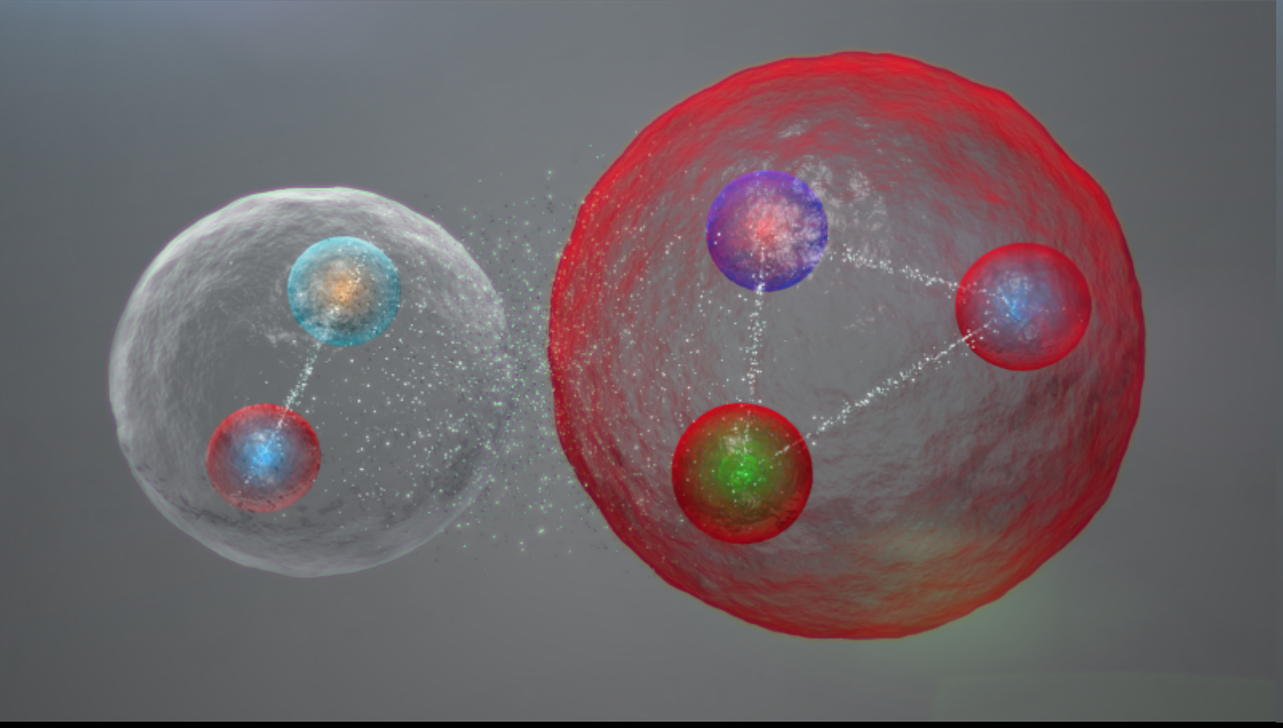
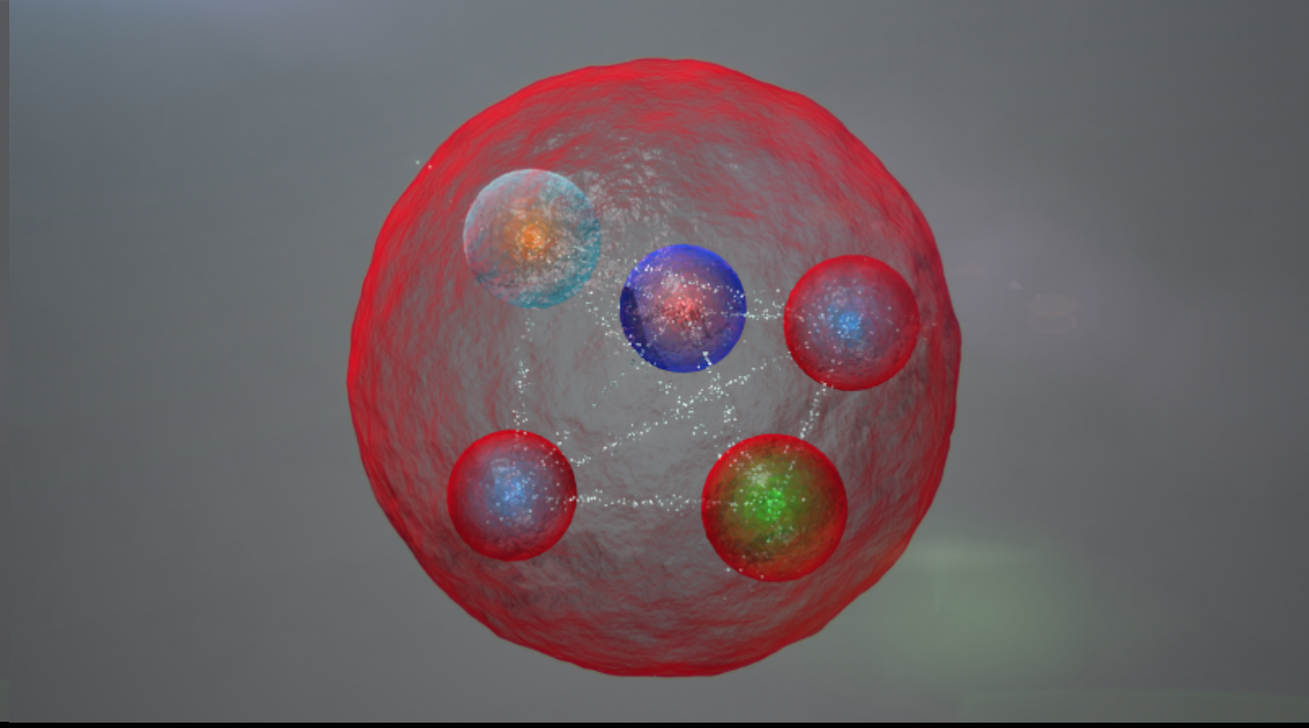




UPDATE ON THE J/Ψ_007 EXPERIMENT

BURCU DURAN

For the E12-16-007 Collaboration

Hall C Collaboration Meeting

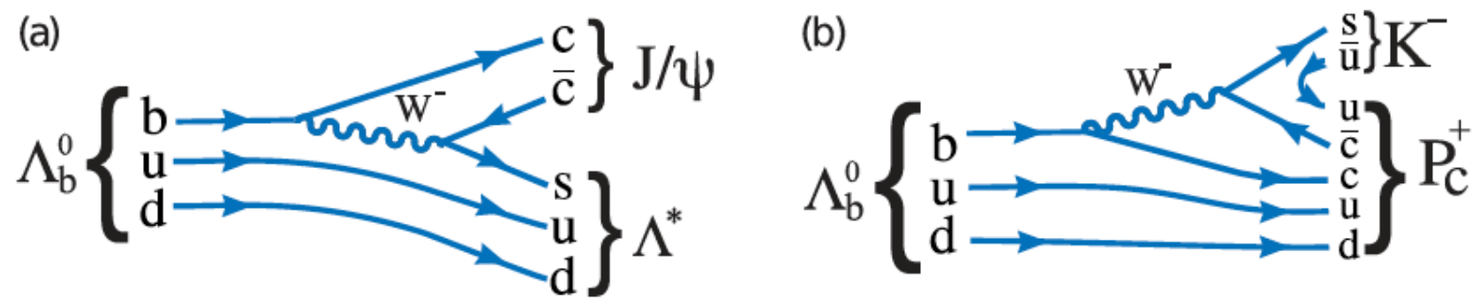
Jefferson Lab

January 29, 2020

LHCB CHARMED (CHARMING!) "PENTAQUARK" P_c

$$\Lambda_b \rightarrow K^- p J/\Psi$$

Aaij, R, et. al (LHCb) PRL 115-7 (2015)



2 *Pc* states needed to describe the results:

Narrow: *M: 4450 ± 2 ± 3 MeV*

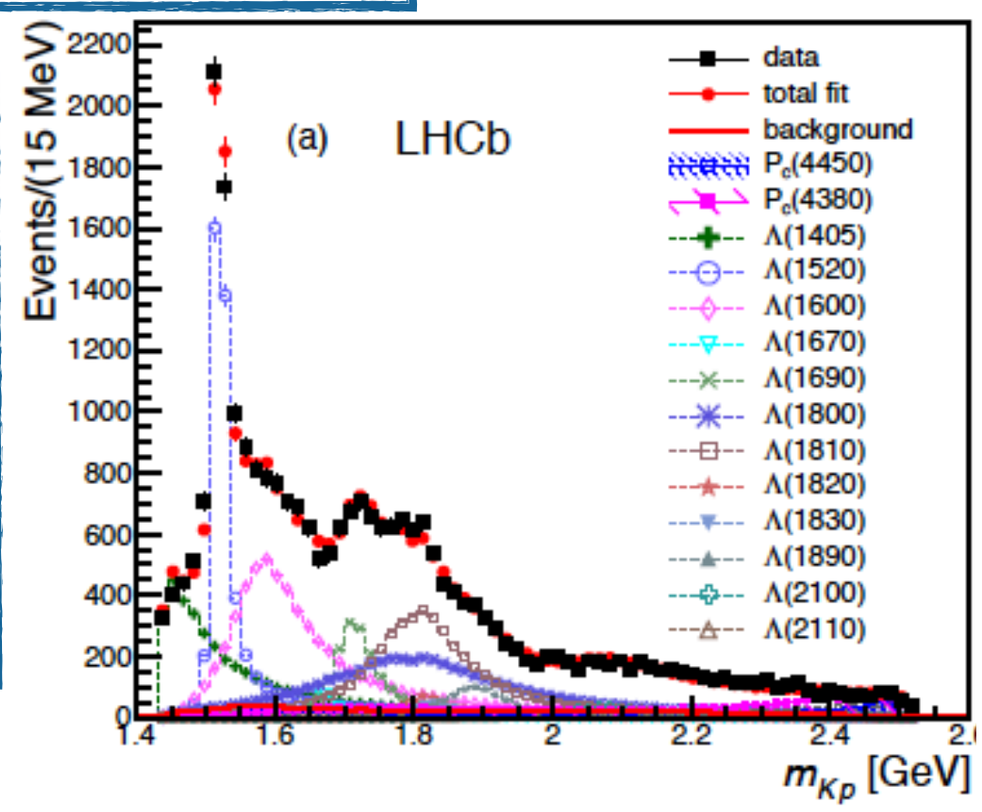
Γ: 39 ± 5 ± *19* MeV

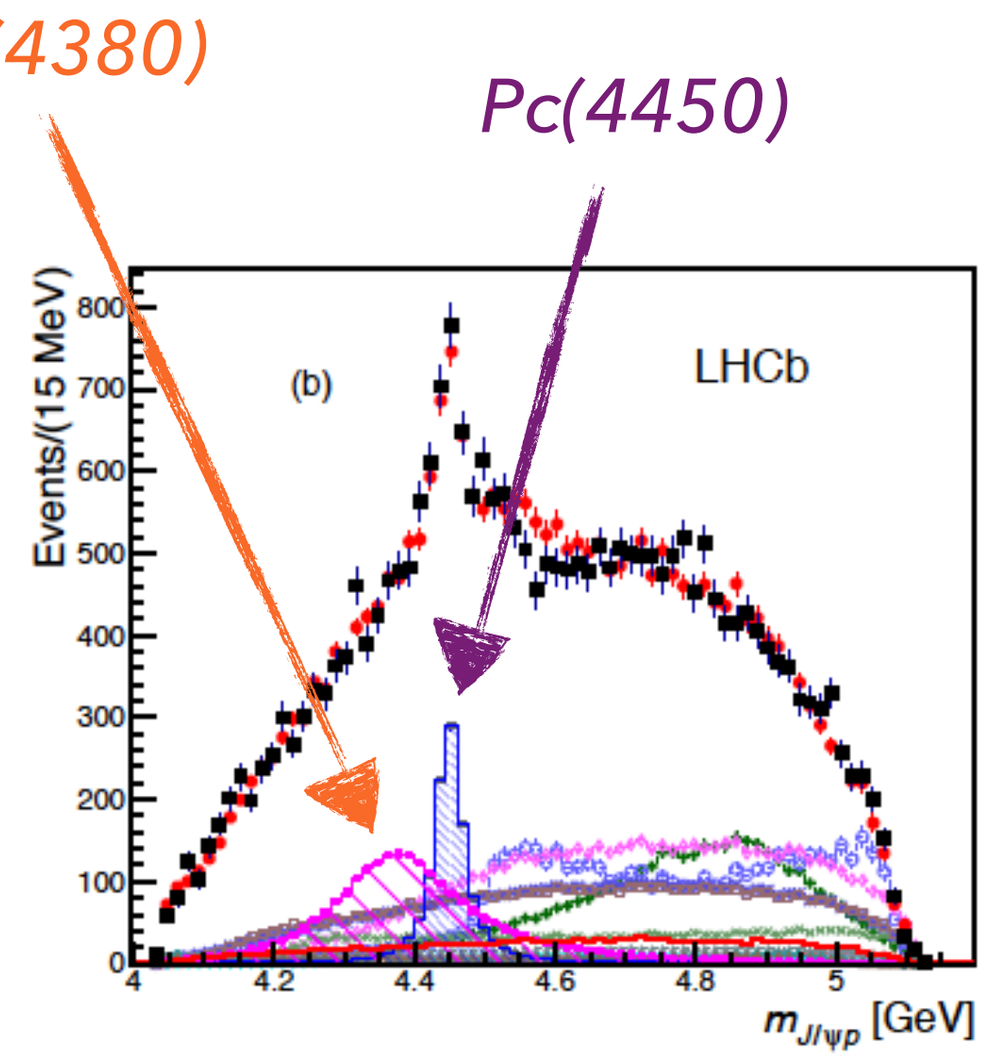
Wide: *M: 4380 ± 8 ± 29 MeV*

Γ: 205 ± *18* ± *86* MeV

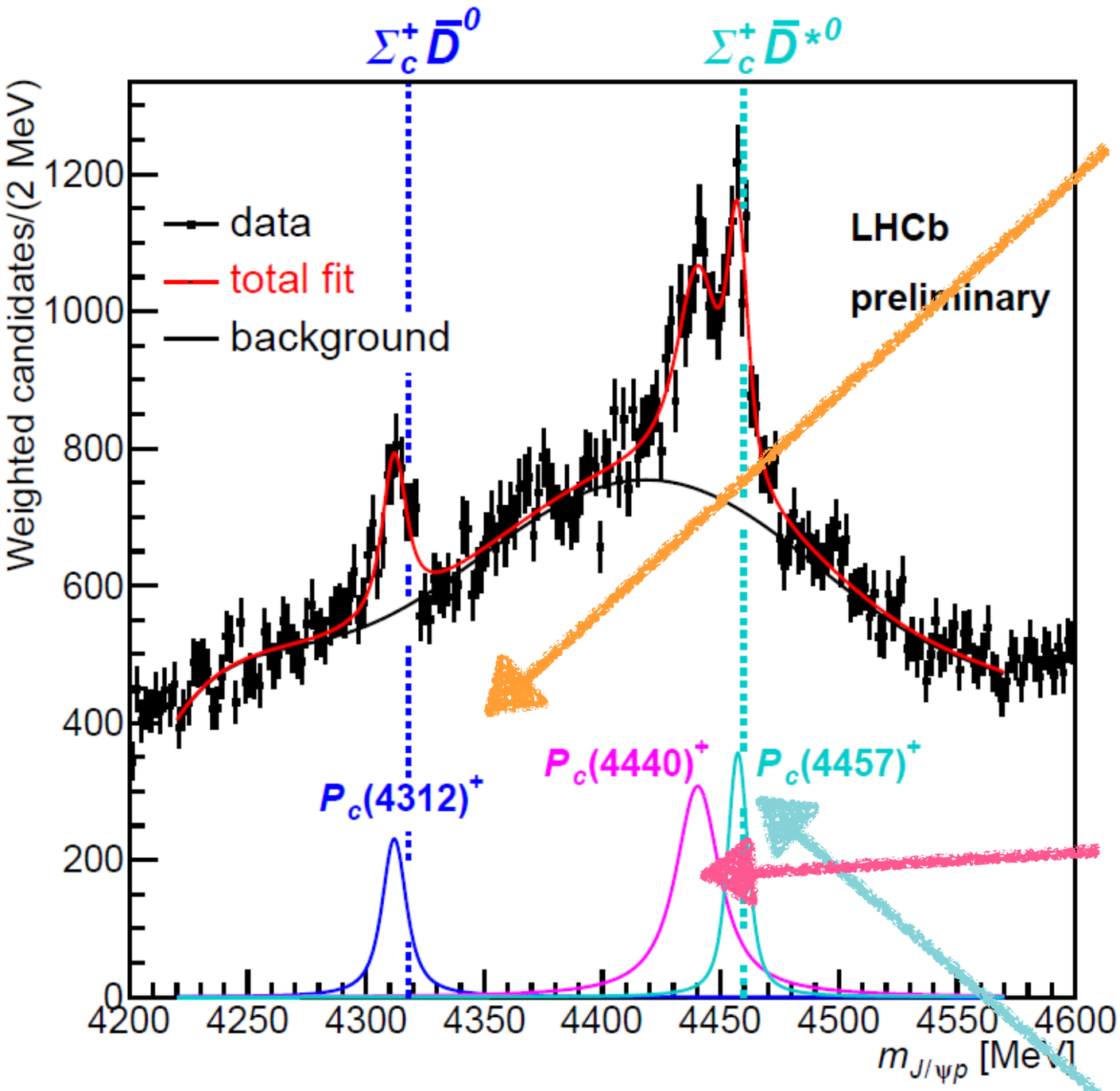
Spin parity either:

- 5/2+, 3/2- (most likely)
- 5/2-, 3/2+
- 3/2-, 5/2+





NEW LHCB RESULTS: OBSERVATION OF NEW PENTAQUARKS (26 MARCH 2019)



- **9x more data than 2015 paper**
- **Previous results are consistent**

BUT!!!

There is a new state:

M: 4311.9±0.7+6.8/-0.6 MeV

Γ: 9.8±2.7+3.7/-4.5 MeV

AND

***Pc(4450)* is resolved into 2 narrow peaks**

★ ***Pc(4440)***

M: 4440.3±1.3+4.1/-4.7 MeV

Γ = 20.6±4.9+8.7/-10.1 MeV

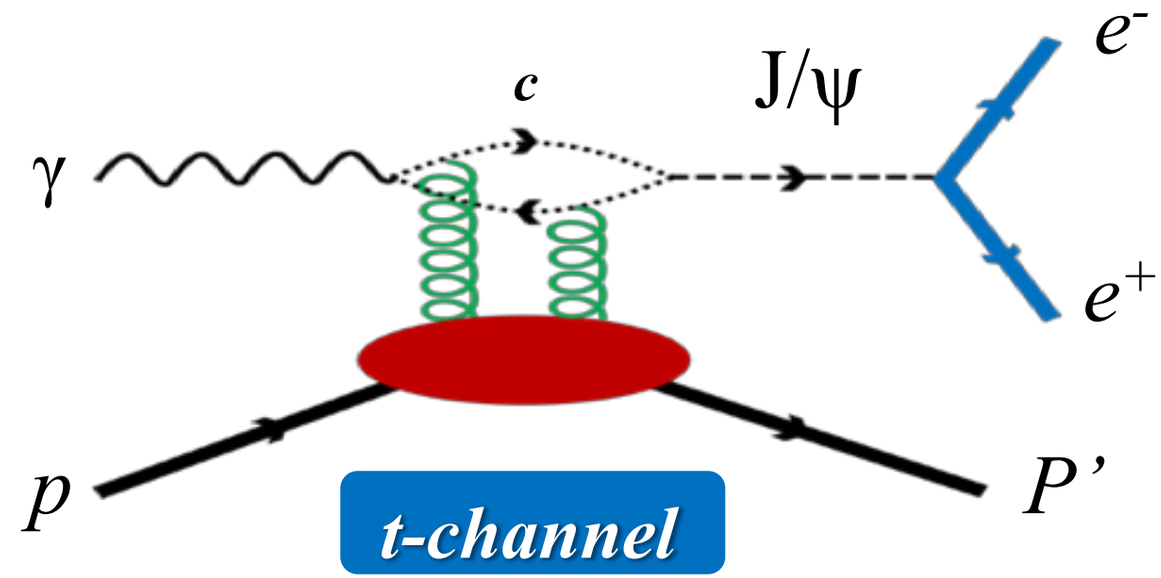
★ ***Pc(4457)***

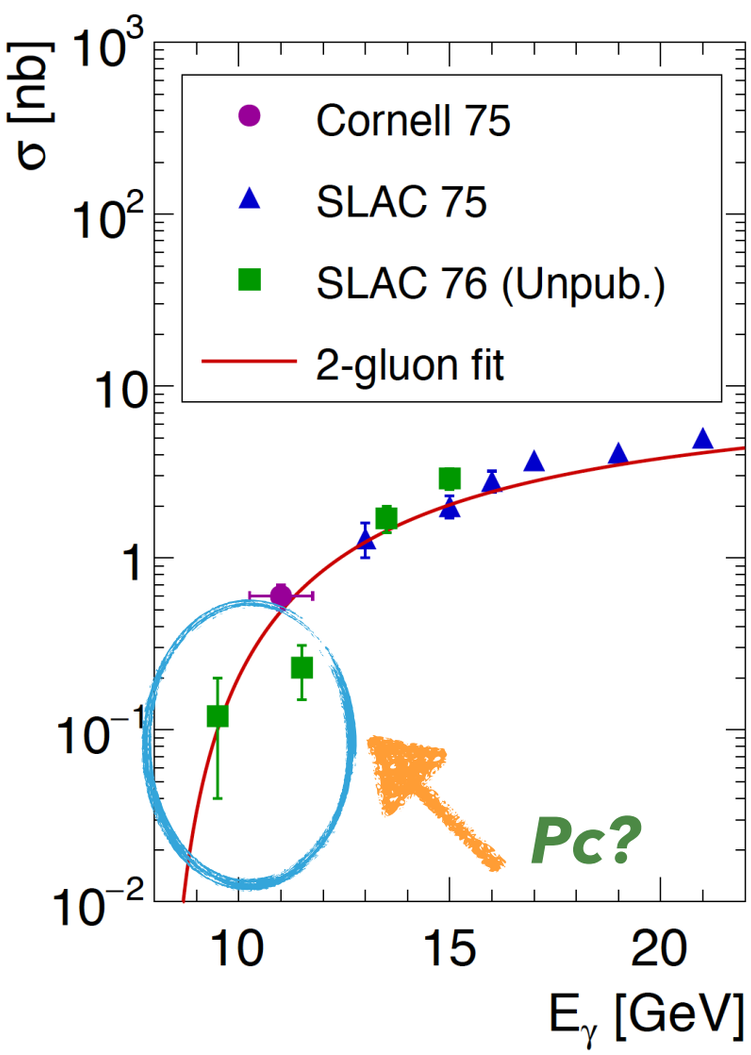
M: 4457.3±0.6+4.1/-1.7 MeV

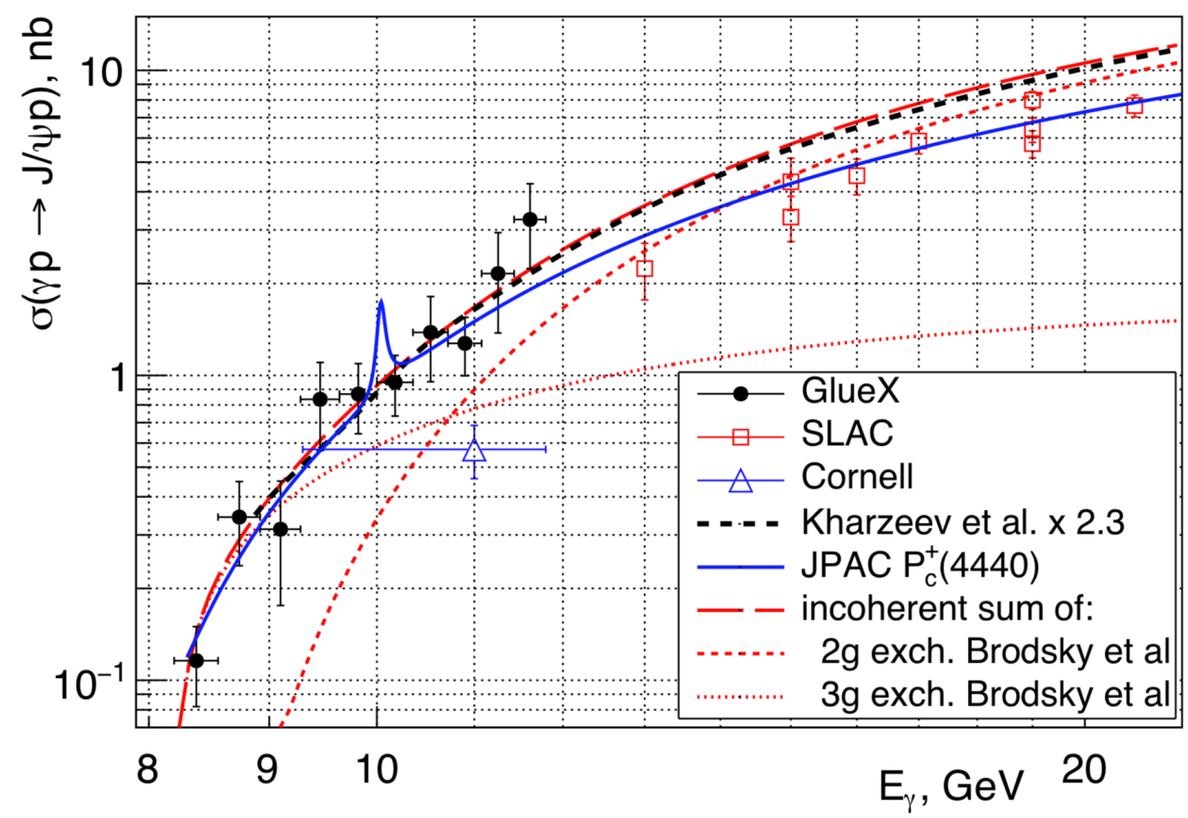
Γ = 6.4±2.0+5.7/-1.9 MeV

J/Ψ PHOTO-PRODUCTION: CURRENT DATA STATUS

- Measured in many experiments at high $W_{\gamma p}$
  - dominated by t-channel 2-gluon exchange
  - Almost no data in threshold region





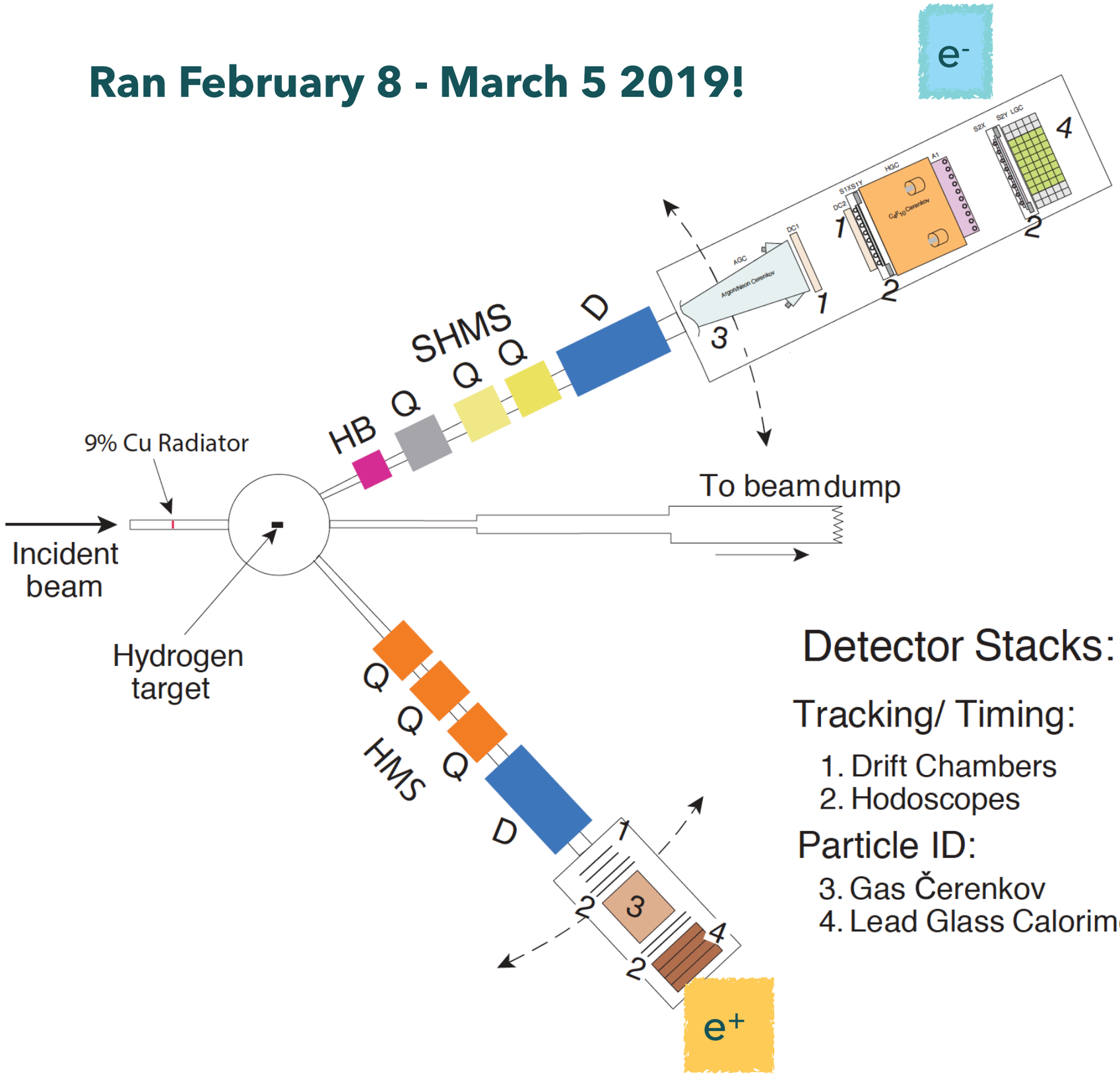


J/Ψ EXPERIMENTS IN JLAB

	GlueX HALL D	HMS+SHMS HALL C	CLAS 12 HALL B	SoLID HALL A
J/ψ counts (photo-prod.)	~400	~2100 (4200 with muons)	45/day	1627/day
J/ψ Rate (electro-prod.)				86/day
Experiment		E12-16-007	E12-12-001	E12-12-006
PAC days		9+2	130	50
When?	Finished	Finished	Ongoing	~10 years?

PENTAQUARK SEARCH WITH E12-16-007 EXPERIMENT IN HALL C

Ran February 8 - March 5 2019!



- ★ 10.6 GeV beam energy
- ★ 50 μA
- ★ 9% copper radiator
- ★ 10 cm LH2 target

Detector Stacks:

Tracking/ Timing:

1. Drift Chambers
2. Hodoscopes

Particle ID:

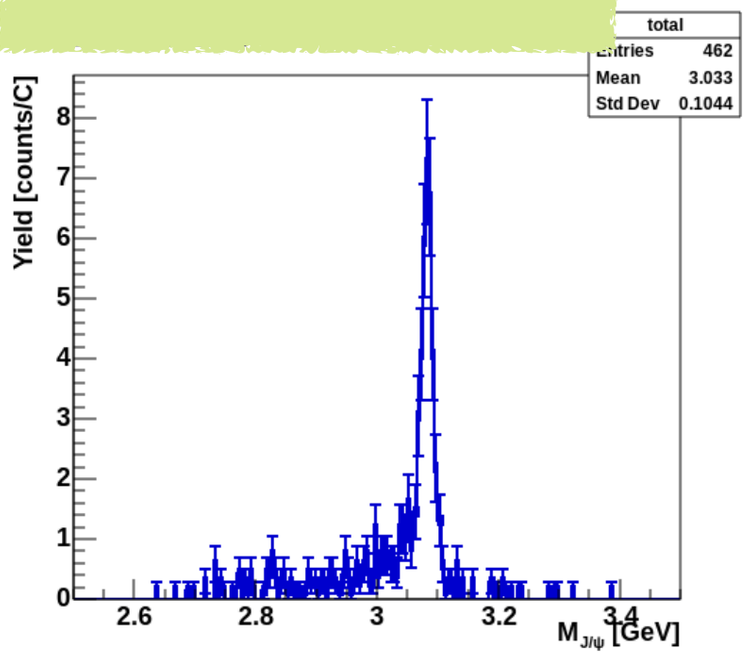
3. Gas Čerenkov
4. Lead Glass Calorimeter

E12-16-007 MEASUREMENTS

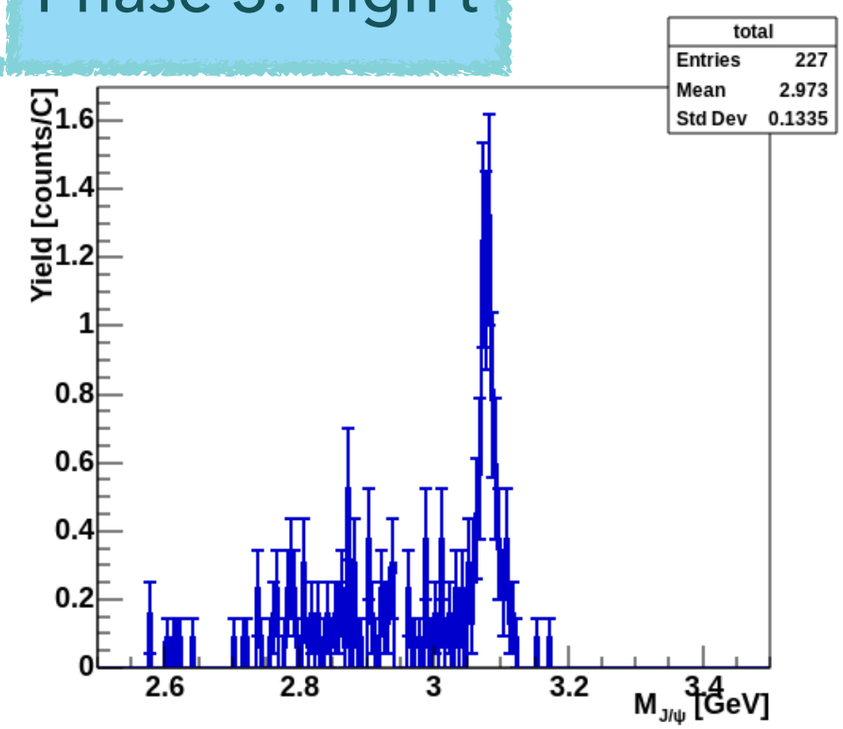
ONLINE ANALYSIS RESULTS

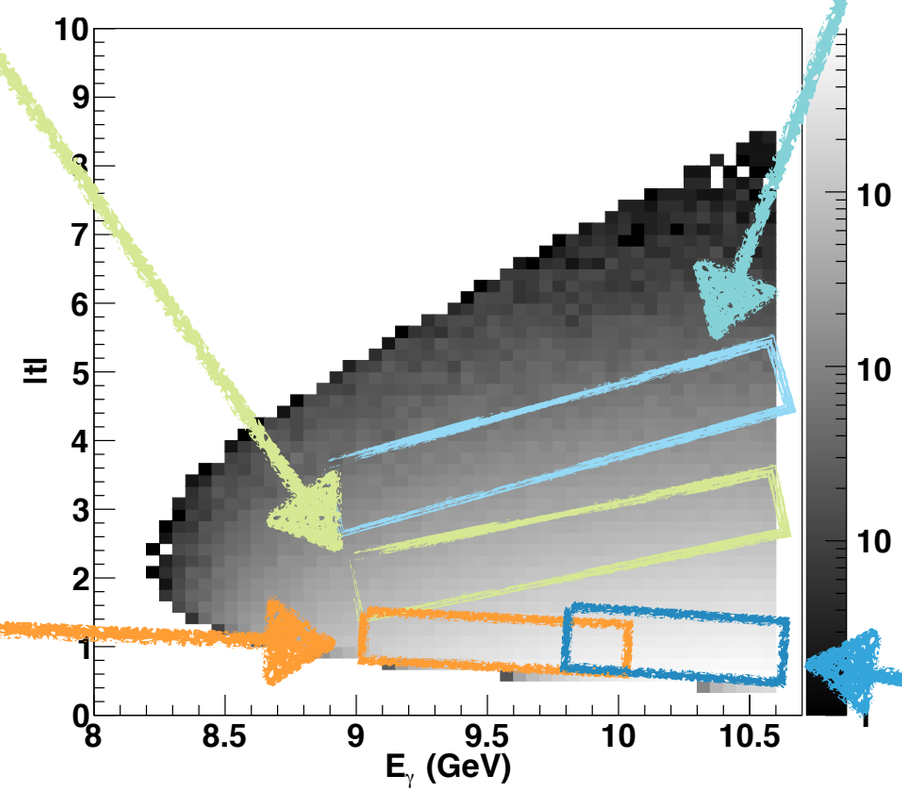
$$J/\psi \rightarrow e^+e^-$$

Phase 4: medium t

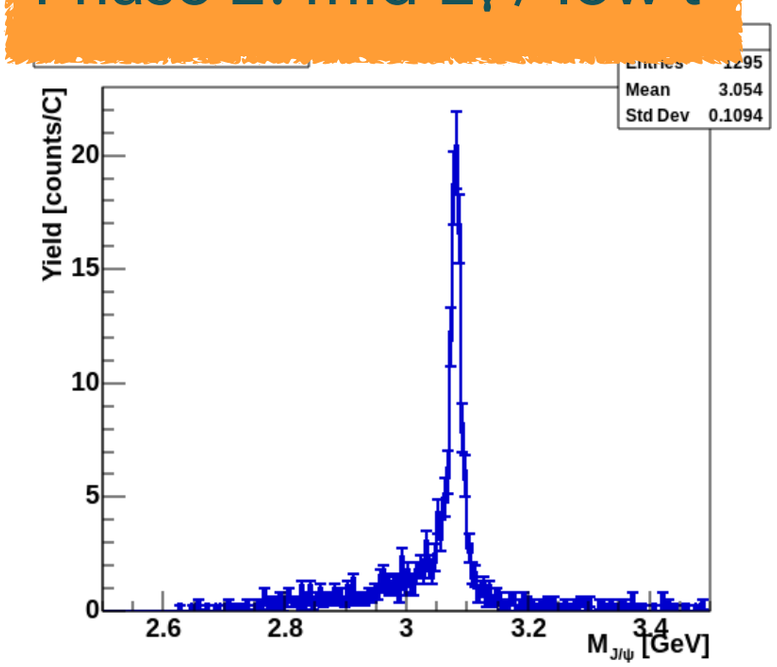


Phase 3: high t

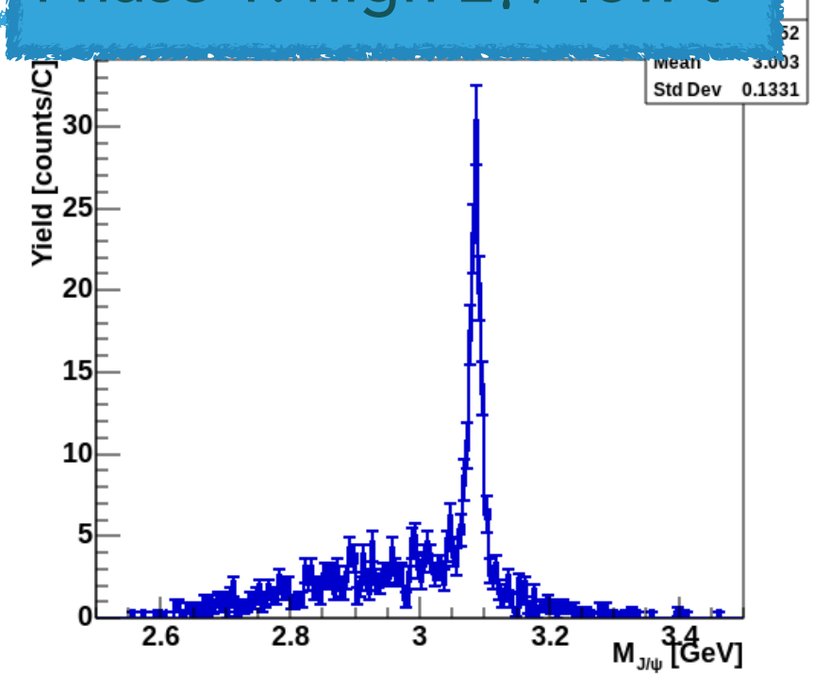




Phase 2: mid E_γ / low t



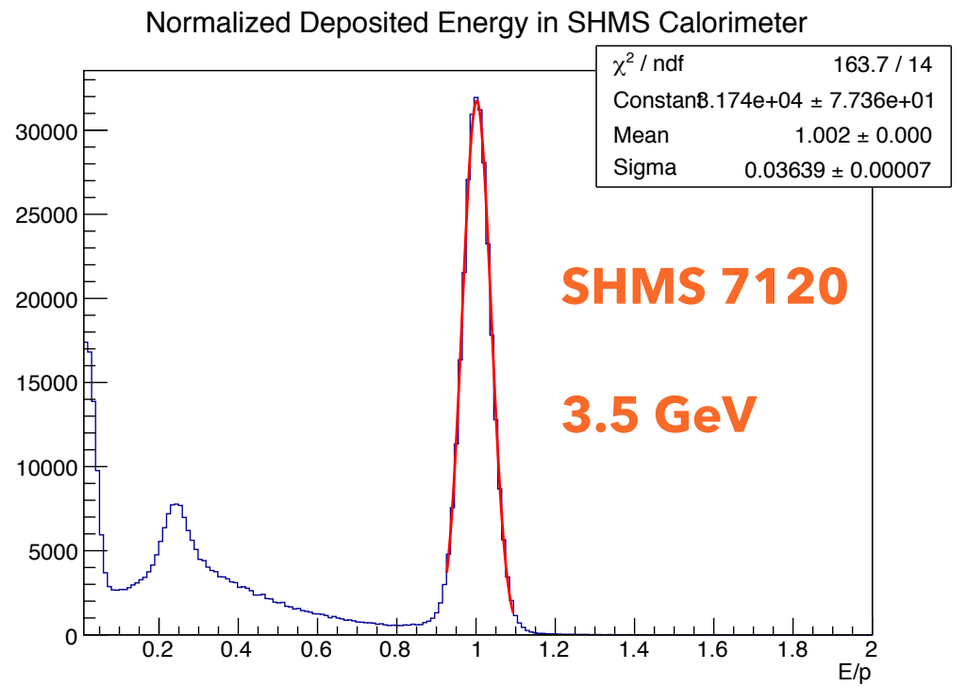
Phase 1: high E_γ / low t

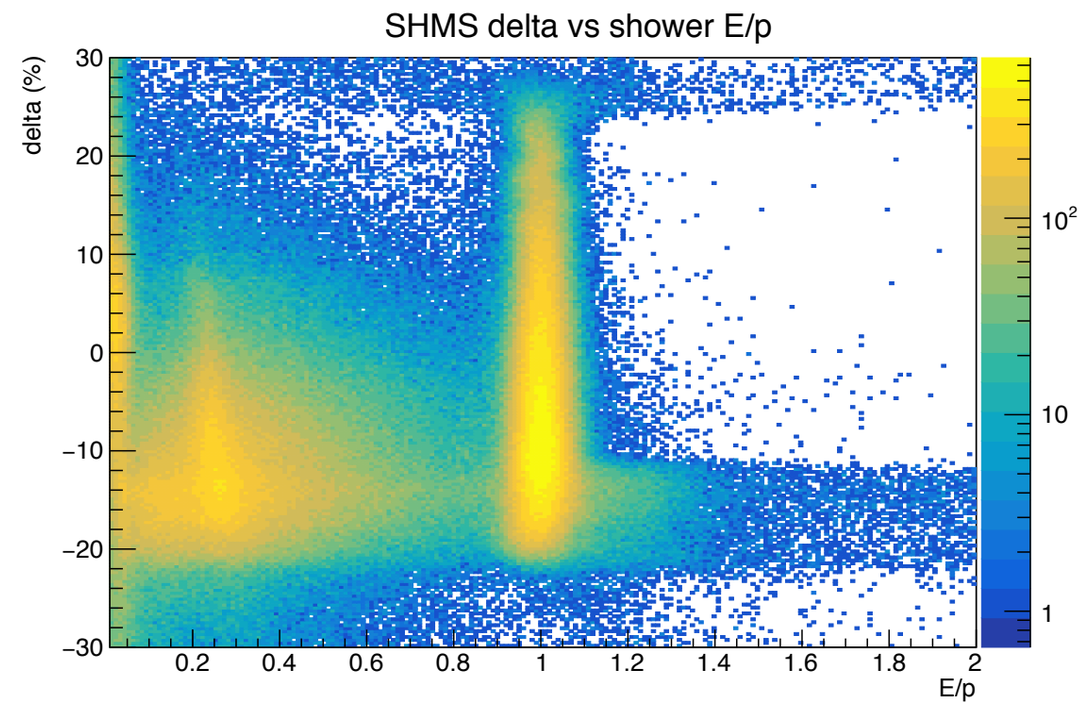


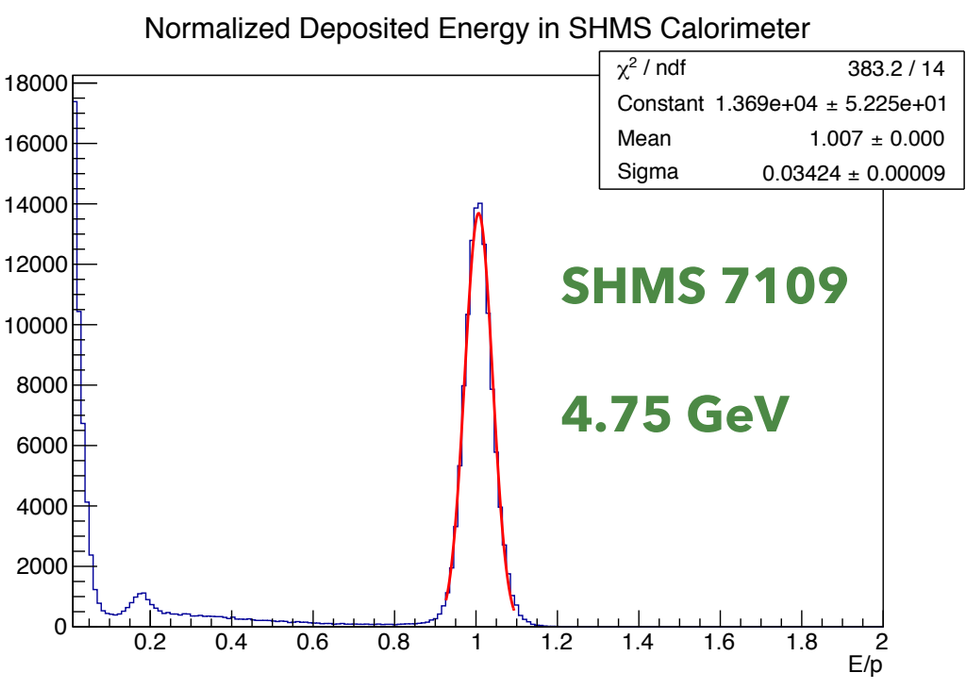
LARGEST DATESET OF J/Ψ WITH REAL PHOTO BEAM

