R^3B Experiments with Final CALIFA Setup

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PSI Seminar 07.06.2023

R^3B @ FAIR

CALIFA Status & Final Configuration

Analysis S444 Experiment

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)
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TUM Members:
Roman Gernhäuser,Lukas Ponnath,Philipp Klenze, Stefan Eder,Tobias Jenegger

Physics Program @ R³B

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

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

Collective Excitations
→ EOS - Giant Dipole Reonances

→ Pygmy Resonances - neutron skin thickness

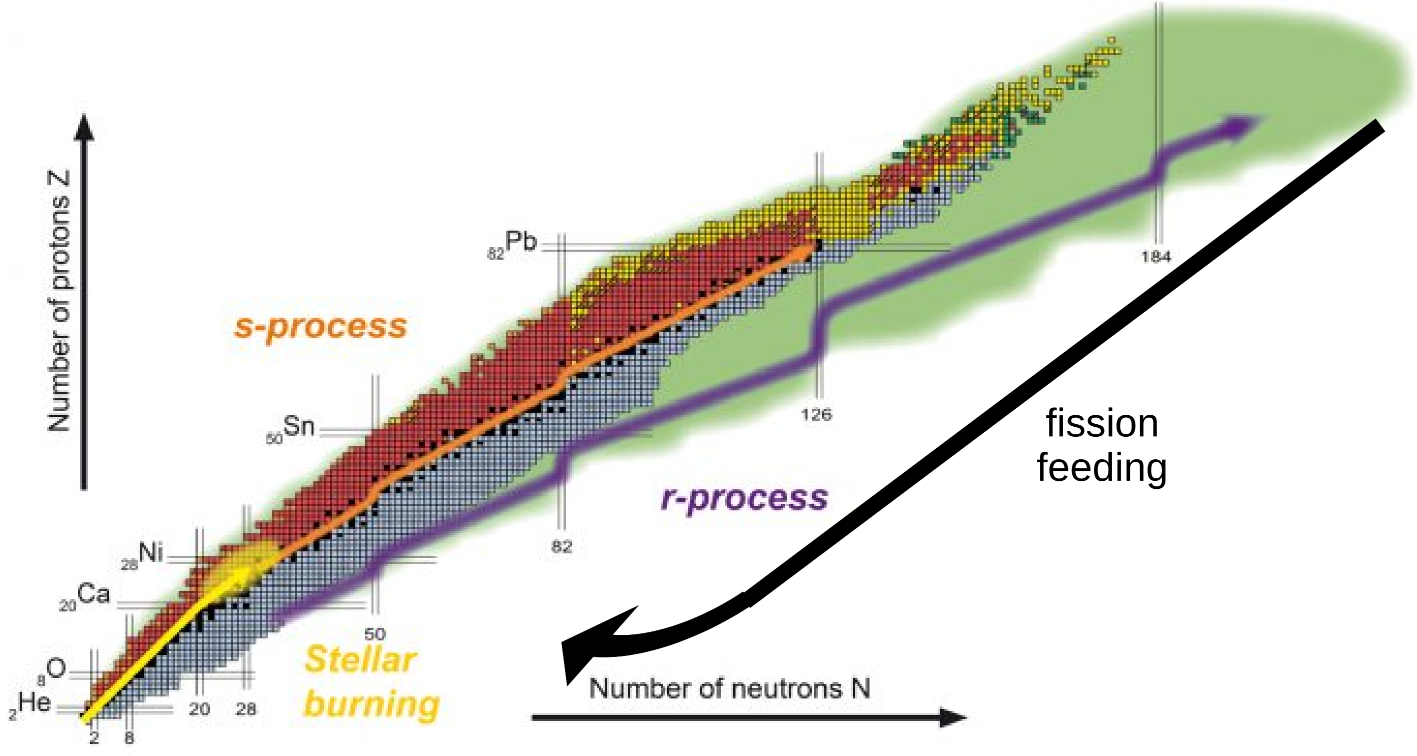
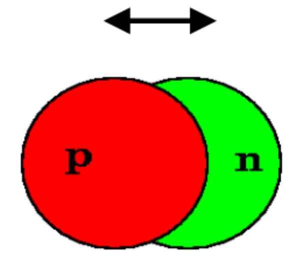


Fig. 1: Nuclear chart showing the nucleosynthesis processes occurring during stellar burning (yellow), the s-process (orange) and the r-process (violet) (credit: EMMI, GSI/Different Arts)



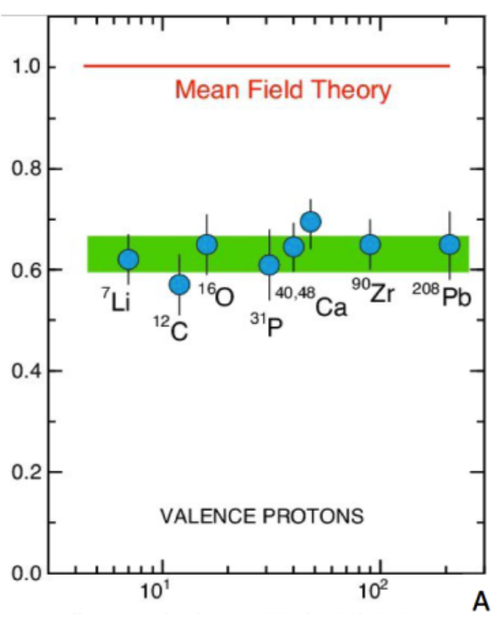
Isovector Electric Giant Dipole Resonance

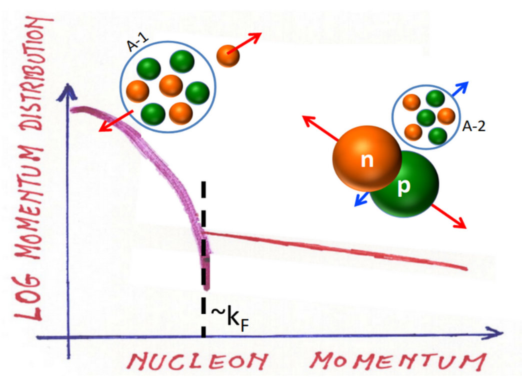
Physics Program @ R3B

Single Particle Properties inside atomic nucleus

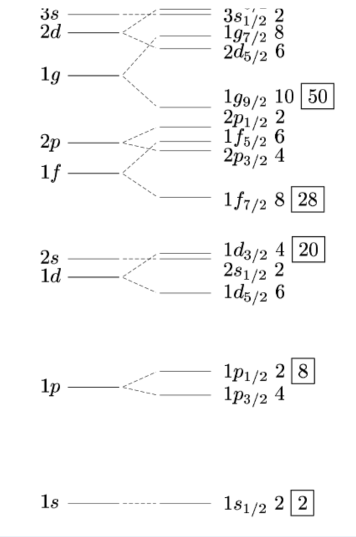
→ Nuclear Structure far off stability

→ Short Range Correlated (SRC) nucleons





Nuclear Shell Model



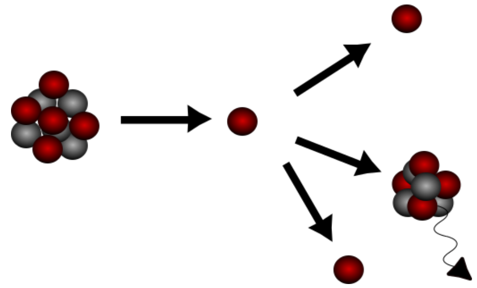
Experimental Setup Requirements:

