“Taller, bigger, more powerful” Trends in High Energy Particle Accelerators and in related Beam Diagnostics

Hermann Schmickler, CERN-BE-BI

IBIC 2012, Tsukuba

Click OCT 9 1979

At 7-foot-7, Hollinden is a center of attention

By Mark Tomasik
Press Staff Reporter

John Hollinden had posed for so many pictures, he was beginnng to see spots in front of his eyes.

It was Picture Day for the Indiana State University Evansville basketball team yesterday and Hollinden was attracting the interest of most of the photographers.

They photographed him dunking the basketball, touching the rim, laying down, standing up and posing with children. They couldn't find enough ways for him to pose.

Hollinden even found time to grant two television interviews.

Hollinden took all the attention well. He was patient and cooperative. It's something he's trying to get used to, because it's not going to stop for a while.

Hollinden said he grew an inch, to 7-foot-7, over the summer. And he may still be growing. He's the tallest player in college basketball and is sure to be the focus of attention in every city in which the Eagles play this year.

"The attention doesn't bother me," said the former Evansville Central High School player. "If reporters want to talk with me or photographers want to take my picture, it's all right. I just put myself in their position. I'd want to do the same.

"I enjoy meeting people, especially when we're visiting different cities. So I don't think all the attention will be a problem."

ISUE coach Wayne Boultinghouse believes the attention Hollinden attracts will help promote the Eagles program. And he's certain Hollinden can handle the demands on his time.

"John is a super kid," said Boultinghouse. "He knows what to expect. He can live up to the pressures."

Now, the only question is how well he can play. Despite all the hoopla, Hollinden has never played a game for ISUE. He spent two seasons at Oral Roberts before transferring to ISUE last season, but under NCAA regulations he was ineligible to play until this

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...expect too much ...e terms, but he's

...h thought to the ...season.

... — maybe a lot ...o it all by myself. ...o help."

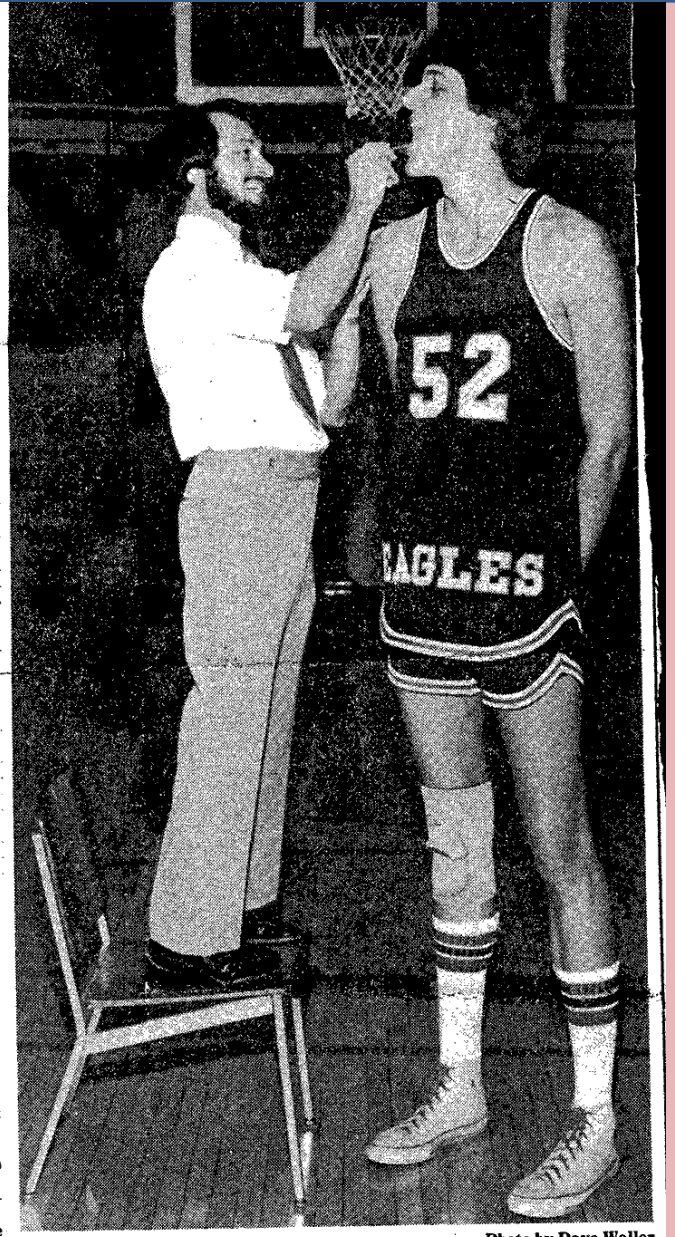
...ting program to

...hin," said Boult-

...ls. Boultinghouse ...ed he should be at 250 or 260.

"But I haven't been able to put on weight, no matter what I do. Still, it's starting to come. It may take a while, but I'm starting to mature physically."

The Eagles will begin practice Monday. They open the season Dec. 1 at home against Hillsdale (Mich.).



—Photo by Dave Waller

Ron Rheinlander, the Indiana State University Evansville team dentist, still has to stretch his toes despite standing on a chair to give John Hollinden a check up. Hollinden, the 7-foot-7 center, was the center of attention at the Eagles' basketball Picture Day.

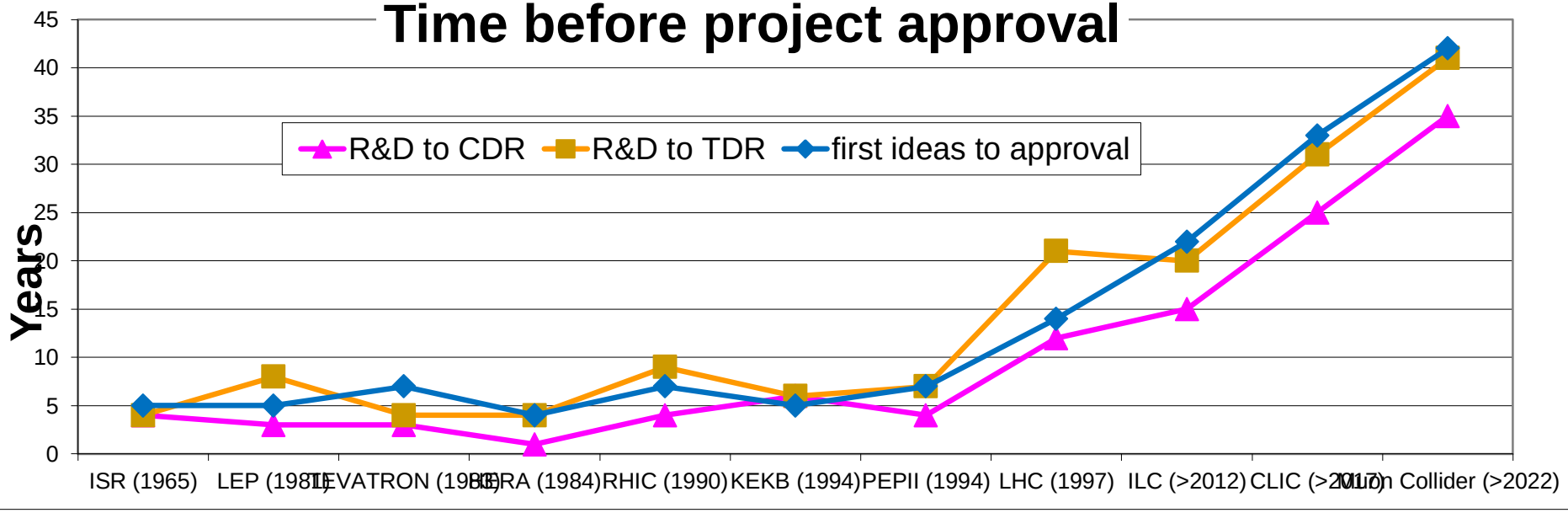
Taller

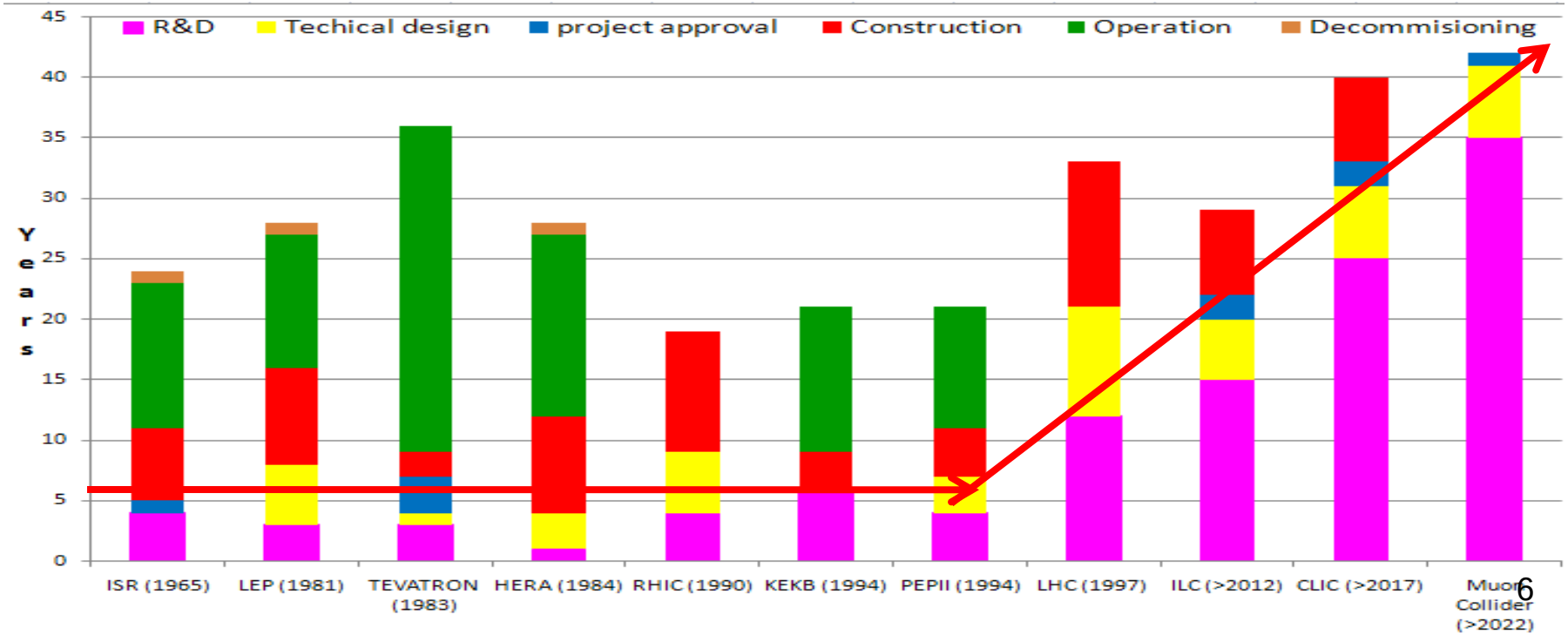

Bigger


More Powerful

Outline

- High Energy Accelerator Projects (> 10 GeV)
- Challenges for Beam Instrumentation
- Conclusions


Time before project approval
Years
R&D to CDR
R&D to TDR
first ideas to approval
ISR (1965)
LEP (1981)
TEVATRON (1983)
HERA (1984)
RHIC (1990)
KEKB (1994)
PEPII (1994)
LHC (1997)
ILC (>2012)
CLIC (>2017)
Muon Collider (>2022)


R&D
Techical design
project approval
Construction
Operation
Decommisioning
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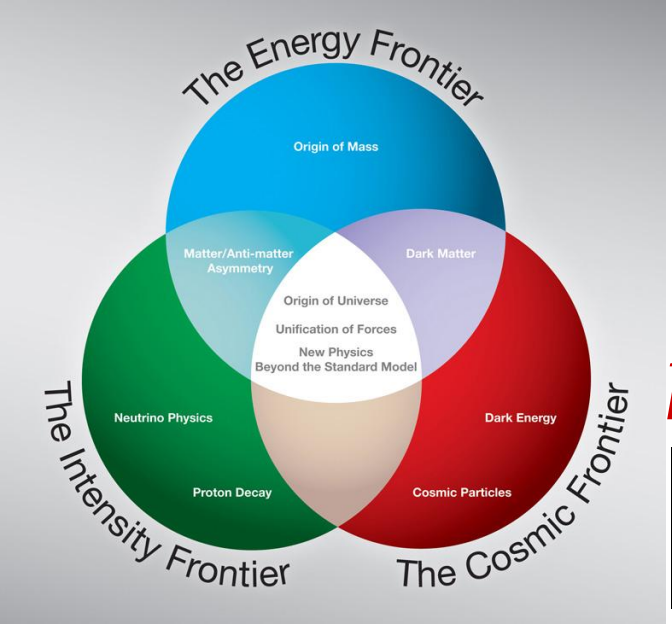
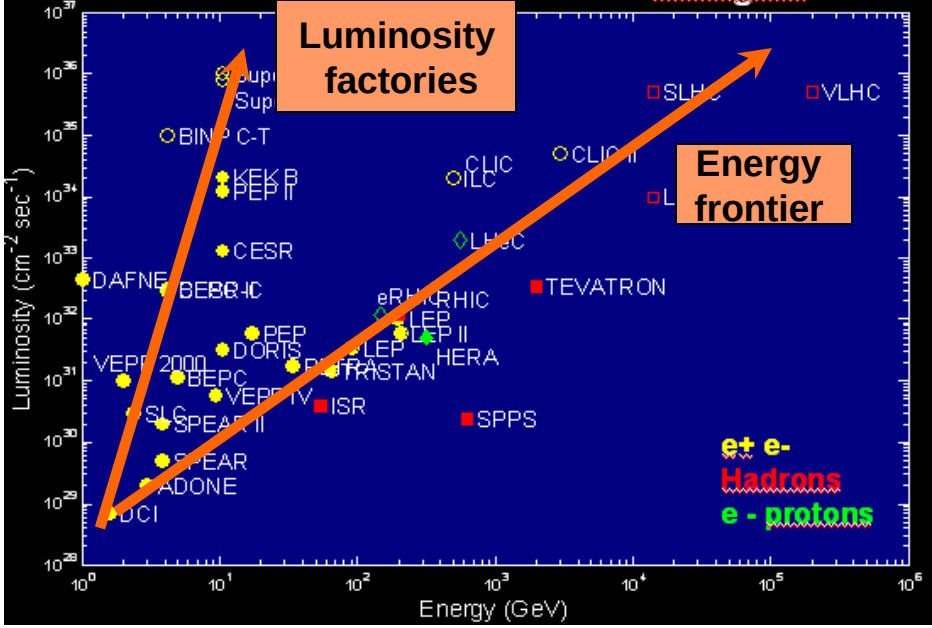
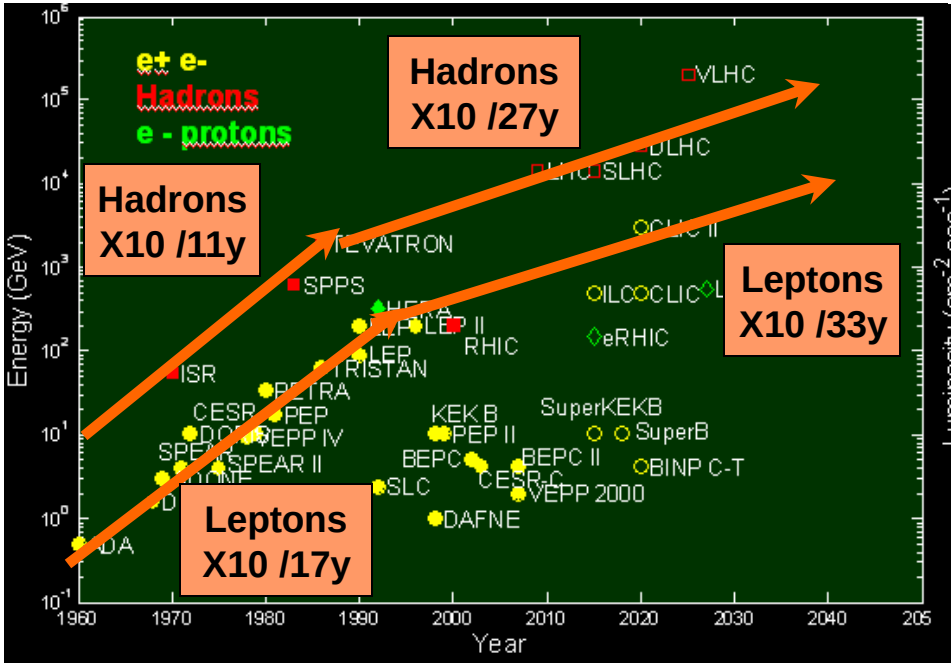
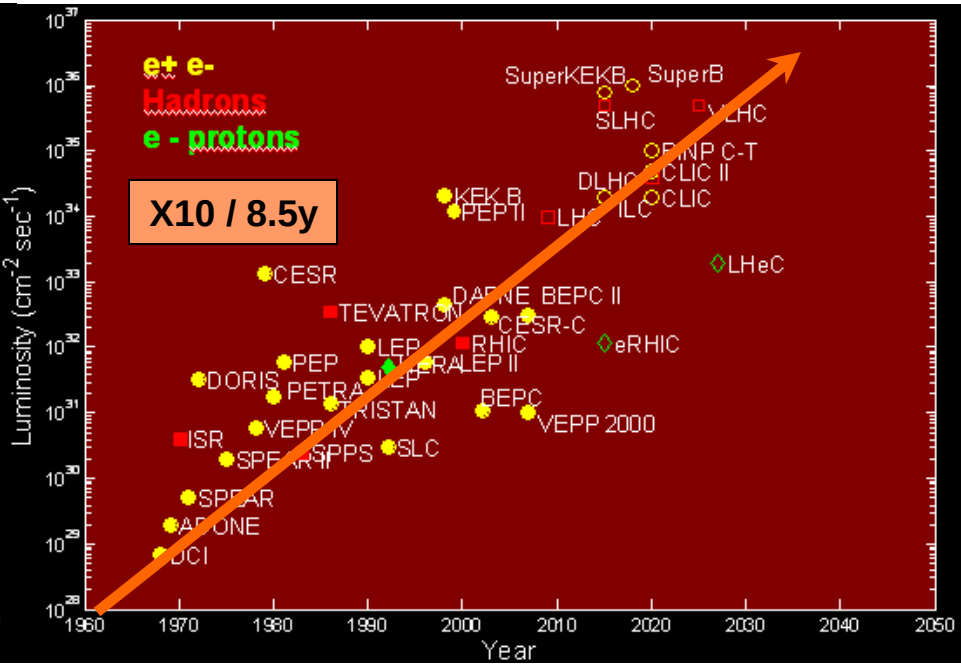


Trends of HEP facilities

Courtesy of M.Biscari EPS-HEP09



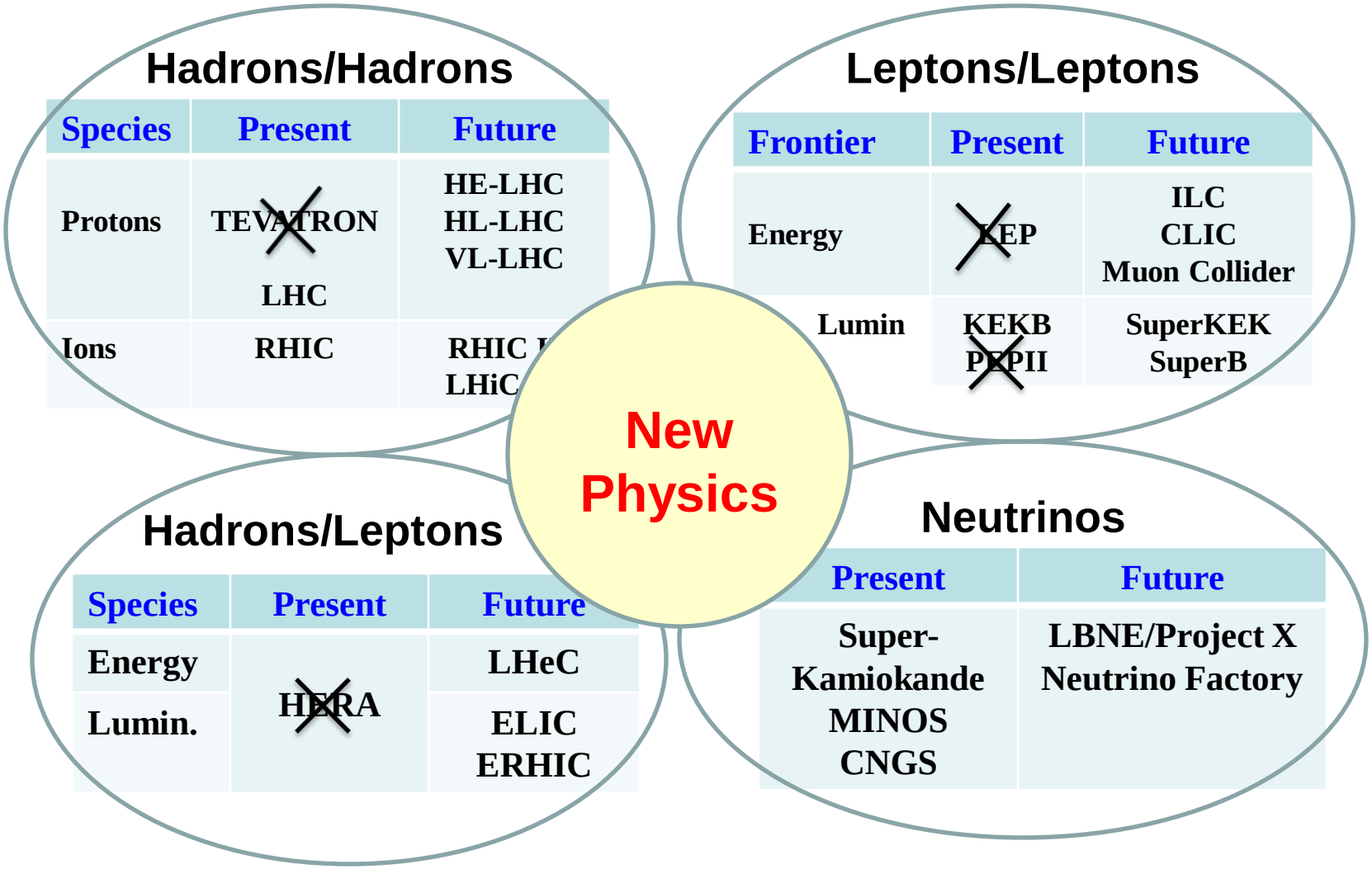




Towards Energy frontier

Towards Luminosity frontier

Complementary facilities of various particle species



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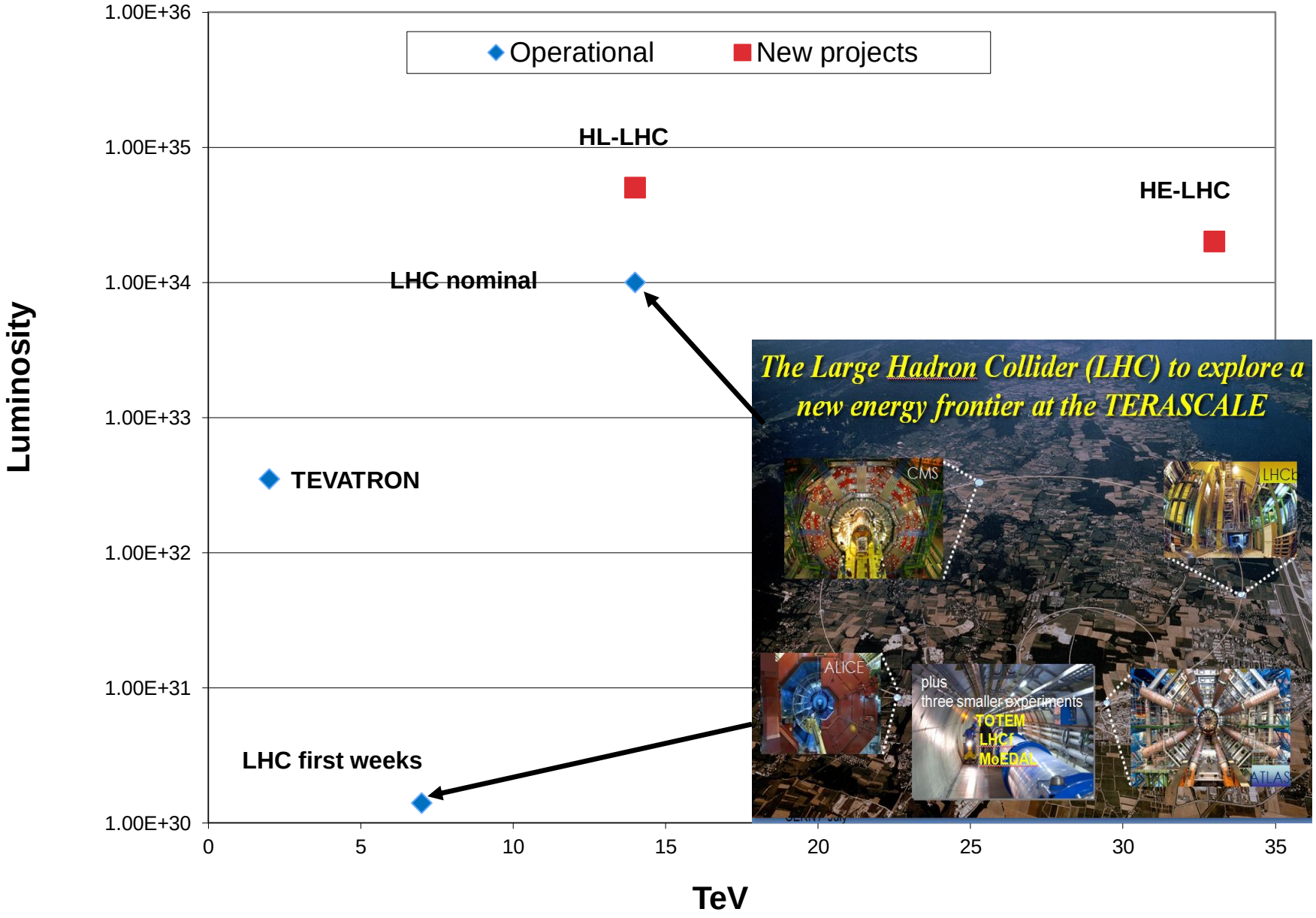
Proton Colliders @ High Energy Frontier



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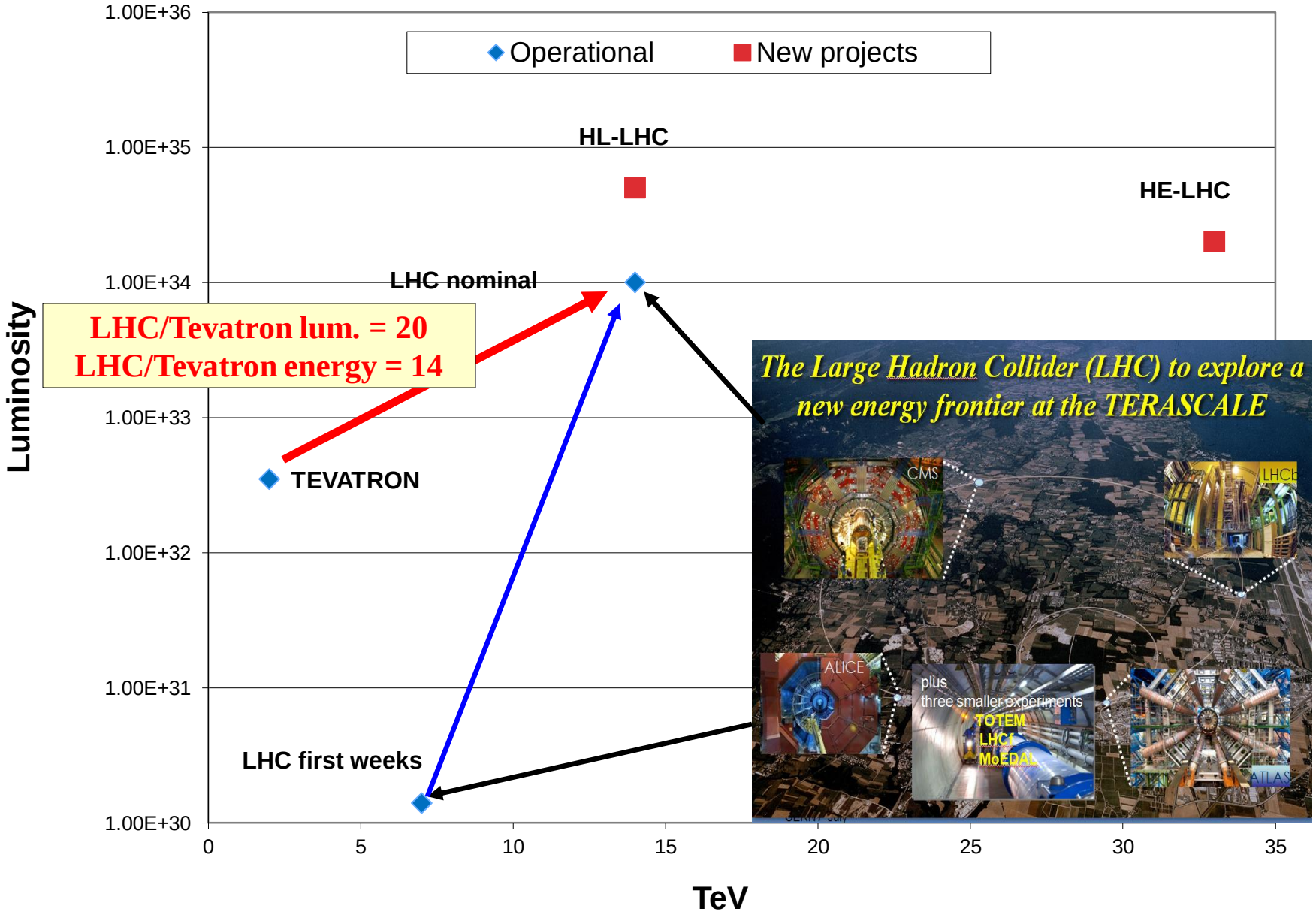

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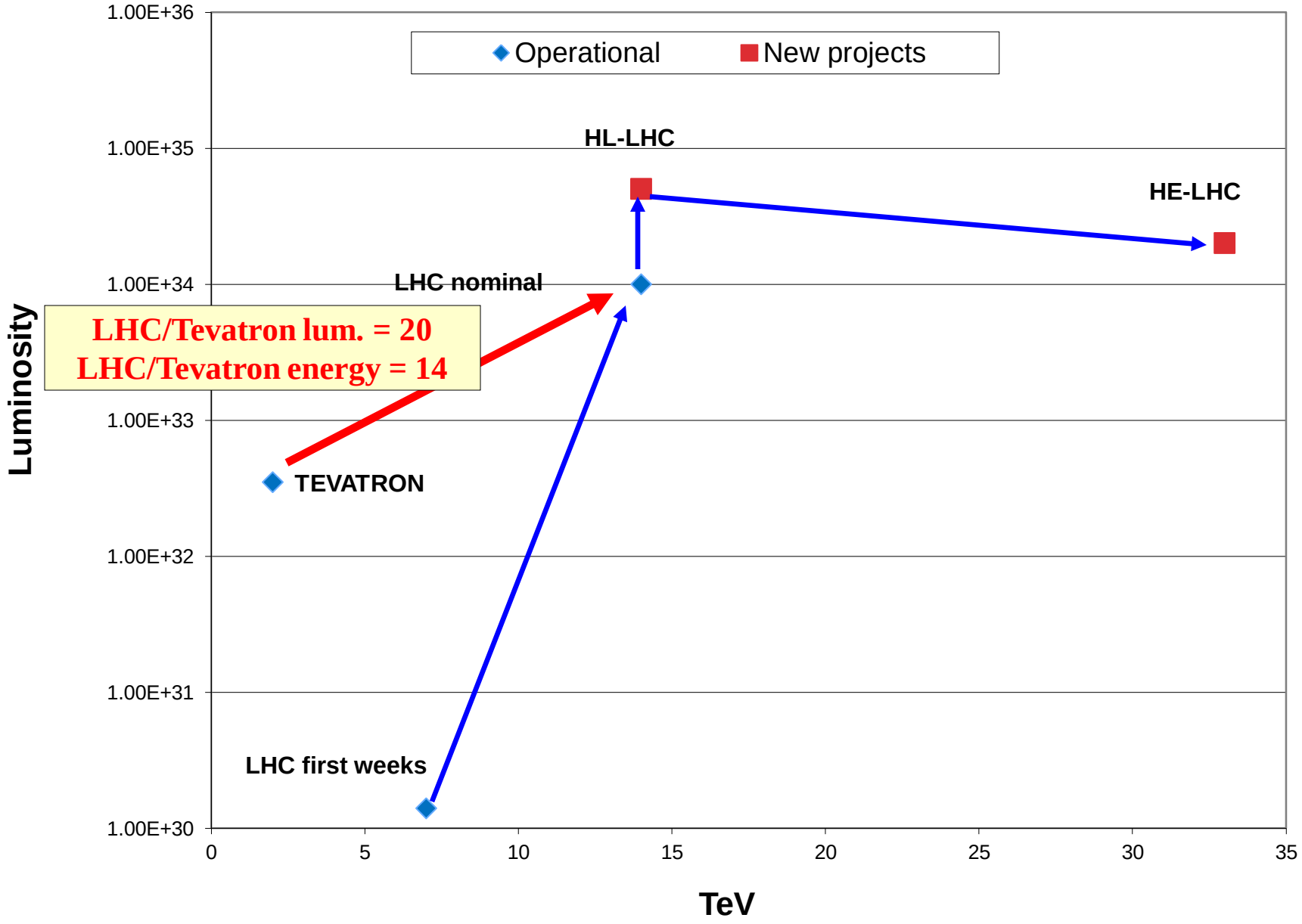

