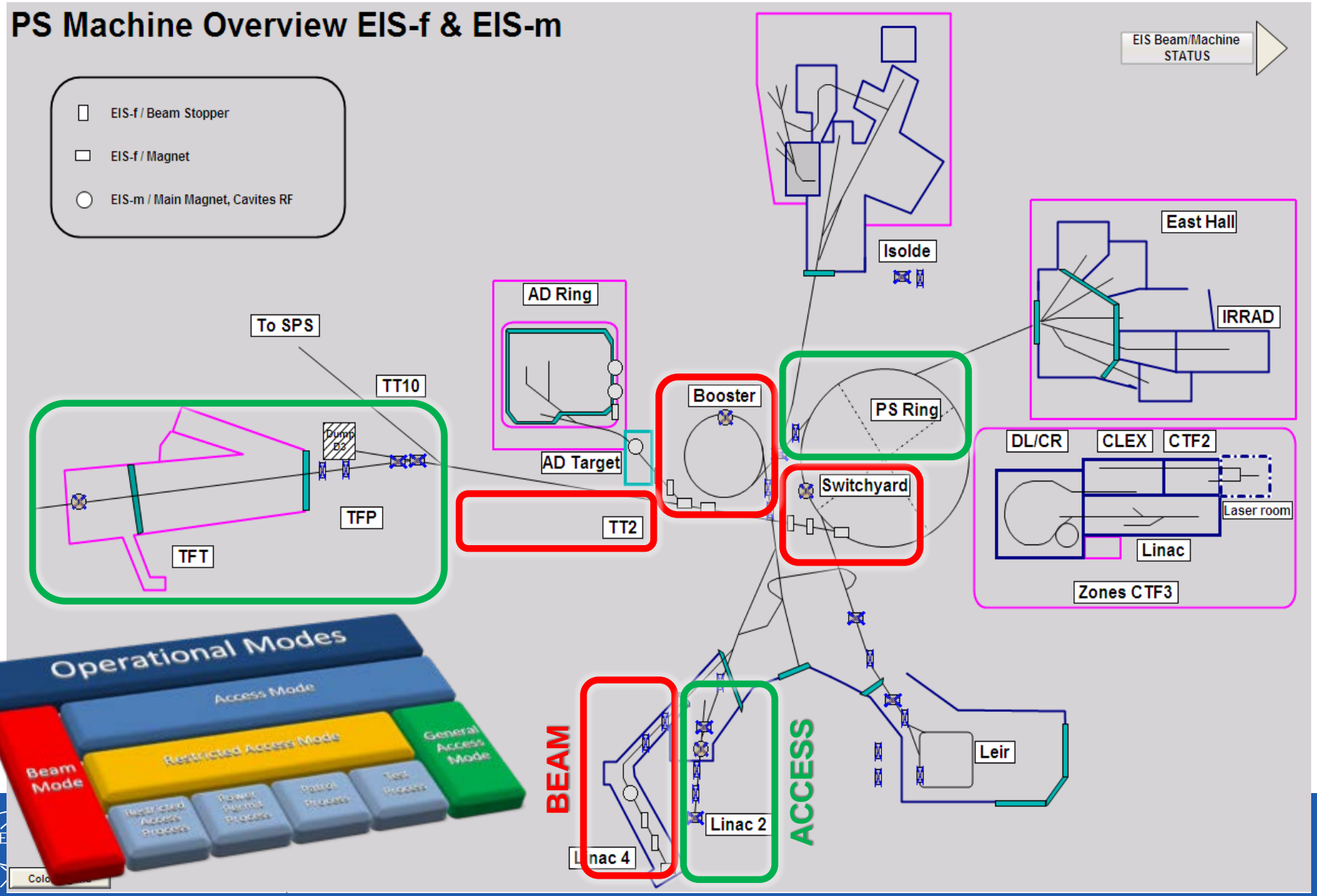

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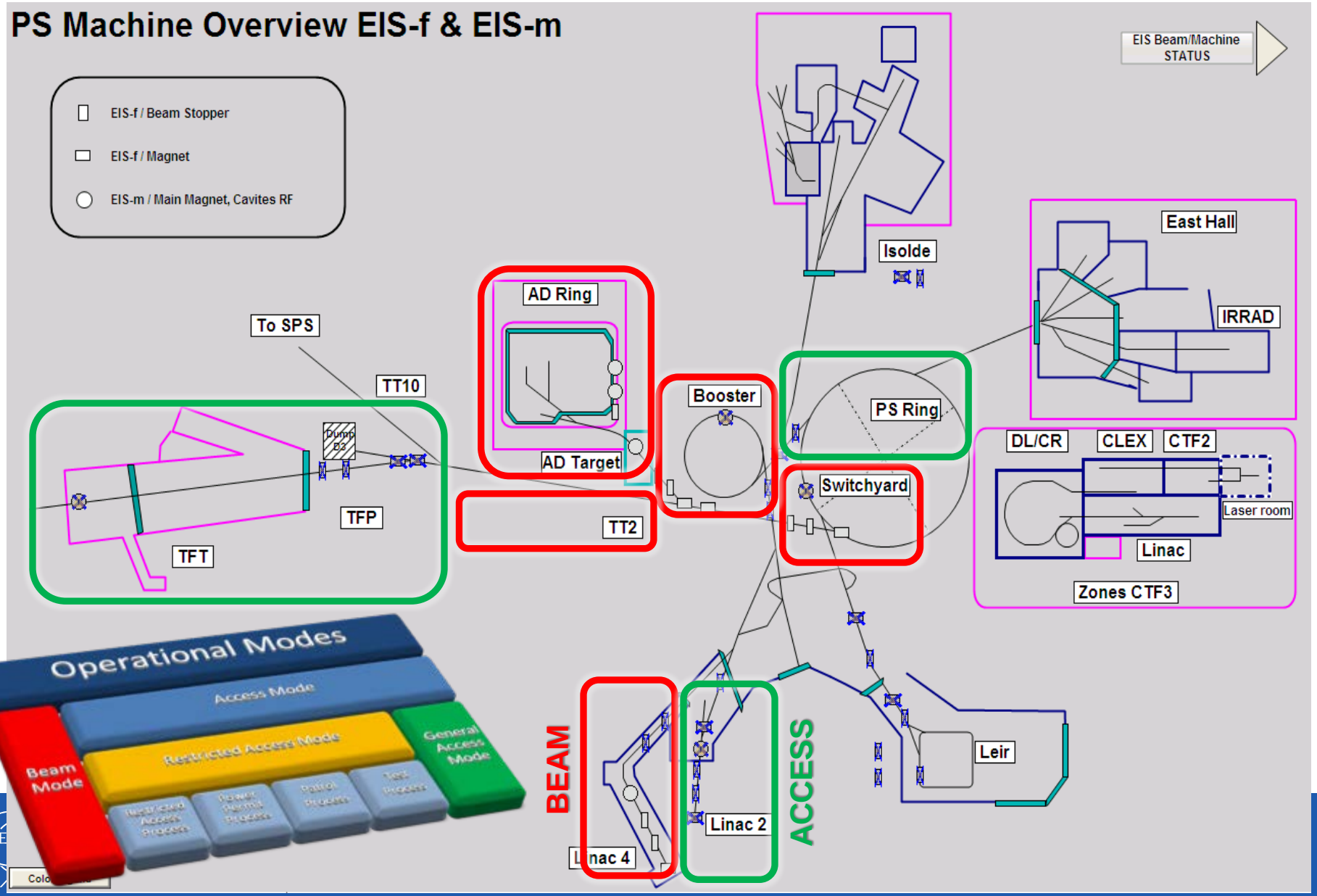

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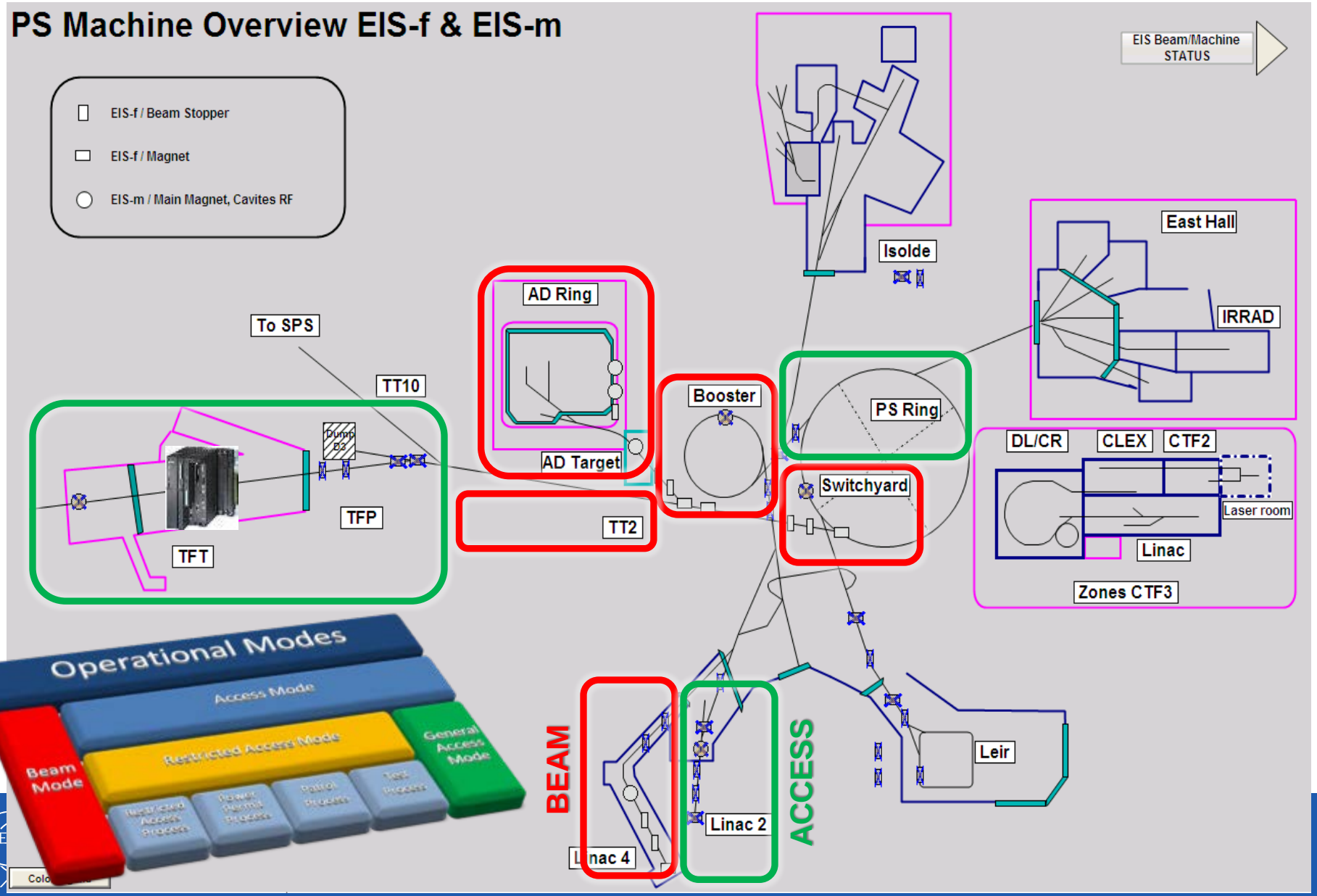

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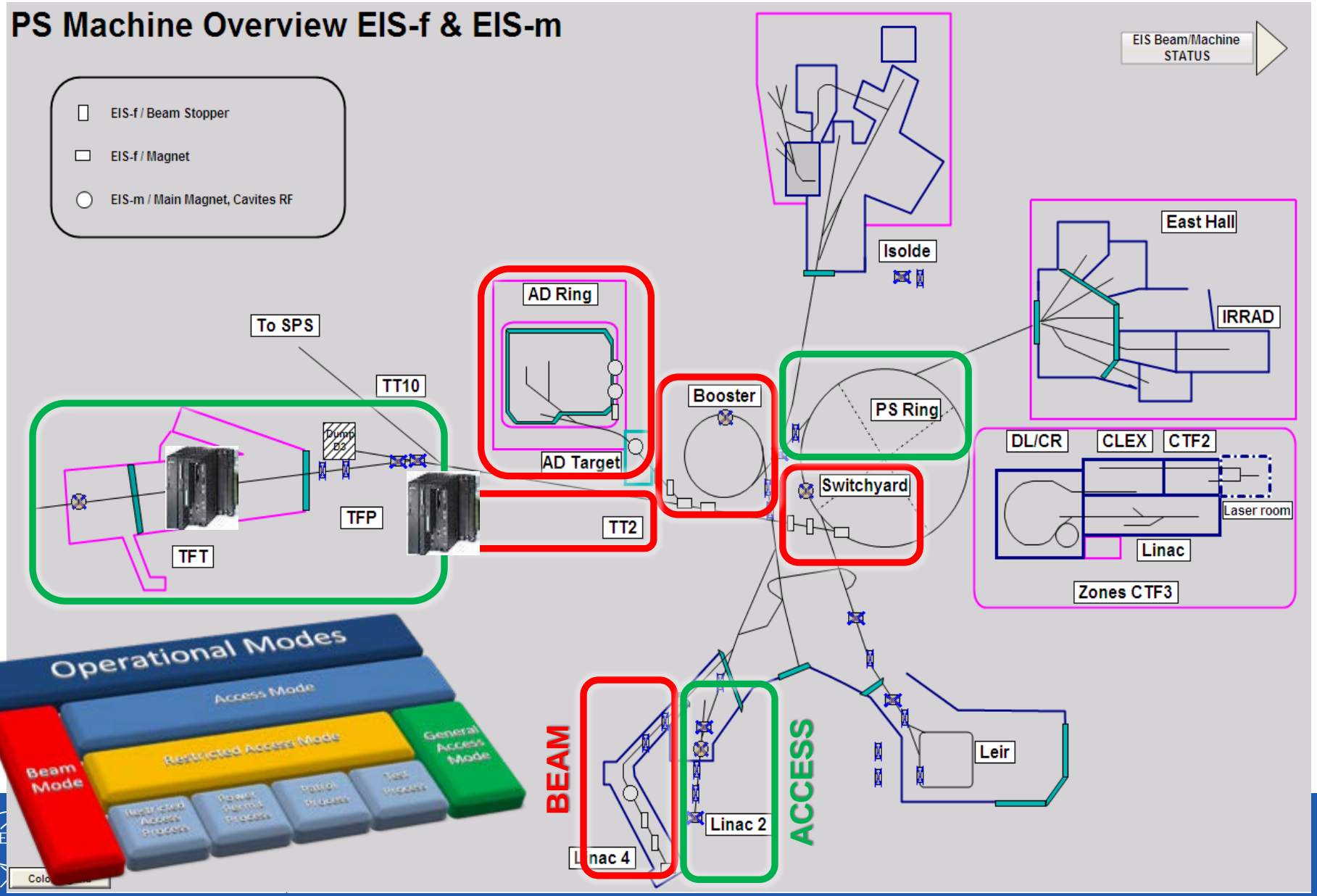

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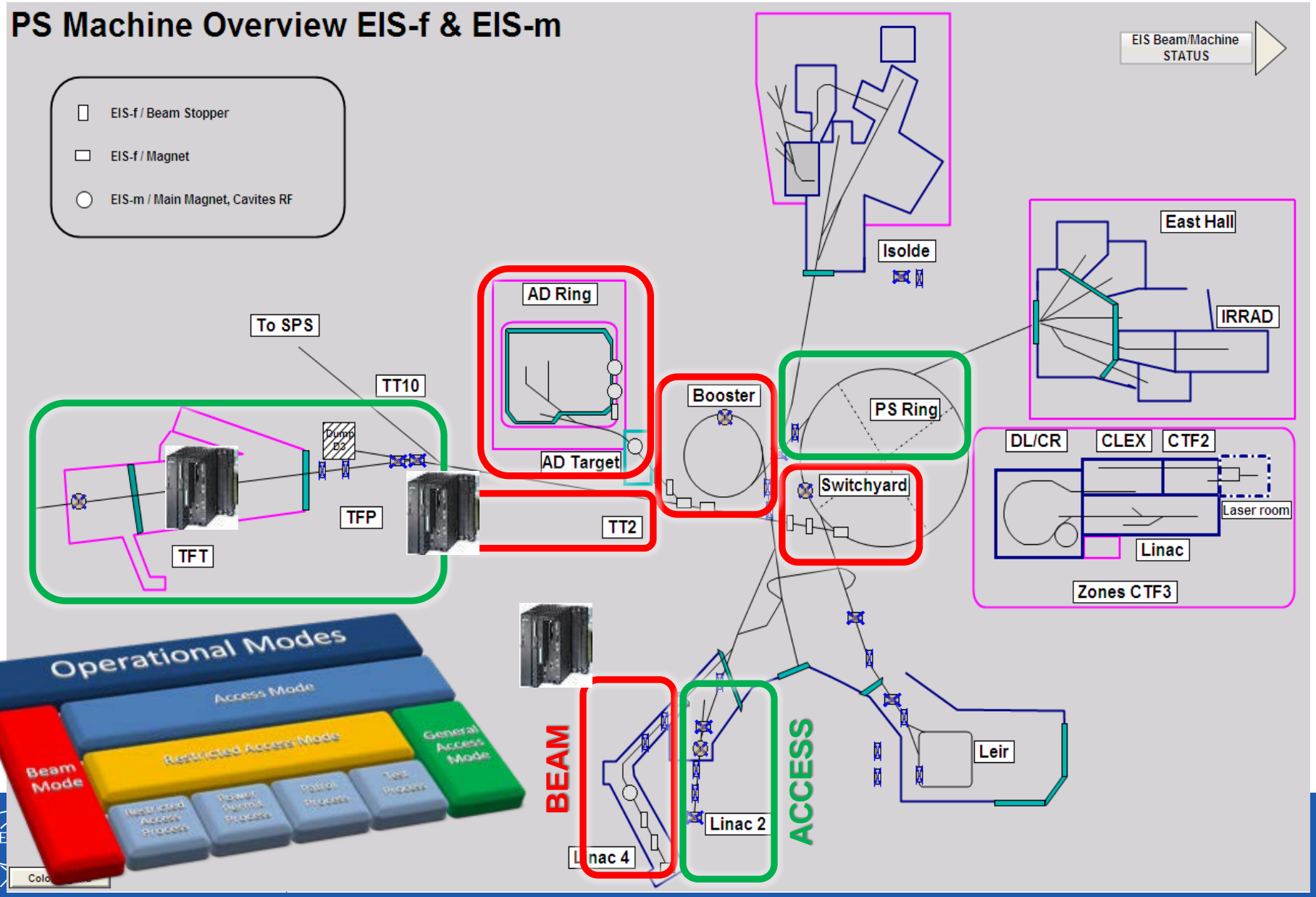

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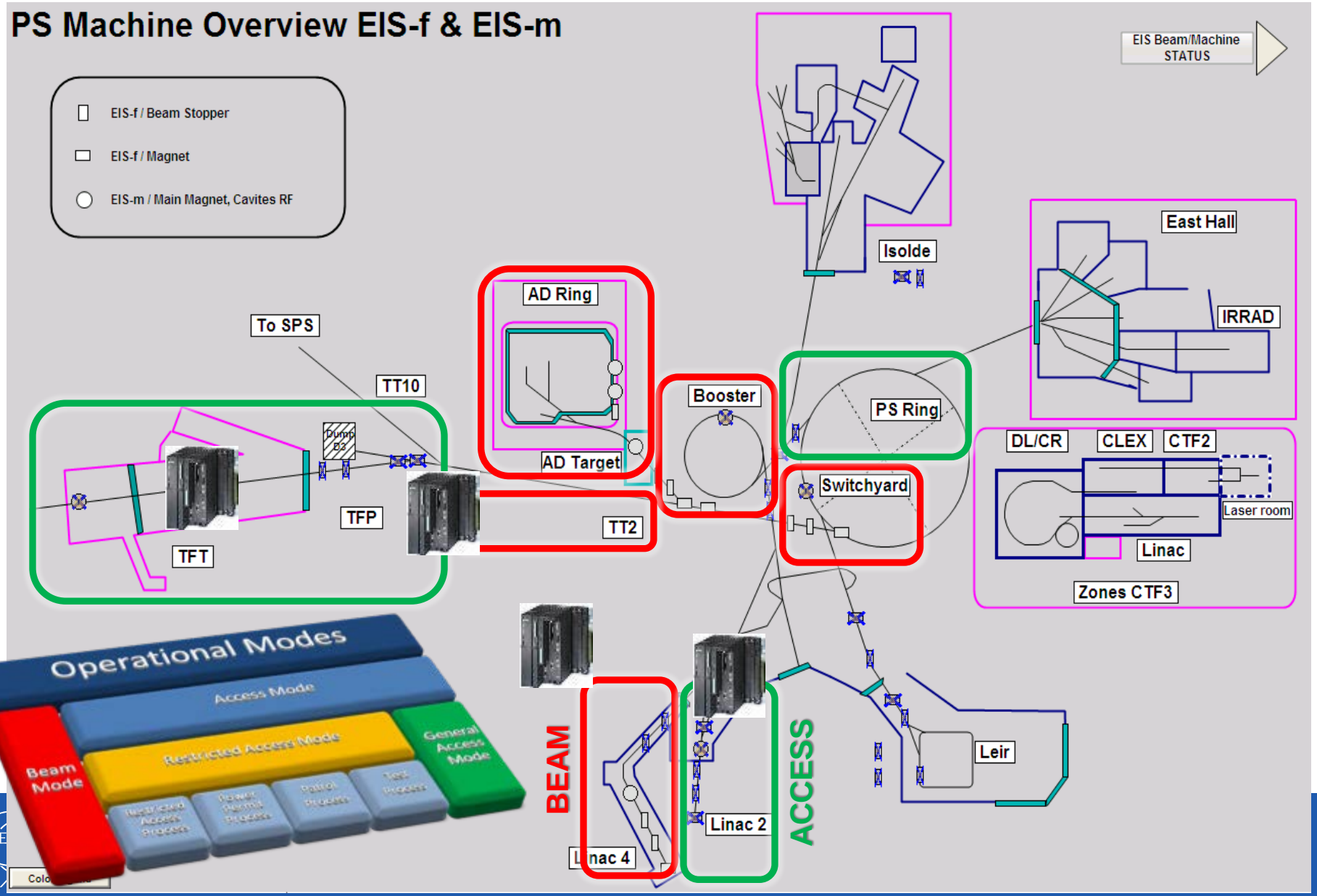

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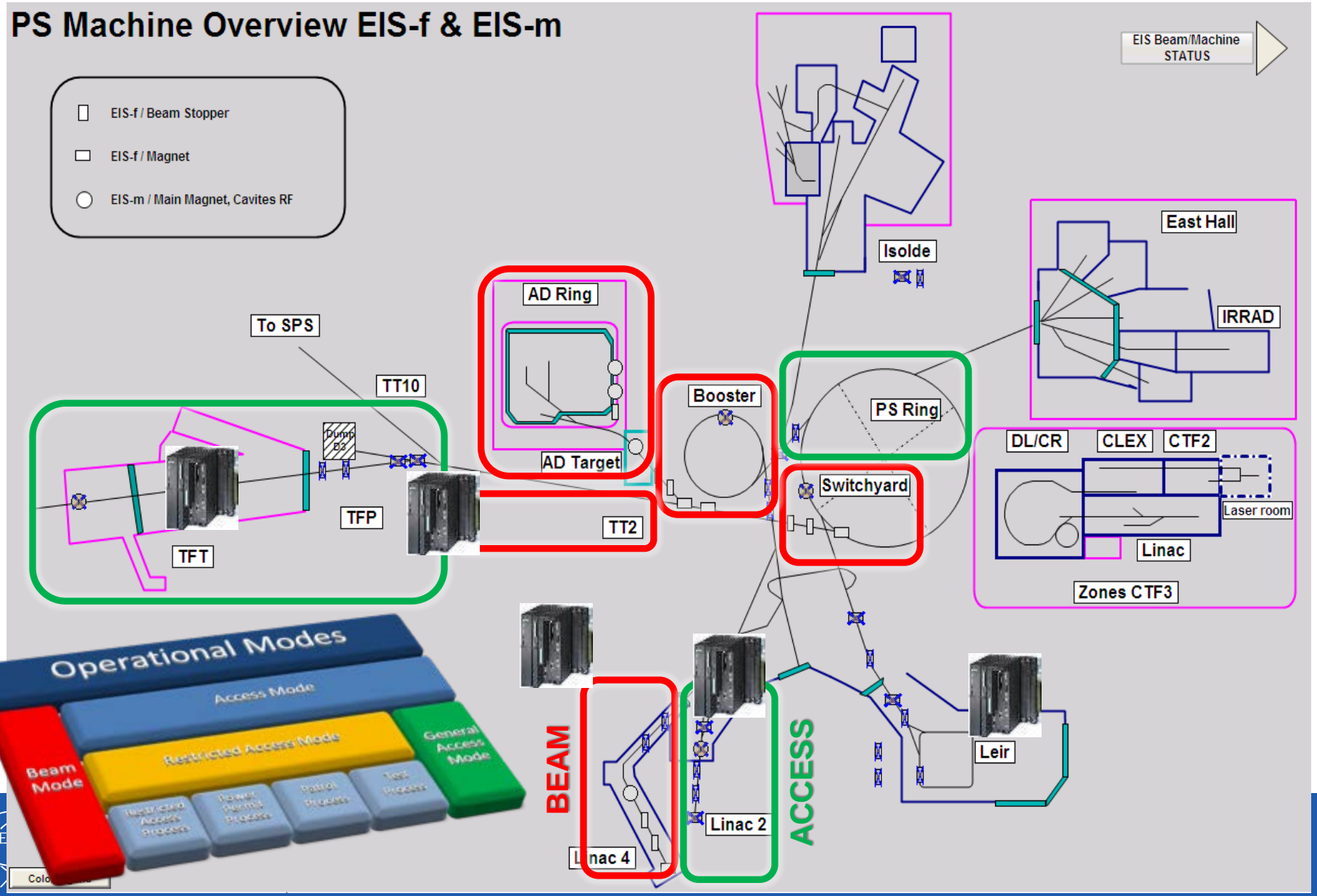

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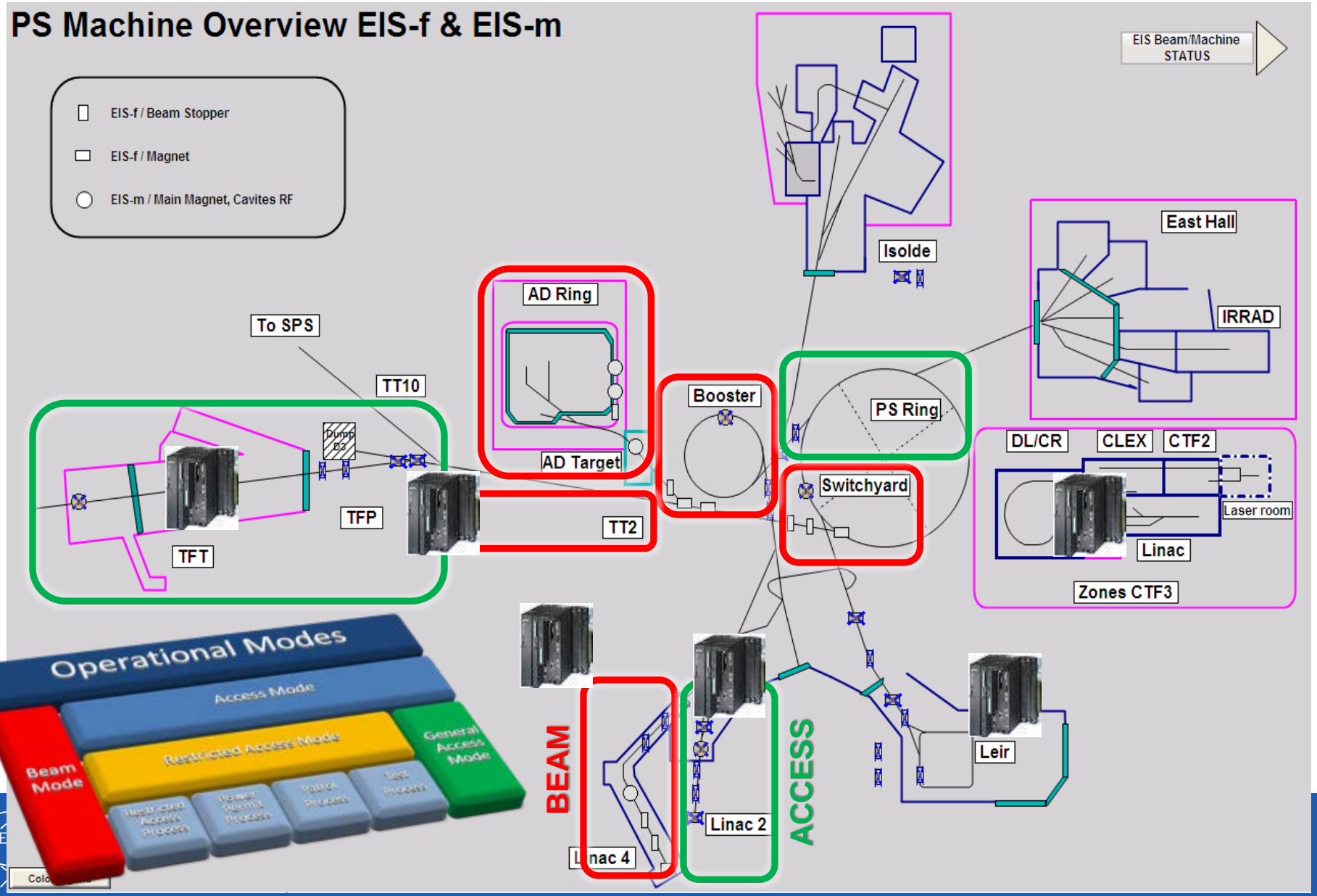

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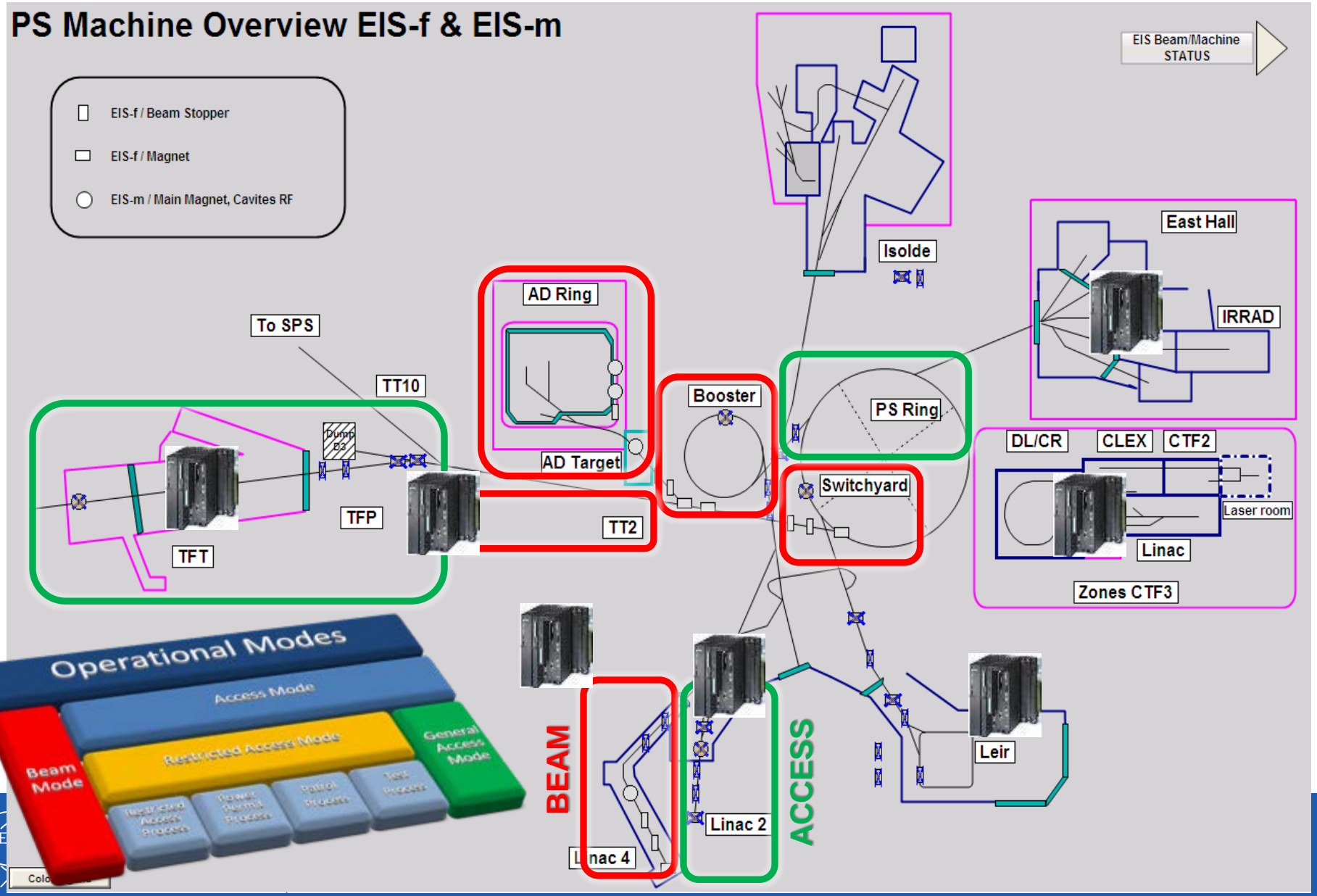

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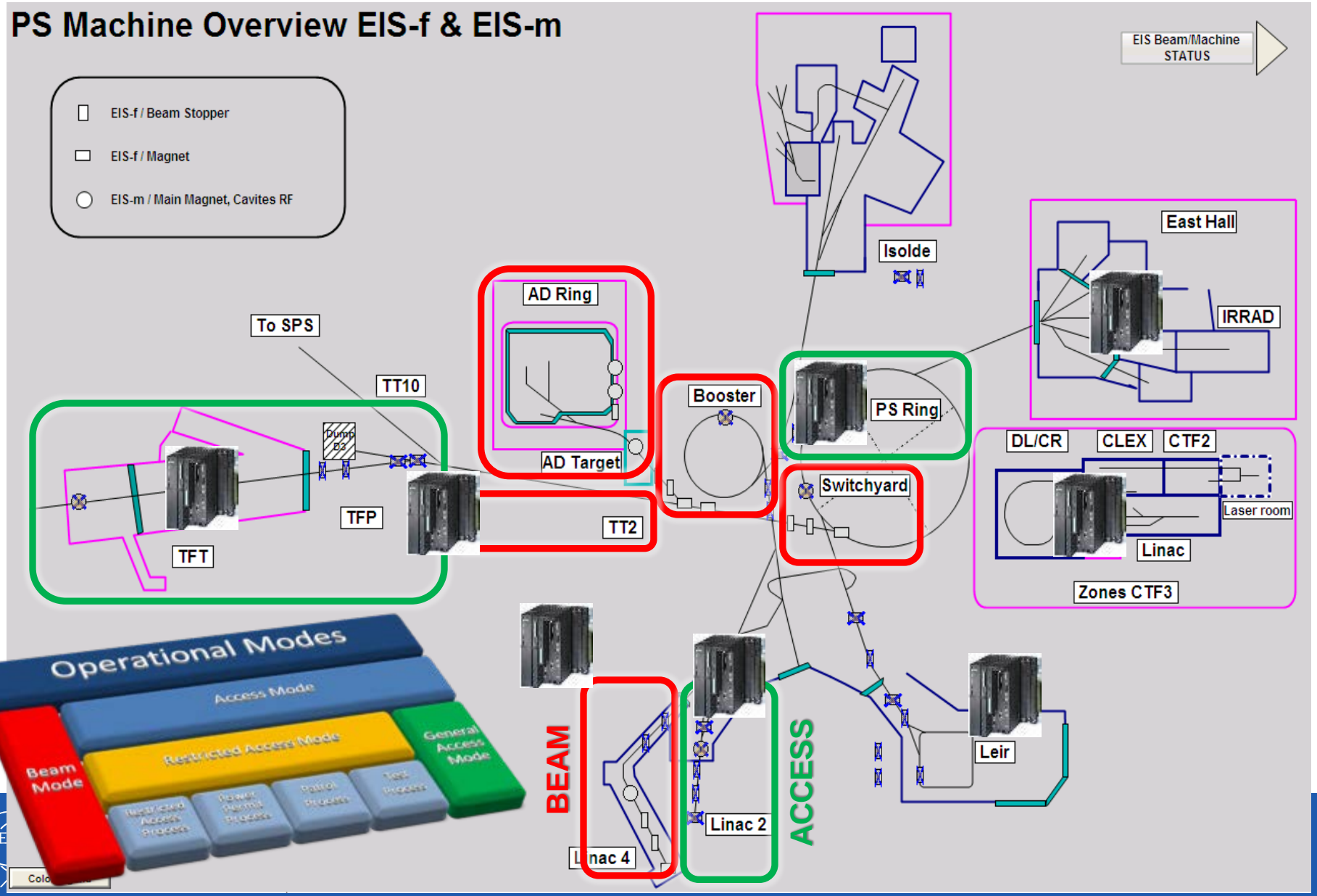

