

# R<sup>3</sup>B Experiments with Final CALIFA Setup



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GEFÖRDERT VOM  
Bundesministerium  
für Bildung  
und Forschung



Tobias Jenegger

PSI Seminar 07.06.2023

R<sup>3</sup>B @ FAIR

CALIFA Status & Final

Configuration

Analysis S444 Experiment

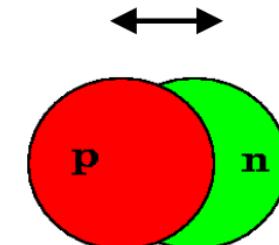
TUM Members:

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Stefan Eder, Tobias Jenegger

## Formation of Elements – Nucleosynthesis

abundances - r-Process - fission feeding

- ### Collective Excitations
- EOS - Giant Dipole Resonances
  - Pygmy Resonances - neutron skin thickness



Isovector Electric  
Giant Dipole Resonance

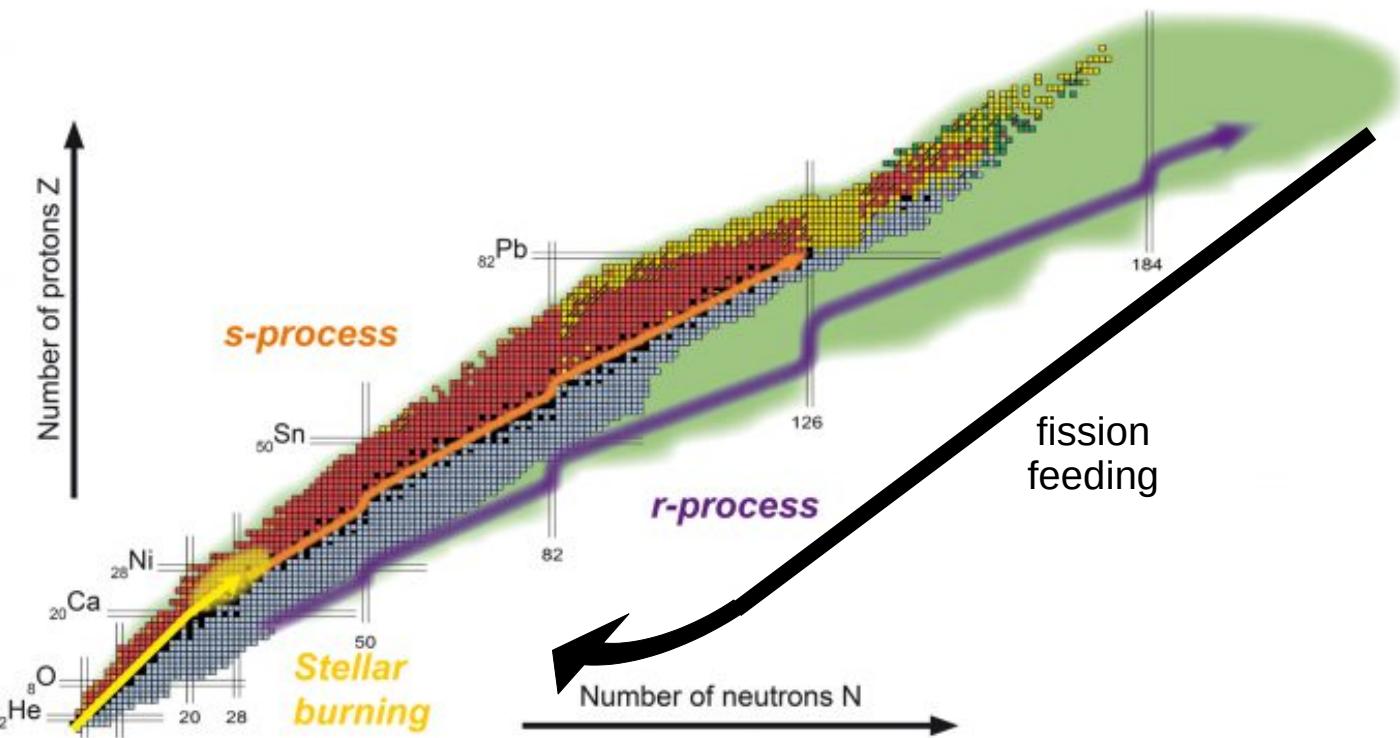
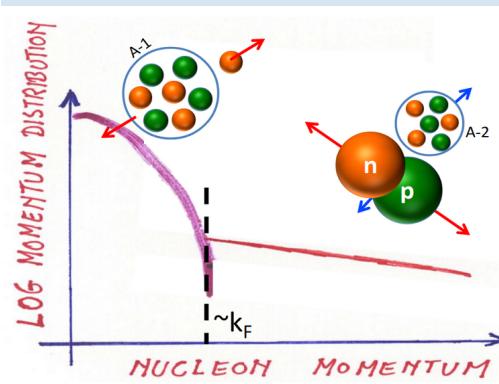
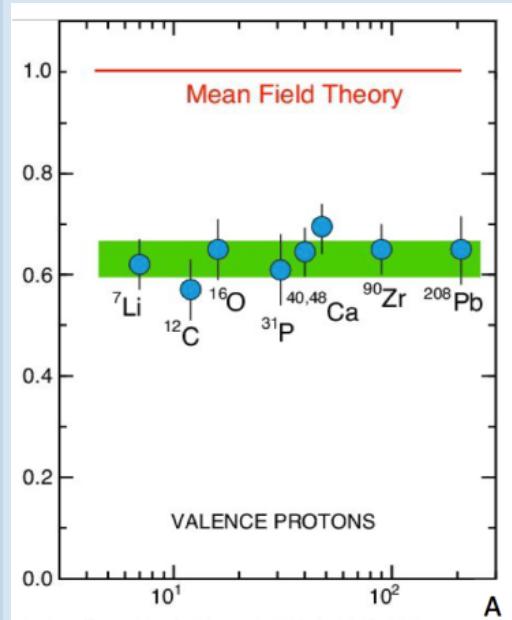


Fig. 1: Nuclear chart showing the nucleosynthesis processes occurring during stellar burning (yellow), the s-process (orange) and the r-process (violet) (credit: EMMI, GSI/Different Arts)

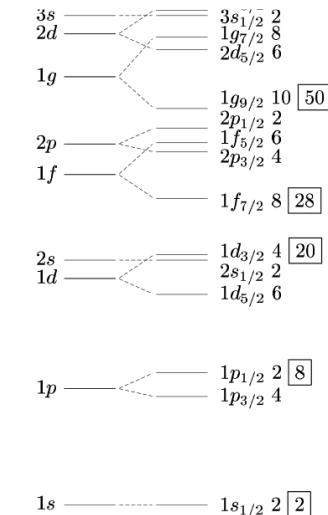
## Physics Program @ R3B

## Single Particle Properties inside atomic nucleus

- Nuclear Structure far off stability
- Short Range Correlated (SRC) nucleons



## Nuclear Shell Model



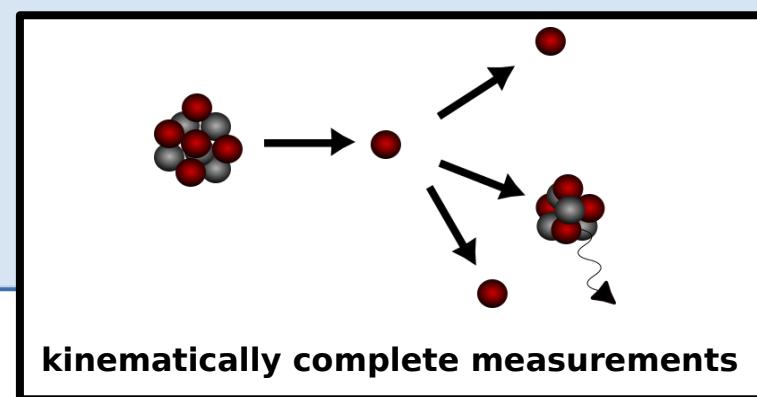
## Experimental Setup Requirements:

FAIR accelerator facility

$$\max \left( \frac{N - Z}{A} \right)$$

+

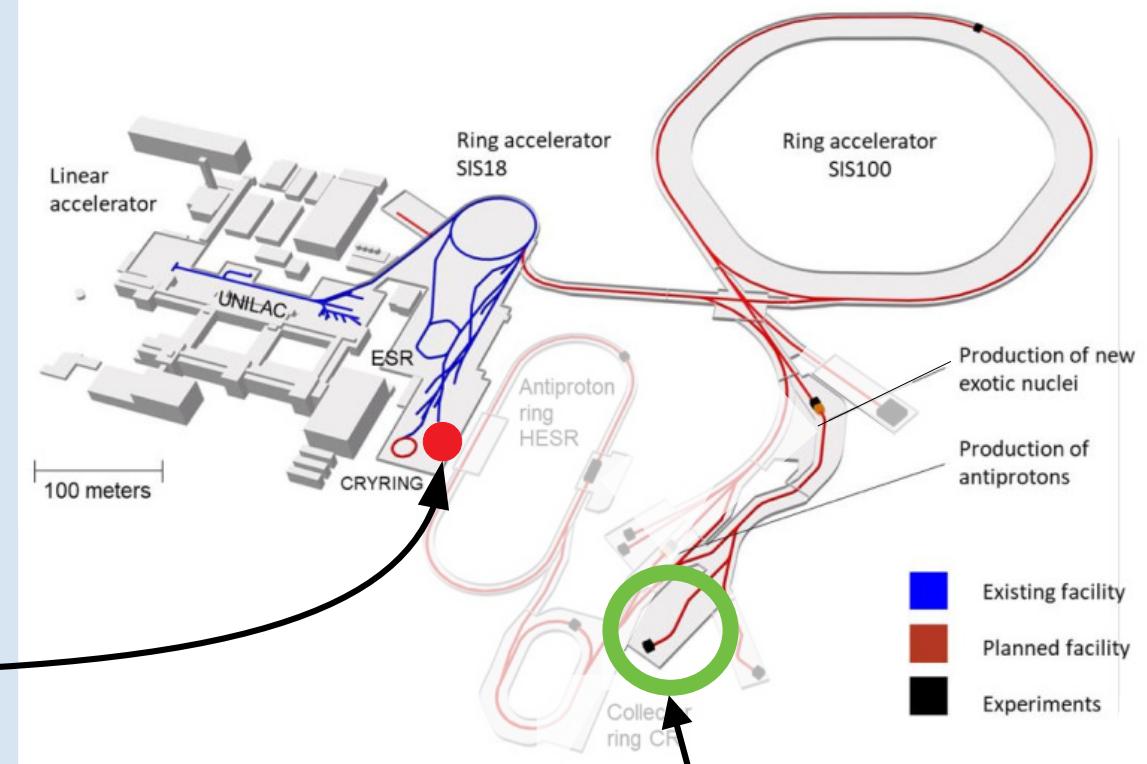
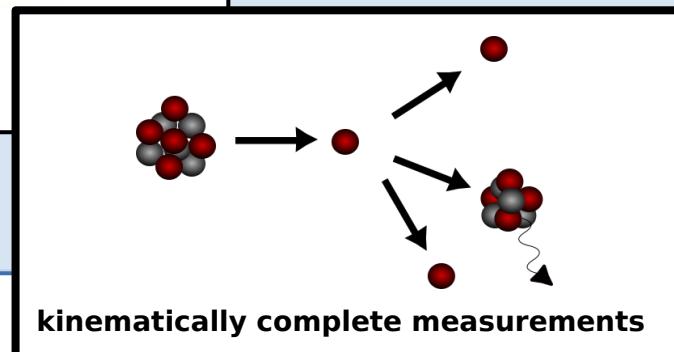
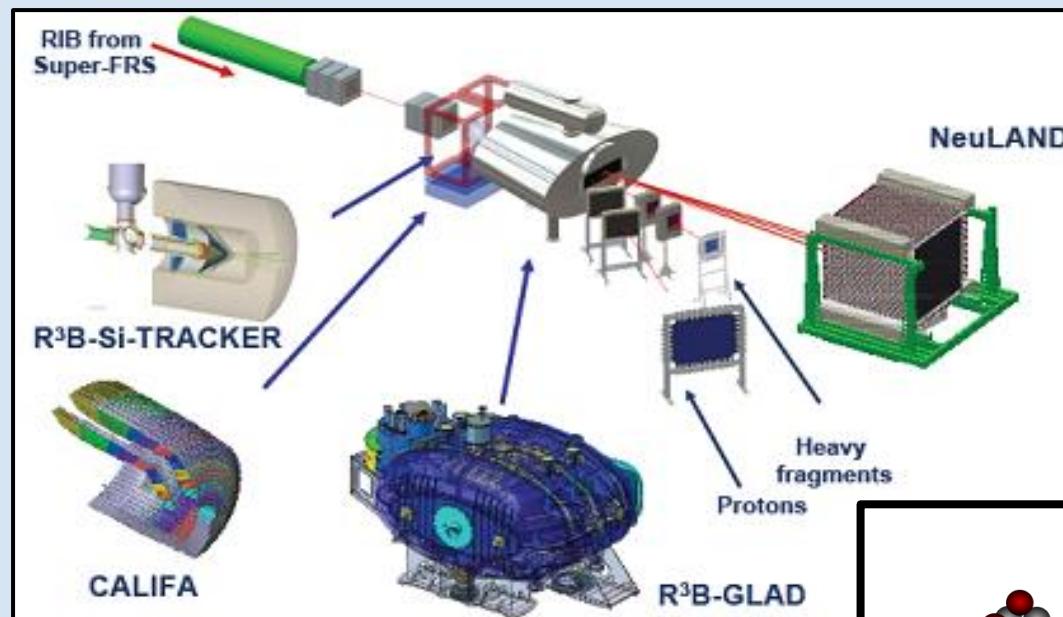
R3B Setup



