A Geant4 Simulation for RTPC 12

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Spectator Tagging Workshop
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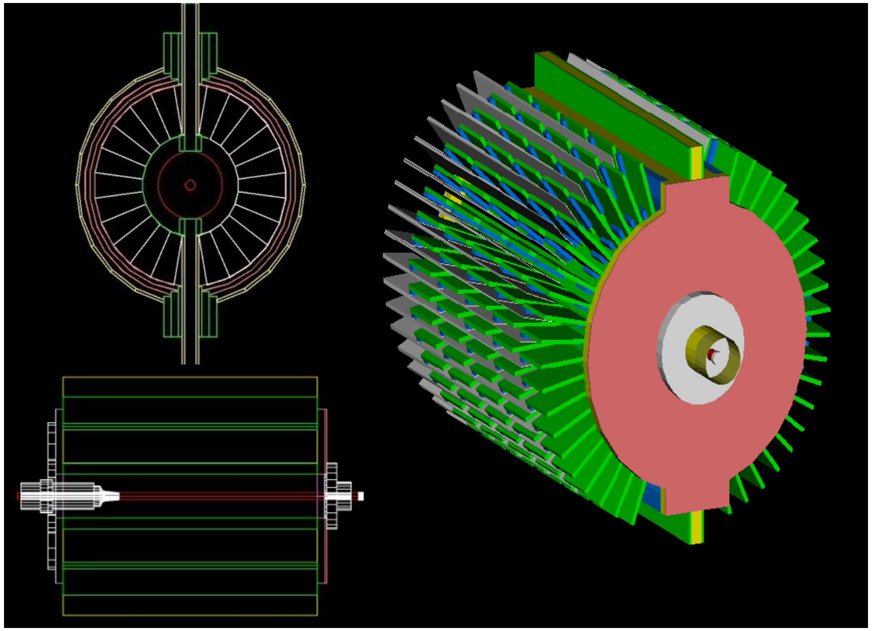
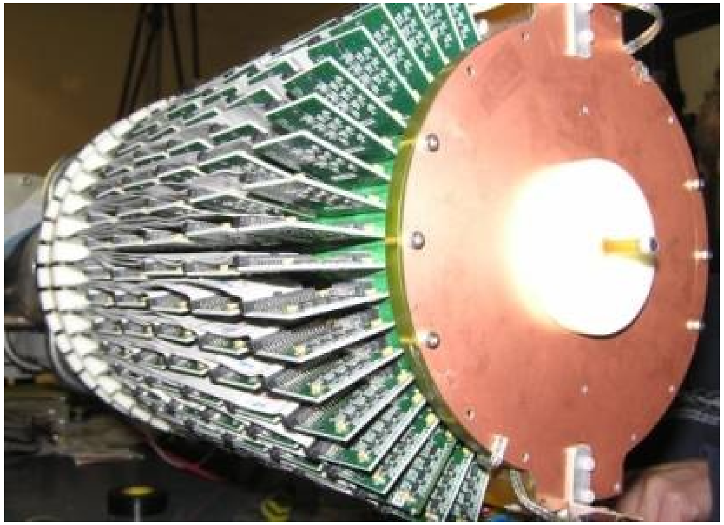
Outline

- 1) What is the design for RTPC 12?
- 2) What kind of resolution in momentum can we achieve (as a function of momentum and angle)?
- 3) What is a realistic momentum range over which we can reliably detect, identify and measure the momentum of protons?
- 4) Particle ID: how reliably can we measure dE/dx (e.g., for the GEM design, how can we improve gain homogeneity and stability)? How well can we separate protons from pions, deuterons etc. and how well can we separate 3He from 3H and 4He?
- 5) What is the maximum total acceptance in theta, phi and p we can achieve?

BoNuS 6 RTPC



Geant4 Simulation



Real Detector

Radial Time Projection Chamber (RTPC)

Sensitive to protons with momenta of 67-250 Mev/c

3 layers of GEM

3200 pads (channels)

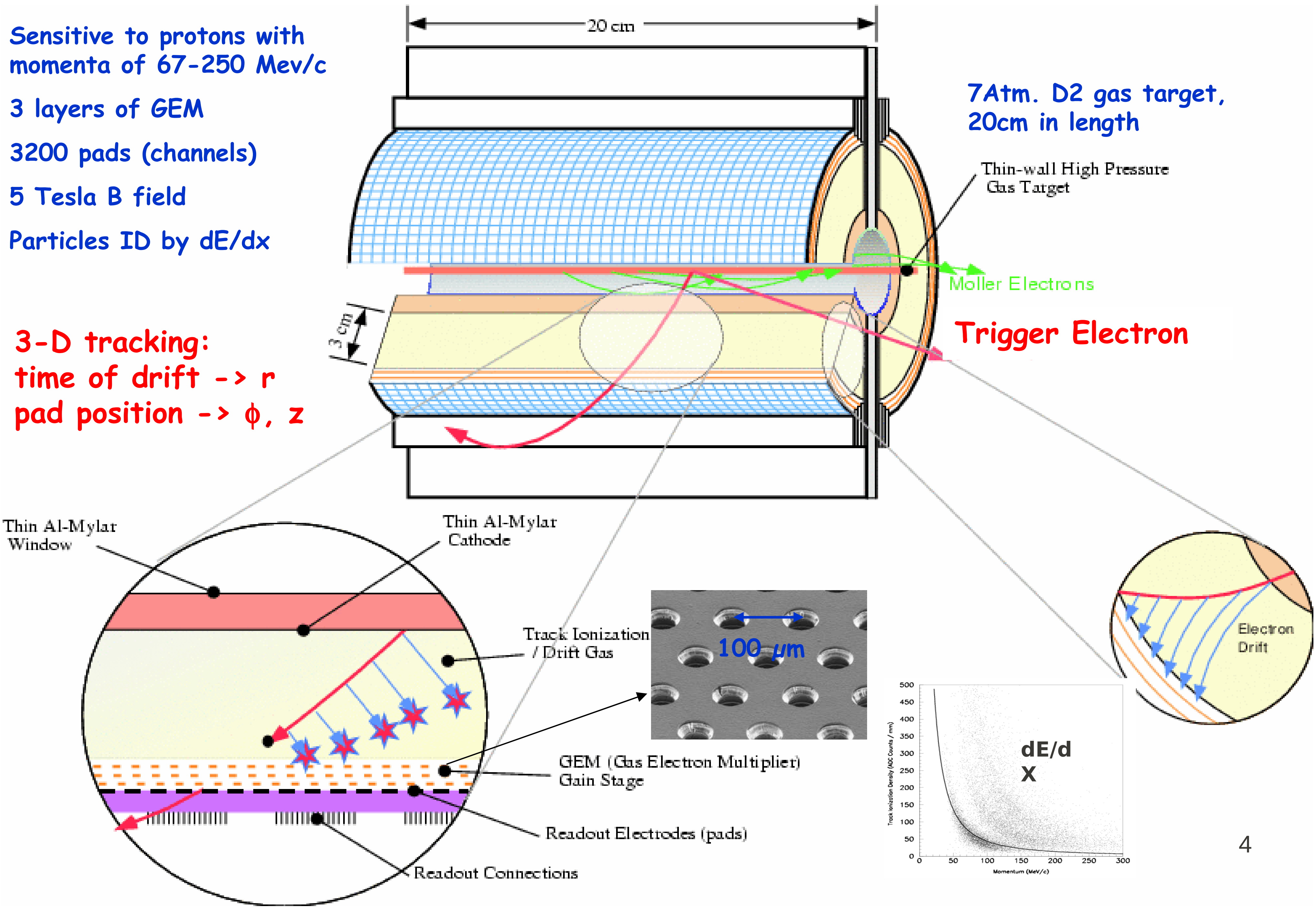
5 Tesla B field

Particles ID by dE/dx

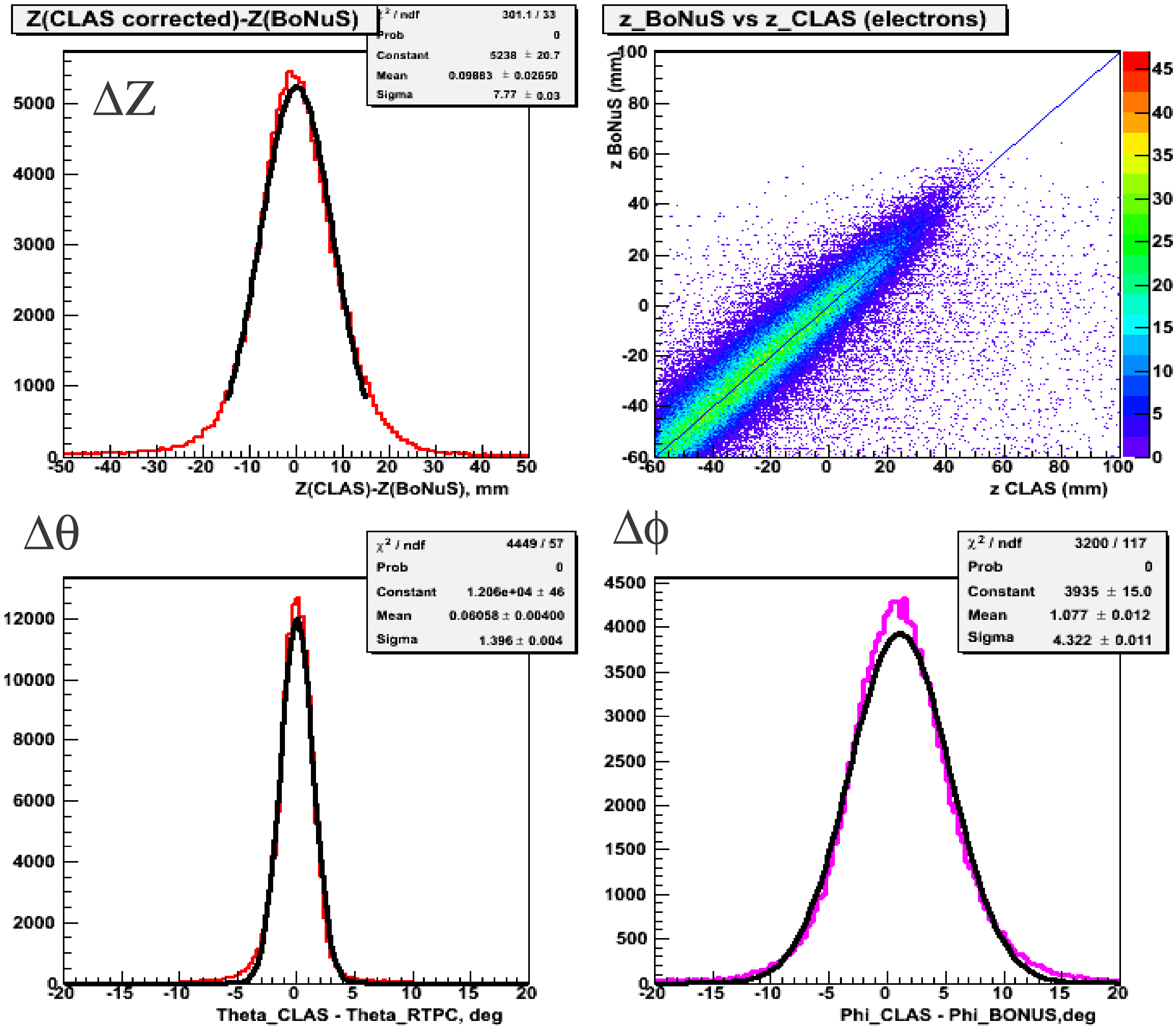
7Atm. D2 gas target, 20cm in length

Trigger Electron

3-D tracking:
time of drift -> r
pad position -> ϕ, z



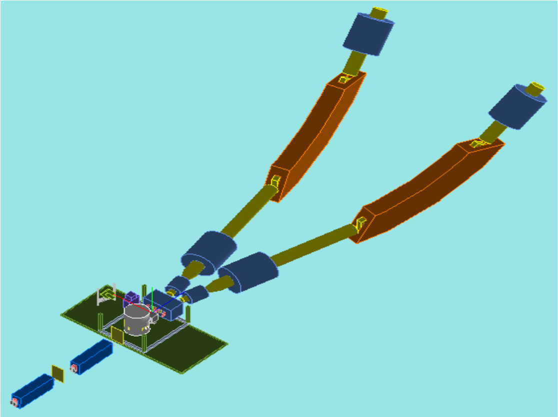
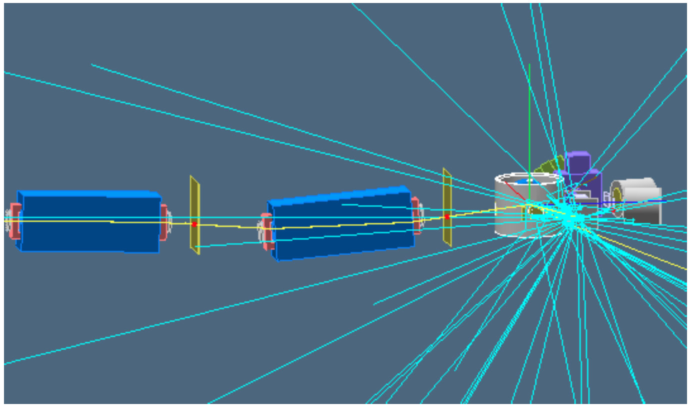
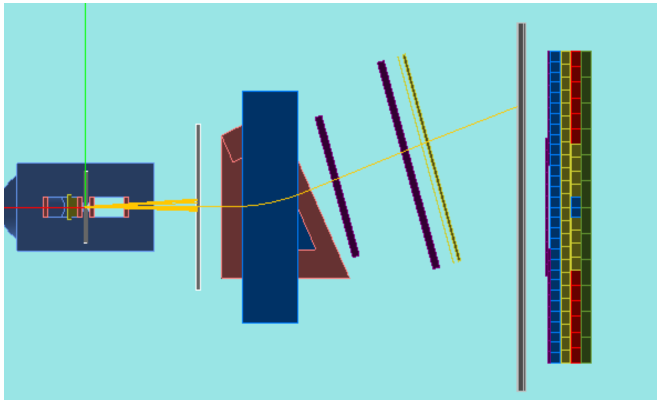
RTPC Resolution In BoNuS (6 GeV)

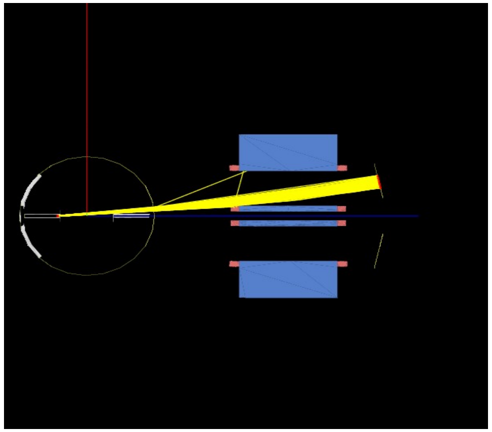
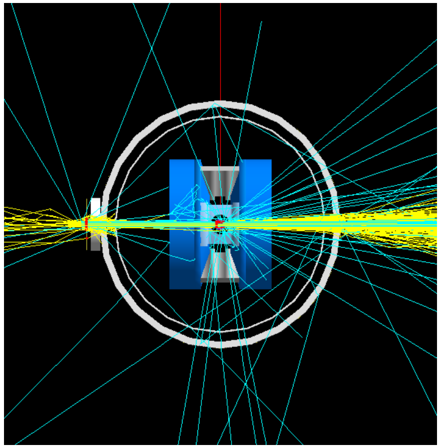
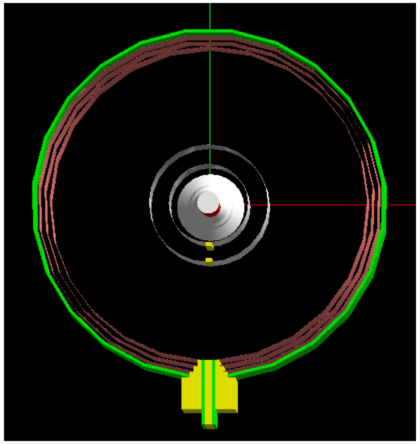
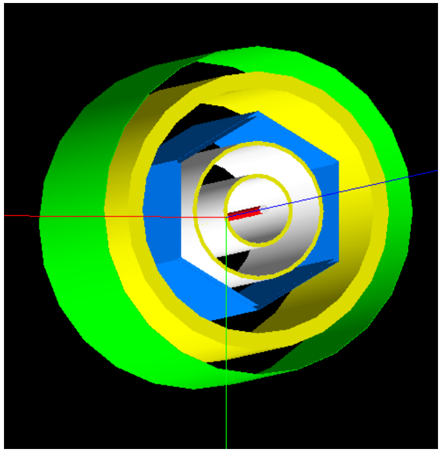


Trigger electrons measured by CLAS are compared to the same electrons measured in BoNuS during High Gain Calibration runs.