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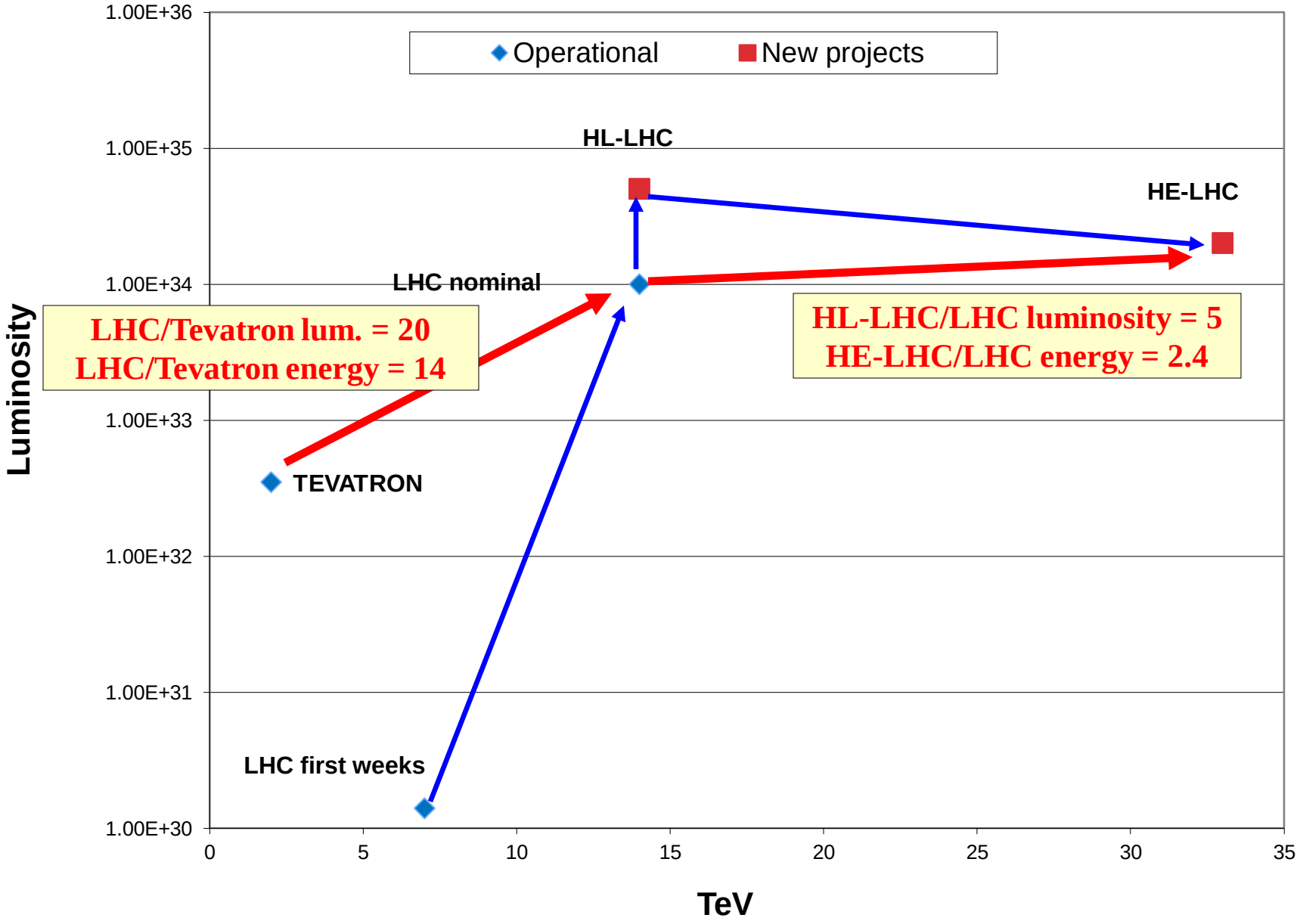
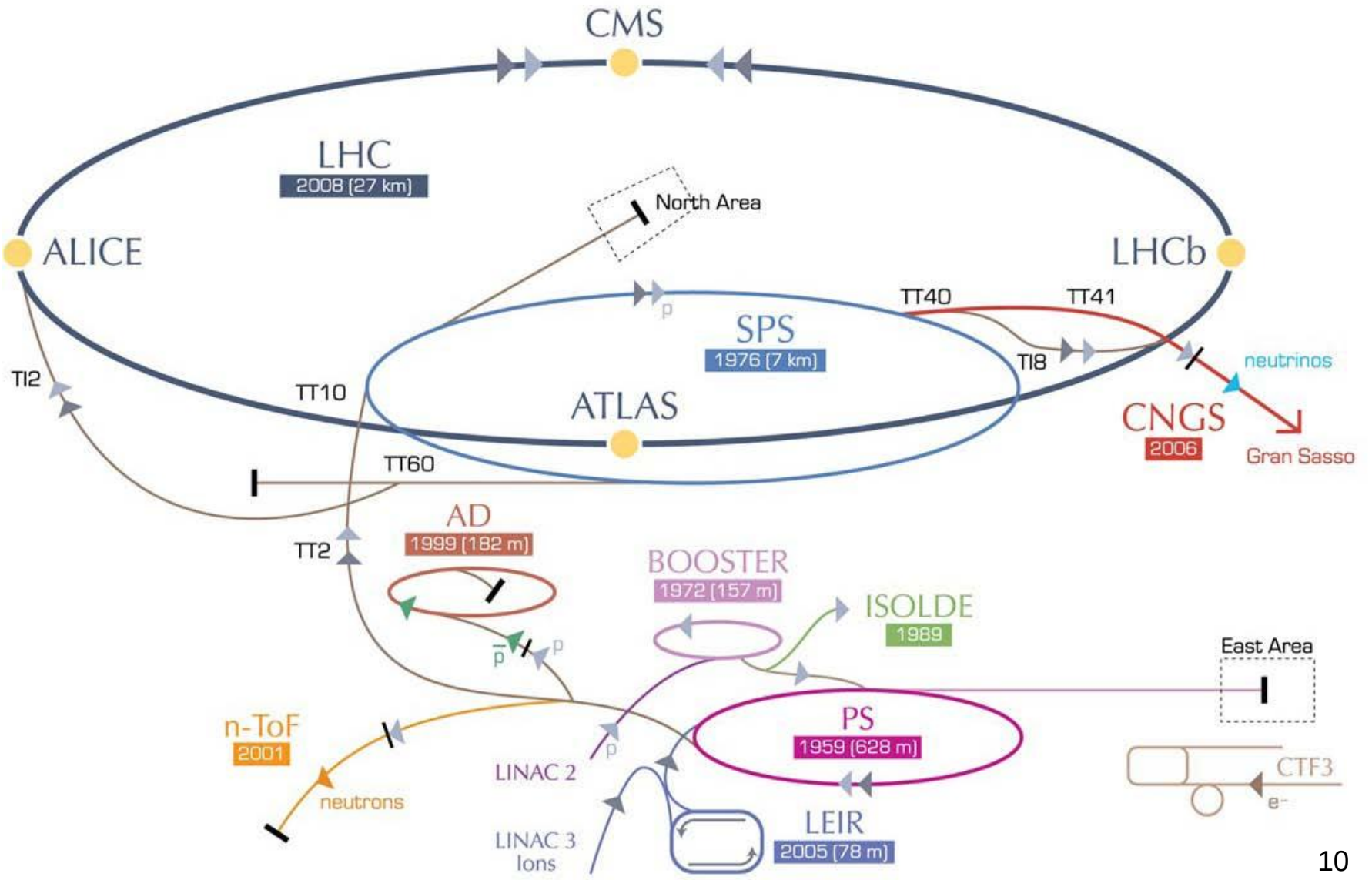


HL-LHC – LHC modifications



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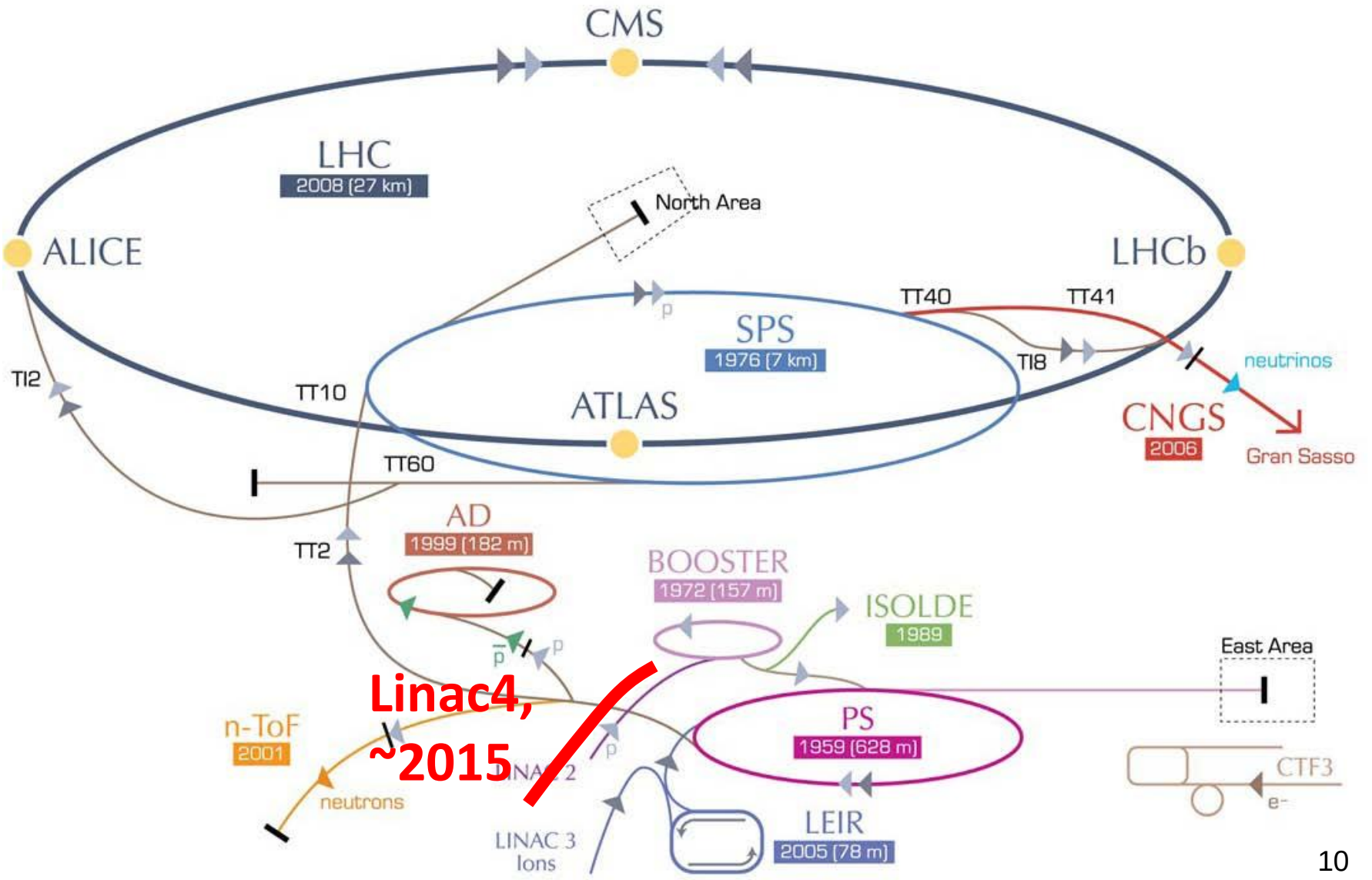

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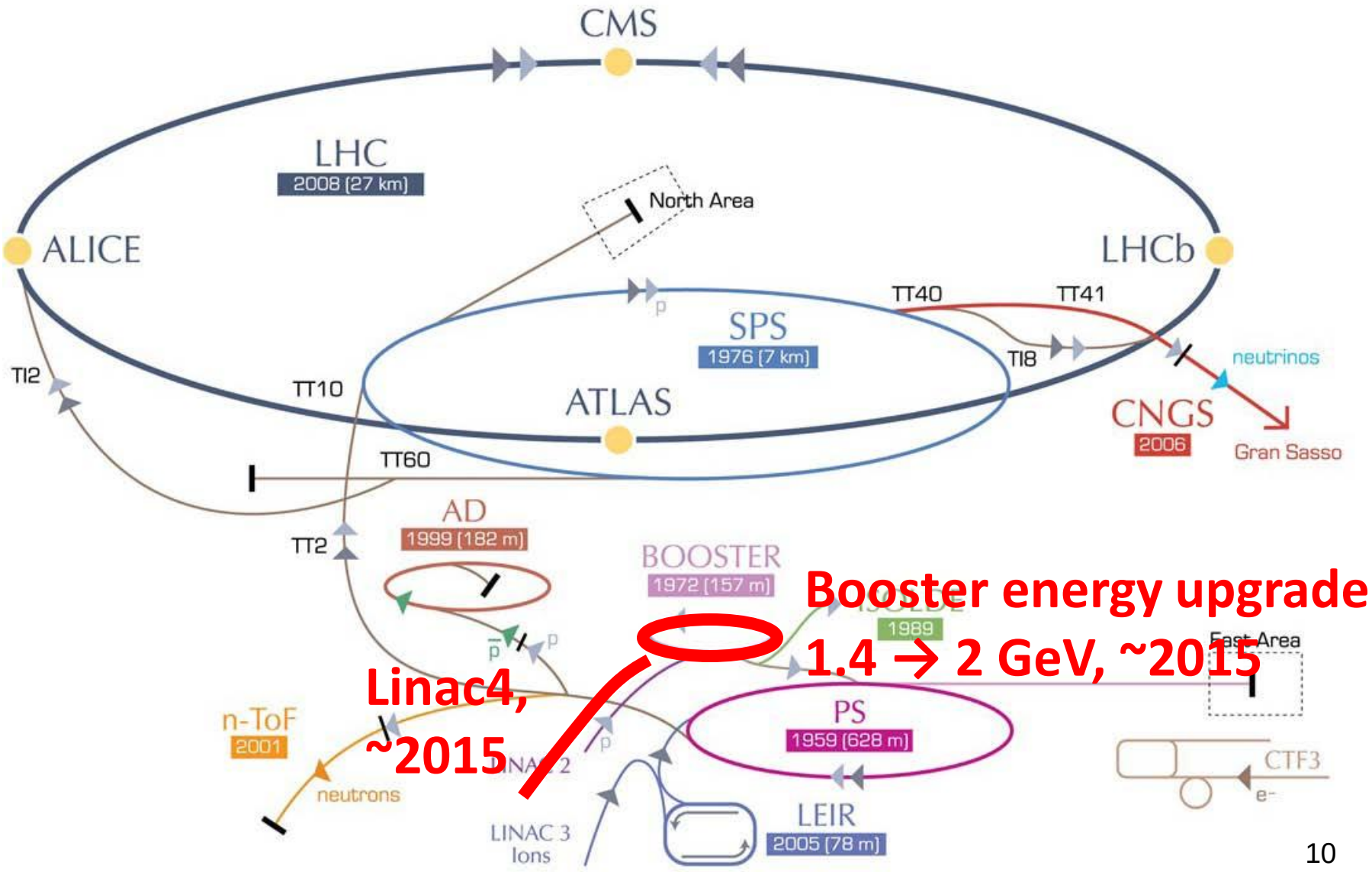

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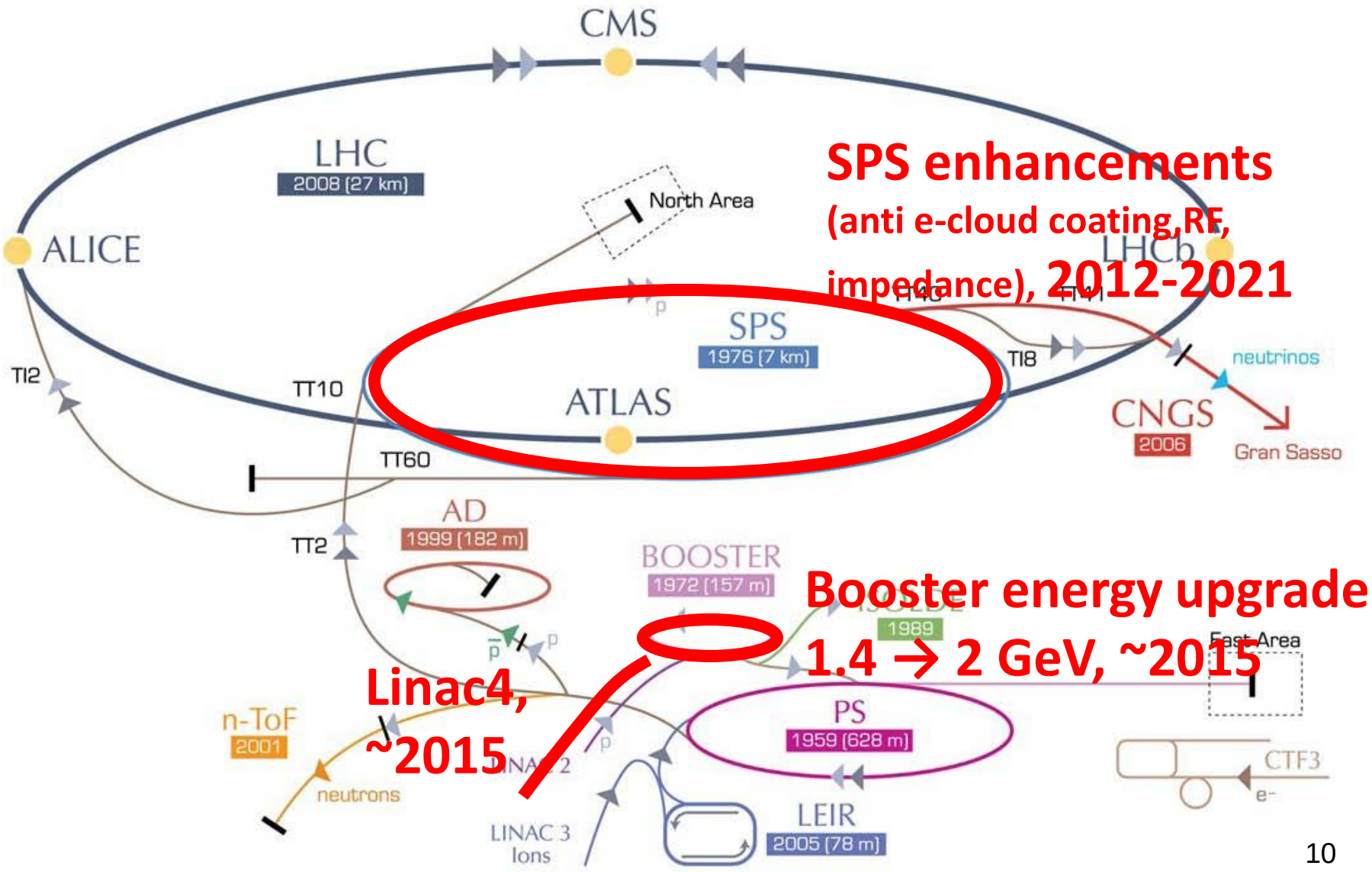

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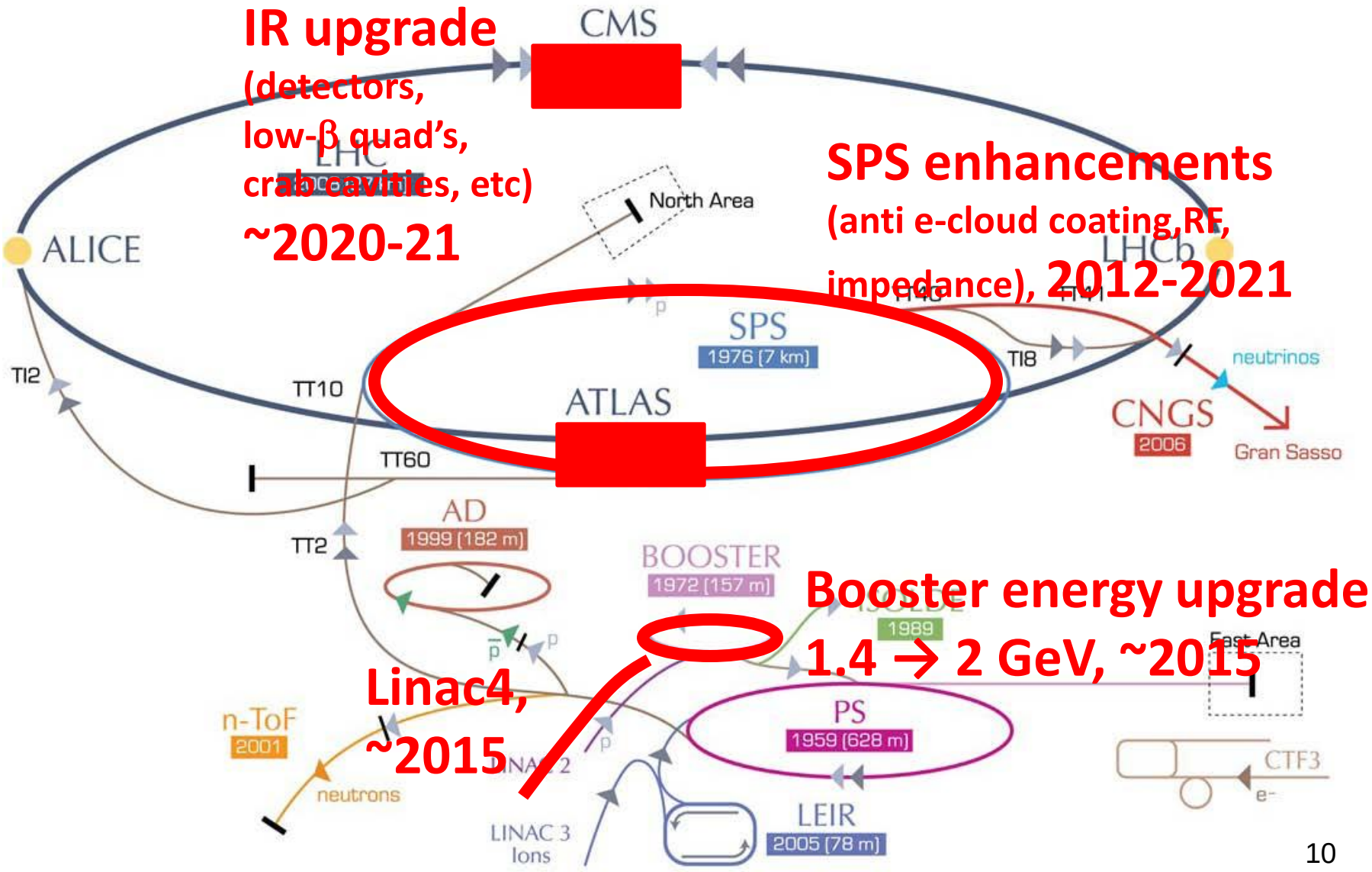

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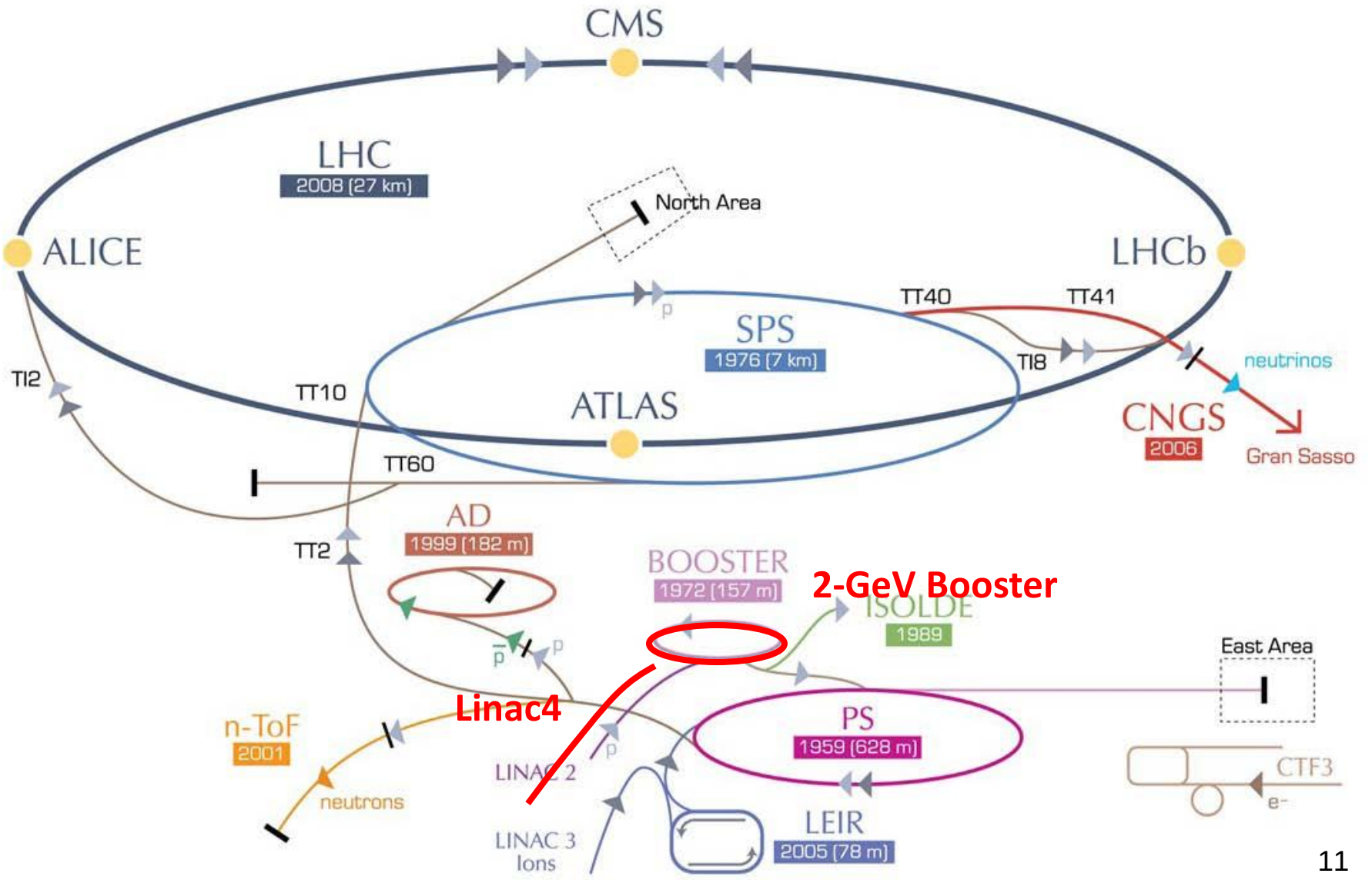

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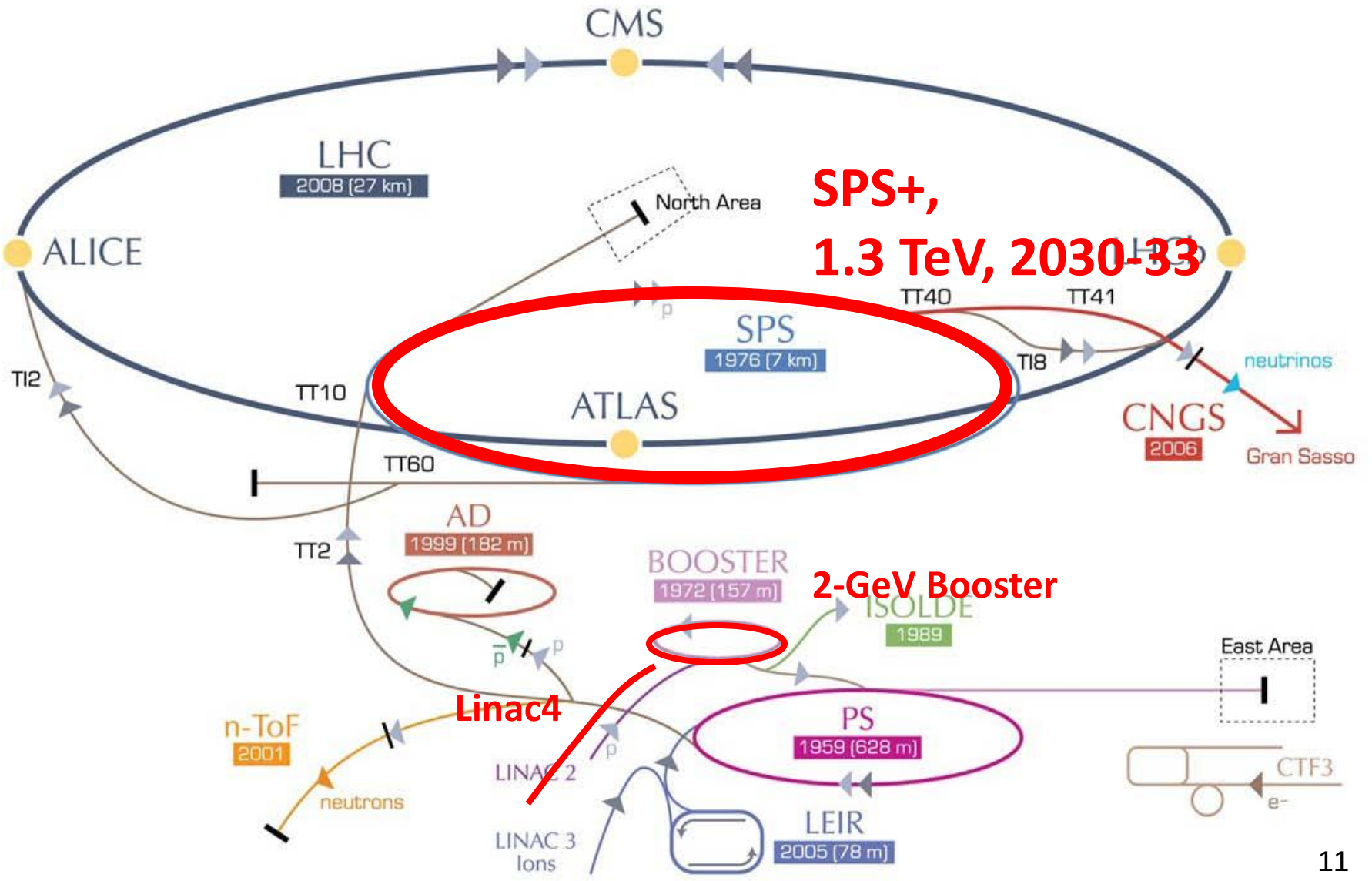

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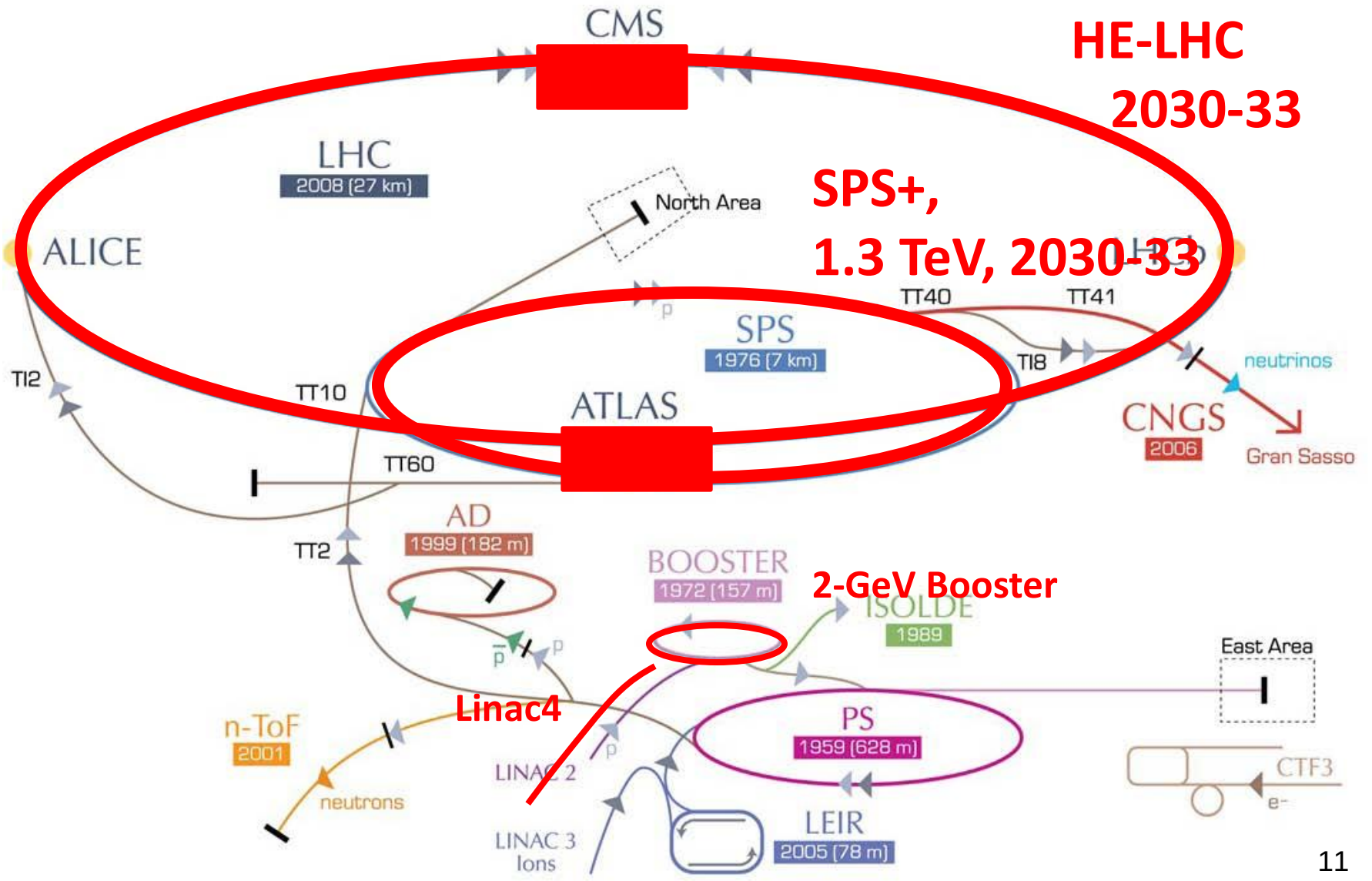
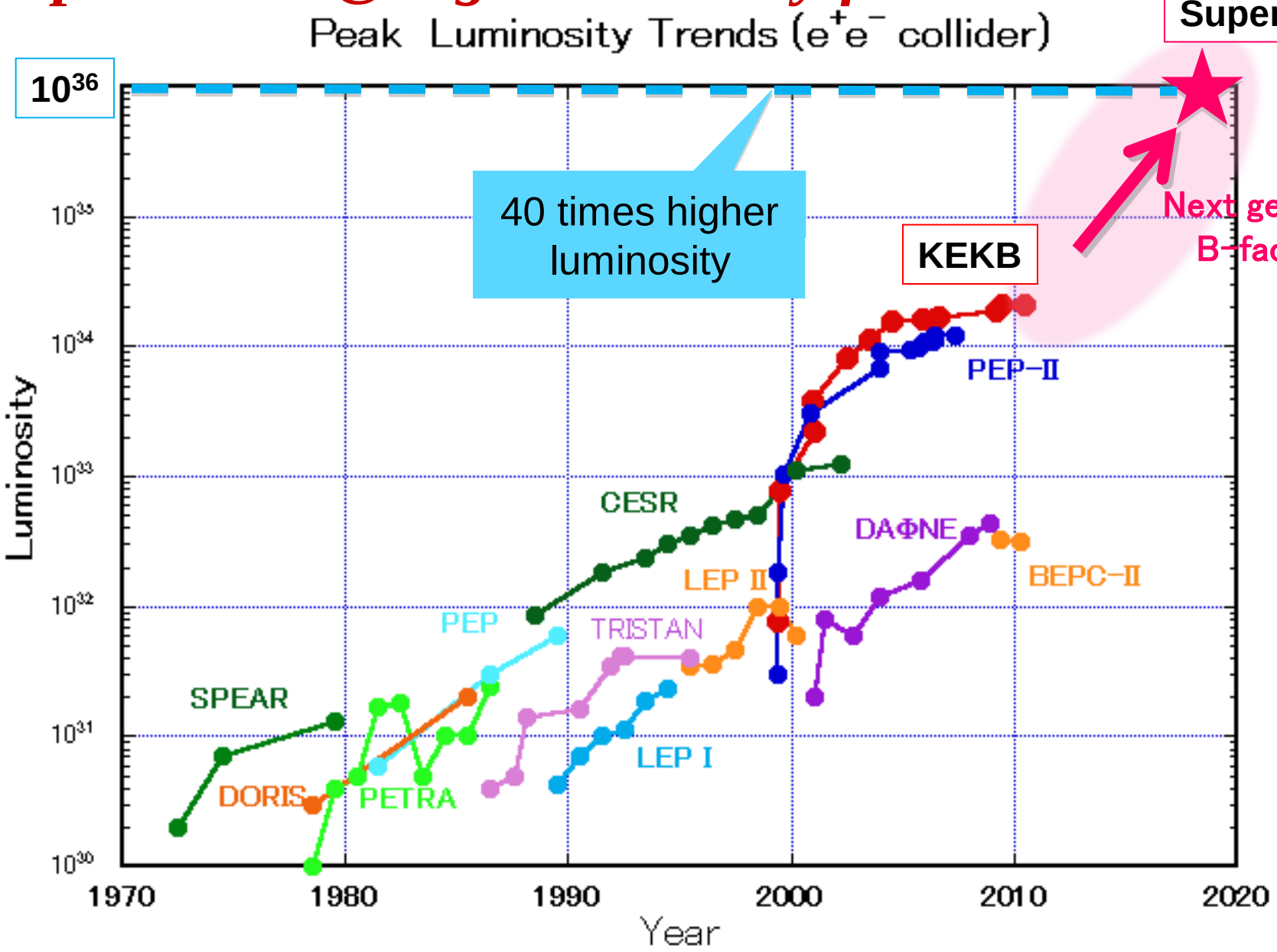


