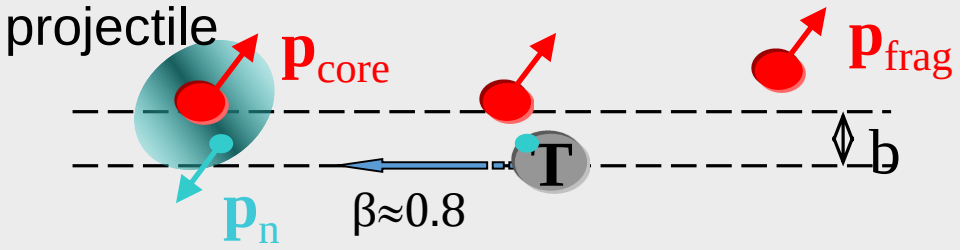
CALIFA Demonstrator @ Krakow

Benjamin Heiss

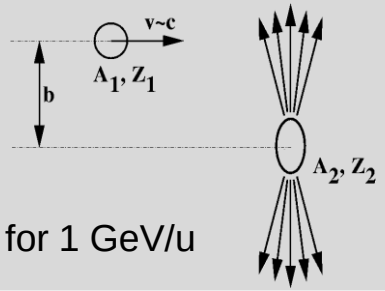
PSI Seminar
January 10th 2018

R³B Reactions with radioactive beams

knockout reactions
- heavy residue + γ

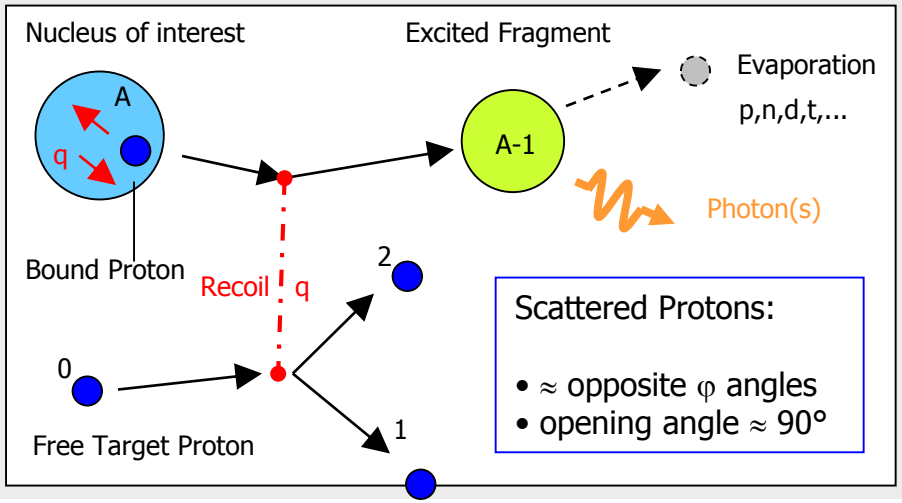


Coulomb excitation
- light + heavy ejectiles + γ



E_{max}=25MeV for 1 GeV/u

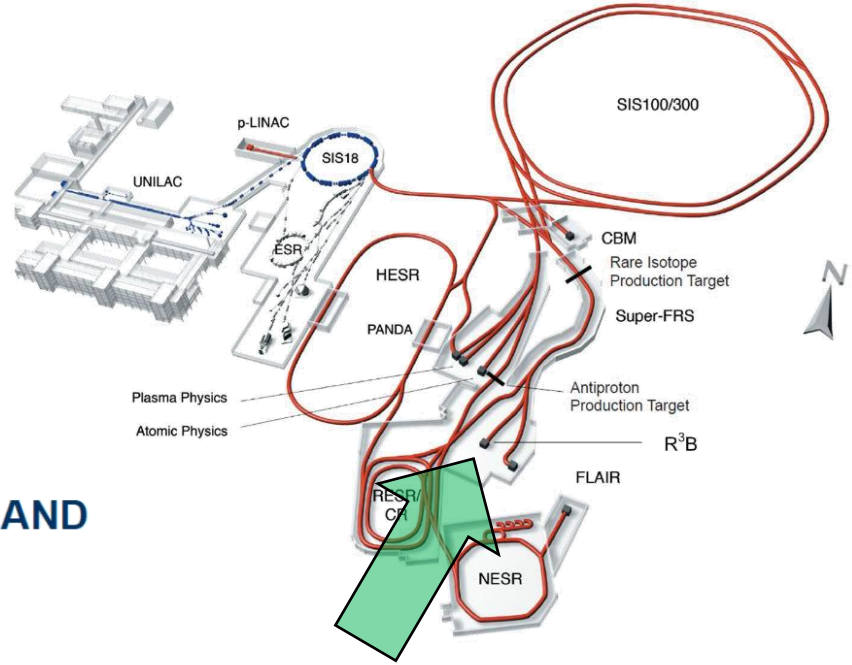
quasi-free scattering
- light + heavy ejectiles + γ

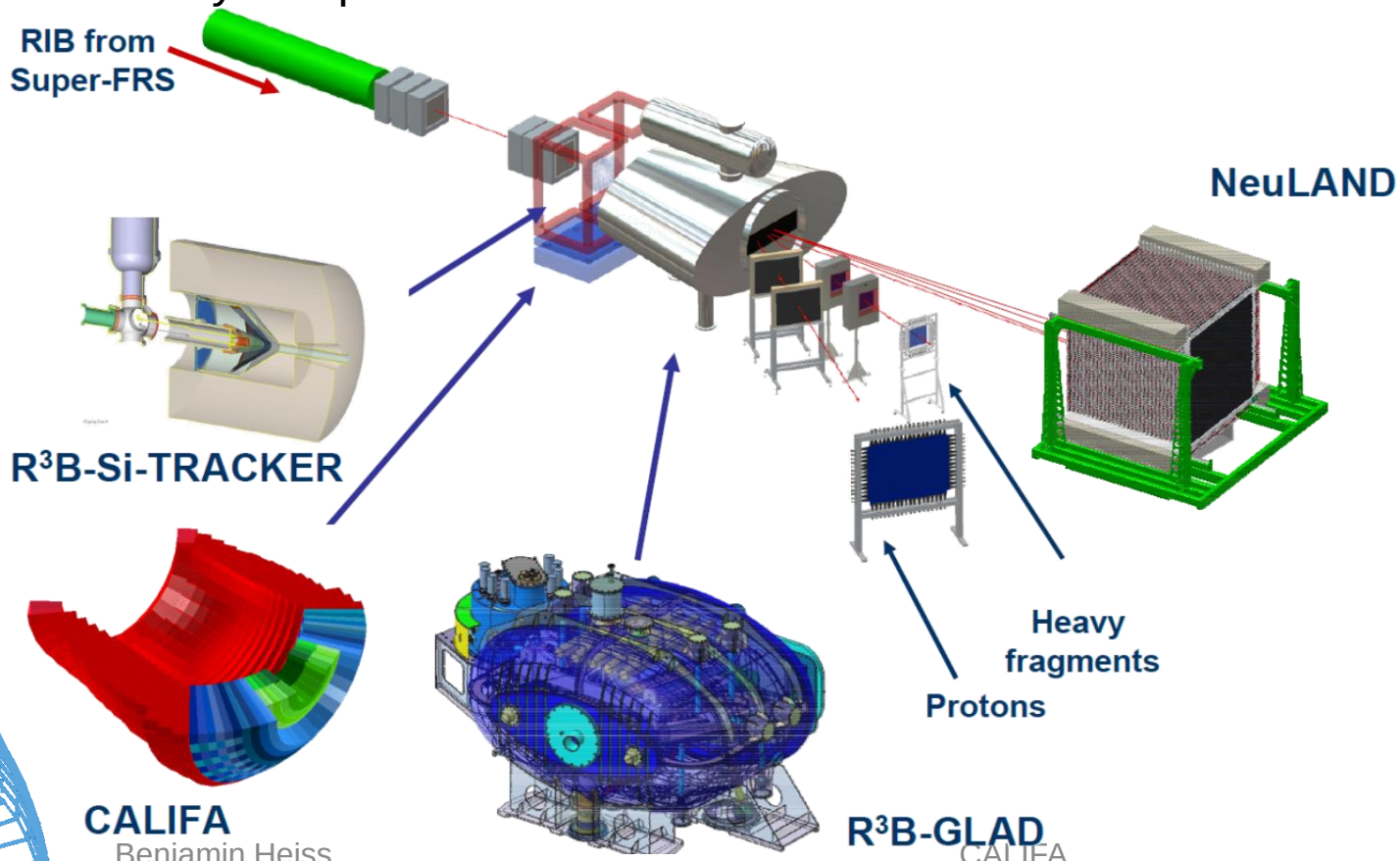


R³B @ FAIR

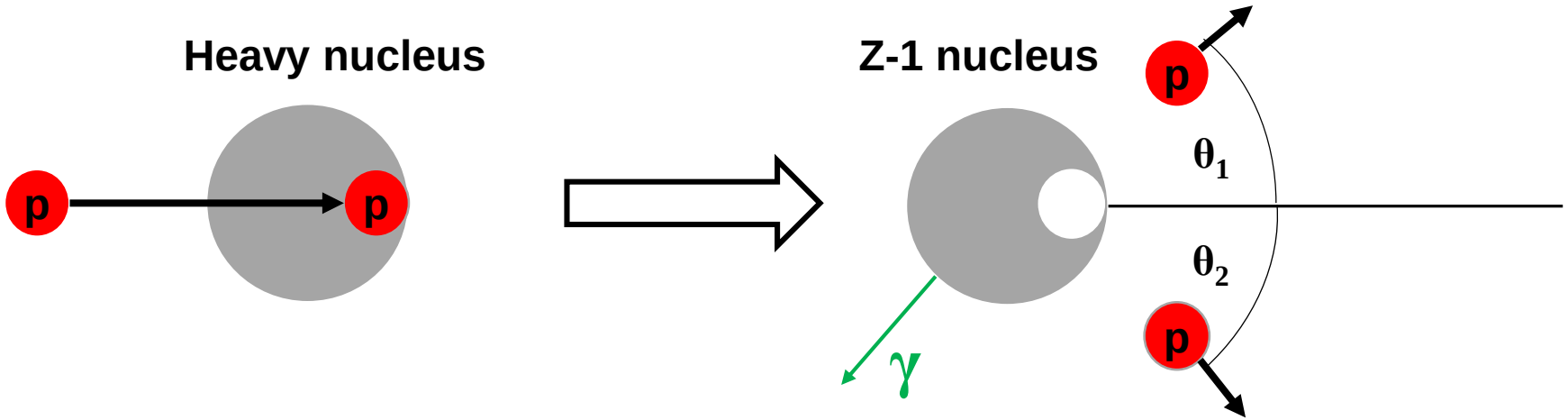
Reactions with **R**adioactive **R**elativistic **B**eams

- One of the pillars of NUSTAR
- Investigation of exotic nuclei in inverse kinematics
- Kinematically complete measurements





QFS challenges: γ rays



high Doppler (β = 0.82) shift of γ rays in inverse kinematics

- **measure emission angle for Doppler reconstruction**

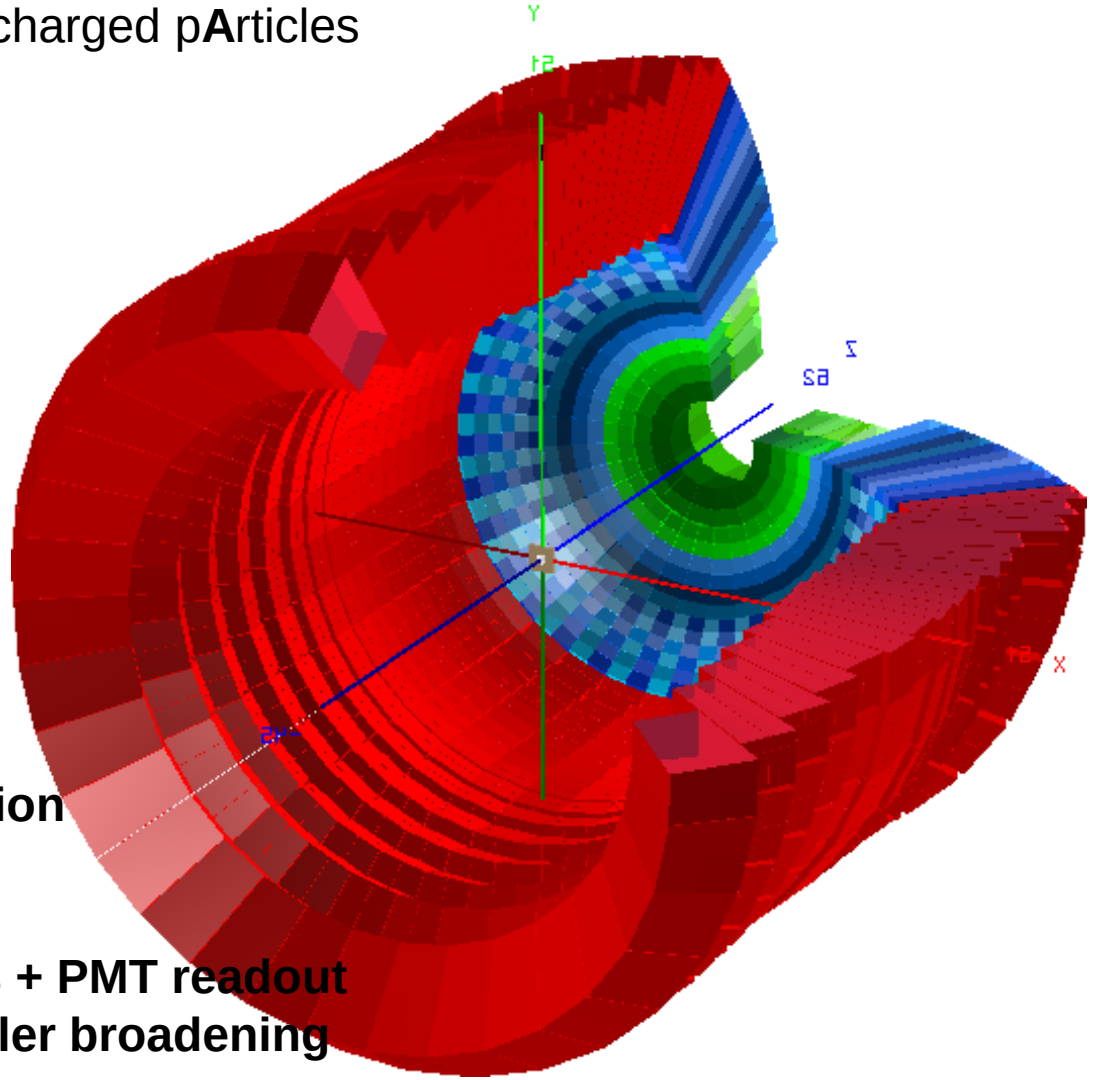
$$E_\gamma = \gamma \mathrm{E_L} \left(1 - \beta \cos\left(\theta\right)\right)$$

CALIFA Requirements

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

$$100\ \text{keV} \lesssim E_\gamma \lesssim 30\ \text{MeV}, \quad \frac{\Delta E}{E}\Big|_\gamma (1\ \text{MeV}) \lesssim 6\%$$

$$E_p \lesssim 700\ \text{MeV}, \quad \frac{\Delta E}{E}\Big|_p (100\ \text{MeV}) \lesssim 2\%$$



Barrel:

- **1952 CsI(Tl) scintillation crystals (0,7 µs + 3,3 µs) + LAAPD readout**
- **Direct energy measurement of stopped protons up to 280 MeV**

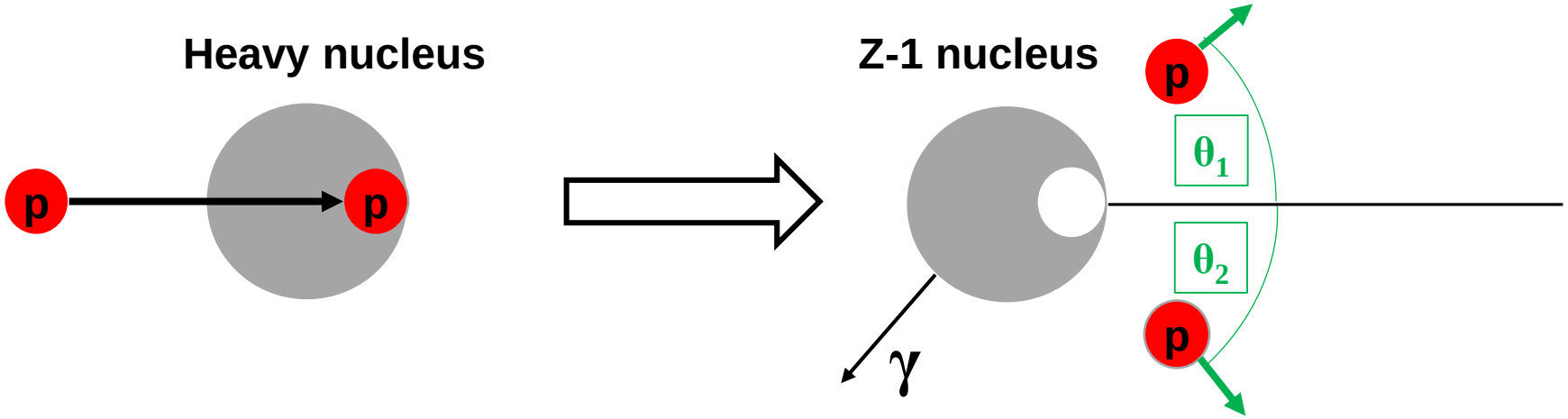
iPhos Endcap:

- **512 CsI(Tl) scintillation crystals**
- **Protons no longer stoppable -> Energy reconstruction**

CEPA:

- **96 $LaBr_3$ (16 ns) + $LaCl_3$ (28 ns) Phoswich detectors + PMT readout**
- **Highest Rates, largest Doppler shift, smallest Doppler broadening**

QFS challenges: LCP



measurements of light charged particles(LCP)

- **emission angle (excitation energy, momentum)**

- **total energy**

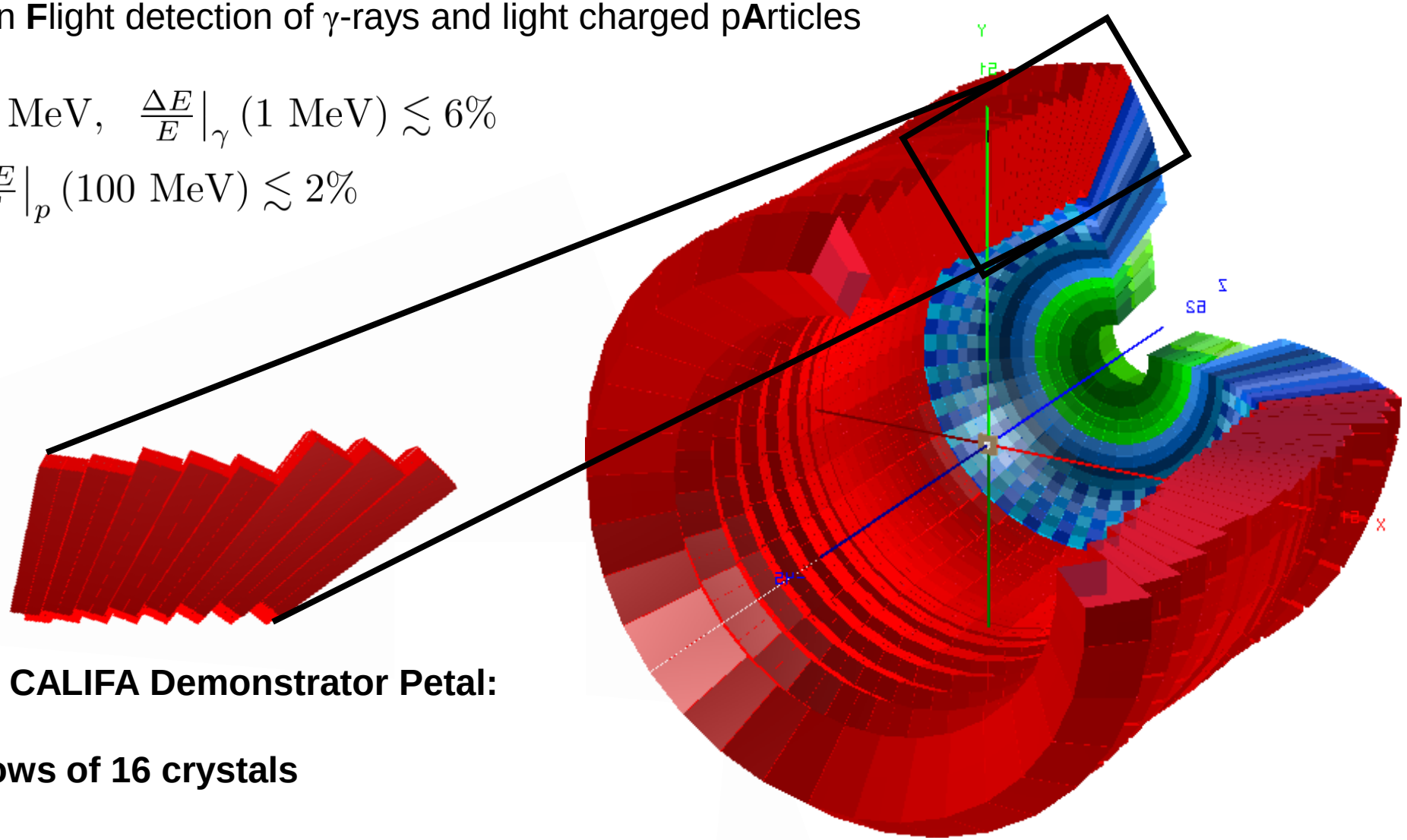
➢ **Punch throughs possible, need energy reconstruction!**

CALIFA Requirements

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

$$100\ \text{keV} \lesssim E_\gamma \lesssim 30\ \text{MeV}, \quad \frac{\Delta E}{E}\Big|_\gamma (1\ \text{MeV}) \lesssim 6\%$$

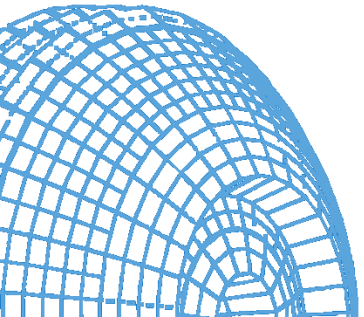
$$E_p \lesssim 700\ \text{MeV}, \quad \frac{\Delta E}{E}\Big|_p (100\ \text{MeV}) \lesssim 2\%$$



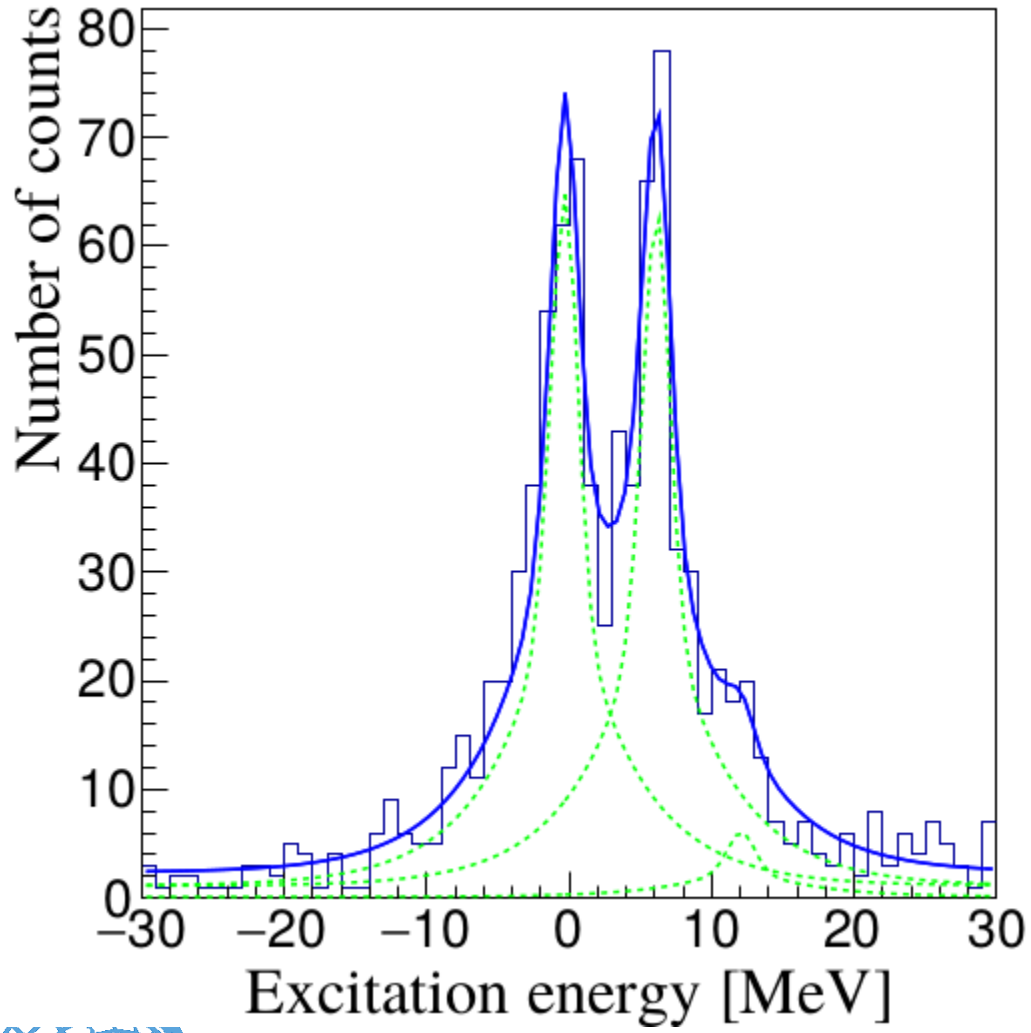
One CALIFA Demonstrator Petal:

4 Rows of 16 crystals

8 petals for FAIR Phase 0

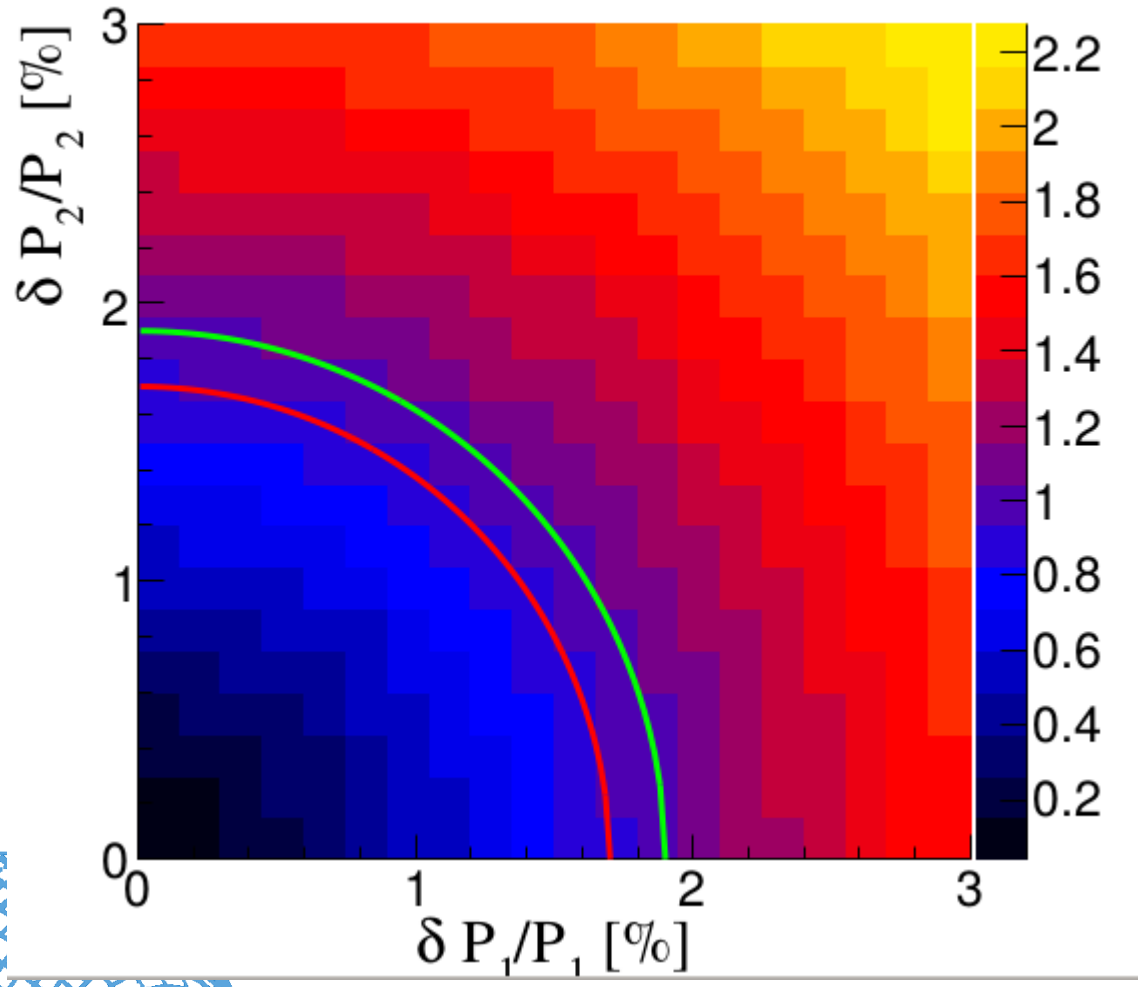


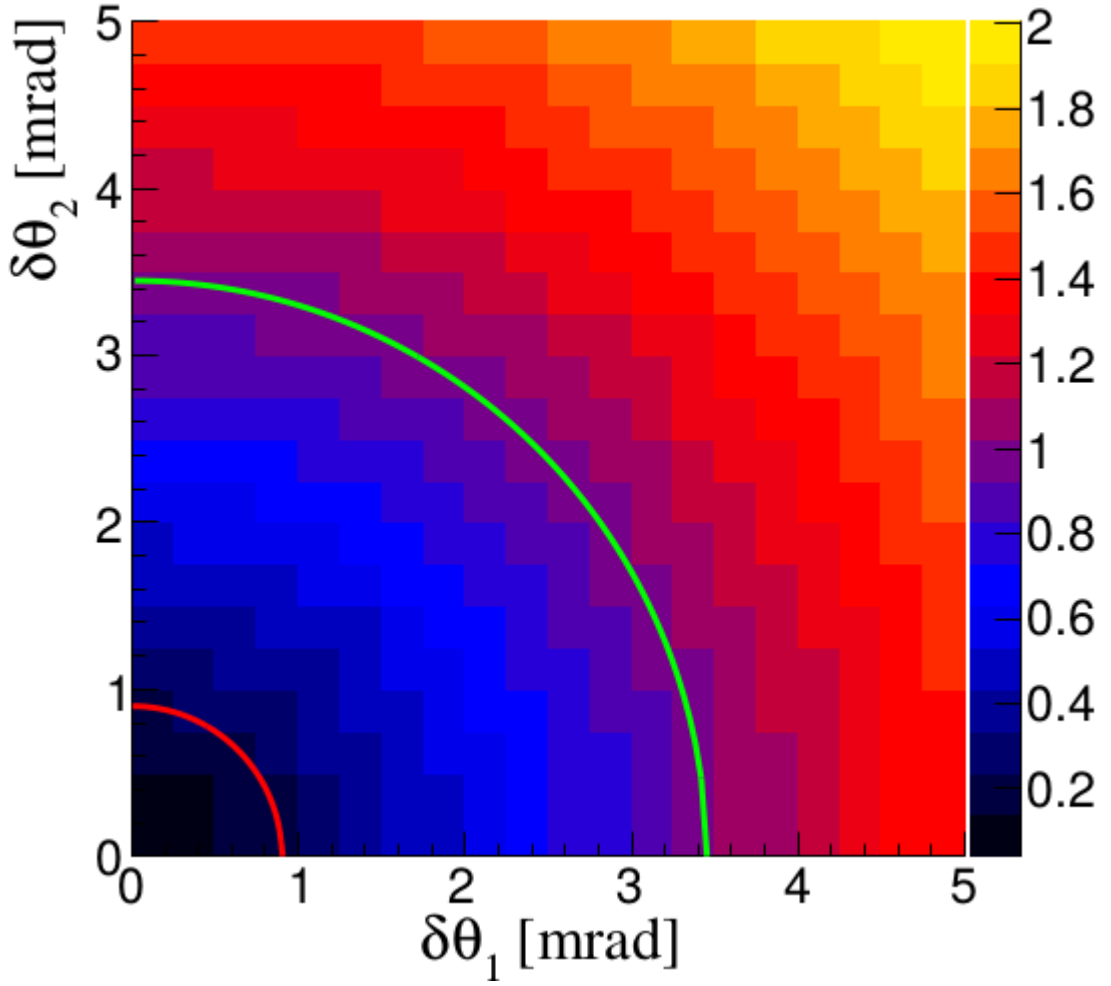
QFS inverse kinematics



- PSI Presentation by Sebastian Reichert this year
- $^{16}O(p,2p)^{15}N$
- Data taken at RIKEN with 290 AMeV ^{16}O beam on PP target (inverse kinematics)
- 1 MeV resolution σ
- Complicated analysis with 1mrad tracking

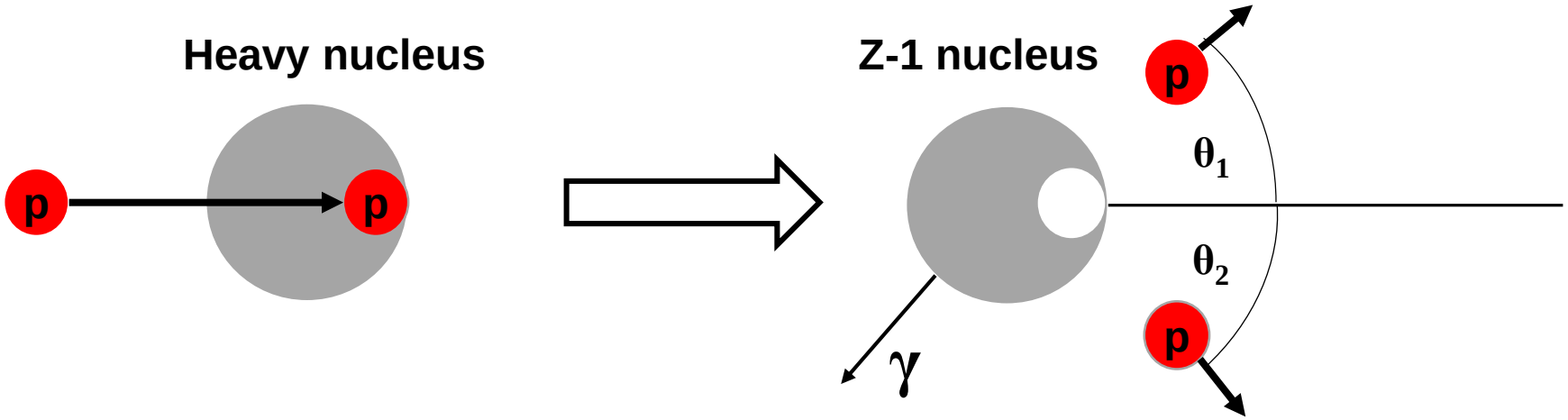
QFS inverse kinematics





z axis: excitation energy resolution (MeV)

QFS normal kinematics



(p,2p) in normal kinematics

- **Small Doppler shift of γ-rays**
- **Both protons define full kinematics**
- **Only stable isotopes for targets**

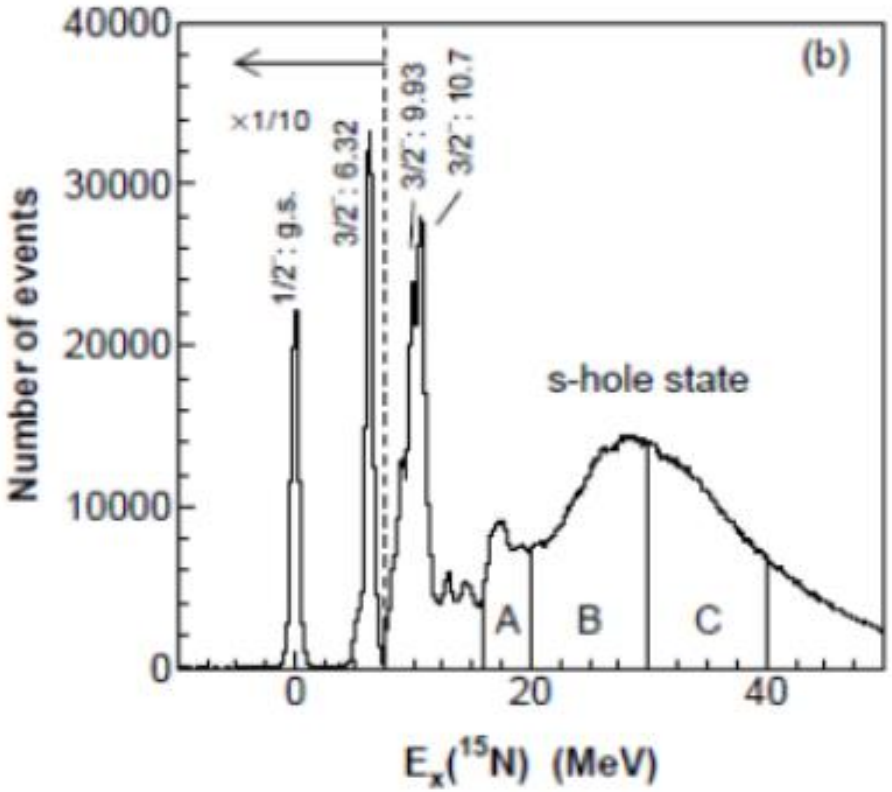
Test experiment in Krakow

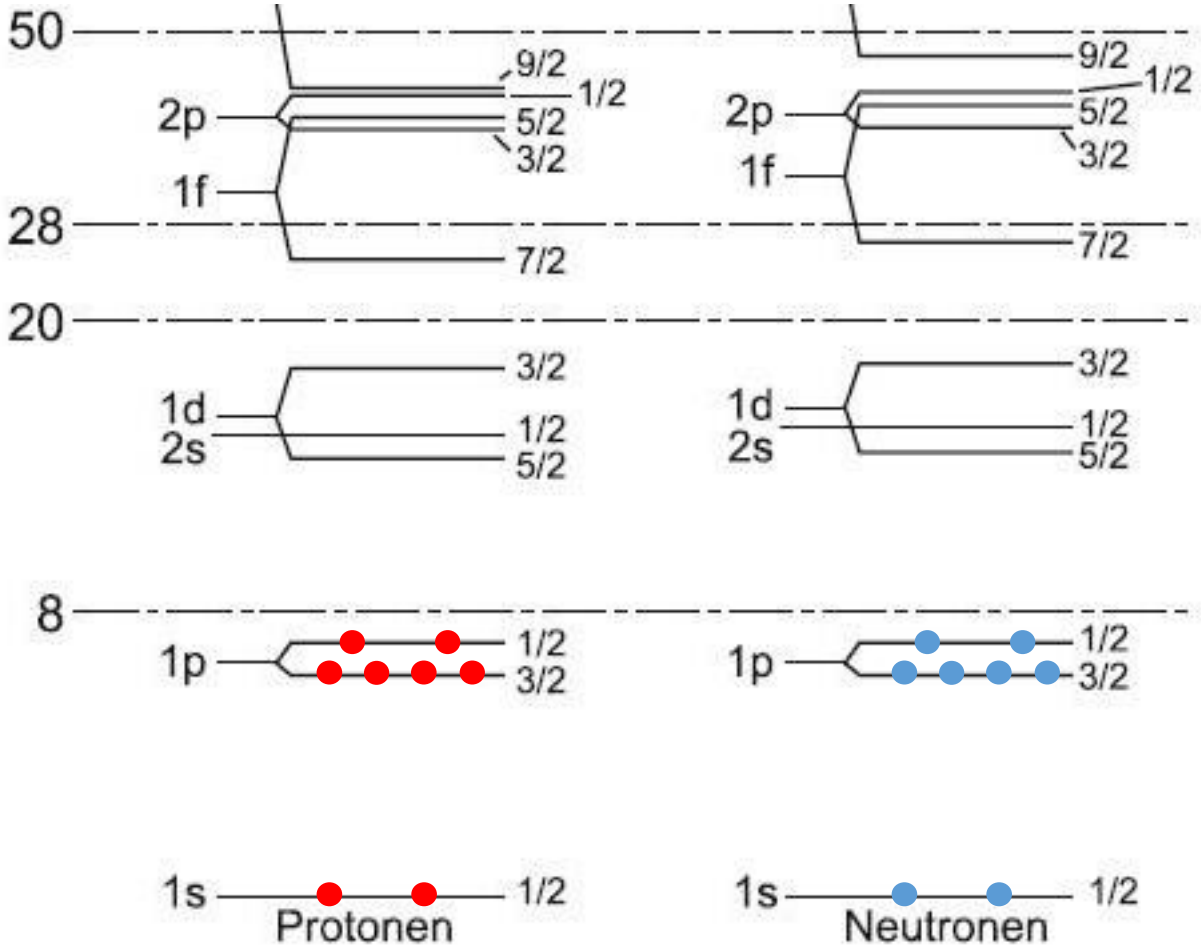
- **Well known system**
- **Well separated γ ray**
- **Test demonstrator detection capabilities**

