R3B Experiments with Final CALIFA Setup

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PSI Seminar 07.06.2023

R3B Setup

CALIFA Status & Final Configuration

Physics in R3B with CALIFA

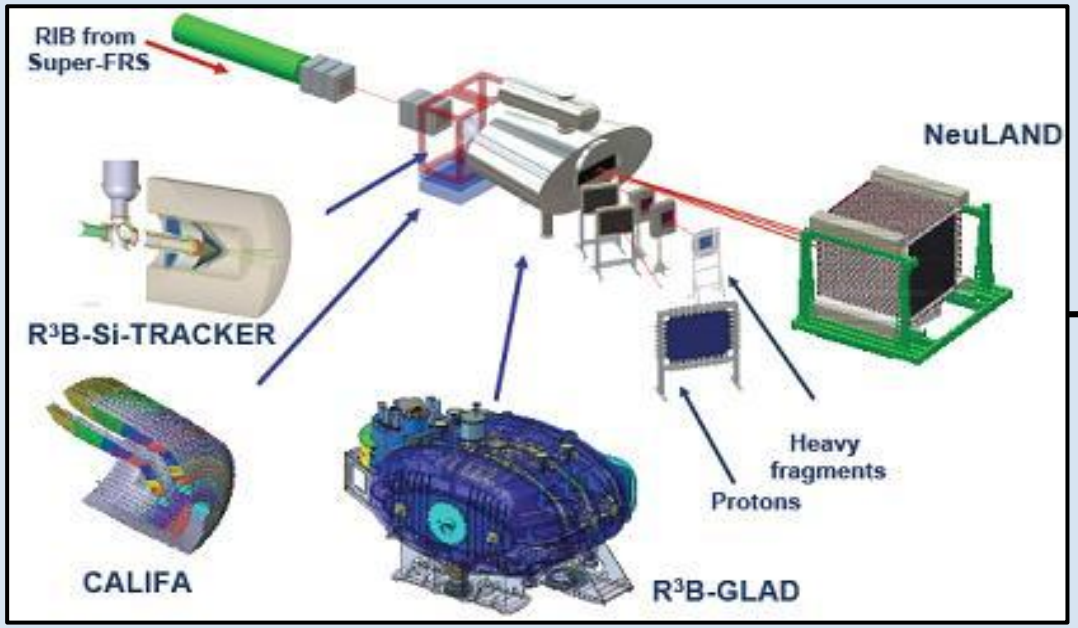
Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2094 – 390783311,
BMBF 05P19WOFN1, 05P21WOFN1
and the FAIR Phase-0 program

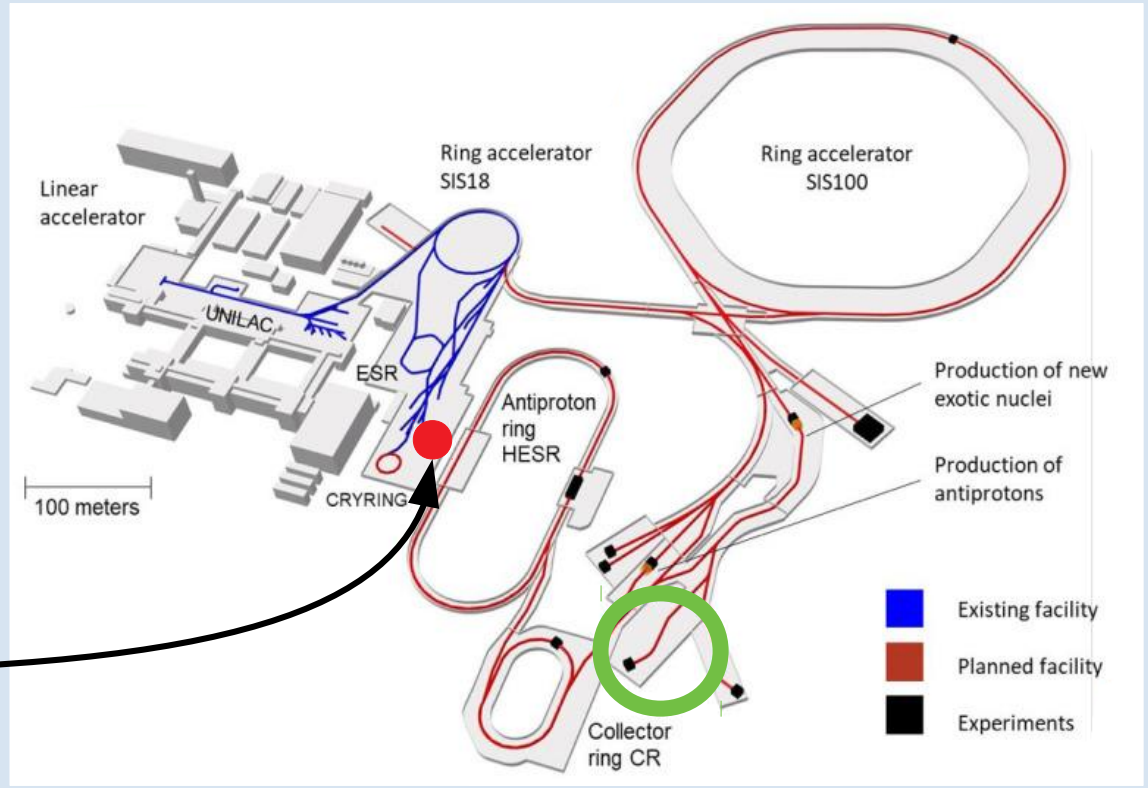
TUM Members:
Roman Gernhäuser,Lukas Ponnath,Philipp Klenze, Stefan Eder,Tobias Jenegger

R³B @ GSI

R³B as part of the
Facility for **A**ntiproton and **I**on **R**esearch (**FAIR**)
in Darmstadt:

Reactions with **R**adioactive **R**elativistic **B**eams





Haik Simon – FAIR & Super-FRS – EPS 20190930

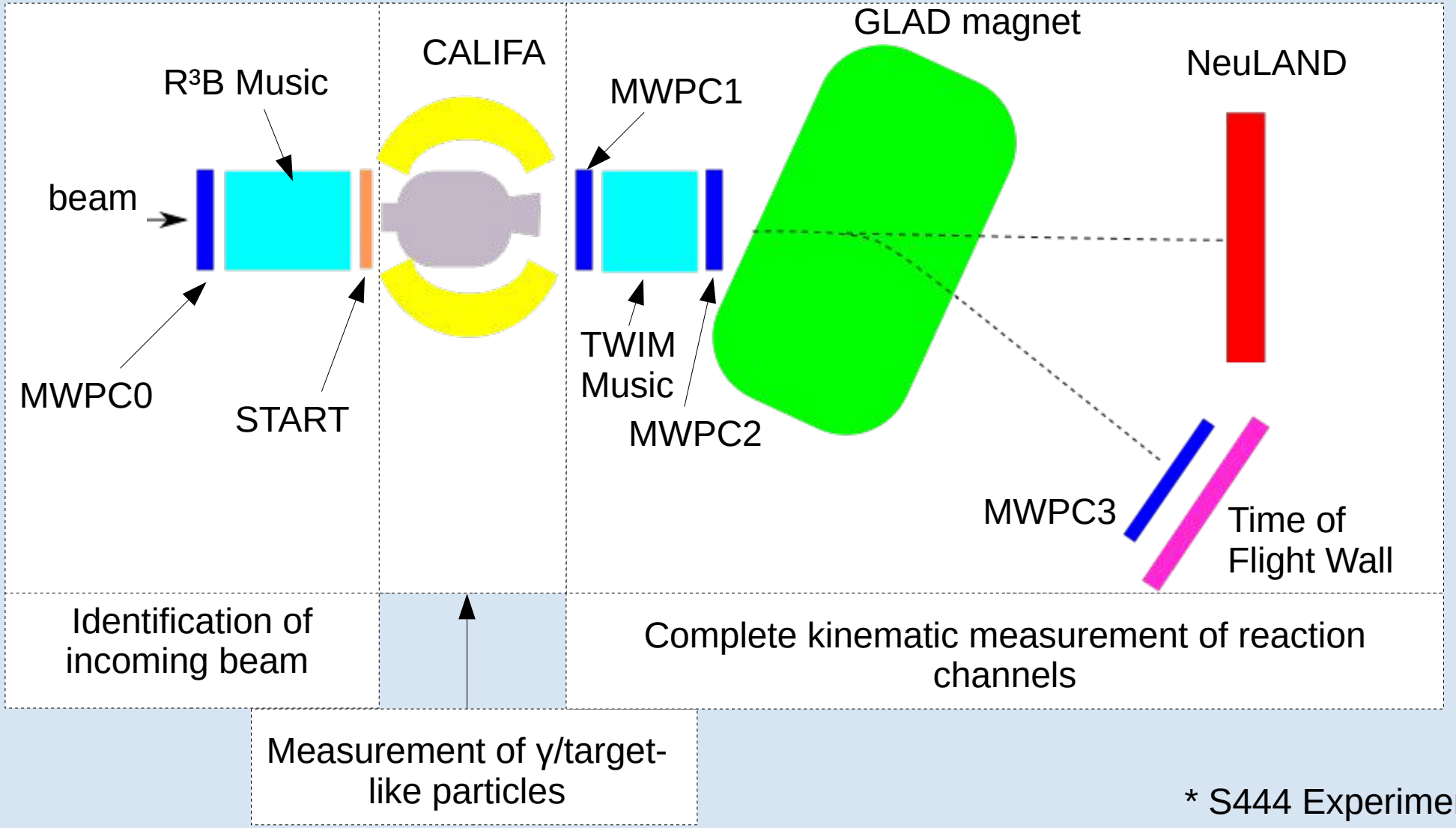
R³B @ GSI

© D. Fehrenz, GSI/FAIR, May 2023

High Energy Cave

Dimensions: 60 x 20 x 7 m

R3B Setup*



* S444 Experiment, 2020

CALIFA Detector @ R³B

CALorimeter for the **I**n **F**light detection of γ-rays and light charged p**A**rticles

Endcap:

iPhos:

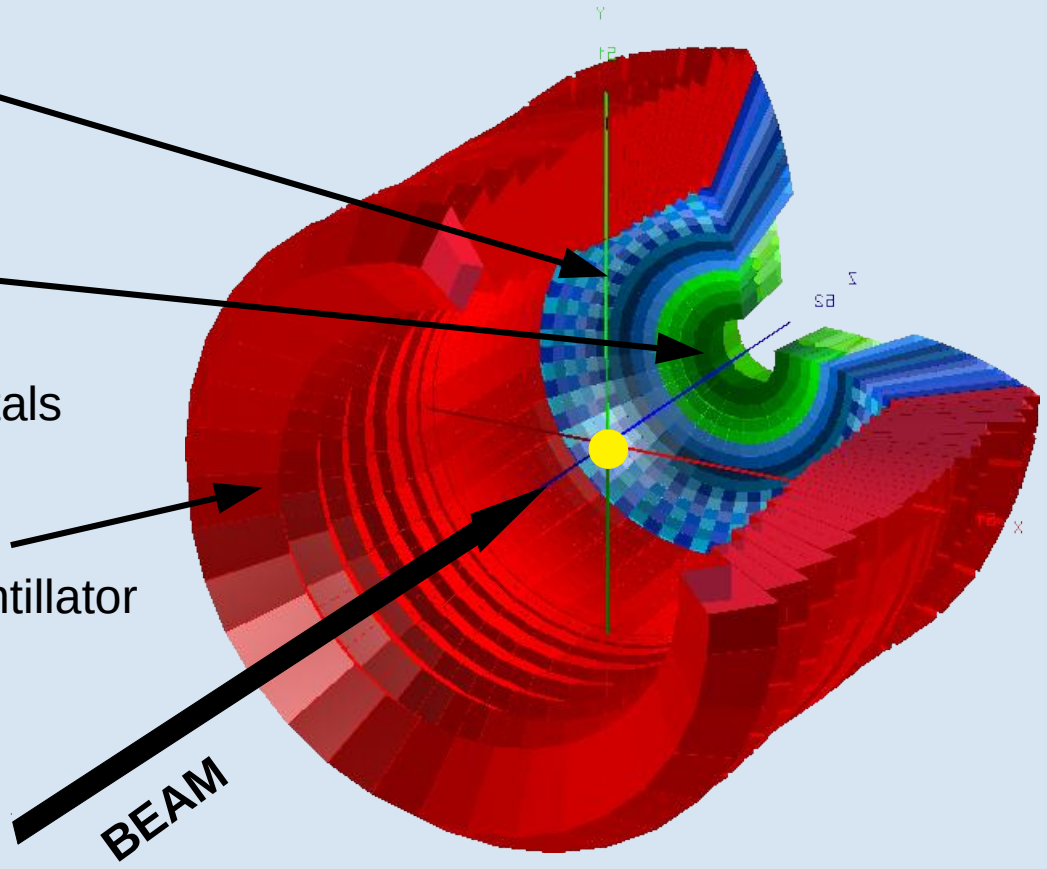
512 CsI(Tl) crystals

CEPA:

96 LaBr3 & LaCl3 crystals

Barrel:

1952 CsI(Tl) scintillator crystals



Highly segmented detector:

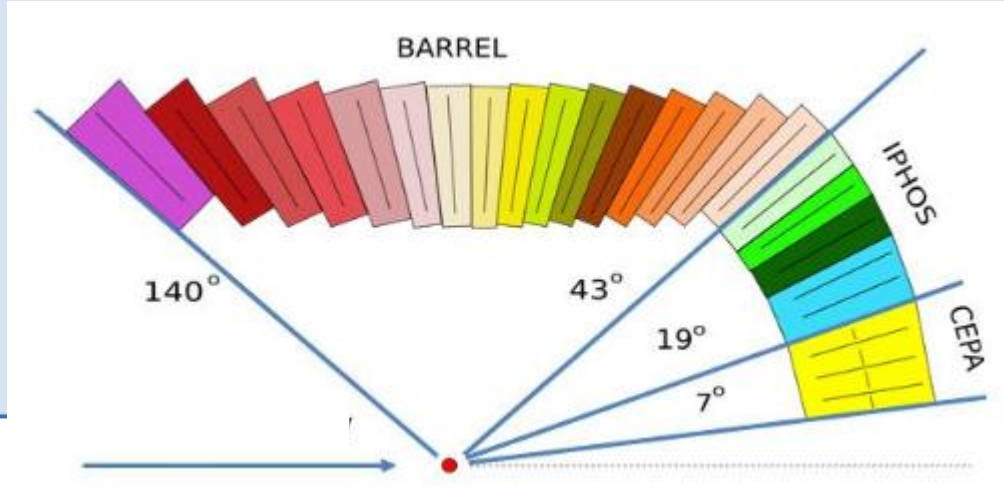
- ➔ good angular reconstruction/ doppler correction

Broad calorimetric energy measurements:

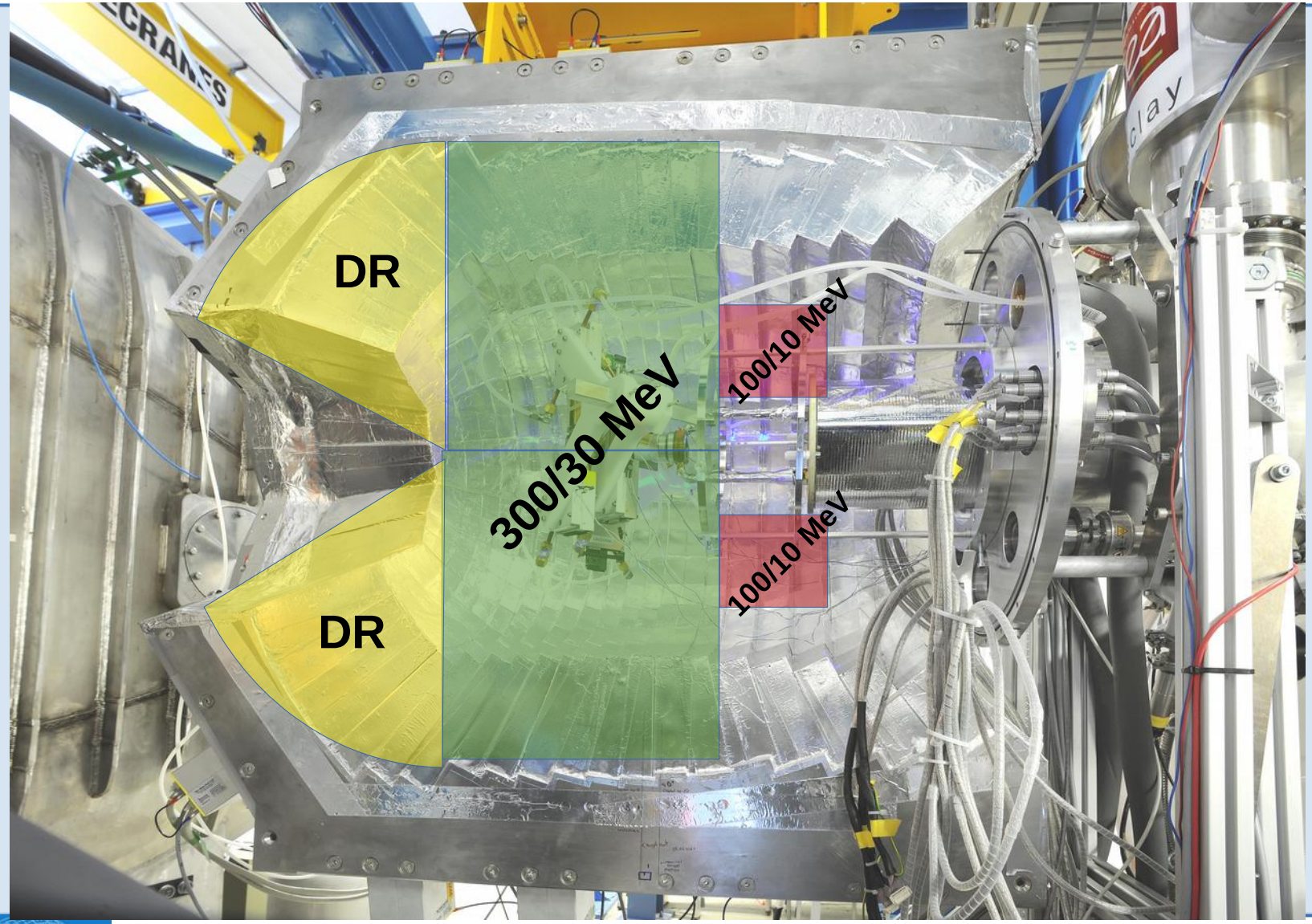
- ➔ From 100 keV γ-rays up to high energetic charged particles

