R^3B Experiments with Final CALIFA Setup

Tobias Jenegger

PSI Seminar 07.06.2023

R^3B @ FAIR

CALIFA Status & Final Configuration

Physics in R^3B 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

Formation of Elements – Nucleosynthesis
abundances - r-Process - fission feeding

Collective Excitations
→ Pygm dipol resonances
→ EOS – ISGDR – ACTAF
→ Neutron Skin thickness

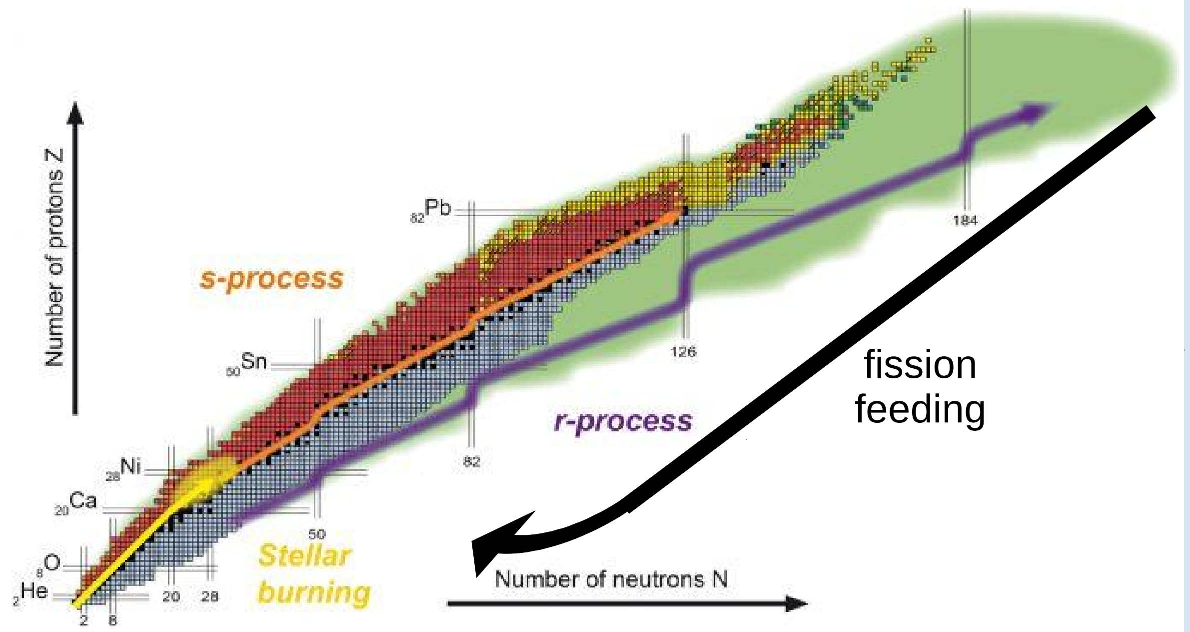
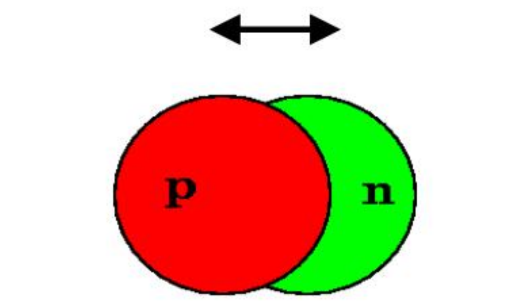


Fig. 1: Nuclear chart showing the nucleosynthesis processes occurring during stellar burning (yellow), the s-process (orange) and the r-process (violet) (credit: EMMI, GSI/Different Arts)

Collective Excitations
→ Giant Dipole Resonances / Pygmy Resonances

→ EOS

→ Neutron skin thickness



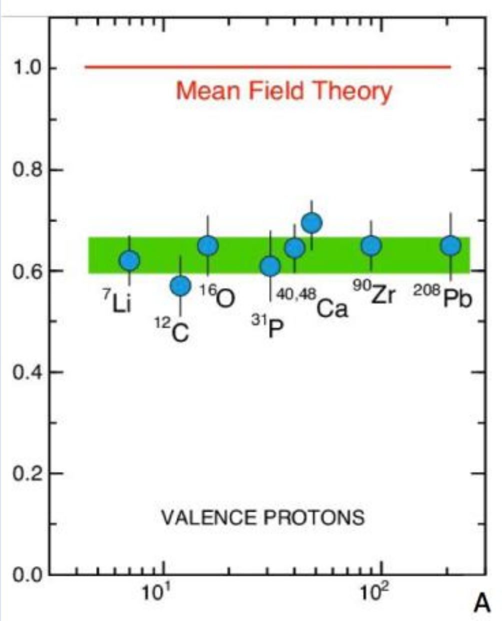
Isovector Electric Giant Dipole Resonance

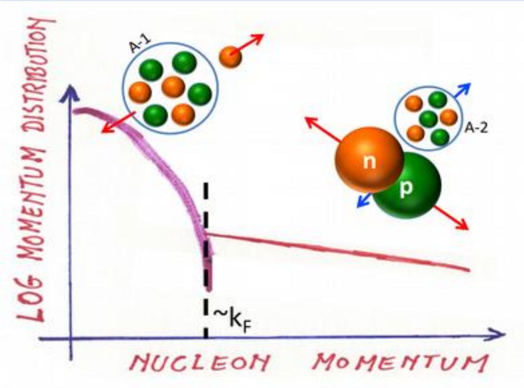
Physics Program @ R3B

Single Particle Properties inside atomic nucleus

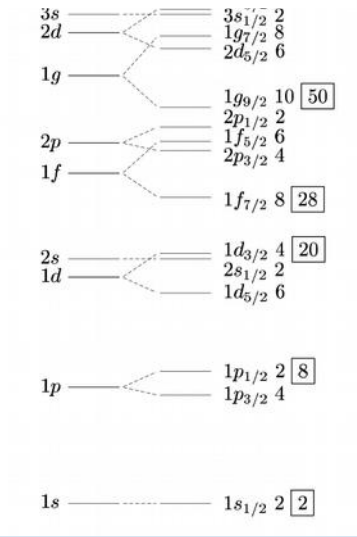
→ Nuclear Structure far off stability

→ Short Range Correlated (SRC) nucleons





Nuclear Shell Model



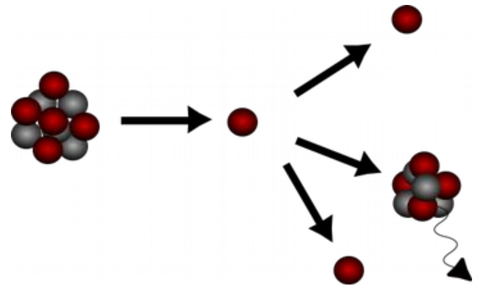
Experimental Setup Requirements:

FAIR accelerator facility

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

+

R3B Setup

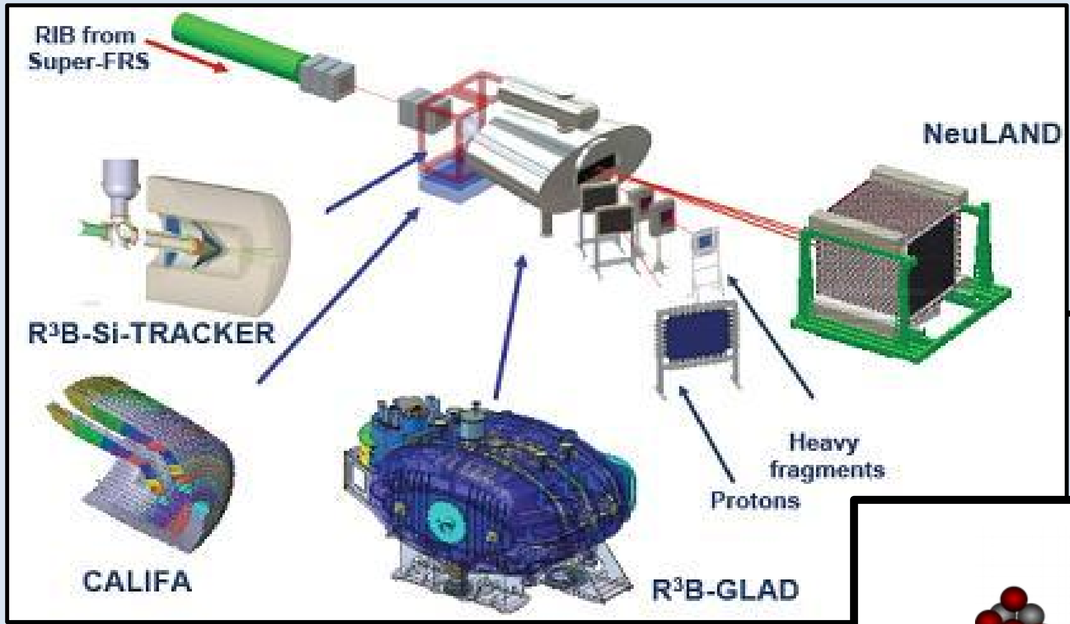


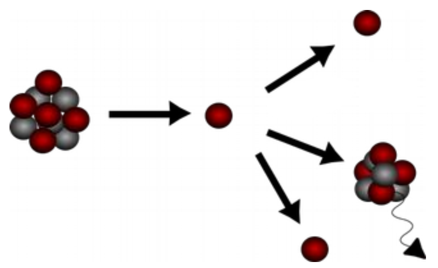
kinematically complete measurements

R³B @ FAIR

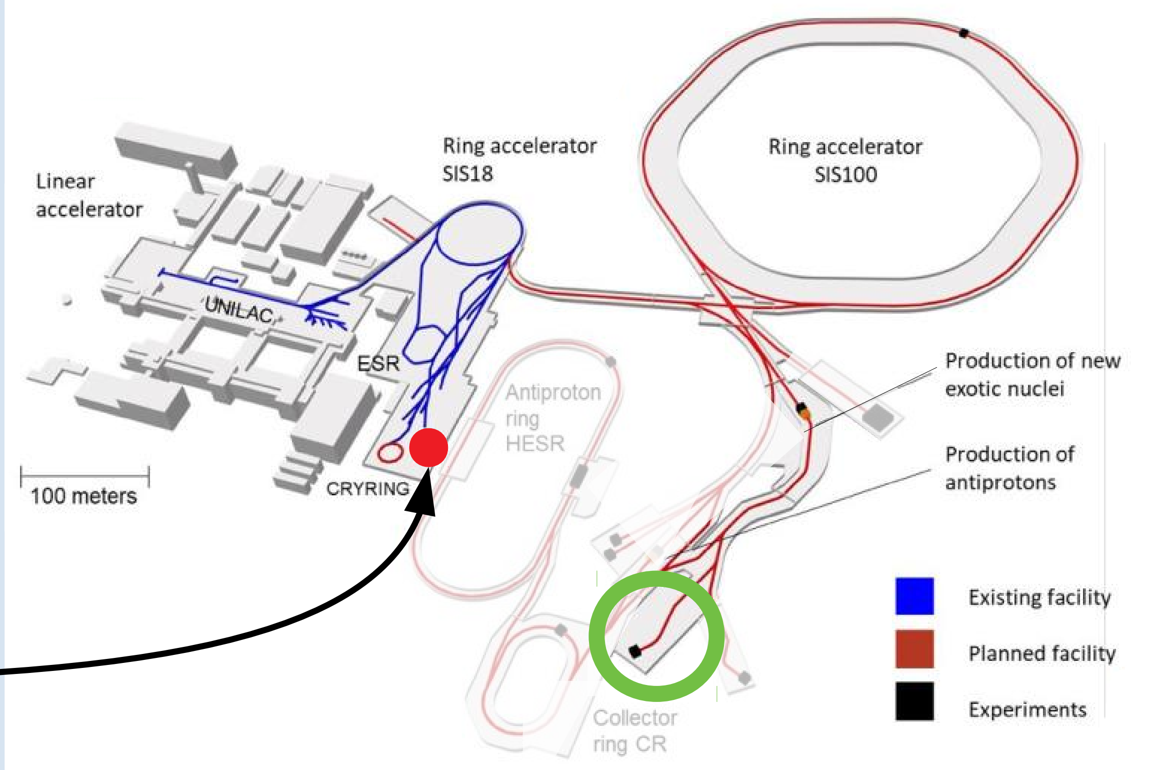
R³B as part of the
Facility for **A**ntiproton and **I**on **R**esearch (**FAIR**)
in Darmstadt:

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





kinematically complete measurements



Haik Simon – FAIR & Super-FRS – EPS 20190930

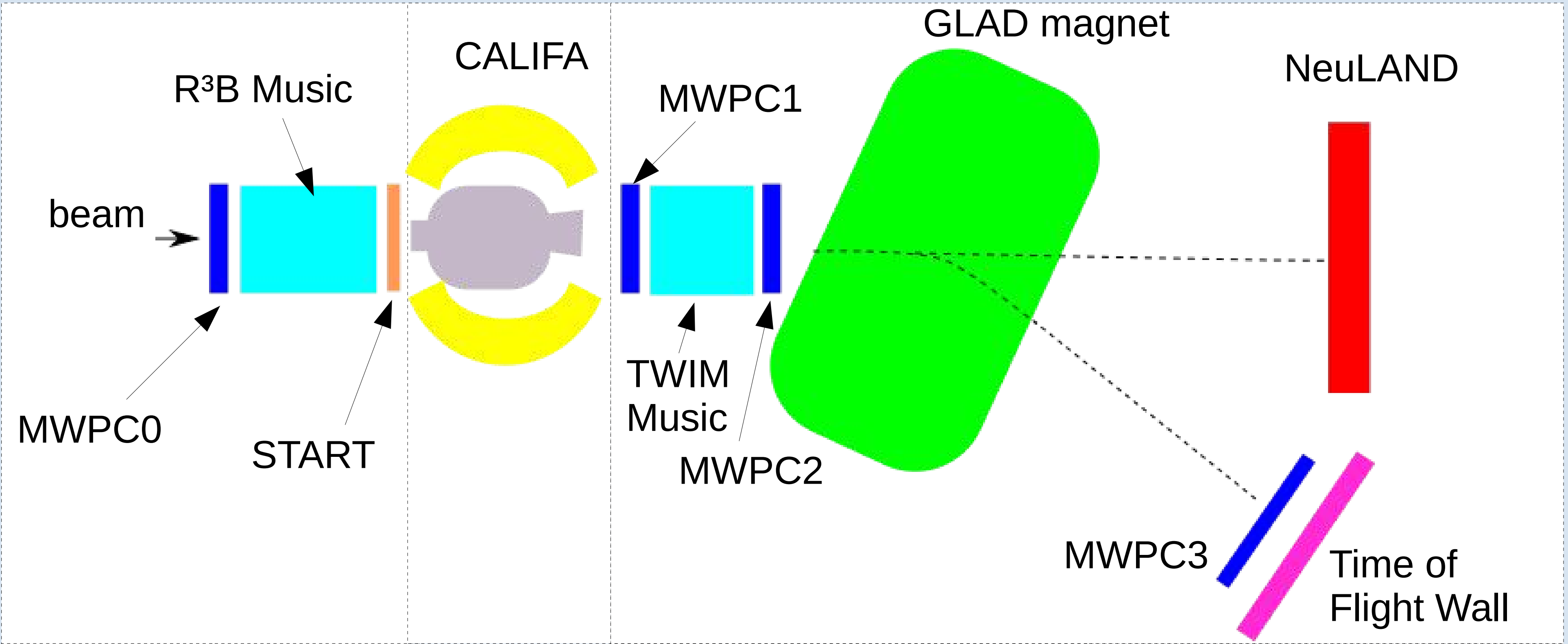
FAIR Construction Site

© D. Fehrenz, GSI/FAIR, May 2023

High Energy Cave

Dimensions: 60 x 20 x 7 m

R3B Setup*



Identification of incoming beam

Complete kinematic measurement of reaction channels

Measurement of γ/target-like particles

* S444 Experiment, 2020

CALIFA Detector @ R³B

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

Endcap:

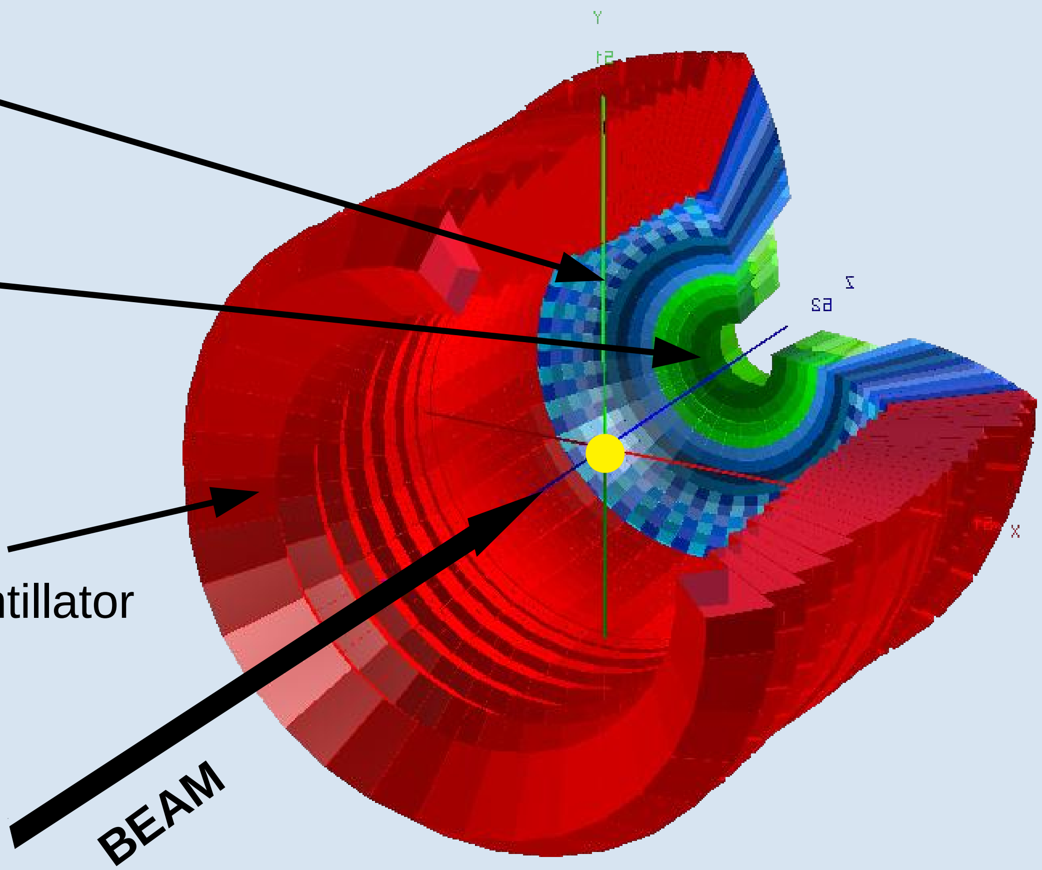
iPhos:

480 CsI(Tl) crystals

CEPA:

96 CsI (Tl) crystals

Barrel:
1952 CsI(Tl) scintillator crystals



Highly segmented detector:

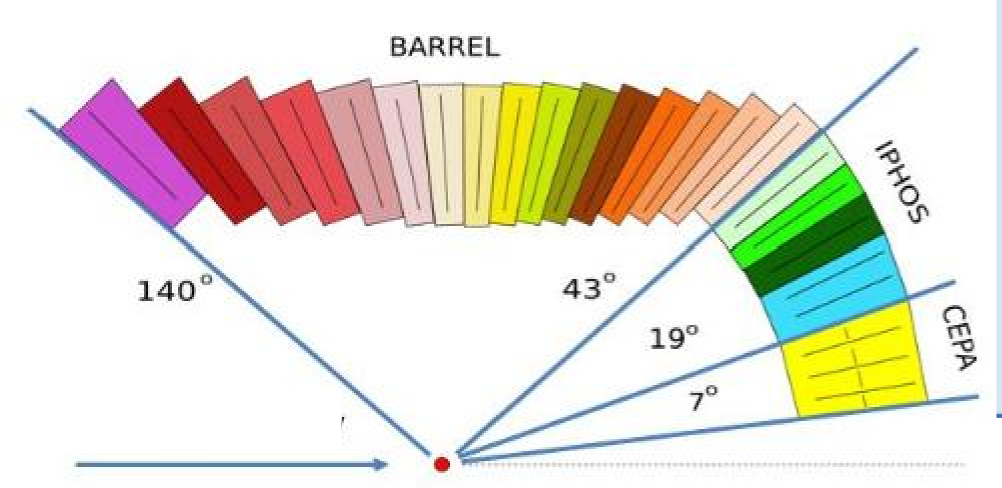
- good angular reconstruction/ doppler correction

Broad calorimetric energy measurements:

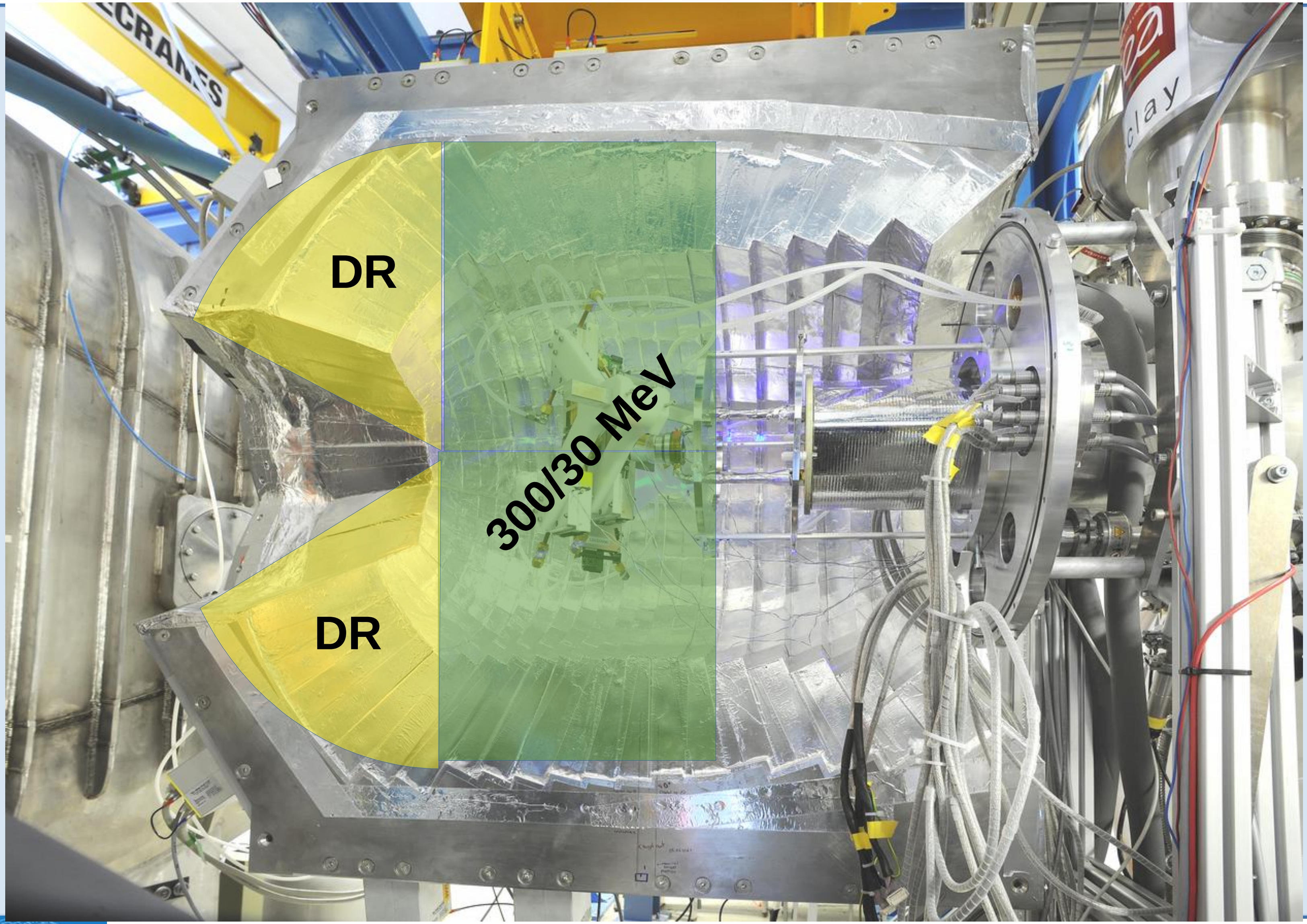
- From 100 keV γ-rays up to high energetic charged particles

Flexible running mode:

- self/external triggering mode



CALIFA Configuration (S522, 2022)

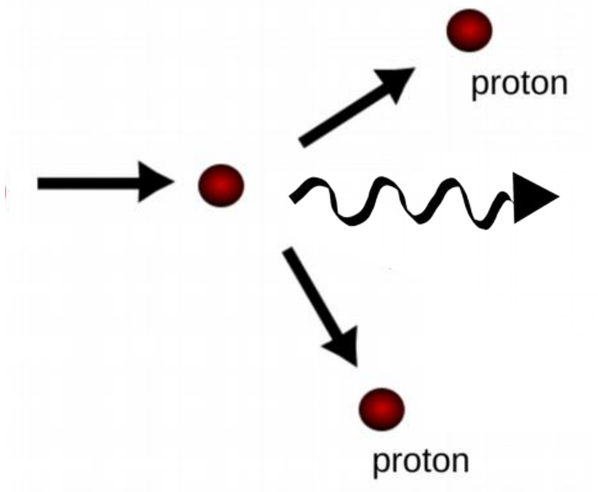


IPhos: 480 crystals
- completely filled
- readout with Dual Range Preamps

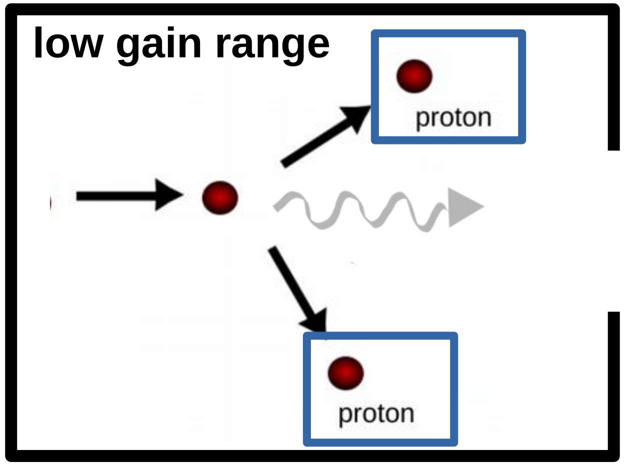
Barrel: 1024 crystals
- half filled
- readout with Single Range (300/30 MeV) Preamps

SingleRange Preamplifier

Dual Range Preamplifier

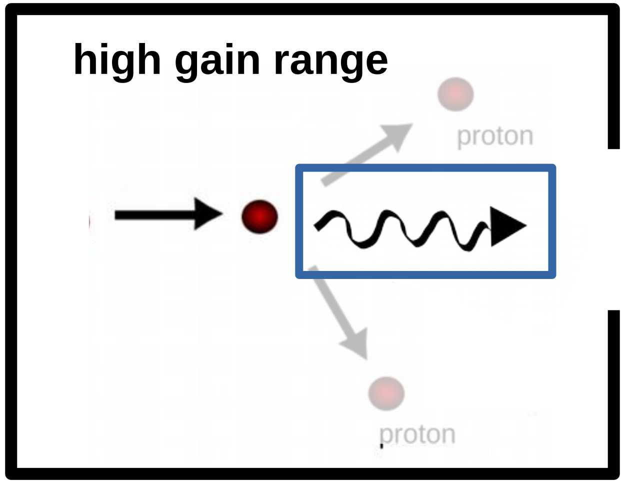


SIMULTANEOUS
high energetic paricle
measurement
&
gamma spectroscopy



Gamma
threshold:
500 keV

OR

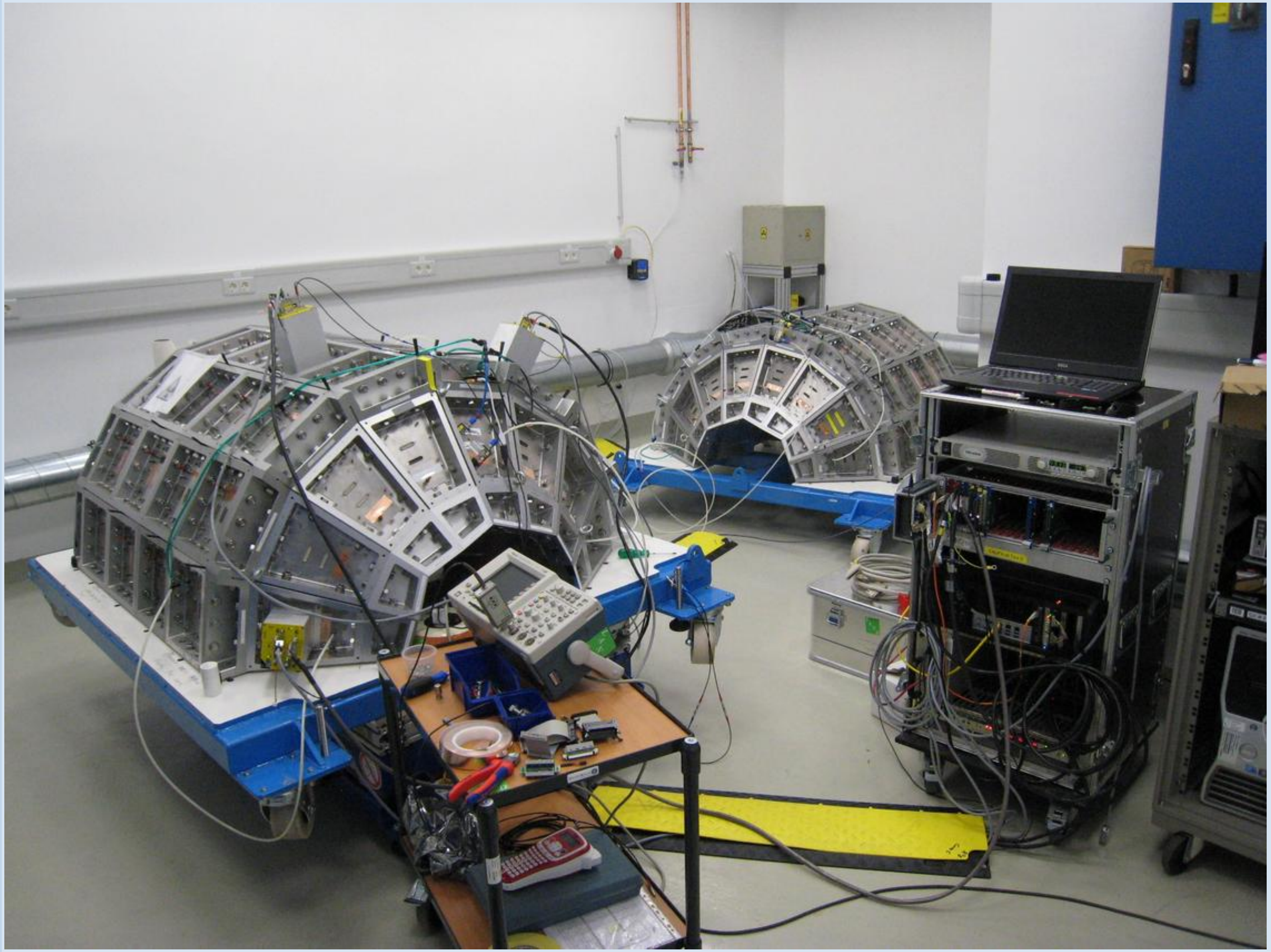


Gamma
threshold:
100 keV

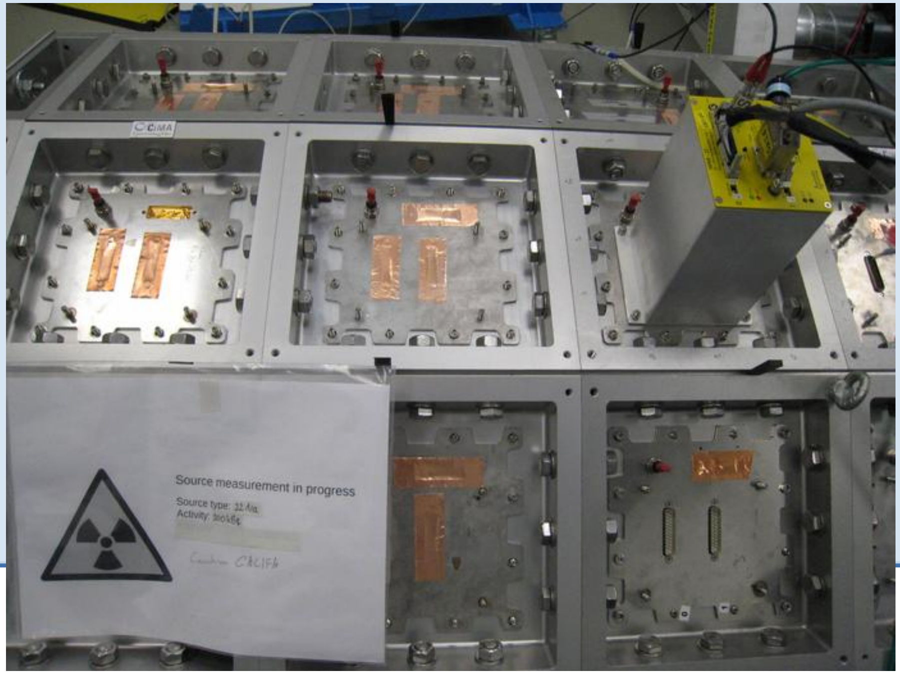
300/30

experiment dependent decision has to be taken beforehand!

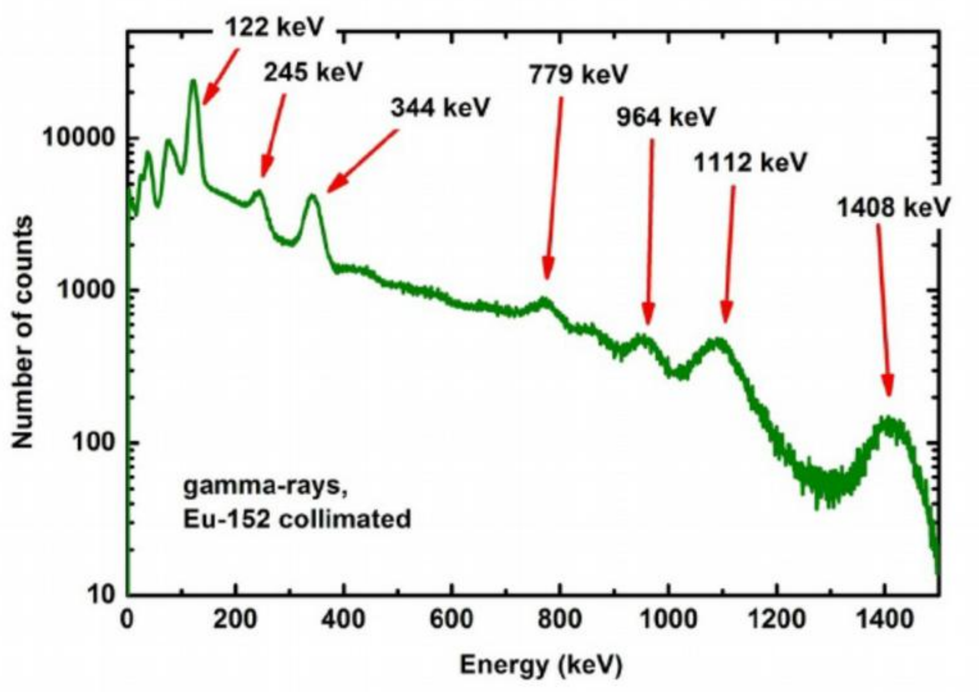
Meanwhile in R³B Preparation ROOM ….

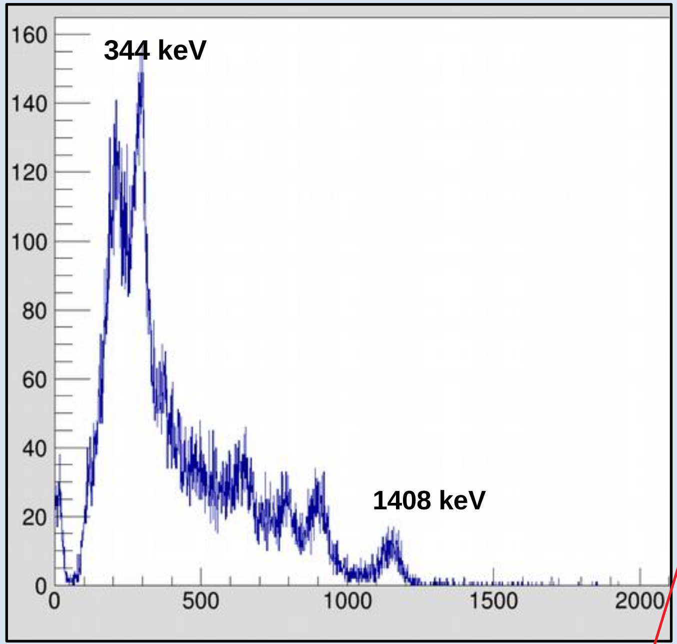


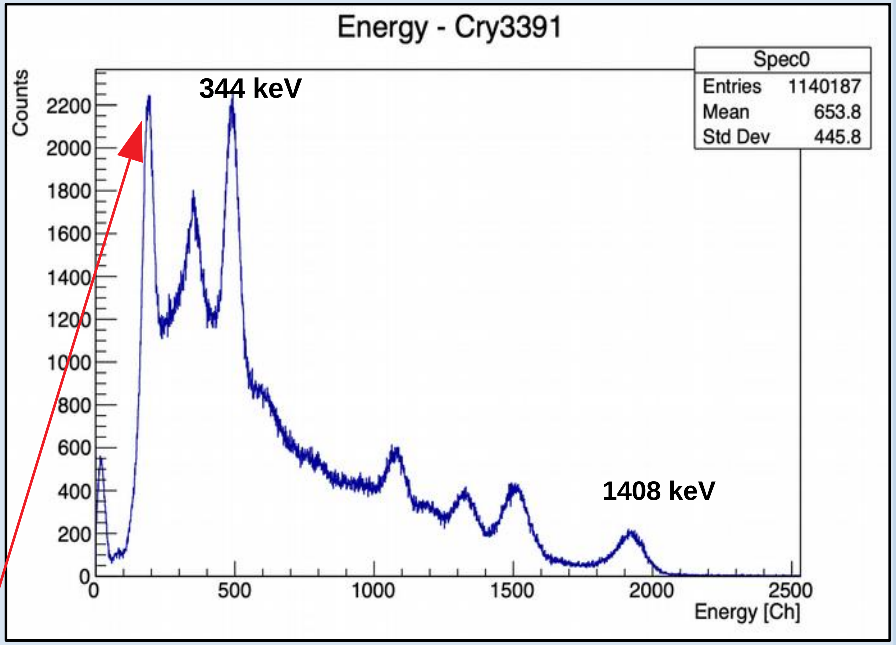
- Noise debugging
- Cable/connectors checking
- SR vs DR checks



Testing Gain





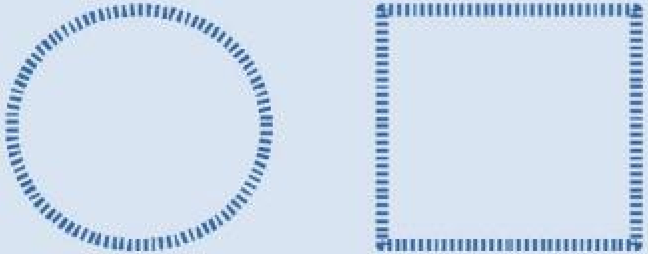


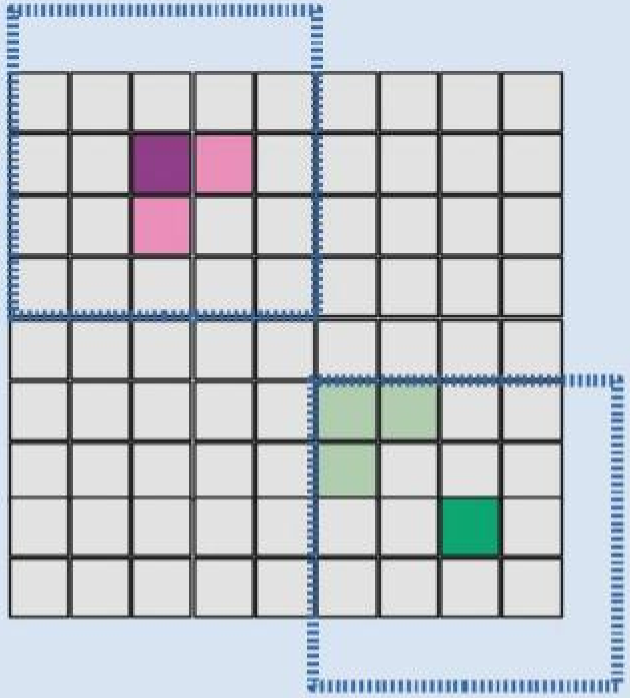
Raising the gain allows to measure down to the **122 keV** peak!