Target choice

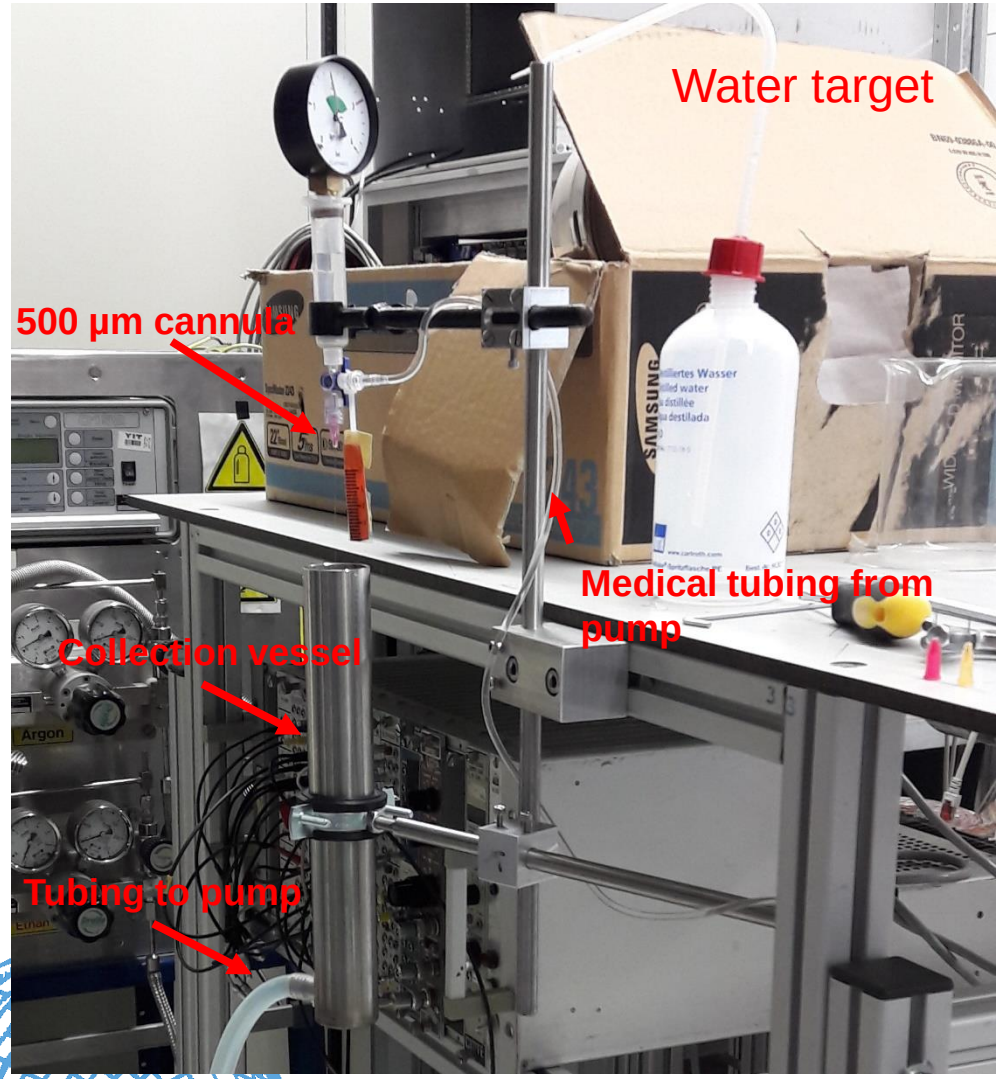
Goal: Measuring p,2p reaction in coincidence with excitation γ rays from residual nucleus

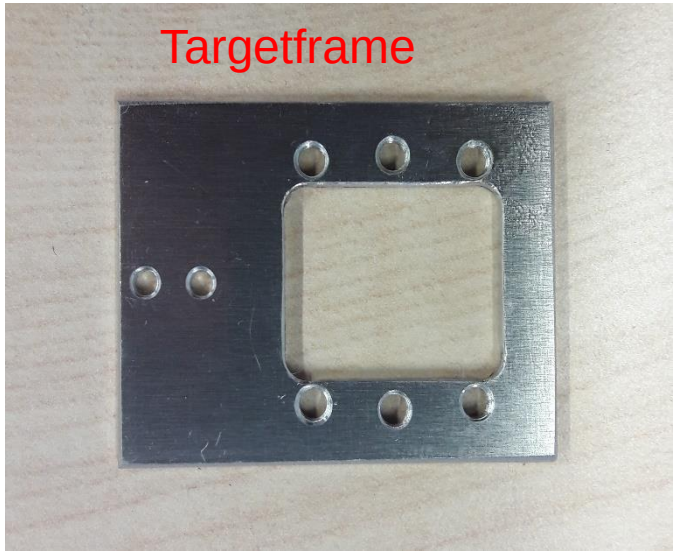
Chosen reaction : $^{16}\mathrm{O}\,(\mathrm{p},2\mathrm{p})^{15}\,\mathrm{N}$



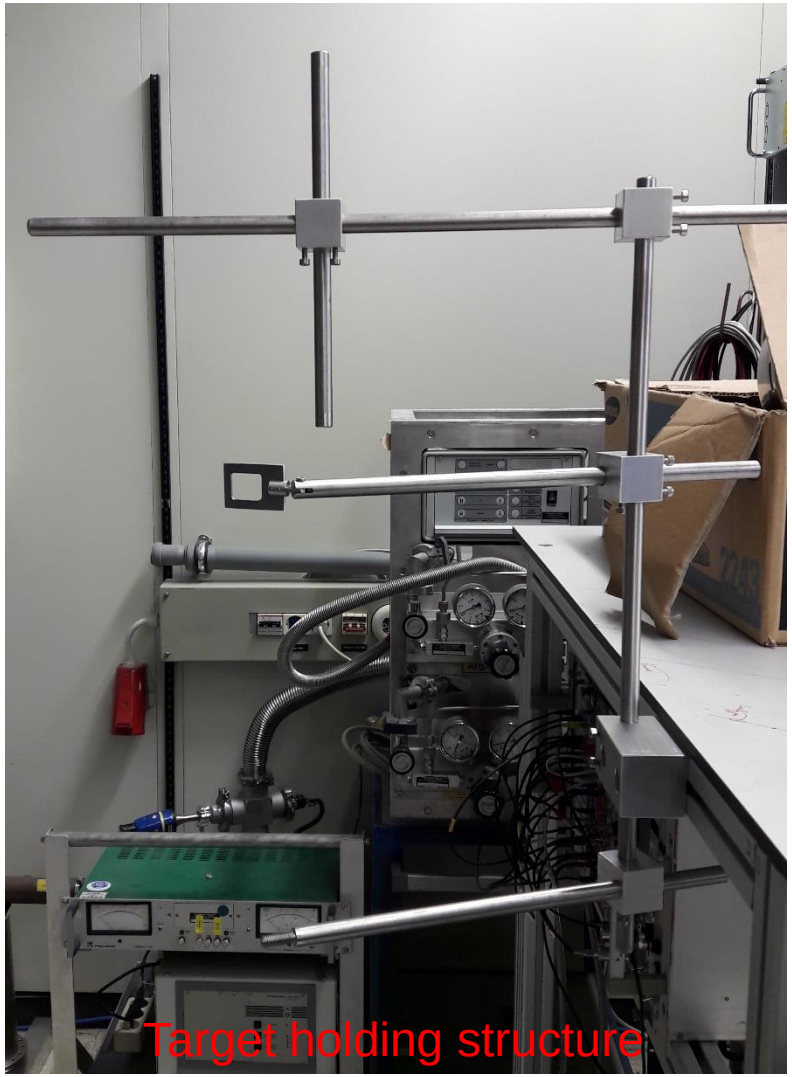


Target


Water target
500 µm cannula
Medical tubing from pump
Collection vessel
Tubing to pump

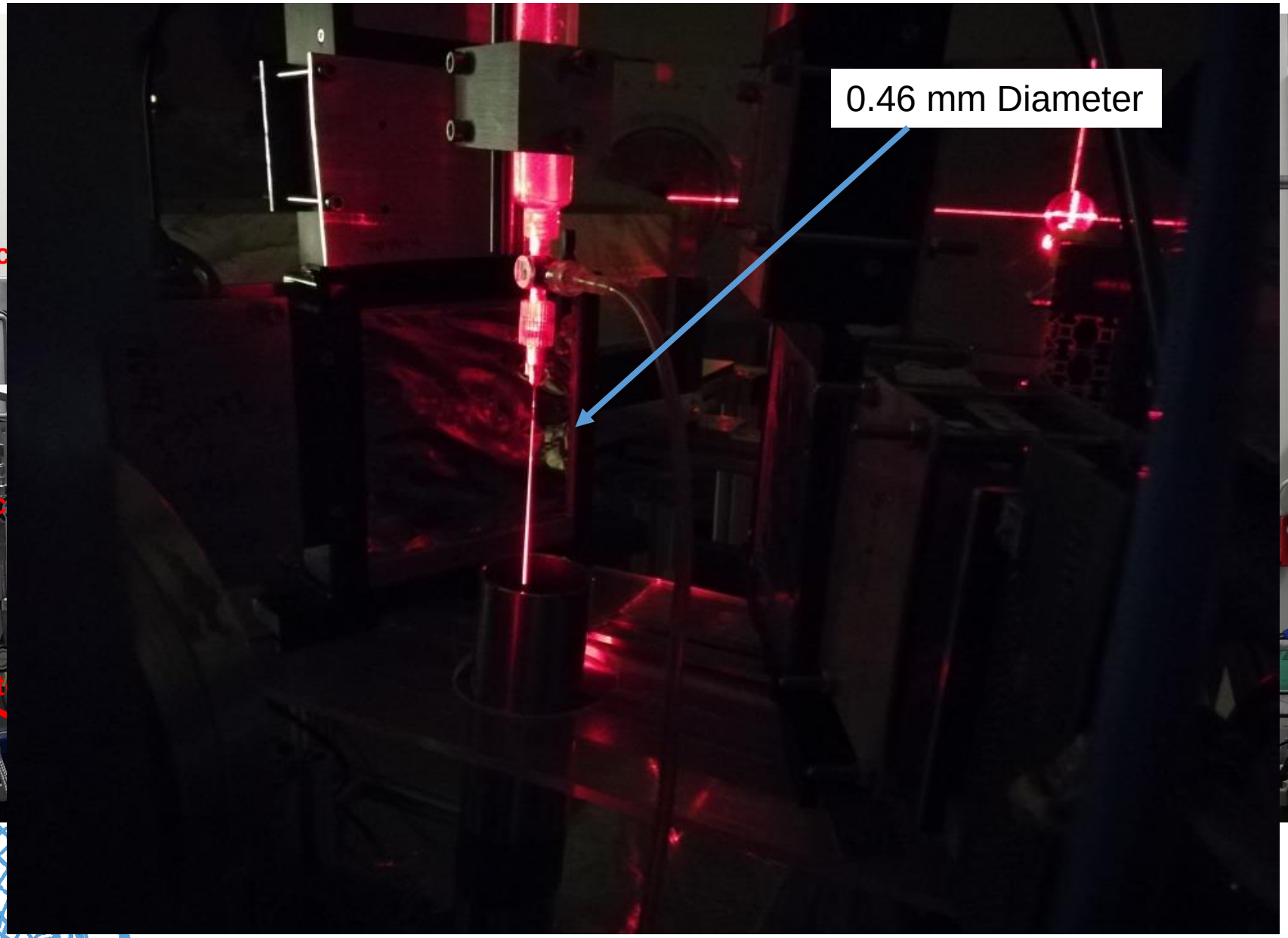

Targetframe

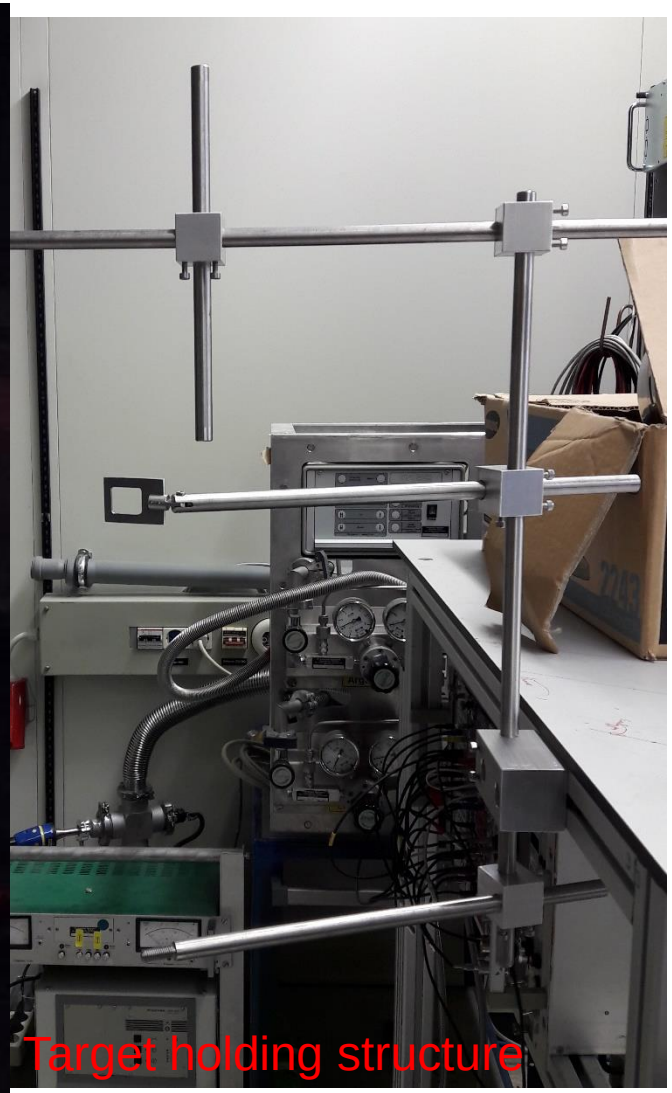

Measures for positioning


Target holding structure

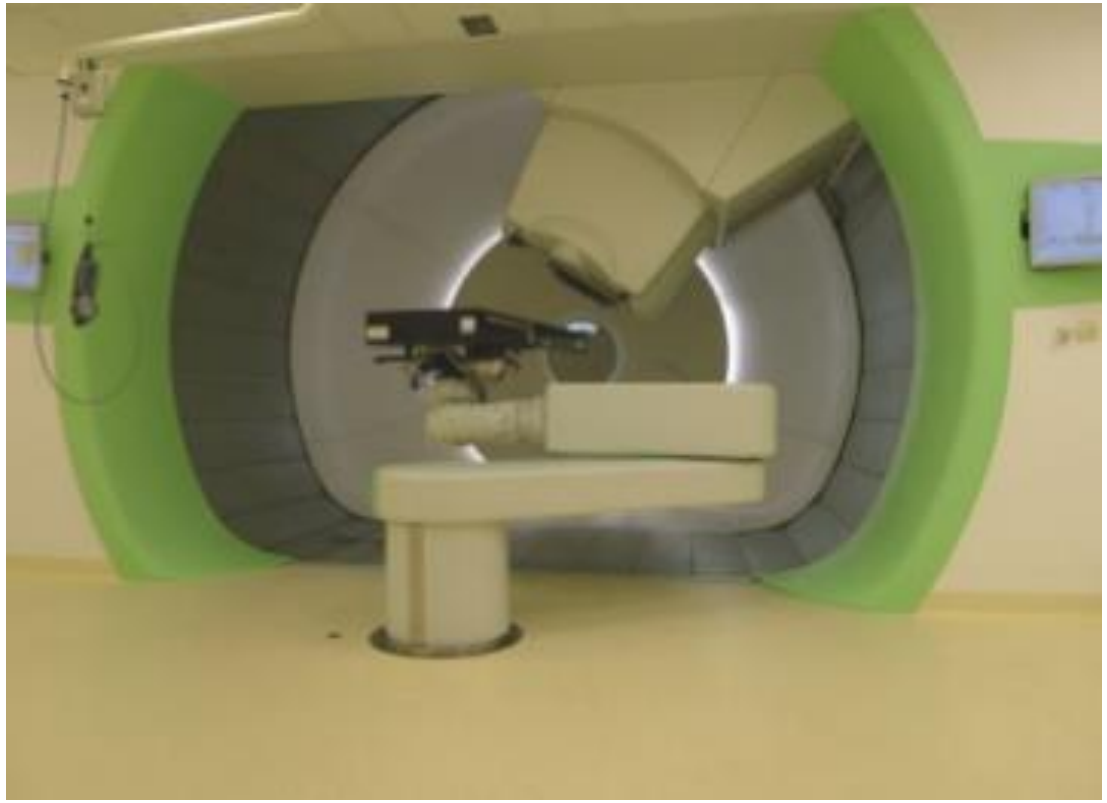
Target


500 µm c
Collec
Argon
Tubing t


0.46 mm Diameter

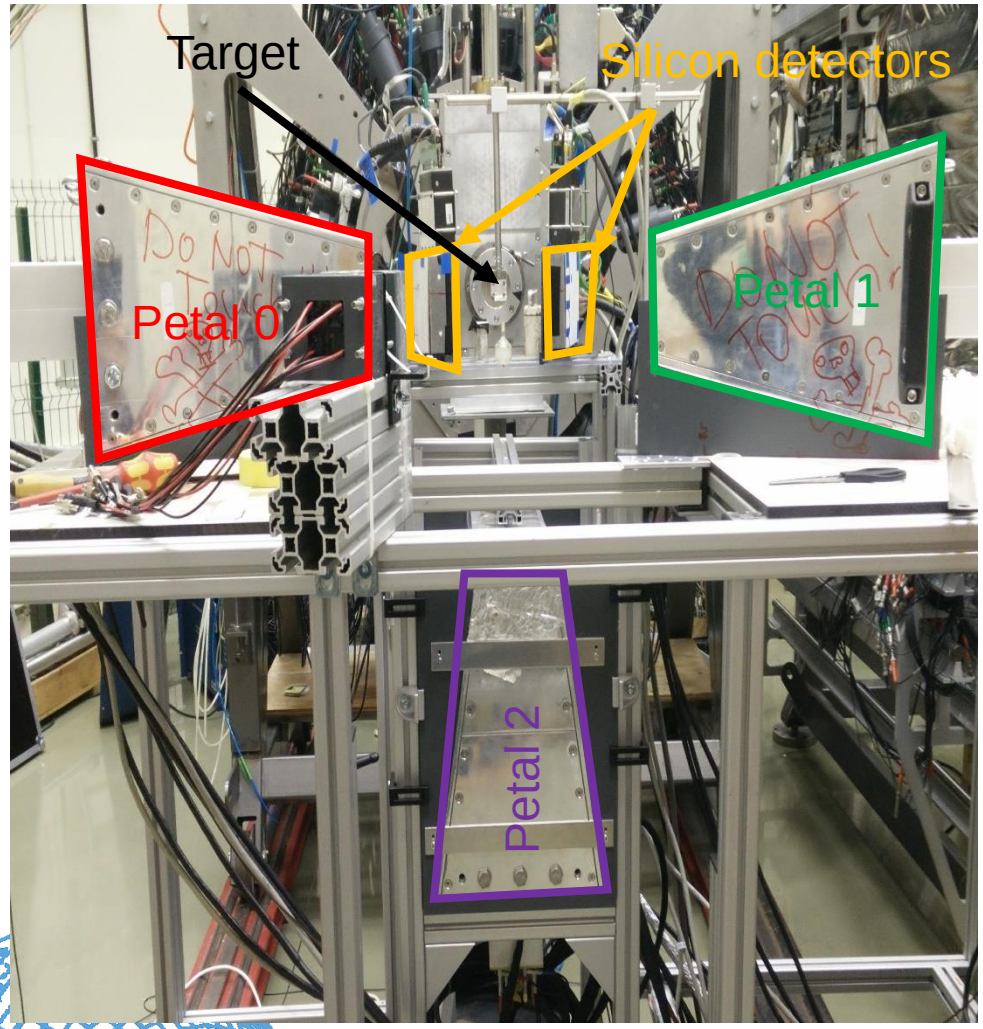

Target holding structure

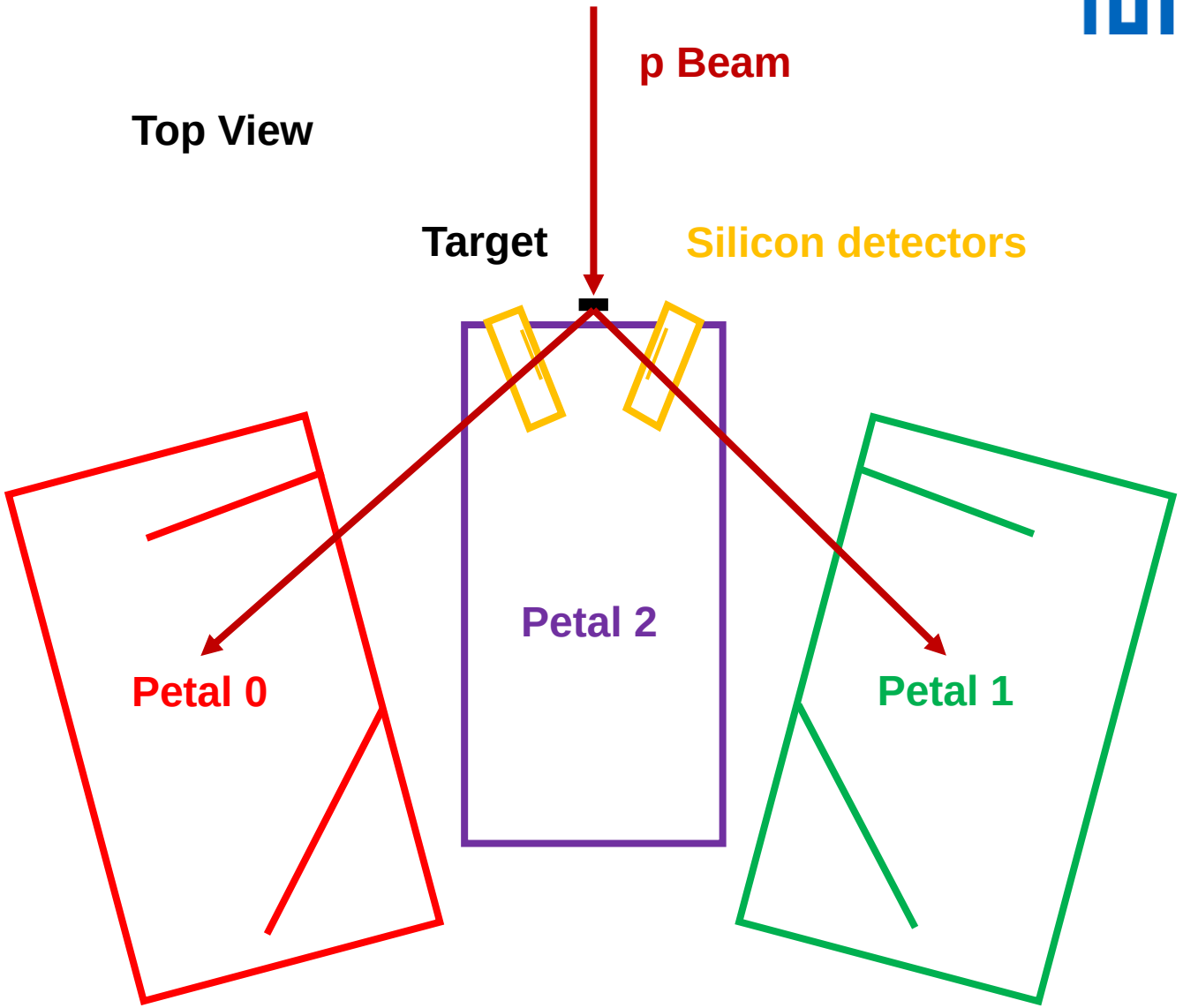
Bronowice Cyclotron Center Krakow



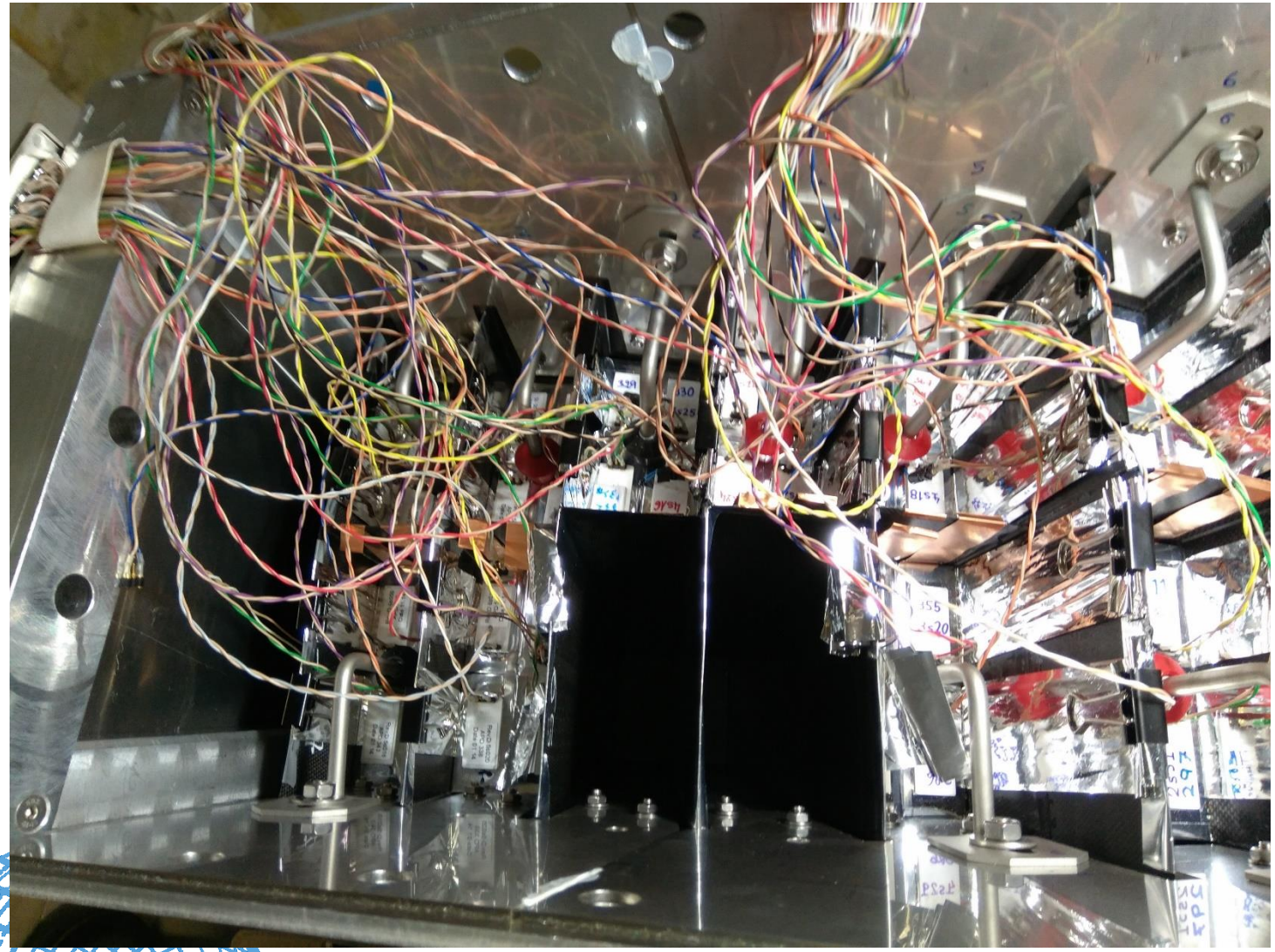
- Proteus C-235 Cyclotron
- E = 70 – 230 MeV monoenergetic proton beam, I= 1 – 500 nA , 200 MeV used in experiment
- Medical and scientific facility (2 medical and 1 scientific beamline)
- Cancer therapy with special rotating gantry

Setup


Target
Silicon detectors
Petal 0
Petal 1
Petal 2


Top View
p Beam
Target
Silicon detectors
Petal 0
Petal 2
Petal 1

CALIFA Demonstrator Petal



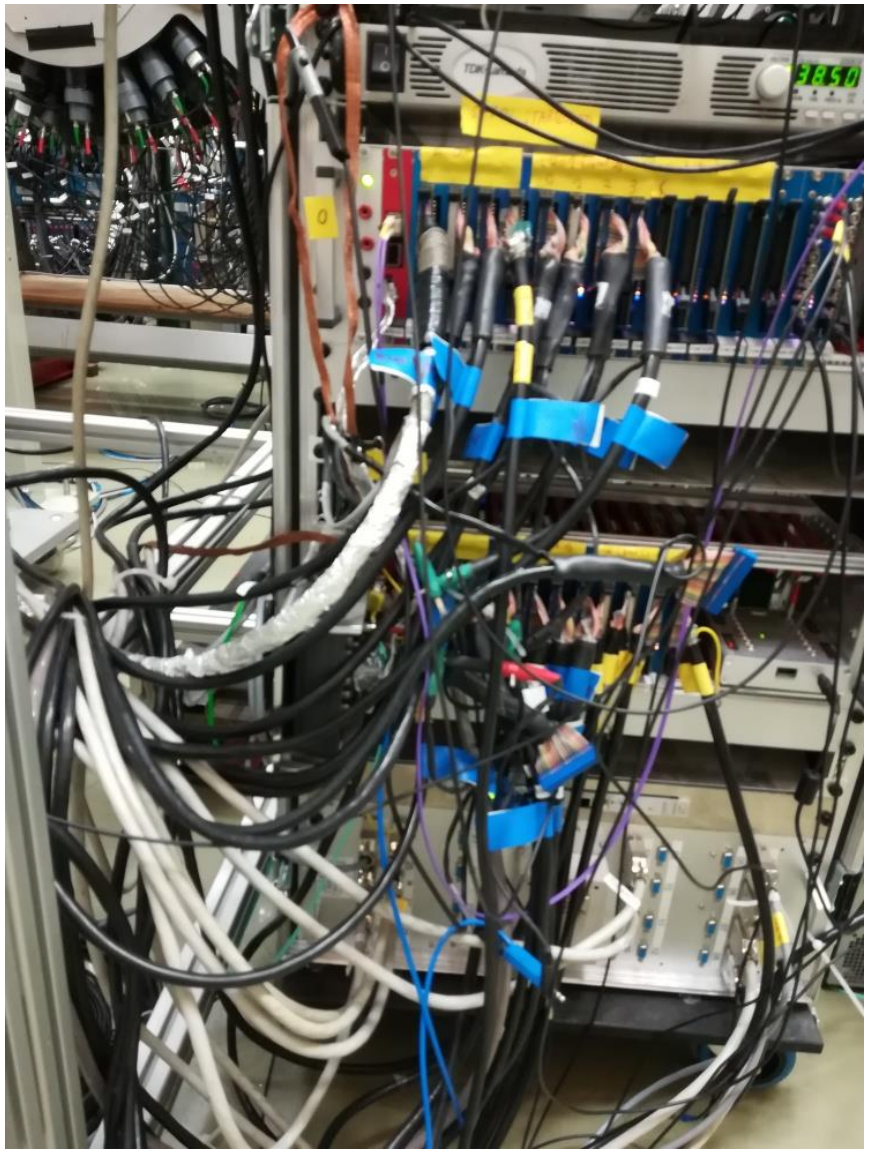
- Detectors constructed at different locations:
  - Darmstadt
  - Santiago de Compostela, Spain
  - Lund, Sweden
- 64 CsI(Tl) crystals in one petal (3 single and 1 double exist)
- Carbon fiber support structure

➢ Systematic testing required

DSSSD and electronics

Double sided silicon strip detector:

- Dimensions: 60 mm x 60 mm x 300 µm
- # Strips: 32 on front and back
- 1.8 mm strip width



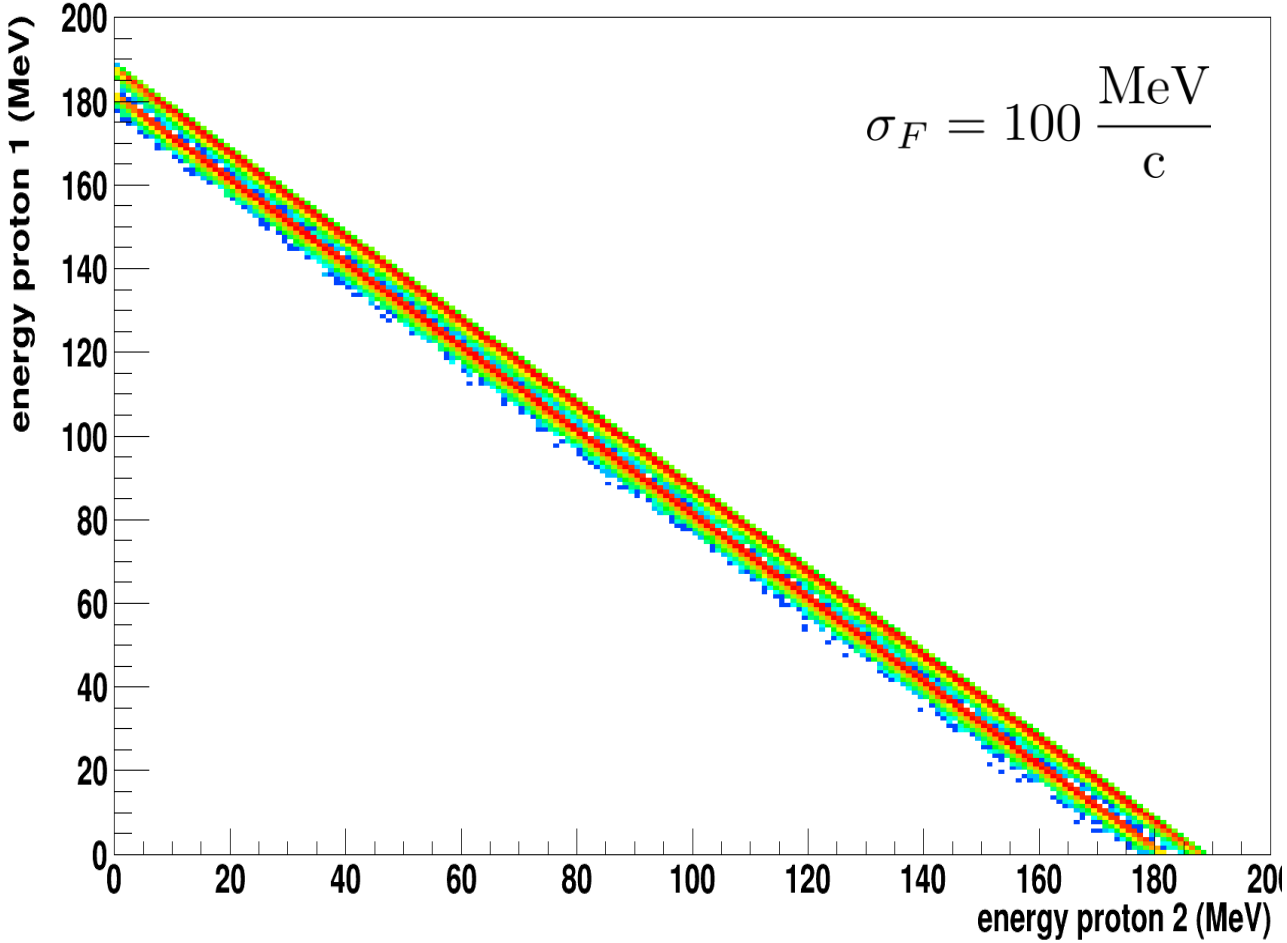
Electronics:

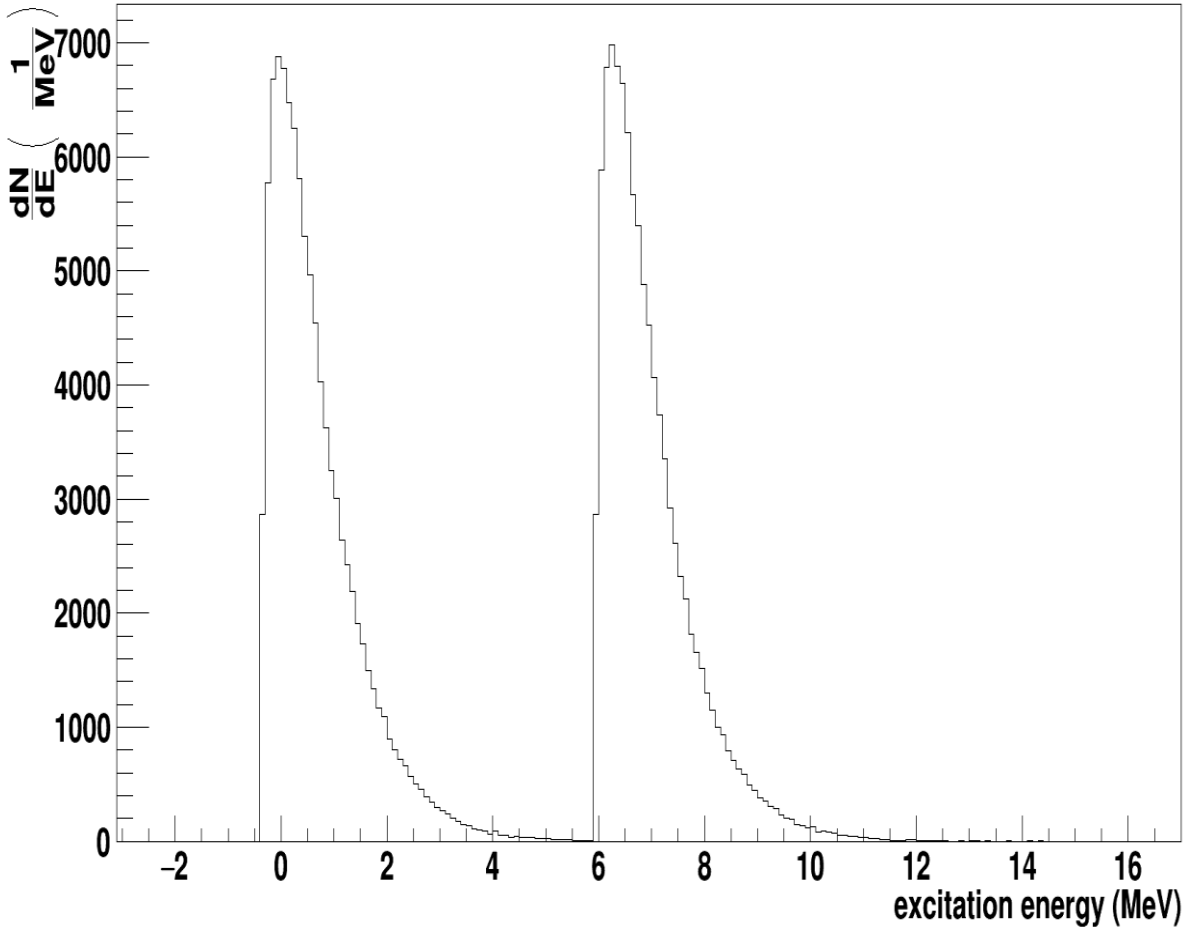
Readout with FEBEX3 , FAB cards and MBS

First time with two crates

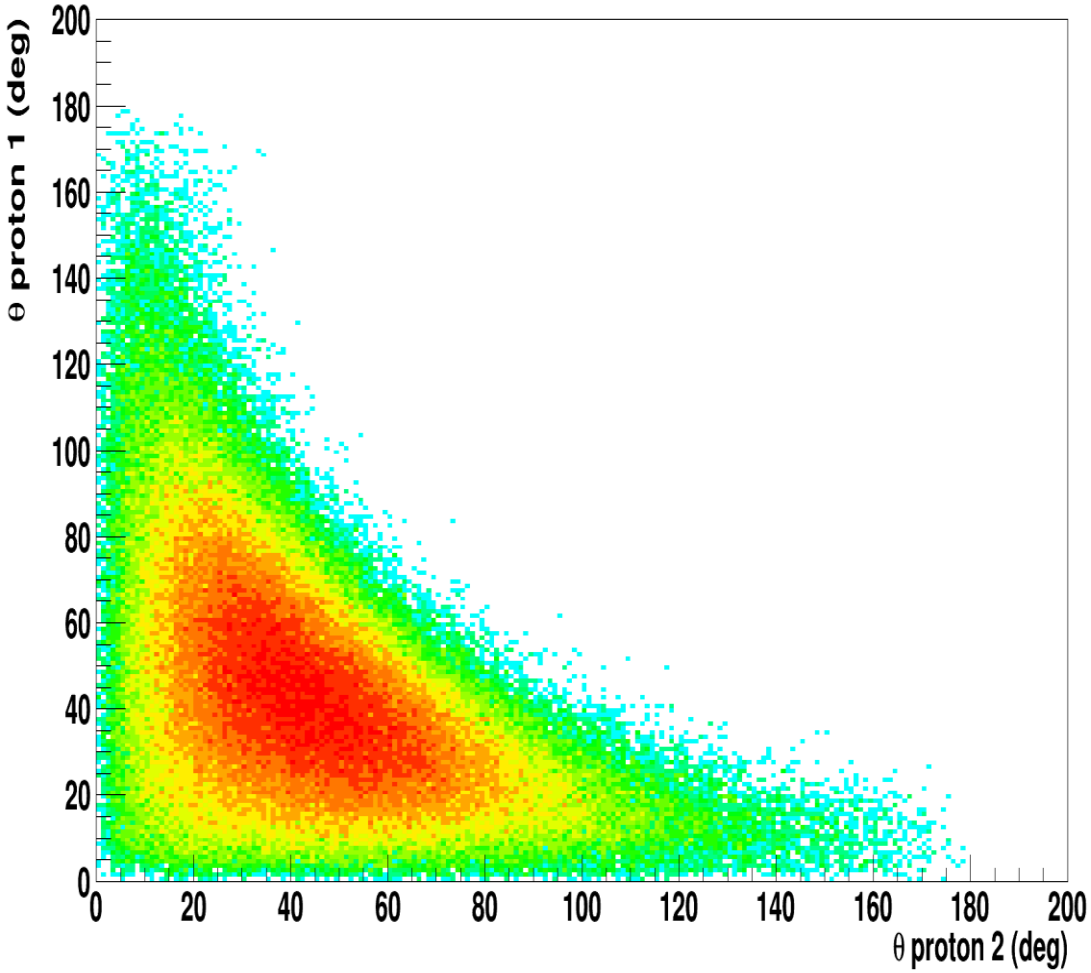
Total channels: 320

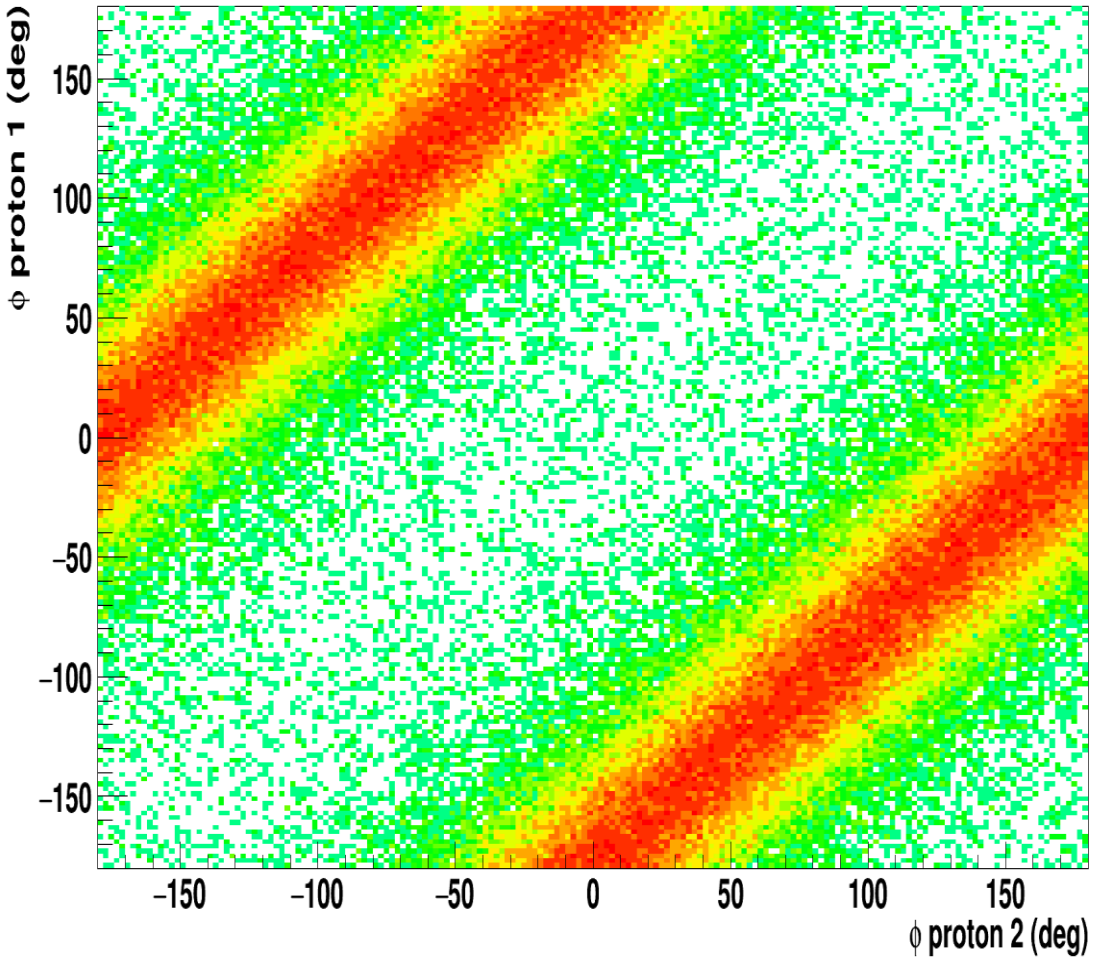
Simulation QFS



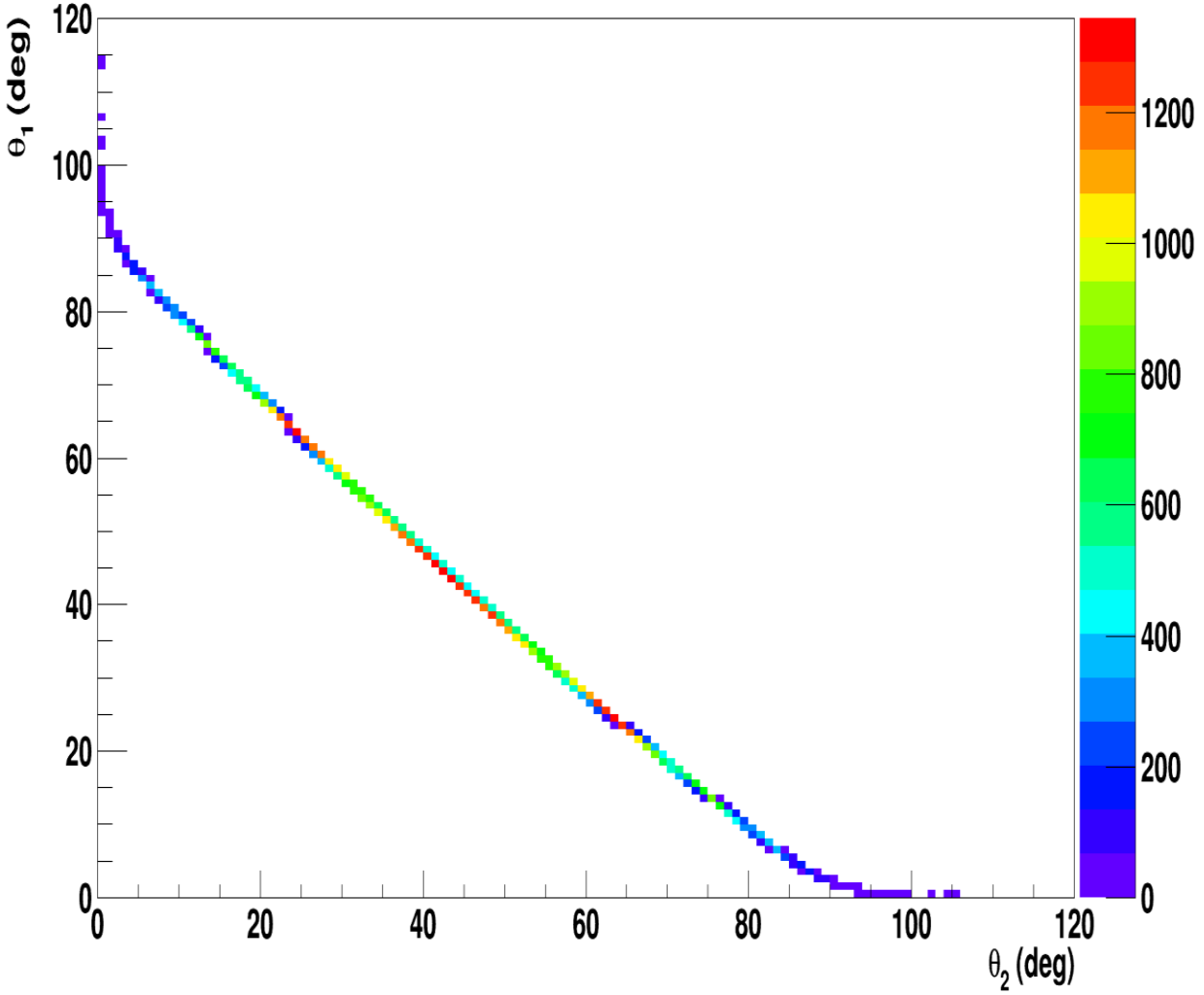


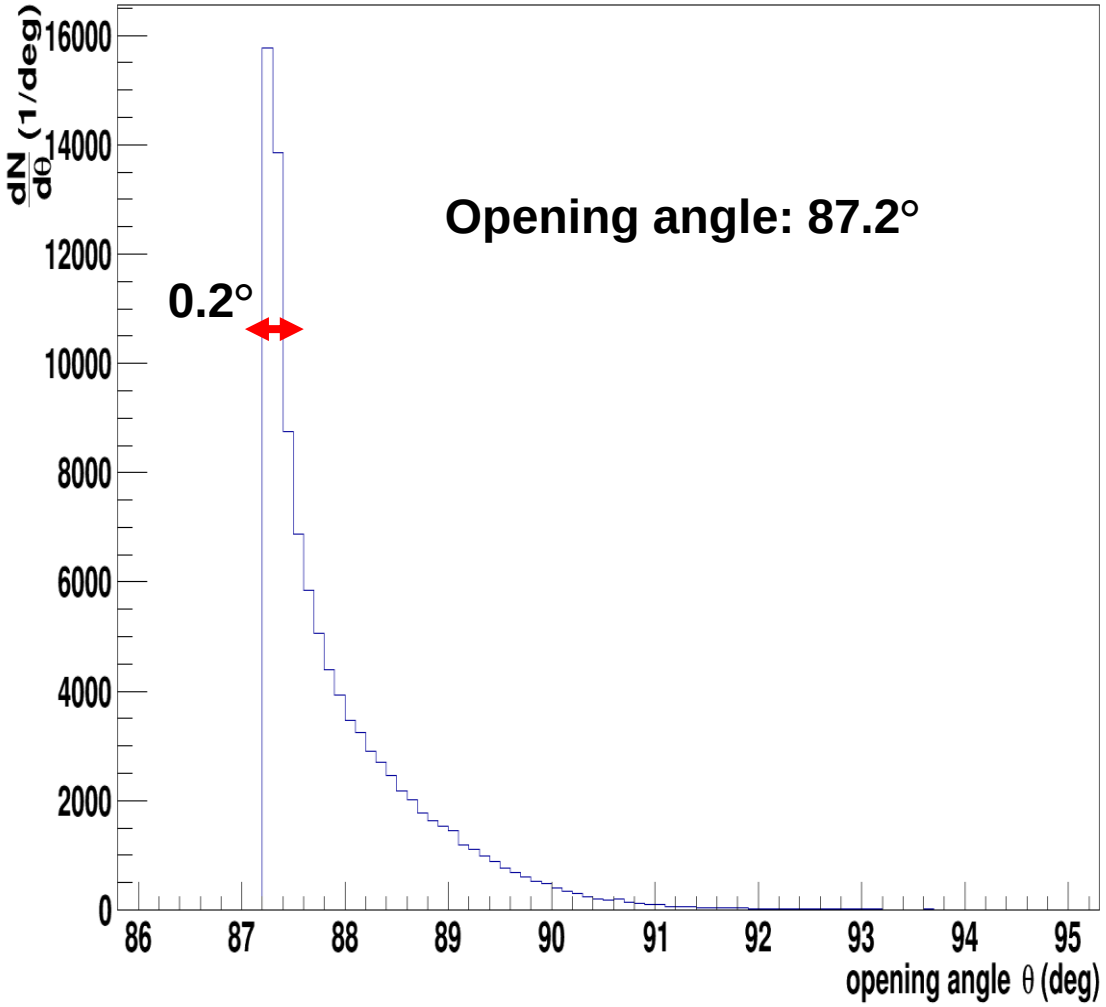
Simulation QFS





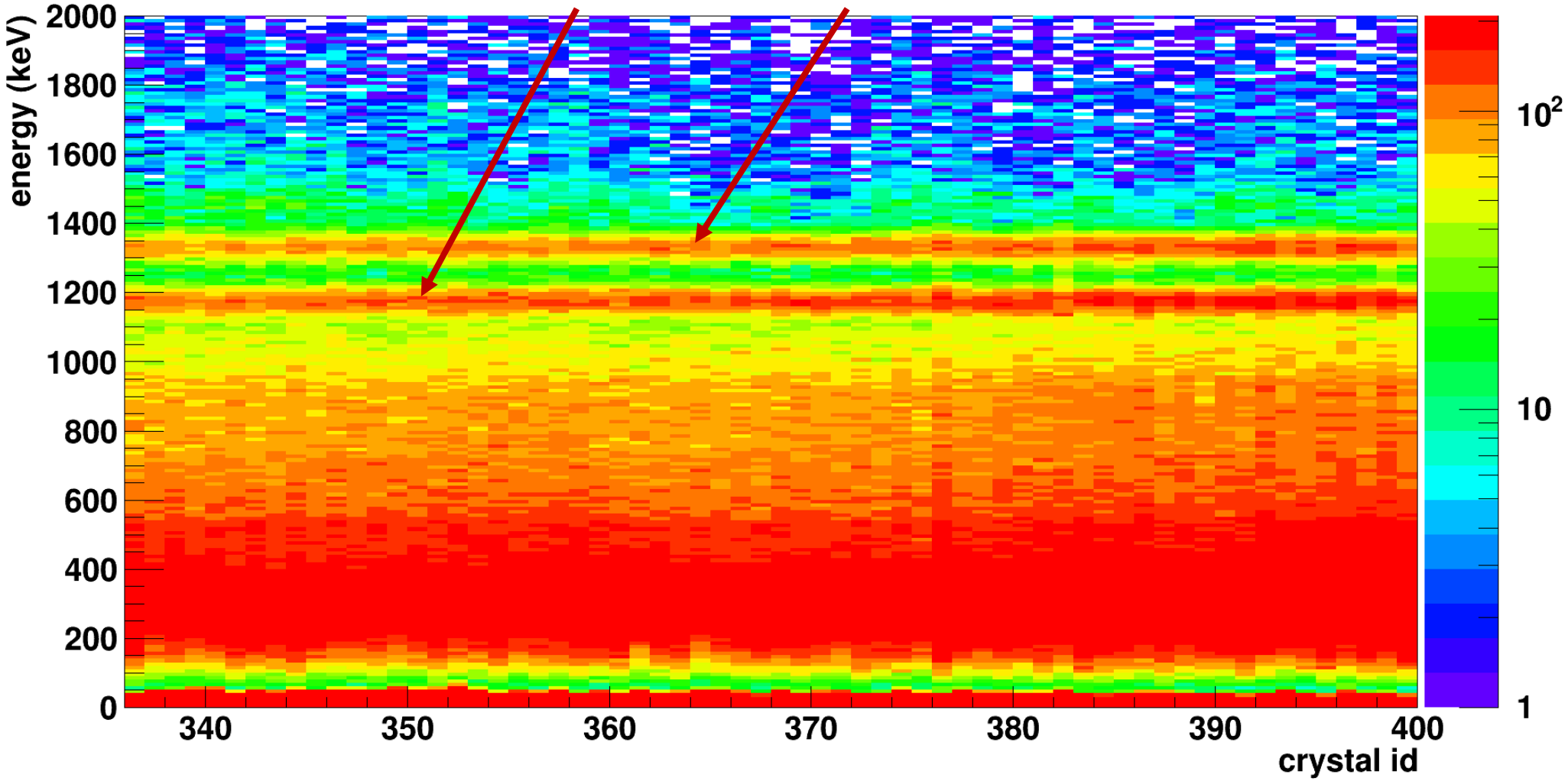
Simulation elastic (p,p) scattering



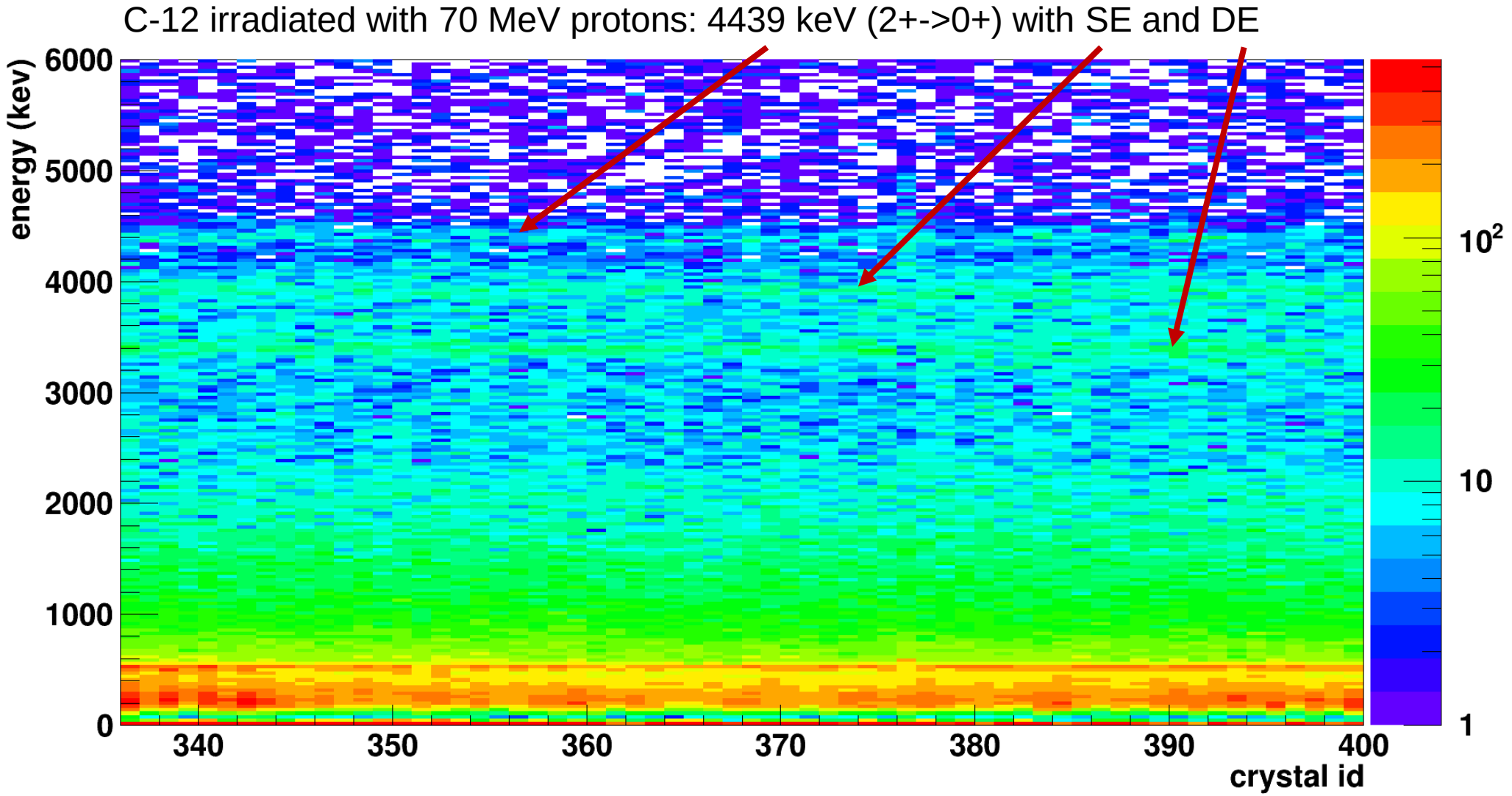


^{60}Co γ calibration

Co calibration source : 1173 keV and 1332 keV

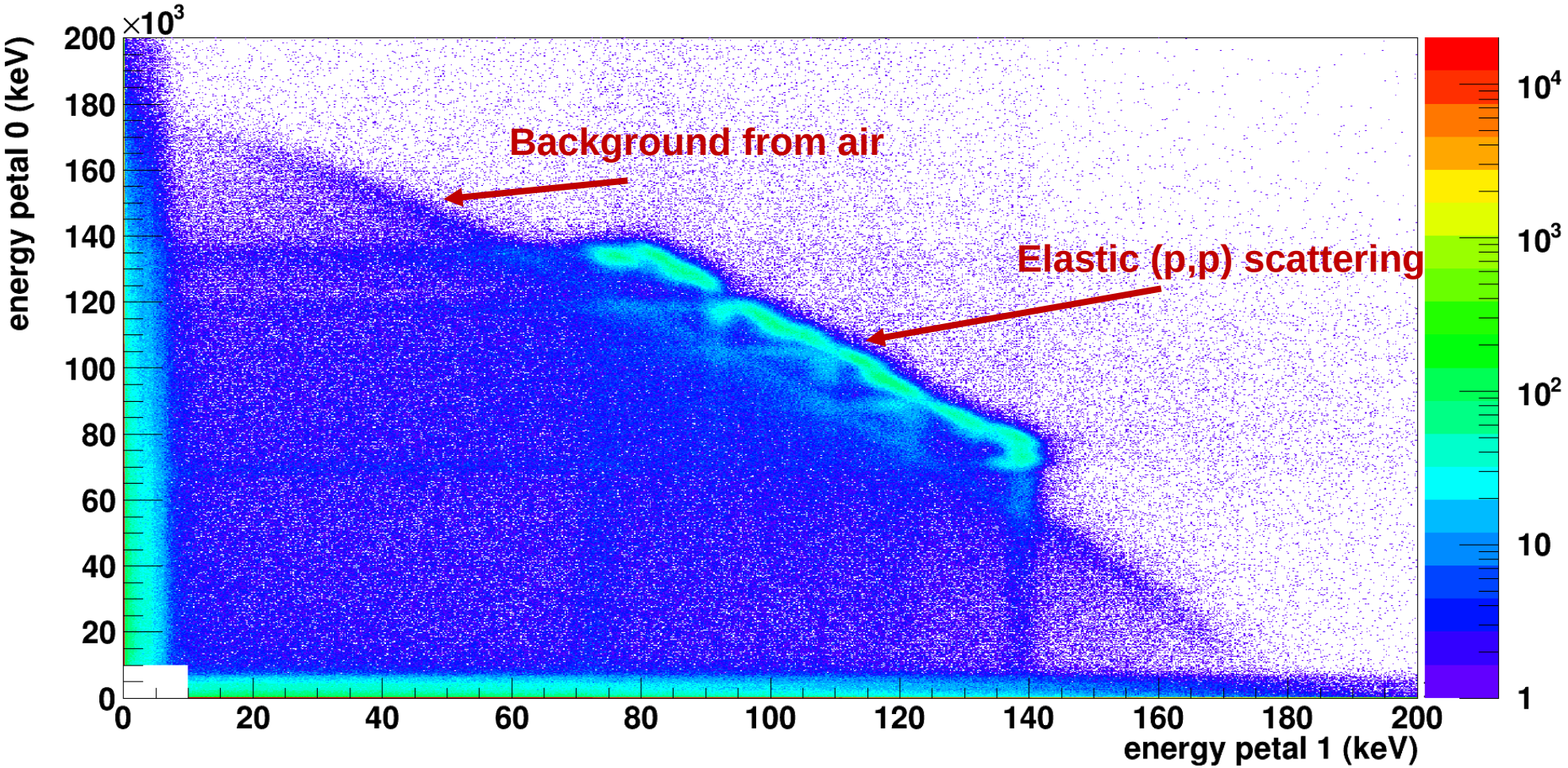


^{12}C calibration

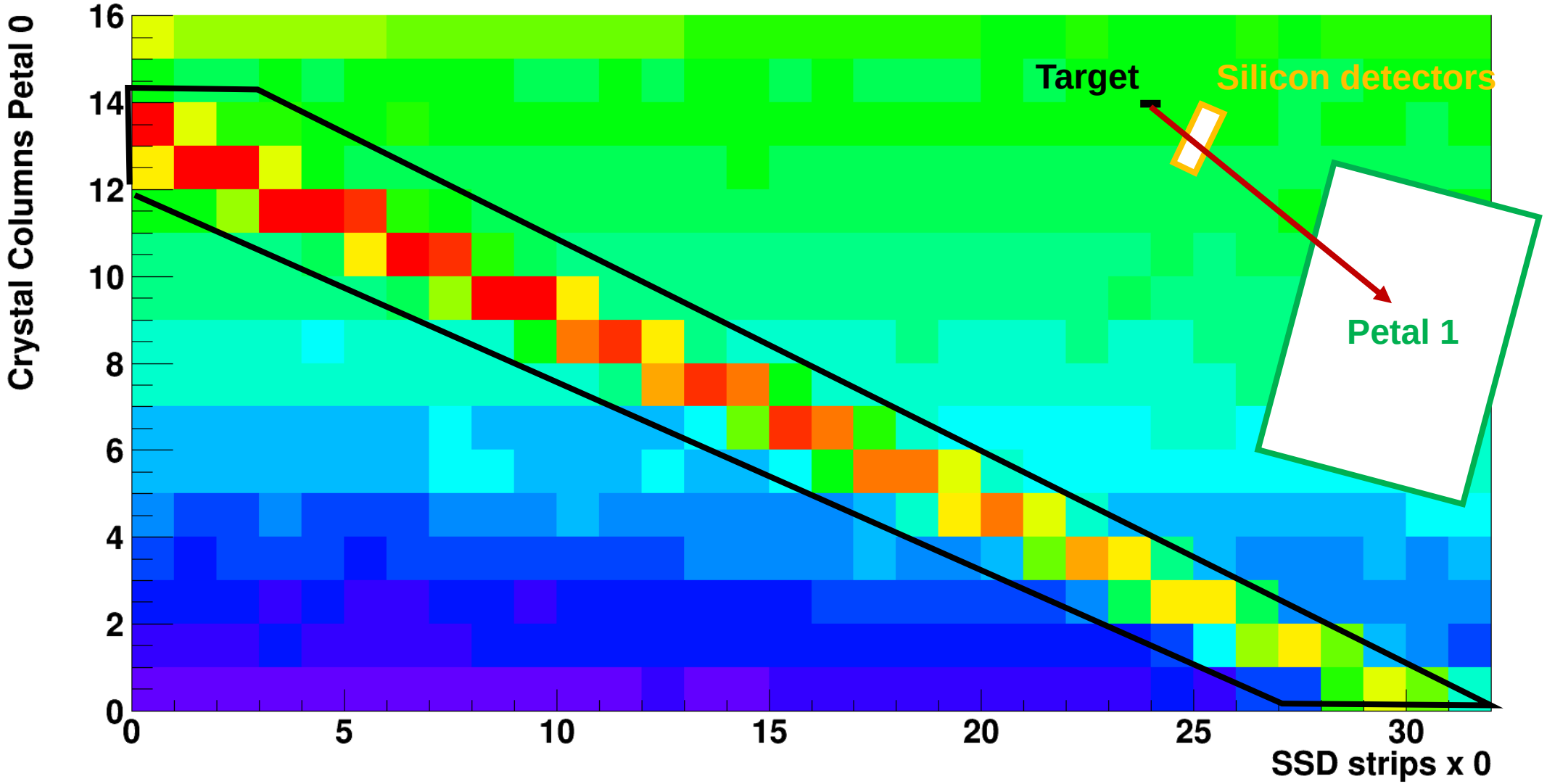


Plastic Target

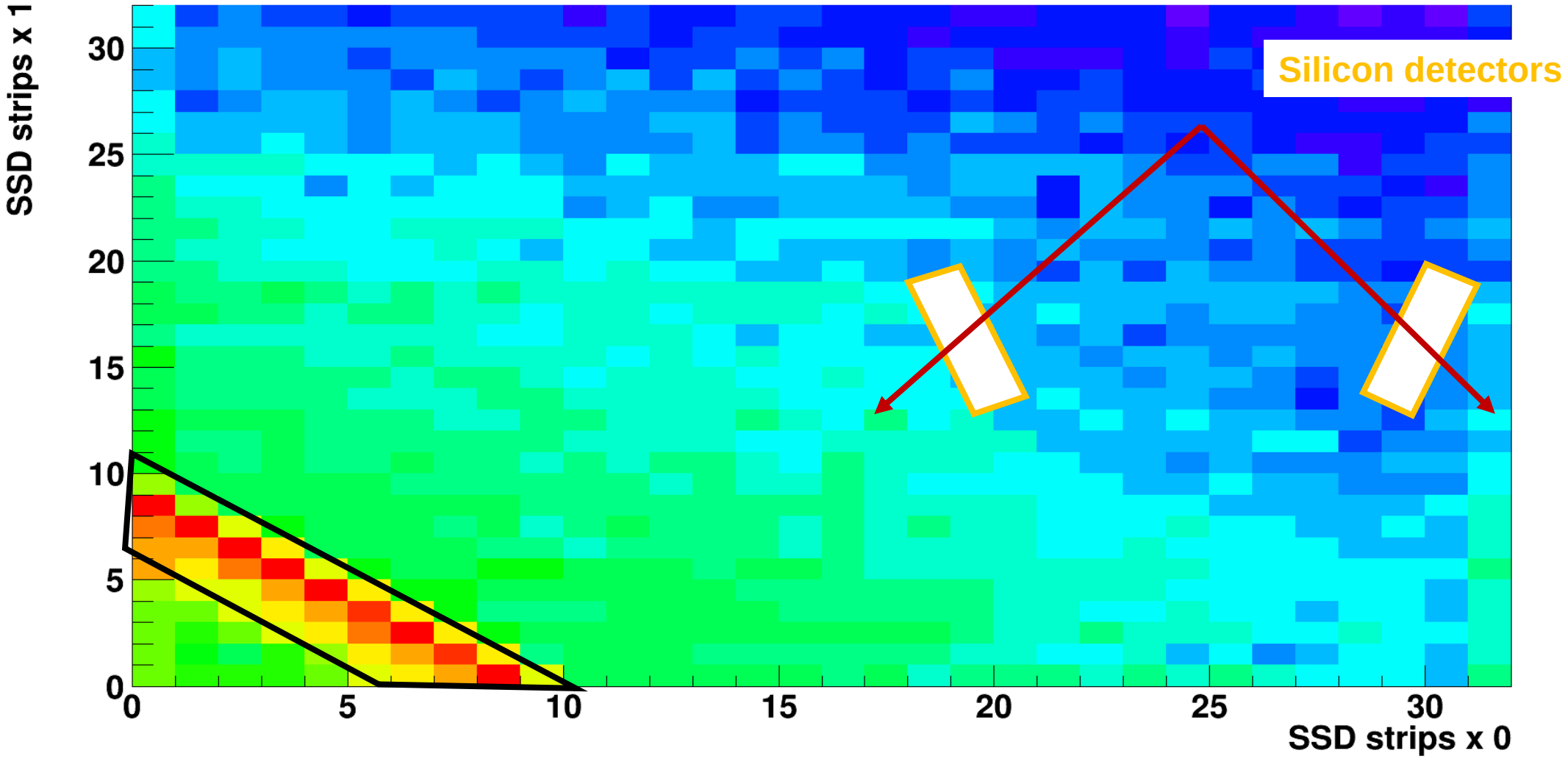
First beam measurements with polypropylene target 600 µm



