Analysis of the direct 3α decay of the Hoyle state in ^{12}C

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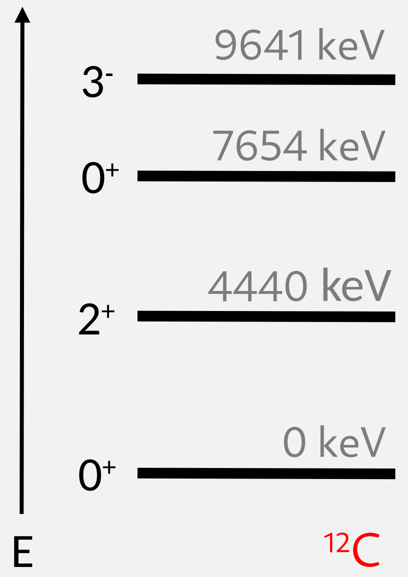
[1]University of Cologne, Institute for Nuclear Physics, Cologne
[2]Lund University, Department of Physics, Lund, Sweden
[3]TU Darmstadt, Institute of Nuclear Physics, Darmstadt

17.03.2023

18th Russbach School on Nuclear Astrophysics

^{12}C 3α decay

- ^{12}C: 4th highest abundance
- Mass gap at A=5 & A=8
- 3 particle process improbable



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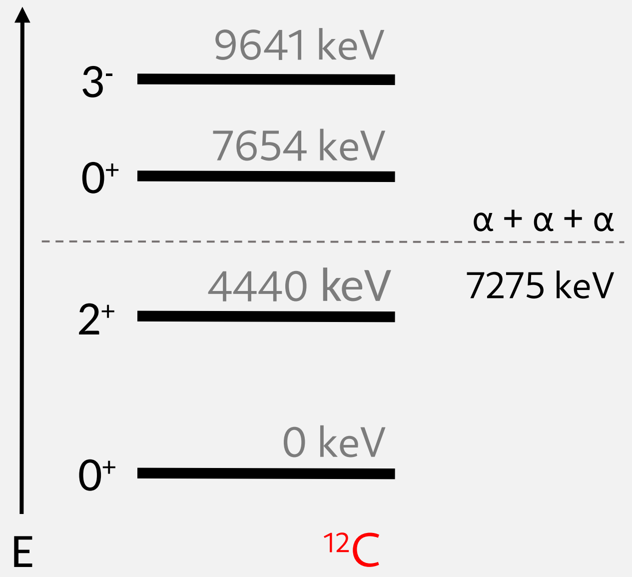

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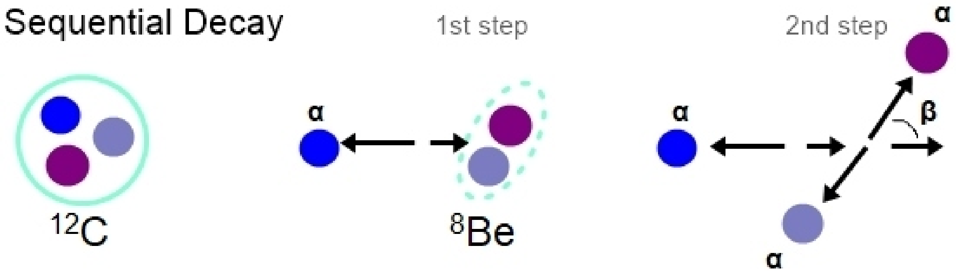

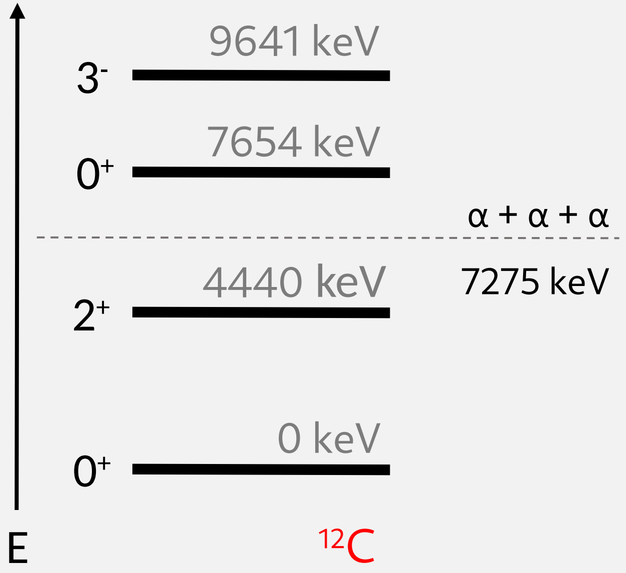

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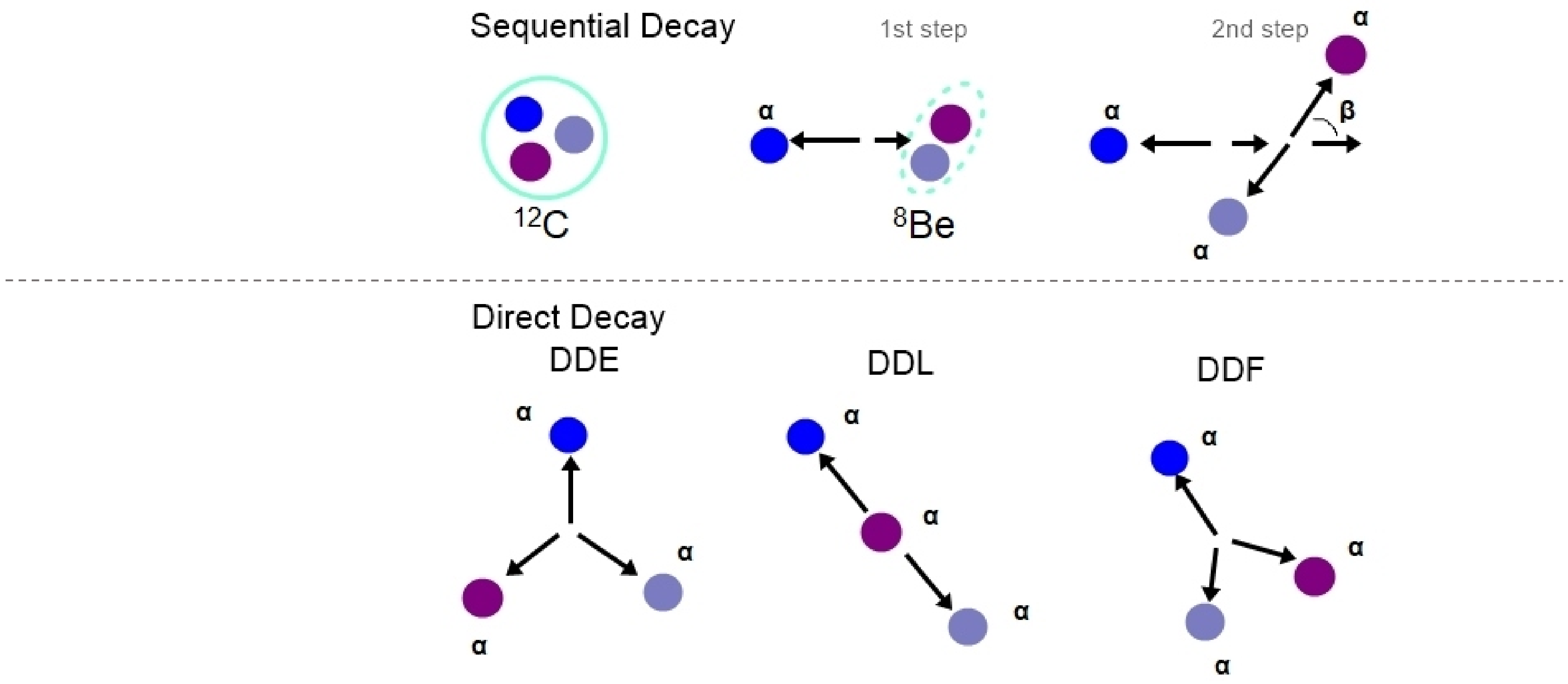

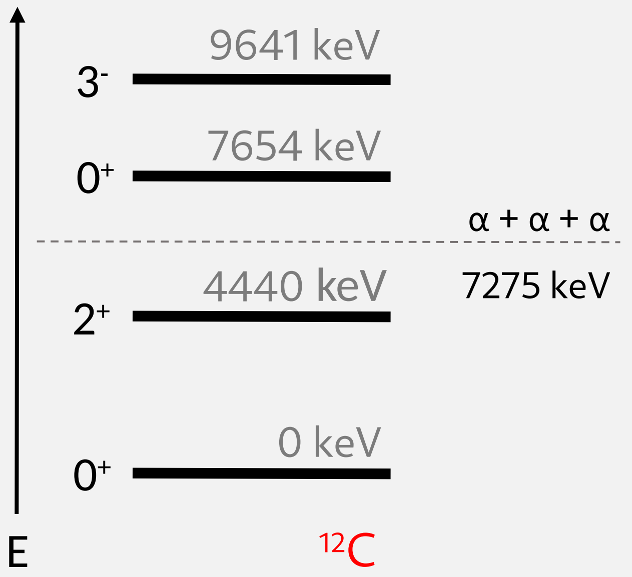

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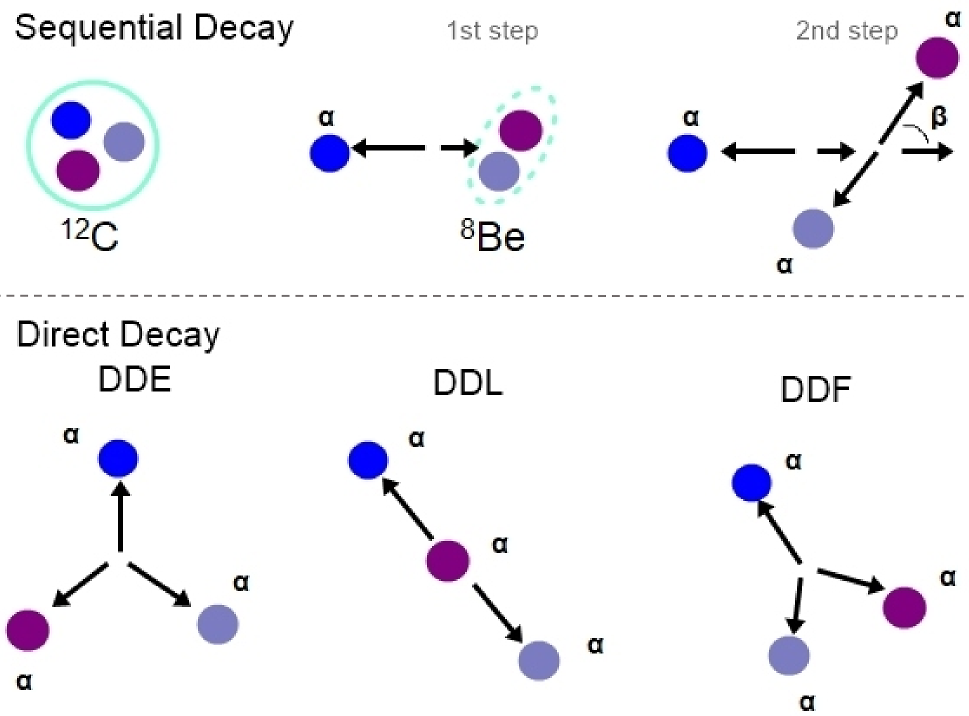
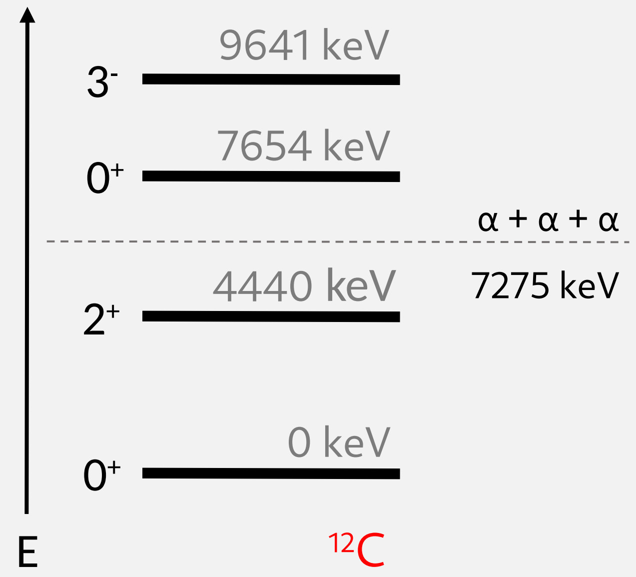


Upper limits:

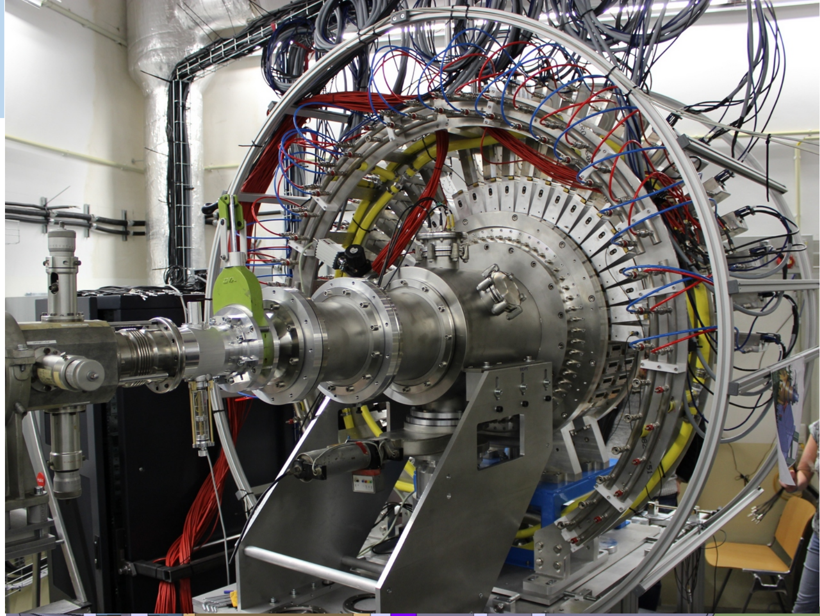
< 0.043%[1]
< 0.035%[2]
< 0.043%[3]
< 0.00057%[4]

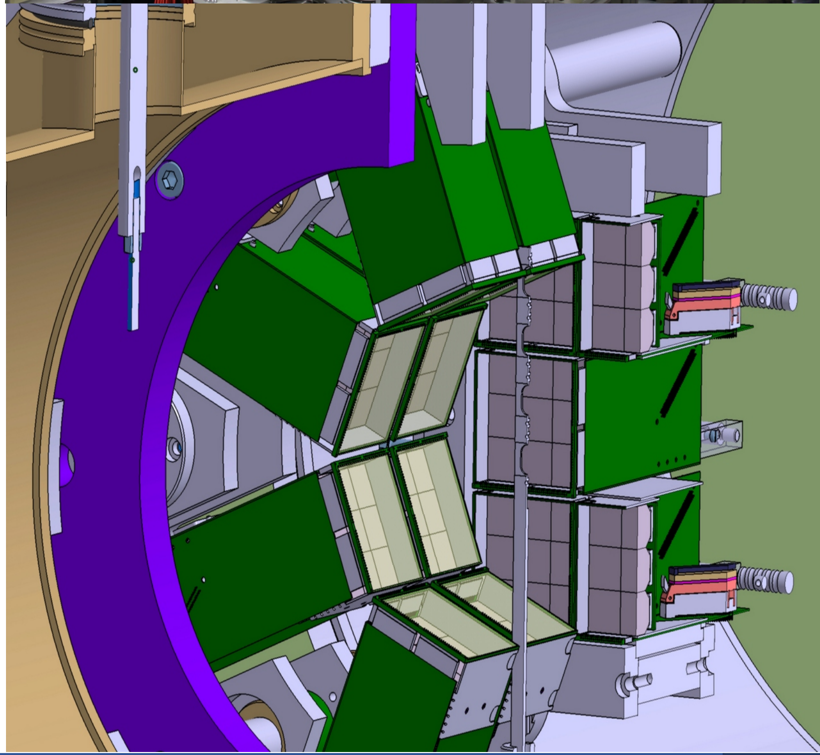


[1] 2017, Del l'Aquila PRL 119, 132501
[2] 2019, T.K. Rana Phys.Lett.B 793(2019)130–133
[3] 2020, J. Bishop et al. Phys.Rev.C 102.041303
[4] 2020, R. Smith et al. Phys.Rev.C 101.021302

Lund-York-Cologne Calorimeter (LYCCA)

Complete setup	Current setup in Cologne
24 DSSSDS 8 in **wall (forward)** 16 in **2 rings (forward)** Angular coverage: Wall: 10° - 29° Ring 1: 30° - 47° Ring 2: 48° - 83°	**18 DSSSDS** 4 in **wall (forward)** 14 in **2 rings (forward)** Reason: not enough AIDA FEE modules in Cologne 24 detectors mounted





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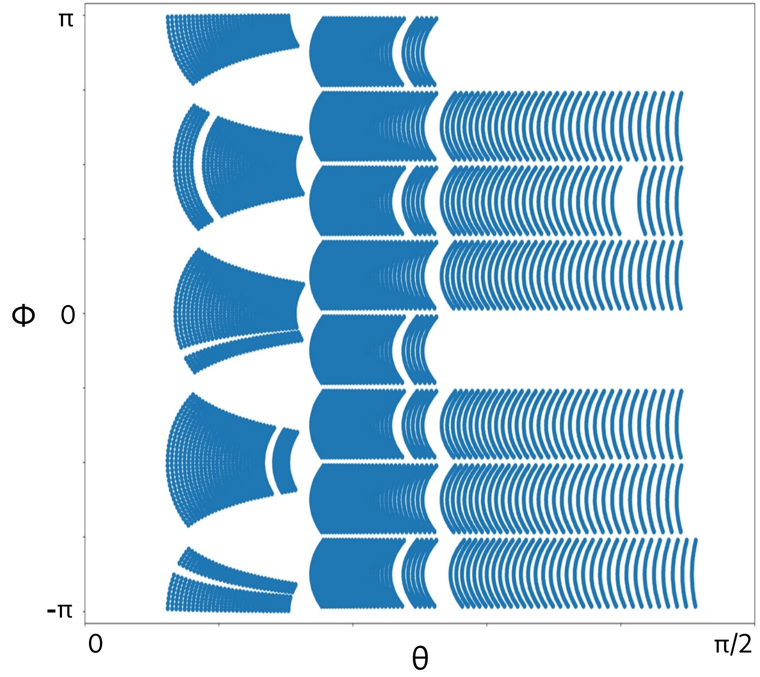

