

R³B Experiments with Final CALIFA Setup



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PSI Seminar 07.06.2023

R³B @ FAIR

CALIFA Status & Final Configuration

Analysis S444 Experiment

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2094 – 390783311, BMBF 05P19WOFN1, 05P21WOFN1 and the FAIR Phase-0 program

Formation of Elements – Nucleosynthesis

abundances - r-Process - fission feeding

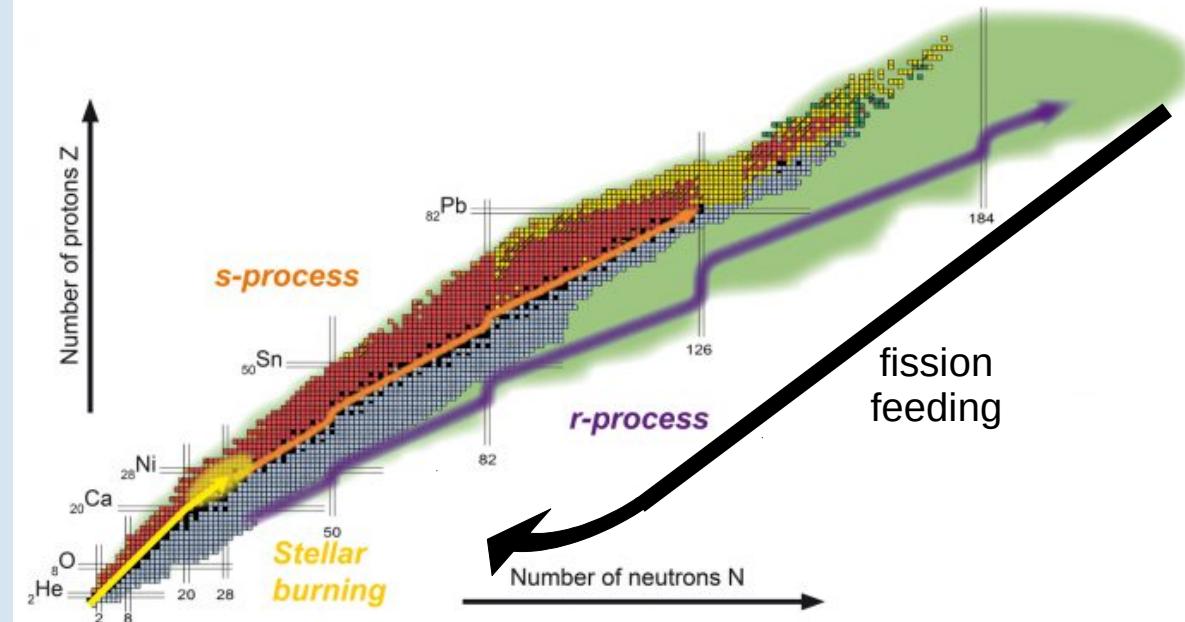
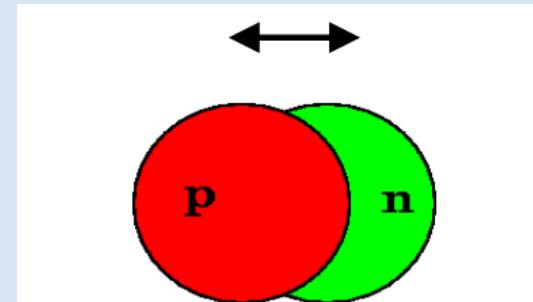


Fig. 1: Nuclear chart showing the nucleosynthesis processes occurring during stellar burning (yellow), the s-process (orange) and the r-process (violet) (credit: EMMI, GSI/Different Arts)

Collective Excitations

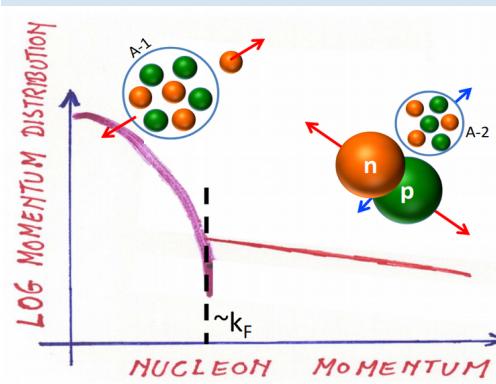
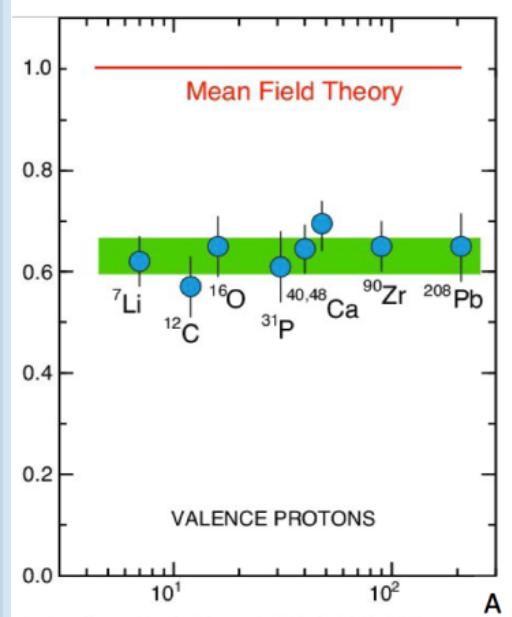
- Giant Dipole Resonances / Pygmy Resonances
- EOS
- Neutron skin thickness



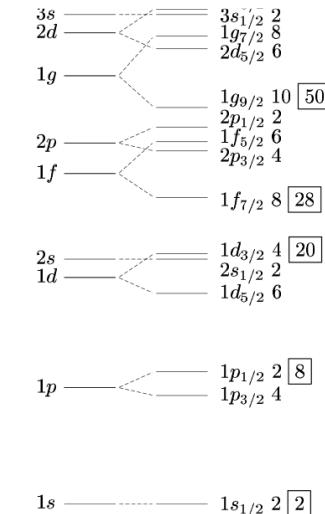
Isovector Electric
Giant Dipole Resonance

Single Particle Properties inside atomic nucleus

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



Nuclear Shell Model



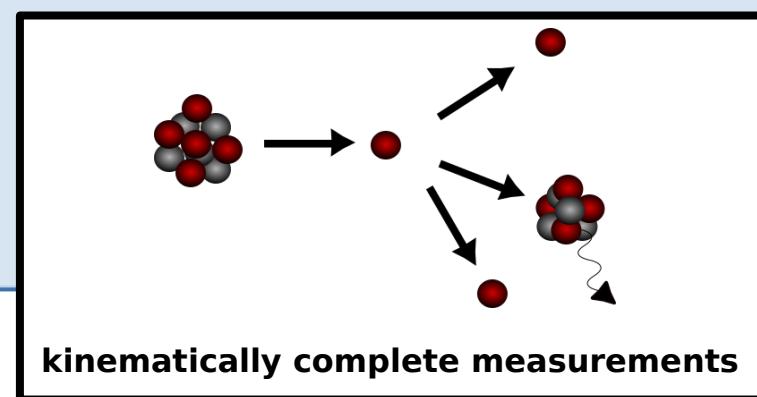
Experimental Setup Requirements:

FAIR accelerator facility

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

+

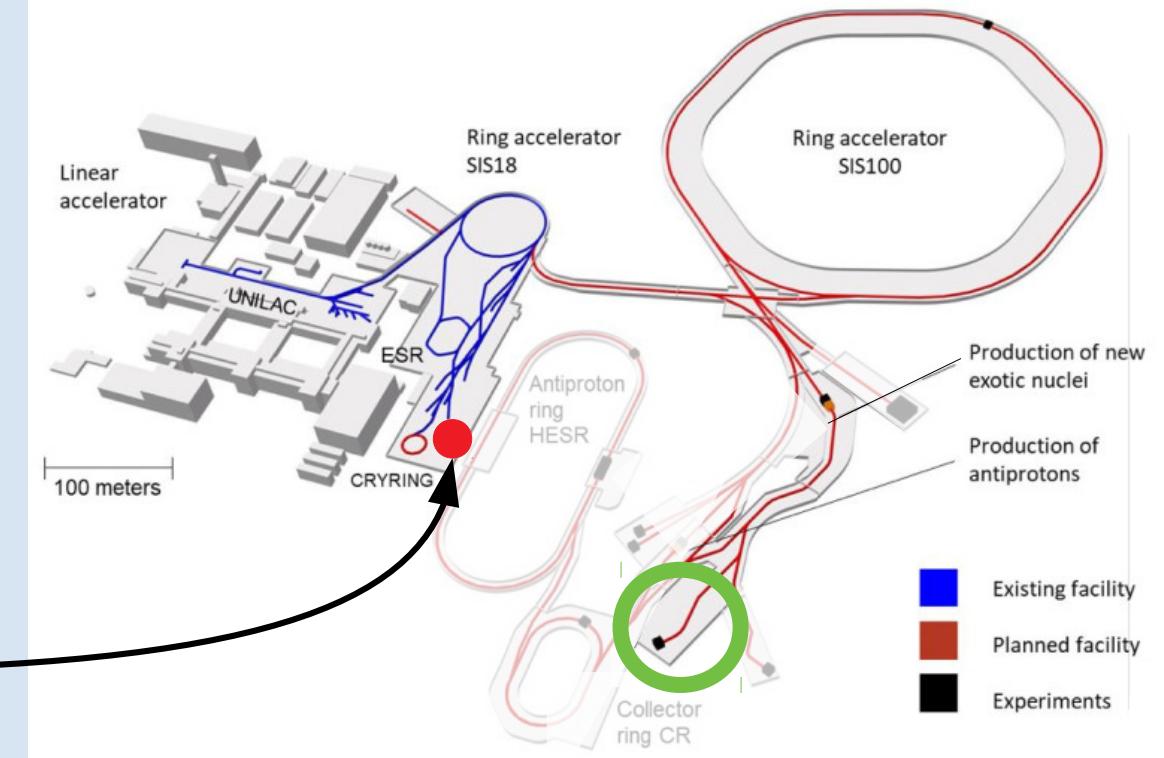
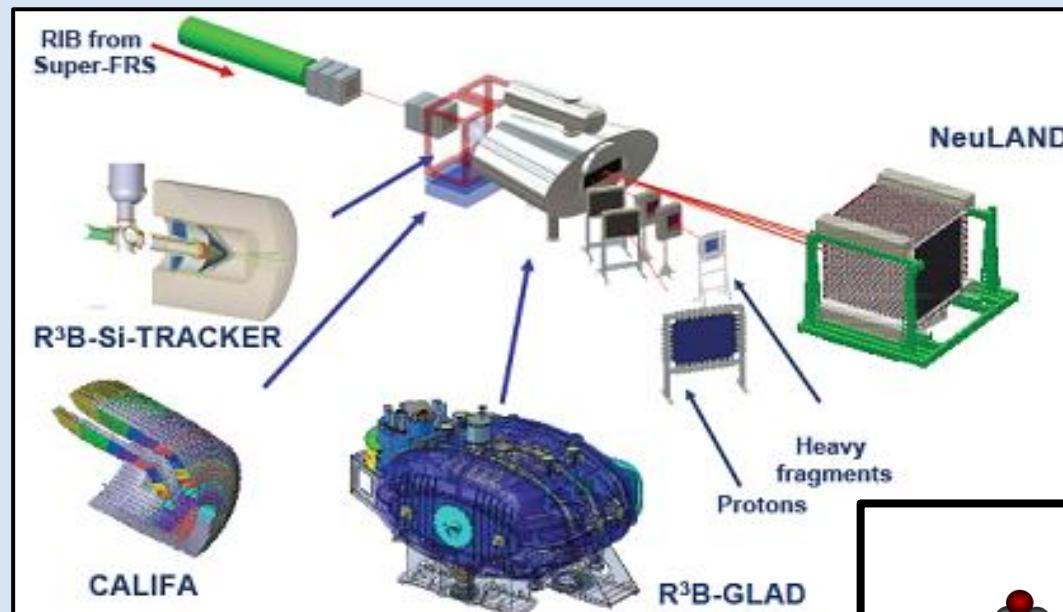
R3B Setup



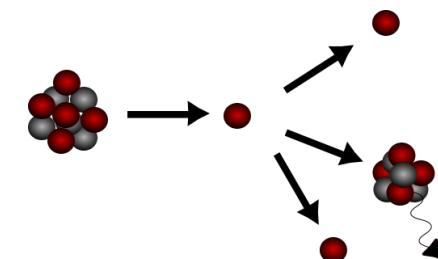
R³B @ FAIR

R³B as part of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt:

Reactions with Radioactive Relativistic Beams



Haik Simon – FAIR & Super-FRS – EPS 20190930



kinematically complete measurements

FAIR Construction Site



High Energy Cave

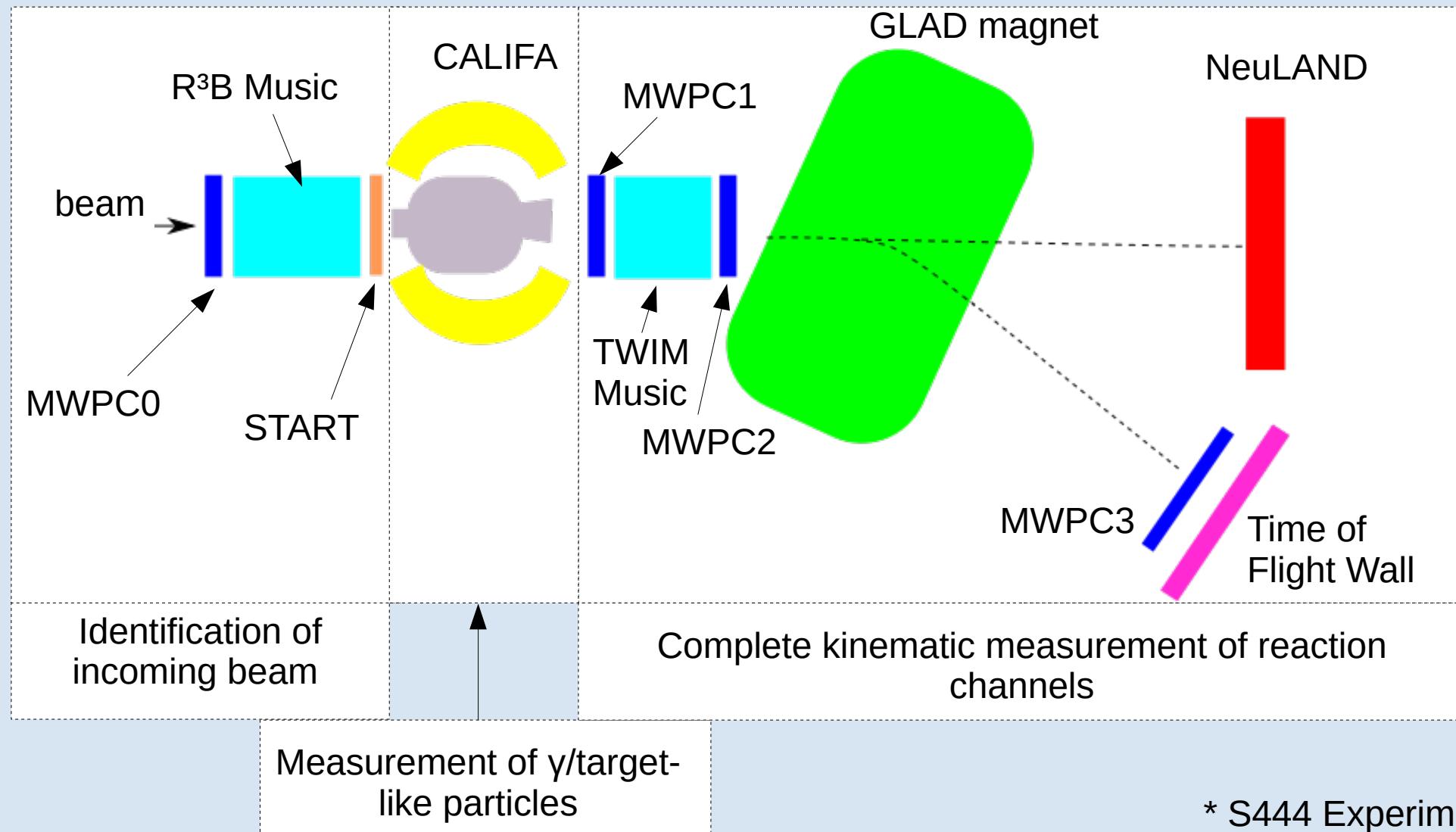
© D. Fehrenz, GSI/FAIR, May 2023



Tobias Jenegger

Dimensions: 60 x 20 x 7 m

R3B Setup*



CALOrimeter for the In Flight detection of γ -rays and light charged pArticles

Endcap:

iPhos:

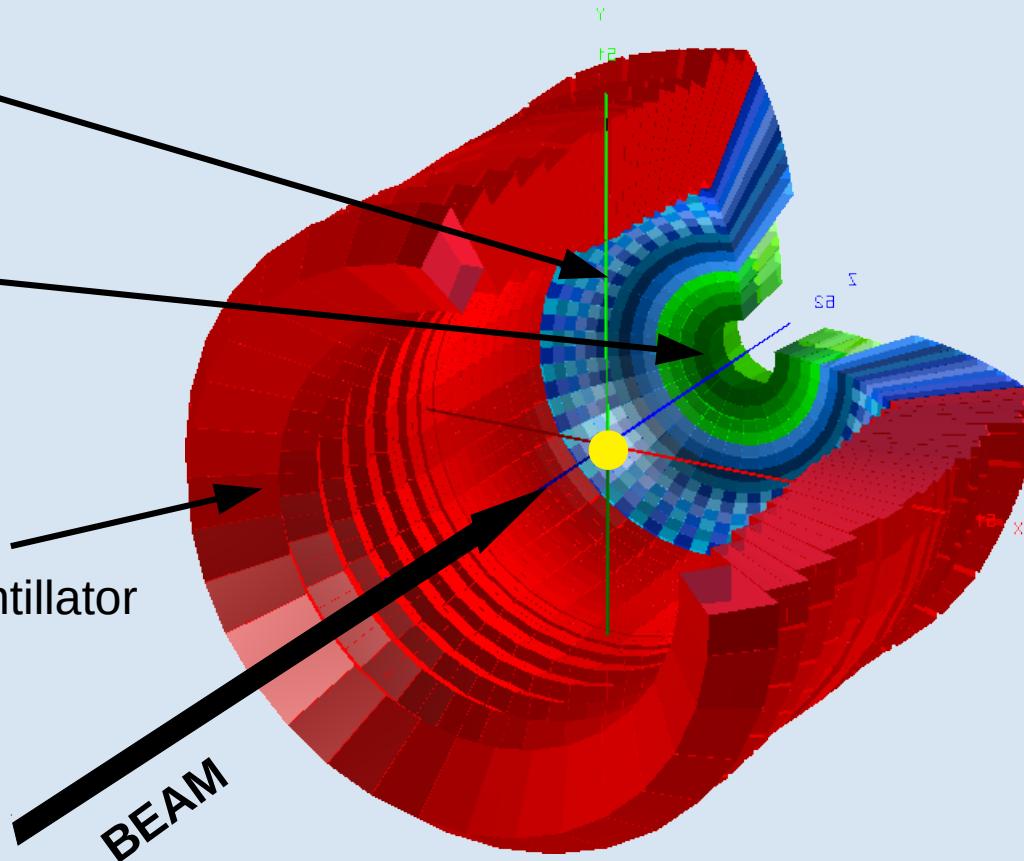
480 CsI(Tl)
crystals

CEPA:

96 CsI (Tl)
crystals

Barrel:

1952 CsI(Tl) scintillator
crystals



Highly segmented detector:

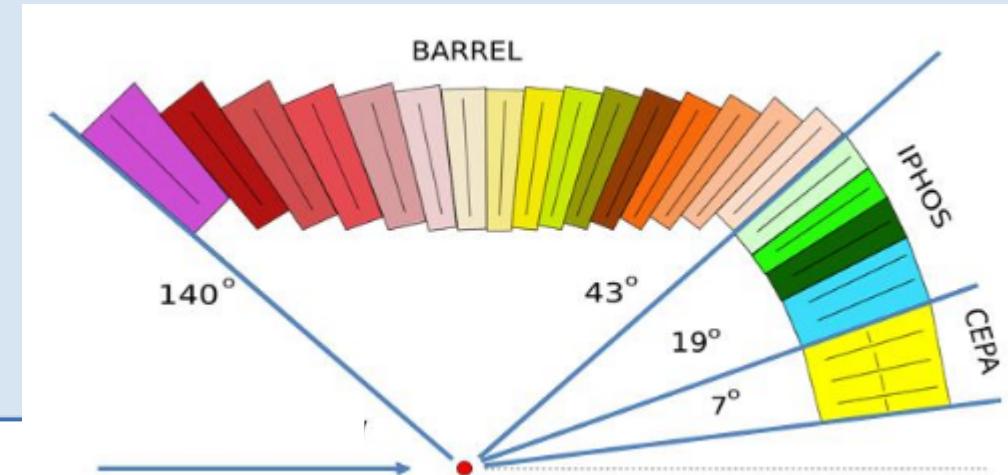
- good angular reconstruction/
doppler correction

Broad calorimetric energy measurements:

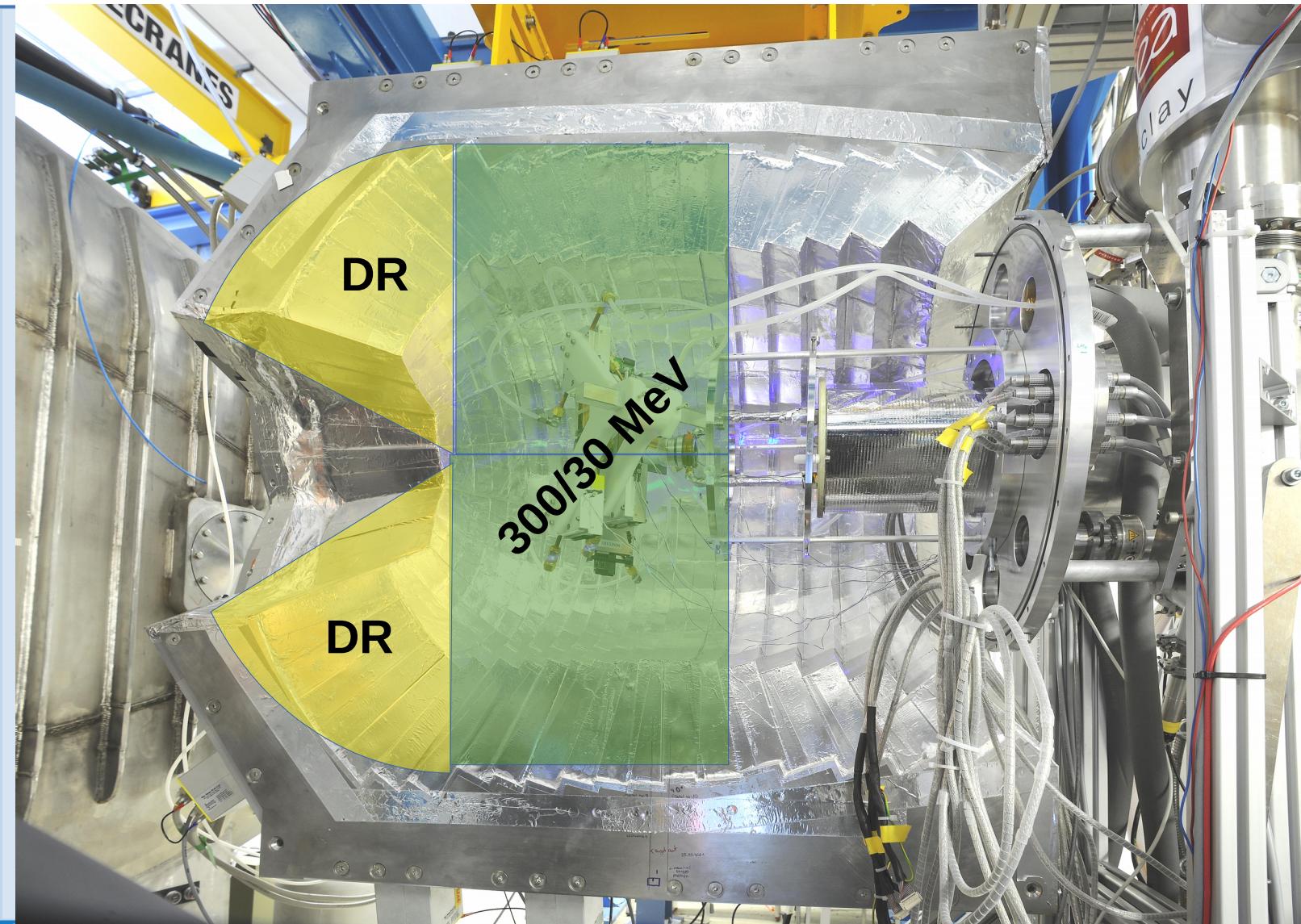
- From 100 keV γ -rays up to high energetic charged particles

Flexible running mode:

- self/external triggering mode



CALIFA Configuration (S522, 2022)

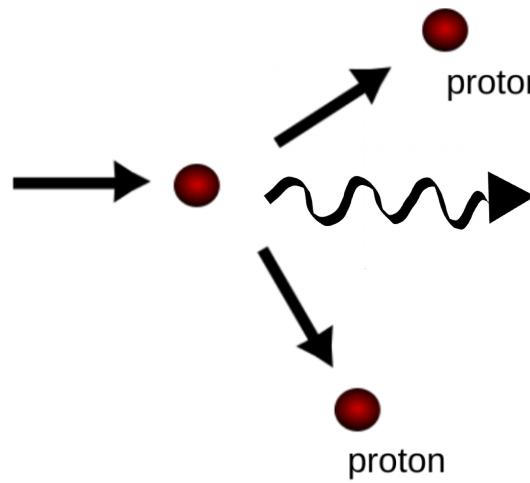


IPhos: 480 crystals

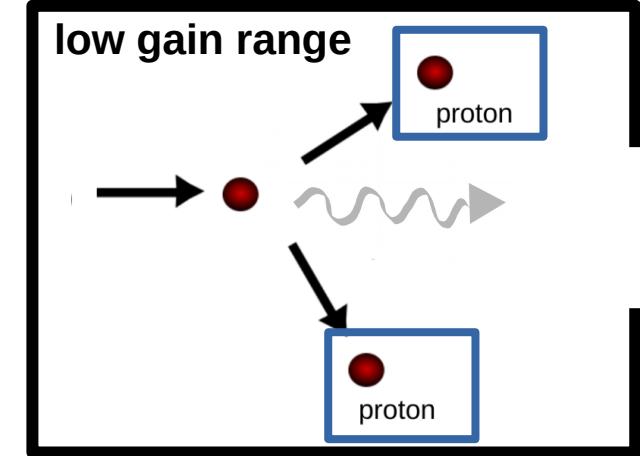
- completely filled
- readout with Dual Range Preamps

Barrel: 1024 crystals

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

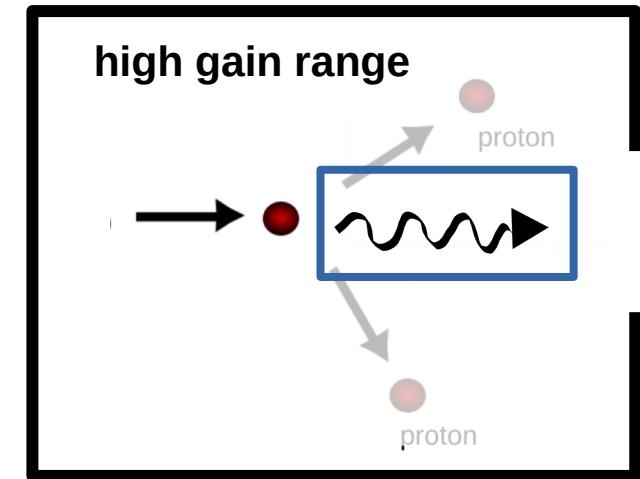
Dual Range Preamplifier

SIMULTANEOUS
high energetic particle
measurement
&
gamma spectroscopy

SingleRange Preamplifier

Gamma
threshold:
500 keV

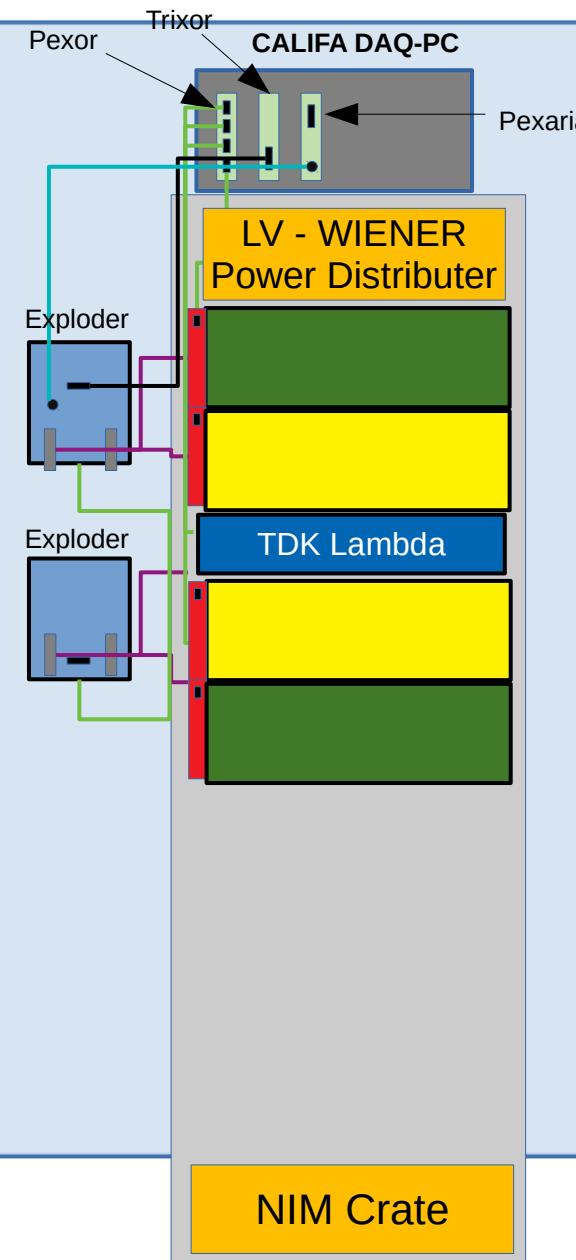
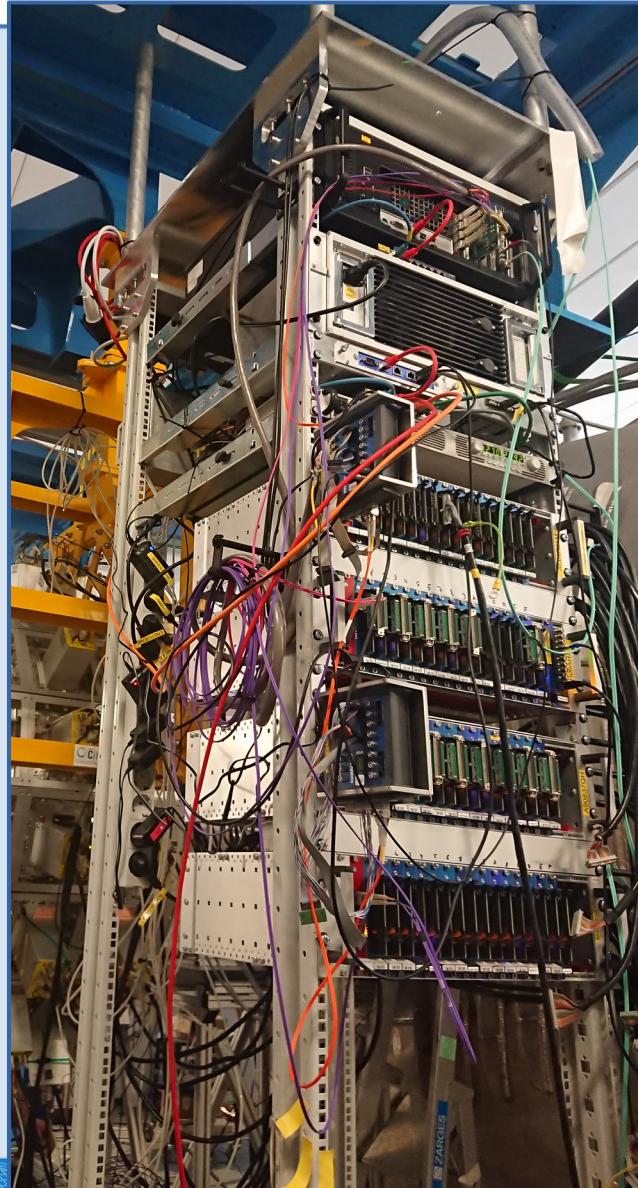
OR



Gamma
threshold:
100 keV

experiment dependent decision has
to be taken beforehand!

CALIFA DAQ Status (S522, 2022)



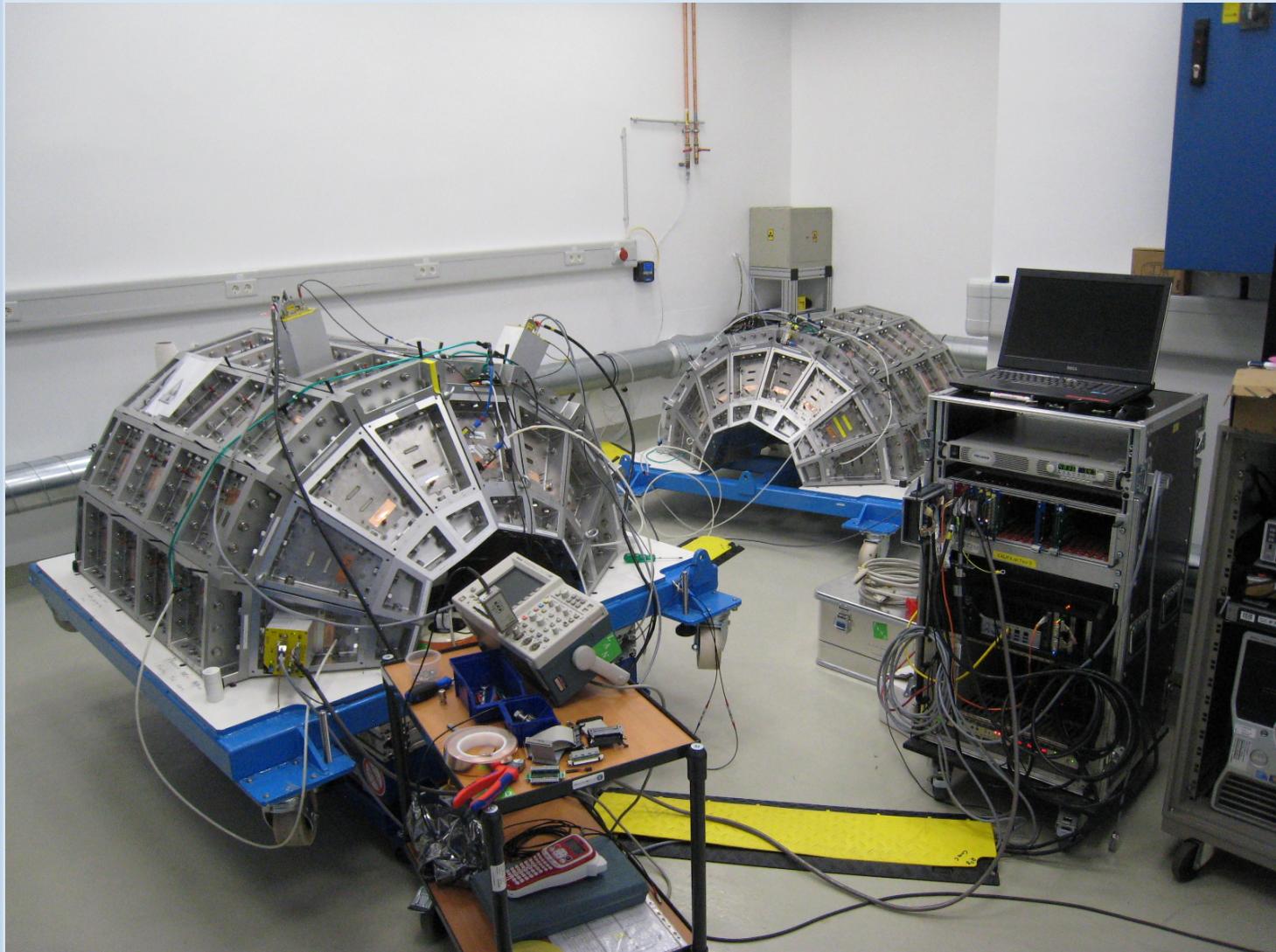
Electronic Rack

- 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

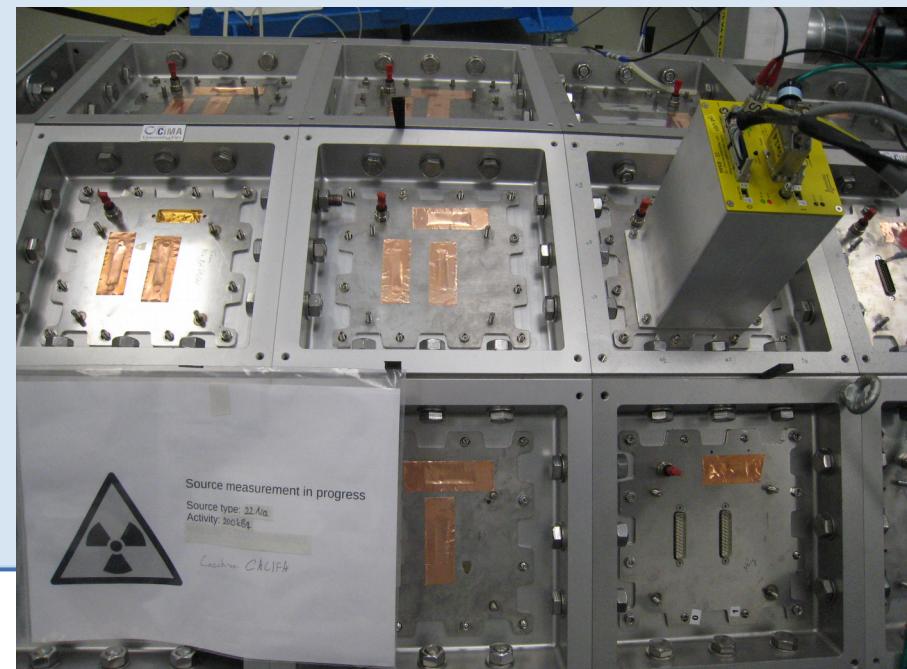
Cables

- 32 SCSI data cables (iPhos)
- 64+2 SR data cables (Barrel)
- 48 LV power cables

