R³B Commissioning Experiments with Final CALIFA Setup

Tobias Jenegger

PSI Seminar
16.06.2021

R³B Experiment @ GSI

CALIFA – Design and Upgrades

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

QFS Analysis

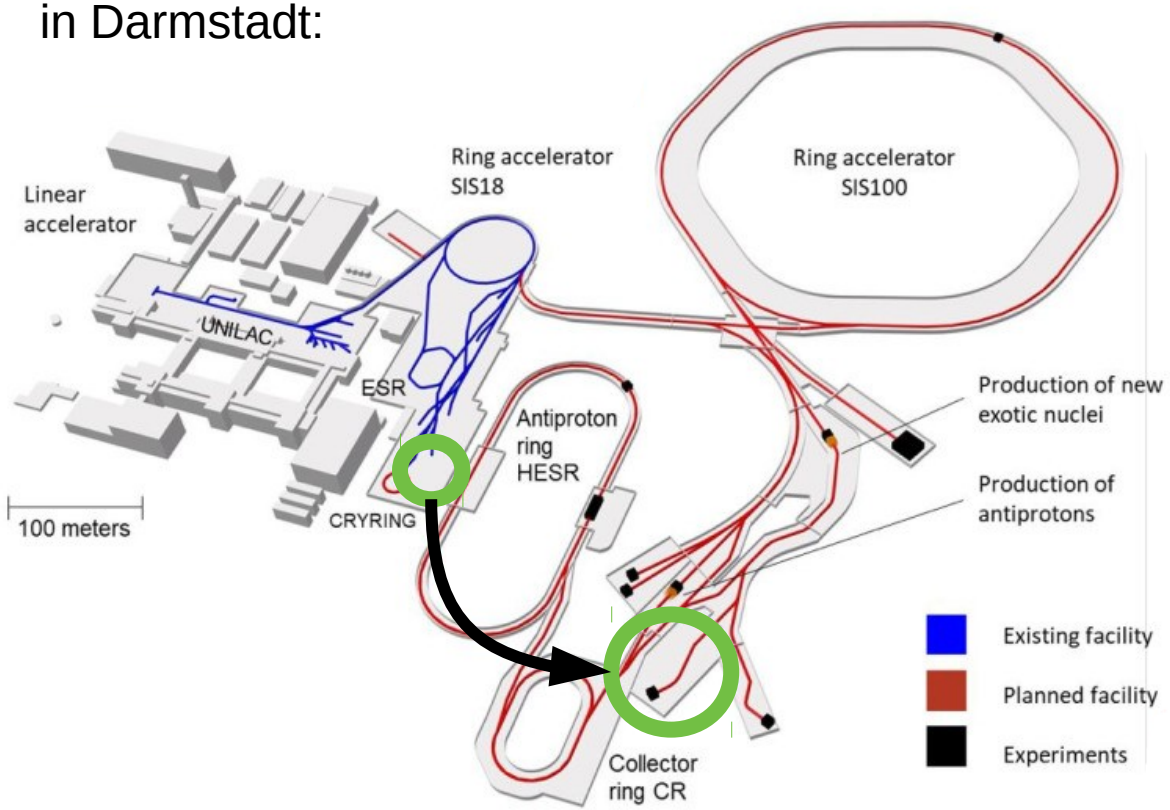
Supported by BMBF 05P15WOFNA and 05P19WOFN1.

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

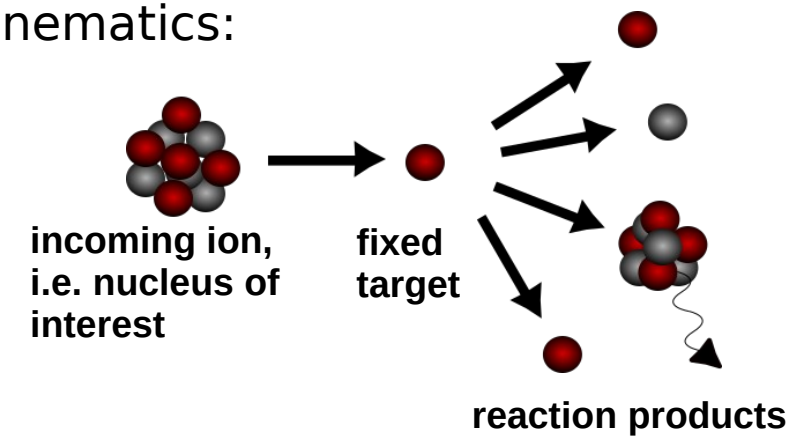
eight Frankfurt soccer stadiums

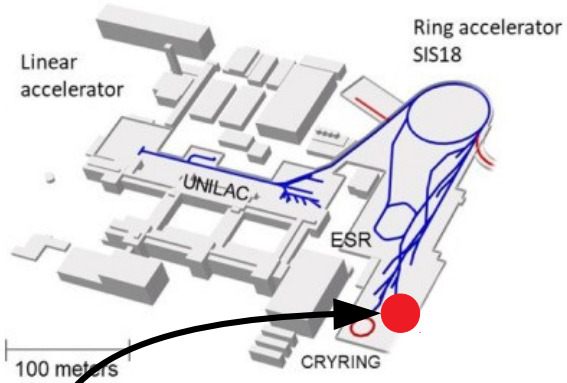
nine Eiffel Towers

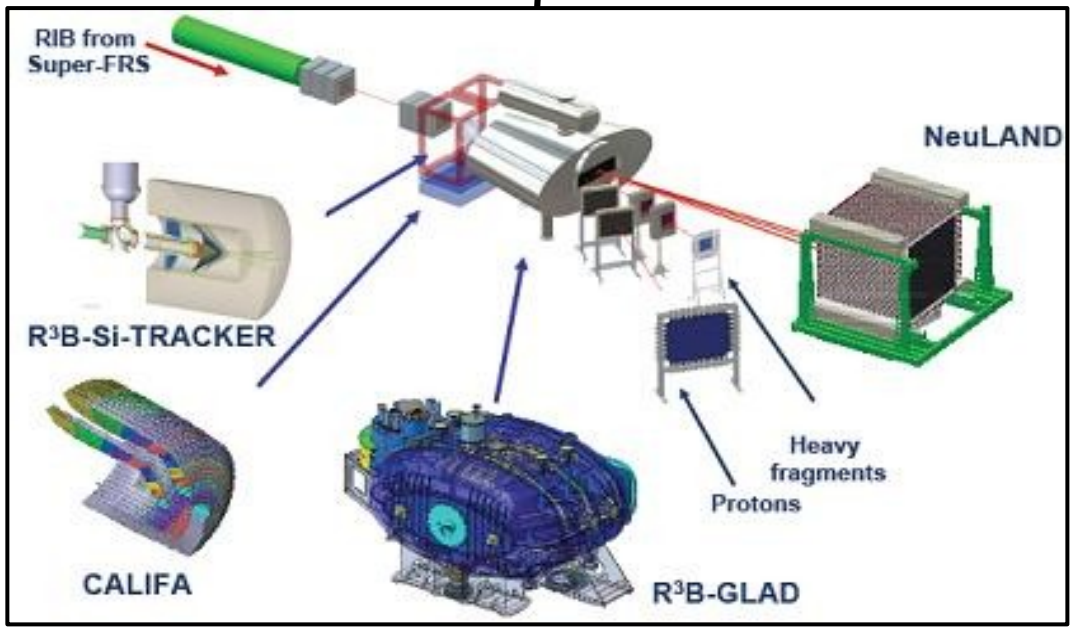
R³B Experiment

Reactions with Radioactive Relativistic Beams

- Physics program on exotic nuclei in inverse kinematics:



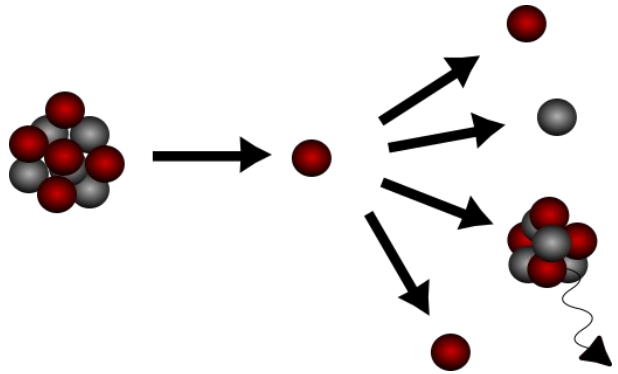




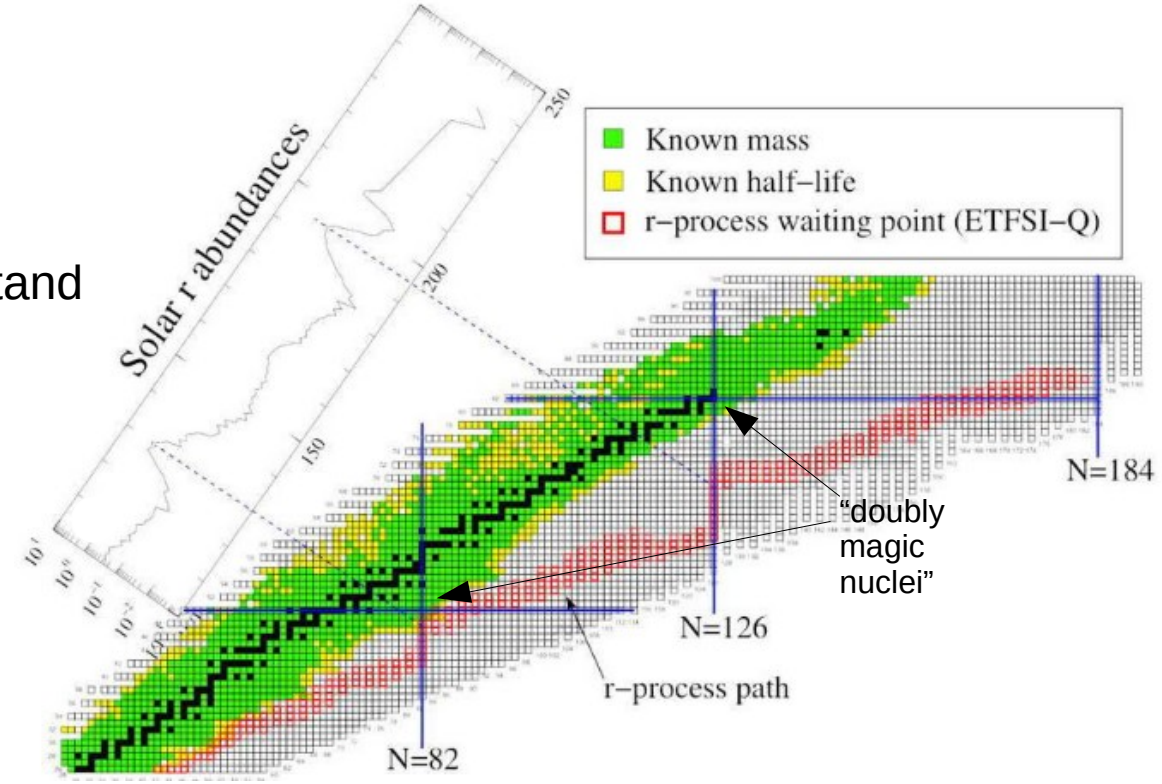
- In flight production of exotic nuclei from fragment separator Super-FRS
- kinematically complete measurements
- Flexible setup, extensive physics schedule (despite pandemic restrictions)

Physics program @ R³B

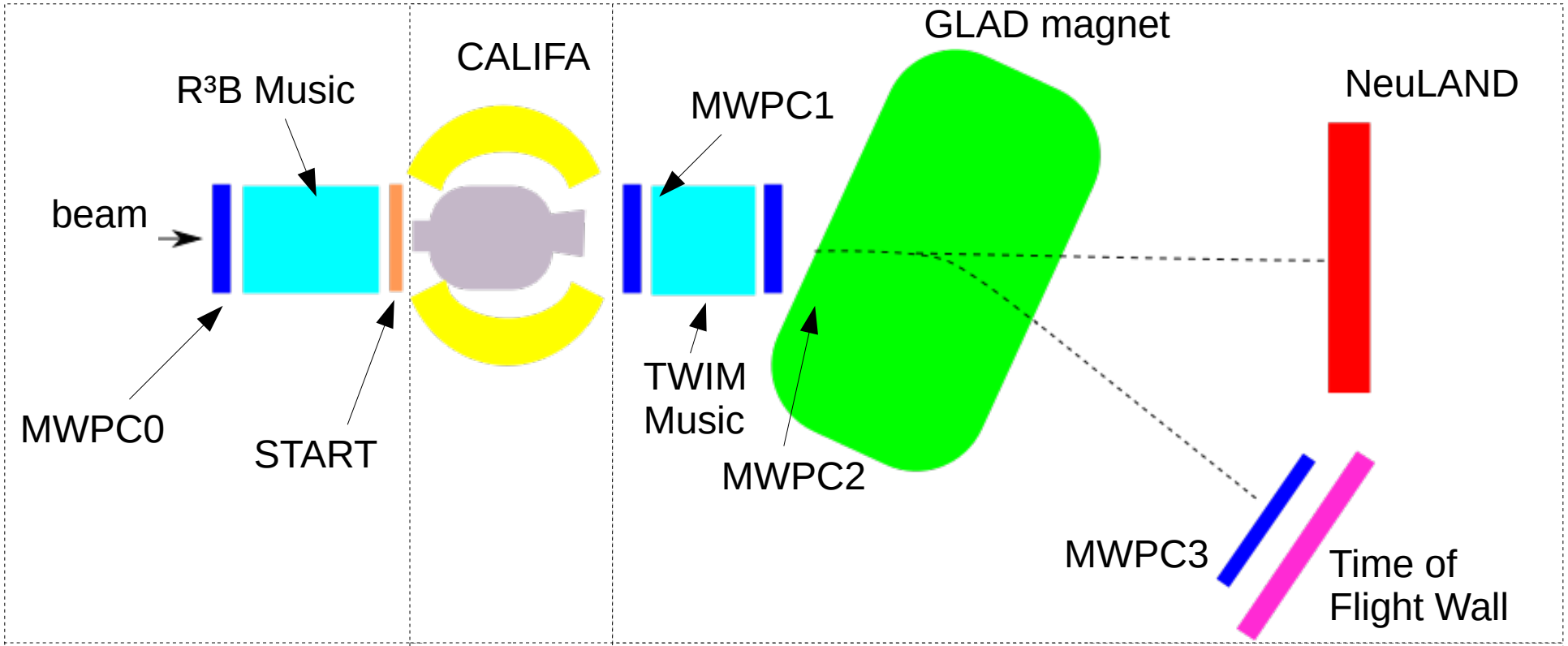
- Quasi Free Scattering (QFS)/Knockout reactions
  - → study single particle properties inside nuclei
  - → analyze shell evolution far off stability
  - → measurement of Fermi-momentum, separation energy, …



- 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



R³B Setup for Experiments s444/467 (2020)

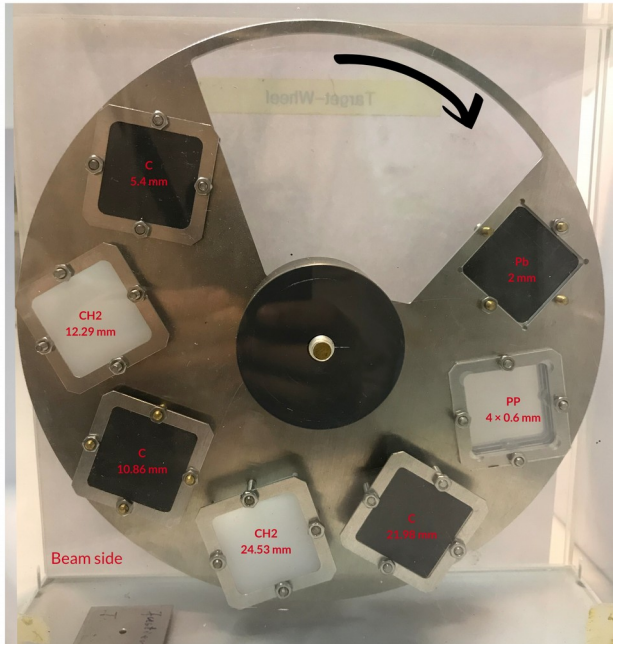


Beam type: 12C / neutron rich Ca isotopes

R³B – Setup and Detectors

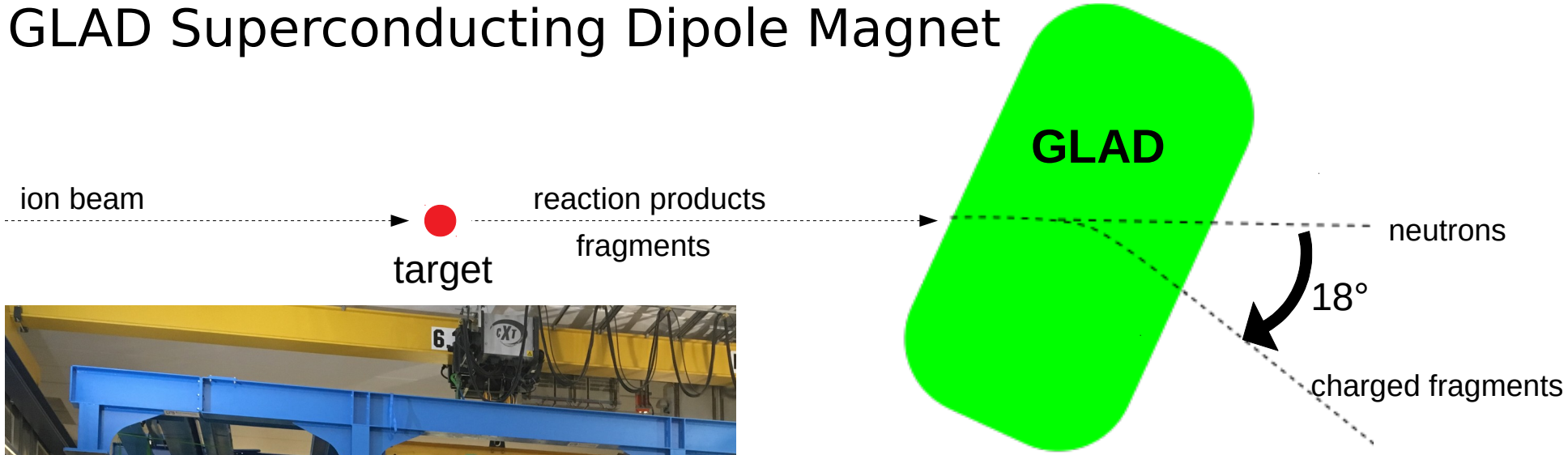
LH2 targets
with length:
15 / 50 / 150 mm

Target Wheel



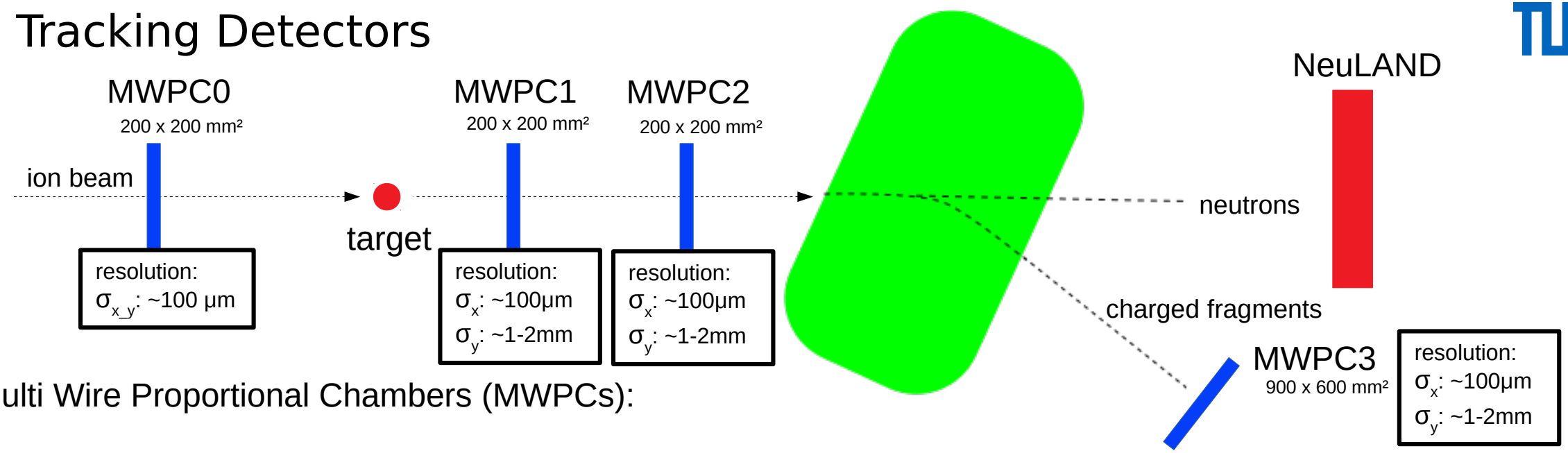
Targets:
→ C with length:
5.4 / 10.86 / 21.98 mm
→ CH2 with length:
12.29 / 24.53 / 24 mm
→ Pb with length:
2 mm