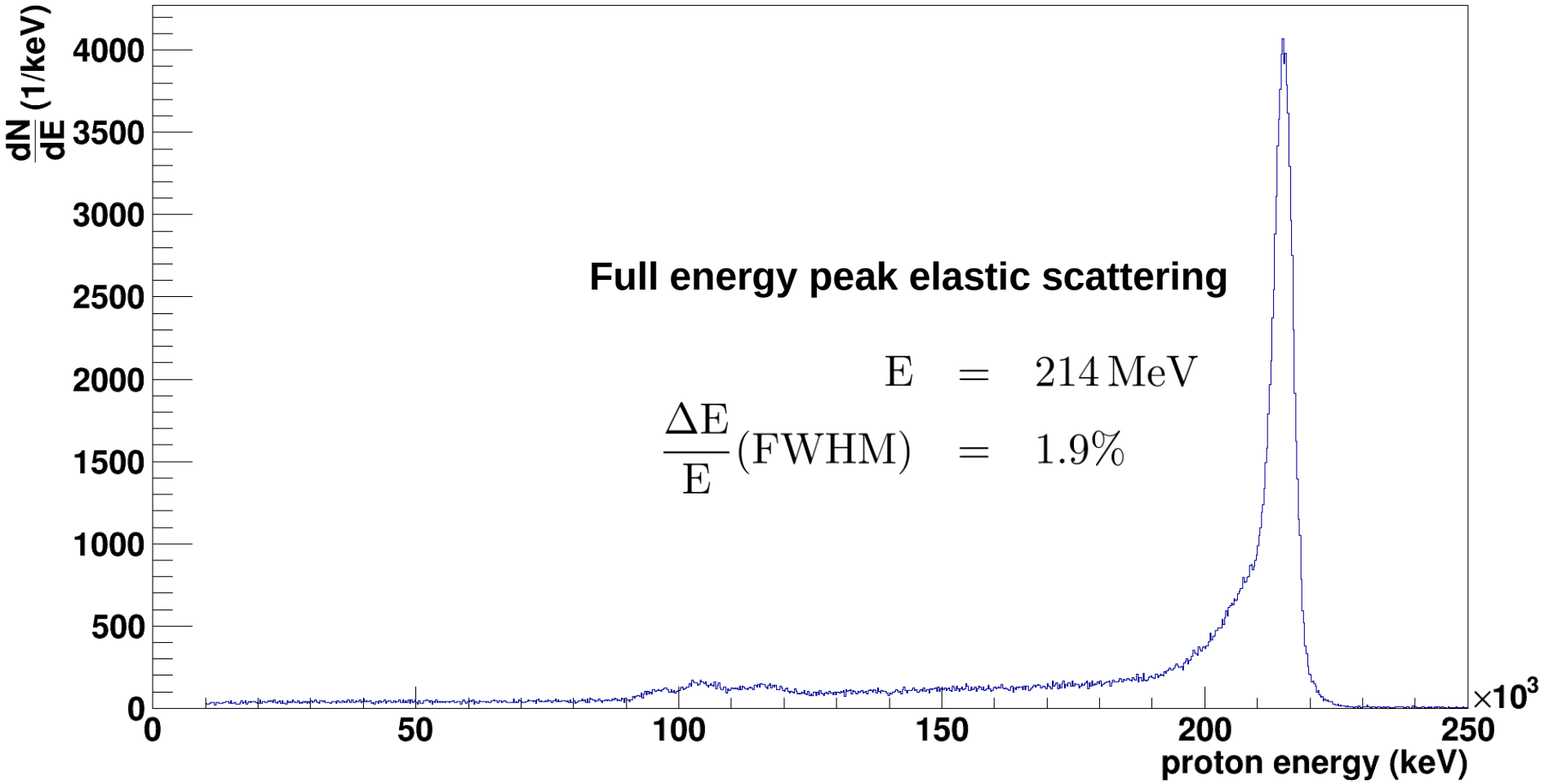
Vertex reconstruction



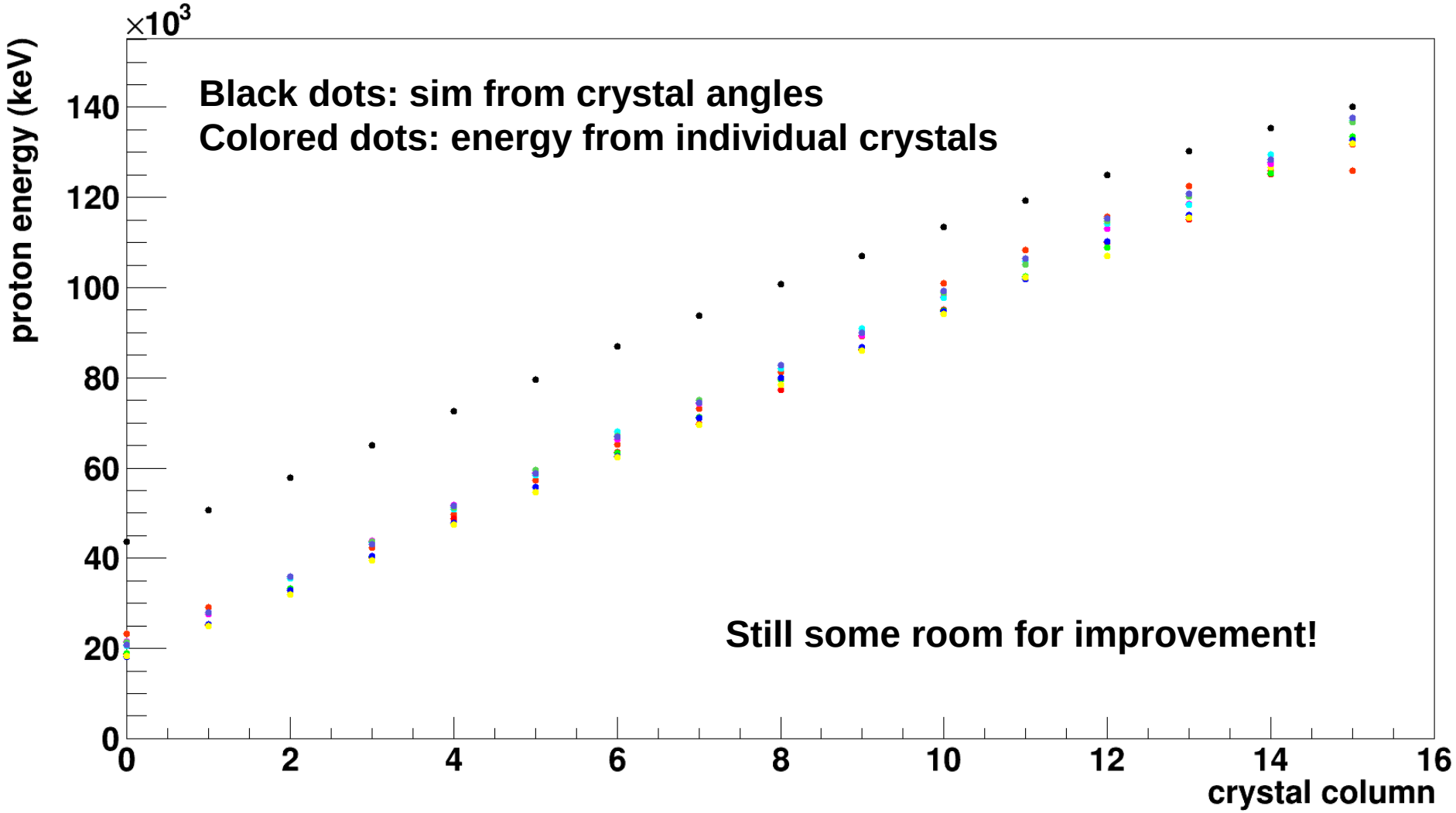
Opening angle cut



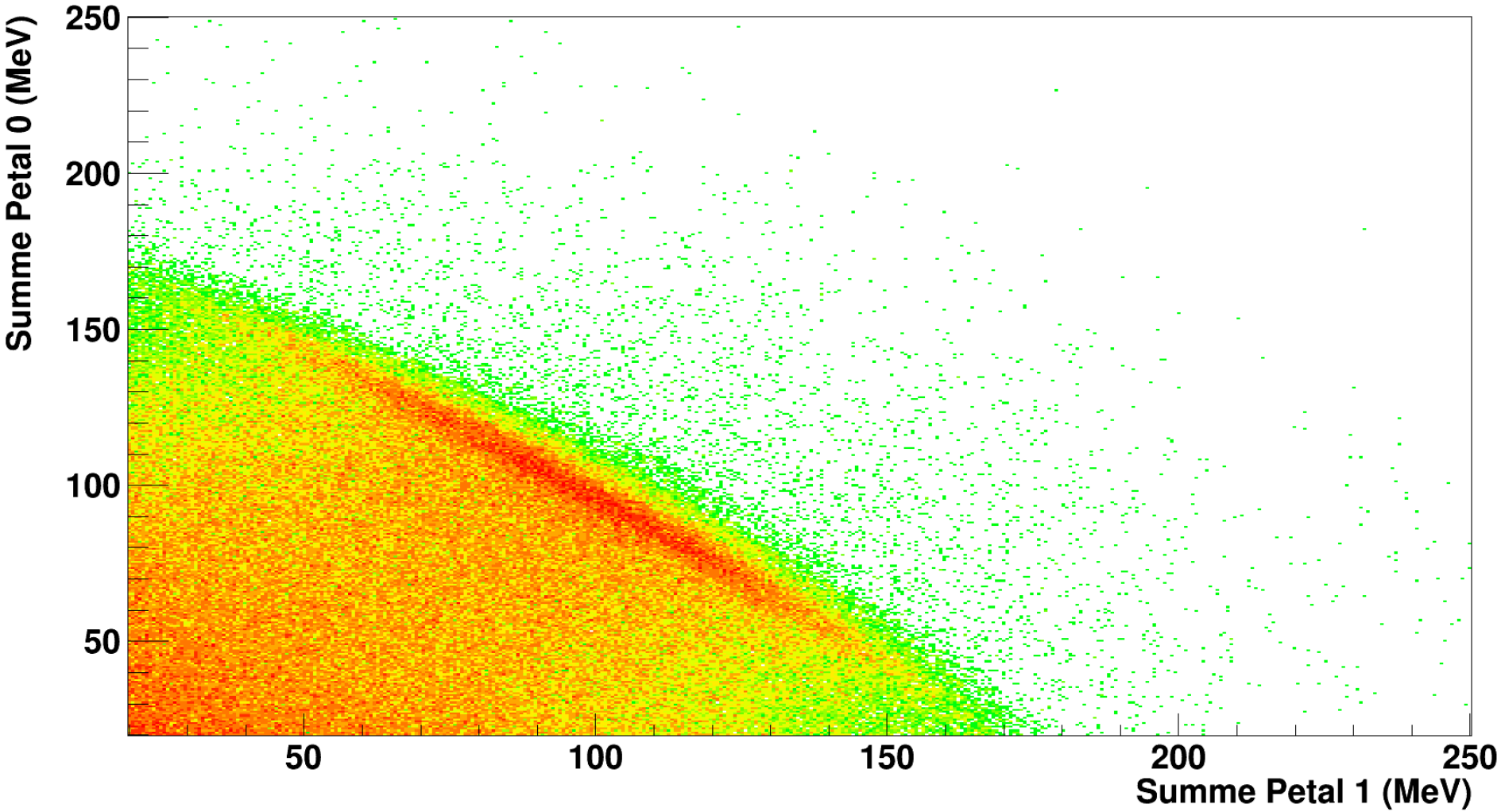
Proton sum energy resolution



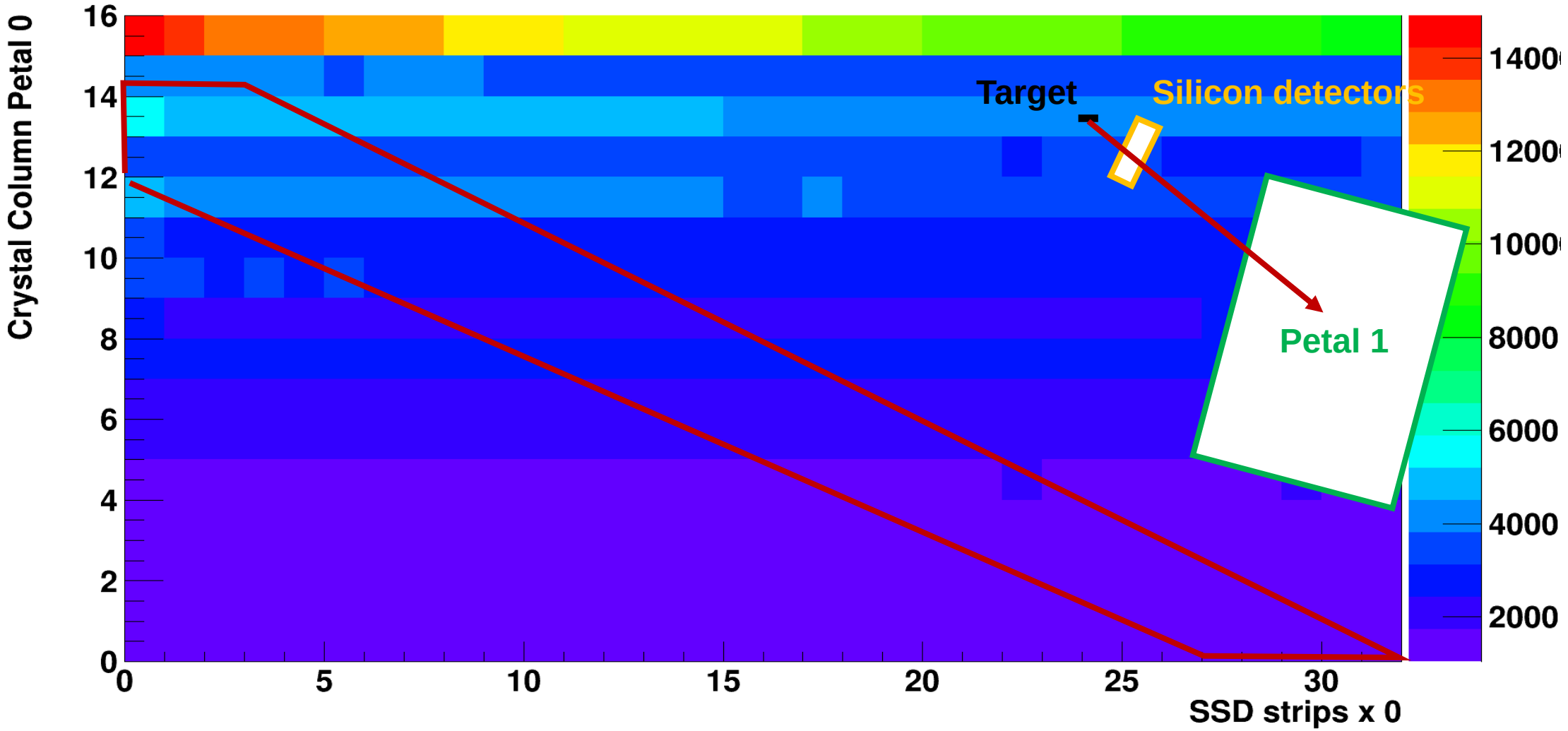
Calibration comparison



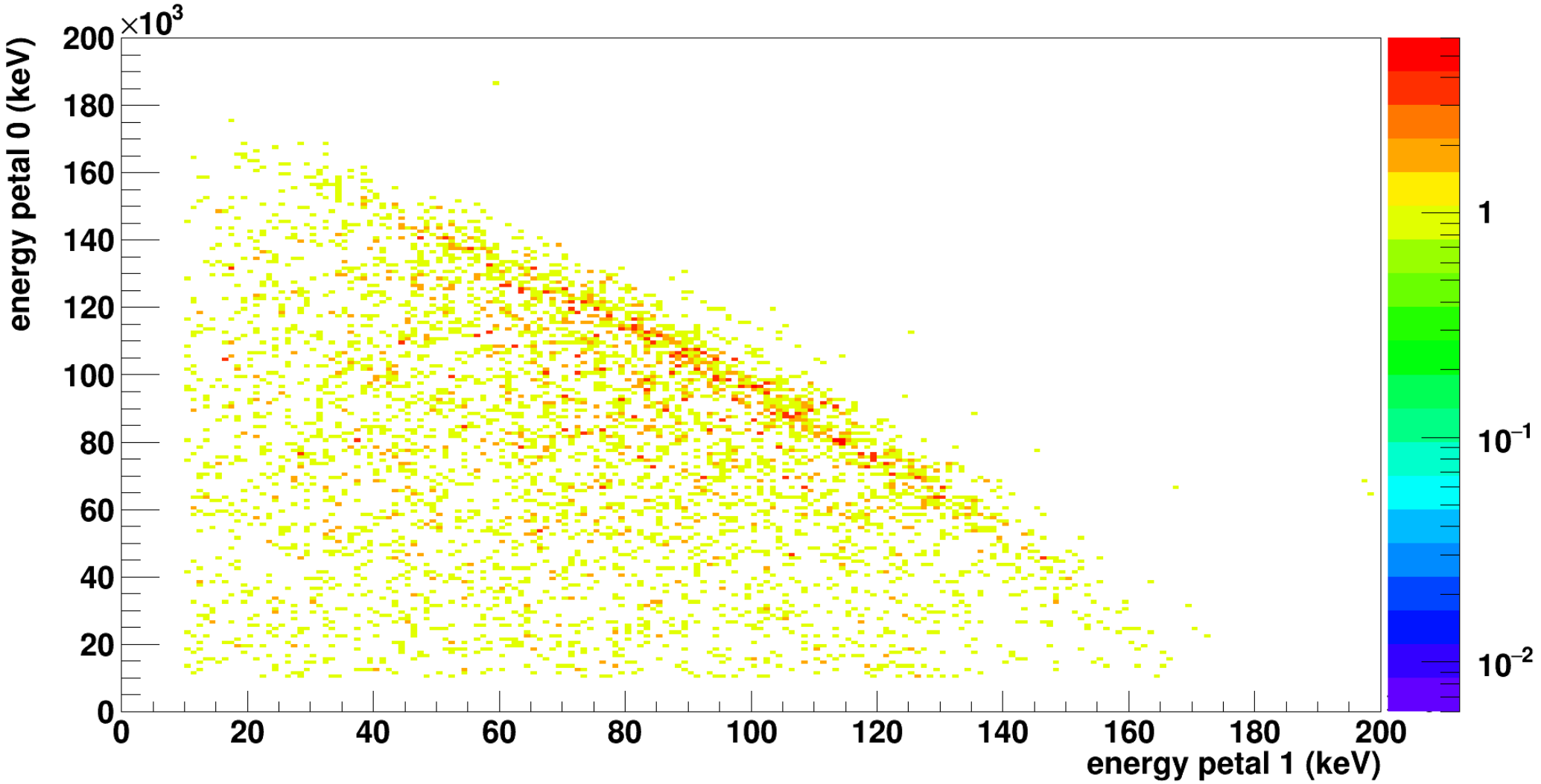
No Target petal correlation



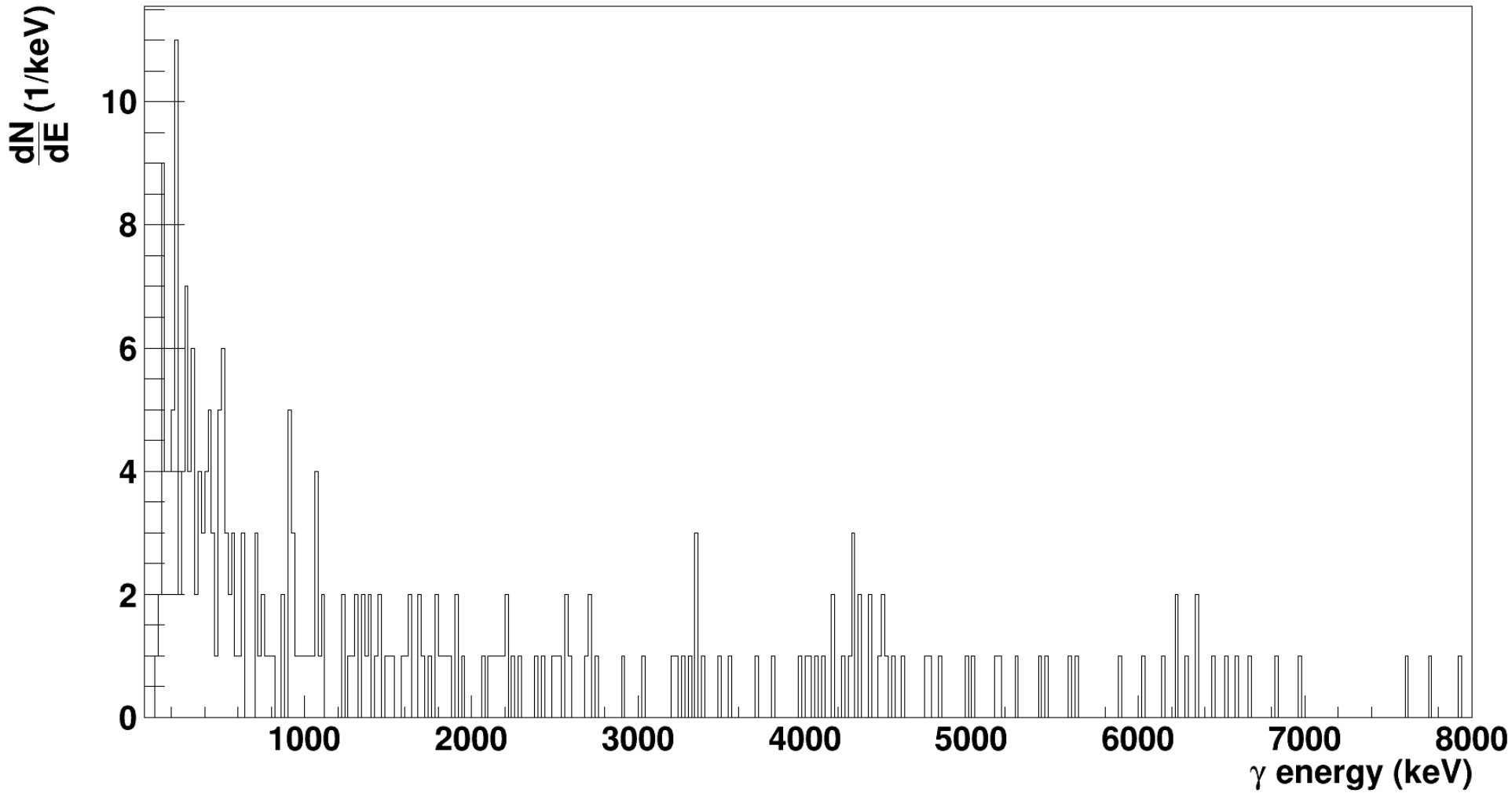
Vertex reconstruction



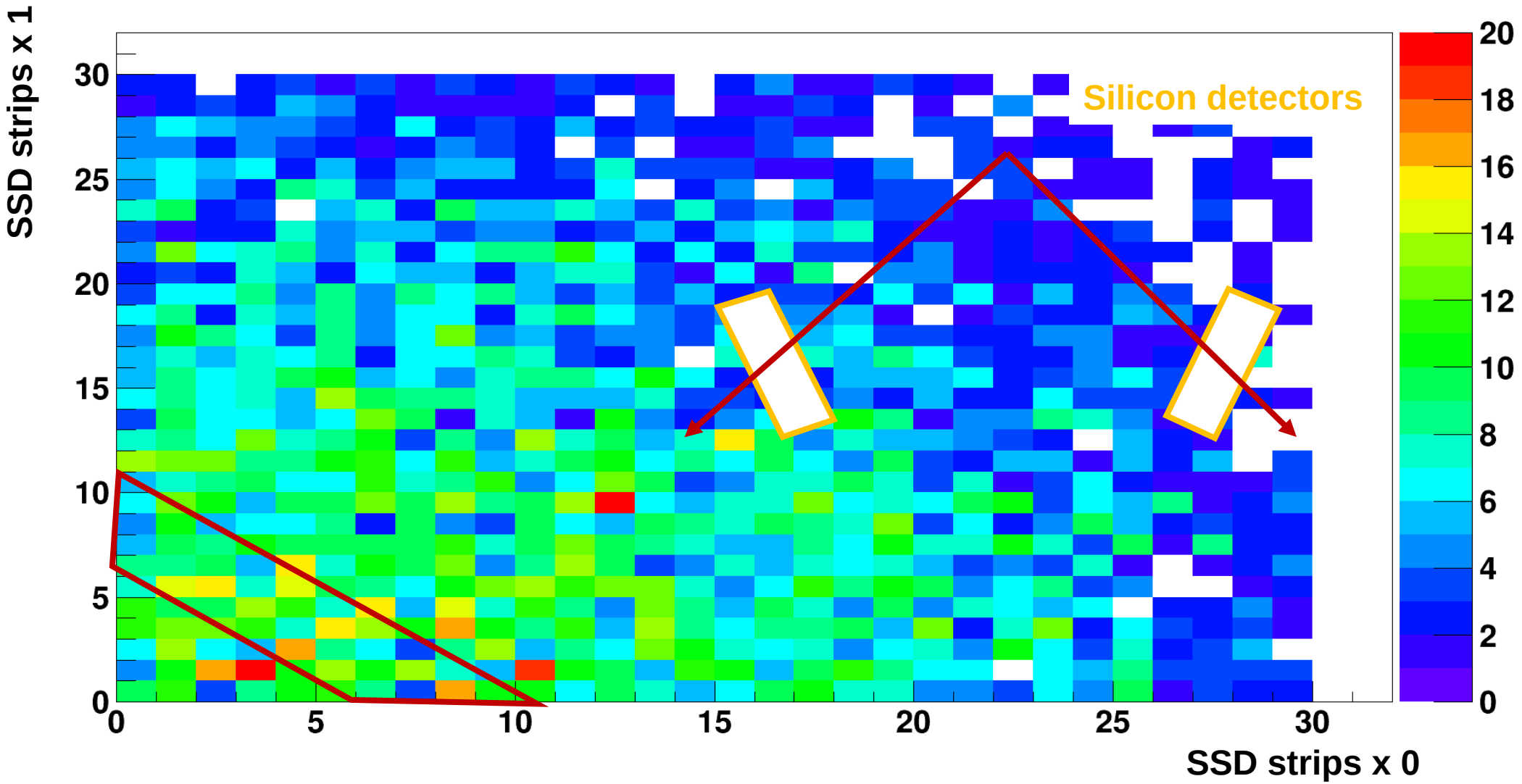
No Target after vertex rec.