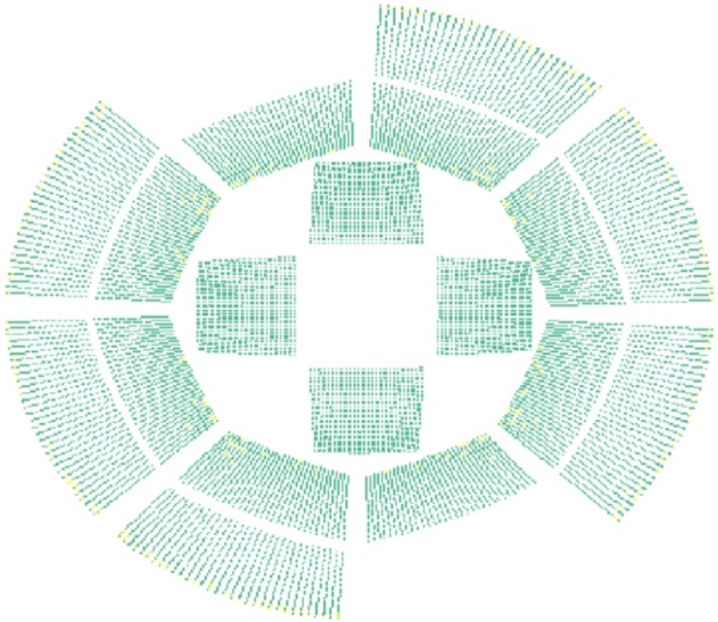

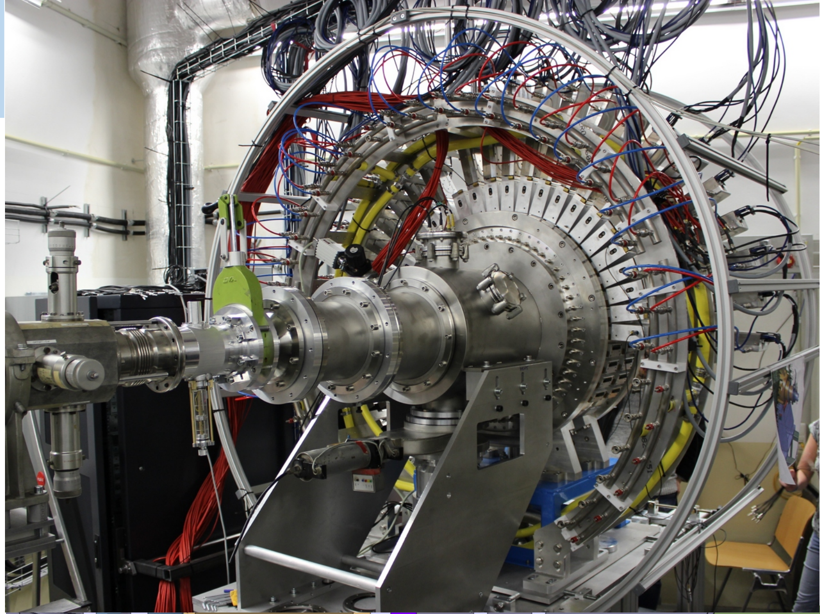

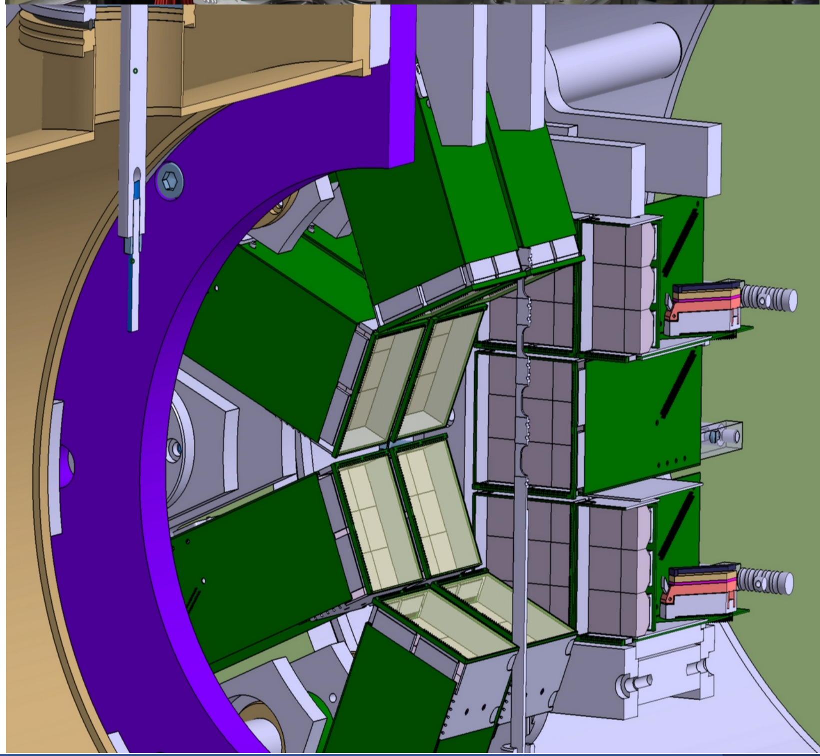

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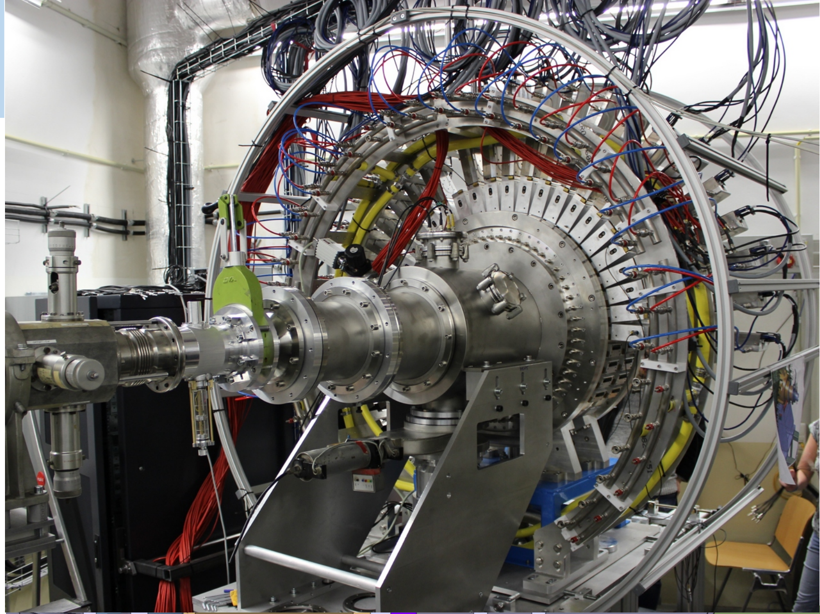

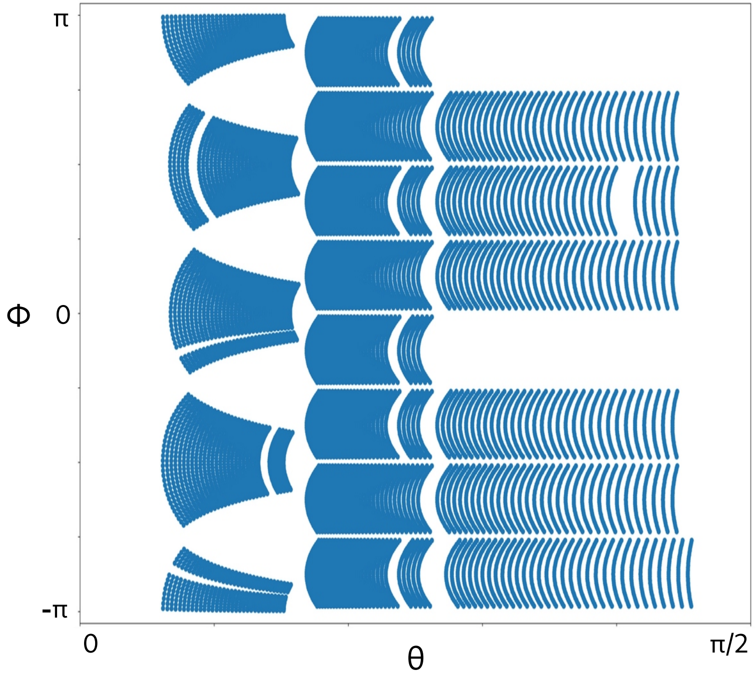

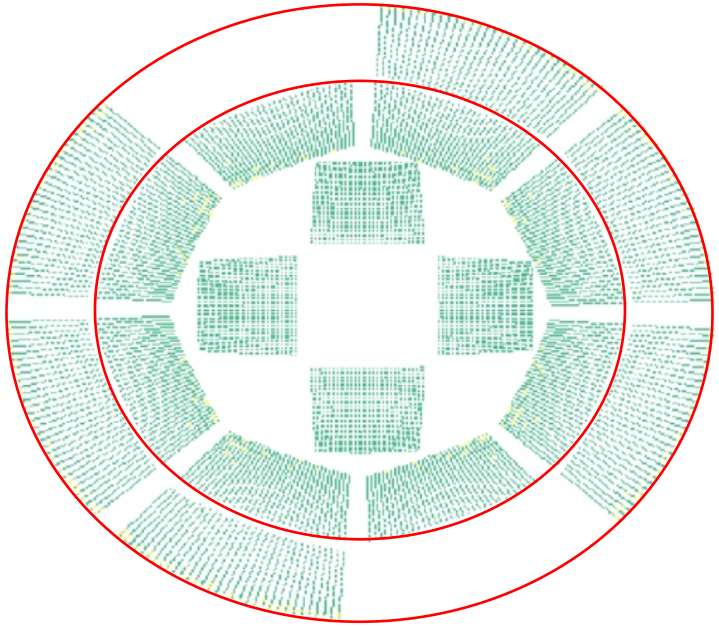

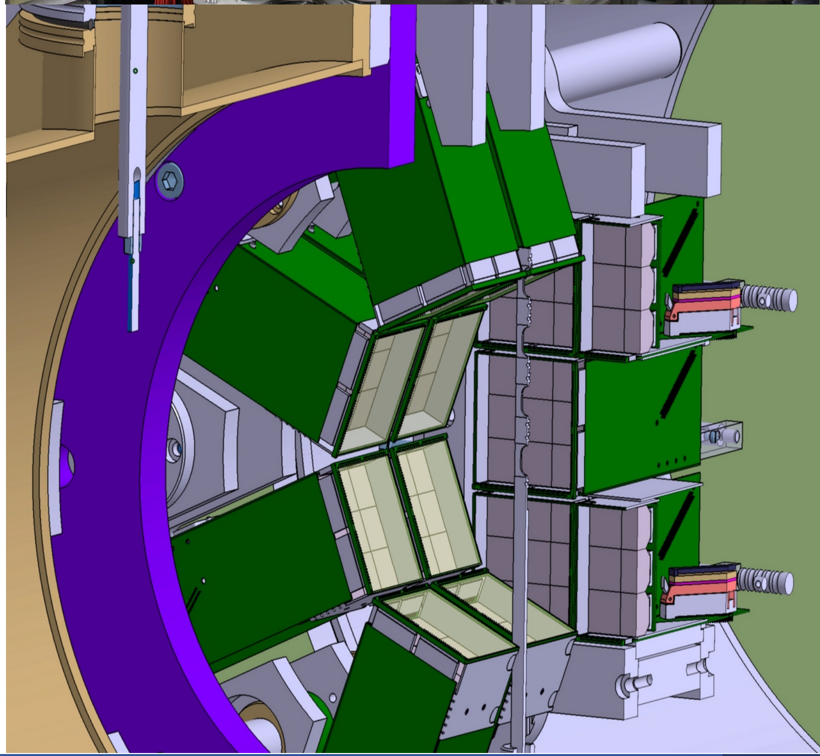

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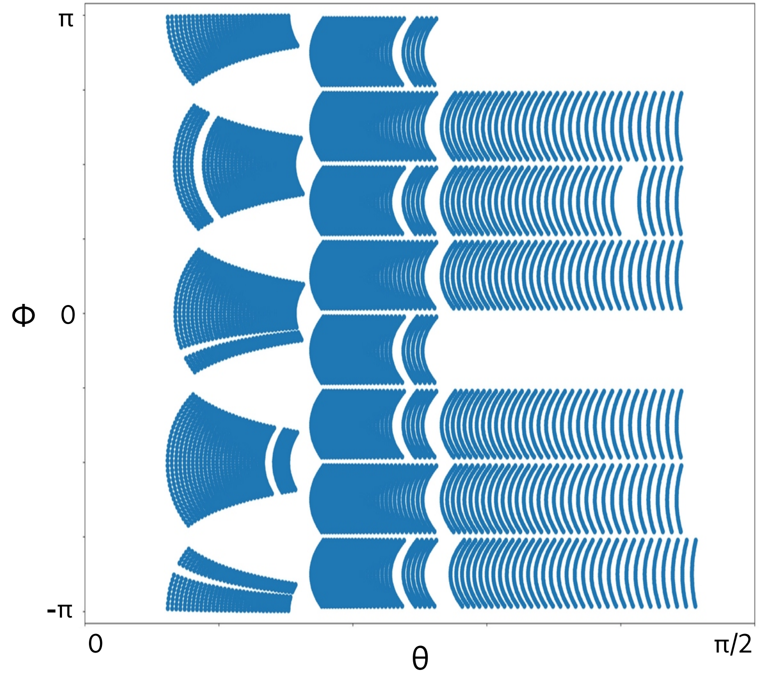