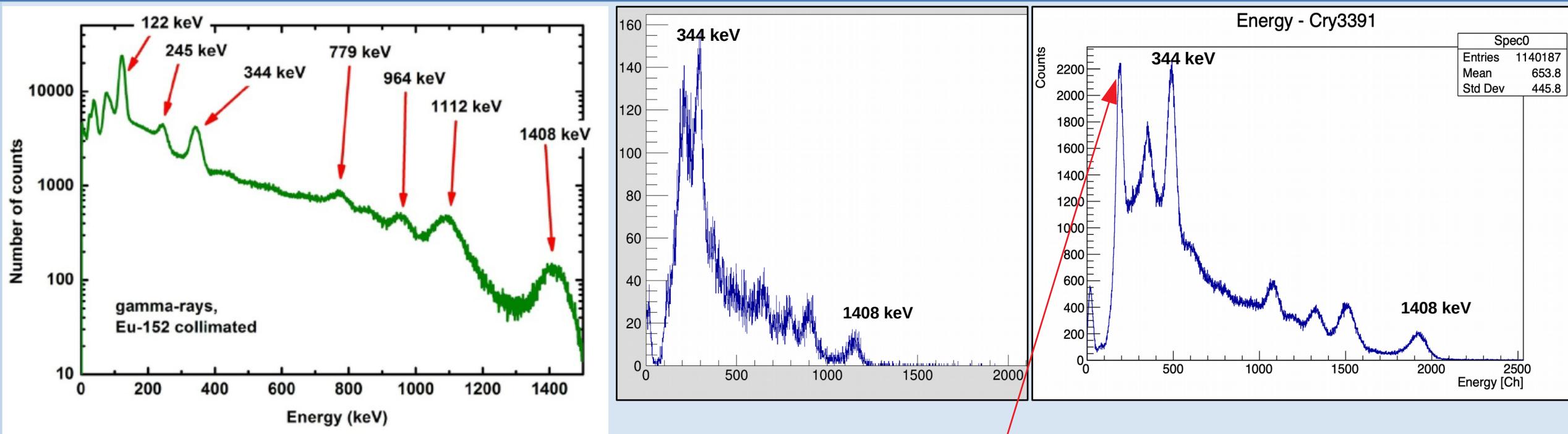
Meanwhile in R³B Preparation ROOM



- Noise debugging
- Cable/connectors checking
- SR vs DR checks



Testing Gain

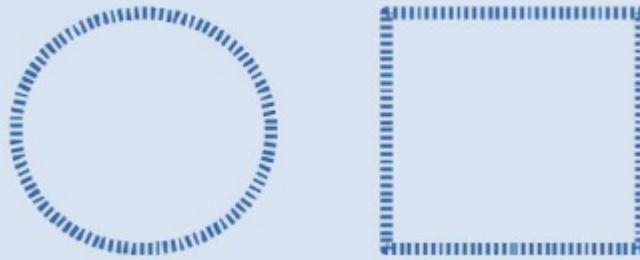


Raising the gain allows to measure down to the **122 keV** peak!

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:

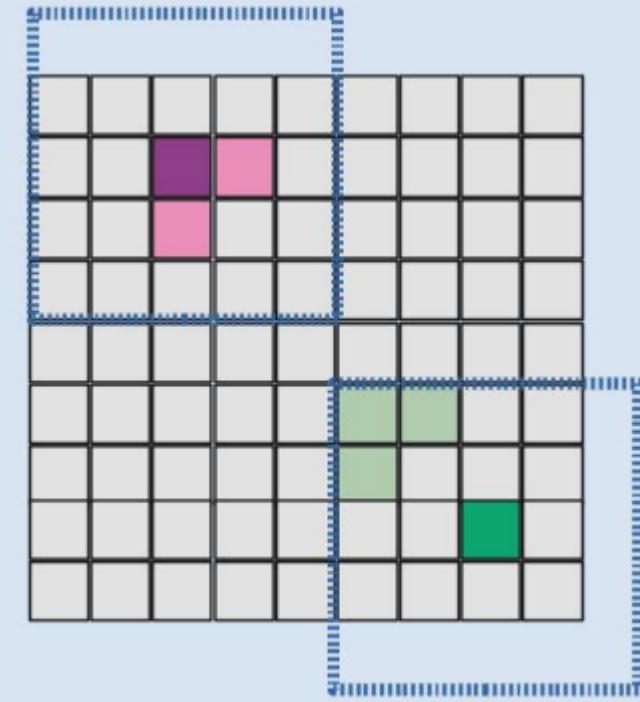


Sort the hit list according to their energy

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

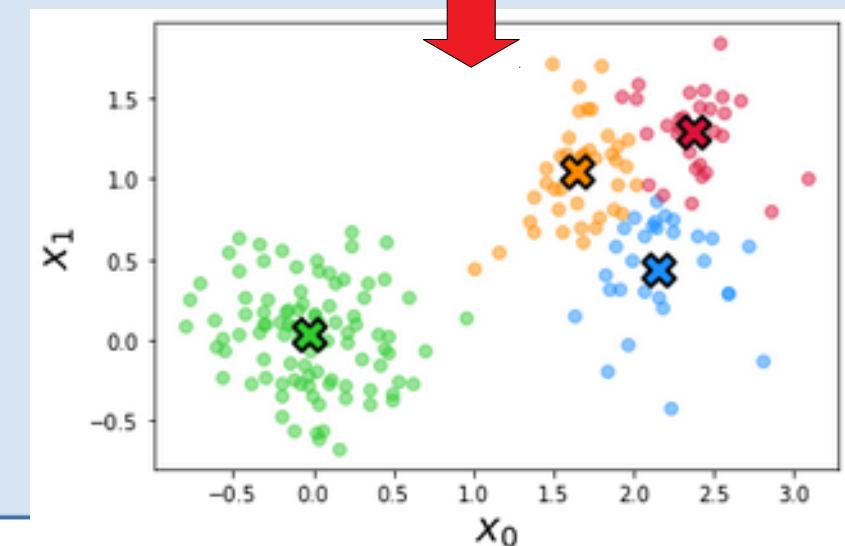
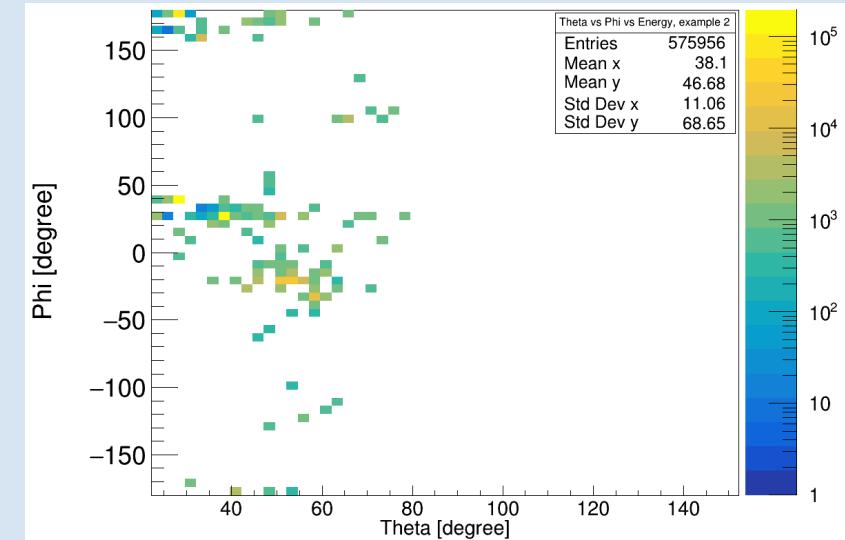
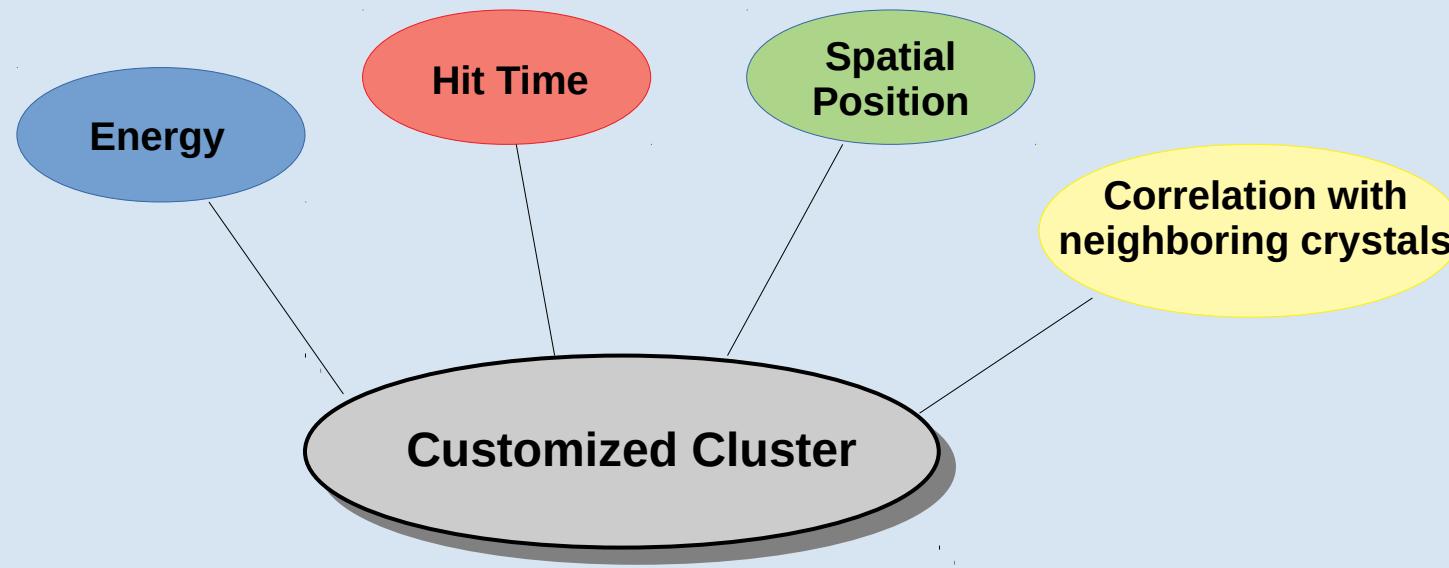
Depending on how low we can get with the threshold we can addup or not !



ODSL Collaboration - Optimize Add-Back Algorithm with AI

Use the power of Machine Learning:

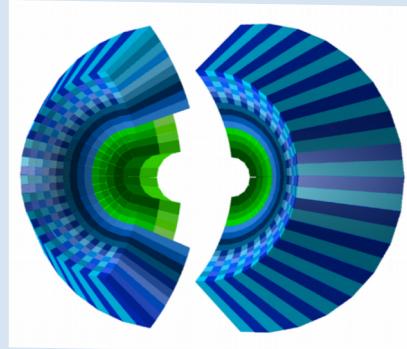
- recognize the physics cases
- optimize the cluster shapes (event by event)
- give probability for fully contained physics event



Filling CALIFA Endcap - CEPA

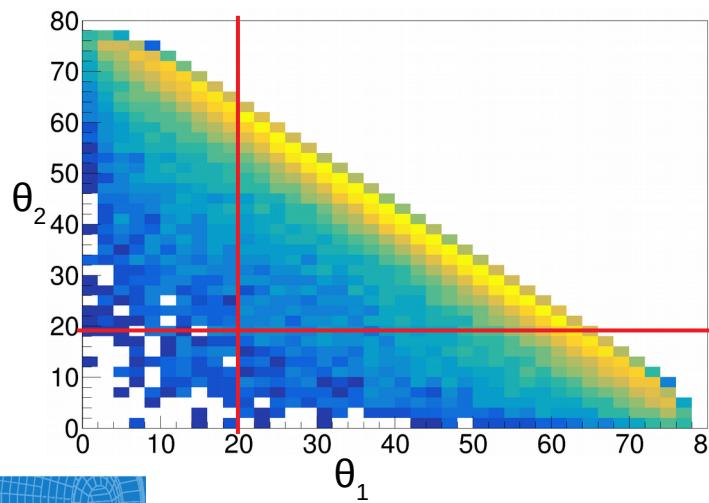
CALIFA Endcap Phoswich Array

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

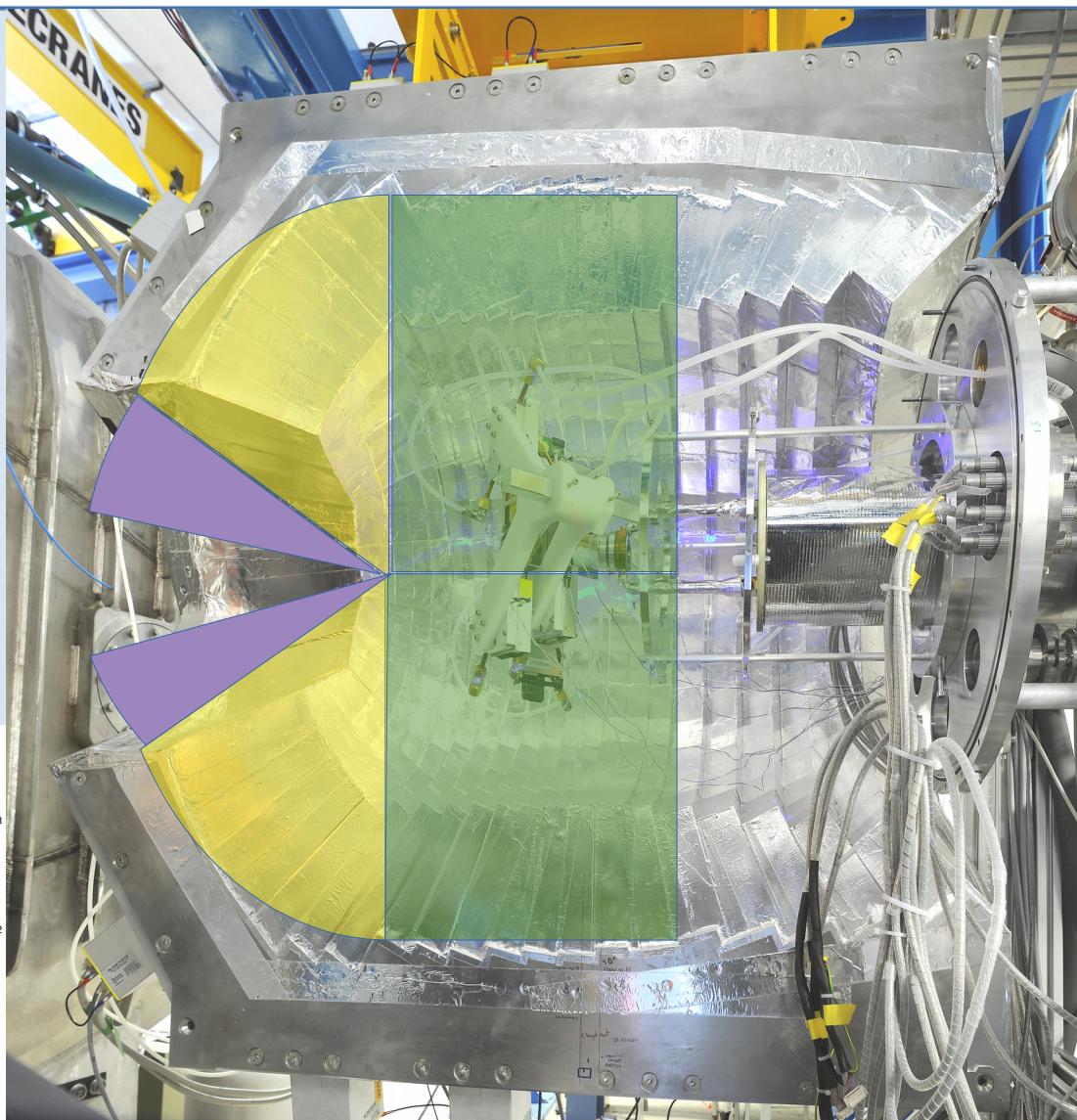
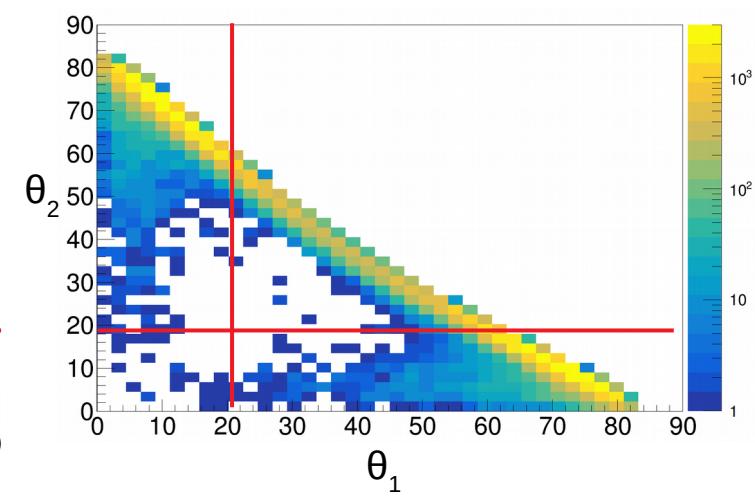


