R³B Commissioning Experiments with Final CALIFA Setup

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PSI Seminar
16.06.2021

R³B Experiment

CALIFA – Design and Upgrades

QFS Analysis

R³B @ GSI

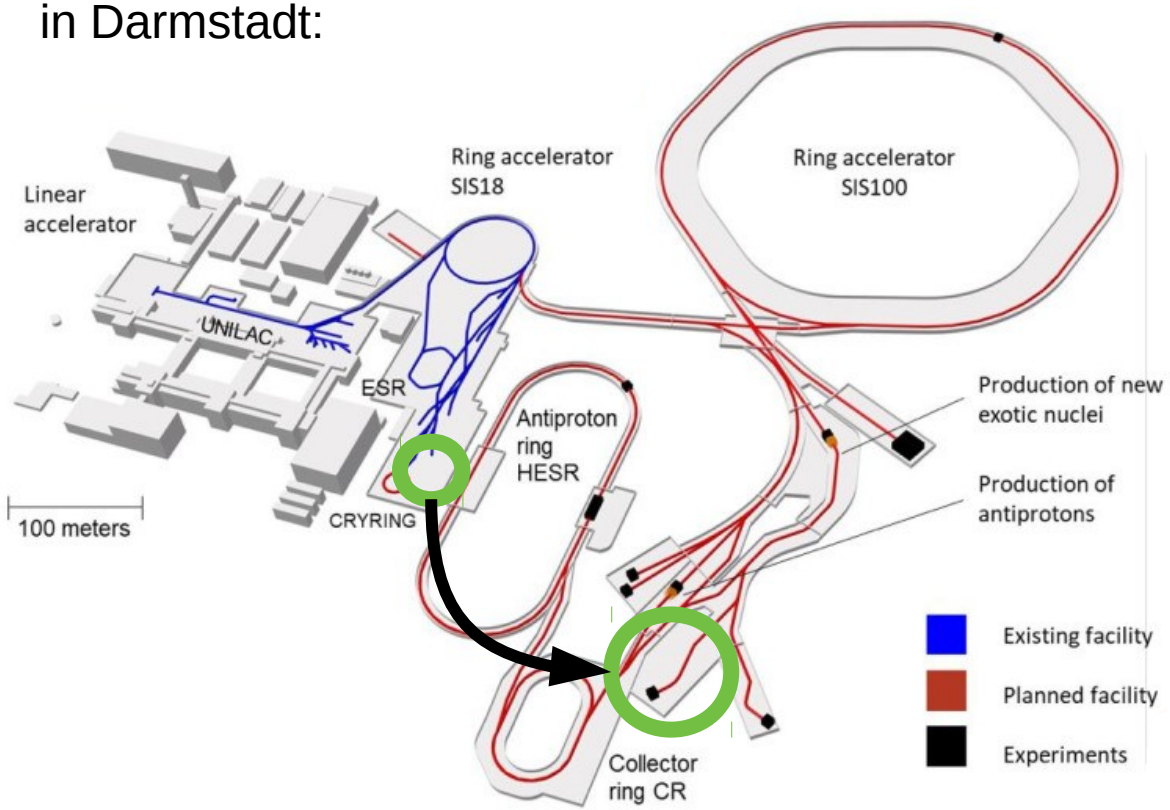
Supported by BMBF 05P15WOFNA and 05P19WOFN1.

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.

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

R³B @ GSI

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



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

5,000 single family homes

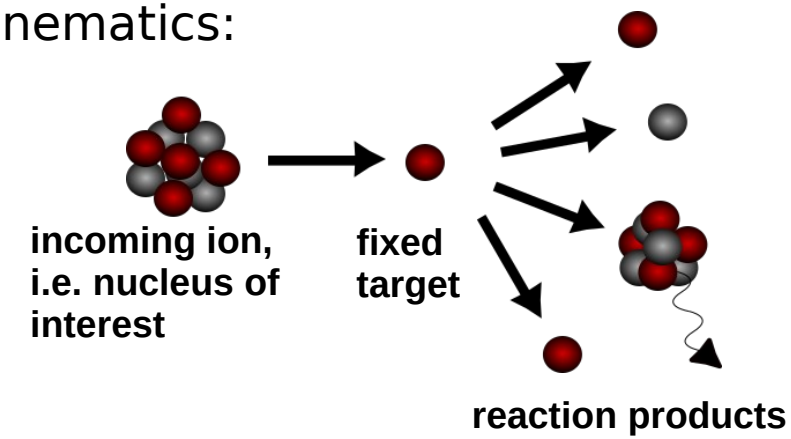
eight Frankfurt soccer stadiums

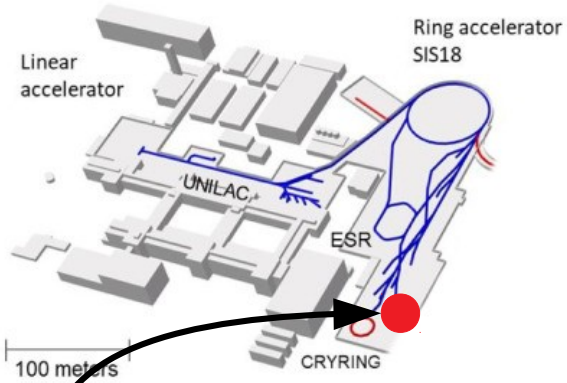
nine Eiffel Towers

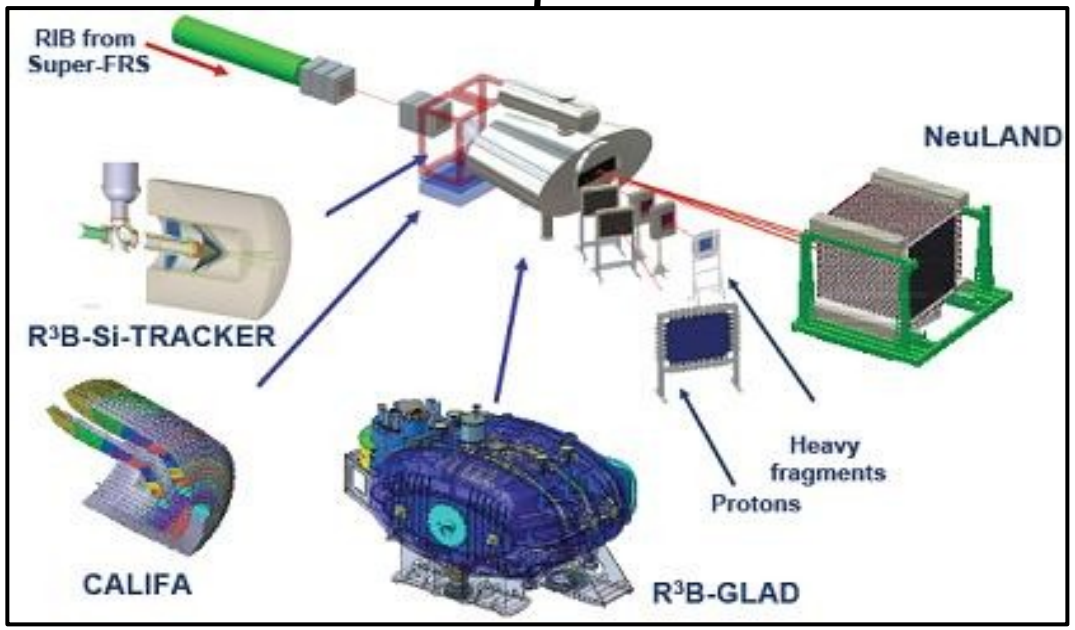
R³B Experiment

Reactions with Radioactive Relativistic Beams

- Physics program on exotic nuclei in inverse kinematics:



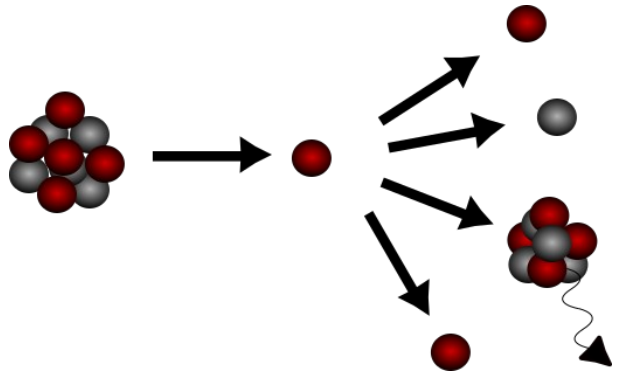




- In flight production of exotic nuclei from fragment separator Super-FRS
- kinematically complete measurements
- Flexible setup, extensive physics schedule (despite pandemic restrictions)

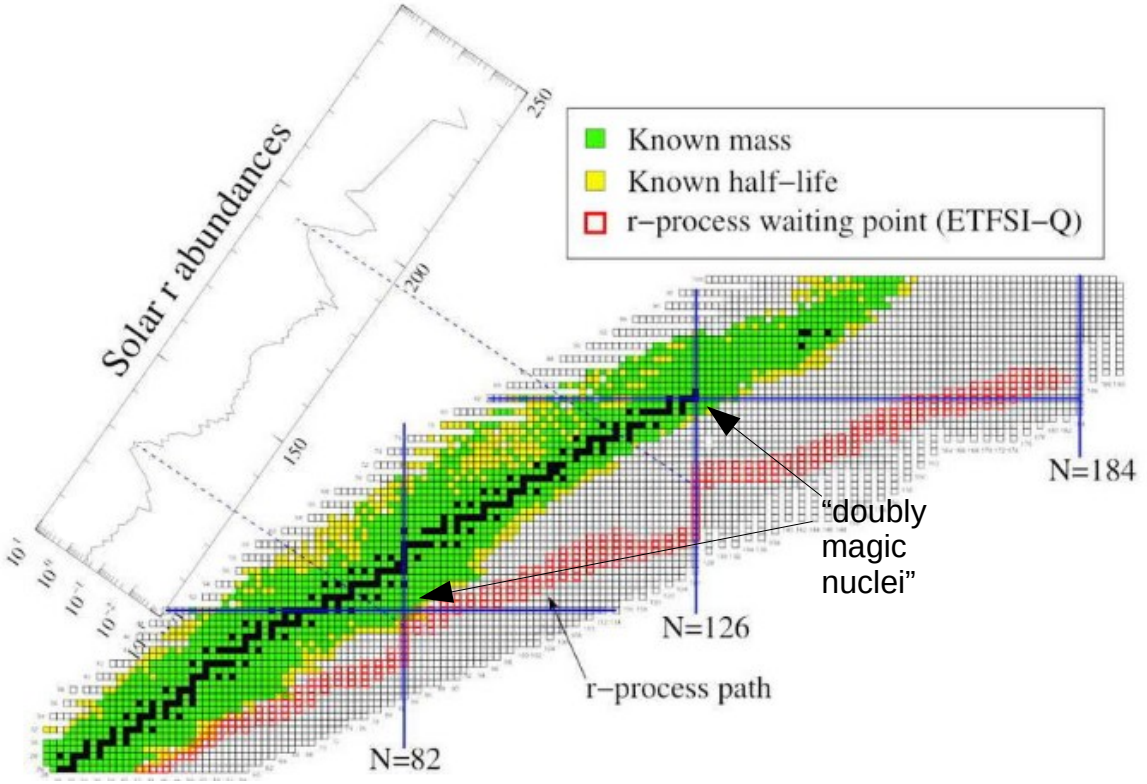
Physics program @ R³B

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, ...

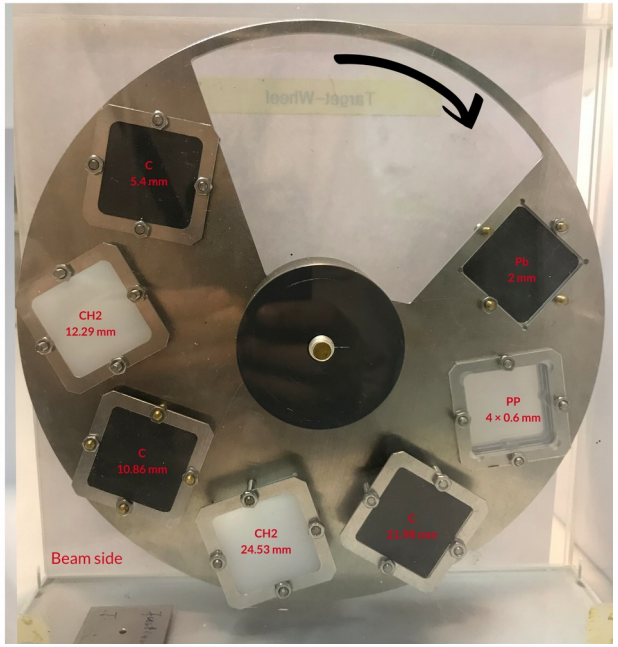
- Fission Studies (up to uranium)
  - → fission yields are important to understand e.g. the final r -process abundance
  - → measurement of the fission barriers far off stability
  - → collective excitations in neutron rich exotic nuclei, e.g. Pygmy dipole – resonance, neutron halos



R³B – Setup and Detectors

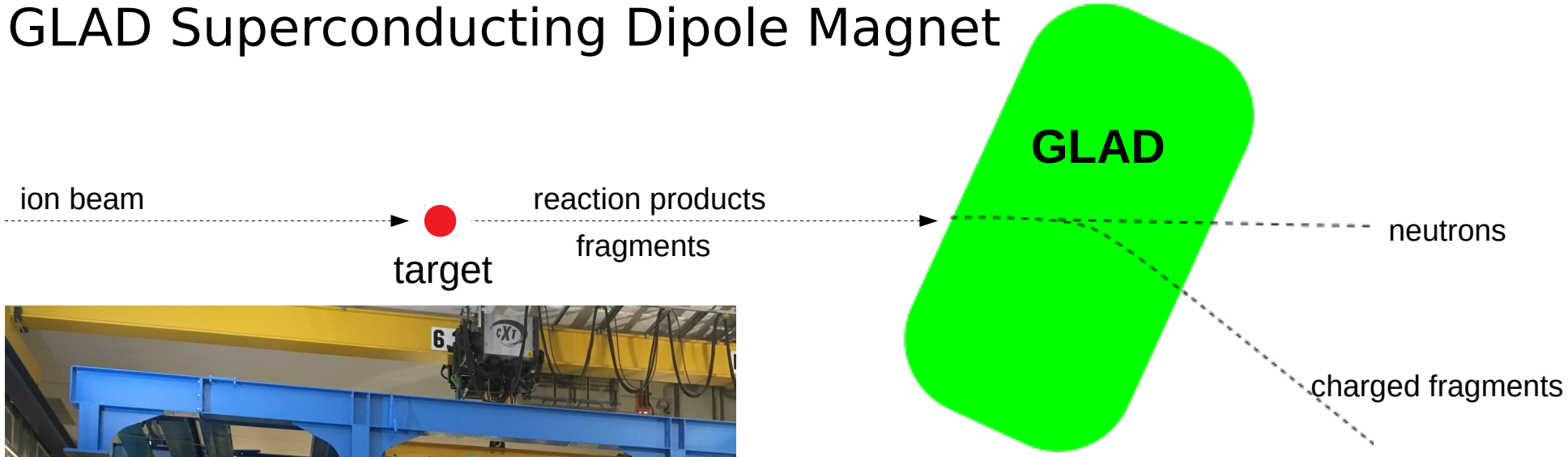
LH2 targets
with width:
15 / 50 / 150 mm