LHC upgrade issues and R&D

Issues	High Luminosity LHC	High energy LHC
Super-Cond. quadrupoles	15 T for low beta @IR	for IR and Ring
Super-Conducting dipoles		20 T (Nb3Sbn, HTS)
Fast cycling SC magnets		For 1.3 TeV injector
Mini beta operation	Chromatic correction and large aperture of matching section	Cryogenic handling of SR heat load
Crab cavities	Novel compact design compatible with machine protection	
Machine protection (500 MJ beam power)	Collimation with high effic, & reliability, low impedance	Cryogenic handling of SR heat load
Luminosity leveling	Control q_c , V_{crab} or b*	Control emittances
Dynamic vacuum		Synchrotron radiation

B Factories (PEPII&KEKB) to SuperB and SuperKEKB @ high luminosity frontier



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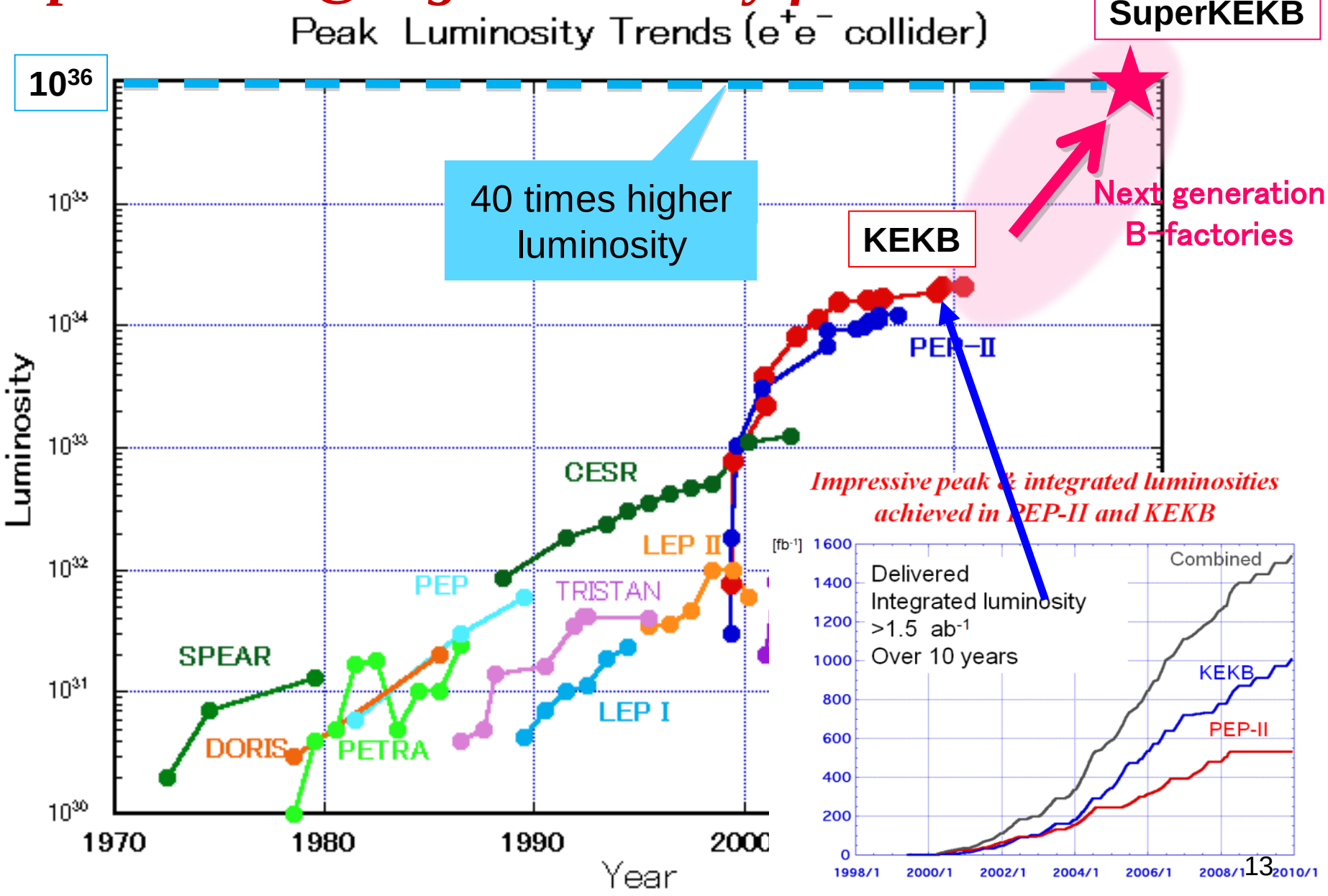


Novel "nanobeam scheme" (P.Raimondi/LNF)

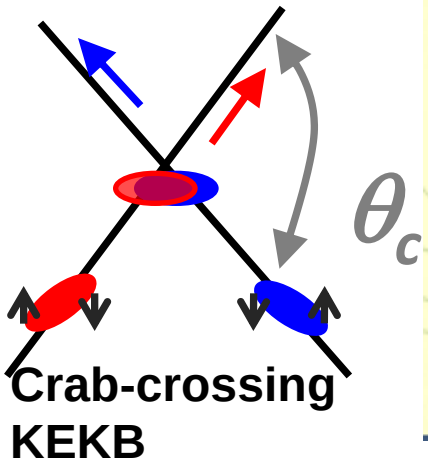
Standard design based on larger beam currents and stronger focusing of short bunches with crab cavities at IP:

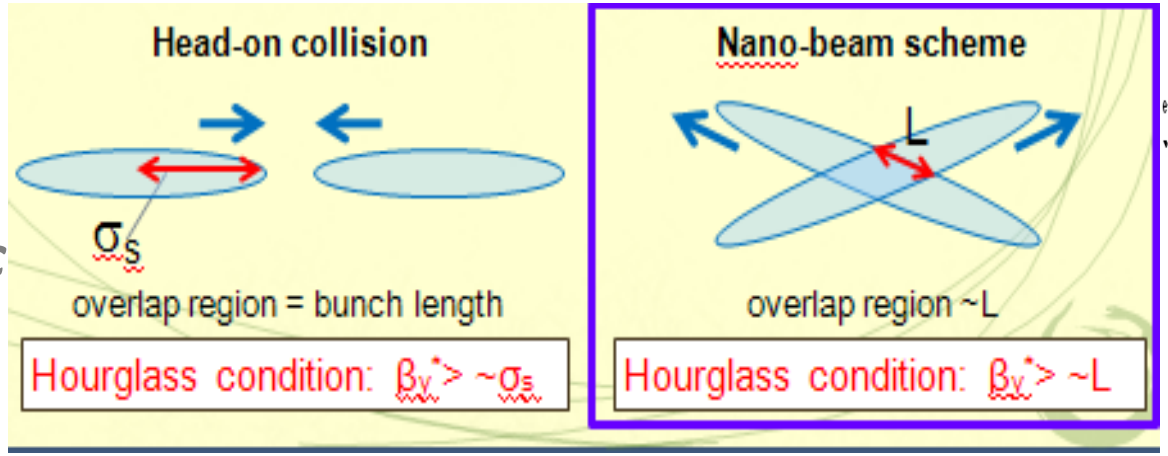
⇒ larger power consumption, high ξ_y, Challenges from HOM heating, Bunch lengthening by coherent Synchrotron Radiation (CSR).

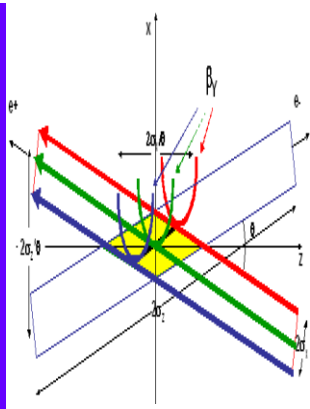
Very small beam spot-size (nm) with large crossing angle (LPA)

Inspired from Linear Colliders Beam Delivery developments

Long bunches (high charge) and collisions at highly focused region only







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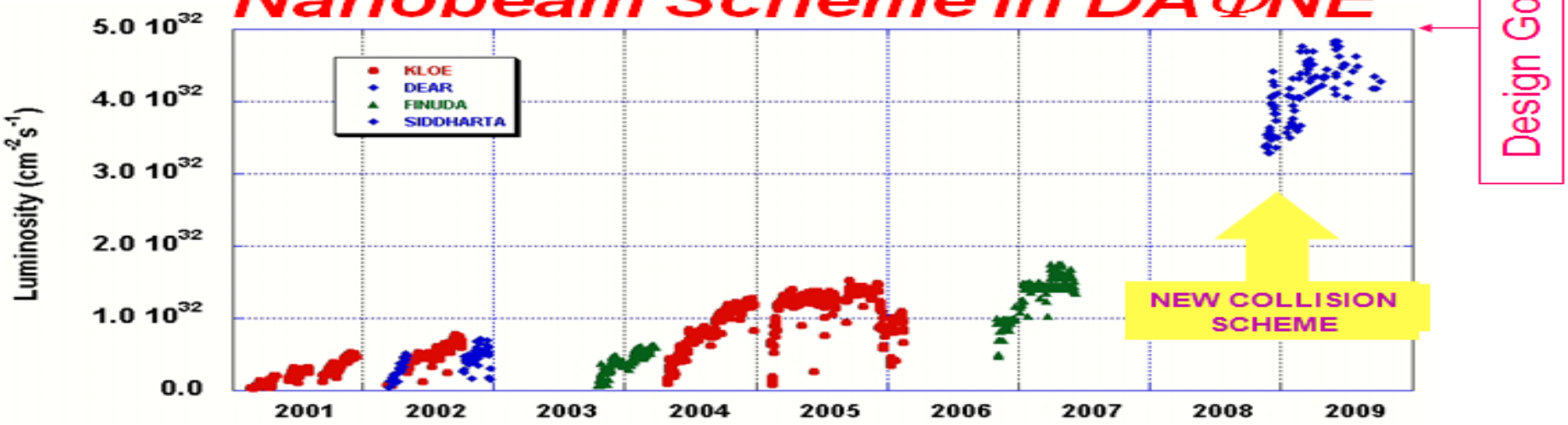
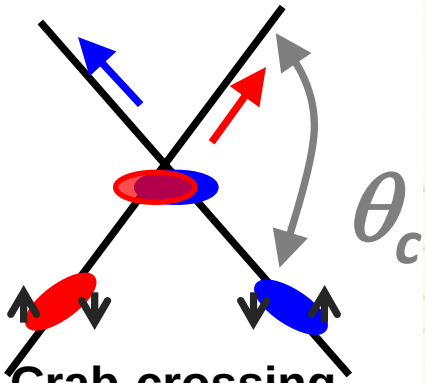
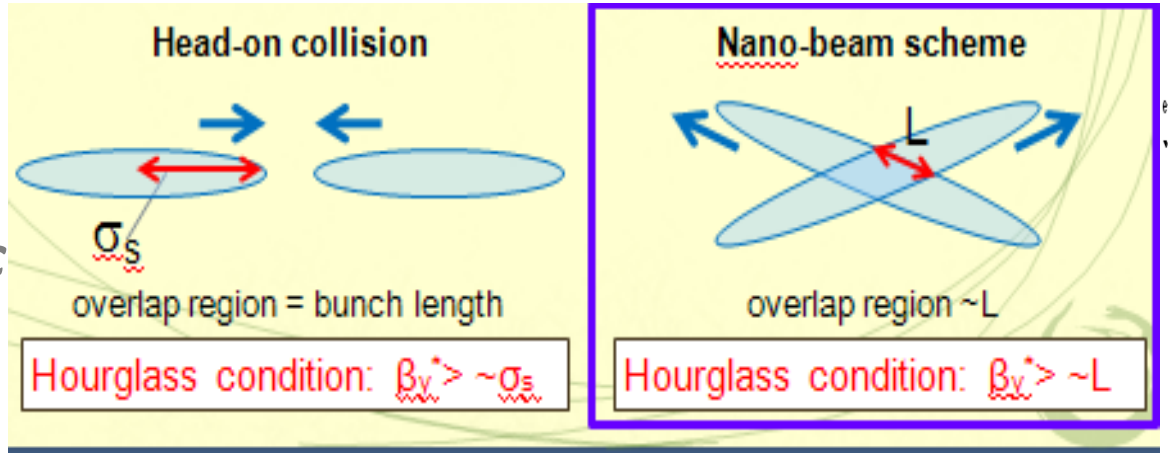
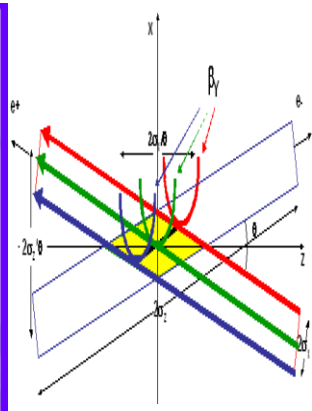
Successful demonstration of Nanobeam Scheme in DAΦNE

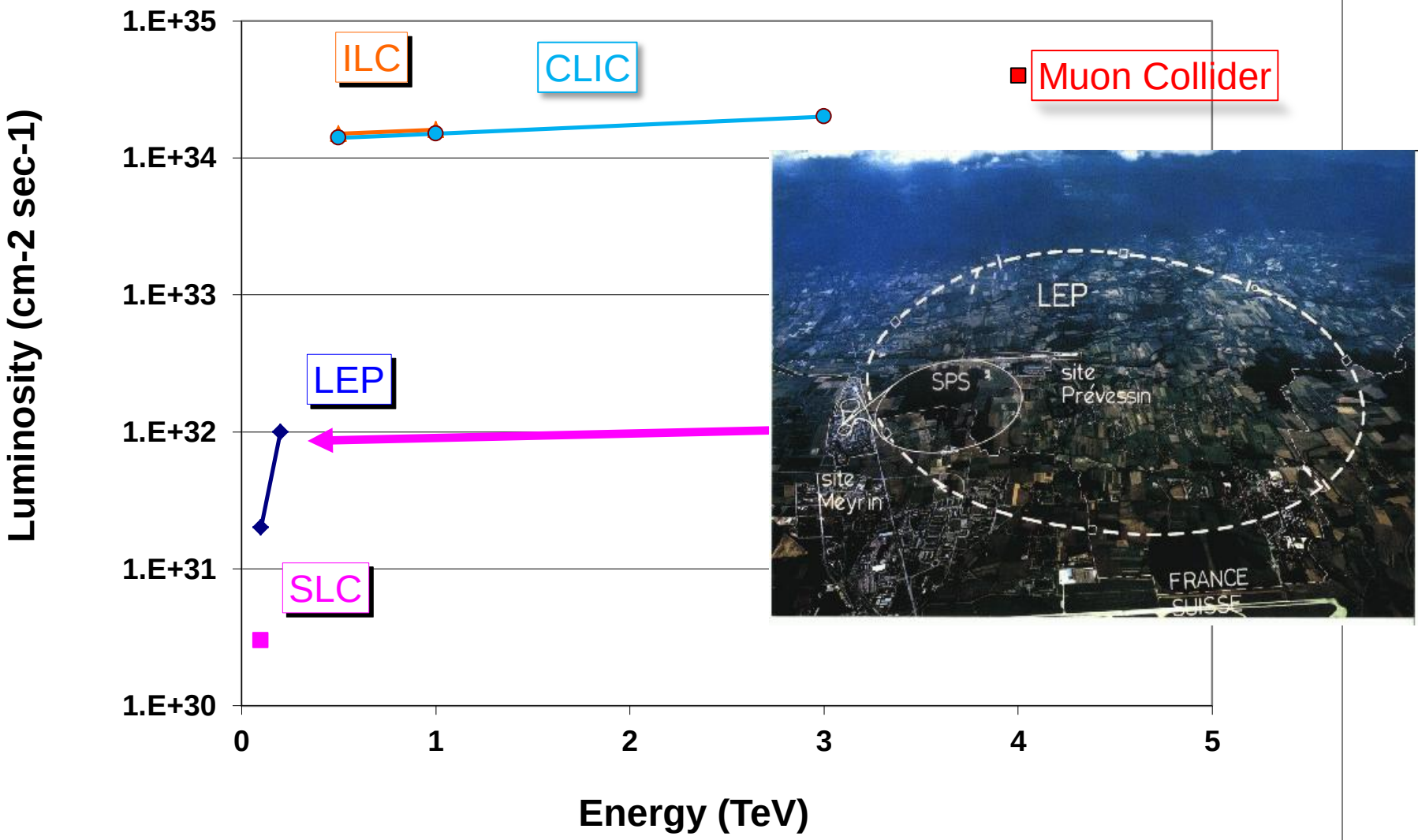








Lepton Colliders at the Energy Frontier



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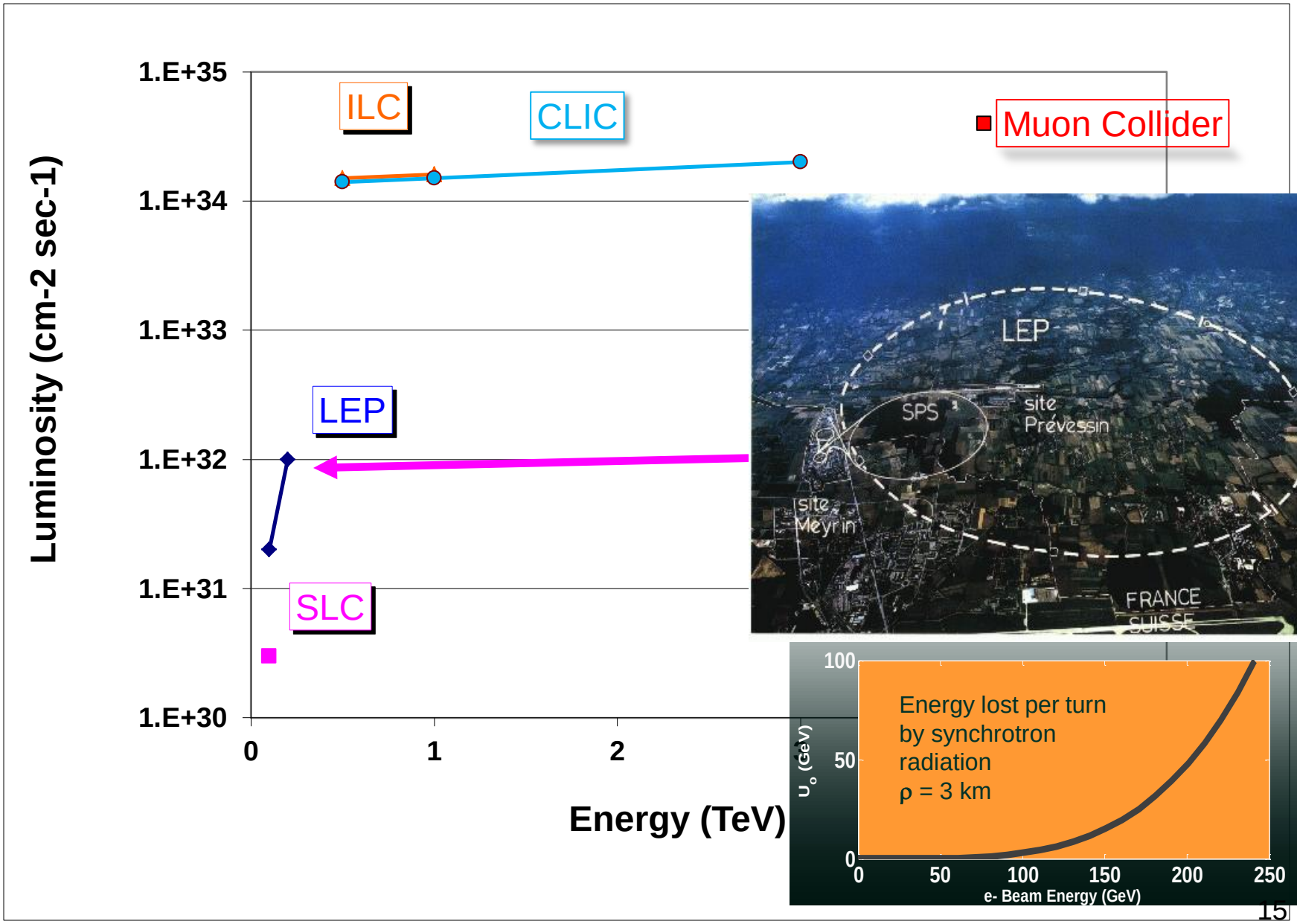

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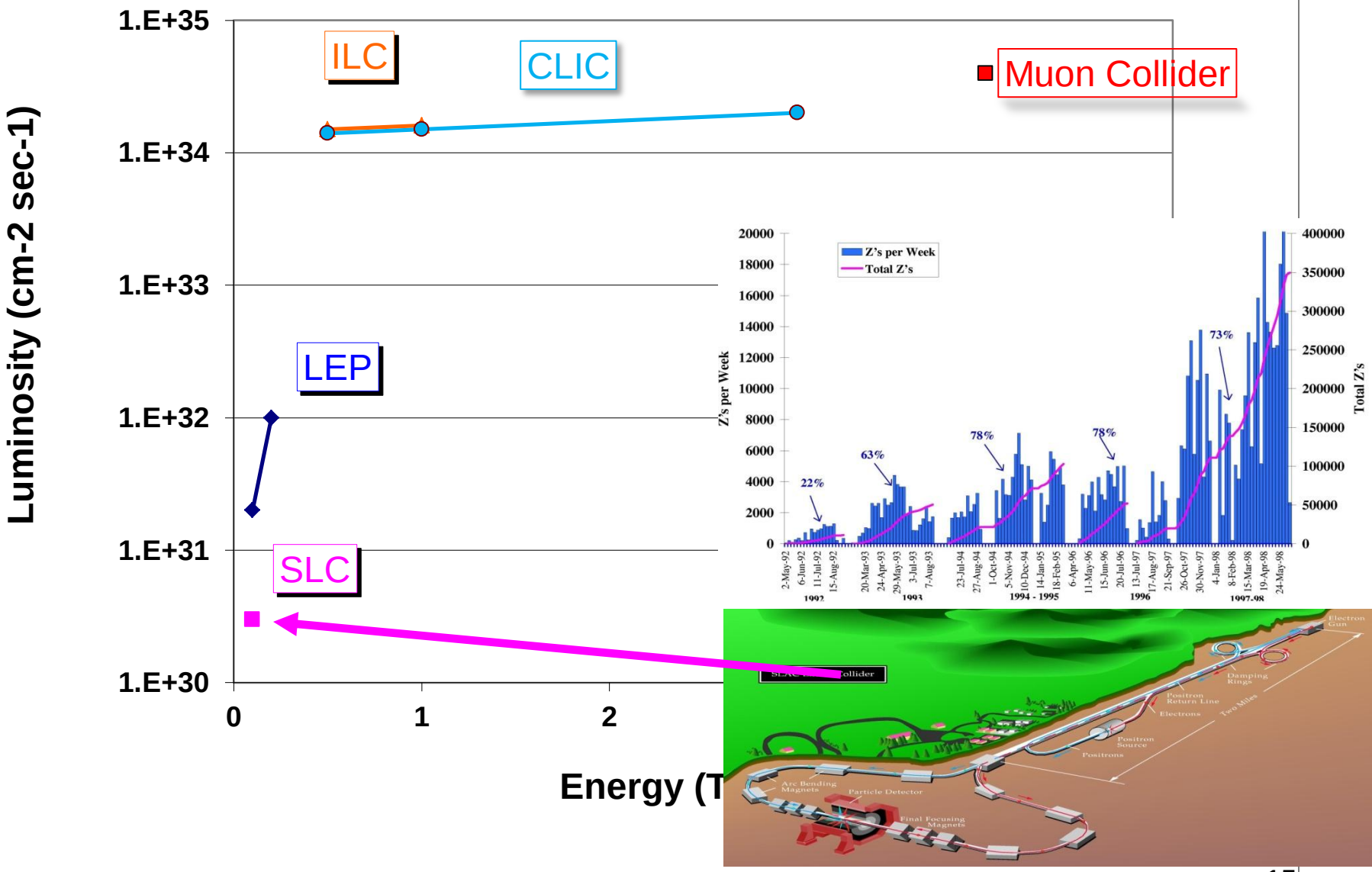

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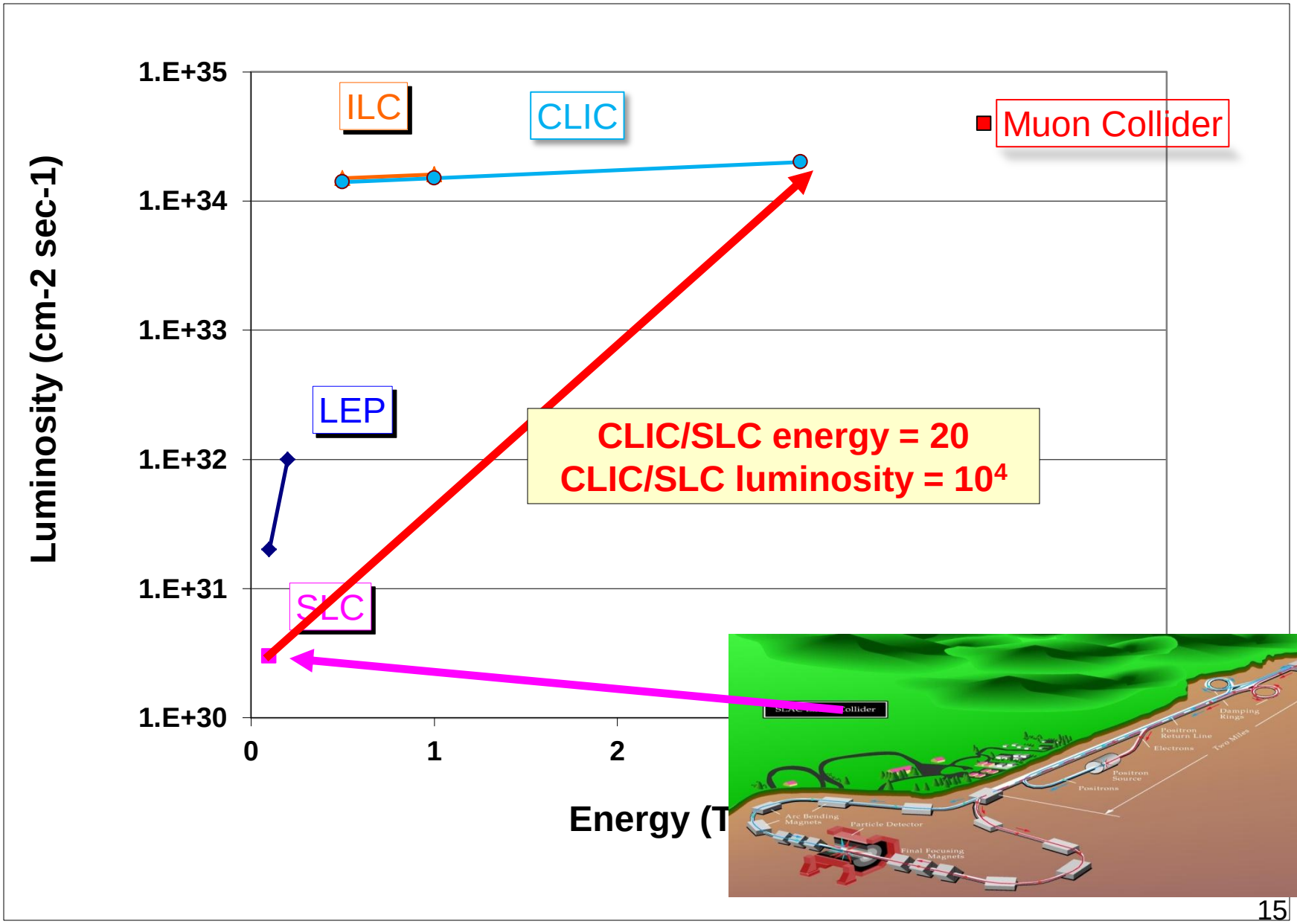
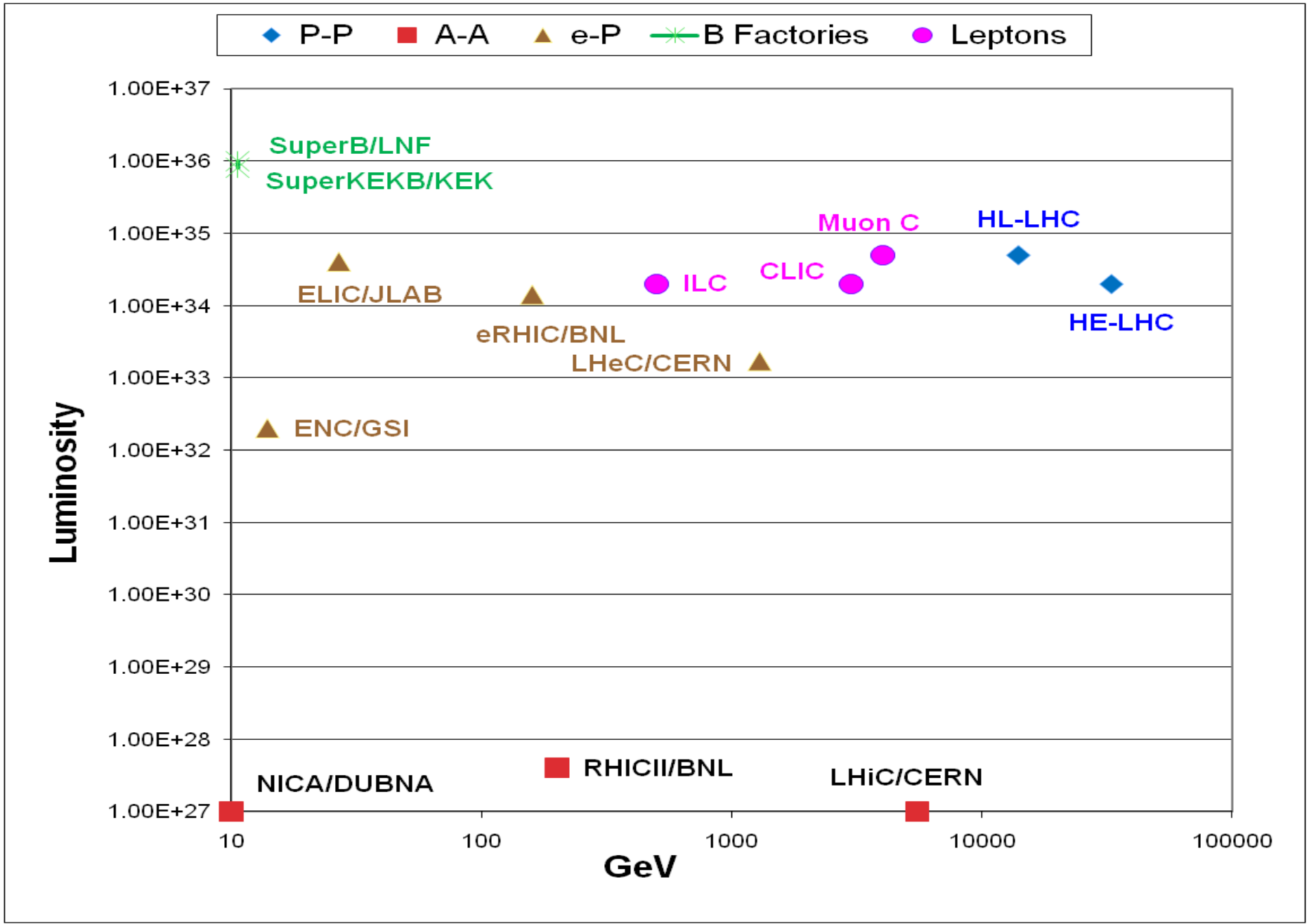


Possible future HEP facilities at Energy/Luminosity frontier



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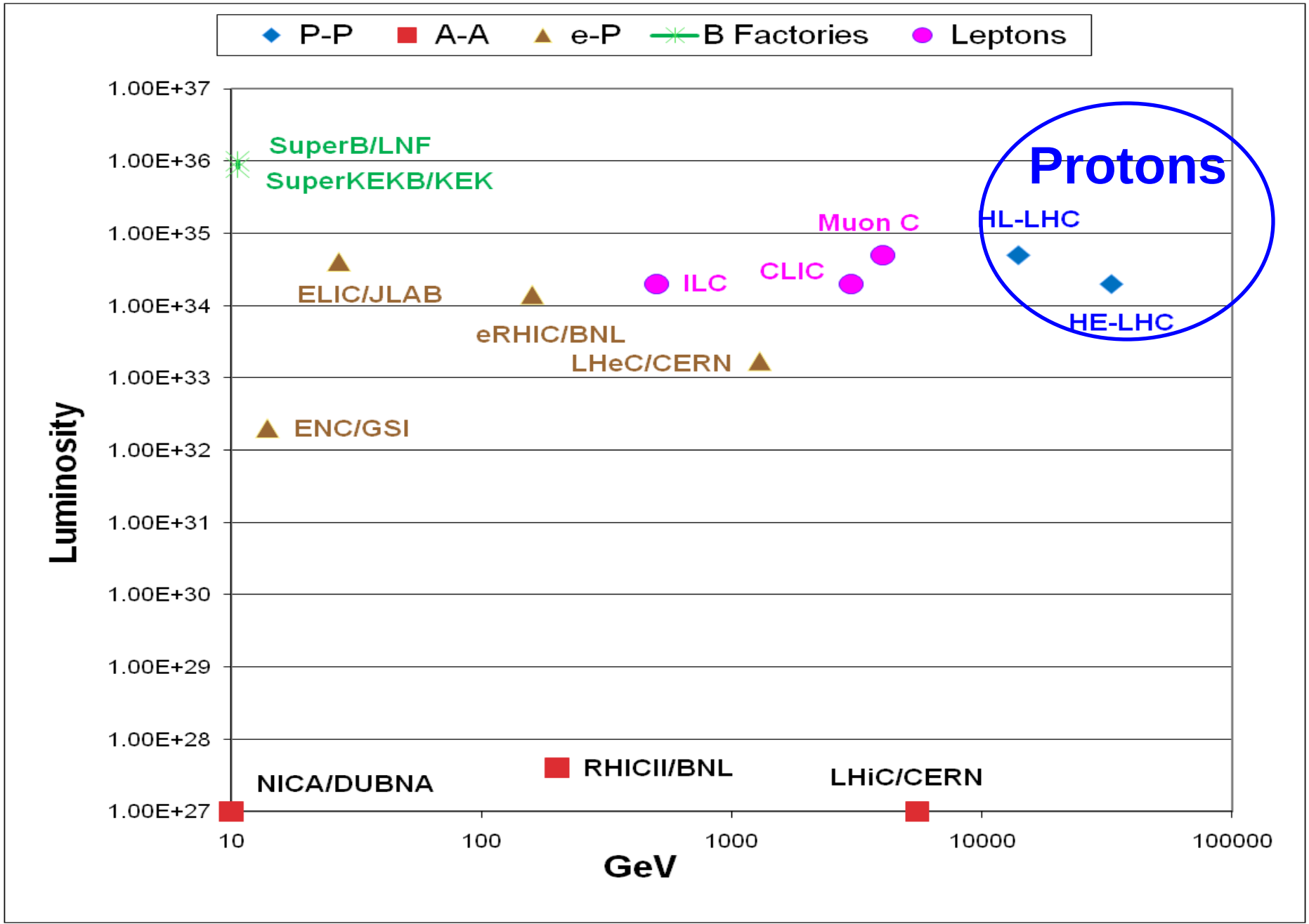