# R<sup>3</sup>B @ FAIR

**R<sup>3</sup>B** as part of the  
**Facility for Antiproton and Ion Research (FAIR)**  
in Darmstadt:

## Reactions with Radioactive Relativistic Beams



in 2027

# FAIR Construction Site



High Energy Cave

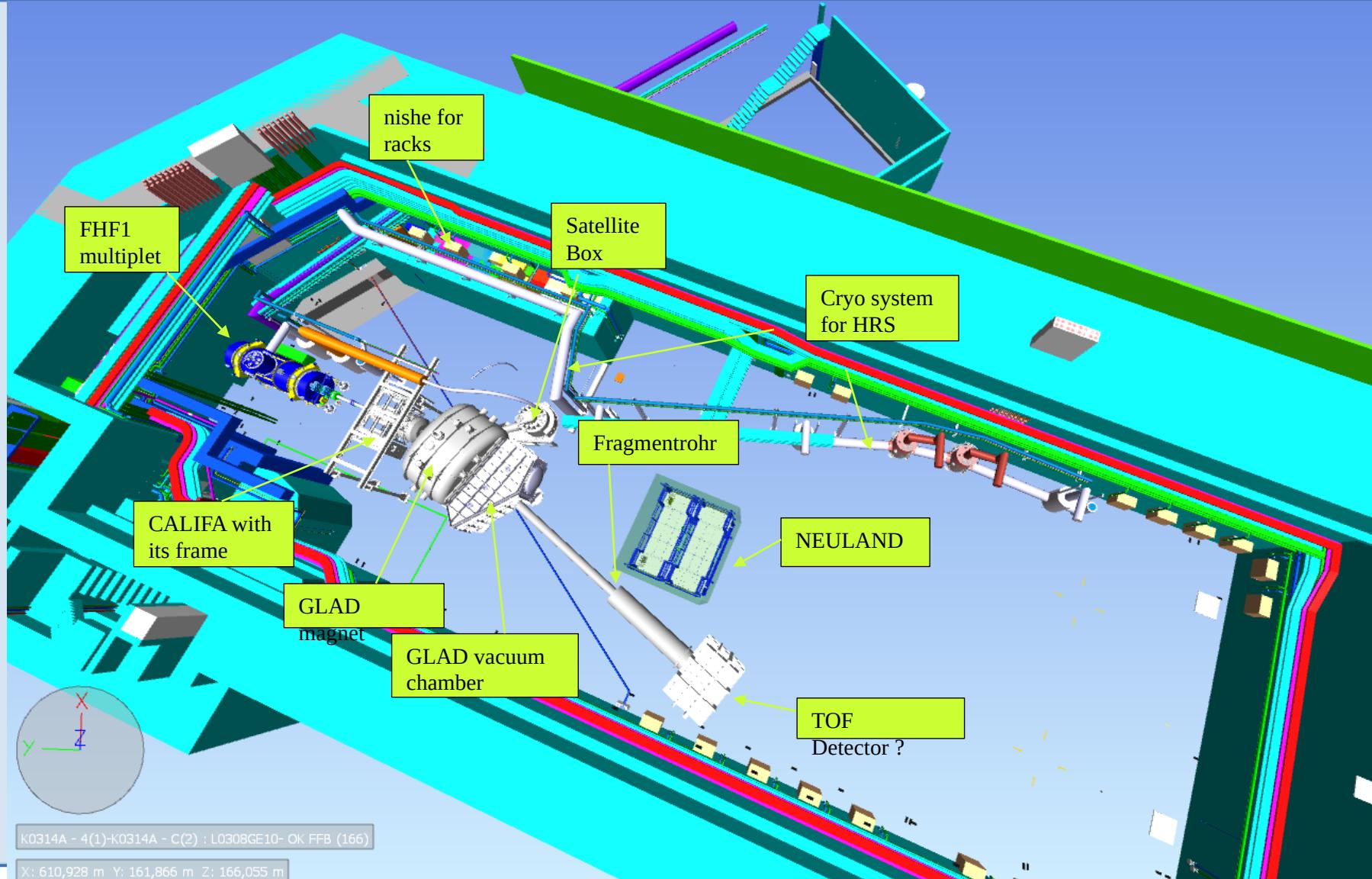
© D. Fehrenz, GSI/FAIR, May 2023



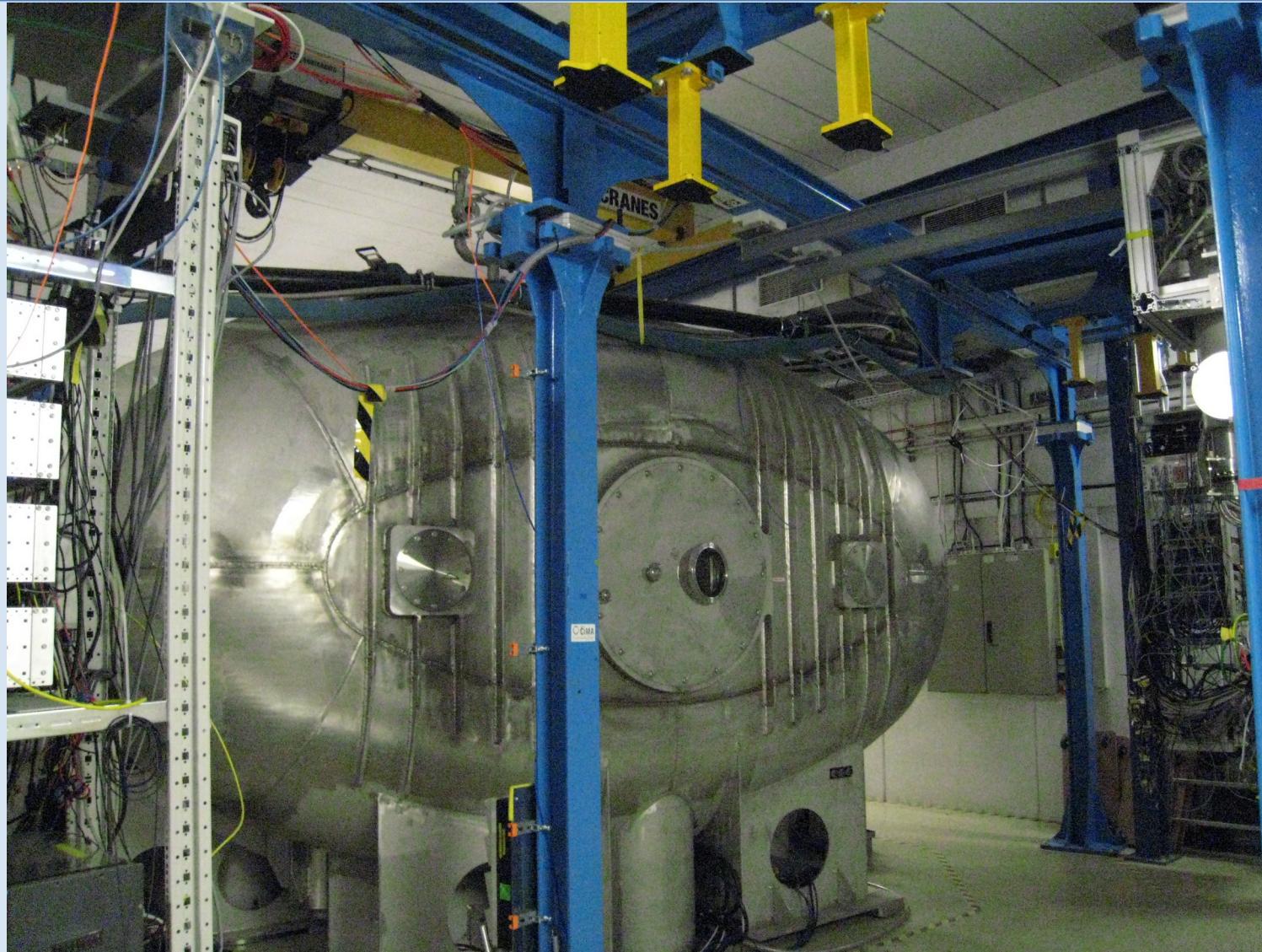
Tobias Jenegger

Dimensions: 60 x 20 x 7 m

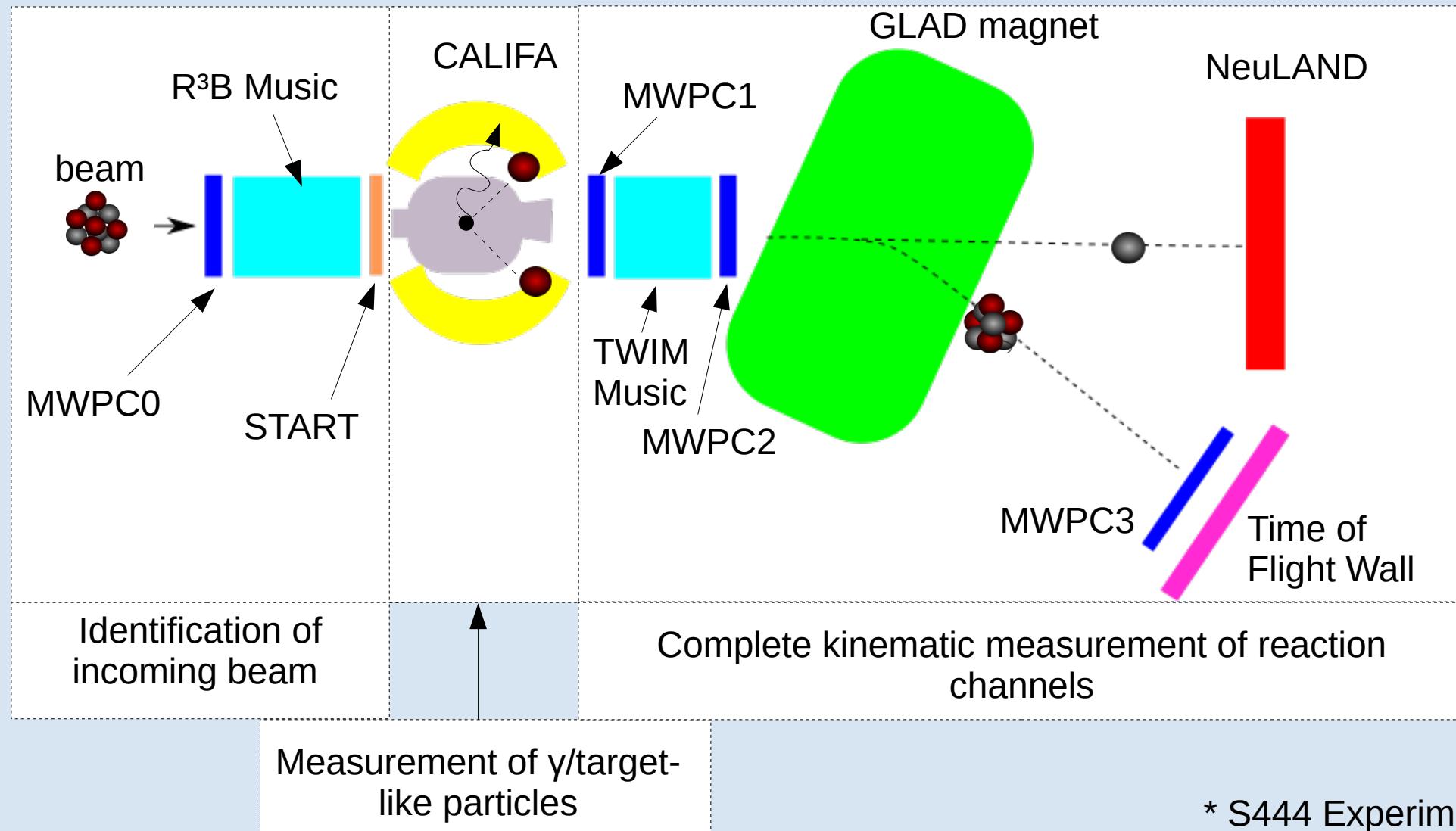
# Final R<sup>3</sup>B Setup



## But space in Cave C is limited...



## R3B Setup\*



CALOrimeter for the In Flight detection of  $\gamma$ -rays and light charged pArticles

Endcap:

iPhos:

480 CsI(Tl)

crystals

CEPA:

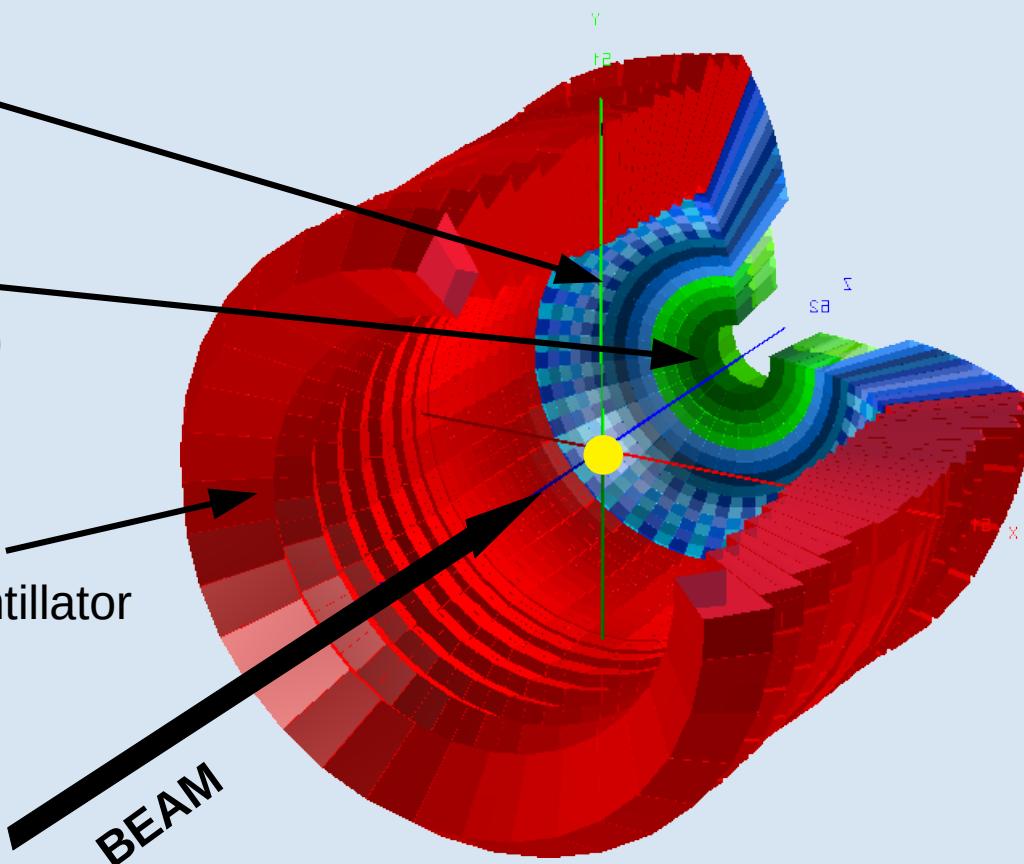
112 CsI (Tl)

crystals

Barrel:

1952 CsI(Tl) scintillator

crystals



**Highly segmented detector:**

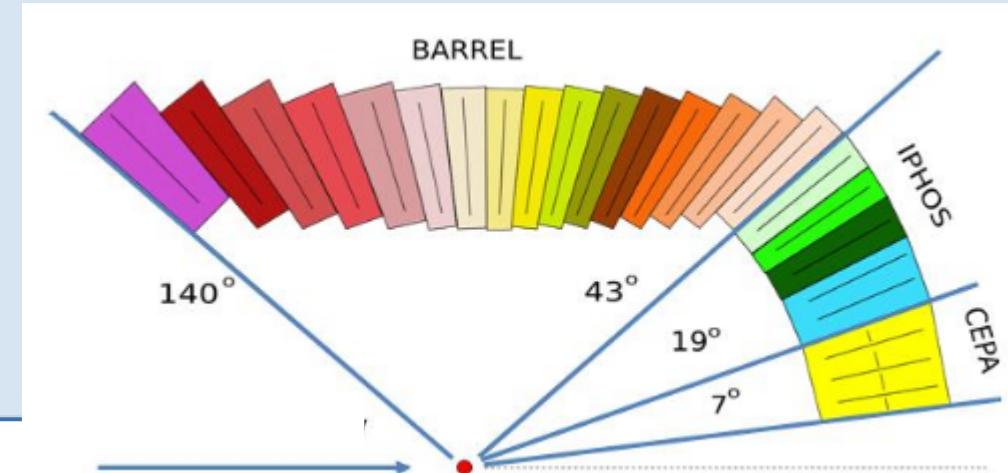
- good angular reconstruction/  
doppler correction

**Broad calorimetric energy measurements:**

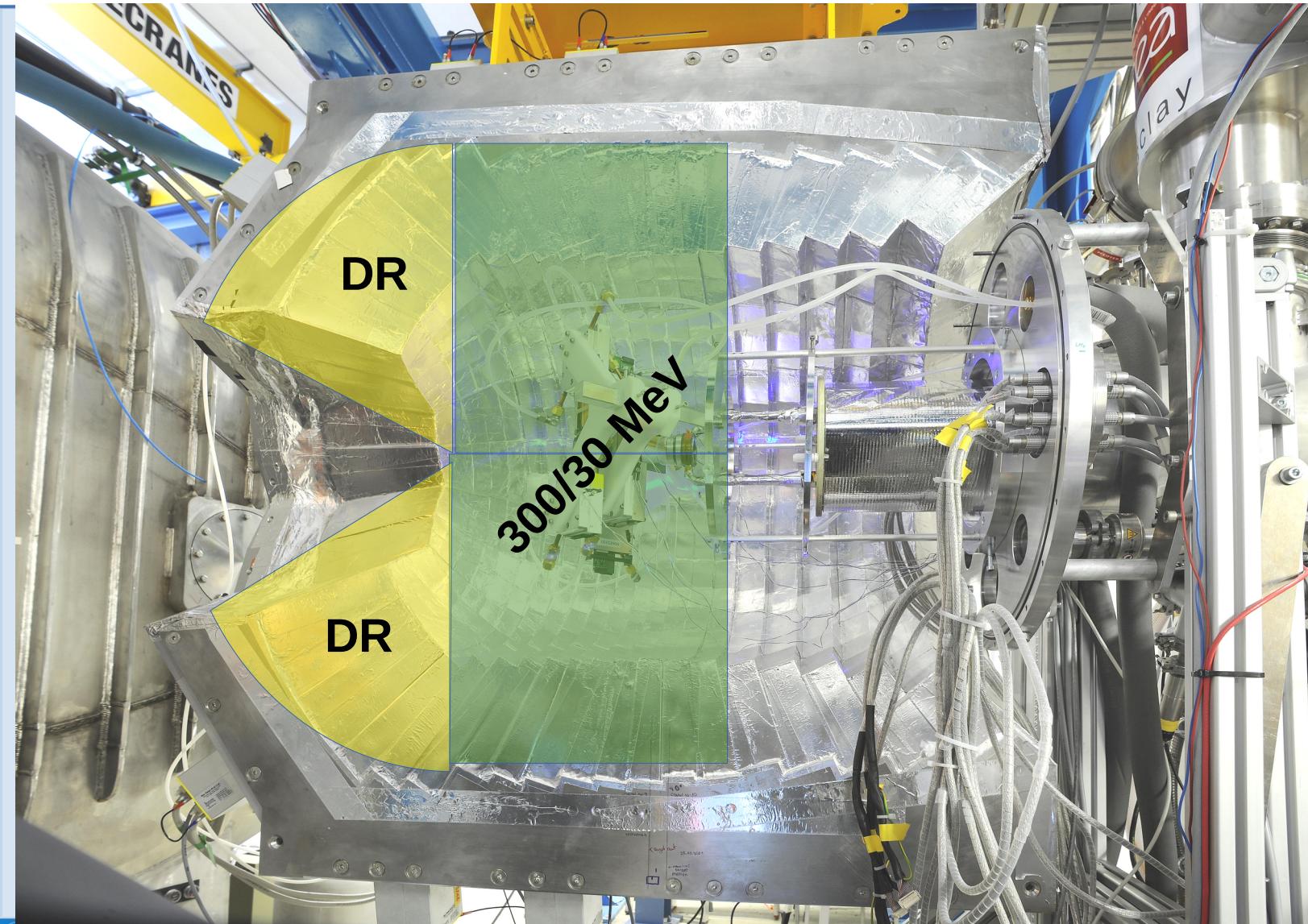
- From 100 keV  $\gamma$ -rays up to high energetic charged particles

**Flexible running mode:**

- self/external triggering mode



# CALIFA Configuration (S522, 2022)

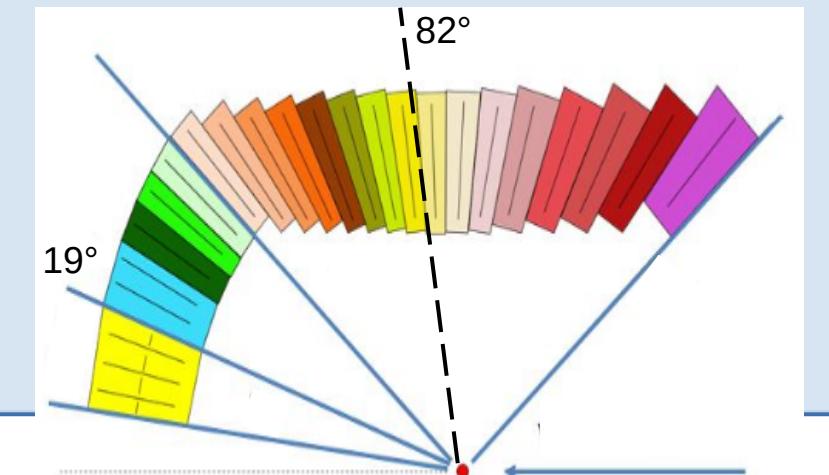


IPhos: 480 crystals

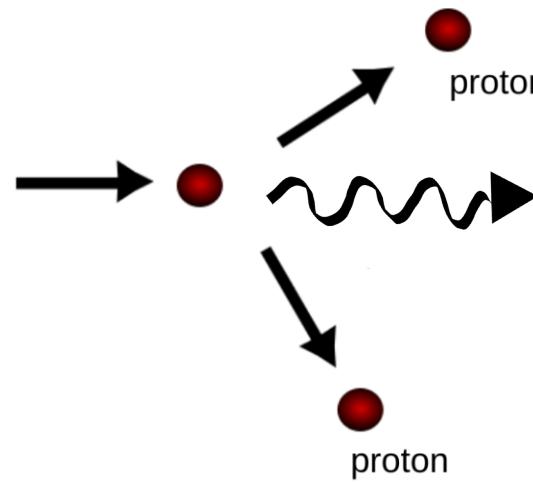
- completely filled
- readout with Dual Range Preamps

Barrel: 1024 crystals

- half filled
- readout with Single Range (300/30 MeV) Preamps



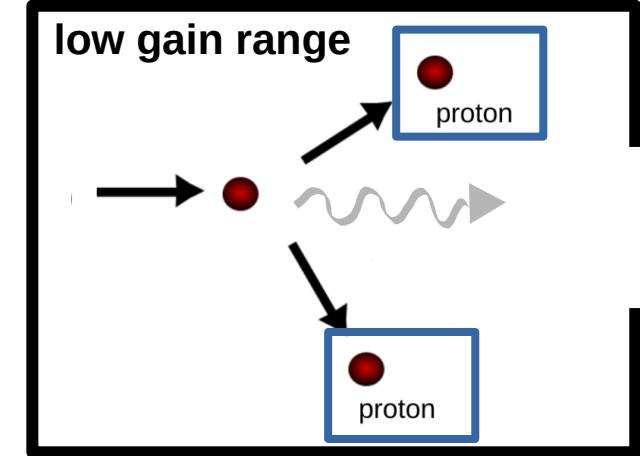
## Dual Range Preamplifier



**SIMULTANEOUS**  
high energetic particle  
measurement  
&  
gamma spectroscopy

2 x channelnr.