Flexible running mode:

- self/external triggering mode



CALIFA Configuration (S522, 2022)



iPhos:

- completely filled
- readout with Dual Range Preamps

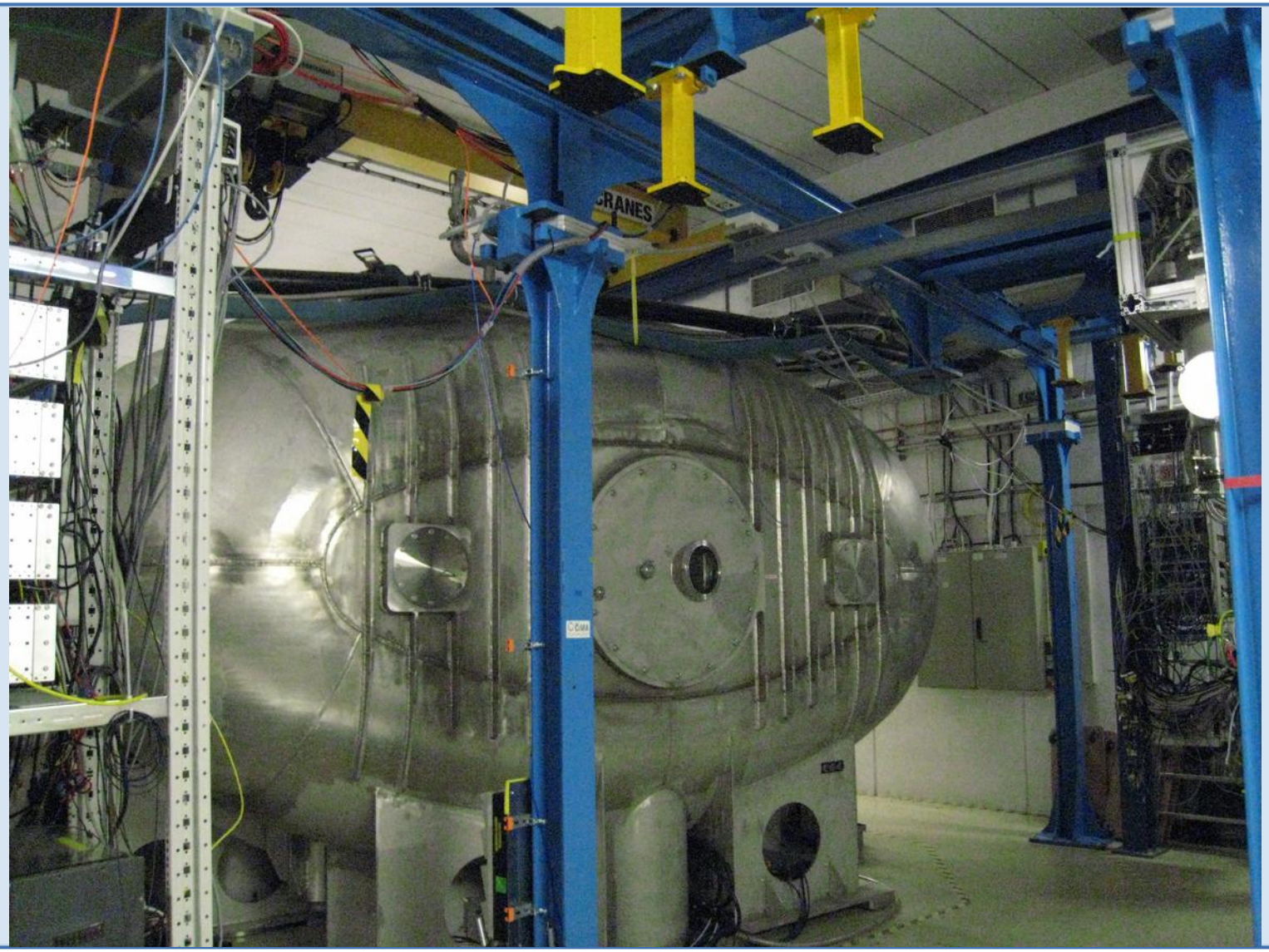
Barrel:

- Half filled (Ring 3&4)
- Readout with Single Range (300/30 MeV) Preamps

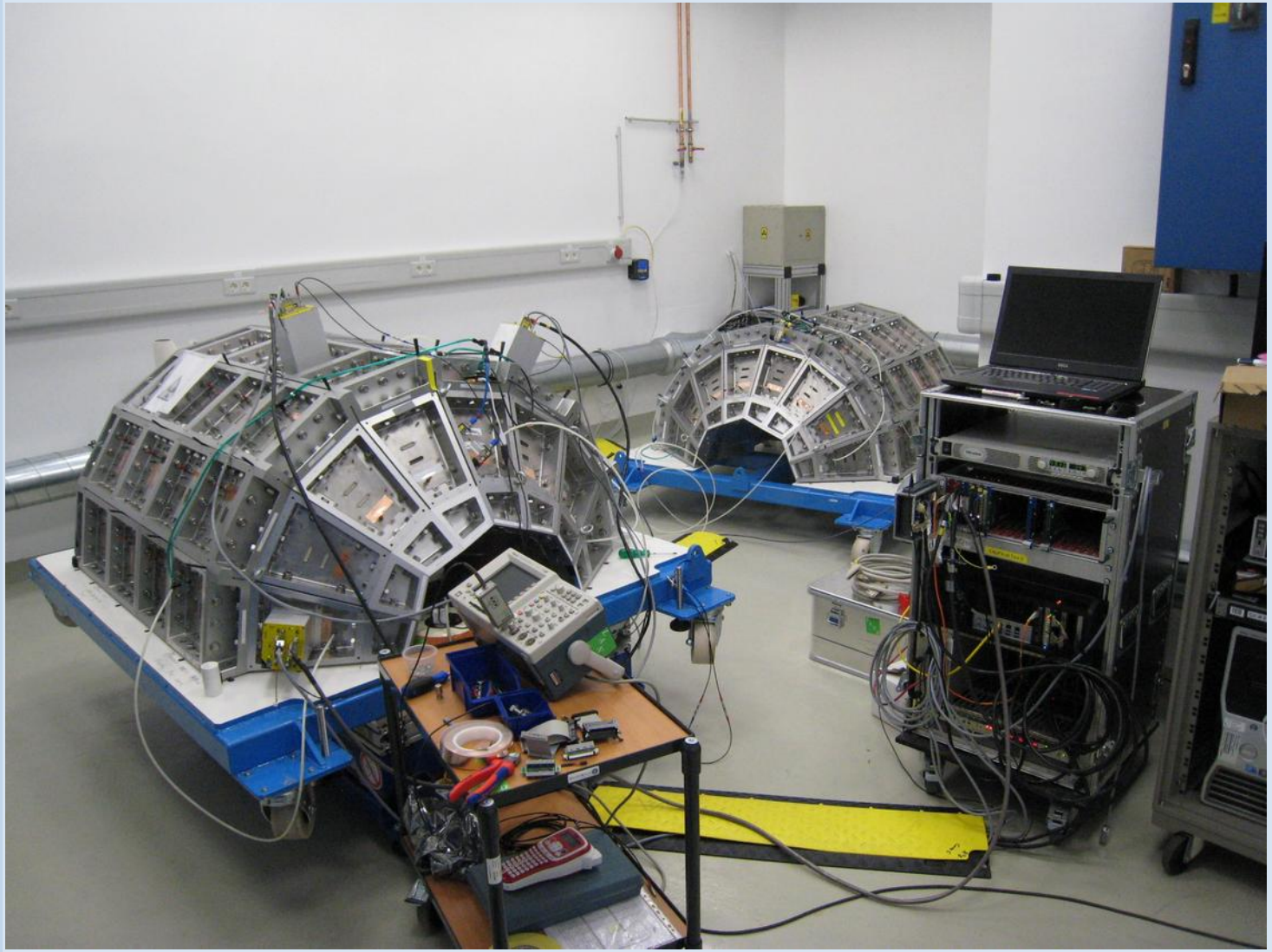
Pulser:

- 2 SR 100/10 MeV Preamps
- For deadtime/sync checking

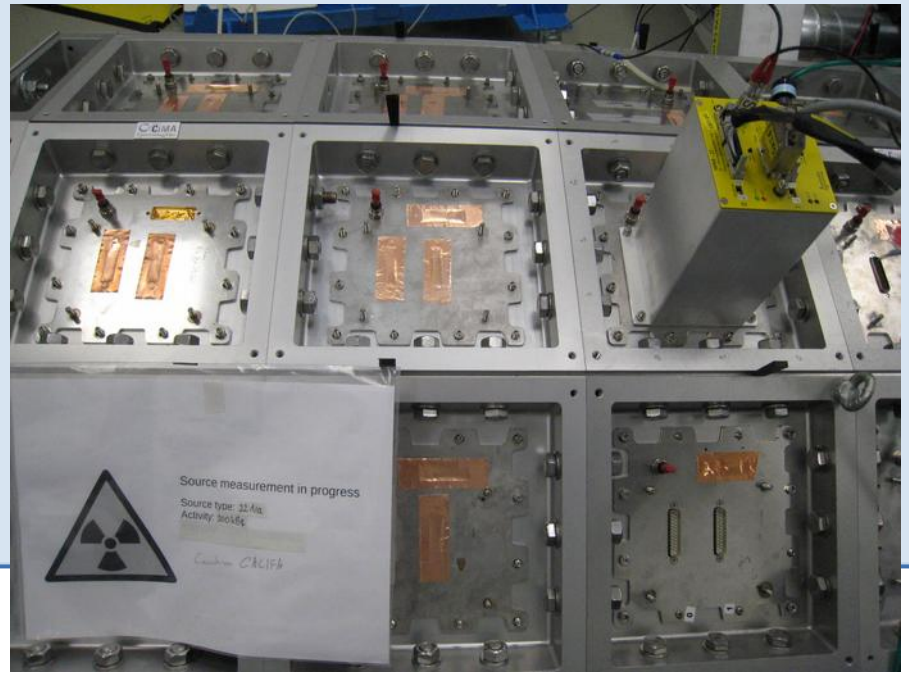
BUT where is CALIFA now?



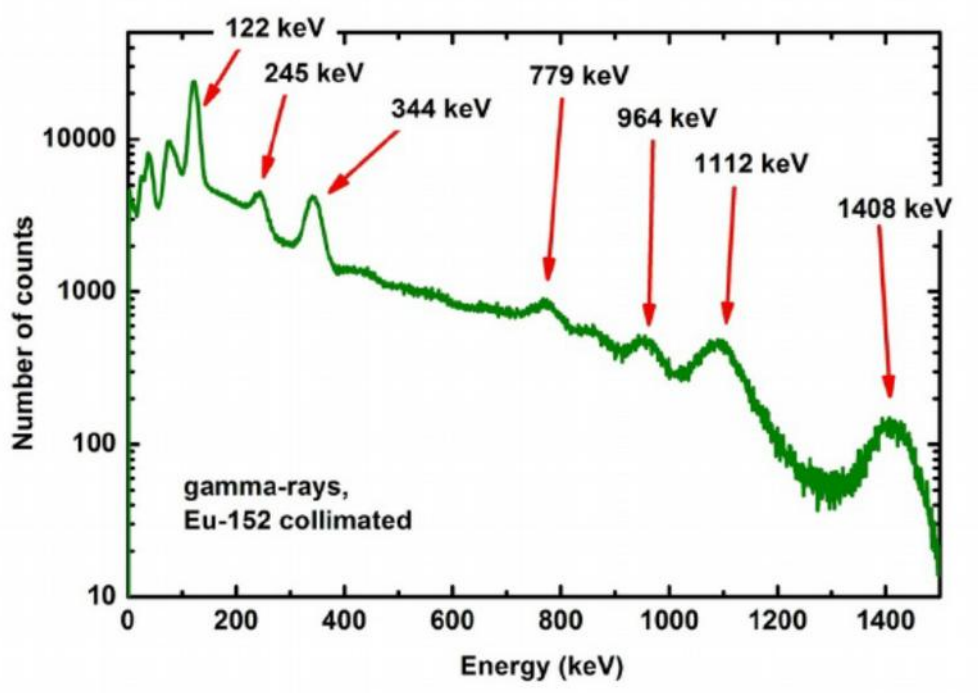
Meanwhile in R³B Preparation ROOM ….

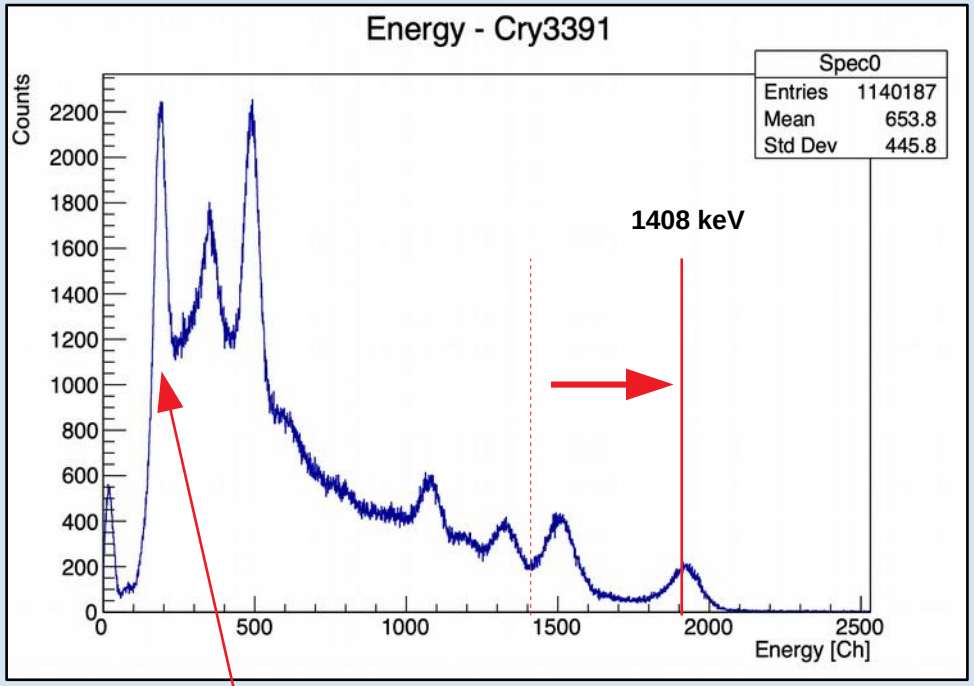


- Noise debugging
- Cable/connectors checking
- SR vs DR checks



Testing Gain



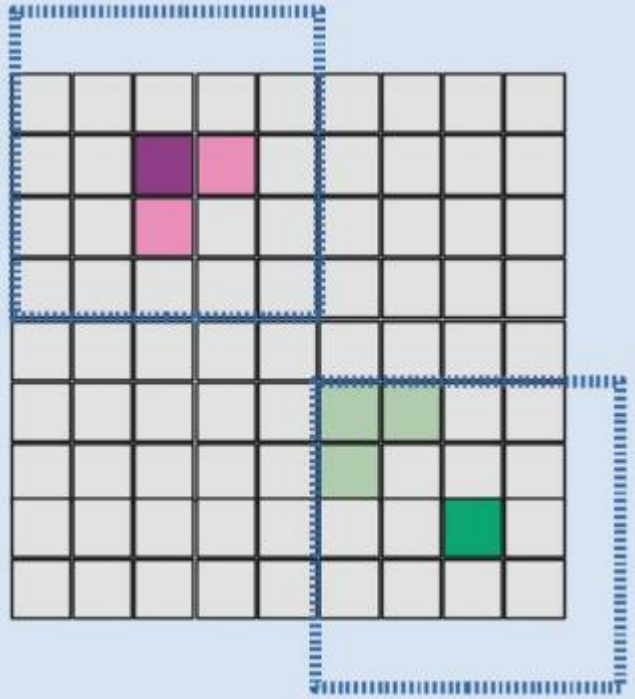


Raising the gain allows to measure down to the **122 keV** peak!

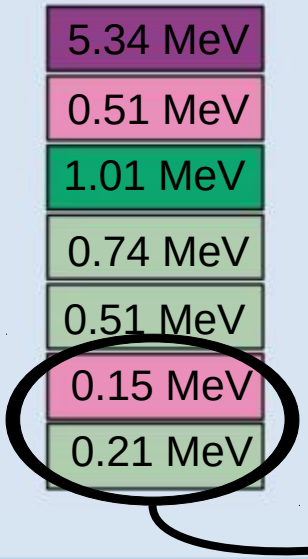
Higher gain leads to better resolution (but reducing the energy-range)
Lower threshold values are possible → crucial for **add-back** algorithm!

