Heavy Photon Search

Simulation, Electromagnetic Calorimeter, Muon Detector, and Trigger

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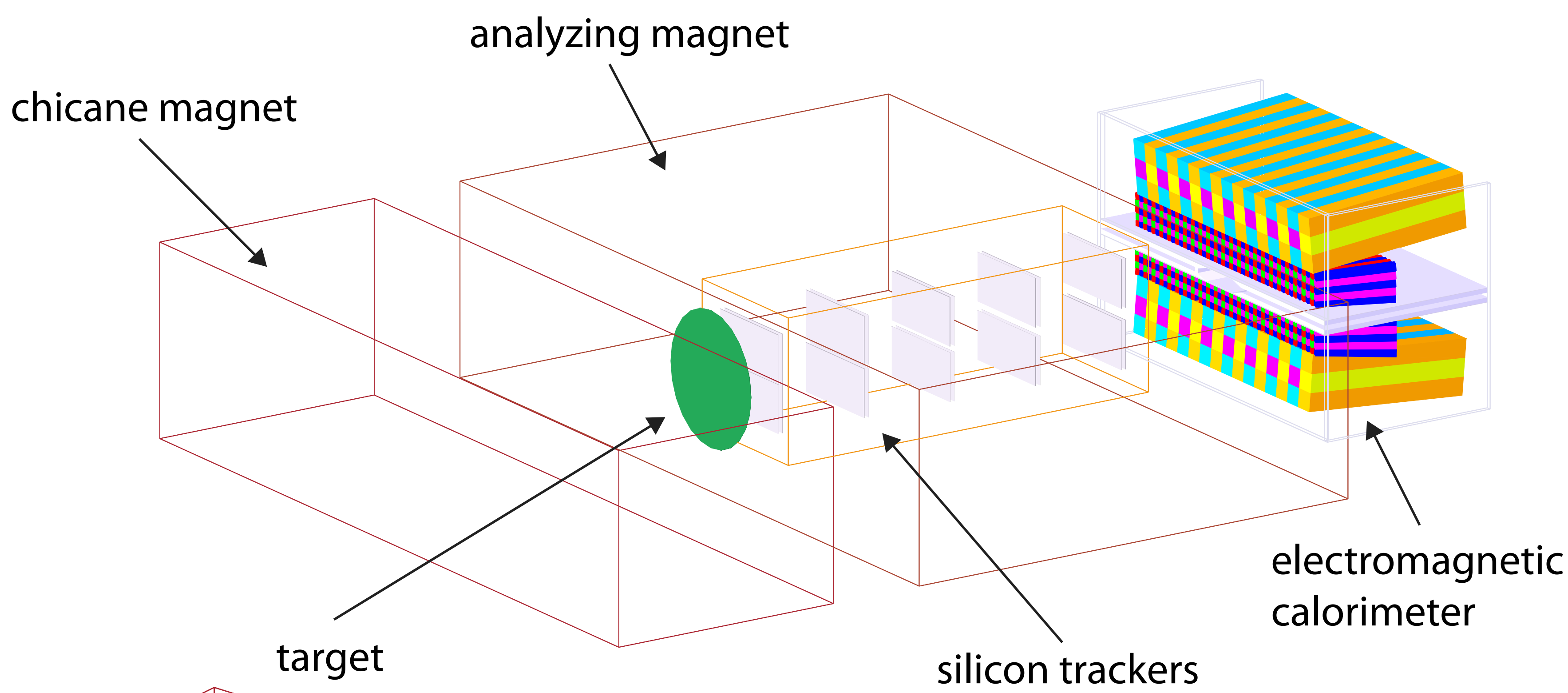
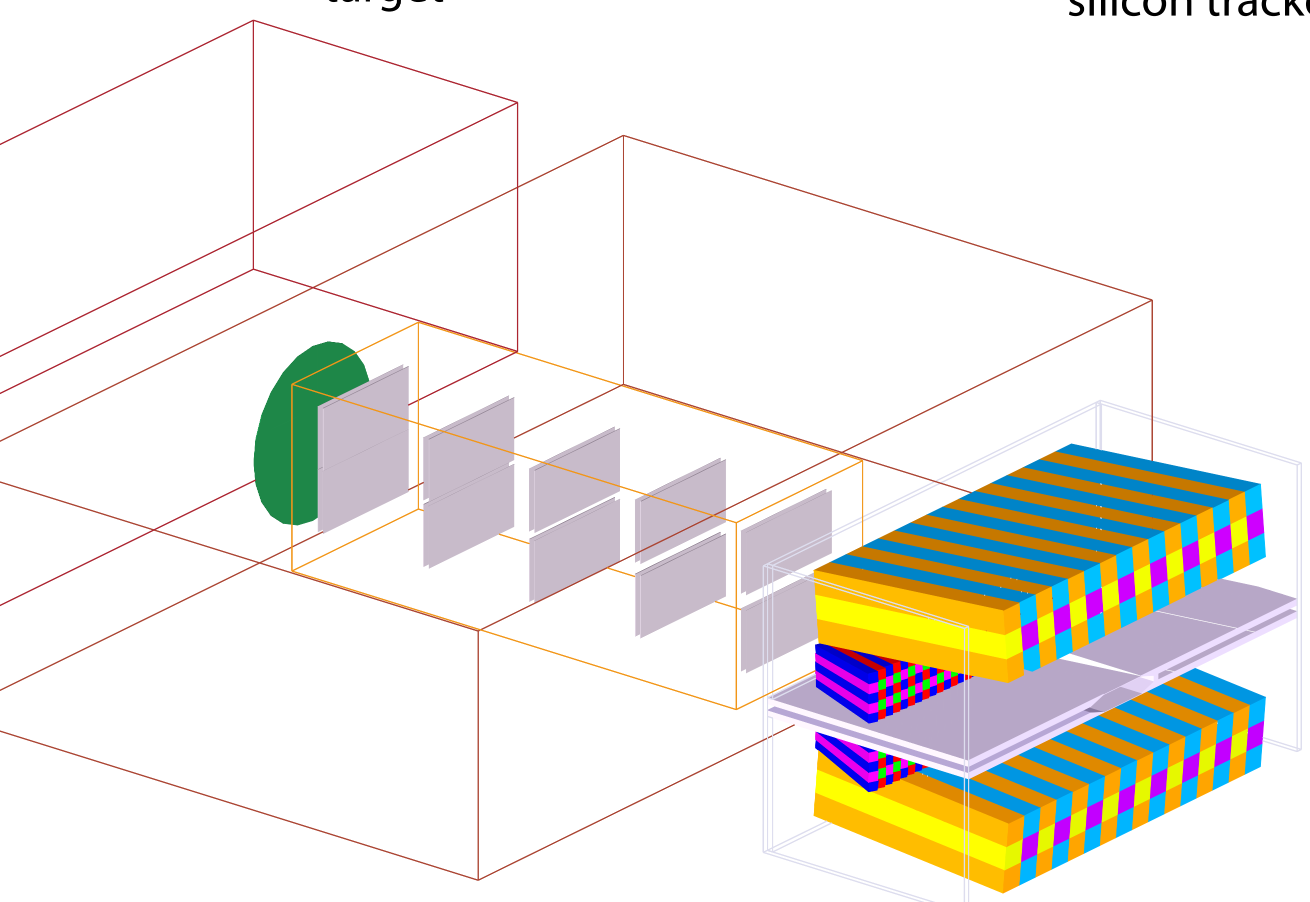
for the HPS Collaboration.

GEANT 4 Simulation

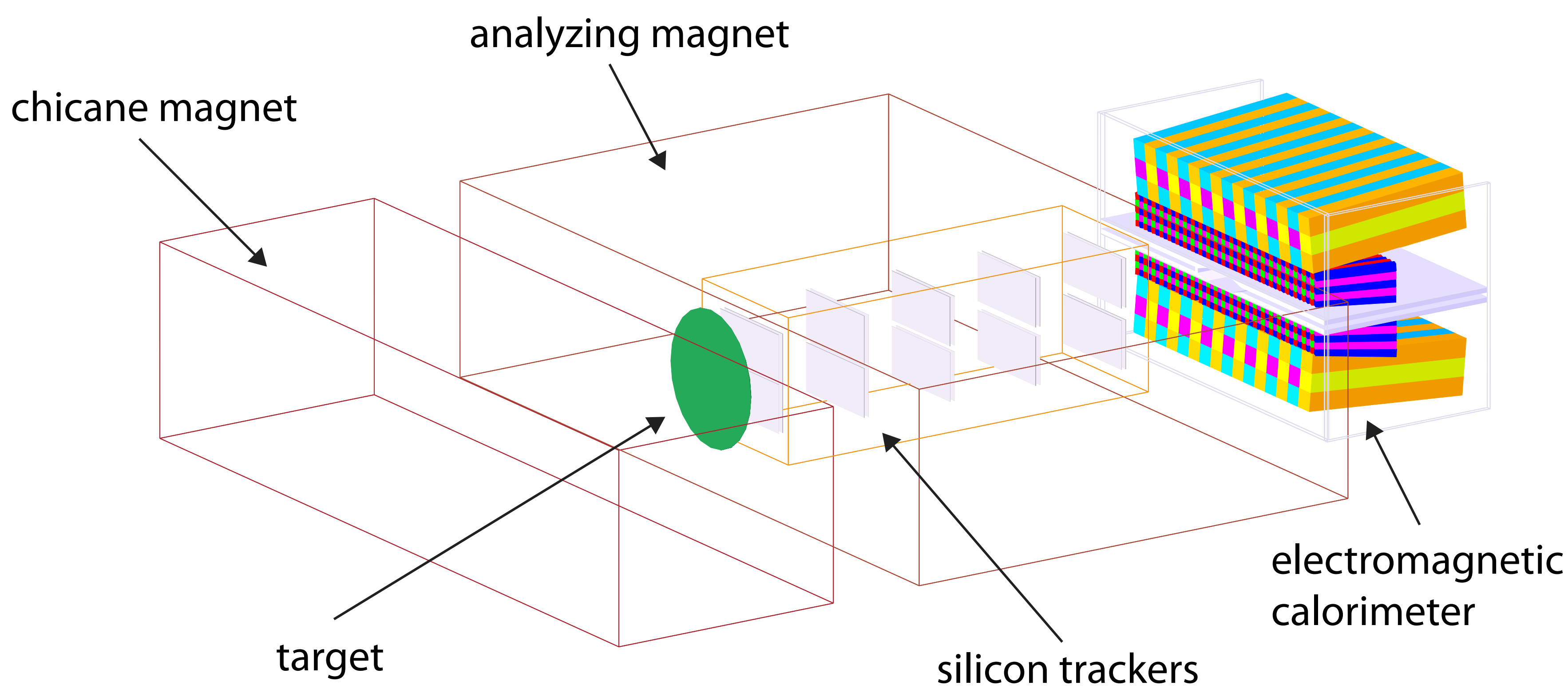




Full simulation of the experiment implemented in GEANT4:

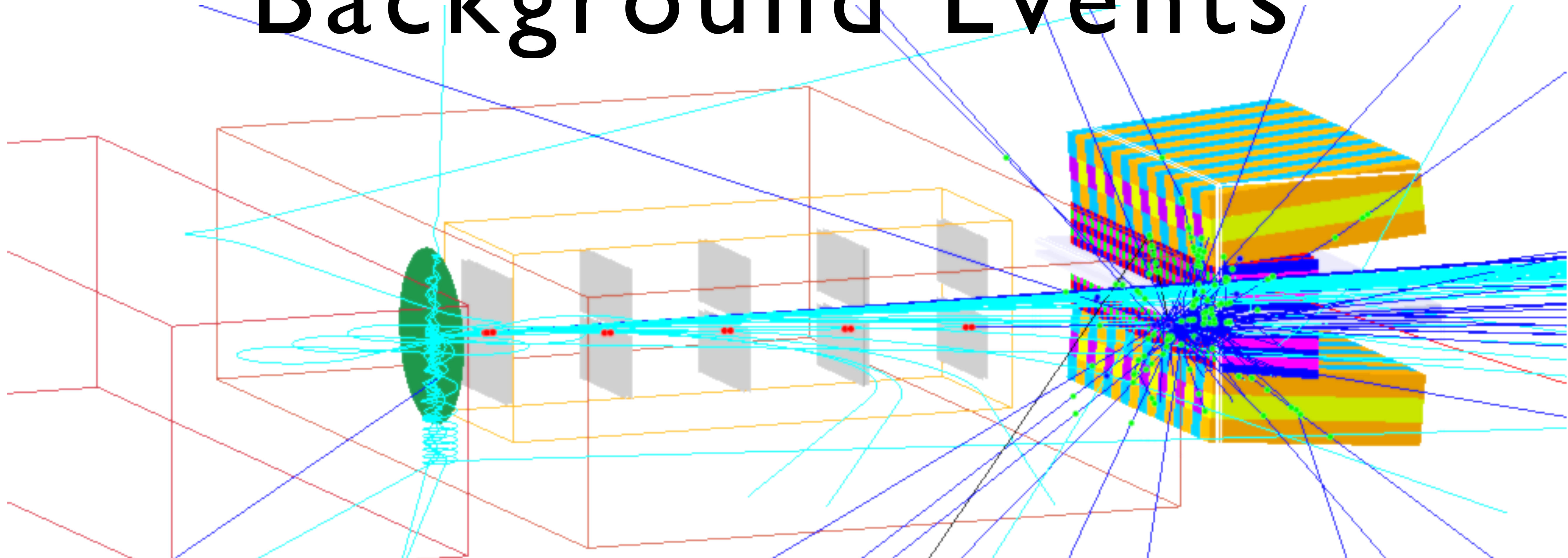
- Based on CLAS12 simulation (gemc)
- Flexible geometry from database allows for rapid prototyping.
- Full GEANT4 physics model.
- A' events from generator (MadEvent)
- Background from electrons through target.

GEANT 4 Simulation



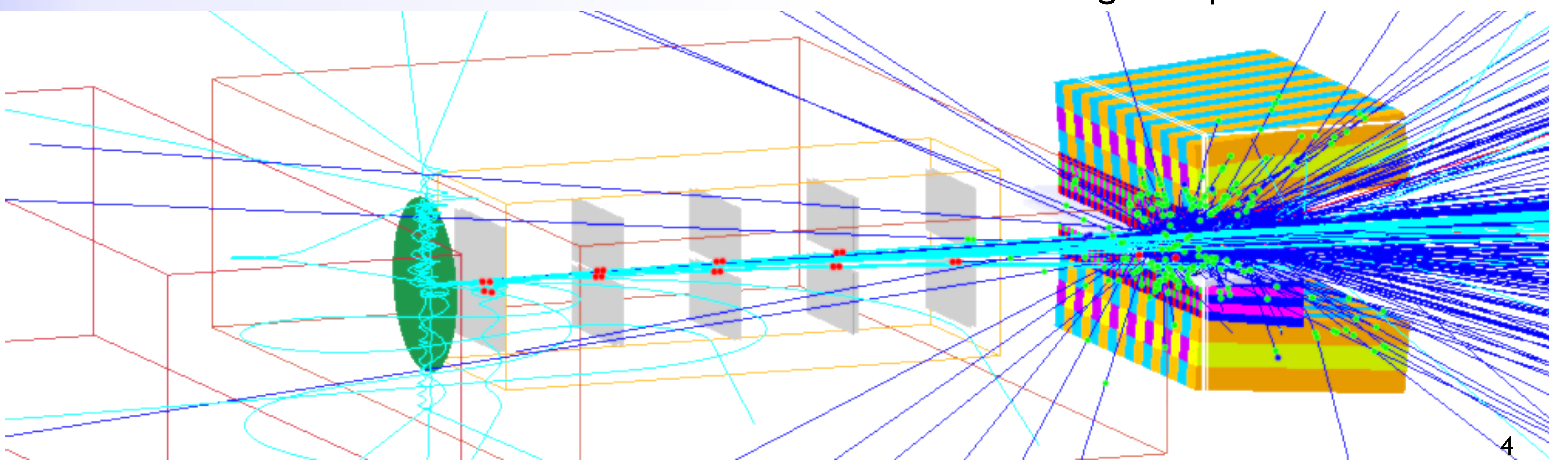
Magnets: 1 T uniform field
Target: 0.25% X_0 Tungsten (9 μm)
Silicon trackers: 320 μm silicon, not segmented.
±15 mrad dead-zone
Calorimeter: hybrid design

Background Events

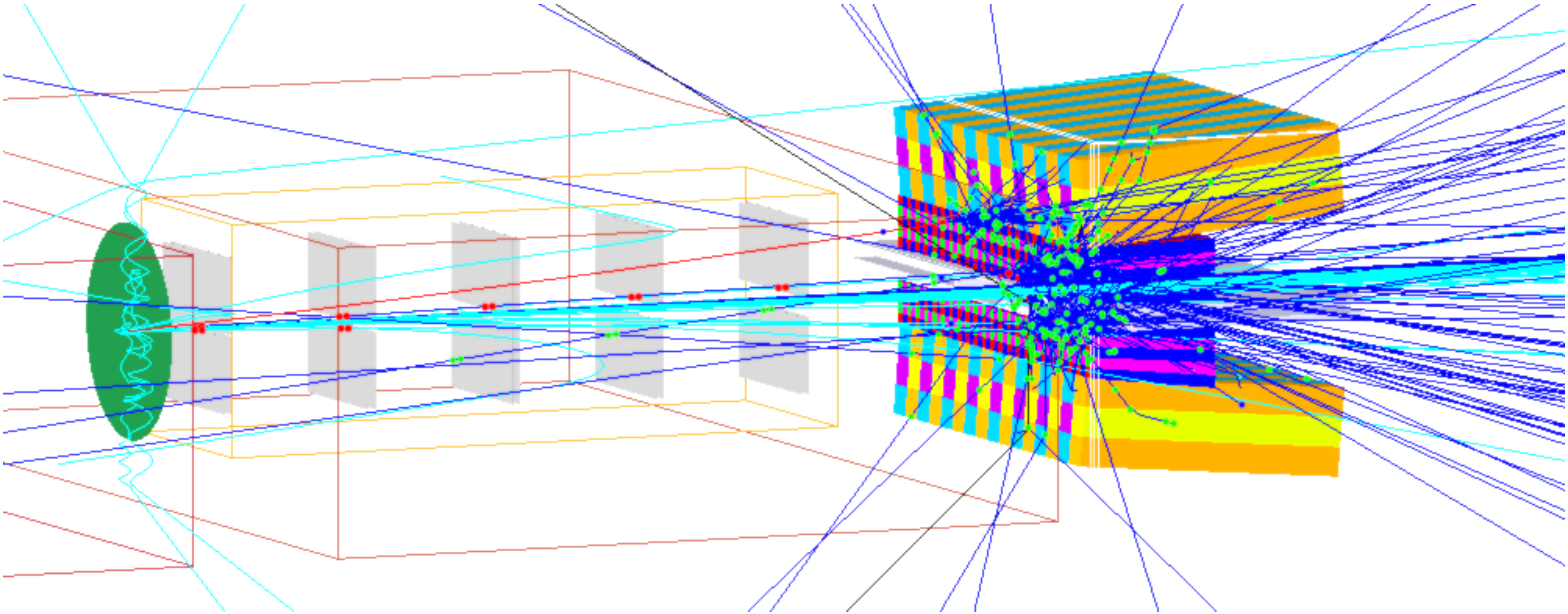


400 nA = 10000 e- in 4 ns (2 beam bunches)
2 events shown with accidental hits.