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



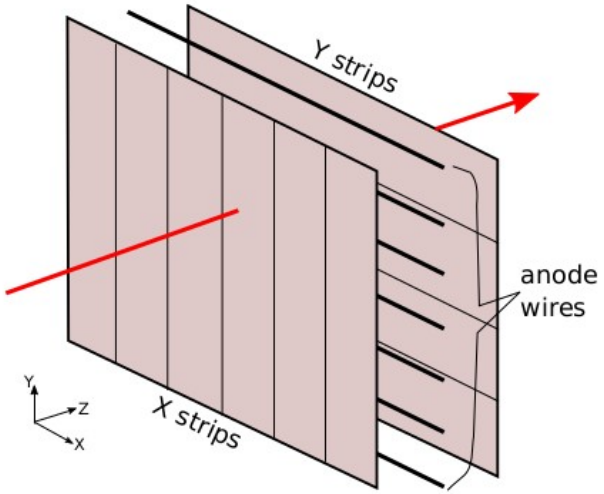
Multi Wire Proportional Chambers (MWPCs):

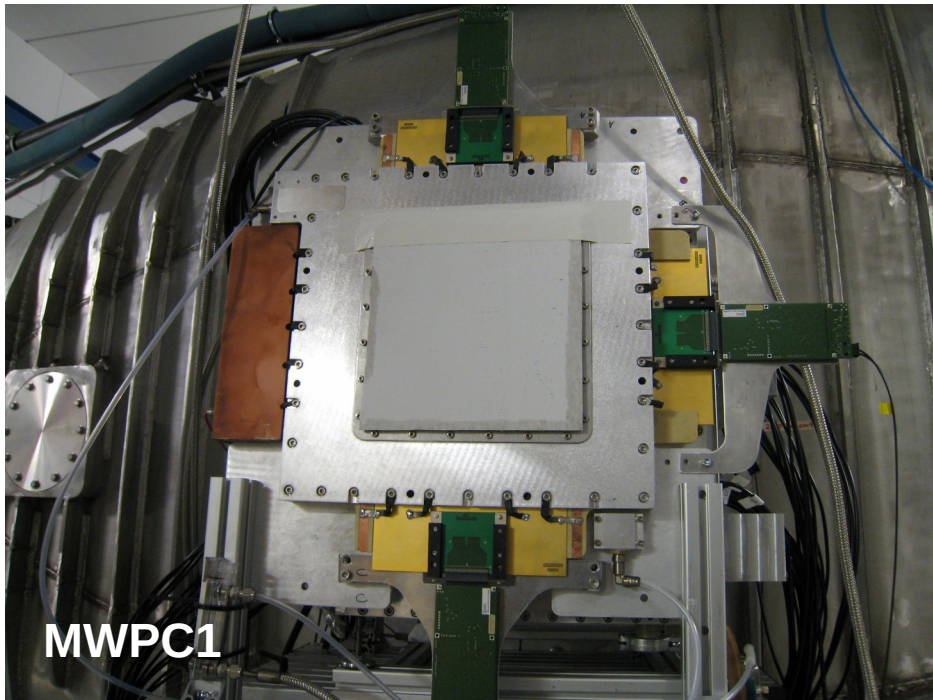
→ vertical/horizontal wires: 50 µm diameter, 2.5 mm spacing

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

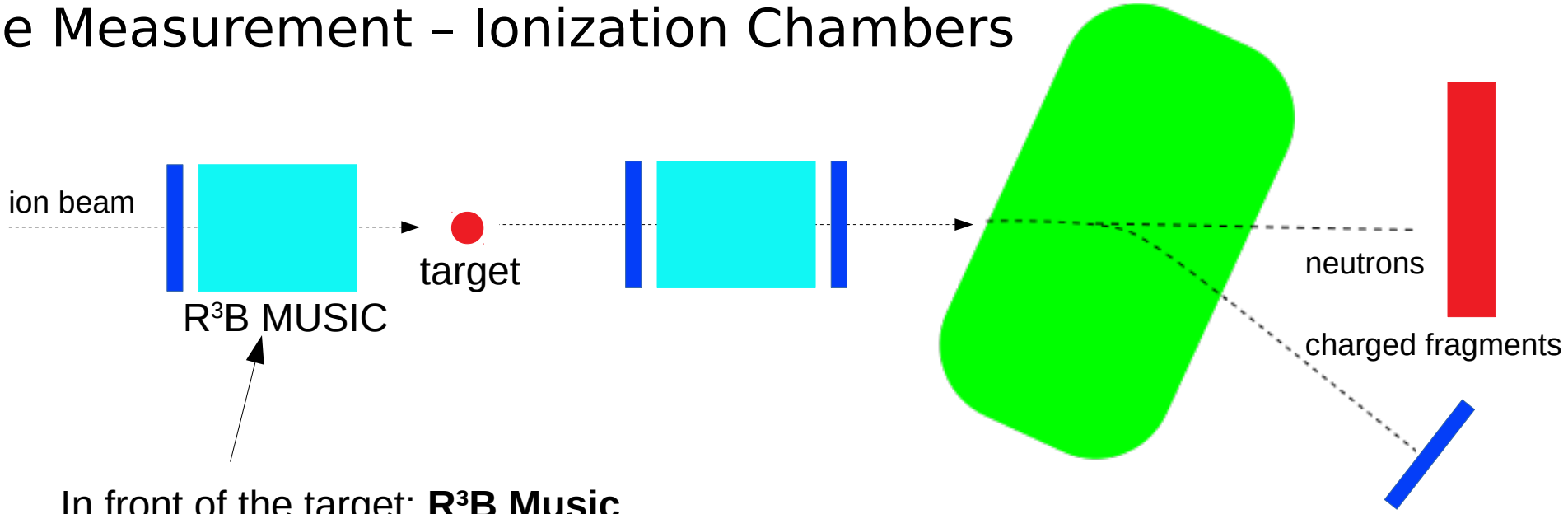
→ gas mixture: 84% Ar, 16% CO2

→ pad readout



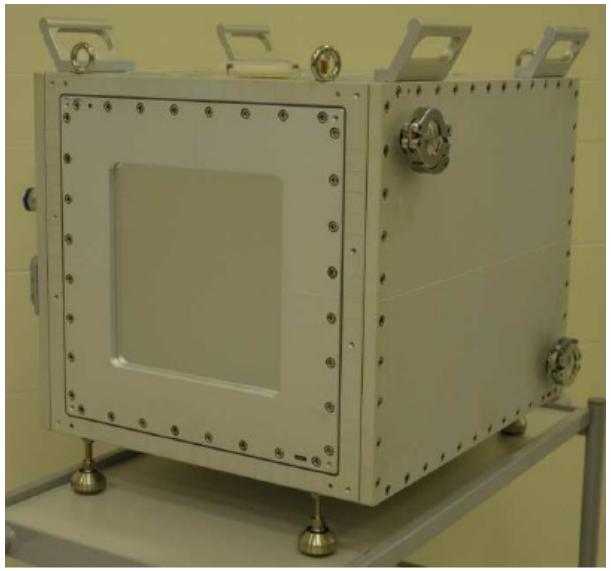


Charge Measurement – Ionization Chambers

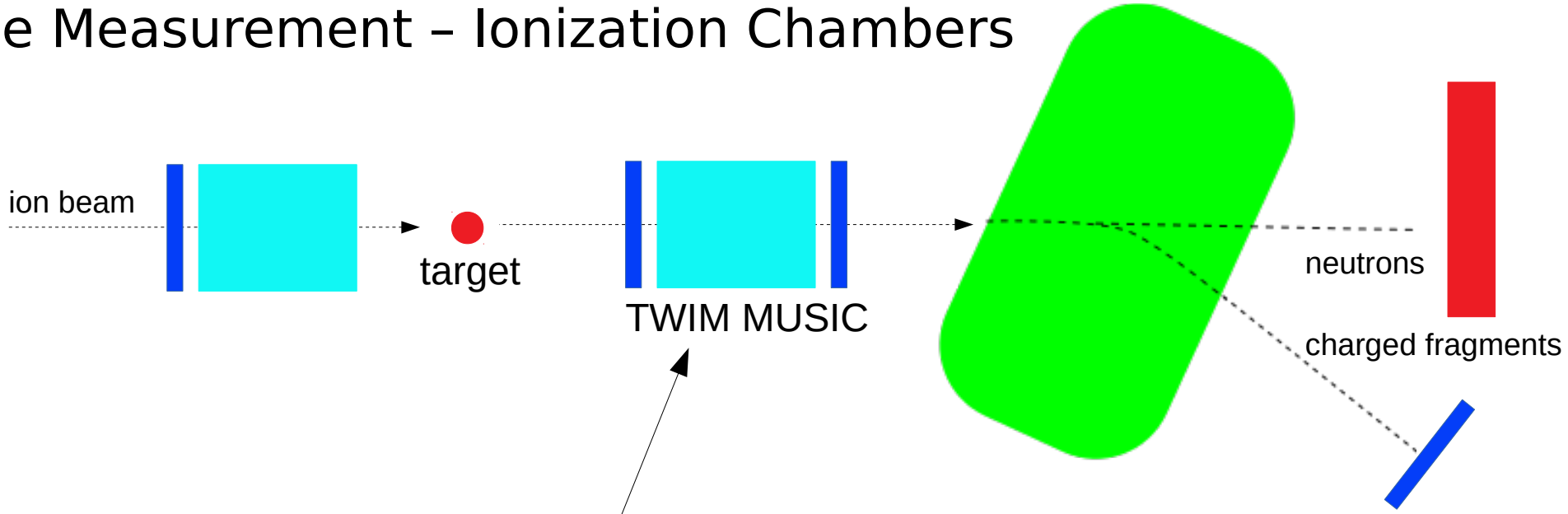


In front of the target: **R³B Music**

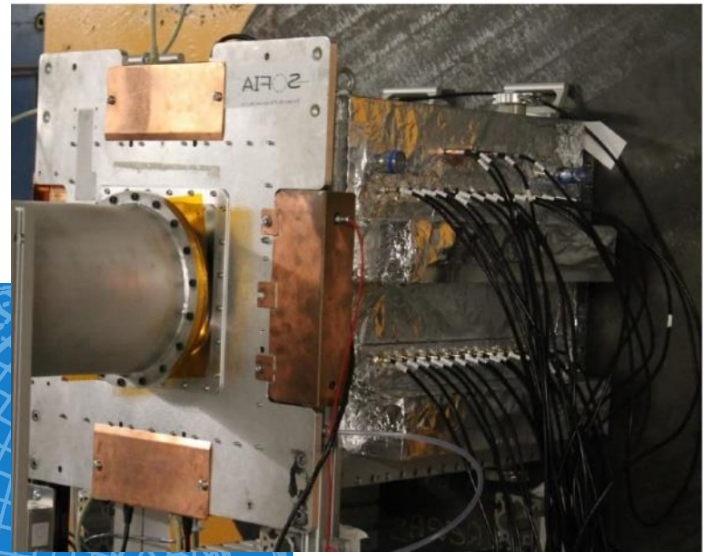
51 x 54 x 53 cm³
Cathode left side -
Anode right side
Gas mixture:
Ar 25%, CH4 75%



Charge Measurement – Ionization Chambers



After the target: **TWIM MUSIC**



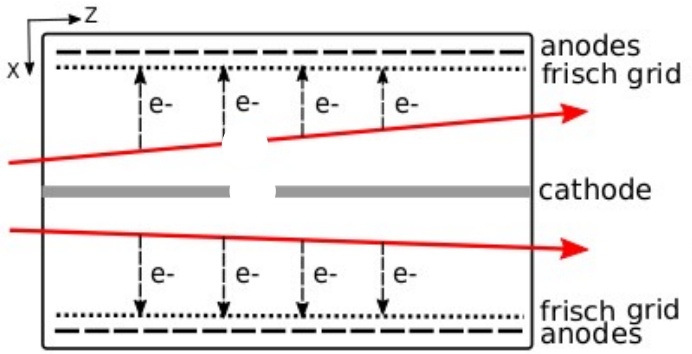
43 x 48 x 55 cm³

Double ionization chamber with central cathode and two anode planes

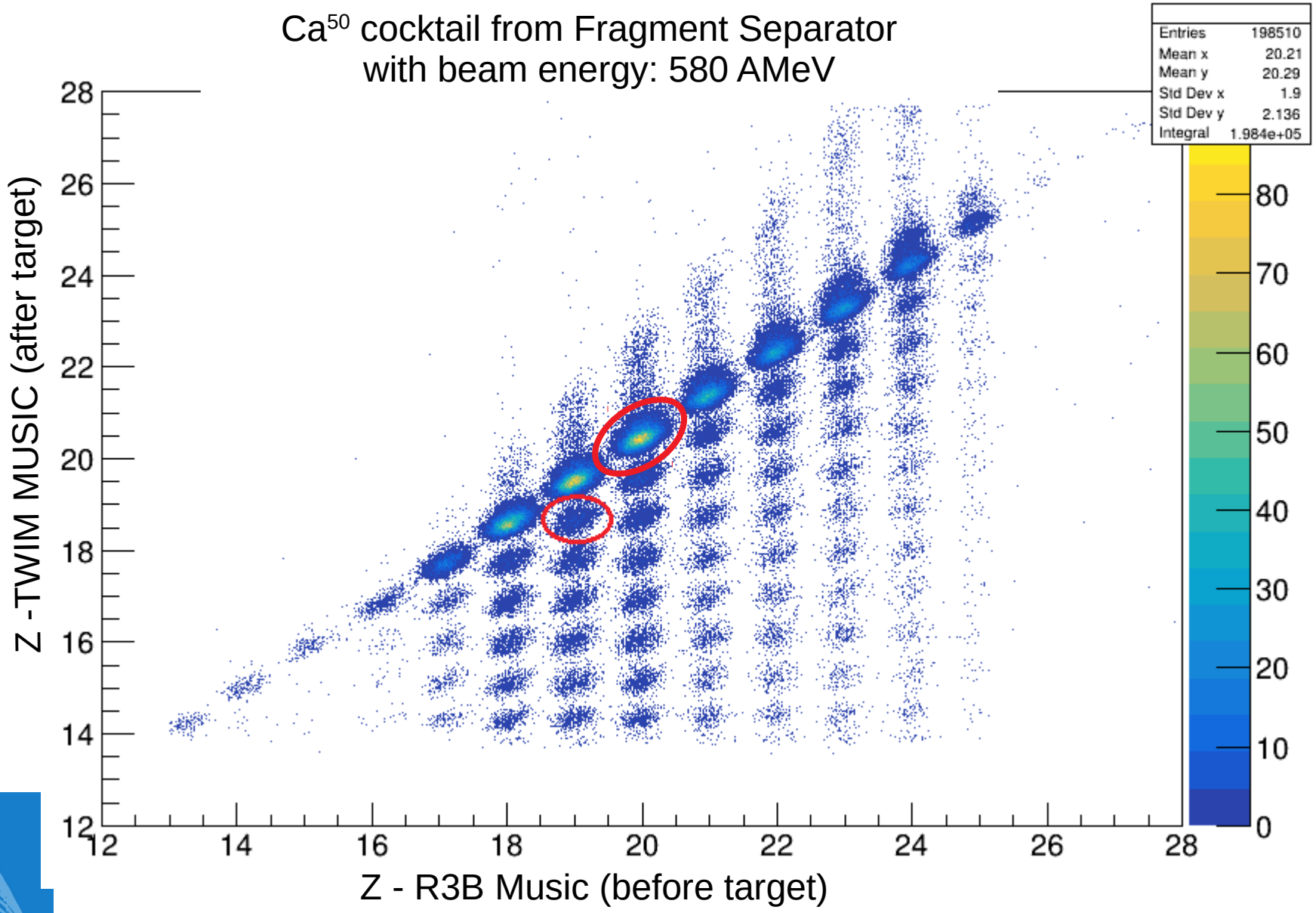
Frisch grid for better signal quality and time resolution

Gas mixture:

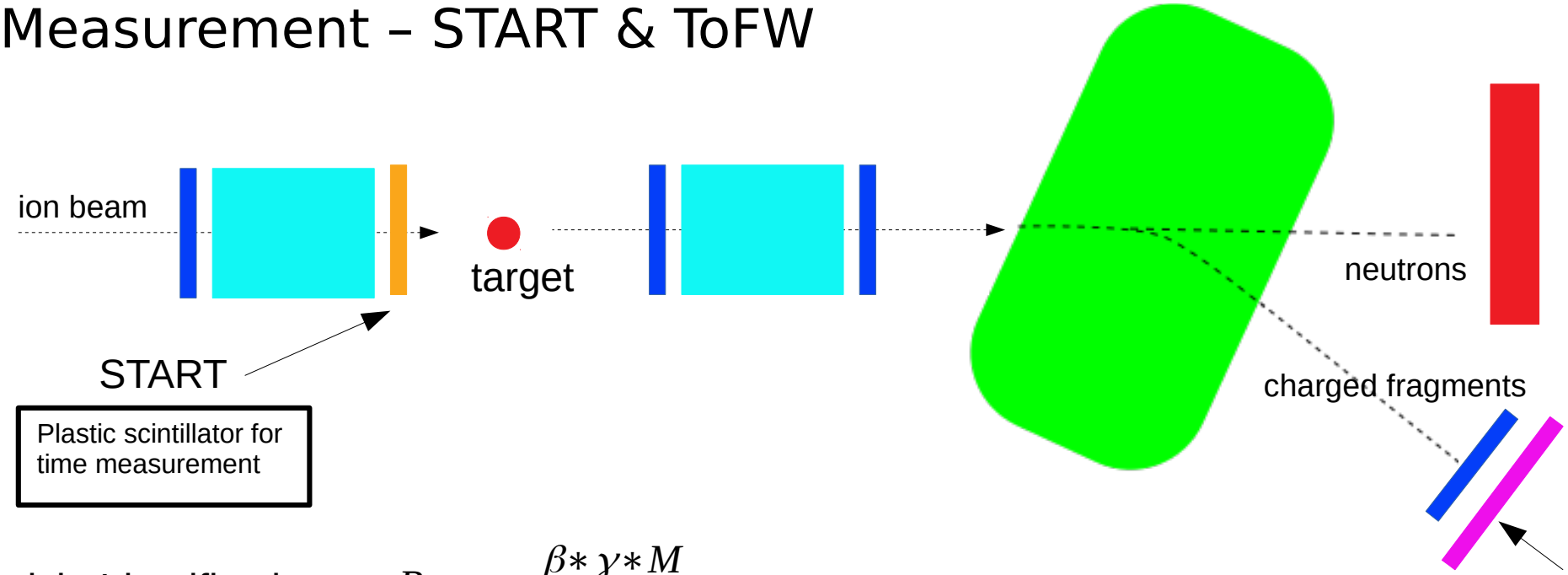
Ar 25%, CH4 75%



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

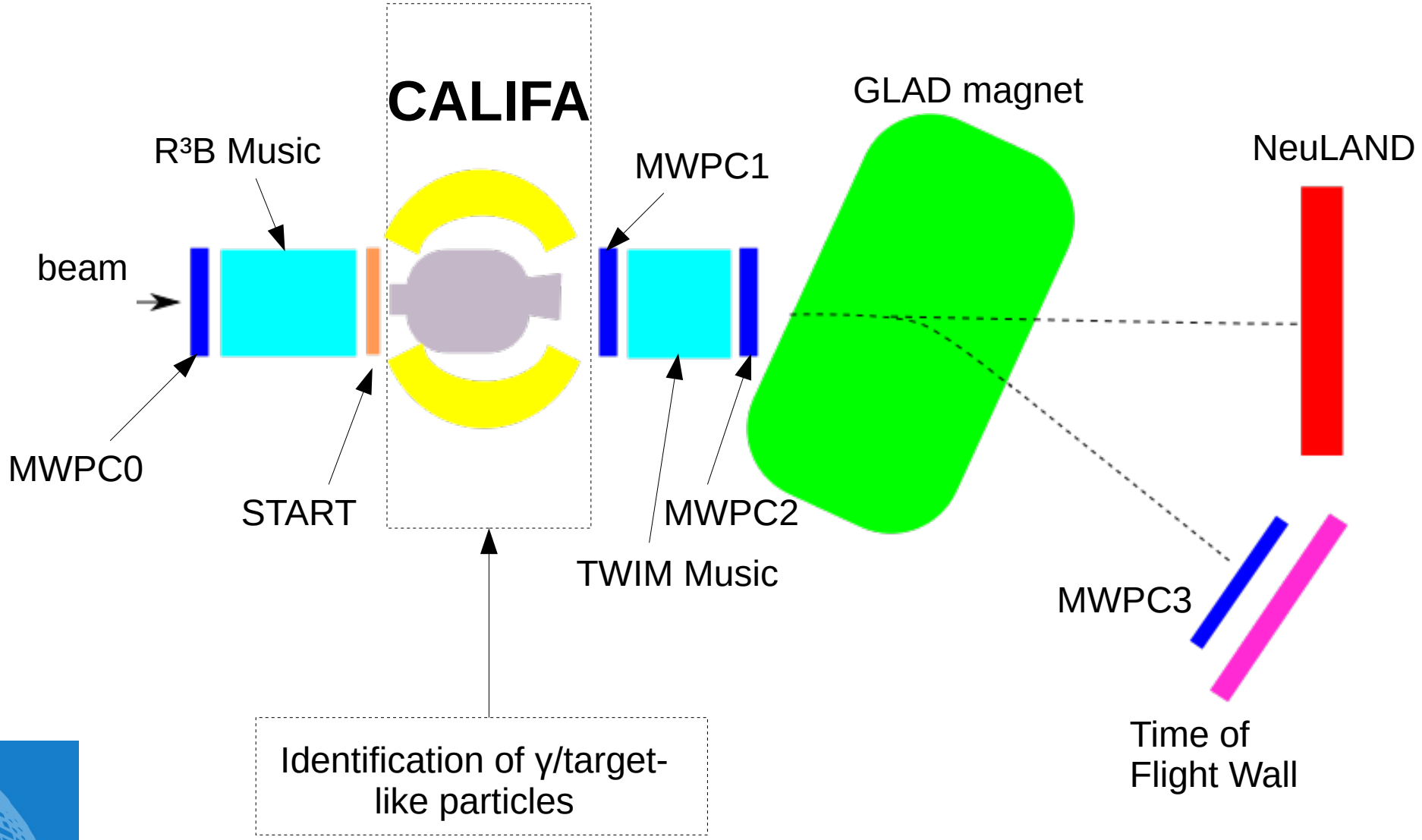
→ flight-path reconstruction: tracking detectors

→ charge measurement: R3B Music &
TWIM MUSIC

Time of Flight Wall (ToFW)

27 vertical scintillators
(54 PMTs, up & down)

time and position measurement


CALIFA
GLAD magnet
NeuLAND
R³B Music
MWPC1
beam
MWPC0
START
MWPC2
TWIM Music
MWPC3
Time of
Flight Wall
Identification of γ/target-
like particles

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

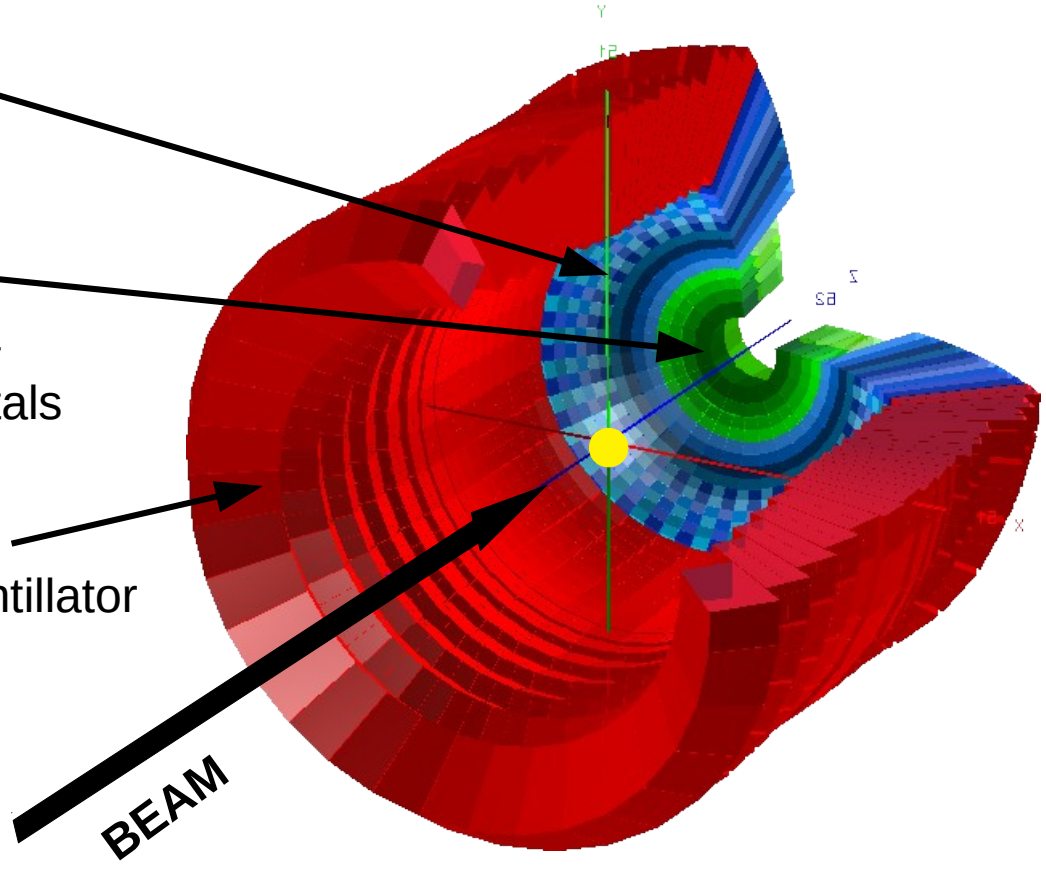
CEPA:

96 LaBr3 &

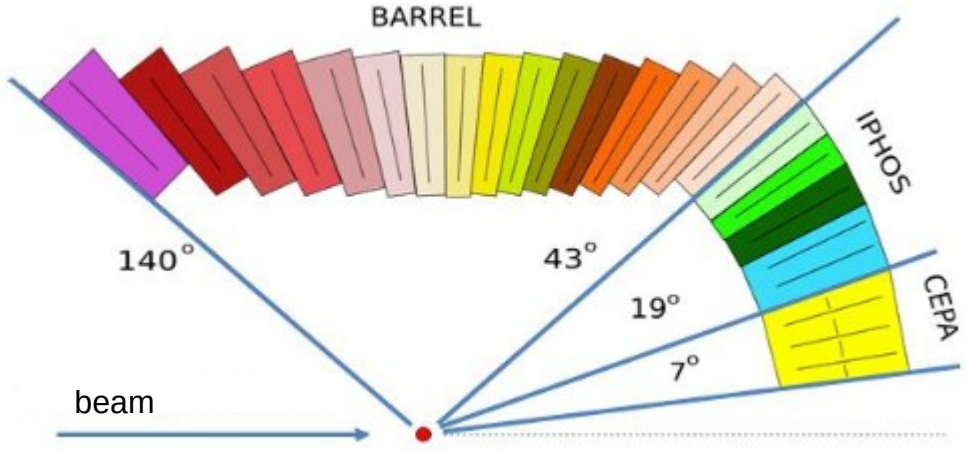
LaCl3 crystals

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

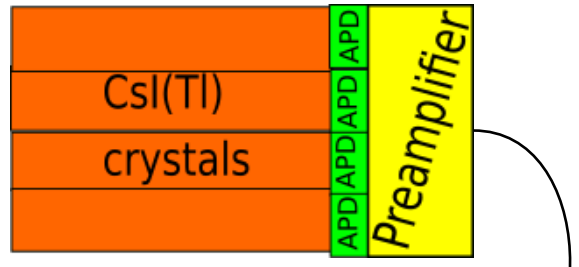


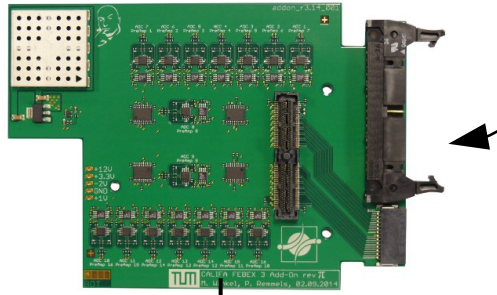
Signal Processing @ CALIFA

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

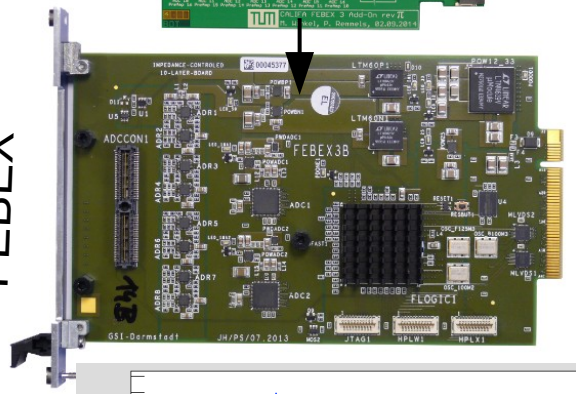
Add-on Board: Filtering

FEBEX Module: ADC + energy & particle identification





Add-on Board



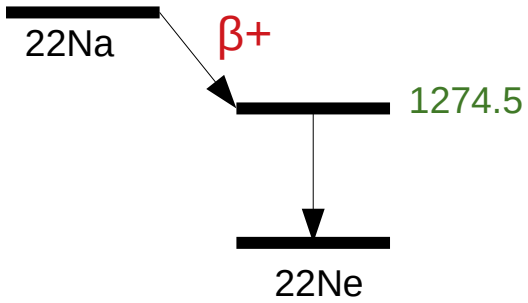
Firmware developed by:
Michael Bendel,
Max Winkel,
Benjamin Heiss,
Philipp Klenze,
Patrick Remmels,
et al.

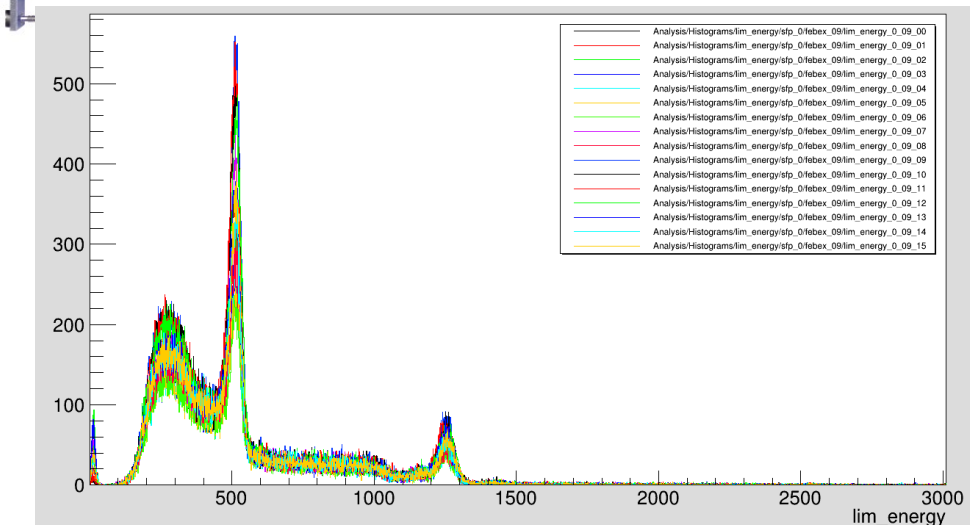
Automated APD Gain matching routine:

→ ensures that all channels cover same range

→ already pre-calibrated

E.g. 22Na decay:





Electronics for CALIFA

Each rack:

→ 1024 channels

→ 50 MHz continuous sampling rate

Dead-time free readout design:

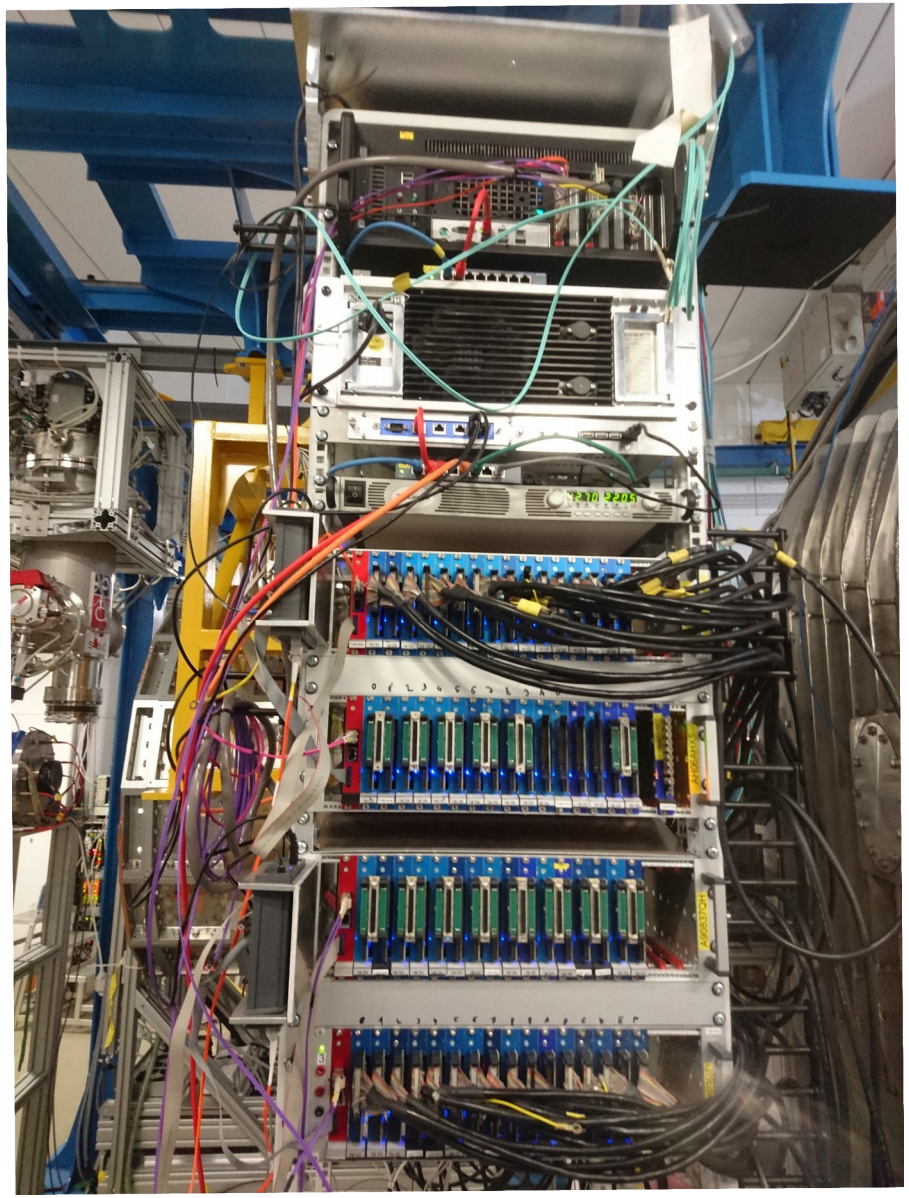
→ PEXOR card

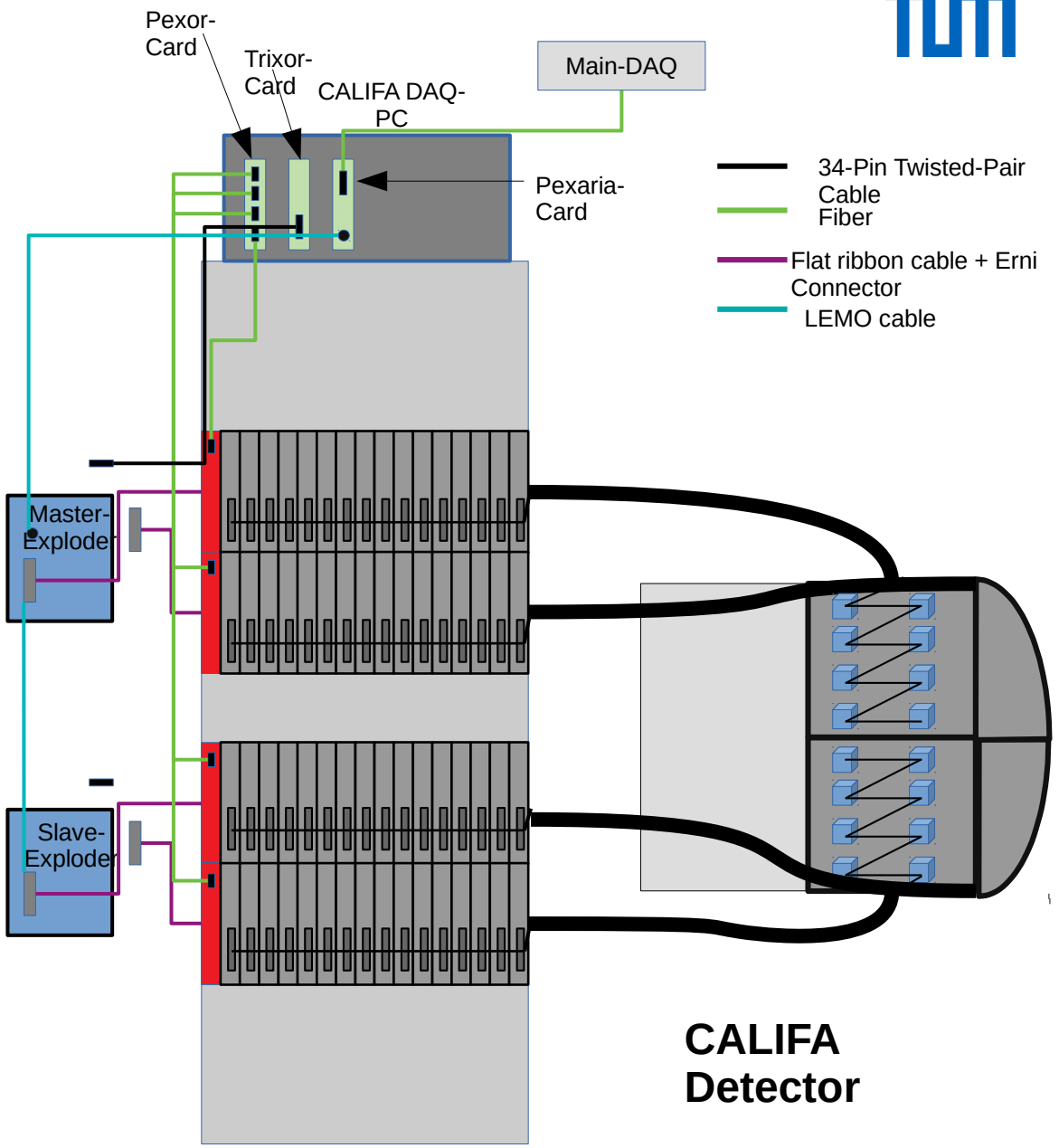
→ TRIXOR card

→ EXPLODER

→ PEXARIA (white

Rabbit timestamp)



