Mitglied der Helmholtz-Gemeinschaft

FAIRNESS
16-21 September 2013
Berlin

p̄anda

JÜLICH
FORSCHUNGSZENTRUM

Simulation and optimization of the P̄ANDA detector to measure the form factor of Ds semileptonic decay

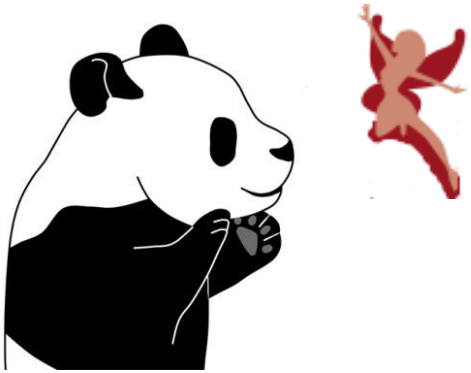
Lu Cao

IKP1, Forschungszentrum Juelich

19th September, 2013

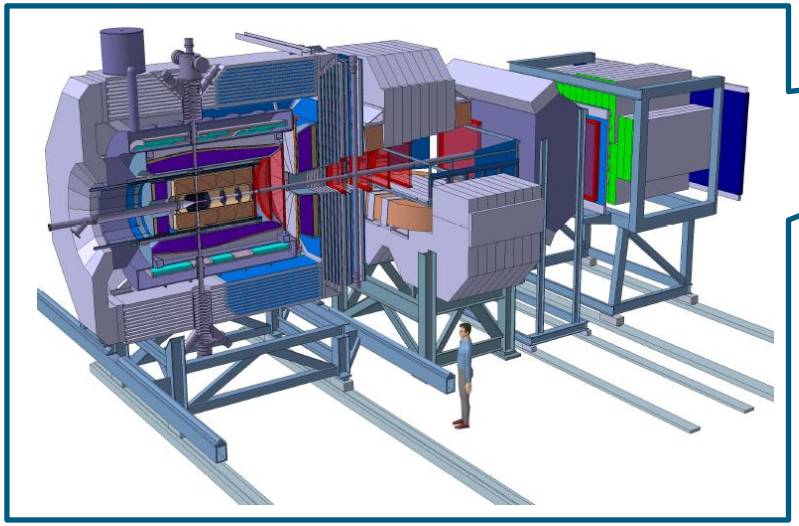
Outline

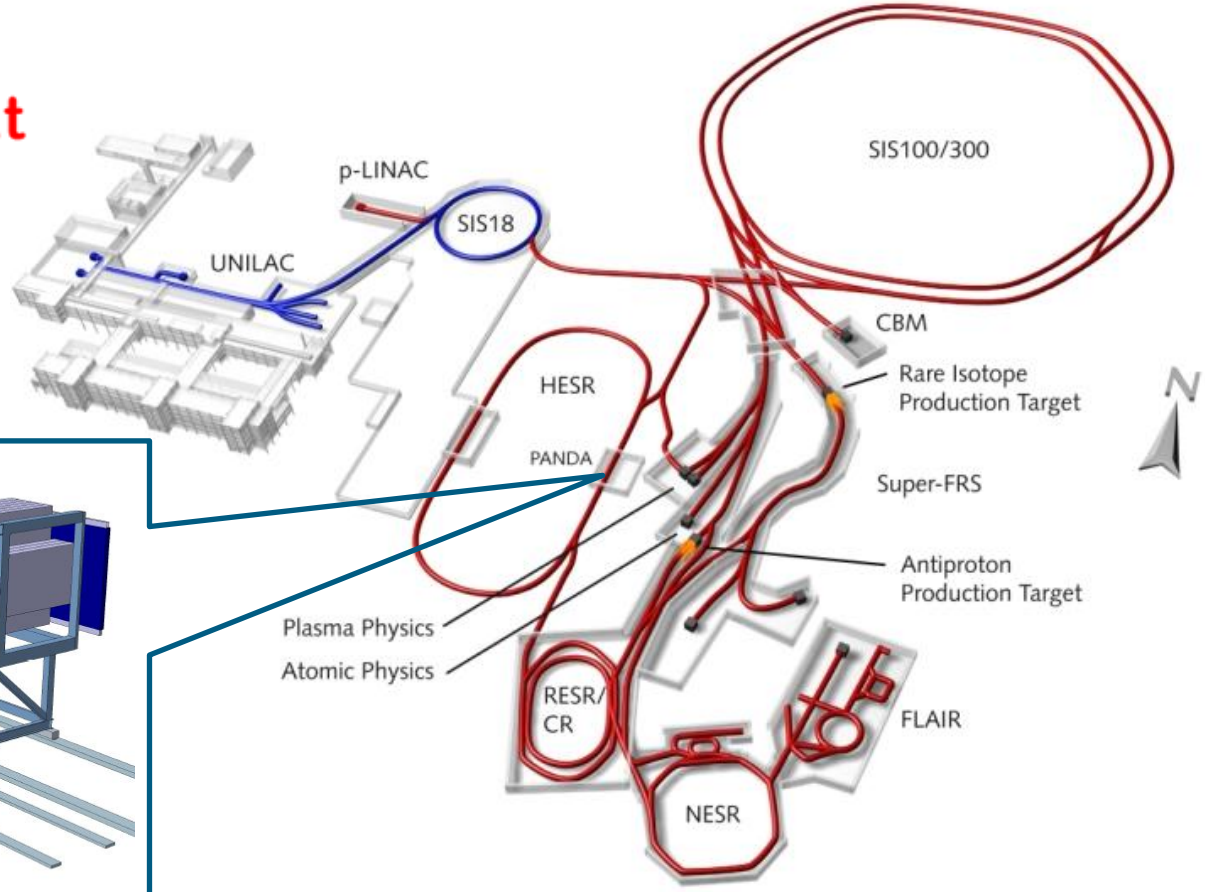
- Introduction of $\bar{P}$anda detector
- Physical significance on Ds semileptonic decay
- Simulation & decay model
- Reconstruction
- Summary & outlook



Introduction of P̄ANDA Detector

Anti-Proton
ANnihilation at
DArmstadt





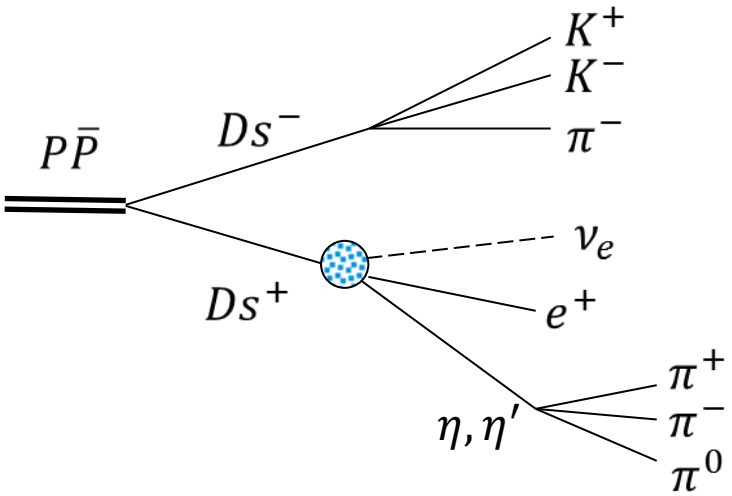
more details will be introduced by FIORAVANTI, Elisa on Friday

Physical Significance on Ds Semileptonic Decay

- Semileptonic decays Ds-> e + v + η,η' are an excellent environment for precision measurements of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$.

- Form factor encapsulates QCD bound-state effects; relates to the probability of forming final state at given invariant mass squared of the lepton-neutrino system q^2.

- The investigation opens a new approach to improve the measurement of mixing angle for η and η'.

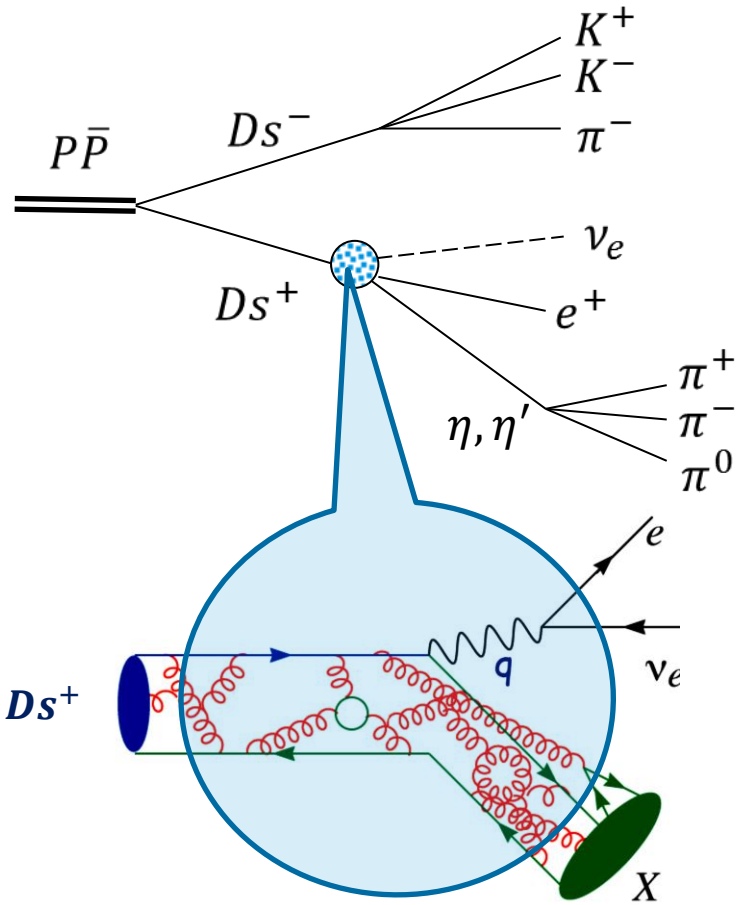


Physical Significance on Ds Semileptonic Decay

- Semileptonic decays Ds-> e + v + η,η' are an excellent environment for precision measurements of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$.

- Form factor encapsulates QCD bound-state effects; relates to the probability of forming final state at given invariant mass squared of the lepton-neutrino system q^2.

- The investigation opens a new approach to improve the measurement of mixing angle for η and η'.

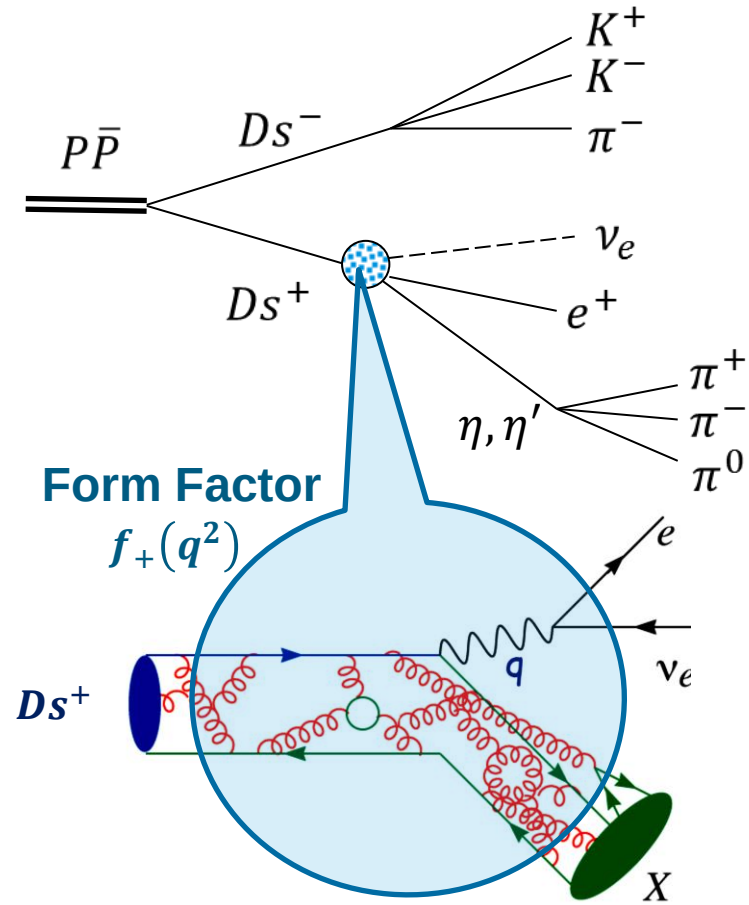


Physical Significance on Ds Semileptonic Decay

- Semileptonic decays Ds-> e + v + η,η' are an excellent environment for precision measurements of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$.

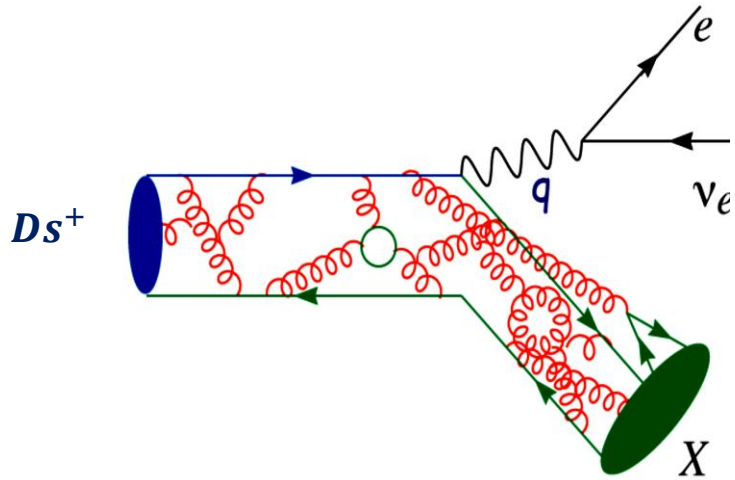
- Form factor encapsulates QCD bound-state effects; relates to the probability of forming final state at given invariant mass squared of the lepton-neutrino system q^2.

- The investigation opens a new approach to improve the measurement of mixing angle for η and η'.



$$\frac{d\Gamma(Ds \to vlX)}{dq^2} = \frac{{G_F}^2}{24\pi^3}|V_{cx}|^2 {p_x}^3 |f_+(q^2)|^2$$

pbarpSystem	
-> Ds- Ds+	BR_{PDG}
| |-> eta e+ nu_e	2.67%
|-> K- K+ pi-	5.49%



Production Rate of Ds pair

$$R = \mathcal{L} \cdot \sigma \cdot \varepsilon \cdot t \cdot \mathcal{BR}$$

$$= 10^{32}(cm^2) \cdot \mathbf{10}(nb) \times 10^{-24}(cm^2/b) \cdot 5 \times 10^{-2} \cdot 3 \times 10^6(s) \cdot 2.67\% \times 5.49\%$$

$$\simeq 220$$

larger cross section?
higher reco. efficiency?

Previous measurements have been carried on CLEO-c, BaBar.

Simulation & Decay Model

- Hadronic decay mode of Ds meson with $K\bar{K}$ pair:

$$Ds^- \rightarrow K^+K^-\pi^-$$

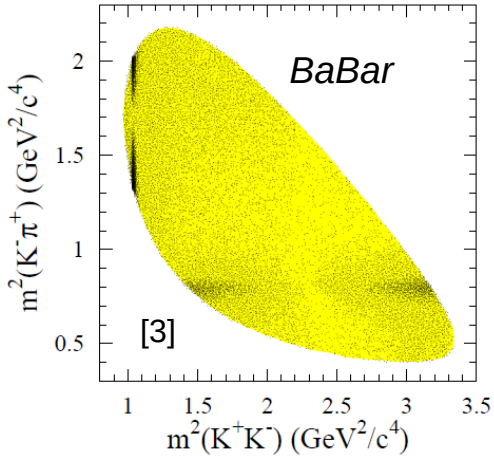
$$Br_{\mathrm{PDG}} = (\,5.49 \pm 0.27)\ \%$$

pbarp system	noPhotos
-> Ds- Ds+	
| |-> eta e+ nu_e	PHOTOS ISGW2
| | -> pi+ pi- pi0	ETA_DALITZ
|-> K- K+ pi-	?

- NOT include in PandaRoot/EvtGen/ D_DALITZ

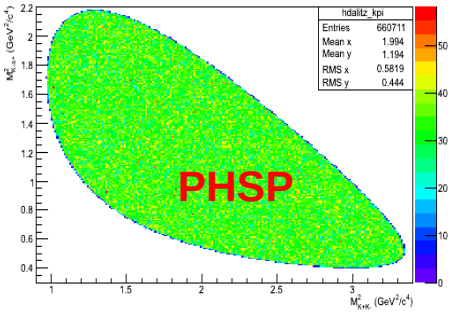
  It provides Dalitz amplitude for three-body $K\pi\pi$ decays:

  $D^+ \rightarrow K^-\pi^+\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$,etc.



- Dalitz plot analyses in experiments:

E687	700 evt	[1] PLB 351, 591 (1995)
CLEO	14,400 evt	[2] PRD 79, 072008 (2009)
BaBar	100,000 evt	[3] PRD 83:052001 (2011)



New Decay Model: DS_DALITZ

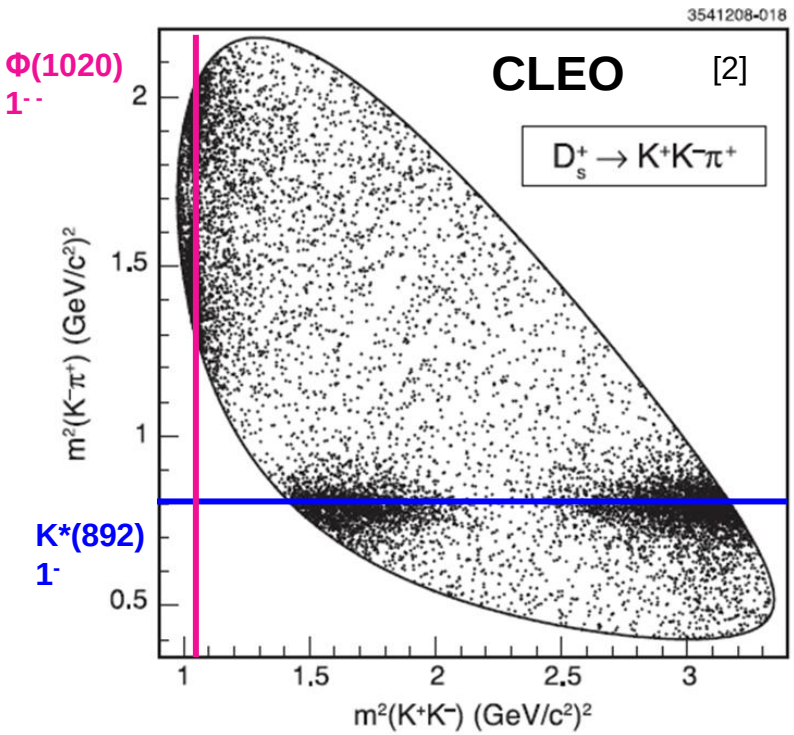
- The original code is part of the EvtGen package developed jointly for the BaBar and CLEO, where *Ds->KKπ* is described by a branch of "D_DALITZ".

- DS_DALITZ has been available since the version #21000 of pgenerators in PandaRoot.