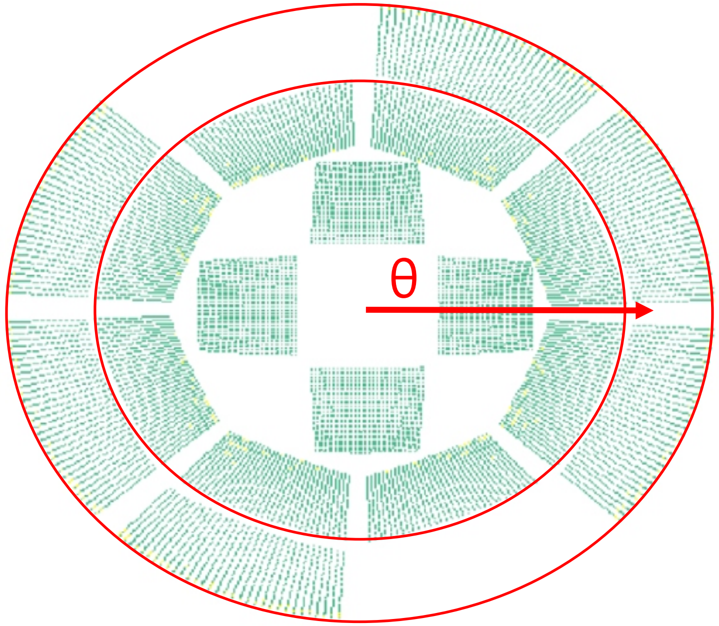

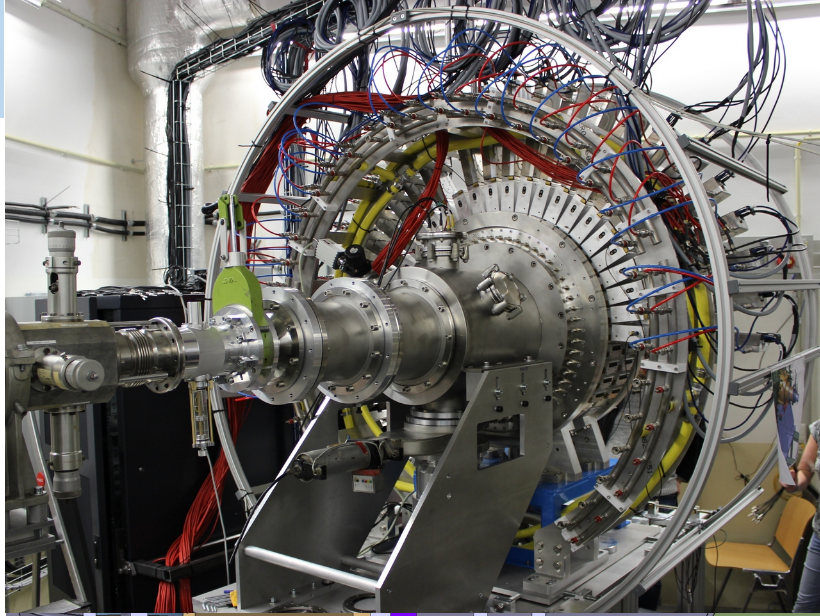

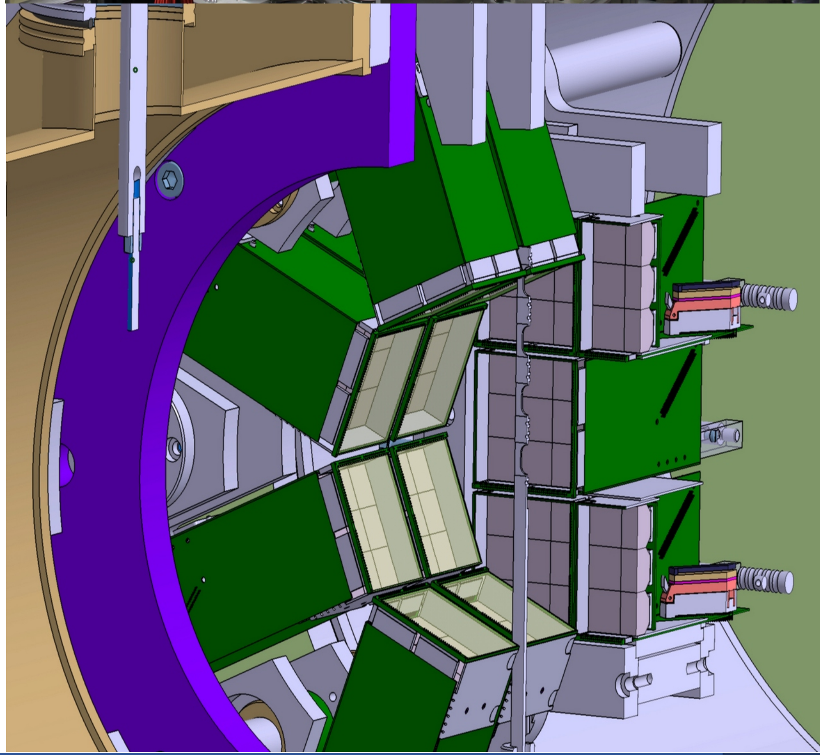

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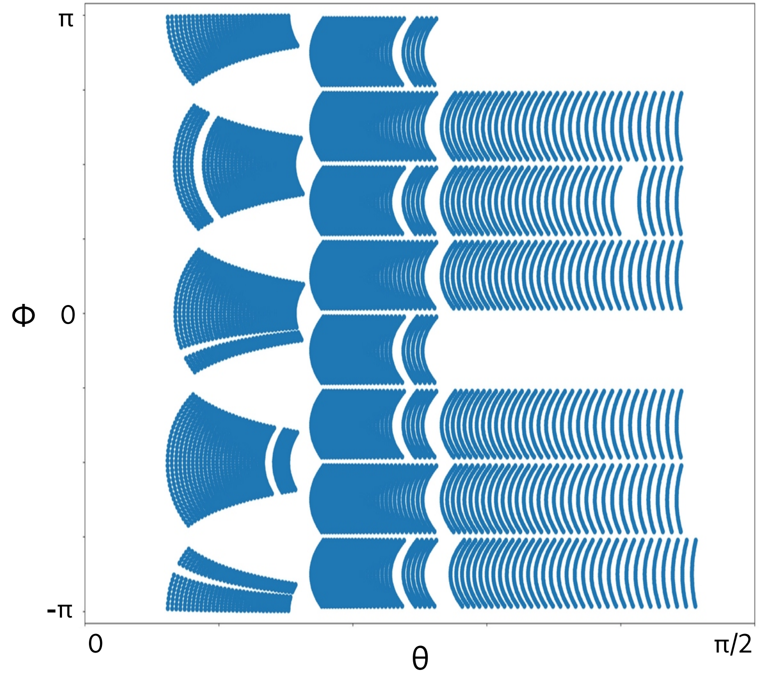
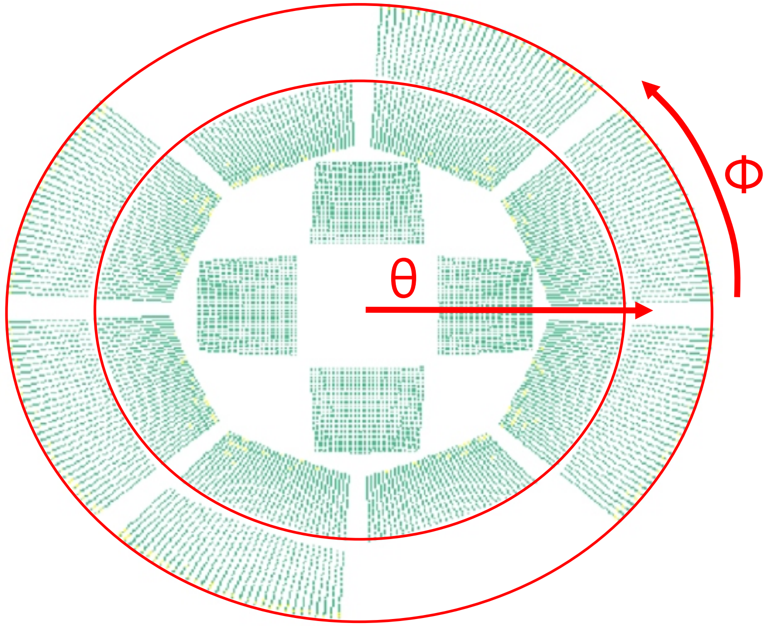
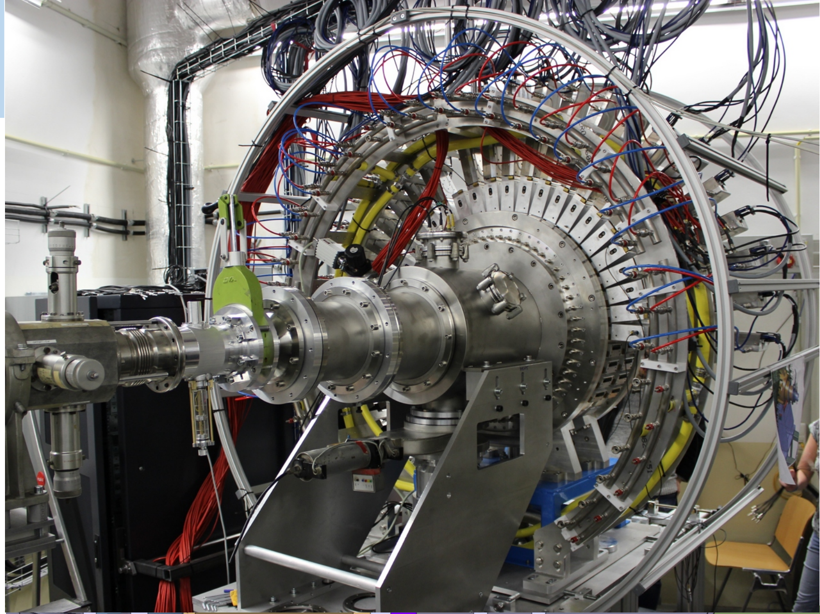
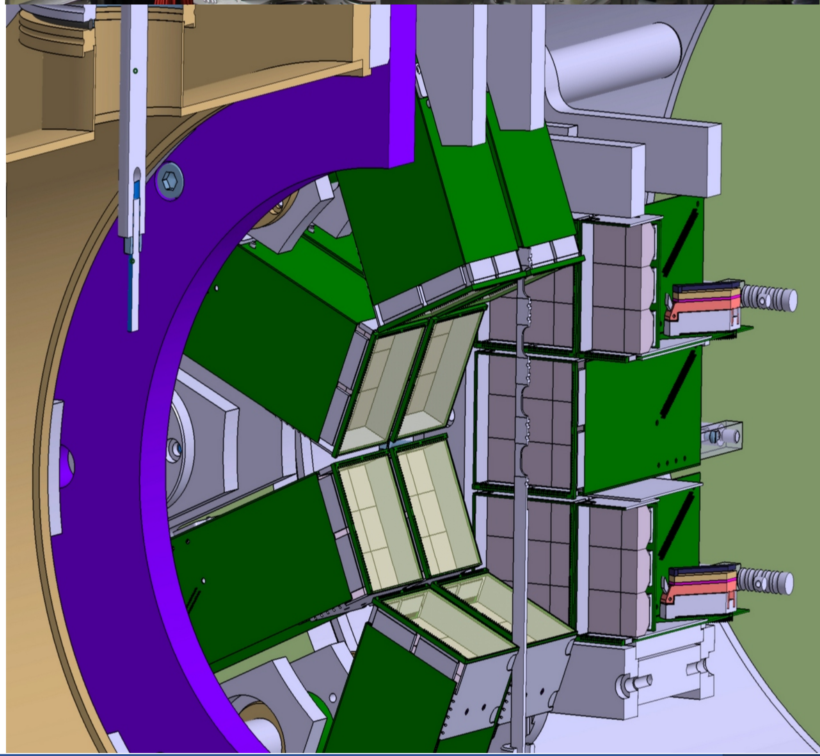
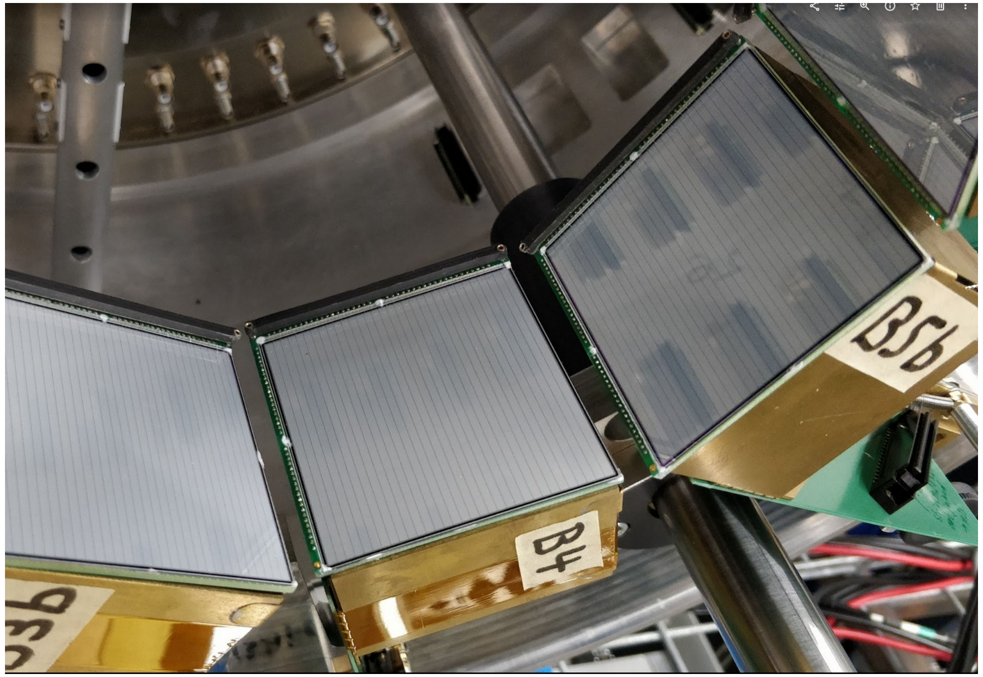






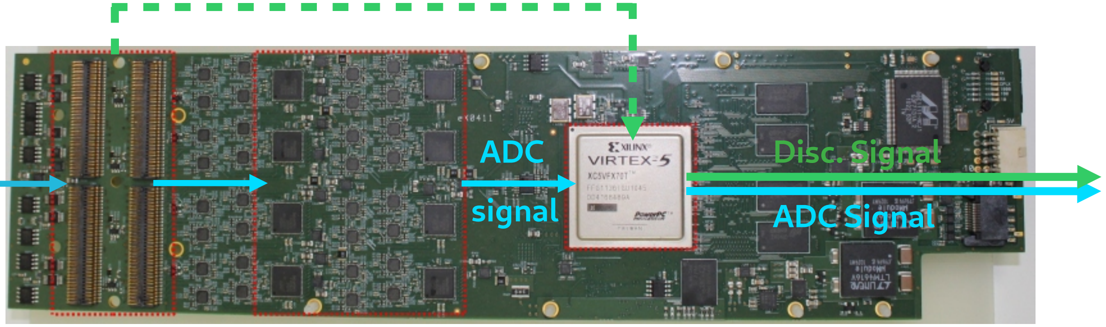


AIDA DAQ



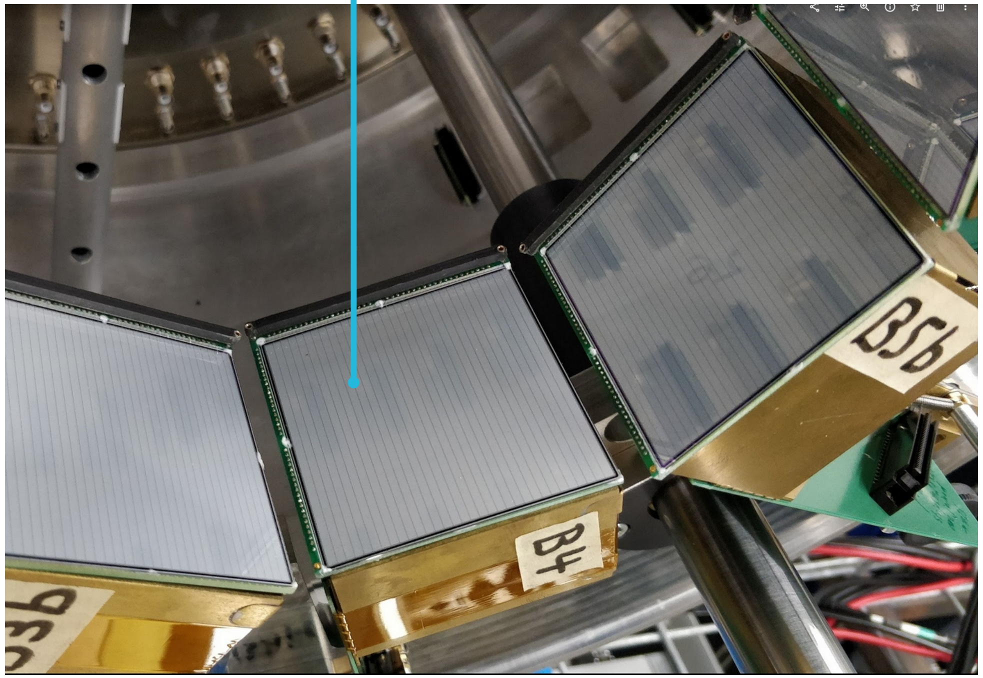
AIDA DAQ

detector
signal



ASICs

ADCs



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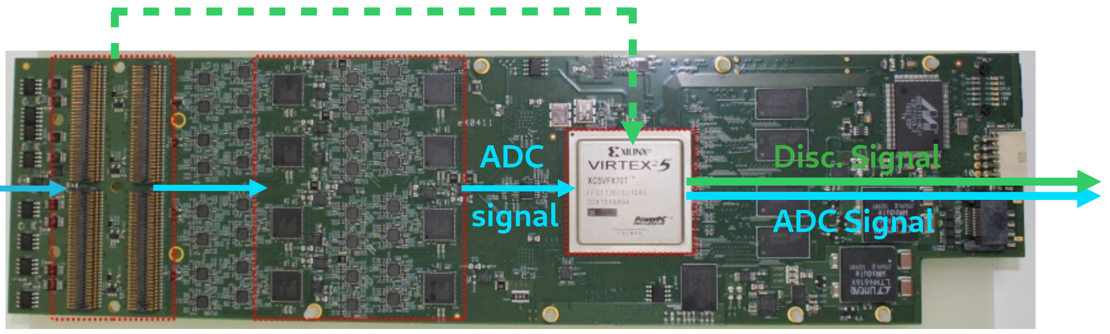

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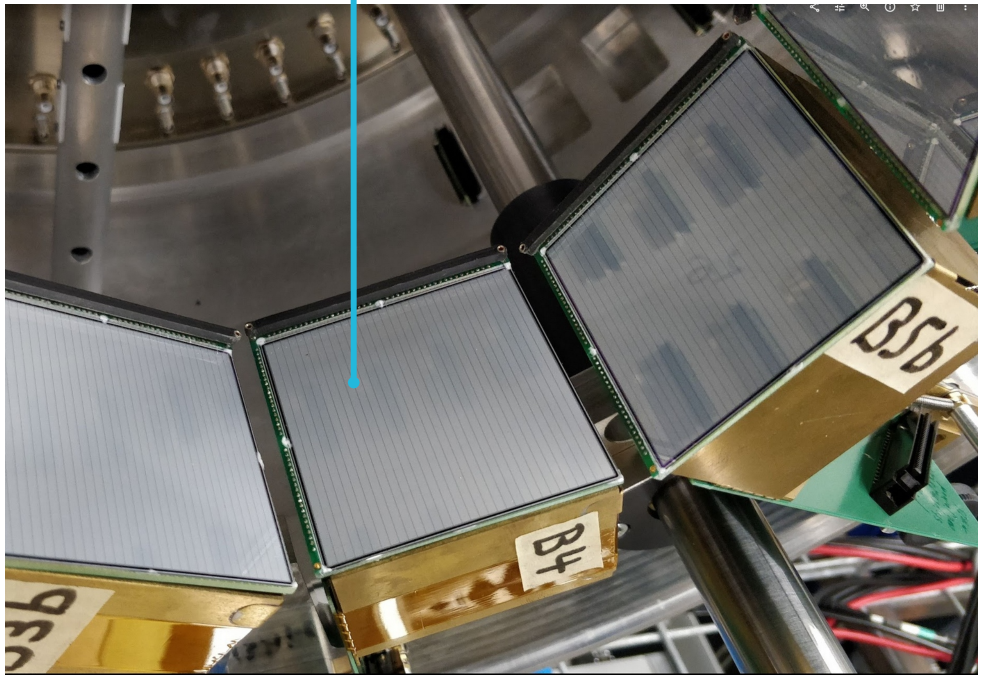

<table>
<tr><th colspan="2">ADC signal</th><th colspan="2">Discriminator signal</th></tr>
<tr><td colspan="4">position (detector + strip)</td></tr>
<tr><td rowspan="2">time</td><td>ADC clock</td><td rowspan="2">time</td><td>FEE clock</td></tr>
<tr><td>500 kHz (2 µs)</td><td>100 MHz (10 ns)</td></tr>
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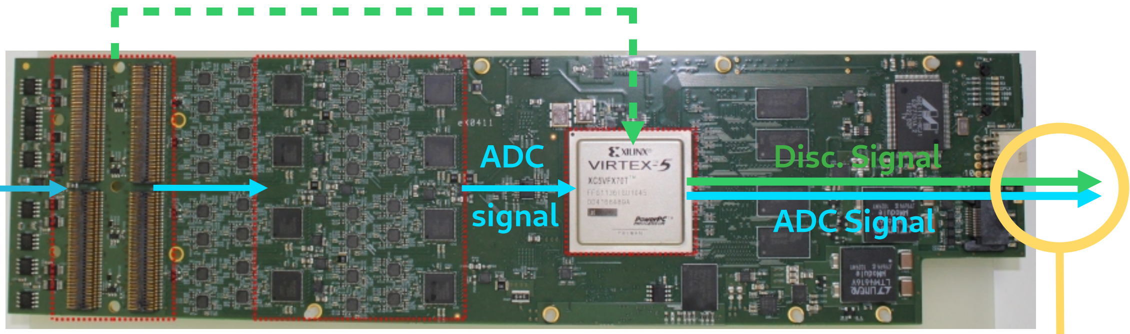

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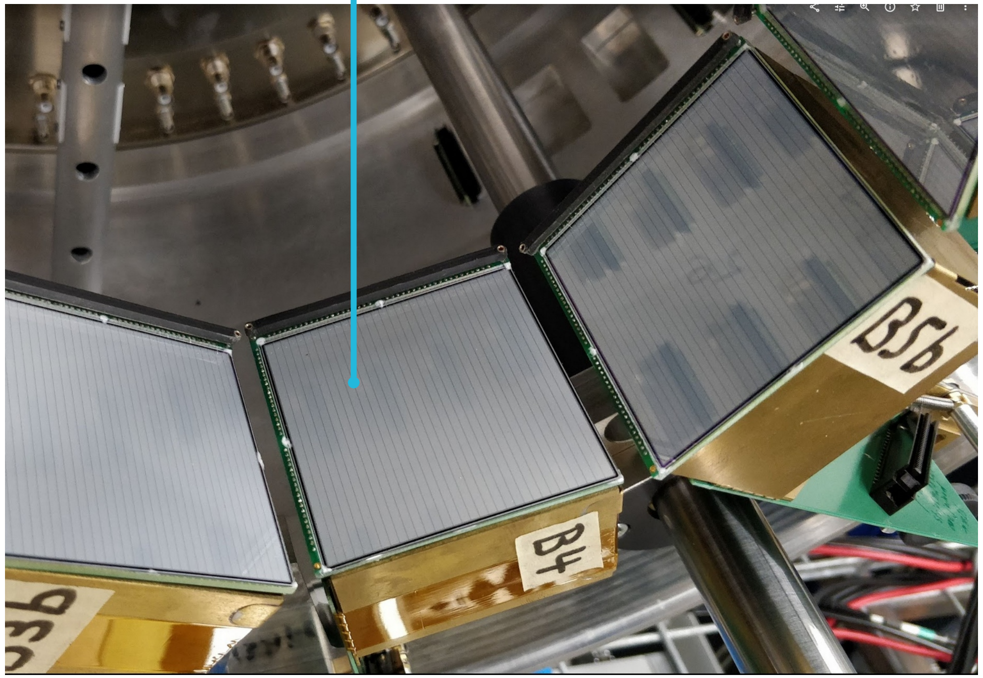