FAIR accelerator facility

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

+

R3B Setup

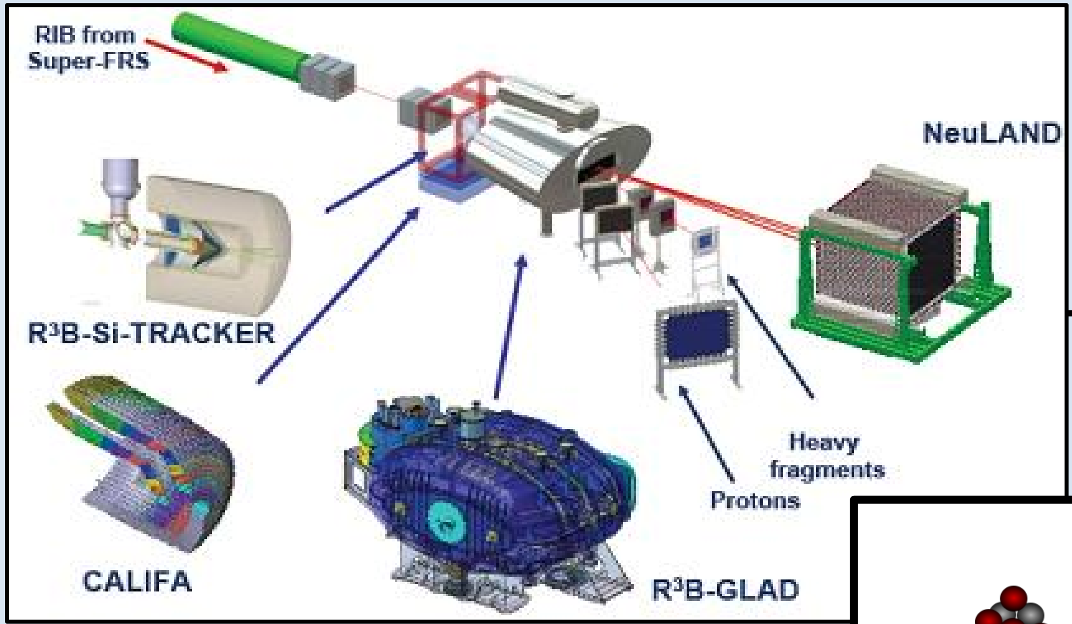


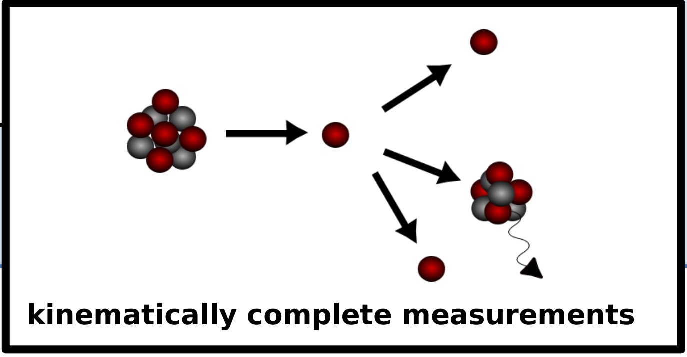
kinematically complete measurements

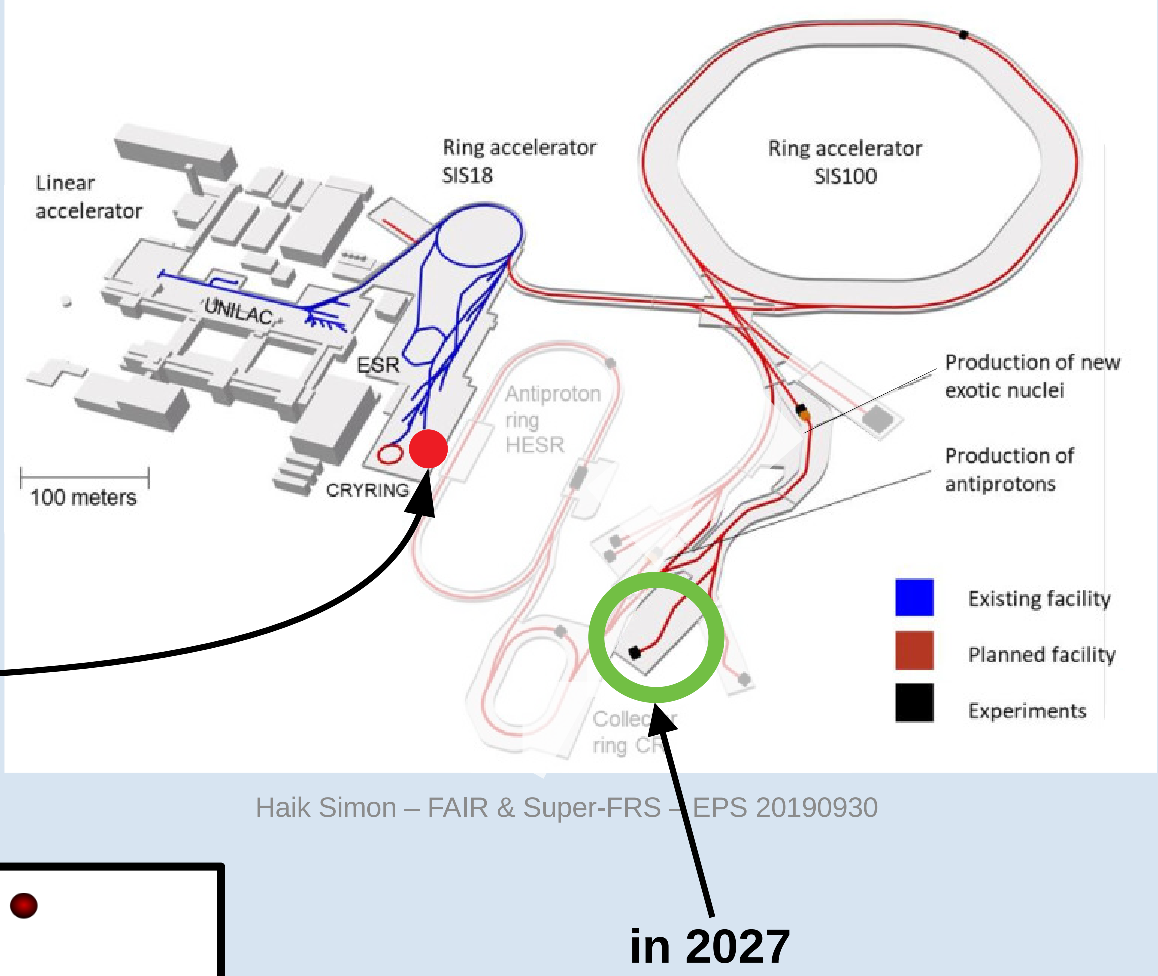
R³B @ FAIR

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







Haik Simon – FAIR & Super-FRS – EPS 20190930

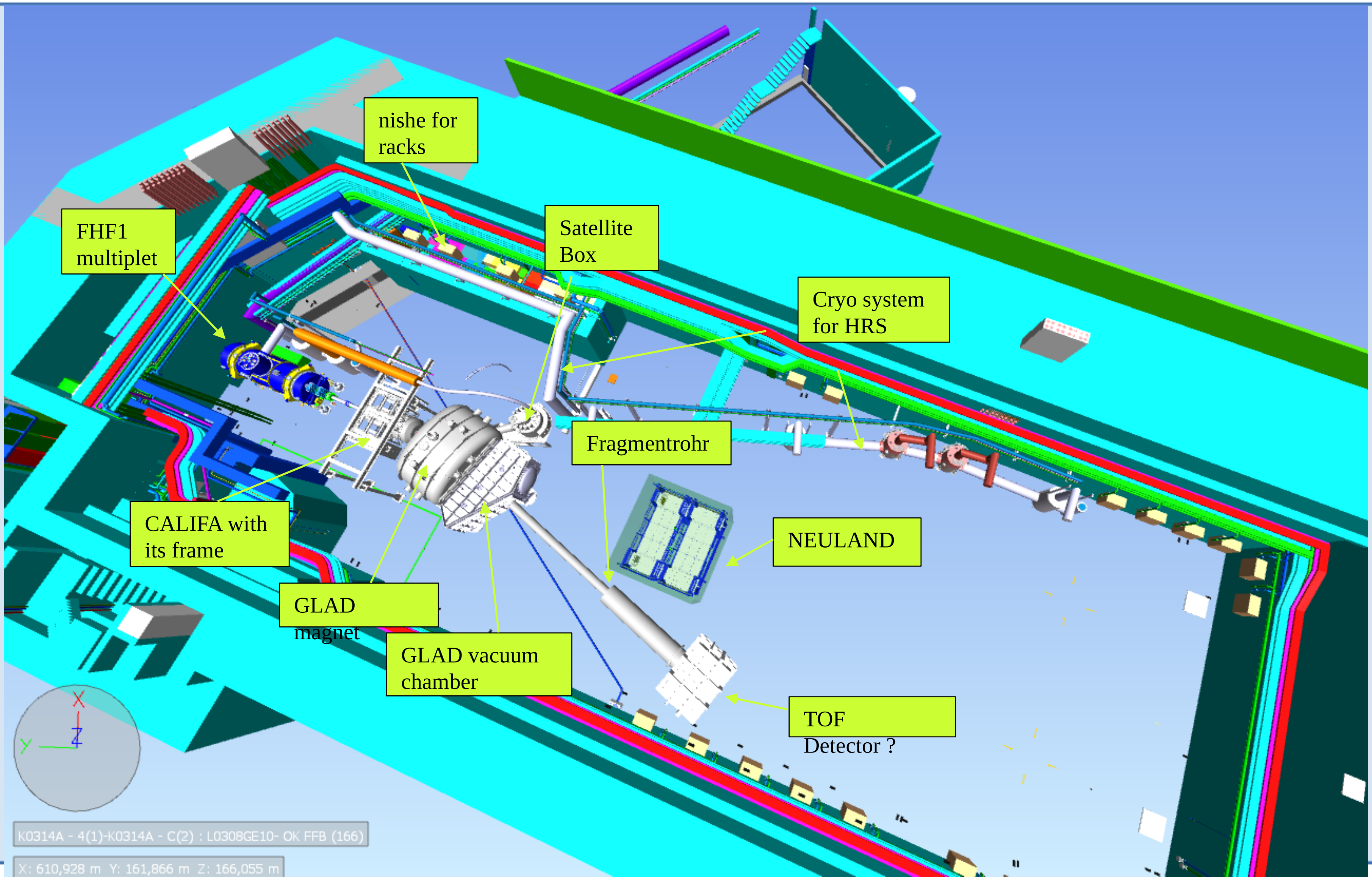
FAIR Construction Site

© D. Fehrenz, GSI/FAIR, May 2023

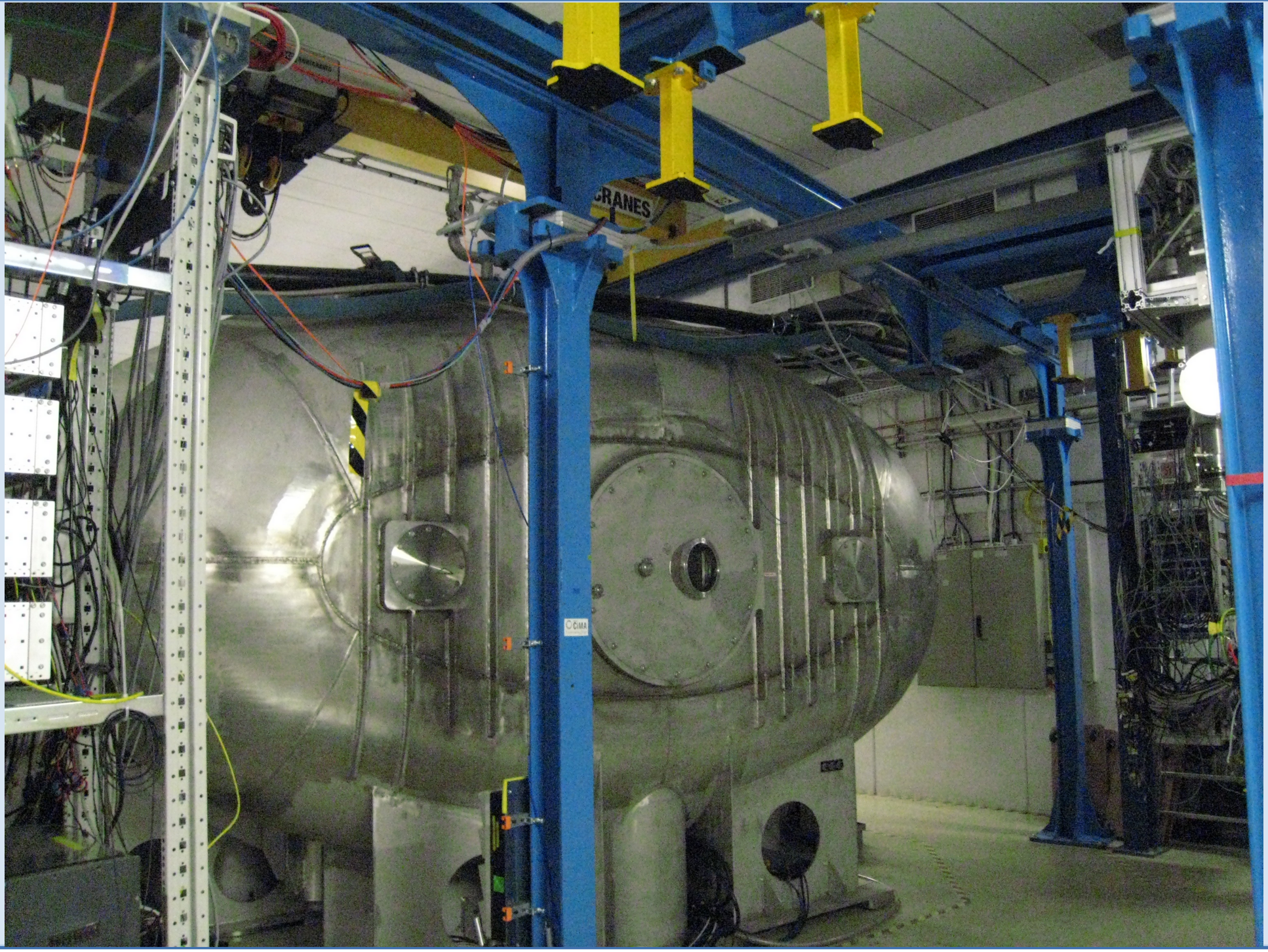
High Energy Cave

Dimensions: 60 x 20 x 7 m

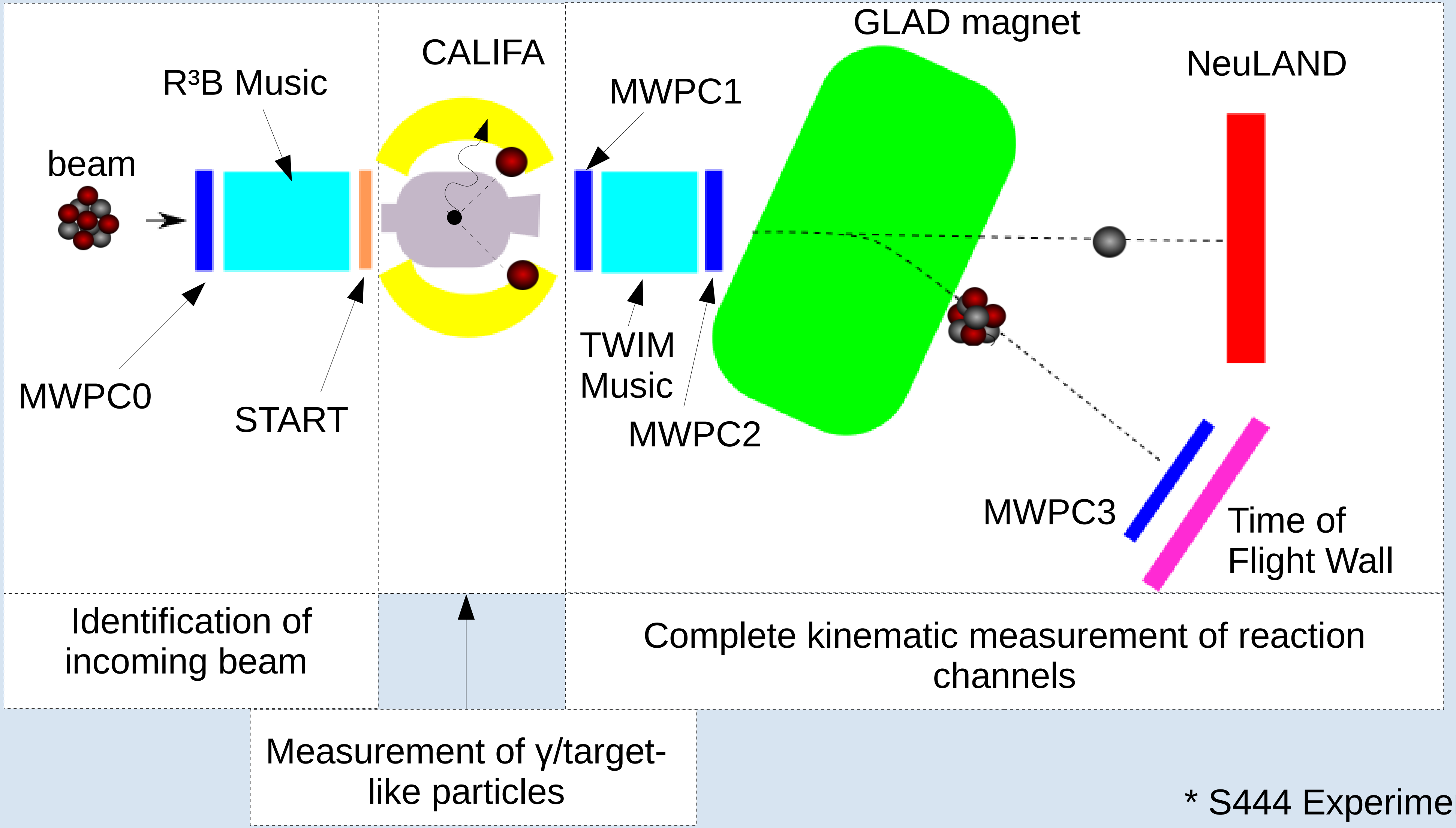
Final R³B Setup



But space in Cave C is limited...



R3B Setup*



* S444 Experiment, 2020

CALIFA Detector @ R^3B

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

Endcap:

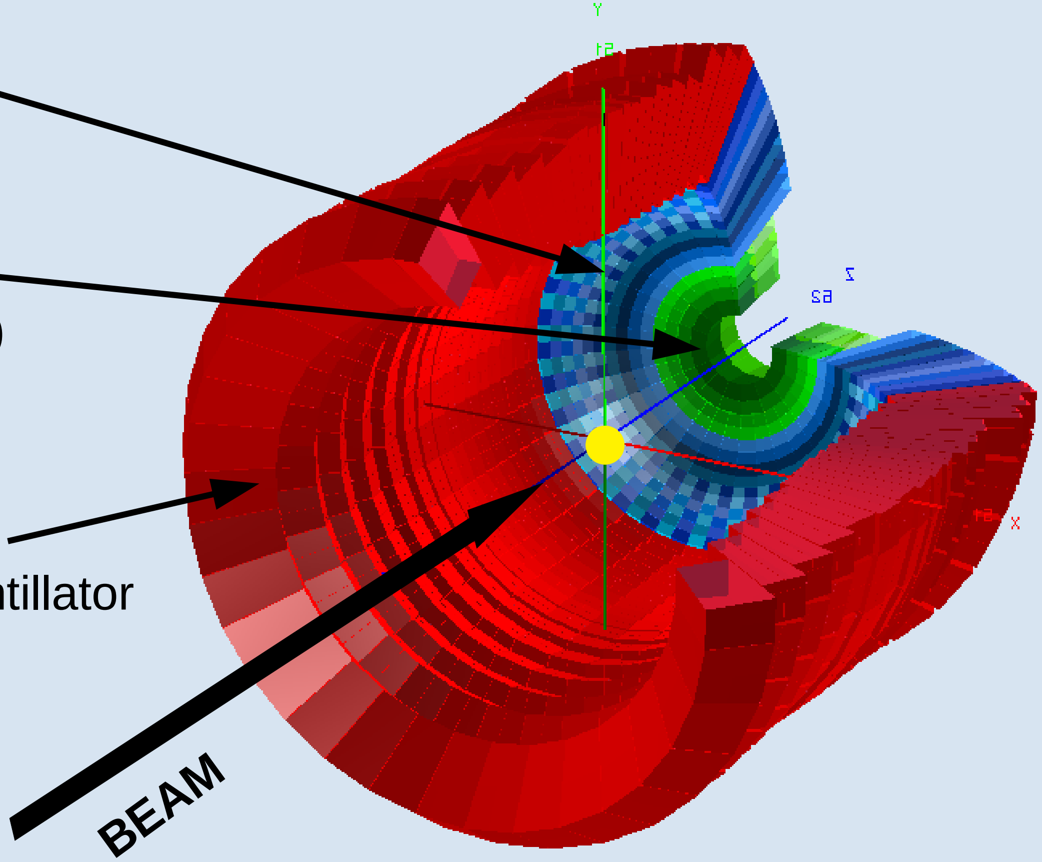
iPhos:

480 CsI(Tl) crystals

CEPA:

112 CsI (Tl) crystals

Barrel:
1952 CsI(Tl) scintillator crystals



Highly segmented detector:

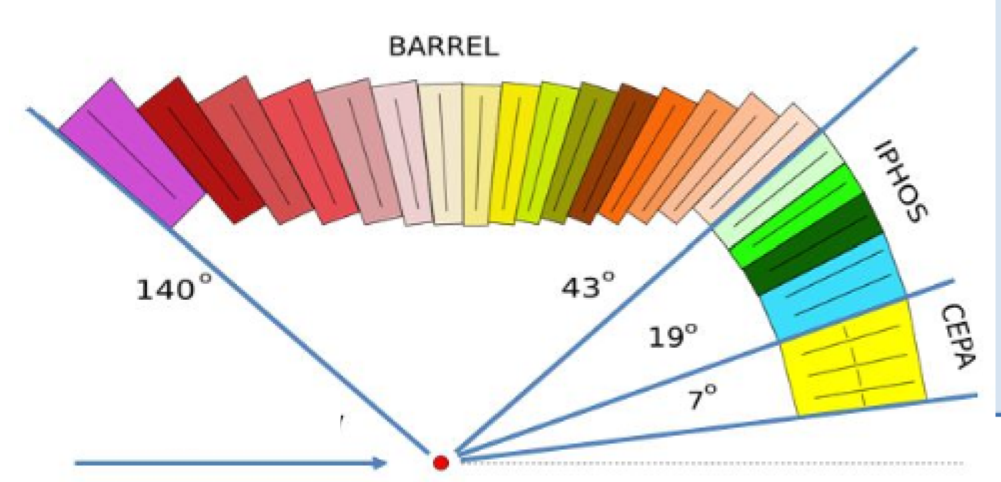
- good angular reconstruction/ doppler correction

Broad calorimetric energy measurements:

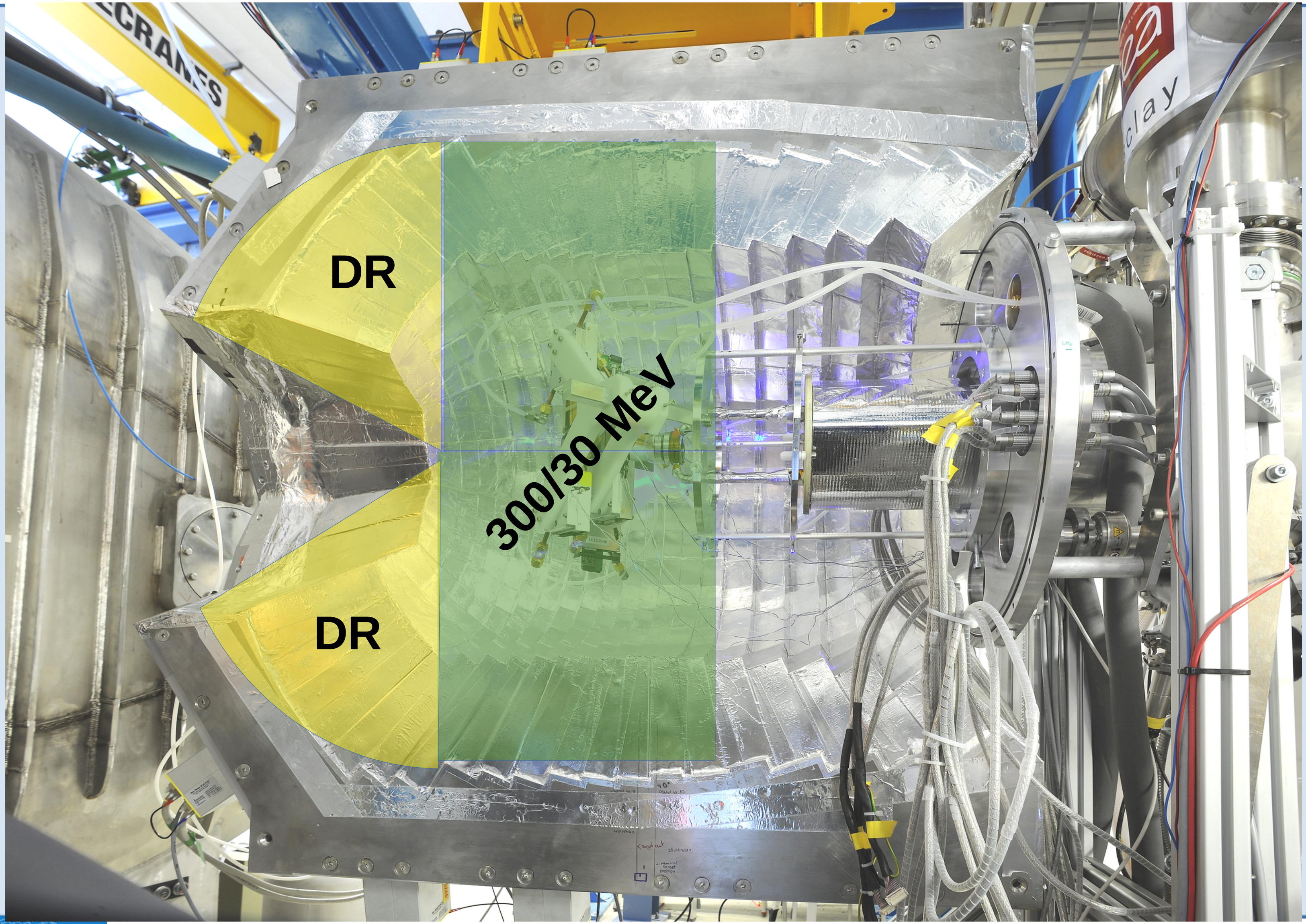
- From 100 keV γ-rays up to high energetic charged particles

Flexible running mode:

- self/external triggering mode



CALIFA Configuration (S522, 2022)

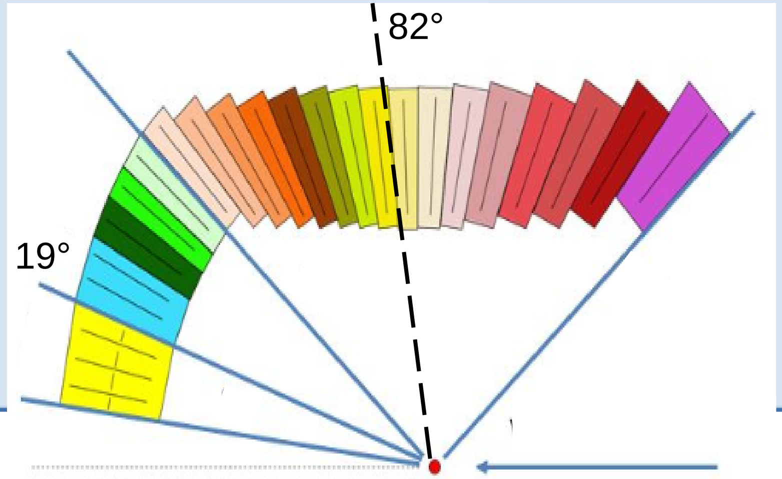


IPhos: 480 crystals

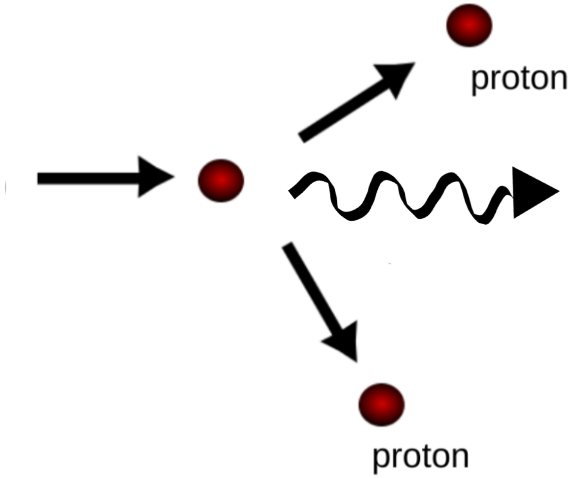
- completely filled
- readout with Dual Range Preamps

Barrel: 1024 crystals

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



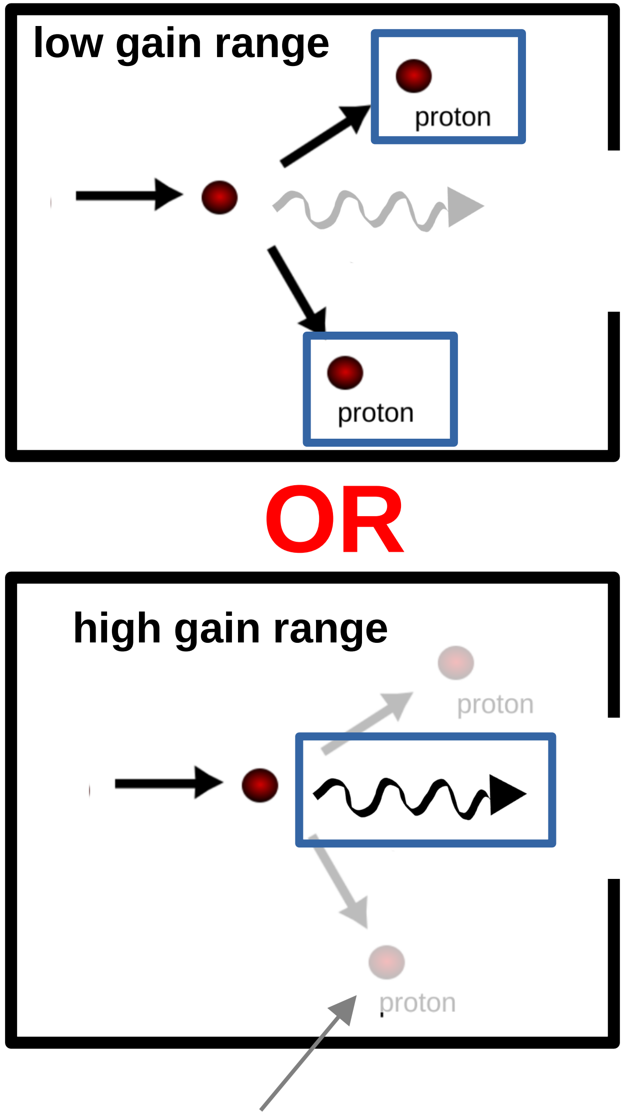
Dual Range Preamplifier



SIMULTANEOUS
high energetic paricle
measurement
&
gamma spectroscopy

2 x channelnr.