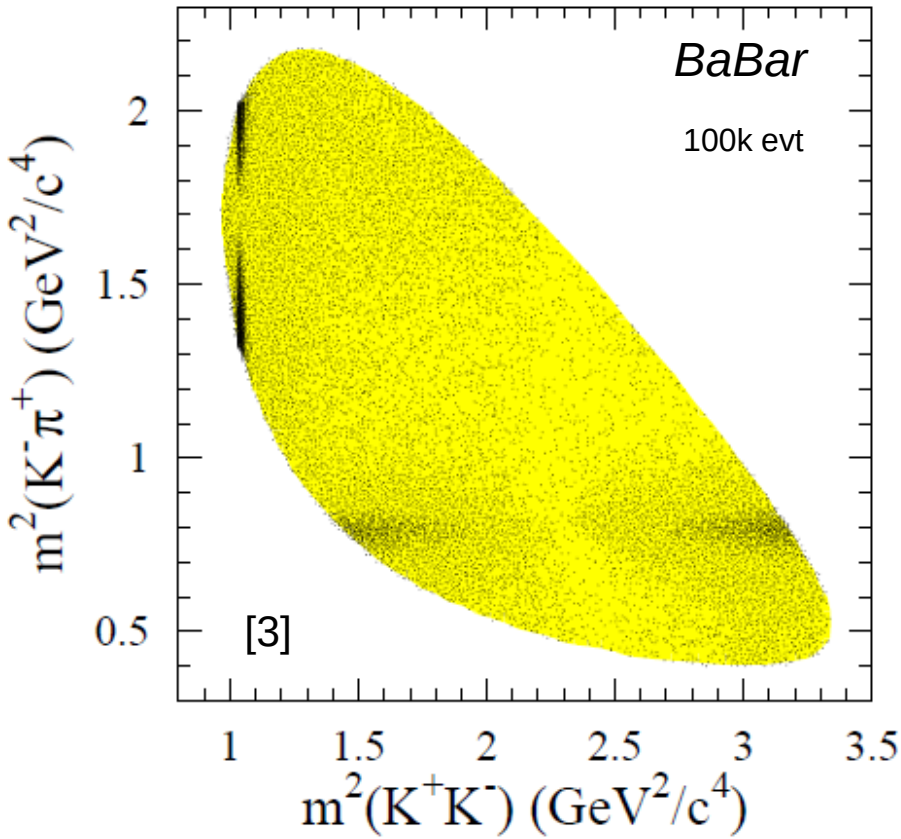
  - ✓ Define model: /EvtGen/EvtGenModels/EvtDsDalitz.cc
  - ✓ Calculate amplitudes: /EvtGen/EvtGenBase/EvtResonance2.cc /EvtGen/EvtGenBase/EvtFlatte.cc

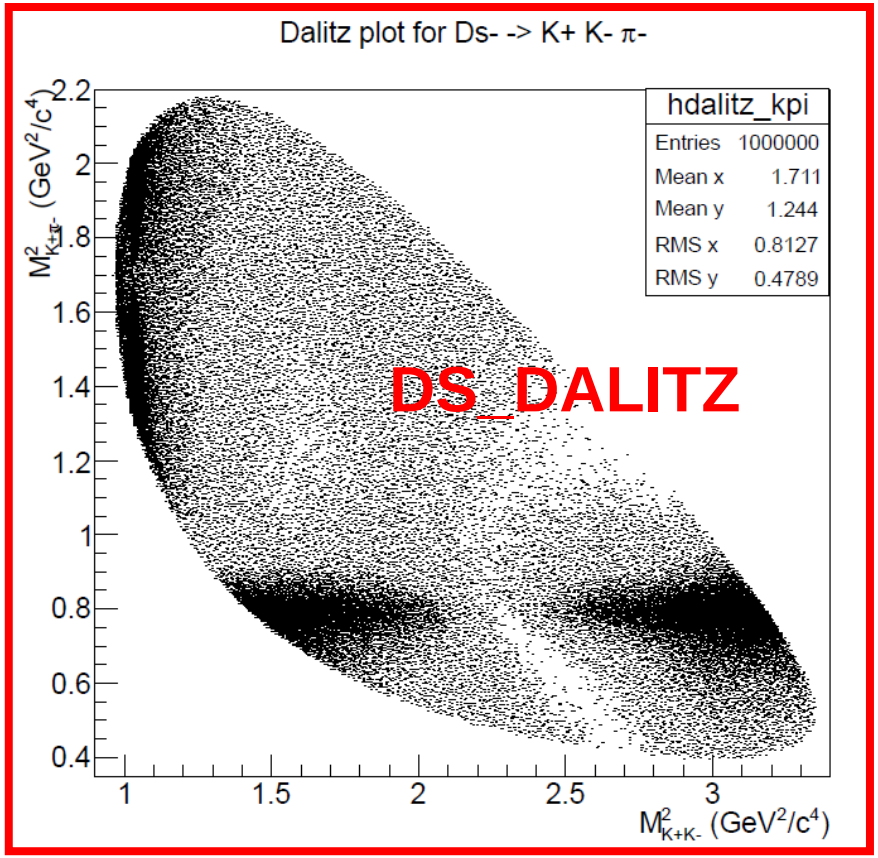
- Amplitude for *Ds->KKπ* mode is the summation of the six resonance contributions:

  $K^*(892)K^+$, $K^*_0(1430)\ K^+$, $f_0\,(980)\ \pi^+$, $\Phi(1020)\ \pi^+$, $f_0\,(1370)\ \pi^+$, $f_0\,(1710)\ \pi^+$.



Testing performance



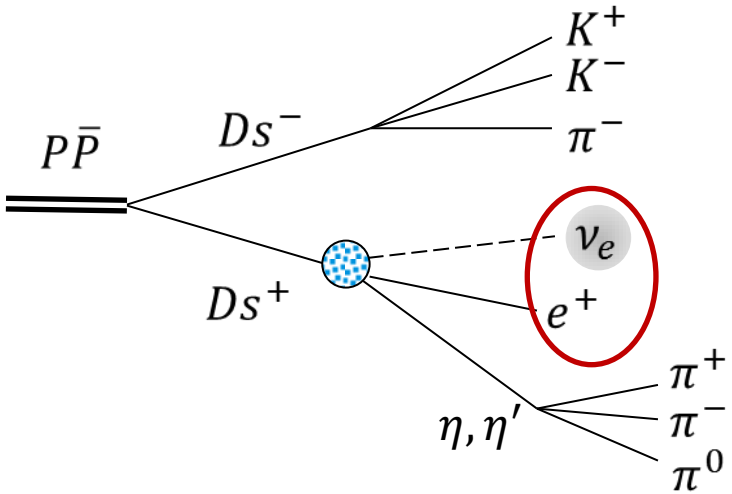


Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$



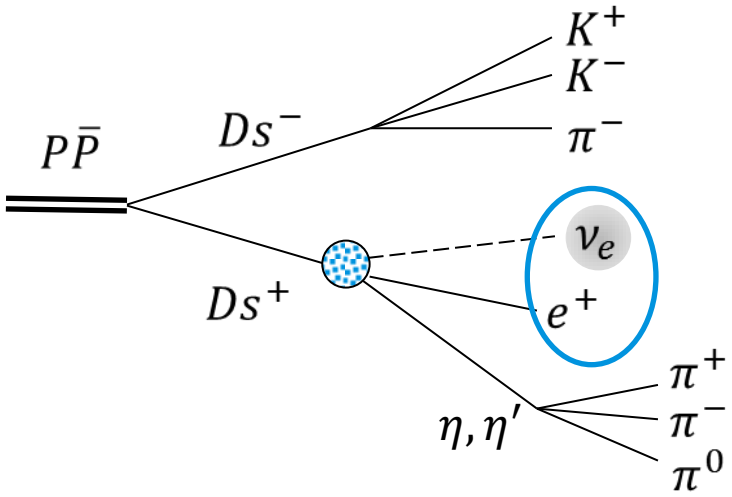
Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$

$\boldsymbol{Ds^+}$ $\boldsymbol{\eta}$



Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

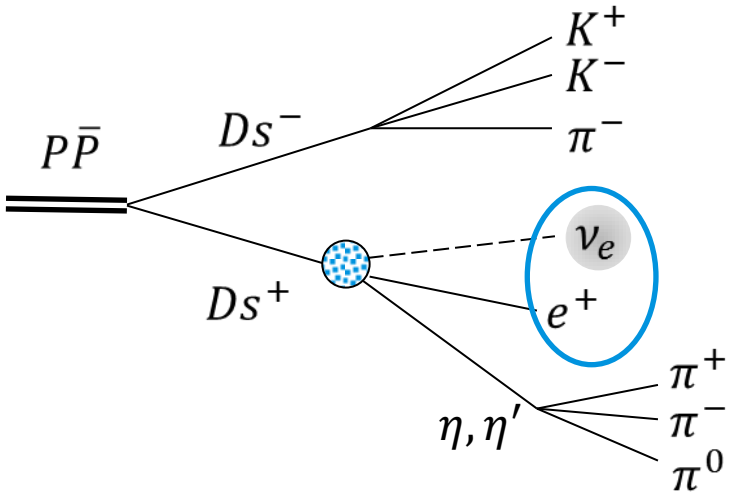
$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$

Ds^+ η

$P\bar{P}$ Ds^-

K^+ K^- π^+

- Vertex fit
- Mass constraint fit



Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$

Ds^+ η

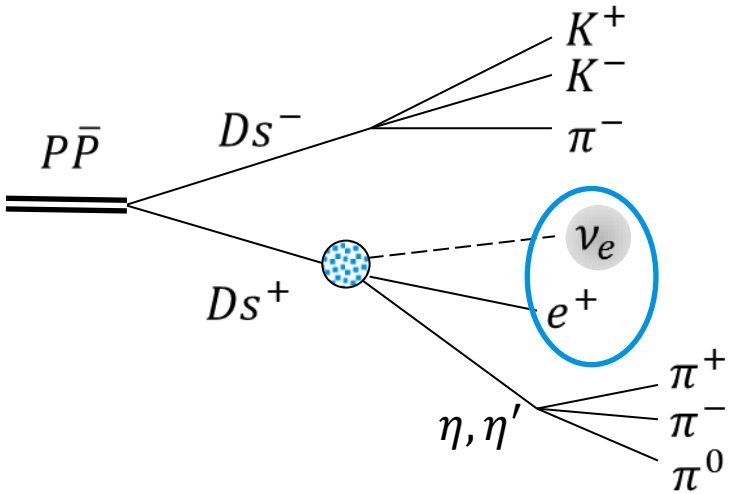
$P\bar{P}$ Ds^-

π^+ π^-
- Vertex fit

π^0

K^+ K^- π^+
- Vertex fit
- Mass constraint fit

γ γ
- Energy selection based on EMC
- Mass constraint fit

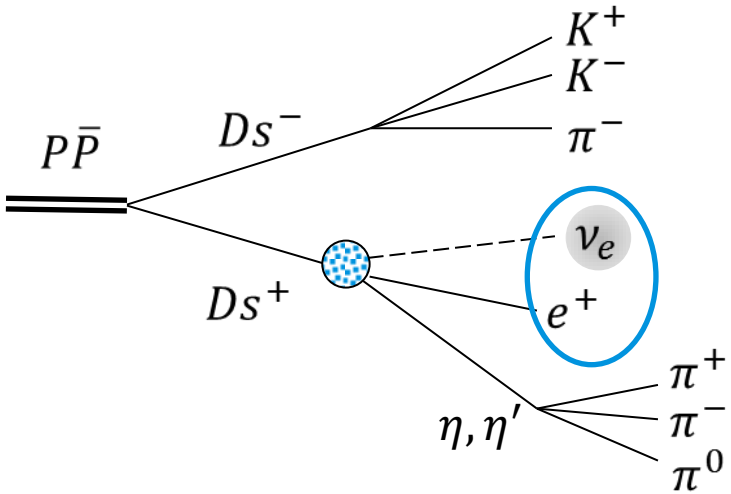


Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$



Ds^+ | η

$P\bar{P}$ | Ds^-

π^+ π^-
- Vertex fit

π^0
- Mass constraint fit

K^+ K^- π^+
- Vertex fit
- Mass constraint fit

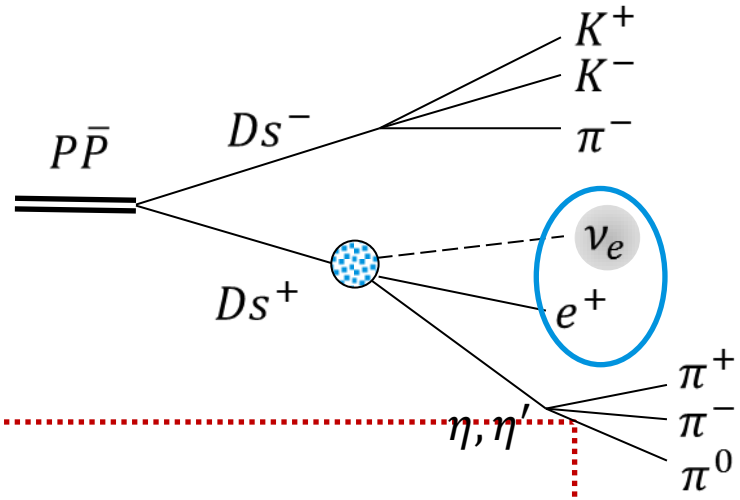
γ γ
- Energy selection based on EMC
- Mass constraint fit

Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

$$q^2 = (E_e + E_\nu)^2 - |\boldsymbol{P}_e + \boldsymbol{P}_\nu|^2$$



Ds^+ η

$P\bar{P}$ Ds^-

π^+ π^-
- Vertex fit

π^0
- Mass constraint fit

K^+ K^- π^+
- Vertex fit
- Mass constraint fit

γ γ
- Energy cutting on EMC components
- Mass constraint fit

Reconstruction of Ds$^-$

Evt = 100k

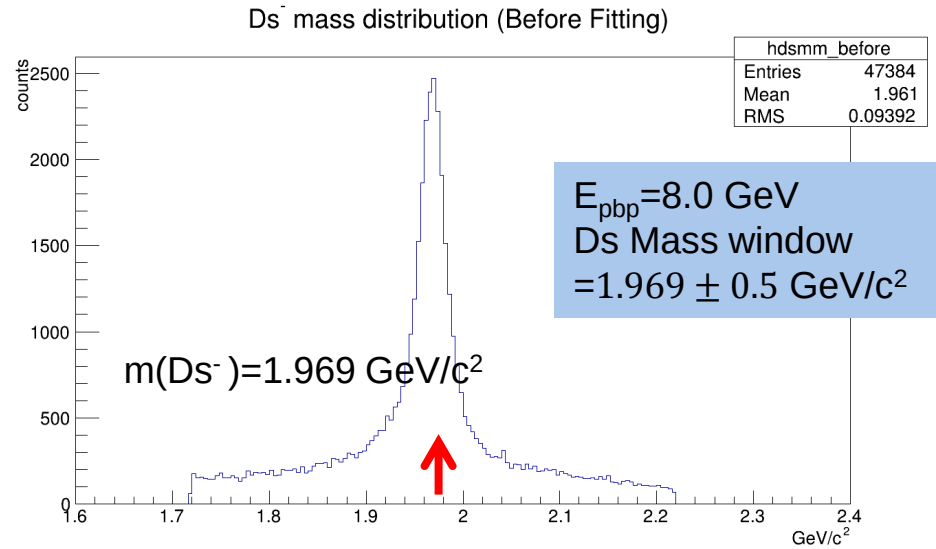
pbarp system **noPhotos**

-> Ds- Ds+

| |-> eta e+ nu_e PHOTOS ISGW2

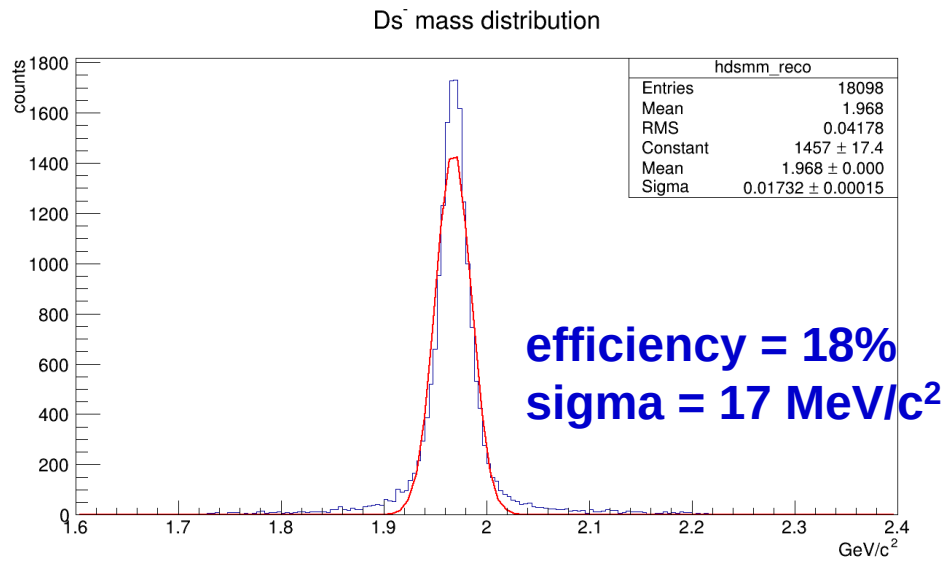
| | -> pi+ pi- pi0 ETA_DALITZ

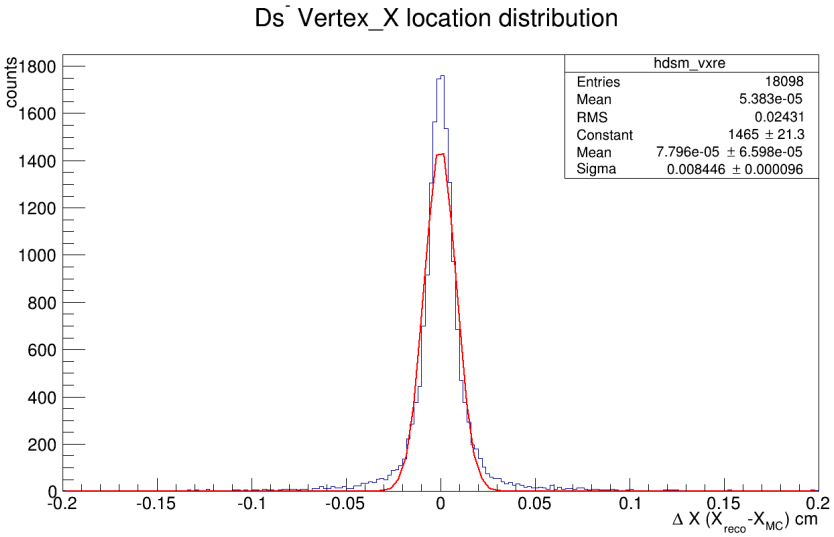
|-> K- K+ pi- DS_DALITZ

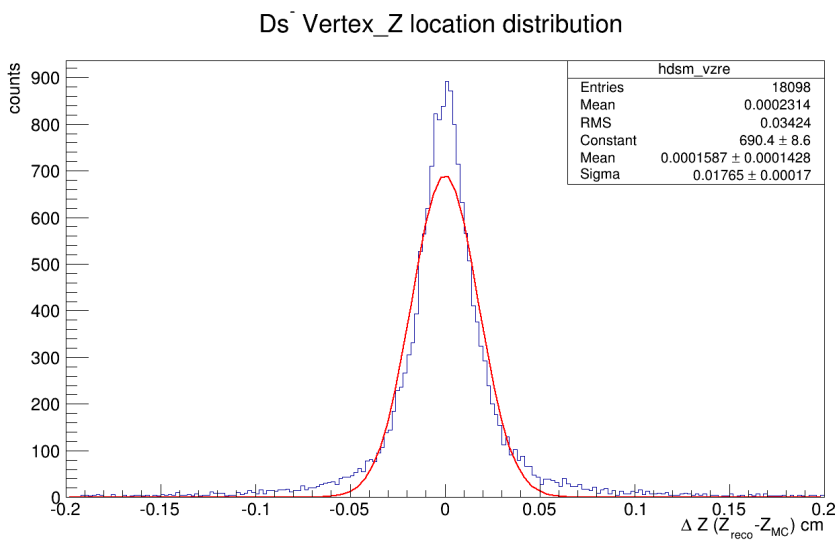


Reco. Strategy

- Combine the final particles (K^+ K^- pi^-) and filter with mass window
- Vertex Fit
- Mass Constraint Fit
- Get resolution of selected candidates