H. Fenker, et.al. Nucl.Instrum. Meth. A592:273-286,2008

The Geant4 Simulation Program, G4MC

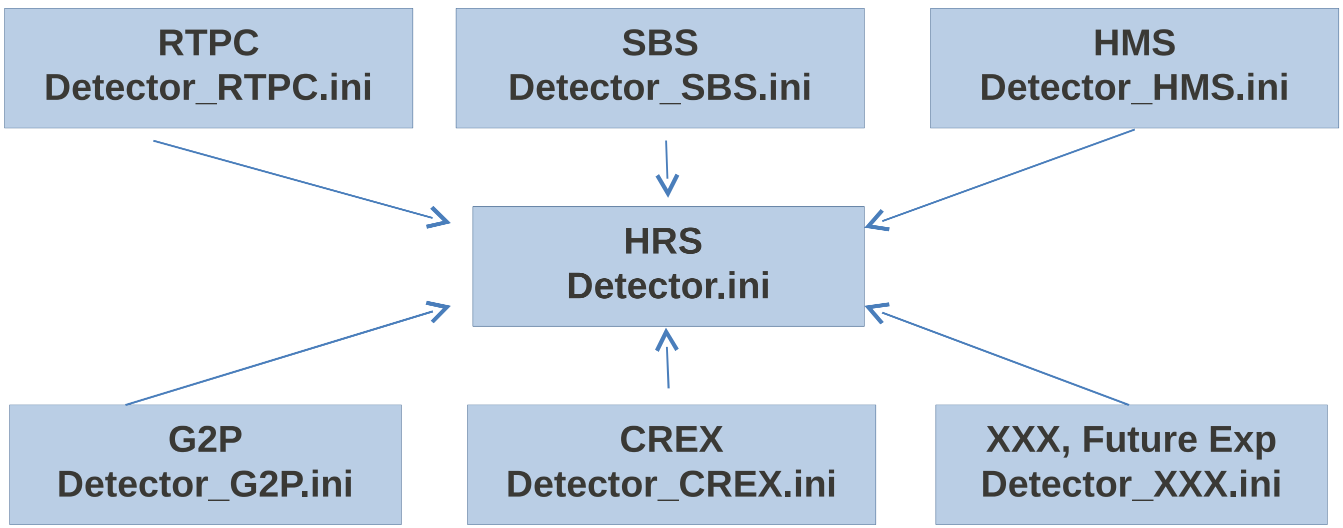





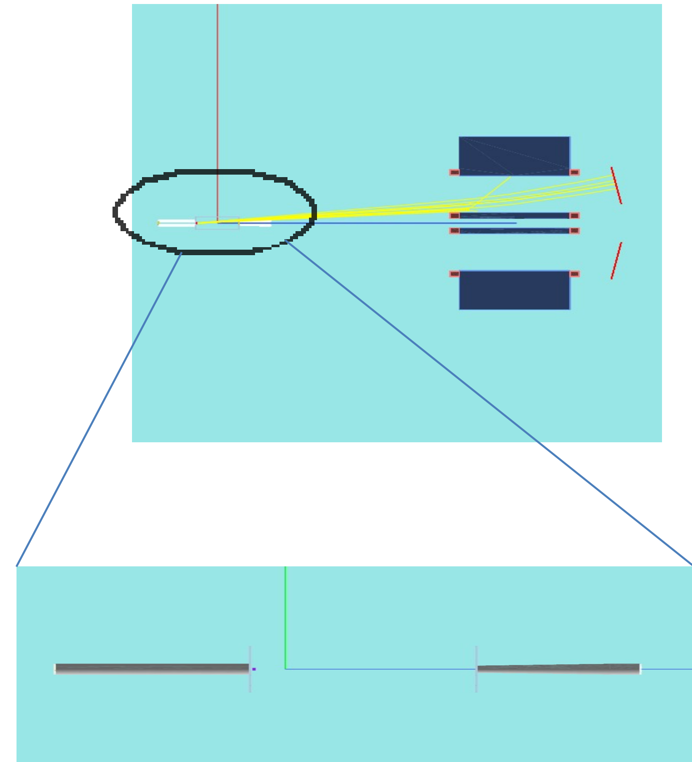
- Designed to support all HRS experiments
- BitBite, HAND, SuperBigBite, LAC, NPS geometries included
- Ready to simulate G2P, GEP, CREX, WACS, RTPC12, LERD.
- Can be extended for other experiments or detectors too.

Adding New Geometries

Different experiments usually vary from geometries on the target platform.

Each target or detector is hard coded, associated with a configuration file to turn each individual component on or off.





CREX target + G2P septum

HRSMC can support any new experiment by adding a new geometry class.

All sensitive detectors share a standard hit processing but vary in Sensirtive Detector ID. All hits will be recorded automatically.

Geant4 can not simulate the drifting of an ionized electron

- Geant4 can simulate particle travel through materials. Energy deposited in a volume is also properly calculated.
- GEANT does not generate low-energy electrons below a cut (default 1keV, can be tuned to 50 eV).
- Drift and diffusion of the low energy electrons can not be simulated since there is no cross section data for such low energy.
- No dirft parameters (drift velocity, longitudinal and transverse diffusion) are available in Geant4.
- Need dedicated program to simulate low energy electron drifting: Garfield or Magboltz

The Drift Path of An Ionized Electron

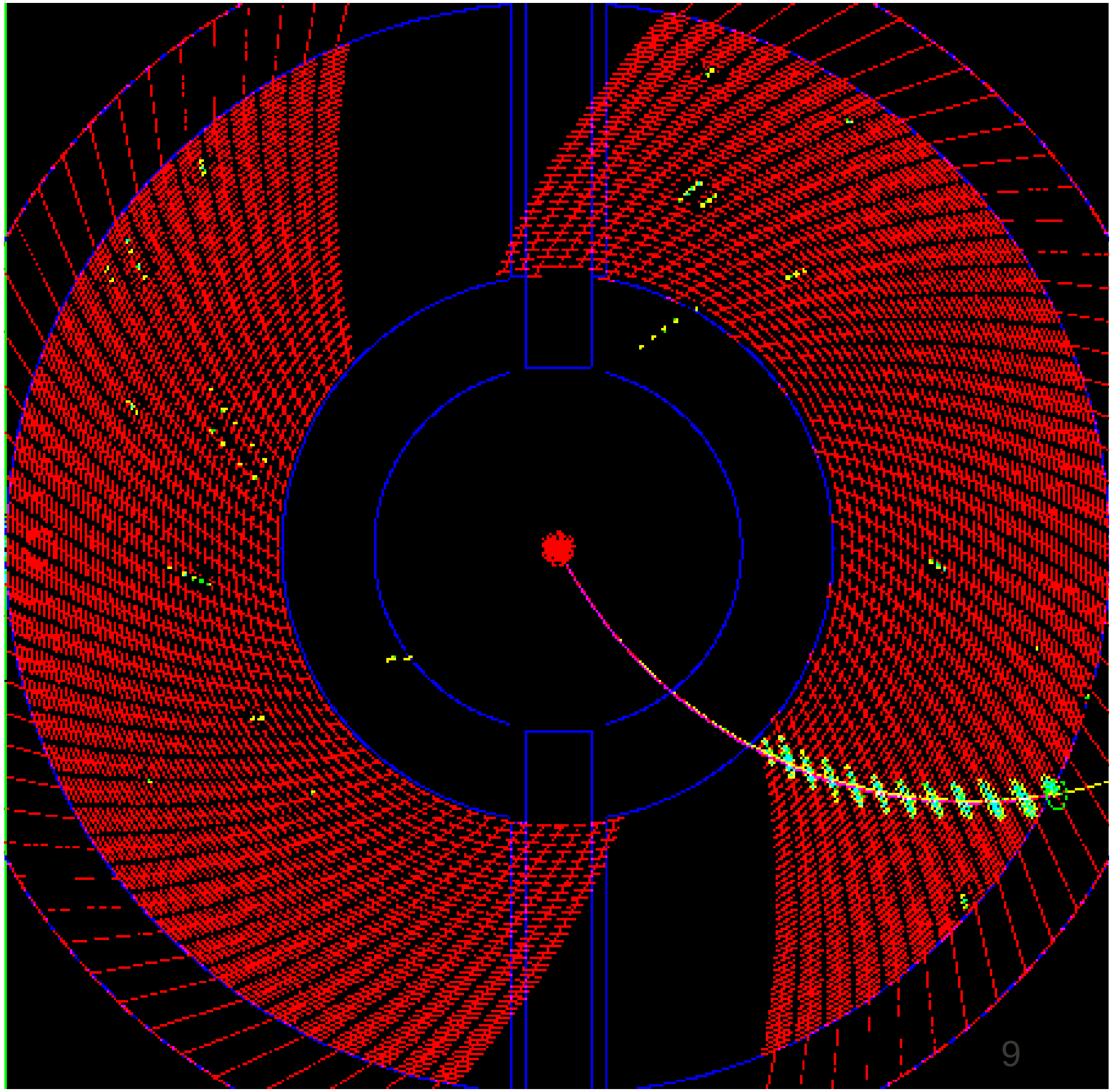
A MAGBOLTZ simulation of the crossed E and B fields, together with the drift gas mixture, determines the drift path and the drift velocity of the electrons.

•The red lines show the drift path of each ionization electron that would appear on a given channel.

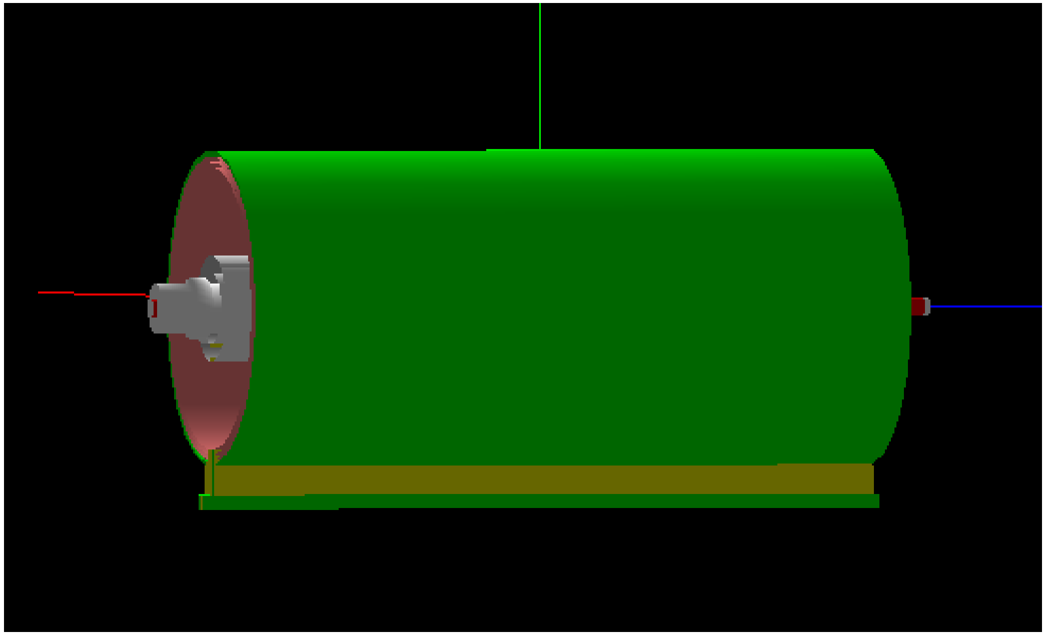
•In green is the spatial reconstruction of where the ionization took place.

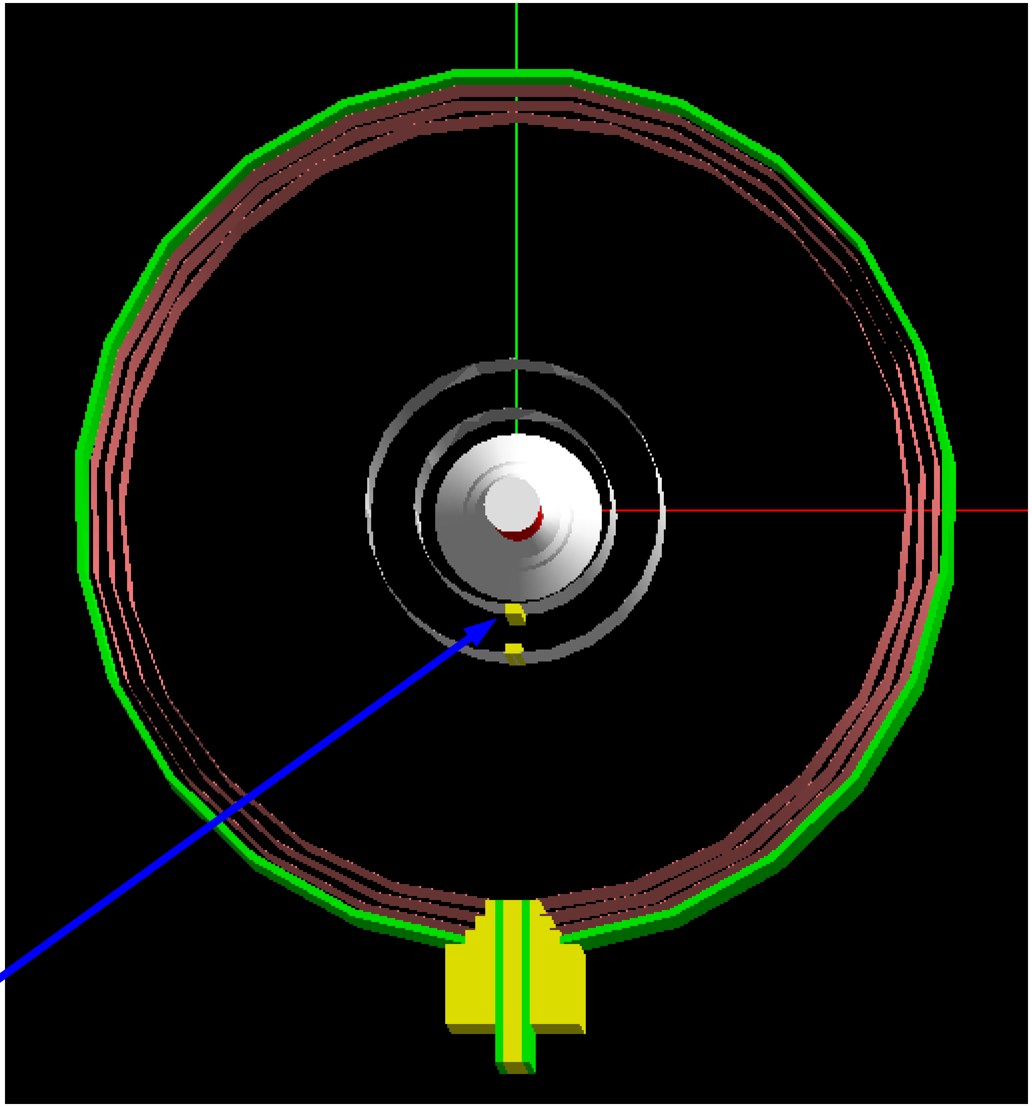
•In reconstruction, hits which are close to each other in space are linked together and fit to a helical trajectory.

•This resulting helix tells us the vertex position and the initial three momentum of the particle.