Multi **i**nstance **da**ta acquisition **s**ystem

by STFC Daresbury

ADC signal		Discriminator signal	
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	500 kHz (2 µs)		100 MHz (10 ns)
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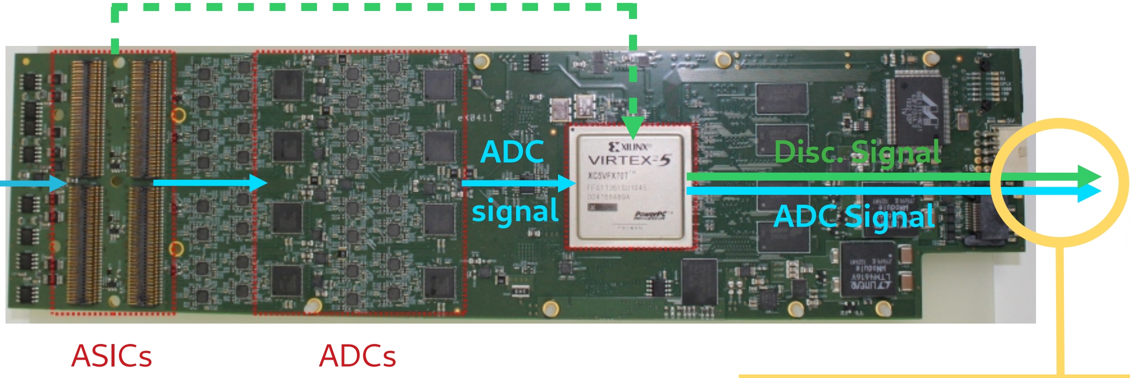

file → Converter → ROOT tree

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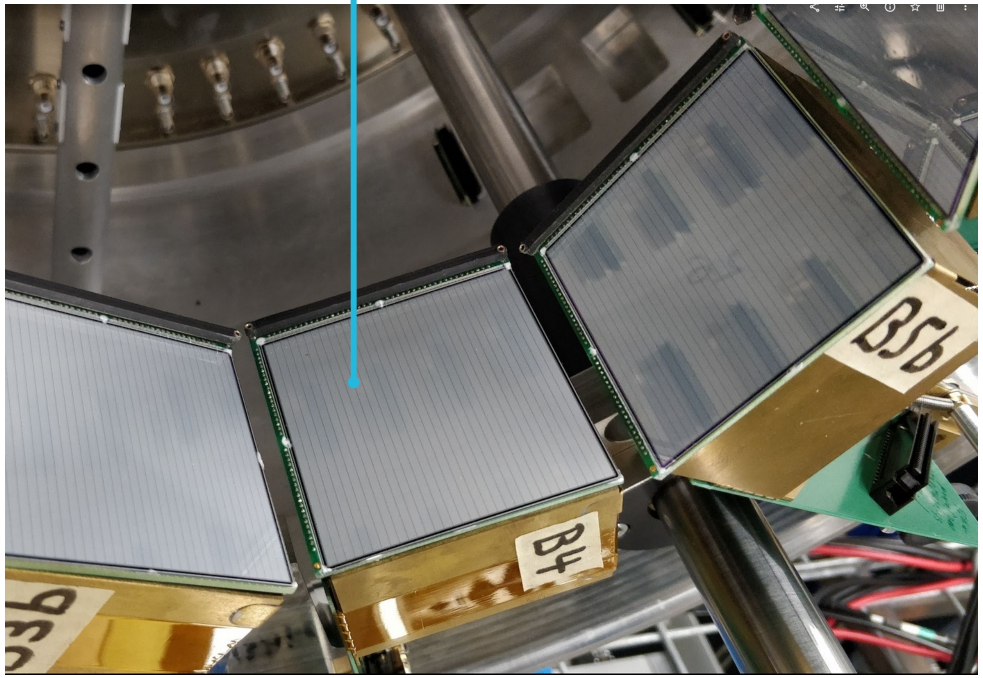

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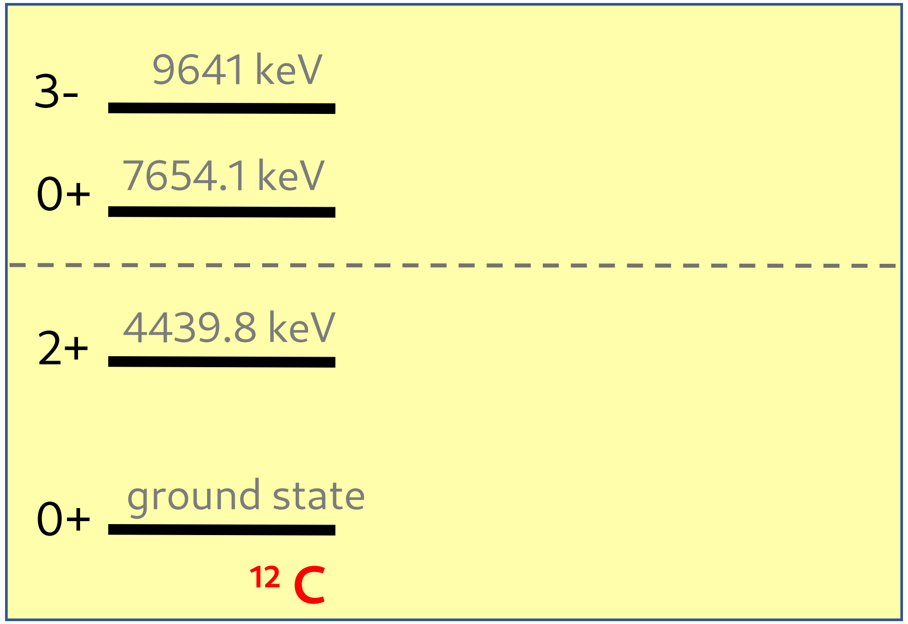
- 2 weeks, $^{12}C(\alpha,\alpha')^{12}C^*$ @ 27 MeV
- Beam current: 0.8 – 2 pnA
- Target: 0.114 mg/cm^2 ^{nat}C
- $> 4 \cdot 10^{10}$ particle events

@ 10MV Cologne
Tandem accelerator

- Calibration: α-source + Au(α,α')Au @ 8, 14, 20 MeV



Experiments

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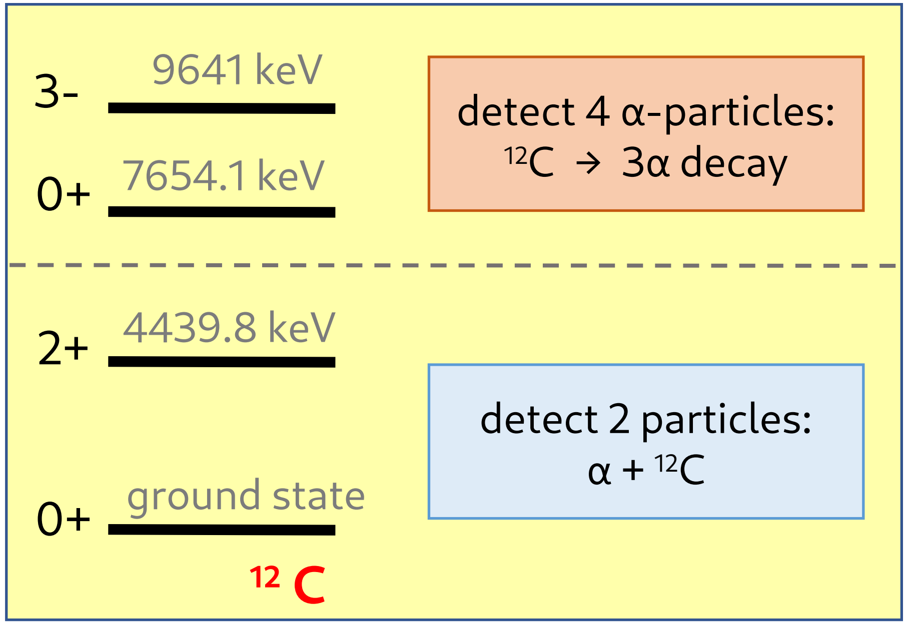
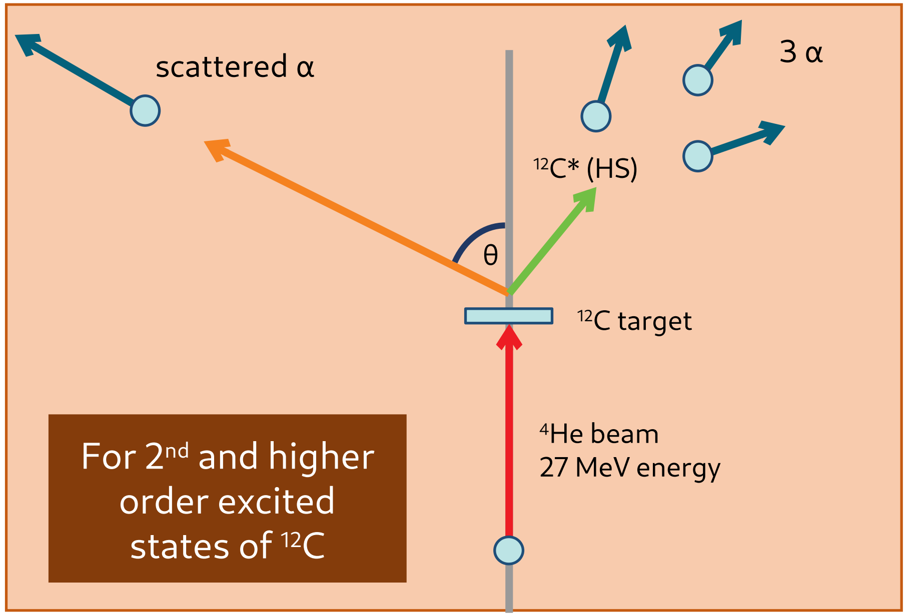
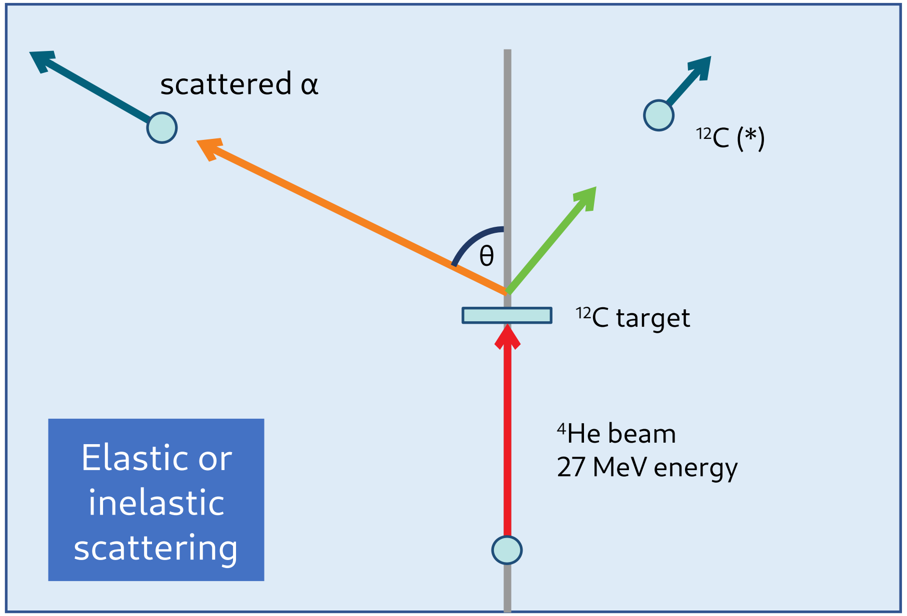
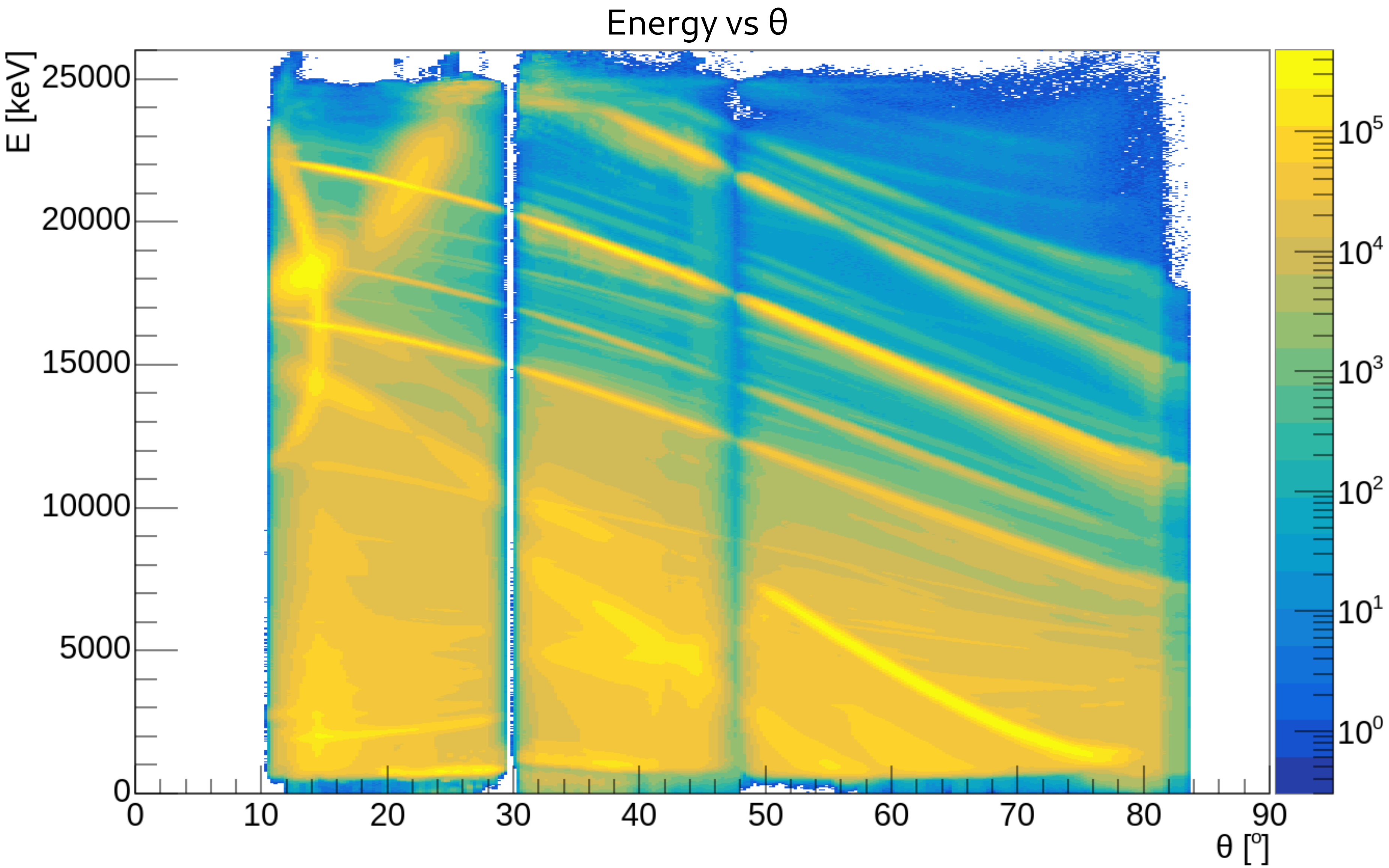






Analysis: Hoyle state gated



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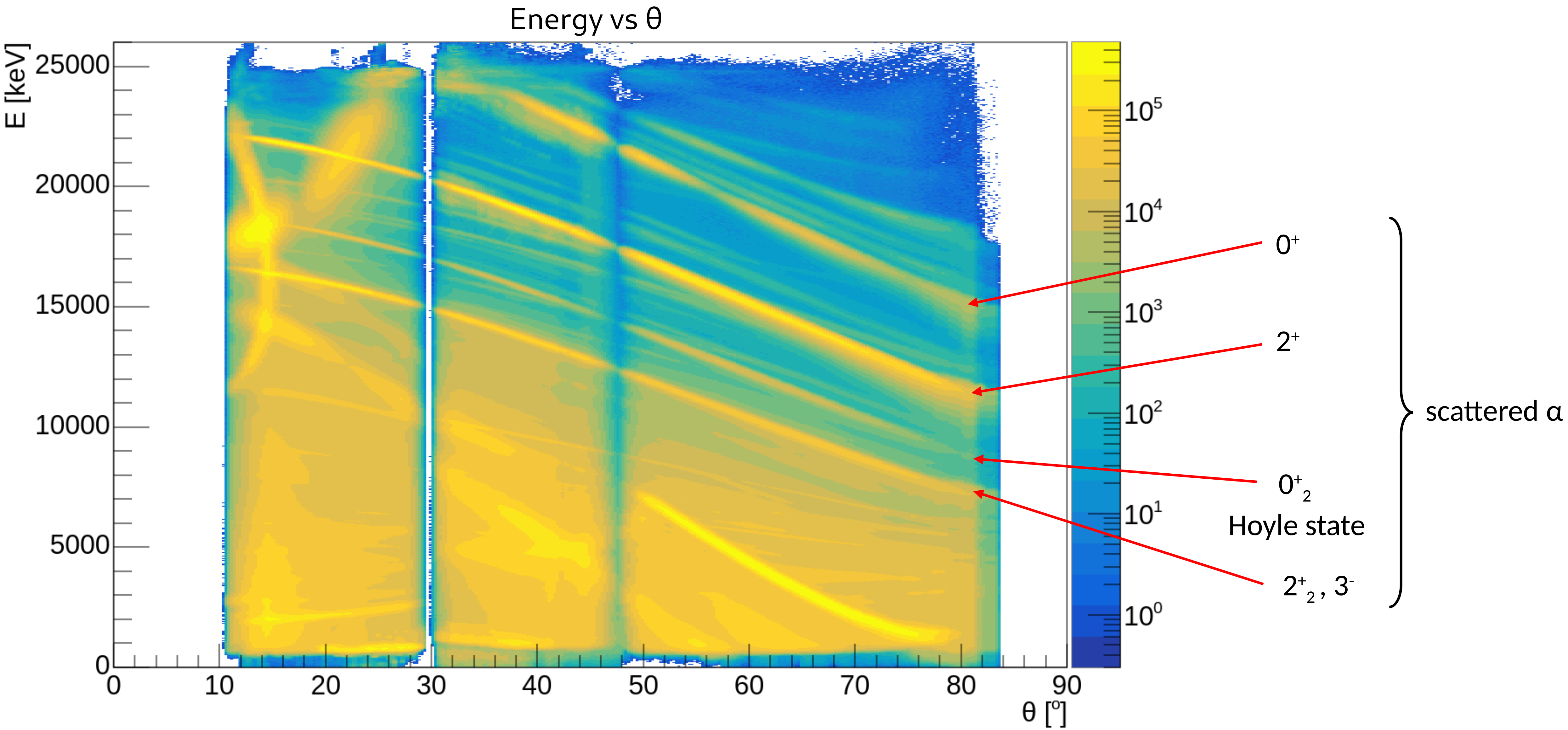