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

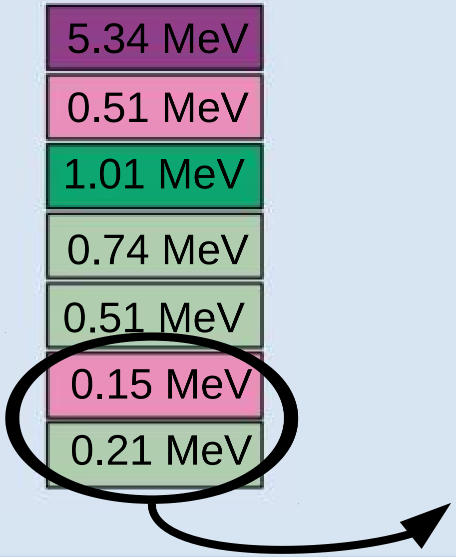
Add-Back Algorithm in CALIFA

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 !

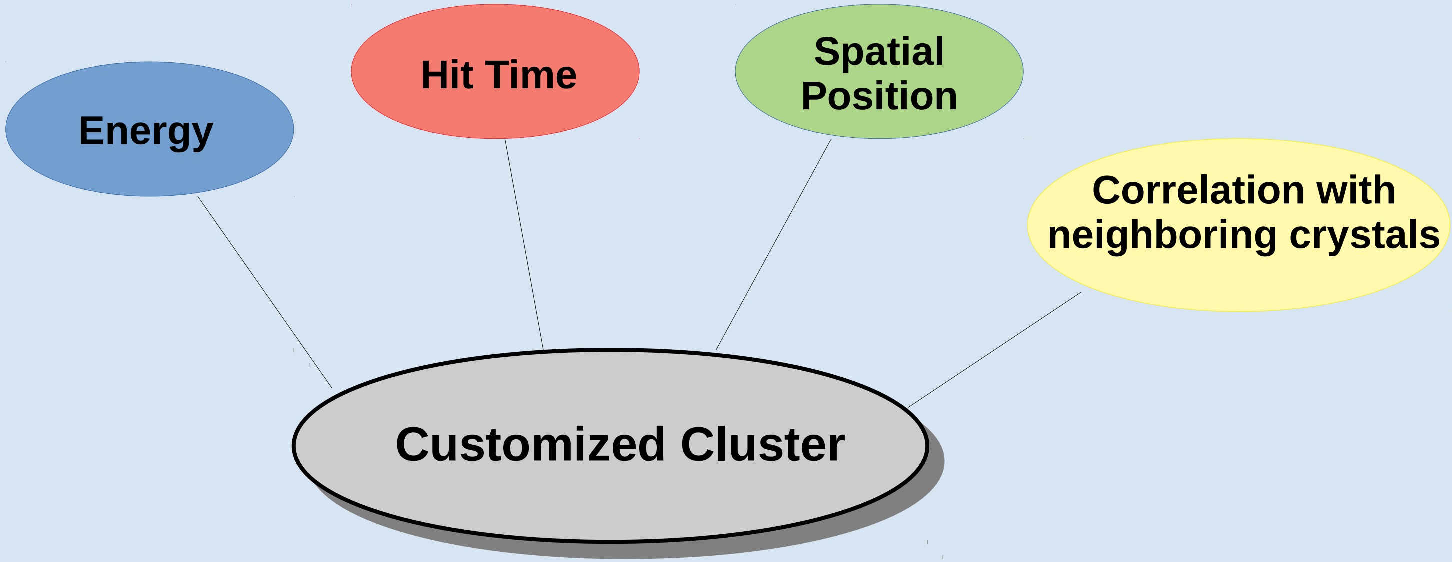
ODSL Collaboration - Optimize Add-Back Algorithm with AI

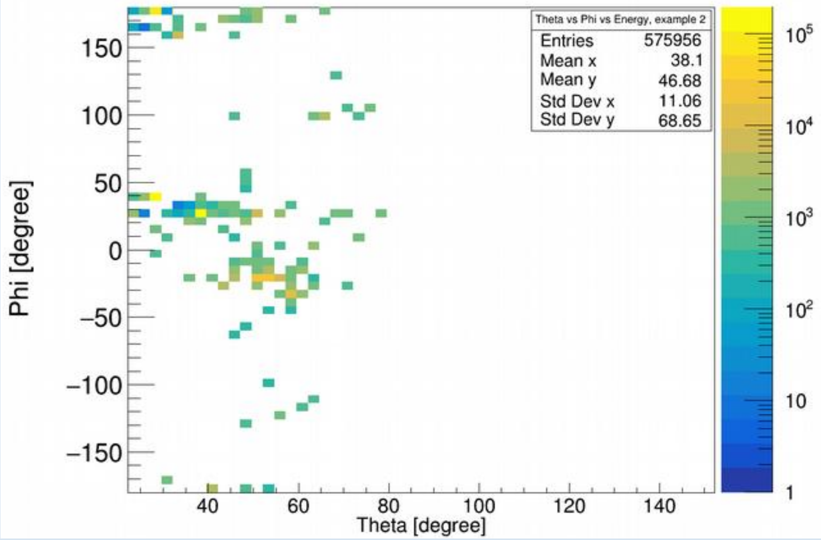
Use the power or Machine Learning:

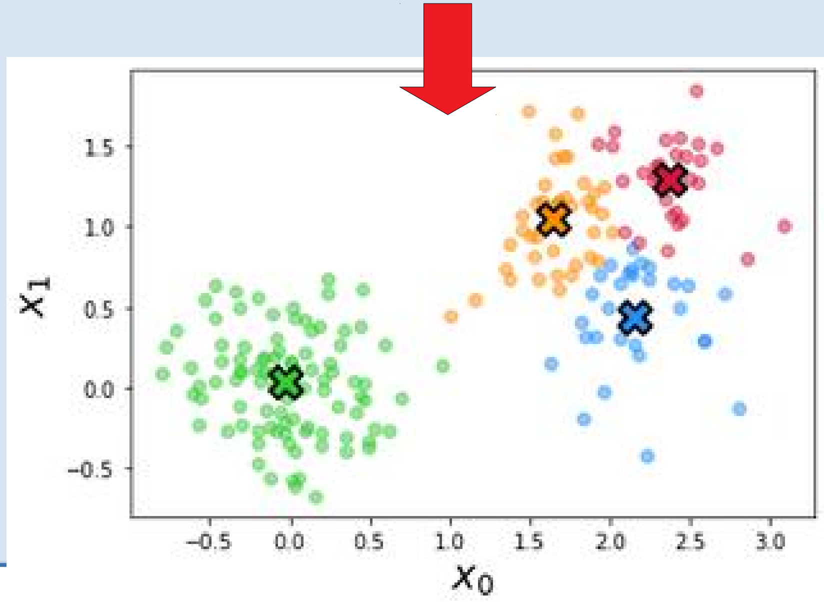
→ recognize the physics cases

→ optimize the cluster shapes (event by event)

→ give probability for fully contained physics event





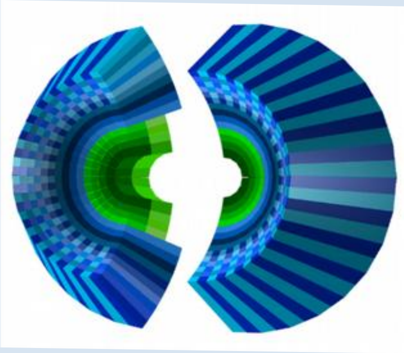


Supervisor: Prof. Dr. Lukas Heinrich

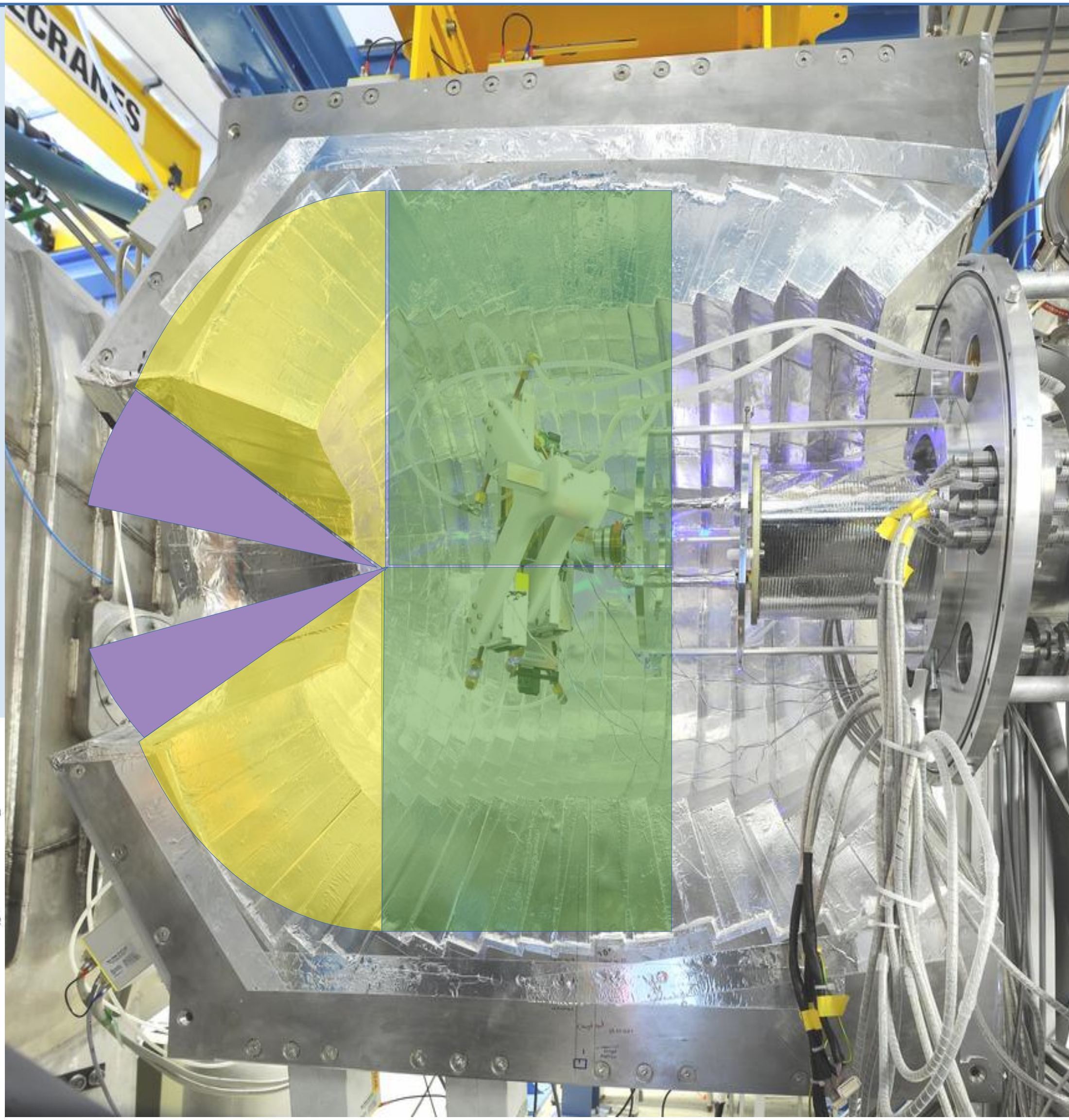
Filling CALIFA Endcap - CEPA

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

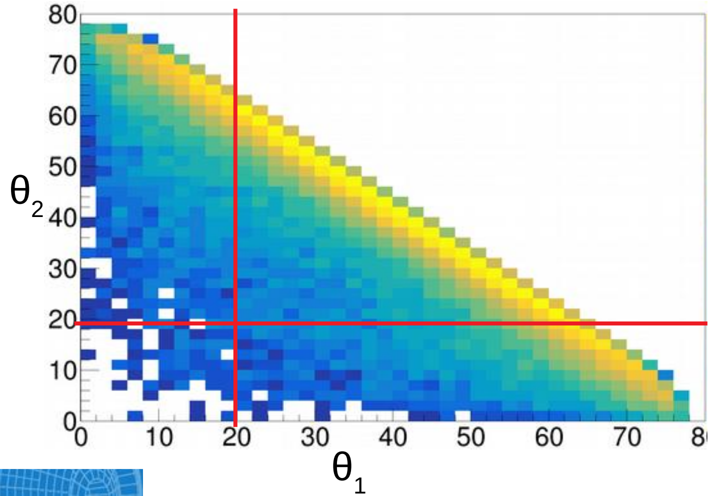
- Most forward section: 7° ≤ θ ≤ 19°
- 96 CsI crystals



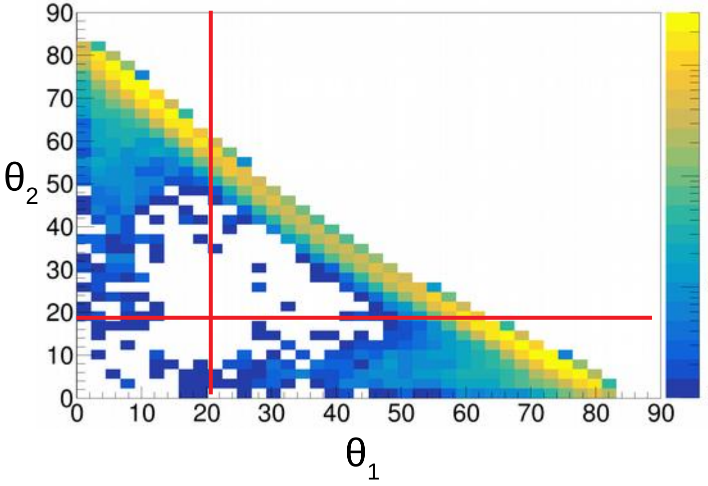
Improves geometric acceptance for high beam energies drastically