Add-Back Algorithm in CALIFA

User defines shape and size of cluster:



Sort the hit list according to their energy



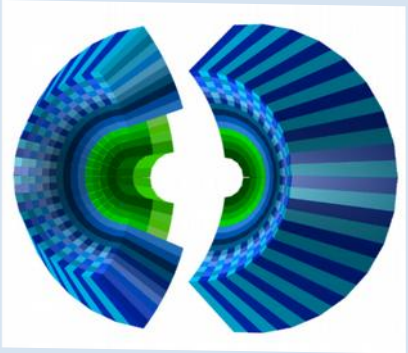
1. create cluster centered around first hit
2. loop over all hits in list
   → if hit inside cluster add it and remove it from the list
3. Do this procedure until list is empty

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

Filling CALIFA Endcap - CEPA

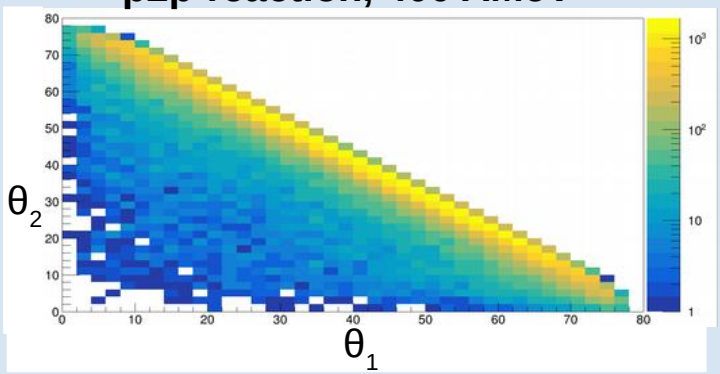
CALIFA **E**ndcap **P**hoswich **A**rray

- Most forward section: 7° ≤ θ ≤ 19°
- 96 CsI crystals

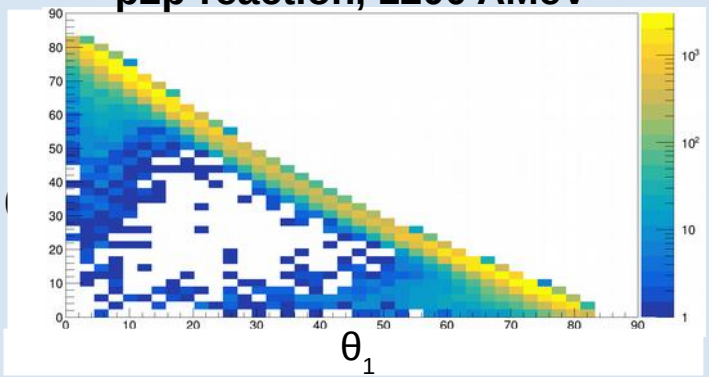


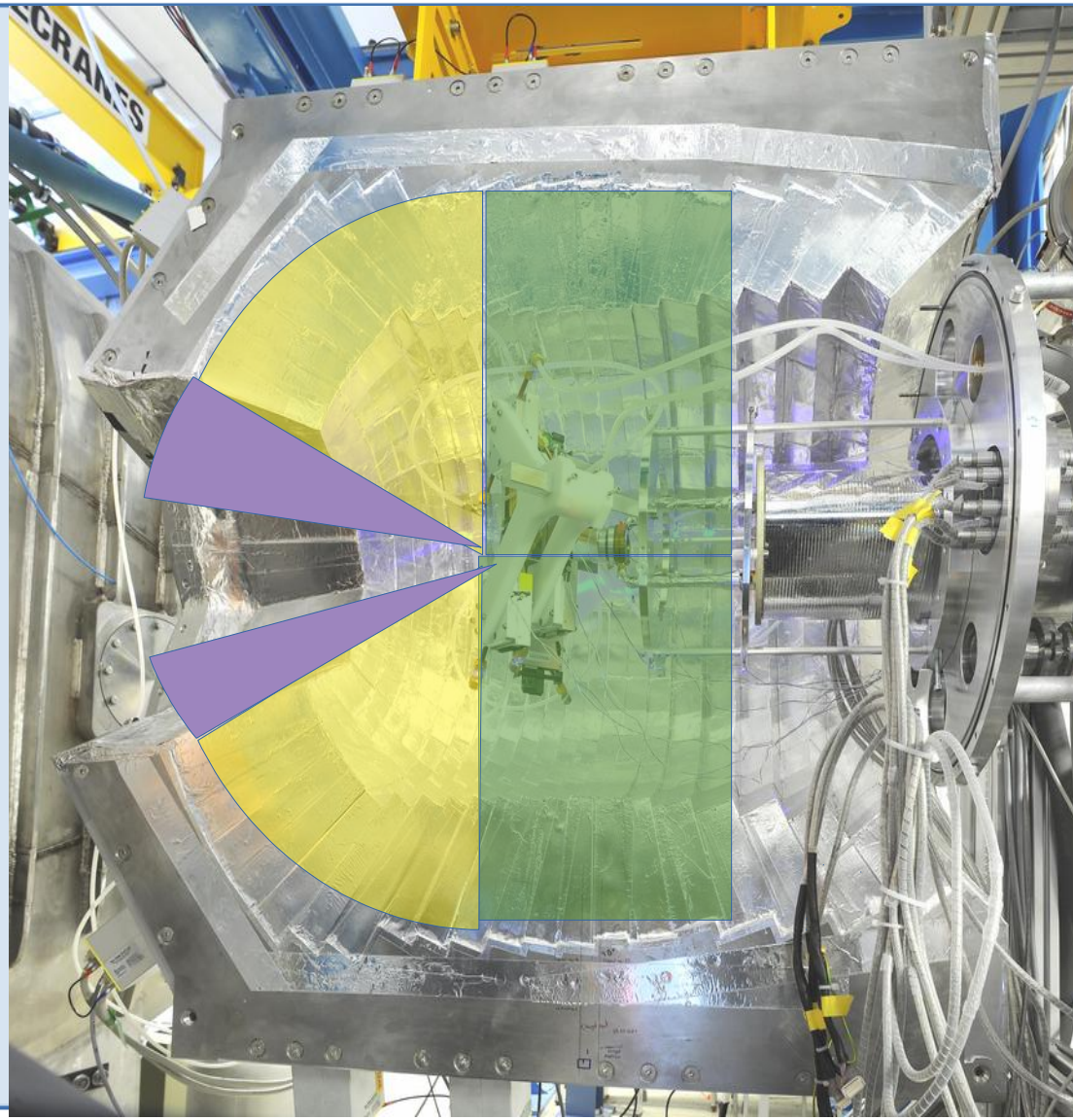
Improves geometric acceptance for high beam energies drastically

p2p-reaction, 400 AMeV



p2p-reaction, 1200 AMeV

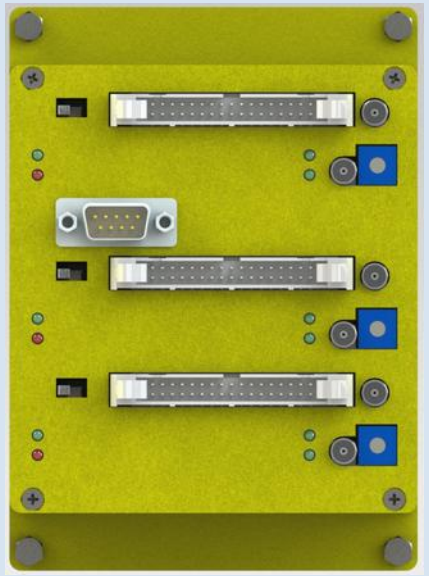




Filling CEPA

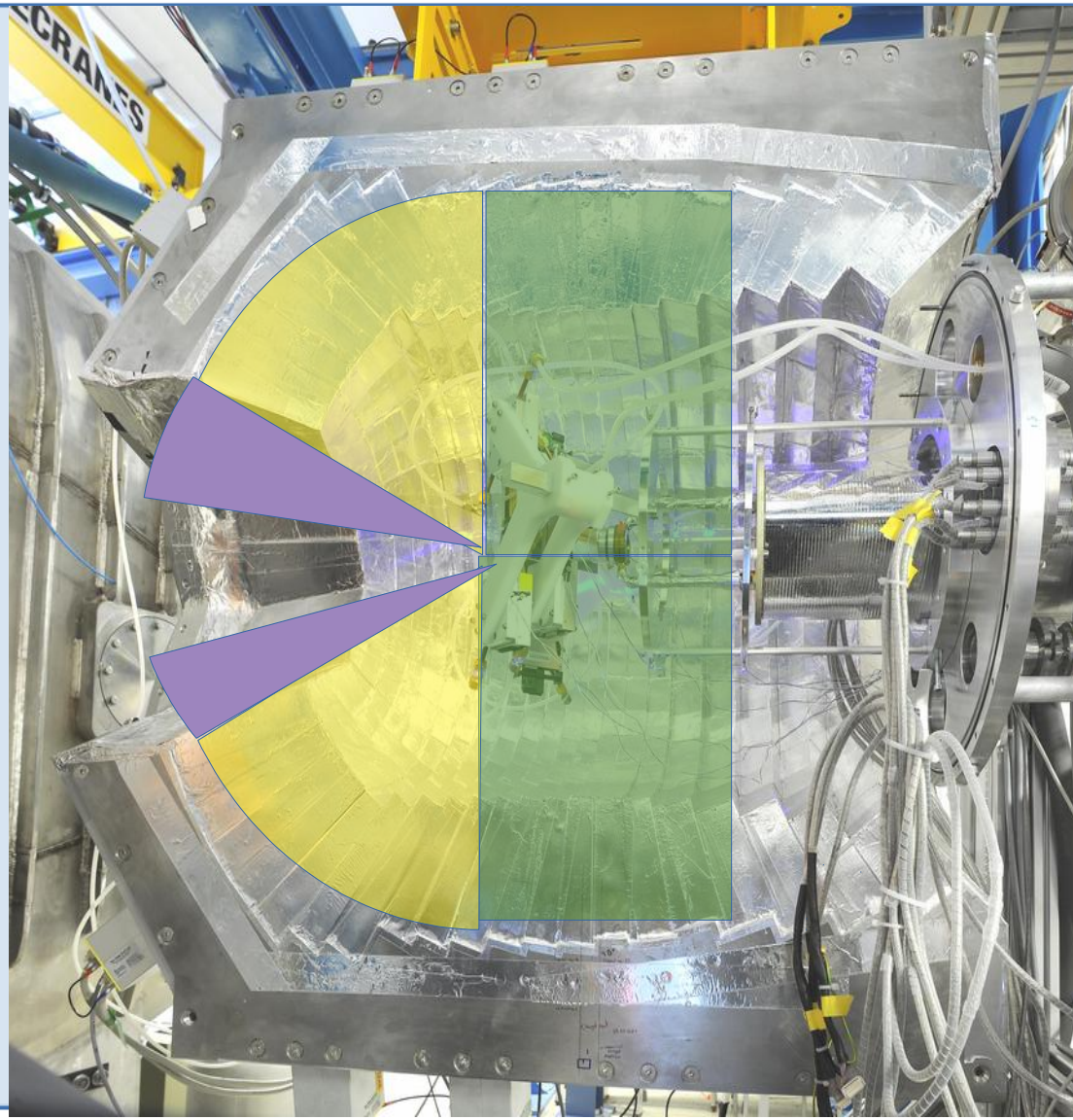
Mesytec MPRB-48 Dual Range Preamps

They get mounted on iPhos tiles

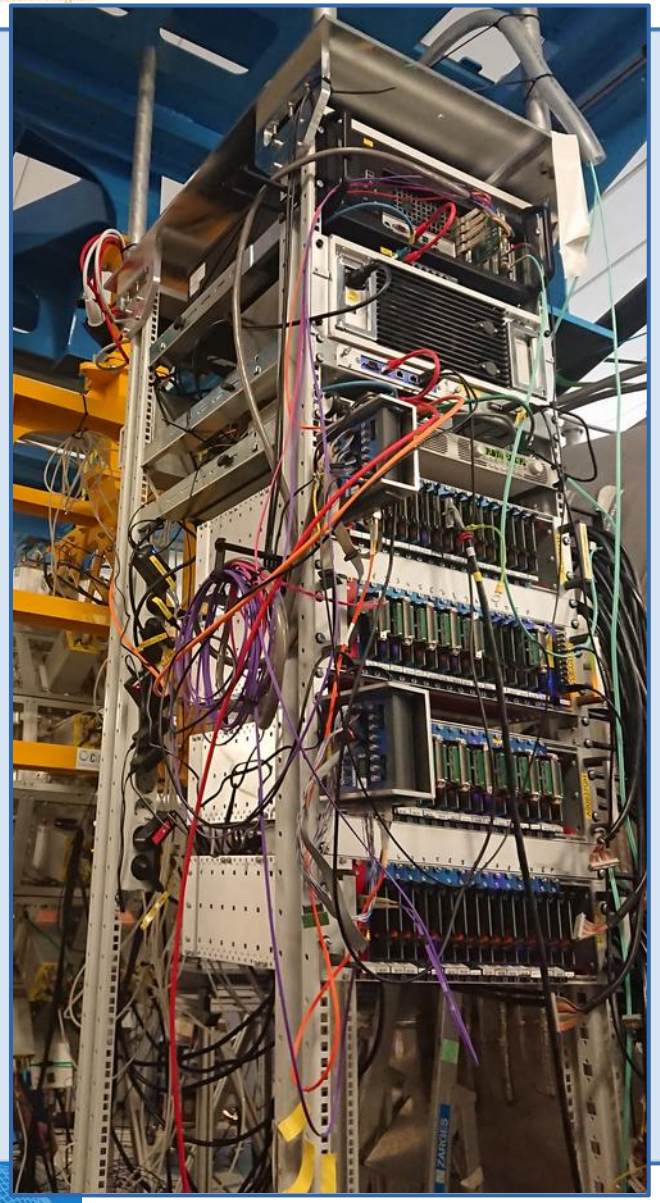


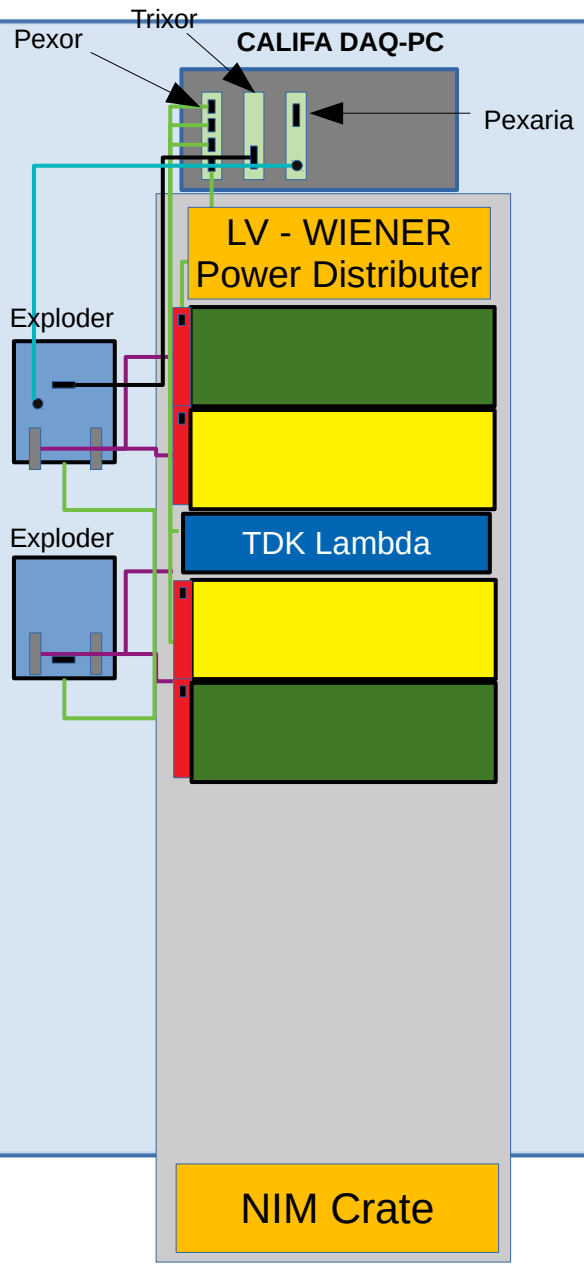
Connected to iPhos APDs
(32 channels)

Connected to CEPA APDs
(16 channels)



CALIFA DAQ Status (S522, 2022)



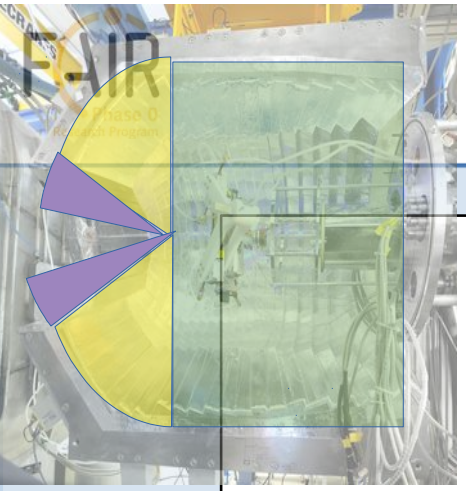


Electronic Rack

- 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

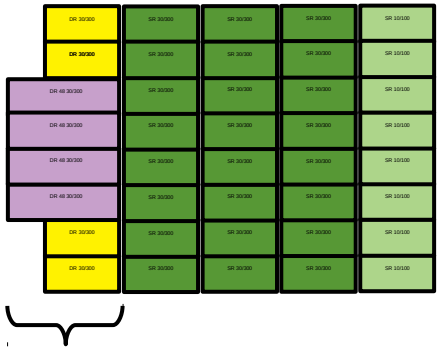
Cables

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

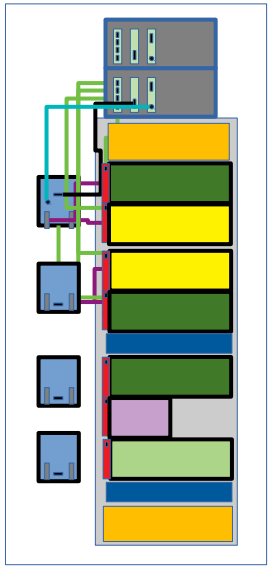


Possible Electronic Configurations

Default Config.



