007$^{J/\Psi}$

J/Ψ PHOTOPRODUCTION IN HALL C

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On behalf of E12-16-007 Collaboration

Joint Hall A & C Summer Collaboration Meeting

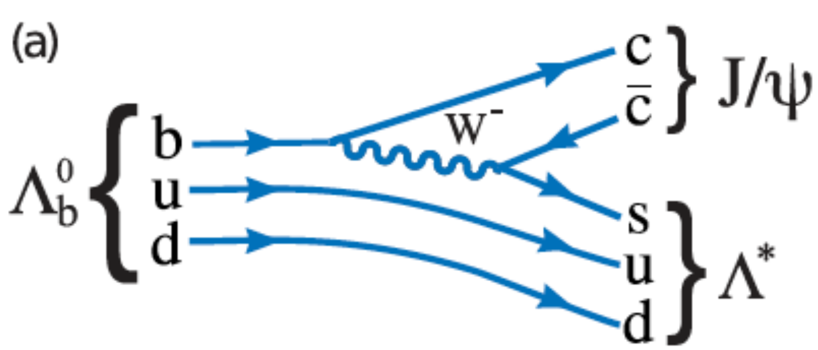
July 16, 2020

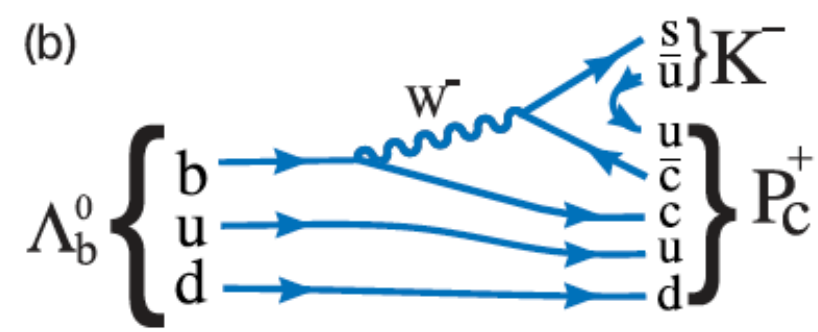
LHCB CHARMED “PENTAQUARK” P_C

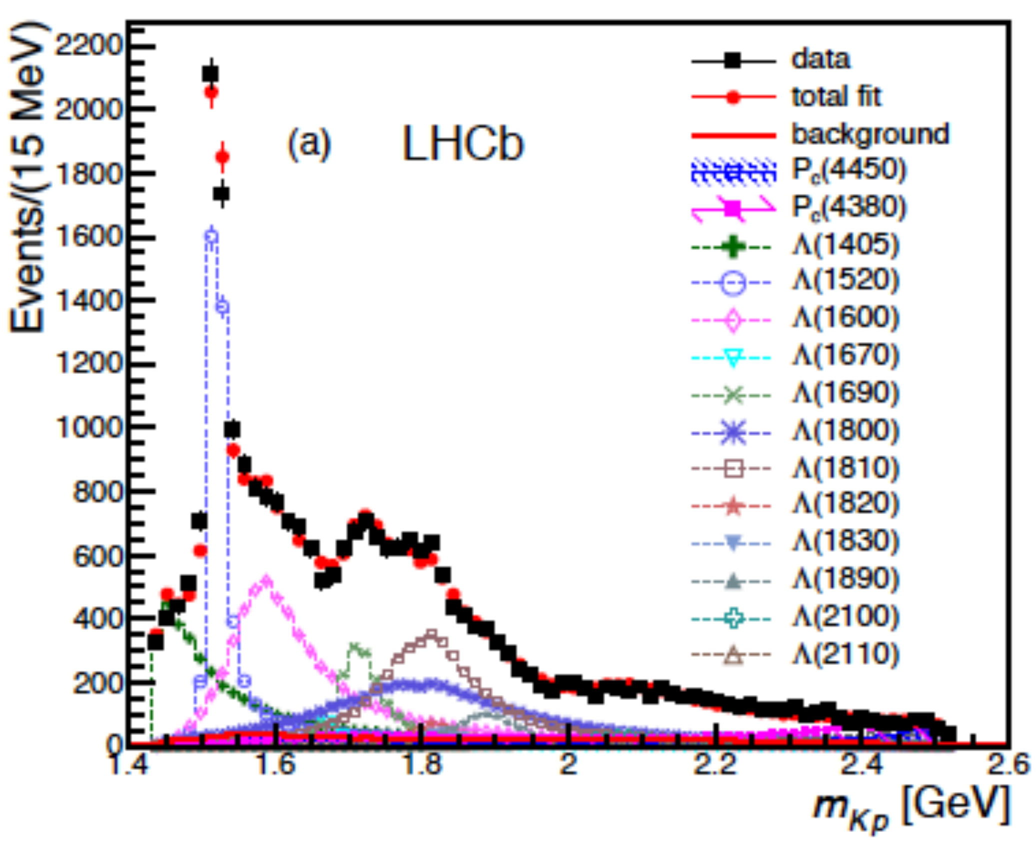
2015

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

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

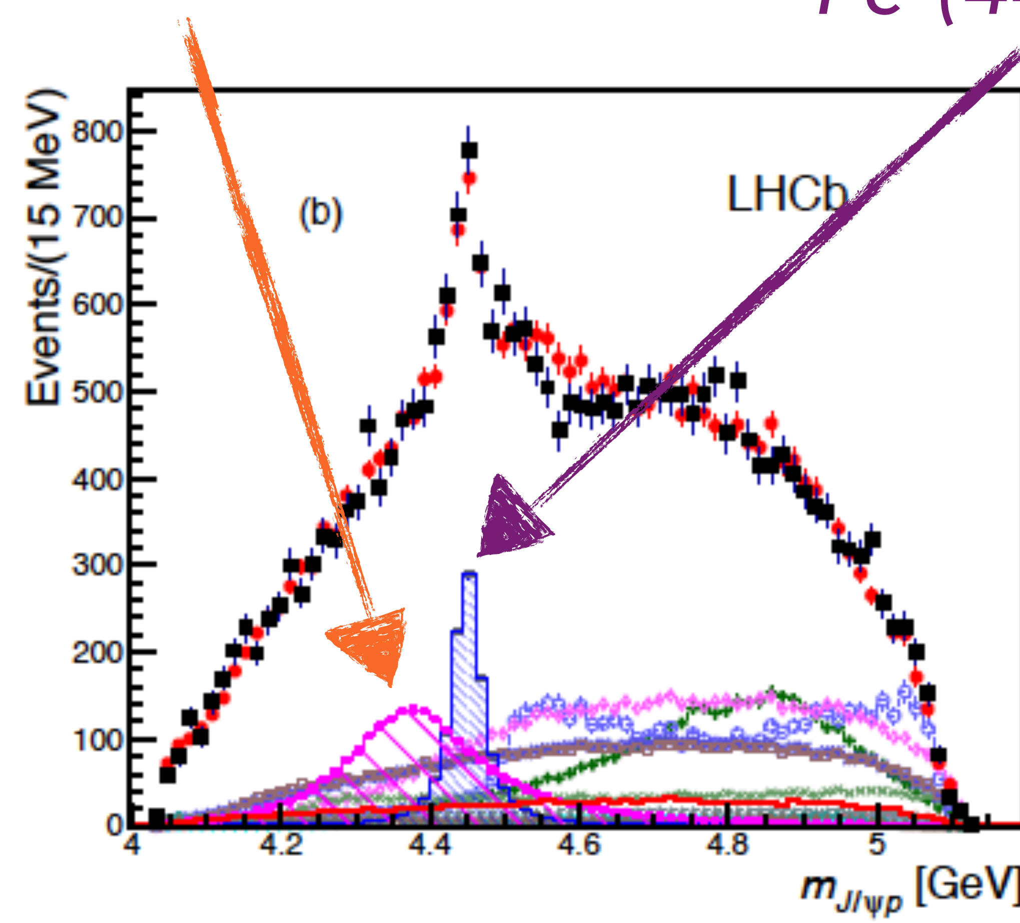


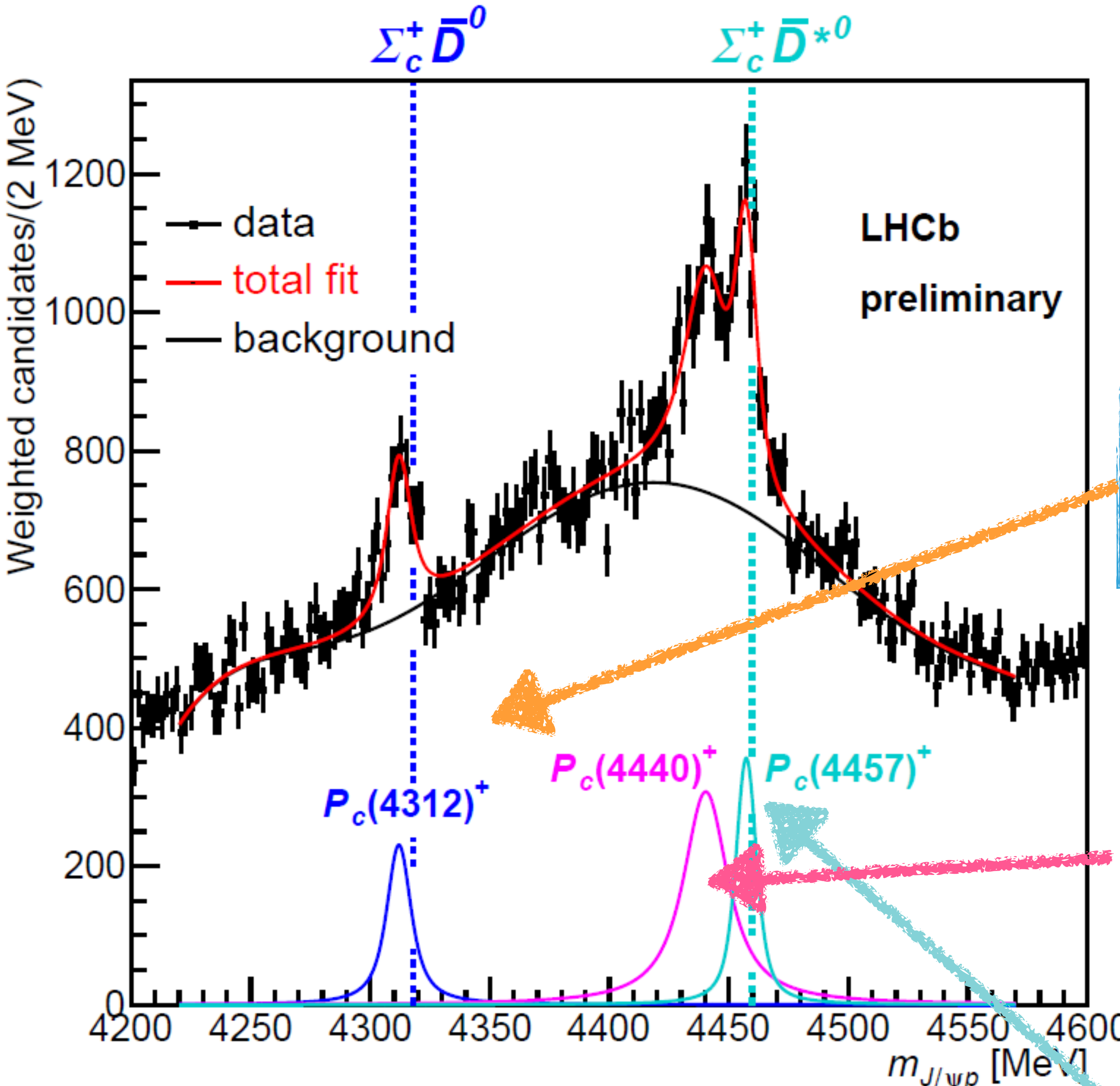




$P_c^+(4380)$

$P_c^+(4450)$





R. Aaij et al. (LHCb) (2019)
PRL 22, 222001

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

BUT ALSO…

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

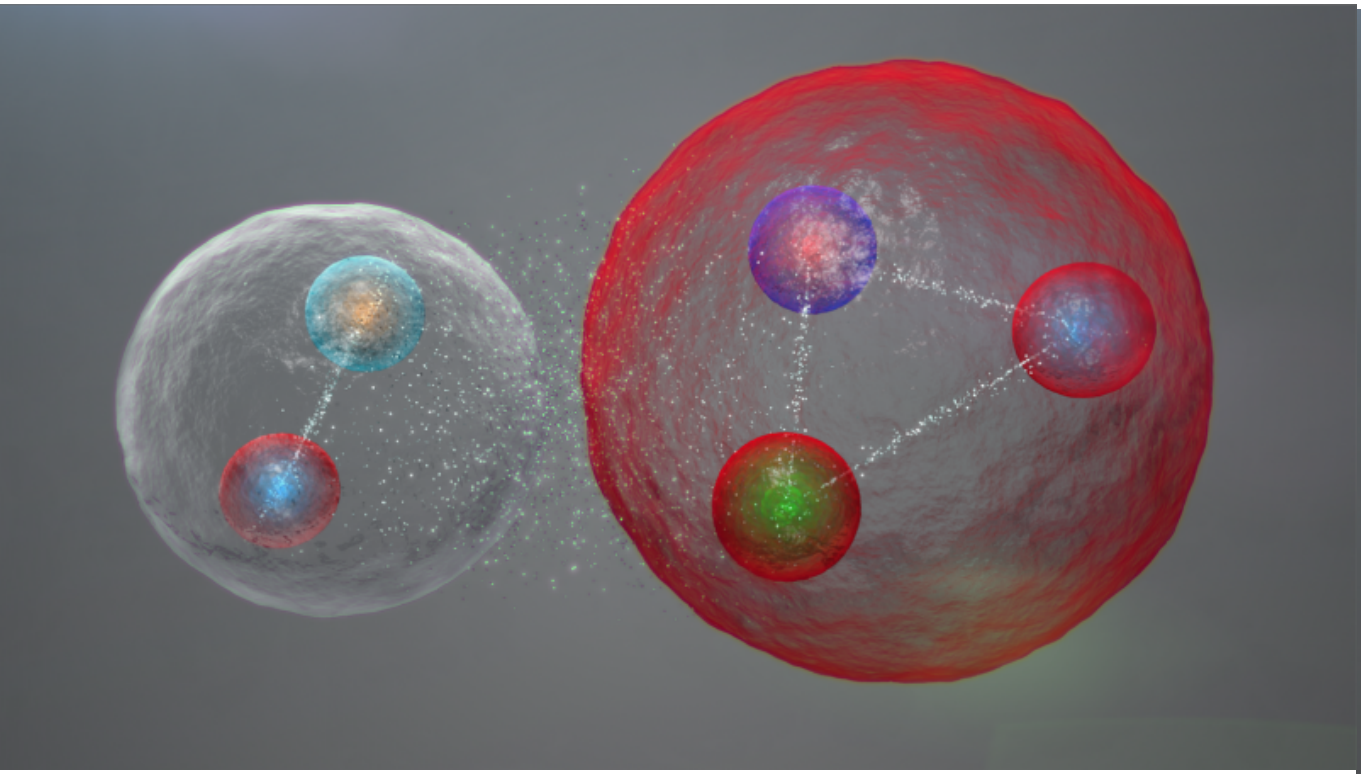
Γ = 20.6±4.9+8.7/-10.1 MeV

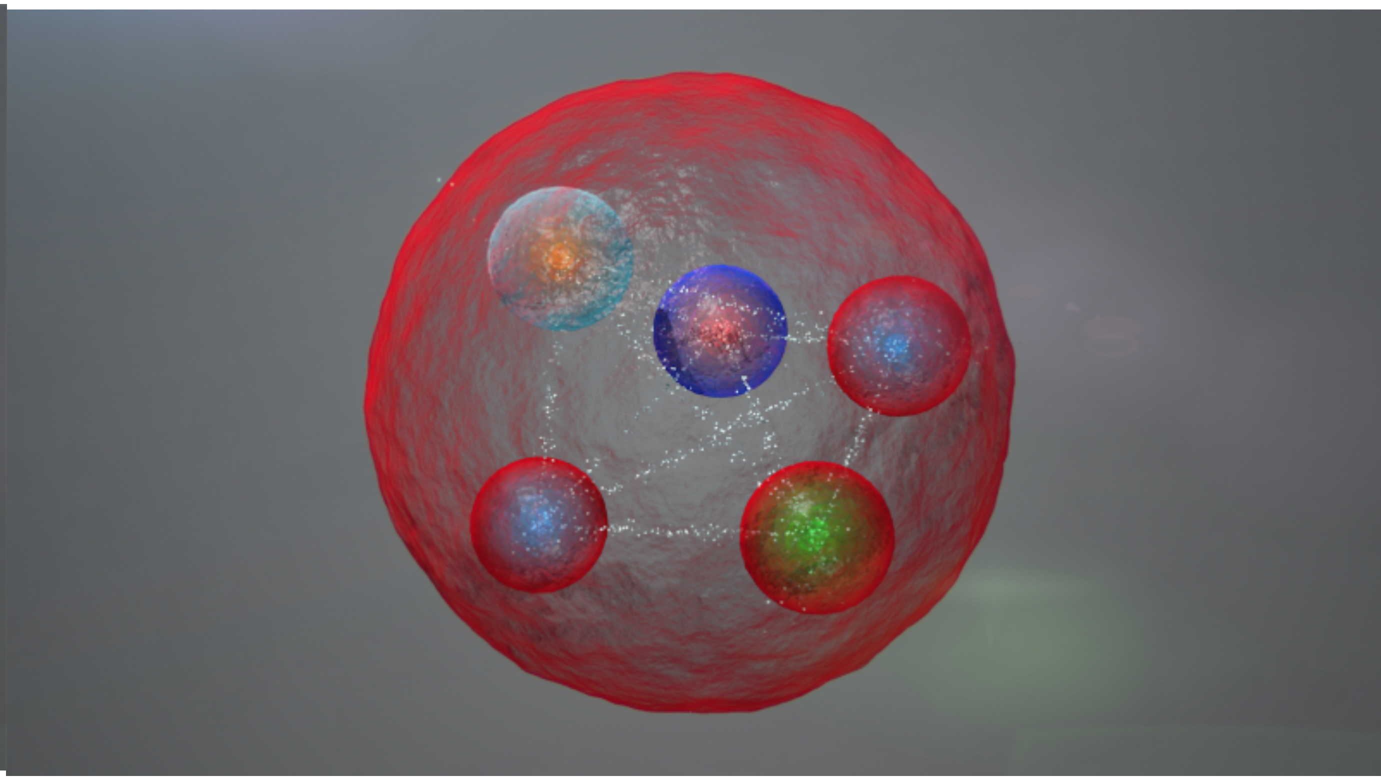
★ ***Pc⁺(4457)***

M: 4457.3±0.6+4.1/-1.7 MeV

Γ = 6.4±2.0+5.7/-1.9 MeV

CHARMED "PENTAQUARK" IN PHOTO-PRODUCTION



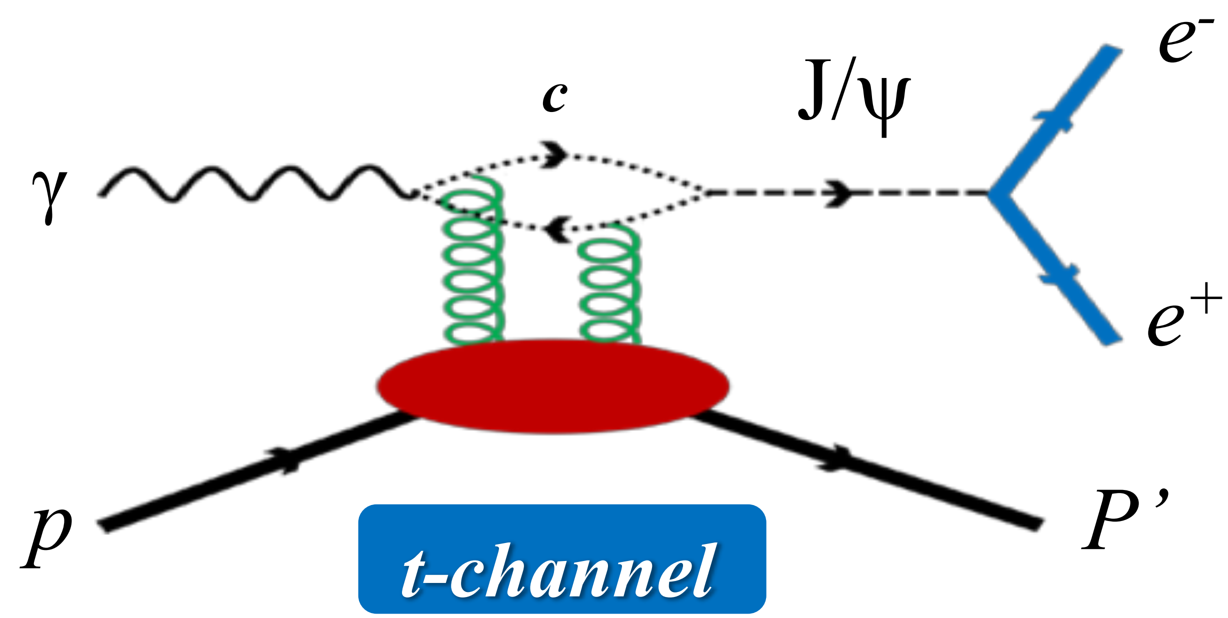


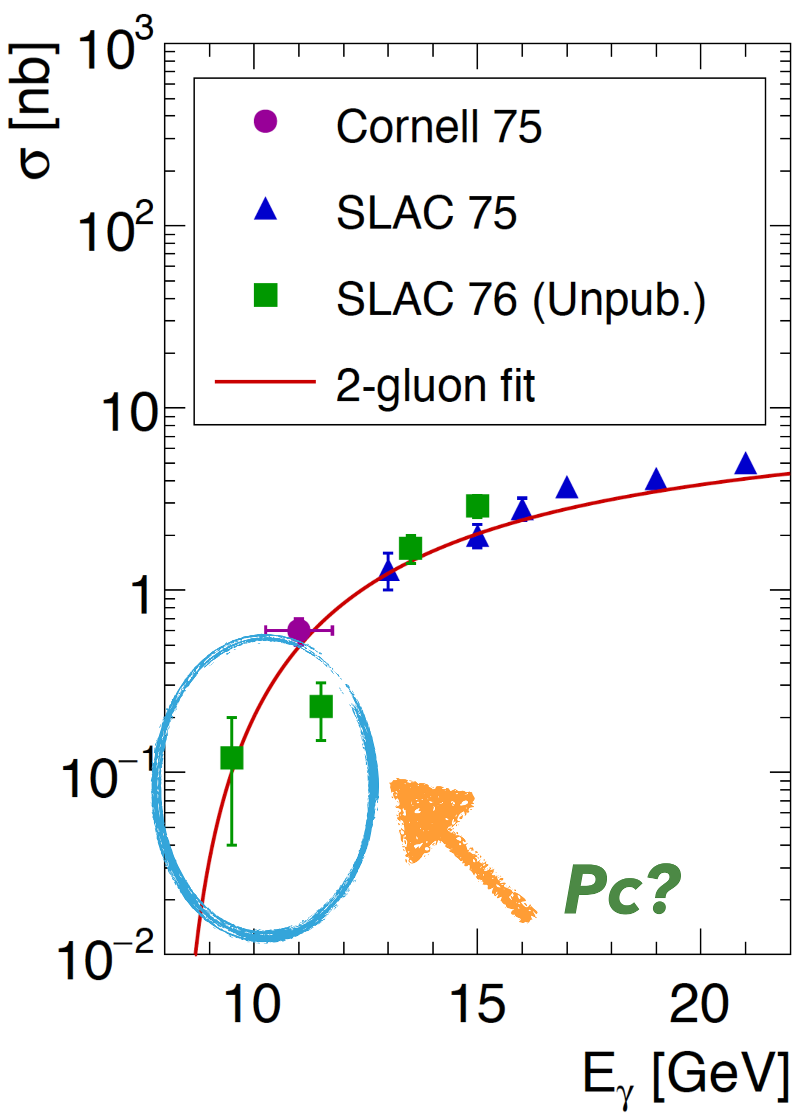
- **Common Interpretations for LHCb Observations**
  - **LHCb:** True resonant "pentaquark" states or molecule
  - **Alternative:** Rescattering interpretation, kinematic enhancement through Anamolous Triangle Singularity (ATS)
- The **photo production** is an ideal tool to distinguish between explanations
  - If Pc states are real states, should **also be created in photo-production**
  - Rescattering kinematic enhancement **not possible** in s-channel photo-production

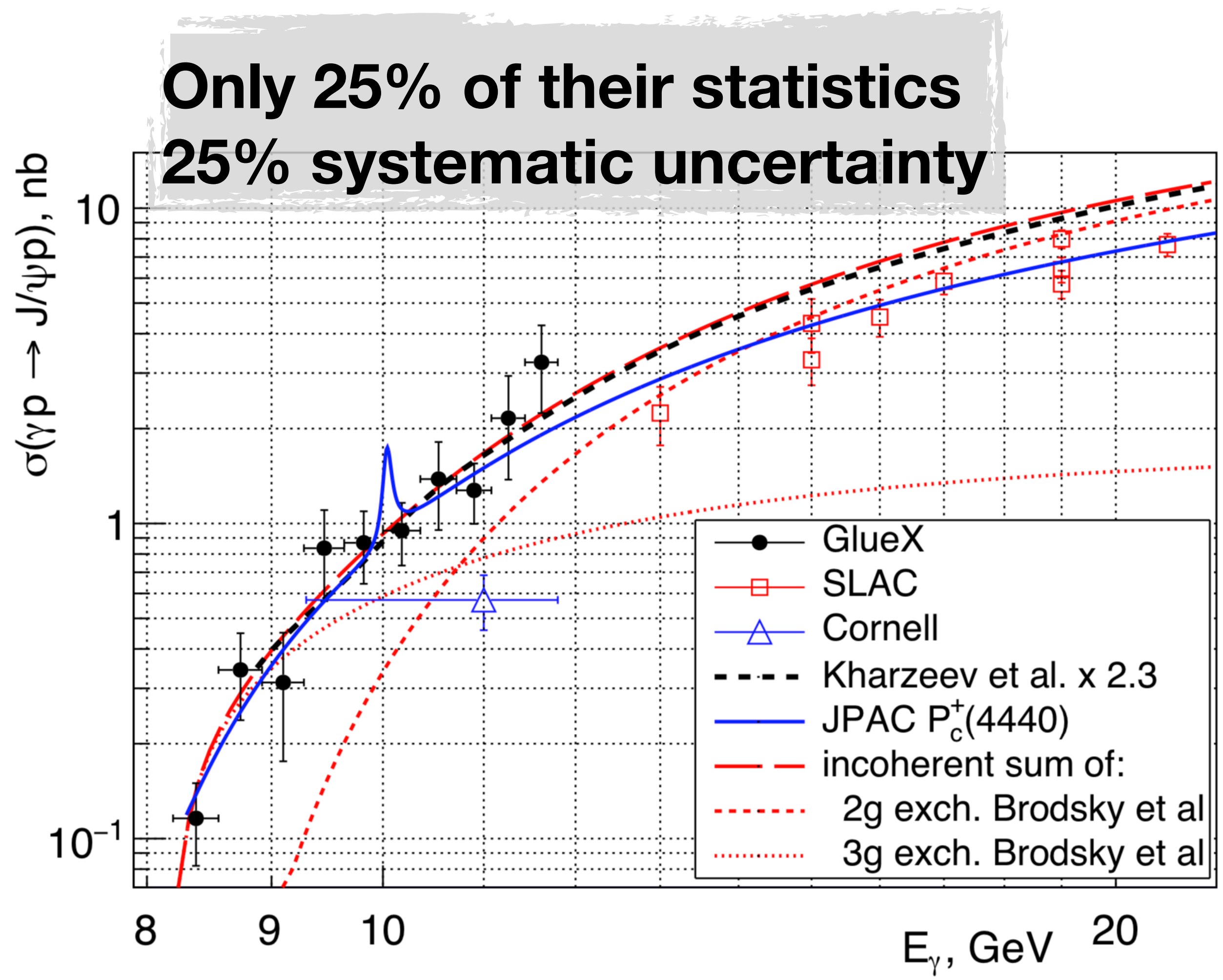
X-H Lui *et al.*, PLB 757, 231 (2016) and references therein
Q. Wang *et al.*, PRD 92-3 034022-7 (2015) and references therein

J/Ψ PHOTO-PRODUCTION: CURRENT DATA STATUS

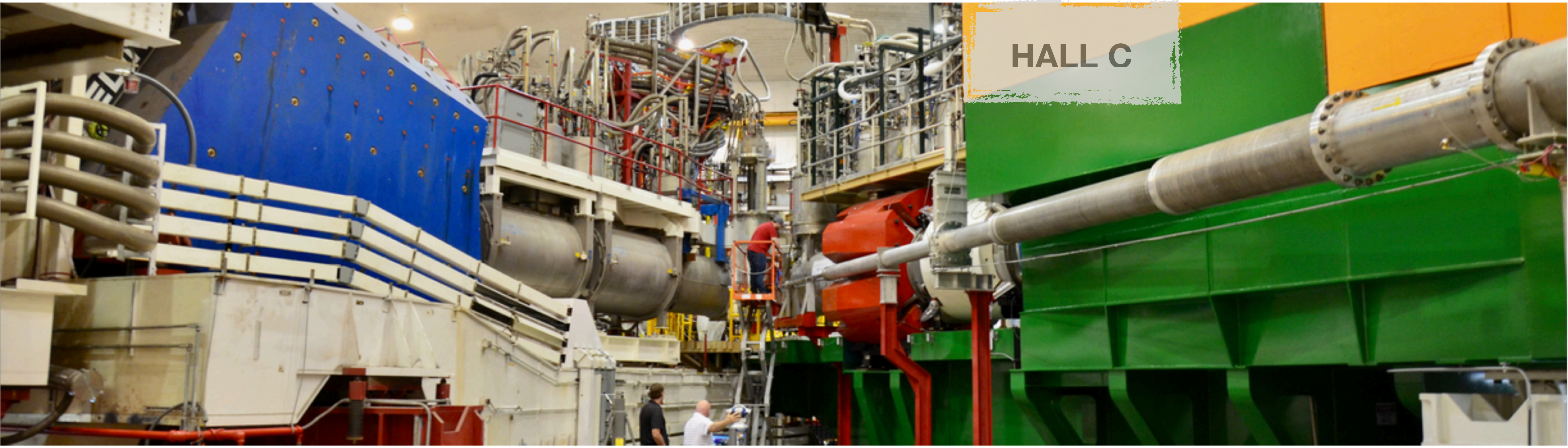
- Measured in many experiments at high $W_{\gamma p}$
  - dominated by t-channel 2-gluon exchange
  - Almost no data in threshold region







A. Ali *et al.* (GlueX Collaboration) (2019) PRL, 123, 072001



Jefferson Lab 12 GeV Upgrade

Hall C: High luminosity & well defined acceptance

Ideal place for our measurement!

Ran February 8 - March 5 2019!