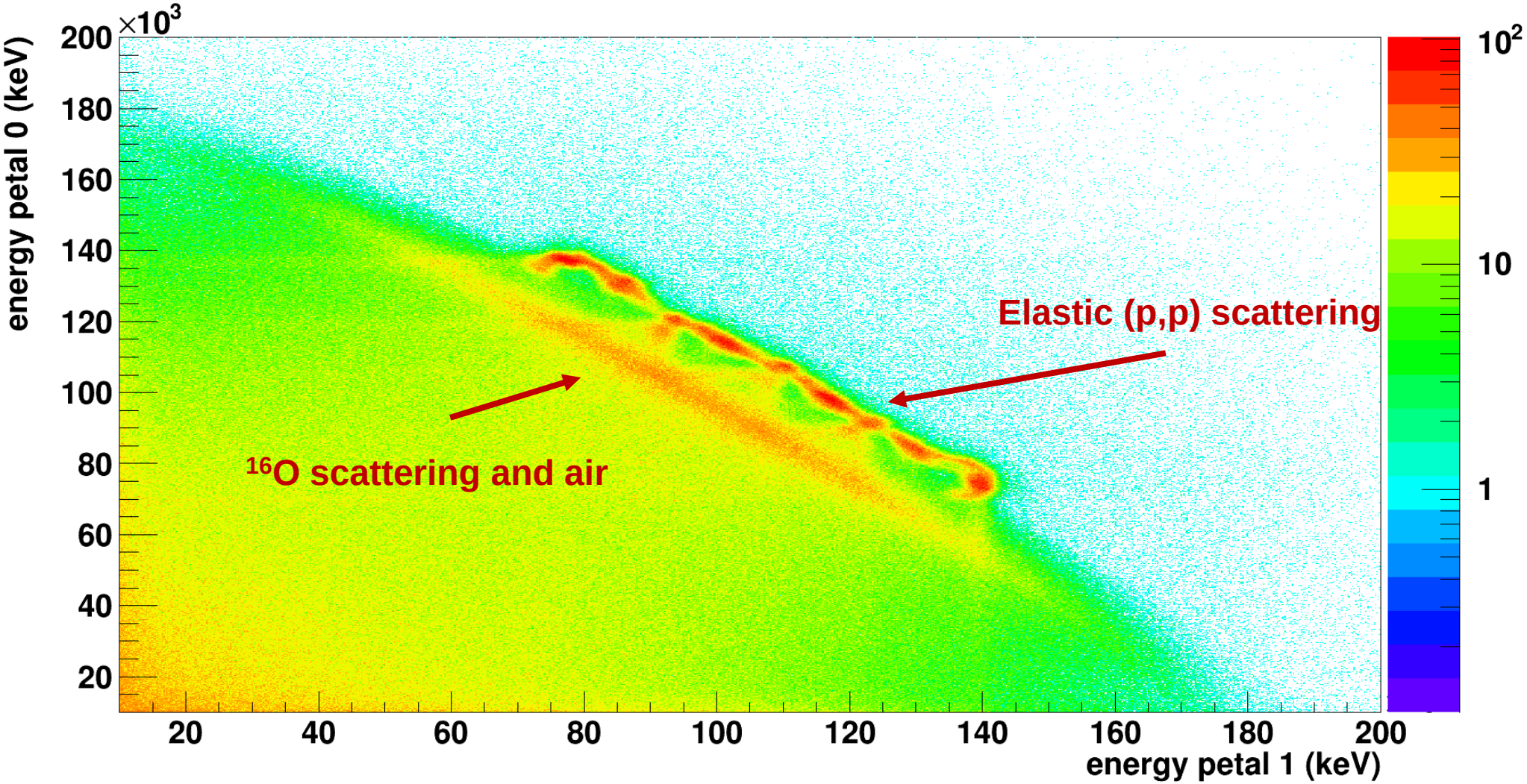
No Target γ rays



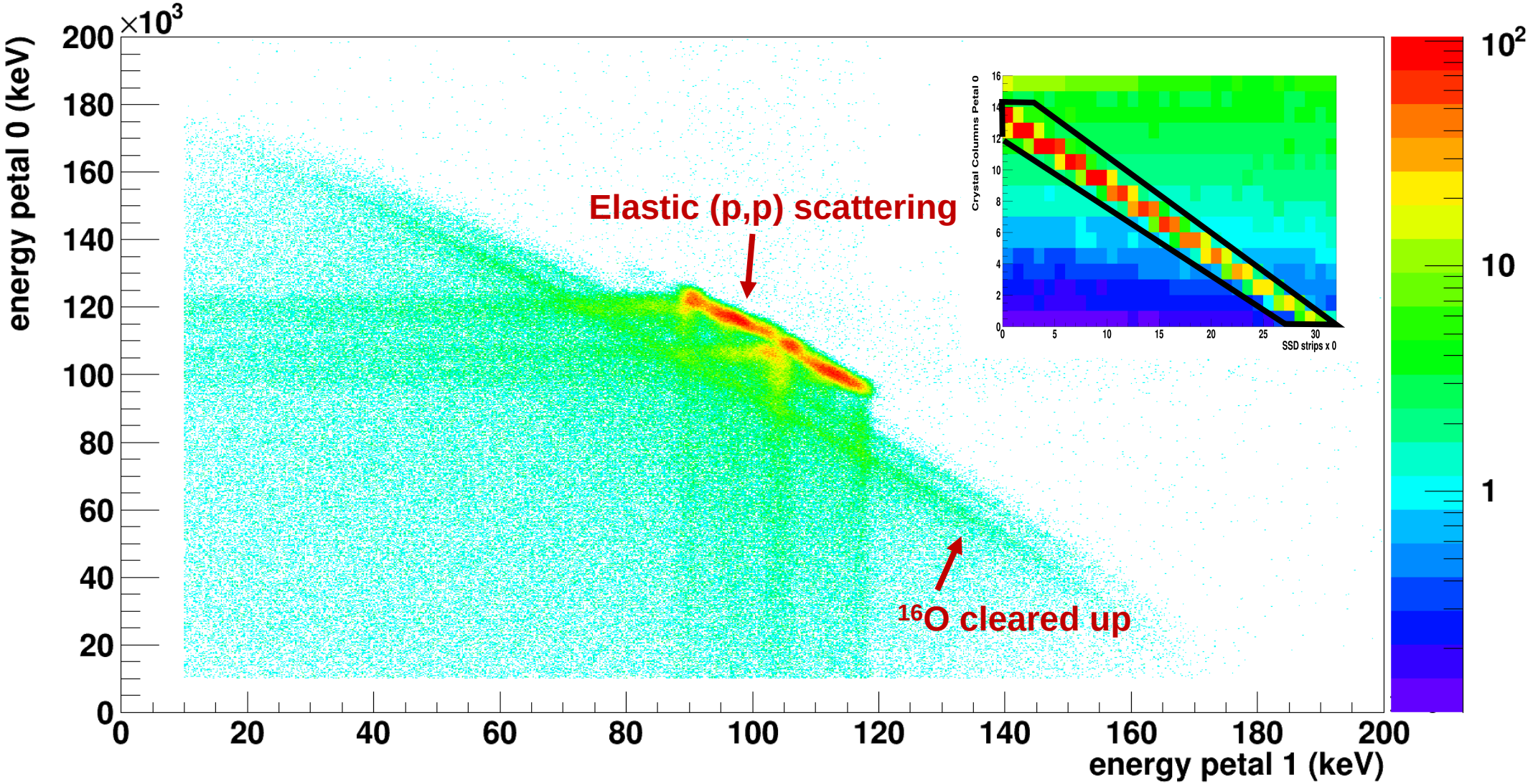
No target opening angle



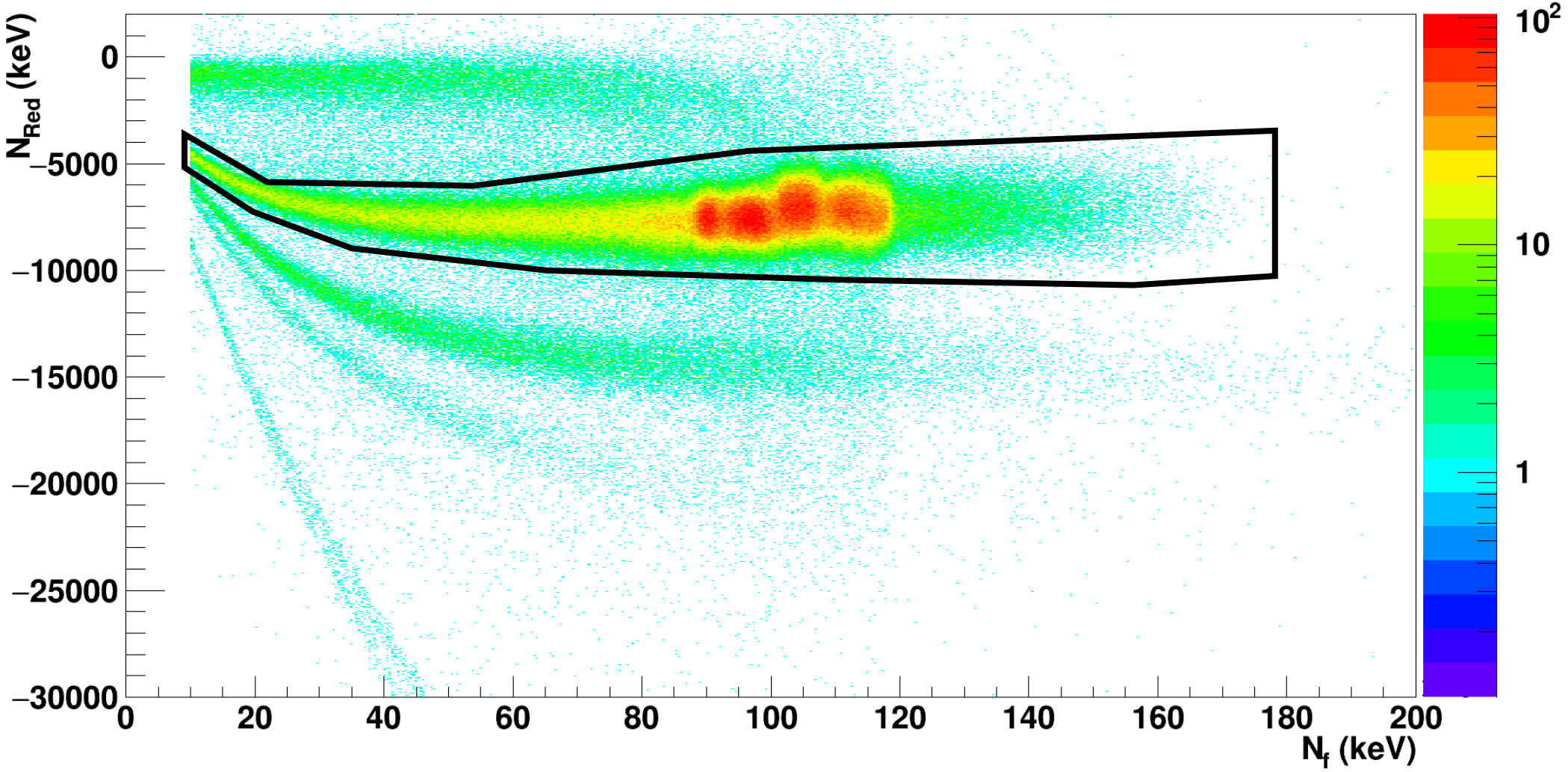
Water Target petal correlation



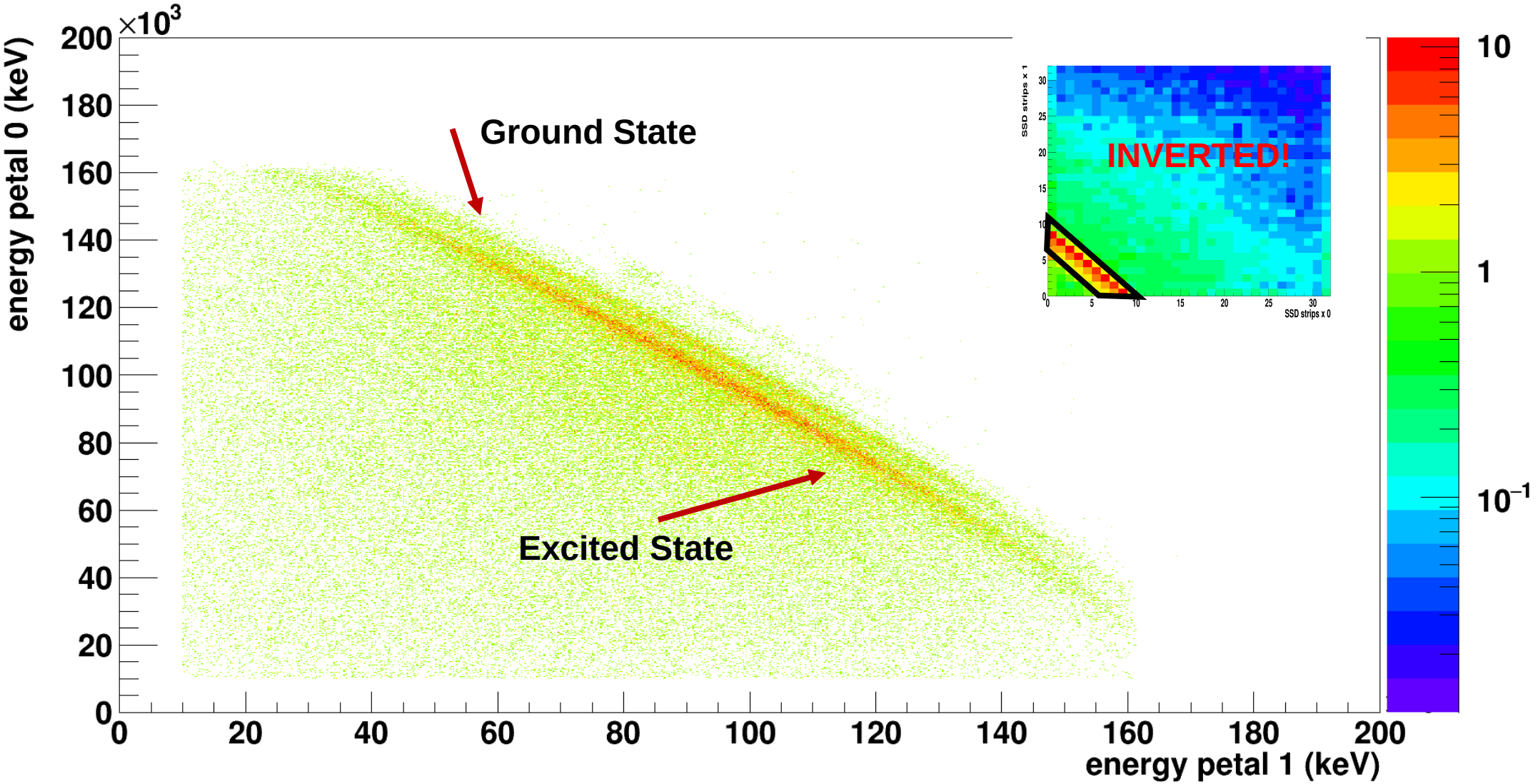
Water Target vertex cut



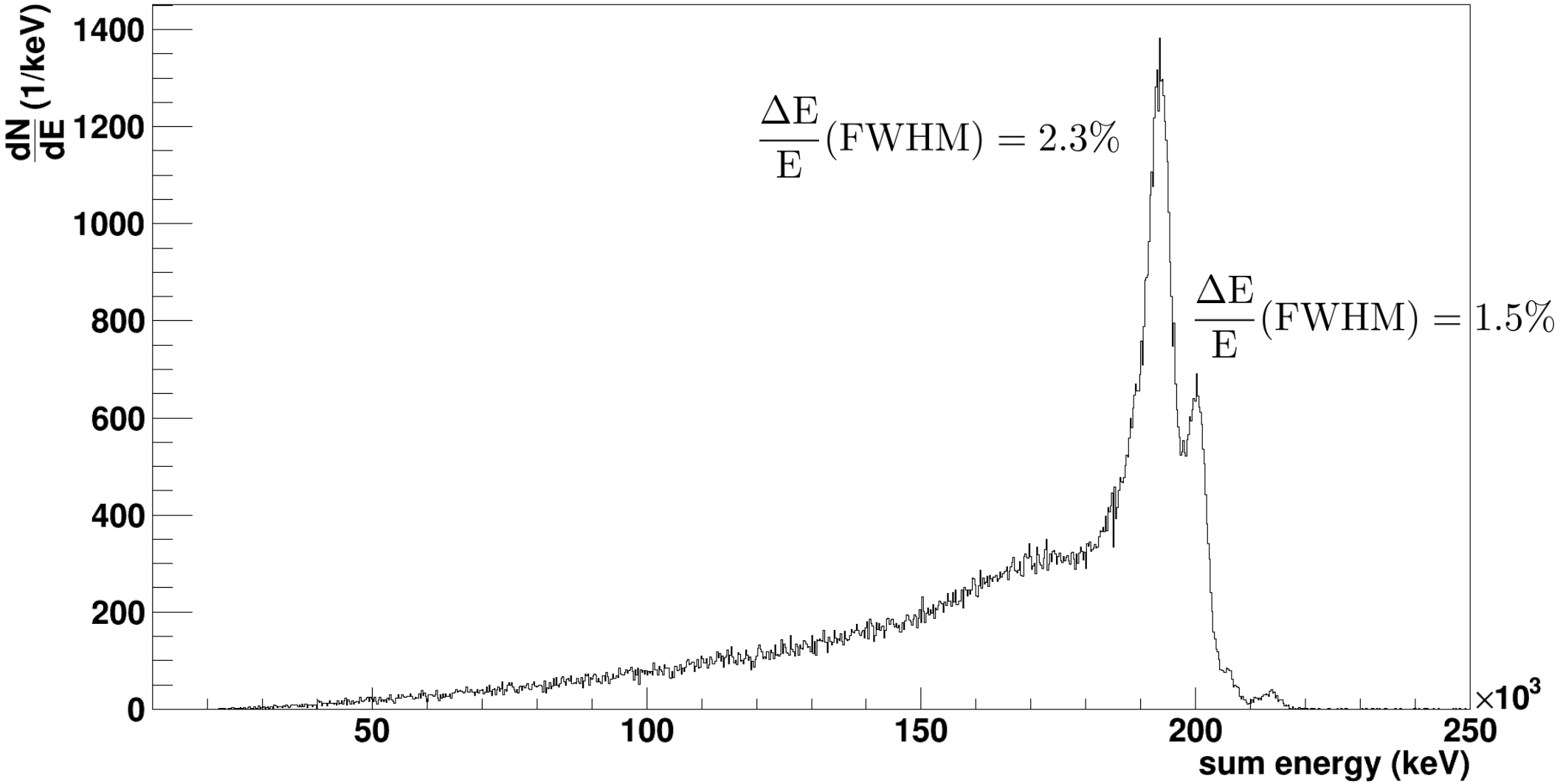
PID proton cut



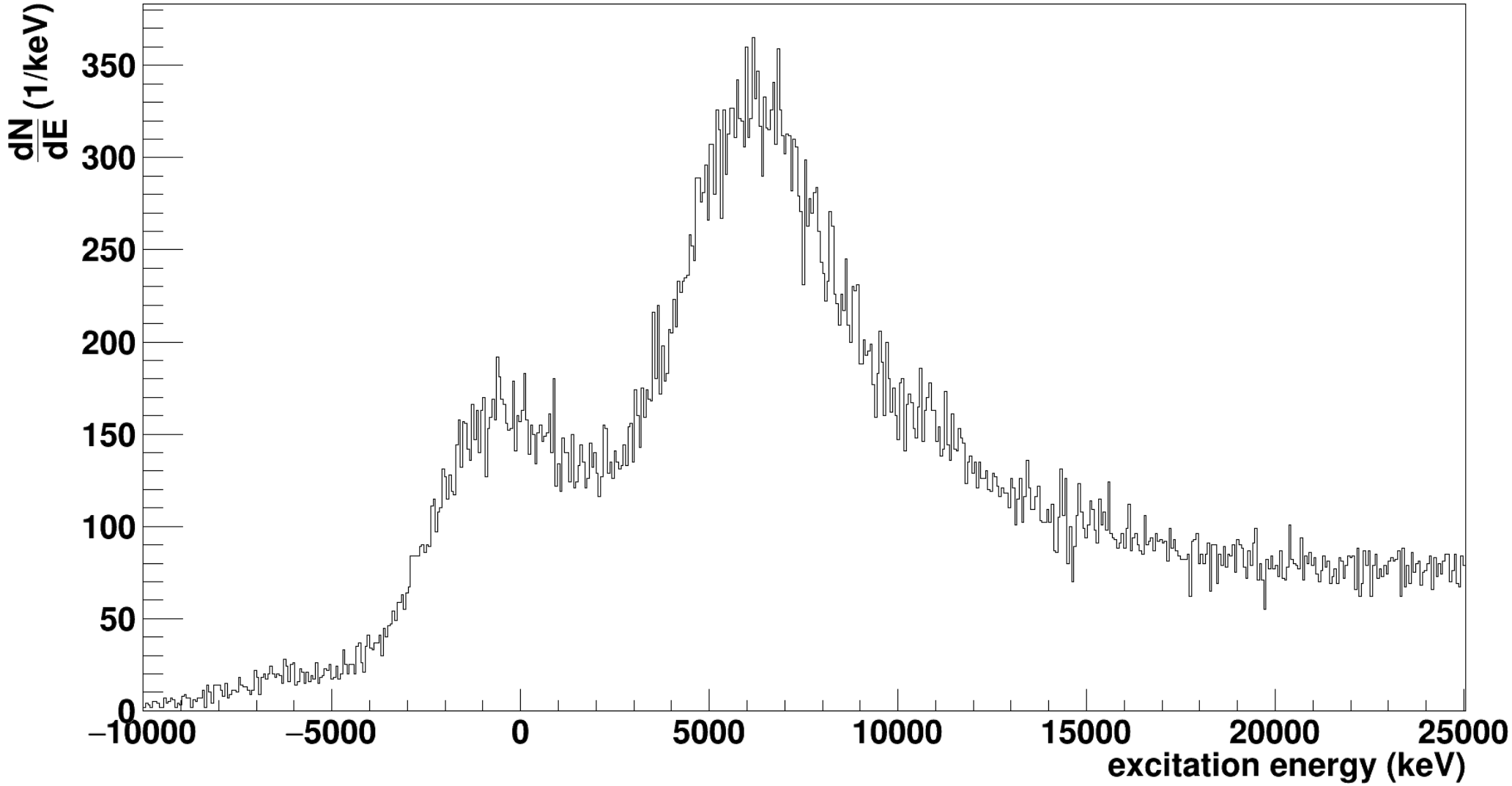
Water target opening angle



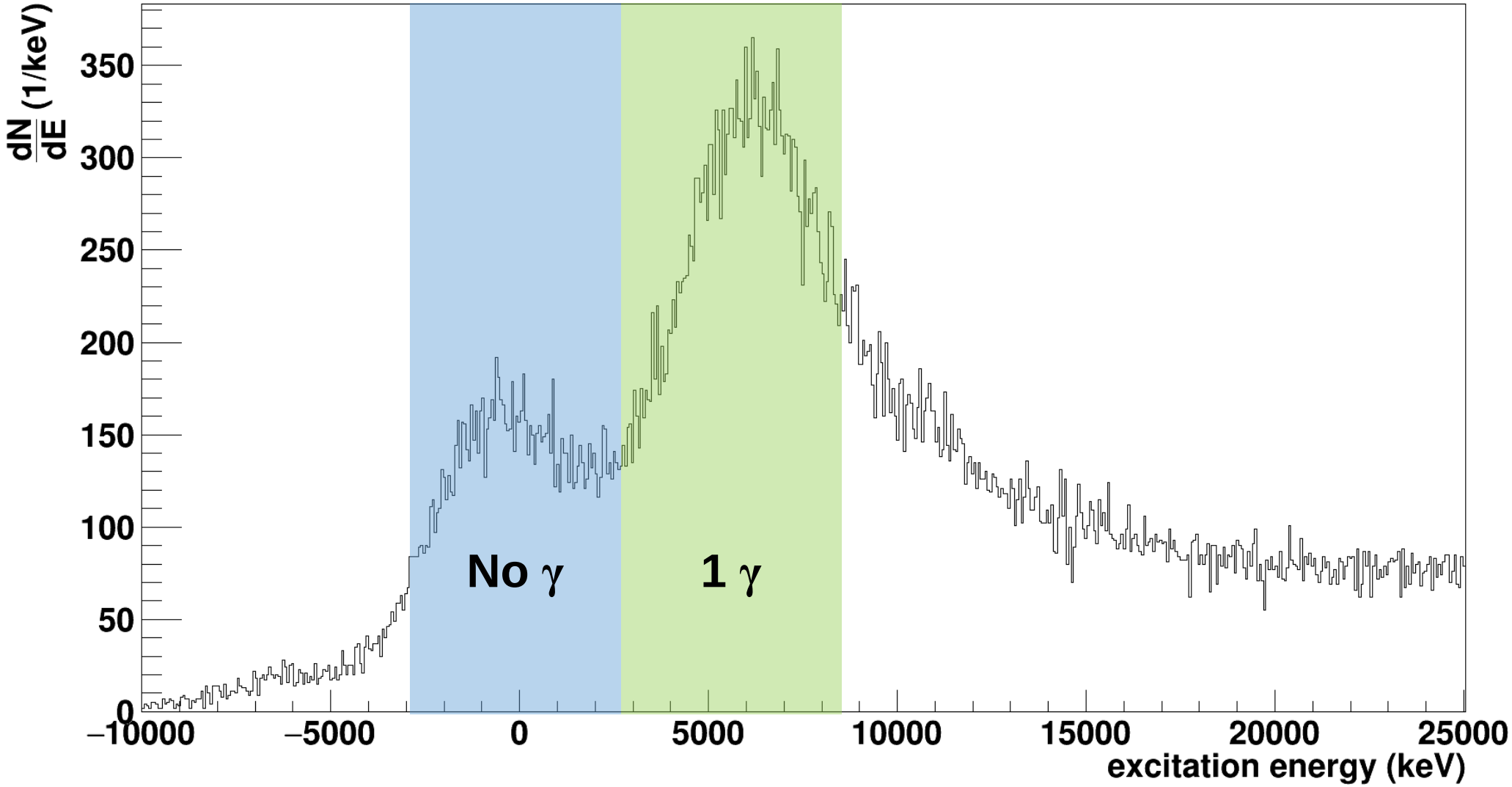
proton sum energy resolution



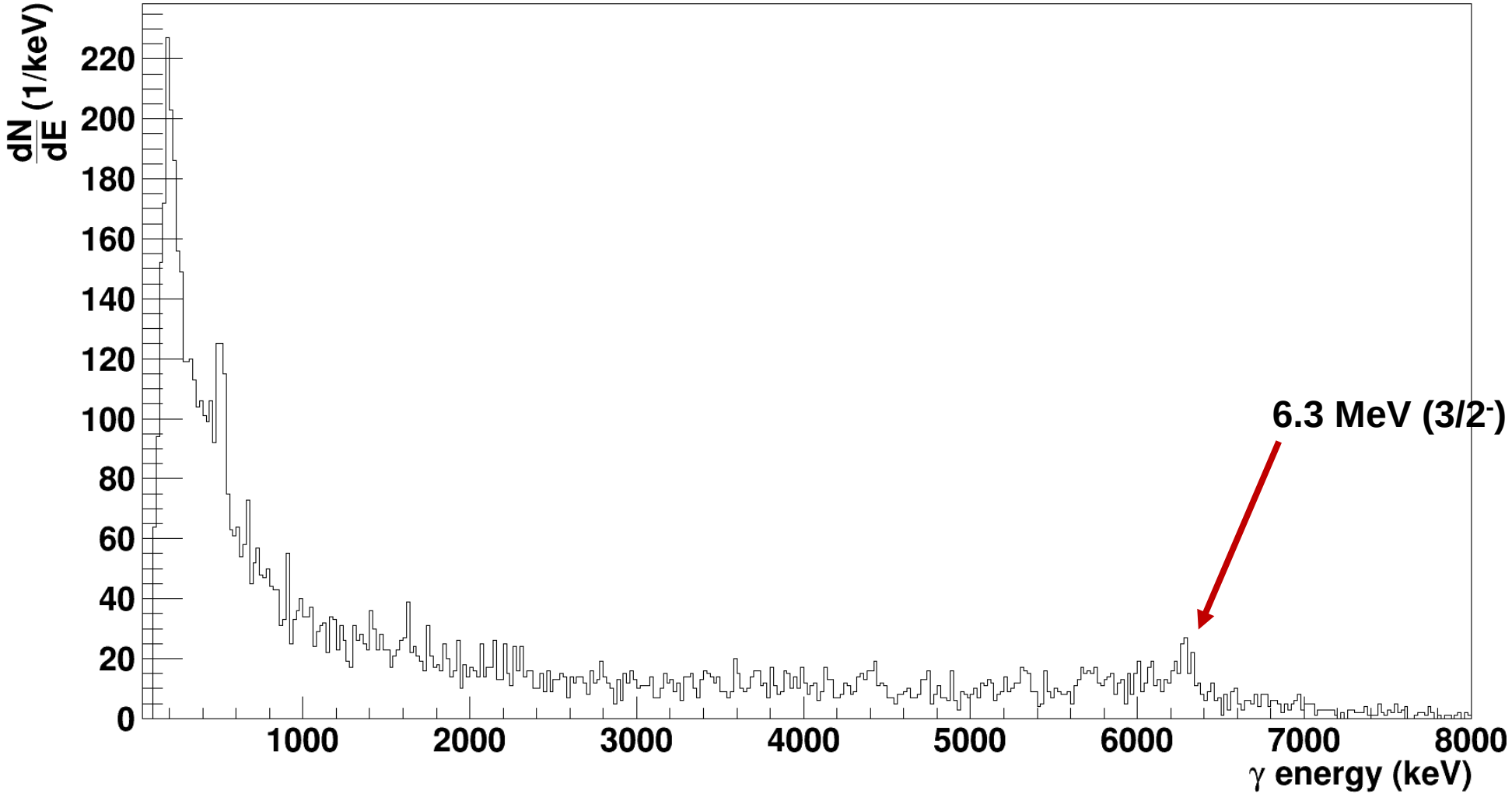
Excitation energy



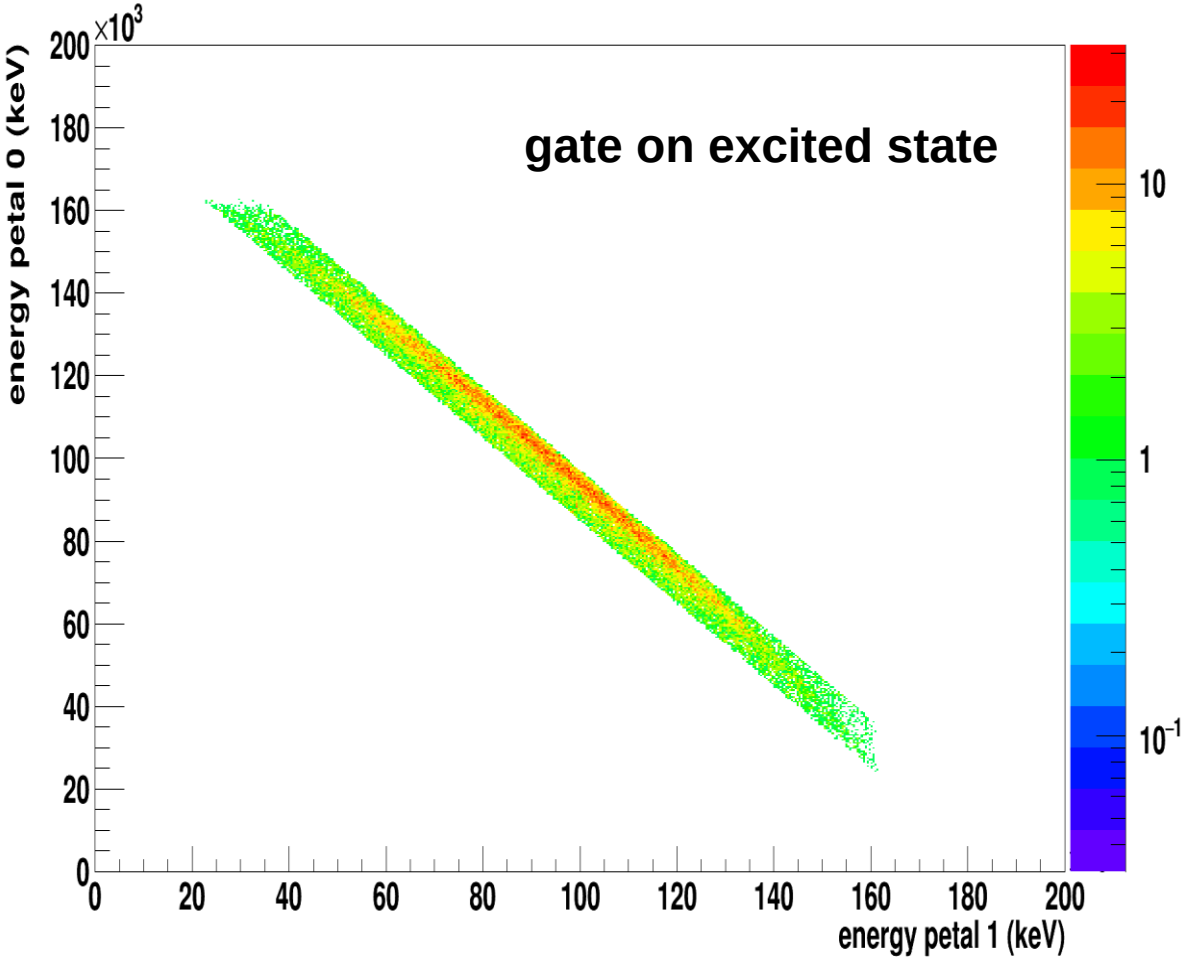
Excitation energy

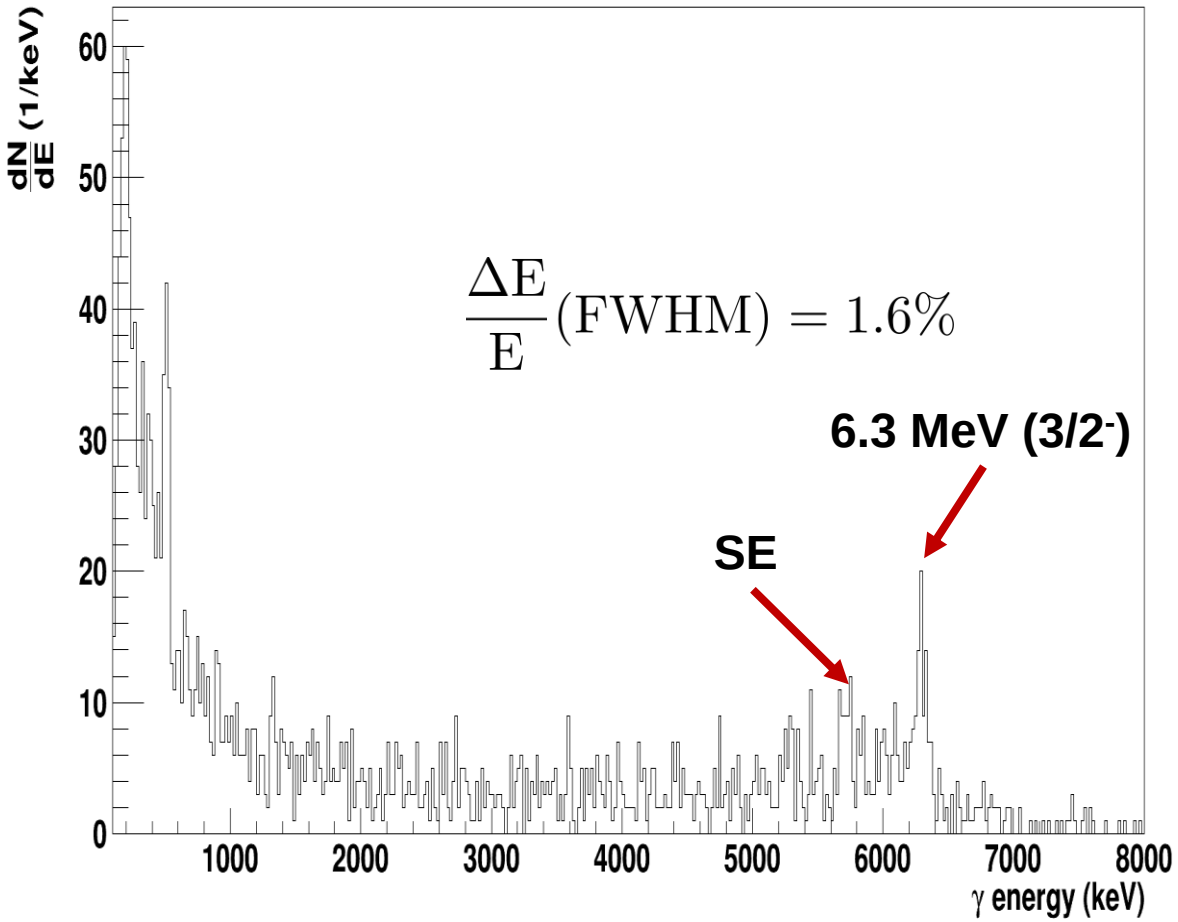


Coincident γ ray spectrum



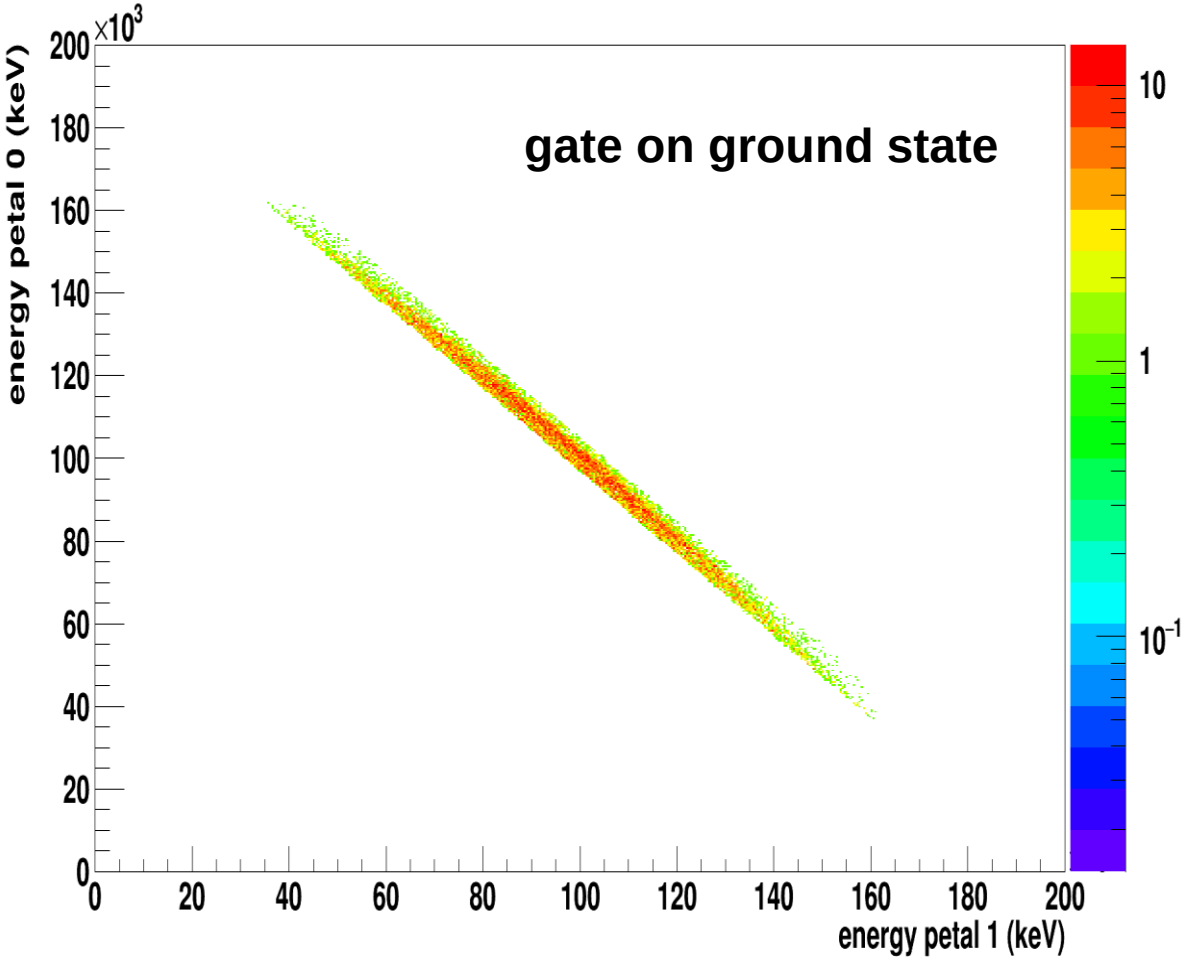
Coincident γ ray spectrum

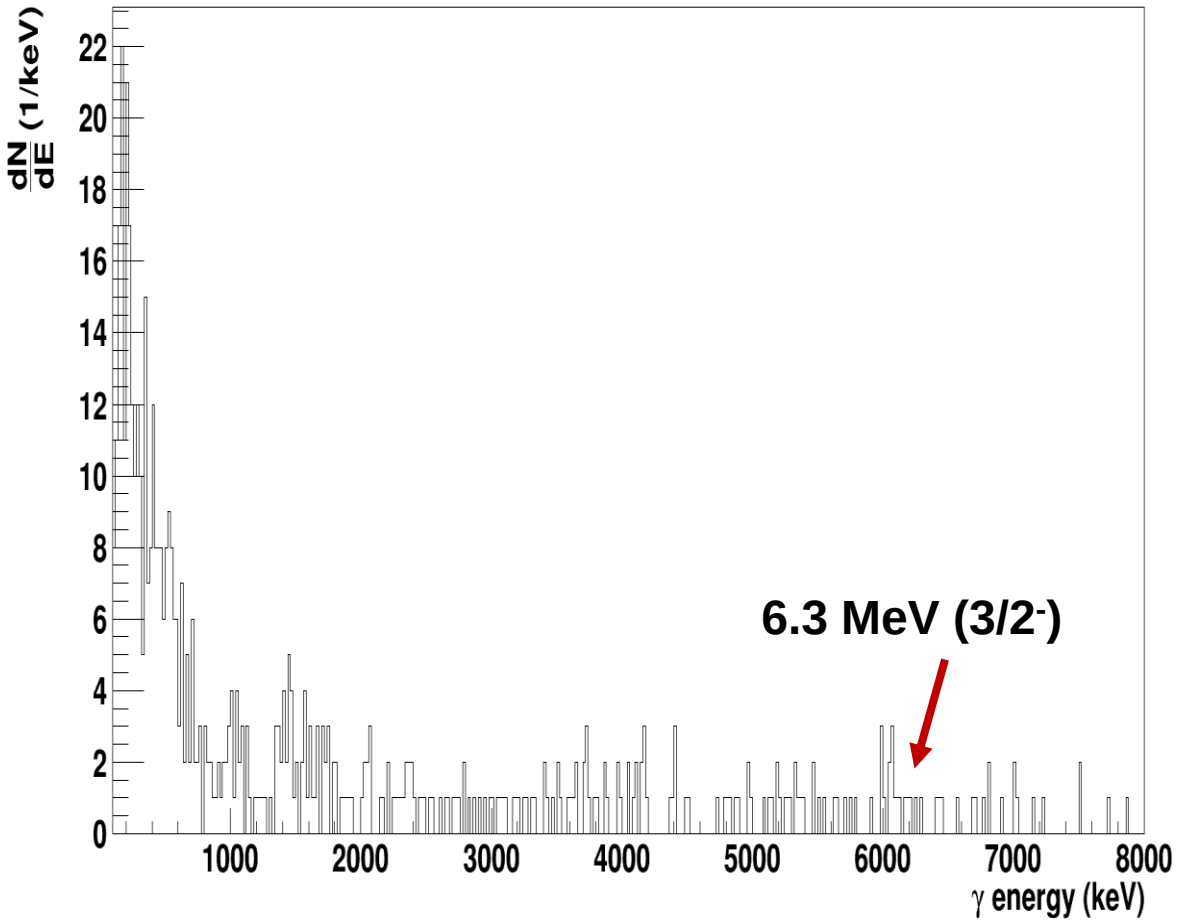




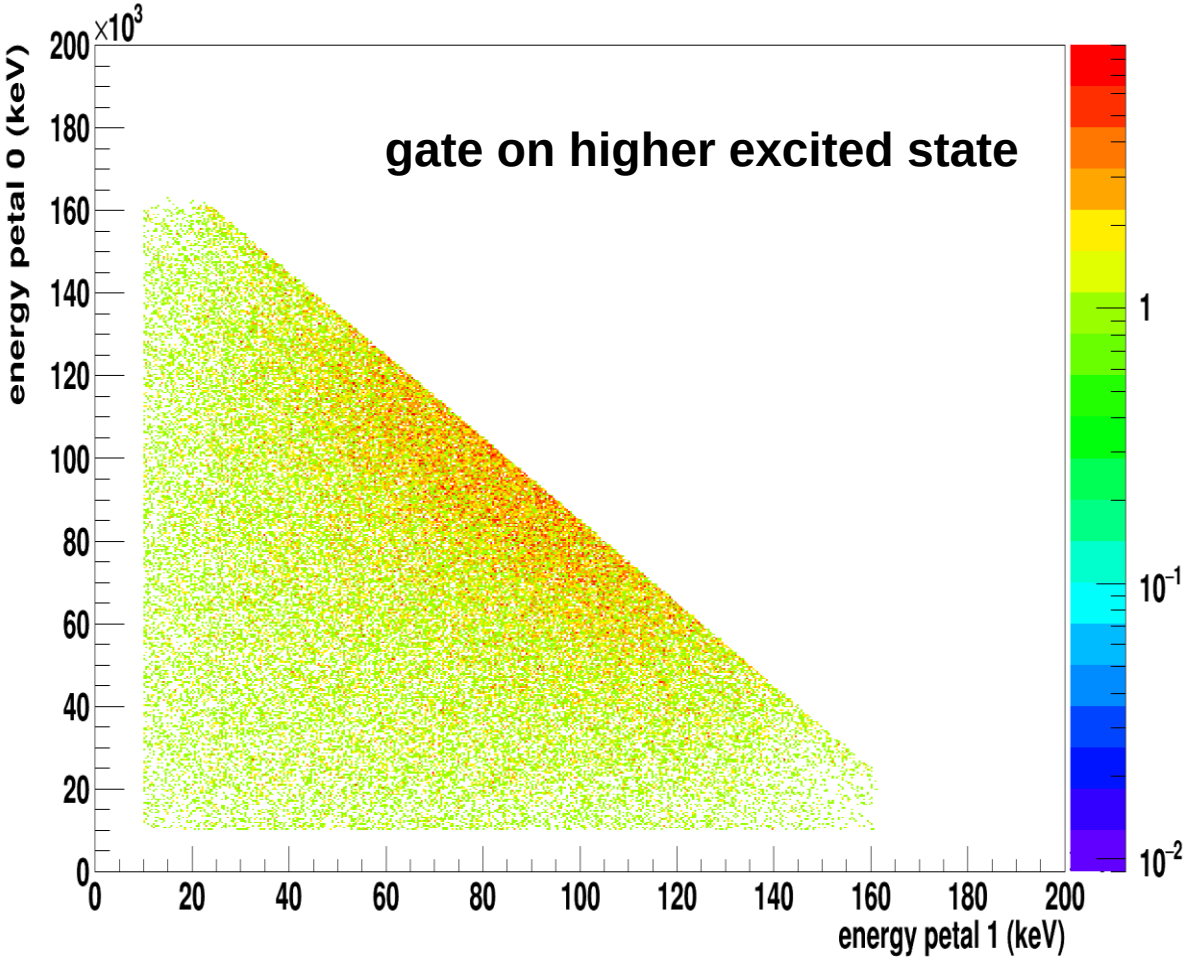
- **absolute Efficiency ongoing!**

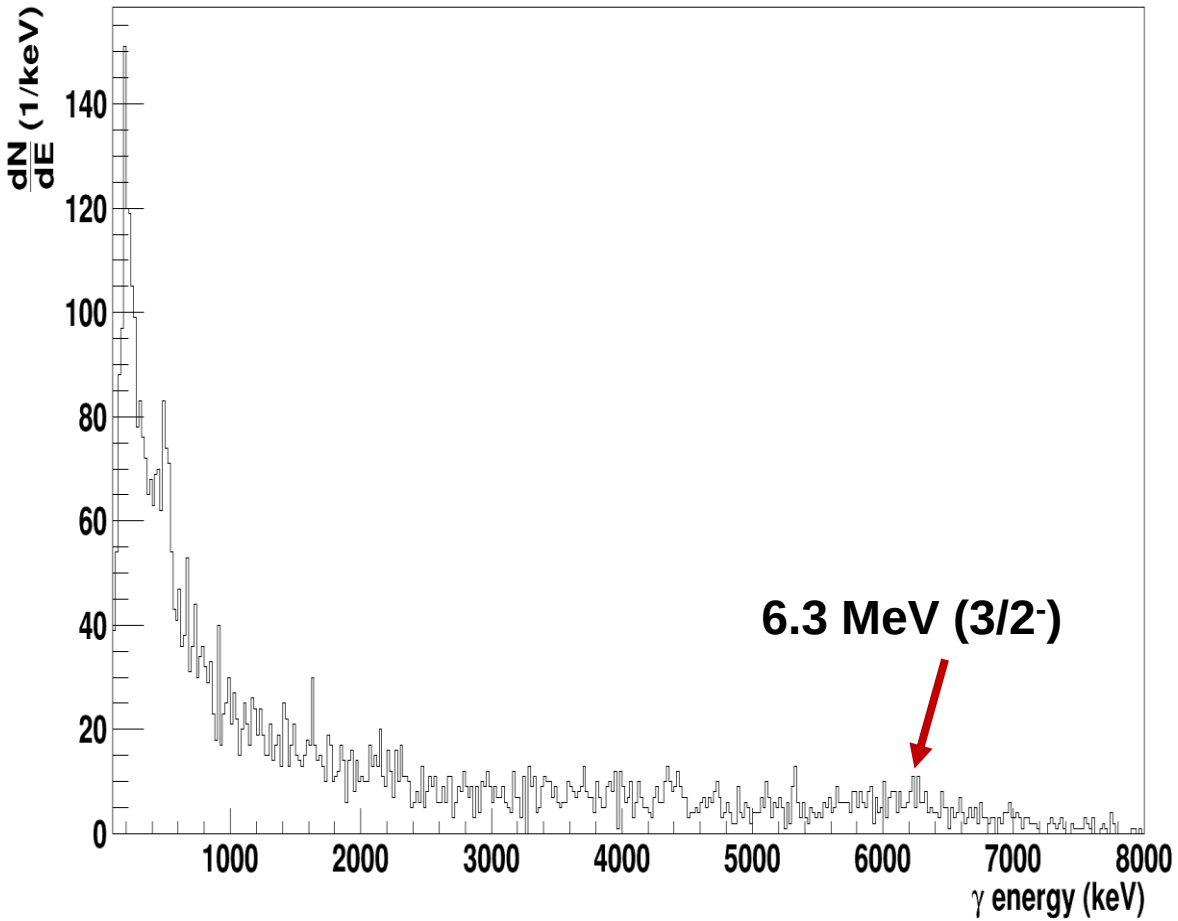
Coincident γ ray spectrum





Coincident γ ray spectrum





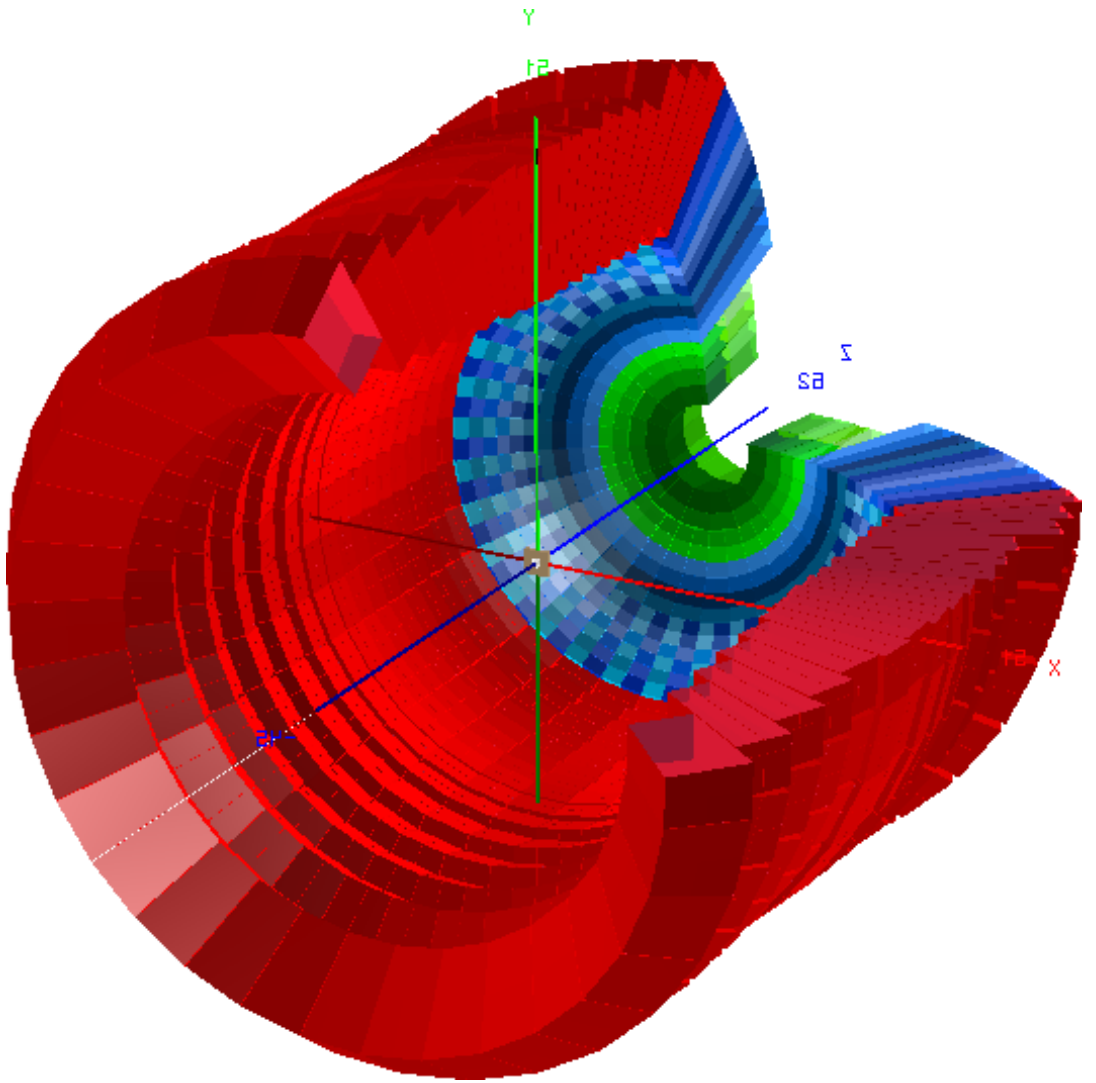
- some feeding visible

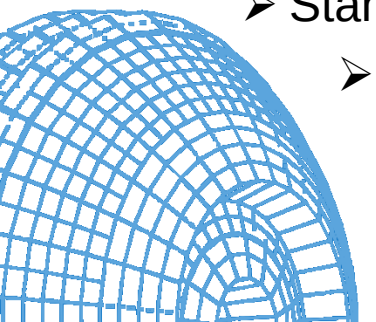
Summary and Outlook

- (p,2p) in normal kinematics is ideal calibration experiment!
- Water jet target works fine, data can be clearly separated from the background
- calibration good starting point for proton calibration
  - ➢ ongoing work!
- First results from the water target look promising, $1/2^-$ and $3/2^-$ states are clearly separated
- γ energy resolution under realistic circumstances (1,6 %)

➢ extract crossection for $^{16}O(p,2p)$

- Phase 0:
  - ➢ more auto calibration for 2000 crystals
  - ➢ proton calibration fine tuning
  - ➢ Standard experiment for CALIFA commissioning
    - ➢ 3x Krakow already planned!

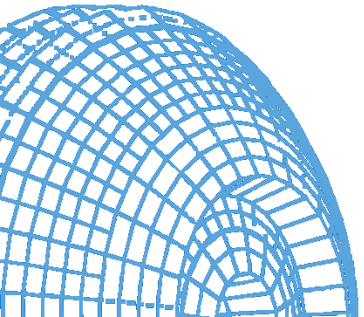




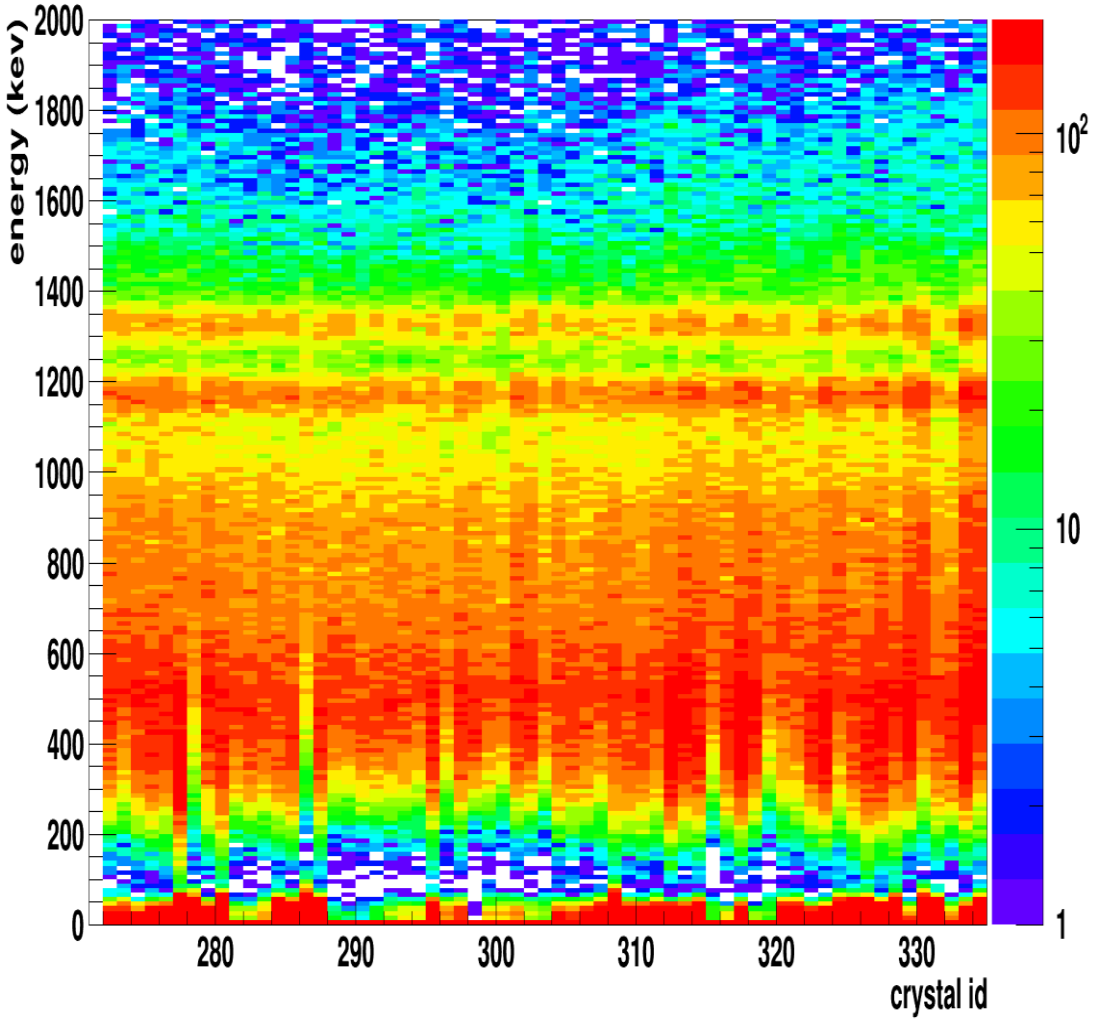
Thank you!

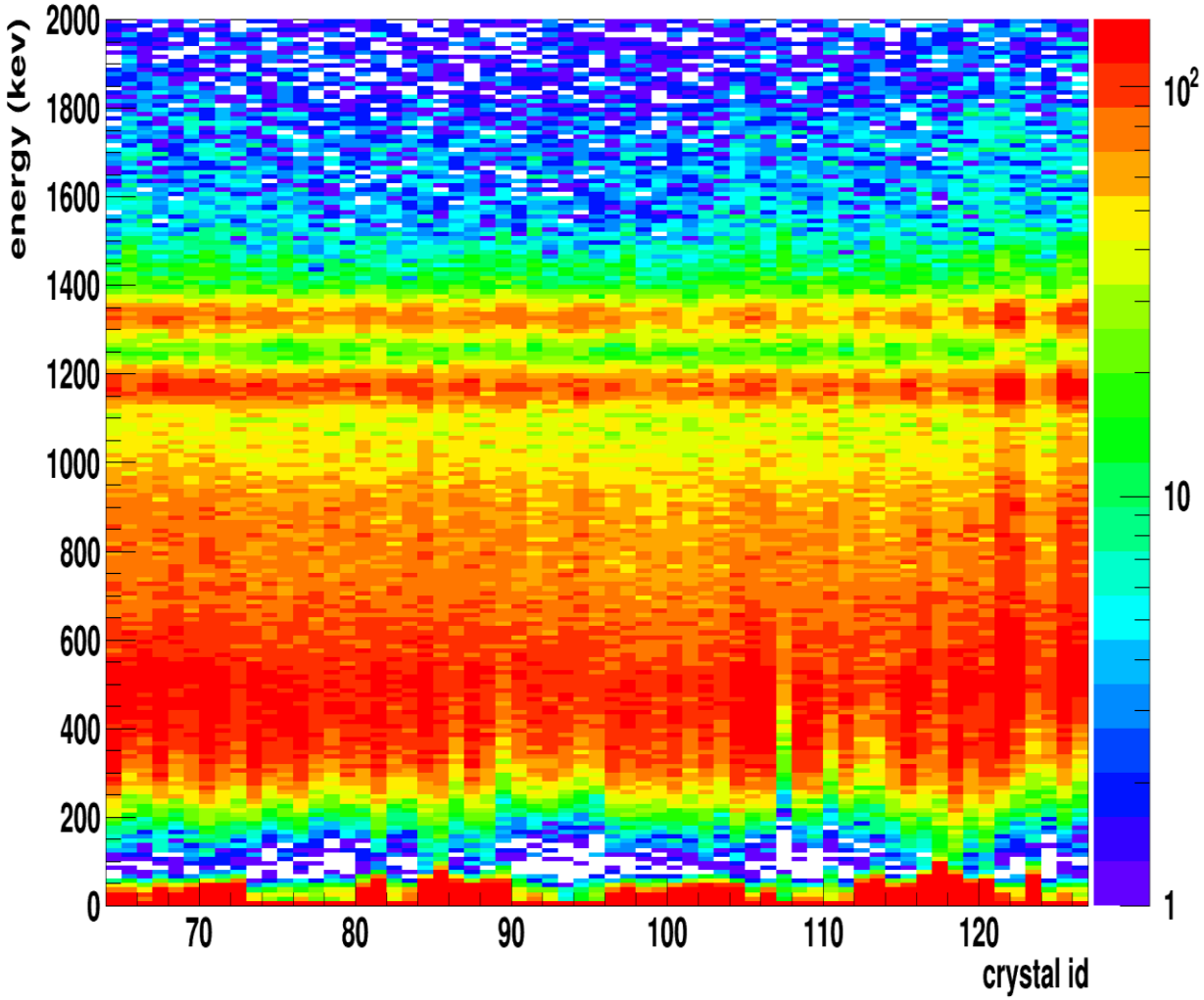
CALIFA @ Technical University of Munich (TUM)

Roman Gernhäuser, Benjamin Heiss, Philipp Klenze, Patrick Remmels, Felix Stark, Max Winkel



Calibration Backup





CALIFA Structural Design

Barrel:

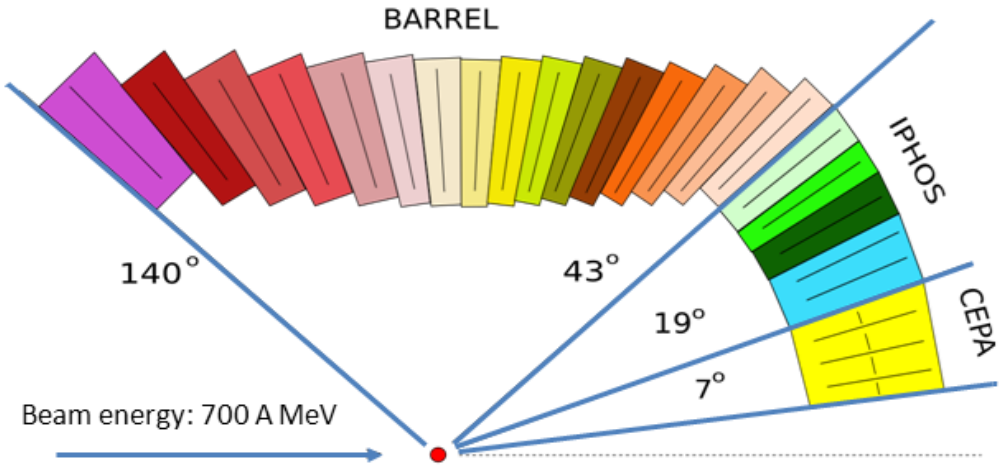
- 1952 CsI(Tl) scintillation crystals (0,7 μs + 3,3 μs) + LAAPD readout
- Direct energy measurement of stopped protons up to ~300 MeV

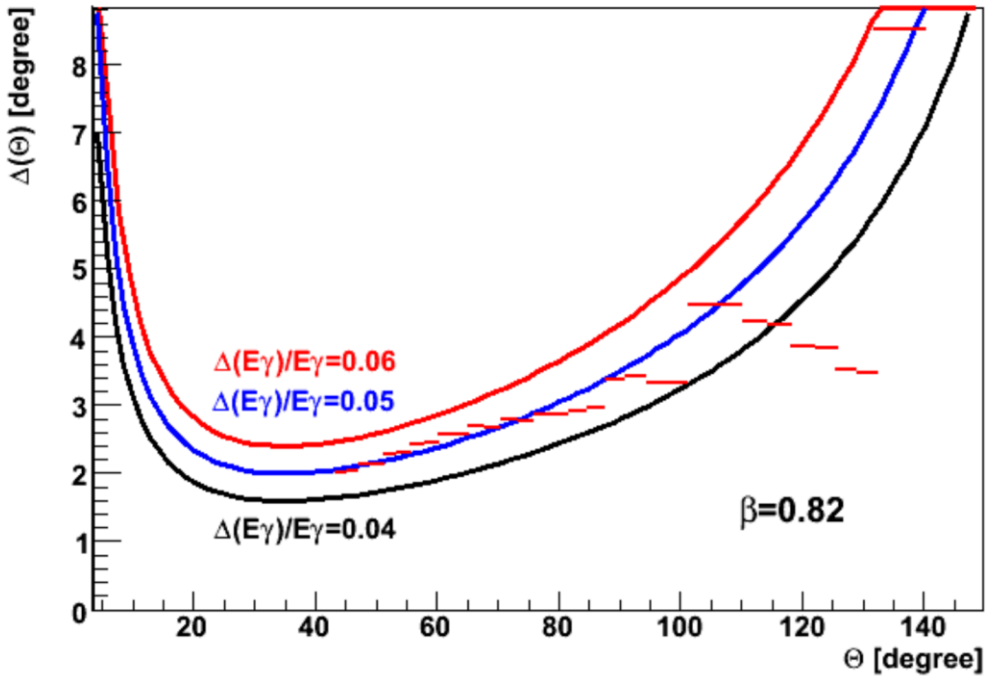
iPhos:

- 512 CsI(Tl) crystals + LAAPD readout
- Full energy reconstruction of punched through protons by PID

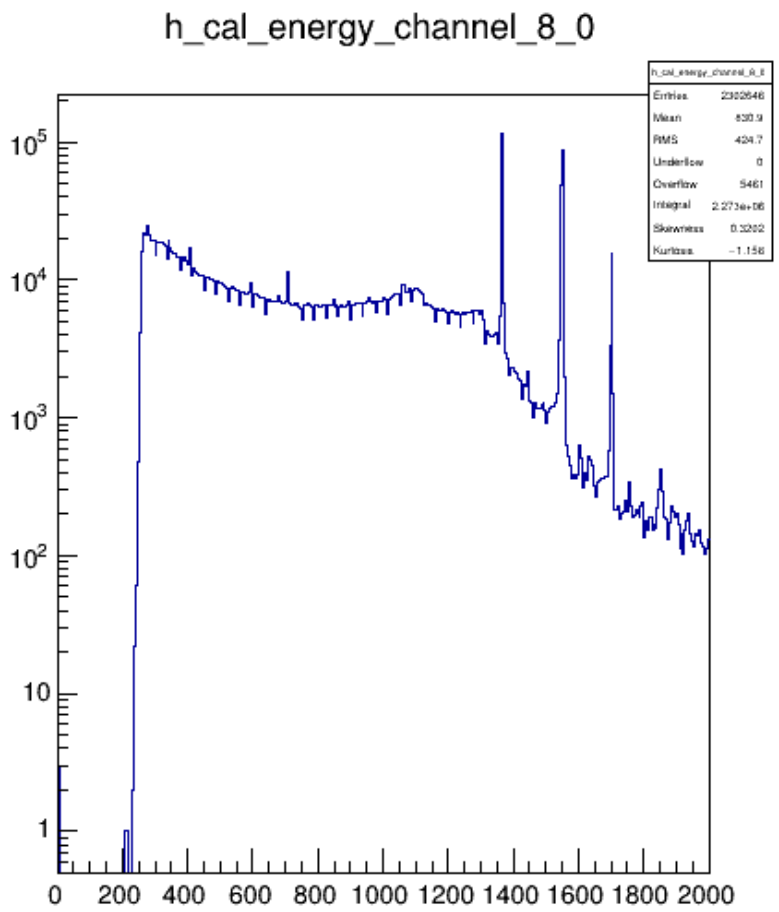
CEPA:

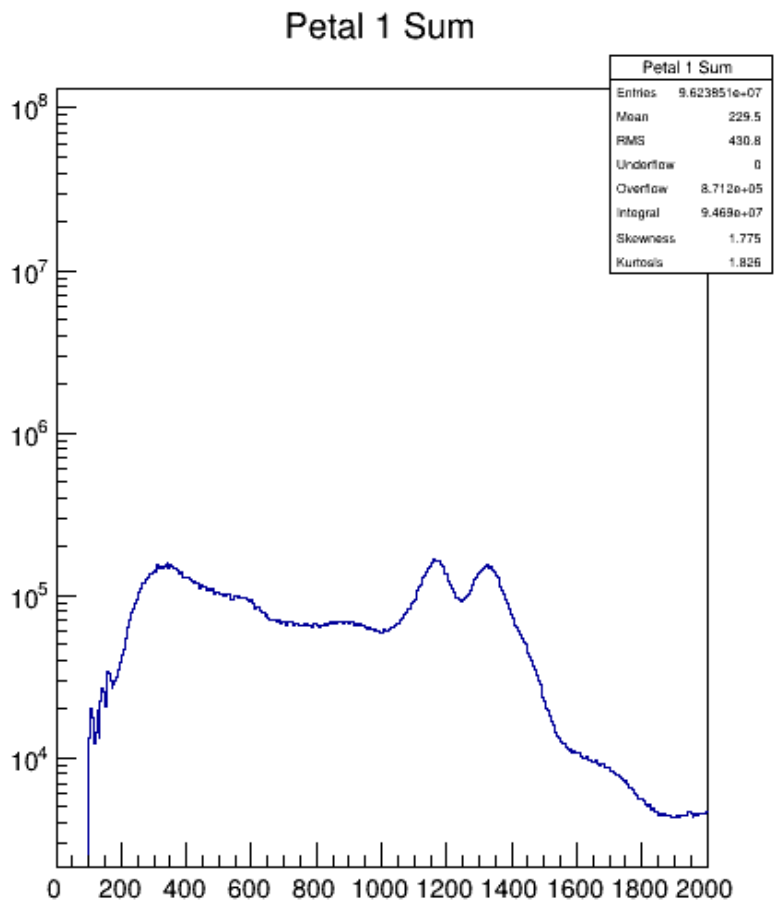
- 96 $LaBr_3$ (16 ns) + $LaCl_3$ (28 ns) Phoswich detectors + PMT readout

