



R³B Commissioning Experiments with Final CALIFA Setup



Supported by BMBF 05P15WOFNA and 05P19WOFN1.

The results presented here are based on the experiment s444/s473, which was performed at the beam line/infrastructure Cave C at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

GEFÖRDERT VOM

Tobias Jenegger

PSI Seminar
16.06.2021

R³B Experiment

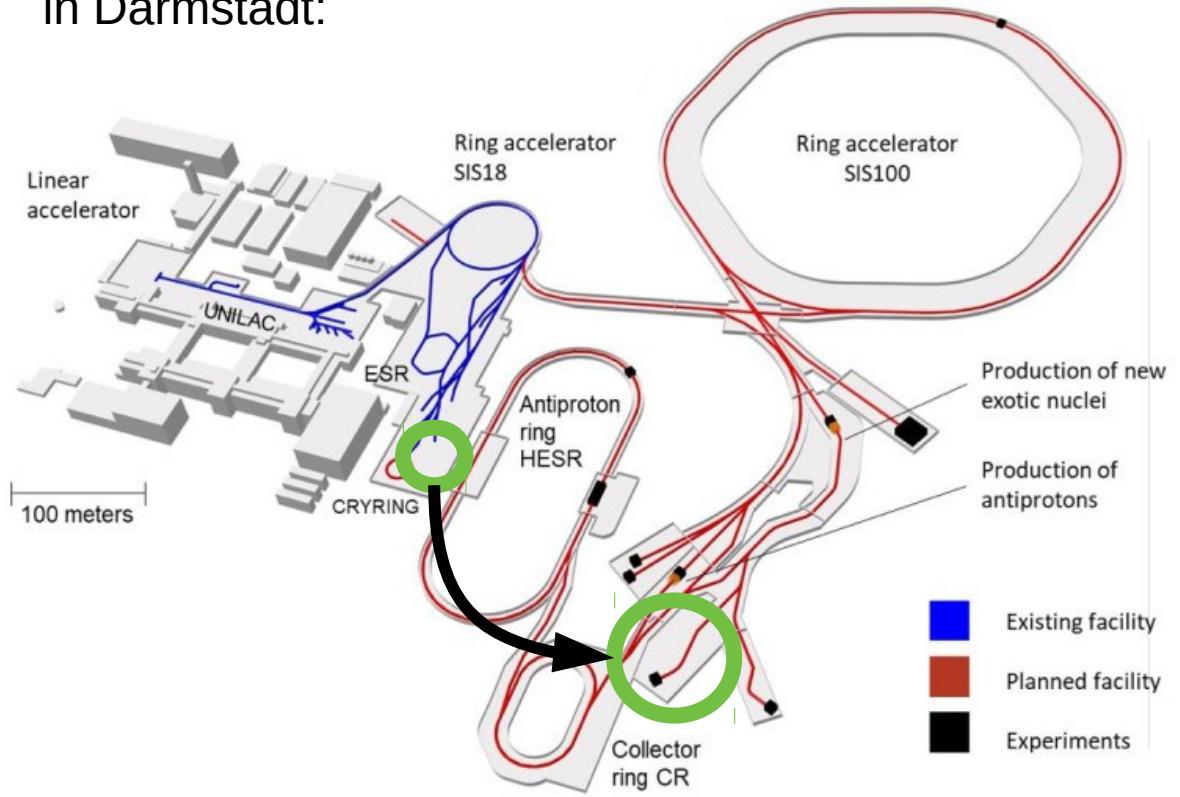
CALIFA - Design and Upgrades

QFS Analysis

R³B @ GSI

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

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



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- 2 mio. m³ of earth excavated
- 600,000 m³ of concrete
- 65,000 tons of steel



5,000 single family homes



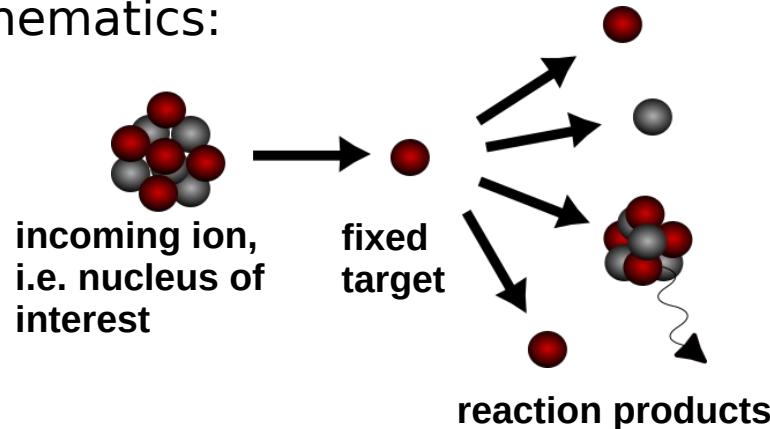
eight Frankfurt soccer stadiums



nine Eiffel Towers

Reactions with Radioactive Relativistic Beams

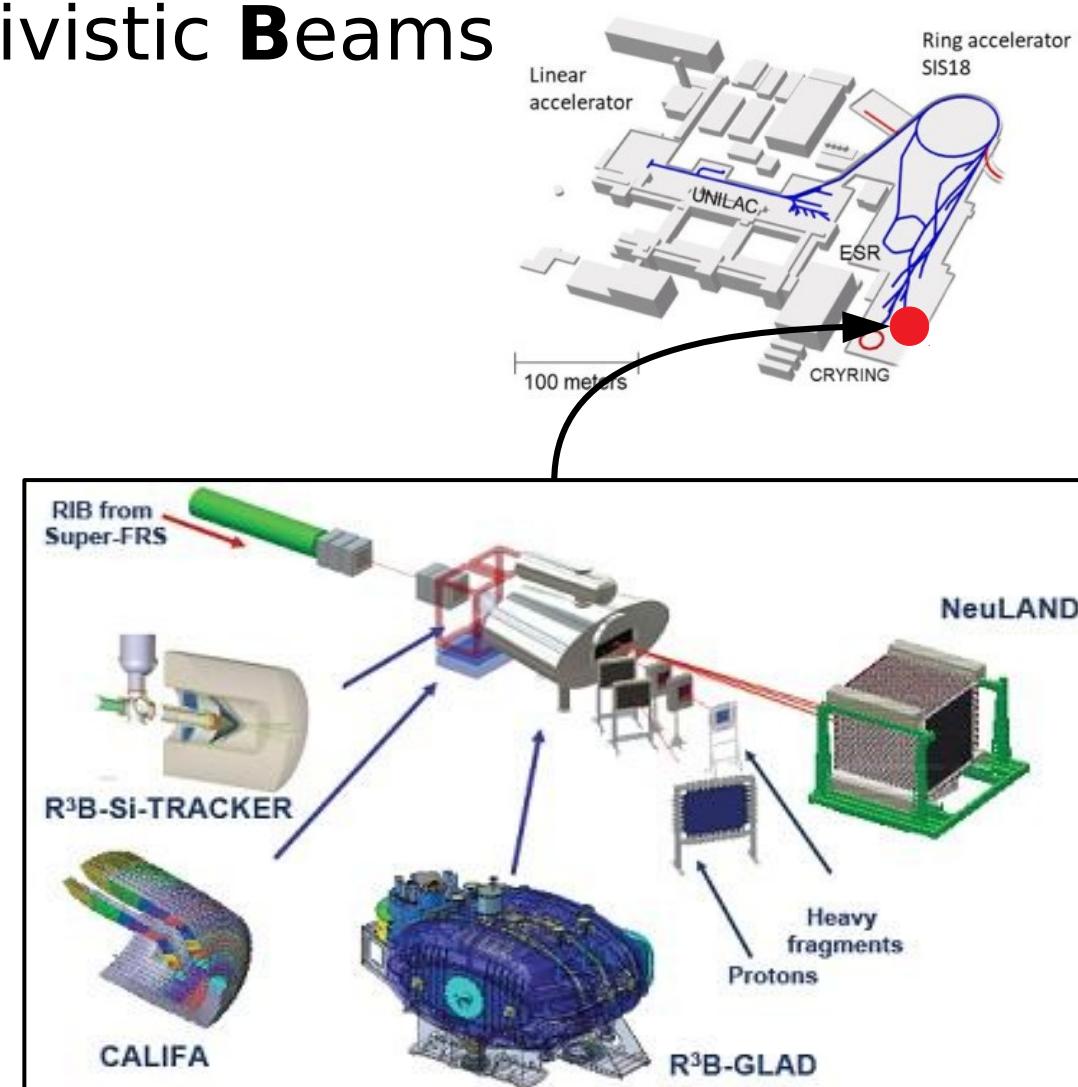
- Physics program on exotic nuclei in inverse kinematics:



- kinematically complete measurements
- In flight production of exotic nuclei from fragment separator Super-FRS
- Flexible setup, extensive physics schedule (despite pandemic restrictions)

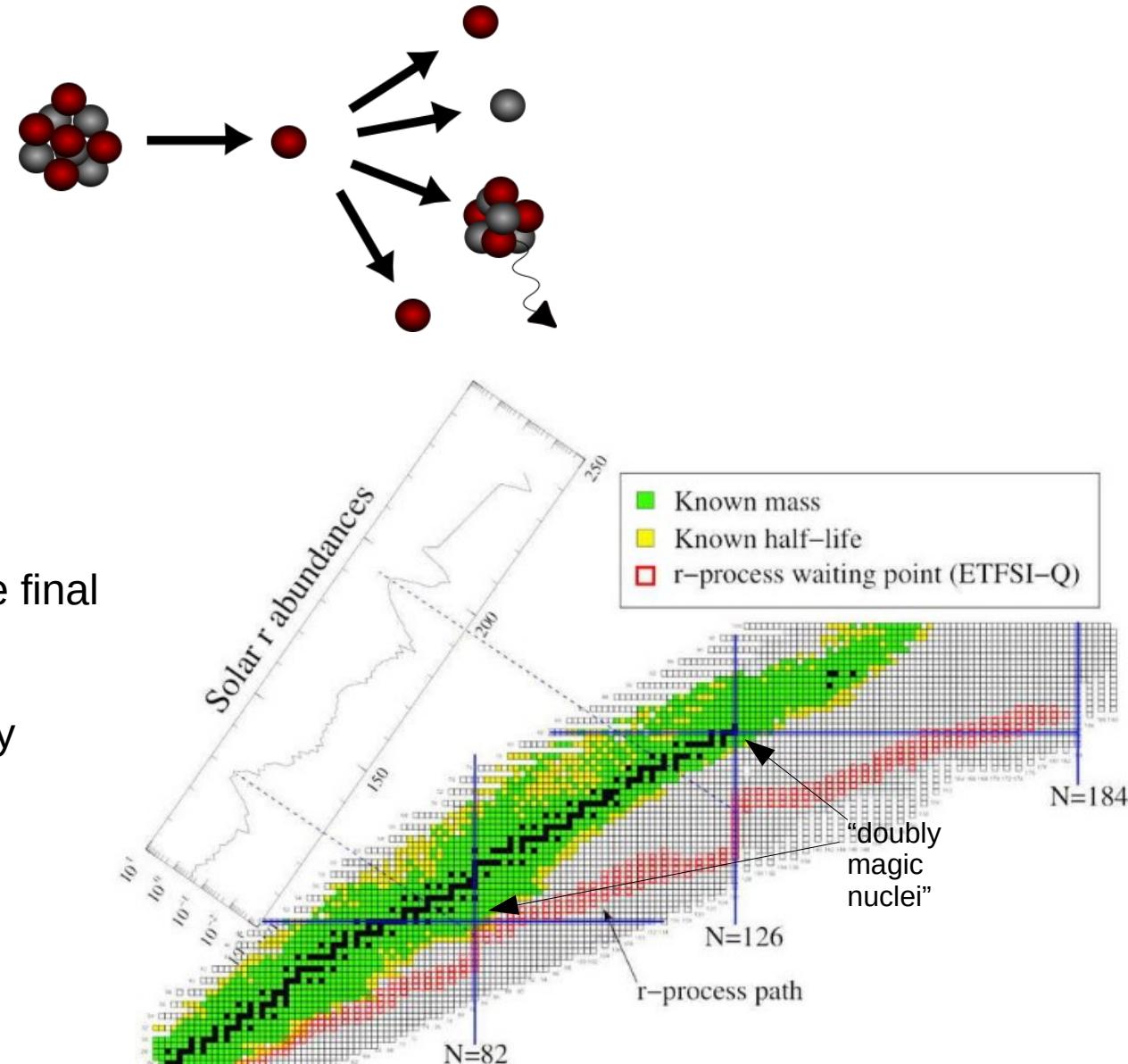


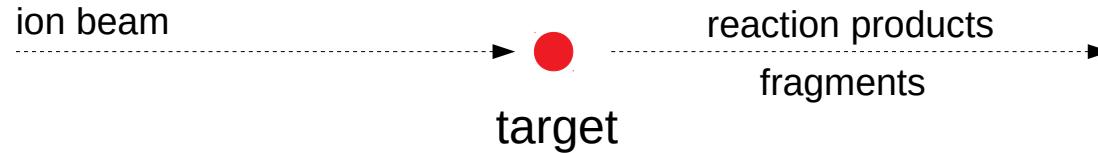
Tobias Jenegger



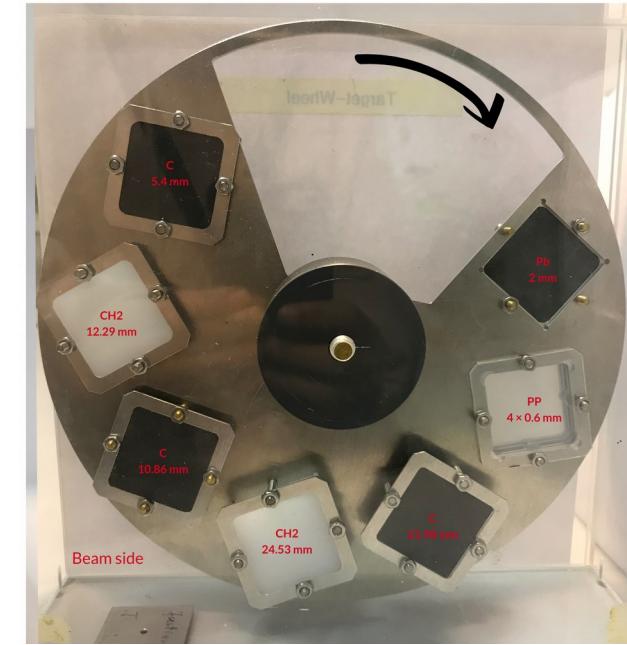
Right now two major physics fields:

- Quasi Free Scattering (QFS)/Knockout reactions
 - study single particle properties inside nuclei
 - analyze shell evolution far off stability
 - measurement of Fermi-momentum, separation energy
- Fission Studies (up to uranium)
 - fission yields are important to understand e.g. the final r-process abundance
 - measurement of the fission barriers far off stability
 - collective excitations in neutron rich exotic nuclei, e.g. Pygmy dipole – resonance, neutron halos