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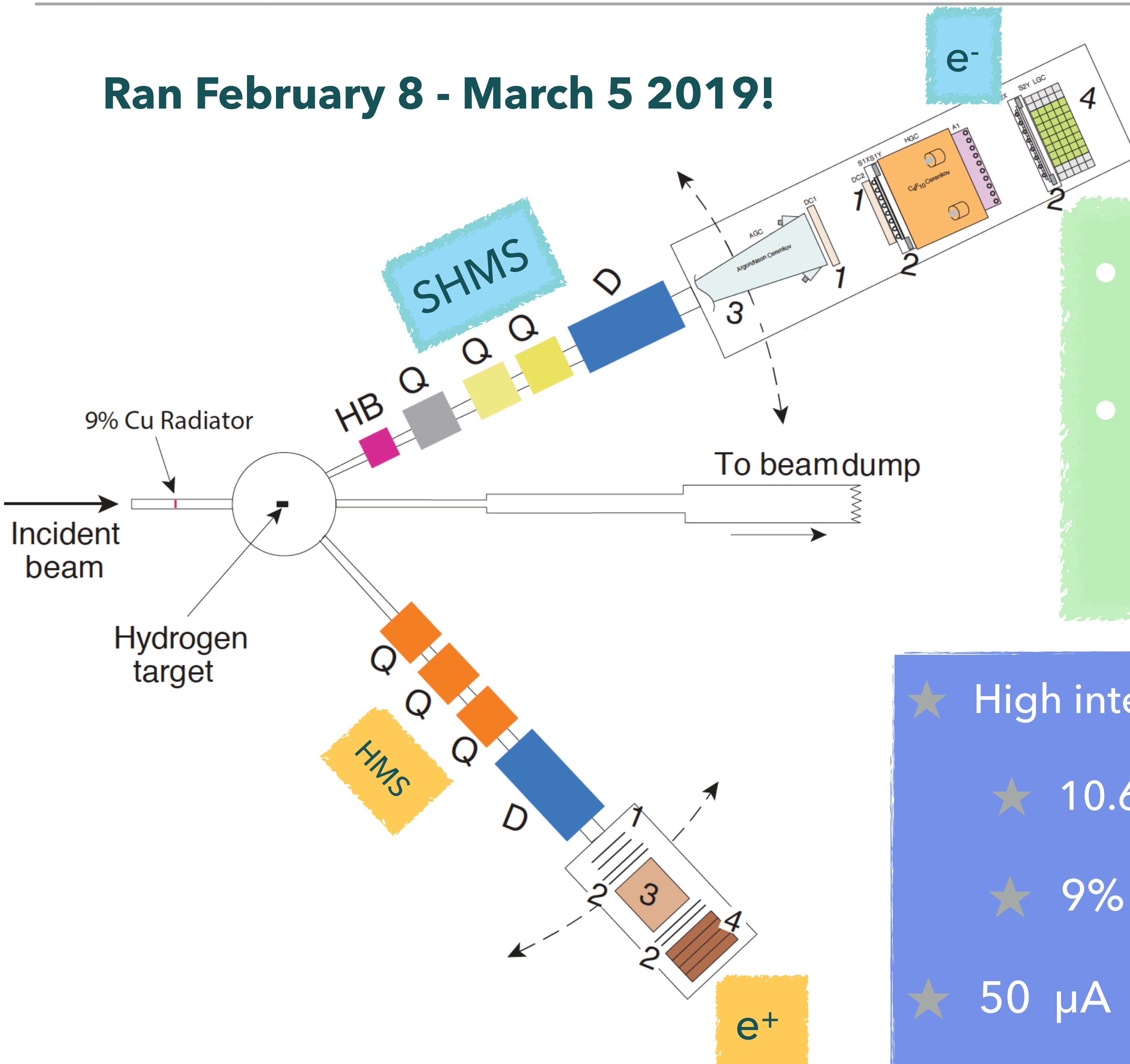
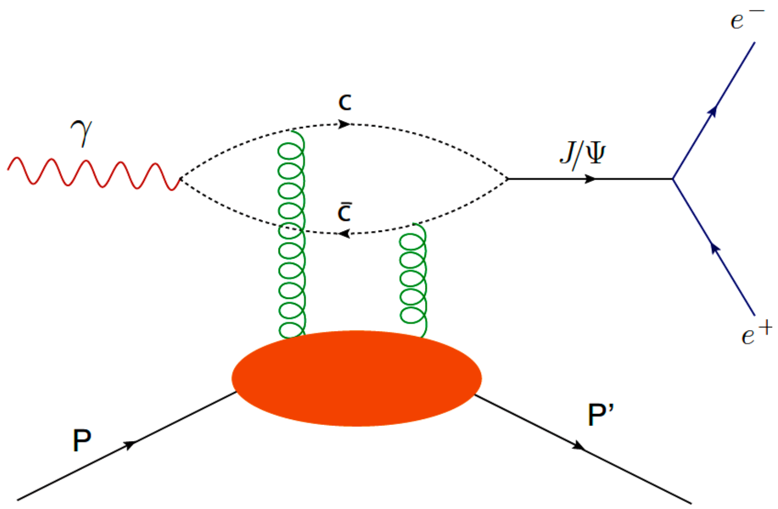


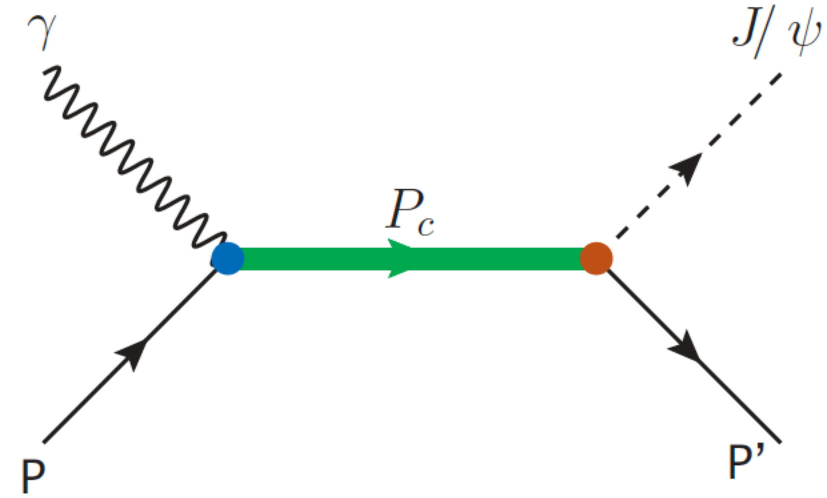
- Detect e^+e^- decay pair from J/Ψ in COINCIDENCE
- Initial photon energy easily reconstructed from reconstructed J/Ψ momentum and energy

- ★ High intensity real photon beam
  - ★ 10.6 GeV electron beam
  - ★ 9% copper radiator
- ★ 50 μA
- ★ 10 cm LH2 target

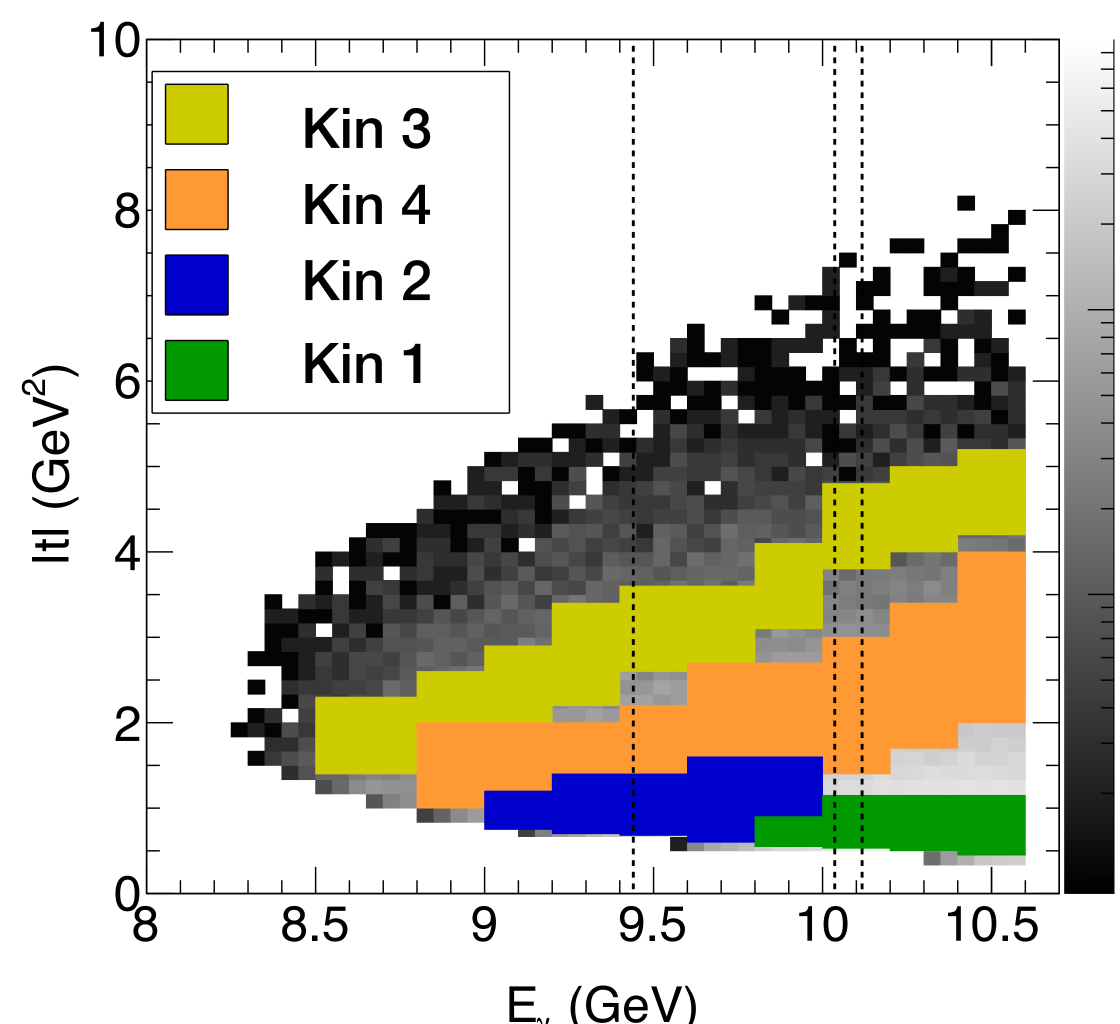
t-channel



s-channel

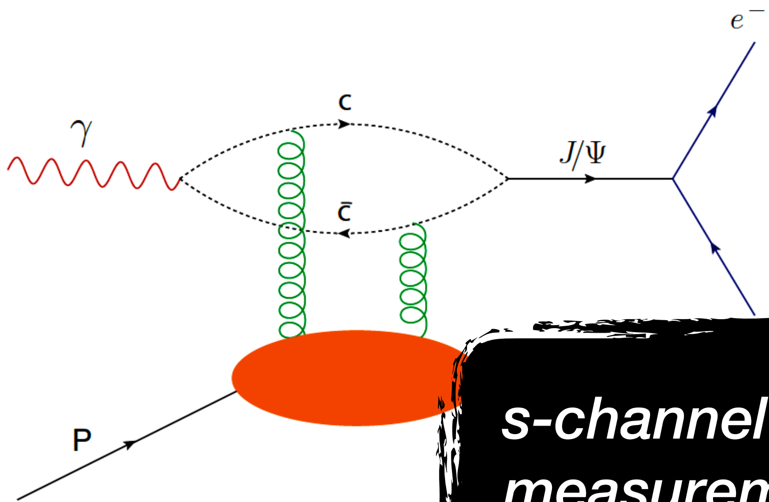


- Different *J/Ψ* angular distribution for *t-channel* and *s-channel* processes.
- Exponential-like *t*-dependence in *t-channel* process (more forward process)
- *t-channel* is suppressed at high t.
- s-channel resonant production ~ flat across the same *t* range

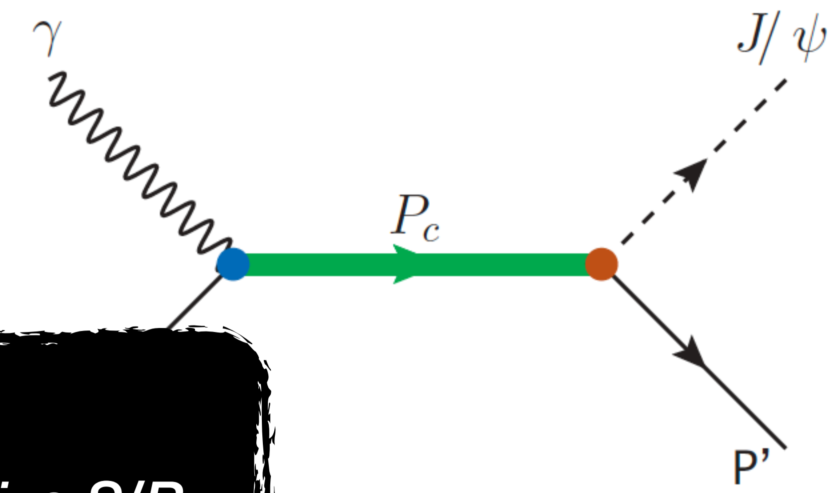


DISTINGUISHING S-CHANNEL RESONANT PRODUCTION FROM T-CHANNEL J/Ψ PRODUCTION

t-channel

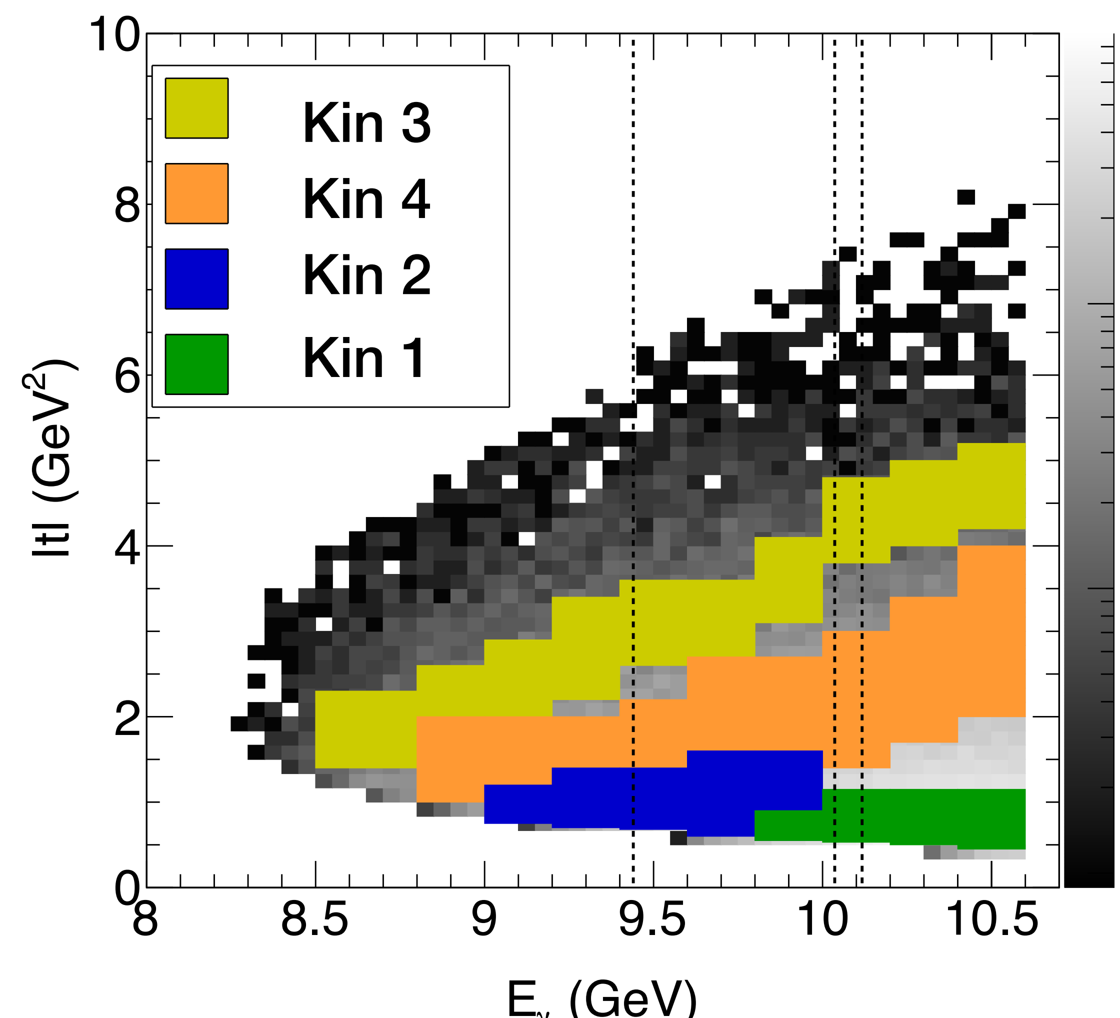


s-channel



s-channel resonant production measurement at high t to maximize S/B

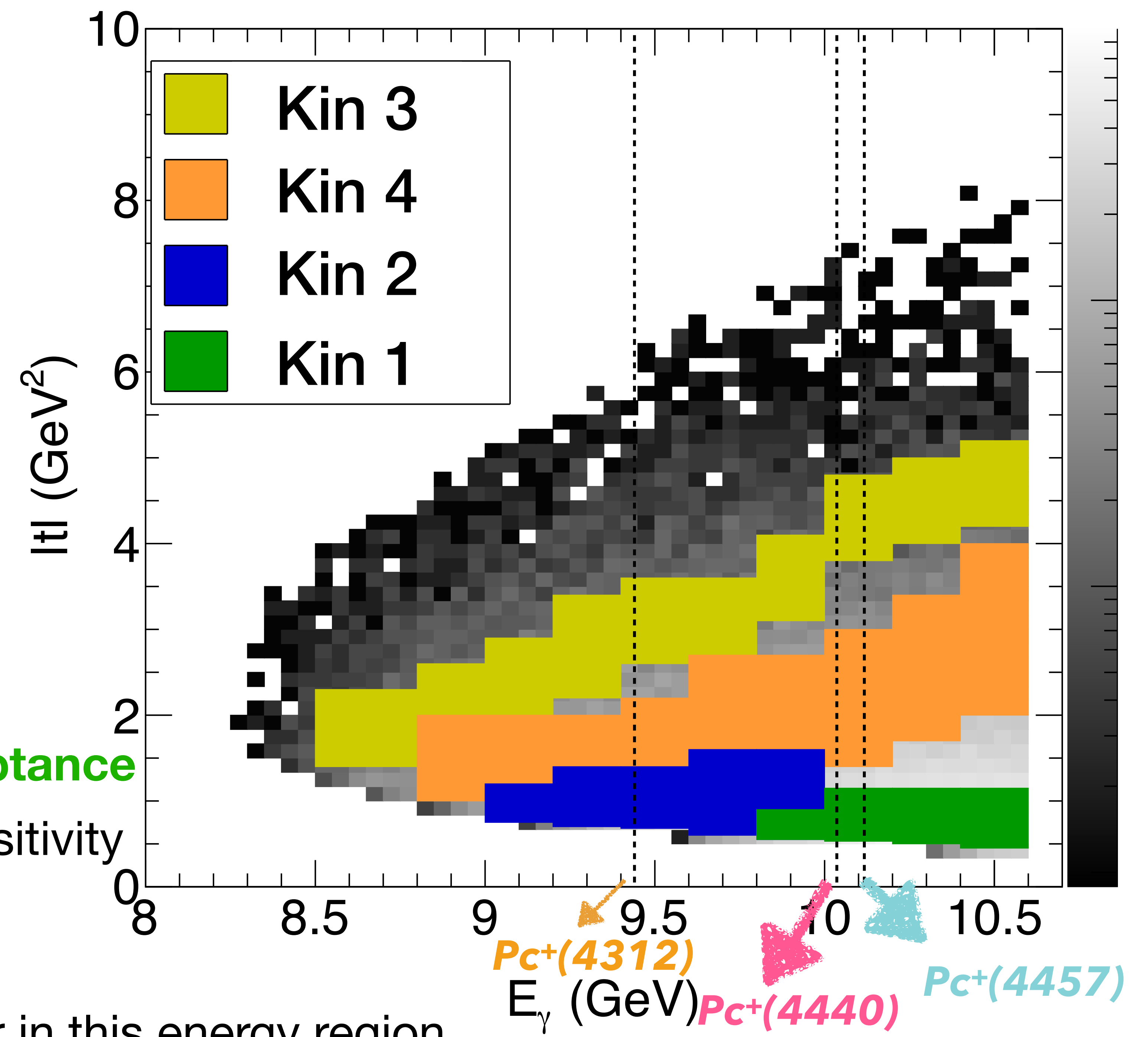
- Different *J/Ψ* angular distribution for *t-channel* and *s-channel* processes.
- Exponential-like *t*-dependence in *t-channel* process (more forward process)
- *t-channel* is suppressed at high t.
- s-channel resonant production ~ flat across the same *t* range



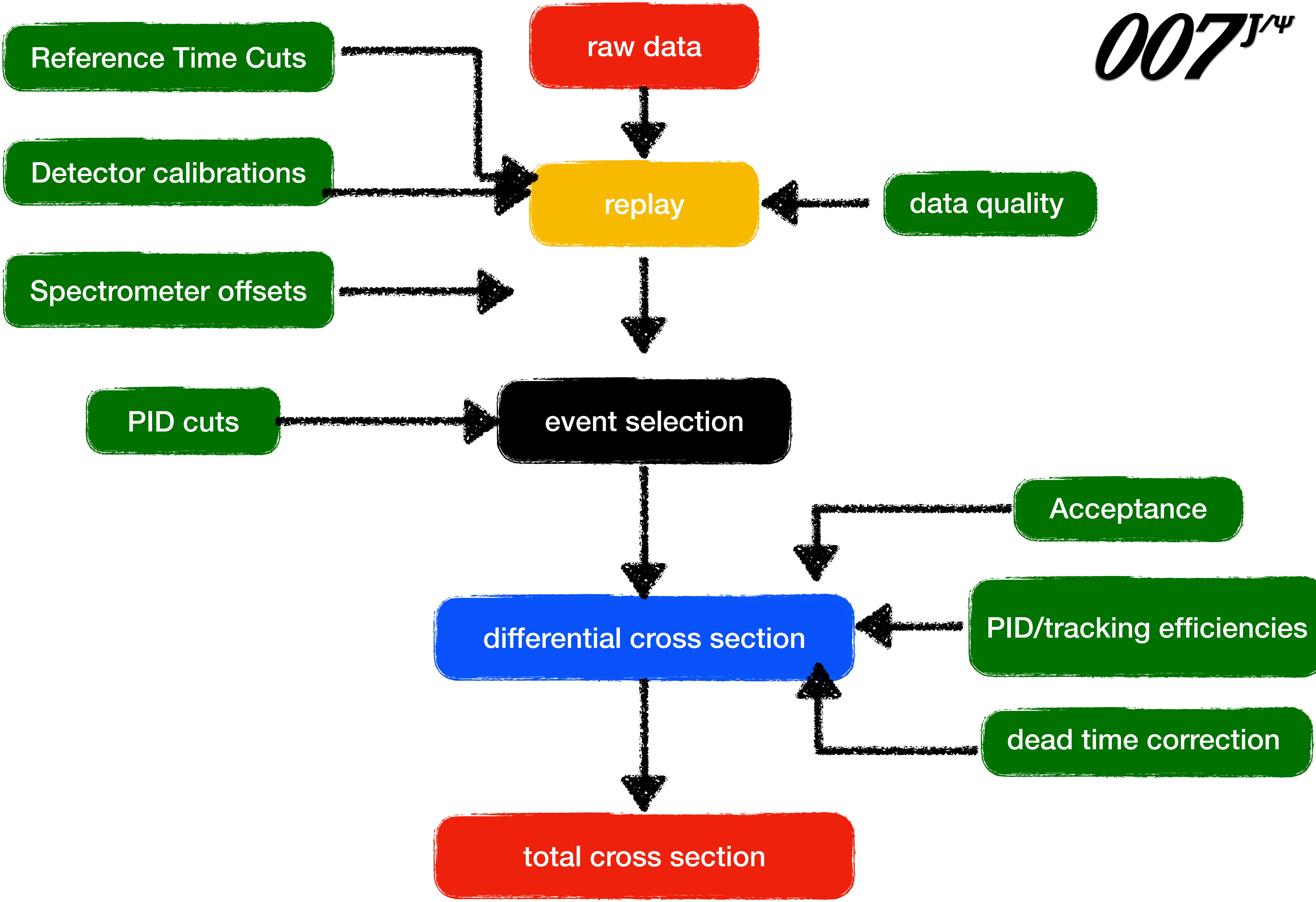
007 J/Ψ LARGEST DATESET OF J/Ψ WITH REAL PHOTON BEAM

- 2D photo-production CS covers an energy range 8.5-10.6 GeV

Wide E_γ and *t* coverage only in J/Ψ-007!



- **Powerful tool in Hall C**:
- **High luminosity** & **well defined acceptance**
- Measurement at high t favors high sensitivity for resonant *J/Ψ* production through *Pc*
- LHCb pentaquark candidates discover in this energy region


raw data
Reference Time Cuts
Detector calibrations
replay
data quality
Spectrometer offsets
PID cuts
event selection
Acceptance
differential cross section
PID/tracking efficiencies
dead time correction
total cross section

Spectrometer Offsets by χ^2 Minimization

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A group of singles elastic data with different energy, momentum and angle is used to determine the spectrometer offsets.

Eb= 3.8 GeV, 4.9 GeV, 6.2 GeV, 8.2 GeV
Pc ~ 2.5 GeV - 4.6 GeV, angle ~ 8.86 deg - 34 deg

METHOD

- $dWpre_d = \frac{\partial W}{\partial Eb}\delta Eb + \frac{\partial W}{\partial E'}\delta E' + \frac{\partial W}{\partial \theta}\delta\boldsymbol{\theta}$

- $dW_{meas} = W_{simc} - W_{data}$

$dW_{meas} = W_{simc} - W_{data}$

- Parameters: $p1 = \frac{\delta Eb}{Eb}$, $p2 = \frac{\delta E'}{E'}$, $p3 = \delta\boldsymbol{\theta}$

$\boldsymbol{\sigma} dW_{meas} = \sqrt{\boldsymbol{\sigma} W_{simc}{}^2 + \boldsymbol{\sigma} W_{data}{}^2}$

- $\chi^2 = \sum_{kg}\left[\frac{dWmeas - dWpred}{\boldsymbol{\sigma} dWmeas}\right]^2$ → *kg: different kinematic groups*

- Reduced $\chi^2 = \frac{\chi^2}{\#\ of\ kg - \#\ of\ parameters}$

Summary of Minimization Results for the SHMS/HMS

SHMS

p1	**=**	**0 (fixed)**		
p2	=	-0.0025	+/-	0.0002
p3	=	0 (fixed)		

p1 = dEb/Eb, p2=dE'/E', p3=dθ

SHMS Minimum: f(p1, p2, p3): χ^2

Pc * 0.9975

SHMS Minimum: f(0,-0.0025,0): 20.8699

Minimization with ROOT minuit2

HMS

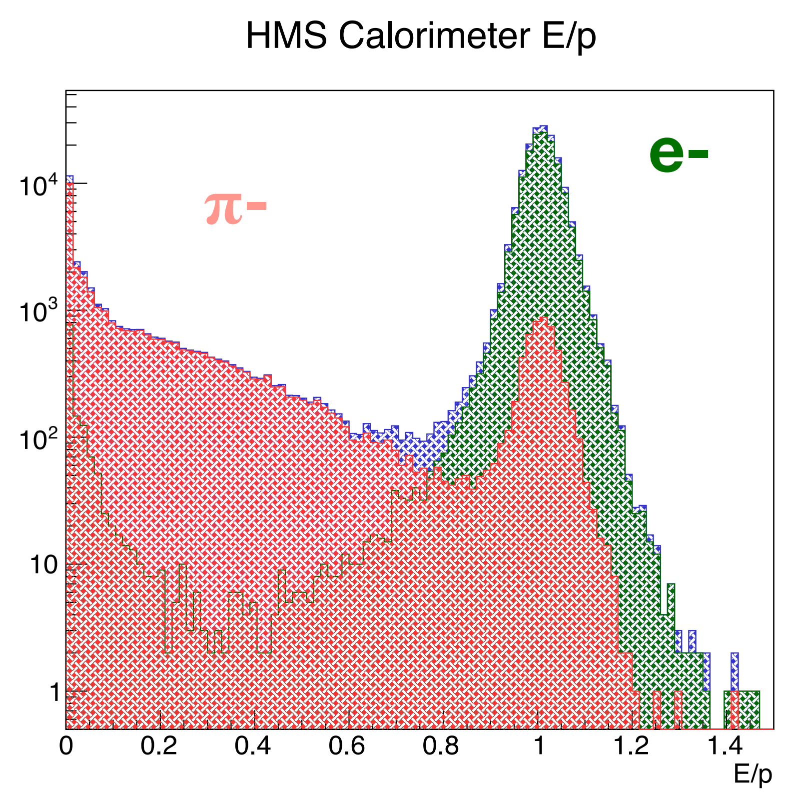
p1	**=**	**0 (fixed)**		
p2	=	-0.0019	+/-	0.0002
p3	=	0 (fixed)		

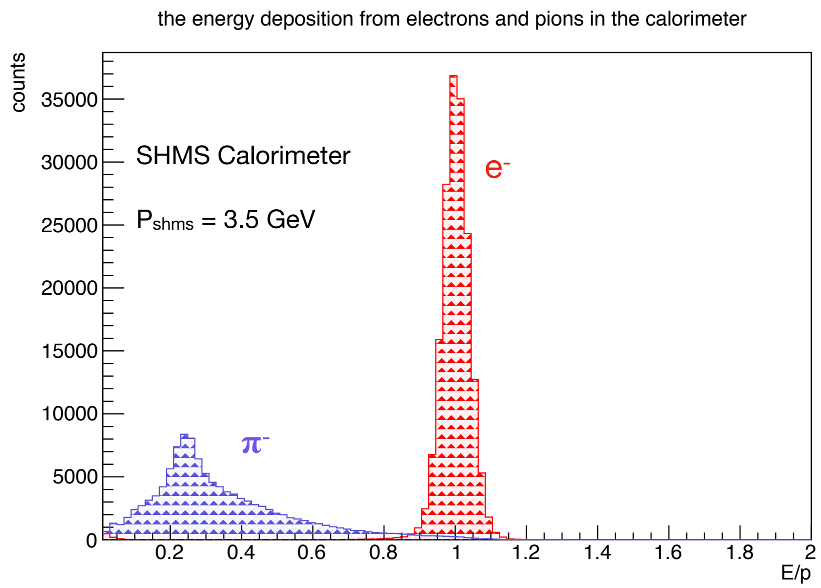
HMS Minimum: f(p1, p2, p3): χ^2

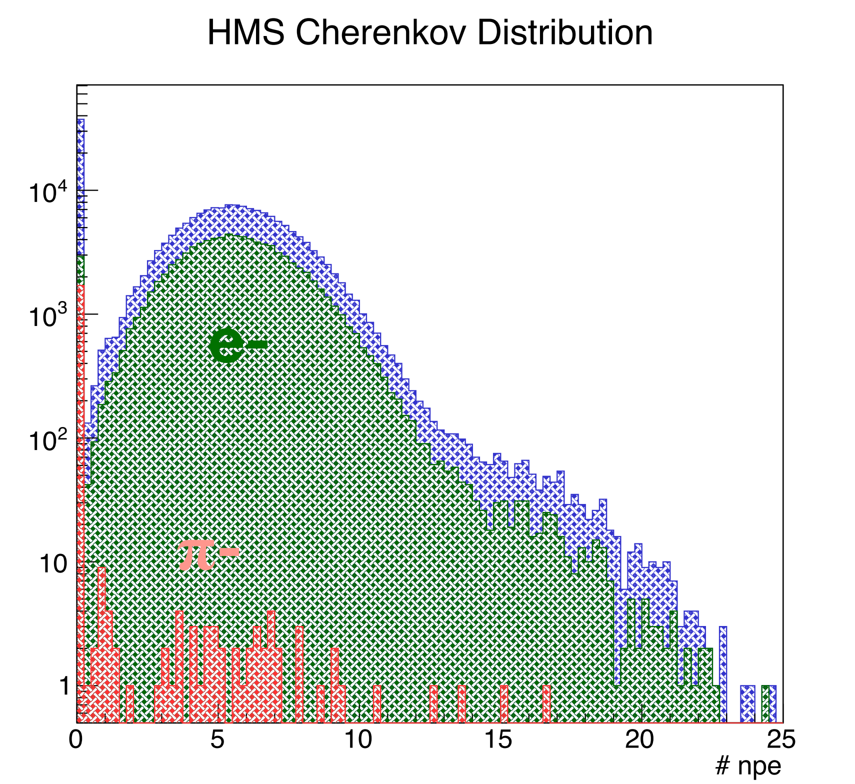
Pc * 0.99881

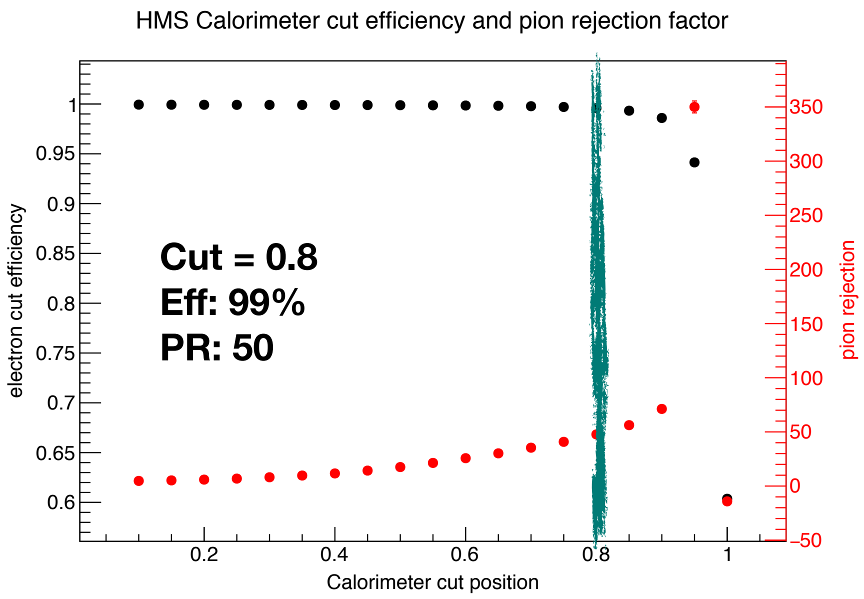
HMS Minimum: f(0,-0.0019,0): 19.4776

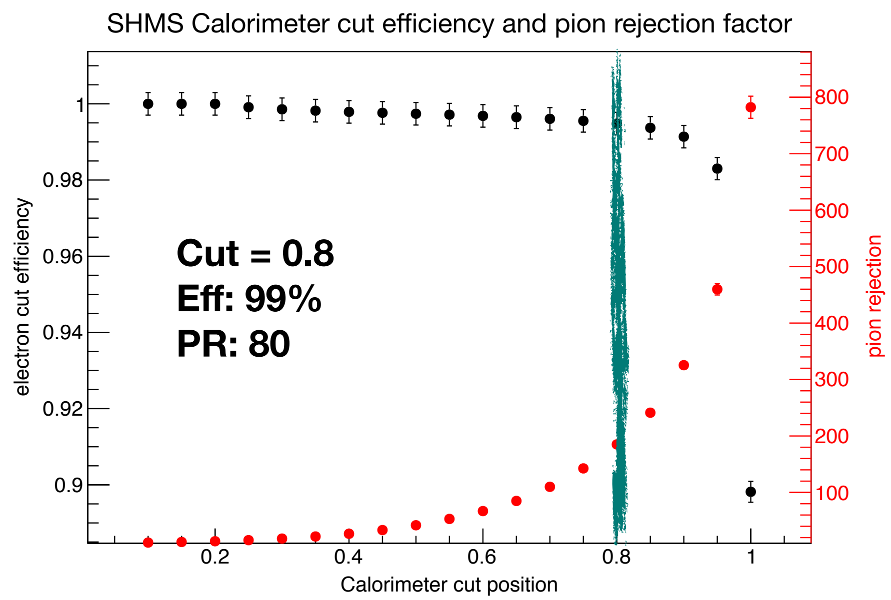
Summary of PID Studies

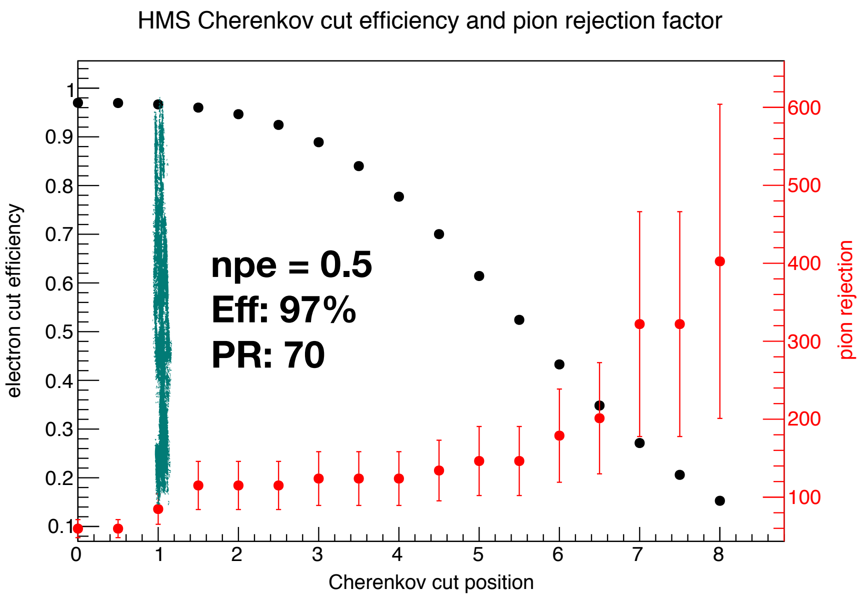












Tracking Efficiencies

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

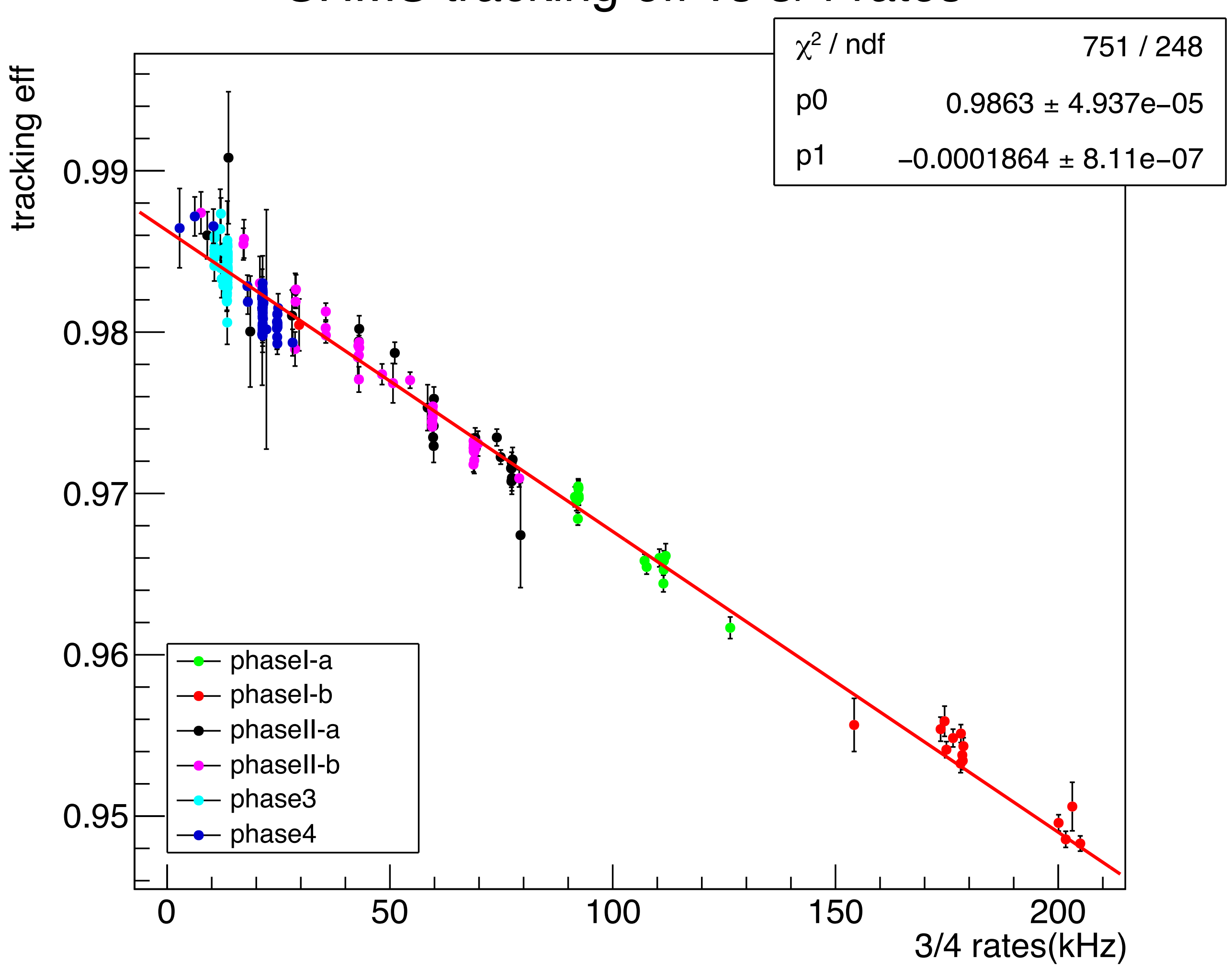
Nshould (events for which one expected a track to be found)