Improves geometric acceptance for high beam energies drastically

p2p-reaction, 400 AMeV



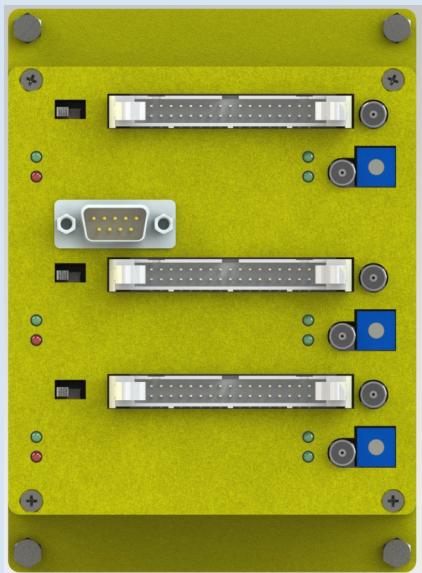
p2p-reaction, 1200 AMeV



Filling CEPA

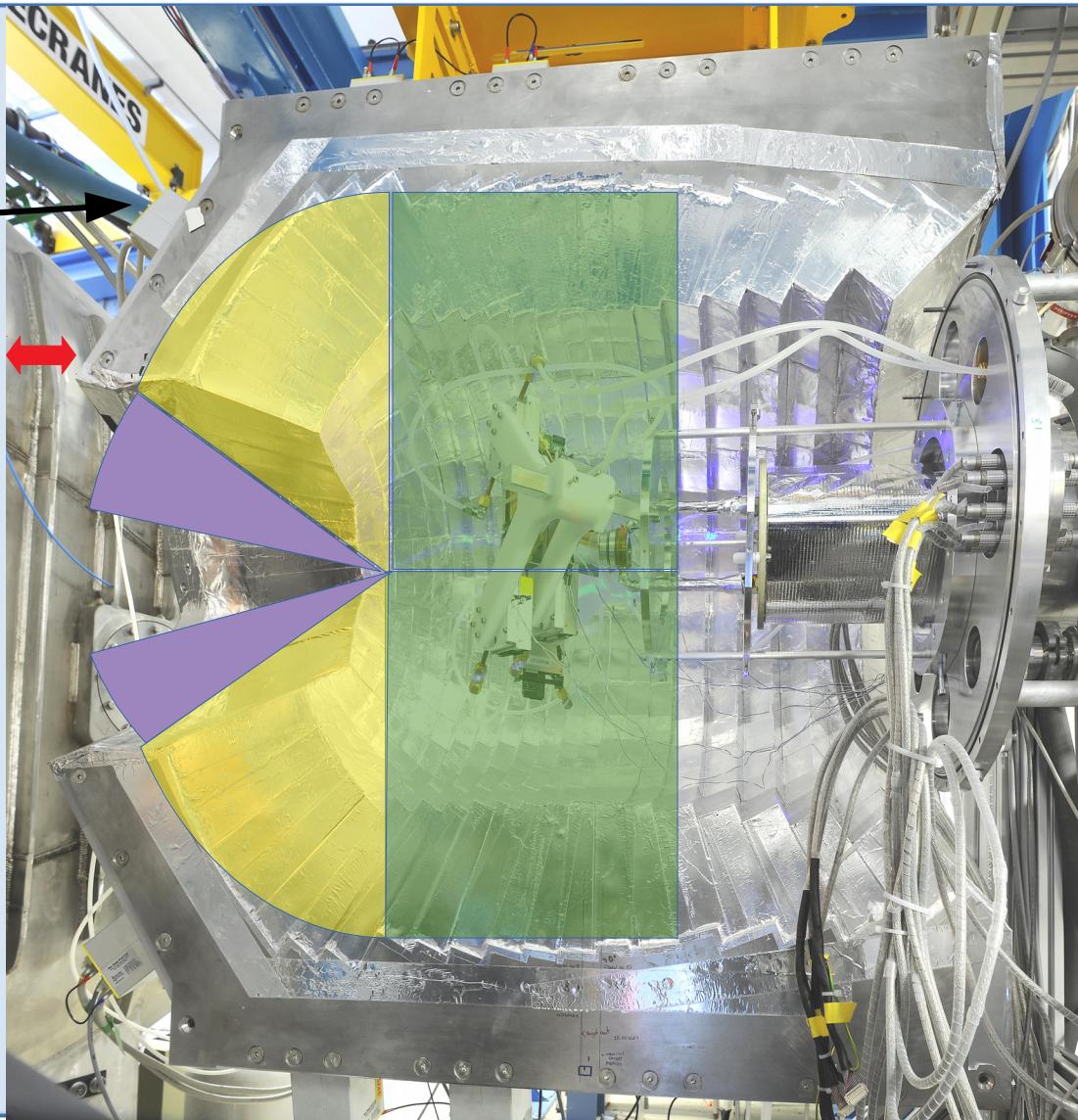
Mesytec MPRB-48 Dual Range Preamps

They get mounted on iPhos tiles

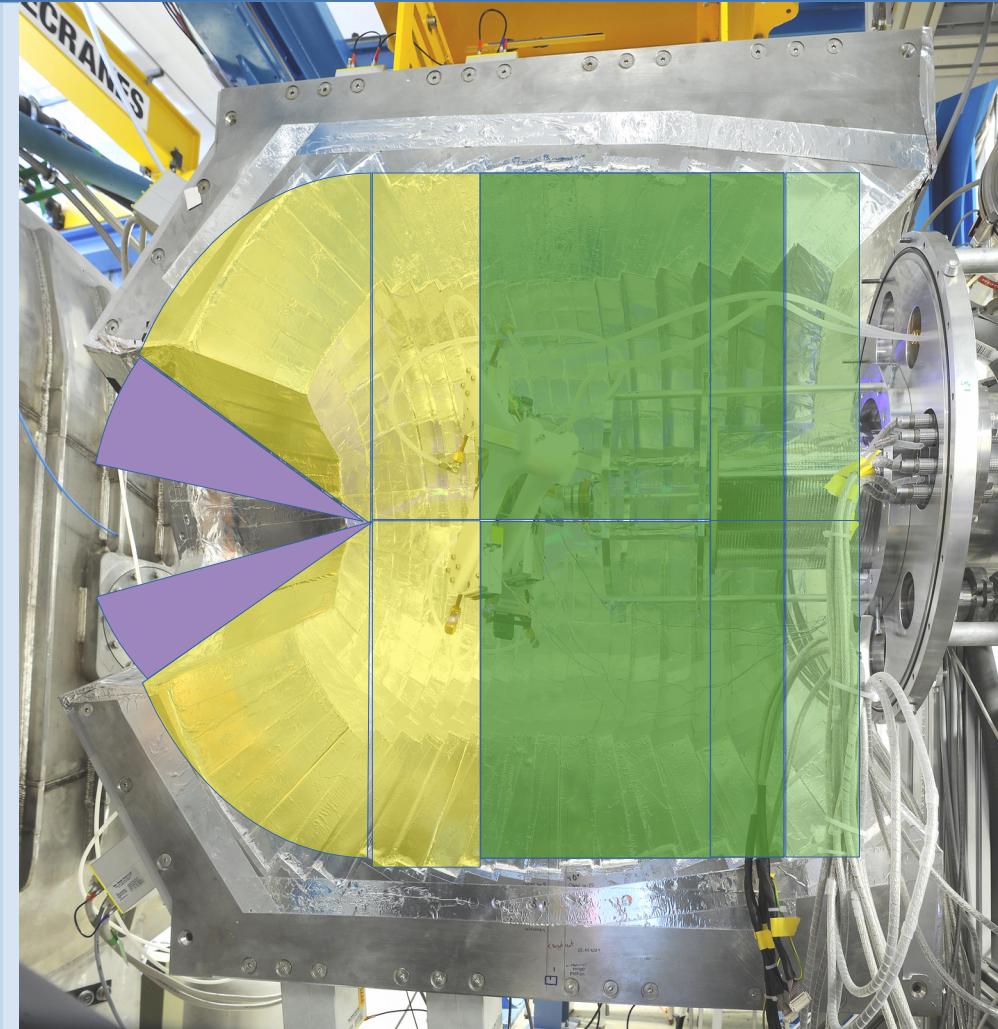


Connected to iPhos APDs
(32 channels)

Connected to CEPA APDs
(16 channels)

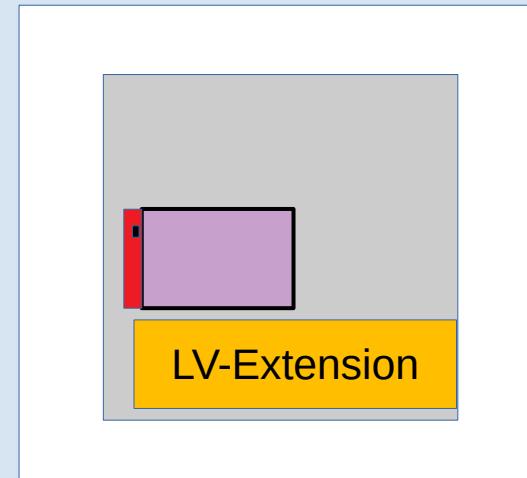


Final CALIFA Electronic Configuration

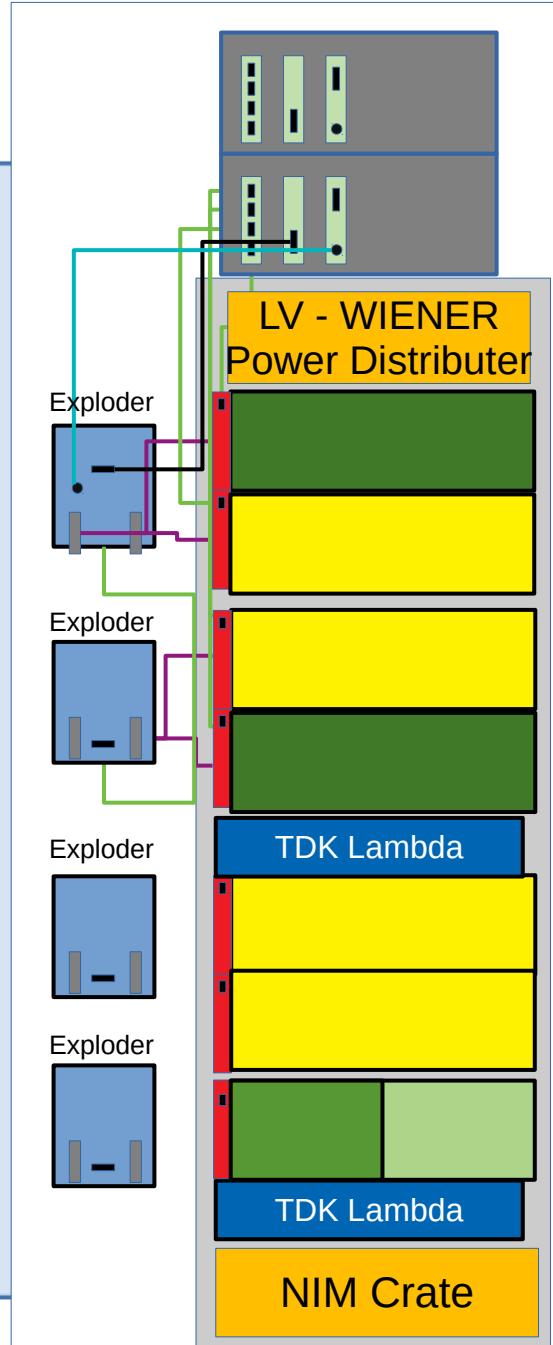


Dual Range Preamplifiers

Second Rack on each side needed!

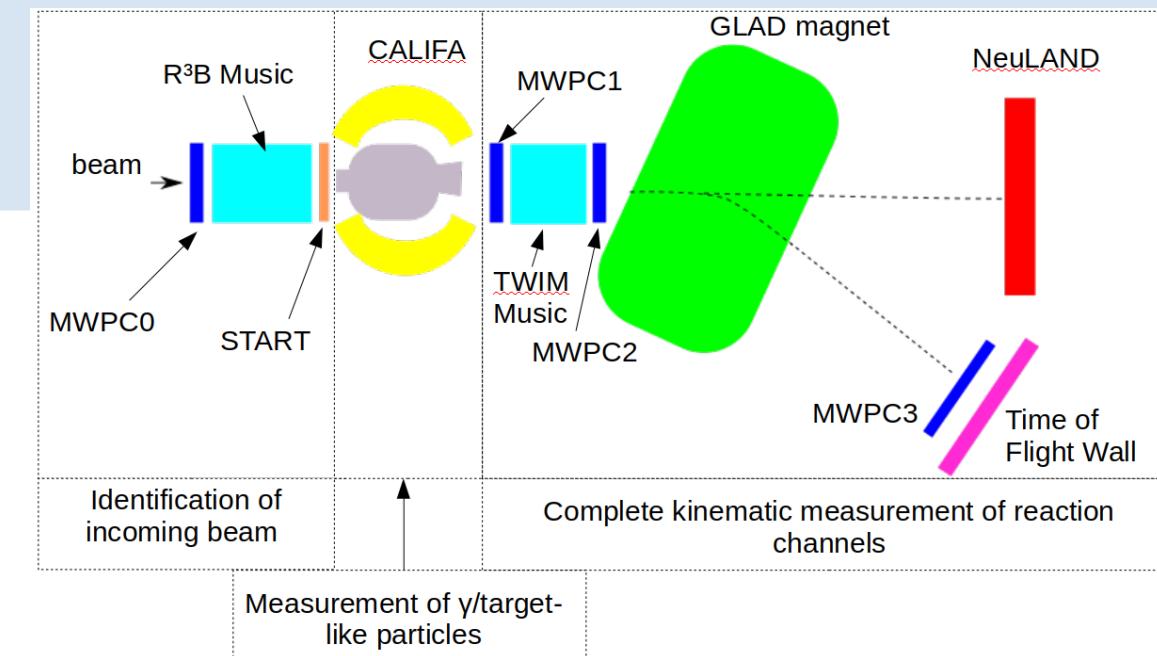
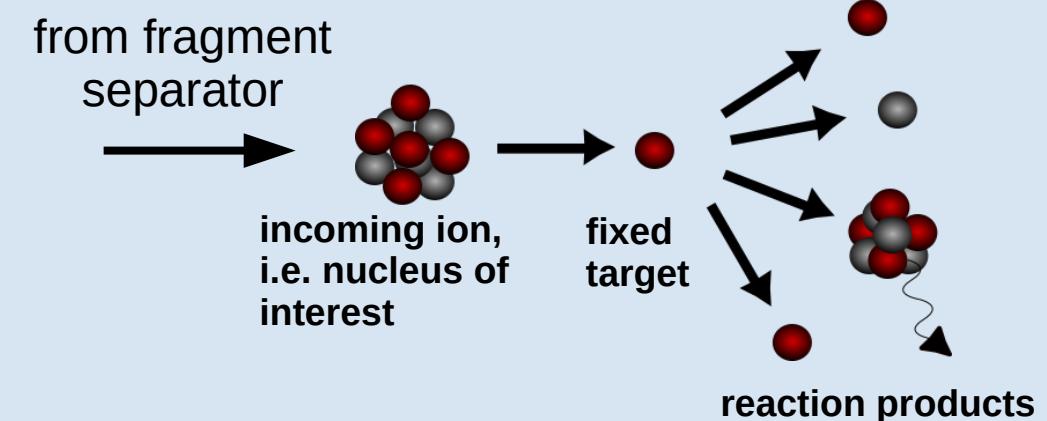
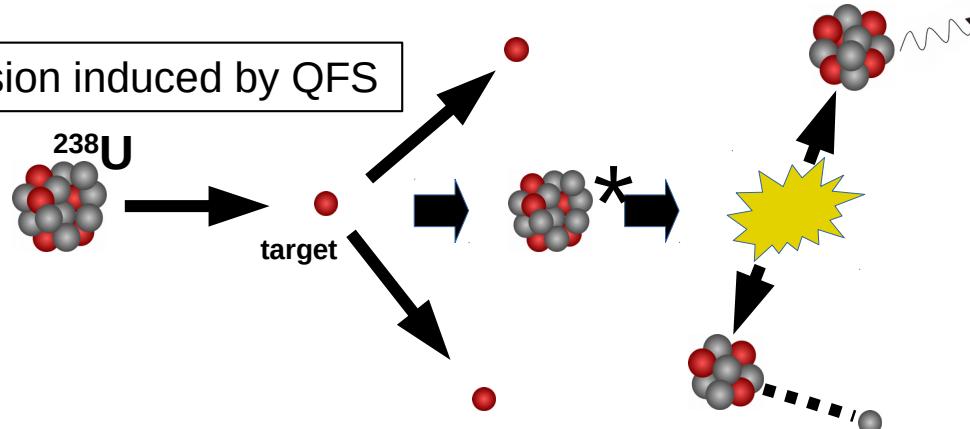


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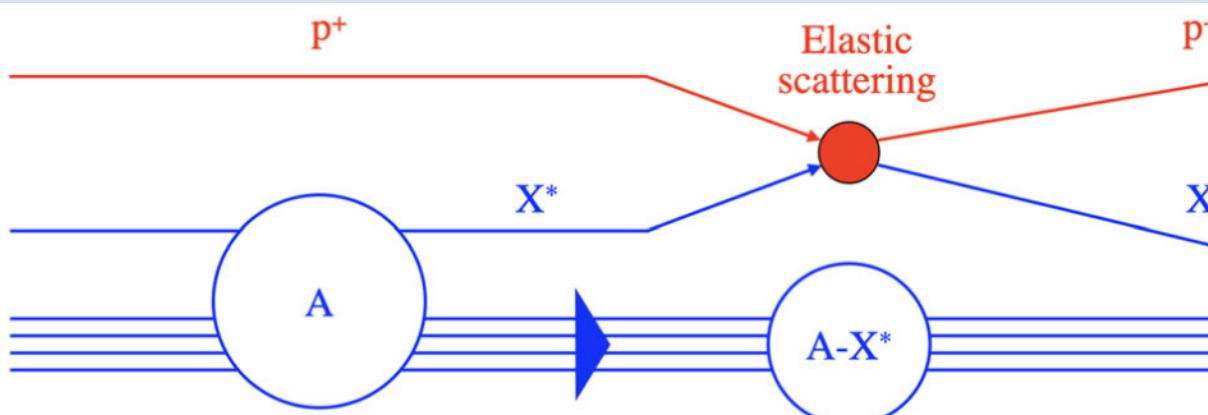
Physics at R3B with CALIFA