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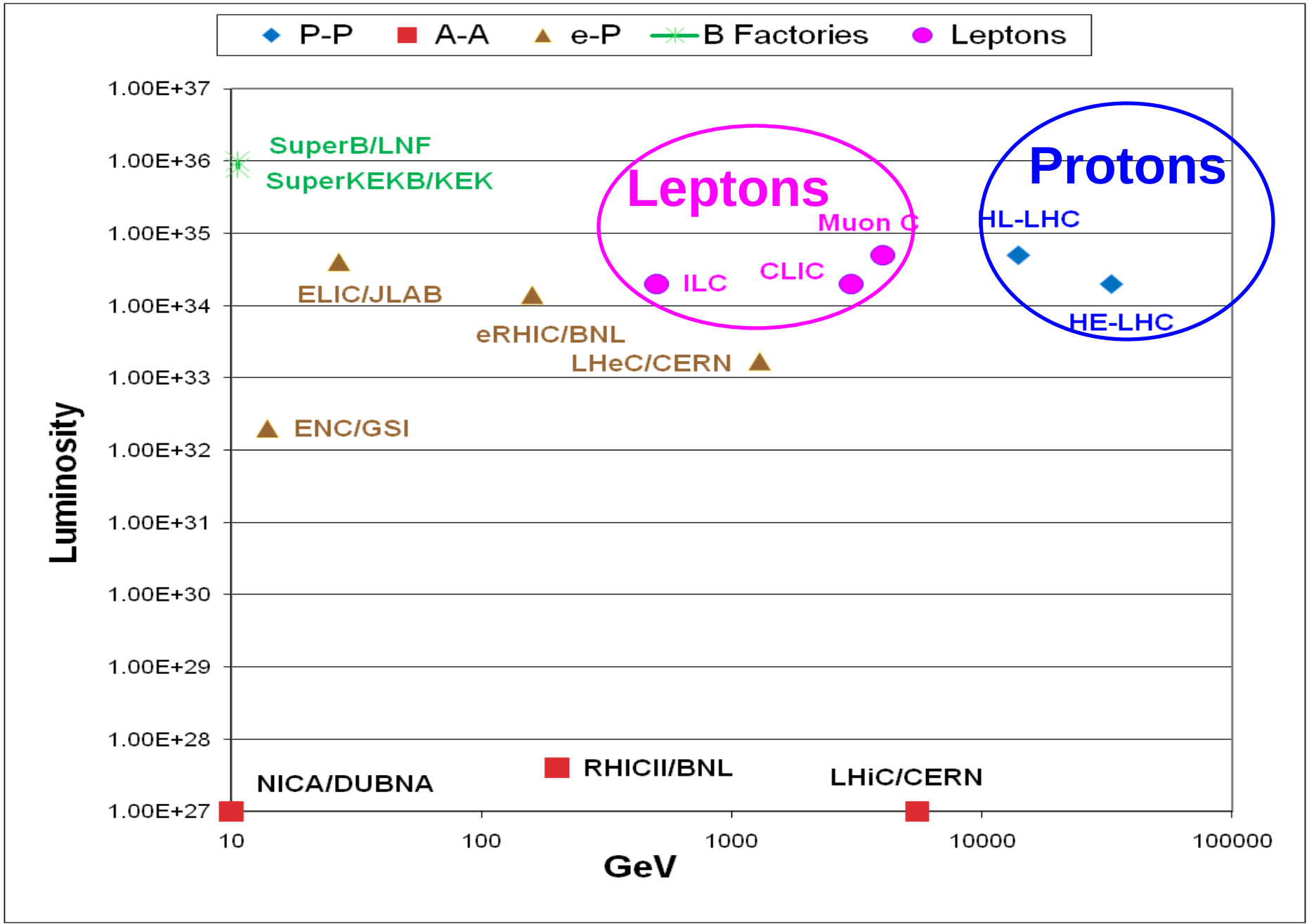

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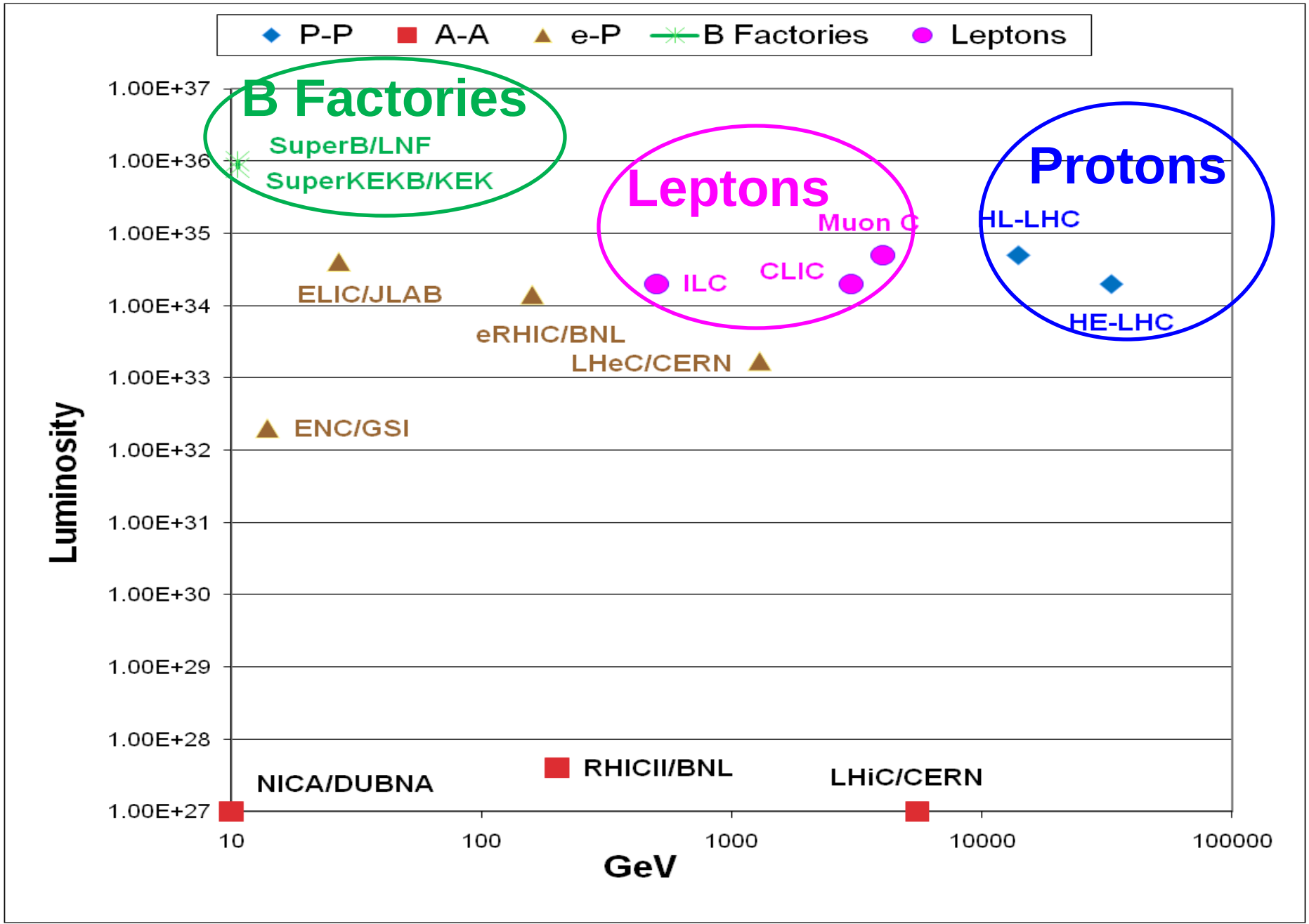

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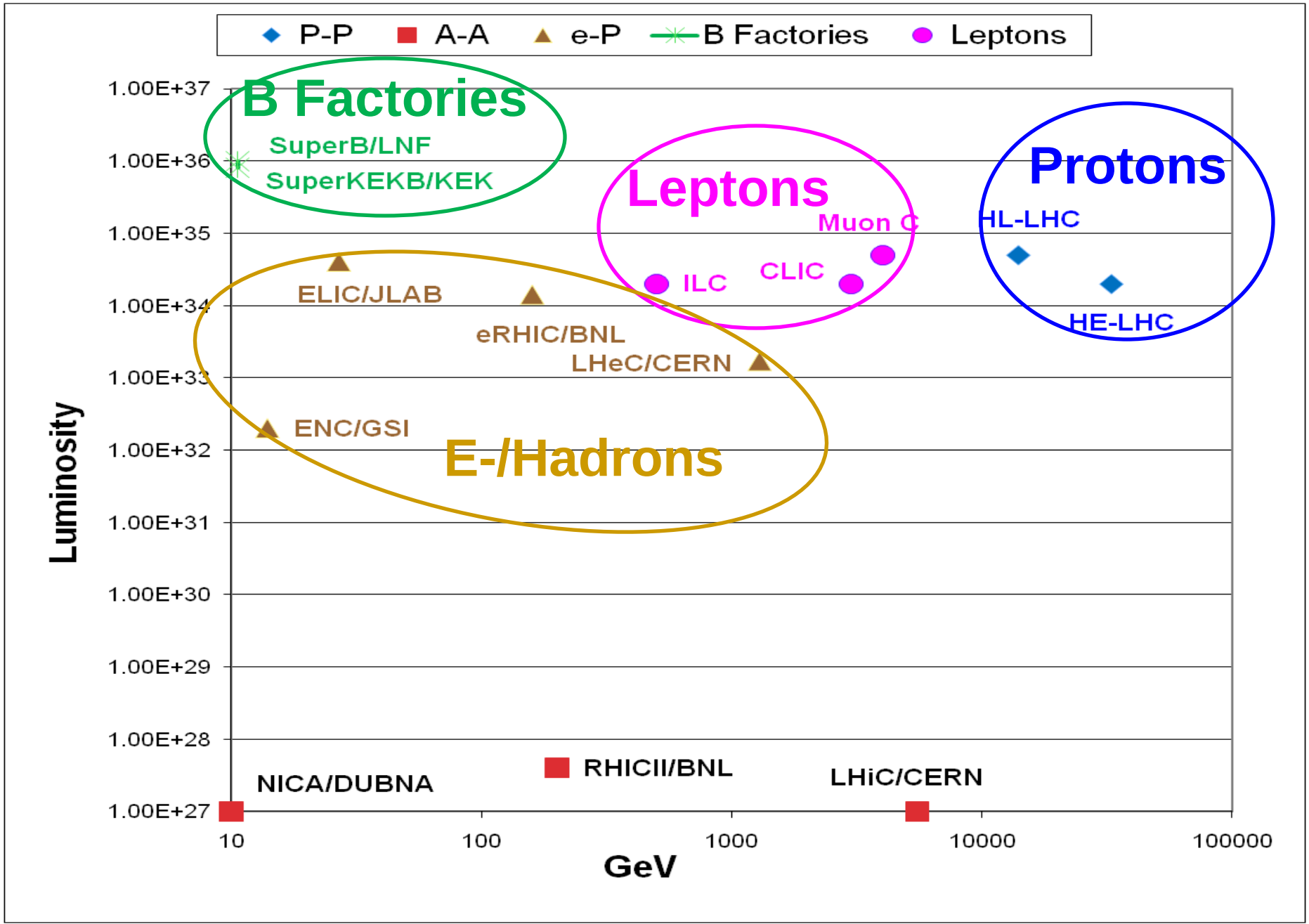

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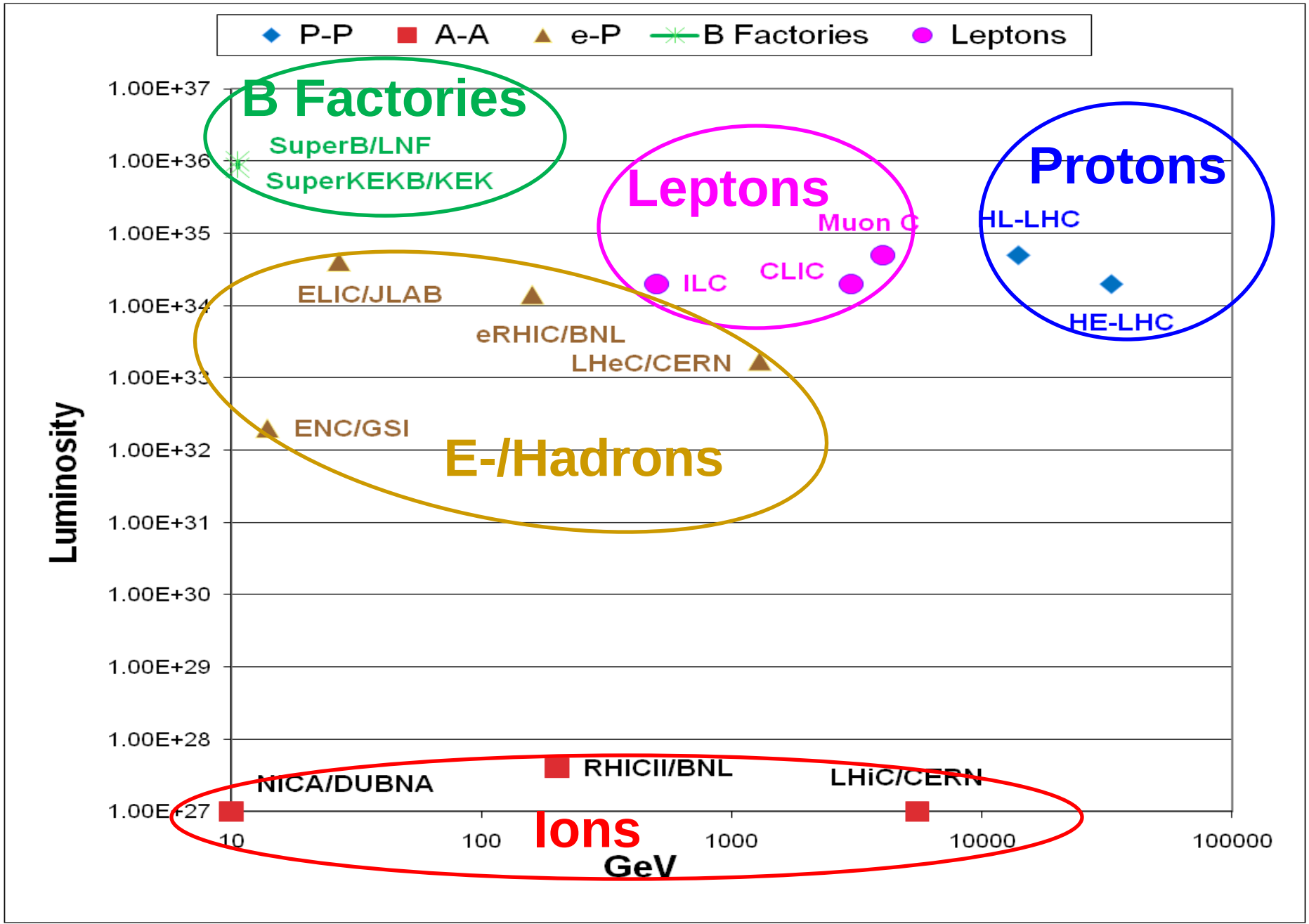
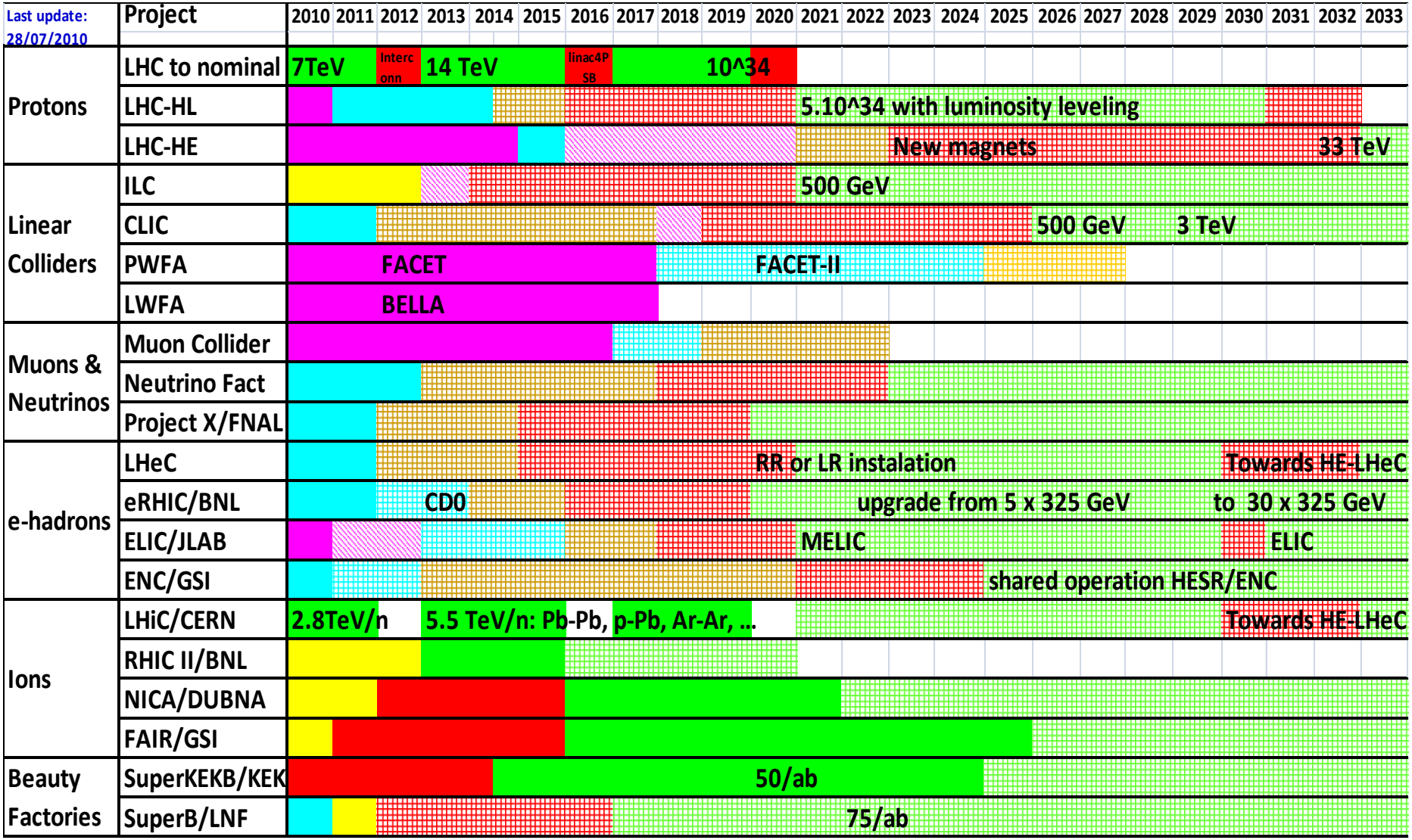


Tentative schedule new projects

Color code	approved	envisaged/proposed
R&D		
R&D to CDR		
Technical design to TDR		
Construction		
Operation		

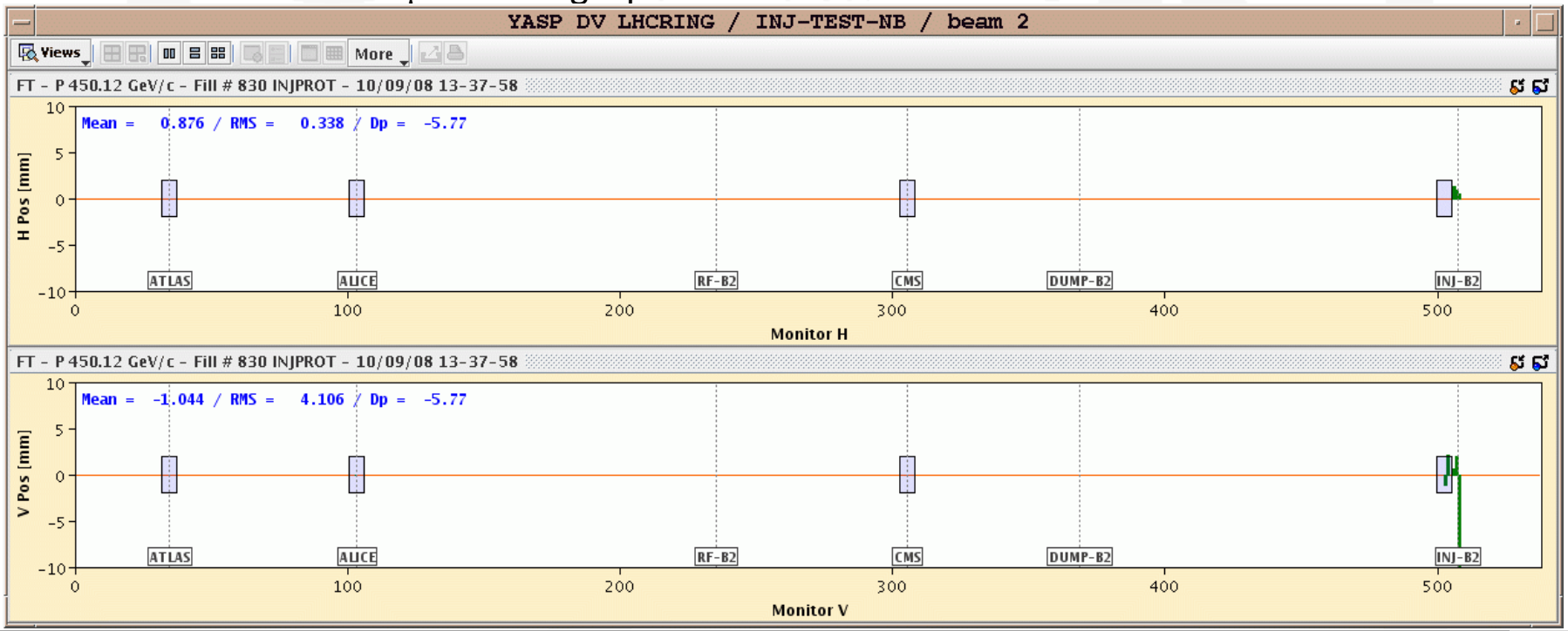


Challenges for Beam Instrumentation

- **Unprecedented request for precision**
  - Positioning down to well below the micron level
- **Treatment of increasingly more data**
  - Bunch by bunch measurements for all parameters
- **Dealing with high beam powers**
  - Non-invasive measurement techniques
  - Robust and reliable machine protection systems
- **Dealing with the ultra-fast**
  - Measurements on the femto-second timescale

Beam Position Monitoring – The Challenges

- **Typically one of the largest BI systems**
  - LHC has 1100 BPMs – CLIC drive beam requires 40000! This implies:
    - Precision engineering at low cost
    - Simple, robust, yet very highly performing electronics
      - Digitise as soon as possible (now doable with advances in ADCs & digital treatment systems)
      - Radiation Tolerant (improves S/N, minimises expensive cabling BUT needs significant testing time)
  - XFEL's and Linear Colliders increasingly asking for very high resolution
    - Well below 1μm for single pass



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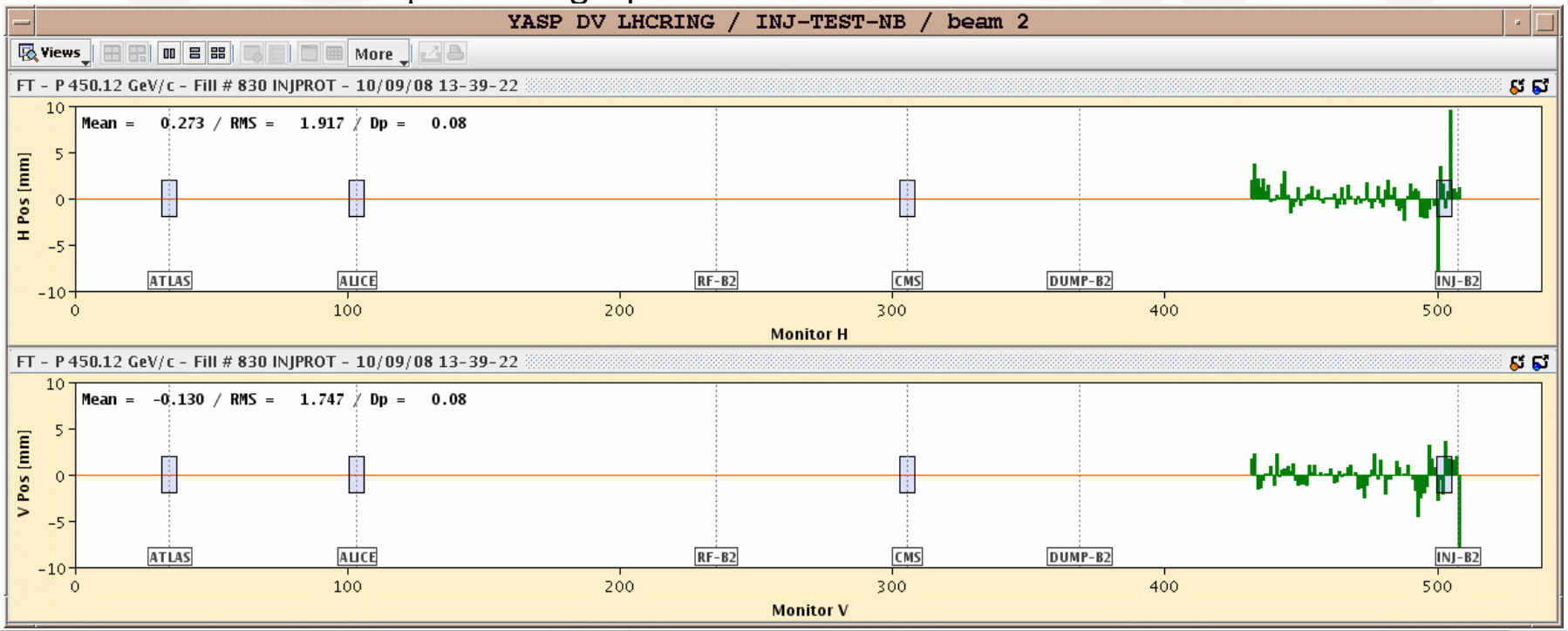

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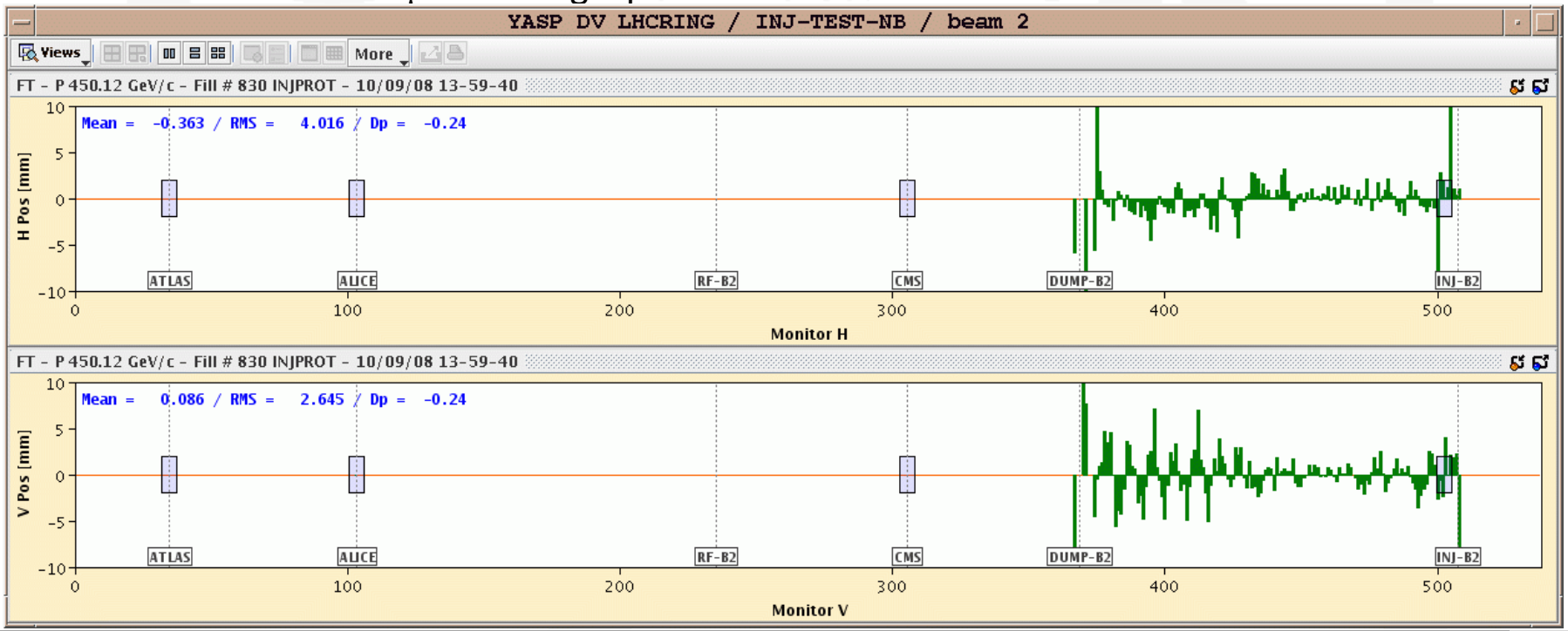

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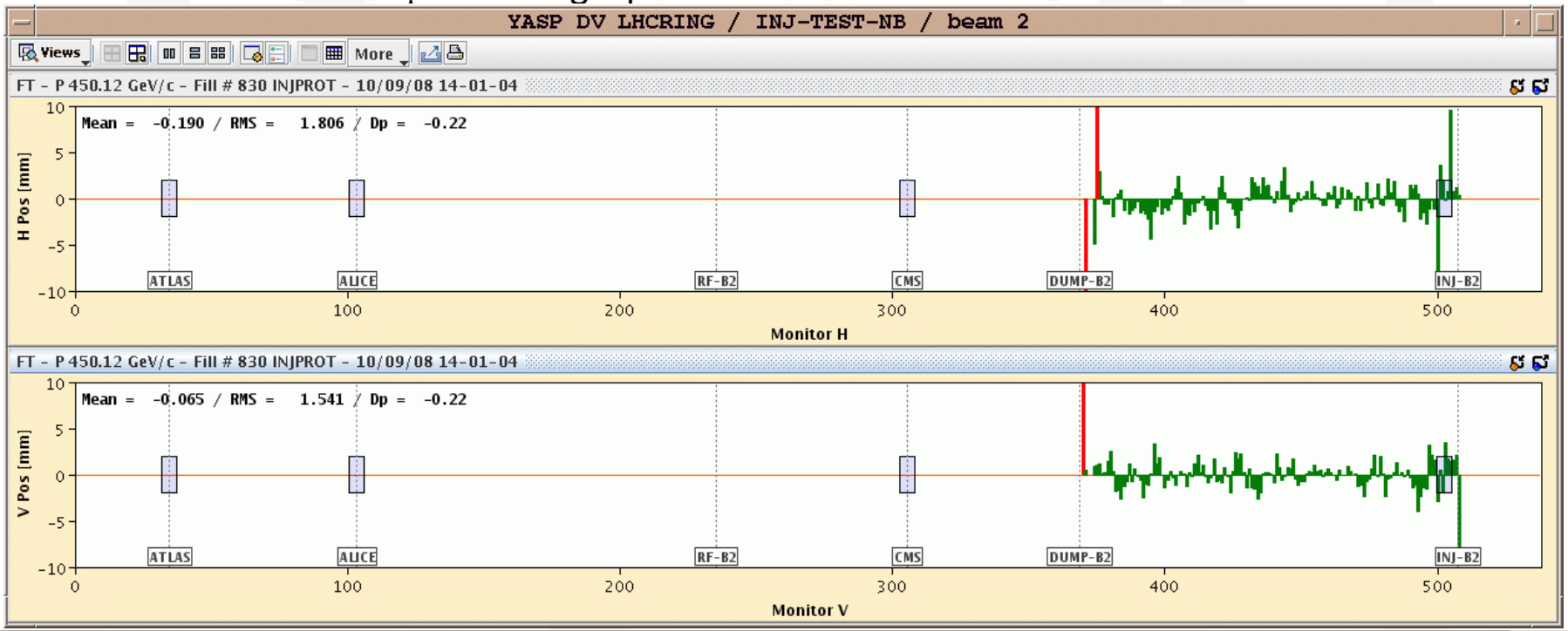

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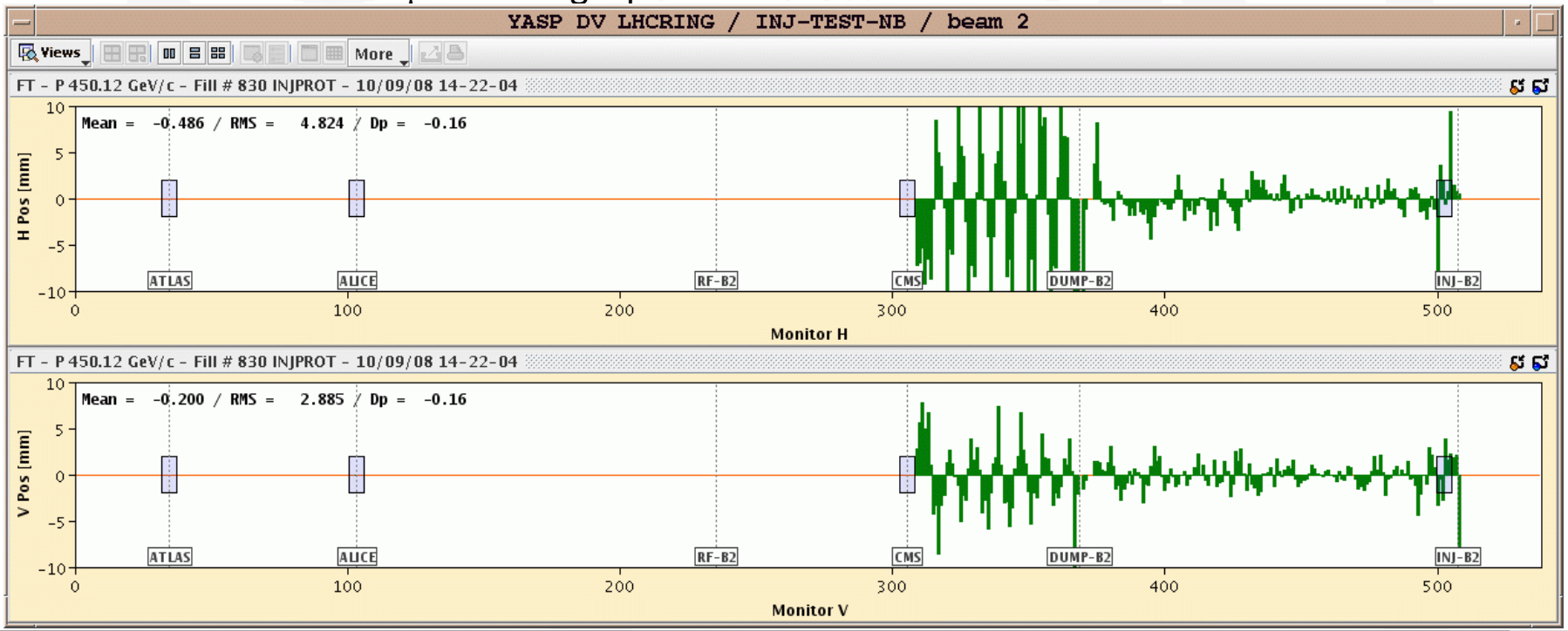