P.hod.goodscinhit==1 && 0.5 < P.hod.betanotrack < 1.4 && 0.6 < P.cal.etotnorm < 1.6

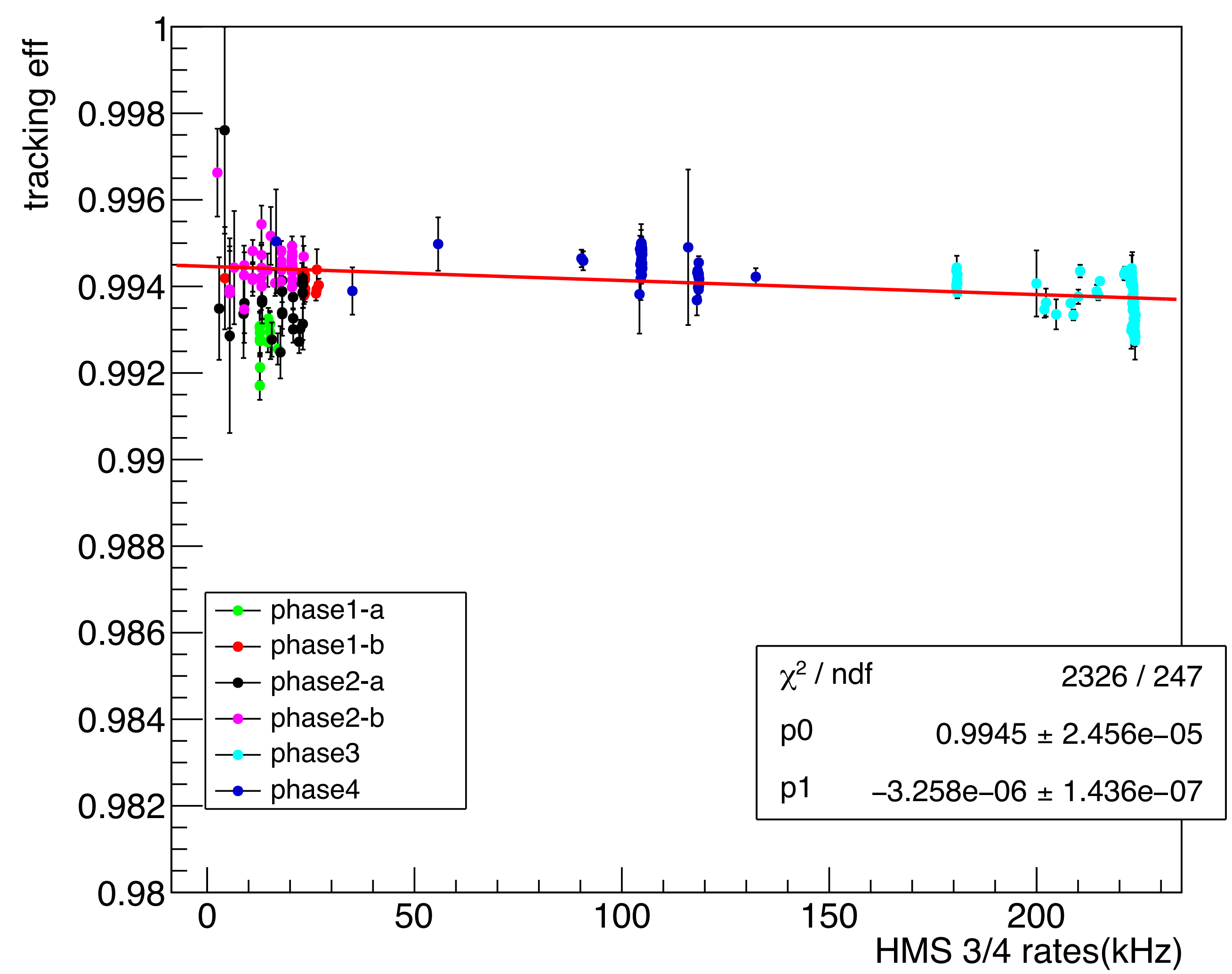
Ndid (events for which a track is found)

Nshould && P.dc.ntrack > 0

SHMS tracking eff vs 3/4 rates

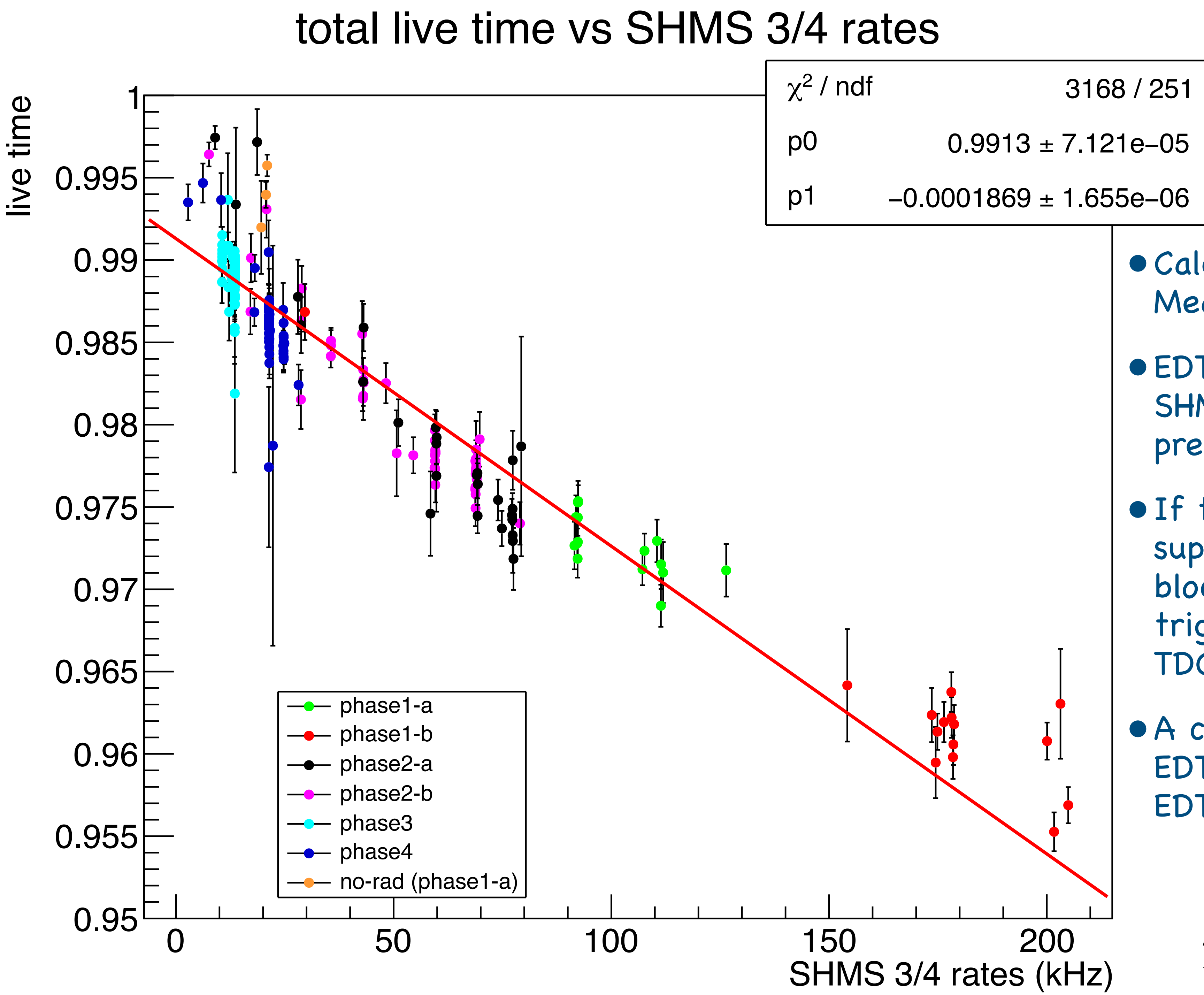


HMS tracking eff vs 3/4 rates



Total Live Time Calculation

TLT = computer live time*electronics live time

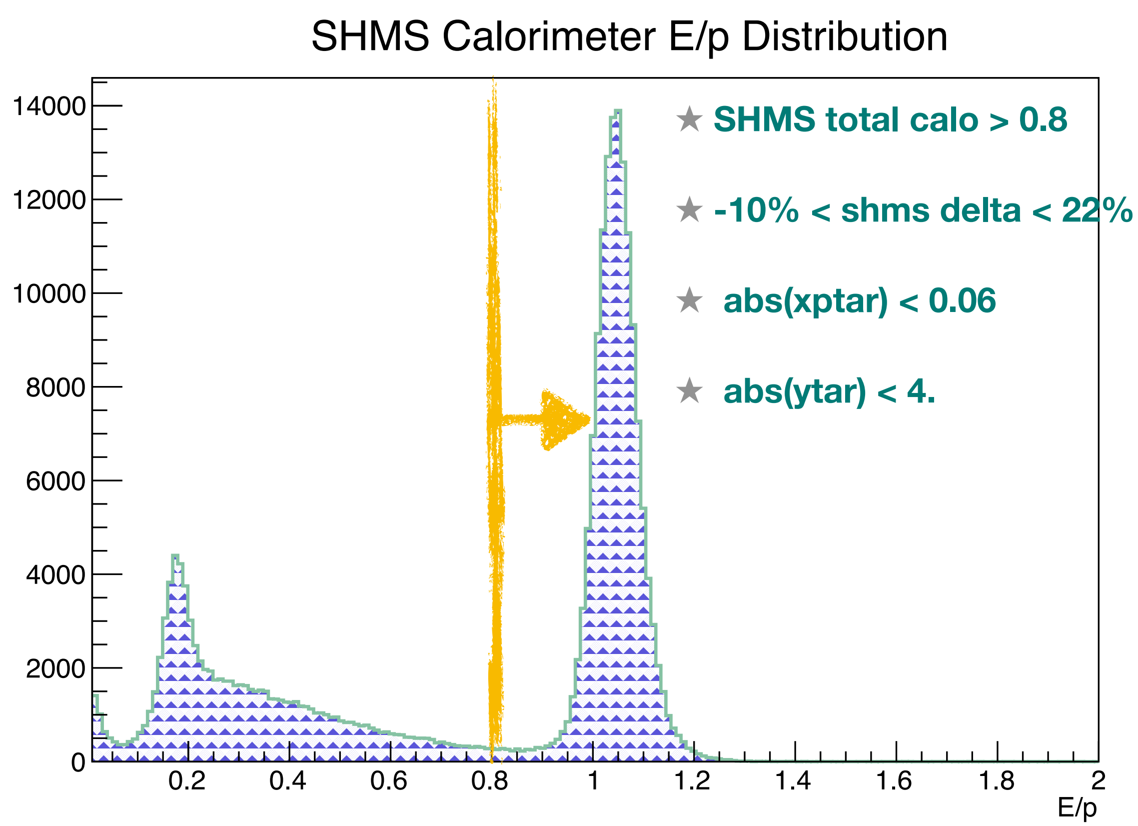


- Calculated using EDTM (Electronic Dead Time Measurement)
- EDTM: fixed frequency pulses inserted to the SHMS/HMS trigger logic like the real physics pre-triggers are.
- If the EDTM pulses make it to the trigger supervisor and get accepted, the DAQ is blocked for a time for the incoming pre-triggers and accepted EDTM is sent to the TDCs.
- A copy of the EDTM is also sent to scalers. EDTM scalers account for the TOTAL input EDTM events.

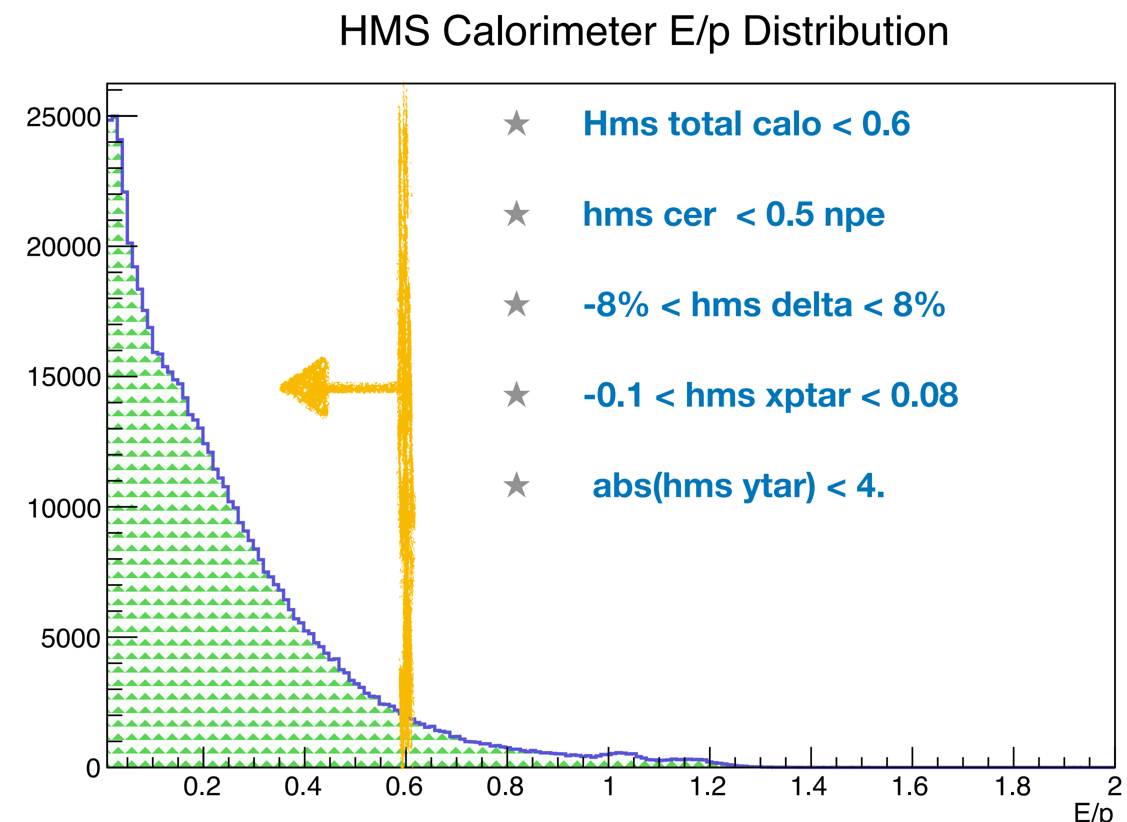
$$TLT = \frac{accepted\ EDTM\ events}{total\ scaler\ EDTM\ events}$$

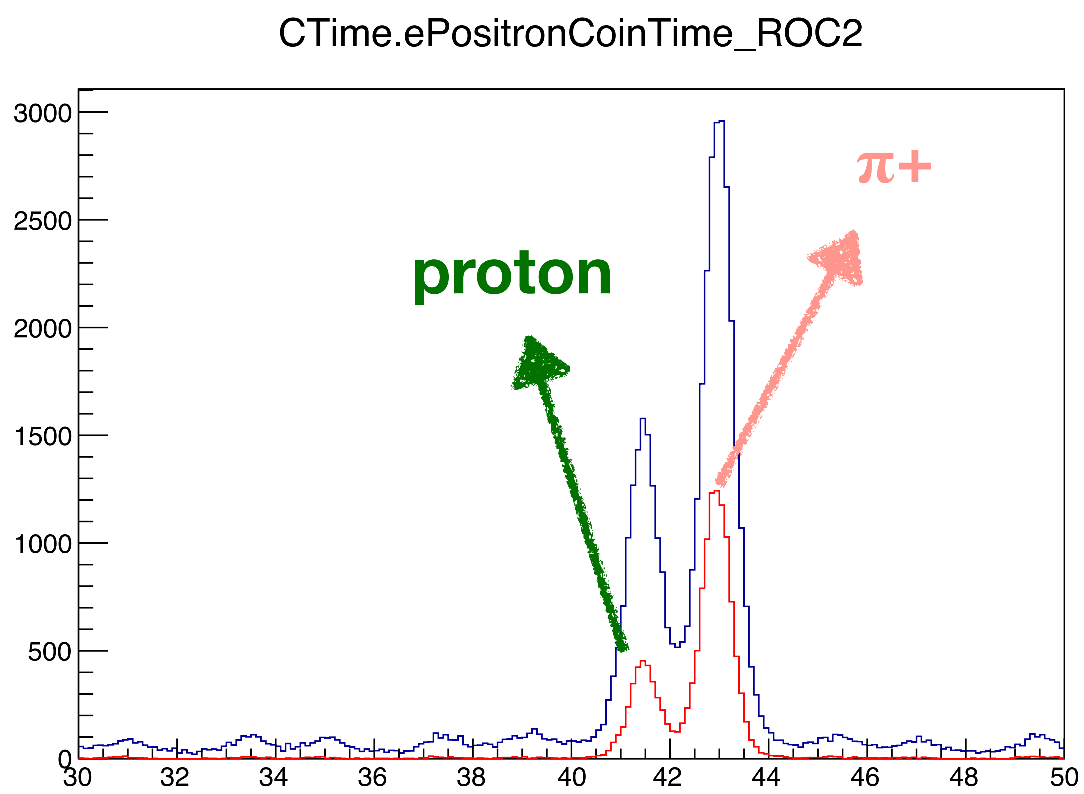
e-π+ Coincidence Yield

Electron selection in SHMS



Pion selection in HMS



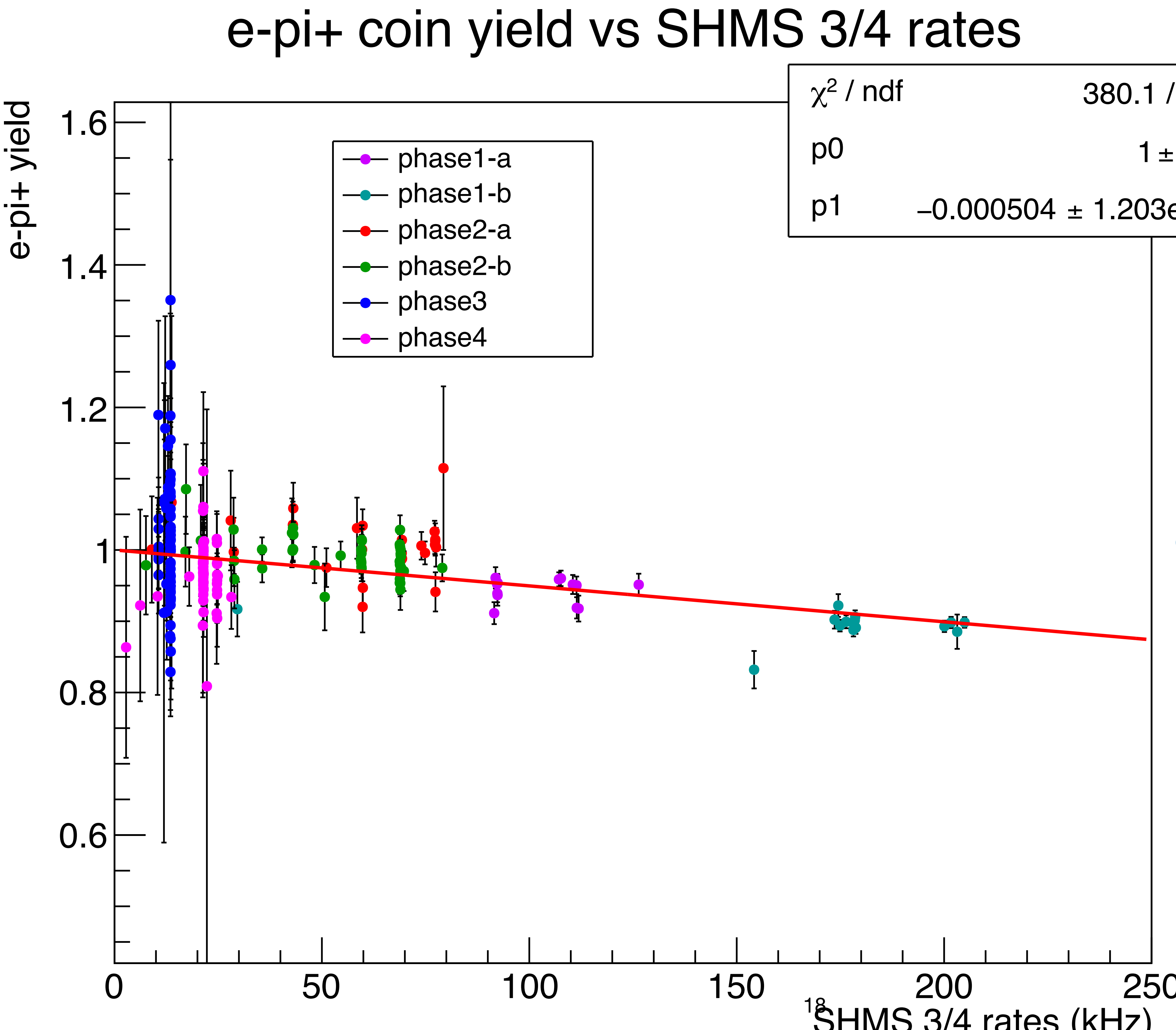


- Coincidence events selected with:

42 ns < coin time < 44 ns

- Events selected outside the two main peaks to estimate the accidentals under cointime peak. The # of events are normalized to the Coincidence peak width.

$$YIELD_{e-pi+} = \frac{(e - pi+)\ COIN\ events - Accidentals}{Q * coin\ live\ time * SHMS\ TE * HMS\ TE}$$

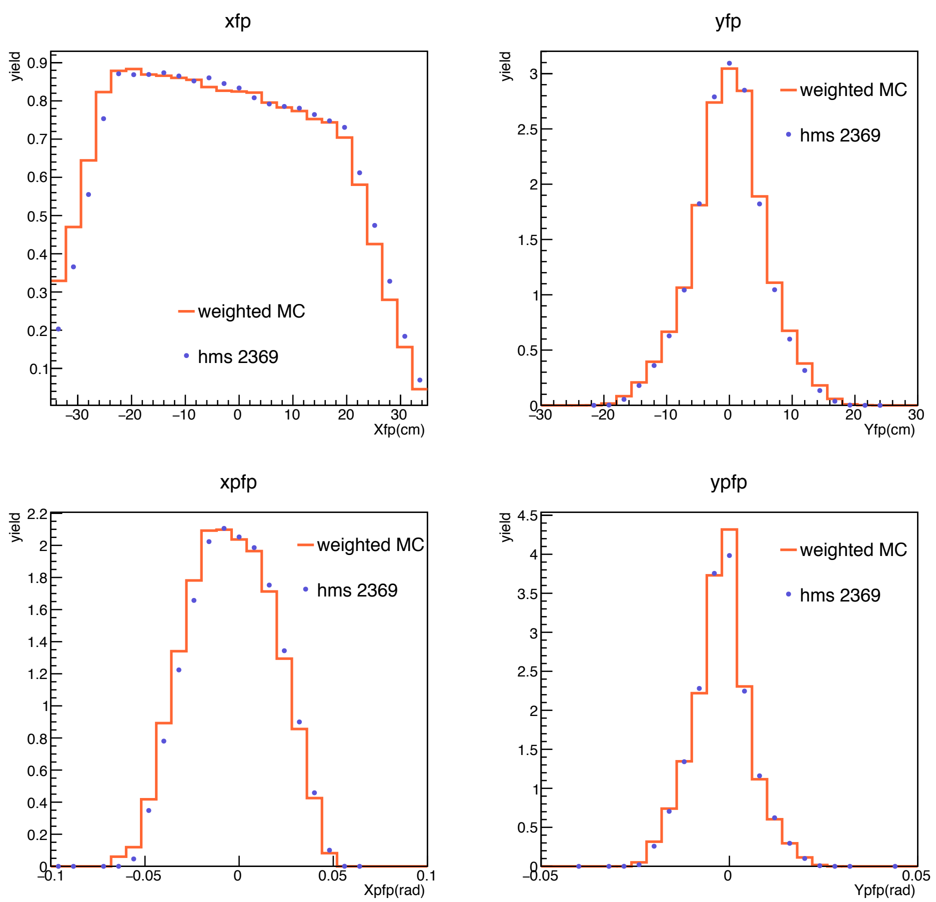


Rate dependent yield correction for the cross section!