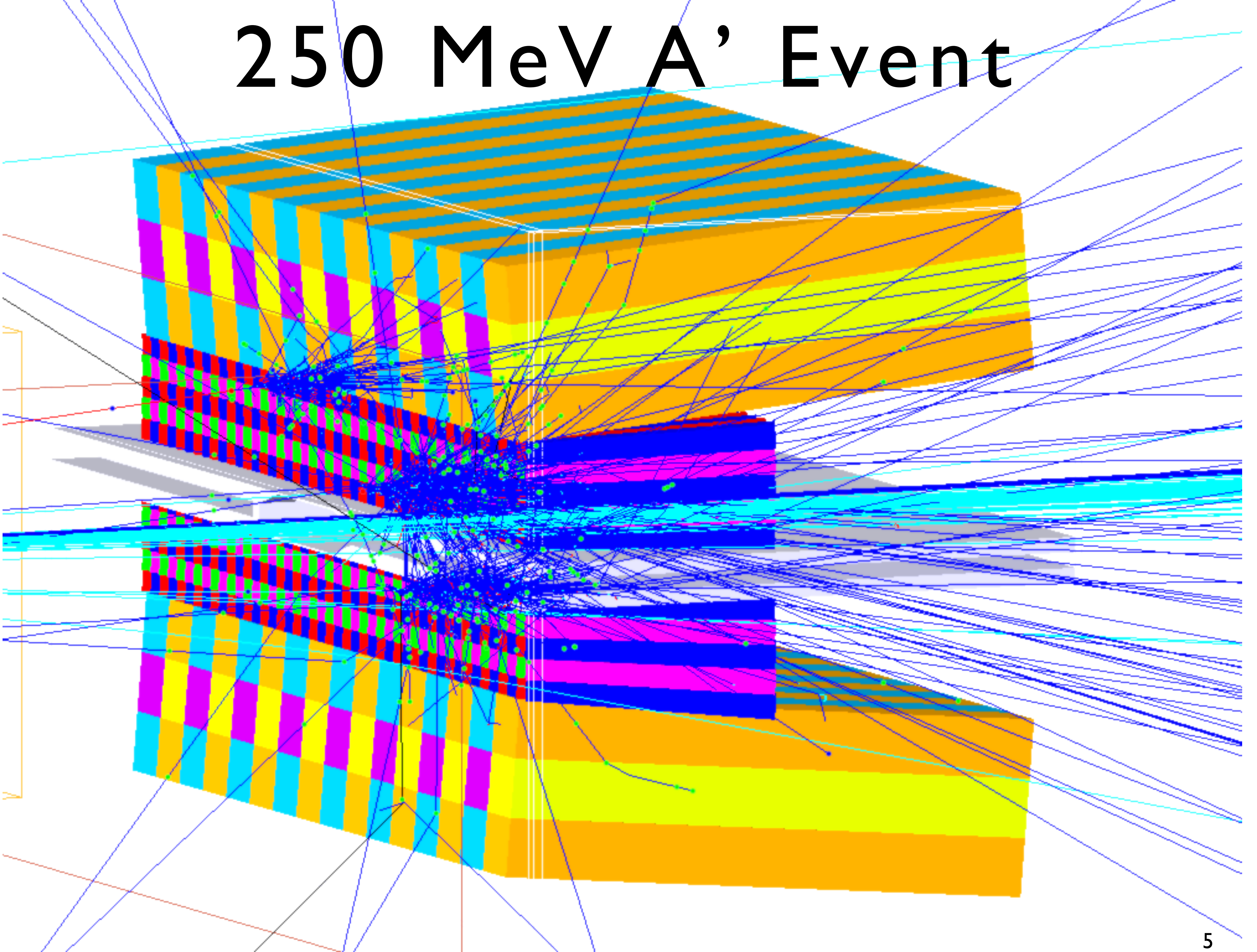
Longer times can be simulated by adding multiple 4 ns events.



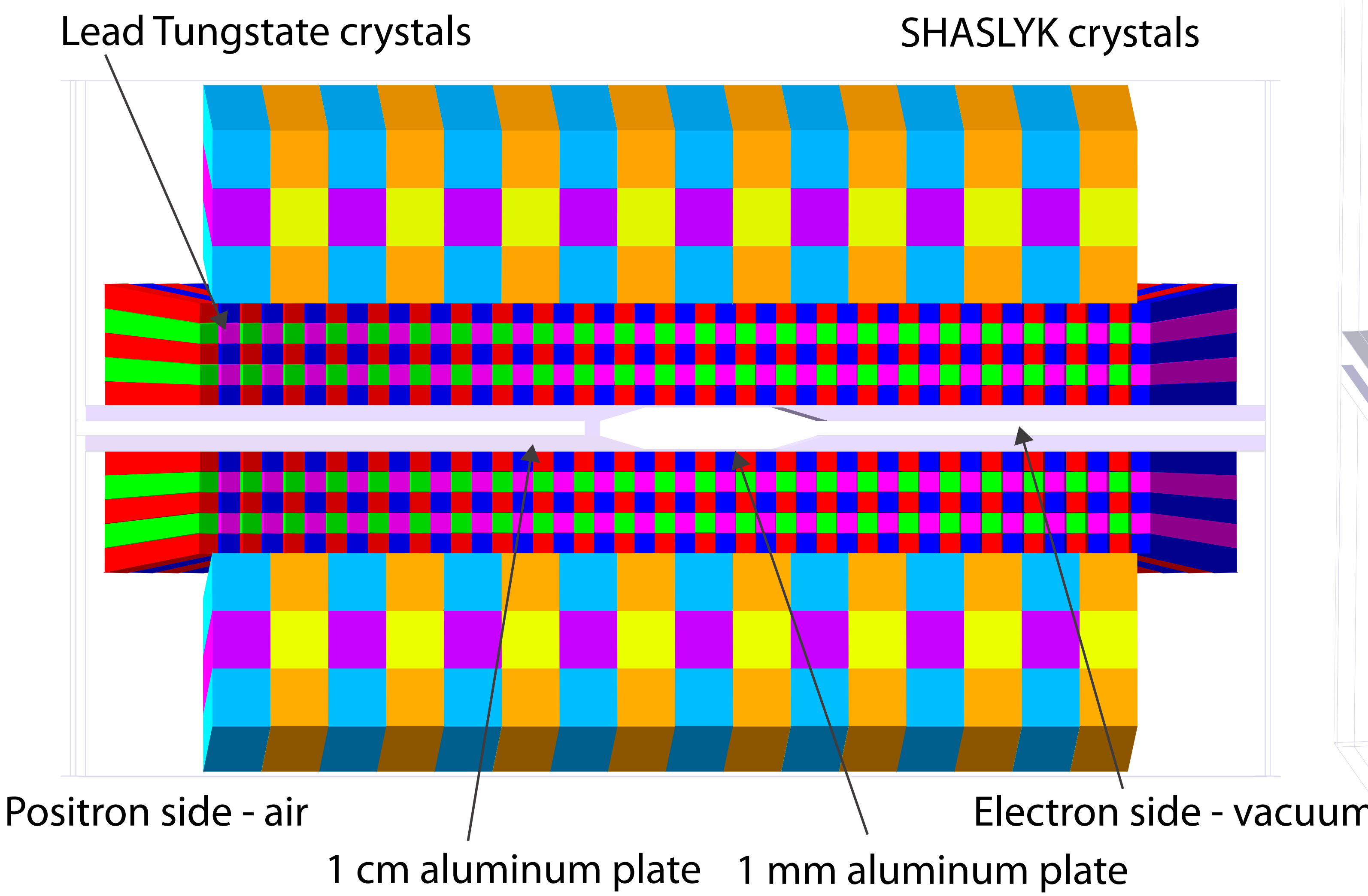
250 MeV A’ Event

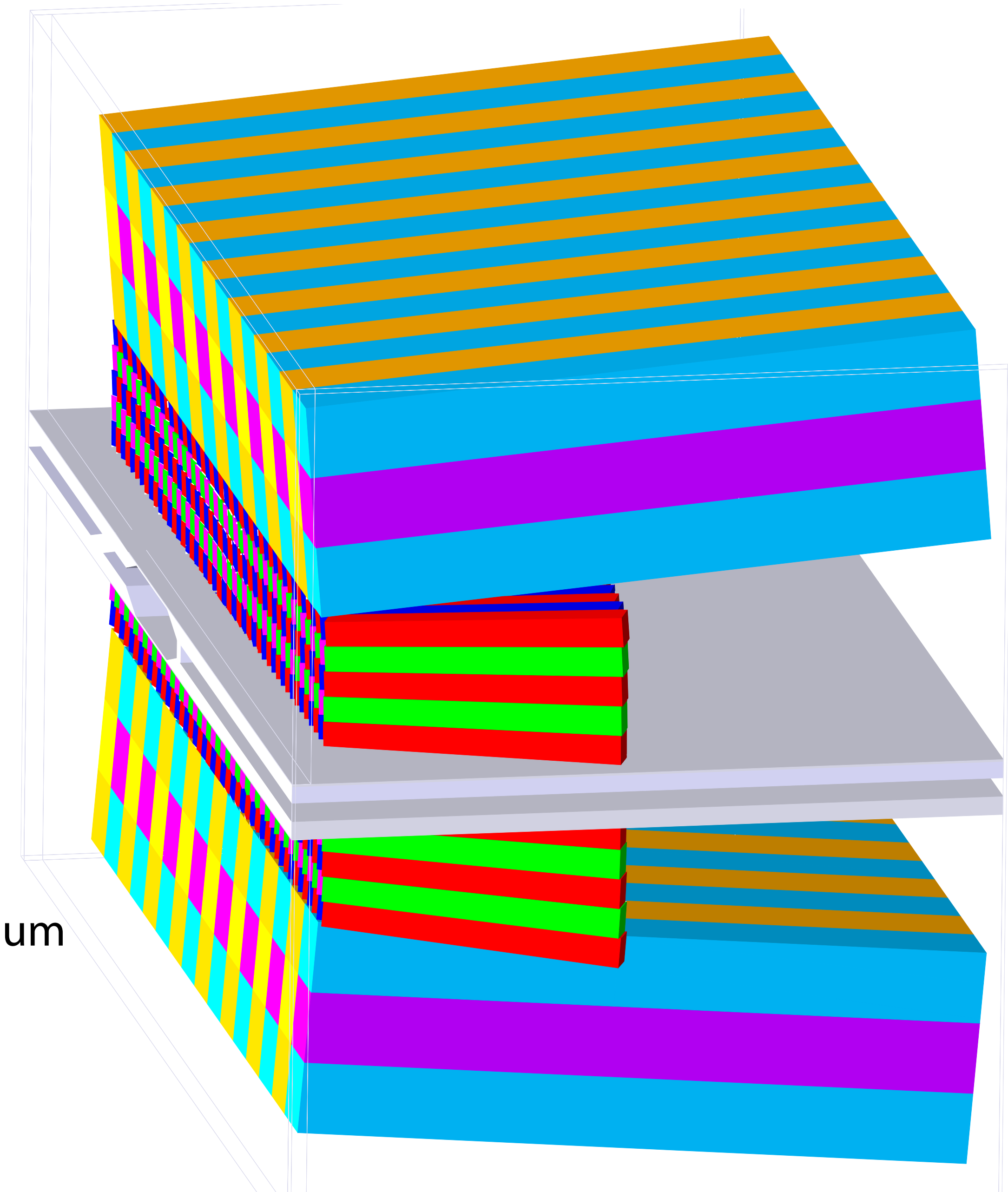


250 MeV A' Event



Hybrid Calorimeter



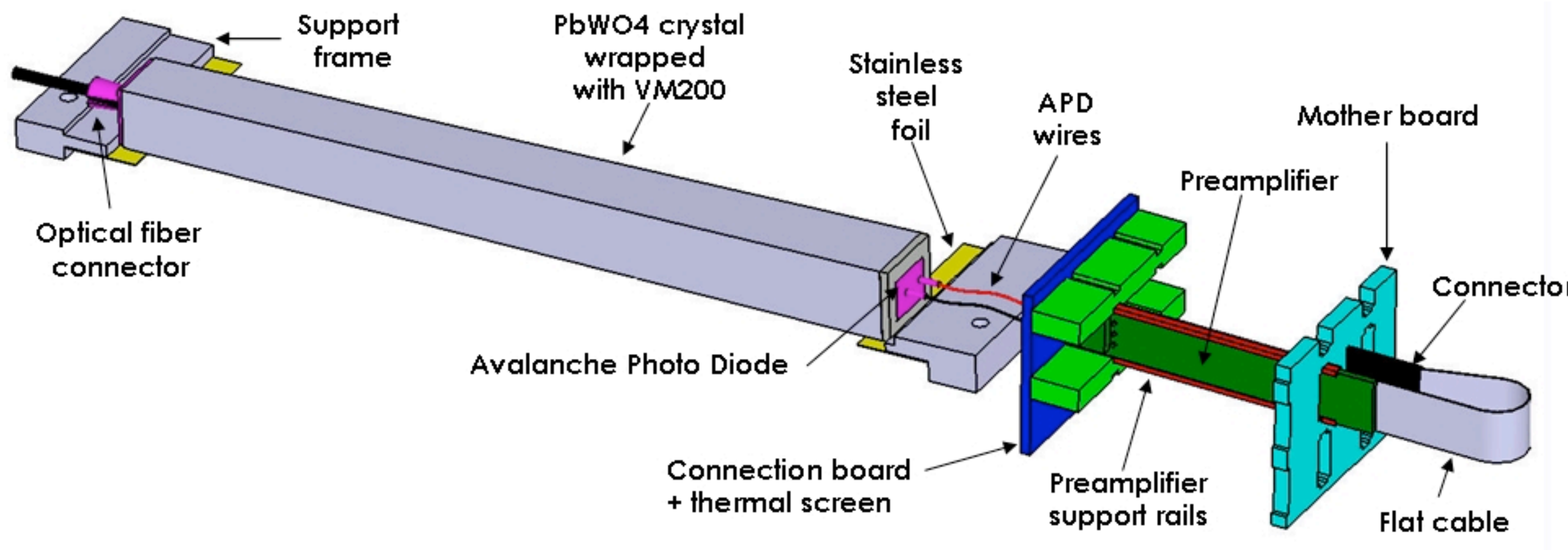


Design criteria: highest acceptance with readily available crystals, low background.