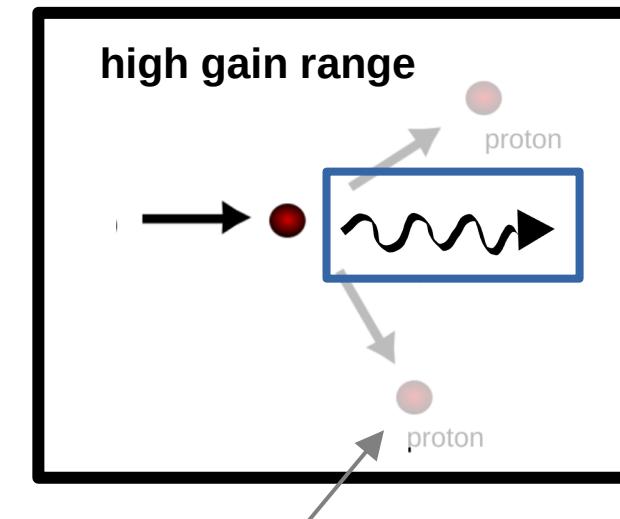
## SingleRange Preamplifier



low gain range

Gamma  
threshold:  
500 keV

**OR**



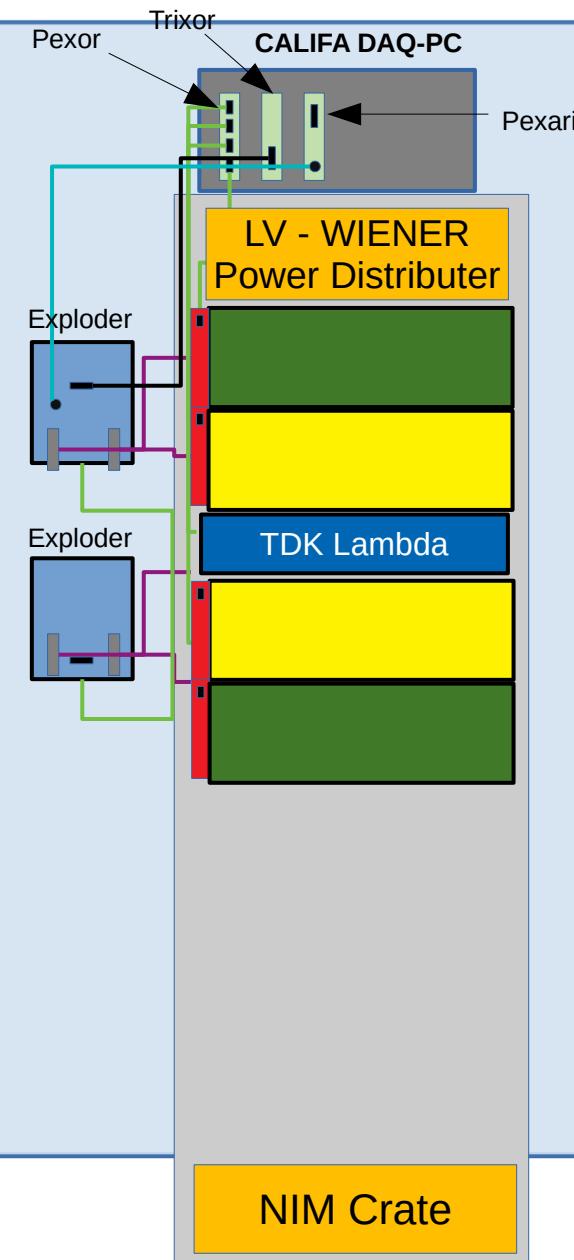
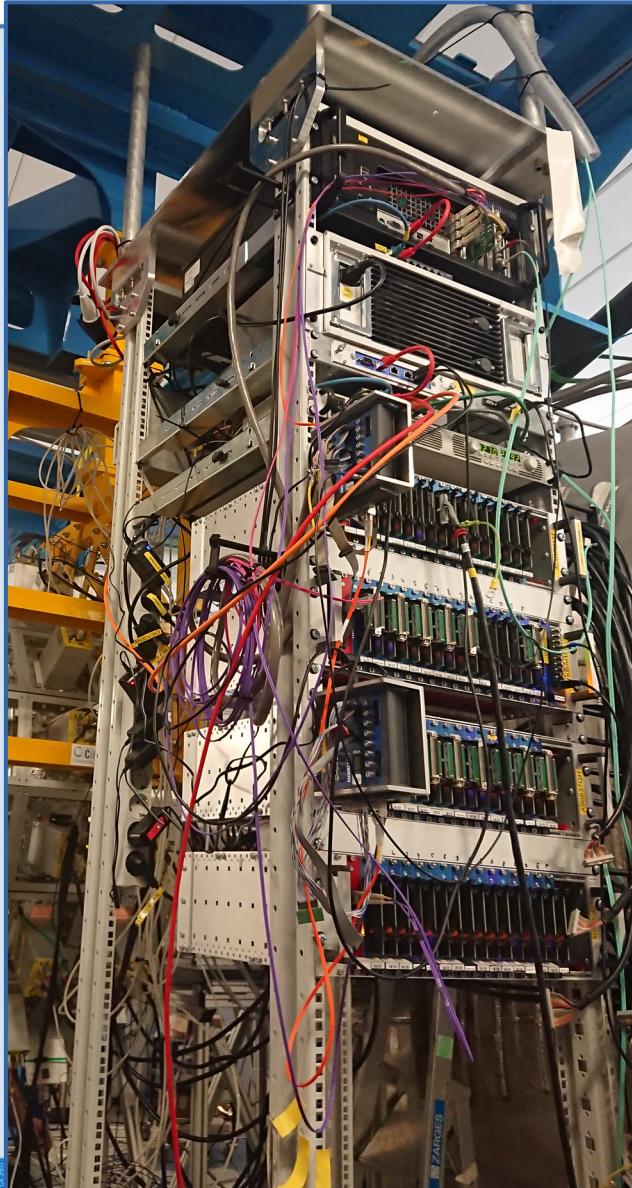
high gain range

Gamma  
threshold:  
100 keV

$E_{\text{proton}}$  via tot-method

300/30

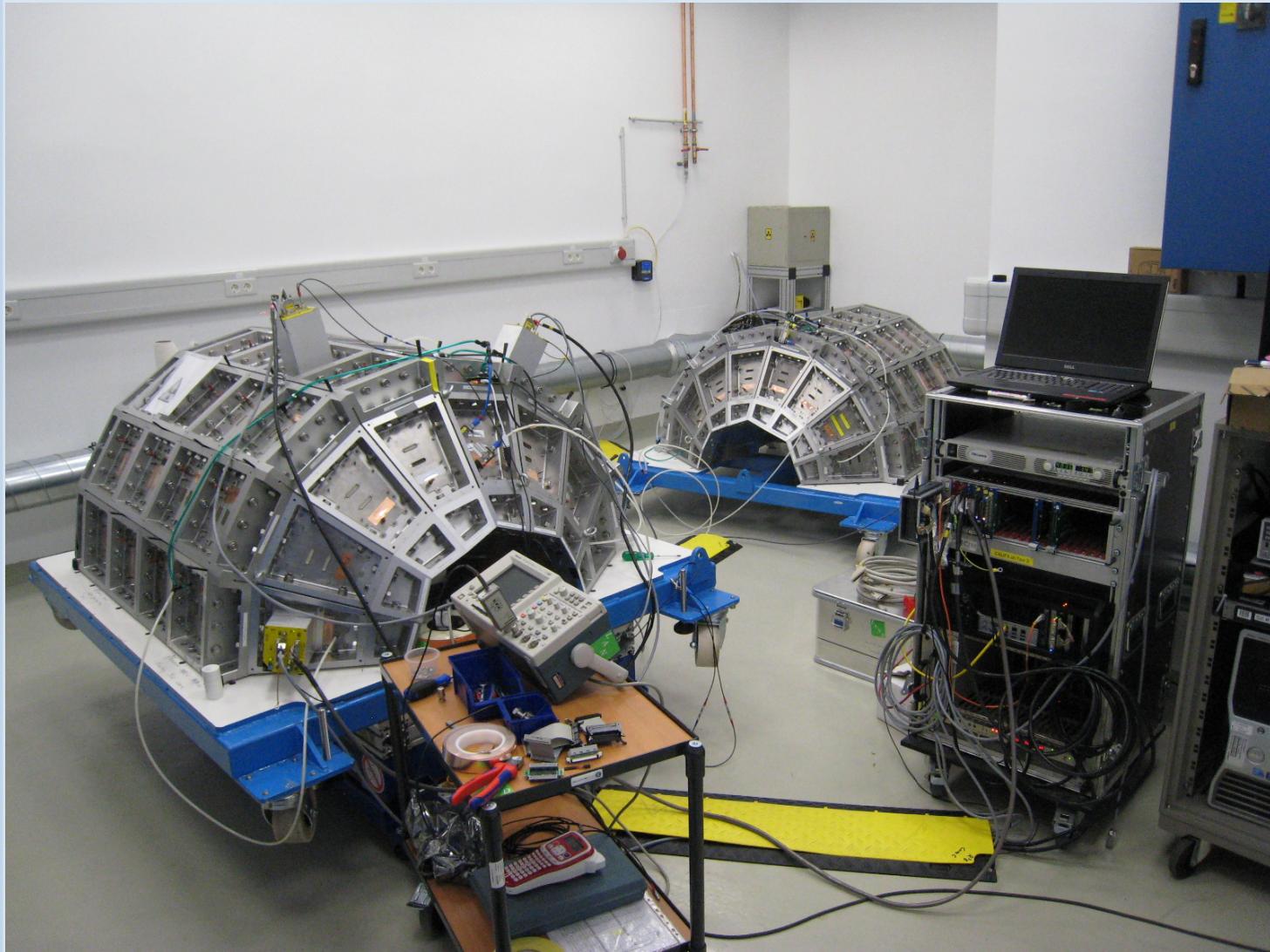
# CALIFA DAQ Status (S522, 2022)



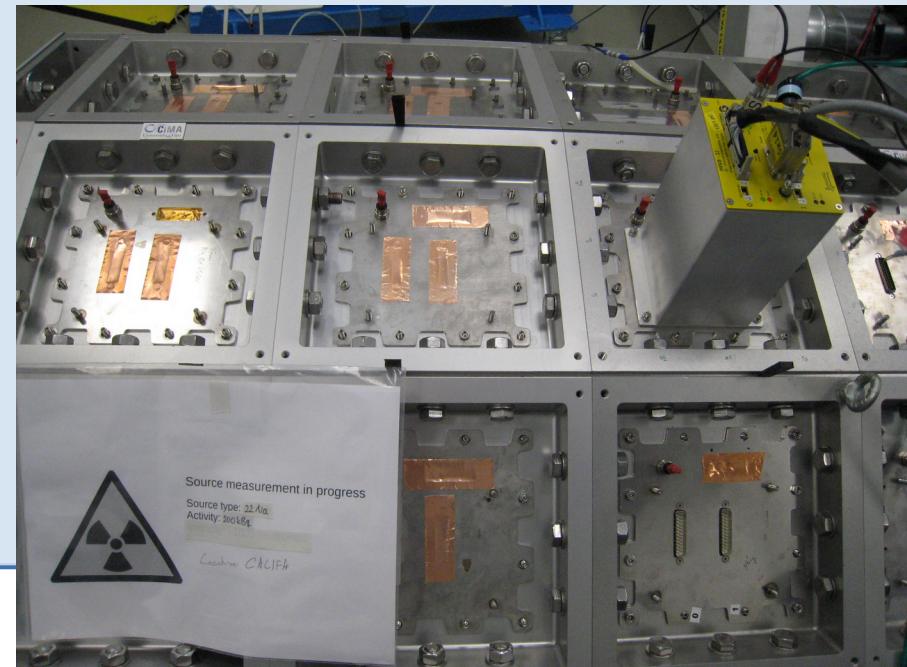
## Electronic Rack

- 8 Crates (each with 18 x FEBEX + Addon)
- 2 PCs (with Knipex+TRIXOR)
- 2 TDK Lambda
- 4 Exploder
- 1 “Overlord” Exploder
- 2 Slow Control PCs

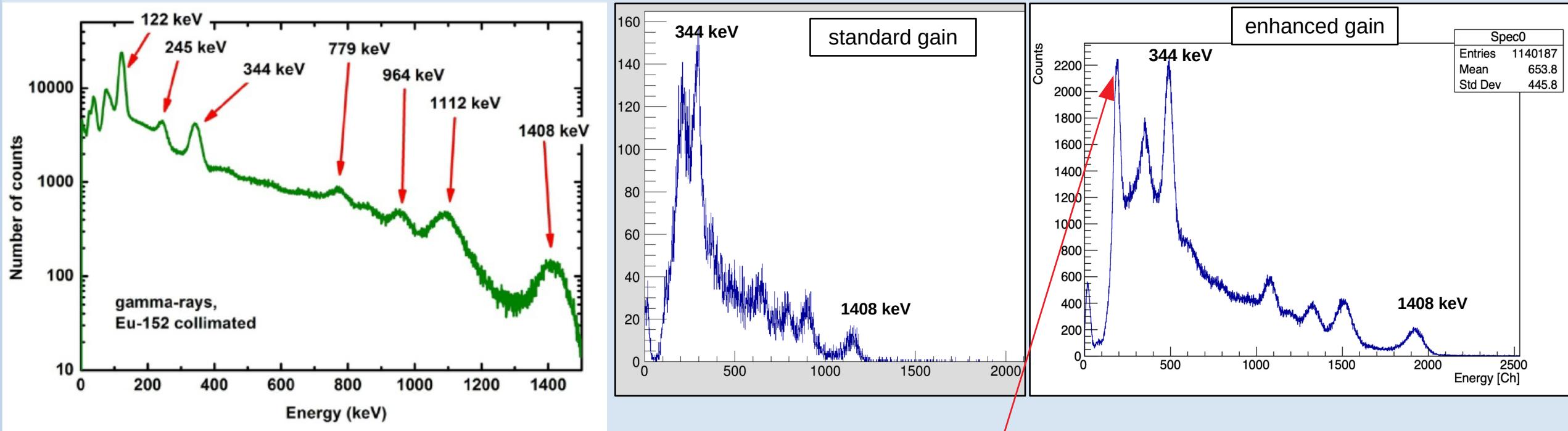
# Meanwhile in R<sup>3</sup>B Preparation ROOM ....



- Add new crystals
- Improve noise figure
- Check and replace some of internal cables



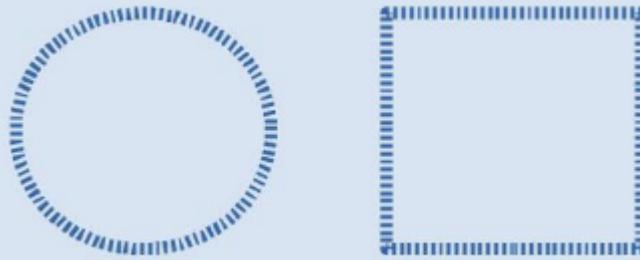
# Testing Gain



Raising the gain allows to measure down to the **122 keV** peak!

Higher gain leads to better resolution (but reducing the energy-range)  
Lower threshold values are possible → crucial for **add-back** algorithm!

User defines shape and size of cluster:



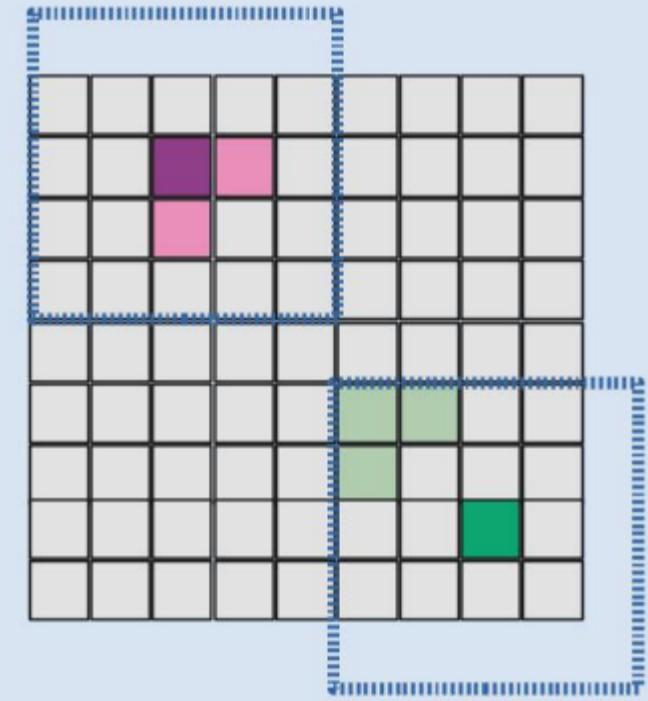
**Sort the hit list according to their energy**

1. create cluster centered around first hit
2. loop over all hits in list
  - if hit inside cluster add it and remove it from the list
3. Do this procedure until list is empty

5.34 MeV
0.51 MeV
1.01 MeV
0.74 MeV
0.51 MeV
0.15 MeV
0.21 MeV



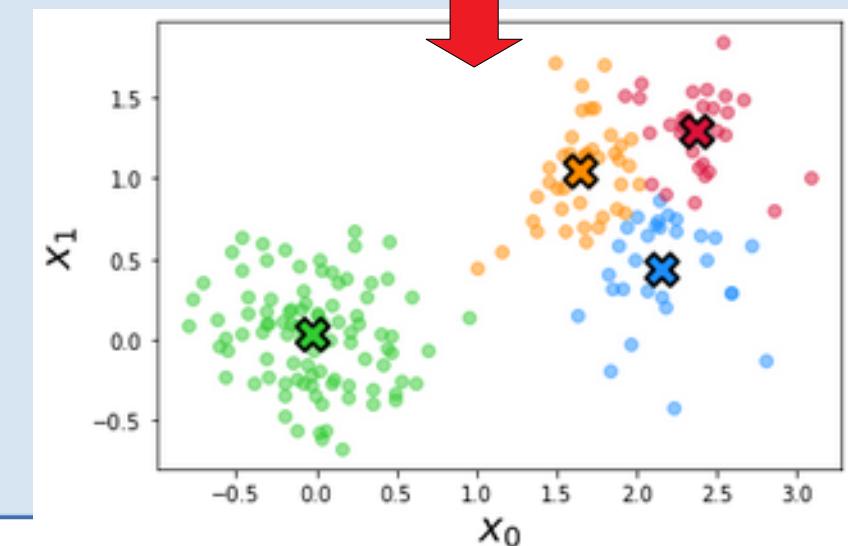
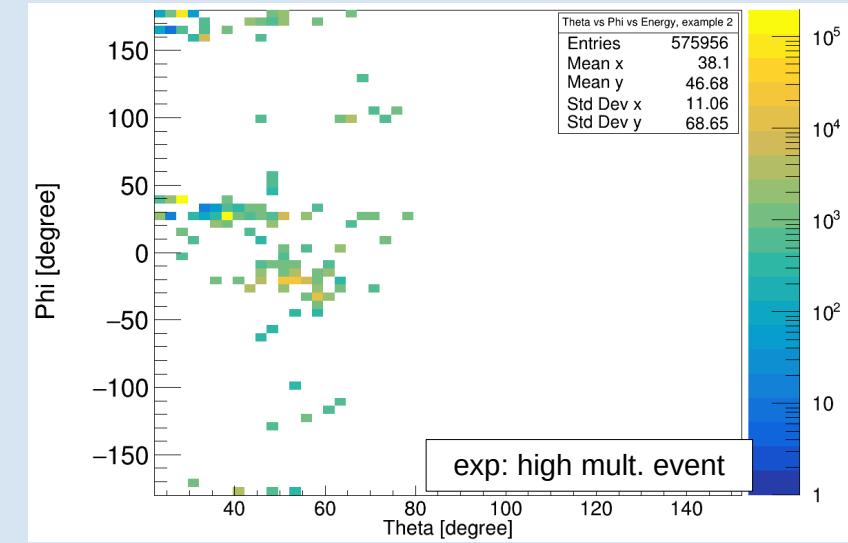
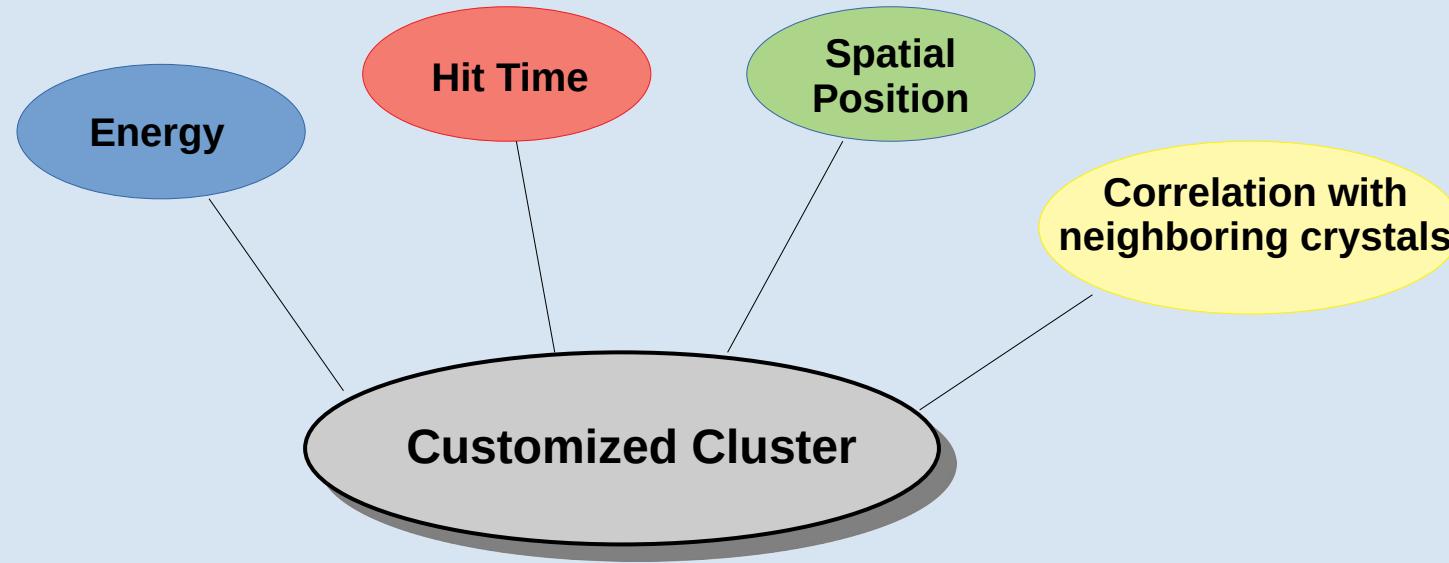
Depending on how low we can get with the threshold we can addup or not !