Target Wheel



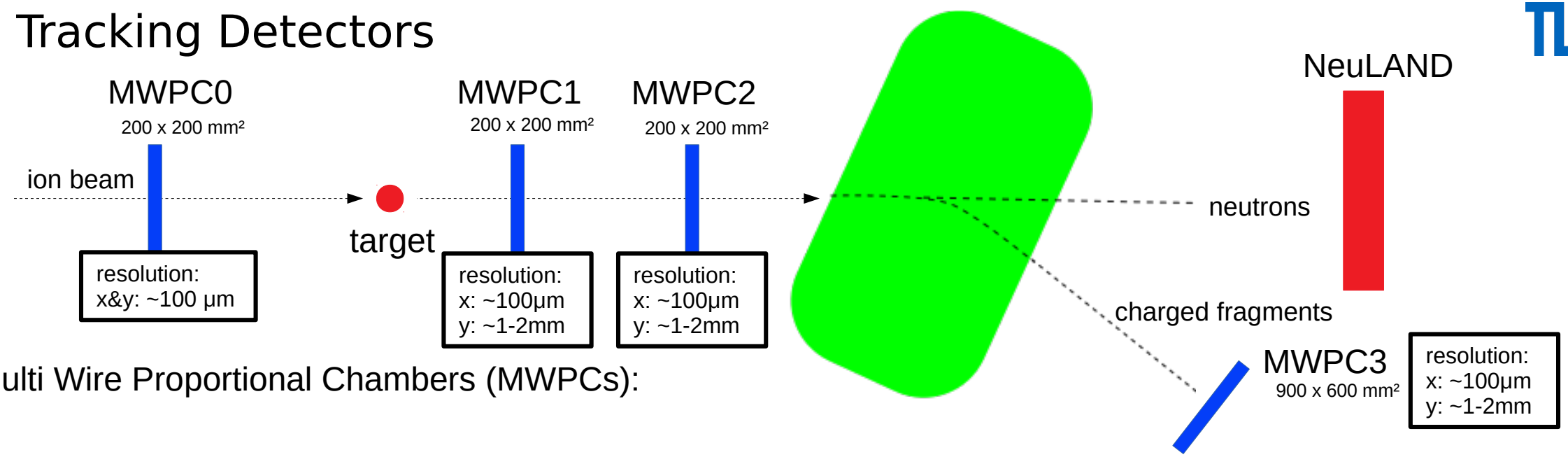
Targets:
→ C with width:
5.4 / 10.86 / 21.98 mm
→ CH2 with width:
12.29 / 24.53 / 24 mm
→ Pb with width:
2 mm

GLAD Superconducting Dipole Magnet



- 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



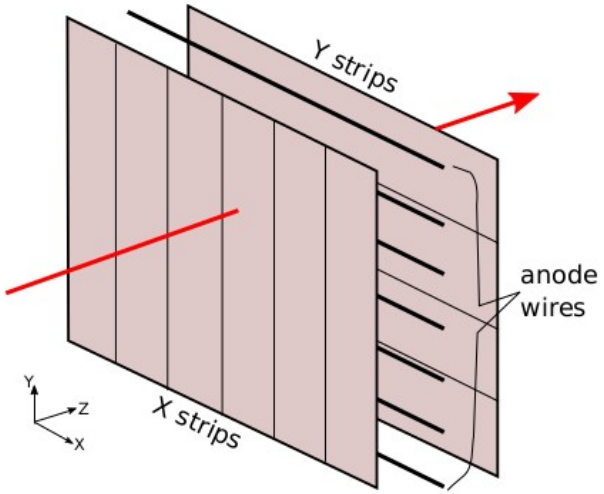
Multi Wire Proportional Chambers (MWPCs):

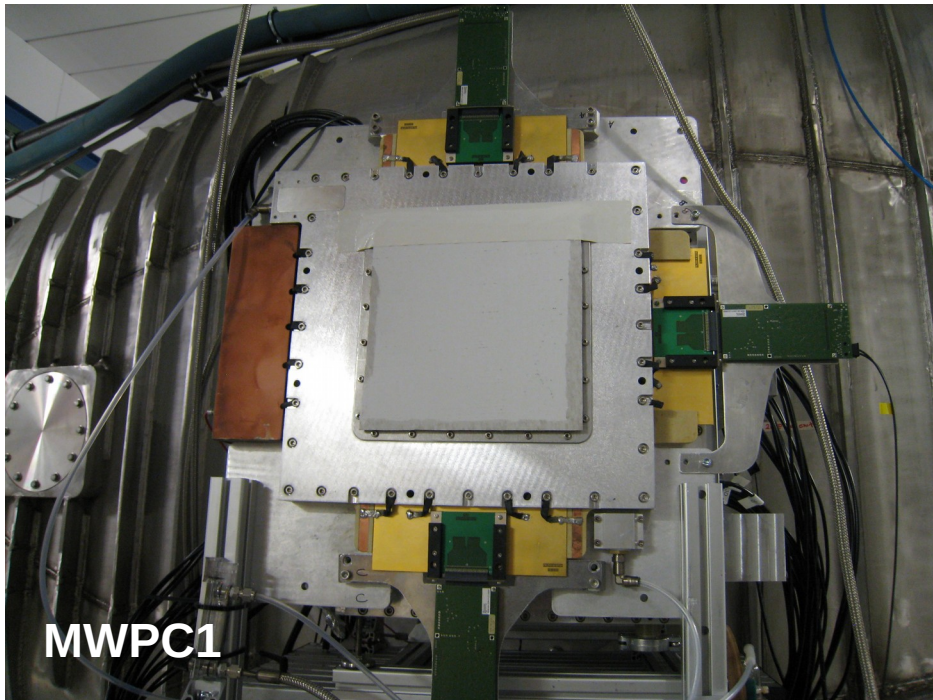
→ vertical/horizontal wires: 50 µm diameter, 2.5 mm spacing

→ vertical/horizontal pads:
Al-evaporated on a 12 µm Mylar foil,
5/3.125 mm width (vertical/horizontal)

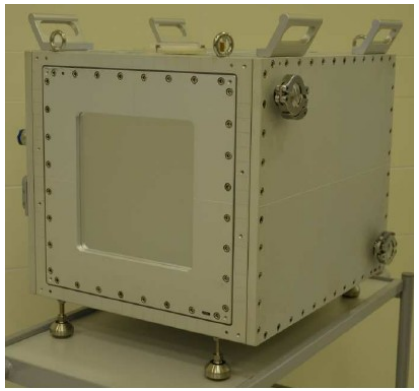
→ gas mixture: 84% Ar, 16% CO2

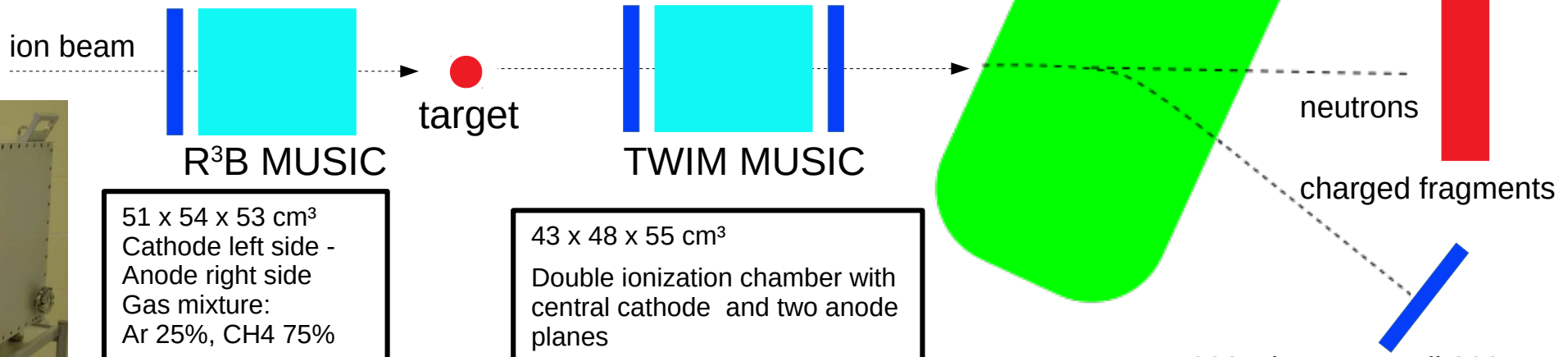
→ readout signal from influenced pads





Charge Measurement – Ionization Chambers





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

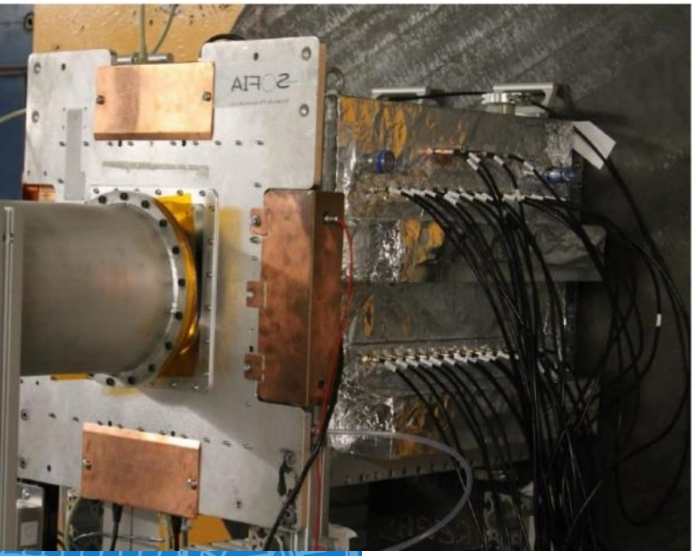
43 x 48 x 55 cm³

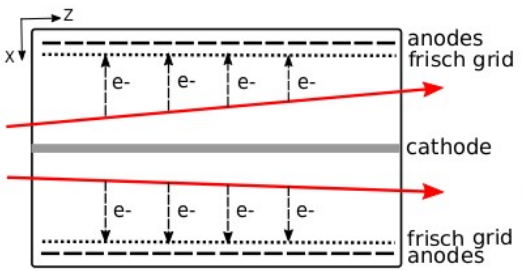
Double ionization chamber with central cathode and two anode planes

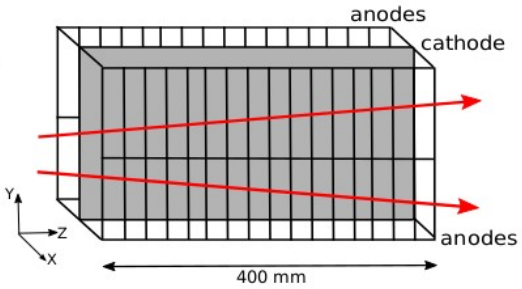
Frisch grid for better signal quality and time resolution

Gas mixture:

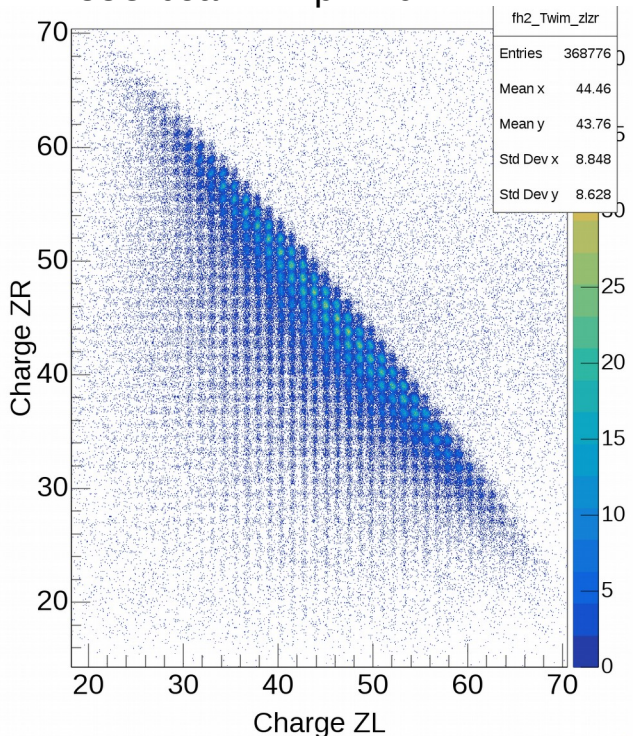
Ar 25%, CH4 75%



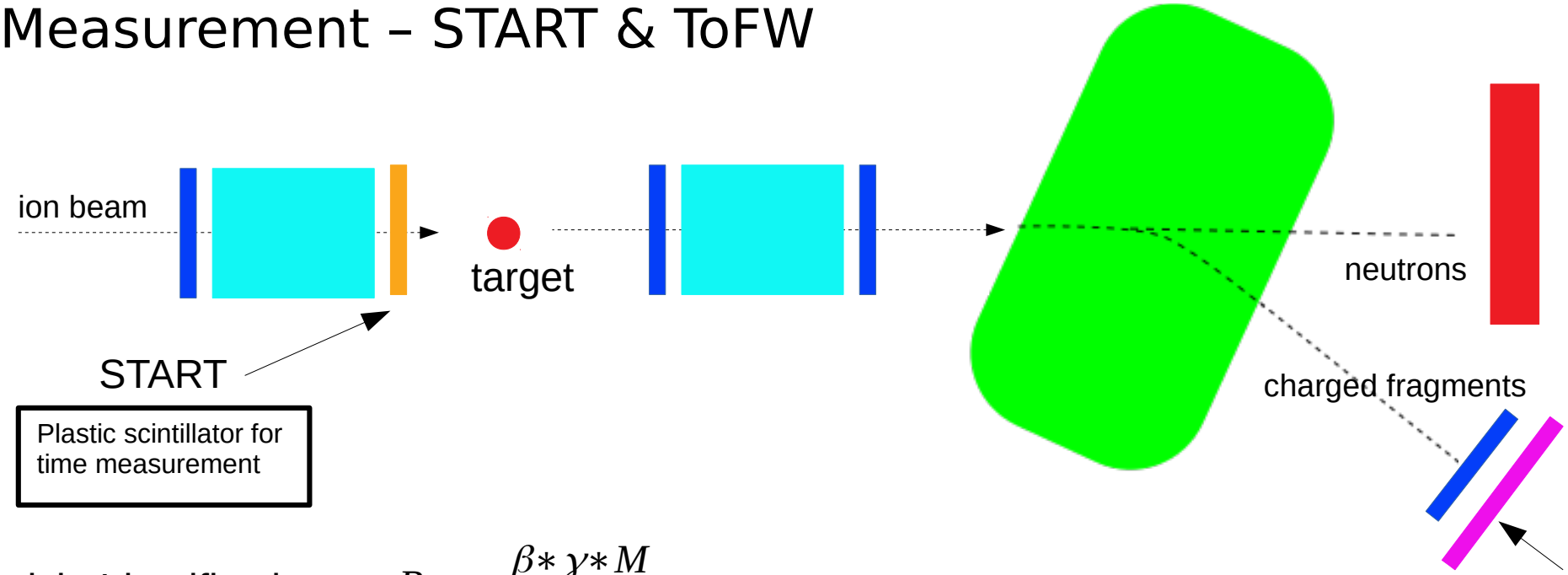




238U beam – April 2021



Time Measurement – START & ToFW



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

→ ToF measurement: START to TOFW

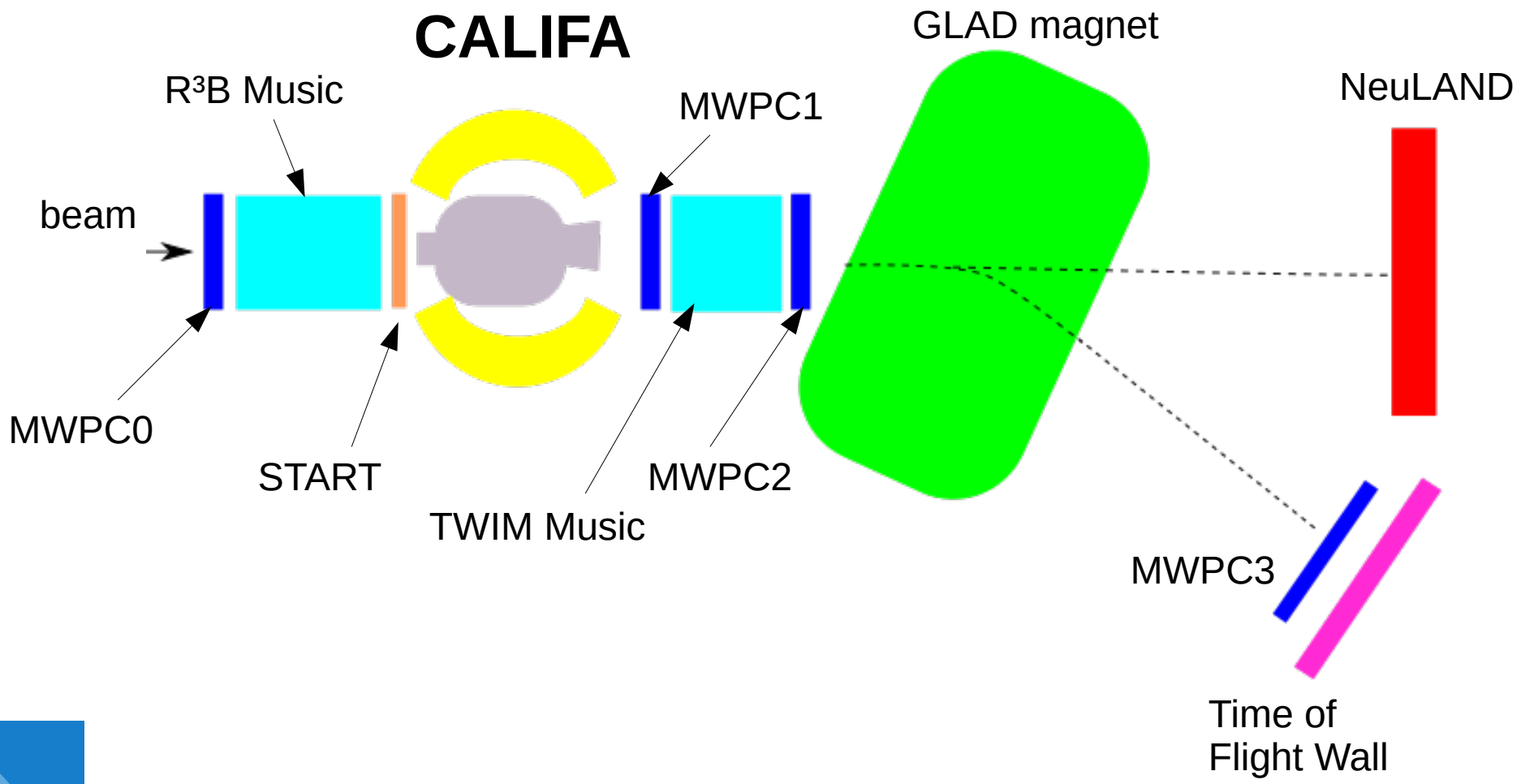
→ flight-path reconstruction: tracking detectors