Vacuum box: 1 cm aluminum plate with cutout area for beam.
5 rows of 46 lead-tungstate crystals, total: 460
3 rows of 16 lead-glass or Shashlyk crystals, total: 96

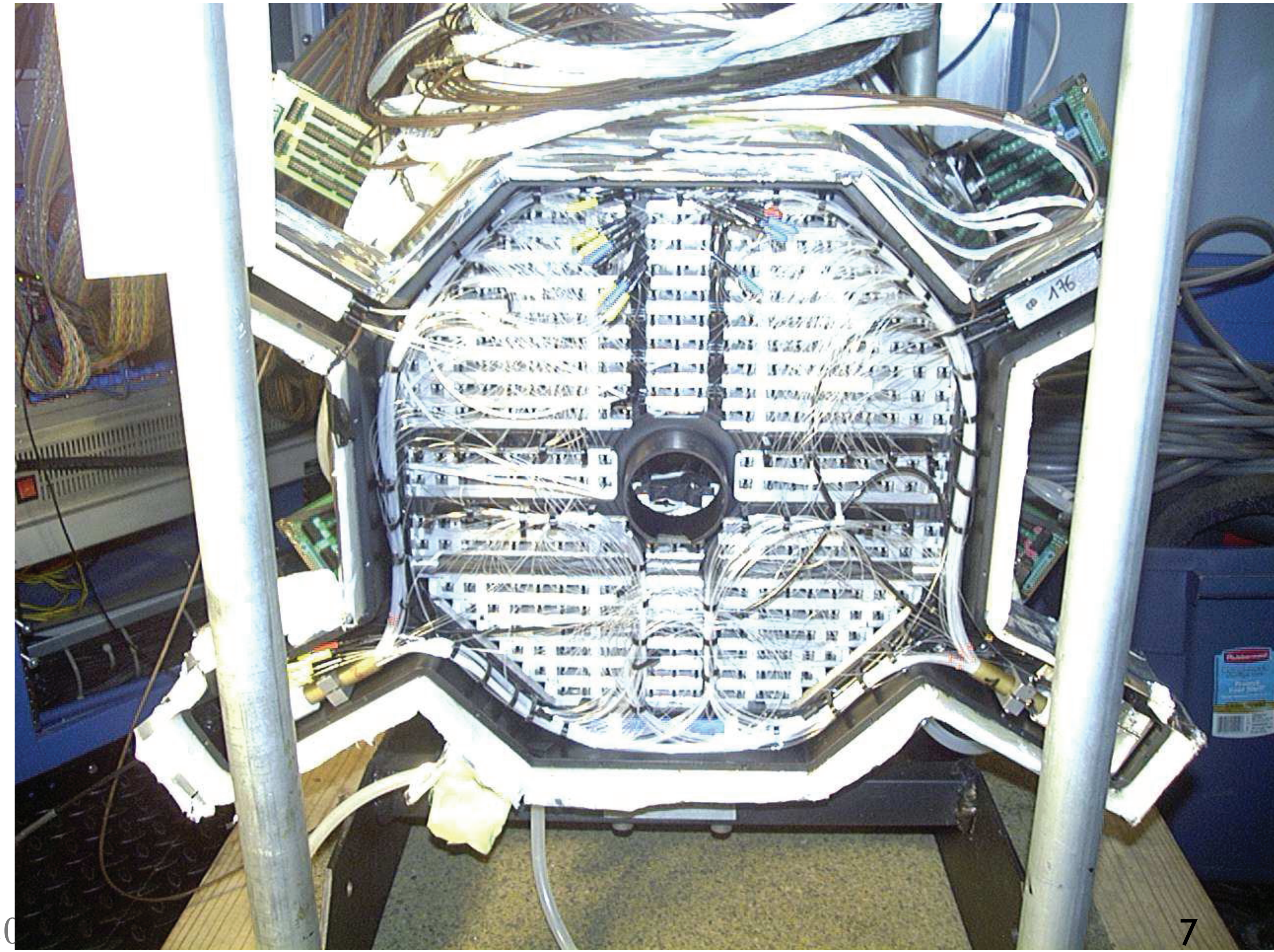
Available Crystals: PbWO4

Lead-Tungstate crystals available from inner calorimeter of CLAS.



Energy resolution:
$\sigma/E \sim 4.5\%/\sqrt{E}$ (GeV)

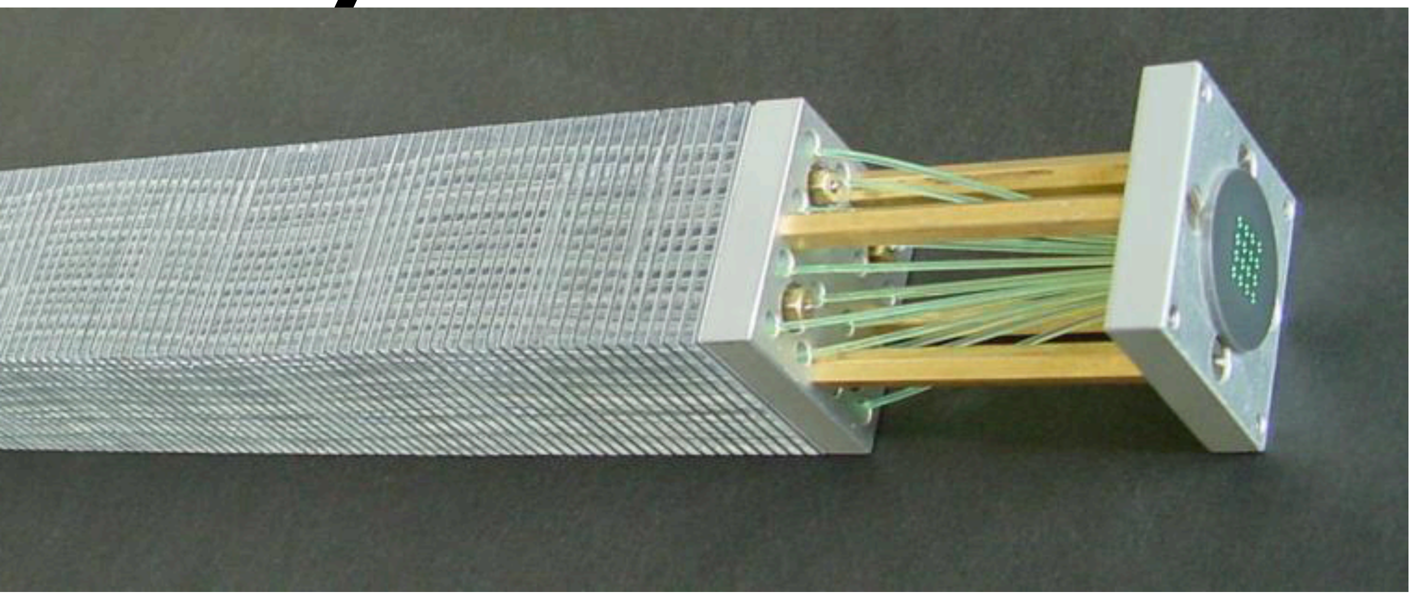
460 crystals available

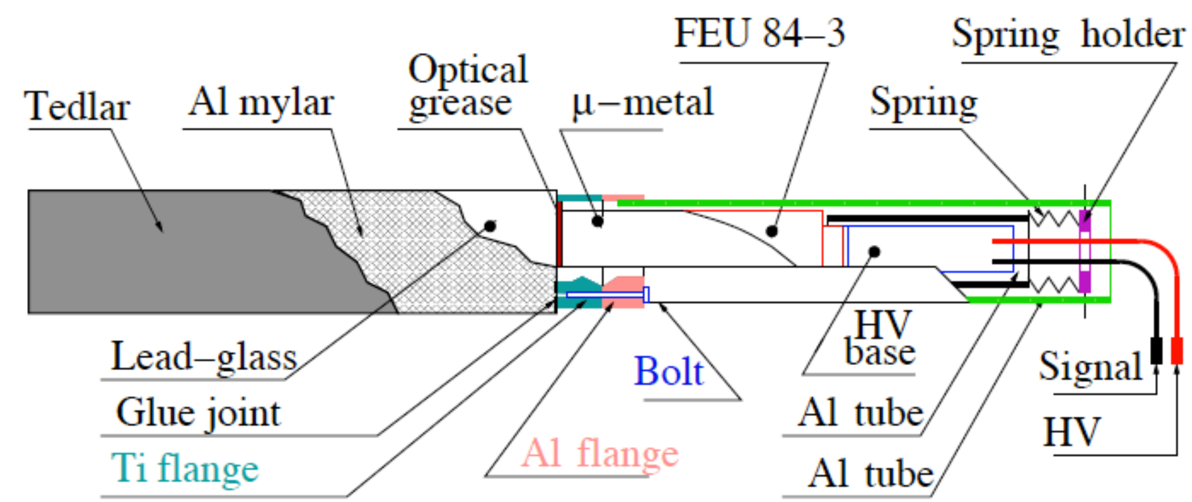


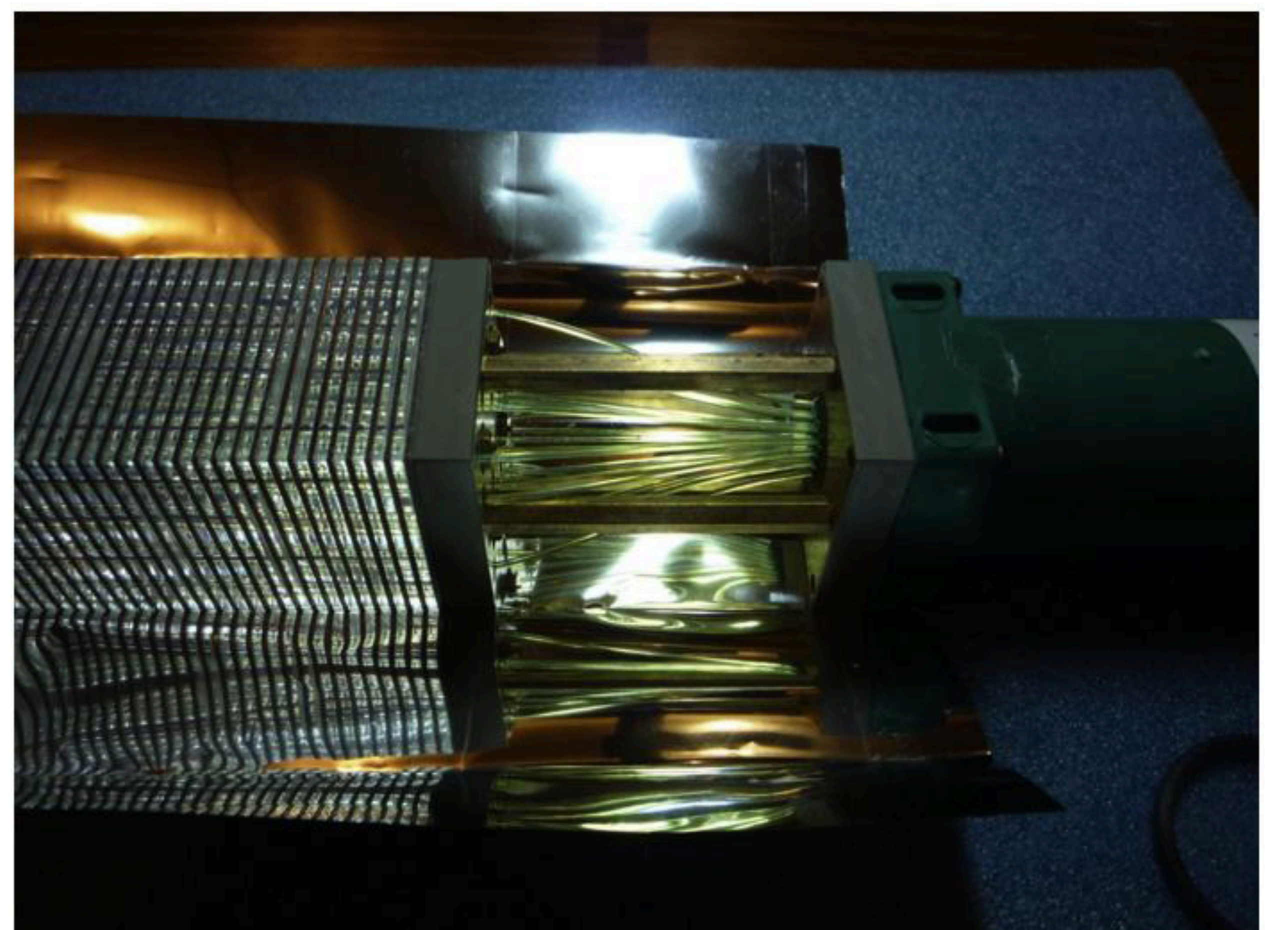
$$\left(\frac{\sigma}{E}\right)^2 \approx \left(\frac{0.023\sqrt{GeV}}{\sqrt{E}}\right)^2 + (0.013)^2$$