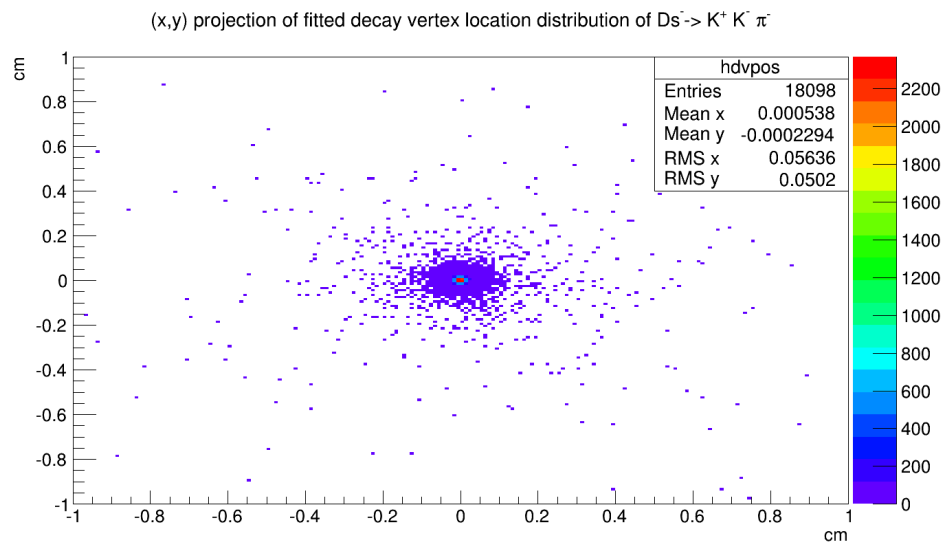


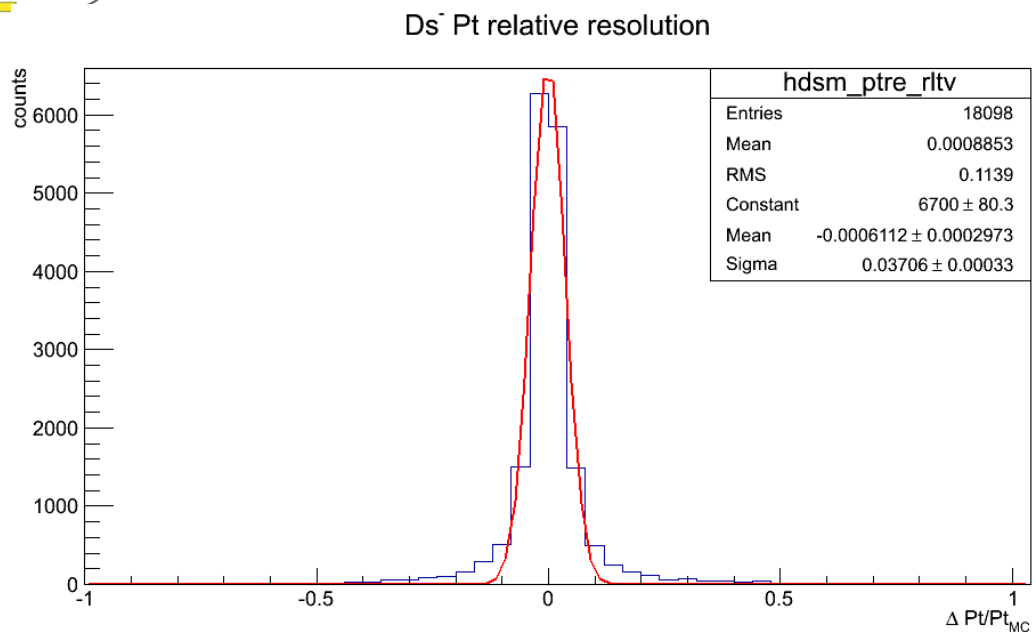


Ds- vertex resolution:

sigma_x = 80 µm

sigma_z = 170 µm

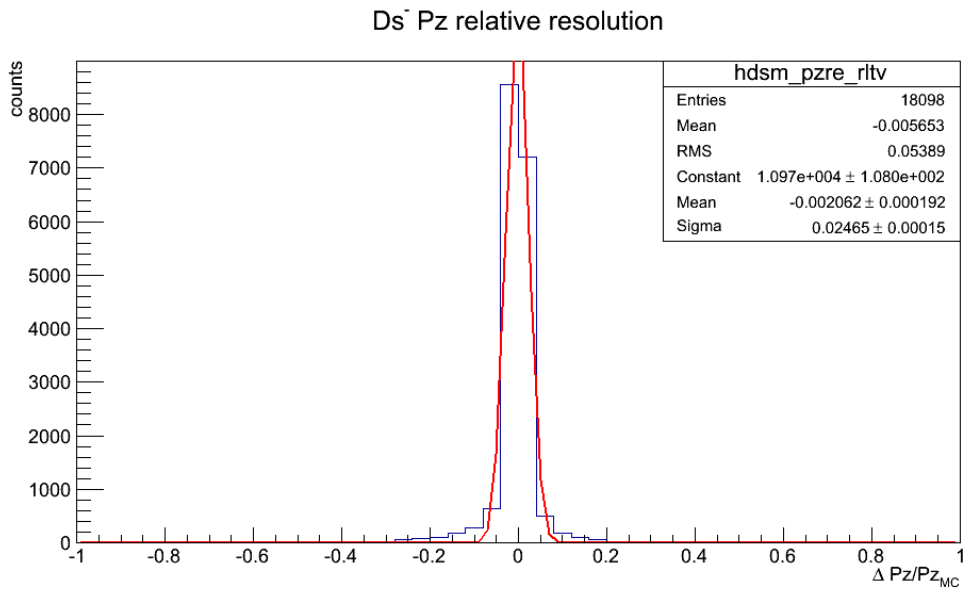




Ds- momentum relative resolution:

sigma_pt = 3.7%

sigma_pz = 2.5%



Reconstructions of pi0 ($\gamma\gamma$) and eta

Evt = 10k

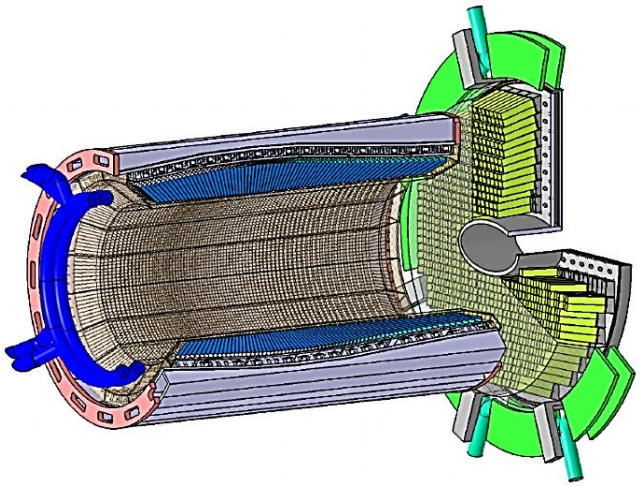
Pi0 candidates are all possible combinations of photons come from the forward end-cap, back end-cap and barrel EMC.

pbarp system **noPhotos**

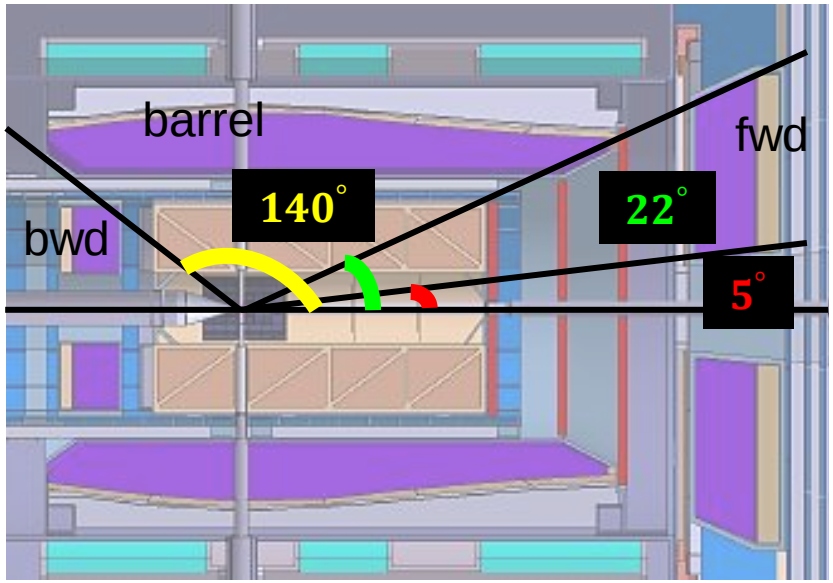
```
-> Ds- Ds+
   |     |-> eta e+ nu_e      PHOTOS   ISGW2
   |           | -> pi+ pi- pi0      ETA_DALITZ
   |-> K- K+ pi-                     DS_DALITZ
```

Minimum Photon Energy

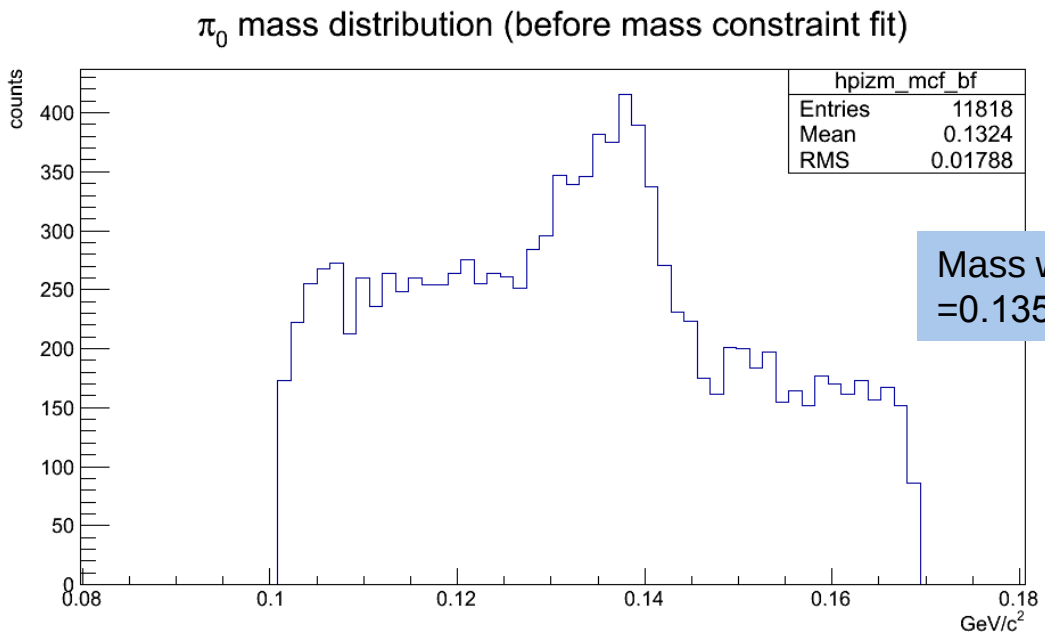
barrel: 50 MeV
fwd: 100 MeV
bwd: 50 MeV



Barrel and forward end-cap EMC

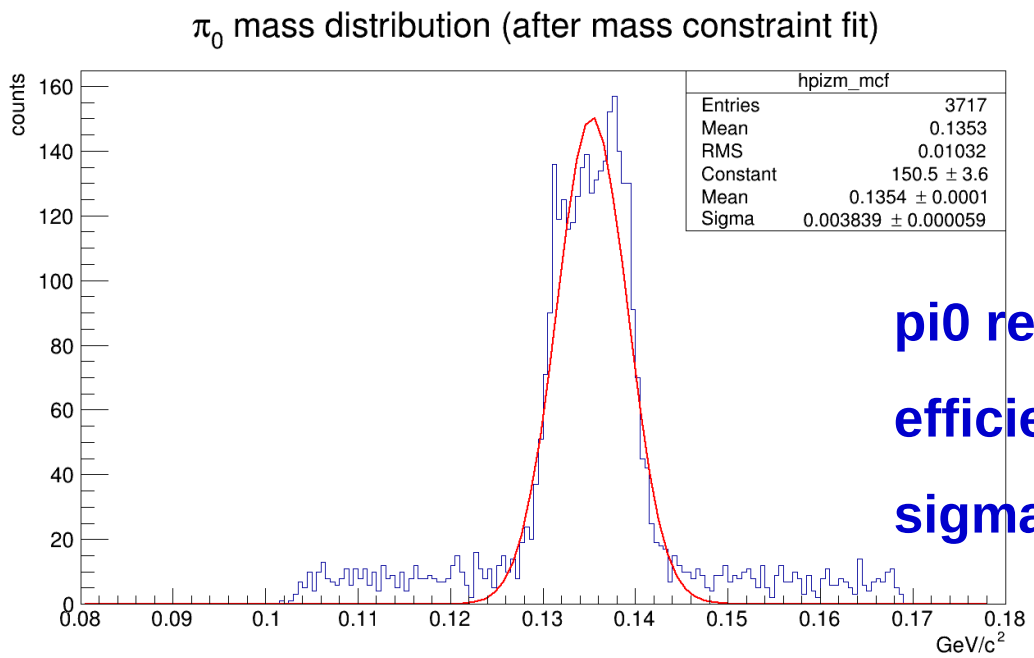


Angular range of EMC components



Evt = 10k

Mass window =0.135 ± 0.07GeV/c^2

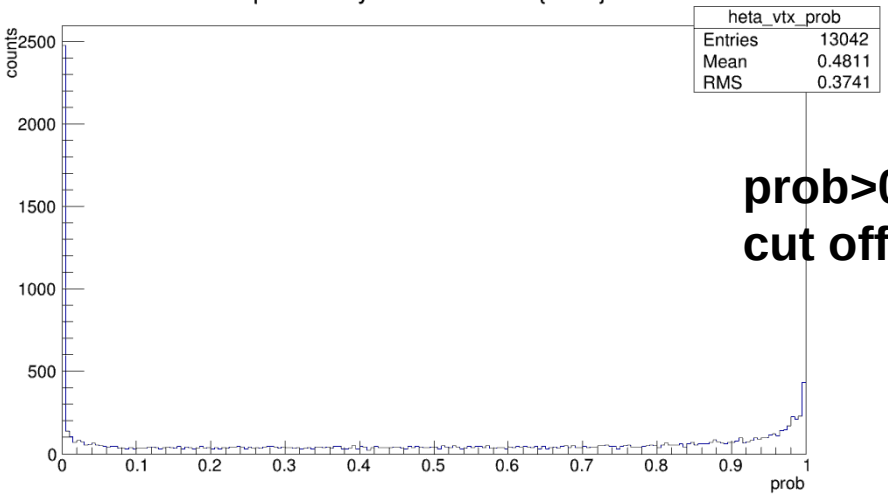


pi0 reconstruction:

efficiency = 37%

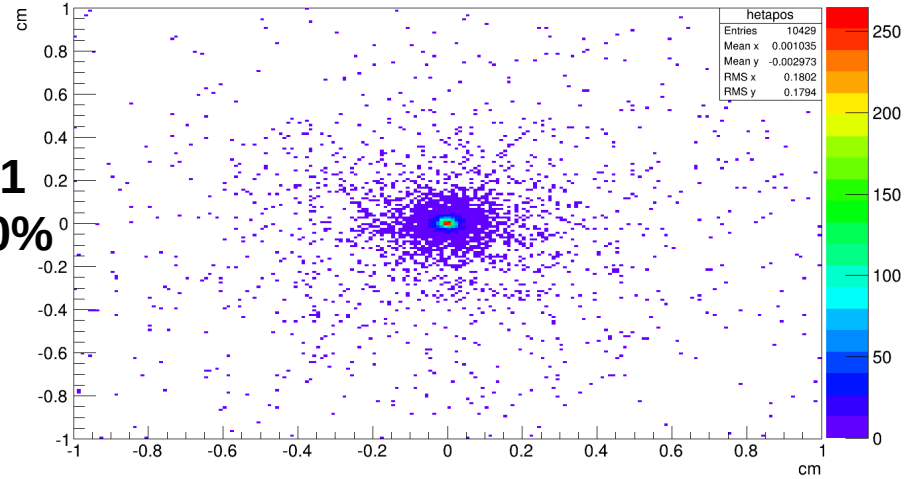
sigma = 4 MeV/c^2

Chi2 probability distribution of { $\pi^+\pi^-$} vtx fit

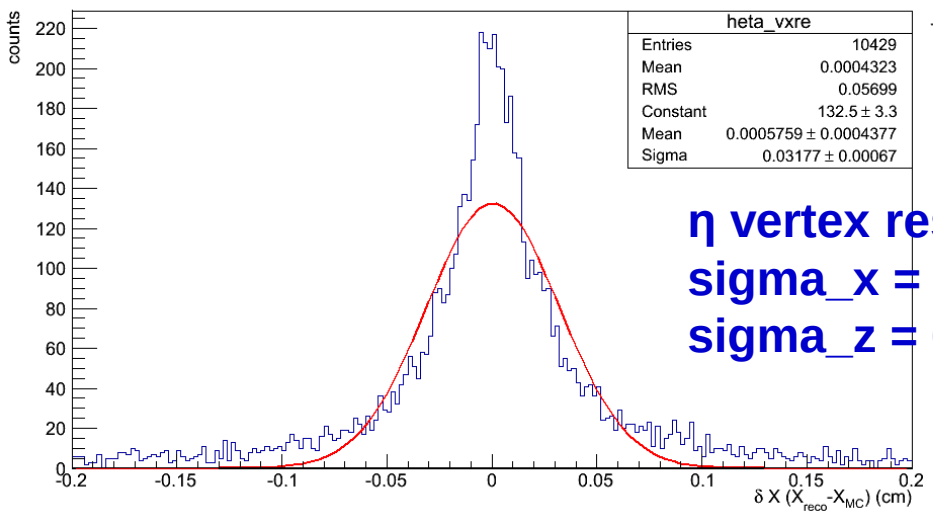


prob>0.01
cut off 80%

(x,y) projection of η decay vertex location distribution

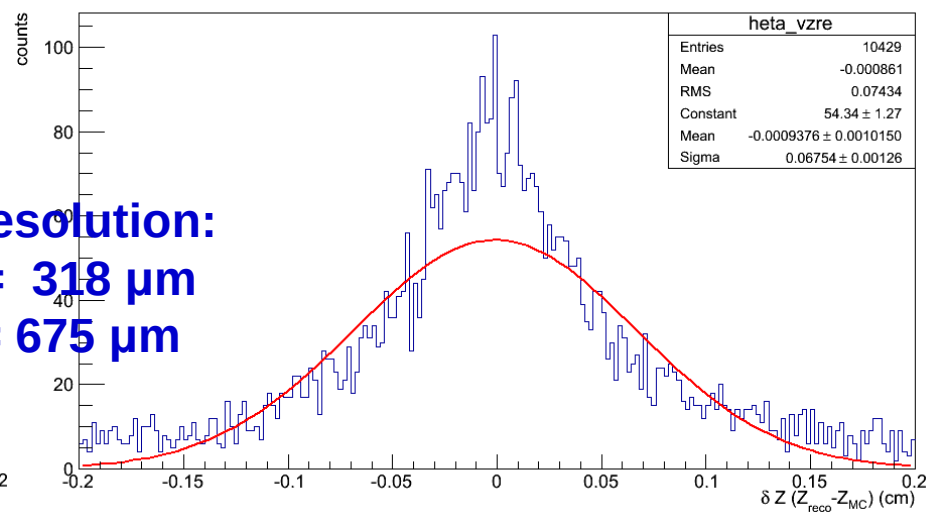


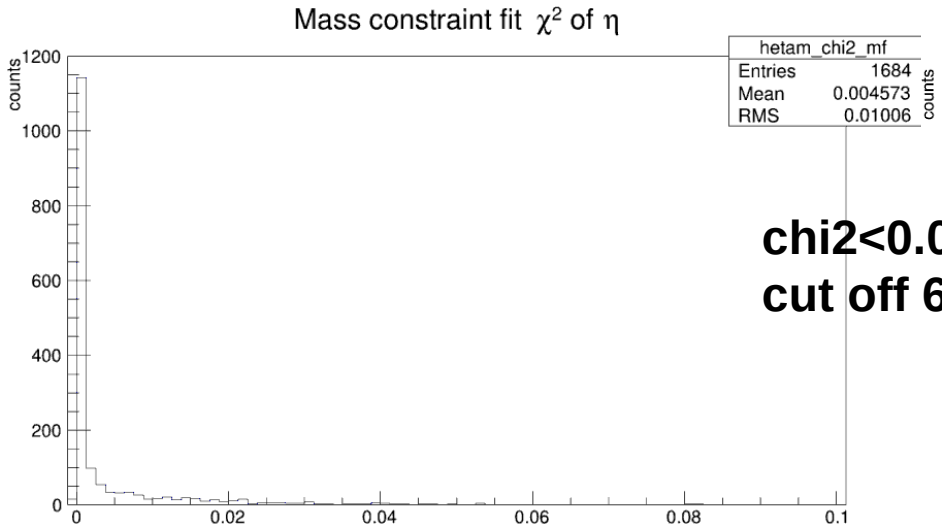
η Vertex location distribution X

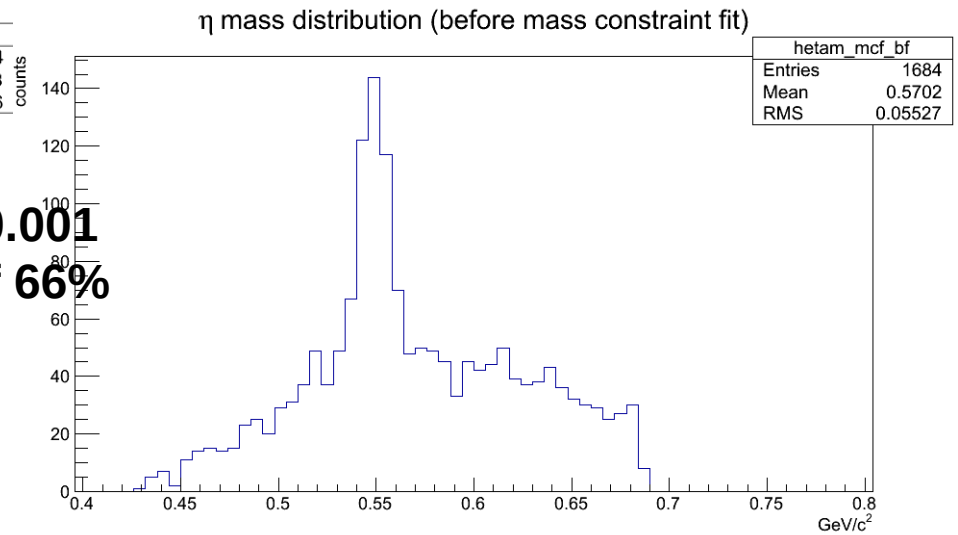


η vertex resolution:
sigma_x = 318 μm
sigma_z = 675 μm

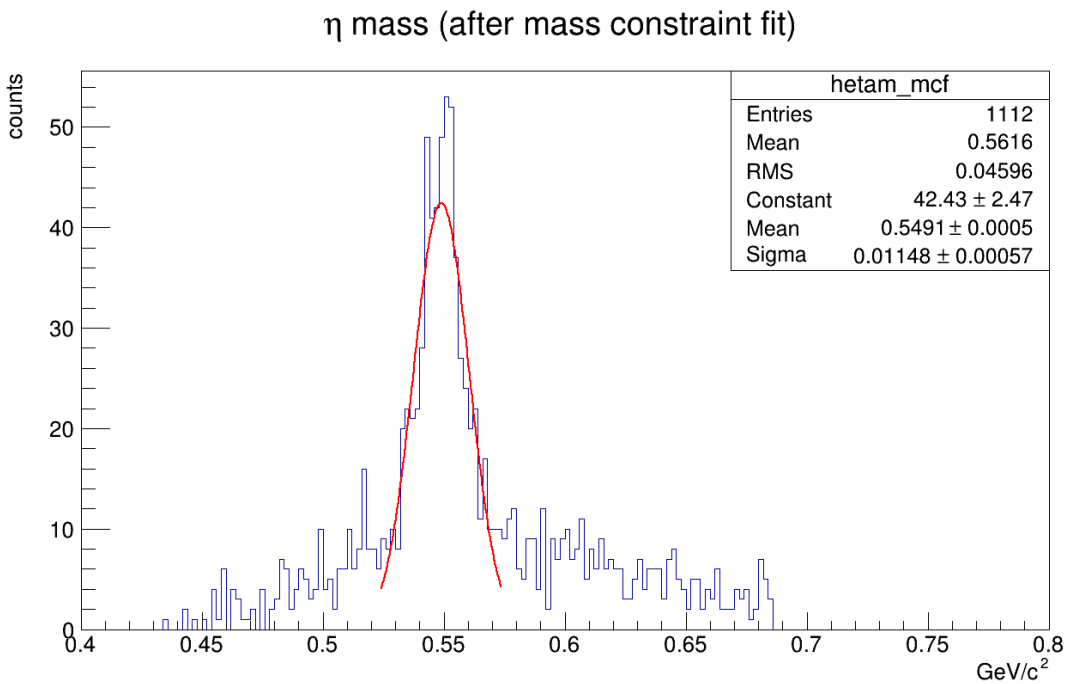
η Vertex location distribution Z







chi2<0.001
cut off 66%



η reconstruction

efficiency = 11%

sigma = 11 MeV/c²

Summary & Outlook

- DS_DALITZ decay model for Ds->K K π is available in PandaRoot
- Ds->K K π has been reconstructed with the good mass resolution:

	Reconstruction efficiency [%]	Mass resolution [MeV/c²]	Vertex resolution [μm]	
Ds-	18	17	x: 80	z: 170
π_0	37	4	-	-
η	11	11	318	675

- Reconstruction of neutral particles (pi0, eta) needs to be improved
- Evaluation of form factor and the total reconstruction efficiency will be obtained
- Extension to Ds-> e + v + η'(958)

Thanks for your attention

l.cao@fz-juelich.de

Backup slides

Form factor and decay rate of Ds+ -> eta e+ nu_e

$$\langle \eta(p)|\bar{s}\gamma_\mu(1-\gamma_5)c|D_s(p+q)\rangle = 2f_+^{D_s\to\eta}(q^2)p_\mu + (f_+^{D_s\to\eta}(q^2) + f_-^{D_s\to\eta}(q^2))q_\mu$$

Light cone QCD sum rules

J.Phys.G 38 (2011) 095001
arXiv:1011.6046[hep-ph]

Differential decay rate (massless lepton):

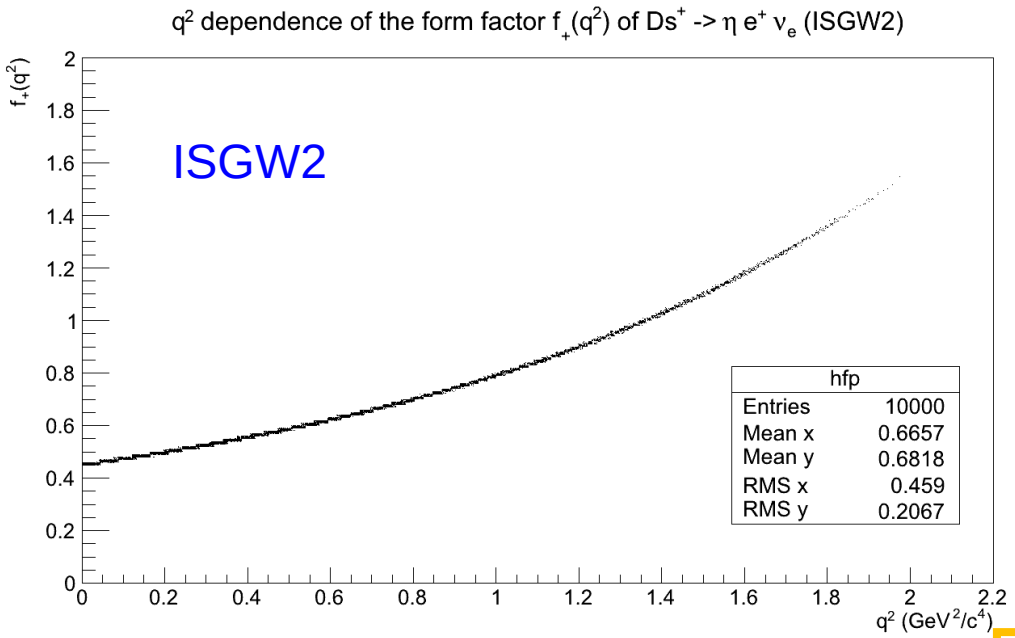
$$\frac{d\Gamma}{dq^2}(D_s \to (\eta,\eta')l\nu_l) = \frac{G_F^2|V_{cs}|^2}{192\pi^3 m_{D_s}^3}\left[(m_{D_s}^2 + m_{\eta^{(\prime)}}^2 - q^2)^2 - 4m_{D_s}^2 m_{(\eta,\eta')}^2\right]^{3/2}|f_+^{D_s\to\eta^{(\prime)}}(q^2)|^2$$

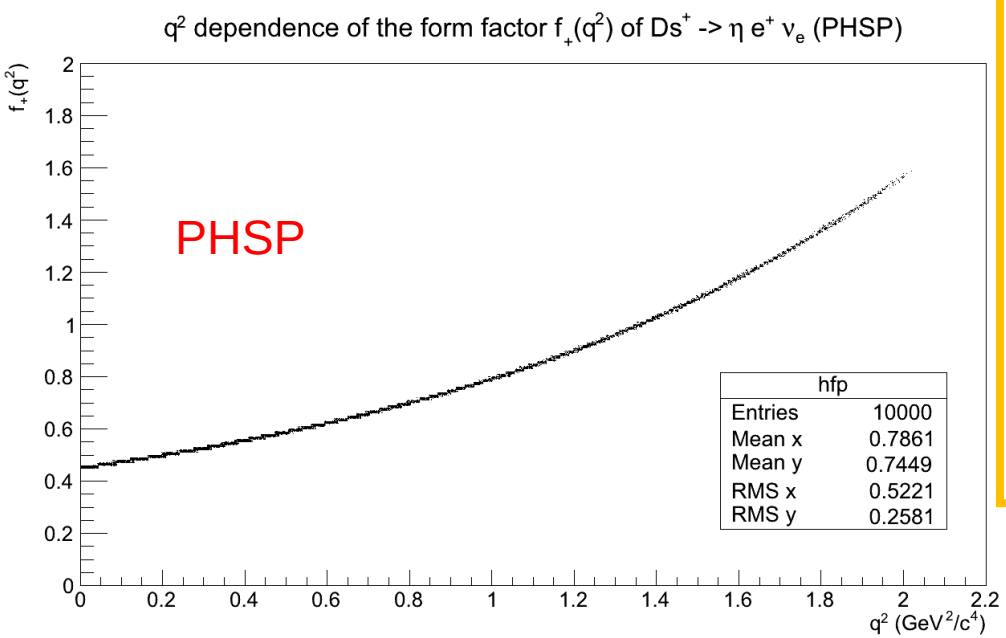
Parameterization of the q^2 dependence so the form factors:

$$f_\pm(q^2) = \frac{f_\pm(0)}{1-\alpha\hat{q}+\beta\hat{q}^2} \qquad \hat{q} = q^2/m_{D_s}^2$$

with

	$f_+^{D_s\to\eta}(0)$	α	β
This Work (LCSR)	0.45 ± 0.14	1.96 ± 0.63	1.12 ± 0.36



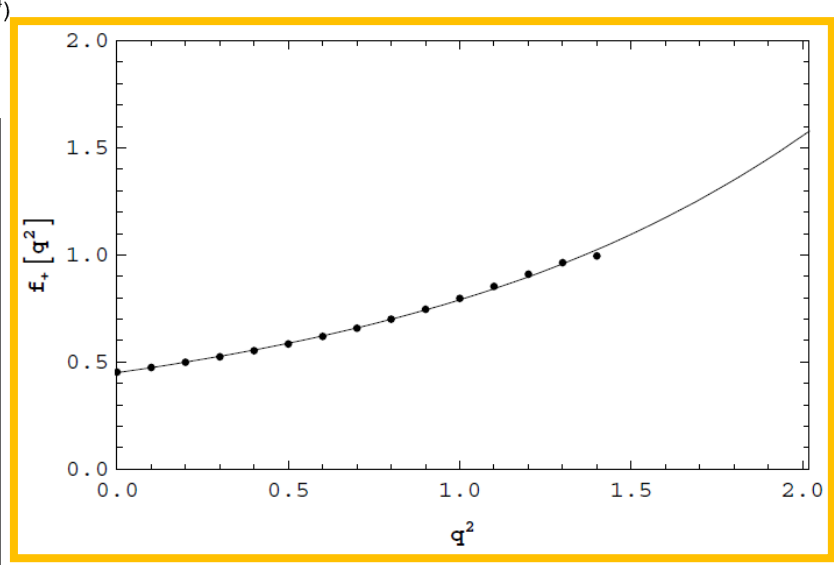


$$f_\pm(q^2) = \frac{f_\pm(0)}{1 - \alpha\hat{q} + \beta\hat{q}^2}$$

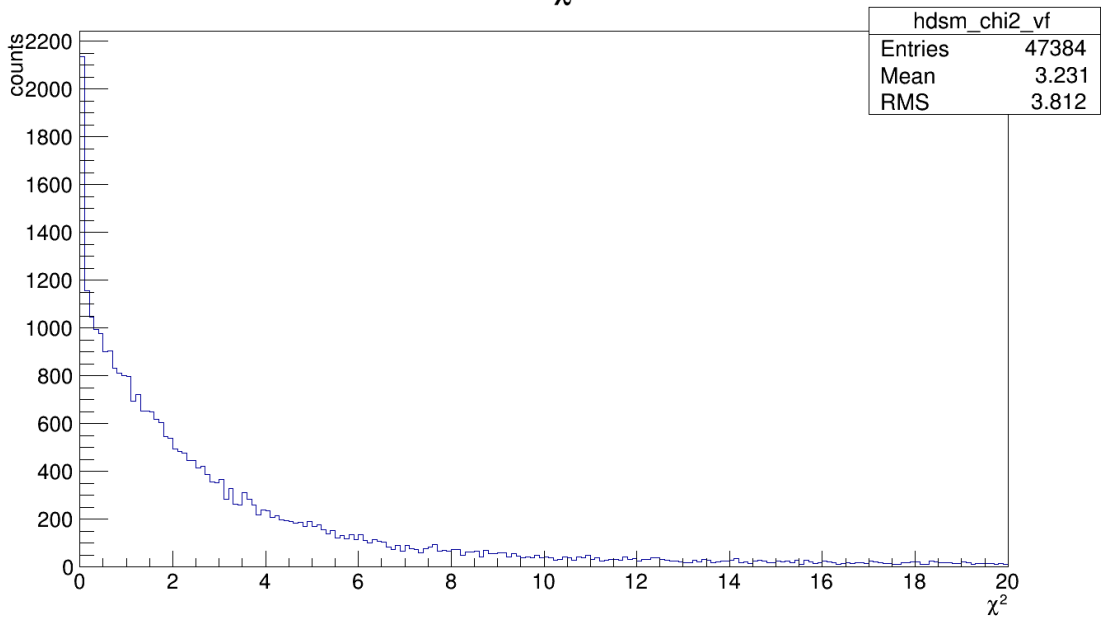
$$\hat{q} = q^2/m_{D_s}^2$$

Light cone QCD sum rules

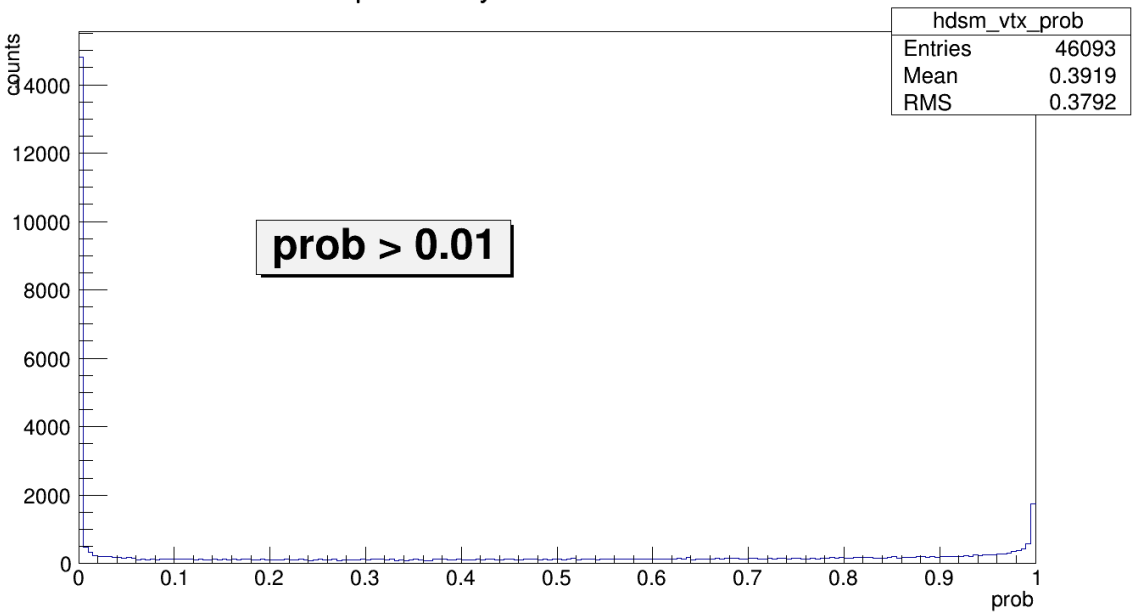
J.Phys.G 38 (2011) 095001
arXiv:1011.6046[hep-ph]