RTPC12 in Geant4

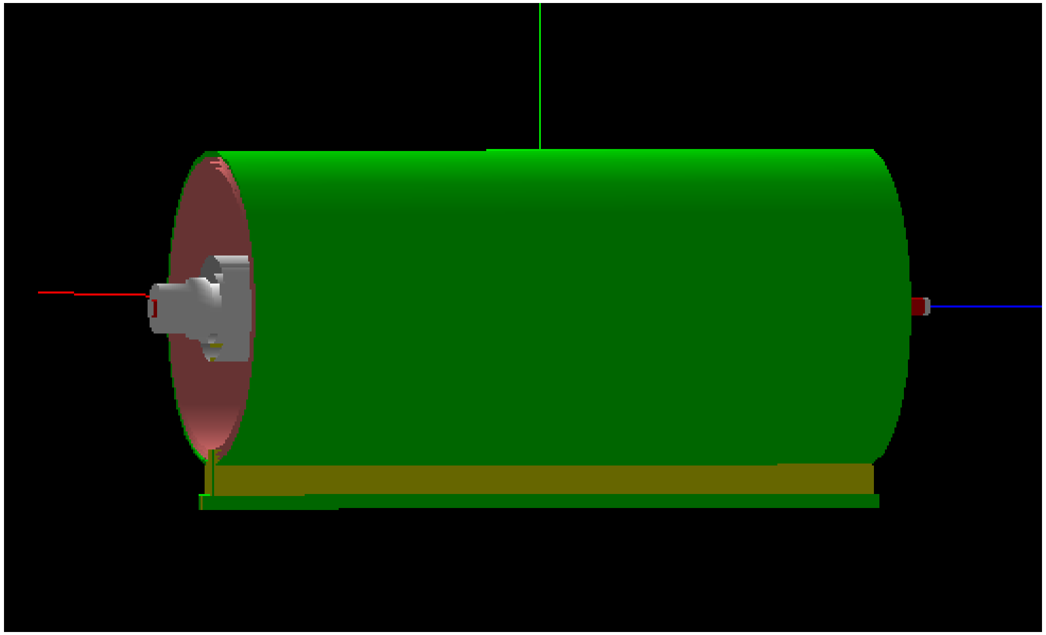


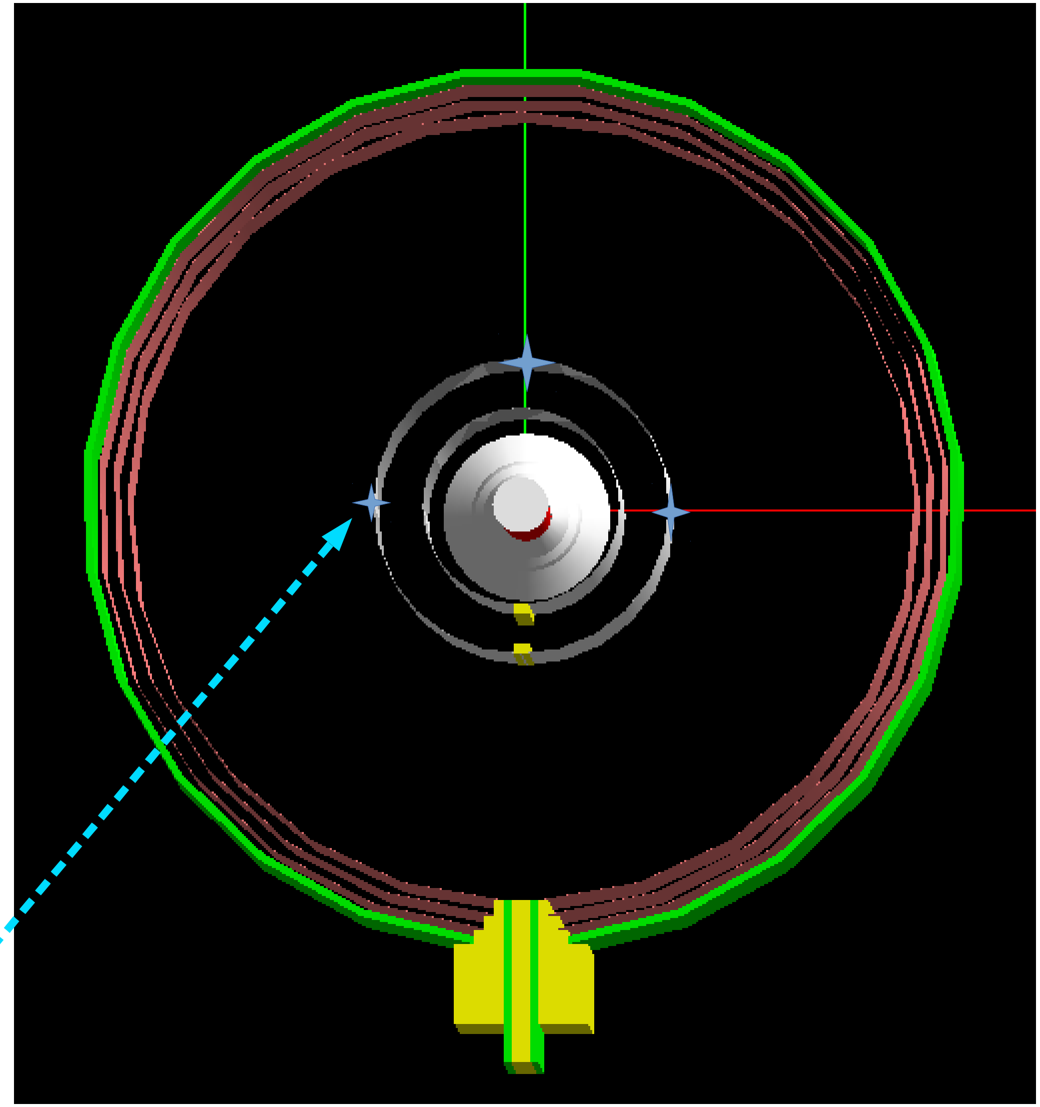


- Target: D2 gas, 300k, 7.5 ATM, 5 mm radius, 40 cm long
- Target Wall: 25 um kapton
- Drift Region: 3<R<8 cm
- Drift Gas: 300k, 1 ATM, He/DME (80/20)
- Use carbon fiber (3.5 x 2 mm) as rib to support Mylar foils
- phi coverage = 350 degrees

Threshold = 59 MeV, barely reach drift region

RTPC12 in Geant4





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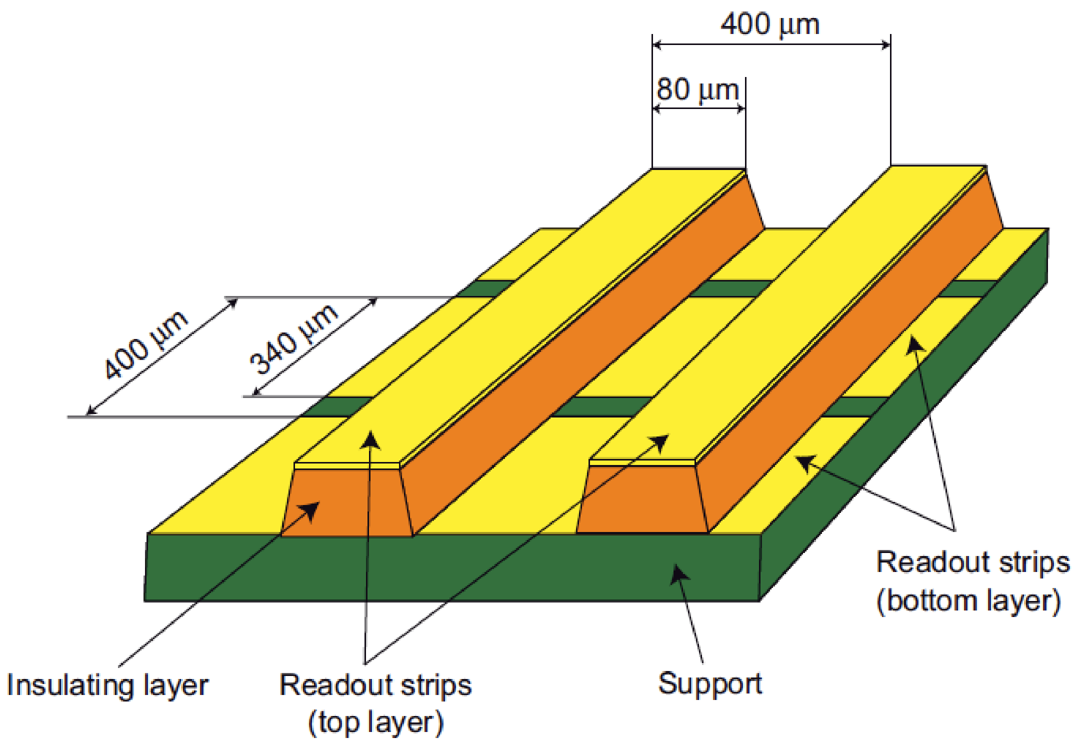
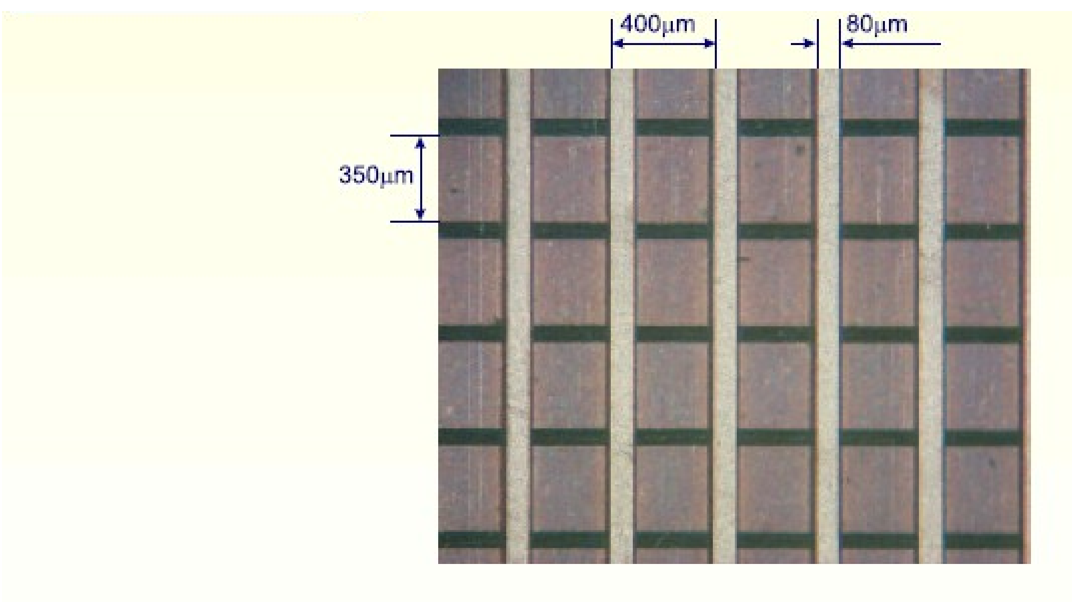
Might need to add support ribs ......

COMPASS GEM 2-D Readout



- Time resolution: 12 ns (using 25 ns sampling APV25 readout)
- Space resolution: 70 um



We will use DREAM chips with
25 ns time sampling in the readout

Pad or u-v double-layer strips?
How long is each strip?

What is DREAM?

- Based on AMS 0.35 um CMOS technology
- 64 channels in each chip
- Will be used in the forward tracker of the central detector of the CLAS12
- Design dead time: 10^-7 for 4 samples/event readout, 40 kHz trigger rate and 16 us trigger latency

- R&D is now carried out in CEA/IRFU.
- Bernd Surrow in Temple University also cooperate with them to do R&D of using this readout for GEM detectors for EIC projects.

Dead-timeless Readout Electronics ASIC for Micromegas

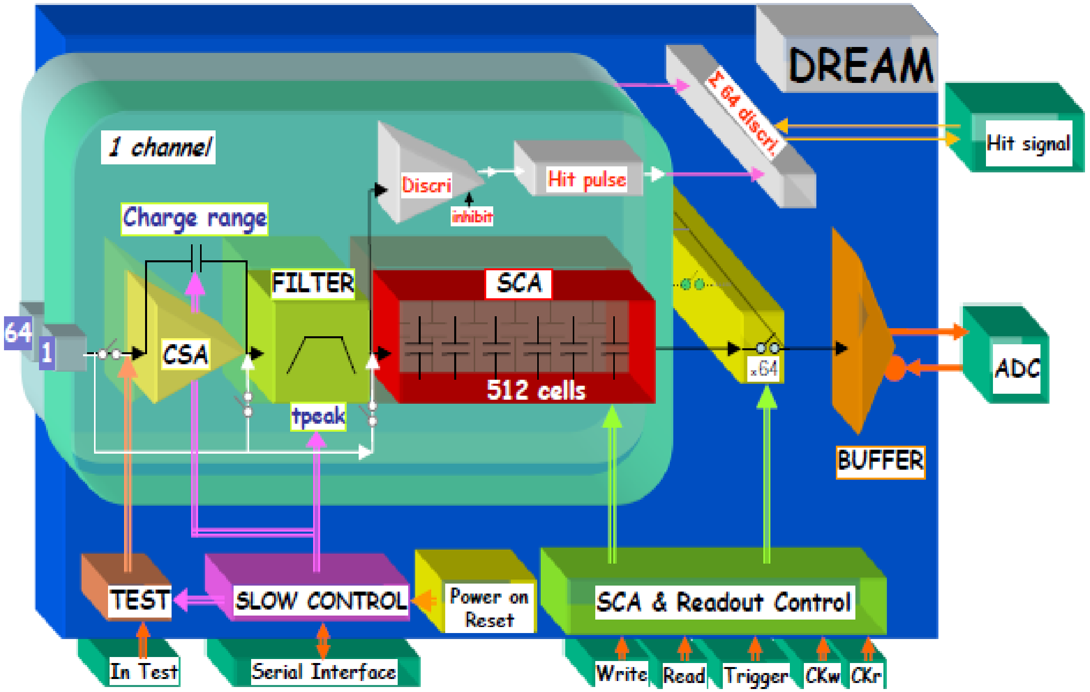


Fig. 1: Block diagram of the DREAM chip.

DREAM vs APV25

	Dream Chip	APV25-S1 Chip
Number of channels	64	128
Memory size	512	160
Latency	16μs	8μs
Noise (e-RMS)	2100 (On 180pF)	1200 (On 20pF)
Sampling frequency	1-40MHz	10-50MHz
Dynamic range	50-600fC	150fC
Input capacitance	150pF	18pF
Shaping time	70ns	50ns

APV25 is no longer in production.
DREAM chip is still under R&D, but is closed to production stage (M. Garcon).

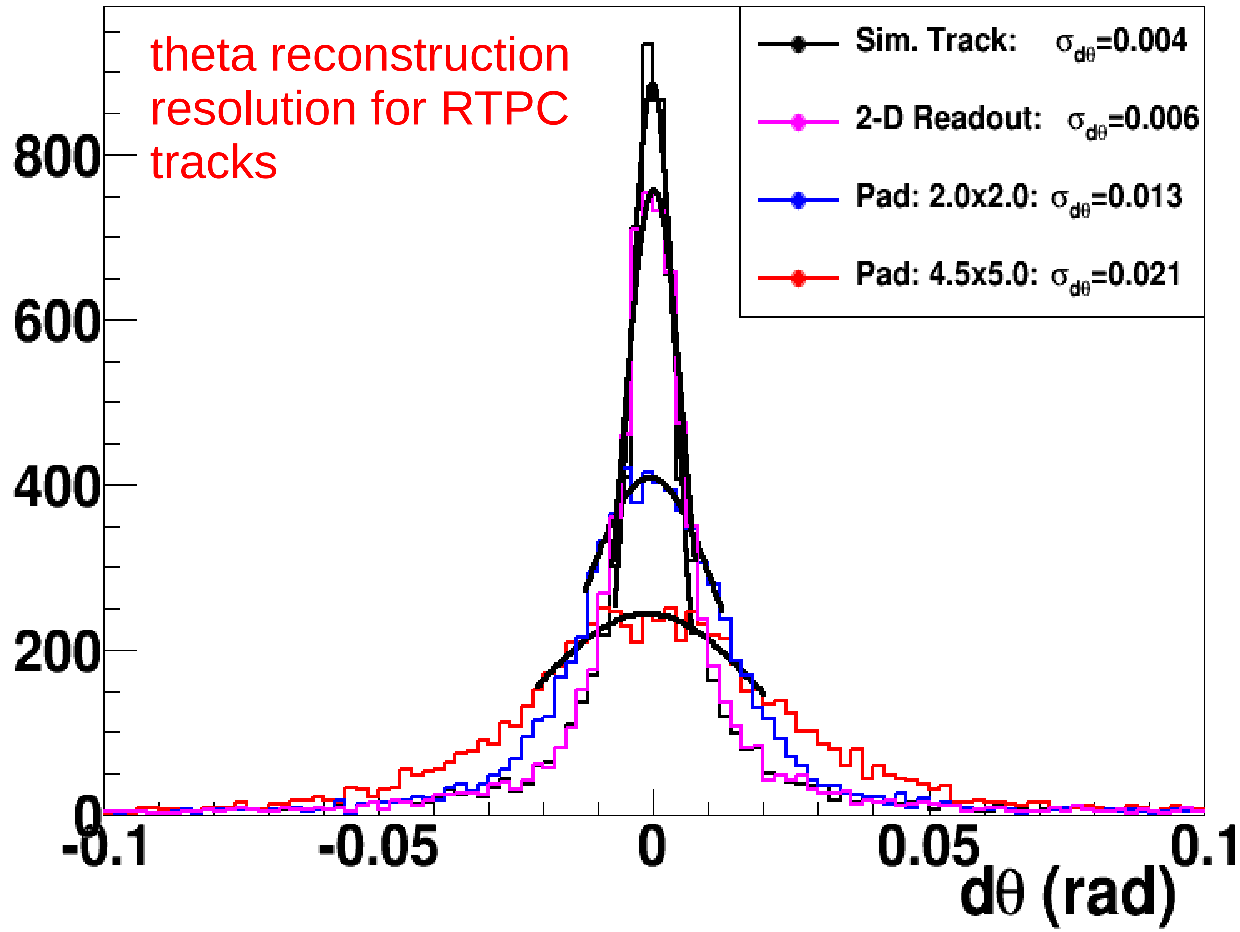
More about DREAM chips

Parameter	Value
Polarity of detector signal	Negative or Positive
Number of channels	64
External Preamplifier option	Yes; access to the filter or SCA inputs
Charge measurement	
Input dynamic range/gain	50 fC; 100 fC; 200 fC; 600 fC, selectable per channel
Output dynamic range	2V p-p
I.N.L	< 2%
Charge Resolution	> 8 bits
Sampling	
Peaking time value	50 ns to 900 ns (16 values)
Number of SCA Time bins	512
Sampling Frequency (*WCk*)	1 MHz to 50 MHz
Triggering	
Discriminator solution	Leading edge
HIT signal	OR of the 64 discriminator outputs in LVDS level
Threshold Range	5% or 17.5% of the input dynamic range
I.N.L	< 5%
Threshold value	(7-bit + polarity bit) DAC common to all channels
Minimum threshold value	≥ noise
Readout	
Readout frequency	Up to 20 MHz
Channel Readout mode	all channels excepted those disabled (statically)
SCA cell Readout mode	Triggered columns only
Test	
Calibration (current input mode)	1 channel among 64; external test capacitor
Test (voltage input mode)	1 channel among 64; internal test capacitor (1/charge range)
Functional (voltage input mode)	1, few or 64 channels; internal test capacitor/channel
Trigger rate	Up to 20kHz (4 samples read/trigger).
Counting rate	< 50 kHz / channel
Power consumption	< 10 mW / channel

Table 1: Summary of the DREAM requirements.

