



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

R³B Experiment @ GSI

PSI Seminar
16.06.2021

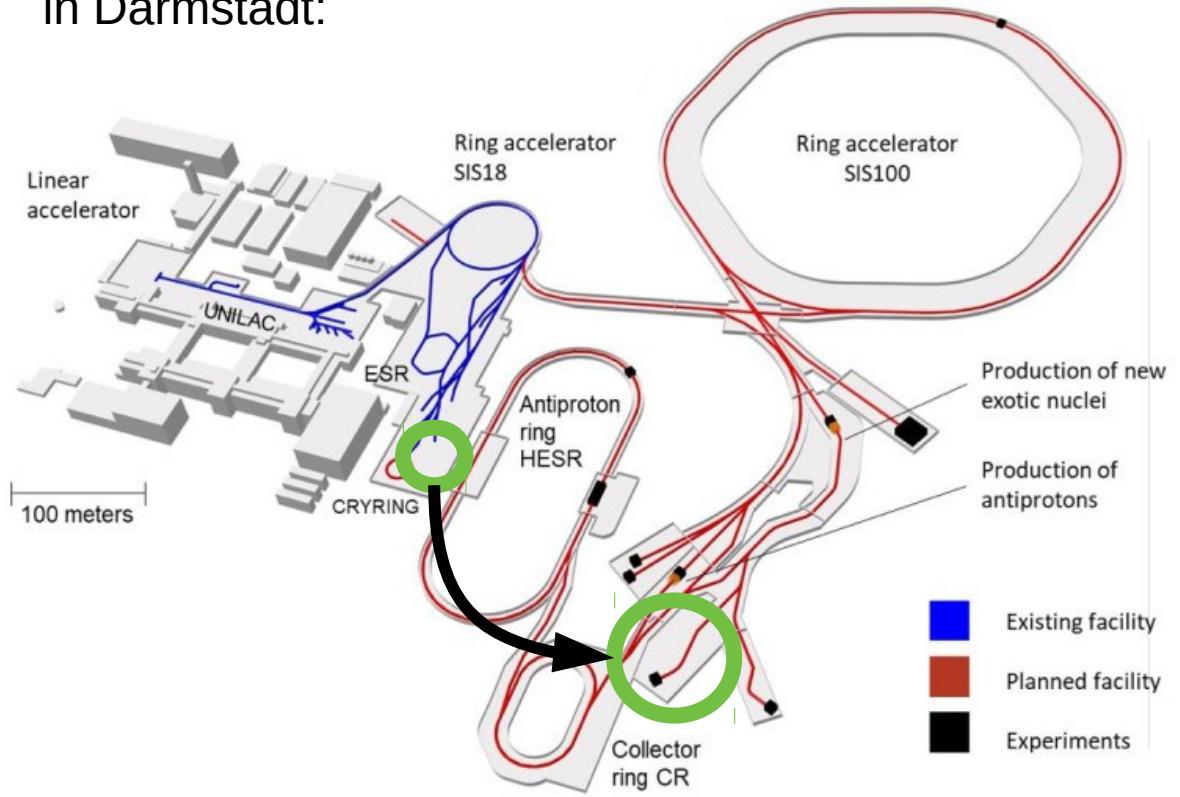
CALIFA - Design and Upgrades

12C(p,2p)11B reaction from Commissioning

QFS Analysis

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



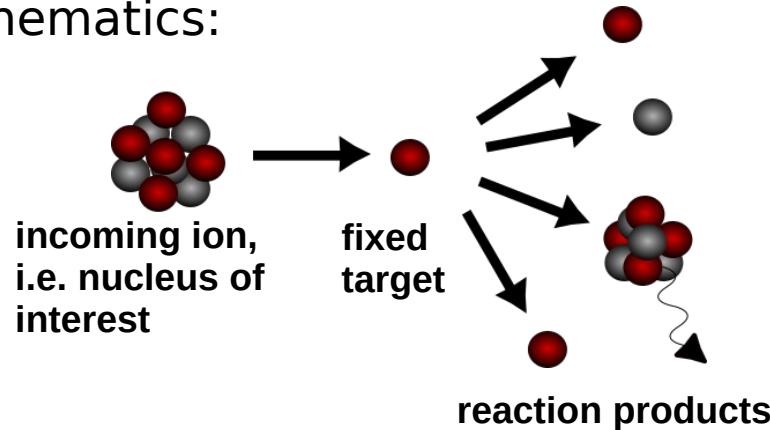
eight Frankfurt soccer stadiums



nine Eiffel Towers

Reactions with Radioactive Relativistic Beams

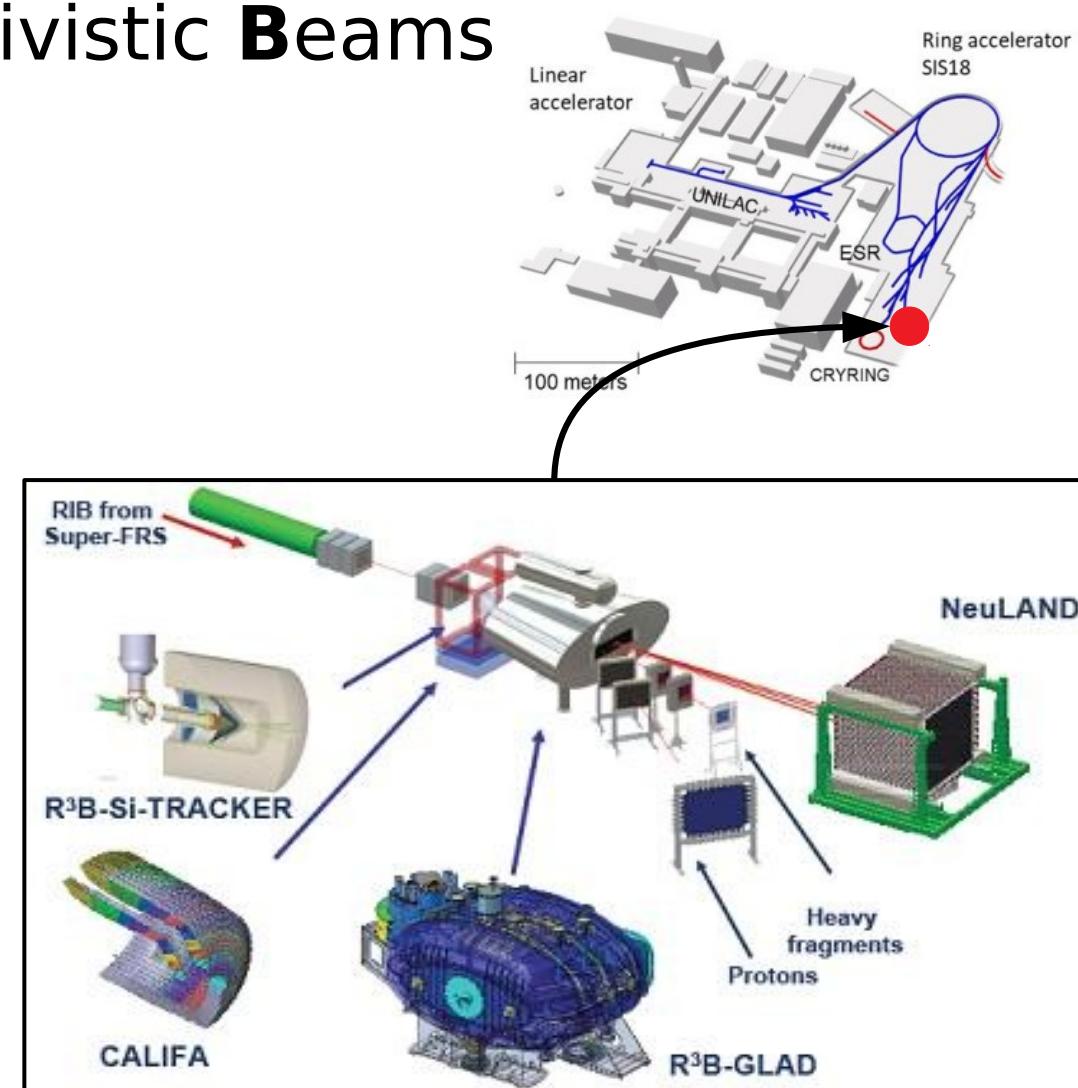
- Physics program on exotic nuclei in inverse kinematics:



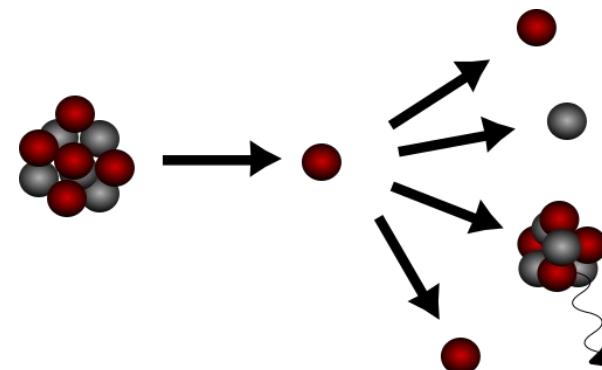
- In flight production of exotic nuclei from fragment separator Super-FRS
- kinematically complete measurements
- Flexible setup, extensive physics schedule
(despite pandemic restrictions)



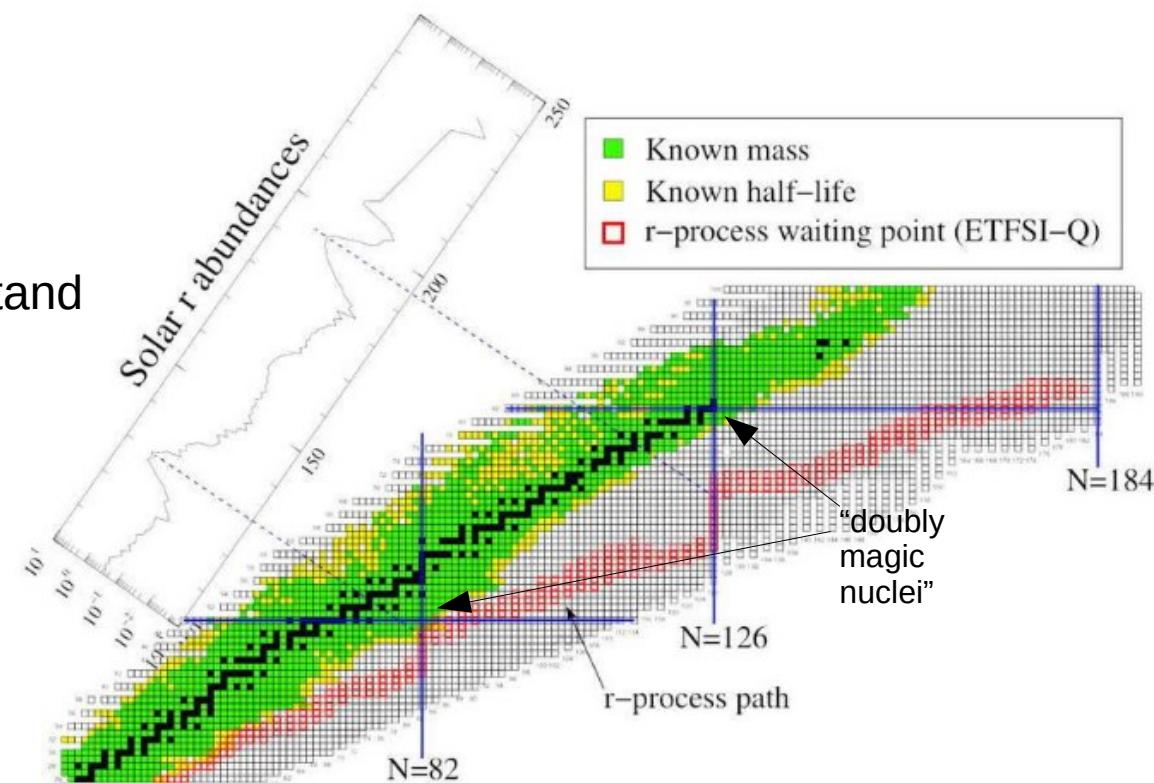
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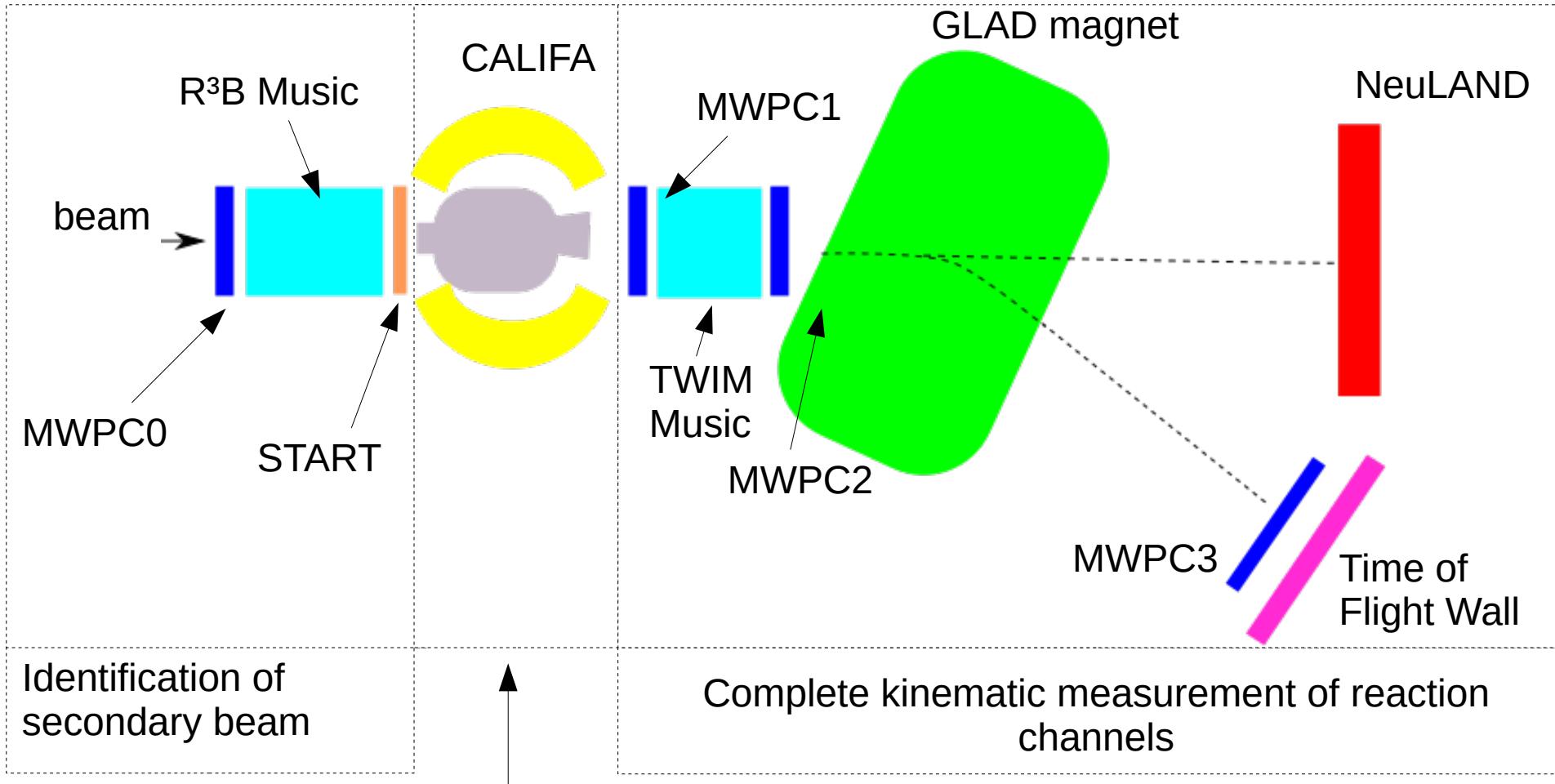


- Quasi Free Scattering (QFS)/Knockout reactions
 - study single particle properties inside nuclei
 - analyze shell evolution far off stability
 - measurement of Fermi-momentum, separation energy, ...