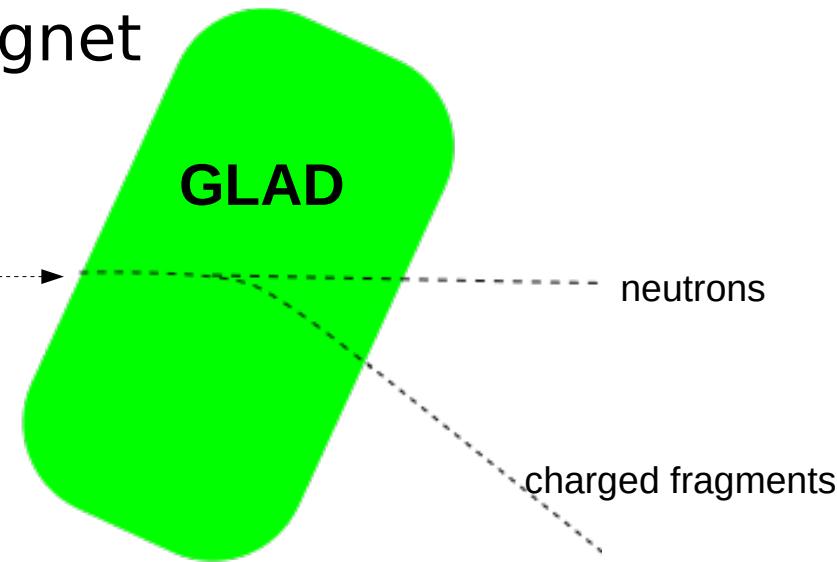
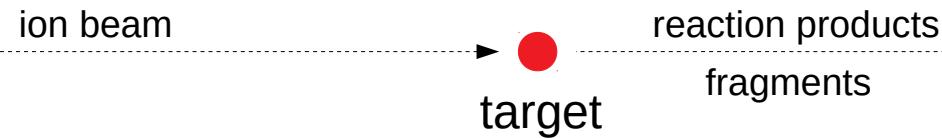
Target Wheel



Targets:

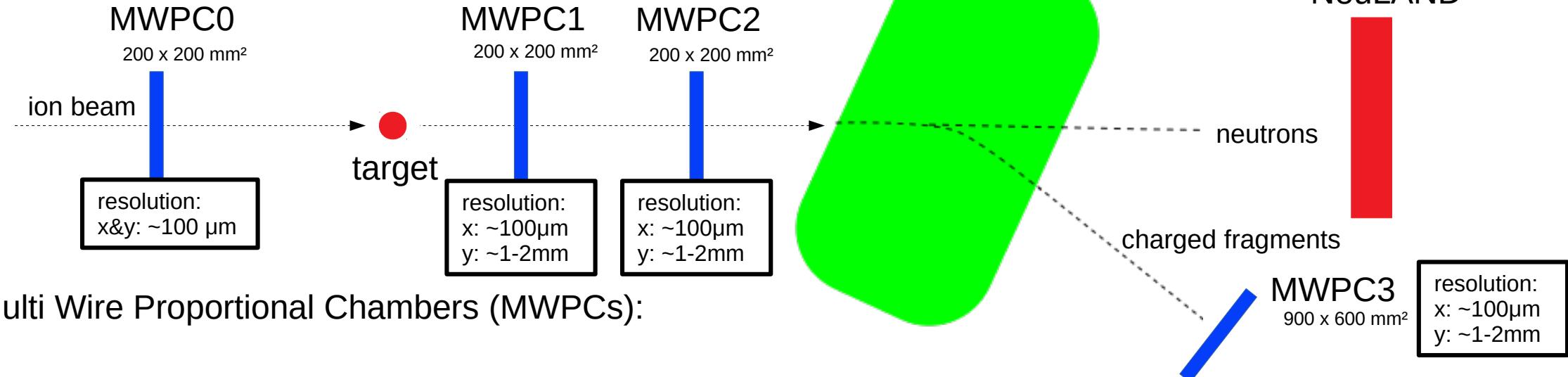
- C with width:
5.4 / 10.86 / 21.98 mm
- CH₂ with width:
12.29 / 24.53 / 24 mm
- Pb with width:
2 mm



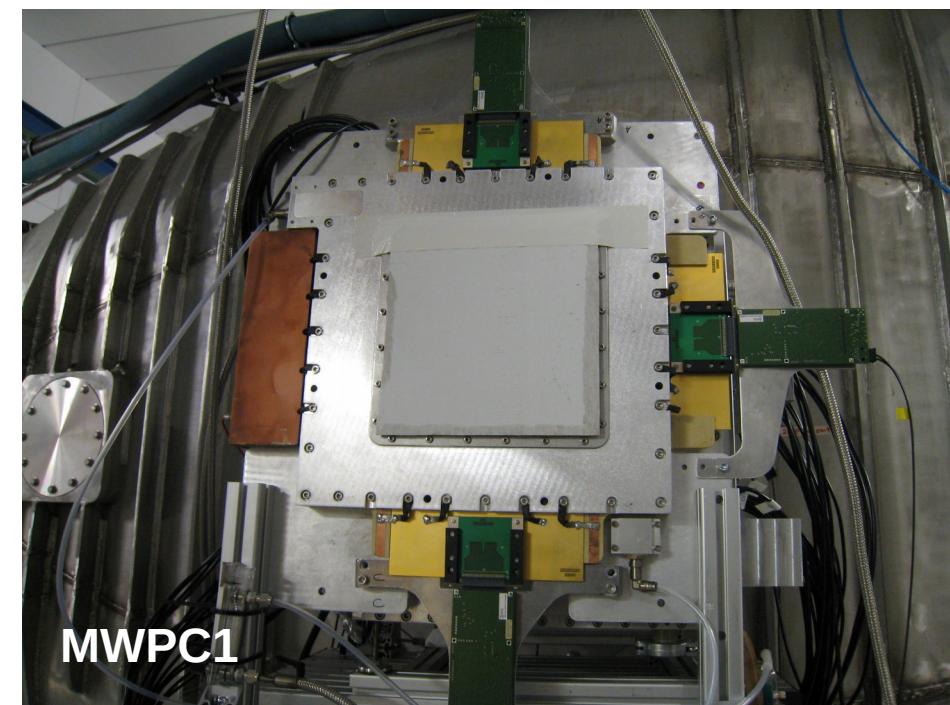
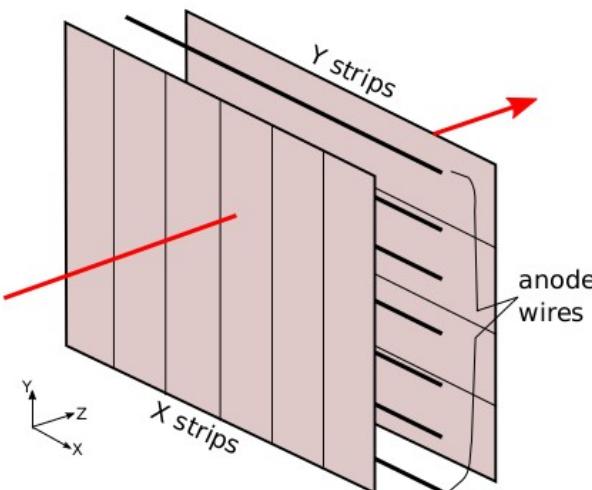


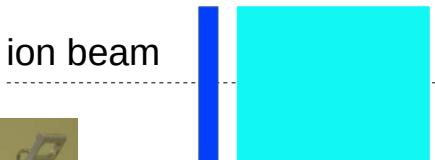
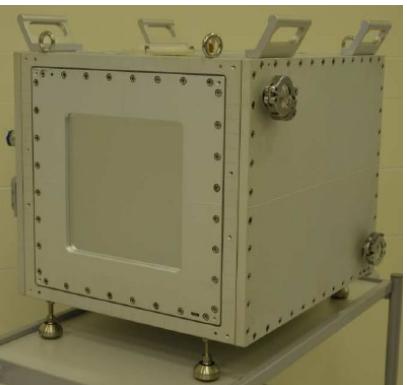
- large vertical gap (+-80 mrad) for neutrons
- High bending angle of 40°
- field integral of about 5 Tm
- momentum resolution $\Delta p/p$ of around 10^{-3}

Tracking Detectors



- vertical/horizontal wires: 50 µm diameter, 2.5 mm spacing
- vertical/horizontal pads:
Al-evaporated on a 12 µm Mylar foil,
5/3.125 mm width (vertical/horizontal)
- gas mixture: 84% Ar, 16% CO₂
- readout signal from influenced pads





R³B MUSIC

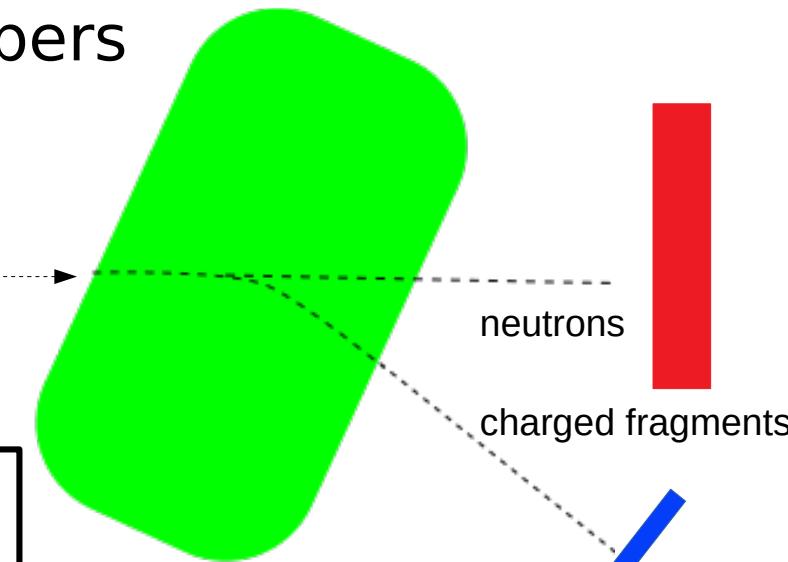
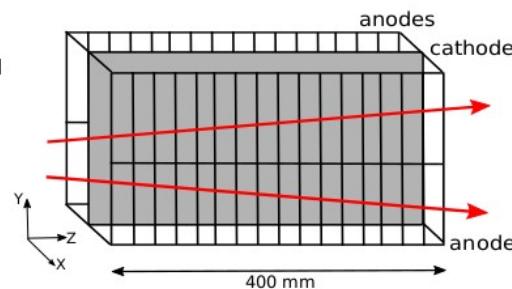
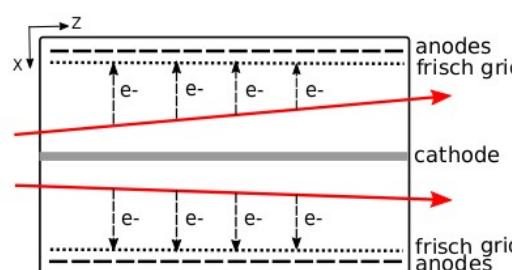
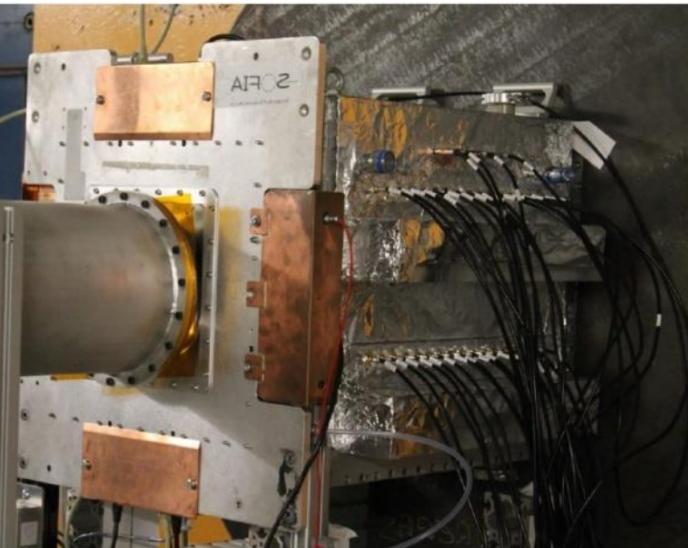
51 x 54 x 53 cm³
Cathode left side -
Anode right side
Gas mixture:
Ar 25%, CH4 75%

target

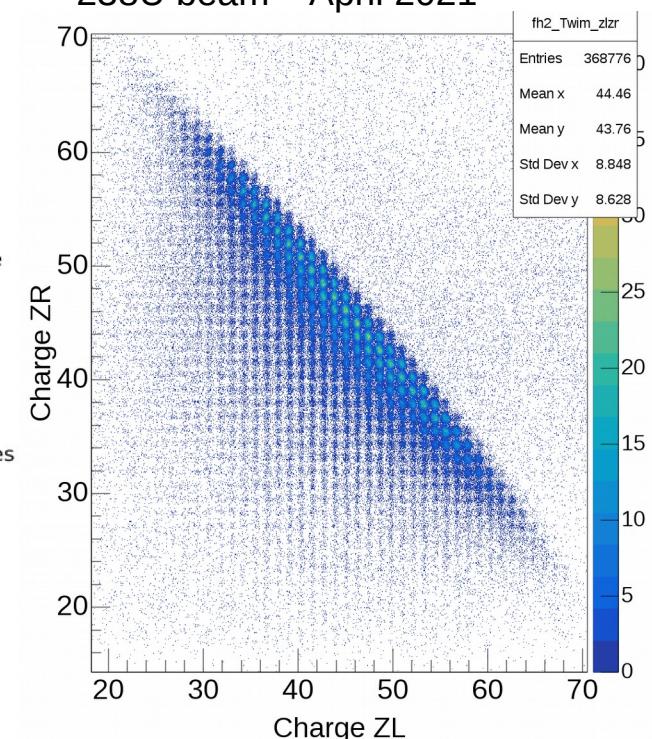


TWIM MUSIC

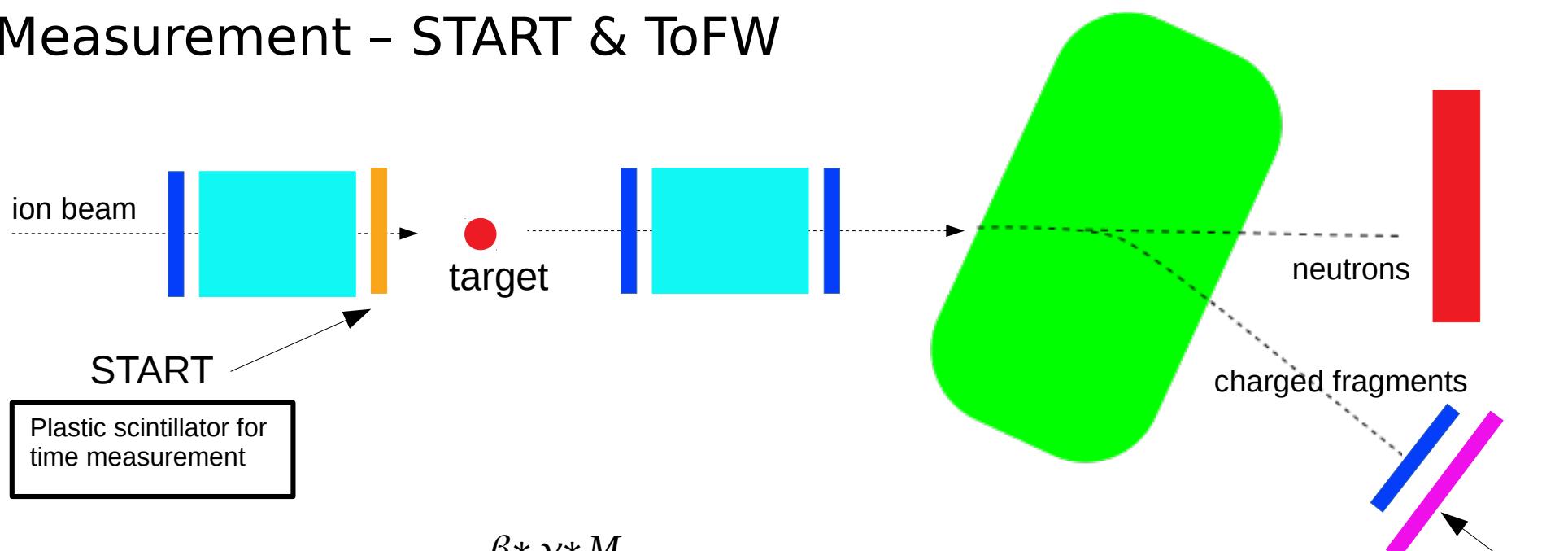
43 x 48 x 55 cm³
Double ionization chamber with
central cathode and two anode
planes
Frisch grid for better signal
quality and time resolution
Gas mixture:
Ar 25%, CH4 75%