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



Quasi-Free Scattering Reactions

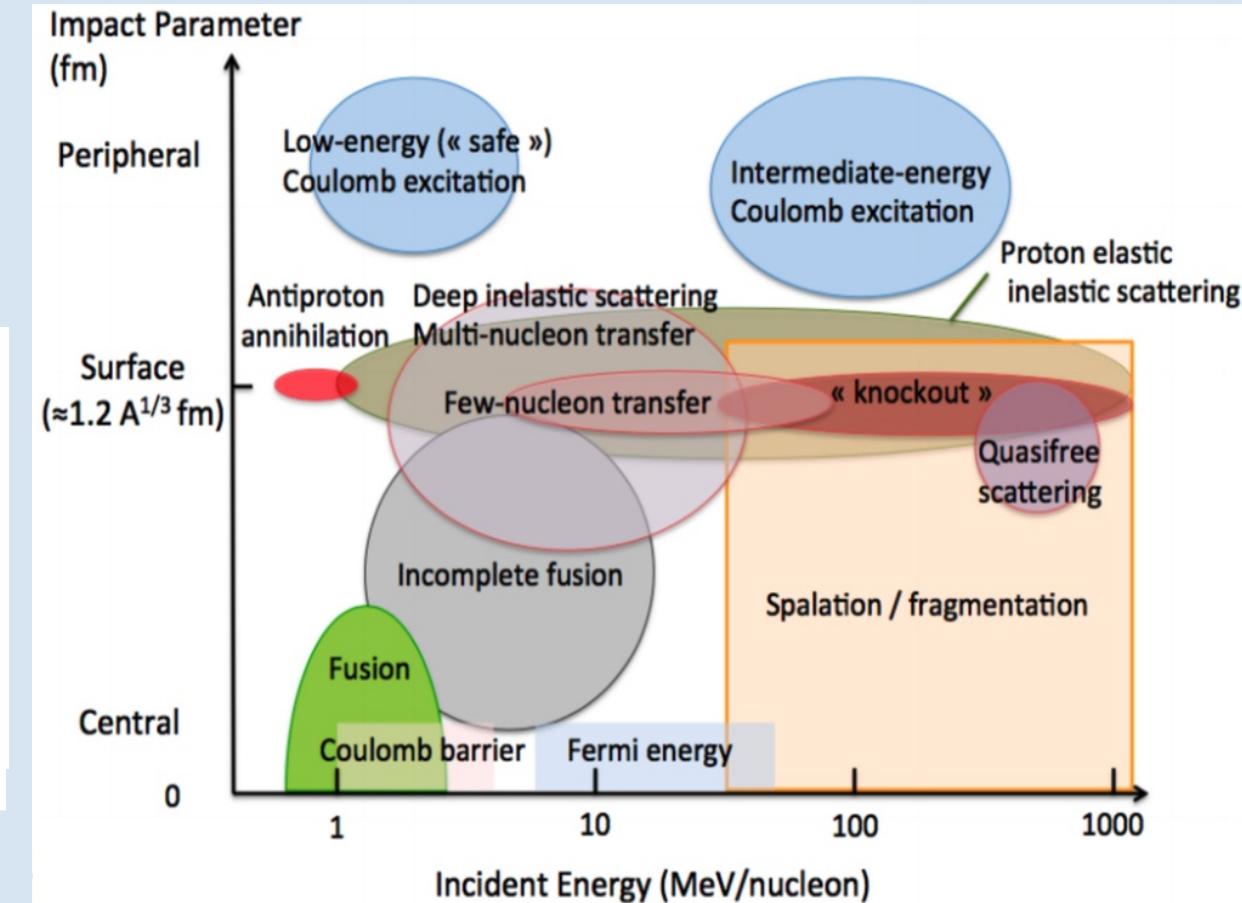
- p^+ or e^- probe is used for sudden knockout of a nuclear constituent
- Can be approximated as two body scattering of free particles



"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

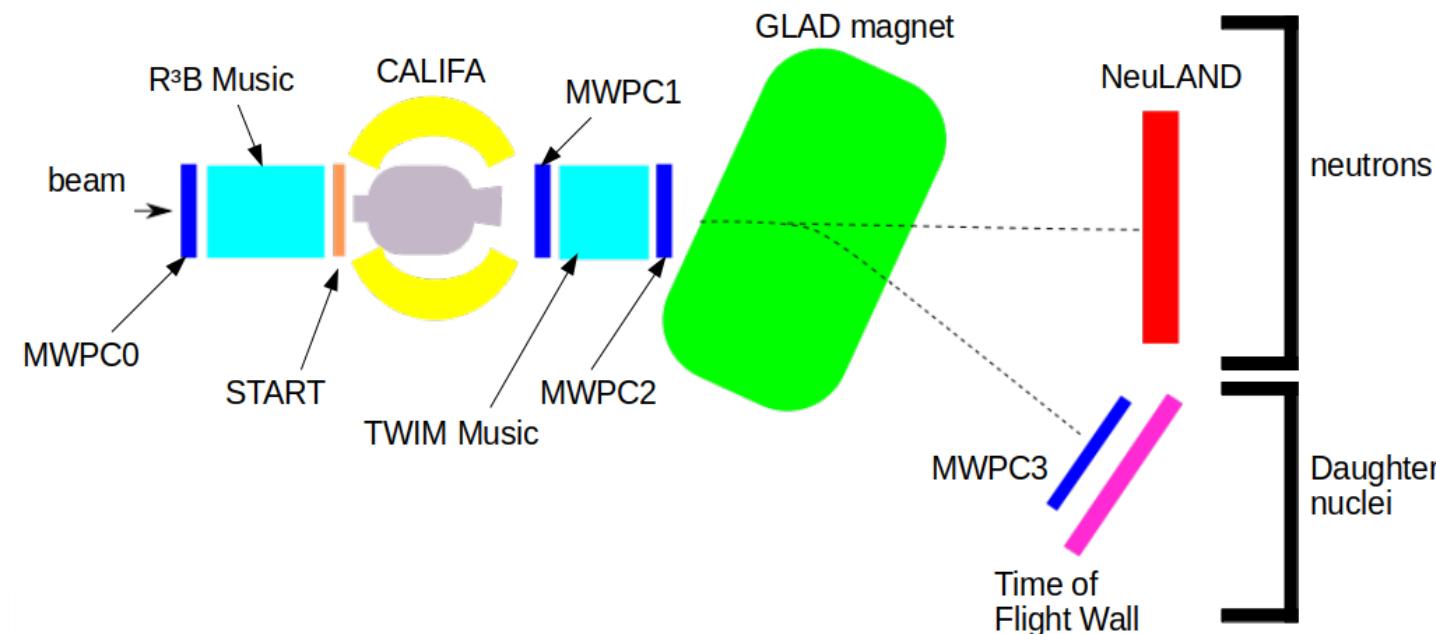
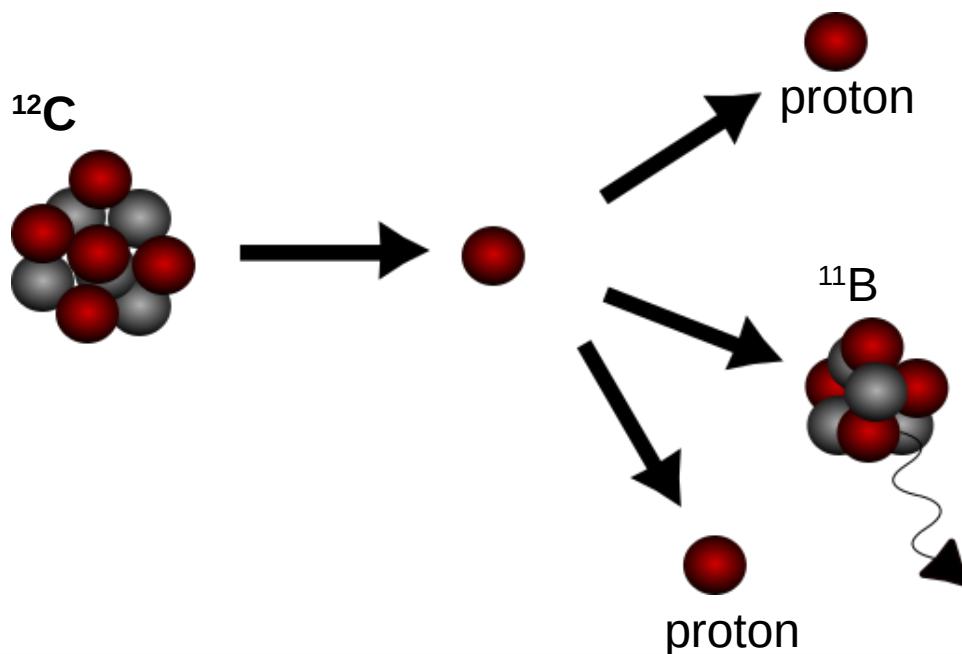
12C(p,2p)11B reaction:

- ^{12}C beam
- proton like target

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

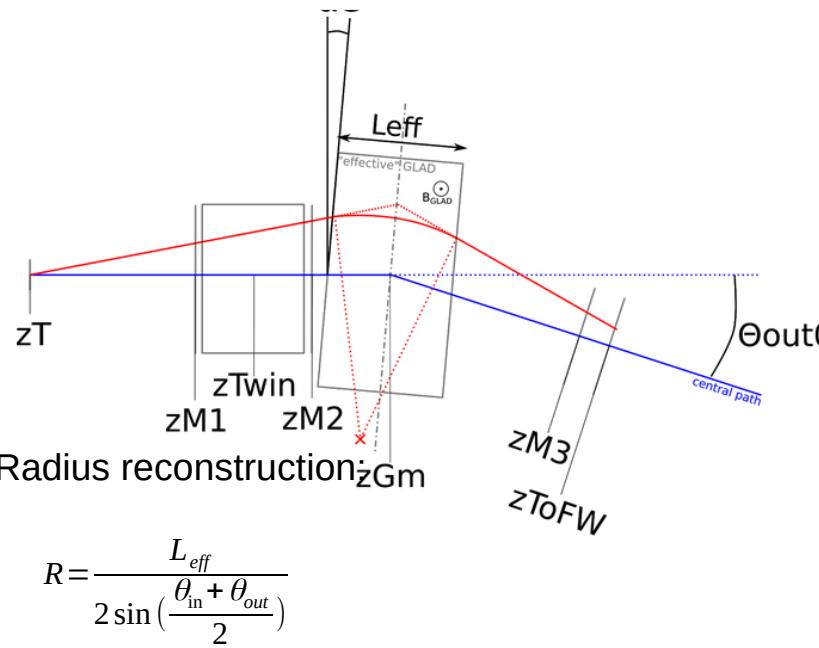
SETUP:

Beam energy: 400 AMeV
Beamtype: ^{12}C
Beamtime: 3 hours
Target: CH_2 (12.29 mm)

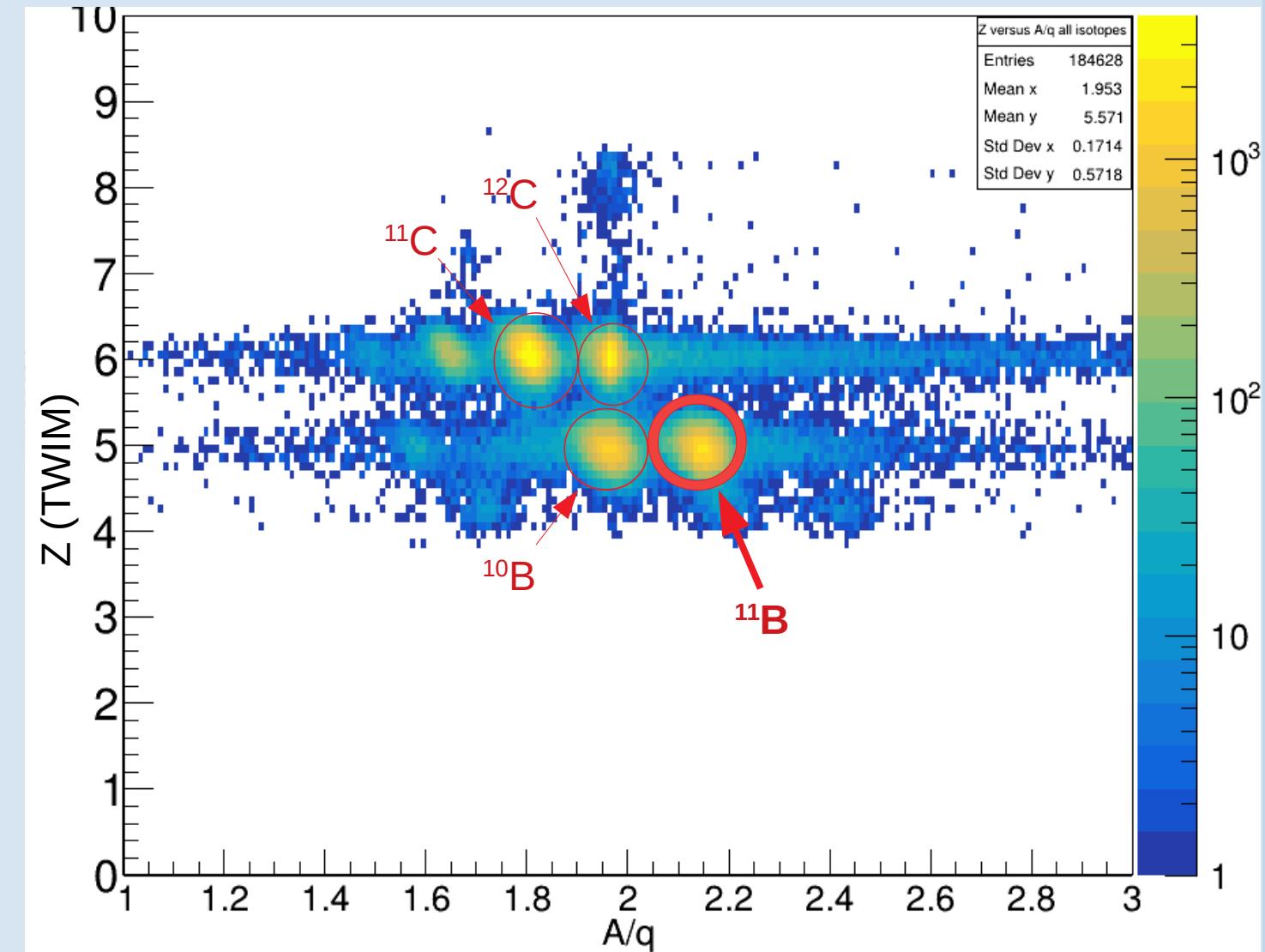


Fragment Particle Identification

Flightpath reconstruction:

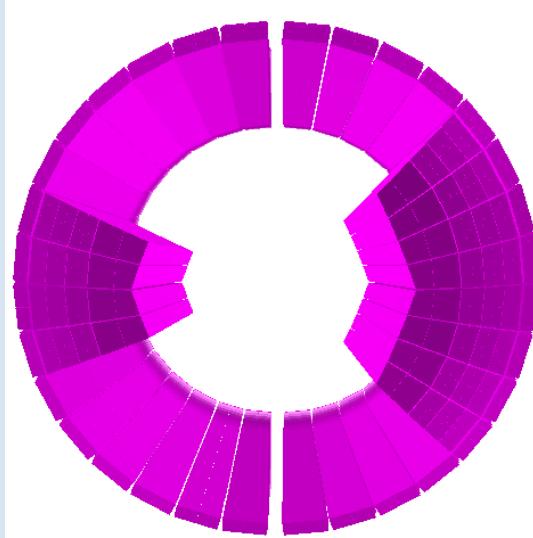


$$B * \rho = \frac{\beta * \gamma * M}{q}$$

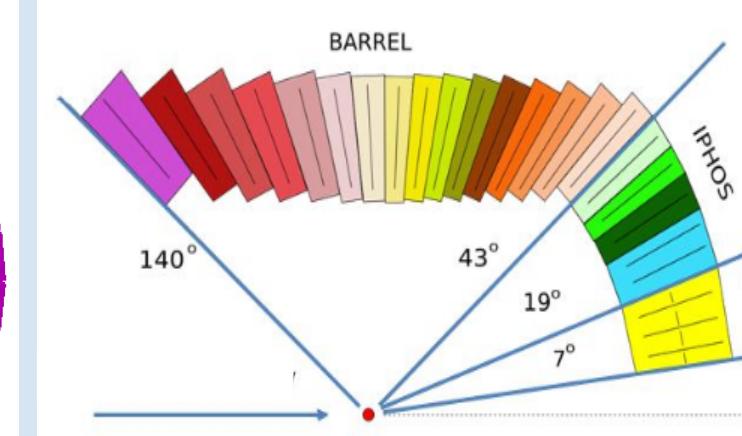
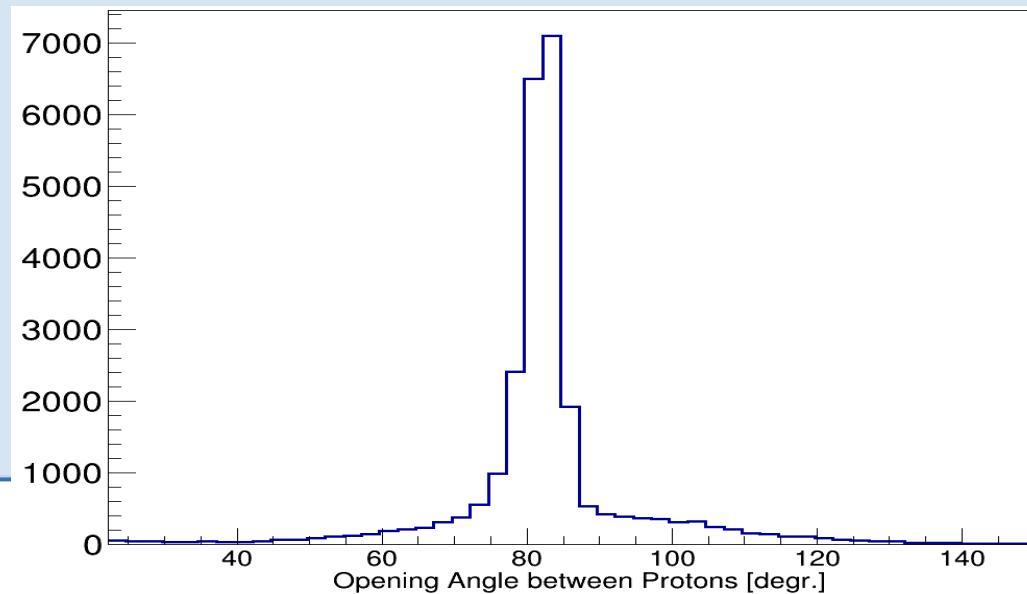
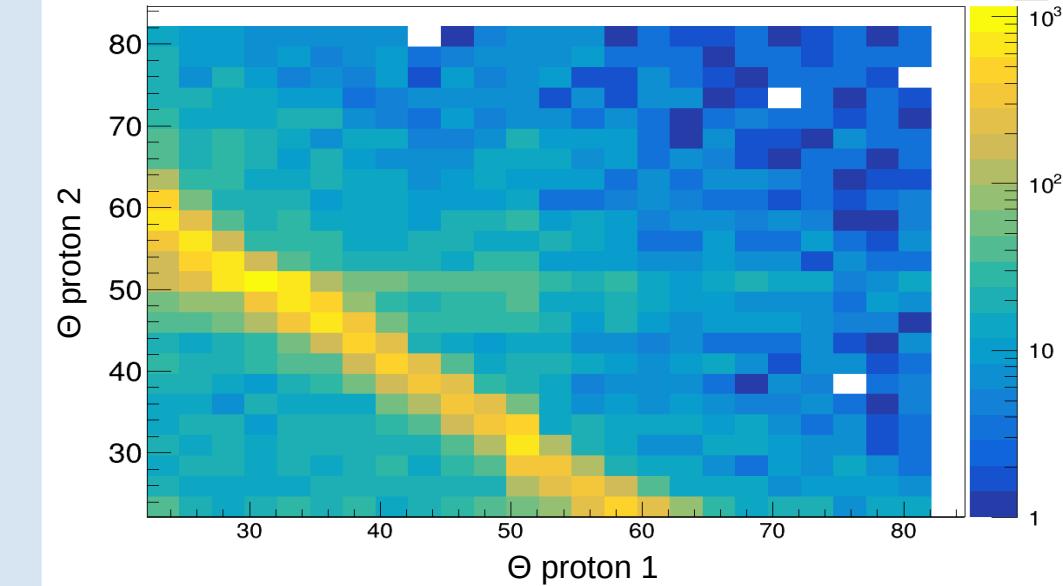