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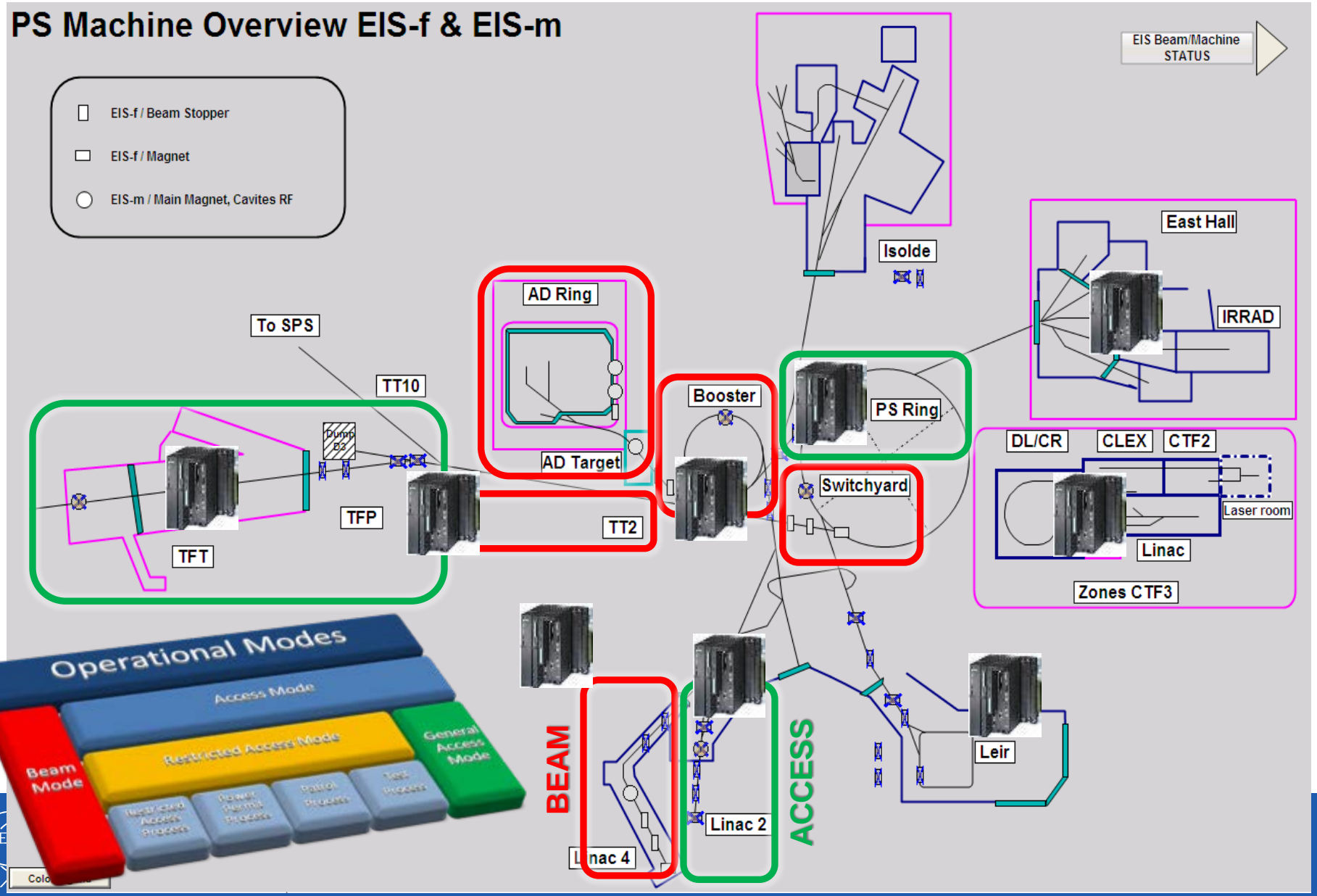

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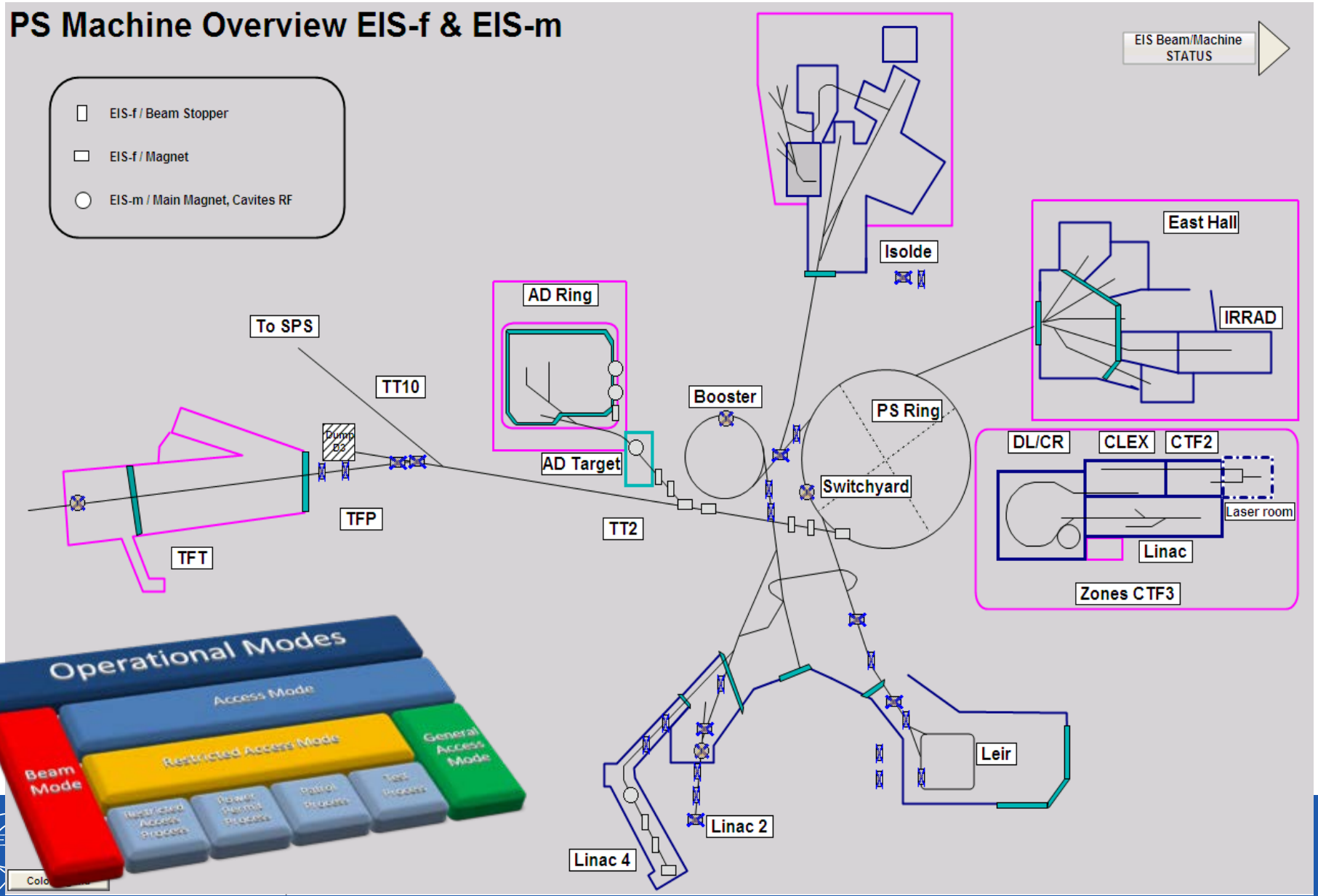

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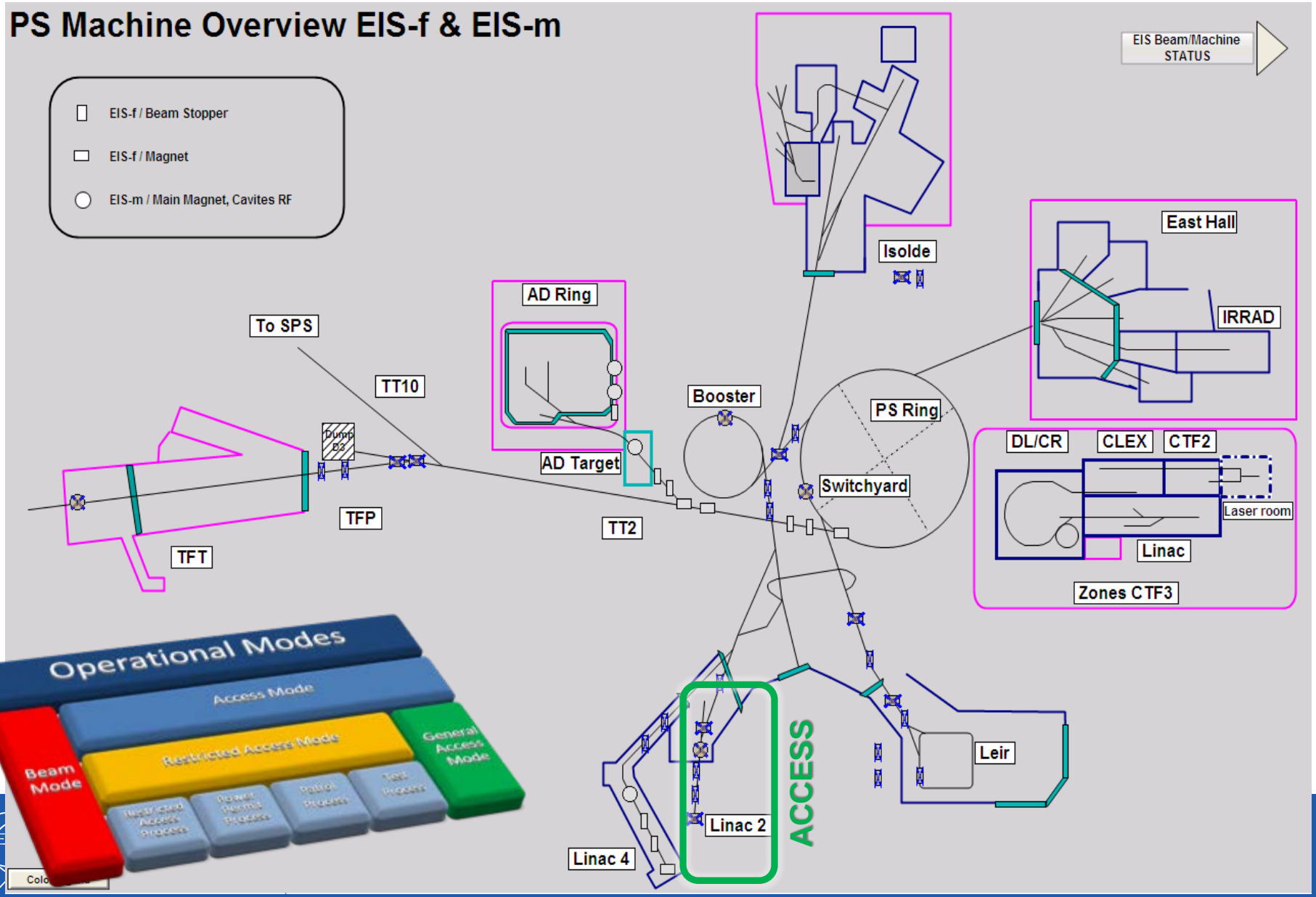

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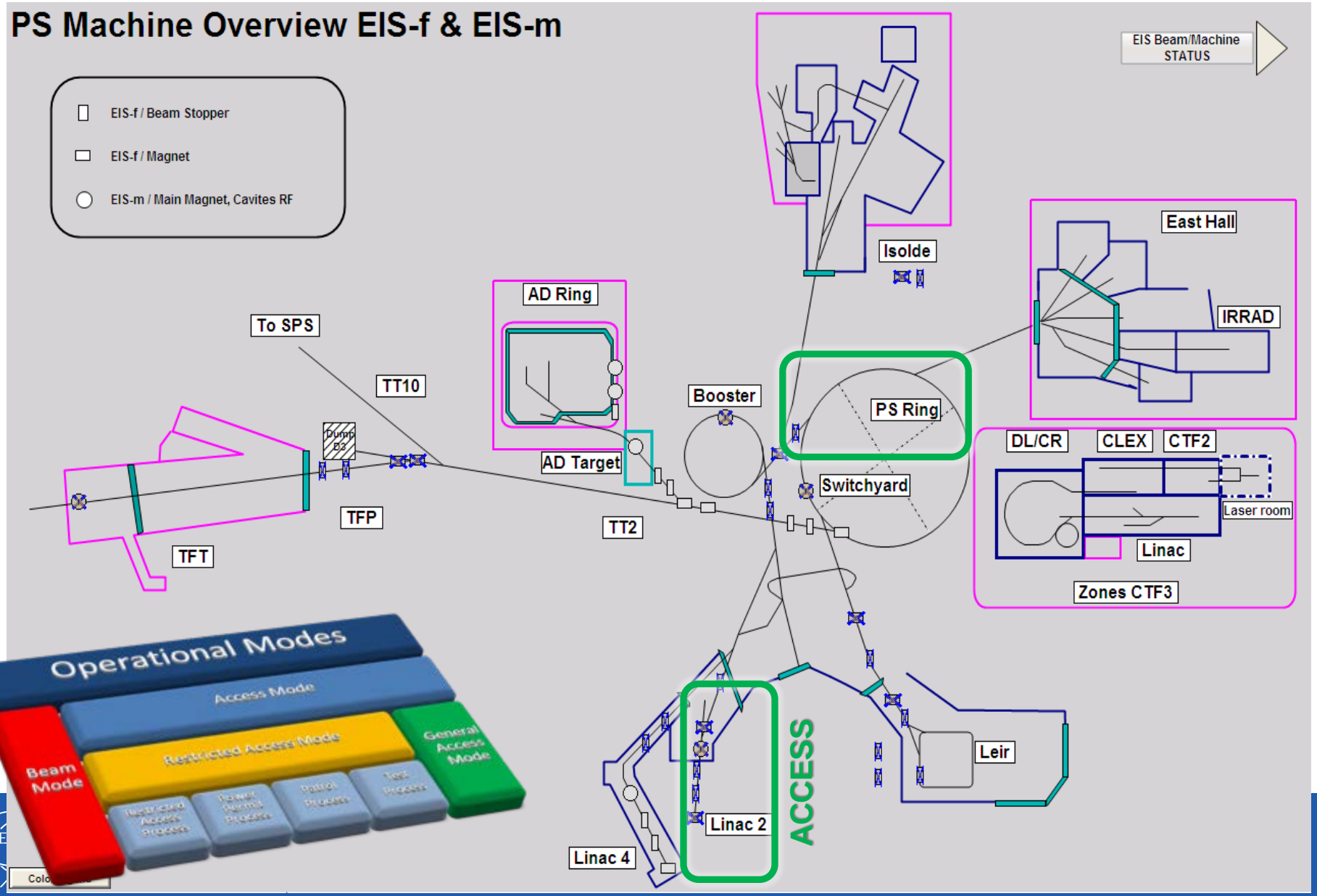

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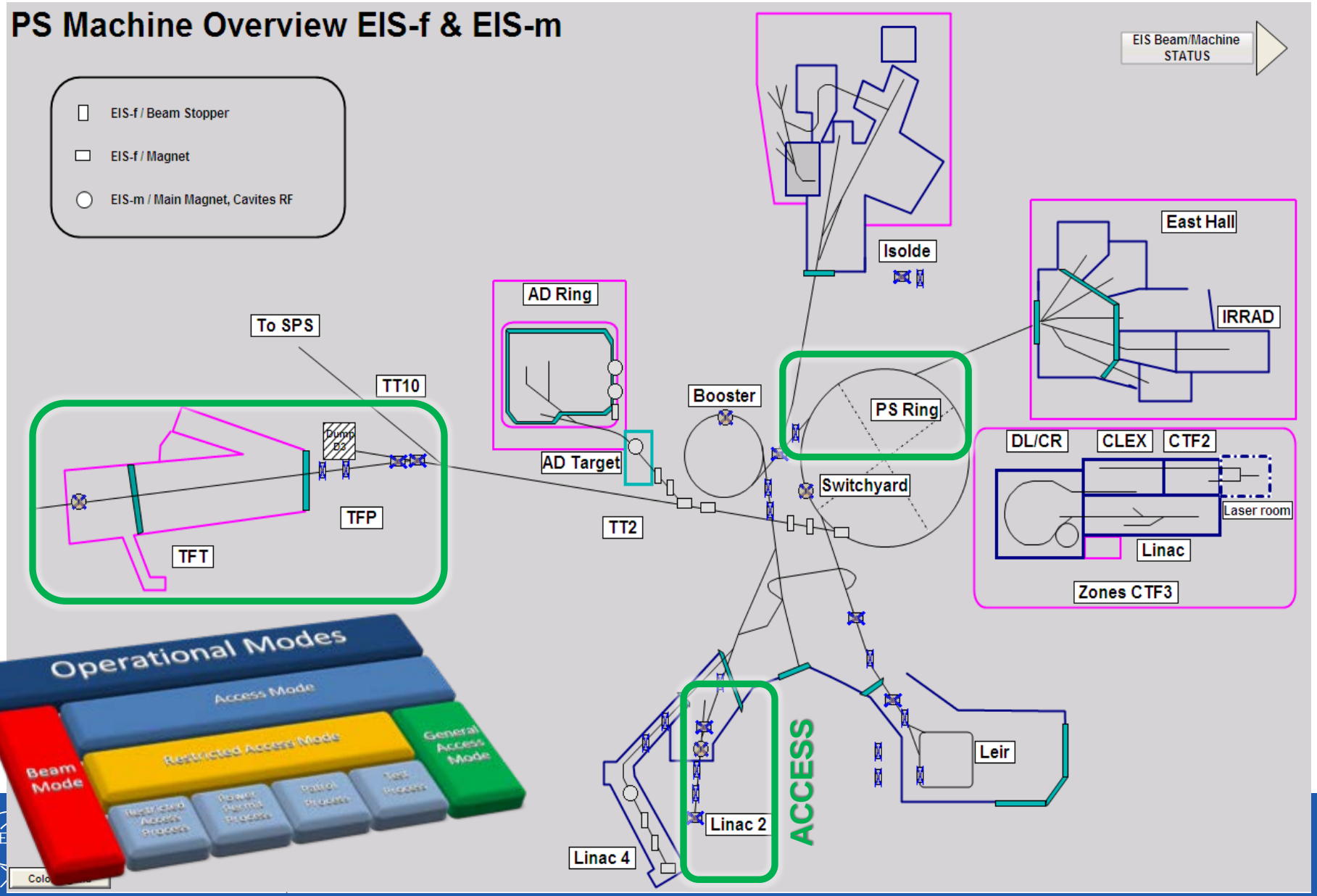

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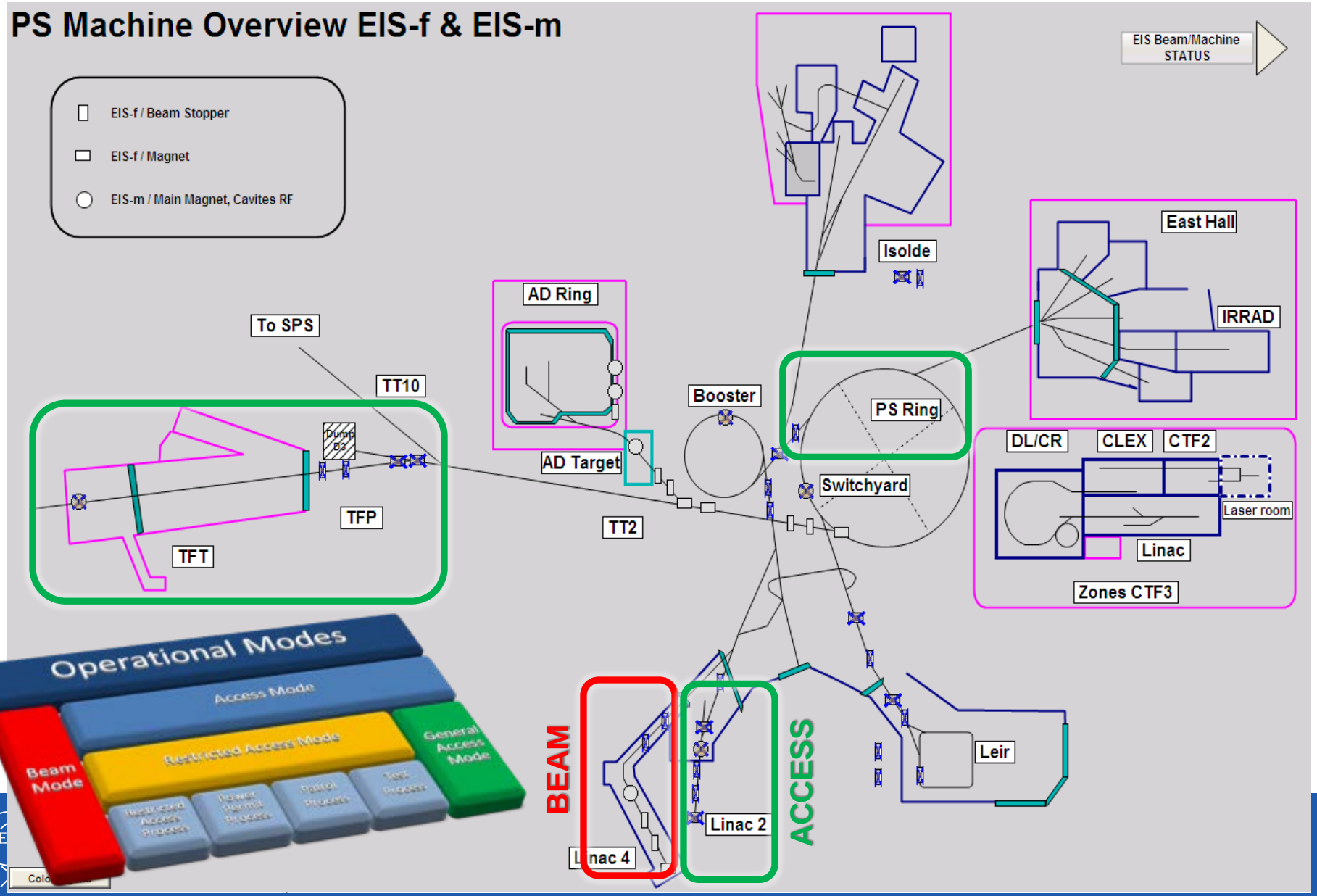

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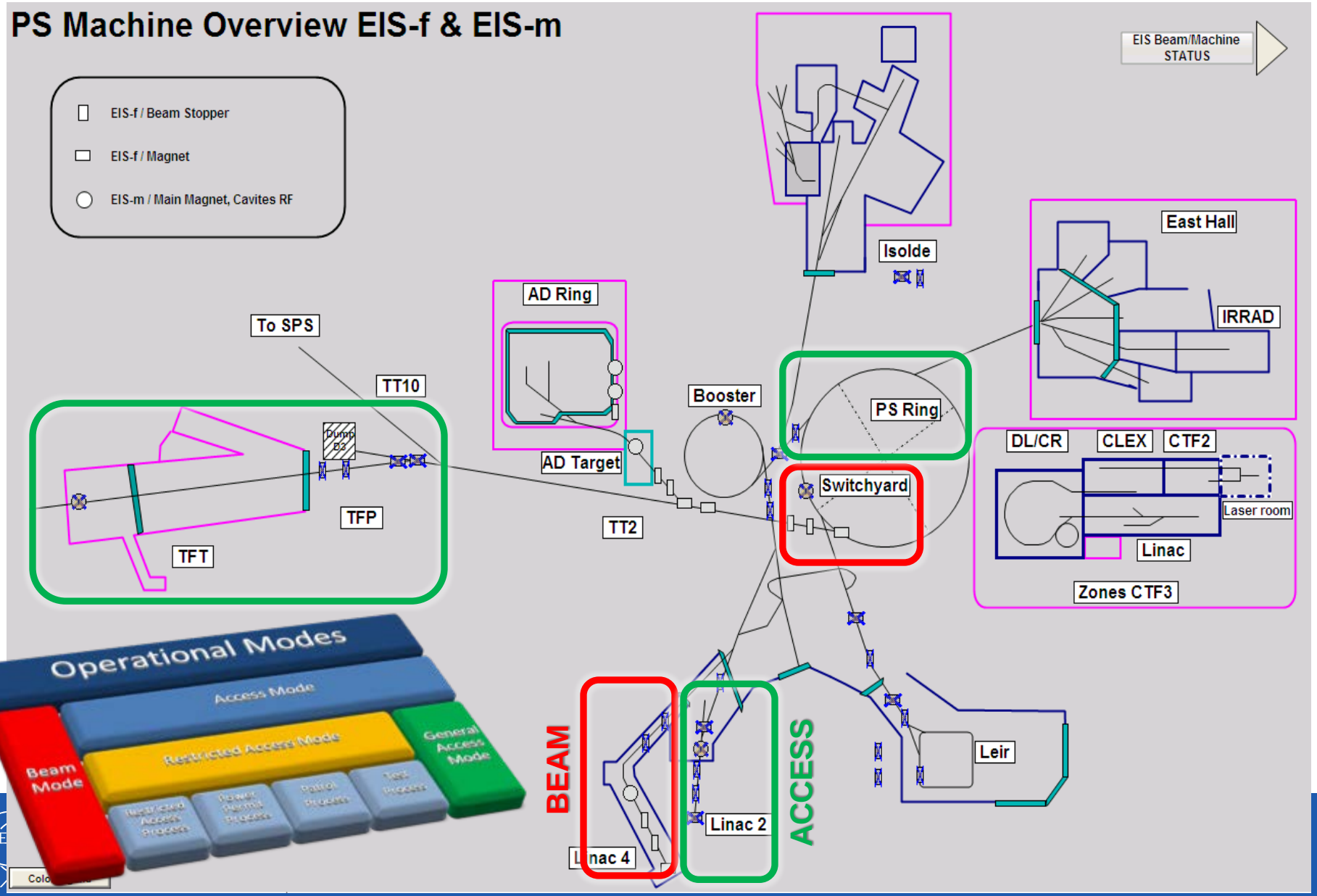

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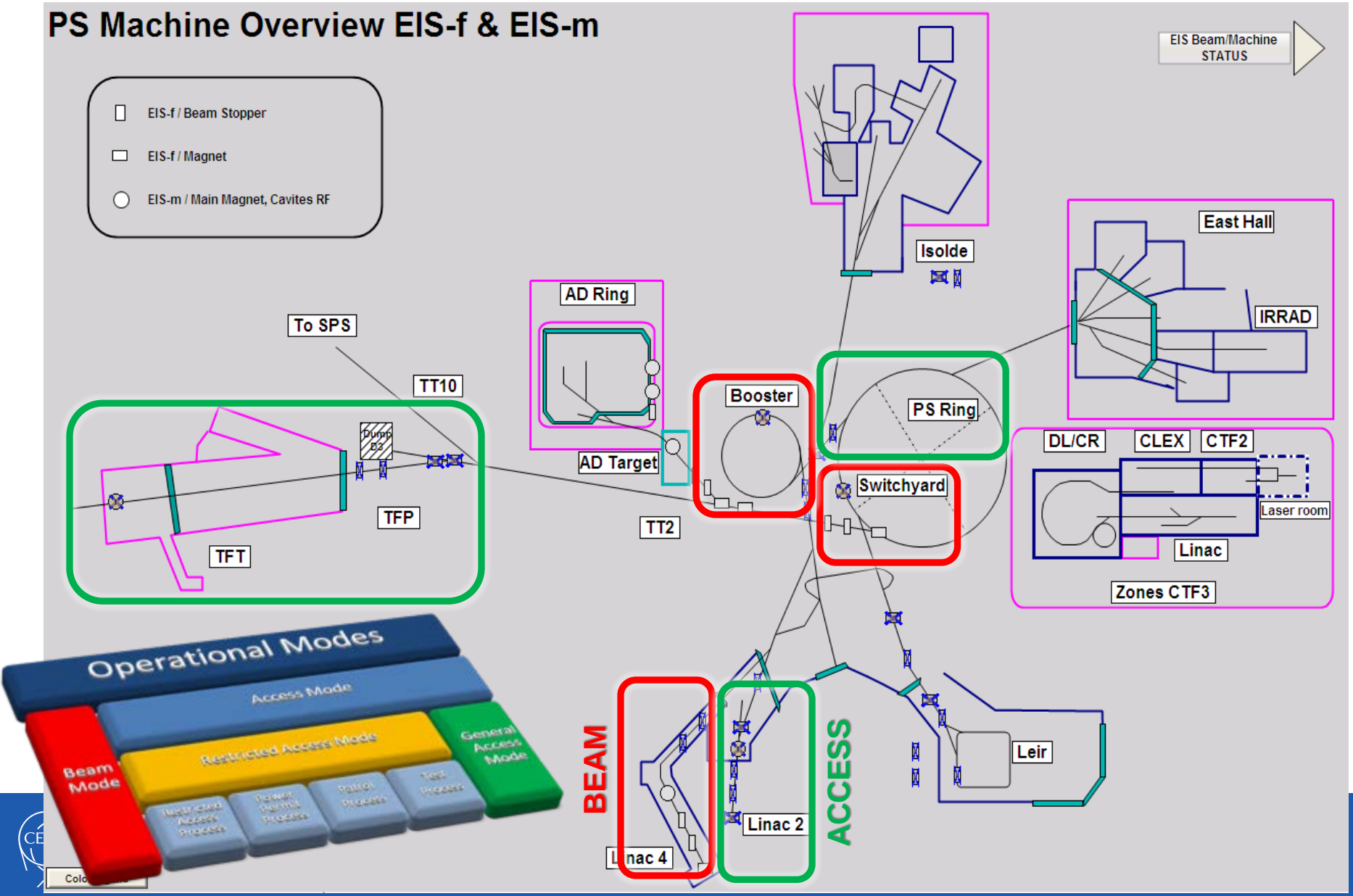

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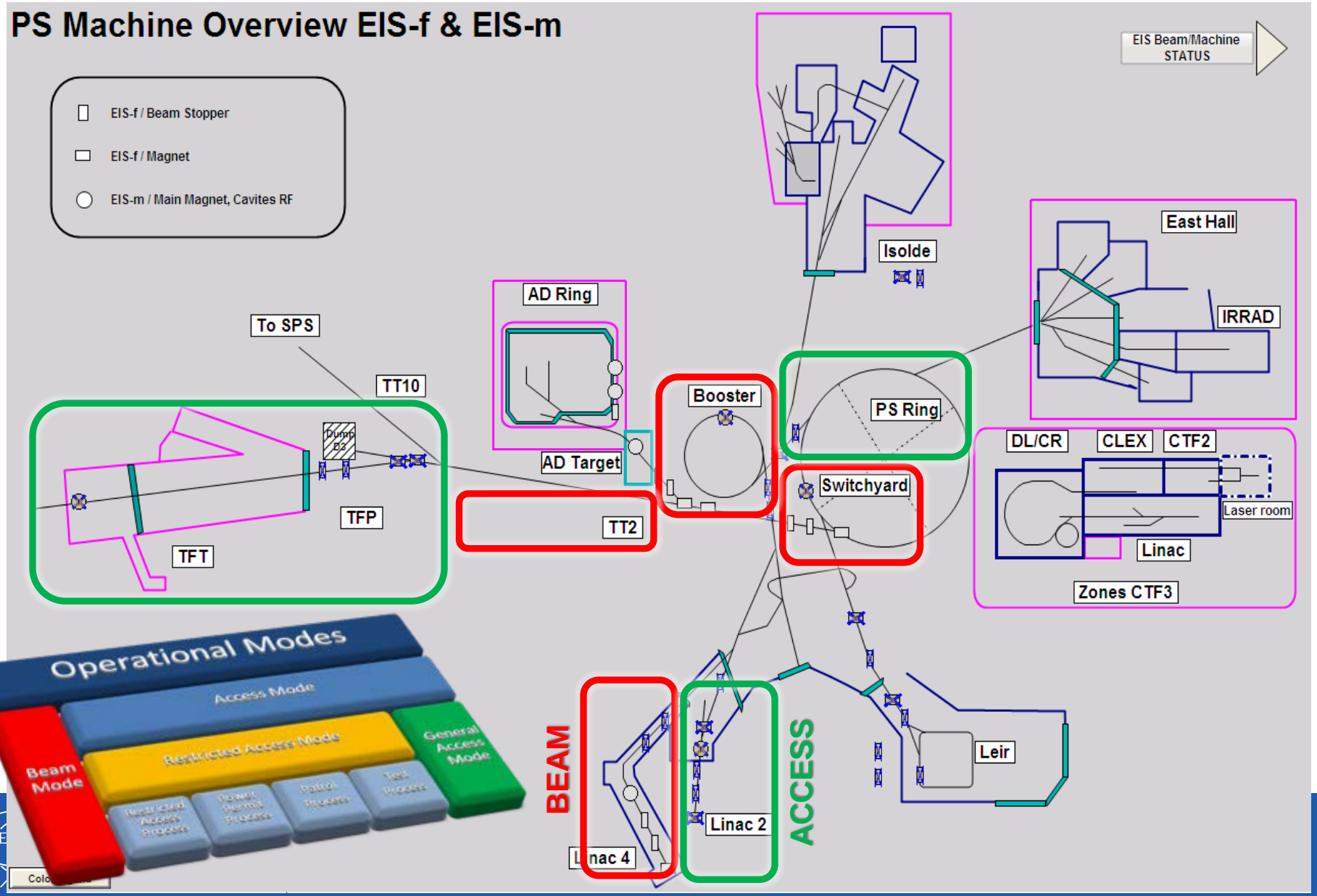