p2p-reaction, 400 AMeV



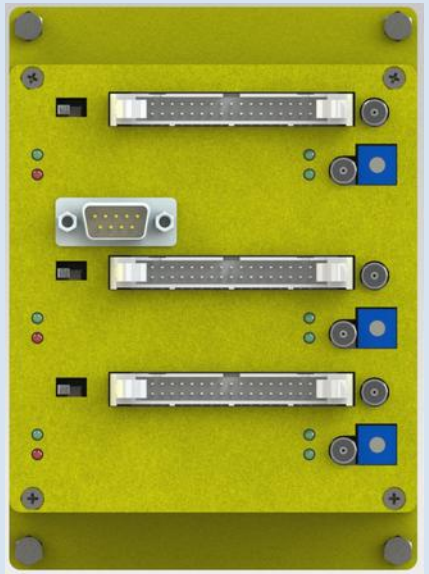
p2p-reaction, 1200 AMeV



Filling CEPA

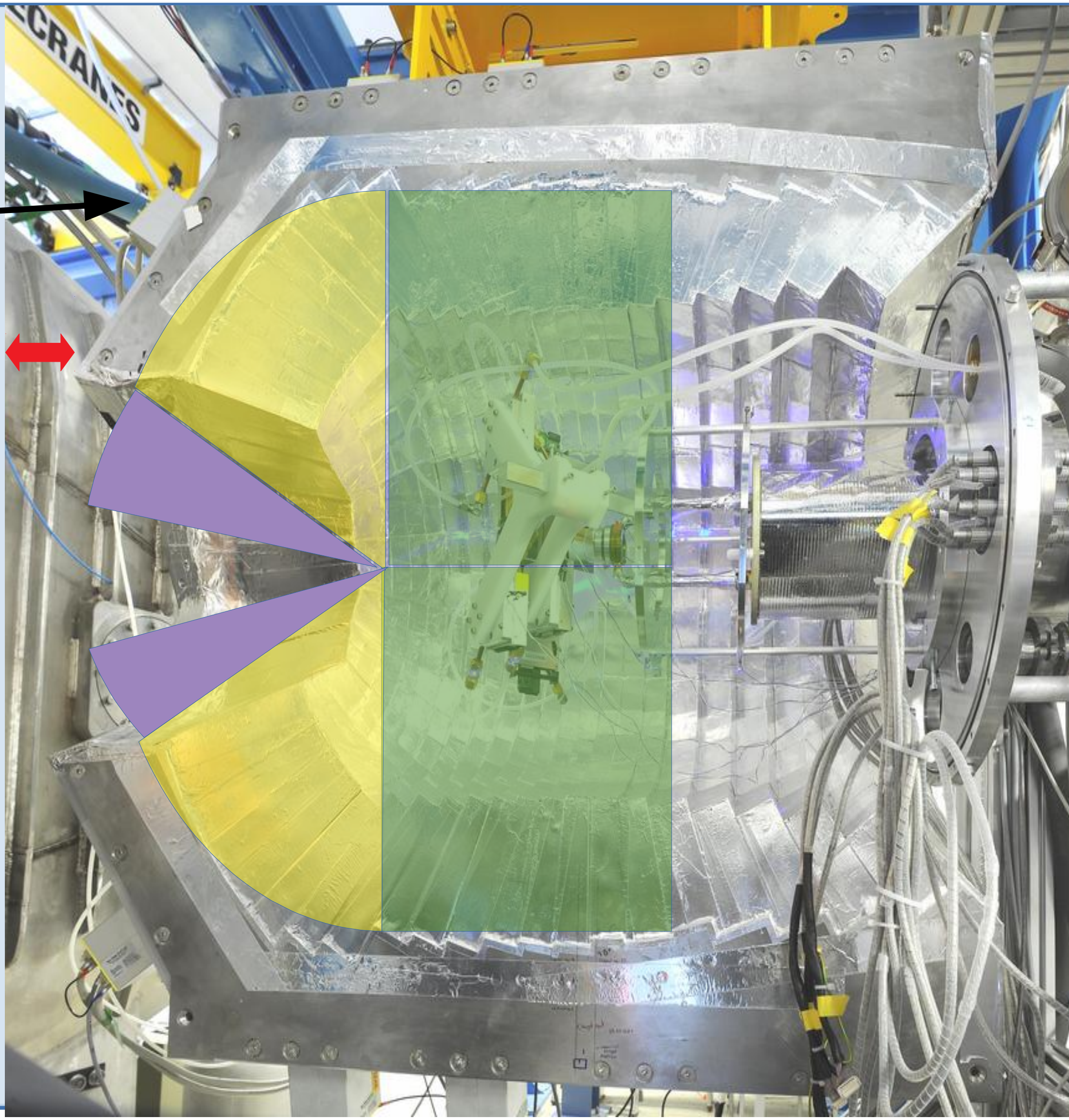
Mesytec MPRB-48 Dual Range Preamps

They get mounted on iPhos tiles

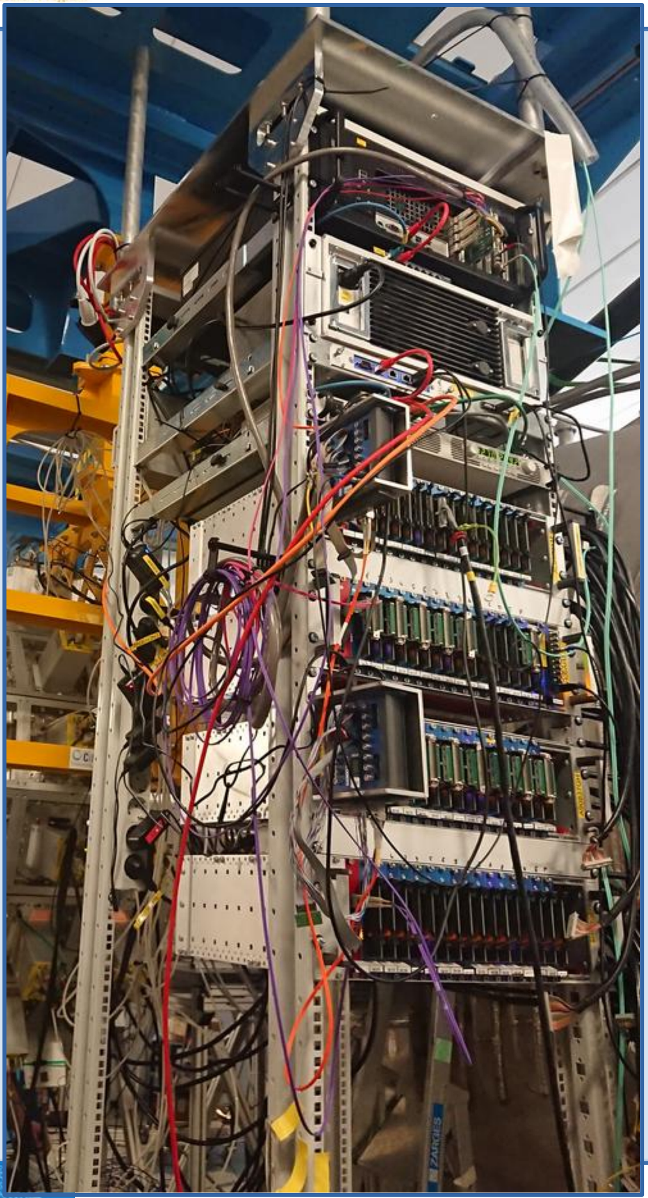


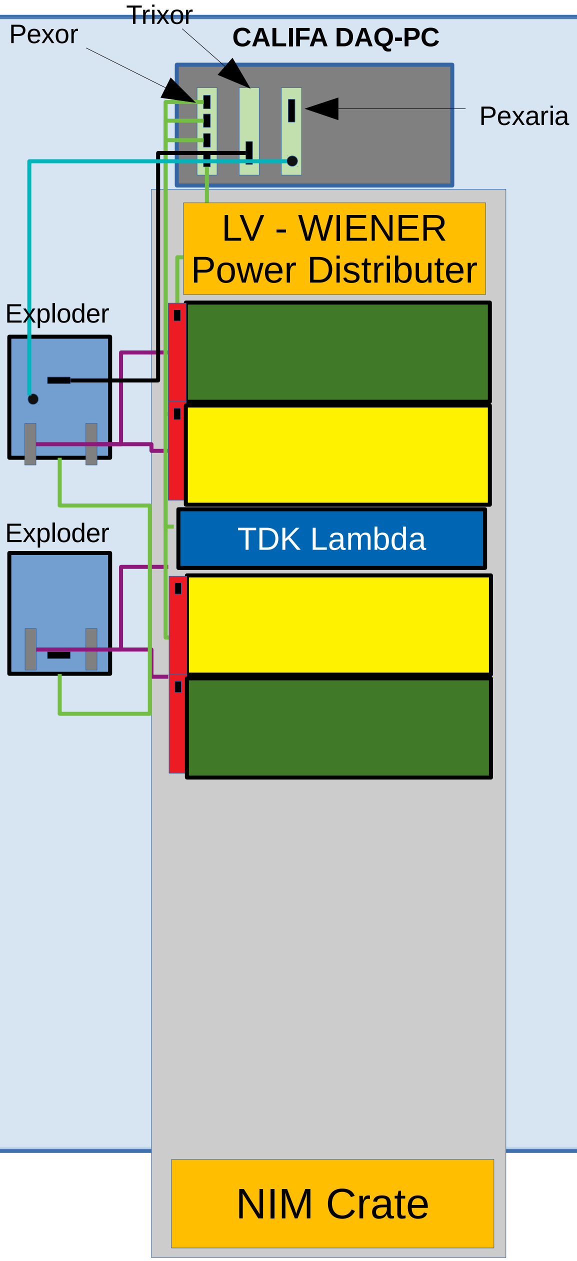
Connected to iPhos APDs
(32 channels)

Connected to CEPA APDs
(16 channels)



CALIFA DAQ Status (S522, 2022)





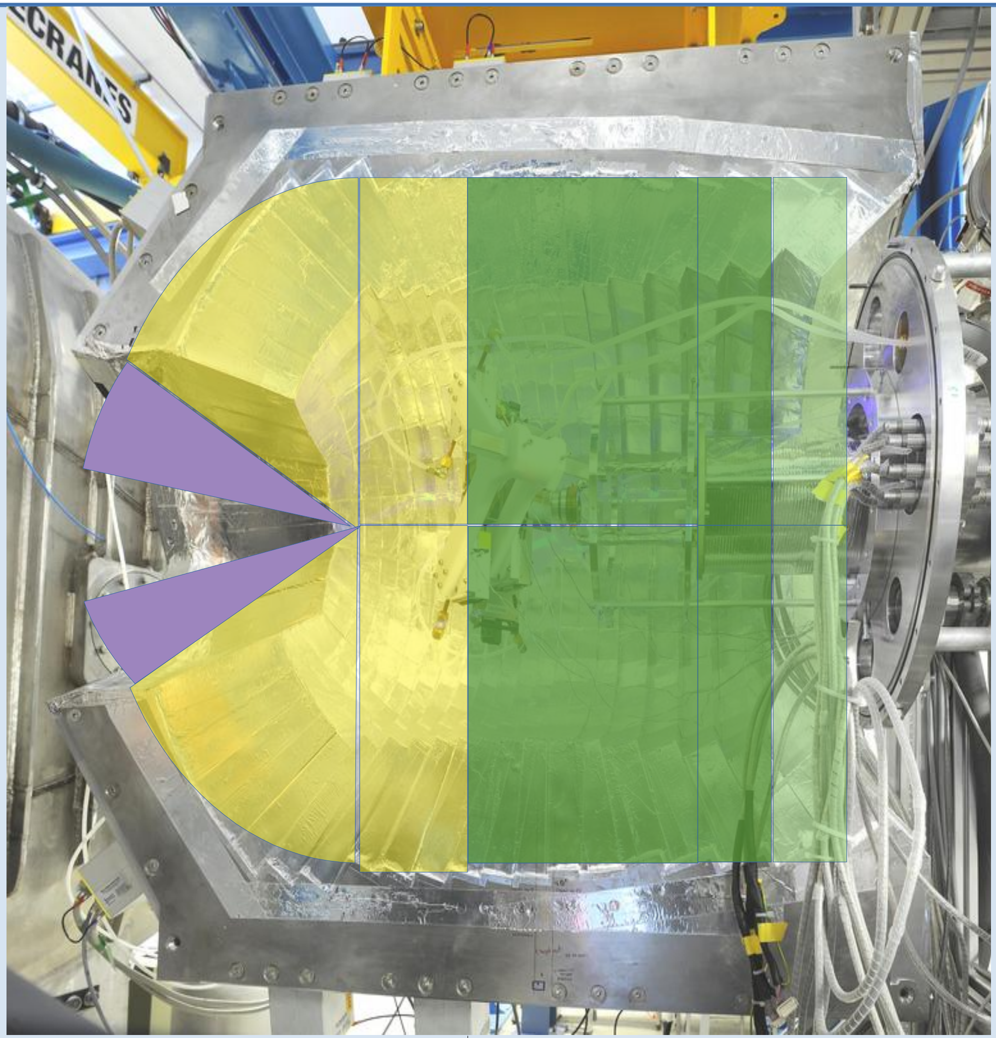
Electronic Rack

- 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

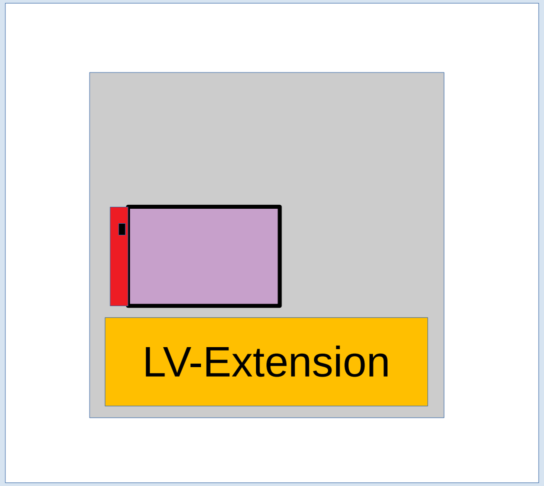
Cables

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

Final CALIFA Electronic Configuration

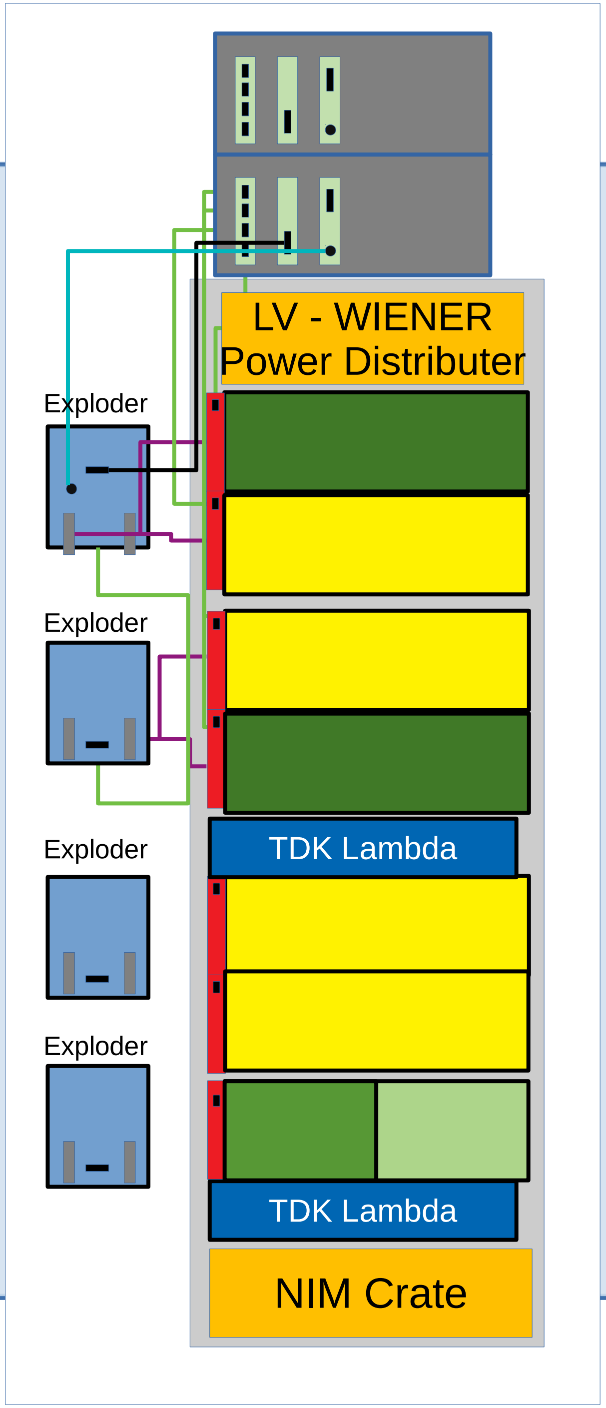


Dual Range Preamplifiers



Second Rack on each side needed!

