EIC - Low Q^2 Taggers

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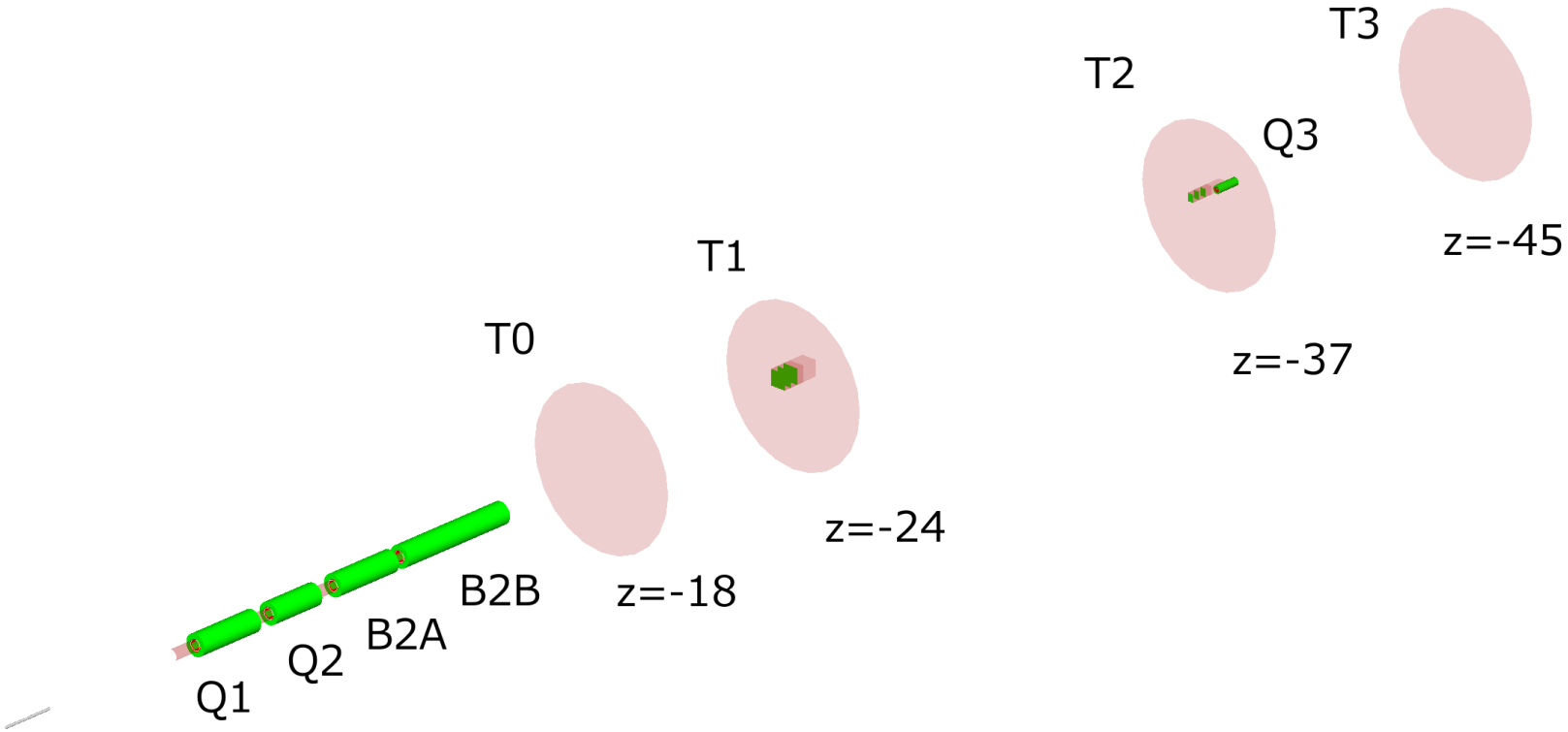
Detector-1 Far Backwards Meeting
12 May 2022

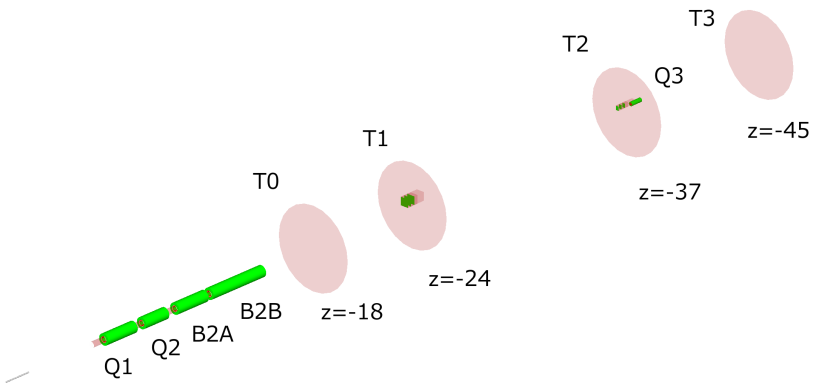
Outline

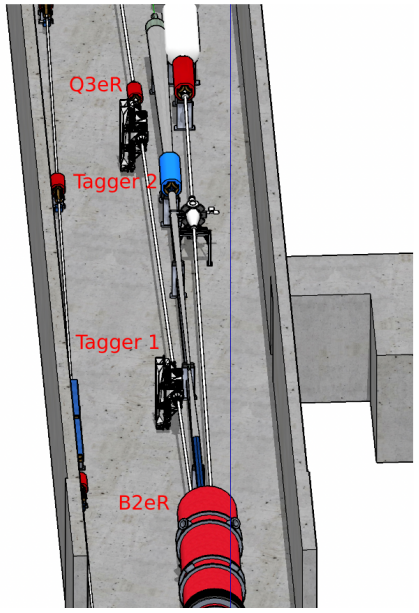
Far-Backwards Tagger Layout



- Adapted DD4hep implementation.
- World set to vacuum so beamline volumes could be removed.
- Virtual detector planes added as thin vacuum calorimeters at magnet exits and tagger positions.
- Magnet beampipe radii increased to HCAL hole radius.
- Central solenoid currently taken out.

Far-Backwards Tagger Layout





- Acceptance of virtual tagger planes T0-T3 investigated.
- (Looking at the machine file, T3 looks impossible, or would need more machine components added.)

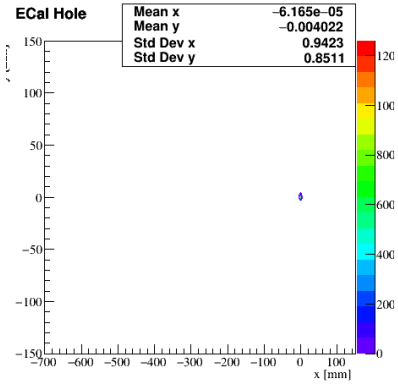
```
Q2ER_6    Quadrupole          +9.000000   1.400000            0 +0.0000000000
-0.000000     9.000000 -0.0000000000    -0.000000     9.000000 -0.0000000000
-0.000000  -0.000000   334.836741   -2.081789   227.614027   +6.770146            0
-12.05946
O2ER_6    Drift               +9.500000   0.500000            0 +0.0000000000
-0.000000     9.500000 -0.0000000000    -0.000000     9.500000 -0.0000000000
-0.000000  -0.000000   336.922512   -2.089754   220.895323   +6.667264            0
0
D2ER_6    Sbend              +15.000075   5.500075 -0.0180766389 +0.0000000000
0.049710    14.999775  0.0180766389     0.049710    14.999775  0.0180766389
-0.049710  -0.018077   360.390696   -2.177363   153.718775   +5.544492 +0.197333528
+0.00000
O3ER_6    Drift              +37.700075  22.700000            0 +0.0000000000
0.460027    37.696067 0.0180766389     0.460027    37.696067  0.0180766389
-0.460061  -0.018077   467.451398   -2.538967     8.401073   +0.857169            0
0
Q3ER_6    Quadrupole         +38.300075   0.600000            0 +0.0000000000
0.470873    38.295969 0.0180766389     0.470873    38.295969  0.0180766389
-0.465495  +0.000000   459.607101  +15.510698     7.629325   +0.439092            0
-3.90130
OQCER_6   Drift              +38.600075   0.300000            0 +0.0000000000
0.476296    38.595920 0.0180766389     0.476296    38.595920  0.0180766389
-0.465495  +0.000000   450.347989  +15.353010     7.379940   +0.392189            0
0
O_CRAB_ER Drift              +42.600075   4.000000            0 +0.0000000000
0.548598    42.595266 0.0180766389     0.548598    42.595266  0.0180766389
-0.465495  +0.000000   335.933938  +13.250503     6.743940   -0.233189            0
0
OQCER_6   Drift              +42.900075   0.300000            0 +0.0000000000
0.554021    42.895217  0.0180766389     0.554021    42.895217  0.0180766389
-0.465495  +0.000000   328.030943  +13.092815     6.897925   -0.280092            0
0
Q4ER_6    Quadrupole         +43.500075   0.600000            0 +0.0000000000
0.564866    43.495119  0.0180766389     0.564866    43.495119  0.0180766389
-0.461090  +0.014660   306.526503  +22.521168     7.426523   -0.606465            0
```

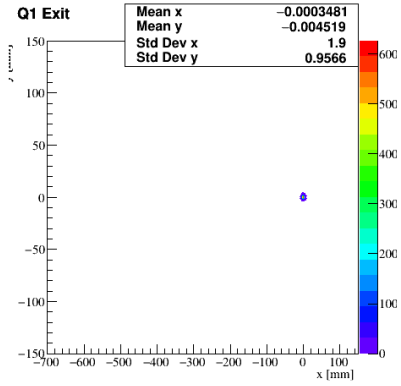
Outline

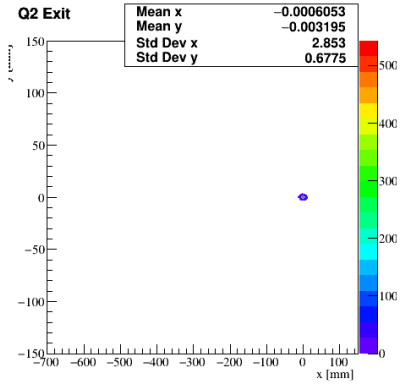
Acceptance studies

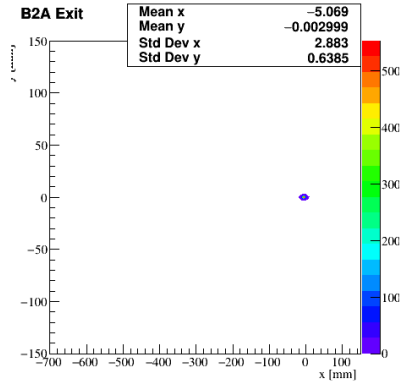
- Beam spot tracked through virtual planes.
- 10σ rectangular cut made physics events.
- Using Jarda's QR generator at 18x275GeV and Derek Glazier's spectrosopy events at 5x10GeV.