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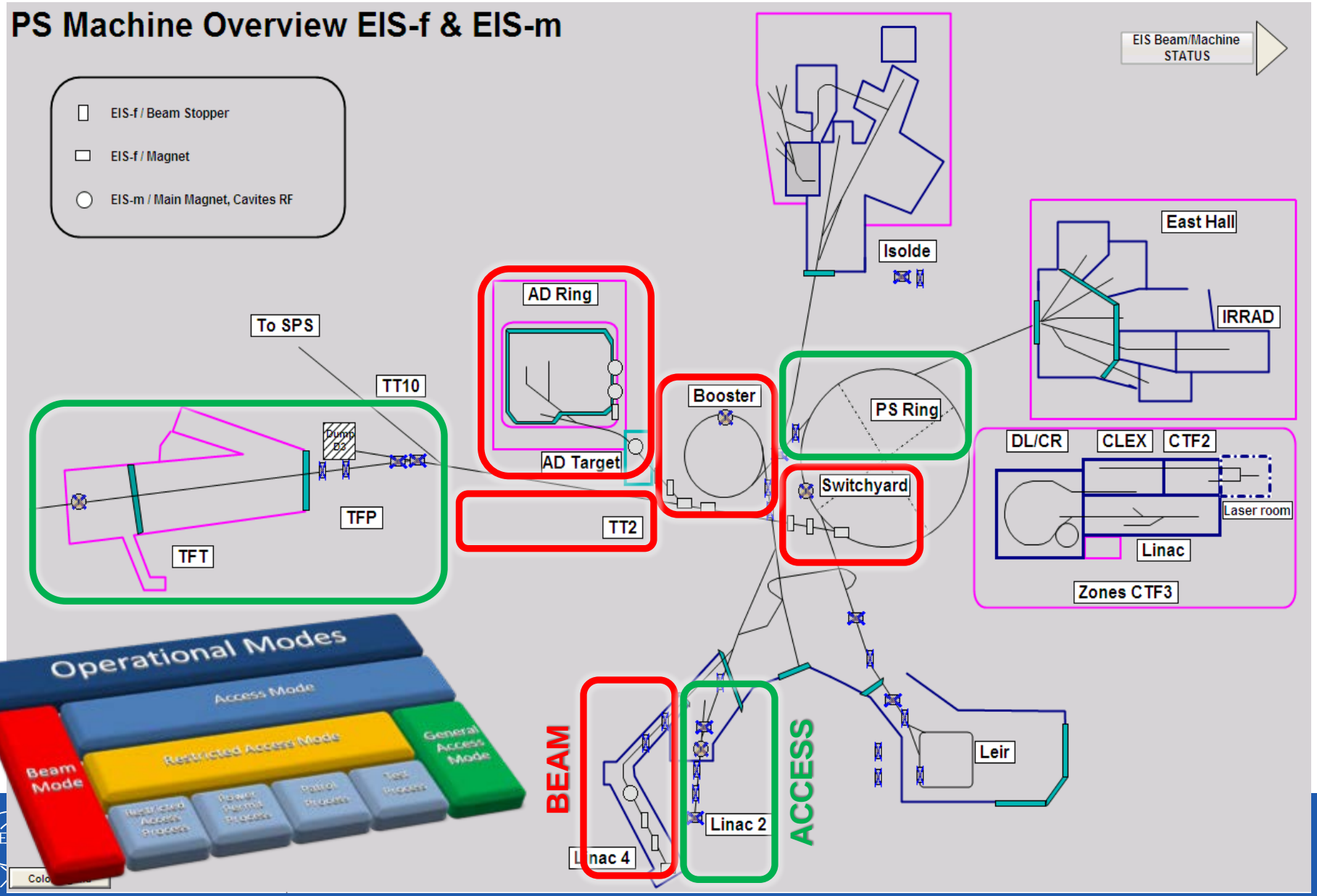

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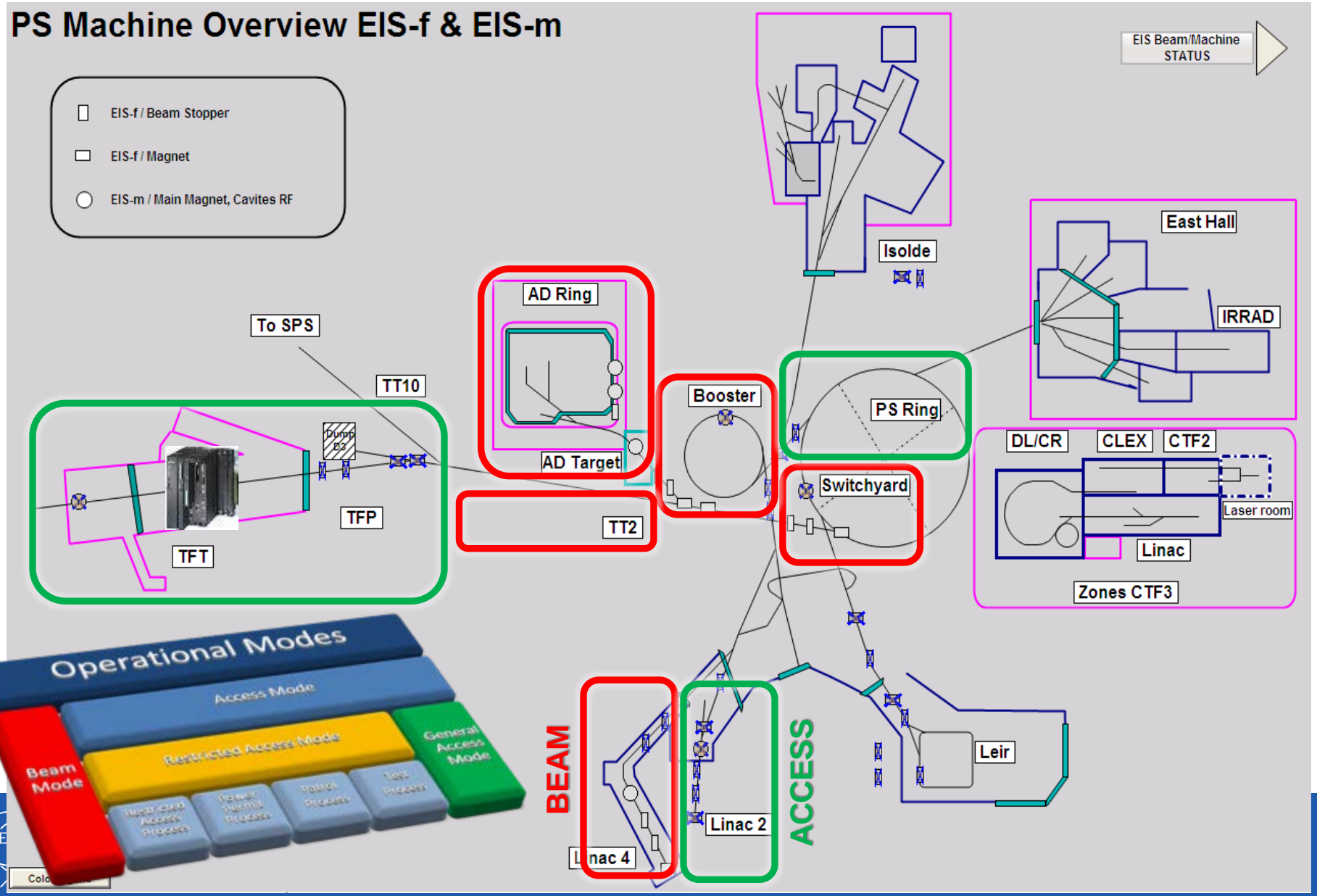

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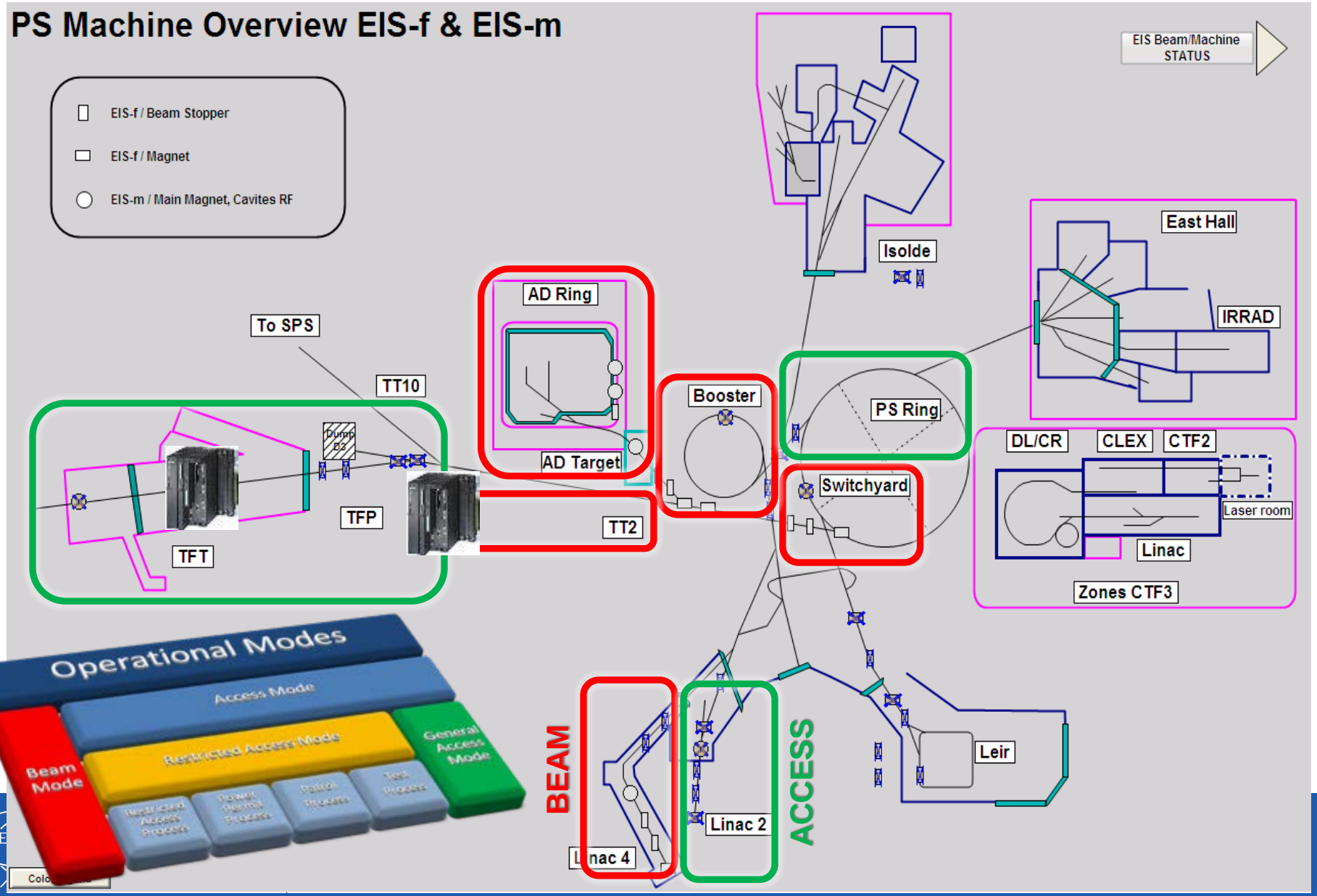

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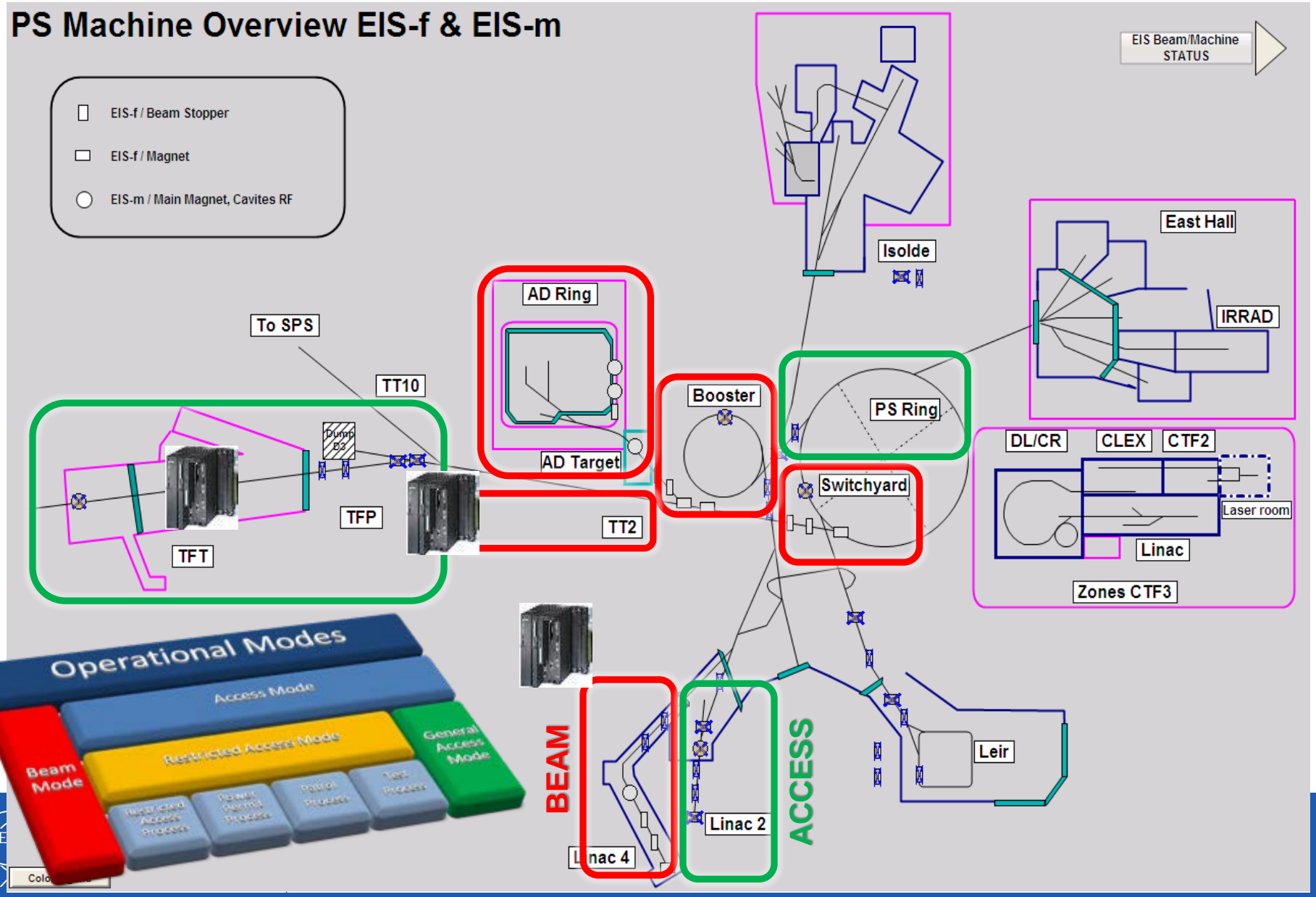

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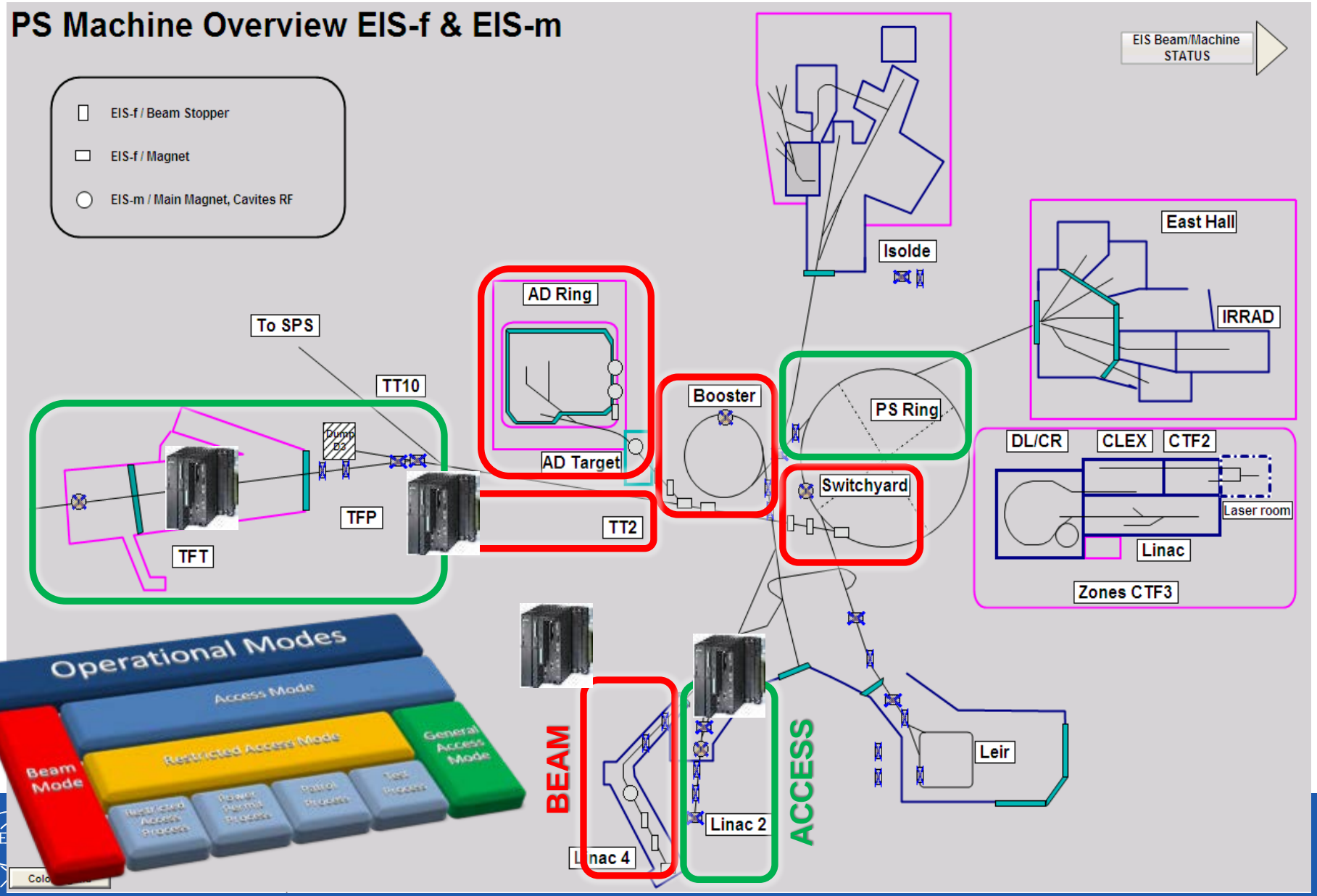

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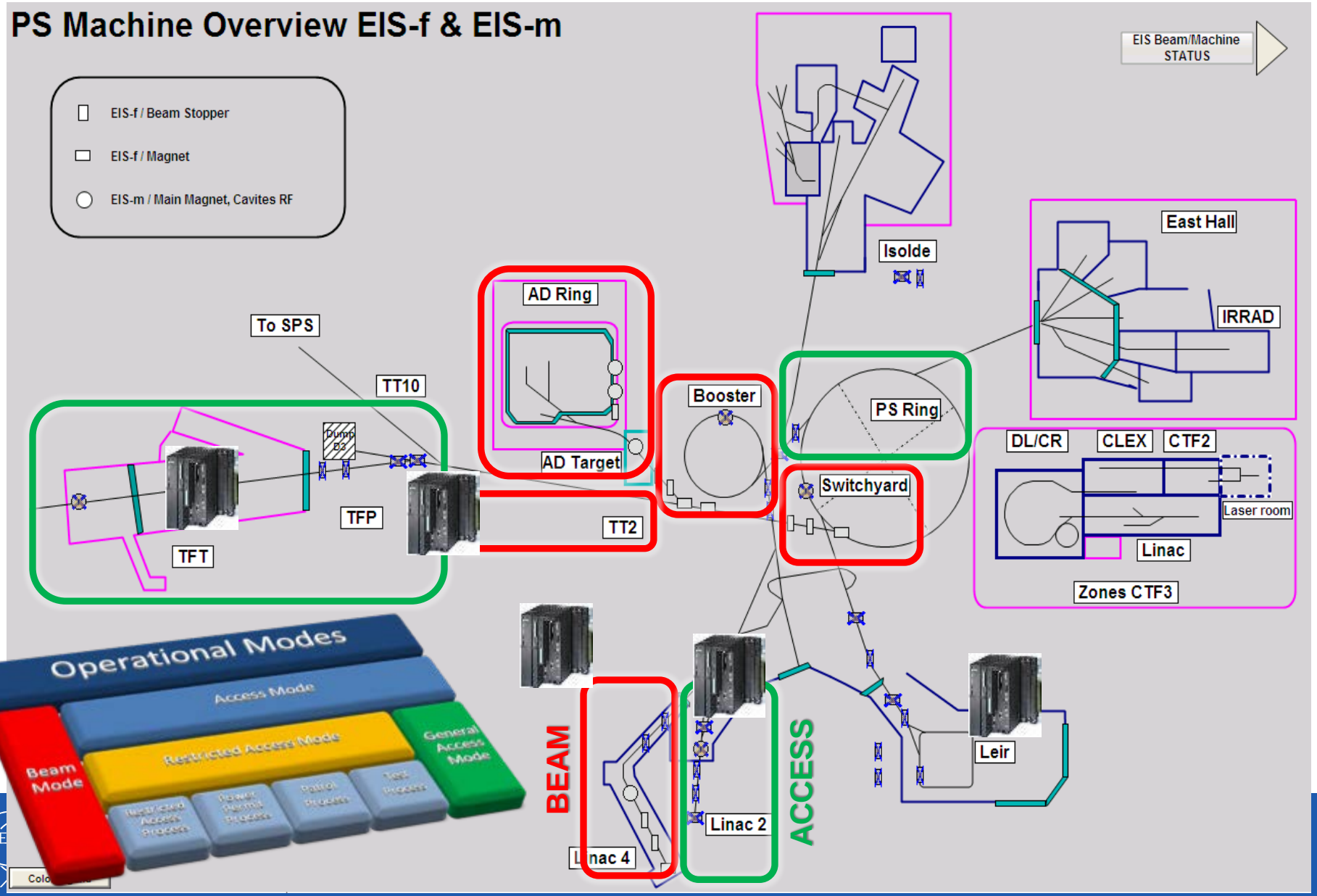

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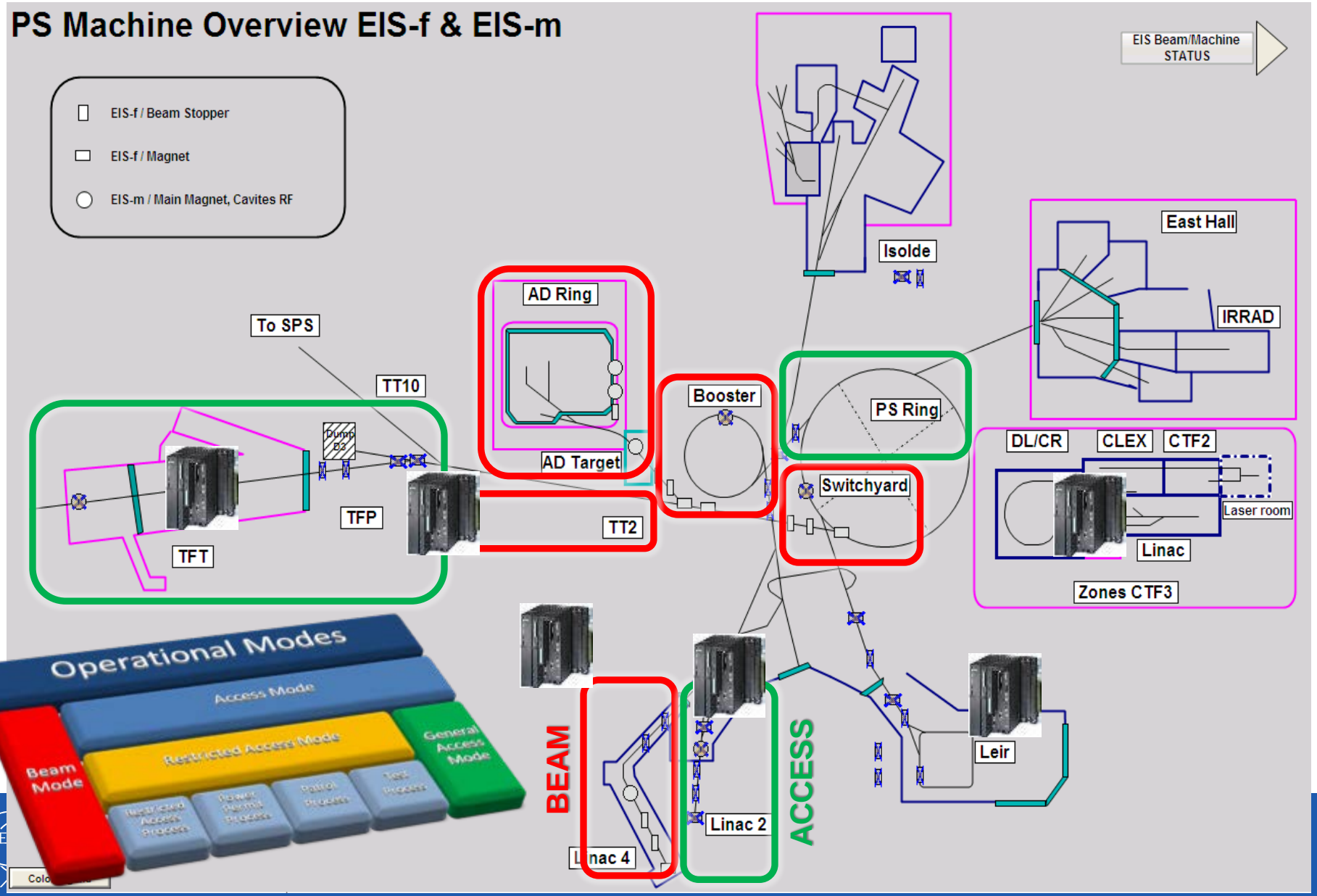

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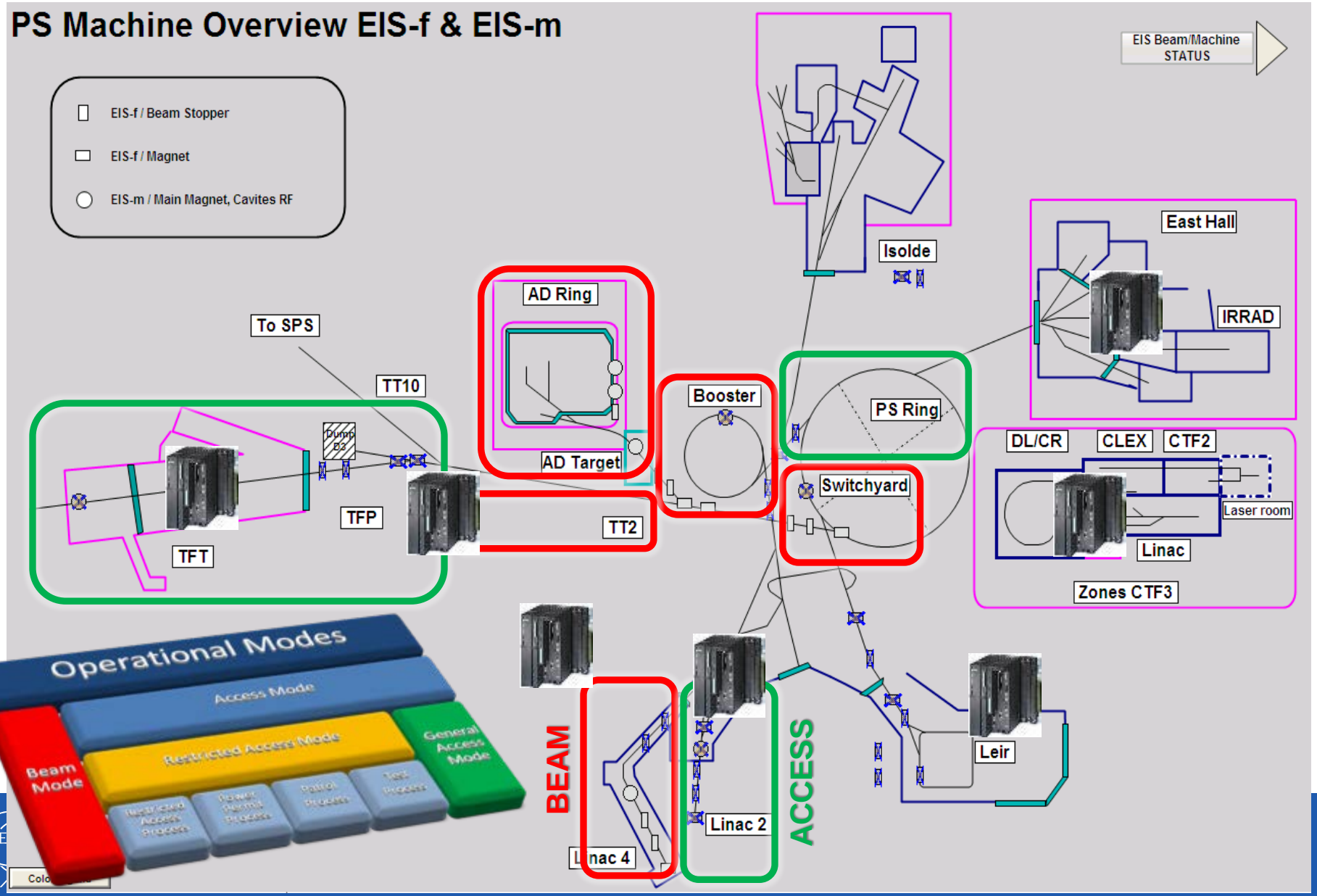

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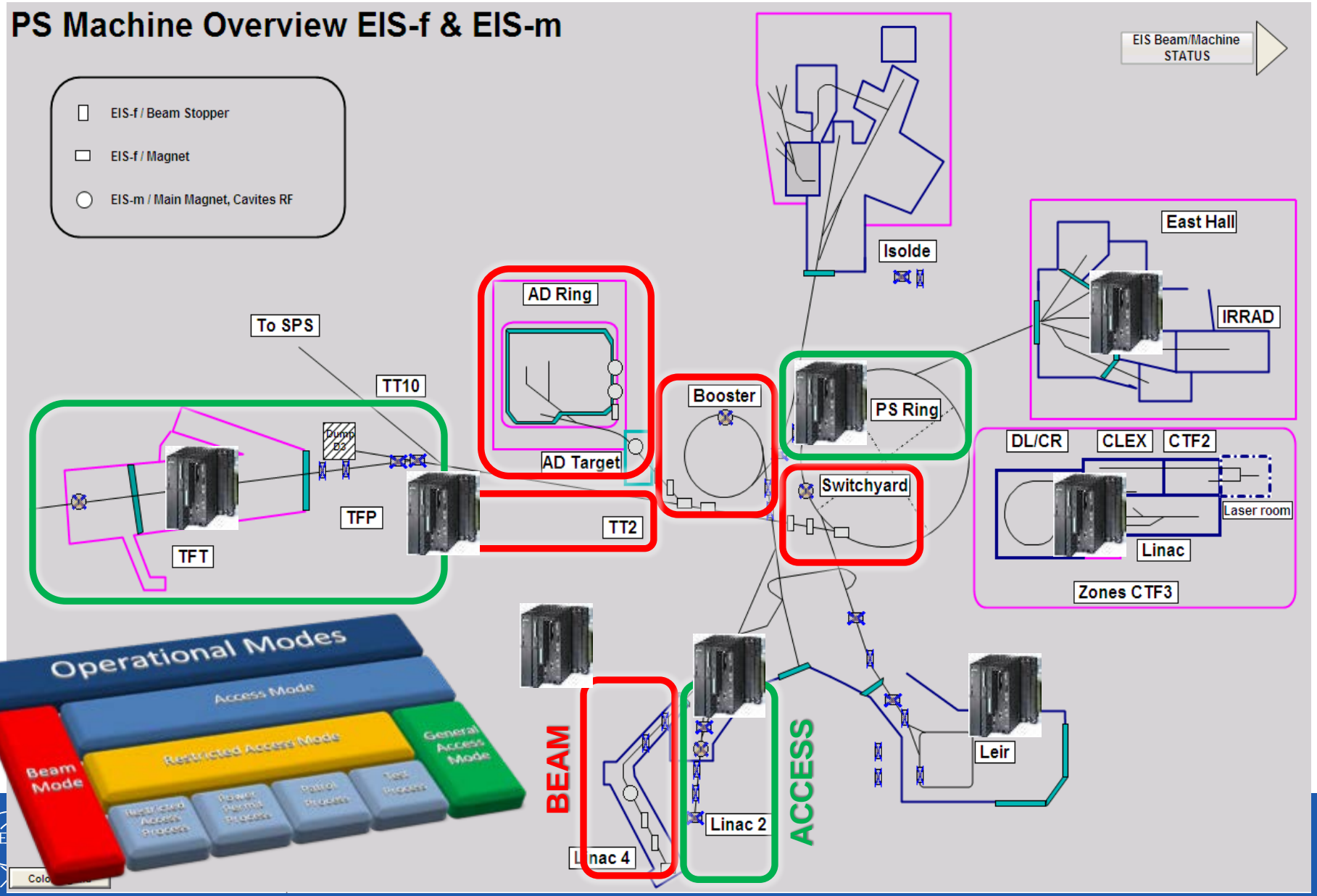

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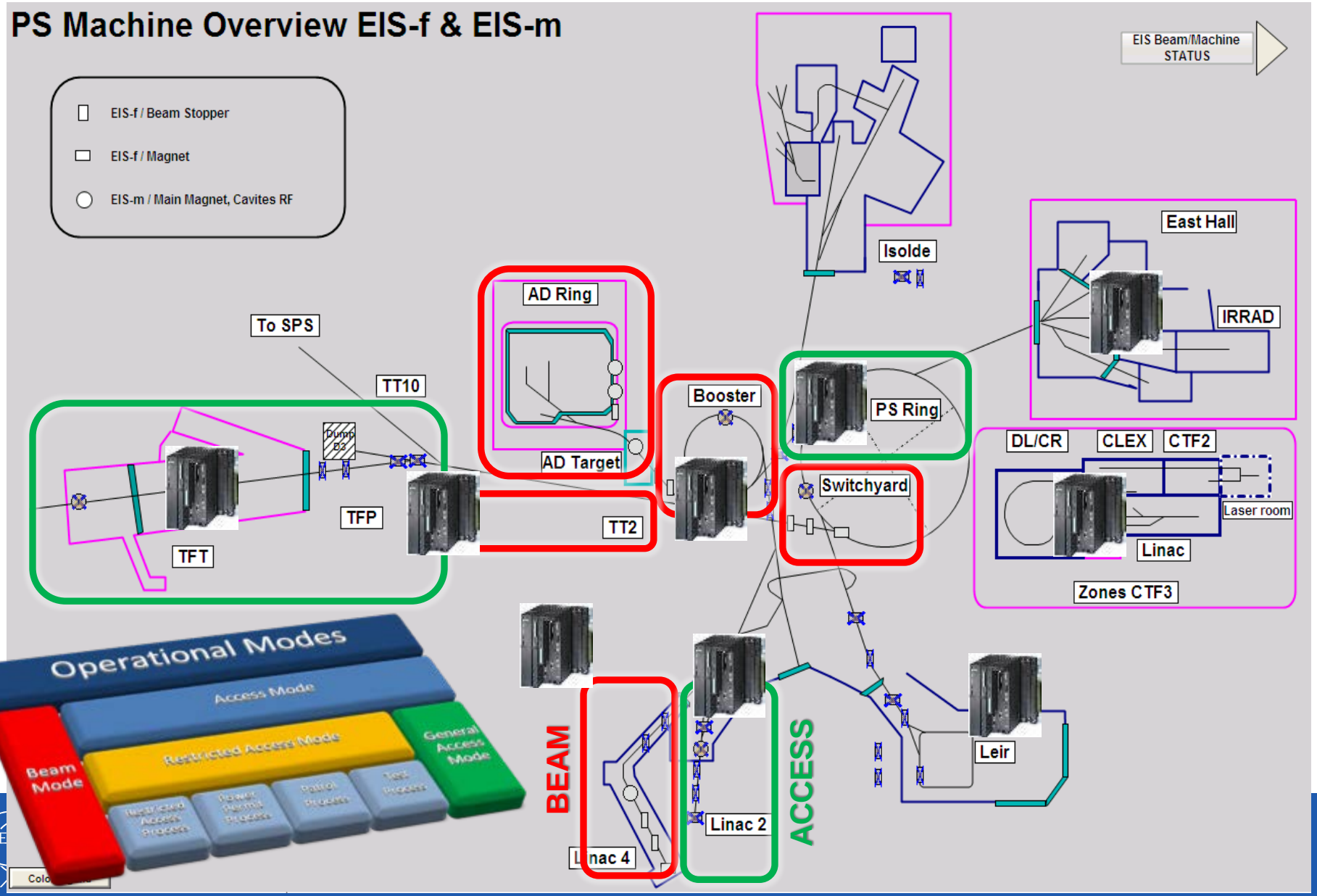