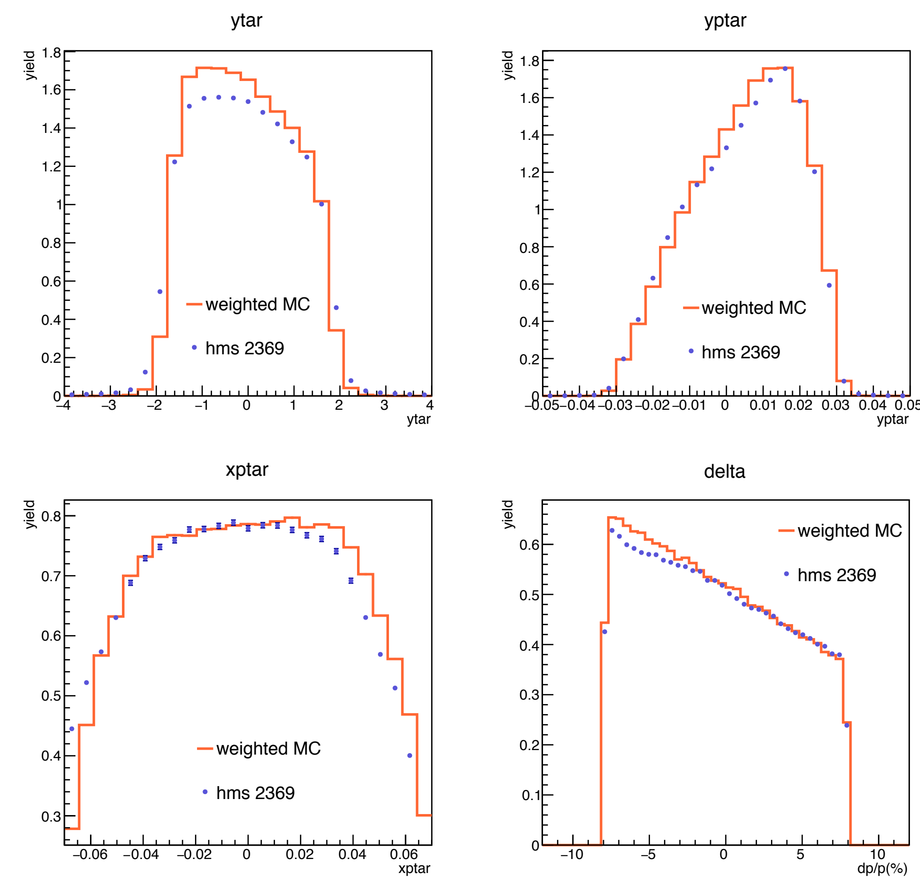
DIS ANALYSIS FOR ACCEPTANCE CORRECTION

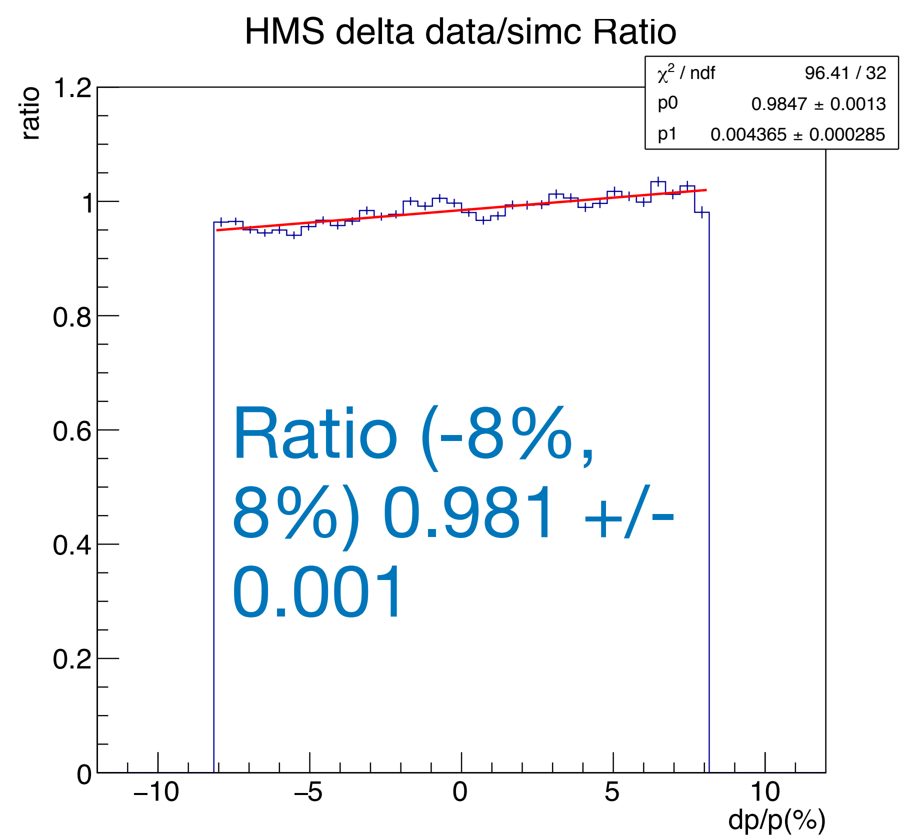
HMS

Focal Plane Quantities



Target Quantities





Ratio (-8%, 8%) 0.981 +/- 0.001

HMS DIS

Eb = 10.6 GeV

Pc=4.1 GeV, θ=21 deg

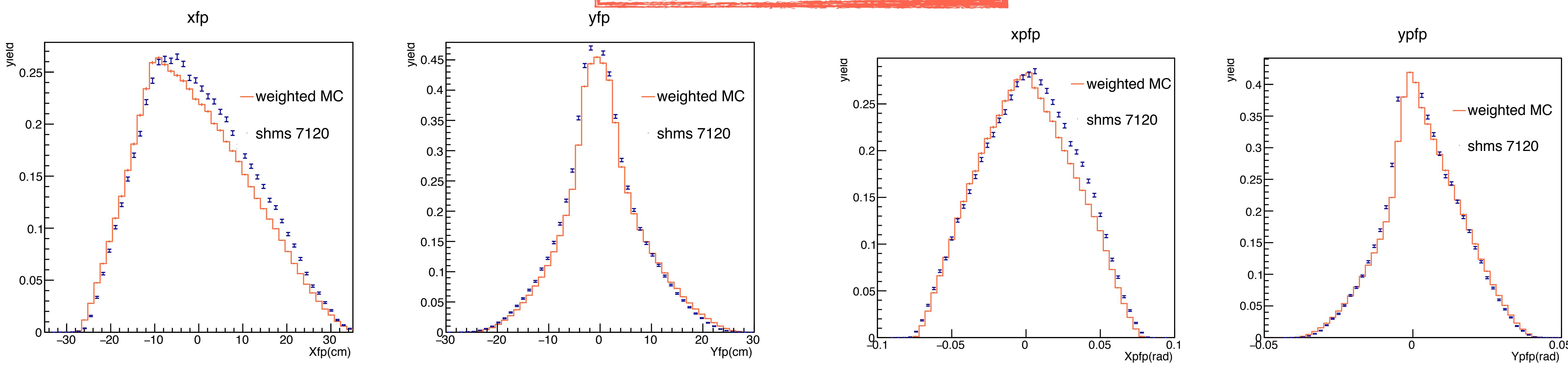
DIS ANALYSIS FOR ACCEPTANCE CORRECTION

SHMS DIS

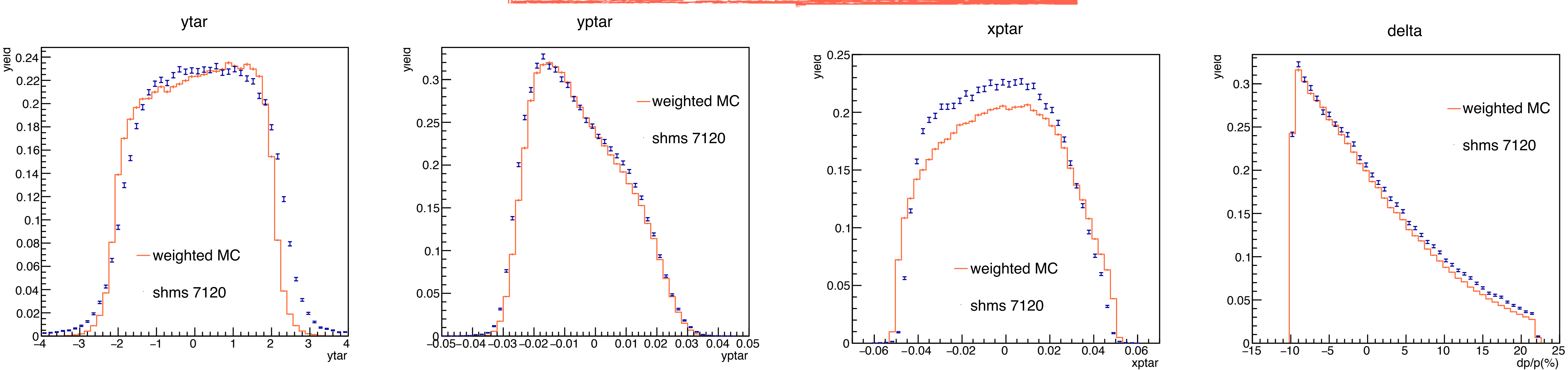
SHMS

Eb = 10.6 GeV Pc = 3.5 GeV, 25 deg

Focal Plane Quantities



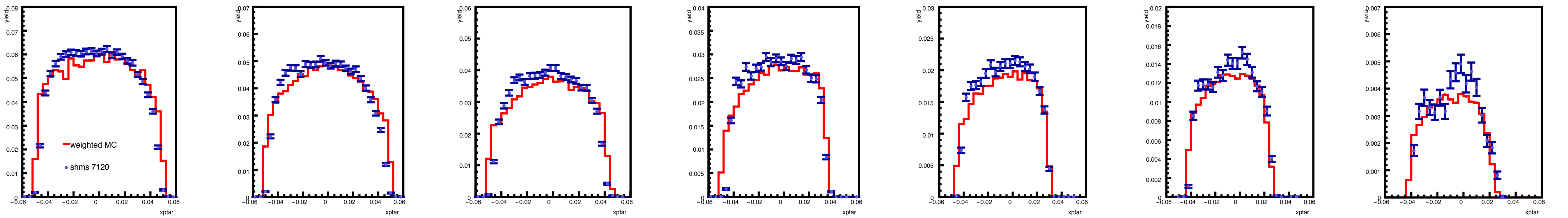
Target Quantities



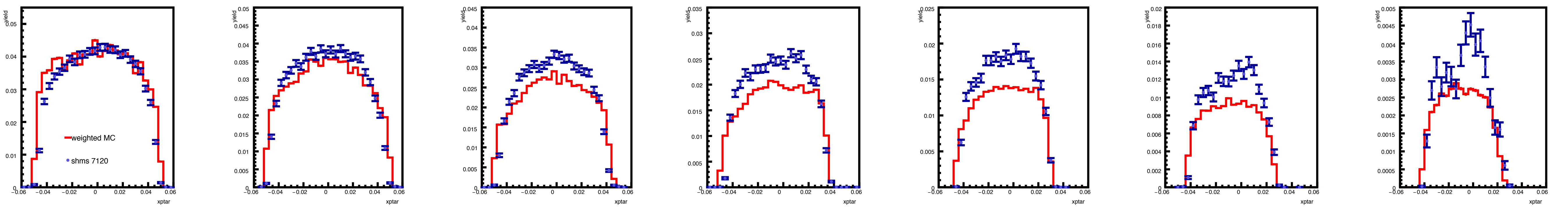
-10<dp<-5 | -5<dp<0 | 0<dp<5 | 5<dp<10 | 10<dp<15 | 15<dp<20 | 20<dp<22

xptar

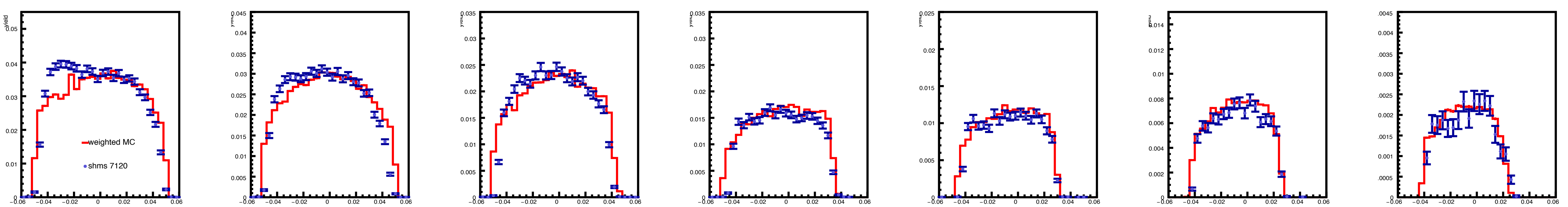
-2 < ytar < 2



0 < ytar < 2

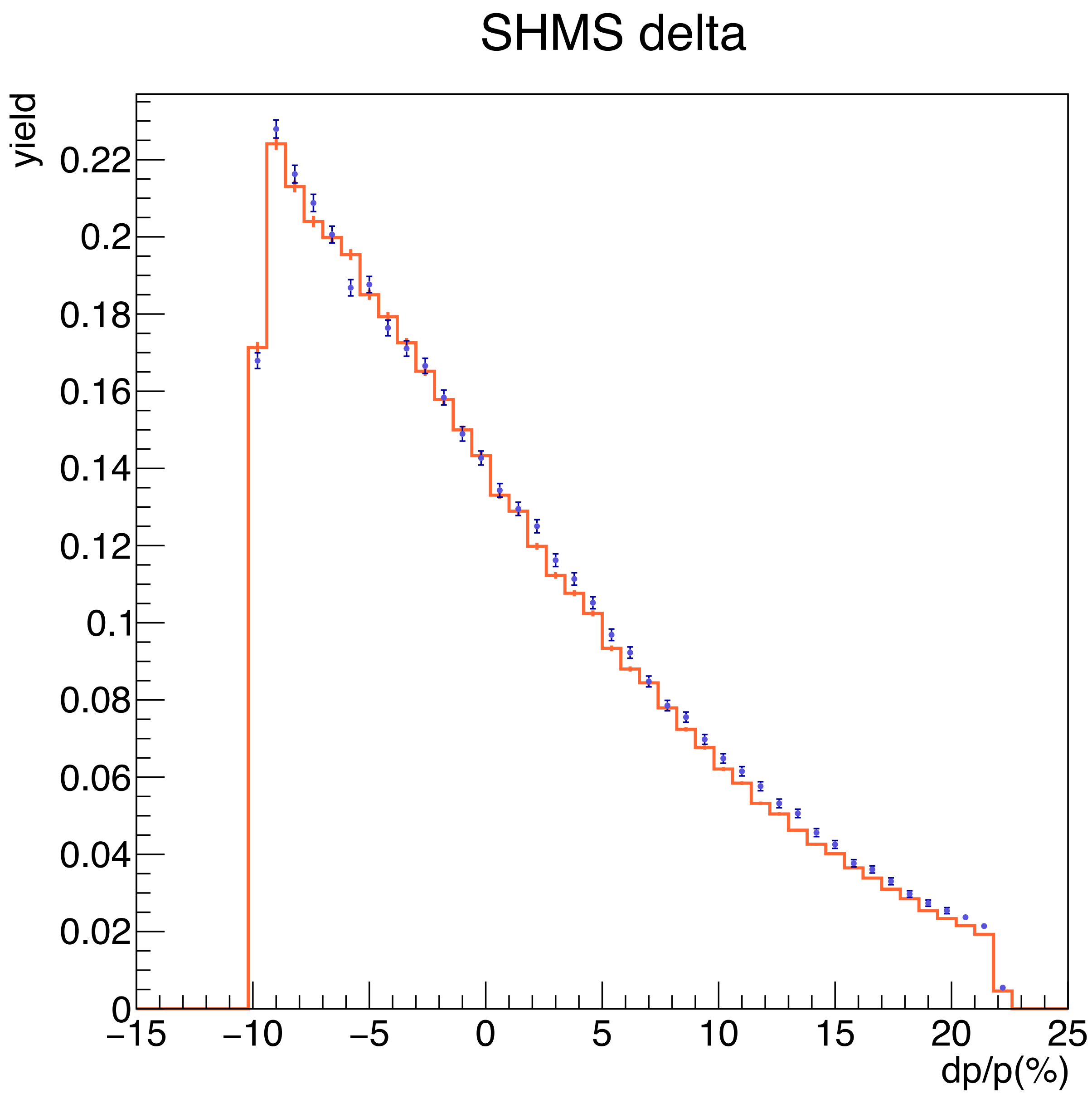


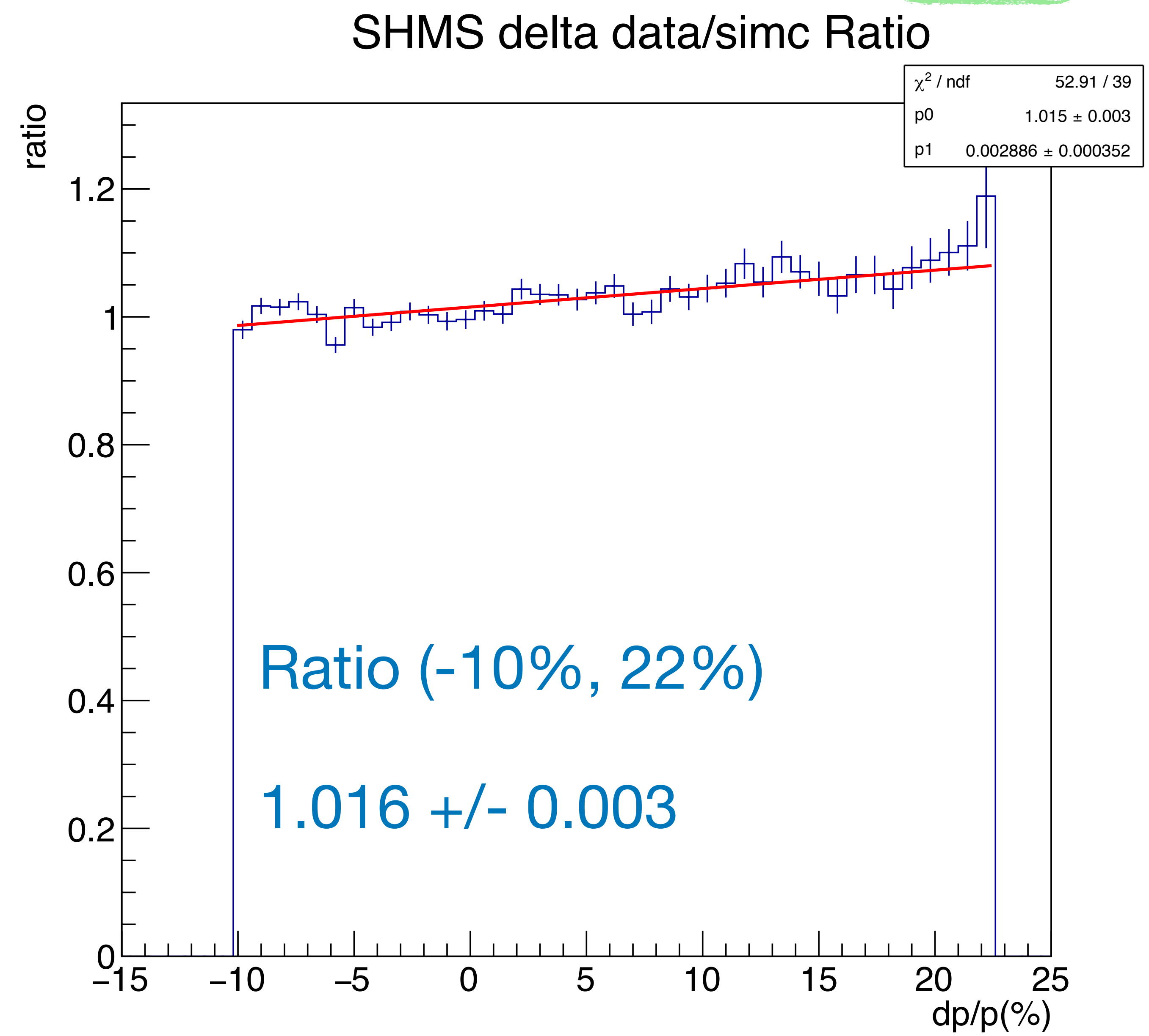
-2 < ytar < 0



DIS ANALYSIS FOR ACCEPTANCE CORRECTION

SHMS





- With a ytar cut between +/- 1.5 cm
- Most of the production data sits at this ytar region
- Looking for ways to recover low statistics setting

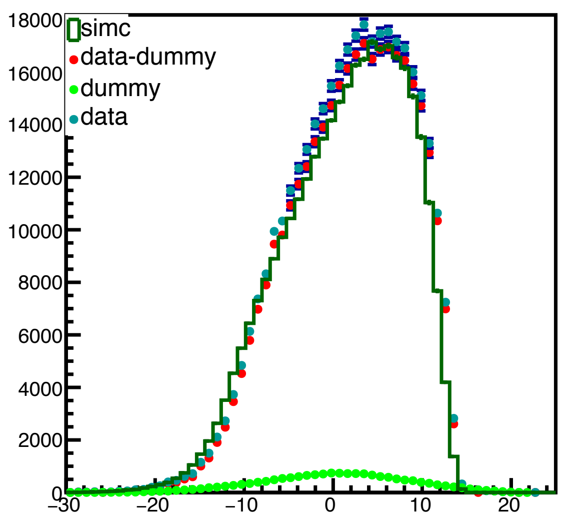
HMS Elastic Data Analysis

Representative plots from one of the kinematic settings

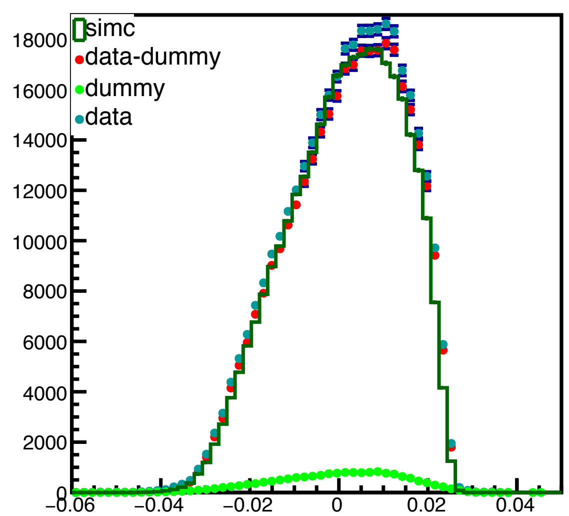
E_{beam} = 4.9409 GeV
P_c = 4.184 GeV
θ_c = 15 deg

Focal Plane Quantities

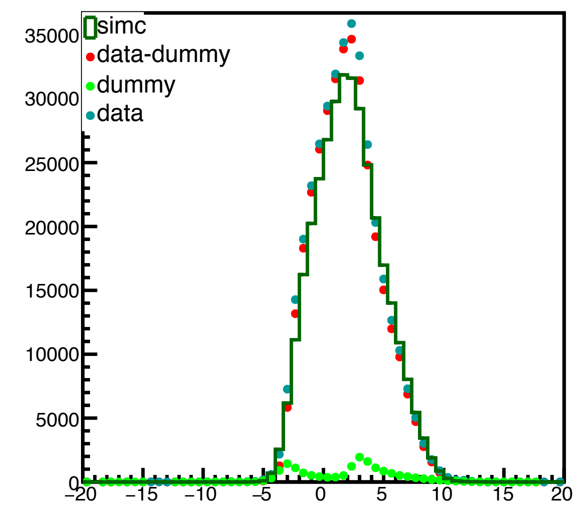
hms fp x



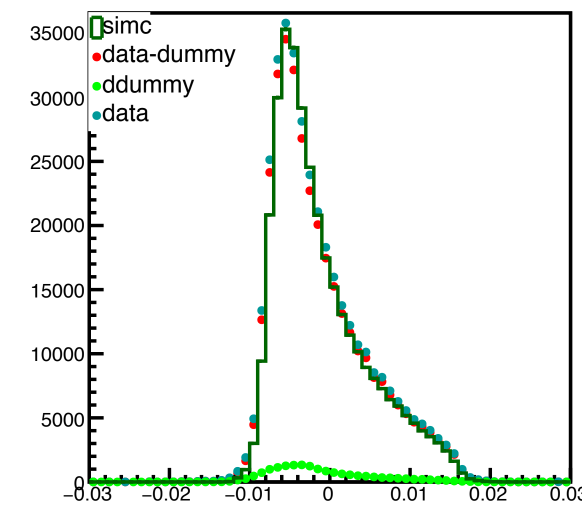
hms fp xp



hms fp y

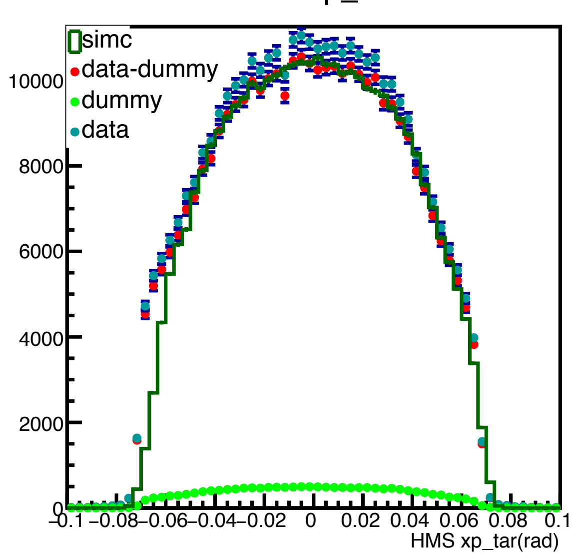


hms fp yp

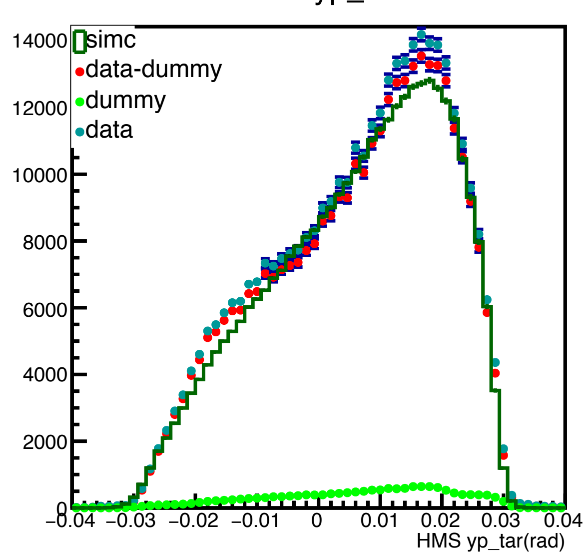


Target Quantities

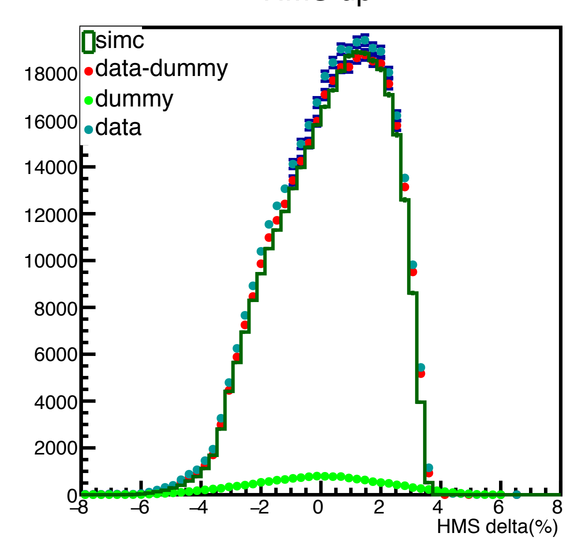
HMS xp_tar



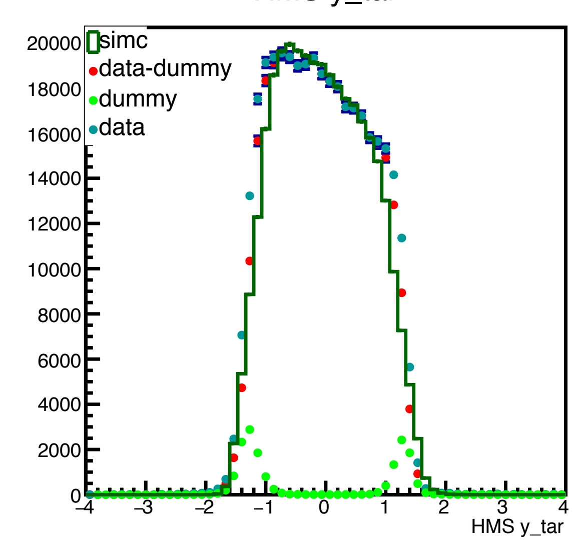
HMS yp_tar



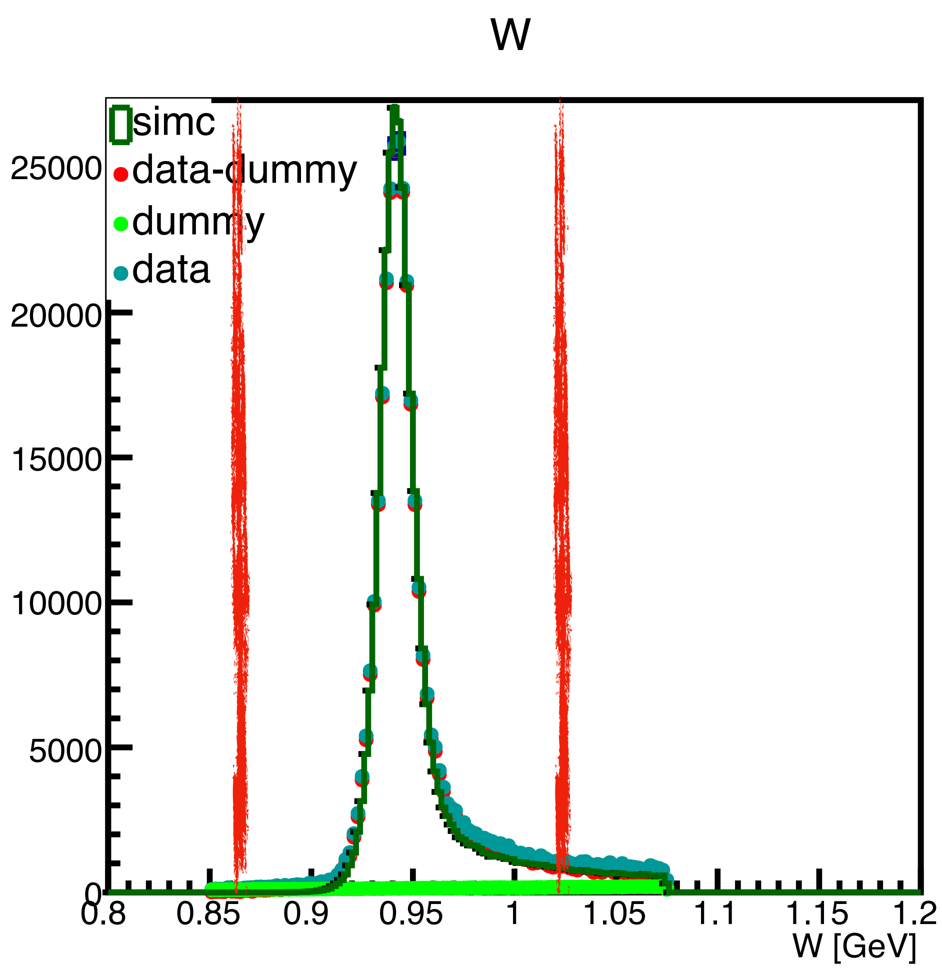
HMS dp

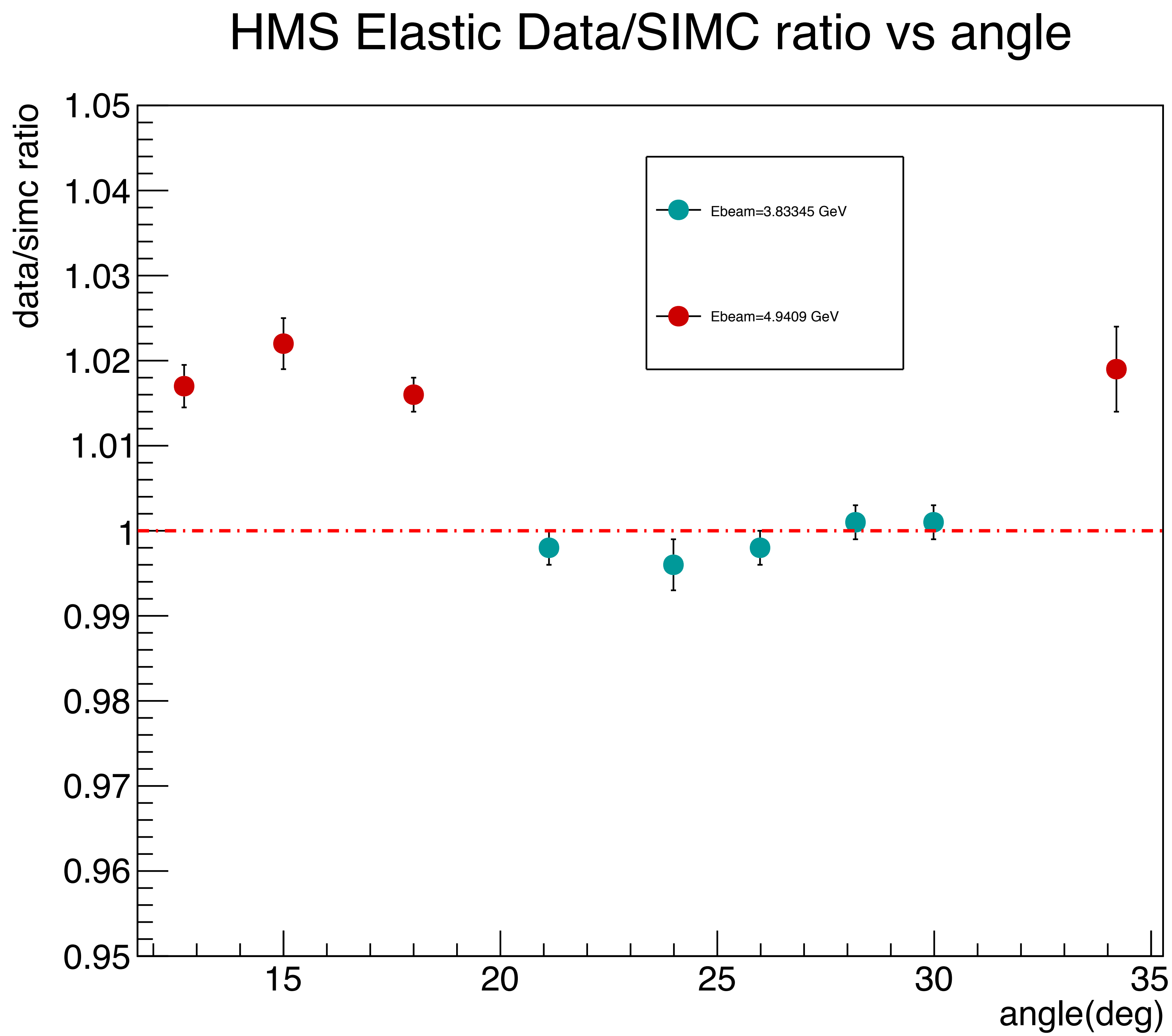


HMS y_tar



HMS Elastic Data Analysis





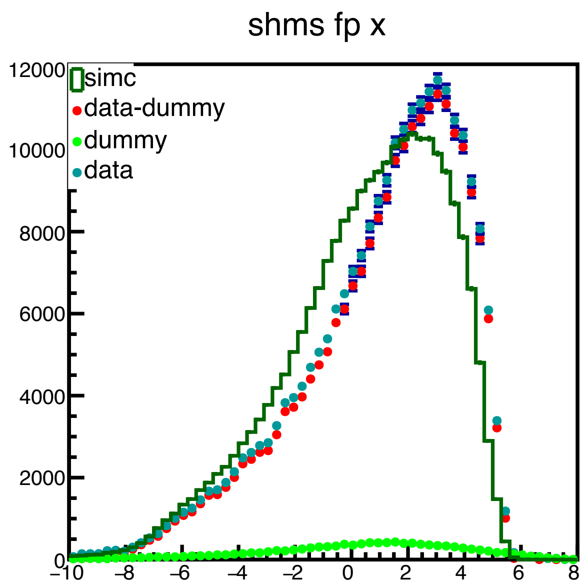
$$Ratio = \frac{Integral\ W\ data\ (0.86{,}1.02)}{Integral\ W\ simc\ (0.86{,}1.02)}$$

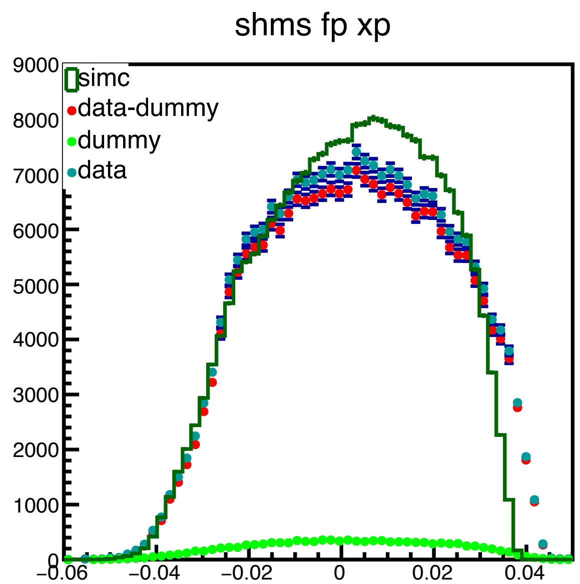
Preliminary SHMS Elastic Data Analysis

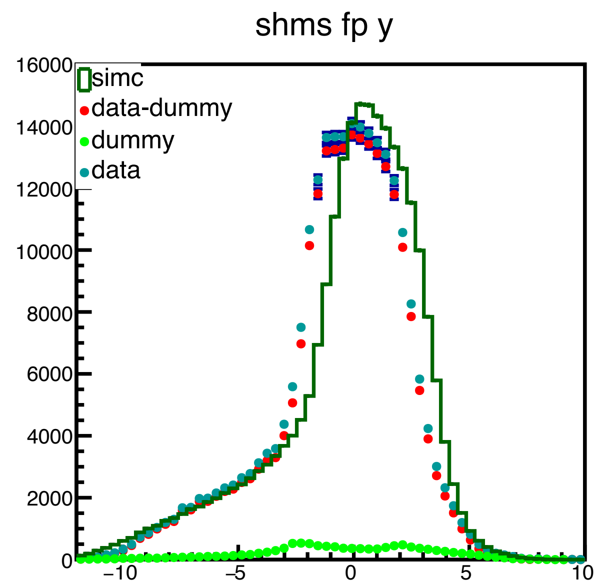
E_{beam} = 4.9409 GeV
P_c = 4.184 GeV
θ_c = 15 deg

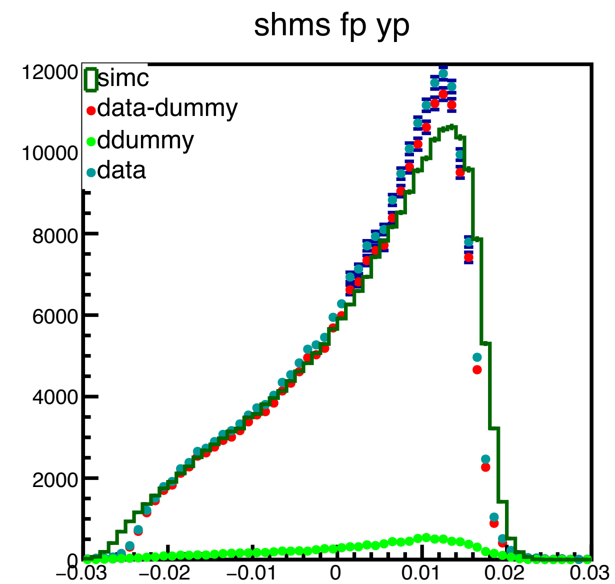
Representative plots from one of the kinematic settings