DR Preamplifiers

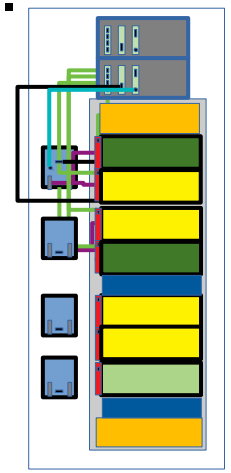


As planned

Issues with punch through at 42-60°

4π Config.

DR Preamplifiers



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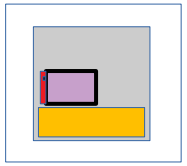
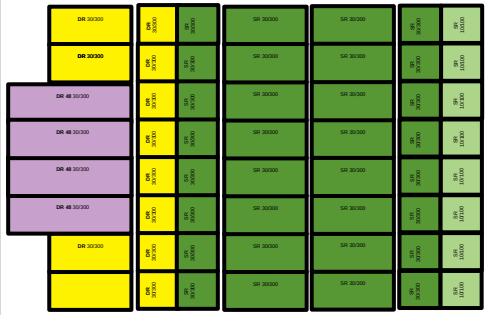


All features in - 4π save

More data, less spares

Mixed Config.



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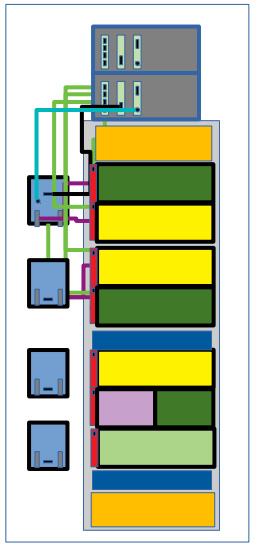
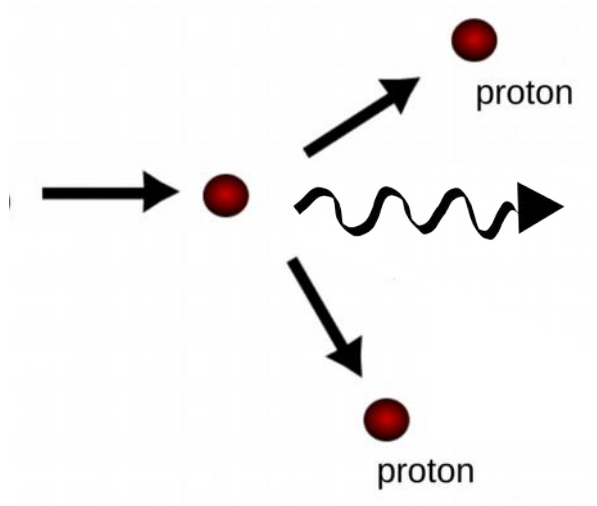


All features in - 4π save

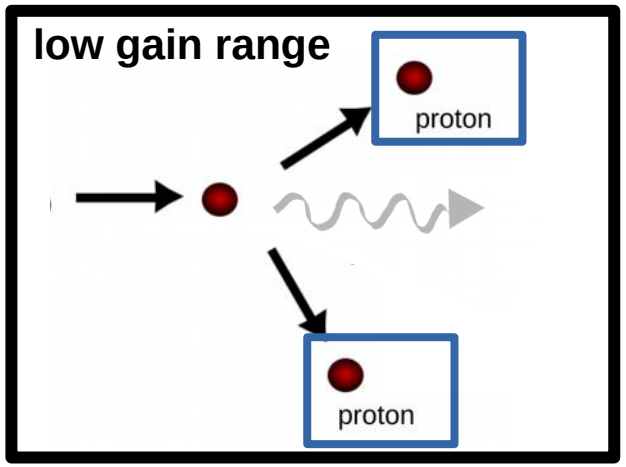
More modifications @ Mesytec

Dual Range Preamplifier

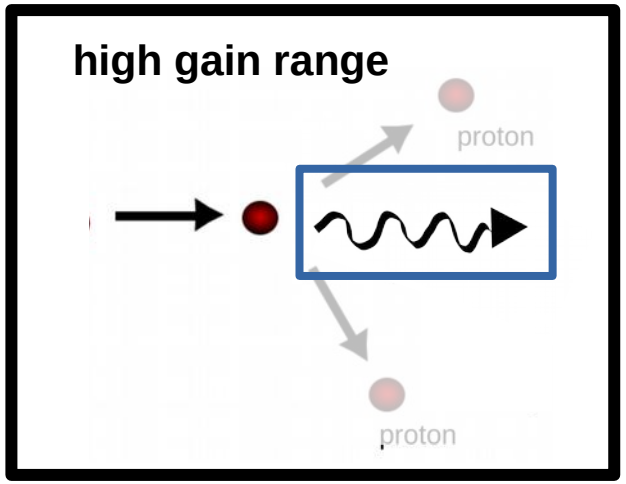


SIMULTANEOUS
high energetic paricle measurement
&
gamma spectroscopy

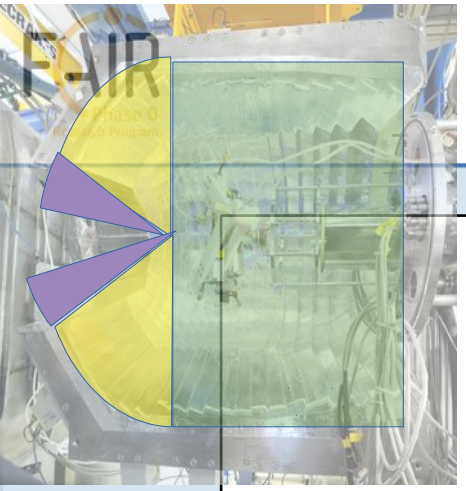
SingleRange Preamplifier



OR



experiment dependent decision has to be taken beforehand!



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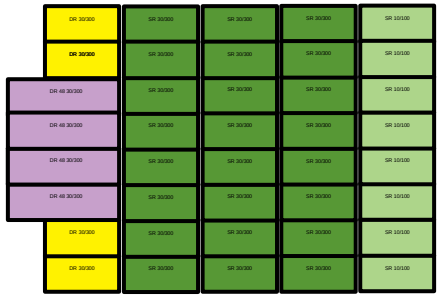

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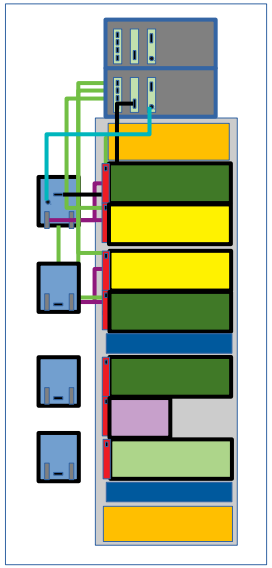

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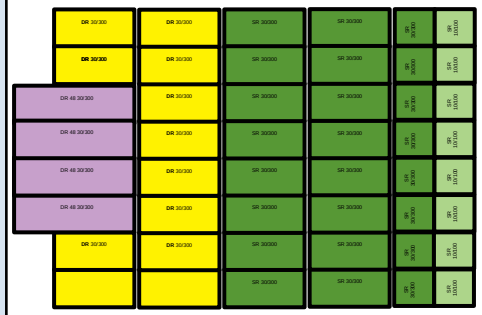

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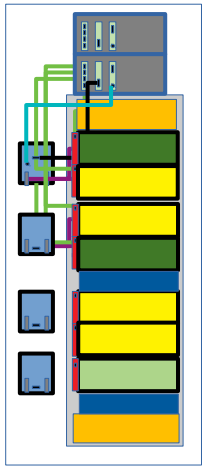

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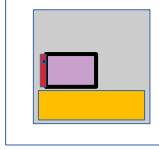

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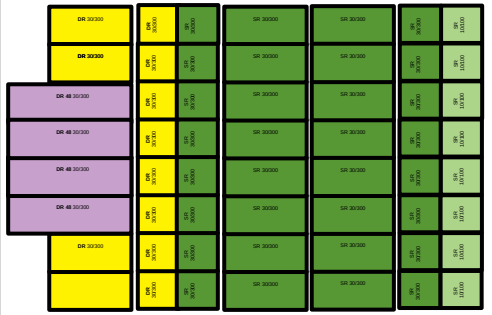
More data, less spares

Mixed Config.



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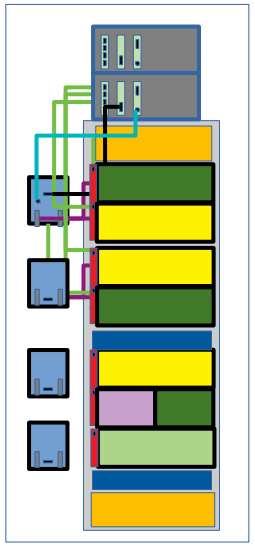


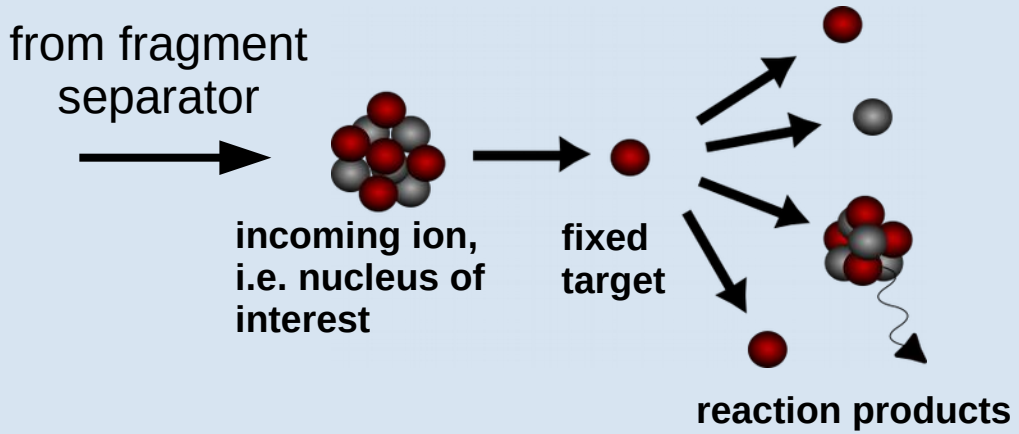
All features in - 4π save

More modifications @ Mesytec

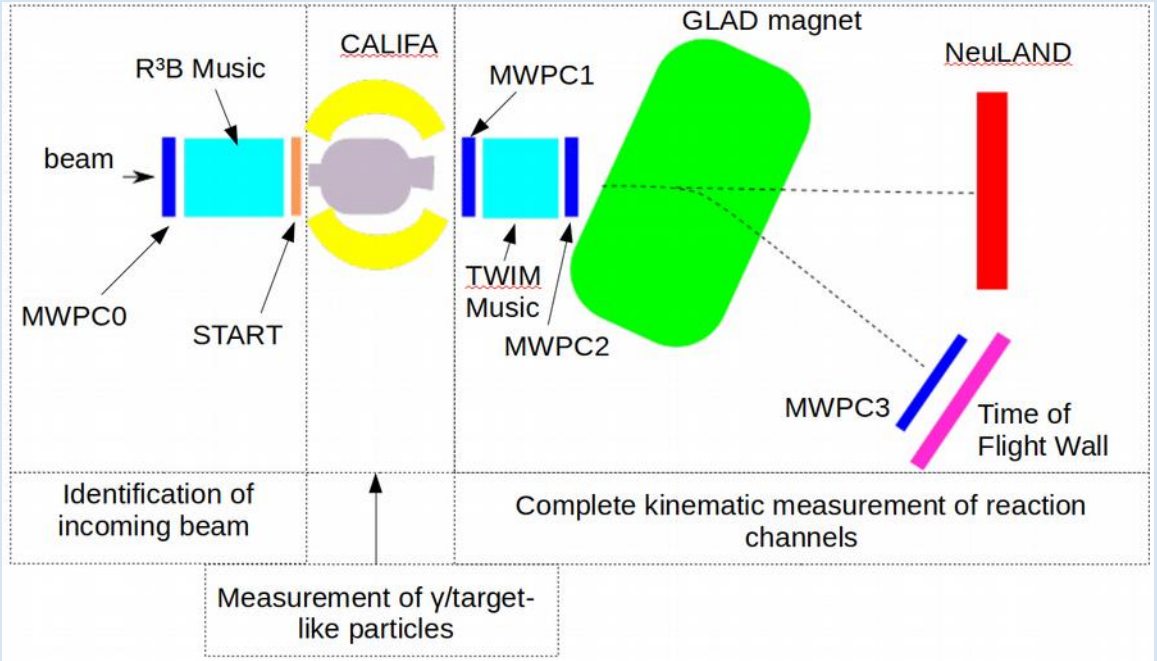
Physics at R3B with CALIFA

Physics Program @ R3B

- Physics program on exotic nuclei in inverse kinematics:

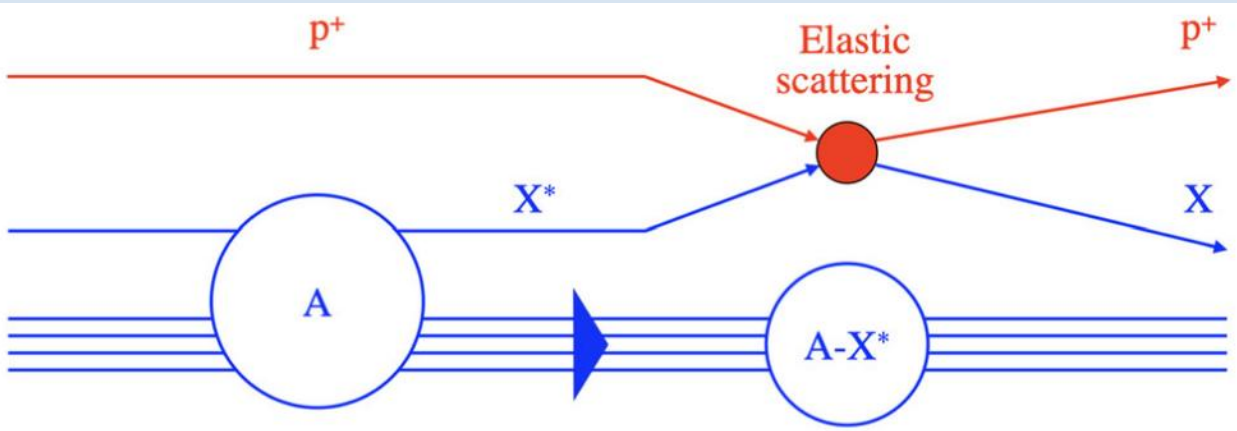


- kinematically complete measurements
- Fission Studies (measure fission yields and barriers far off stability)
- **Key physics program:** Quasi-Free Scattering Reactions

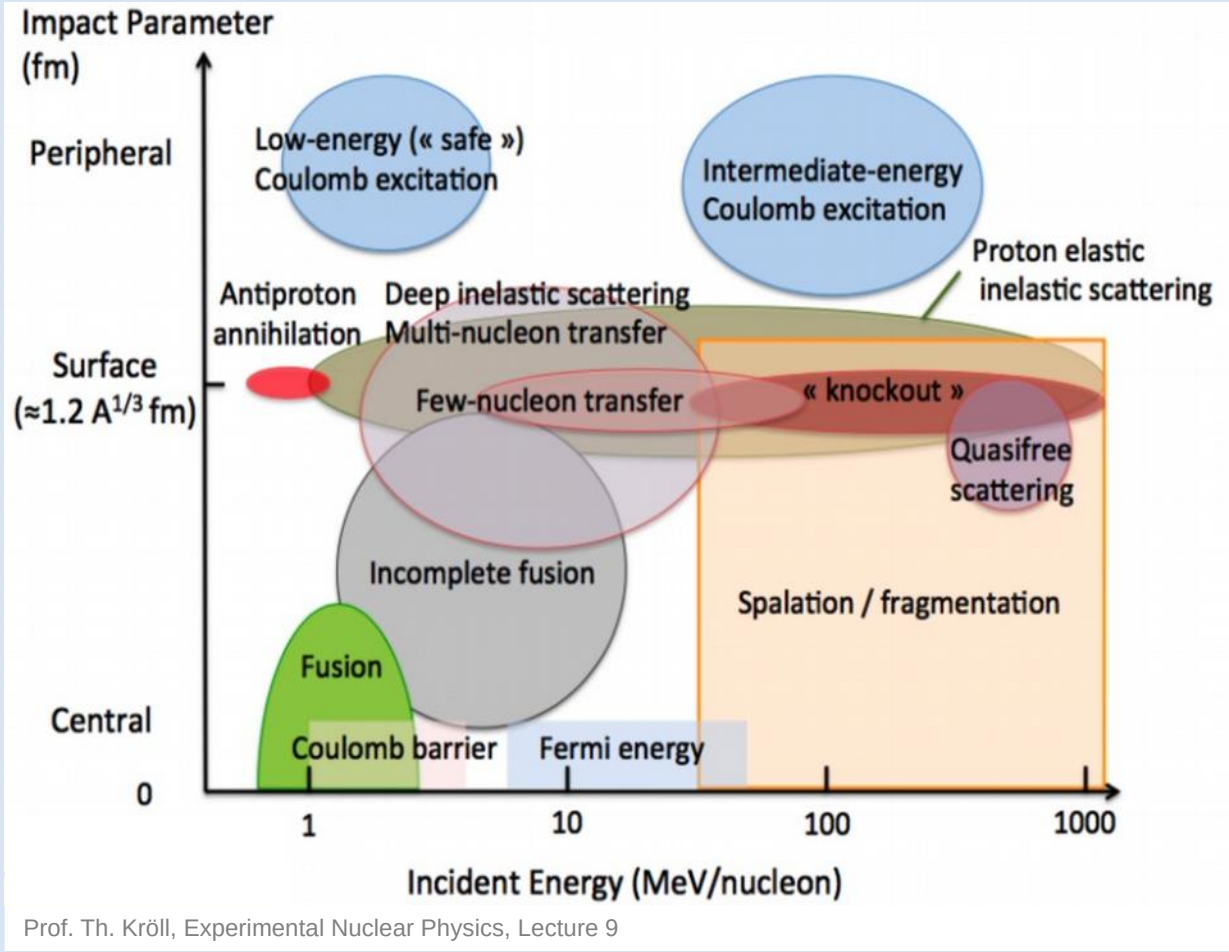


Quasi-Free Scattering Reactions

- 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.