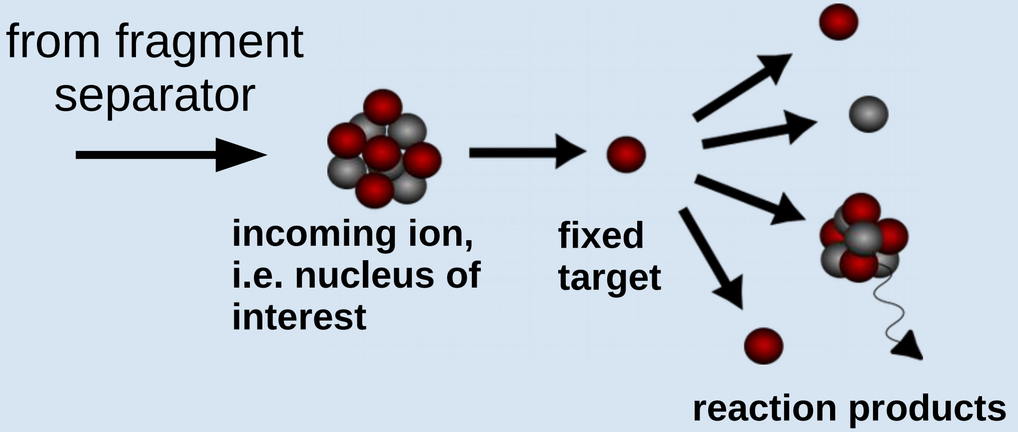
+

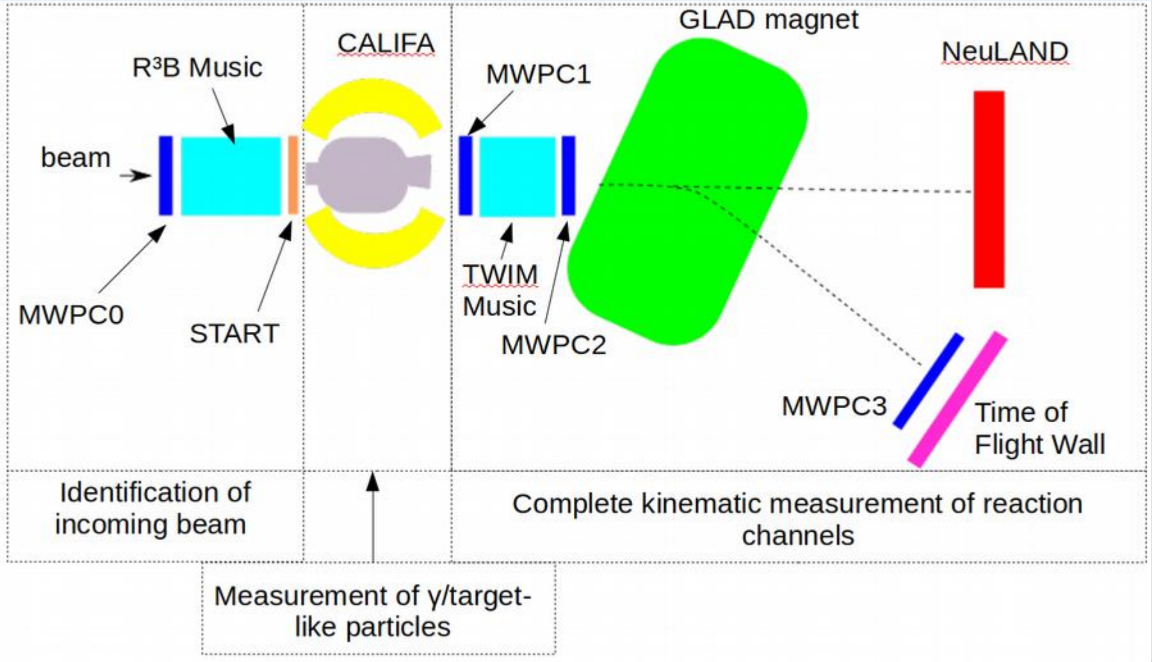


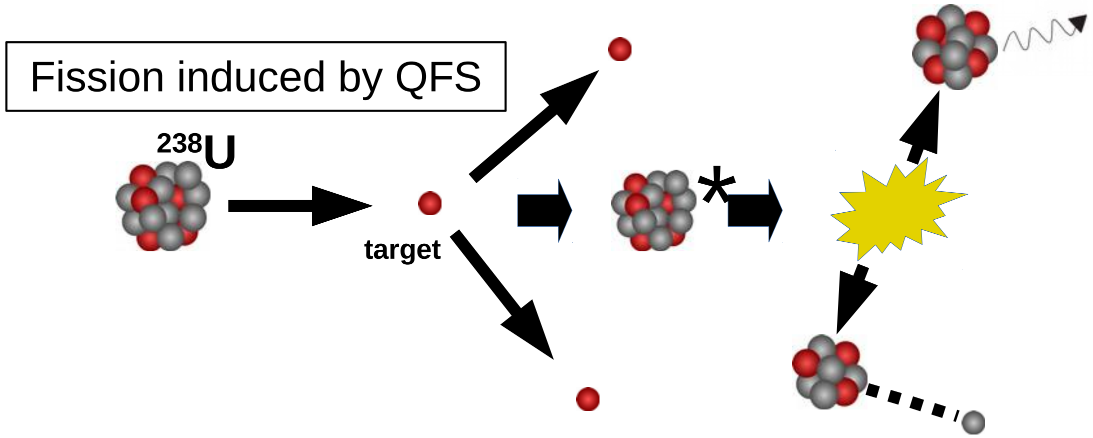
Physics at R3B with CALIFA

Physics Program @ R3B

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



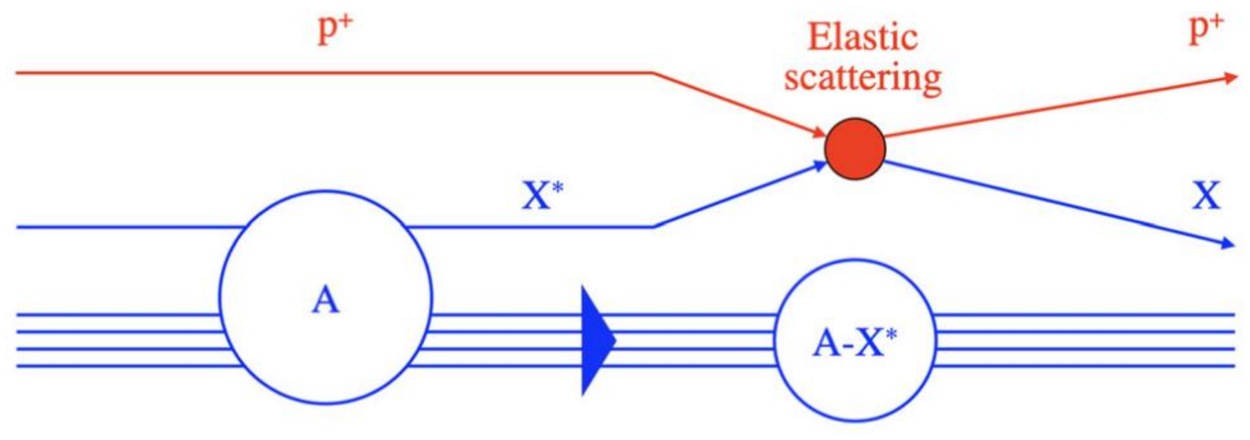




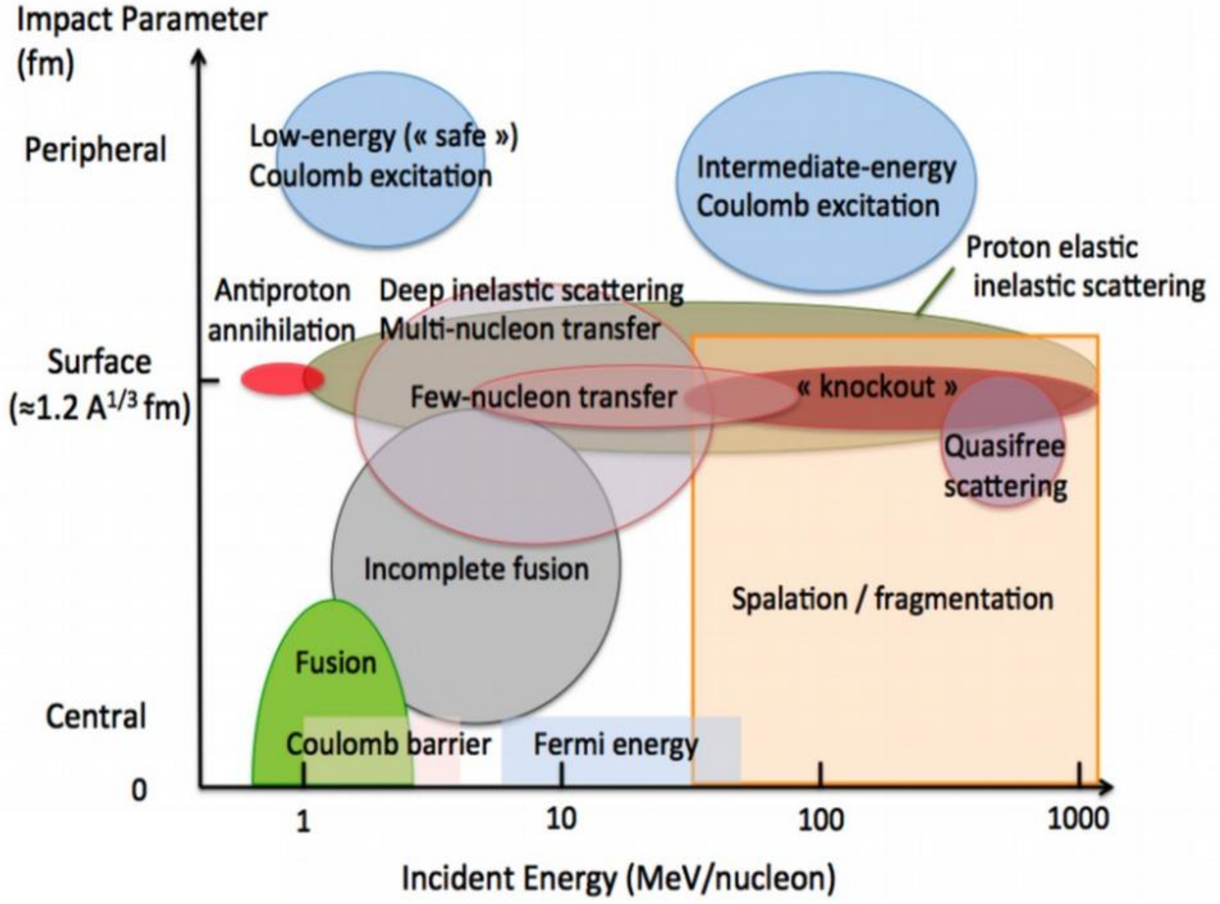
Quasi-Free Scattering Reactions

- 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.



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)

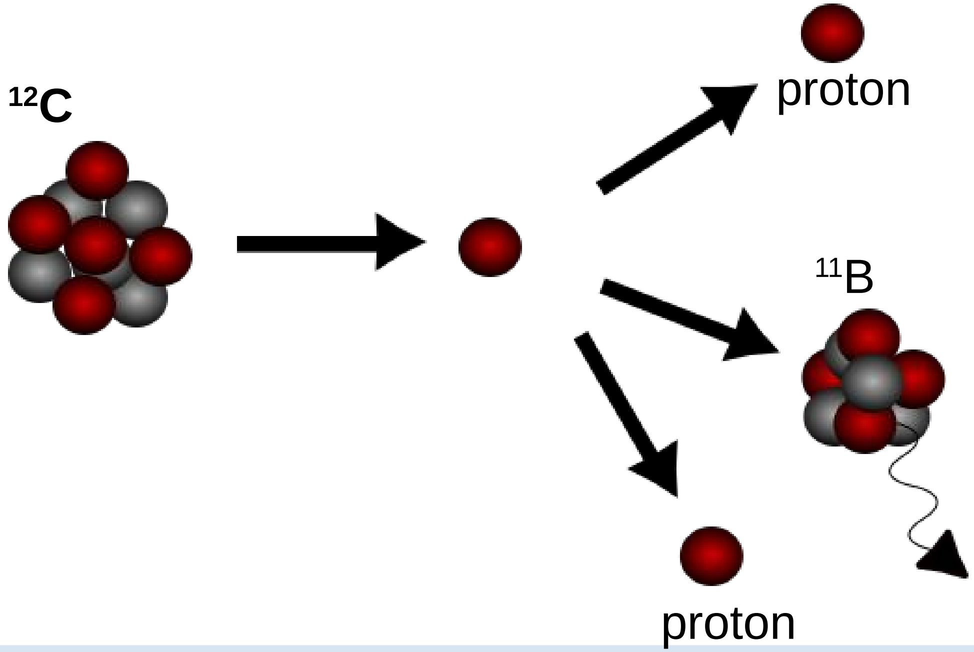
12C(p,2p)11B reaction:

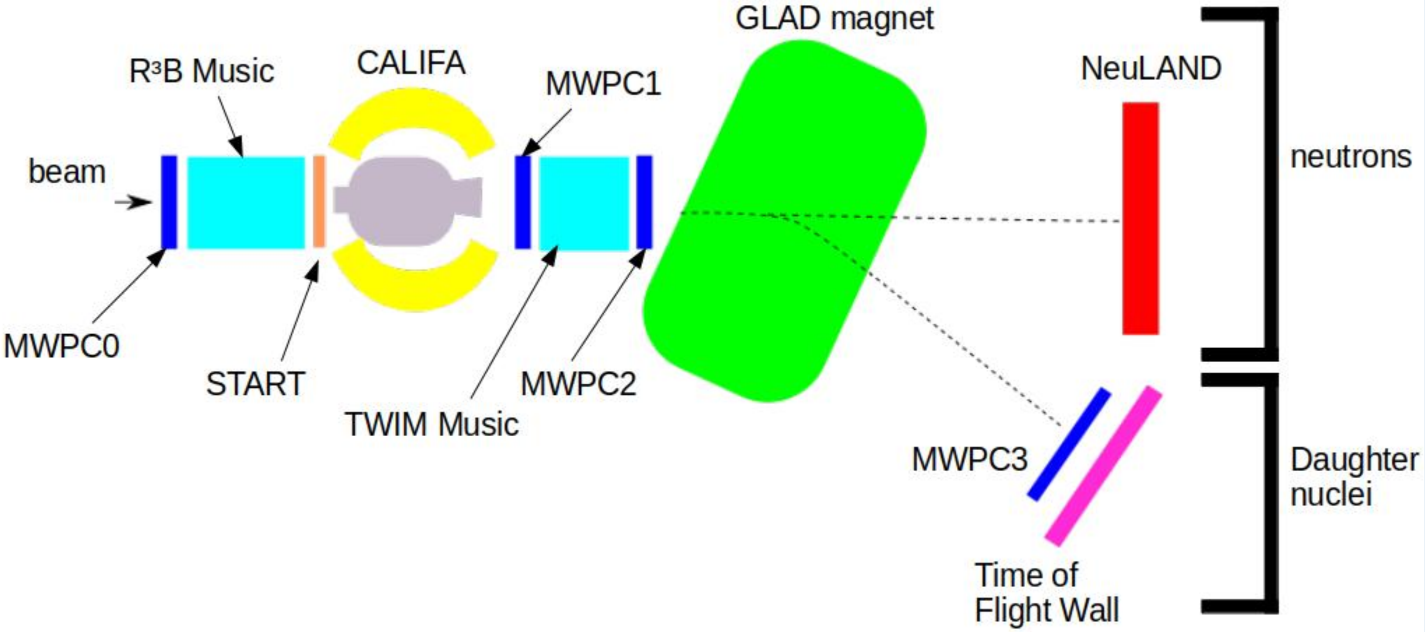
- ^{12}C beam
- proton like target

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

SETUP:

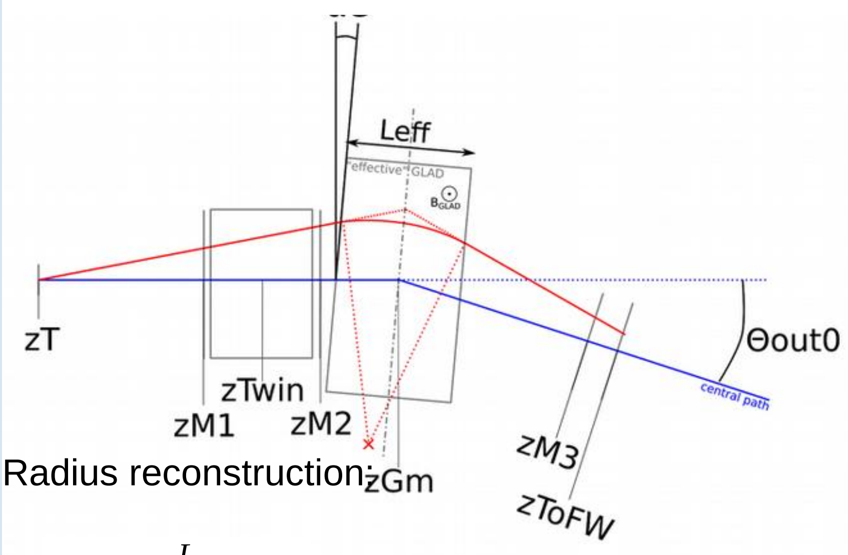
Beam energy: 400 AMeV
Beamtype: ^{12}C
Beamtime: 3 hours
Target: CH_2 (12.29 mm)





Fragment Particle Identification

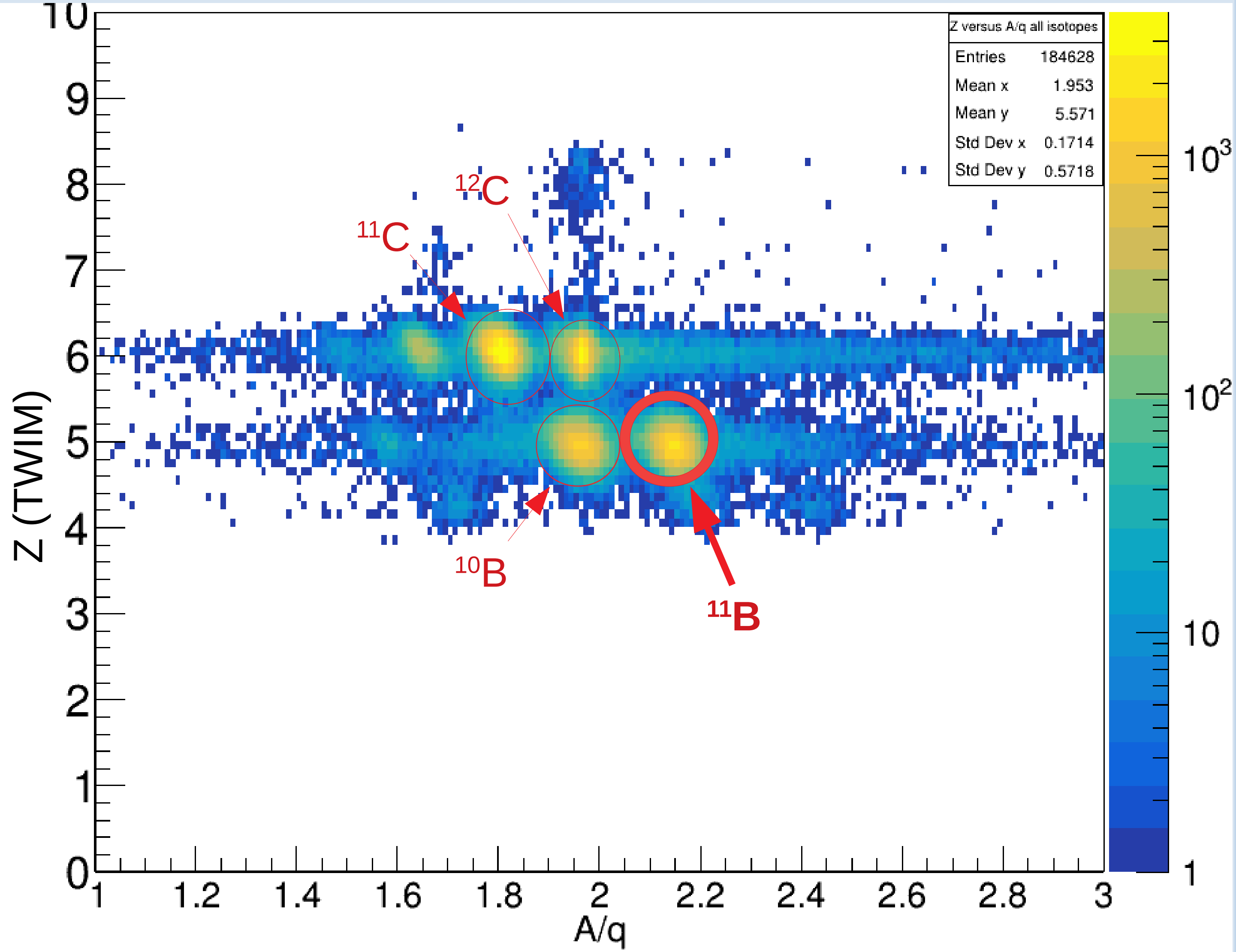
Flightpath reconstruction:



Radius reconstruction:

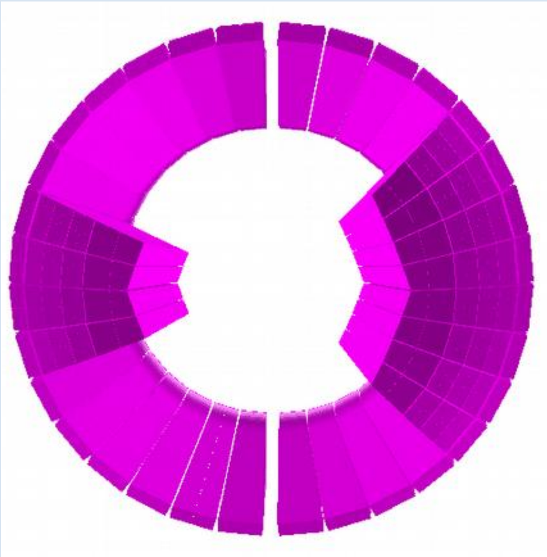
$$R = \frac{L_{eff}}{2\sin\left(\frac{\theta_{in}+\theta_{out}}{2}\right)}$$