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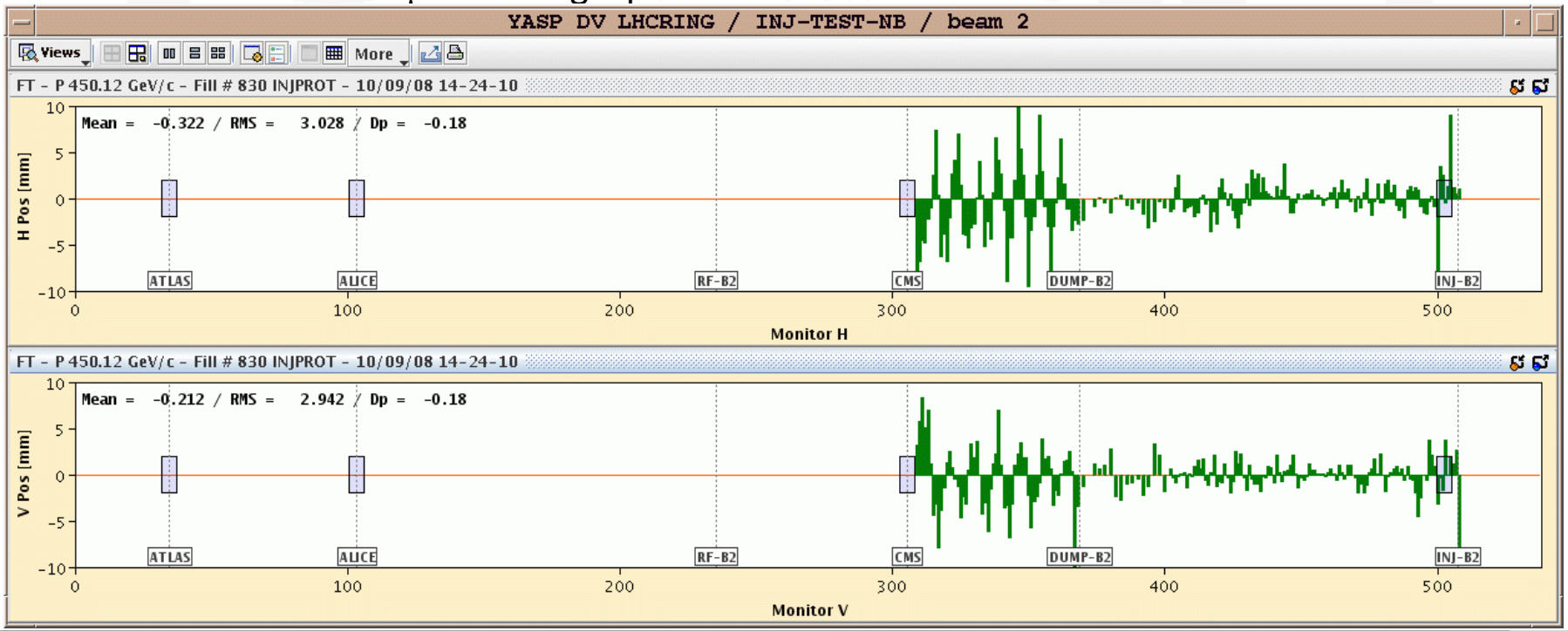

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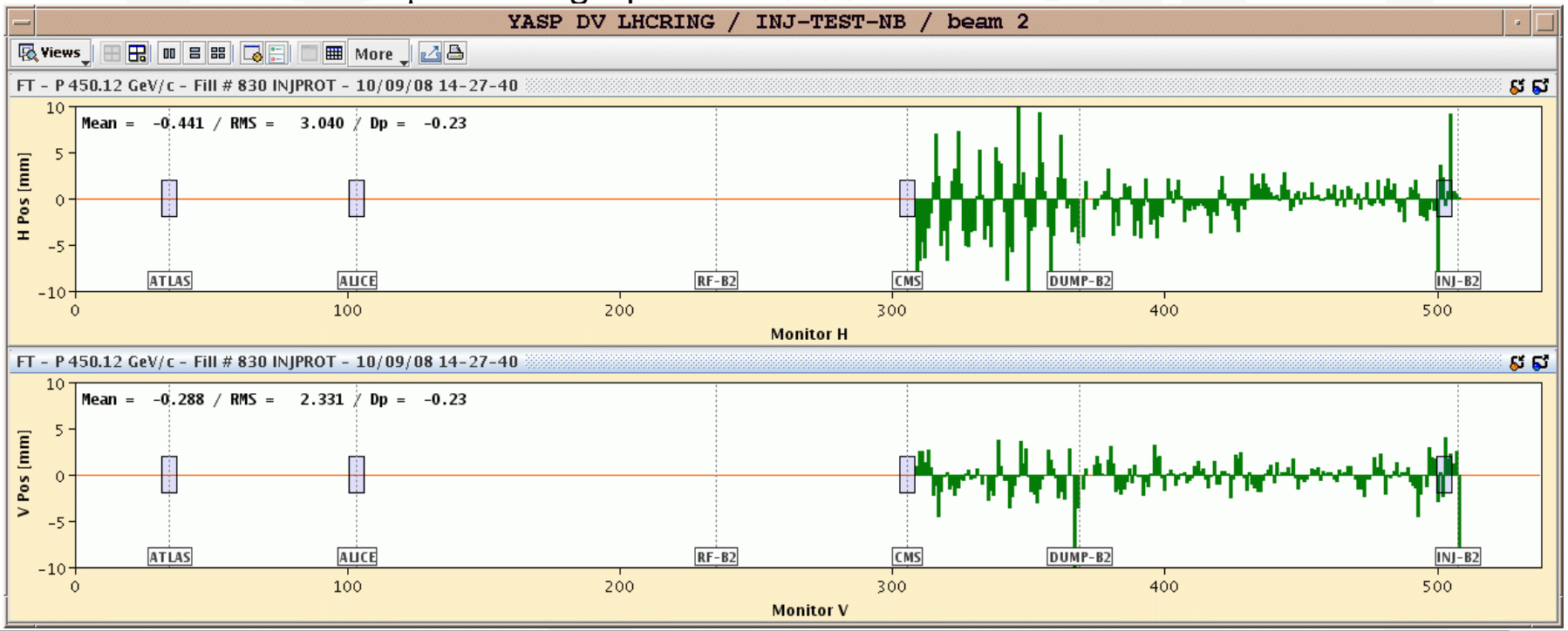

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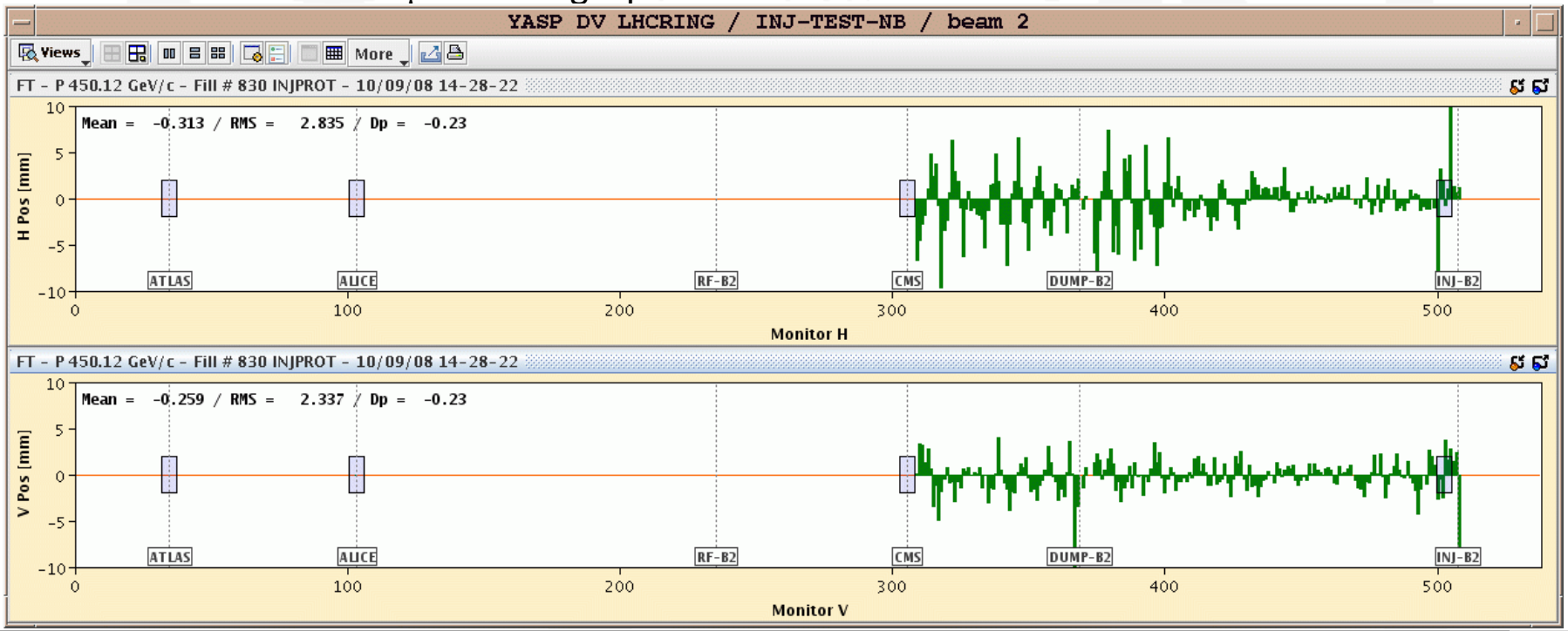

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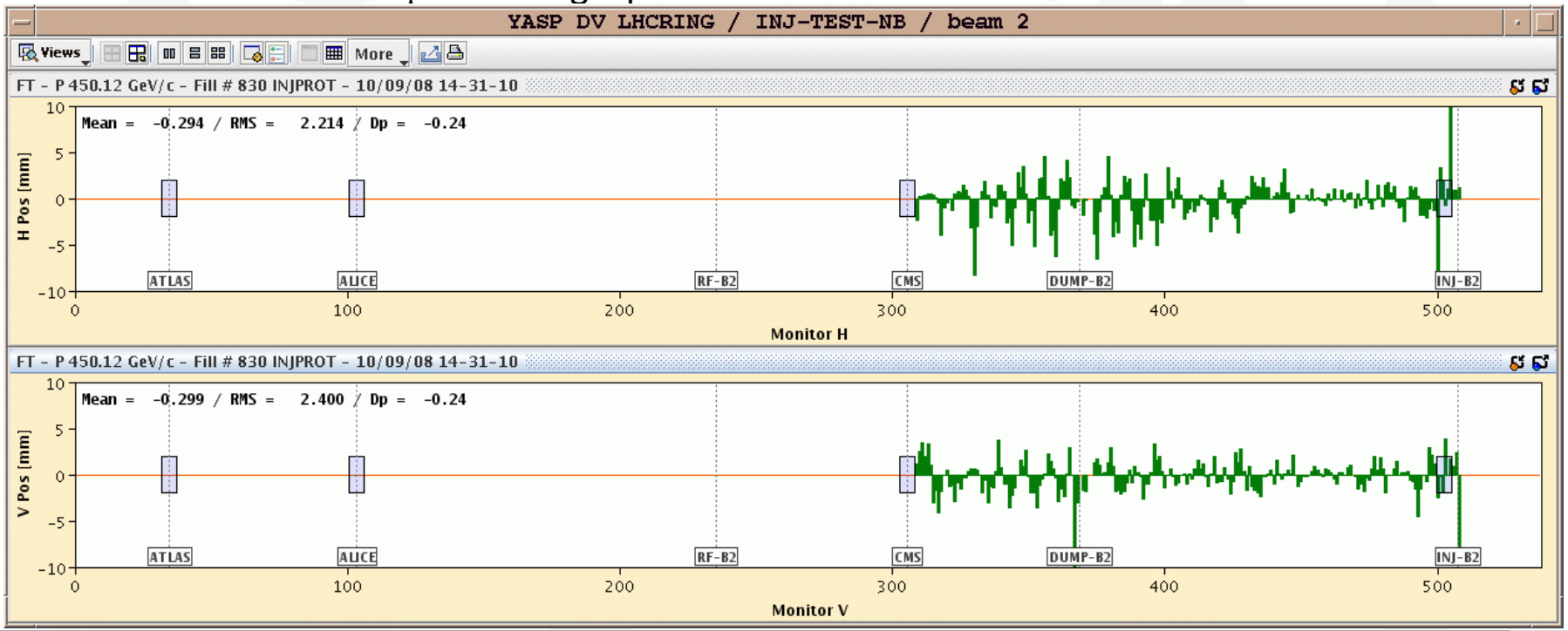

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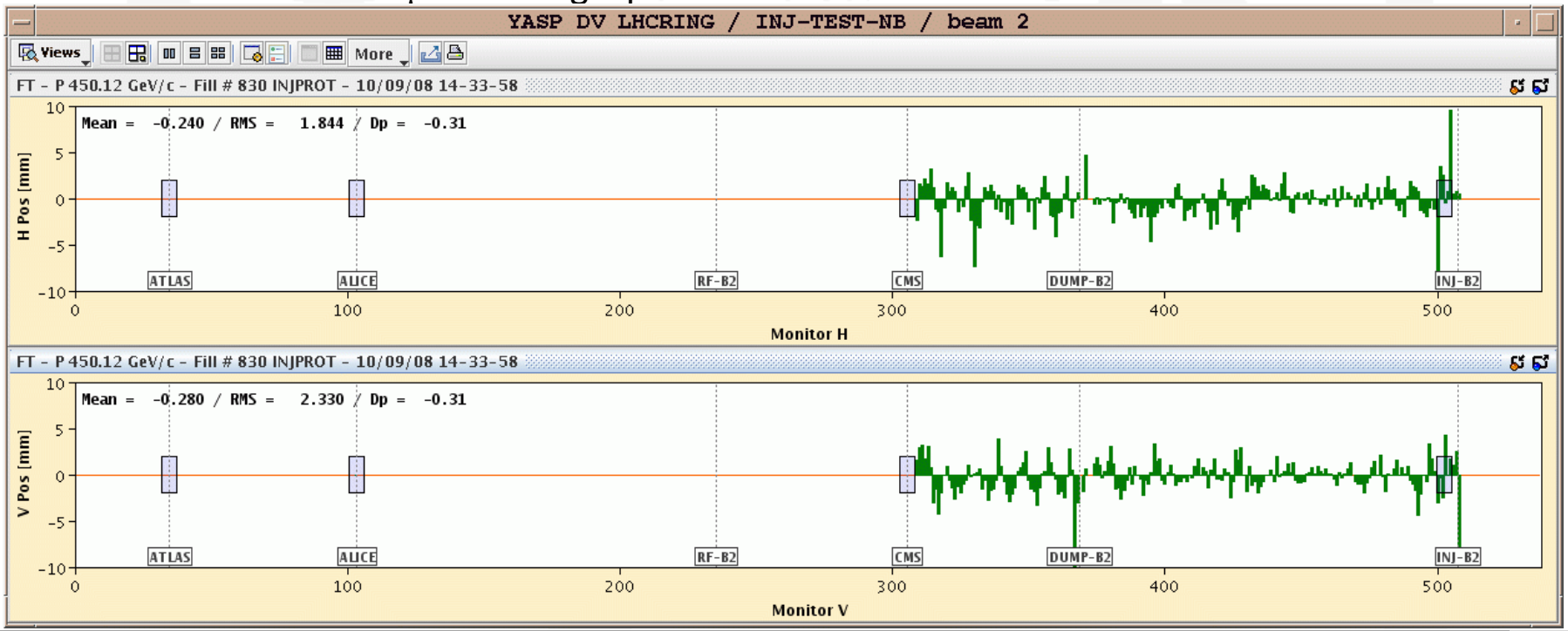

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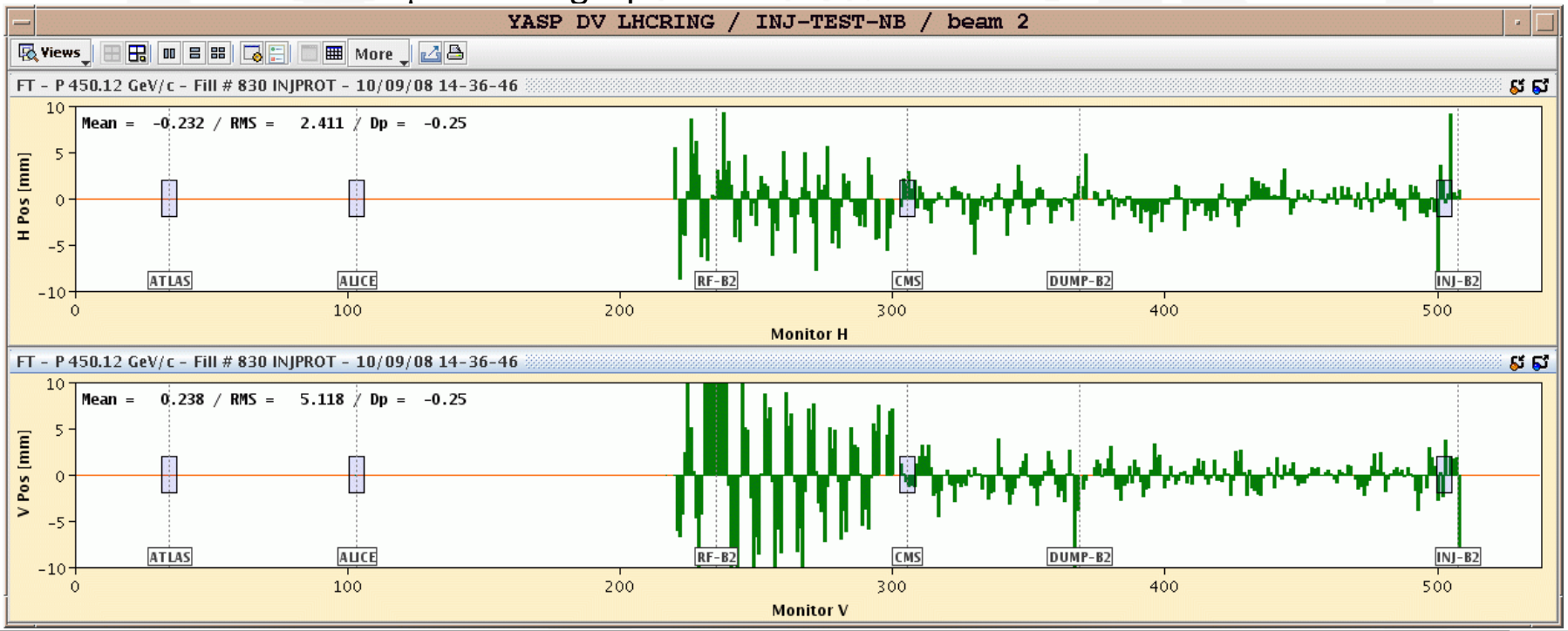

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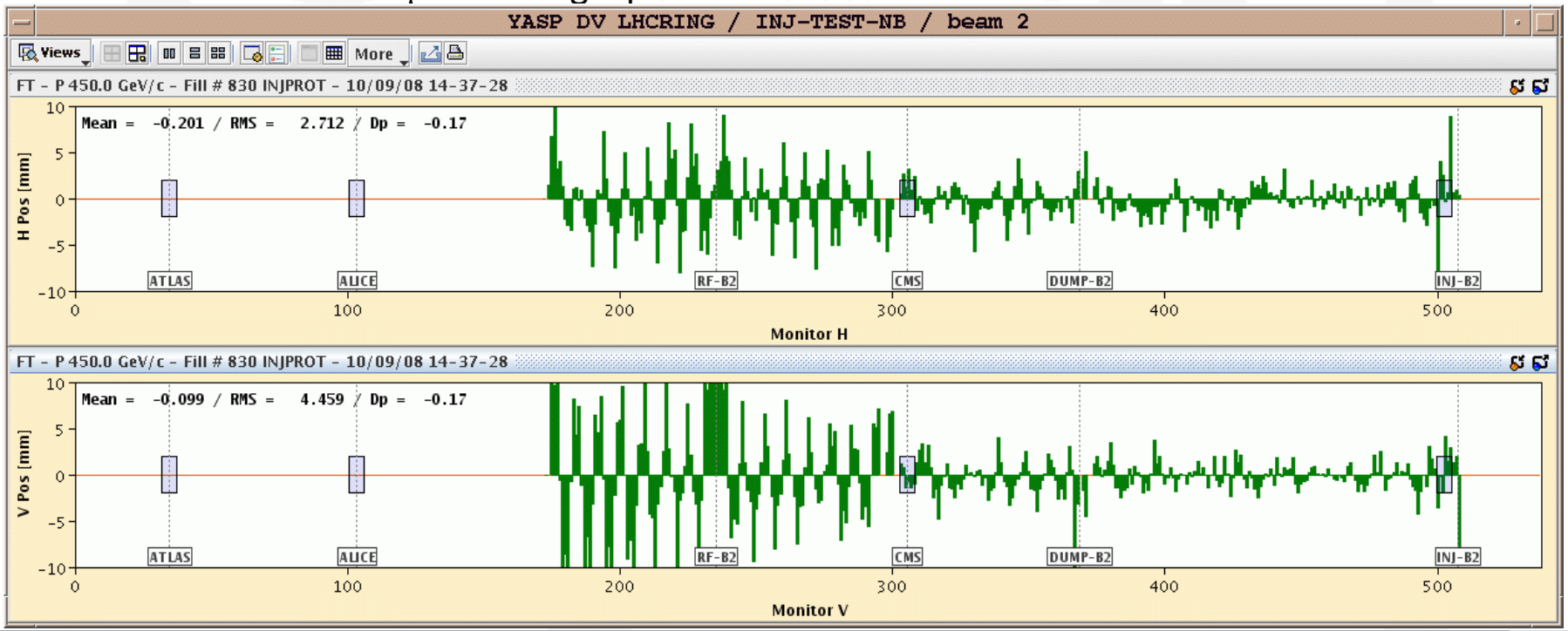

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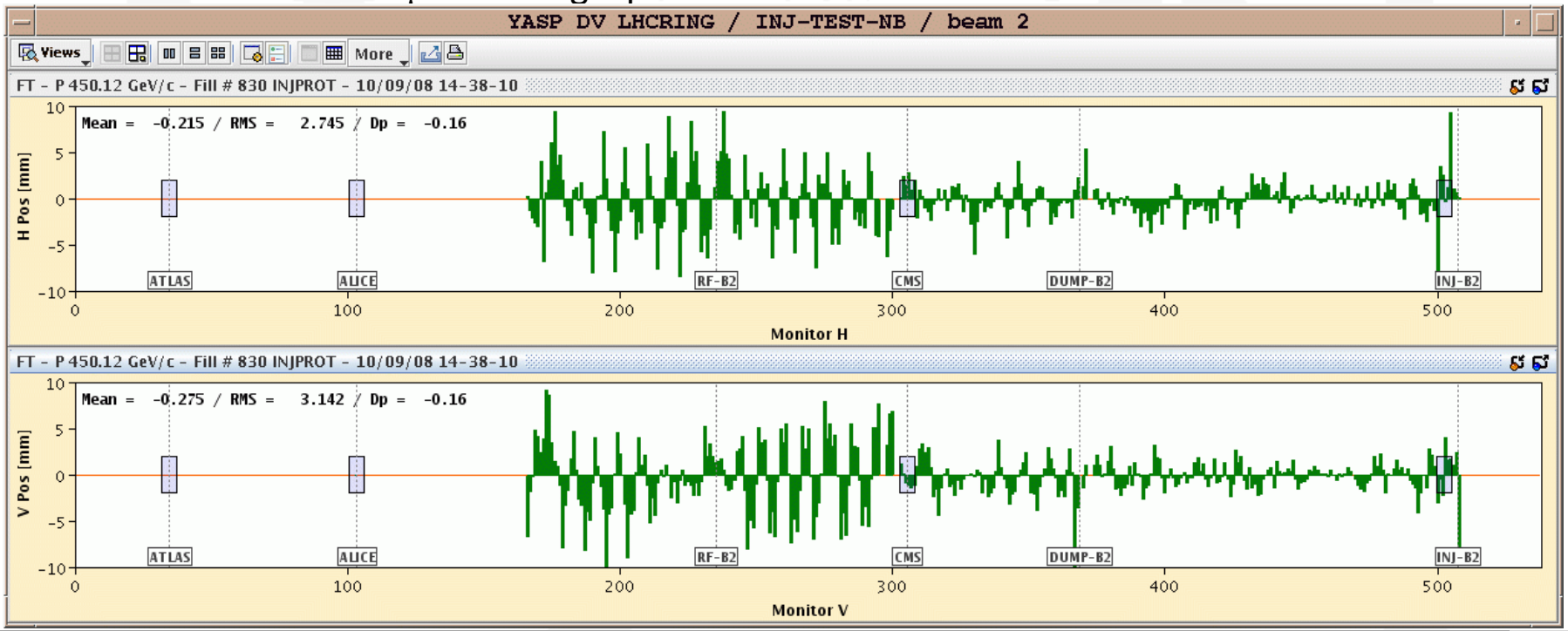

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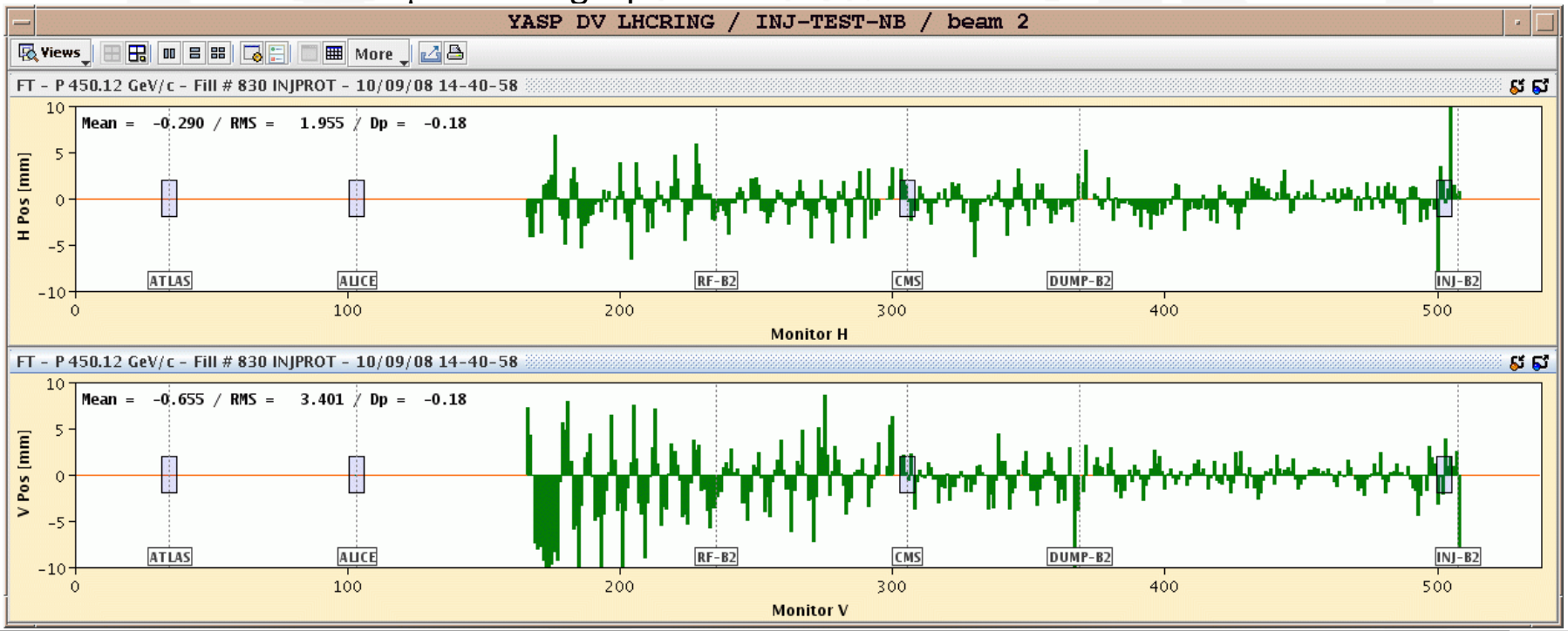

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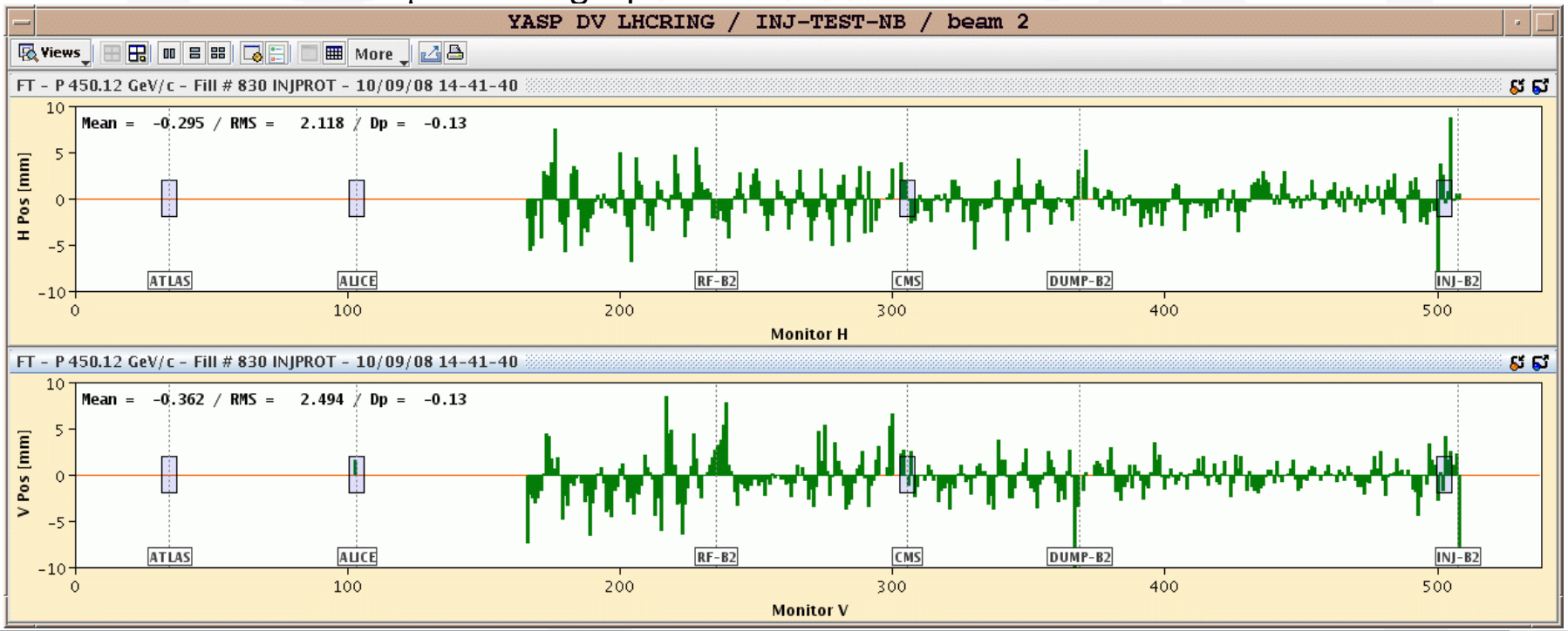

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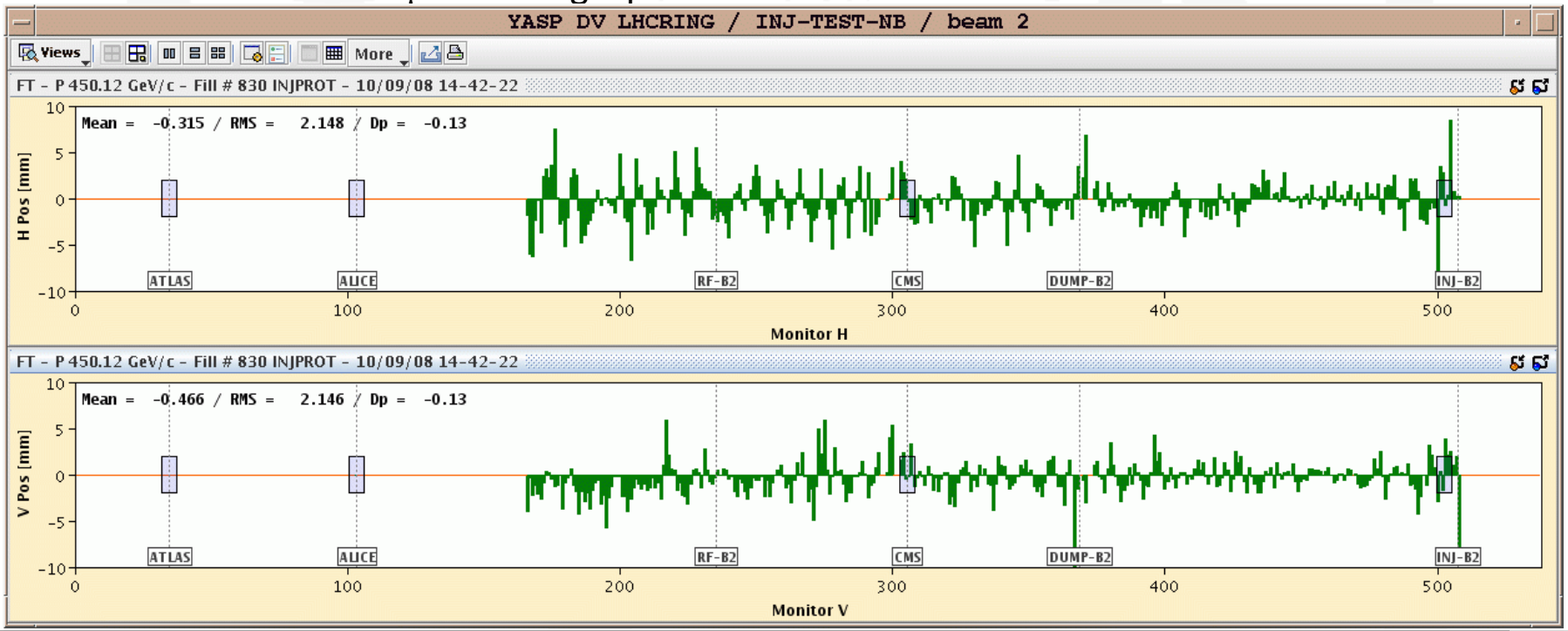

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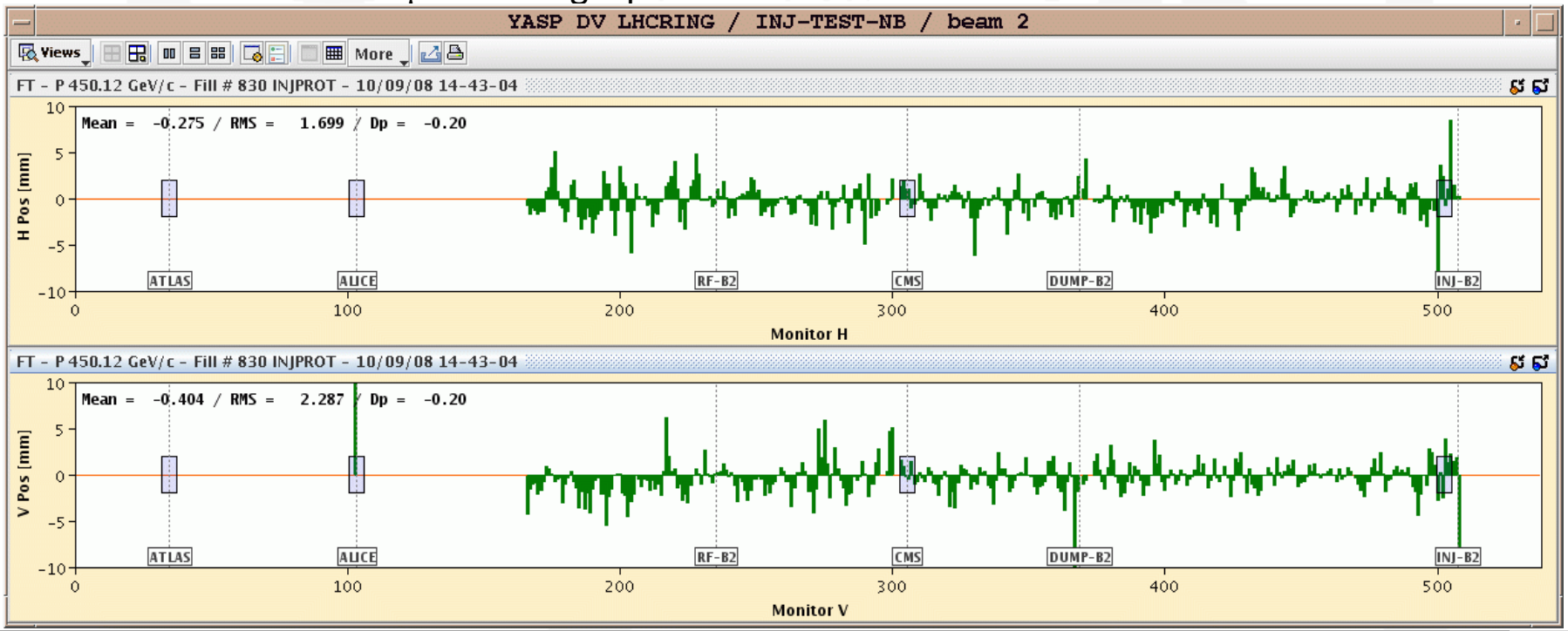