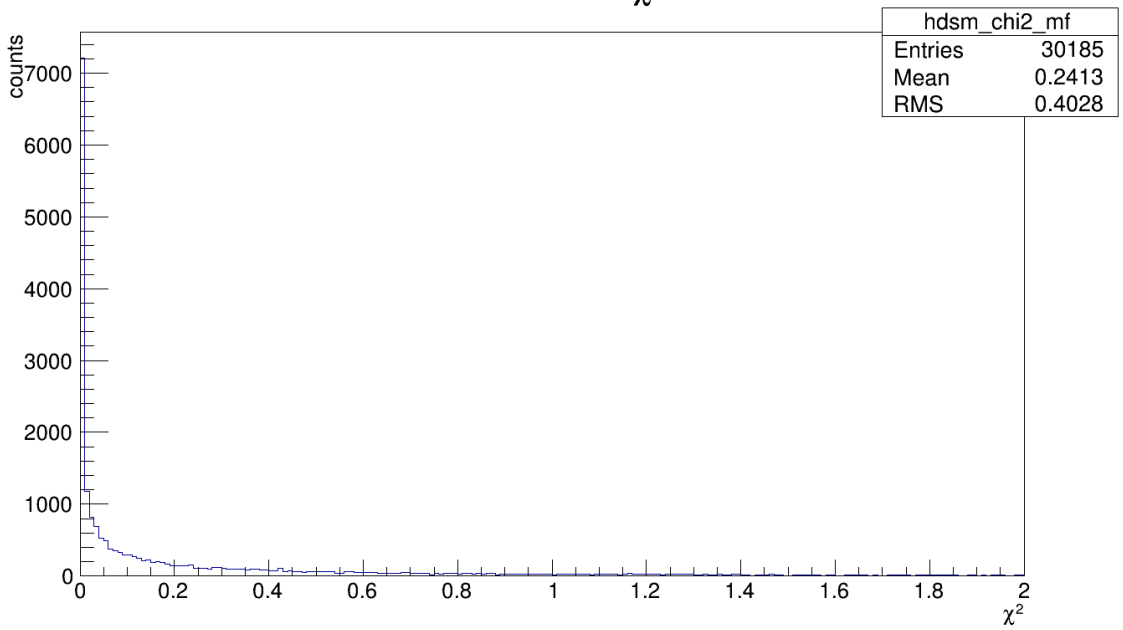
Vertex fit χ^2 of Ds$^-$



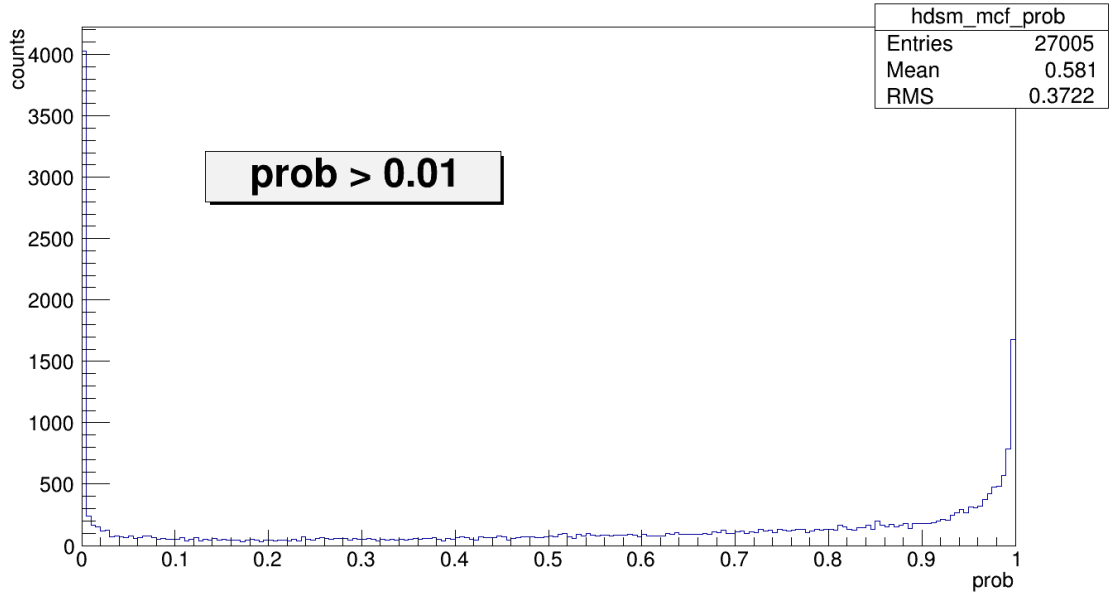
Chi2 probability distribution of Ds$^-$ vtx fit

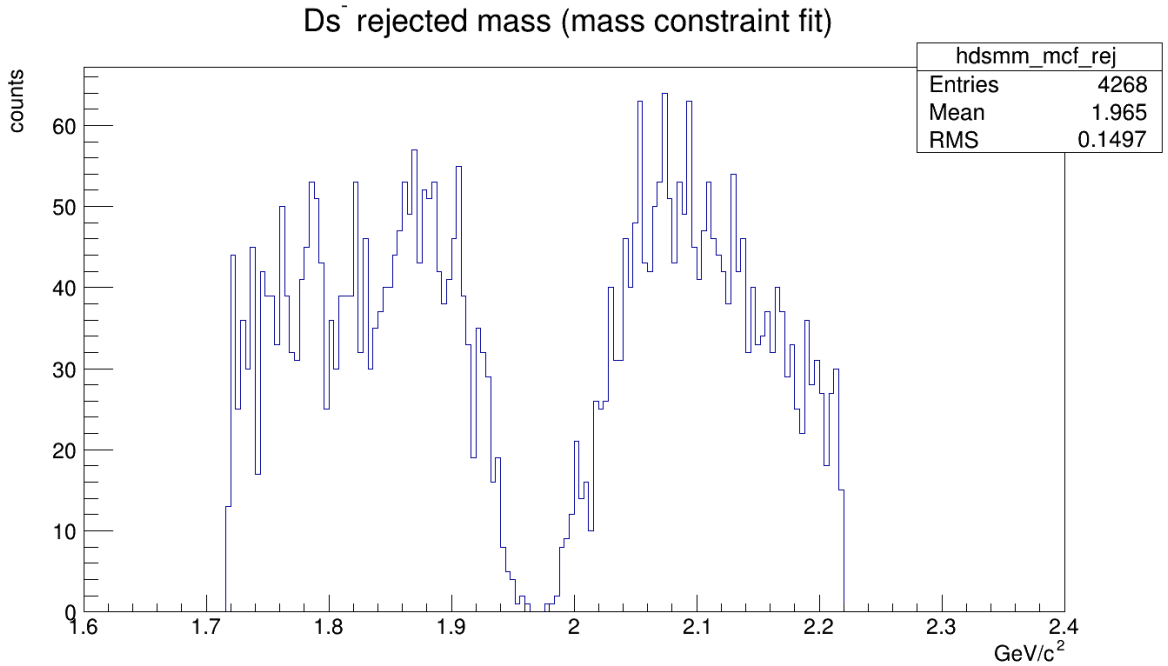


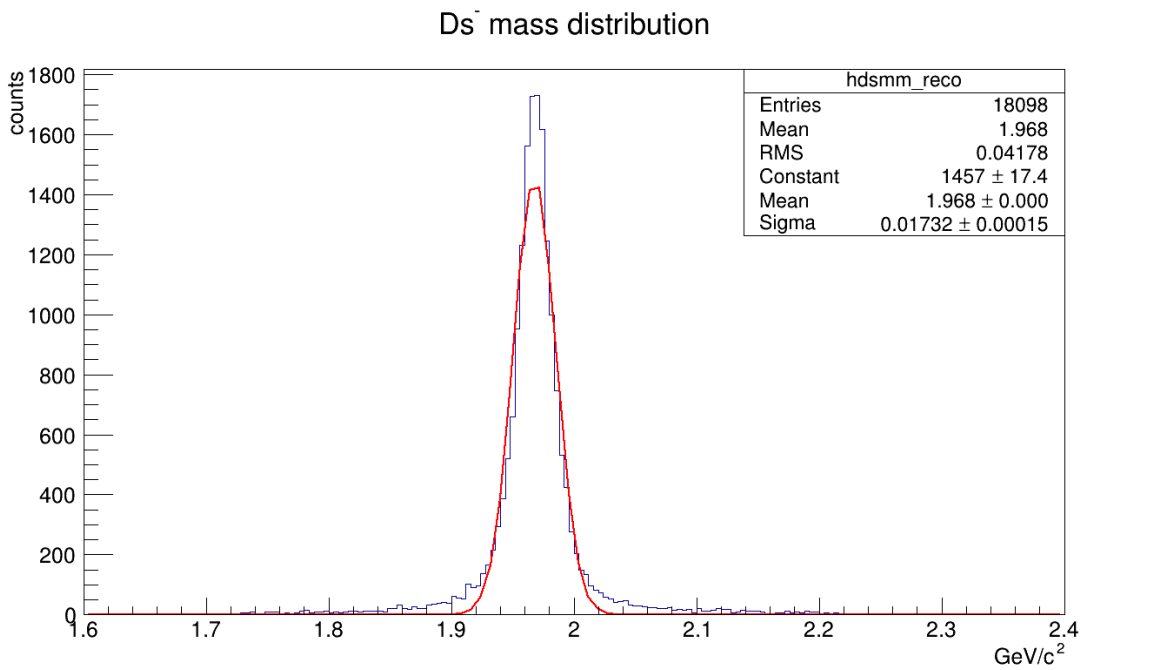
Mass constraint fit χ^2 of Ds^-

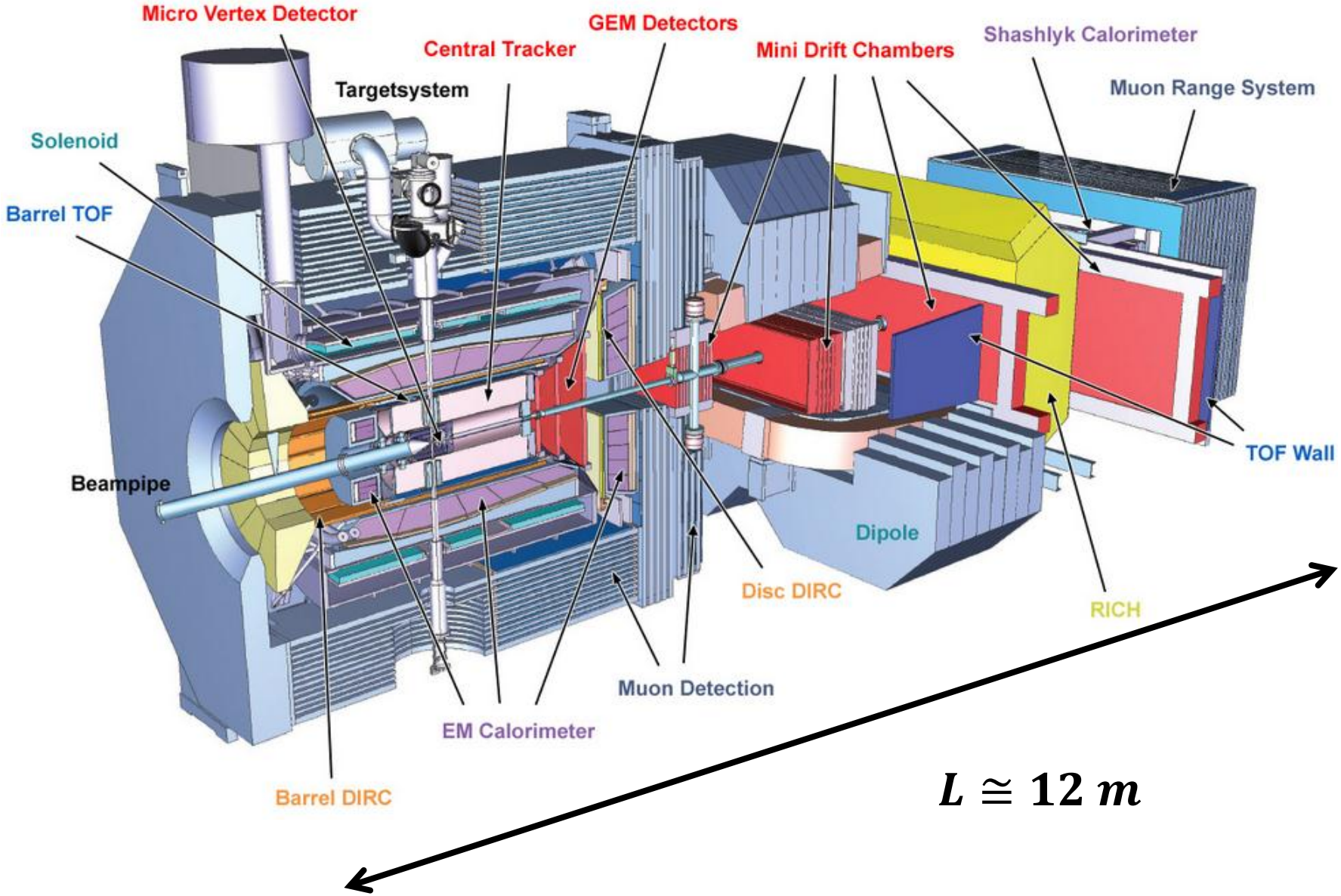


Chi2 probability distribution of Ds^- mass constraint fit

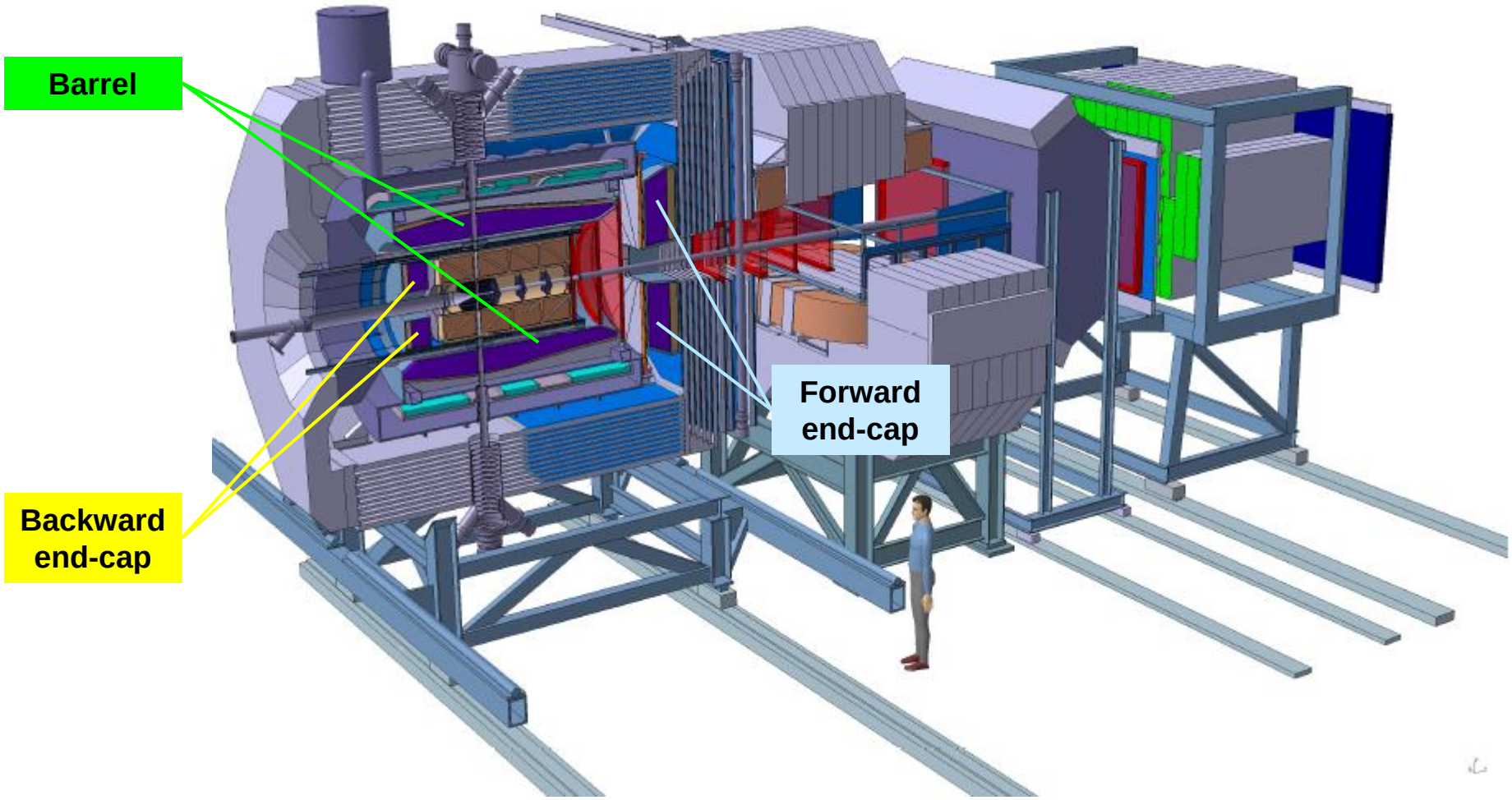



Ds⁻ rejected mass (mass constraint fit)
hdsmm_mcf_rej
Entries 4268
Mean 1.965
RMS 0.1497
counts
GeV/c²

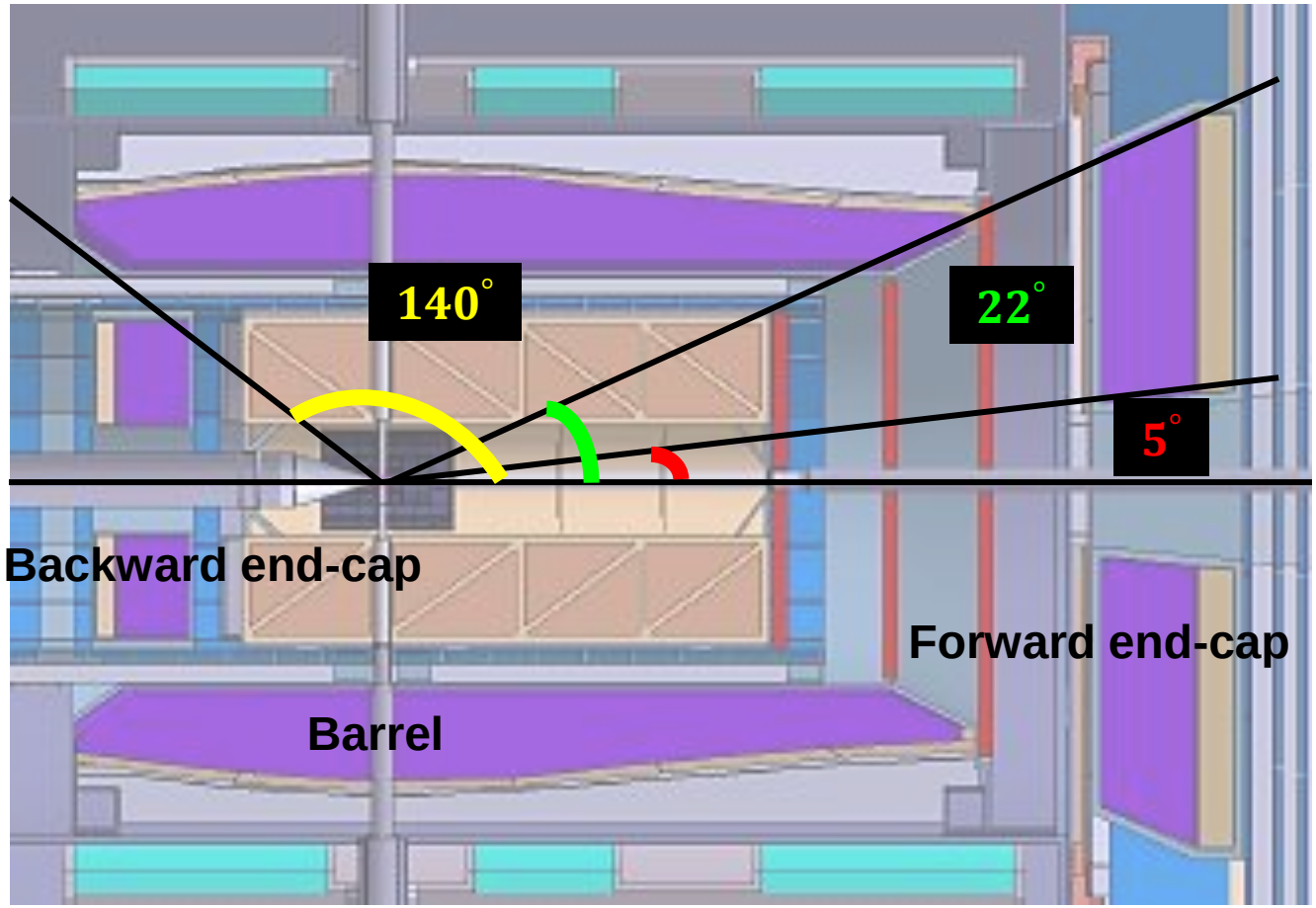

Ds⁻ mass distribution
hdsmm_reco
Entries 18098
Mean 1.968
RMS 0.04178
Constant 1457 ± 17.4
Mean 1.968 ± 0.000
Sigma 0.01732 ± 0.00015
counts
GeV/c²