SingleRange Preamplifier



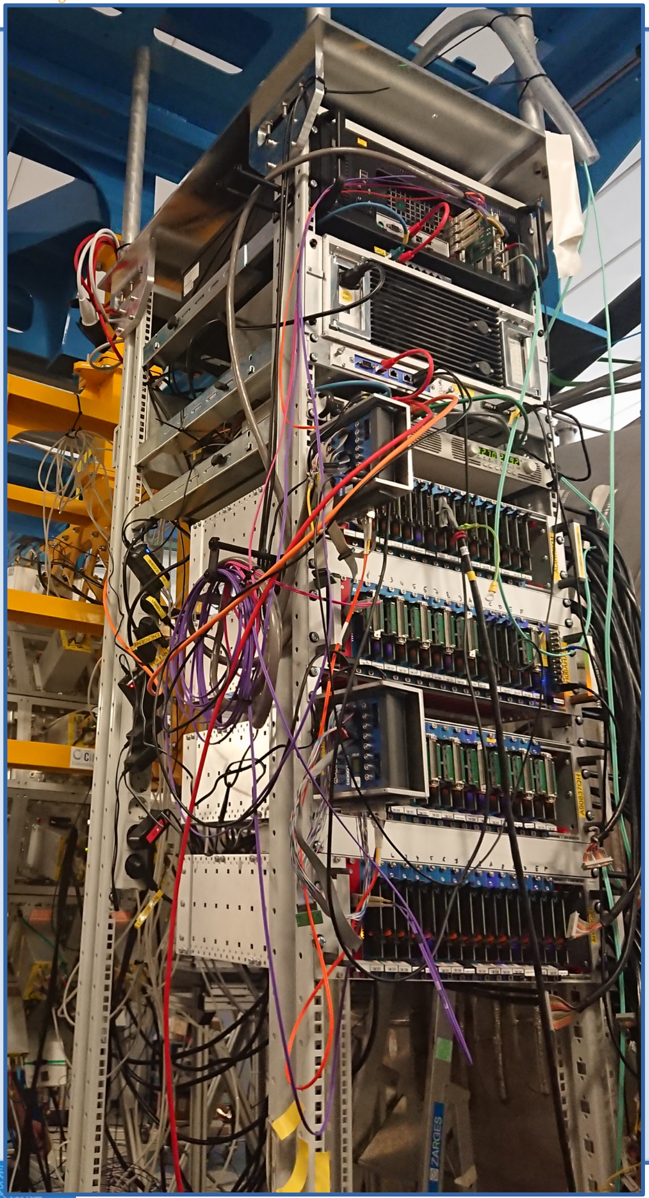
Gamma threshold: 500 keV

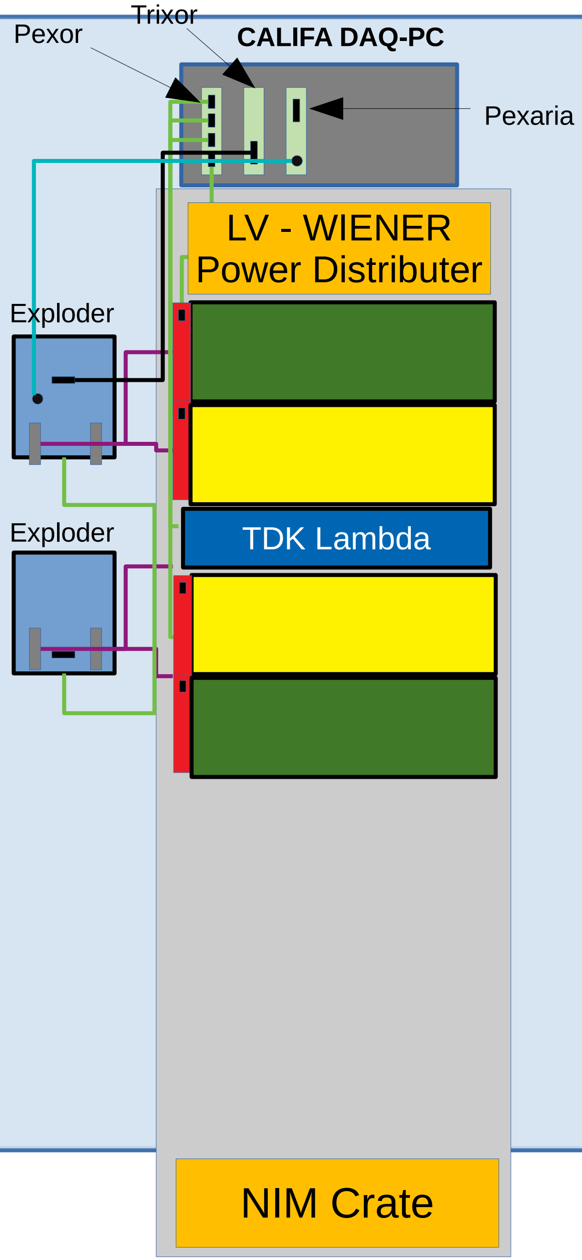
Gamma threshold: 100 keV

E_{proton} via tot-method

300/30

CALIFA DAQ Status (S522, 2022)

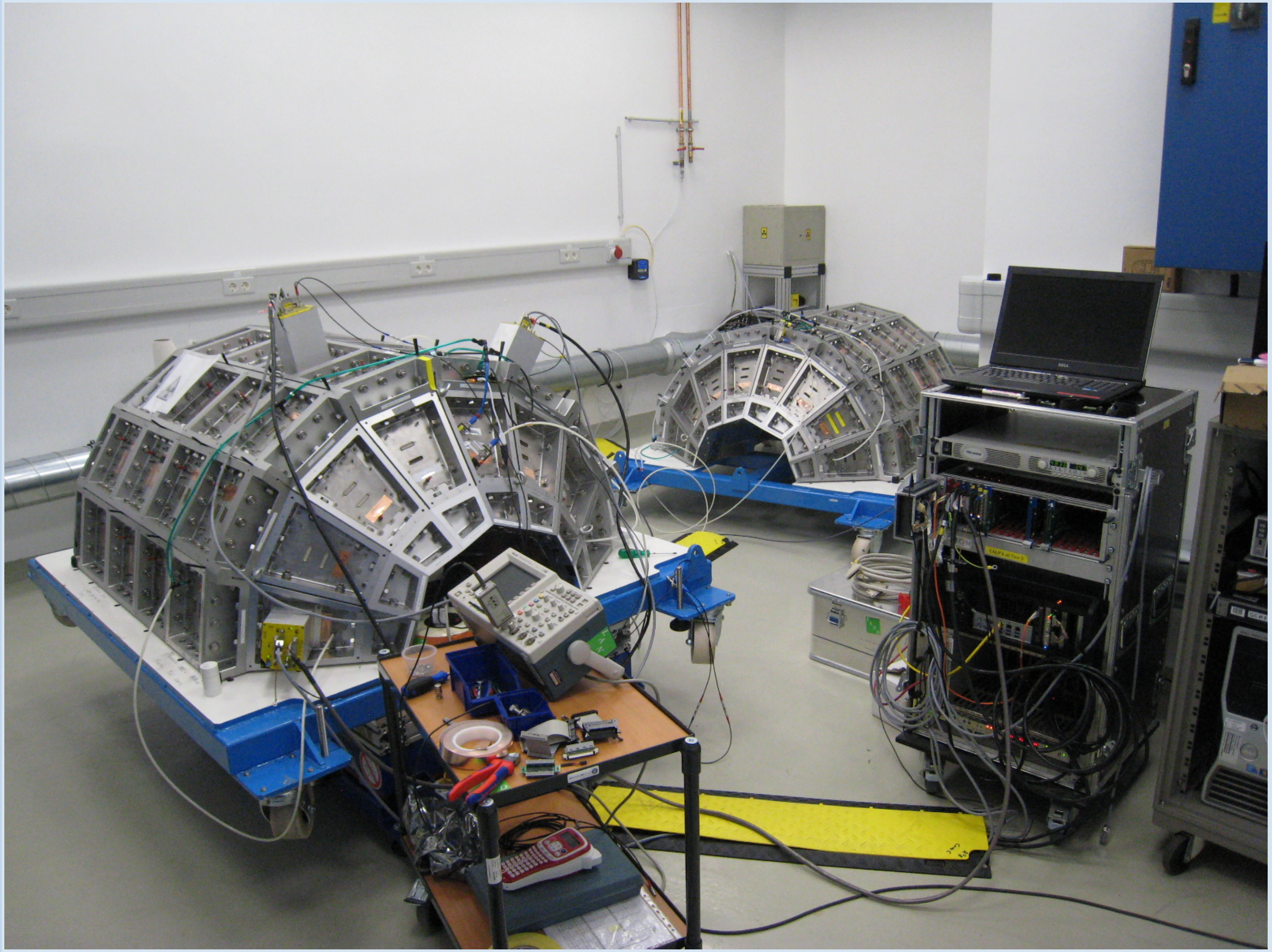




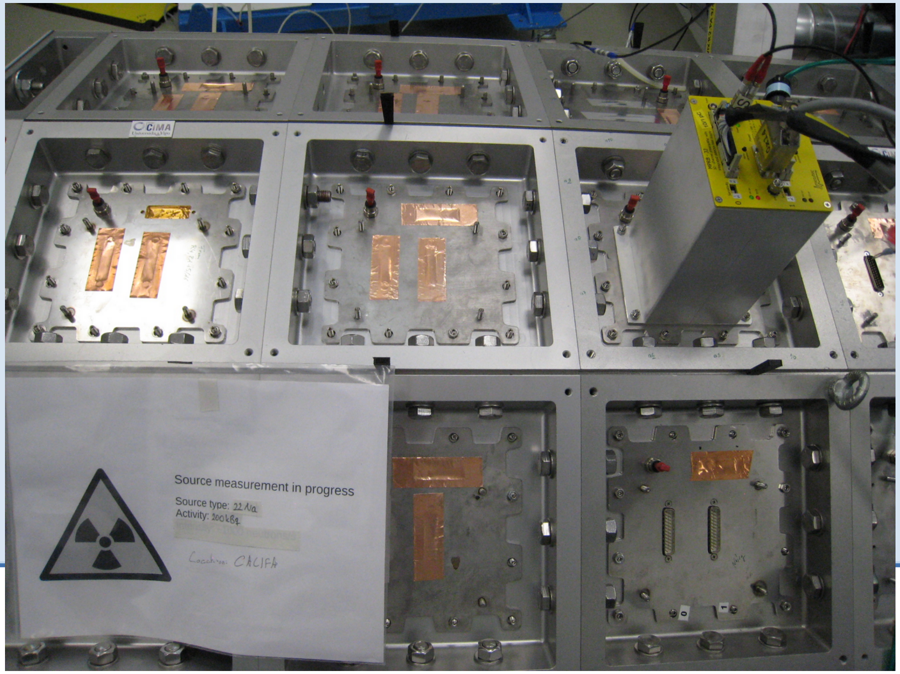
Electronic Rack

- 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

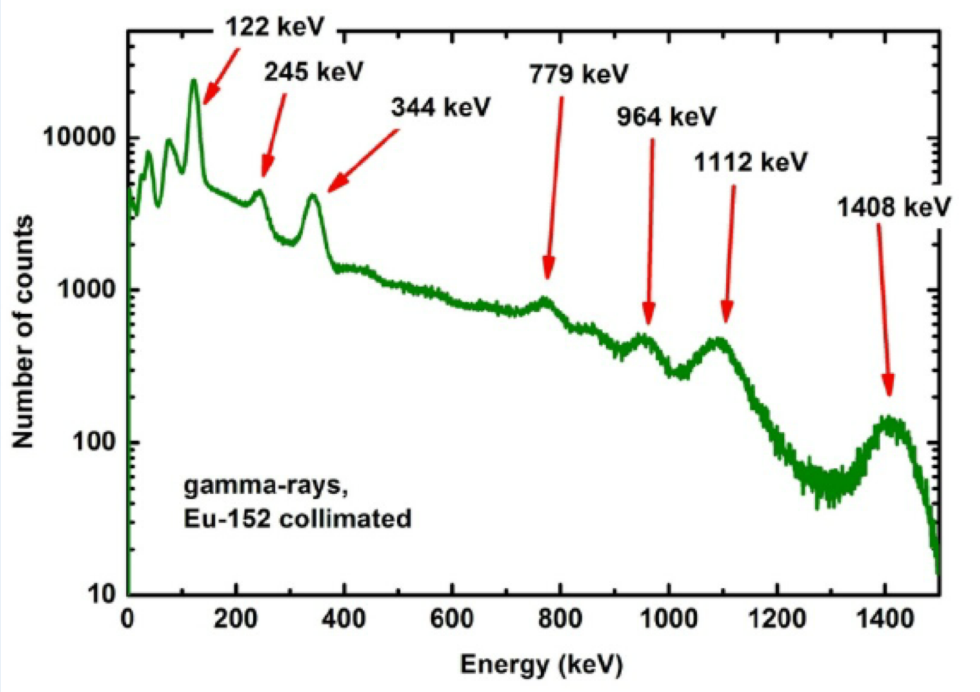
Meanwhile in R³B Preparation ROOM ….

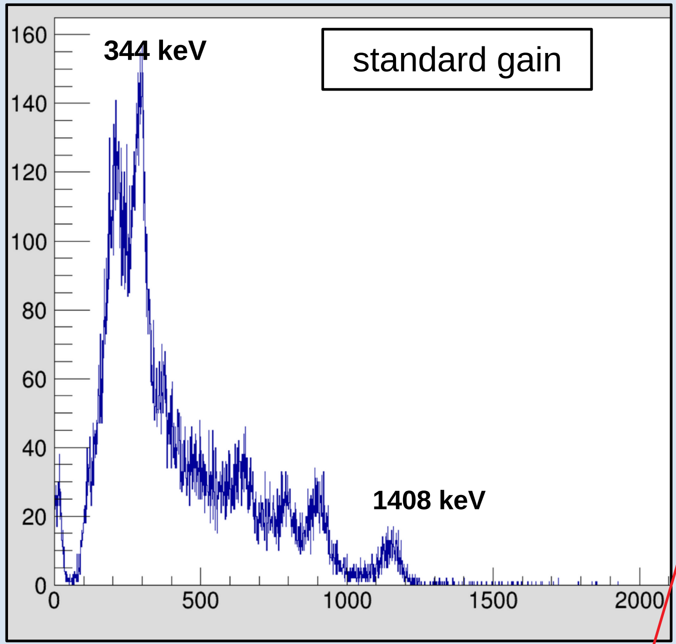


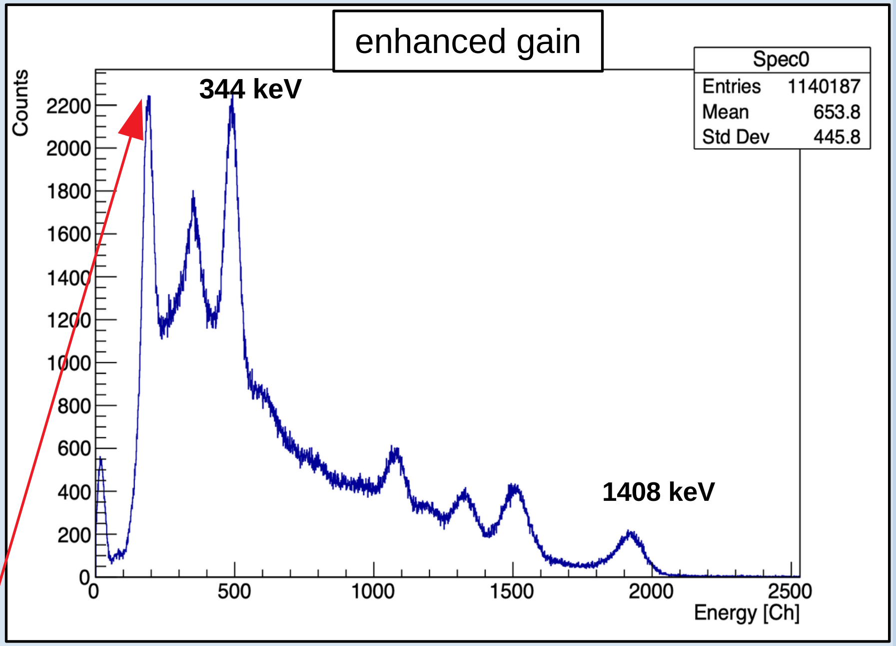
- Add new crystals
- Improve noise figure
- Check and replace some of internal cables



Testing Gain







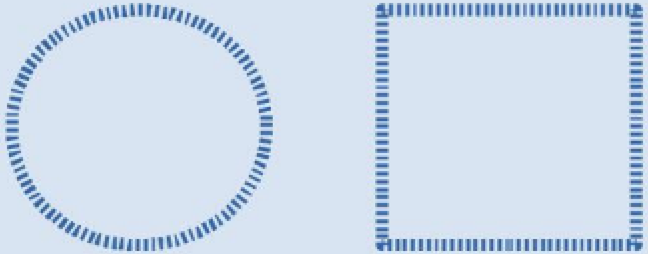
Raising the gain allows to measure down to the **122 keV** peak!

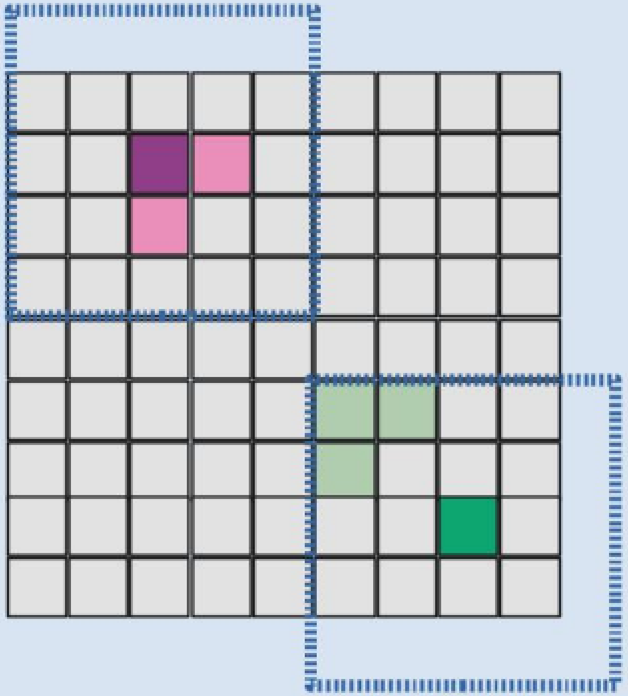
Higher gain leads to better resolution (but reducing the energy-range)

$$\frac{\sigma}{\mu}(1275\text{keV}) = 3.19\ \% \longrightarrow \frac{\sigma}{\mu}(1275\text{keV}) = 2.50\ \%$$

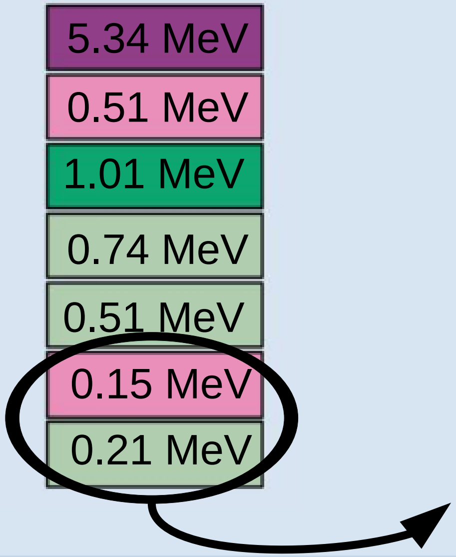
Lower threshold values are possible → crucial for **add-back** algorithm!

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

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

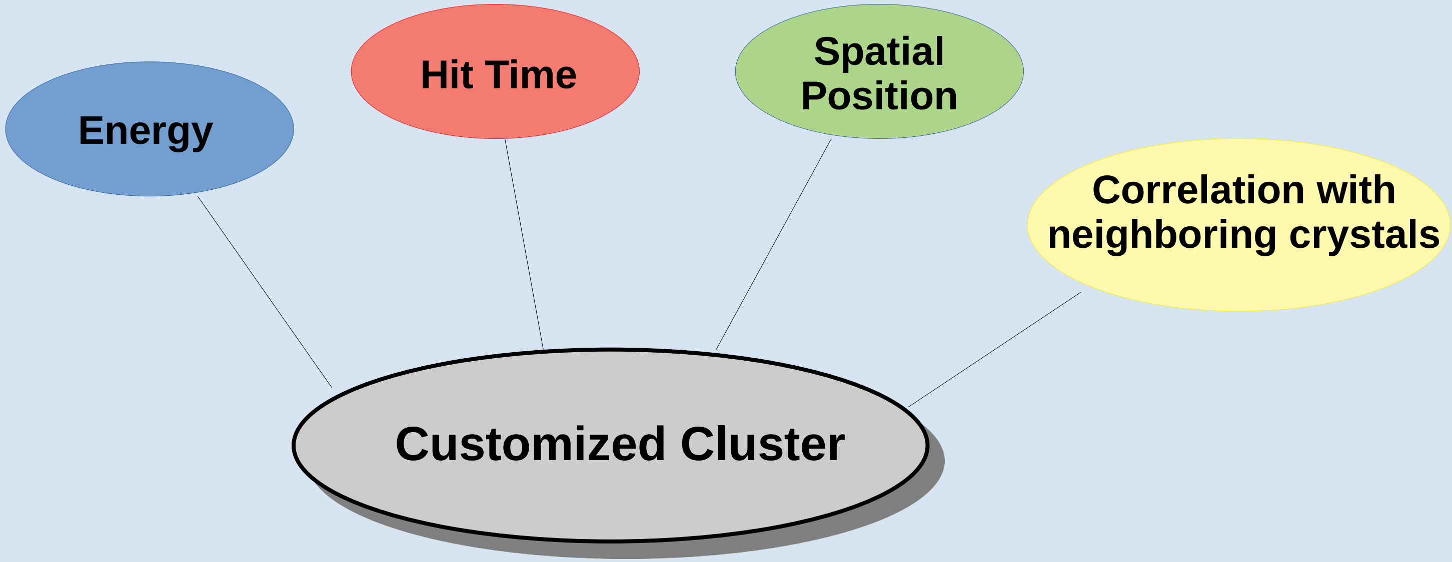
ODSL Collaboration - Optimize Add-Back Algorithm with AI

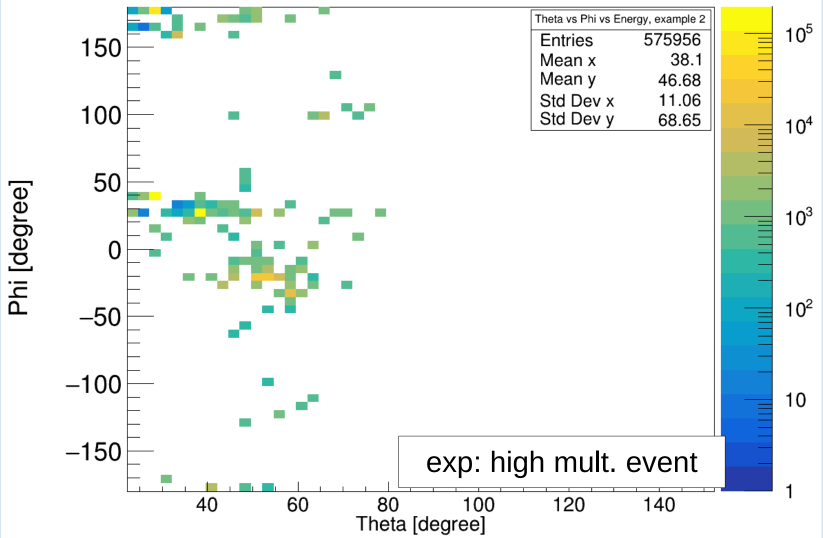
Use the power or Machine Learning:

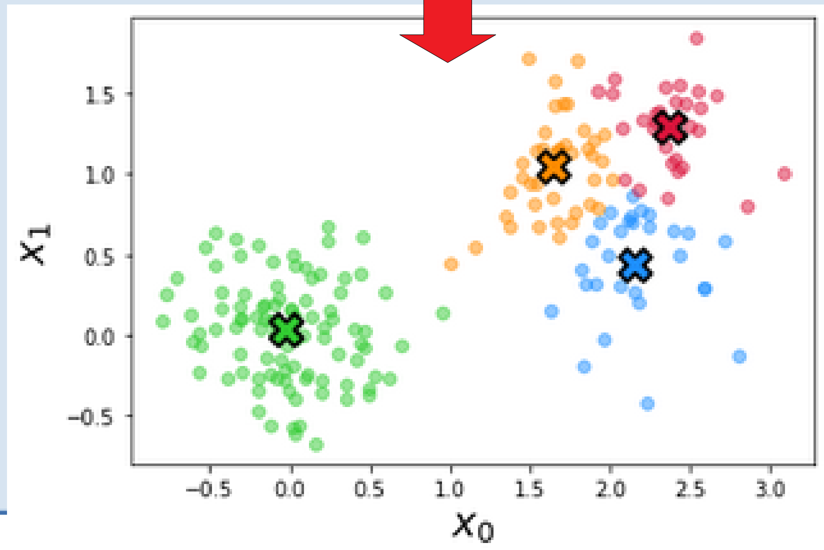
→ recognize the physics cases

→ optimize the cluster shapes (event by event)

→ give probability for fully contained physics event





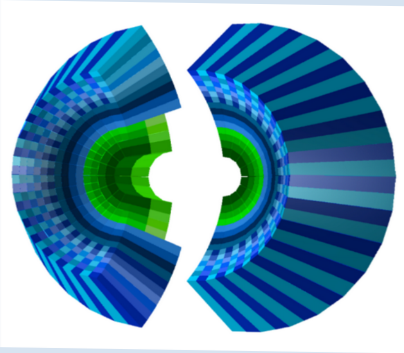


Supervisor: Prof. Dr. Lukas Heinrich

Filling CALIFA Endcap - CEPA

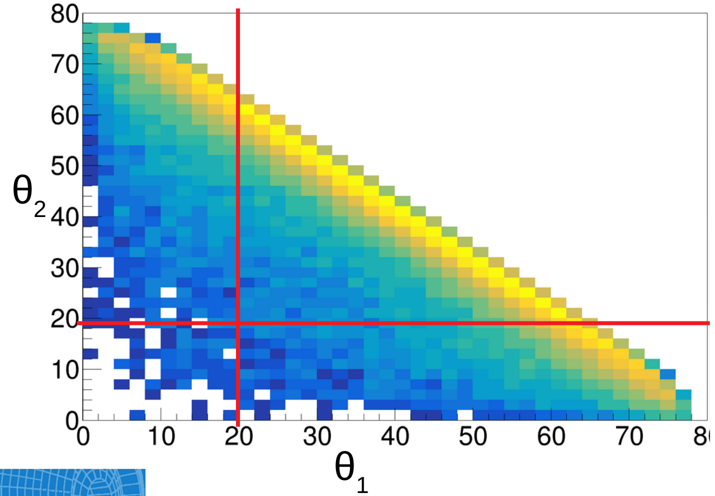
CALIFA **E**ndcap **P**hoswich **A**rray

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

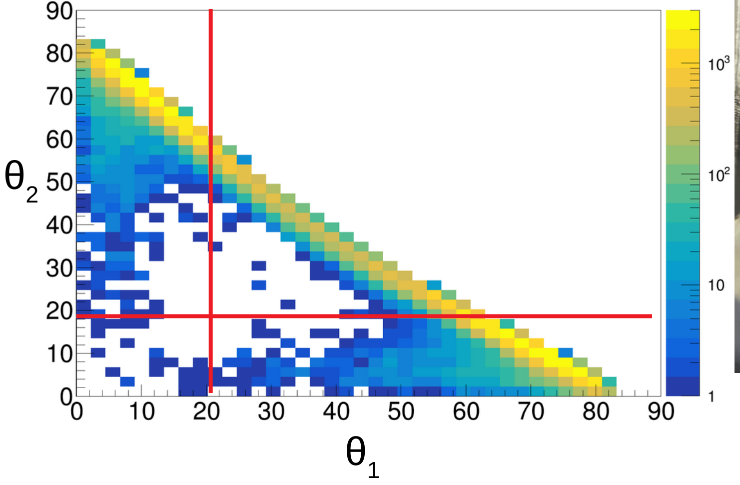


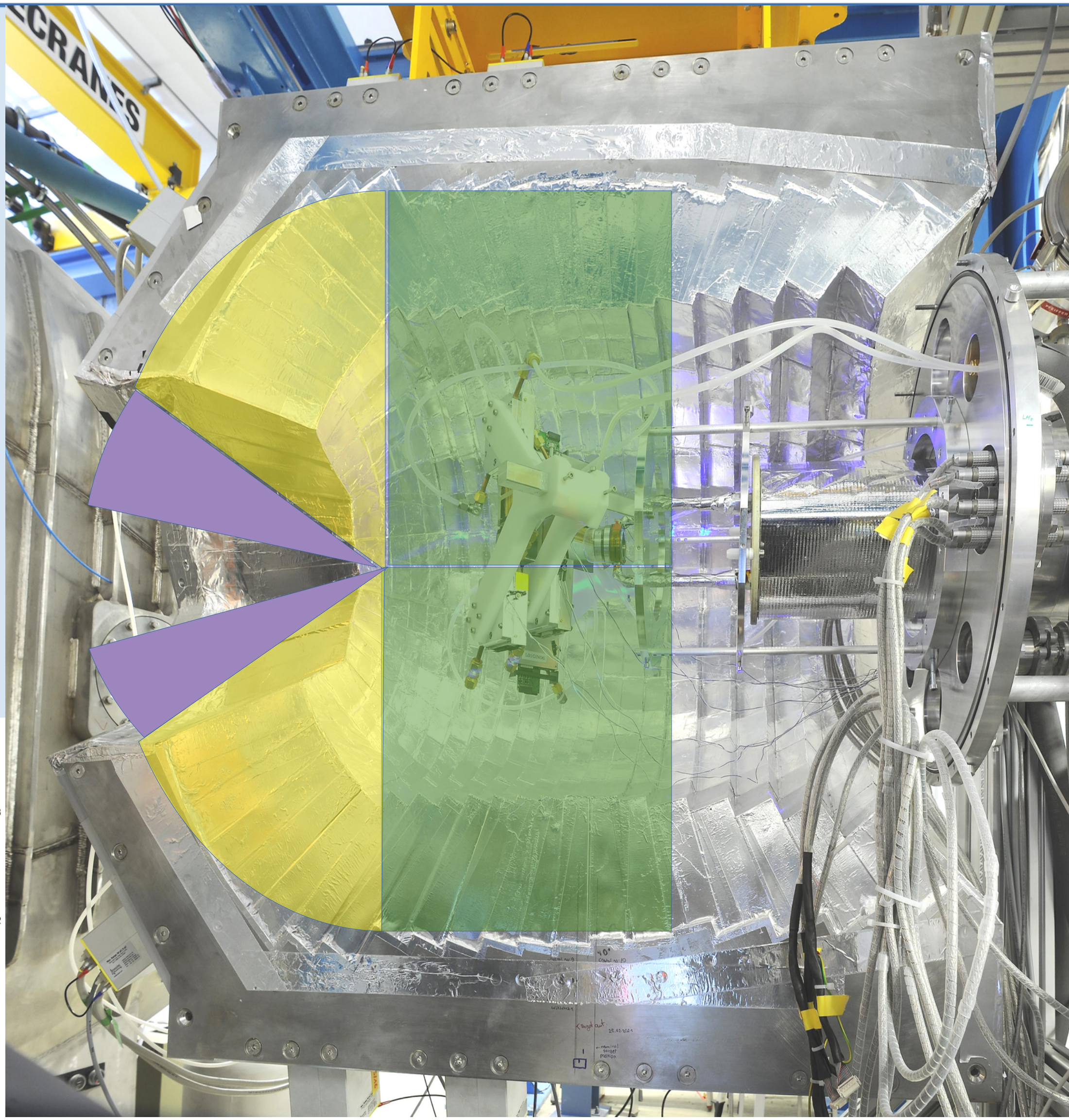
Improves geometric acceptance for high beam energies drastically

p2p-reaction, 400 AMeV



p2p-reaction, 1200 AMeV

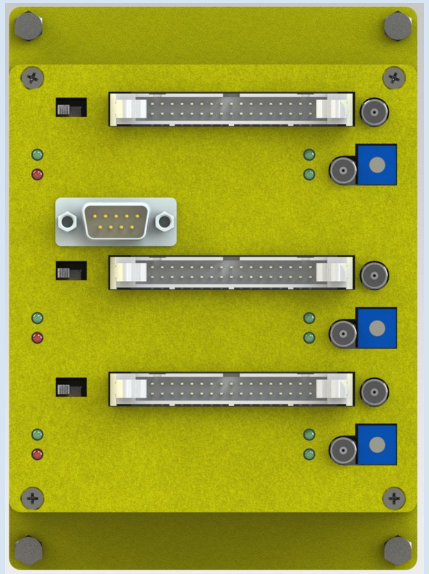




Filling CEPA

Mesytec MPRB-48 Dual Range Preamps

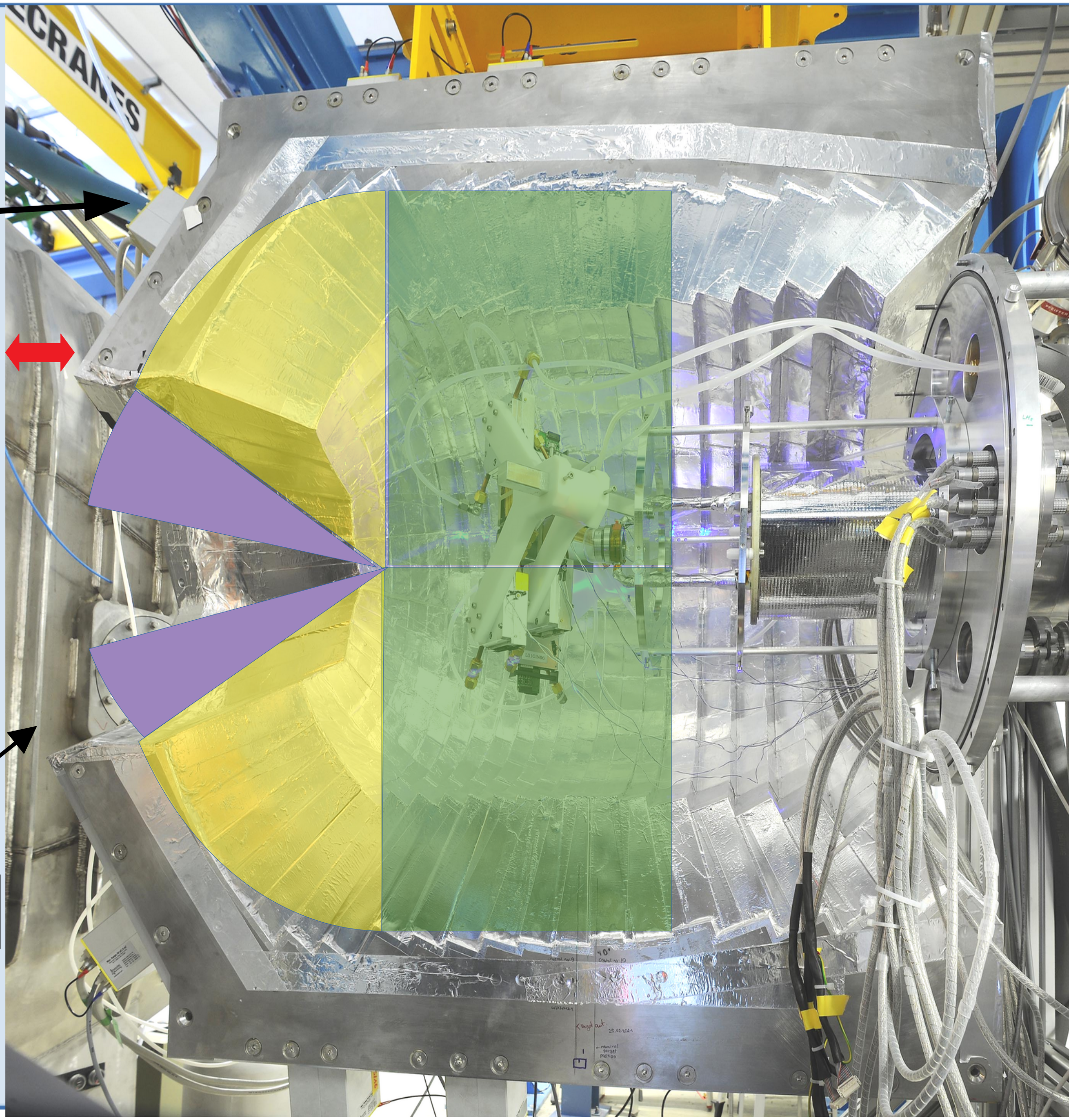
They get mounted on iPhos tiles



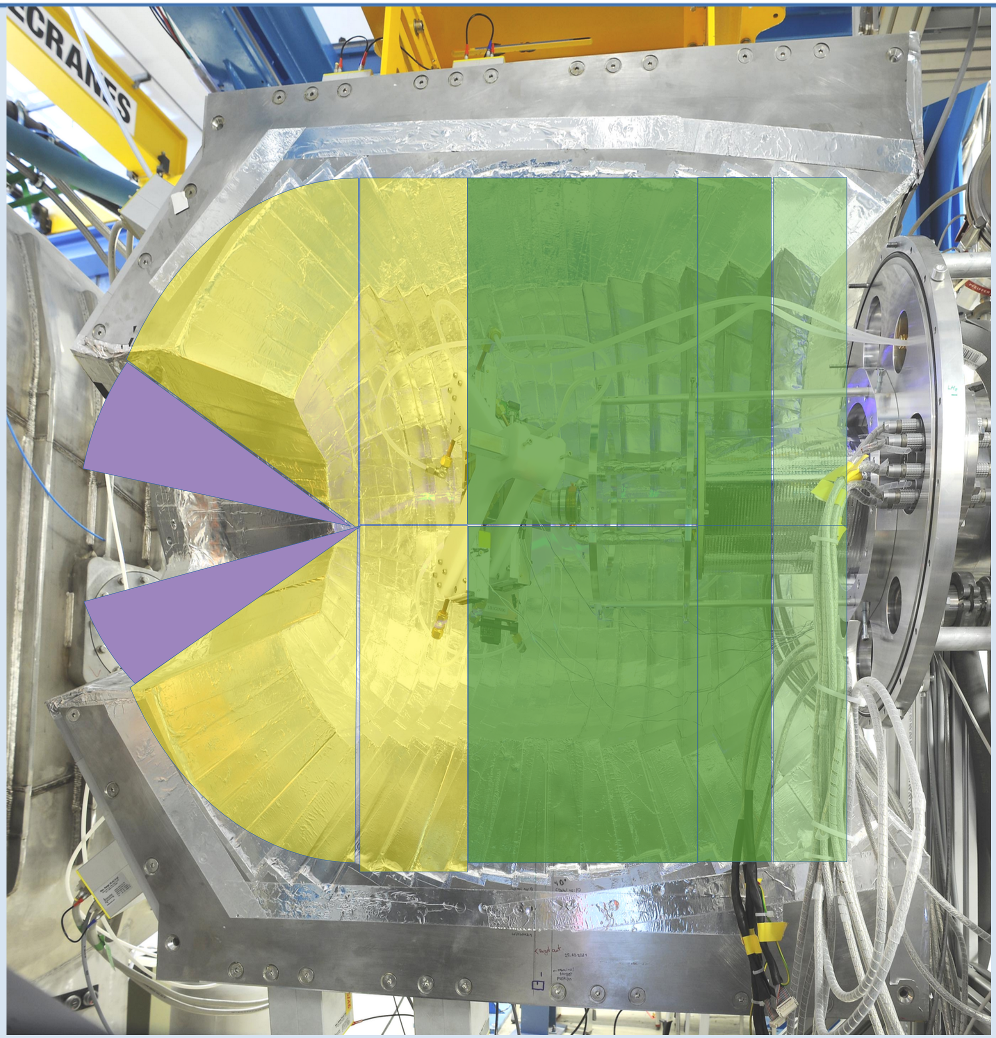
Connected to iPhos APDs
(32 channels)

Connected to CEPA APDs
(16 channels)

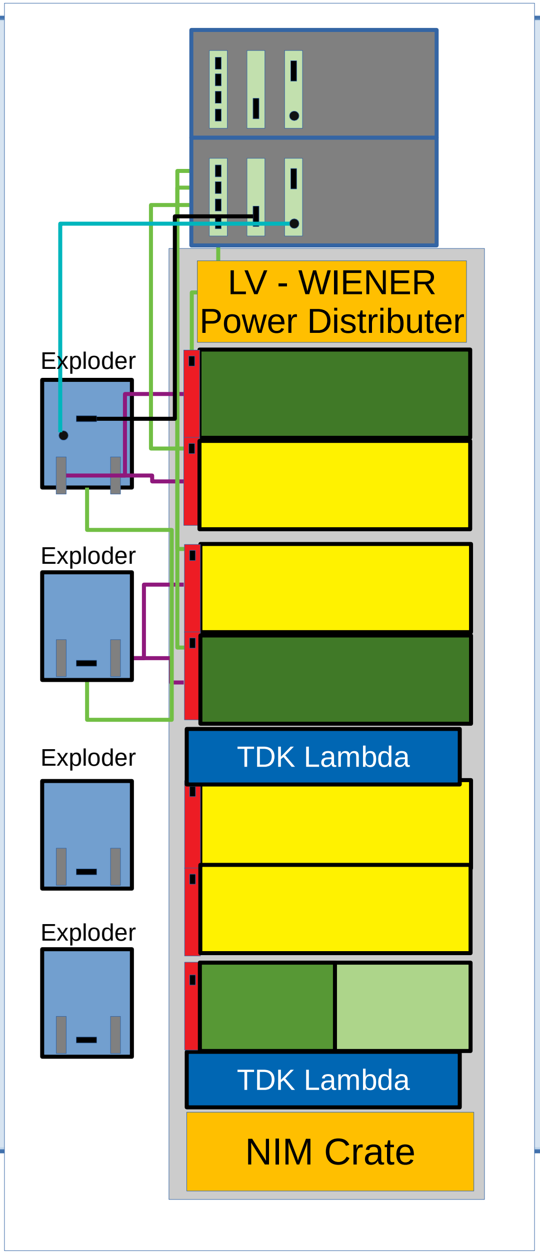
no space !