→ charge measurement: TWIM MUSIC

Time of Flight Wall (ToFW)

27 vertical scintillators (54 PMTs, up & down)

time and position measurement


CALIFA
GLAD magnet
R³B Music
MWPC1
NeuLAND
beam
MWPC0
START
TWIM Music
MWPC2
MWPC3
Time of
Flight Wall

CALIFA Detector @ R³B

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

Endcap:

iPhos:

512 CsI(Tl) crystals

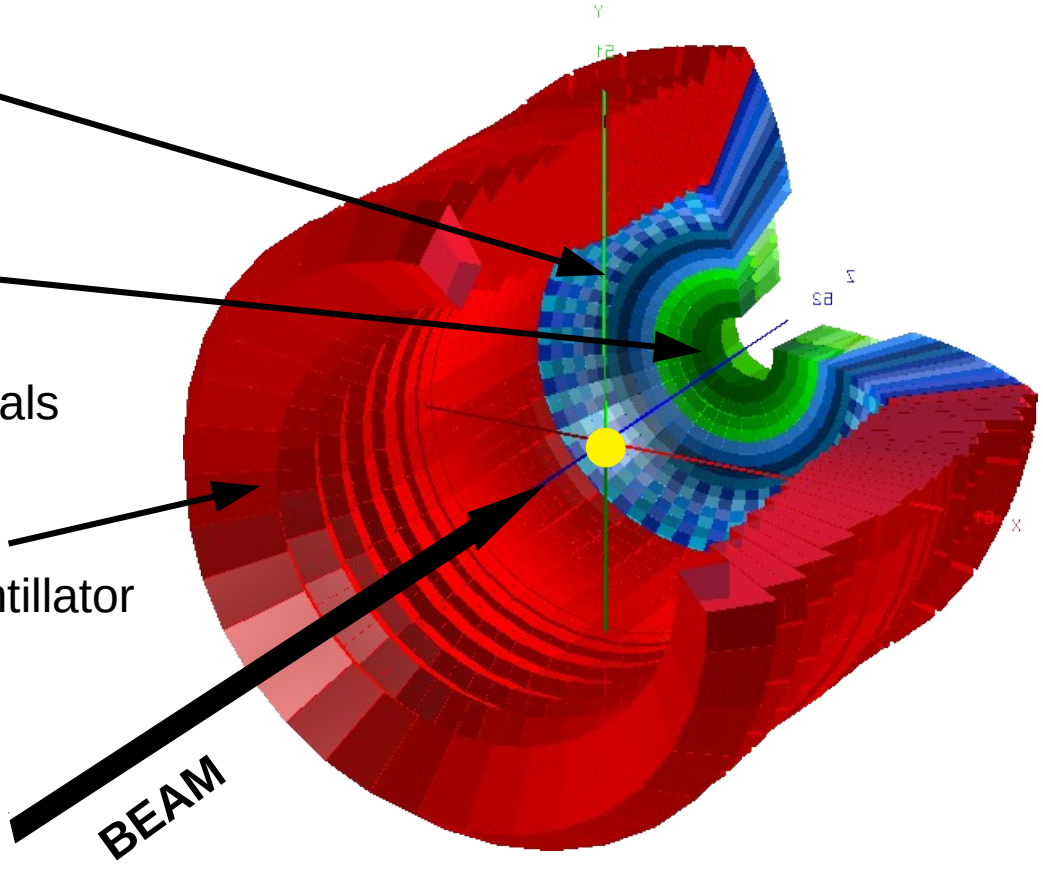
CEPA:

96 LaBr3 &

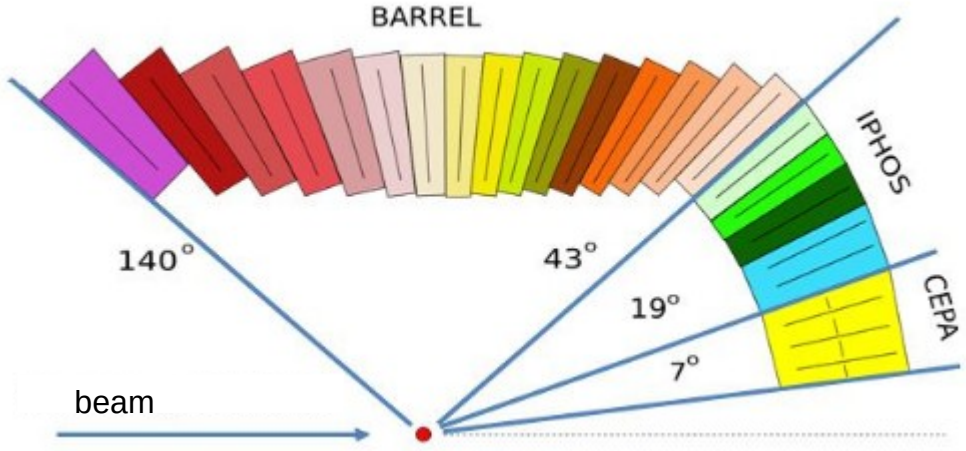
LaCl3 crystals

Barrel:

1952 CsI(Tl) scintillator crystals



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

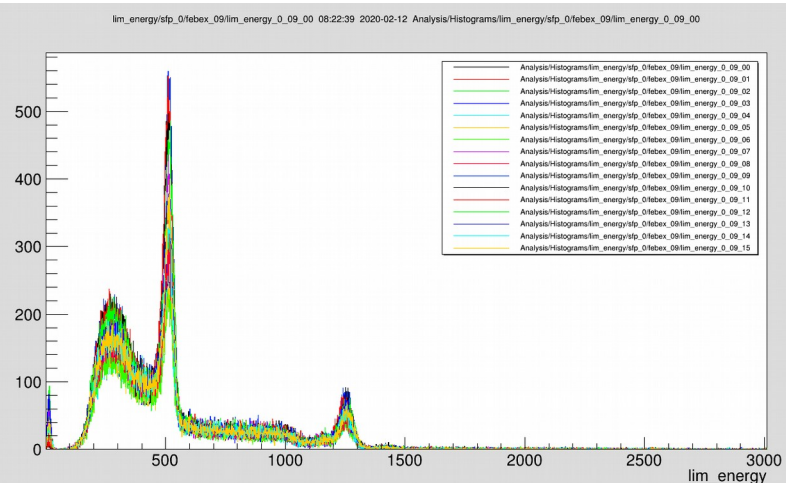


Signal Processing @ CALIFA

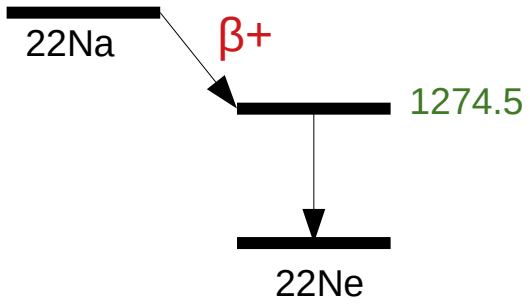
γ/particle interaction in **crystal** → scintillatorlight (550nm)
Every crystal connected to one **APD** → signal current
APDs connected to preamplifier:
→ generates HV for APD bias
→ amplifies (integrates) the signal from the APDs

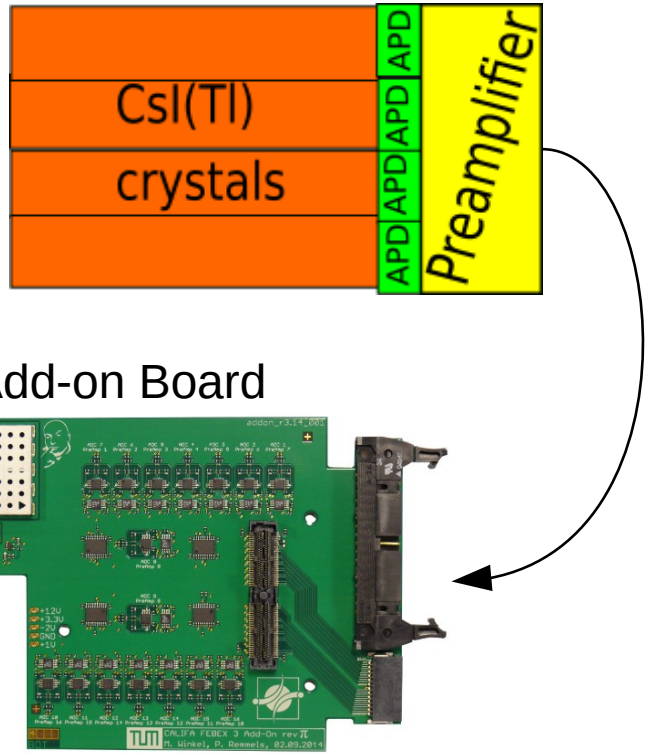
Add-on Board:
→ Nyquist Filtering (<25 MHz)
→ DC offset:Signal from preamp is positive, ADC range of FEBEX ADC ±0.9V

FEBEX Module:
→ Energy and particle identification

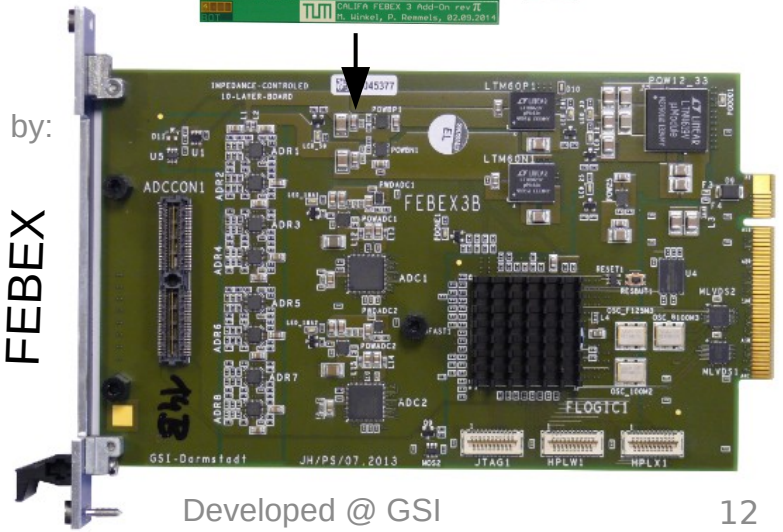


E.g. 22Na decay:





Add-on Board



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

Developed @ GSI

Electronics for CALIFA

Each rack:

→ 1024 channels

→ 50 MHz continuous sampling rate

Dead-time free readout design:

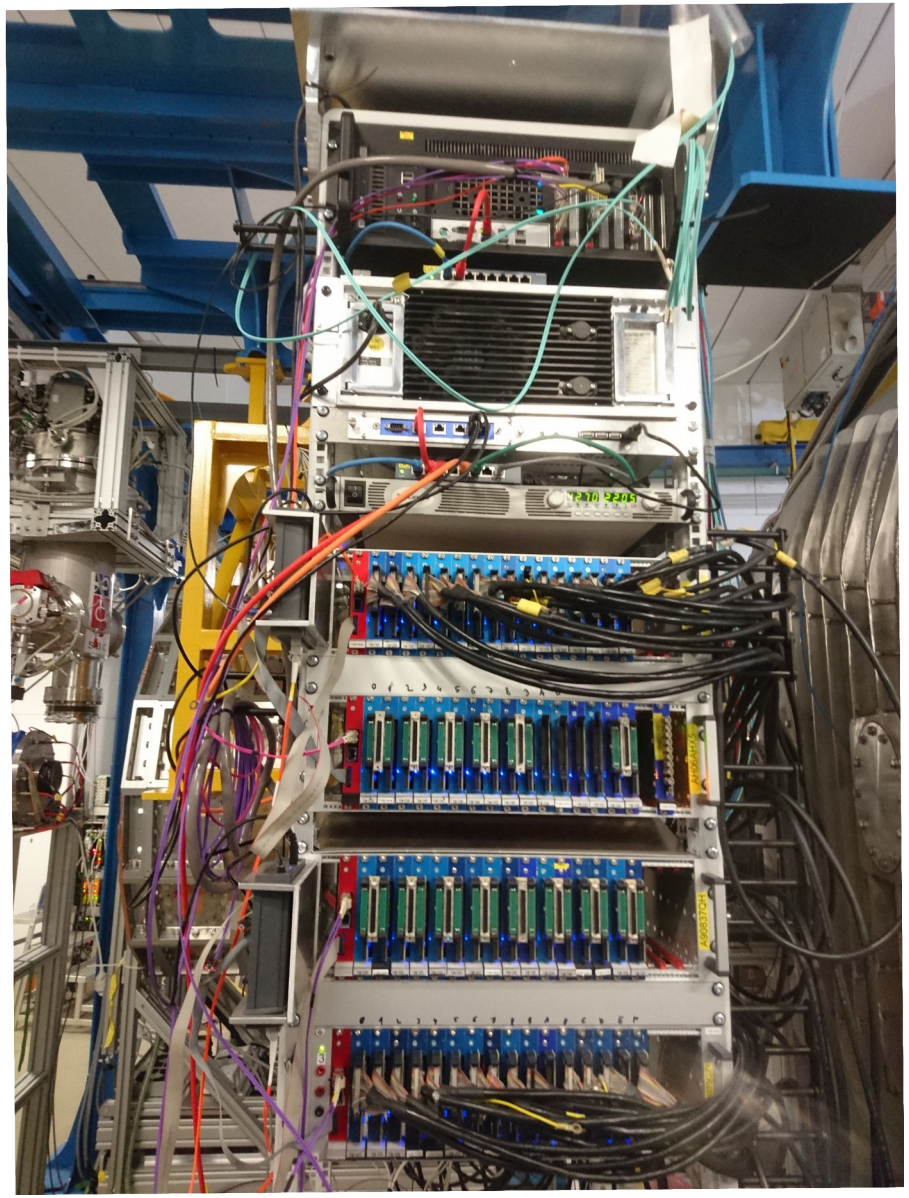
→ PEXOR card

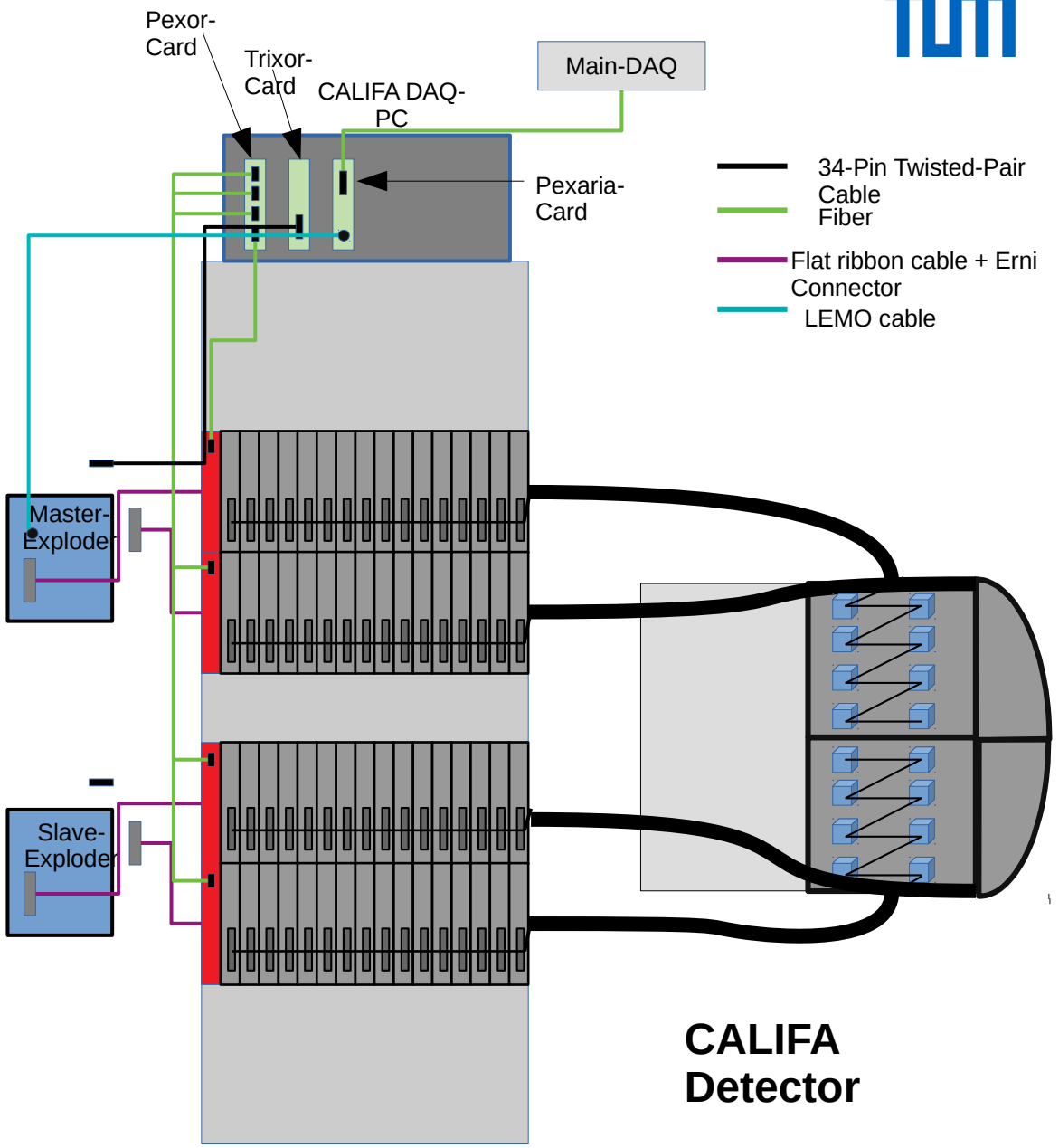
→ TRIXOR card

→ EXPLODER

→ PEXARIA (white

Rabbit timestamp)



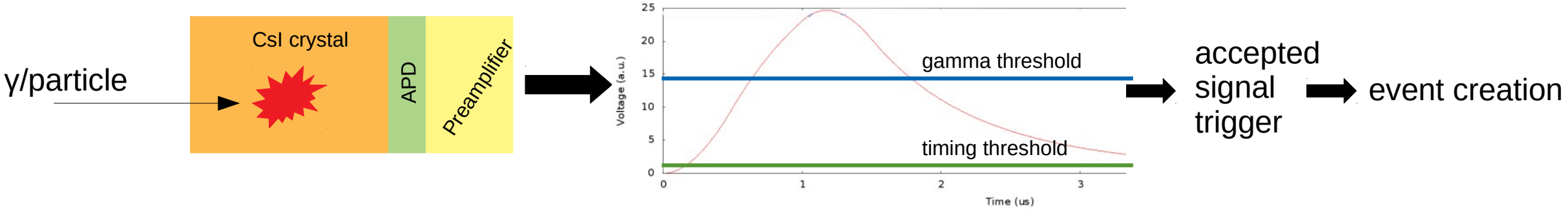


CALIFA Trigger Logic for Event Building

Discriminator-Threshold Logic:

→ Timing Trigger:event time assignment
→ Gamma Trigger: event validation/gamma reconstruction
→ Proton Trigger: external trigger/proton reconstruction

Intuitive event building logic…



→ discriminators can be used flexibly over trigger matrices
(e.g. timing and proton trigger for external detector triggering)

Trigger and Readout Modes

-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
- it one module reaches a certain eventnr. value, all data is read out

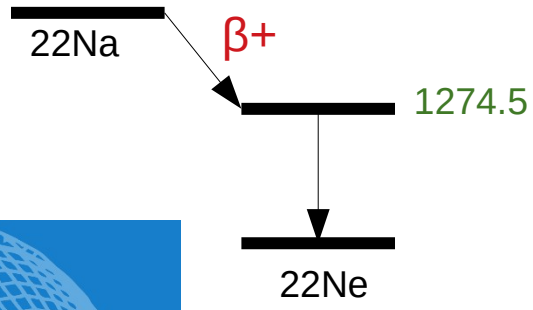
Setting CALIFA to Synchronous and Coincident Trigger Mode

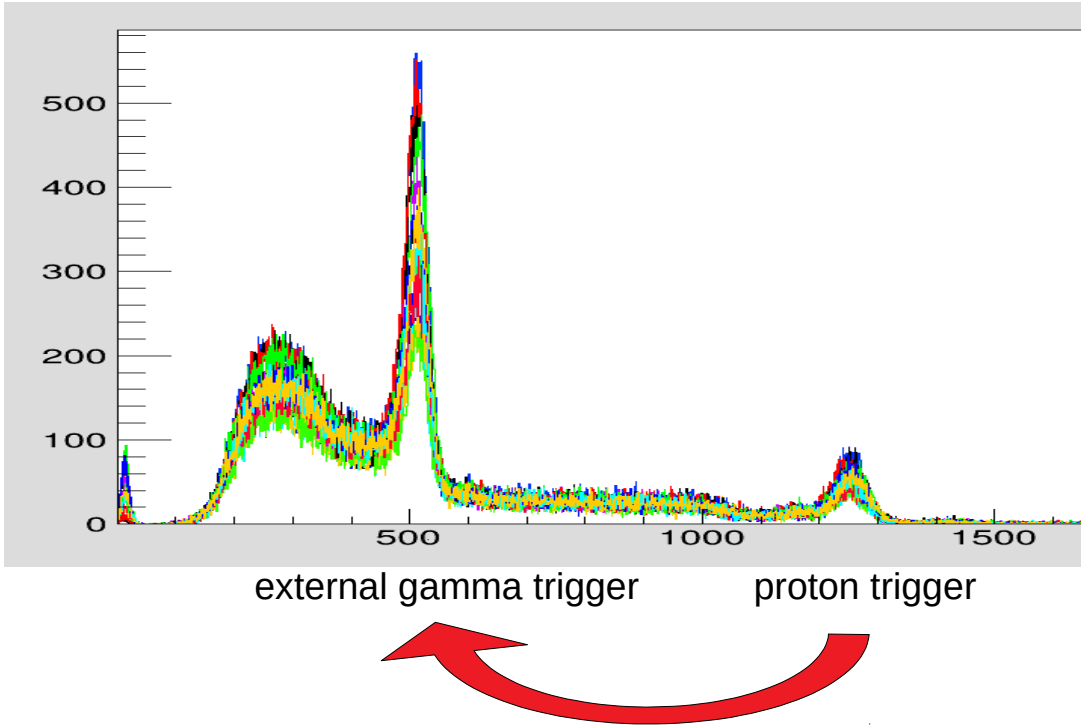
→ for experiment in May 2021 with He test beam

→ external gamma trigger input from START detector, internal timing trigger

→ allows to only select CALIFA events in coincidence with other detector events

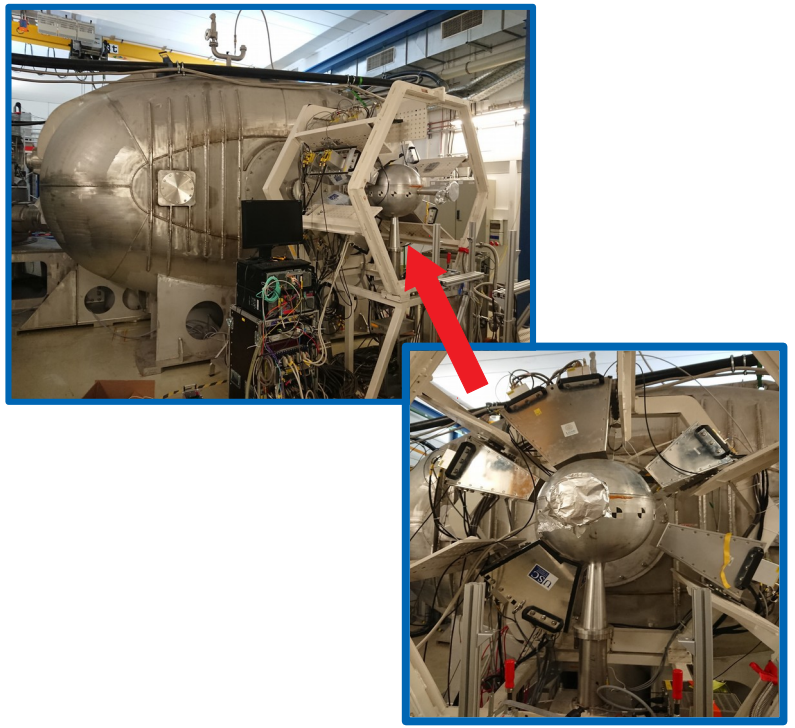
Testing:
- 22Na source
- Use γ - 1274.5 keV as proton trigger
- redirect proton trigger as external gamma trigger