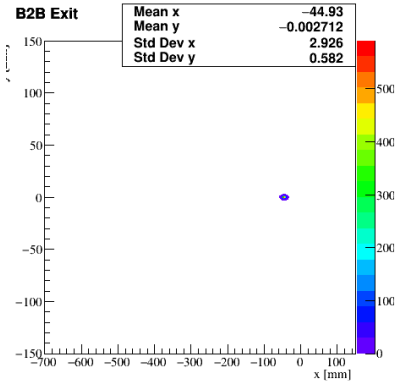
Beamspot - 18GeV

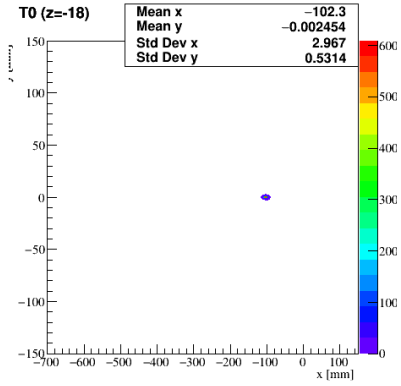


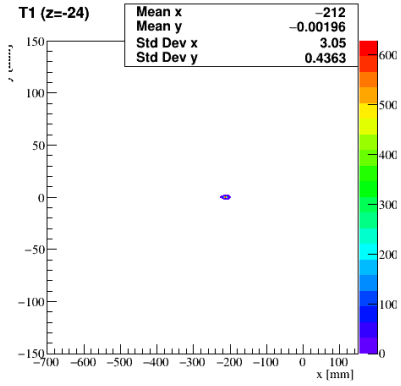


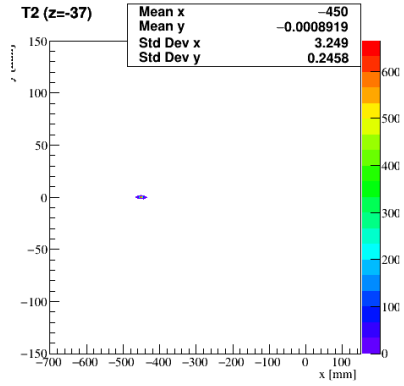


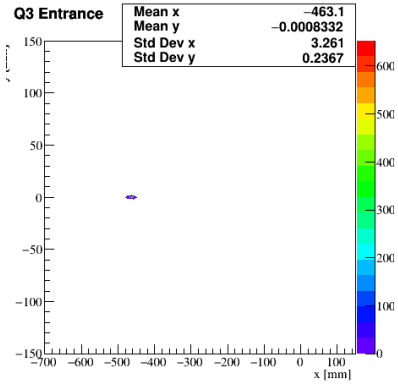


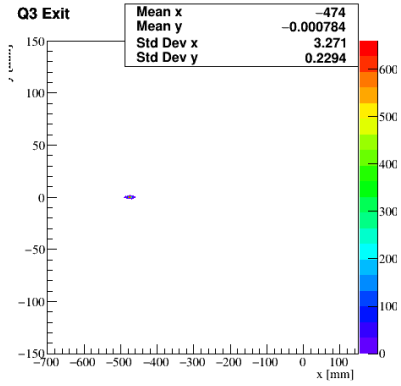


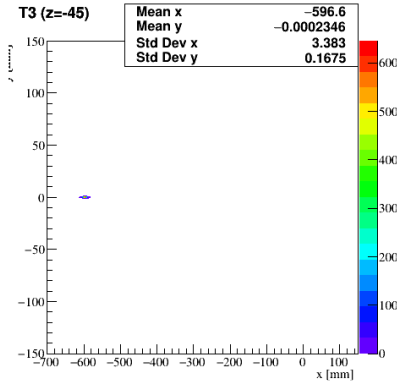




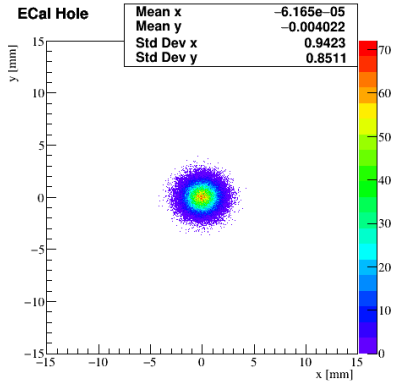


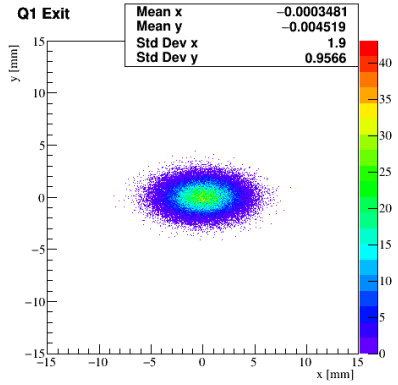


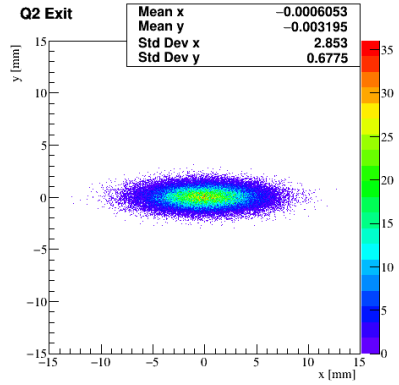


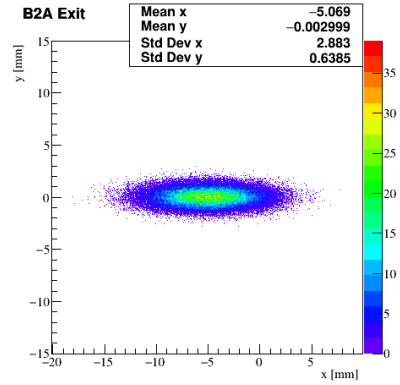


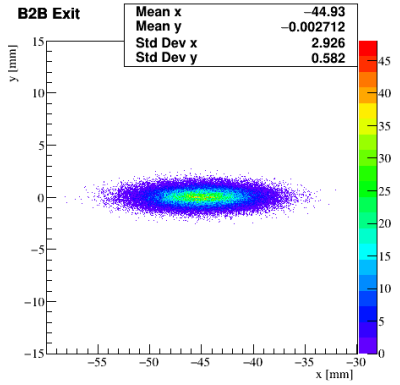
Beamspot - 18GeV

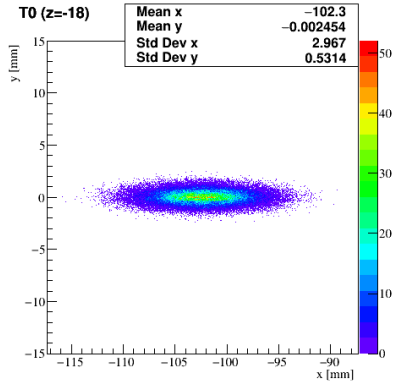


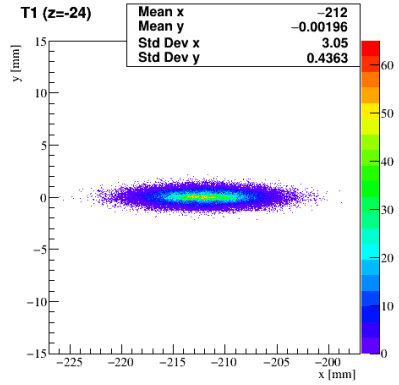


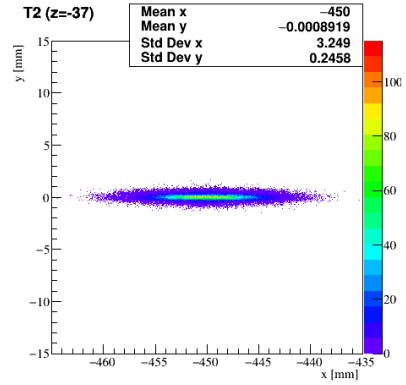


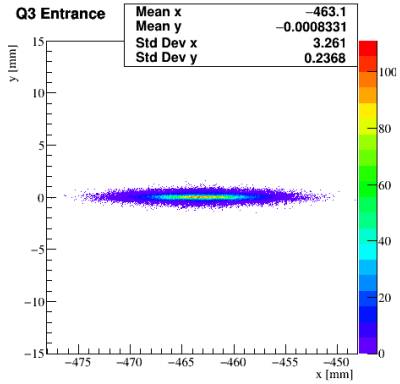


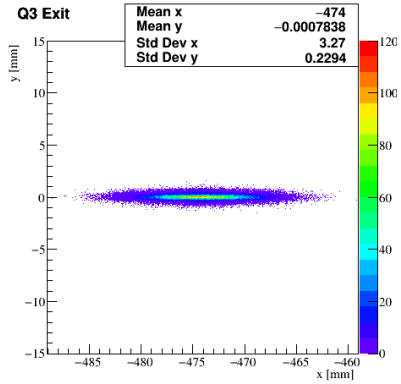


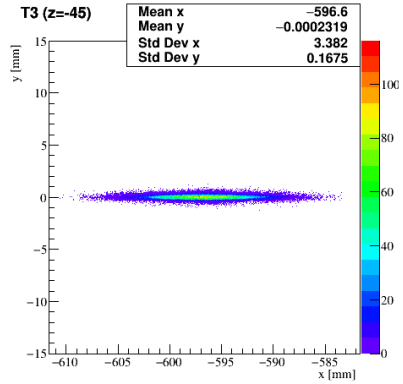






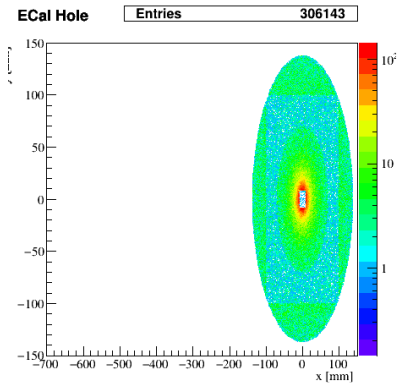


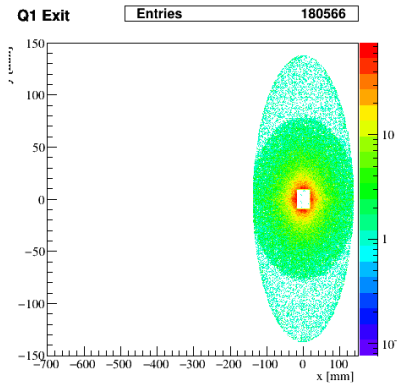


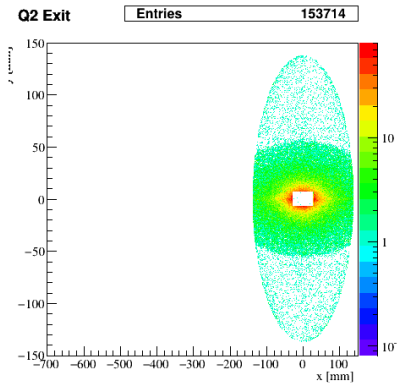


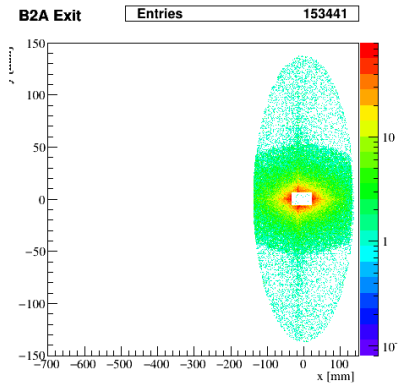
QR Distribution - 18GeV

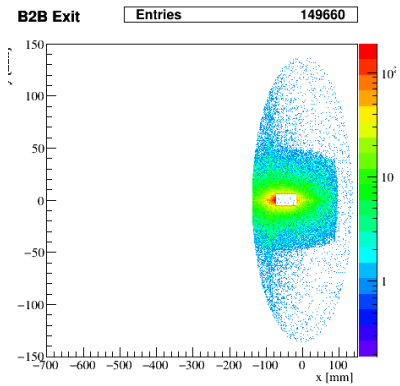
Events from QR generator by Jarda.