# ODSL Collaboration - Optimize Add-Back Algorithm with AI

## Use the power of Machine Learning:

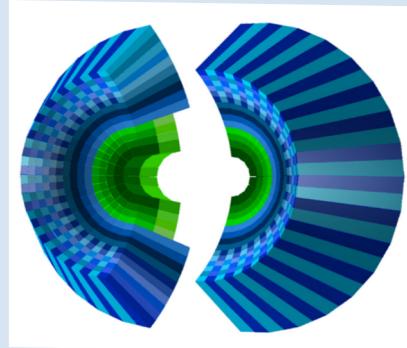
- recognize the physics cases
- optimize the cluster shapes (event by event)
- give probability for fully contained physics event



# Filling CALIFA Endcap - CEPA

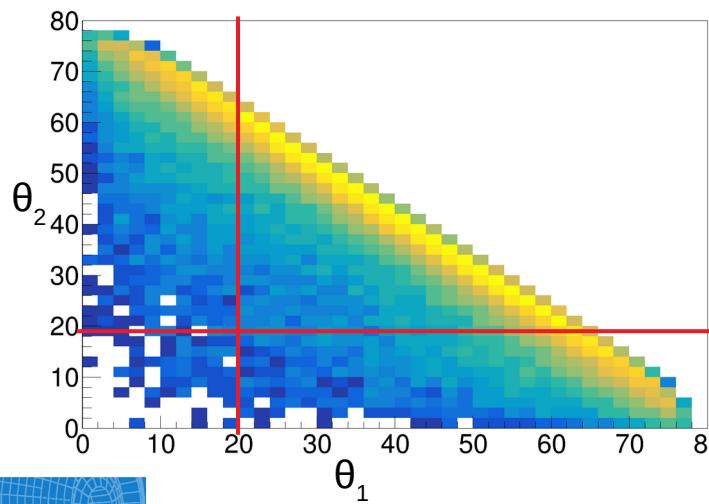
## CALIFA Endcap Phoswich Array

- Most forward section:  $7^\circ \leq \theta \leq 19^\circ$
- 112 CsI crystals

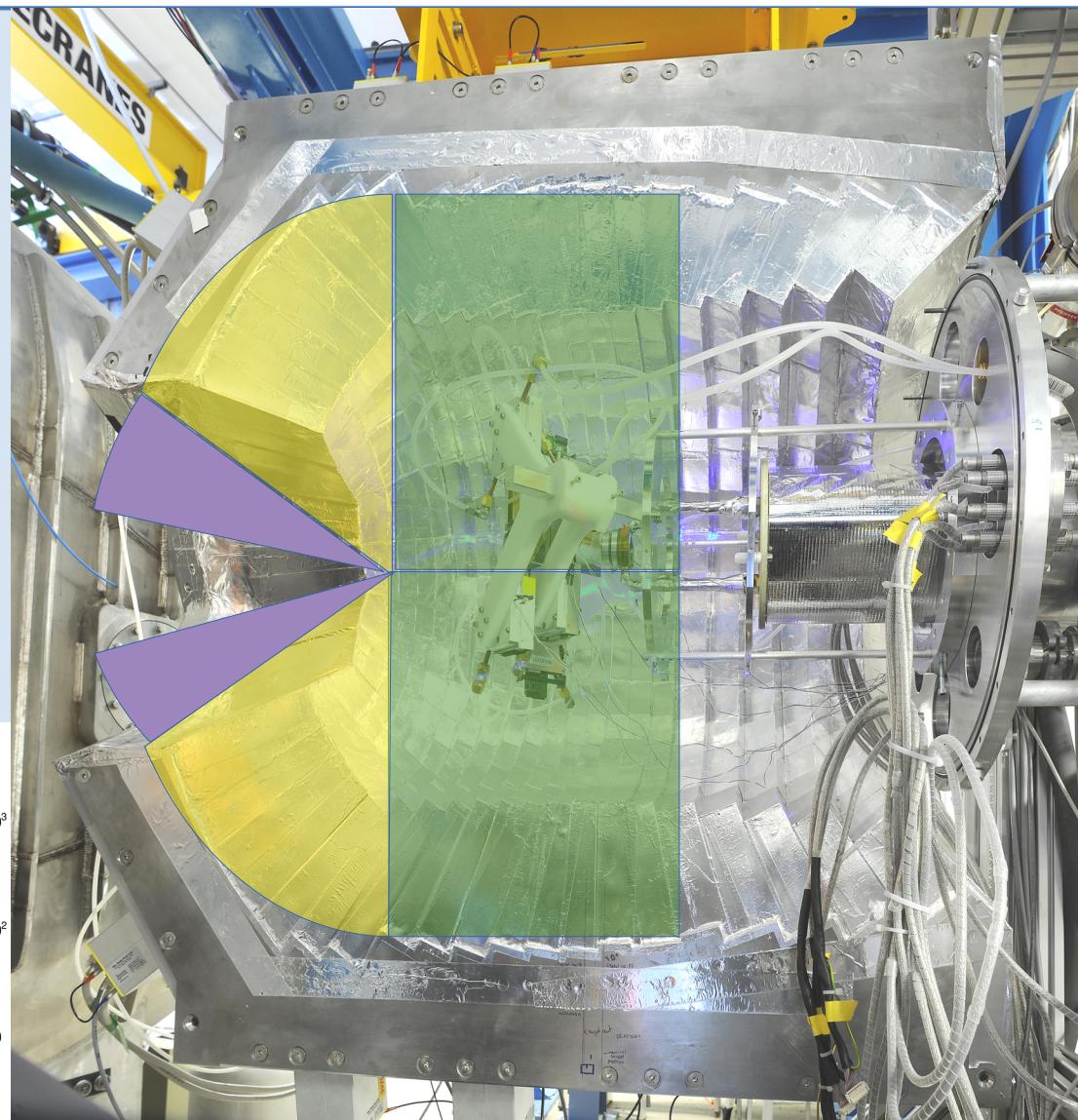
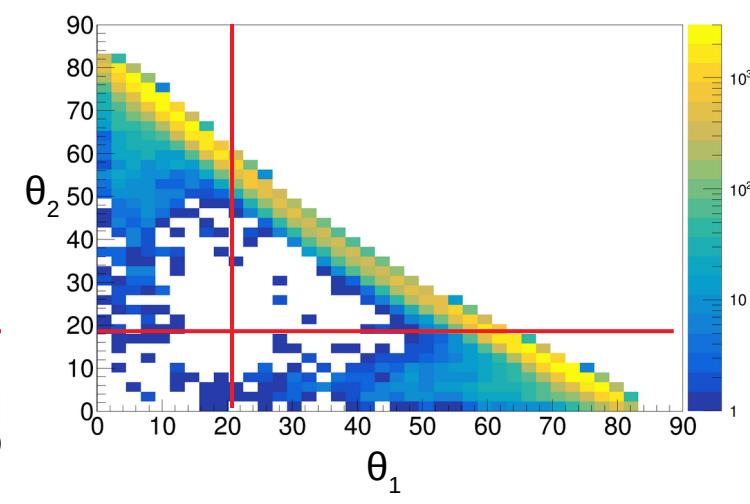


Improves geometric acceptance for high beam energies drastically

p2p-reaction, 400 AMeV



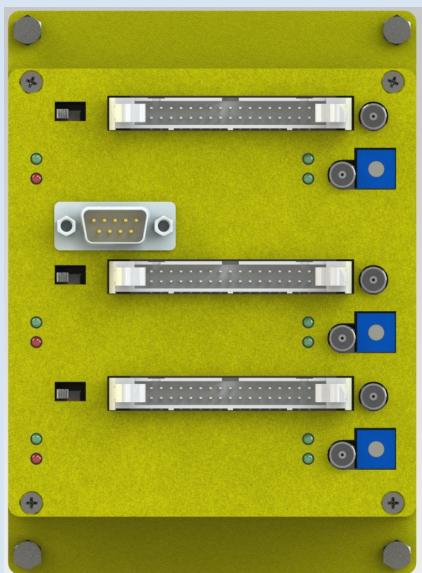
p2p-reaction, 1200 AMeV



# Filling CEPA

## Mesytec MPRB-48 Dual Range Preamps

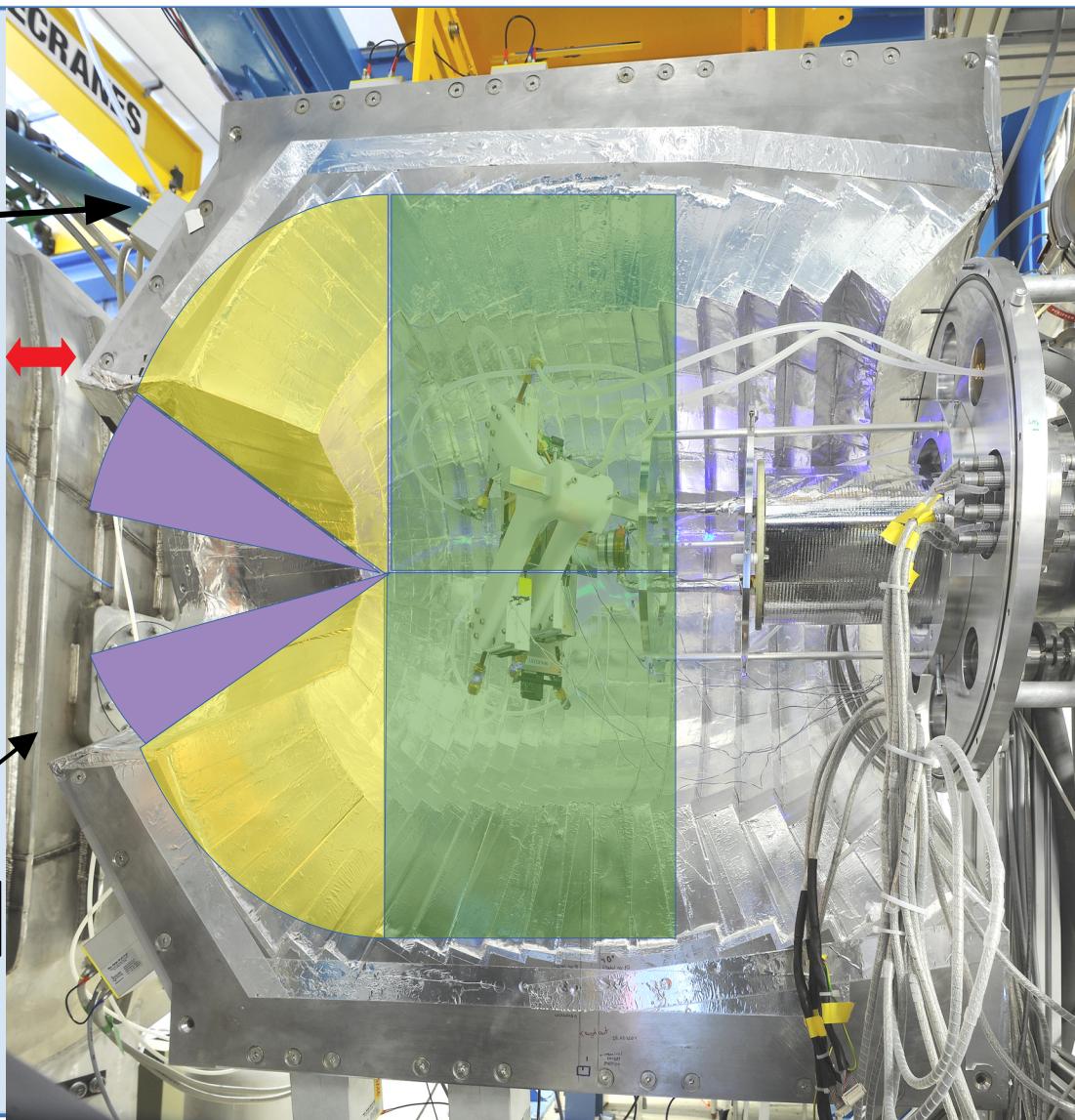
They get mounted on iPhos tiles



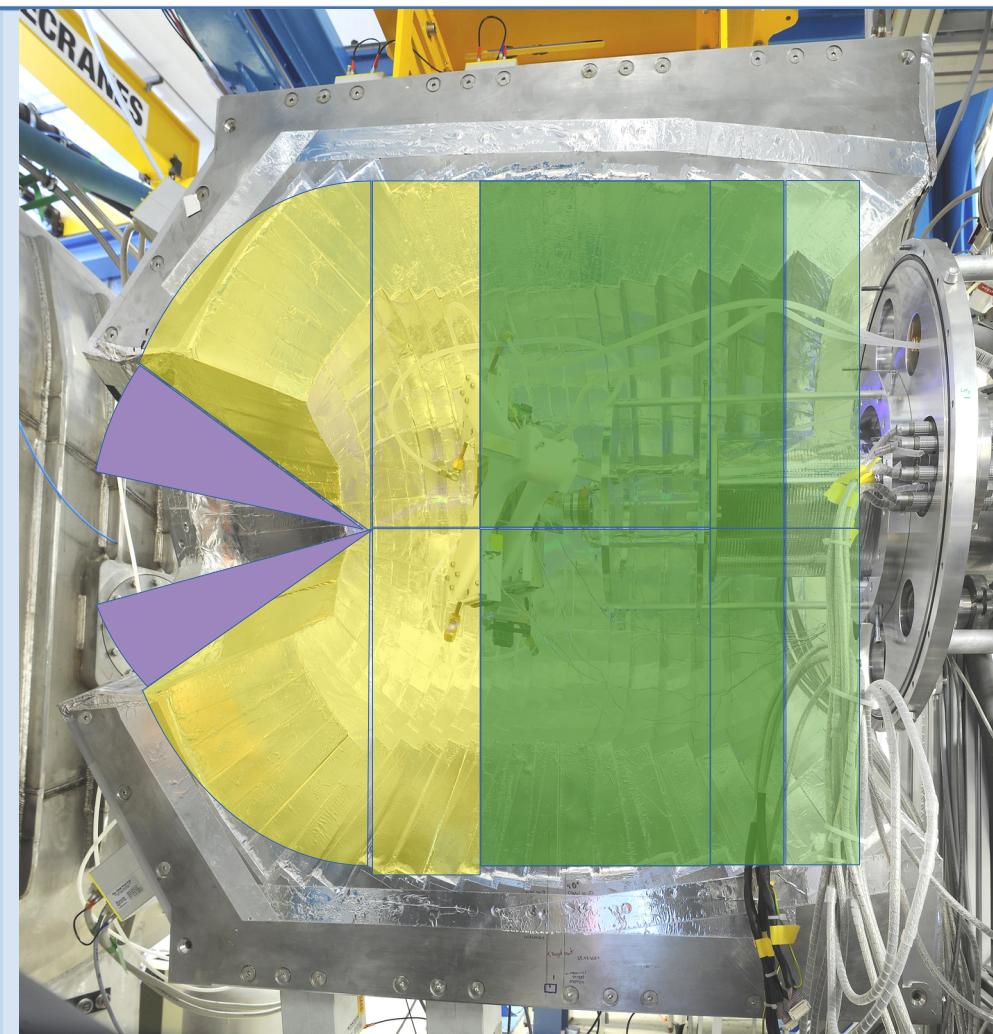
Connected to iPhos APDs  
(32 channels)

Connected to CEPA APDs  
(16 channels)

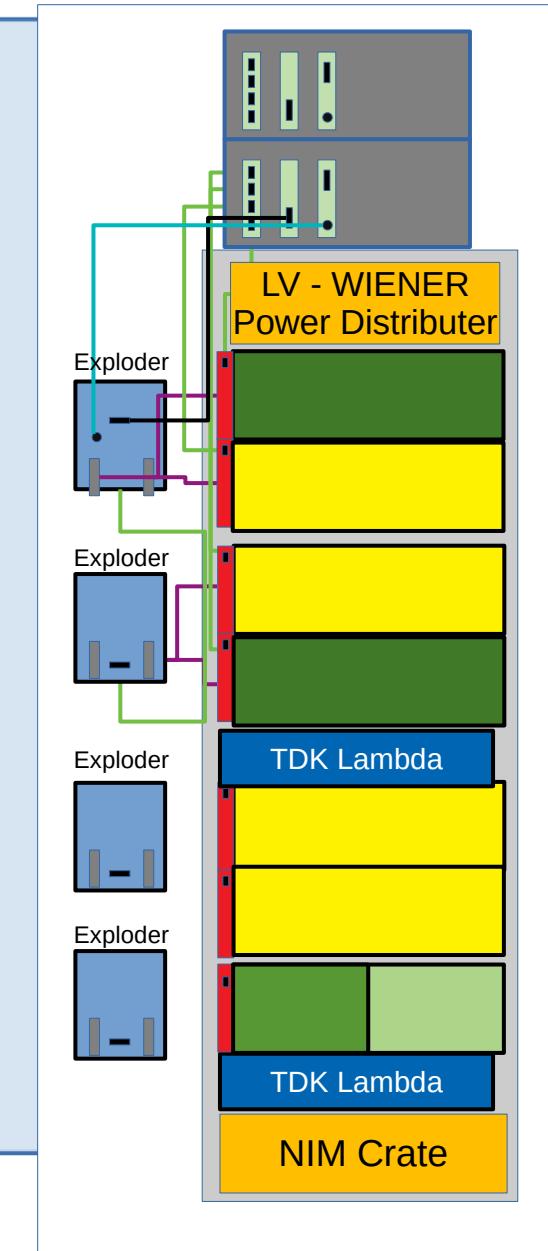
no space !