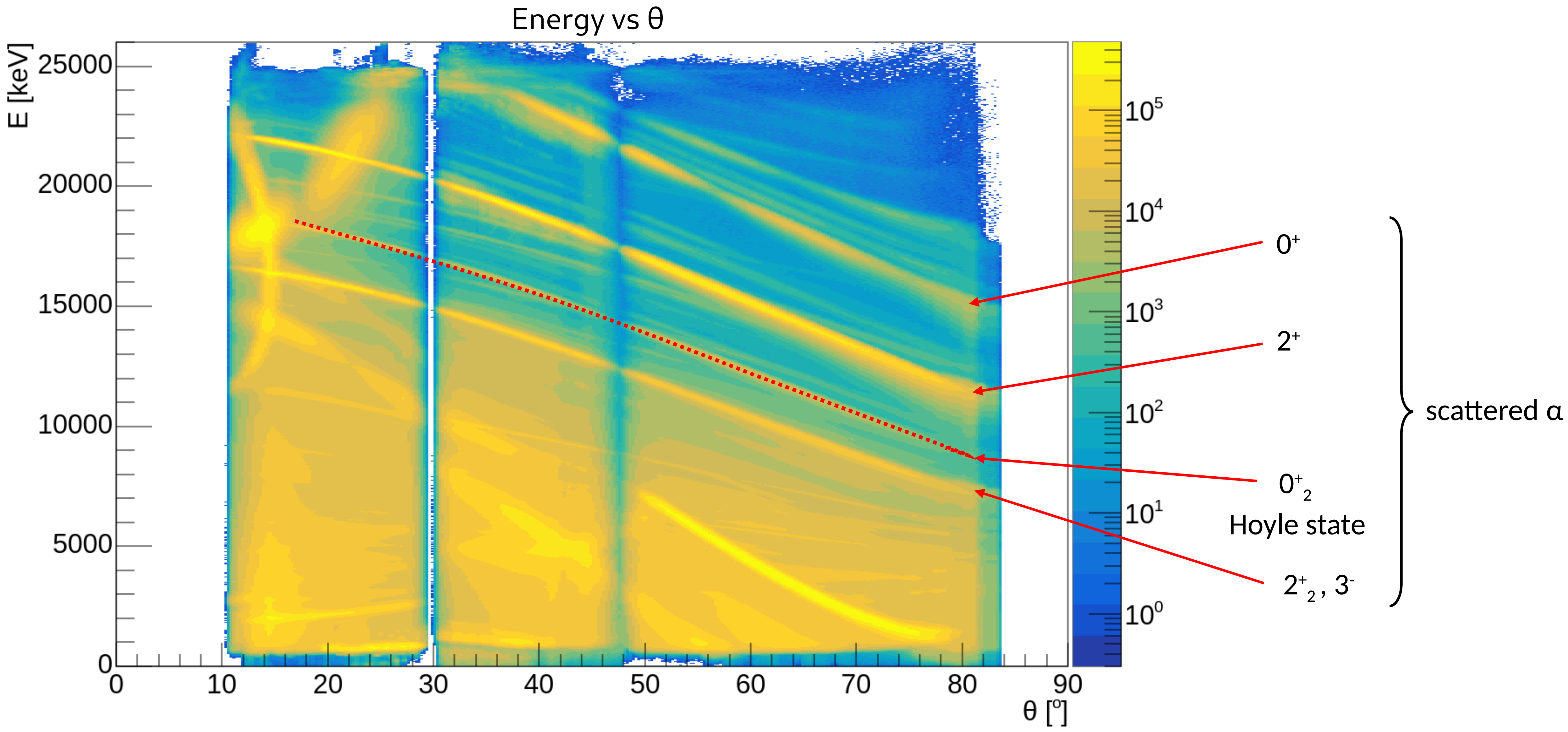
Energy vs θ
E [keV]
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80
90
θ [º]
10^5
10^4
10^3
10^2
10^1
10^0
0^+
2^+
0^+_2
Hoyle state
2^+_2, 3^-
scattered α

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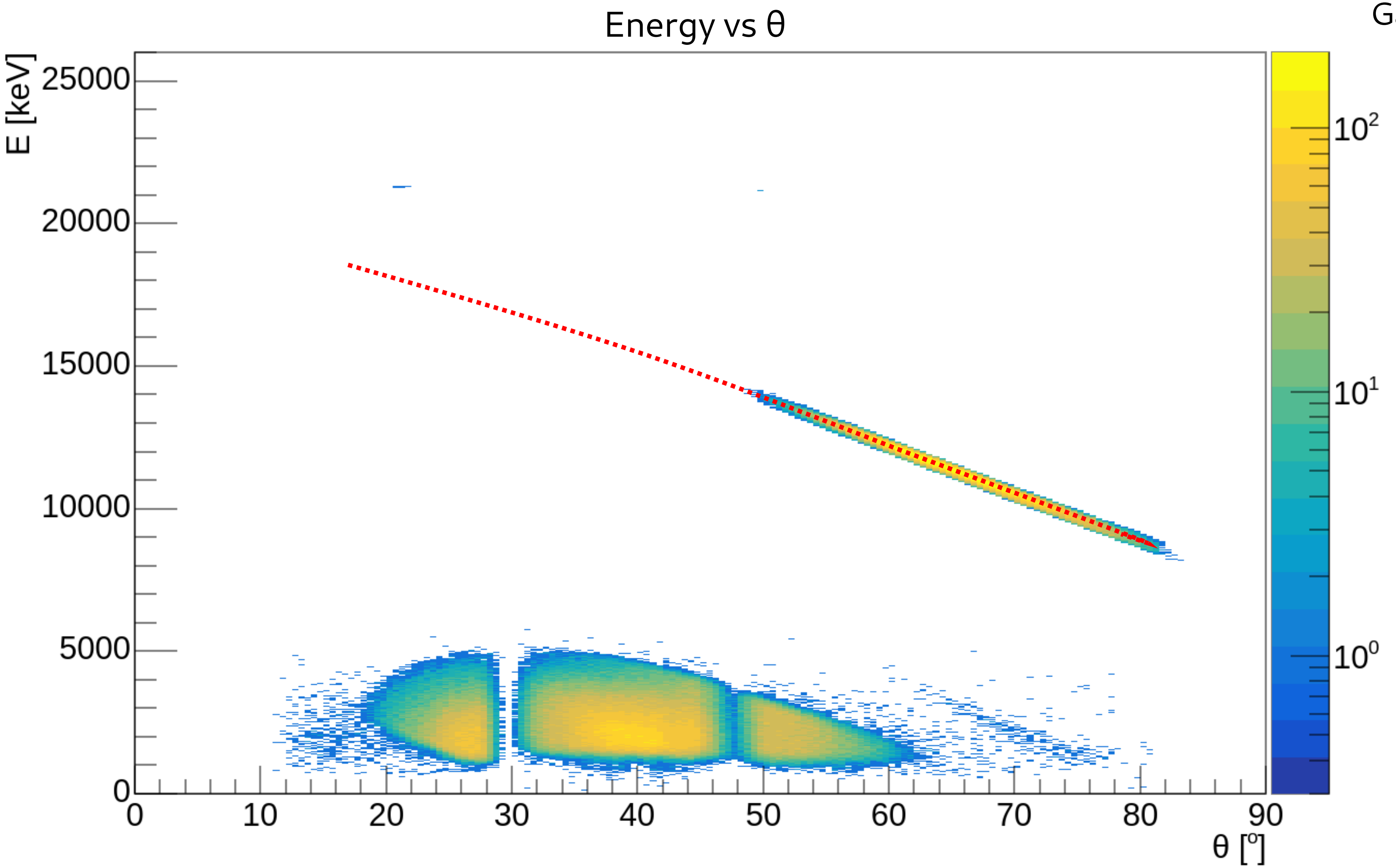
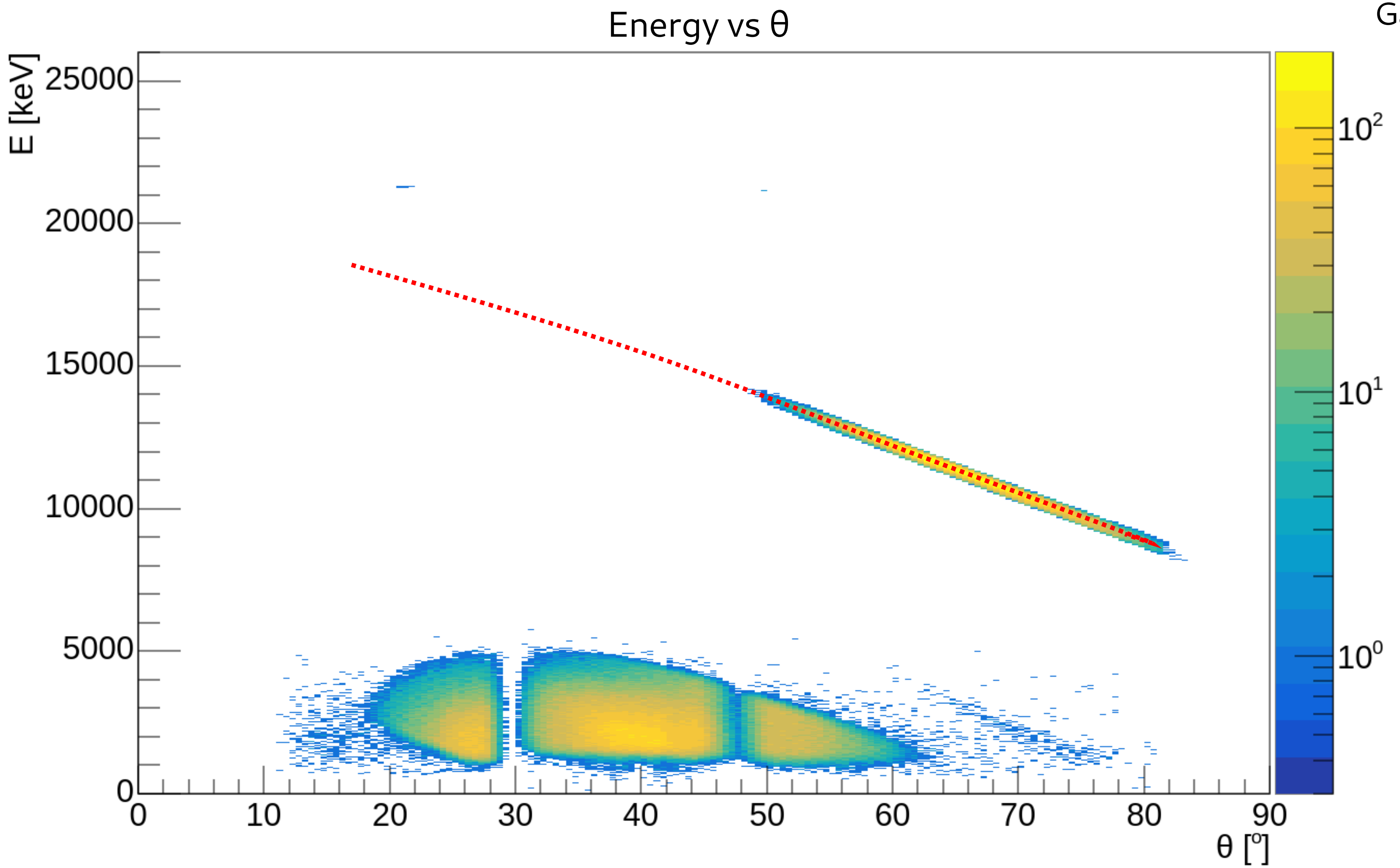


Gate conditions:



Gate conditions:

- $E_{\text{scattered } \alpha}$ (kinematics)
- time difference (< 90 ns)
- multiplicity (4 particles)

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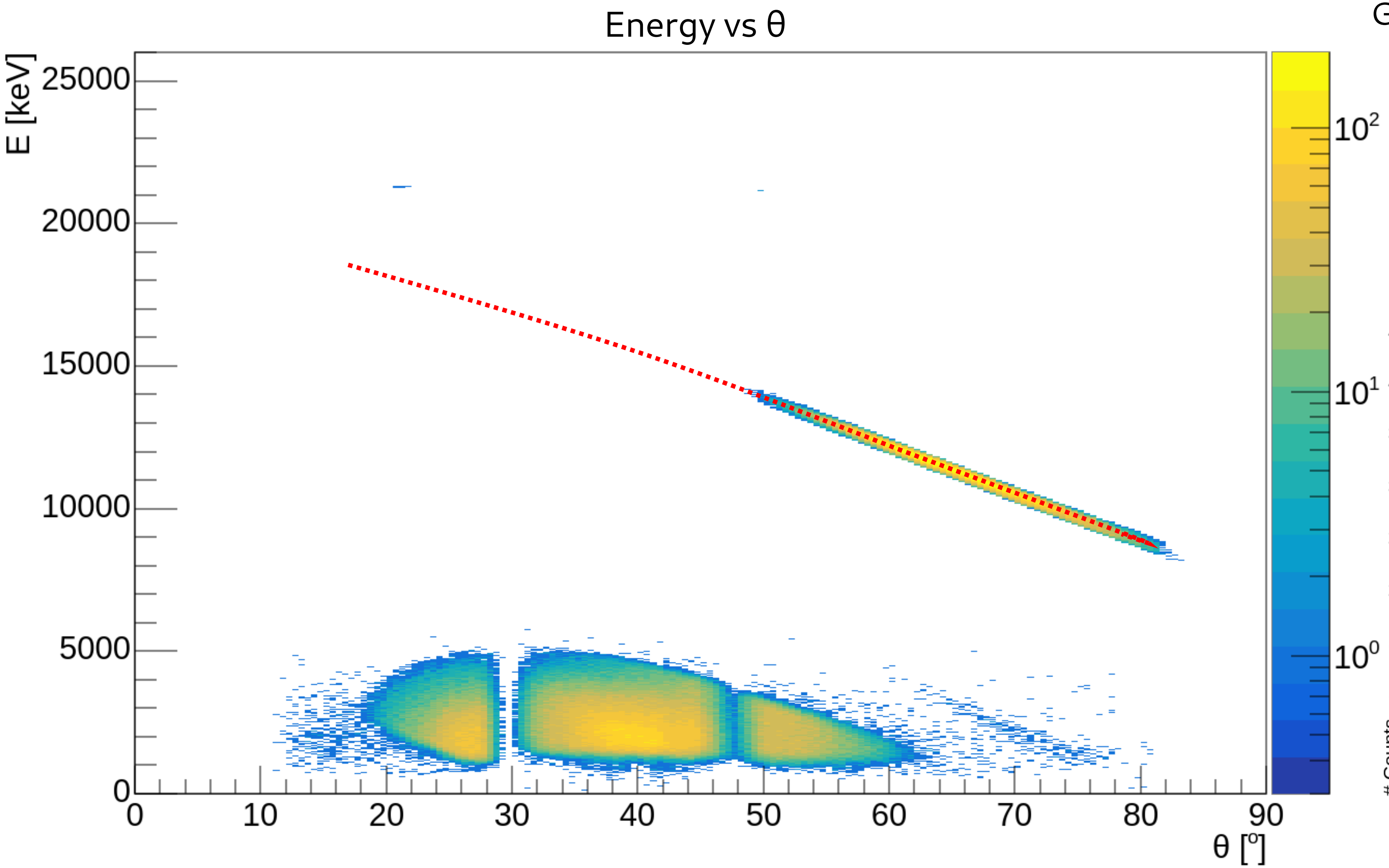

Gate conditions:

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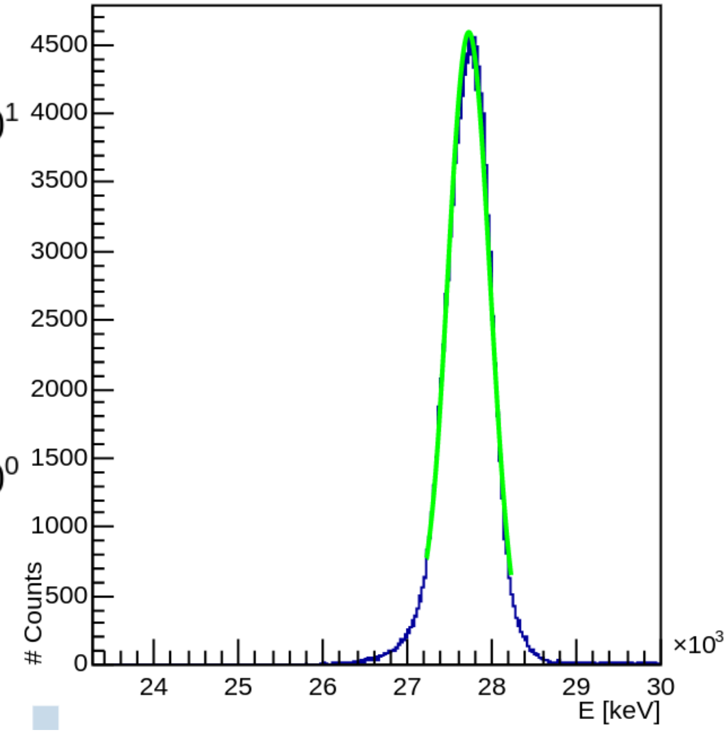

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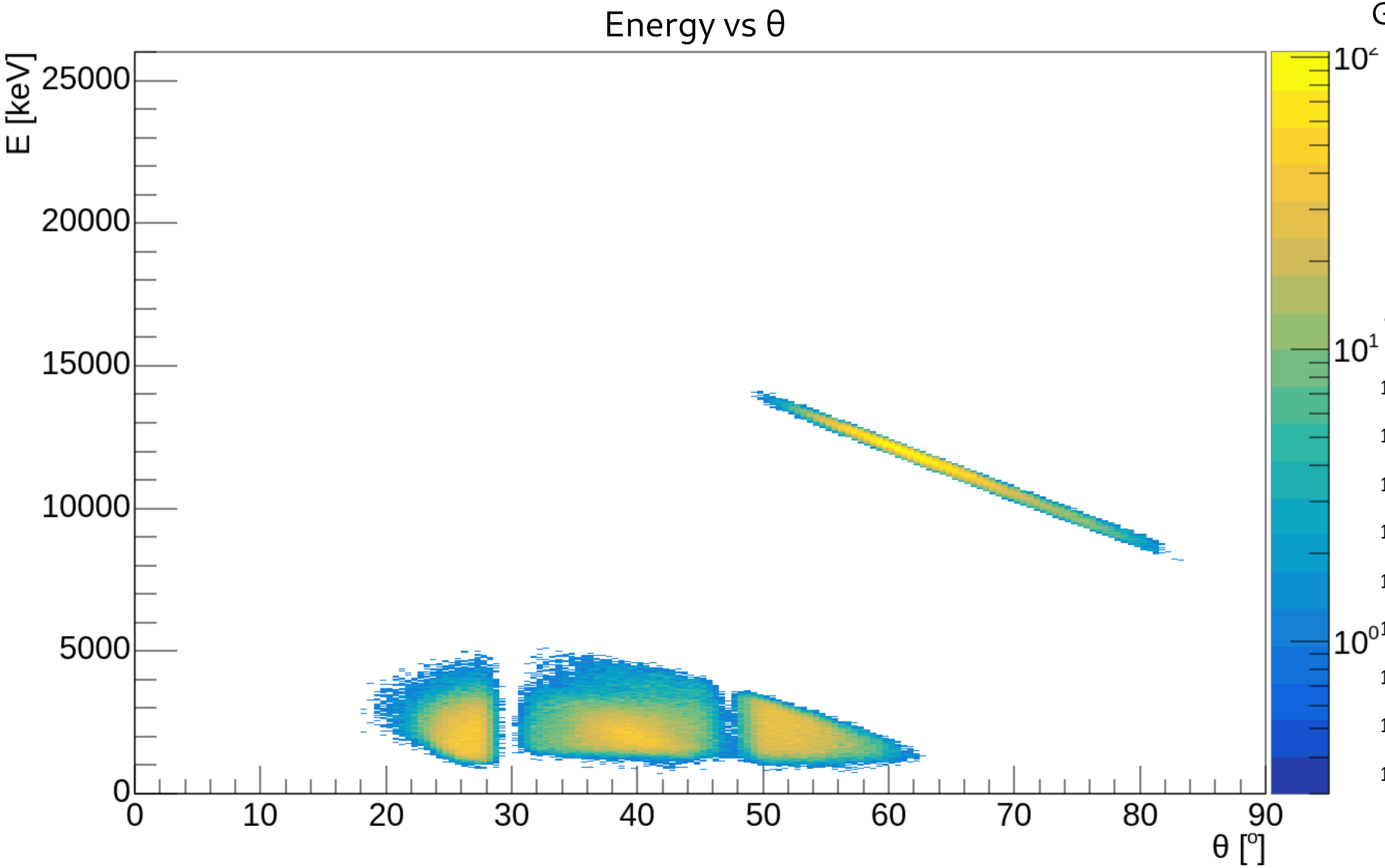