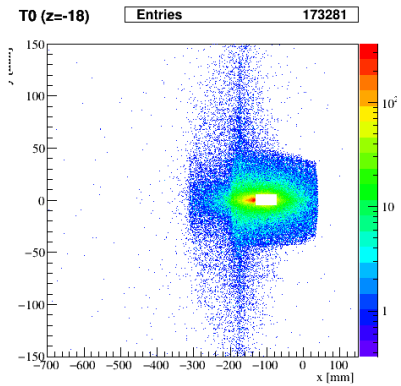


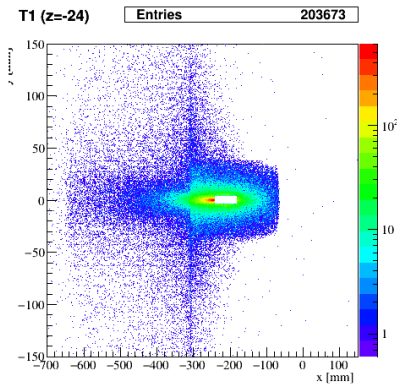


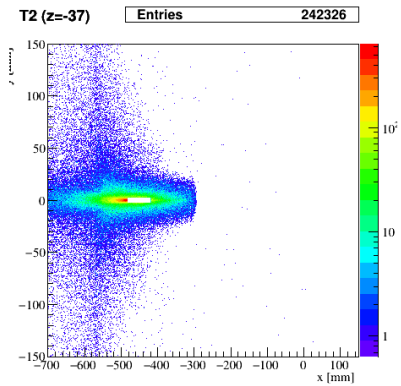


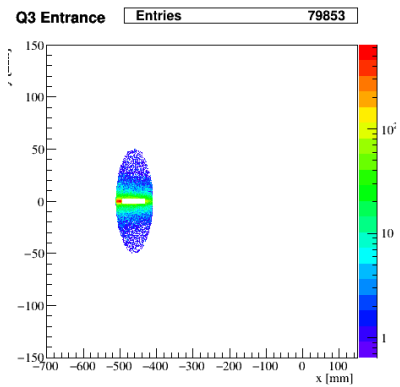


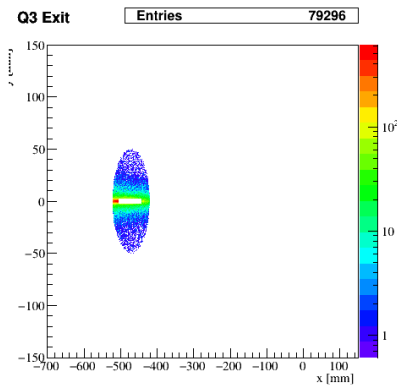


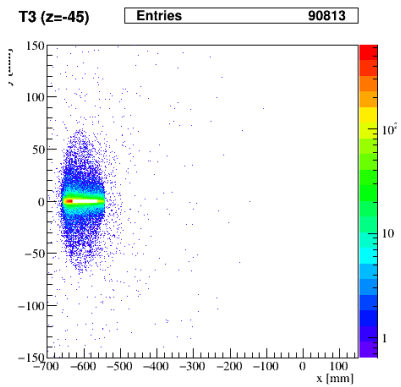






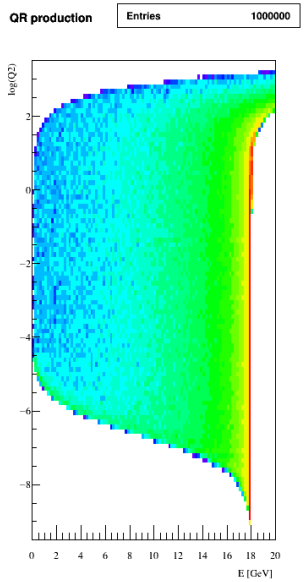


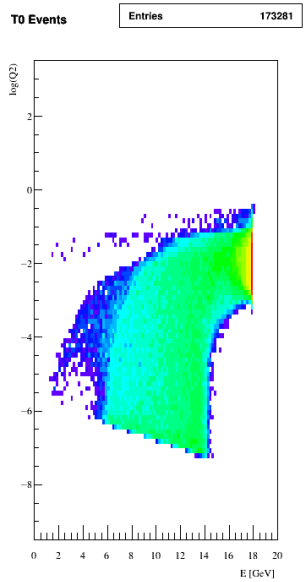


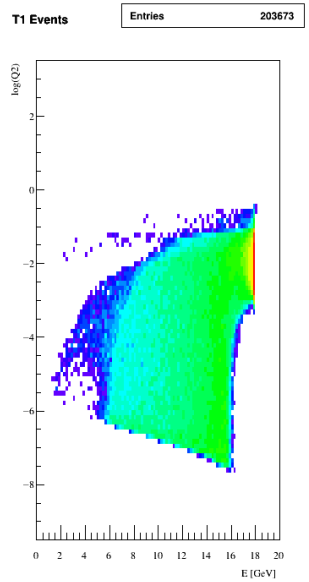


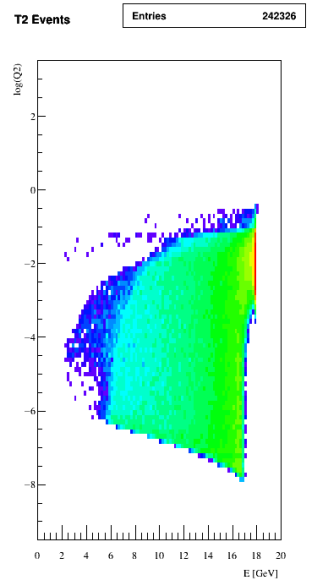
QR E-log(Q^2) Acceptance - 18GeV

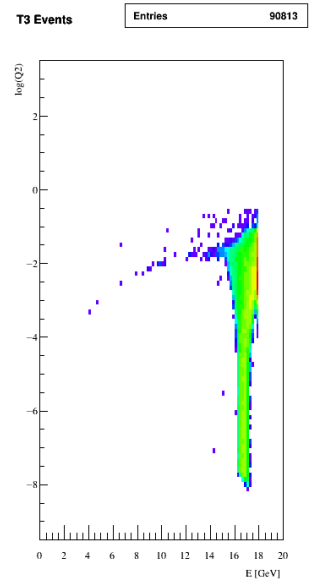
x-y 10σ cut

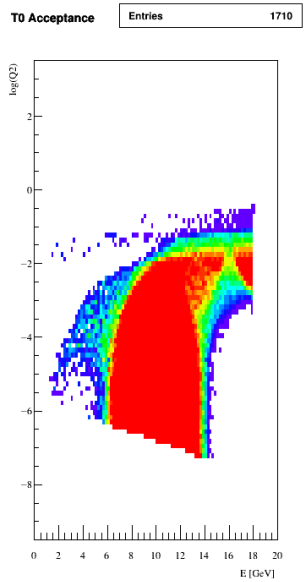


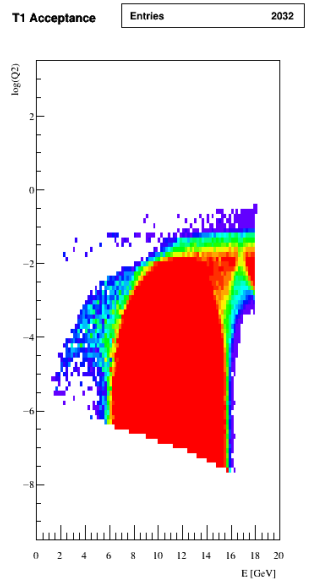


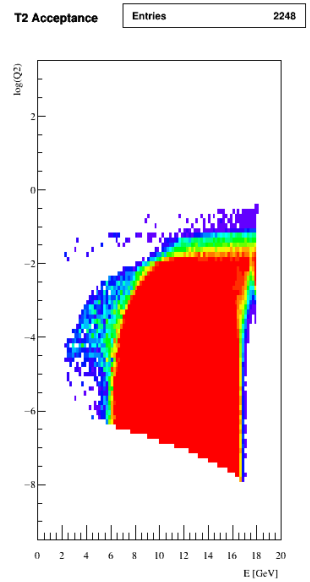


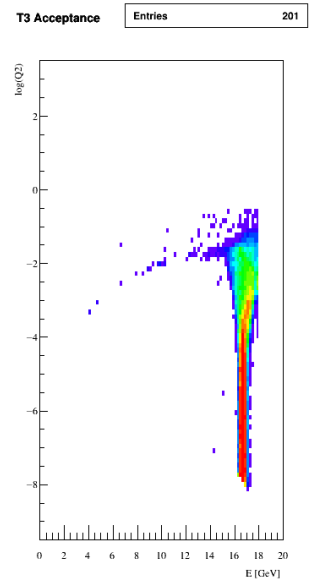






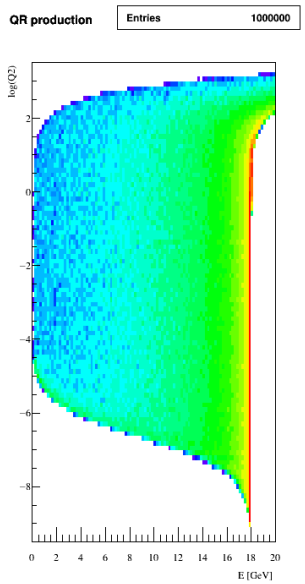


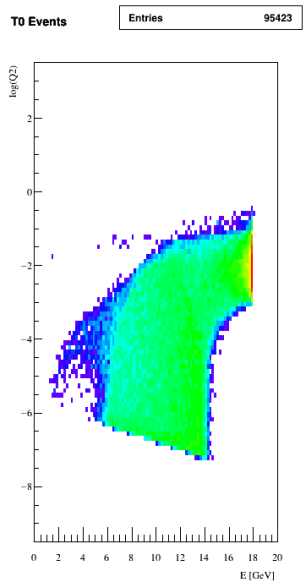


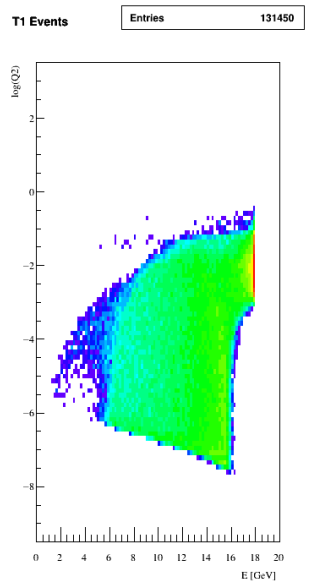


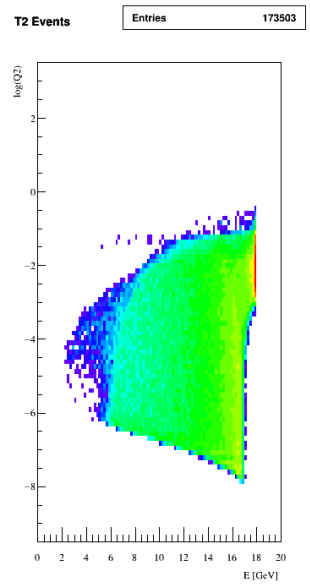
QR E-log(Q^2) Acceptance - 18GeV

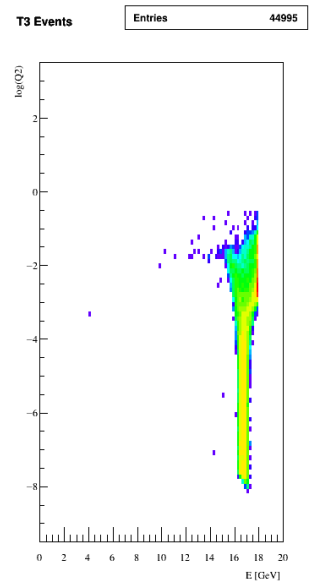
x negative 10σ cut

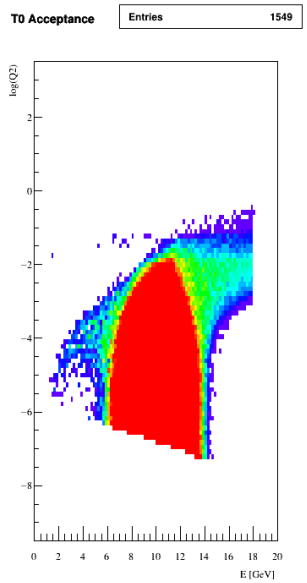


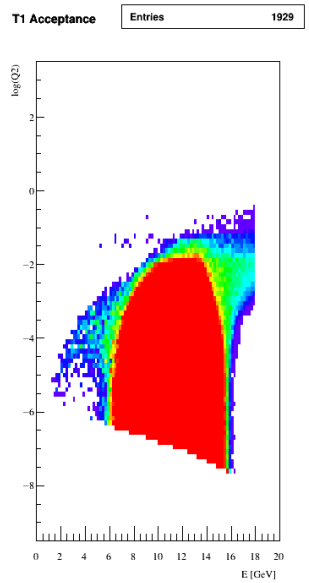


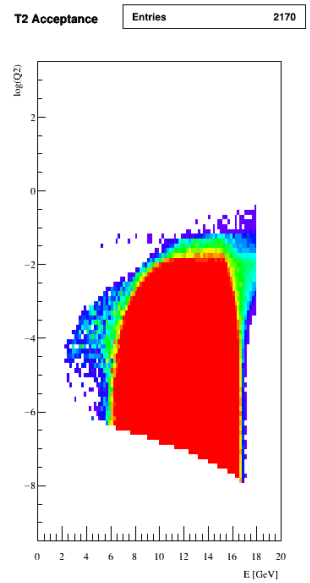


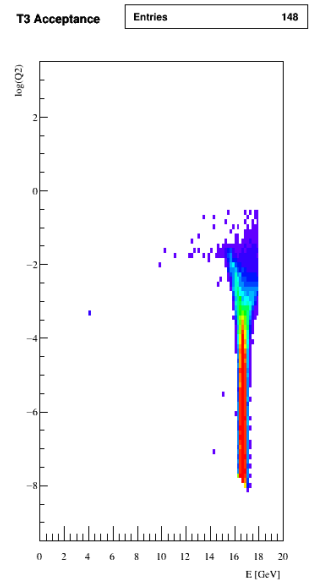




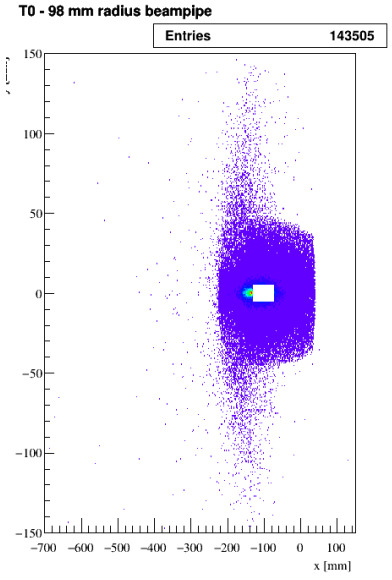


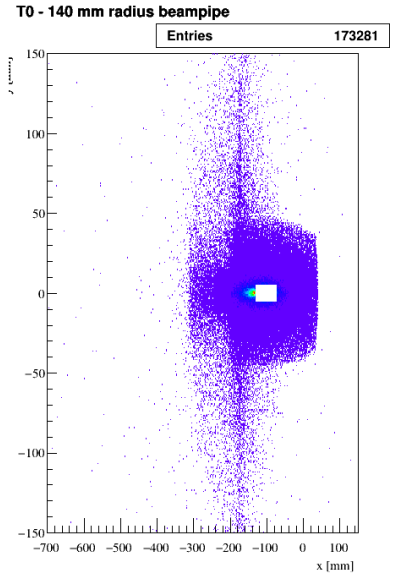


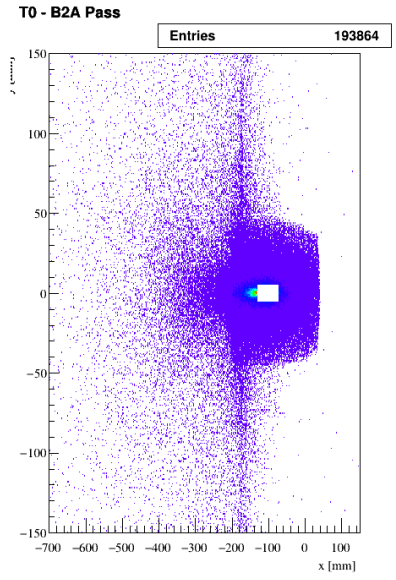


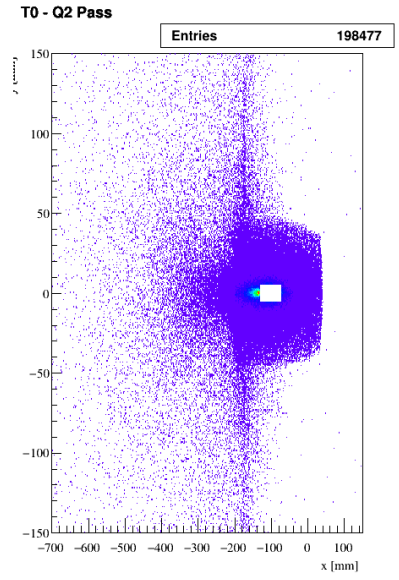


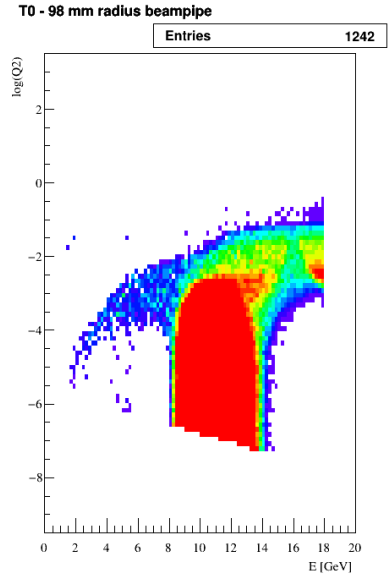
Extending Acceptance - 18GeV

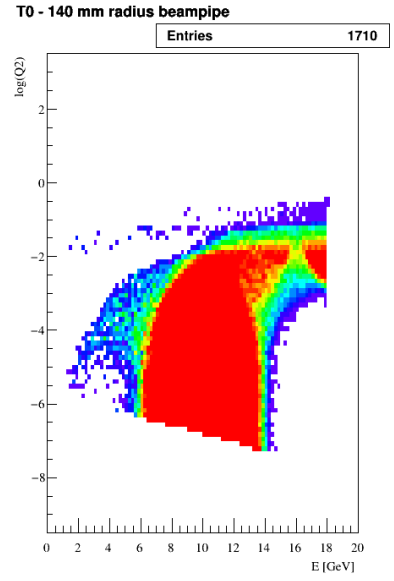


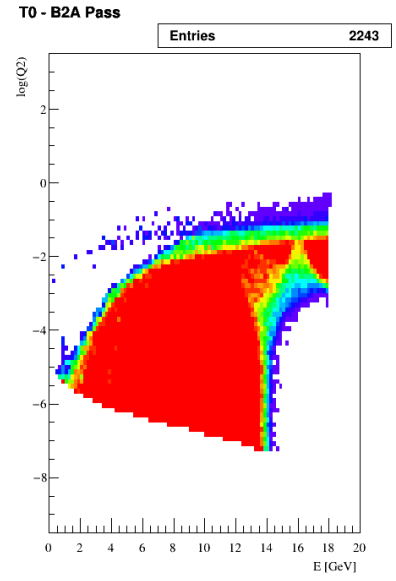


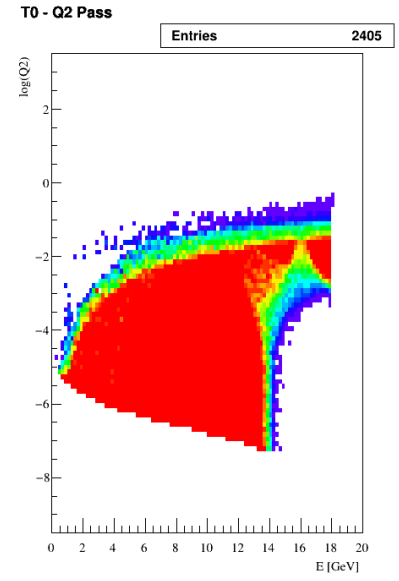




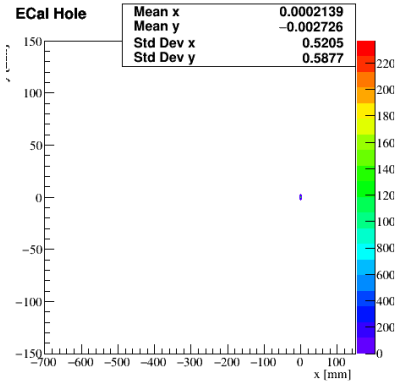


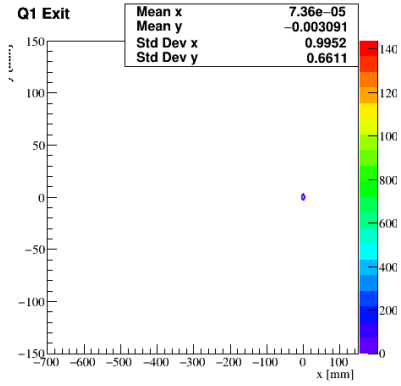


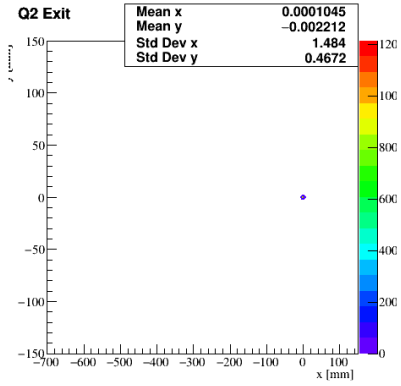


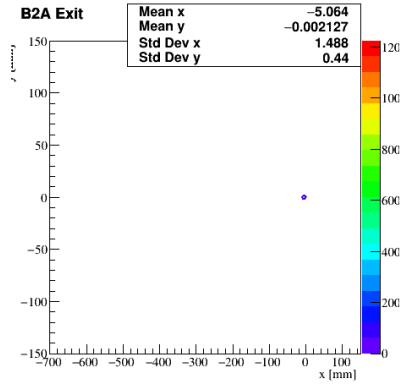


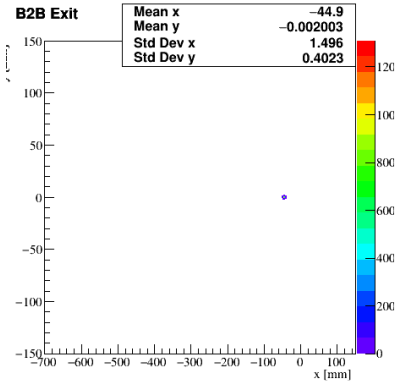
Beamspot - 5GeV

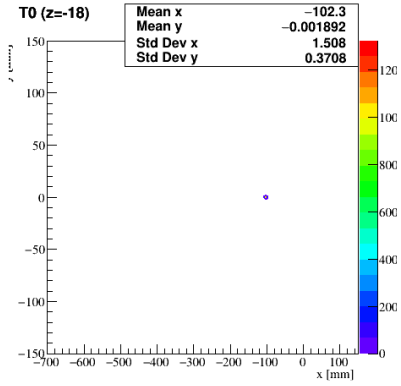


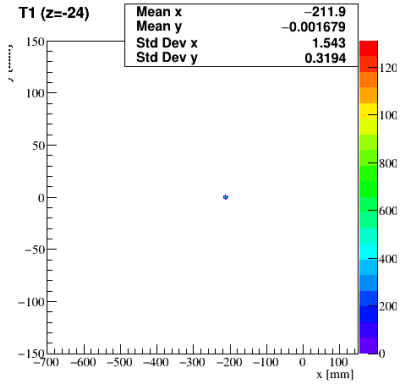


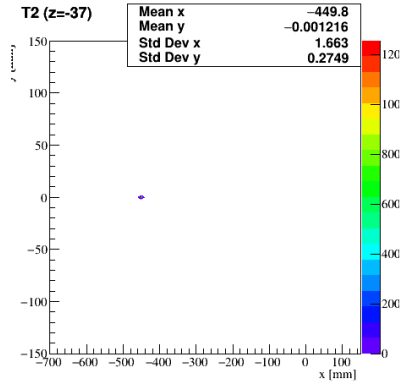


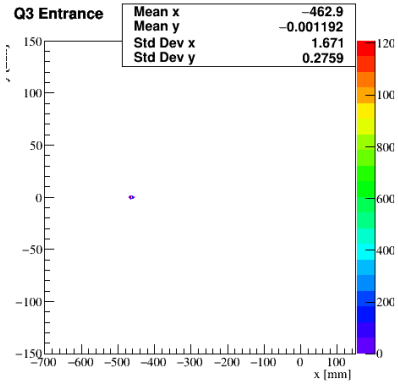


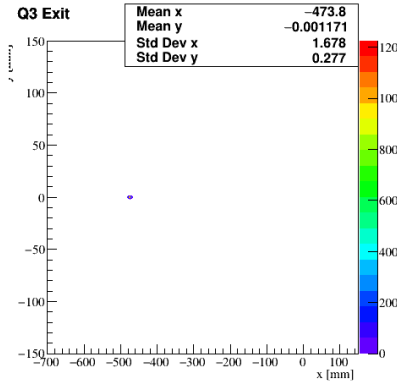


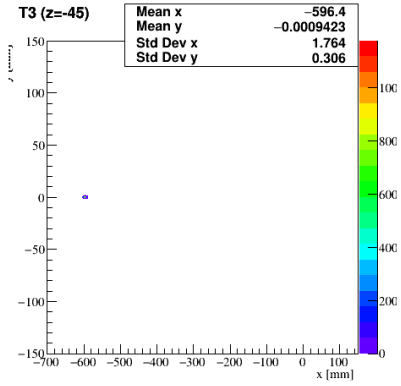