- Collective excitations in neutron rich exotic nuclei via Coulomb excitation
- Fission Studies (up to uranium)
 - fission barriers on heavy neutron rich nuclei to understand e.g. final r-process abundance
 - fission yields: symmetry/asymmetry of fission products

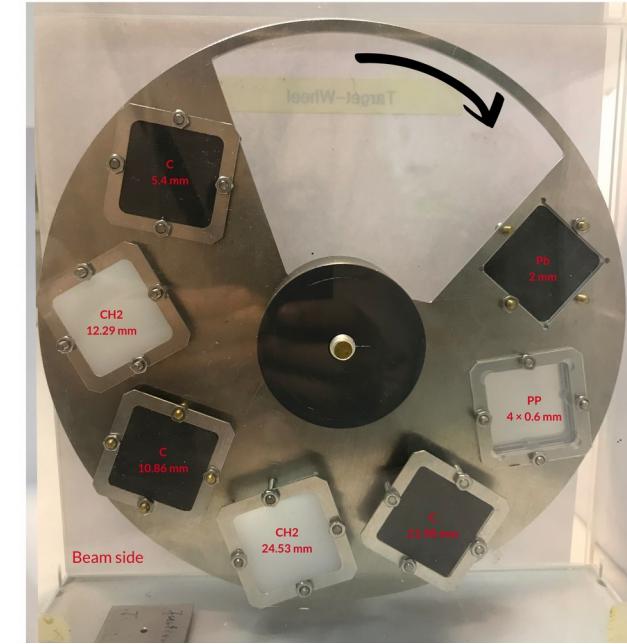






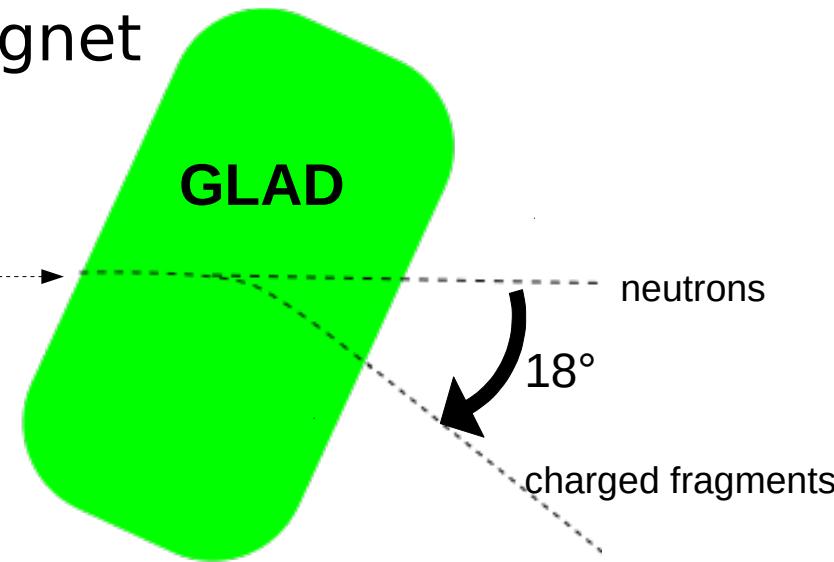
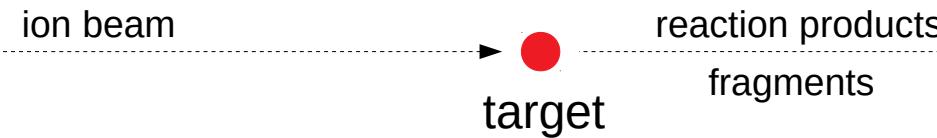
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Target Wheel



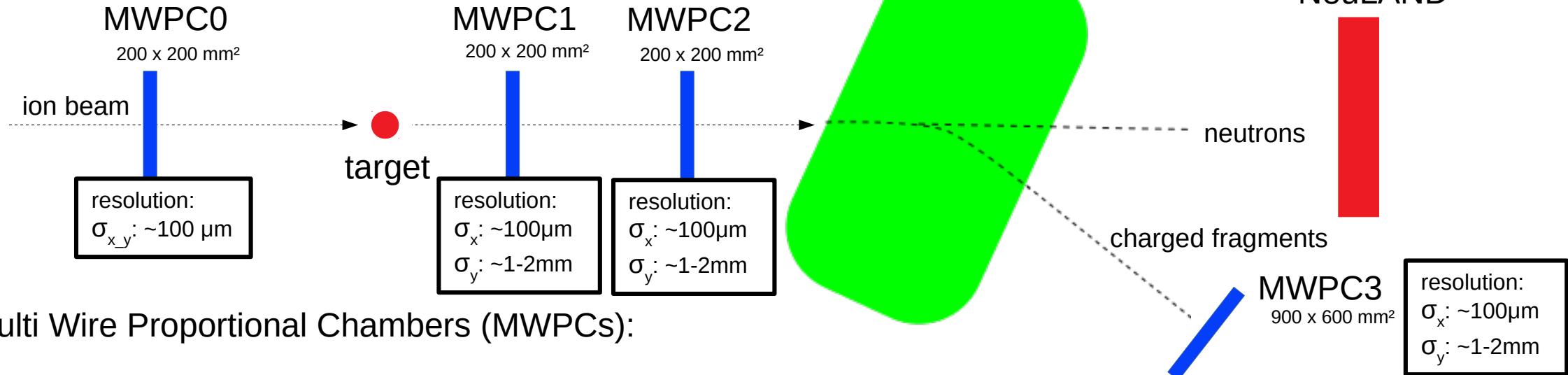
Targets:

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

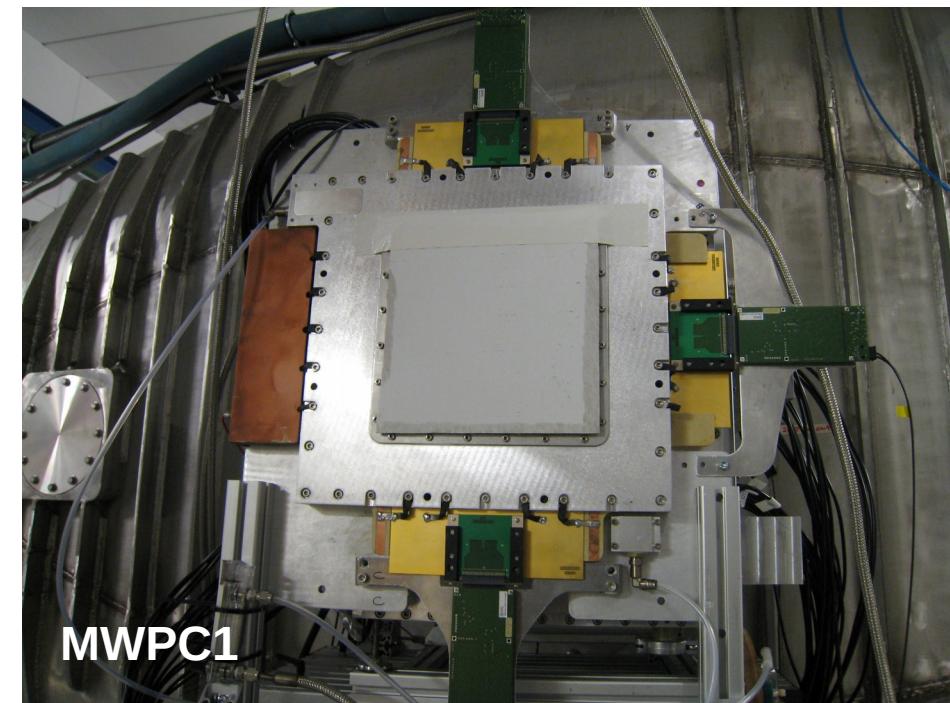
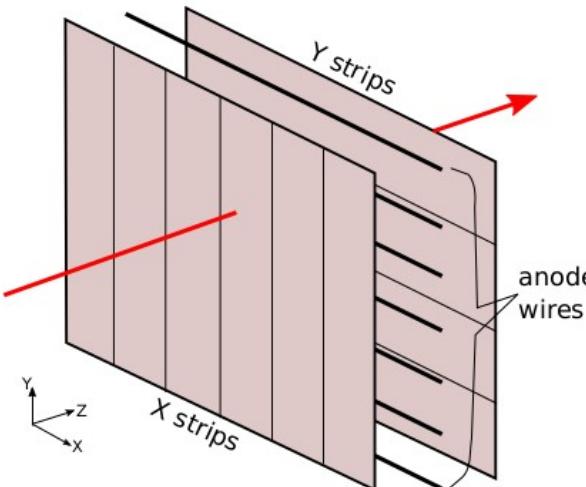


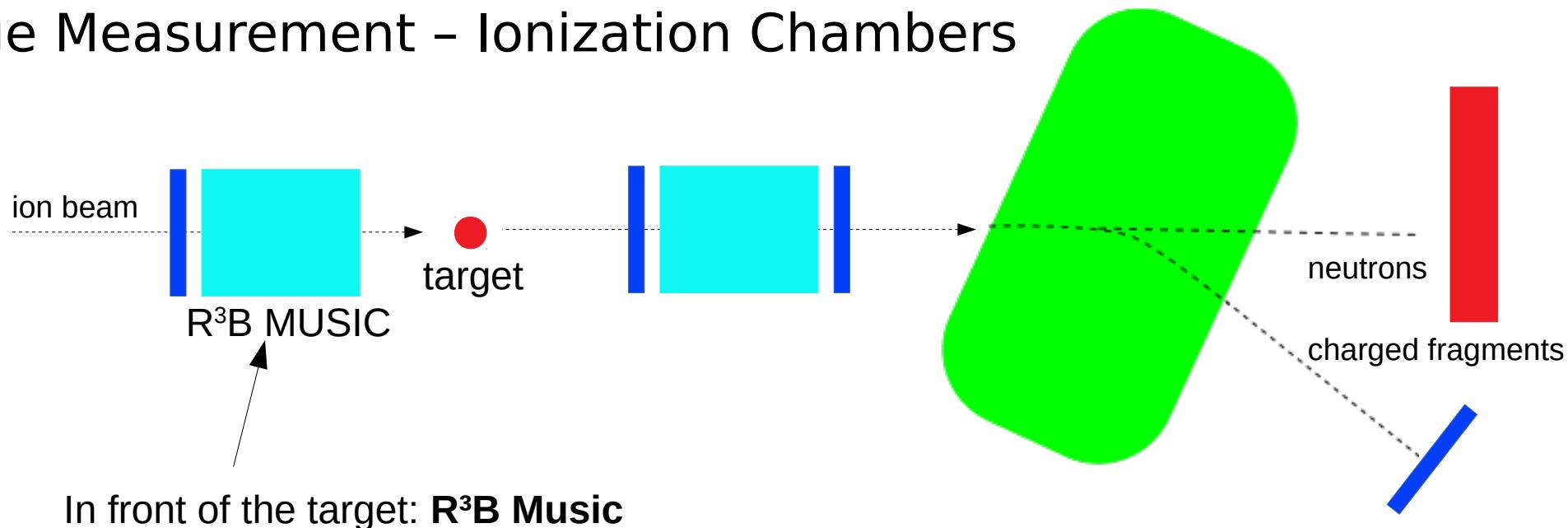
- large vertical gap (+-80 mrad) for neutrons
- high bending angle of 40°
- field integral of about 5 Tm
- momentum resolution $\Delta p/p$ of around 10^{-3}

Tracking Detectors



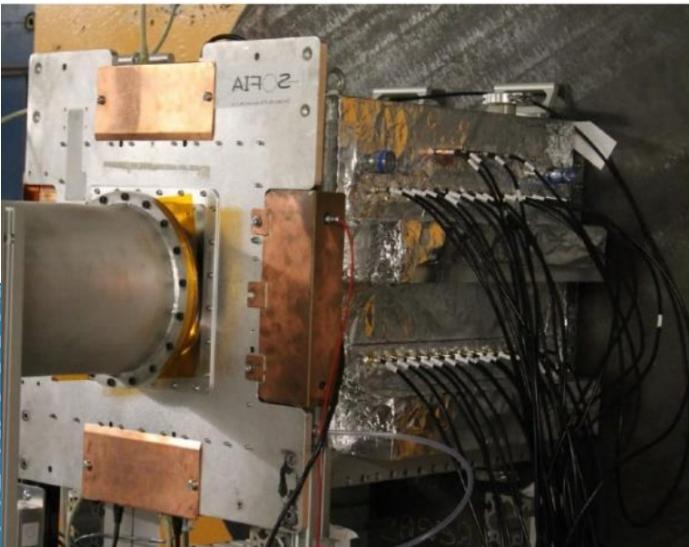
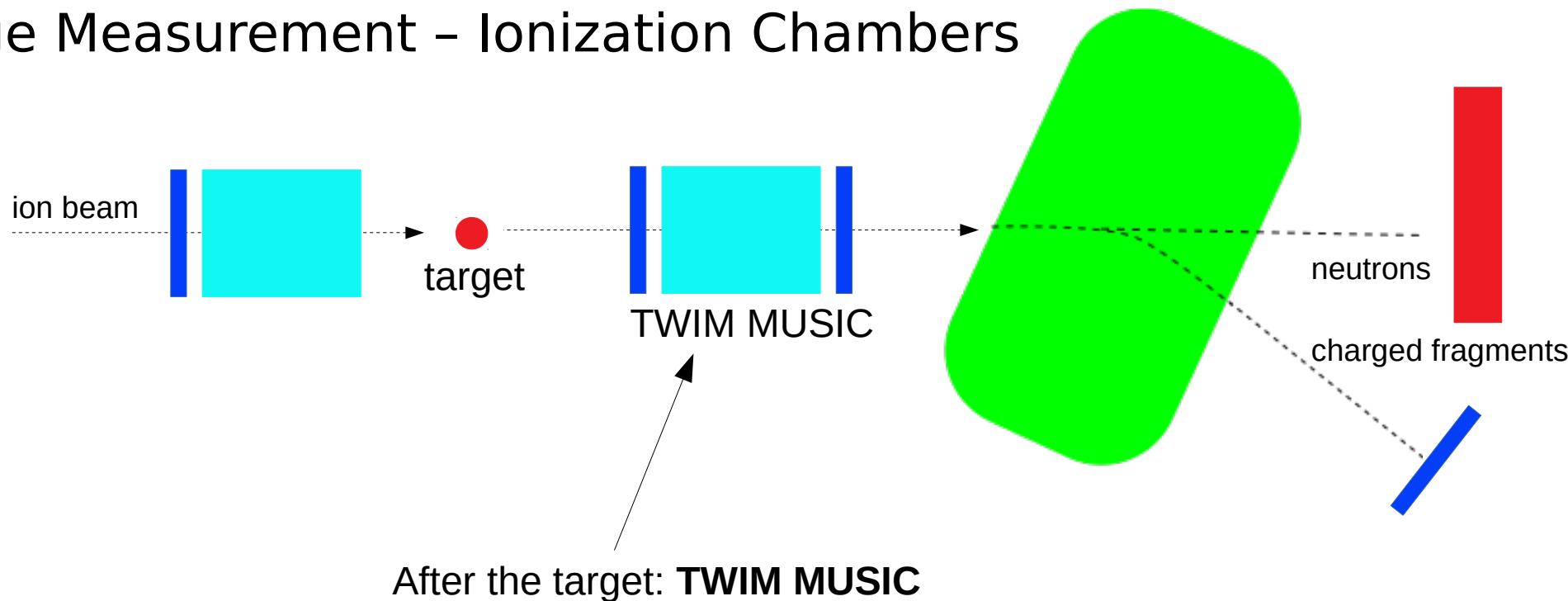
- vertical/horizontal wires: $50 \mu\text{m}$ diameter, 2.5 mm spacing
- vertical/horizontal pads:
Al-deposited on a $12 \mu\text{m}$ Mylar foil,
 $5/3.125 \text{ mm}$ width (vertical/horizontal)
- gas mixture: 84% Ar, 16% CO₂
- pad readout





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





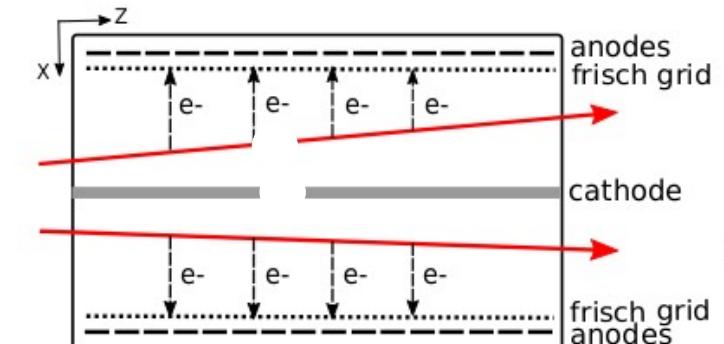
43 x 48 x 55 cm³

Double ionization chamber with central cathode and two anode planes

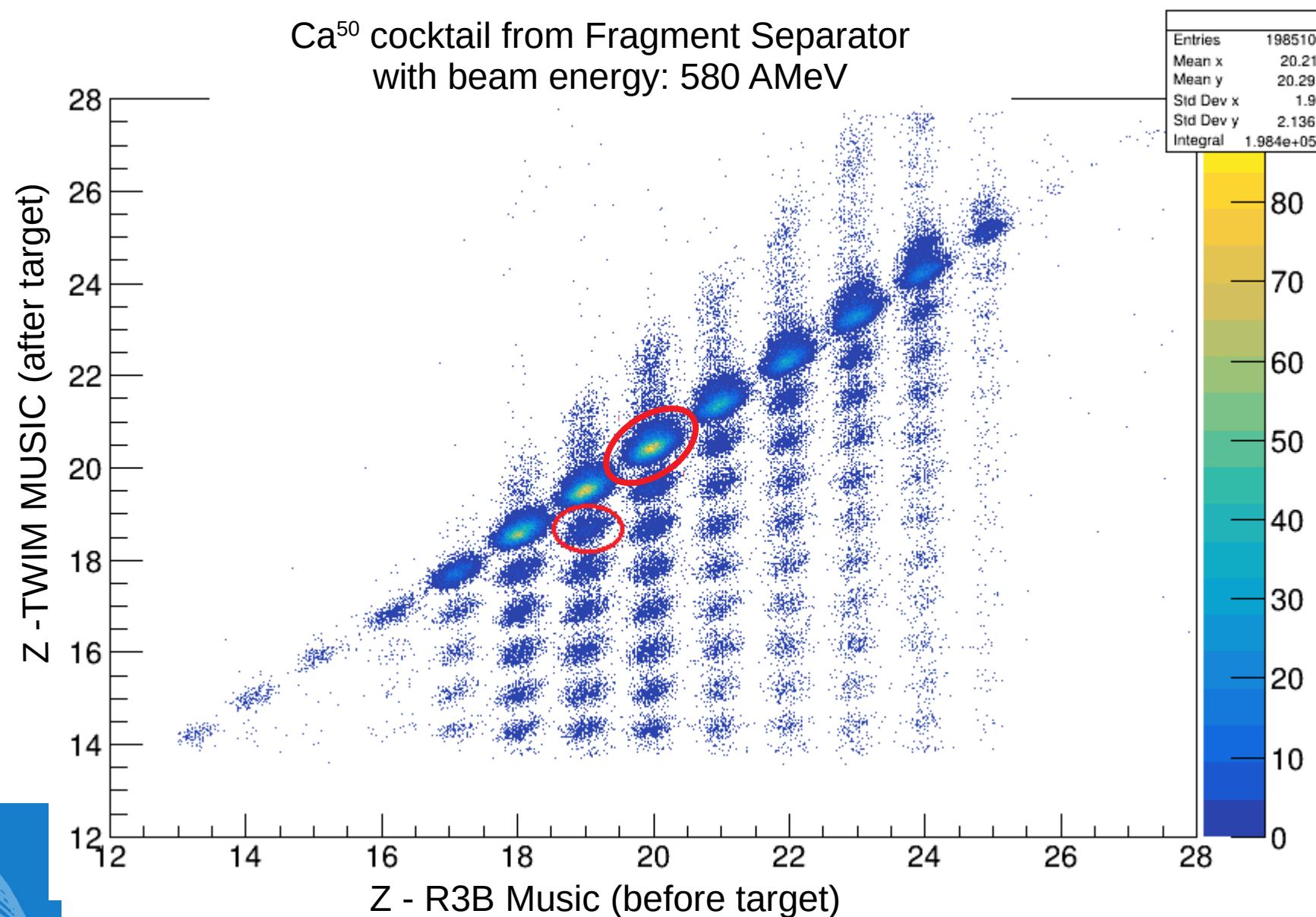
Frisch grid for better signal quality and time resolution

Gas mixture:

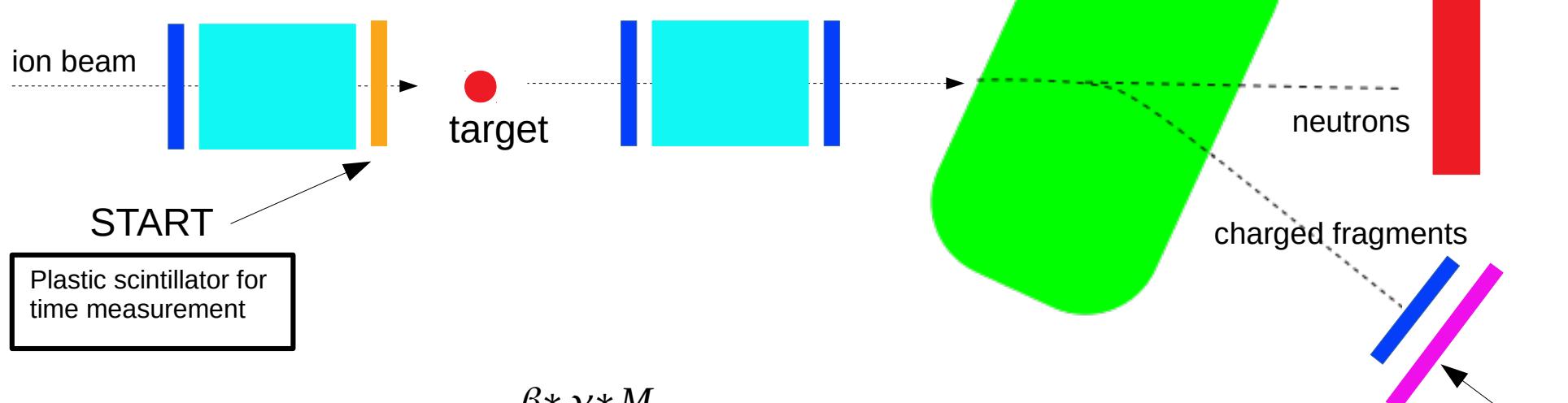
Ar 25%, CH₄ 75%



Ca^{50} cocktail from Fragment Separator with beam energy: 580 AMeV

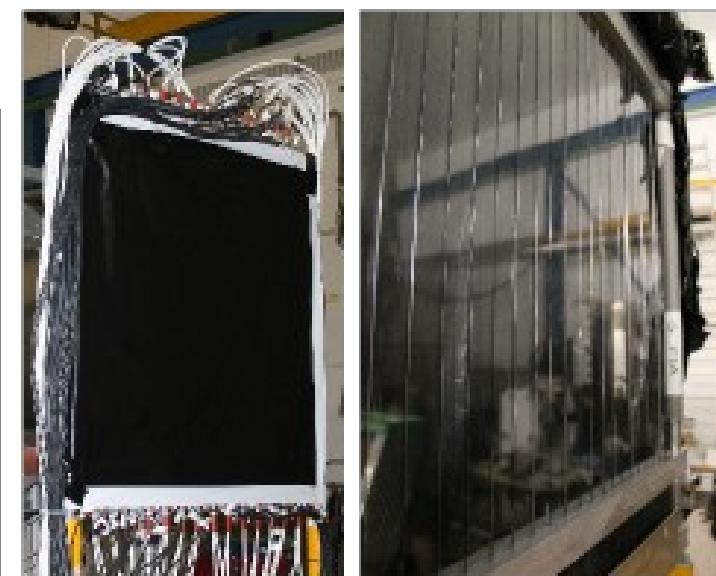


Time Measurement - START & ToFW



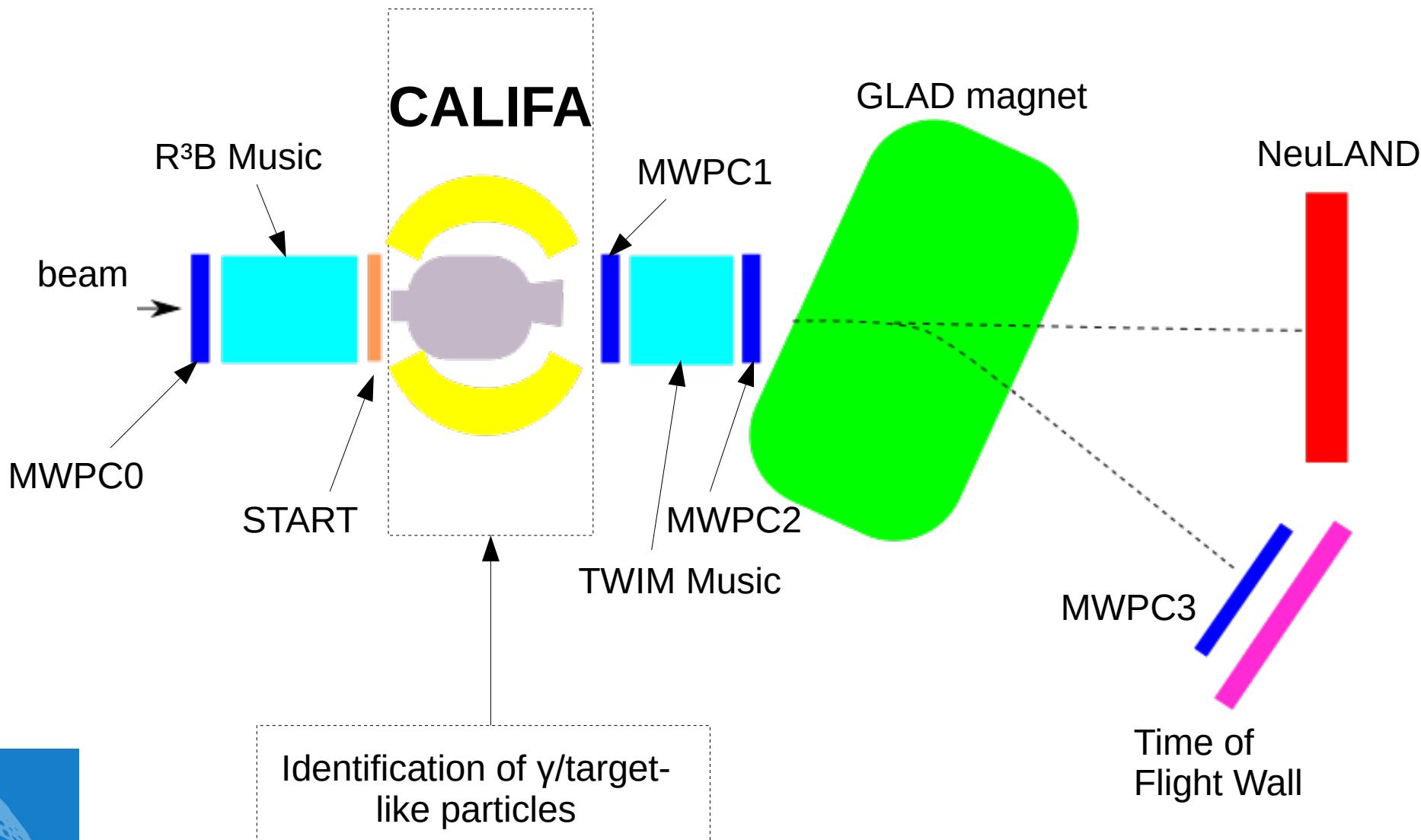
Particle Identification: $B*\rho = \frac{\beta*\gamma*M}{q}$

- 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



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

Endcap:

iPhos:

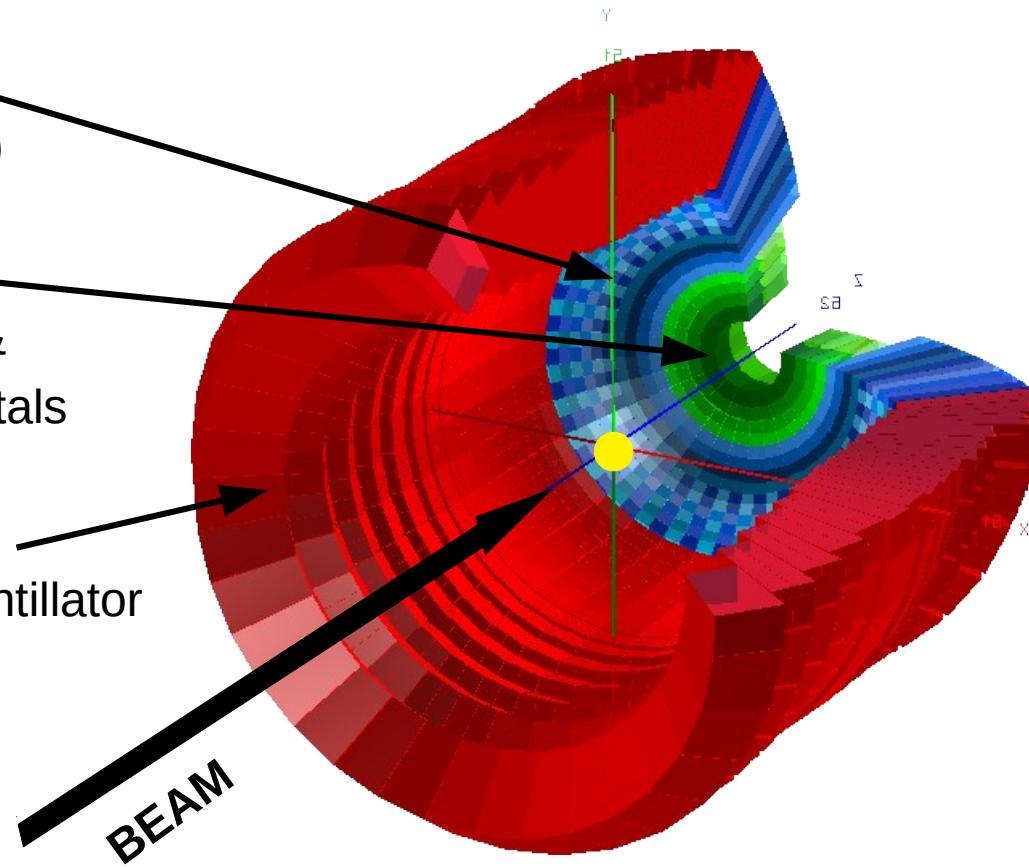
512 CsI(Tl)
crystals

CEPA:

96 LaBr₃ &
LaCl₃ crystals

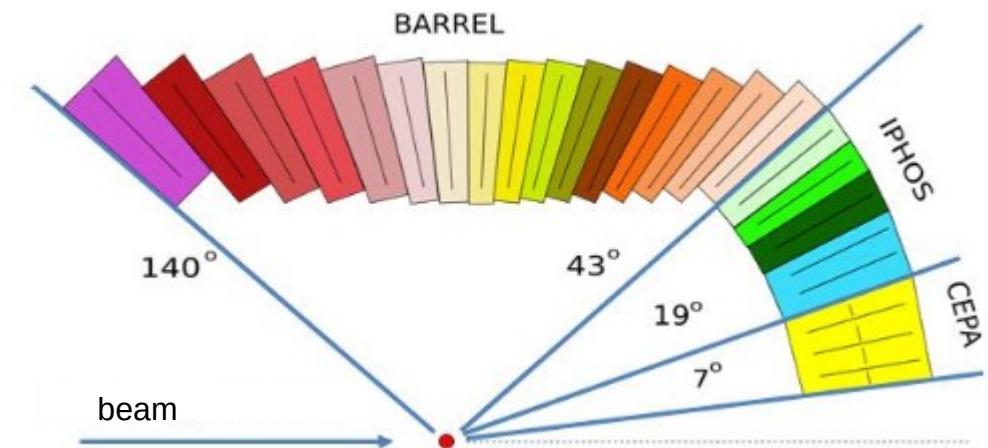
Barrel:

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

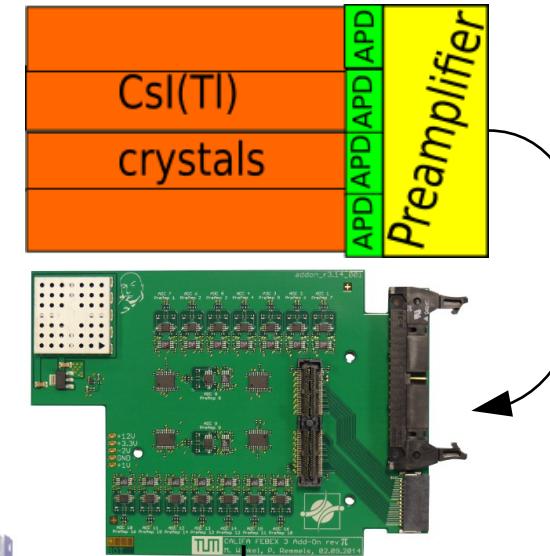
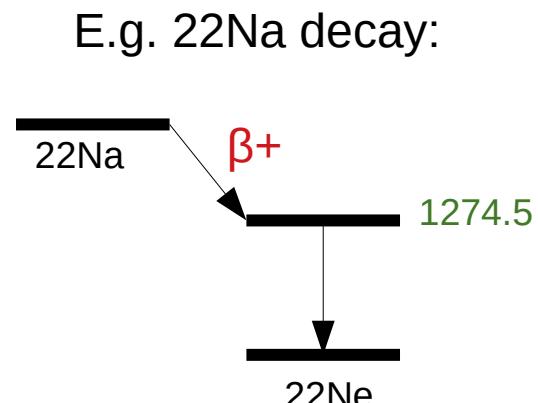
Preamplifier: generates HV for APD bias +
amplifies/integrates signal

Add-on Board: Filtering

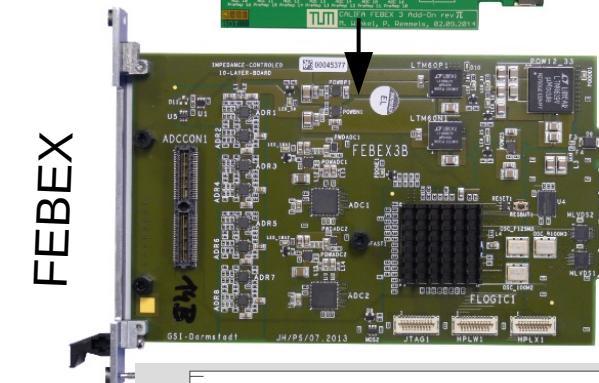
FEBEX Module: ADC + energy & particle identification

Automated APD Gain matching routine:

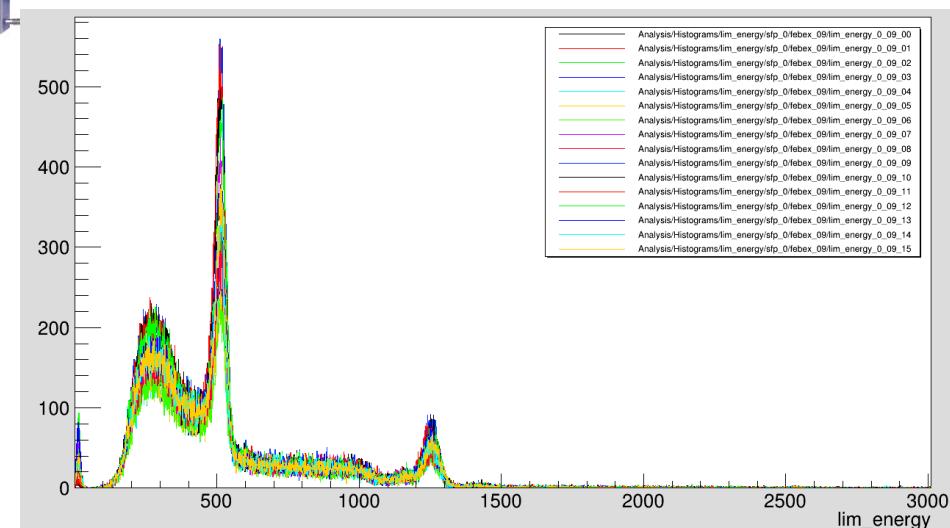
- ensures that all channels cover same range
- already pre-calibrated



Add-on Board



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



Tobias Jenegger



Electronics for CALIFA



Each rack:
→ 1024 channels

→ 50 MHz
continuous
sampling rate

Dead-time free
readout design:

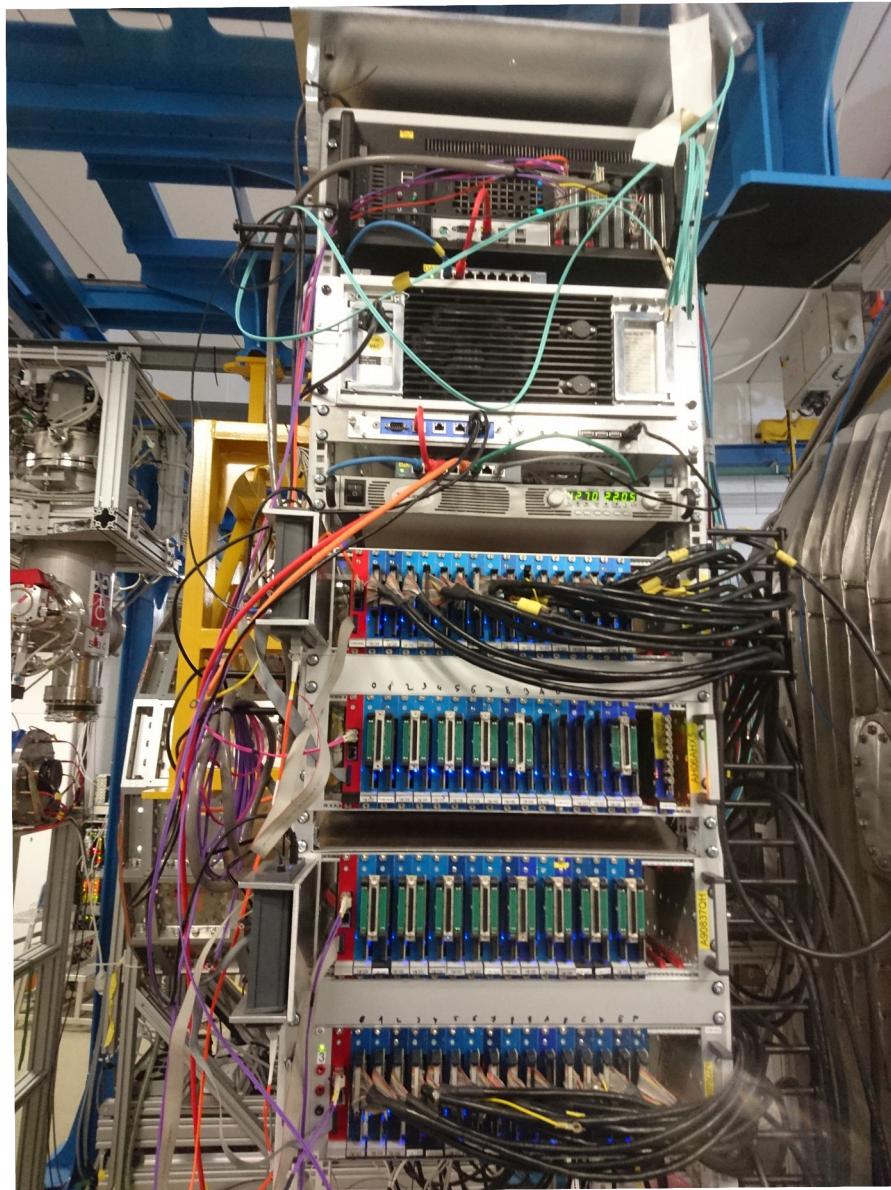
→ PEXOR card

→ TRIXOR card

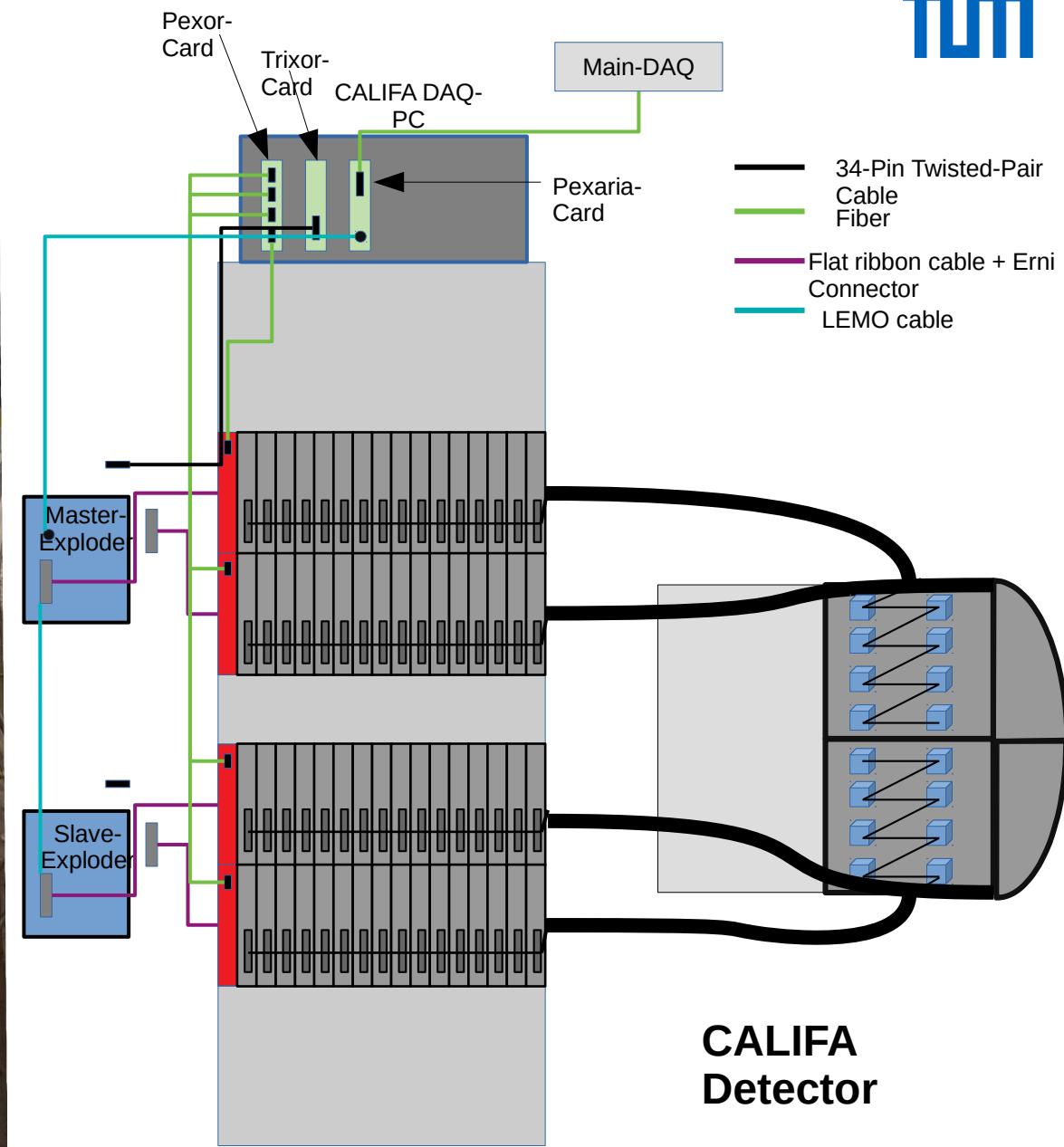
→ EXPLODER

→ PEXARIA
(white

Rabbit
timestamp)



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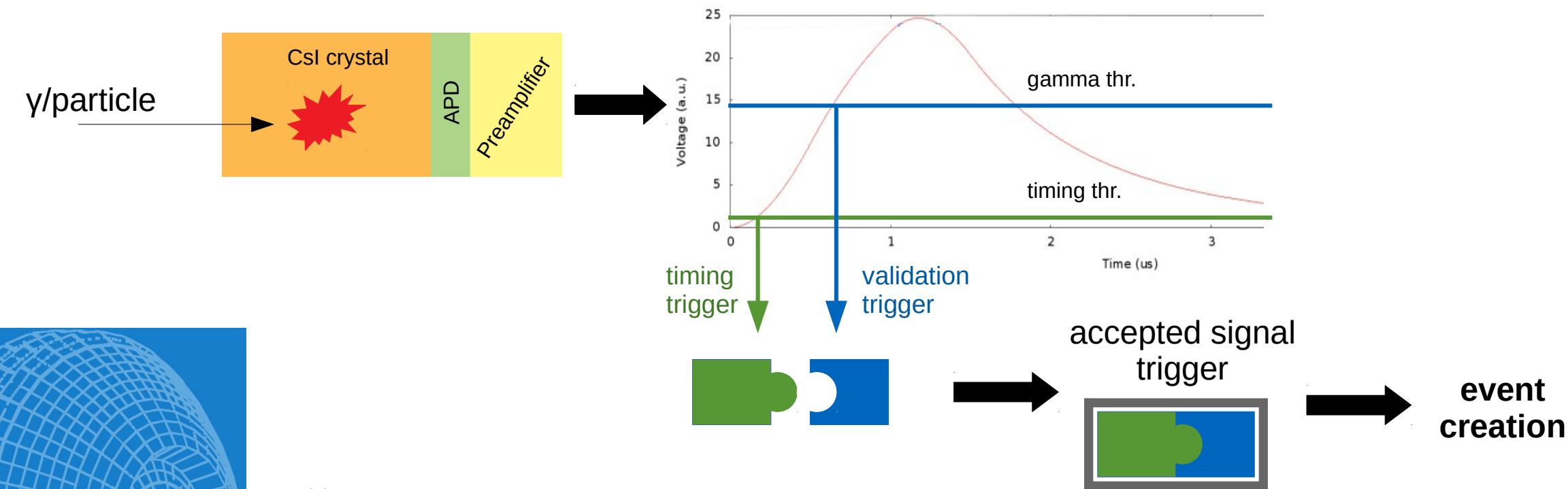


CALIFA
Detector

Trigger-Discriminator Logic:

- **Timing Trigger**: event time assignment
- **Gamma Trigger**: event validation
- **Proton Trigger**: external trigger

Intuitive event building logic (free running mode):

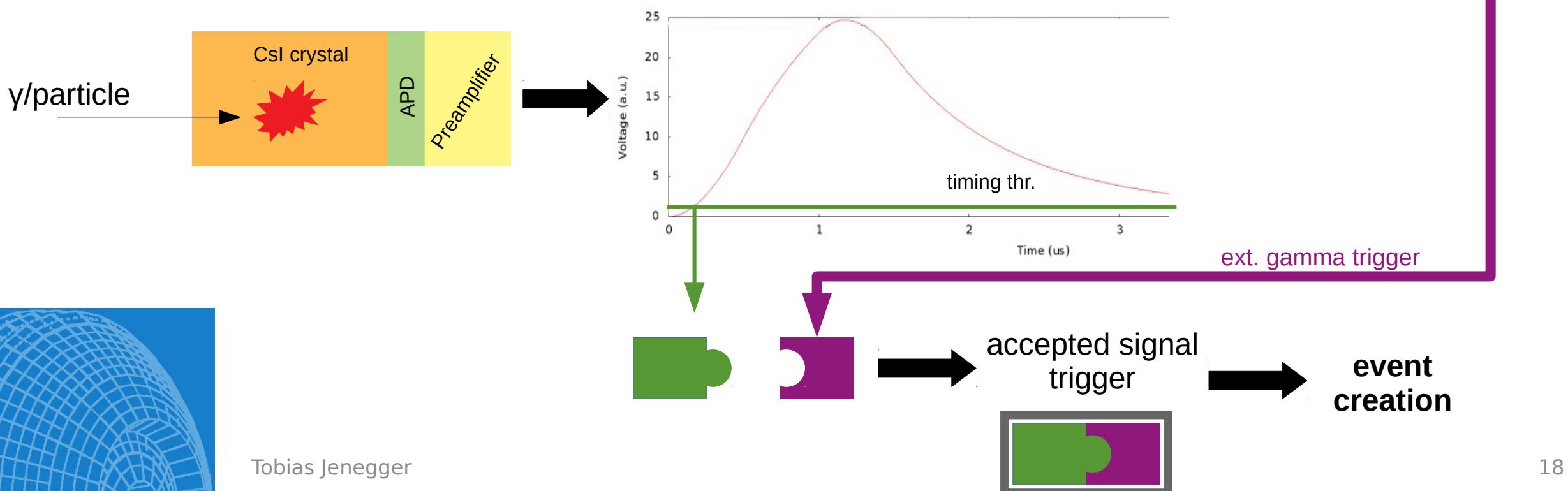


Trigger-Discriminator Logic:

- **Timing Trigger**: event time assignment
- **Gamma Trigger**: event validation
- **Proton Trigger**: external trigger

Ext.
Detector

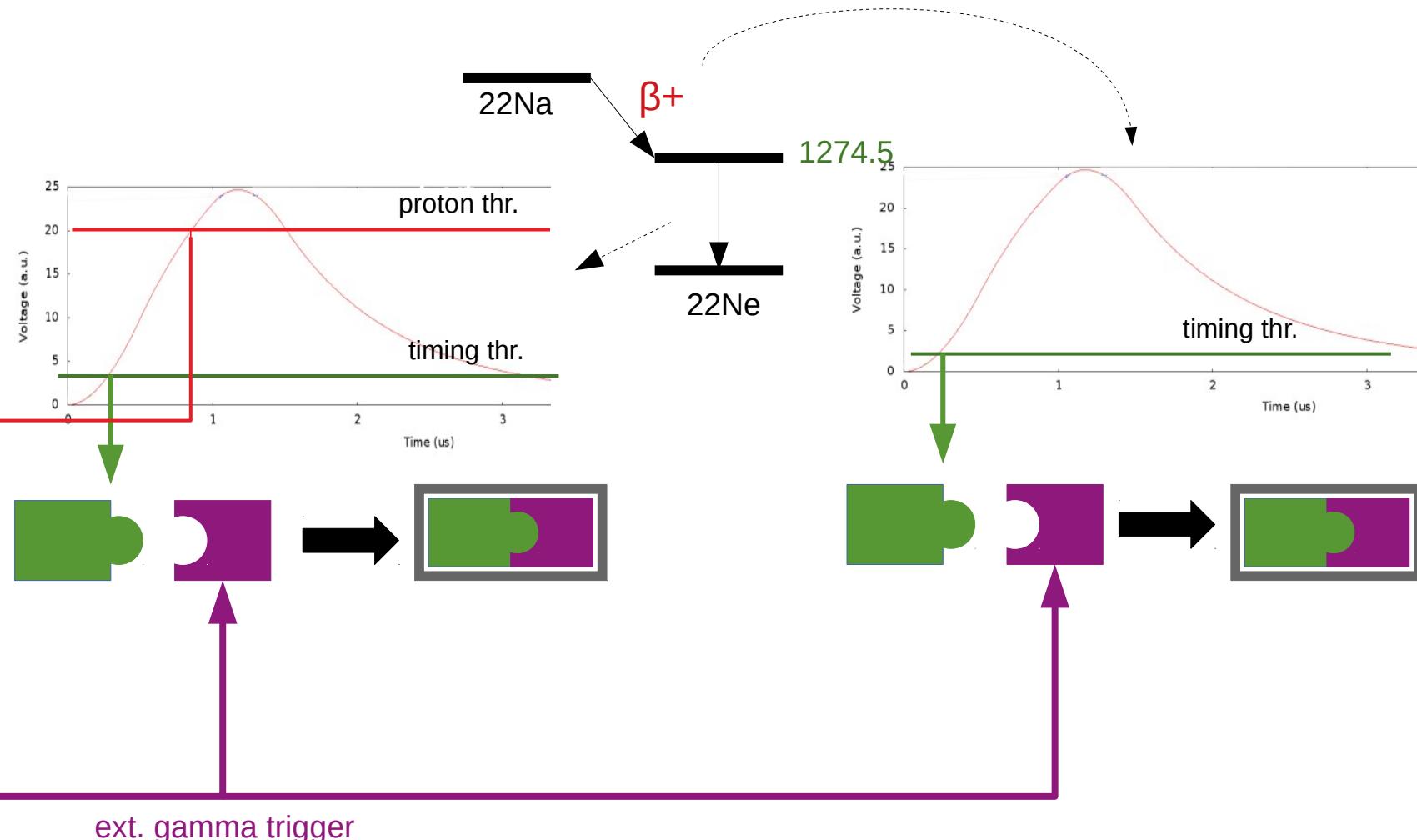
synchronous and coincident trigger mode (ext. validation trigger):



- for experiment in May 2021 with He test beam
- ext. gamma trigger from START detector

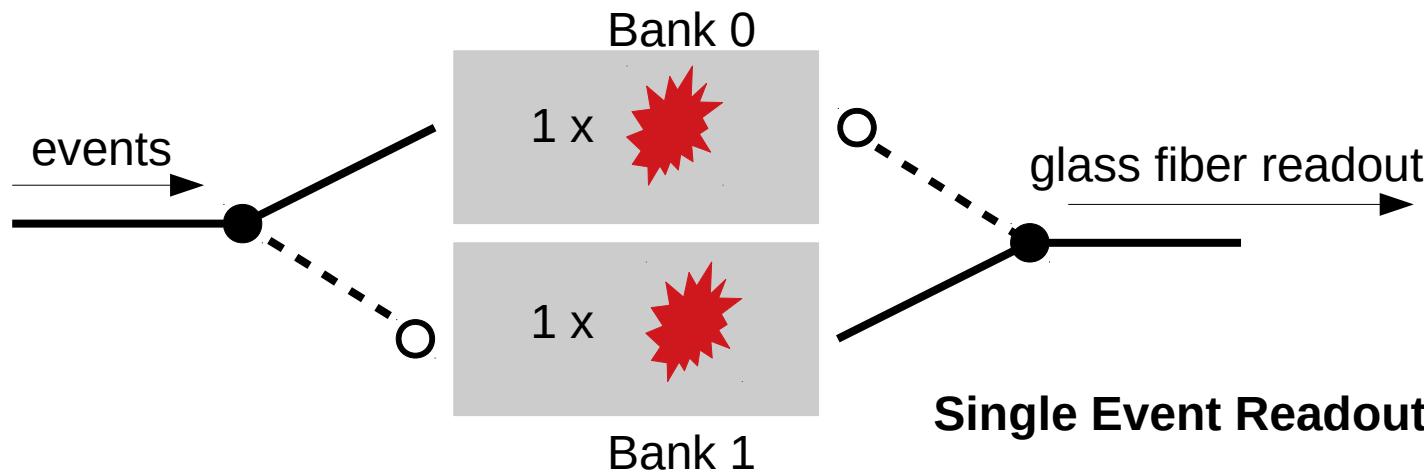
Testing:

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



Exploder

CALIFA Readout Modes

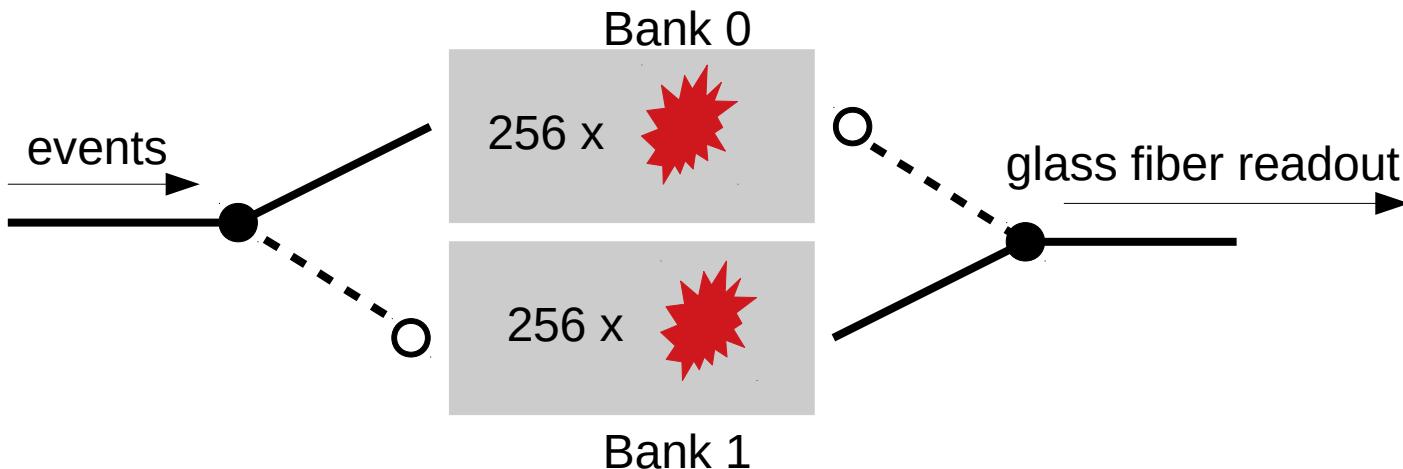


Single Event Readout (std. Firmware):

- data is read out after each accepted signal trigger
- **dead time:**
 - if 2 events in $\Delta t <$ readout time
- readout speed depends on data size:
 - larger data blocks increase readout speed (max. 190MB/s)



CALIFA Readout Modes



Multi Event Readout (free running mode) :

- max. 256 events saved on each FEBEX bank
- **(almost) no dead time!**
- not until 512 events in $\Delta t <$ readout time

Given: 100kHz reaction rate at target

How many crystals can be hit per reaction event ?

$$190 \text{ MB/s} = 40 \text{ Byte} * 10^5 * x$$

max. readout speed per glass fiber ↓
data size of single event ↓
reaction rate ↓
max. crystal hits per reaction event:
 ≈ 45

A brace on the right side of the equation groups the "x" term and the result "max. crystal hits per reaction event: ≈ 45 ".