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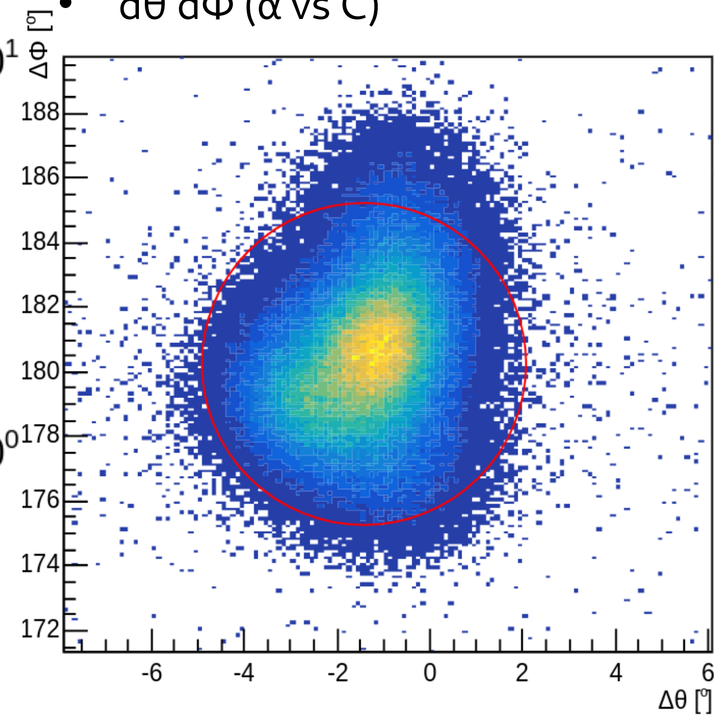
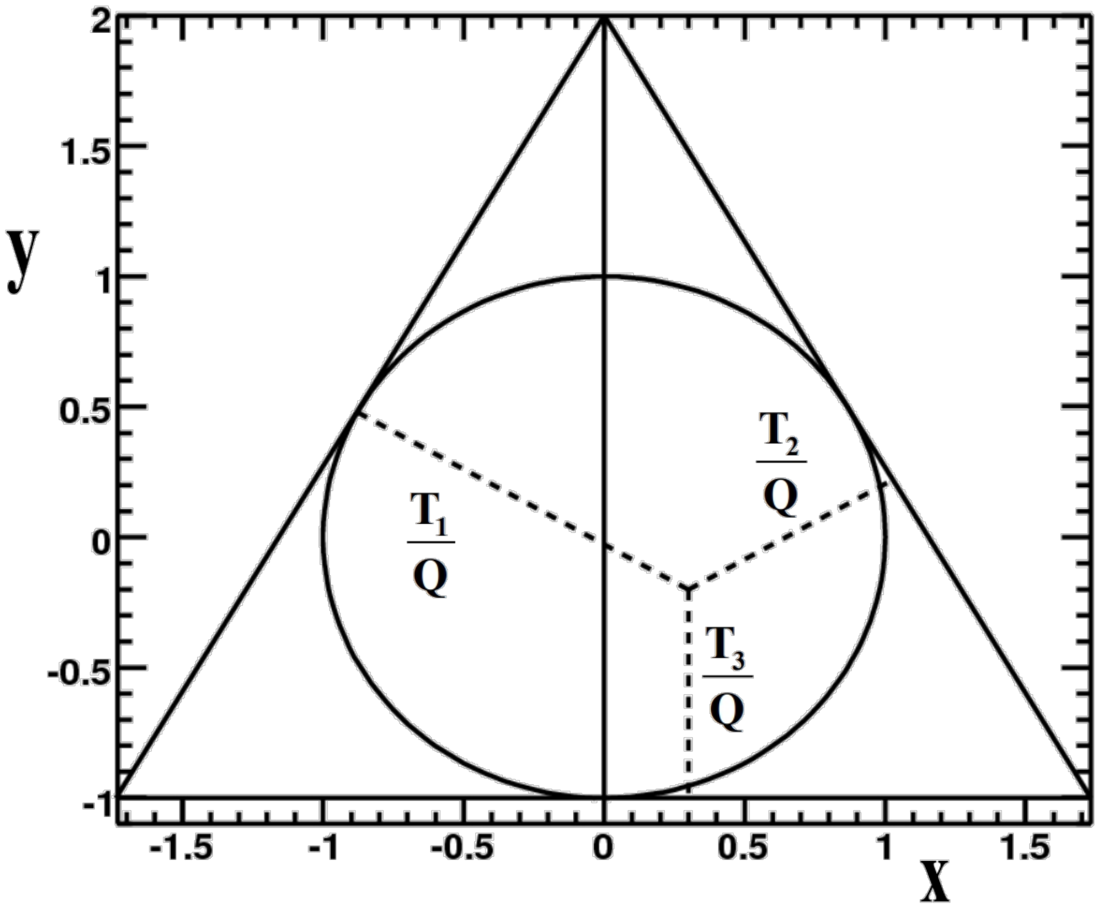
- dθ dΦ (α vs C)