Comparing Theta Resolution @ various Pad Size

- **Main feature:**
- **Drift Region = 3<R<8 cm**
- **Readout pad|strips R=9cm**
- **Time resolution: 12 ns (using 25 ns sampling DREAM readout)**

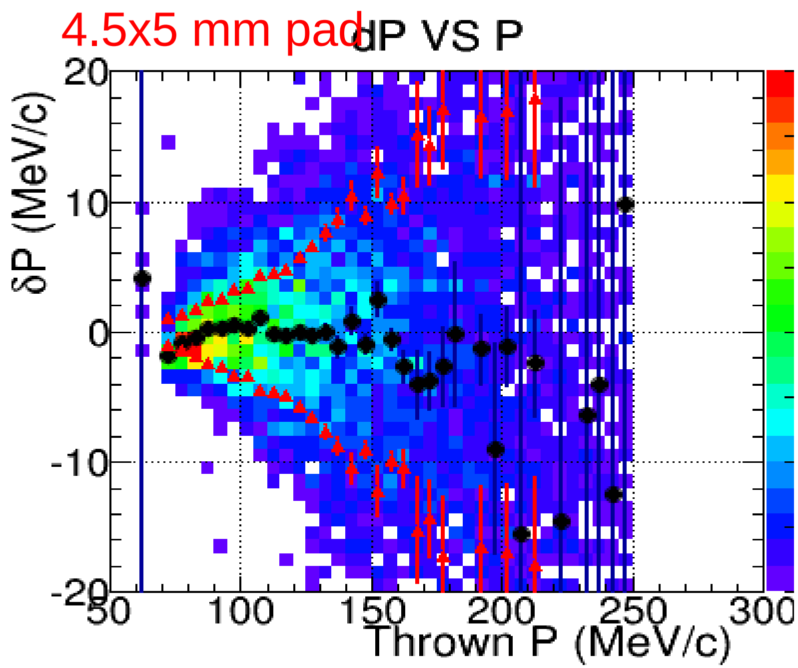


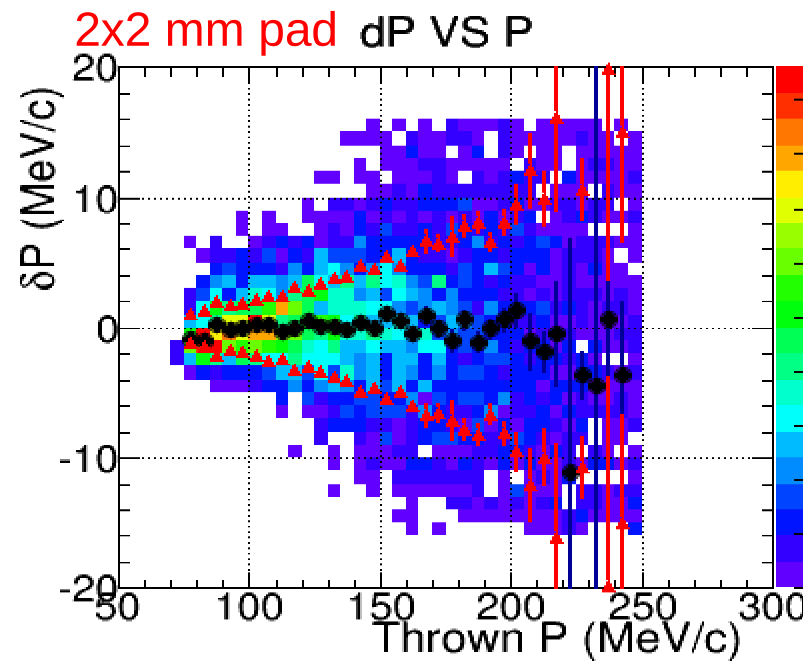
RTPC hit resolution in cylindrical coordinate:

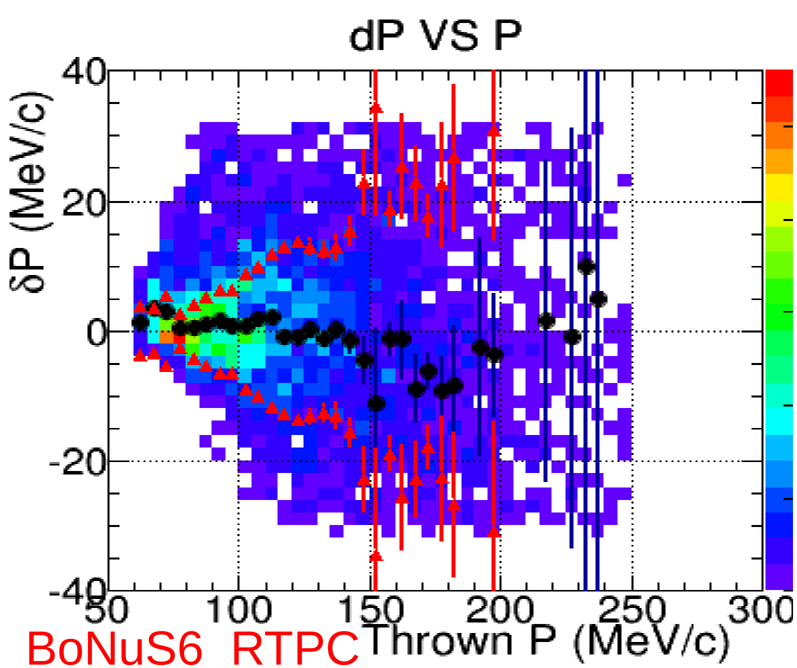
- S resolution dS =0.07 mm, which is corresponding to 12ns drift distance.

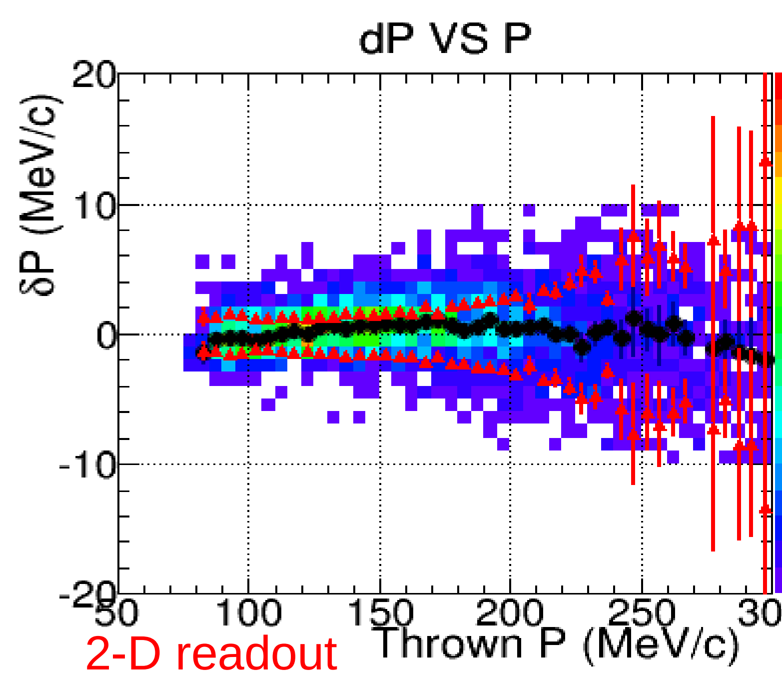
- Angle resolution for hits reconstruction: dθ= RTPC_Pad_W/sqrt(12)/RTPC_ReadOut_R.
  - For 4.5(w)x5(z) pad: dθ = 14.4 mrad, or 0.83 degrees.
  - For 2(w)x2(z) pad: dθ = 6.4 mrad, or 0.37 degrees.
  - For x-y stripes 2-D readout: dθ = 1.3 mrad, or 0.07 degrees
- Z resolution dZ = RTPC_Pad_Z/sqrt(12)

Comparing P Resolution



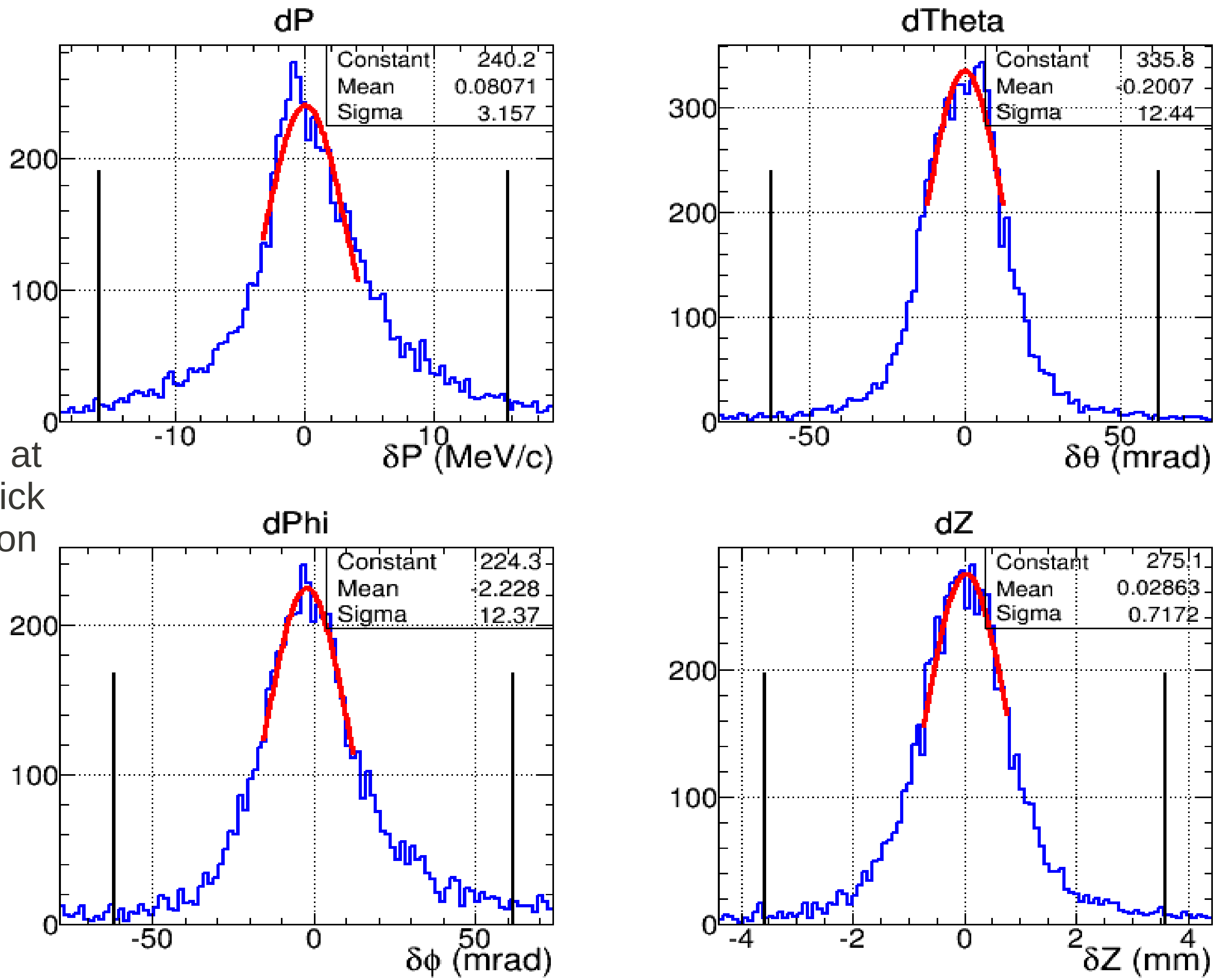






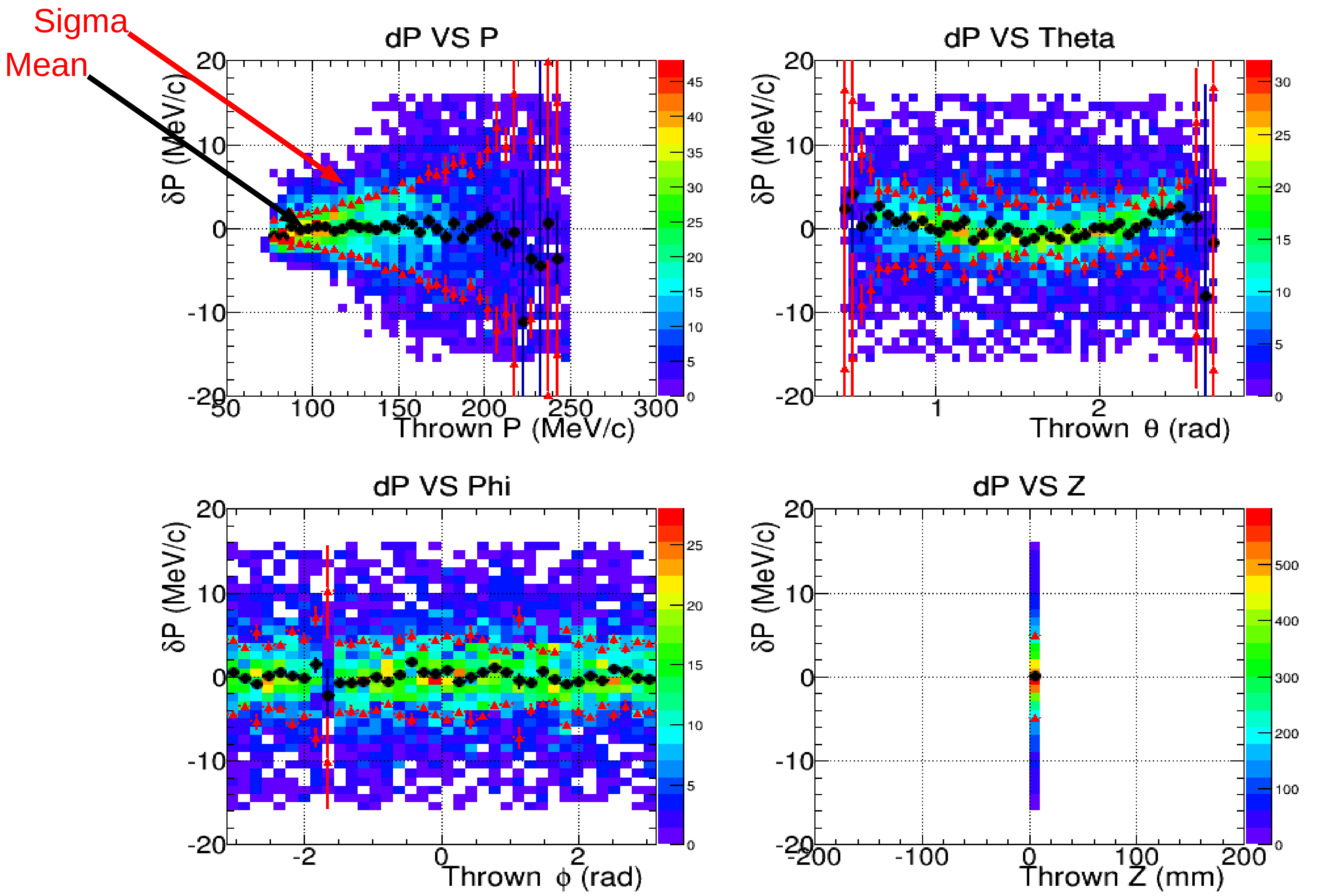
RTPC 12 Performance: 2x2 mm pad

Only thrown at z=0 for a quick demonstration

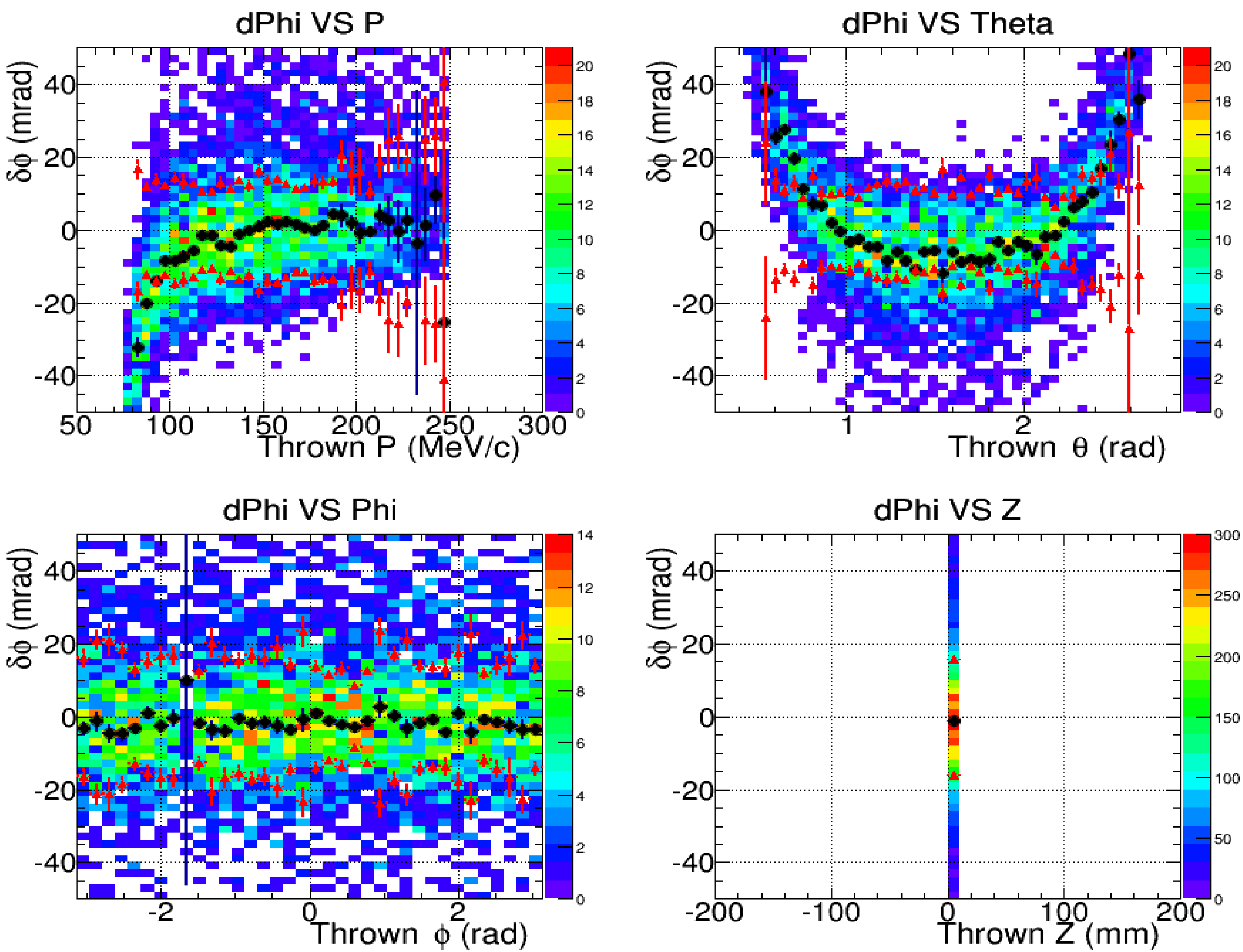


See their dependencies on other variables in next 3 pages.