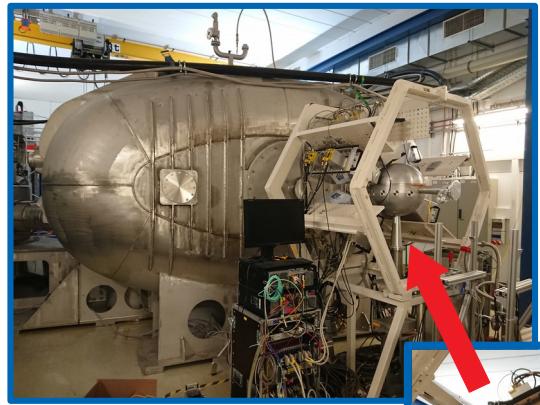
For final design we have
10 glass fiber lines

↓
max. 450 crystal hits for
100kHz reaction rate

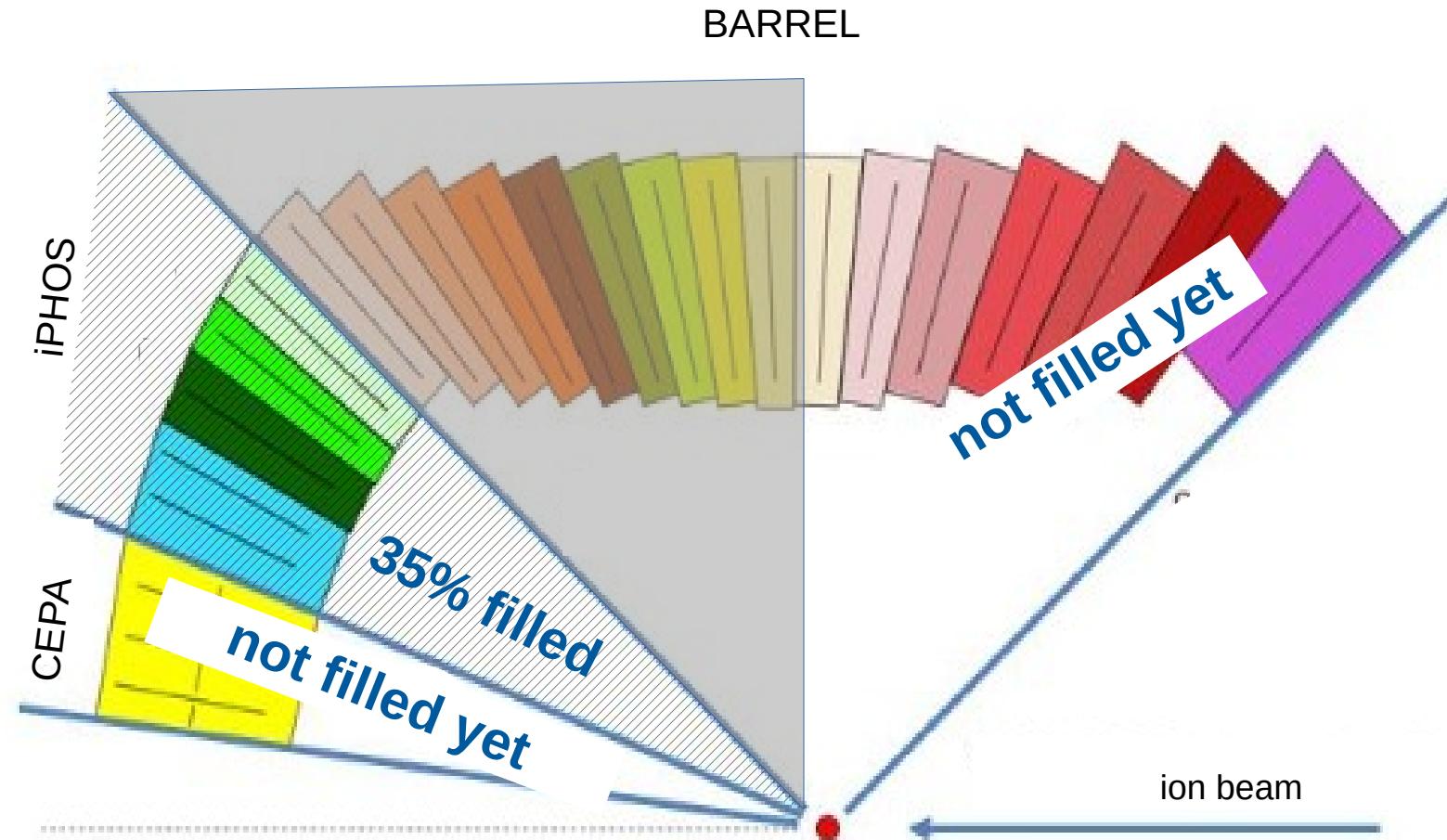
CALIFA Upgrade 2021

Tobias Jénegger

From Demonstrator to Final Setup



experiment of Lukas Ponnath



UPGRADE: iPHOS region fully filled!



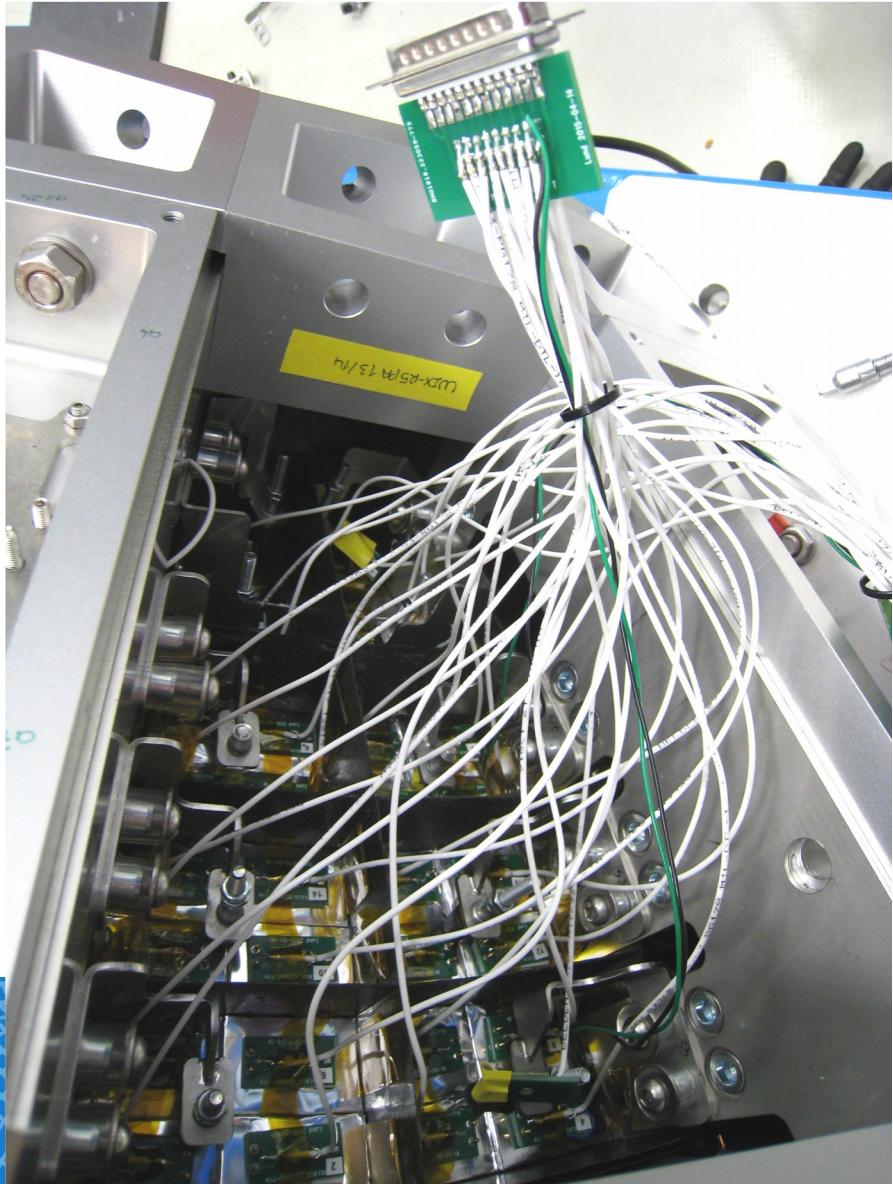
unmounting:



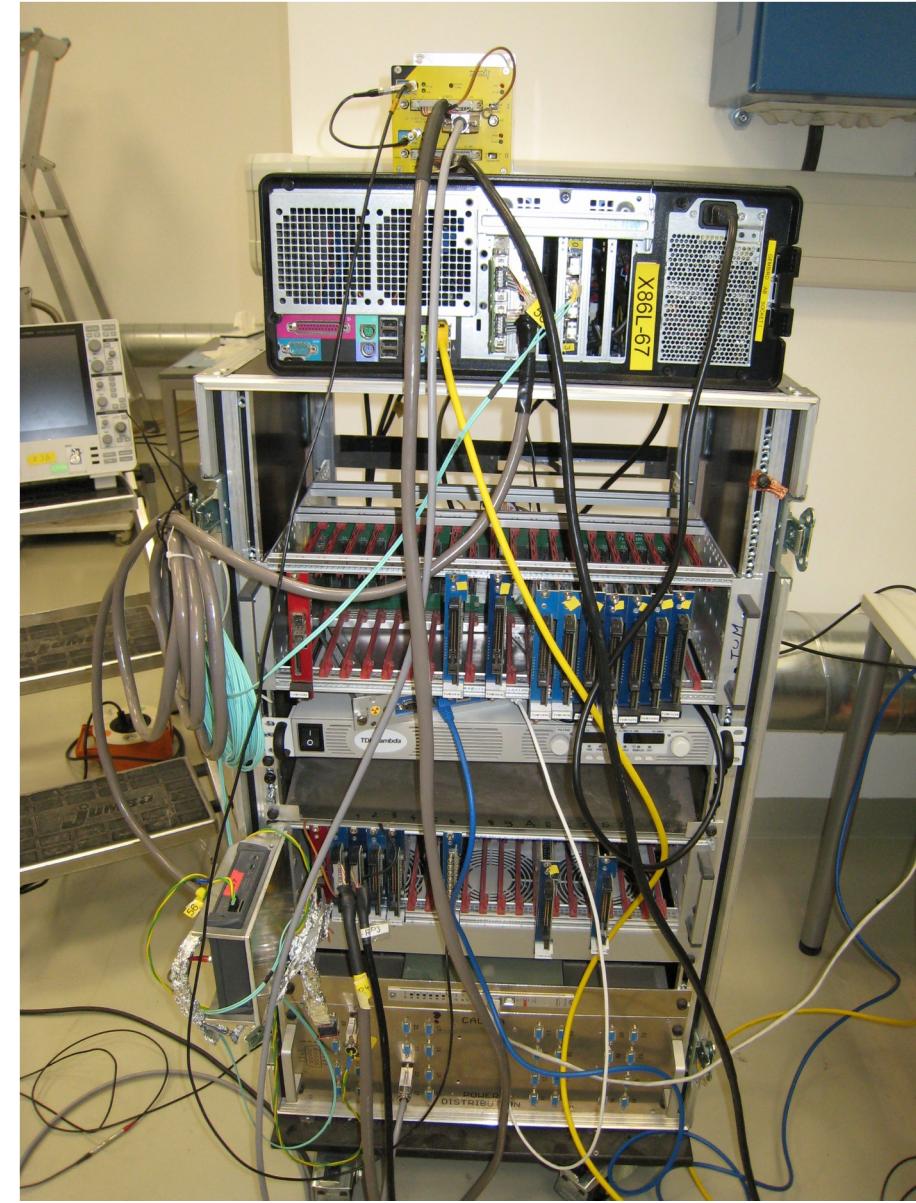
open tiles & measure crystals:



crystal filling:



testing with mobile DAQ:



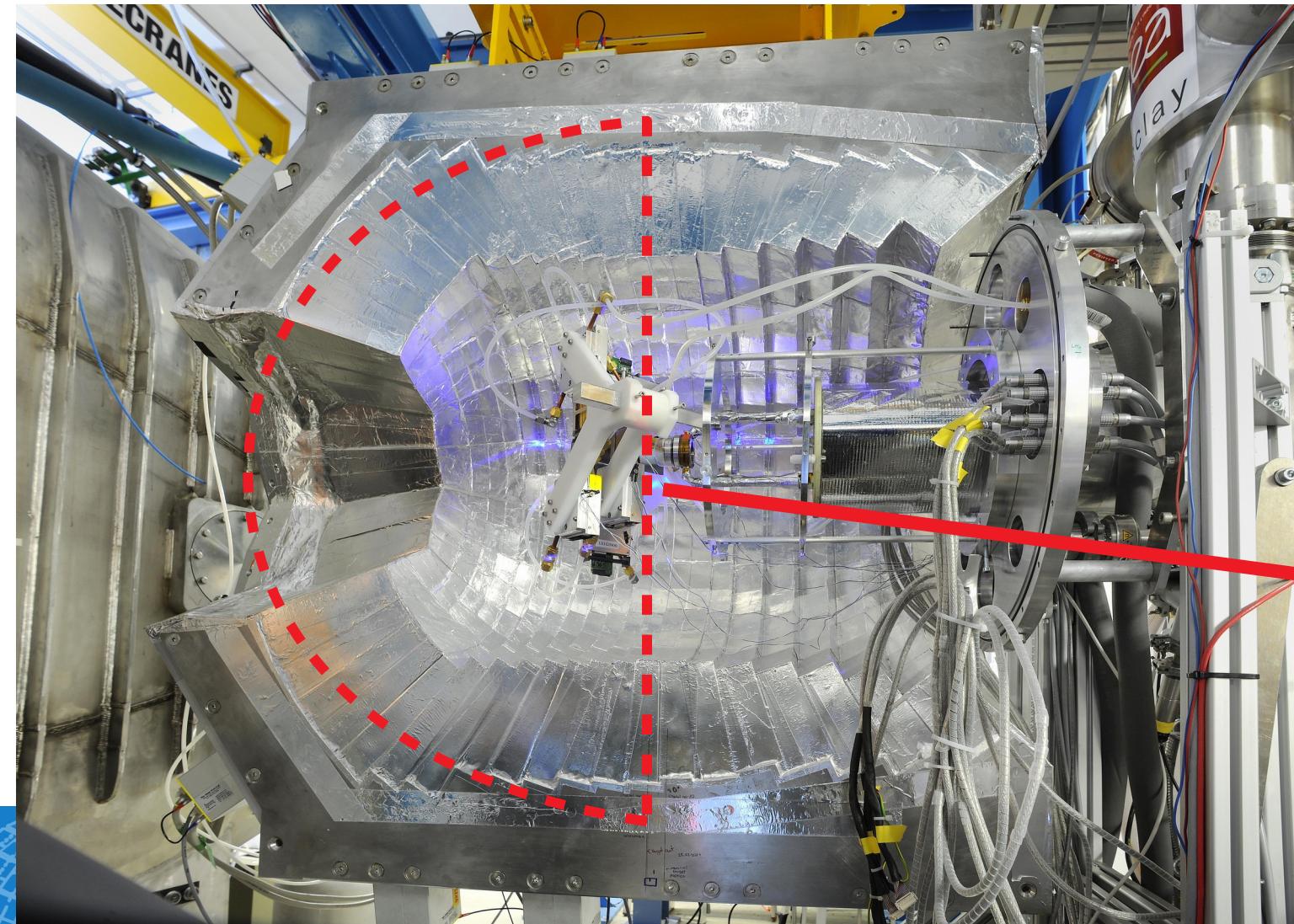
bring back to Cave C:

1.2 tons !

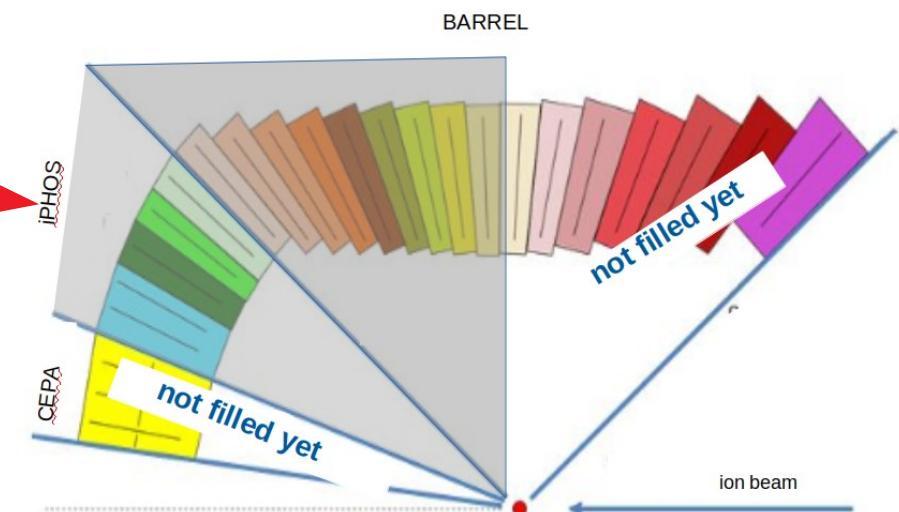


mount and align:



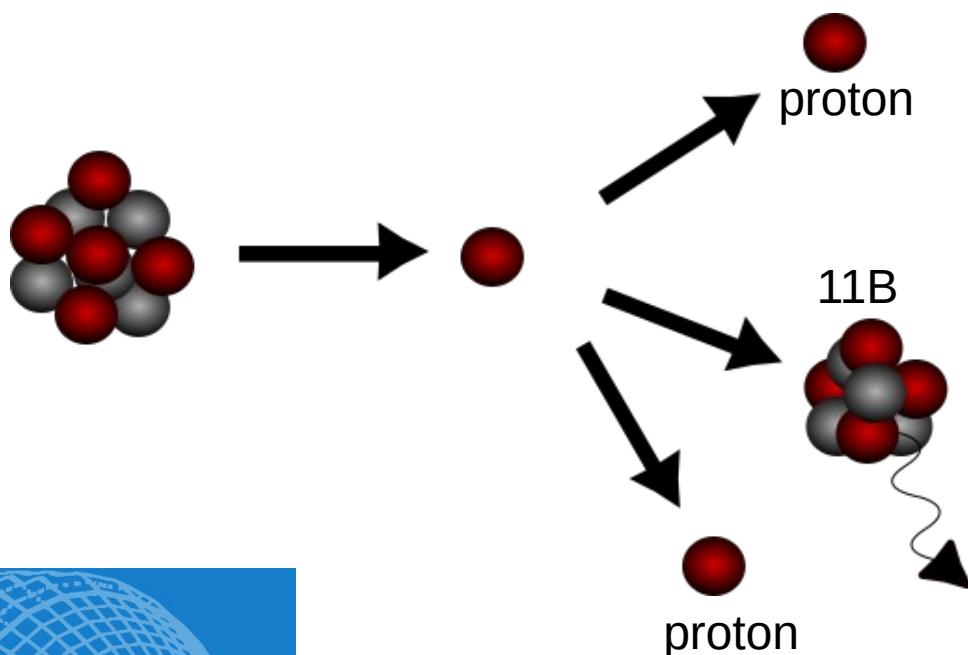


Fully filled forward half !