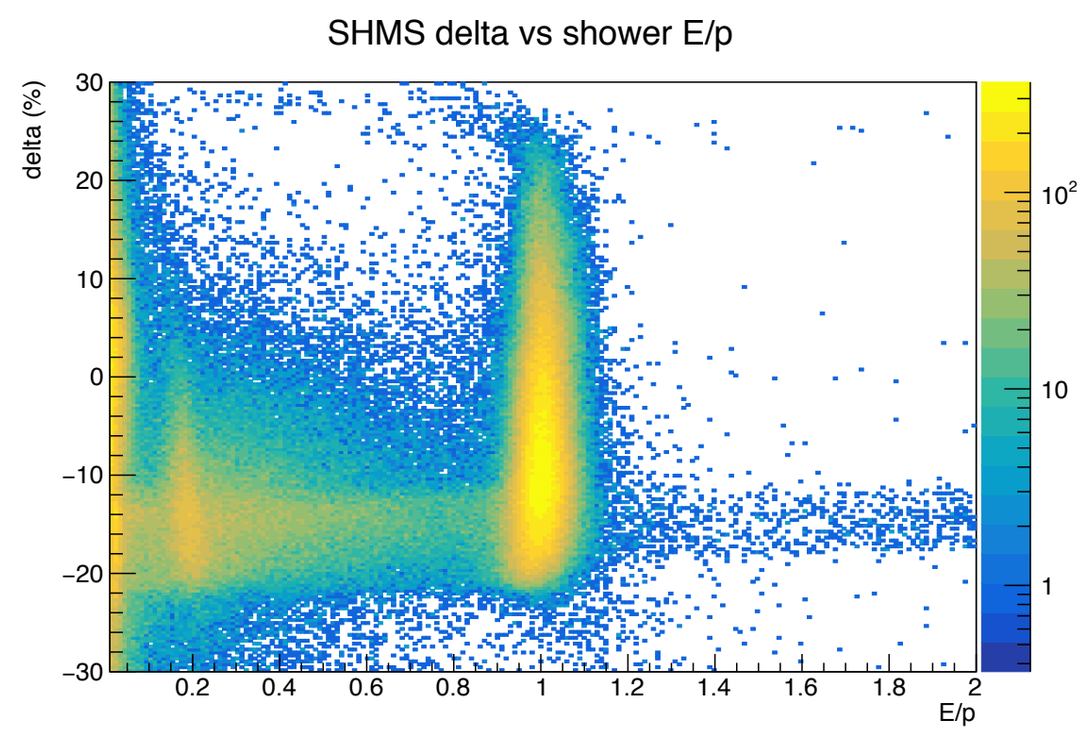
DETECTOR CALIBRATIONS

SHMS Calorimeter: 2 calibration runs at 3.5 GeV and 4.75 GeV





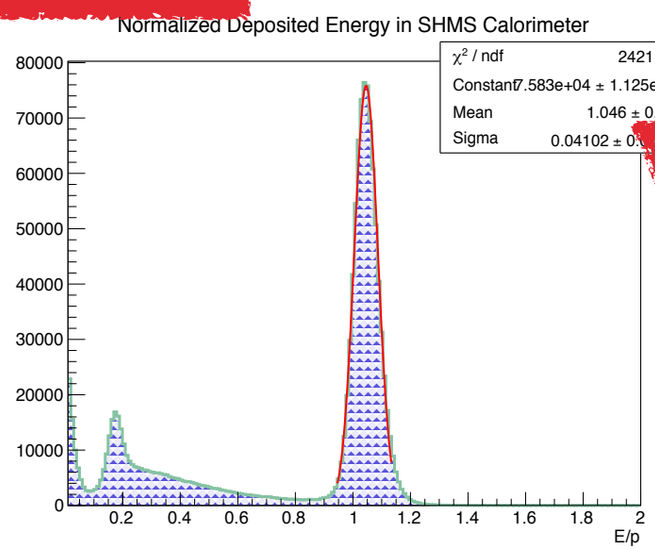




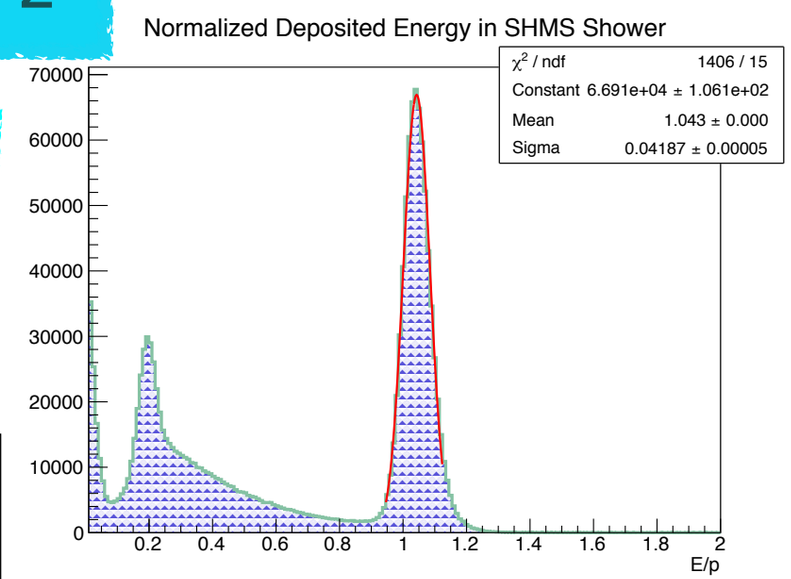
DETECTOR CALIBRATIONS

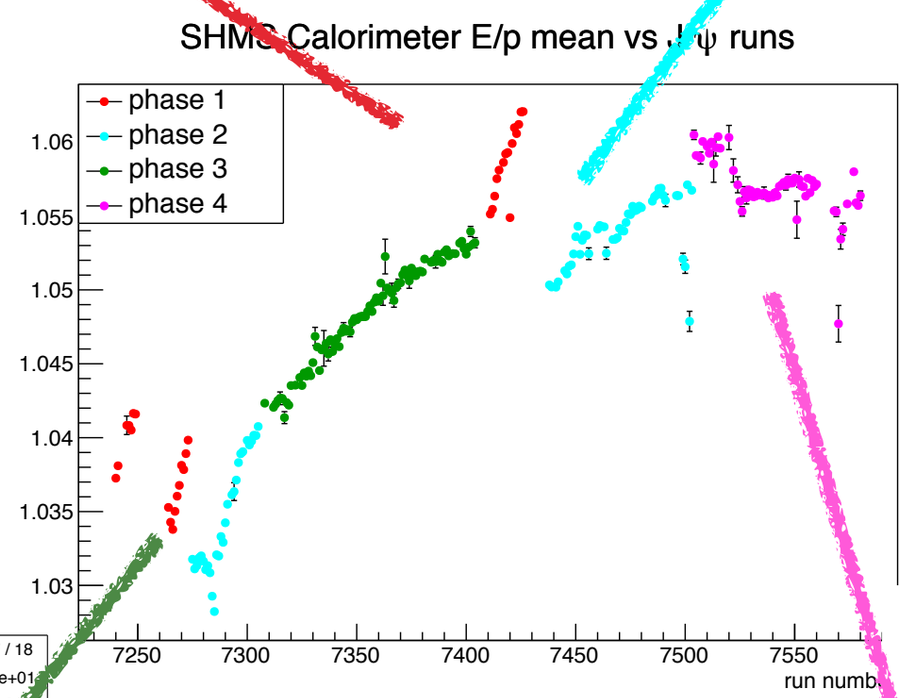
SHMS Calorimeter calibration check with the production runs

Phase 1

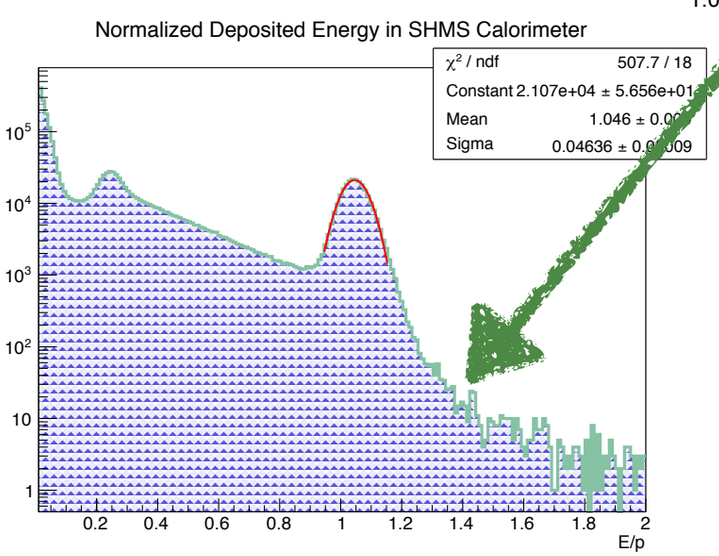


Phase 2

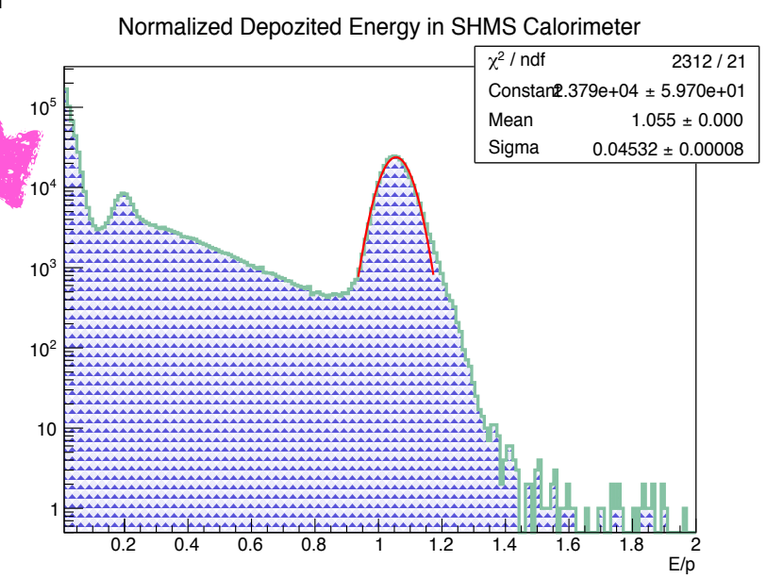




Phase 3

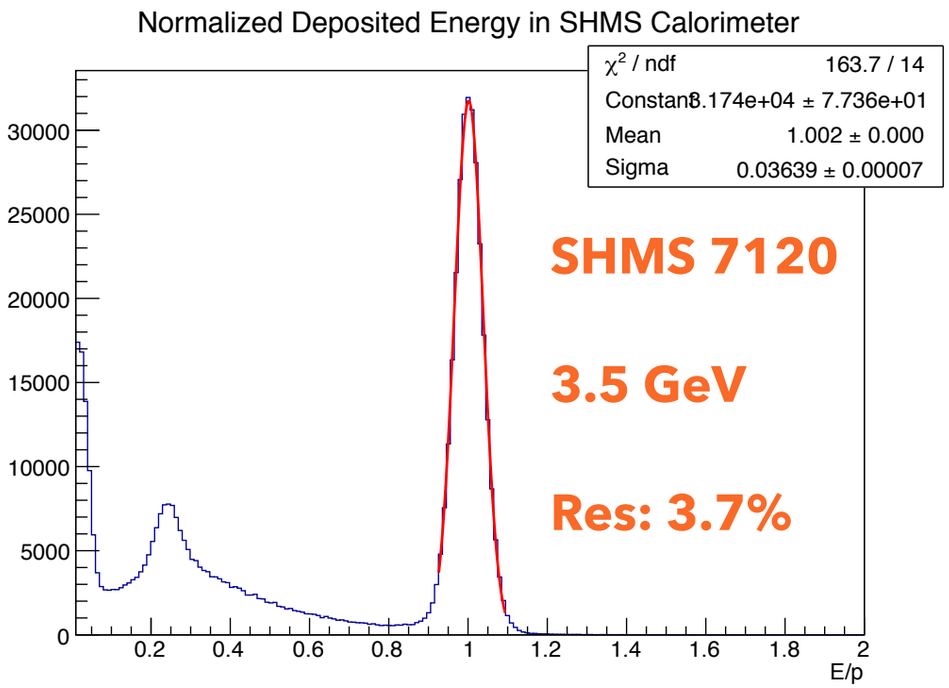


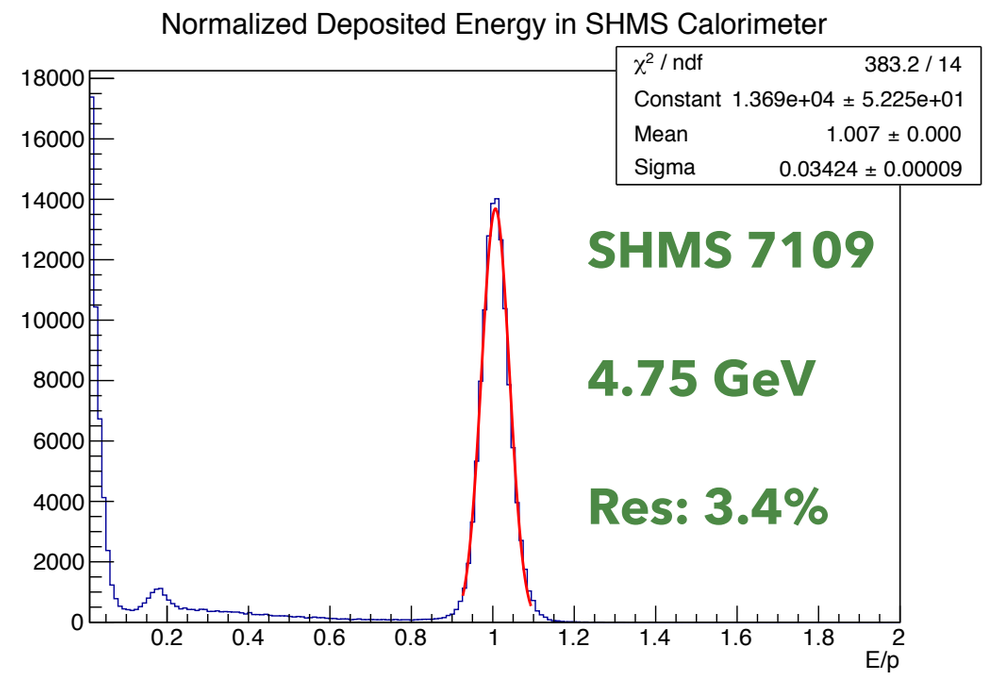
Phase 4

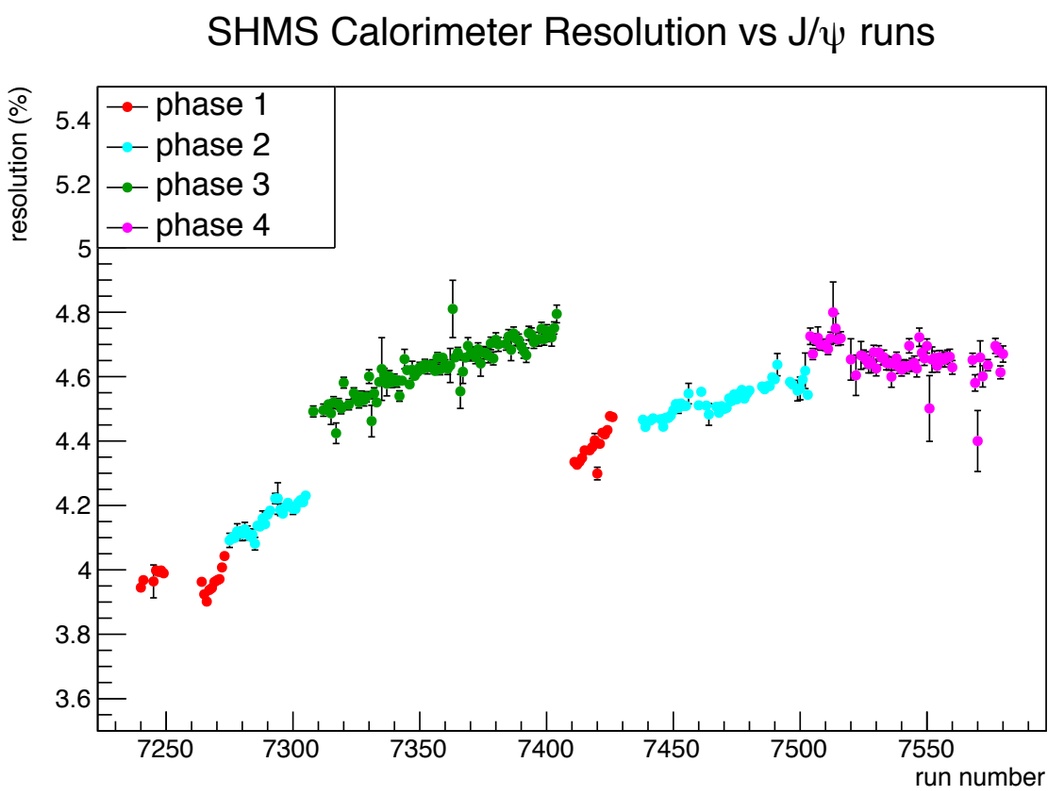


DETECTOR CALIBRATIONS

SHMS Calorimeter Resolution - obtained from sigma of the Gaussian fit to the E/p peak







4.835GeV

4.3 GeV

3.5 GeV

4.4 GeV

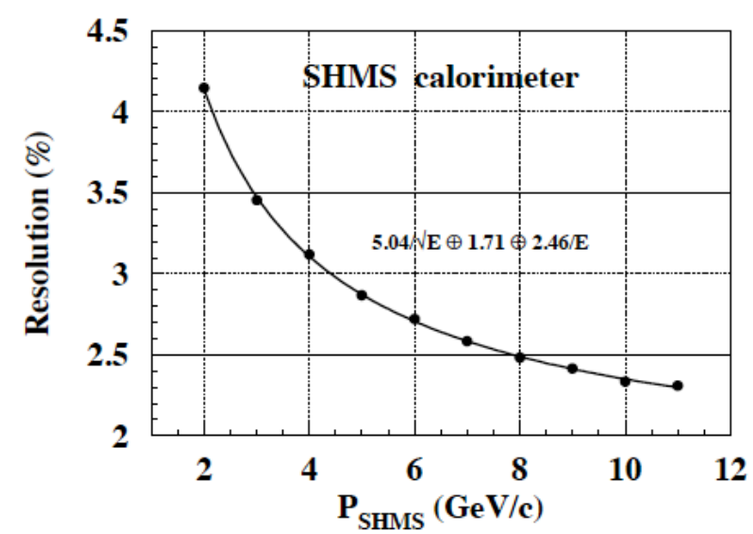
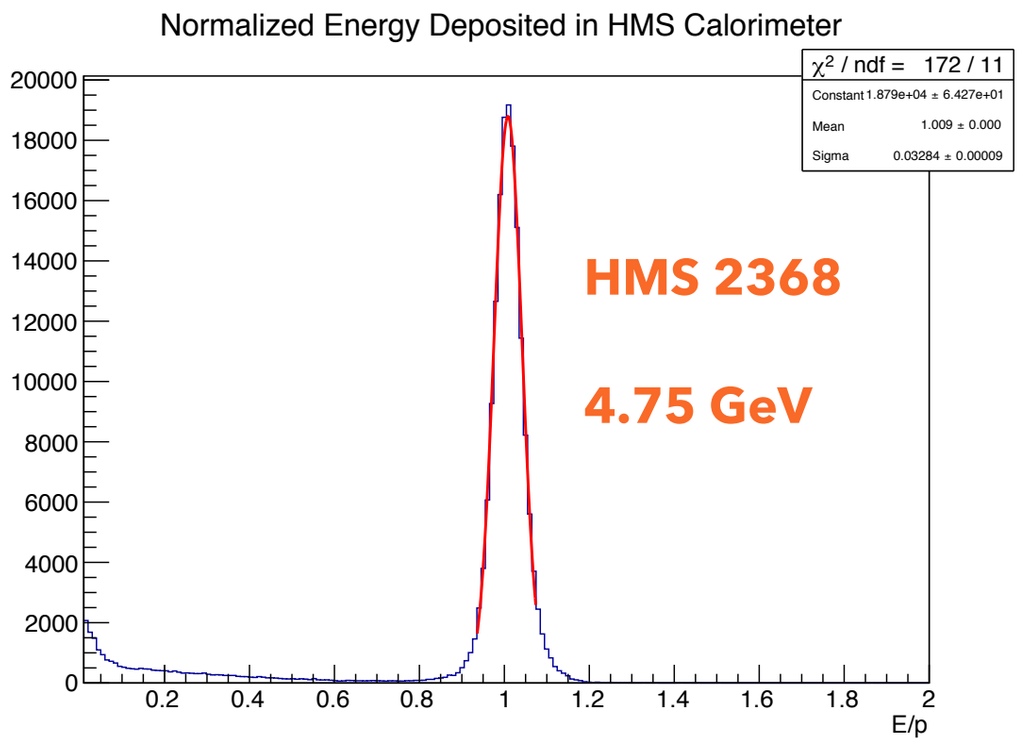
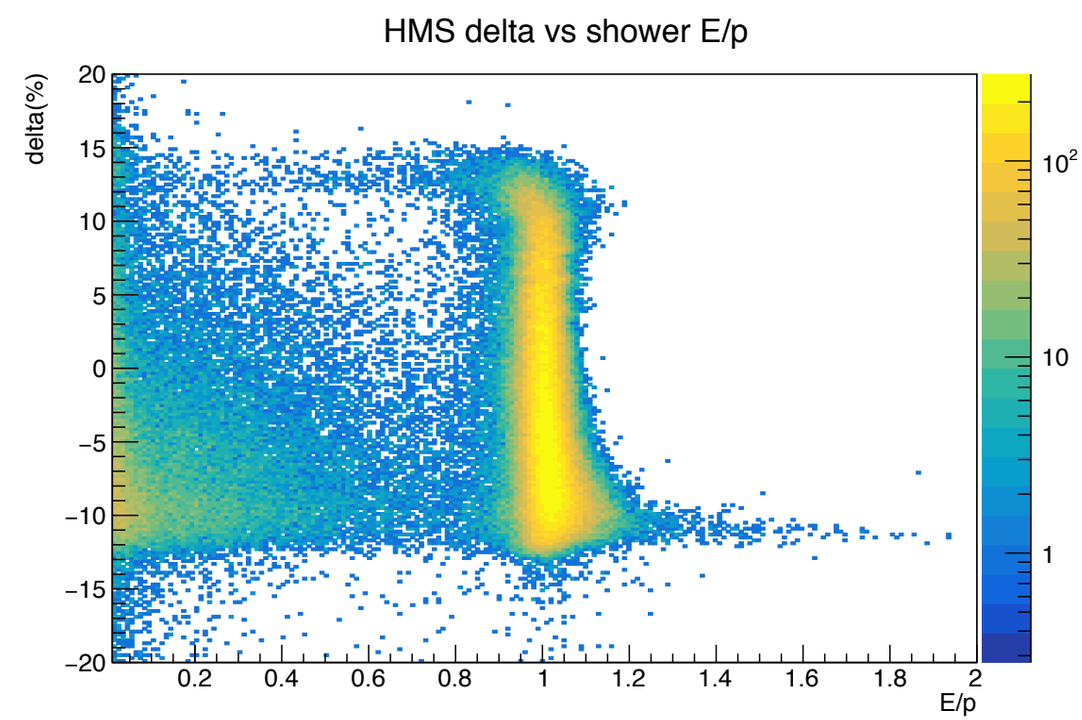


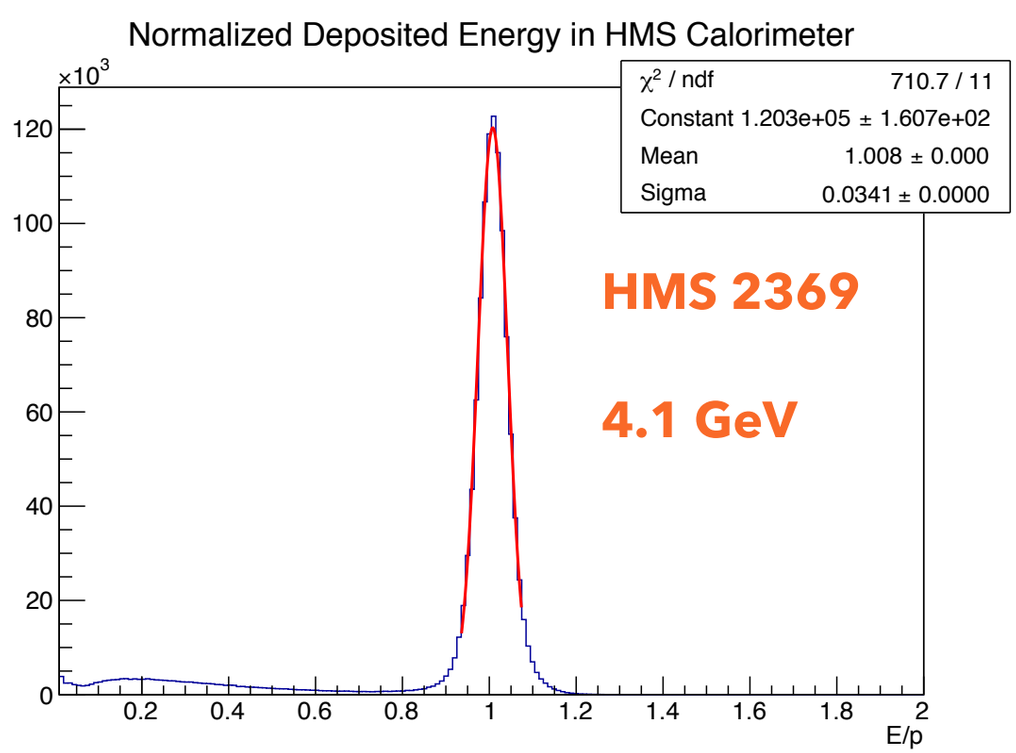
FIG. 28: Resolution of the modeled SHMS calorimeter. The small bullet symbols are data from the GEANT4 simulation, the line is the conventional 3-parameter fit [36] to them.

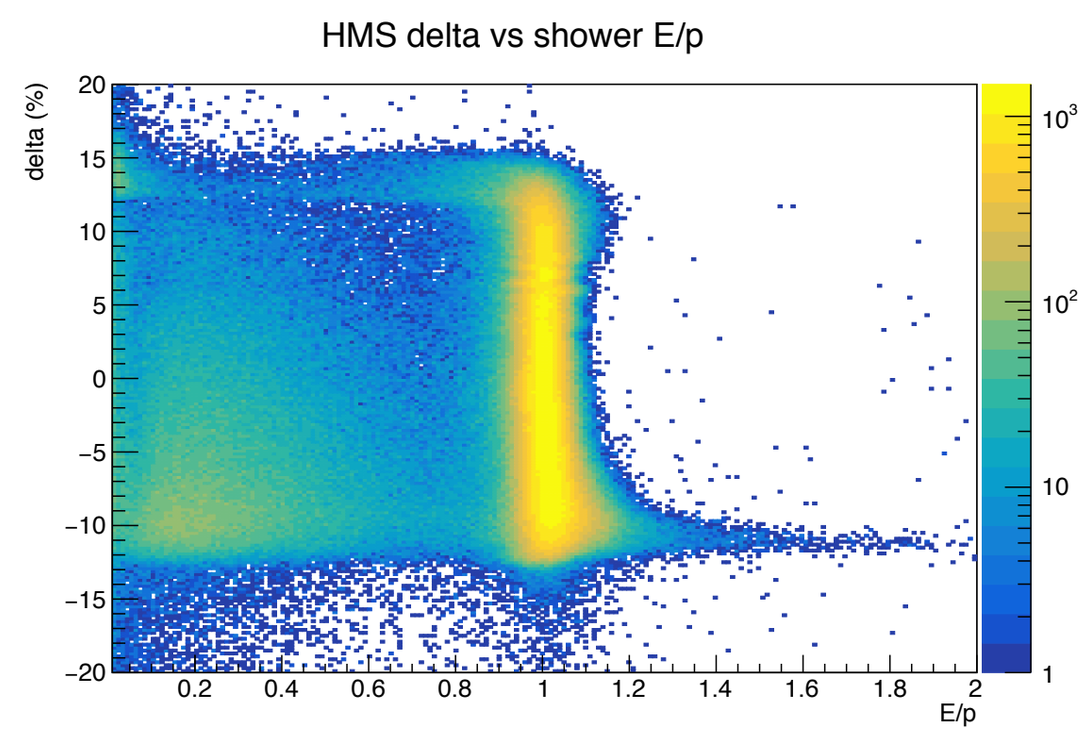
DETECTOR CALIBRATIONS

HMS Calorimeter: 2 calibration runs 4.1 GeV and 4.75 GeV





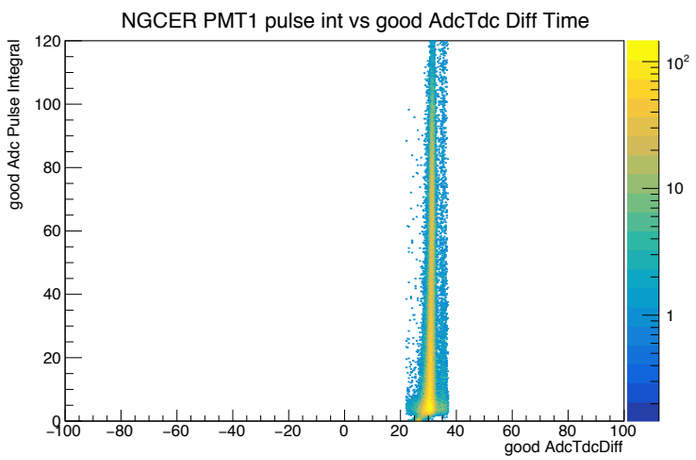


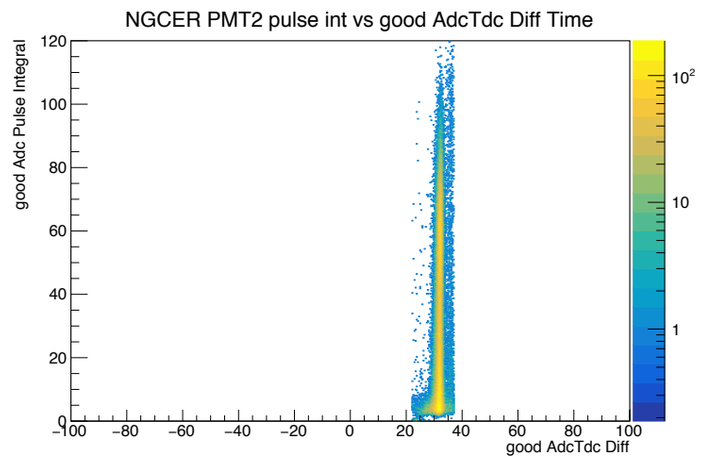


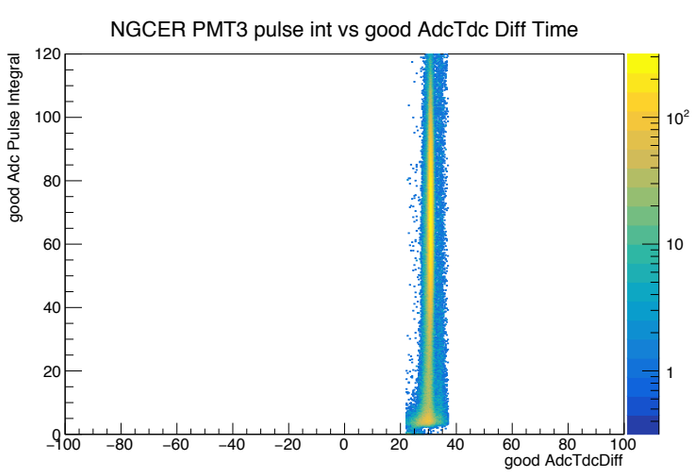
DETECTOR CALIBRATIONS

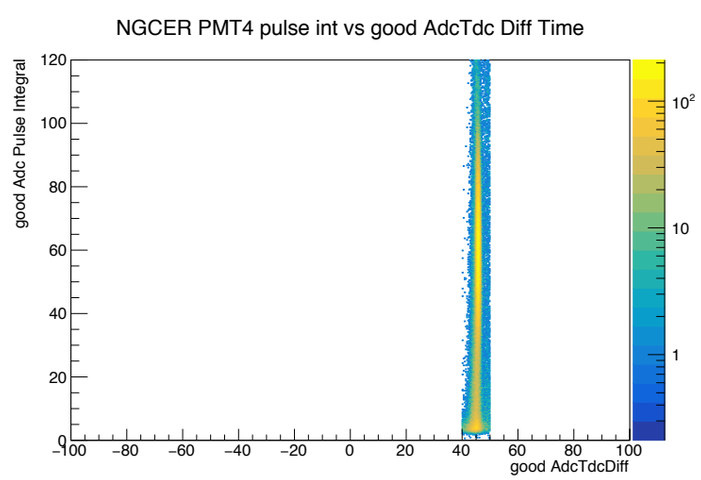
SHMS NGCER Calibration with Run 7120

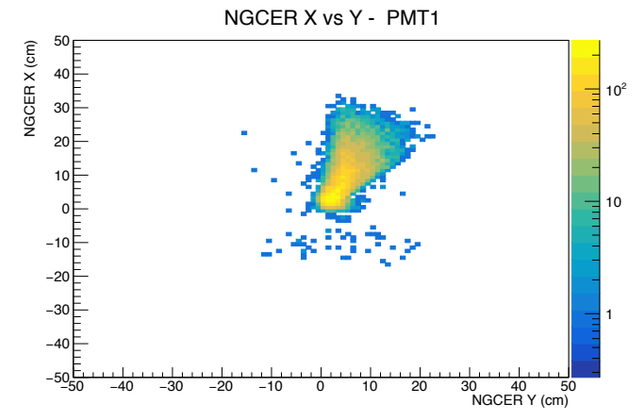
- ★ Timing cut to reject hits per event with super low amplitude
- ★ Calorimeter cut to choose electrons (P.cal.etottracknorm > 0.8)
- ★ Multiplicity cut to ensure only the pmt under calibration has a hit
- ★ X and Y cuts at the mirror planes
- ★ Pulse Integrals for each pmt were fit to get the calibration constants