238U beam – April 2021



Time Measurement - START & ToFW



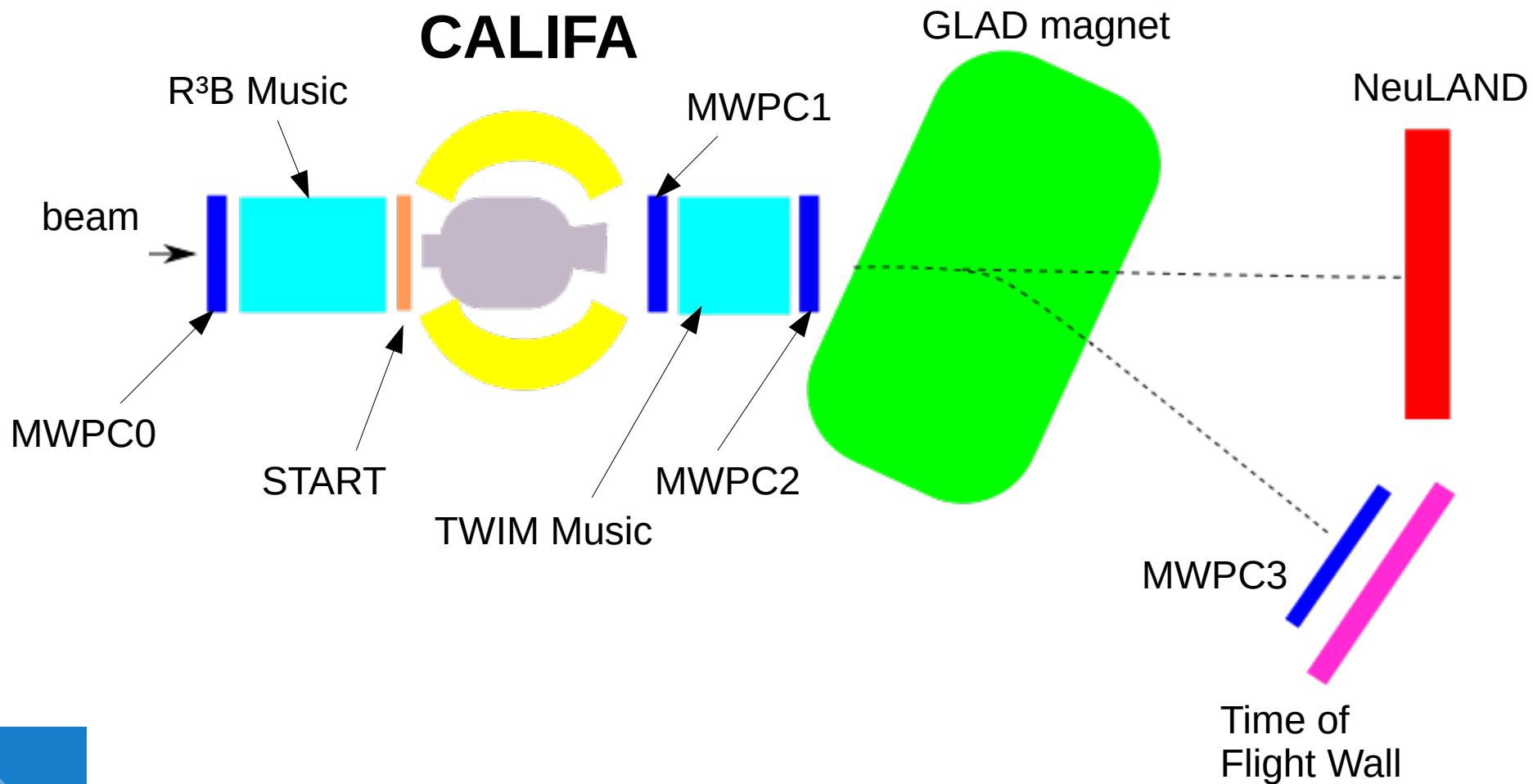
Particle Identification: $B * \rho = \frac{\beta * \gamma * M}{q}$

- ToF measurement: START to TOFW
- flight-path reconstruction: tracking detectors
- charge measurement: TWIM MUSIC



Time of Flight Wall
(ToFW)

27 vertical scintillators
(54 PMTs, up & down)
time and position
measurement



CALIFA Detector @ R³B

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

Endcap:

iPhos:

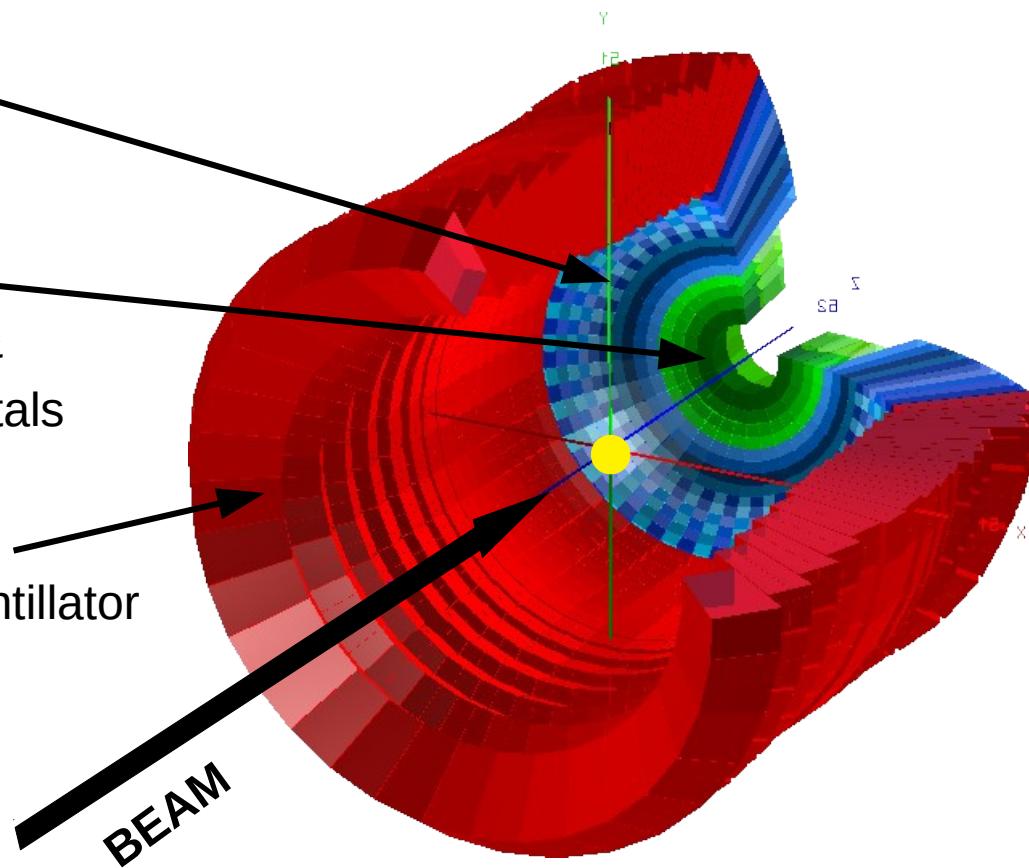
512 CsI(Tl)
crystals

CEPA:

96 LaBr₃ &
LaCl₃ crystals

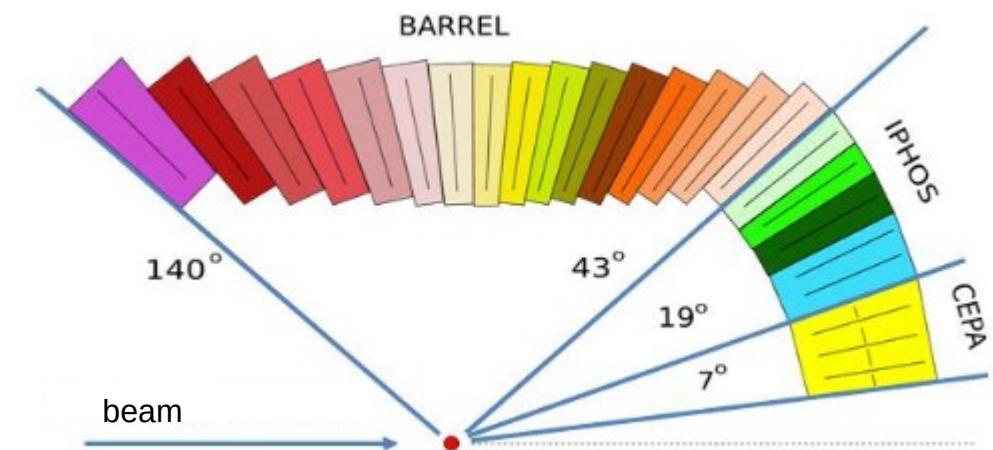
Barrel:

1952 CsI(Tl) scintillator
crystals



Requirements:

- high dynamic range:
100 keV γ -rays – 700 AMeV charged particles
- high efficiency
- high granularity → Doppler correction
- particle identification



Signal Processing @ CALIFA

γ /particle interaction in **crystal** → scintillatorlight (550nm)

Every crystal connected to one **APD** → signal current

APDs connected to preamplifier:

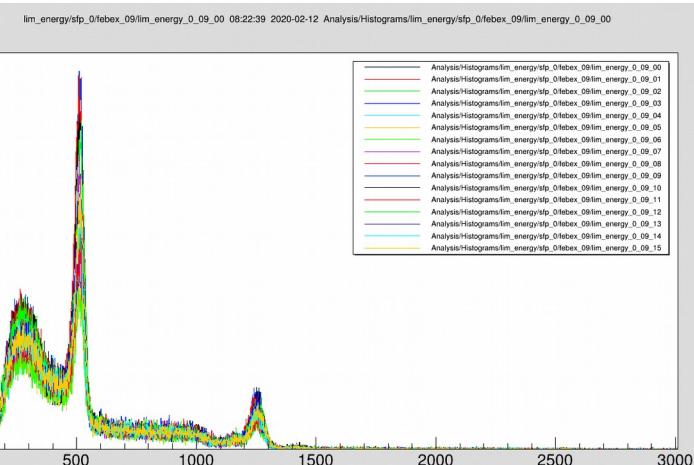
- generates HV for APD bias
- amplifies (integrates) the signal from the APDs

Add-on Board:

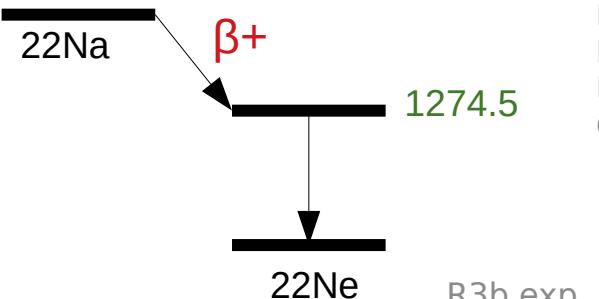
- Nyquist Filtering (<25 MHz)
- DC offset: Signal from preamp is positive, ADC range of FEBEX ADC $\pm 0.9V$

On FEBEX:

- Energy and particle identification



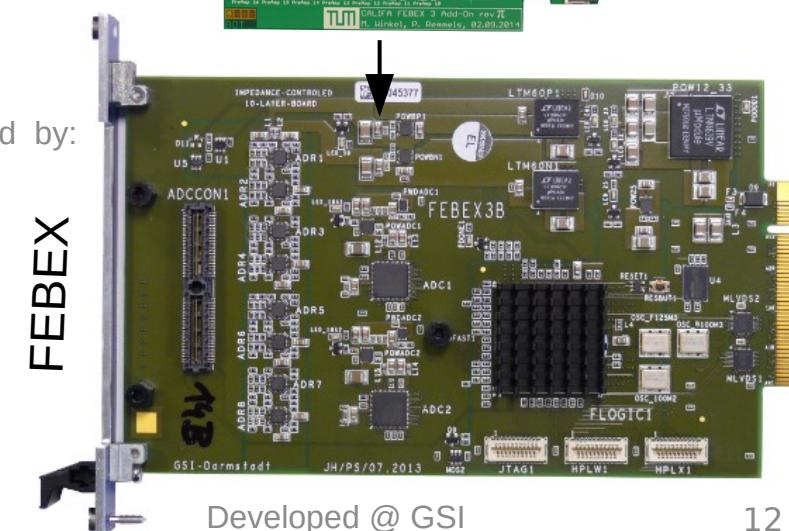
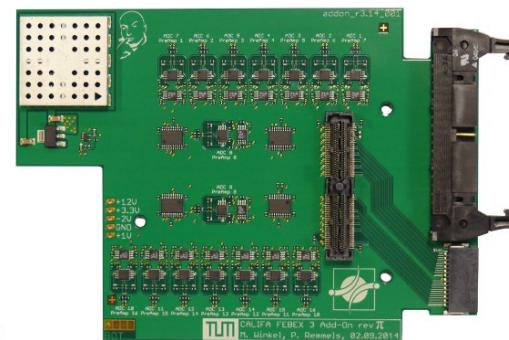
E.g. 22Na decay:



Firmware developed by:
Michael Bendel,
Max Winkel,
Benjamin Heiss,
Philipp Klenze,
Patrick Remmels,
et al.