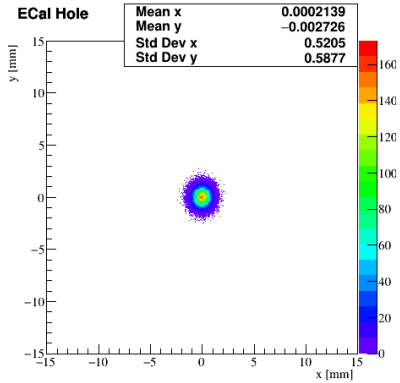


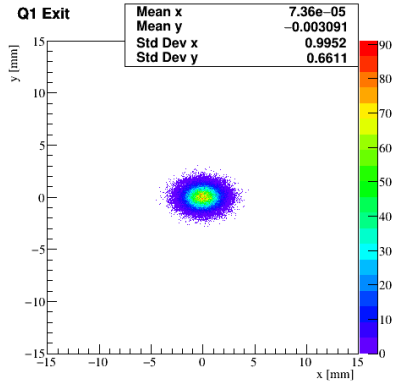


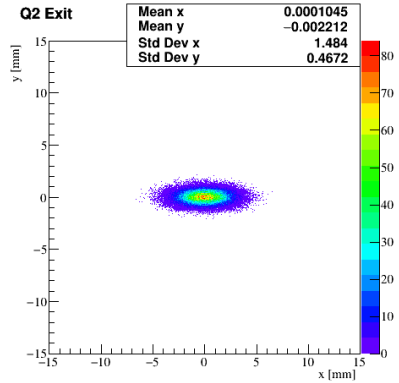


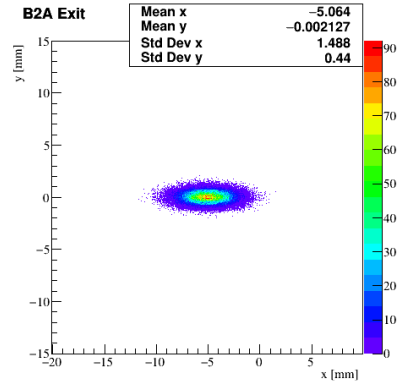


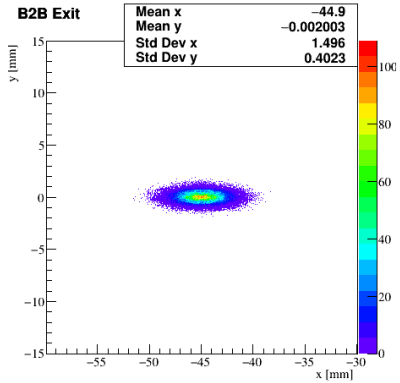
Beamspot - 5GeV

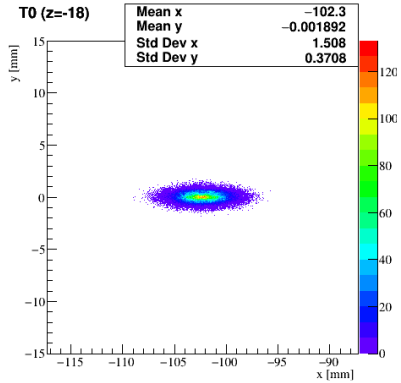


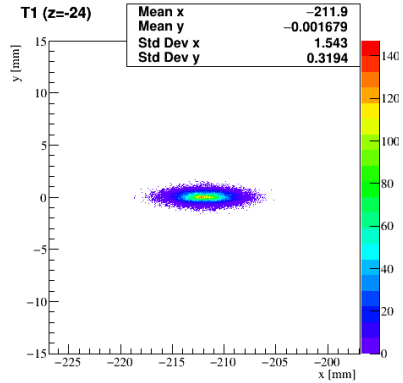


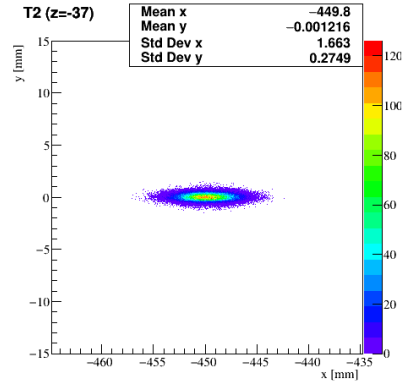


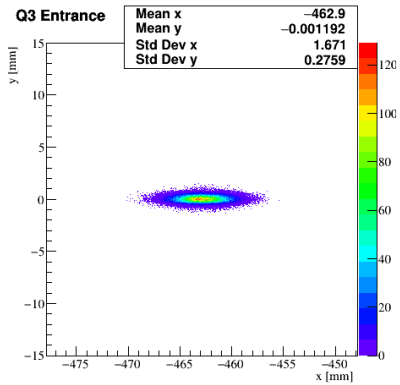


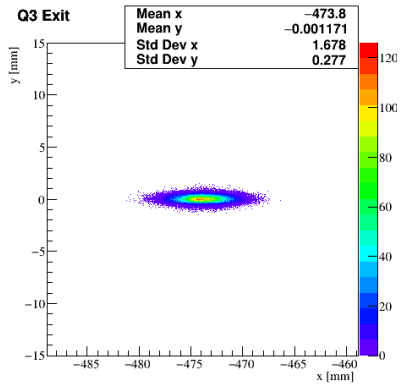


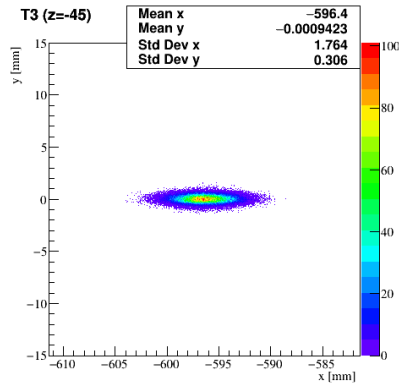






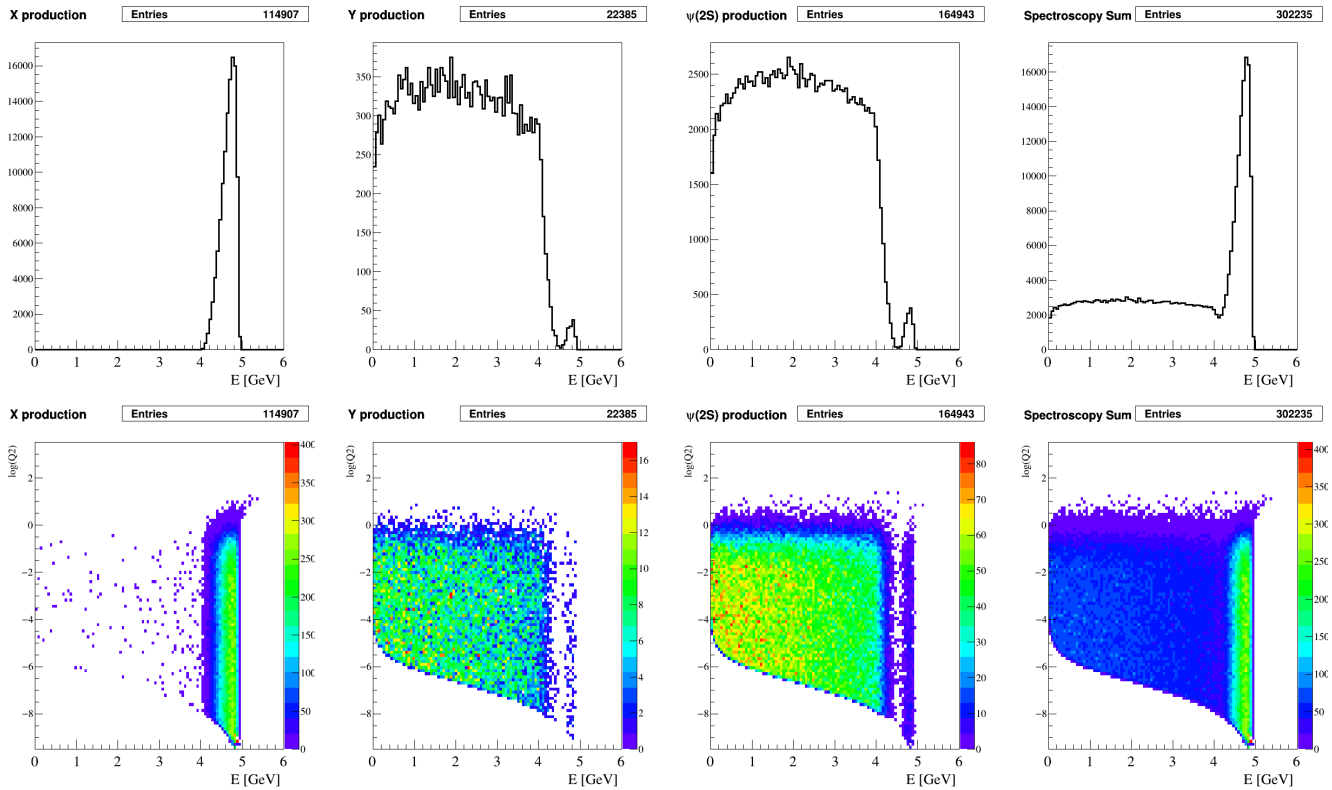




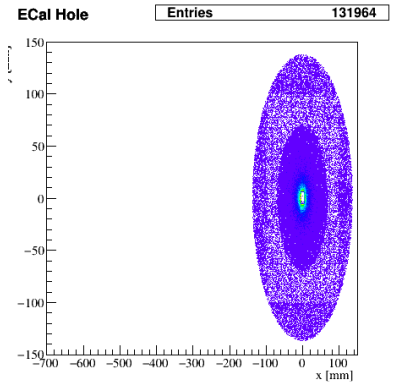


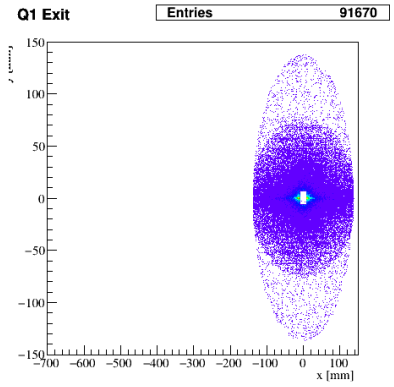
Spectroscopy Events - 5GeV

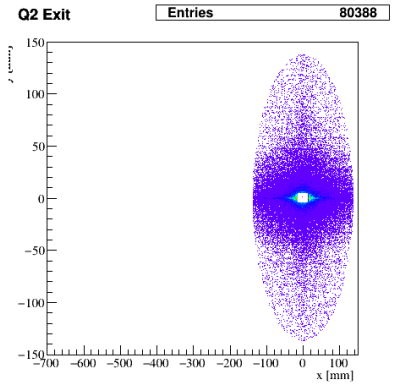
Events from generator by Derek Glazier:
https://github.com/dglazier/elSpectro/
Also on ECCE event database somewhere.
No beam effects or crossing angle in these events
Crossing angle has since been implemented

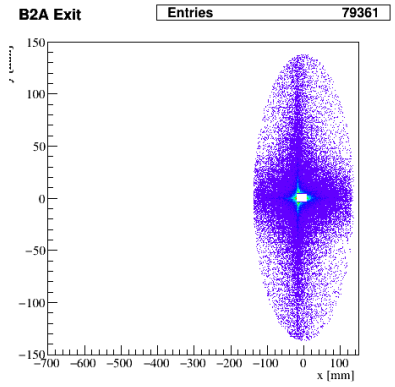


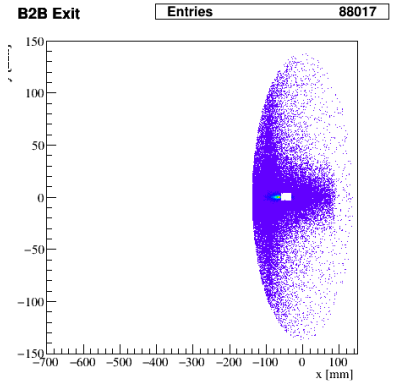
Spectroscopy Distribution - 5GeV

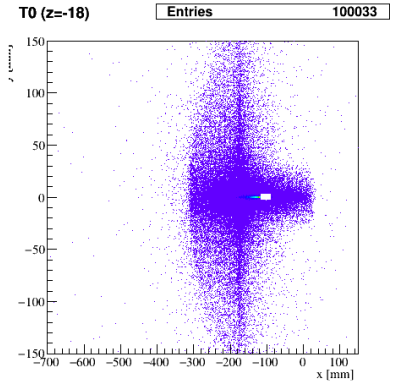


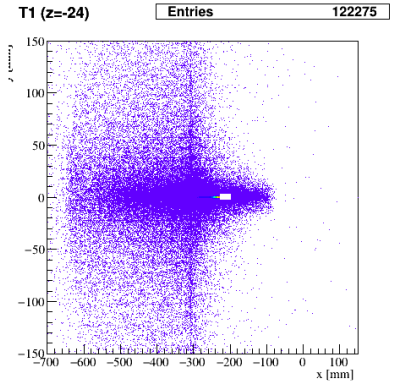


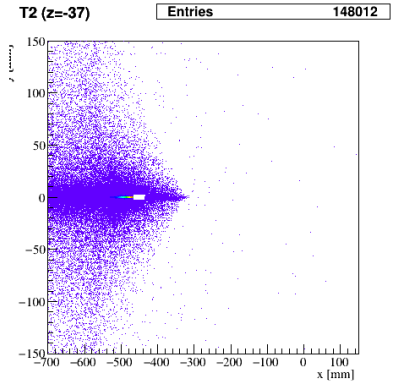


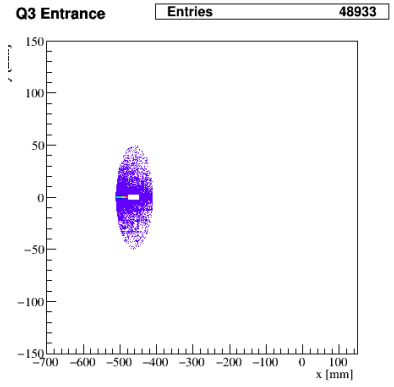


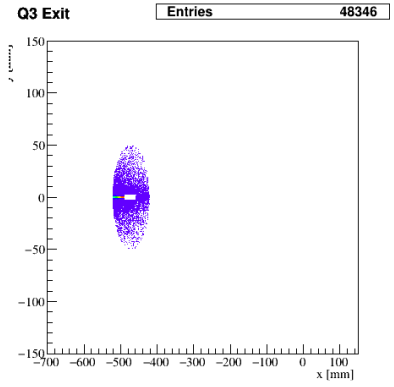


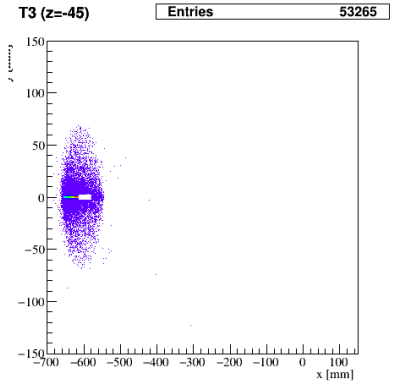




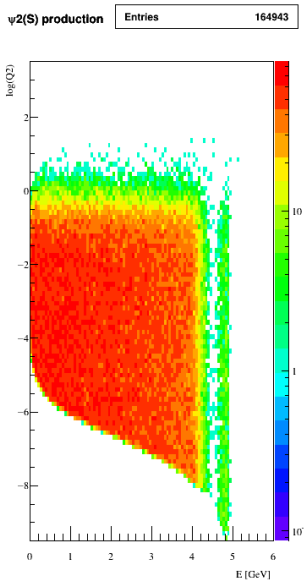


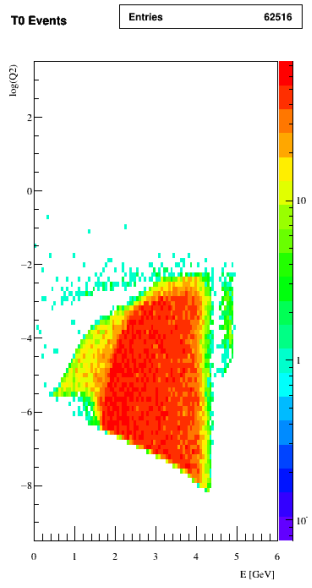


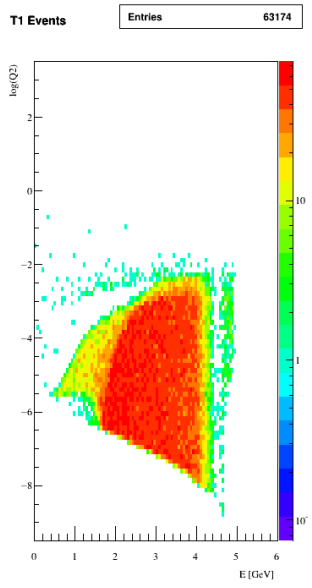


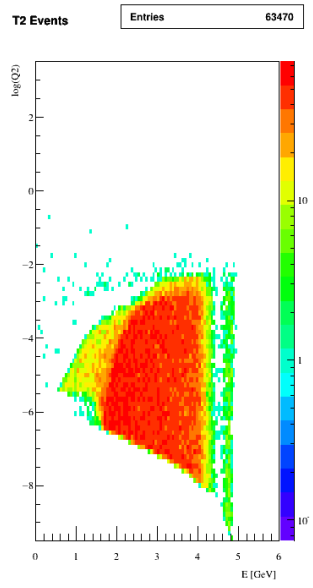


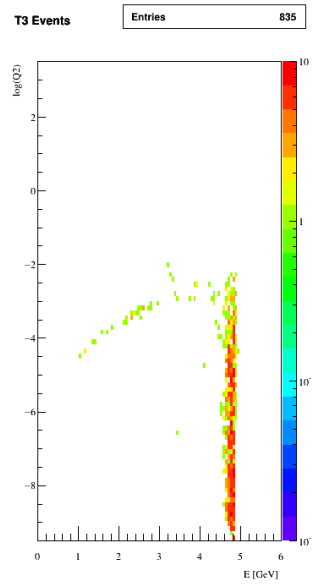
Spectroscopy Acceptance $\phi(2S)$ - 5GeV

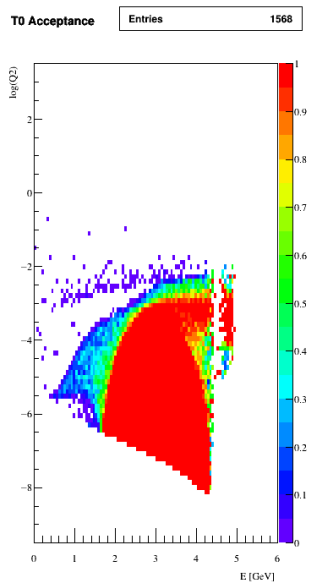


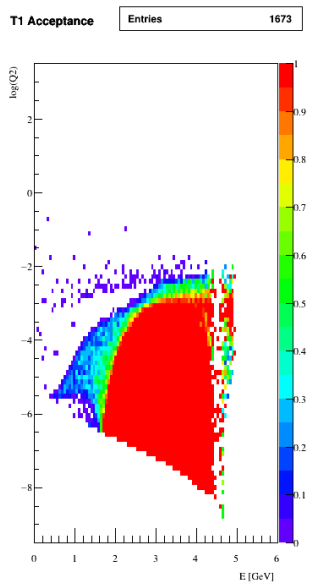


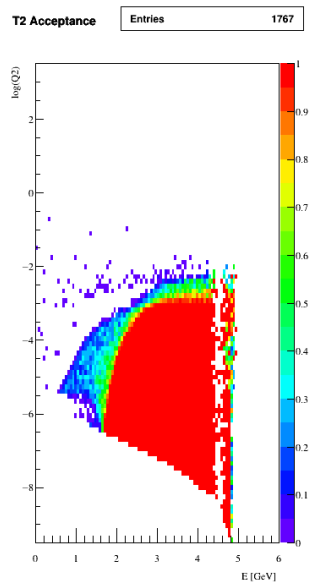


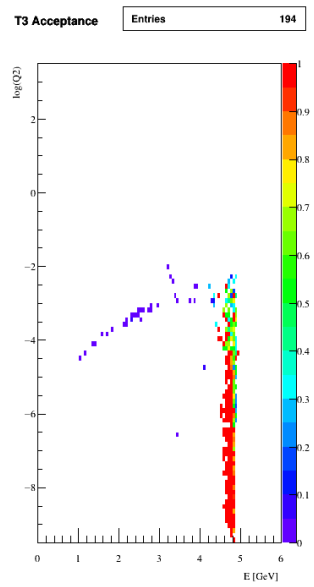






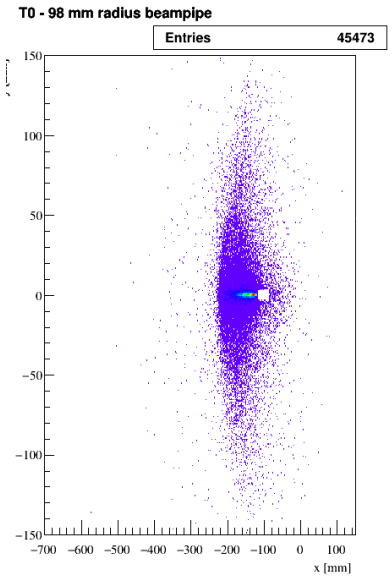


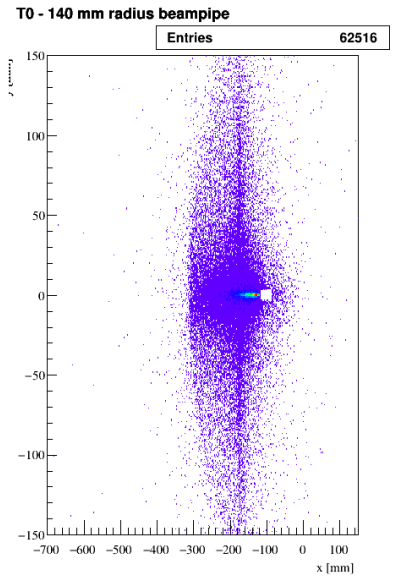


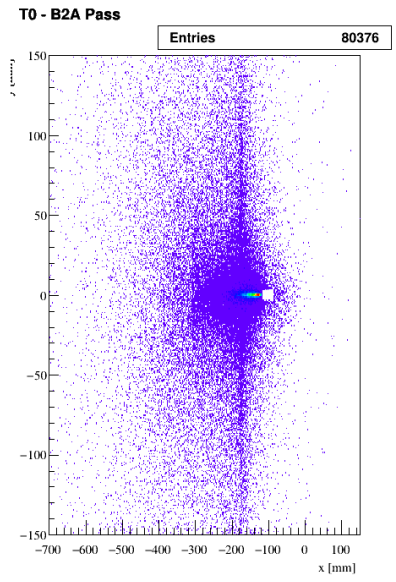


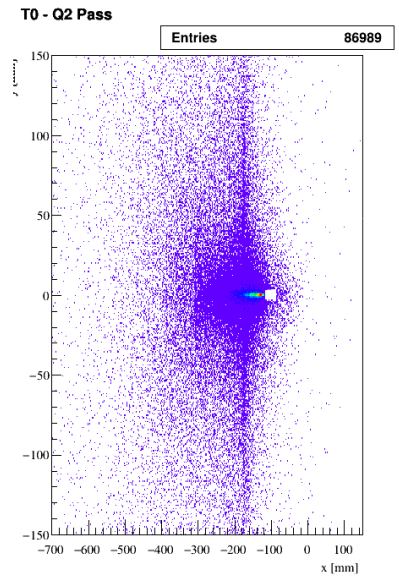
Extending Acceptance ϕ(2S) - 5GeV

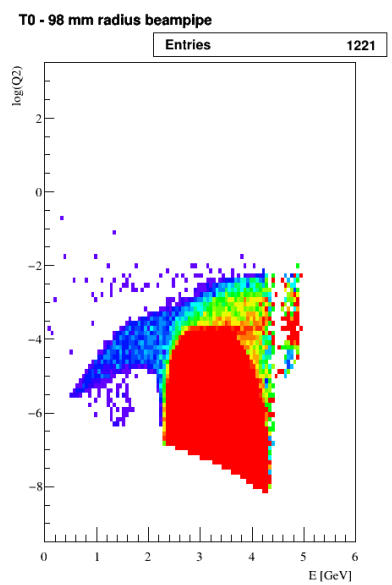
Almost doubling the number of ϕ(2S) events detectable.