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

- 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**

Quasi Free Scattering Analysis with Experiment S444/467 (2020)

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

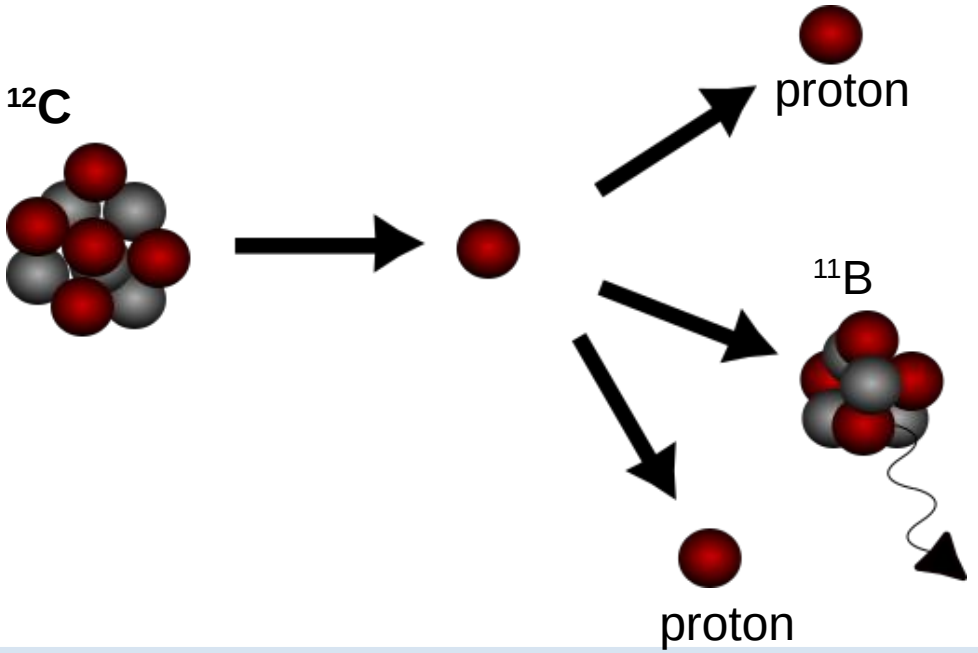
- ^{12}C beam
- proton like target

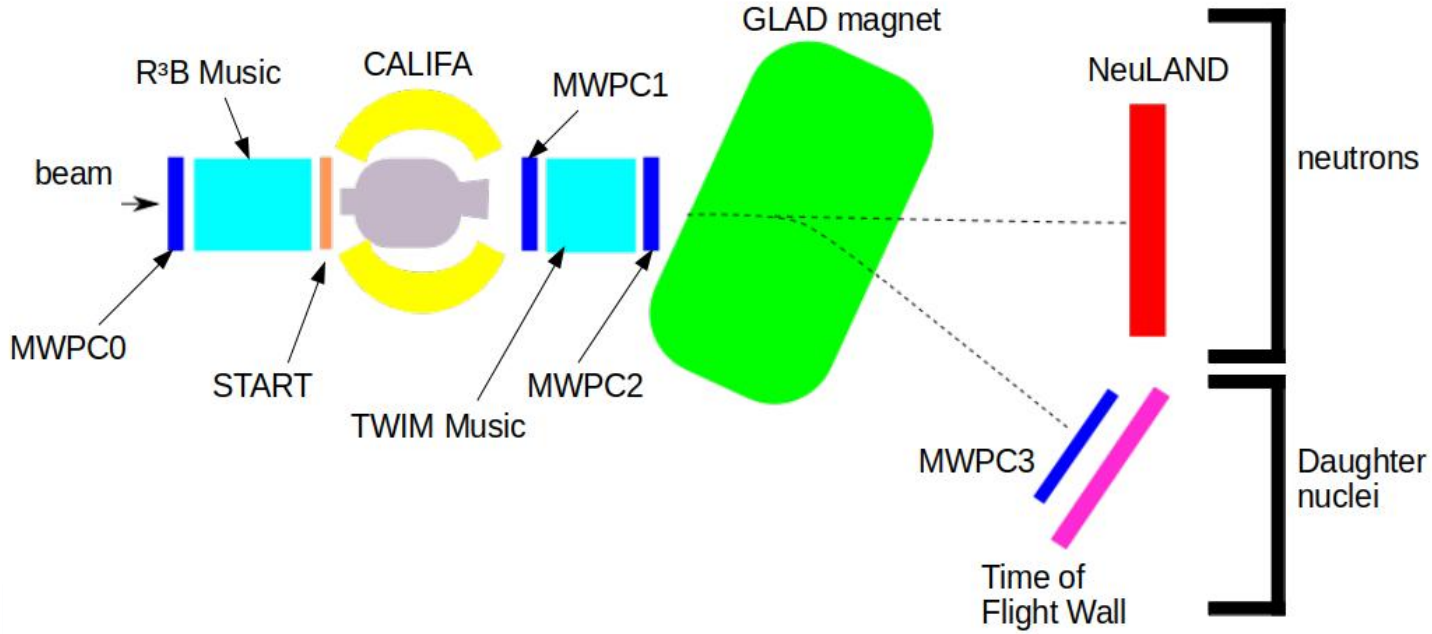
→

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

SETUP:

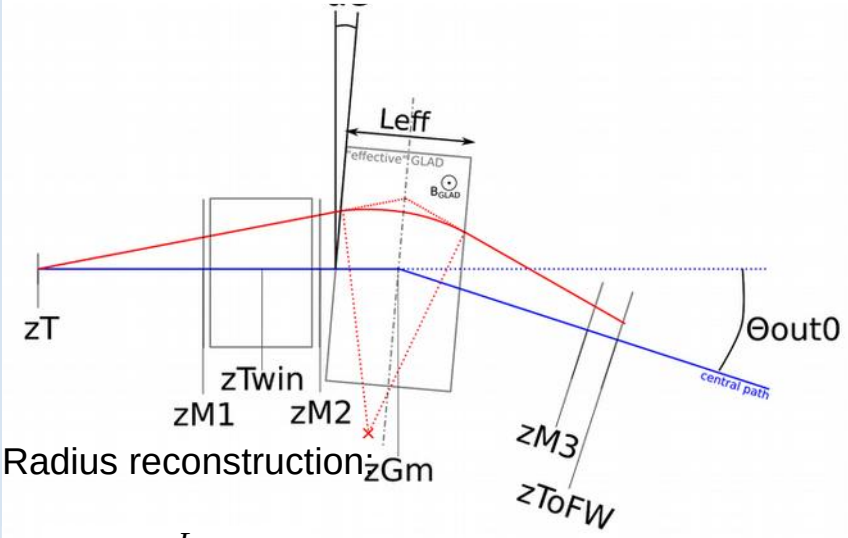
Beam energy: 400 AMeV
Beamtype: ^{12}C
Beamtime: 3 hours
Target: CH_2 (12.29 mm)





Fragment Particle Identification

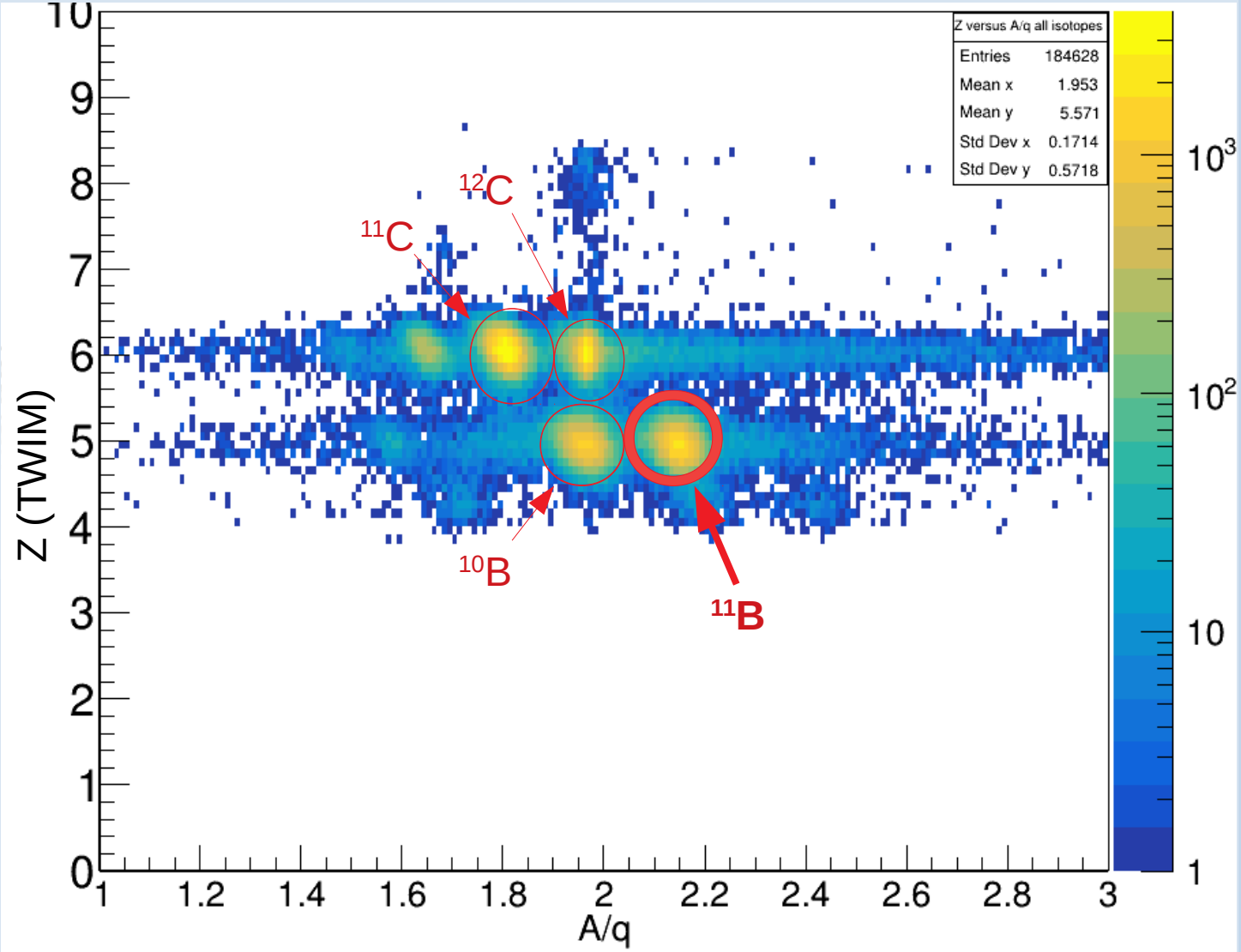
Flightpath reconstruction:



Radius reconstruction:

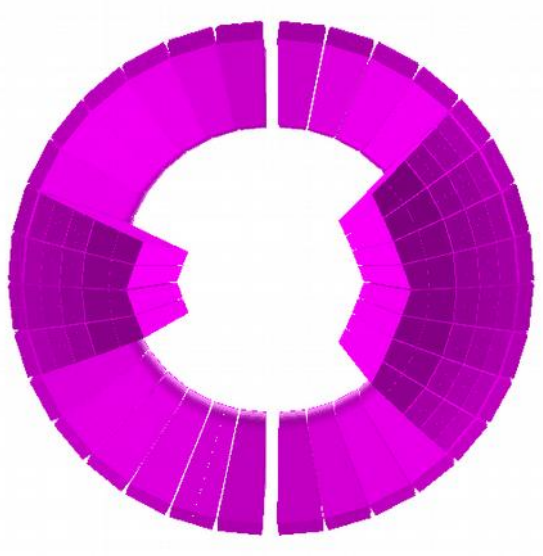
$$R = \frac{L_{eff}}{2\sin\left(\frac{\theta_{in} + \theta_{out}}{2}\right)}$$