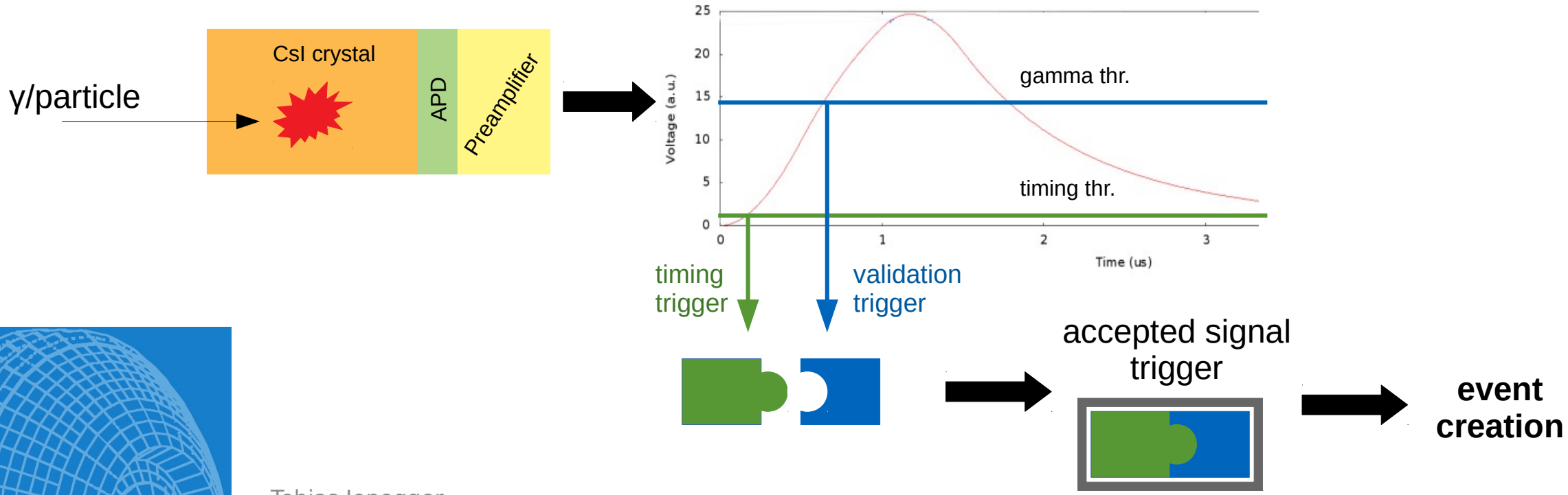


CALIFA Trigger Logic for event building

Trigger-Discriminator Logic:

→ Timing Trigger:event time assignment
→ Gamma Trigger: event validation
→ Proton Trigger: external trigger

Intuitive event building logic (free running mode):

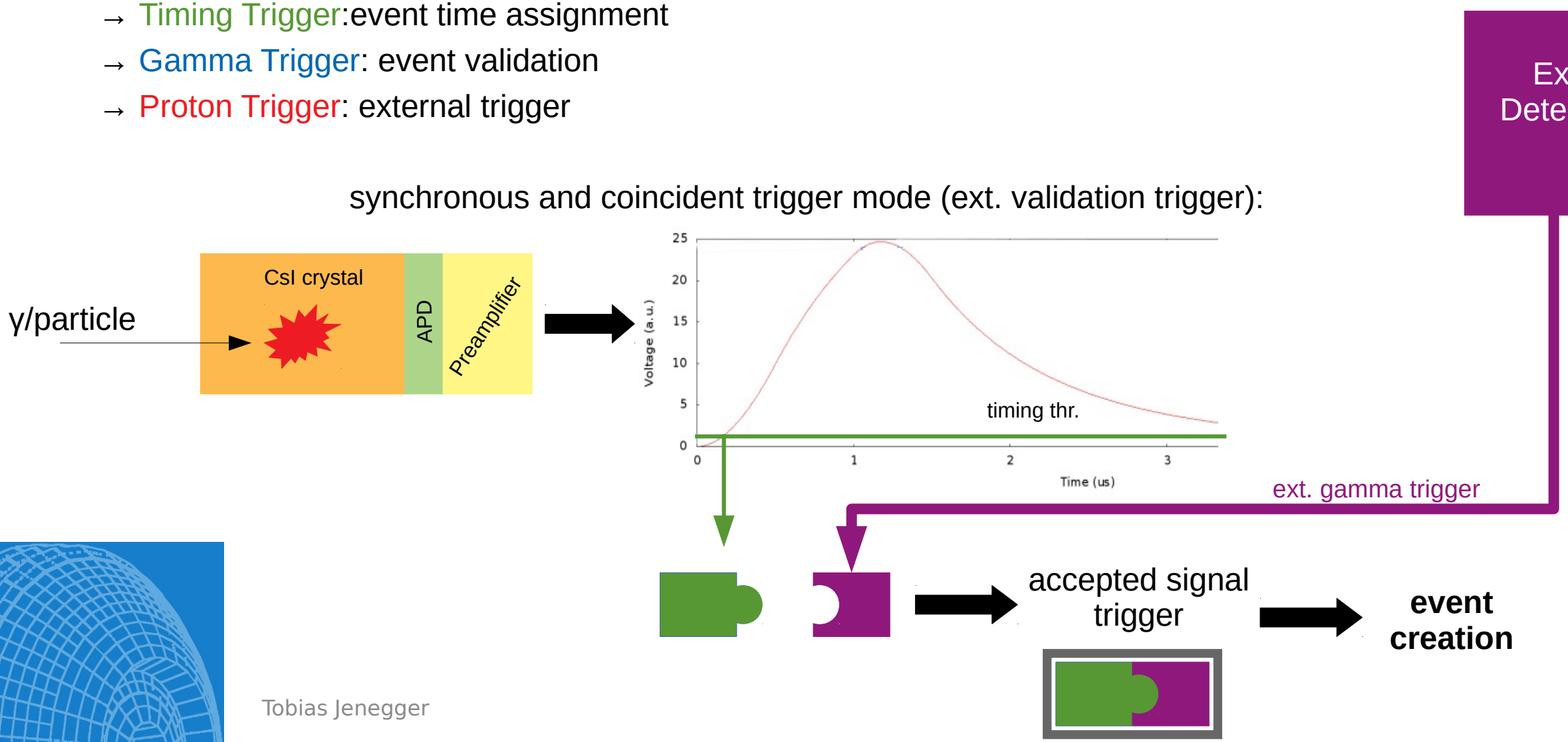


CALIFA Trigger Logic for event building

Trigger-Discriminator Logic:

→ Timing Trigger:event time assignment
→ Gamma Trigger: event validation
→ Proton Trigger: external trigger

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

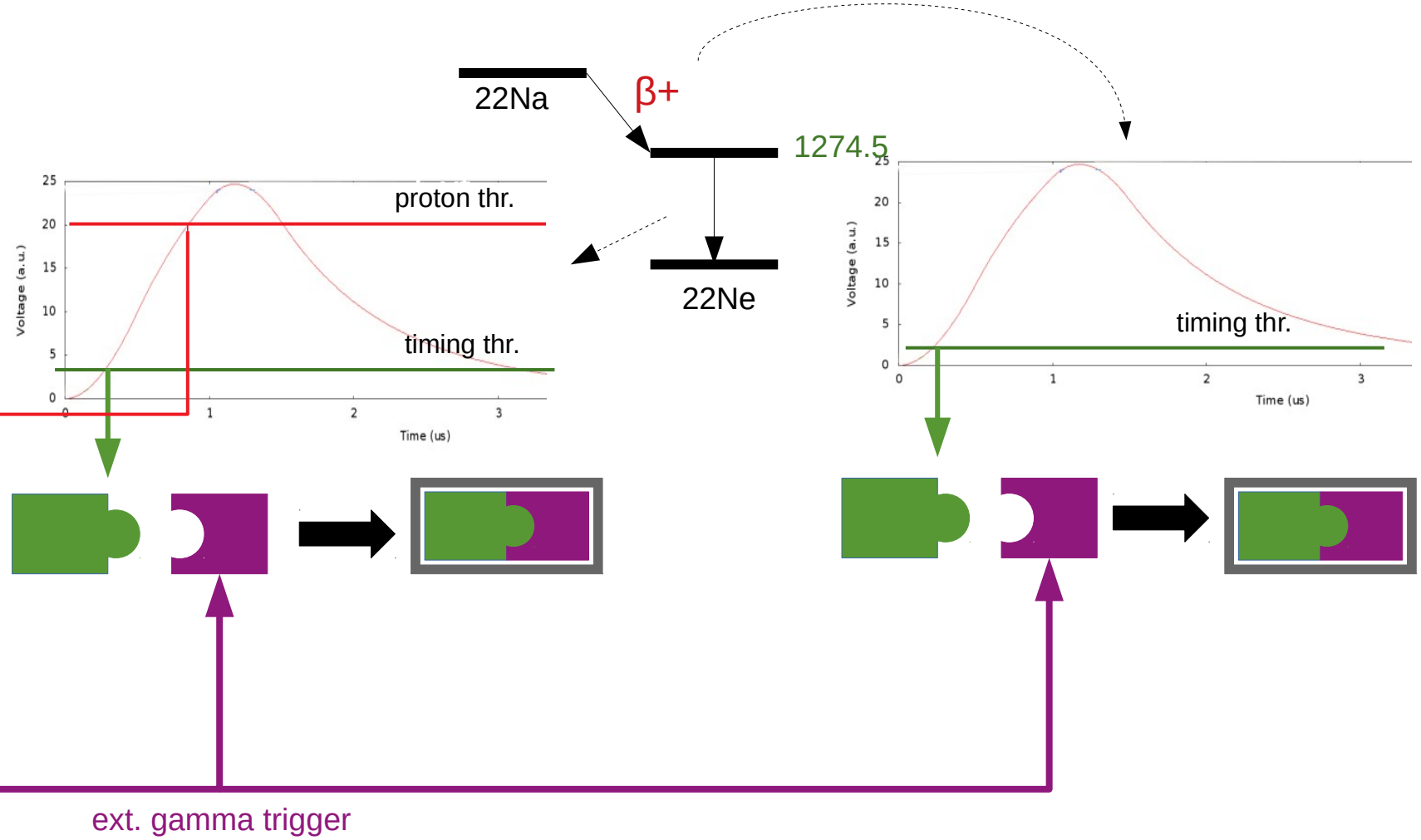


Setting to Synchronous and Coincident Trigger Mode

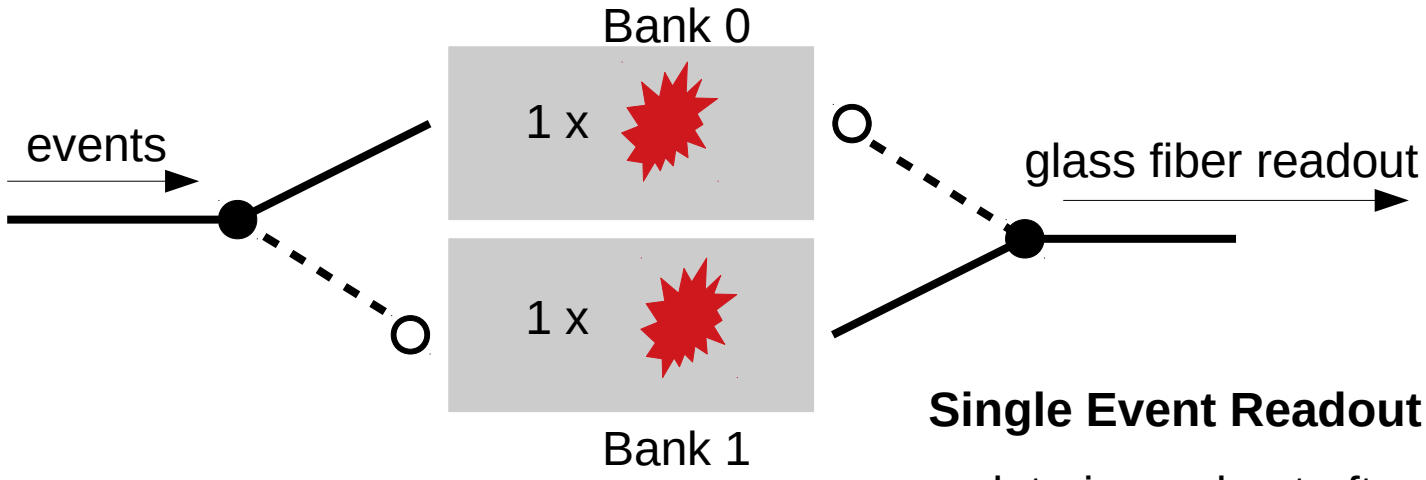
→ for experiment in May 2021 with He test beam
→ ext. gamma trigger from START detector

Testing:

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



CALIFA Readout Modes



Single Event Readout (std. Firmware):

→ data is read out after each accepted signal trigger

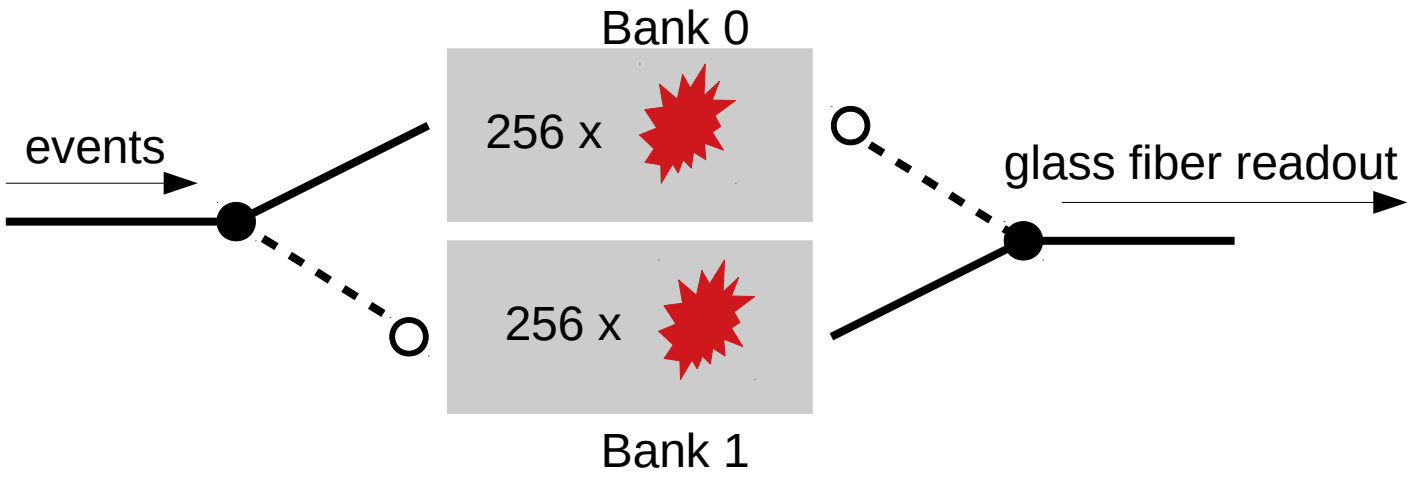
→ **dead time:**

if 2 events in Δt < 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 Δt < readout time

Given: 100kHz reaction rate at target

How many crystals can be hit per reaction event ?

$$190\,MB/s = 40\ Byte * 10^5 * x$$

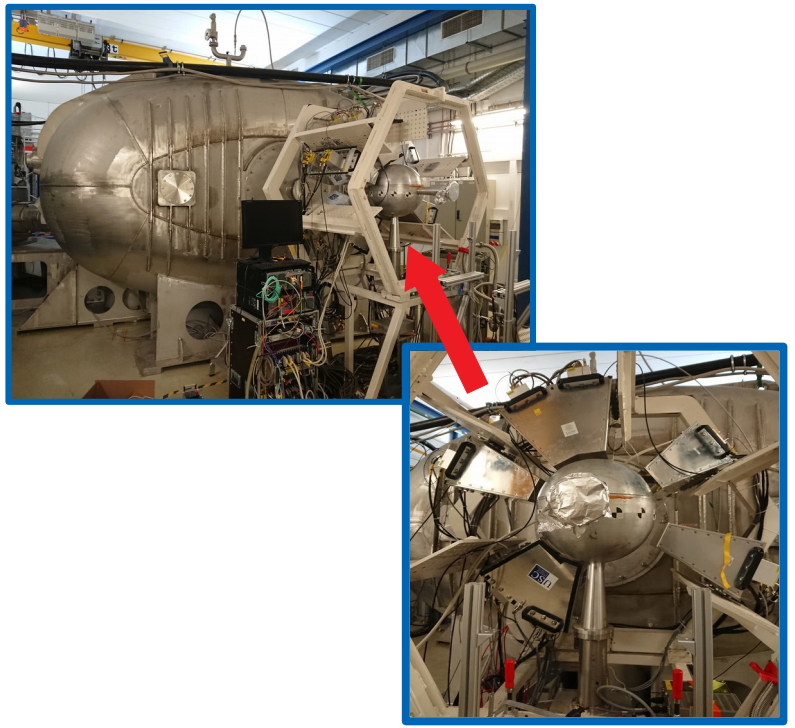
- $190\,MB/s$: max. readout speed per glass fiber
- $40\ Byte$: data size of single event
- 10^5: reaction rate
- x: max. crystal hits per reaction event: ≈ 45

For final design we have 10 glass fiber lines

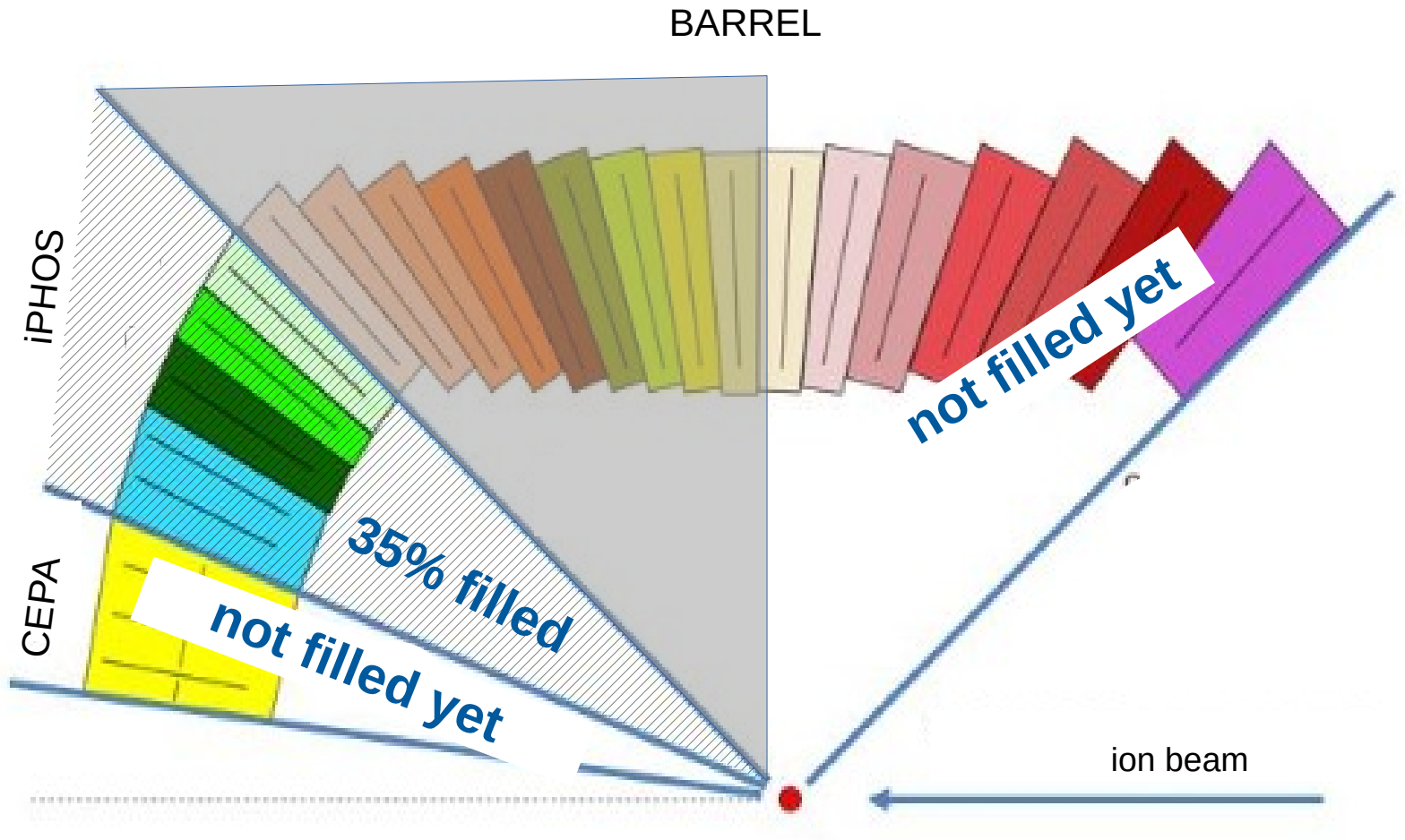
max. 450 crystal hits for 100kHz reaction rate