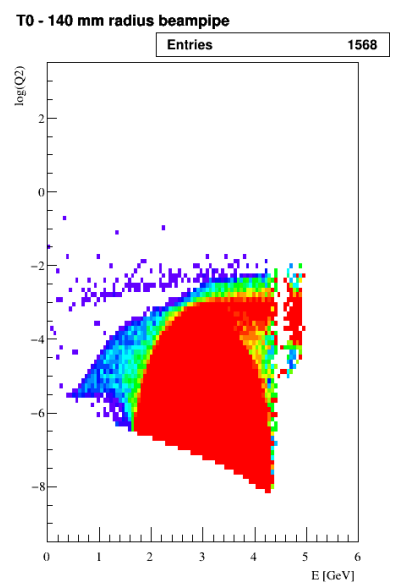


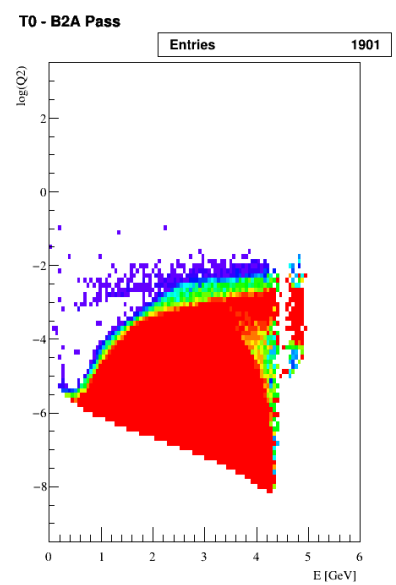


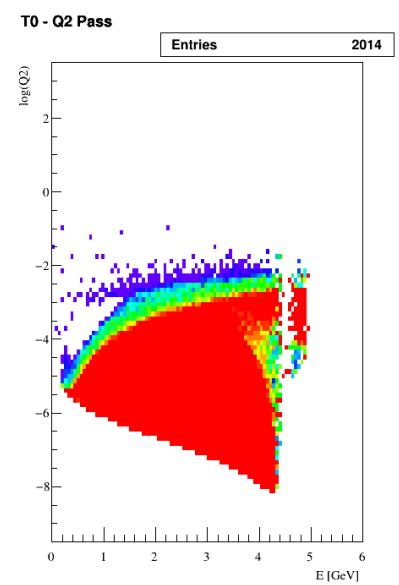




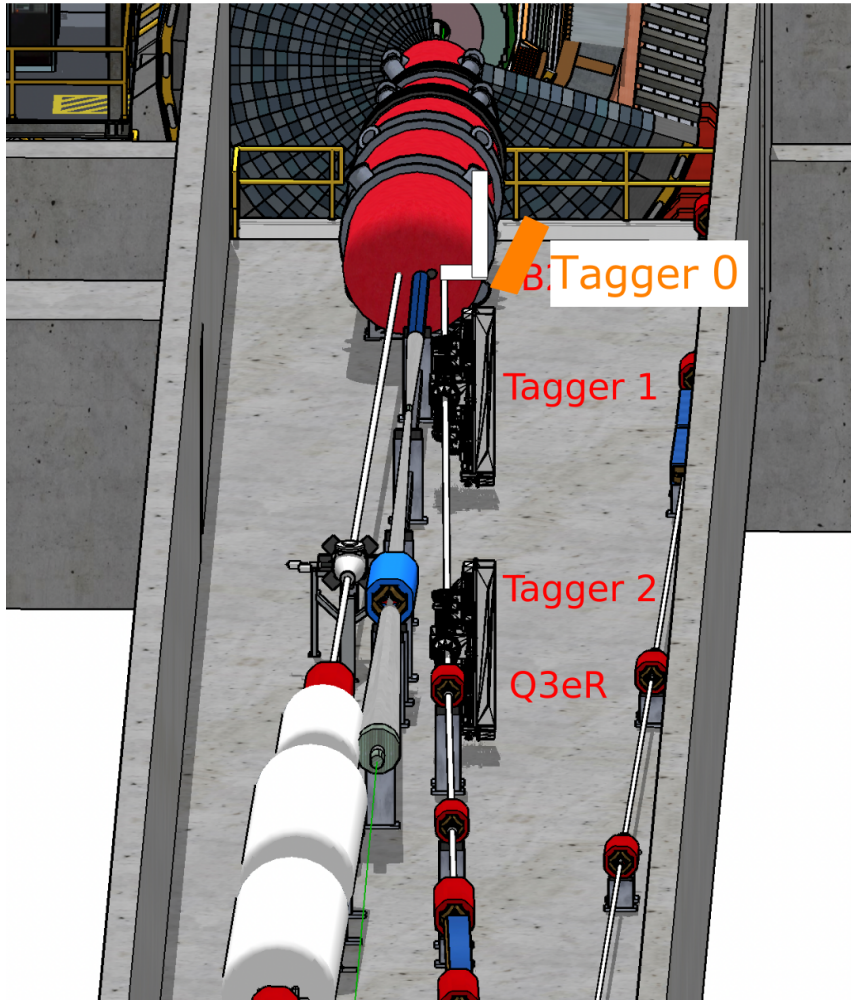








Extending Acceptance

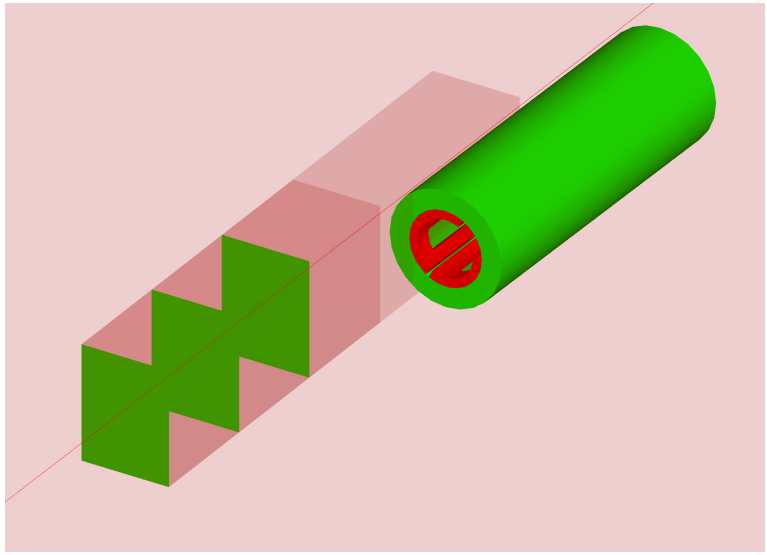


XYZ spectroscopy events show use for lower energy tagging.
Much lower Brems background.
Could make smaller tagger much closer for low E.
Need to change dipole from cylinder?

Outline

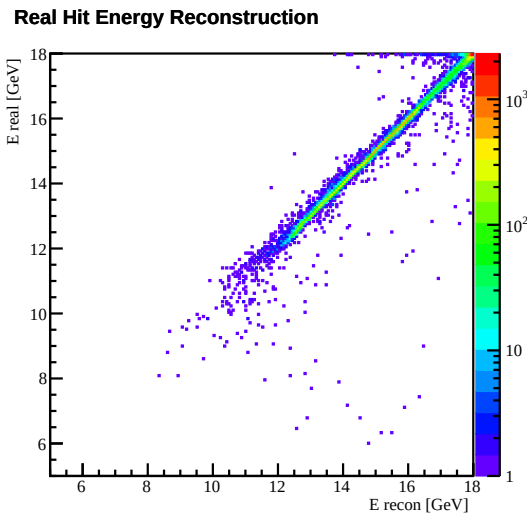
Interaction Reconstruction

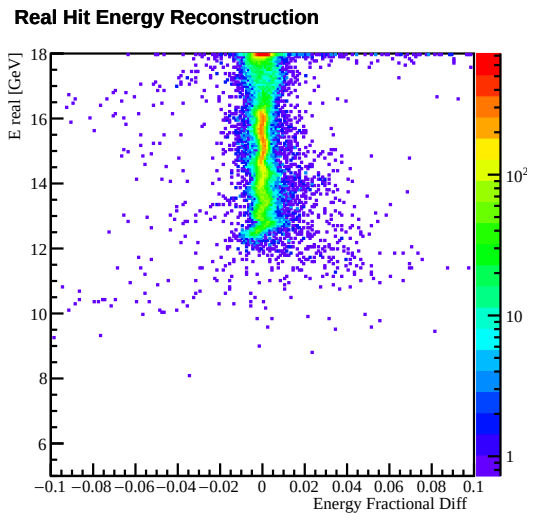
- Machine learning approach using simple ROOT TMVA (DNN) neural network.
- Focus on Tagger 2.
- Two methods:
  - Position and vector of front detector hit.
  - x-y hit pixel number on two or more layers.
- 55 μm initial pixel size
- 20 cm initial layer separation
- Increased pixel size by using floor(pixX/N)