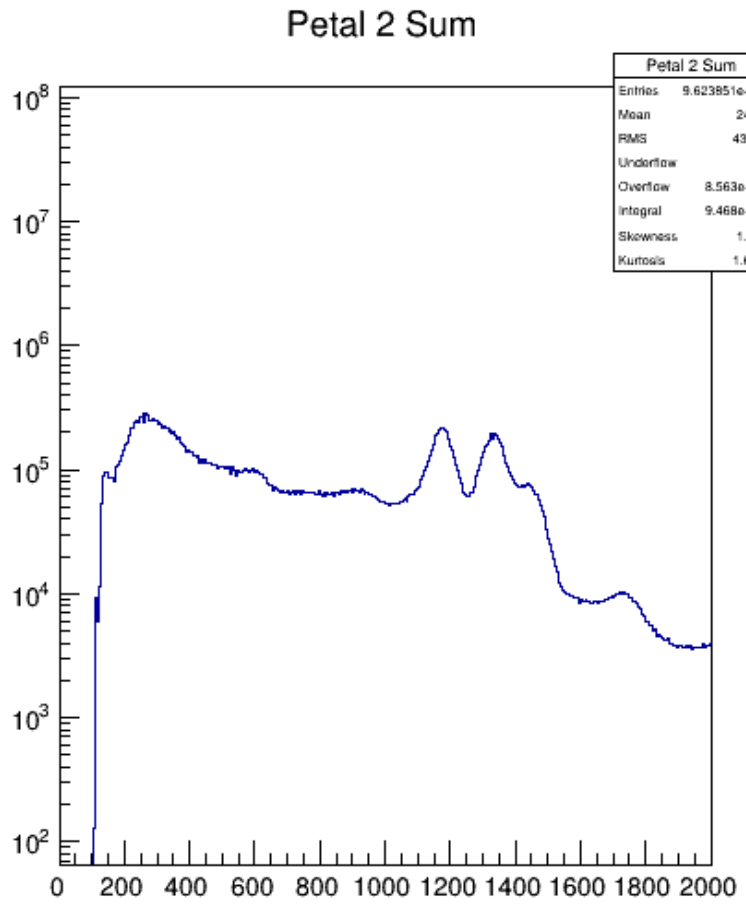




Calibration Spectra



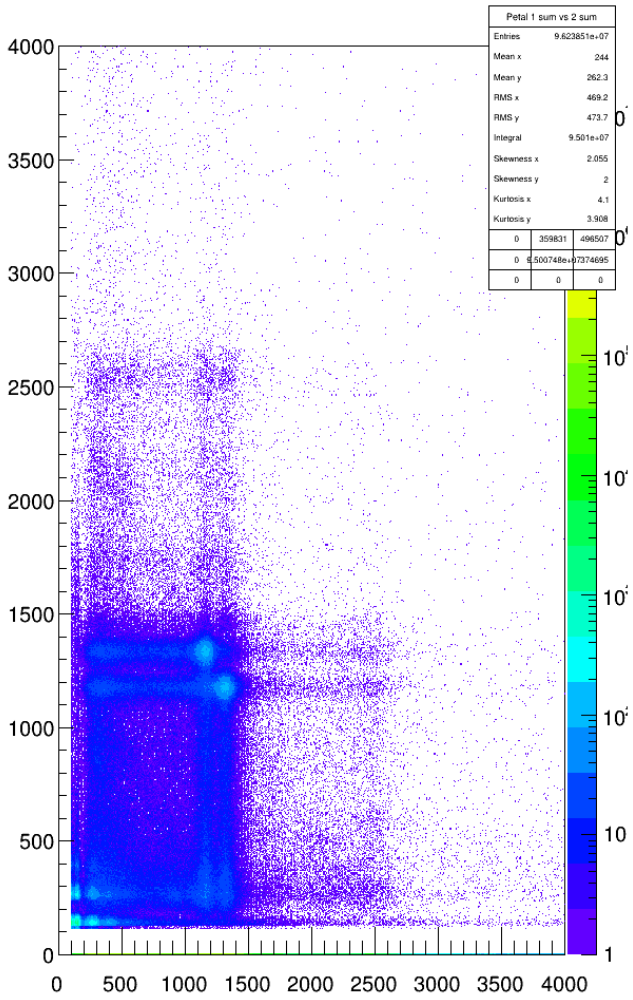




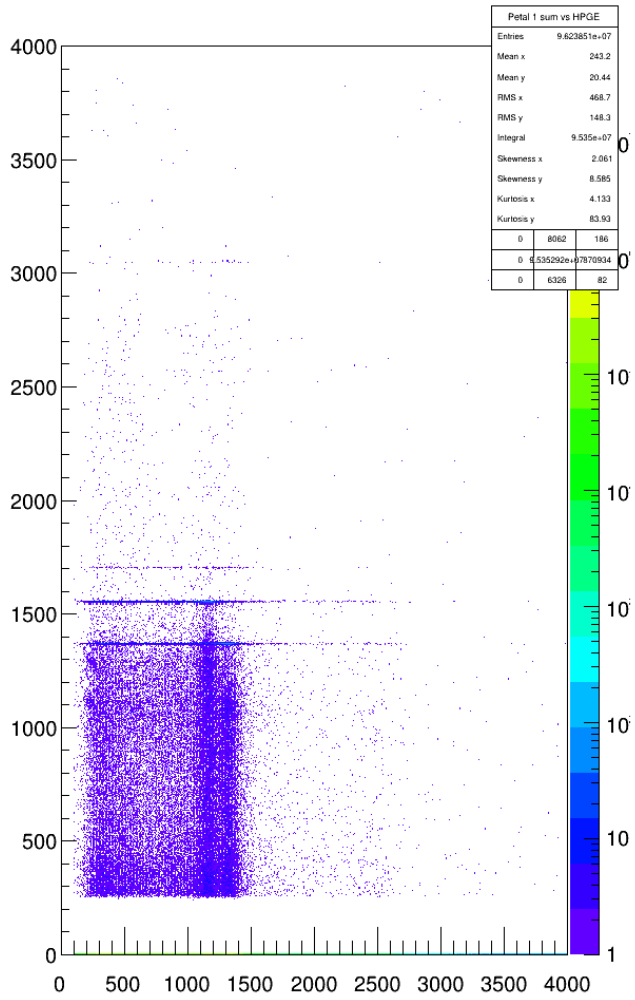
	HPGe	Petal 1	Petal 2
1173 keV	0.4 % (FWHM)	7.9 % (FWHM)	6.0 % (FWHM)
1332 keV	0.3 % (FWHM)	6.9 % (FWHM)	5.1 % (FWHM)

Correlations ^{60}Co

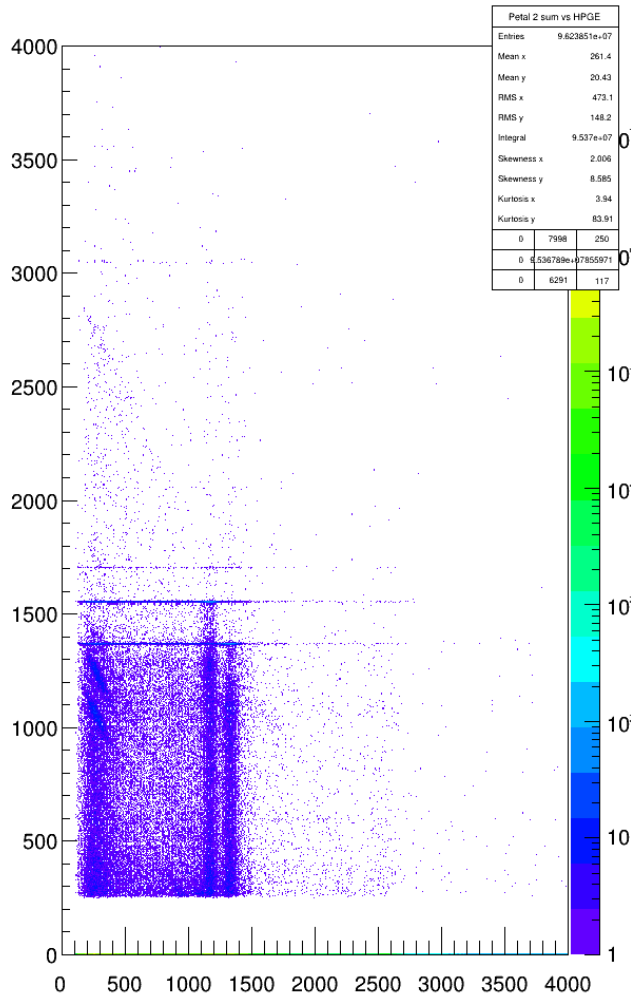
Petal 1 sum vs 2 sum



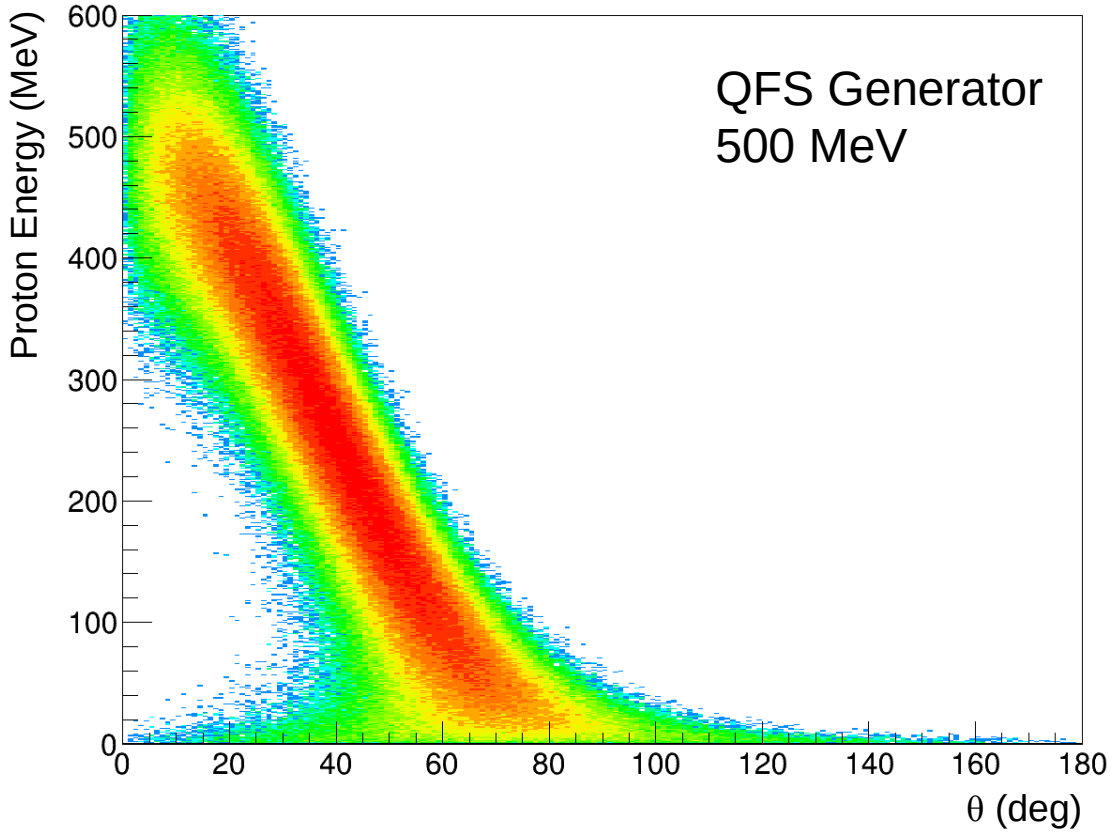
Petal 1 sum vs HPGE



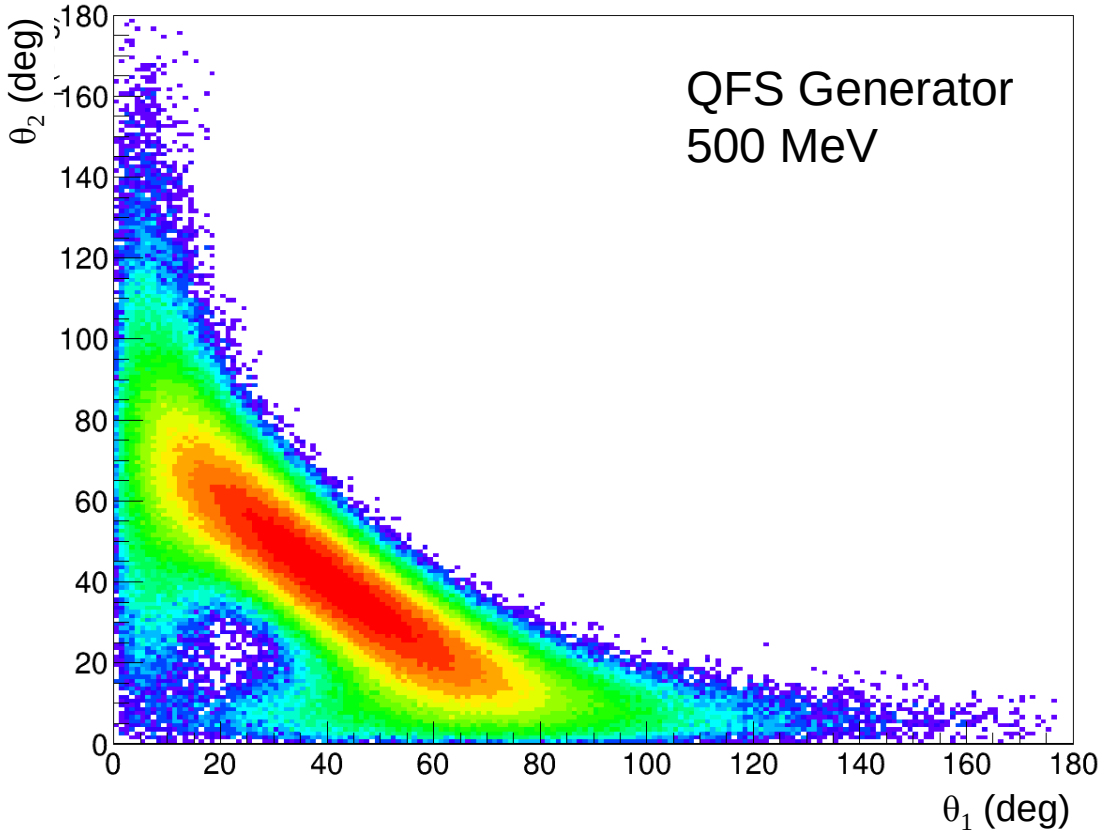
Petal 2 sum vs HPGE



QFS Generator

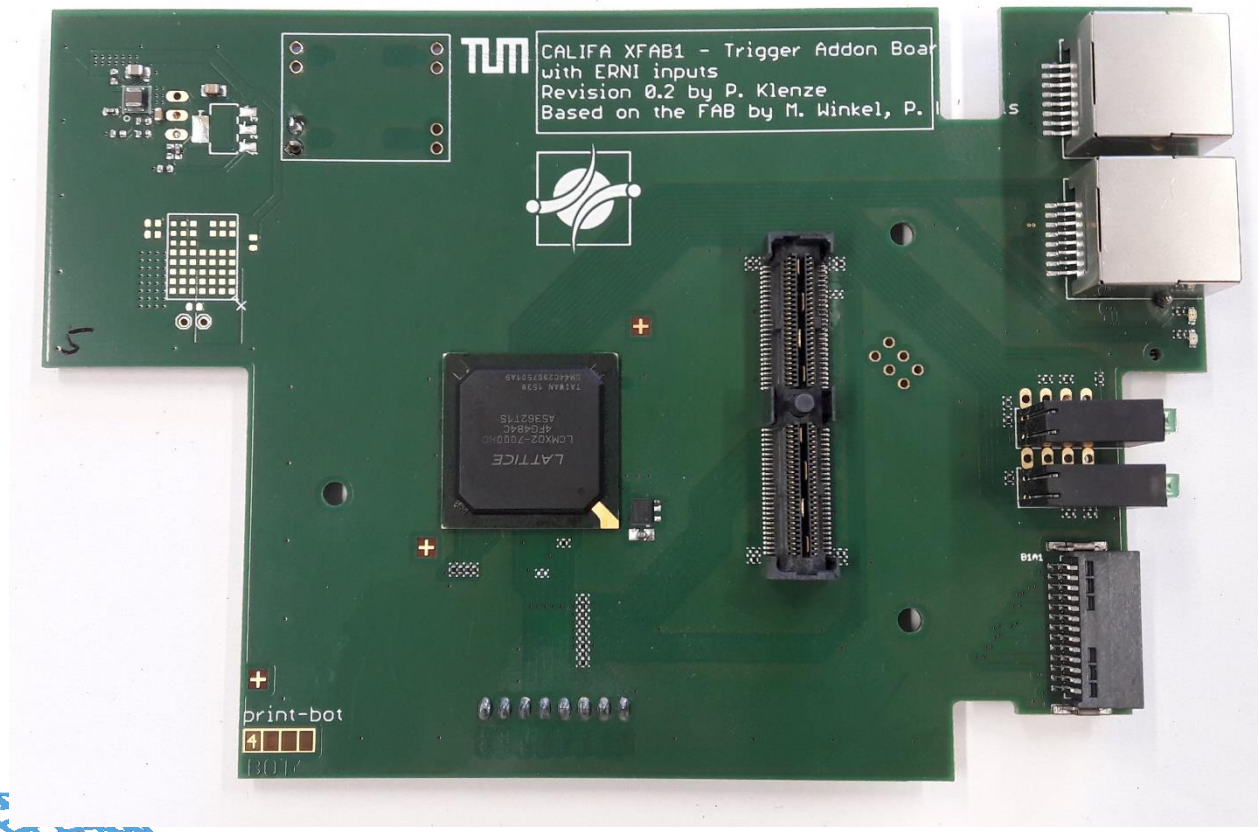


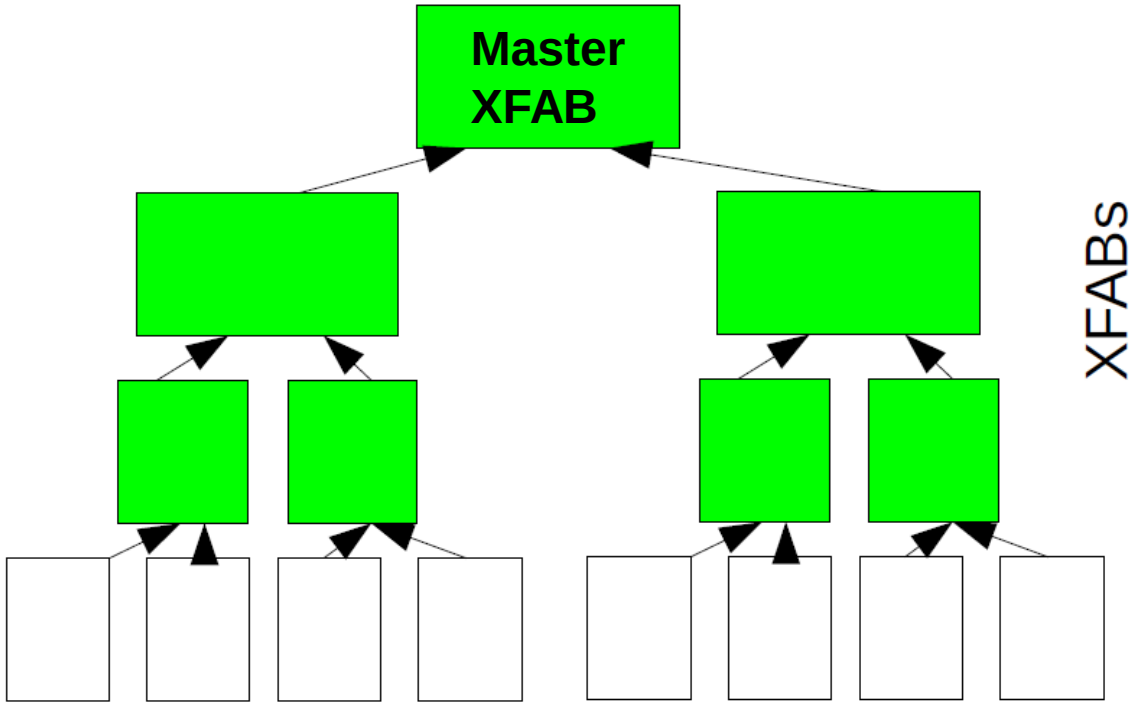
Angular distribution of protons



High Level Trigger

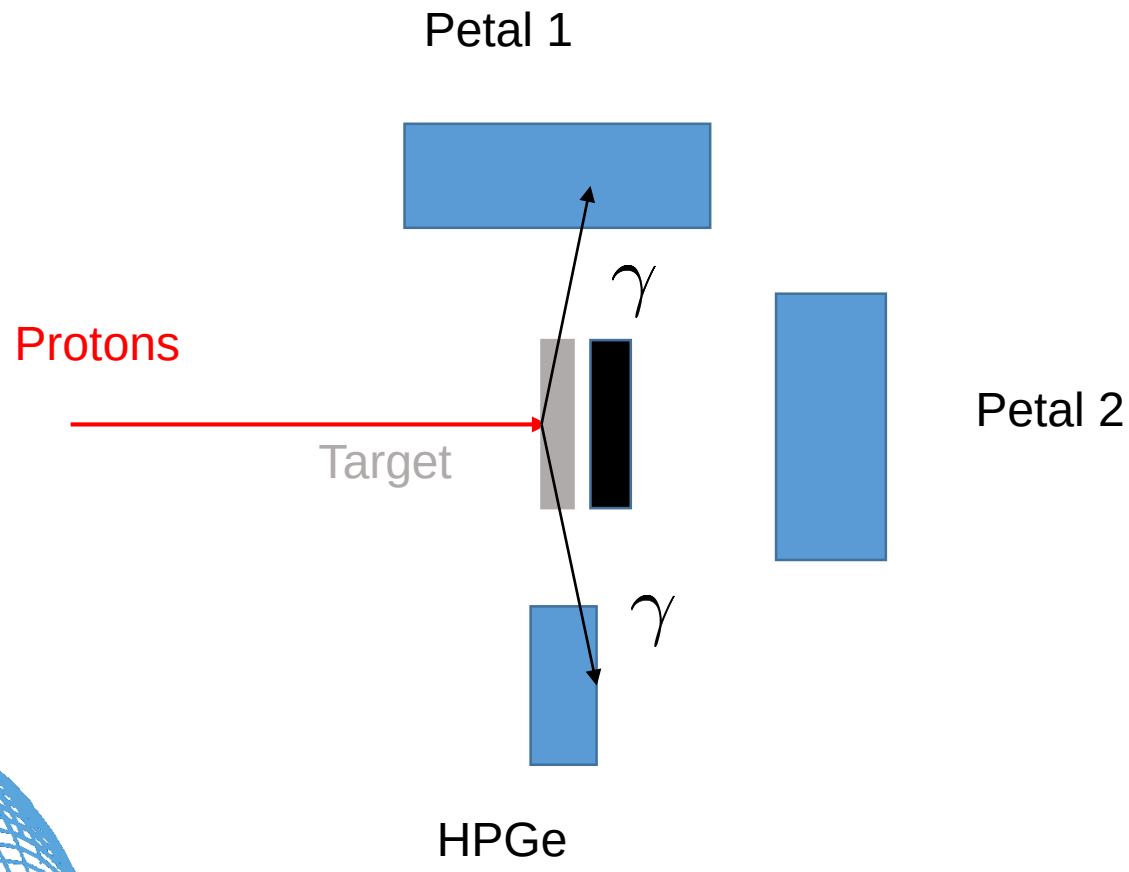
Fast, detector-wide multiplicity, sum energy, geometry trigger generation

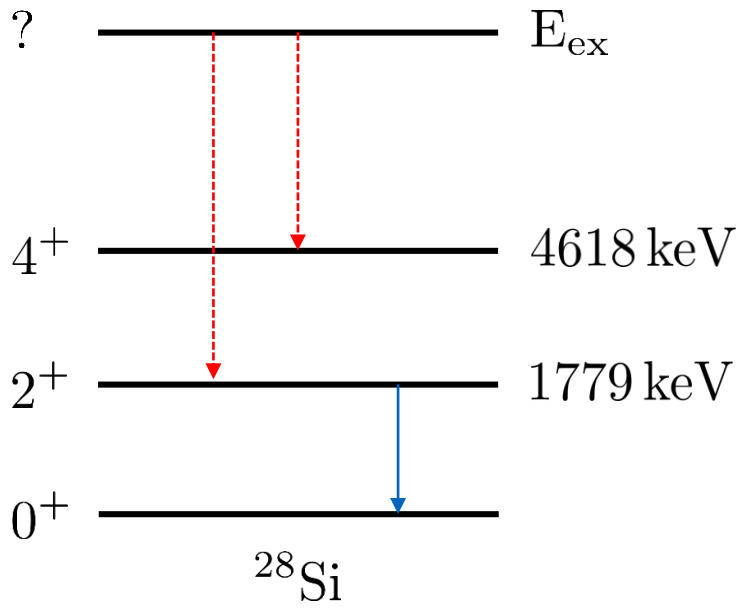




γ rays

$$^{27}\mathrm{Al}\ (\mathrm{p},\gamma)\ ^{28}\mathrm{Si} \qquad \mathrm{Q} = 11.59\,\mathrm{MeV}$$

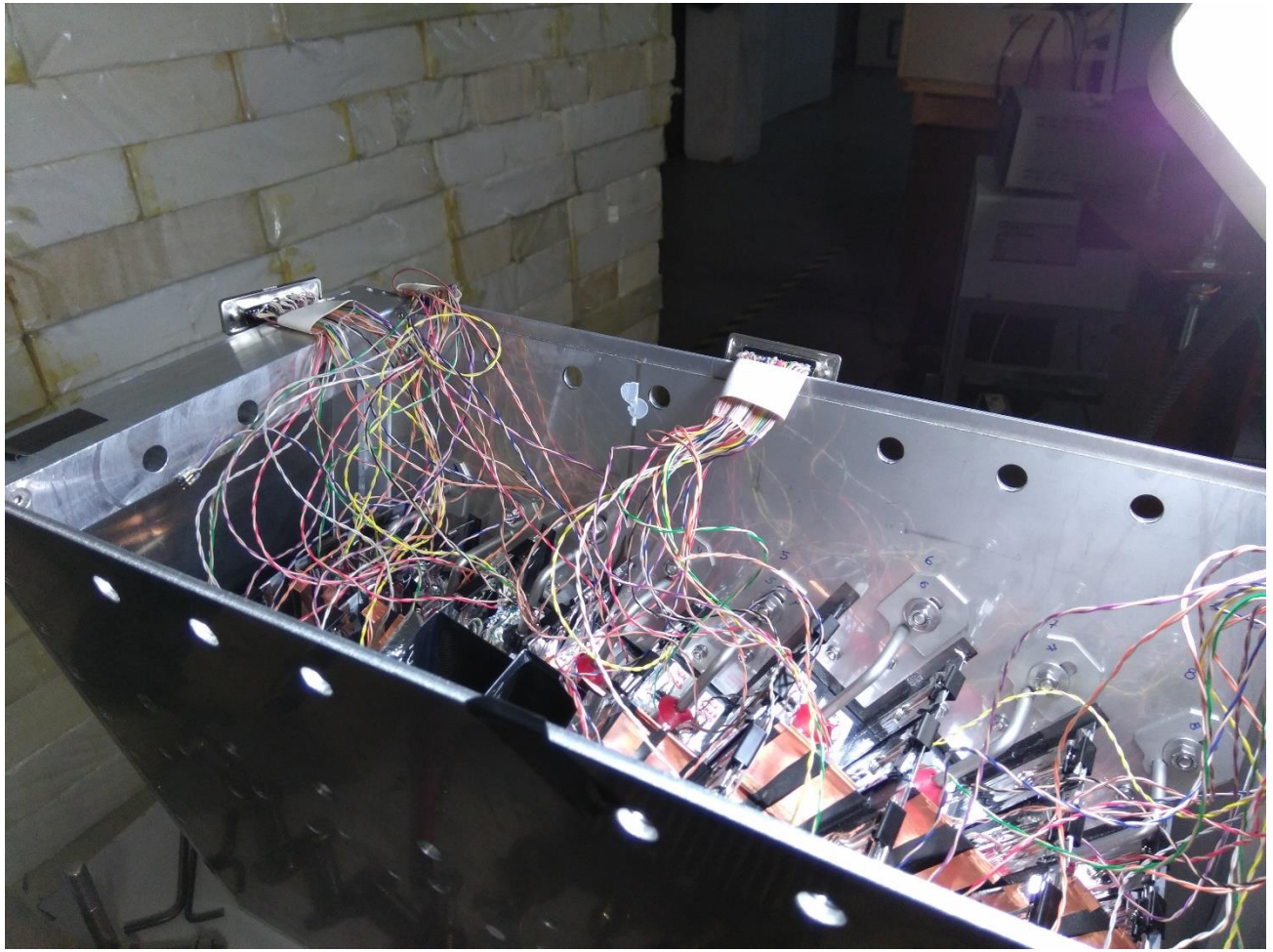




CALIFA Demonstrator

- Detectors constructed at different locations:
  - Darmstadt
  - Santiago de Compostela, Spain
  - Lund, Sweden
- 64 CsI(Tl) crystals in one petal (3 single and 1 double exist)
- Carbon fiber support structure

➢ Systematic testing required

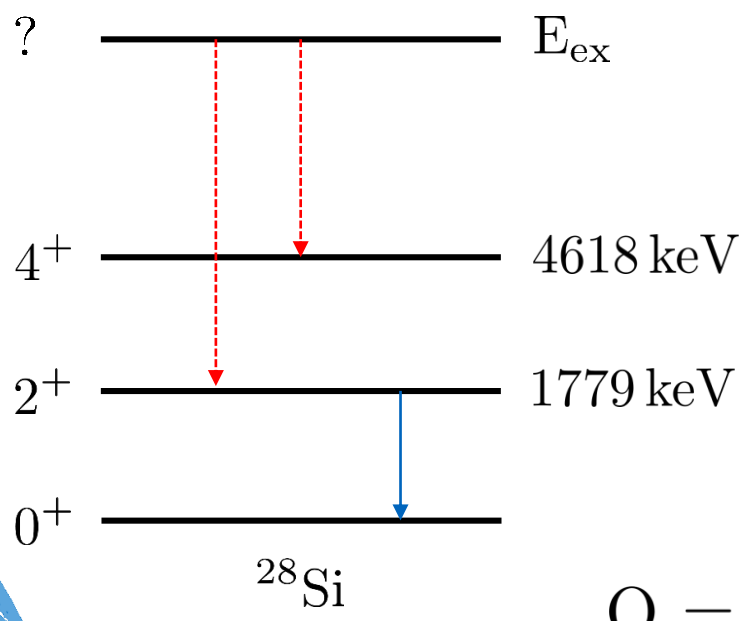


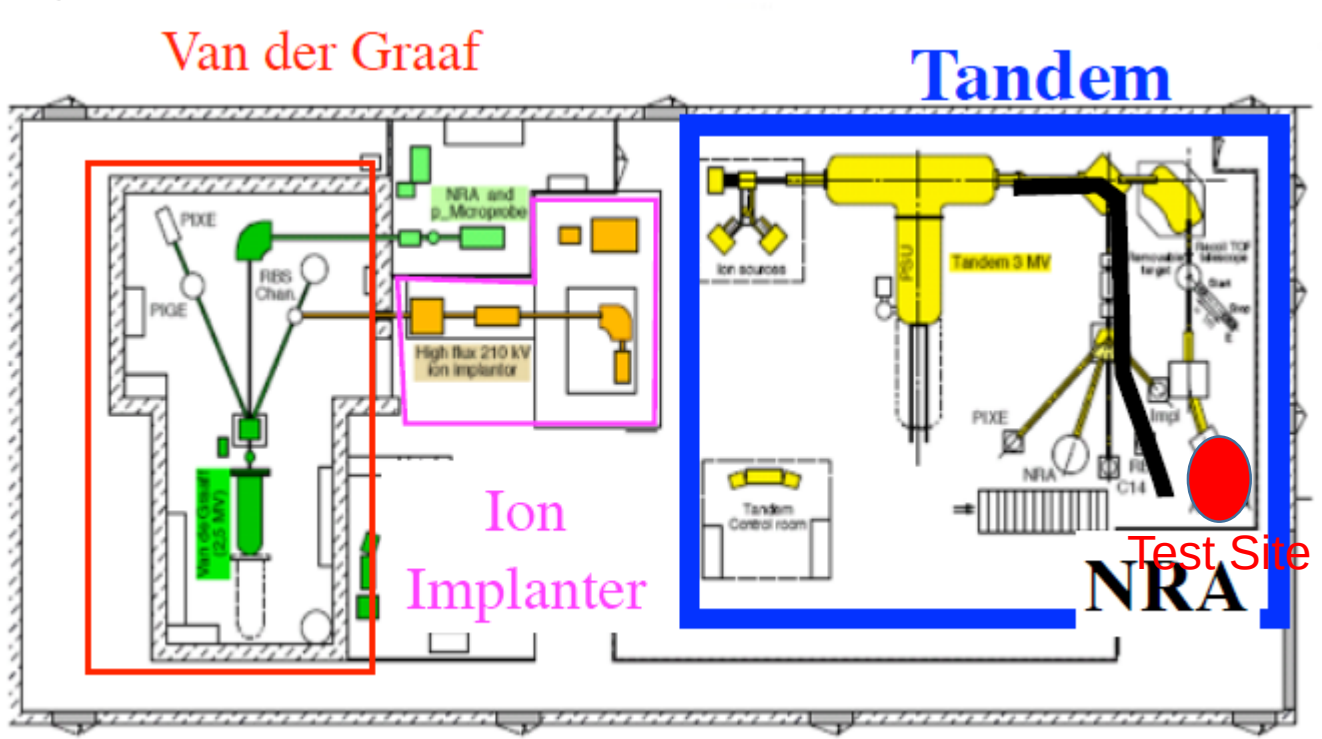
Detection of γ rays

CALIFA@Lisbon (Campus Technologico e Nuclear CTN)

- 3 MV Tandem Accelerator
- Ion beams with high stability at low energies

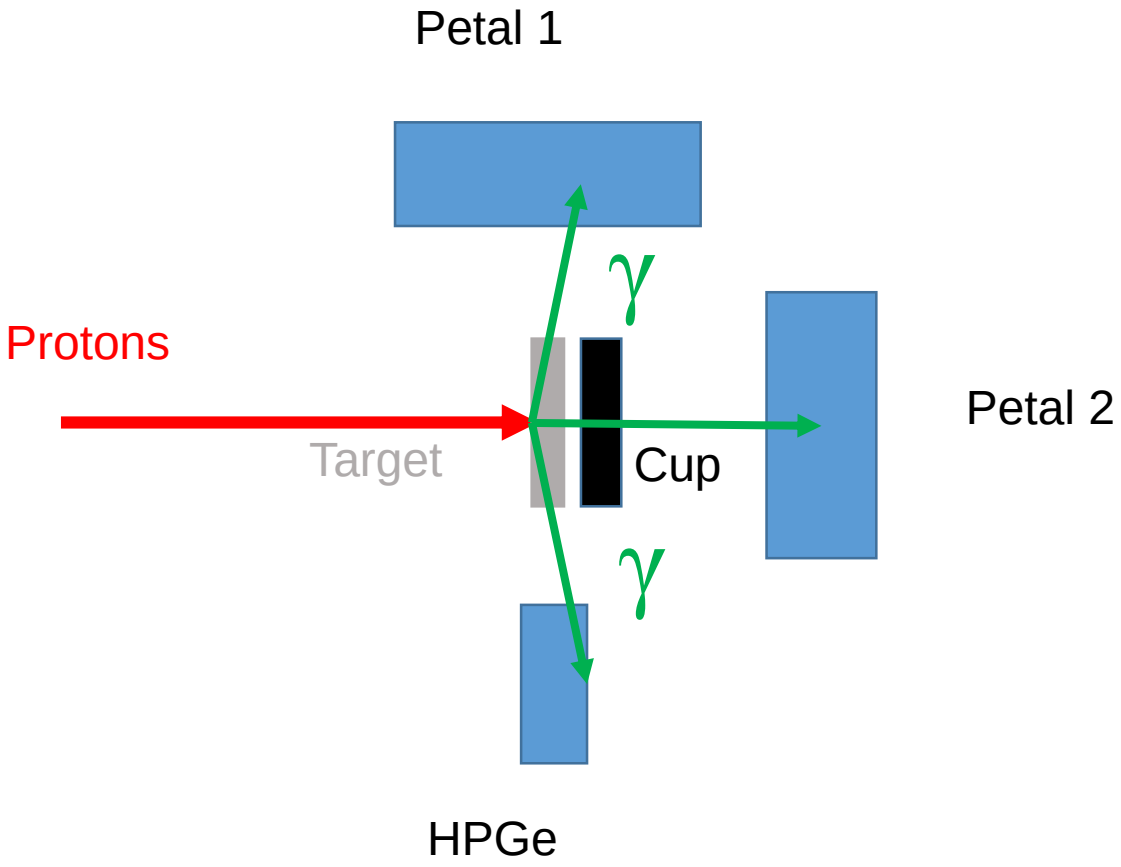
$^{27}\mathrm{Al}\ (\mathrm{p},\gamma)\ ^{28}\mathrm{Si}$