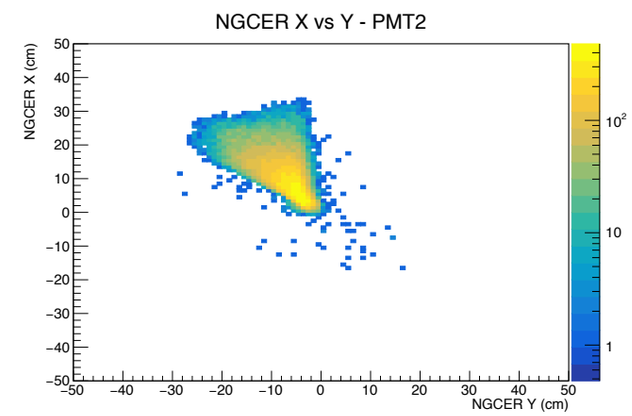


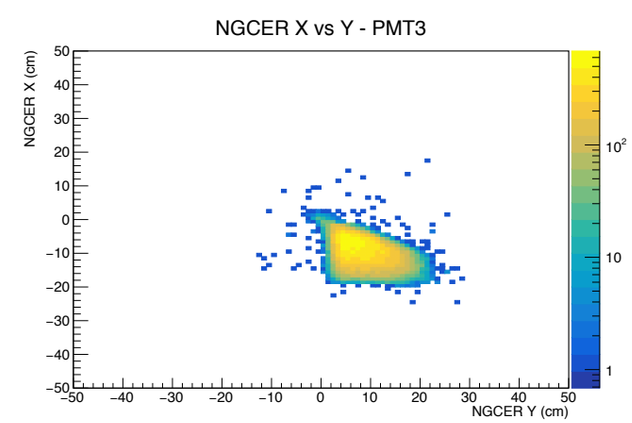


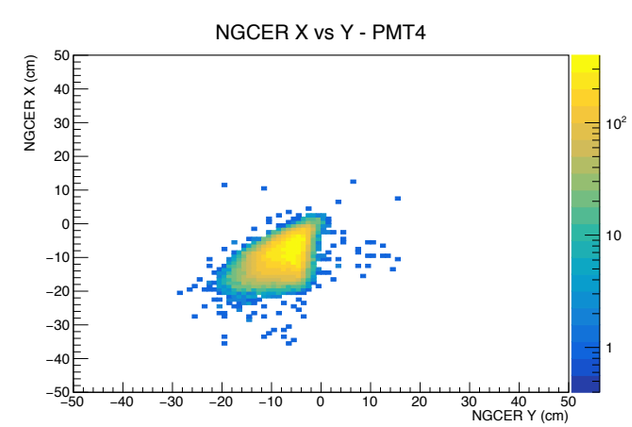






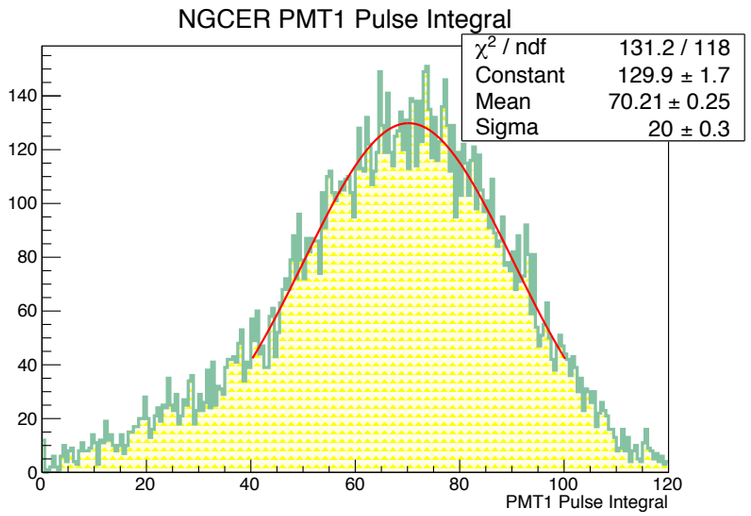


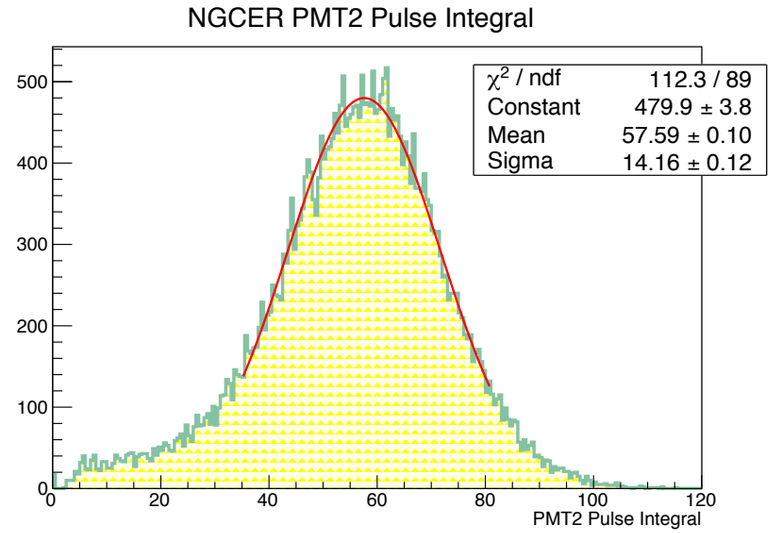


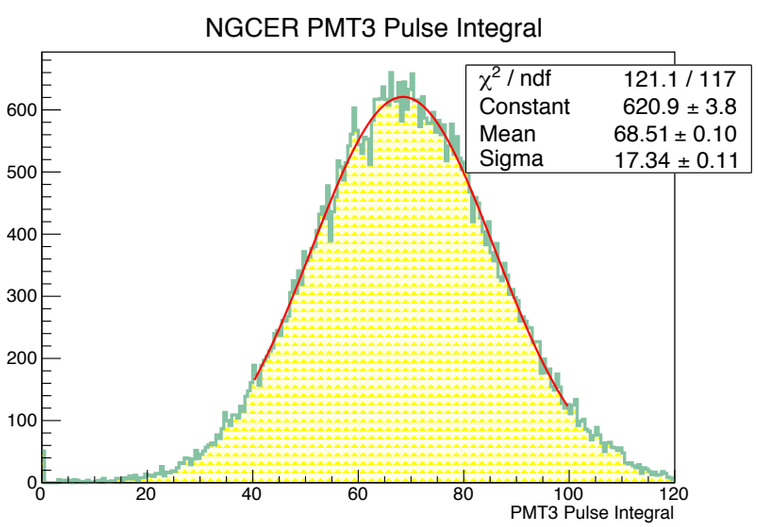


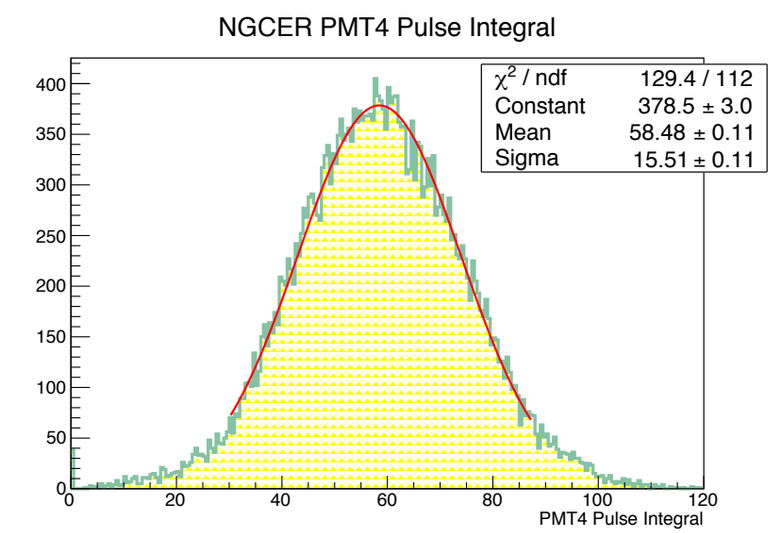
DETECTOR CALIBRATIONS

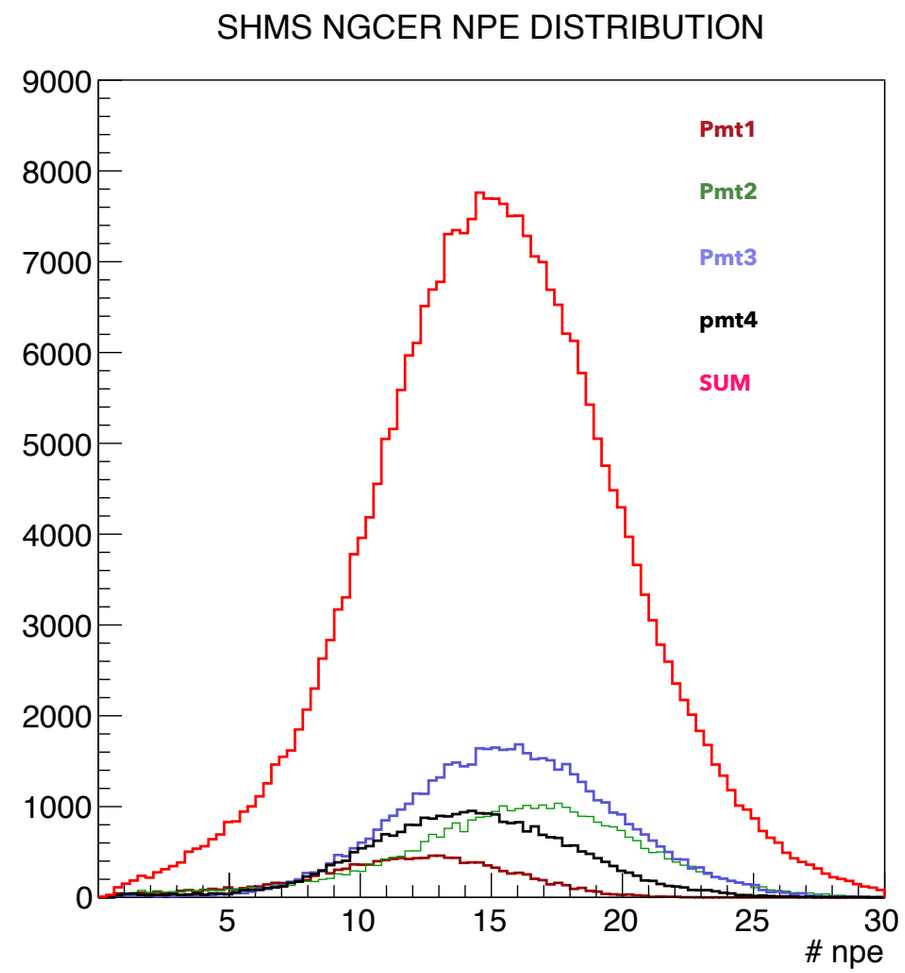
SHMS NGCER Calibration with Run 7120

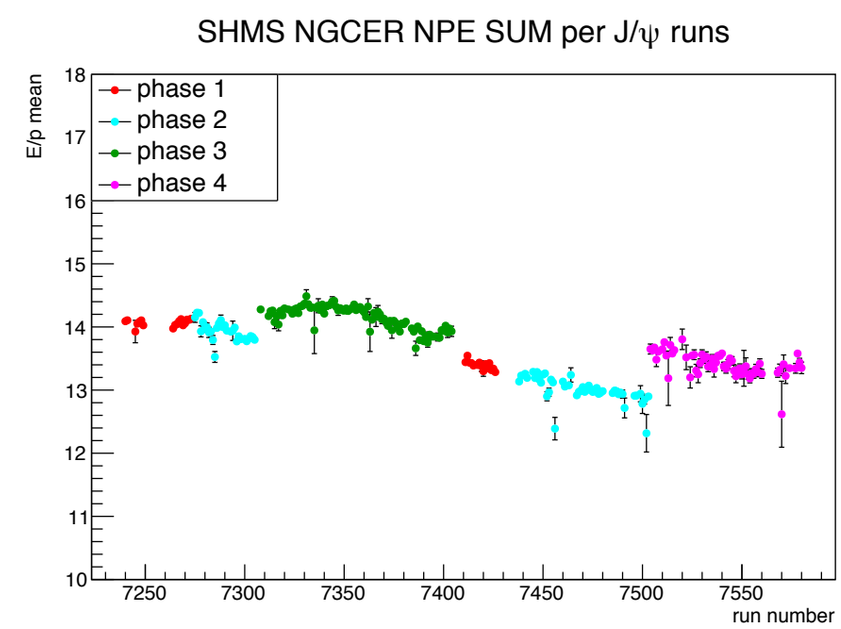












Estimated npe = (mean/sigma)^2

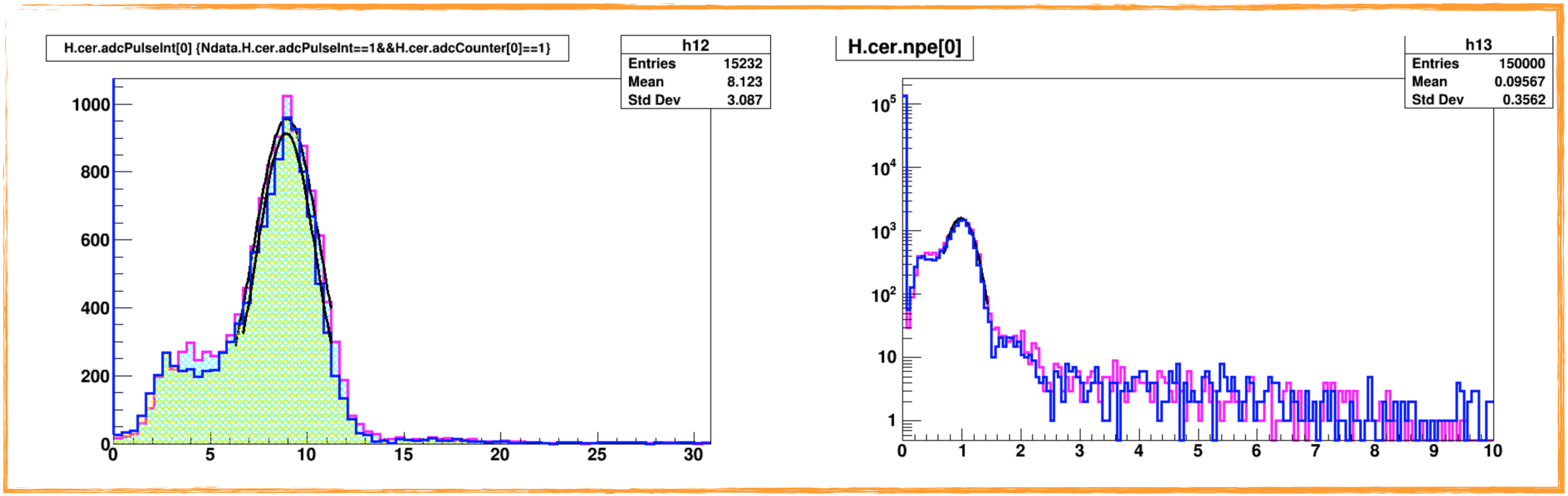
Estimated spe pulse int = mean / npe

Nitrogen at 1 atm, ~14 npes, 5.7 GeV pion threshold

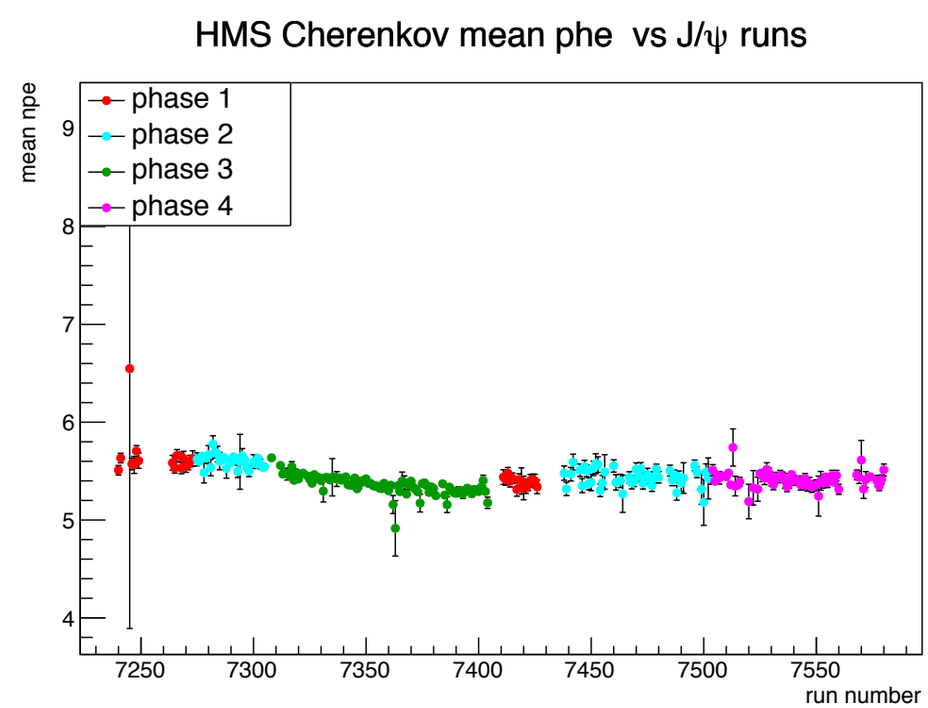
DETECTOR CALIBRATIONS

HMS Cerenkov Calibration

Simona's Calibration Plots with cosmic data



C4F80 at 0.225 atm, ~5.5 npes, 5.5 GeV pion threshold



PARTICLE IDENTIFICATION (PID) STUDIES

Electron Detection Efficiency - the ability to separate electrons from pions.

Electron Cut Efficiency - investigating the electron detection efficiency as a function of cut position.

$$Efficiency = \frac{electrons\ fired\ in\ the\ detector\ of\ interest}{electron\ sample\ selected\ with\ a\ detector\ not\ under\ investigation}$$

$$Cherenkov\ Efficiency = \frac{electrons\ fired\ in\ the\ Cherenkov}{electron\ sample\ selected\ with\ calorimeter}$$

$$Calorimeter\ Efficiency = \frac{electrons\ fired\ in\ the\ Calorimeter}{electron\ sample\ selected\ with\ Cherenkov}$$

Clean sample is the key!

Pion Rejection Factor

$$PR\,factor = \frac{particles\ identified\ as\ pions}{particles\ misidentified\ as\ electrons}$$

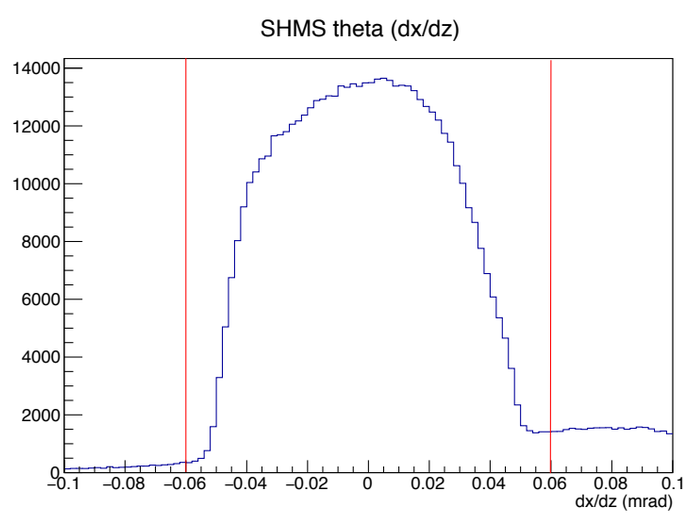
$$Cherenkov\ PR\ factor = \frac{pion\ sample\ selected\ with\ calorimeter}{pions\ fired\ the\ Cherenkov}$$

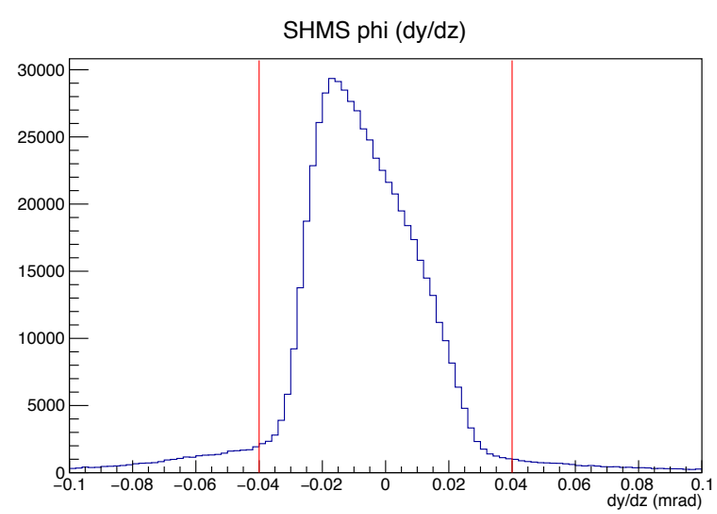
$$Calorimeter\ PR\ factor = \frac{pion\ sample\ selected\ with\ Cherenkov}{pions\ fired\ the\ calorimeter}$$

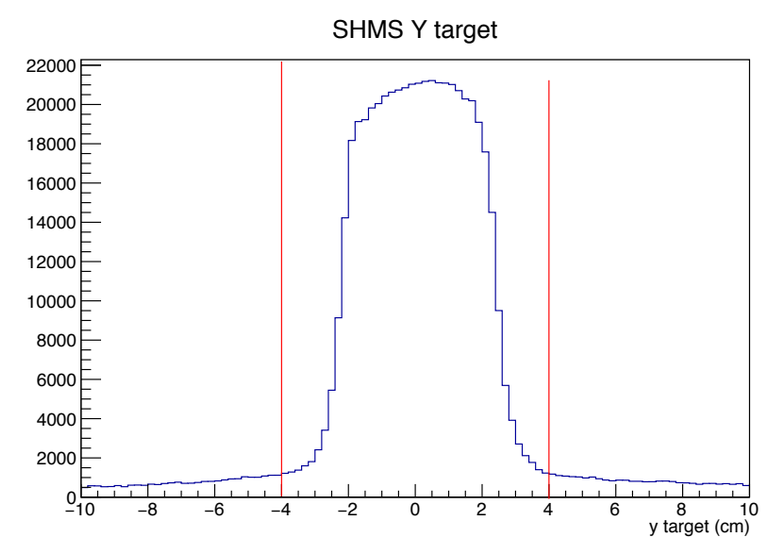
PARTICLE IDENTIFICATION (PID) STUDIES

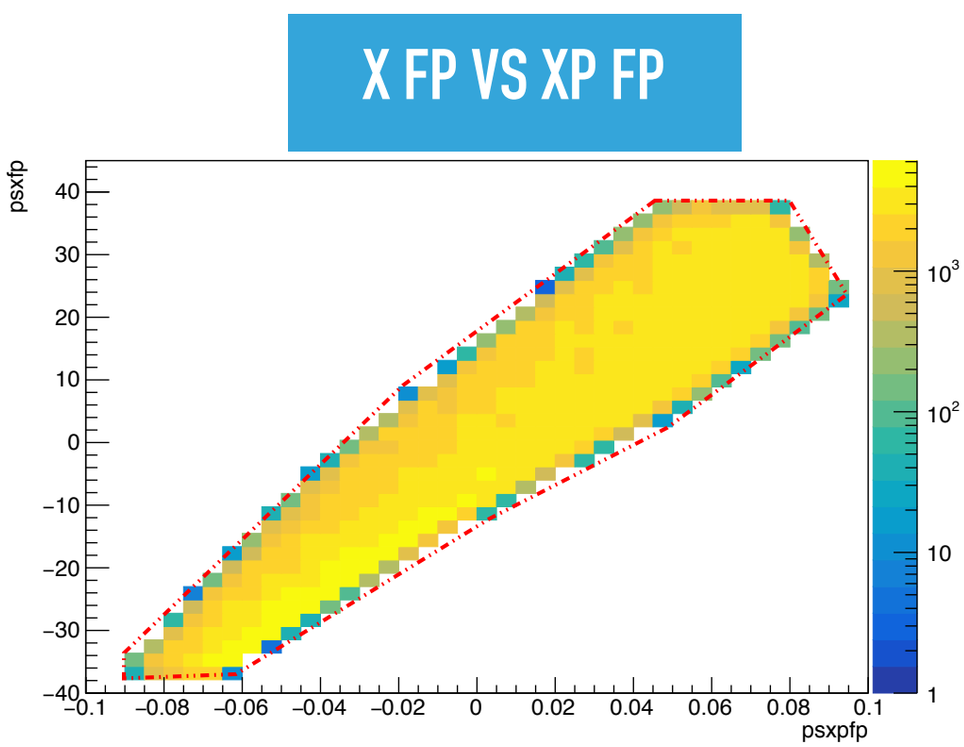
SHMS Calorimeter Electron Efficiency (SHMS 7120 DIS data)

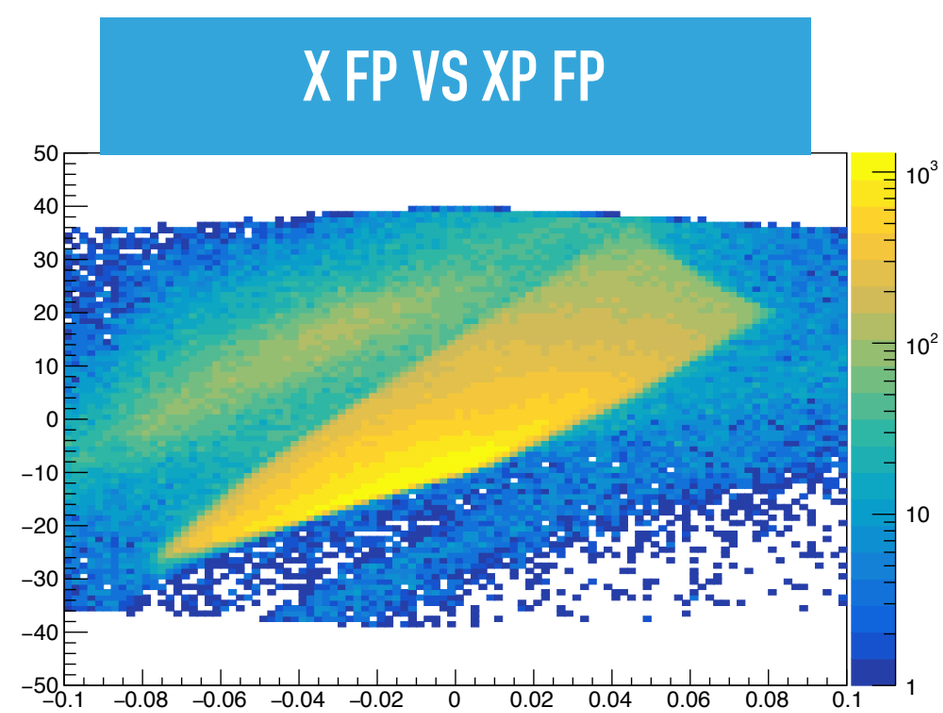
All with a cut on delta: P.gtr.dp > -10 & P.gtr.dp < 22.







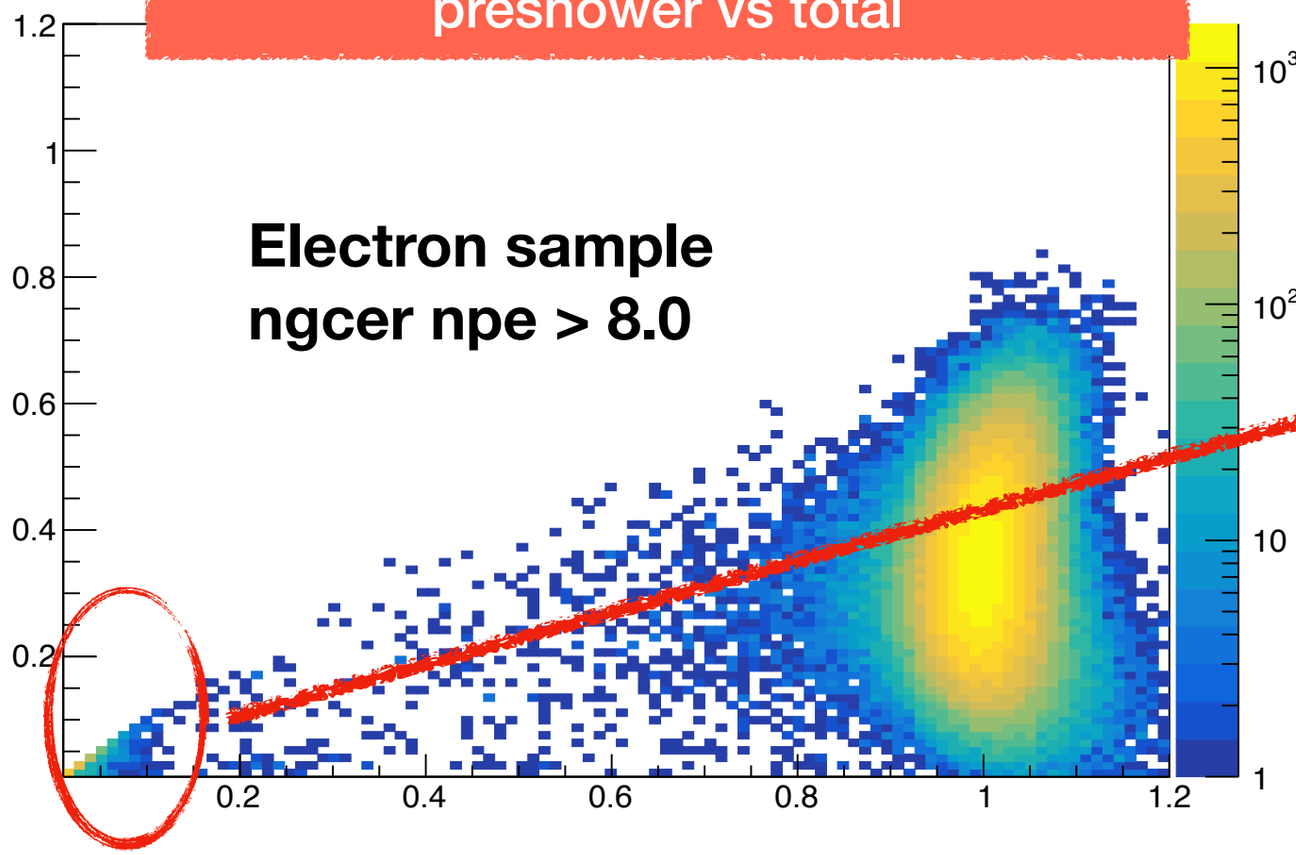




PARTICLE IDENTIFICATION (PID) STUDIES

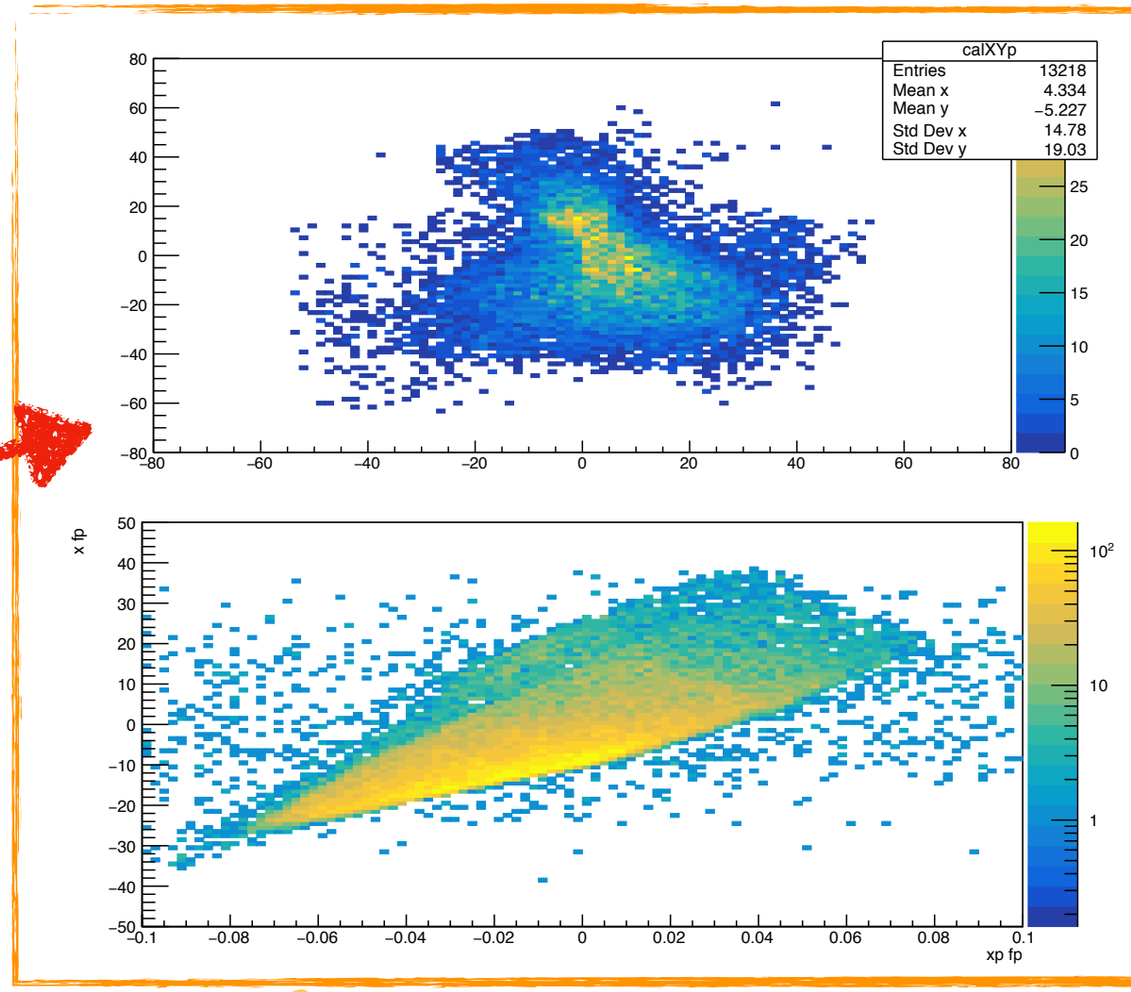
SHMS Calorimeter Electron Efficiency

preshower vs total

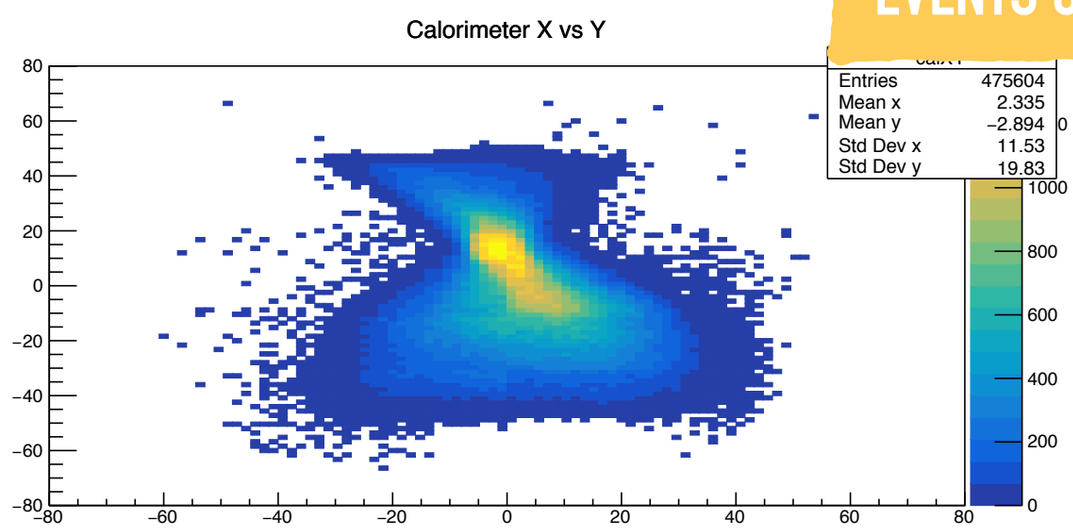


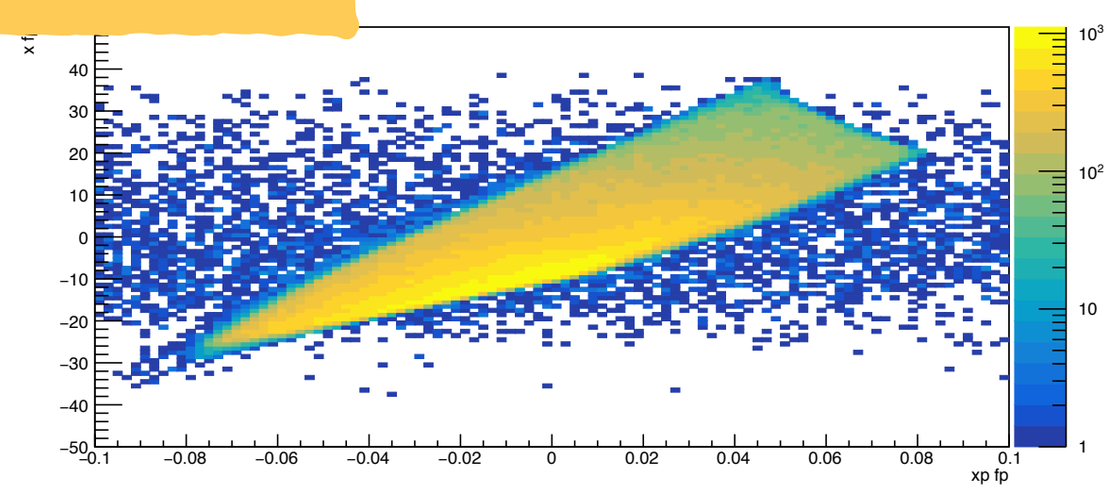
???

Projection of the mystery events
inside the red circle on CAL XY plane and focal plane



EVENTS OUTSIDE THE CIRCLE



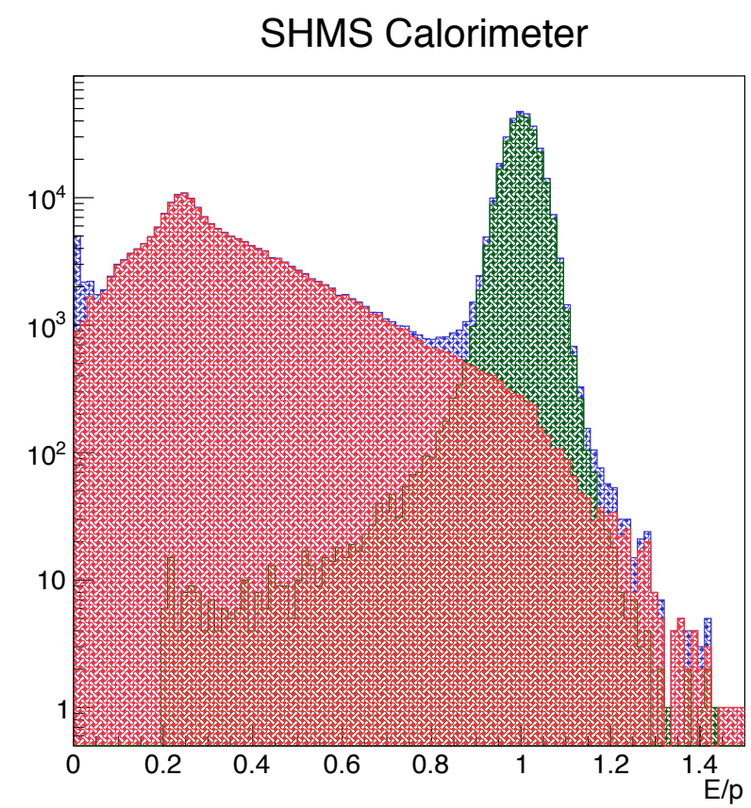


PARTICLE IDENTIFICATION (PID) STUDIES

SHMS Calorimeter Electron Efficiency

Electron sample chosen with:

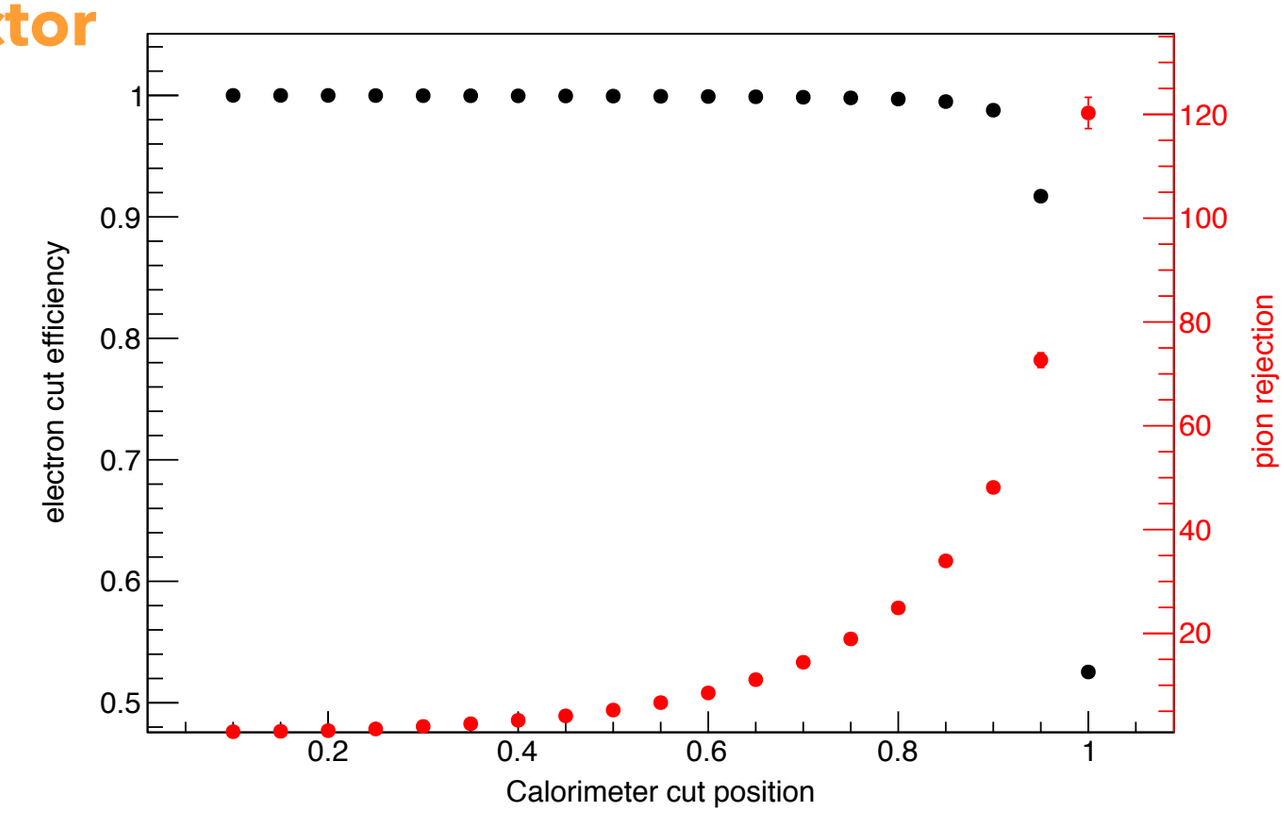
- Target cuts, excluding mystery events and ngcer car > 8 npes.
- Check how many of them passed the calorimeter cut.
- Study the efficiency as a function of cut position by varying it.



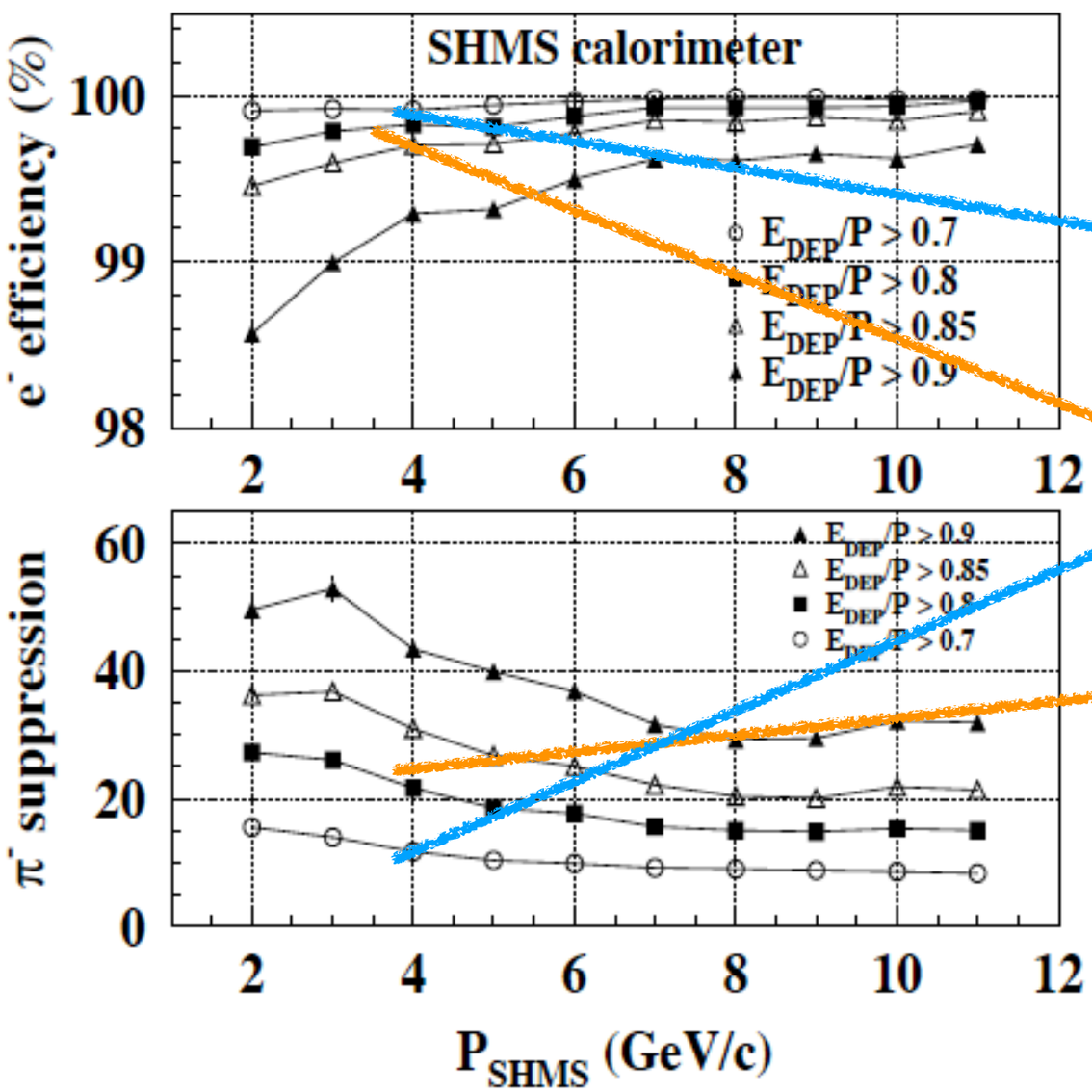
SHMS Calorimeter Pion Rejection Factor

Pion sample chosen with:

- Target cuts, ngcer < 0.5 npe.
- Check how many of them passed the calorimeter.
- Study the efficiency as a function of cut position by varying it.