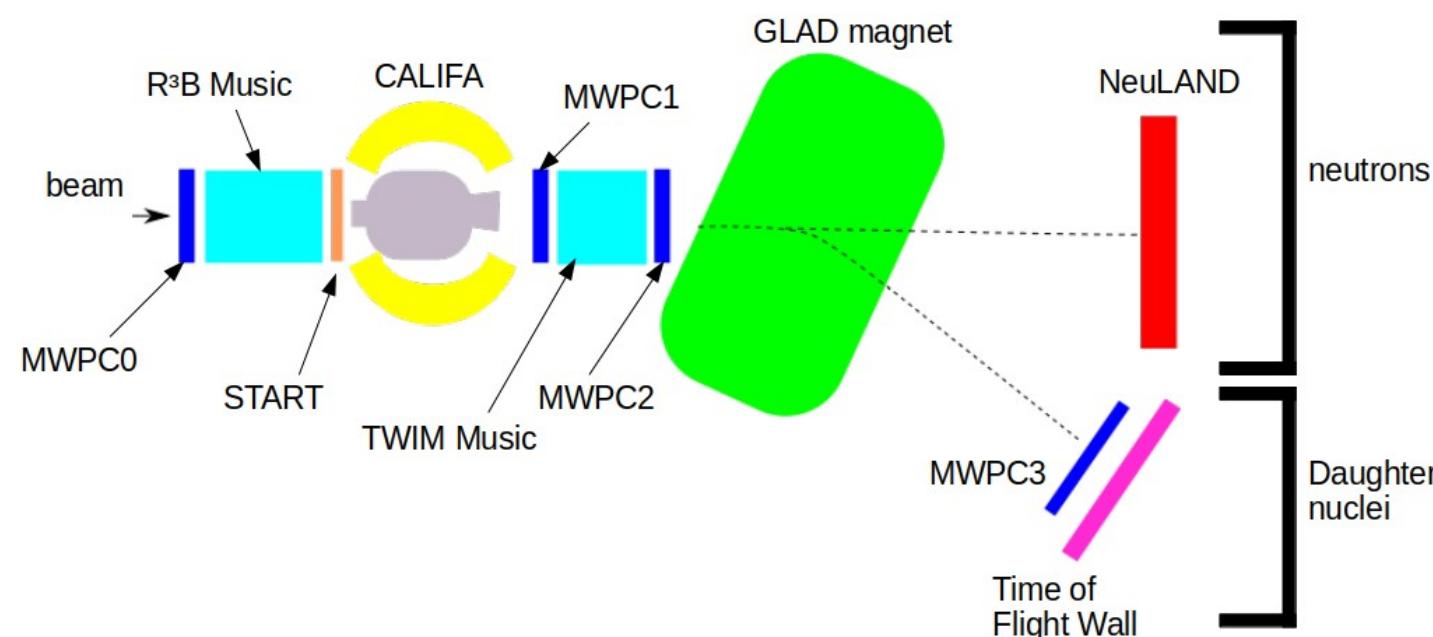


12C(p,2p)11B reaction:

- 12C beam
 - proton like target
- 2 protons
- 11B fragment (spectator)

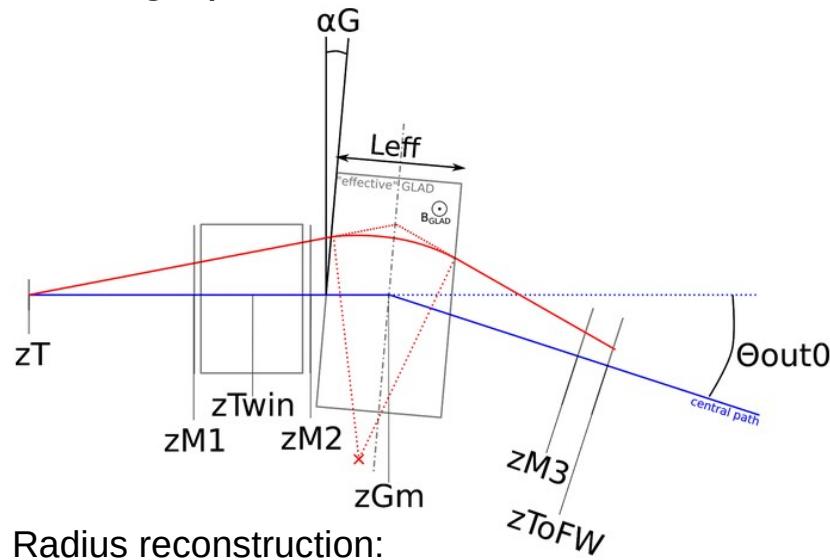
**SETUP:**

Beam energy: 400 AMeV
Beamtype: C¹²
Target: CH₂



Fragment Particle Identification

Flightpath reconstruction:



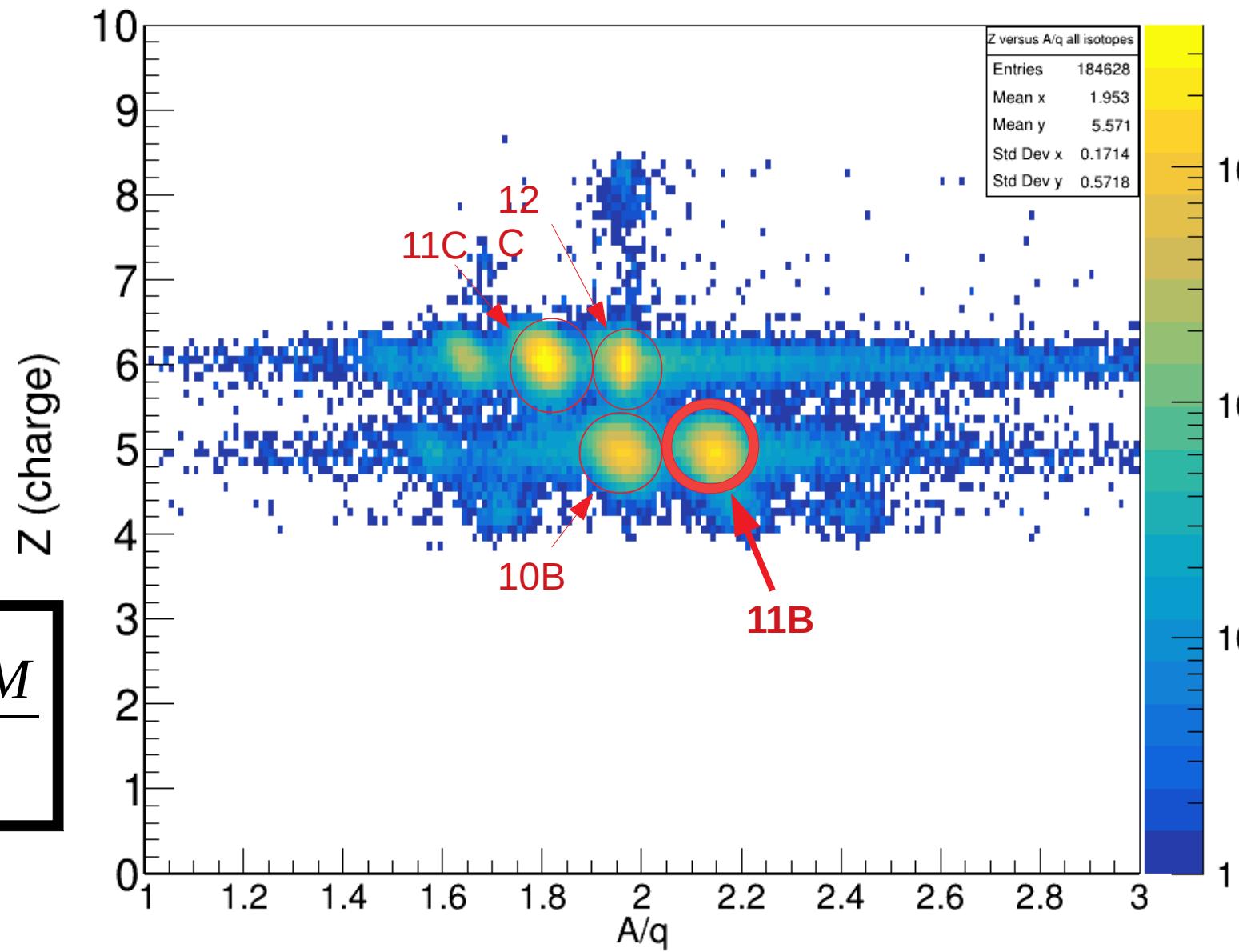
Radius reconstruction:

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

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

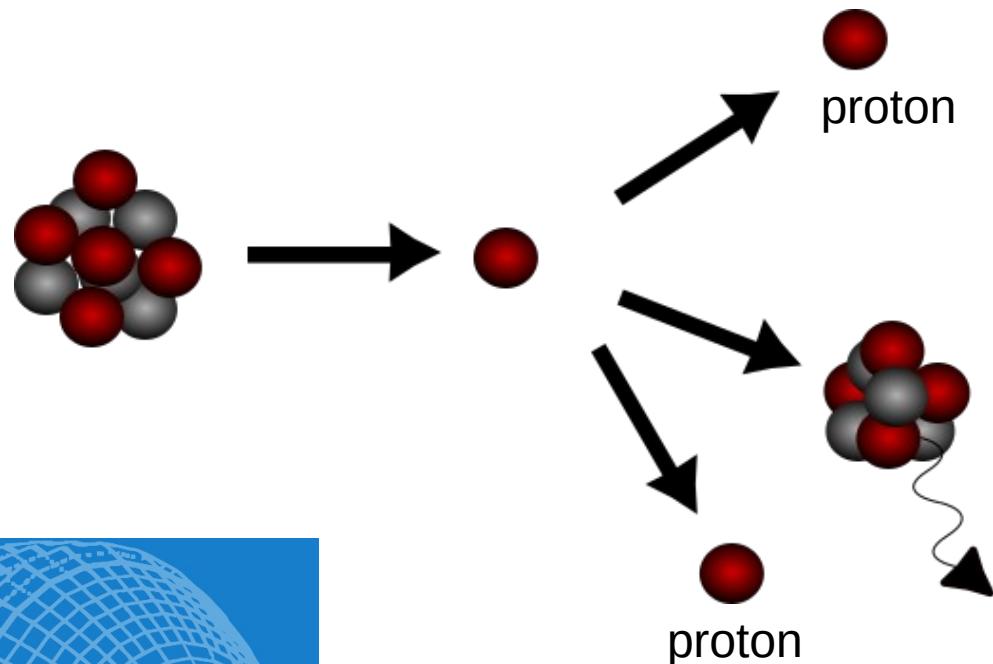


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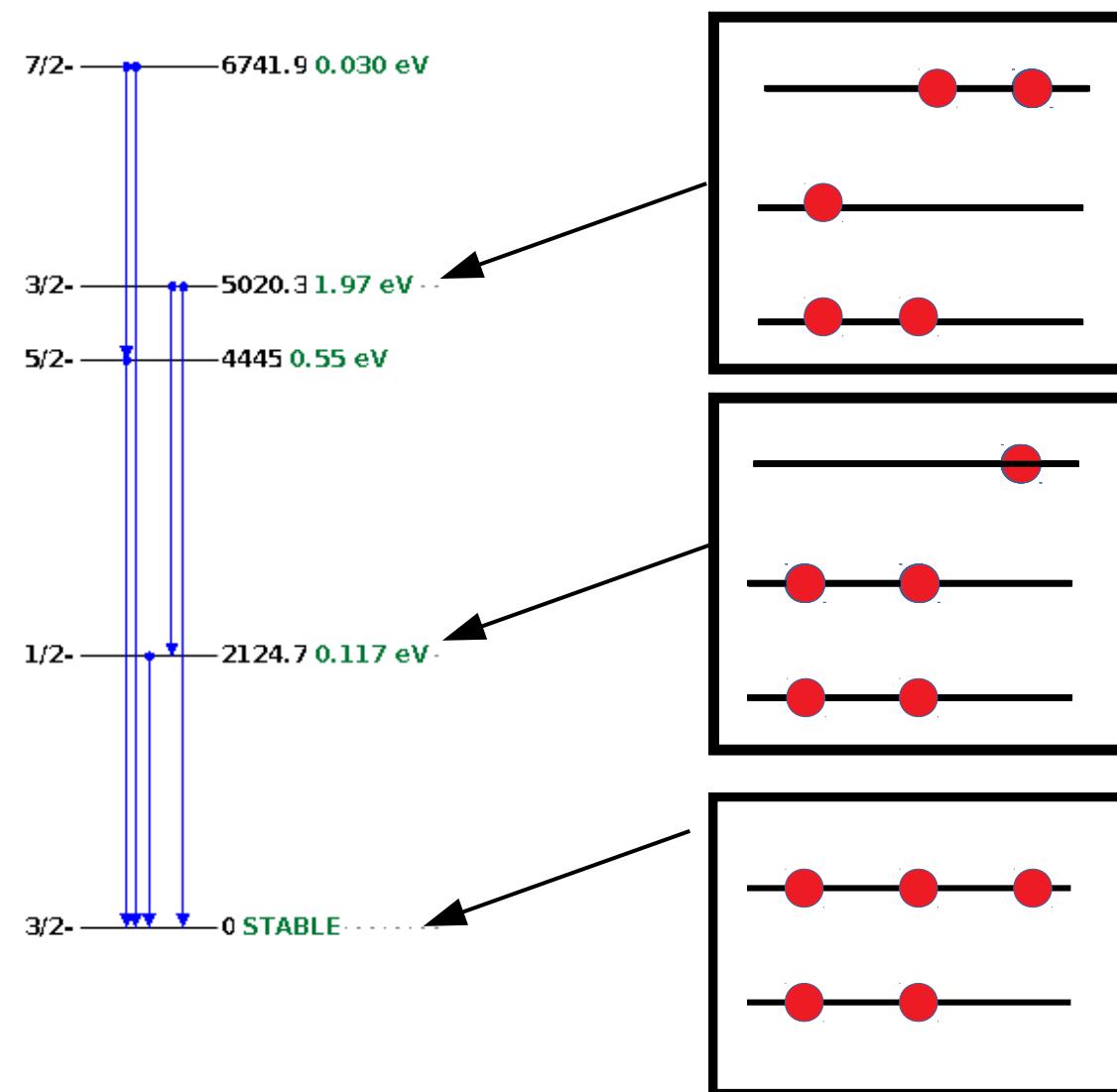