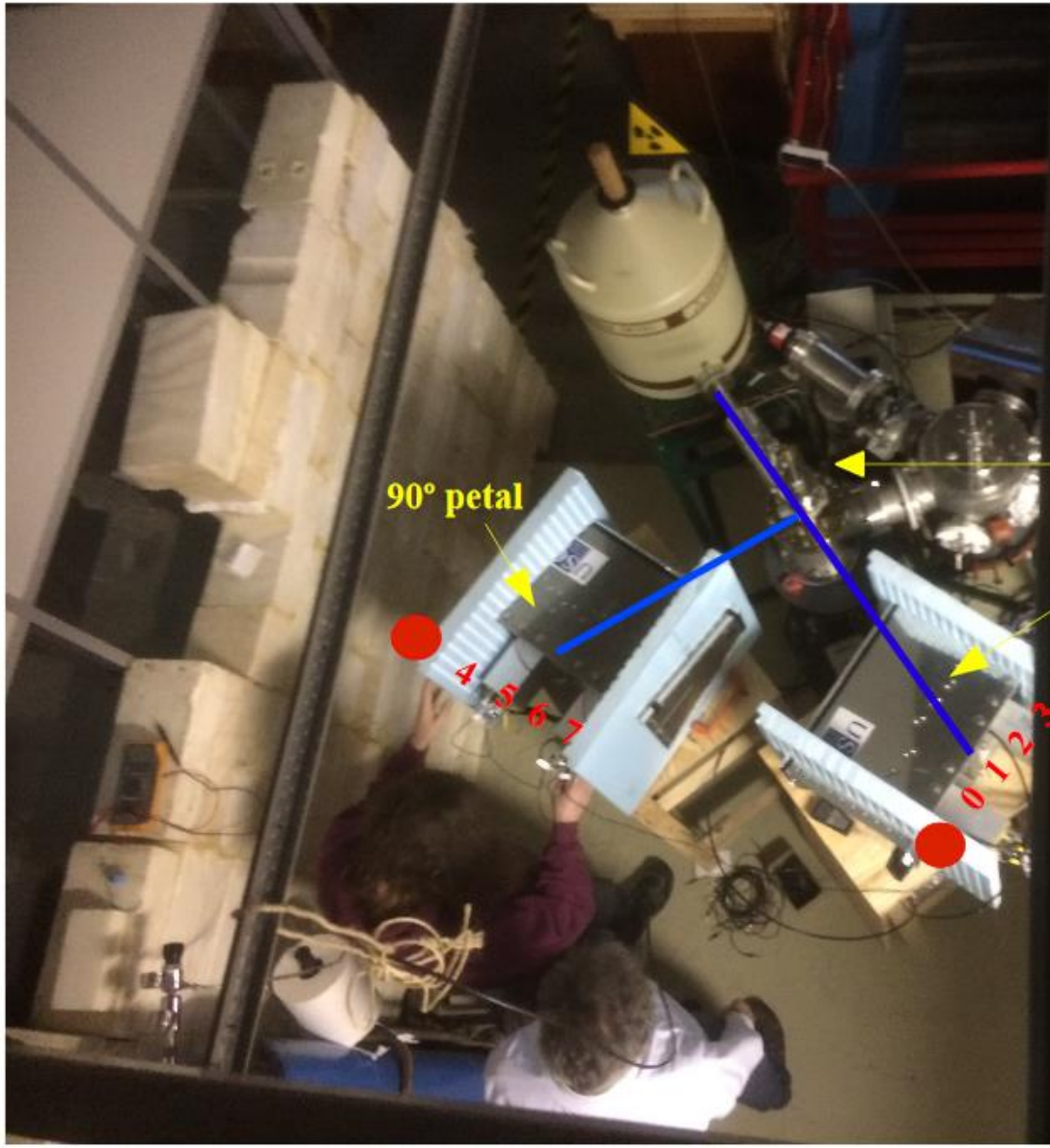




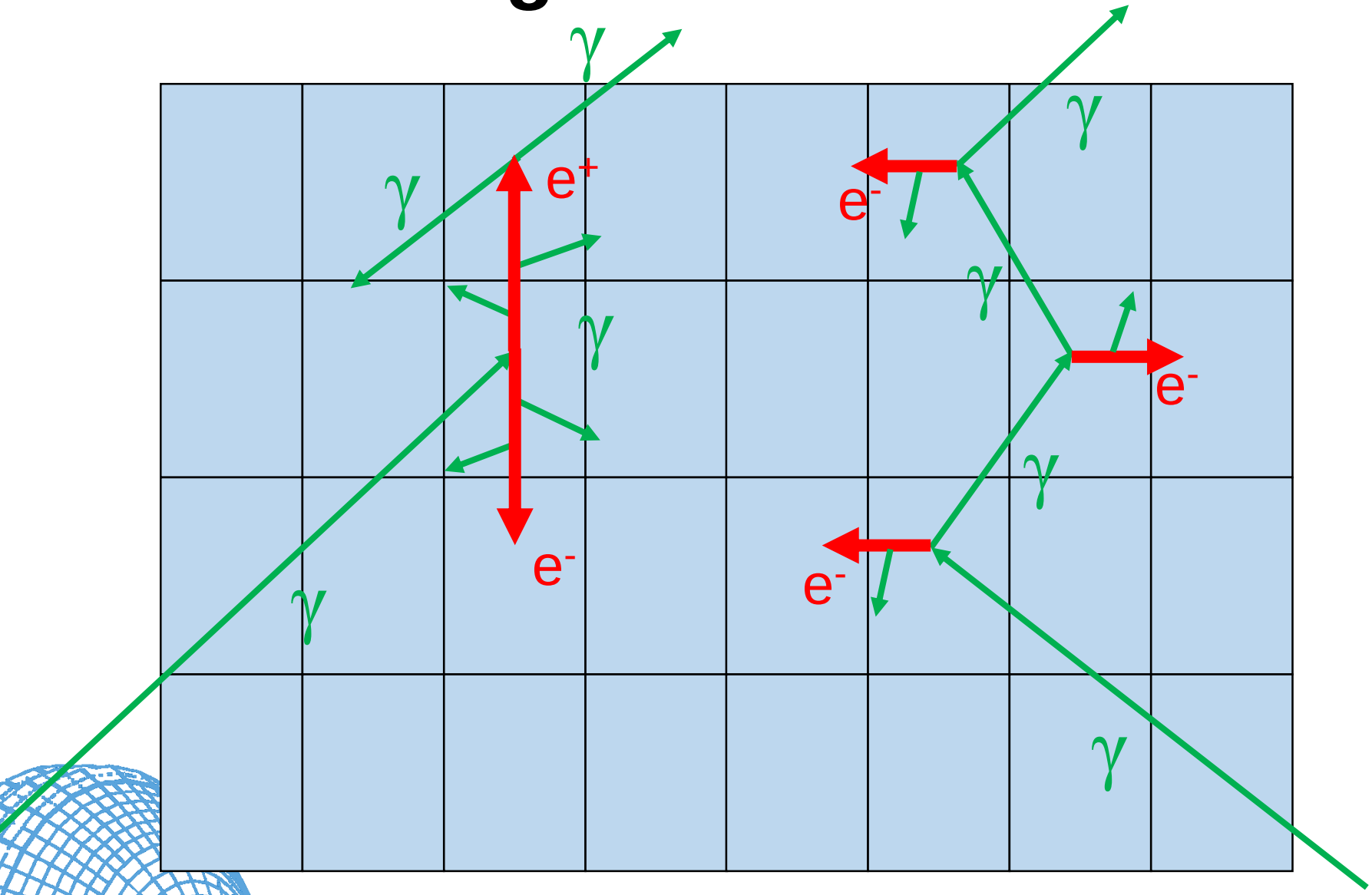
$$Q = 11.59\,\mathrm{MeV}$$

Setup



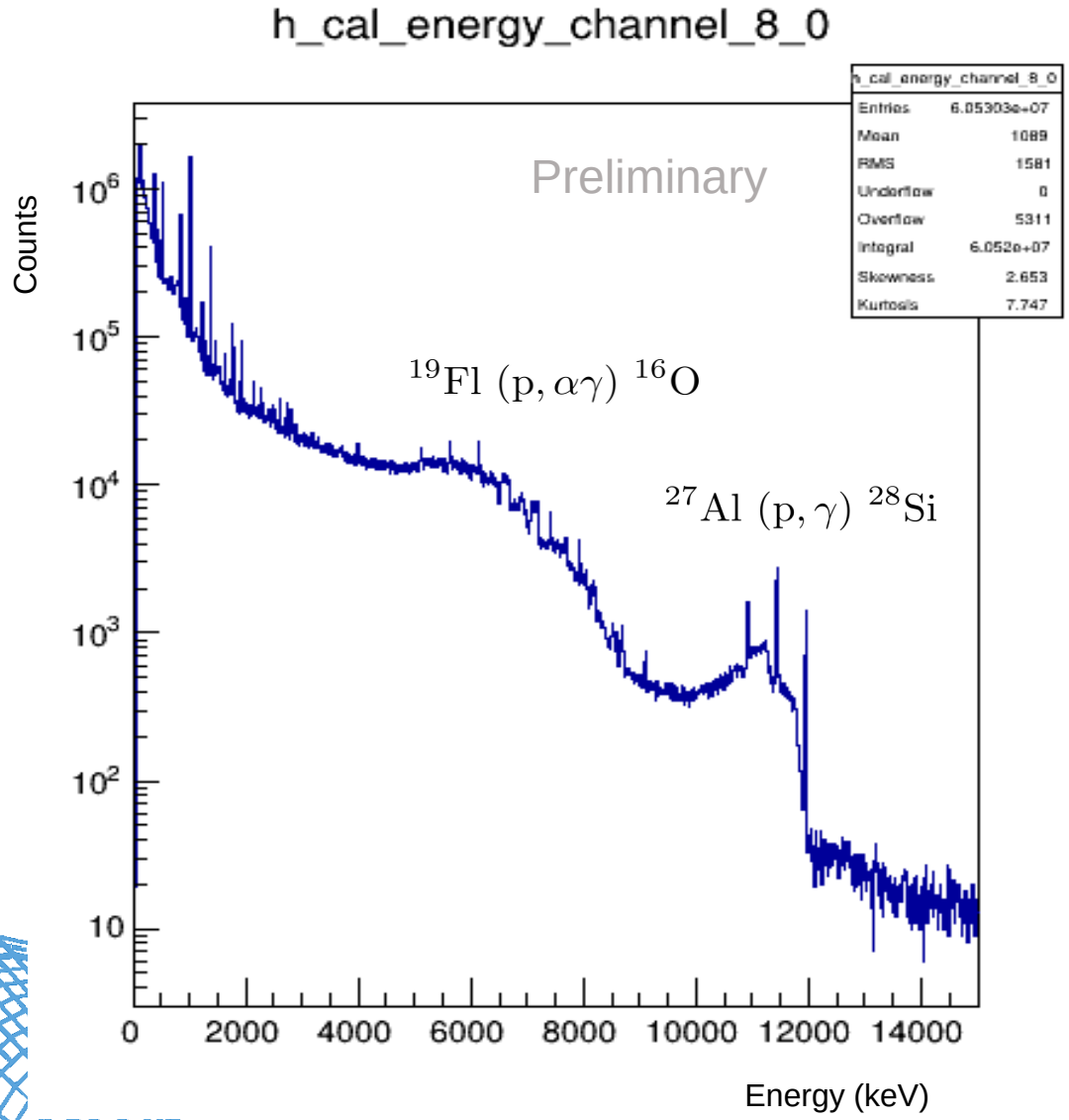


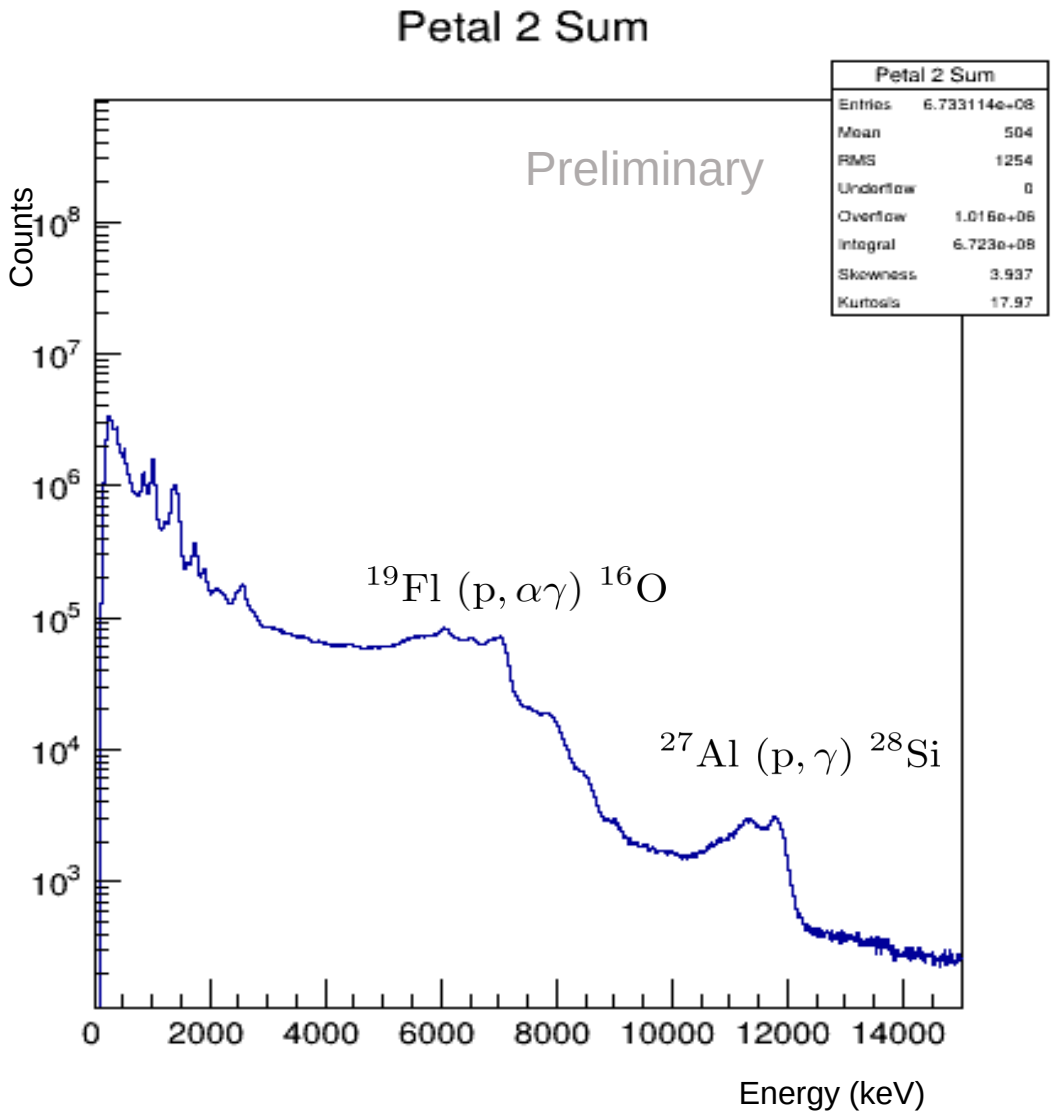
Clustering



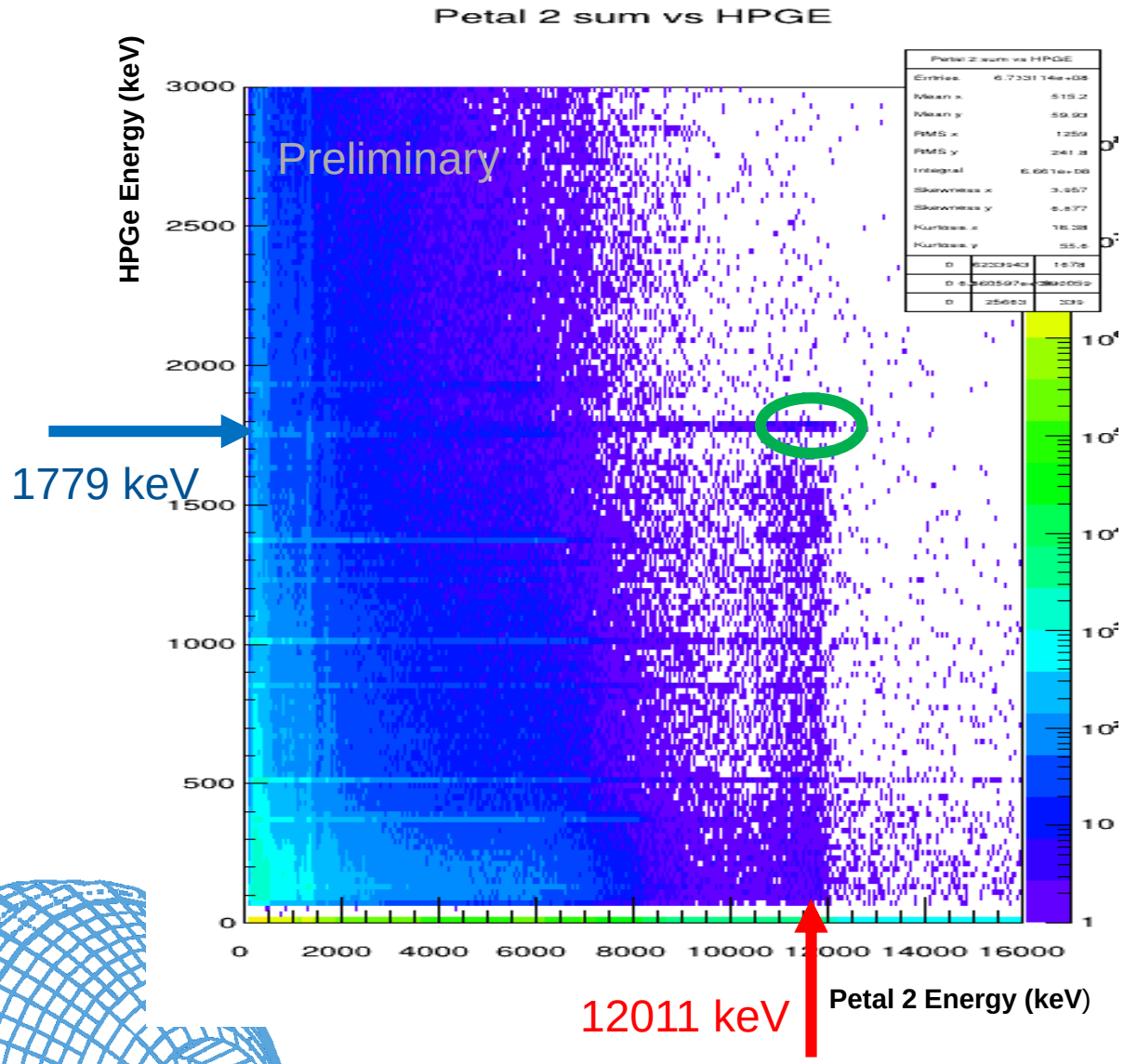
- Energy reconstruction
- Point of first interaction
- ➢ Clustering Algorithms

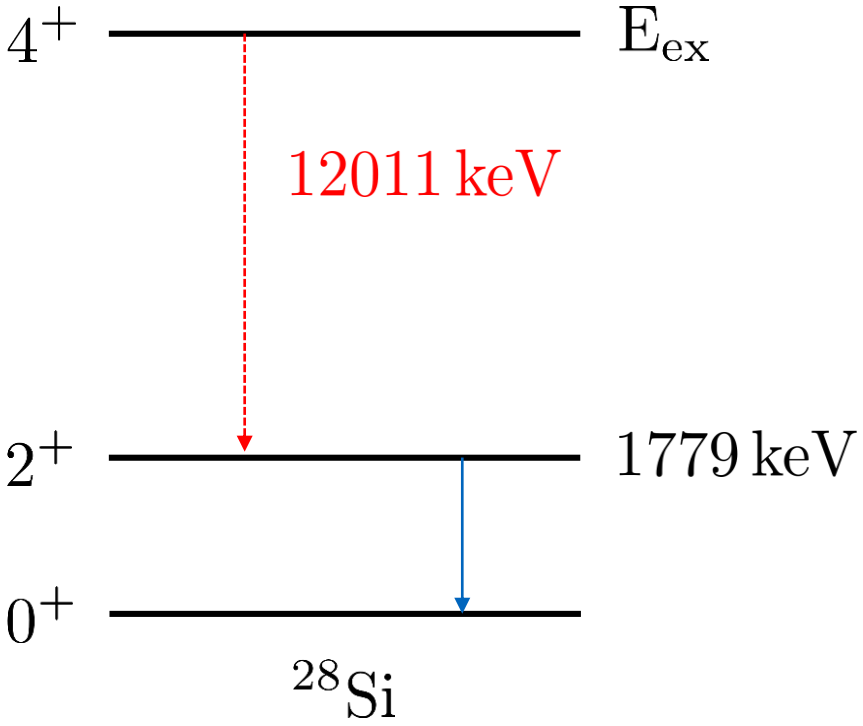
γ spectra E_p= 2.2 MeV





Correlations

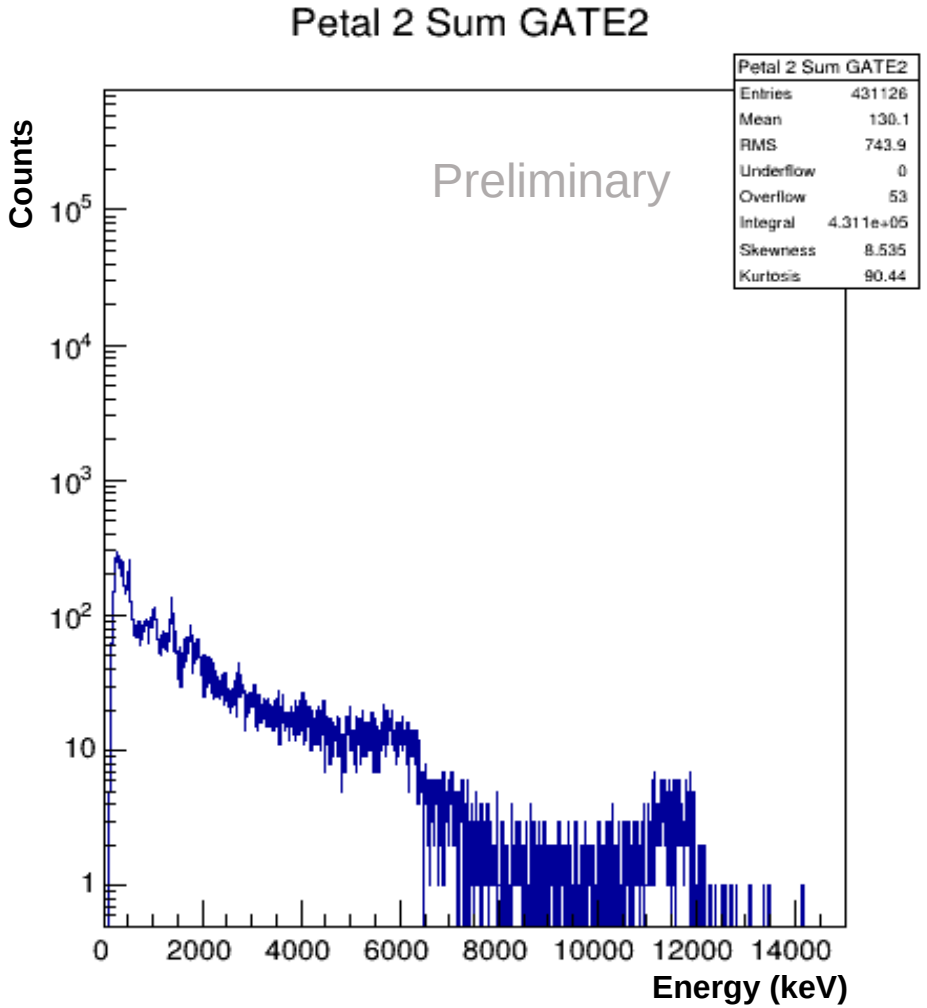


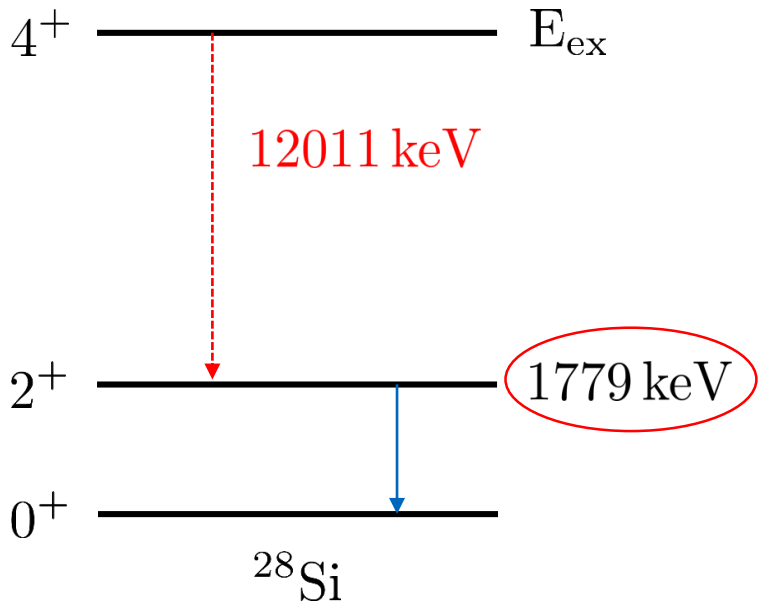


Correlations $^{27}Al(p,\gamma)^{28}Si$

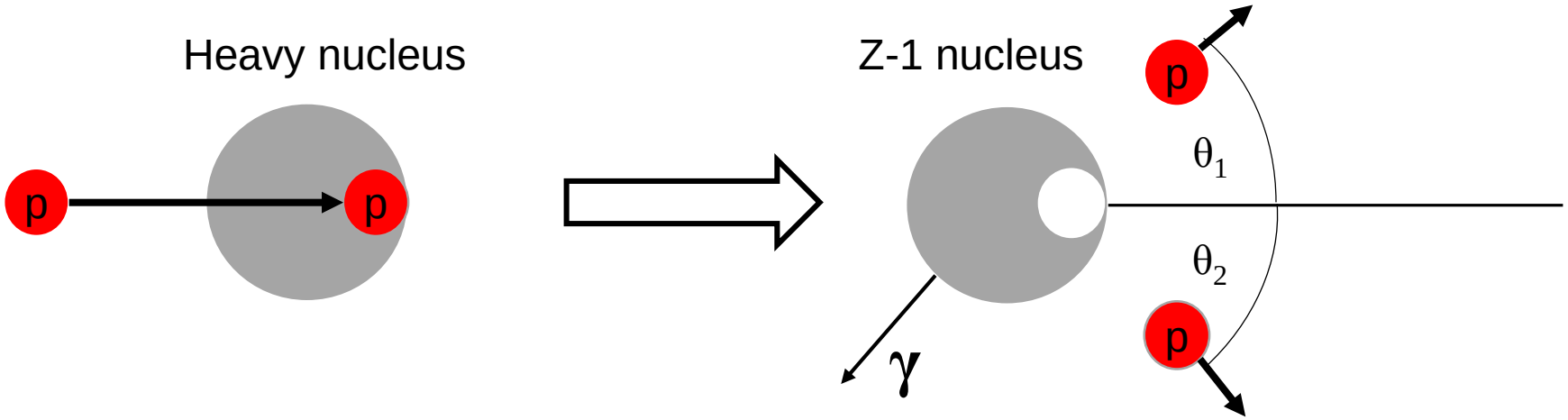
- $^{27}Al(p,\gamma)^{28}Si$ with E_{ex} = (11.59 + 2.2) MeV = 13.79 MeV

- Coincidence with 1779 keV in HPGe Detector
- Select 12 MeV γ here
- Look at pattern in petal
- Calibrate detector
- Select 12 MeV without cuts





Detection of charged particles



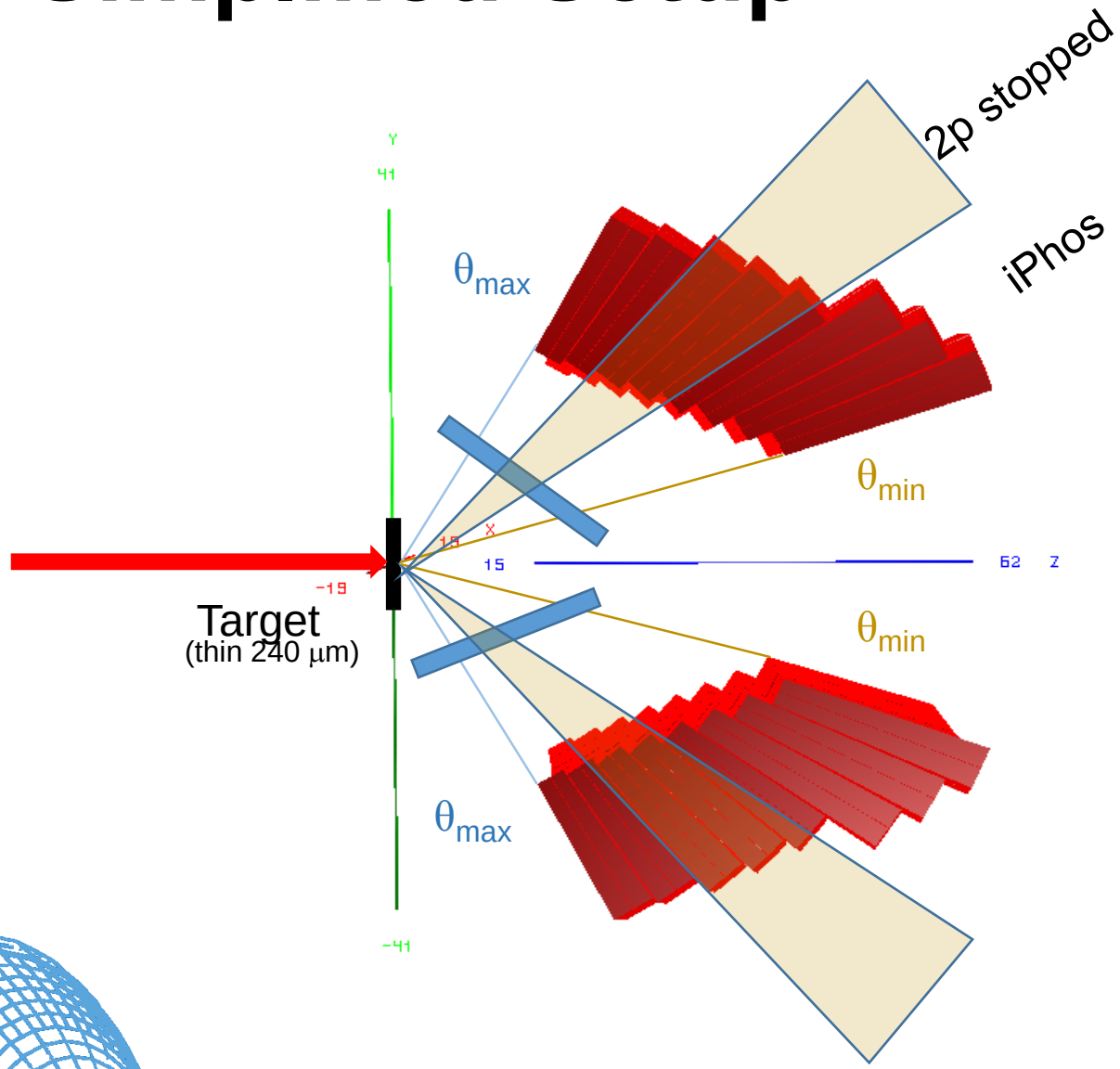
(p,2p) in direct kinematics

- Small Doppler shift of γ-rays
- Only stable isotopes for targets

Test experiment in St. Petersburg

- Well known system like ^{12}C
- Test with heavy nucleus

Simplified Setup



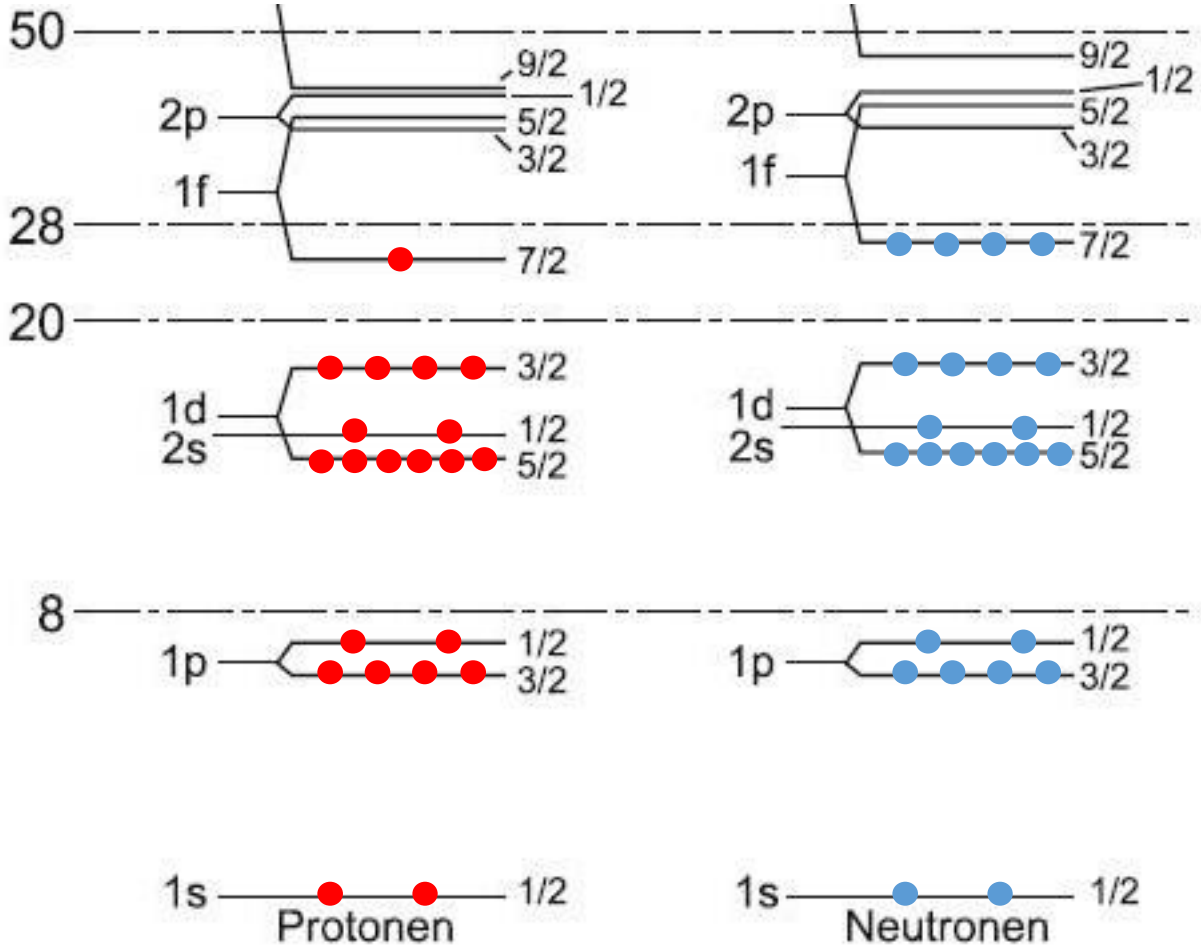
- Possible with this setup?
- Signature w/o residual nucleus signal?
- Vacuum in target region?
- Optimum detector geometry?
- Which reaction?

Possible Target ^{45}Sc

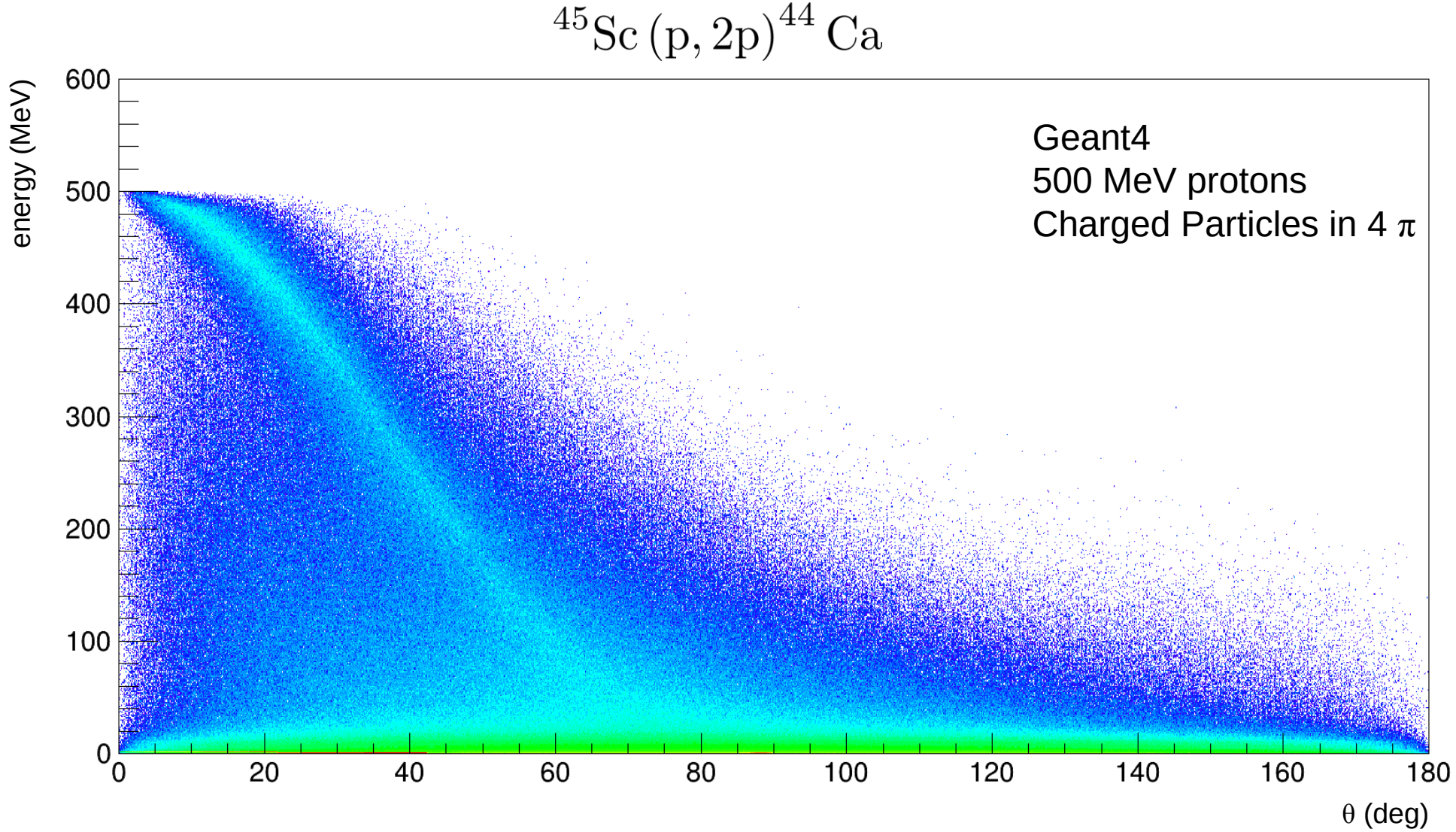
Study reaction ^{45}Sc(p,2p)^{44}Ca

^{45}Sc is one proton away from the proton magic number 20

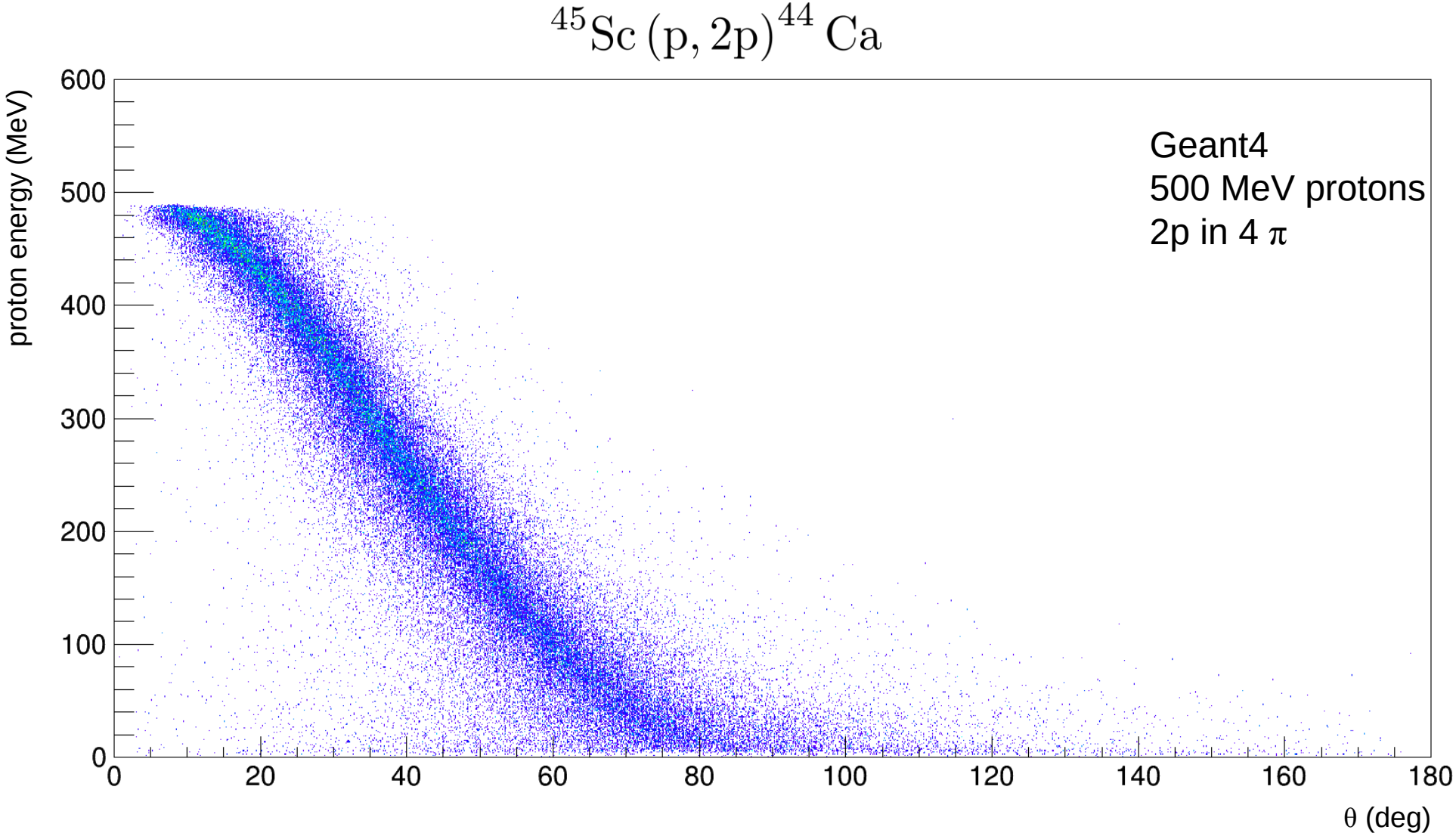
Enables to study shell structure of ^{44}Ca for different excited states (semi magic configuration)