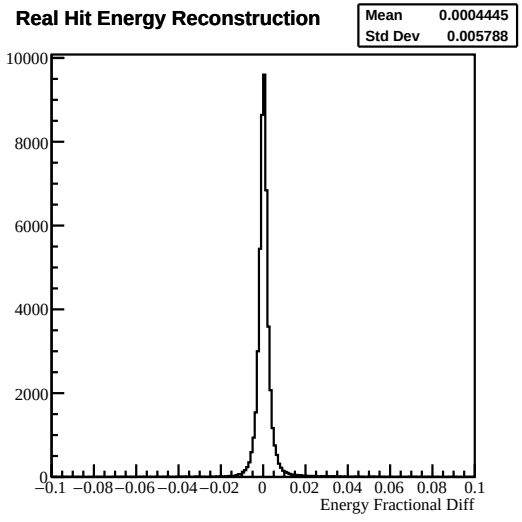


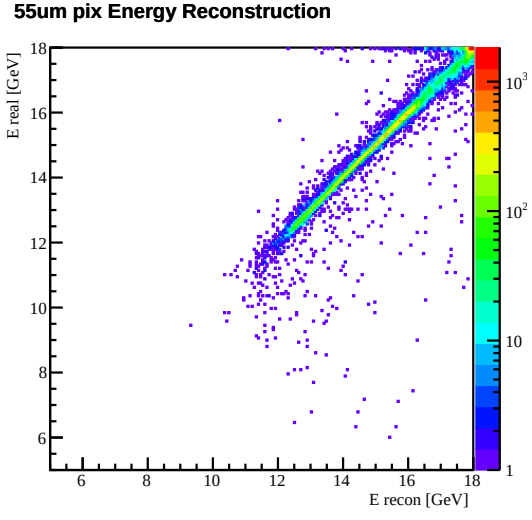
Native DD4Hep pixelization

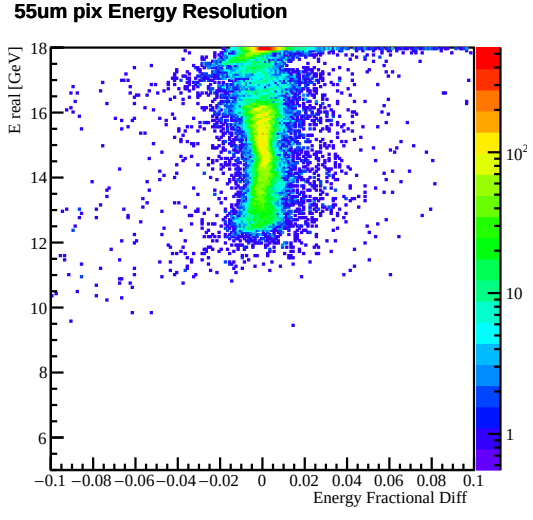
Energy Resolution - Tagger 2 - 18GeV

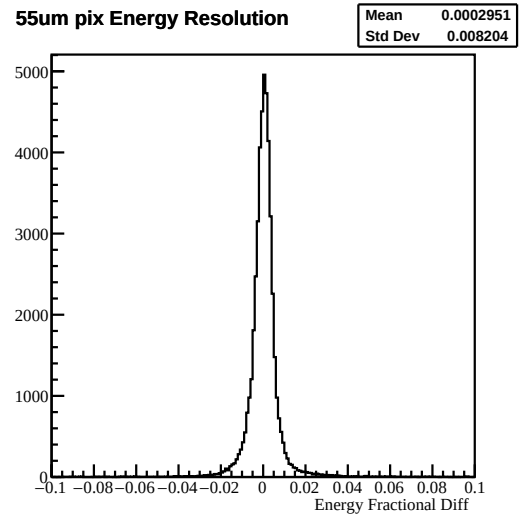




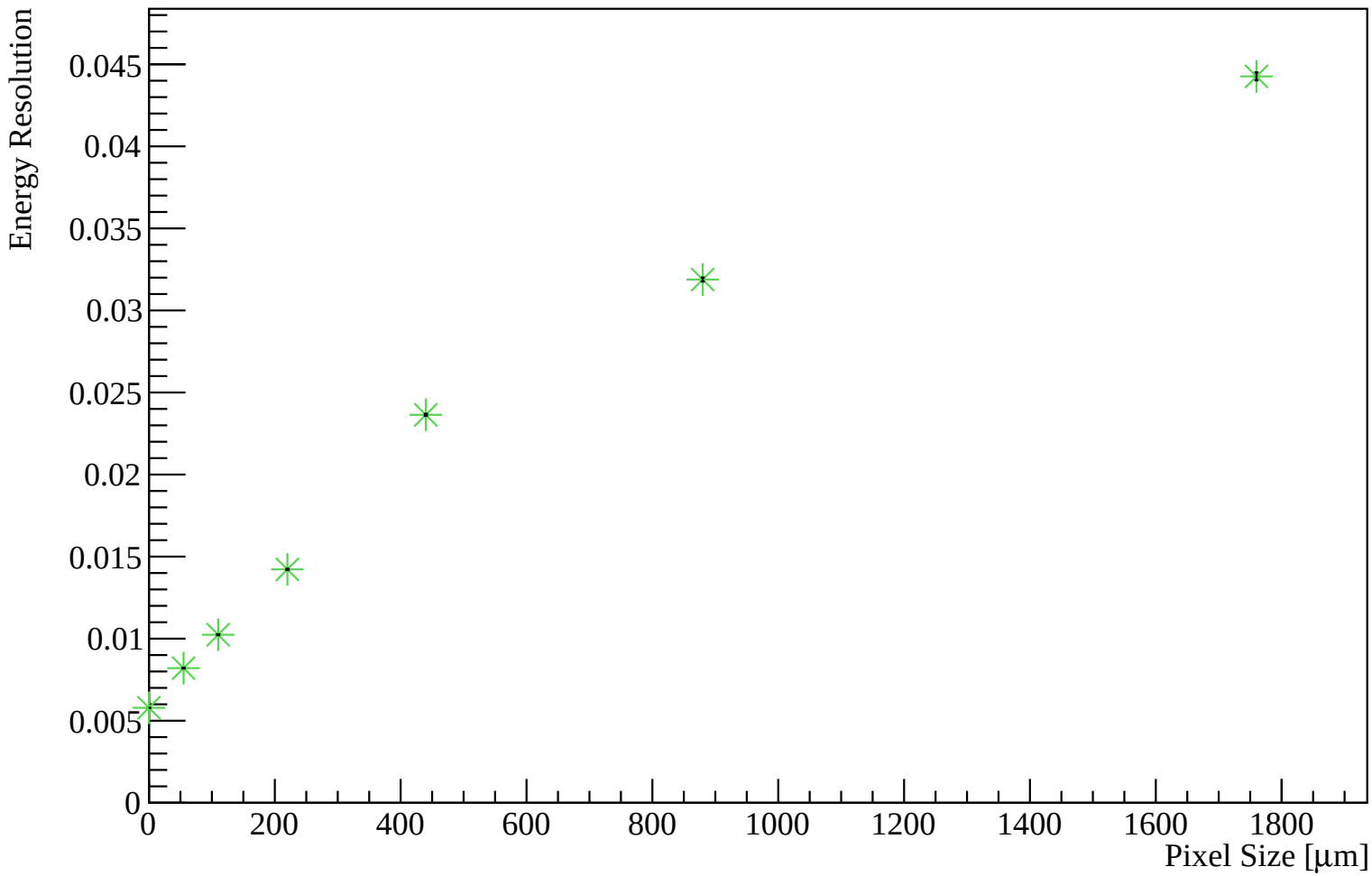






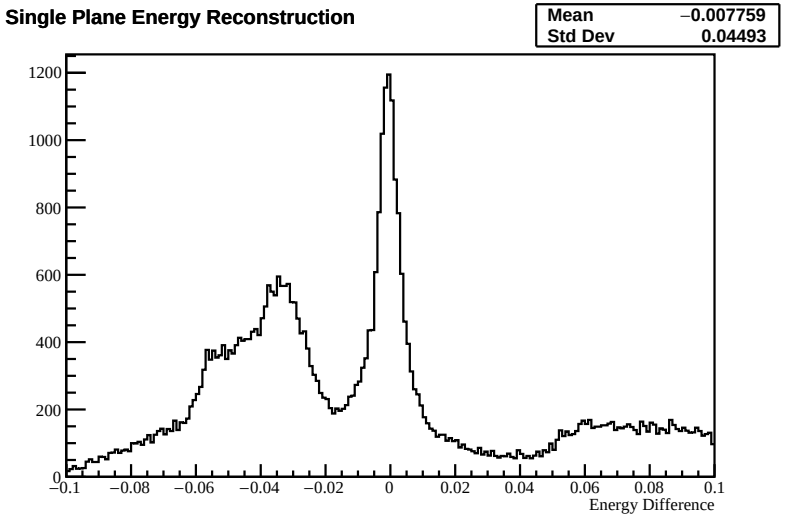


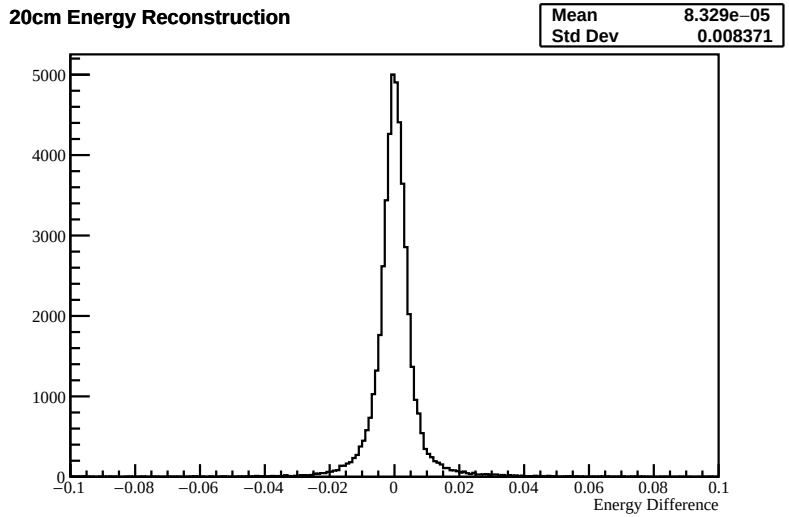
Energy Resolution - Tagger 2 - 18GeV

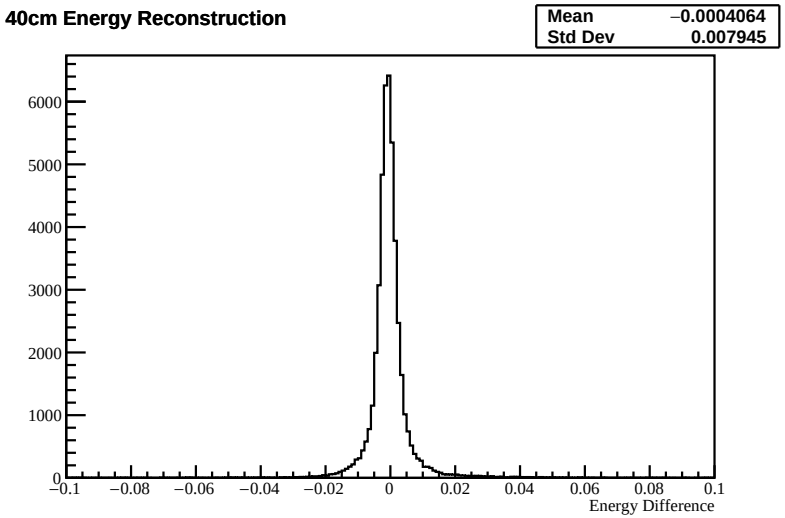


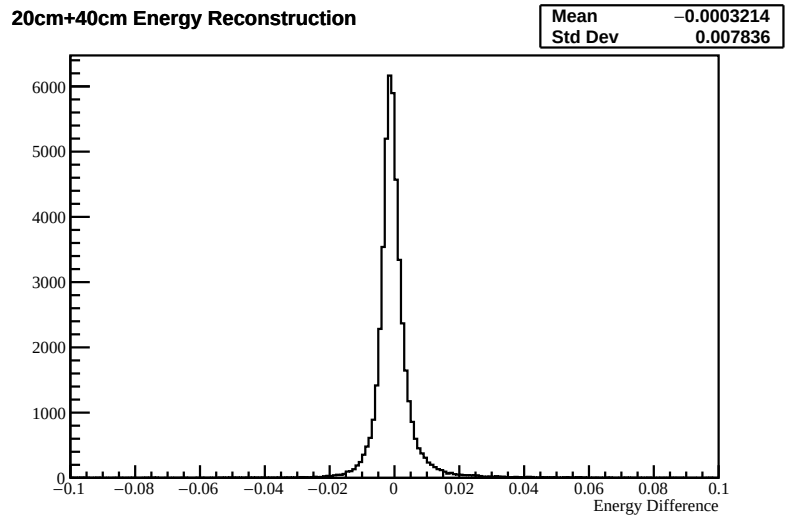
Energy Resolution - Tagger 2 - 18GeV

55 μm pixels using different combination of tagger layers.

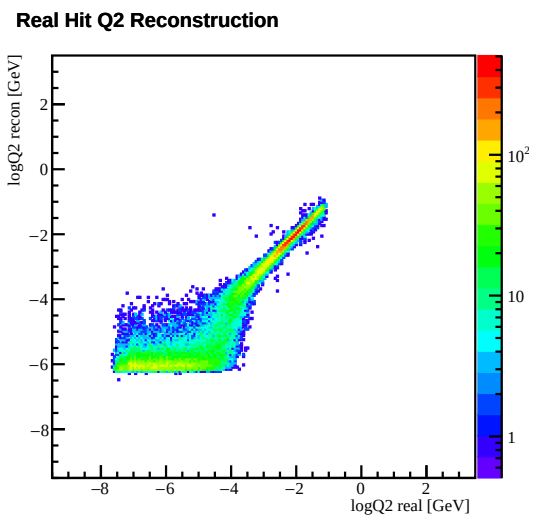


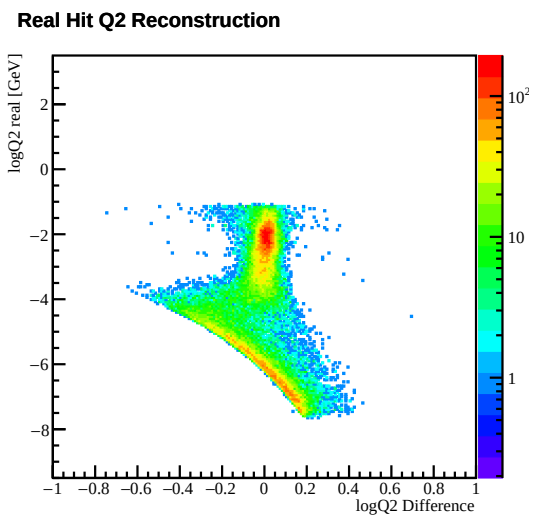


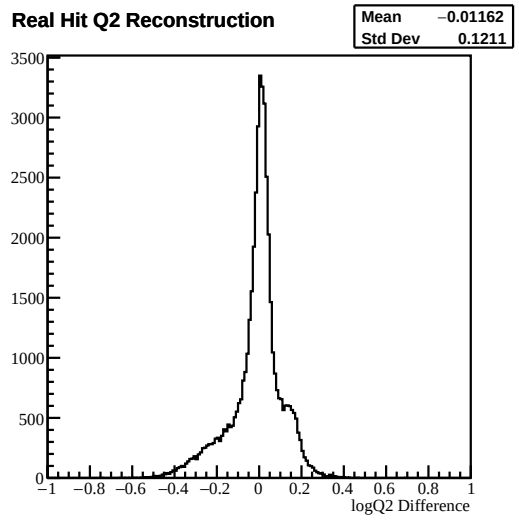


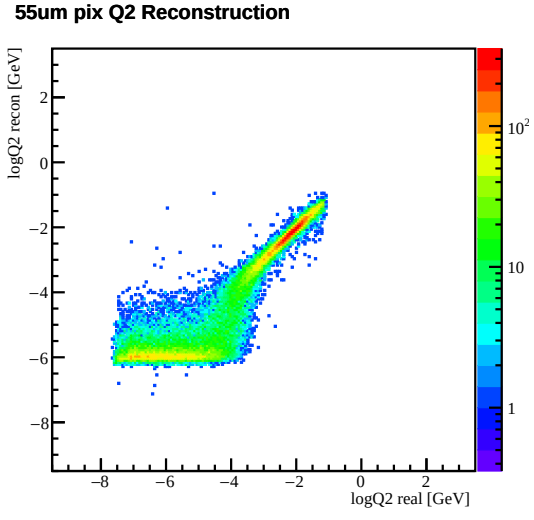


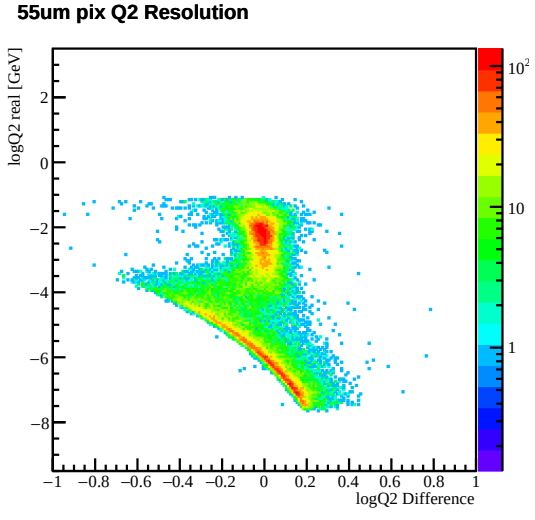
$\log Q^2$ Resolution - Tagger 2 - 18GeV

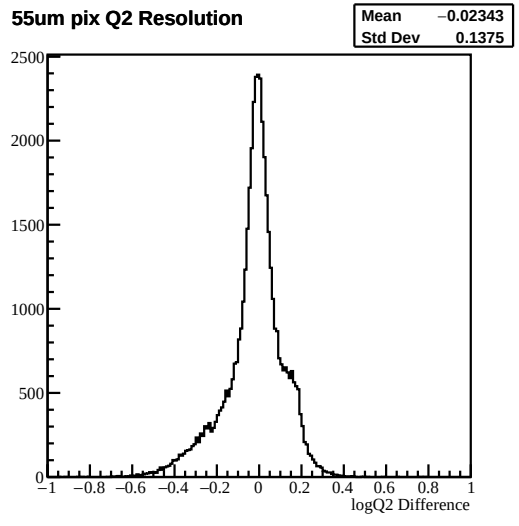




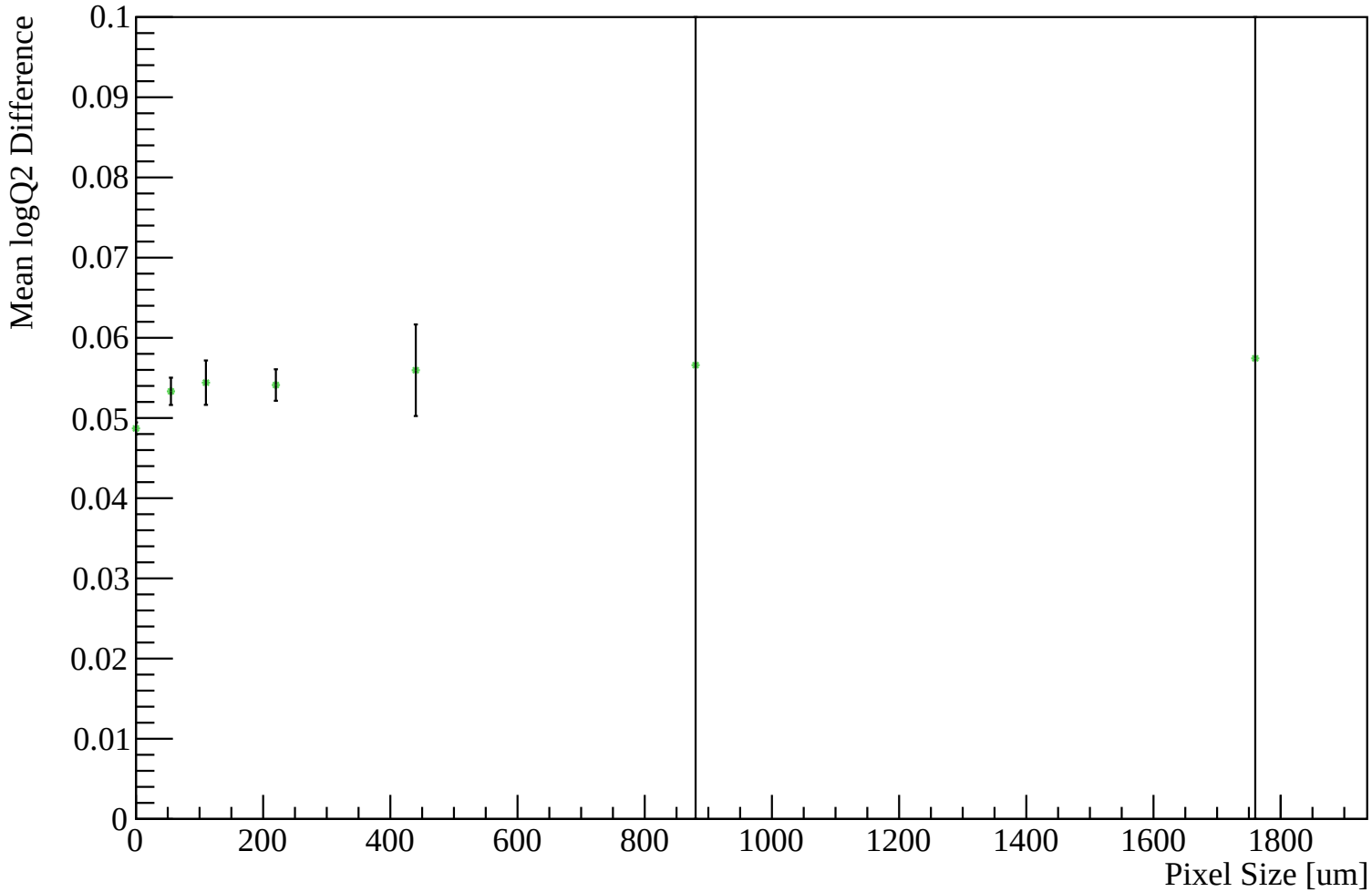




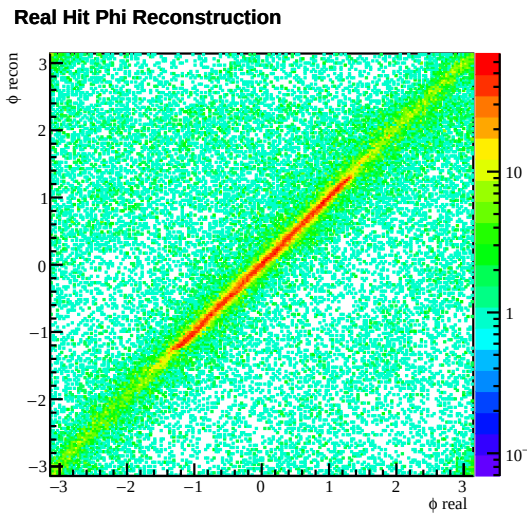


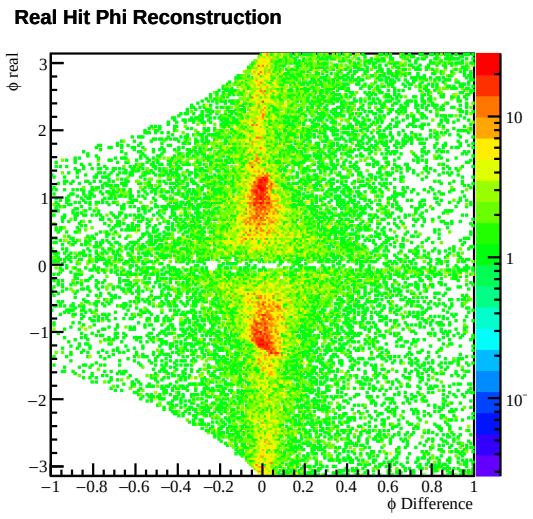


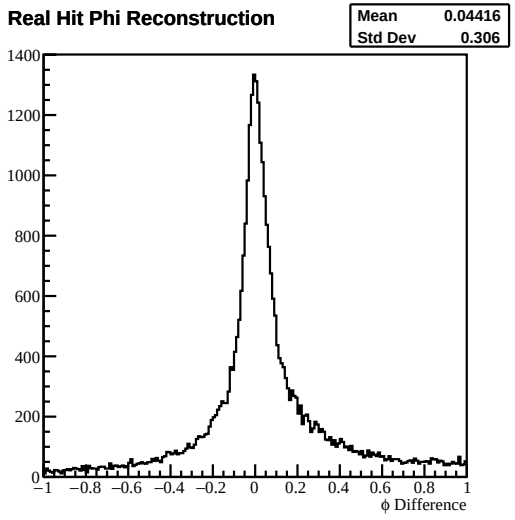
$\log Q^2$ Resolution - Tagger 2 - 18GeV