Micro Vertex Detector
GEM Detectors
Central Tracker
Mini Drift Chambers
Shashlyk Calorimeter
Targetsystem
Muon Range System
Solenoid
Barrel TOF
TOF Wall
Beampipe
Dipole
Disc DIRC
RICH
Muon Detection
EM Calorimeter
Barrel DIRC
$L \cong 12\ m$

Electromagnetic Calorimeter in P̄ANDA

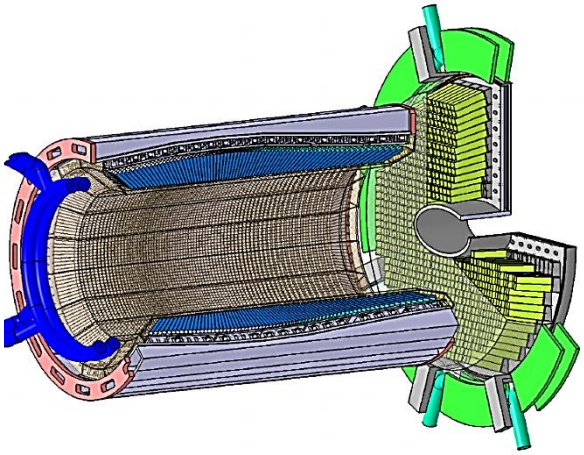


Electromagnetic Calorimeter (EMC)



Main requirements for EMC

	Required performance value		
Common properties			
energy resolution σ_E/E	$\leq 1\,\% \oplus \frac{<2\,\%}{\sqrt{E/\mathrm{GeV}}}$		
energy threshold (photons) E_{thres}	10 MeV (20 MeV tolerable)		
energy threshold (single crystal) E_{xtl}	3 MeV		
rms noise (energy equiv.) $\sigma_{E,noise}$	1 MeV		
angular coverage % 4π	99 %		
mean-time-between-failures t_{mtbf} (for individual channel)	2000 y		
Subdetector specific properties	backward ($\geq 140°$)	barrel ($\geq 22°$)	forward ($\geq 5°$)
energy range from E_{thres} to	0.7 GeV	7.3 GeV	14.6 GeV
angular equivalent of crystal size θ	4°		1°
spatial resolution σ_θ	0.5°	0.3°	0.1°
maximum signal load f_γ ($E_\gamma > E_{xtl}$)	60 kHz		500 kHz
($p\bar{p}$-events) maximum signal load f_γ ($E_\gamma > E_{xtl}$)	100 kHz		500 kHz
(all events) shaping time t_s	400 ns		100 ns
radiation hardness (maximum annual dose $p\bar{p}$-events)	0.15 Gy	7 Gy	125 Gy
radiation hardness (maximum annual dose from all events)	10 Gy		125 Gy



Barrel and forward end-cap EMC

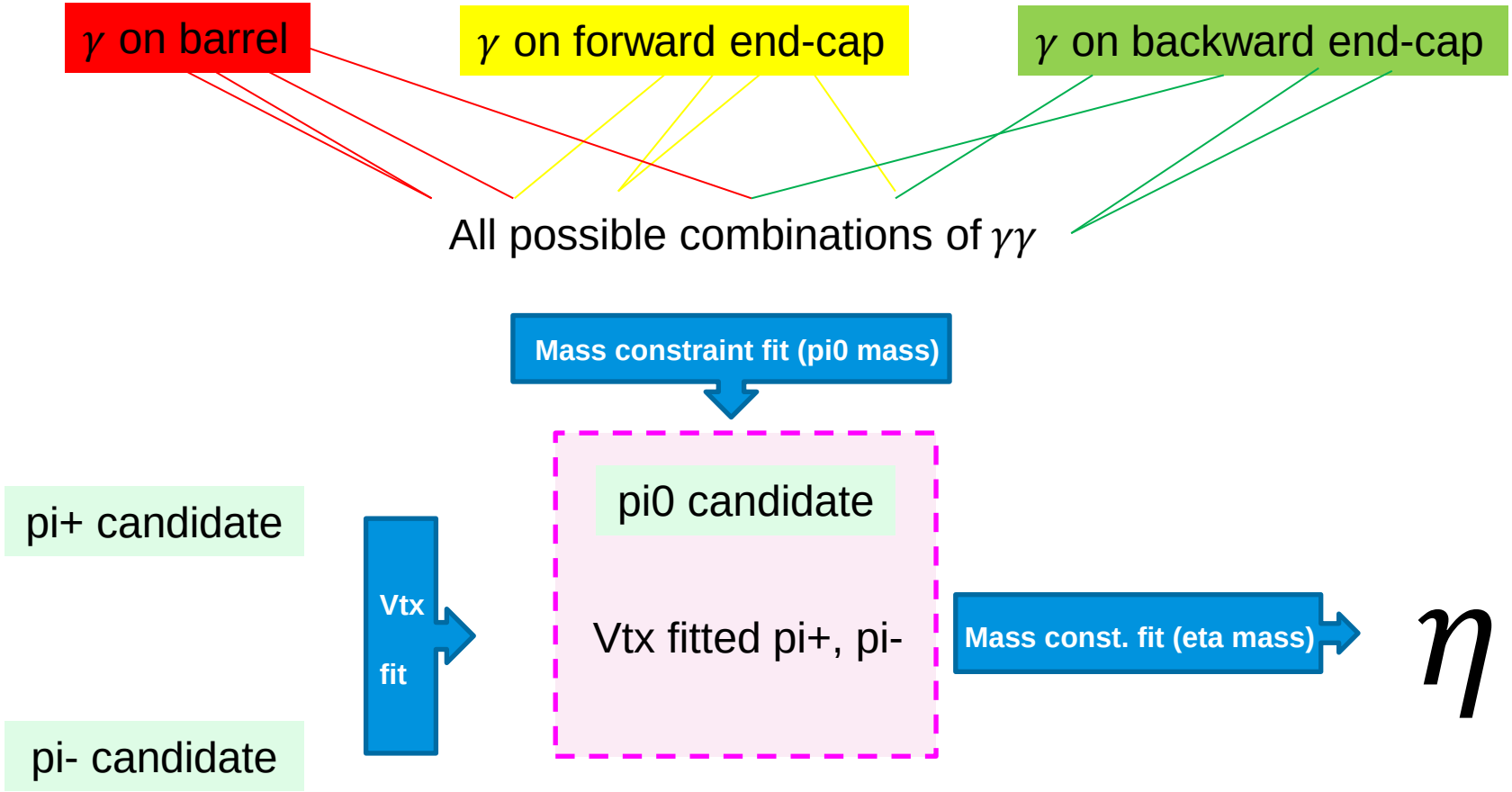
Reconstruction thresholds

- $E_{xtl} = 3\,\mathrm{MeV}$
- $E_{cl} = 10\,\mathrm{MeV}$
- $E_{max} = 20\,\mathrm{MeV}$

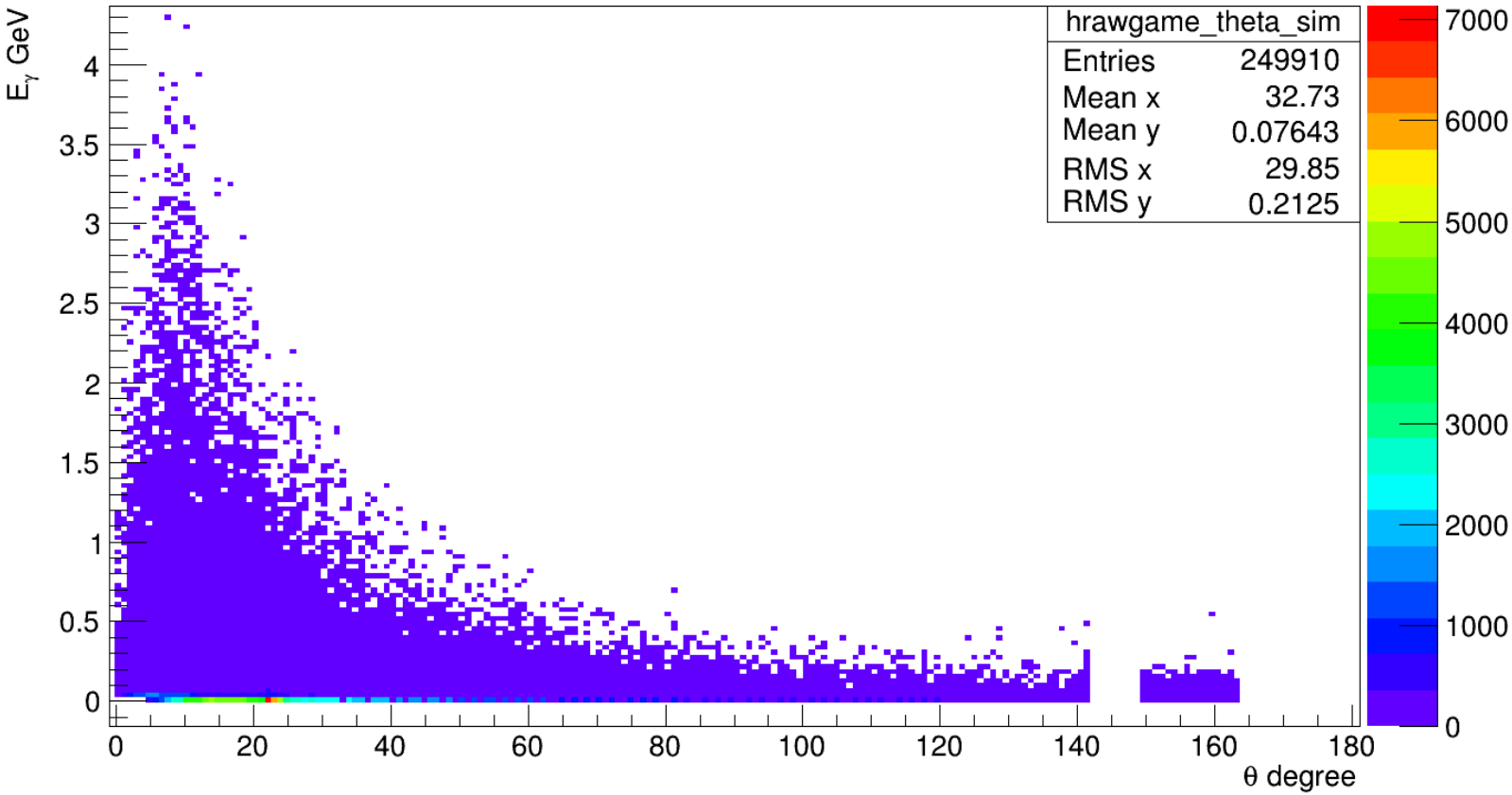
Dynamical Energy Range

- backward endcap EMC: 10(20) MeV- 0.7 GeV
- barrel EMC: 10(20) MeV- 7.3 GeV, and
- forward endcap EMC: 10(20) MeV- 14.6 GeV.

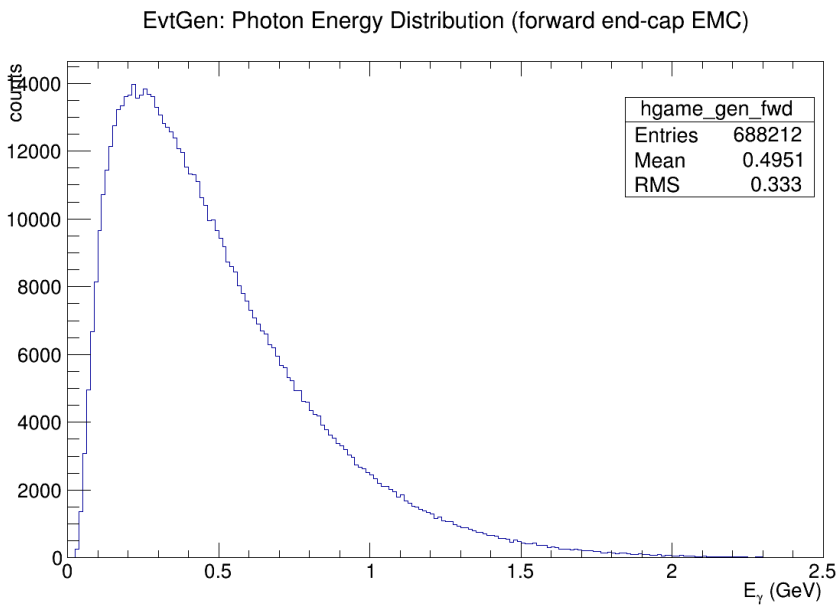
Reconstruction of eta (pi+, pi-, pi0)



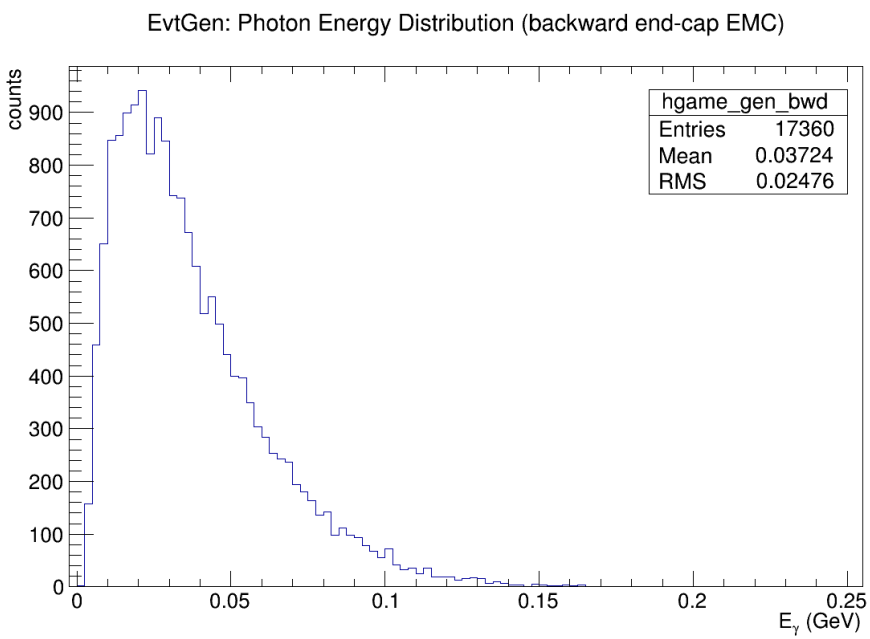
Photon energy distribution vs. θ



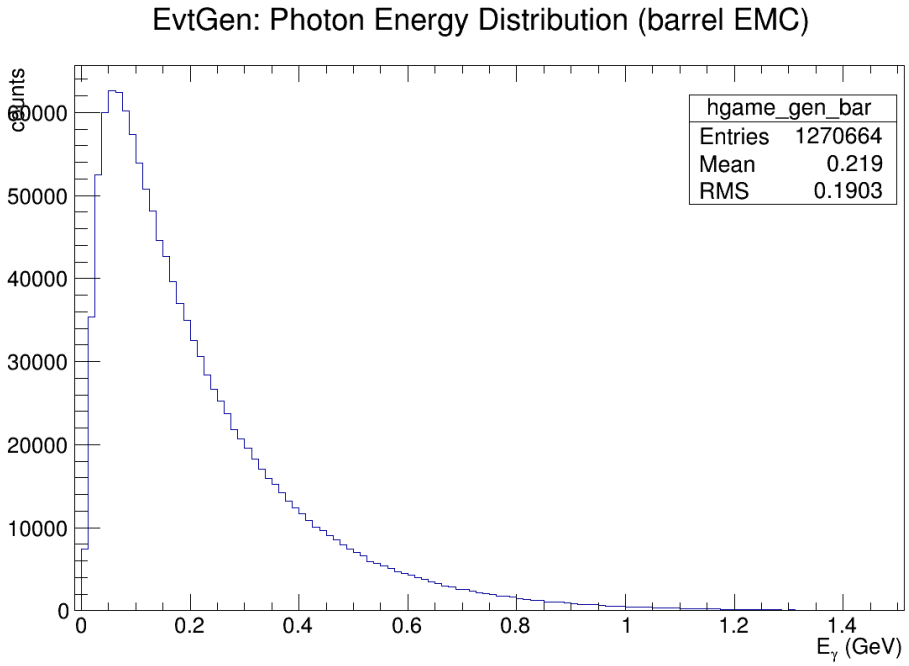
Photon Energy Distribution (EvtGen)

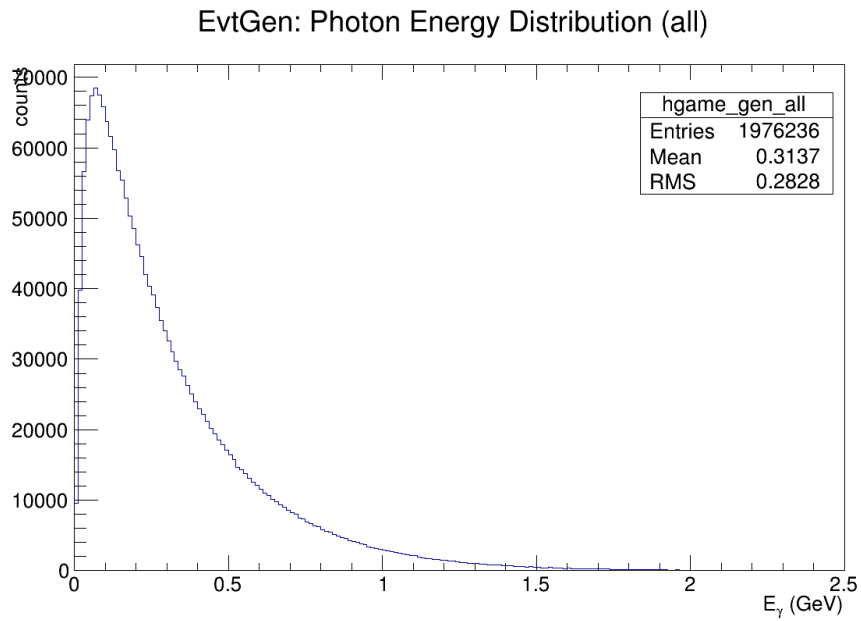


1 M evt
Generator: EvtGenDirect
Sim. via SimpleEvtGenRO

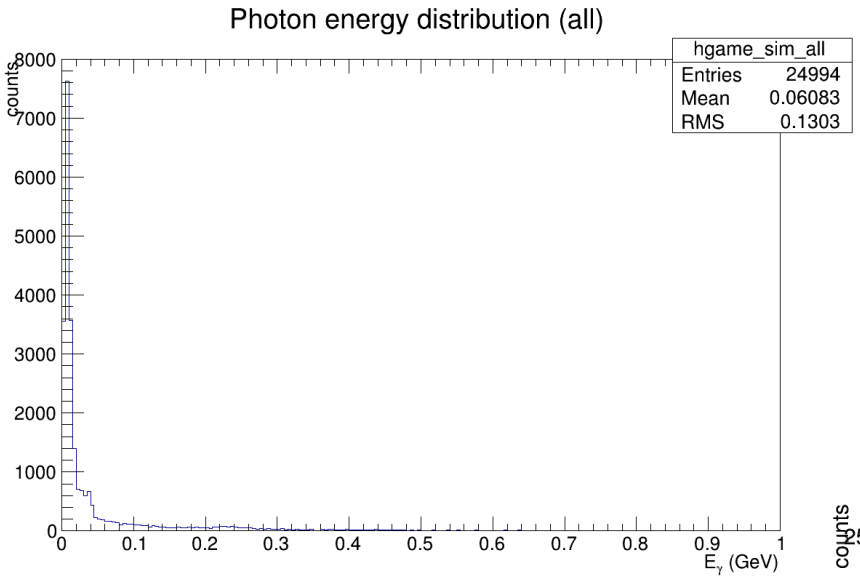


Photon Energy Distribution (EvtGen)