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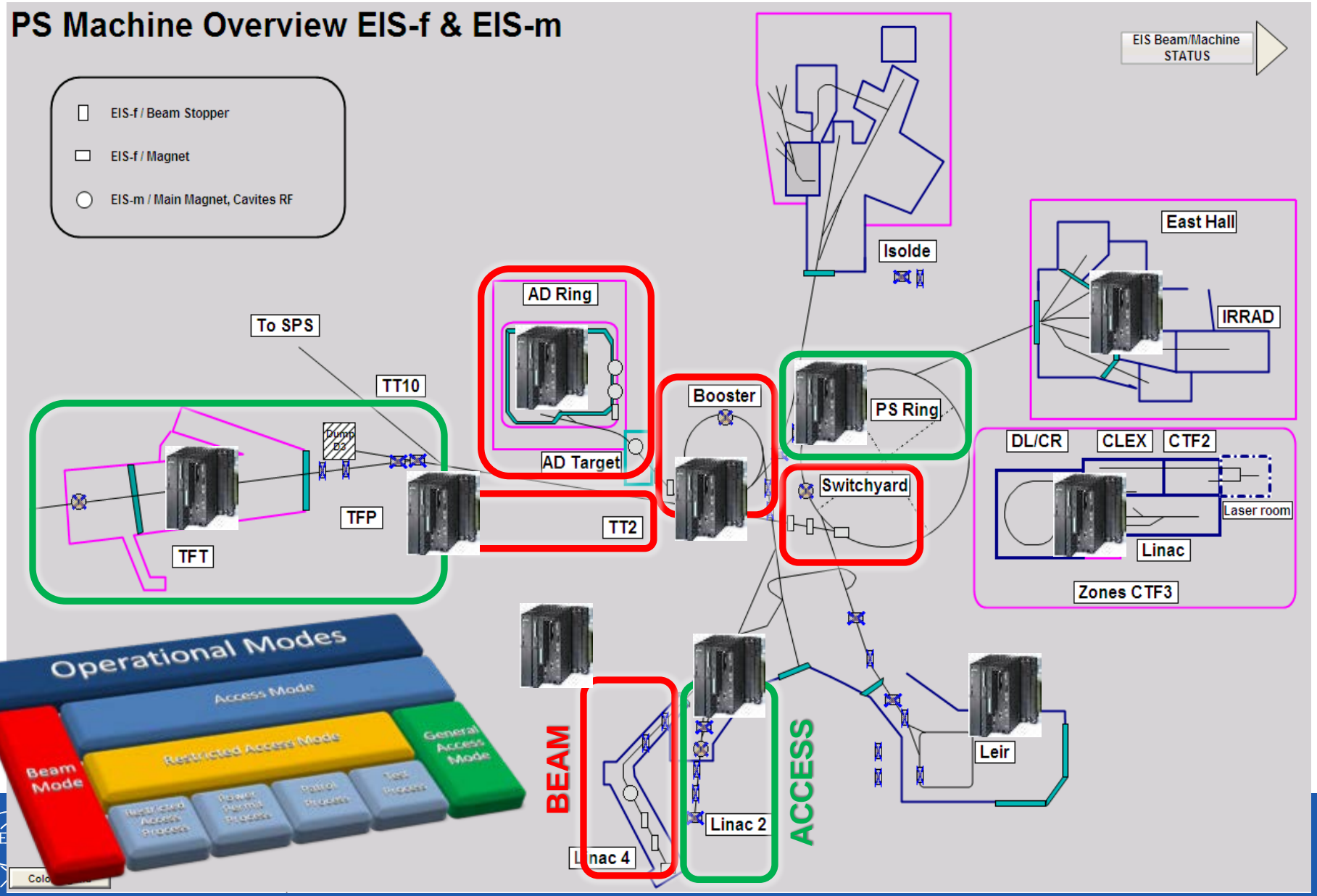

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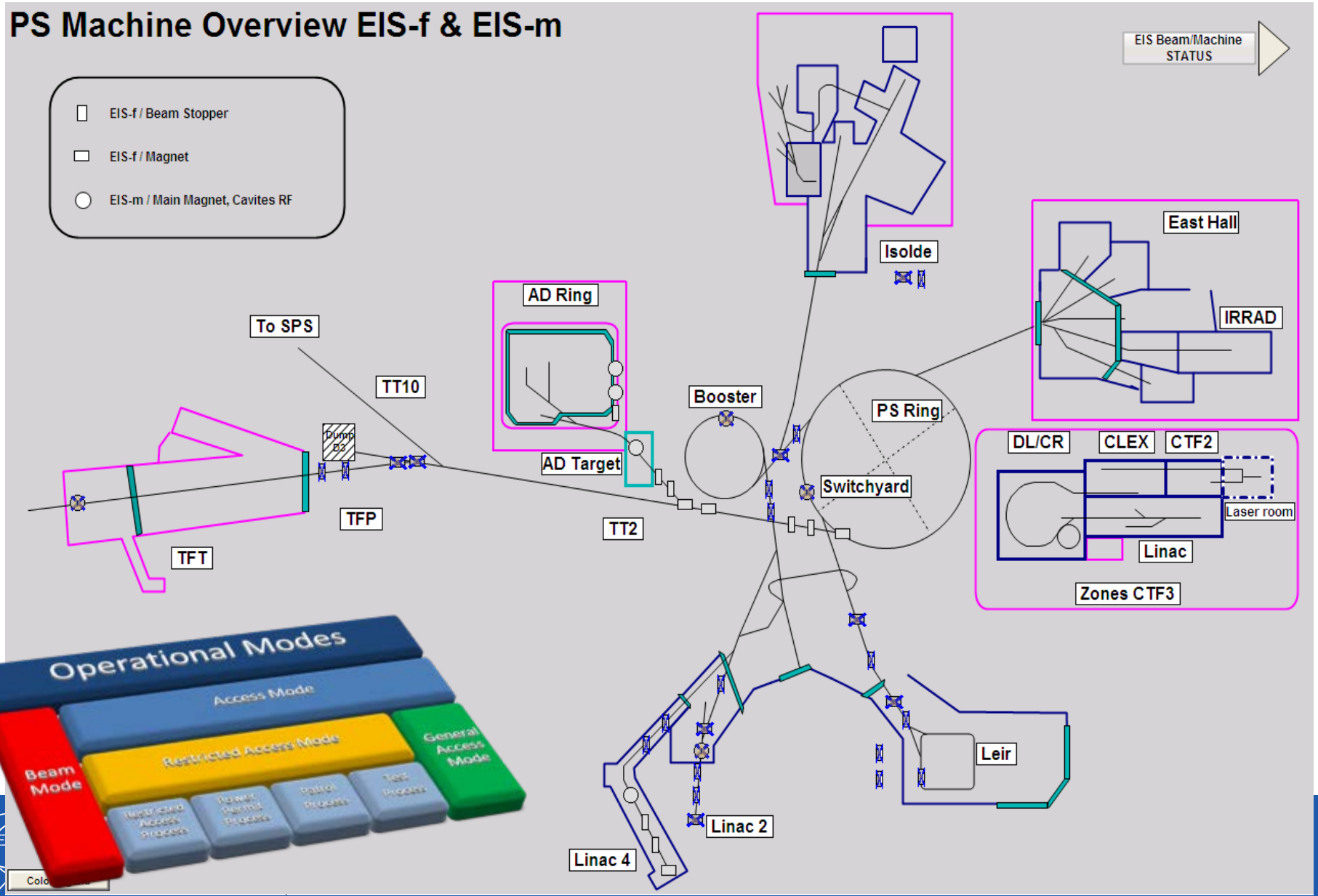

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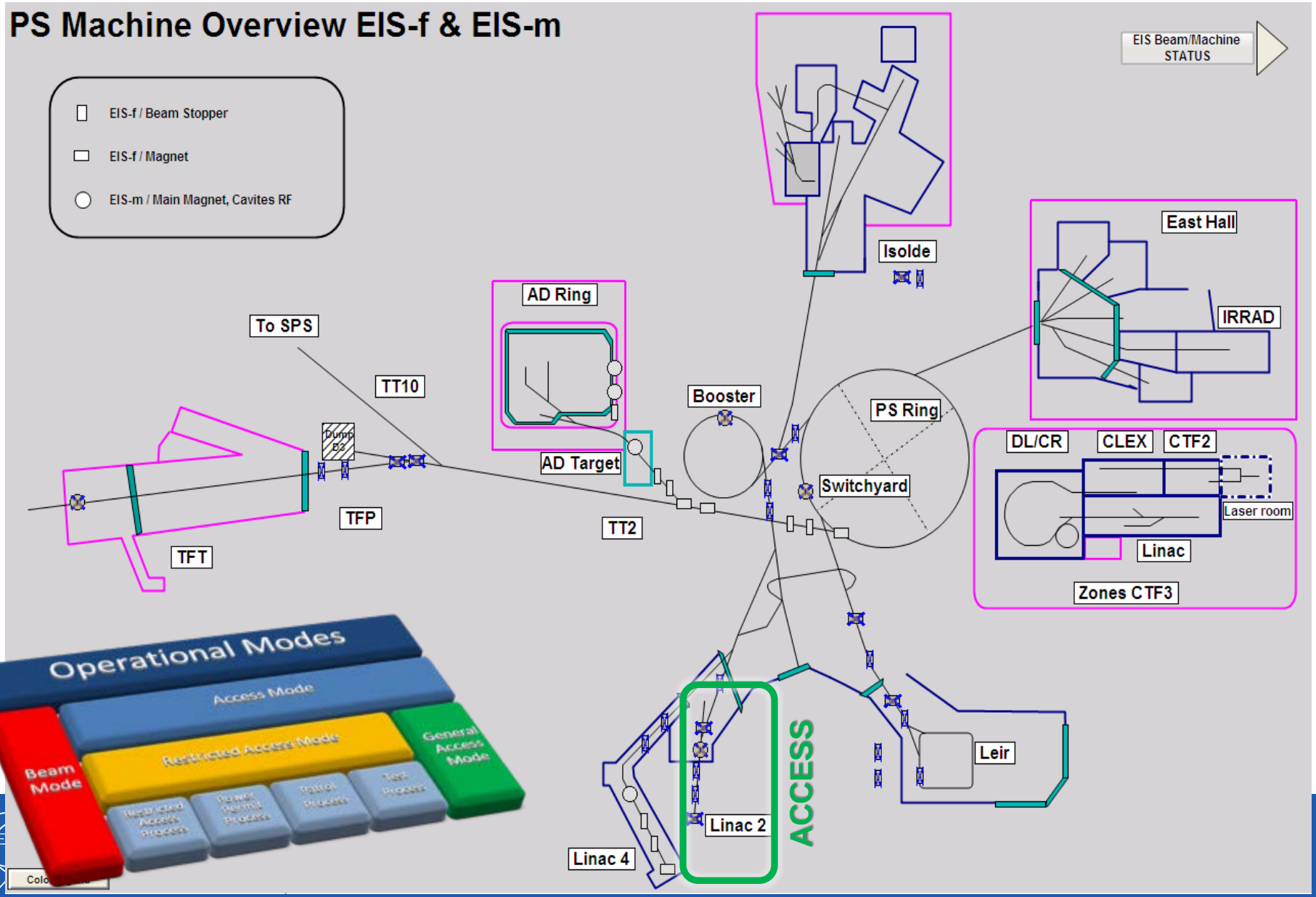

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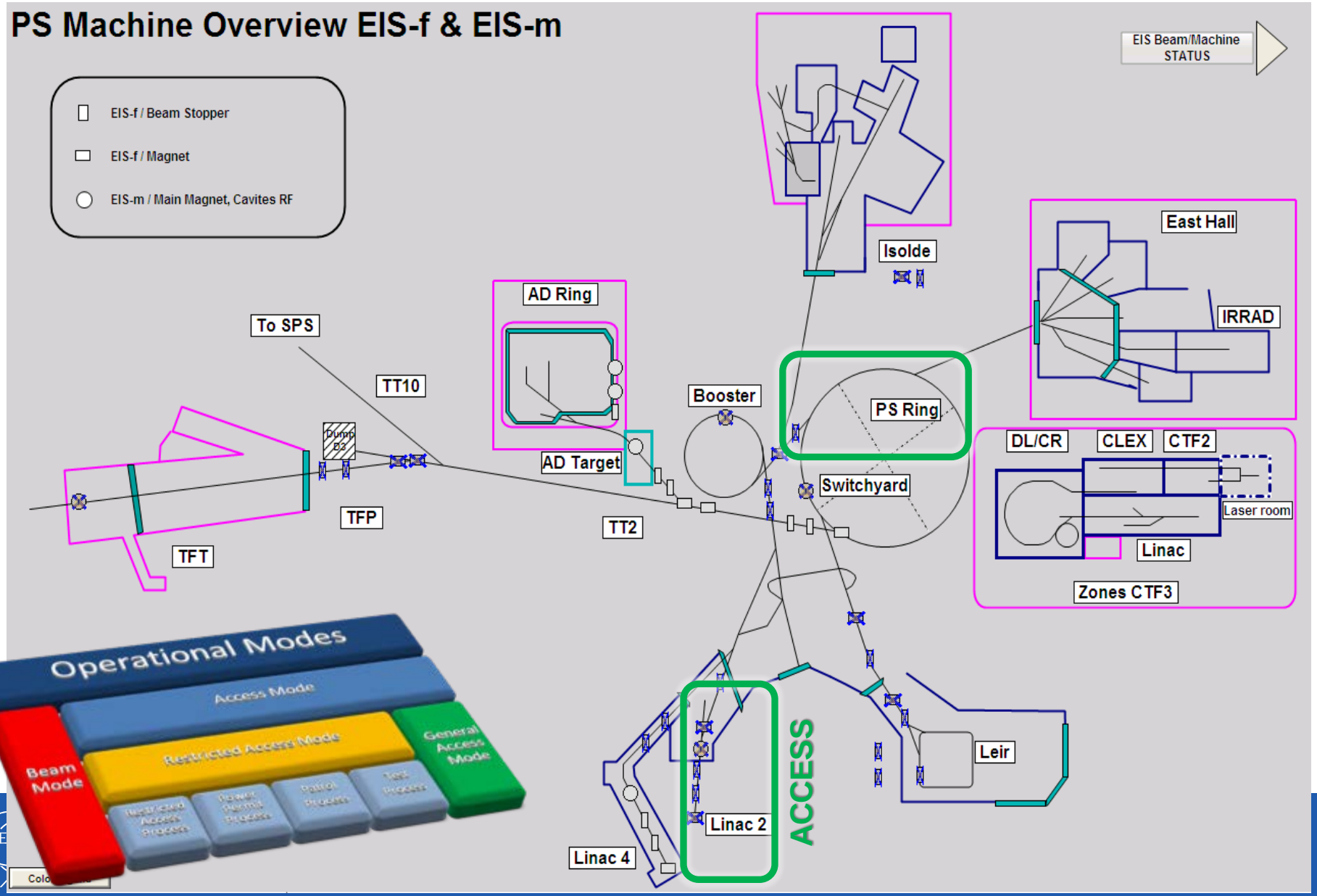

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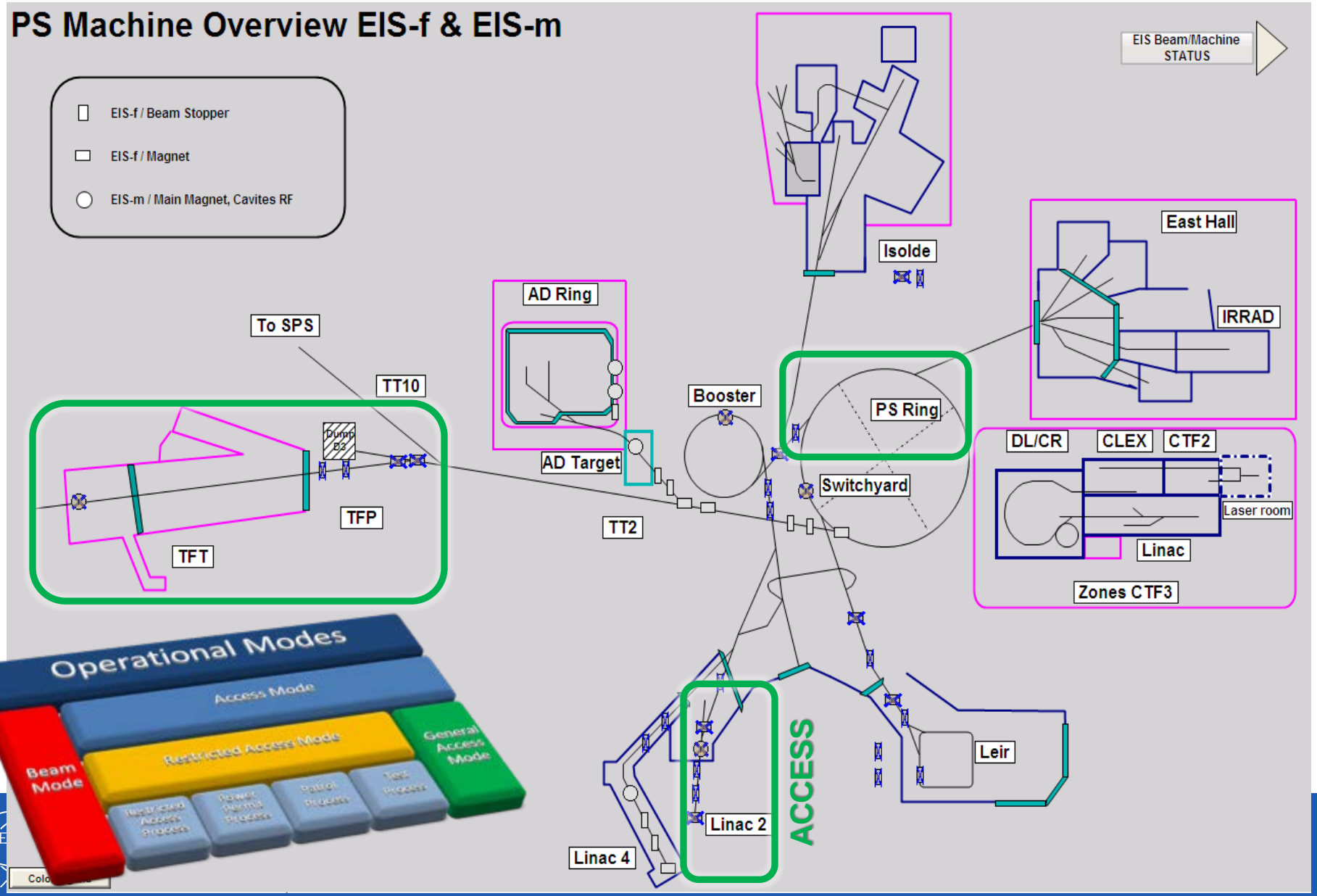

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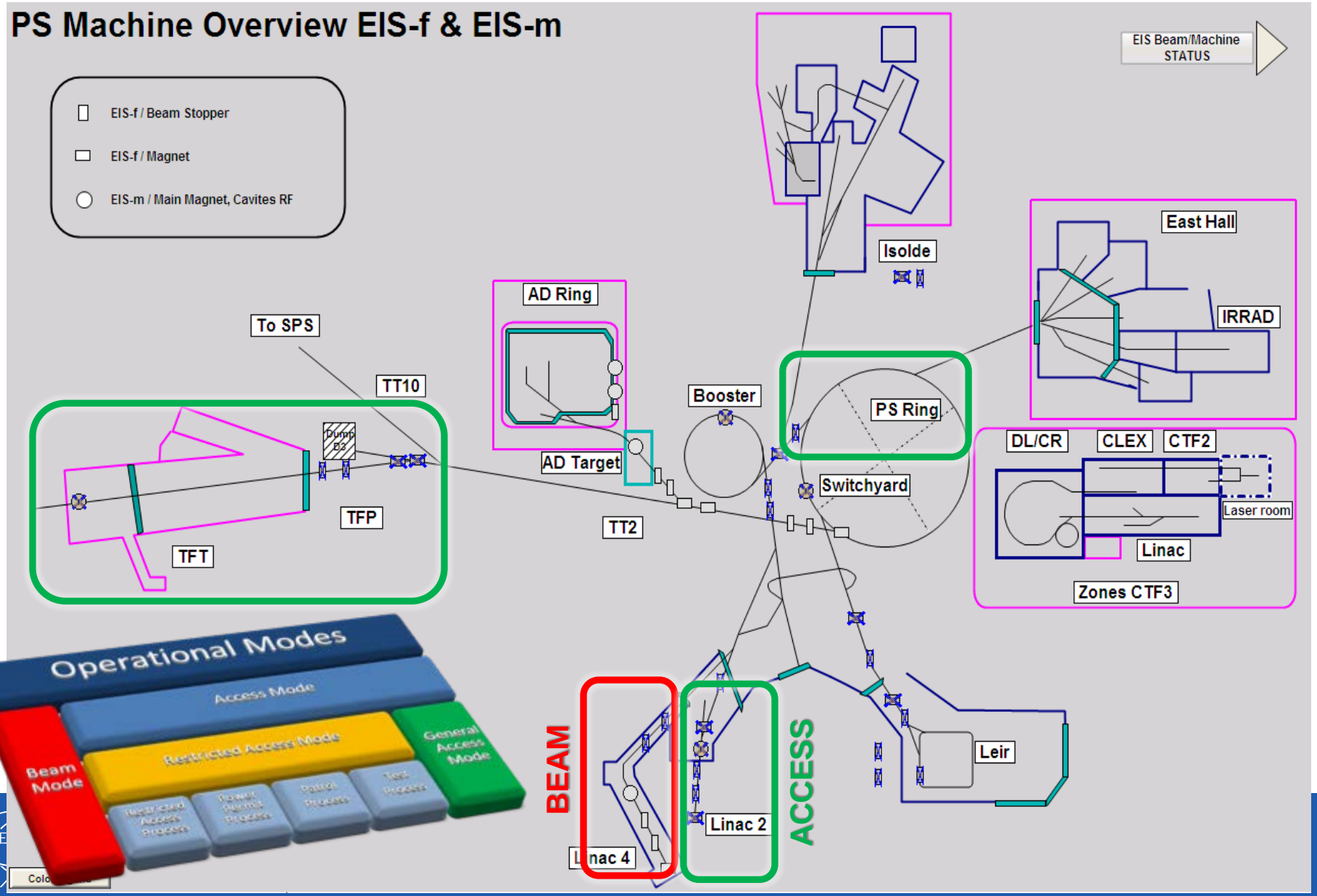

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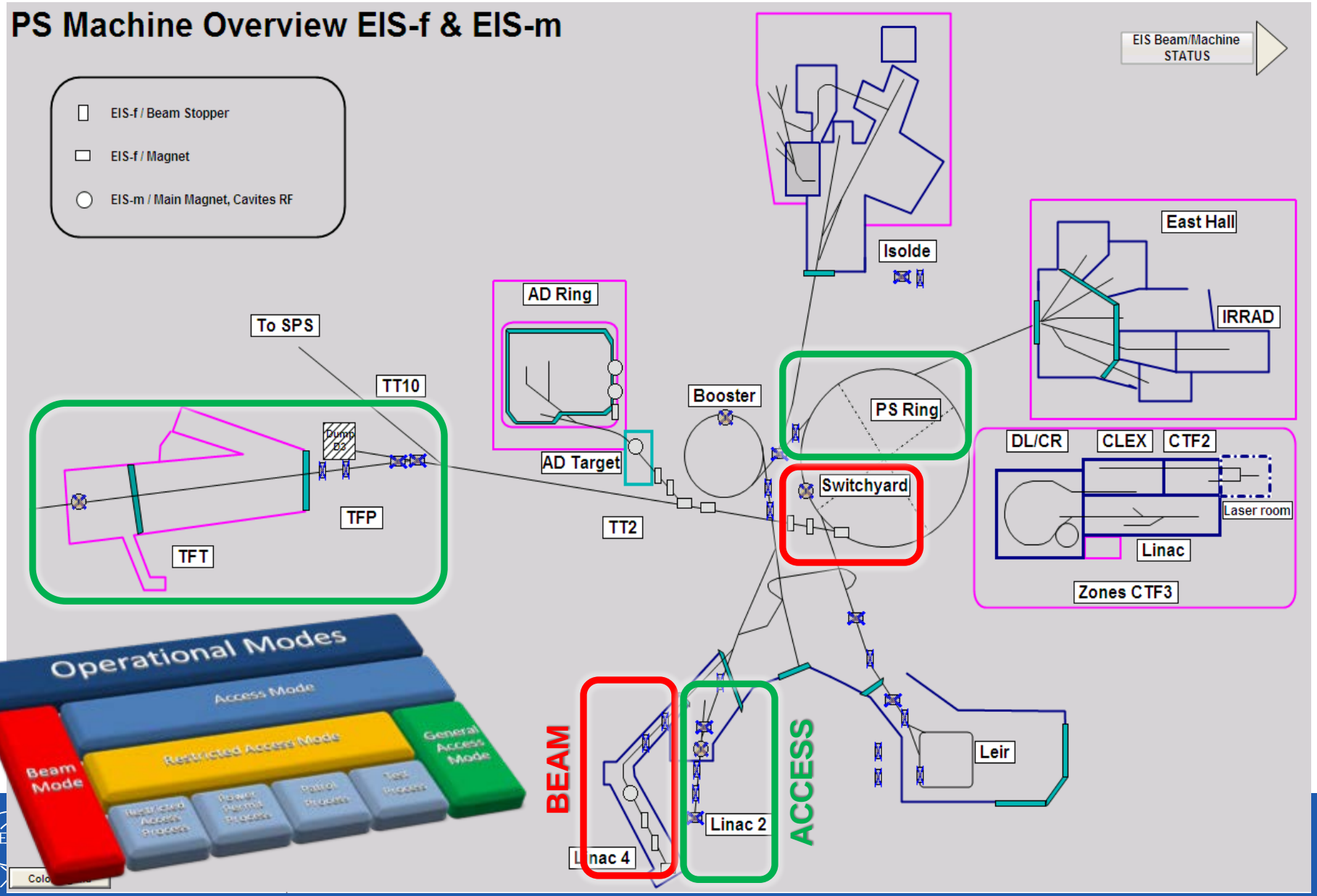

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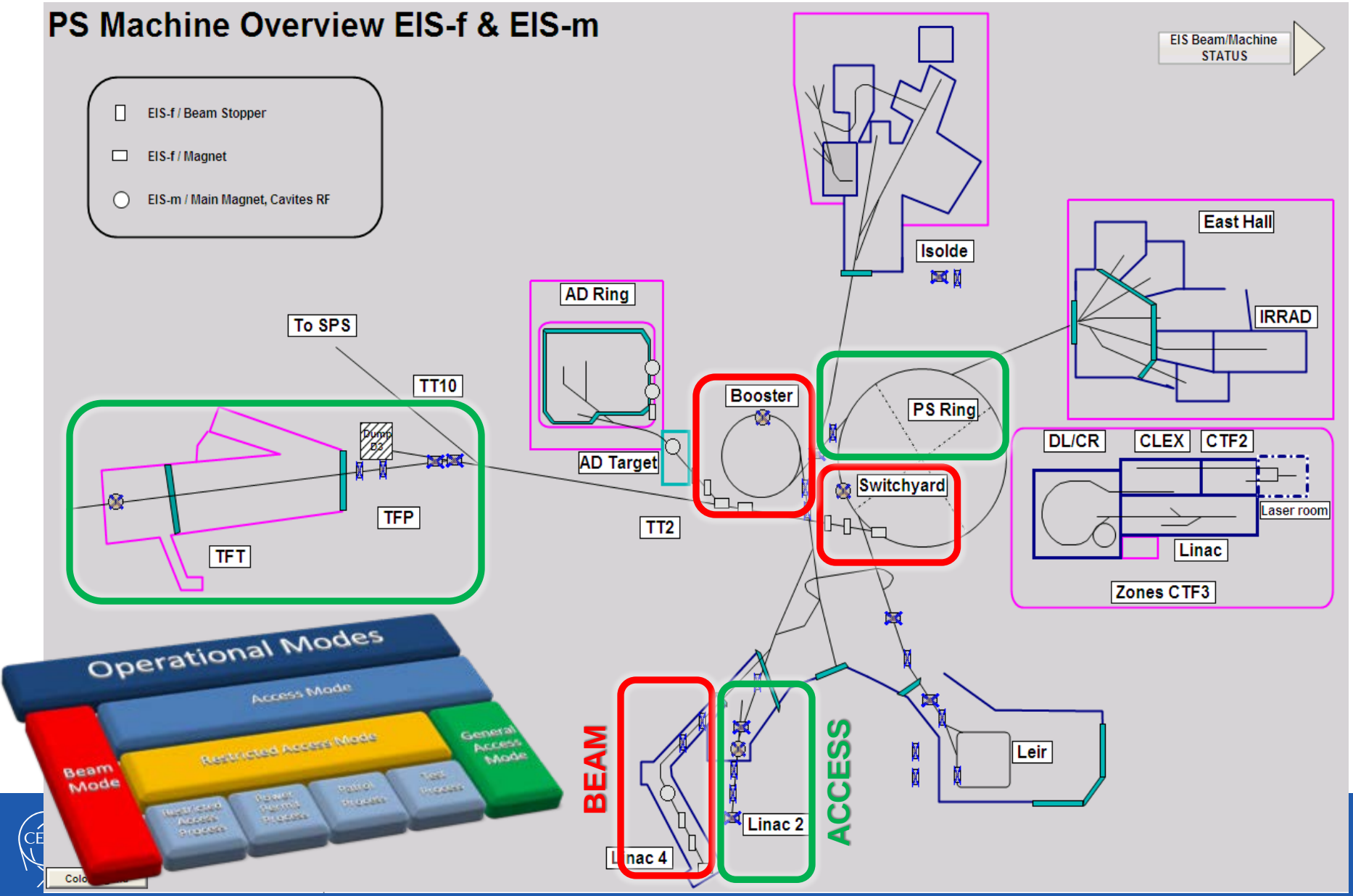

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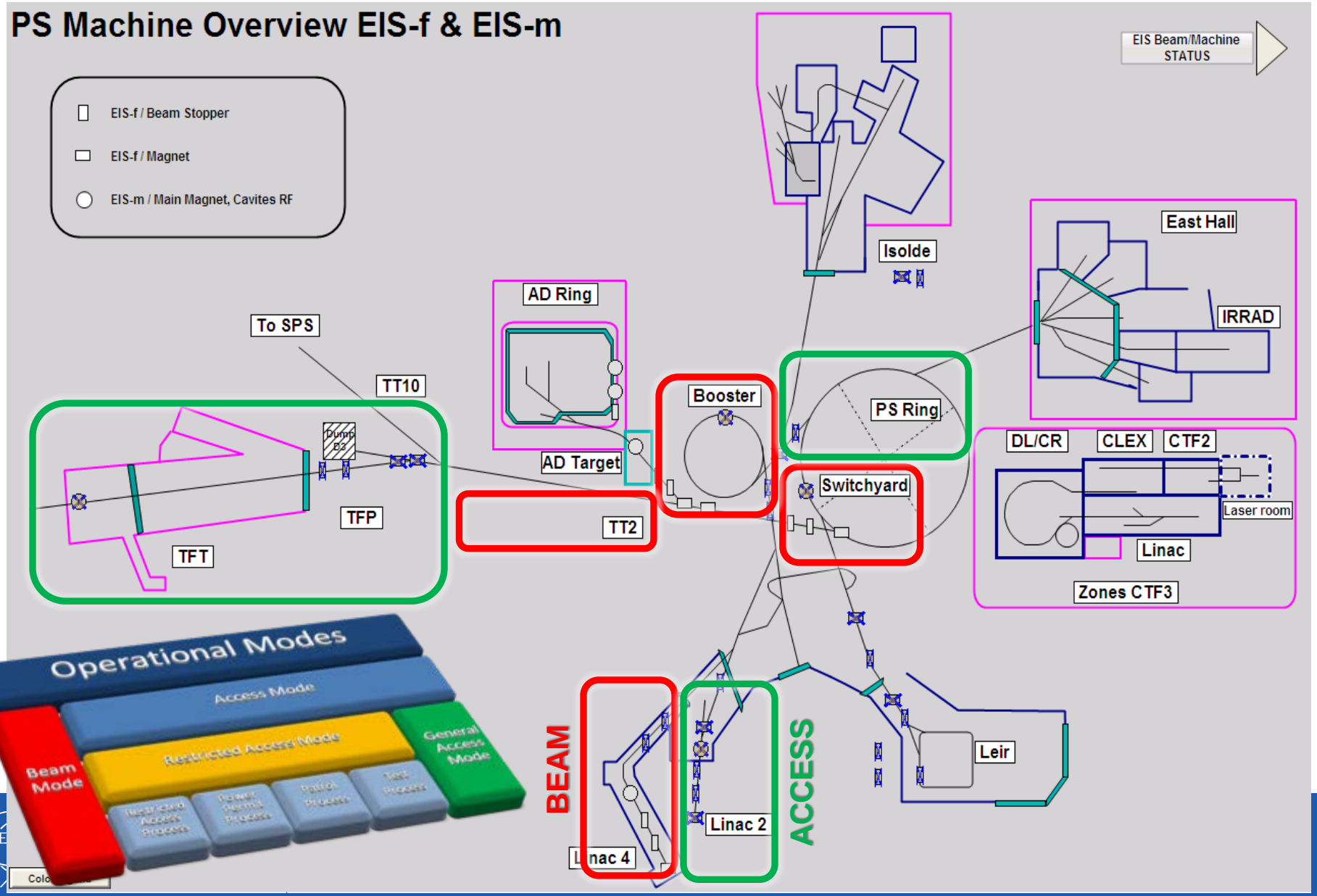

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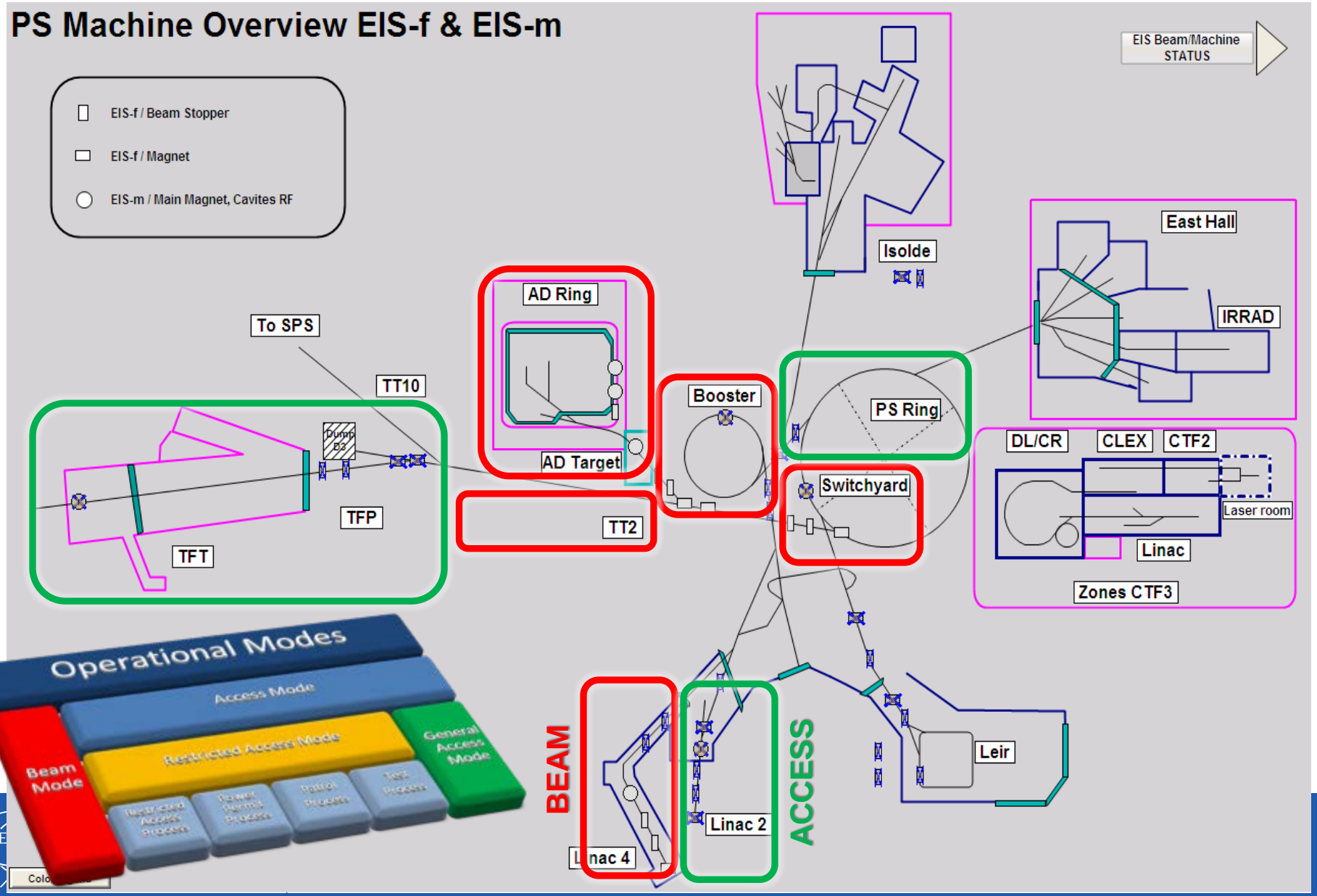