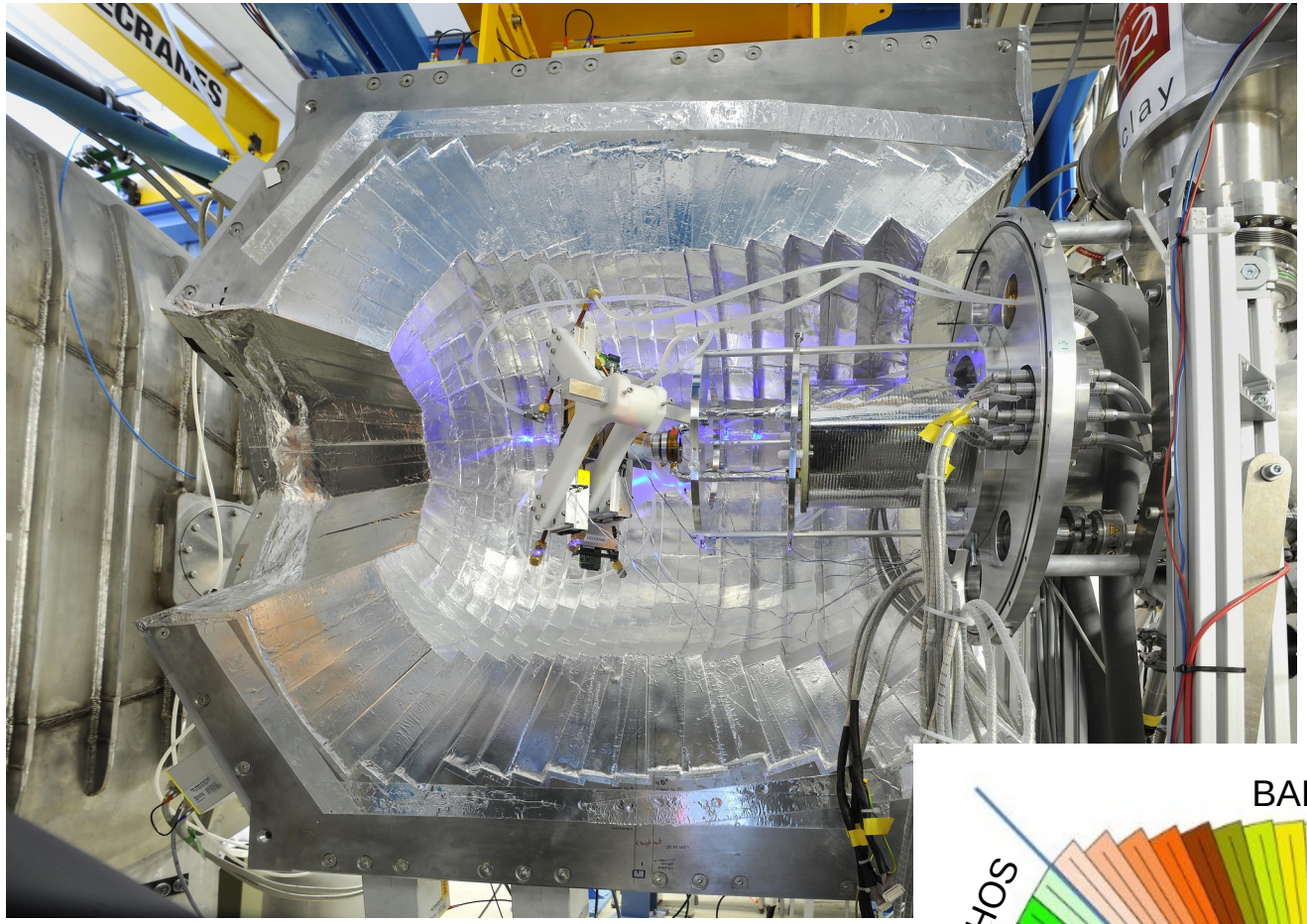


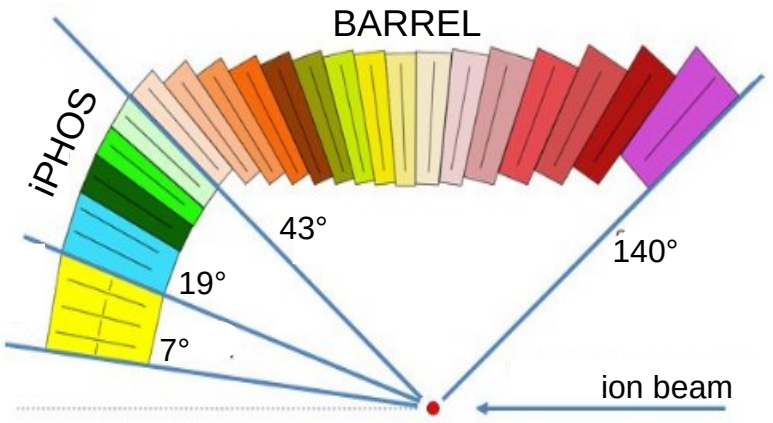


CALIFA Upgrade 2021

From Demonstrator to Final Setup



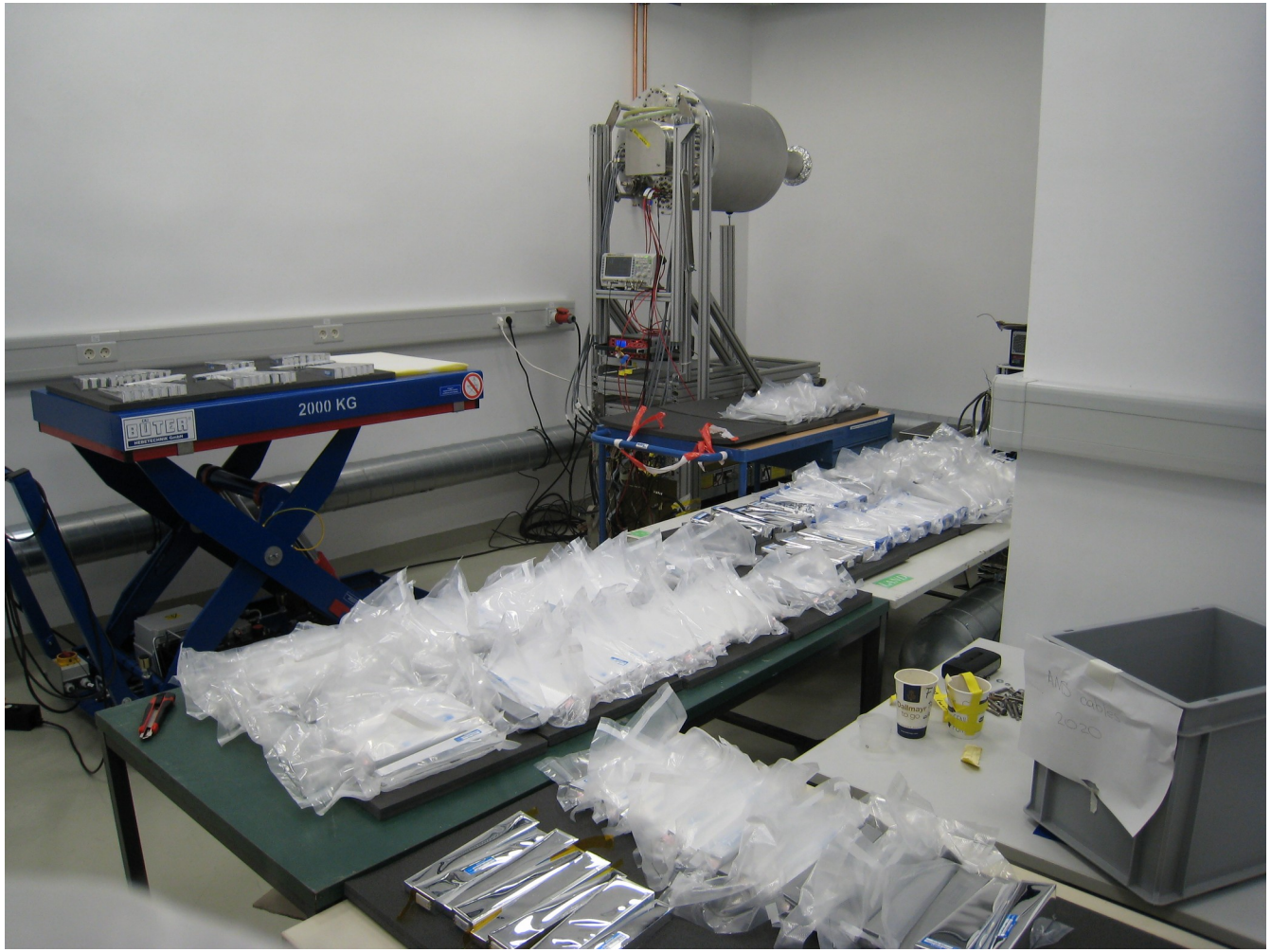




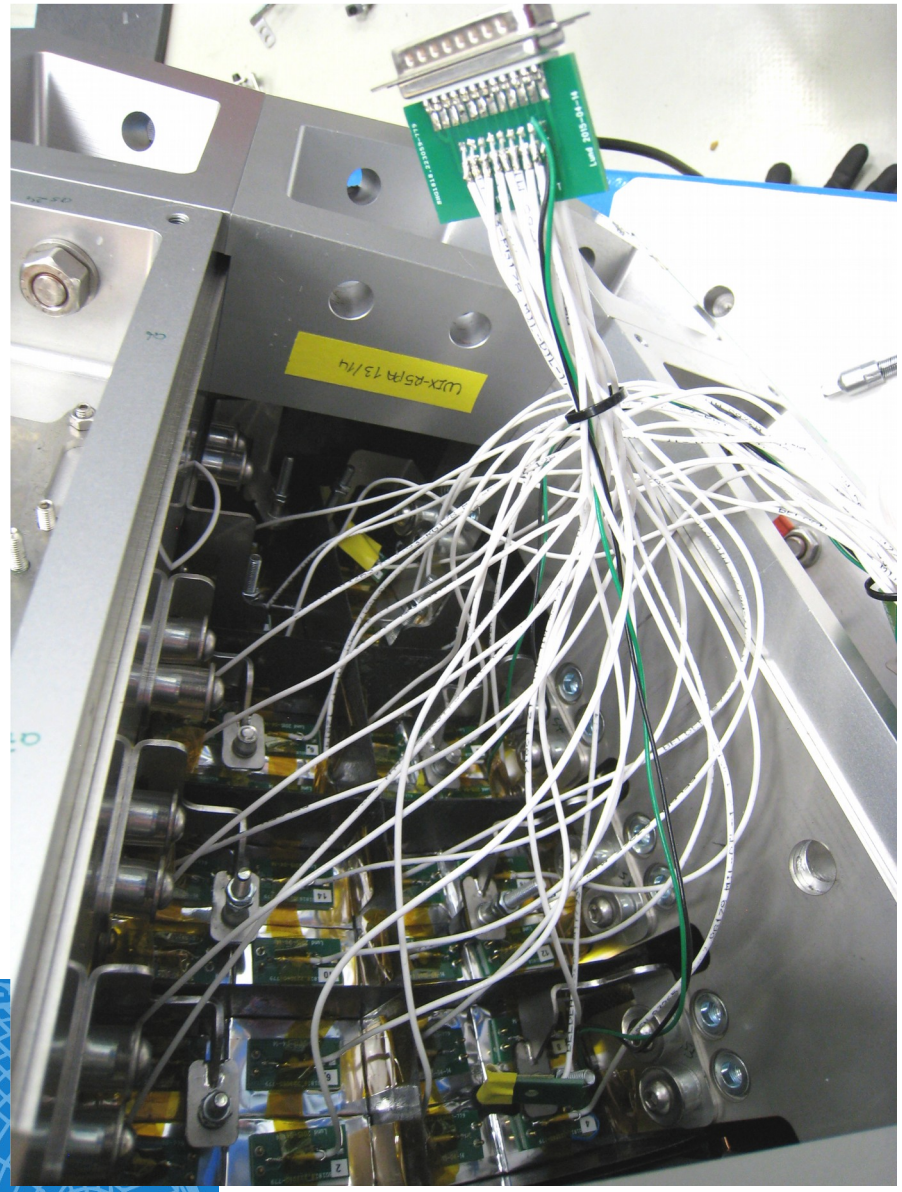
IPHOS region fully filled!

unmounting:

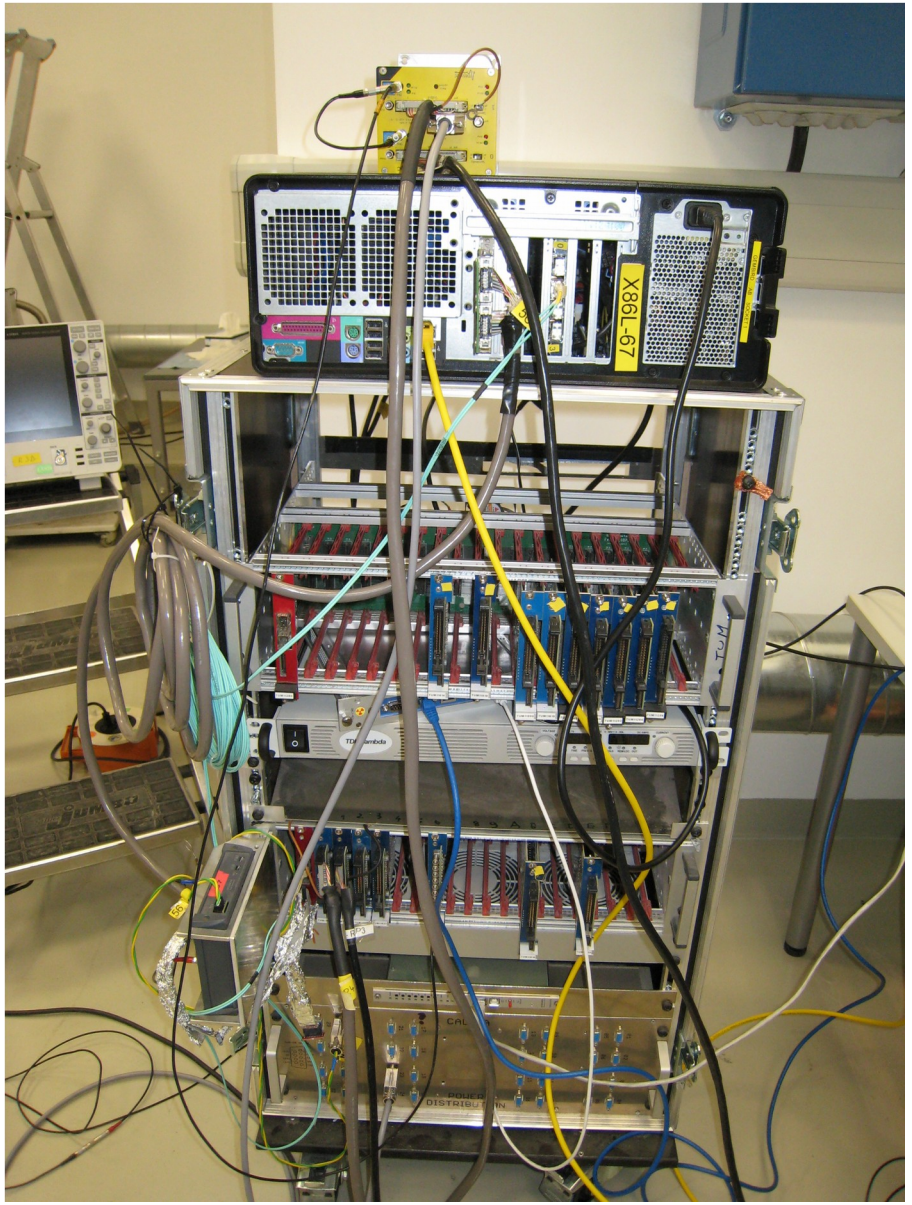
open tiles & measure crystals:



crystal filling:



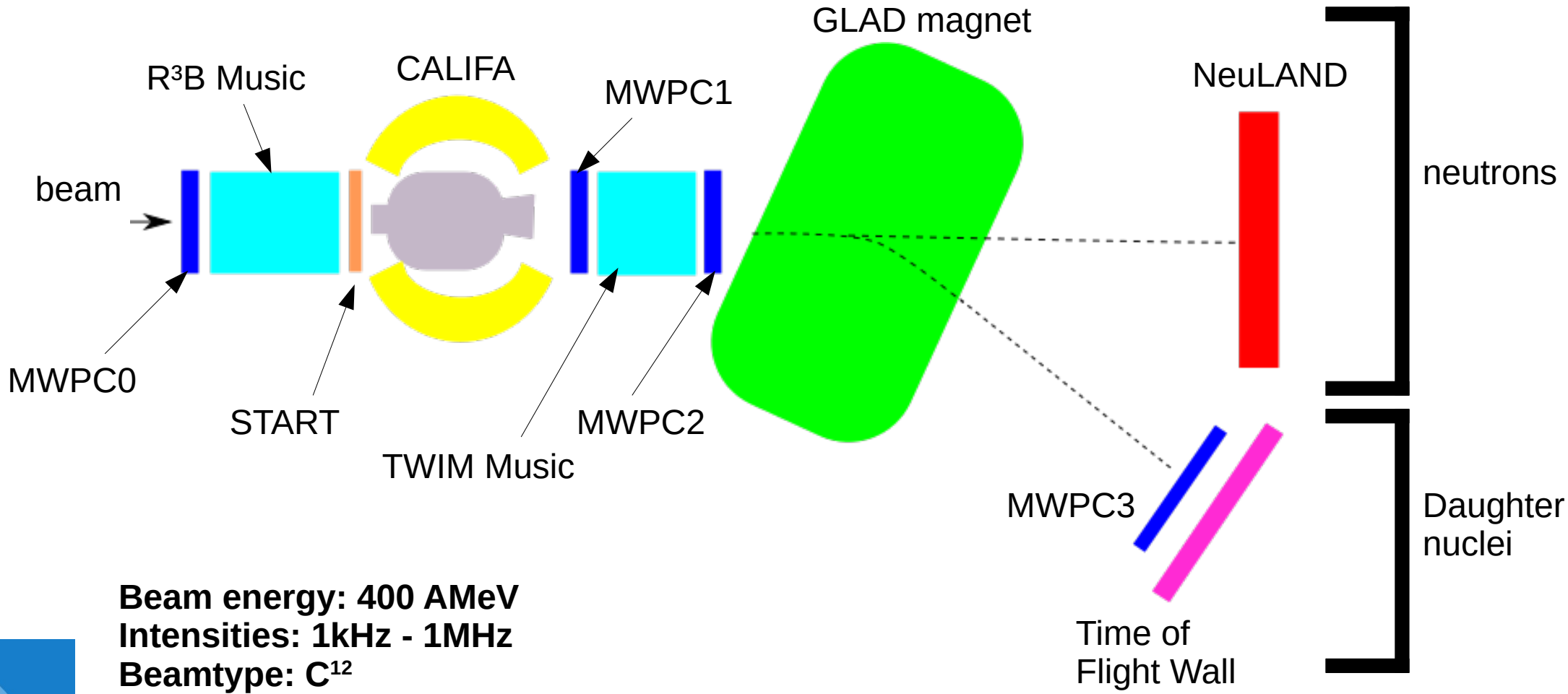
testing with mobile DAQ:



bring back to Cave C:

mount and align:

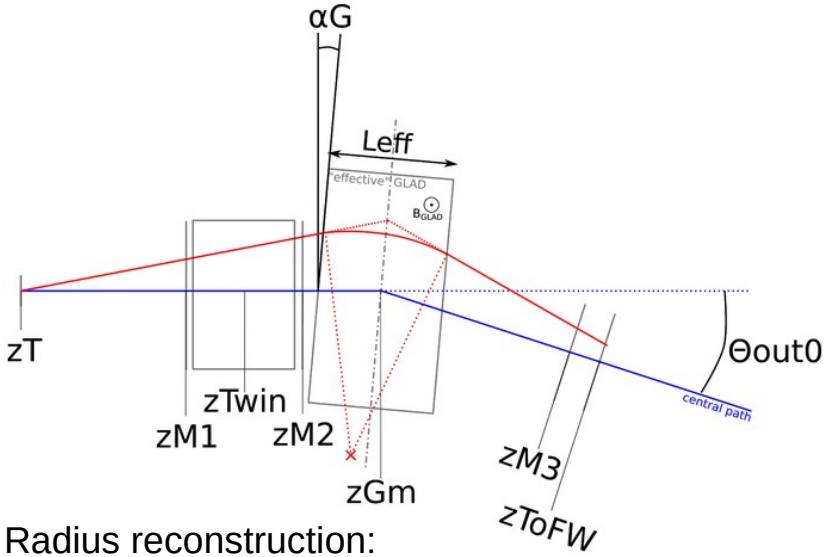
Quasi Free Scattering Analysis with Experiment S444/467 (2020)



Beam energy: 400 AMeV
Intensities: 1kHz - 1MHz
Beamtype: C^{12}
Target: C, CH2

Particle Identification

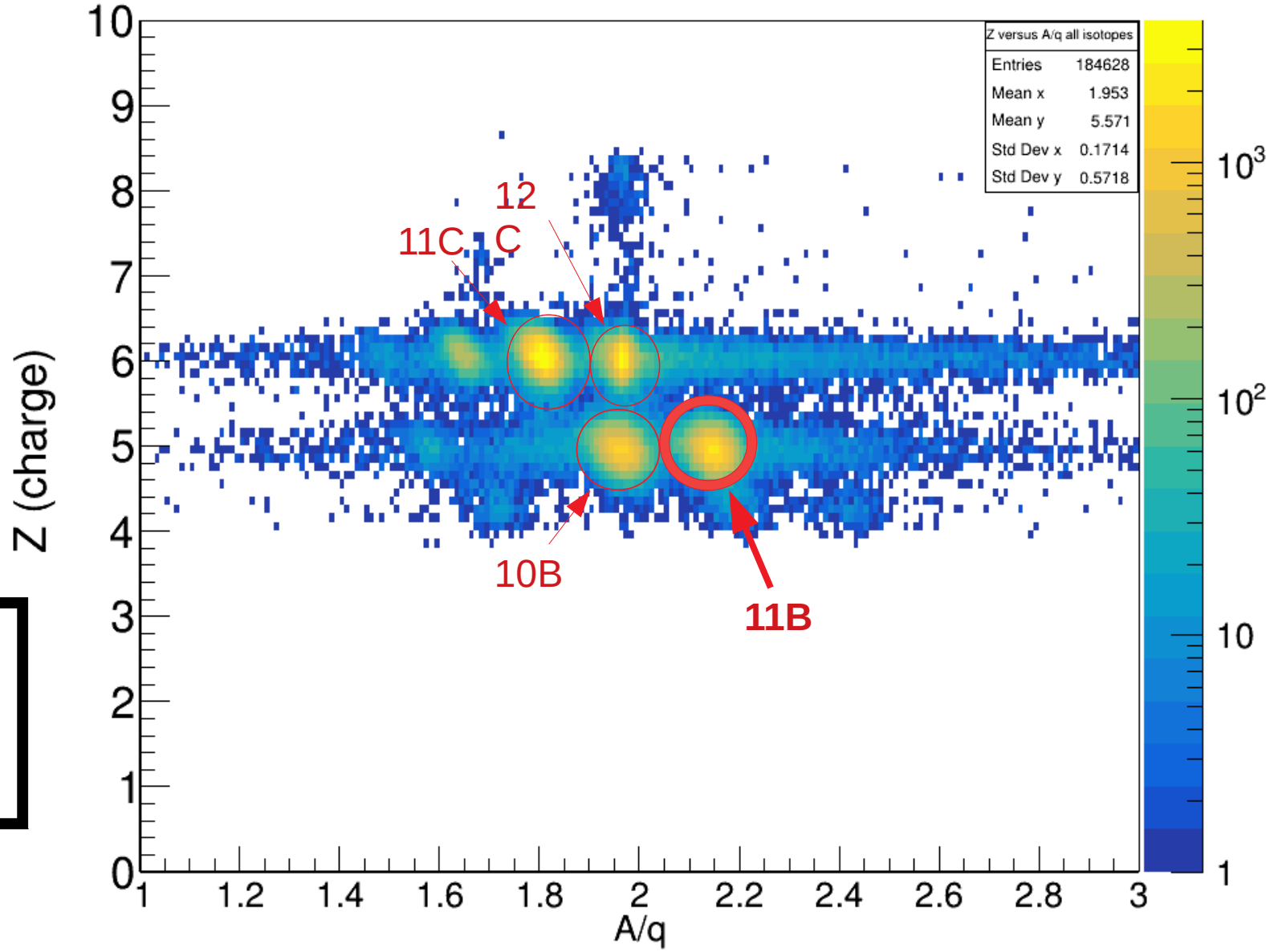
Flightpath reconstruction:



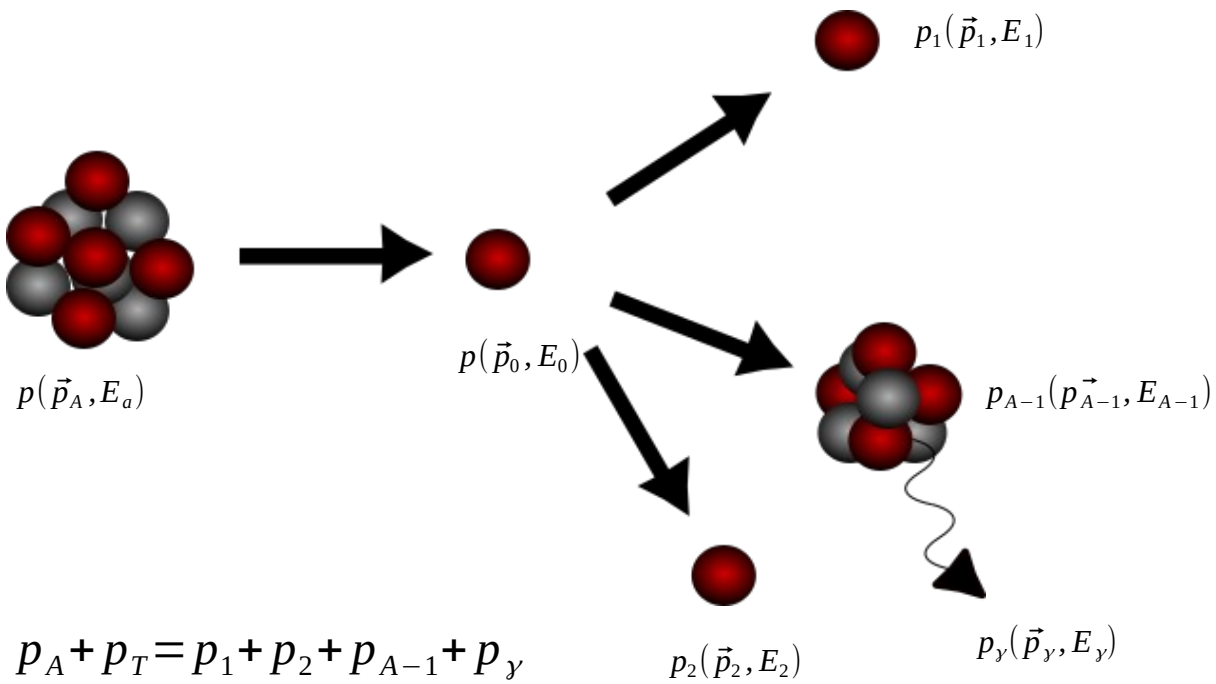
Radius reconstruction:

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

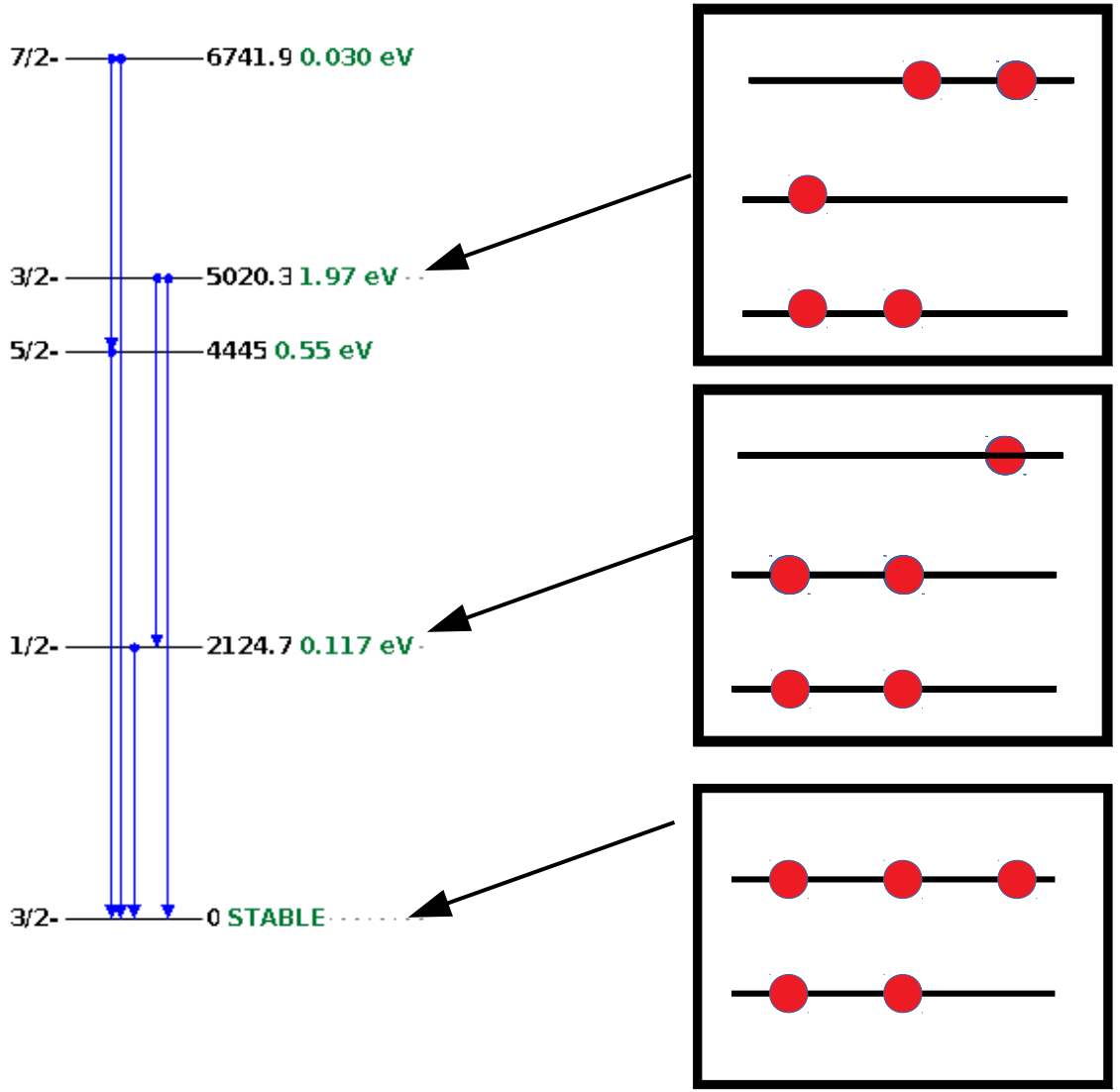
$$B * \rho = \frac{\beta * \gamma * M}{q}$$



12C(p,2p)11B reaction

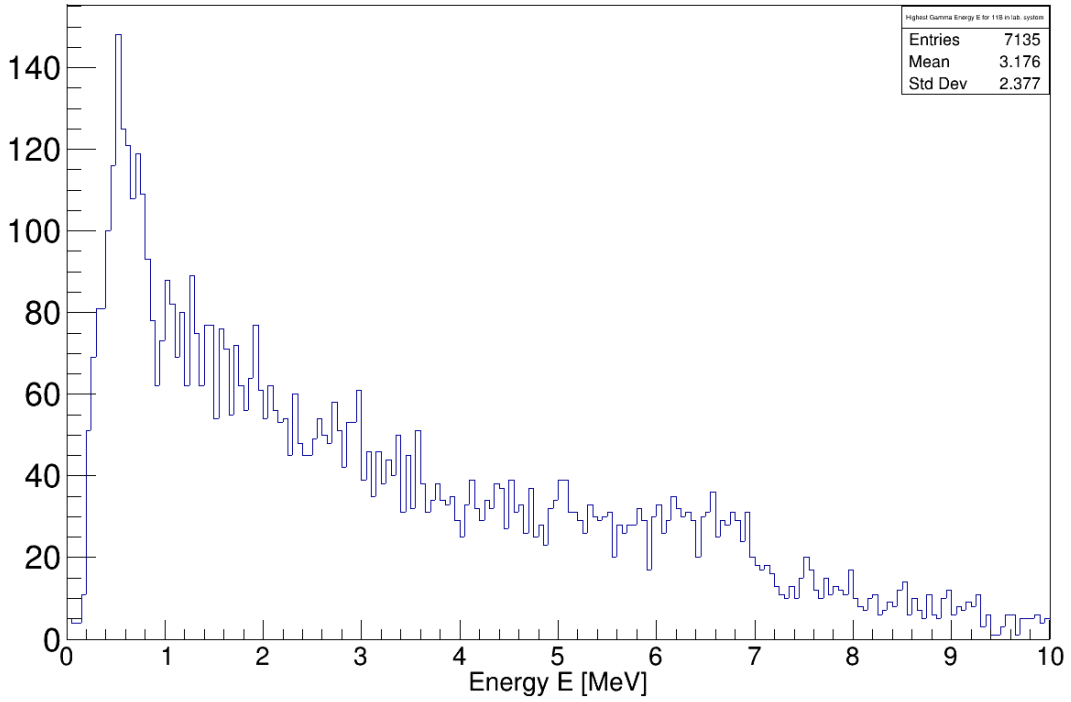


$$p_A + p_T = p_1 + p_2 + p_{A-1} + p_\gamma$$



Gamma Spectrum of 11B

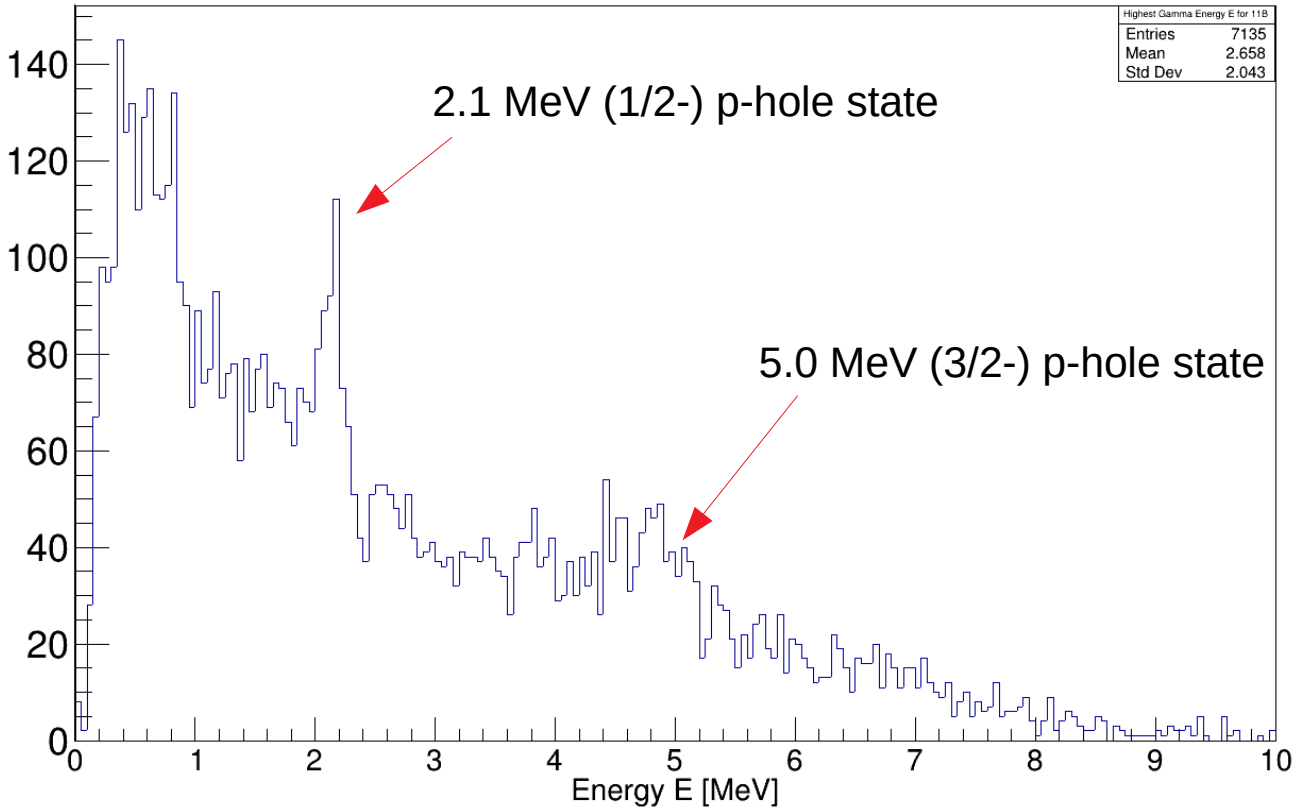
laboratory system



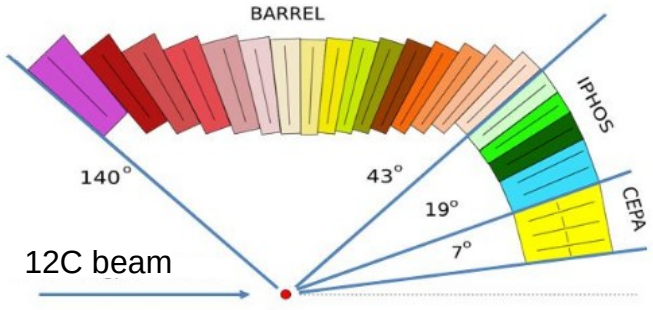
Doppler Correction:

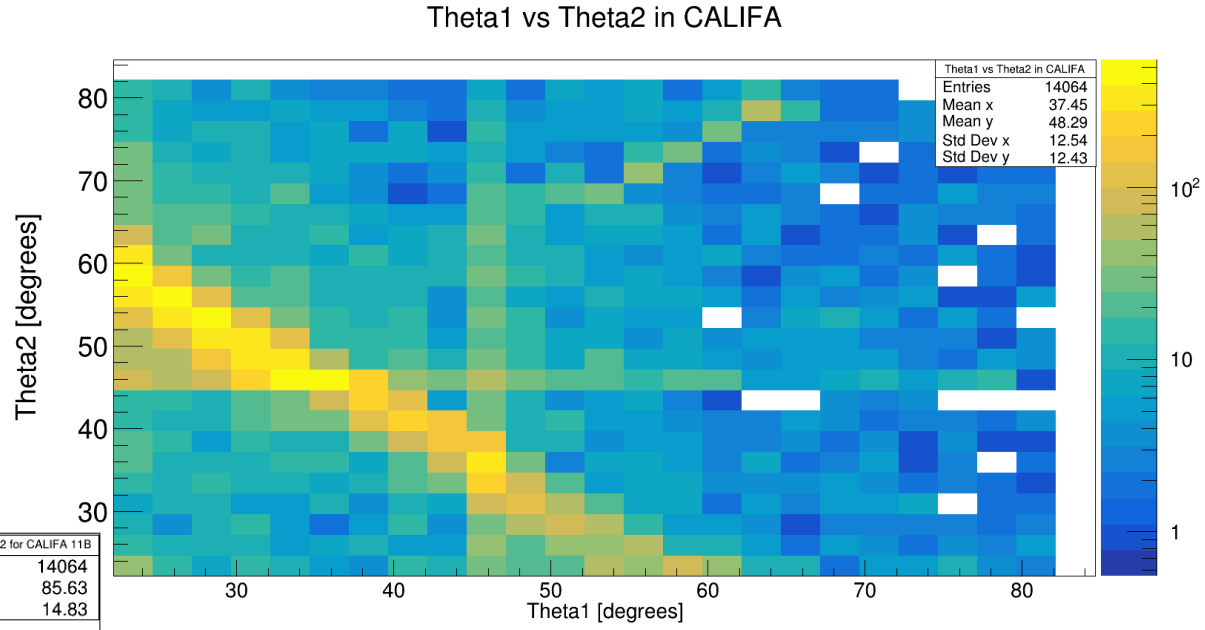
$$E_\gamma = \gamma E_{lab}\left(1-\beta\cos\left(\theta\right)\right)$$