Comparison of the SHMS Calorimeter Efficiency and PR factor to the NIM Article



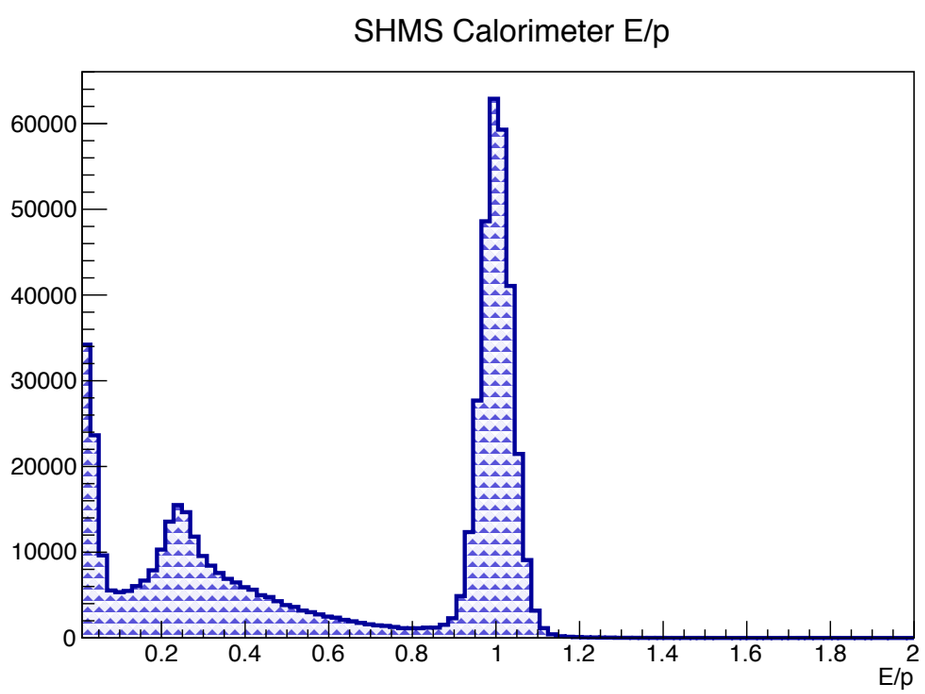
My results with 1D etottracknorm cut

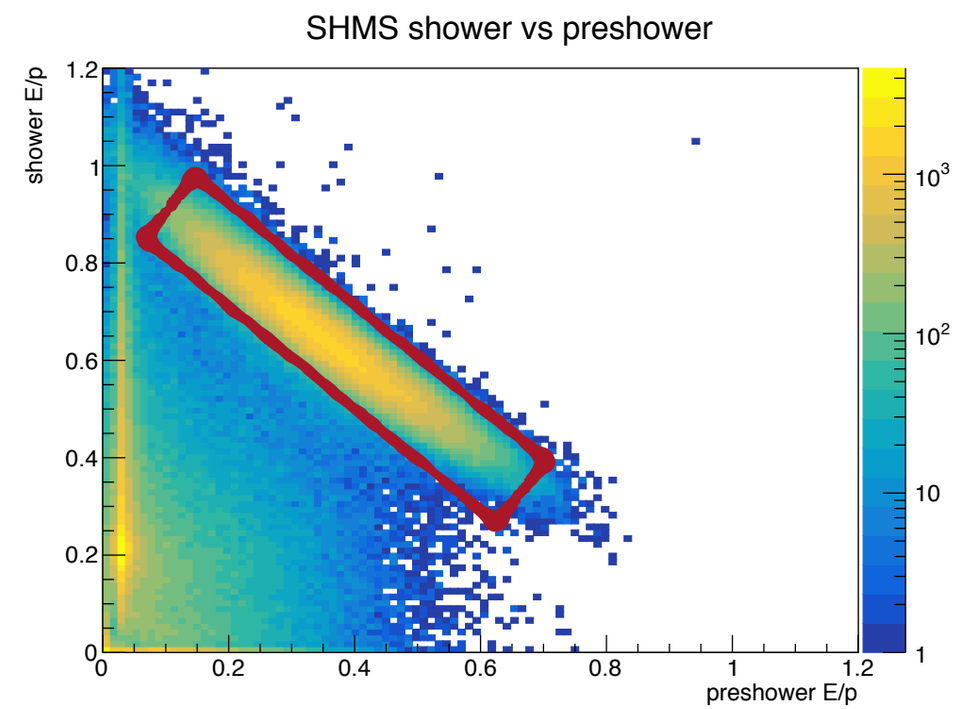
E/p = 0.7
Efficiency = 99.85%
PR factor = 15

E/p = 0.8
Efficiency = 99.70
PR factor = 25

- **Pion Rejection factors and efficiencies for the SHMS calorimeter are pretty consistent with the NIM article.**

Pion Rejection Factor Calculation
Method II: 2D etottracknorm + preshower cut





Etottracknorm > 0.8 & preshower > 0.05

$$Efficiency = \frac{electrons\ passed\ etottracknorm\ and\ preshower\ cut}{electron\ sample}$$

$$PR\,factor = \frac{pion\ sample}{pions\ passed\ etottracknorm\ and\ preshower\ cut}$$

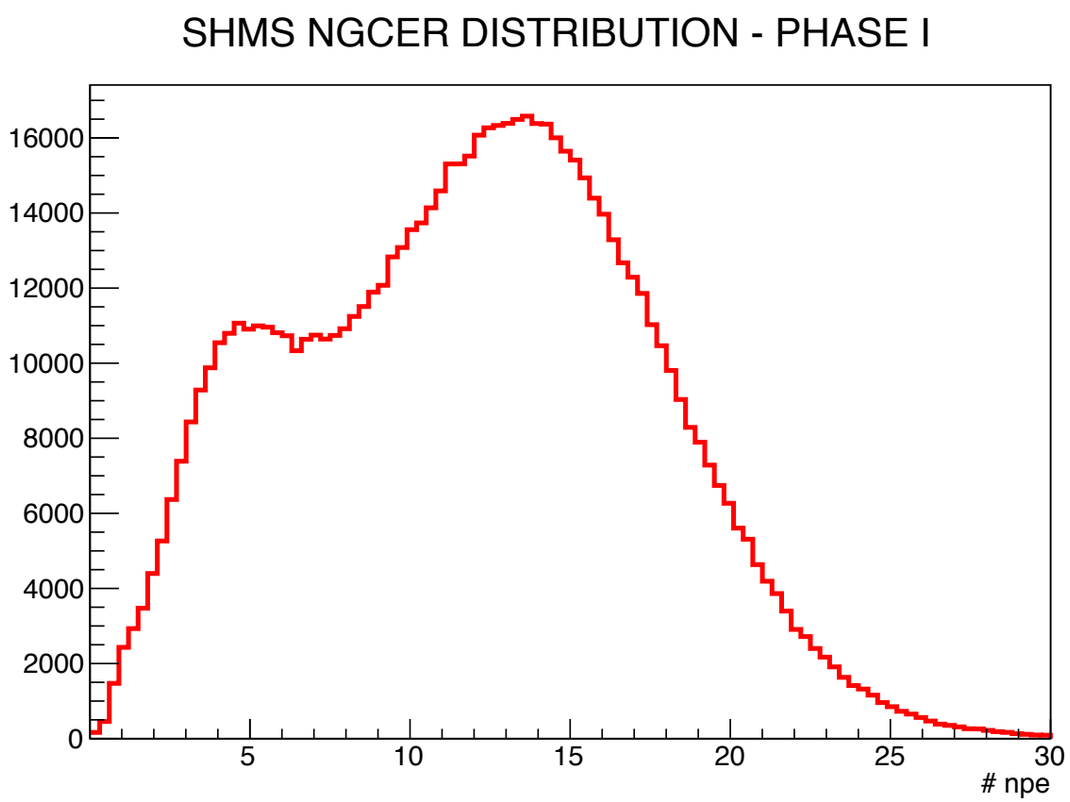
99.37% efficiency

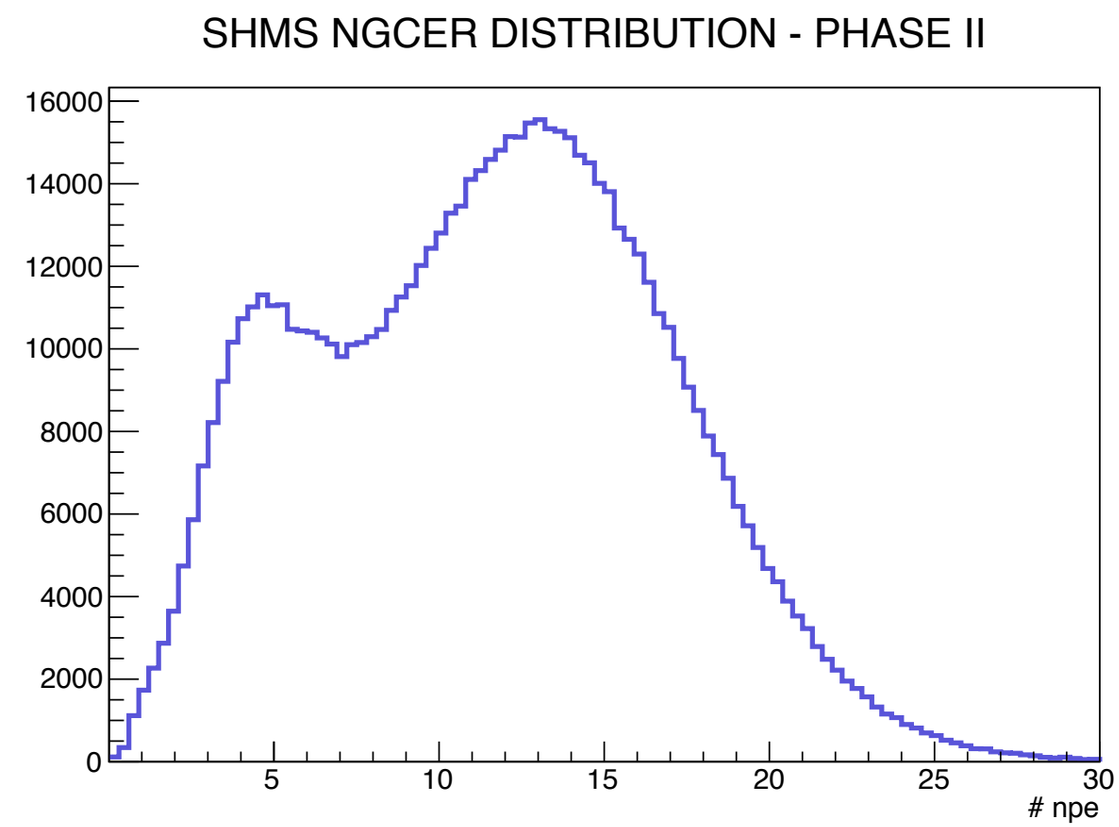
60 PR factor

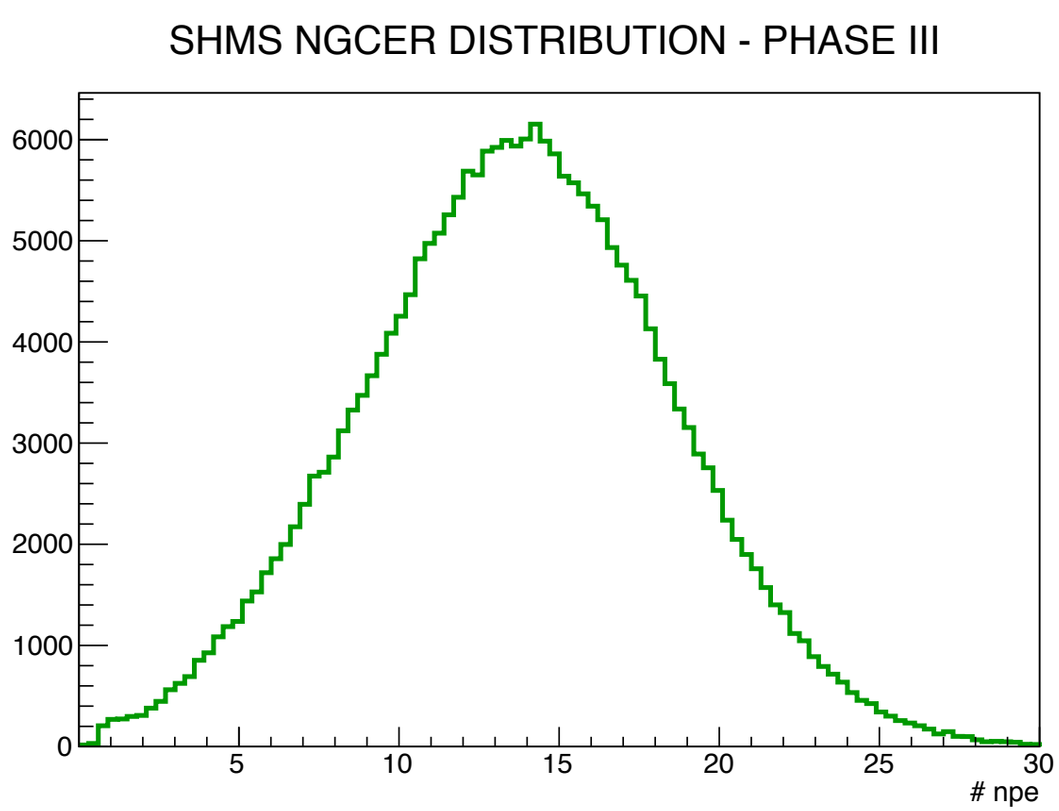
at E/p=0.8

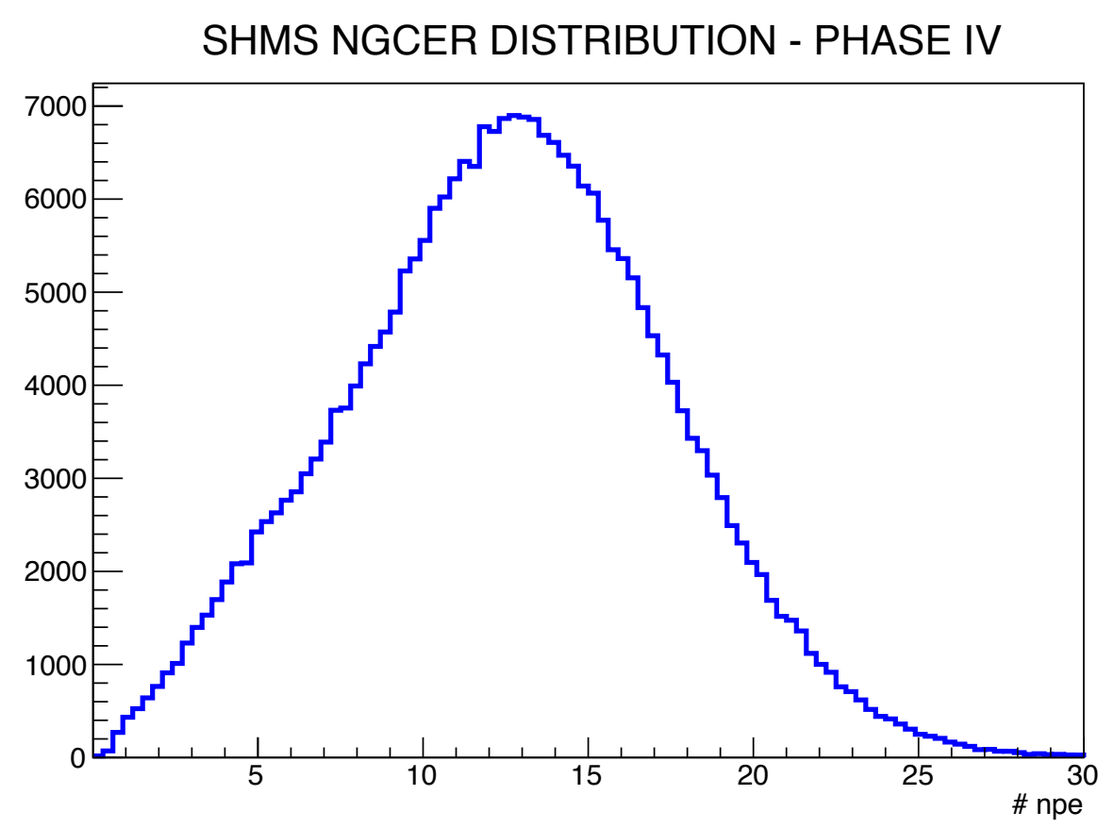
SHMS CALORIMETER	EFF	PR	CUTS	Calorimeter cut position for Eff and PR factor
PHASE I	99.66 +/- 0.18	58 +/- 0.4	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	Preshower > 0.05 Total calo. > 0.8
PHASE II	99.06 +/- 0.19	68 +/- 0.5	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	Preshower > 0.05 Total calo. > 0.8
PHASE III	99.58 +/- 0.31	80 +/- 0.9	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	Preshower > 0.05 Total calo. > 0.8
PHASE IV	99.73 +/- 0.30	74 +/- 1.2	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	Preshower > 0.05 Total calo. > 0.8

SHMS Noble Gas Cherenkov Efficiency and Pion Rejection Factor





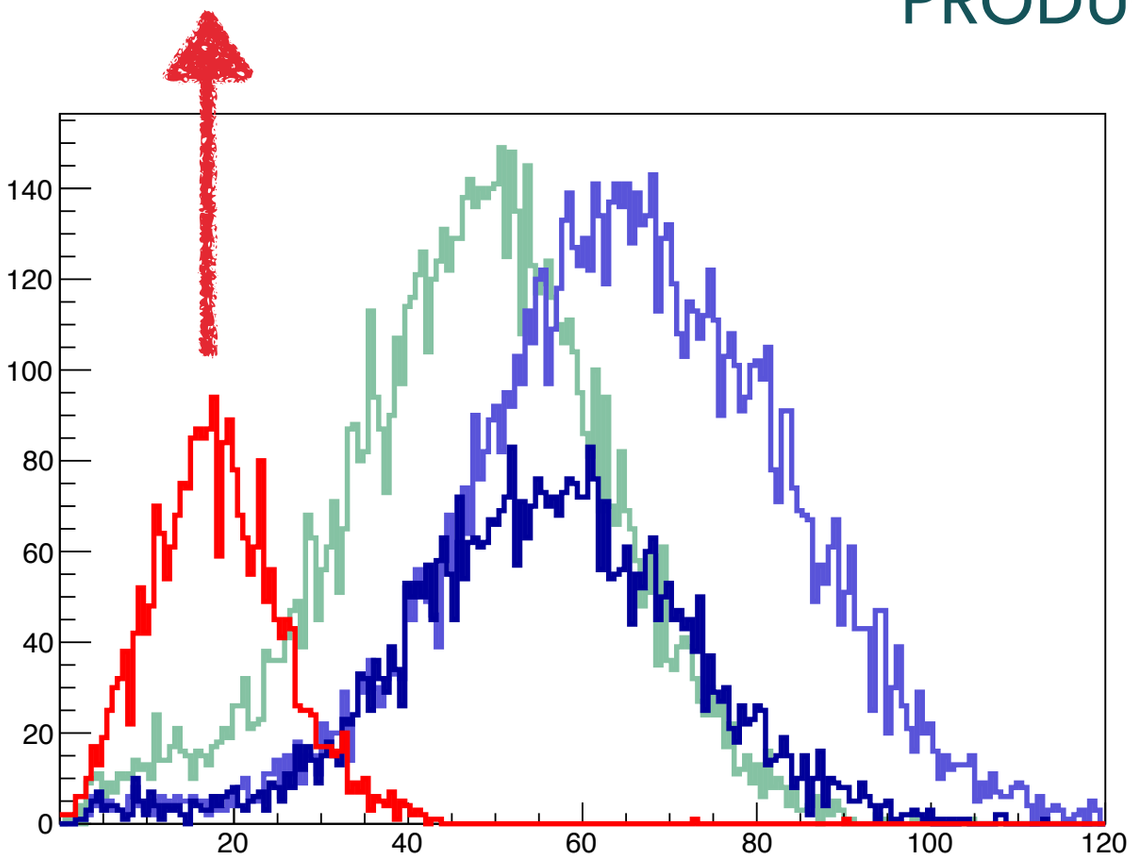


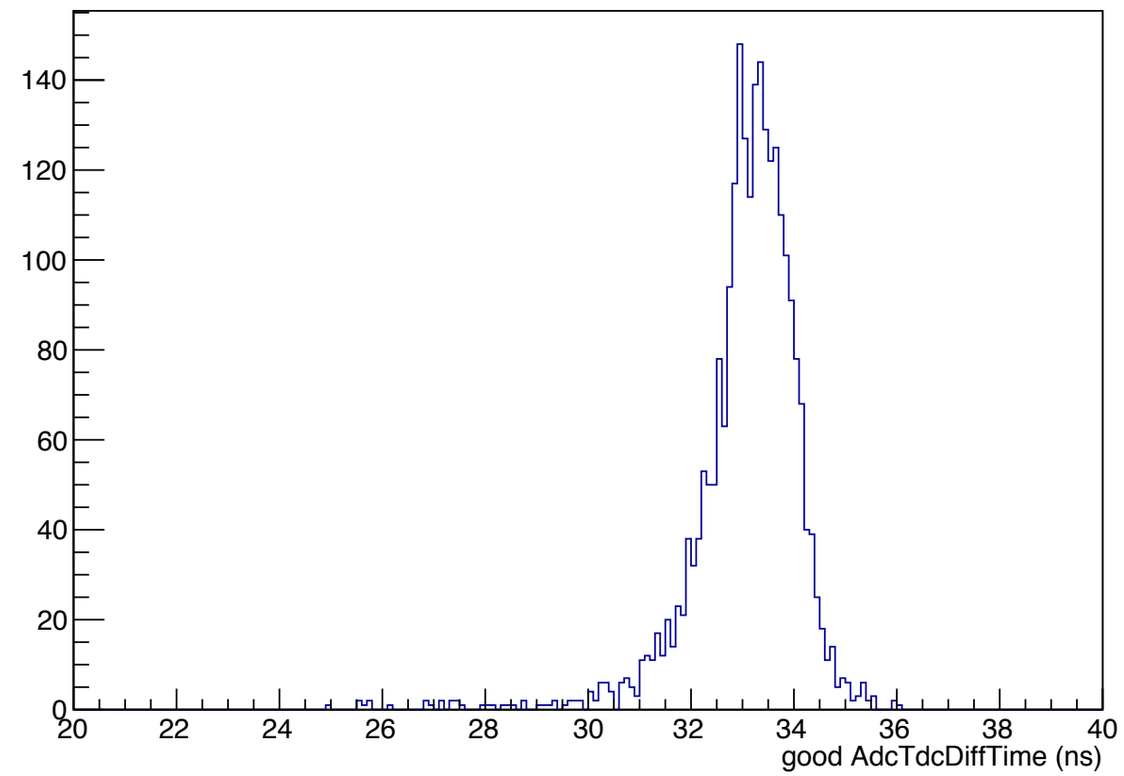


PMT1

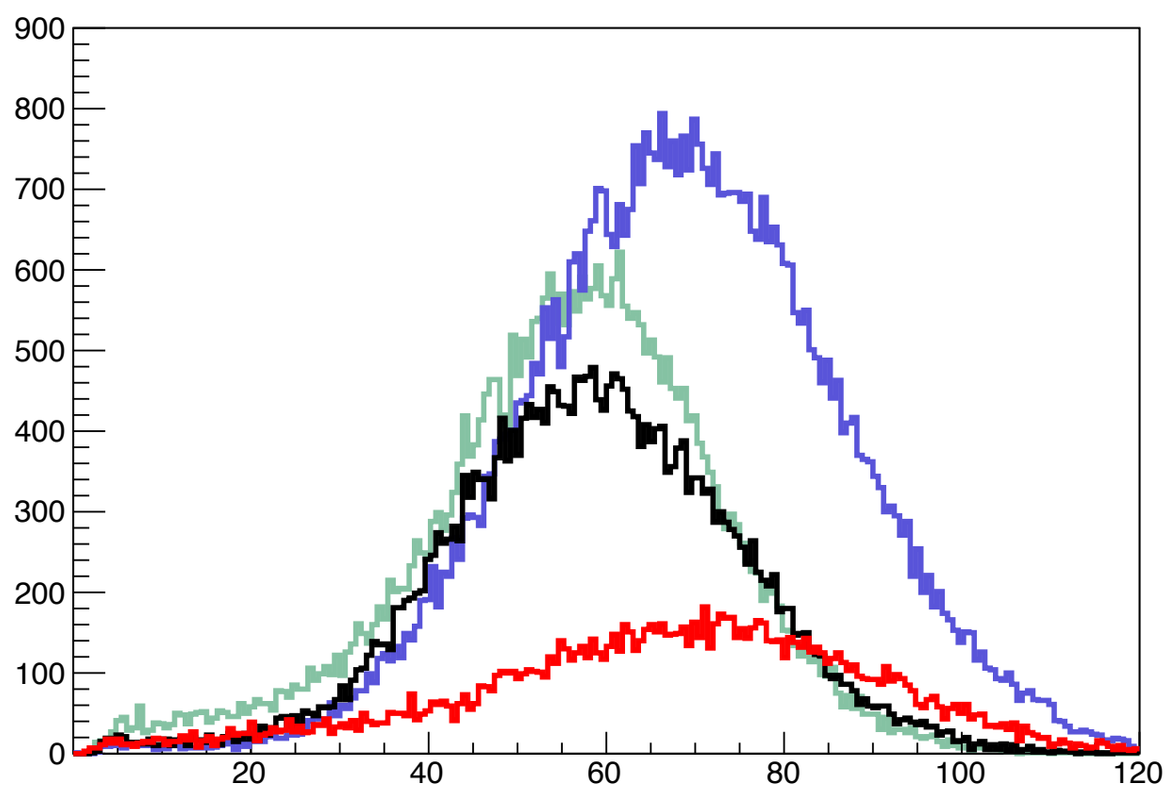
PMT1 TIMING WINDOW

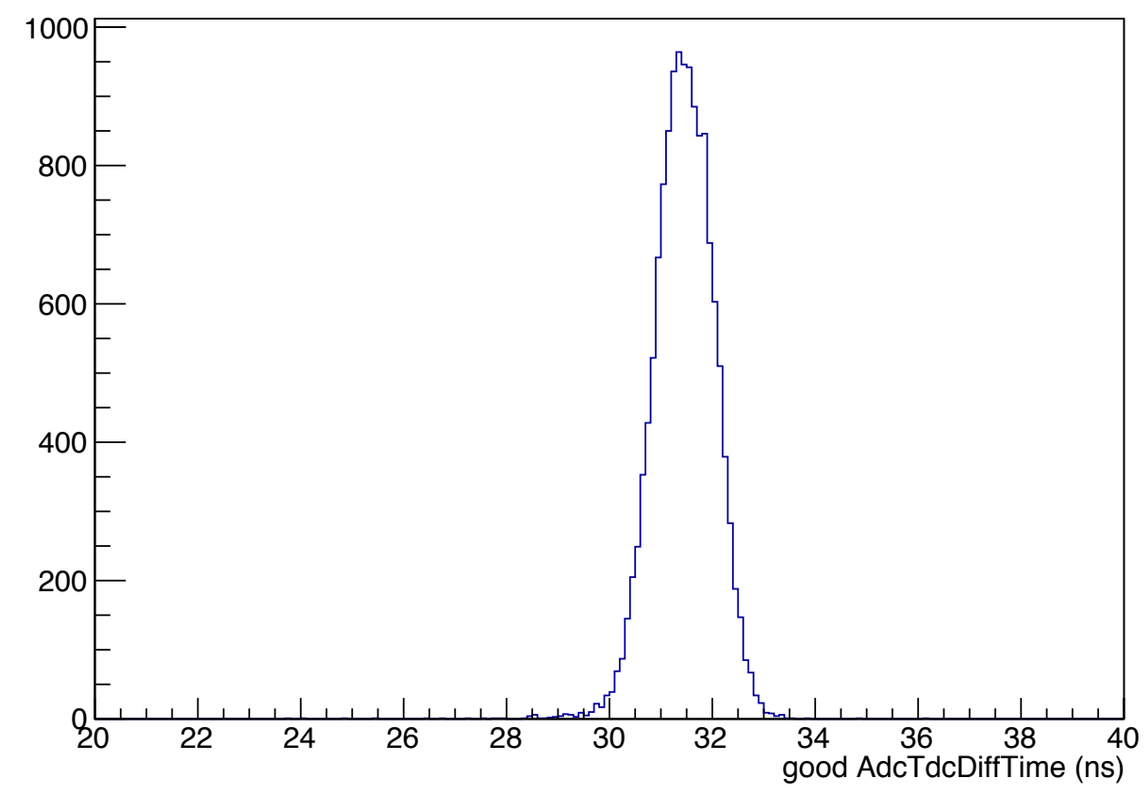
PRODUCTION DATA





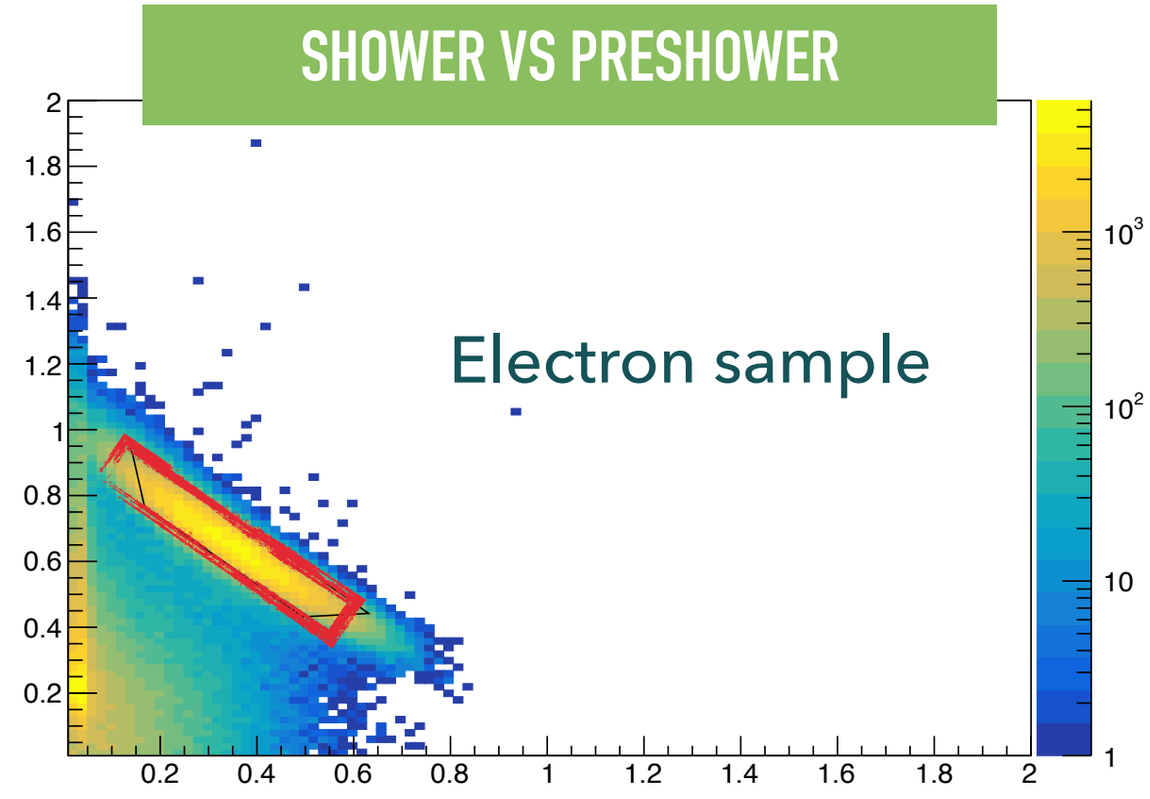
DIS / CALIBRATION DATA





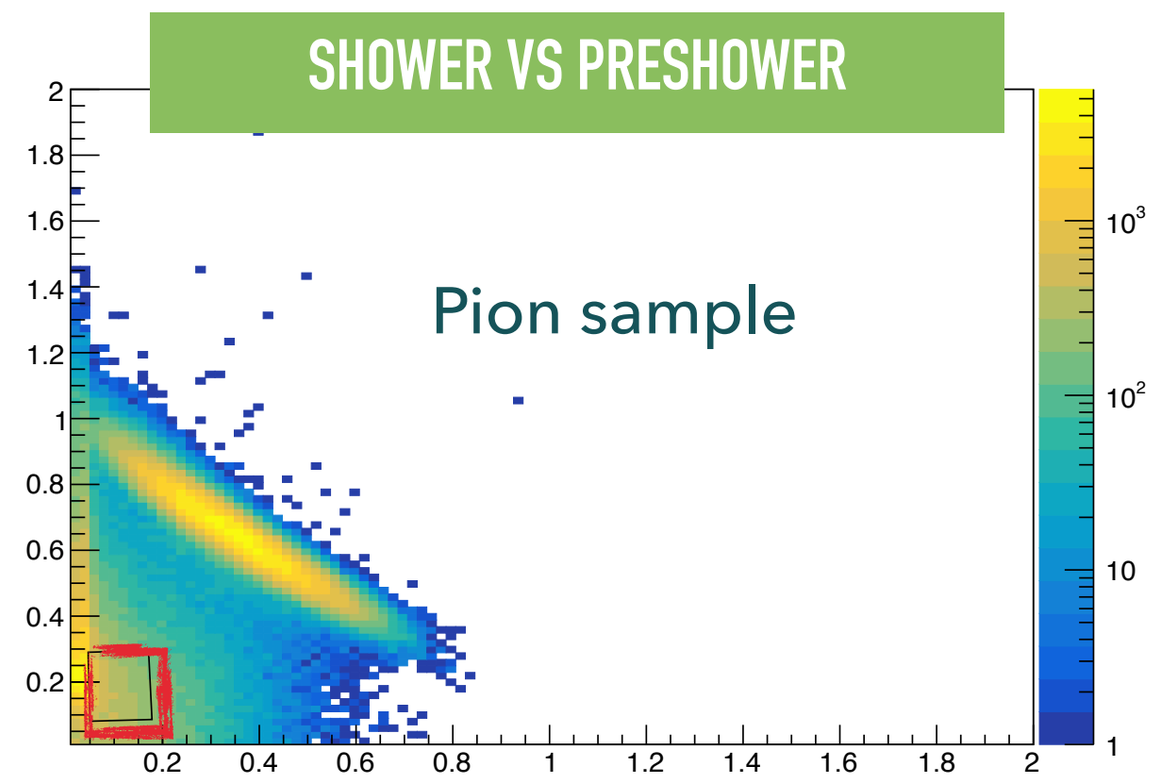
Electron sample chosen with:

- Target cuts and 2D calorimeter graphical cut.
- Check how many of them passed the Cherenkov cut.
- Study the efficiency as a function of cut position by varying it.

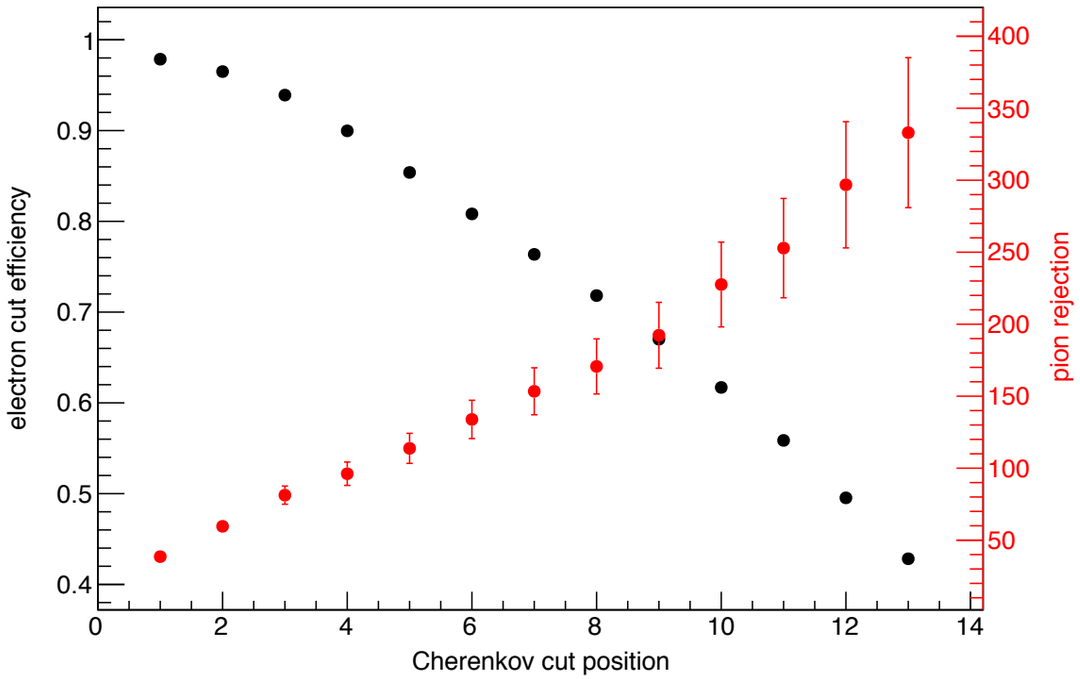


Pion sample chosen with:

- Target cuts, 2D calorimeter graphical cut.
- Check how many of them passed the Cherenkov.
- Study the efficiency as a function of cut position by varying it.



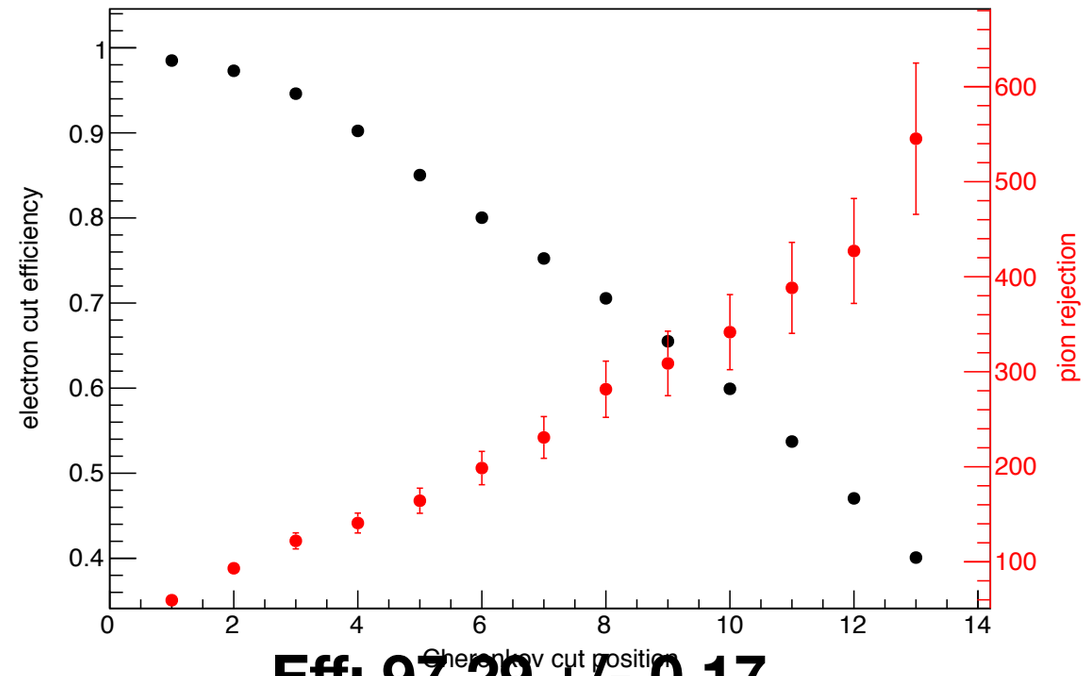
PHASE I



Eff: 96.50 +/- 0.17

PR: 60 +/- 3.9 at 2 npe

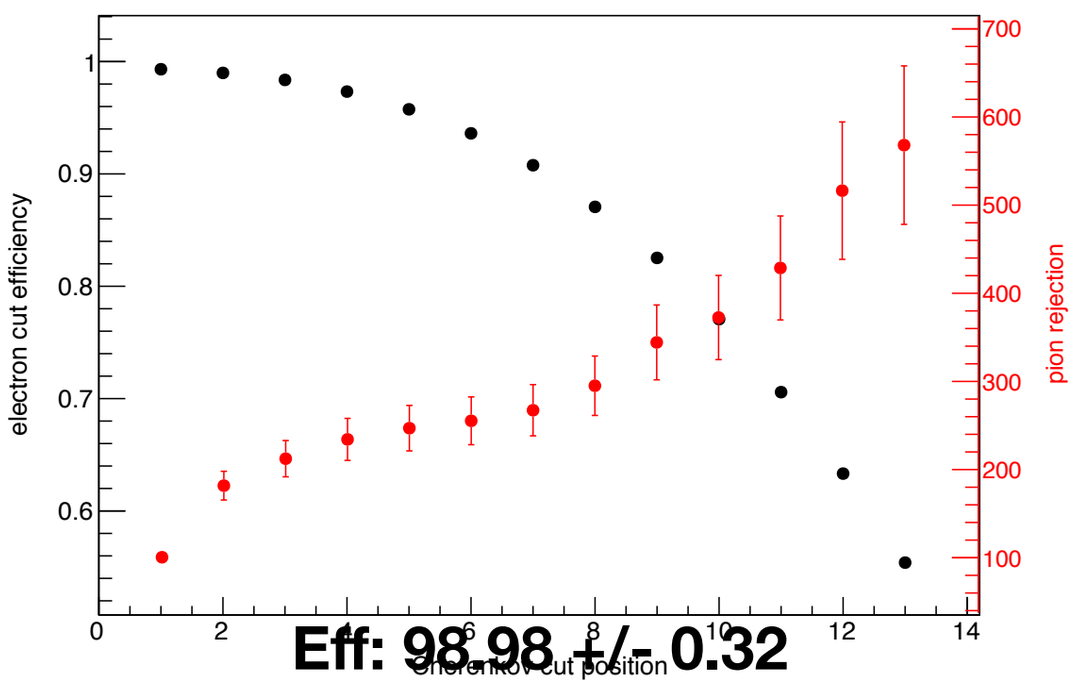
PHASE II



Eff: 97.29 +/- 0.17

PR : 93 +/- 5.6 at 2 npe

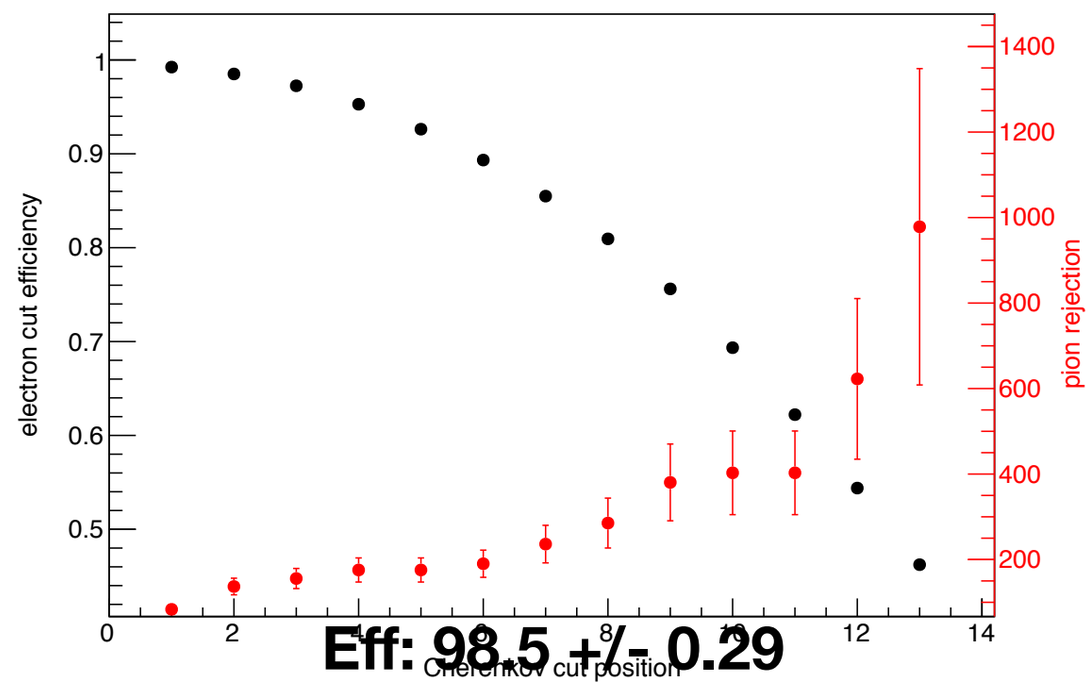
PHASE III



Eff: 98.98 +/- 0.32

PR: 181 +/- 16.3 at 2 npe

PHASE IV



Eff: 98.5 +/- 0.29

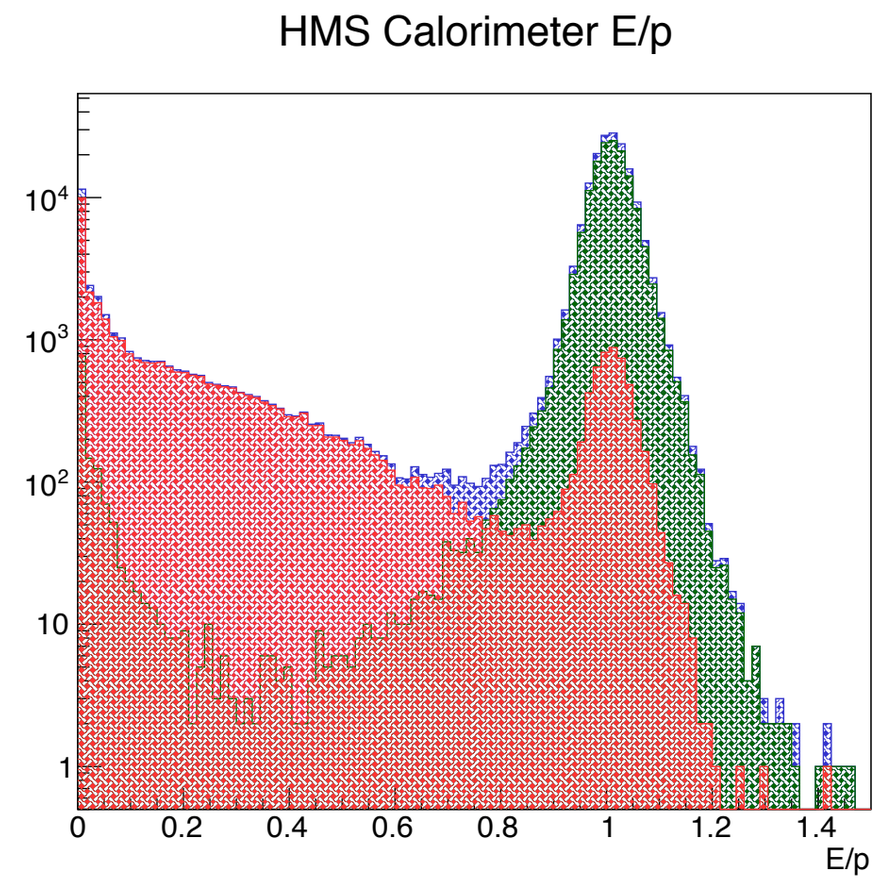
PR: 137+/- 19 at 2 npe

SHMS CHERENKOV	EFF	PR	CUTS	Cherenkov cut position for Eff and PR factor
PHASE I	96.50 +/- 0.17	60 +/- 3.9	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	2 npes
PHASE II	97.29 +/- 0.17	93 +/- 5.6	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	2 npes
PHASE III	98.98 +/- 0.32	181 +/- 16.3	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	2 npes
PHASE IV	98.5 +/- 0.29	137+/- 19	abs(y tar) < 4. -10 < delta < 22 abs(xp tar) < 0.06	2 npes