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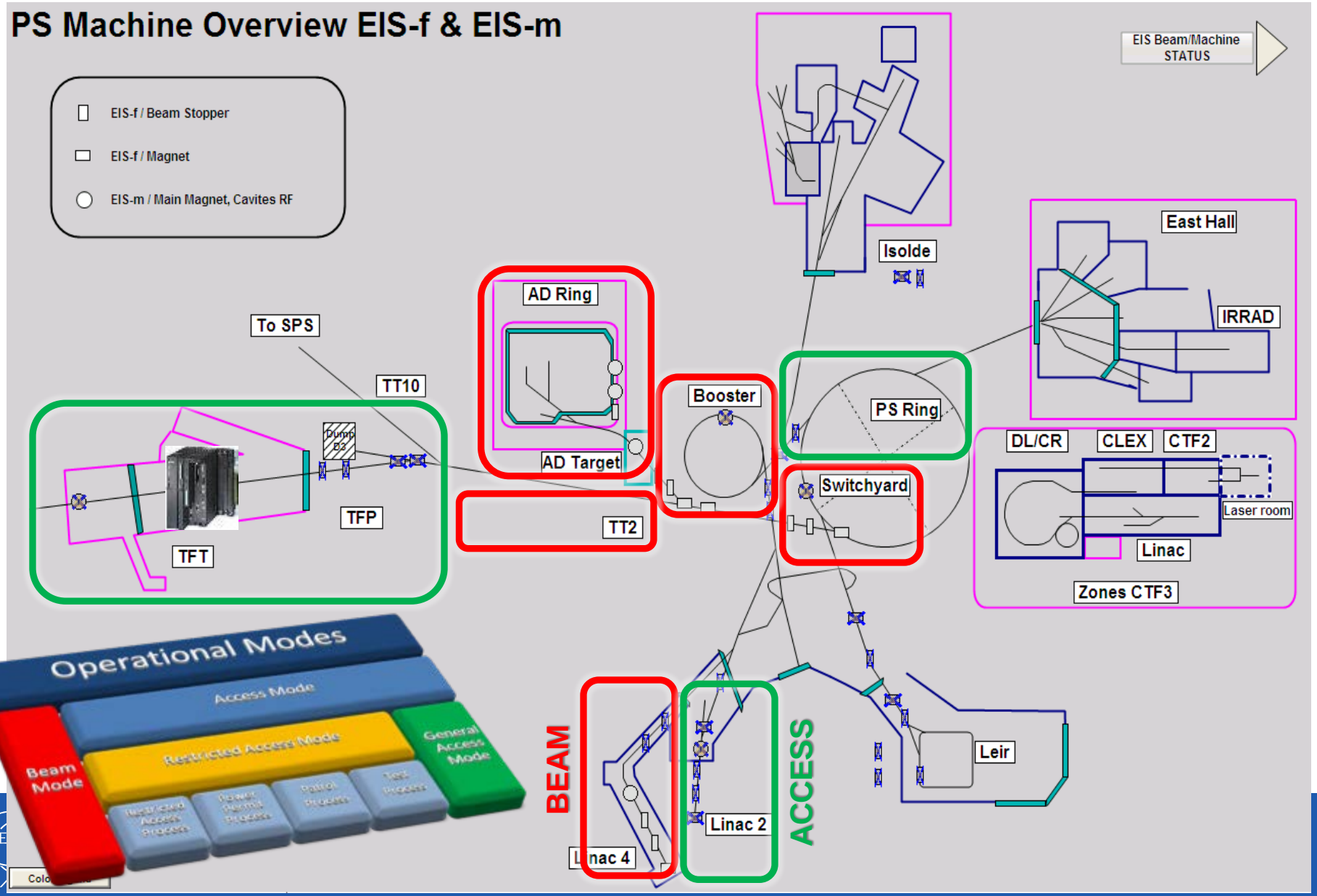

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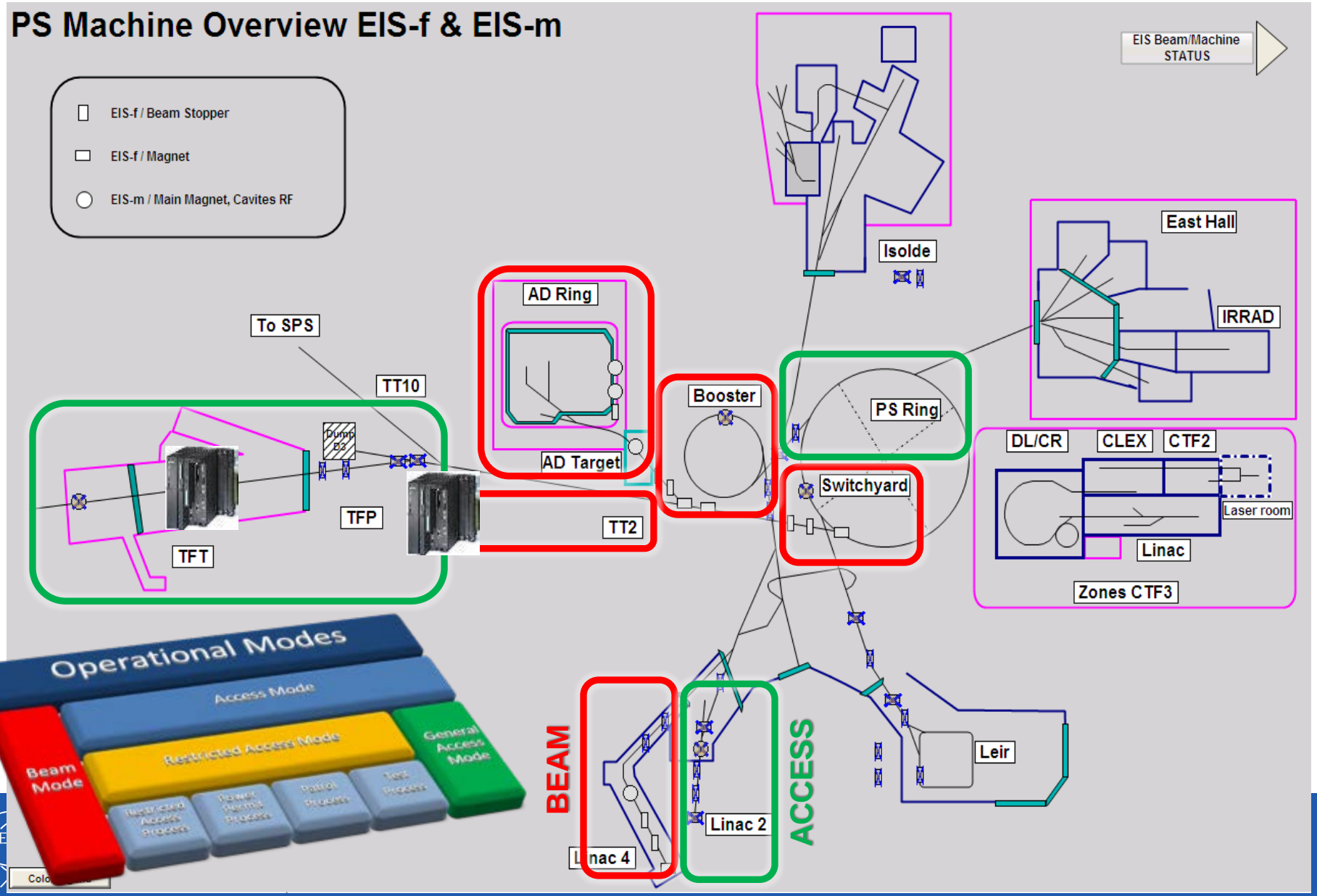

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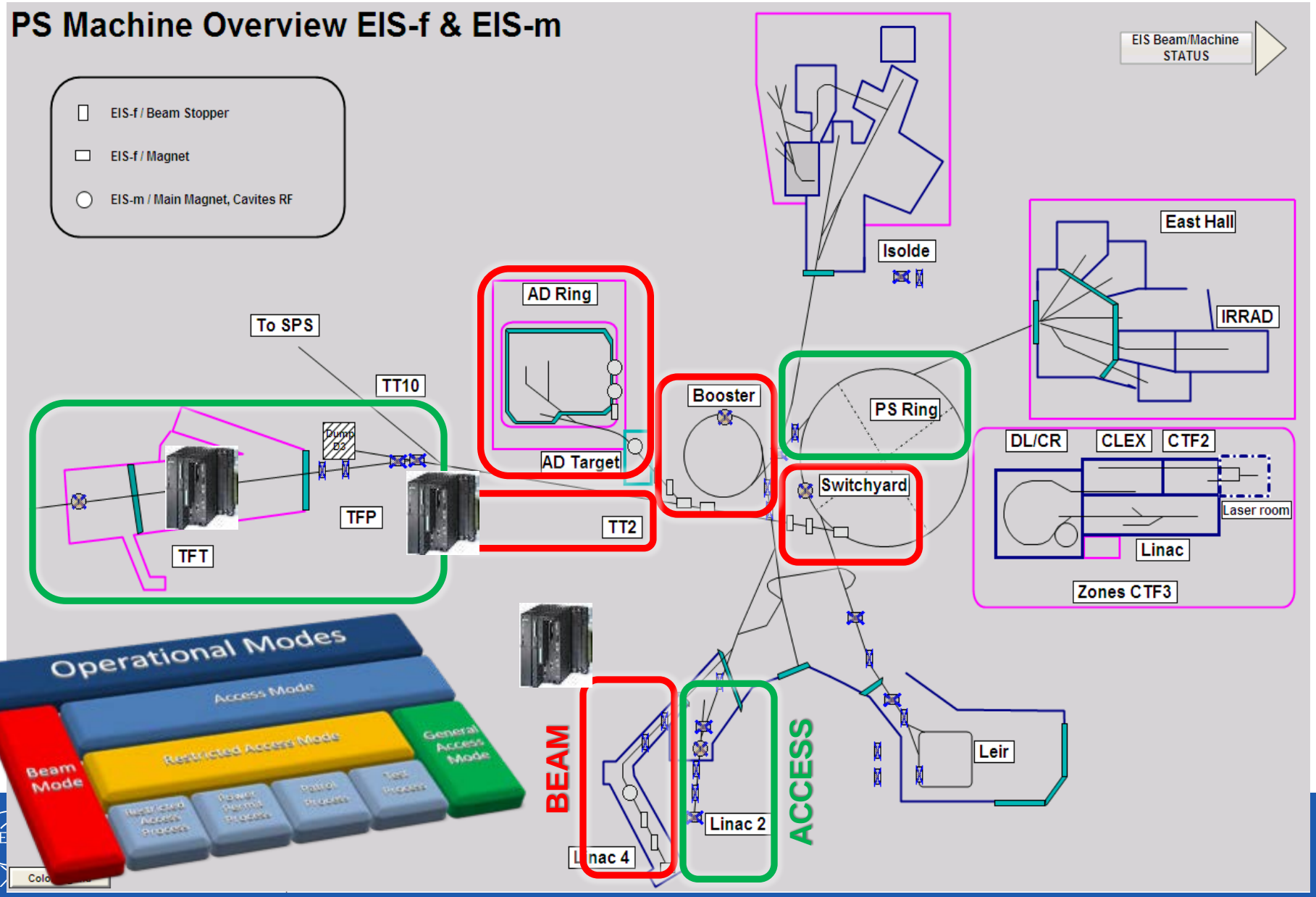

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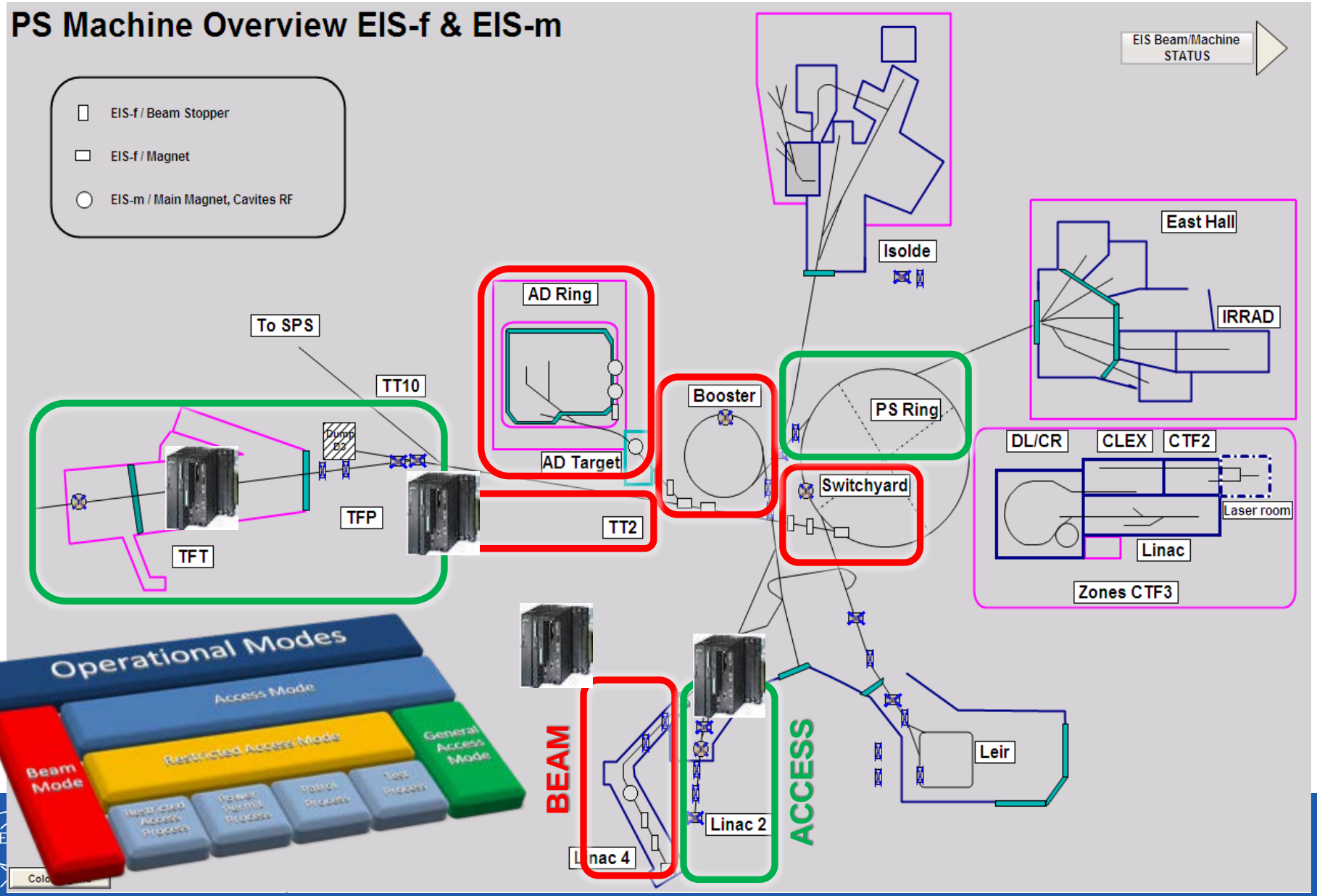

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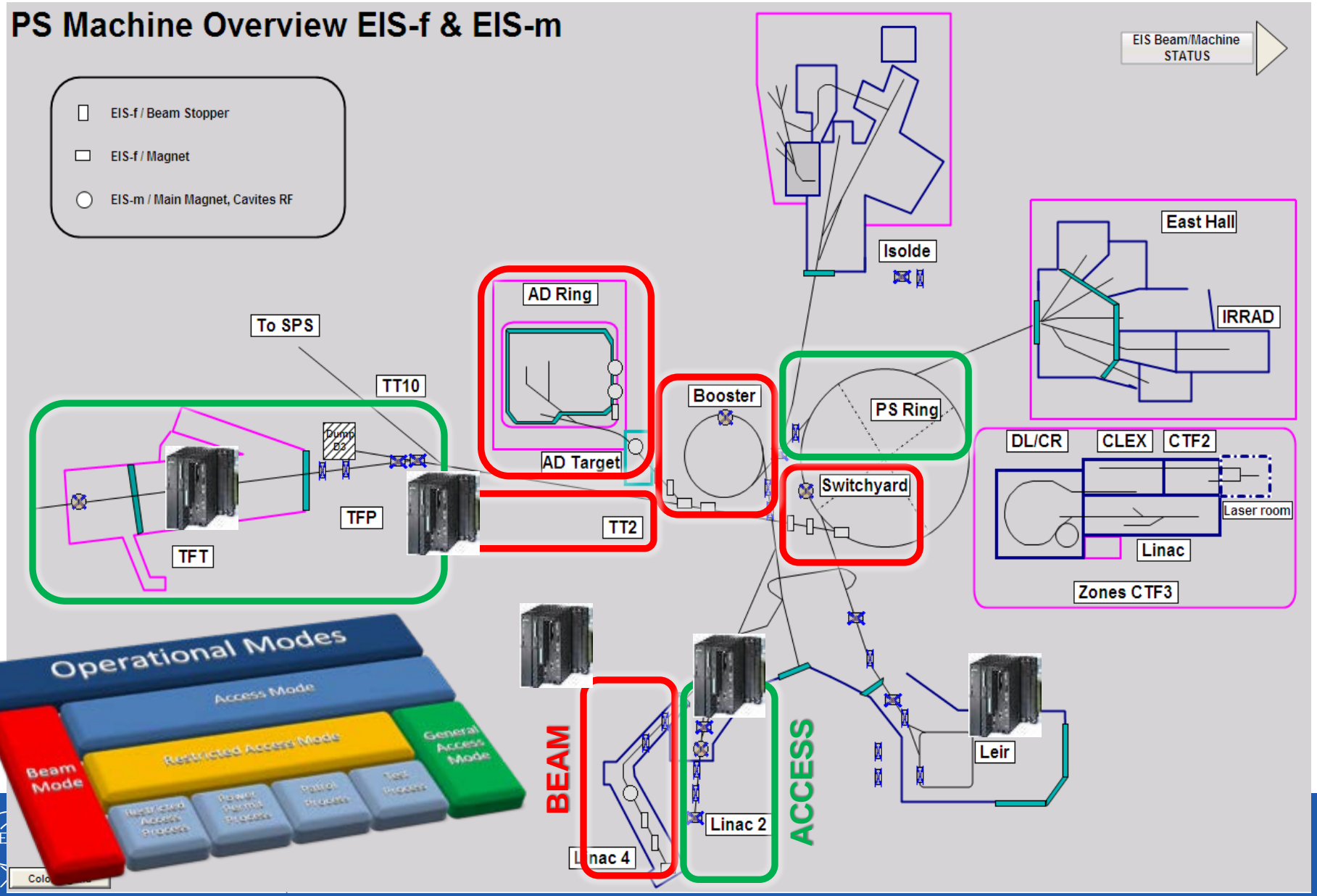

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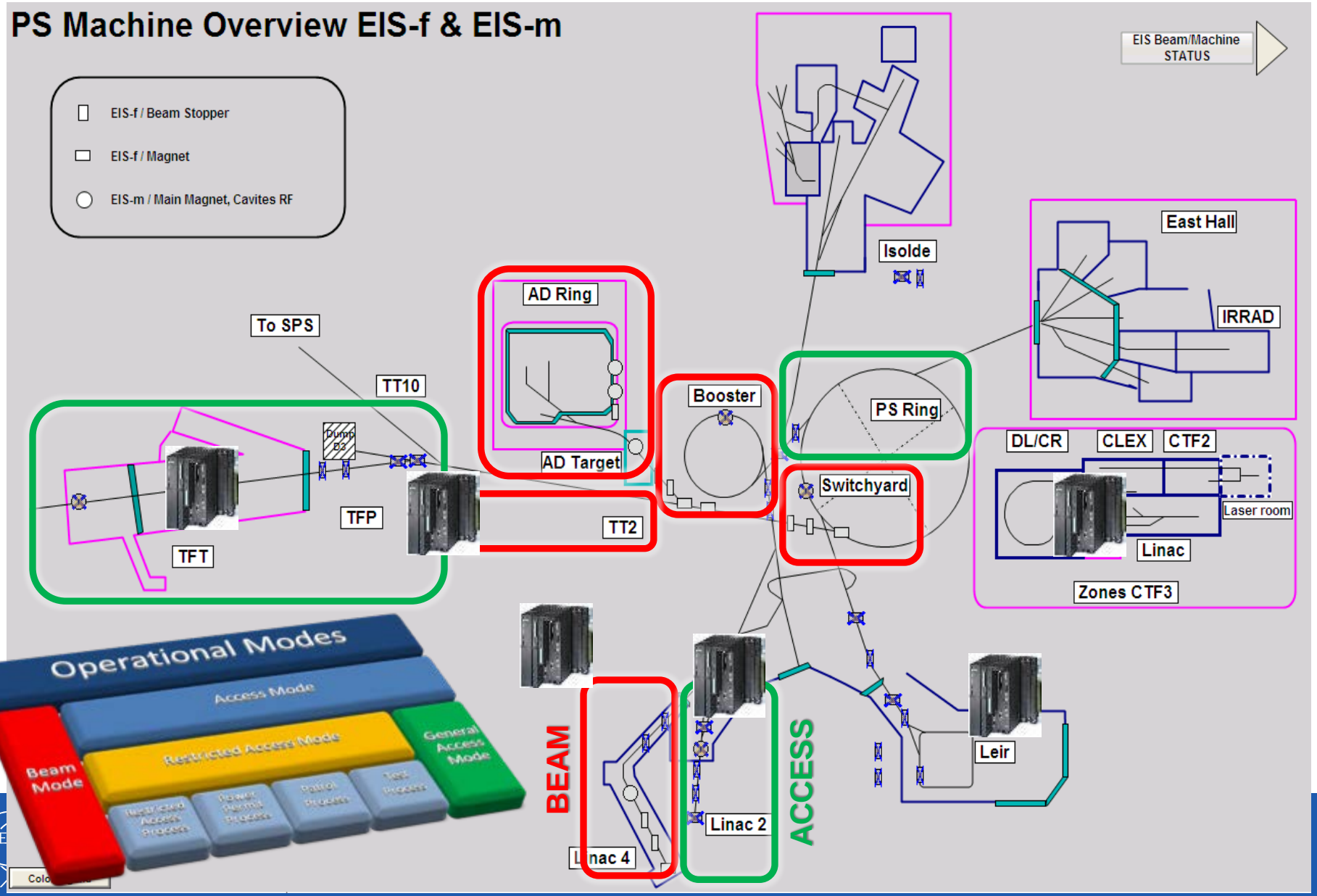

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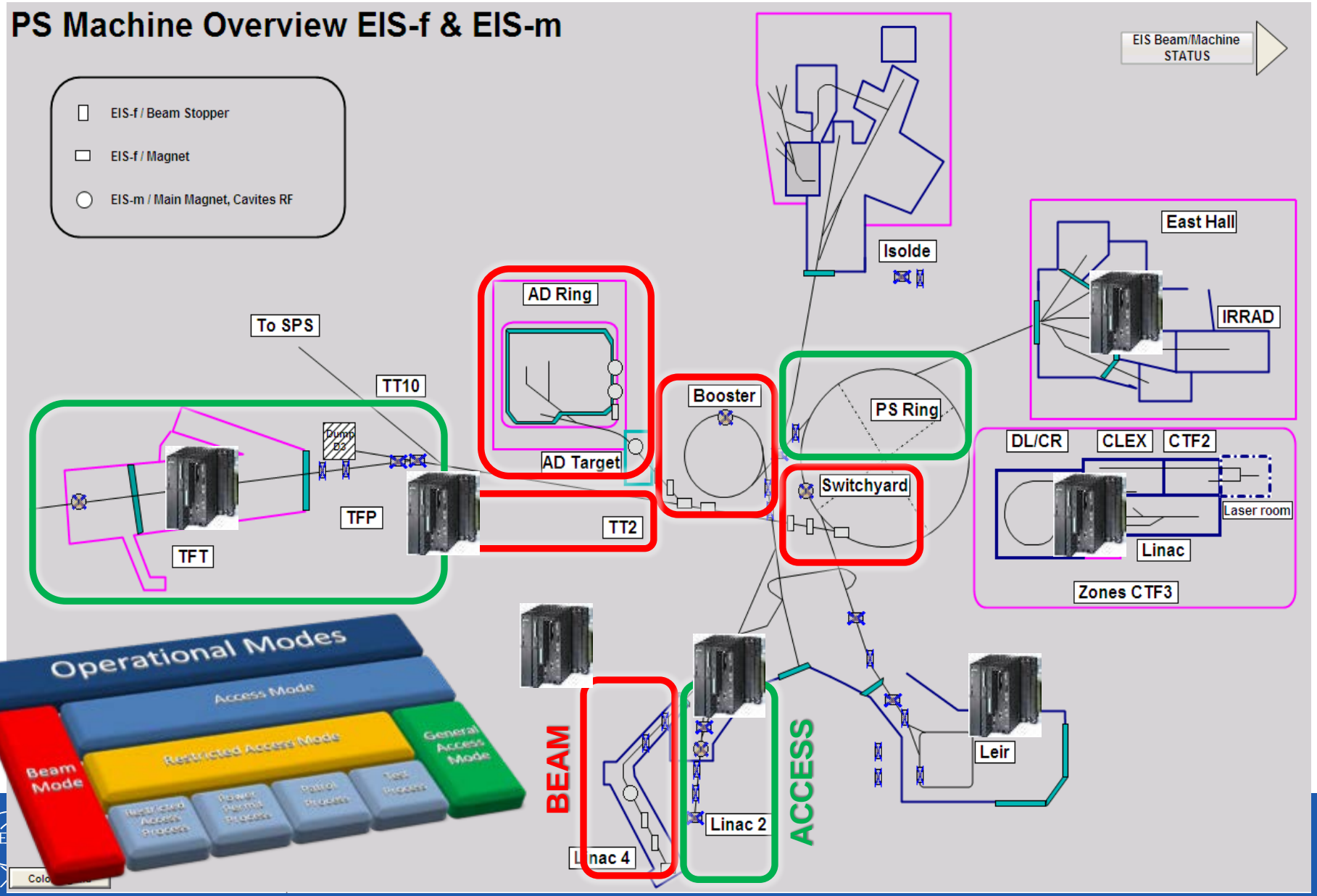

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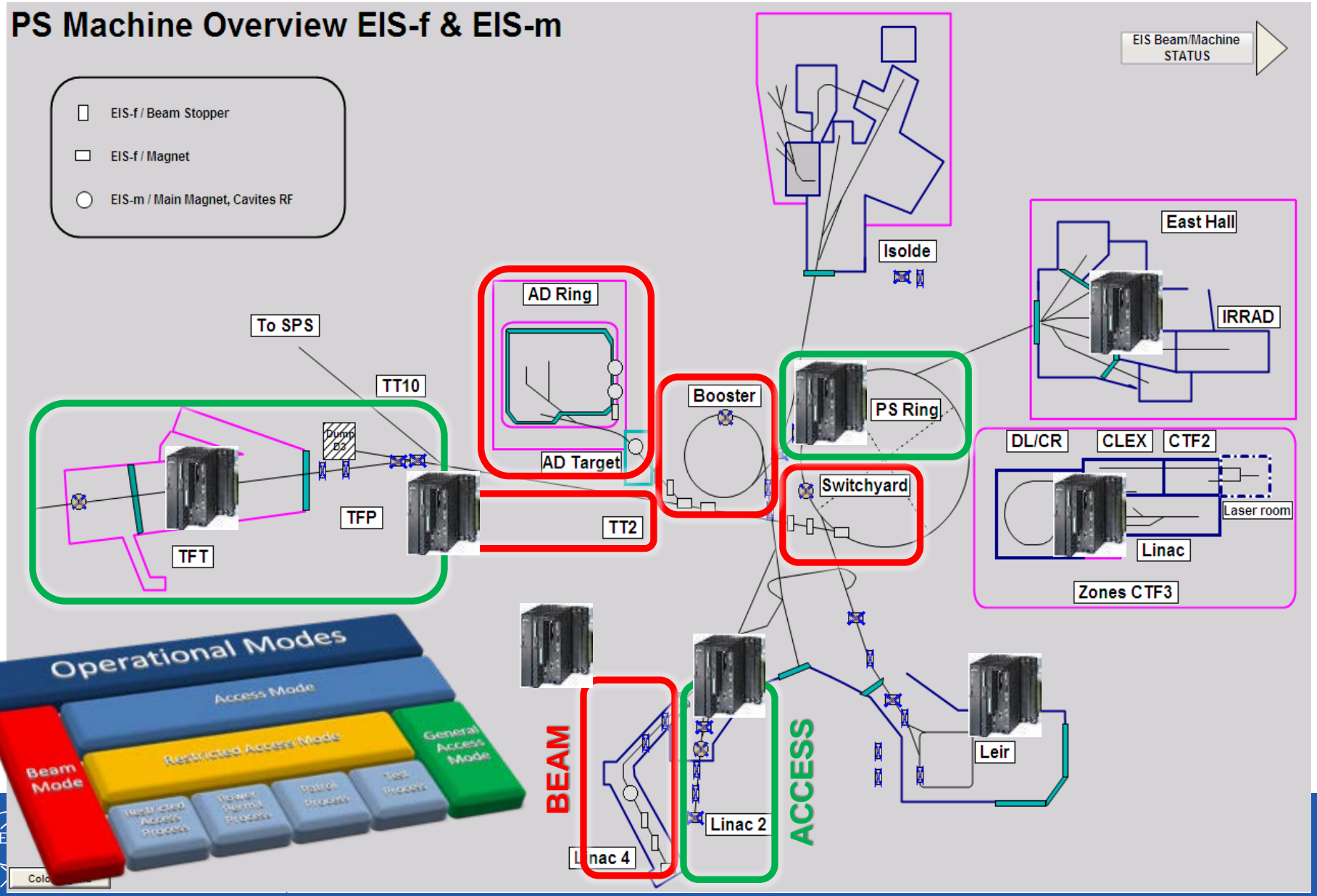

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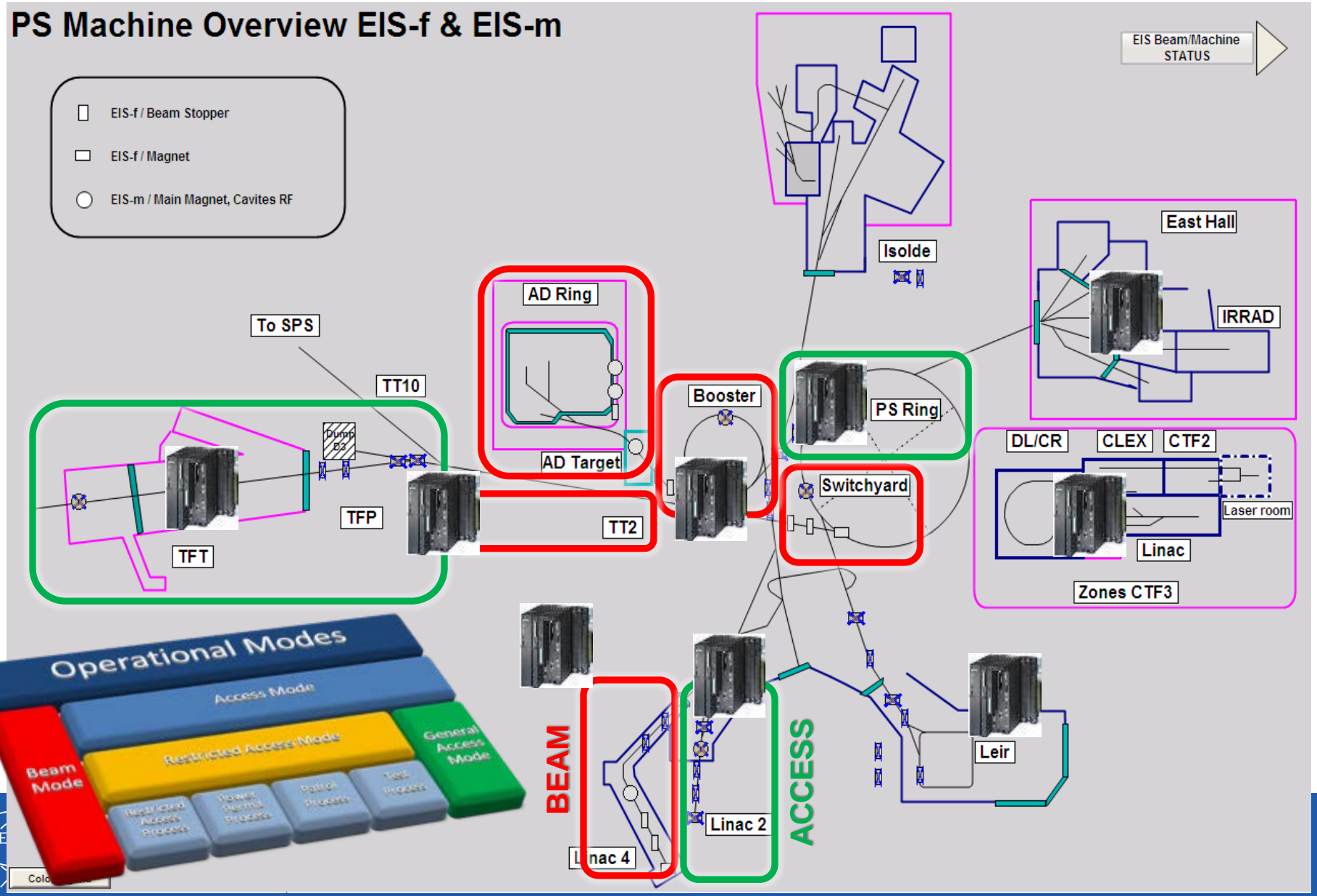