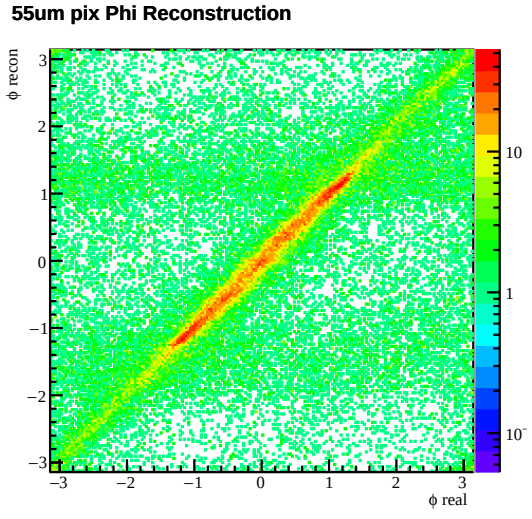


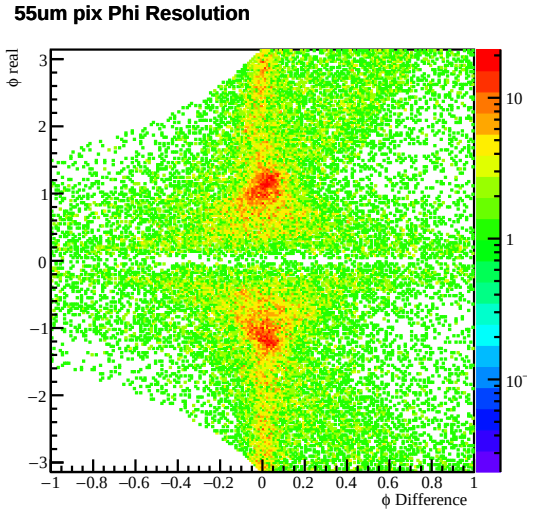
Phi Resolution - Tagger 2 - 18GeV

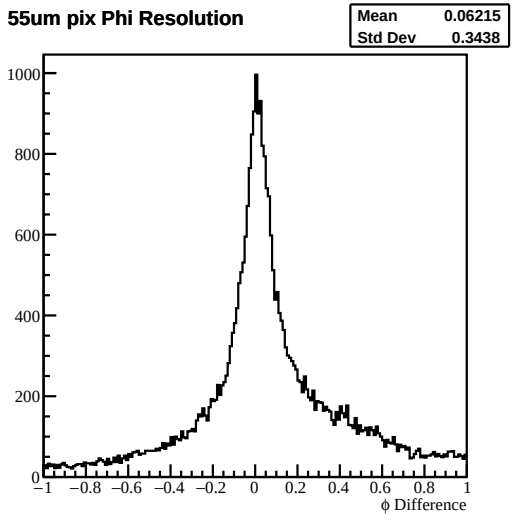






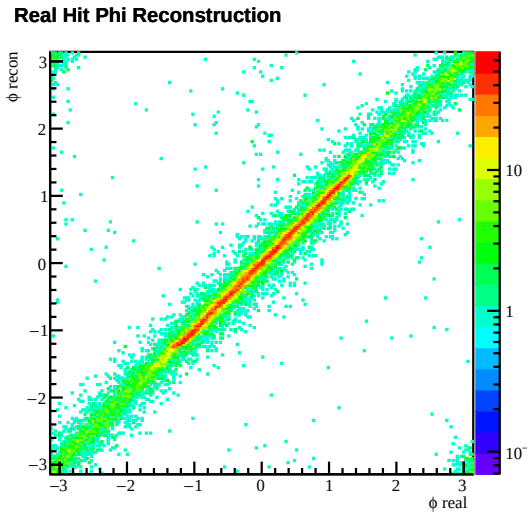


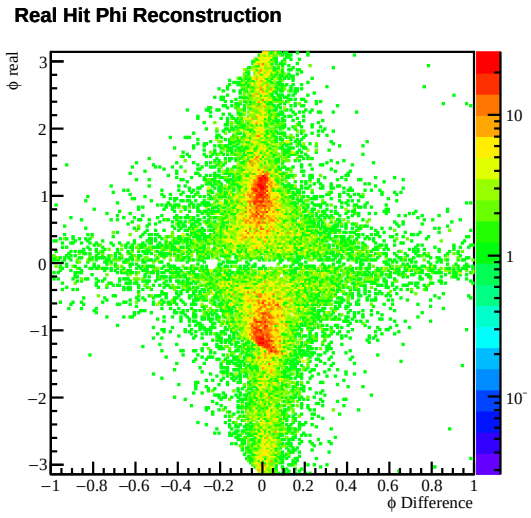


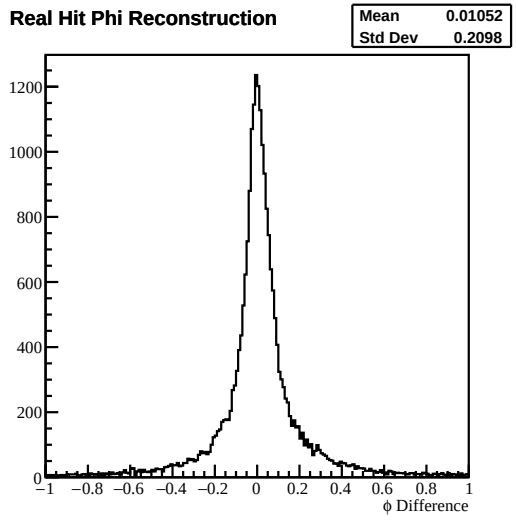


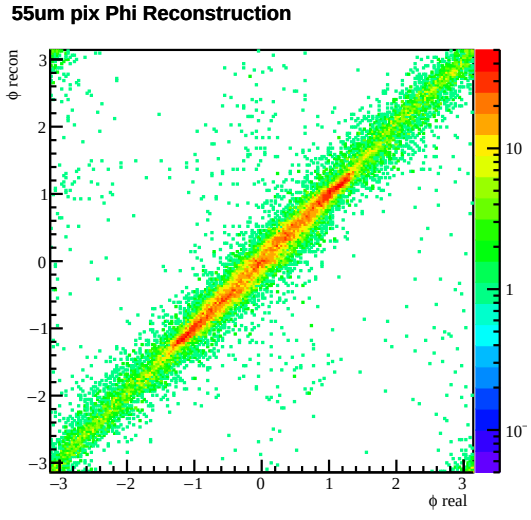
Phi Resolution - Tagger 2 - 18GeV

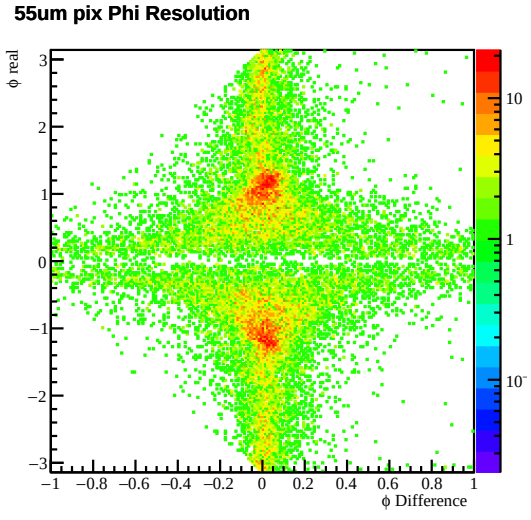
Cut Q^2 >-4

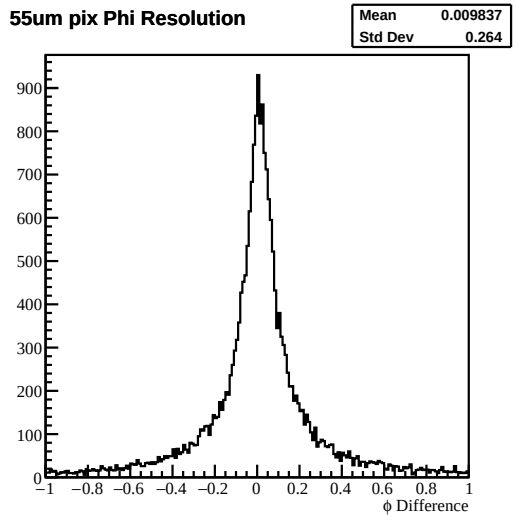






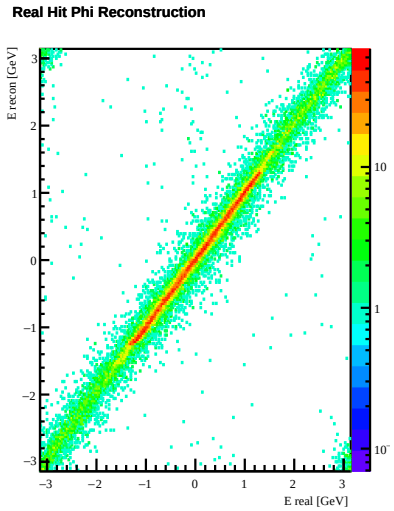


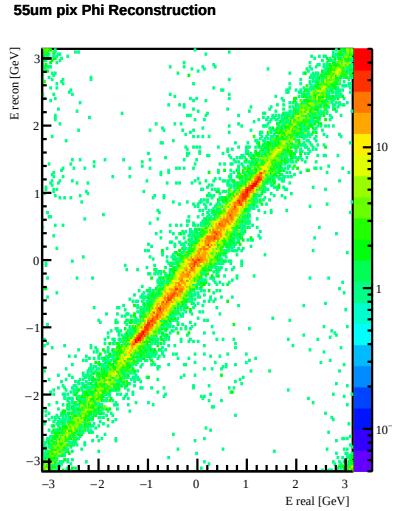


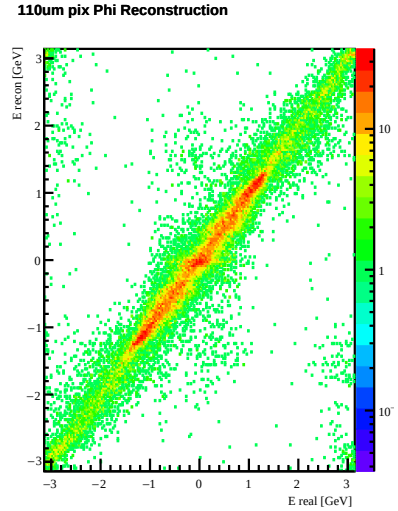


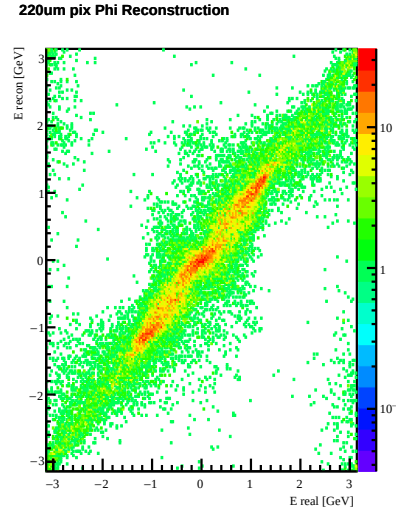
Phi Resolution - Tagger 2 - 18GeV

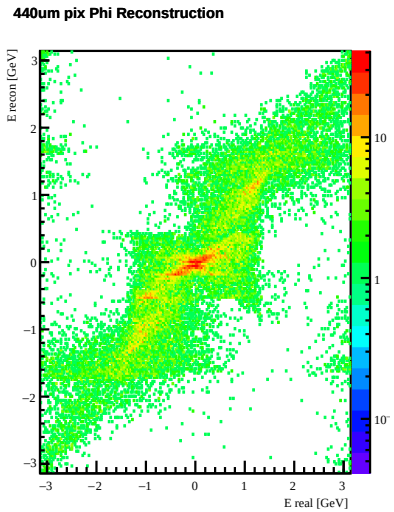
Cut Q^2 >-4

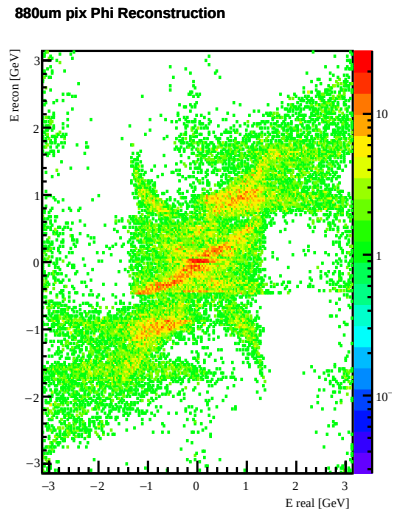


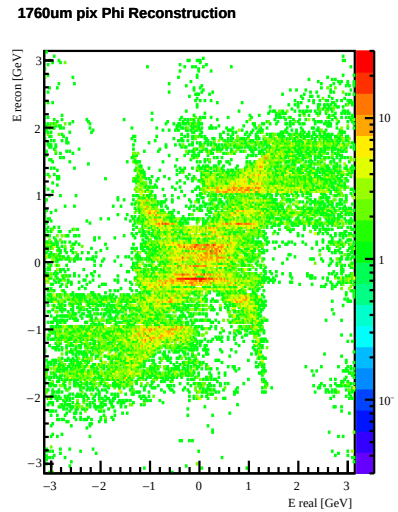












Reconstruction Improvements

- Need to be careful of initial kinematics.
- Training on small dataset (100k hits) with quick/relaxed convergence requirements.
- Prior position and vector reconstruction may help at least guide the network.
- Tinker with network structure and parameters.

Outline

Timepix4 ASIC

- Brand new but existing ASIC already exceeds criteria of our tracking detectors.
- 55 μm pixel pitch.
- Would increases rate capabilities and/or allow for smaller stations closer to the IP.
- Future within EIC timescales
  - Coupled to Inverse LGAD for finer timing
  - Generation beyond Timepix 4 planned.

Timepix4 ASIC

Timepix3 → Timepix4

Timepix4: A 4-side tillable large single threshold particle detector chip with improved energy and time resolution and with high-rate imaging capabilities

			Timepix3 (2013)	Timepix4 (2019)	
Technology			130nm – 8 metal	65nm – 10 metal	
Pixel Size			55 x 55 µm	55 x 55 µm	
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448	**3.5x**
Sensitive area			1.98 cm^2	6.94 cm^2	
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit	**33%**
		Max rate	0.43x10^6 hits/mm^2/s	**3.58x10^6 hits/mm^2/s**	**8x**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**	
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)	
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)	
		Max count rate	~0.82 x 10^9 hits/mm^2/s	~5 x 10^9 hits/mm^2/s	**6x**
TOT energy resolution			< 2KeV	< **1Kev**	**2x**
Time resolution			1.56ns	**195.3125ps**	**8x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	≤163.84 Gbps (16x @10.24 Gbps)	**32x**
Target global minimum threshold			<500 e^-	<500 e^-	

Timepix4 ASIC

CERN Detector Seminar last Friday "Applications of Timepix technology for Beam Instrumentation at CERN"

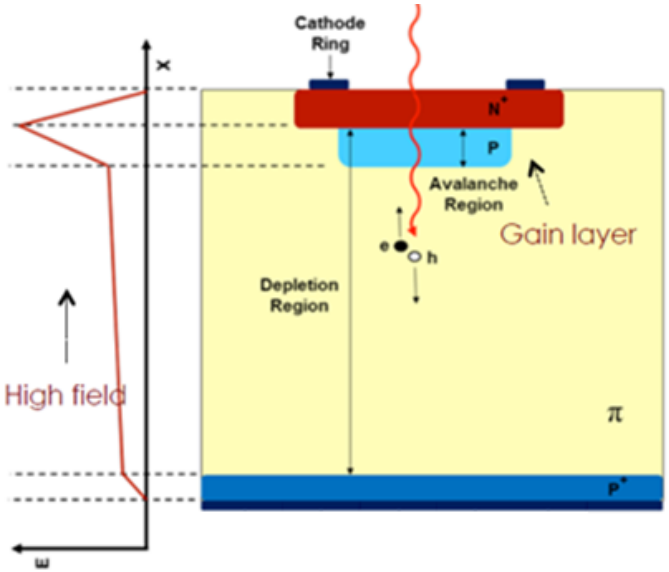
Indico Link

Demonstration of Timepix3 for beam profile monitoring in the vacuum.

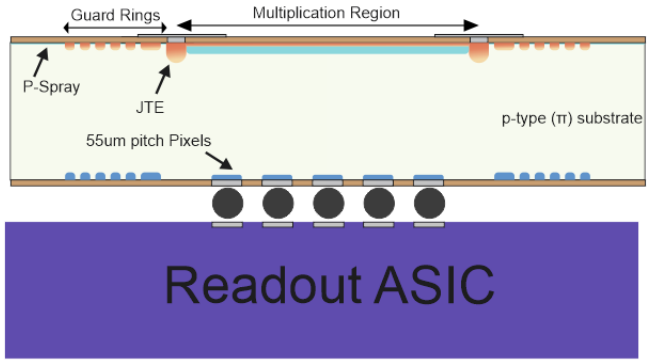
Key point - Detector and readout from beam vacuum with cooling.

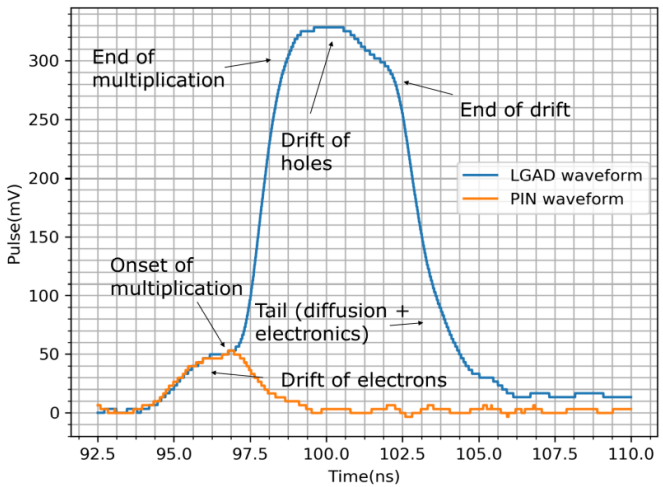
Timepix4 ASIC

LGAD sensor bonding



Sub 100 ps timing
Aimed towards LHCb VELO upgrade.



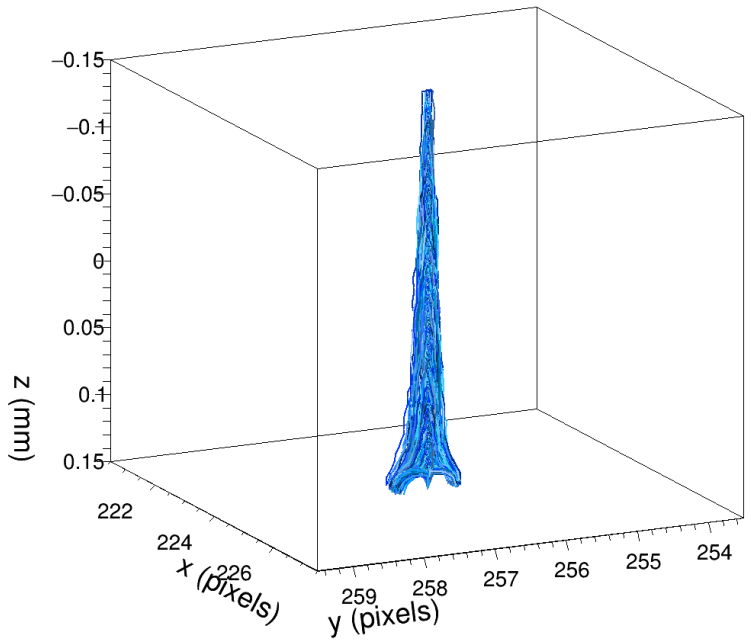


Moffat (2020) PhD thesis

Outline

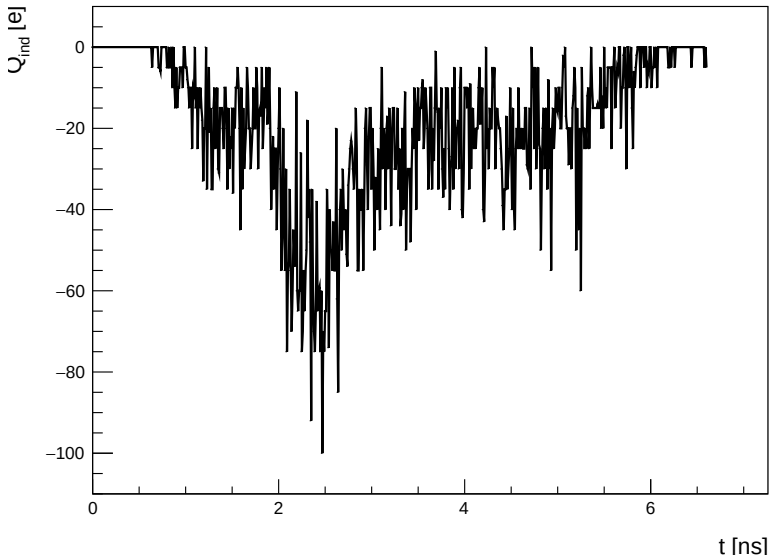
Allpix^2

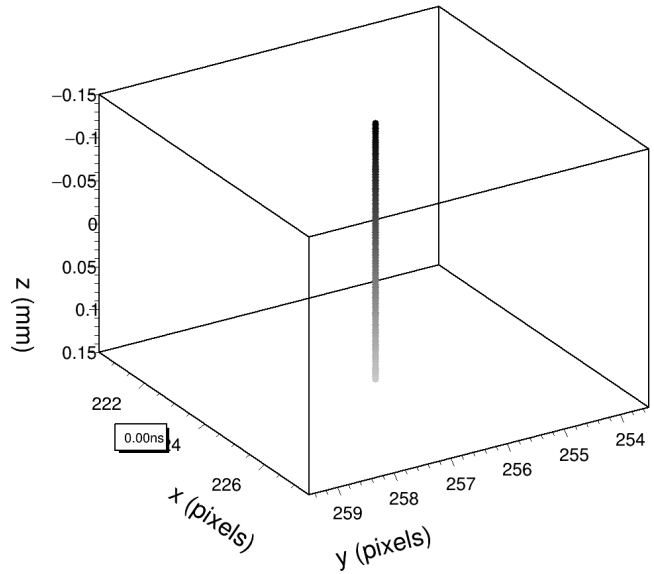
- Framework for simulating the performance of silicon detectors.
- Propagation of charge carriers.
- Signal digitisation and readout.
- Remove background early via cluster classification in hardware.