HMS Calorimeter Electron Efficiency

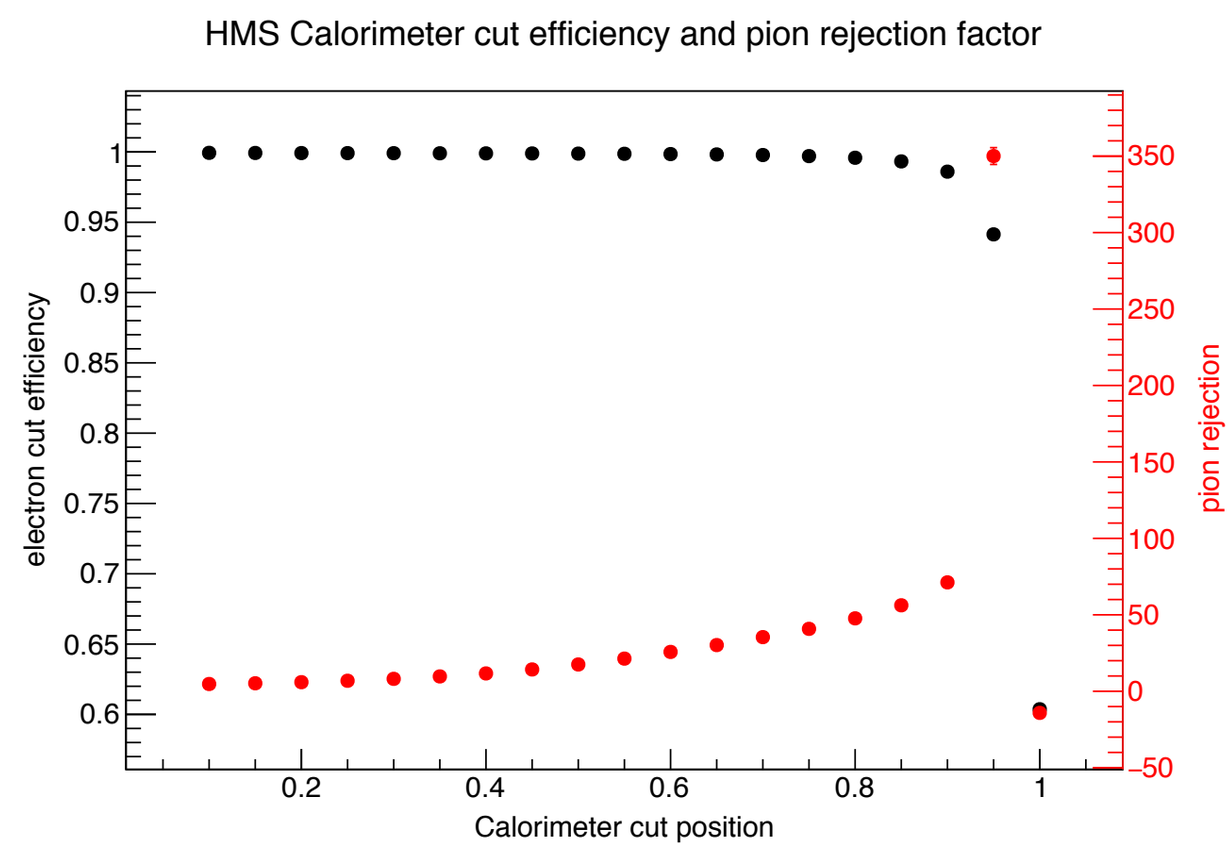
Electron sample chosen with:

- Target cuts, hms cherenkov > 3 npe
- Check how many of them passed the calorimeter + preshower cut.
- Study the efficiency as a function of cut position by varying it.



Pion sample chosen with:

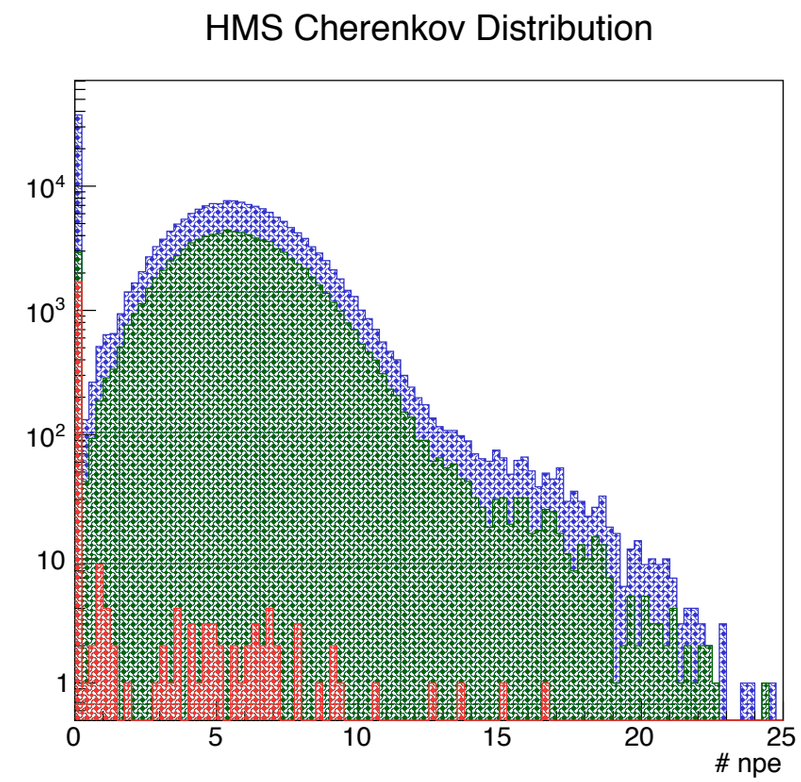
- Target cuts, hms cherenkov not fire.
- Check how many of them passed the calorimeter + preshower cut.
- Study the efficiency as a function of cut position by varying it.



HMS Cherenkov Electron Efficiency

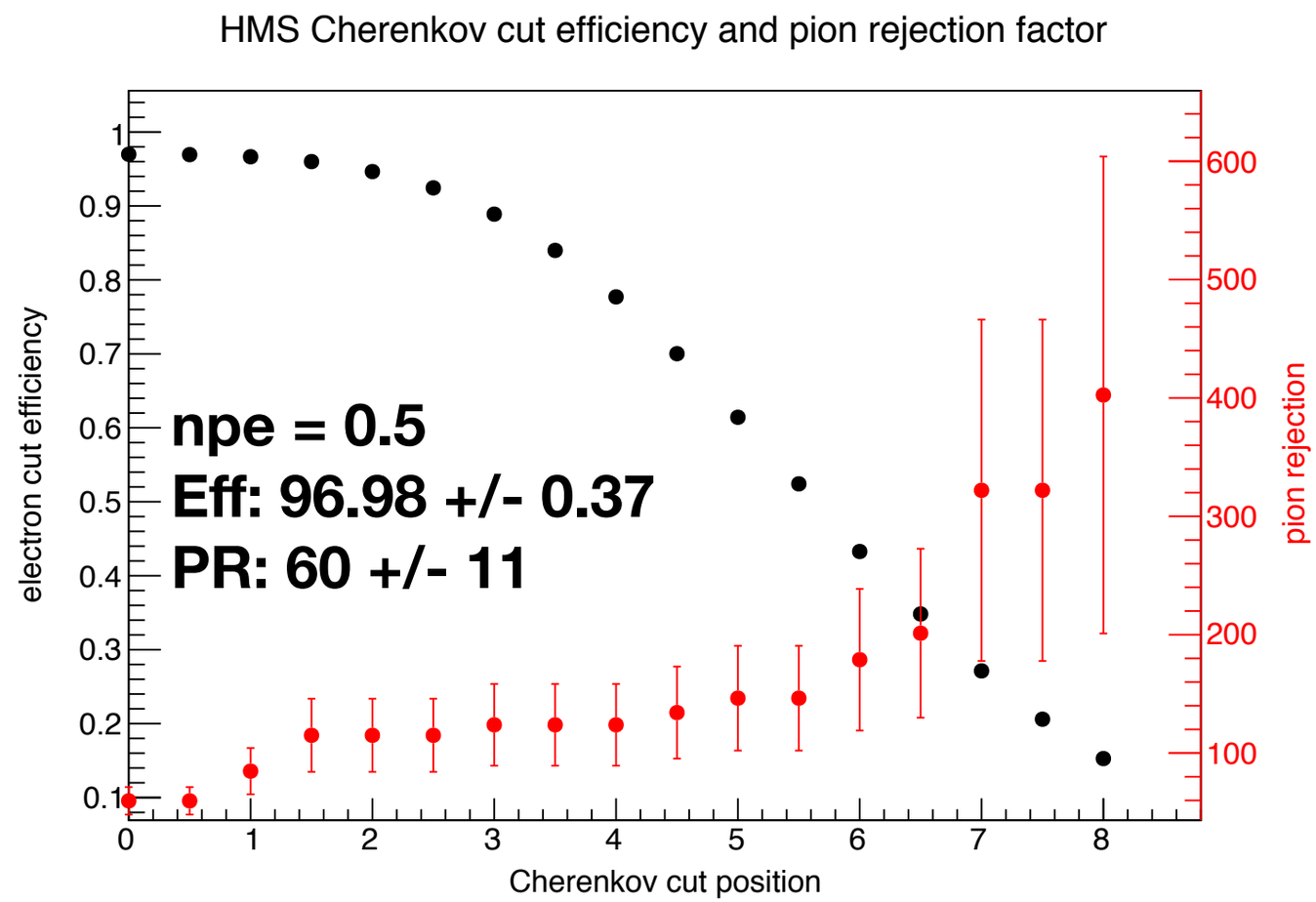
Electron sample chosen with:

- Target cuts, 2D calorimeter cut (not giving clean sample)
- Check how many of them fired the Cherenkov.
- Study the efficiency as a function of cut position by varying it.



Pion sample chosen with:

- Target cuts, 2D calorimeter cut.
- Check how many of them fired the Cherenkov.
- Study the efficiency as a function of cut position by varying it.



Initial Look at Tracking Efficiencies & Yields with Luminosity Scans

- Loop through the scaler tree and put a flag for the events that provide the following current threshold statement:
  - abs(current-central current) < 3 uA.
- Loop through the data and analyze events only when the current flag is true.

Tracking Efficiency Calculation

The tracking efficiency for the particles is defined as the ratio of the number of events for which a track was found to the number of events for which one expected a track to be found.

$$\epsilon_{tracking} = \frac{Ndid}{Nshould}$$

Nshould is the number of events for which an event passed calorimeter and Cherenkov cuts for electron selection. For the calorimeter cut, the total deposited energy is used. This does NOT depend on tracking. It's normalized by the spectrometer central momentum.

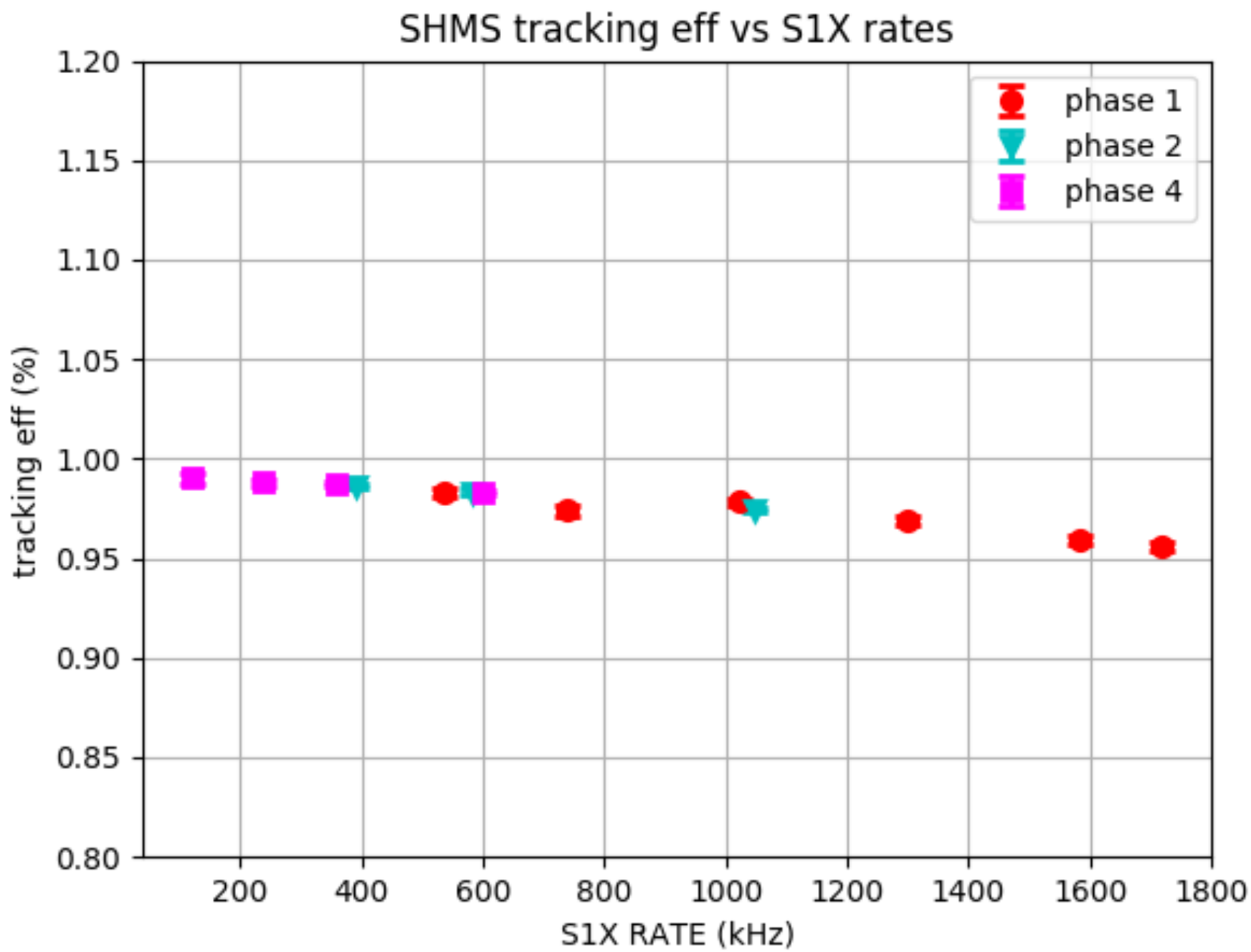
Ndid is Nshould & TRACK FOUND.

***Nshould*:**

P.hod.goodscinhit==1 && 0.5 < P.hod.betanotrack < 1.4 && 0.6 < P.cal.etotnorm < 1.6 && P.ngcer.npeSum > 2.0

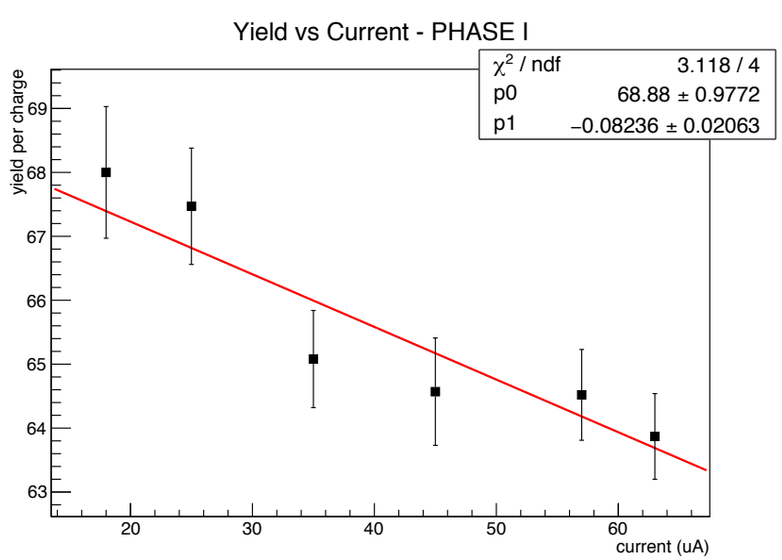
***Ndid*:**

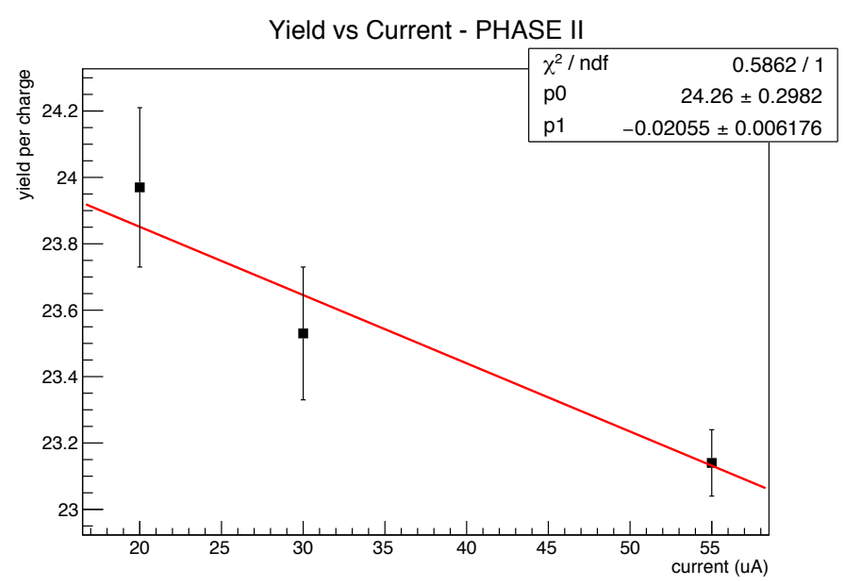
Nshould && P.dc.ntrack > 0.

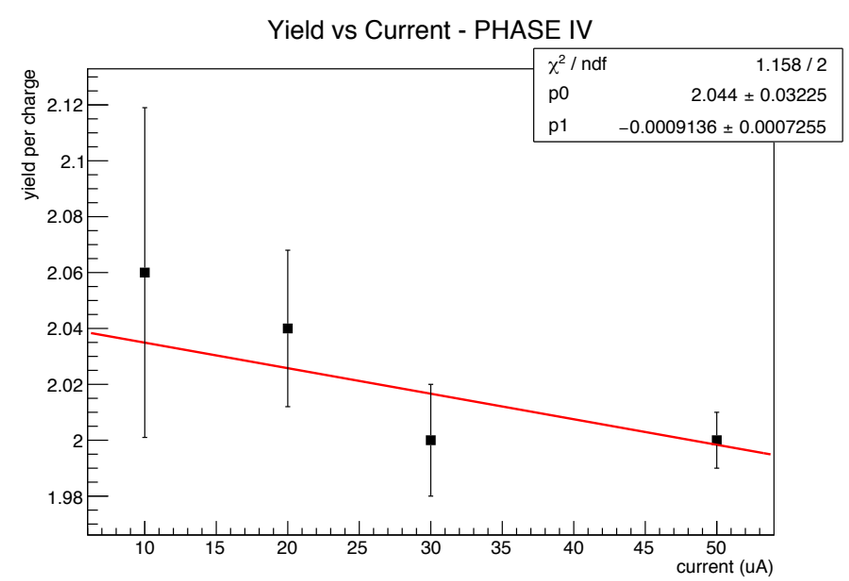

SHMS tracking eff vs S1X rates
phase 1
phase 2
phase 4
tracking eff (%)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
200
400
600
800
1000
1200
1400
1600
1800
S1X RATE (kHz)

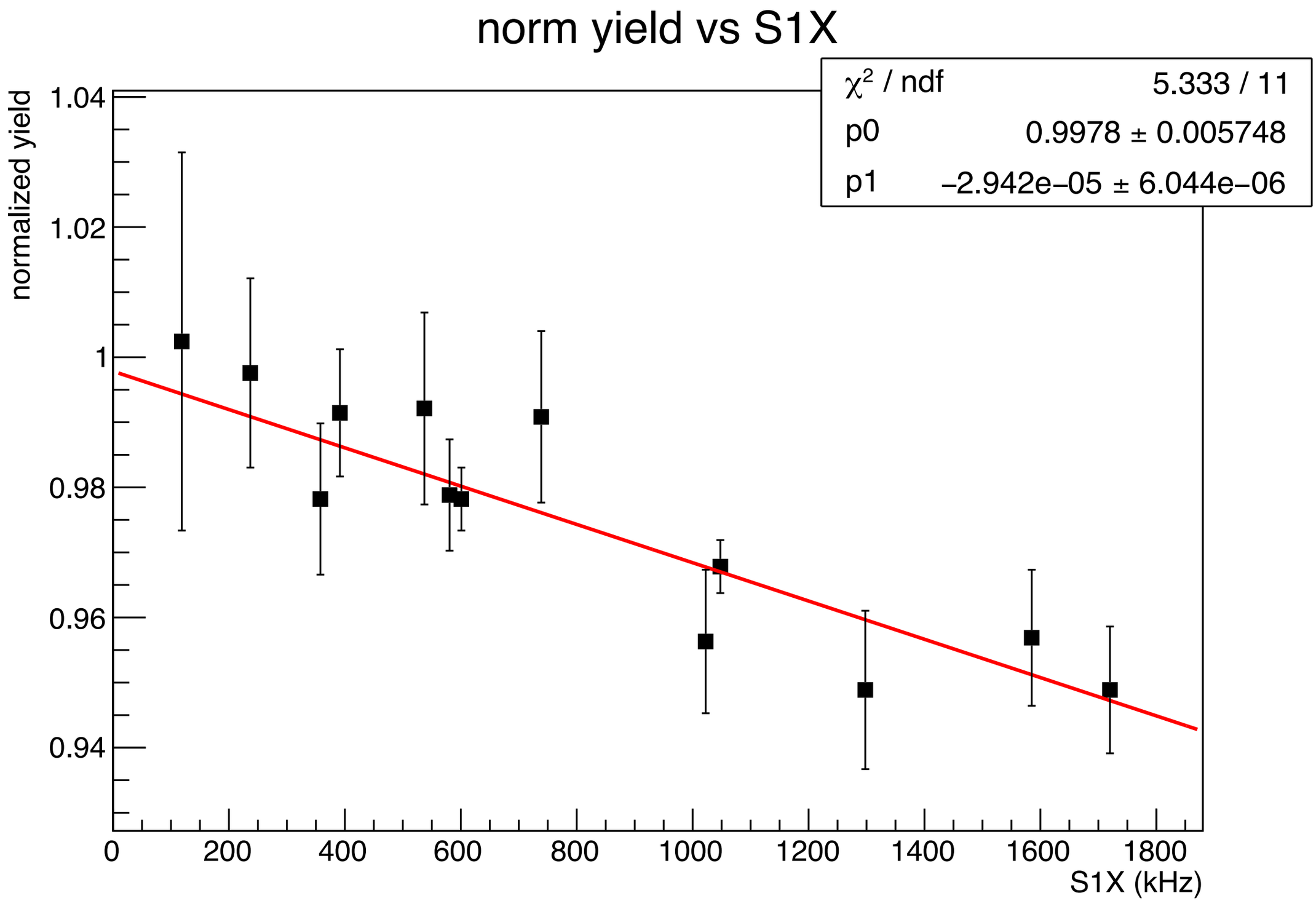
Yield Calculation

- Select events etottracknorm > 0.8 && eprtracknorm > 0.05 && P.ngcer.npeSum > 2. && -10. < delta < 22. && abs(target_theta) > 0.06 && abs(target_phi) > 0.08
- While calculating the yields, separate the SHMS single events (prescaled) and the coincidence events with the event type cut == 1 and == 4 respectively.
- Total events = ((shms_singles)* prescale value + coin events)
- Yield per charge = total events / (tracking eff * charge)








norm yield vs S1X
χ² / ndf 5.333 / 11
p0 0.9978 ± 0.005748
p1 −2.942e−05 ± 6.044e−06
normalized yield
1.04
1.02
1
0.98
0.96
0.94
0
200
400
600
800
1000
1200
1400
1600
1800
S1X (kHz)

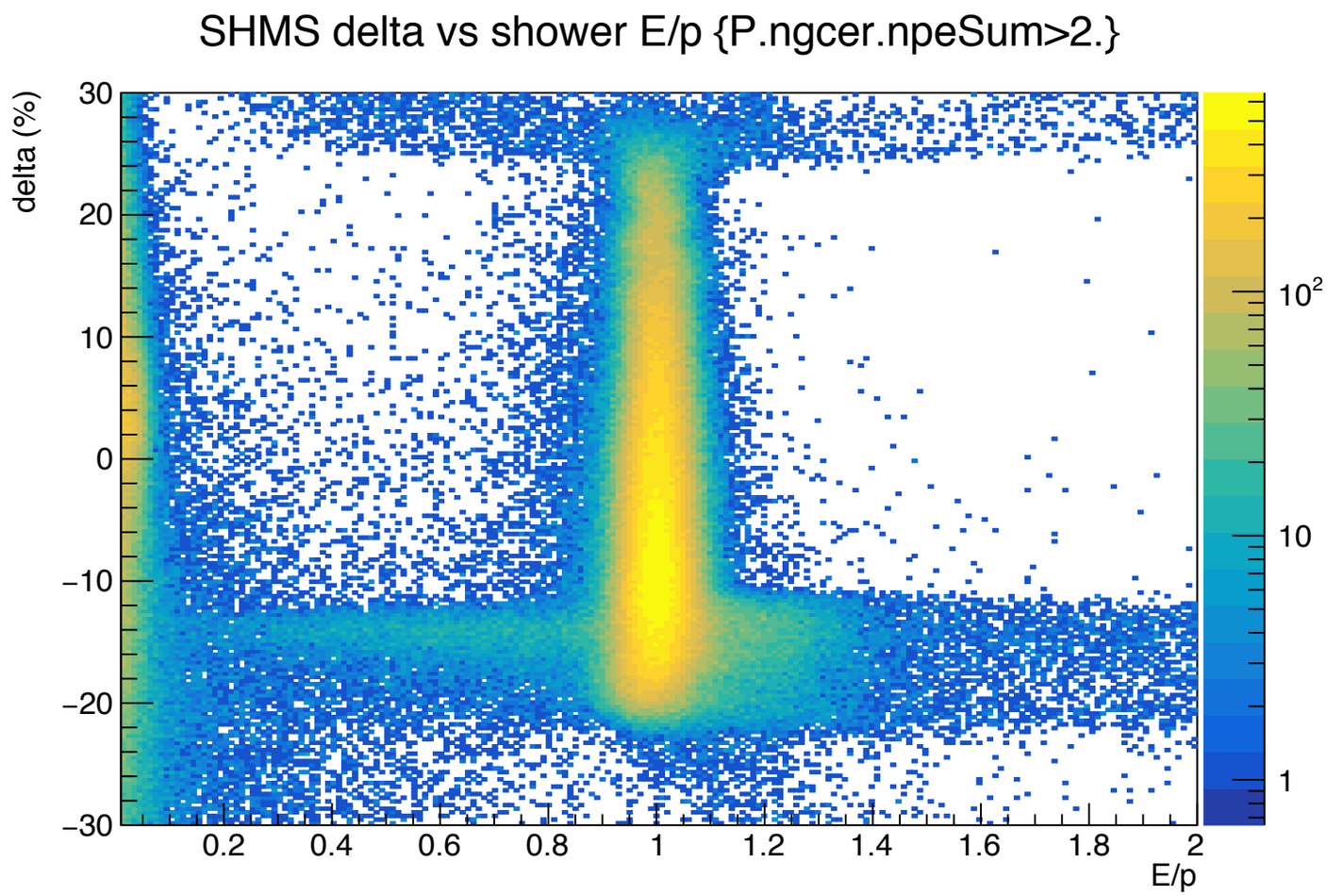
SUMMARY

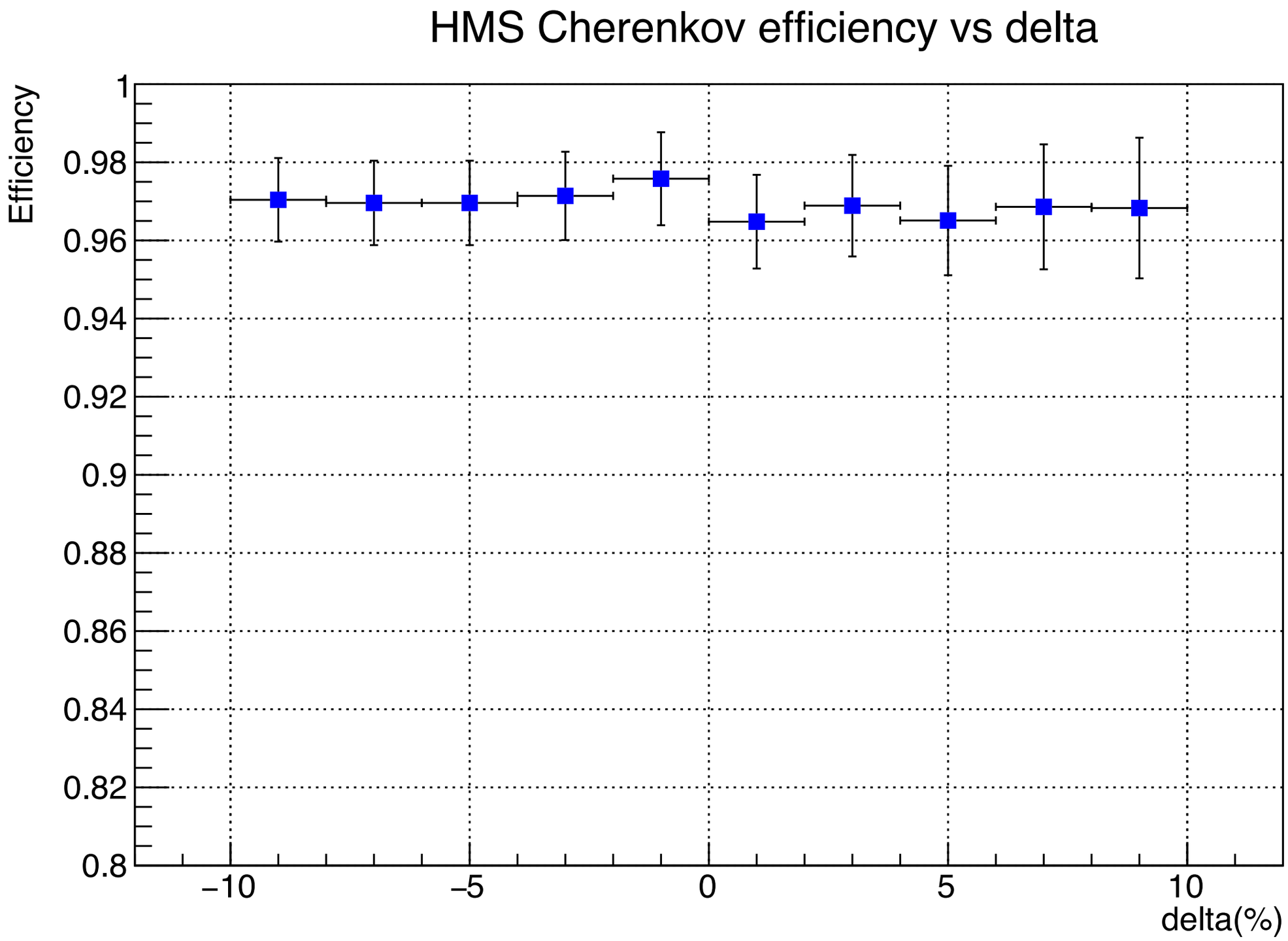
E12-16-007, high impact experiment

- ★ True nature of the LHCb pentaquark "*Pc*"
- ★ *J/Ψ photo production absolute cross section.*
- ★ High precision measurement of t dependent cross section between 9-10.6 GeV
- ★ Largest dataset of ***J/ψ*** produced with real photon beam.

This work is supported by the Department of Energy through grant DE-FG02-94ER4084

BACK UP SLIDES


SHMS delta vs shower E/p {P.ngcer.npeSum>2.}
delta (%)
30
20
10
0
−10
−20
−30
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
E/p
10^2
10
1

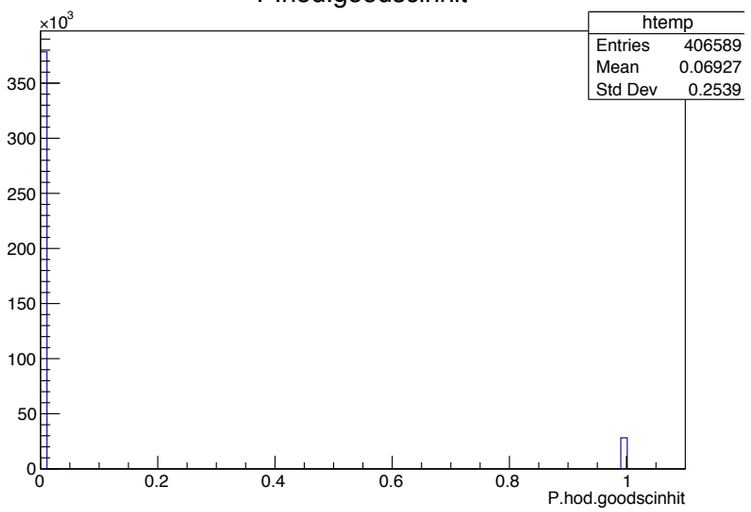


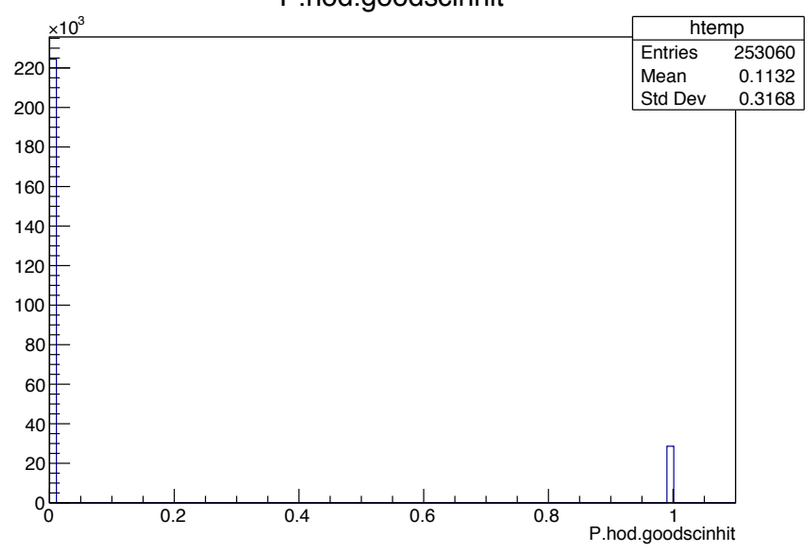
Cherenkov efficiency seems stable over the delta range of -10% to 10% with intervals of 2%

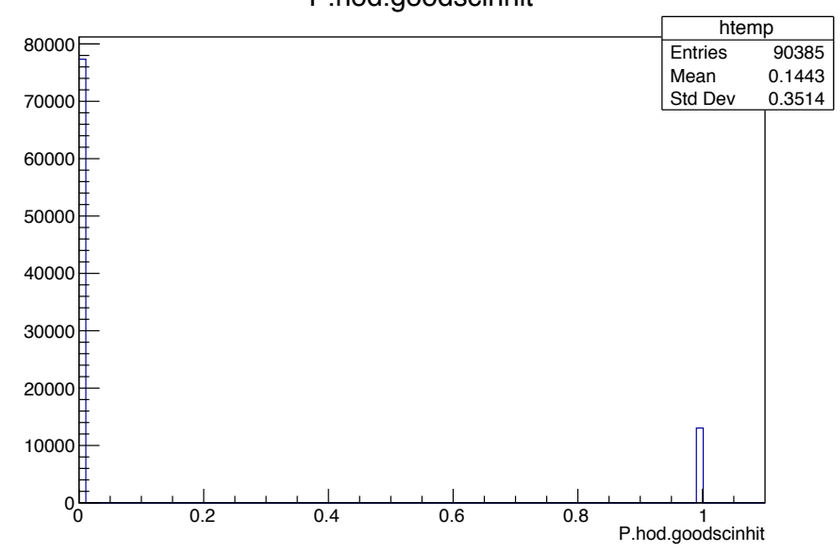
P.hod.goodscinhit==1

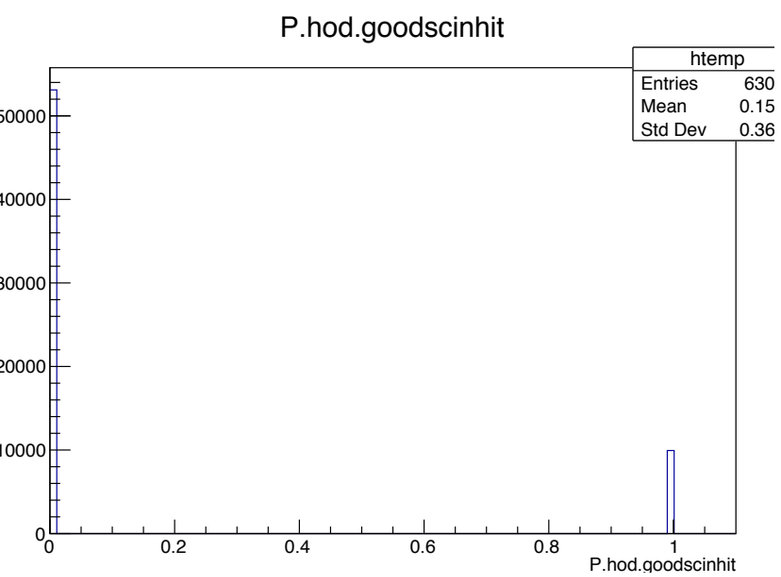
- This is a flag and it's on when the value is 1.

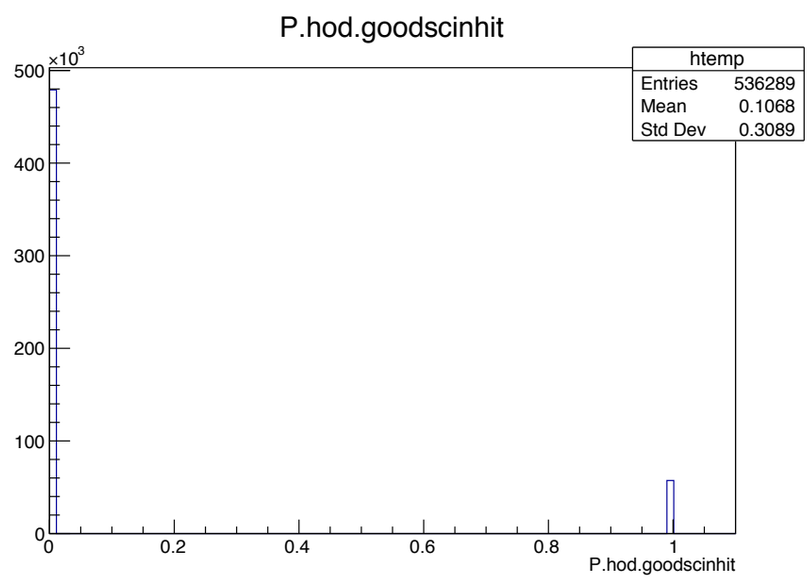
1) All planes have a hit. (4/4 trigger)
2) Defines a fiducial region for a possible track.
3) Possible track definition:
    - The code looks to see if there are hits within the certain hood paddles in each plane.
        - 4-11 paddles in 1X
        - 4-10 paddles in 2X
        - 4-11 paddles in 1Y
        - 6-16 paddles in 2Y
    - Certain distance between 1X and 2X and also 1Y and 2Y.