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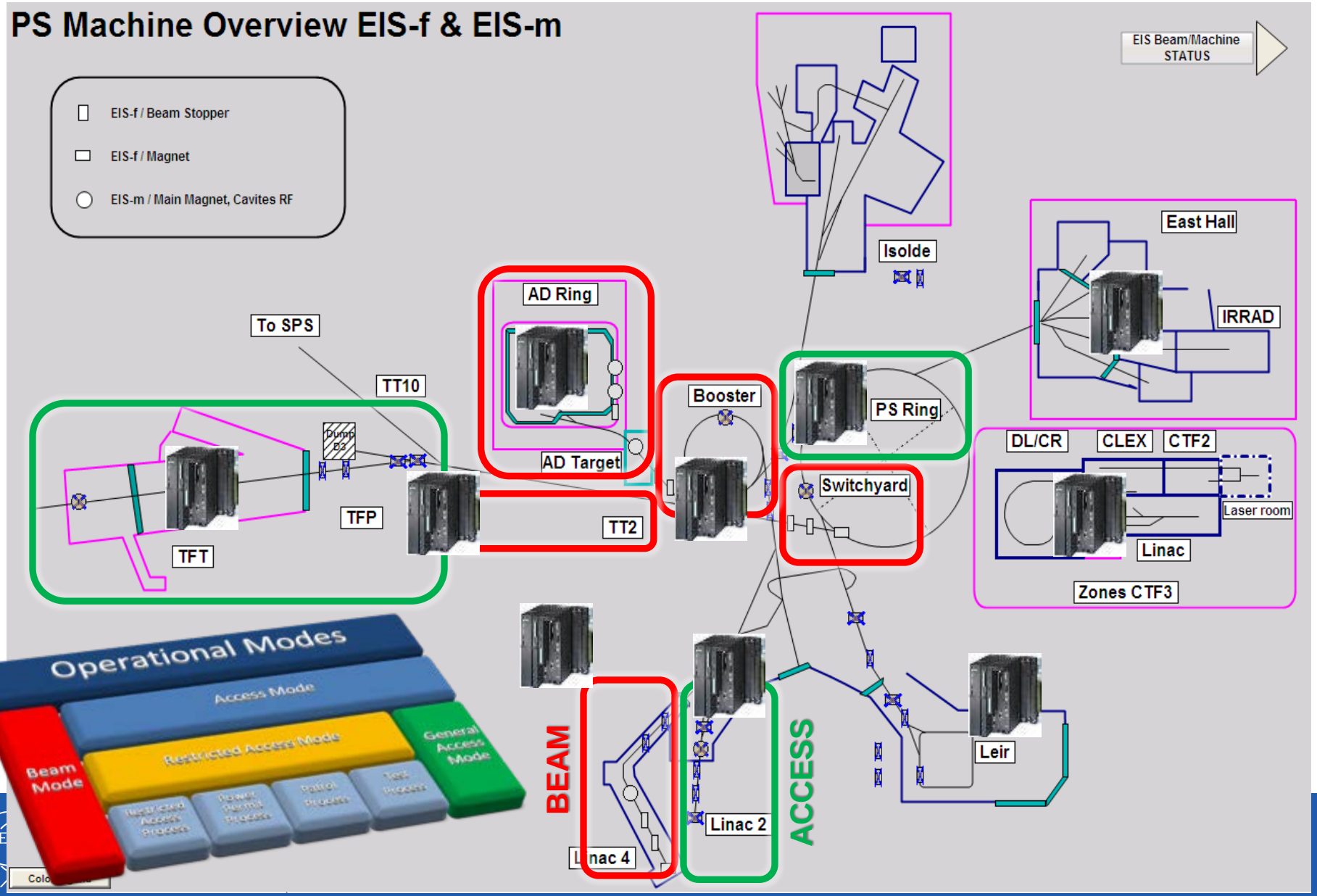

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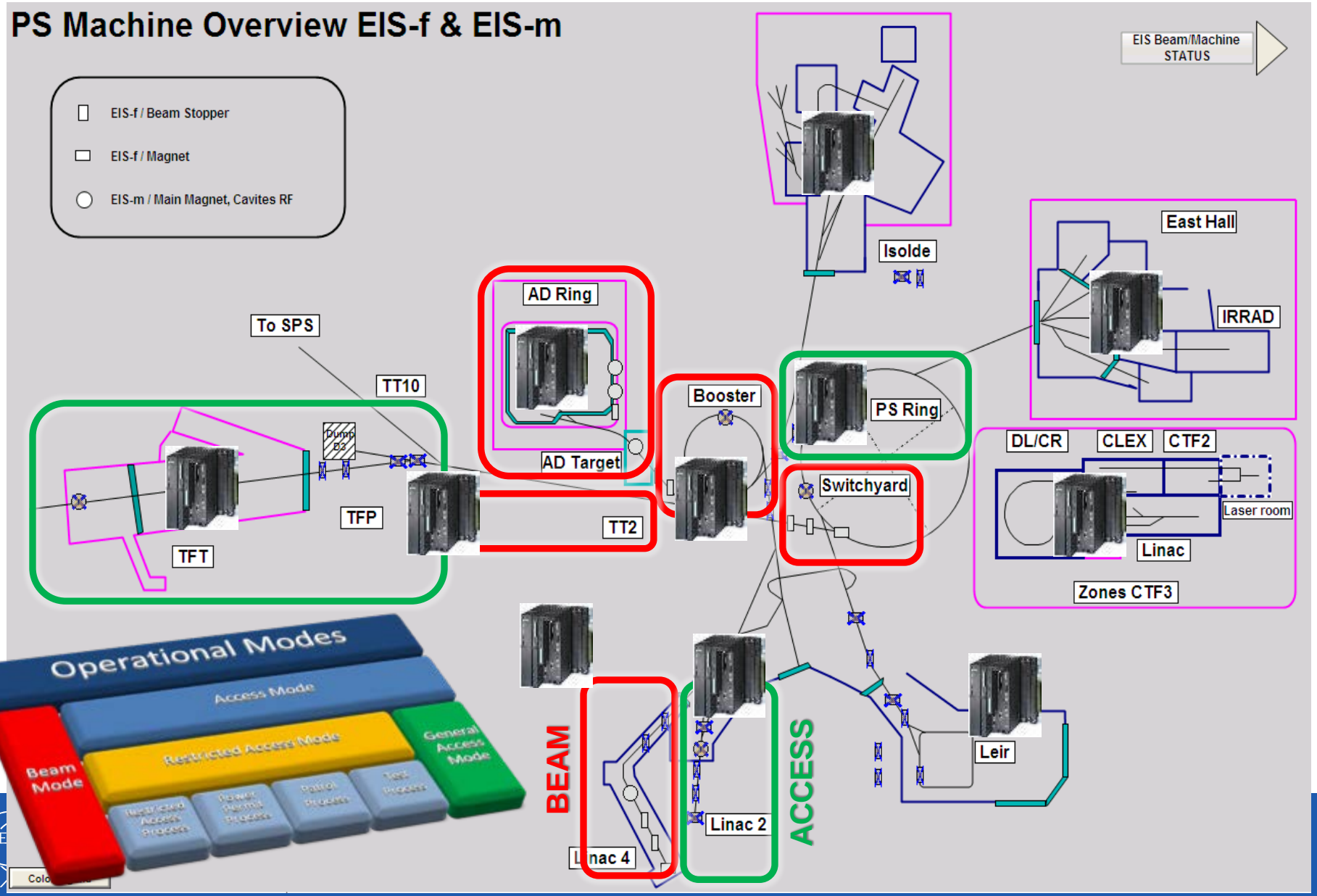


Safety Test Bench Conception

Safety

- Validate Safety Software of each zone controller.
- Validate safety communication between zone controllers (min. 3).

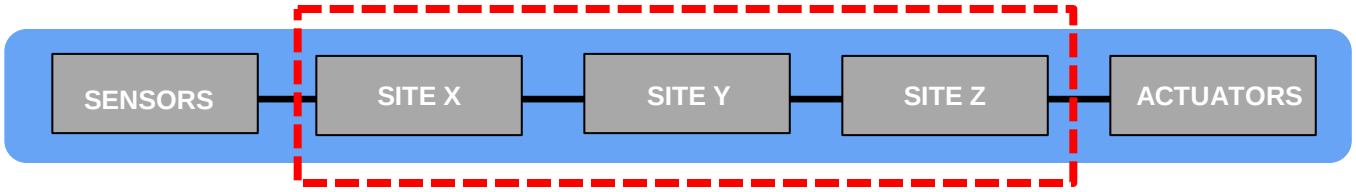
Operation

- Validate all operational synoptic.
- Integrate real access devices (PAD/MAD) within the simulated signals.

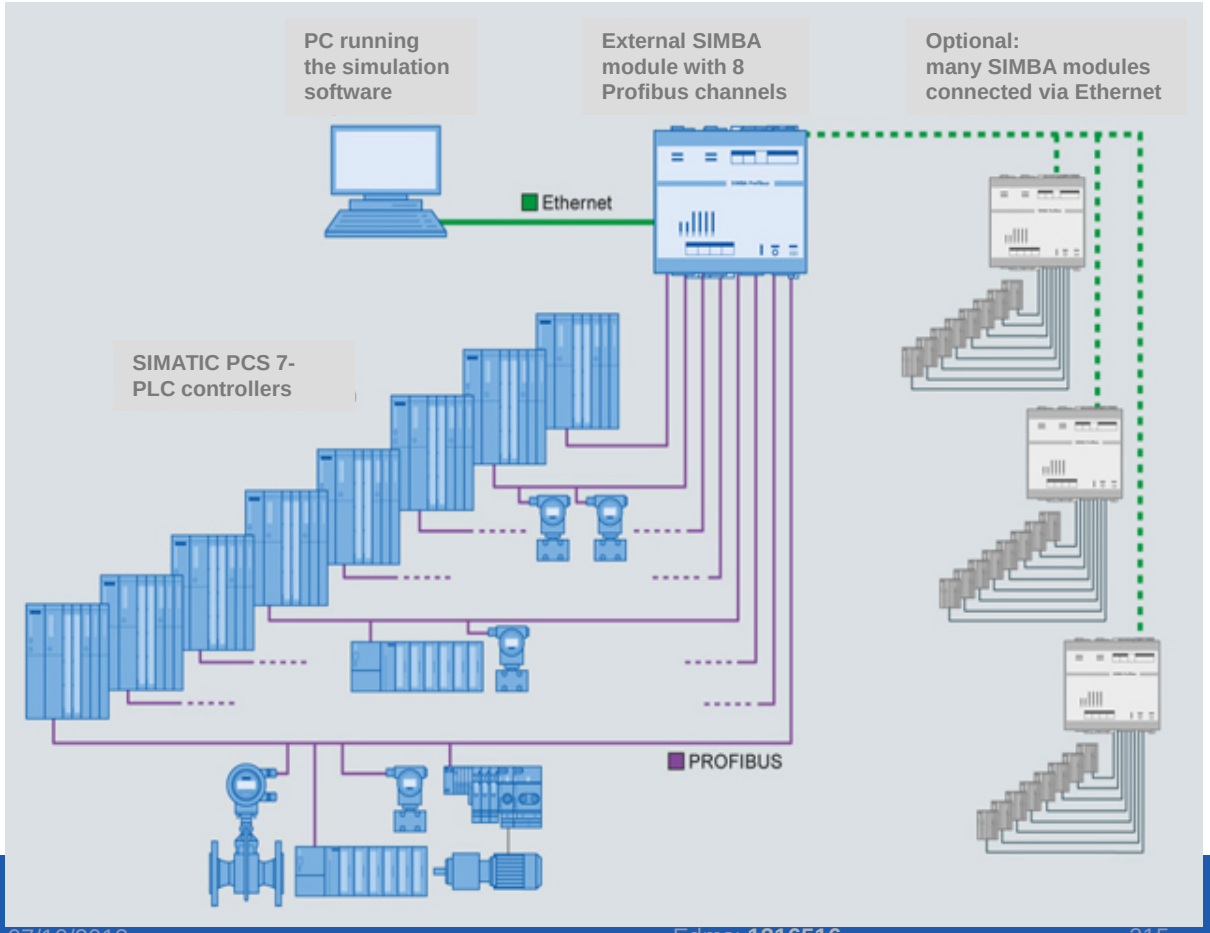
Usability

- Quick reconfiguration of the Platform (max. 2h to load new PS sites).
- Quick modification of Platform architecture (ADD/REMOVE access devices).
- Be able to run automatic test case scenarios.

Safety Test Bench Conception



SIEMENS SIMBA Box



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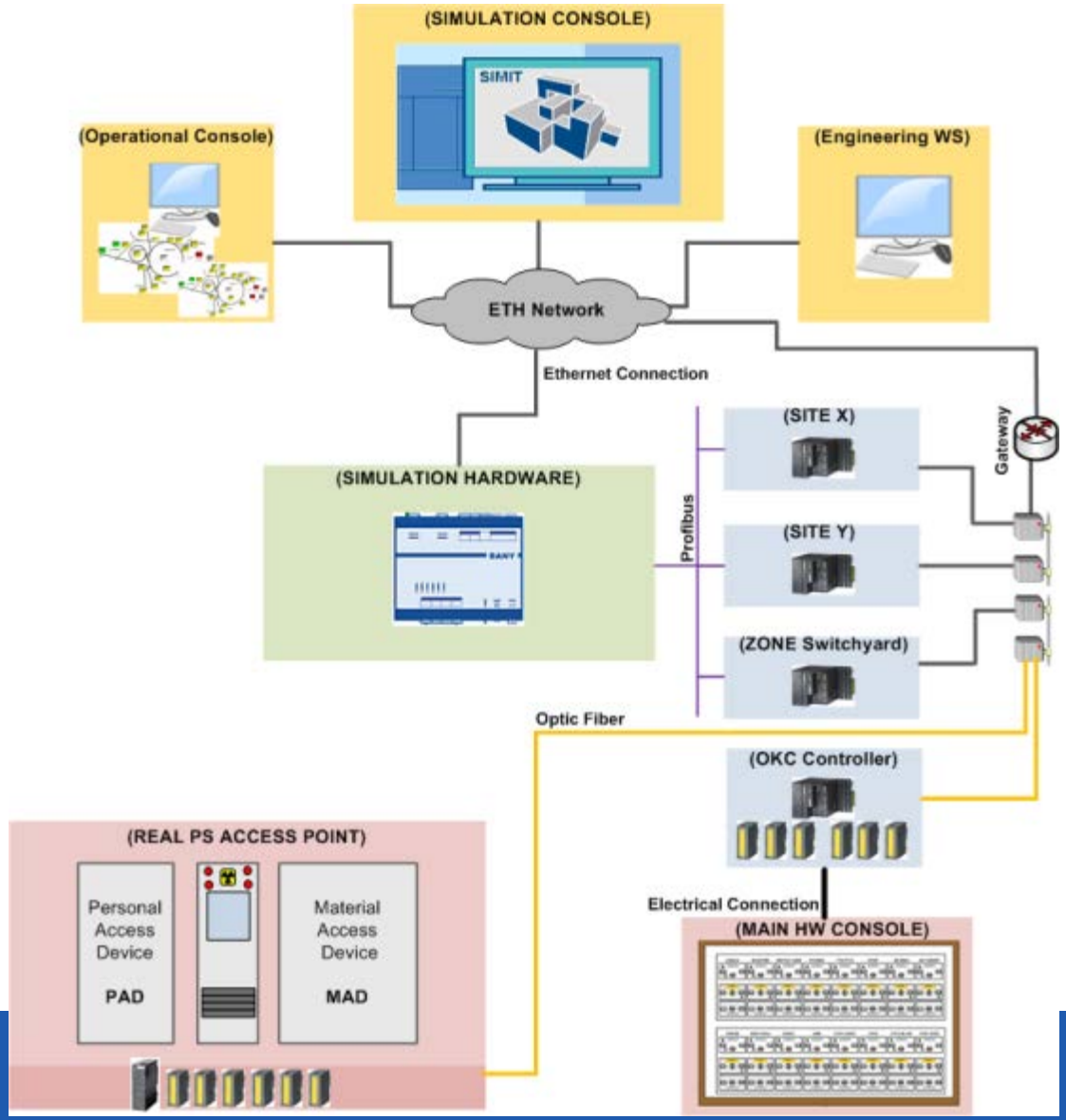

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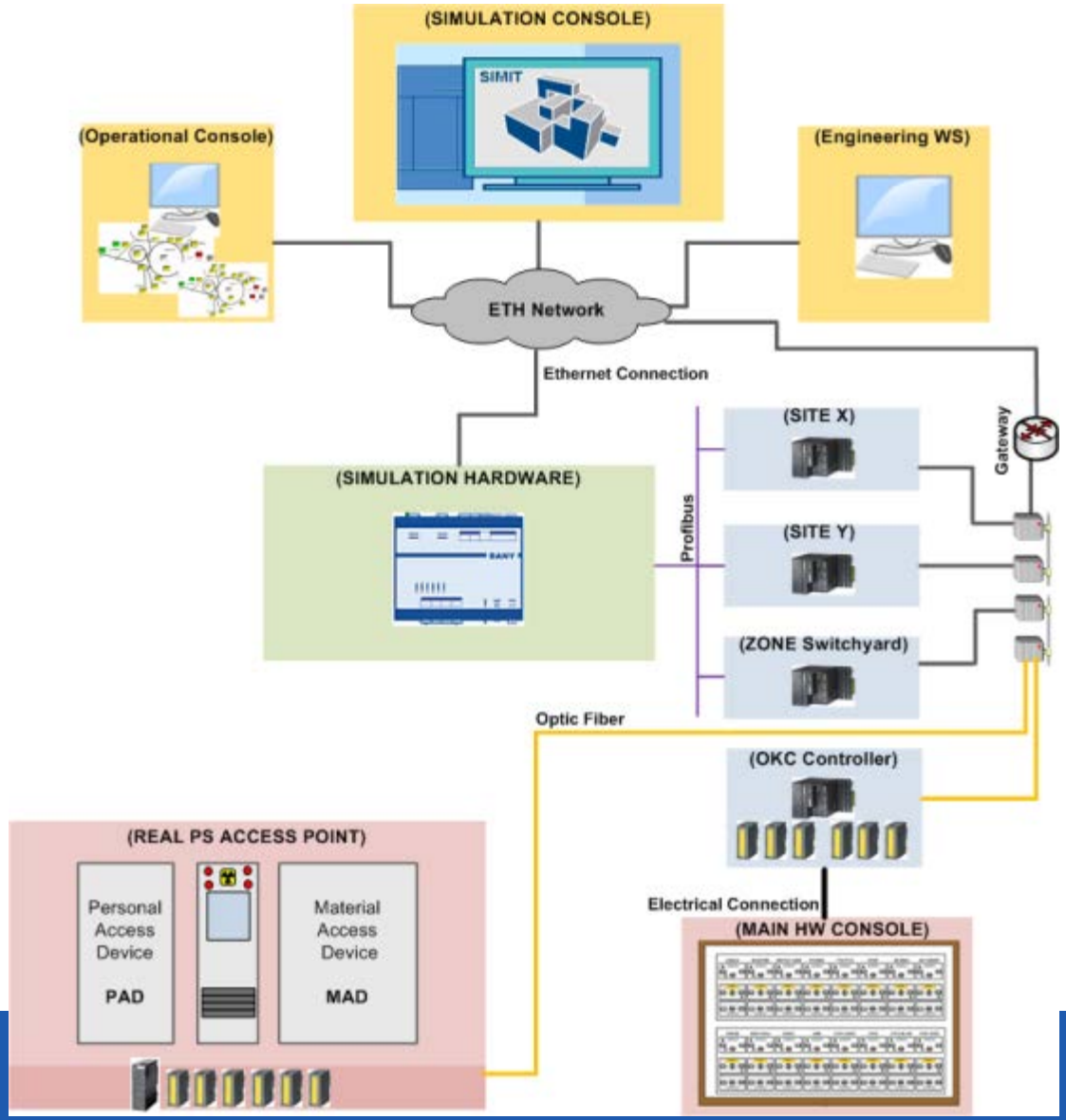
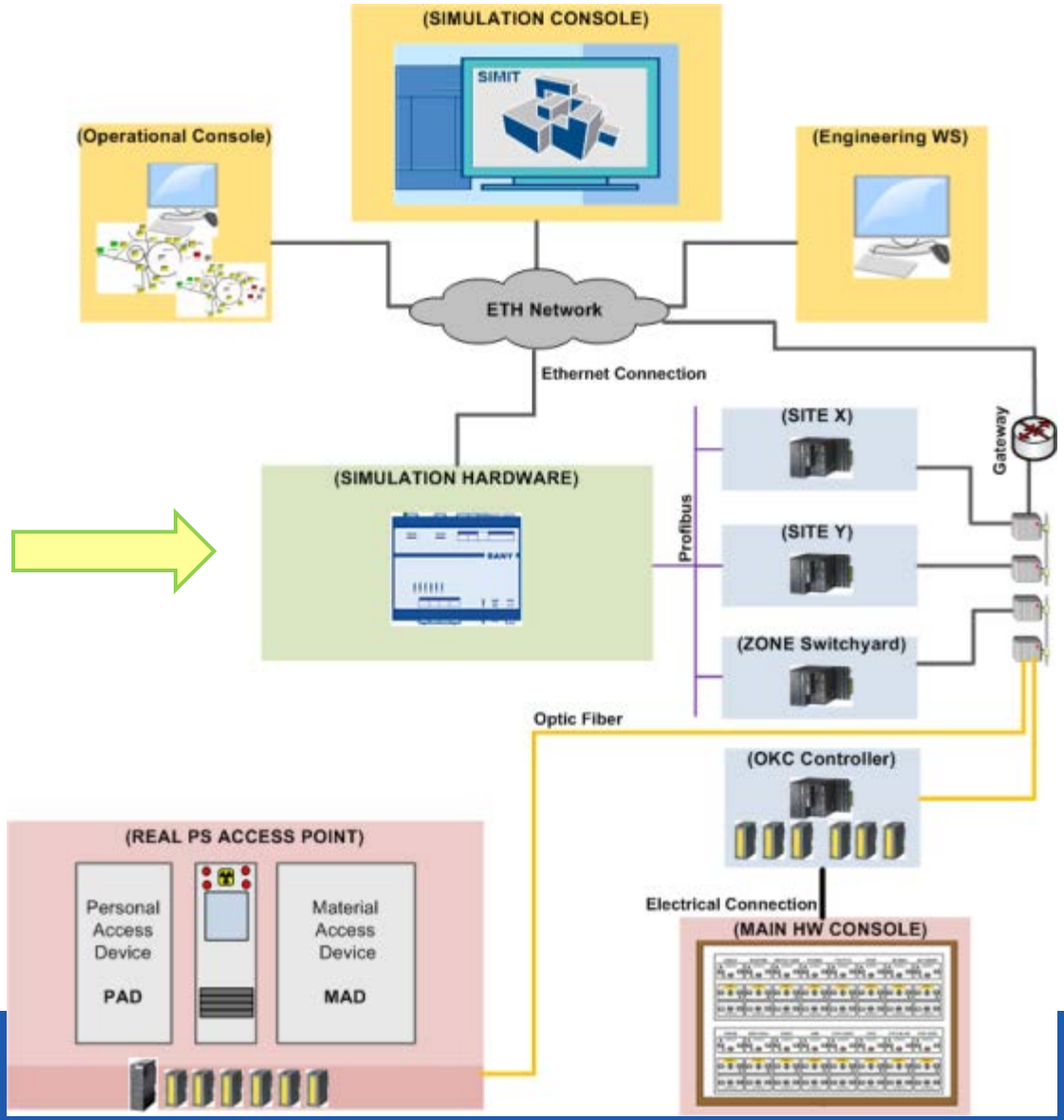


Safety Test Bench Conception



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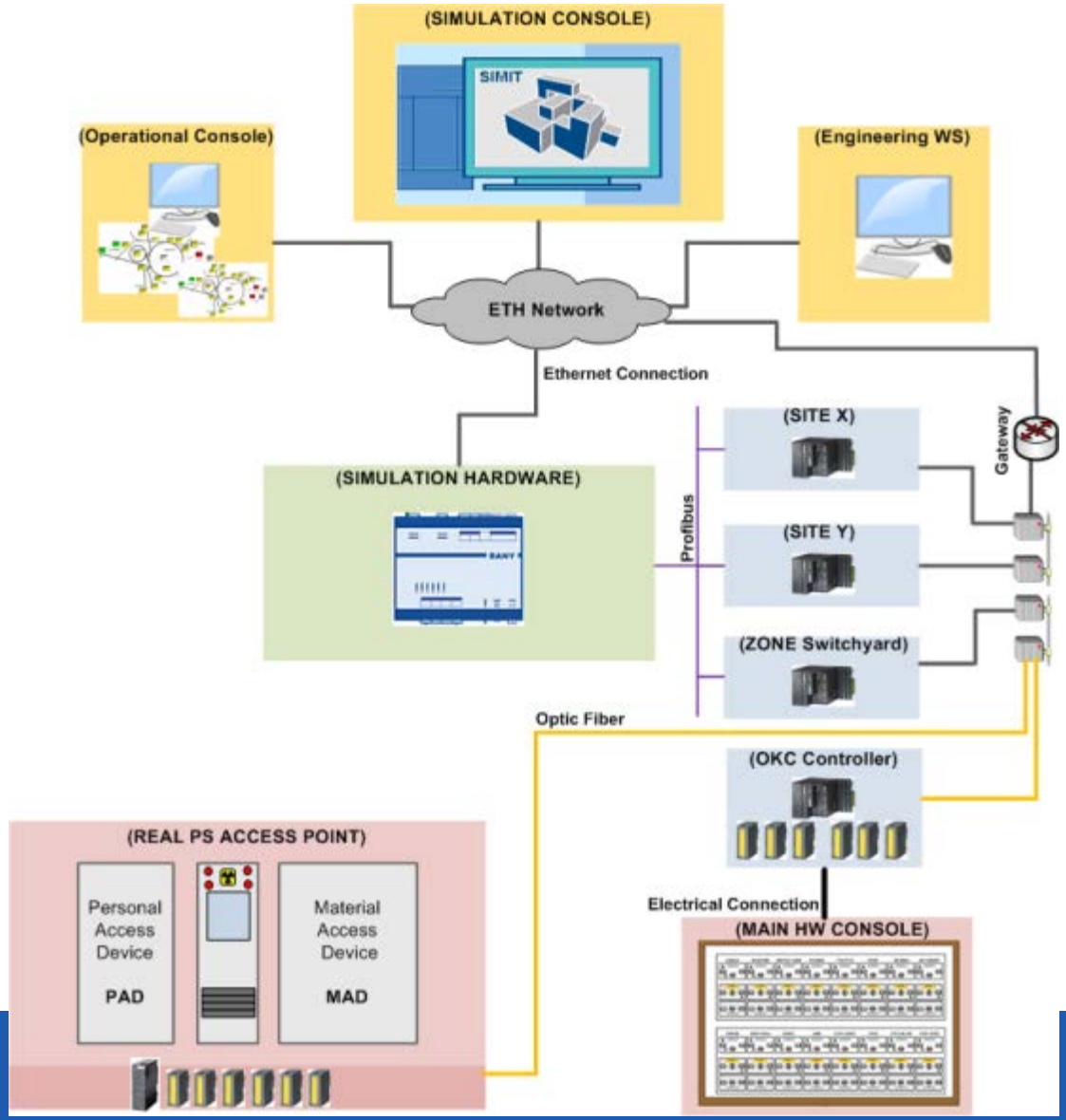

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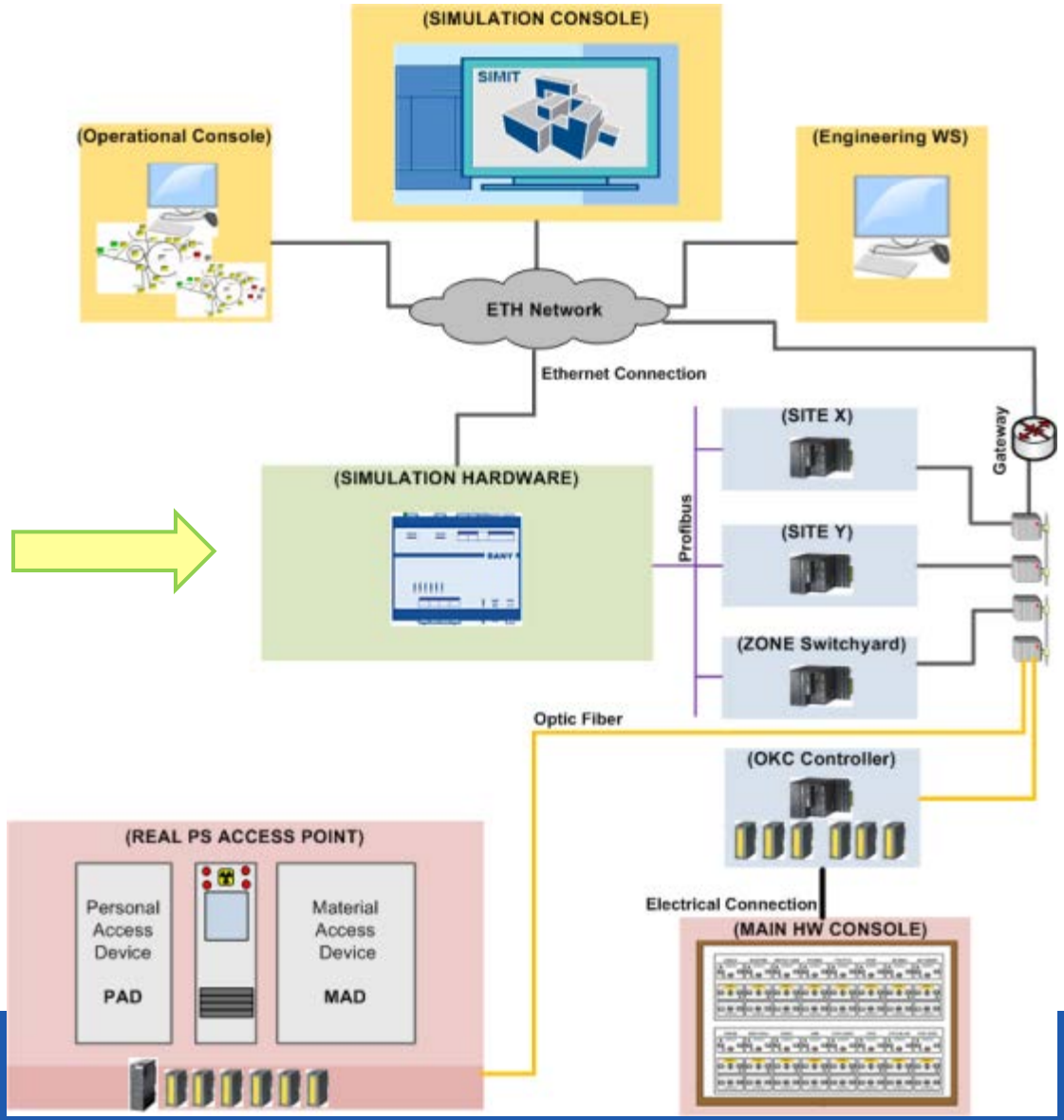

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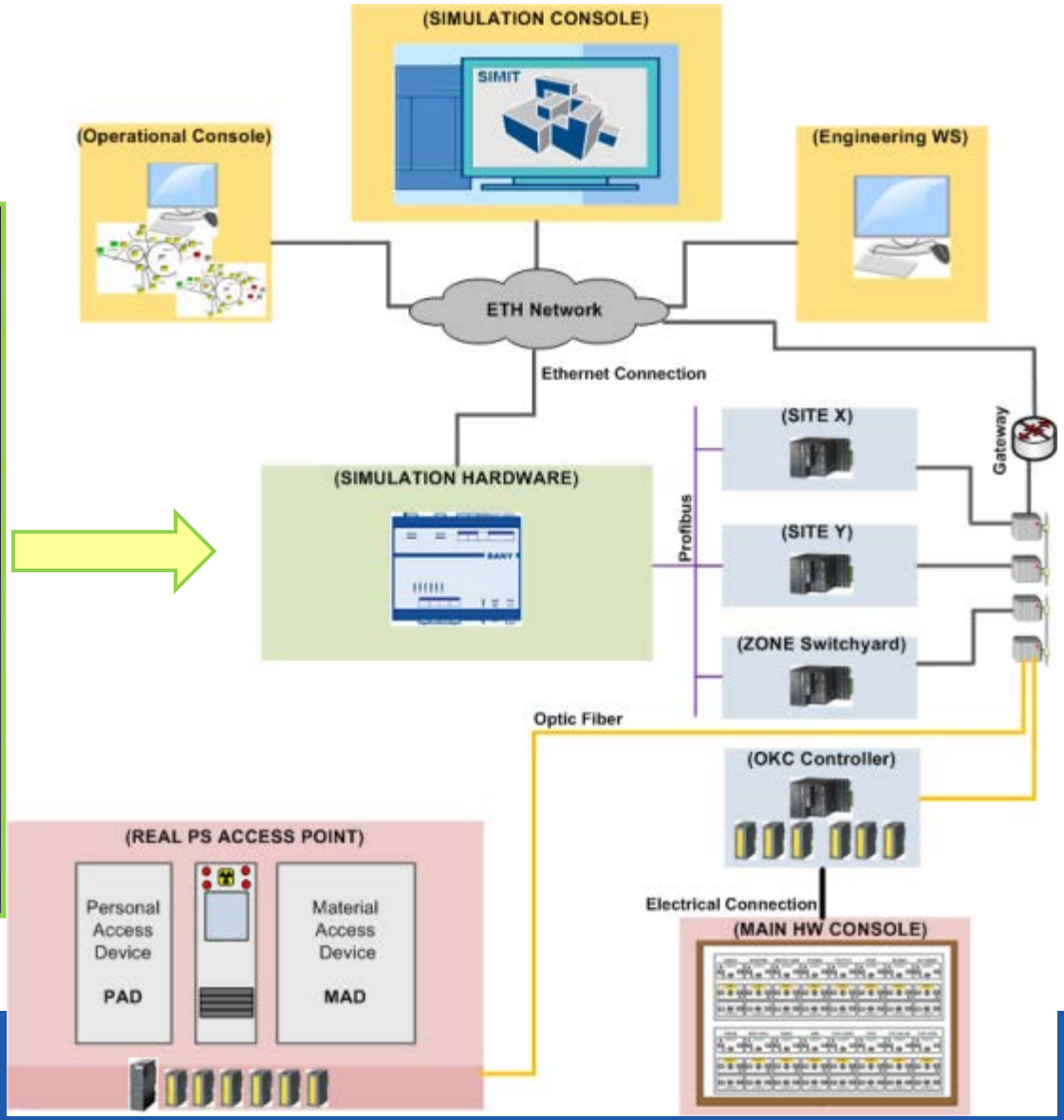

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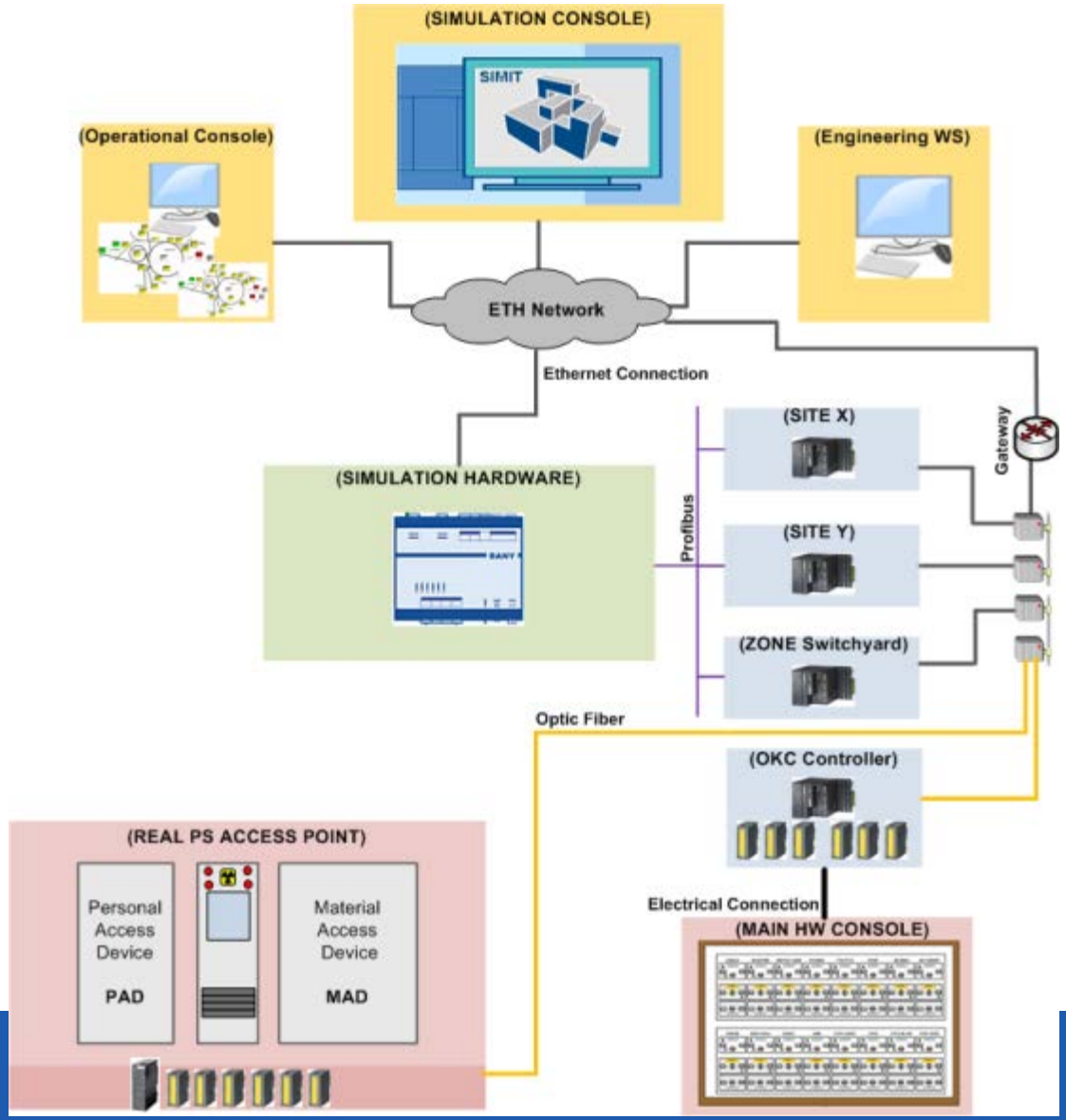