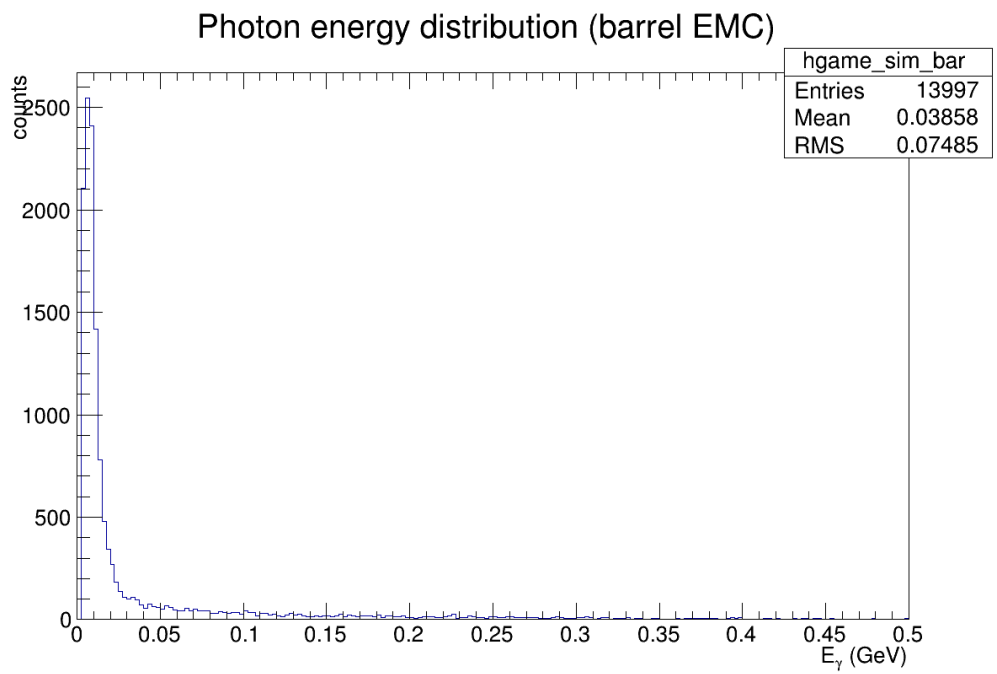




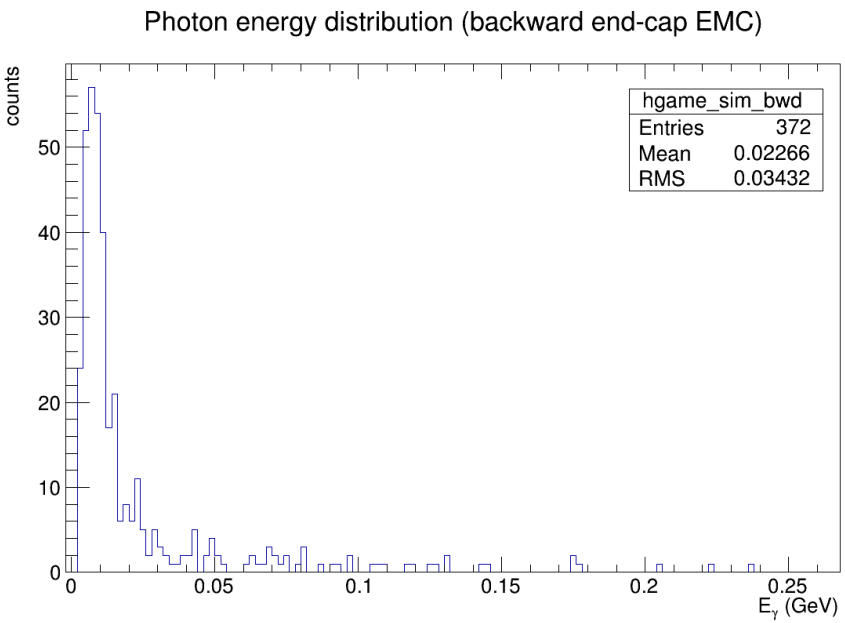
Photon Energy Distribution (“Neutral” list)

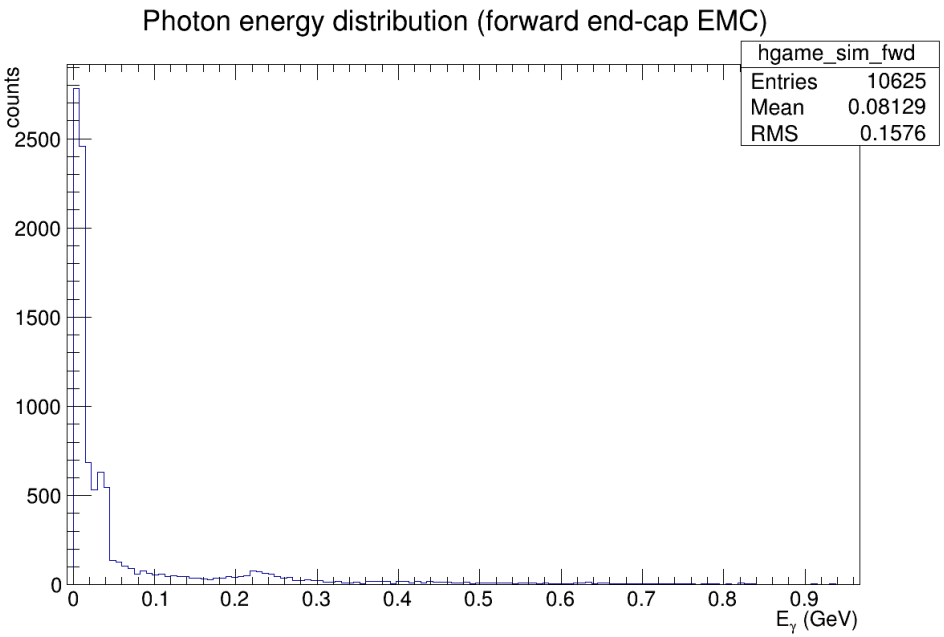


1 k evt
Generator: EvtGenDirect
FillList(gamma, “Nuetral”)

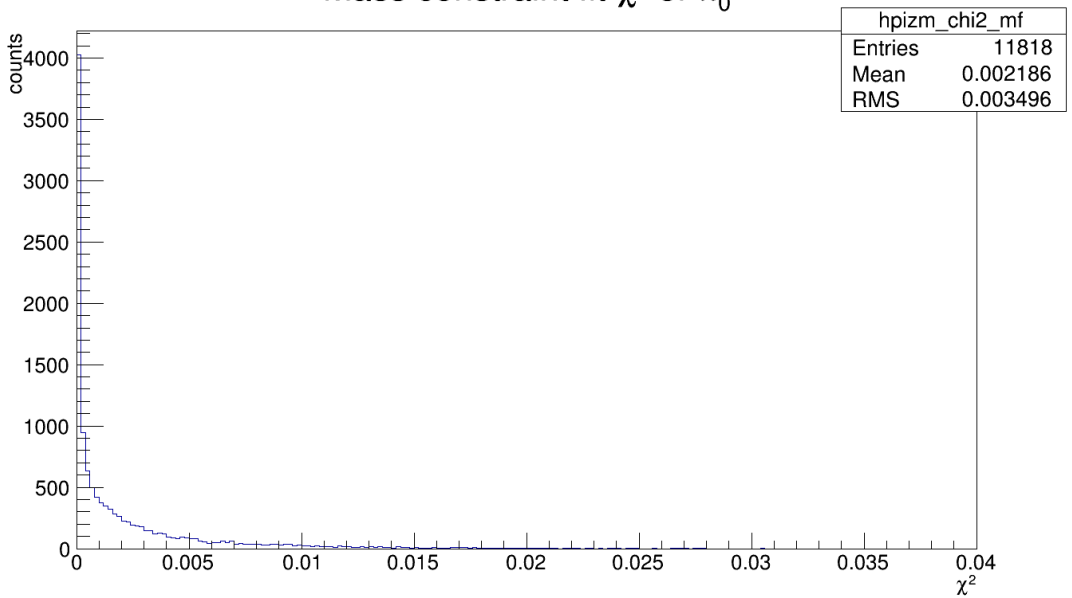


Photon Energy Distribution (“Neutral” list)

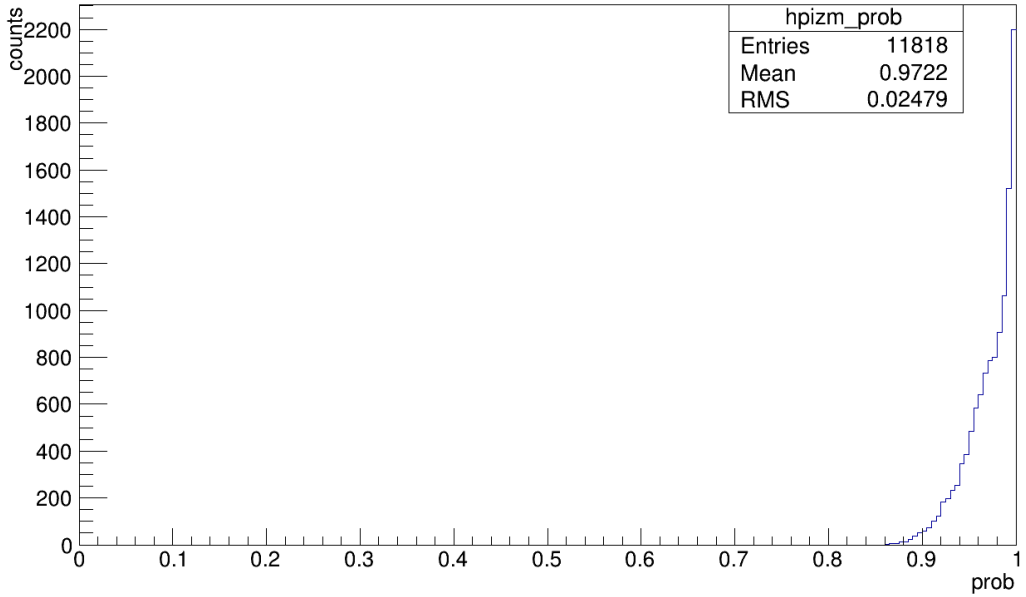




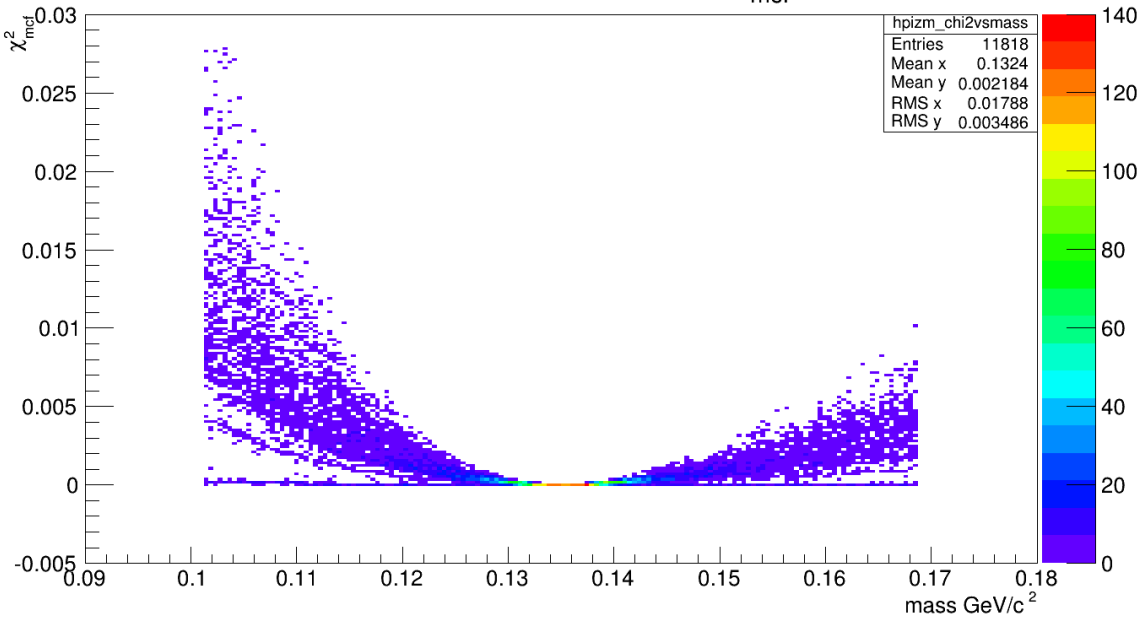
Mass constraint fit χ^2 of π_0



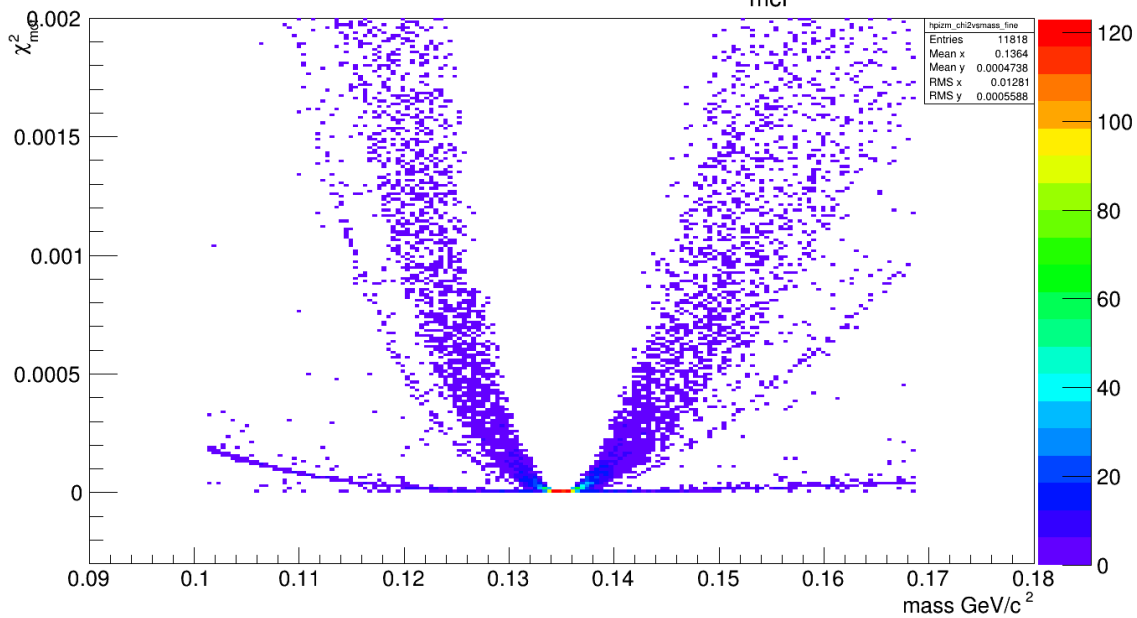
Chi2 probability distribution of π_0 mass constraint fit