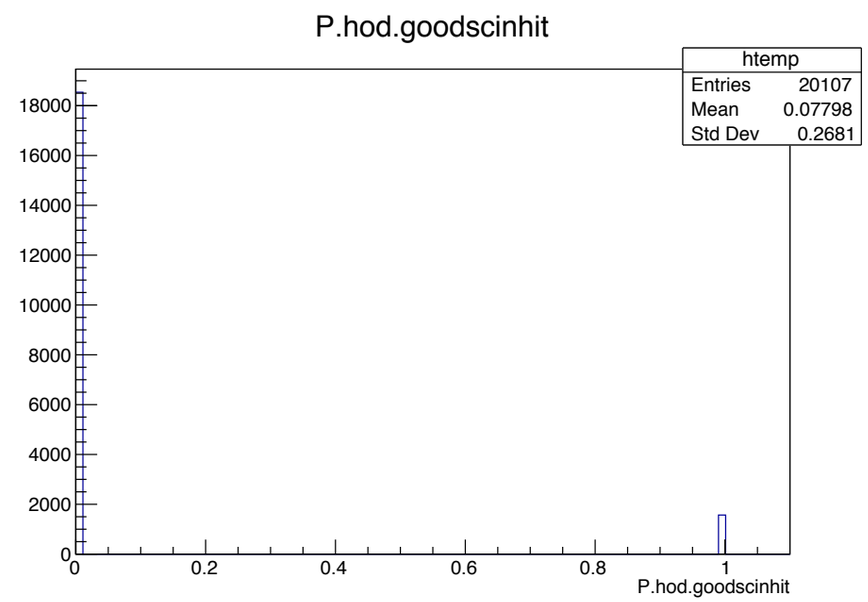

P.hod.goodscinhit
htemp
Entries 406589
Mean 0.06927
Std Dev 0.2539
×10^3
P.hod.goodscinhit

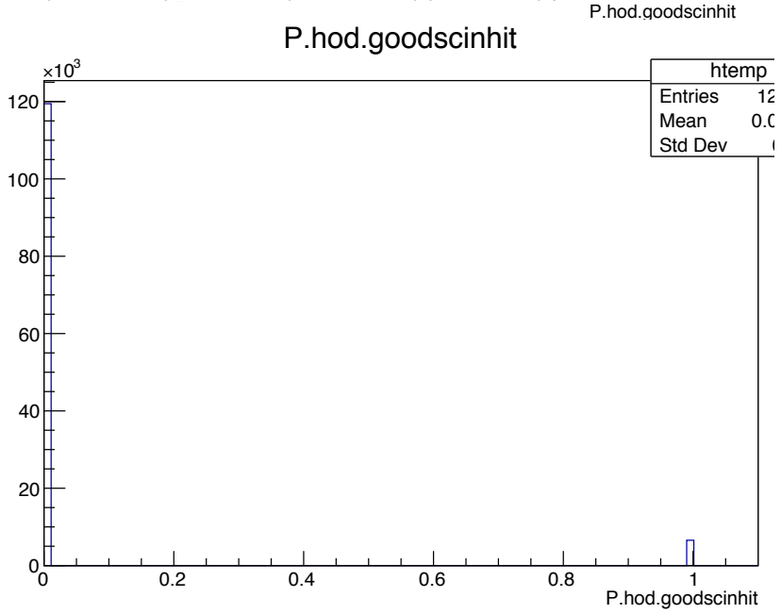

P.hod.goodscinhit
htemp
Entries 253060
Mean 0.1132
Std Dev 0.3168
×10^3
P.hod.goodscinhit

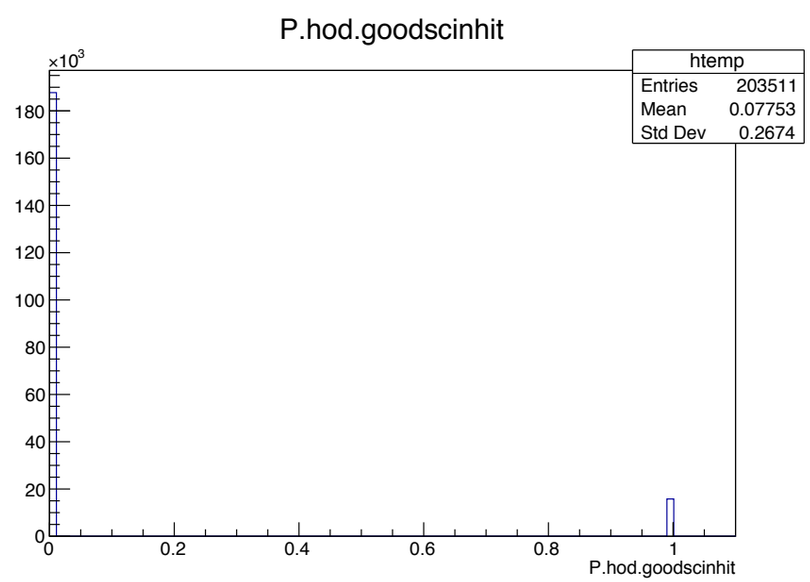

P.hod.goodscinhit
htemp
Entries 90385
Mean 0.1443
Std Dev 0.3514
P.hod.goodscinhit

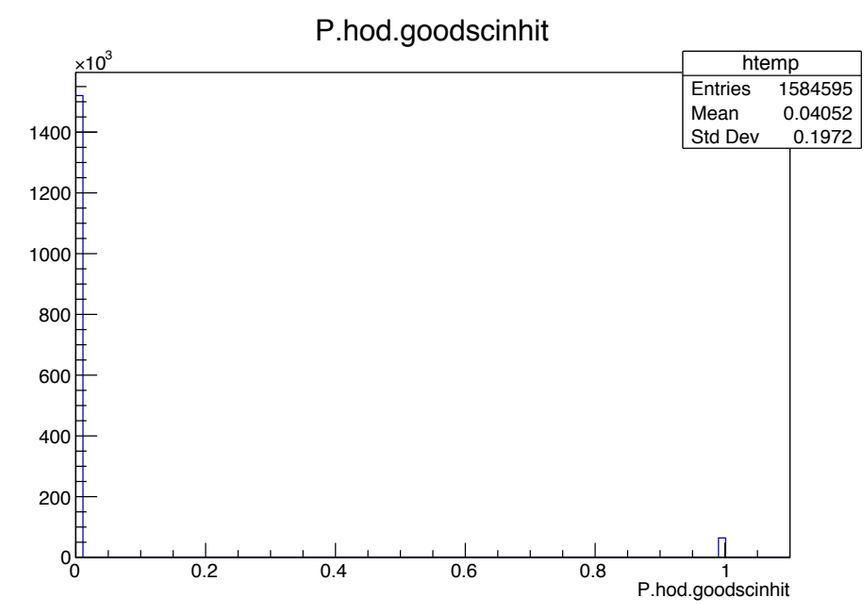

P.hod.goodscinhit
htemp
Entries 630
Mean 0.15
Std Dev 0.36
P.hod.goodscinhit


P.hod.goodscinhit
htemp
Entries 536289
Mean 0.1068
Std Dev 0.3089
×10^3
P.hod.goodscinhit

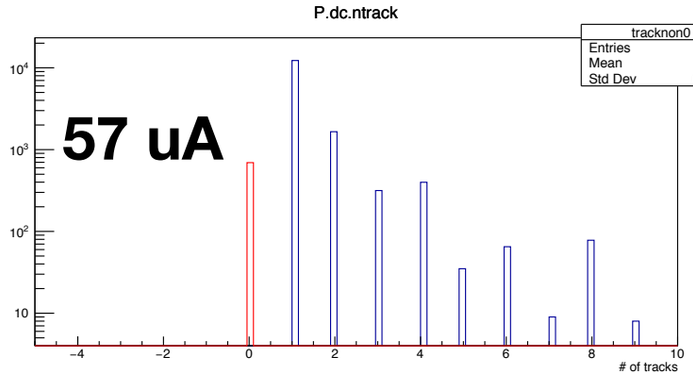

P.hod.goodscinhit
htemp
Entries 20107
Mean 0.07798
Std Dev 0.2681
P.hod.goodscinhit

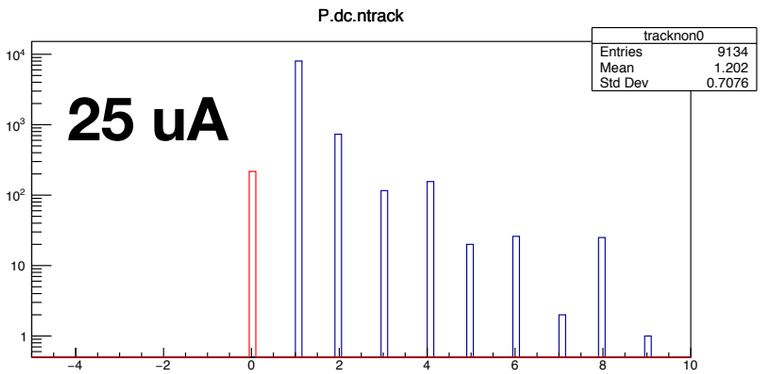

P.hod.goodscinhit
htemp
Entries 12
Mean 0.0
Std Dev
×10^3
P.hod.goodscinhit

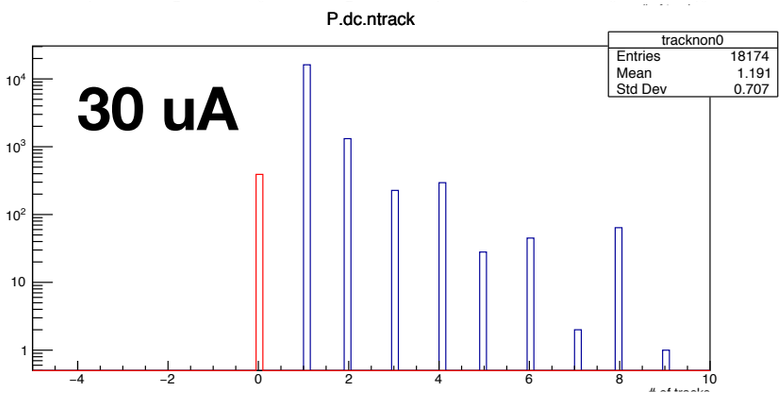

P.hod.goodscinhit
htemp
Entries 203511
Mean 0.07753
Std Dev 0.2674
×10^3
P.hod.goodscinhit

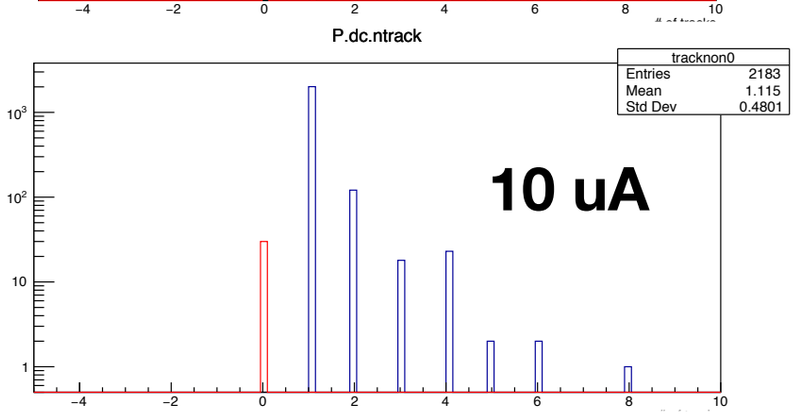

P.hod.goodscinhit
htemp
Entries 1584595
Mean 0.04052
Std Dev 0.1972
×10^3
P.hod.goodscinhit

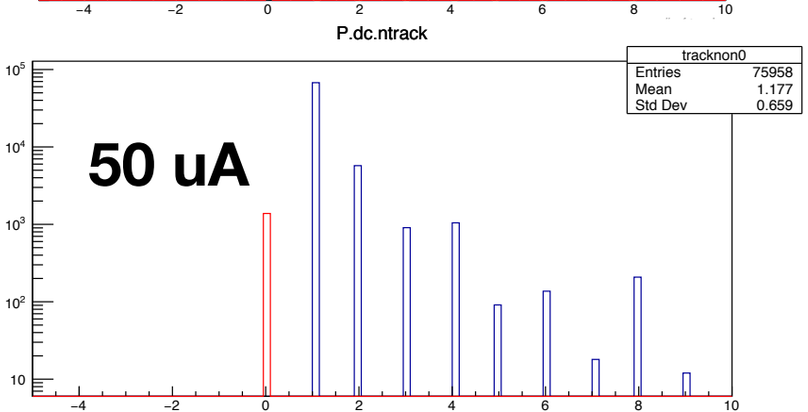
P.dc.ntrack plots

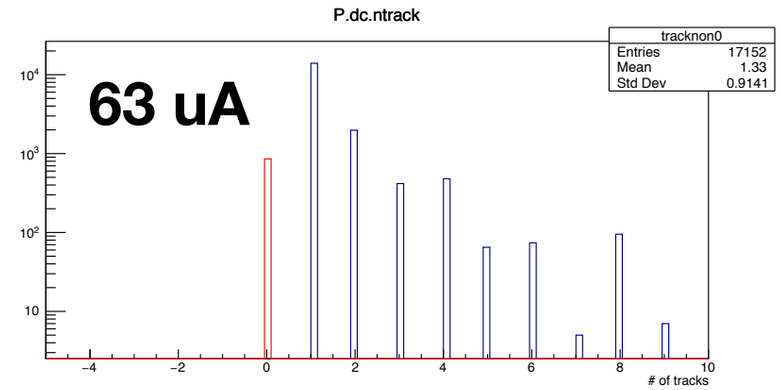


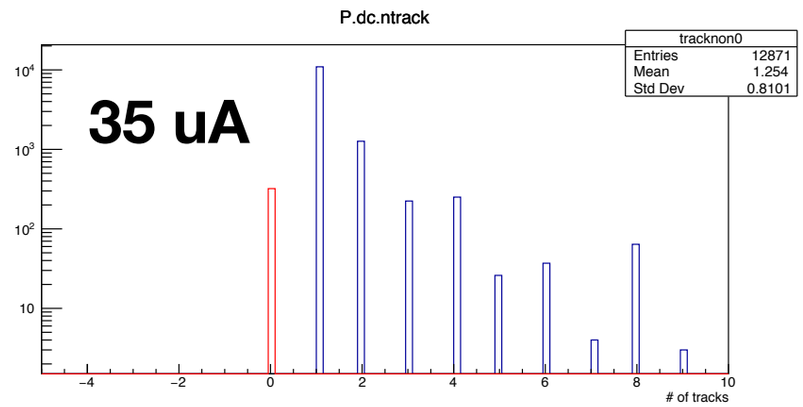


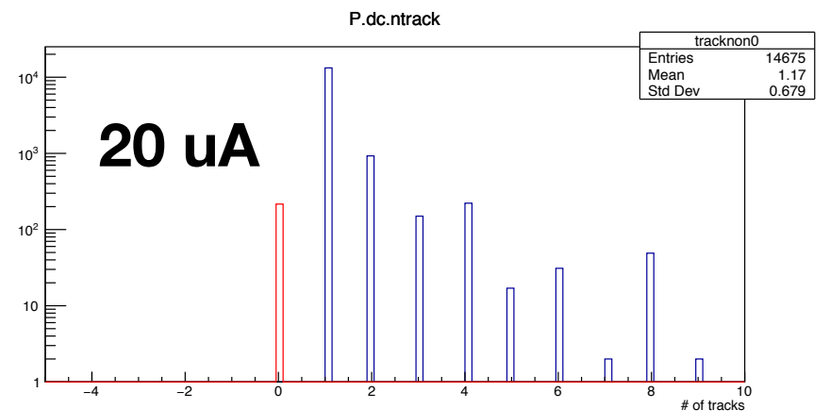


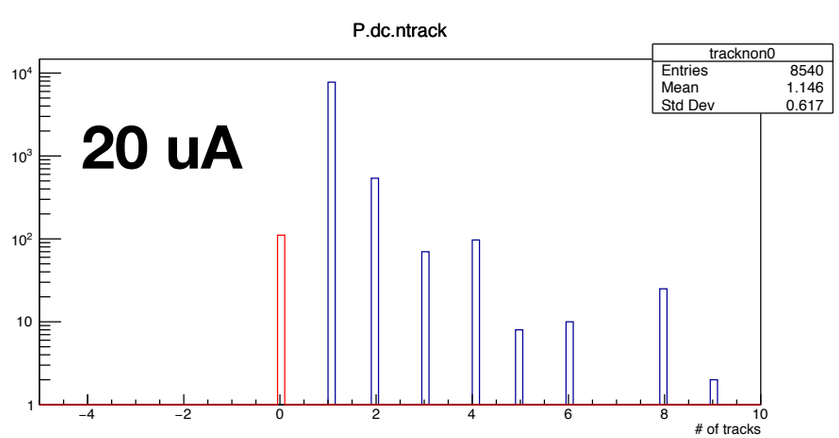


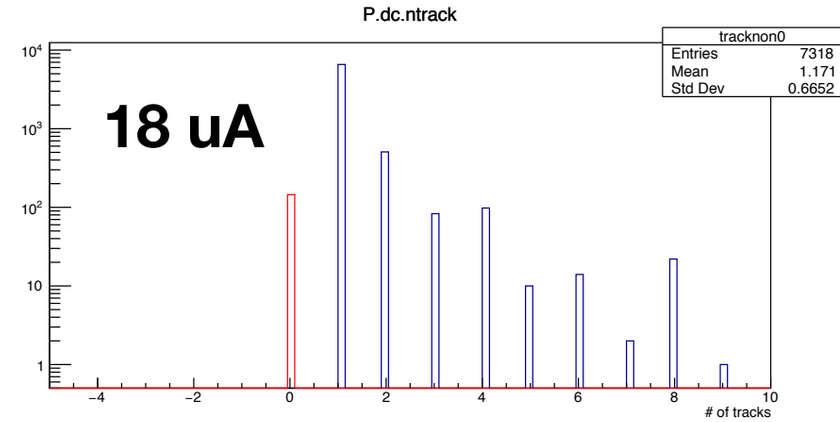


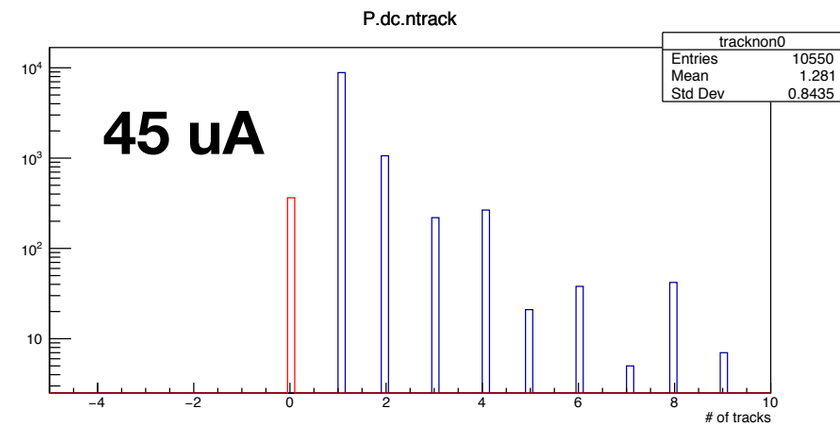


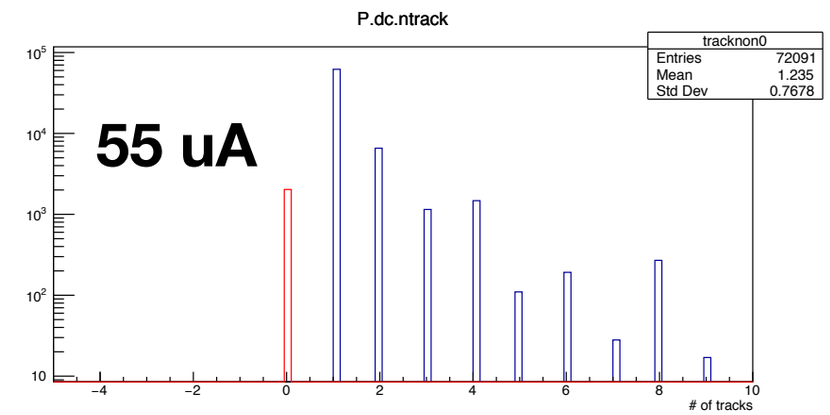


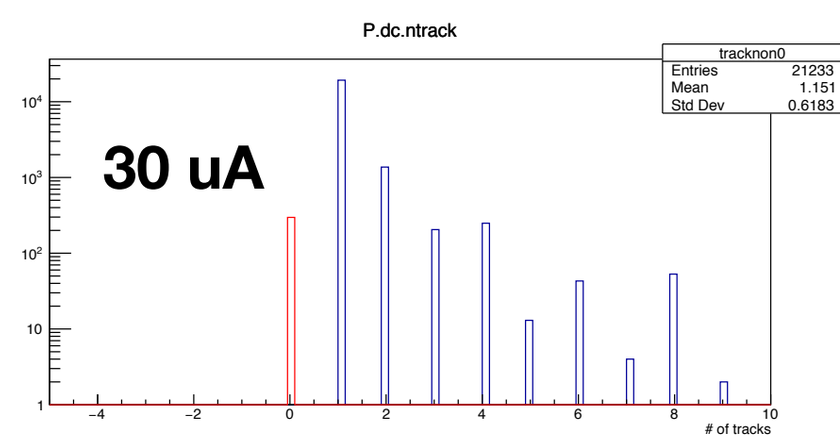


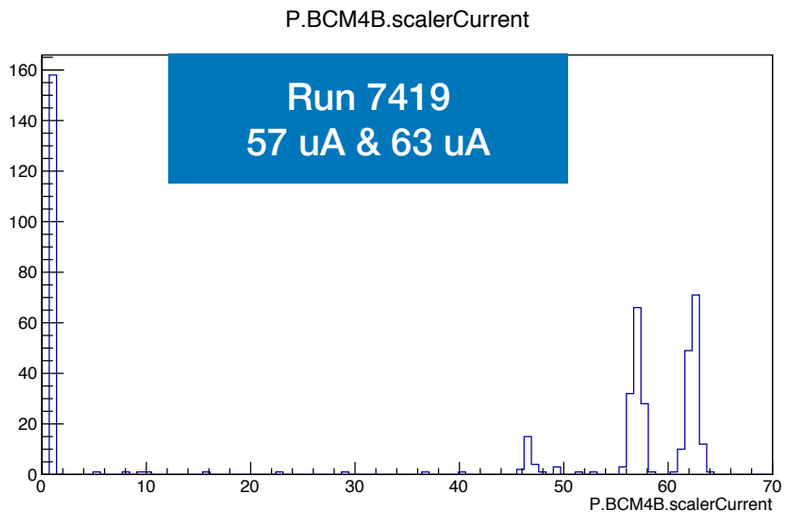


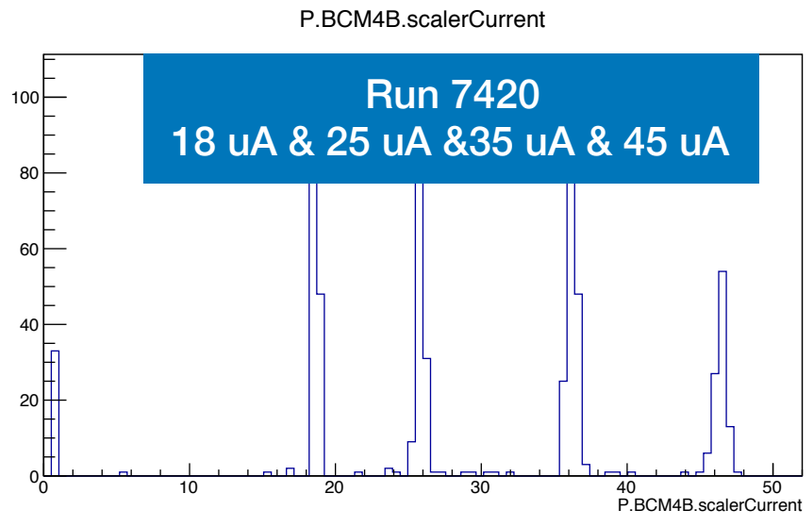


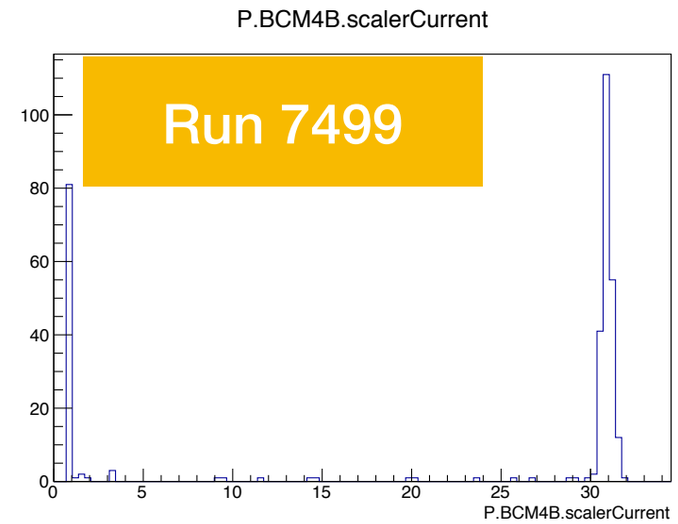


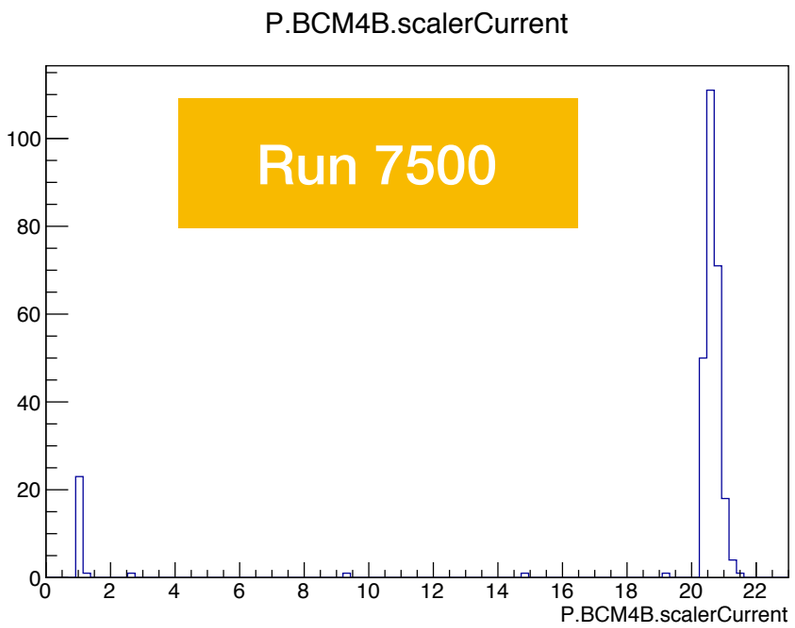


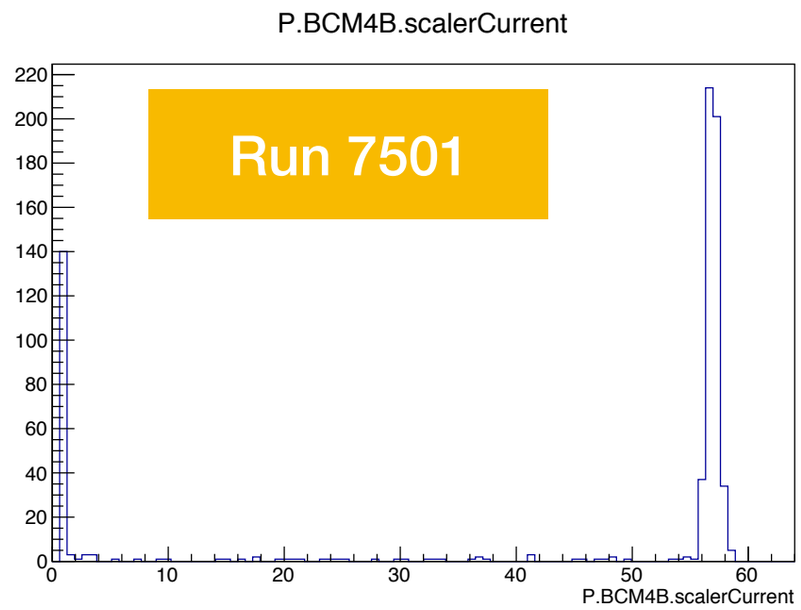


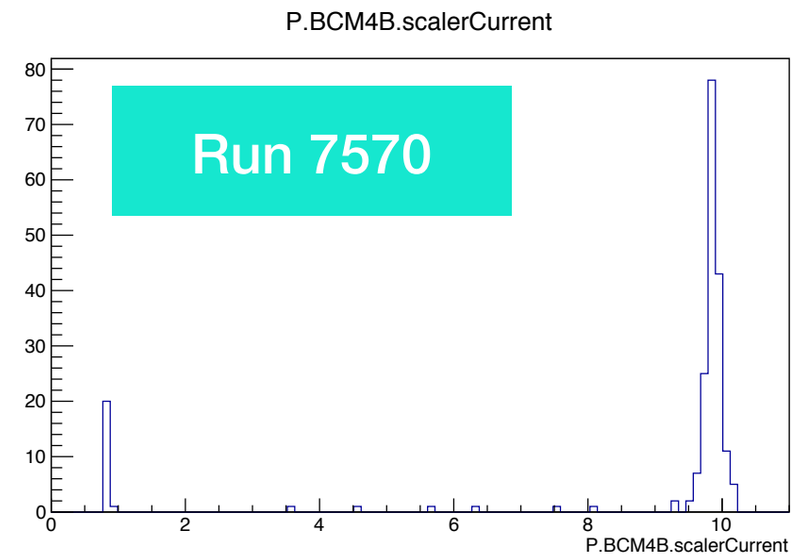

P.BCM4B.scalerCurrent
Run 7419
57 uA & 63 uA
P.BCM4B.scalerCurrent

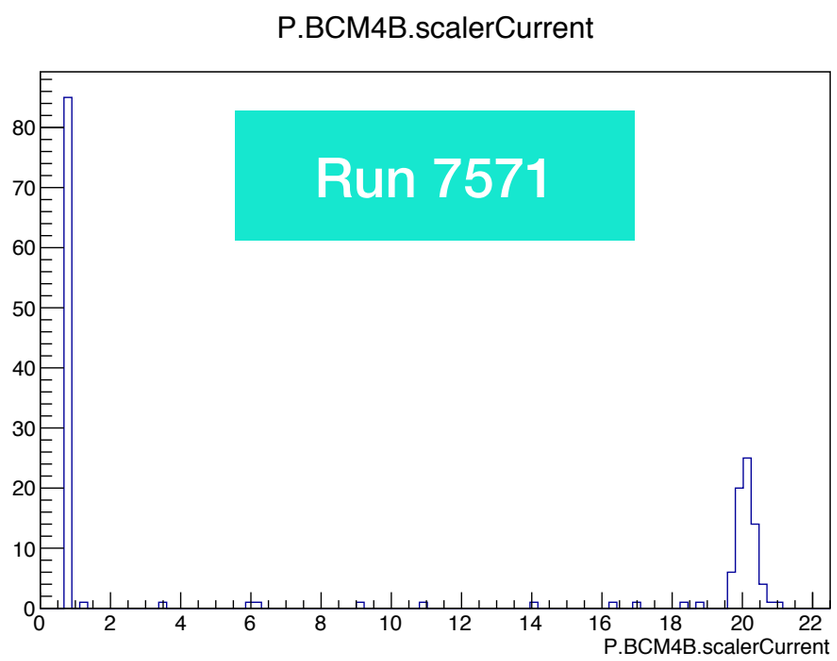

P.BCM4B.scalerCurrent
Run 7420
18 uA & 25 uA &35 uA & 45 uA
P.BCM4B.scalerCurrent

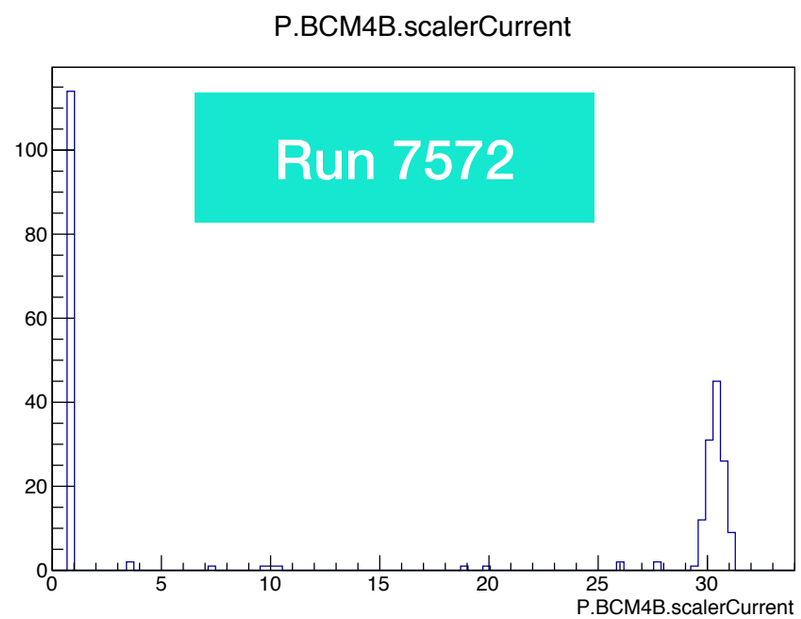

P.BCM4B.scalerCurrent
Run 7499
P.BCM4B.scalerCurrent

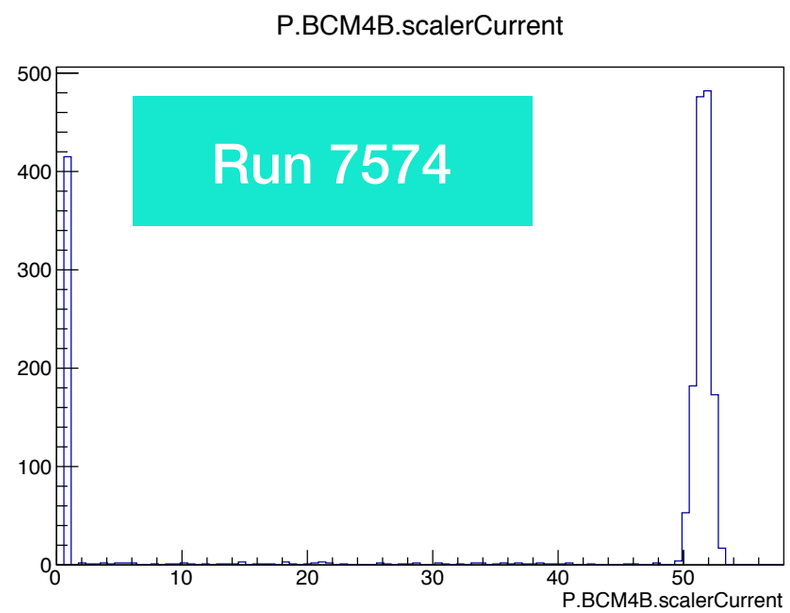

P.BCM4B.scalerCurrent
Run 7500
P.BCM4B.scalerCurrent


P.BCM4B.scalerCurrent
Run 7501
P.BCM4B.scalerCurrent

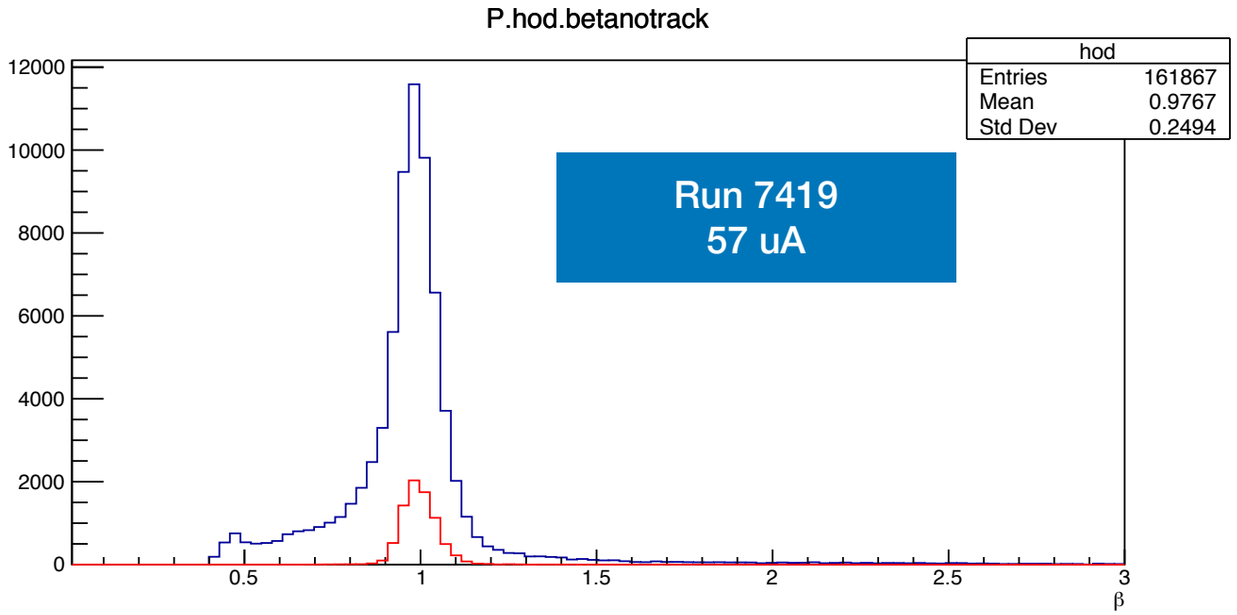

P.BCM4B.scalerCurrent
Run 7570
P.BCM4B.scalerCurrent

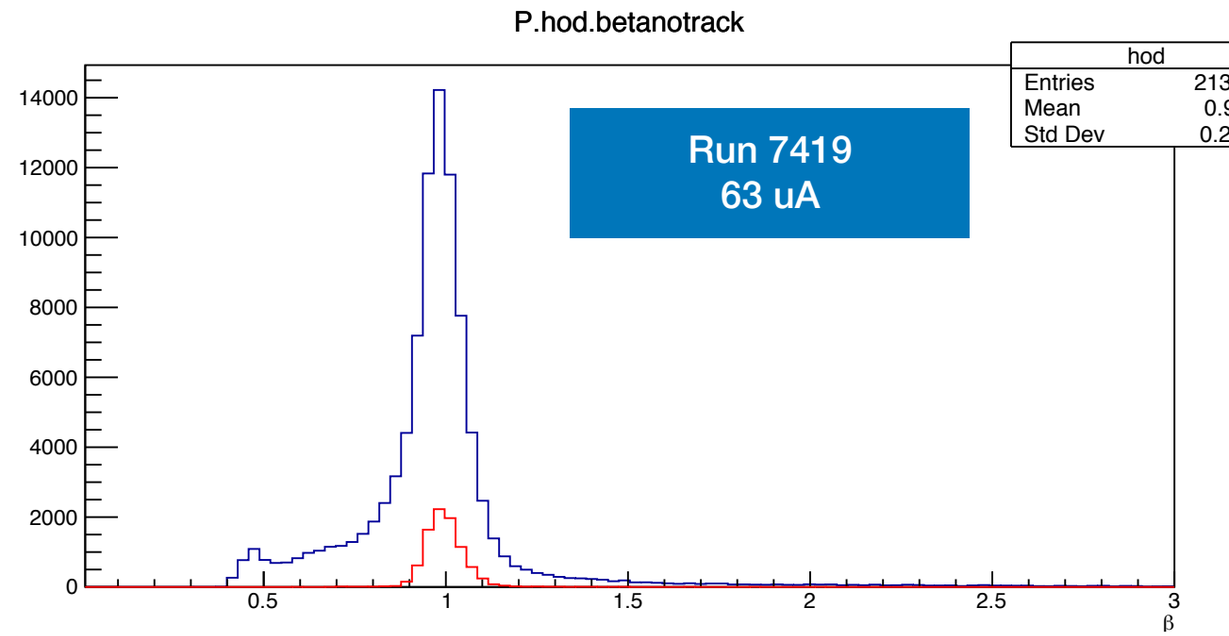

P.BCM4B.scalerCurrent
Run 7571
P.BCM4B.scalerCurrent

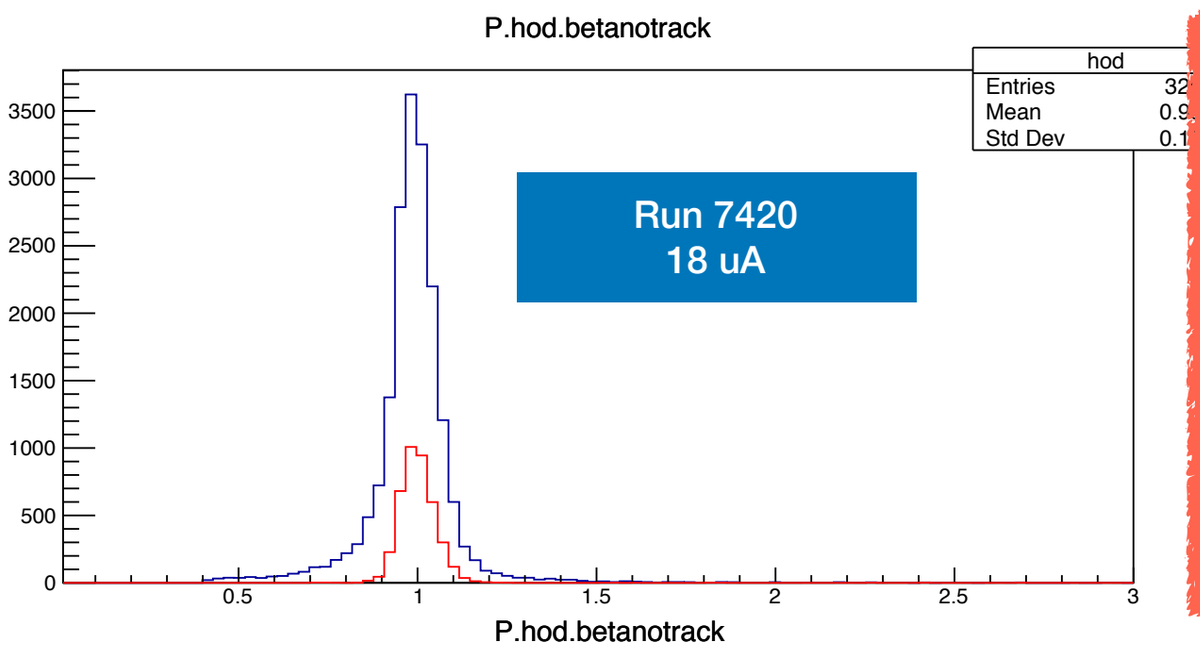

P.BCM4B.scalerCurrent
Run 7572
P.BCM4B.scalerCurrent


P.BCM4B.scalerCurrent
Run 7574
P.BCM4B.scalerCurrent

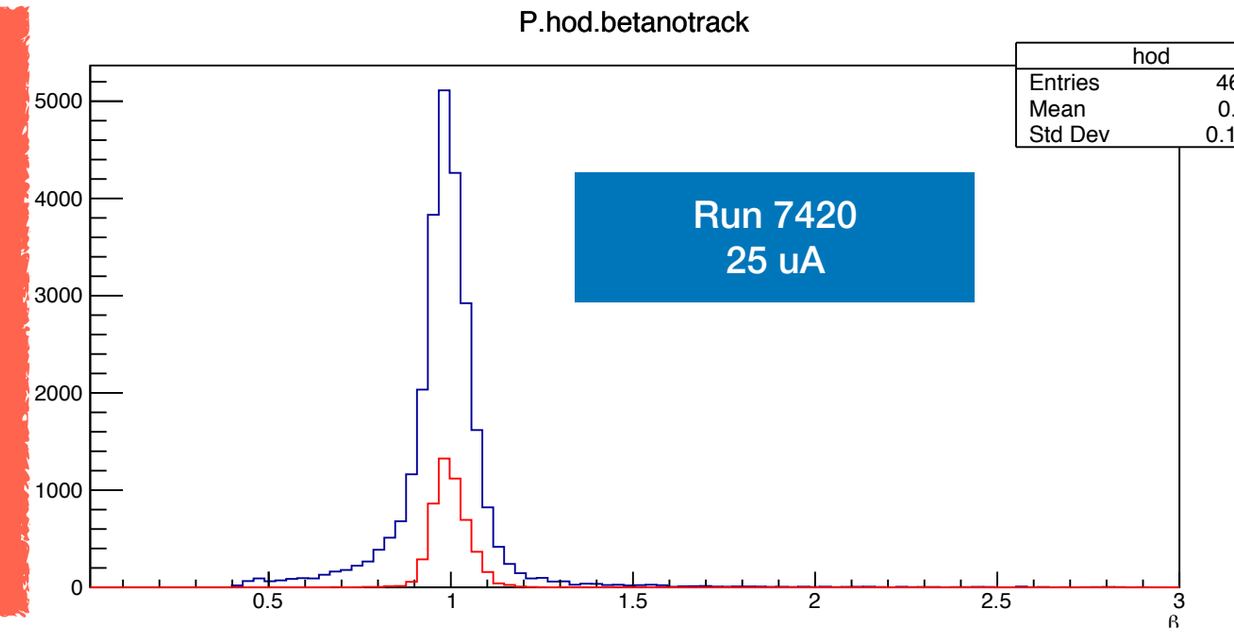
- P.hod.betanotrack
- Beta = v / c where v = d / t
- The code selects hodoscope hits which have a hit in both sides of the PADDLE (each pmt at each end of the paddle)
- d = the distance between the centers of the paddles of different planes.
- t = time passed between the paddles in question