See: CLAS-Note 2005-007

Crystals: Lead Glass / Shashlyk



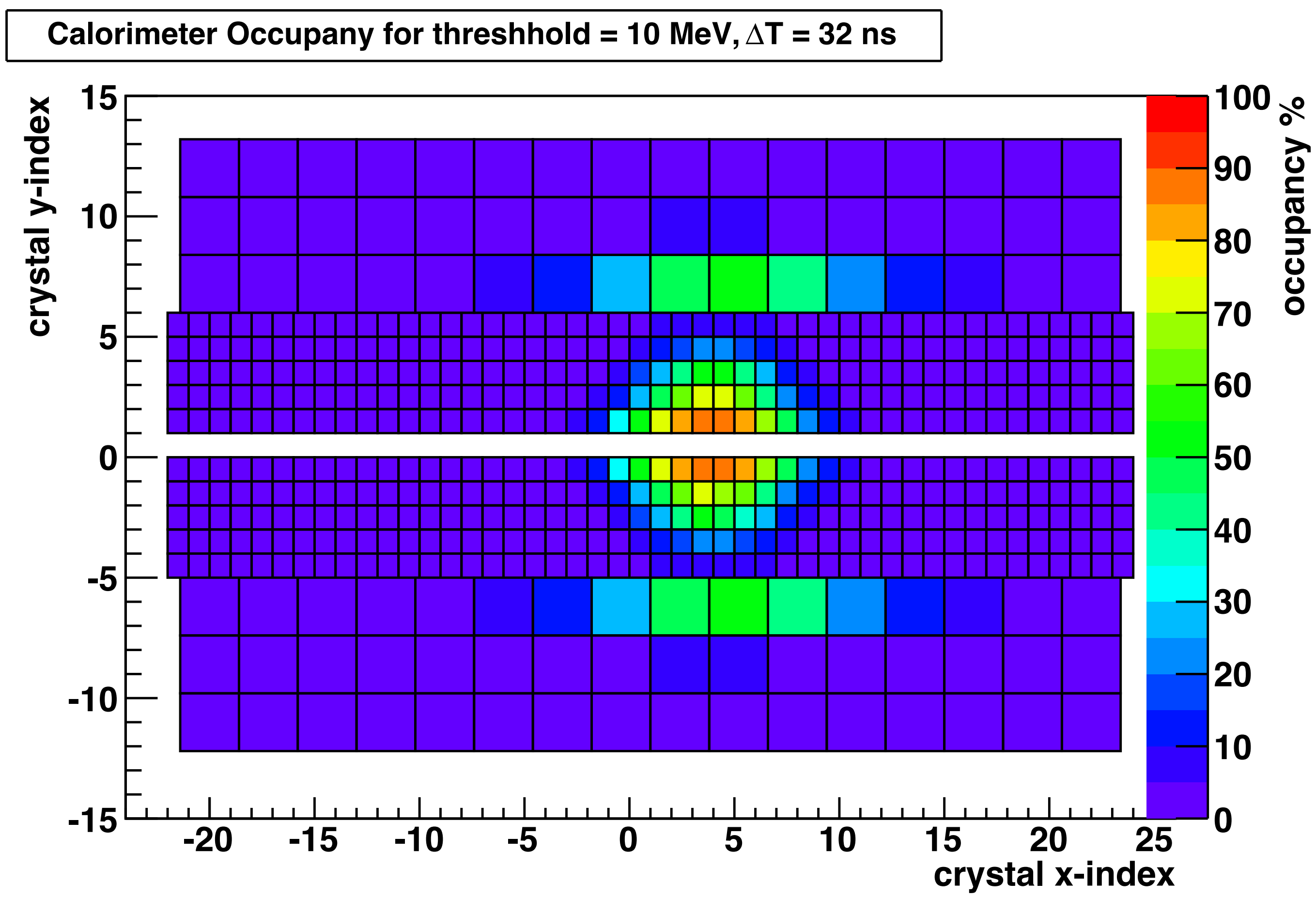


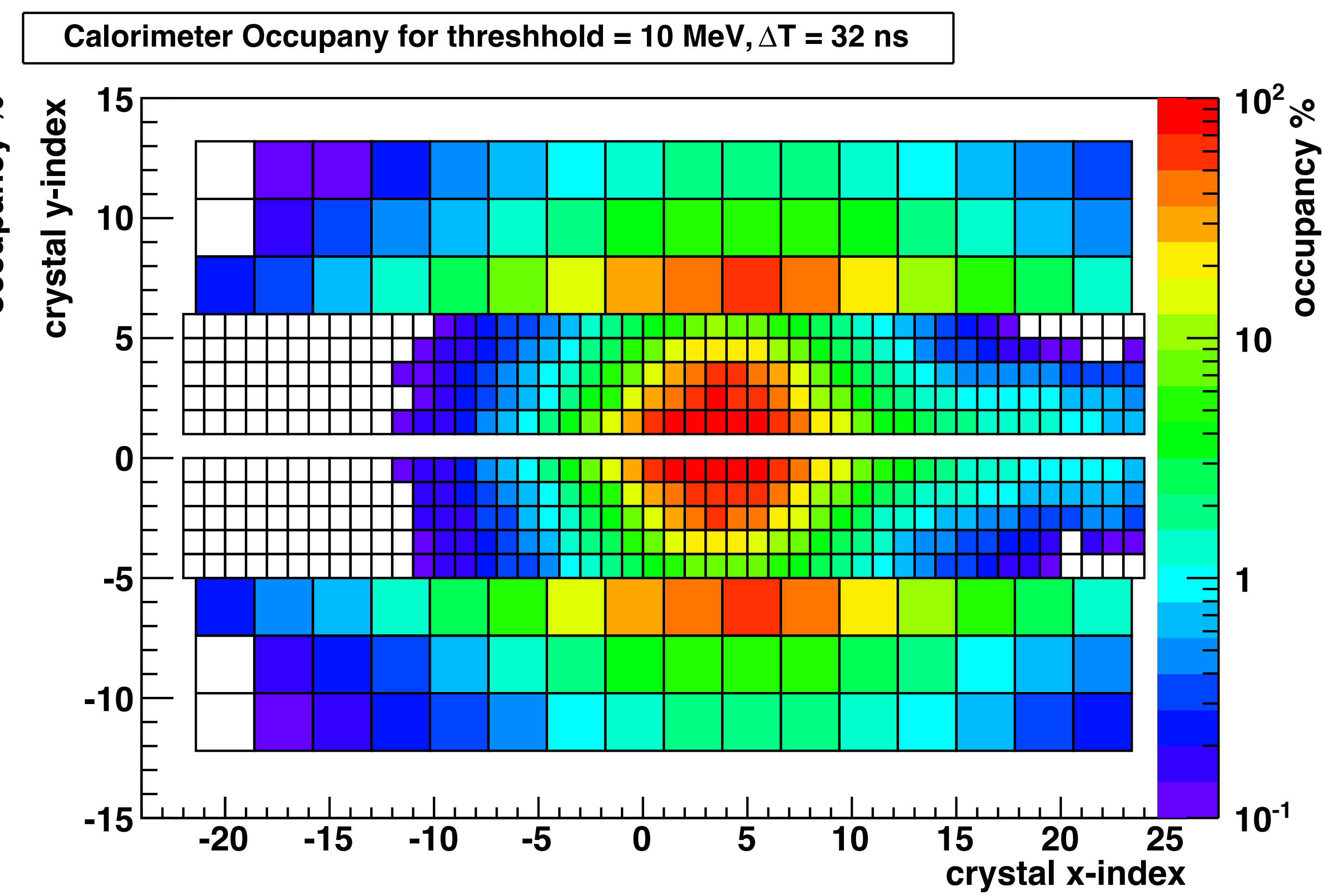


Energy resolution $\sigma/E \sim 5.5\% / \sqrt{E}$

Ecal Performance: occupancies

Check the single hit rates on the ecal crystals.





Plots show the fraction of events that have at least one hit with an energy deposit of 10 MeV or more in a 32ns time window.

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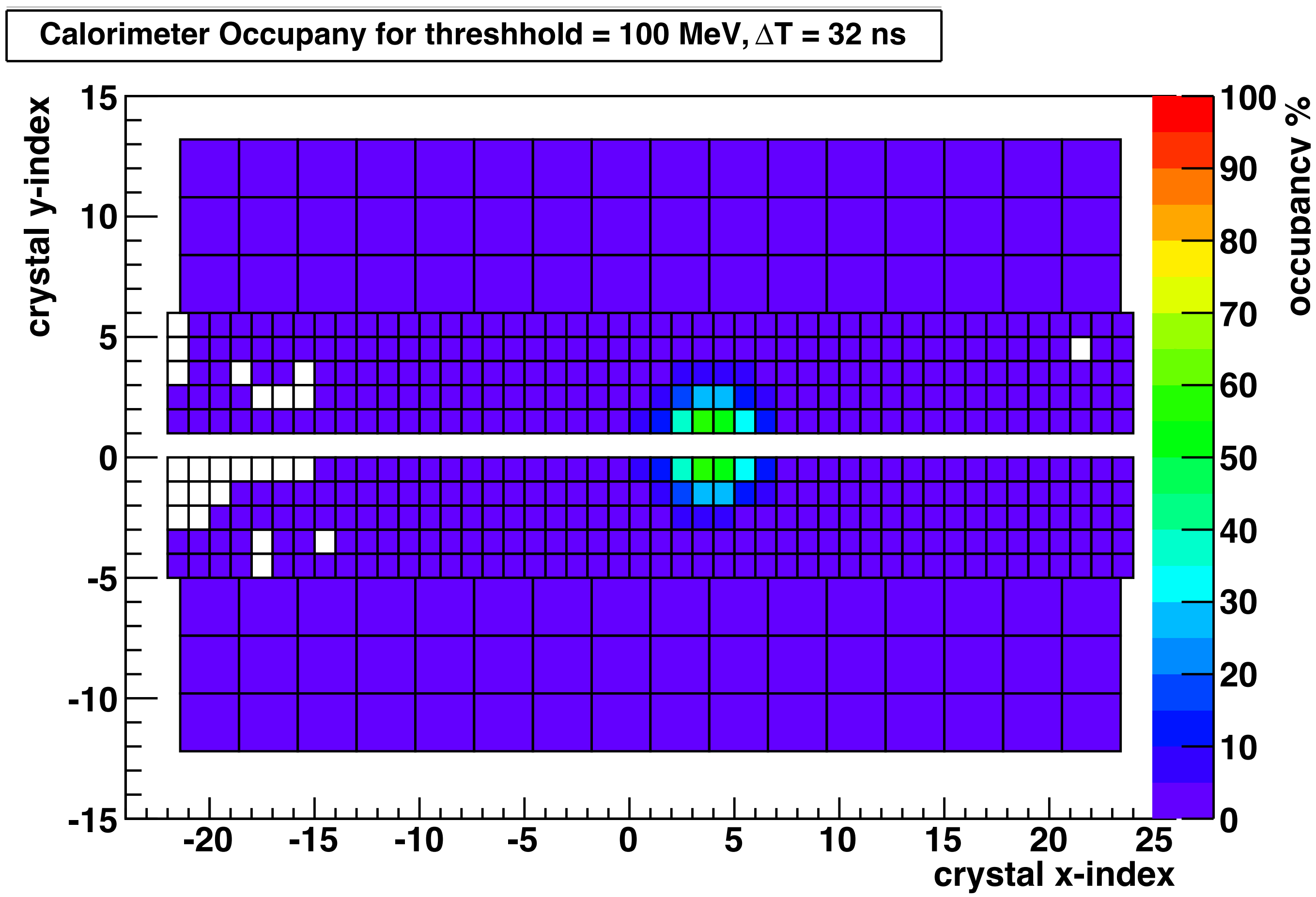

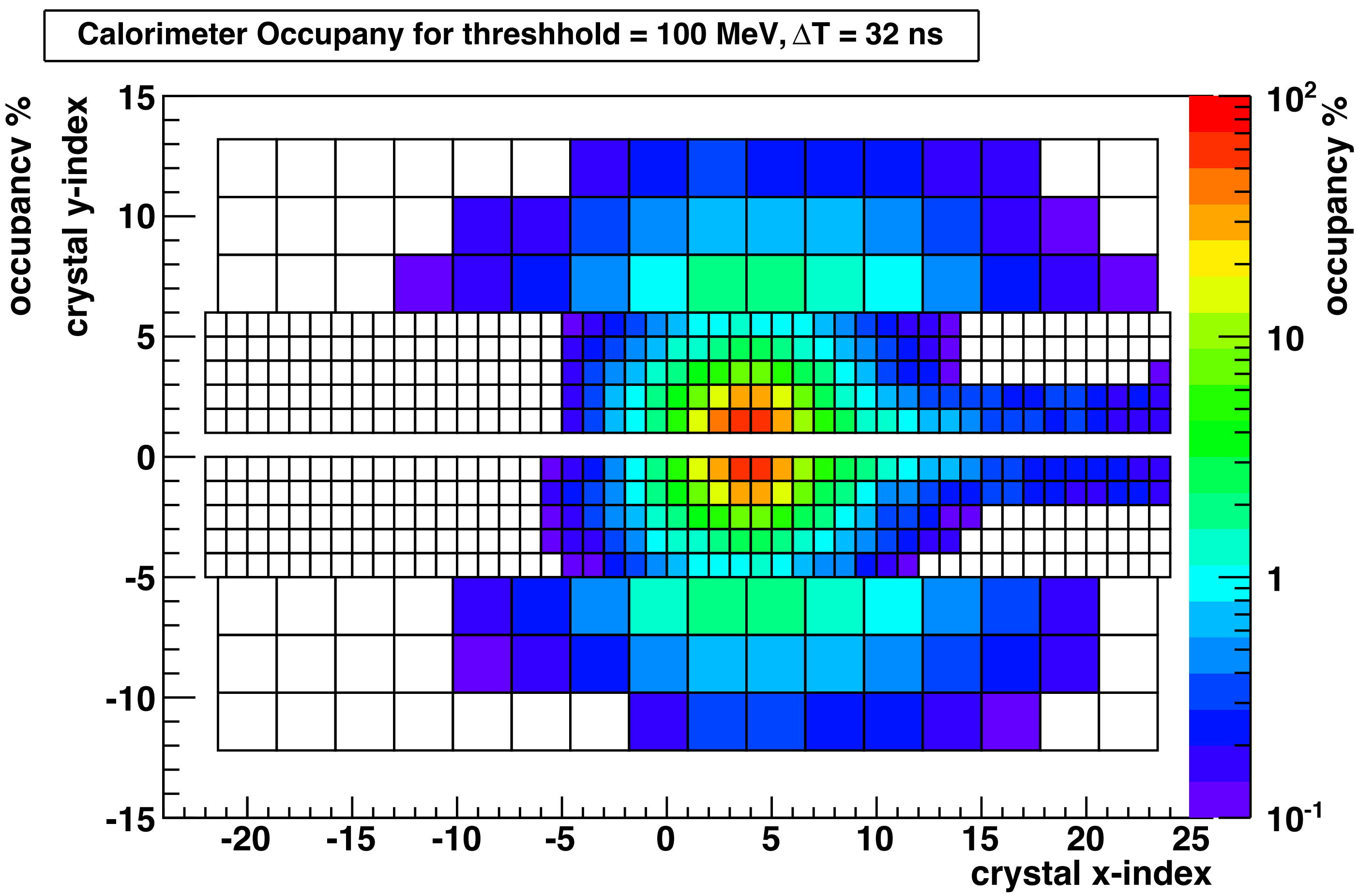

Plots show the fraction of events that have at least one hit with an energy deposit of 10 MeV or more in a 32ns time window.

⇒ Raise threshold to 100 MeV

Ecal Performance: occupancies

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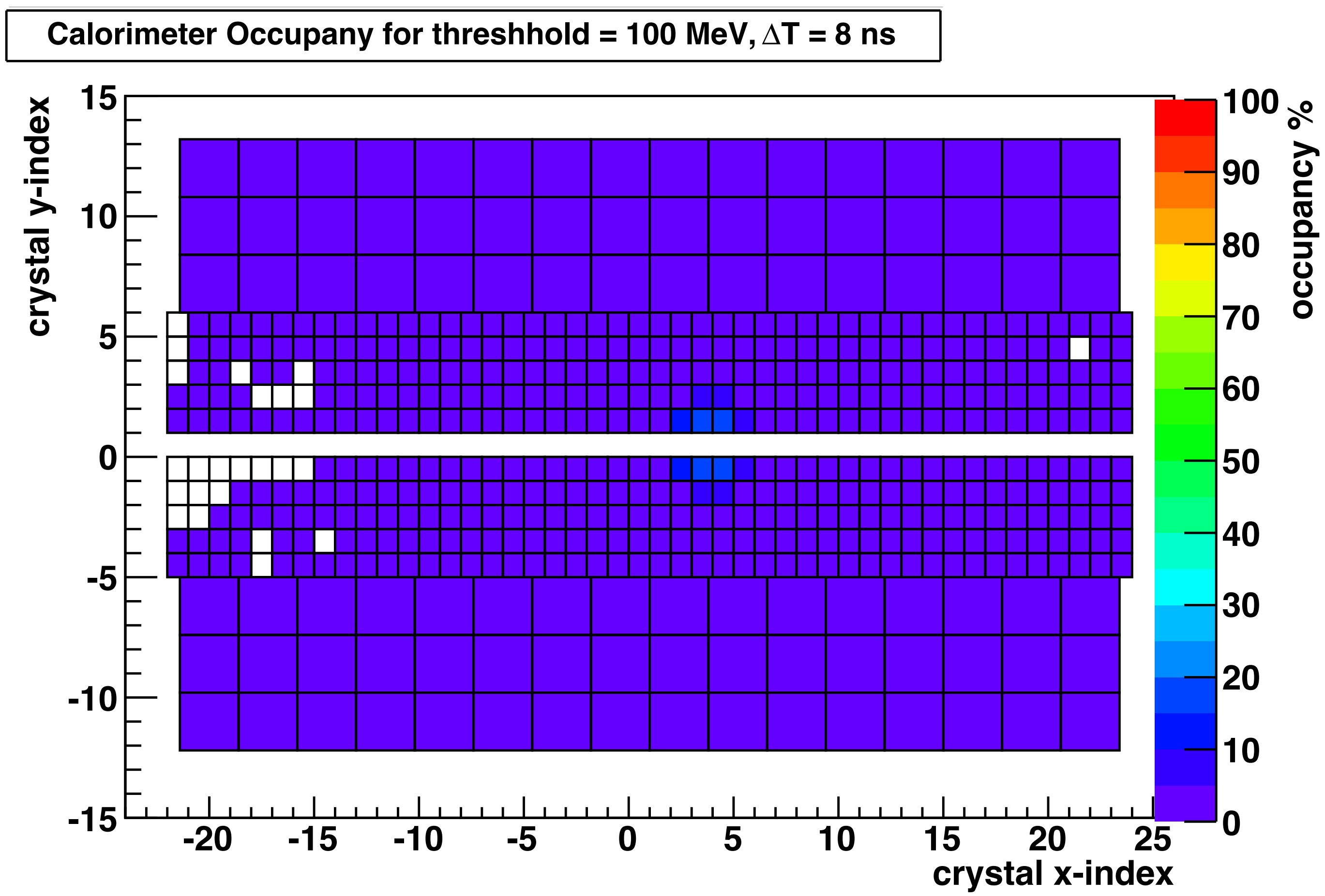
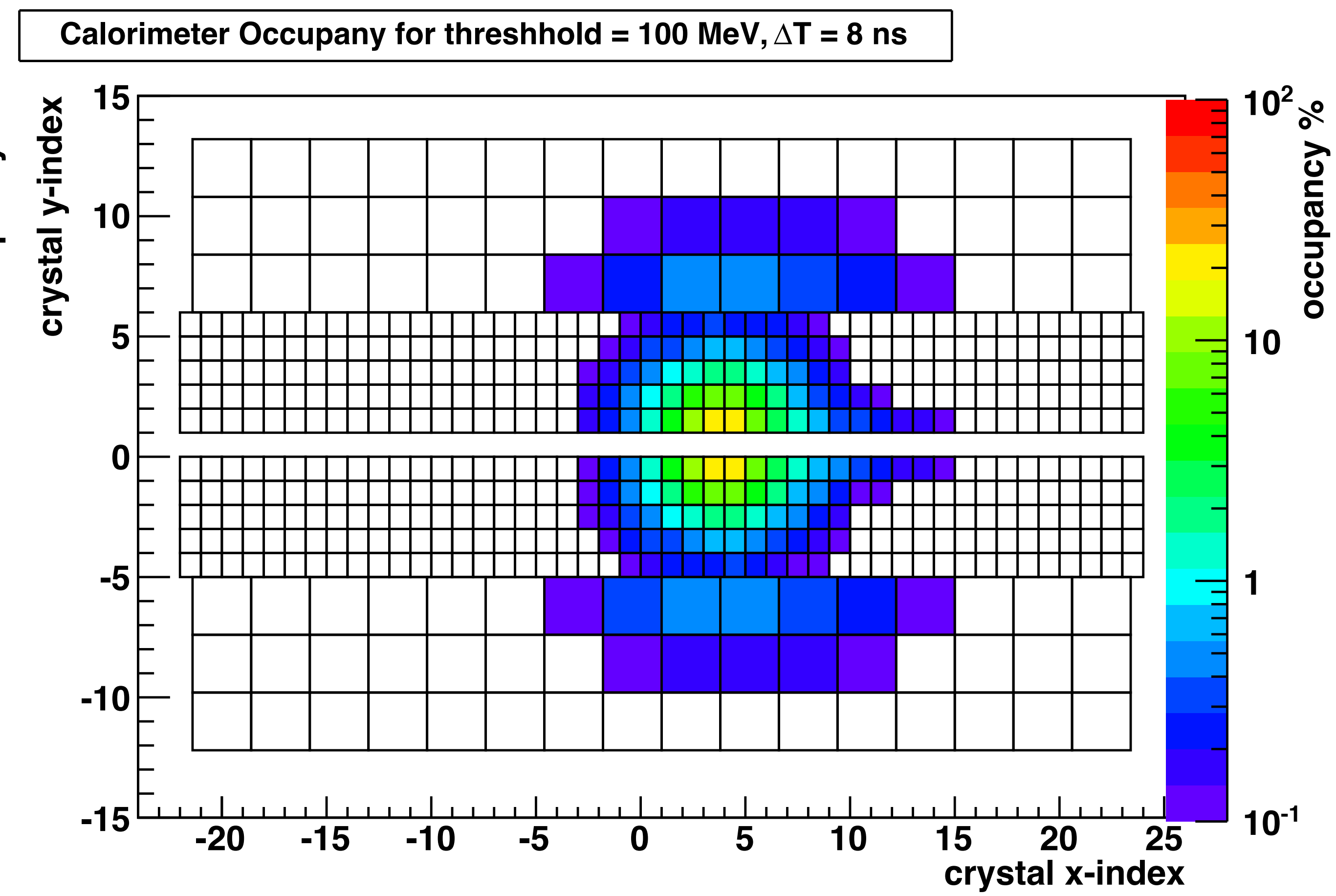