Focal Plane Quantities

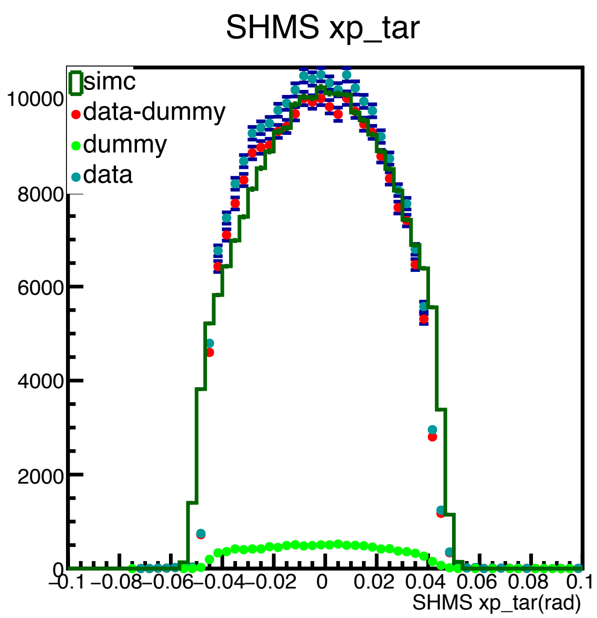


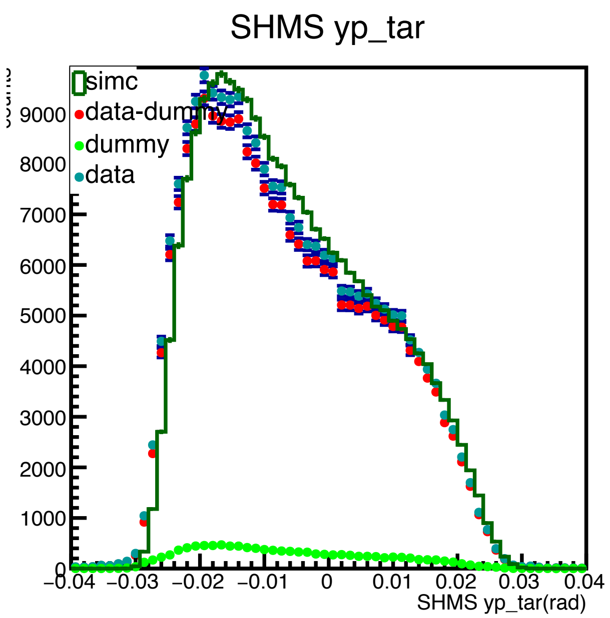


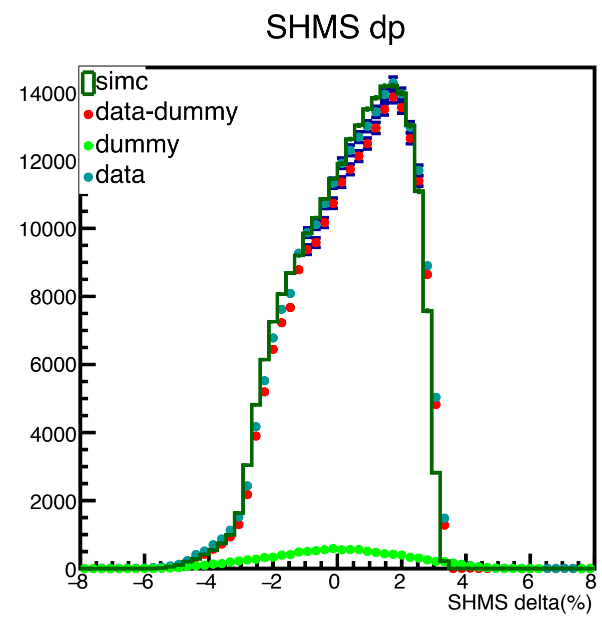


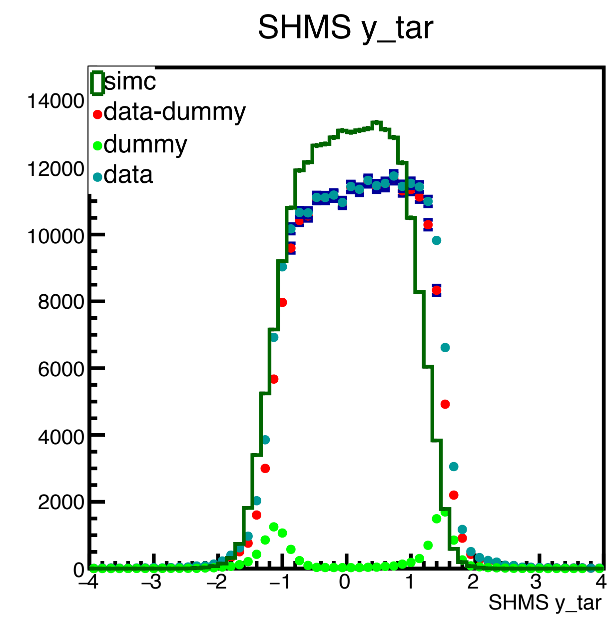


Target Quantities

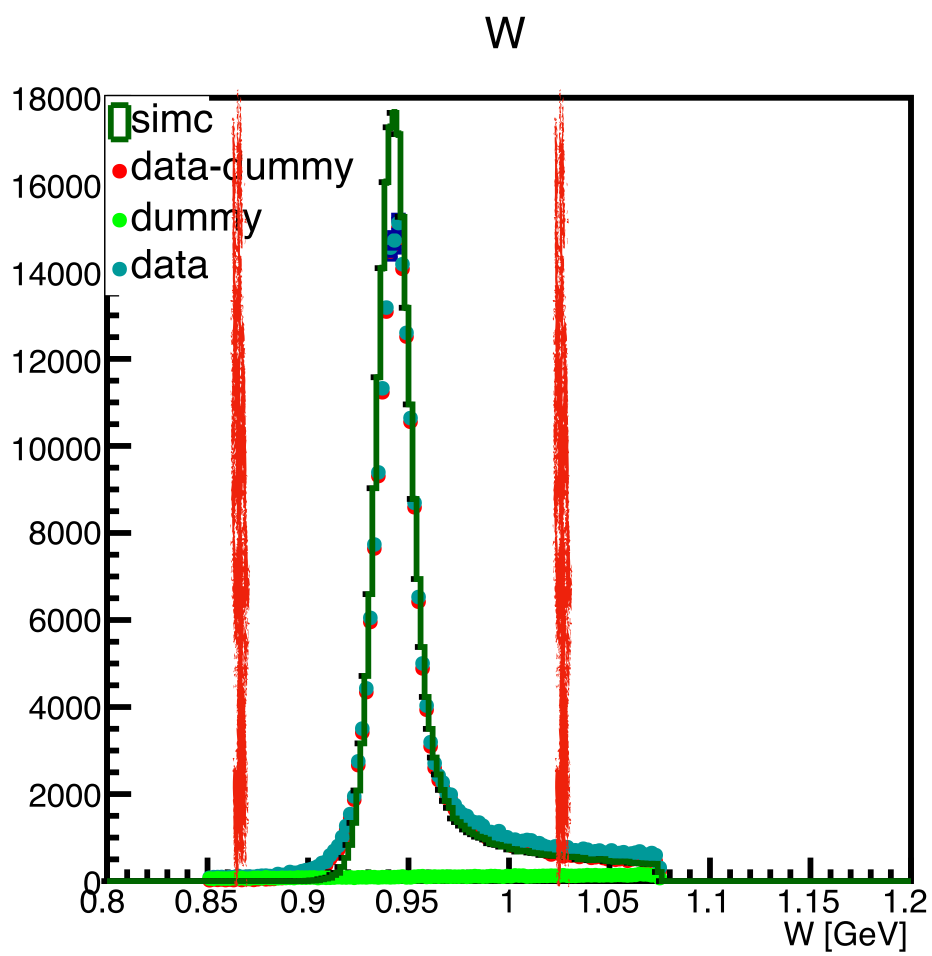


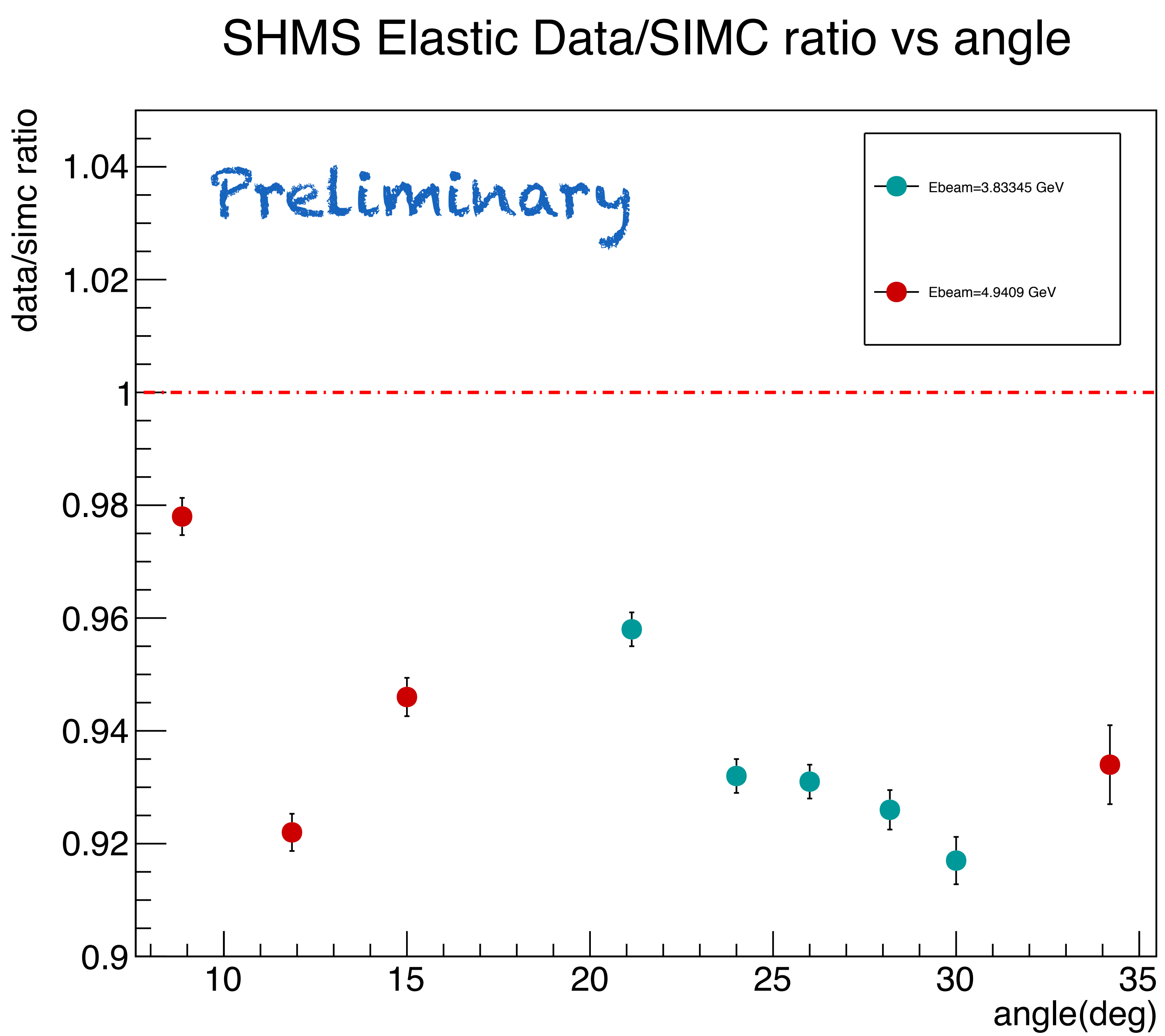






Preliminary SHMS Elastic Data Analysis

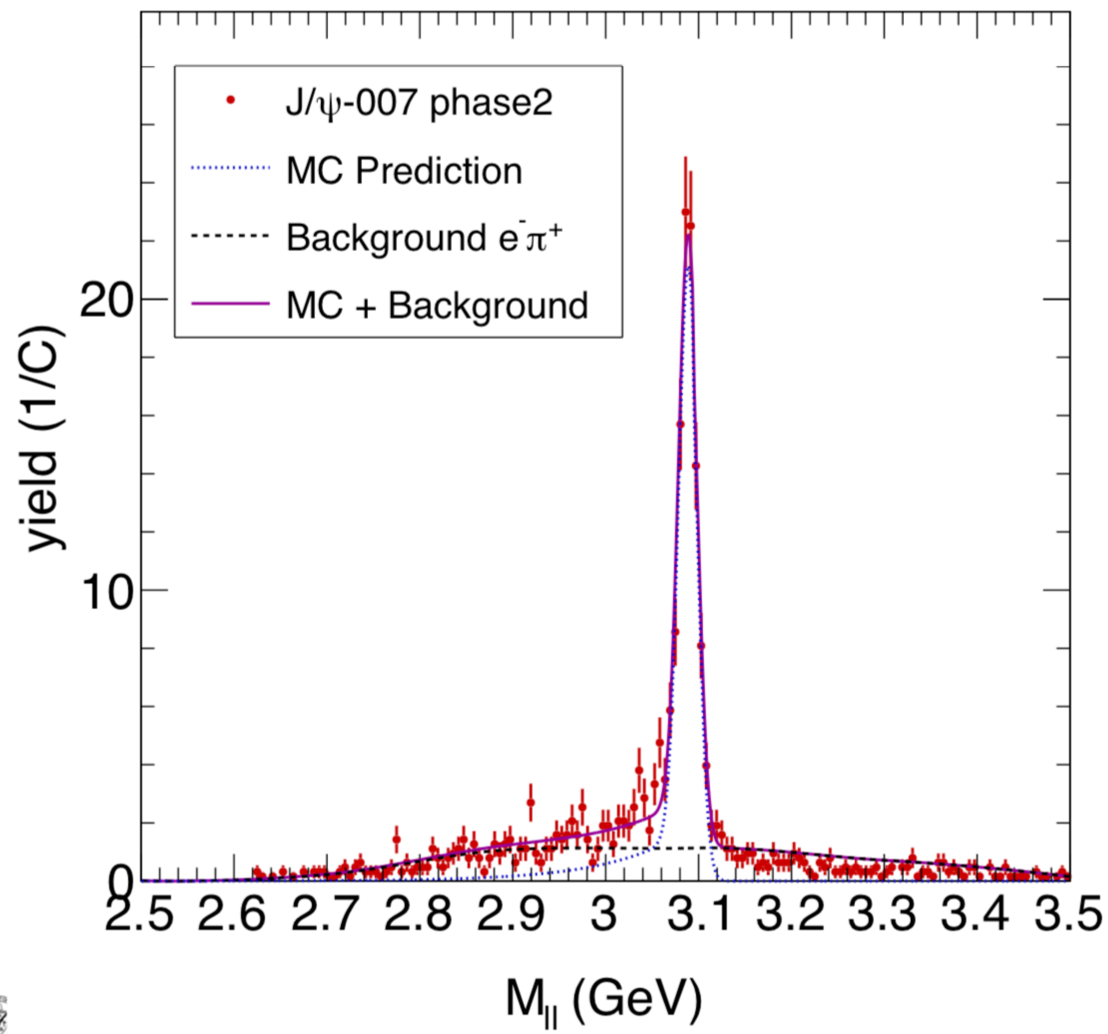




$$Ratio = \frac{Integral\ W\ data\ (0.86,1.02)}{Integral\ W\ simc\ (0.86,1.02)}$$

SIGNAL SHAPE WELL UNDERSTOOD

007[J/ψ]



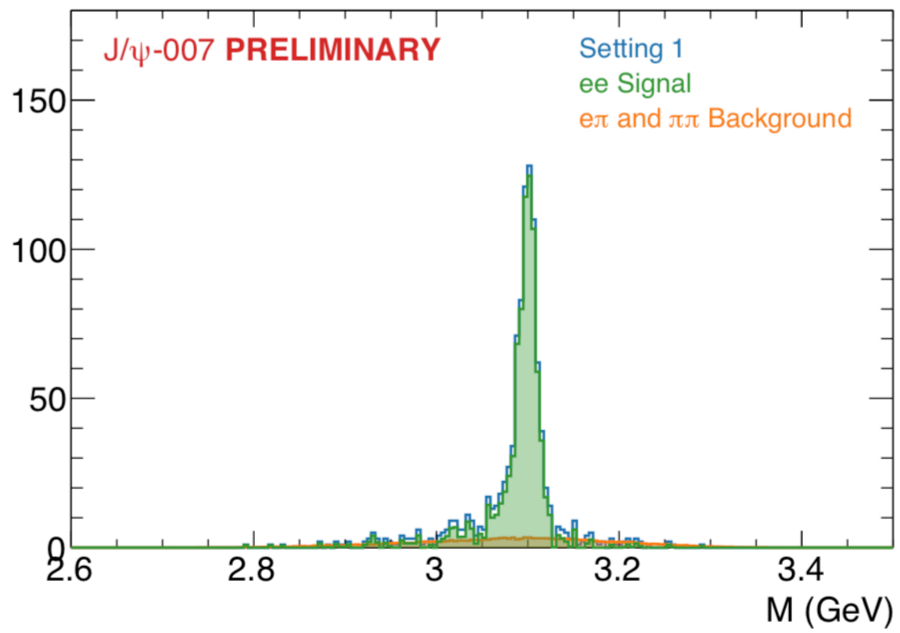
- MC has model of radiator, realistic target, detector and RC (using PHOTOS)
- Measured signal well described by MC for all settings.
- Background dominated by pion electro-production and 2-pion production
- Bethe-Heitler contamination very small due to large spectrometer angles
- Took data with open trigger: **background shape from real data!**

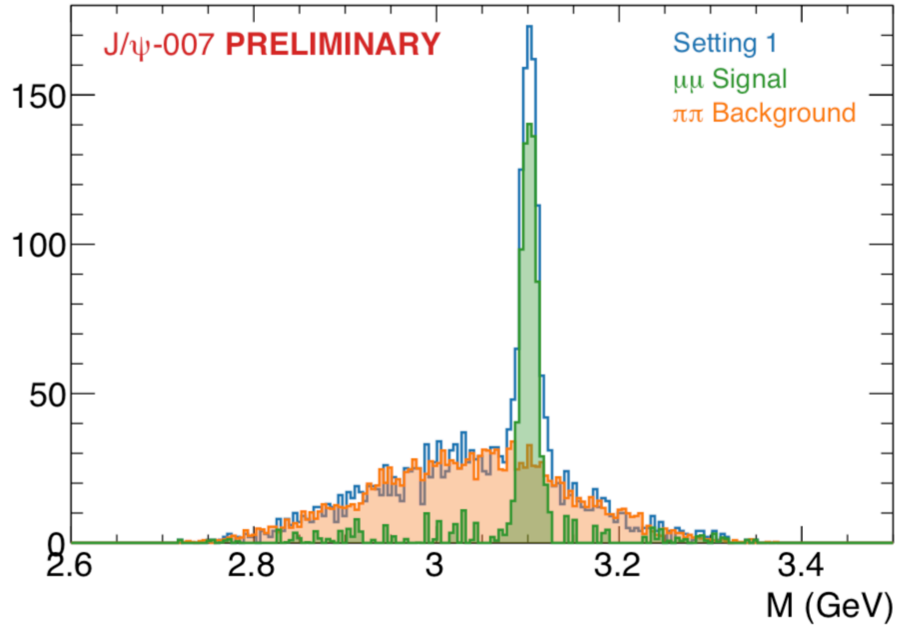
S. Joosten Argonne NATIONAL LABORATORY

Slide Credit: Sylvester Joosten

SIGNAL SHAPE WELL UNDERSTOOD

007$^{J/\psi}$



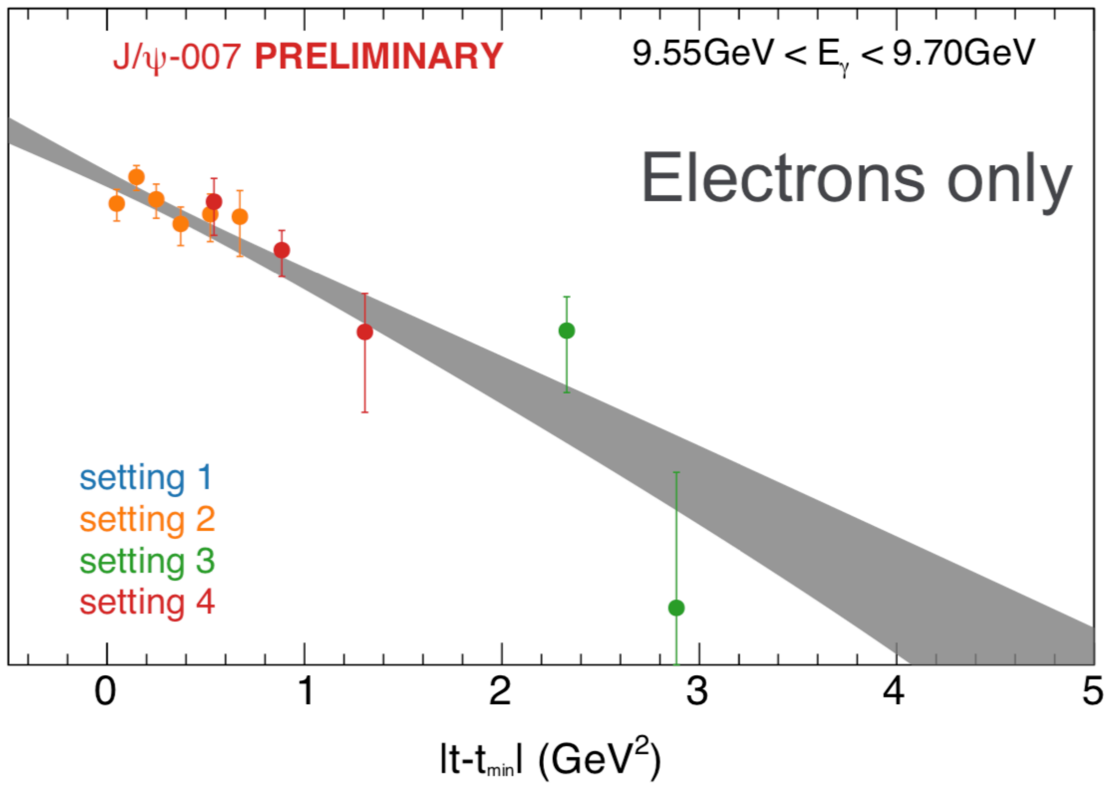


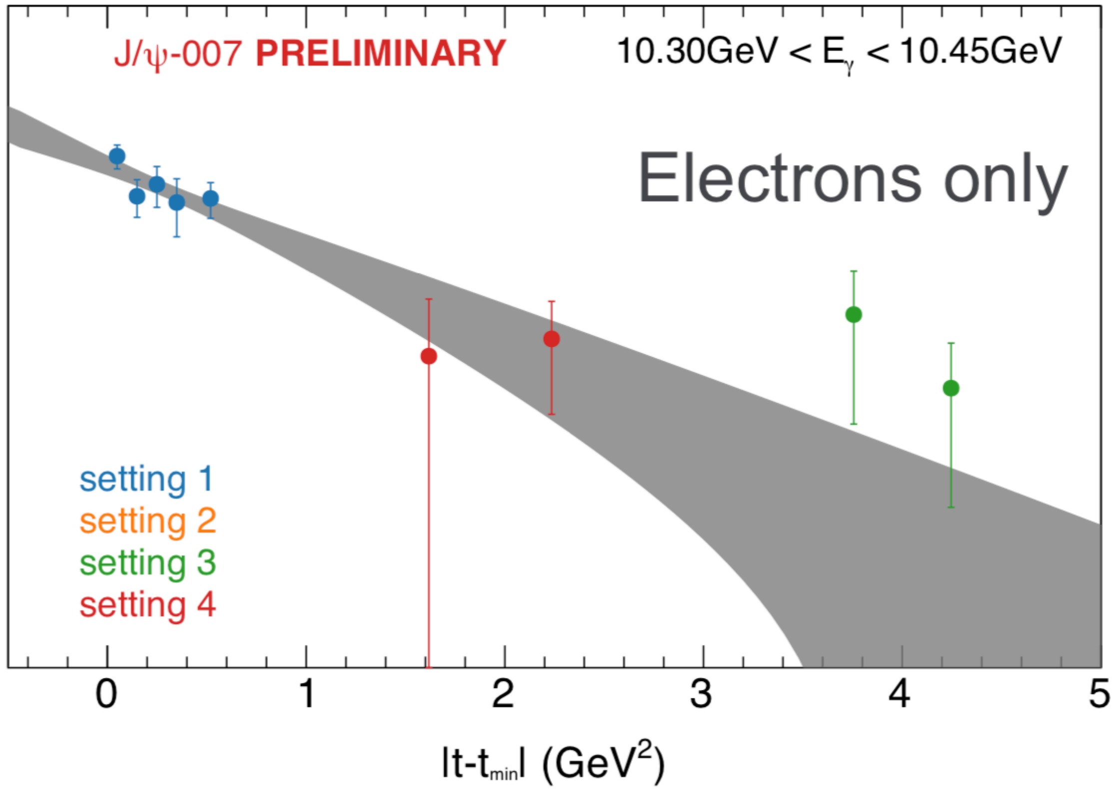
- **Electron and muon channels independent measurements, same statistics but different systematics**
- **Electrons:**
  - Low background with Cherenkov and ECAL for PID
  - Undergo multiple scattering and more sensitive to radiative losses
  - Slightly worse resolution (10MeV)
- **Muons**
  - More background using only ECAL (require coincidence MIP in 4 layers in HMS and 2 layers in SHMS), but still reasonable
  - Background dominated by 2-pion events, can get shape from dataset
  - Less sensitive to multiple scattering and radiative losses
  - Better resolution (8MeV)
- **Invariant mass positition *stable* between phases, well described by Monte Carlo!**

S. Joosten Argonne NATIONAL LABORATORY

Slide Credit: Sylvester Joosten

SNEAK PREVIEW OF RESULTS





- First ever determination of t-dependence of the cross section in bins of 150MeV of photon energy between 9.1 and 10.6 GeV
- Highly sensitive to presence of s-channel resonance
- Only showing electron data, muon data is separate experiment with same statistics!

Slide Credit: Sylvester Joosten

THANK YOU!

This work is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No DE-FG02-94ER4084 and in part DEAC02-06CH11357.

BACK UP SLIDES

- W (Eb, E', $\boldsymbol{\theta}$)

Correction on Eb assuming no contribution from E' and θ

- $\frac{\partial W}{\partial Eb} = \frac{E\prime}{Eb}$ → $dEb = \frac{Eb \;\, dw}{E\prime}$ $\quad Eb_{corr} = Eb + dEb = Eb\ (1 + \frac{dw}{E\prime})$

- *Correction on E' assuming no contribution from Eb and θ*

- $\frac{\partial W}{\partial E\prime} = - \frac{Eb}{E\prime}$ → $dE' = -\frac{E\prime \; dw}{Eb}$ $\quad E'corr = E' + dE' = E'\ (1 - \frac{dw}{Eb})$

Correction on θ assuming no contribution from E' and Eb

- $\frac{\partial W}{\partial \boldsymbol{\theta}} = - \frac{Eb * E' * sin\boldsymbol{\theta}}{Mp}$ → $d\boldsymbol{\theta} = - \frac{Mp * dW}{Eb * E' * sin\boldsymbol{\theta}}$

Summary of Minimization Results for the SHMS

007 $^{J/\psi}$

Table 1

p1	**0.0008**	**+/-**	**0.000987585**
p2	-0.00233786	+/-	0.000691074
p3	0.000255028	+/-	0.000424399

SHMS Minimum: f(p1, p2, p3): χ^2

p1 = dEb/Eb, p2=dE'/E', p3=dθ

SHMS Minimum: f(0.0008,-0.00233786,0.000255028): 17.6498

Table 1-1

p1	**=**	**0 (fixed)**		
p2	=	-0.00322227	+/-	0.000690196
p3	=	0.000461619	+/-	0.000424445

SHMS Minimum: f(0,-0.00322227,0.000461619): 19.6901

Minimization with ROOT minuit2

Table 1-1-1

p1	**=**	**0 (fixed)**		
p2	=	-0.00249502	+/-	0.000180913
p3	=	0 (fixed)		

SHMS Minimum: f(0,-0.00249502,0): 20.8699

Pc * 0.9975

Summary of Minimization Results for the HMS

007 $^{J/\psi}$

Table 1

p1	**=**	**0.000799998**	**+/-**	**0.00138583**
p2	=	-0.00412396	+/-	0.000882243
p3	=	0.00181553	+/-	0.000568871

HMS Minimum: f(p1, p2, p3): χ^2

p1 = dEb/Eb, p2=dE'/E', p3=dθ

HMS Minimum: f(0.000799998,-0.00412396,0.00181553): 5.68389

Table 1-1

p1	**=**	**0 (fixed)**		
p2	=	-0.00506089	+/-	0.00089314
p3	=	0.00207486	+/-	0.000569175

HMS Minimum: f(0,-0.00506089,0.00207486): 6.20531

Minimization with ROOT minuit2

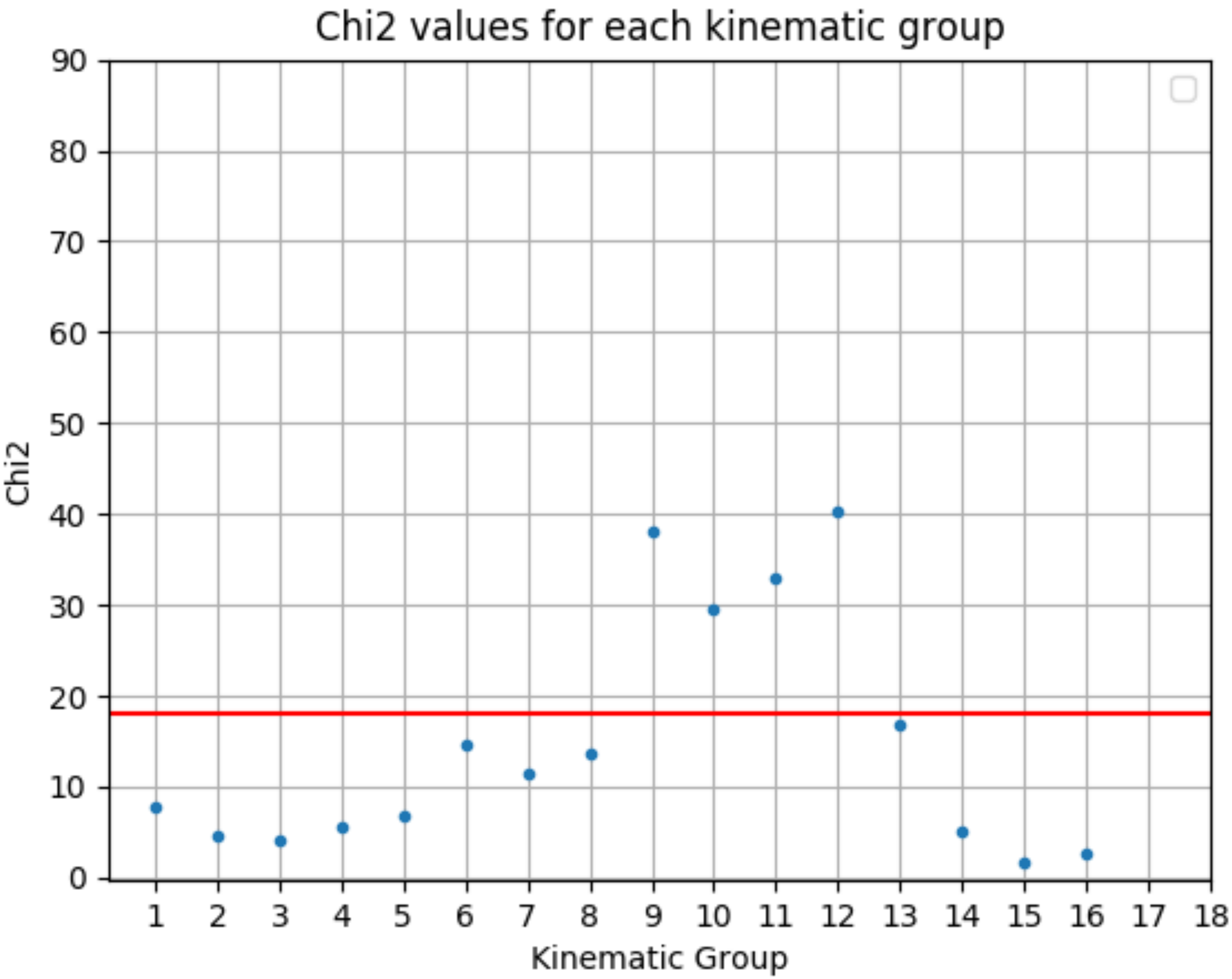
Table 1-1-1

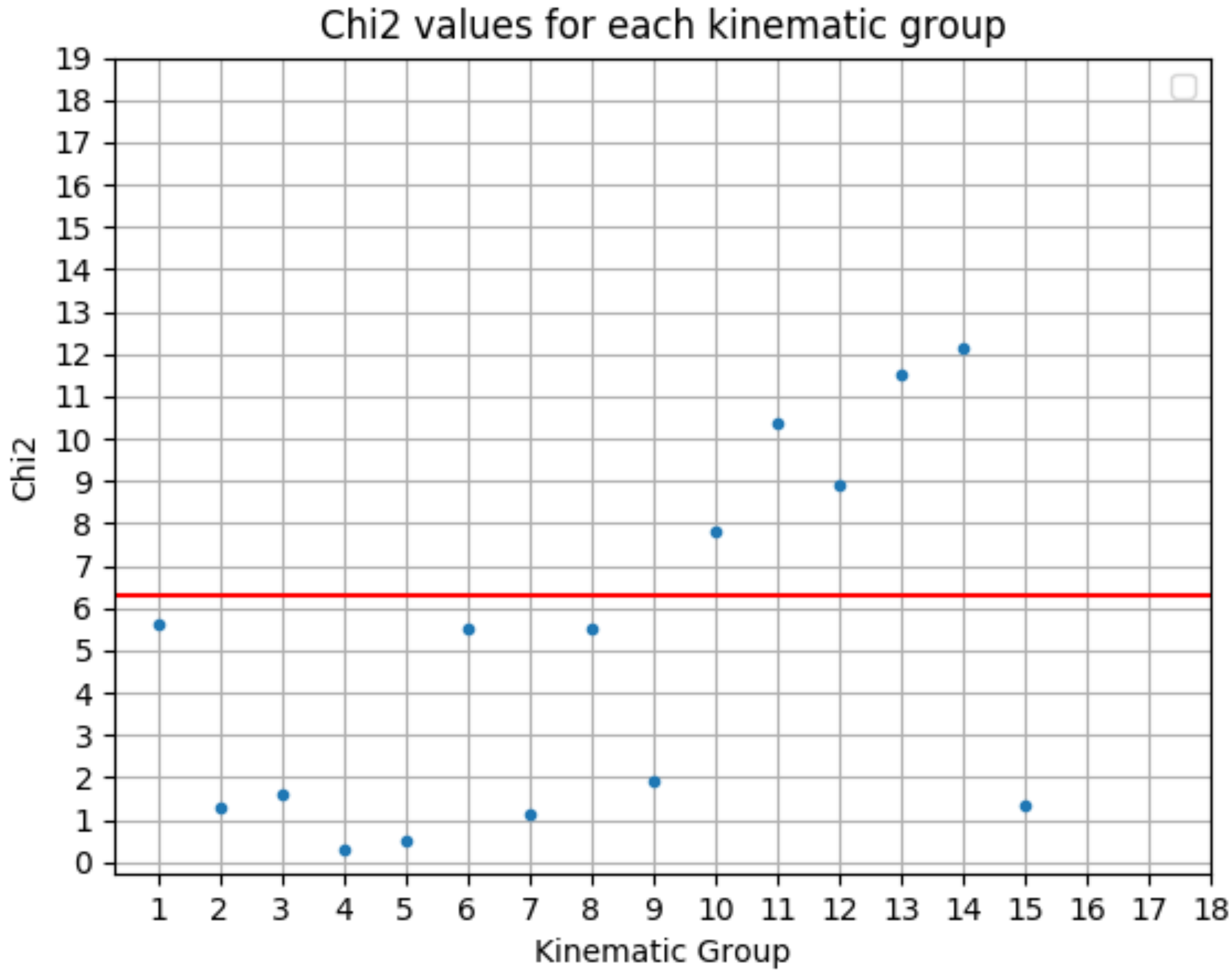
p1	**=**	**0 (fixed)**		
p2	=	-0.00188021	+/-	0.000201595
p3	=	0 (fixed)		