Final CALIFA Electronic Configuration



Dual Range Preamplifiers



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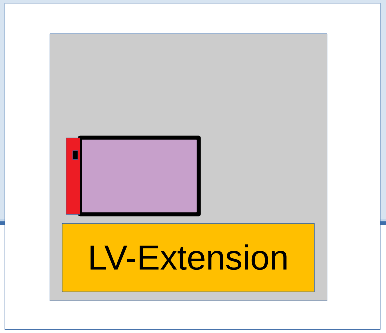


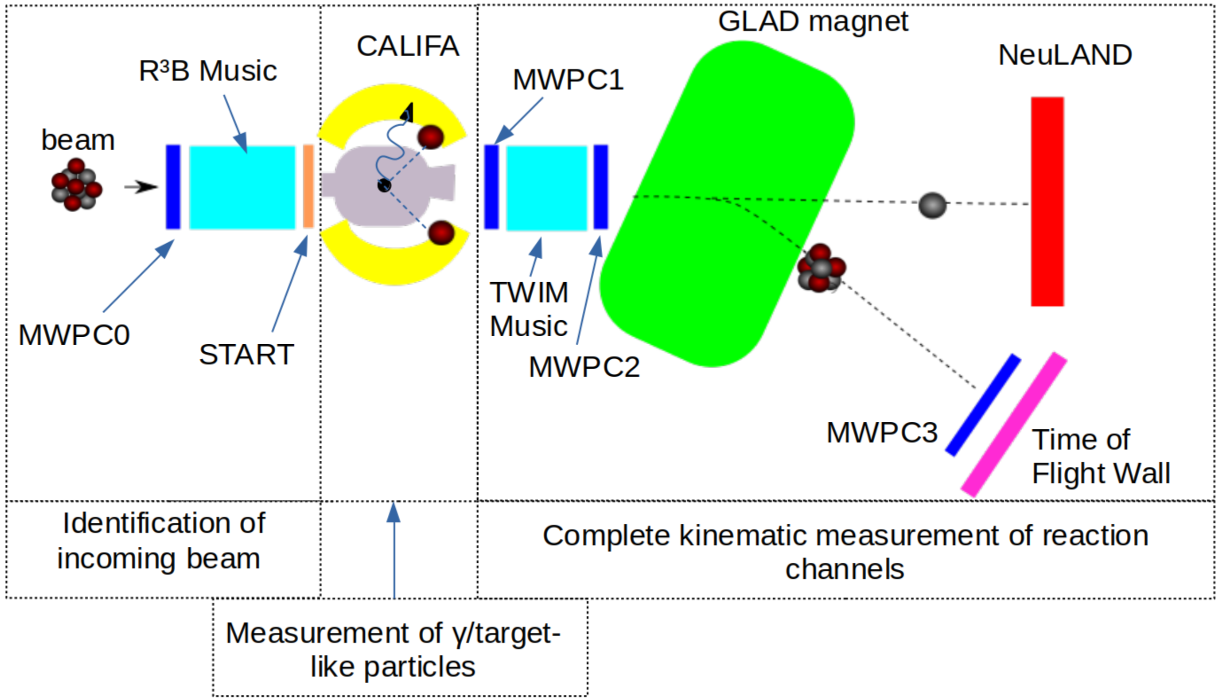
Workload:

- DAQ
- Slow Control
- Analysis

} extend to its full glory

Physics at R3B with CALIFA

Physics Program @ R3B



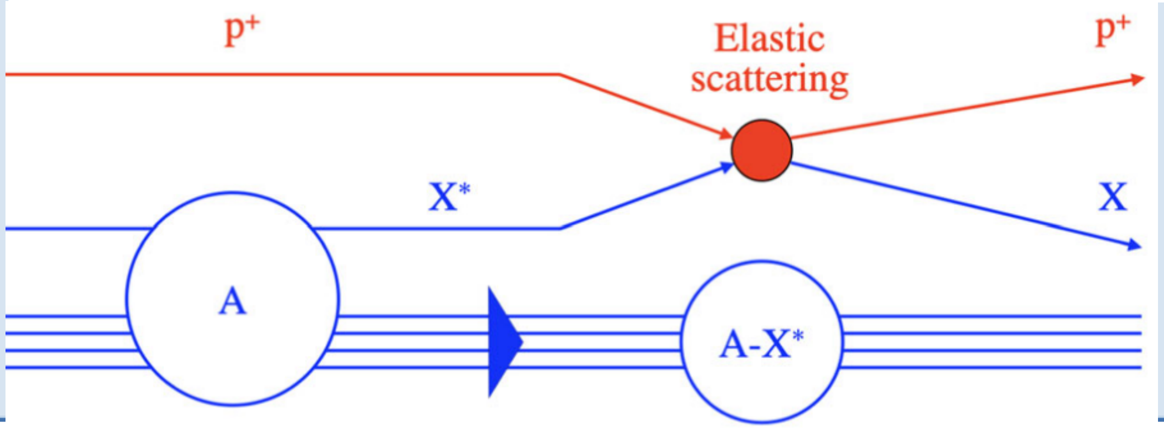
- Physics program on exotic nuclei in inverse kinematics:

- kinematically complete measurements

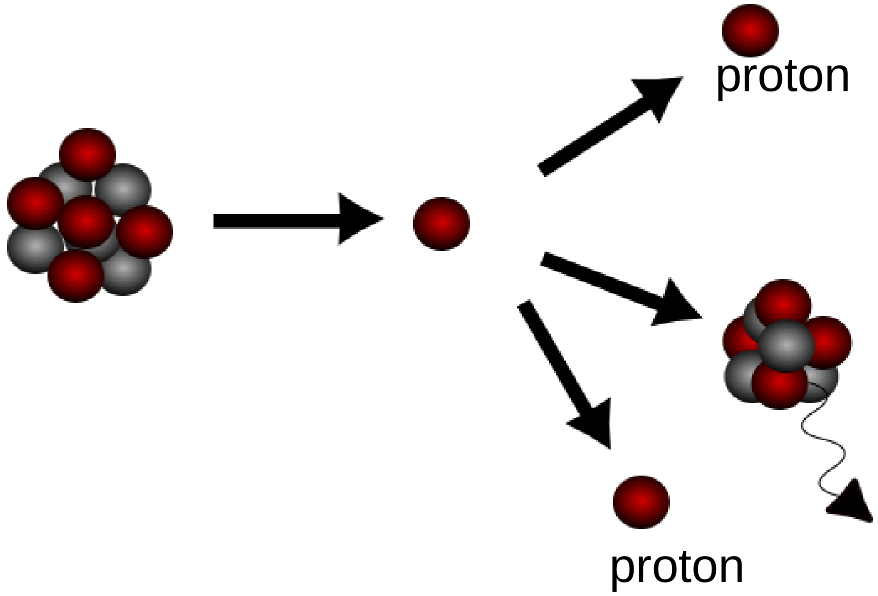
Key physics Progam

→ Quasi-Free Scattering Reactions:

proton probe is used for sudden knockout of a nuclear constituent

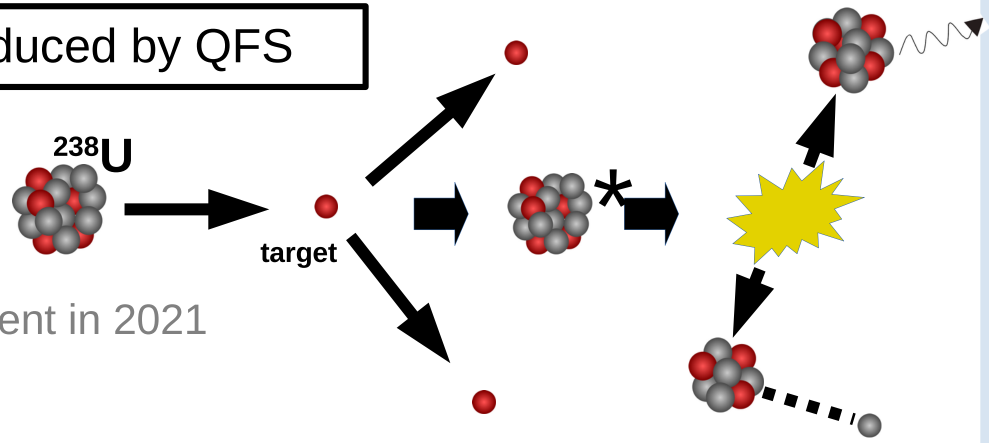


Quasi-Free Scattering Reactions @ R^3B

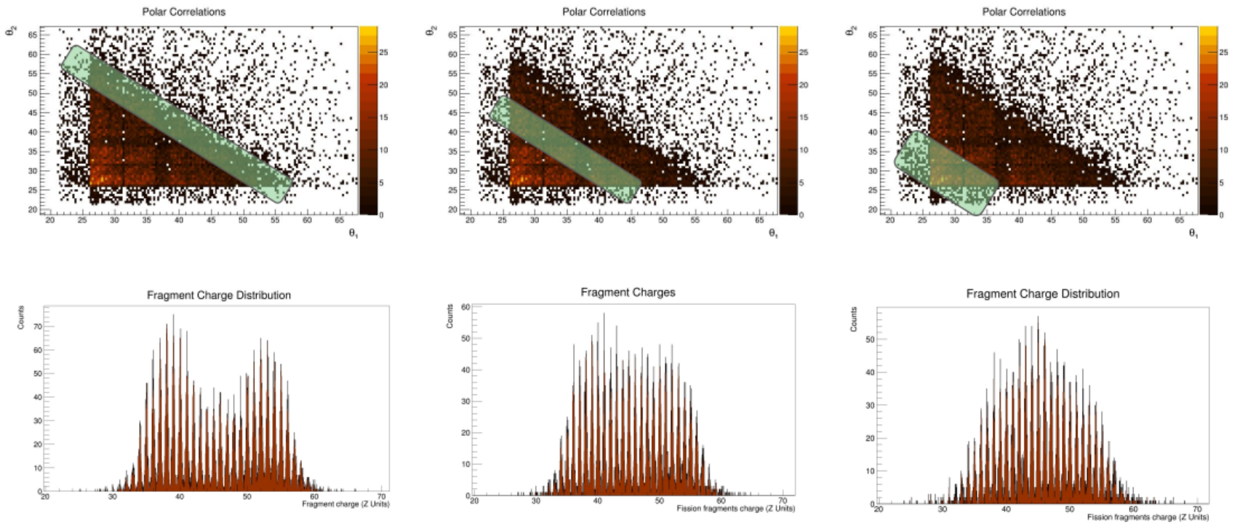


- Gives direct access to single particle properties inside nuclei
- Allows to study in detail the nuclear shell structure and its evolution far off stability

Fission induced by QFS



Pilot experiment in 2021



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

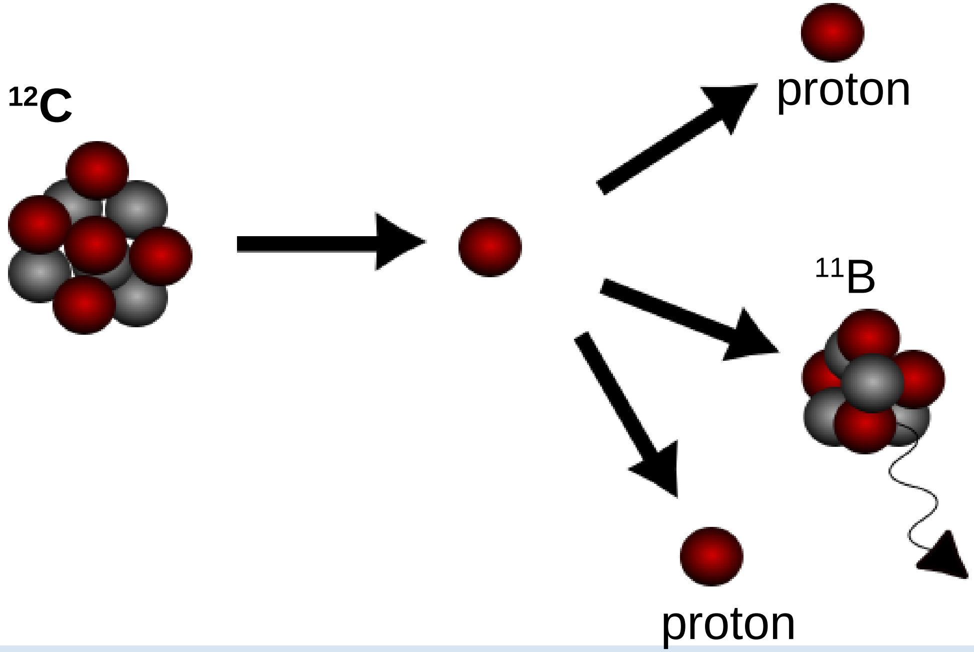
- ^{12}C beam
- proton like target

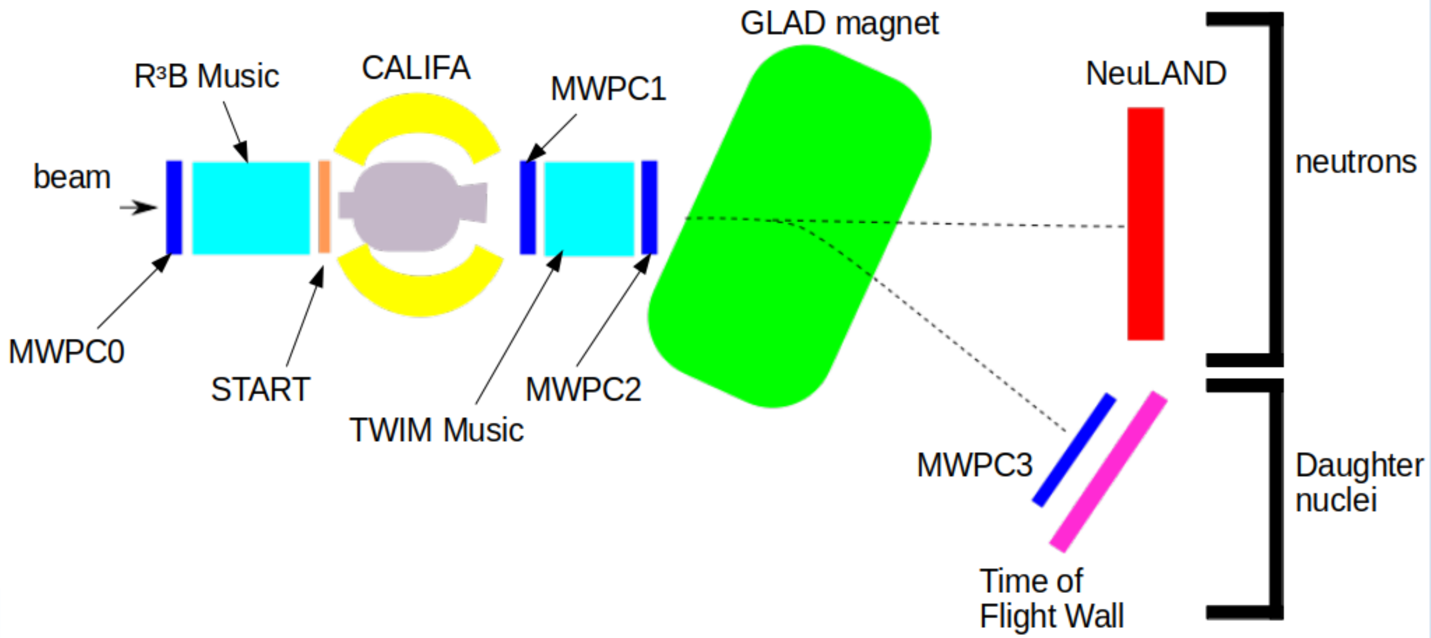
→

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

SETUP:

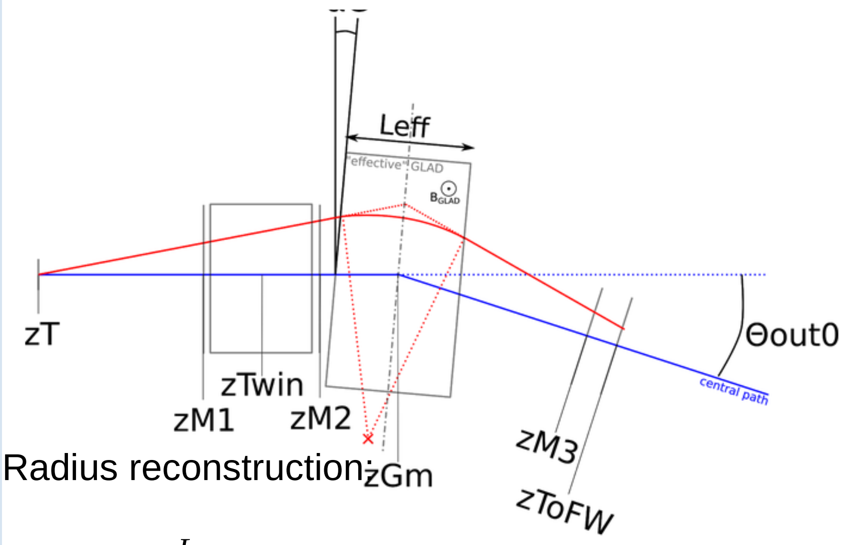
Beam energy: 400 AMeV
Beamtype: ^{12}C
Beamtime: 3 hours
Target: CH_2 (12.29 mm)





Fragment Particle Identification

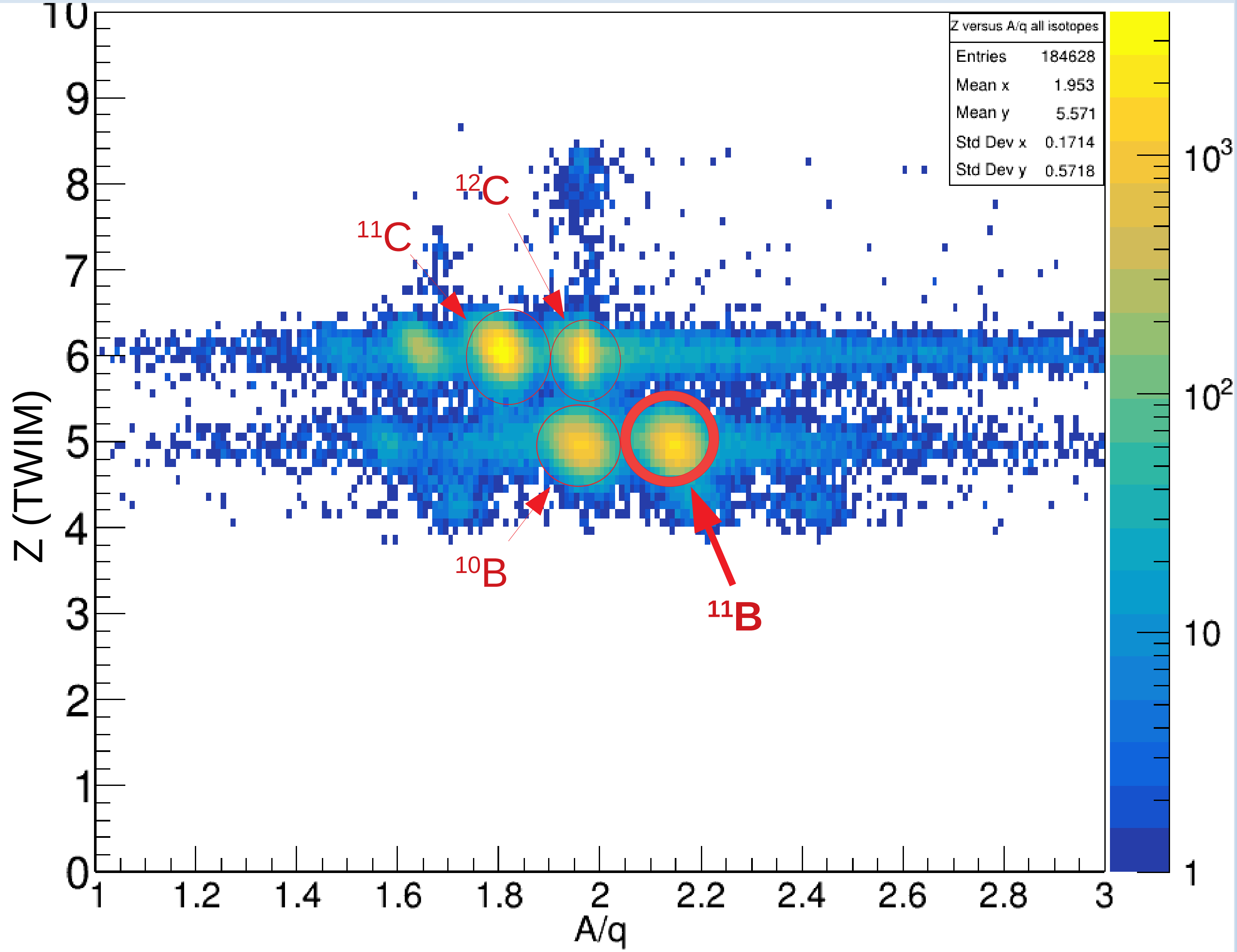
Flightpath reconstruction:



Radius reconstruction:

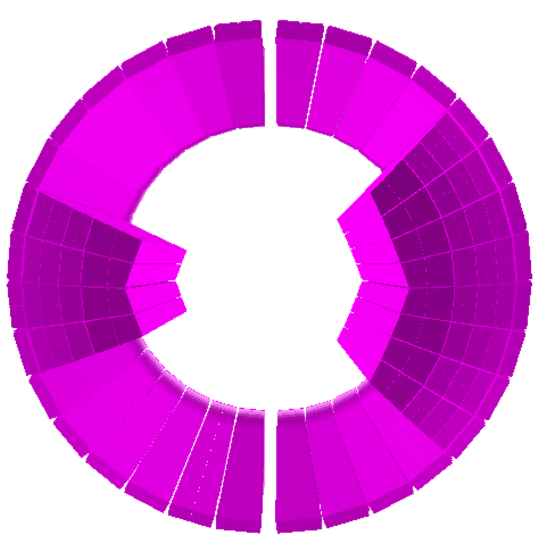
$$R = \frac{L_{eff}}{2\sin\left(\frac{\theta_{in}+\theta_{out}}{2}\right)}$$