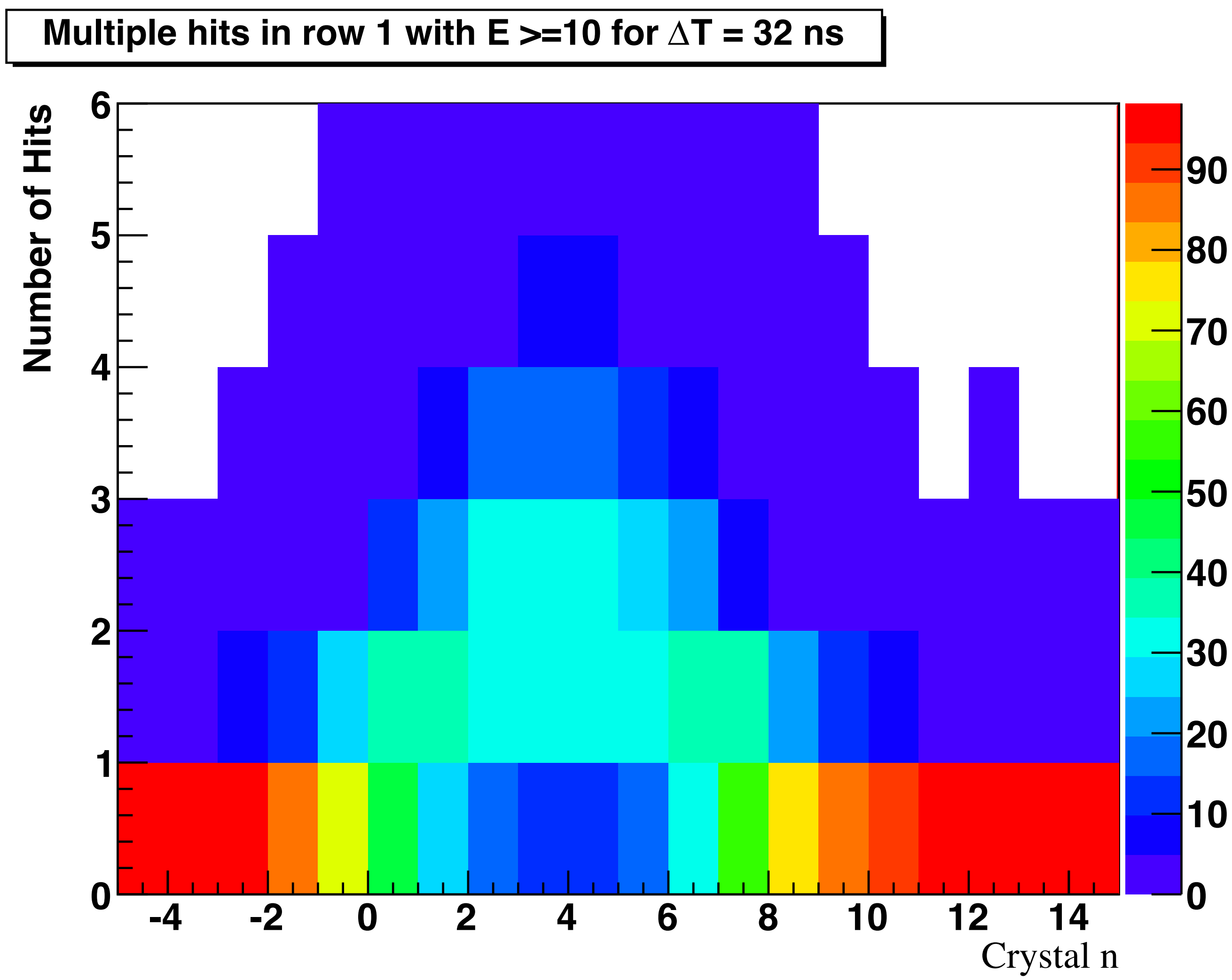
Plots show the fraction of events that have at least one hit with an energy deposit of 10 MeV or more in a 32ns time window.

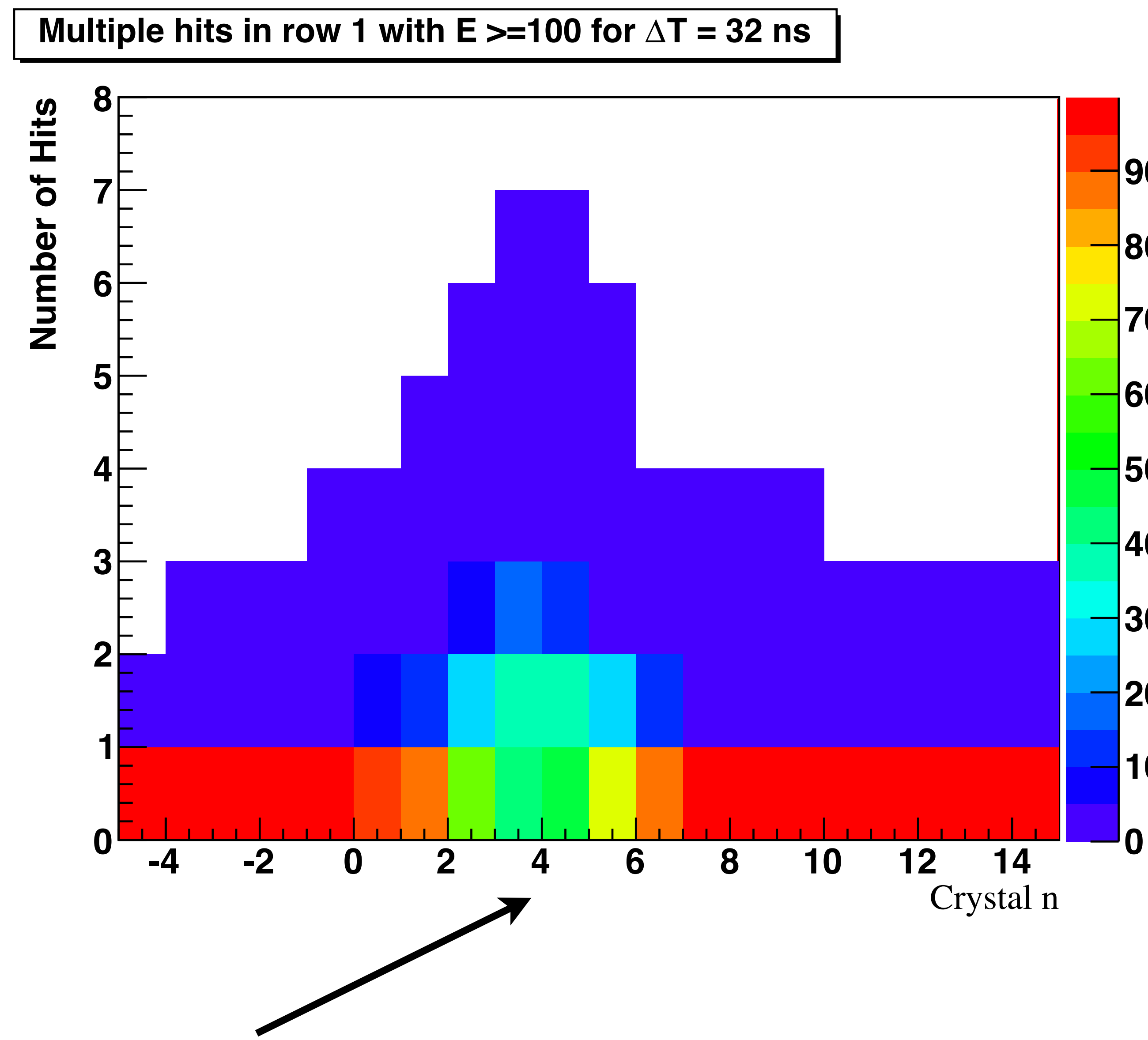
⇒ Raise threshold to 100 MeV

⇒ Shorten time window to 8 ns

Ecal performance: multiplicity

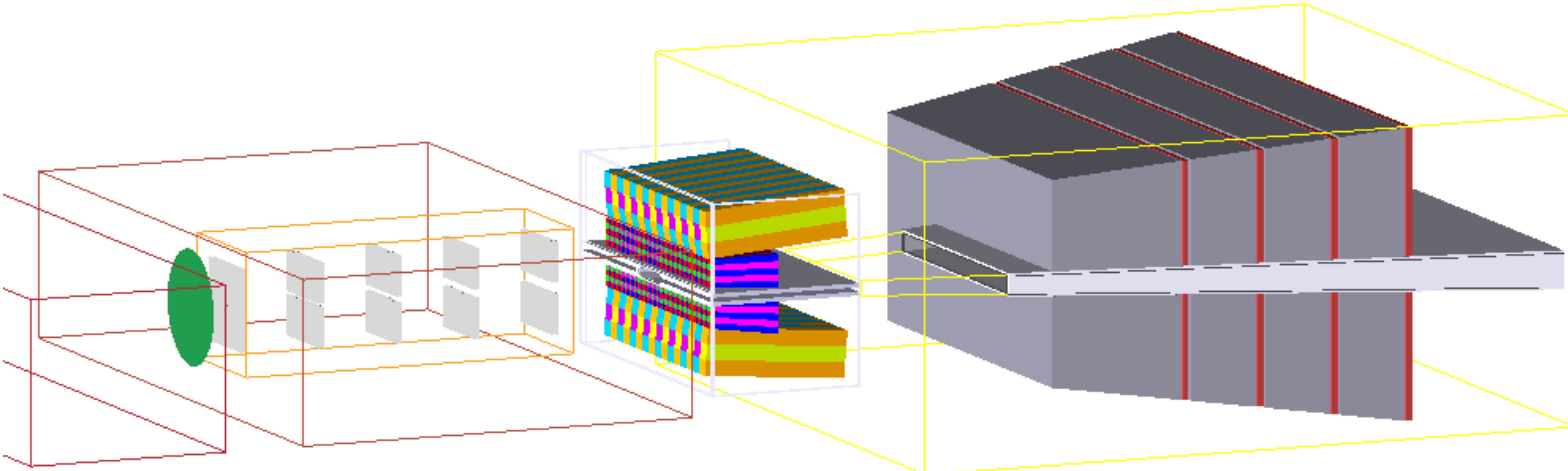
First row of crystals, fraction of events with N hits.





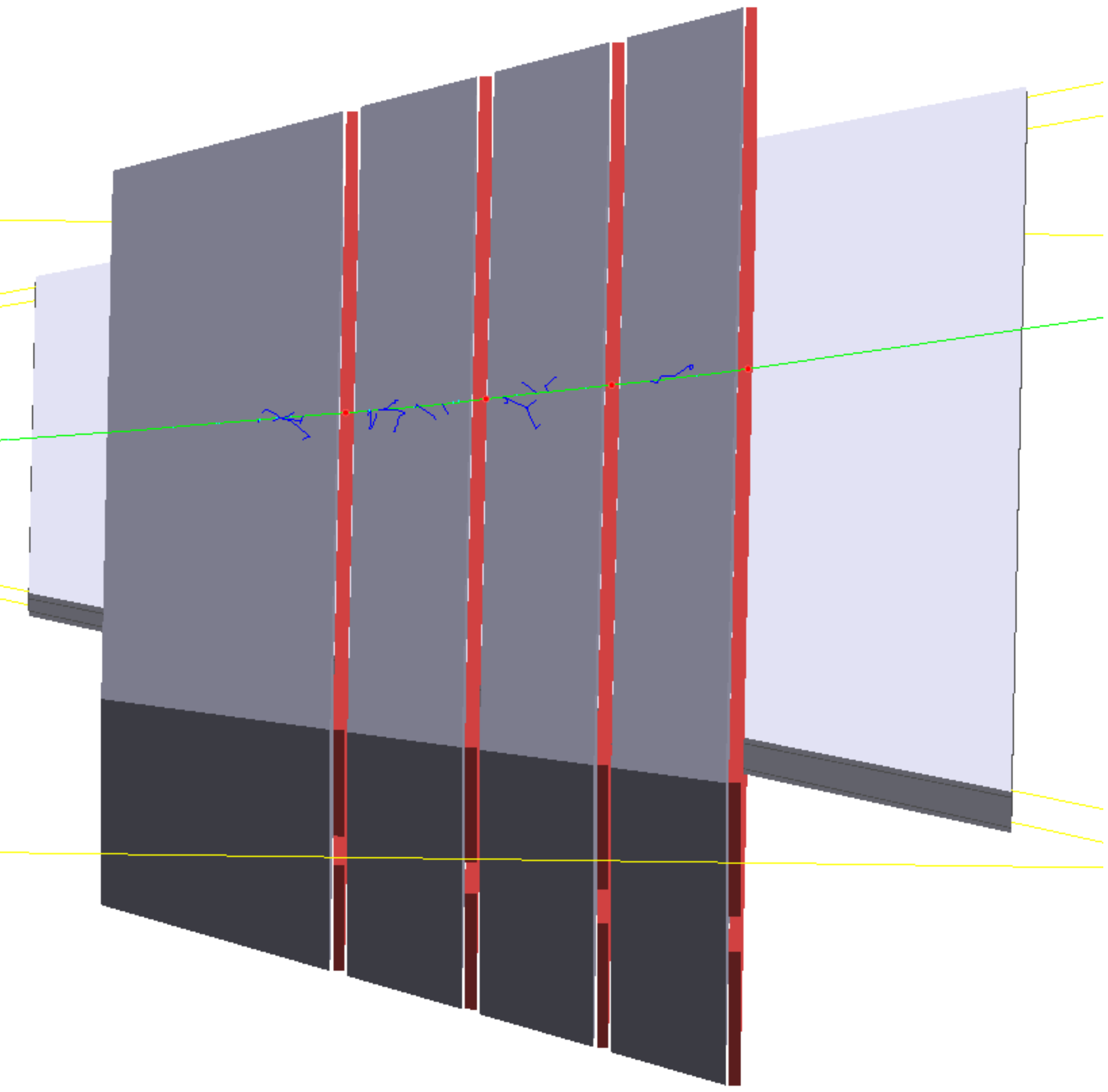
Only a few crystals around the beam exit run "hot".