Add-on Board





Electronics for CALIFA



Each rack:

→ 1024 channels

→ 50 MHz continuous sampling rate

Dead-time free readout design:

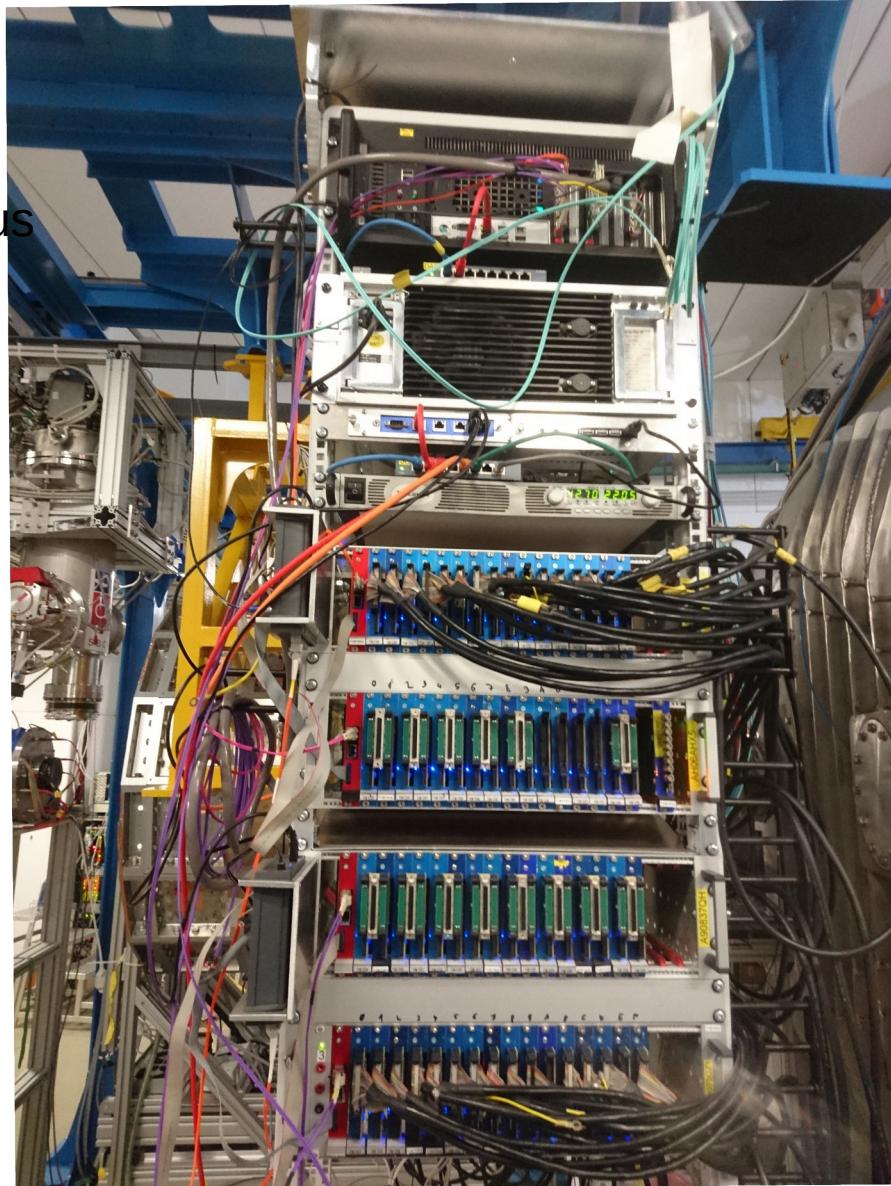
→ PEXOR card

→ TRIXOR card

→ EXPLODER

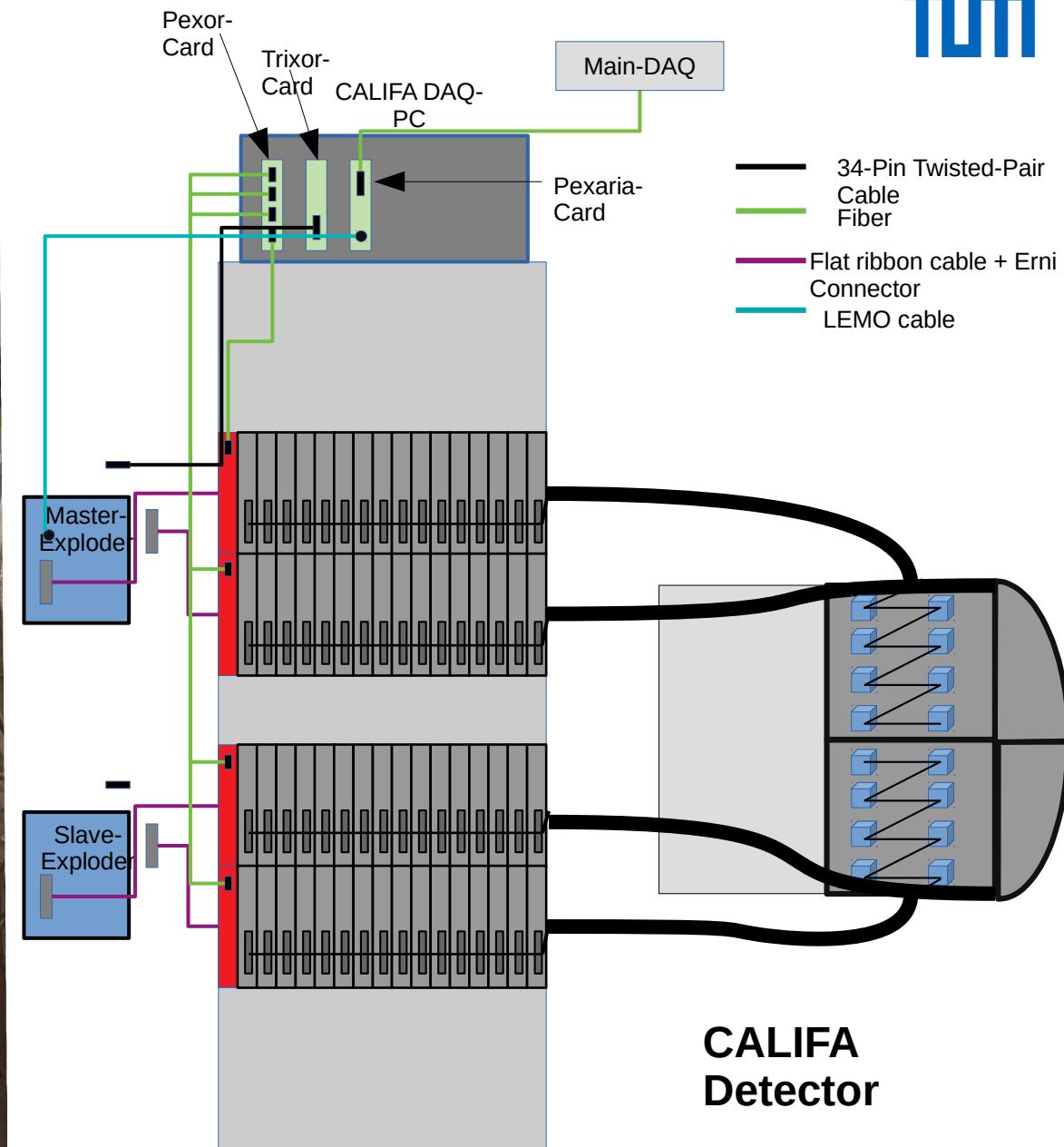
→ PEXARIA (white

Rabbit timestamp)



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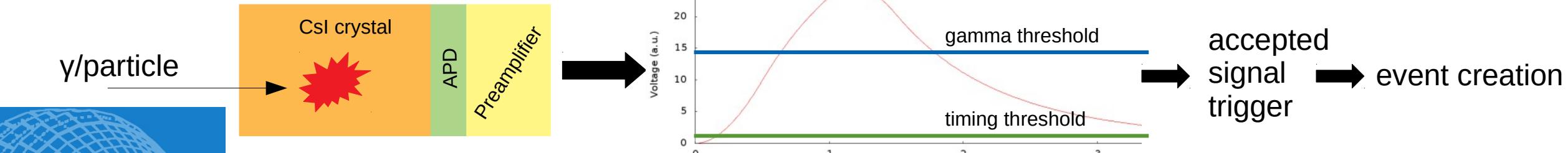
R3b exp



Discriminator-Threshold Logic:

- **Timing Trigger**: event time assignment
 - **Gamma Trigger**: gamma reconstruction
 - **Proton Trigger**: proton reconstruction
-
- discriminators can be used flexibly over trigger matrices
(e.g. timing and proton trigger for external detector triggering)

Intuitive event building logic...



-timing/gamma/proton trigger can be generated internally (exceeding threshold) or externally (trigger signal from other detector)

Trigger Modes:

- free running: each channel has its own signal trigger (e.g. internal timing & gamma trigger)
- synchronous and coincident (e.g. internal timing & external gamma trigger)

Readout Modes:

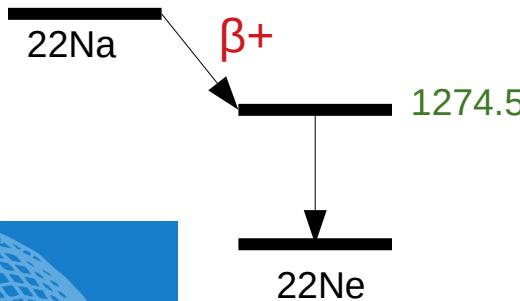
- single event readout: data is read out after each accepted signal trigger
- multi event readout (e.g. for free running trigger mode) :
 - events/data saved on FEBEX modules
 - if one module reaches a certain eventnr. value, all parameters are read out



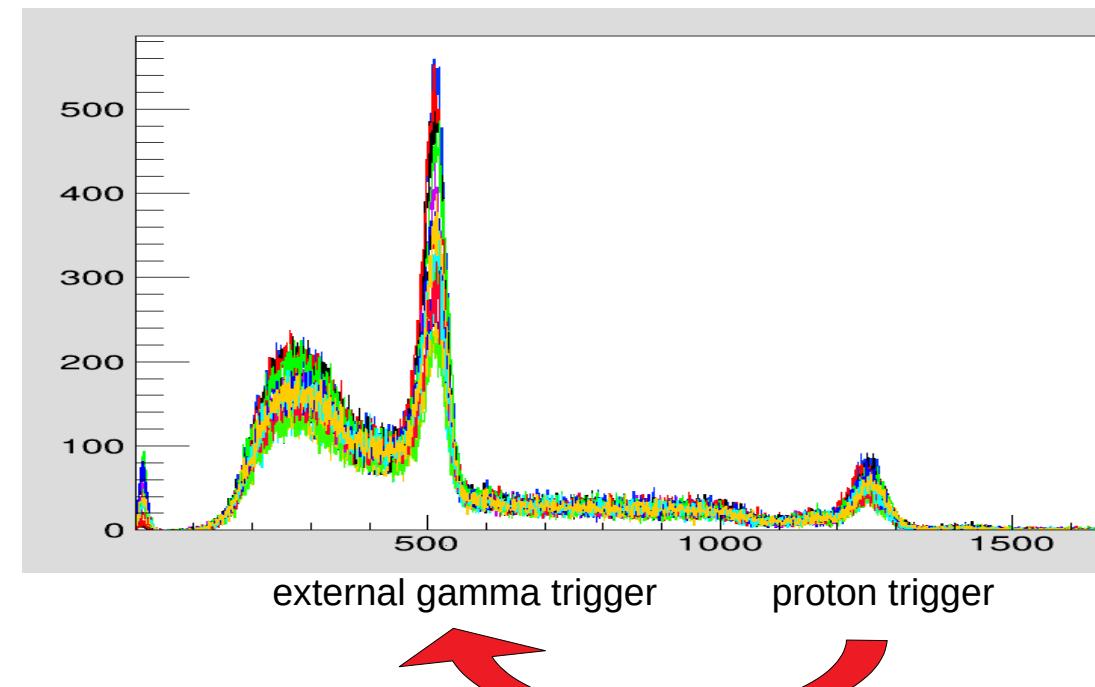
- for experiment in May 2021 with He test beam
- external gamma trigger input from START detector, internal timing trigger
- allows to only select CALIFA events in coincidence with other detector events

Testing:

- 22Na source
- Use γ - 1274.5 keV as proton trigger
- redirect proton trigger as external gamma trigger



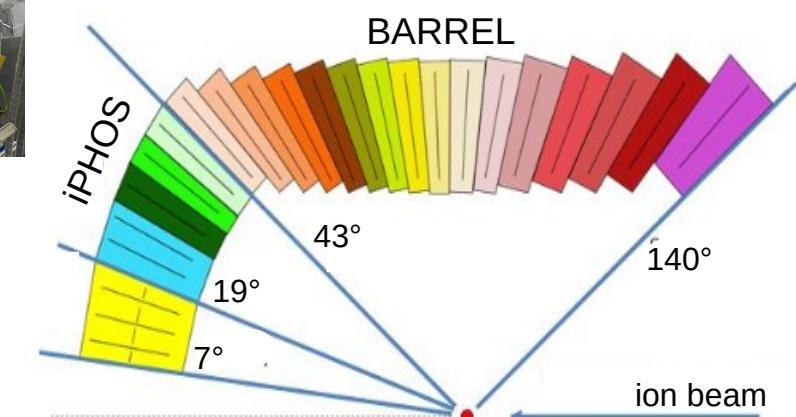
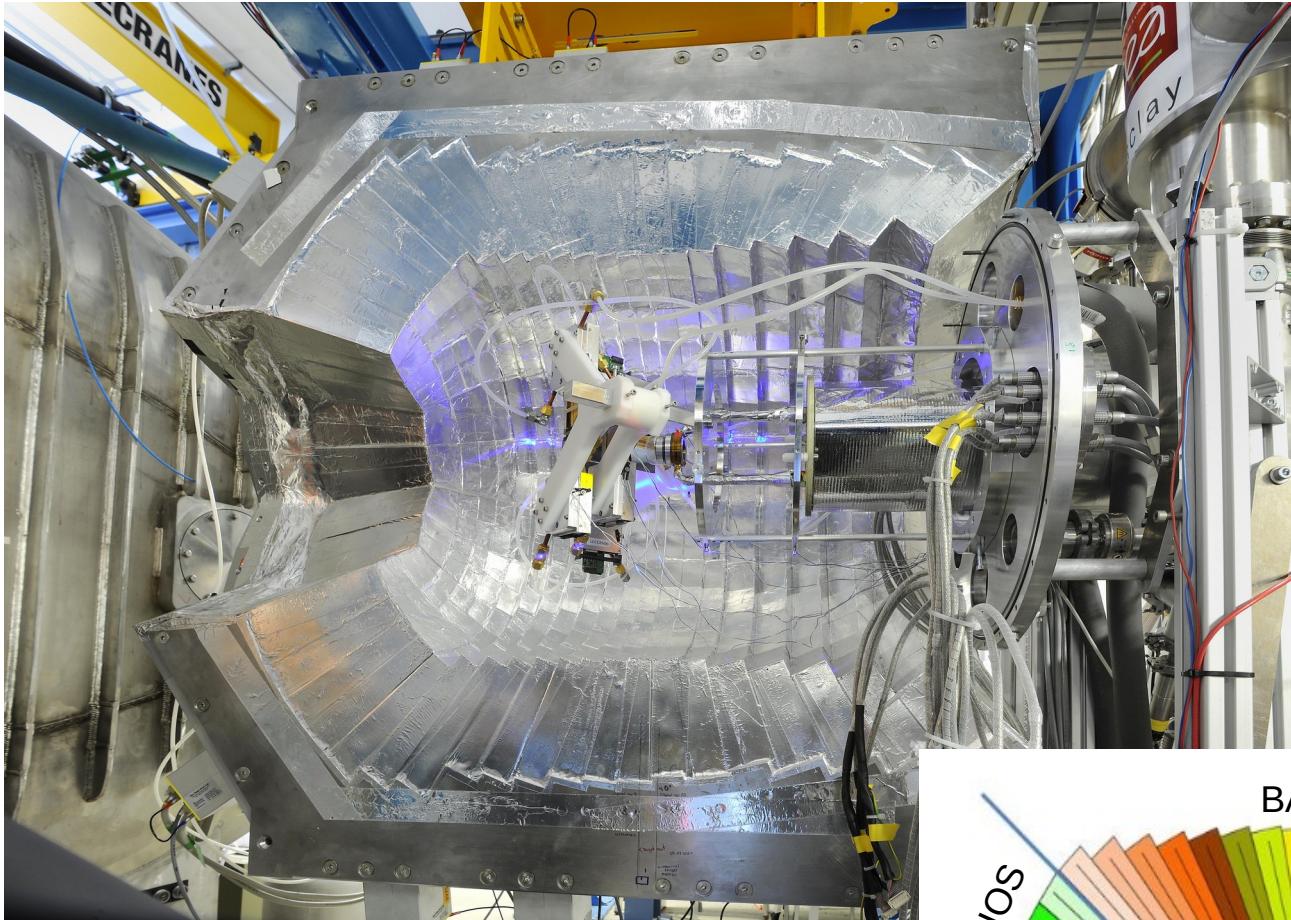
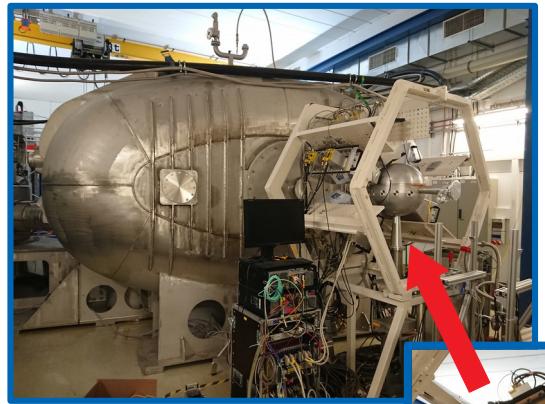
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CALIFA Upgrade 2021

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From Demonstrator to Final Setup



IPHOS region fully filled!