HMS Minimum: f(0,-0.00188021,0): 19.4776

Pc * 0.9988

p1 = 0.0008, p2=-0.002, p3=0.0




Chi2 values for each kinematic group
Chi2
Kinematic Group
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

HMS Elastic Data Analysis

HMS	Ebeam (GeV)	P (GeV)	θ (deg)	Target
6595	3.8334	3.007	21.12	LH2
6597	3.8334	3.007	21.12	DUMMY
6598	3.8334	2.834	23.989	DUMMY
6601	3.8334	2.834	23.989	LH2
6602	3.8334	2.713	25.985	LH2
6604	3.8334	2.713	25.985	DUMMY
6606	3.8334	2.583	28.185	DUMMY
6609	3.8334	2.583	28.185	LH2
6611	3.8334	2.478	29.985	LH2
6612	3.8334	2.478	29.985	DUMMY
6871	4.9409	4.371	12.71	LH2
6872	4.9409	4.371	12.71	DUMMY
6874	4.9409	4.184	15	DUMMY
6875	4.9409	4.184	15	LH2
6876	4.9409	3.923	18	LH2
6877	4.9409	3.923	18	DUMMY
6878	4.9409	2.583	34.2	DUMMY
6879	4.9409	2.583	34.2	LH2

Preliminary SHMS Elastic Data Analysis

SHMS	Ebeam (GeV)	P (GeV)	θ (deg)	Target
6621	3.8334	3.007	21.14	LH2
6622	3.8334	3.007	21.14	DUM
6623	3.8334	2.834	24	LH2
6625	3.8334	2.834	24	DUM
6626	3.8334	2.713	26	DUM
6627	3.8334	2.713	26	LH2
6629	3.8334	2.583	28.19	LH2
6630	3.8334	2.583	28.19	DUM
6632	3.8334	2.478	30	DUM
6633	3.8334	2.478	30	LH2
6871	4.9409	4.642	8.86	LH2
6872	4.9409	4.642	8.86	DUM
6874	4.9409	4.436	11.86	DUM
6875	4.9409	4.436	11.86	LH2
6876	4.9409	4.184	15	LH2
6877	4.9409	4.184	15	DUM
6878	4.9409	2.583	34.2	DUM
6879	4.9409	2.583	34.2	LH2

$$LH2\ yield = \frac{counts * PS}{Q_{LH2} * TE_{LH2} * LT_{LH2}}$$

$$DUMMY\ yield = \frac{counts * PS}{Q_{dum} * TE_{dum} * LT_{dum}}$$

Cuts on data:

-10< delta < 22

Calorimeter > 0.8

0.85 < W < 1.075

$$dummy\ subtracted\ yield = LH2\ yield - (DUMMY\ yield * \frac{LH2\ thickness}{DUMMY\ thickness})$$

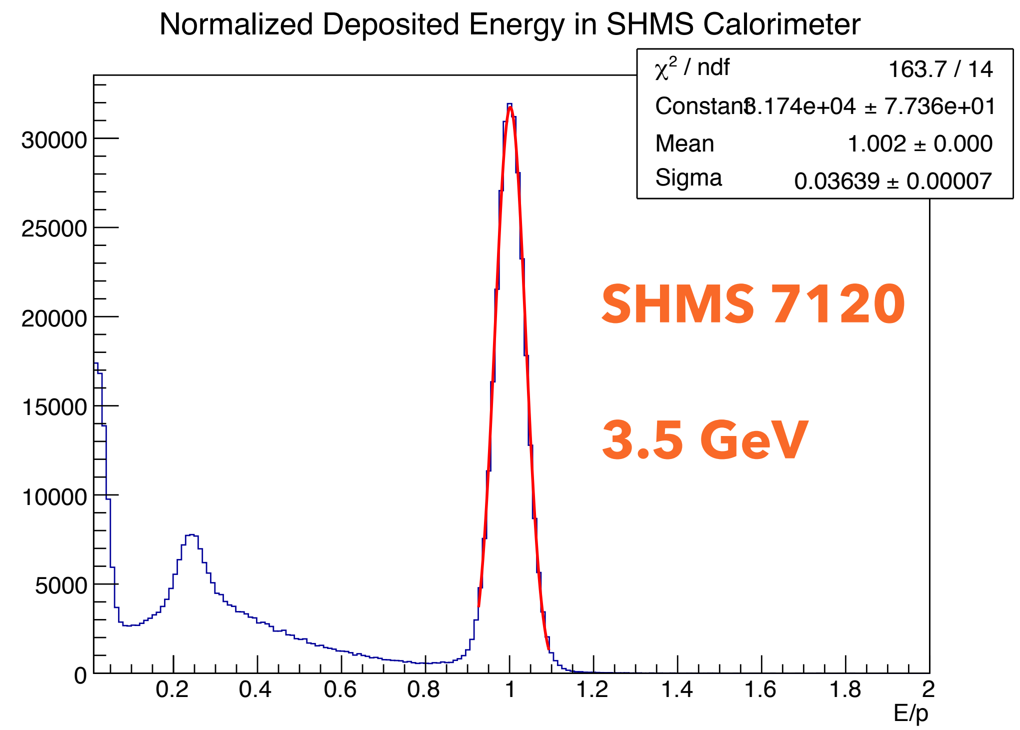
Live time = computer live time * (1 - estimated electronic dead time)

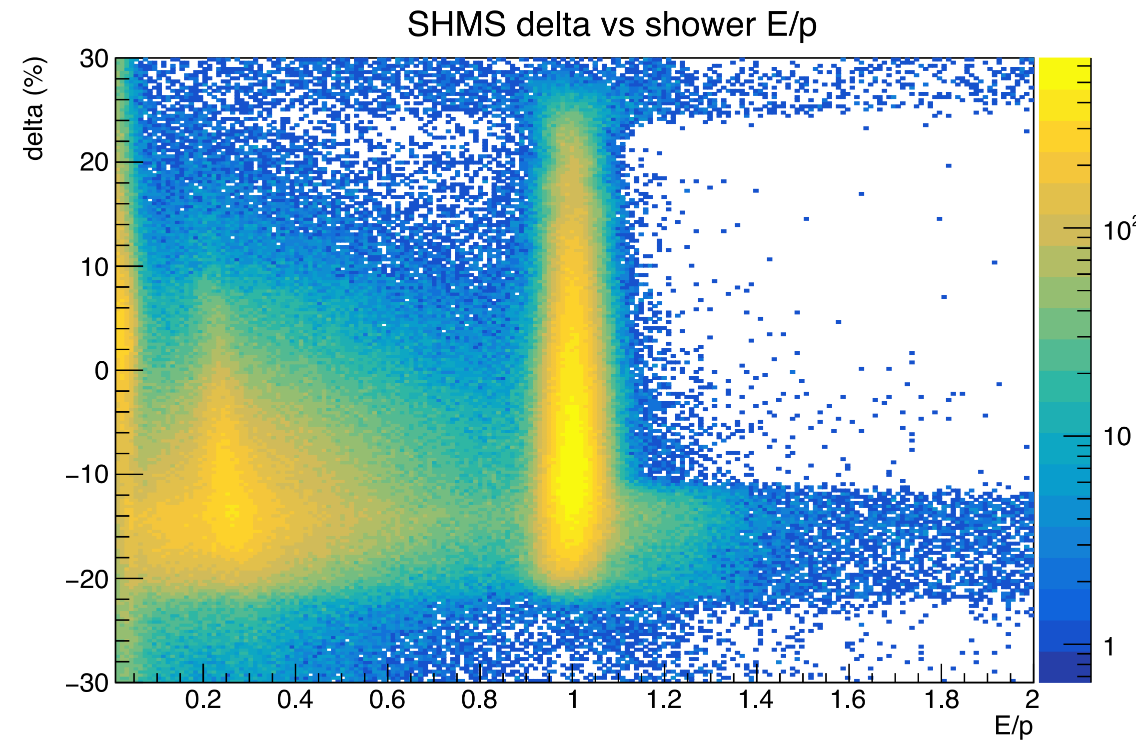
Accepted ptrig2 events / scaler ptrig2 events

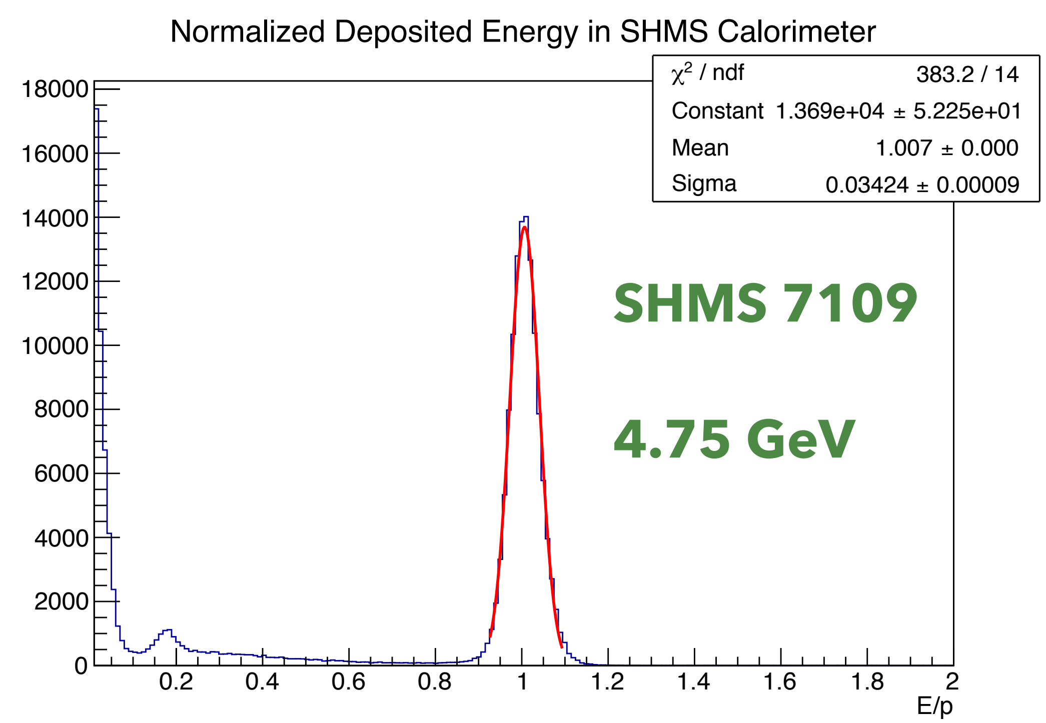
50 ns * ptrig2 rate

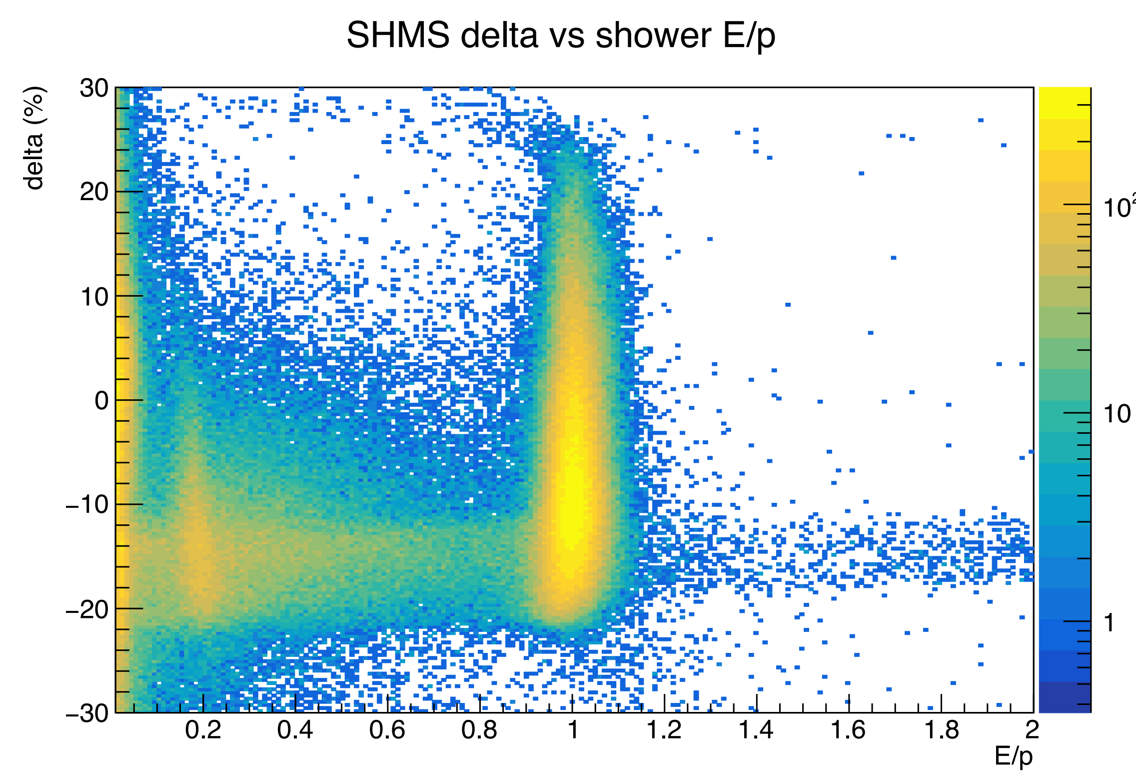
DETECTOR CALIBRATIONS

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

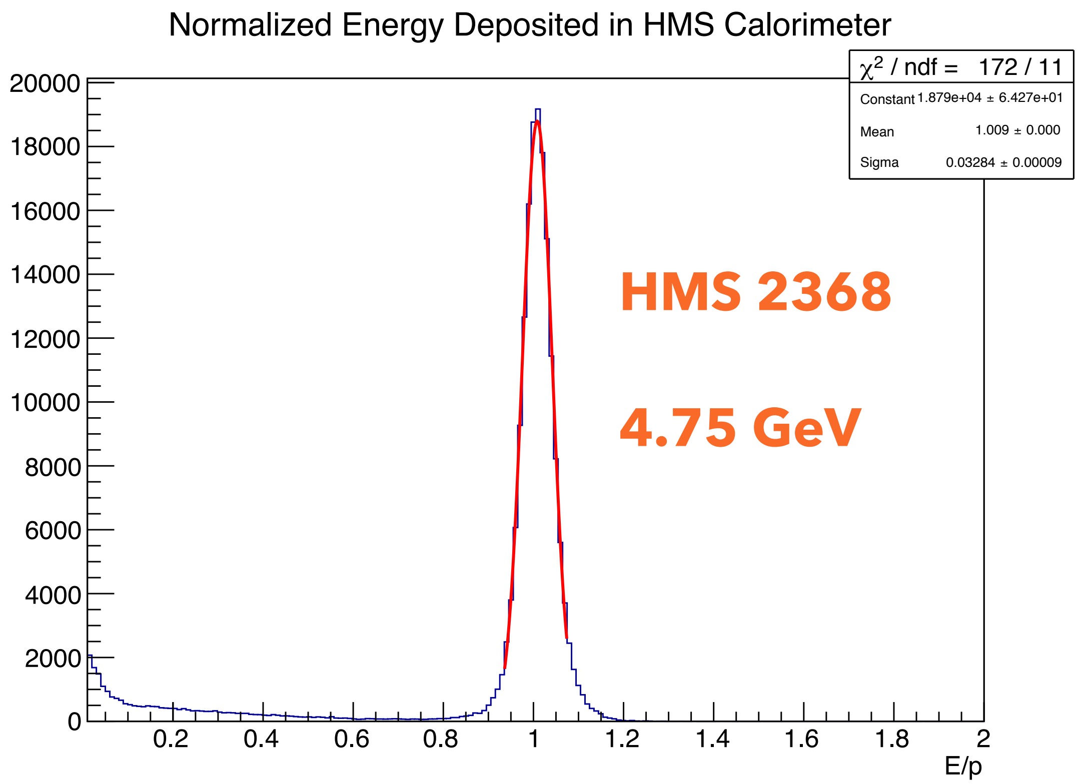


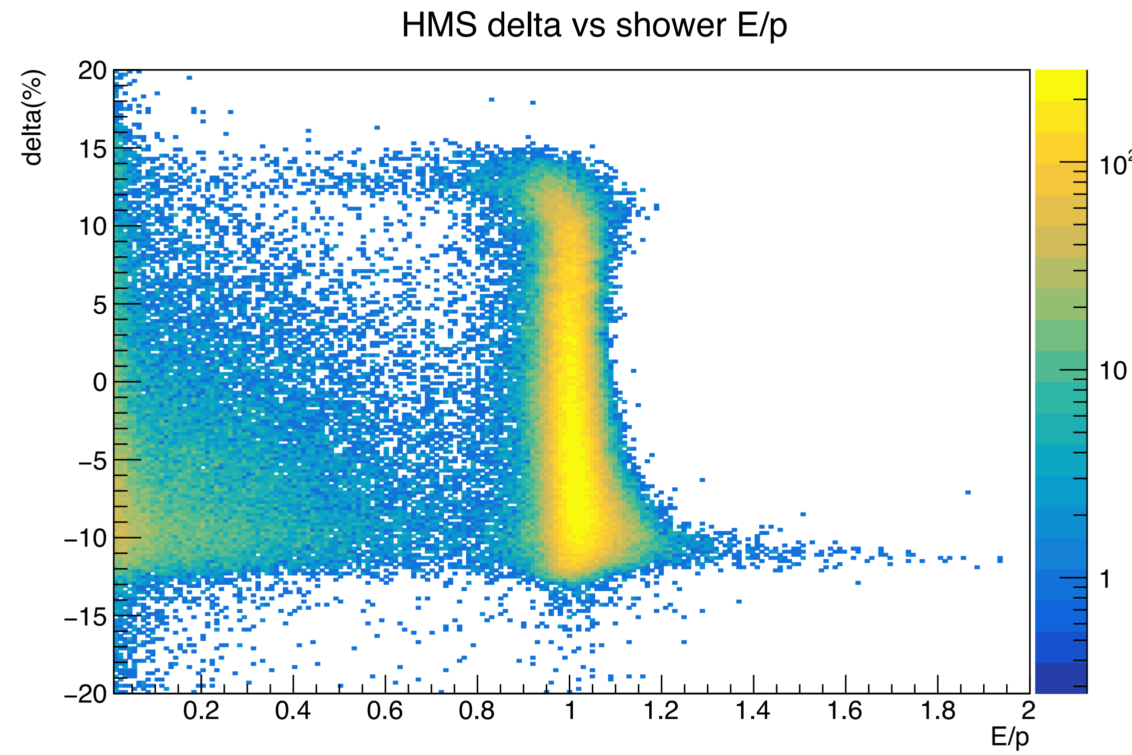


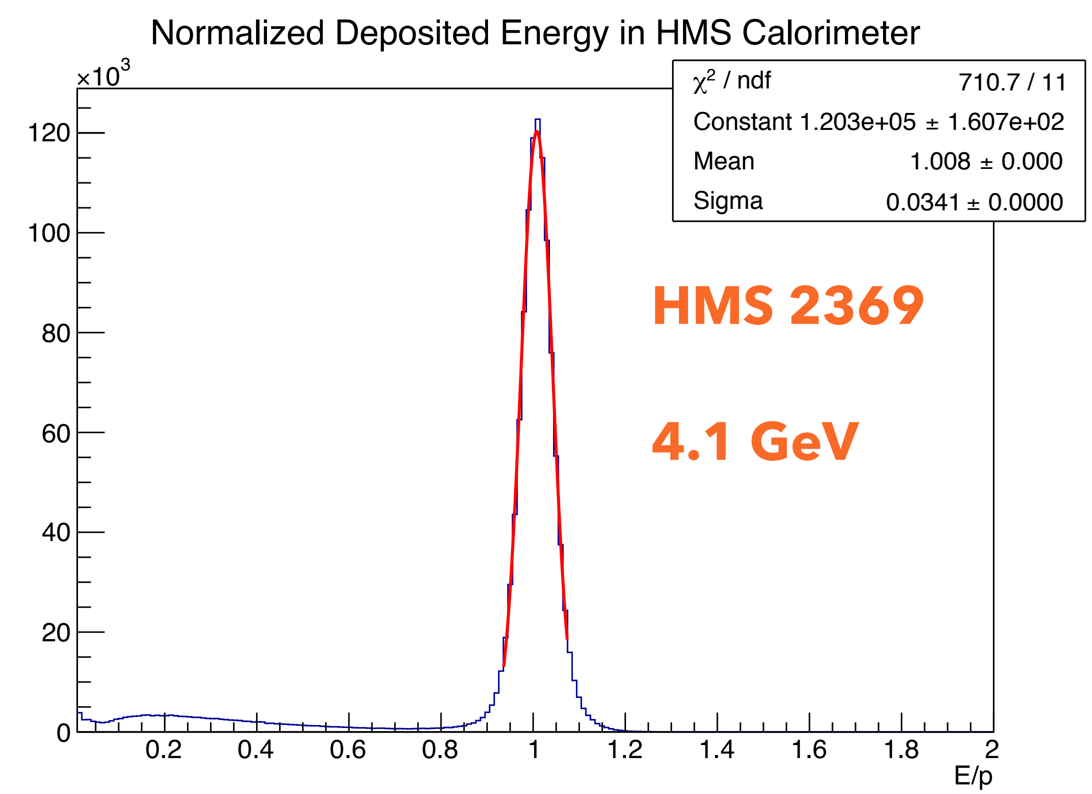


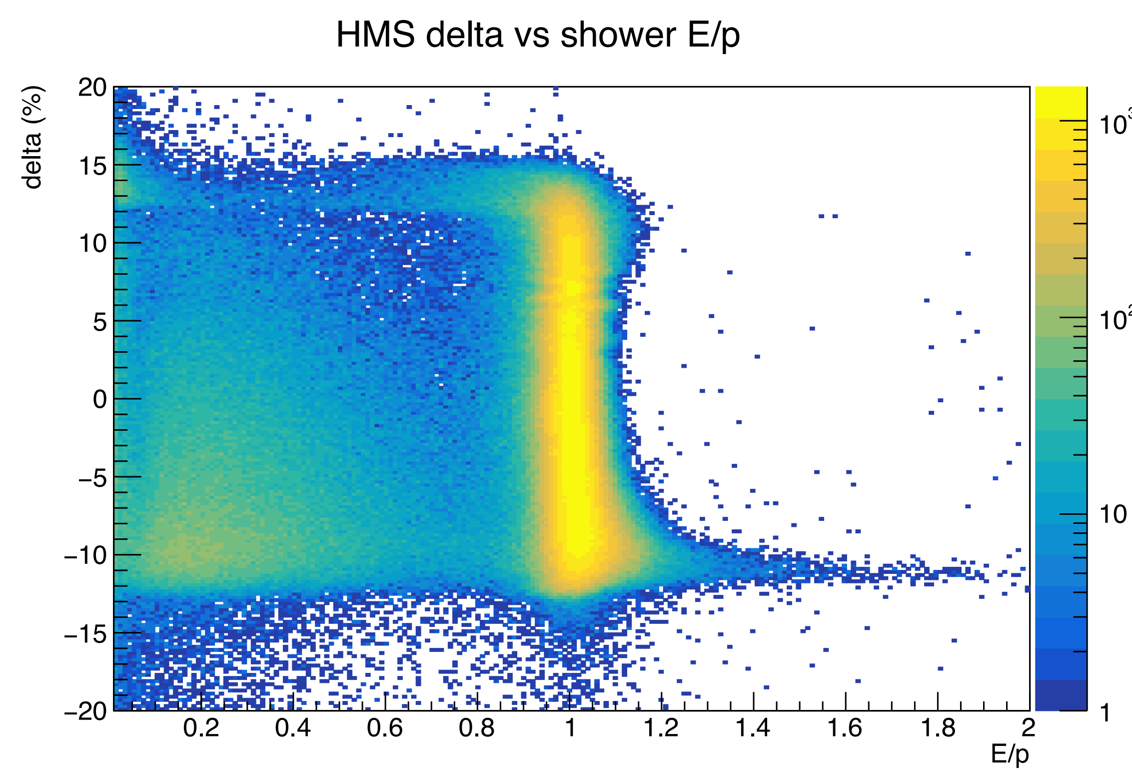


HMS Calorimeter: 2 calibration runs 4.1 GeV and 4.75 GeV





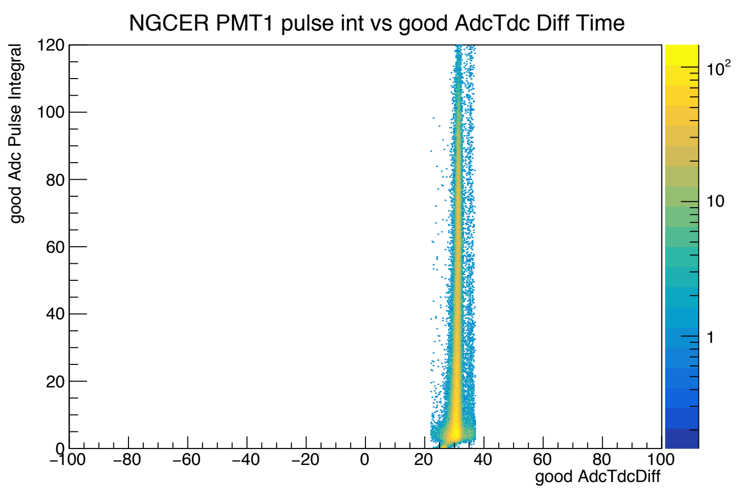


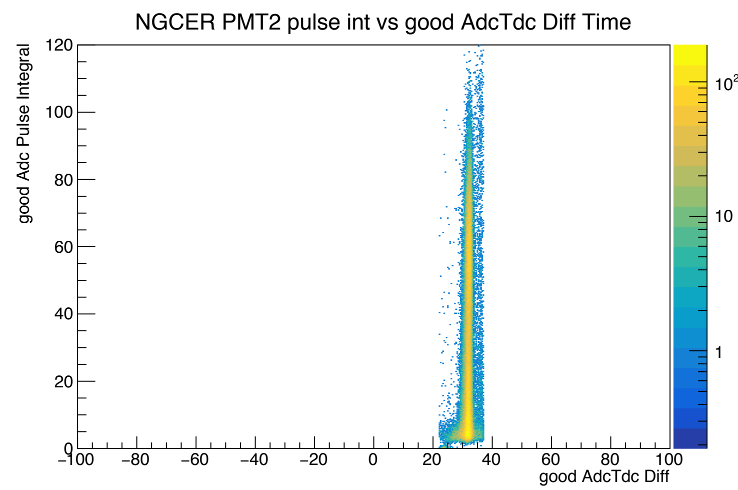


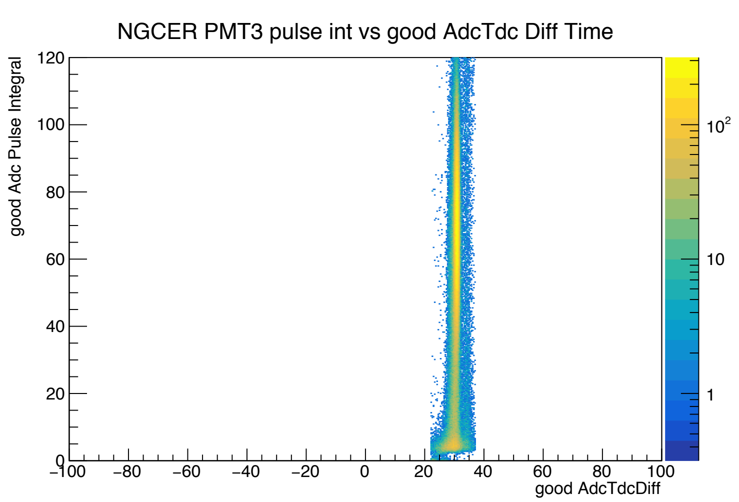
DETECTOR CALIBRATIONS

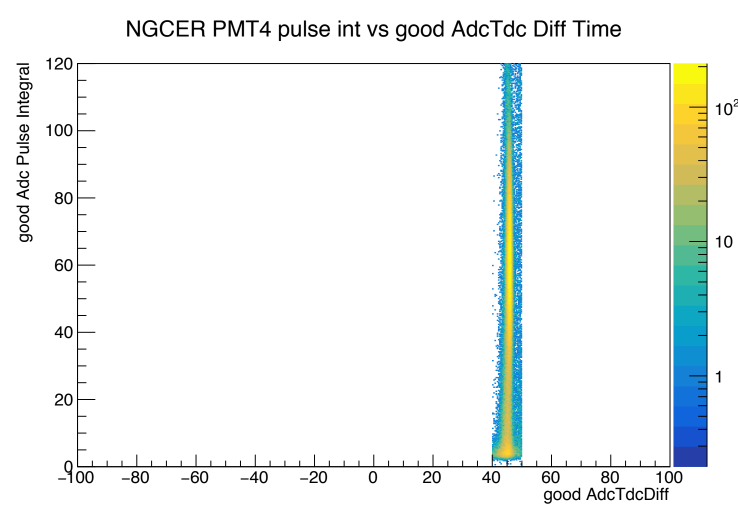
SHMS NGCER Calibration with Run 7120

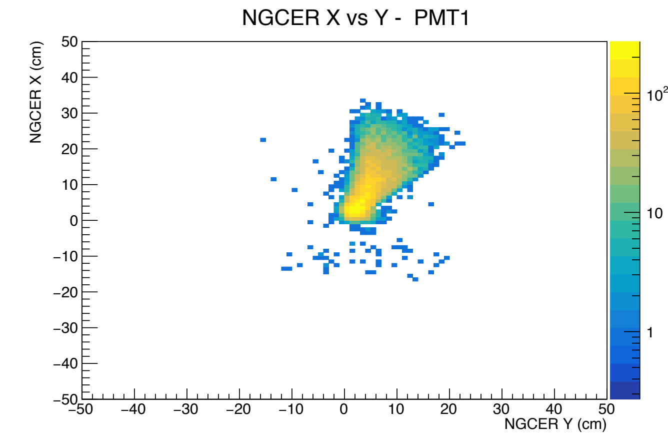
- ★ Timing cut to reject hits per event with super low amplitude
- ★ Calorimeter cut to choose electrons (P.cal.etottracknorm > 0.8)
- ★ Multiplicity cut to ensure only the pmt under calibration has a hit
- ★ X and Y cuts at the mirror planes
- ★ Pulse Integrals for each pmt were fit to get the calibration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