Muon Detector

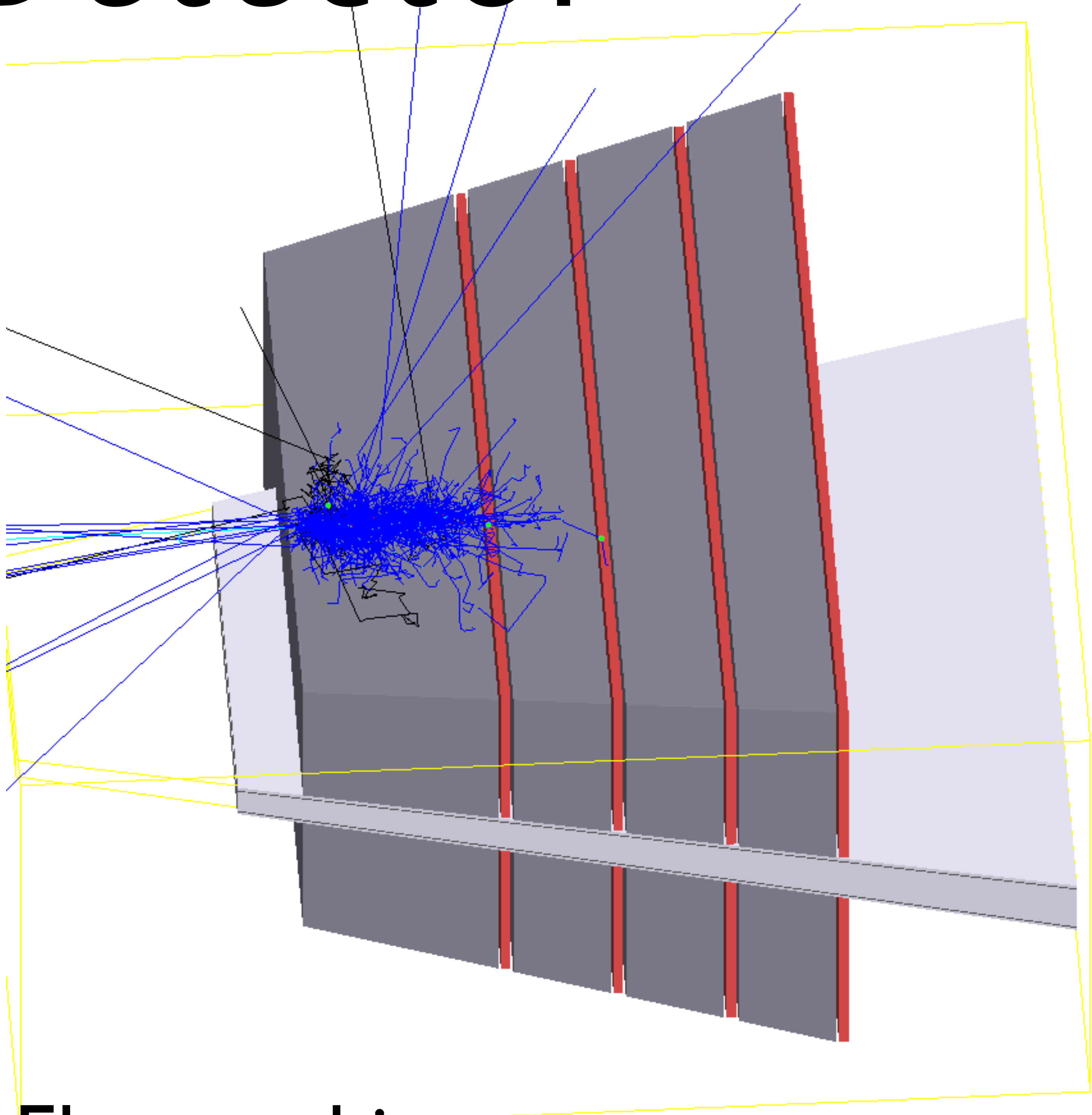


Conceptual design:
Location ~ 2m from target
Iron absorbers: 30 cm + 3x 15 cm
Four segmented hodoscopes, 1.5 cm thick

Muon Detector

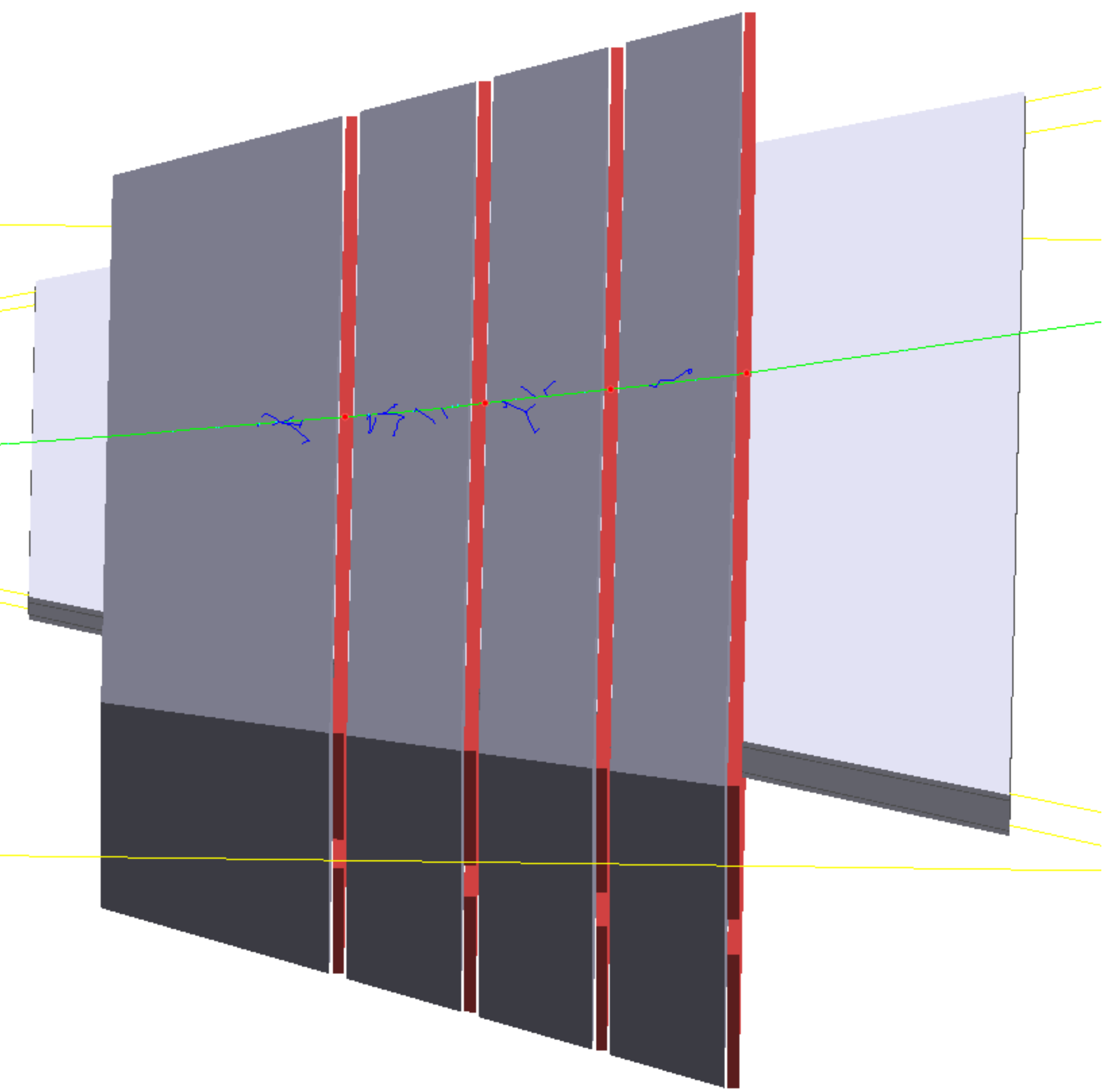


Muon Hit: ~ 1 MeV energy deposit per hodoscope

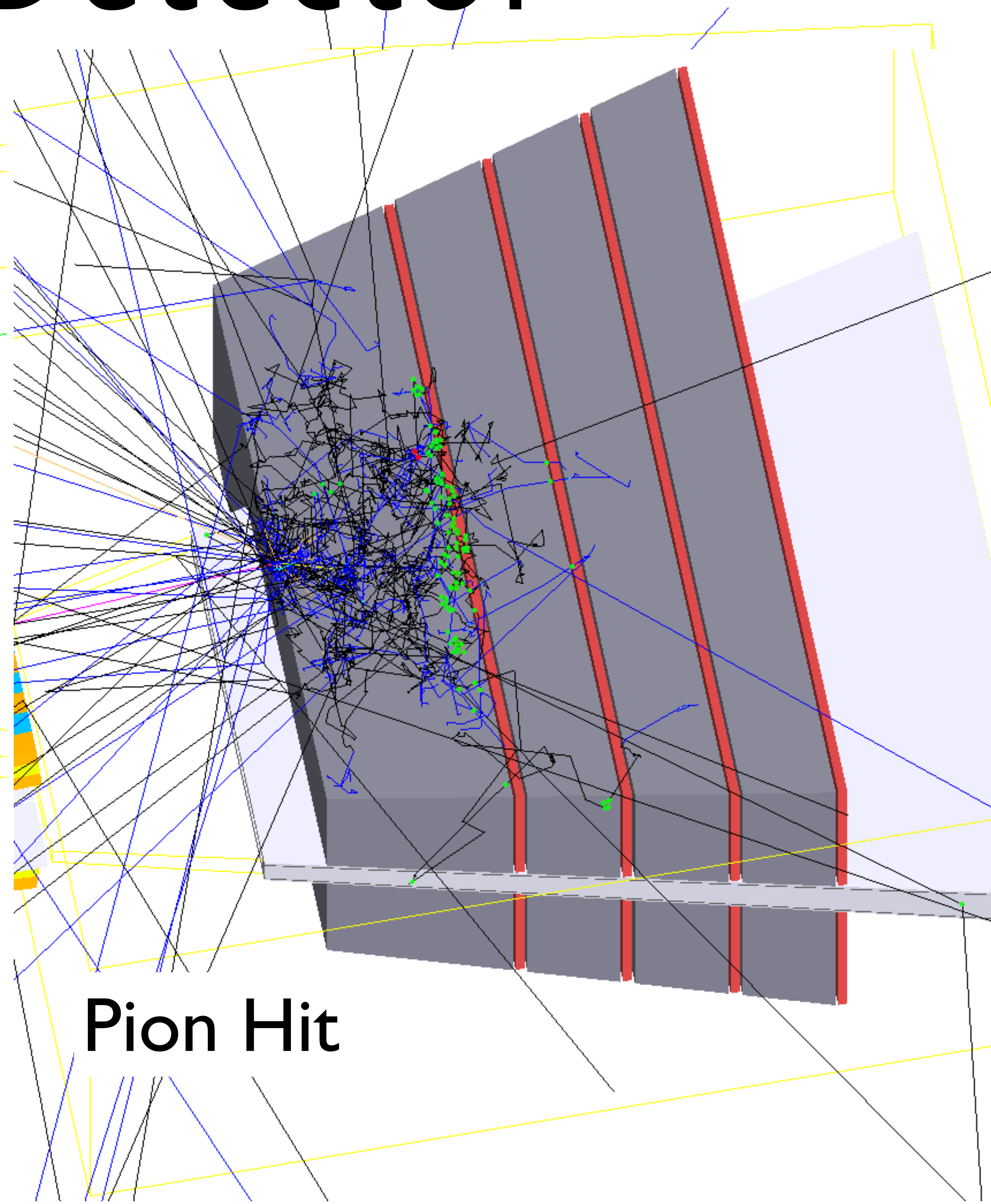


Electron hit.

Muon Detector



Muon Hit: ~ 1 MeV energy deposit per hodoscope

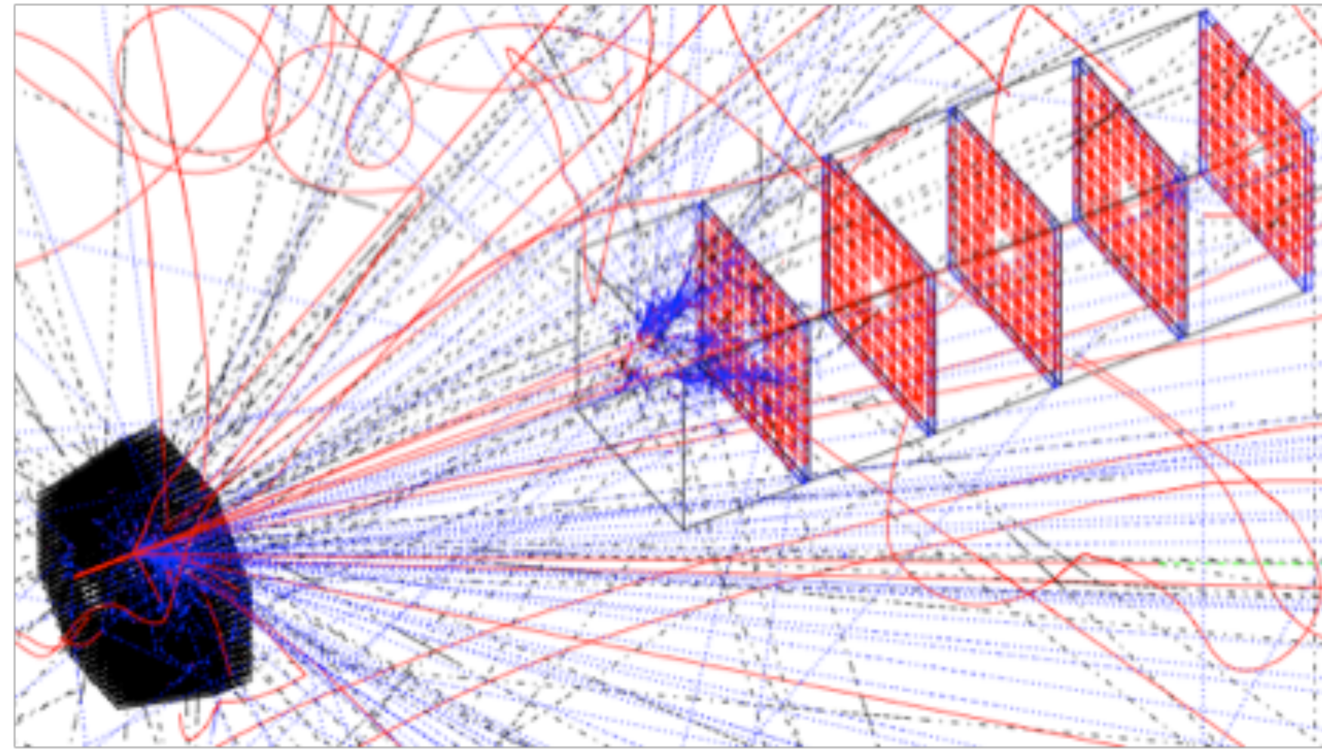


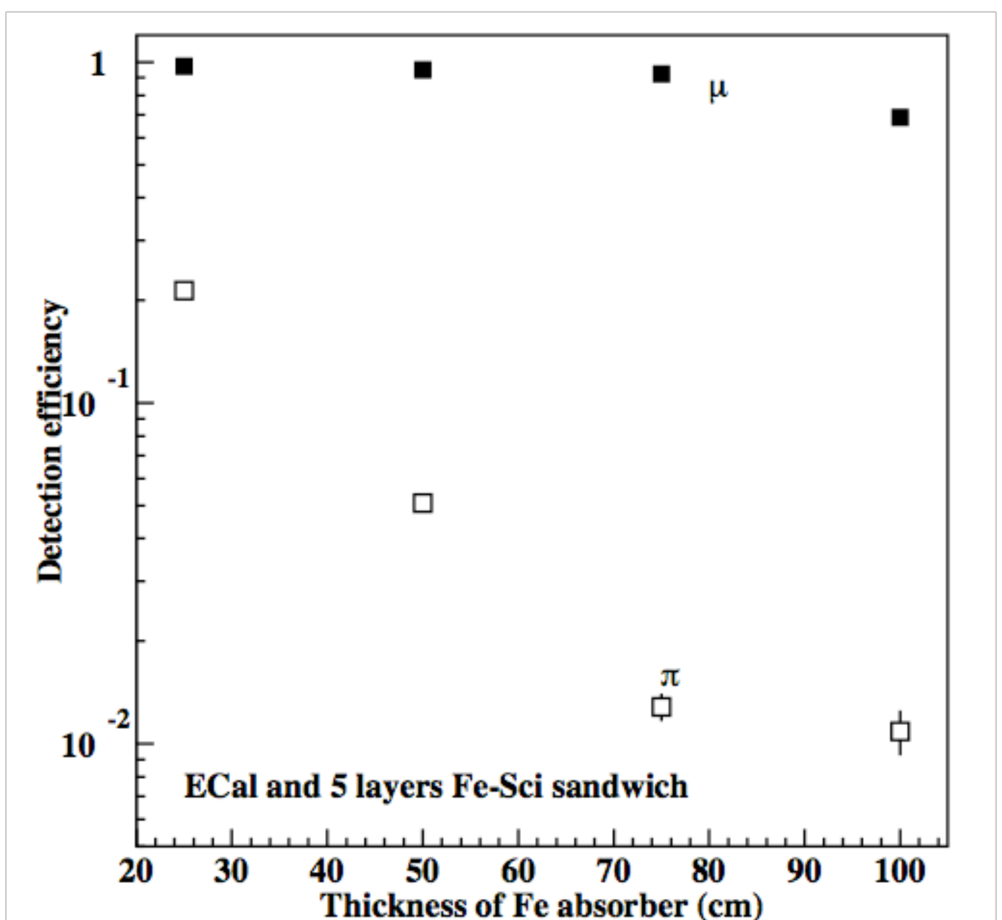
Pion Hit

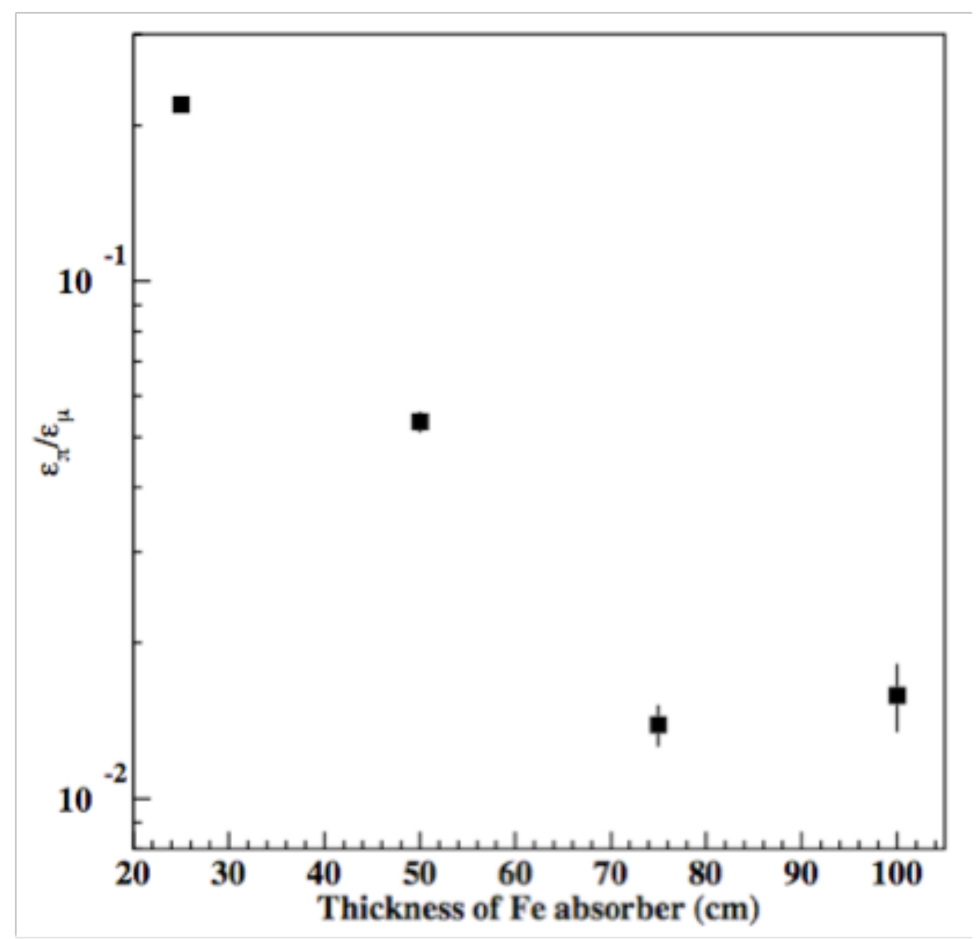
Muon Detector Optimization

Detector simulation in GEANT3 (initial) & GEANT4 (in progress)

Est. background trigger rate
≈ 250 Hz (0.1 MeV threshold)
≈ < 1 Hz (0.4 MeV threshold)







Level 1 Trigger Algorithm

Trigger algorithm will be implemented in FPGA units.