Identification of the two correlated Protons

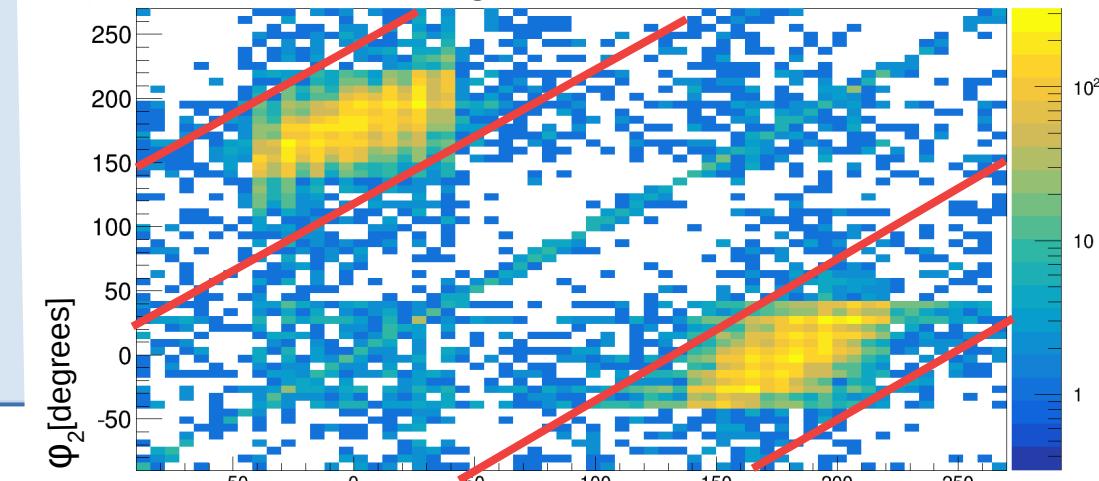
CALIFA Front View



CALIFA Side View

Polar Angle of p_1 and p_2 

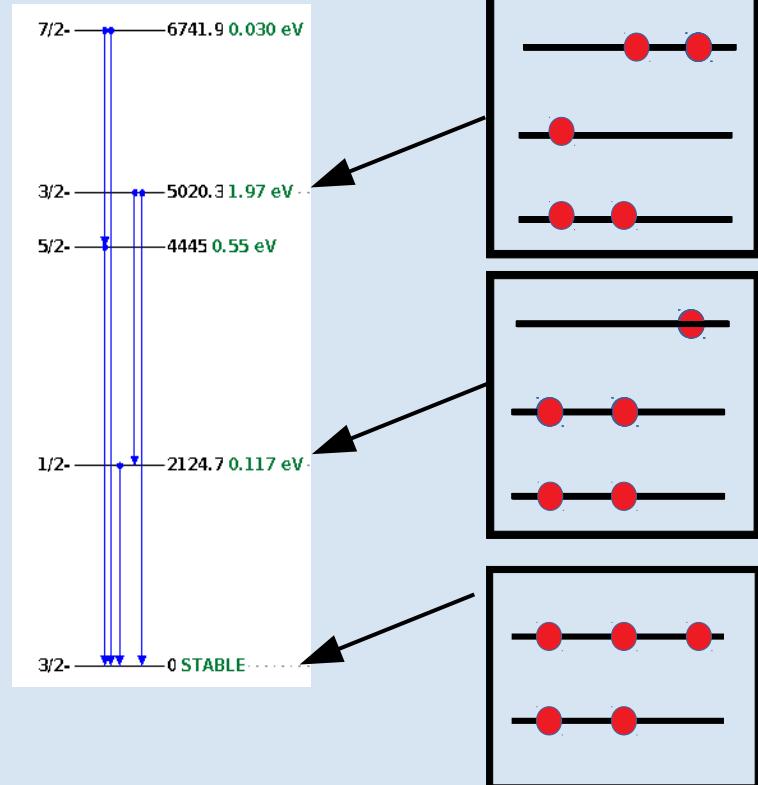
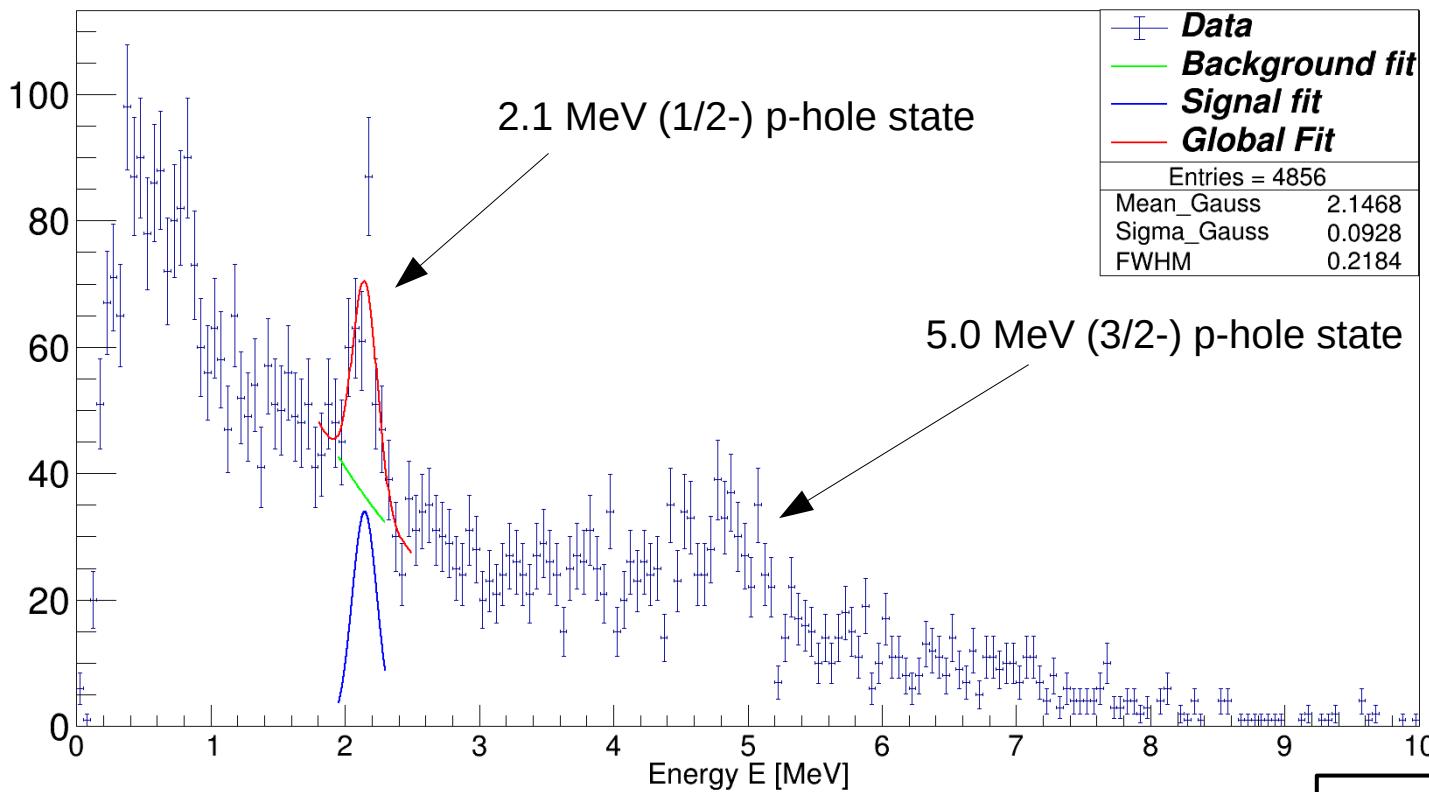
Azimuthal Angle Proton 1 vs Proton2



Gamma Spectrum of ^{11}B

Doppler Corrected Gamma Spectrum

$$E_\gamma = \gamma E_{lab} (1 - \beta \cos(\theta))$$

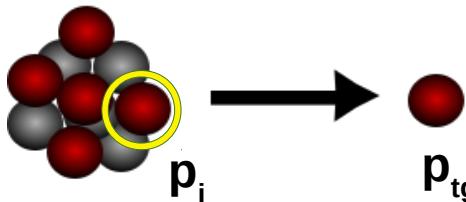


Event Selection Criteria:

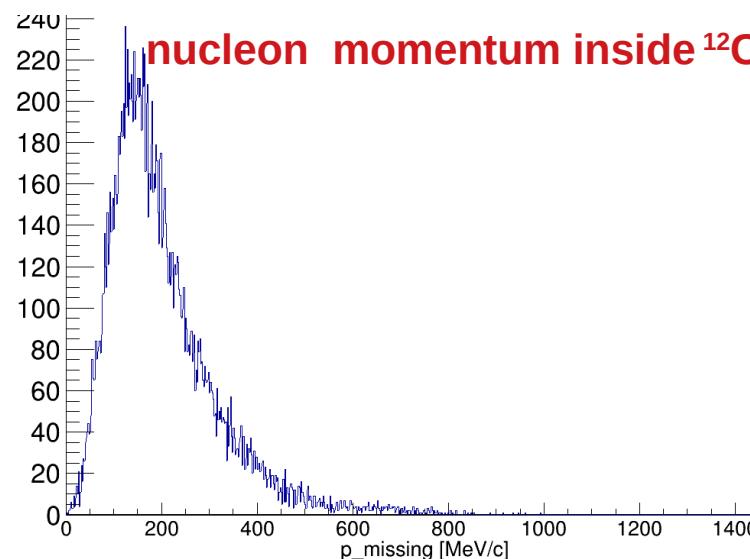
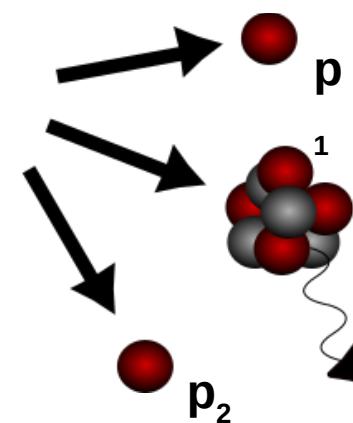
- ^{11}B fragment identification
- Two hits (protons) with $E_{\text{hit}} > 30 \text{ MeV}$
- $\theta_1 + \theta_2 < 90^\circ$
- $\Delta\phi = 180^\circ \pm 40^\circ$

Reconstruction of Inner Momenta

Before Scattering:

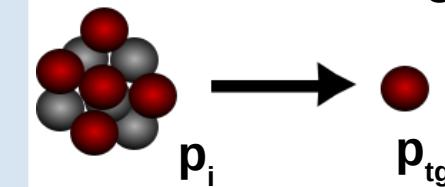


After Scattering:

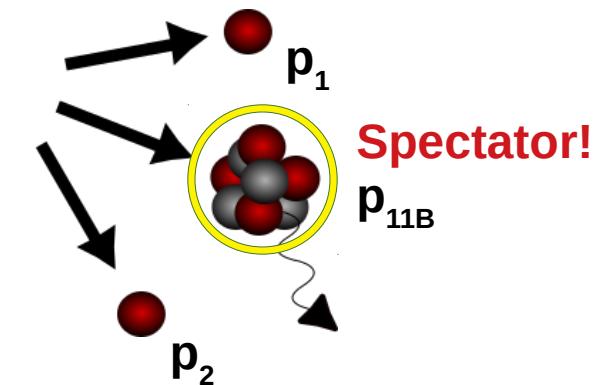


$$\mathbf{p}_i \approx \mathbf{p}_{\text{missing}} = \mathbf{p}_1 + \mathbf{p}_2 - \mathbf{p}_{\text{tg}} \quad (\text{no ISI/FSI})$$

Before Scattering:



After Scattering:

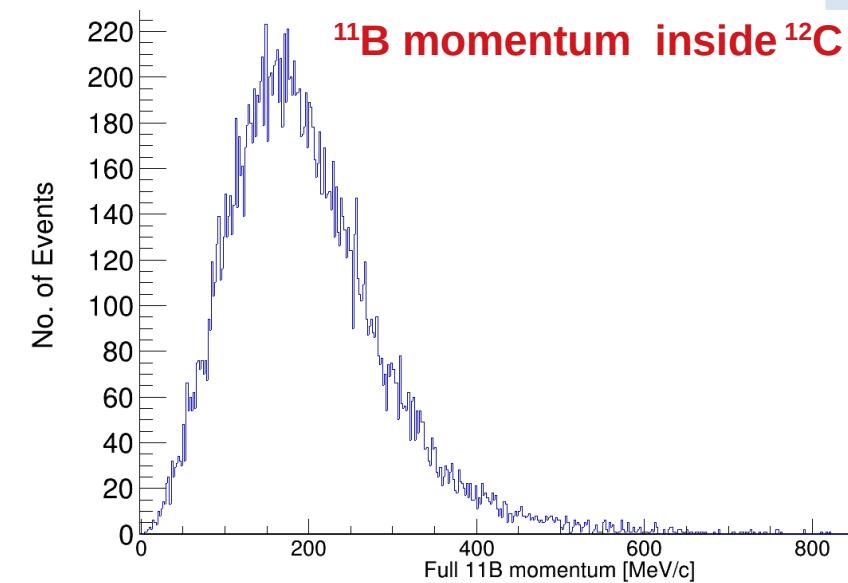


(Four-)Momentum conservation relation:

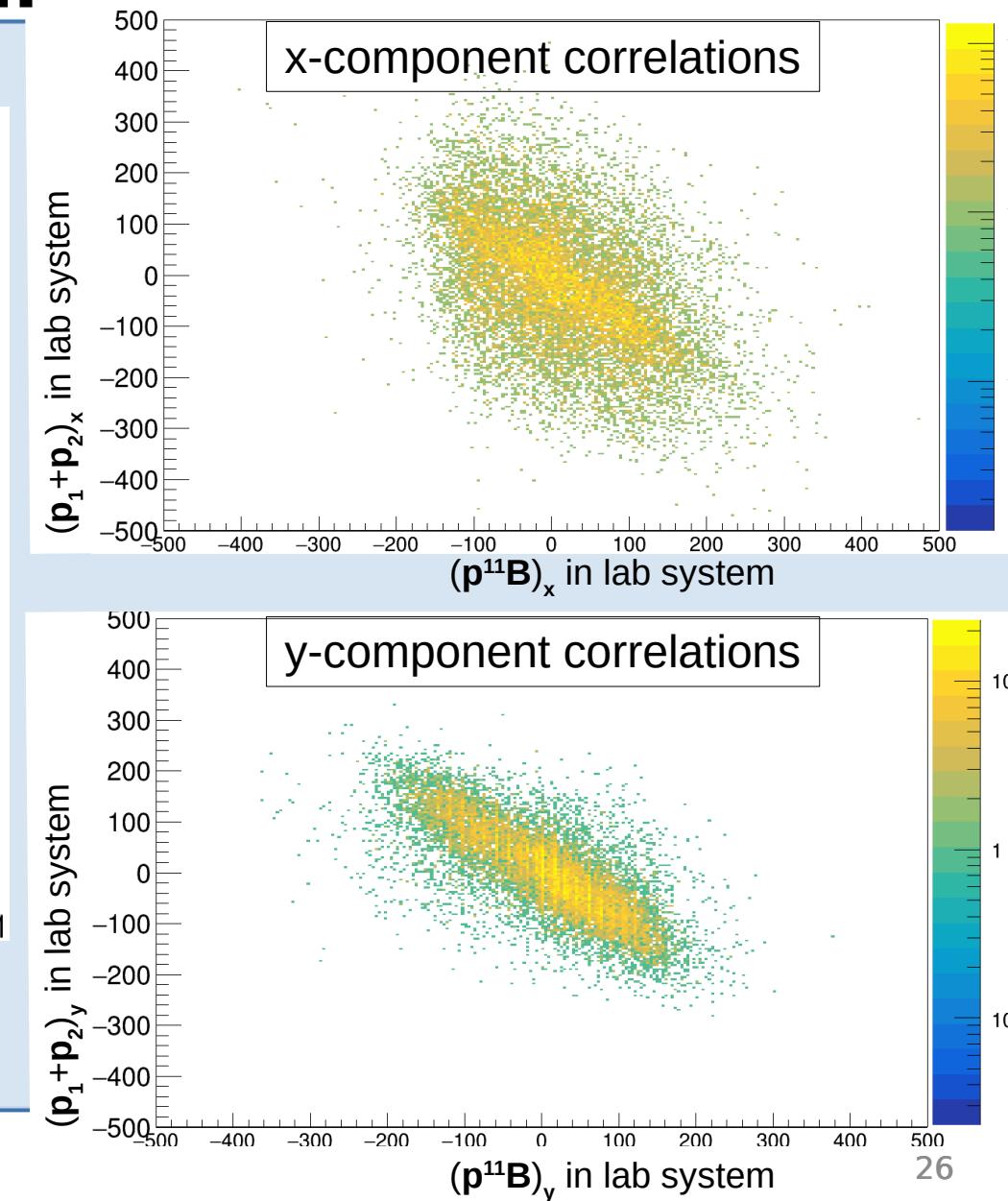
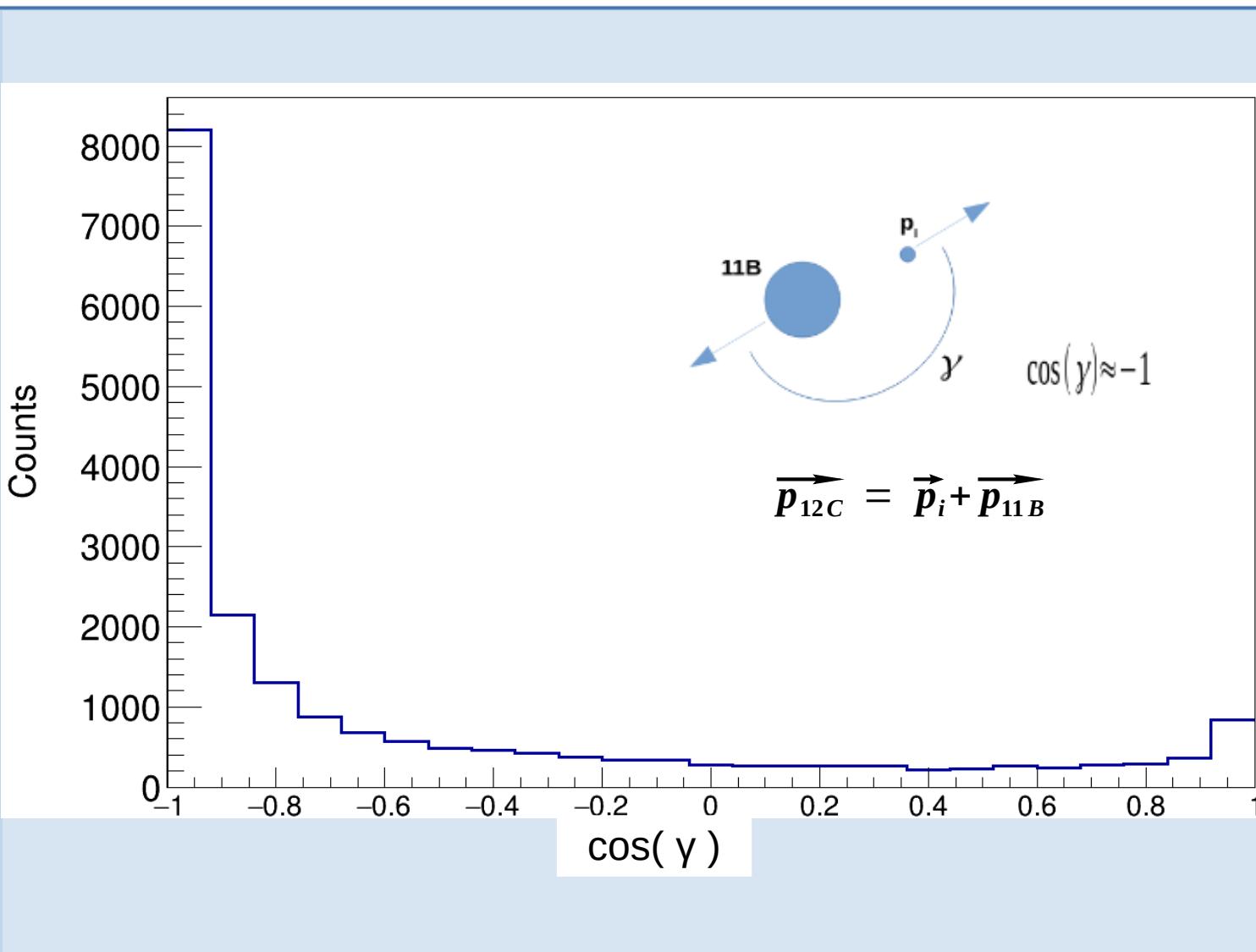
$$\mathbf{p}_{^{12}\text{C}} + \mathbf{p}_{\text{tg}} = \mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_{^{11}\text{B}}$$

assuming QE scattering in mean field potential:

$$\mathbf{p}_{^{12}\text{C}} = \mathbf{p}_i + \mathbf{p}_{^{11}\text{B}}$$



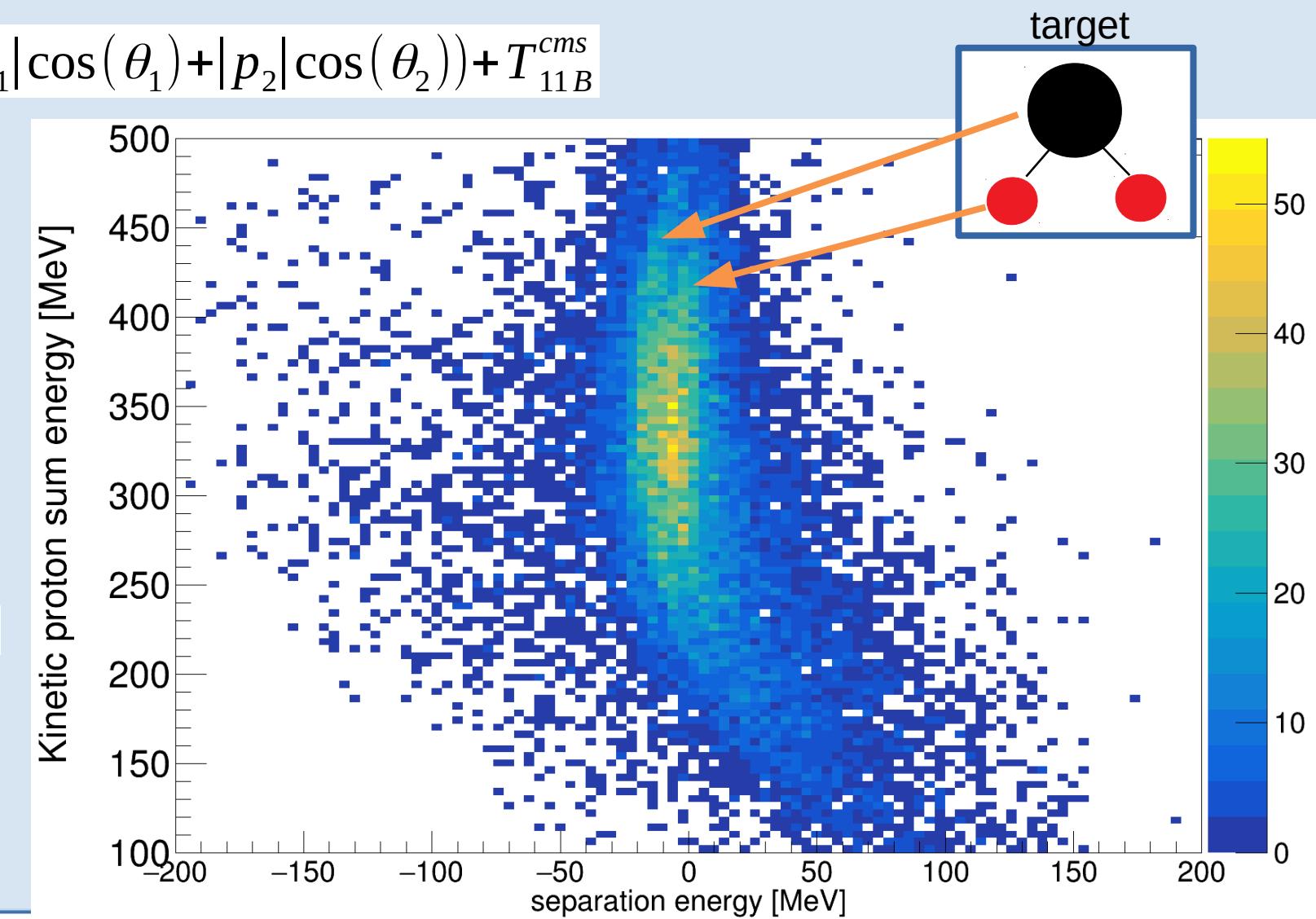
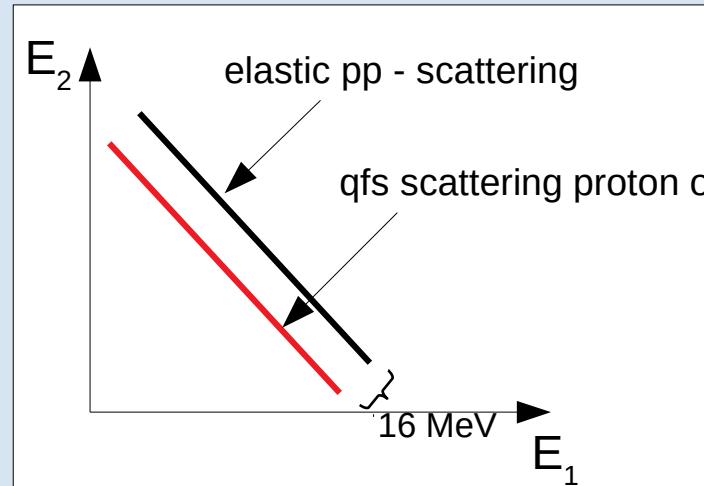
Correlations between Fragment and Proton Pair



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

S_p = Energy needed to remove one proton from the nucleus

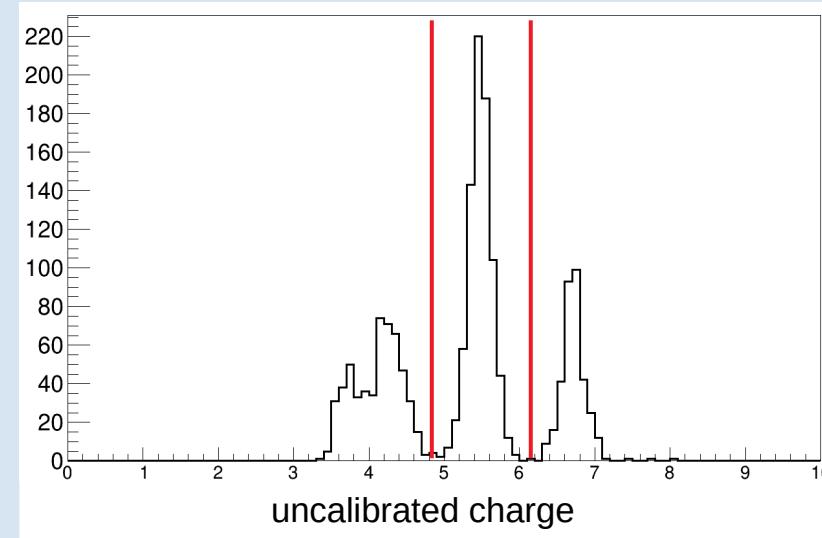
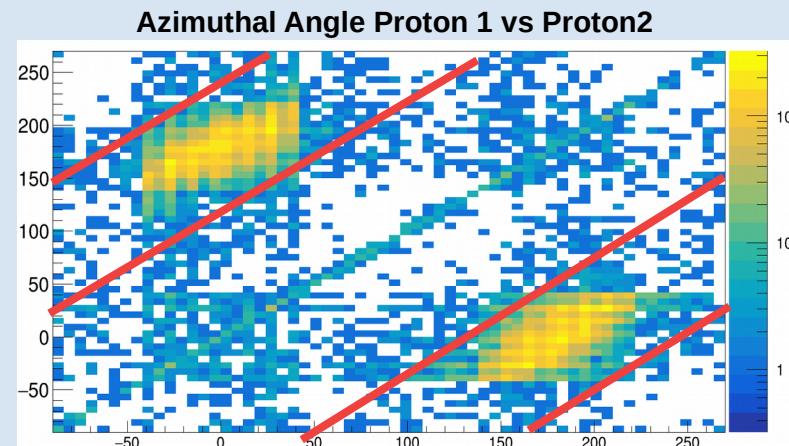
In direct kinematics it would be:



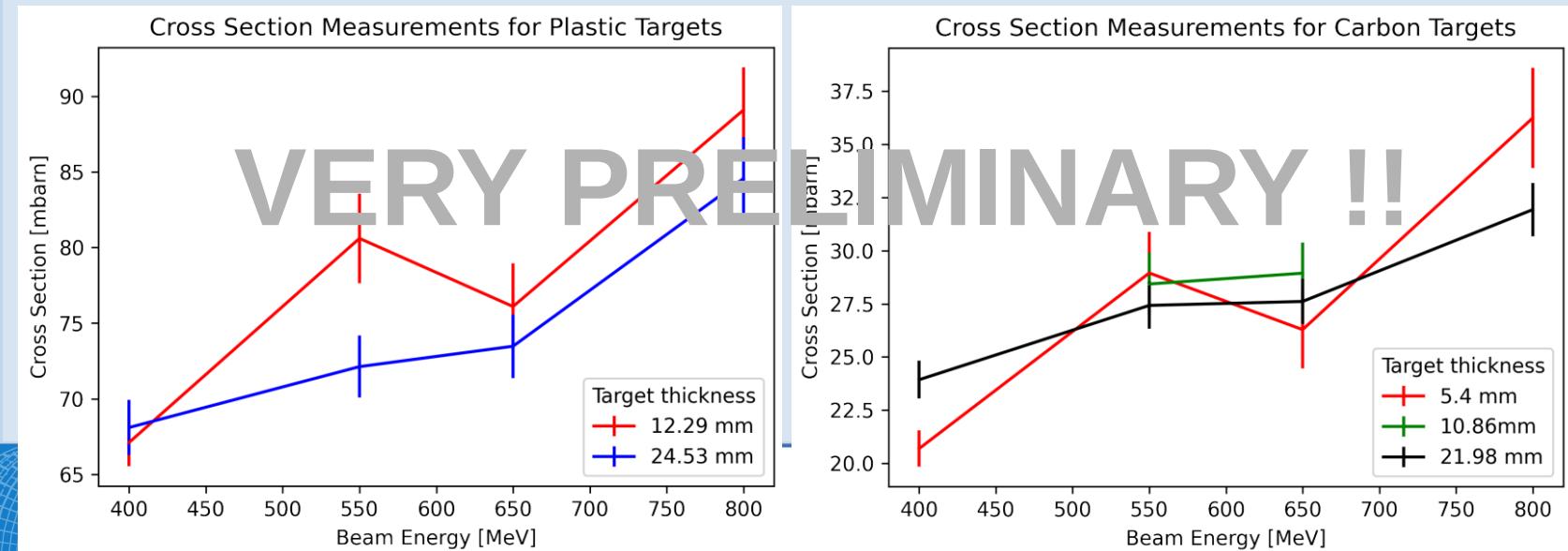
$^{12}\text{C}(\text{p},2\text{p})^{11}\text{B}/^{10}\text{B}$ Cross Section Measurements

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	CH ₂	Carbon
$^{12}\text{C}(\text{p}, 2\text{p})X$		81.5 ± 4.0	20.5 ± 1.9
$^{12}\text{C}(\text{p}, 2\text{p})^{11}\text{B}$		47.3 ± 3.3	11.1 ± 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:

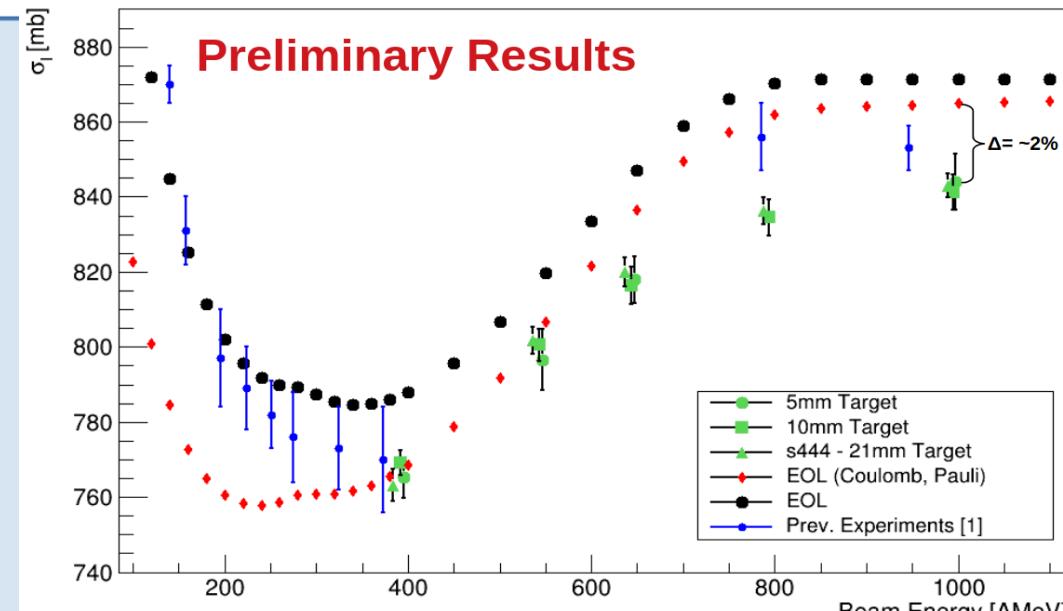
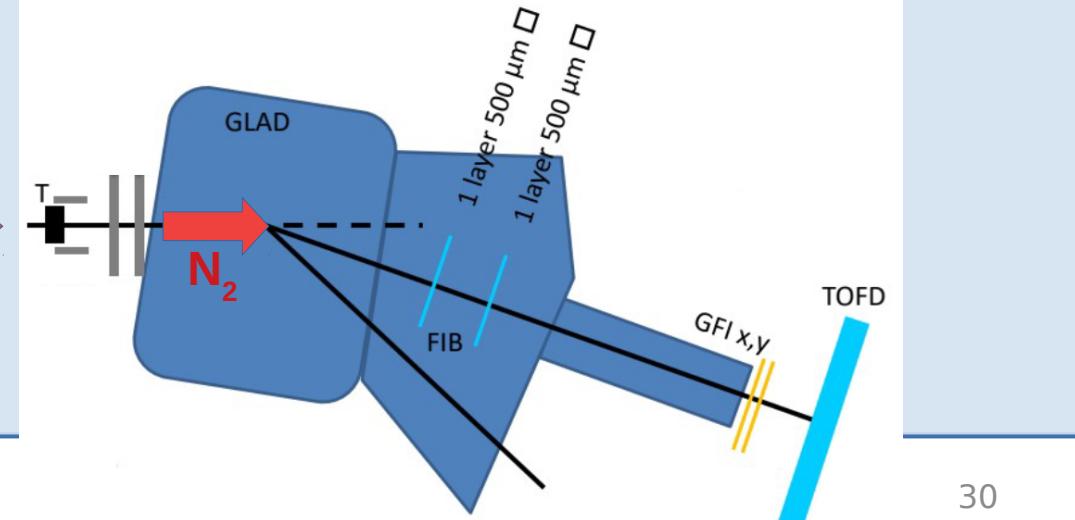
$$\frac{\frac{N_2^i}{N_1^i}}{\frac{N_2^o}{N_1^o}} = e^{-N_t \cdot \sigma_R}$$