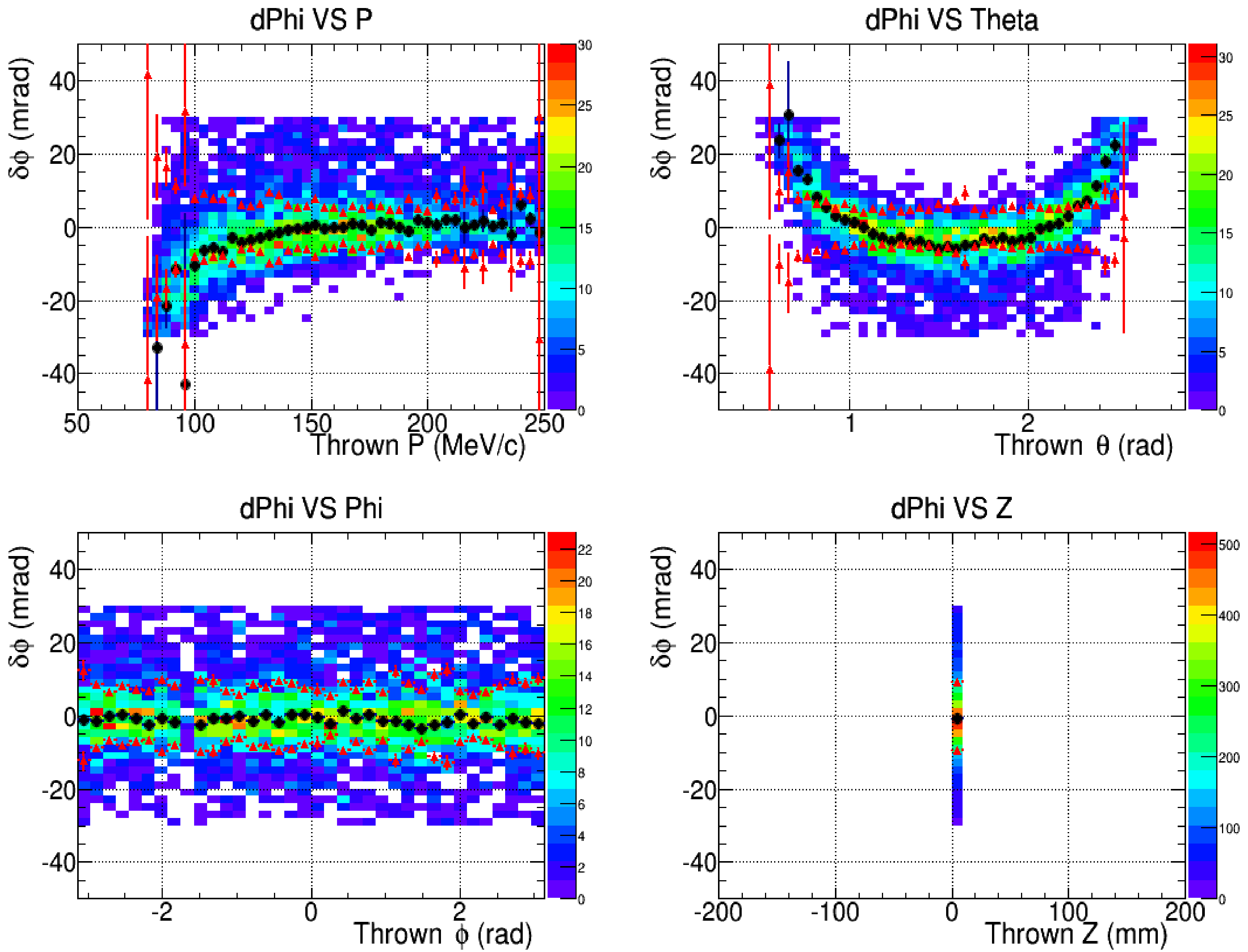
P Resolution: 2x2 mm pad



Theta Resolution: 2x2 mm pad



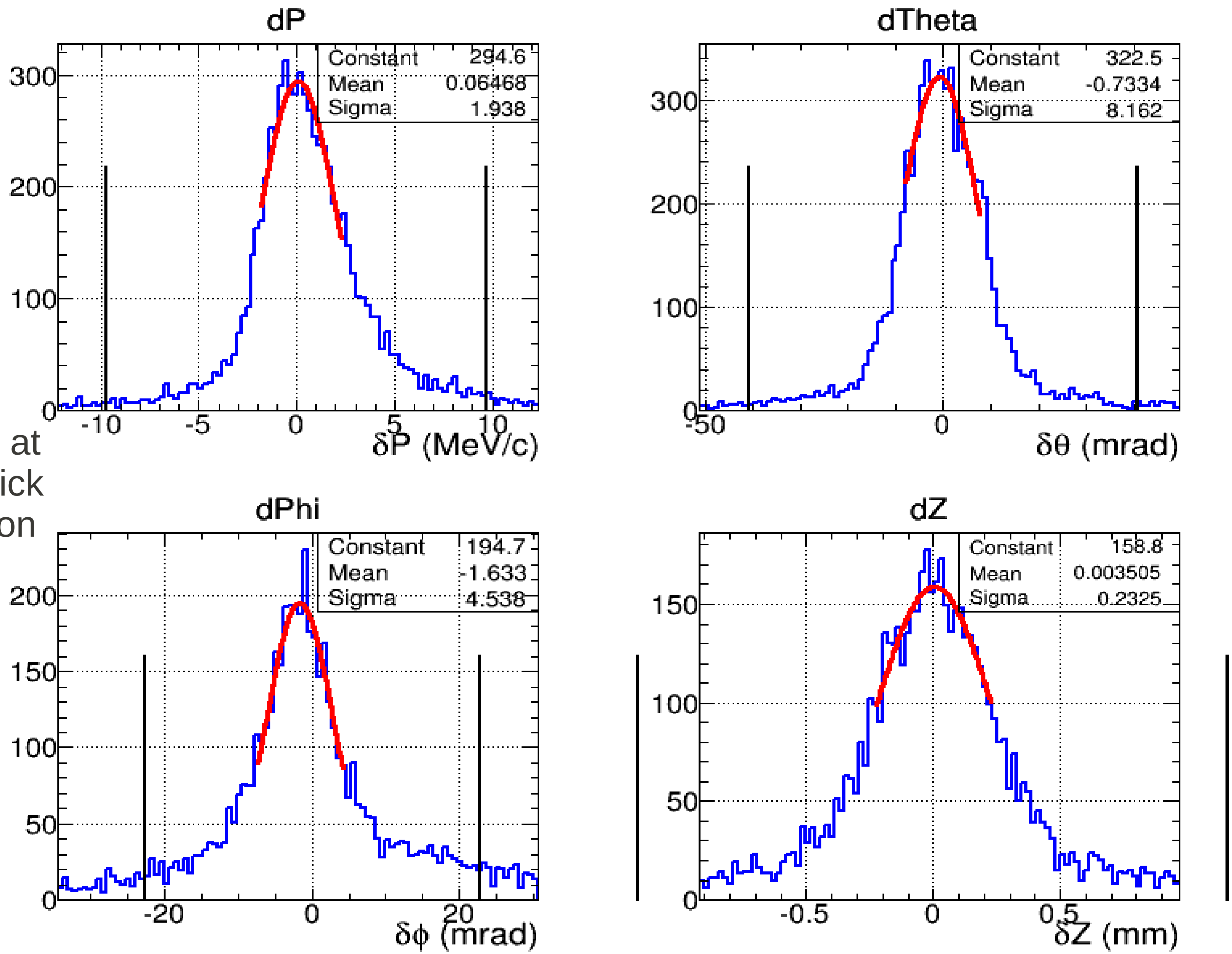
Phi Resolution: 2x2 mm pad



Phi reconstruction is bad! But can be improved. See details in next page.

RTPC Performance: 2-D readout

Only thrown at z=0 for a quick demonstration



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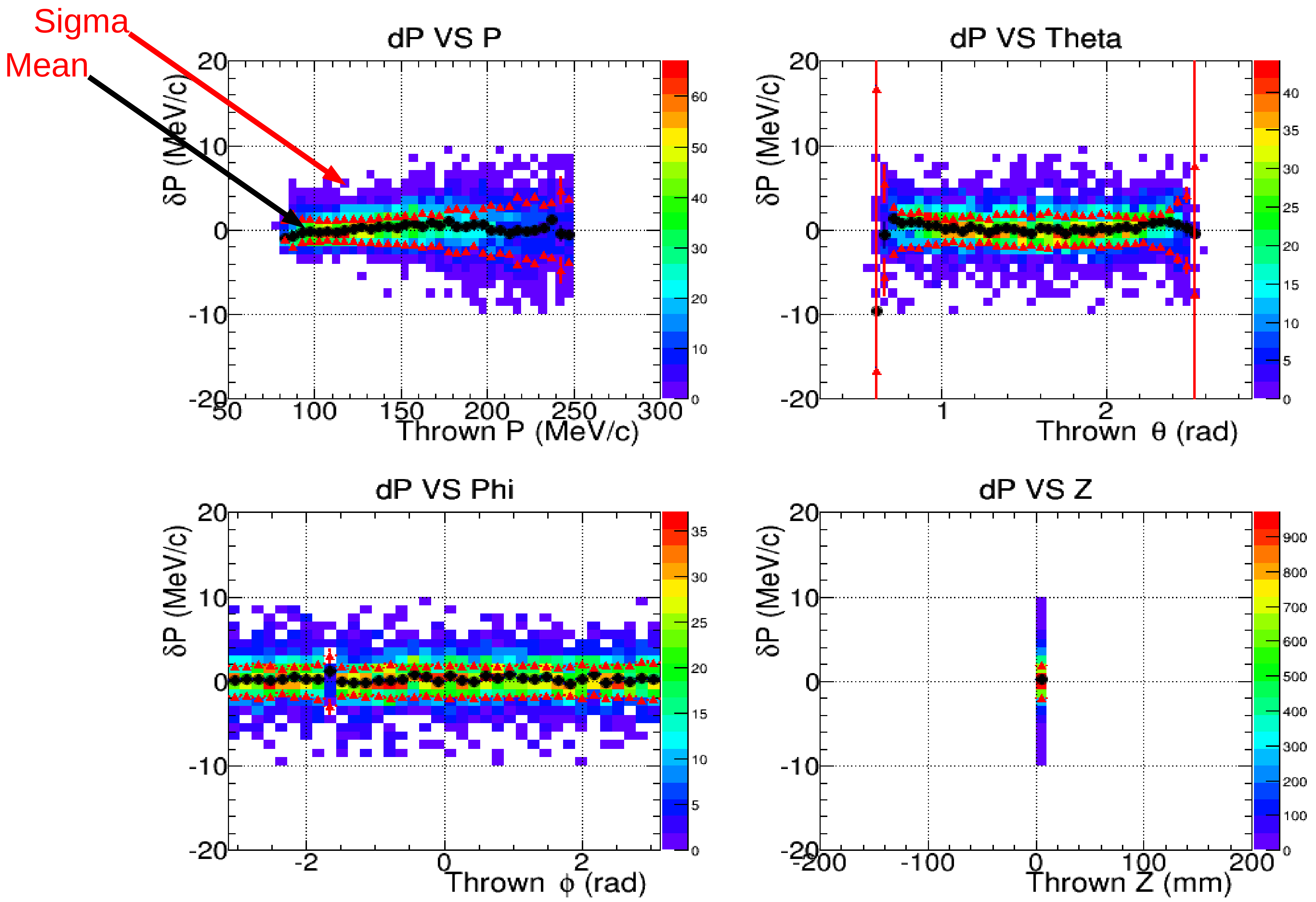
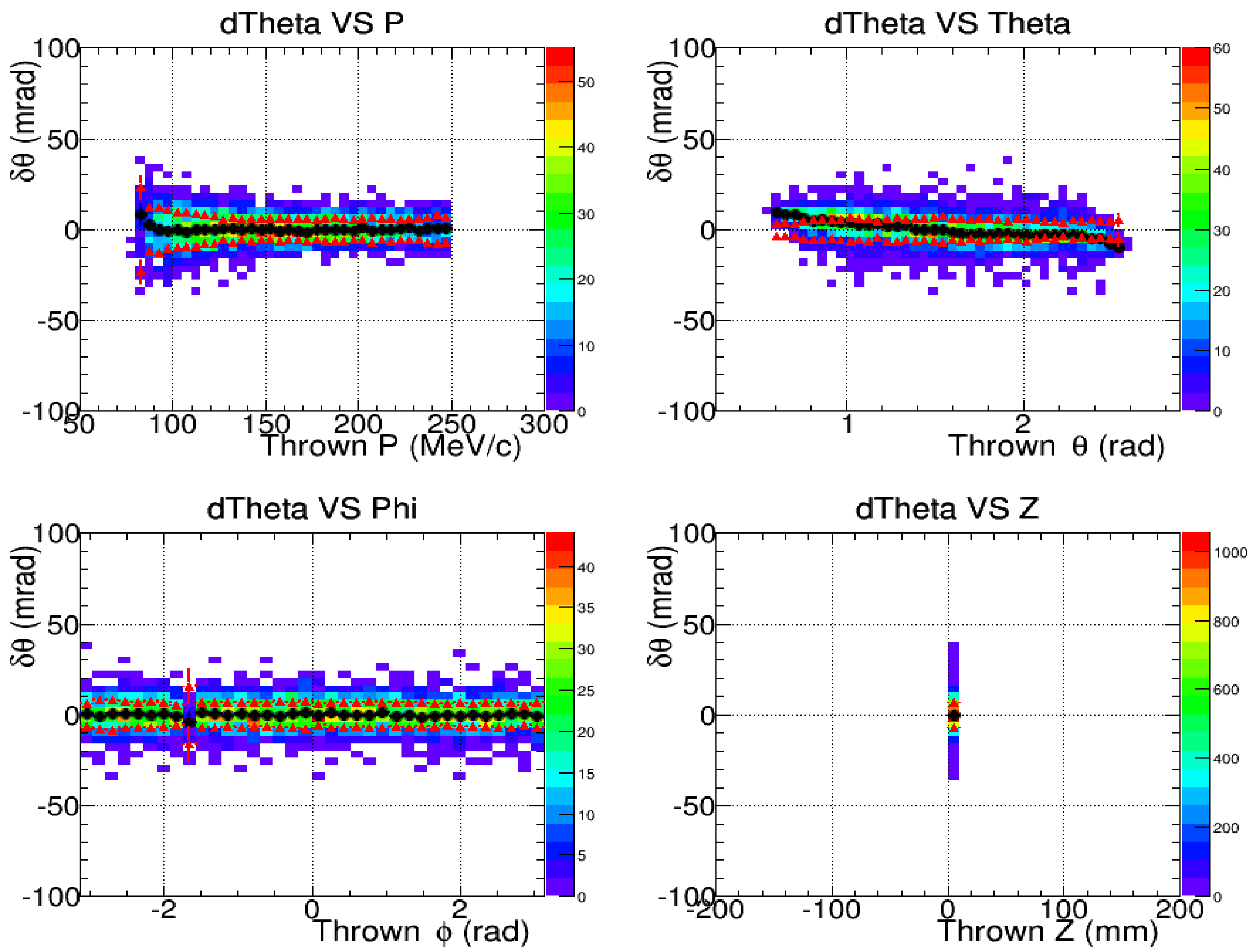
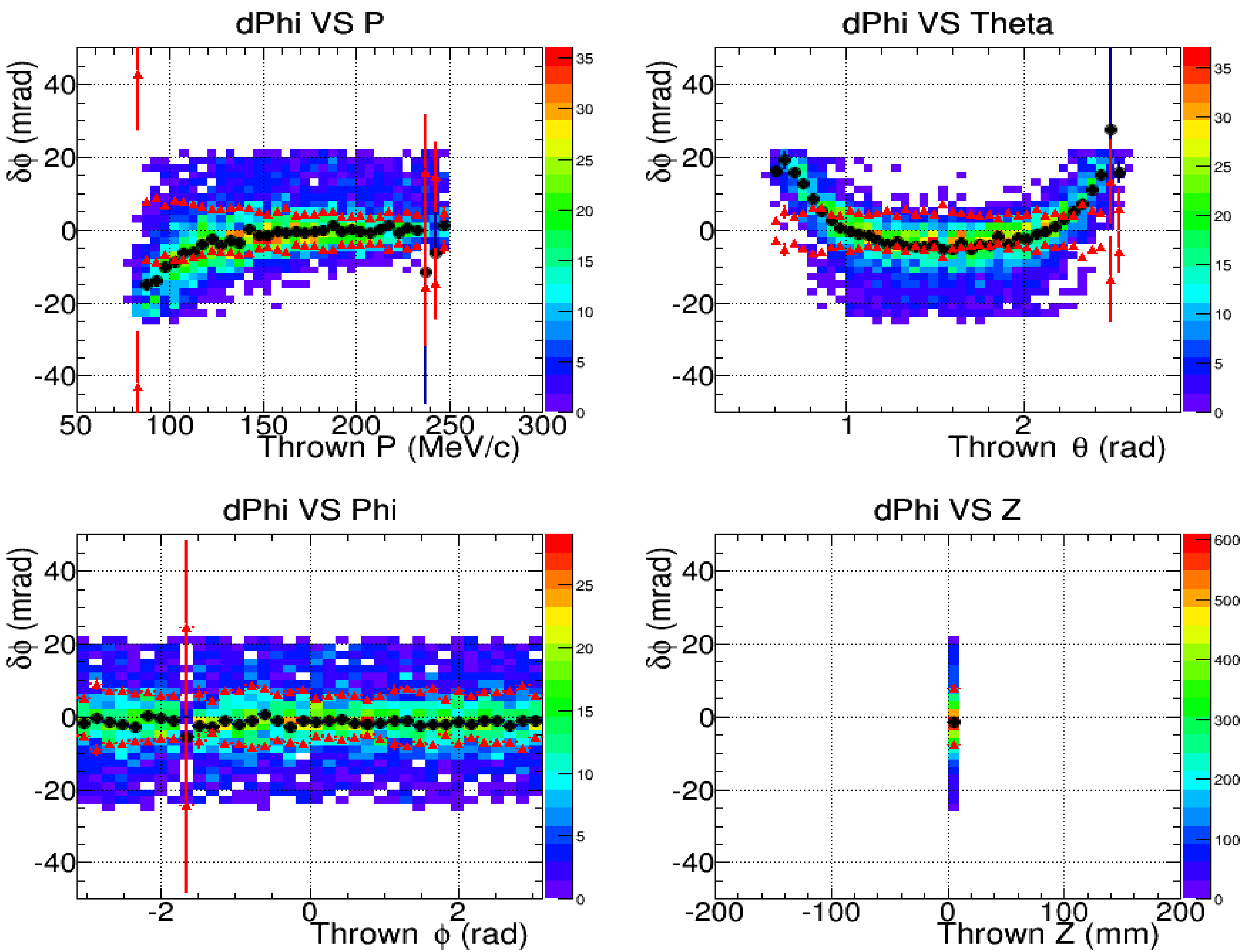
P Resolution: 2-D readout