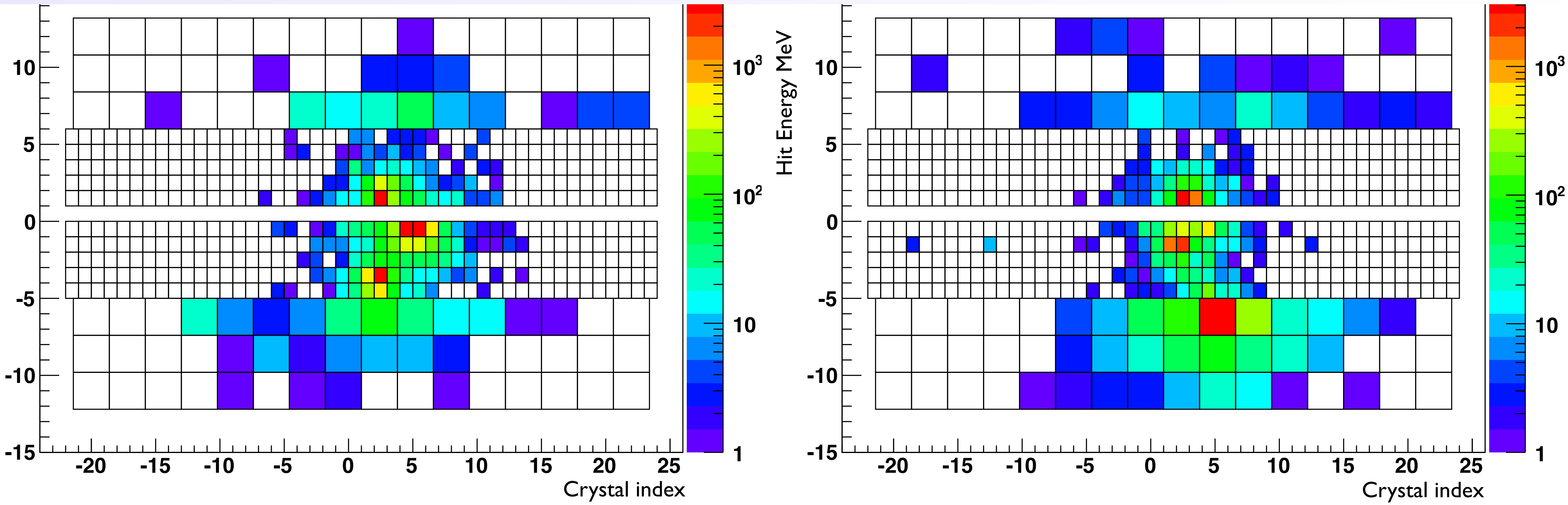
- Fast parallel processing of information.
- Fairly sophisticated operations possible.
- 4 ns clock cycle, allows for trigger coincidence down to $\Delta T = 8$ ns.

Simulation of trigger in two steps:

- Simple cluster finding algorithm.
- Strict trigger selection criteria

Trigger: Cluster Finding

Two "interesting" events in the calorimeter: ΔT=32 ns.



Set loose criteria to find many clusters:

1. For each hit with E > 50 MeV.
2. Search 3x3 square for other hits.
3. If no hit has more energy → Store hit
4. Else → move to next hit.

Algorithm takes special care of border regions:

- Edges of calorimeter
- Edges between lead-tungstate and Shashlyk.

Store hit: Add energies of 3x3 square if within 8 ns of center hit.

Trigger Selection

Find additional criteria to reduce background rates.

Objective:

- Reduce the background rate to < 20 kHz
- Keep acceptance of A' particles close to maximum

Simulated Data sample:

2.4 M background events representing 4 ns of beam each.

400 nA ≈ 10,000 e- per 4 ns event

0.25% X_0 Tungsten target.

Multiple 4 ns events could be combined to simulate larger event times.

Simulated A' masses:

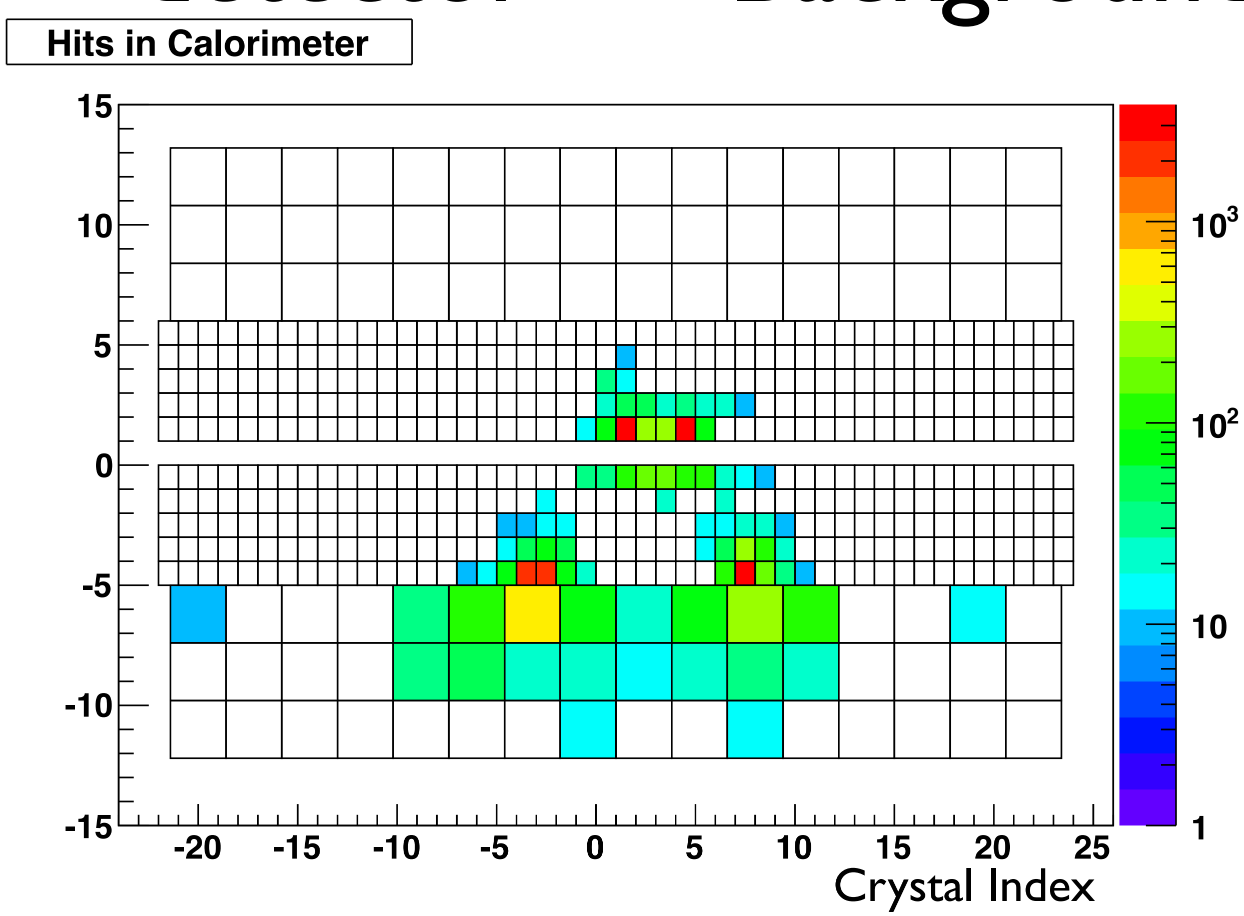
50, 100, 200, 250, 300, 400, 500, 600, 700 MeV.

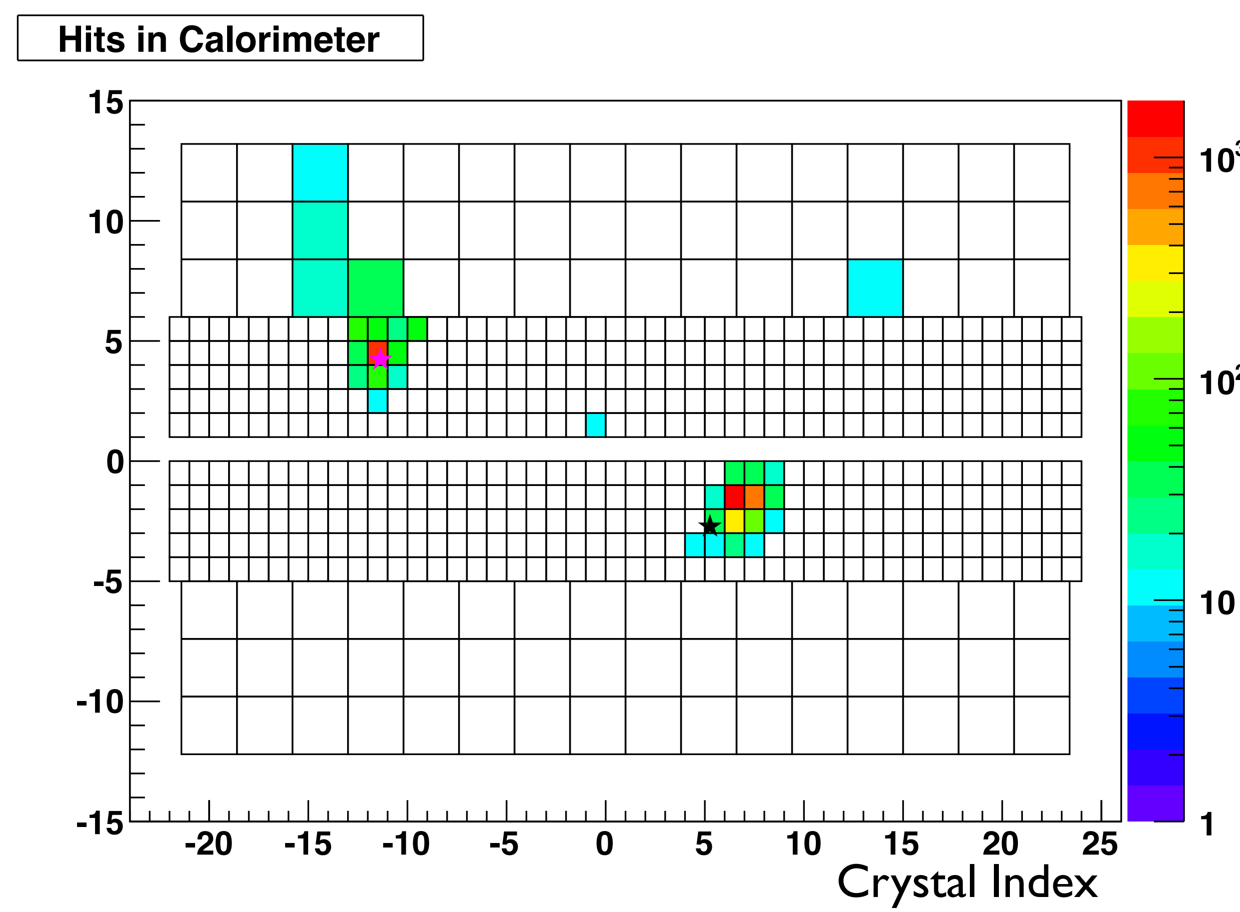
Trigger Selection

Trigger Cut.	**A' (250 MeV) Acceptance**	**Background Acceptance**	**Estimated Background rate**
Events with least two opposite clusters	44.6%	1.26%	1.6 MHz

0-th cut:

Two clusters, one e- one e+: Opposite quadrants of detector ⇒ Background rate ≈ 1.6 MHz





Trigger Selection

Trigger Cut.	**A' (250 MeV) Acceptance**	**Background Acceptance**	**Estimated Background rate**
Events with least two opposite clusters	44.6%	1.26%	1.6 MHz
Cluster energy > 0.5 GeV and < 4.4 GeV	46.4 %	0.239%	0.3 MHz

1-st cut:

Both clusters have energies between 0.5 and 4.4 GeV

$\Rightarrow$ Background rate $\approx$ 0.3 MHz

(Details of cut depend on actual sampling fraction)

Caveat: Double counting! Three clusters can now account for 2 triggers, both of which are counted!

Trigger Selection

Trigger Cut.	A' (250 MeV) Acceptance	Background Acceptance	Estimated Background rate
Events with least two opposite clusters	44.6%	1.26%	1.6 MHz
Cluster energy > 0.5 GeV and < 4.4 GeV	46.4 %	0.239%	0.3 MHz
Energy sum < 5.1 GeV	46.4 %	0.0959%	120 kHz

2-nd cut:

Energy sum of clusters is below beam energy:

$E_{sum} < 5.1$ GeV (takes into account sampling fraction)

⇒ Background rate ≈ 120 kHz

Trigger Selection

Trigger Cut.	**A' (250 MeV) Acceptance**	**Background Acceptance**	**Estimated Background rate**
Events with least two opposite clusters	44.6%	1.26%	1.6 MHz
Cluster energy > 0.5 GeV and < 4.4 GeV	46.4 %	0.239%	0.3 MHz
Energy sum < 5.1 GeV	46.4 %	0.0959%	120 kHz
Energy difference < 3.2 GeV	46.1 %	0.0823%	102 kHz

3-nd cut:

Energy difference of clusters, $E_{diff} < 3.2$ GeV

$\Rightarrow$ Background rate $\approx$ 102 kHz

Trigger Selection

Trigger Cut.	**A' (250 MeV) Acceptance**	**Background Acceptance**	**Estimated Background rate**
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Energy sum < 5.1 GeV	46.4 %	0.0959%	120 kHz
Energy difference < 3.2 GeV	46.1 %	0.0823%	102 kHz
Lower energy - distance slope cut	45.4%	0.0601%	75 kHz

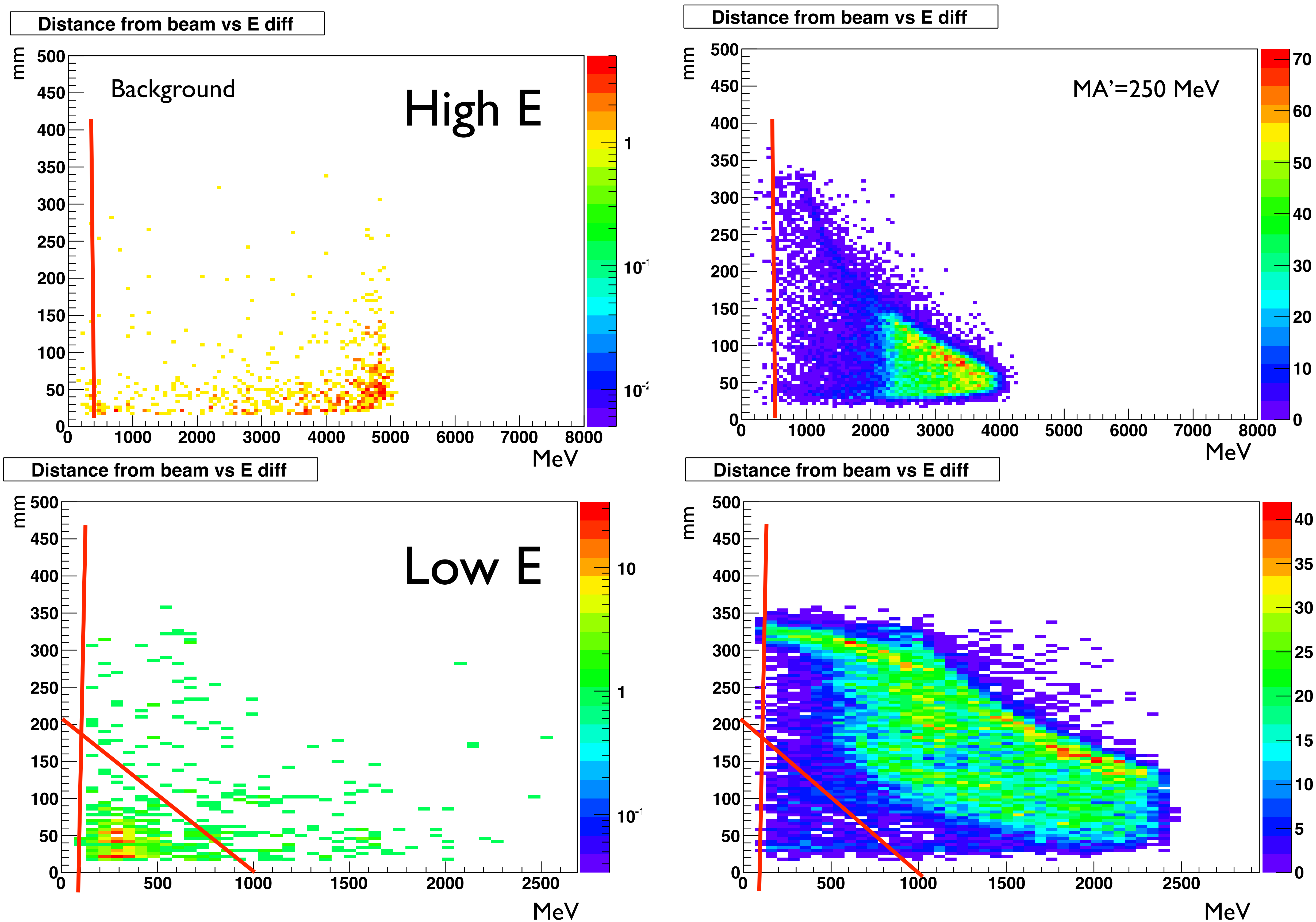
4-th cut:

Look at the cluster with the lower energy.