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

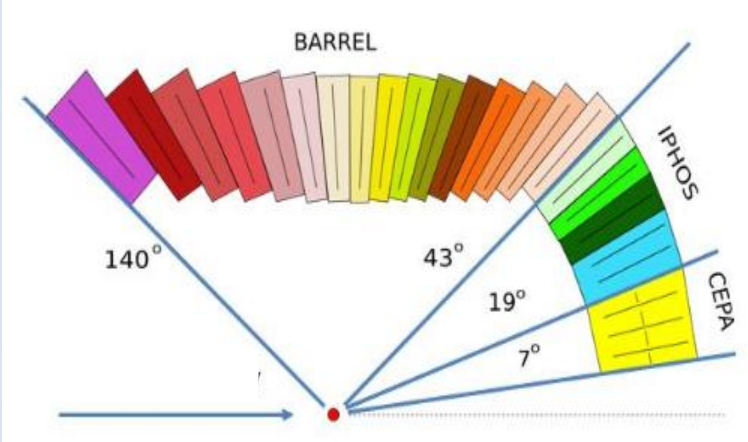


Identification of the two correlated Protons

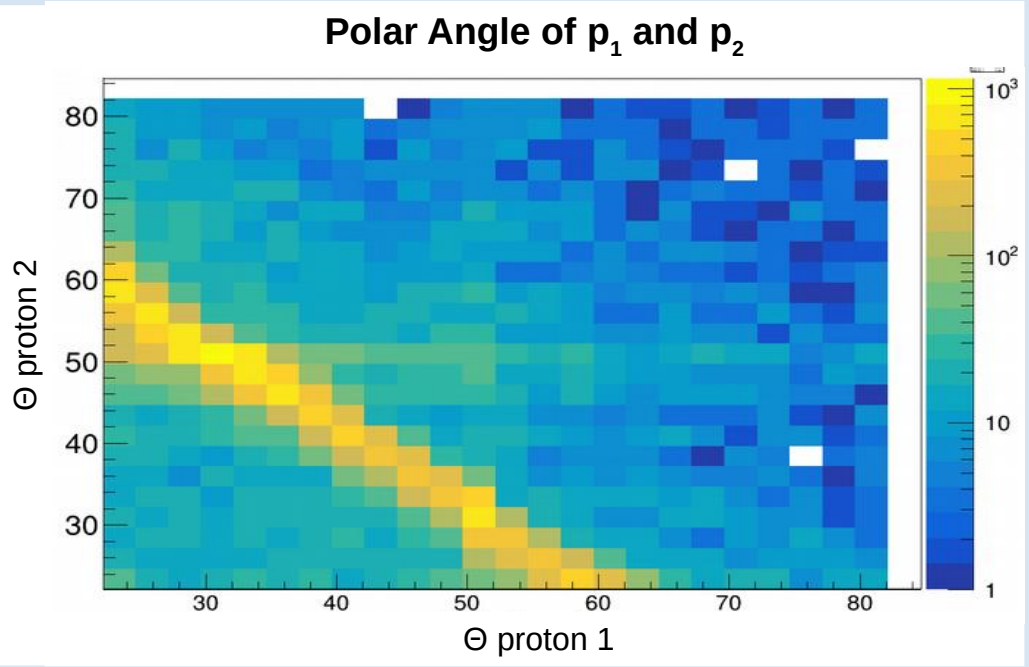
CALIFA Front View

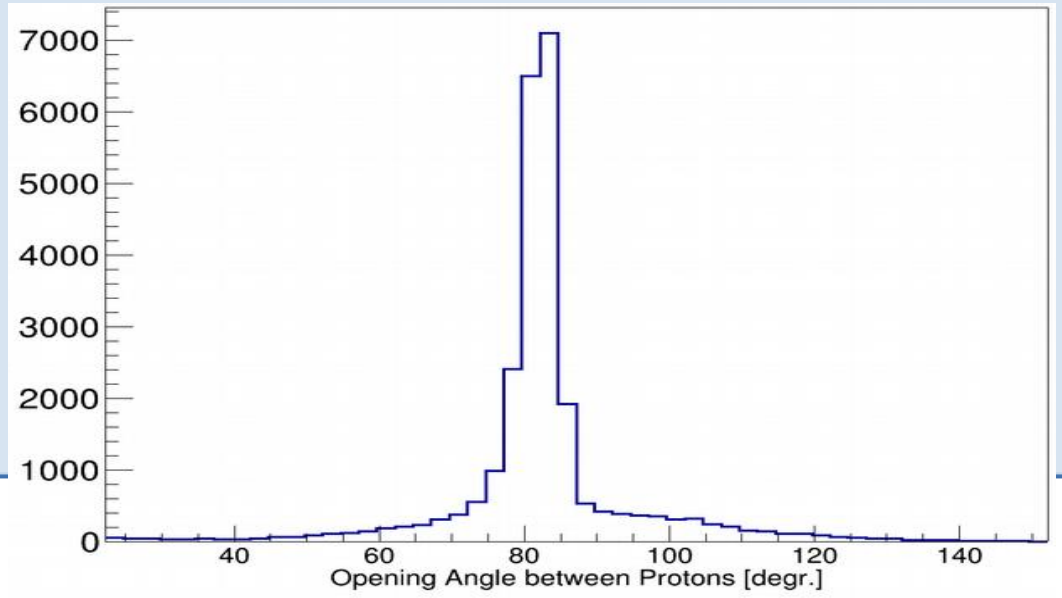


CALIFA Side View

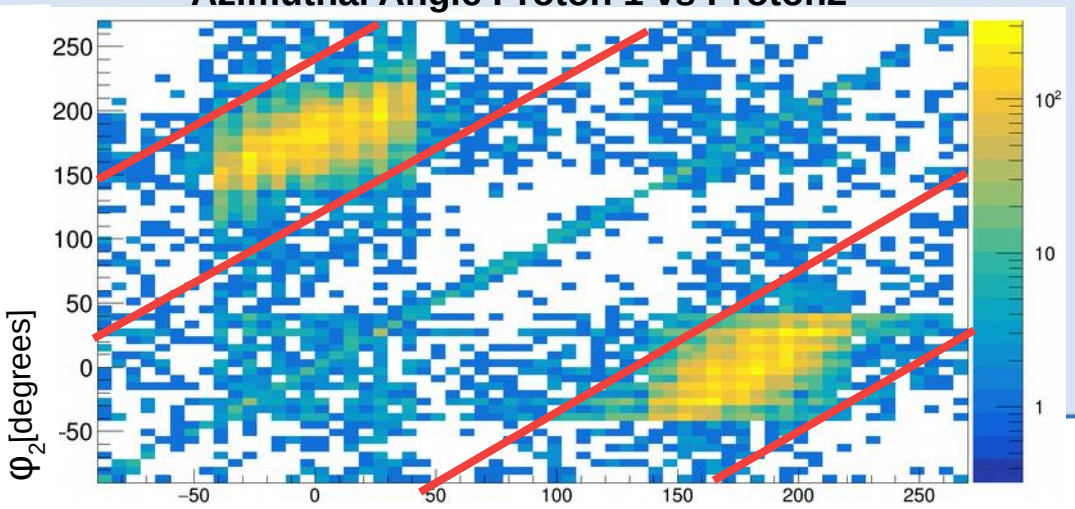


Polar Angle of p_1 and p_2





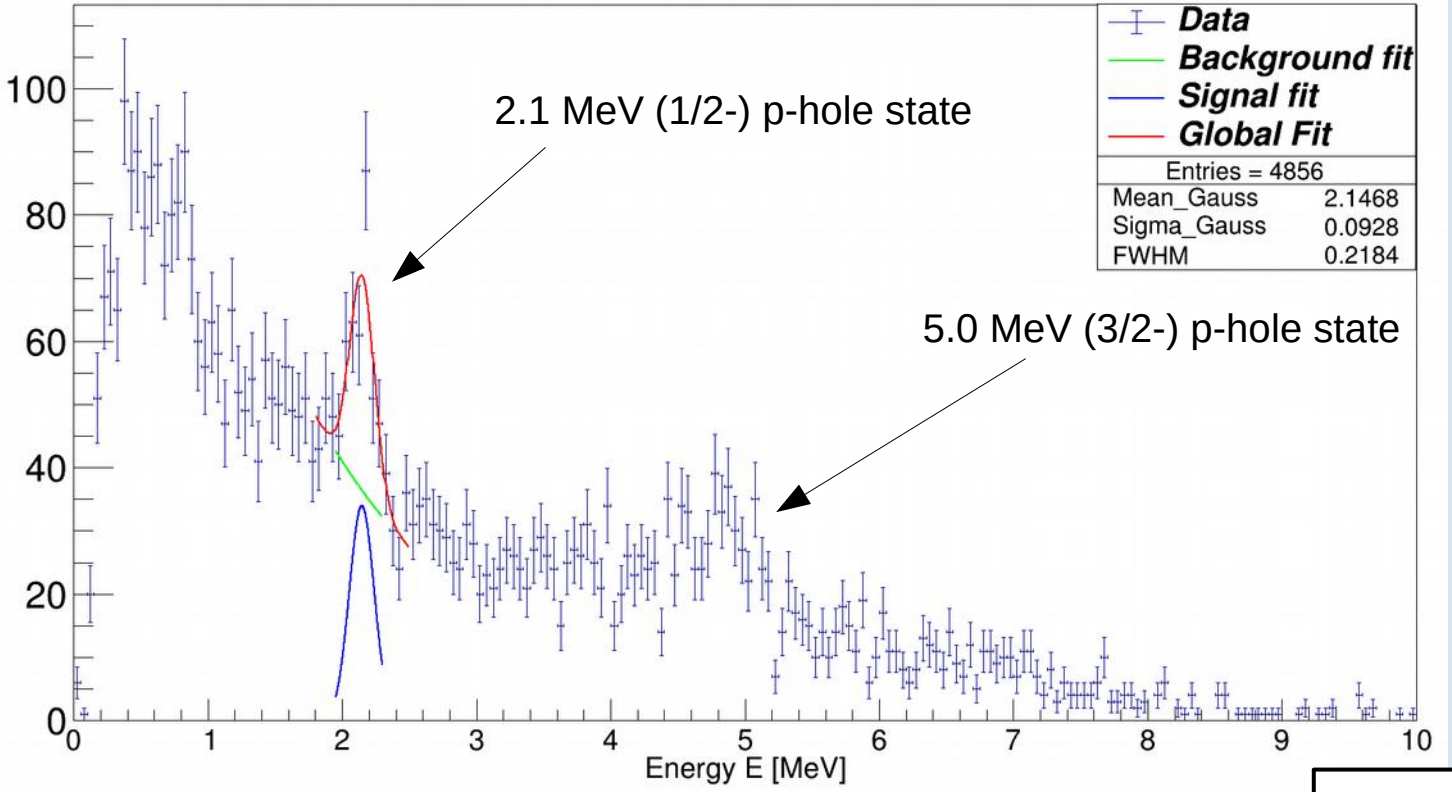
Azimuthal Angle Proton 1 vs Proton2

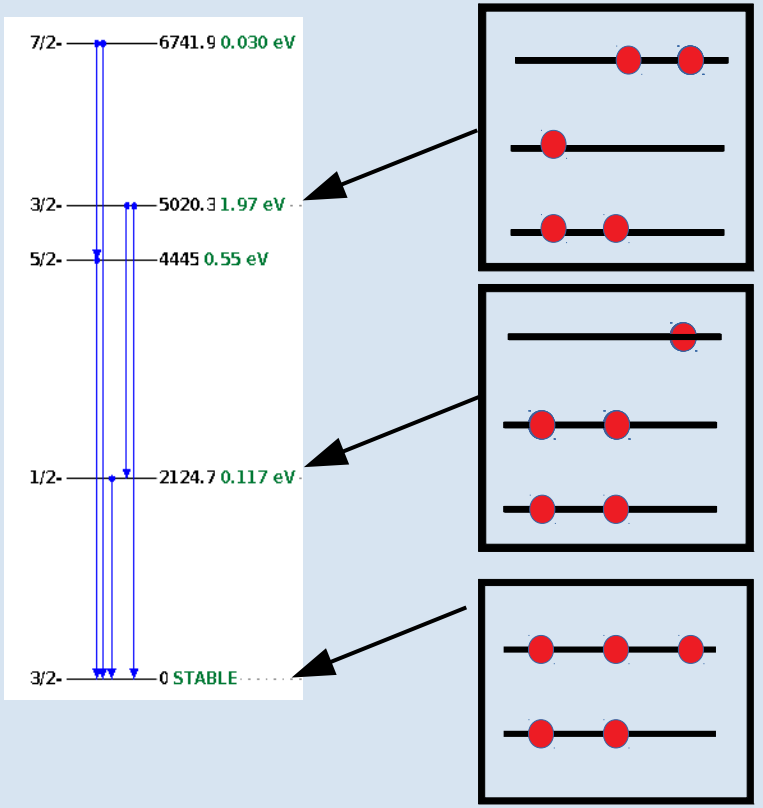


Gamma Spectrum of ^{11}B

Doppler Corrected Gamma Spectrum

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



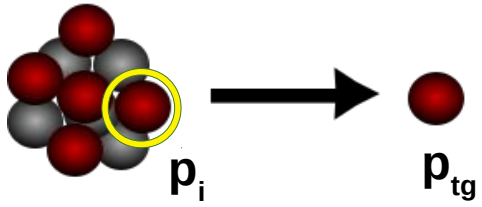


Event Selection Criteria:

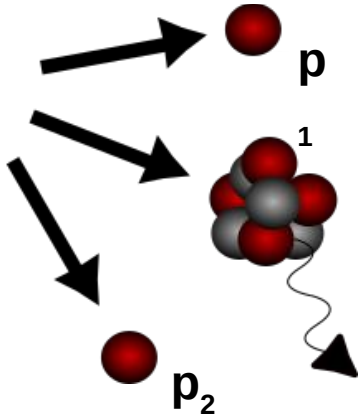
- ^{11}B fragment identification
- Two hits (protons) with E_{hit} > 30 MeV
- θ1 + θ2 < 90°
- Δφ = 180° +- 40°

Reconstruction of Inner Momenta

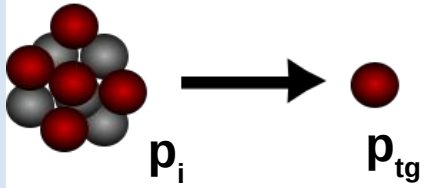
Before Scattering:



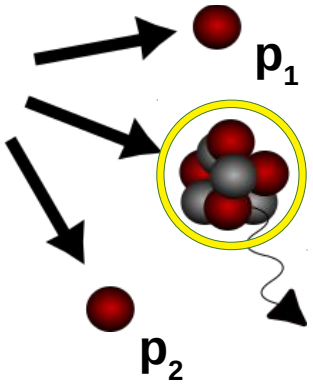
After Scattering:



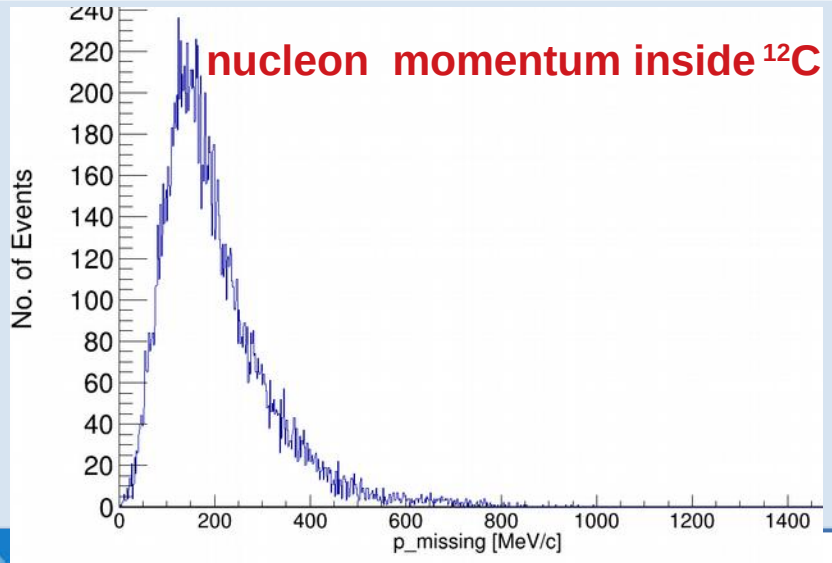
Before Scattering:

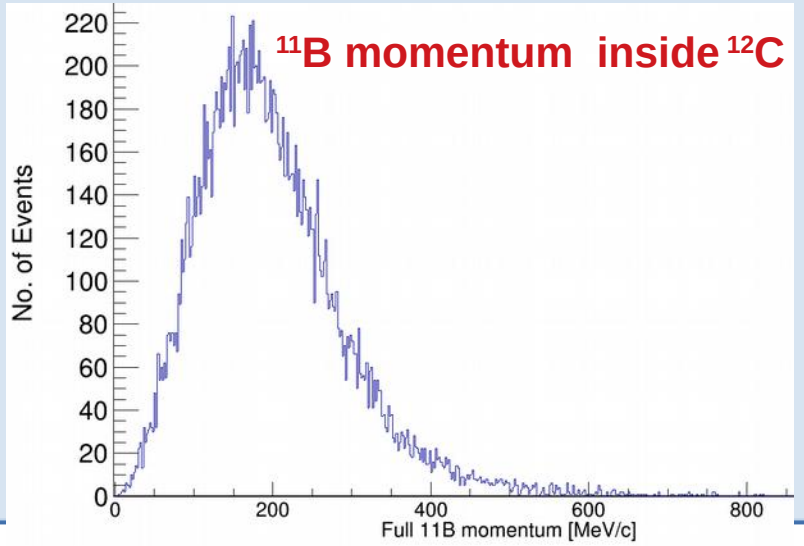


After Scattering:

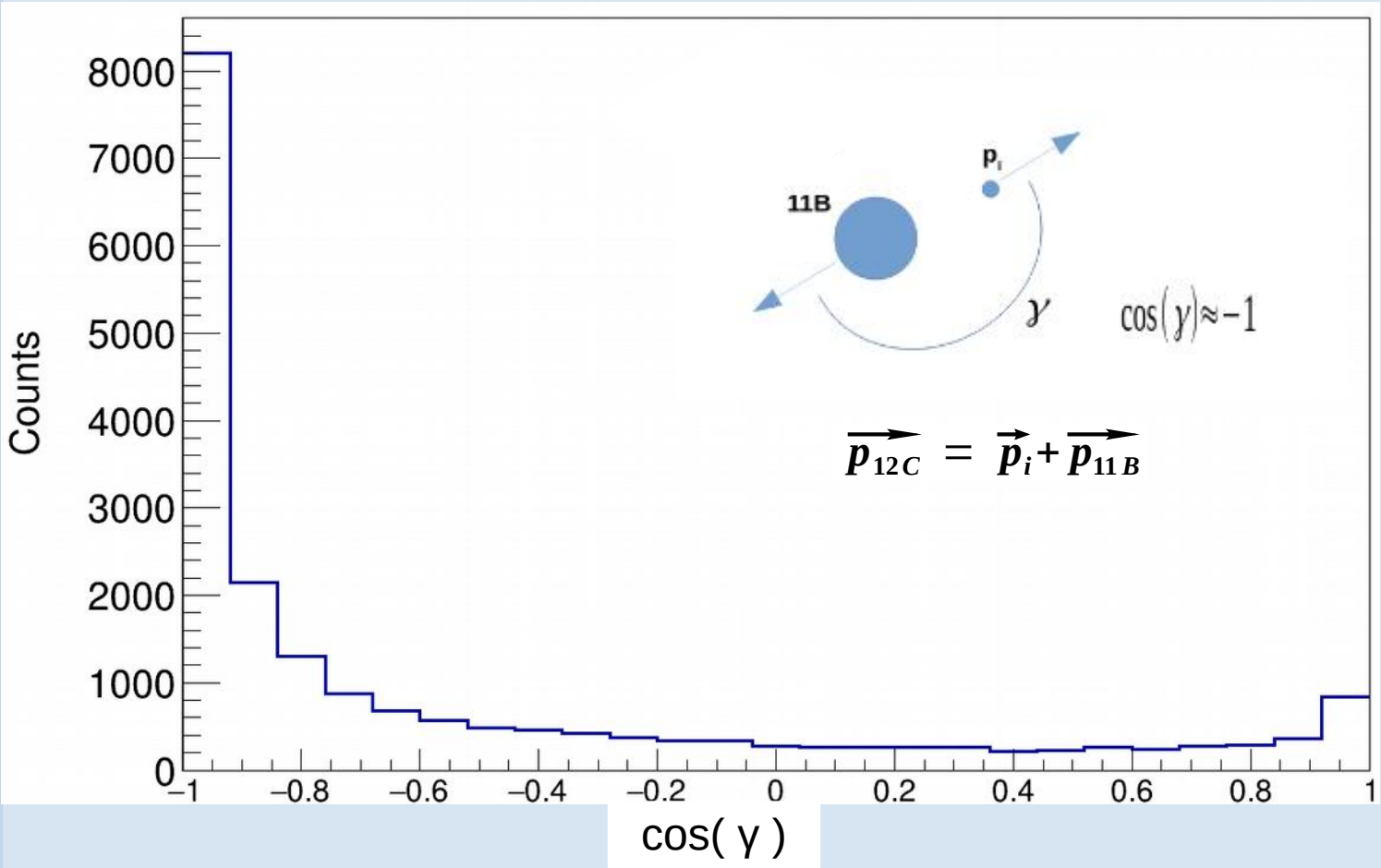


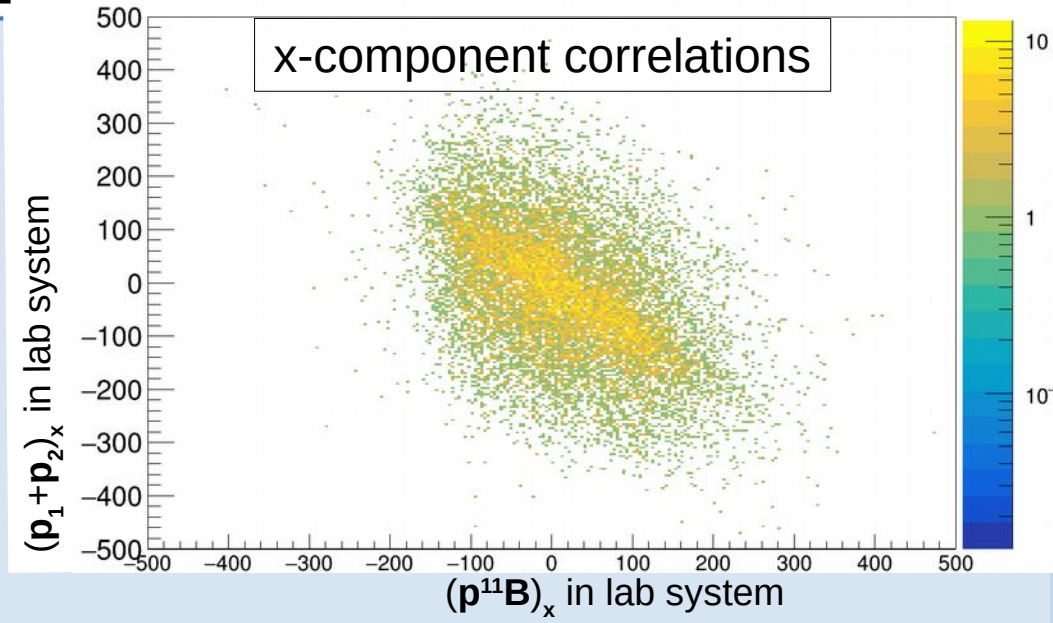
Spectator!