Dalitz Plot Geometry

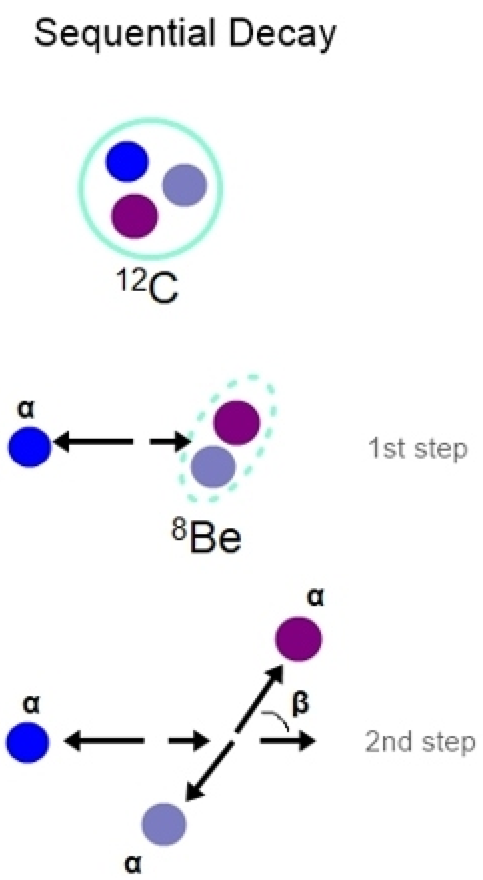


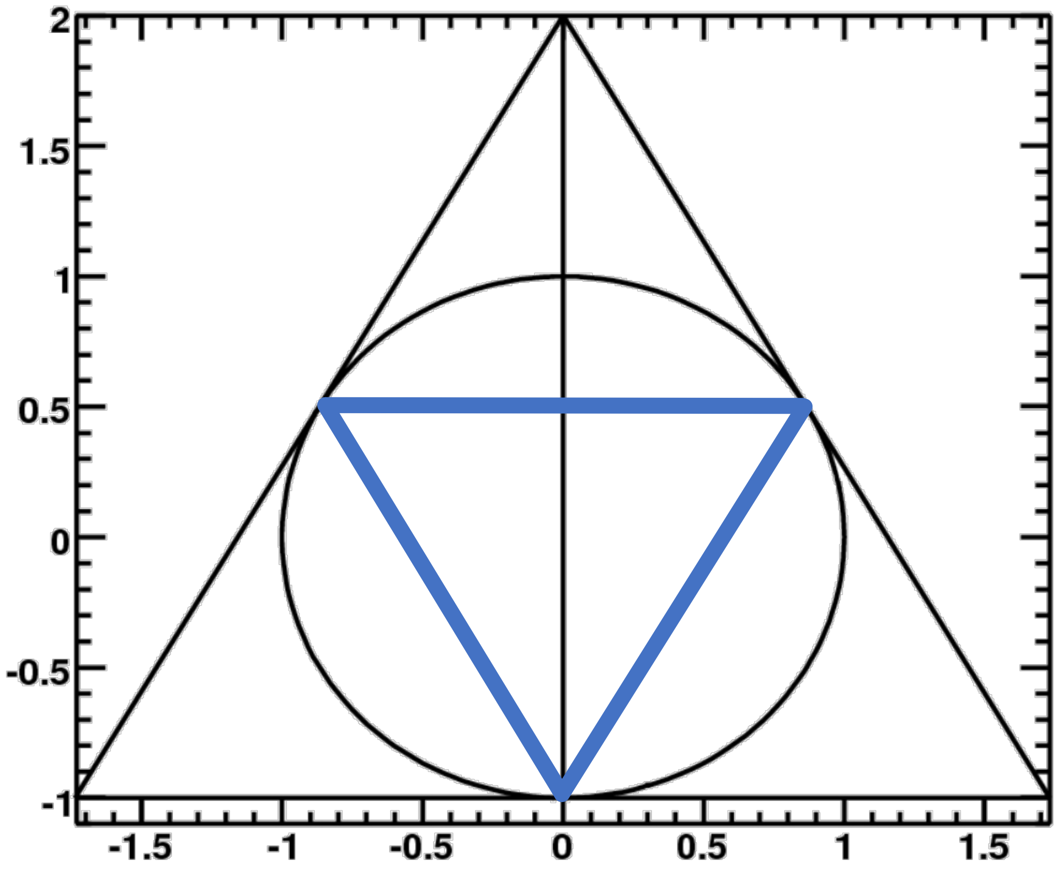
$X = (T_1 - T_2) / \sqrt{3}$

$Y = (2T_3 - T_1 - T_2) / 3$

Brian Lindquist, Dalitz Plots SASS Talk

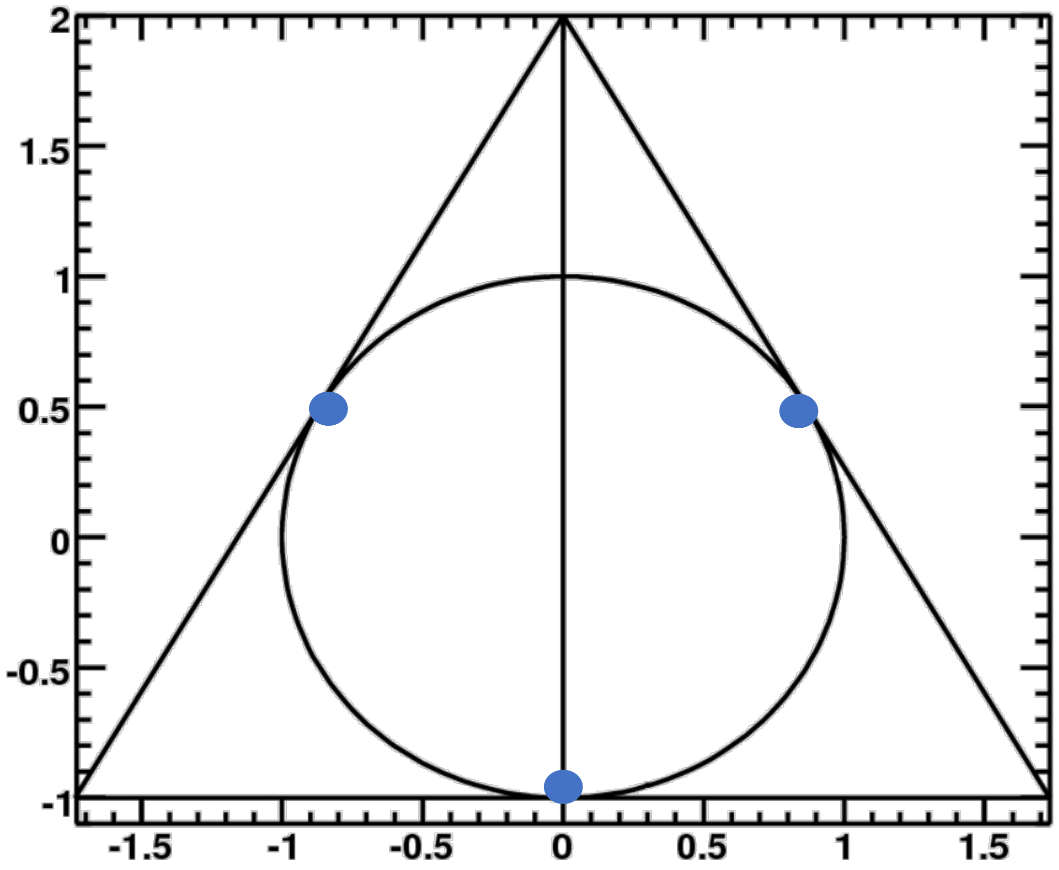
Dalitz Plot Geometry



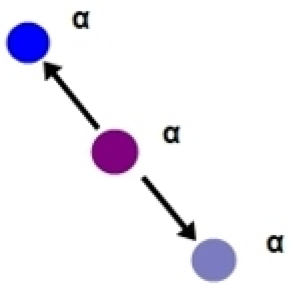


Dalitz Plot Geometry

Sequential Decay



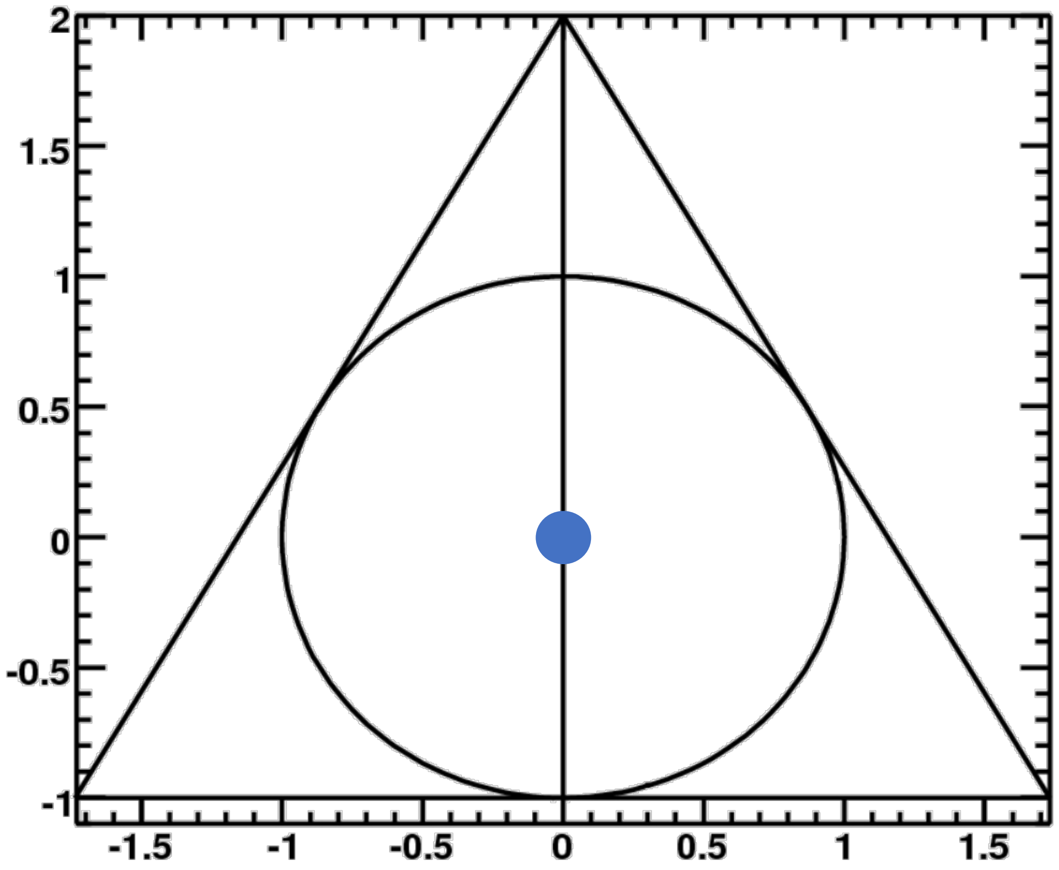
DDL

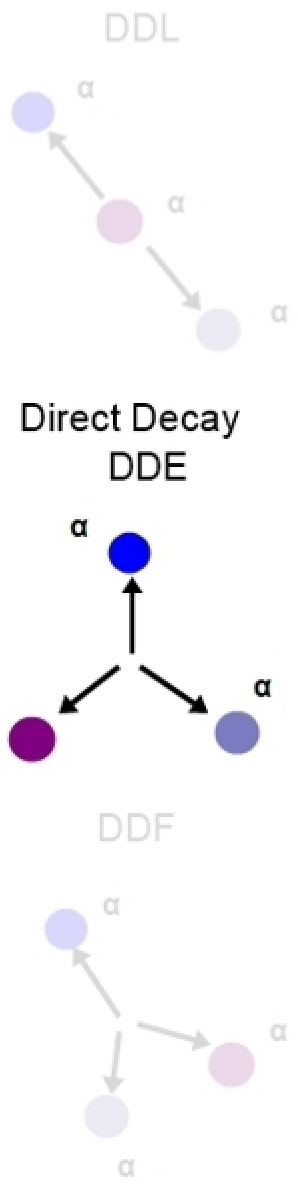


Direct Decay
DDE

Center of mass system

Dalitz Plot Geometry





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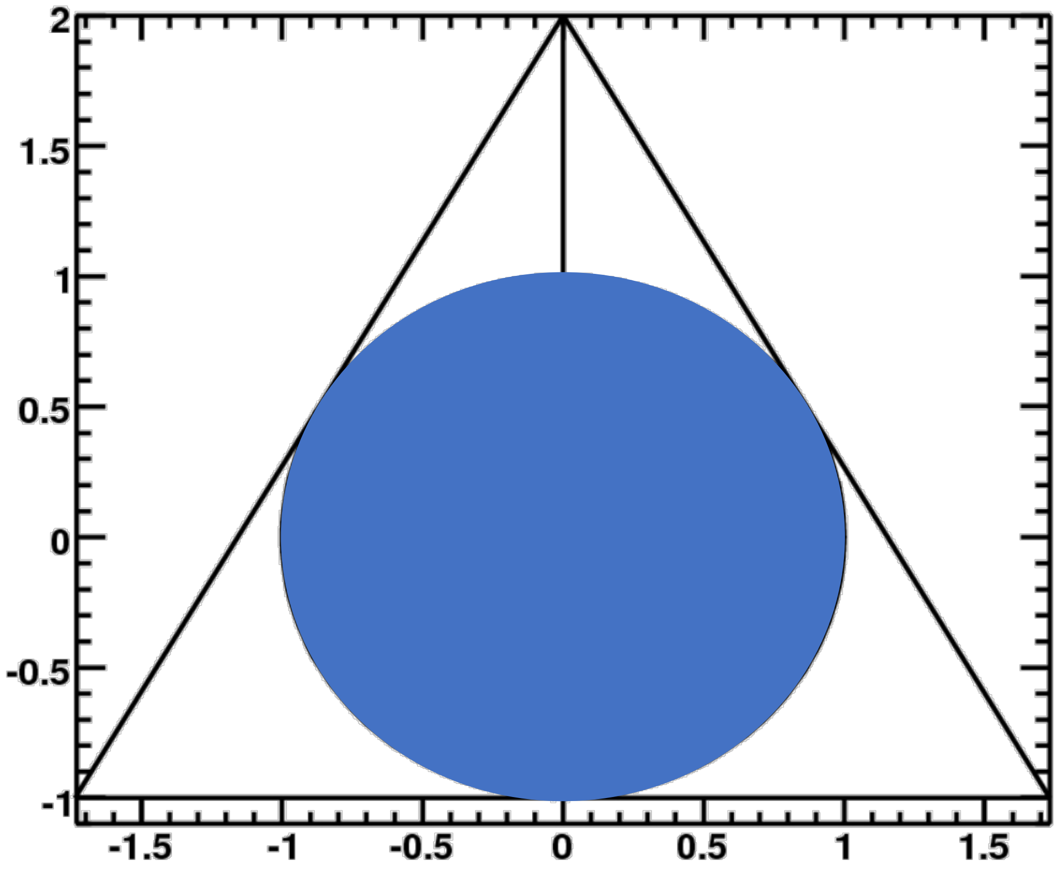
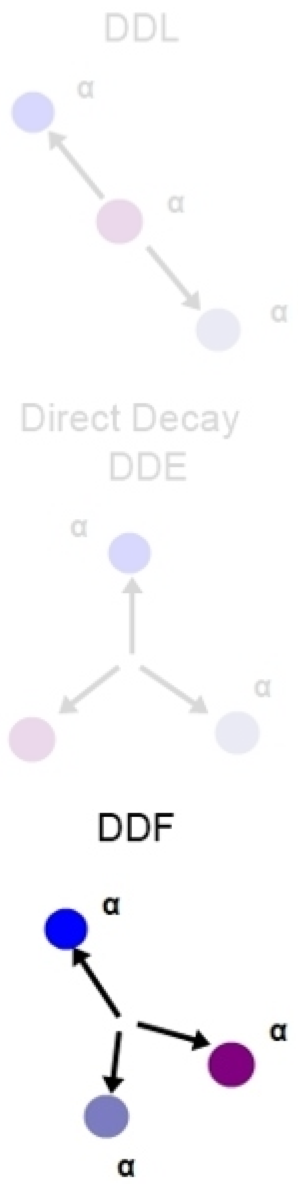
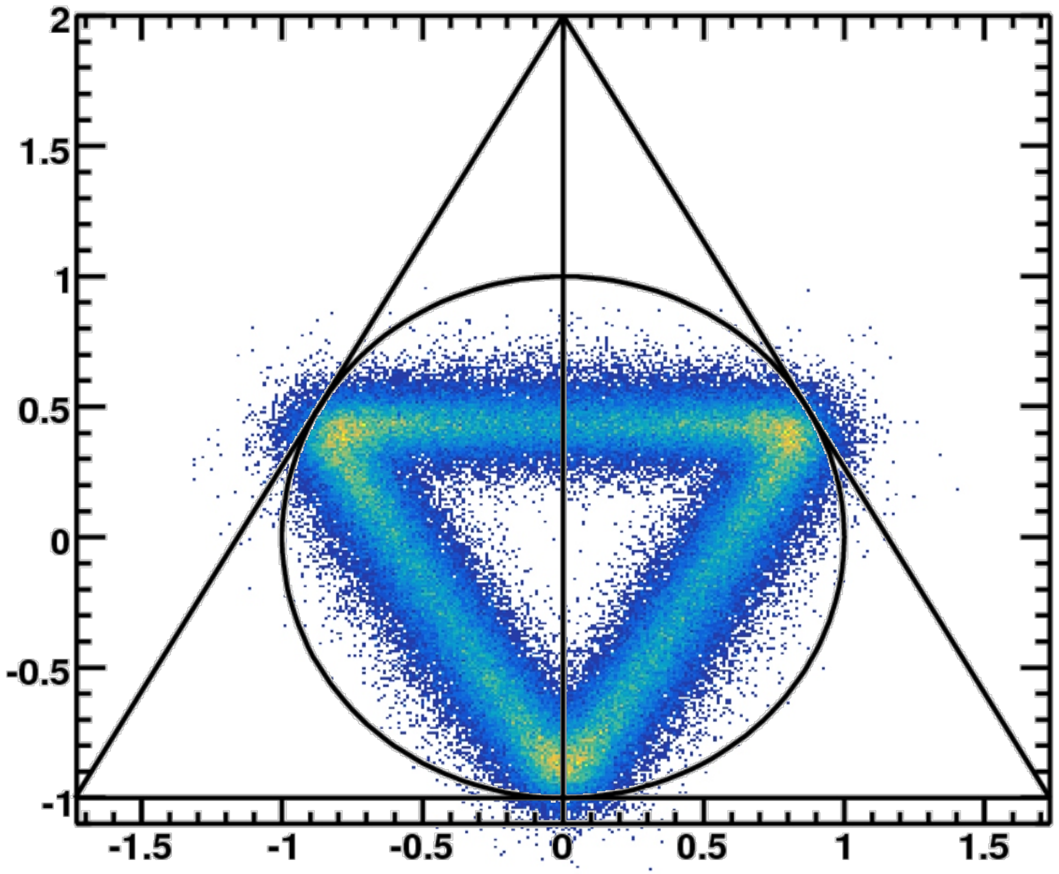
Dalitz Plot Geometry