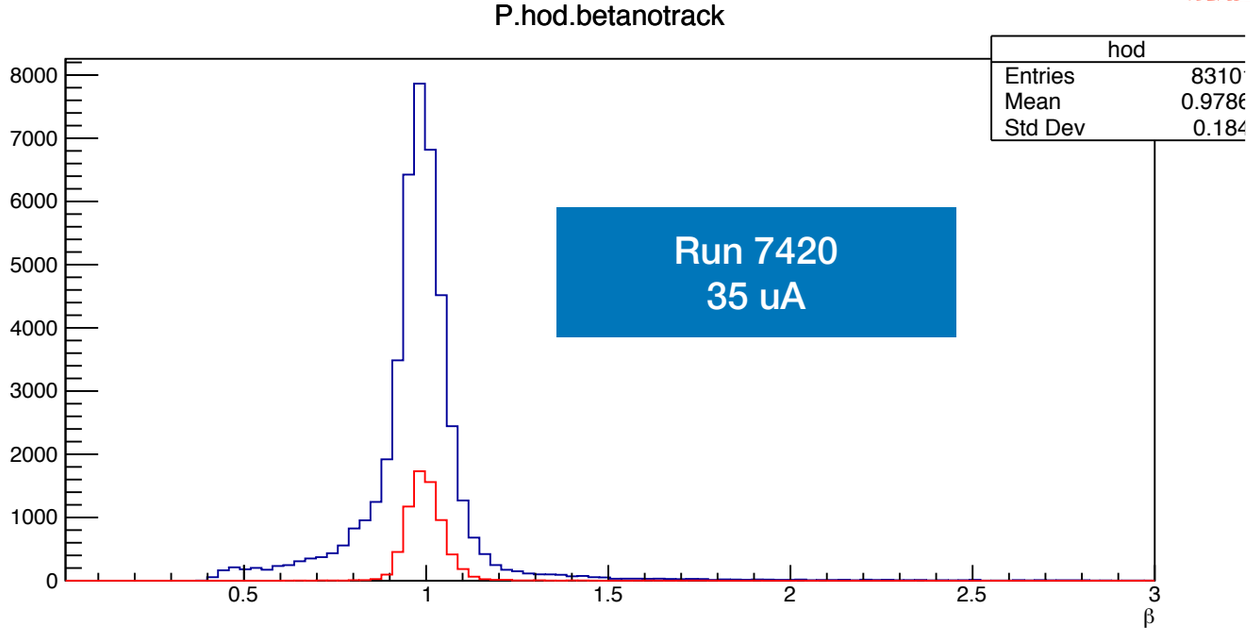

P.hod.betanotrack
hod
Entries 161867
Mean 0.9767
Std Dev 0.2494
Run 7419
57 uA
β

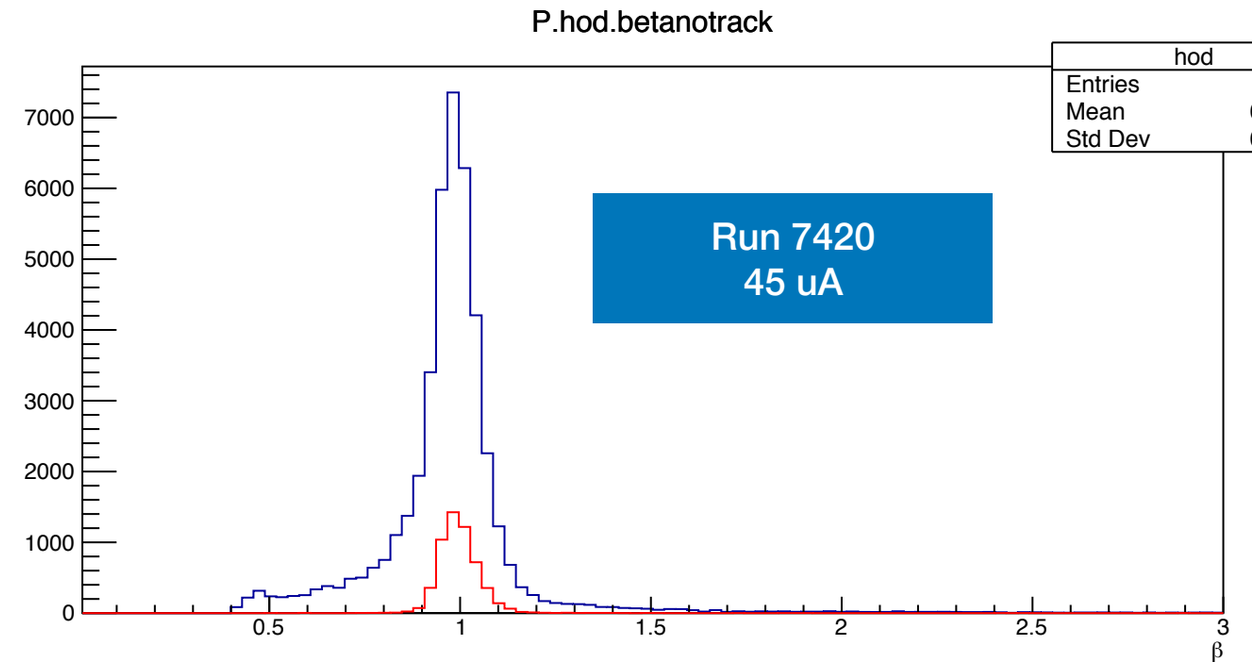

P.hod.betanotrack
hod
Entries 213
Mean 0.9
Std Dev 0.2
Run 7419
63 uA
β

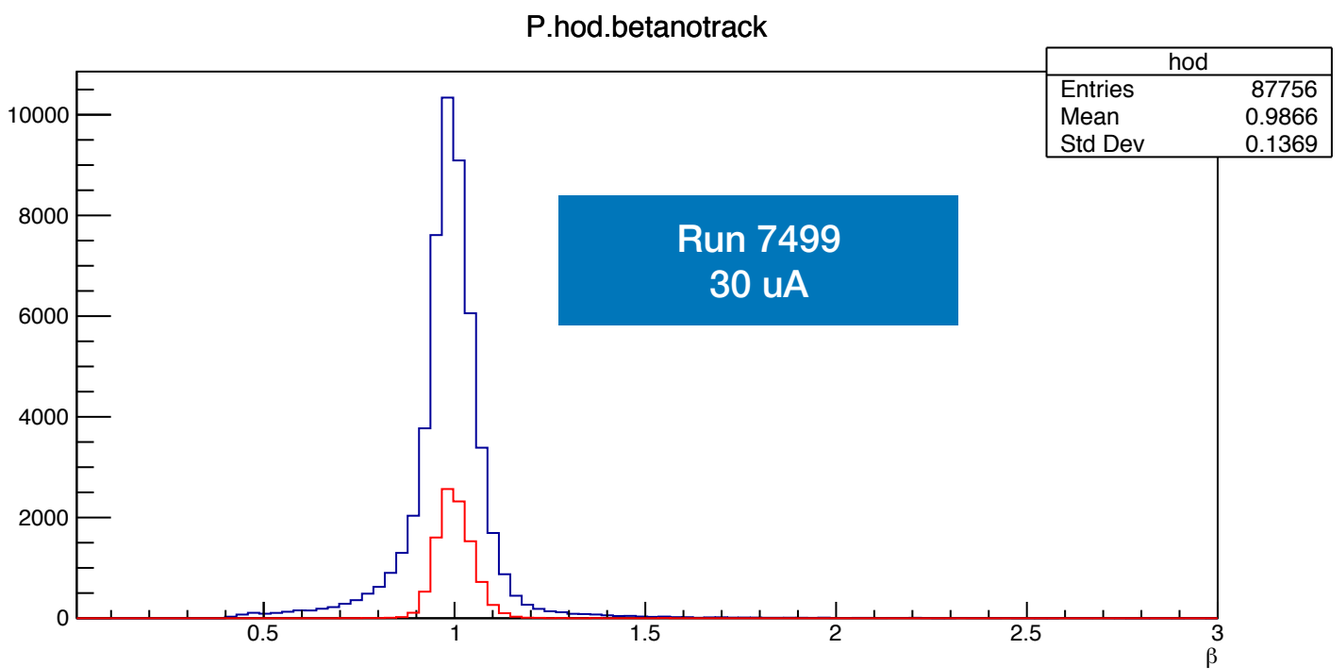

P.hod.betanotrack
hod
Entries 32
Mean 0.9
Std Dev 0.1
Run 7420
18 uA

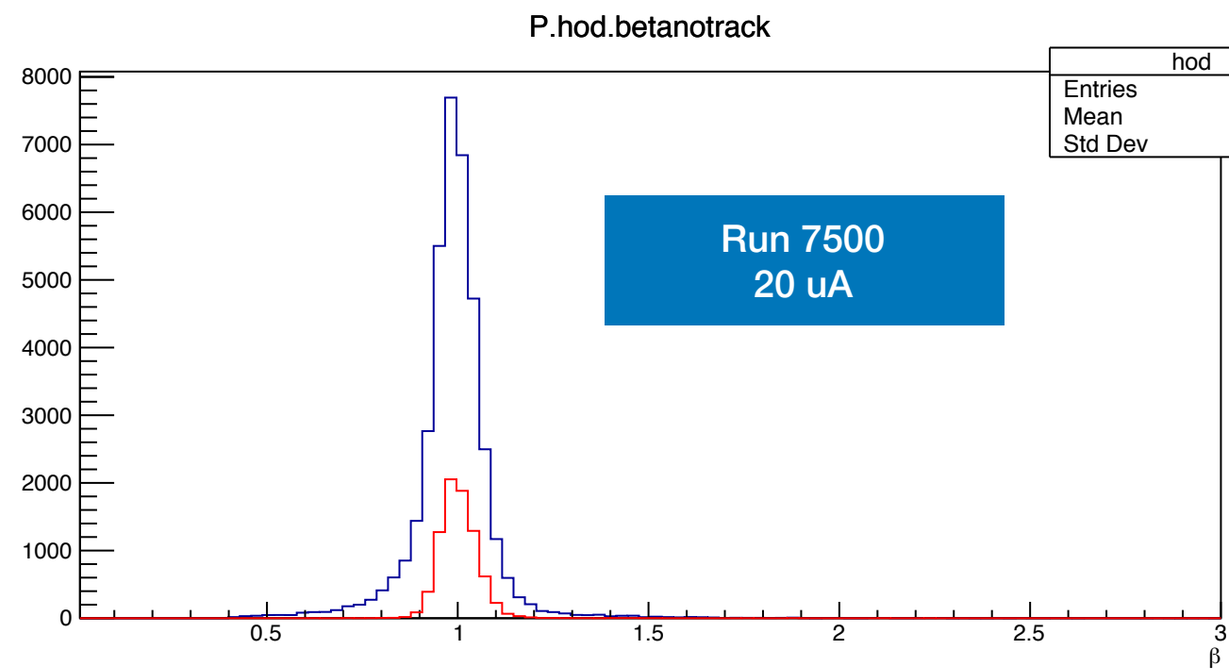
PHASE I

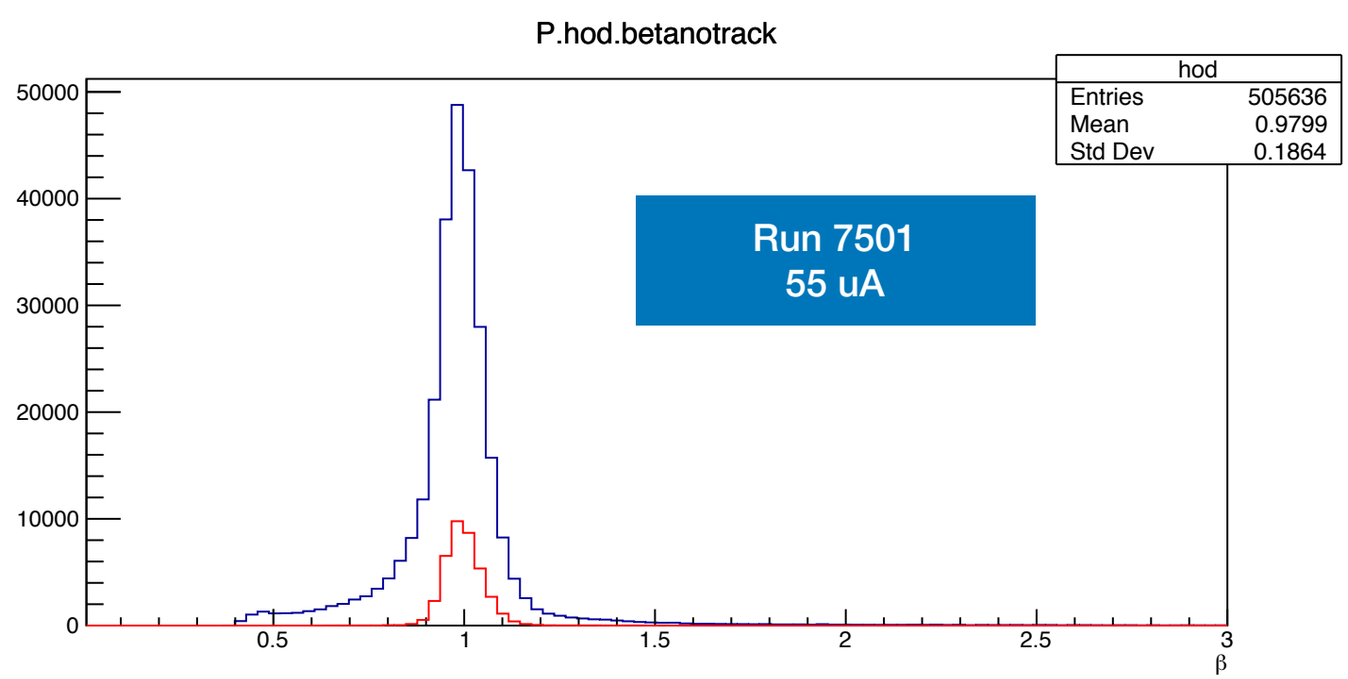

P.hod.betanotrack
hod
Entries 46
Mean 0.
Std Dev 0.1
Run 7420
25 uA
β


P.hod.betanotrack
hod
Entries 8310
Mean 0.9786
Std Dev 0.184
Run 7420
35 uA
β

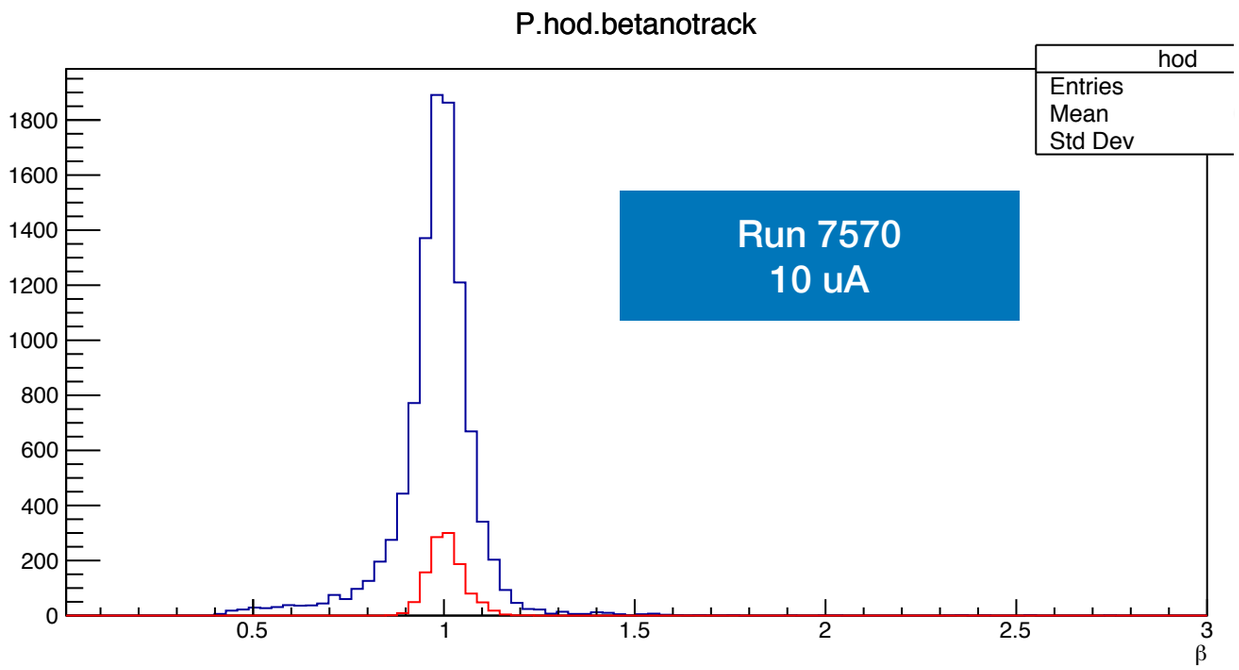

P.hod.betanotrack
hod
Entries
Mean
Std Dev
Run 7420
45 uA
β

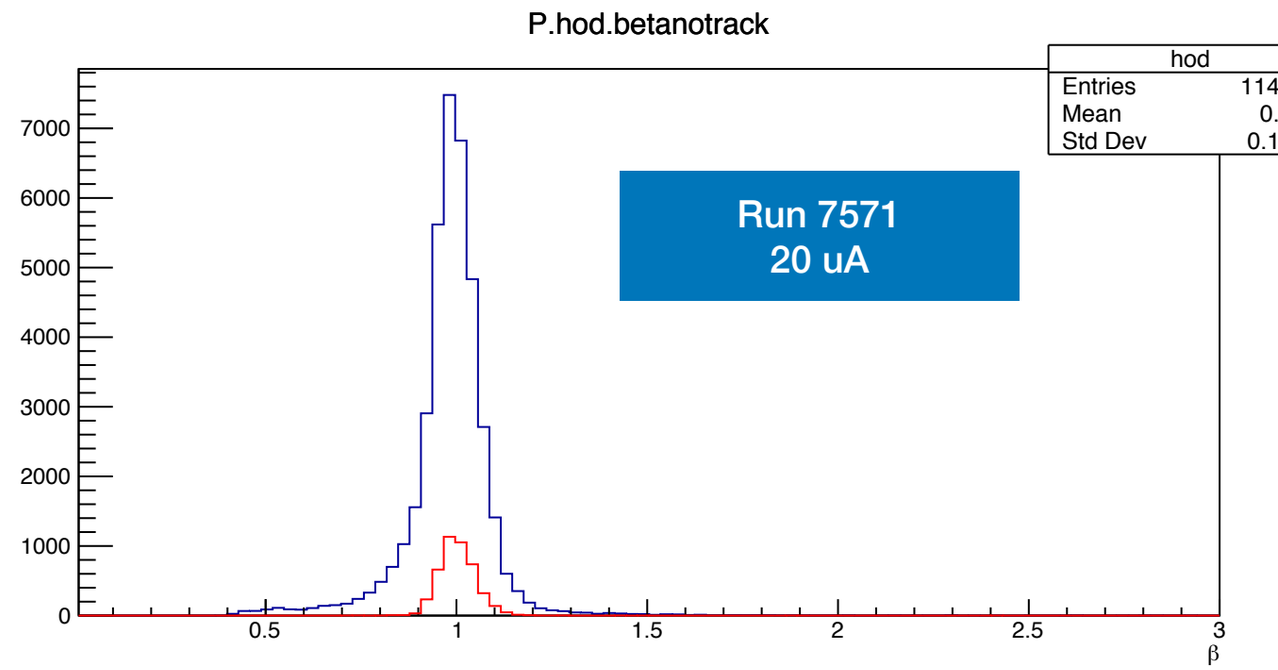

P.hod.betanotrack
hod
Entries 87756
Mean 0.9866
Std Dev 0.1369
Run 7499
30 uA
β

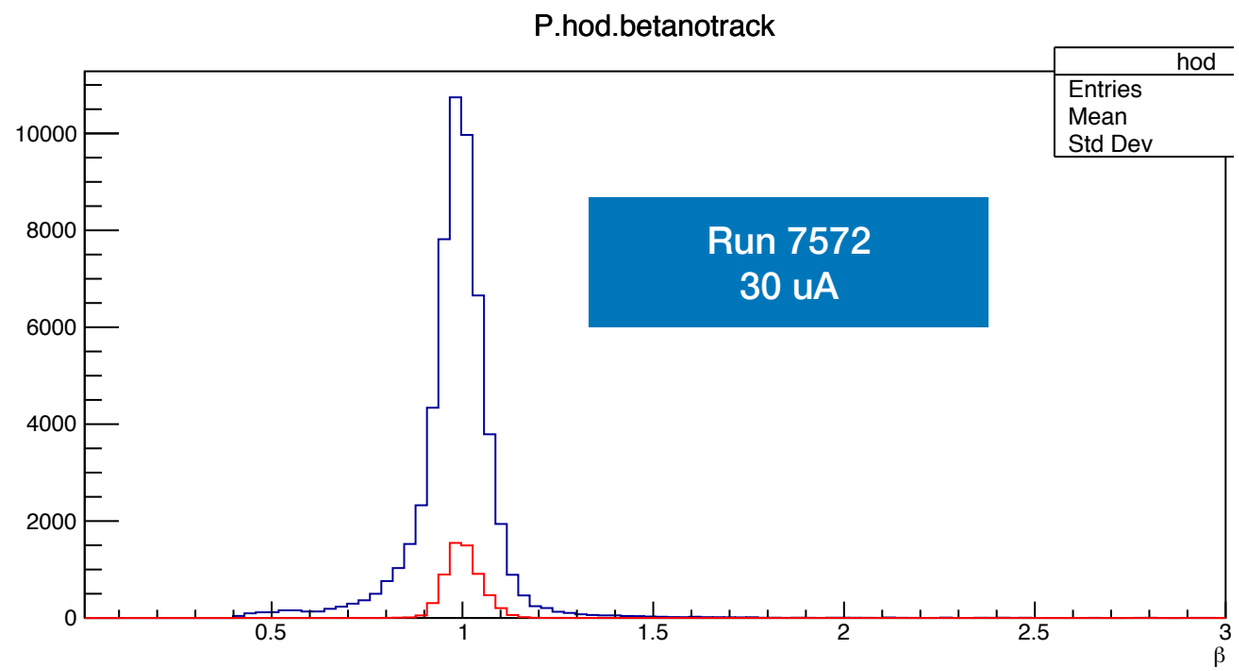

P.hod.betanotrack
hod
Entries
Mean
Std Dev
Run 7500
20 uA
β

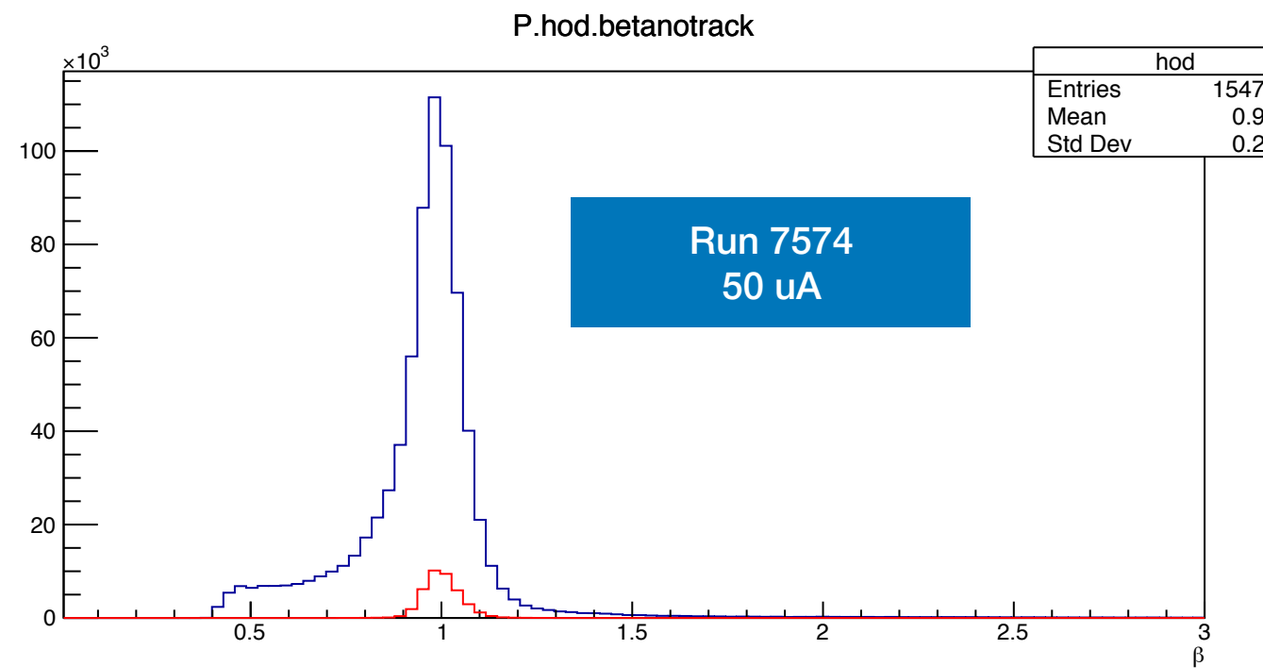

P.hod.betanotrack
hod
Entries 505636
Mean 0.9799
Std Dev 0.1864
Run 7501
55 uA
β

PHASE II


P.hod.betanotrack
hod
Entries
Mean
Std Dev
Run 7570
10 uA
β

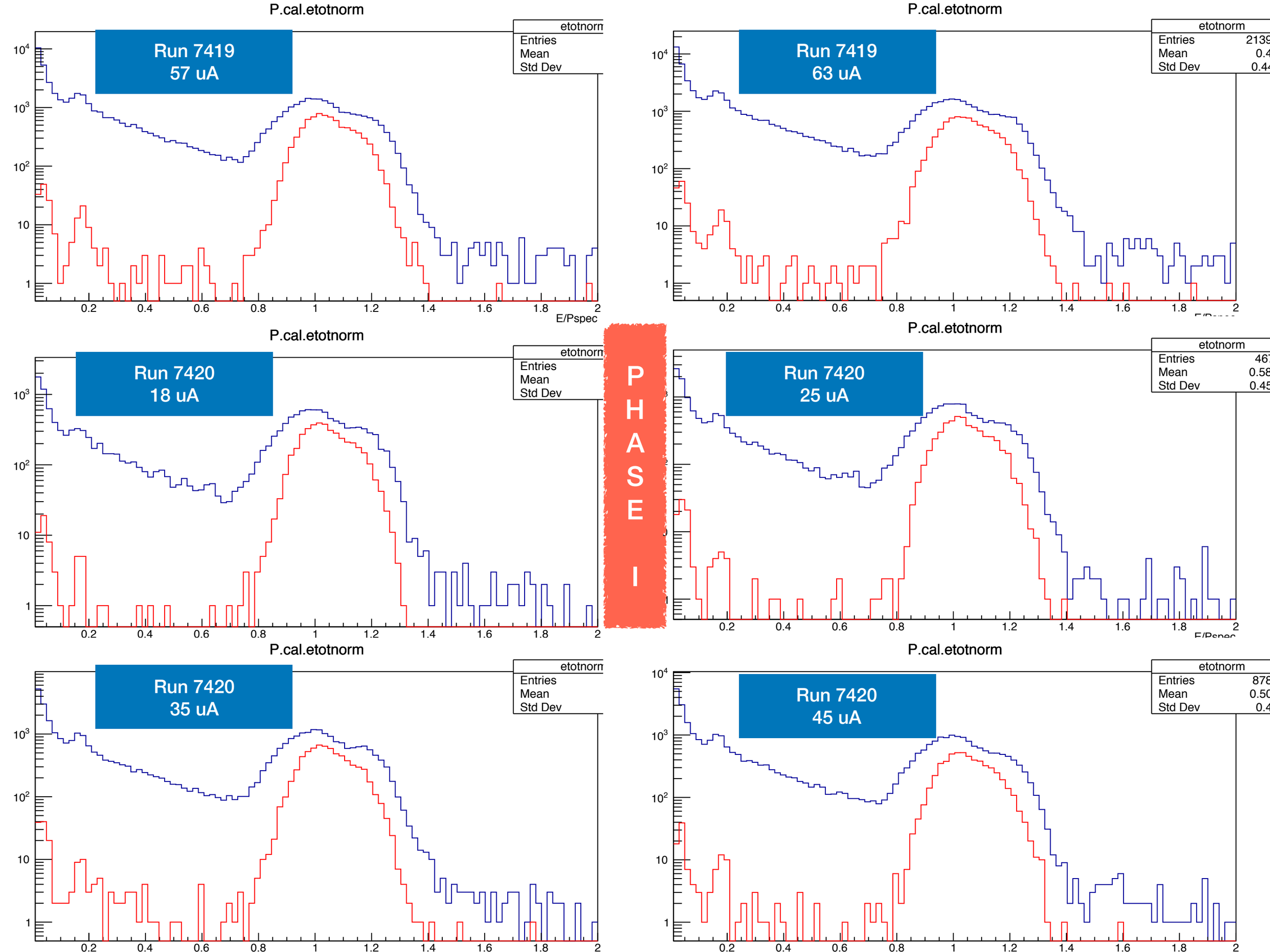

P.hod.betanotrack
hod
Entries 114
Mean 0.
Std Dev 0.1
Run 7571
20 uA
β

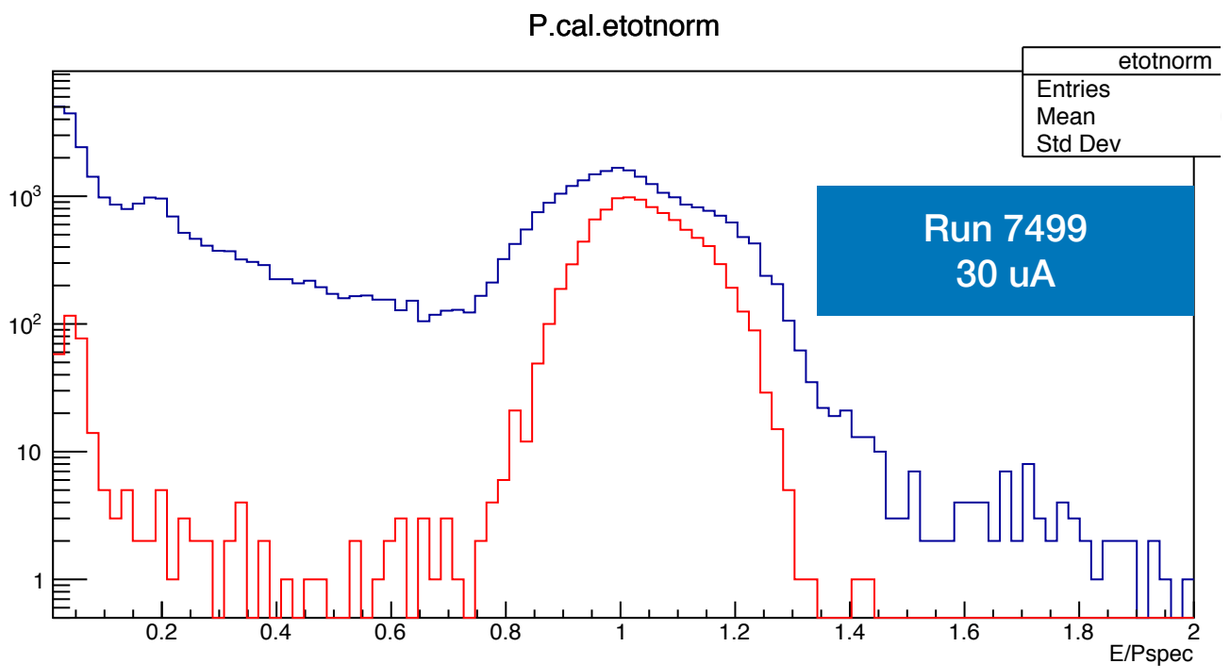

P.hod.betanotrack
hod
Entries
Mean
Std Dev
Run 7572
30 uA
β

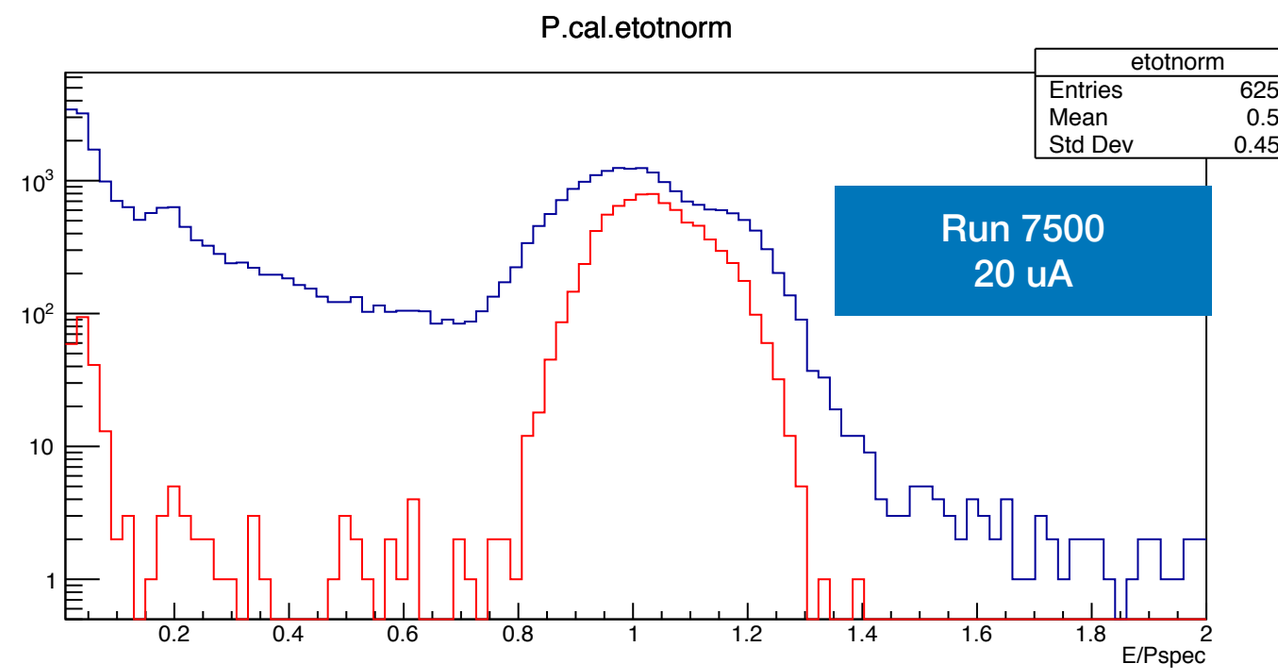

P.hod.betanotrack
×10^3
hod
Entries 1547
Mean 0.9
Std Dev 0.2
Run 7574
50 uA
β

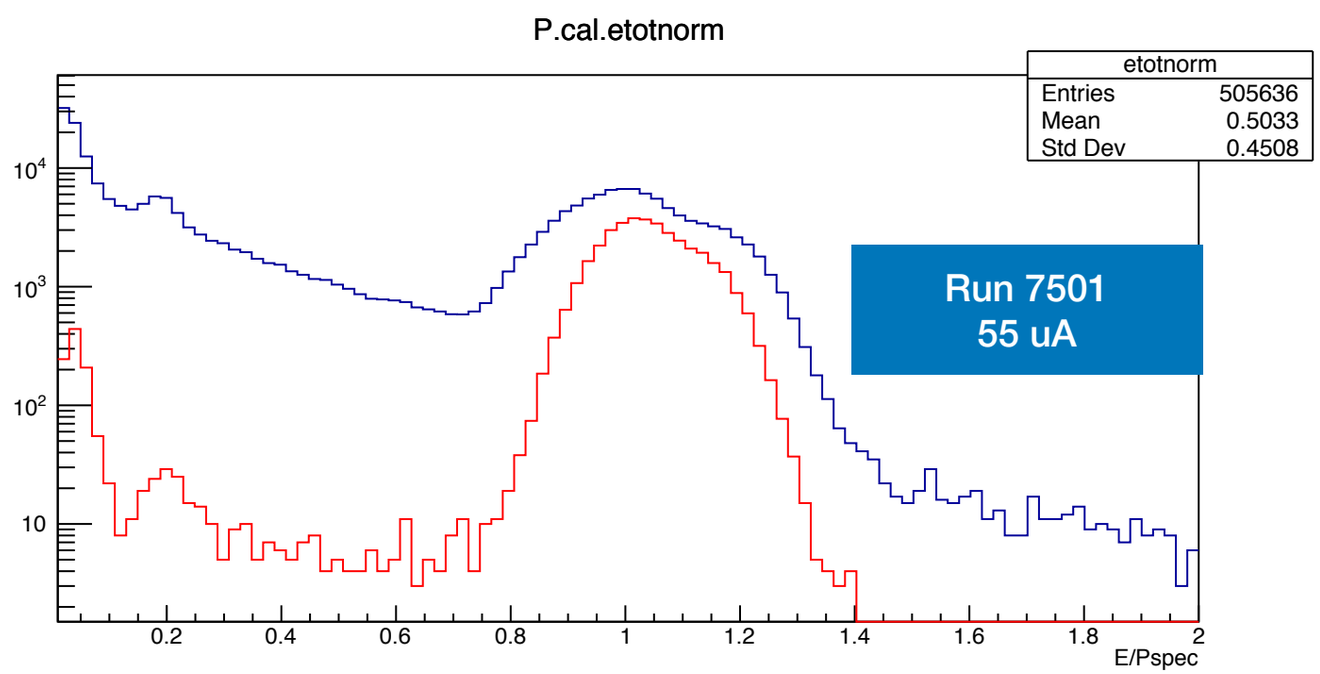
PHASE IV

- P.cal.etotnorm
- Total energy deposited in the calorimeter normalized by the spectrometer momentum (no track dependence)

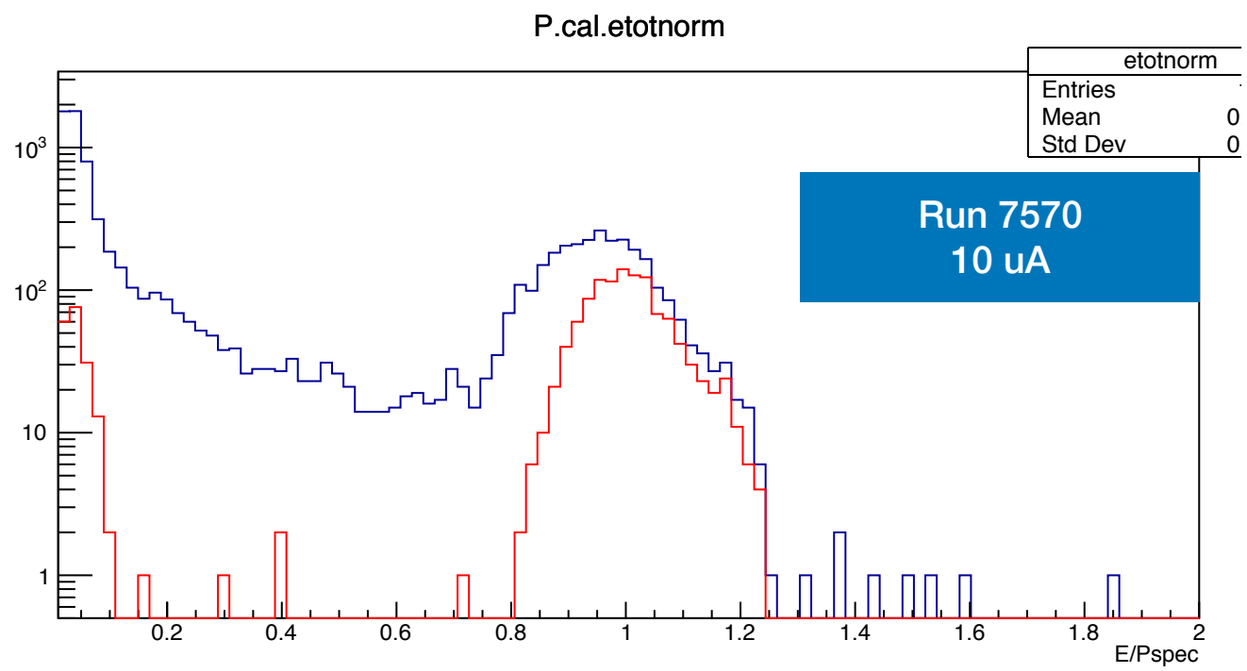

P.cal.etotnorm
Run 7419
57 uA
etotnorm
Entries
Mean
Std Dev
E/Pspec
P.cal.etotnorm
Run 7419
63 uA
etotnorm
Entries
Mean
Std Dev
P.cal.etotnorm
Run 7420
18 uA
etotnorm
Entries
Mean
Std Dev
P.cal.etotnorm
Run 7420
25 uA
etotnorm
Entries
Mean
Std Dev
P.cal.etotnorm
Run 7420
35 uA
etotnorm
Entries
Mean
Std Dev
P.cal.etotnorm
Run 7420
45 uA
etotnorm
Entries
Mean
Std Dev
PHASE I