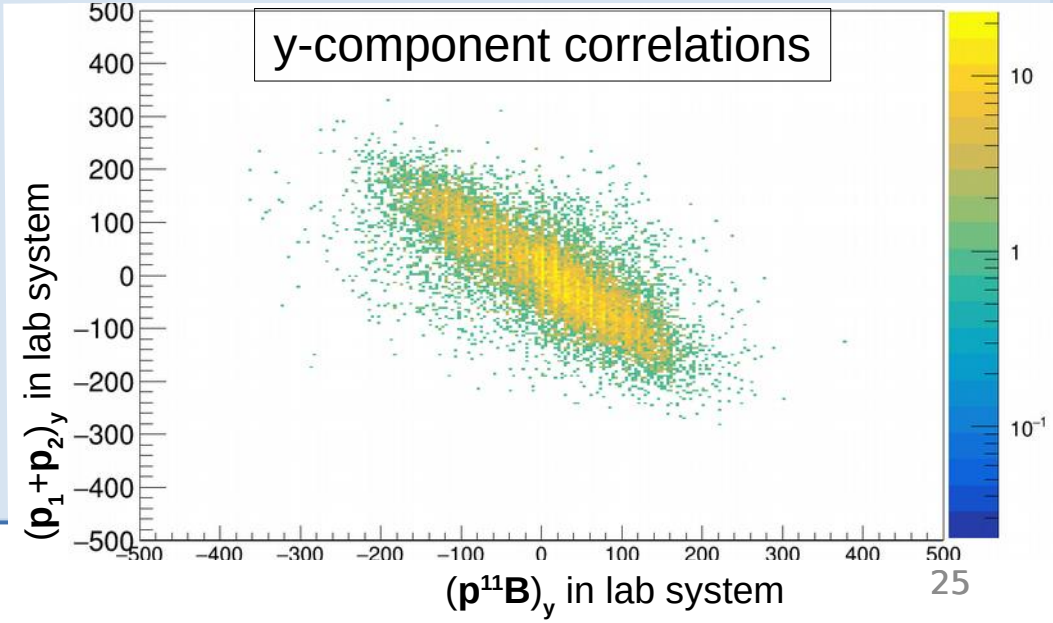




Correlations between Fragment and Proton Pair





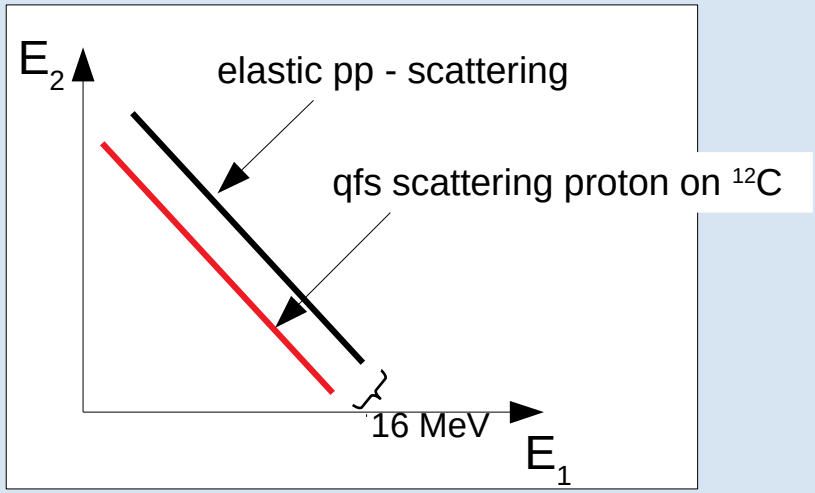


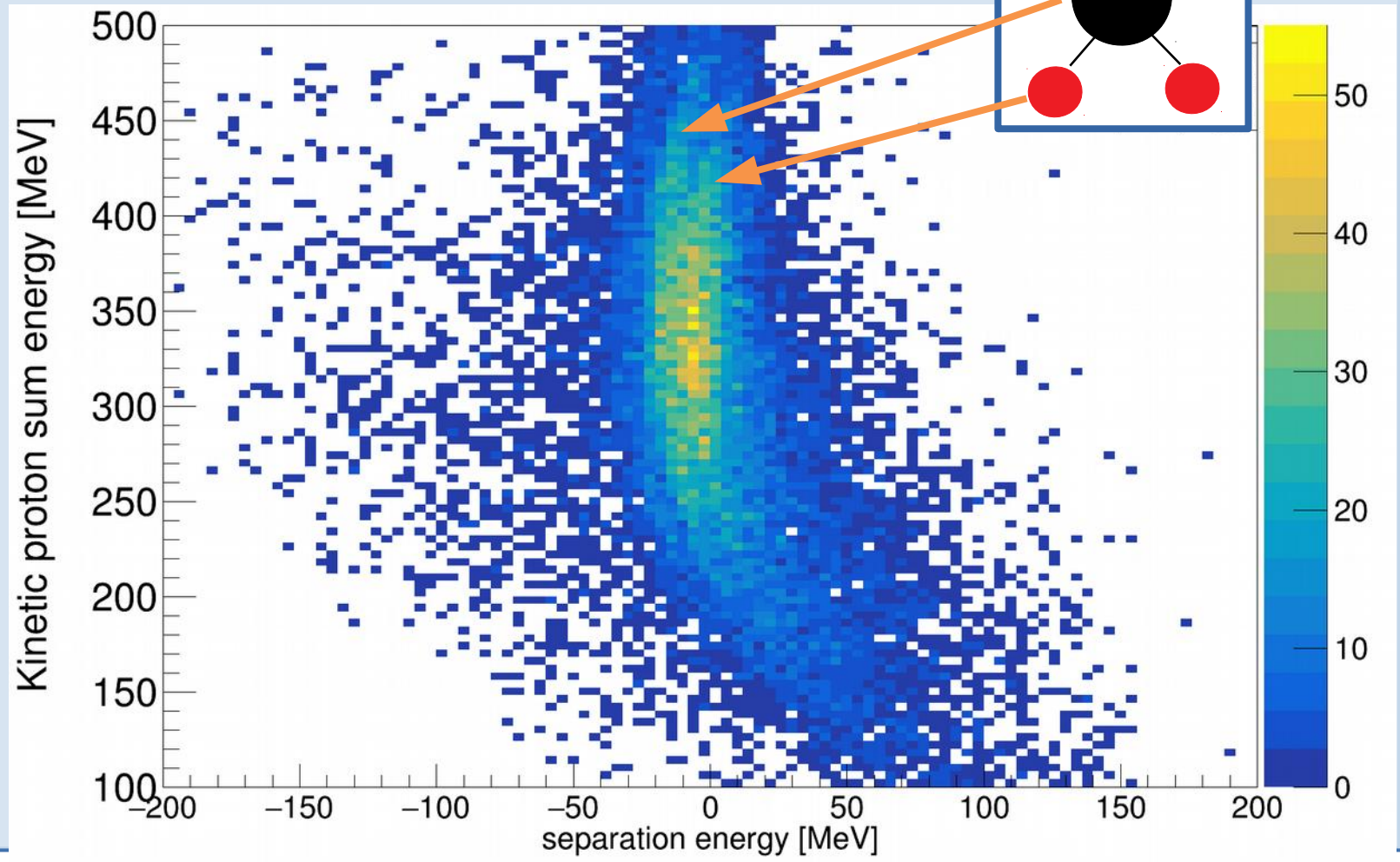
Proton Separation Energy of 12C

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

S_p = Energy needed to remove one proton from the nucleus

In direct kinematics it would be:





12C(p,2p)11B Cross Section Measurements

Selection Cuts:

→ strict event selection in front of target

→ 2 hits in CALIFA with $E_{1/2}$ > 30 MeV

→ Δφ = 180 +- 40°

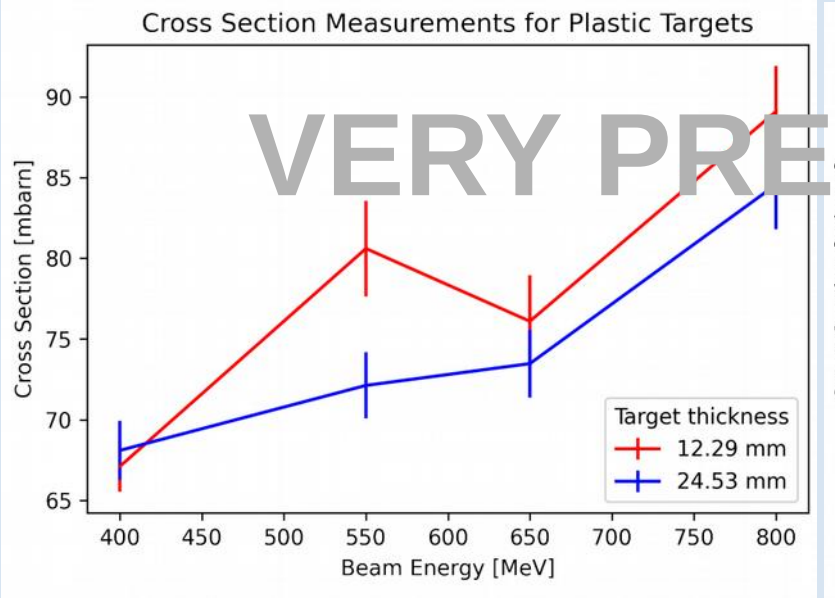
→ Boron as Fragment (Z = 5)

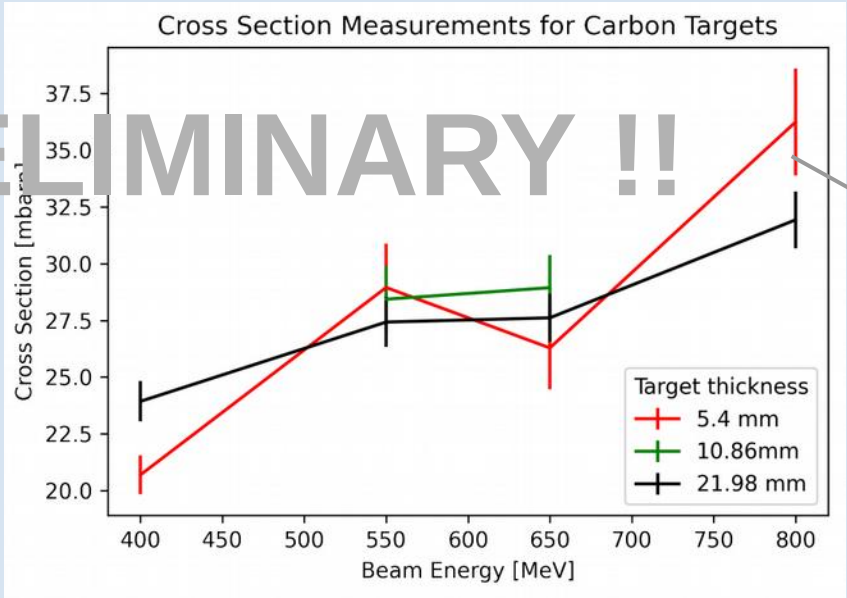
CALIFA only 35% filled in forward region → large correction factors

Cross sections im mbarn

Reaction \ Target	CH_2	Carbon
$^{12}C(p, 2p)X$	81.5 ± 4.0	20.5 ± 1.9
$^{12}C(p, 2p)^{11}B$	47.3 ± 3.3	11.1 ± 1.5
p-removal	82.7 ± 7.7	45.9 ± 4.4
pn-removal	48.1 ± 5.3	30.7 ± 2.3
Inel. breakup to ^{11}B	2.64 ± 0.97	0.96 ± 0.65

Source: Valerii Panin, Thesis 2012





VERY PRELIMINARY !!

only statistical errors

What else can we analyse with the S444 Experiment ?

Total Reaction cross section – Lukas Ponnath

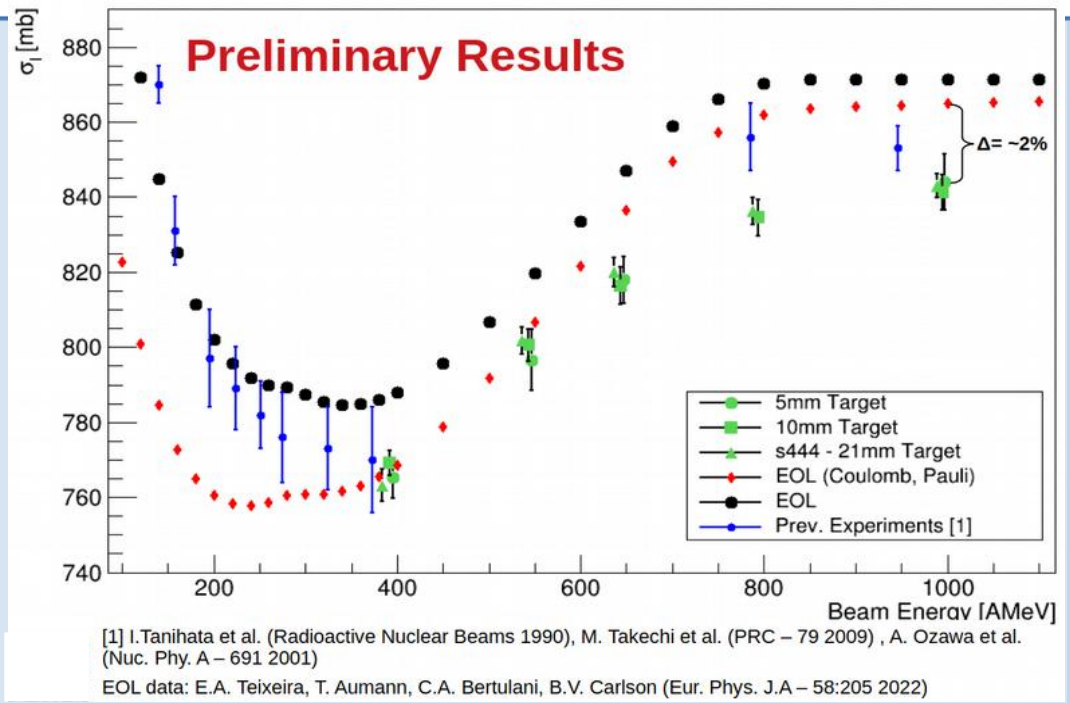
Surviving-Probability: $$P_{surv.} = \frac{N_2}{N_1} = e^{-N_t \cdot \sigma_R}$$

Exclude reactions in Setup:

$$\frac{\overbrace{N_2^i / N_1^i}^{\text{Target-In}}}{\underbrace{N_2^o / N_1^o}_{\text{Target-Out}}} = e^{-N_t \cdot \sigma_R}$$

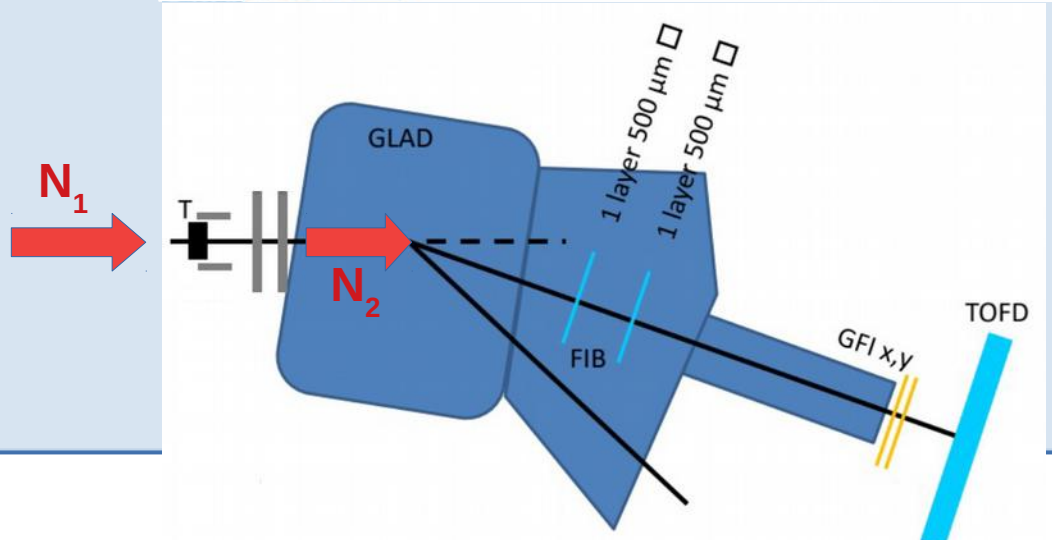
Using the Transmission Method:

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



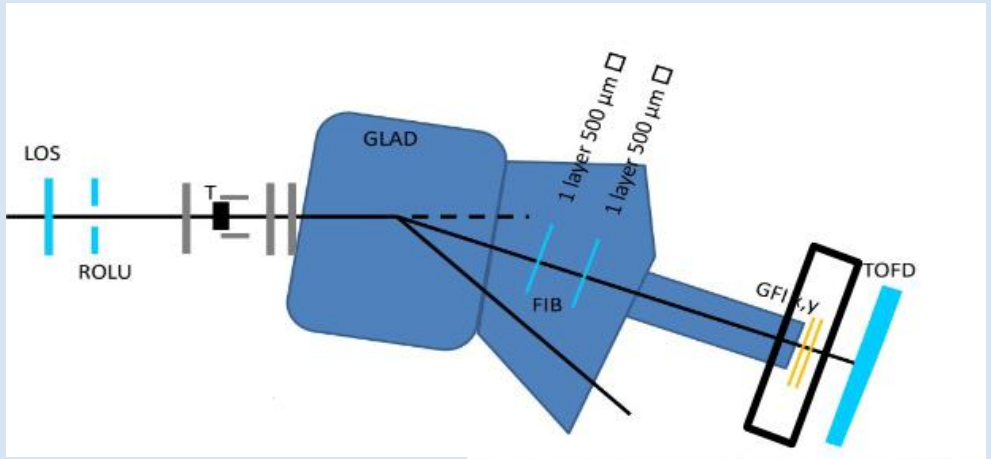
[1] I.Tanihata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009) , A. Ozawa et al. (Nuc. Phy. A – 691 2001)