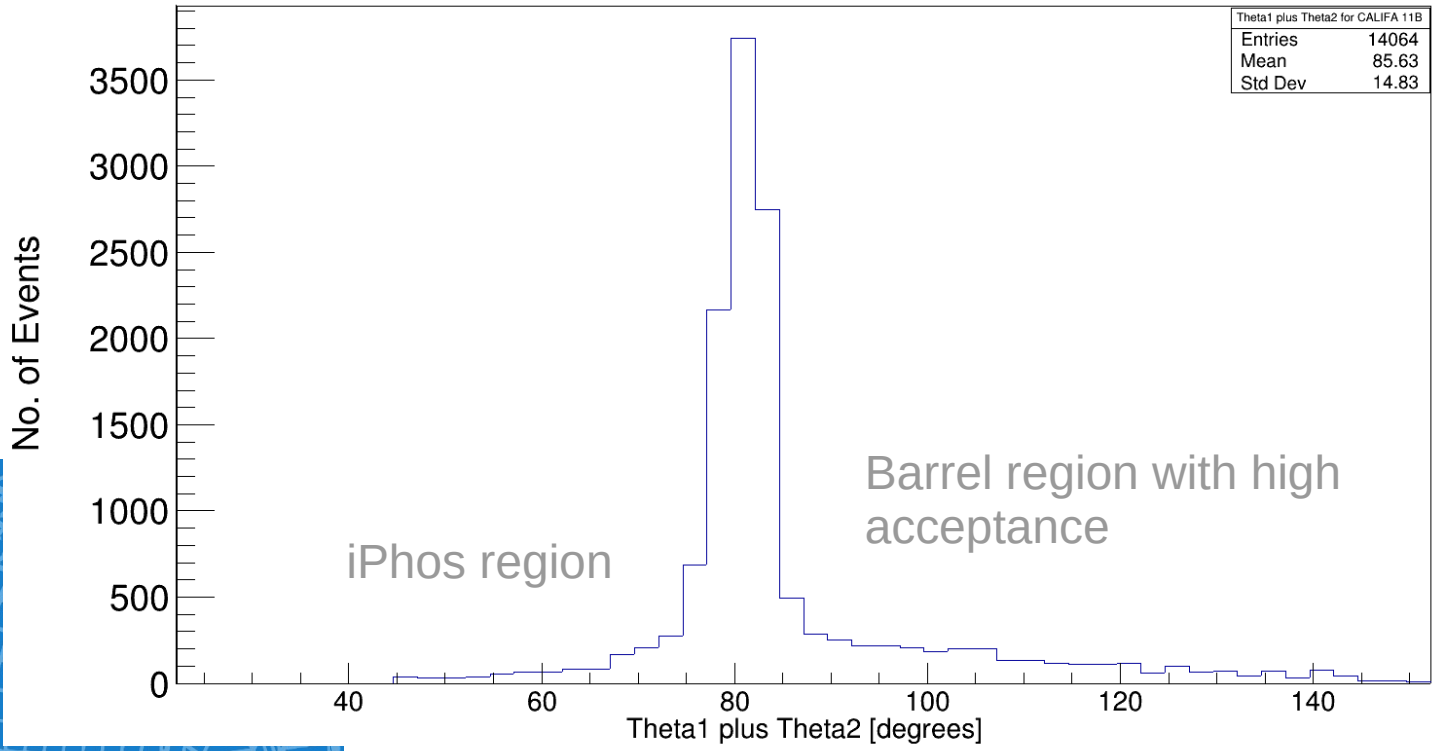
12C rest frame



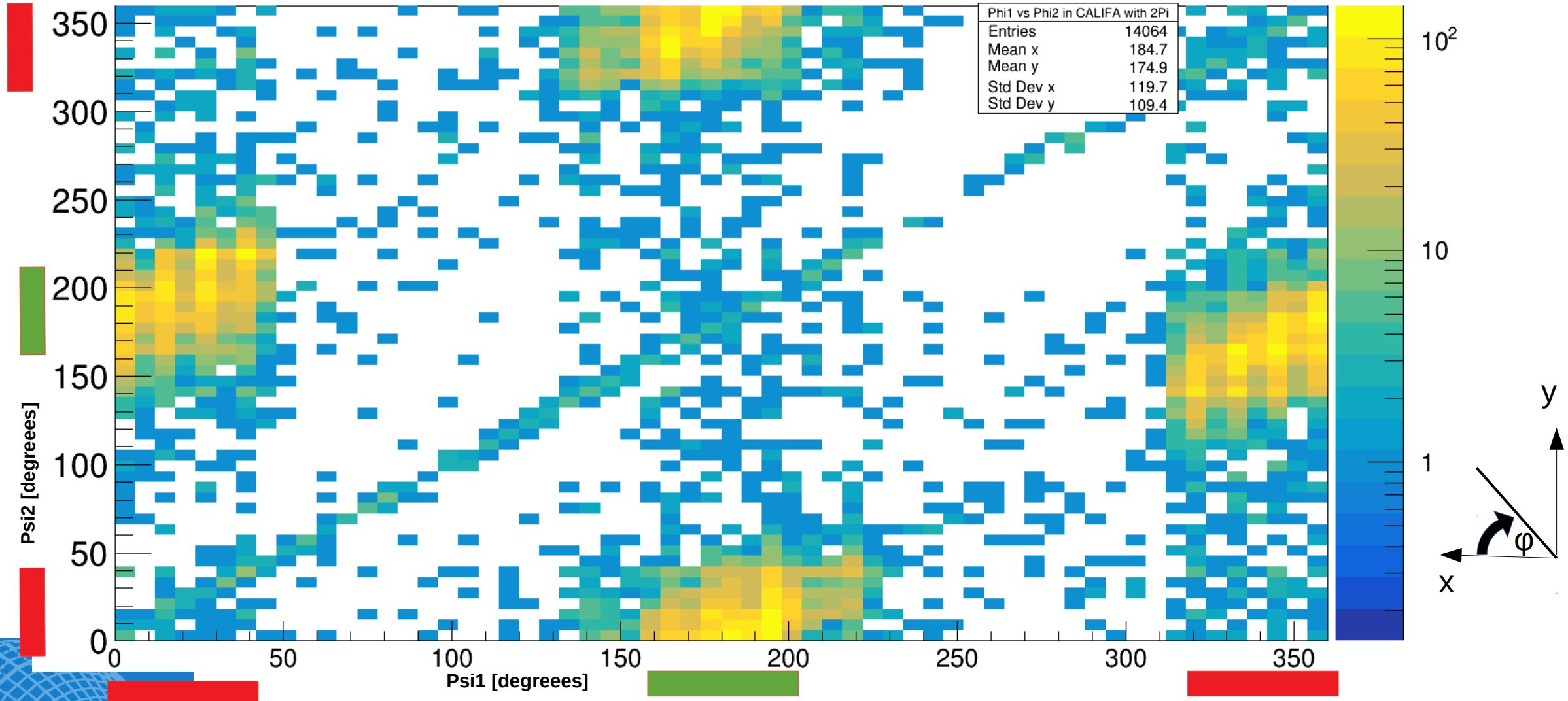
Polar Angular Distribution of protons for 12C(p,2p)11B







Arzimuthal Distribution of protons for 12C(p,2p)11B

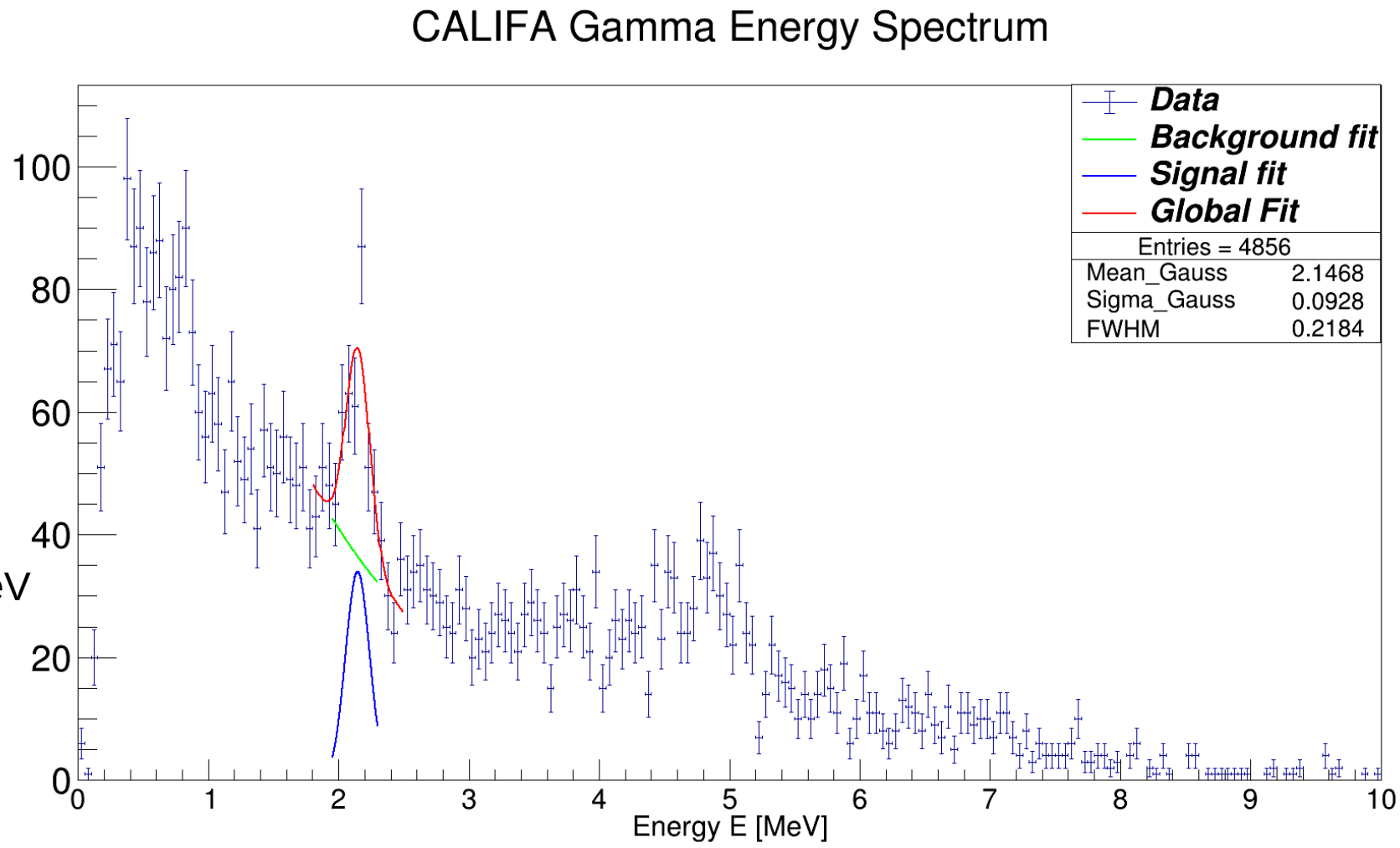


CALIFA left half (90°) iPhos

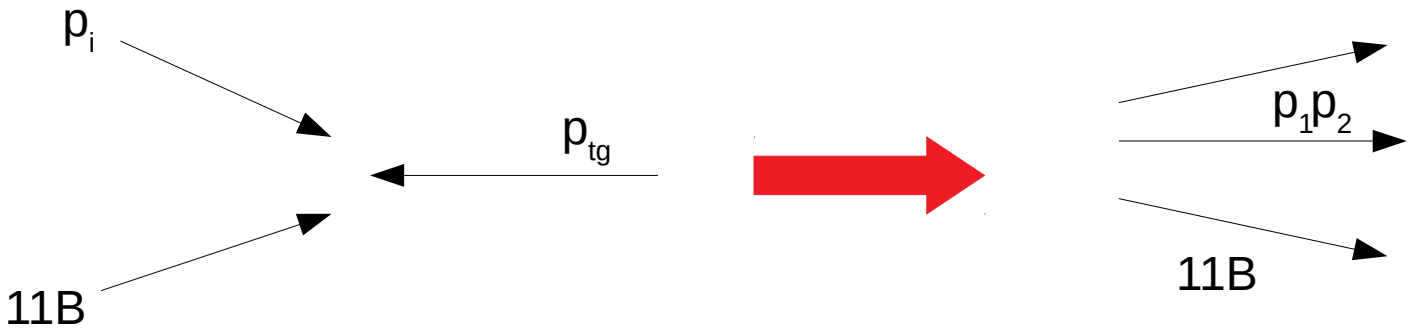
CALIFA right half (45°) iPhos

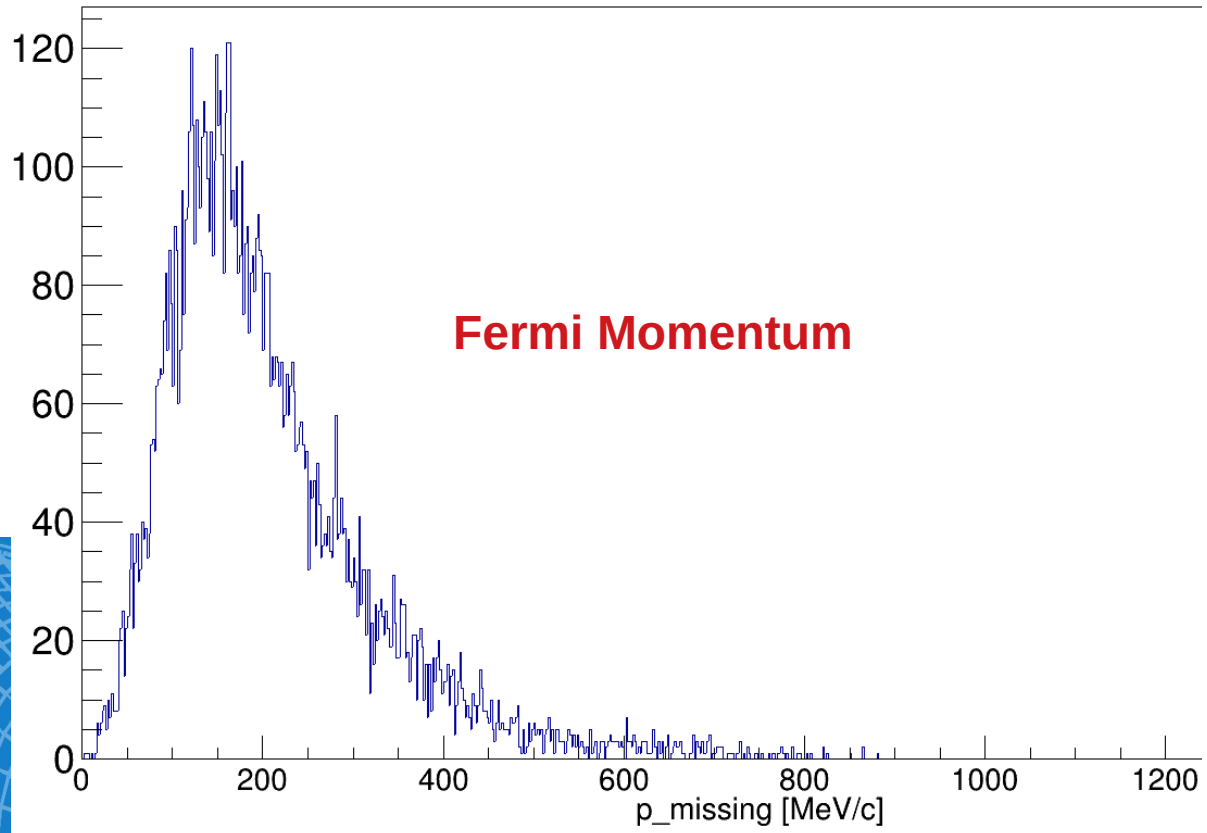
Gamma Spectrum with Angular Cuts

- 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_{hit} > 30 MeV
  - → θ1 + θ2 < 90°
  - → Δφ = 180° +- 40°