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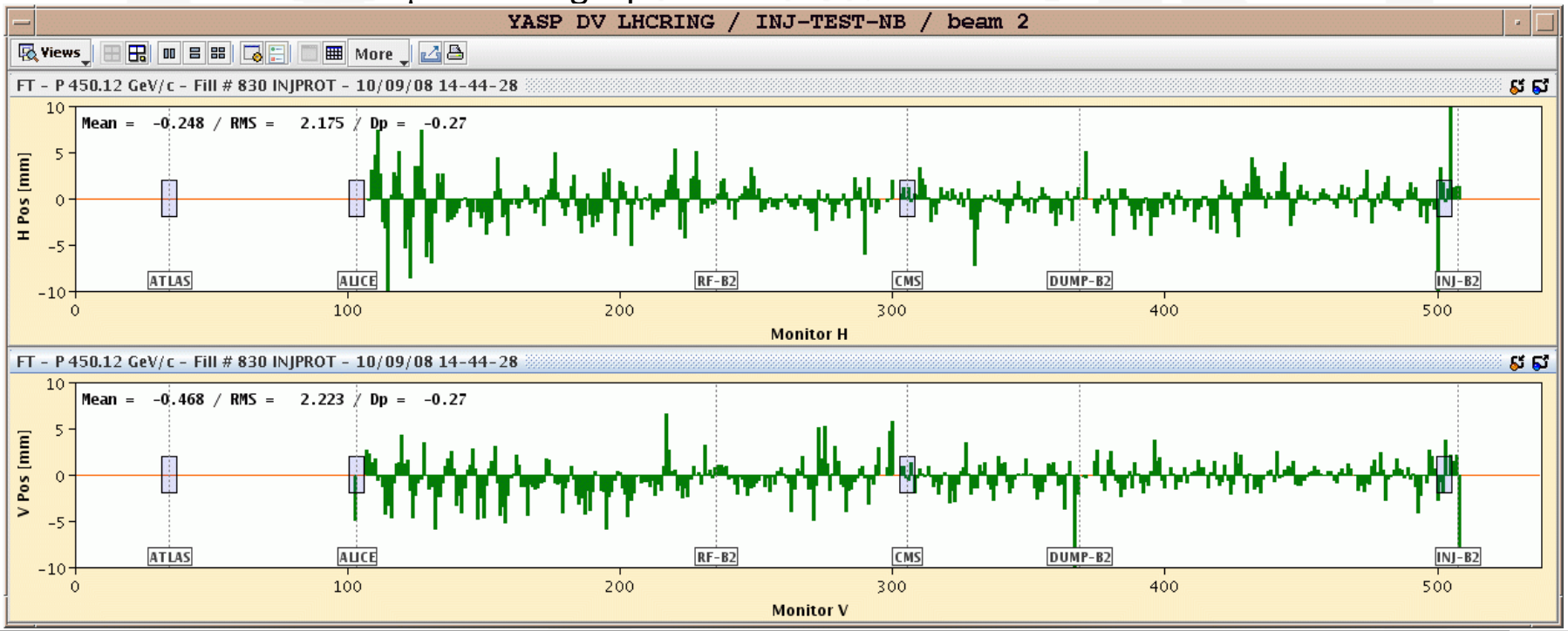

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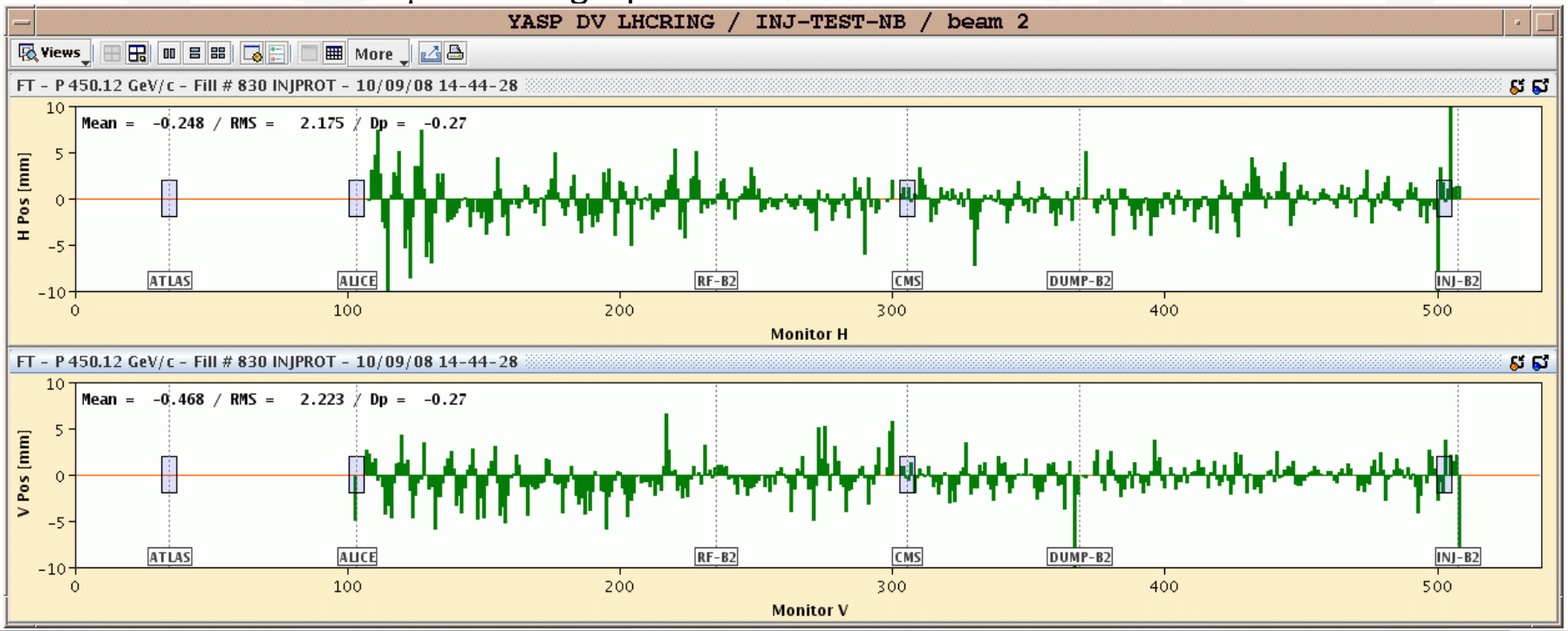

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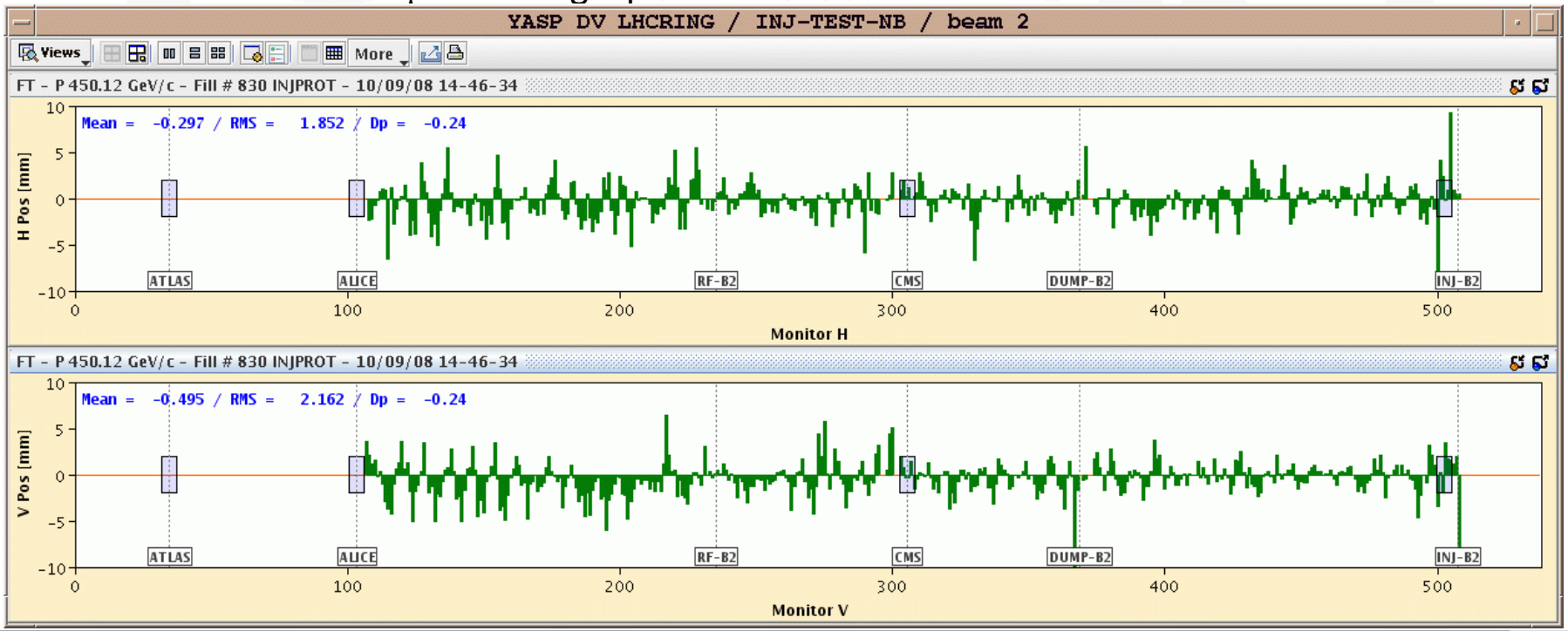

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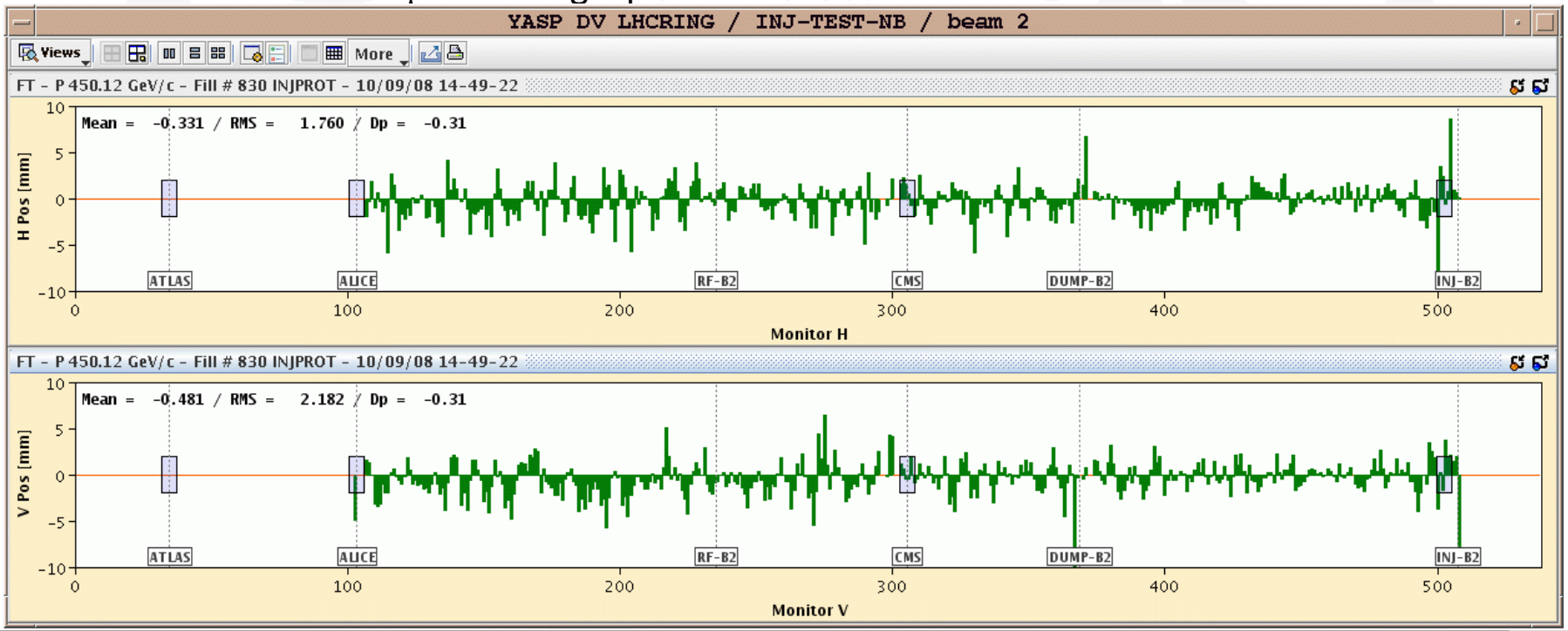

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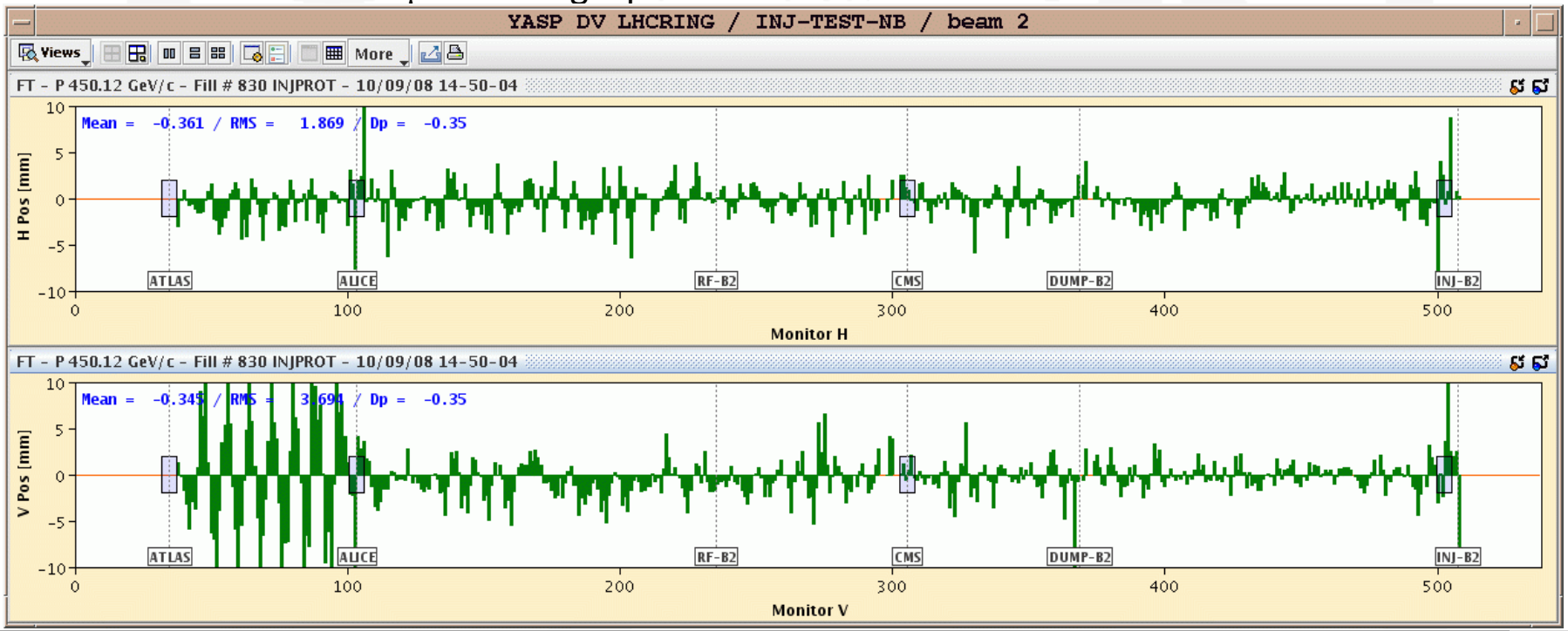

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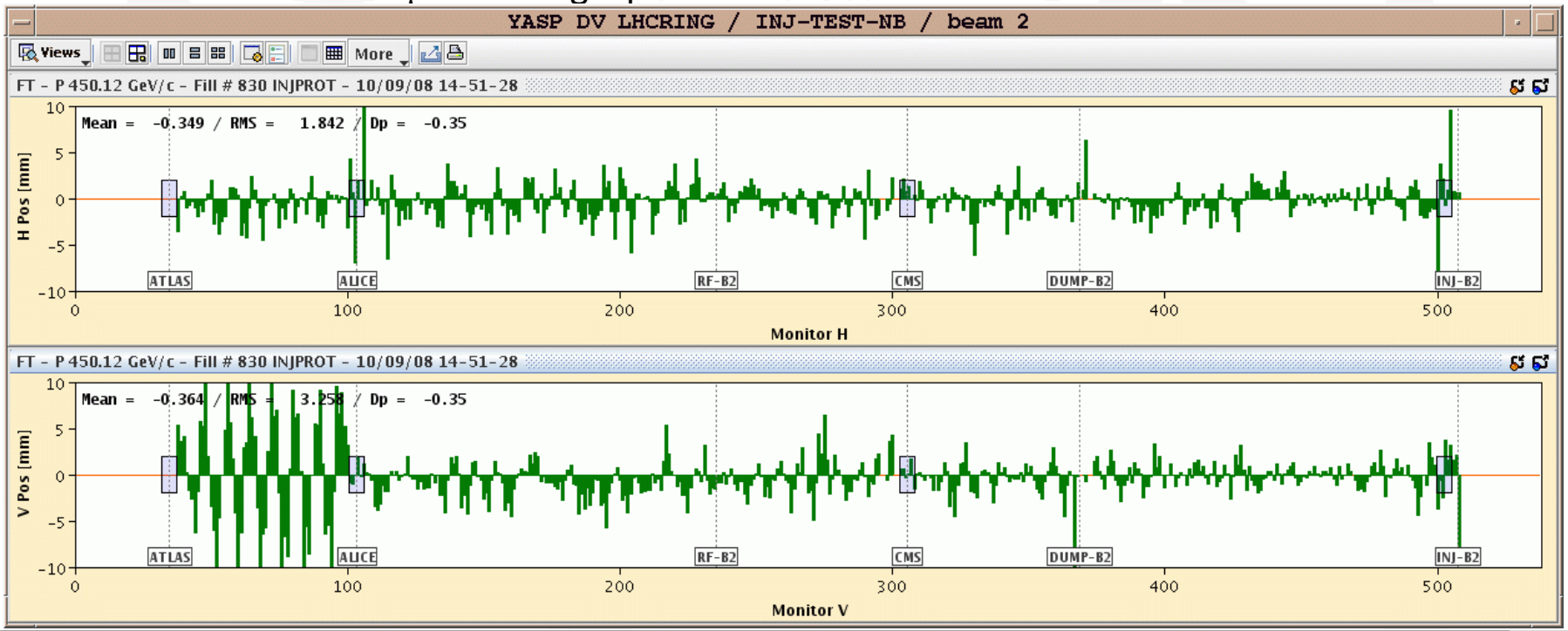

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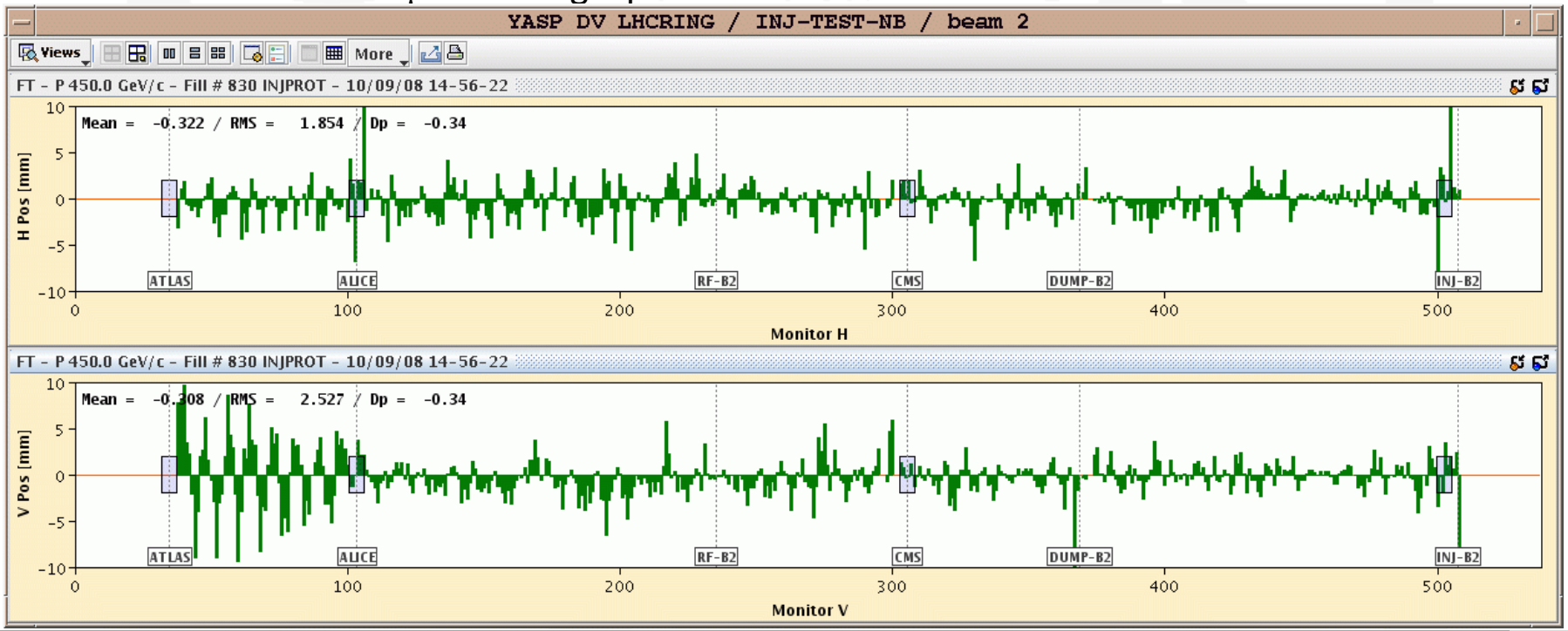

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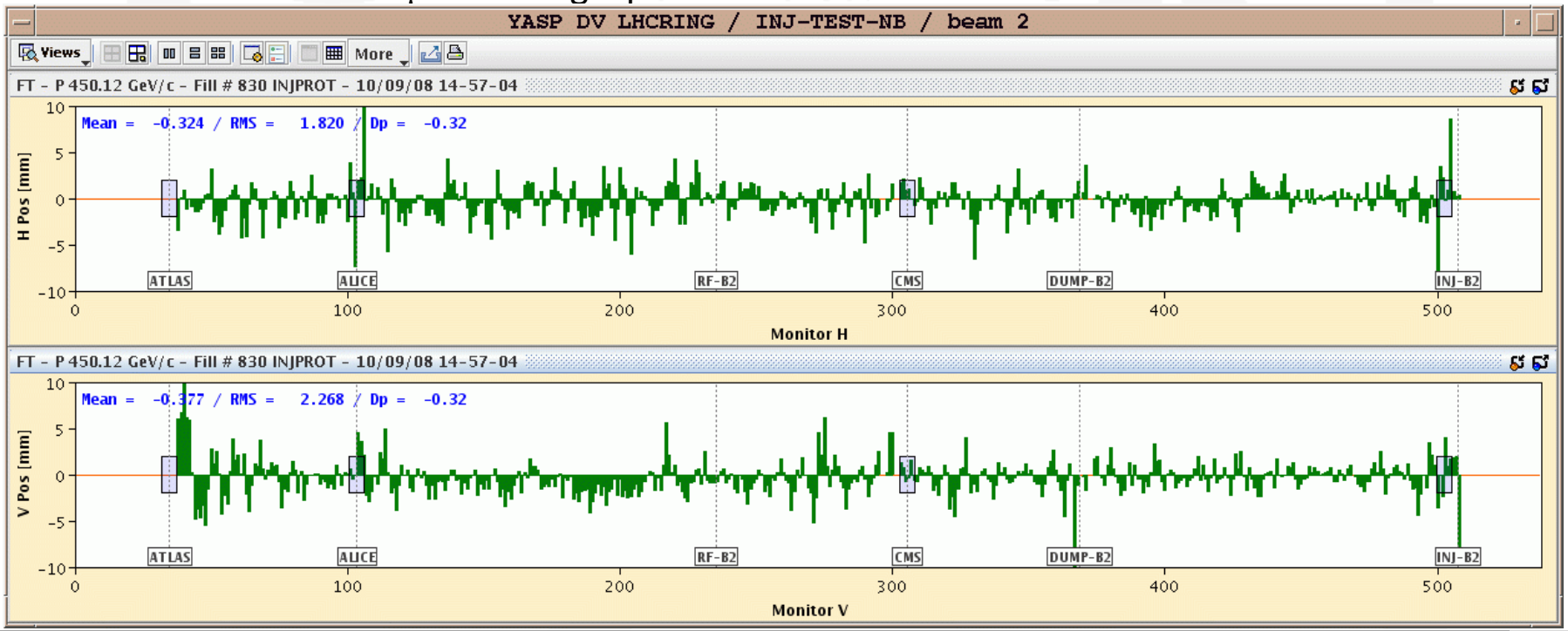

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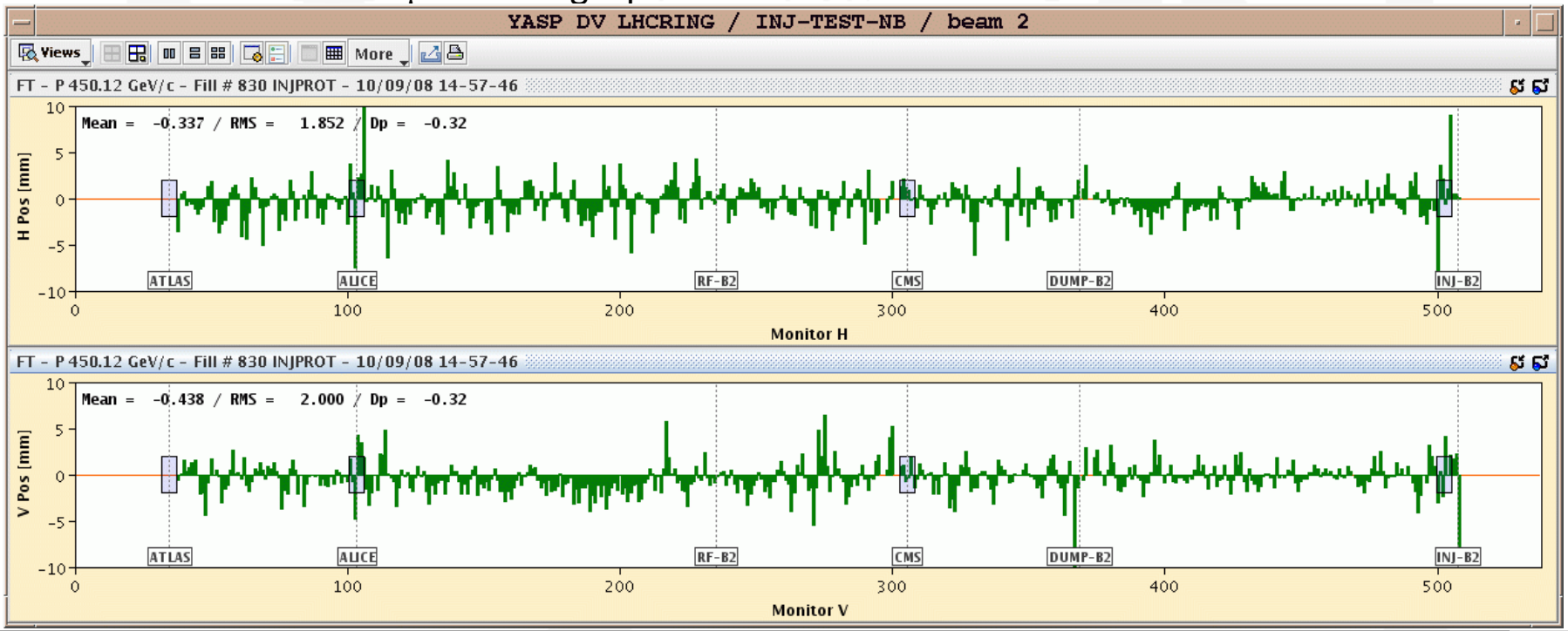

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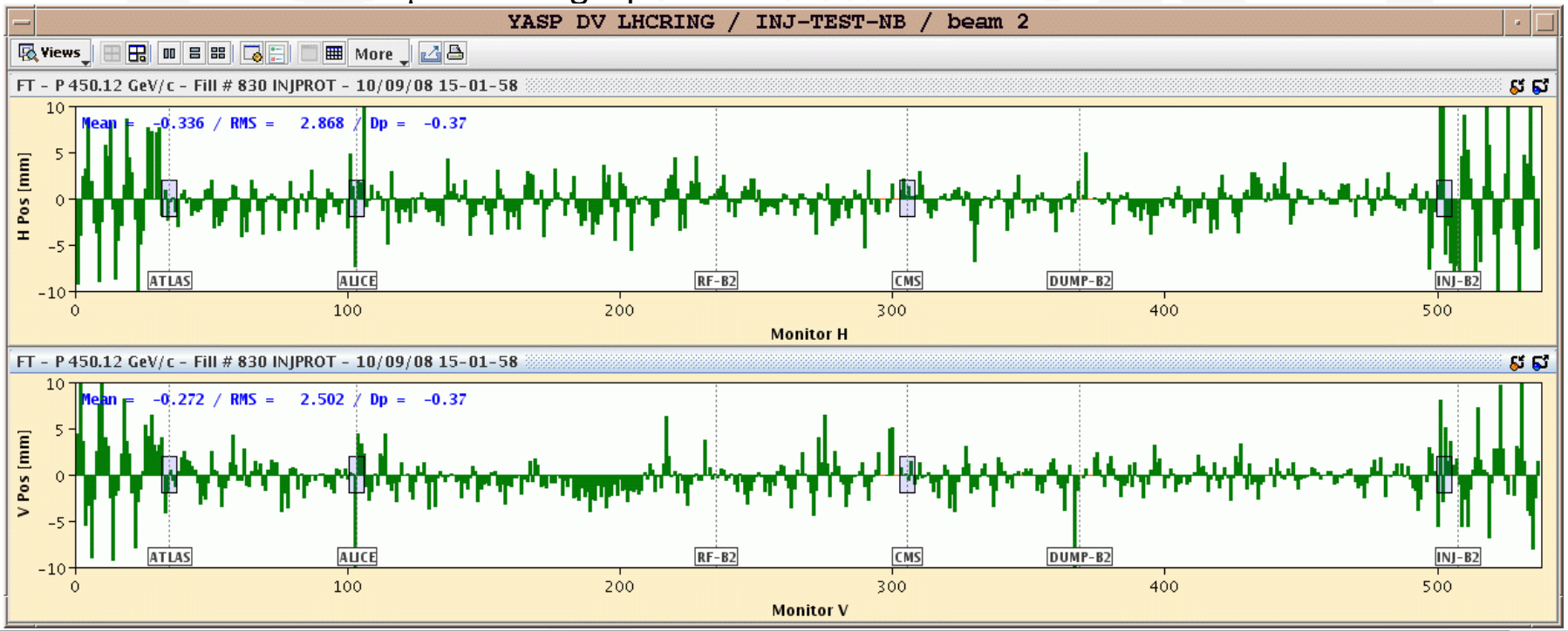

Improving the Precision for Next Generation Accelerators

- **Standard BPMs give intensity signals - need to subtract them to obtain a difference which is proportional to position**
  - Difficult to do electronically without some of the intensity information leaking through
    - When looking for small differences this leakage can dominate the measurement

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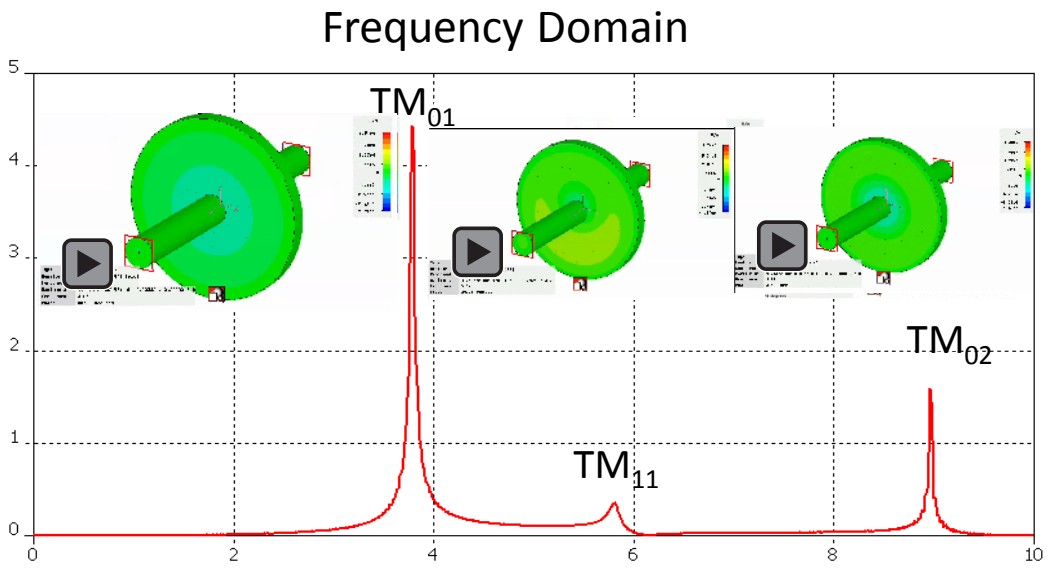
  - Difficult to do electronically without some of the intensity information leaking through
    - When looking for small differences this leakage can dominate the measurement
- **Solution – cavity BPMs allowing sub micron resolution**
  - Design the detector in such a way as to only collect only the difference signal
    - Dipole Mode TM_{11} proportional to position & shifted in frequency with respect to monopole mode