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

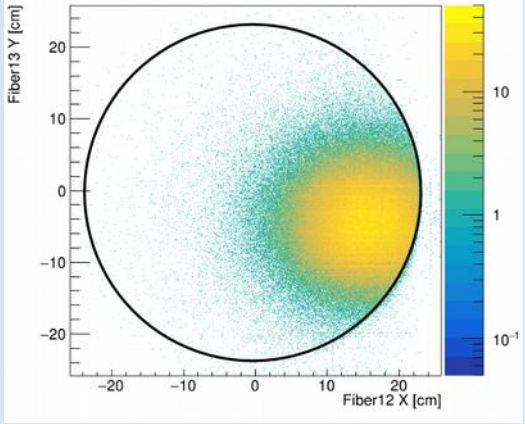


Comparing the two Setups

Setup - Lukas

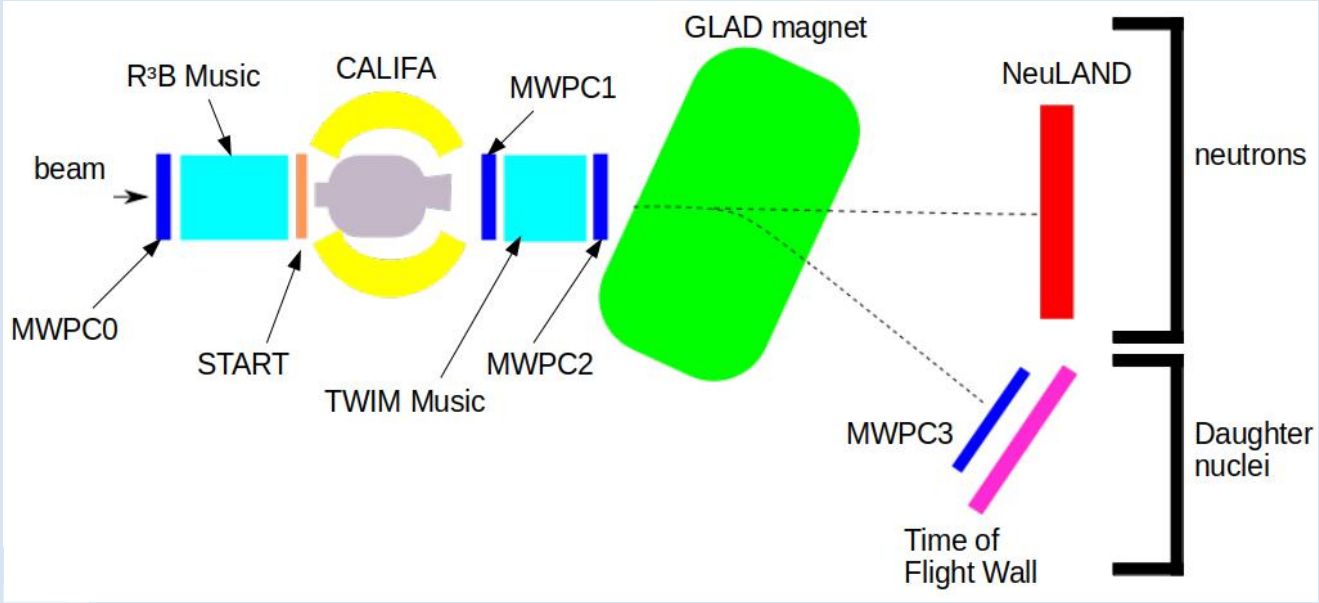


Acceptance issues due to the beam pipe confinement



Fine tuned acceptance corrections needed

S444 (2020) Setup → with carbon target



High acceptance:

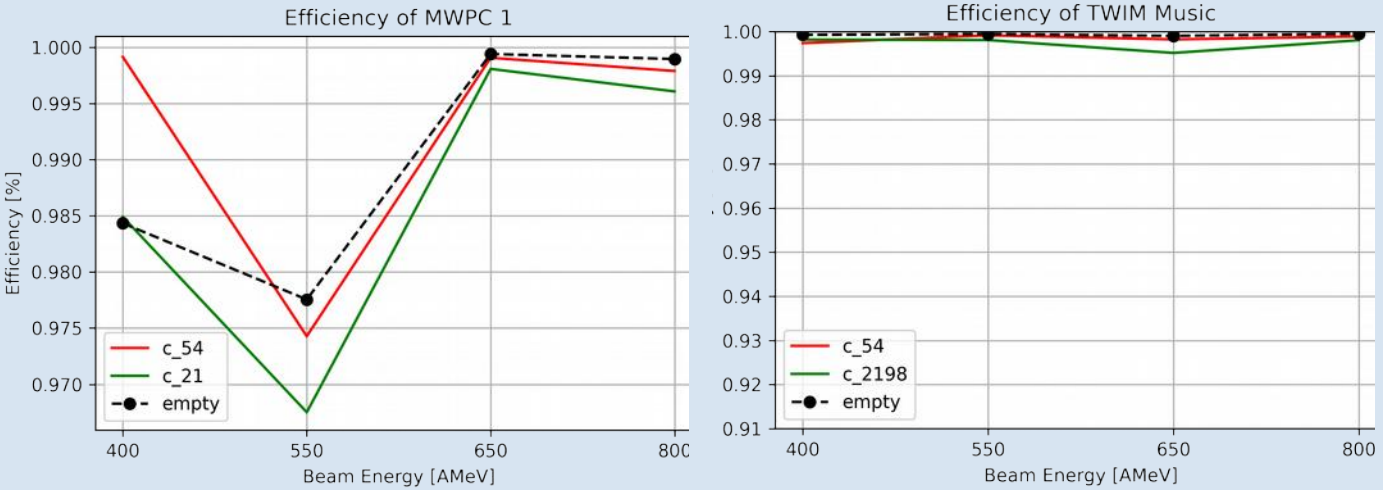
→ charge measured right after target by TWIM Music

→ no beam pipe (= no vacuum) restrictions

Convenient setup to compare with Lukas' results

Starting with Charge Changing Cross Section

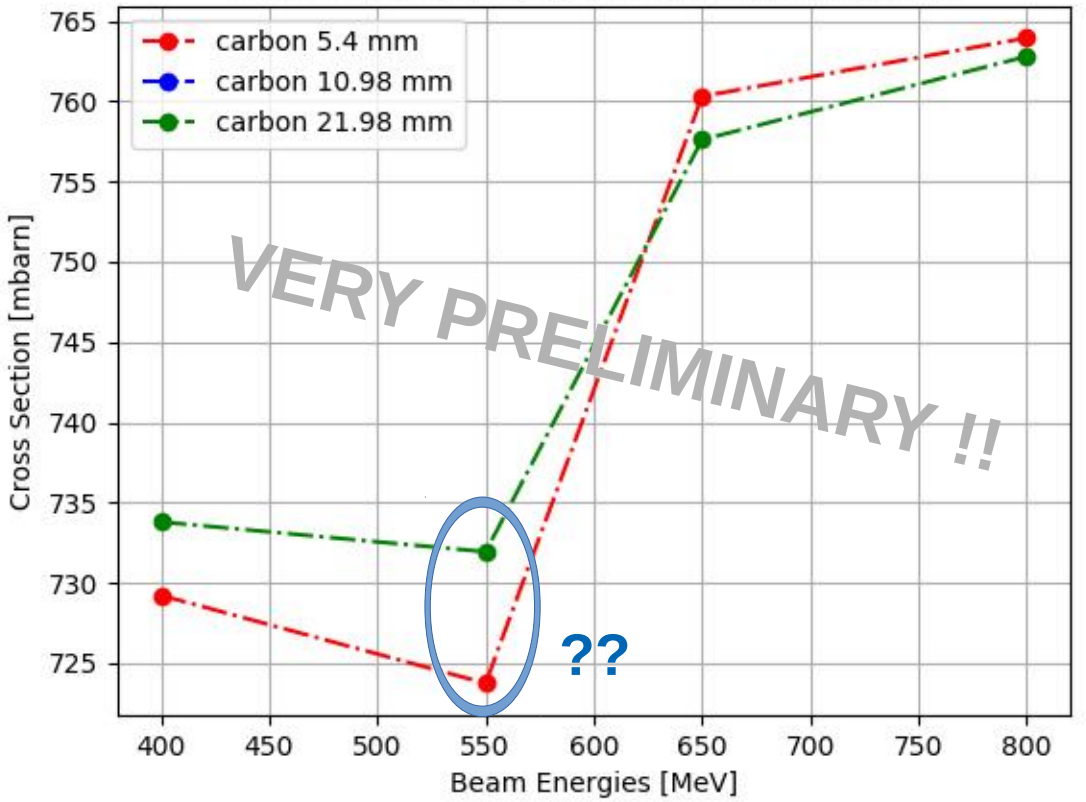
Why not starting directly with total reaction cross section measurement?



Strong fluctuations,
energy (or runwise) corrections to be done

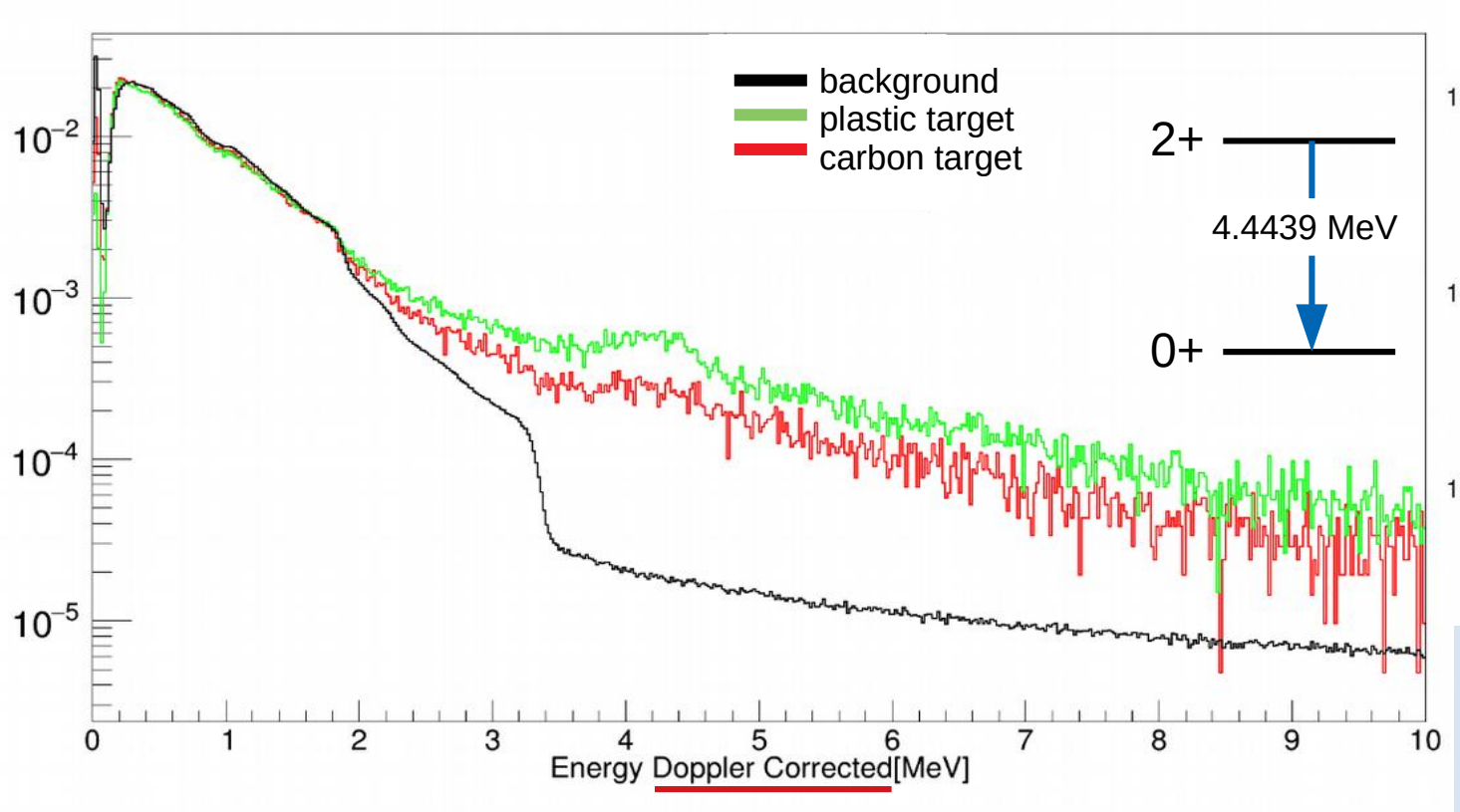
Z = 6

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

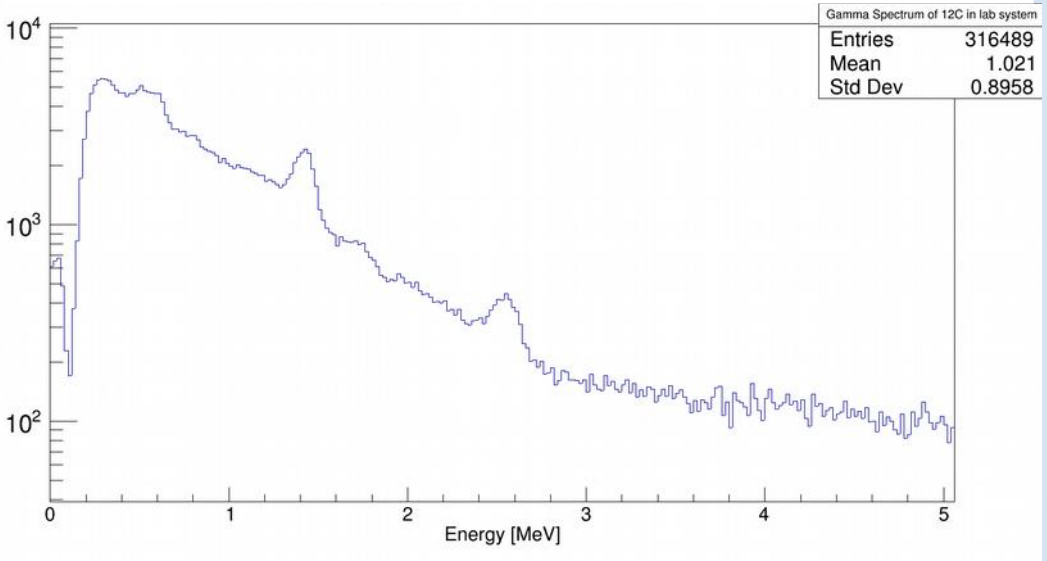


What more ?

12C-12C inelastic cross section



Plastic target , laboratory system

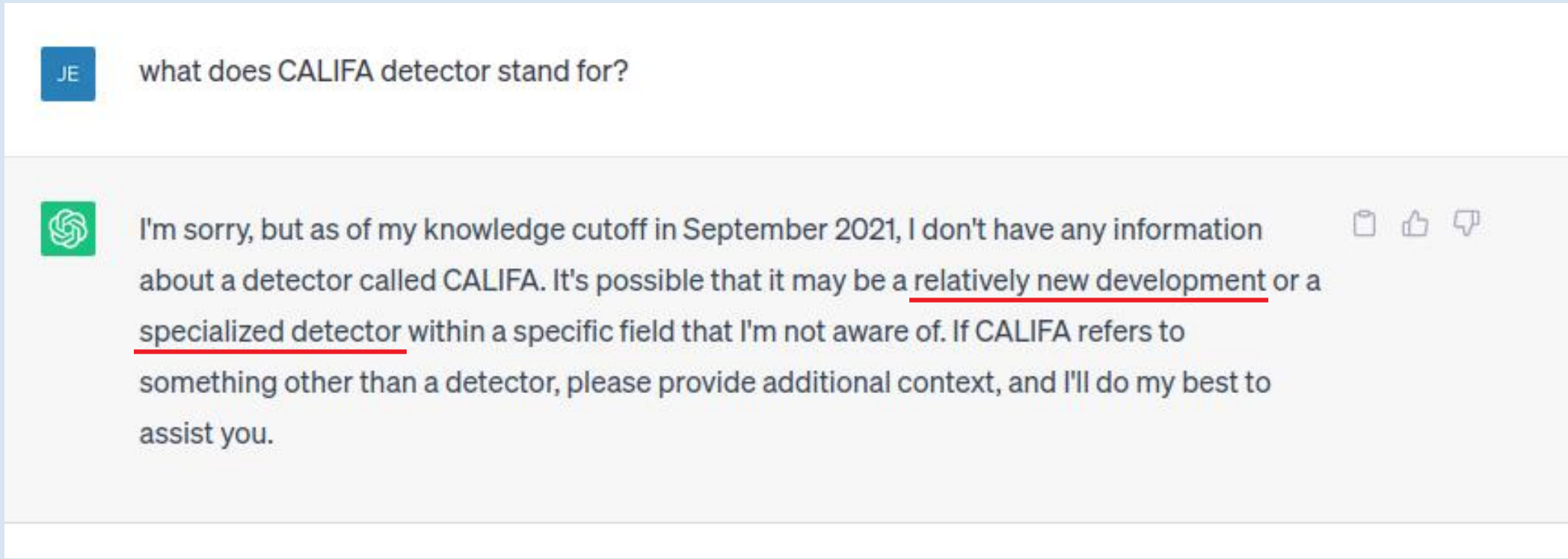


Doppler corrected spectrum: reaction in incoming ^{12}C

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

Note: could instert here plot of gamma spectrum for eg. 400 amev, carbon target, doppler and not doppler corrected

Summary and Outlook



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

ORIGINS Excellence Cluster

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

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FAIR Phase 0 Research Program