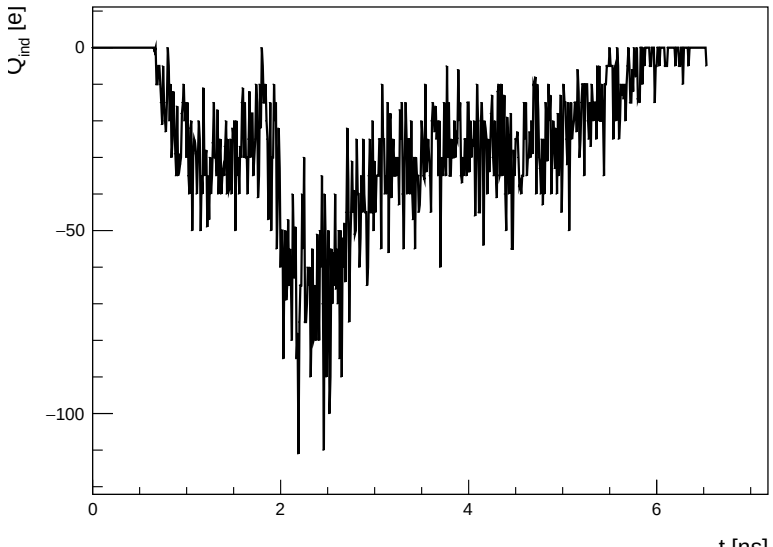


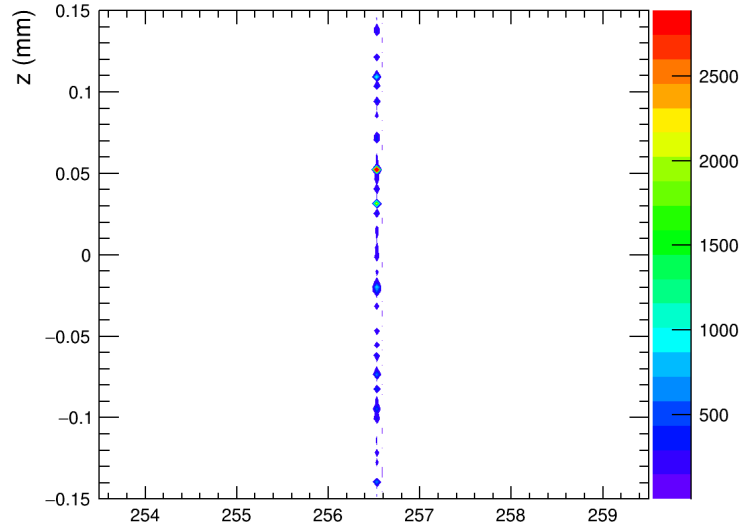
Allpix^2

14 GeV e^- on 300um silicon sensor

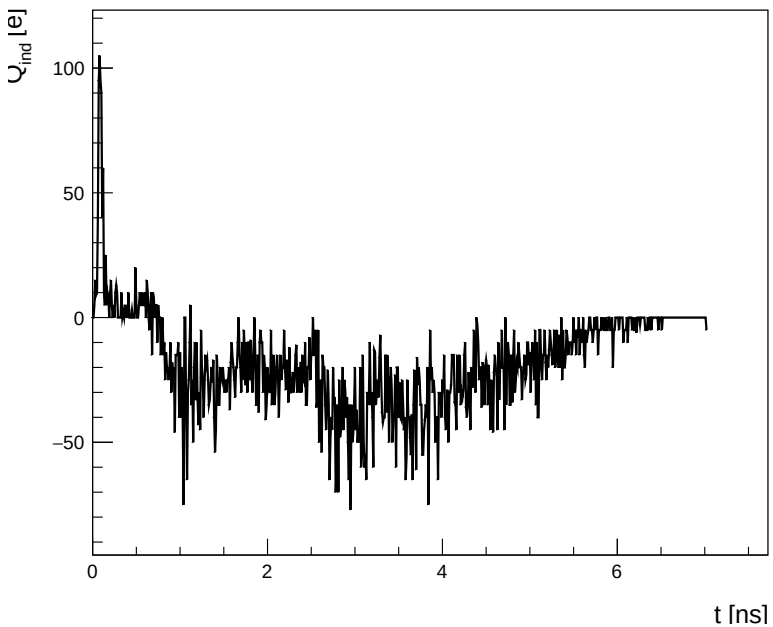


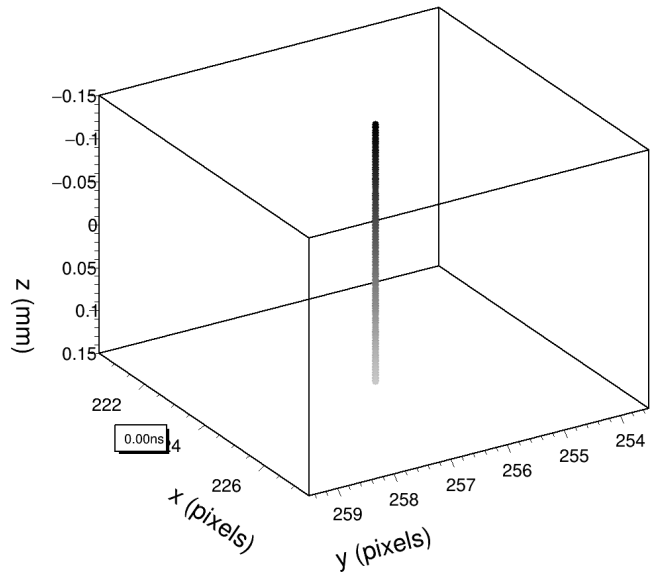






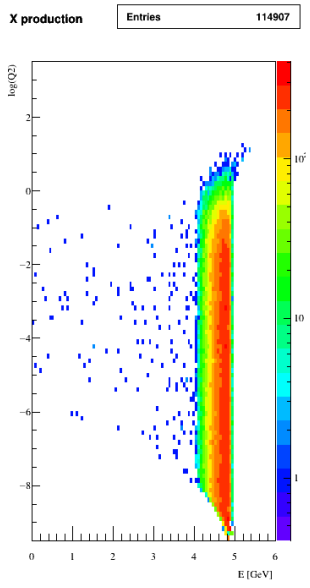
Allpix^2

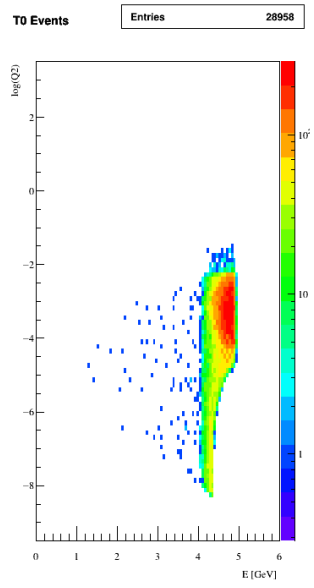

Ψ_{ind} [e]
100
50
0
−50
0
2
4
6
t [ns]

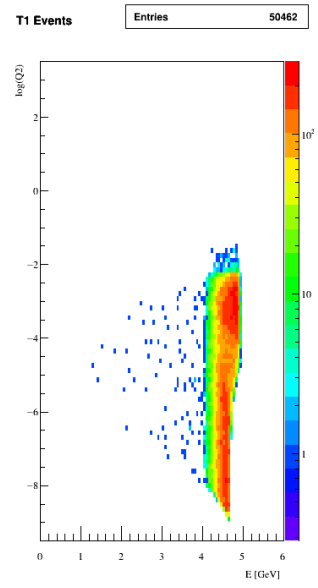

z (mm)
−0.15
−0.1
−0.05
0
0.05
0.1
0.15
222
0.00ns
226
x (pixels)
259
258
257
256
255
254
y (pixels)

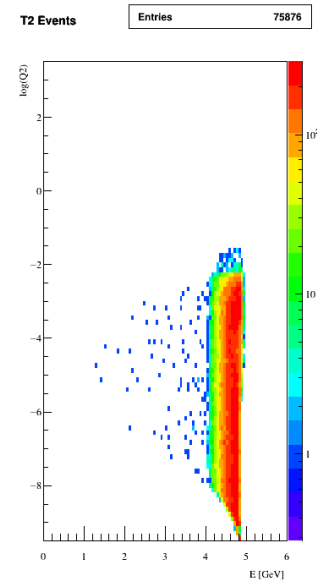
Backup

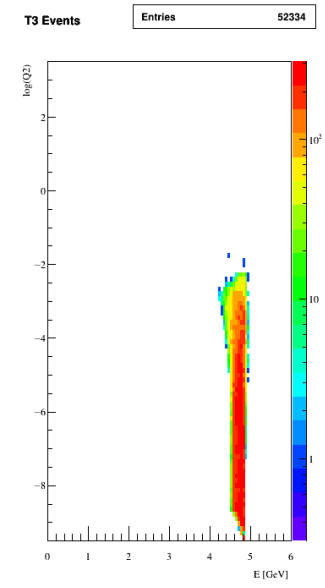
Spectroscopy Acceptance X - 5GeV

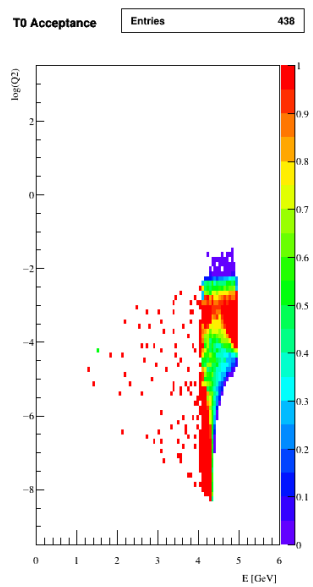


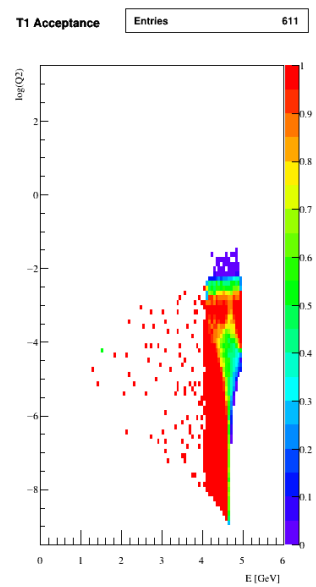


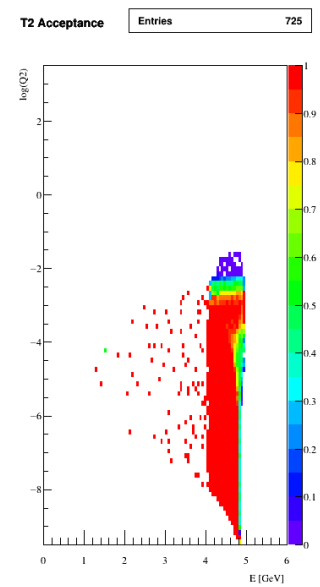


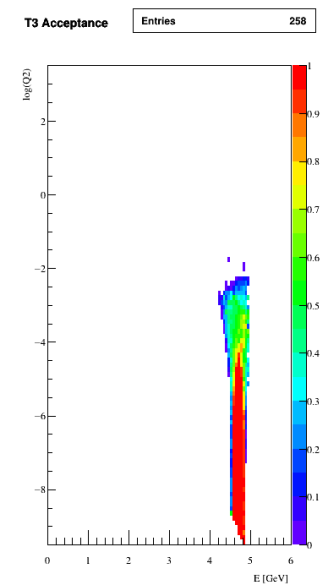




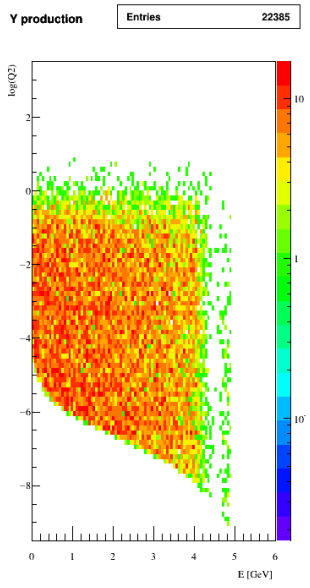


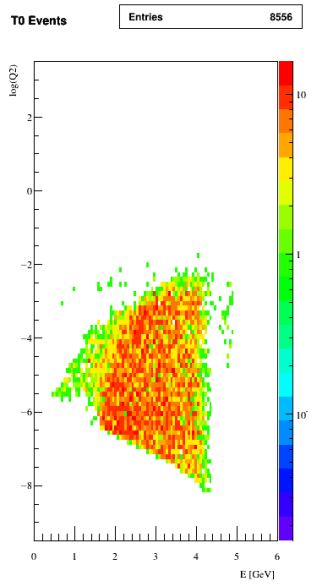


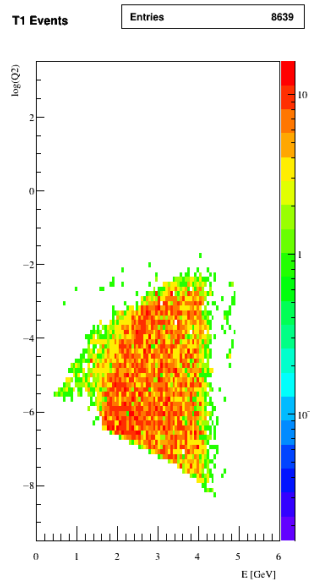


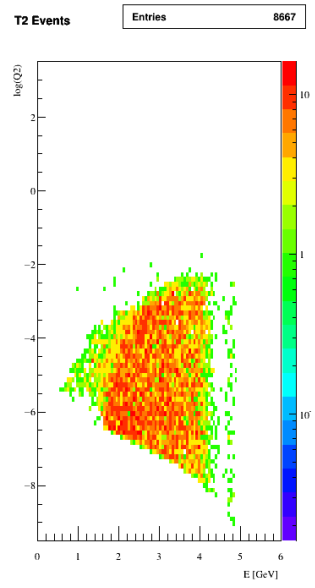


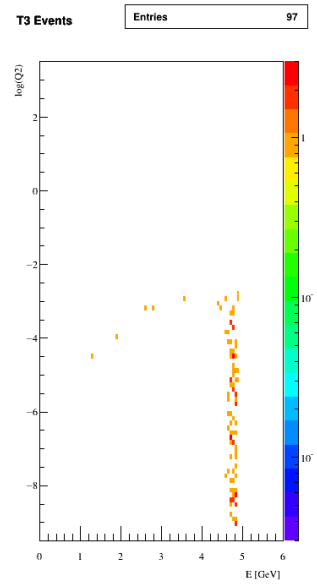
Spectroscopy Acceptance Y - 5GeV

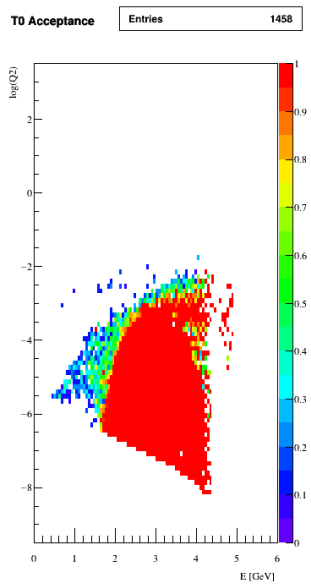


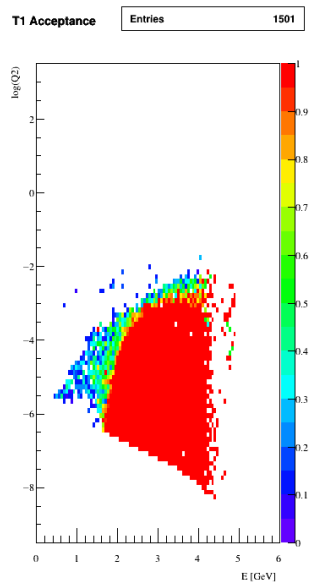


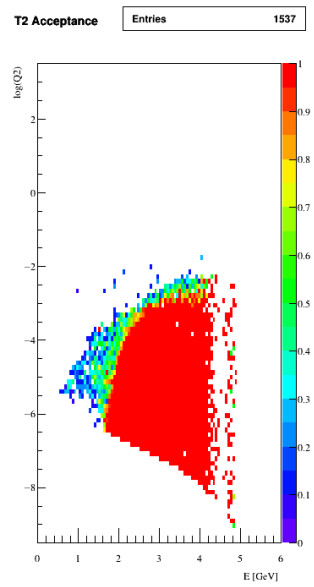


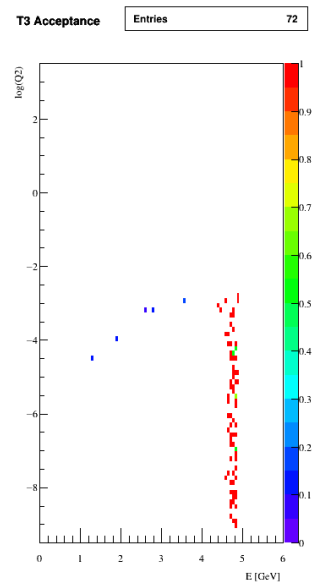












Raw training correlations