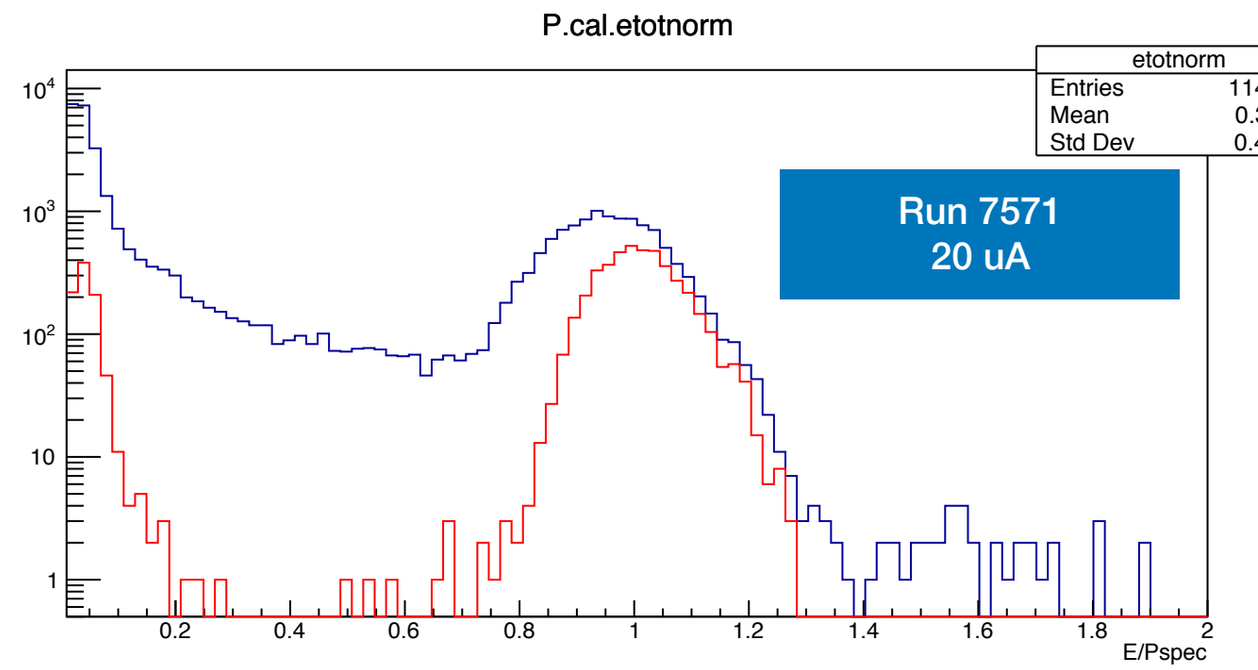

P.cal.etotnorm
etotnorm
Entries
Mean
Std Dev
Run 7499
30 uA
E/Pspec


P.cal.etotnorm
etotnorm
Entries 625
Mean 0.5
Std Dev 0.45
Run 7500
20 uA
E/Pspec

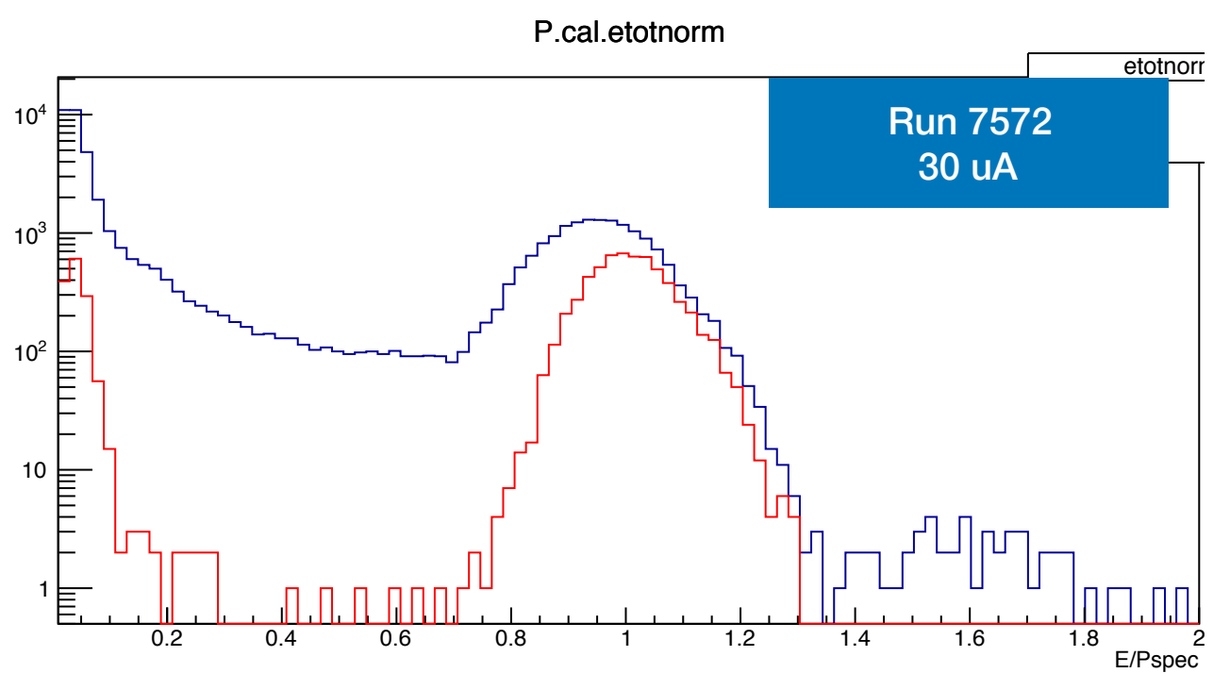

P.cal.etotnorm
etotnorm
Entries 505636
Mean 0.5033
Std Dev 0.4508
Run 7501
55 uA
E/Pspec

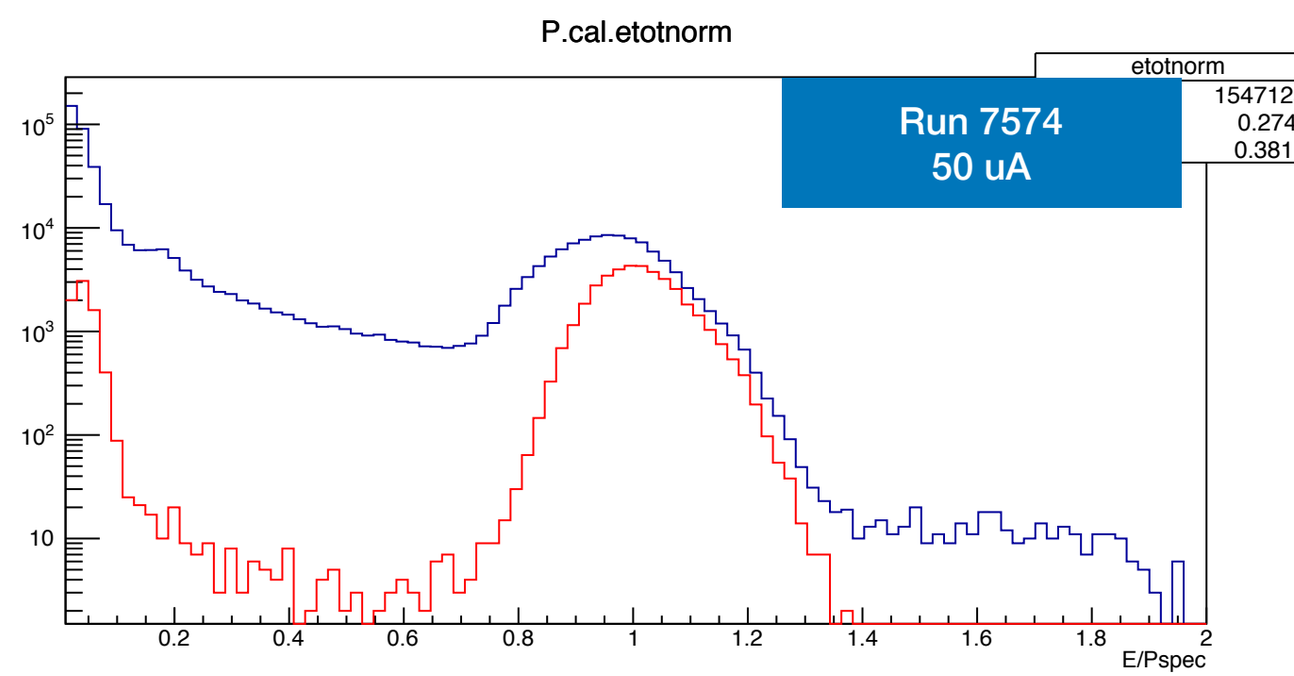
PHASE II


P.cal.etotnorm
etotnorm
Entries
Mean 0
Std Dev 0
Run 7570
10 uA
E/Pspec

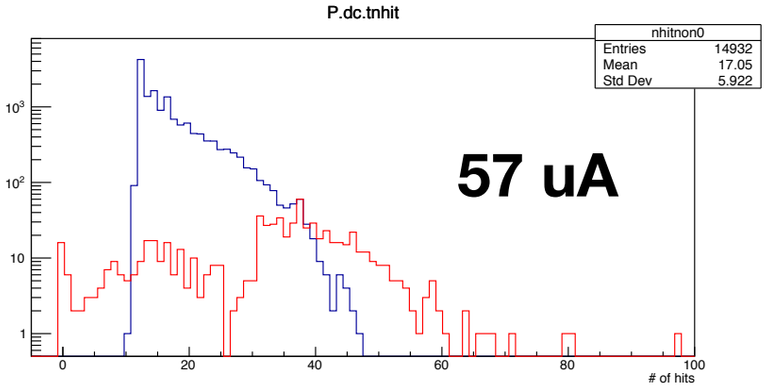

P.cal.etotnorm
etotnorm
Entries
Mean
Std Dev
Run 7571
20 uA
E/Pspec

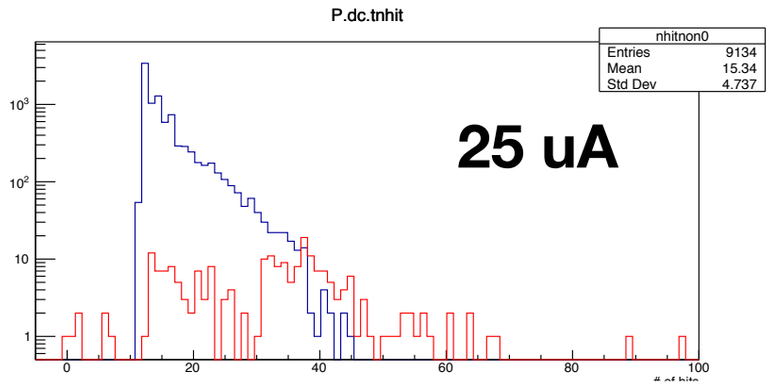
PHASE IV

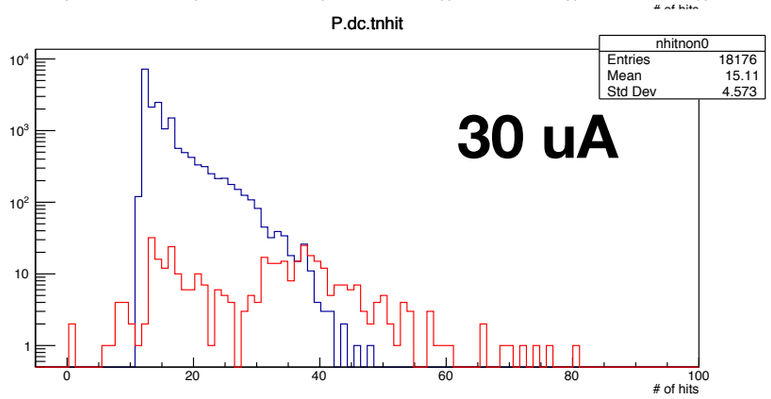

P.cal.etotnorm
etotnorm
Run 7572
30 uA
E/Pspec

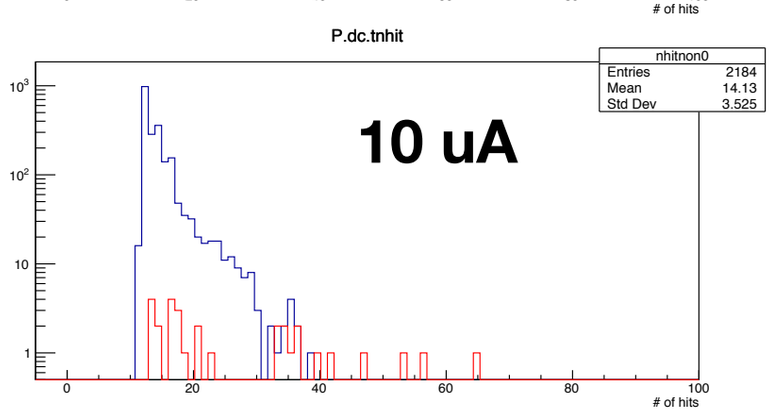

P.cal.etotnorm
etotnorm
154712
0.274
0.381
Run 7574
50 uA
E/Pspec

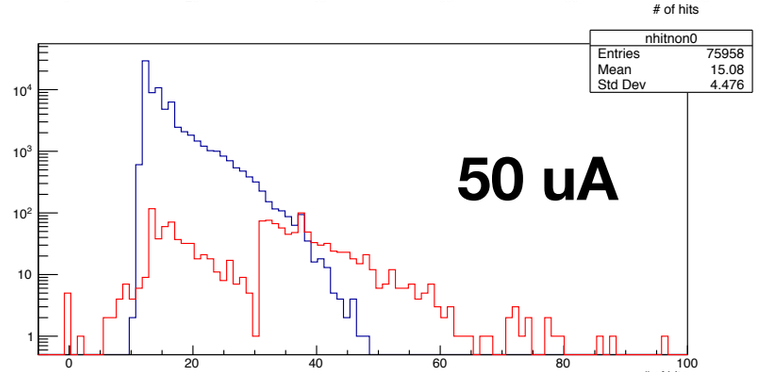
P.dc.tnhit

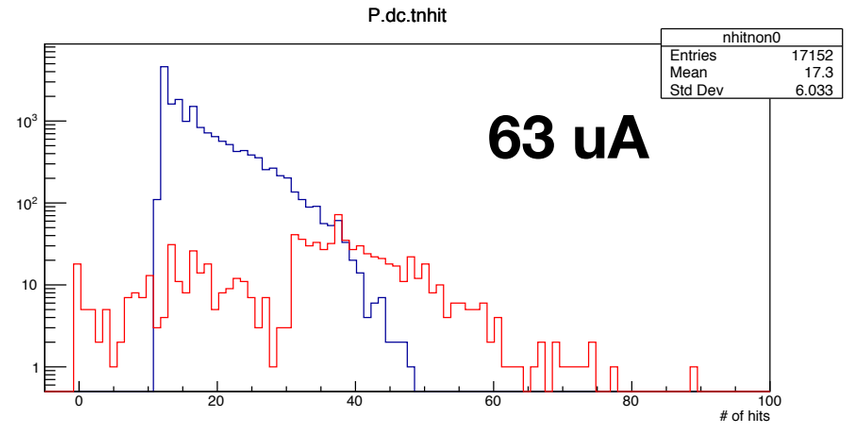

P.dc.tnhit
nhitnon0
Entries 14932
Mean 17.05
Std Dev 5.922
57 uA
# of hits

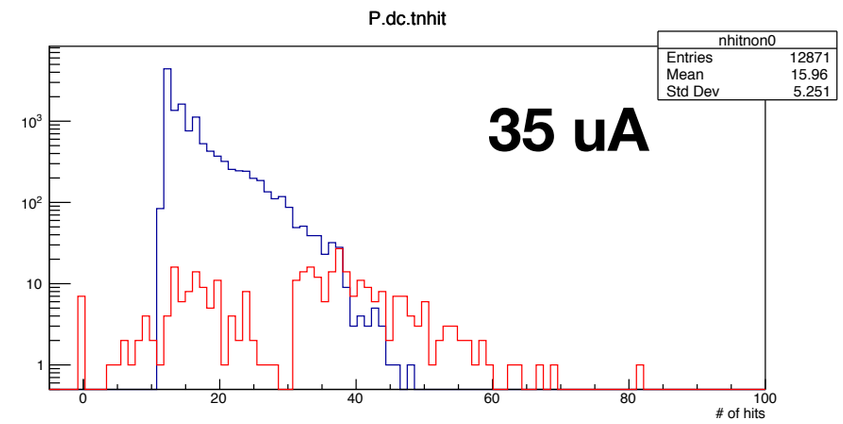

P.dc.tnhit
nhitnon0
Entries 9134
Mean 15.34
Std Dev 4.737
25 uA

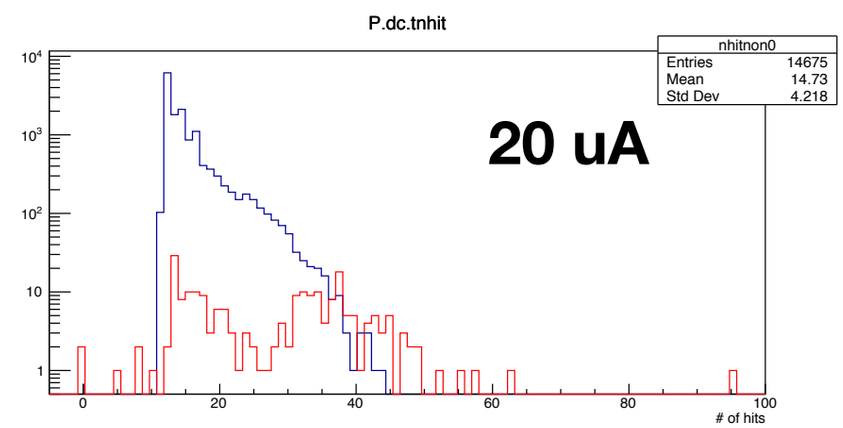

P.dc.tnhit
nhitnon0
Entries 18176
Mean 15.11
Std Dev 4.573
30 uA
# of hits

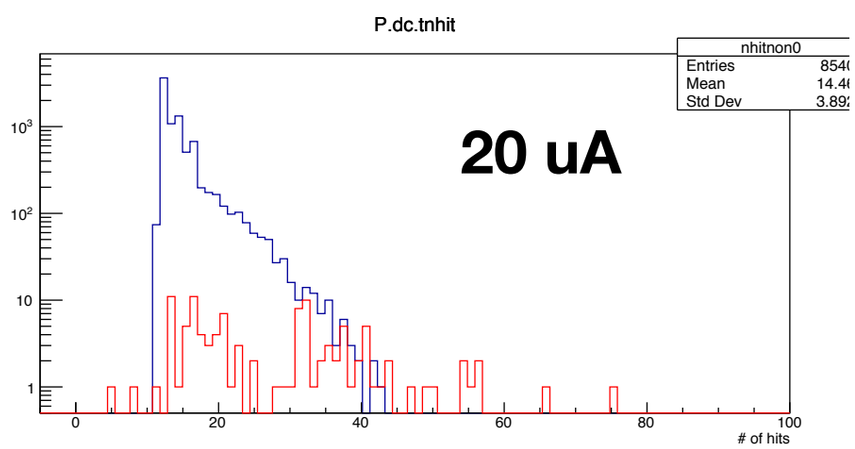

P.dc.tnhit
nhitnon0
Entries 2184
Mean 14.13
Std Dev 3.525
10 uA
# of hits

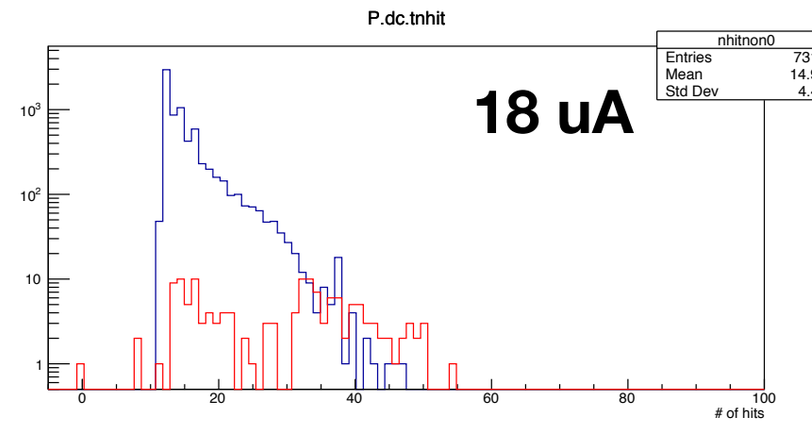

nhitnon0
Entries 75958
Mean 15.08
Std Dev 4.476
50 uA

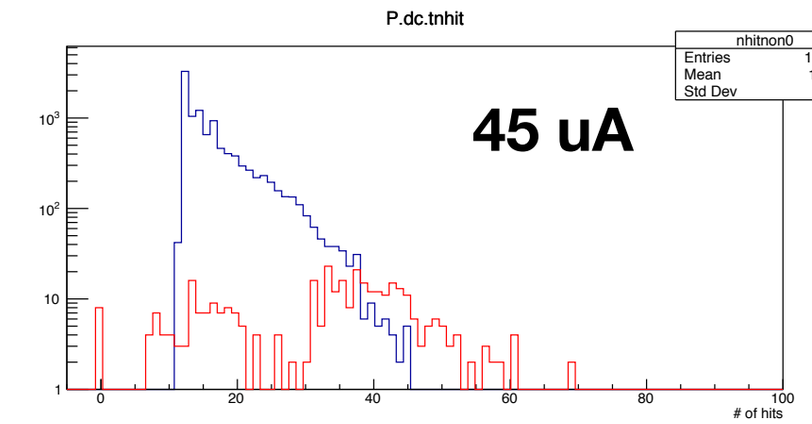

P.dc.tnhit
nhitnon0
Entries 17152
Mean 17.3
Std Dev 6.033
63 uA
# of hits

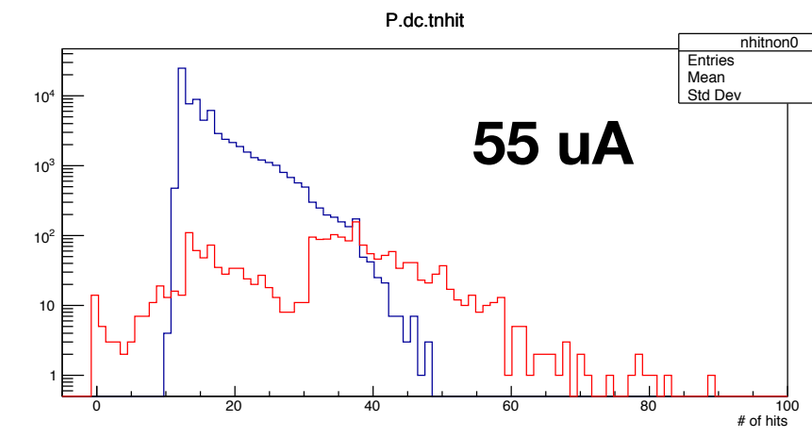

P.dc.tnhit
nhitnon0
Entries 12871
Mean 15.96
Std Dev 5.251
35 uA
# of hits

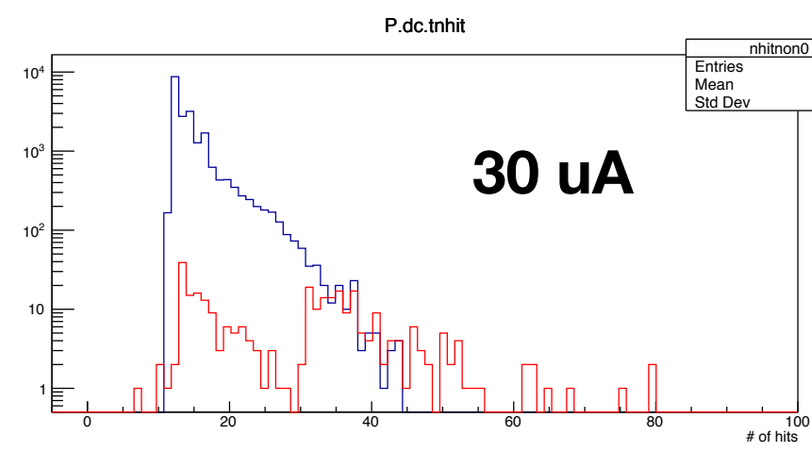

P.dc.tnhit
nhitnon0
Entries 14675
Mean 14.73
Std Dev 4.218
20 uA
# of hits


P.dc.tnhit
nhitnon0
20 uA
# of hits

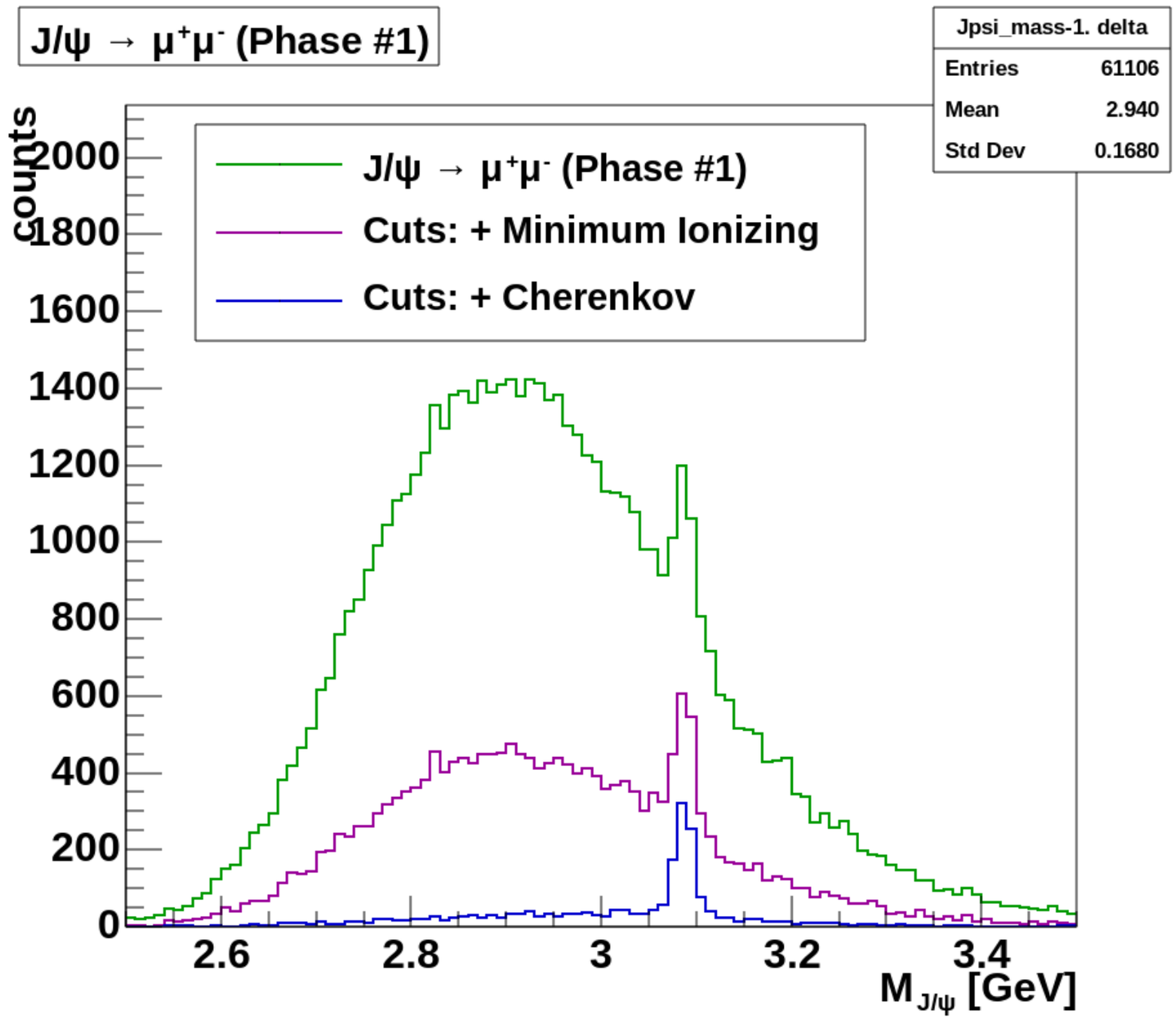

P.dc.tnhit
nhitnon0
18 uA
# of hits


P.dc.tnhit
nhitnon0
45 uA
# of hits


P.dc.tnhit
nhitnon0
55 uA
# of hits


P.dc.tnhit
nhitnon0
30 uA
# of hits

MUON CHANNEL: ONLINE RESULTS



Background: Inelastic t Channel γp -> J/ψpπ

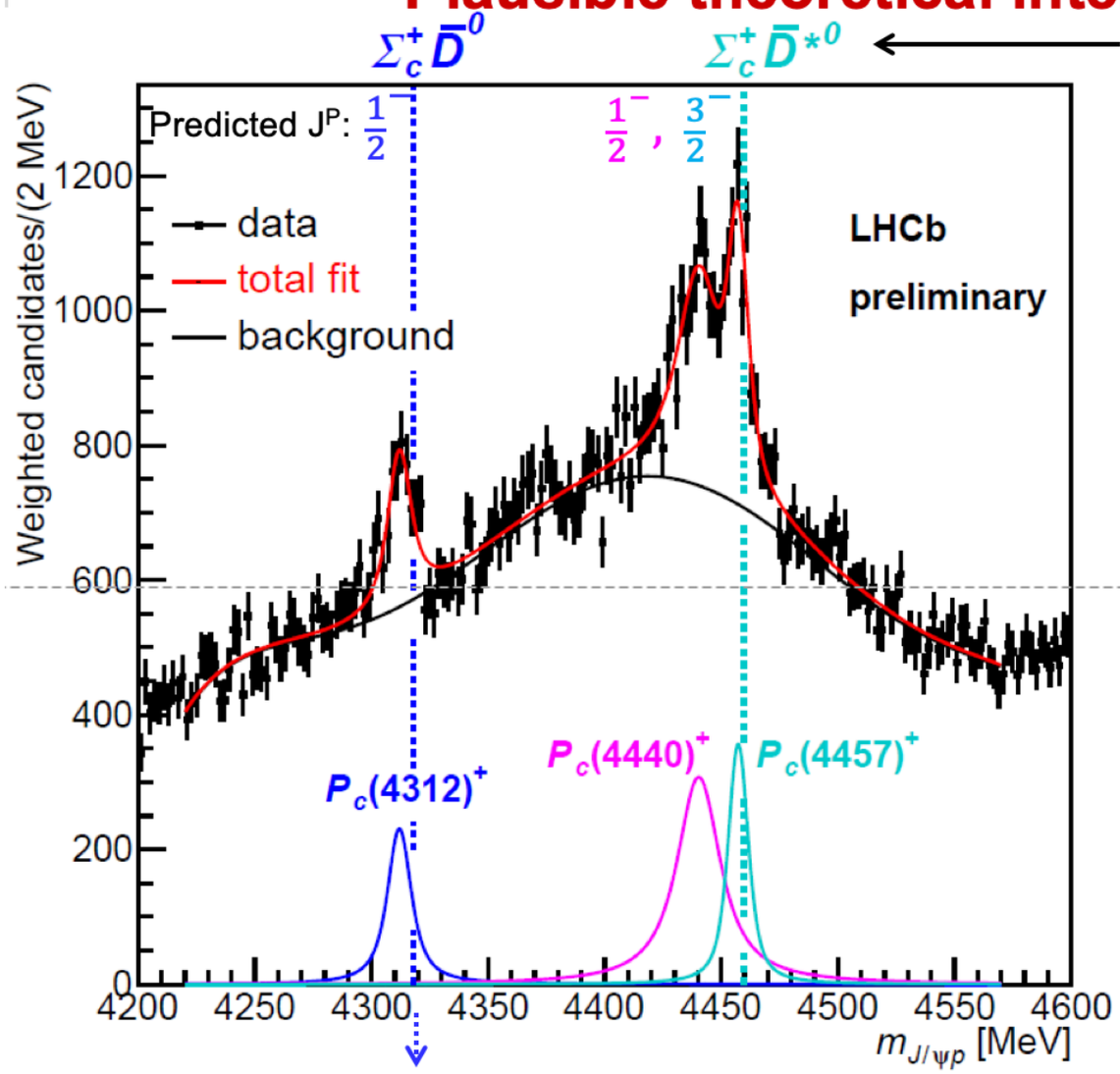
- Threshold at 9 GeV
- Reconstructed photon energy Erc is 1 GeV too low
- Contribution to the Contaminates the 8 GeV $<$ Erc $<$ 9.7 GeV range for a photon end-point energy of 10.7 GeV
  - not an issue for the Pc(4450) (Erc $>$ 9.7GeV)!

Photon Energy Reconstruction

- Initial photon energy can be unambigously reconstructed from the reconstructed J/ψ momentum and energy
  - **Assumptions**
    - ★ proton target at rest
    - ★ photon beam along the z axis
    - ★ proton and J/ψ are the two final state particles

$$E_\gamma = \frac{M_\psi^2 - 2E_J M_P}{2(E_\psi - M_p - P_\psi \cos\theta_\psi)}$$

Plausible theoretical interpretation



The **only** thresholds below which molecular bound states are expected in this mass range

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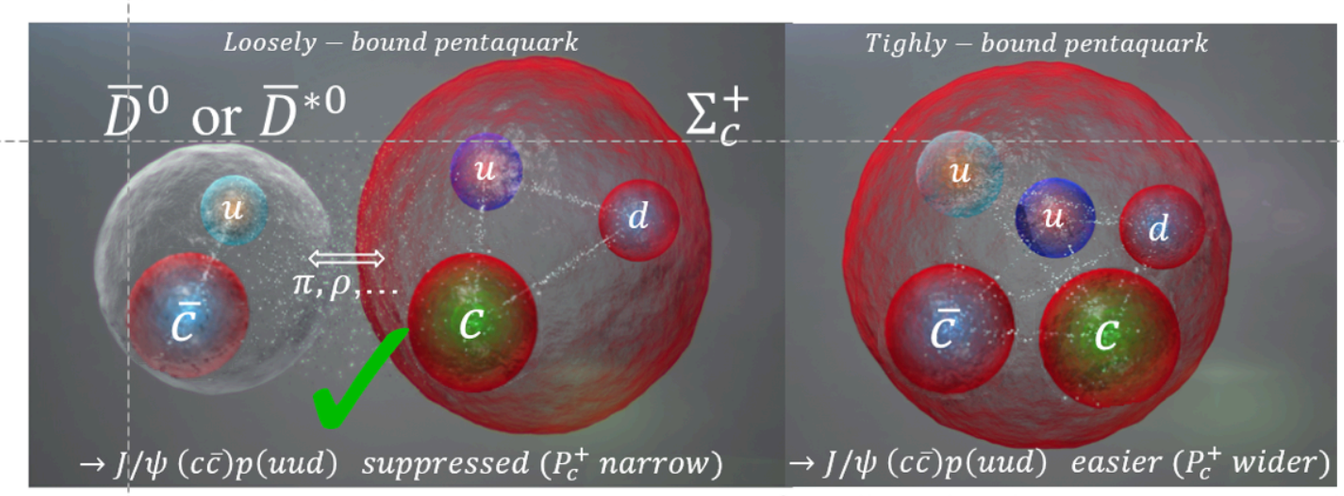
in preparation

The near-threshold masses and the narrow widths of $P_c(4312)^+$, $P_c(4440)^+$ and $P_c(4457)^+$ favor "molecular" pentaquarks with meson-baryon substructure!



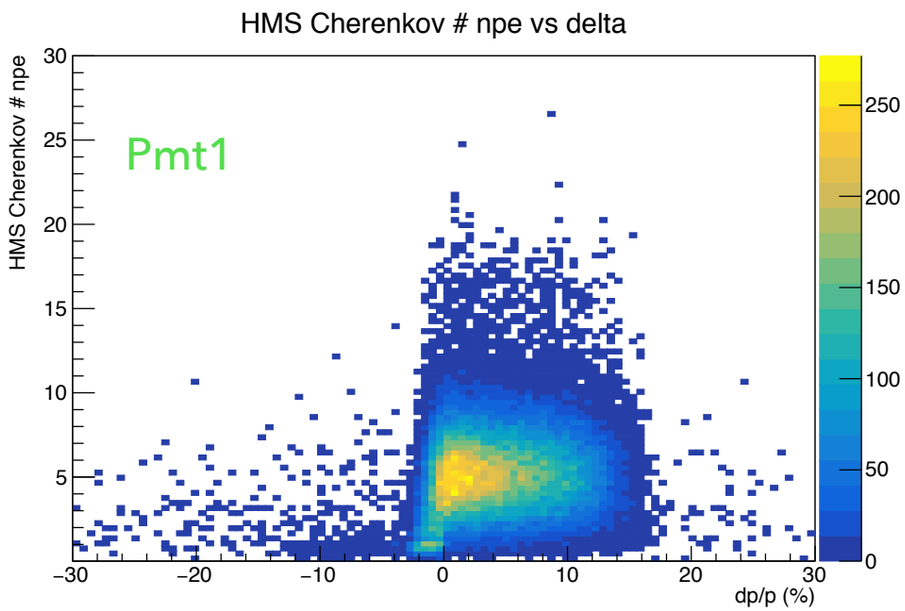
Existence of $\Sigma_c^+\bar{D}^0$ molecule would imply importance of ρ-exchange

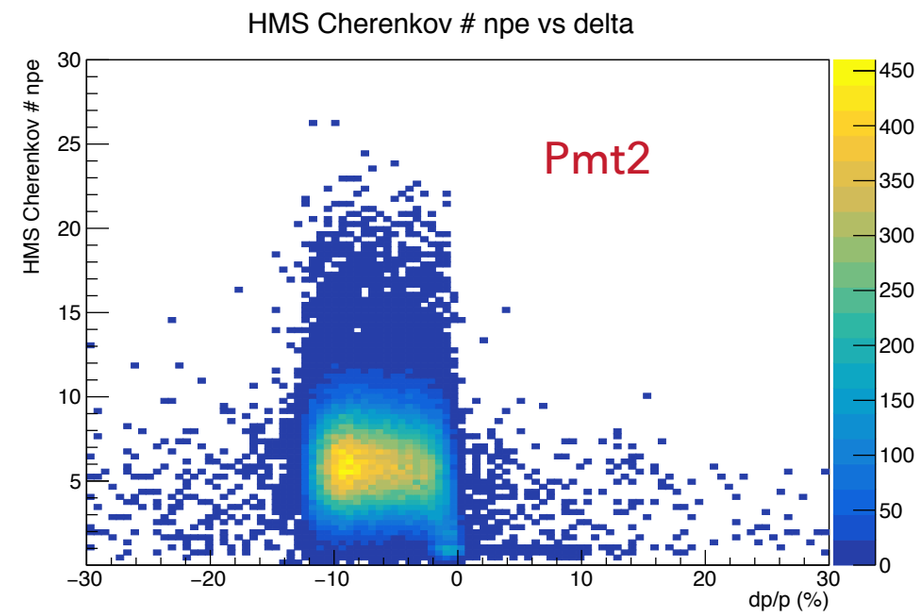
However, we need to measure J^Ps to confirm molecular hypothesis, find isospin partners, …

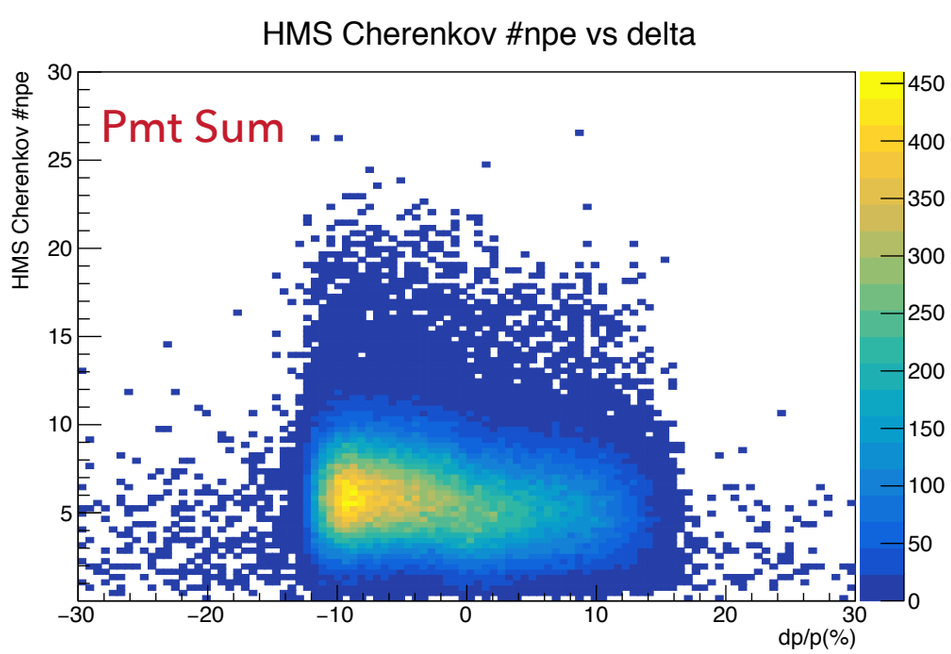
Can diquark substructure separated by a potential barrier [Maiani, Polosa, Riquer, PL,B778, 247 (2018)] produce width suppression?
Are masses near thresholds just by coincidence?
This hypothesis is not ruled out

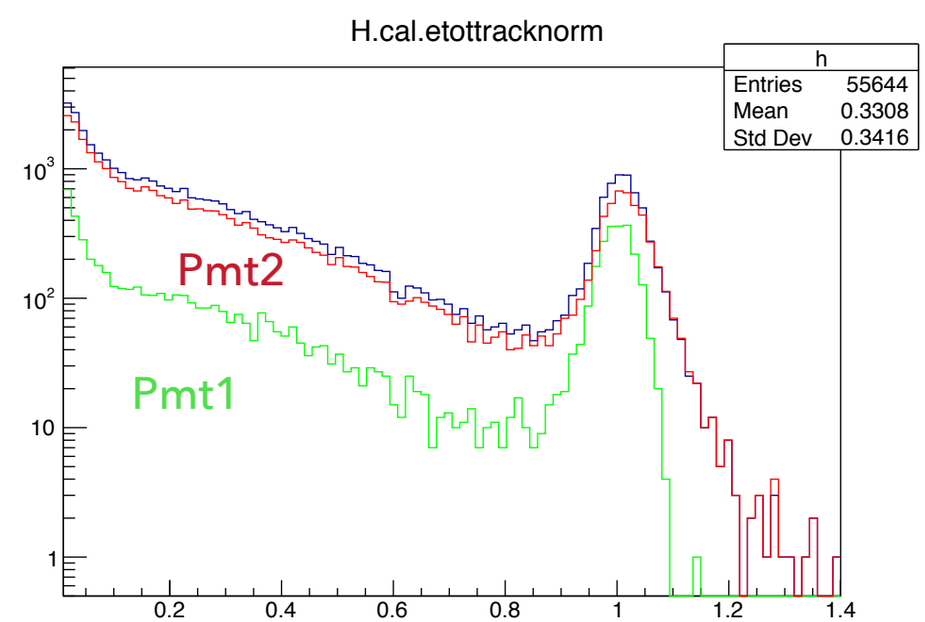
$P_c(4312)^+$, $P_c(4440)^+$ not near triangle diagram thresholds, $P_c(4457)^+$ is (see backup slides).

TEXT


HMS Cherenkov # npe vs delta
Pmt1
HMS Cherenkov # npe
dp/p (%)


HMS Cherenkov # npe vs delta
Pmt2
HMS Cherenkov # npe
dp/p (%)


HMS Cherenkov #npe vs delta
Pmt Sum
HMS Cherenkov #npe
dp/p(%)


H.cal.etottracknorm
h
Entries 55644
Mean 0.3308
Std Dev 0.3416
Pmt2
Pmt1