Reconstruction of Inner Momenta





Fermi Momentum

Momentum conservation relation:

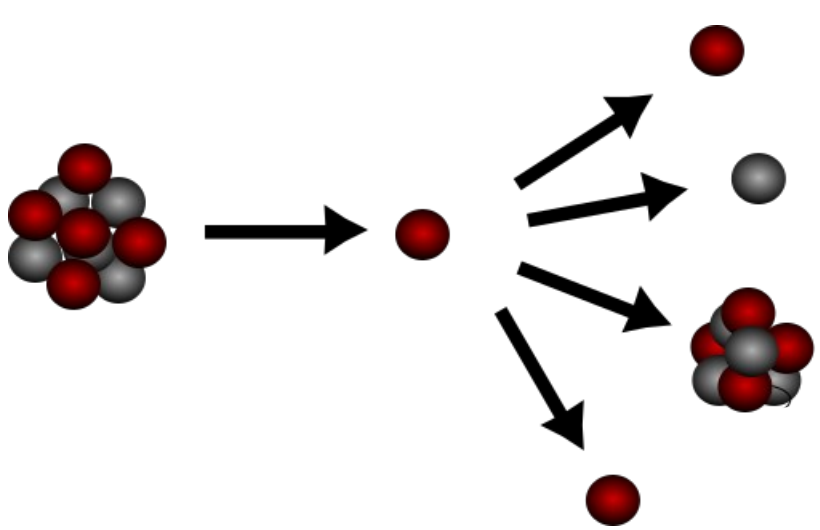
$$p_{12C} + p_{tg} = p_1 + p_2 + p_{11B}$$

assuming QE scattering in mean field potential:

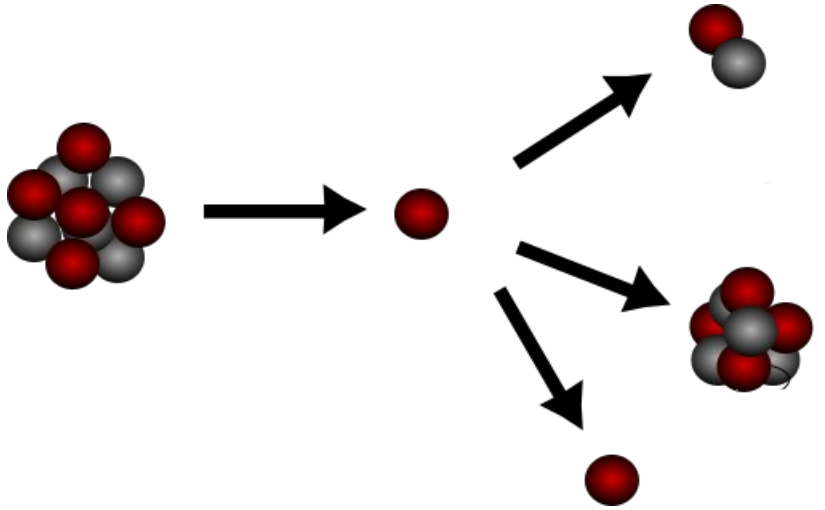
$$p_{12C} = p_i + p_{11B}$$

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

12C(p,pn/d)10B reaction



or

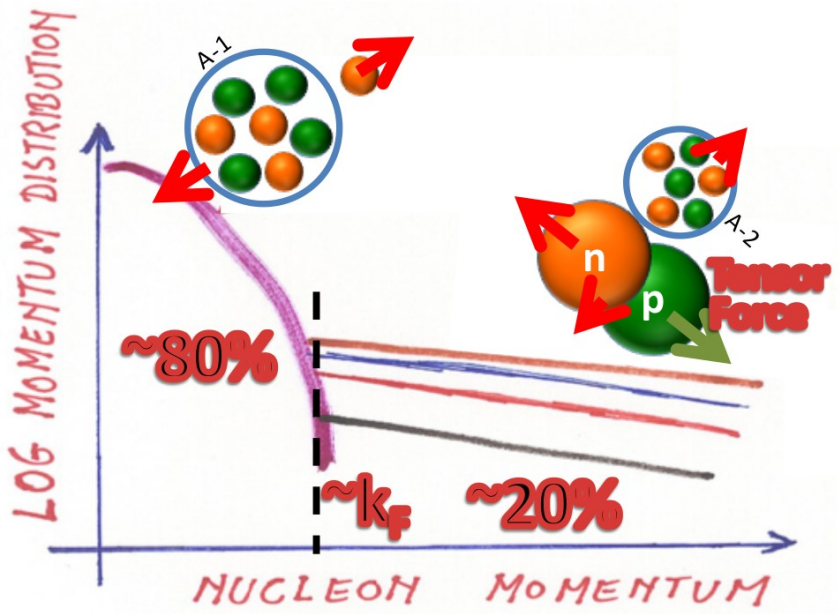


Short Range Correlations (SRC):

→ Possible explanation for EMC - effect

→ nucleon pairs with high relative and low c.m. momentum (compared to Fermi momentum k_F)

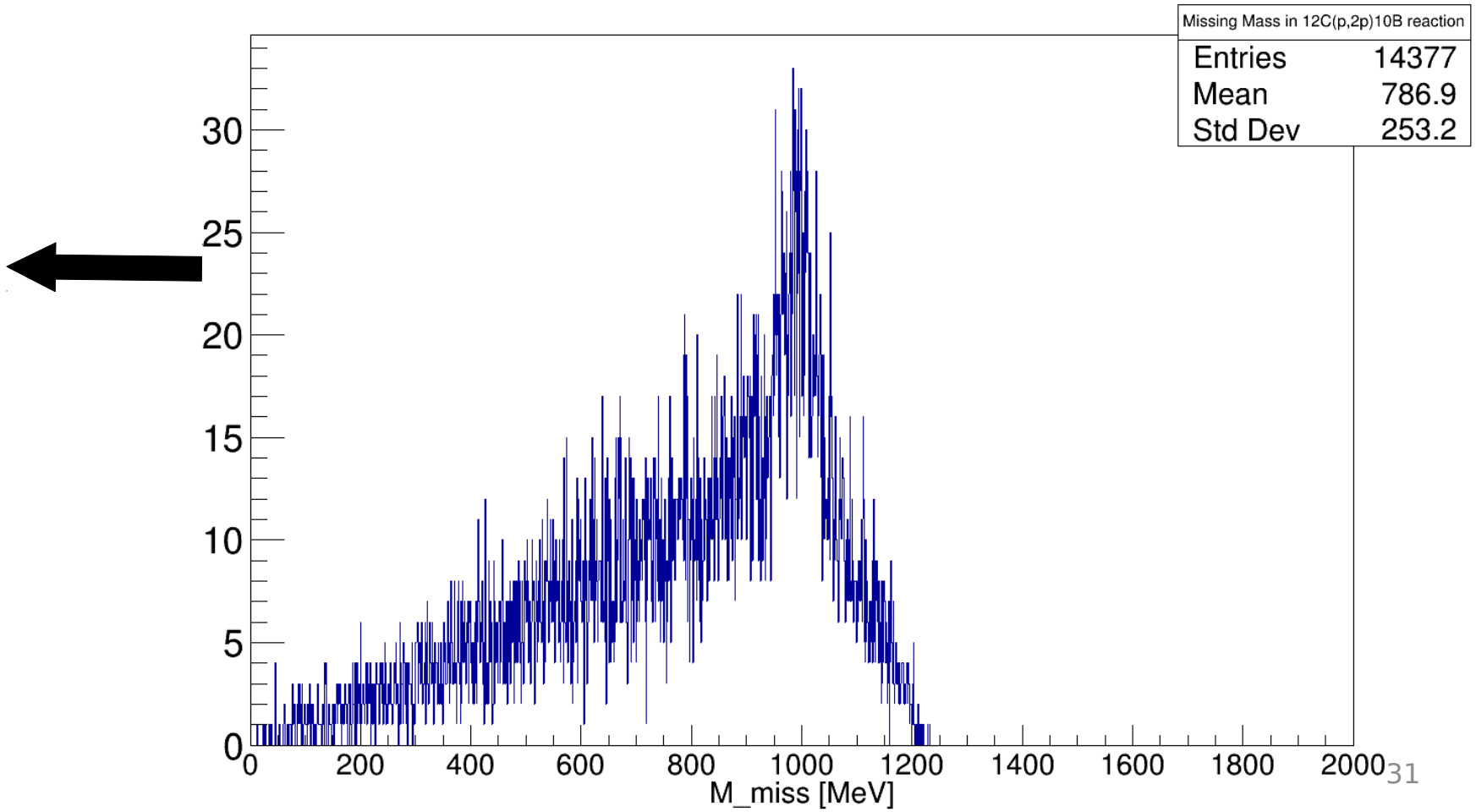
→ SRC exist in nuclei and account for about 20% of nucleons



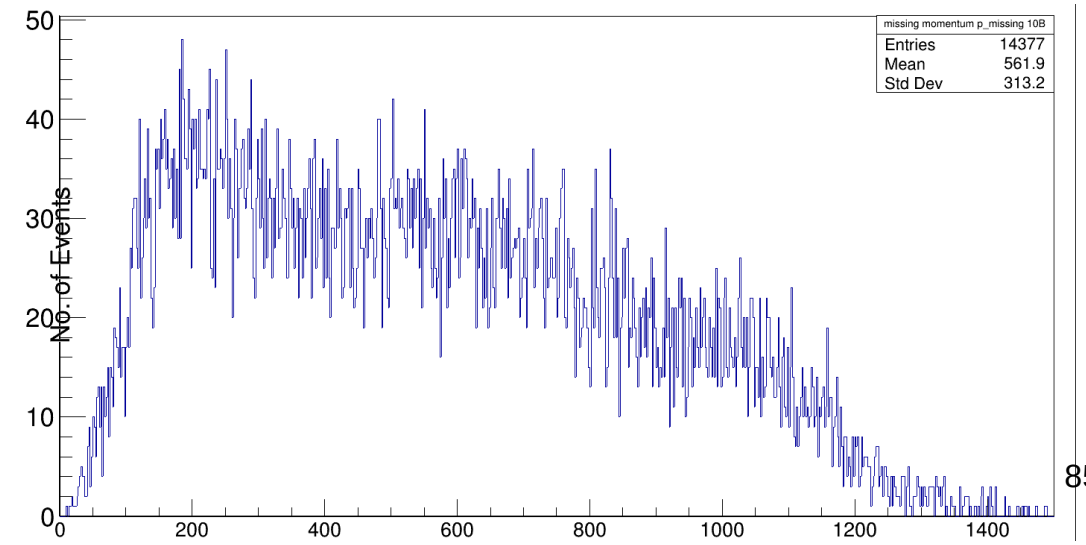
Neutron mass reconstruction...

$$M^2_{missing} = \left(p_{12C} + p_{tg} - p_1 - p_2 - p_{10B} \right)^2$$

use $M_{missing}$ as cut variable

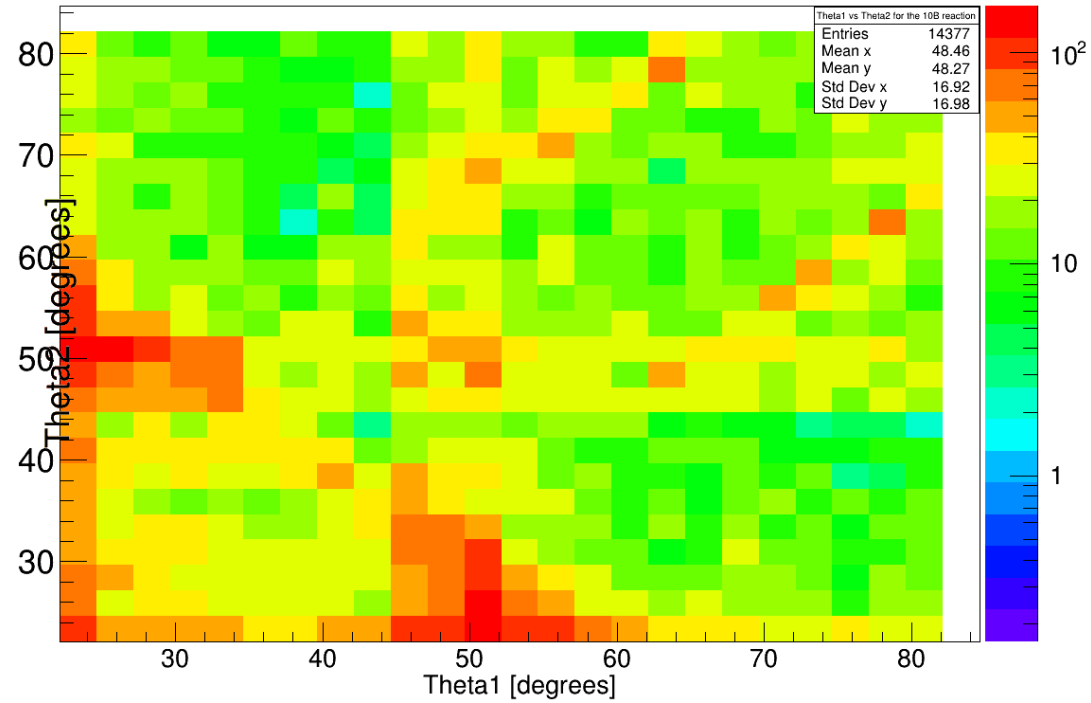


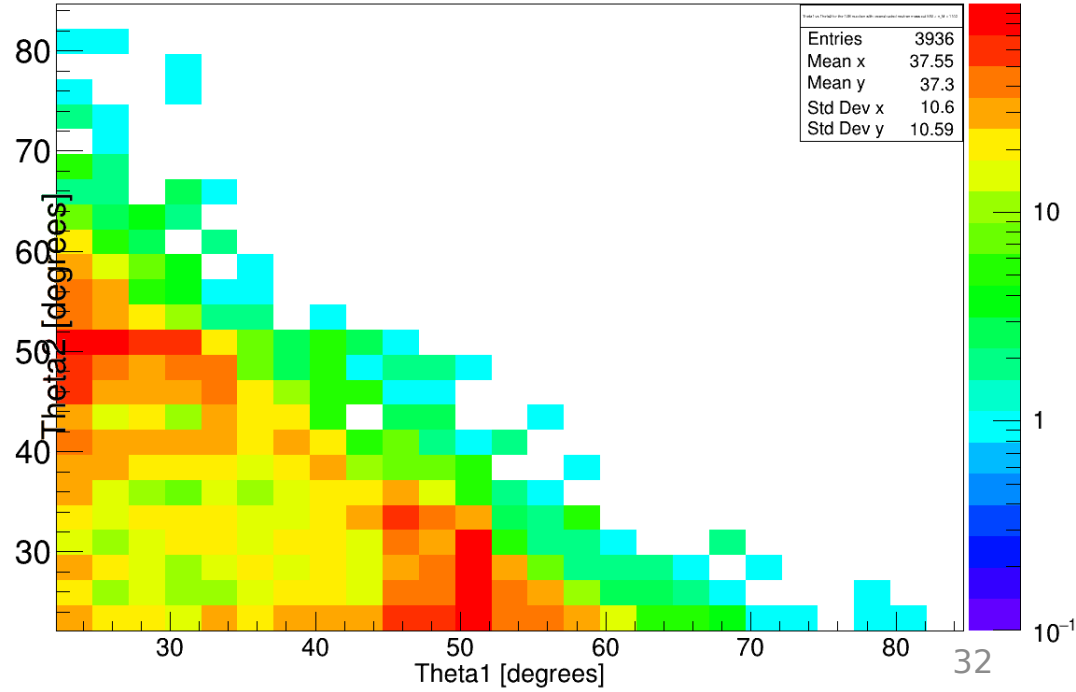
Angular and Momentum Plots



$M_{missing}$ cut

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





Summary & Outlook

Thank you!

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FAIR Phase 0 Research Program

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