Cut on the distance from beam vs. E of cluster.

$\Rightarrow$ Background rate $\approx$ 75 kHz

Trigger Selection



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4-th cut:

Look at the cluster with the lower energy.

Cut on the distance from beam vs. E of cluster.

⇒ Background rate ≈ 75 kHz

Trigger Selection

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Lower energy - distance slope cut	45.4%	0.0601%	75 kHz
Clusters coplanar to 45°	44.6%	0.0344%	43 kHz

5-th cut:

Clusters are coplanar with beam to 45°

⇒ Background rate ≈ 43 kHz

Trigger Selection

Trigger Cut.	**A' (250 MeV) Acceptance**	**Background Acceptance**	**Estimated Background rate**
Events with least two opposite clusters	44.6%	1.26%	1.6 MHz
Cluster energy > 0.5 GeV and < 4.4 GeV	46.4 %	0.239%	0.3 MHz
Energy sum < 5.1 GeV	46.4 %	0.0959%	120 kHz
Energy difference < 3.2 GeV	46.1 %	0.0823%	102 kHz
Lower energy - distance slope cut	45.4%	0.0601%	75 kHz
Clusters coplanar to 45°	44.6%	0.0344%	43 kHz
Eliminate crystals in row 1, column 0,3,4	41.3 %	0.0158%	20 kHz
Not counting double triggers	38.1%	0.0135%	17 kHz

5-th cut:

Eliminate hottest crystals: row 1, column 0,3,4

⇒ Background rate ≈ 20 kHz

Not including double counted events ≈ **17±1 kHz**

Rates and Acceptance

A' Mass (MeV)	50	100	200	250	300	400	500	600	700
Ecal Acceptance	3.1%	18.5%	33.7%	38.1%	40.5%	36.3%	30.3%	25.1%	21.3%

Background trigger rates

GEANT4: 17. kHz

Coherent trident:

- Bethe-Heitler 6. kHz
- Radiative 0.1 kHz

Incoherent trident: 0.2 kHz

Trident background estimated with MadGraph/MadEvent & EGS5

Conclusions

An advanced simulation in GEANT4 has been developed and is continuing to be improved

The simulation show that running conditions (400 nA on 0.25% X0 target) are reasonable for the proposed equipment.

Trigger rates are well under control and could be reduced ever further with tighter cuts or the additional elimination of a few more crystals.

Backup Slides

High rates on $PbWO_4$ Crystals

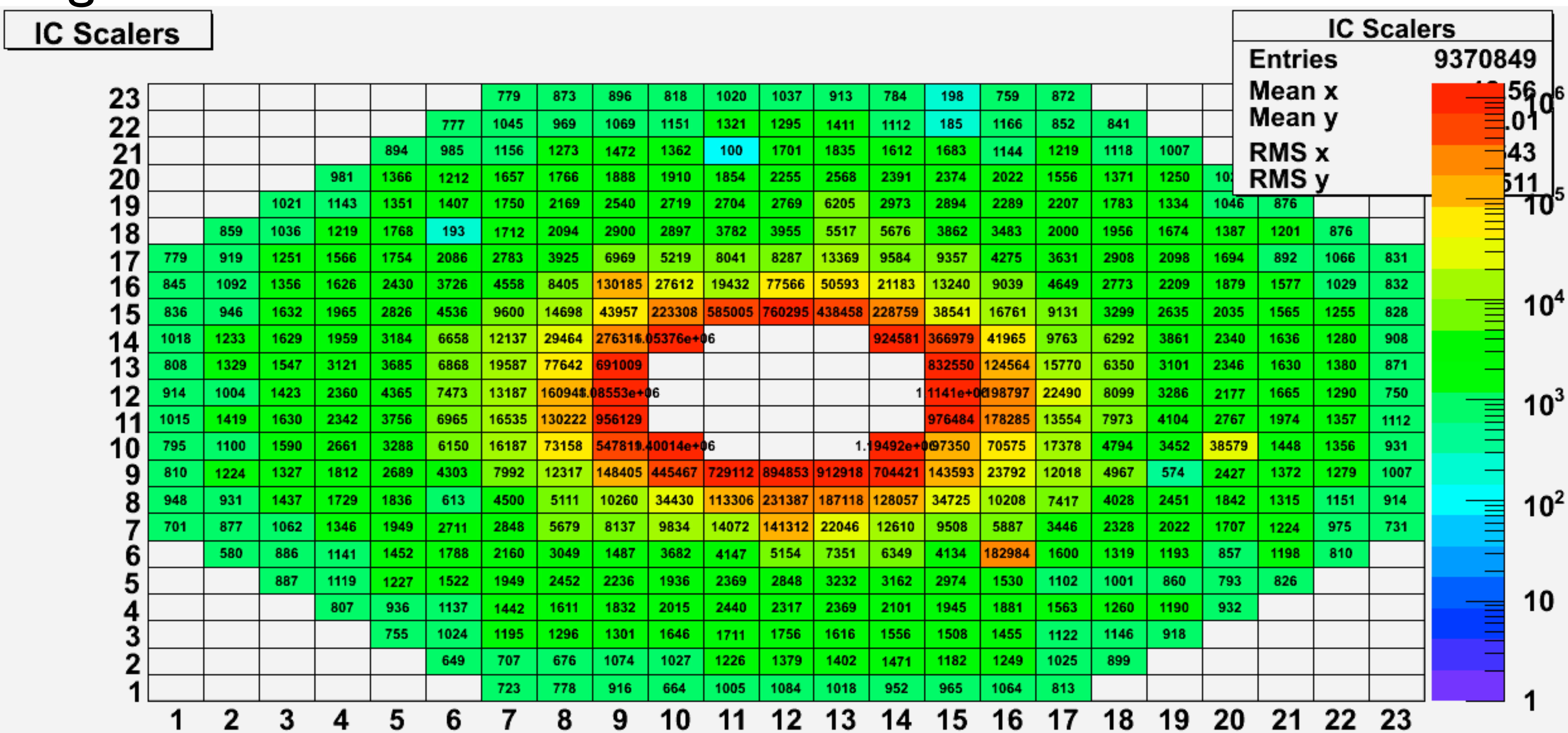
Rates on PbWO4 crystals during the EG1 run:

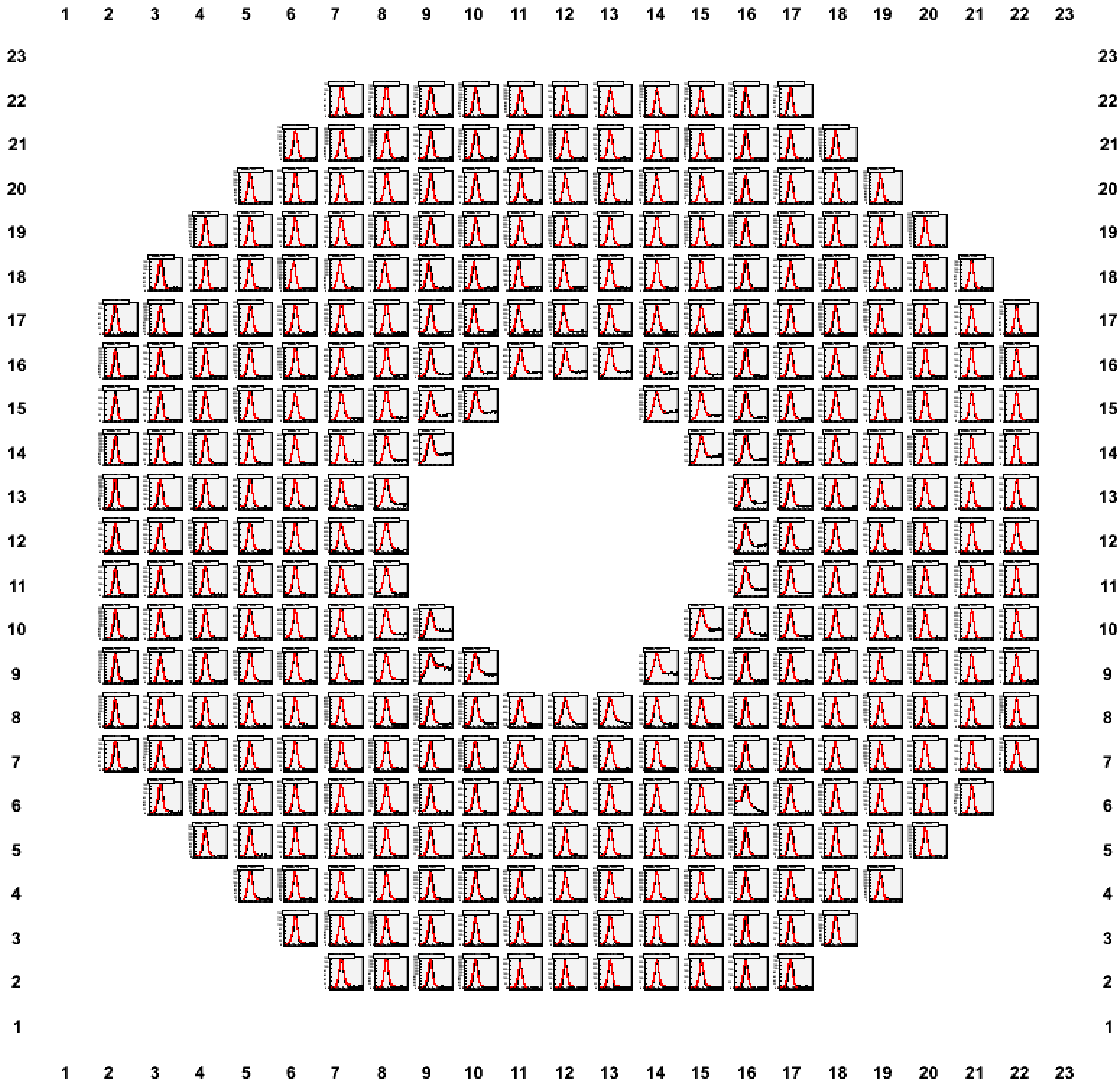
Threshold was 50-60 MeV

Highest rates ~ 1 MHz.

APDs and amplifiers can go up to 10 MHz.

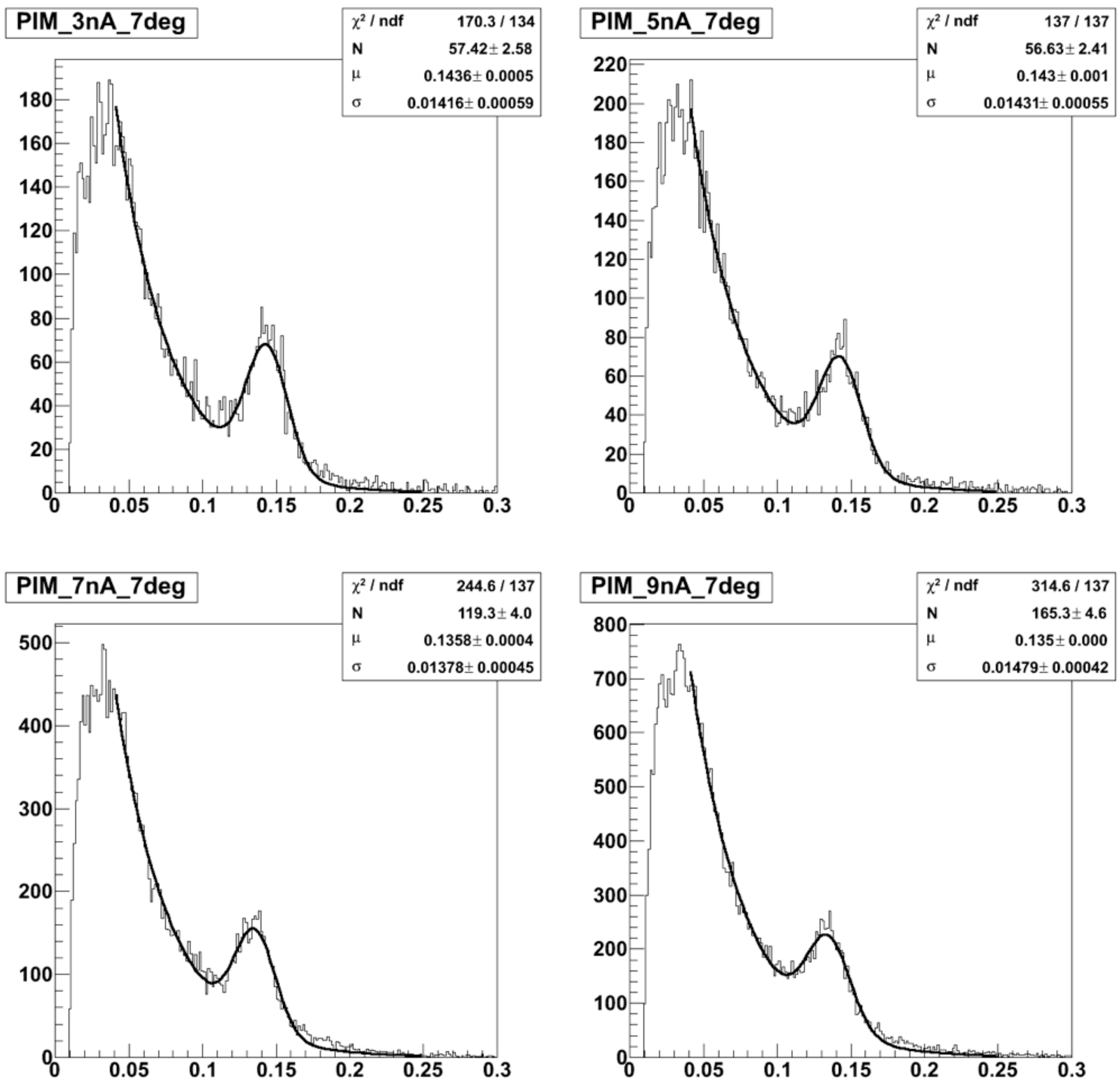
Pulse width could be reduced from 60 ns by factor of 2 to ~ 30 ns.





H-target
E1-DVCS

π^0 Mass peaks vs current



Data: EG1 Luminocity scans
Target: NH3

Eliminating more Crystals

A' Mass (MeV)	BCK	50	100	200	250	300	400	500	600	700
x 0, 3, 4	0.0153%	3.48%	19.5%	34.9%	39.2%	41.5%	37.2%	31.3%	26.2%	21.3%
x 0,1,2,3,4,5,6	0.0082%	3.08%	13.8%	31.7%	36.2%	38.7%	35.9%	30.3%	25.4%	20.7%
x 0,1,2,3,4,5,6,7	0.0079%	2.87%	11.7%	30.7%	35.5%	38.1%	35.8%	30.3%	25.4%	20.6%
x -1,0,1,2,3,4,5,6,7	0.0059%	2.66%	10.4%	29.9%	33.8%	35.9%	35.1%	29.8%	25.0%	20.3%