CALIFA Upgrade 2021

From Demonstrator to Final Setup



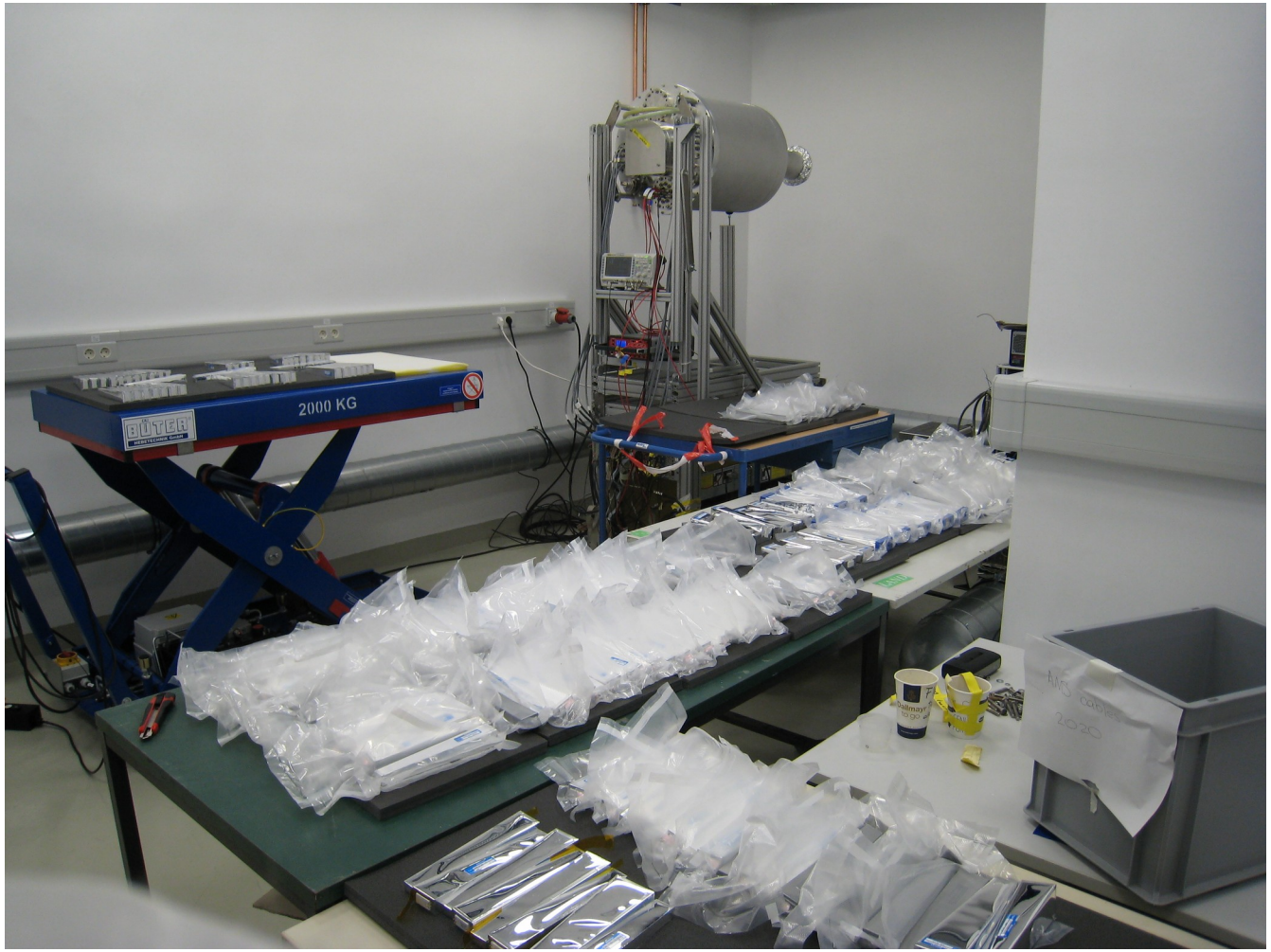
experiment of Lukas Ponnath



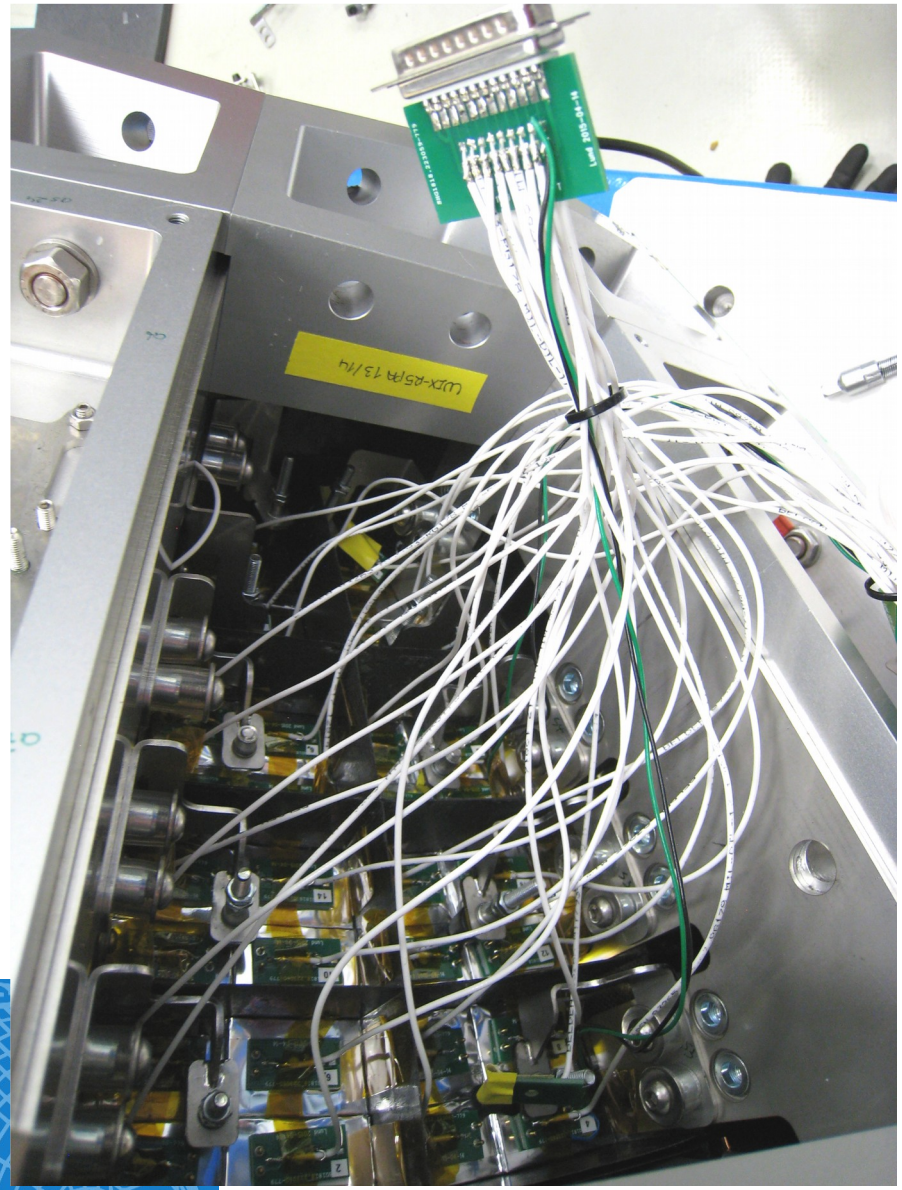
UPGRADE: iPHOS region fully filled!

unmounting:

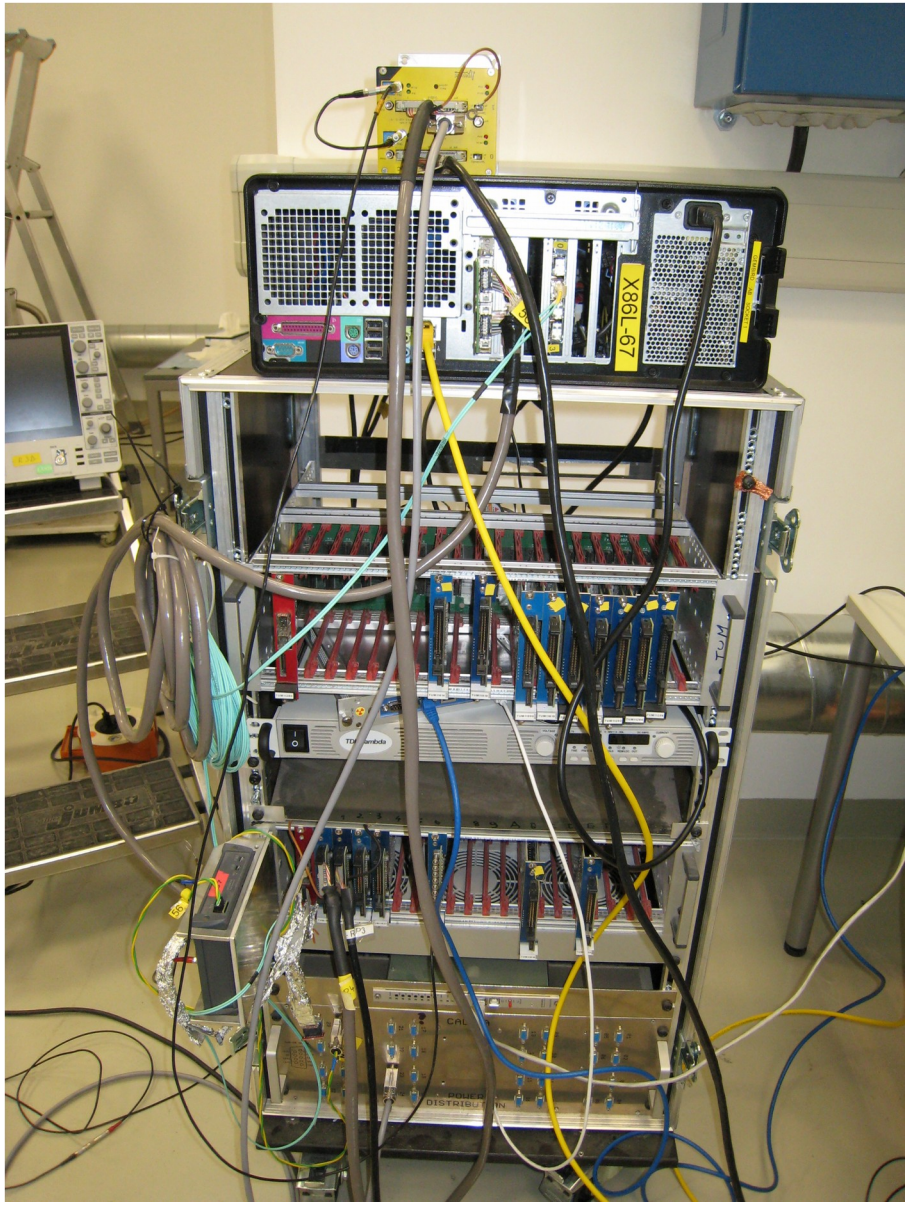
open tiles & measure crystals:



crystal filling:



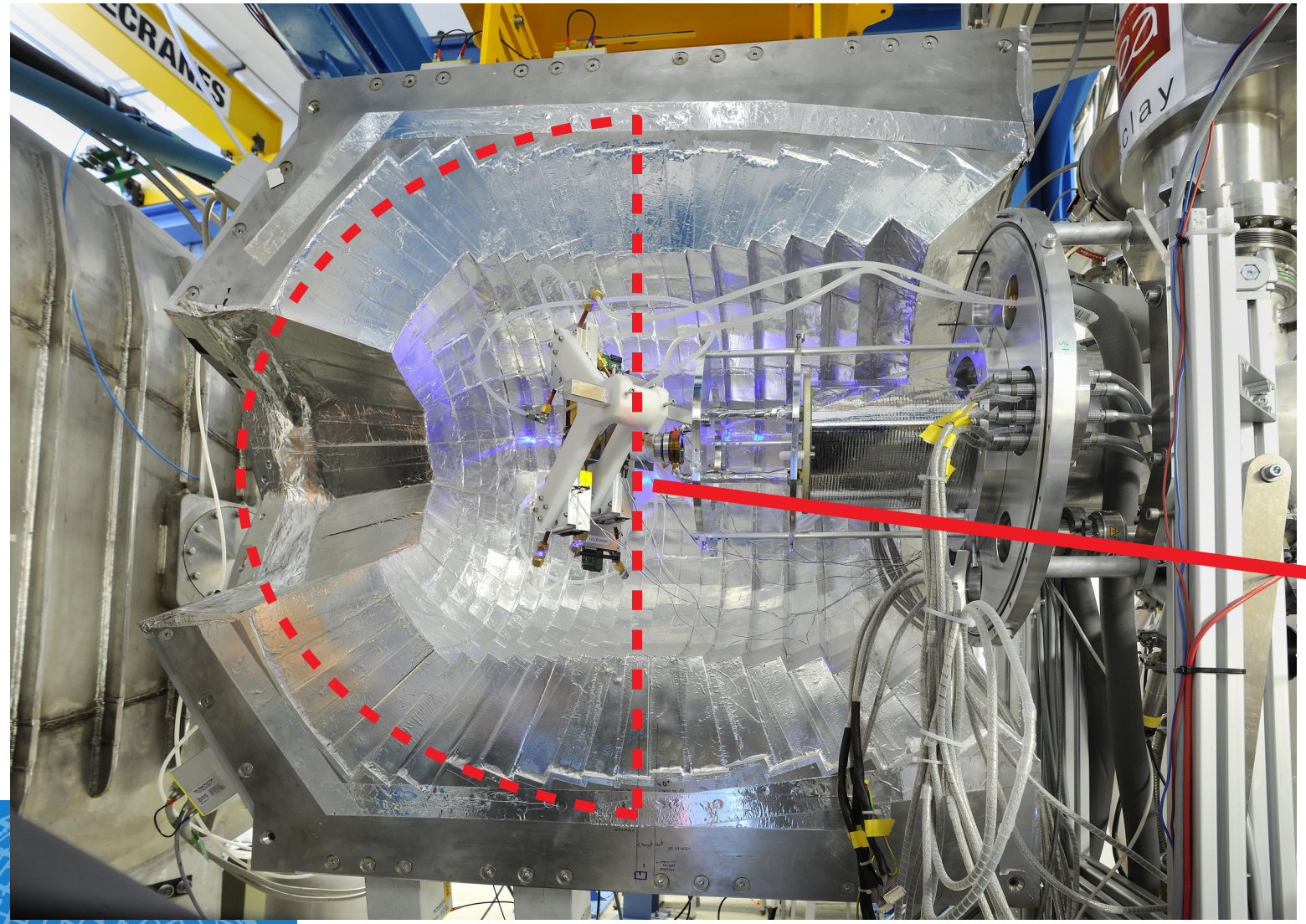
testing with mobile DAQ:



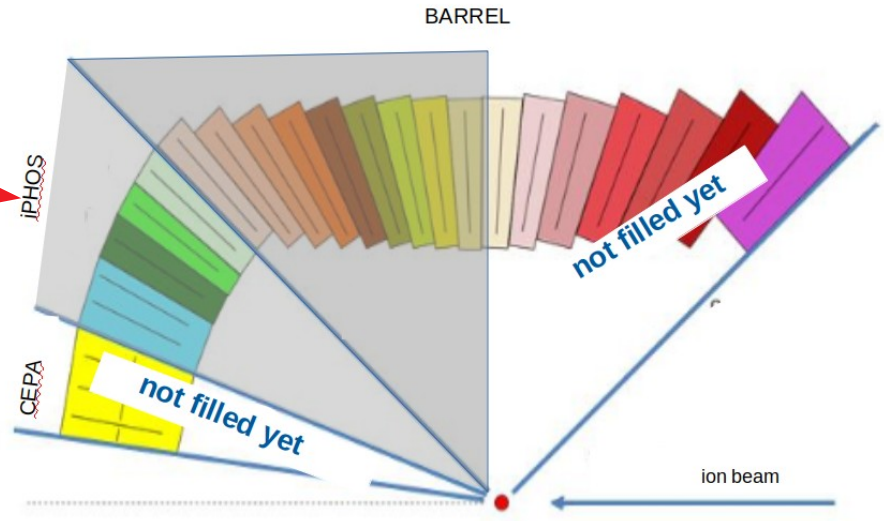
bring back to Cave C:

1.2 tons !

mount and align:



Fully filled forward half !