Theta Resolution: 2-D readout

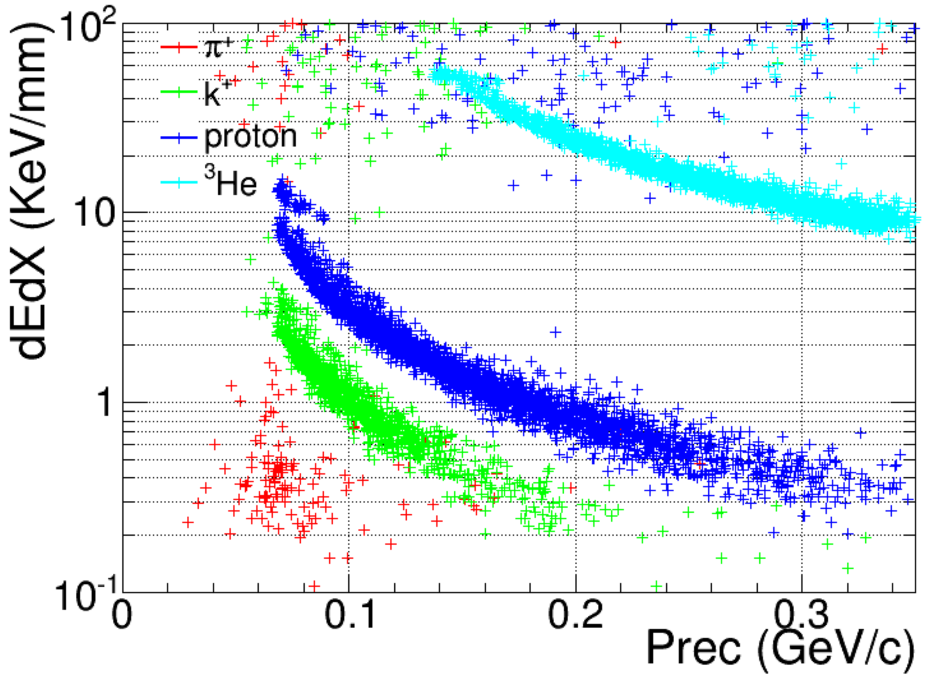


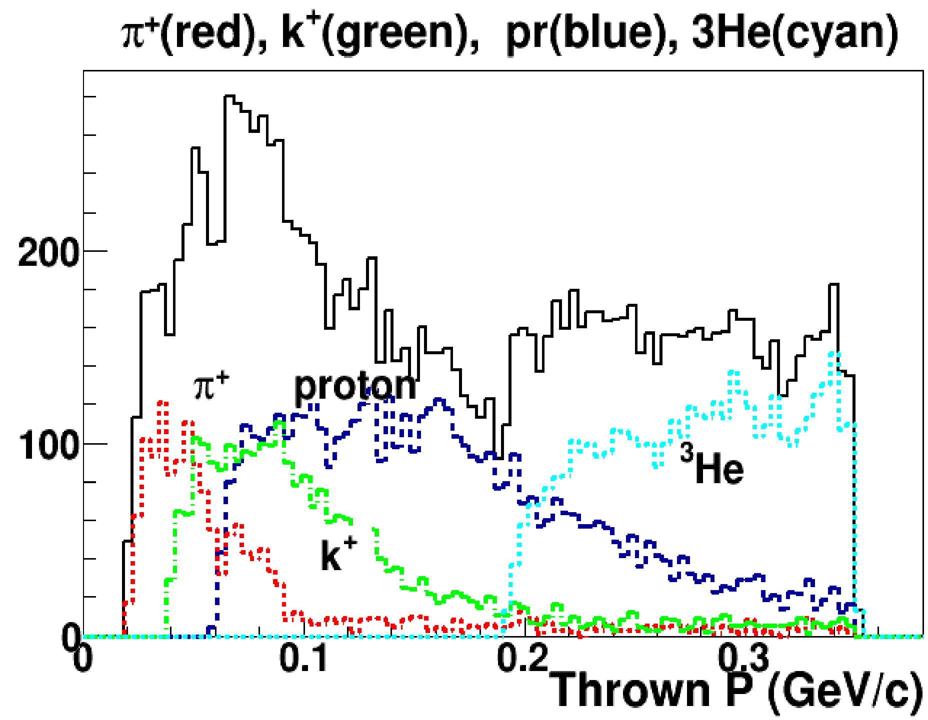
Phi Resolution: 2-D readout

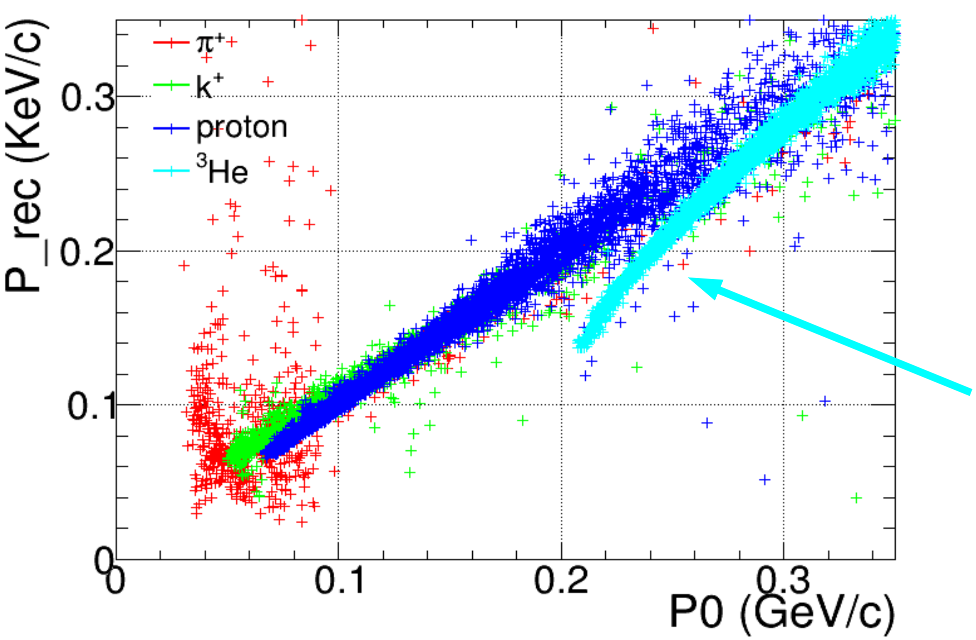


Phi reconstruction is bad! But can be improved. See details in next page.

Particle Identification





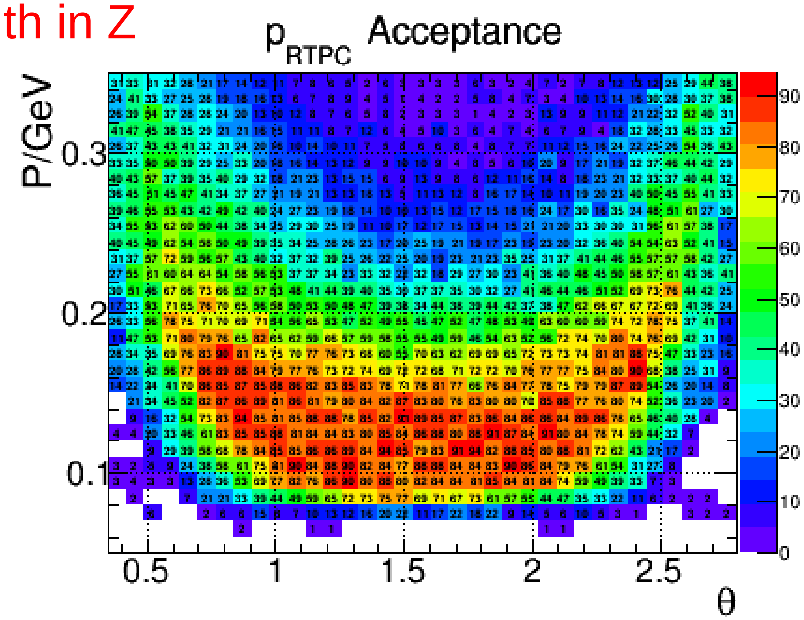


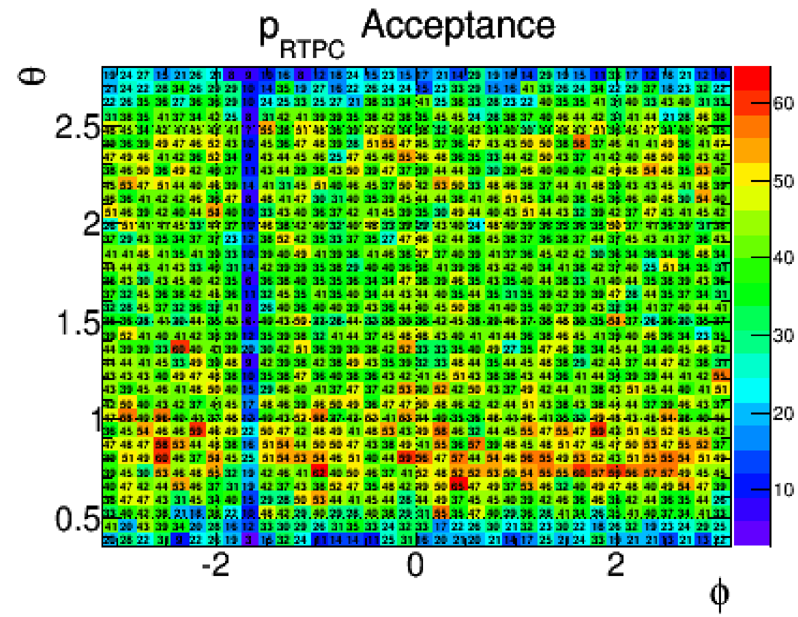
Throw 10k particles of each type randomly in range of [0.02,0.35]

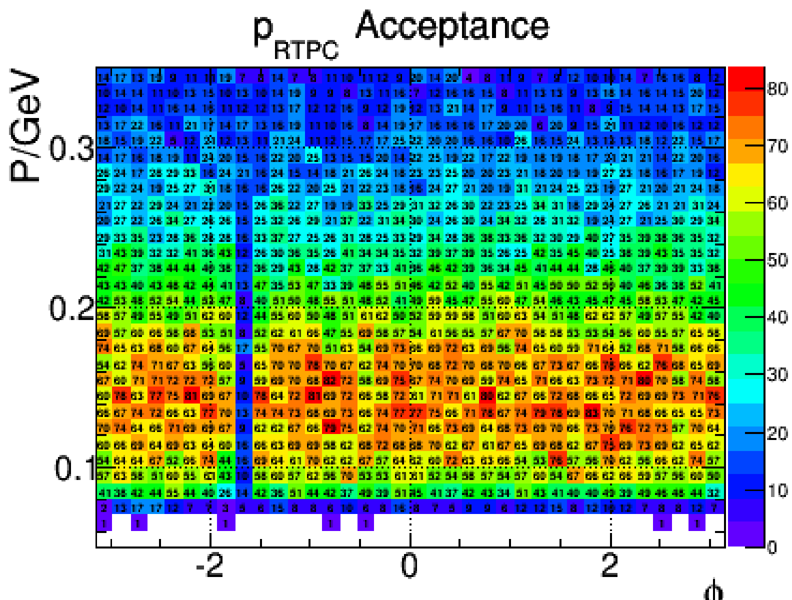
Assuming 2x2 pad
Using proton reconstruction code to reconstruct 3He

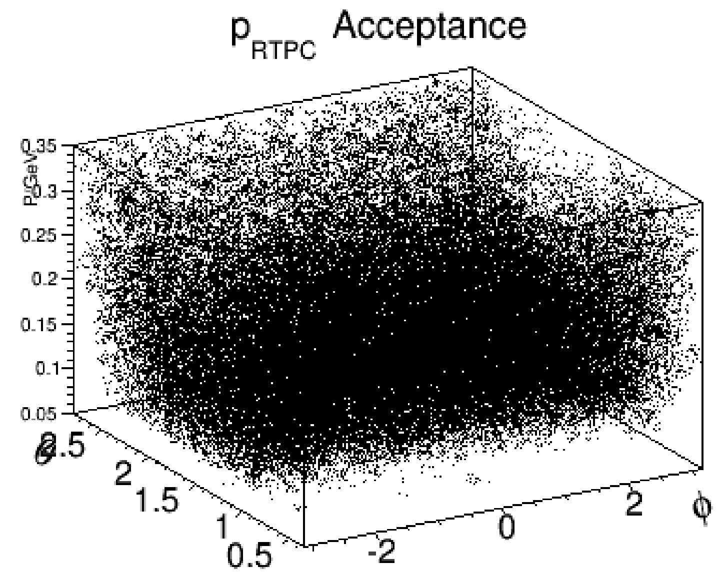
RTPC Acceptance

2x2 mm pad
Full length in Z









Averaged over all Z! This figure is for demonstration only! Should provide 4-D maps

Number of Channels

Common feature:

- Drift Region = 3<R<8 cm
- Readout pad|strips R=9cm
- Time resolution: 12 ns (using 25 ns sampling DREAM readout)

Option 1: 4.5 x 5.0 mm pad --> 122 x 80 = 9760 channels
Option 2: 2.0 x 2.0 mm pad --> 274 x 200 = 54800 channels
Option 3: (550x0.4) – (0.4x400) mm x-y strips --> 1374 + 1000 = 2374 channels
Option 4: (110x0.4) – (0.4x80) mm x-y strips --> 5x1374 + 5x1000 = 11870
Option 5: (55x0.4) – (0.4x40) mm x-y strips --> 10x1374 + 10x1000 = 23740

(need to study total rates (bg+signal) to make further decision)