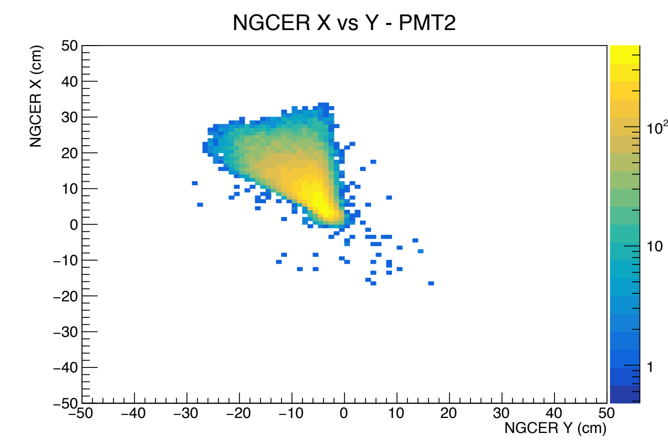


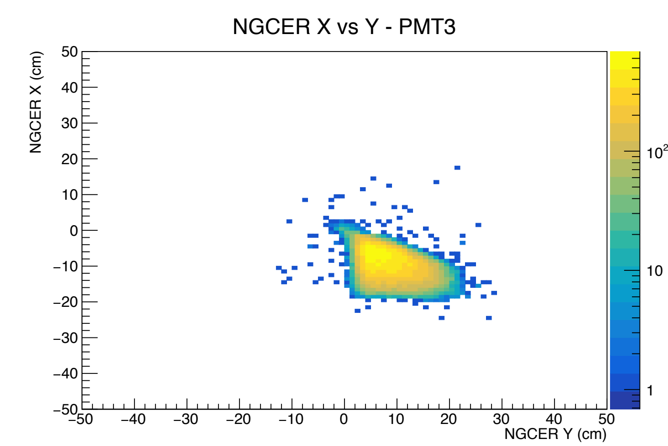


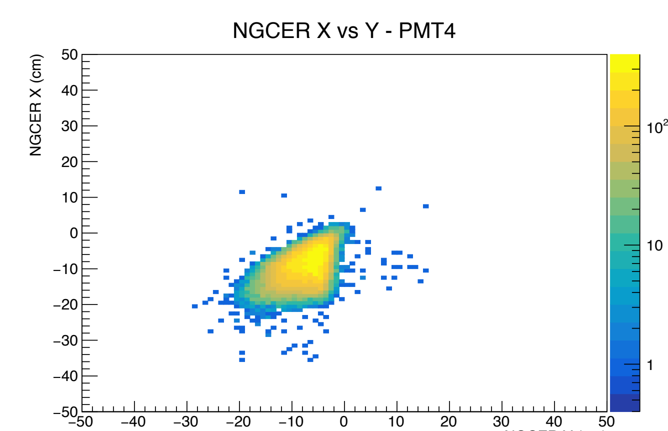






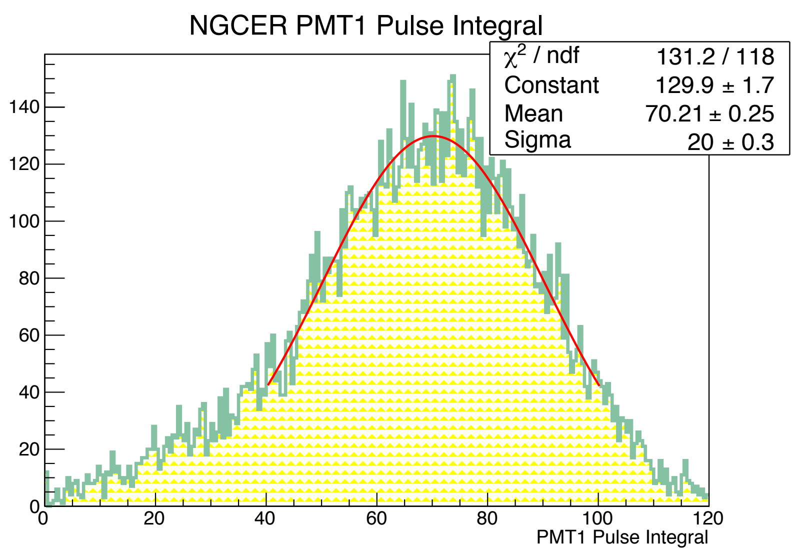


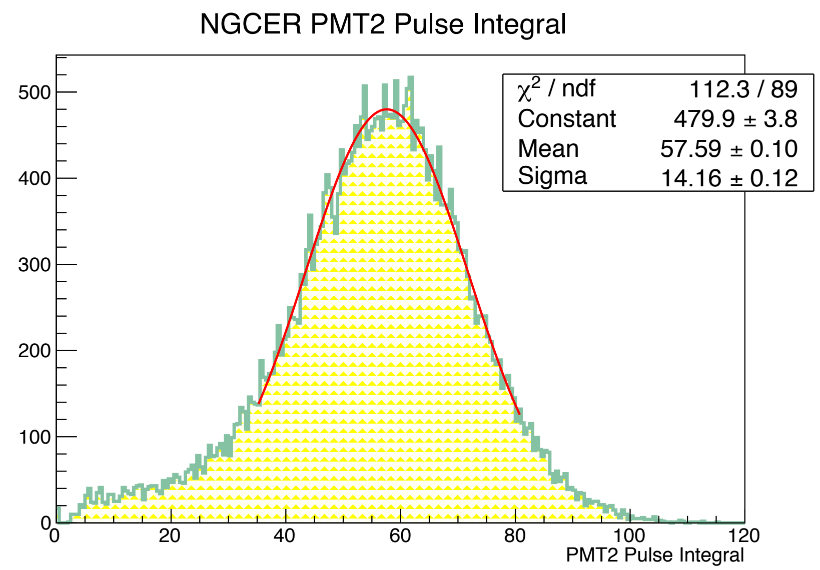


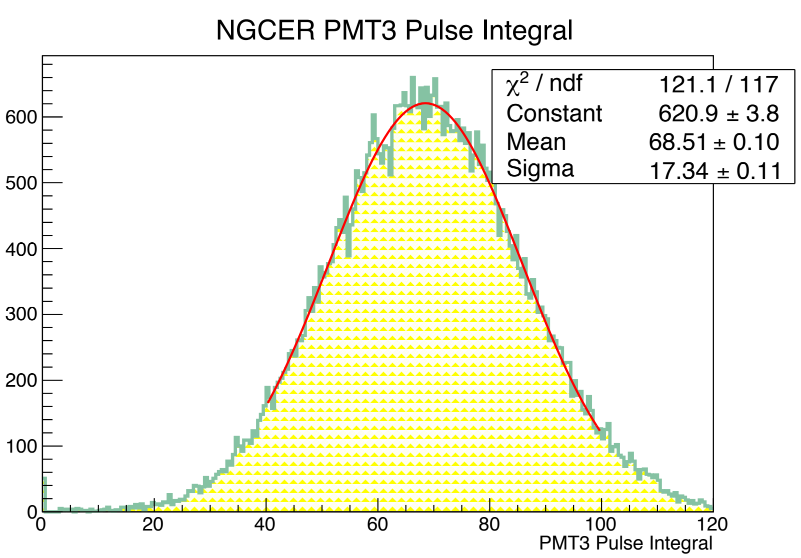


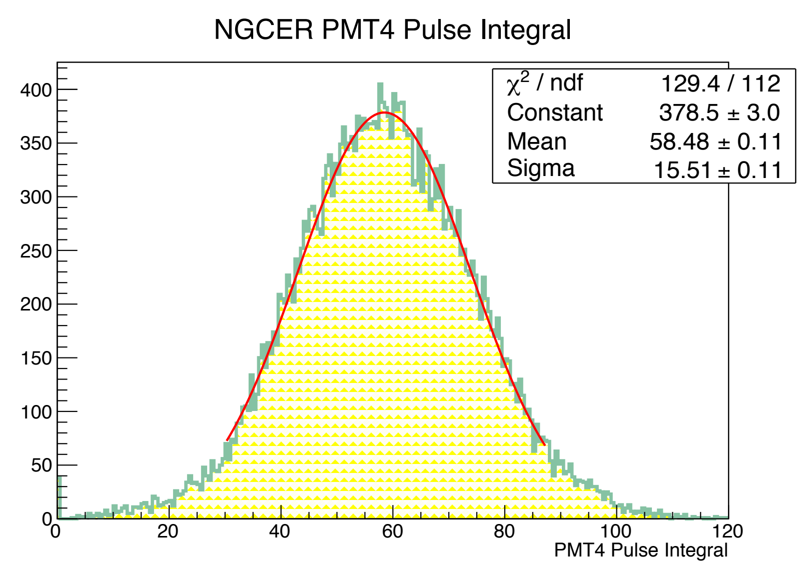
DETECTOR CALIBRATIONS

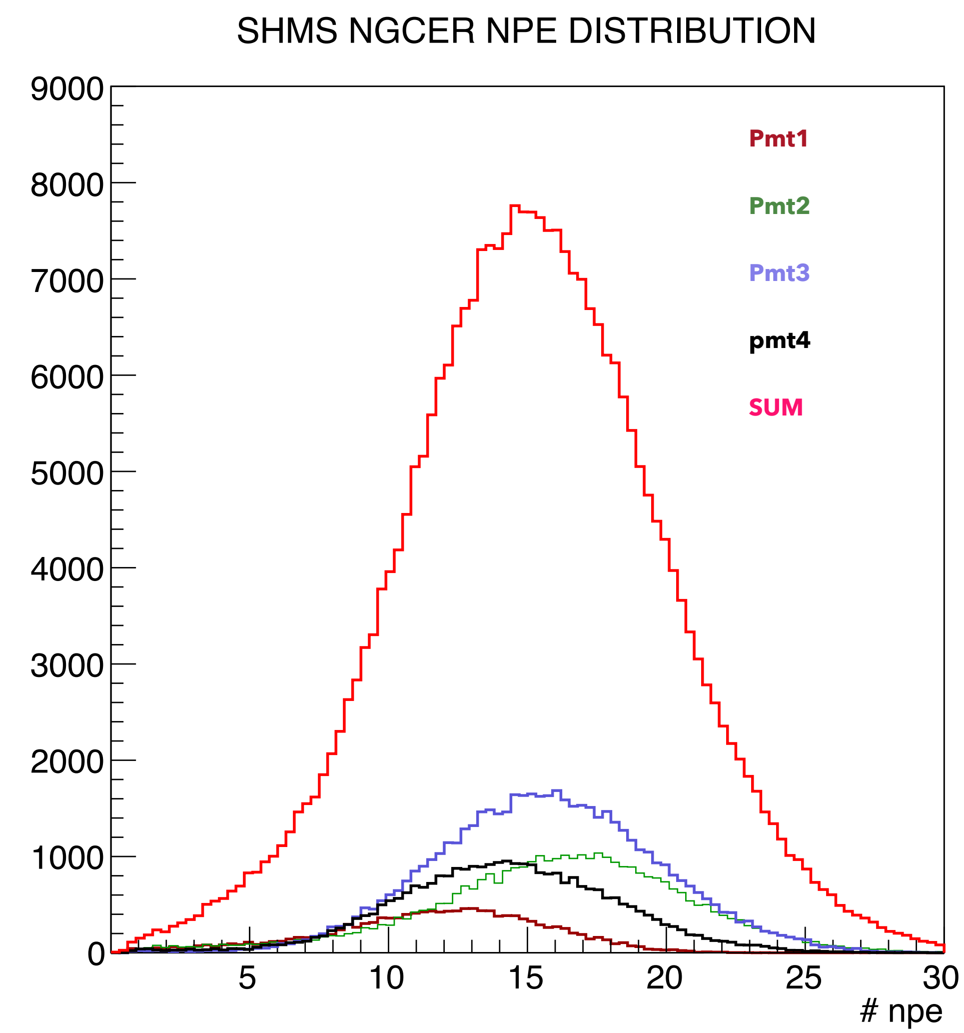
SHMS NGCER Calibration with Run 7120

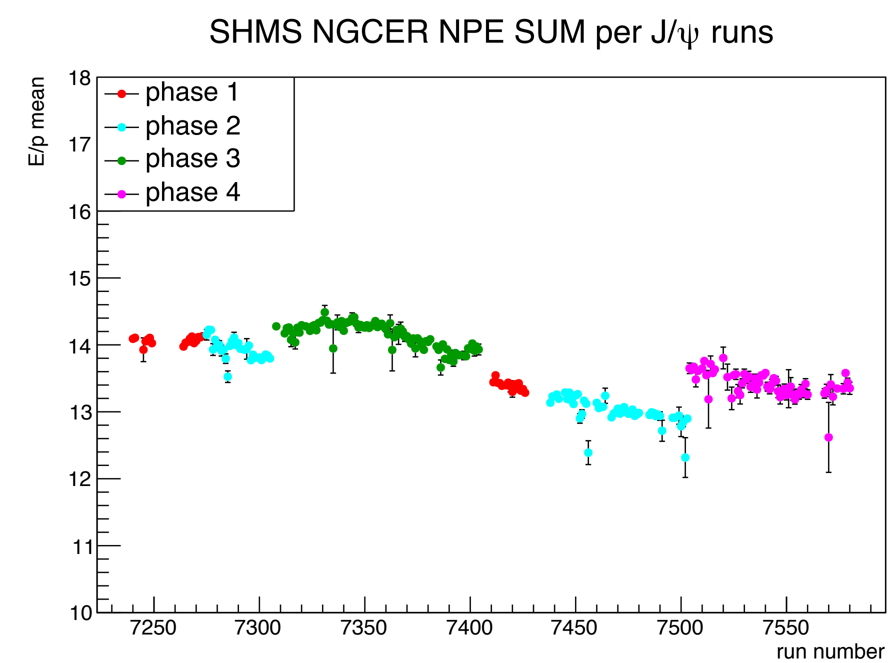












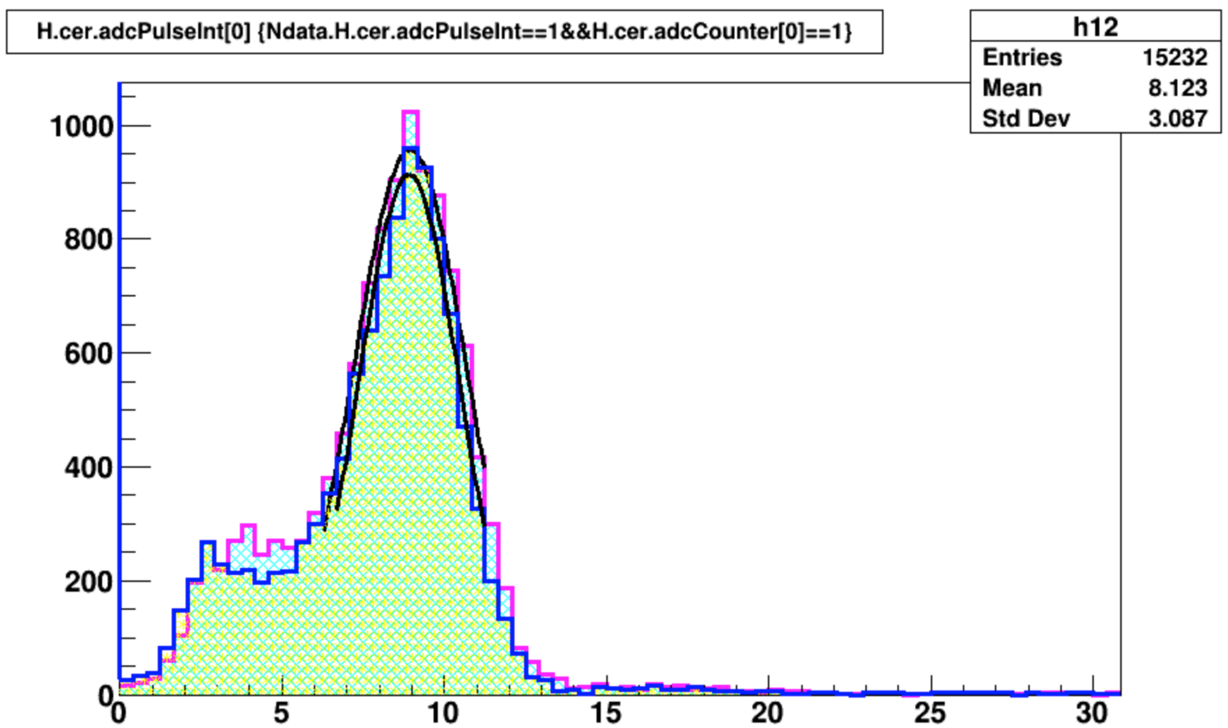
Estimated npe = (mean/sigma)^2

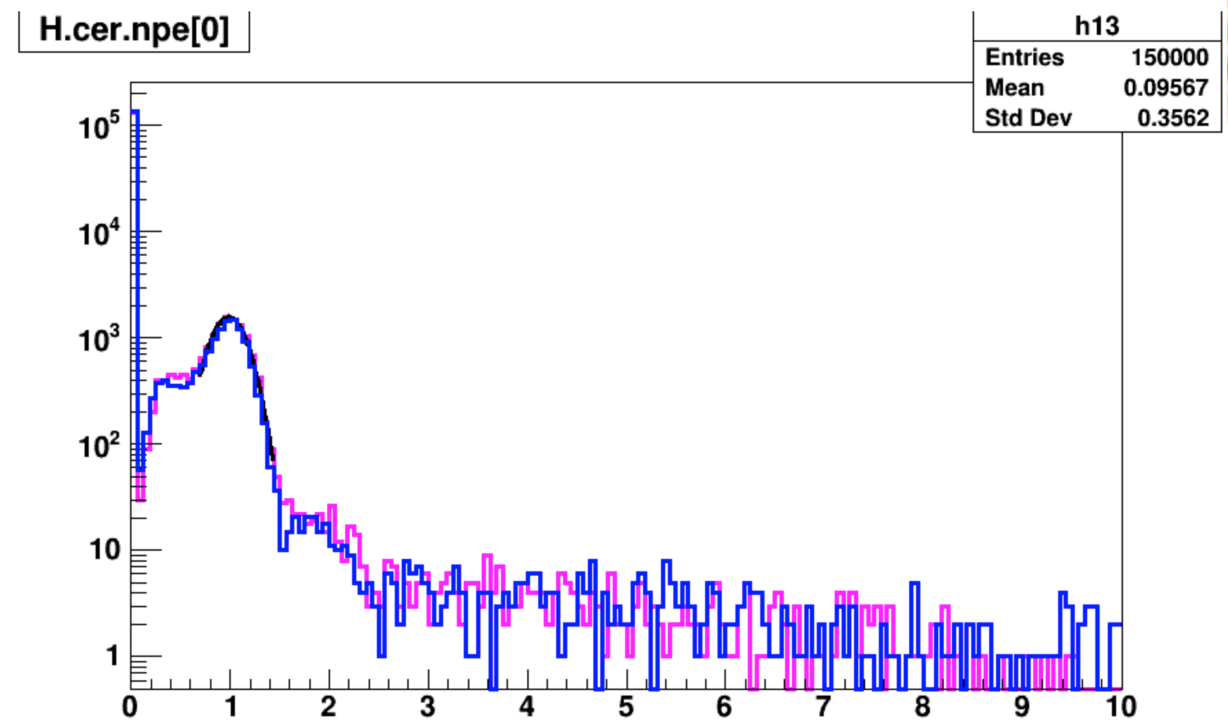
Estimated spe pulse int = mean / npe

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

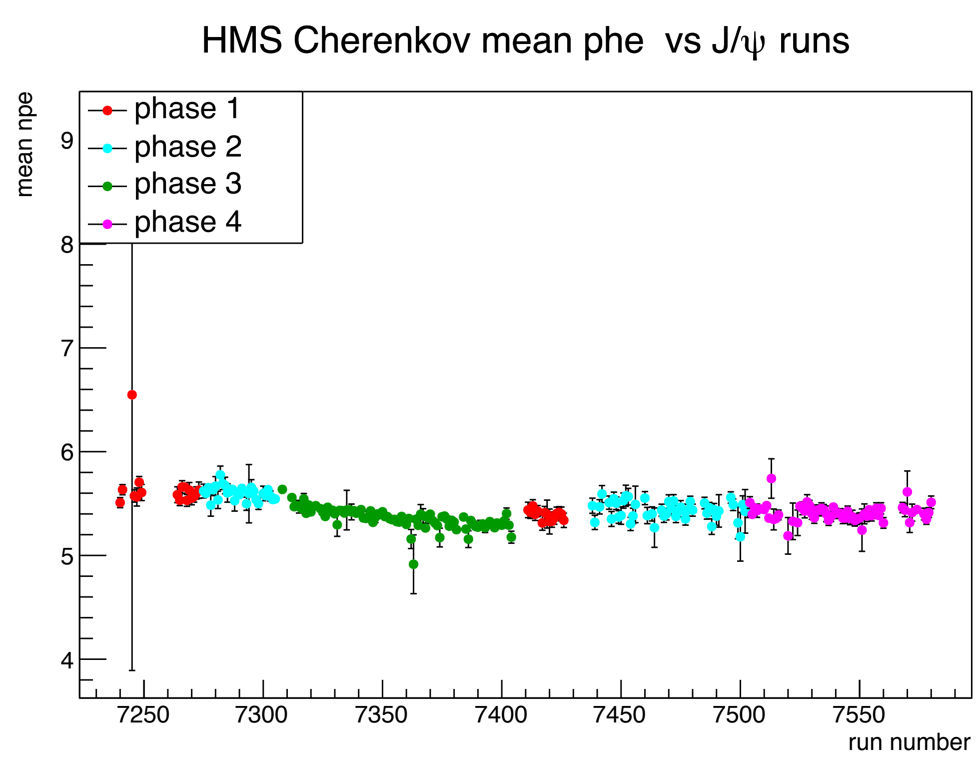
HMS Cerenkov Calibration

Simona's Calibration Plots with cosmic data





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



PARTICLE IDENTIFICATION (PID) STUDIES

$007^{J/\psi}$

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

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

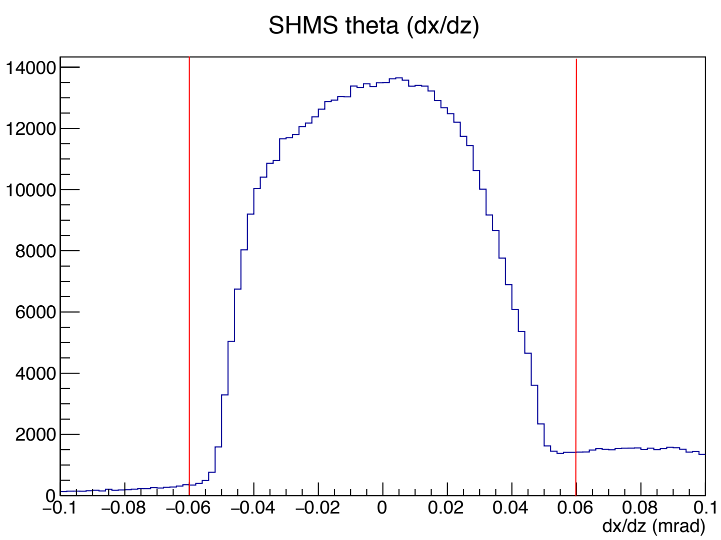
$$Cherenkov\ PR\ factor = \frac{pion\ sample\ selected\ with\ calorimeter}{pions\ fired\ the\ Cherenkov}$$

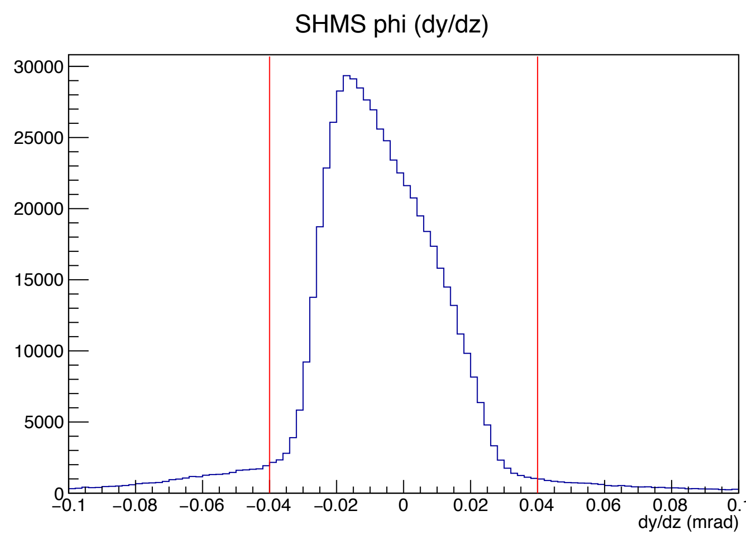
$$Calorimeter\ PR\ factor = \frac{pion\ sample\ selected\ with\ Cherenkov}{pions\ fired\ the\ calorimeter}$$

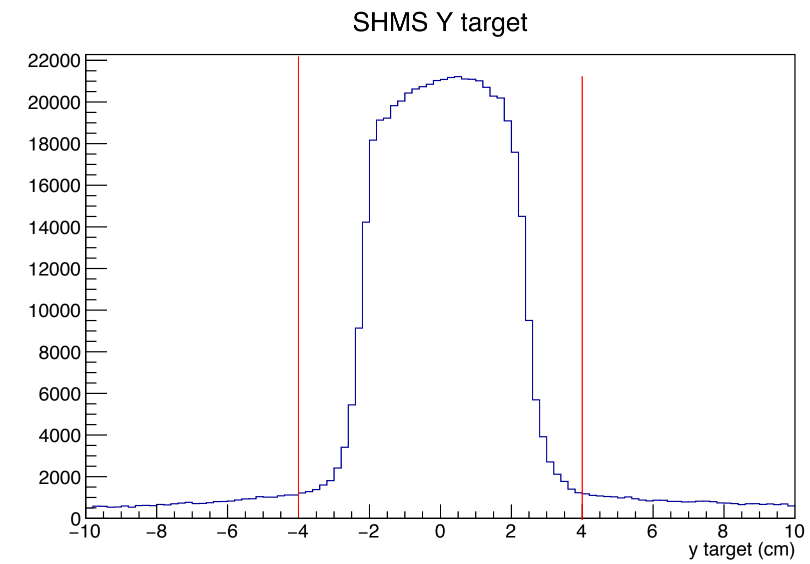
PARTICLE IDENTIFICATION (PID) STUDIES

SHMS Calorimeter Electron Efficiency (SHMS 7120 DIS data)

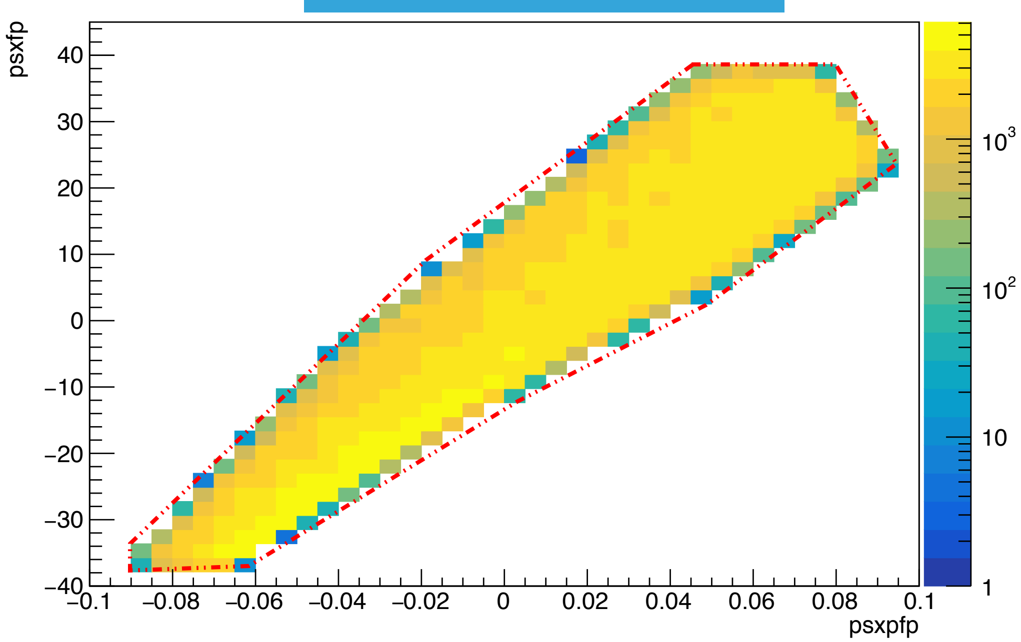
All with a cut on delta: P.gtr.dp > -10 & P.gtr.dp < 22.