# Final CALIFA Electronic Configuration



Dual Range Preamplifiers



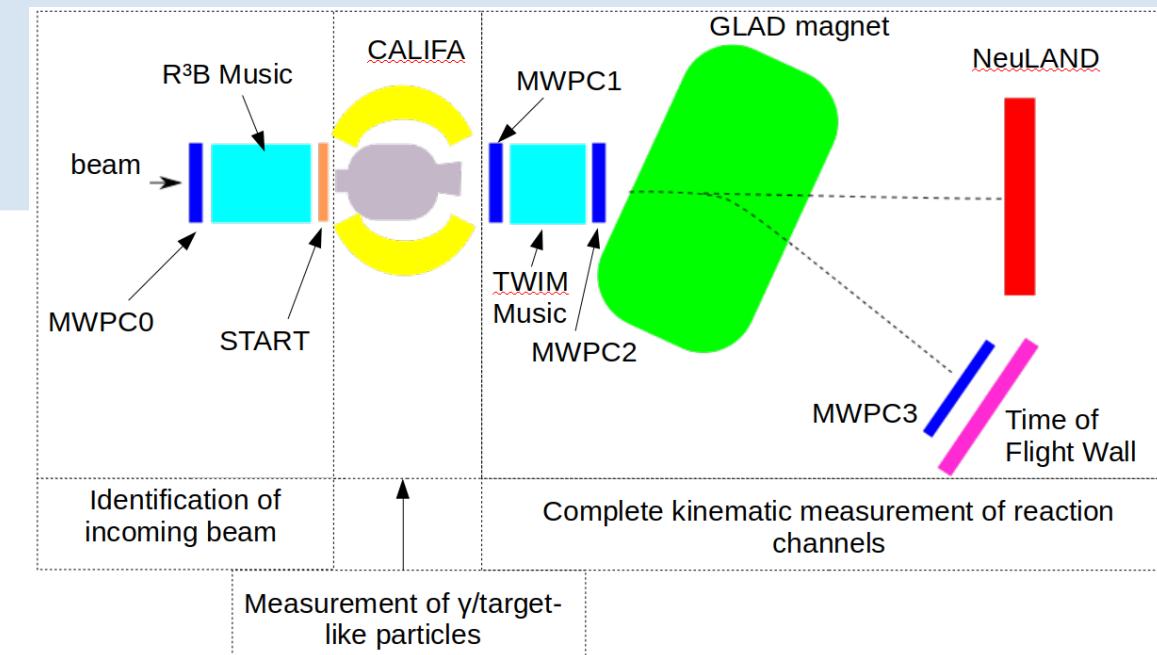
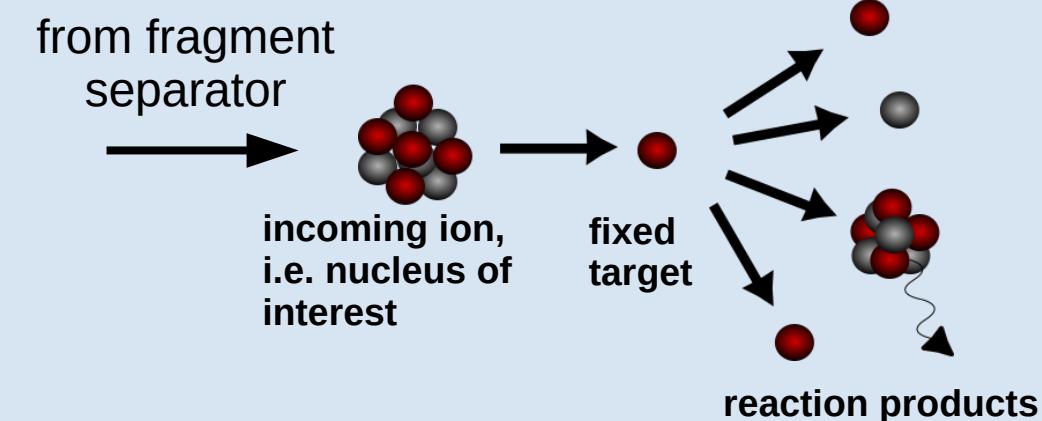
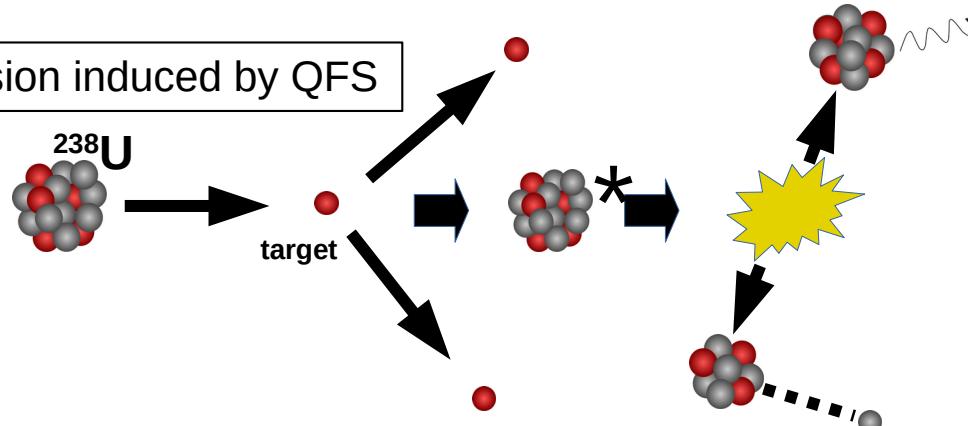
## Workload:

- DAQ
- Slow Control
- Analysis

} extend to its full glory

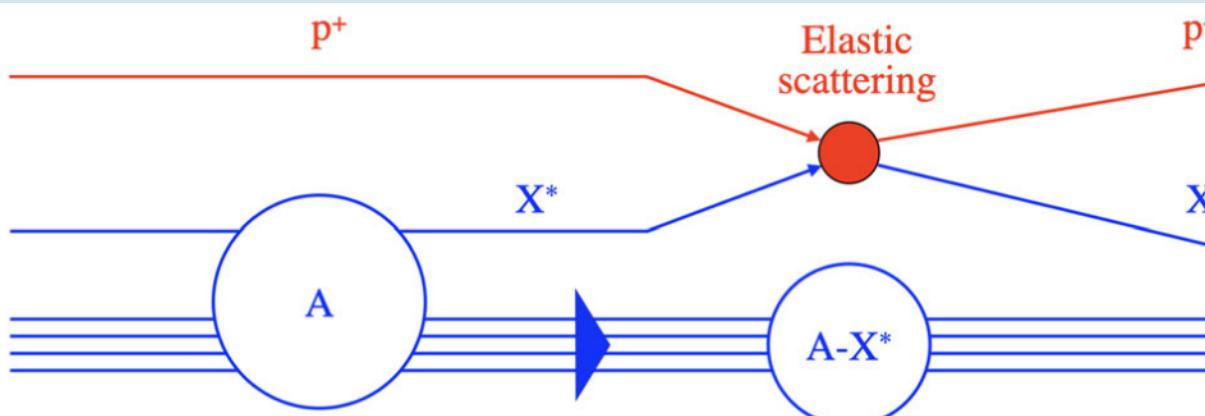
# Physics at R3B with CALIFA

- Physics program on exotic nuclei in inverse kinematics:
- kinematically complete measurements
- **Key physics program:** Quasi-Free Scattering Reactions



# Quasi-Free Scattering Reactions

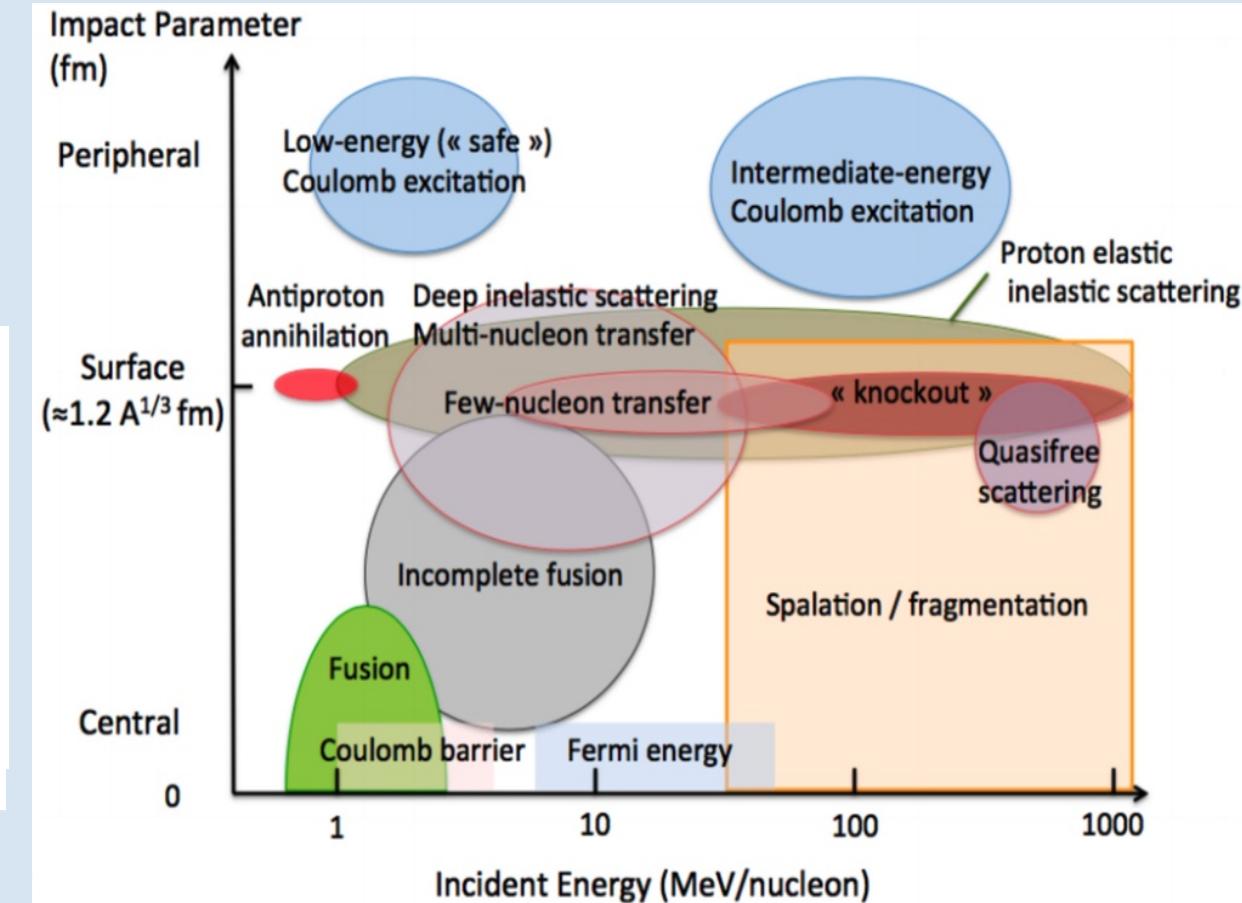
- $p^+$  or  $e^-$  probe is used for sudden knockout of a nuclear constituent
- Can be approximated as two body scattering of free particles



"Quasi-free scattering in inverse kinematics as a tool to unveil the structure of nuclei", V.Panin et. al.

- Gives direct access to single particle properties inside nuclei
- Allows to study in detail the nuclear shell structure and its evolution far off stability

→ for the study of QFS a dedicated experimental setup is needed



Prof. Th. Kröll, Experimental Nuclear Physics, Lecture 9

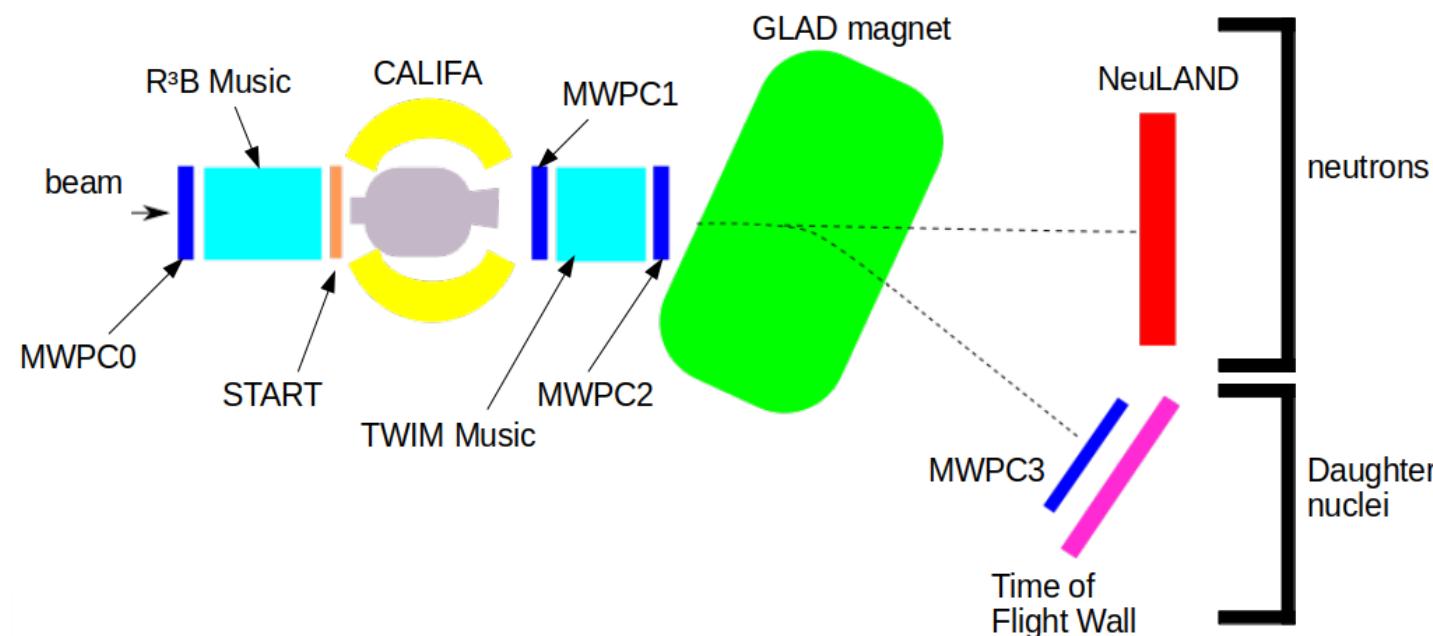
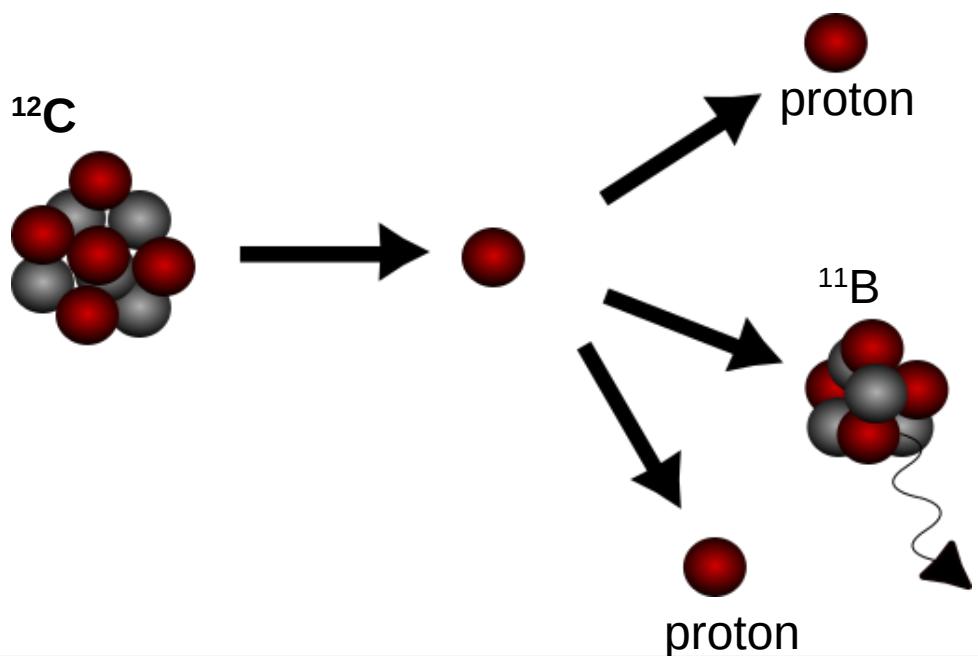
**12C(p,2p)11B reaction:**

- $^{12}\text{C}$  beam
- proton like target

- 2 protons
- $^{11}\text{B}$  fragment (spectator)

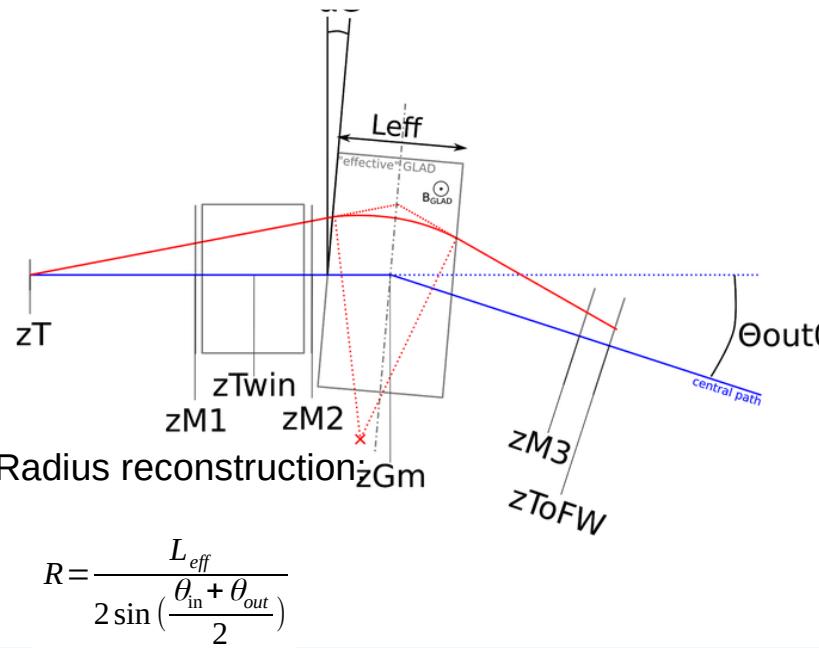
**SETUP:**

Beam energy: 400 AMeV  
Beamtype:  $^{12}\text{C}$   
Beamtime: 3 hours  
Target:  $\text{CH}_2$  (12.29 mm)

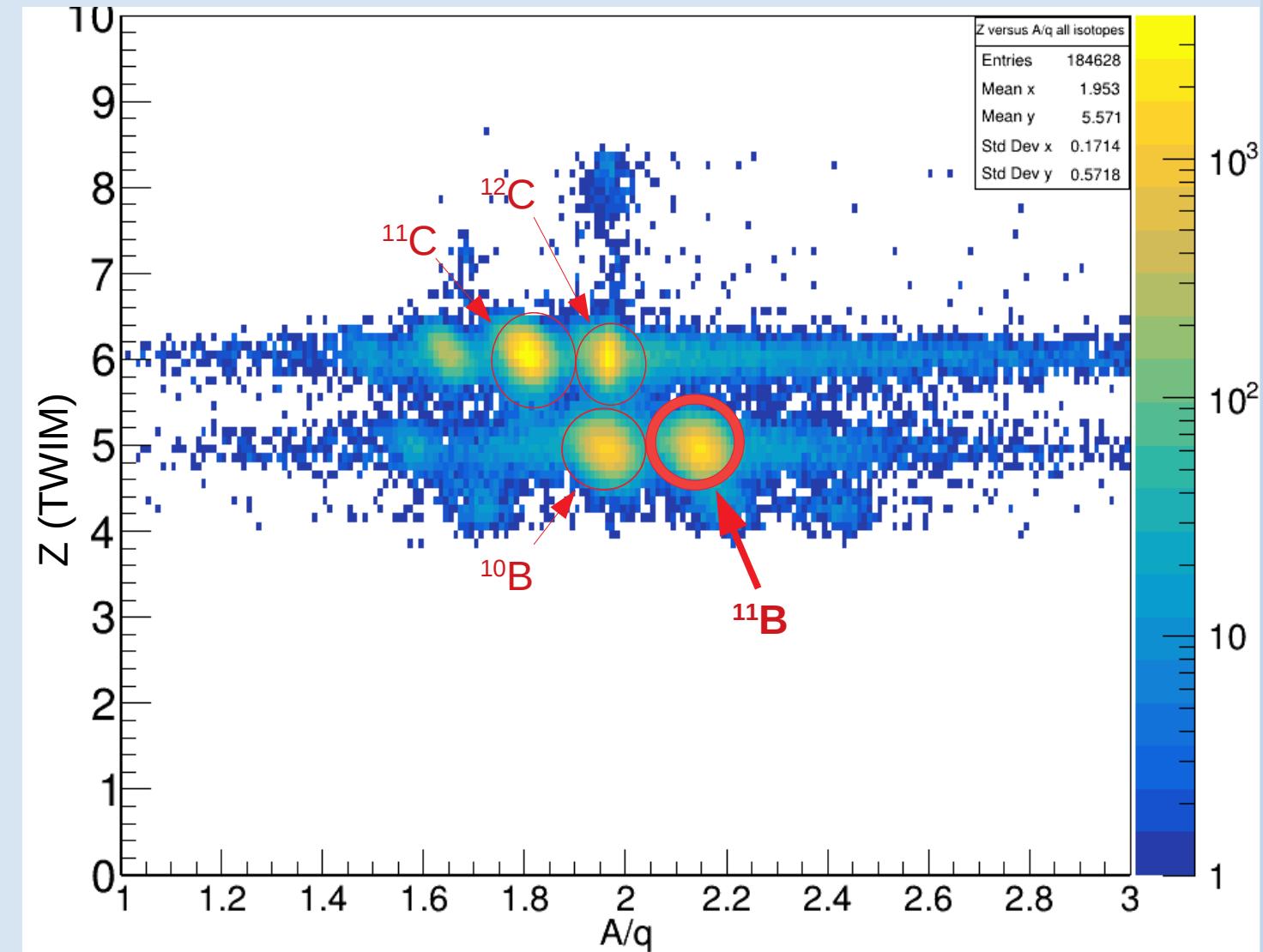


# Fragment Particle Identification

Flightpath reconstruction:

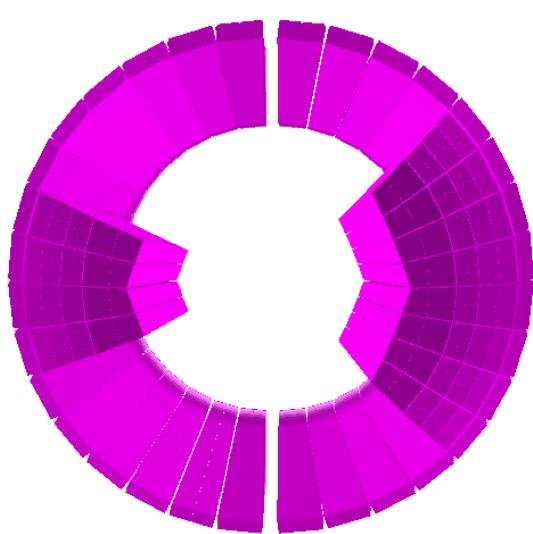


$$B * \rho = \frac{\beta * \gamma * A}{q}$$

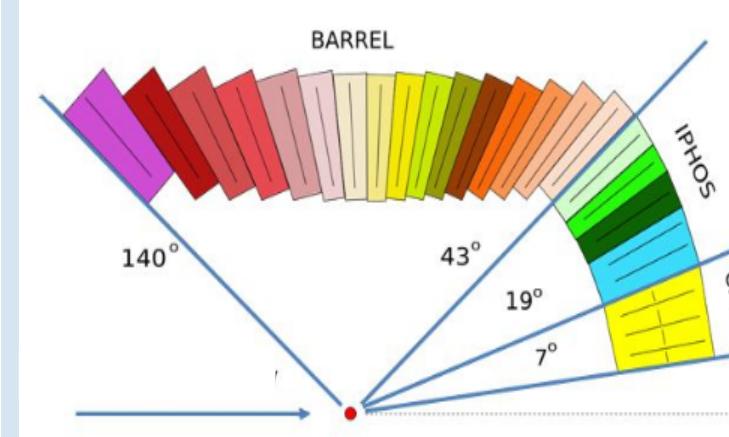


# Identification of the two correlated Protons

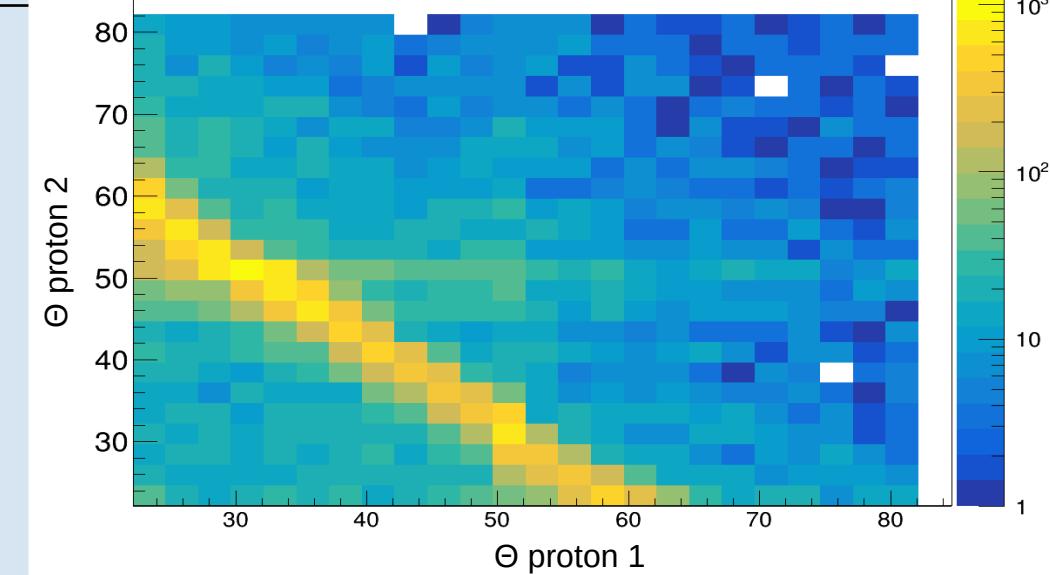
CALIFA Front View



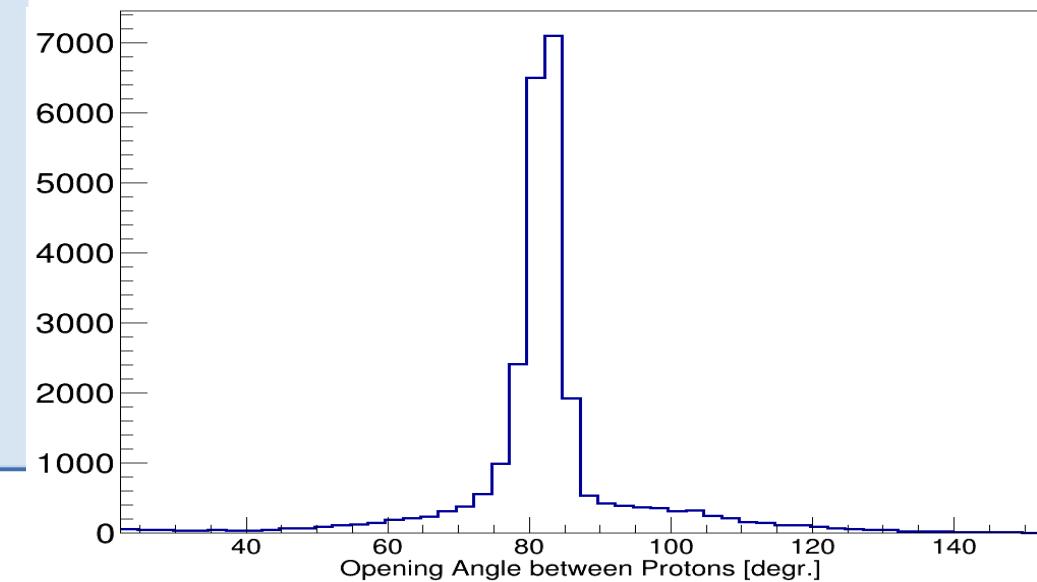
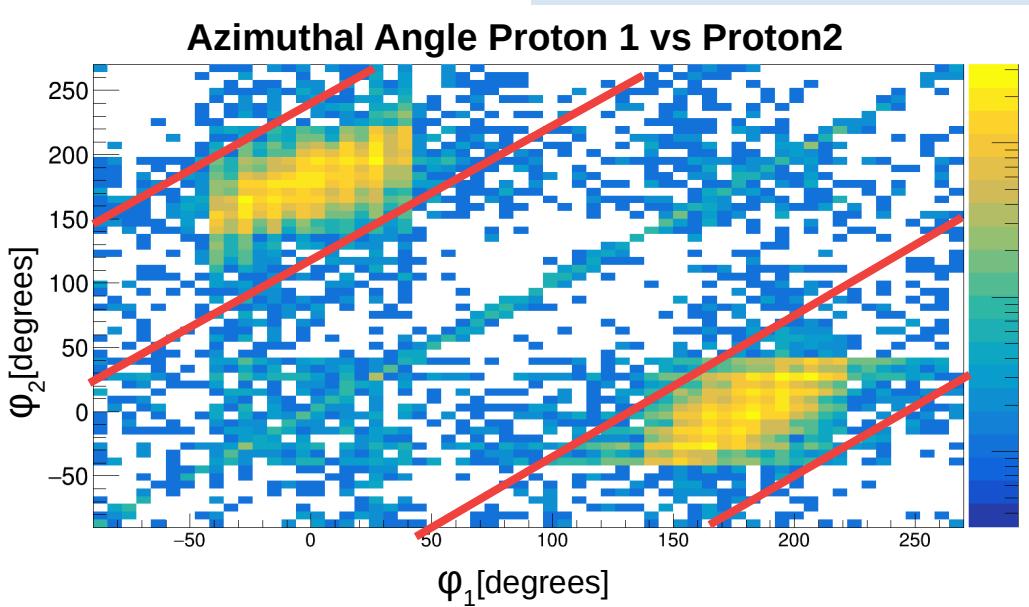
CALIFA Side View



Polar Angle of  $p_1$  and  $p_2$

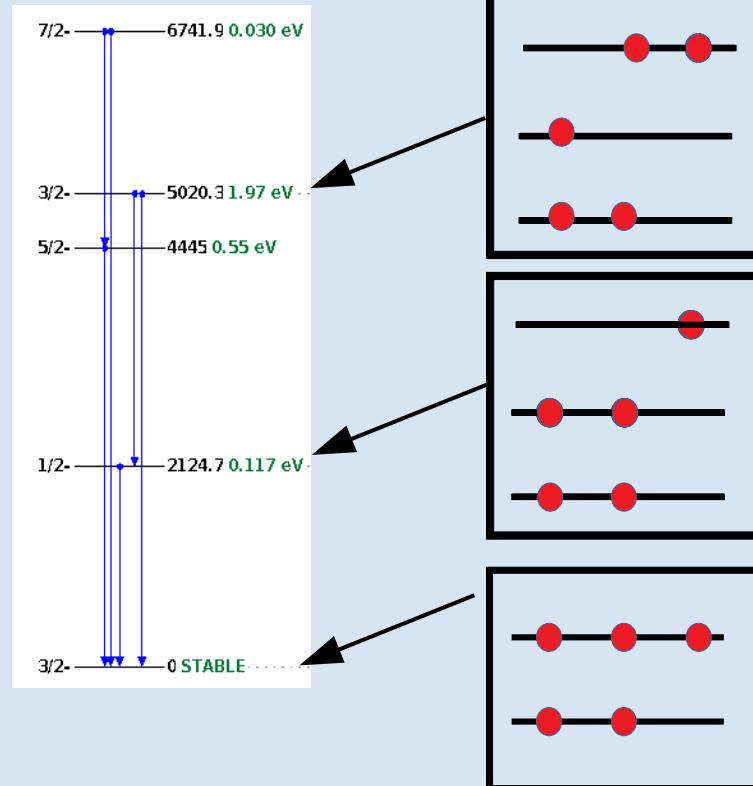
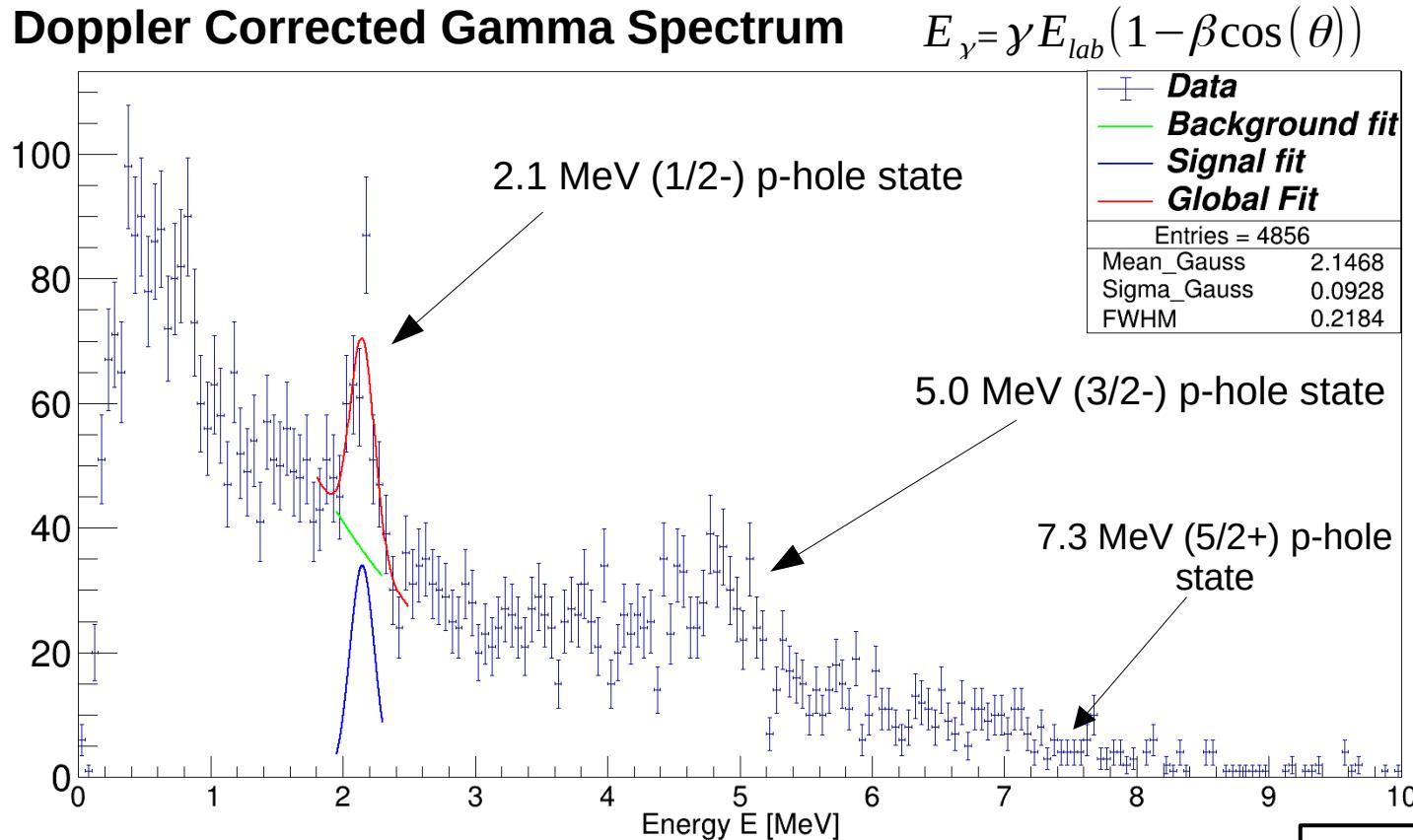


Azimuthal Angle Proton 1 vs Proton2



# Gamma Spectrum of $^{11}\text{B}$

## Doppler Corrected Gamma Spectrum

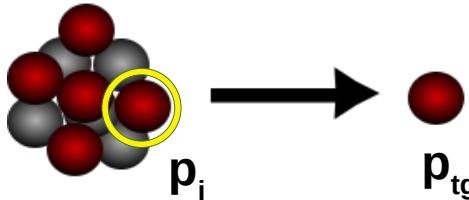


## Event Selection Criteria:

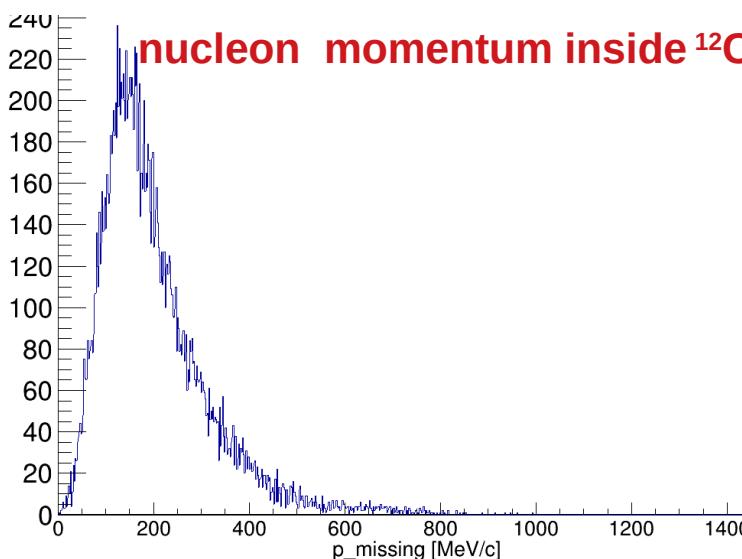
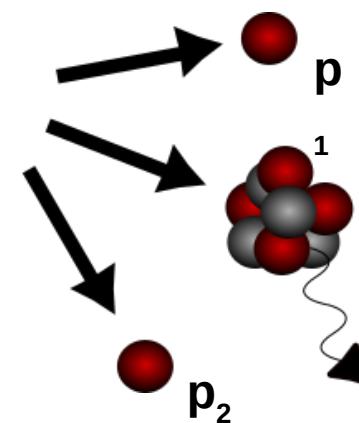
- $^{11}\text{B}$  fragment identification
- Two hits (protons) with  $E_{\text{hit}} > 30$  MeV
- $\theta_1 + \theta_2 < 90^\circ$
- $\Delta\phi = 180^\circ \pm 40^\circ$

# Reconstruction of Inner Momenta

Before Scattering:



After Scattering:



(Four-)Momentum conservation relation:

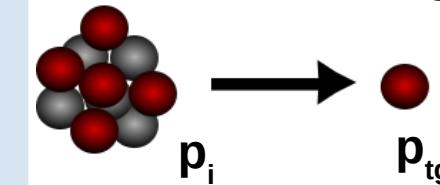
$$p_{^{12}\text{C}} + p_{tg} = p_1 + p_2 + p_{^{11}\text{B}}$$

assuming QE scattering in mean field potential:

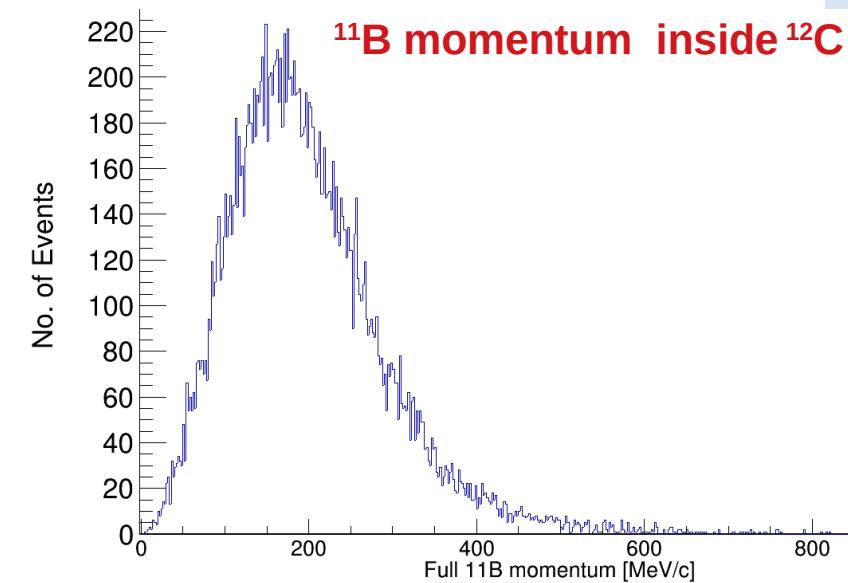
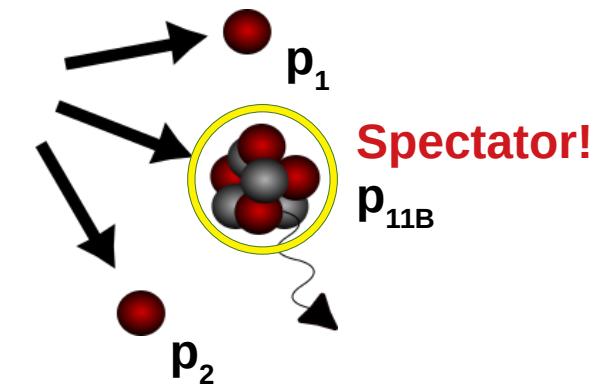
$$p_{^{12}\text{C}} = p_i + p_{^{11}\text{B}}$$

$$p_i \approx p_{\text{missing}} = p_1 + p_2 - p_{tg} \quad (\text{no ISI/FSI})$$