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

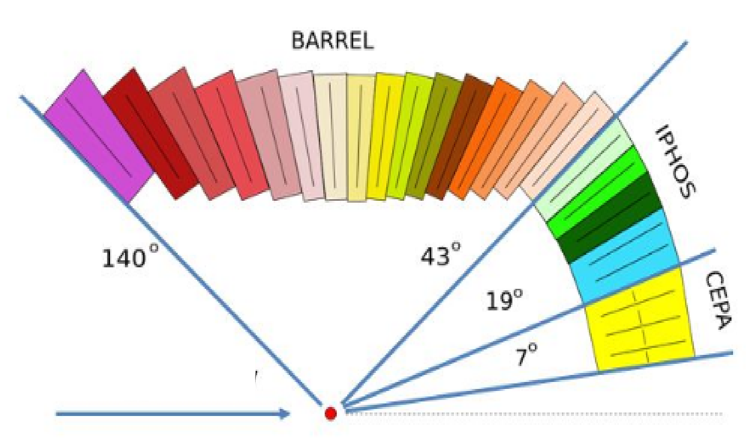


Identification of the two correlated Protons

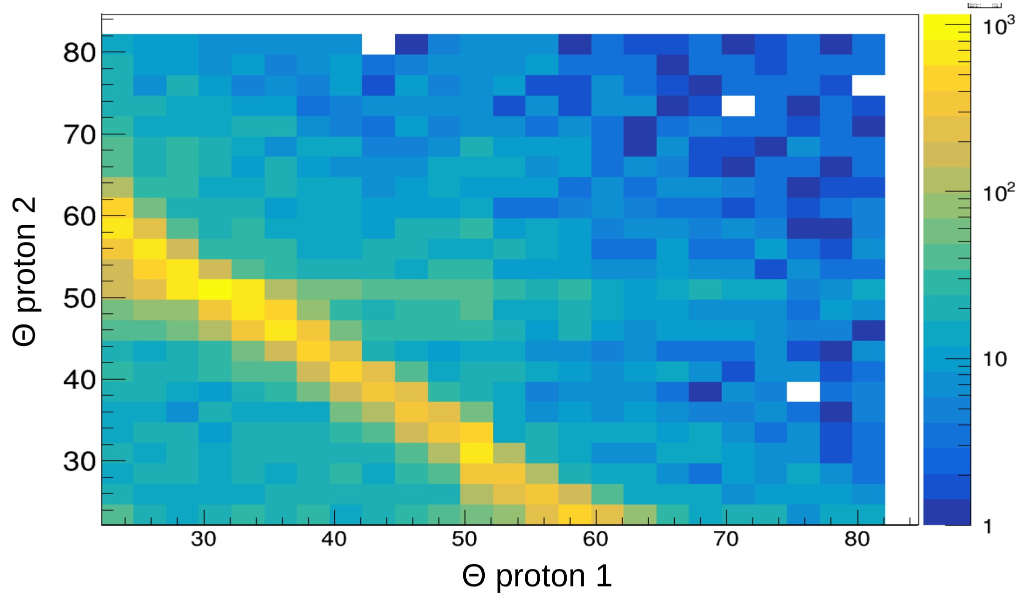
CALIFA Front View



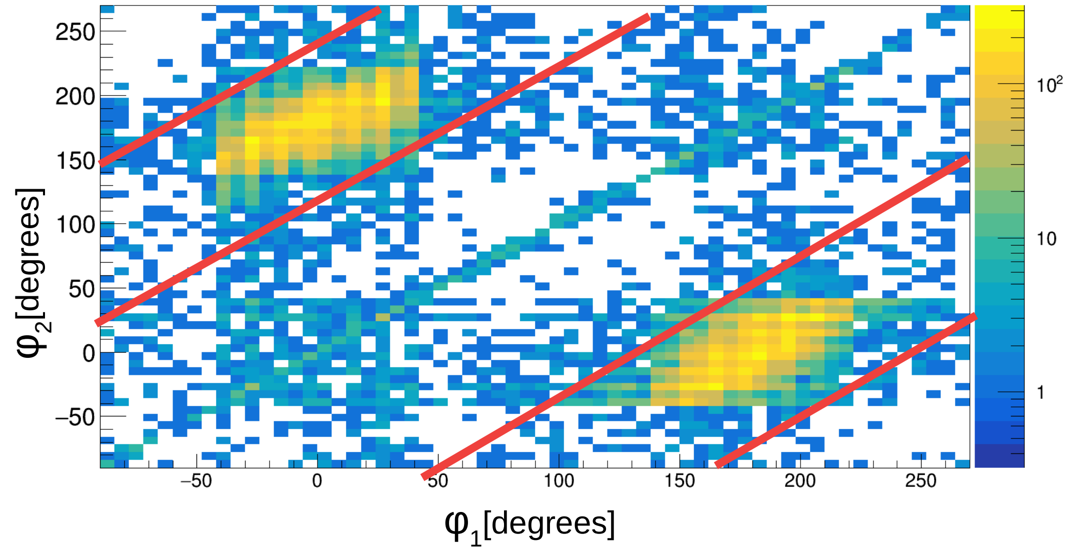
CALIFA Side View

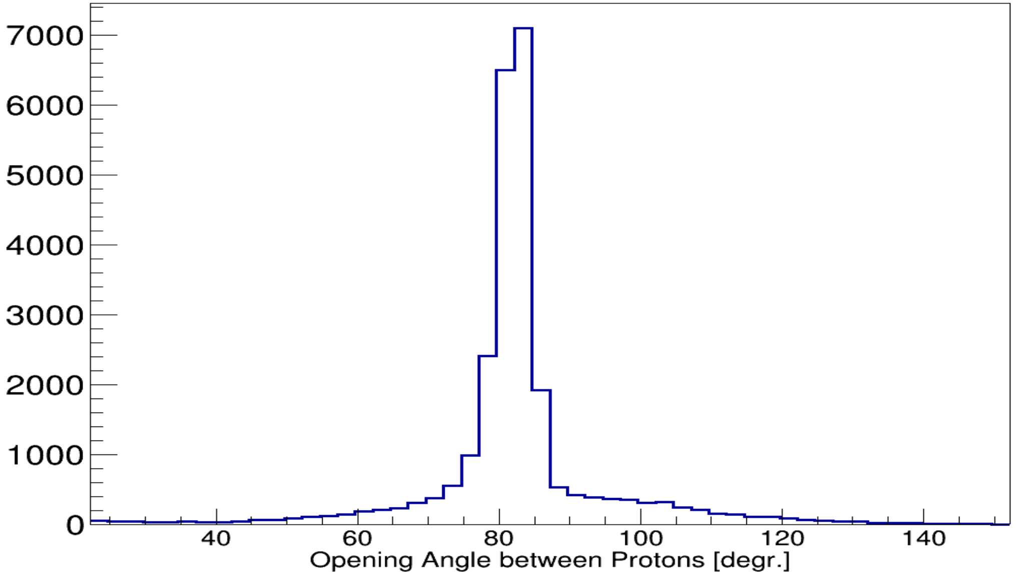


Polar Angle of p_1 and p_2



Azimuthal Angle Proton 1 vs Proton2

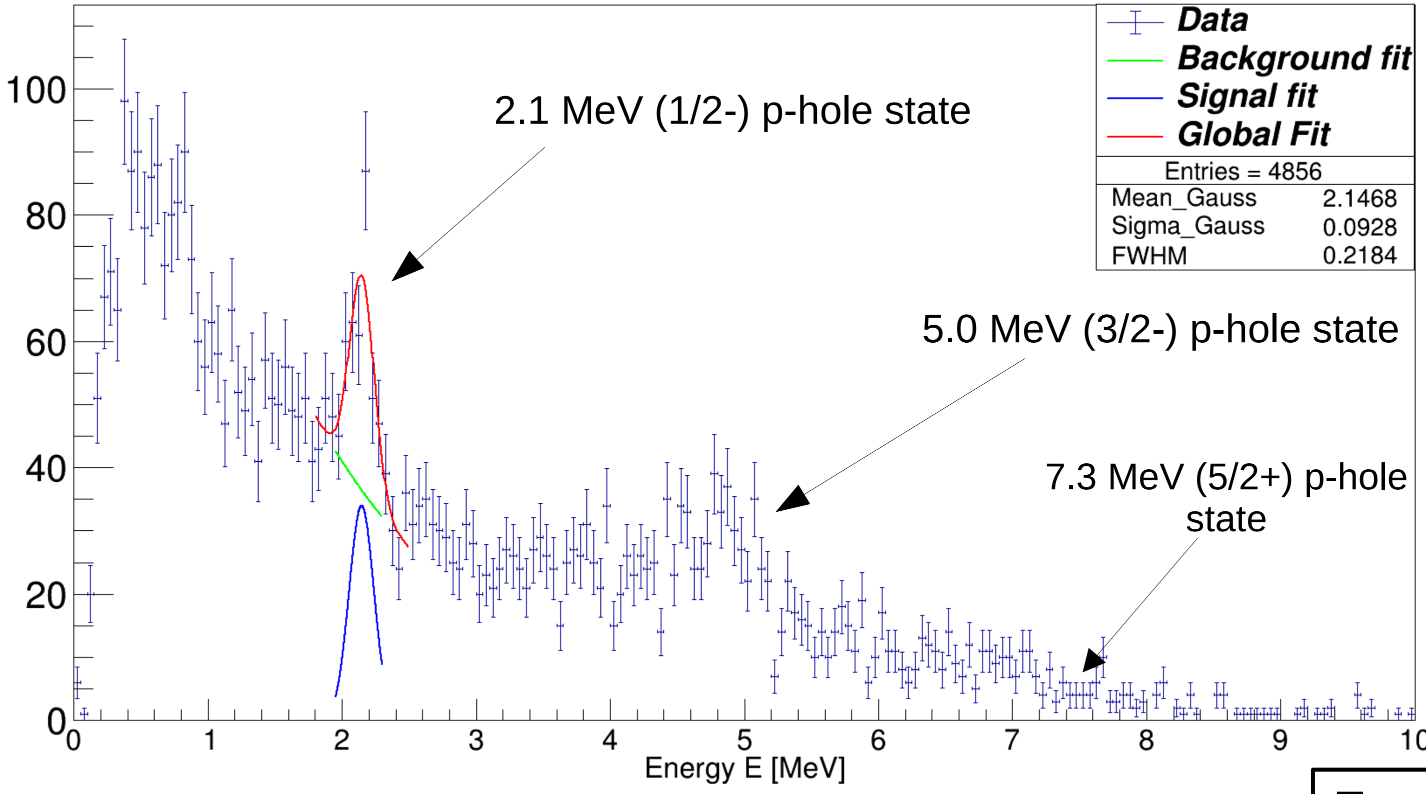


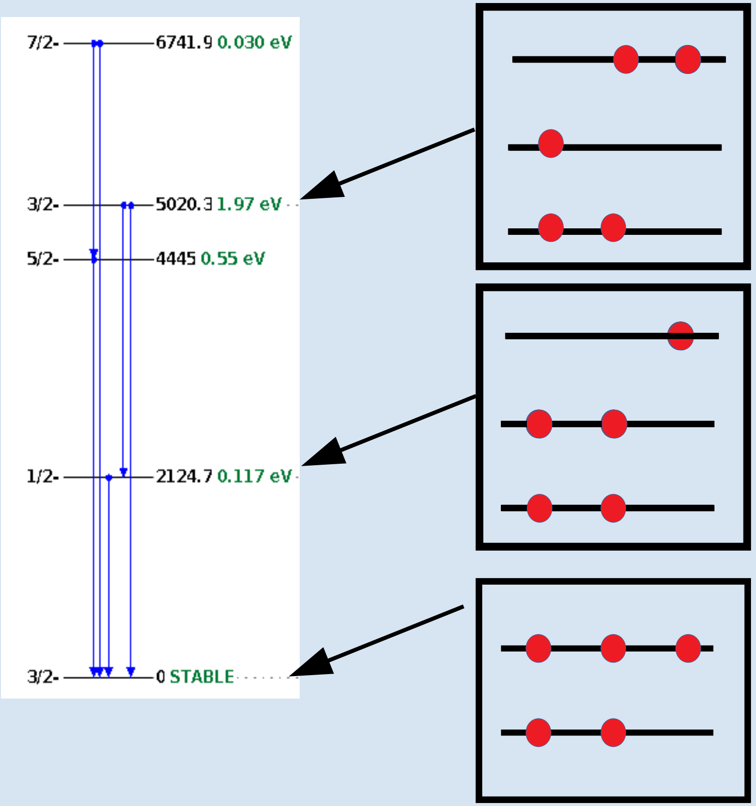


Gamma Spectrum of ^{11}B

Doppler Corrected Gamma Spectrum

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

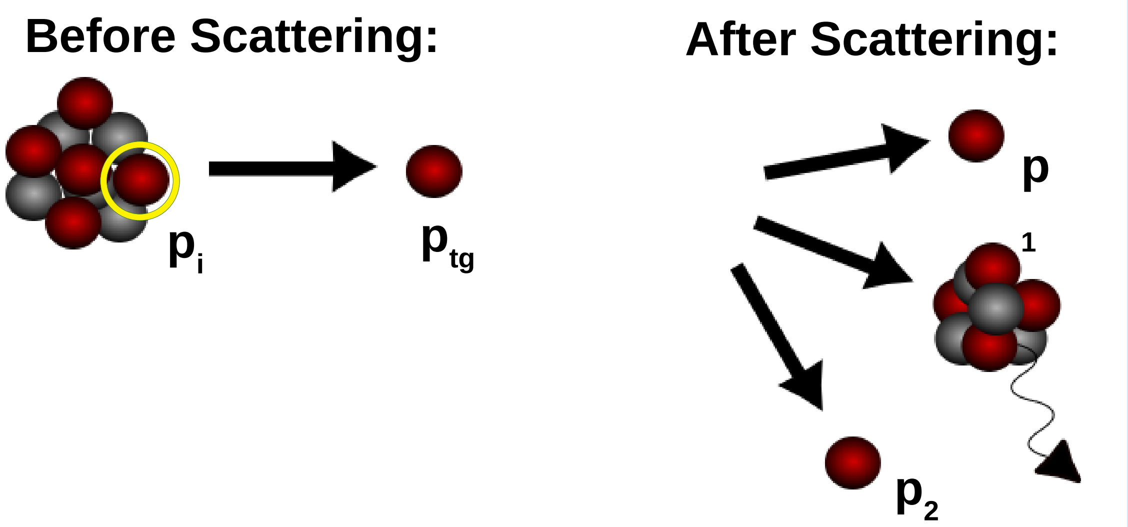


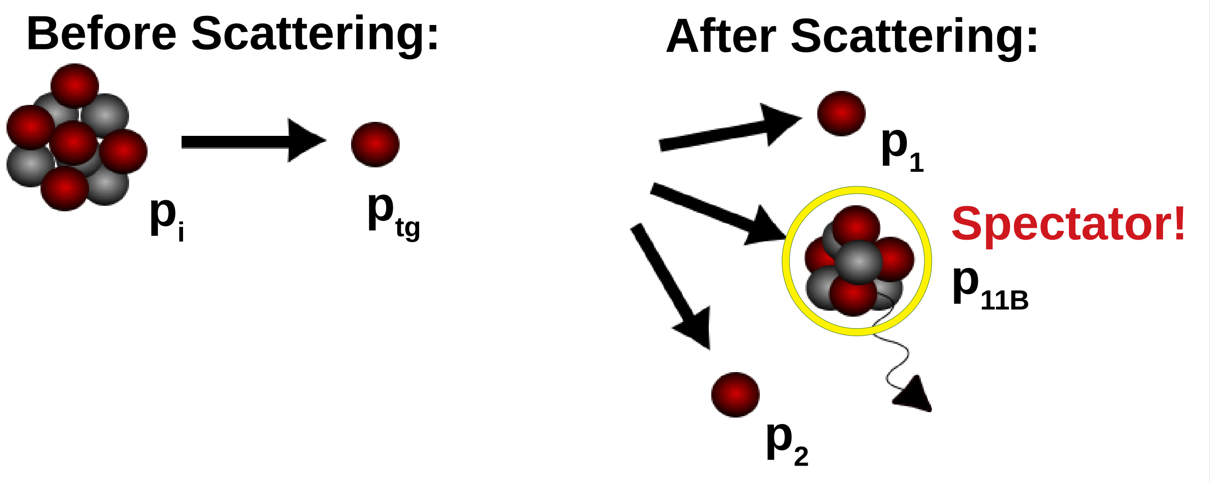


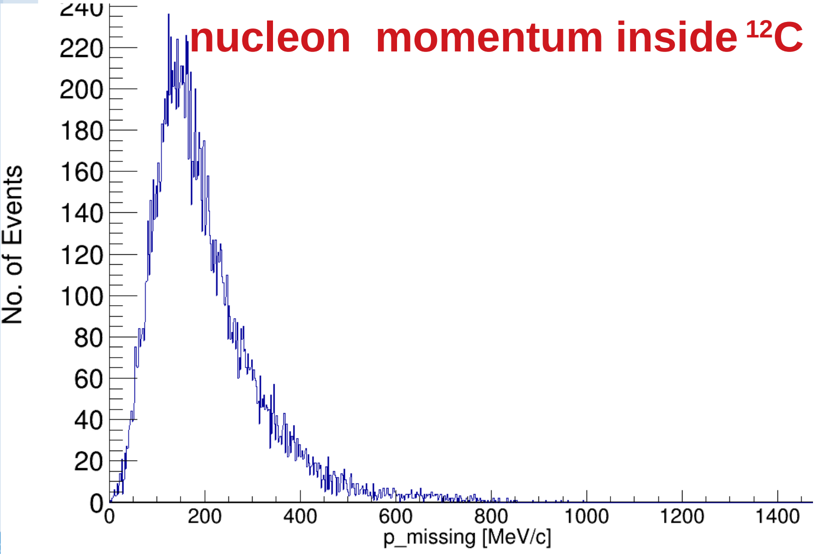
Event Selection Criteria:

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

Reconstruction of Inner Momenta







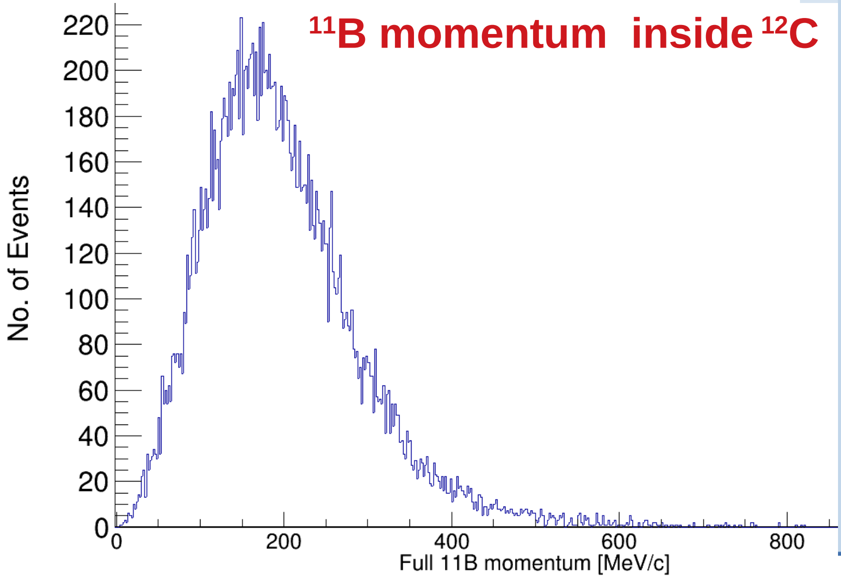
(Four-)Momentum conservation relation:

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

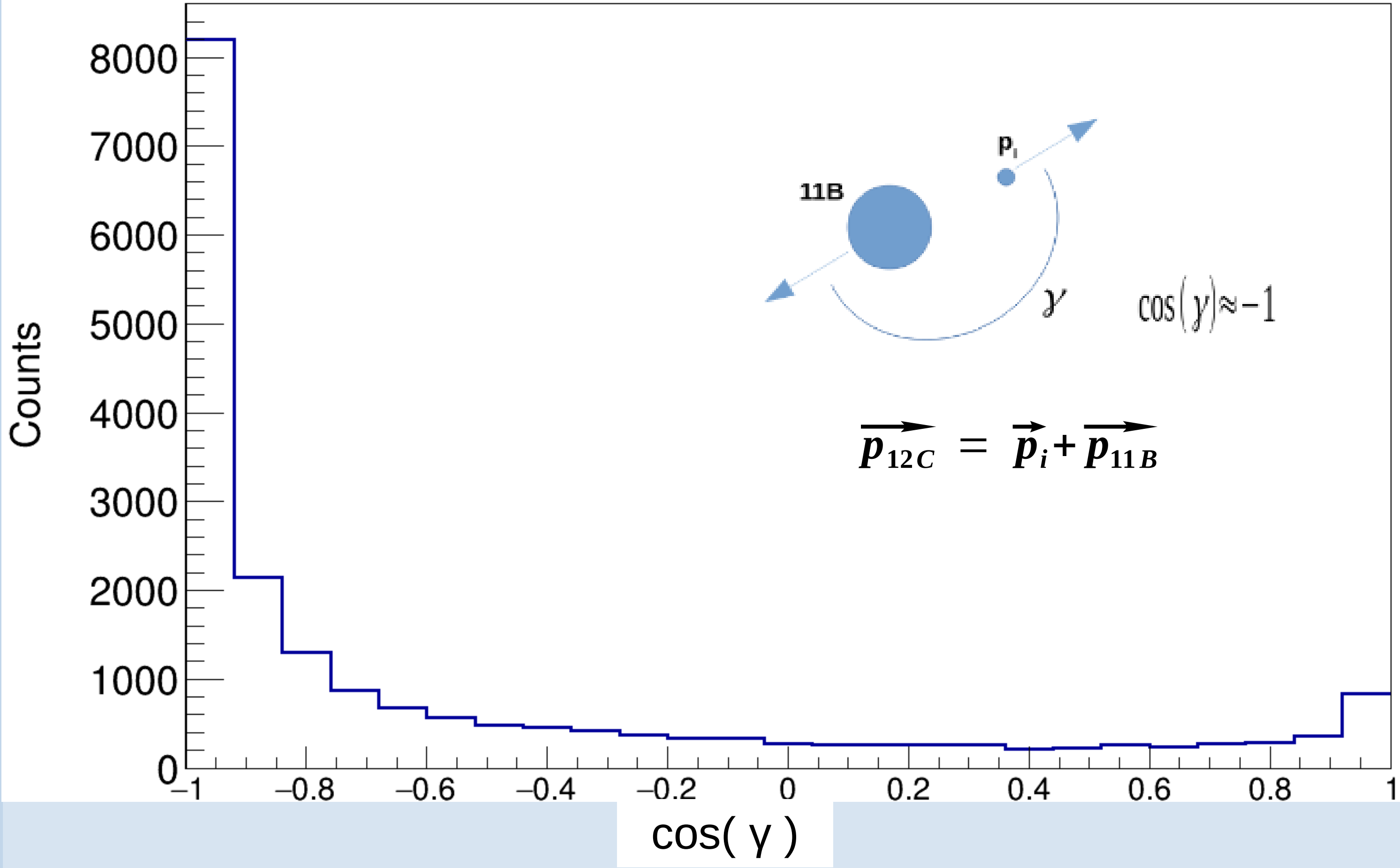
assuming QE scattering in mean field potential:

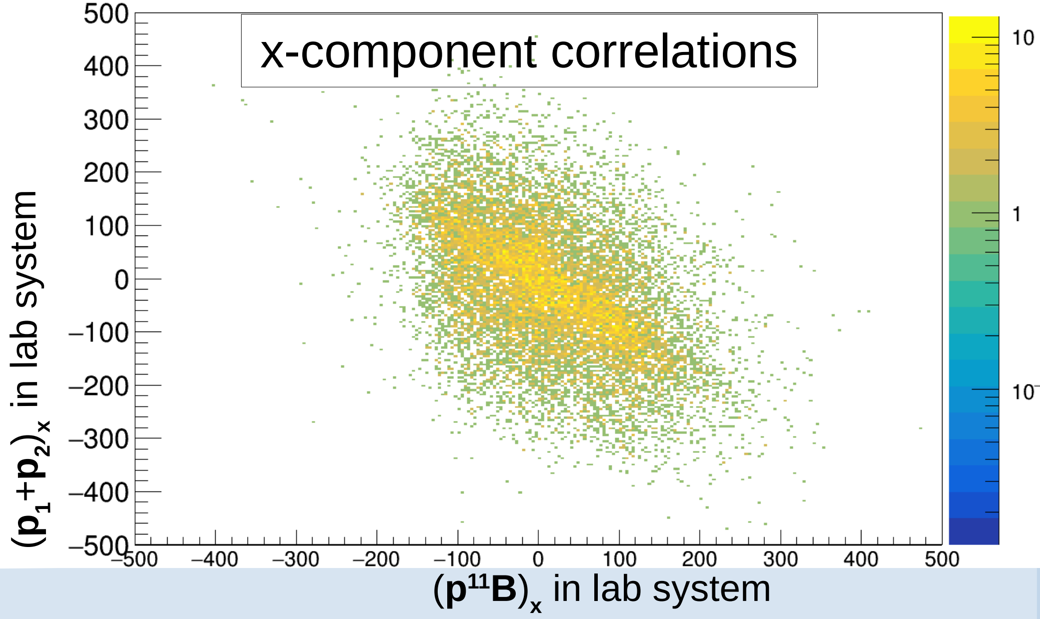
$$p_{12C} = p_i + p_{11B}$$

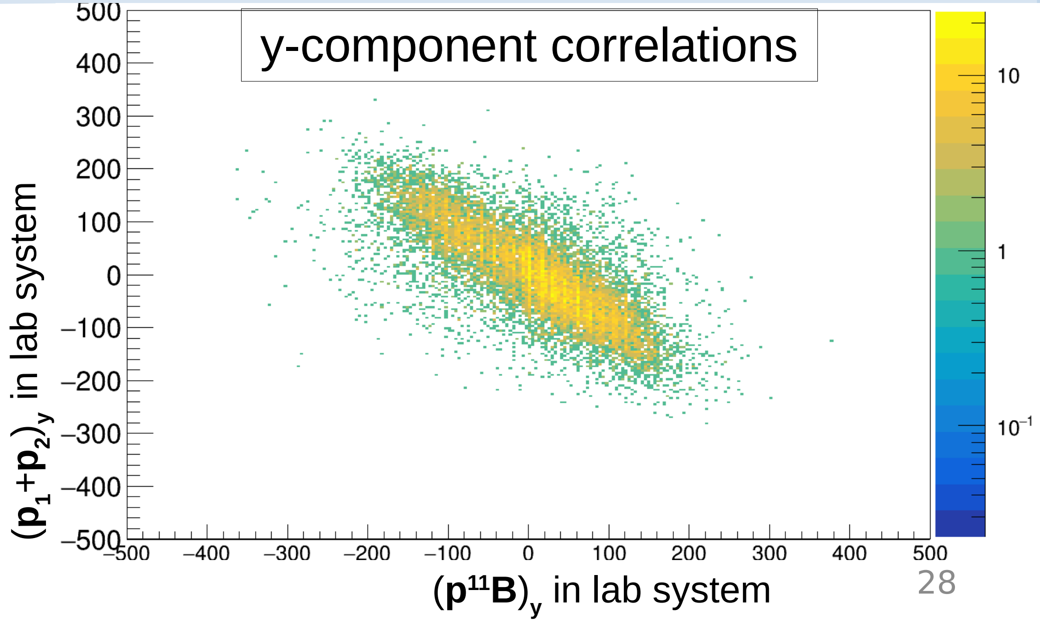
$$p_i \approx p_{missing} = p_1 + p_2 - p_{tg} \left(no\ ISI / FSI \right)$$



Correlations between Fragment and Proton Pair







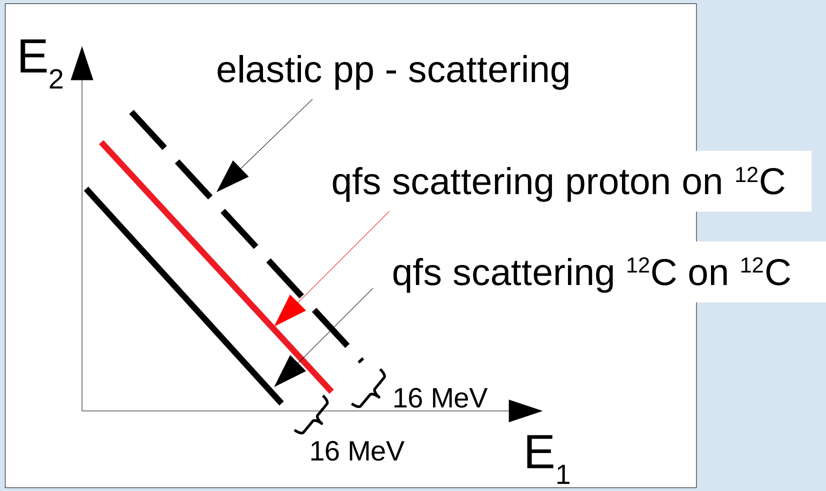
Tobias Jenegger

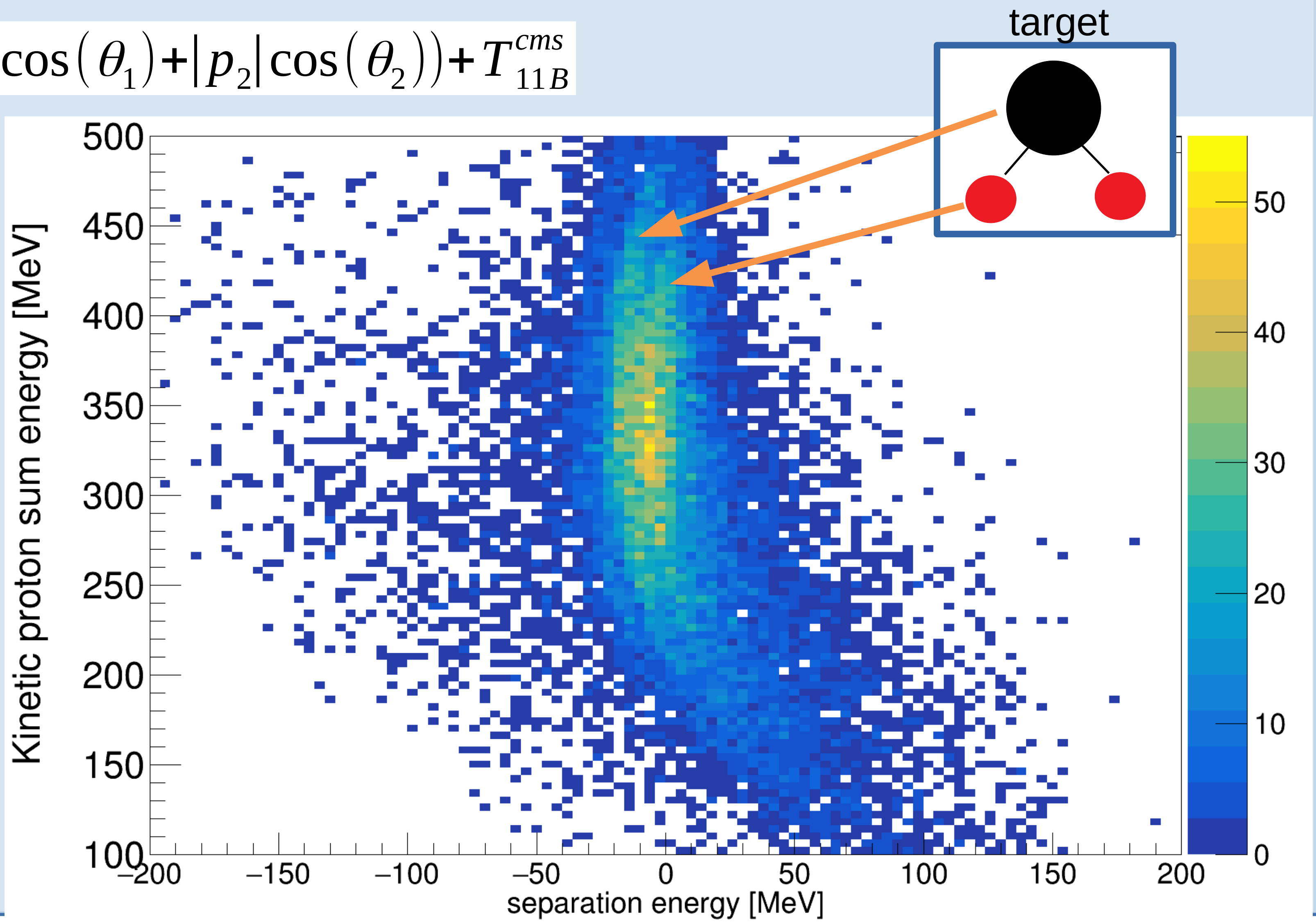
Proton Separation Energy of 12C

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

S_p = Energy needed to remove one proton from the nucleus

In direct kinematics it would be:





no tracker in target region

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

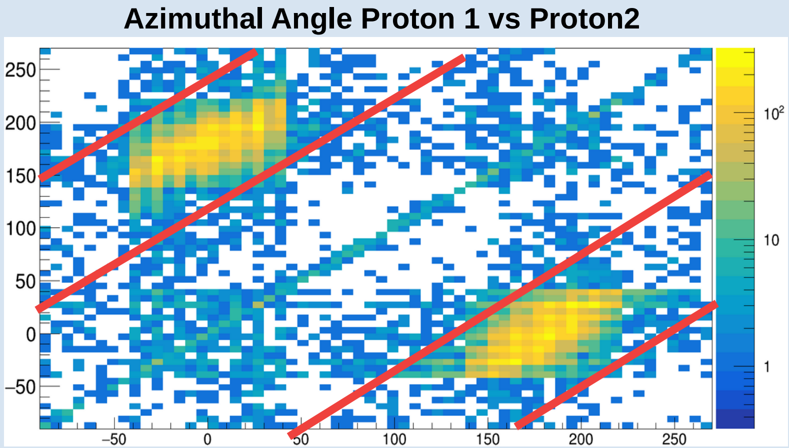
Selection Cuts:

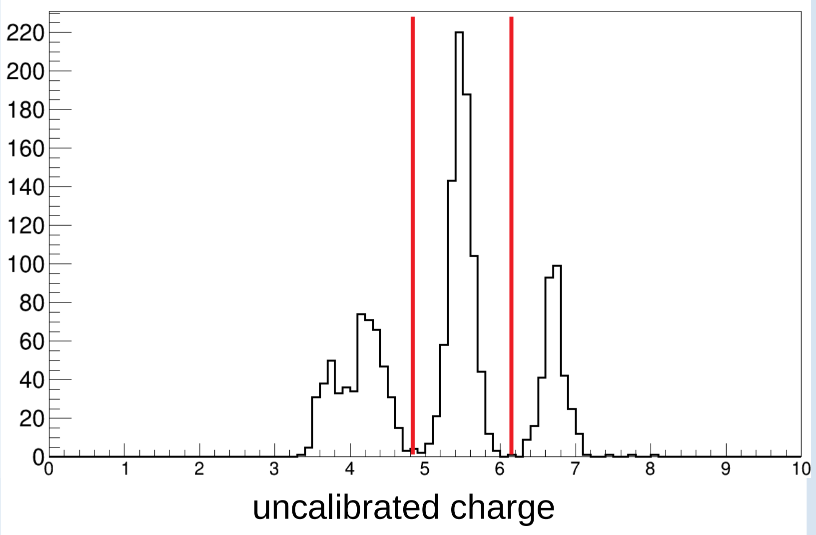
→ strict event selection in front of target

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

→ $\Delta\varphi = 180 \pm 40°$

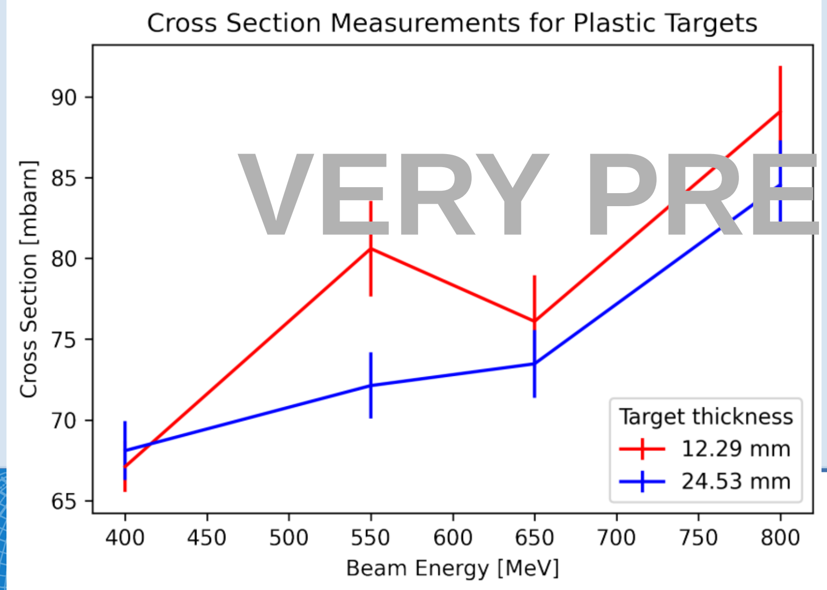
→ Boron as Fragment (Z = 5)

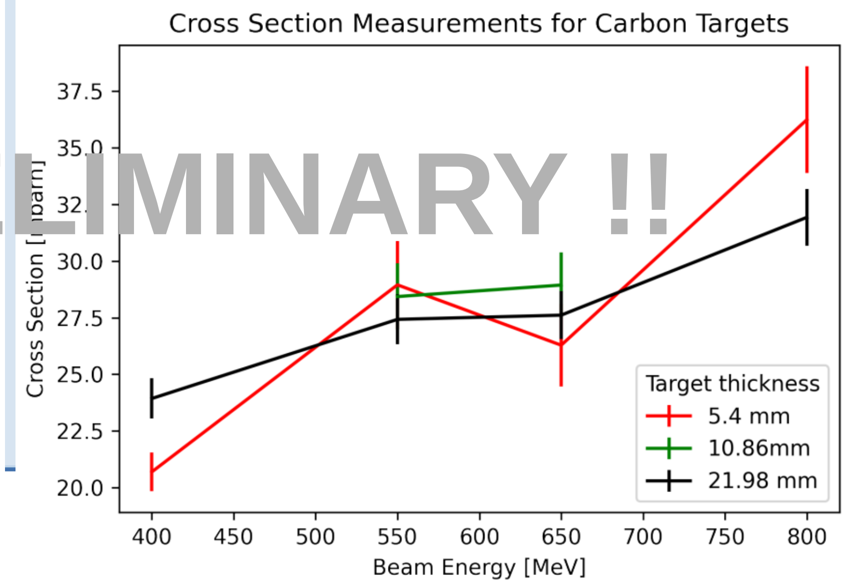




CALIFA only 35% filled in forward region → large correction factors

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

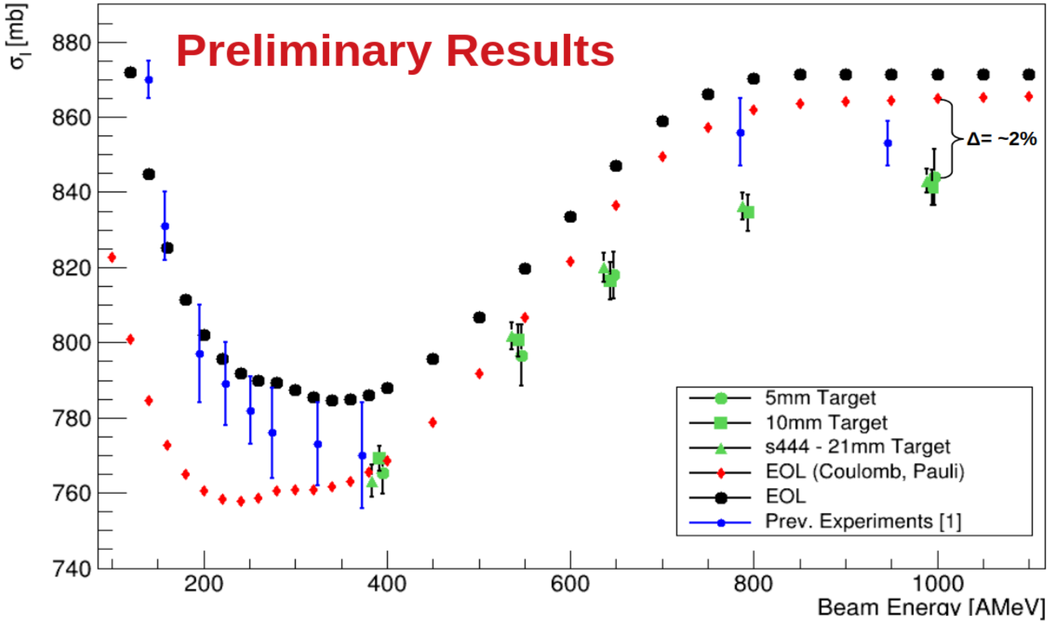
Survival Probability: $P_{surv.} = \frac{N_2}{N_1} = e^{-N_t \cdot \sigma_R}$

Exclude reactions in Setup:

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

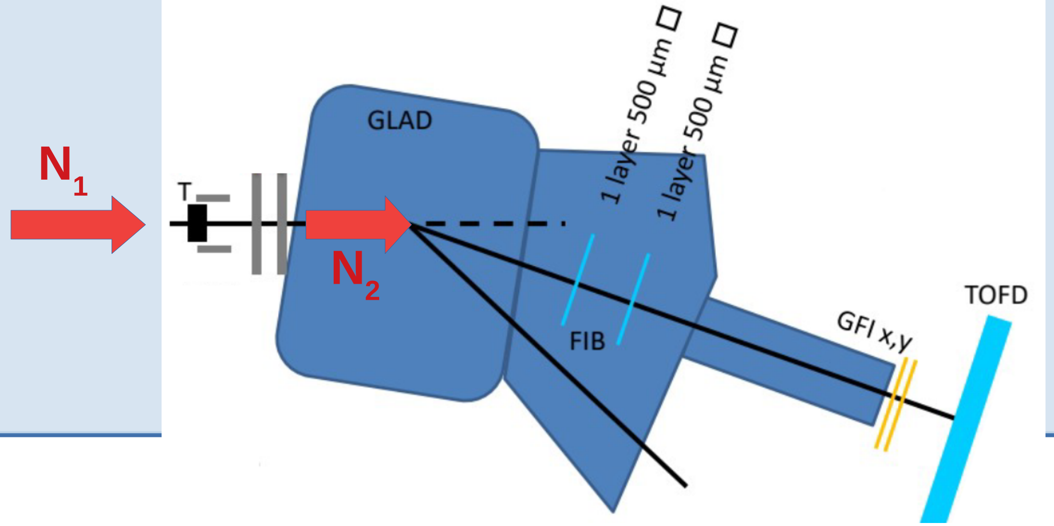
Using the Transmission Method:

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



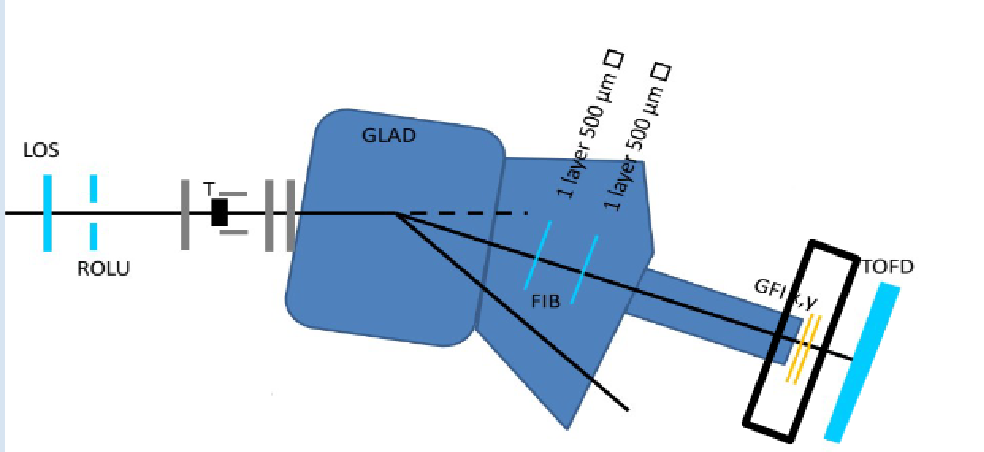
[1] I.Tanihata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009) , A. Ozawa et al. (Nuc. Phy. A – 691 2001)

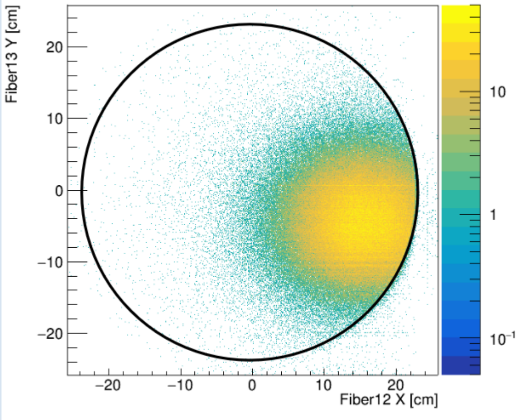
EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)



Comparing the two Setups

Setup - Lukas

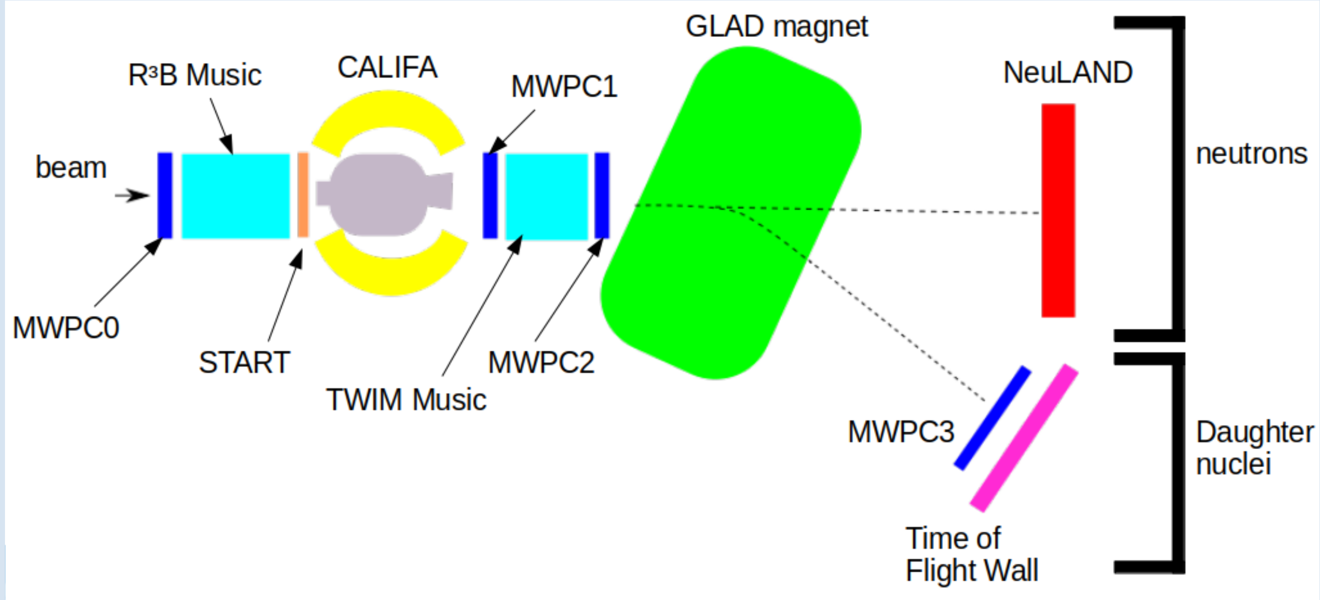




Acceptance issues due to the beam pipe confinement

Fine tuned acceptance corrections needed

S444 (2020) Setup → with carbon target



High acceptance:

→ charge measured right after target by TWIM Music

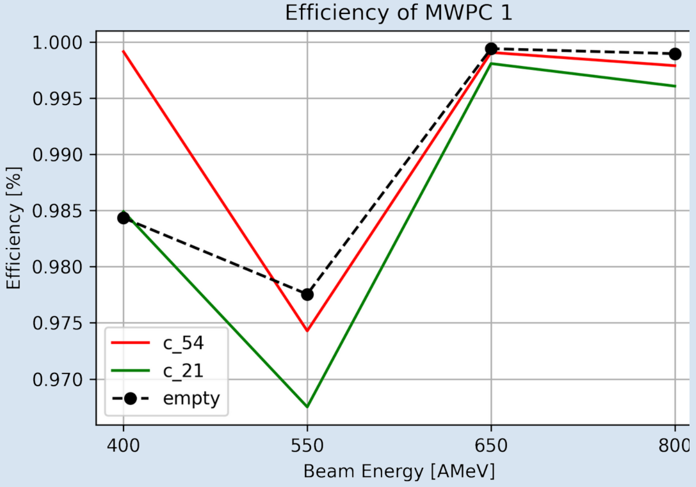
→ no beam pipe (= no vacuum) restrictions

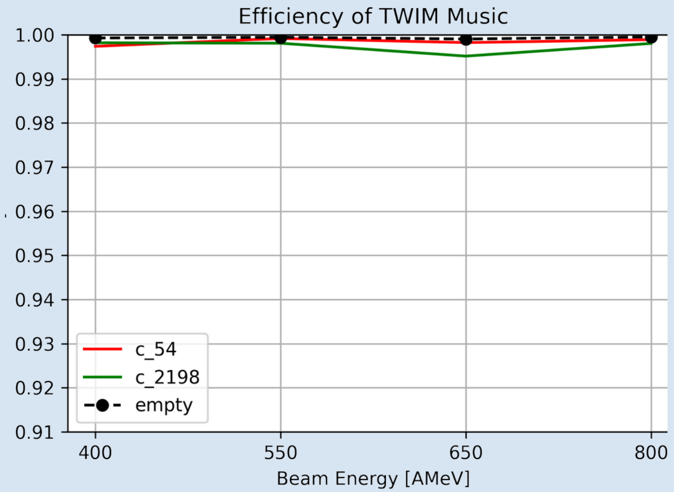
more background

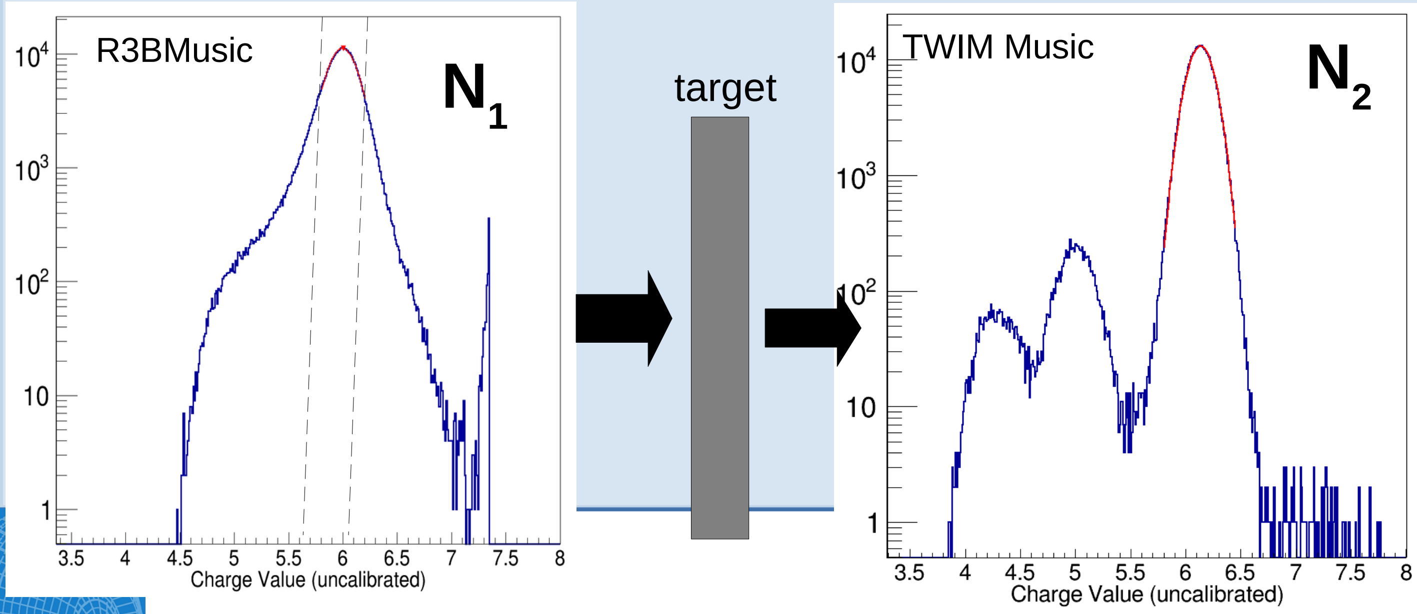
Convenient setup to compare with Lukas' results

Starting with Charge Changing Cross Section

Why not starting directly with total reaction cross section measurement?

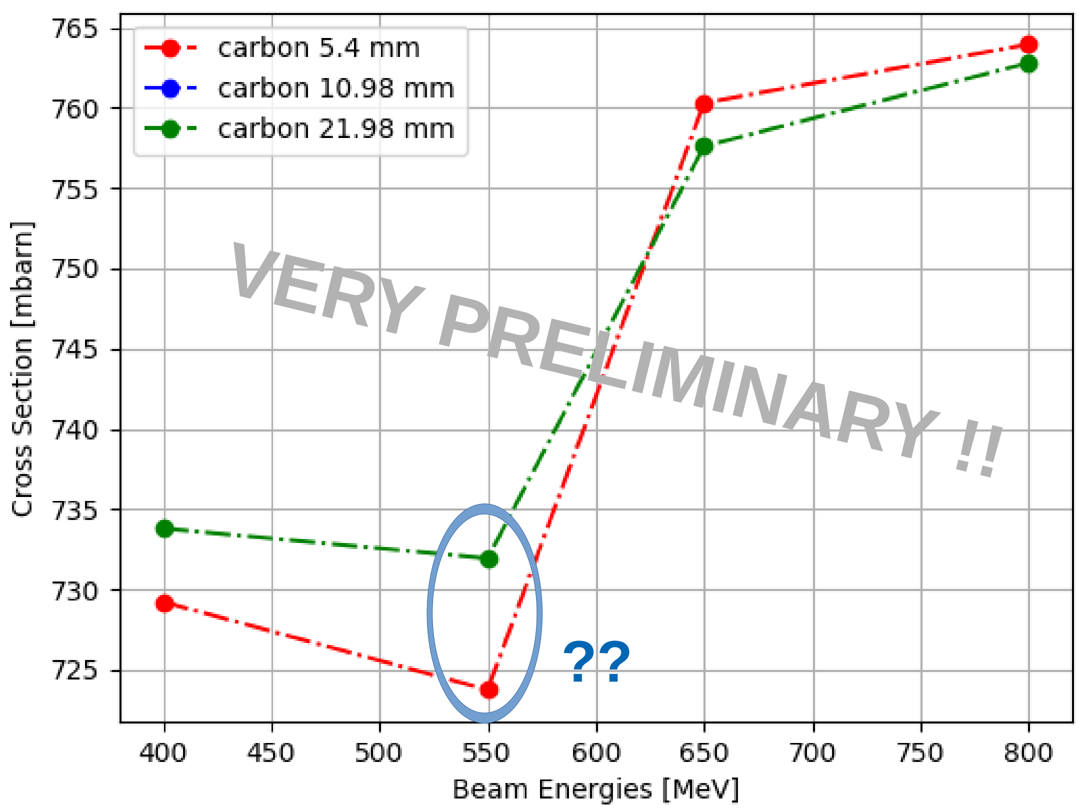






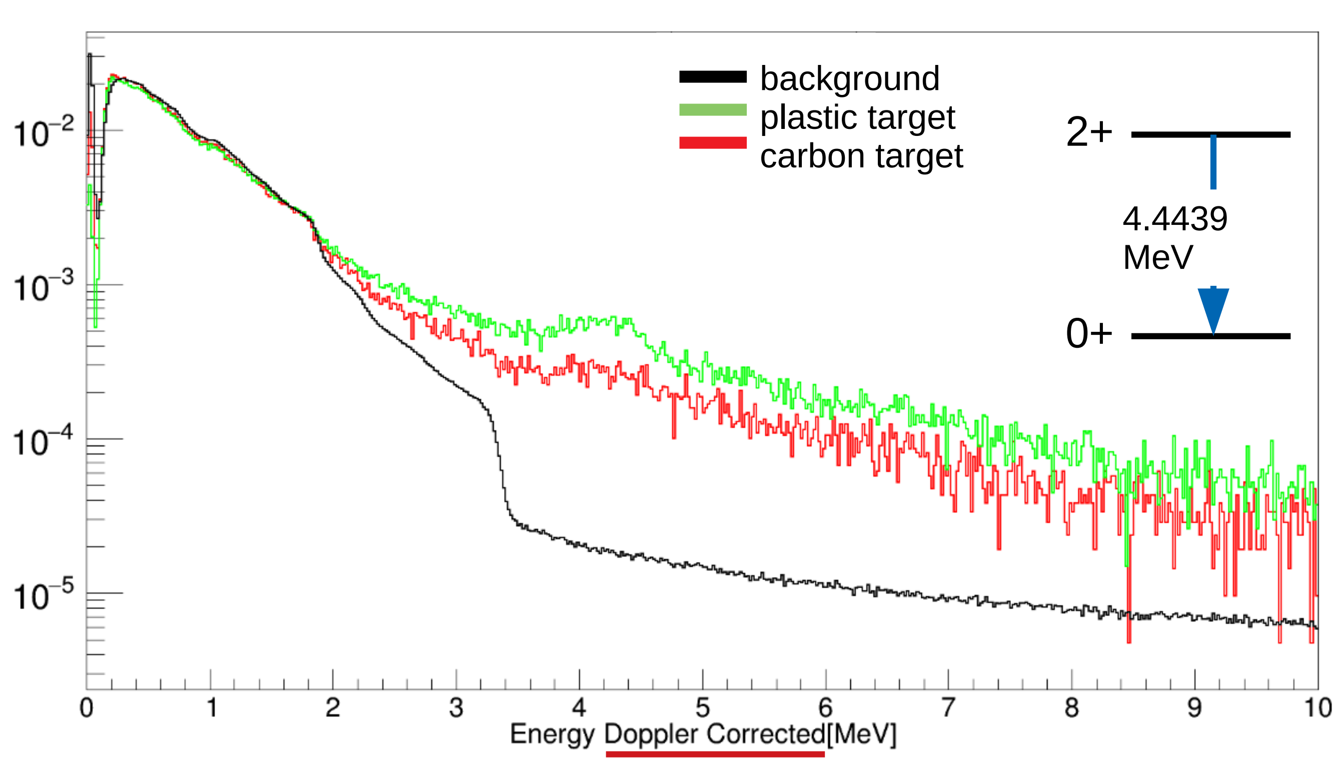
Z = 6

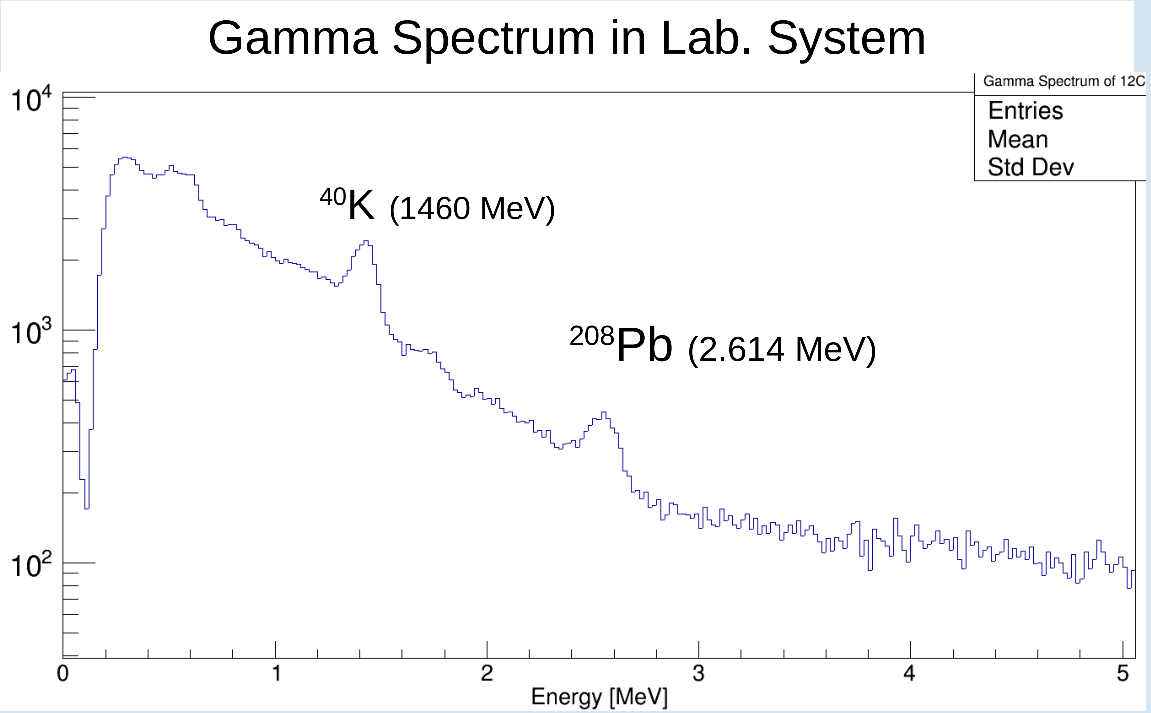
Surviving-Probability: $P_{surv} = \frac{N_2}{N_1} = e^{-N_t \cdot \sigma_R}$



What more ?

12C-12C inelastic reaction





Doppler corrected spectrum: reaction in incoming ^{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

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Bundesministerium
für Bildung
und Forschung