DAQ Cost: ~4 dollars per channel

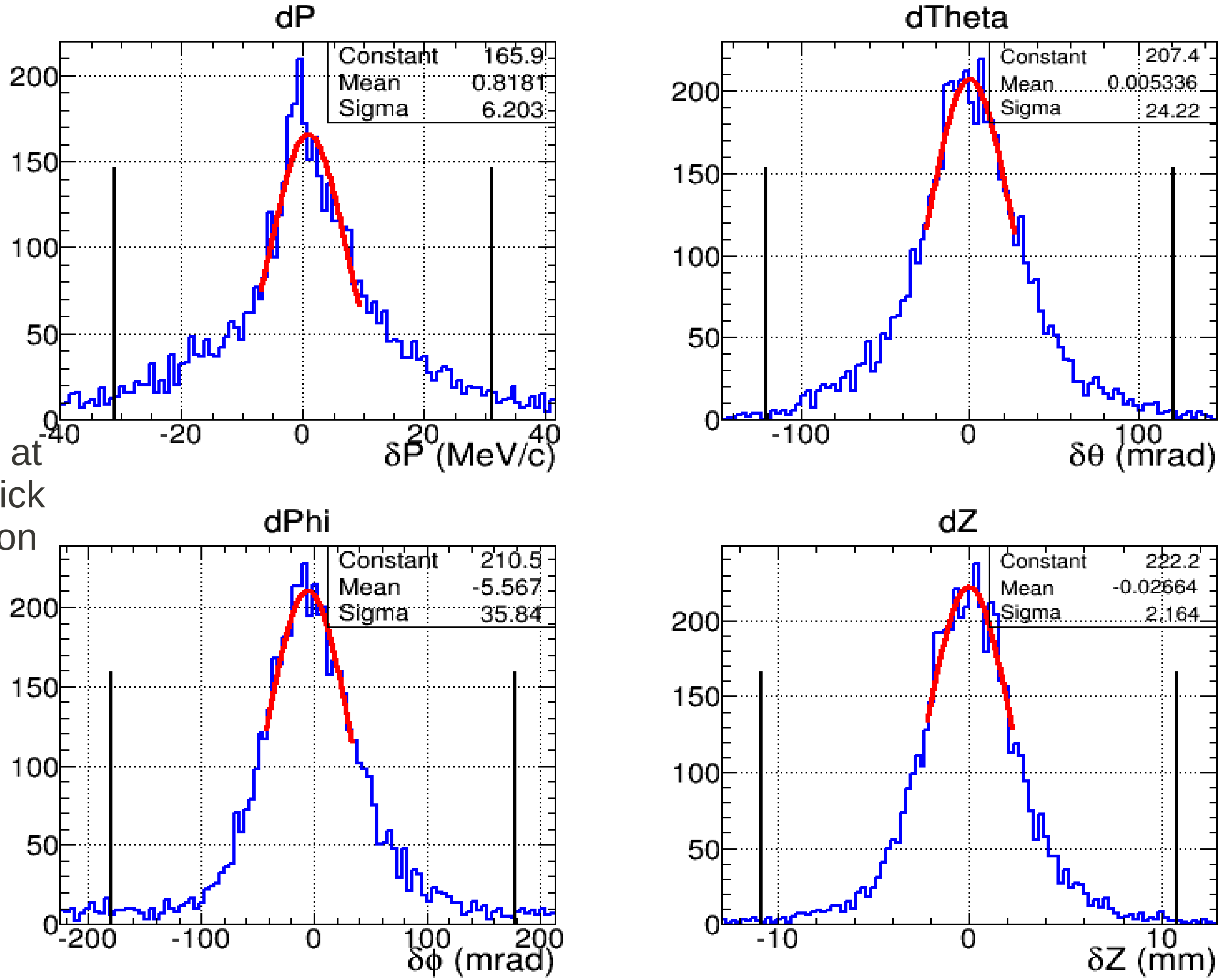
Summary

- A Geant4 program is ready to simulate RTPC12
- RTPC momentum resolution and valid reconstruction range depend on readout pad size. Assuming 5 cm drift chamber and readout locates at R=9cm,
  - For pad 4.5x5.0 mm, the dP resolution is 10 MeV for 150 MeV/c proton.
  - For pad 2.0x2.0 mm, the dP resolution is 10 MeV for 200 MeV/c proton.
  - For compass 2-D readout, the dP resolution is 10 MeV for ~290 MeV/c proton.
- Particle ID: Proton can be separated easily from pion, 3He and 4He.
- RTPC12 will have large acceptance in theta, phi and p:
  - For pad 2.0x2.0 mm: 350 degrees for phi, 15<theta<165, 60<P<250
  - For 2-D readout: 350 degrees for phi, 15<theta<165, 60<P<290

- 2-D readout will have the best performance and relative less number of channels than pad readout. Need to study total rates to make final decision.

Back up

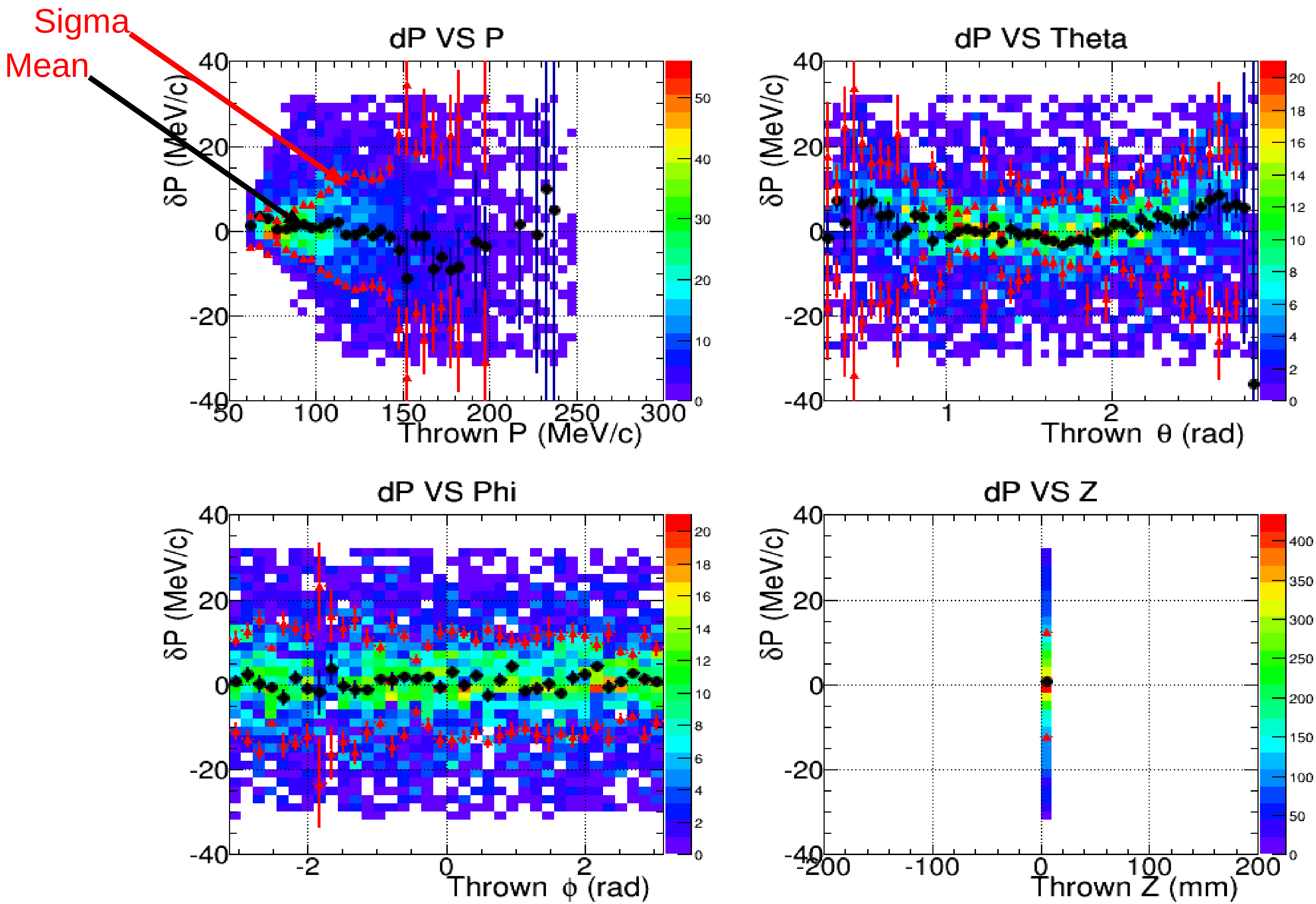
RTPC6 Performance: 4.5x5 mm pad



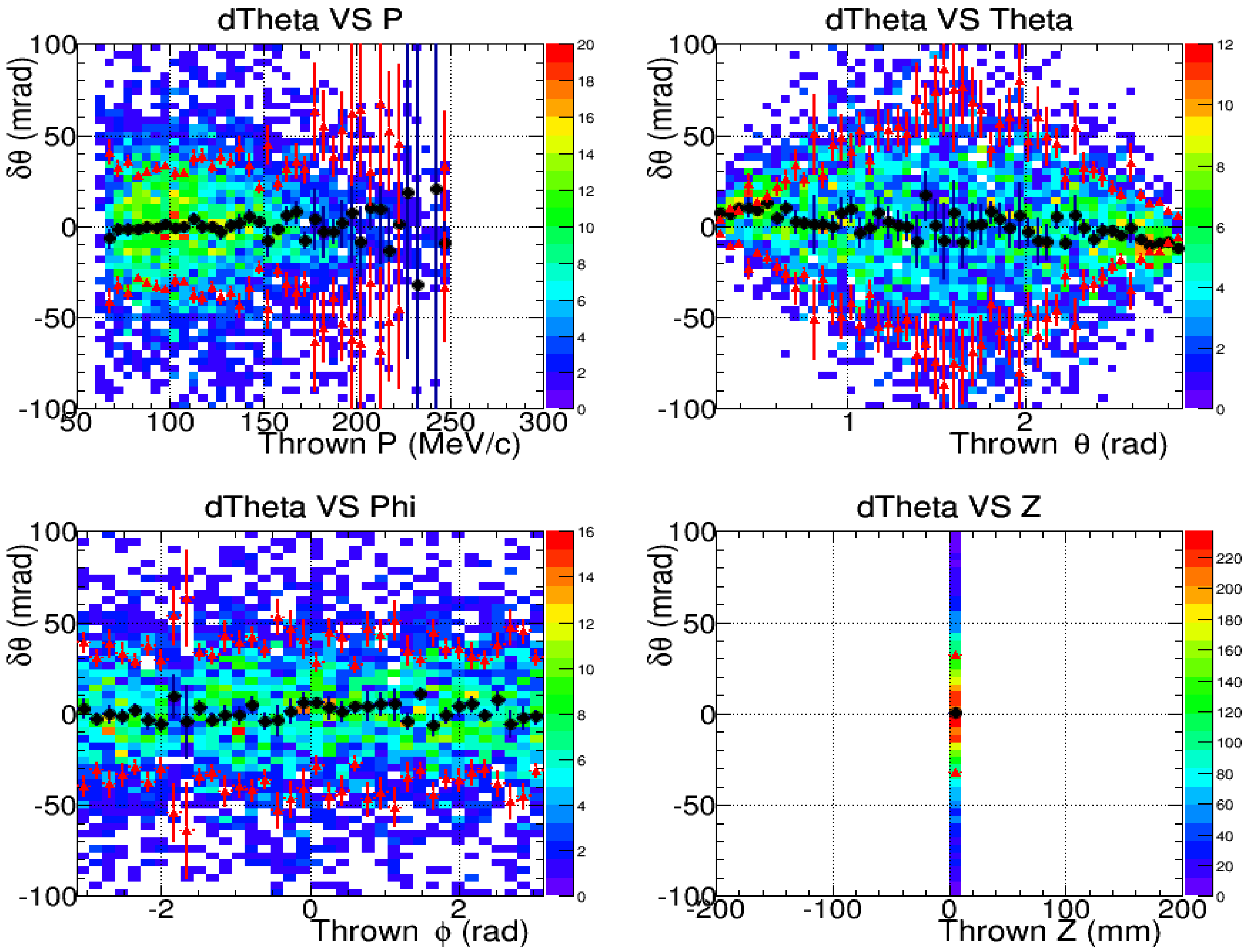
Only thrown at z=0 for a quick demonstration

See their dependencies on other variables in next 3 pages.

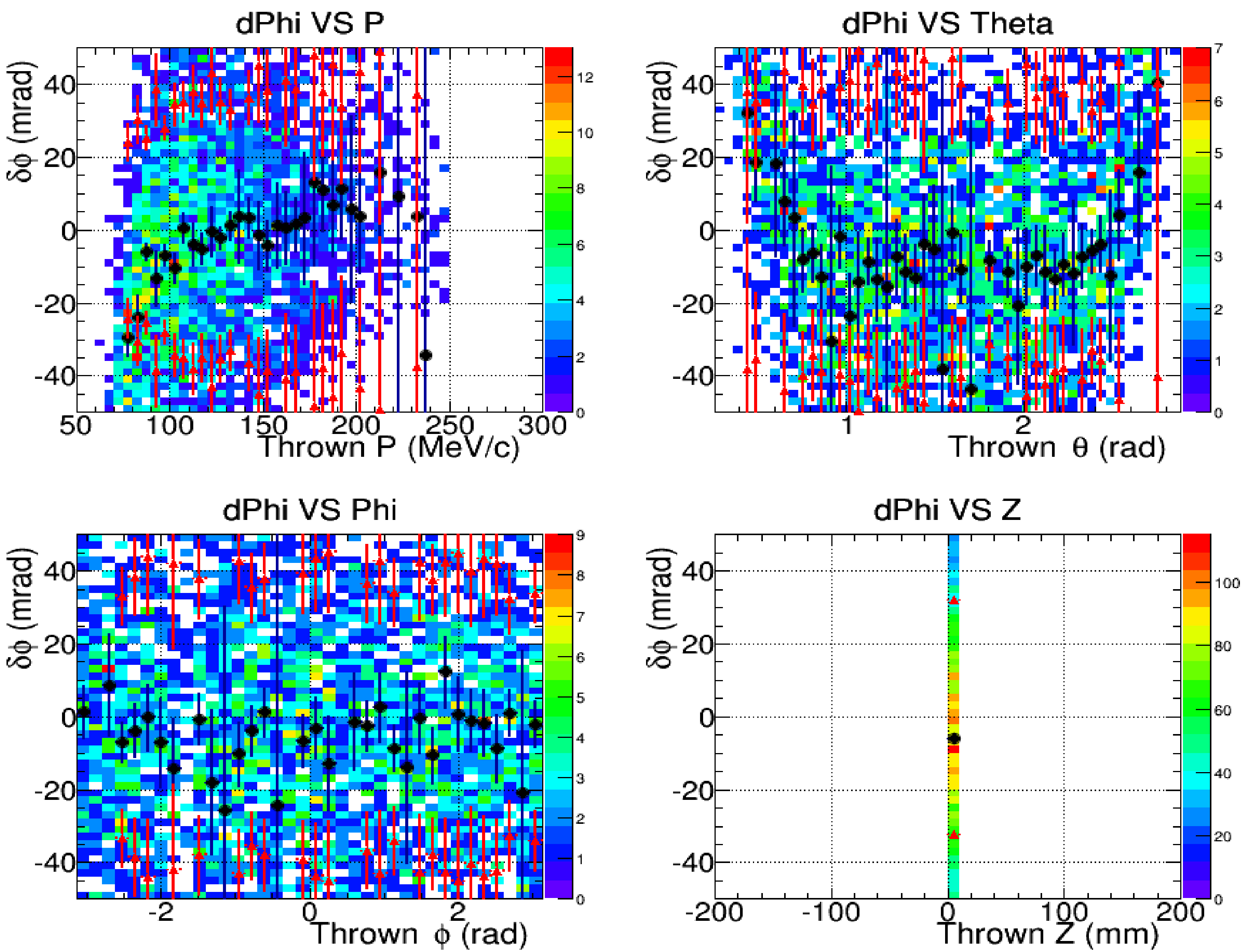
RTPC6 P Resolution: 4.5x5 mm pad



RTPC6 Theta Resolution: 4.5x5 mm pad



RTPC6 Phi Resolution: 4.5x5 mm pad



RTPC Performance: 4.5x5 mm pad

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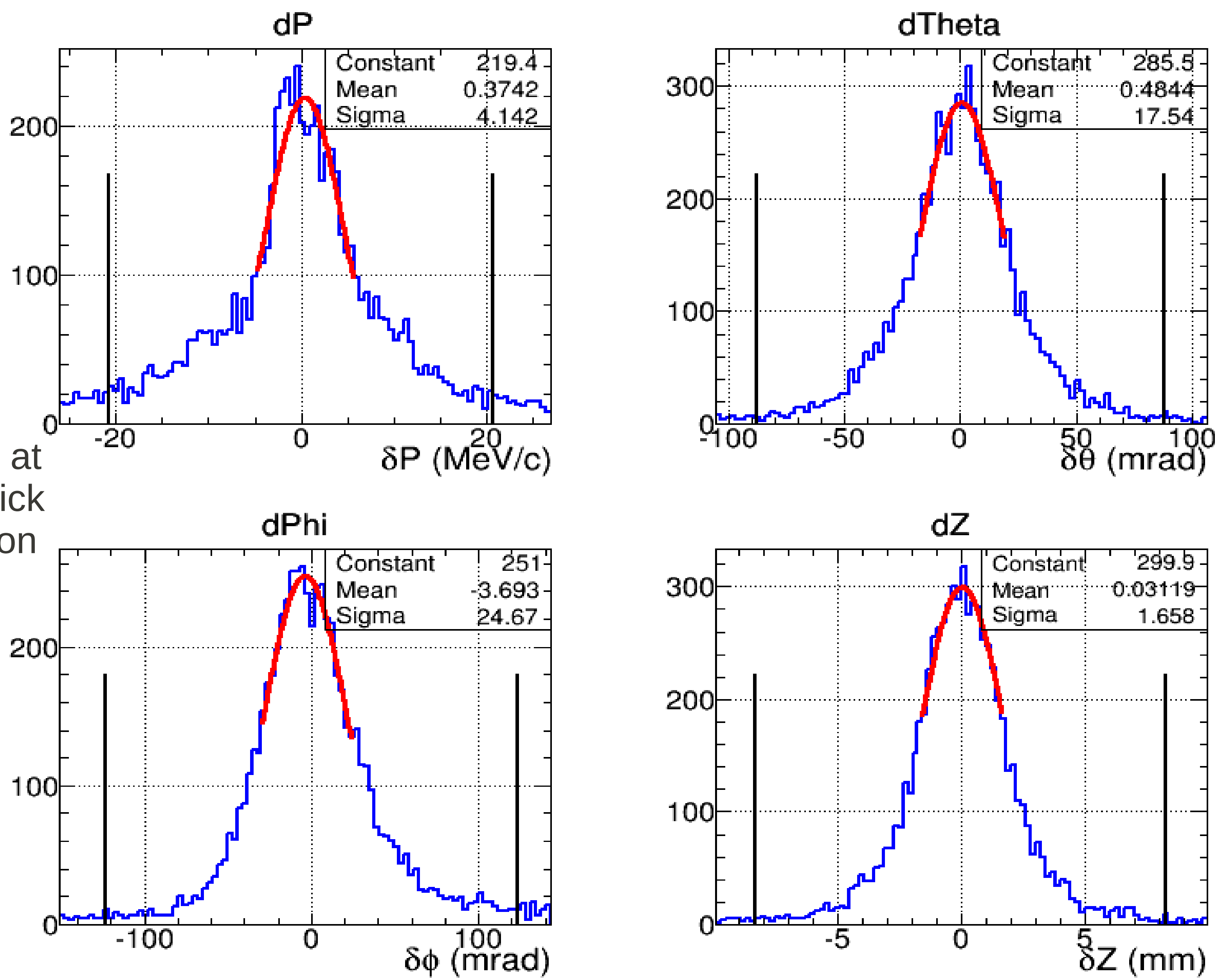