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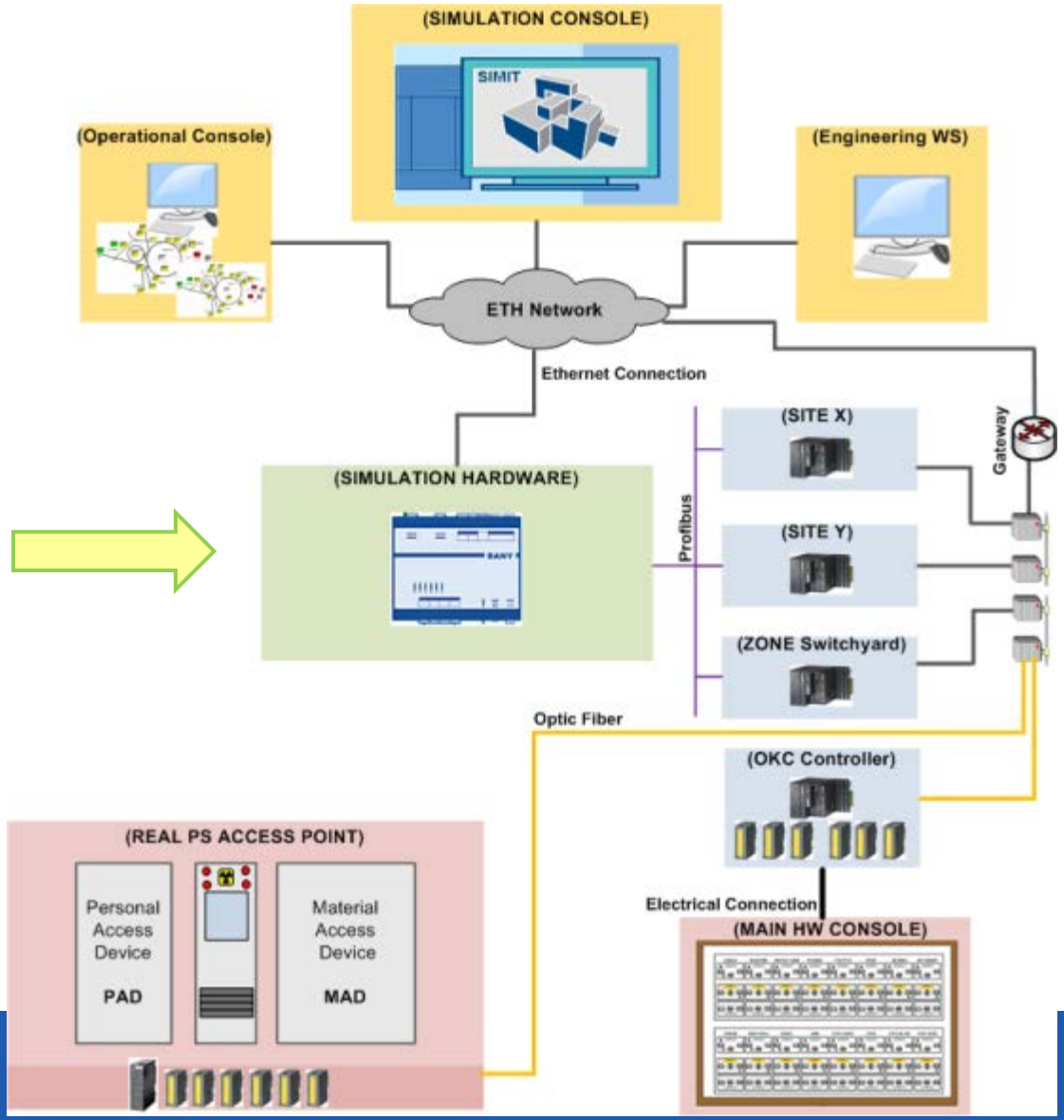

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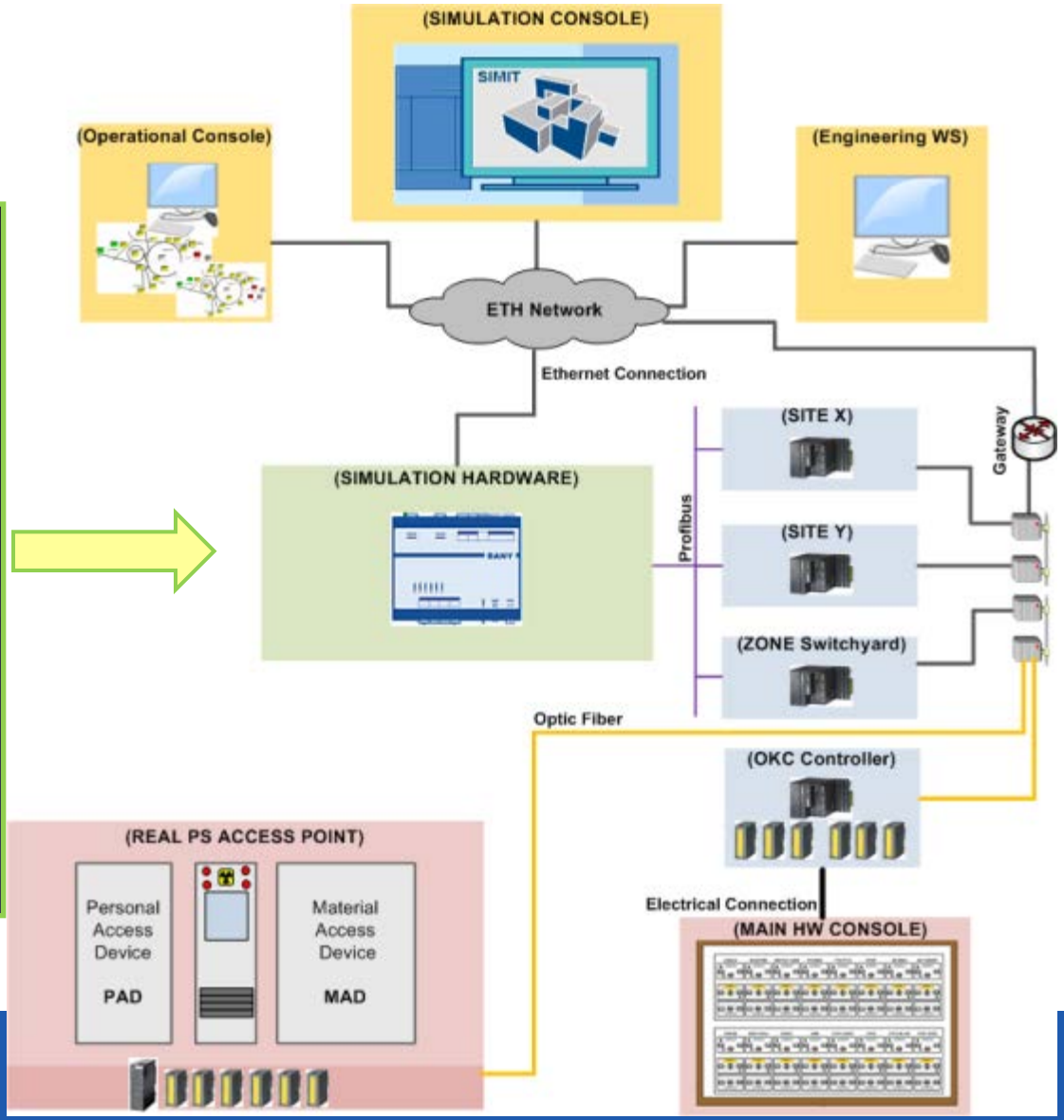

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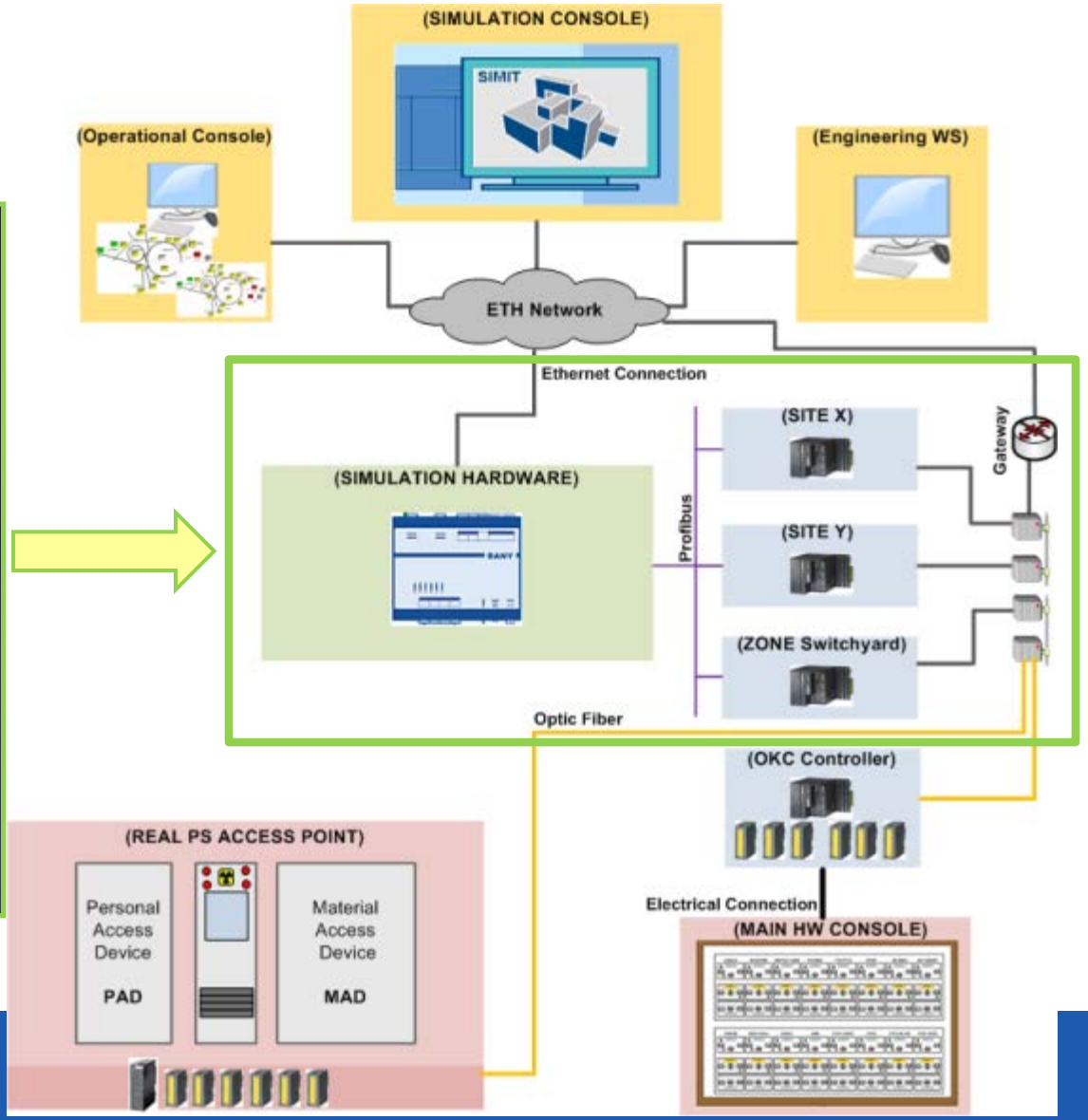

SIF – Formal Definition Language

SECTION 1: SIF Informal Presentation

FIS CODE	SIL TARGET	OPERATING MODE	PROBABILITY	REDUNDANCY
FIS_1	SIL3	CONTINUOUS	PFH	1oo2

MITIGATED HAZARDS: Exposition to radiations coming from injected/circulating beam, activated materials or radiation coming from a source (LINAC4). Other risks covered are related to the exposition to X-Rays from RF cavities, SEPTA Electrostatic Magnets (PS RING and BOOSTER), working KLISTRONS or Deflecting Cavities (CTF3-DL-CR).

Exposition Conditions: unintended start of the Beam. Intrusion during Beam operations.

SAFETY ACTIONS: Computation of REPLI Mode (NO ACCESS/NO BEAM) of the ZIV.
Activation of Evacuation Sirens.
Sending of protection requests to all Upstream ZIVs.
Computation of the Safe State signal (SECU_OK) for all Downstream ZIVs.

GENERAL DESCRIPTION: The function main scope is to ensure that **NO Beam** is permitted when the Access mode is set and **NO Access** is granted when Beam is allowed in the ZIV. In case of loss of this invariant condition (ex. intrusion during beam mode or loss of the Safe state of at least 1 *EIS beam* during access) the function disables the current exploitation mode and activates the REPLI MODE (No Access – No Beam) described by the **FIS_17**.

During the REPLI MODE, the Function asks to all upstream ZIVs to put in SAFE state all their *EIS_b* if at least 1 *EIS_b* of the ZIV is in an UNSAFE position.
The Function starts the EVACUATION sirens if at least 2 *EIS_b* are in an UNSAFE position.

Additionally, this FIS computes continuously the signal SECU_OK sent to all downstream zones to inform that all the EIS-beams of the ZIV are SAFE.

Logic Solver Technology:	*Safety PLC Wired System*	**Reaction Time:**	*2s*	**Spurious Trip Frequency:**	*< 1/year*
Failsafe Behavior:	*Application of REPLI Mode for the ZIV.*	**By-pass needs:**	*FIS_2*	**Periodical Tests frequency:**	*1/year*

SIF – Formal Definition Language

SECTION 2: SIF Input / Output Interface

3.1.1 FIS INPUT SIGNALS

VARIABLE	SIGNAL	SOURCE	PLC Type
EISa_Safe	Position (SAFE/UNSAFE) resultant for all EIS-access of the ZIV. Refer to the specific definition of SAFE/UNSAFE state given for the different models of EIS-A: **EISa_Safe=0** → 1 EISa is UNSAFE	2 Mechanical switches	FDI
EISb_Pos	Position of all EIS-beam of the ZIV: **EISb_Pos=1** → All EIS-beam are SAFE	2 Mechanical switches	FDI
KEY_Out	Position of all keys used to put out of chain the Downstream ZIVs. **KEY_Out=1** → The ZIV is out of chain	2 Micro-switches	FDI
MODE_Bea	The Beam mode status of the ZIV: **MODE_Bea=1** → ZIV in BEAM ON	Network (OKC PLC)	INT VAR
MODE_Acc	The Access mode status for the ZIV: **MODE_Acc=1** → ZIV in ACCESS ON	Network (OKC PLC)	INT VAR
MODE_Tra	Status of TRANSITION RFA/RFB Mode: **MODE_Tra=1** → ZIV in RFA/RFB Mode	Network (OKC PLC)	INT VAR
MODE_TFA	Status of TRANSITION FROM ACCESS Mode: **MODE_TFA=1** → ZIV in TFA mode	Program	INT VAR
ACCE_Tst	Status of the mode TEST EIS-b for the ZIV: **ACCE_Tst=1** → TEST mode authorized	Program	INT VAR
ACCE_TfT	Status of the mode TFT for the ZIV: **ACCE_TfT=1** → TFT Mode activated	Program	INT VAR
SECU_Dwn	Request from downstream ZIV for setting all EIS-b of the ZIV in a SAFE state: **SECU_Dwn=0** → Safety requested	Cabled signal from downstream PLC	FDI
ZIV_Srch	Search state for the ZIV: **ZIV_Srch=1** → ZIV Search is Armed	Program	INT VAR

3.1.2 FIS Output Signals

VARIABLE	SIGNAL	SOURCE	PLC Type
MODE_Rep	The REPLI mode status for the ZIV: **MODE_Rep=1** → ZIV in REPLI Mode	PLC Program	INT VAR
EVAC_Cmd	Command to the BIW system to start the Evacuation sirens: **EVAC_Cmd=1** → Evacuation activated	PLC output	FDO
SECU_Ok	Signal sent to all downstream ZONES to inform that all EIS beam of the ZIV are safe: **SECU_Ok=1** → All EIS-beam are SAFE	PLC output	FDO
SECU_UP	Signal sent to all upstream Zones to ask them to put in SAFE state their EIS beam: **SECU_Up=0** → Safety Request activated	PLC output	FDO

SIF – Formal Definition Language

SECTION 3: SIF Formal Description

TRIGGERING EVENT- ACTIVATION OF THE REPLI MODE FOR THE ZIV:

((MODE_Acc = 1 V MODE_TFA = 1 V MODE_Tra = 1) Λ ACC_Tst = 0 Λ ACC_TfT = 0 Λ EISb_Pos = 0) V (MODE_Acc = 0 Λ EISa_Safe = 0)

OUTPUT → **MODE_Rep = 1**

TRIGGERING EVENT- ACTIVATION OF THE EVACUATION SIREN FOR THE ZIV:

((MODE_Bea = 1 V MODE_TFB = 1) Λ ZIV_Srch = 0) V (MODE_Rep = 1 Λ EISb_Pos{>1} = 0 Λ EISa_Safe = 0)

PLC OUTPUT → **EVAC_Cmd = 1**

TRIGGERING EVENT- PROTECTION REQUEST TO ALL THE UPSTREAM ZONES:

(MODE_Rep = 1 Λ EISb_Pos = 0 Λ EISa_Safe = 0)

PLC OUTPUT → **SECU_Up = 0**

TRIGGERING EVENT- ZIV SAFE STATE SENT TO ALL DOWNSTREAM ZONES:

(EISb_Pos = 1 Λ MODE_Bea = 0) V (ACC_Tst = 1) V (ACC_TFT = 1)

PLC OUTPUT → **SECU_Ok = 1**

Safety Functions – Testing Problem

MAIN OBJECTIVE: *Validate efficiently all Safety Instrumented Functions in order to discover all major bugs related to safety before the final system deployment phase.*

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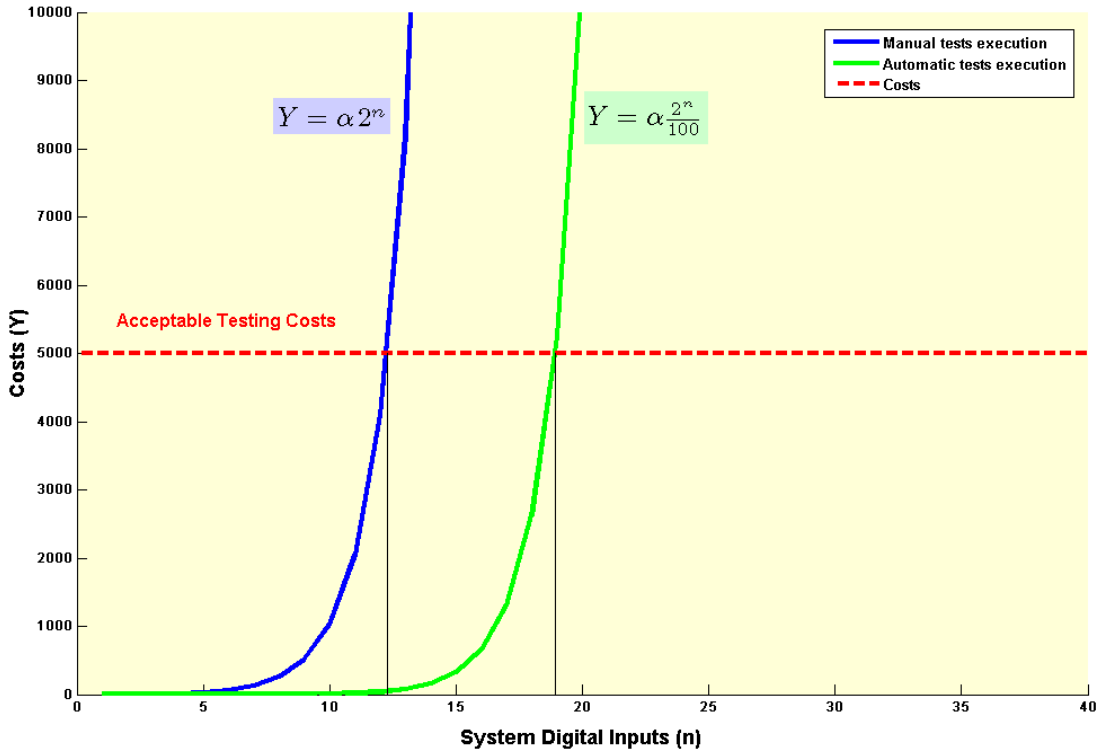
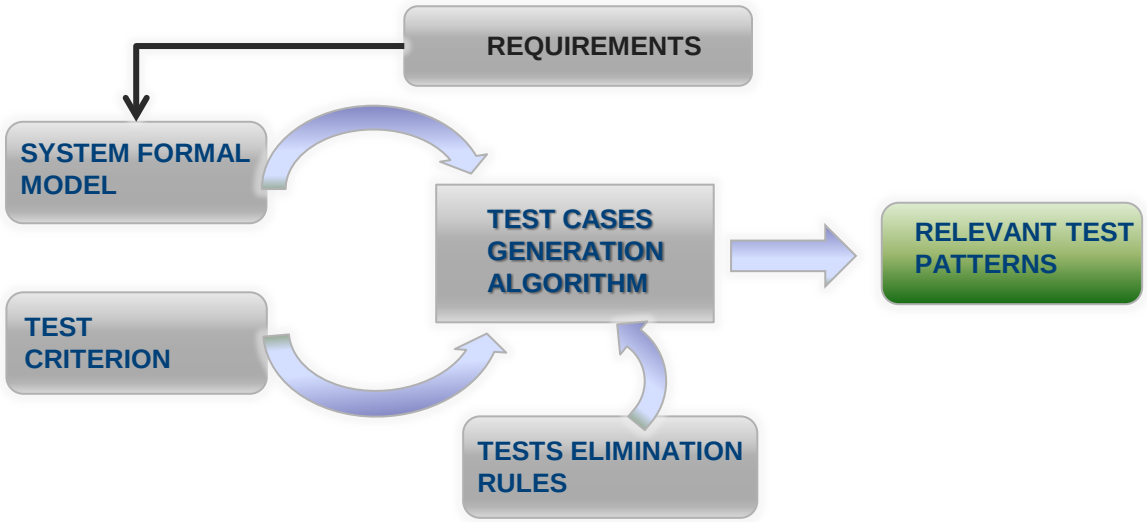
Solution 1: **EXAUSTIVE TESTING STRATEGY**



- Simple to implement
- Detect 100% of system errors
- Unsustainable execution times and costs

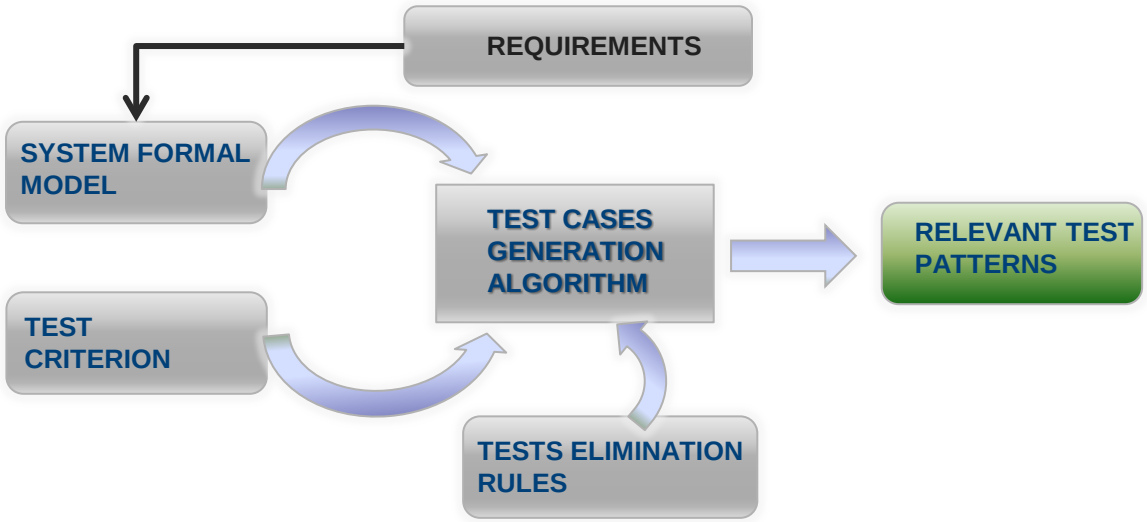
Safety Functions – Testing Problem

Solution 2: **MODEL-BASED TESTING STRATEGY**



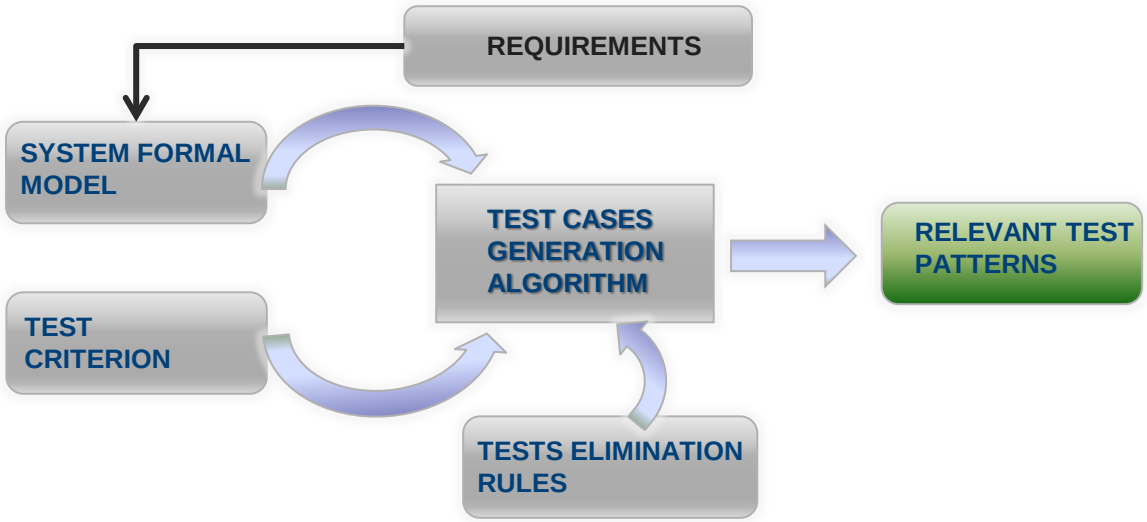
Safety Functions – Testing Problem

Solution 2: **MODEL-BASED TESTING STRATEGY**



Safety Functions – Testing Problem

Solution 2: **MODEL-BASED TESTING STRATEGY**



Maximize the probability of detecting errors, reducing the tests execution costs.

Mathematical proof of the test Coverage (**C**) obtained:

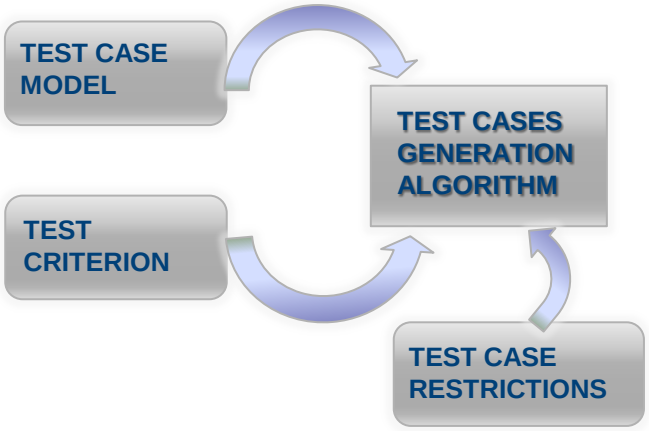
C = <# *Executed Tests*> / <# *Total Tests*>

Do not guarantee 100% detection of all system errors. In general:

Er(x) = *C* * *P(x)* **(Confidence index for detecting an error x)**

Safety Functions Model-Based Testing

Test Criterion: *Verify the output values for all possible events triggering the SIF interlock actions.*



FIS CODE	TEST CASE SCENARIO	CATEGORY
FIS_1	ACTIVATION OF THE REPLI MODE FOR THE ZIV	SAFETY

TEST CASE MODEL:

$\Phi_1_1 = ((MODE_Acc = 1 \vee MODE_TFA = 1 \vee MODE_Tra = 1) \wedge ACC_Tst = 0 \wedge ACC_TfT = 0 \wedge EISb_Pos = 0) \vee (MODE_Acc = 0 \wedge EISa_Safe = 0)$

TEST CASE RESTRICTIONS:

$R_1 = (MODE_Acc=1 \wedge MODE_TFA=1) \vee (MODE_Acc=1 \wedge MODE_Tra = 1) \vee (MODE_TFA=1 \wedge MODE_Tra = 1)$

$R_2 = (ACC_Tst=1 \wedge ACC_TfT=1)$

$R_3 = (MODE_Acc=0) \wedge (ACC_Tst=1 \vee ACC_TfT=1)$

TEST CASE GENERATION MODEL:

$$\omega : (\Phi_1_1 = 1) \wedge (R_1 = 0) \wedge (R_2 = 0) \wedge (R_3 = 0)$$

SYSTEM VERIFICATION PROPERTY:

$$(MODE_Rep = 1)$$

Total Variables:	*7*	**Total State Space:**	*128*	**Scenario State Space:**	*10*
I/O Types:	*DIGITAL*	**Test Impact:**	*PLC ZIVx PLC OKC*	**Execution Strategy:**	*MANUAL*

Safety Functions Model-Based Testing

Test Instances auto-generated by MATLAB:

	MODE_Acc	MODE_TFA	MODE_Tra	ACC_Tst	ACC_TtT	ElSb_Pos	ElSa_Safe	RESULTS
Test 1	0	0	0	0	0	1	0	
Test 2	0	0	0	0	0	0	0	
Test 3	0	0	1	0	0	0	1	
Test 4	0	0	1	0	0	0	0	
Test 5	0	0	1	0	0	1	0	
Test 6	0	1	0	0	0	0	1	
Test 7	0	1	0	0	0	0	0	
Test 8	0	1	0	0	0	1	0	
Test 9	1	0	0	0	0	0	1	
Test 10	1	0	0	0	0	0	0	

Safety Functions Model-Based Testing

Test Instances auto-generated by MATLAB:

	MODE_Acc	MODE_TFA	MODE_Tra	ACC_Tst	ACC_TtT	ElSb_Pos	ElSa_Safe	RESULTS
Test 1	0	0	0	0	0	1	0	
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Test 3	0	0	1	0	0	0	1	
Test 4	0	0	1	0	0	0	0	
Test 5	0	0	1	0	0	1	0	
Test 6	0	1	0	0	0	0	1	
Test 7	0	1	0	0	0	0	0	
Test 8	0	1	0	0	0	1	0	
Test 9	1	0	0	0	0	0	1	
Test 10	1	0	0	0	0	0	0	

Safety Functions Model-Based Testing

Test Instances auto-generated by MATLAB:

	MODE_Acc	MODE_TFA	MODE_Tra	ACC_Tst	ACC_TIT	ElSb_Pos	ElSa_Safe	RESULTS
Test 1	0	0	0	0	0	1	0	
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Test 3	0	0	1	0	0	0	1	
Test 4	0	0	1	0	0	0	0	
Test 5	0	0	1	0	0	1	0	
Test 6	0	1	0	0	0	0	1	
Test 7	0	1	0	0	0	0	0	
Test 8	0	1	0	0	0	1	0	
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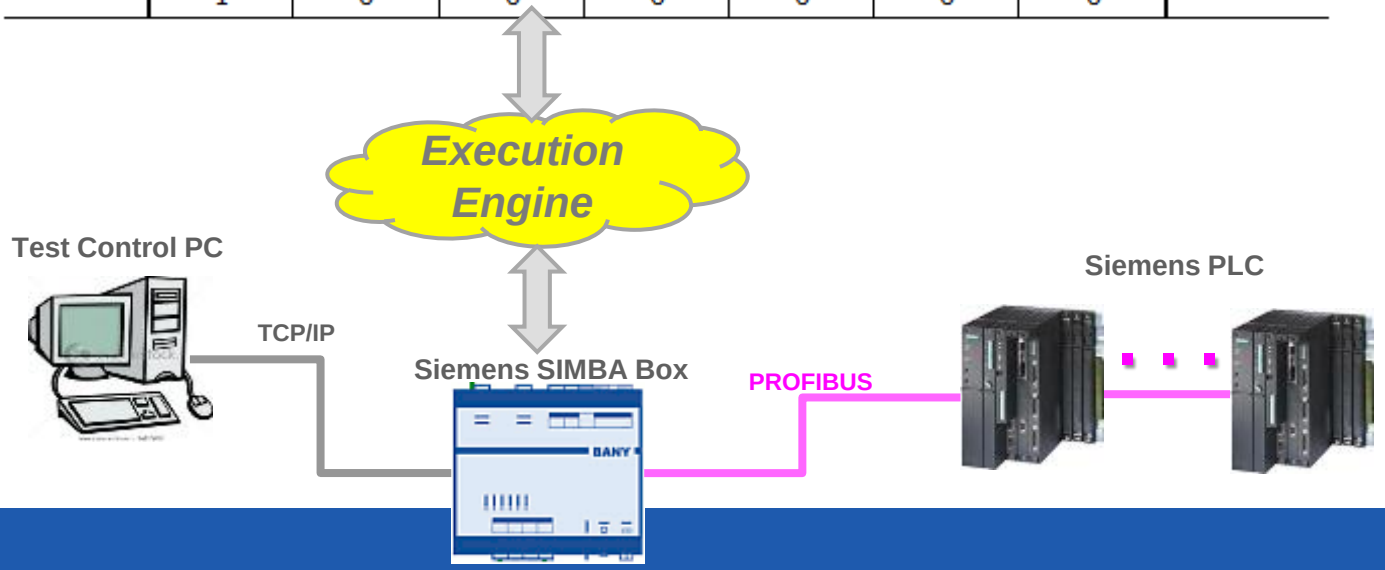
Future Works



Conclusions

- **It is essential to clearly fix the testing objectives in order to obtain a performing Test Bench for Safety Validation.**
- **The main Test Bench realization principles shall be related to: Scalability, Flexibility, coherence with the real system, easy operability and maintainability.**
- **The adoption of formal languages for the Safety Functions modeling is an essential key to implement a Model-Based Testing strategy, improving the quality of the final Validation Test Plan.**