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

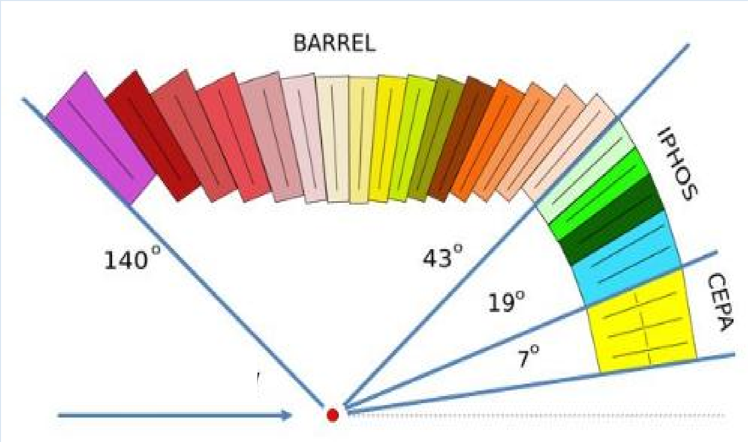


Identification of the two correlated Protons

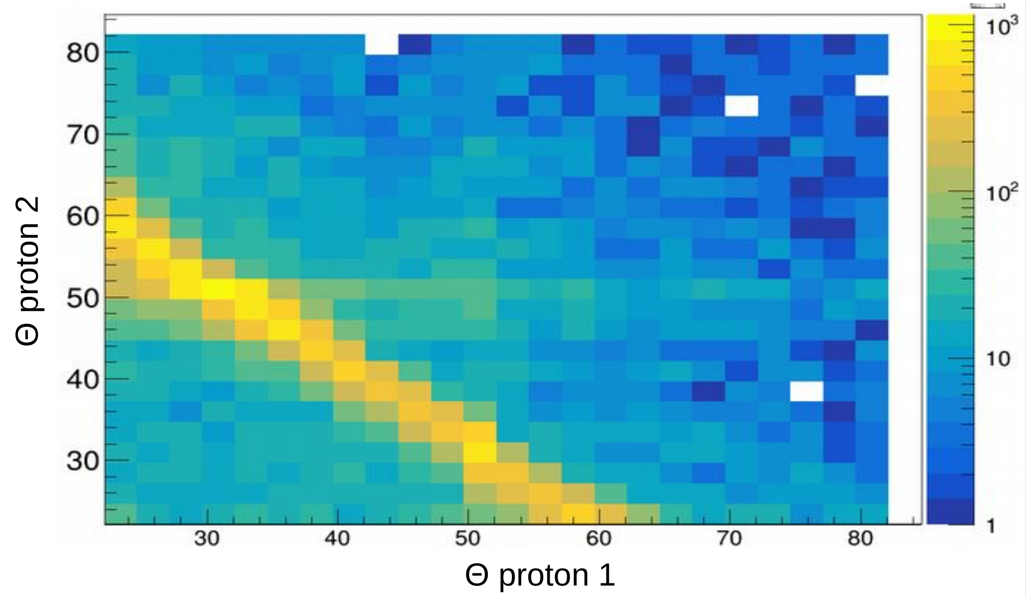
CALIFA Front View

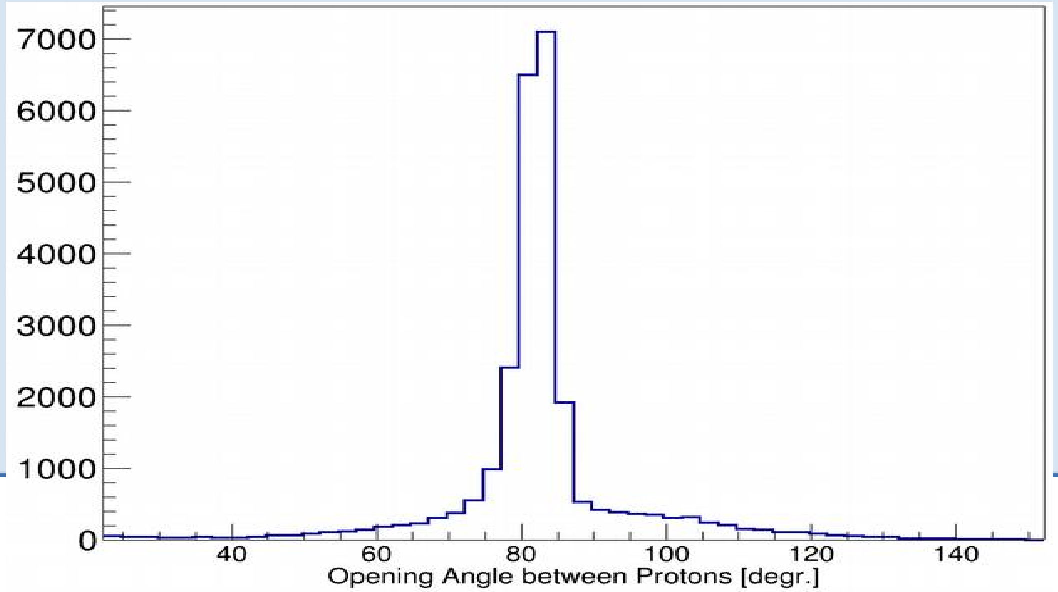


CALIFA Side View

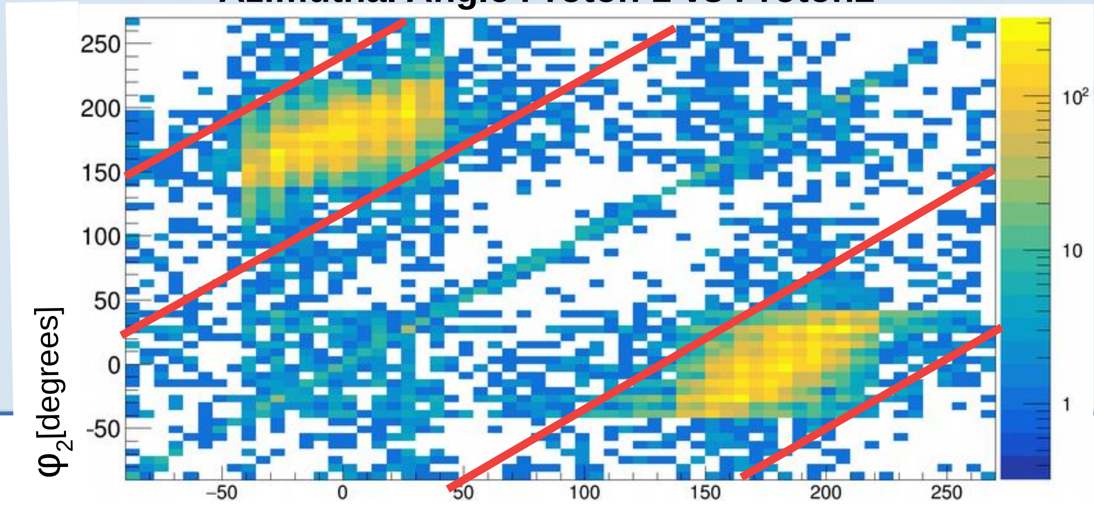


Polar Angle of p_1 and p_2





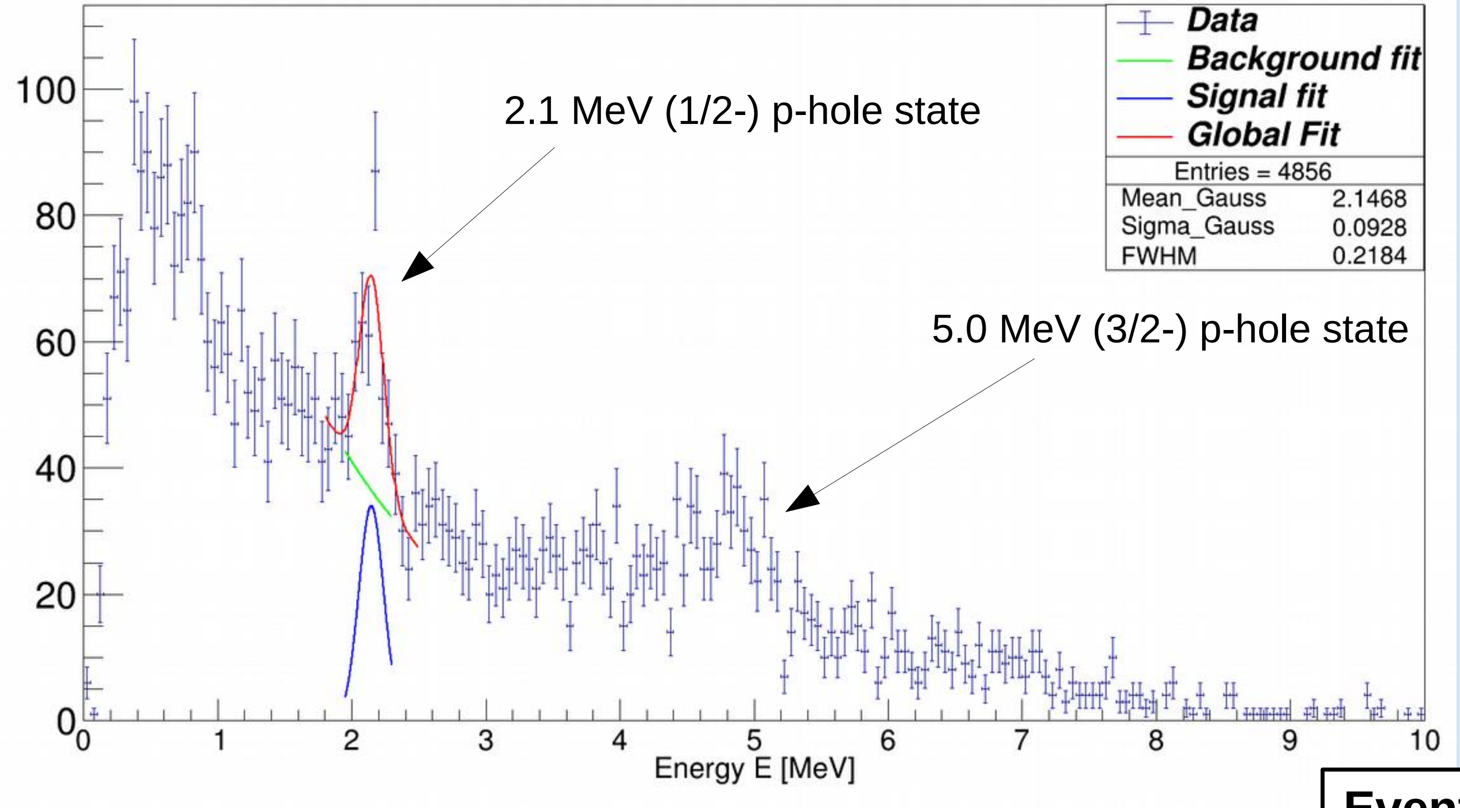
Azimuthal Angle Proton 1 vs Proton2

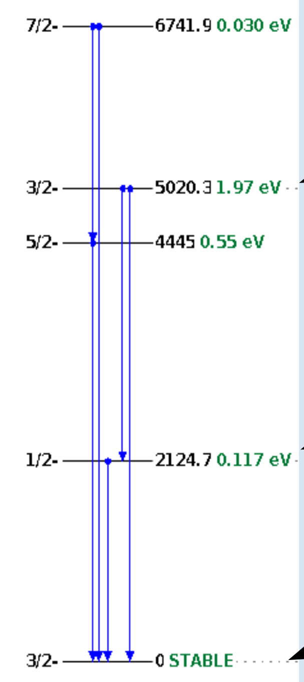


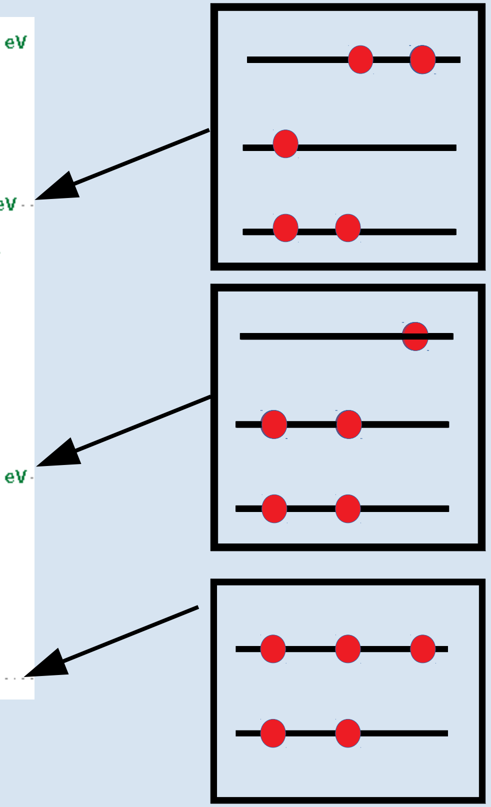
Gamma Spectrum of ^{11}B

Doppler Corrected Gamma Spectrum

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



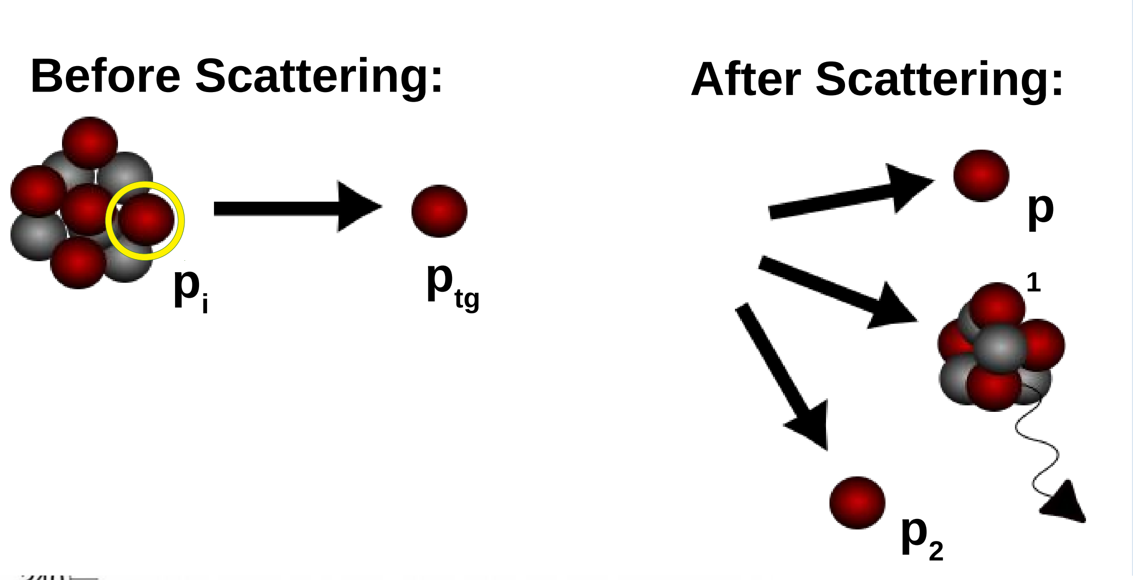


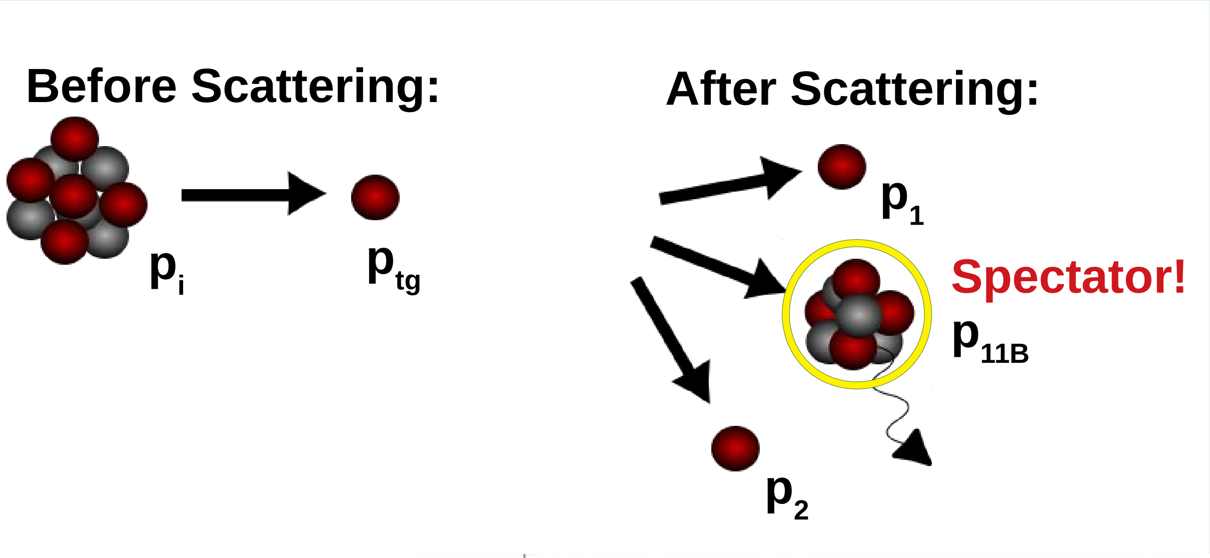


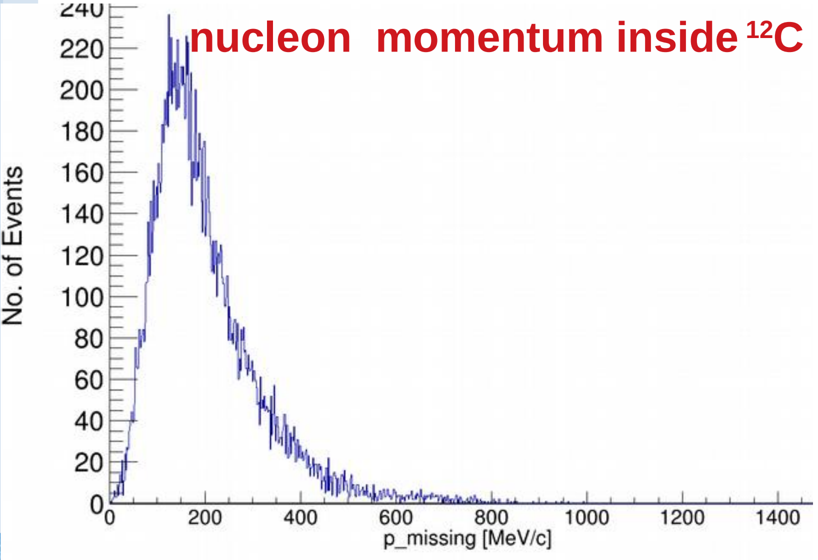
Event Selection Criteria:

- ^{11}B fragment identification
- Two hits (protons) with E_{hit} > 30 MeV
- $\theta1 + \theta2 < 90°$
- $\Delta\varphi = 180° \pm 40°$

Reconstruction of Inner Momenta







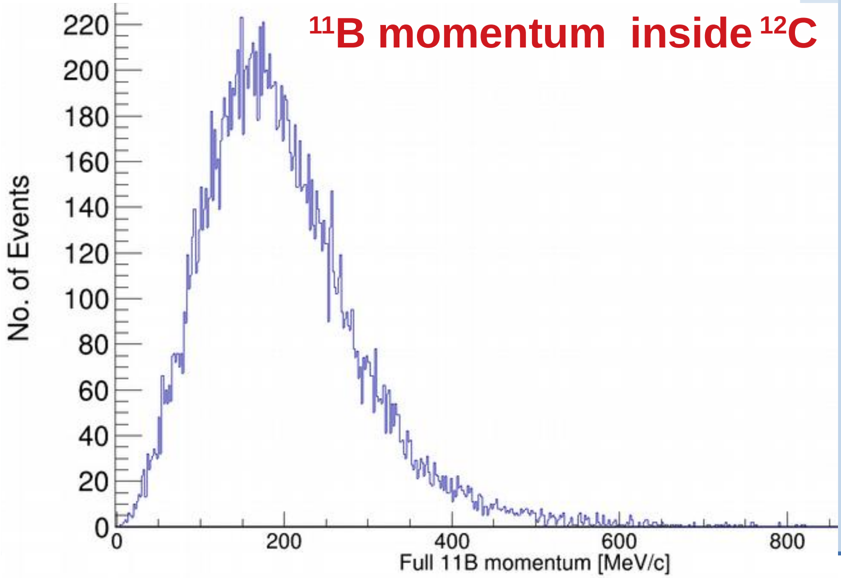
(Four-)Momentum conservation relation:

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

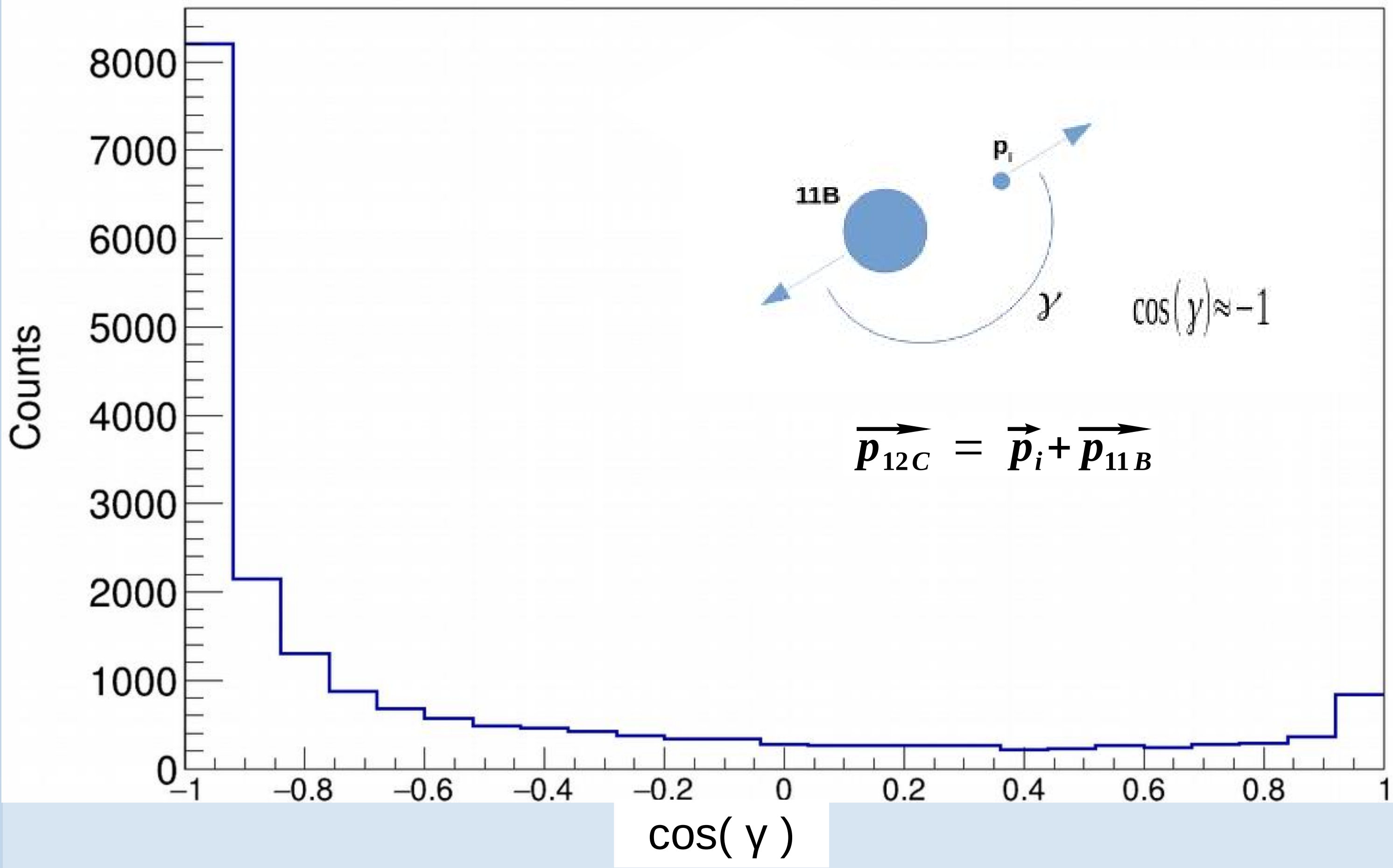
assuming QE scattering in mean field potential:

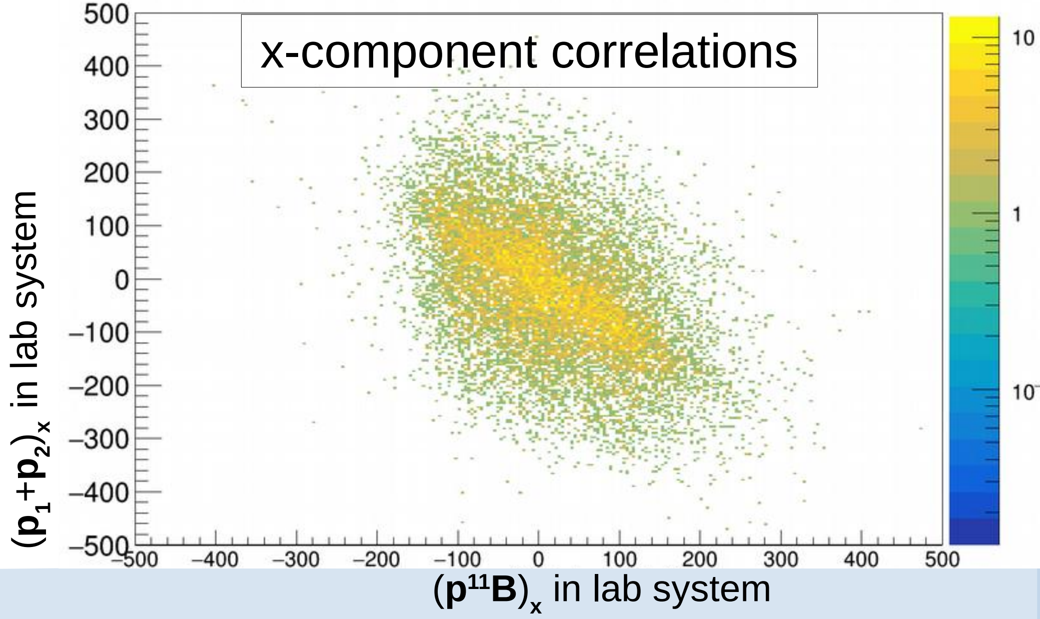
$$p_{12C} = p_i + p_{11B}$$

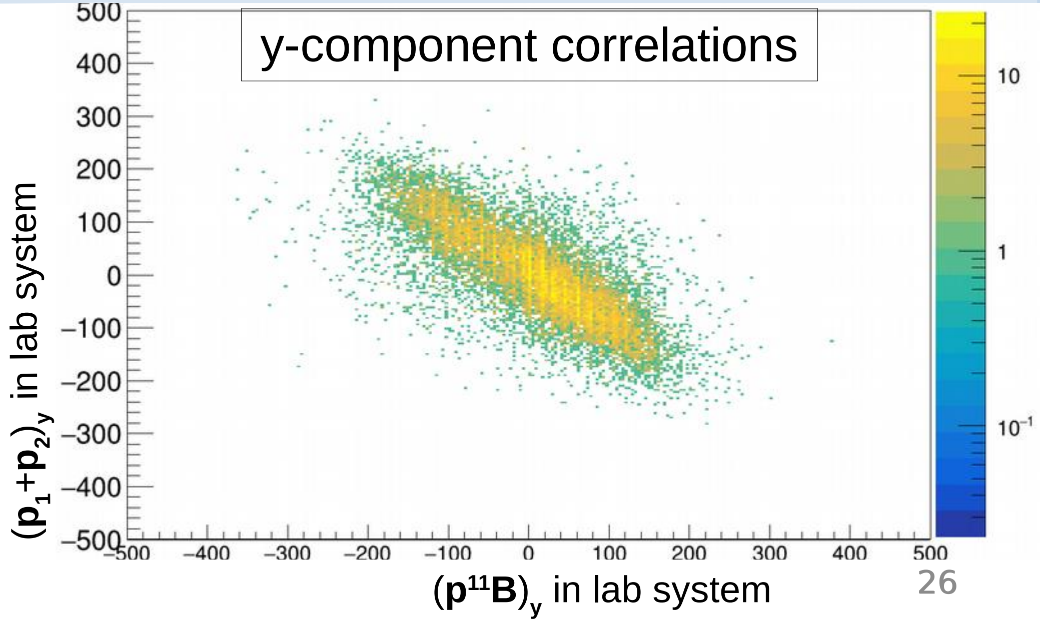
$$p_i \approx p_{missing} = p_1 + p_2 - p_{tg} \left(no\ ISI / FSI \right)$$



Correlations between Fragment and Proton Pair



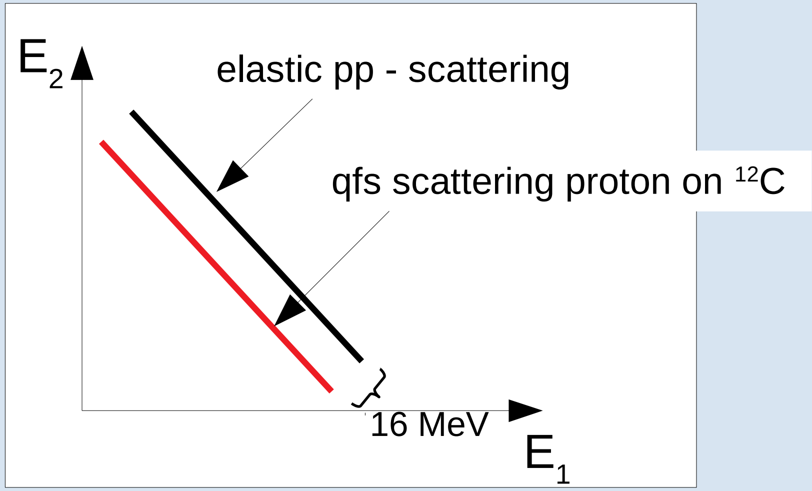


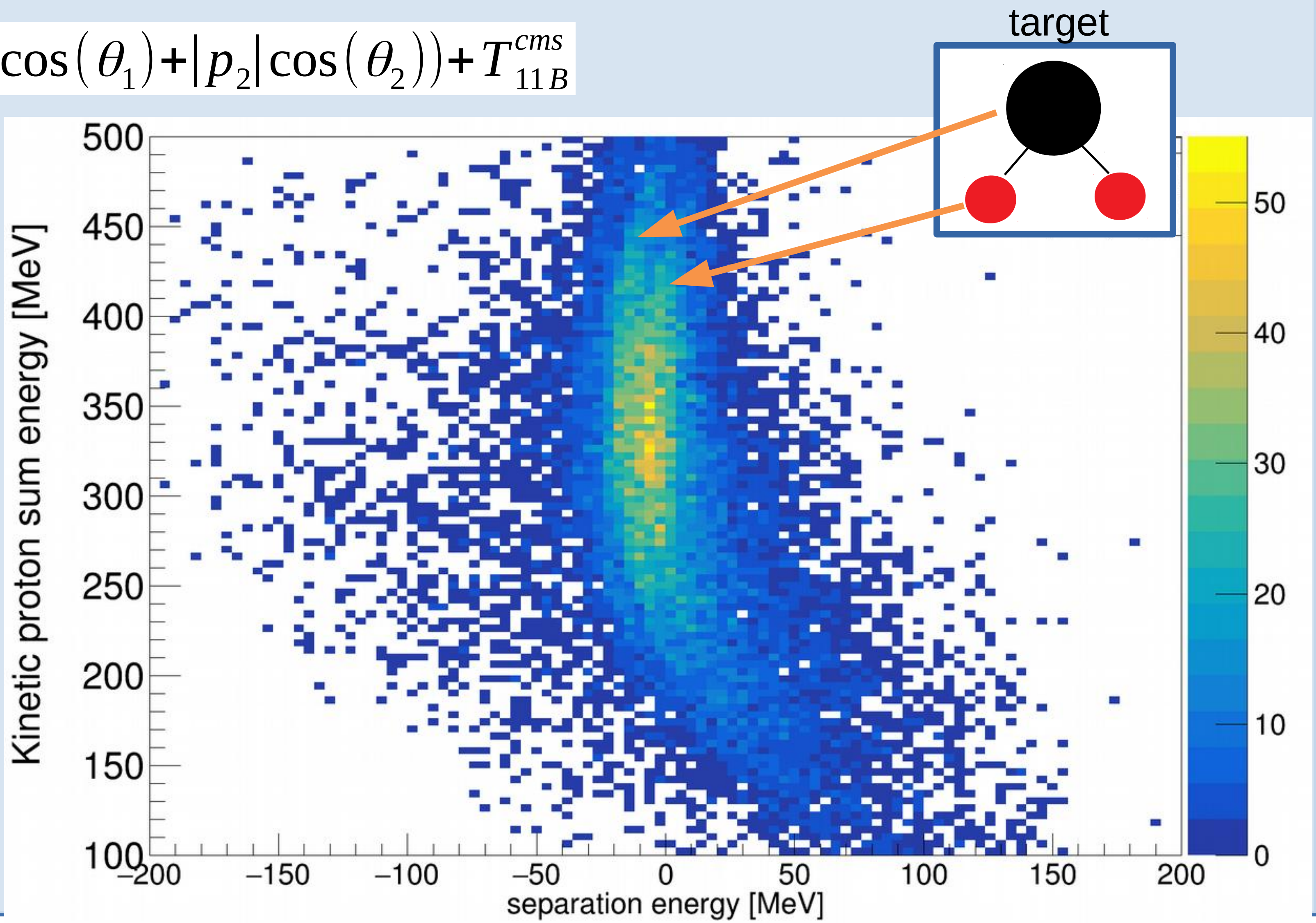


$$S_p = (\gamma - 1) m_p + \gamma (T_1 + T_2) - \beta \gamma (|p_1| \cos(\theta_1) + |p_2| \cos(\theta_2)) + T^{cms}_{11B}$$

S_p = Energy needed to remove one proton from the nucleus

In direct kinematics it would be:





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

Selection Cuts:

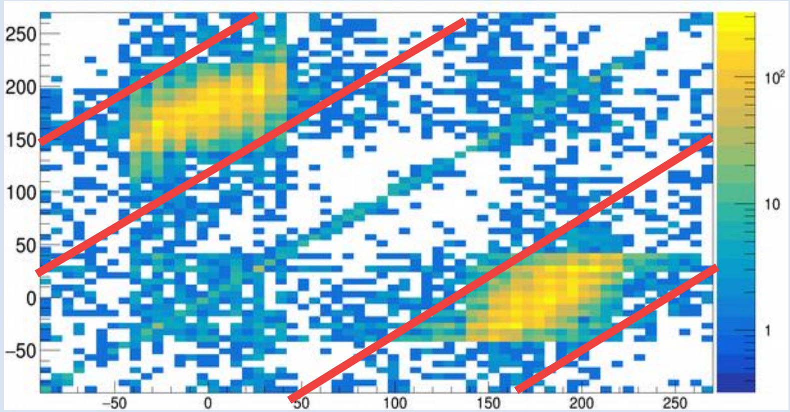
→ strict event selection in front of target

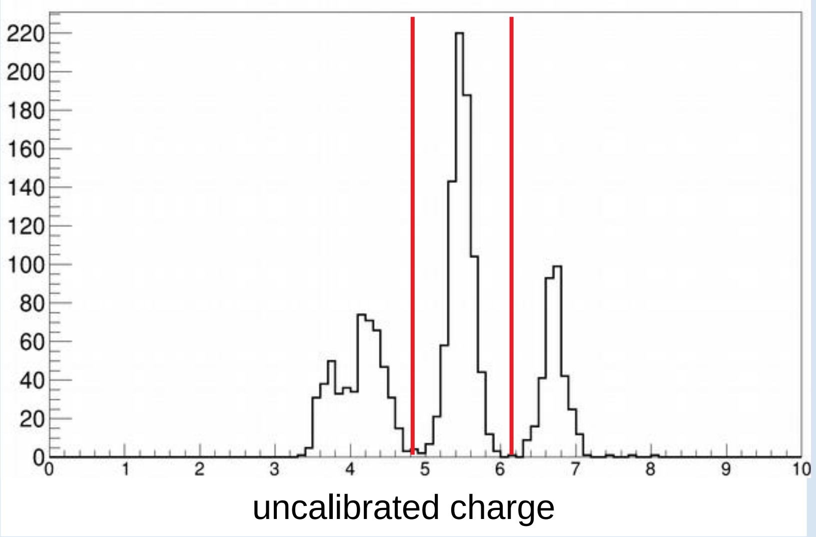
→ 2 hits in CALIFA with $E_{1/2}$ > 30 MeV

→ $\Delta\varphi$ = 180 +- 40°

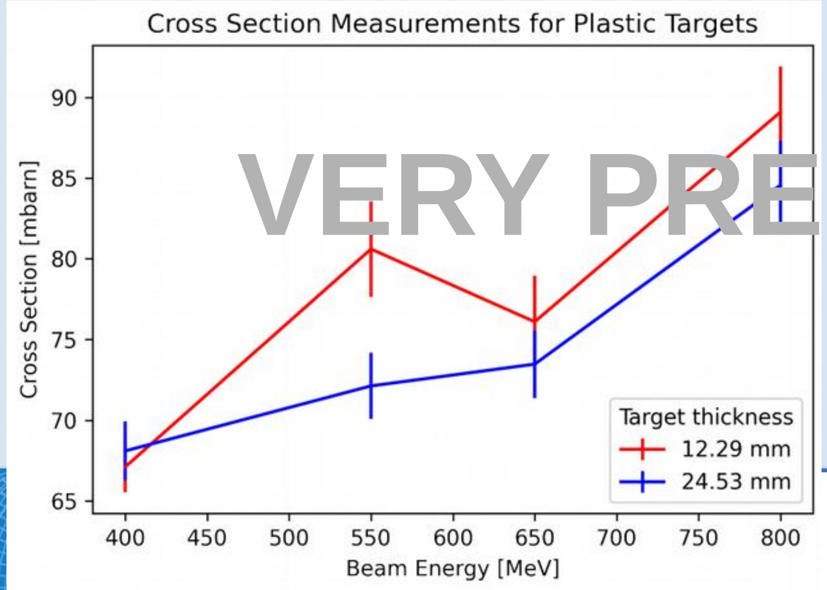
→ Boron as Fragment (Z = 5)

Azimuthal Angle Proton 1 vs Proton2

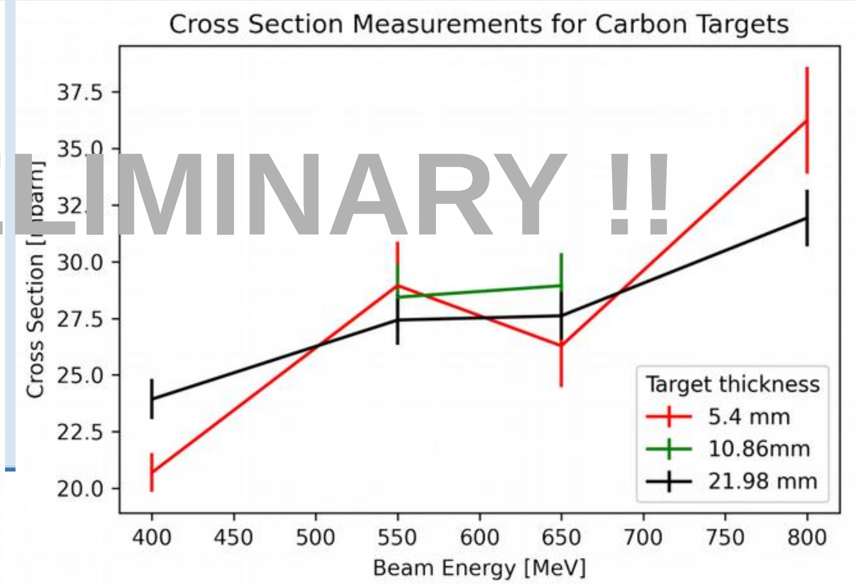




CALIFA only 35% filled in forward region → large correction factors



VERY PRELIMINARY !!



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

Source: Valerii Panin, Thesis 2012

What else can we analyse with the S444 Experiment ?

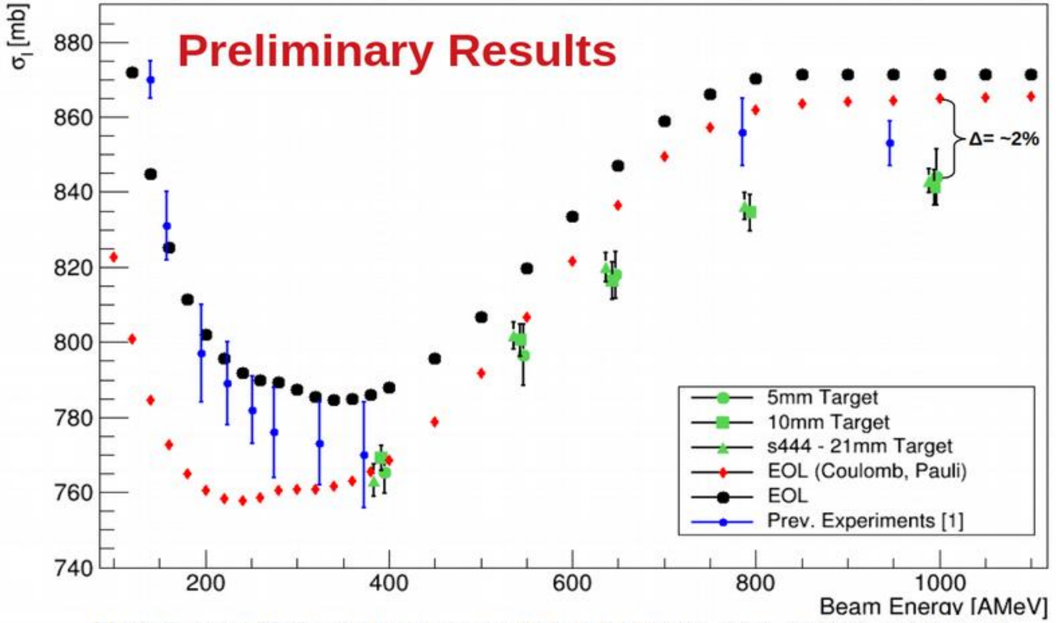
Total Reaction cross section – Lukas Ponnath

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

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

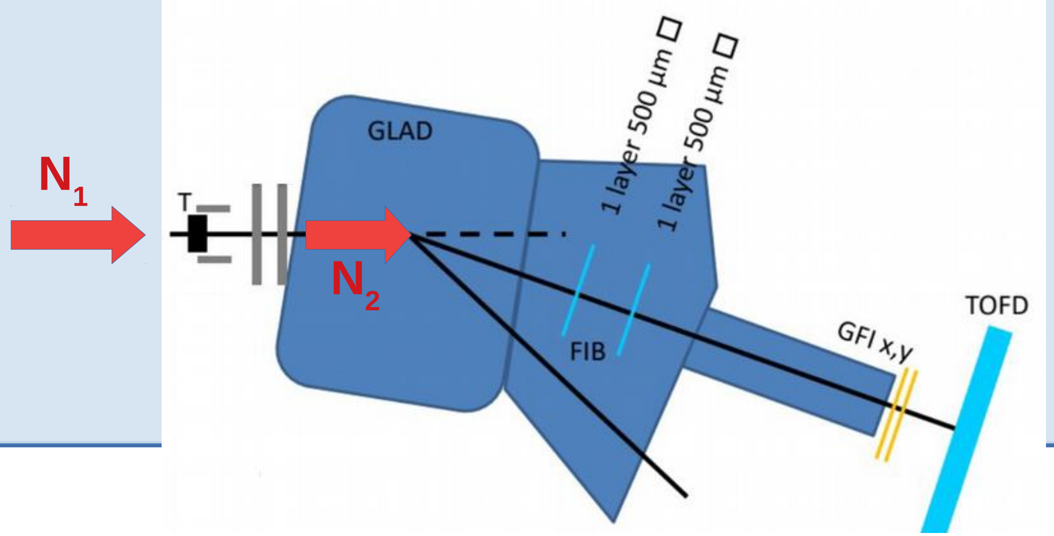
Using the Transmission Method:

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



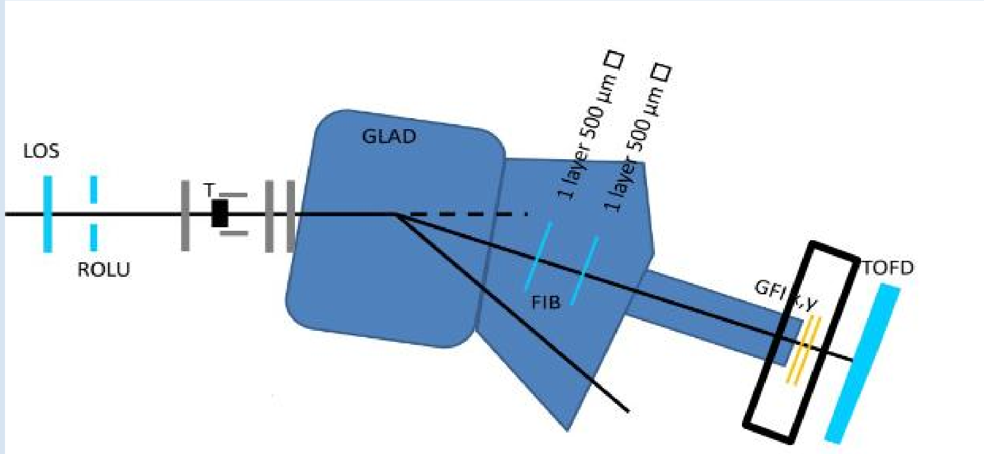
[1] I.Tanihata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009) , A. Ozawa et al. (Nuc. Phy. A – 691 2001)

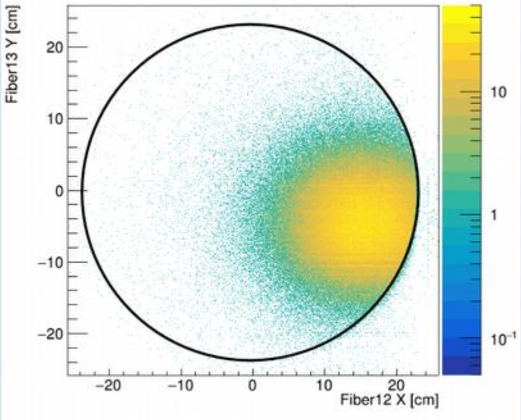
EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)



Comparing the two Setups

Setup - Lukas

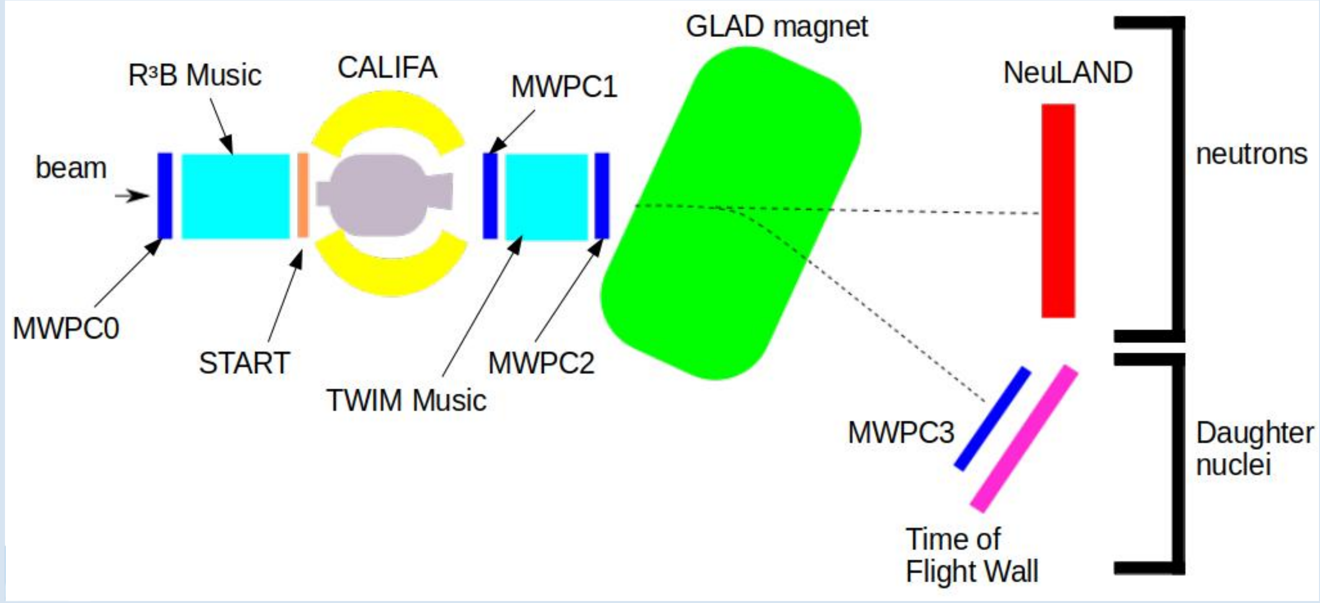




Acceptance issues due to the beam pipe confinement

Fine tuned acceptance corrections needed

S444 (2020) Setup → with carbon target



High acceptance:

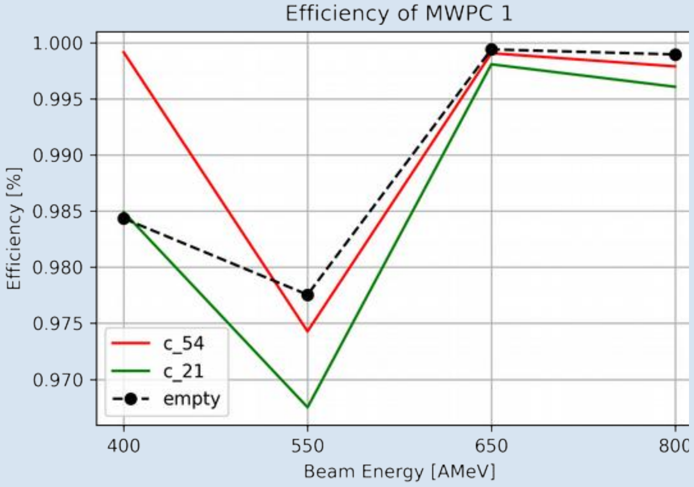
→ charge measured right after target by TWIM Music

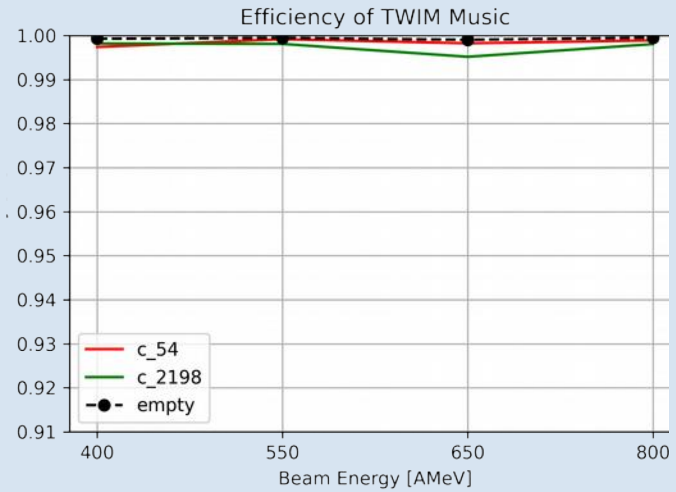
→ no beam pipe (= no vacuum) restrictions

Convenient setup to compare with Lukas' results

Starting with Charge Changing Cross Section

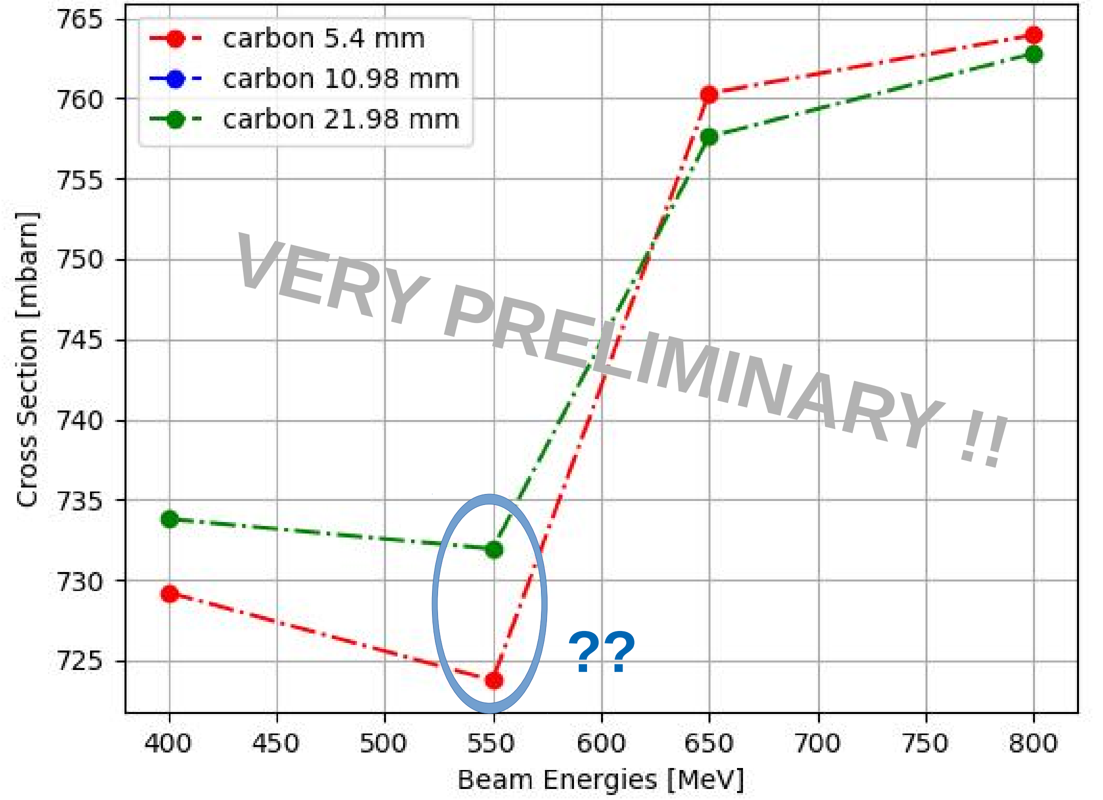
Why not starting directly with total reaction cross section measurement?

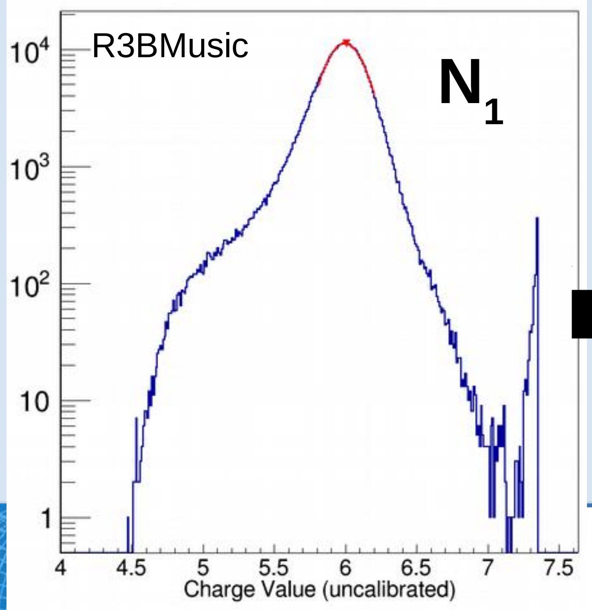


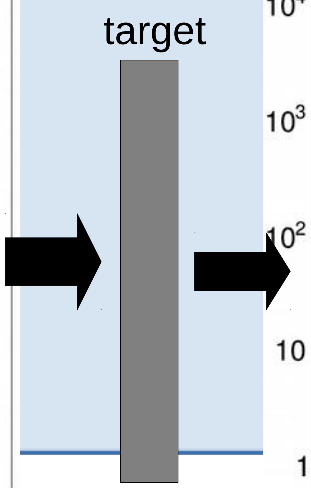


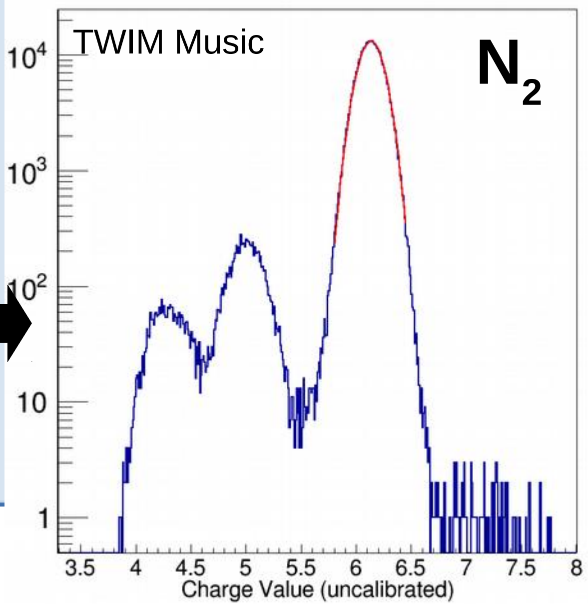
Z = 6

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



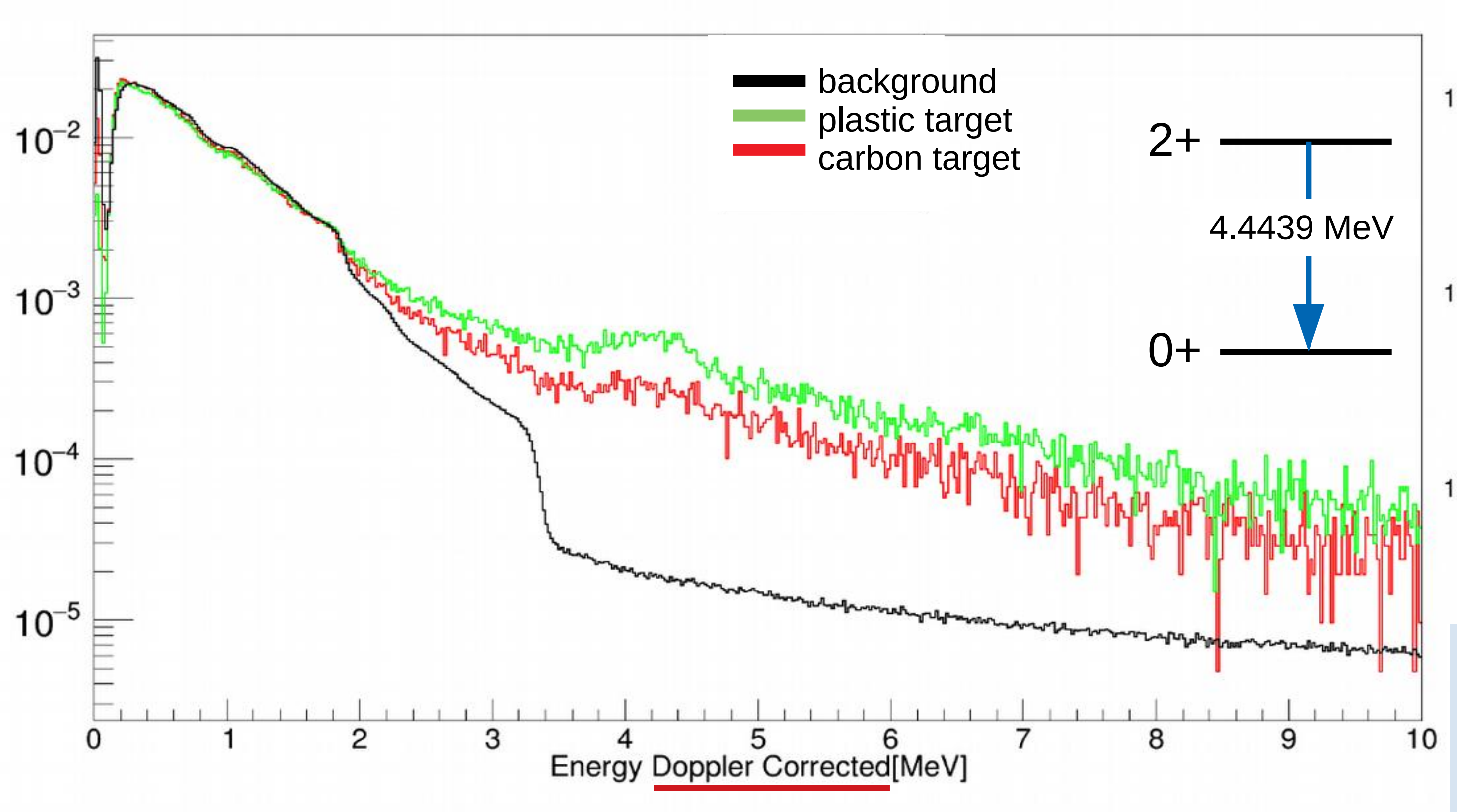




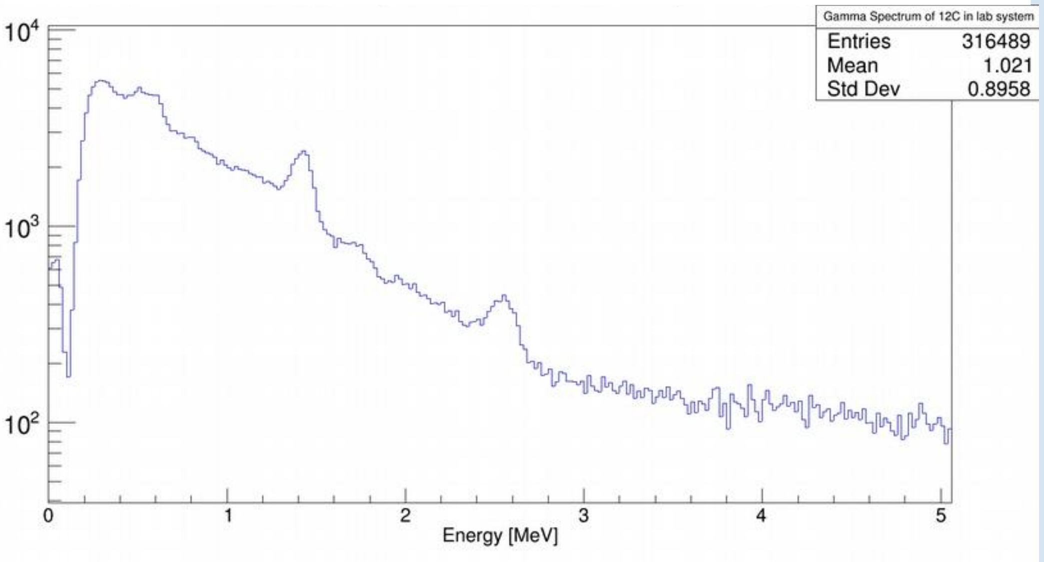


What more ?

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

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