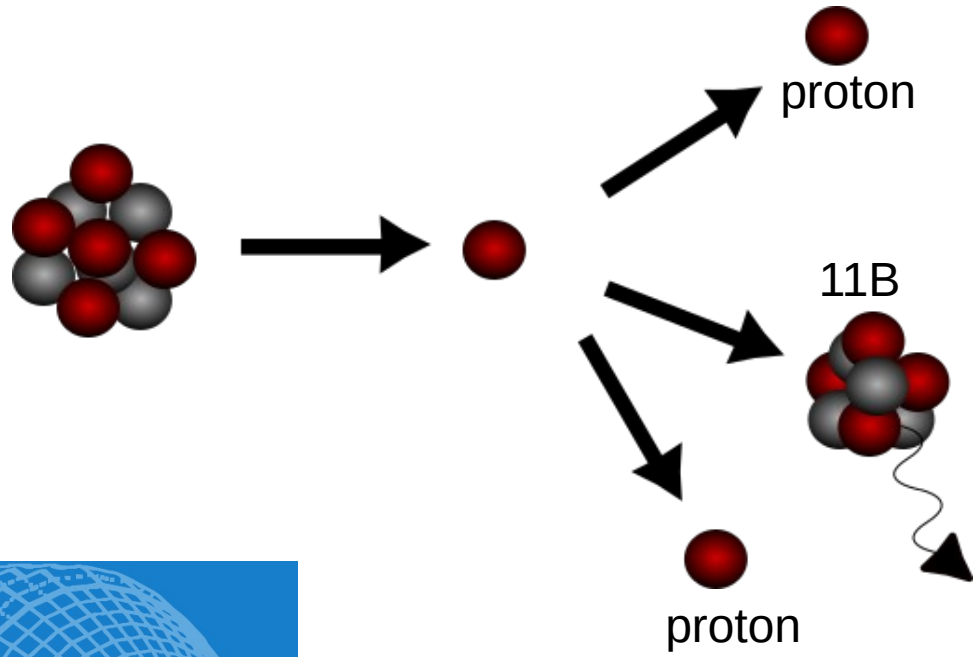
Quasi Free Scattering Analysis with Experiment S444/467 (2020)

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

- 12C beam
- proton like target

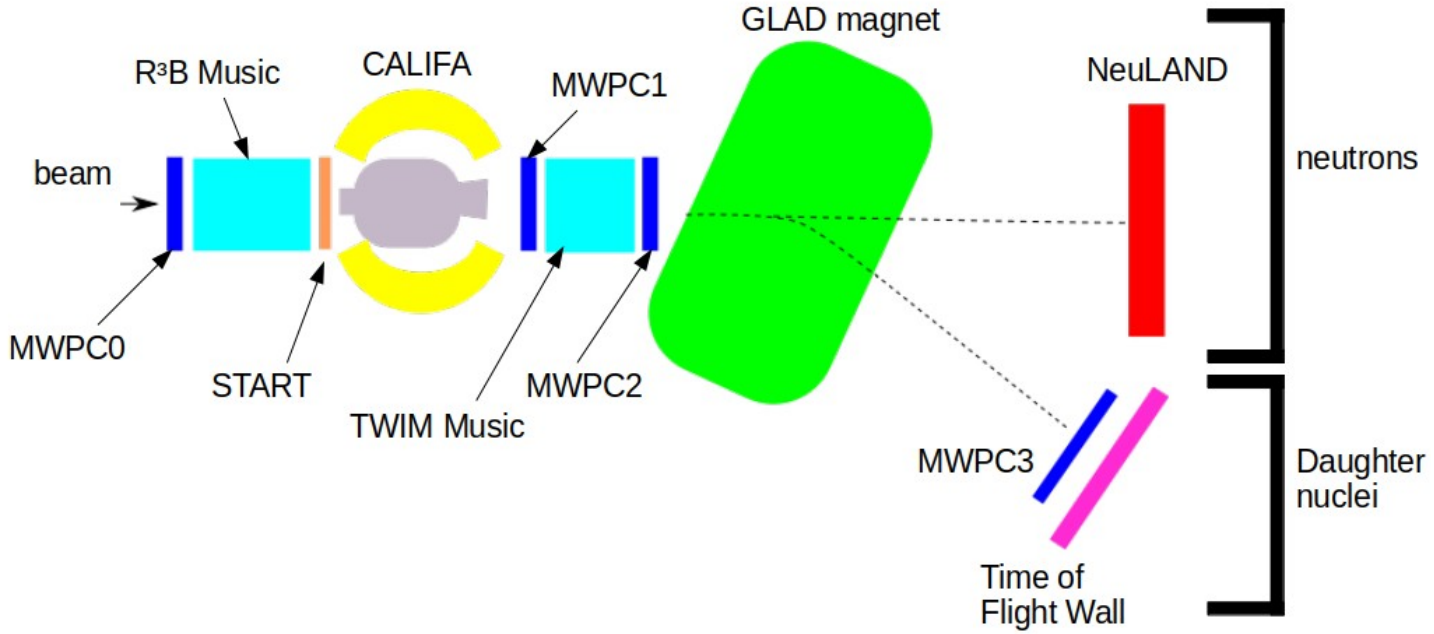
→

- 2 protons
- 11B fragment (spectator)



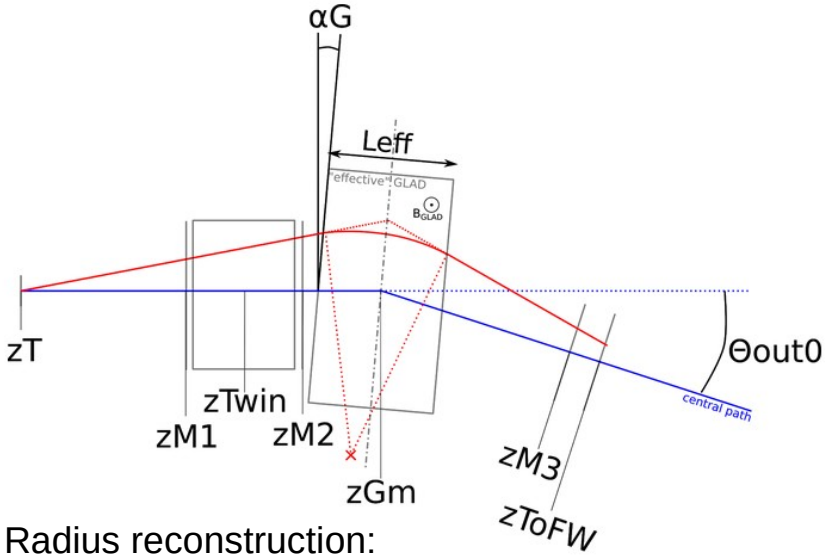
SETUP:

Beam energy: 400 AMeV
Beamtype: C^{12}
Target: CH2



Fragment Particle Identification

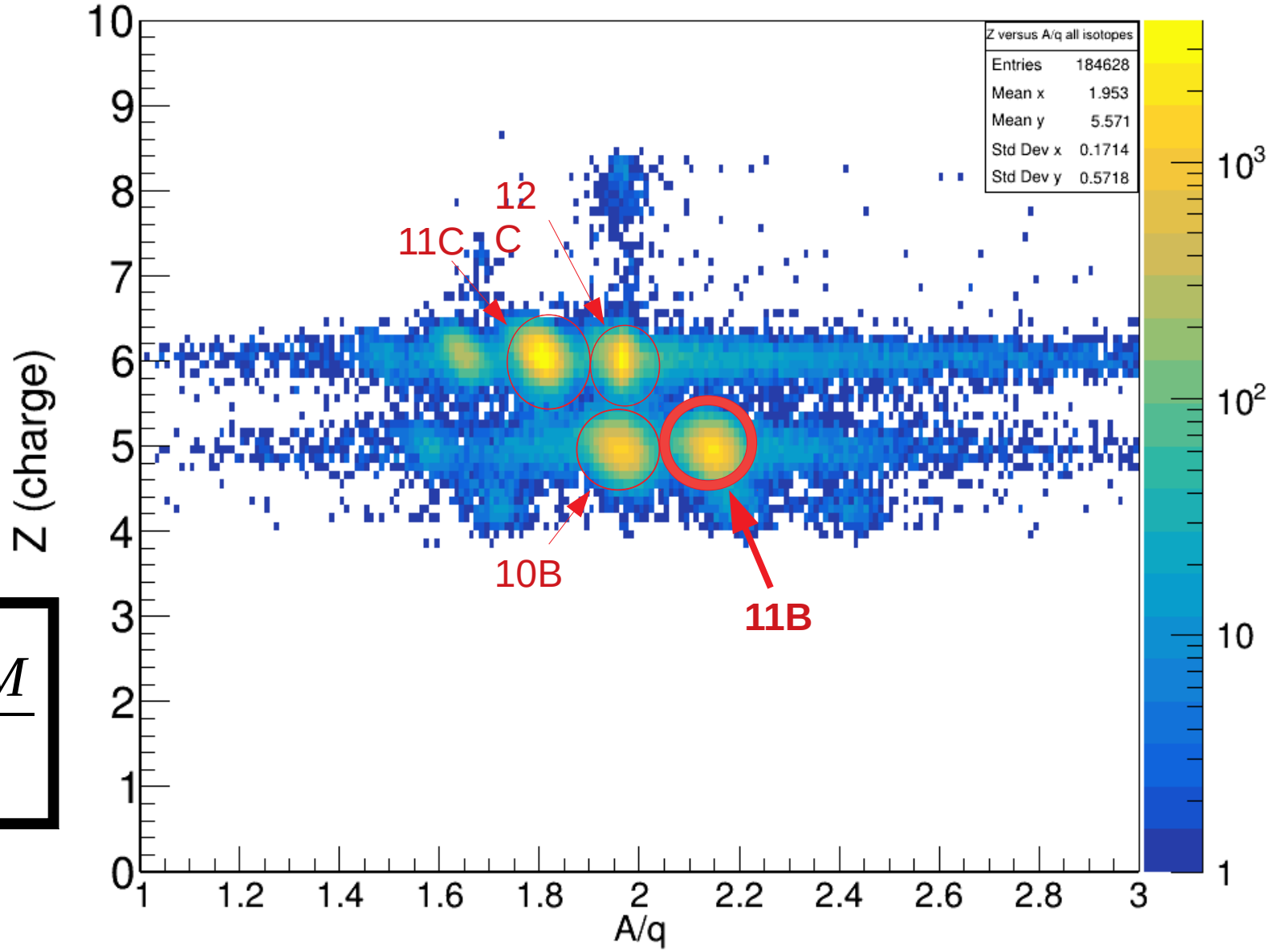
Flightpath reconstruction:



Radius reconstruction:

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

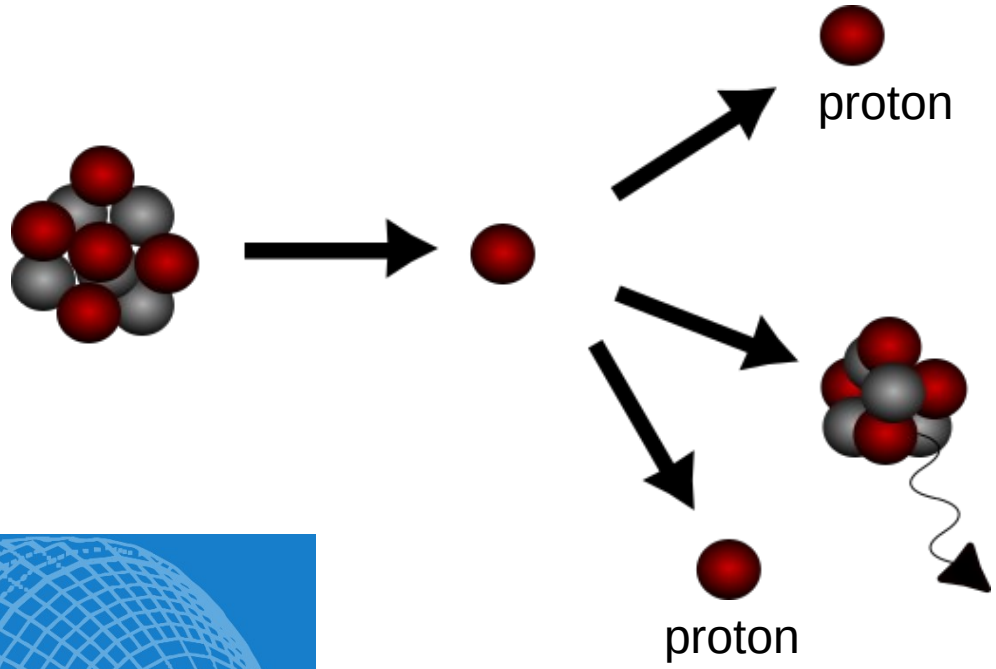
$$B*\rho = \frac{\beta * \gamma * M}{q}$$

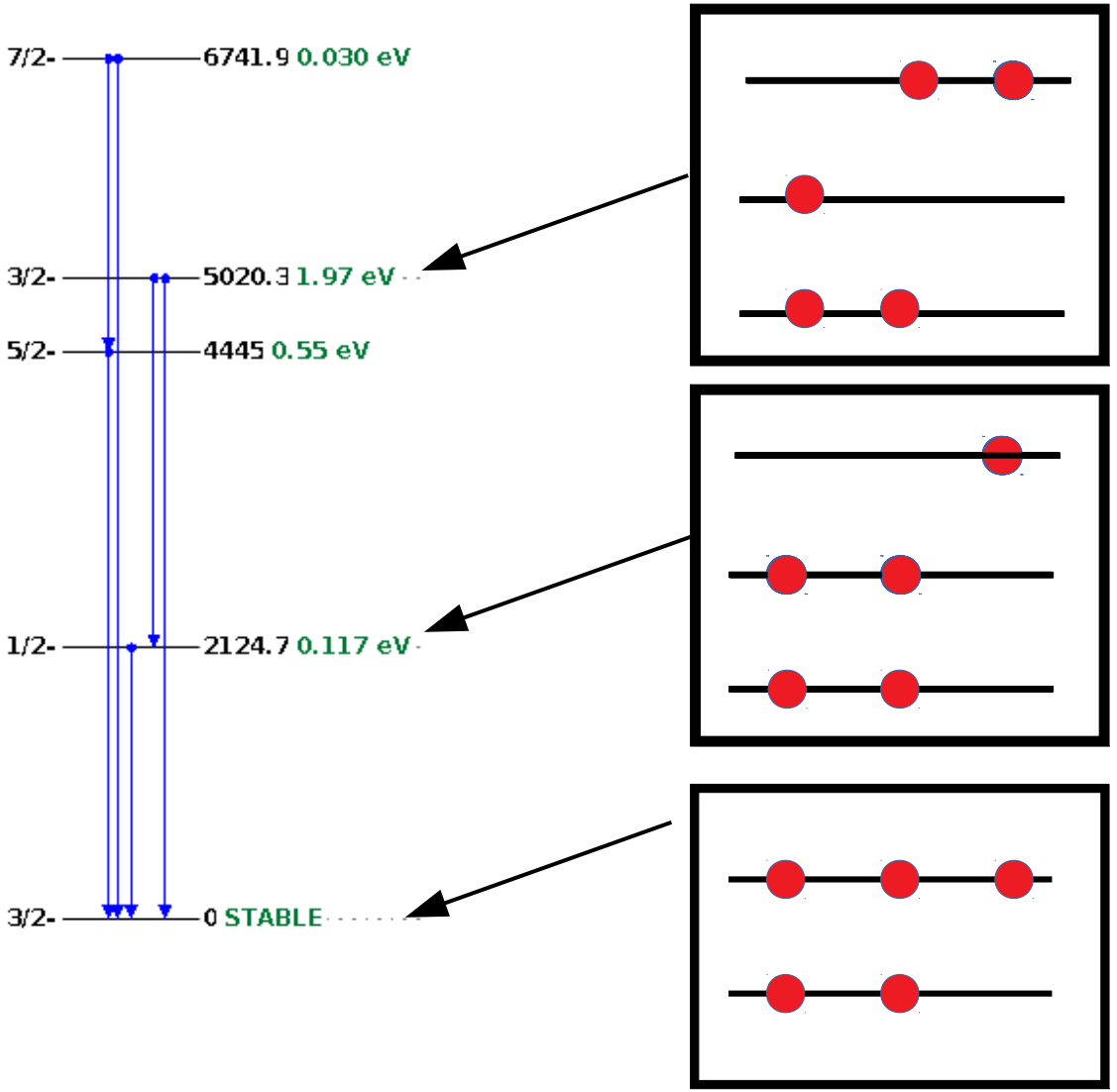


12C(p,2p)11B reaction

Two Proton Identification:

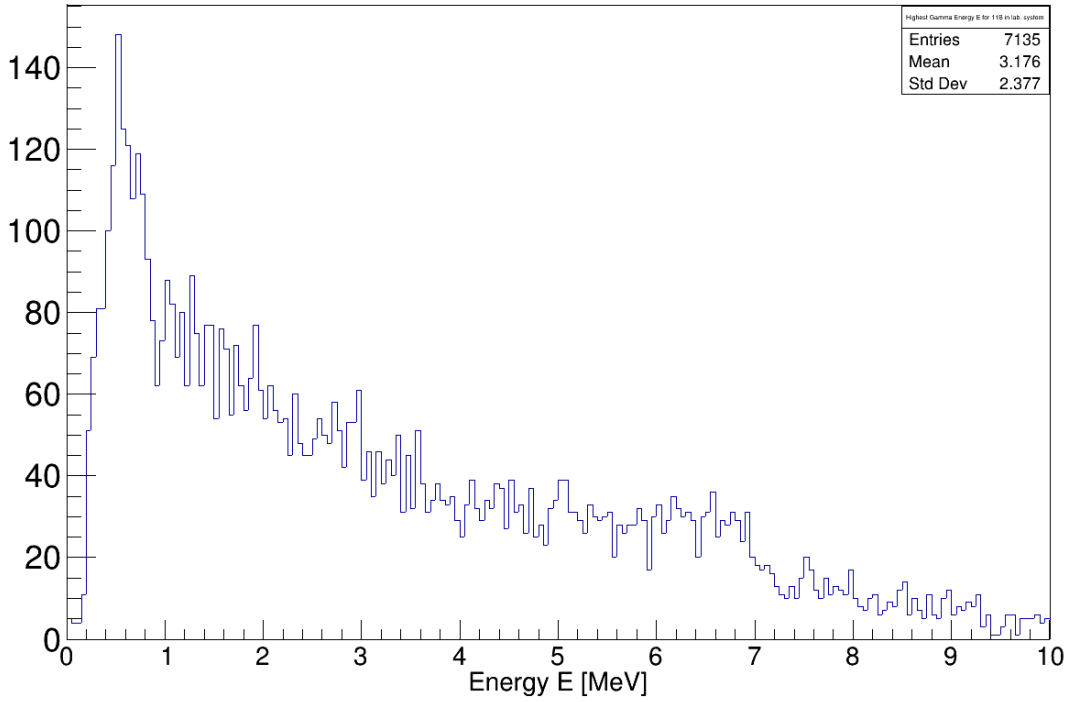
→ two hits with E_{hit} > 30 MeV





Gamma Spectrum of 11B

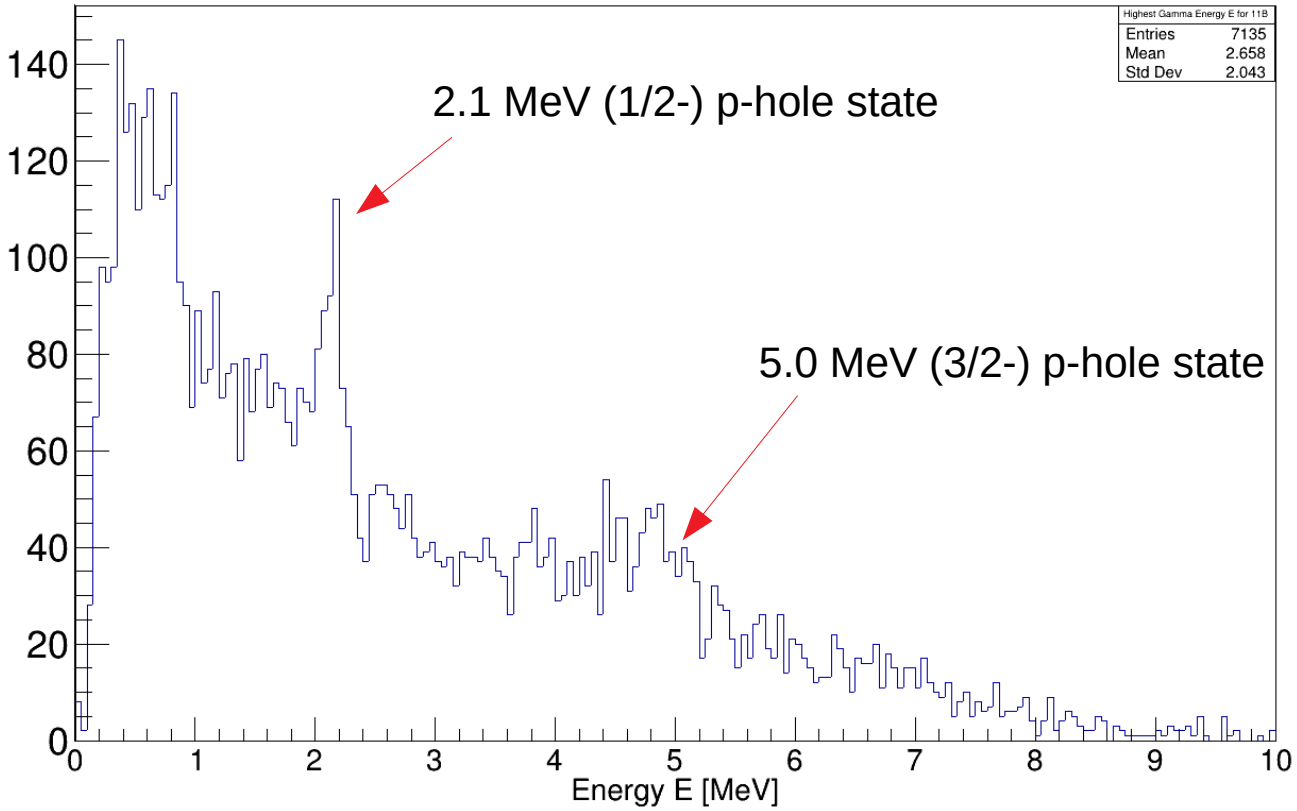
laboratory system



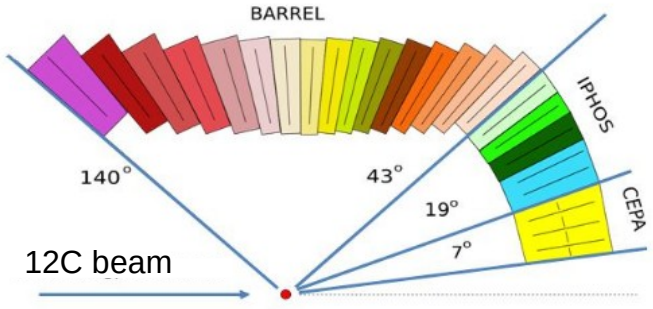
Doppler Correction:

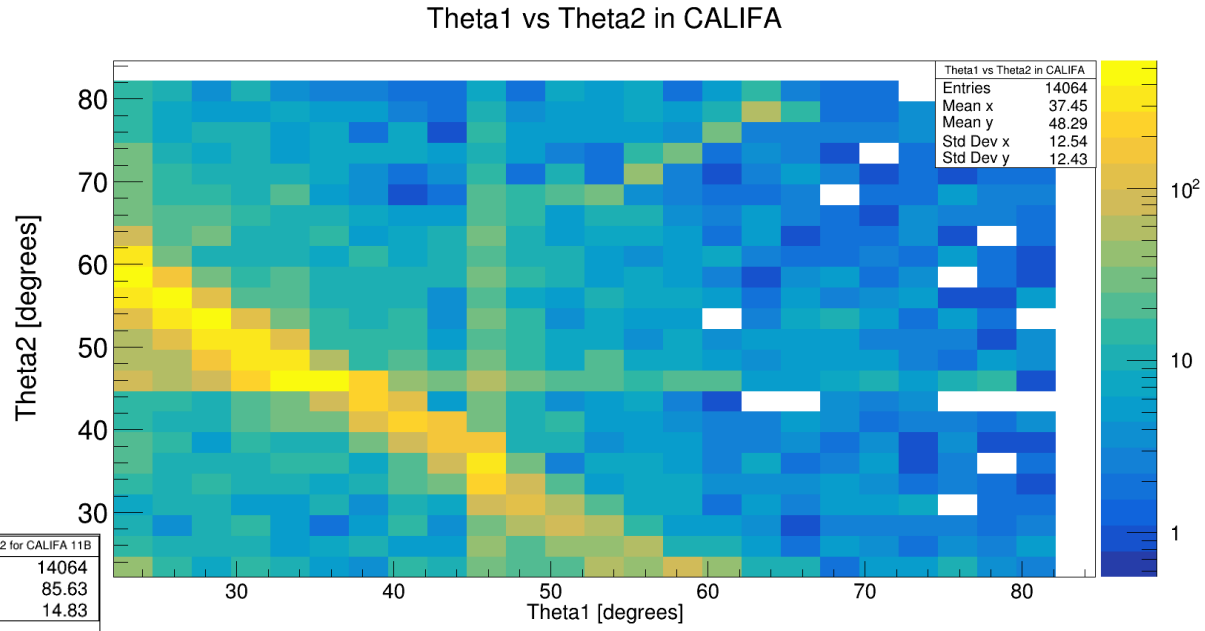
$$E_\gamma = \gamma E_{lab}\left(1-\beta\cos\left(\theta\right)\right)$$

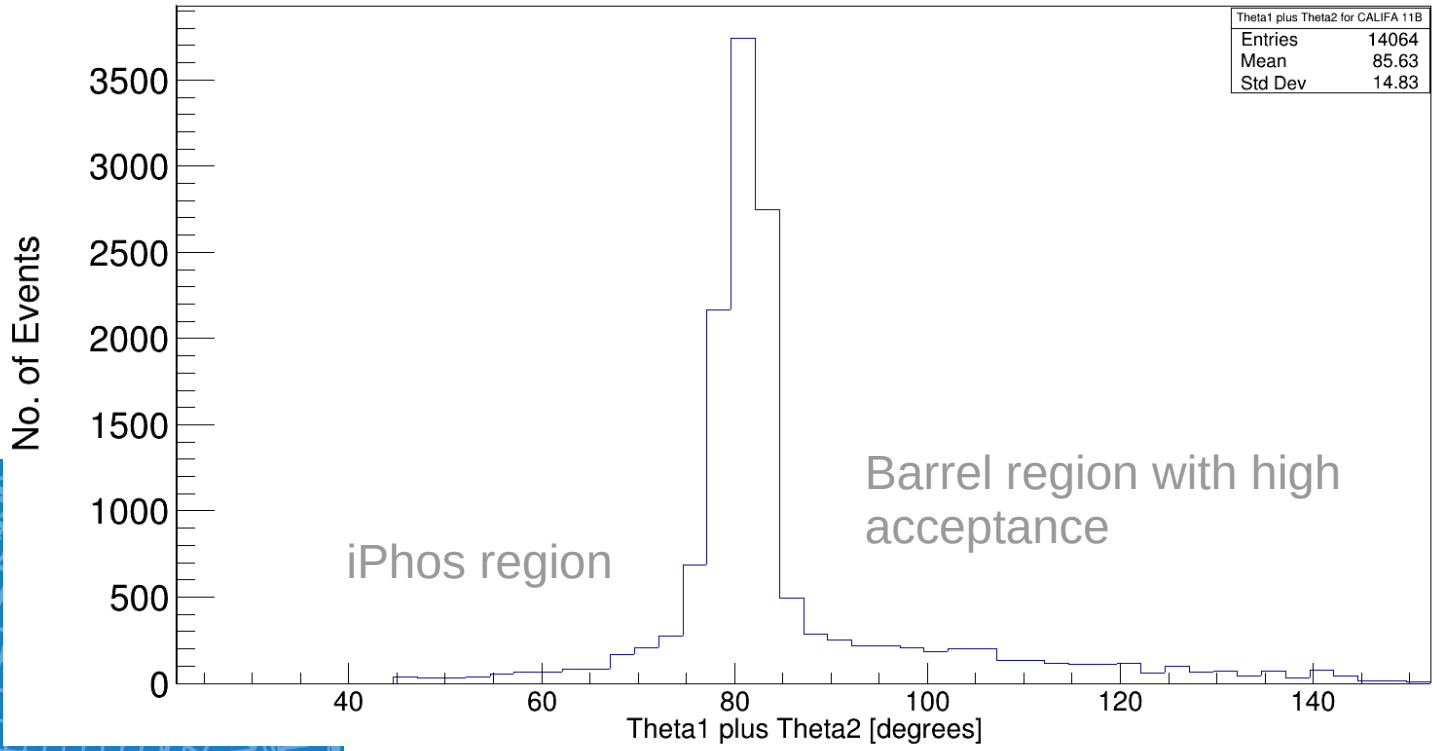
12C rest frame

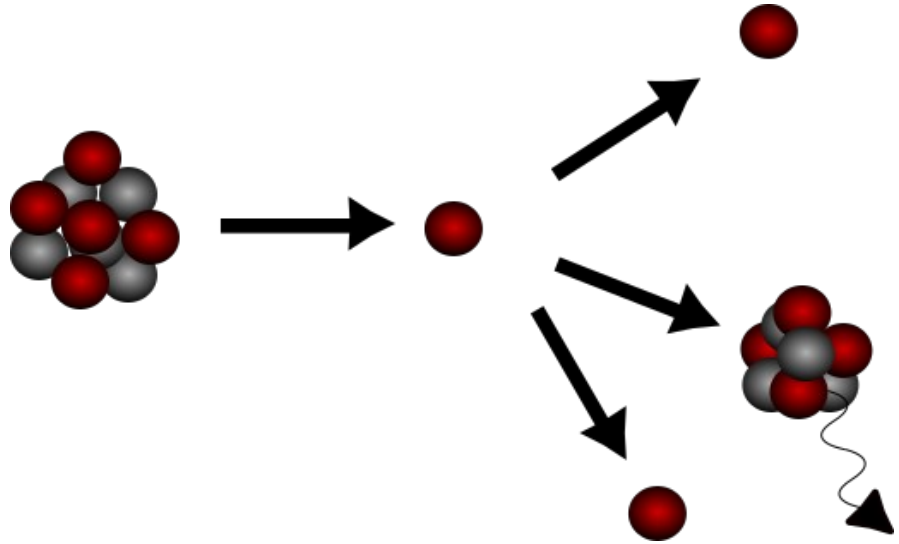


Polar Angular Distribution of protons for 12C(p,2p)11B

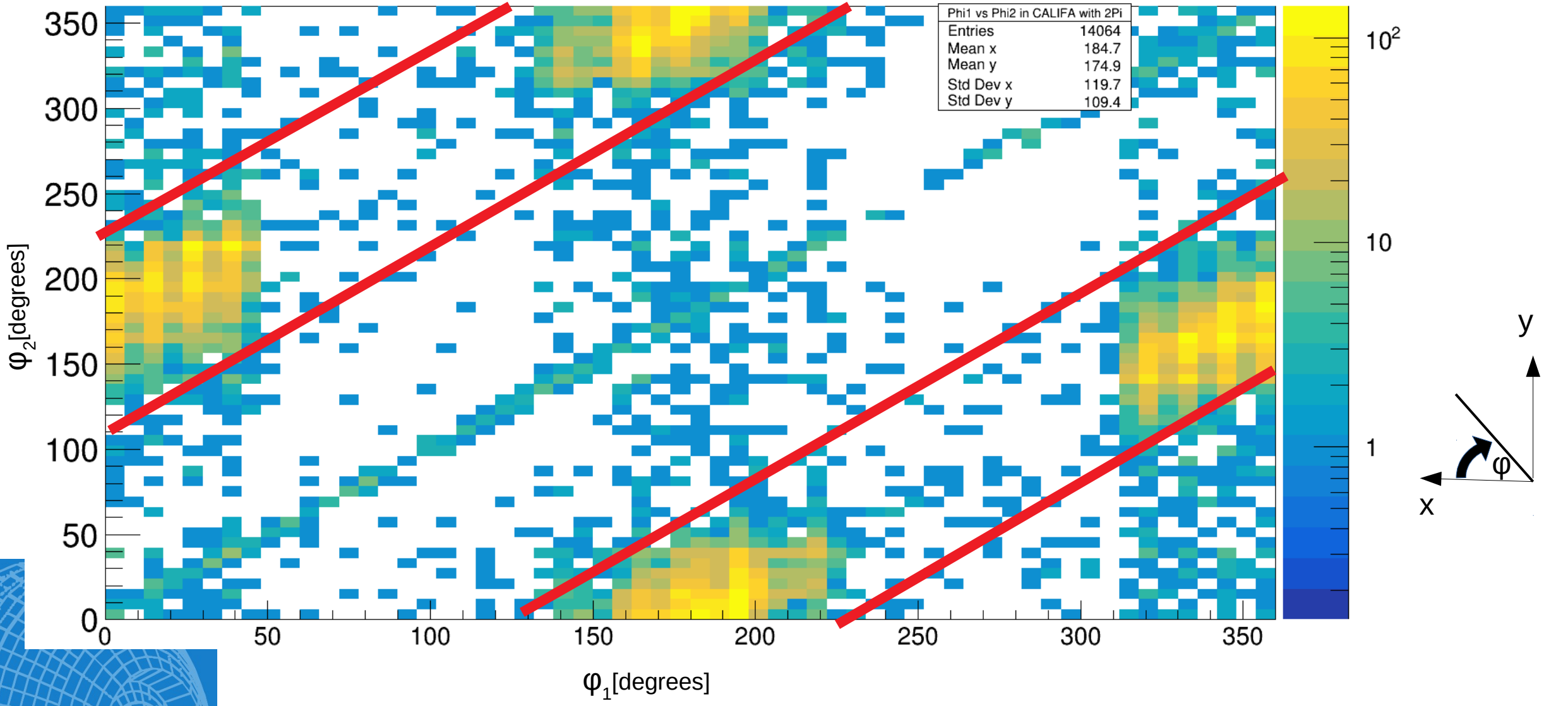








Arzimuthal Distribution of protons for 12C(p,2p)11B



Gamma Spectrum with Angular Cuts

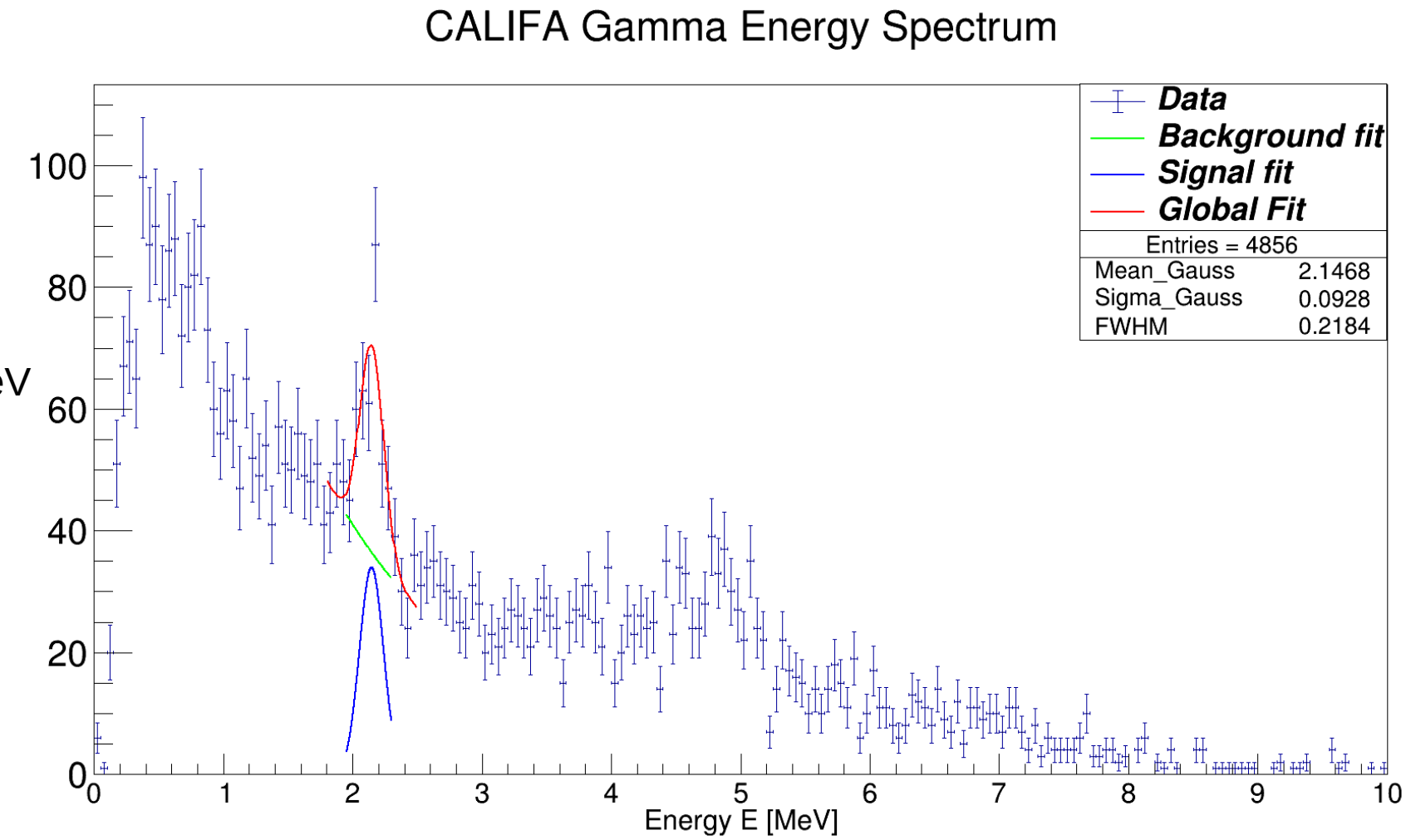
Event selection criteria for CALIFA:

→ 11B fragment identification

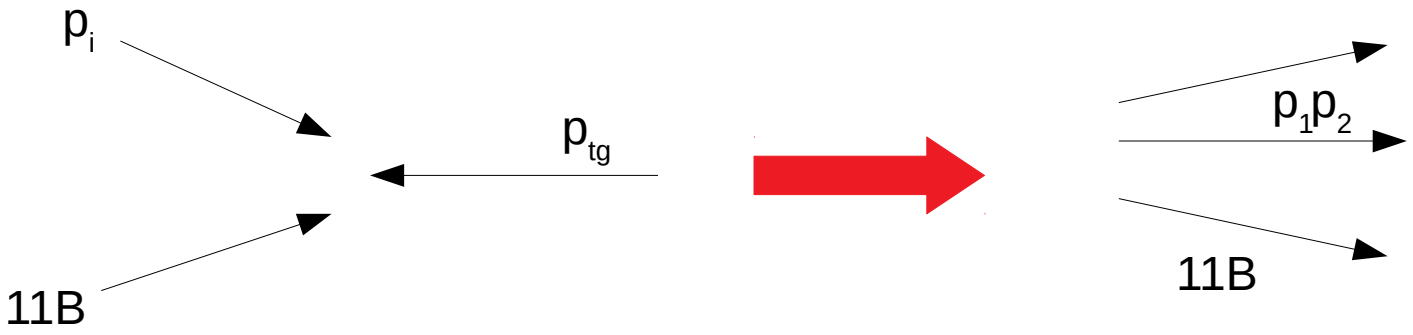
→ two hits (protons) with E_{hit} > 30 MeV

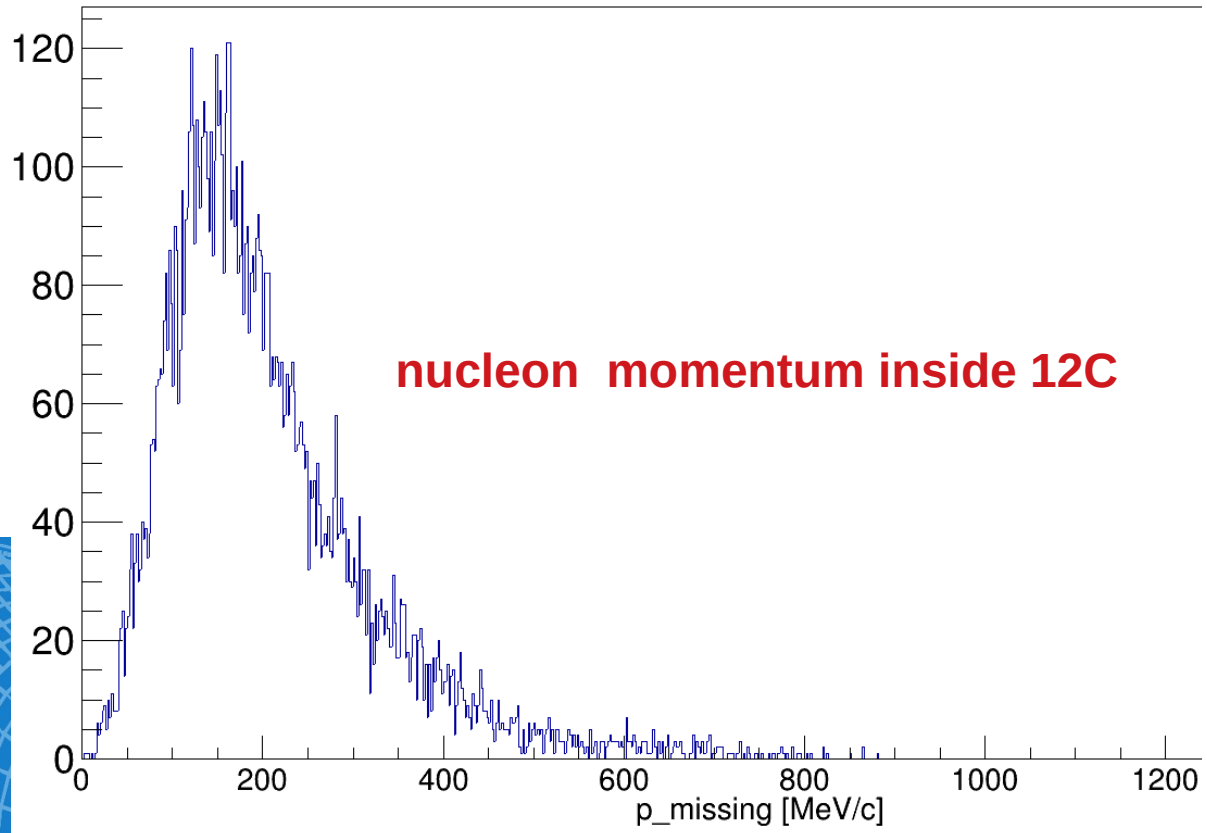
→ θ1 + θ2 < 90°

→ Δφ = 180° +- 40°



Reconstruction of Inner Momenta





nucleon momentum inside 12C

Momentum conservation relation:

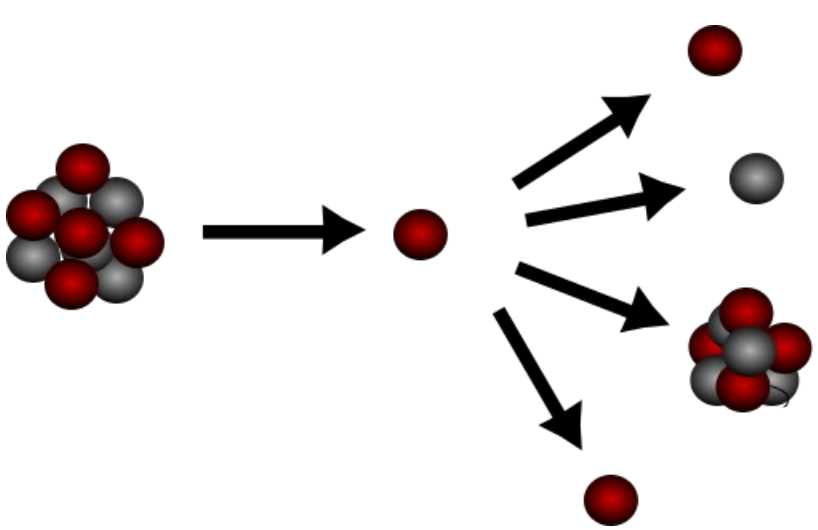
$$p_{12C} + p_{tg} = p_1 + p_2 + p_{11B}$$

assuming QE scattering in mean field potential:

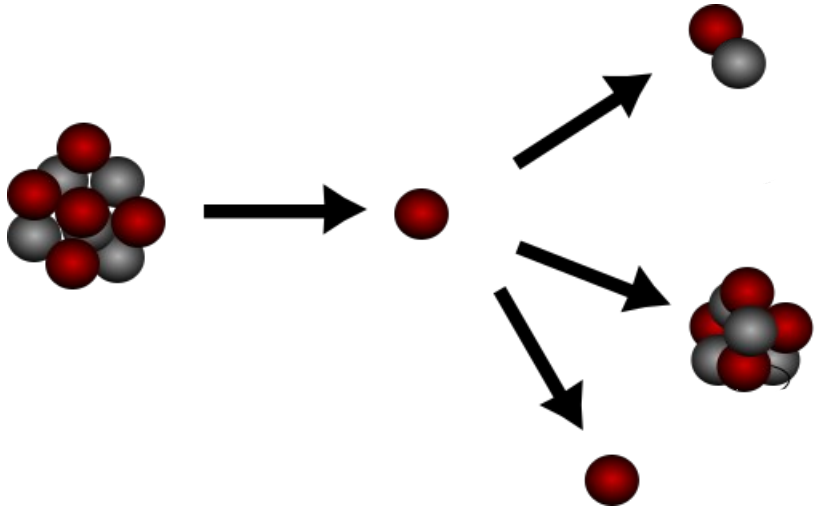
$$p_{12C} = p_i + p_{11B}$$

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

12C(p,ppn/pd)10B Reaction



or

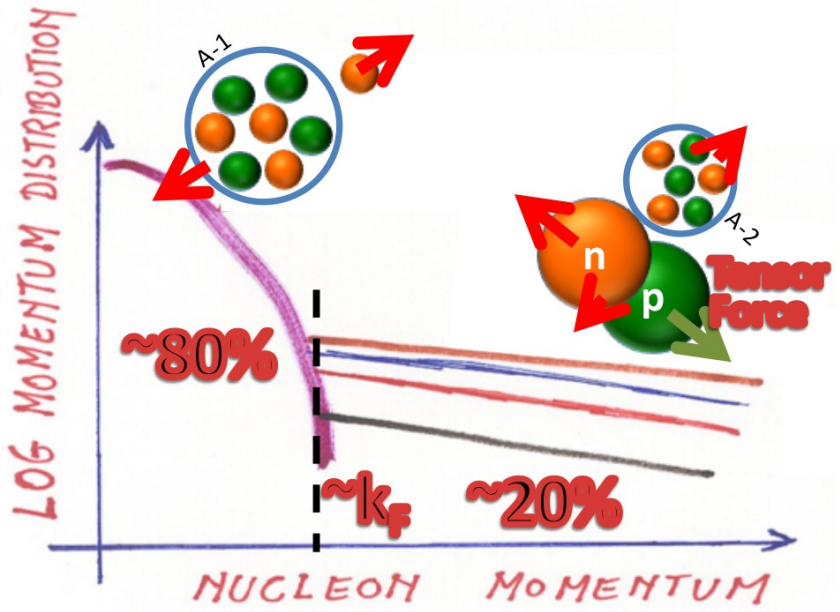


Short Range Correlations (SRC):

→ Possible explanation for EMC - effect

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

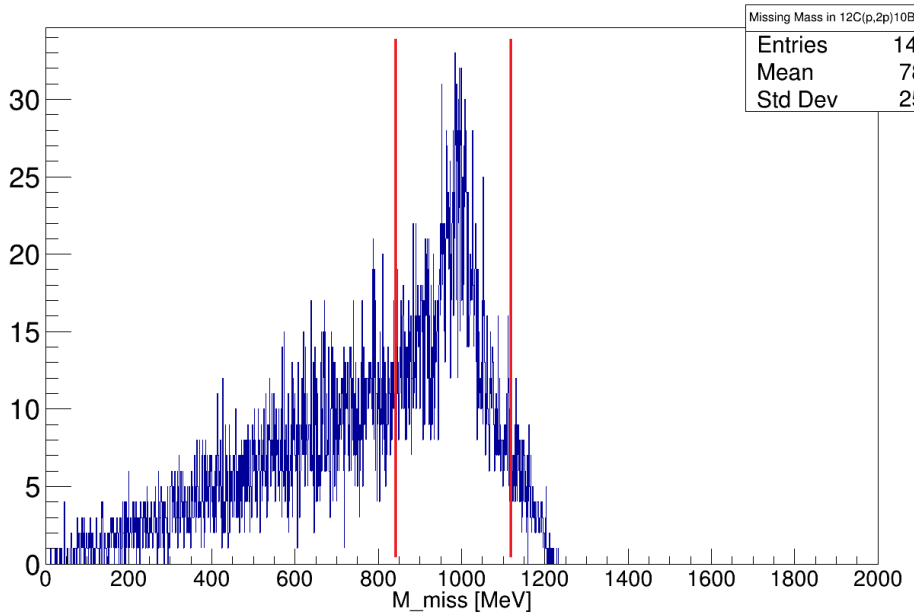
→ SRC exist in nuclei and account for about 20% of nucleons



First Angular and Momentum Plots …

Making cut on the reconstructed neutron:

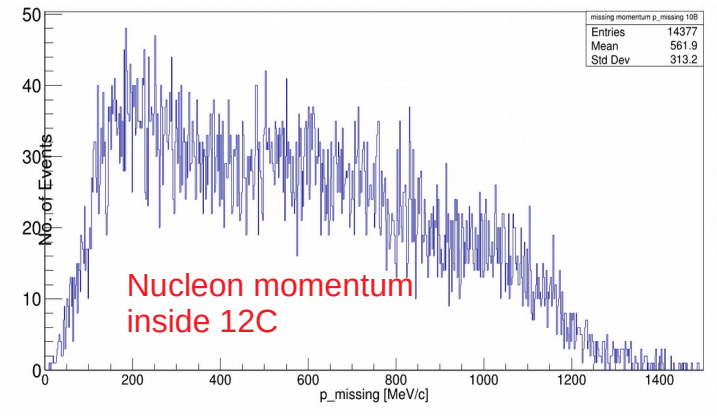
$$M^2_{missing} = (p_{12C} + p_{tg} - p_1 - p_2 - p_{10B})$$



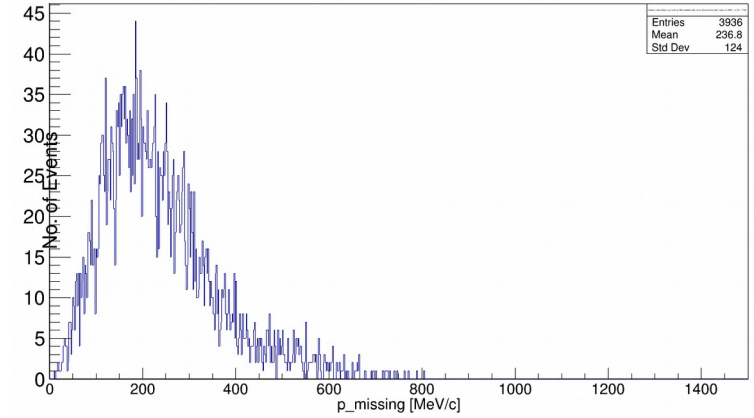
$M_{missing}$ cut

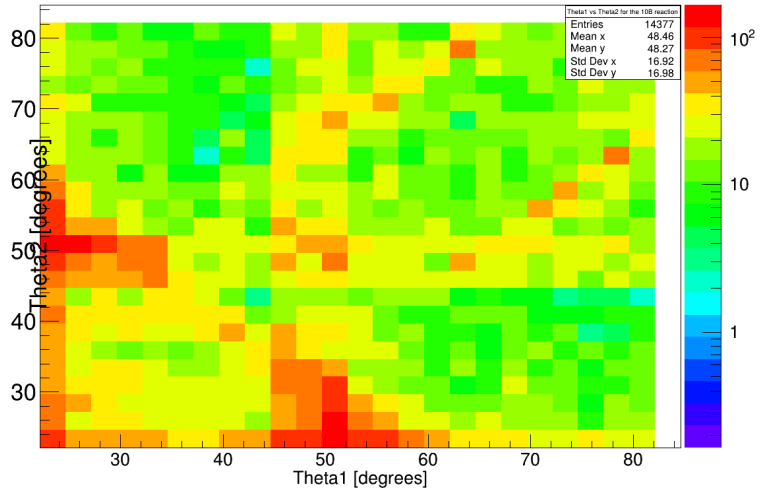
850 MeV < $M_{missing}$ < 1100 MeV

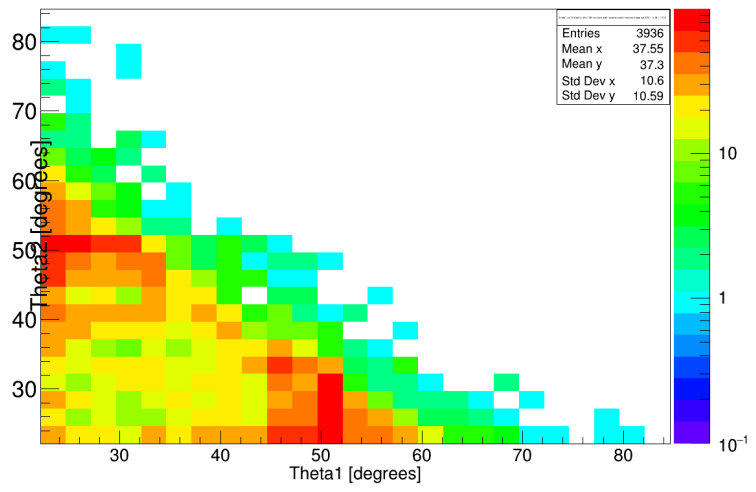
Without cut:



With reconstructed neutron mass cut:



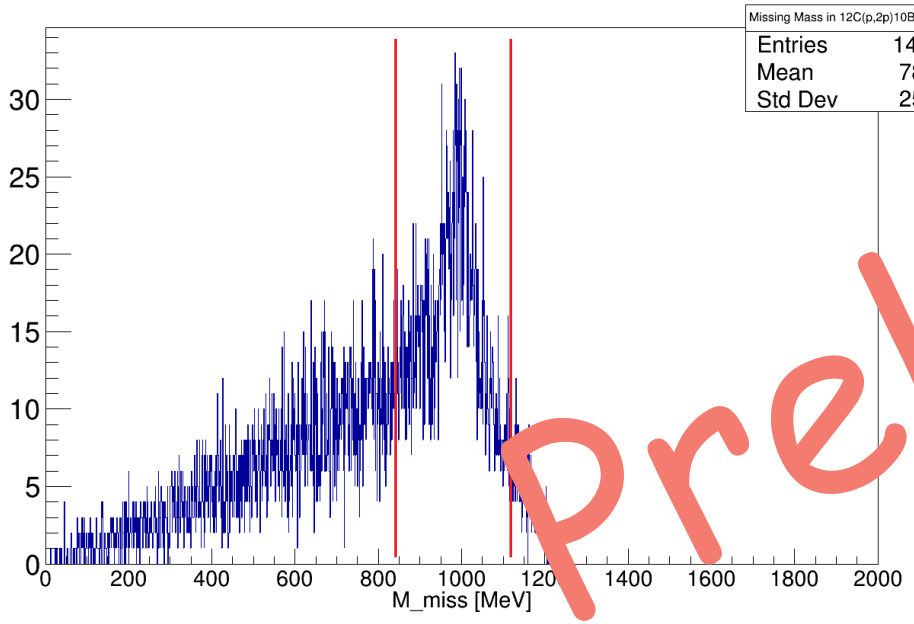




First Angular and Momentum Plots …

Making cut on the reconstructed neutron:

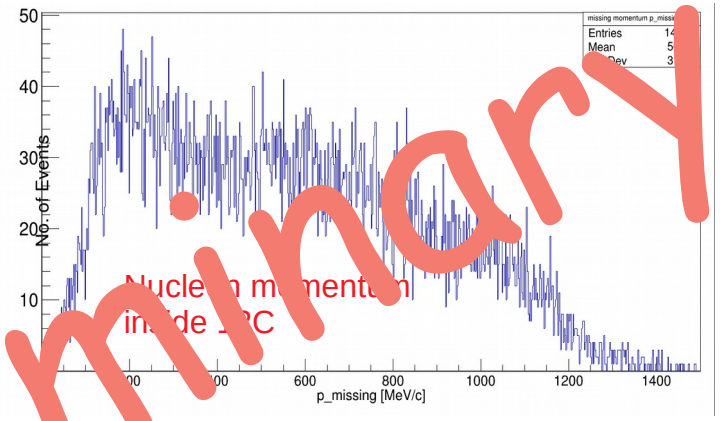
$$M^2_{missing} = (p_{12C} + p_{tg} - p_1 - p_2 - p_{10B})$$



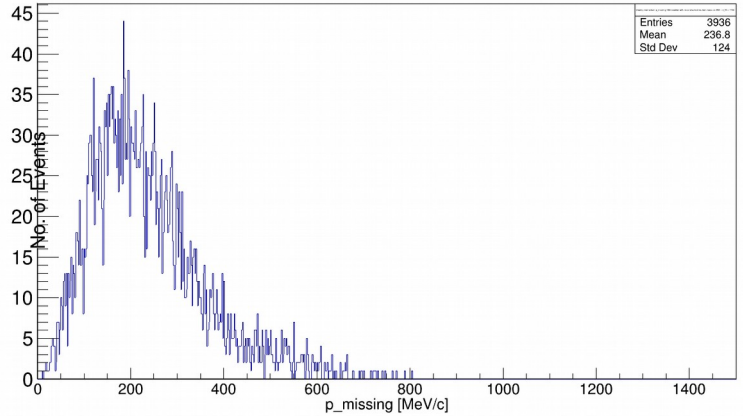
$M_{missing}$ cut

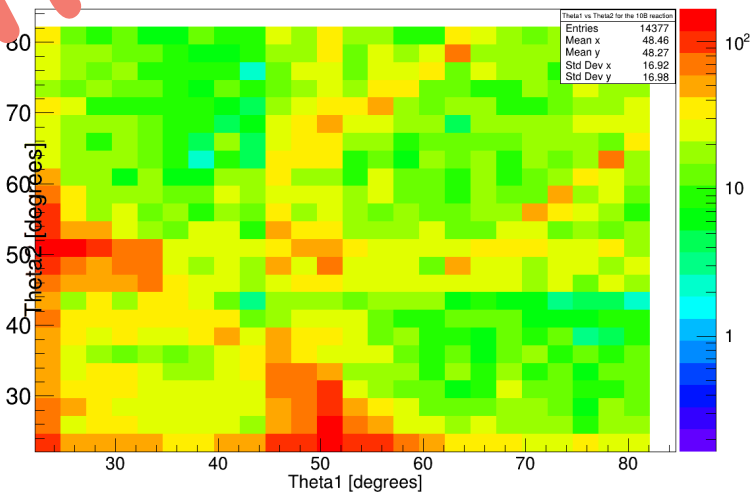
850 MeV < $M_{missing}$ < 1100 MeV

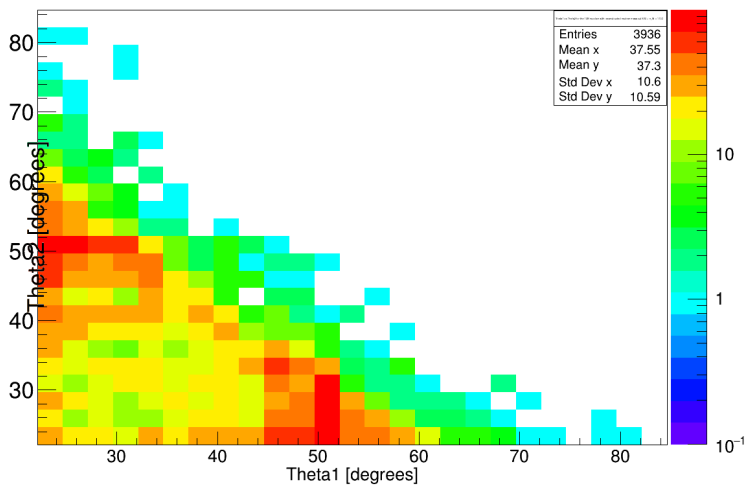
Without cut:



With reconstructed neutron mass cut:







Summary & Outlook

→ further investigations for the 12C(p,ppn/pd)10B reaction channel needed

→ promising first analysis results from 12C(p,2p)11B reconstruction

→ looking forward to exciting upgrade of CALIFA filling the Barrel (backward) region and the most forward CEPA region

Thank you!

CALIFA @ Technical University of Munich (TUM)

Roman Gernhäuser, Lukas Ponnath, Philipp Klenze, Tobias Jenegger

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

GSI

FAIR Phase 0 Research Program

Backup