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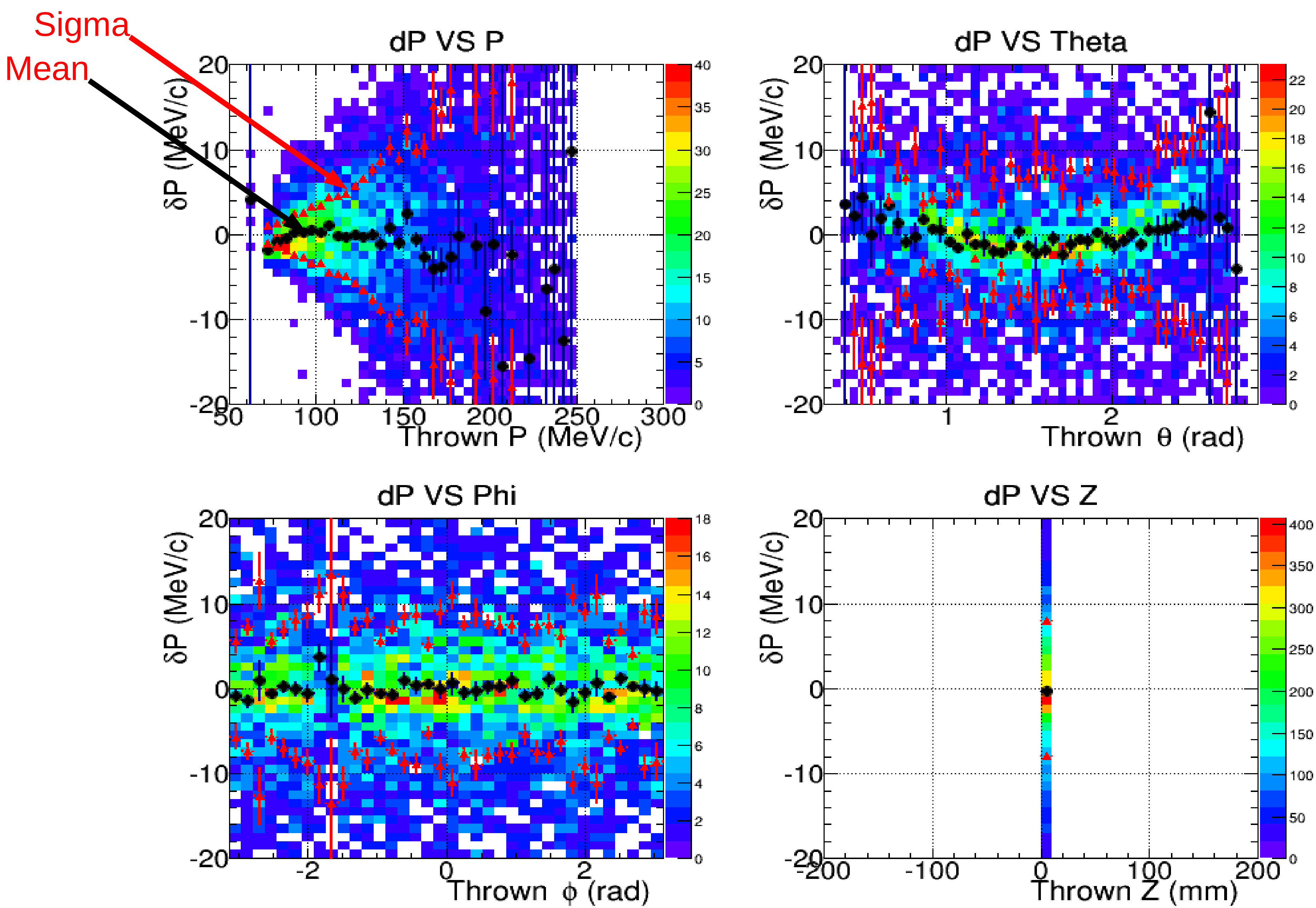
P Resolution: 4.5x5 mm pad



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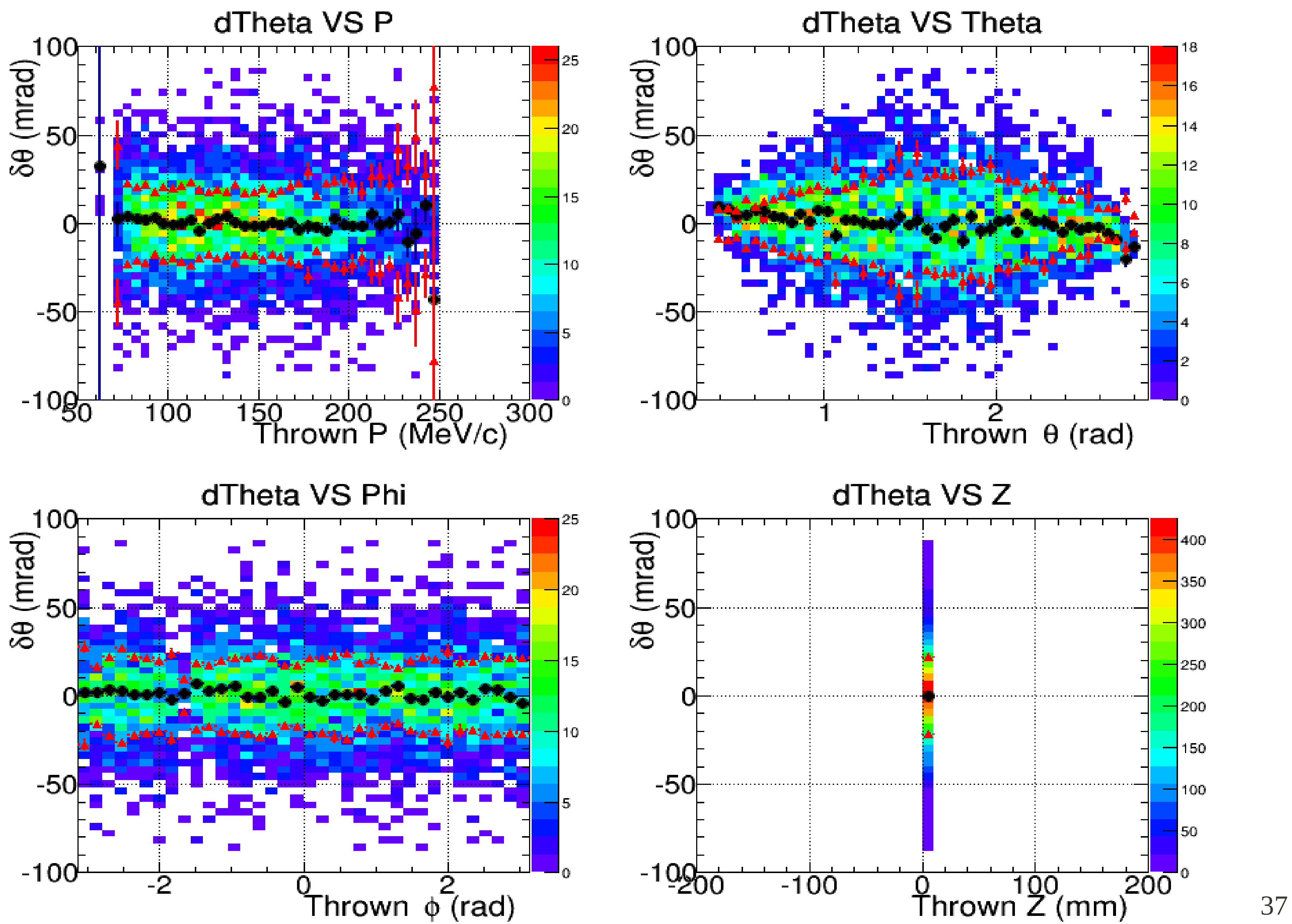
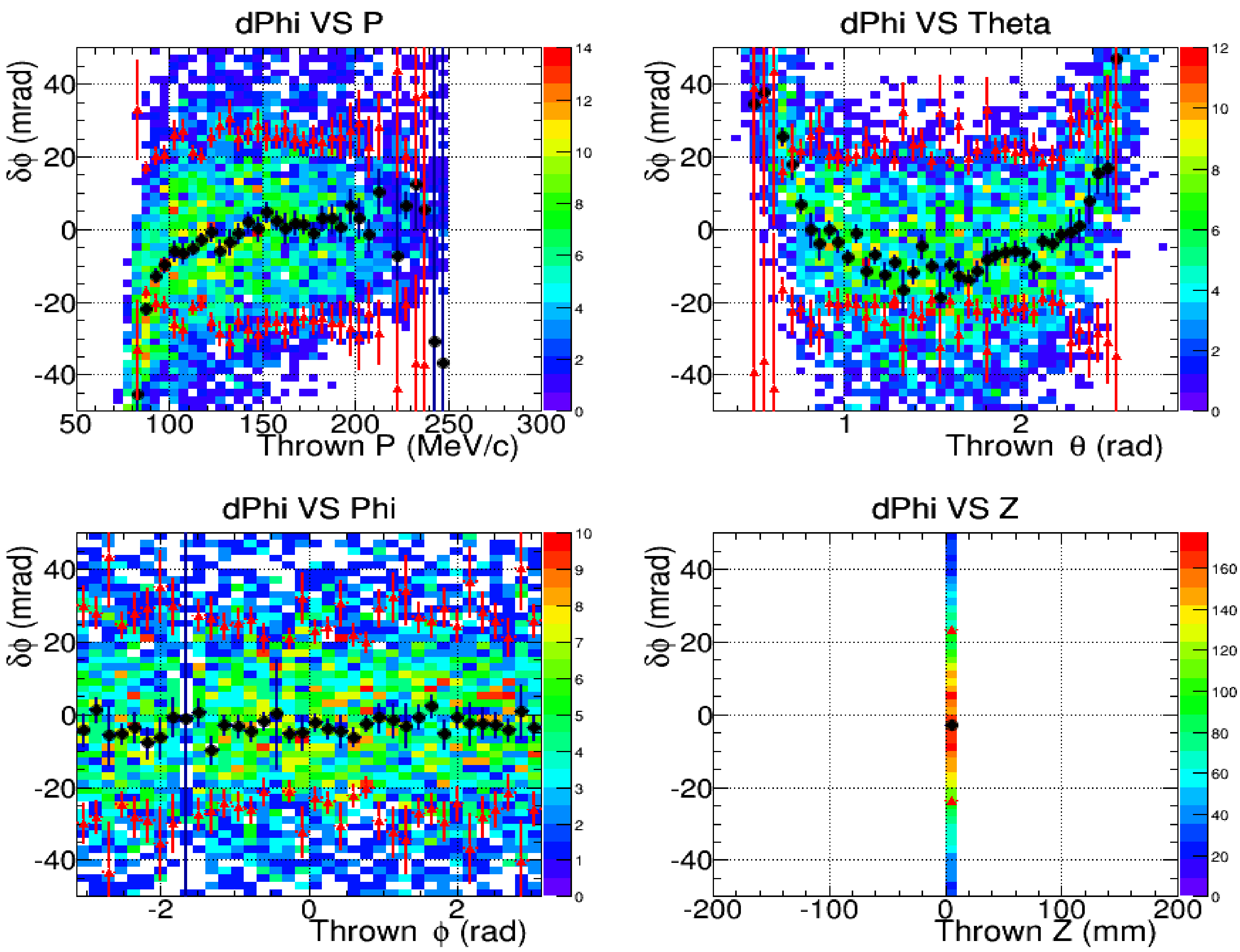
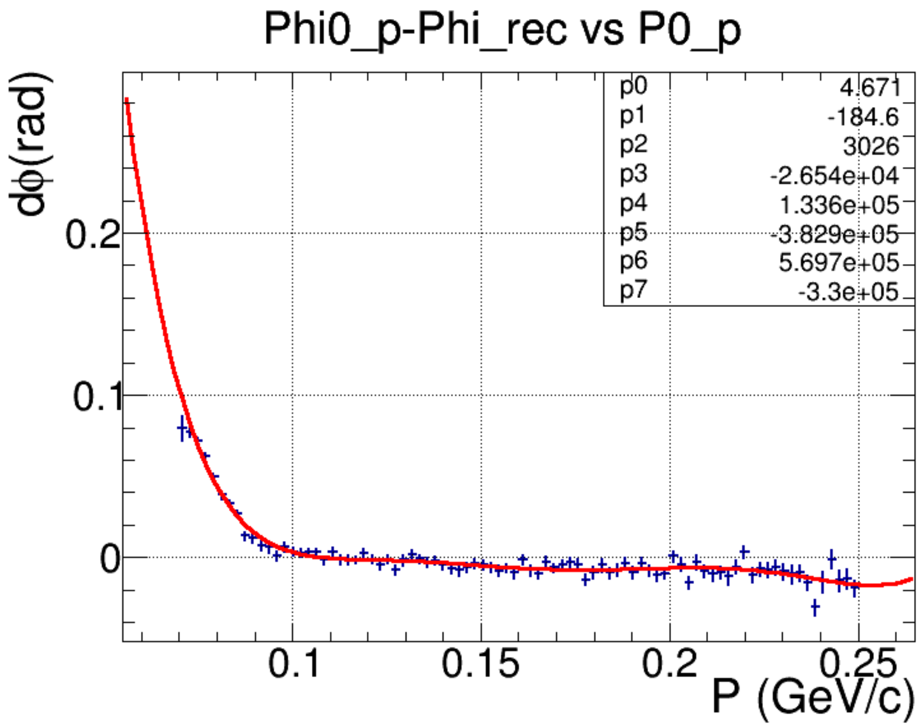
Theta Resolution: 4.5x5 mm pad

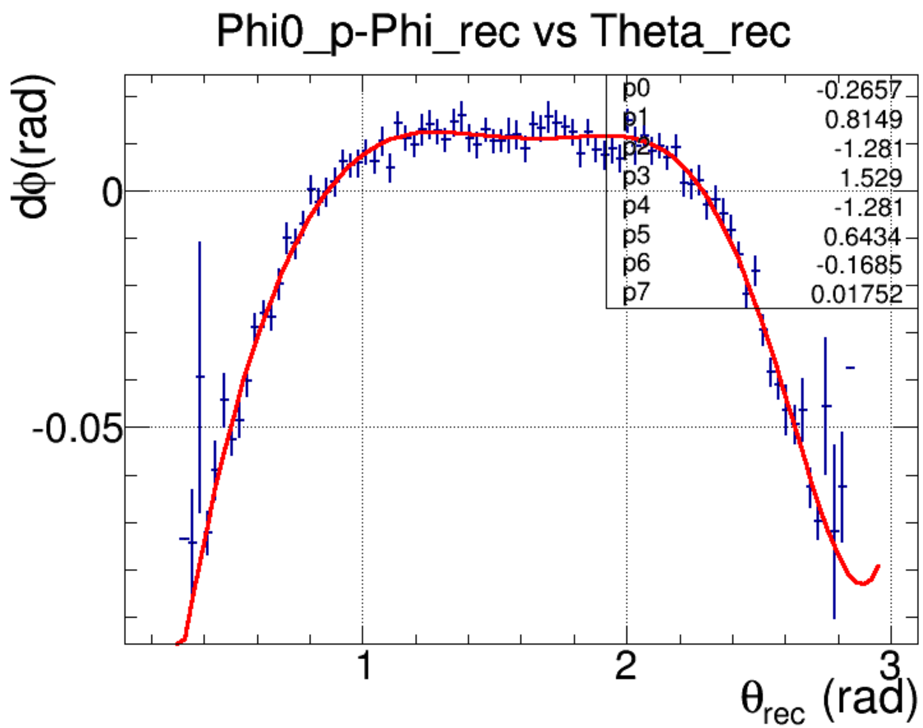


Phi Resolution: 4.5x5 mm pad



Phi Reconstruction





Try to improve phi angle reconstruction by 1-D function of f(P) or g(theta), but it does not work.
It should be corrected by 2-D function h(P,Theta). Need to write Minuit code to do the job. (Future job)