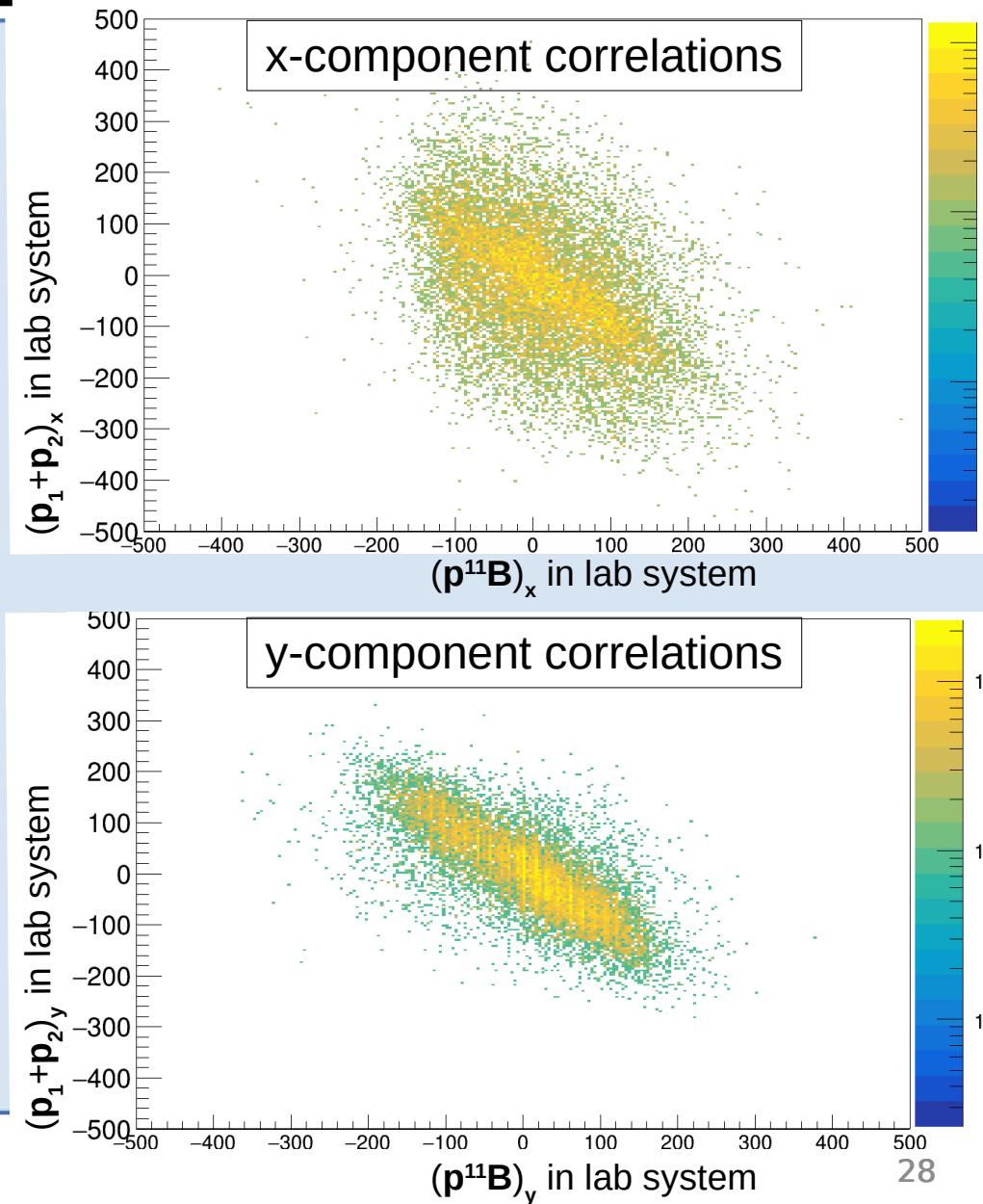
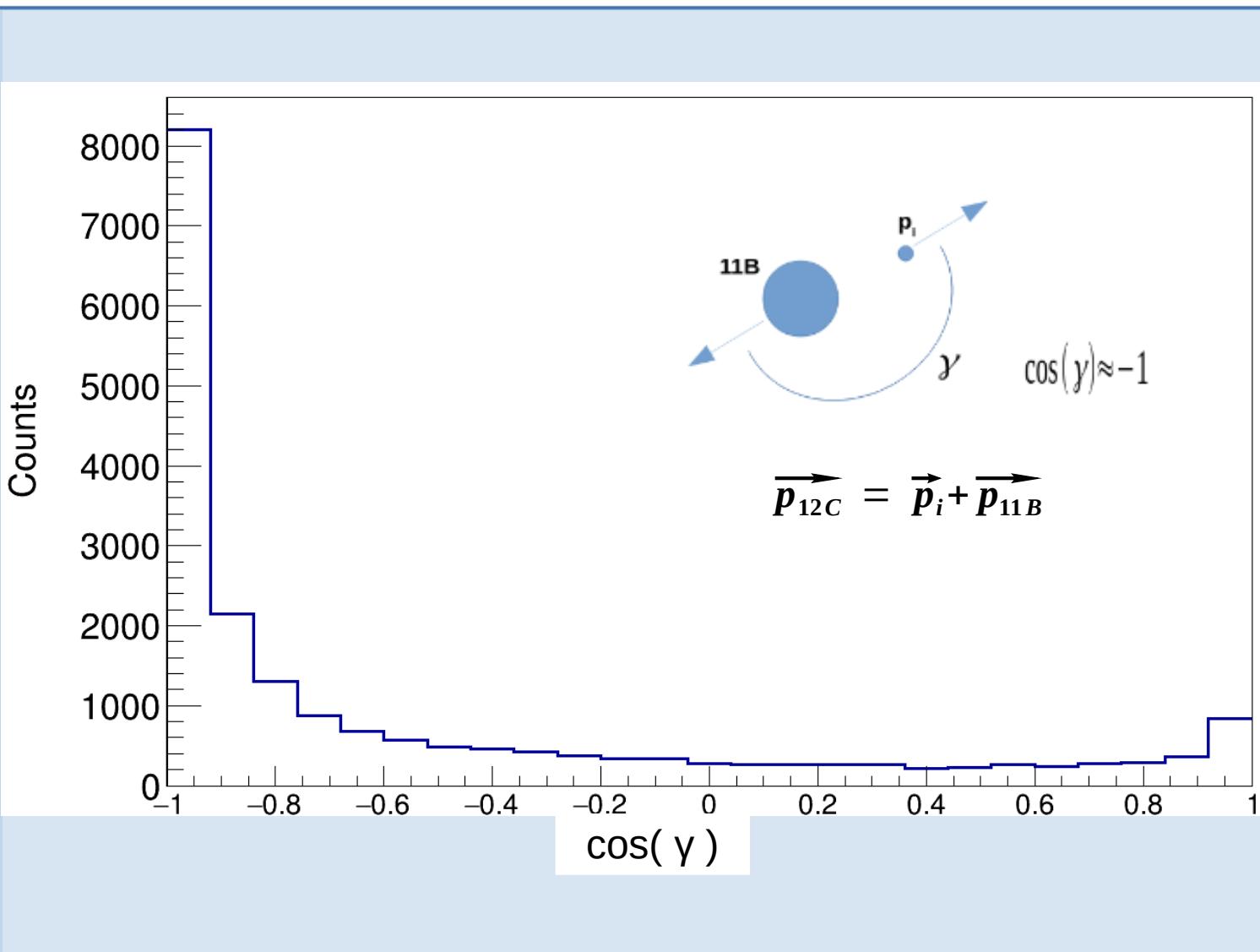
Before Scattering:



After Scattering:



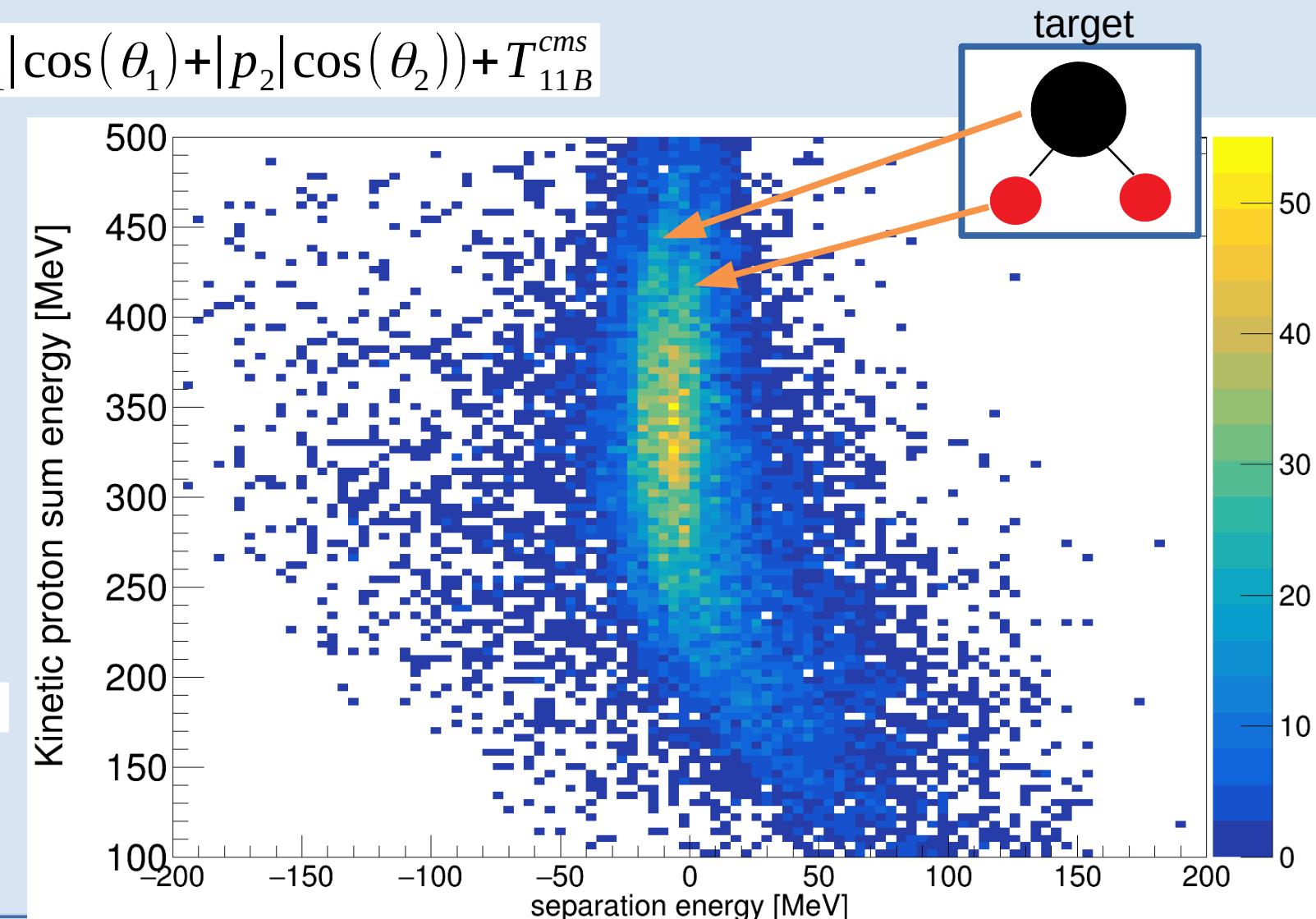
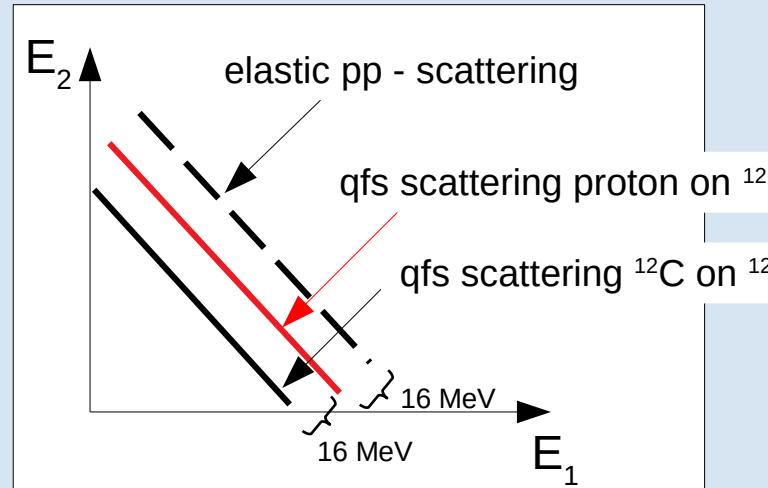
# Correlations between Fragment and Proton Pair



$$S_p = (\gamma - 1)m_p + \gamma(T_1 + T_2) - \beta\gamma(|p_1|\cos(\theta_1) + |p_2|\cos(\theta_2)) + T_{11B}^{cms}$$

$S_p$  = Energy needed to remove one proton from the nucleus

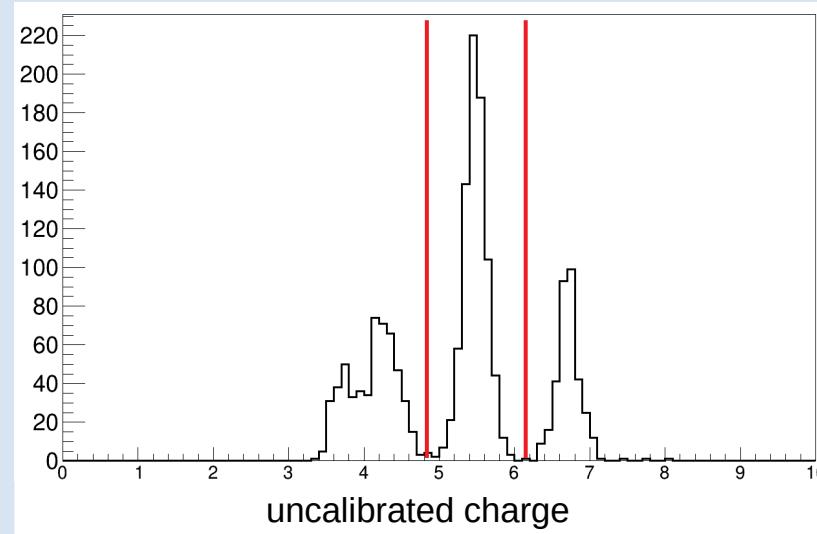
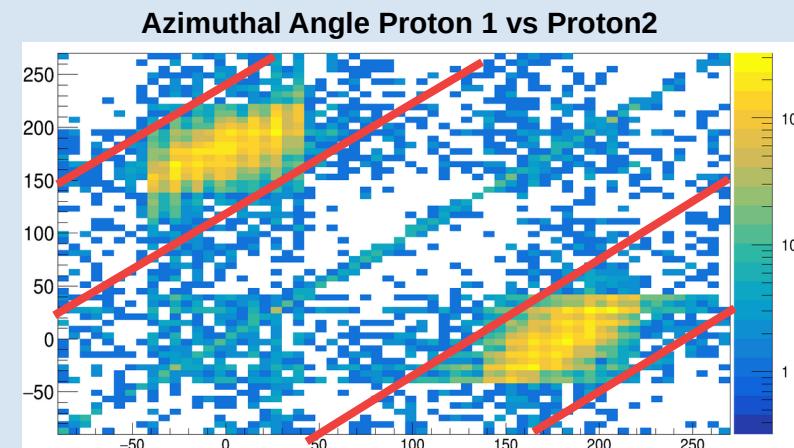
In direct kinematics it would be:



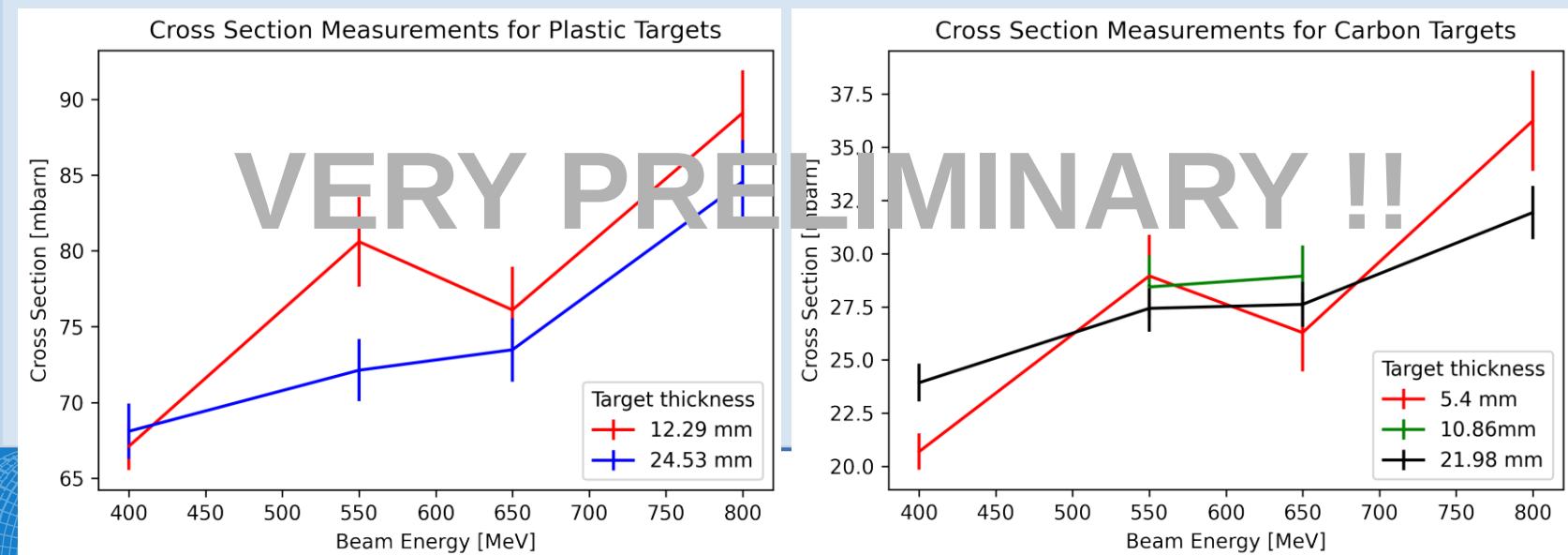
# $^{12}\text{C}(\text{p},2\text{p})^{11}\text{B}/^{10}\text{B}$ Cross Section Measurements

## Selection Cuts:

- strict event selection in front of target
- 2 hits in CALIFA with  $E_{1/2} > 30$  MeV
- $\Delta\phi = 180 \pm 40^\circ$
- Boron as Fragment ( $Z = 5$ )



CALIFA only 35% filled in forward region → large correction factors



Cross sections im mbarn			
Reaction	Target	$\text{CH}_2$	Carbon
$^{12}\text{C}(\text{p}, 2\text{p})X$		$81.5 \pm 4.0$	$20.5 \pm 1.9$
$^{12}\text{C}(\text{p}, 2\text{p})^{11}\text{B}$		$47.3 \pm 3.3$	$11.1 \pm 1.5$

Source: Valerii Panin, Thesis 2012

# What else can we analyse with the S444 Experiment ?

# Total Reaction cross section – Lukas Ponnath

Survival Probability:  $P_{\text{surv.}} = \frac{N_2}{N_1} = e^{-N_t \cdot \sigma_R}$

Exclude reactions in Setup:

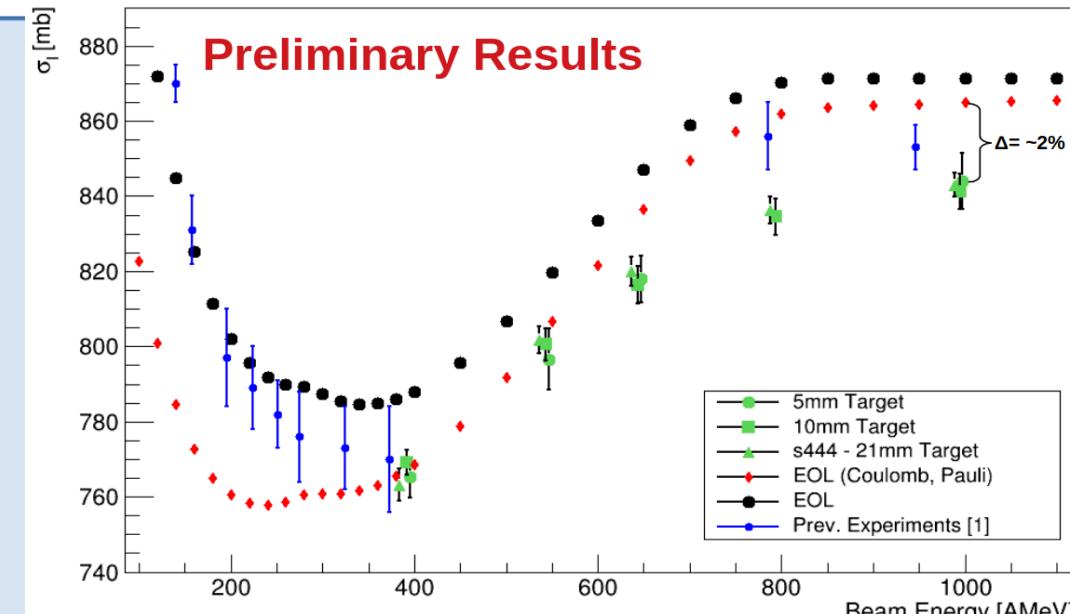
$$\frac{N_2^i / N_1^i}{N_2^o / N_1^o} = e^{-N_t \cdot \sigma_R}$$