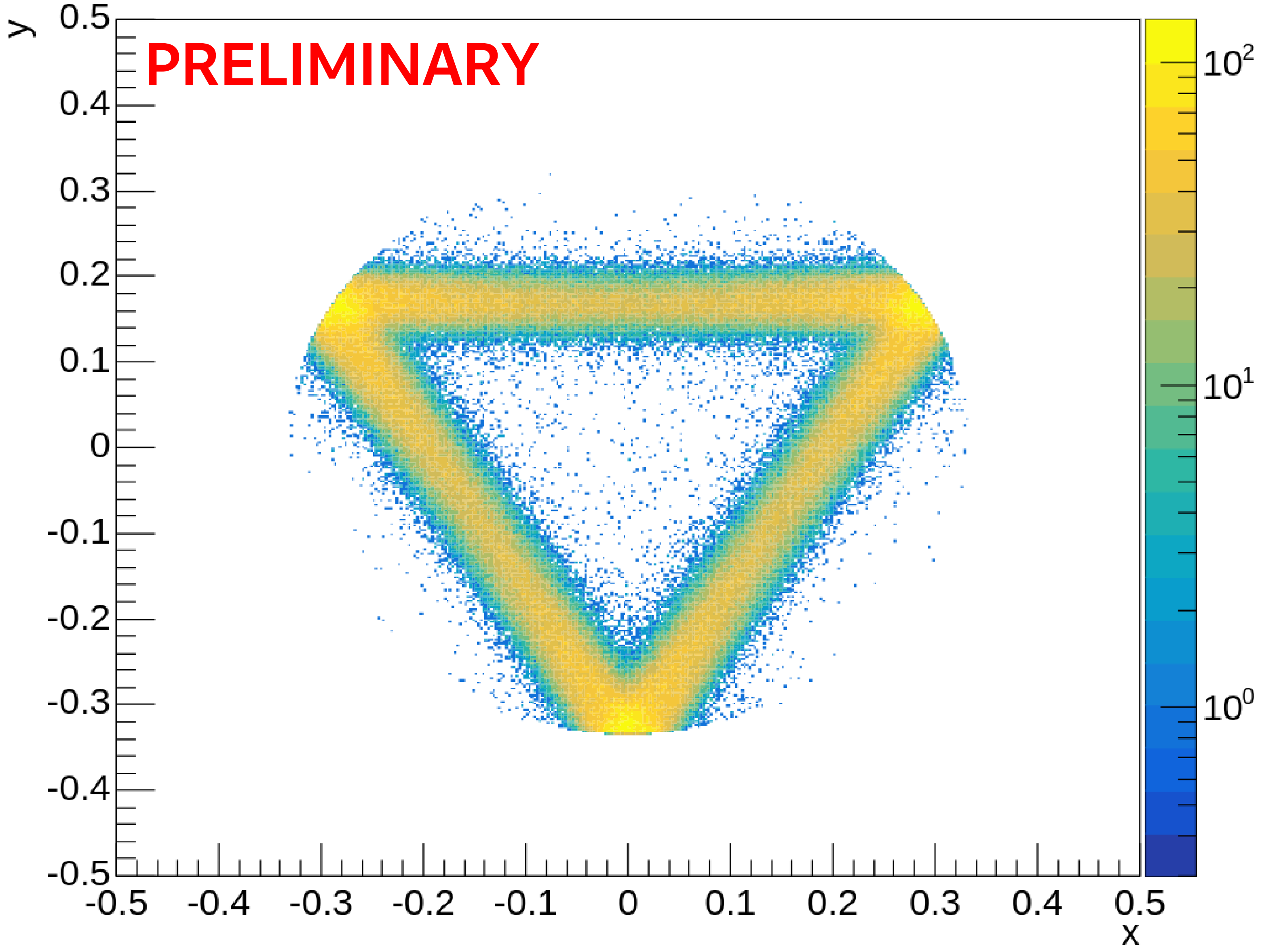




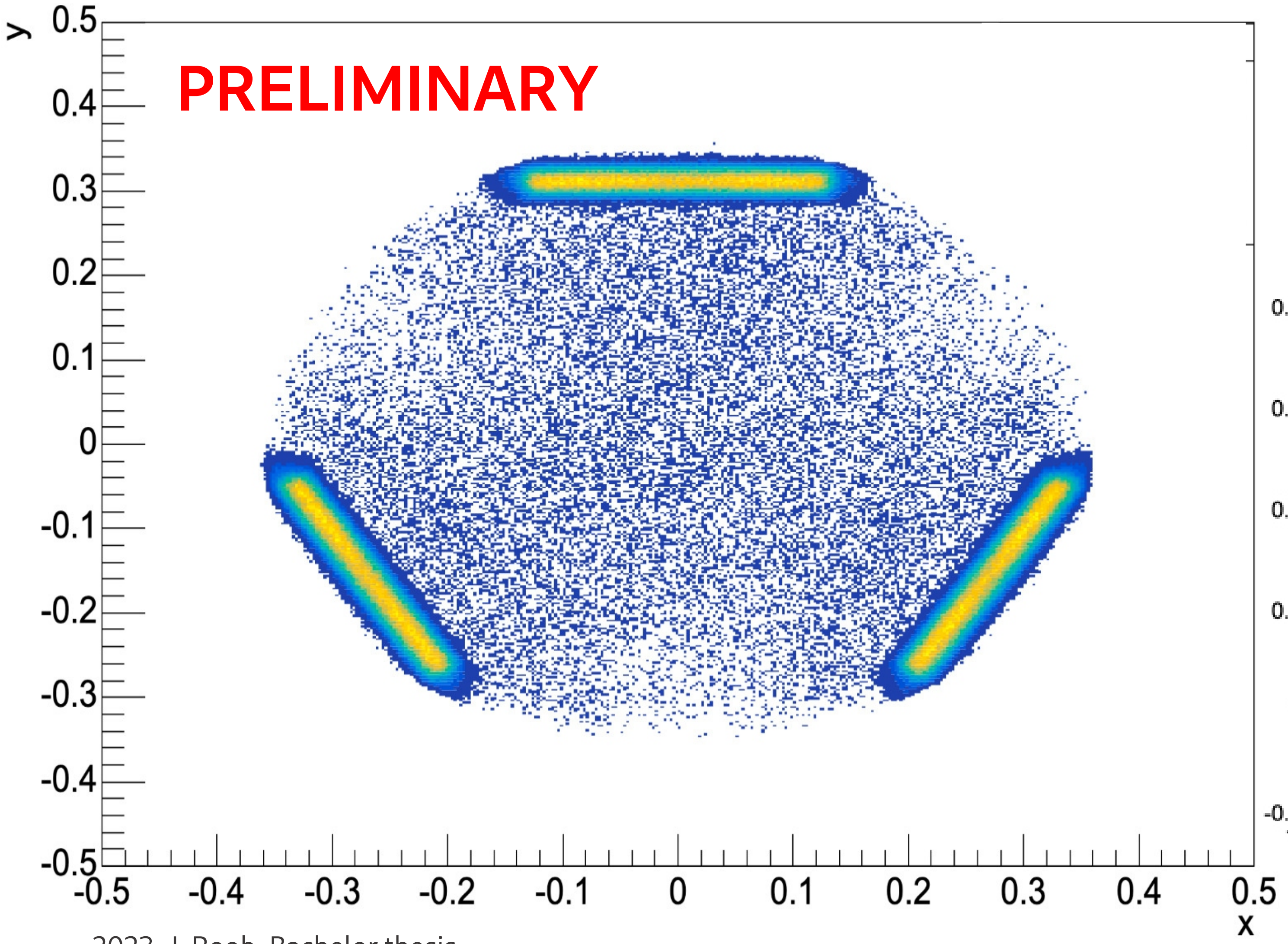
Center of mass system

Dalitz Plot Geometry

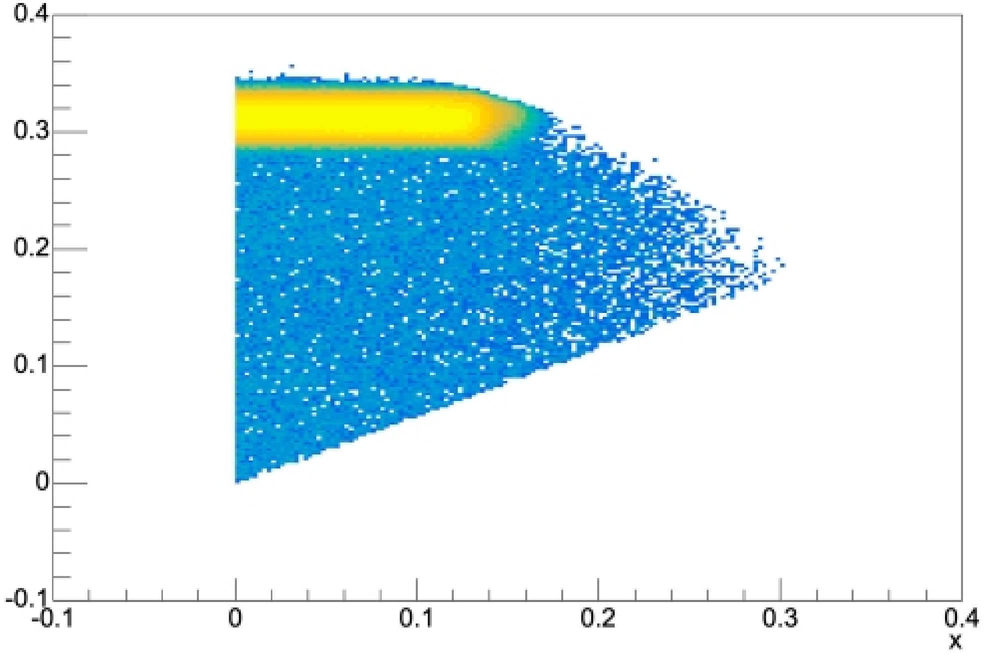




~ 10^6 Hoyle state events



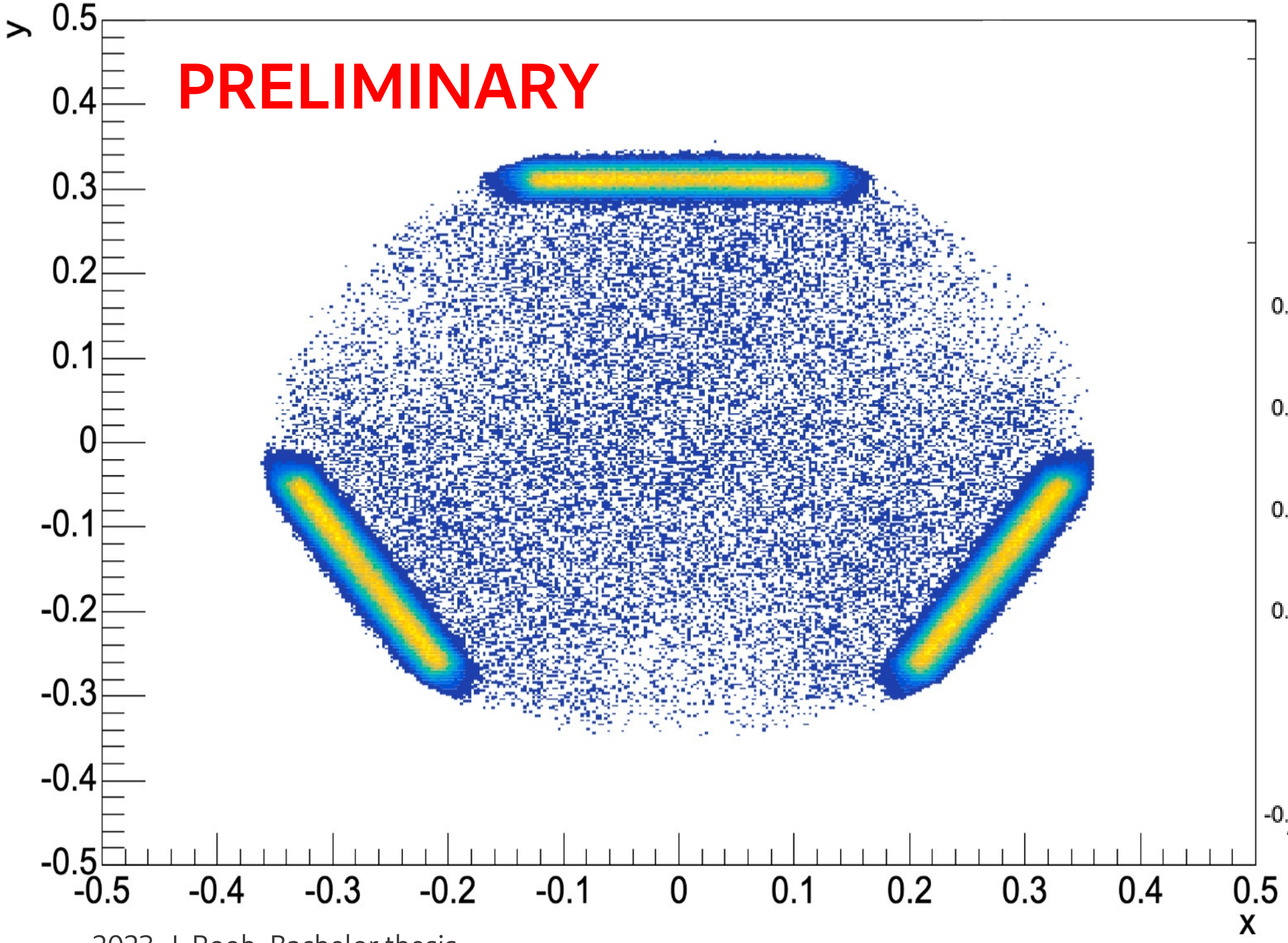
$3 \cdot 10^6$ events



2023, J. Roob, Bachelor thesis

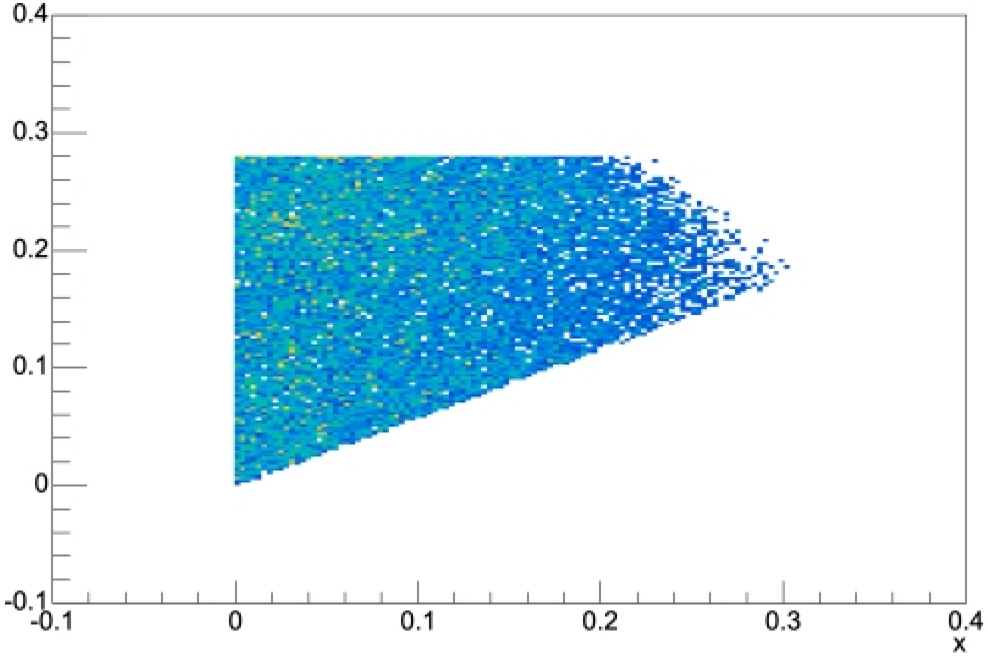
[1] 2008, R. Álvarez-Rodríguez, *et al.* Phys. Rev. C **77**, 064305

3^- state



$3 \cdot 10^6$ events

- 1.6% remaining after cut
- 4% theory prediction[1]



2023, J. Roob, Bachelor thesis

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Outlook

- Improve Dalitz plots
  - Enhance energy calibration
  - Kinematic fitting (over-specified)

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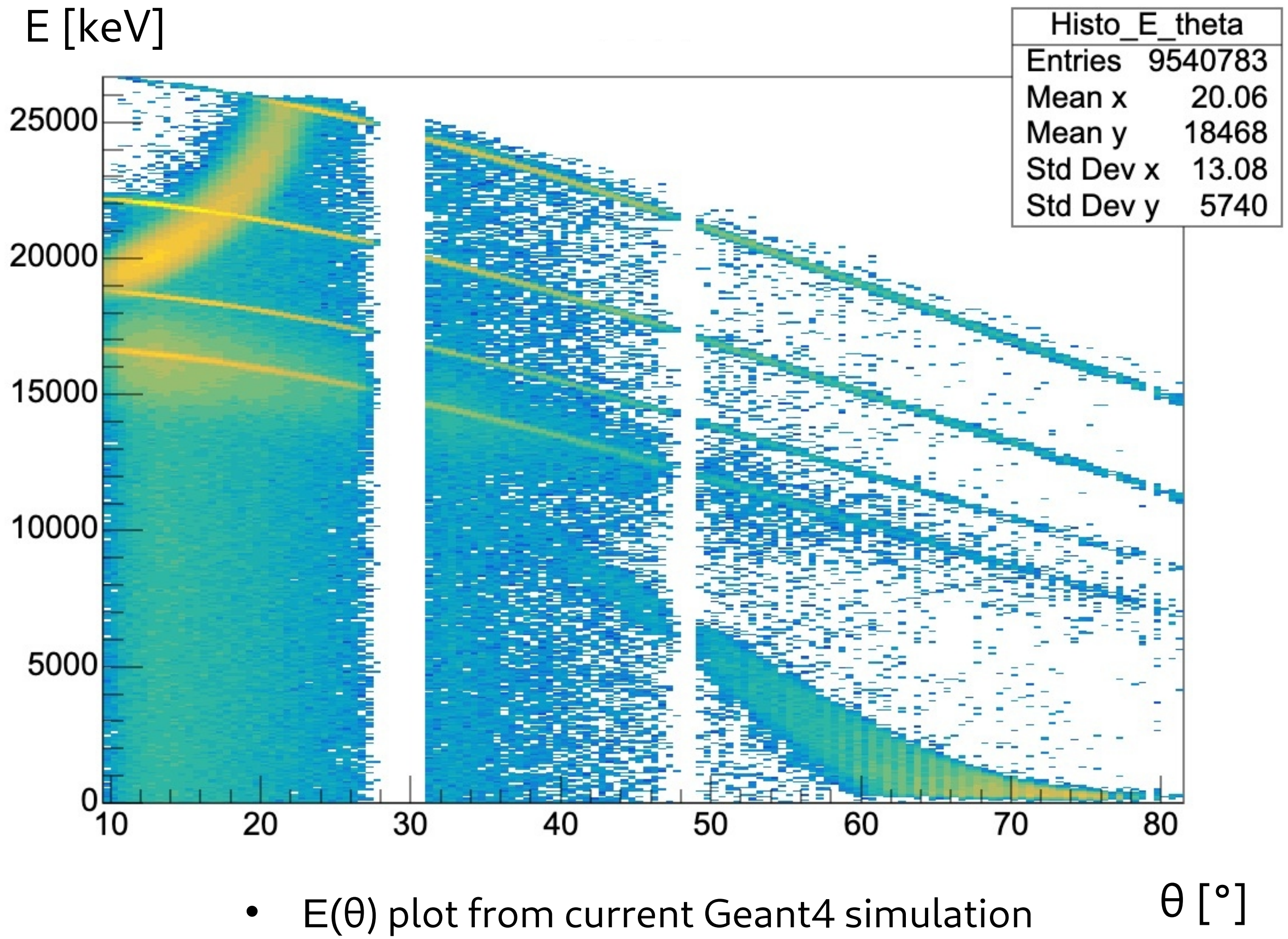
  - Kinematic fitting (over-specified)

- Comparison to MC simulation



- E(θ) plot from current Geant4 simulation

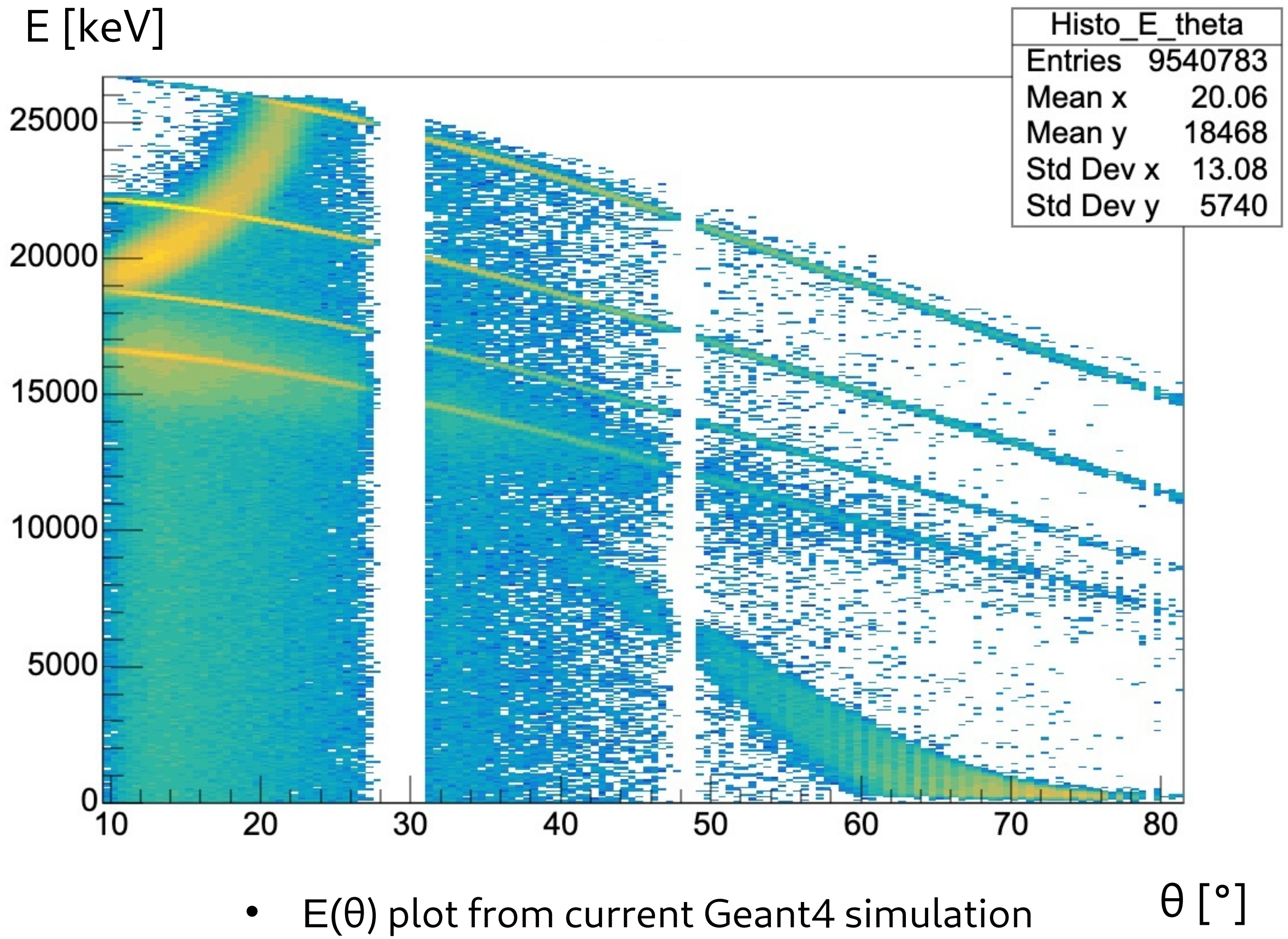
2023, T. Biesenbach, private communication

Outlook

- Improve Dalitz plots
  - Enhance energy calibration
  - Kinematic fitting (over-specified)

- Comparison to MC simulation

→ Extract branching ratios



- E(θ) plot from current Geant4 simulation

2023, T. Biesenbach, private communication

Thank you for your attention and to the collaboration

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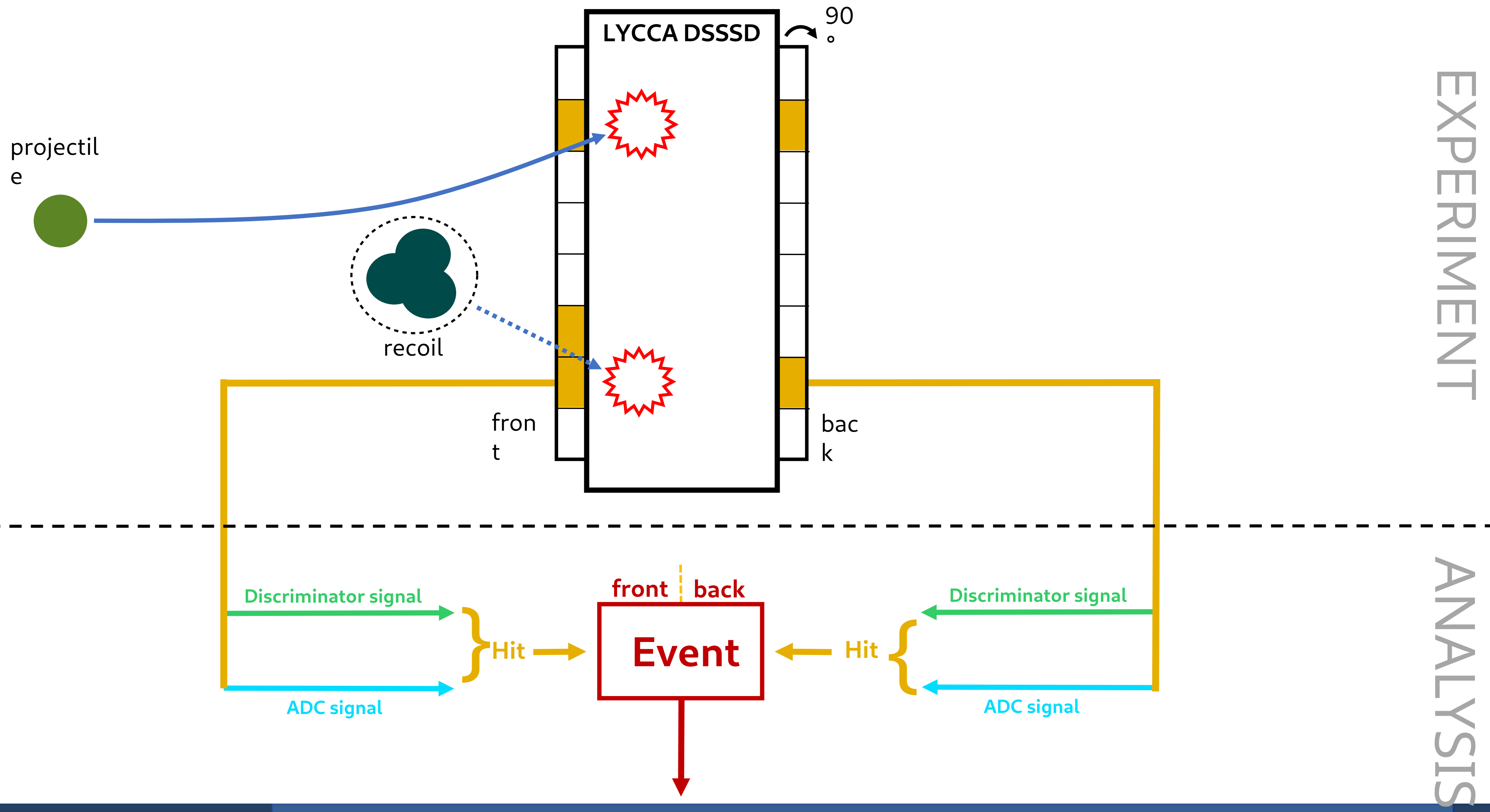
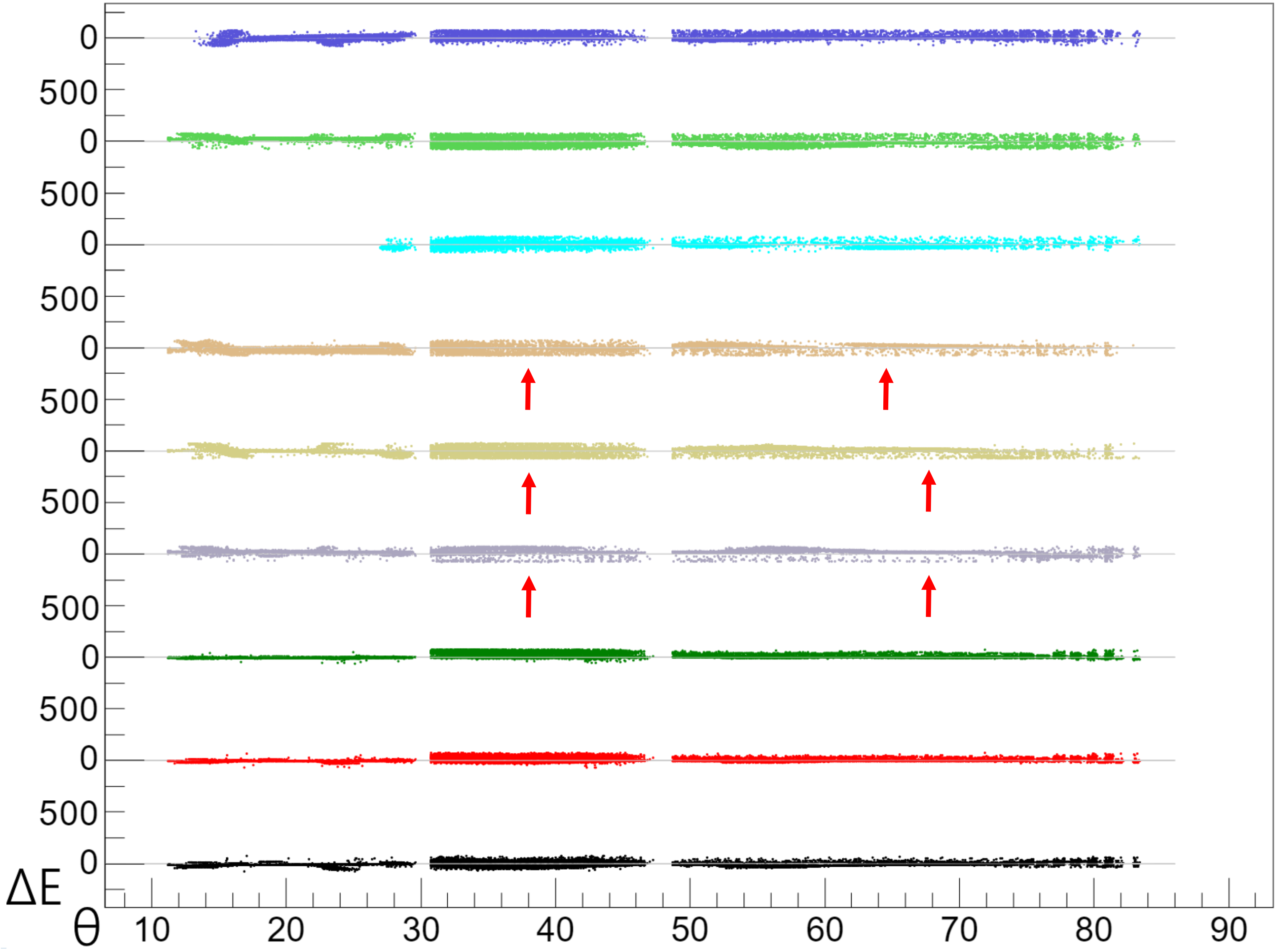
Backup

Detection & analysis pipeline



Calibration



C(α,α')C*
27 MeV

Au(α,α')Au'
8, 14, 20 MeV

3α source