Target-In Target-Out

Using the Transmission Method:

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

N_1 →

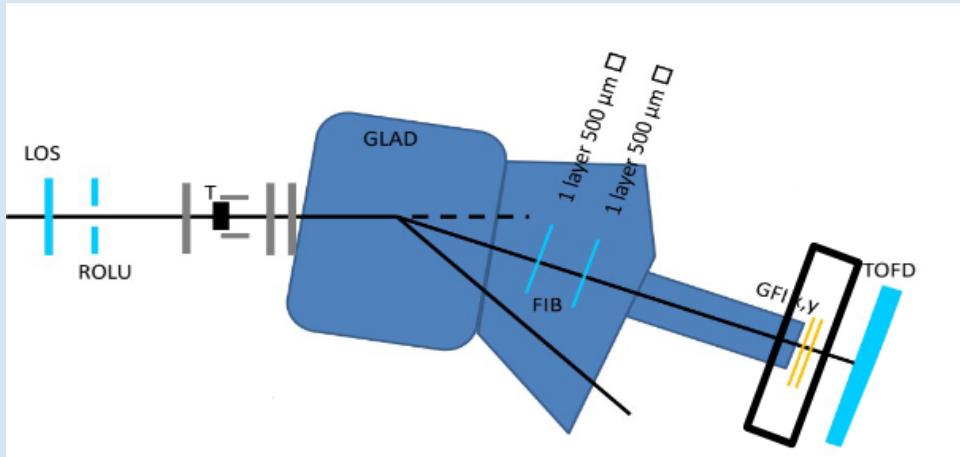


[1] I.Tanigata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009), A. Ozawa et al. (Nuc. Phys. A – 691 2001)

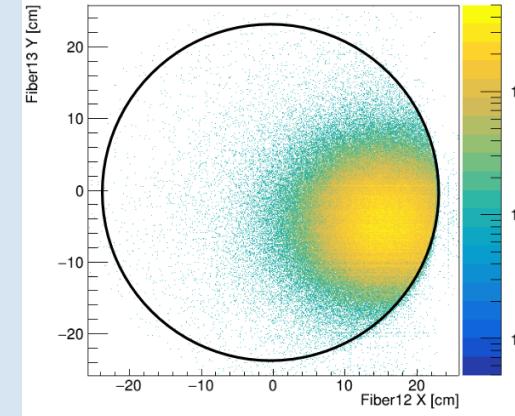
EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)

Comparing the two Setups

Setup - Lukas

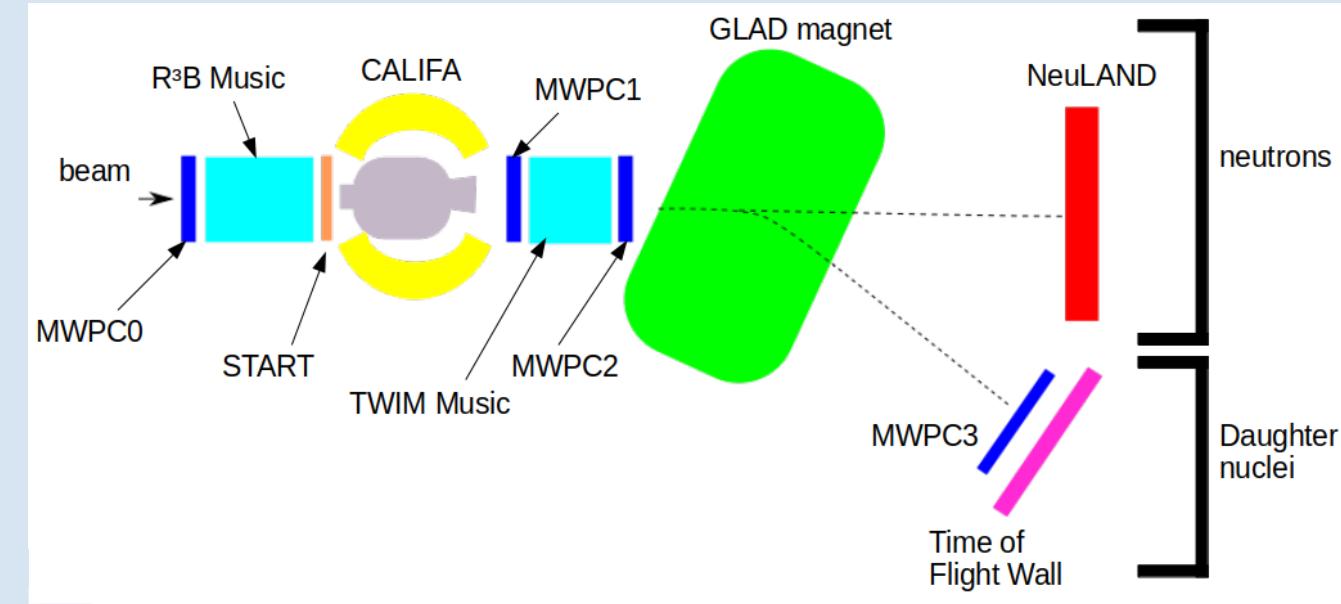


Acceptance issues
due to the beam
pipe confinement



Fine tuned acceptance corrections
needed

S444 (2020) Setup → with carbon target



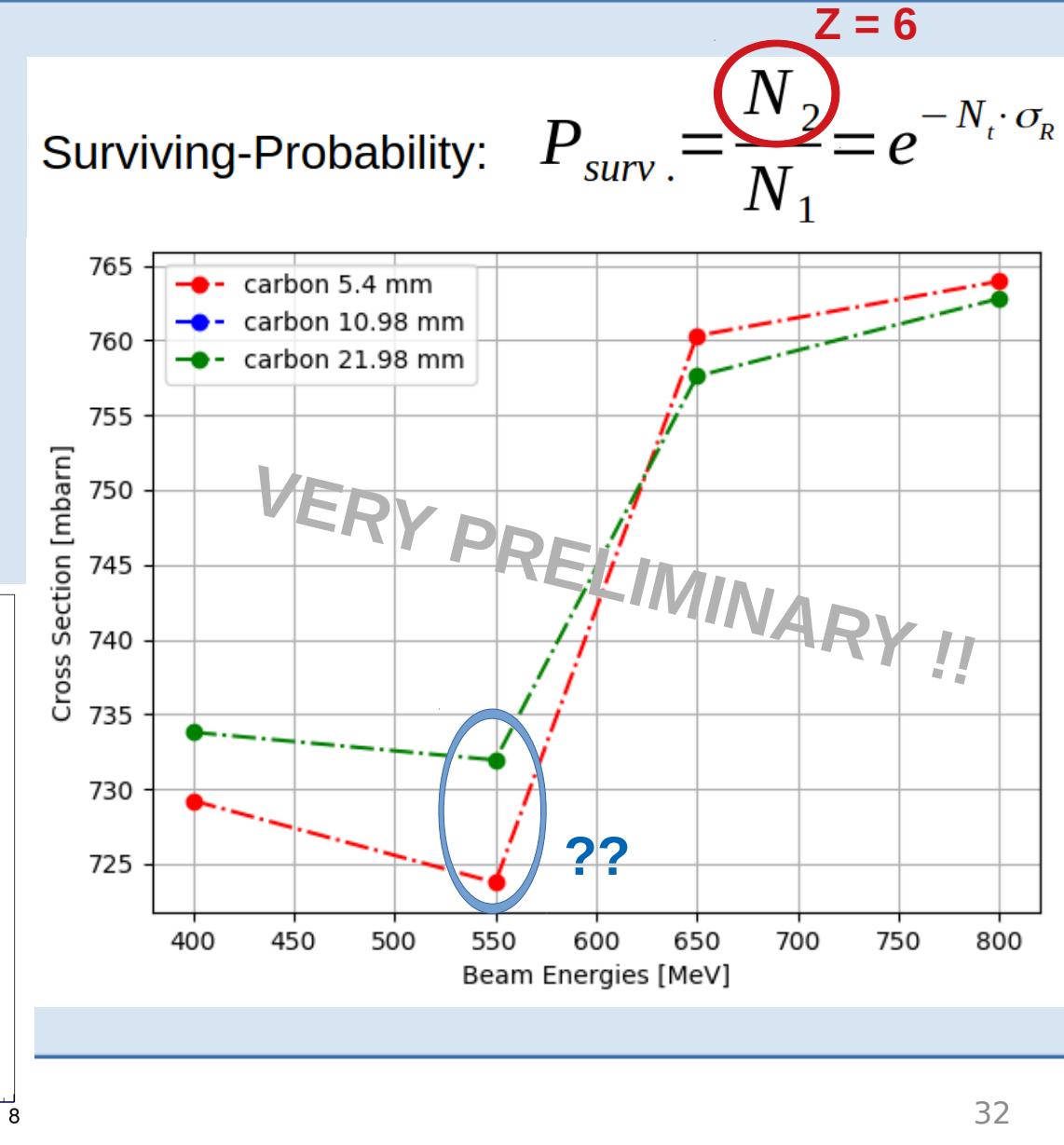
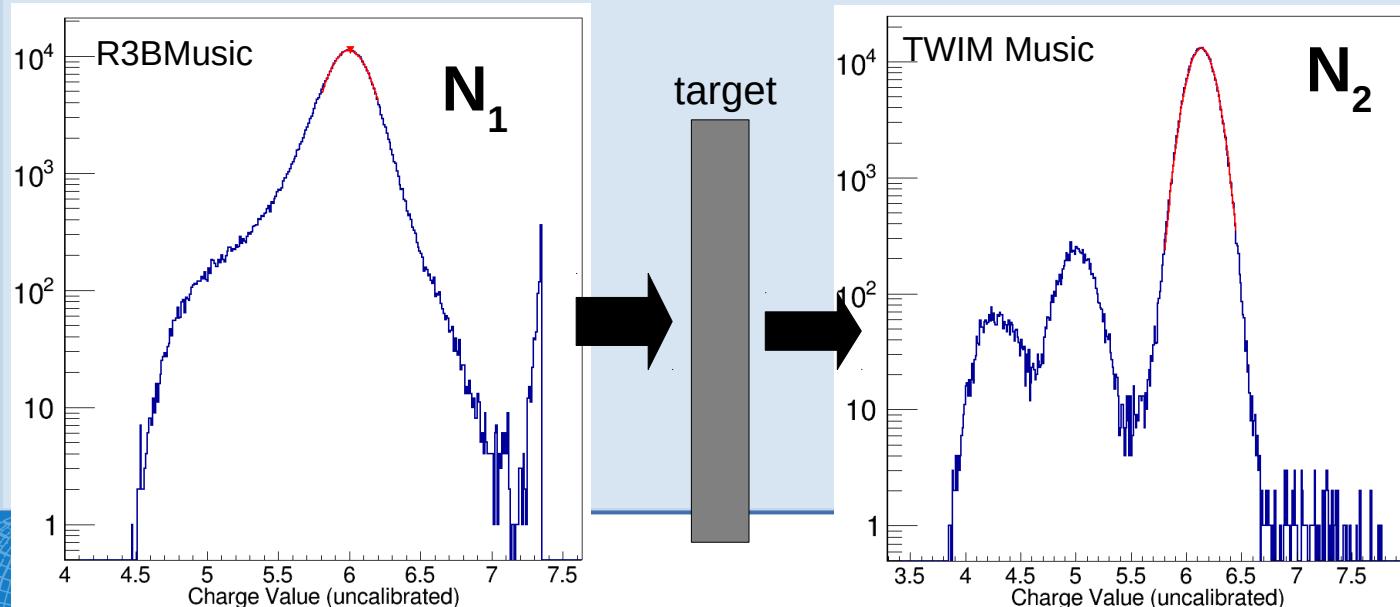
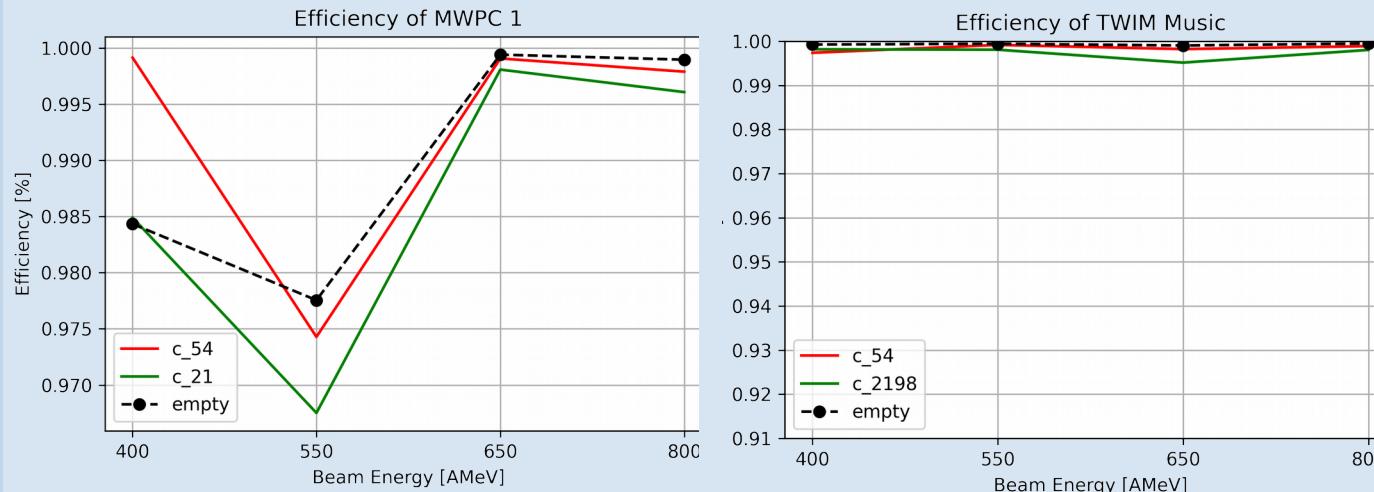
High acceptance:

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

Convenient setup to compare with Lukas' results

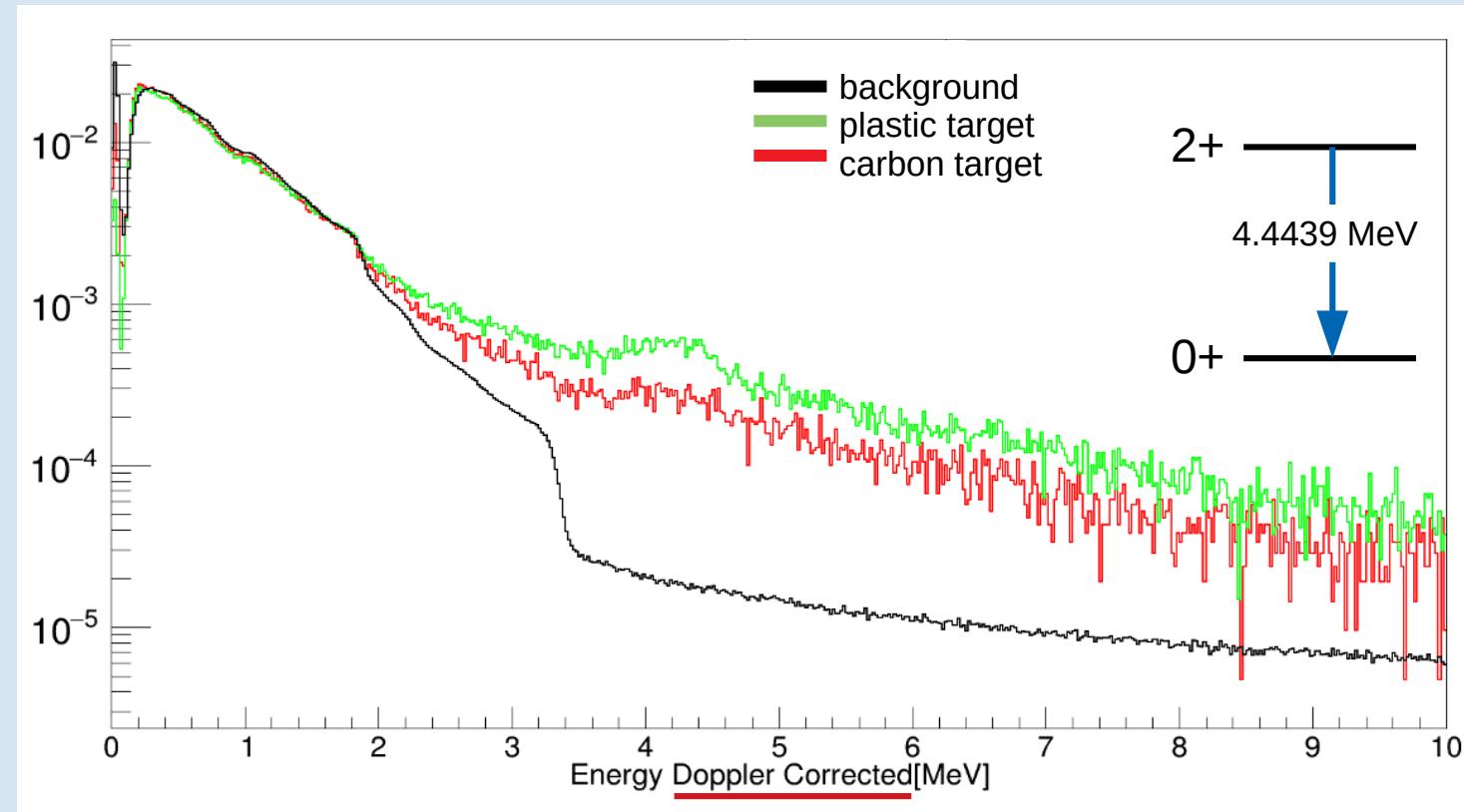
Starting with Charge Changing Cross Section

Why not starting directly with total reaction cross section measurement?



What more ?

^{12}C - ^{12}C inelastic reaction



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