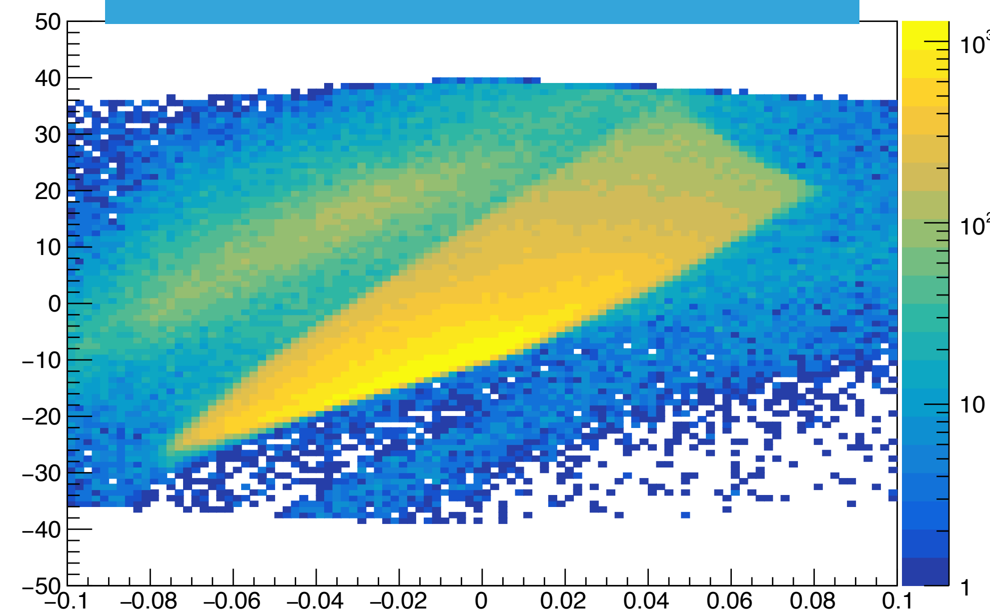




X FP VS XP FP



X FP VS XP FP

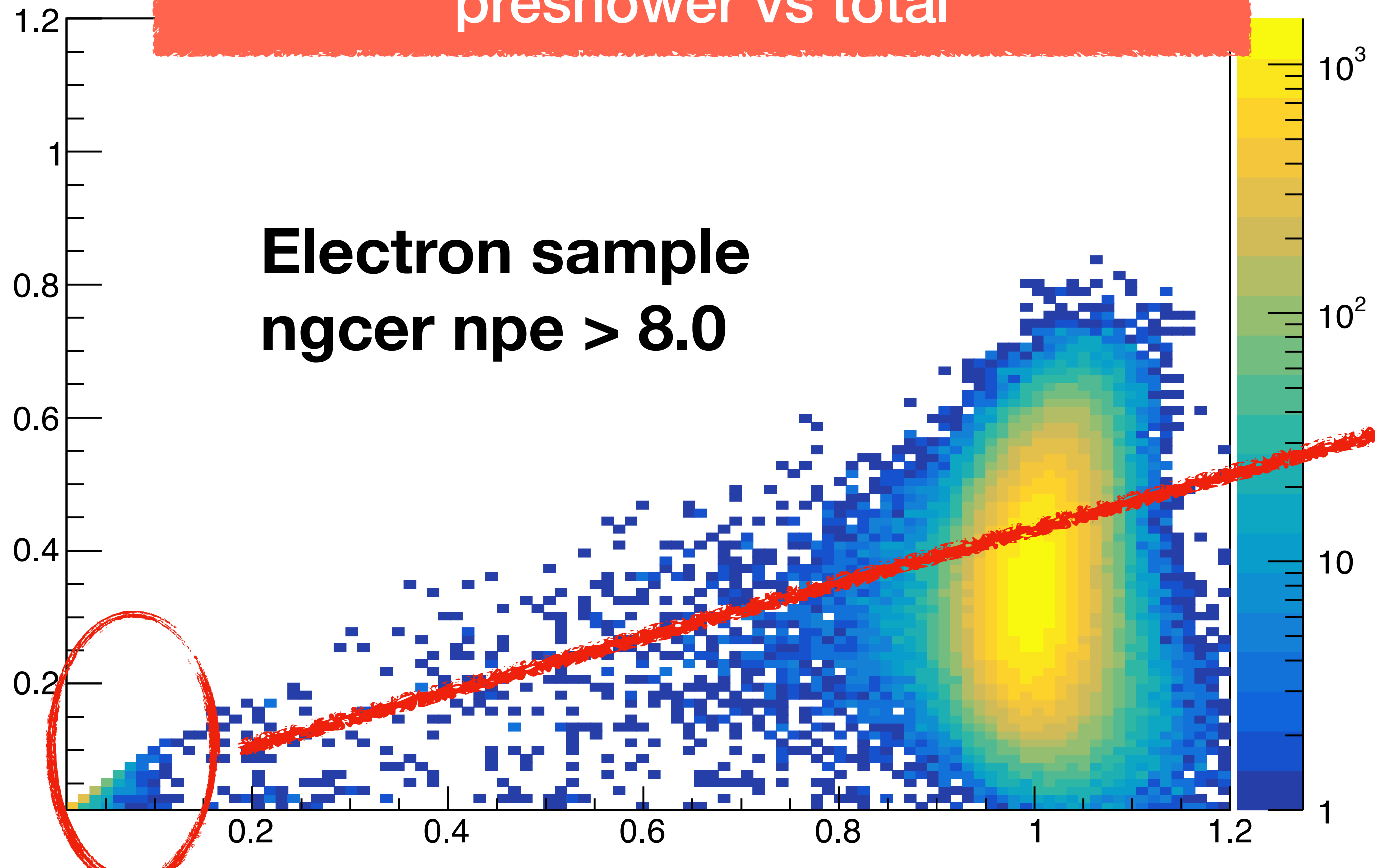


PARTICLE IDENTIFICATION (PID) STUDIES

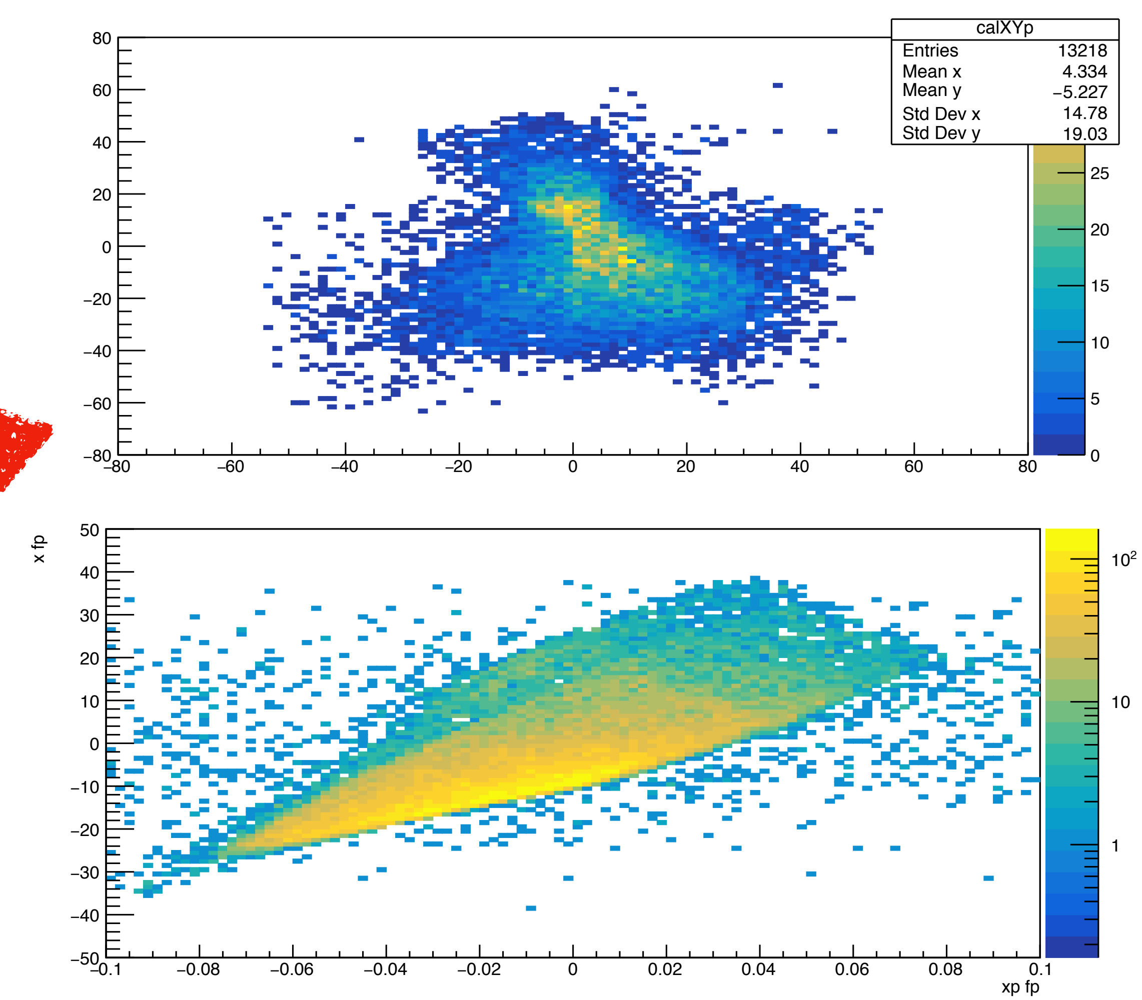
007 J/ψ

SHMS Calorimeter Electron Efficiency

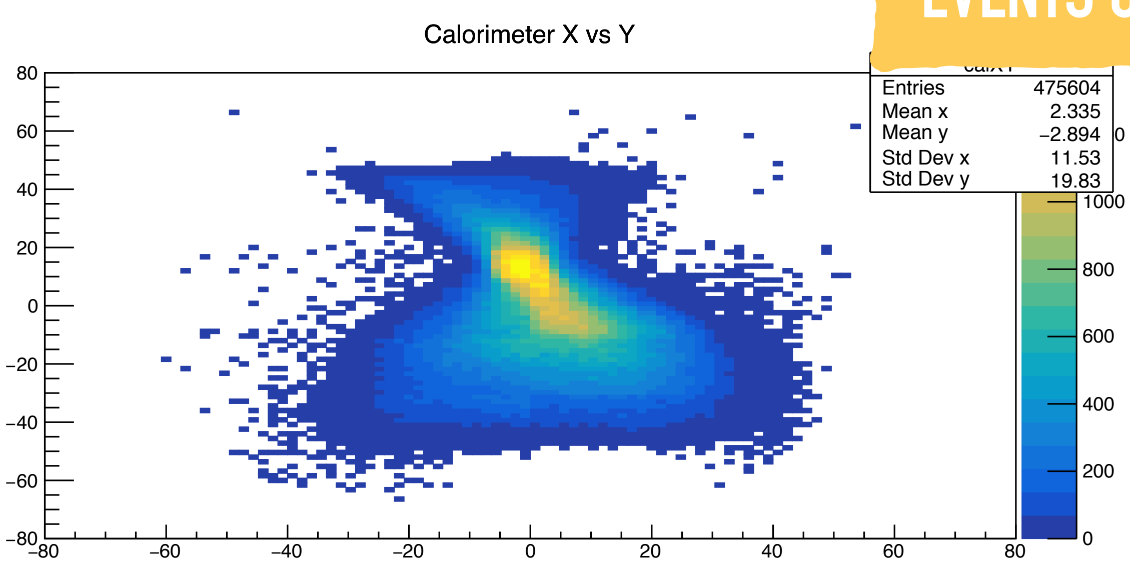
preshower vs total

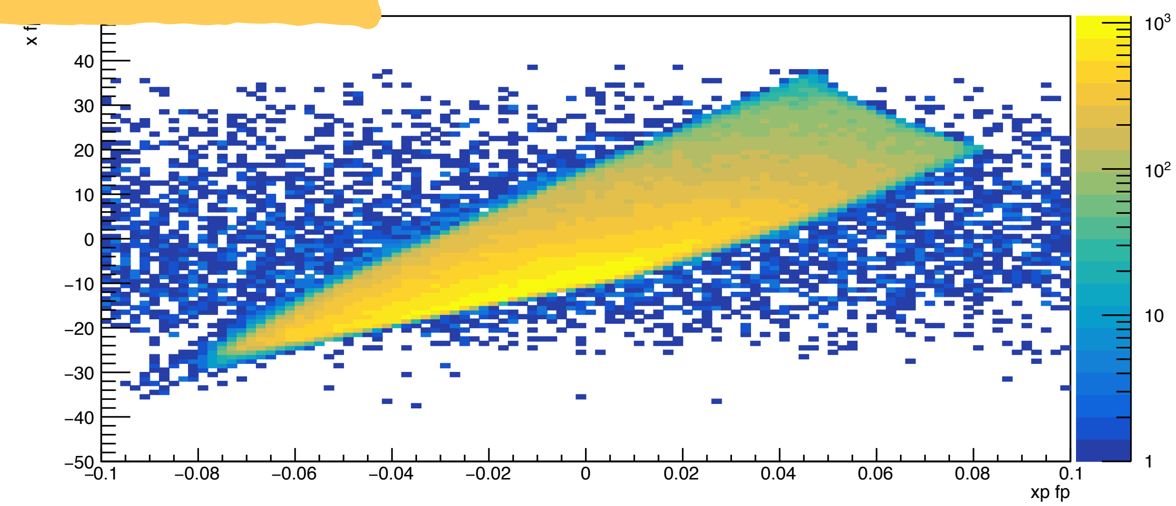


Projection of the mystery events inside the red circle on CAL XY plane and focal plane



EVENTS OUTSIDE THE CIRCLE





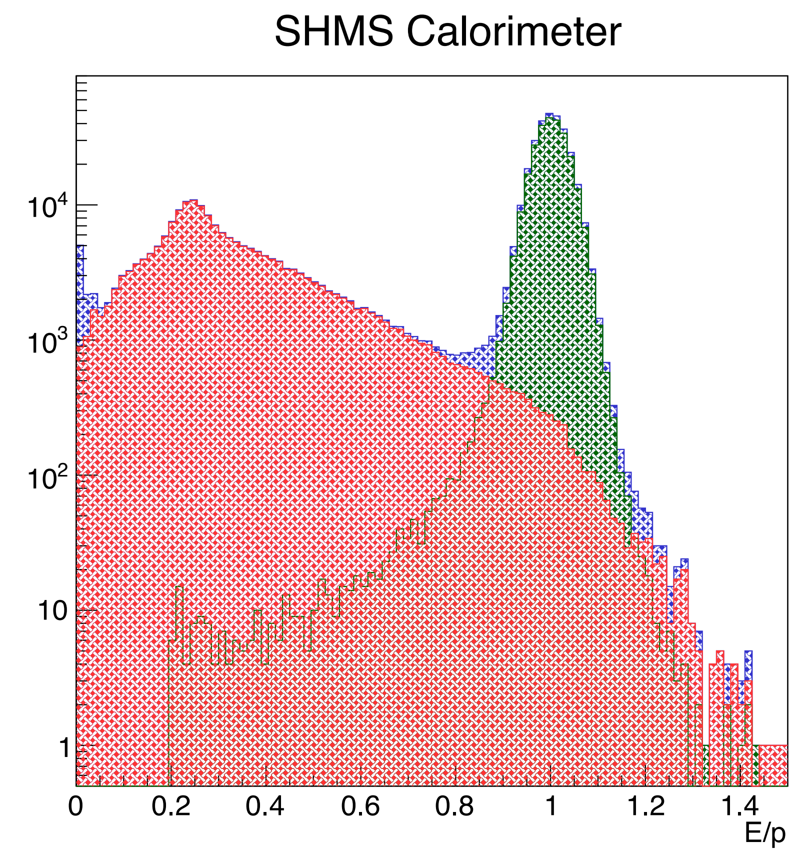
PARTICLE IDENTIFICATION (PID) STUDIES

007$^{J/\psi}$

SHMS Calorimeter Electron Efficiency

Electron sample chosen with:

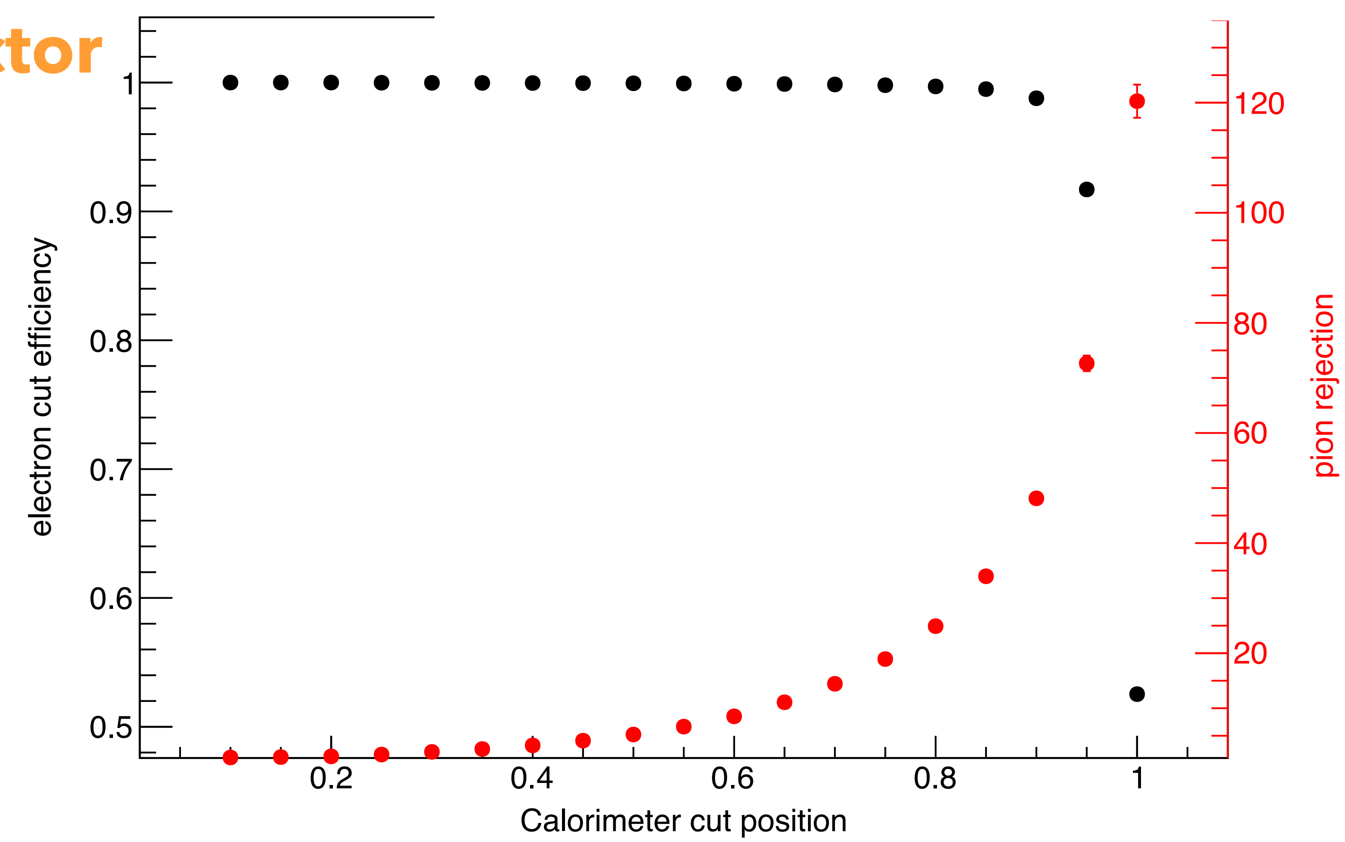
- Target cuts, excluding mystery events and ngcer car > 8 npes.
- Check how many of them passed the calorimeter cut.
- Study the efficiency as a function of cut position by varying it.



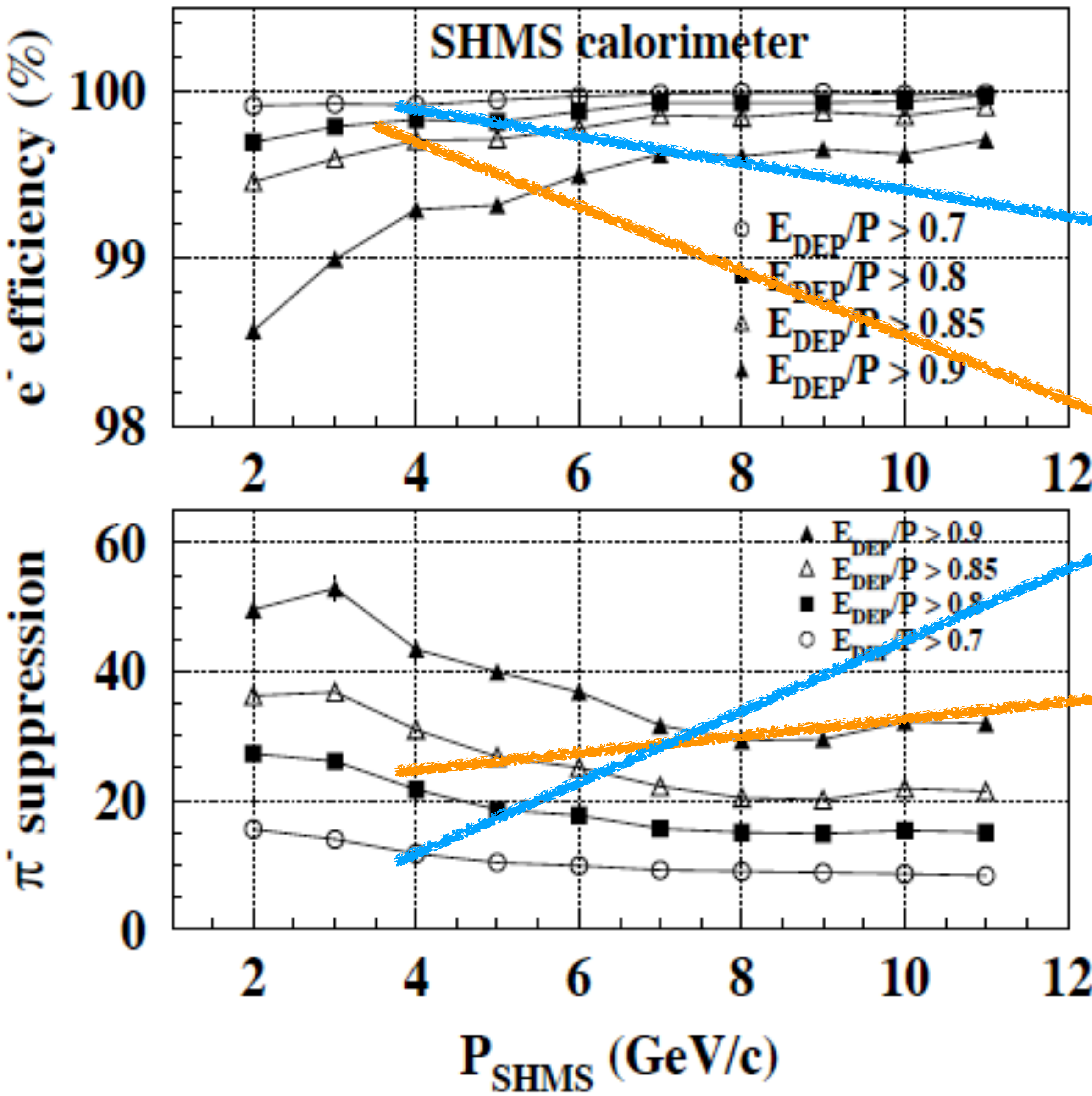
SHMS Calorimeter Pion Rejection Factor

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



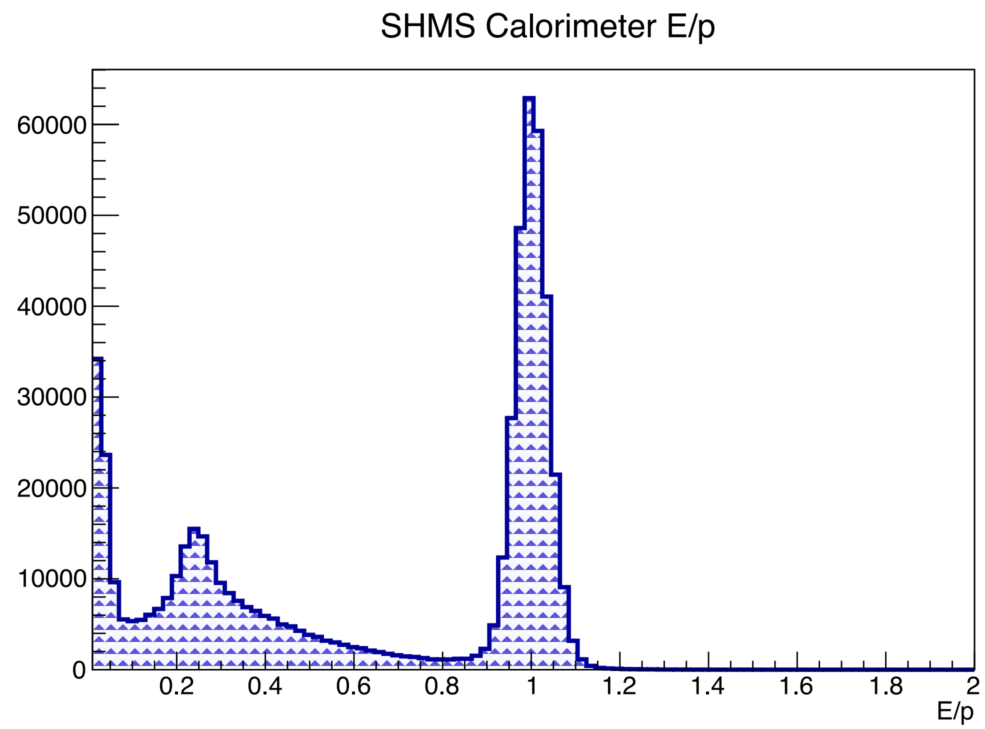
My results with 1D etottracknorm cut

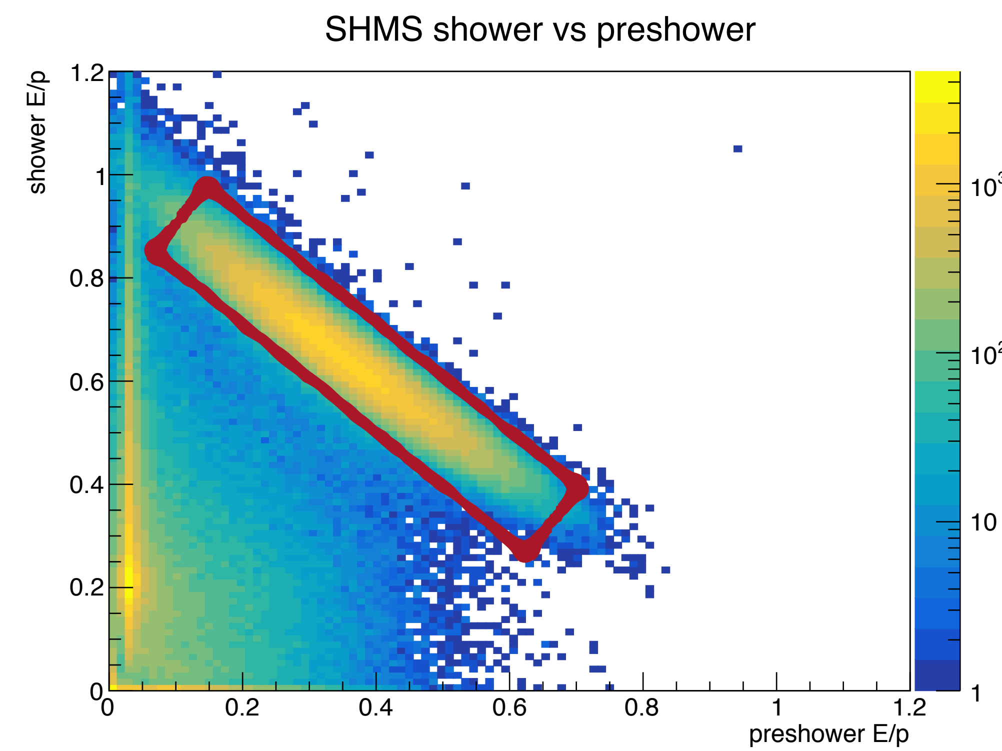
E/p = 0.7
Efficiency = 99.85%
PR factor = 15

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

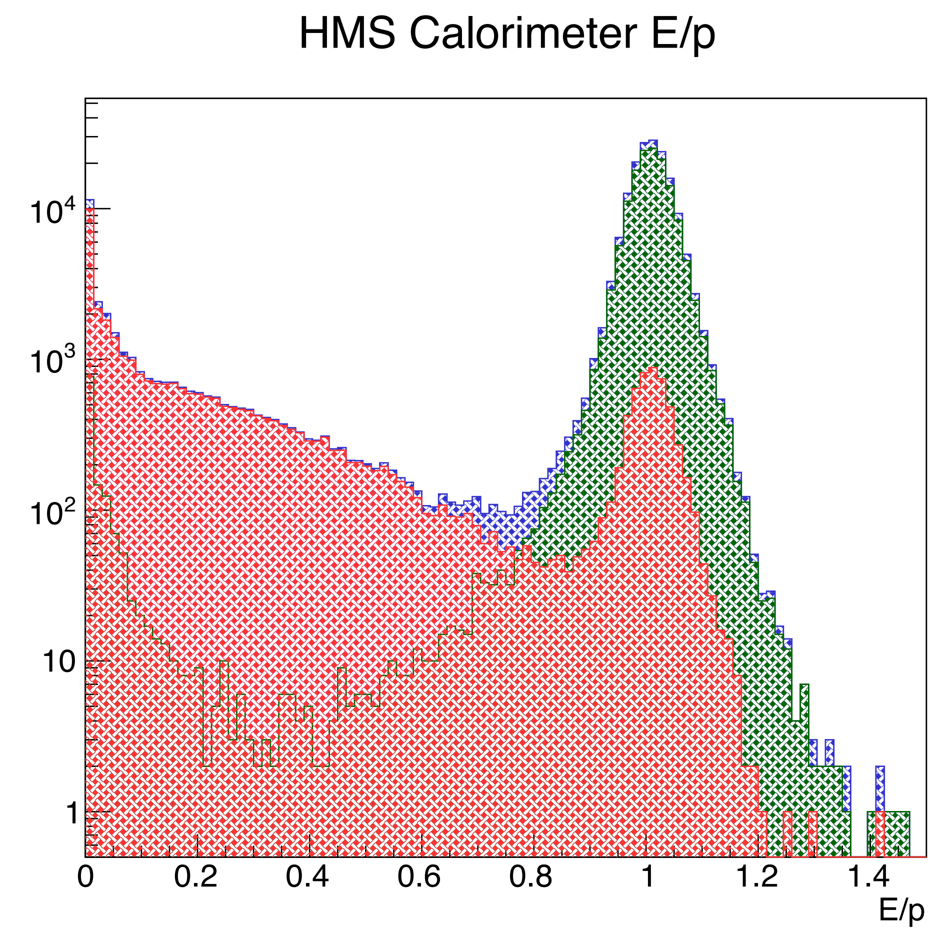
at E/p=0.8

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

HMS Calorimeter Electron Efficiency

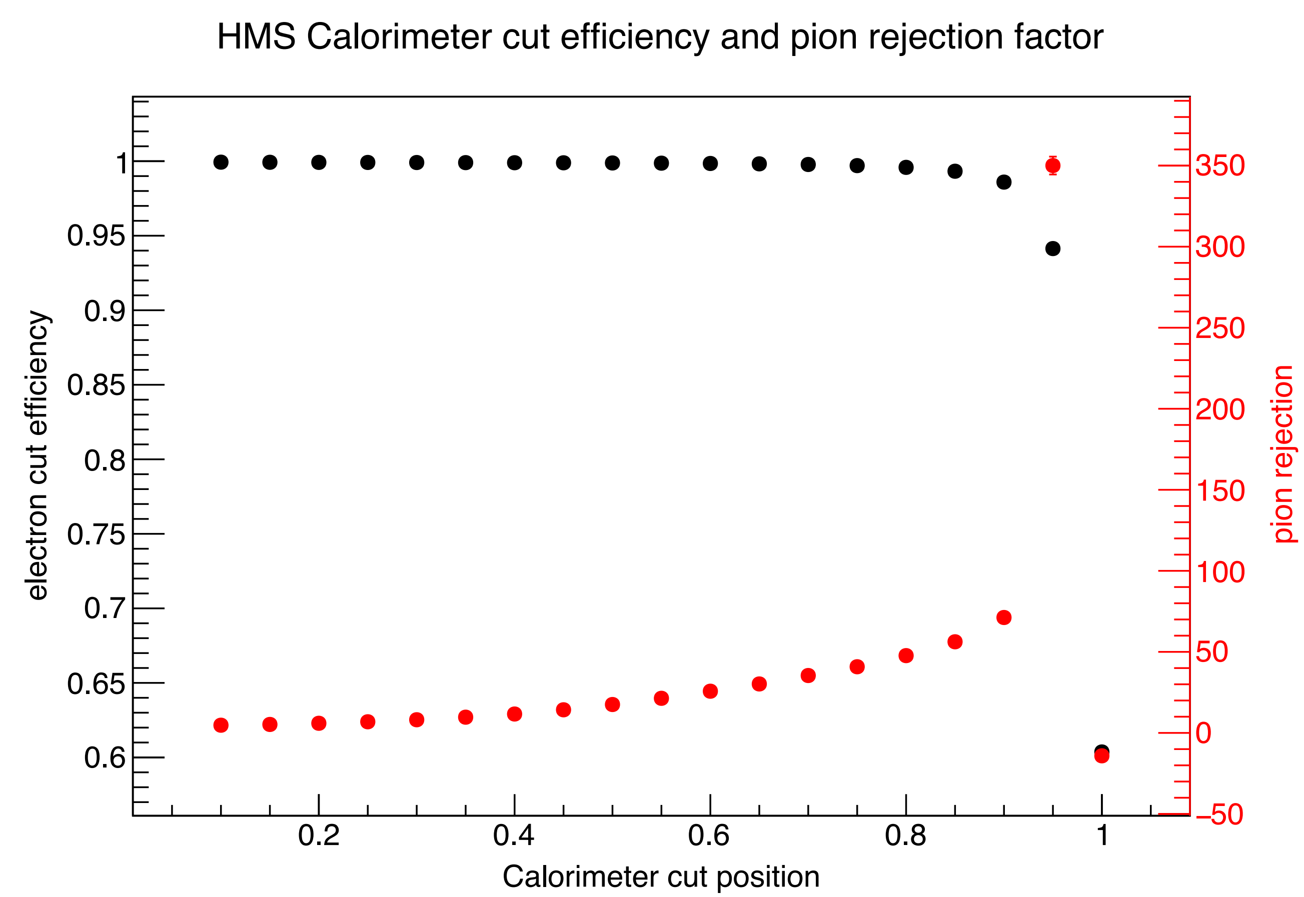
Electron sample chosen with:

- 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.

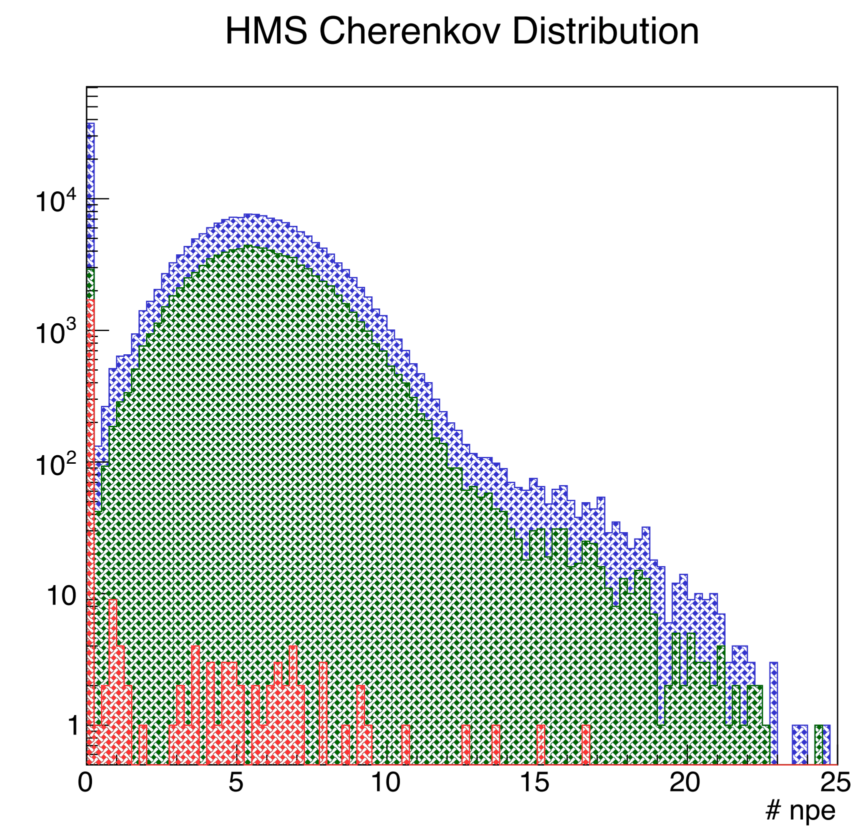


Pion sample chosen with:

- 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

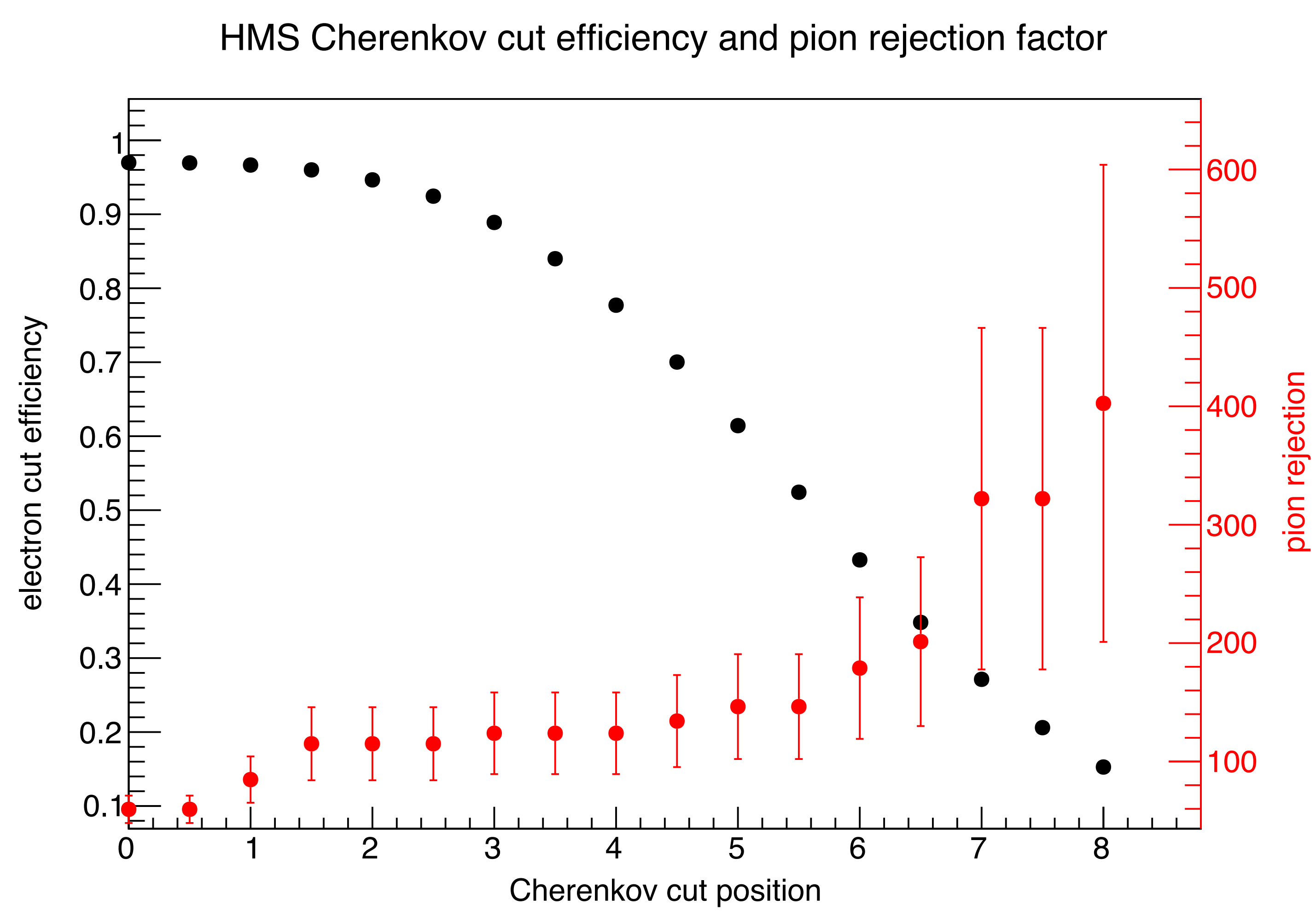


Electron sample chosen with:

- 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.



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

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

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?	ongoing	finished	ongoing	~10 years?