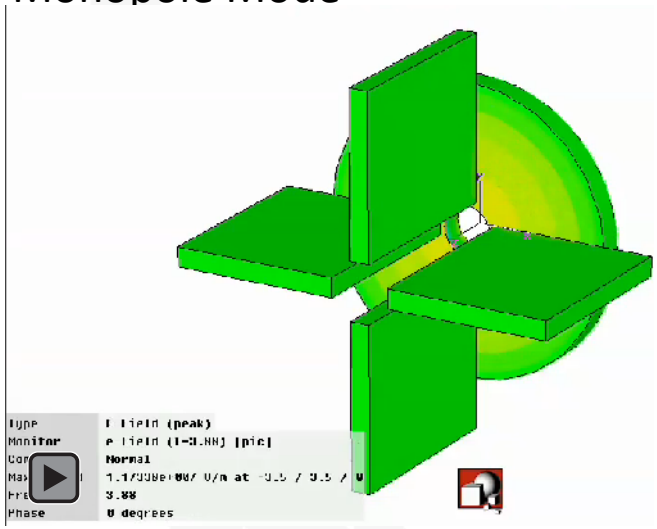
Courtesy of D. Lipka, DESY, Hamburg

U~Q *U~Qr* *U~Q*

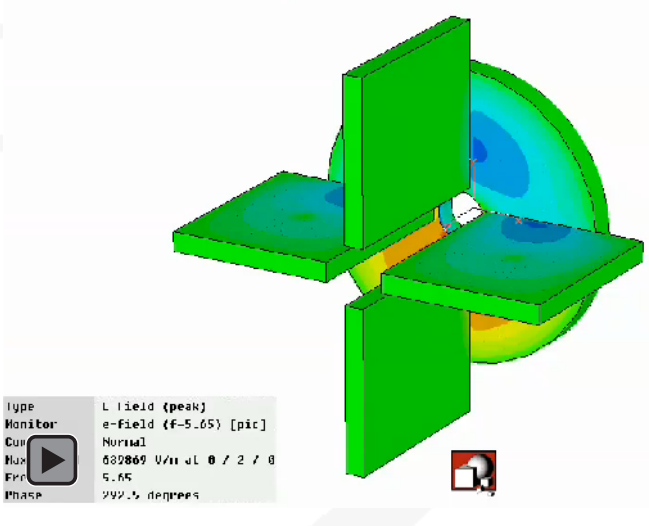
Today's State of the Art BPMs

- **Obtain signal using waveguides that only couple to dipole mode**
  - Further suppression of monopole mode

Monopole Mode



Dipole Mode



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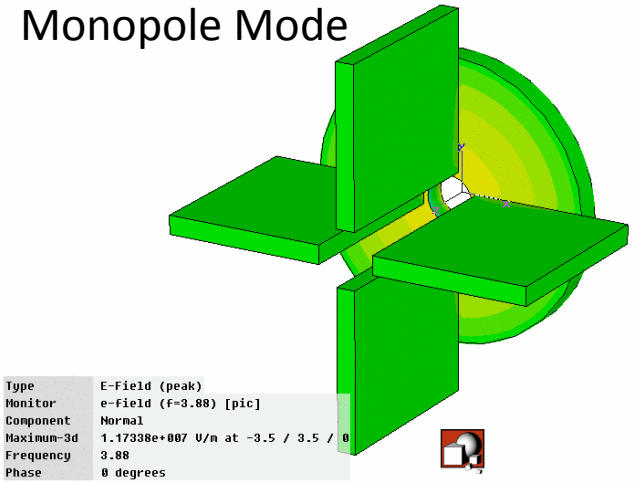

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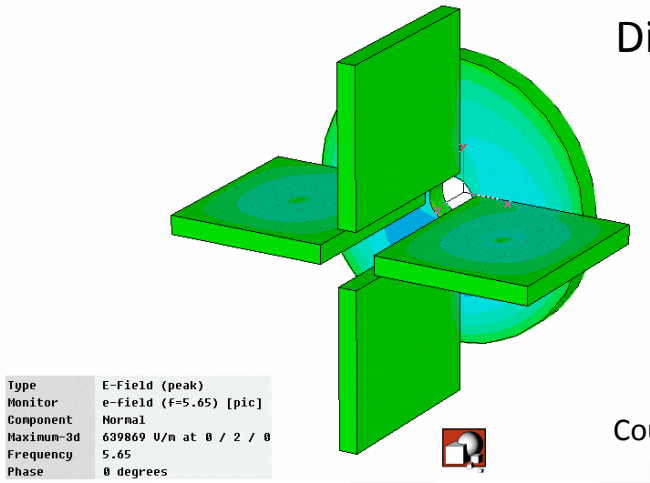
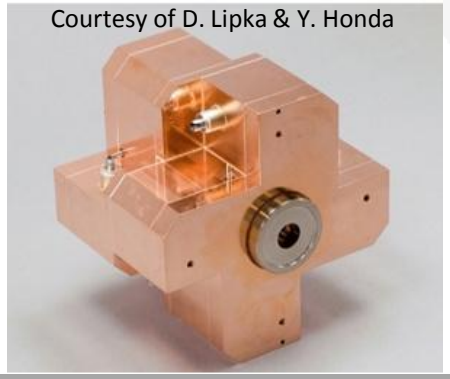
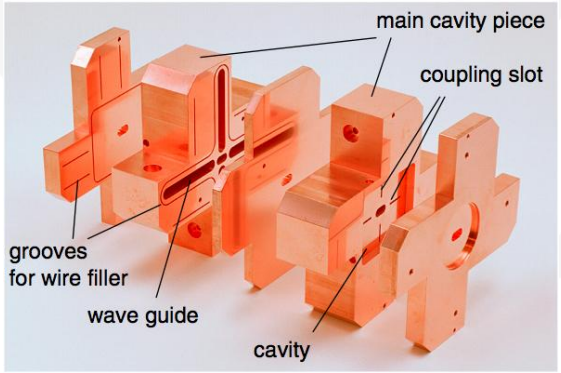
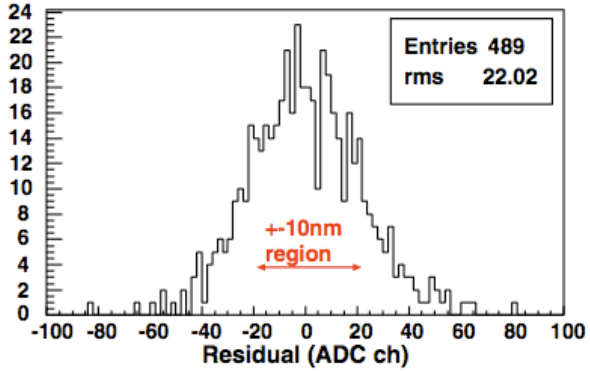


Courtesy of D. Lipka, DESY, Hamburg

- **Prototype BPM for ILC Final Focus**
  - Required resolution of 2nm (yes nano!) in a 6×12mm diameter beam pipe
  - Achieved World Record (so far!) resolution of 8.7nm at ATF2 (KEK, Japan)





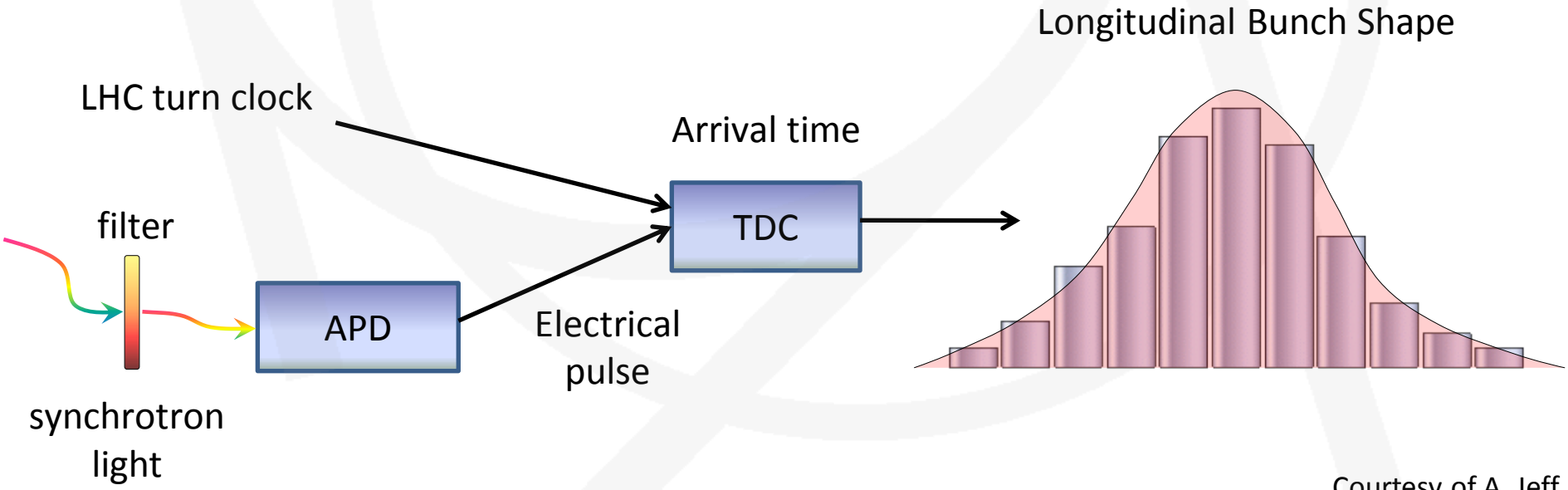


Challenges for Beam Instrumentation

Maximising the Available Data

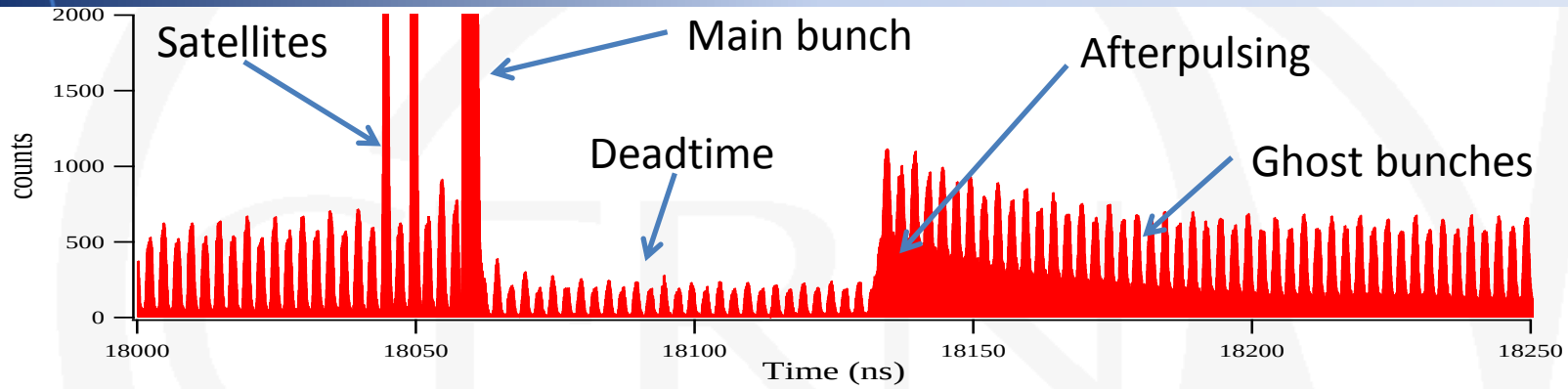
Maximising the Available Data - Example

- **LHC Longitudinal Density Monitor**
  - Aims:
    - Profile of the whole LHC ring with 50ps resolution
    - High dynamic range for ghost charge measurement
  - Method:
    - Single photon counting with Synchrotron light
      - Avalanche photodiode detector
      - 50ps resolution TDC

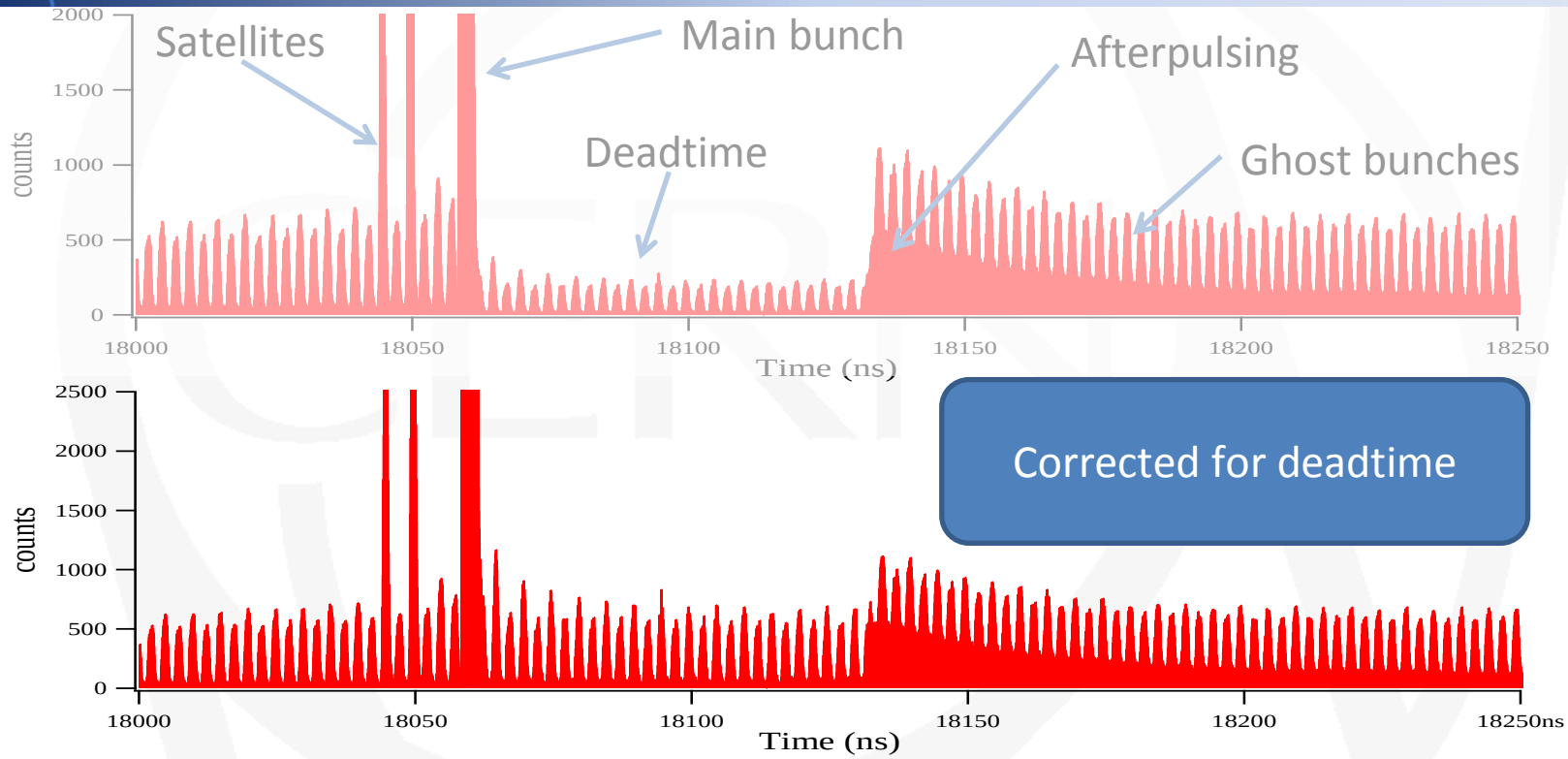


Courtesy of A. Jeff

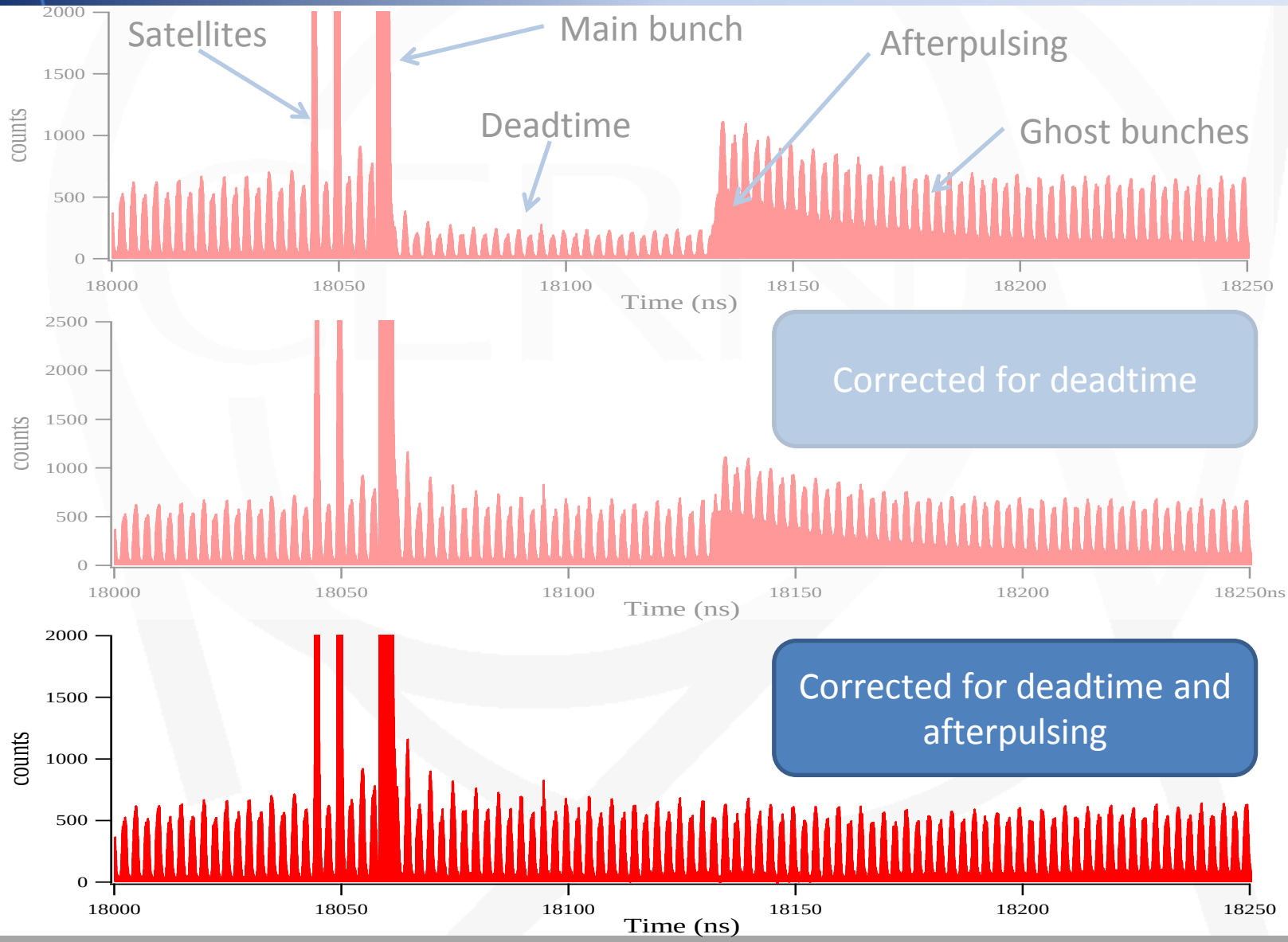
LDM On-line Correction



LDM On-line Correction

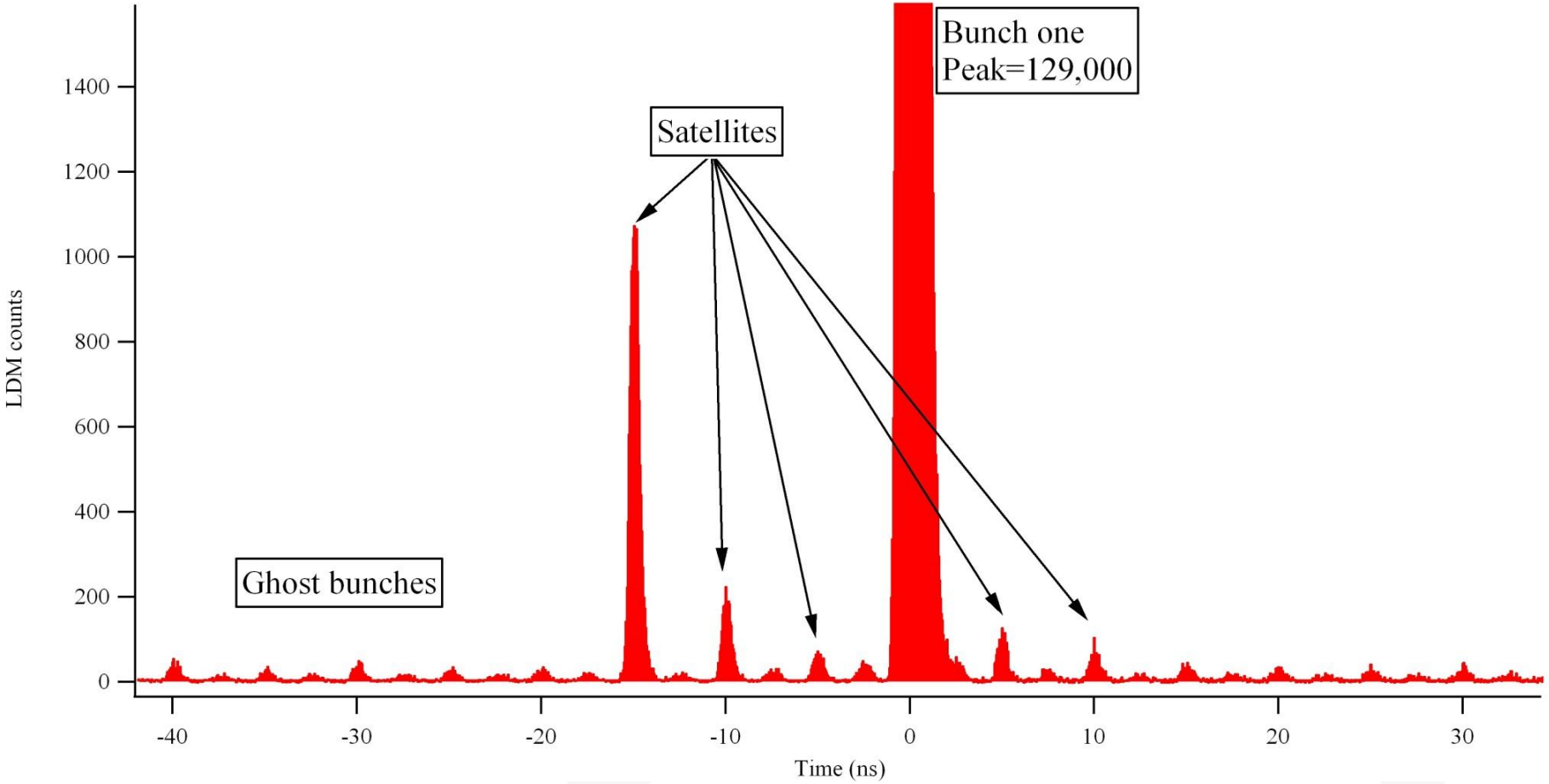


LDM On-line Correction



LDM Results

- **Results**
  - Able to profile the whole ring within a matter of minutes
  - Critical input for accurate luminosity calibration of the experiments



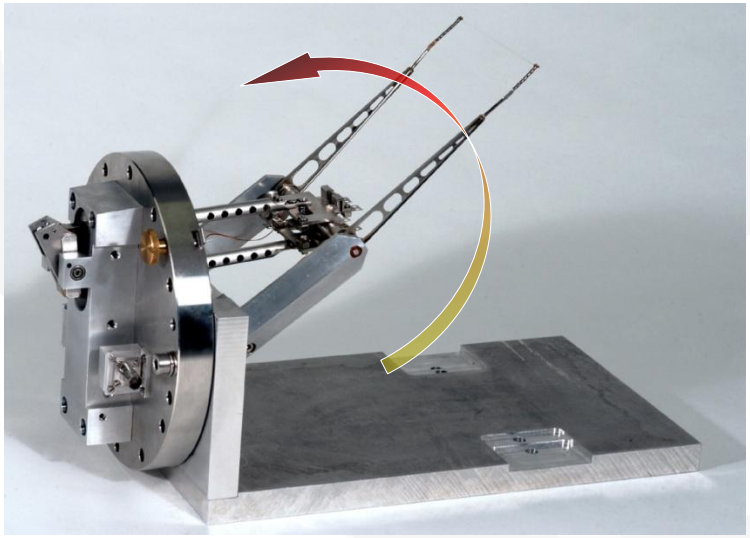
Challenges for Beam Instrumentation

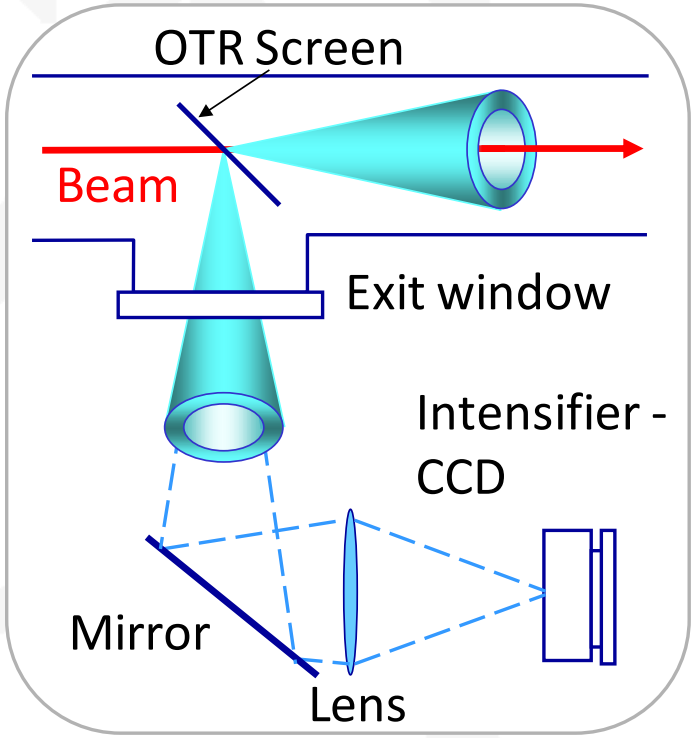
Dealing with high beam powers

Non-invasive measurement techniques

Dealing with High Beam Power - The Issues

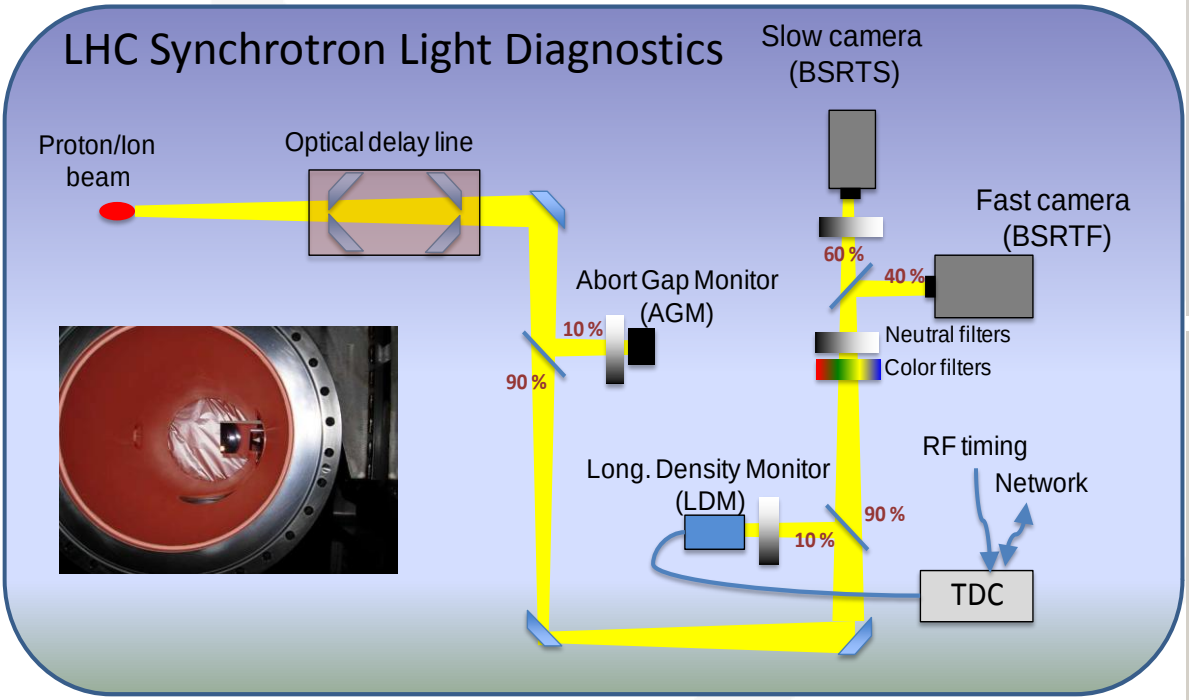
- **Traditional invasive diagnostics no longer suitable**
  - Materials do not withstand energy deposition
    - Burning of holes or breaking of wires
  - Use of superconducting RF structures
    - Risk of contamination on breakage or sputtering of the intercepted material

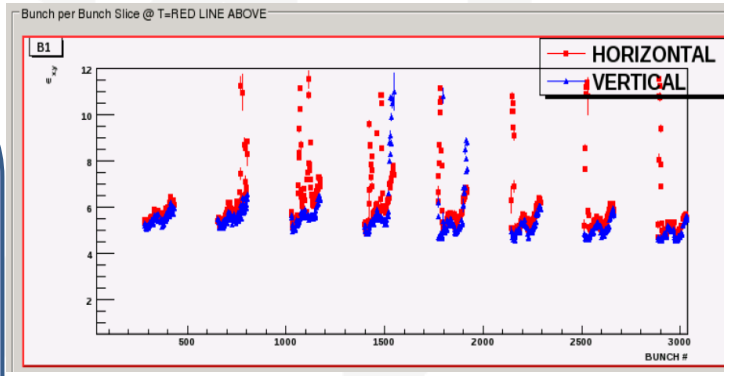


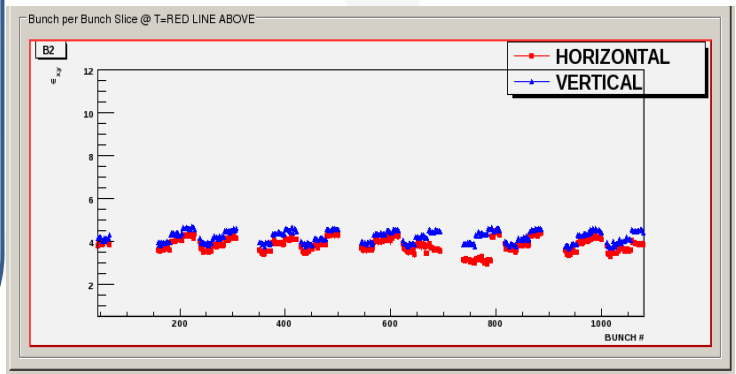


Measuring the Size of High Power Beams

- **Synchrotron Light Diagnostics**
  - Only for electron & very high energy proton/ion machines (LHC)
    - Difficult to separate the light from the beam for linear accelerators
  - Difficult to get absolute calibration
    - Image correction factors typically bigger than the beam size!
  - Additional challenges lie in fast cameras & signal treatment chains for bunch by bunch measurement

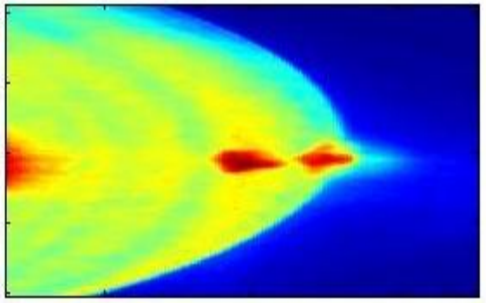




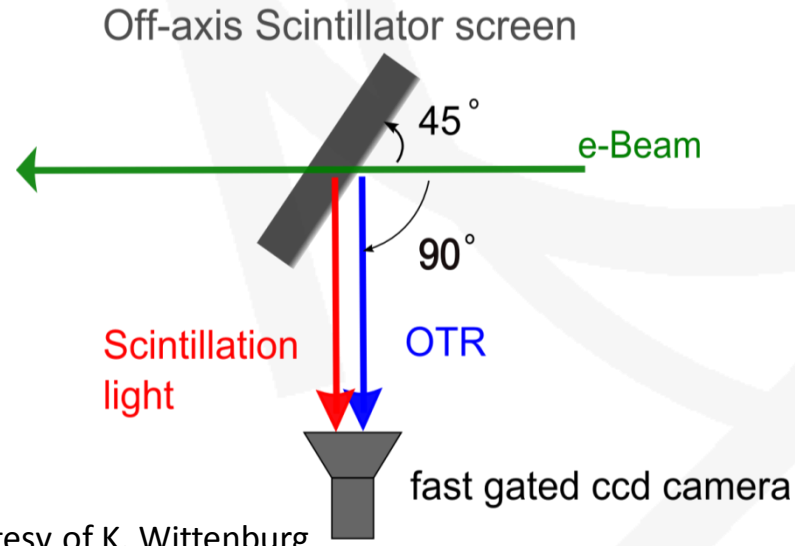


Measuring the Size of Intense Bunches

- **Standard OTR not an option for short intense bunches (main issue for LCLS)**
  - Signal swamped by Coherent OTR from micro-bunching within the main bunch



Al coated Si OTR screen,
COTR light,
Coherent SR

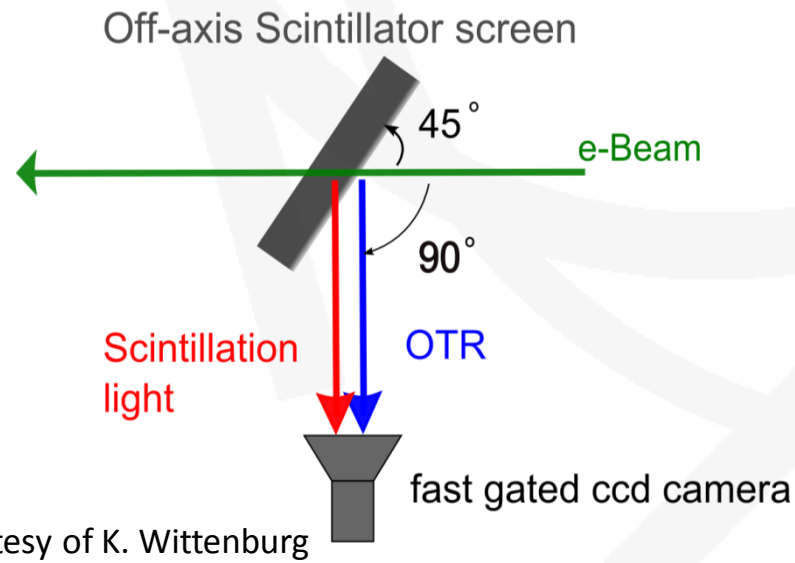


Courtesy of K. Wittenburg

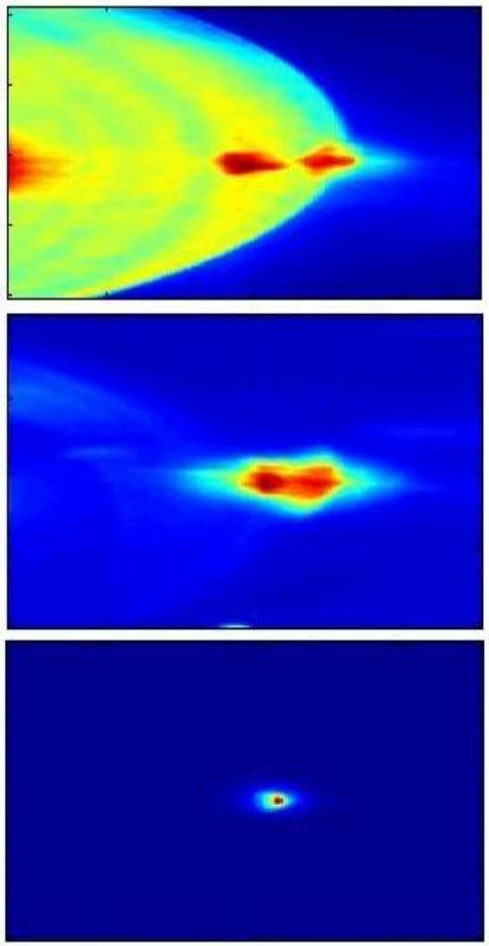
Courtesy of M. Yan

Measuring the Size of Intense Bunches

- **Standard OTR not an option for short intense bunches (main issue for LCLS)**
  - Signal swamped by Coherent OTR from micro-bunching within the main bunch
- **One proposal is to go to luminescent Screens**
  - There will still be COTR at polished surfaces
  - Resolution might be a problem
- **Investigation of temporal suppression of COTR**
  - Scintillation screen + fast gated camera
  - Proof-of-principle at FLASH, DESY