Target-In                                  Target-Out

Using the Transmission Method:

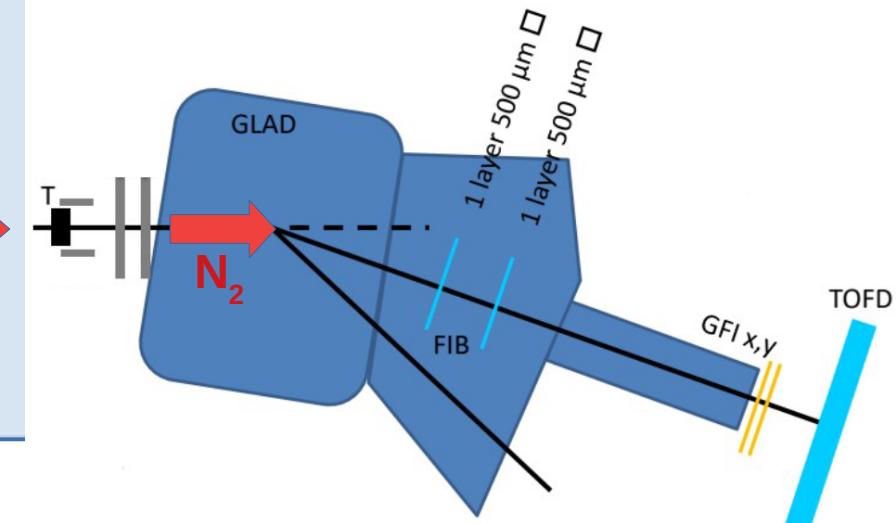
$$\sigma_R = -\frac{1}{N_t} \ln \left( \frac{N_2^i / N_1^i}{N_2^o / N_1^o} \right)$$

$N_1$



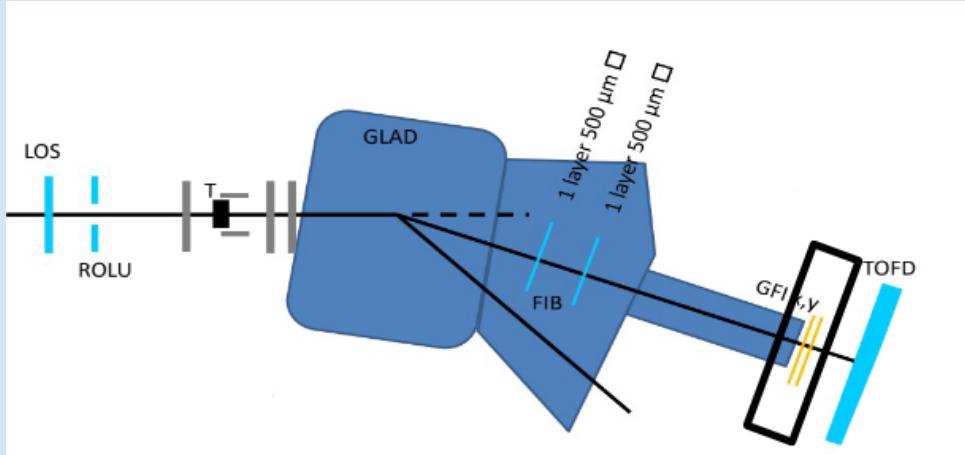
[1] I.Tanihata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009), A. Ozawa et al. (Nuc. Phys. A – 691 2001)

EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)

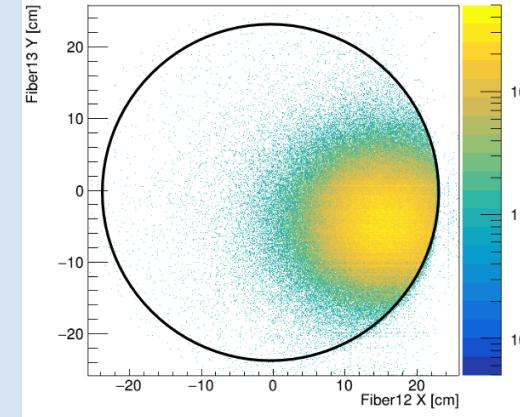


# Comparing the two Setups

## Setup - Lukas

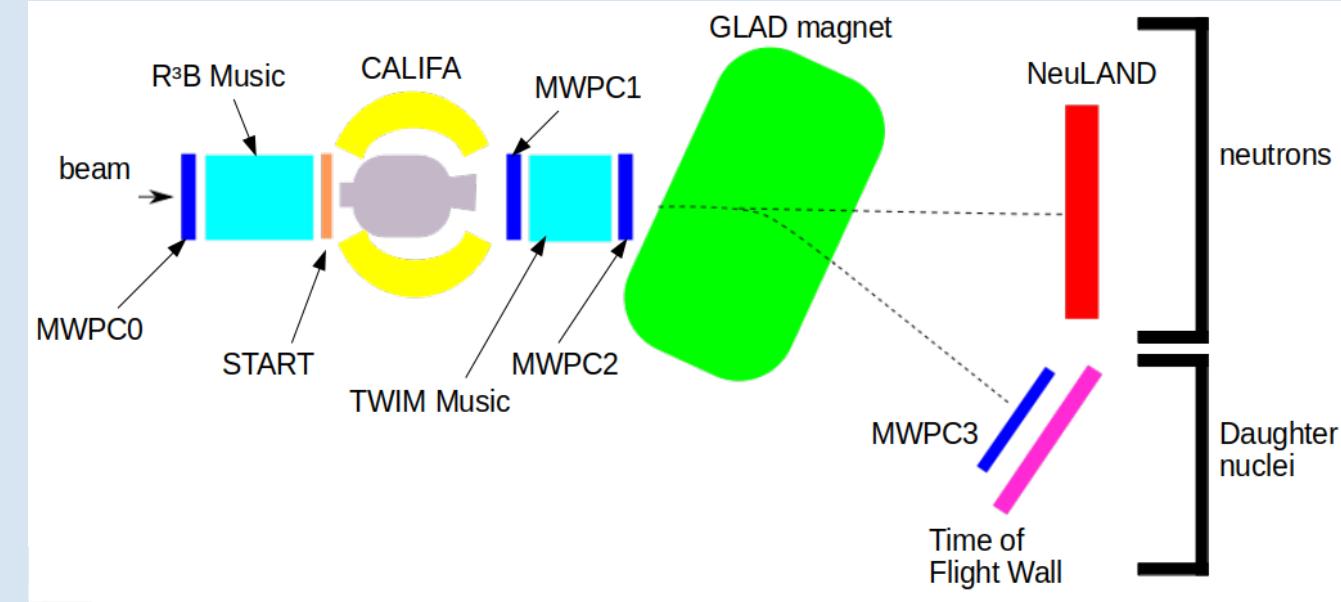


Acceptance issues  
due to the beam  
pipe confinement



Fine tuned acceptance corrections  
needed

## S444 (2020) Setup → with carbon target



High acceptance:

- charge measured right after target by TWIM Music
- no beam pipe (= no vacuum) restrictions

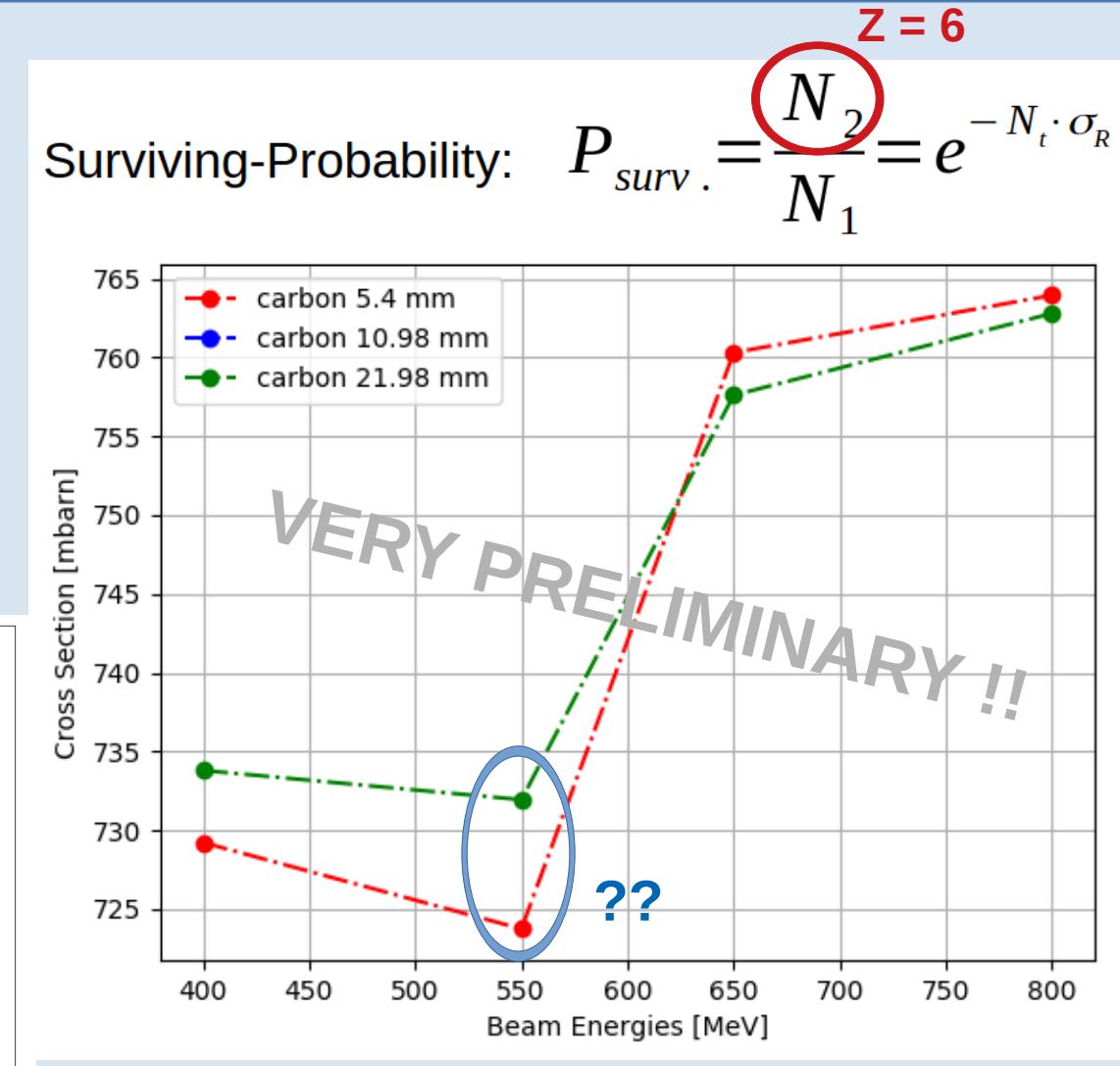
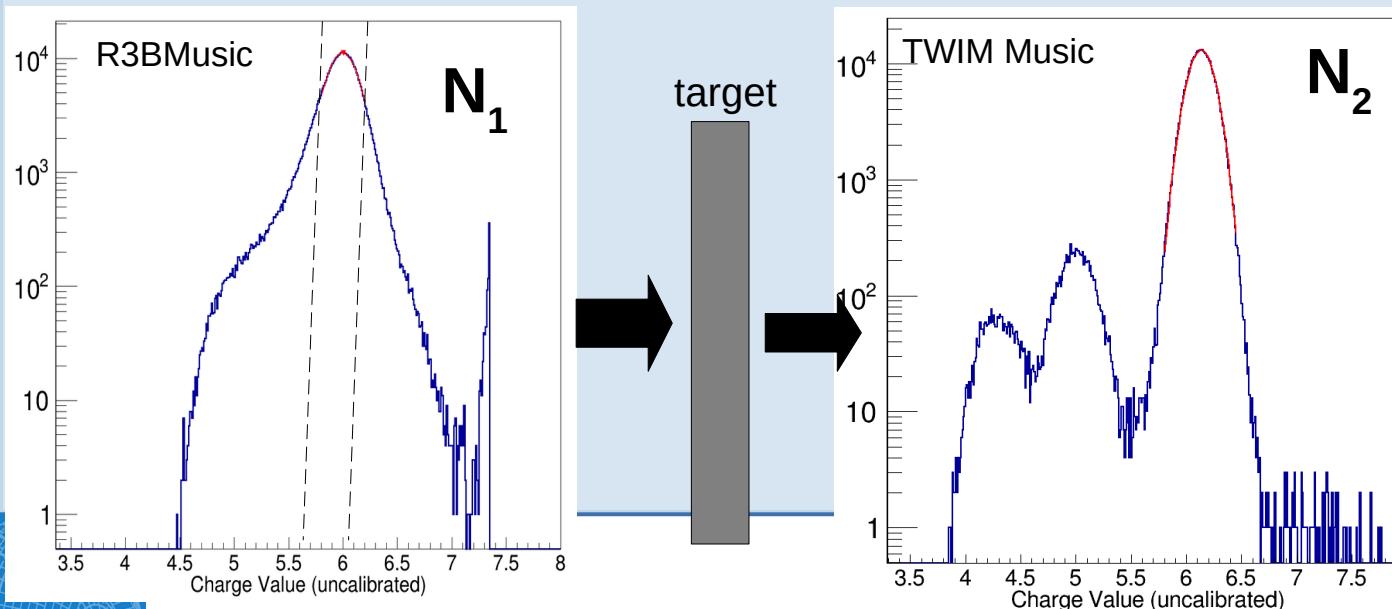
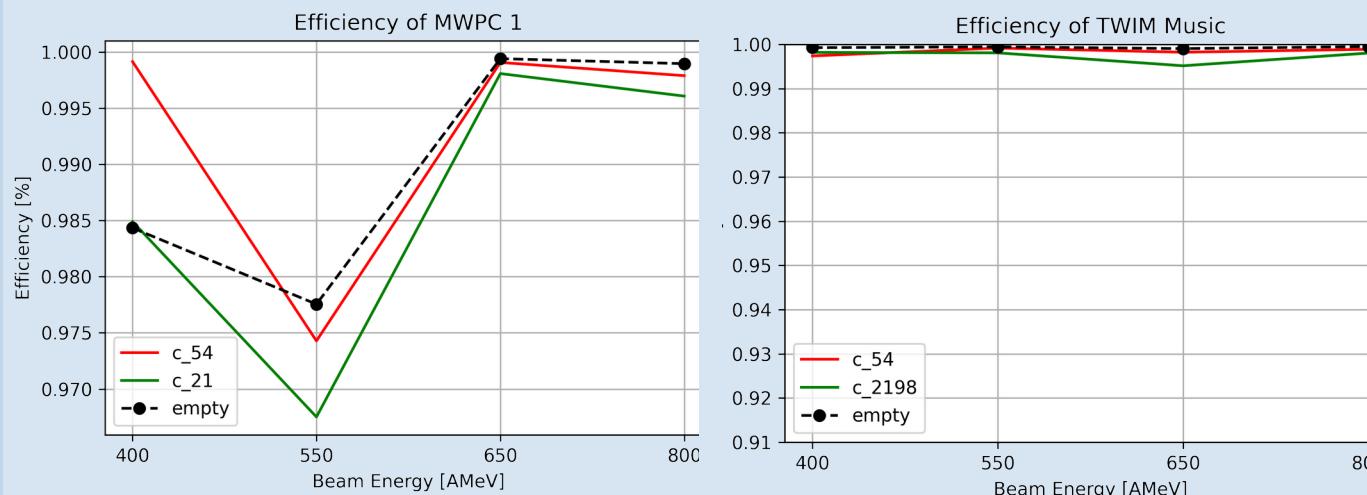


more background

Convenient setup to compare with Lukas' results

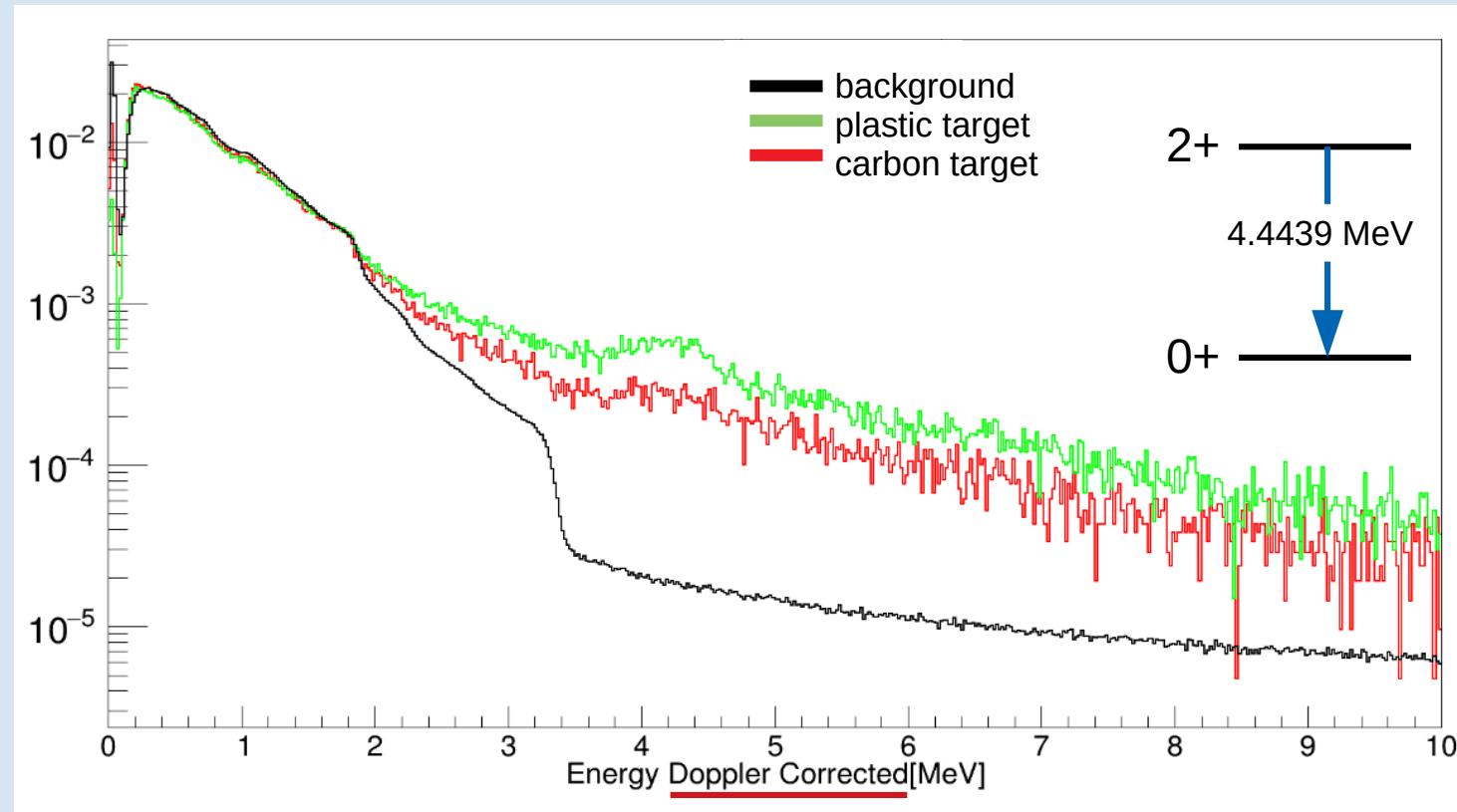
# Starting with Charge Changing Cross Section

Why not starting directly with total reaction cross section measurement?



# What more ?

## $^{12}\text{C}$ - $^{12}\text{C}$ inelastic reaction



Doppler corrected spectrum: reaction in incoming  $^{12}\text{C}$   
Laboratory system, spectrum: reaction in target  $^{12}\text{C}$

# Summary and Outlook

JE

what does CALIFA detector stand for?



I'm sorry, but as of my knowledge cutoff in September 2021, I don't have any information about a detector called CALIFA. It's possible that it may be a relatively new development or a specialized detector within a specific field that I'm not aware of. If CALIFA refers to something other than a detector, please provide additional context, and I'll do my best to assist you.



Hopefully ChatGPT will know CALIFA soon !

STAY TUNED !



# Thank you!

**CALIFA @ Technical University of Munich (TUM)**

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Stefan Eder, Tobias Jenegger