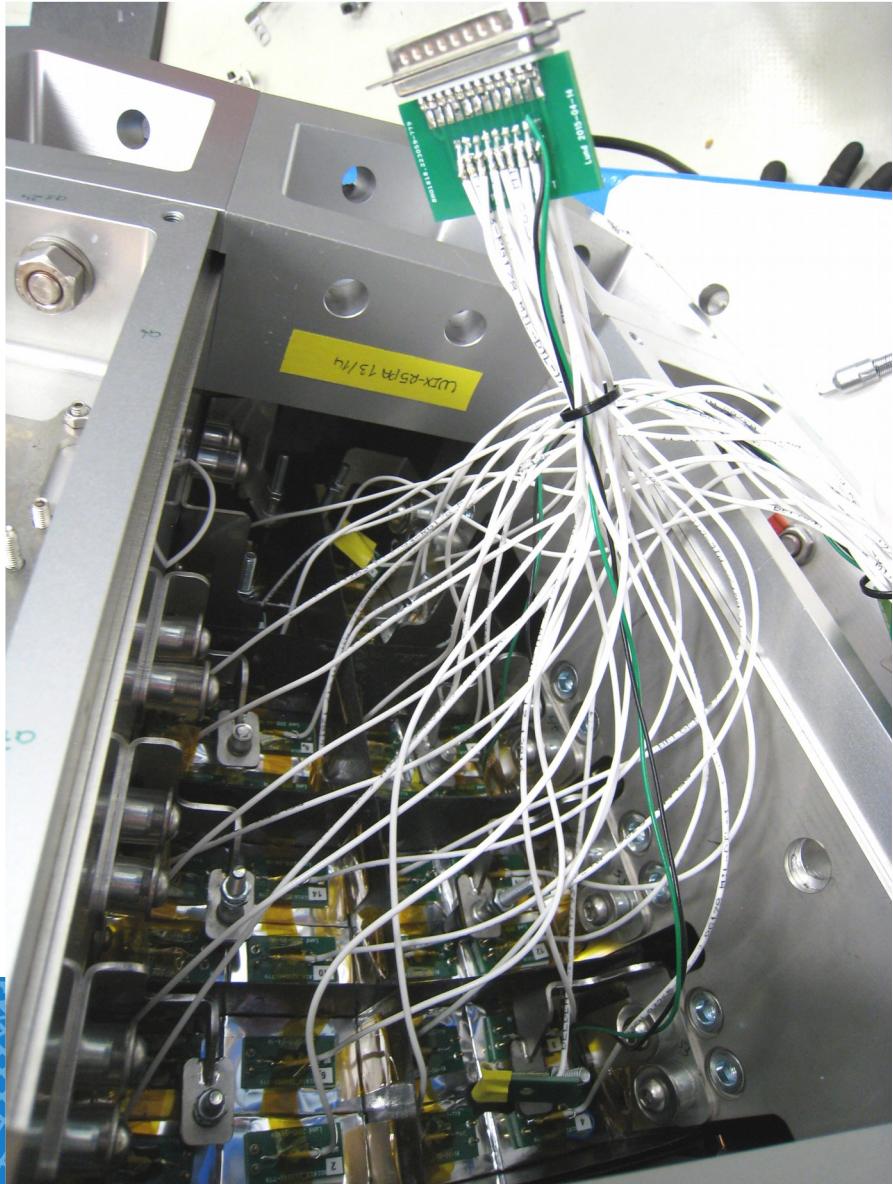
unmounting:



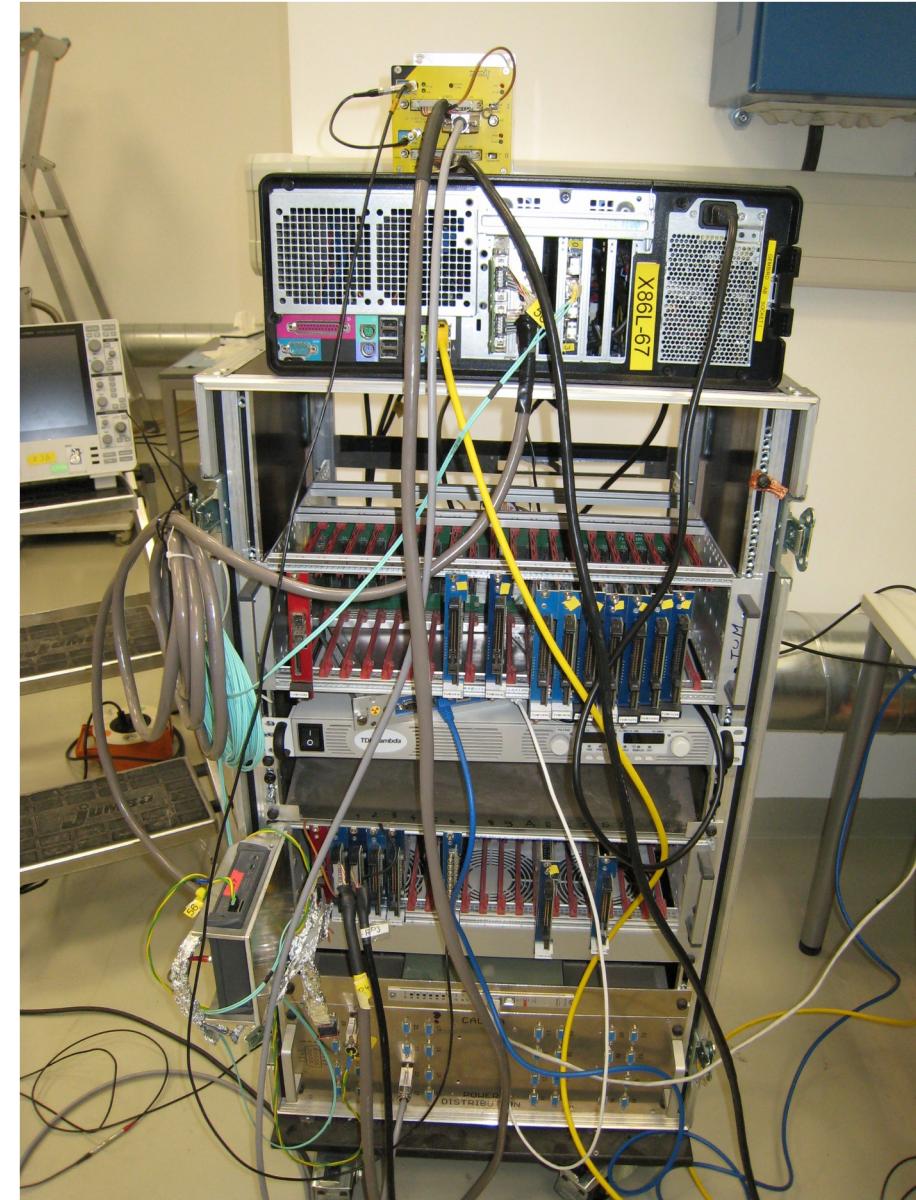
measure crystals & open tiles:



crystal filling:



testing with mobile DAQ:

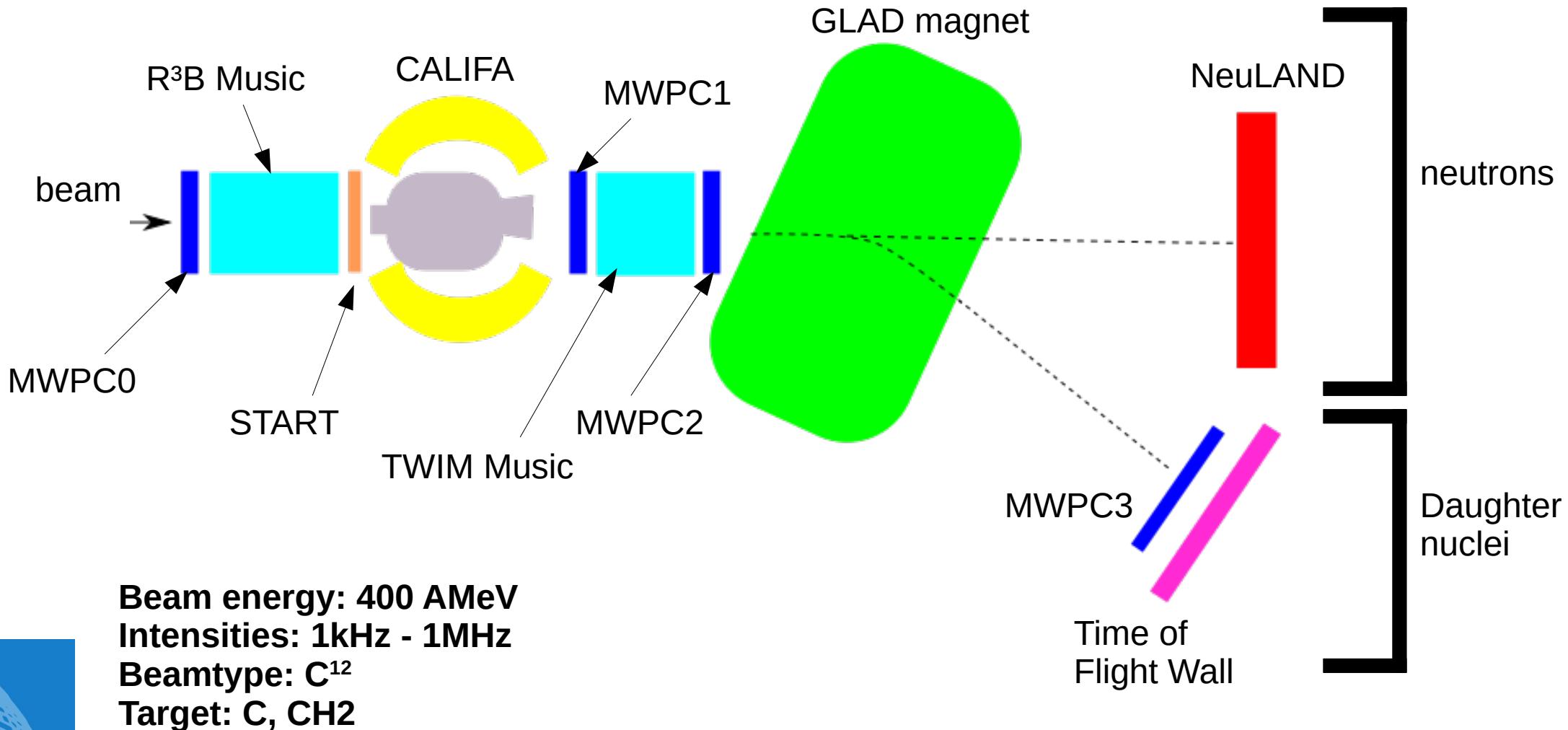


bring back to Cave C:



mount and align:

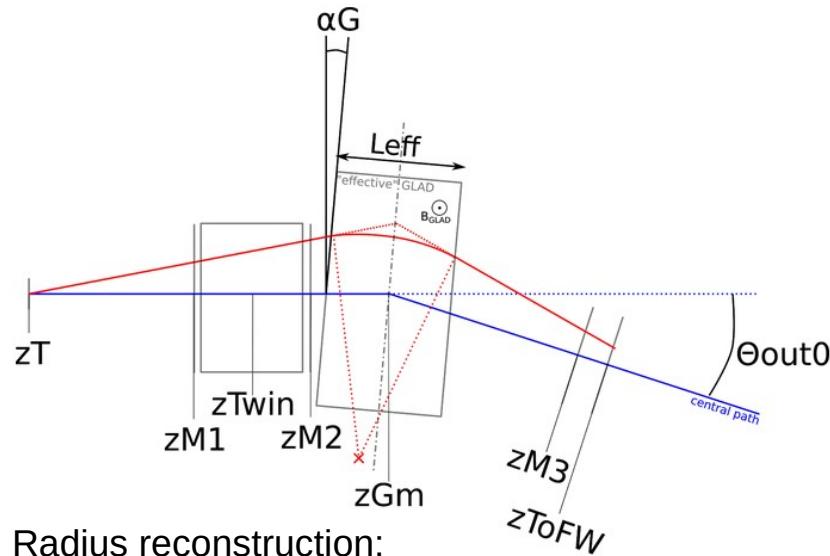




Beam energy: 400 AMeV
Intensities: 1kHz - 1MHz
Beamtype: C¹²
Target: C, CH₂

Particle Identification

Flightpath reconstruction:



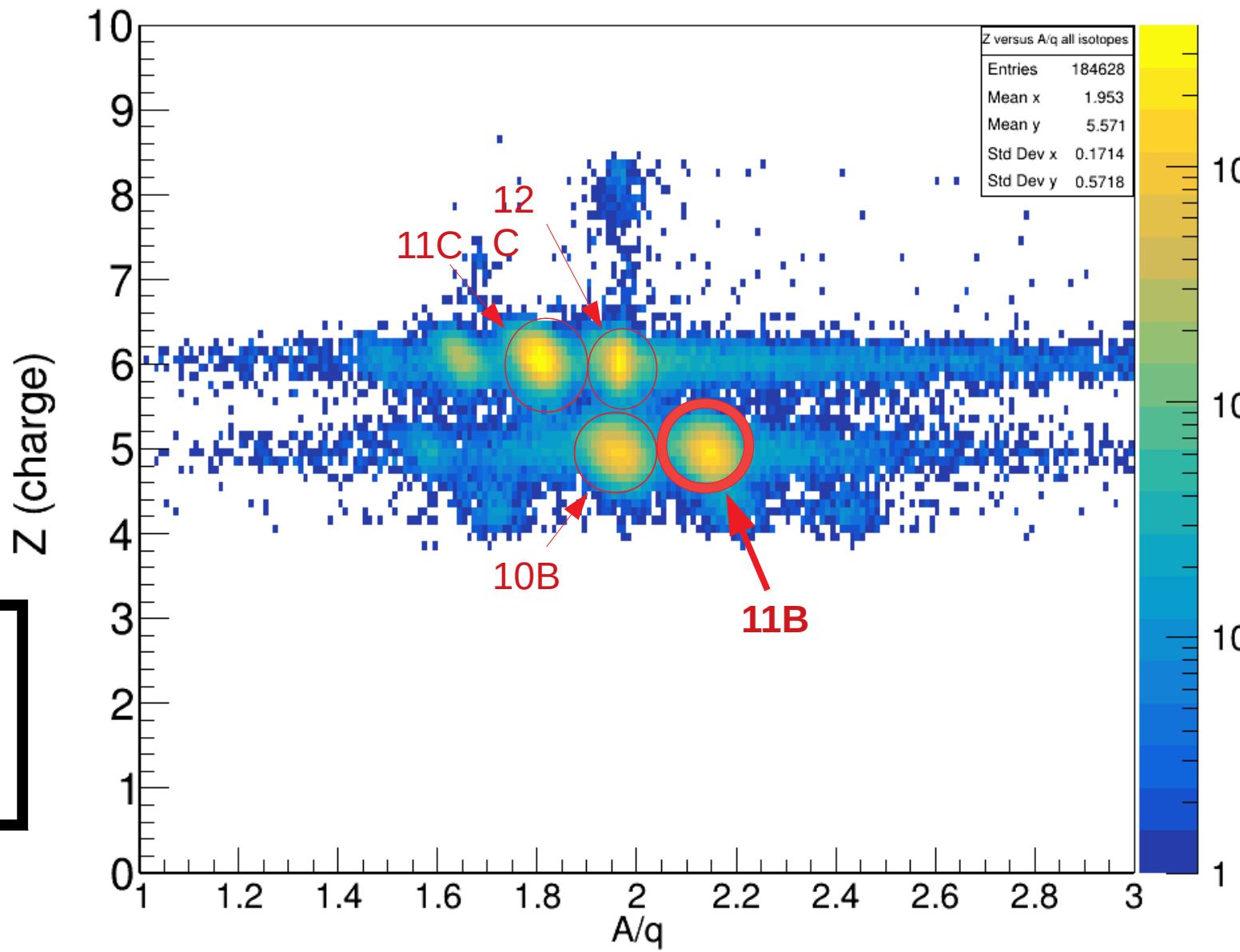
Radius reconstruction:

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

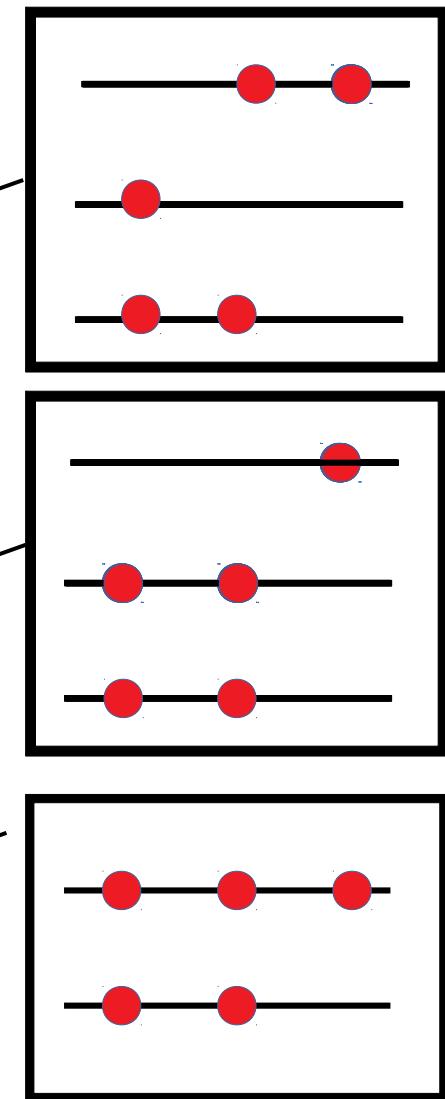
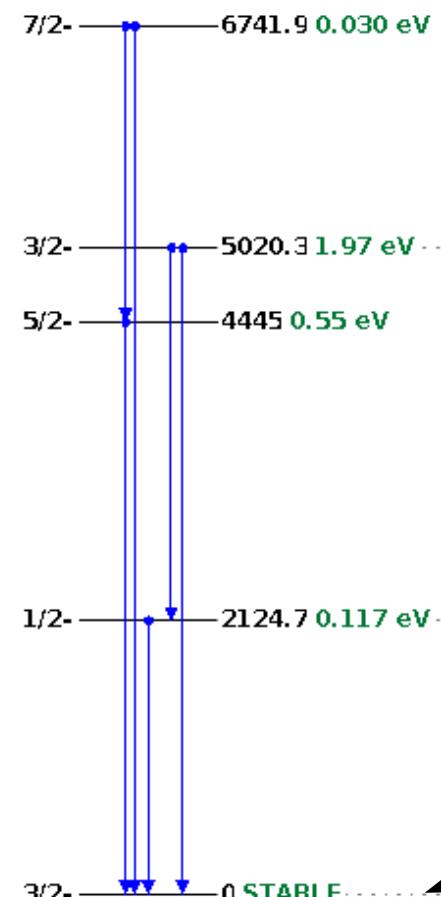
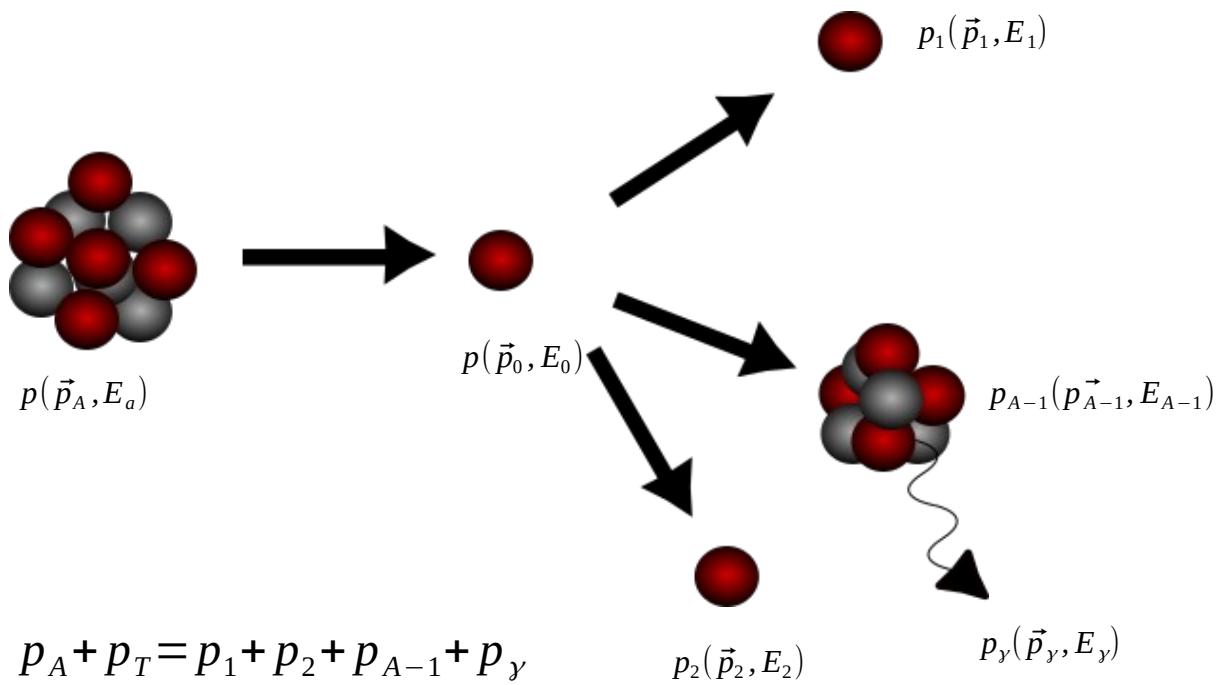
$$B * \rho = \frac{\beta * \gamma * M}{q}$$



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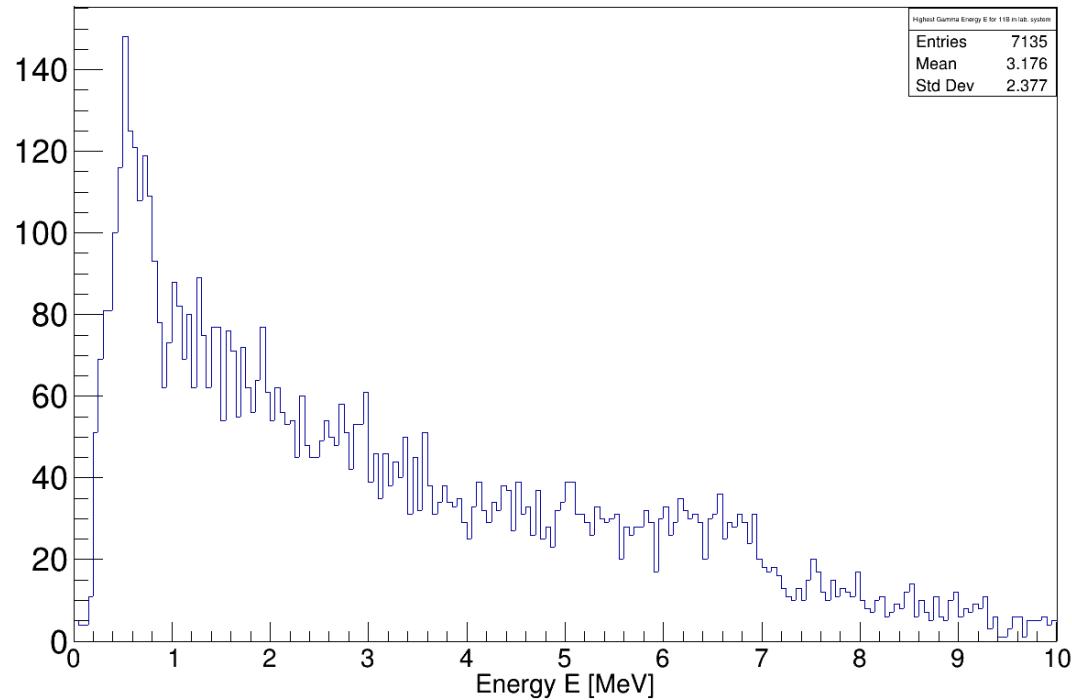