Courtesy of K. Wittenburg



Al coated Si OTR screen,
COTR light,
Coherent SR

LuAG screen,
COTR &
scintillation light

LuAG screen
+100ns delay
Only scintillation light

Courtesy of M. Yan

Measuring the Size of Intense Bunches

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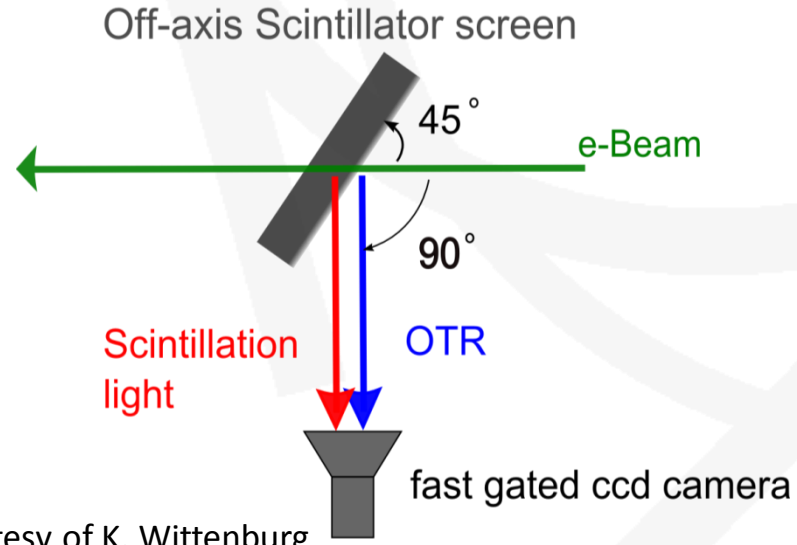
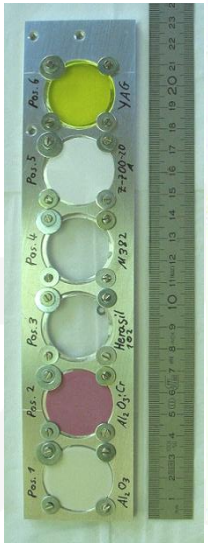
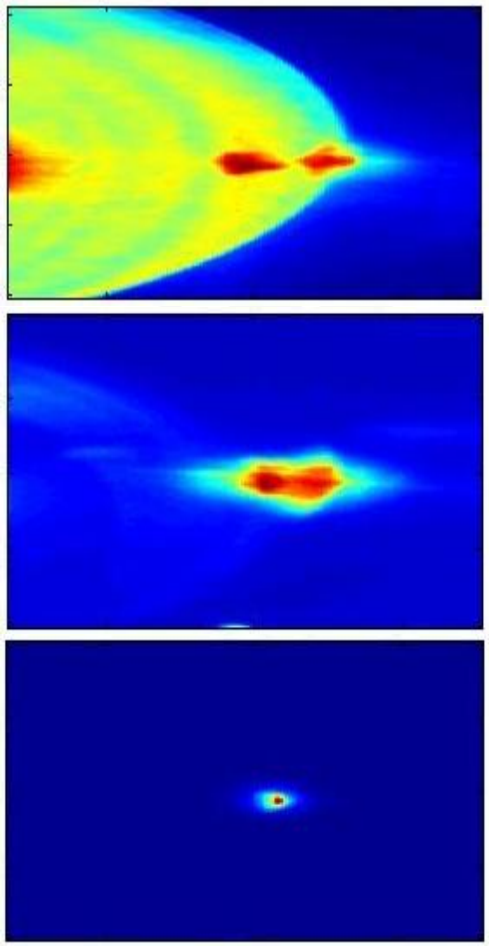
- **Investigation of temporal suppression of COTR**
  - Scintillation screen + fast gated camera
  - Proof-of-principle at FLASH, DESY
- **Resolution of scintillation screens needs study**
  - Synergy with ion beam diagnostics
  - Similar studies ongoing for FAIR



Courtesy of K. Wittenburg





Al coated Si OTR screen,
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LuAG screen
+100ns delay
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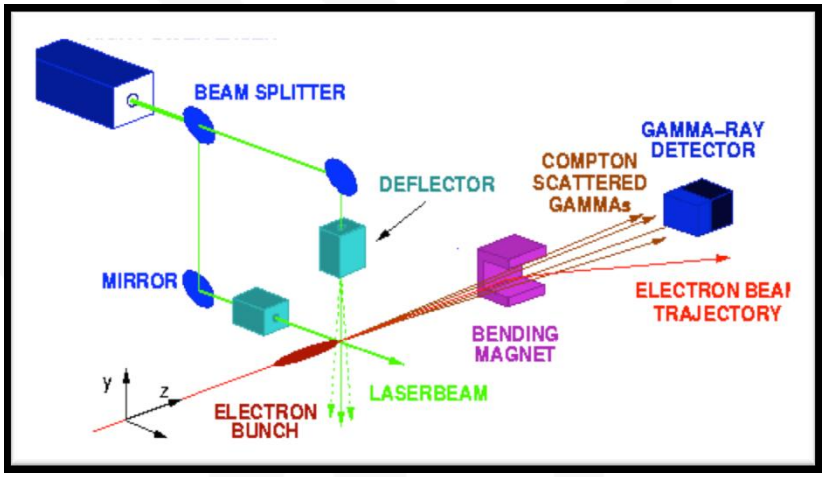
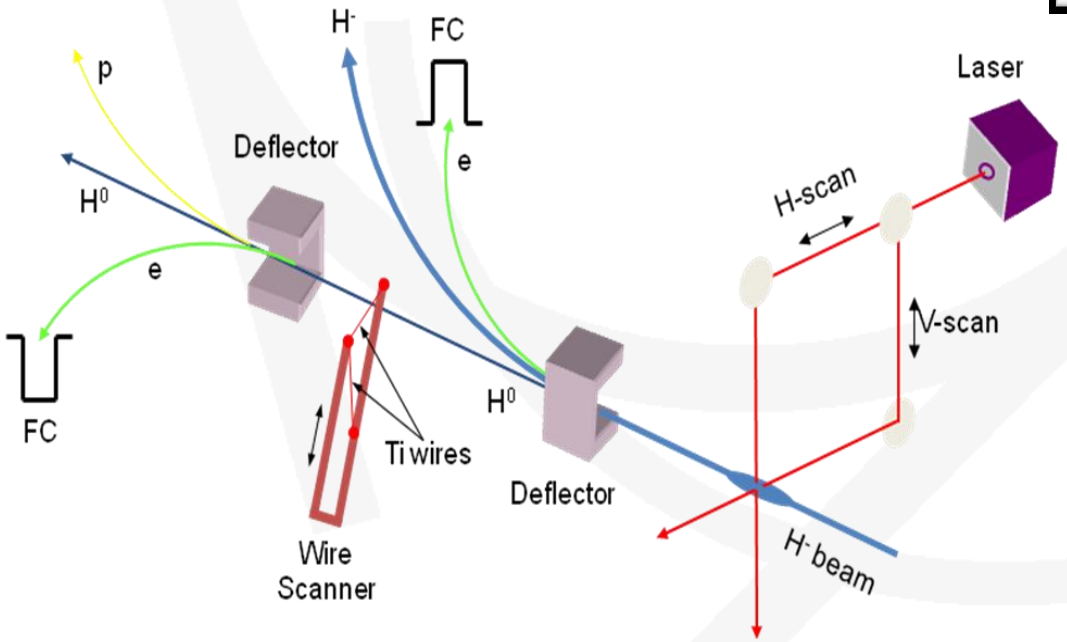
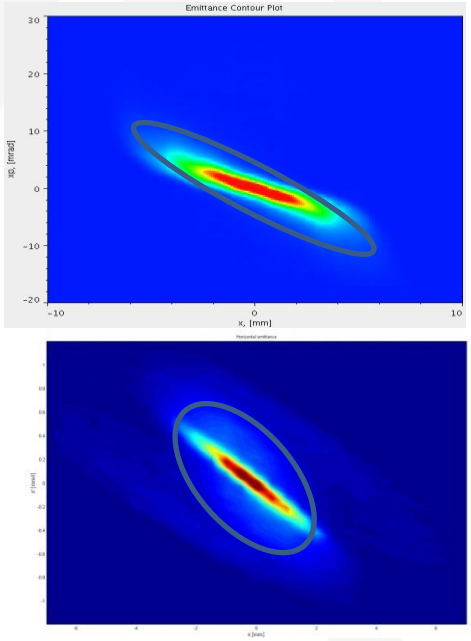
Courtesy of M. Yan

Non-Invasive Beam Size Measurement

- **Laser wire scanner**
  - Good candidate for H^- & electrons
    - Can measure down to micron level
  - Needs conversion to turn-key instrument
    - Reliable laser system
    - Laser distribution to multiple measurement stations



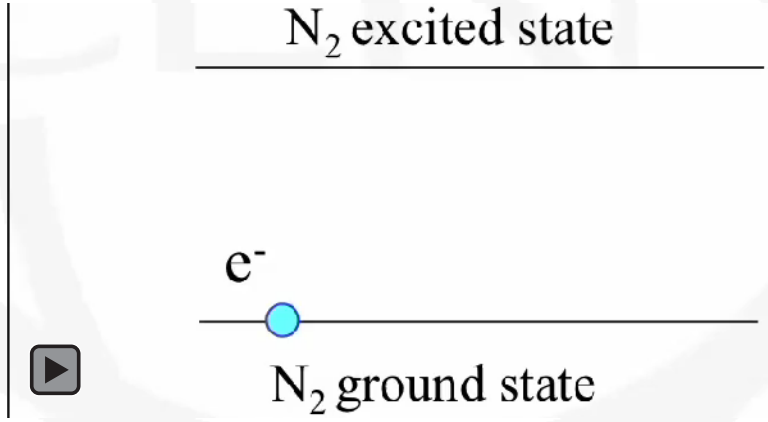




Courtesy of A. Alexandrov

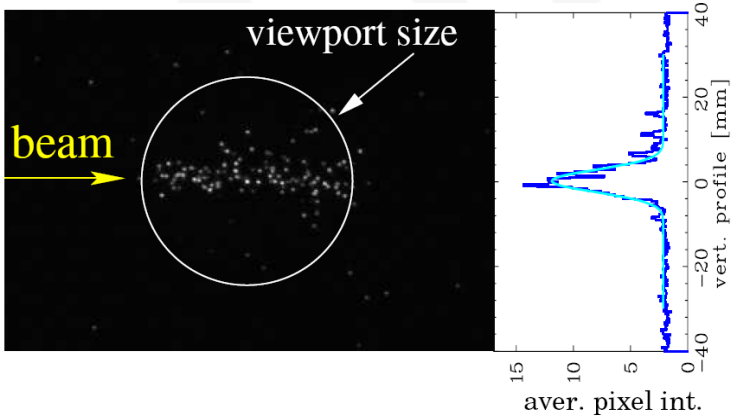
Non-Invasive Beam Size Measurement

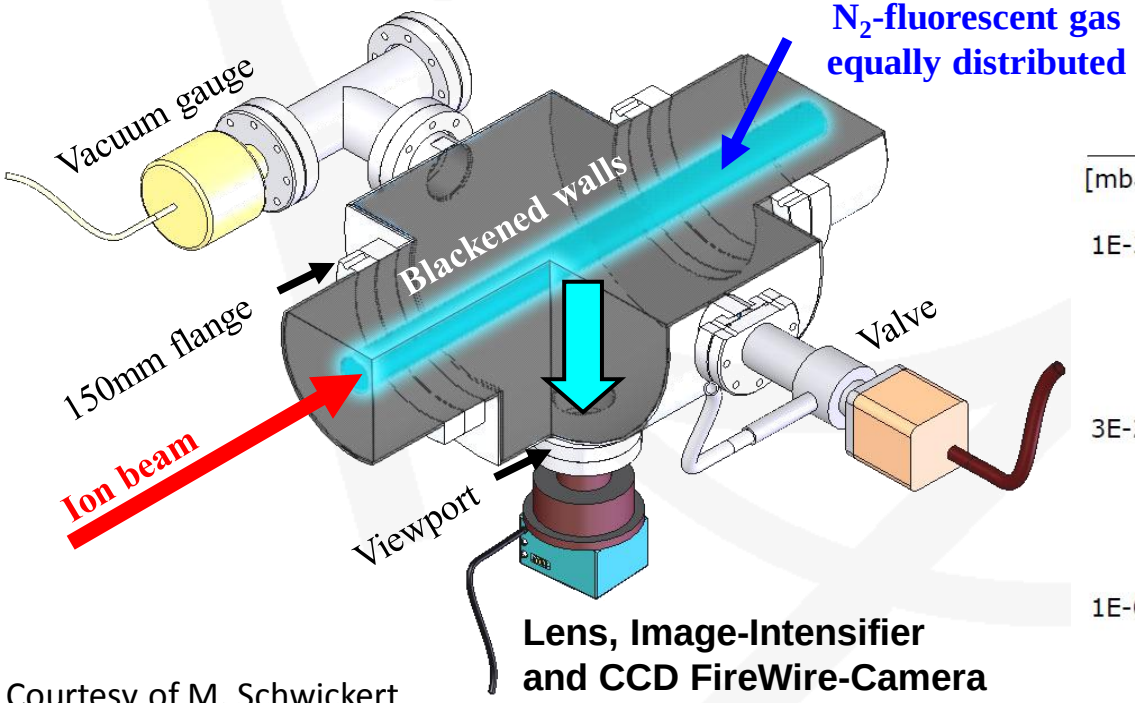
- **Beam Induced Fluorescence**

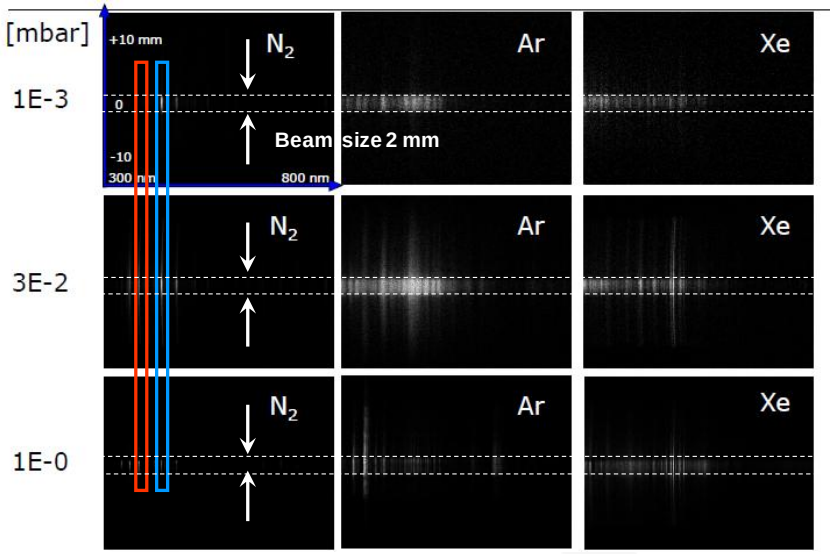


Non-Invasive Beam Size Measurement

- **Beam Induced Fluorescence**
  - Issues
    - Sensitivity to radiation
    - Low signal yield ⇒ vacuum bump



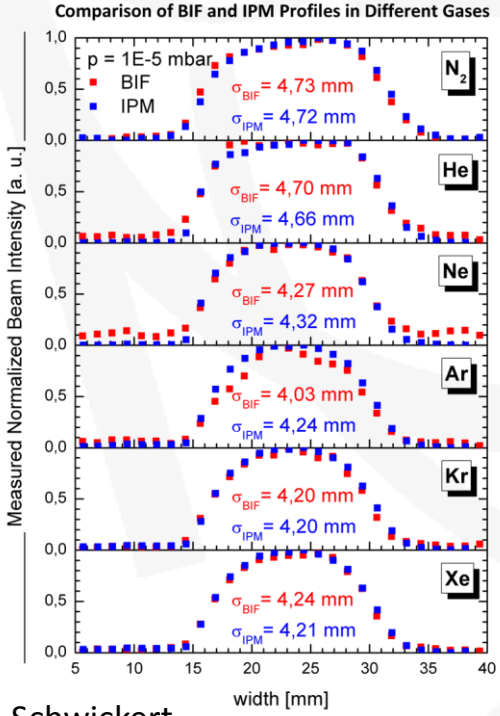




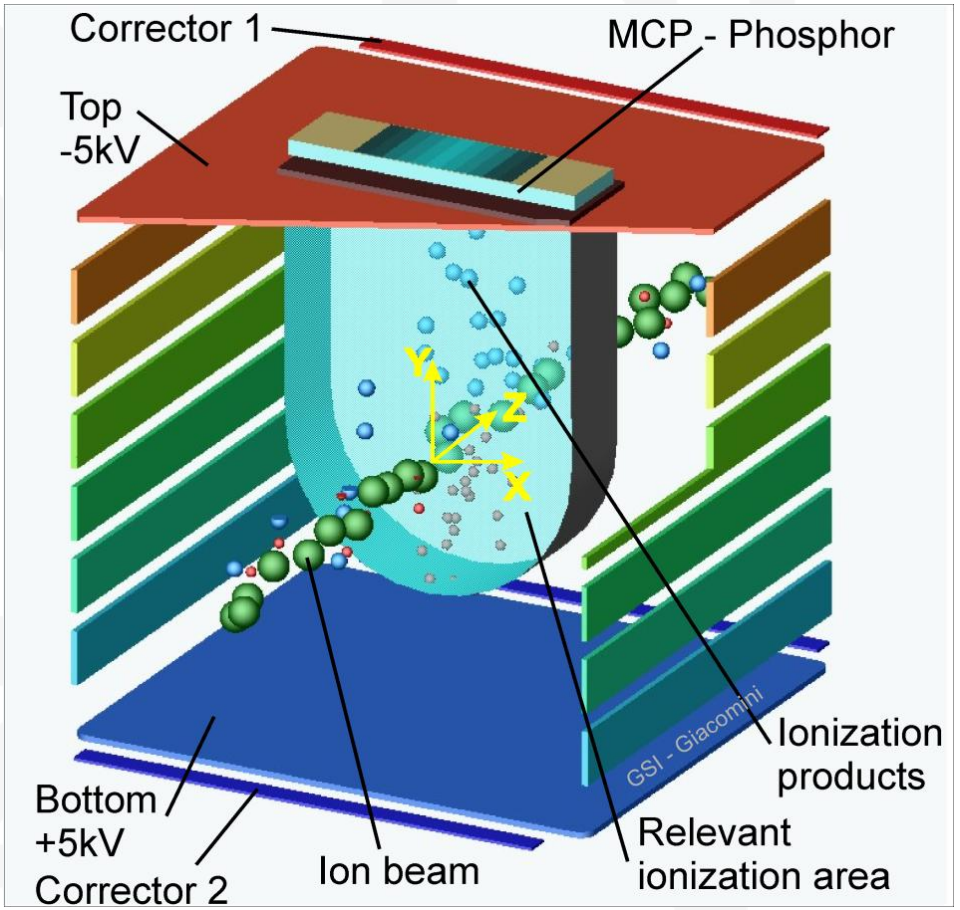
Courtesy of M. Schwickert

Non-Invasive Beam Size Measurement

- **Residual Gas Ionisation**
  - Some 10 times more sensitive than BIF
  - More complicated to build
    - High voltage network
    - Guiding magnetic field
  - Image broadening due to space charge
  - Ageing of detectors an issue



Courtesy of M. Schwickert



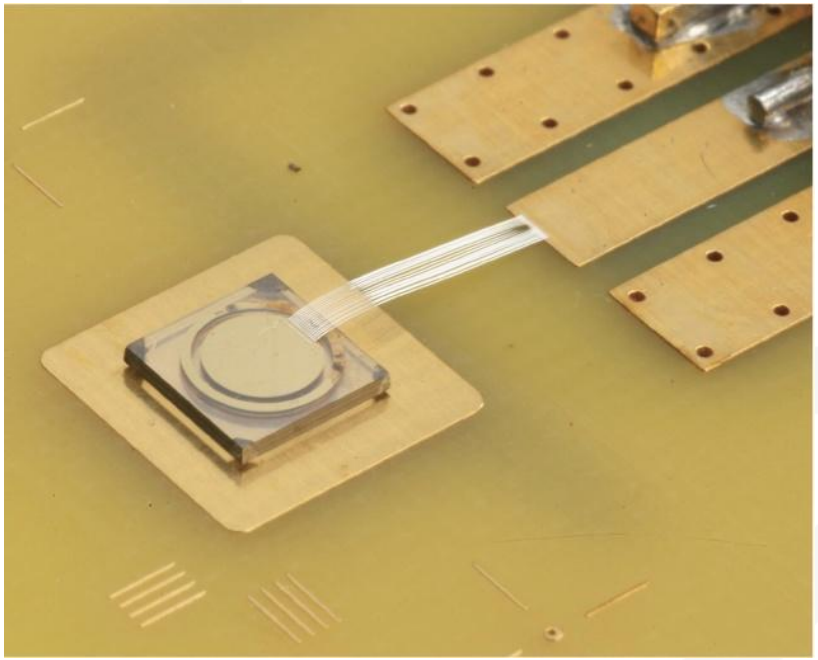
Challenges for Beam Instrumentation

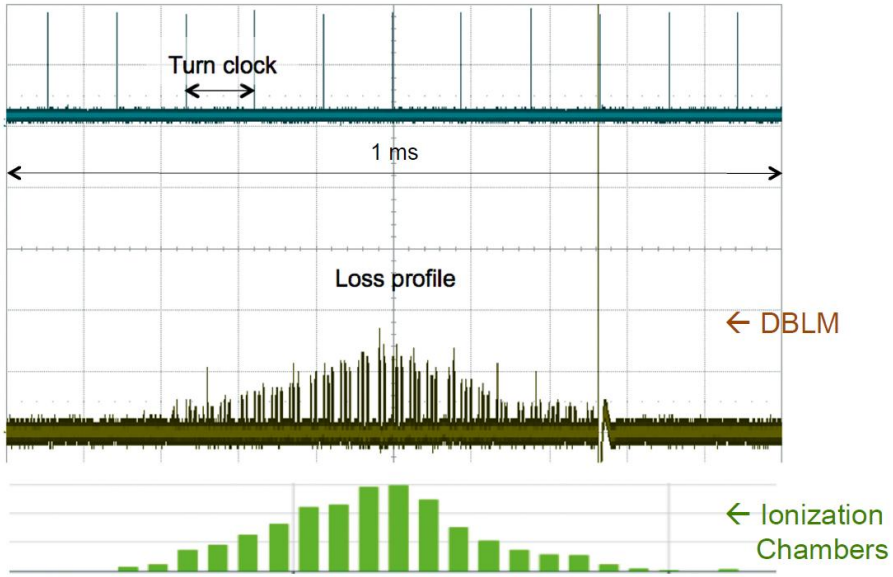
Dealing with high beam powers

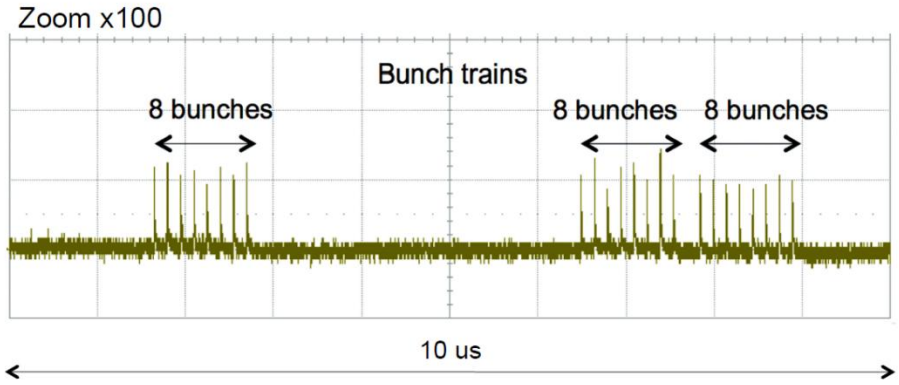
Robust and Reliable Machine Protection Systems

Beam Loss Monitors – New Materials

- **Diamond Detectors**
  - Fast & sensitive
  - Used in LHC to distinguish bunch by bunch losses
  - Investigations now ongoing to see if they can work in cryogenic conditions







Courtesy of E. Griesmayer

Challenges for Beam Instrumentation

Dealing with the ultra-fast

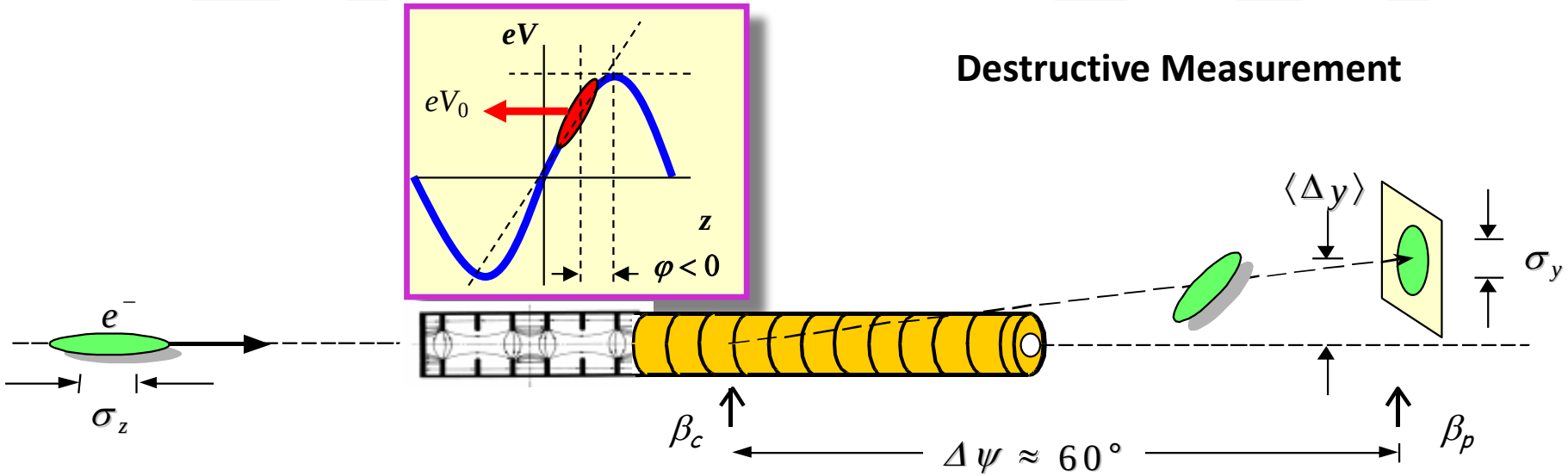
Measurements on the femto-second timescale

Ultra-Short Bunch Length Diagnostics

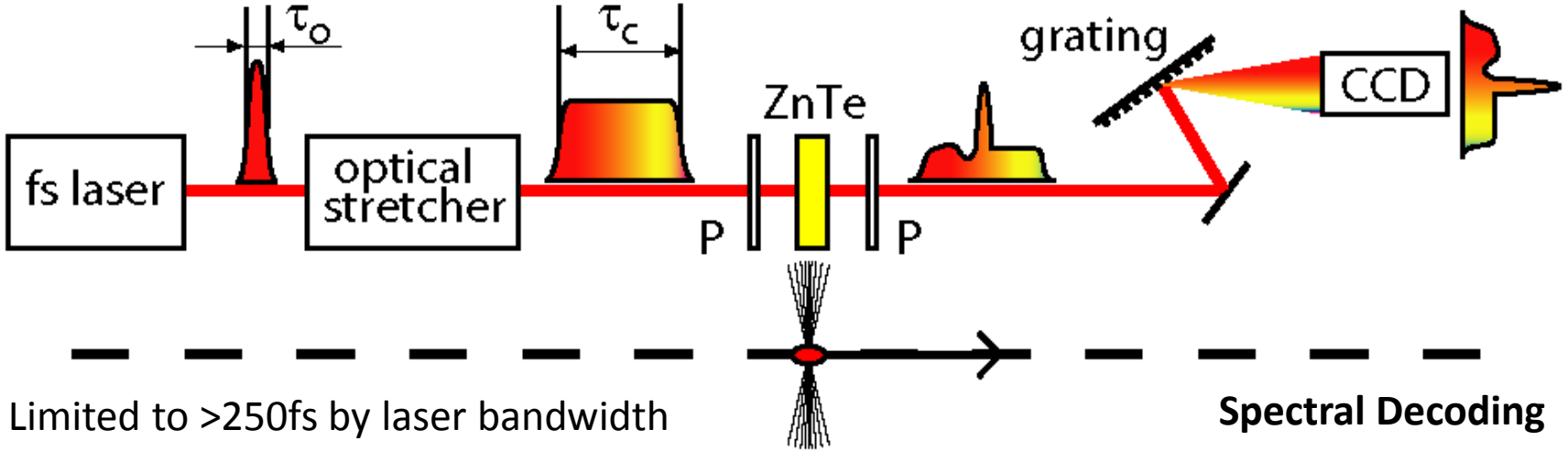
- **Next Generation FELs & Linear Colliders**
  - Use ultra short bunches to increase brightness or improve luminosity
- **How do we currently measure such short bunches?**
  - Transverse deflecting cavity

p^+ @ LHC	250ps
H^- @ SNS	100ps
e^- @ ILC	500fs
e^- @ CLIC	130fs
e^- @ XFEL	80fs
e^- @ LCLS	75fs

Destructive Measurement

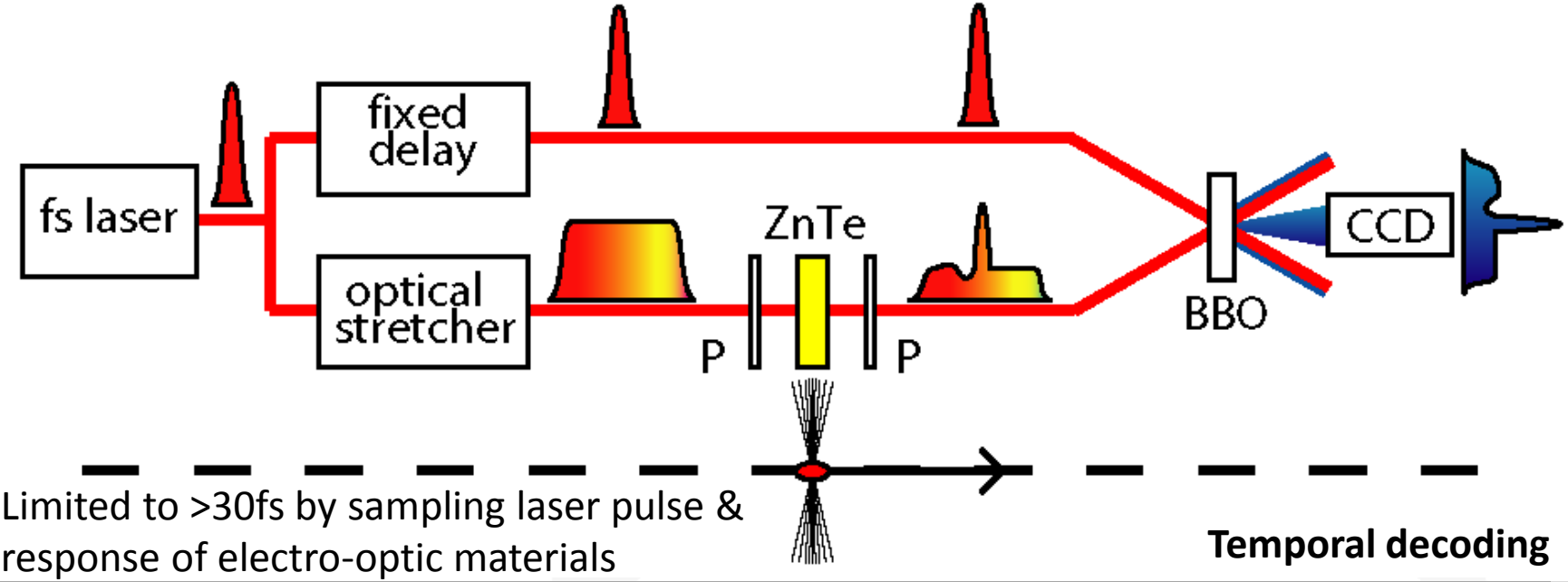


Non Destructive – Electro-Optic Sampling



Limited to >250fs by laser bandwidth

Spectral Decoding

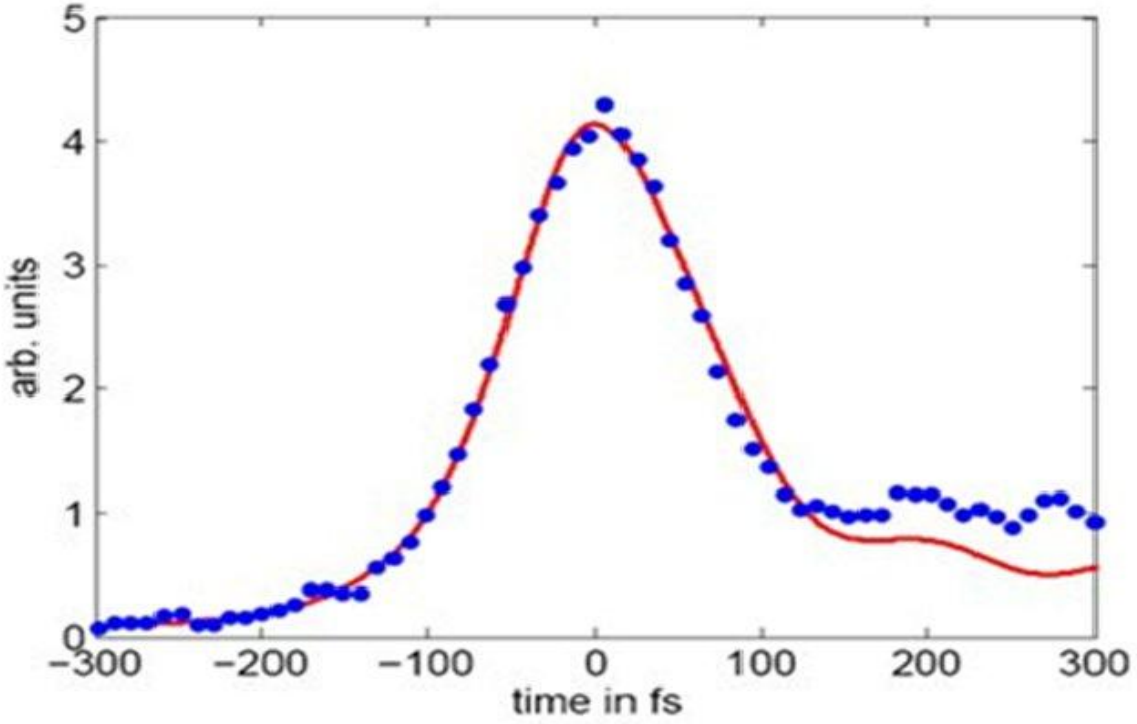


Limited to >30fs by sampling laser pulse & response of electro-optic materials

Temporal decoding

Non Destructive – Electro-Optic Sampling

- **Shortest measured electron bunch profile**
  - 79.3 ± 7.5 fs at DESY FLASH
  - Using 65um thick GaP crystal



Courtesy of A. Gillespie

Conclusion

- **Particle Beam Diagnostic systems are continually evolving to meet the requirements of ever more demanding specifications**
  - ever more powerful and sophisticated accelerators
  - ever more demanding specifications
- **For the upcoming new large scale facilities (ILC, CLIC…)**
  - Maximizing system availability by design (for machine protection, for short commissioning time)
  - Integrated remote diagnostics (collaborations, general maintenance)
- **Many synergies between the developments required for all types of new accelerator facilities**
  - Ideal subject for collaboration on an international level
  - Was already underway between the major accelerator laboratories worldwide
  - Now strengthened and extended to universities and industry

A big "Thank You" to
Rhodri Jones (CERN) for his great and animated slides
Jean-Pierre Delahaye (now SLAC) for his survey data made for ICHEP2010