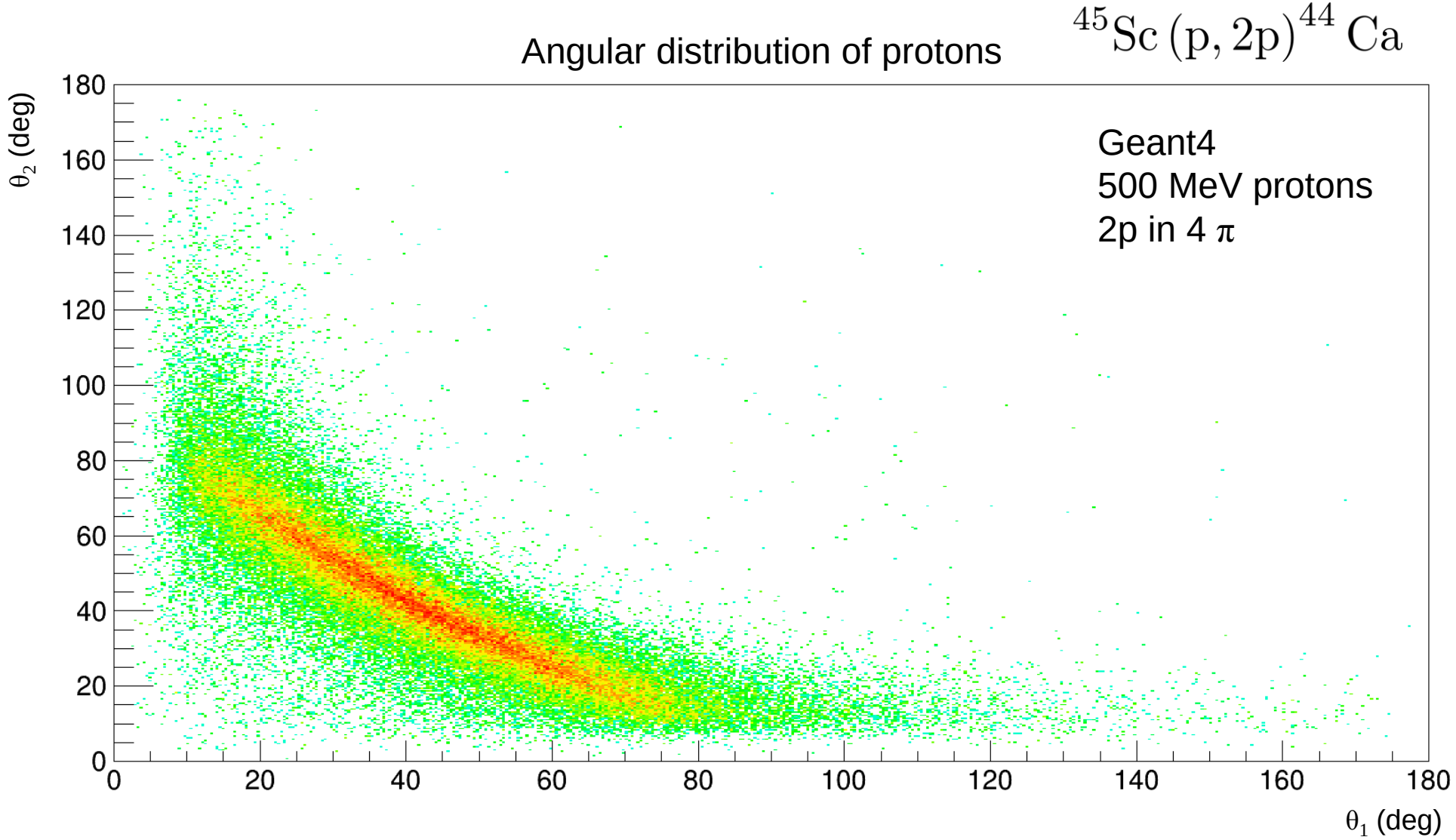
Geant4 Simulation 500 MeV



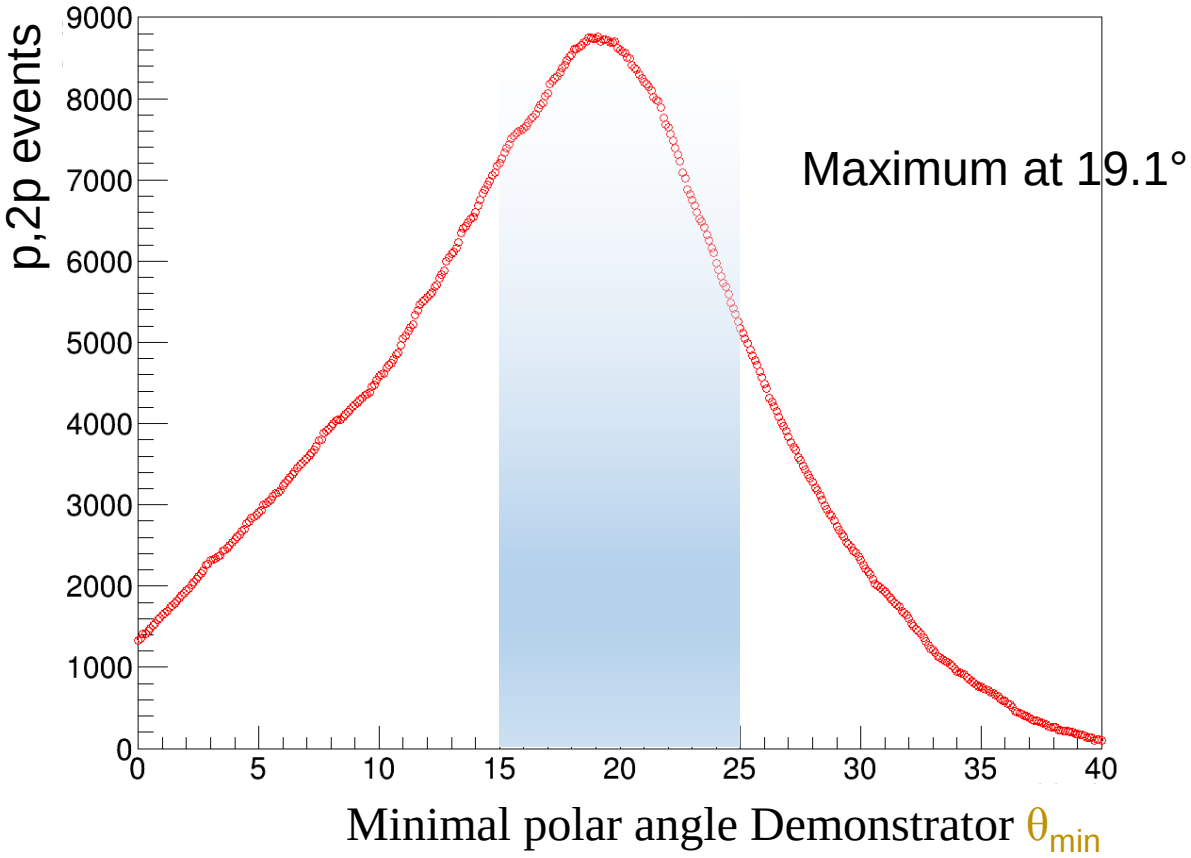
Geant4 Simulation 500 MeV

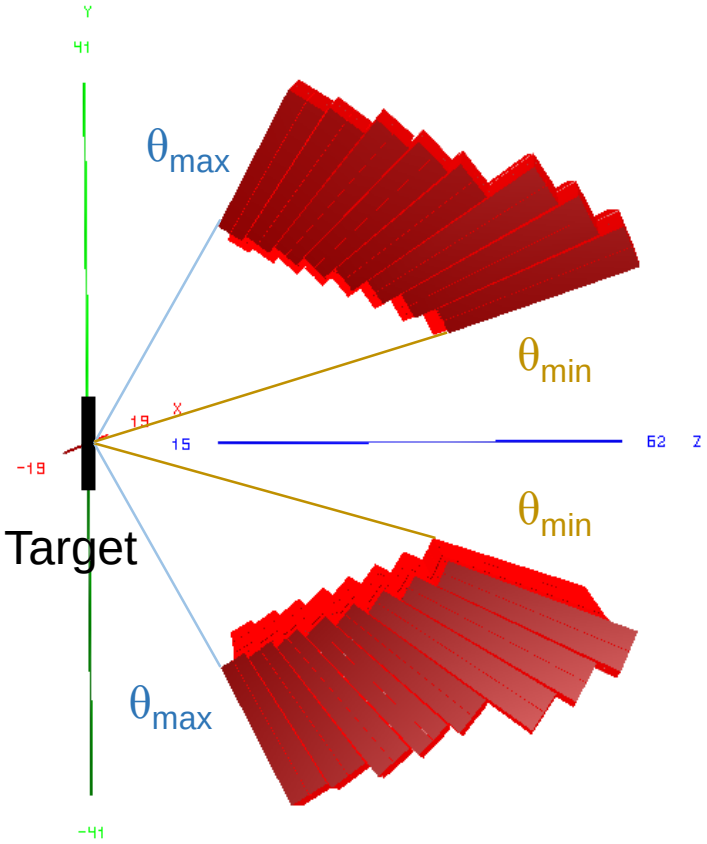


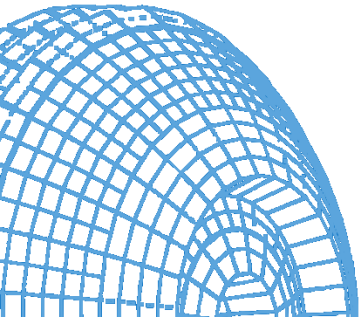
Geant4 Simulation 500 MeV



P-P coincidences in Demonstrator

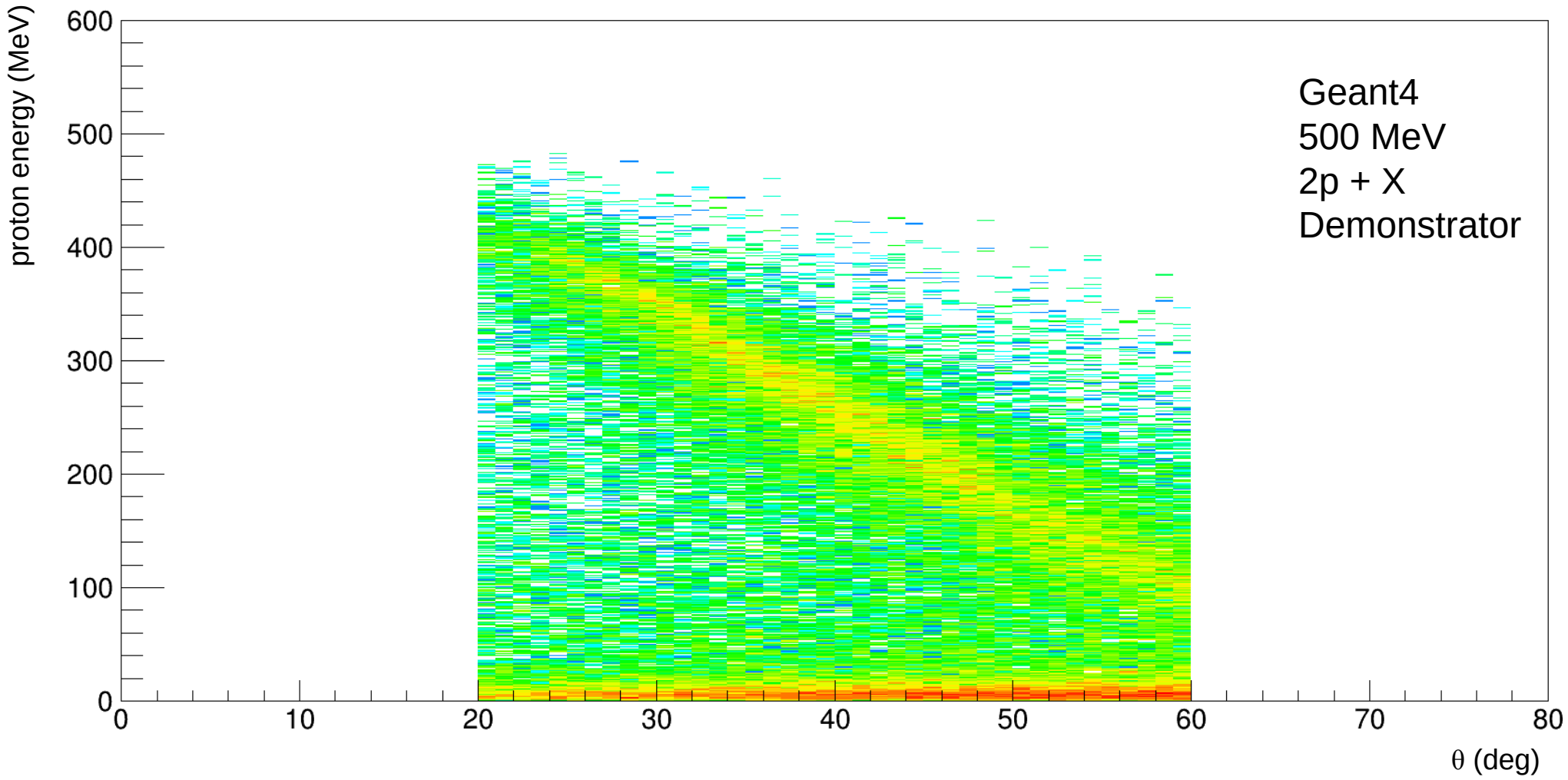




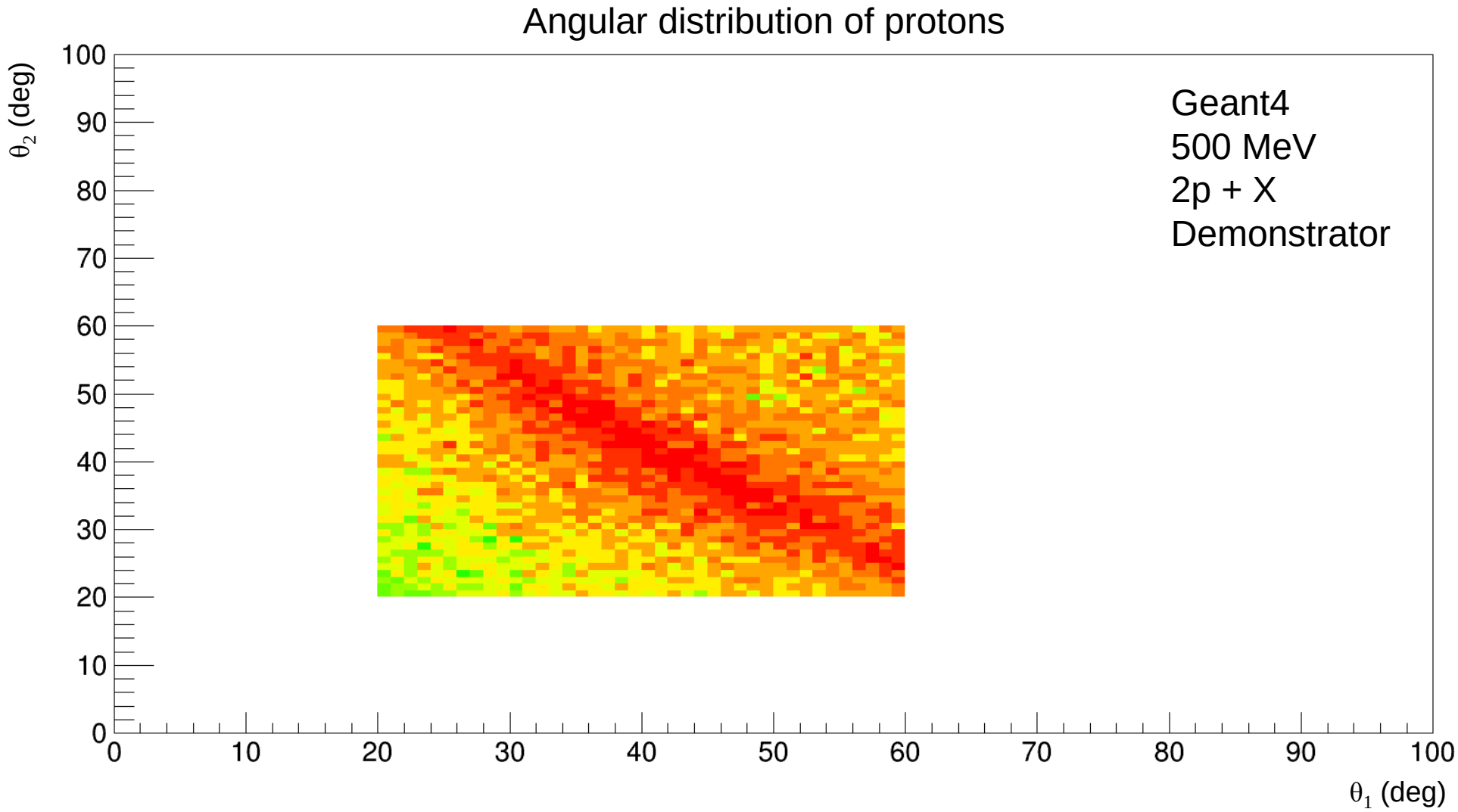


Primary rate	Target rate	Demo rate	Rate per ch.	(p,2p) rate
10^6 Hz	24.7 kHz	5.66 kHz	22.1 Hz	~2.77 Hz

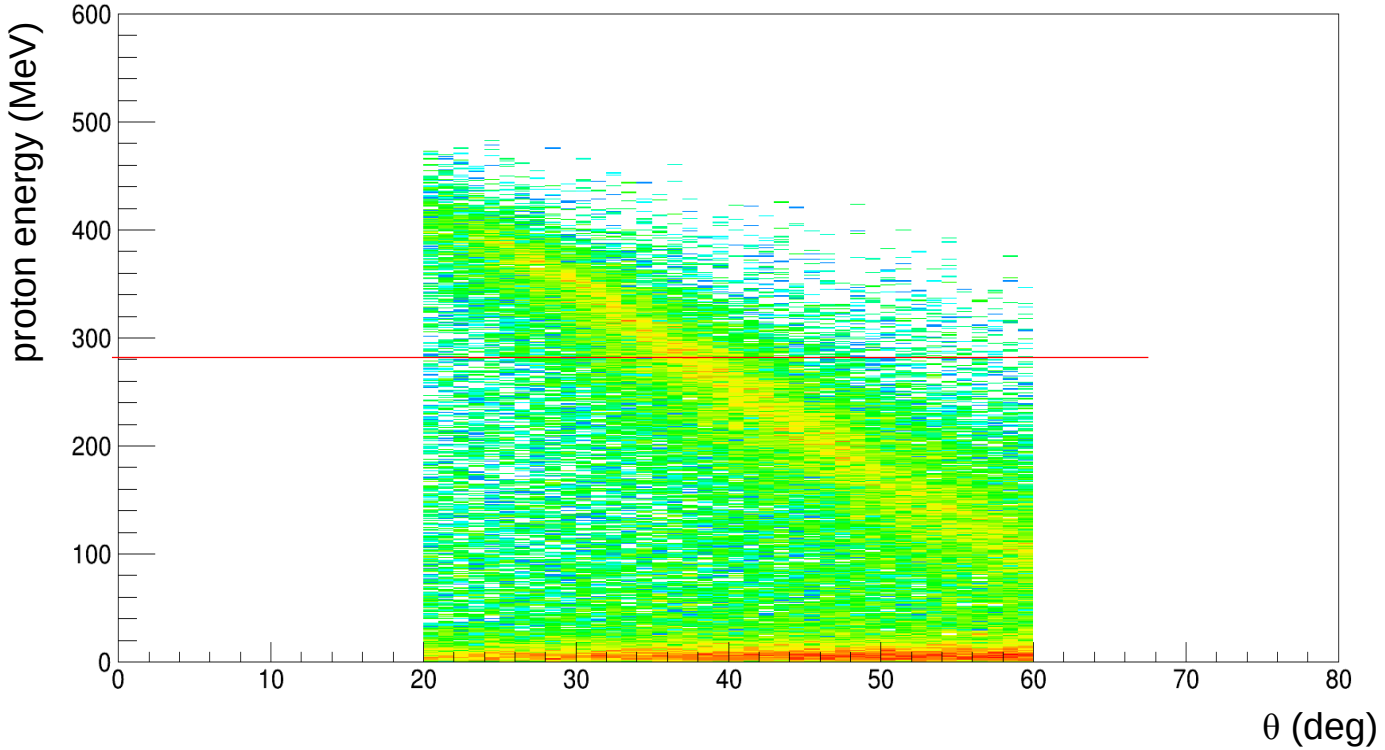
Geant4 Simulation 500 MeV

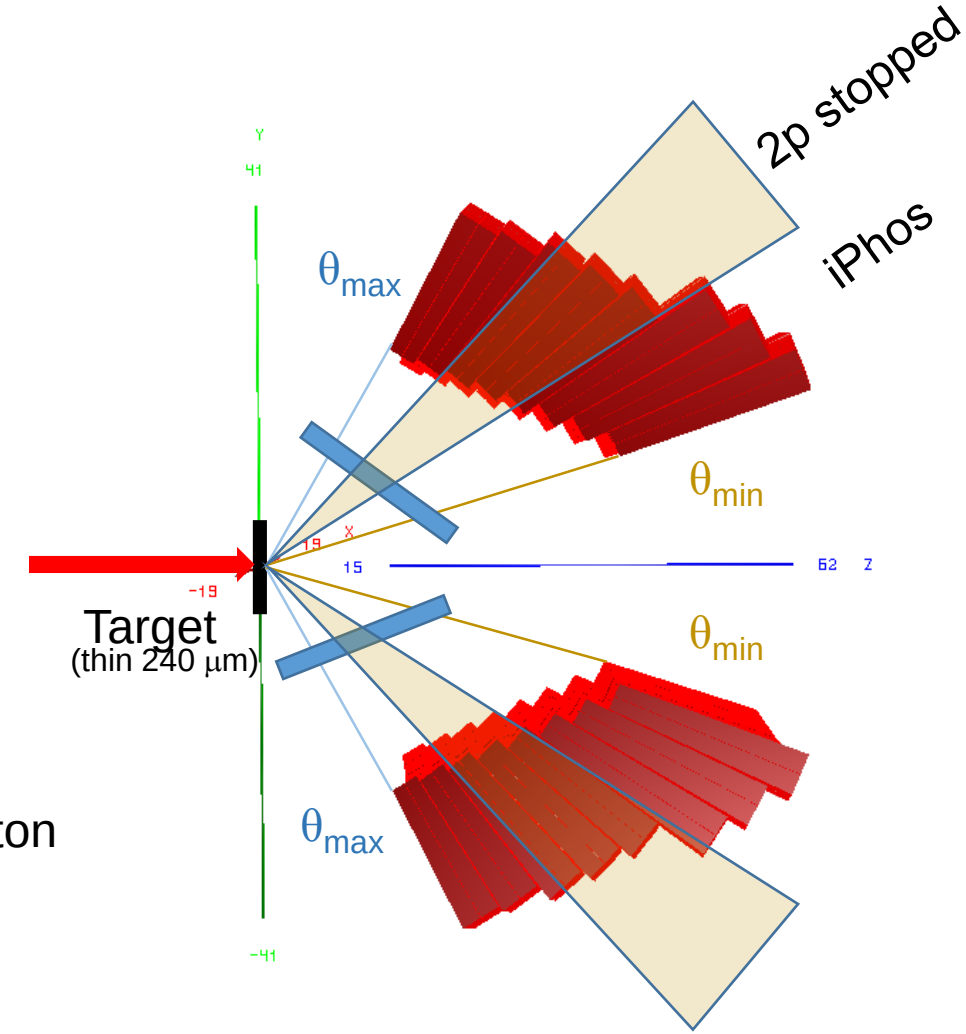


Geant4 Simulation 500 MeV



Summary (p,2p) experiment





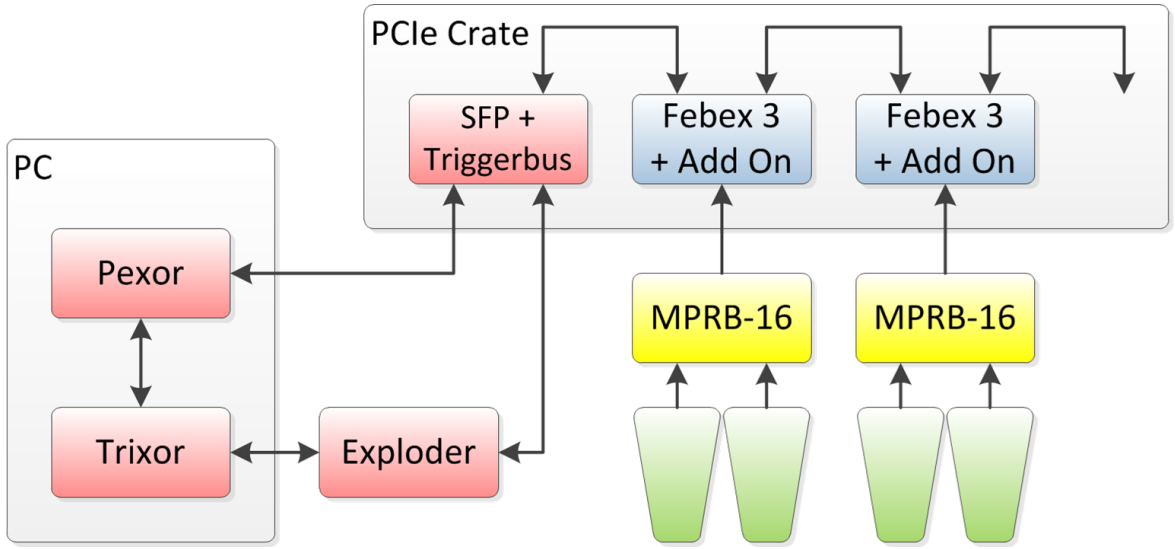
Separation of stopped and non stopped proton

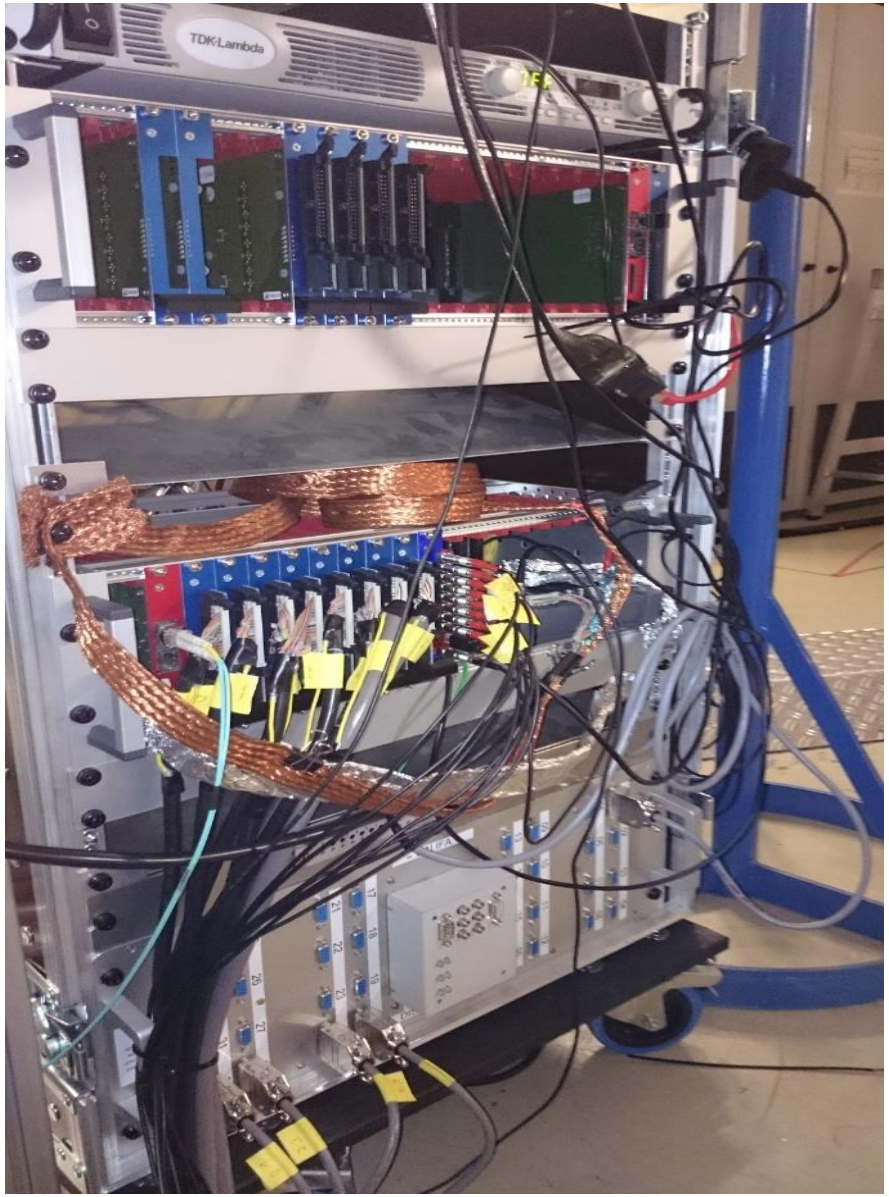
Different detectors

Combination into one system

Readout Overview

- Readout by Large Area Avalanche Photo Diodes
- Analog preamplification
- Completely digital, real-time signal processing
- GOSIP/FEBEX system by GSI
- 1.6 Gbps optical fibre readout

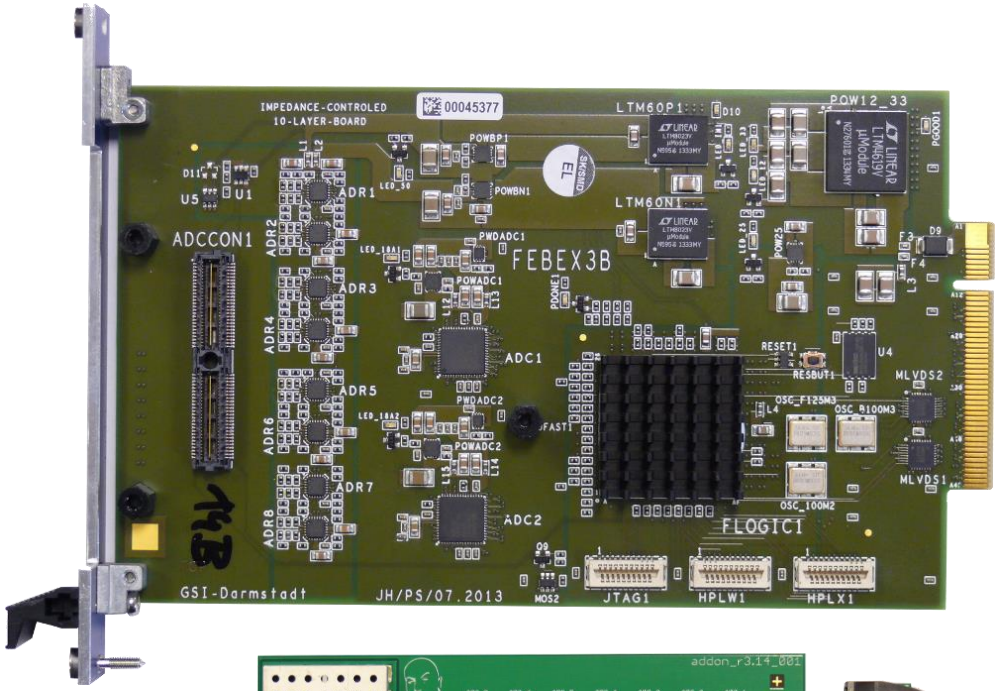


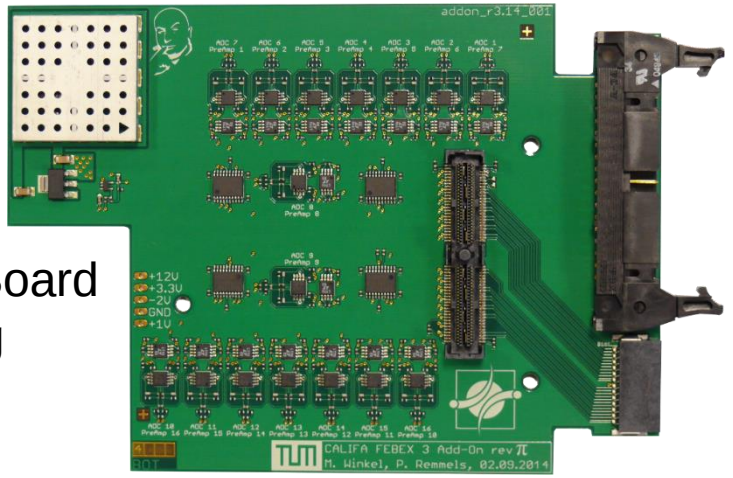


Readout **F**ront-**E**nd **B**oard with Optical Link **Ex**tension

- **Universal hardware platform for CALIFA**
- 16x 14-bit, 50 MS/s fast sampling ADCs
- Lattice ECP3 150 FPGA
- 1.6 Gbps optical fibre readout
- 8x MLVDS trigger bus
- **Extension slot for add-on boards**
- PCIe for create assembly

- Continous sampling of input signal
- **On-board real-time signal processing**



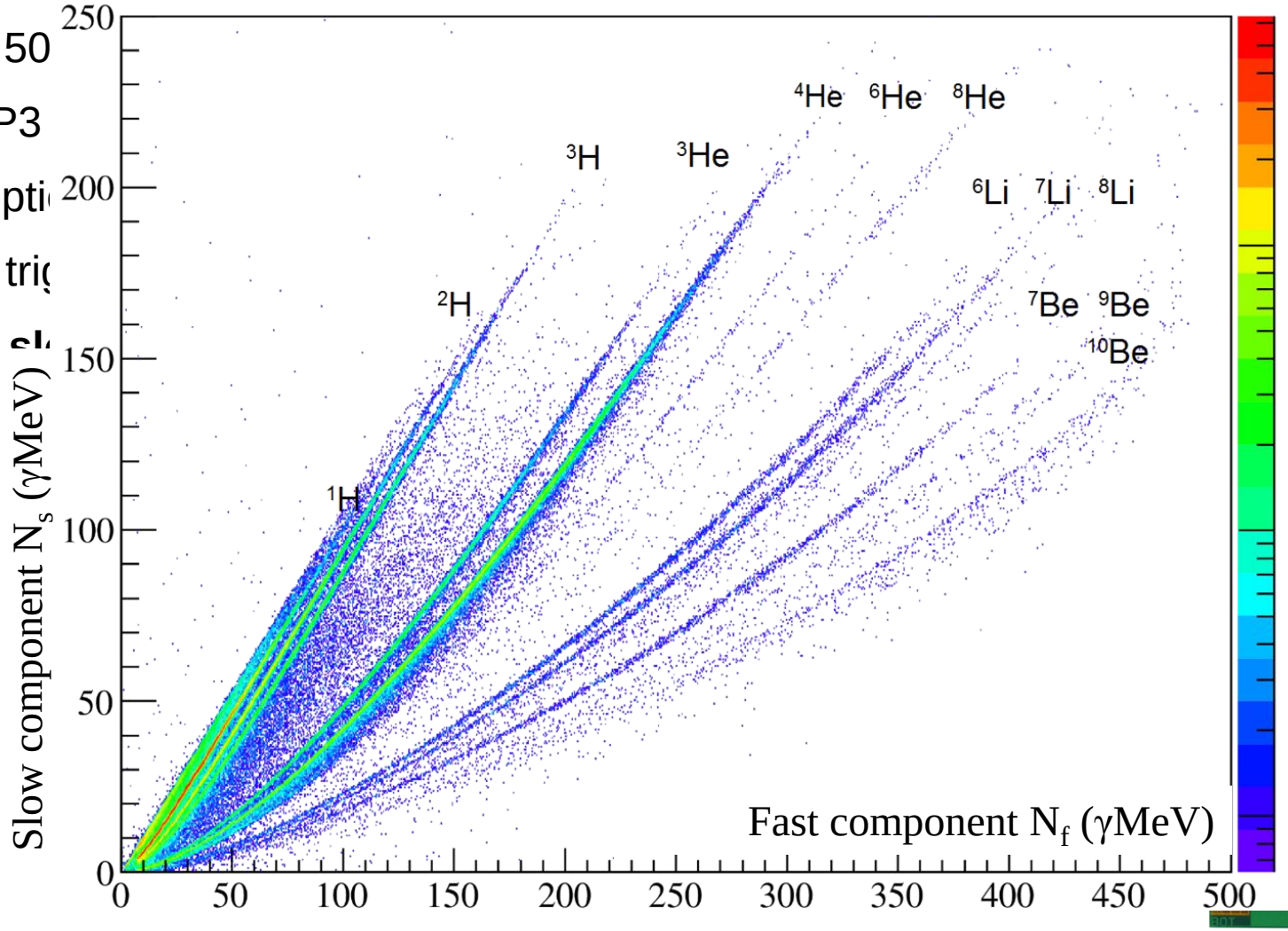


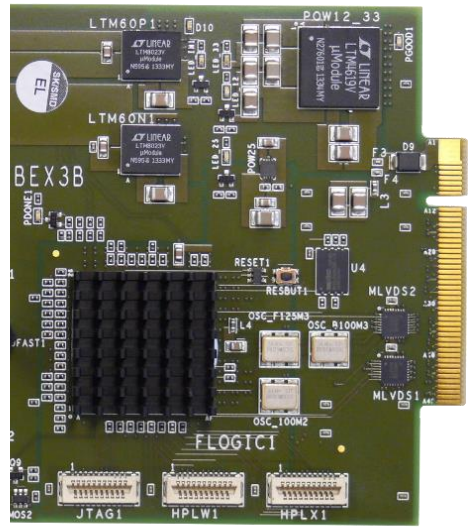
FEBEX **A**dd-On **B**oard
- Nyquist filtering
- Baseline offset

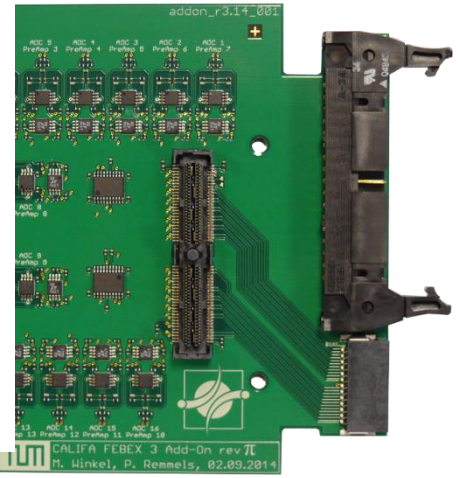
Courtesy of M. Winkel

Readout **F**ront-**E**nd **B**oard with Optical Link **Ex**tension

- **Universal hardware platform for CALIFA**
- 16x 14-bit, 50
- Lattice ECP3
- 1.6 Gbps opti
- 8x MLVDS trig
- **Extension sl**
- PCIe for cr
- Continous
- **On-board**







Courtesy of M. Winkel

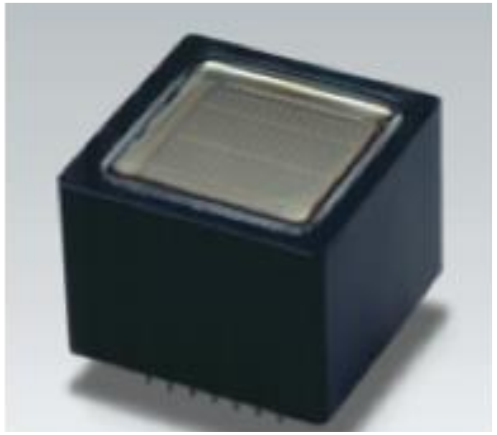
CEPA CALIFA End-Cap Phoswich Array

Most forward region of CALIFA

- Highest rates
- High background
- Highest energies

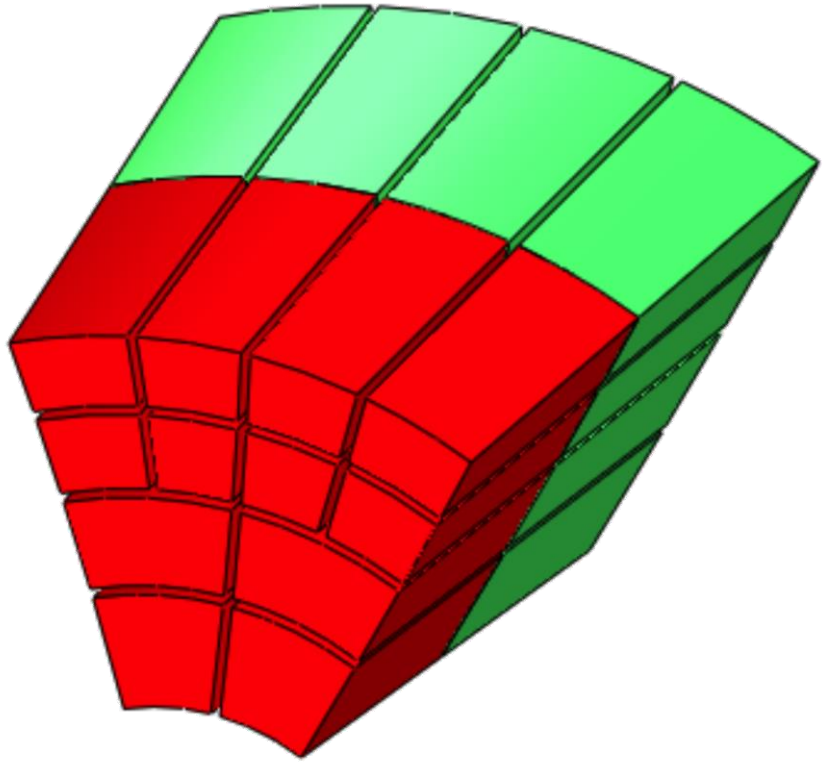
➢ **Fast, high resolution phoswich array**

PMT: Hamamatsu R7600U-200



8cm **$LaCl_3(Ce)$**

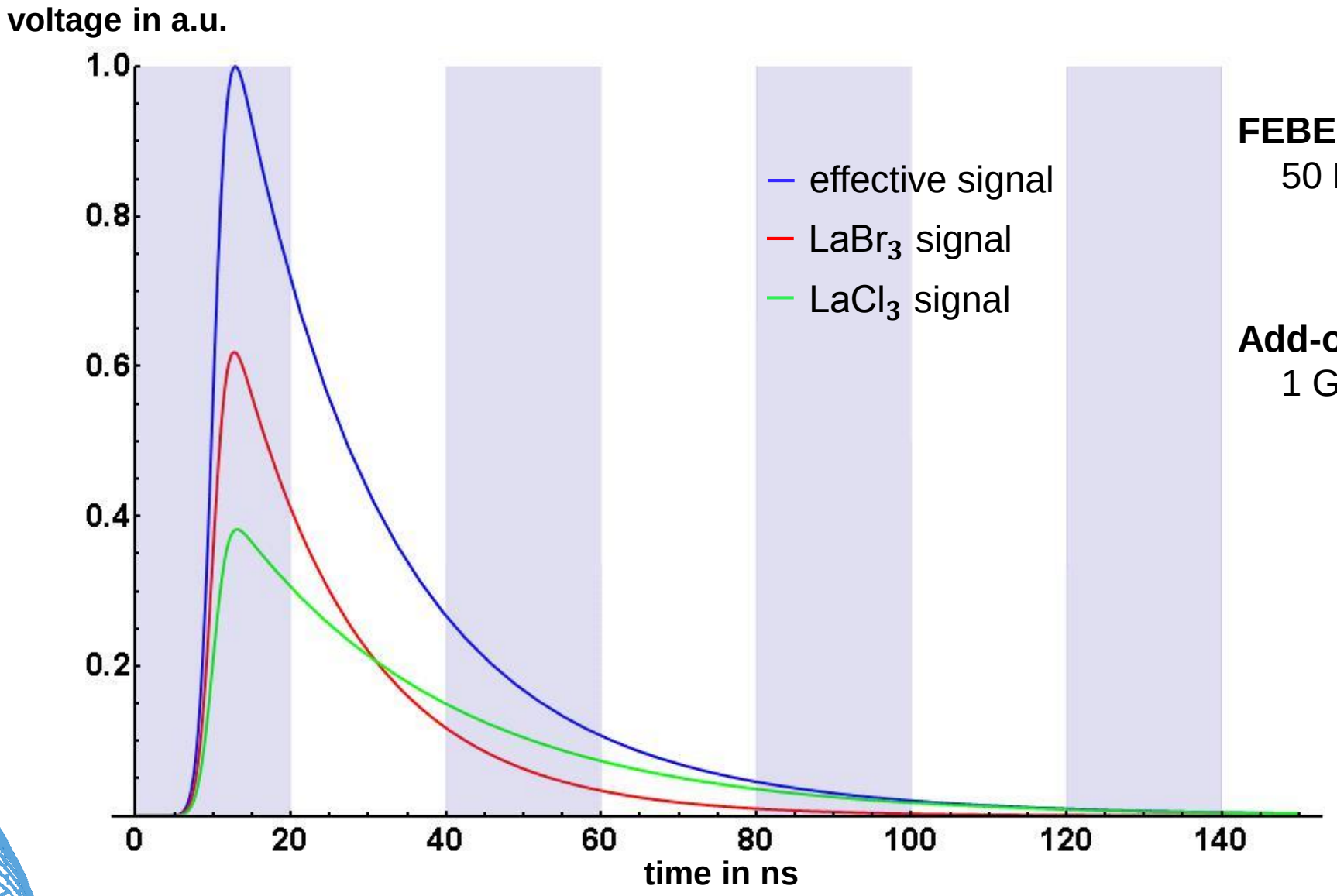
$\tau = 28\ \mathrm{ns},\ \frac{\Delta E}{E}(662\ \mathrm{keV}) \sim 3.5\%$



7cm **$LaBr_3(Ce)$**

$\tau = 16\ \mathrm{ns},\ \frac{\Delta E}{E}(662\ \mathrm{keV}) \sim 3\%$

CEPA Expected Signal



FEBEX3B:
50 MHz sampling frequency

Add-on board:
1 GHz sampling frequency

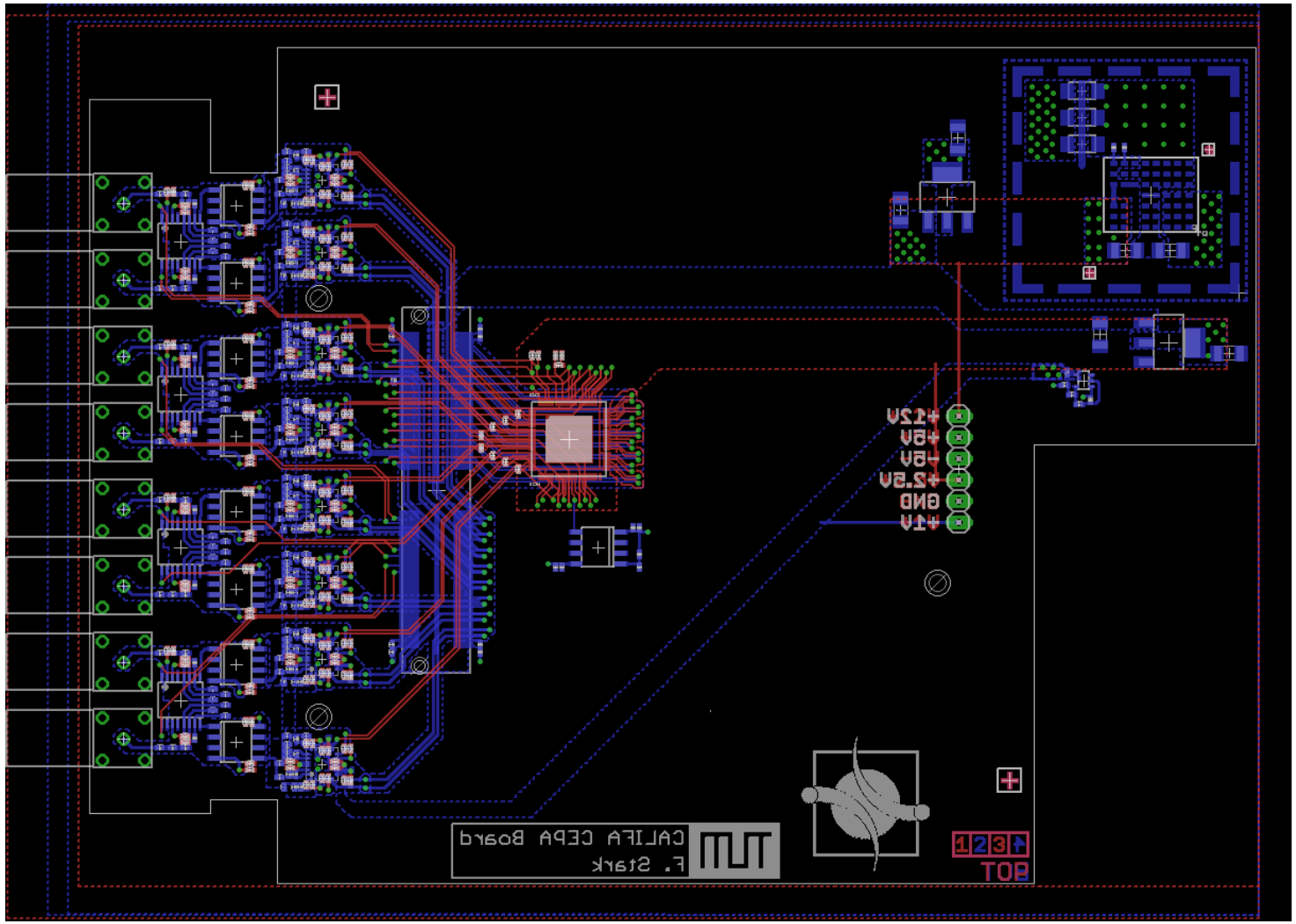
Courtesy of F. Stark

CEPA Addon

Master Thesis Felix Stark

Add-on board:

- eight channels
- eight multiplexers (3 g)
- eight-channel DRS4 GHz chip
- eight integrators



Courtesy of F. Stark