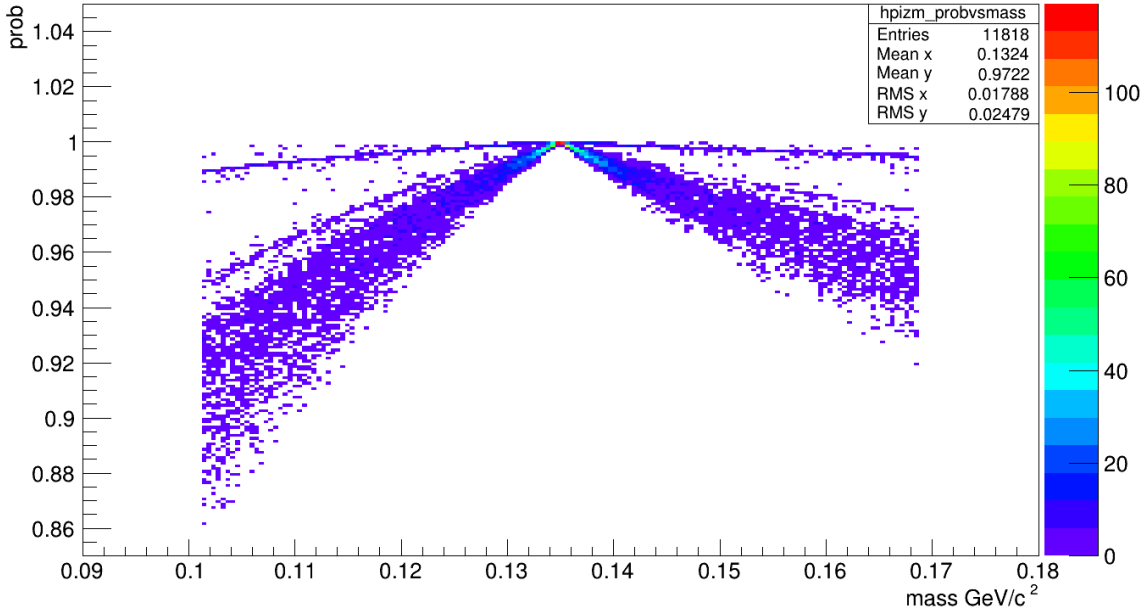
π_0 mass distribution vs. χ^2_{mcf}



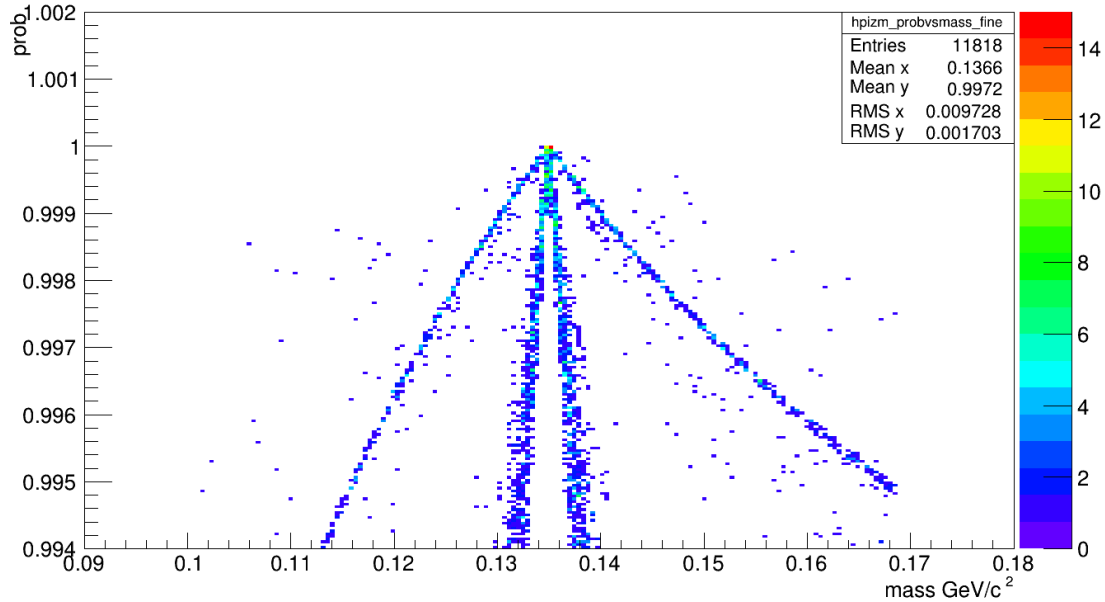
π_0 mass distribution vs. χ^2_{mcf}



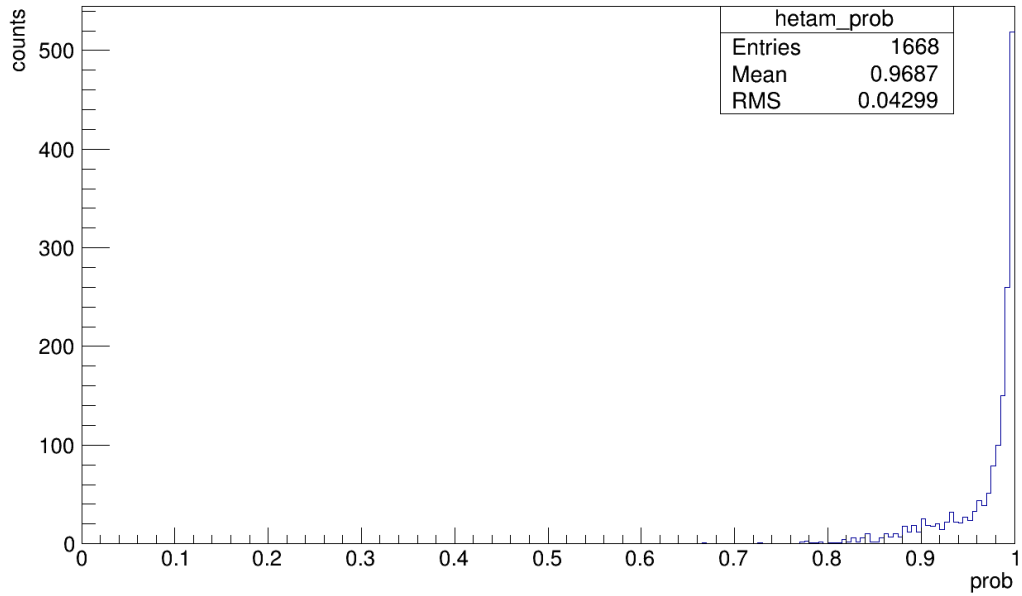
π_0 mass vs. probability distribution



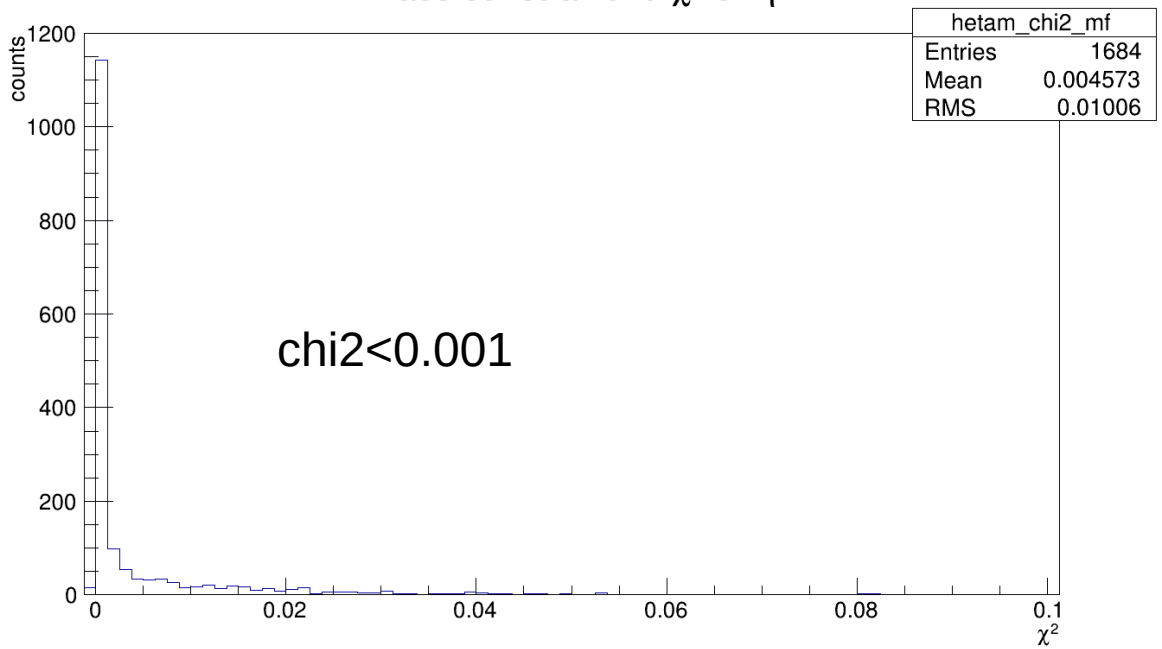
π_0 mass vs. probability distribution



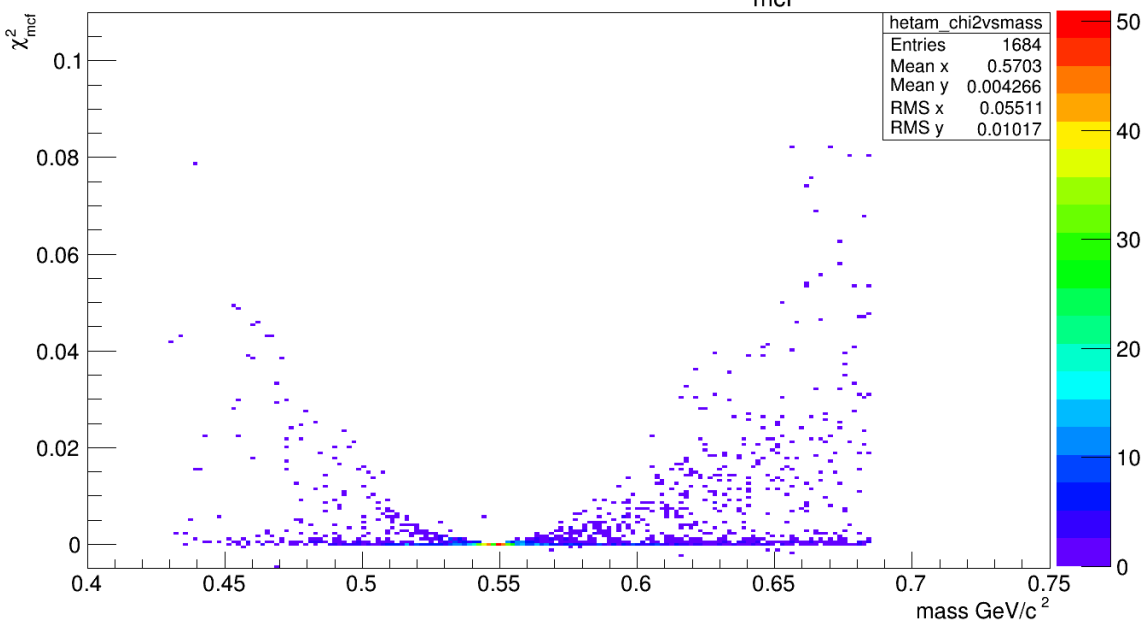
Chi2 probability distribution of η mass constraint fit



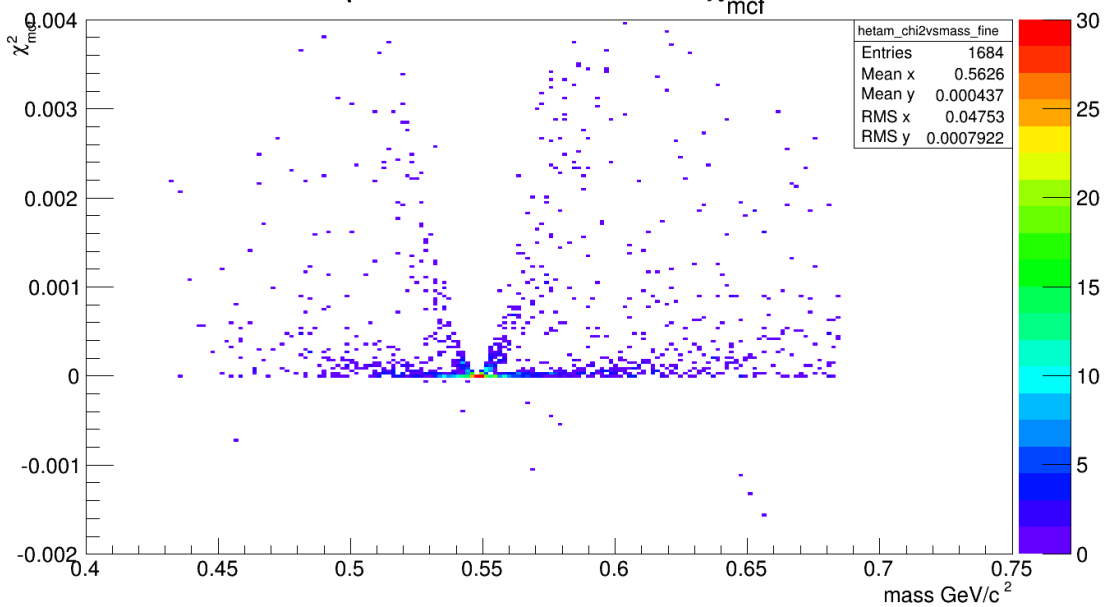
Mass constraint fit χ^2 of η



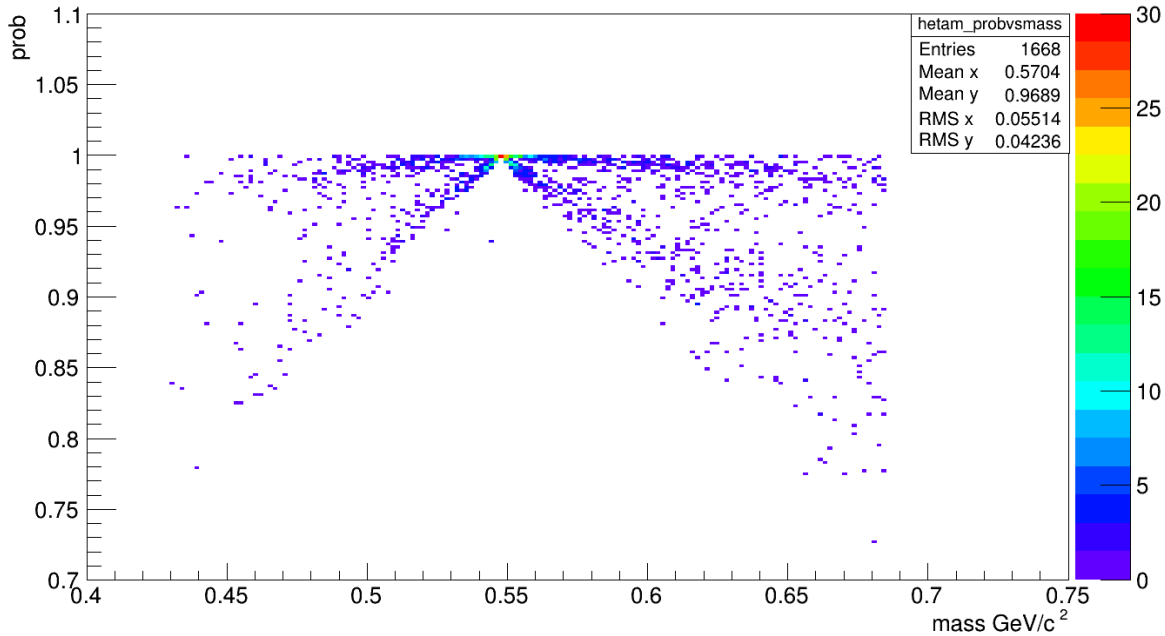
η mass distribution vs. χ^2_{mcf}



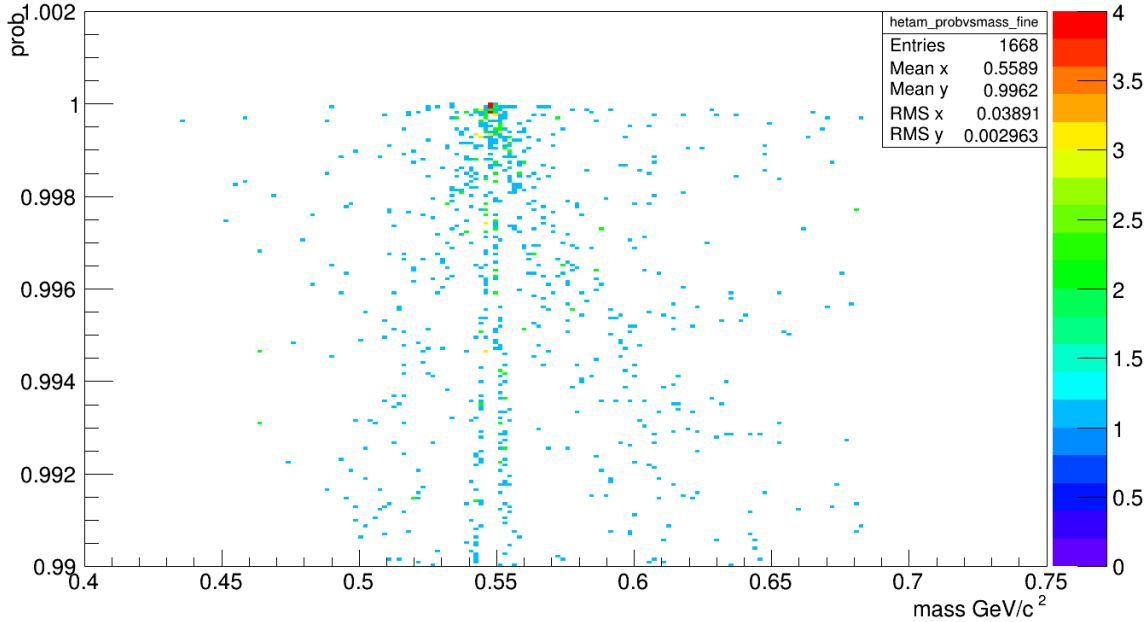
η mass distribution vs. χ^2_{mcf}

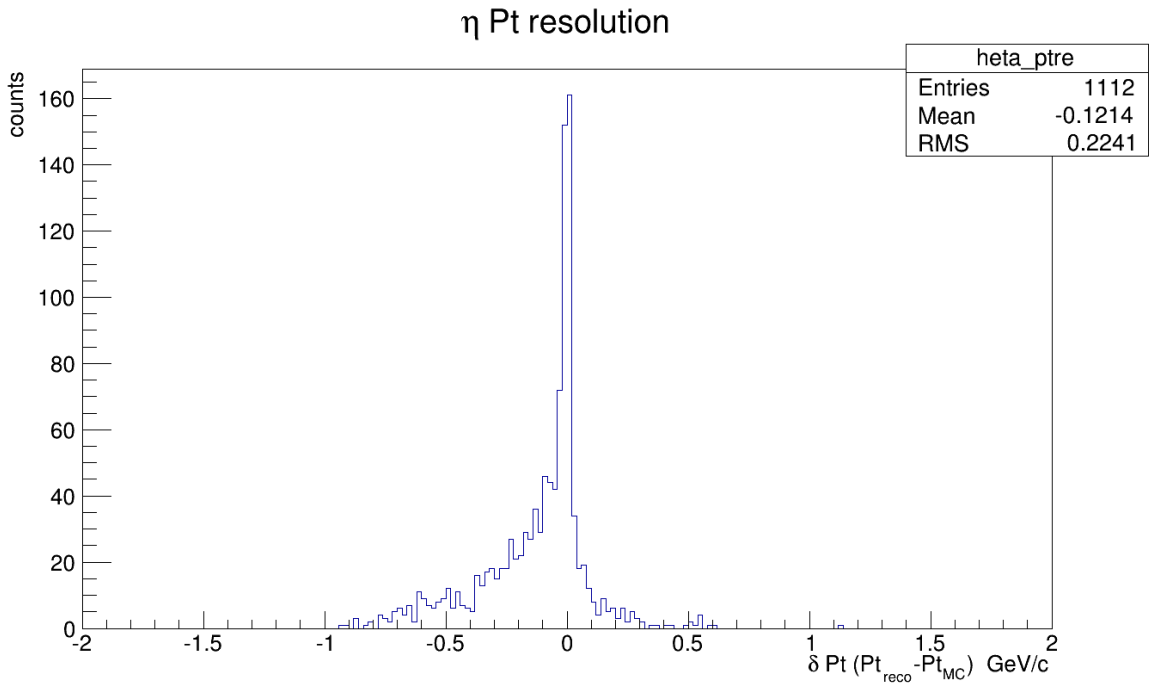


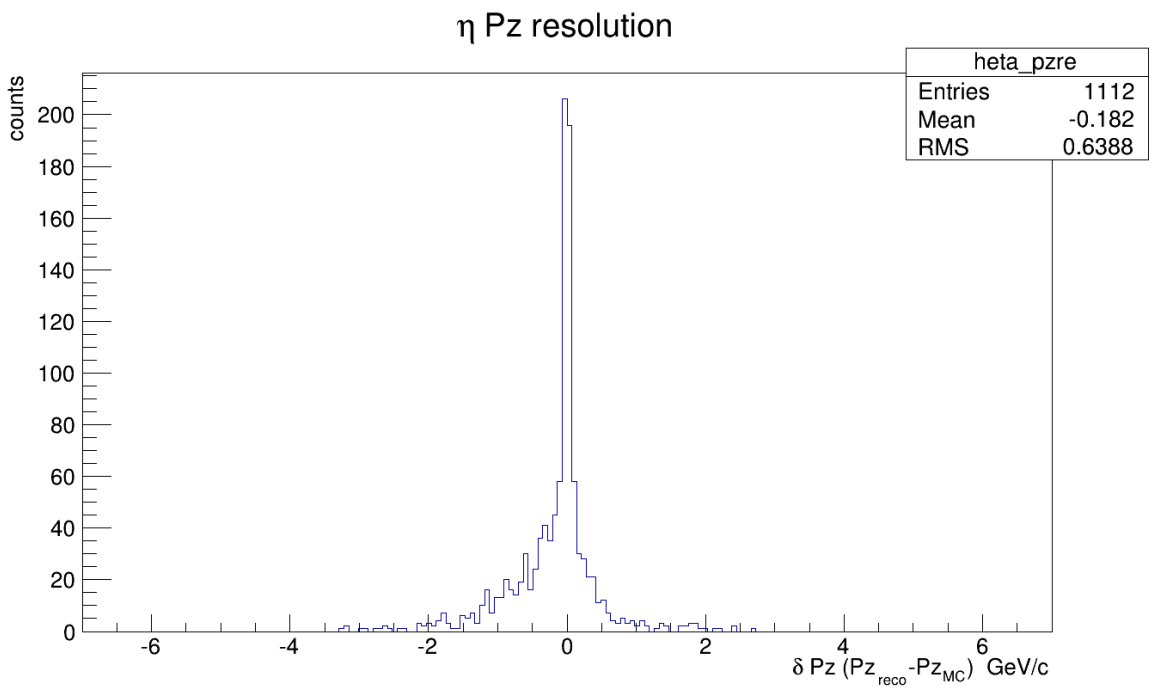
η mass vs. probability distribution



η mass vs. probability distribution




η Pt resolution
heta_ptre
Entries 1112
Mean -0.1214
RMS 0.2241
counts
δ Pt (Pt_reco-Pt_MC) GeV/c


η Pz resolution
heta_pzre
Entries 1112
Mean -0.182
RMS 0.6388
counts
δ Pz (Pz_reco-Pz_MC) GeV/c