$^{12}\text{C}(\text{p},2\text{p})^{11}\text{B}$ reaction



Gamma Spectrum of ^{11}B

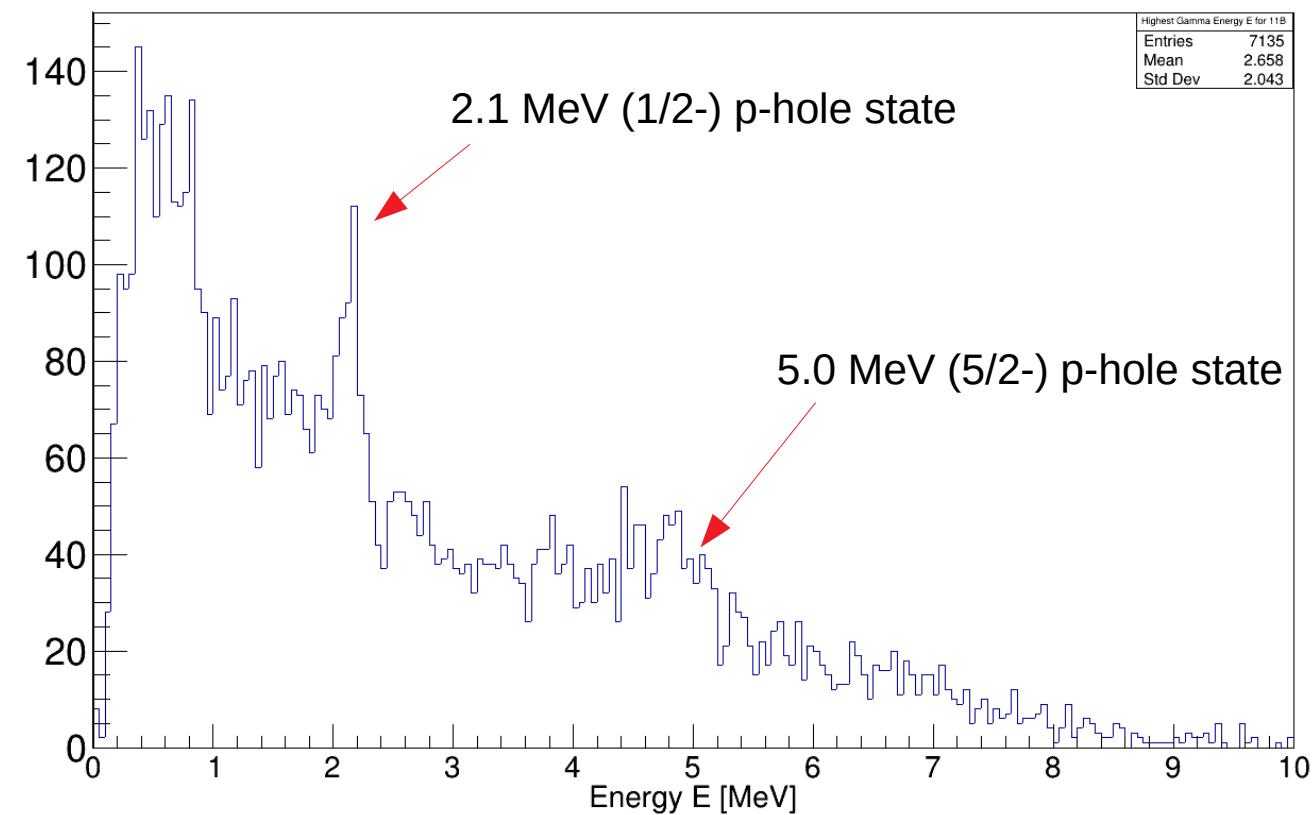
laboratory system



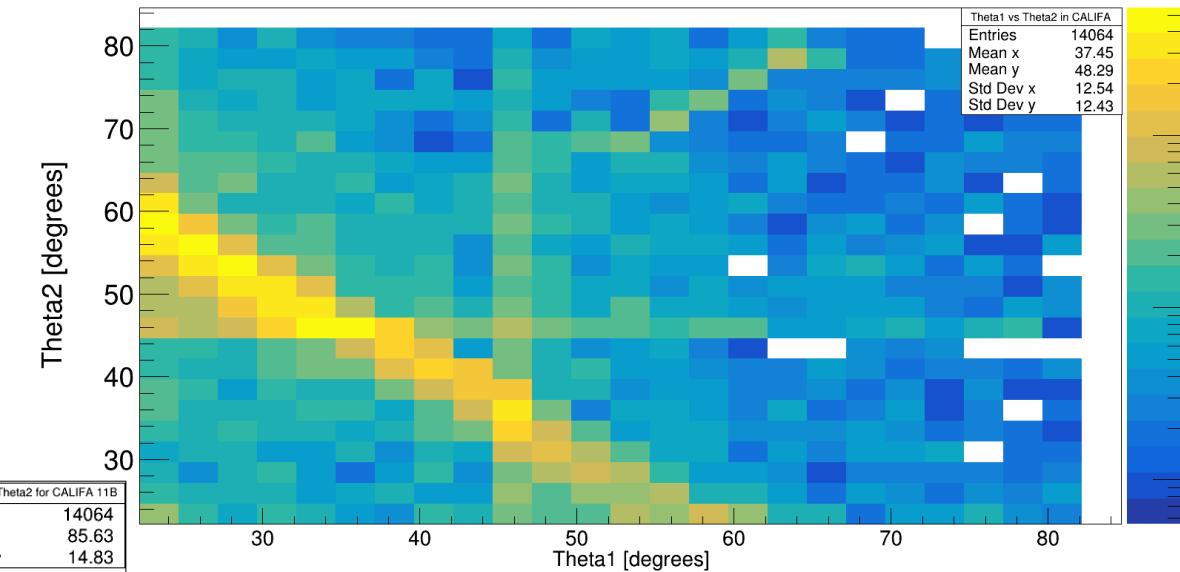
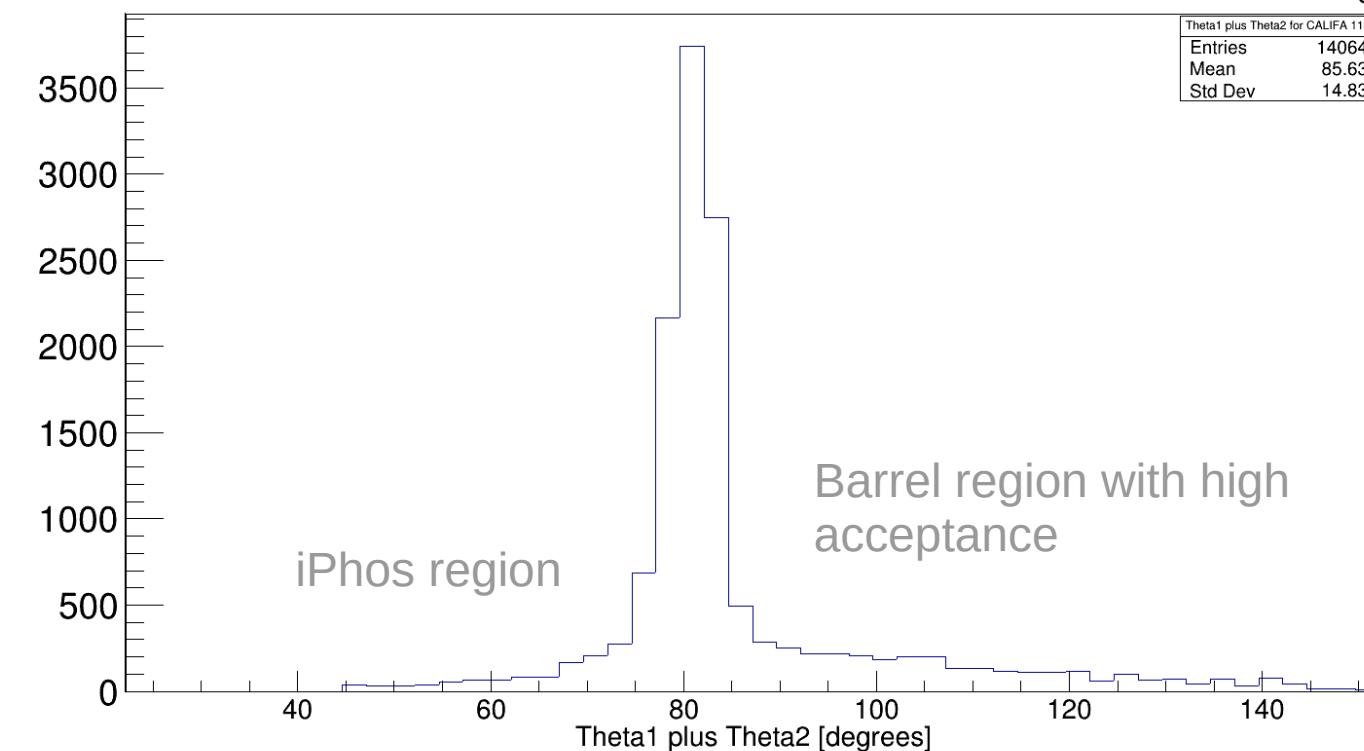
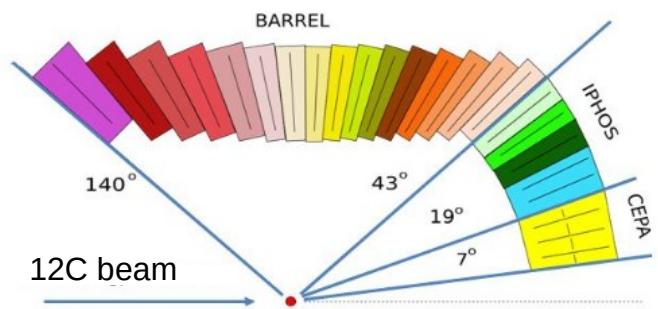
Doppler Correction:

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

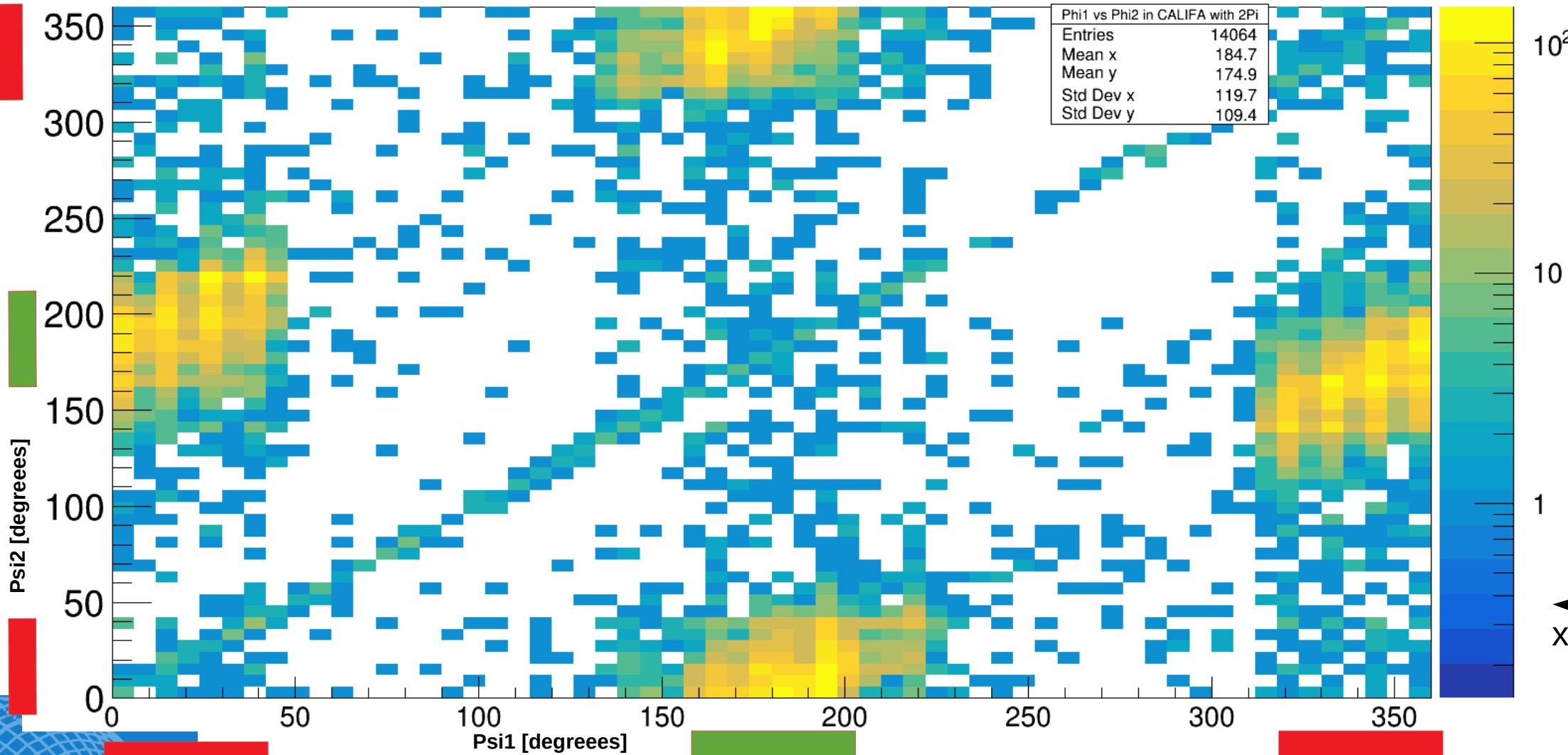
12C rest frame



Theta1 vs Theta2 in CALIFA



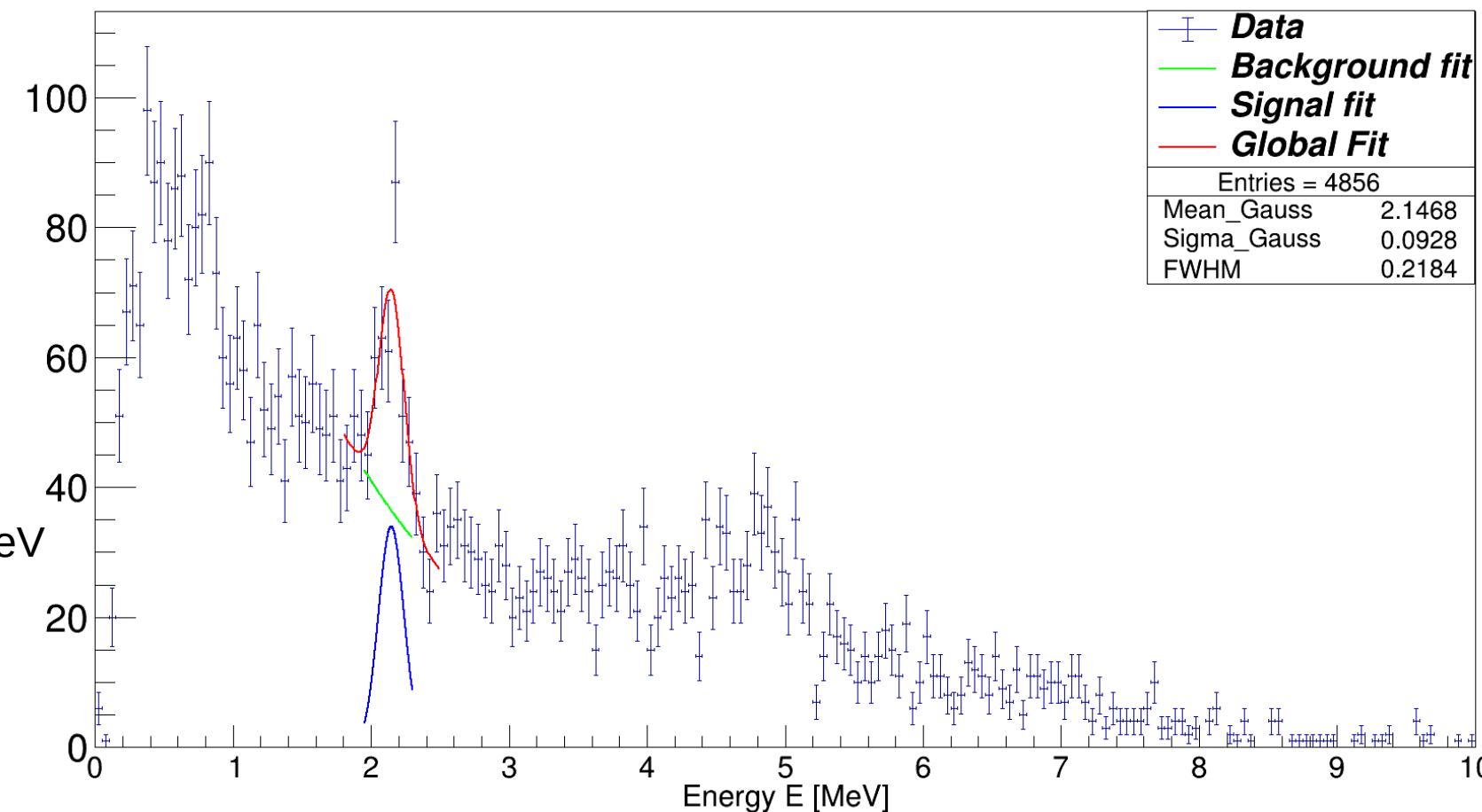
Arzimuthal Distribution of protons for $^{12}\text{C}(\text{p},2\text{p})^{11}\text{B}$



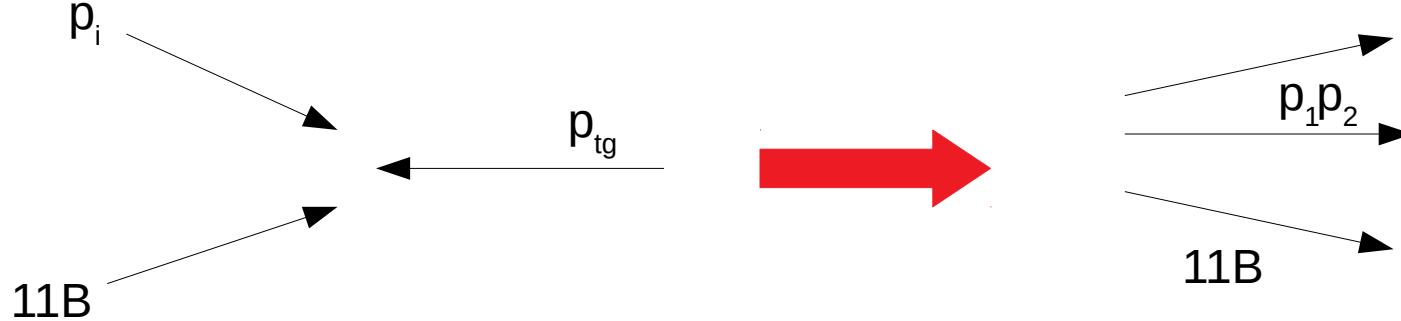
- CALIFA left half (90°) iPhos
- CALIFA right half (45°) iPhos

CALIFA Gamma Energy Spectrum

- Beam energy: 400 AmeV
- Beamtype: 12C
- Beam Time: 3 hours
- Target: CH₂ (12.29 mm)
- Tracking Detectors: MWCP 1,2,3
- ToF measurement: START to ToFW
- Charge measuement: TWIM Music
- Event selection criteria for CALIFA:
 - 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



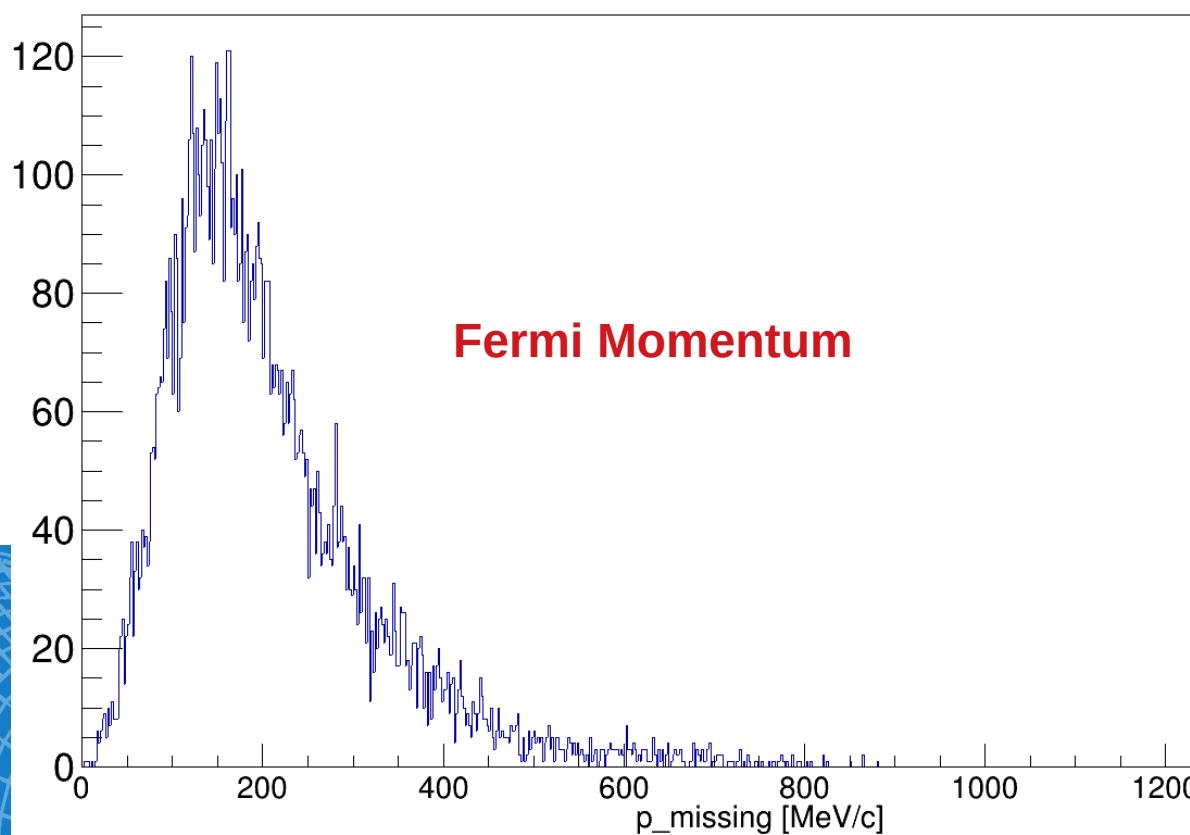
Momentum conservation relation:

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

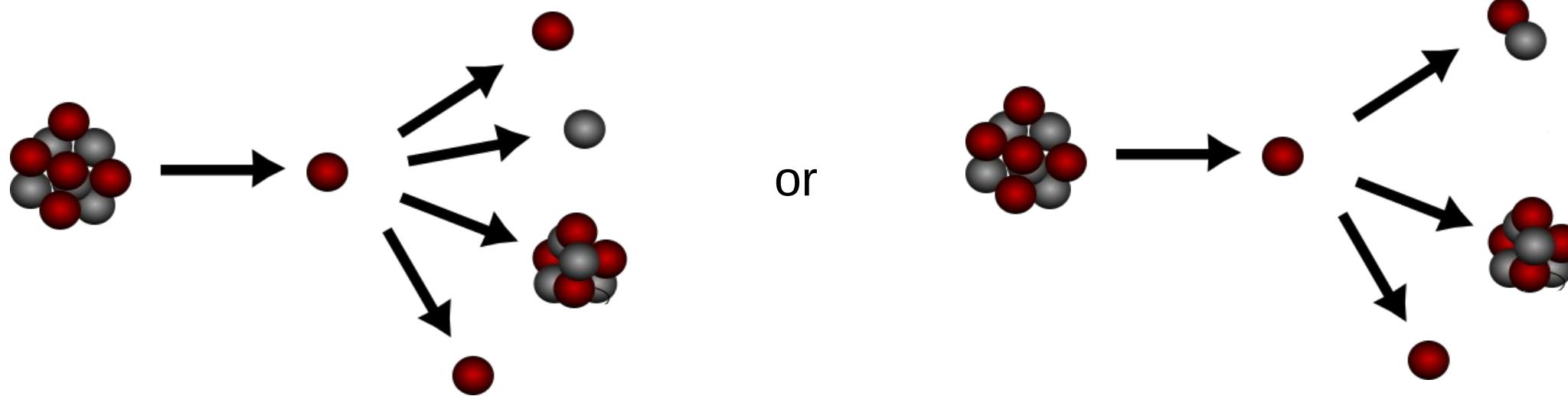
assuming QE scattering in mean field potential:

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

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

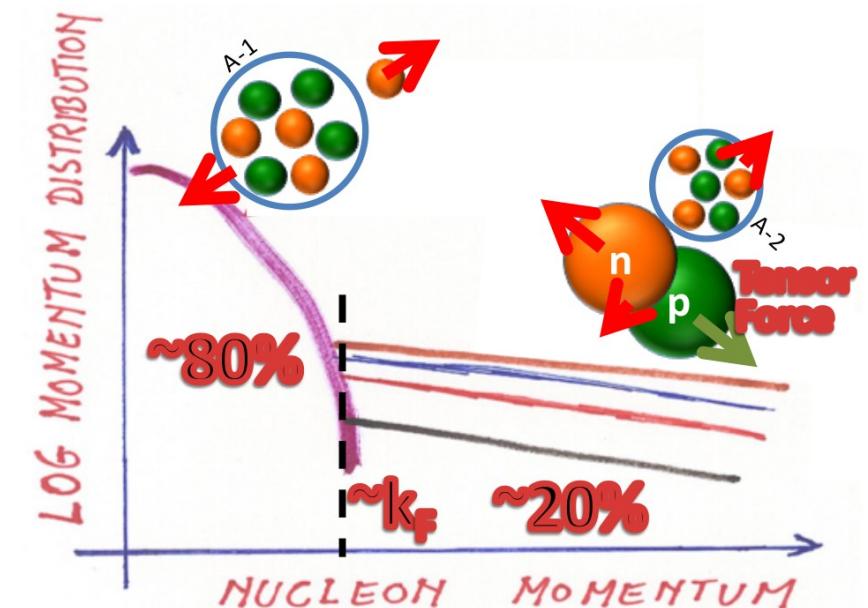


$^{12}\text{C}(\text{p},\text{pn/d})^{10}\text{B}$ reaction



Short Range Correlations (SRC):

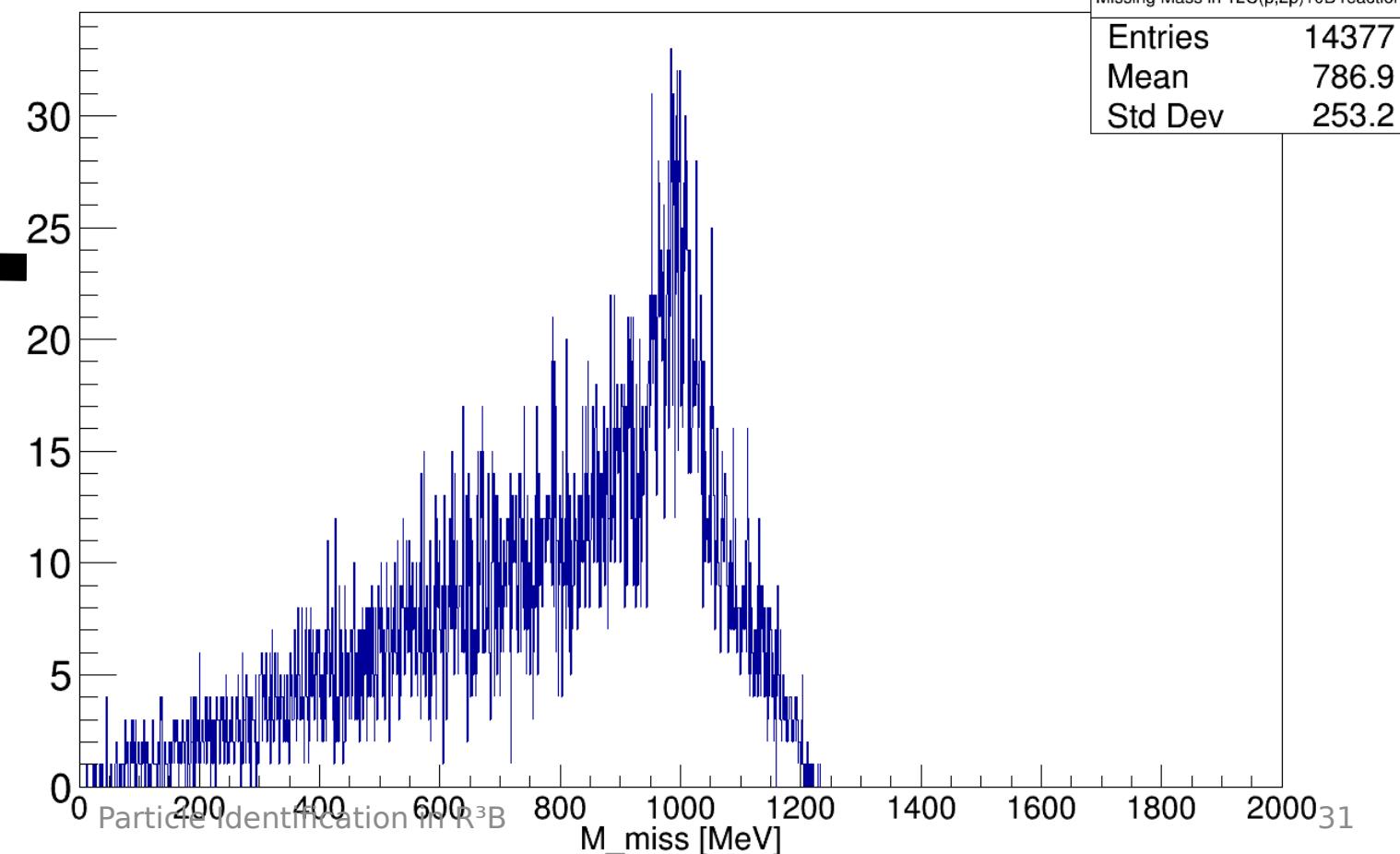
- Possible explanation for EMC - effect
- nucleon pairs with high relative and low c.m.
- Momentum (compared to Fermi momentum k_F)
- SRC exist in nuclei and account for about 20% of nucleons



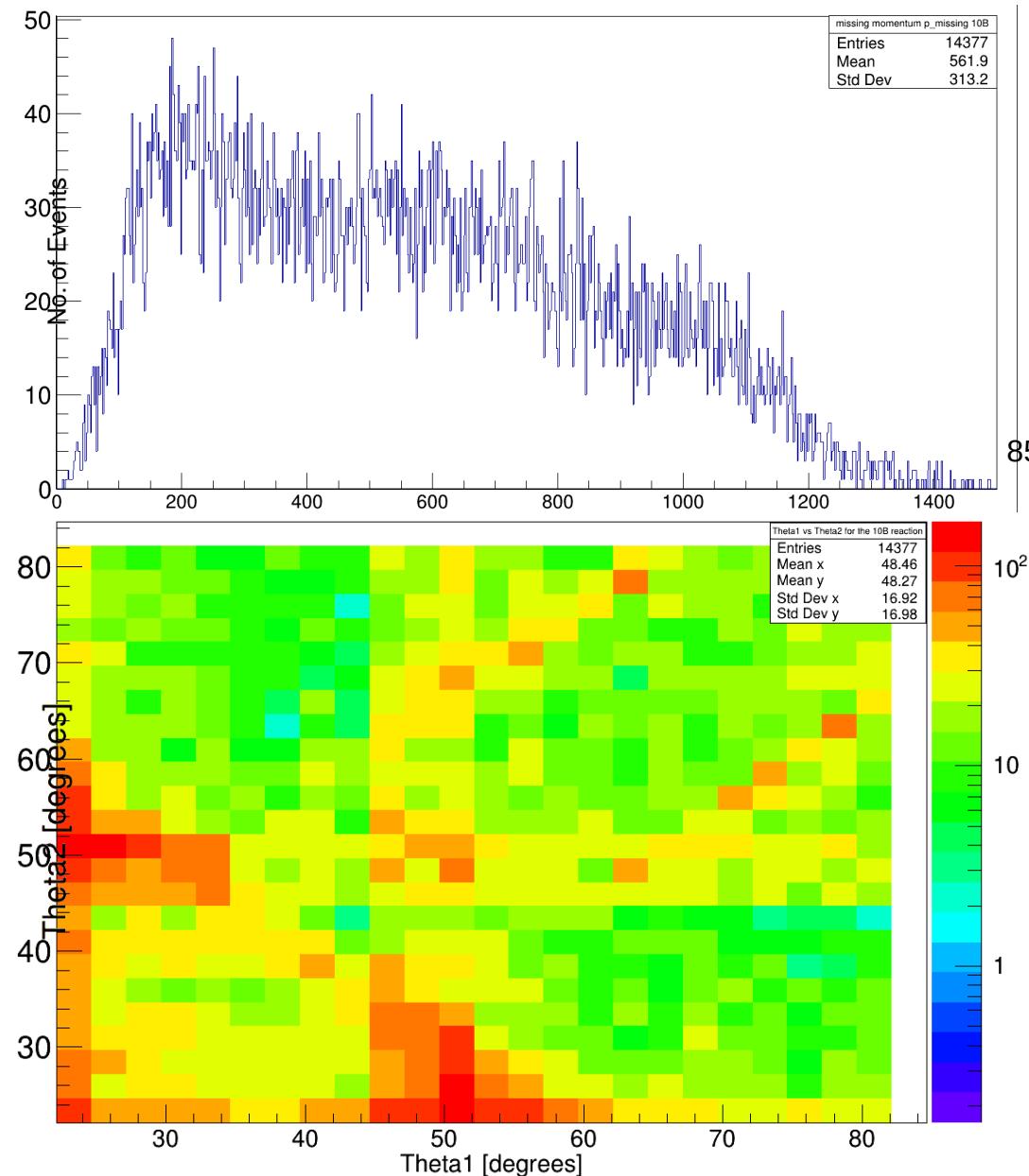
Neutron mass reconstruction...

$$M_{missing}^2 = \underline{p_{12C} + p_{tg}} - \underline{p_1 - p_2 - p_{10B}}$$

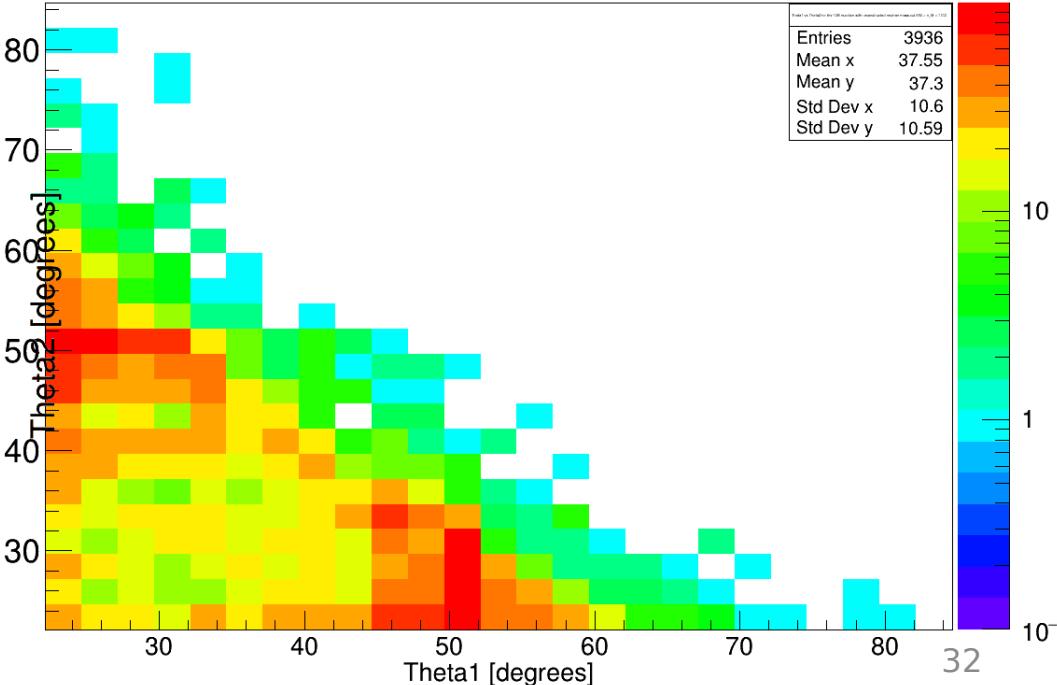
use $M_{missing}$ as cut variable



Angular and Momentum Plots



M_{missing} cut
850 MeV < M_{missing} < 1100 MeV





Summary & Outlook





R³B



Thank you!

CALIFA @ Technical University of Munich (TUM)

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Tobias Jenegger



Tobias Jenegger

Particle Identification in R³B





Backup