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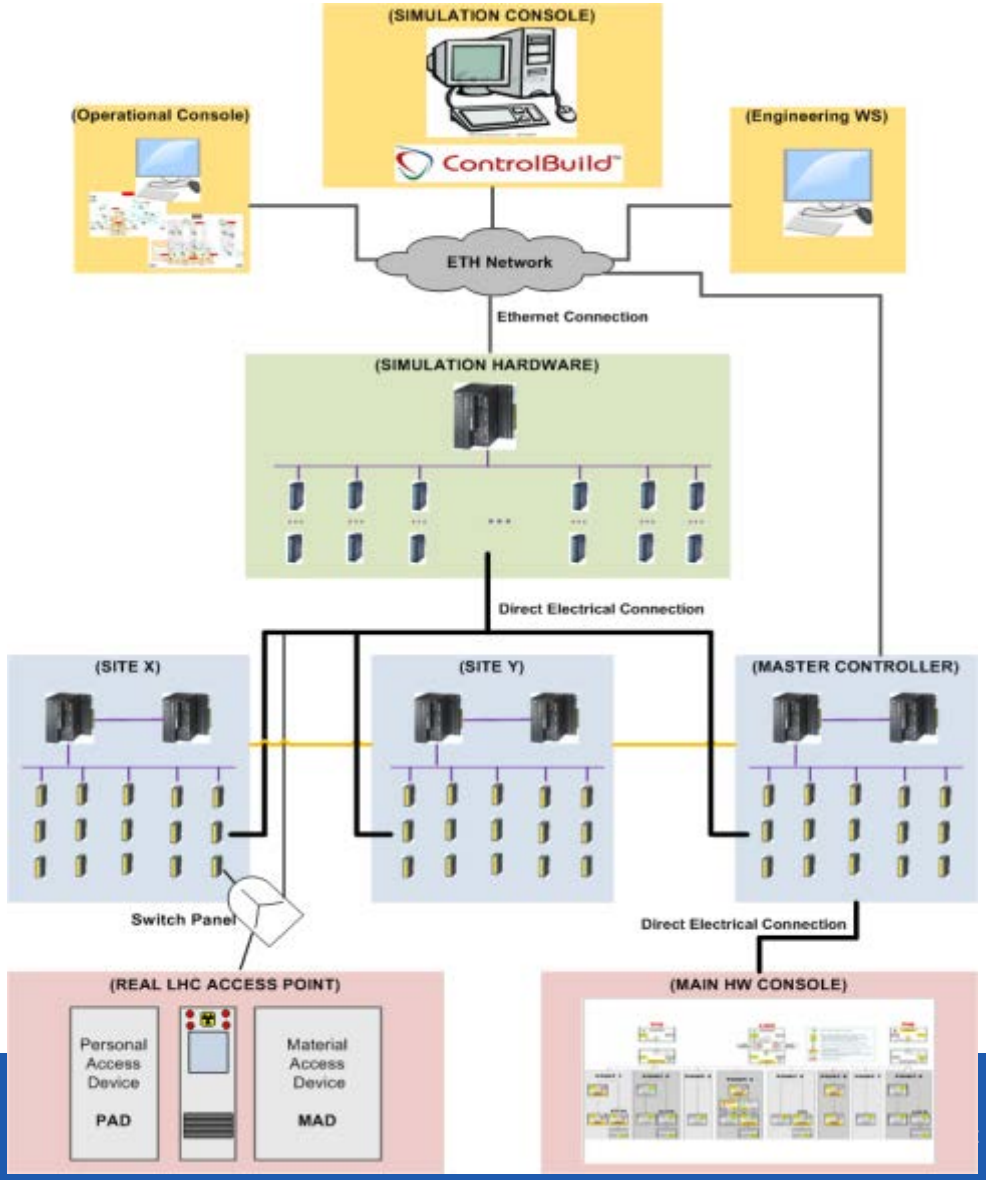
Safety Test Bench Conception

Classic Architectural Model Example



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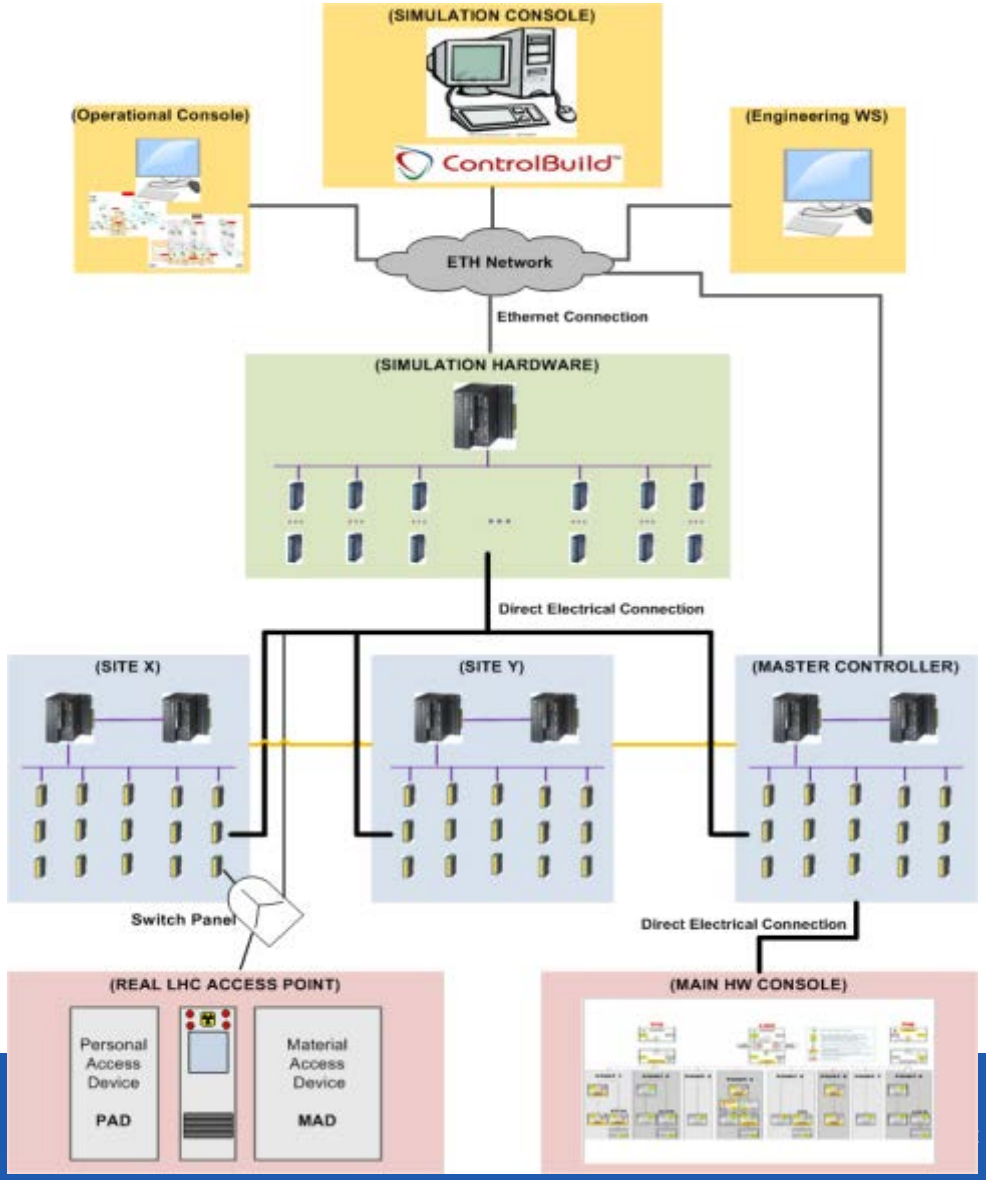

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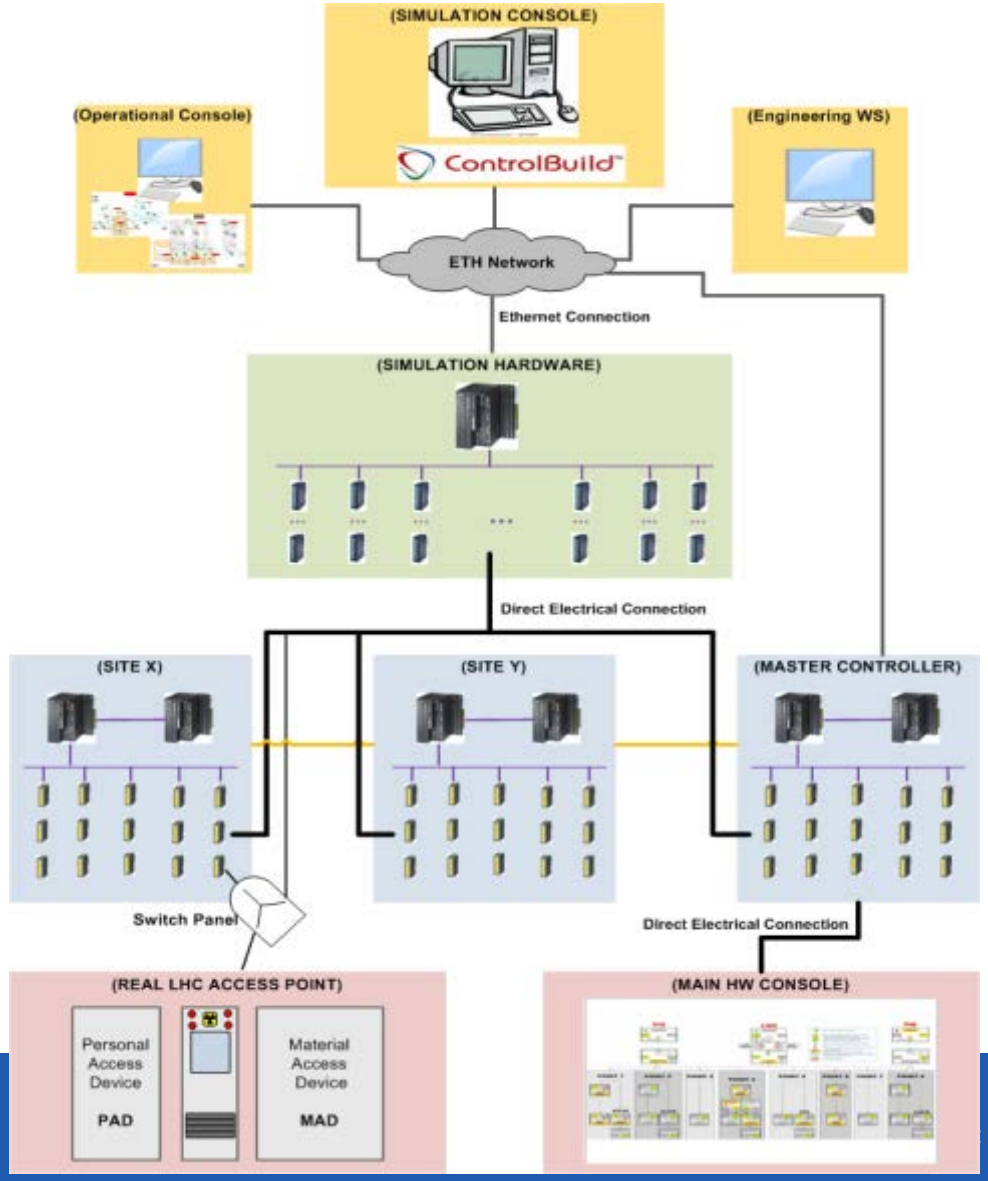

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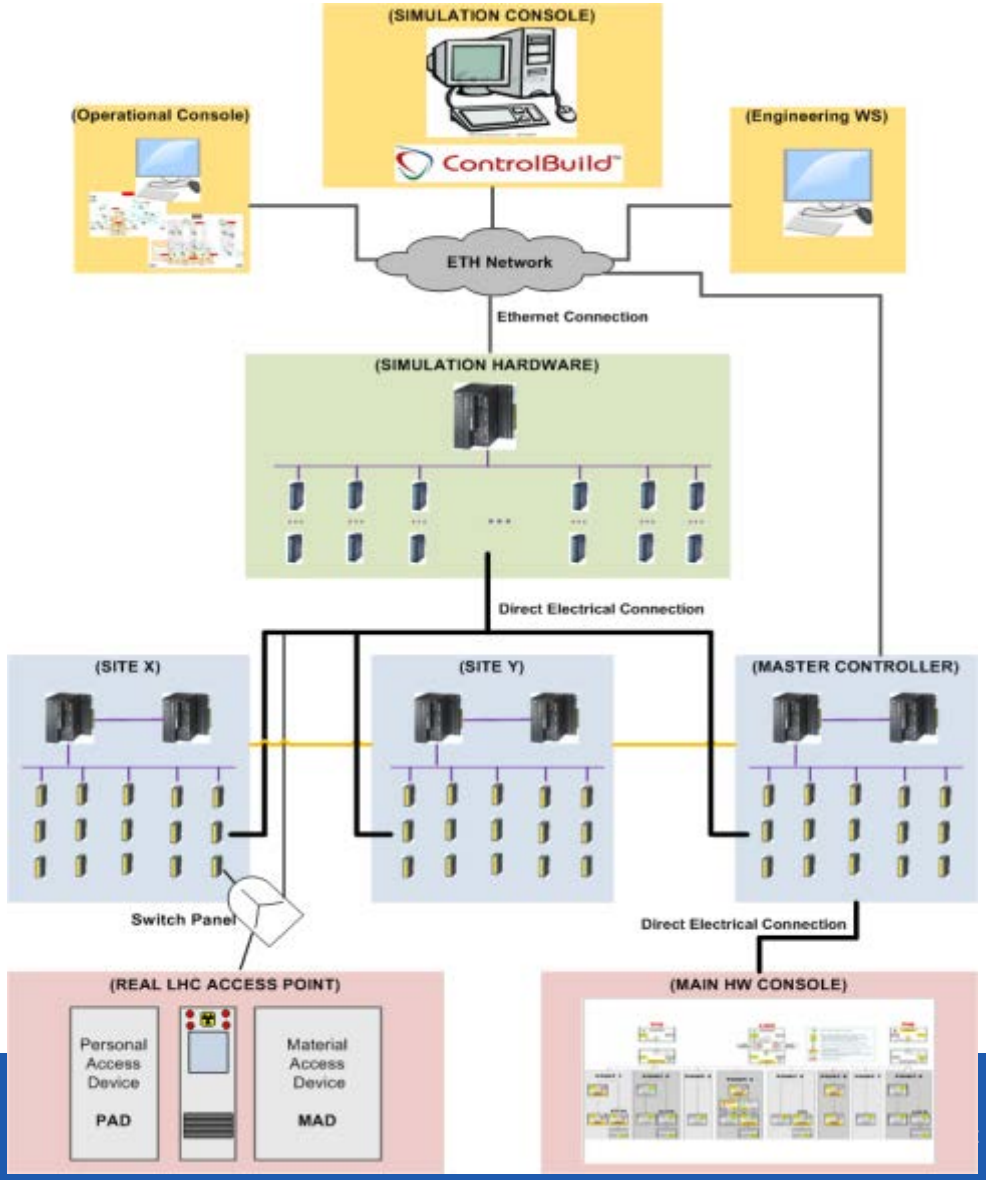

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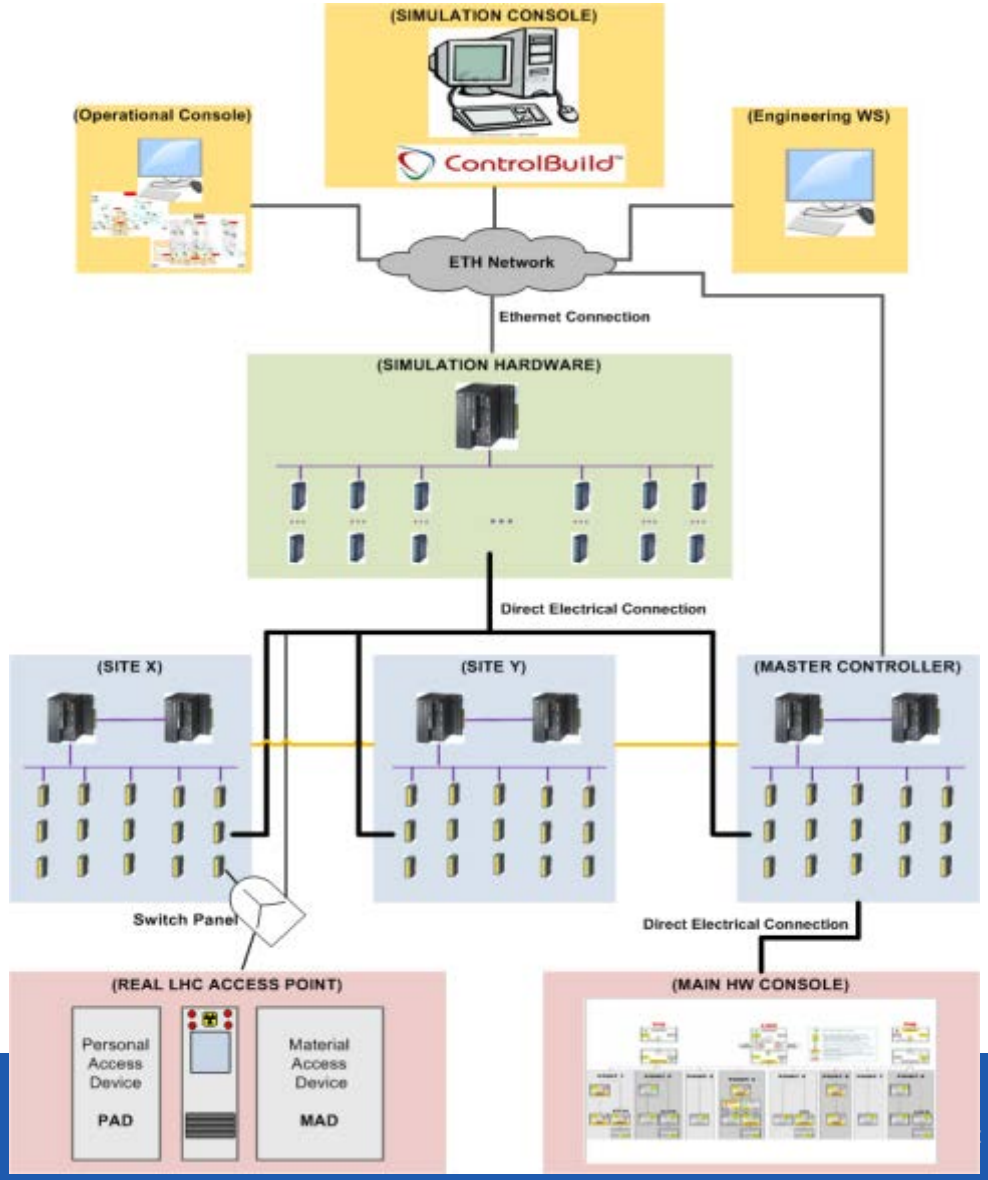

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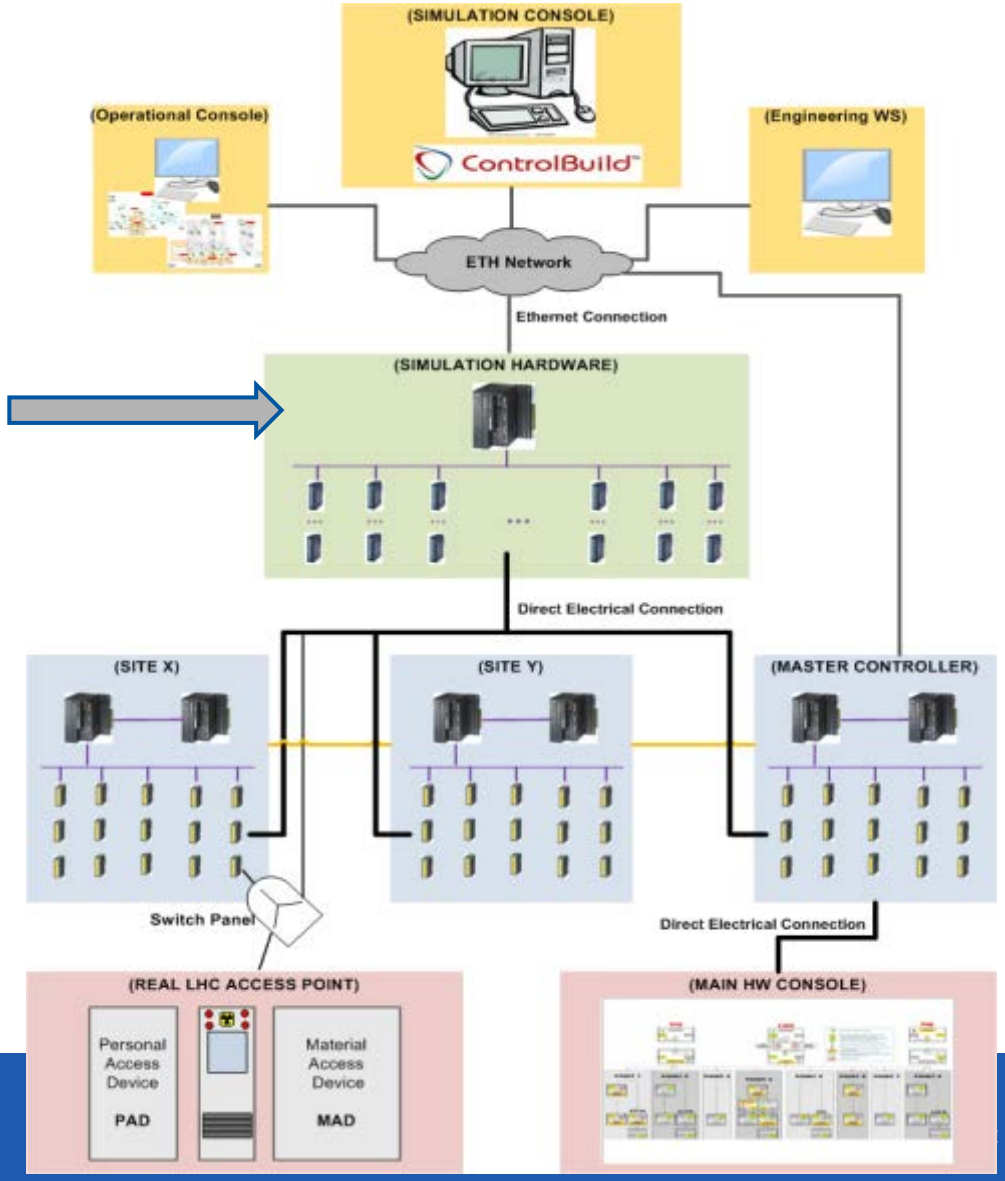

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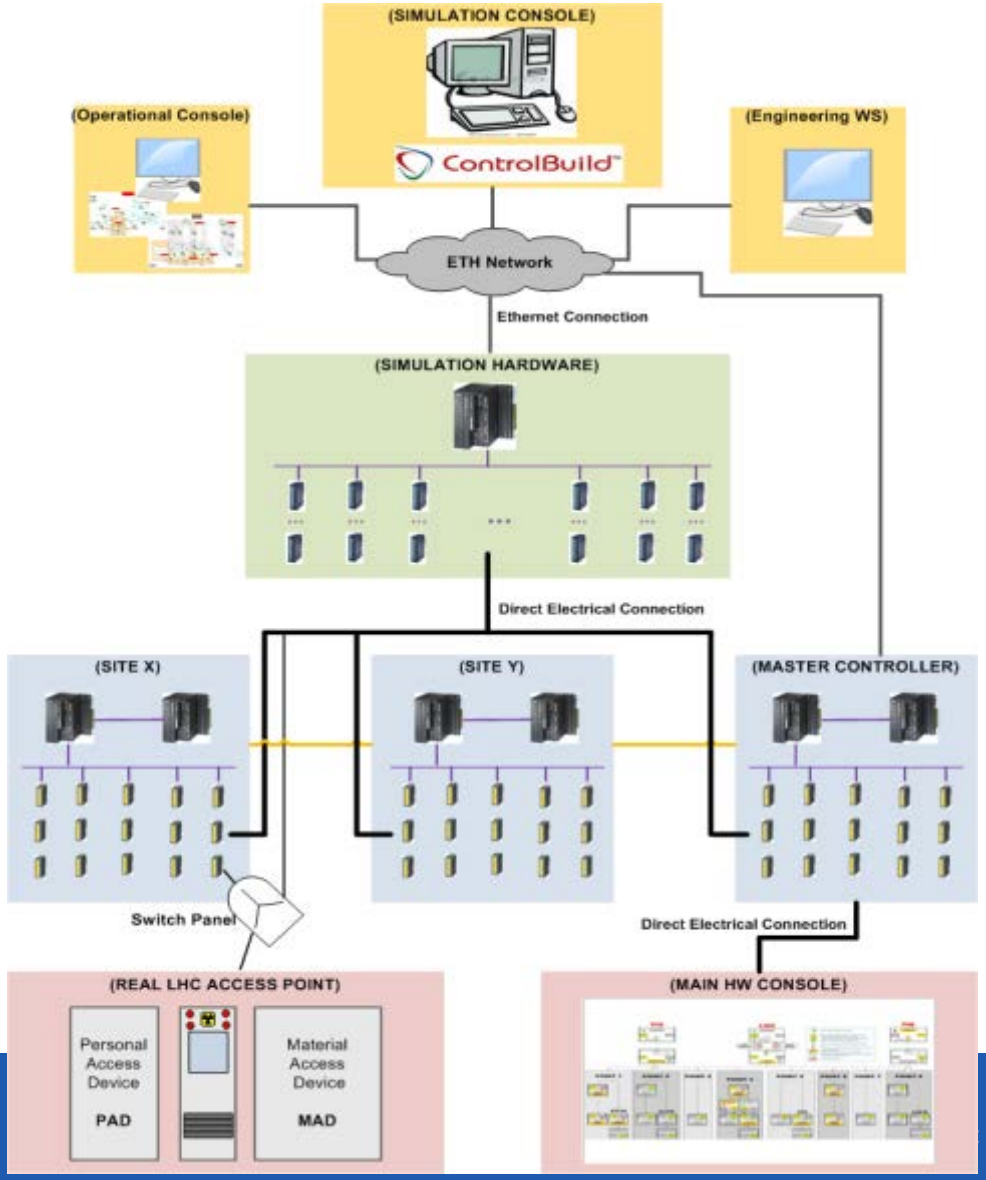

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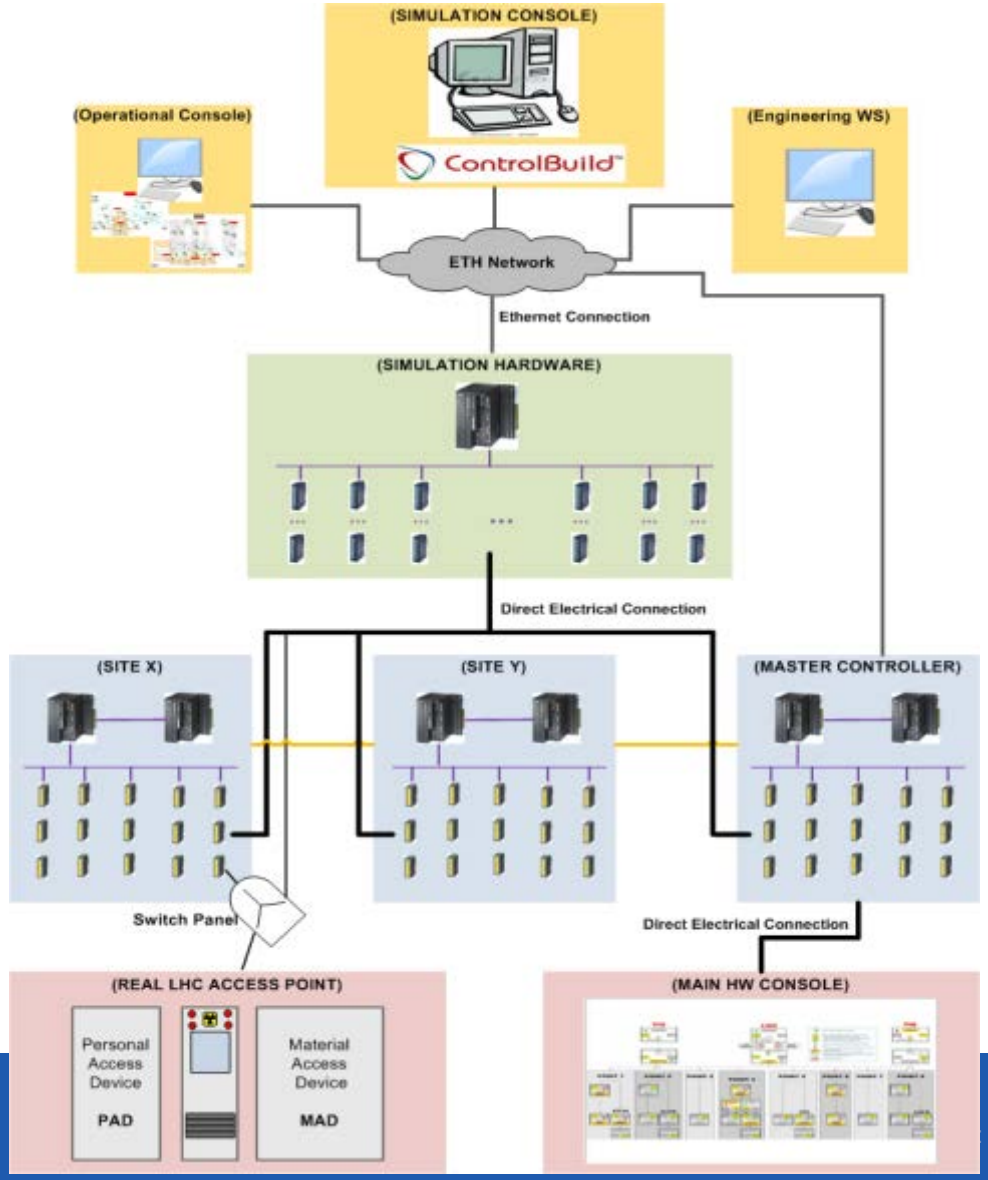

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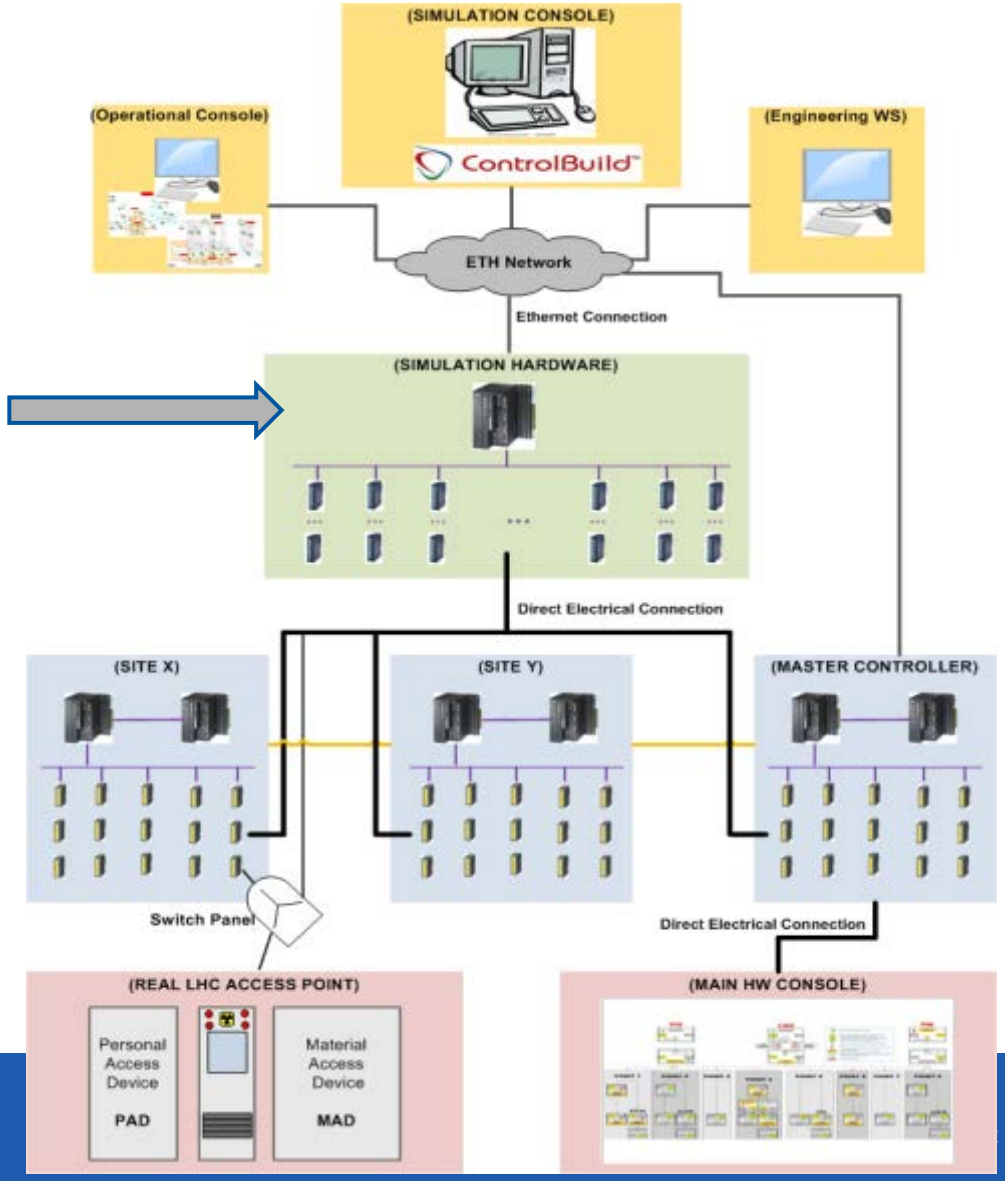

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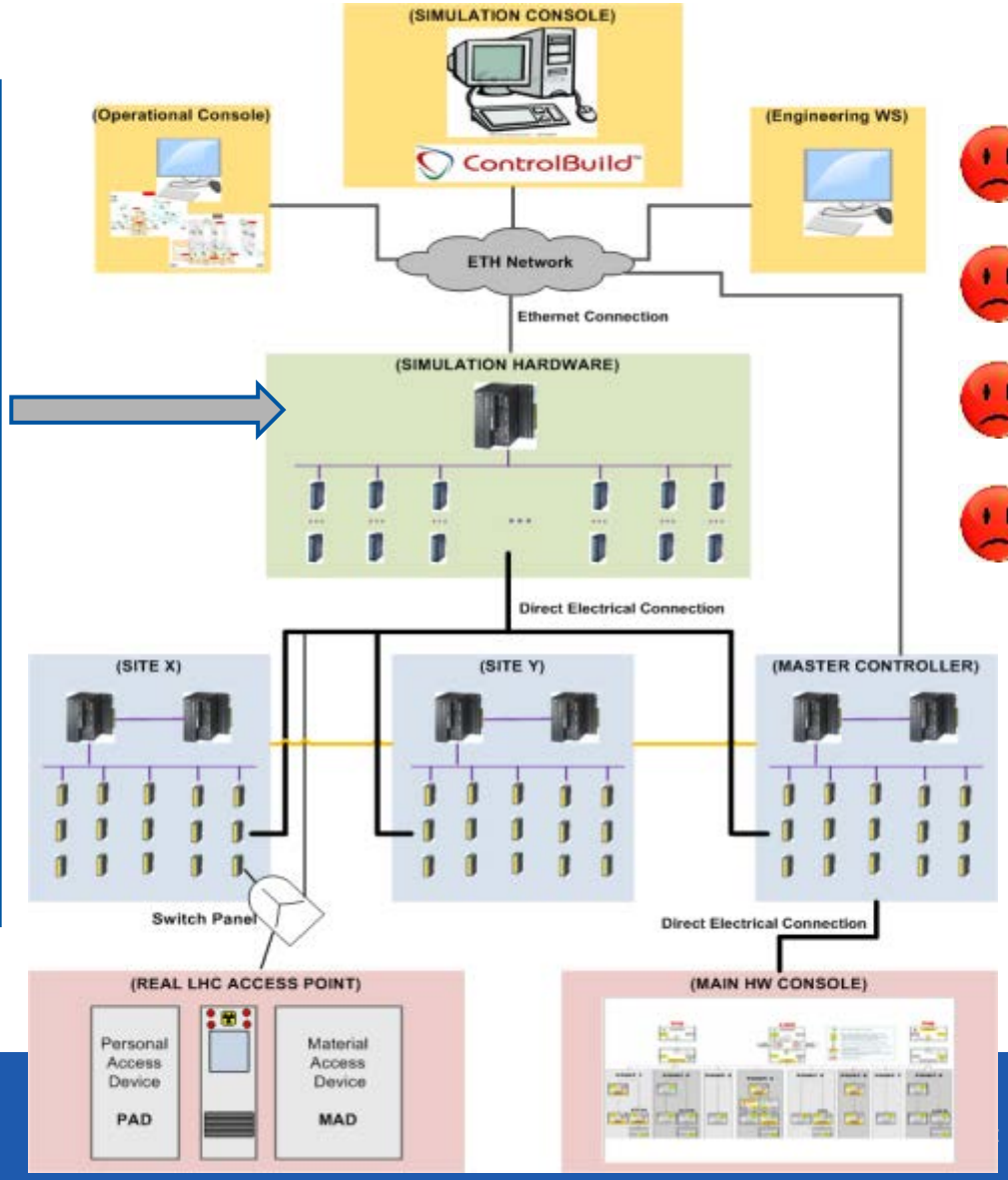

- Low Scalability / Flexibility
- Simulation Constraints
- Hard integration of real equipment
- Platform reconfiguration complex and time consuming