12C(p,2p)11B reaction

Two Proton Identification:
→ two hits with $E_{\text{hit}} > 30 \text{ MeV}$

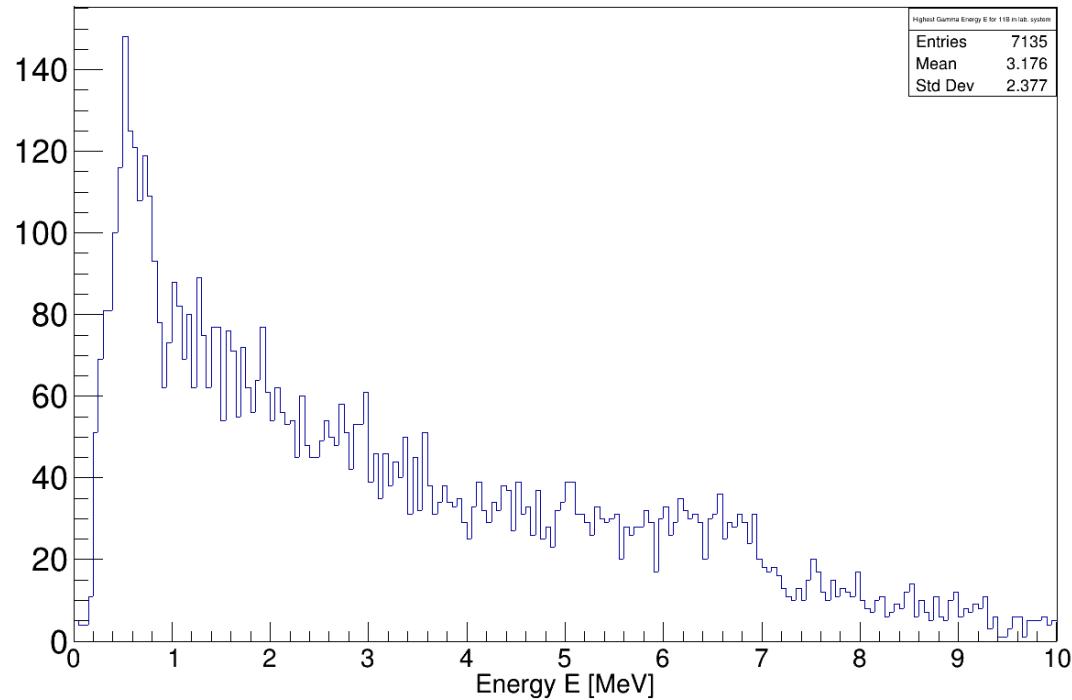


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Gamma Spectrum of ^{11}B

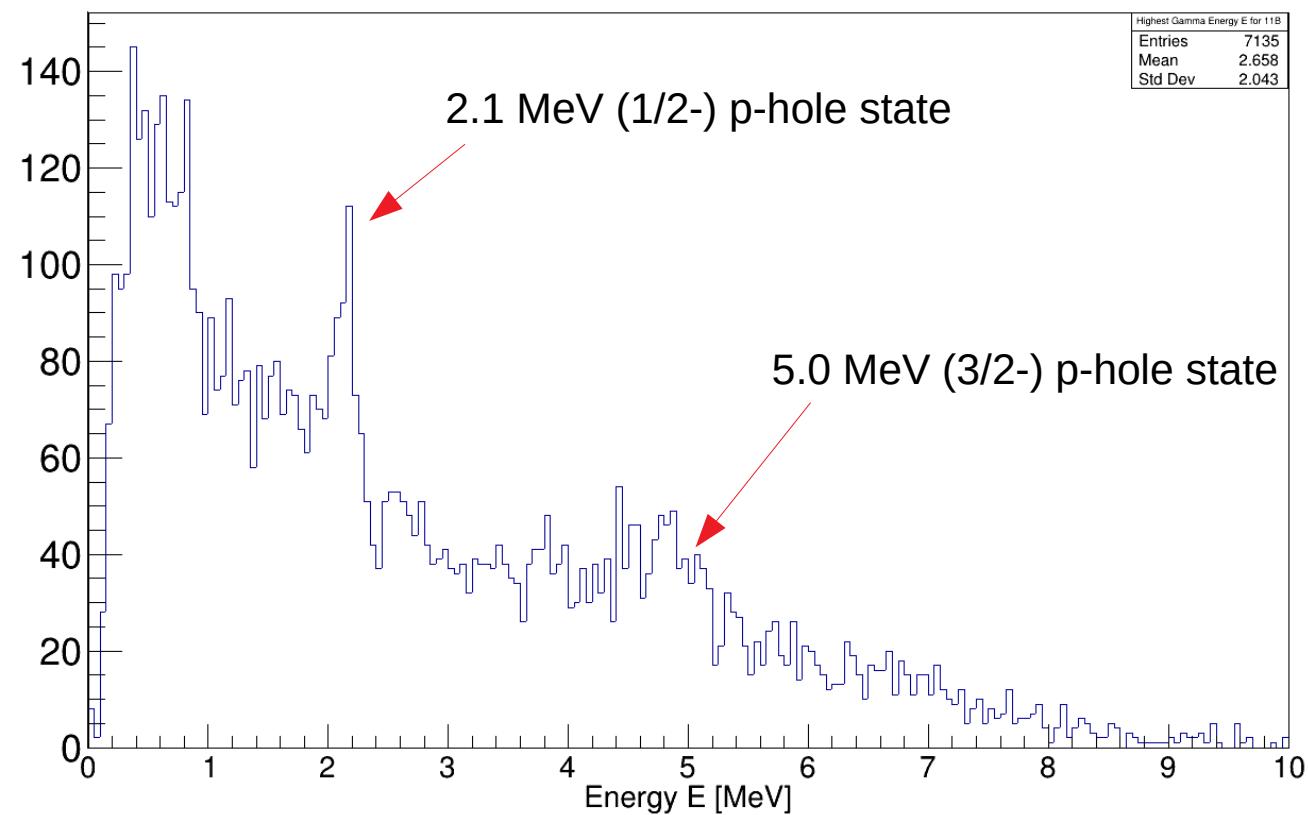
laboratory system



Doppler Correction:

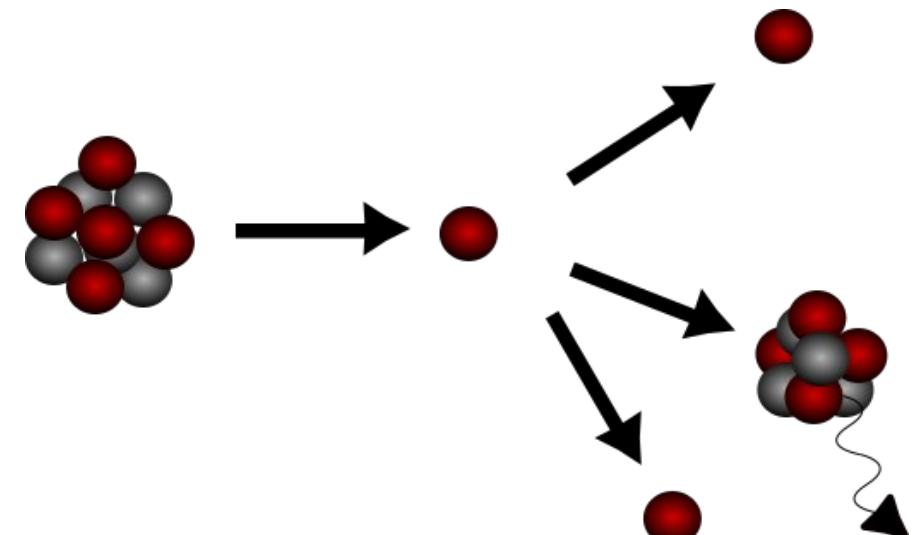
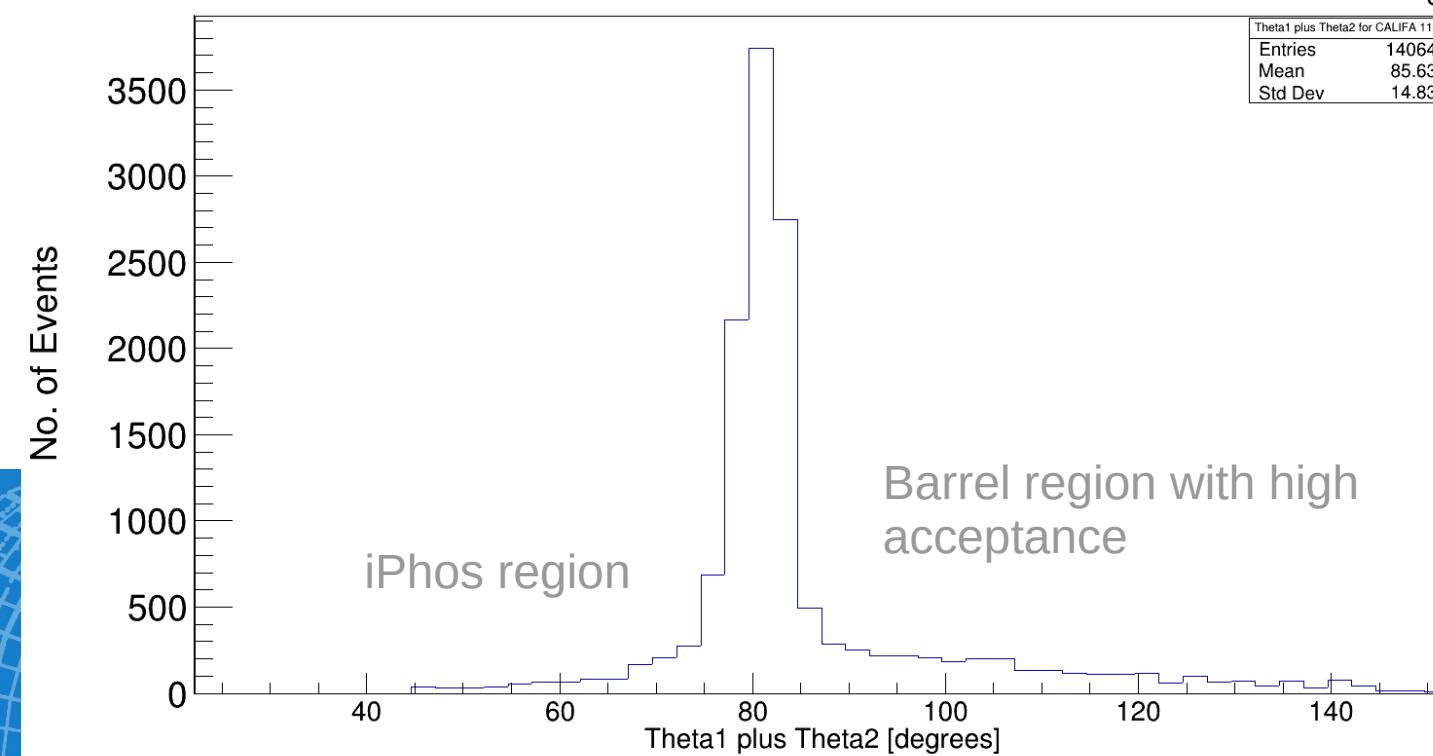
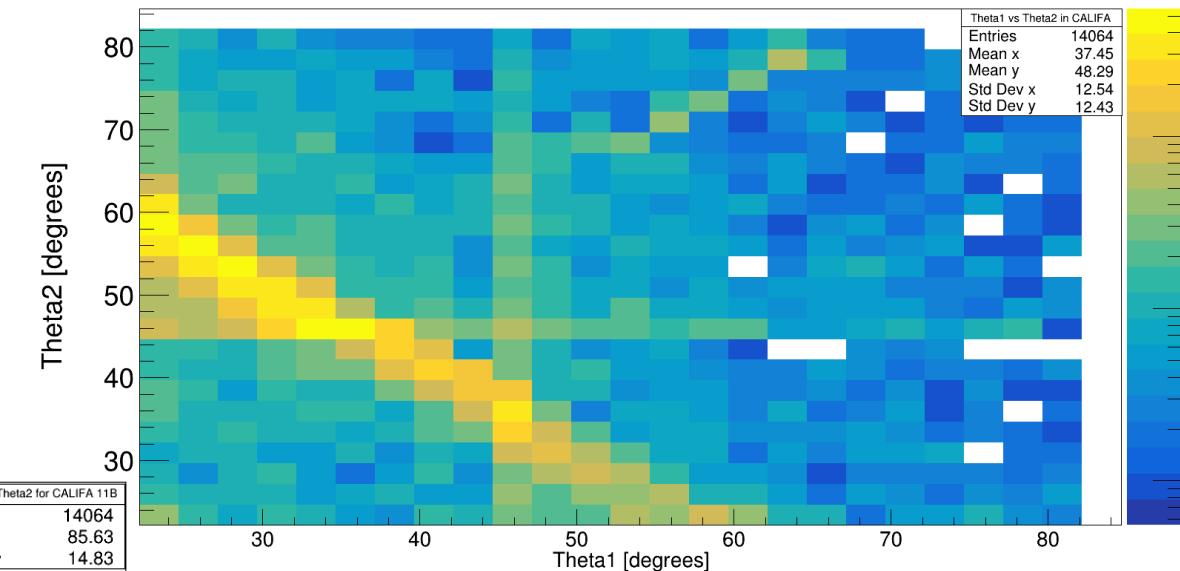
$$E_{\gamma} = \gamma E_{lab} (1 - \beta \cos(\theta))$$

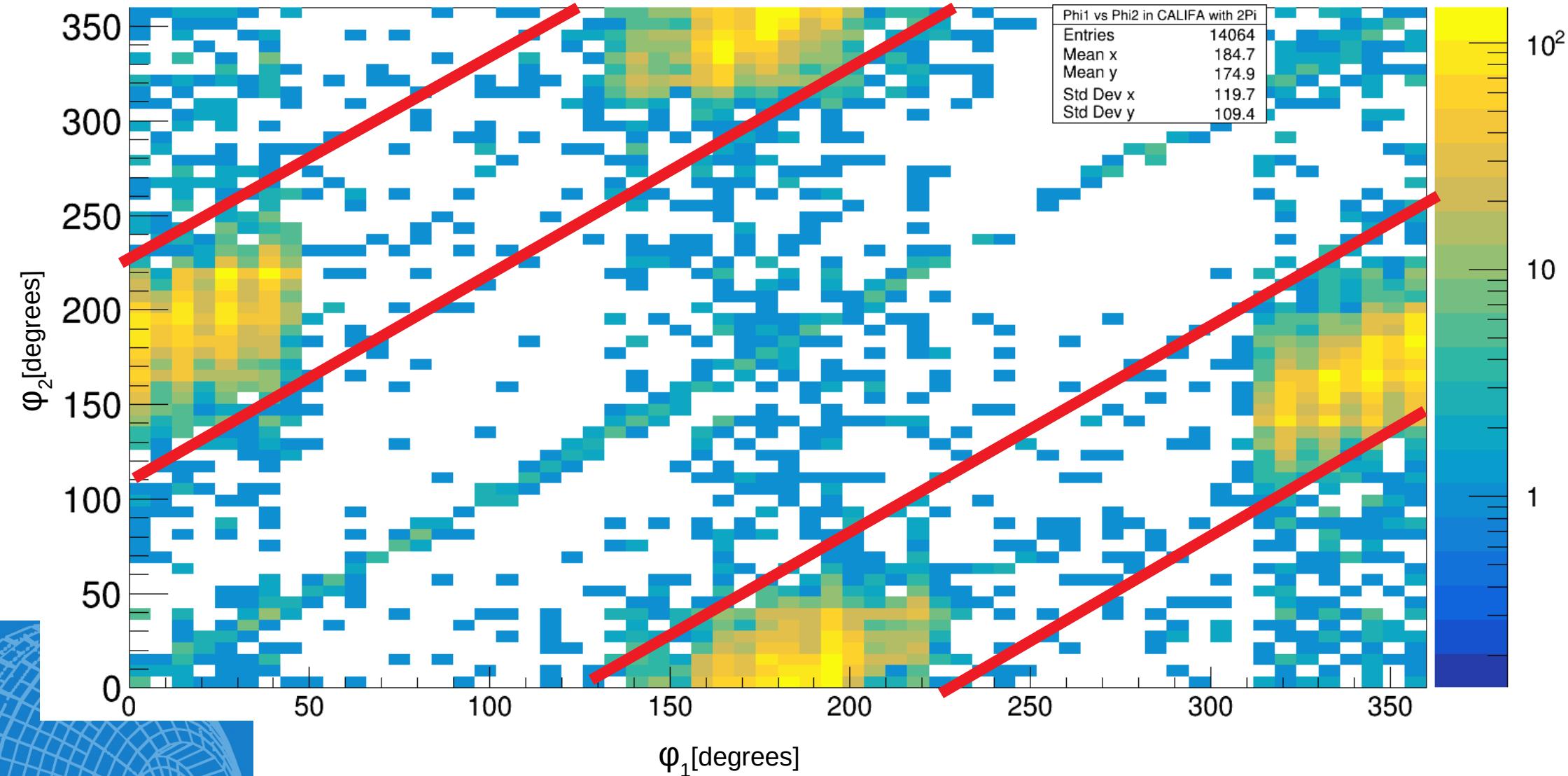
12C rest frame



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

Theta1 vs Theta2 in CALIFA

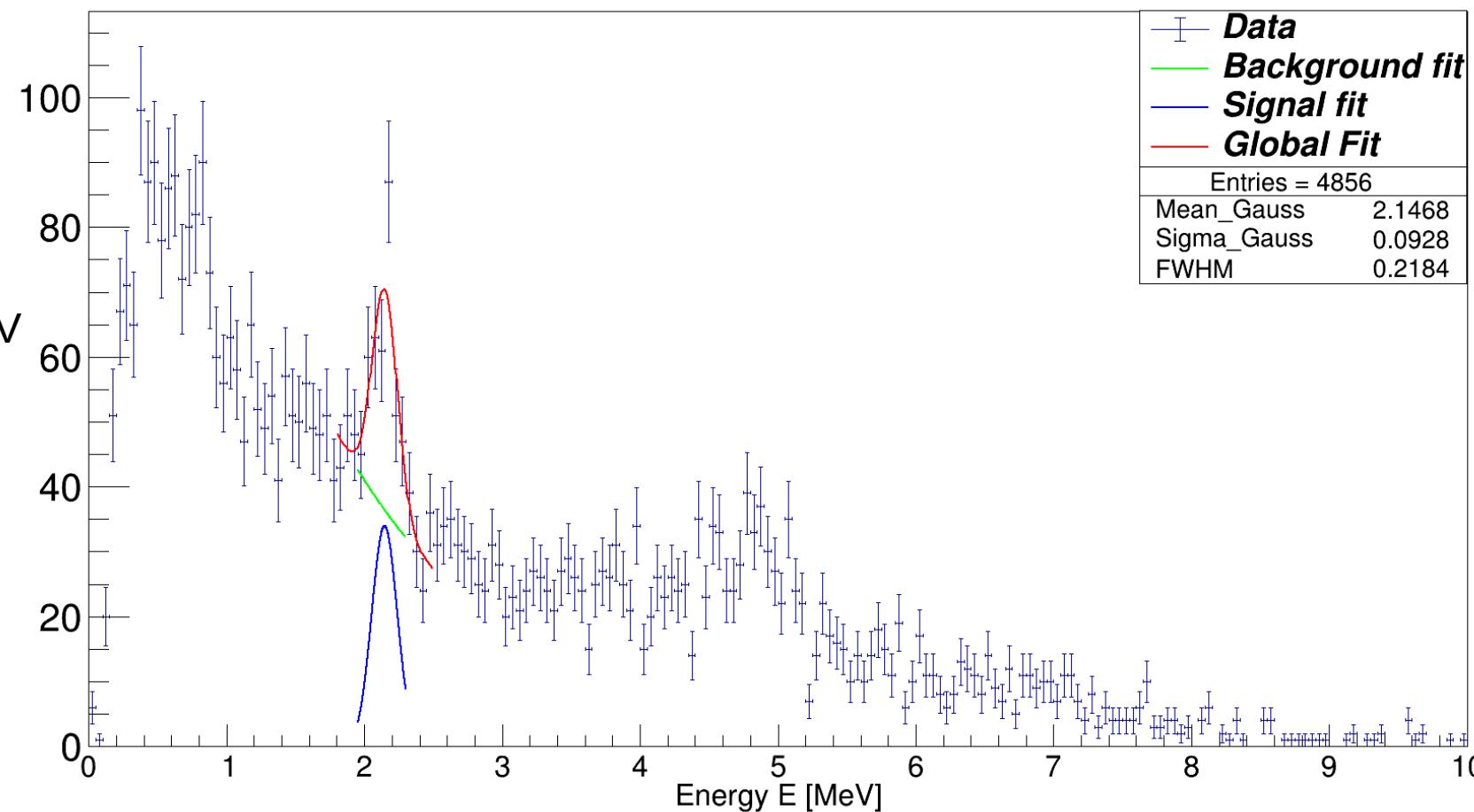




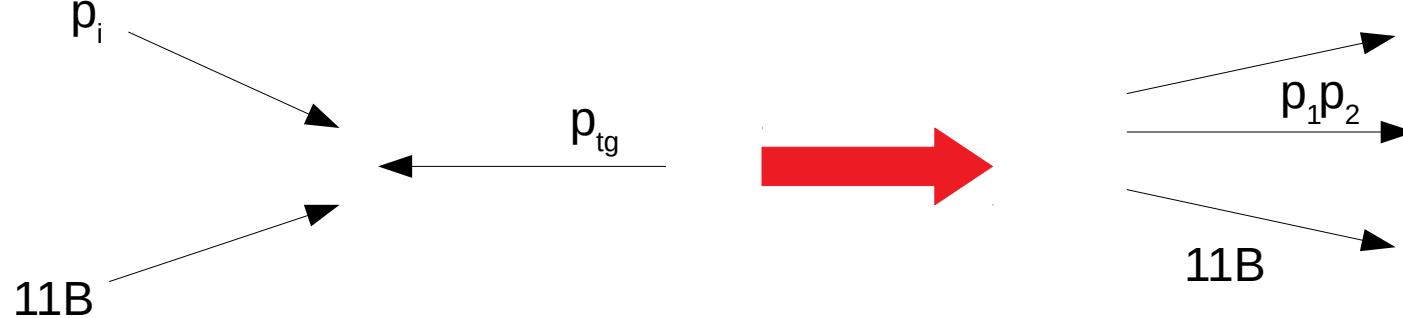
CALIFA Gamma Energy Spectrum

Event selection criteria for CALIFA:

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



Reconstruction of Inner Momenta



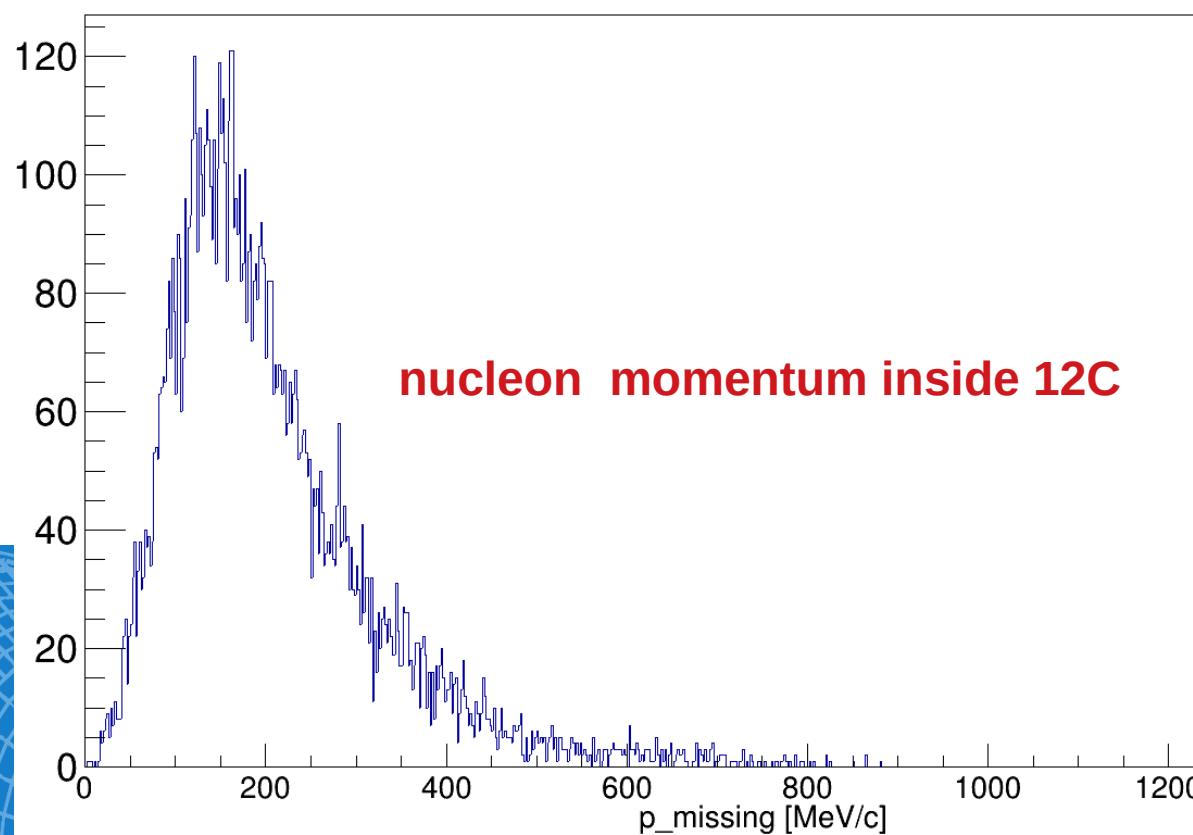
Momentum conservation relation:

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

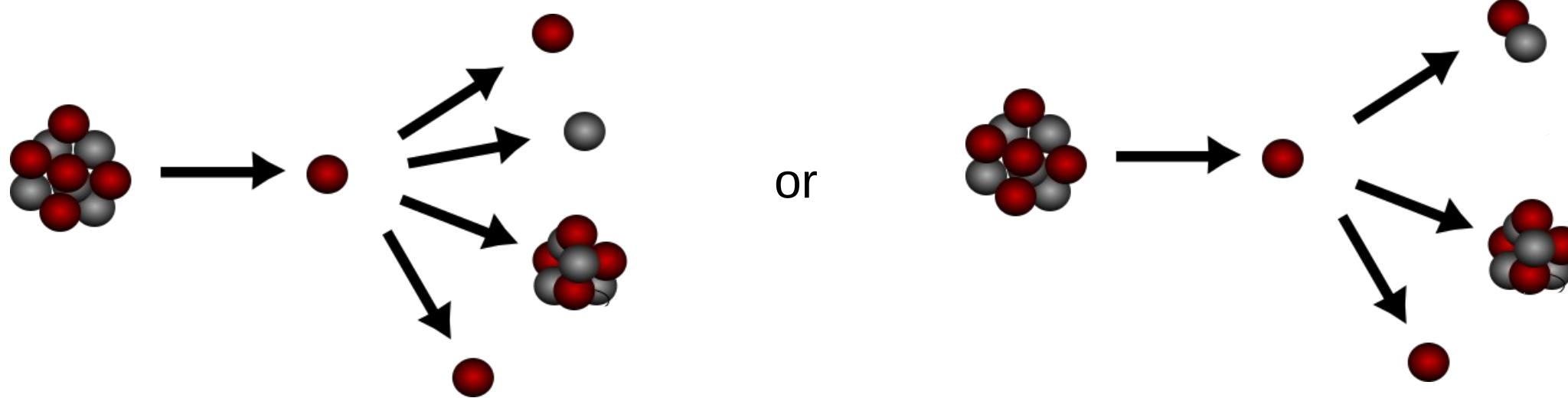
assuming QE scattering in mean field potential:

$$p_{^{12}\text{C}} = p_i + p_{^{11}\text{B}}$$

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

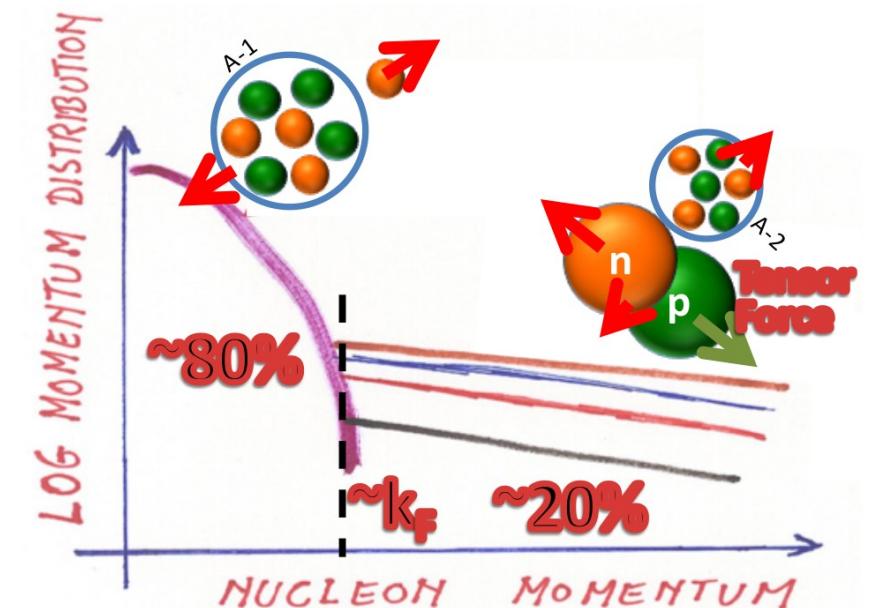


$^{12}\text{C}(\text{p},\text{pn/d})^{10}\text{B}$ reaction



Short Range Correlations (SRC):

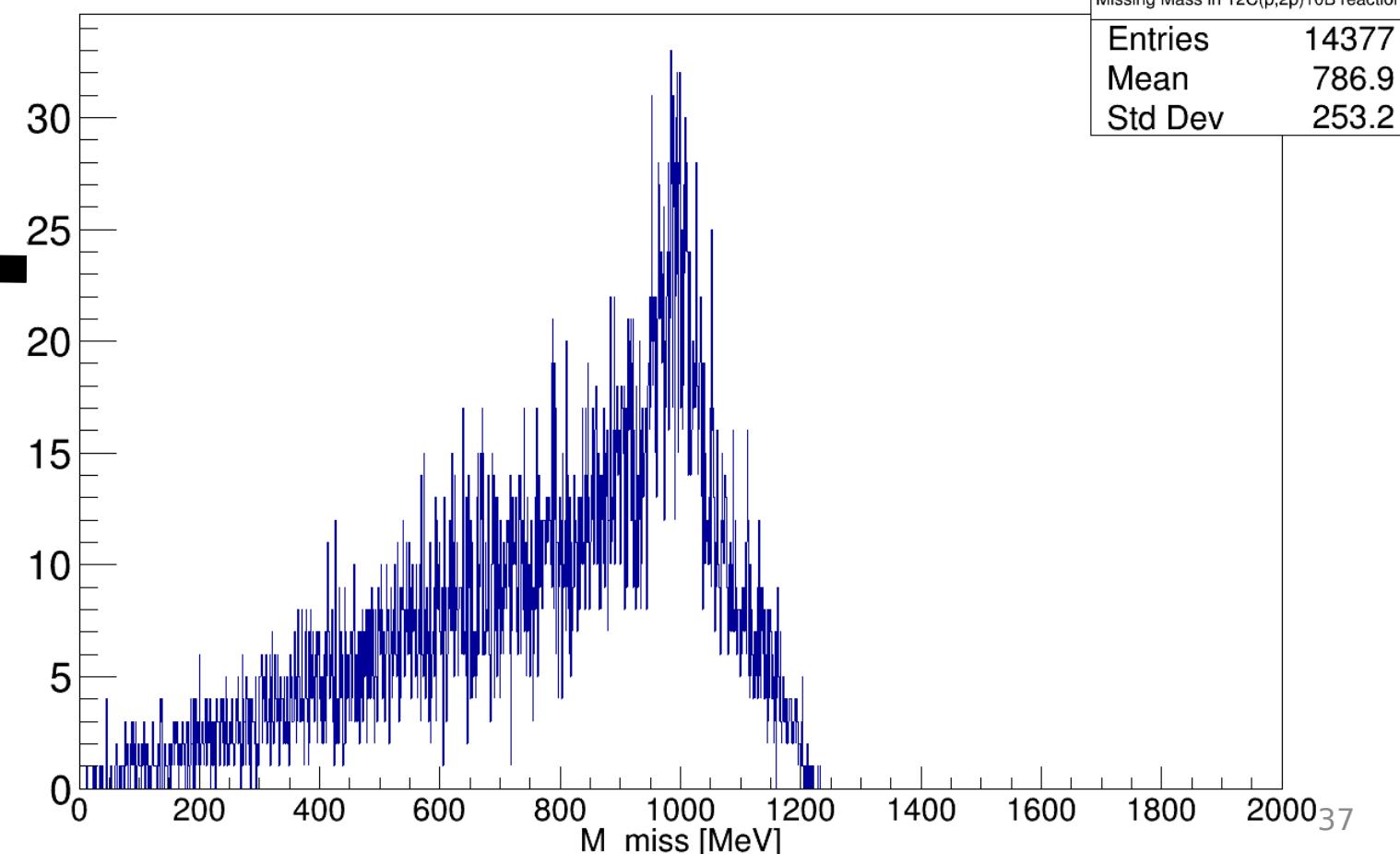
- Possible explanation for EMC - effect
- nucleon pairs with high relative and low c.m. momentum (compared to Fermi momentum k_F)
- SRC exist in nuclei and account for about 20% of nucleons



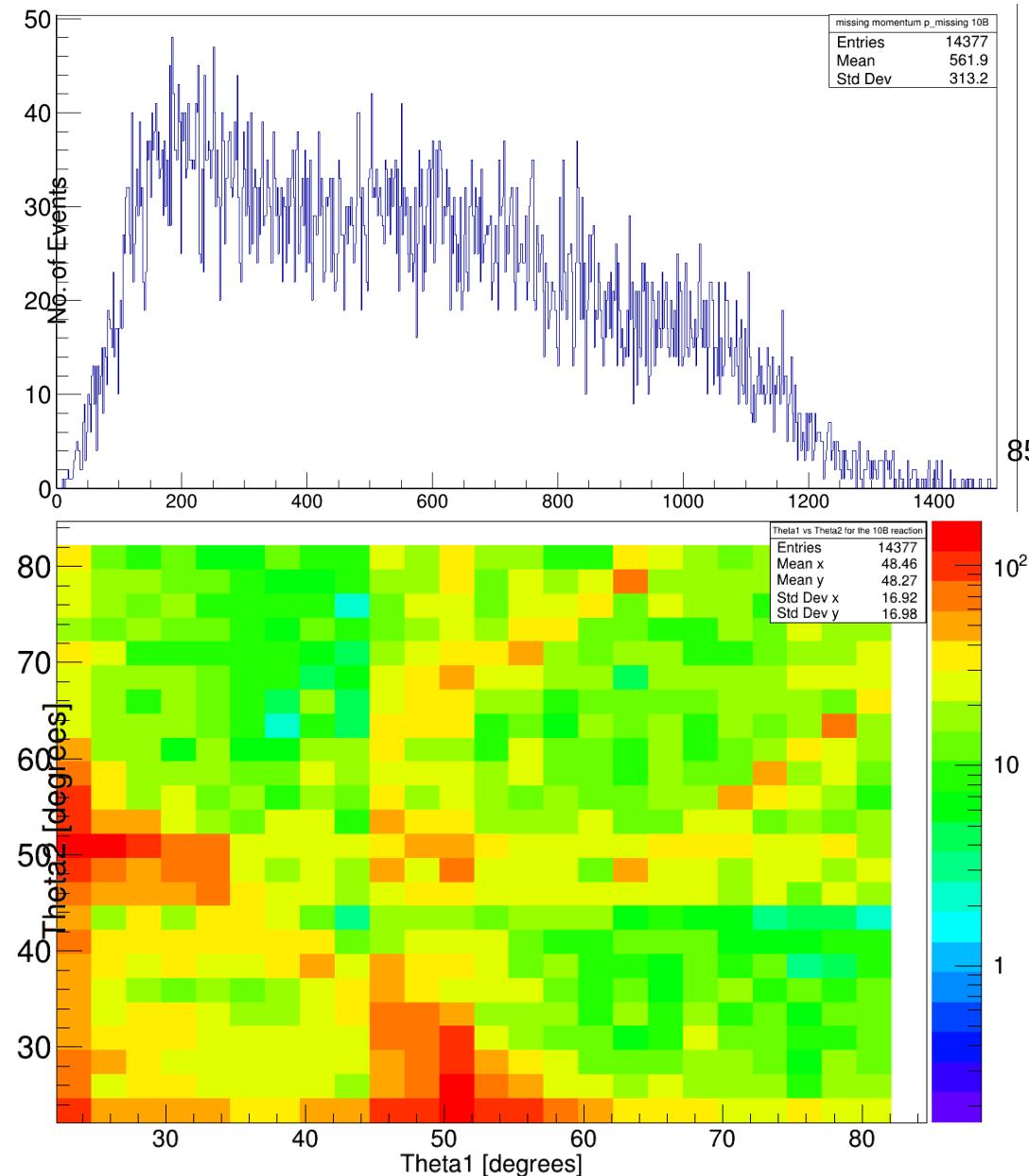
Neutron mass reconstruction...

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

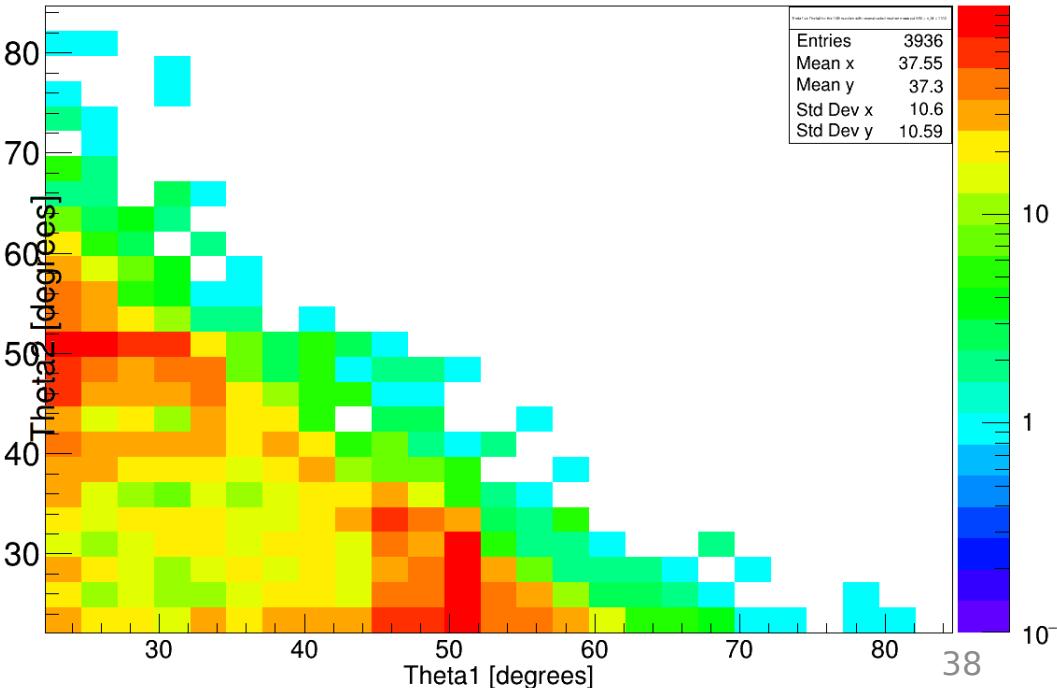
use $M_{missing}$ as cut variable



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

