PANDA XLVII. Collaboration Meeting

Updates on the Simulation of Ds Semileptonic Decay

Lu Cao

9th December, 2013

Outline

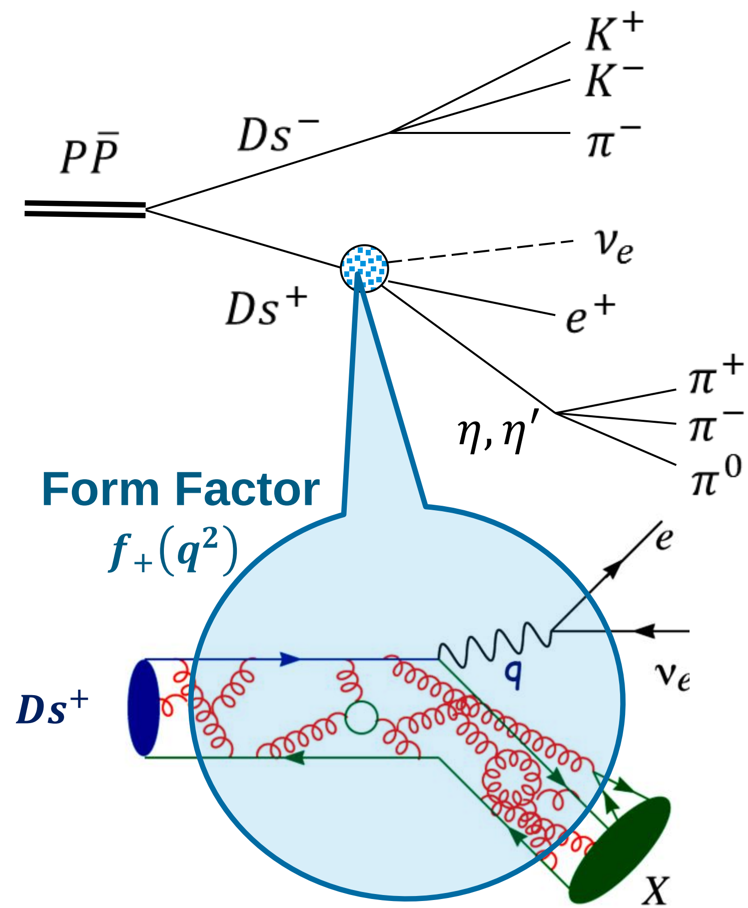
- Significance on Ds semileptonic decay
- Reconstruction (ongoing)
  - Charged Ds : hypothesis in Kalman track finder
  - Neutral pi0/eta: photon energy cutting on EMC
- Summary & outlook

Significance on Ds Semileptonic Decay

- Semileptonic decays Ds-> e + ν + 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’.



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

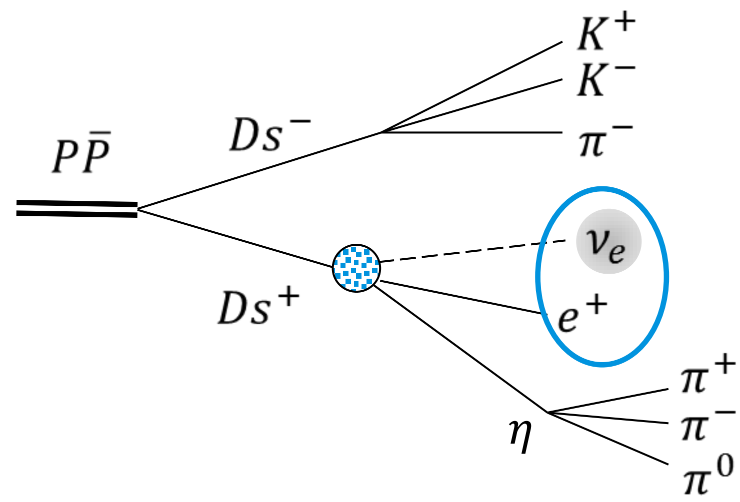
Reconstruction

Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

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

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



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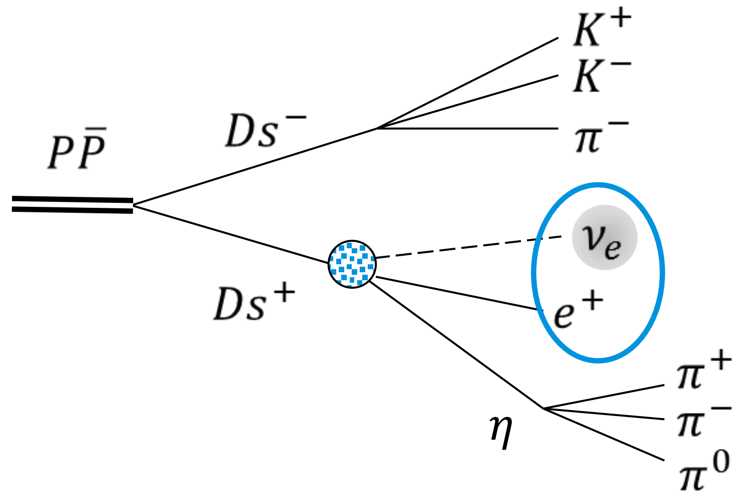
$\boldsymbol{Ds^+}$ $\boldsymbol{\eta}$

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

$\boldsymbol{K^+}$ $\boldsymbol{K^-}$ $\boldsymbol{\pi^+}$

- MC particle hypothesis
- Vertex fit
- Mass constraint fit



Reconstruction

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

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

$\boldsymbol{\pi^+}$ $\boldsymbol{\pi^-}$

- Vertex fit

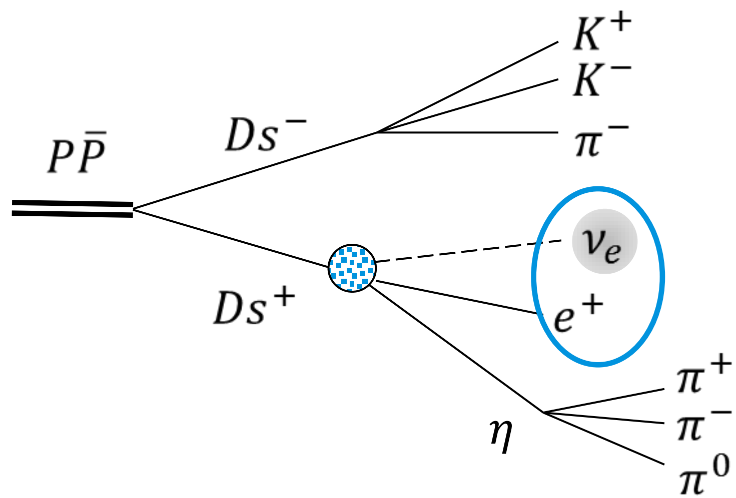
$\boldsymbol{\pi^0}$

$\boldsymbol{K^+}$ $\boldsymbol{K^-}$ $\boldsymbol{\pi^+}$

- MC particle hypothesis
- Vertex fit
- Mass constraint fit

$\boldsymbol{\gamma}$ $\boldsymbol{\gamma}$

- Pre-selection $(E_\gamma, \theta_\gamma)$
- Mass constraint fit



Reconstruction

Form Factor $f_+(q^2)$

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

Ds^+ | η

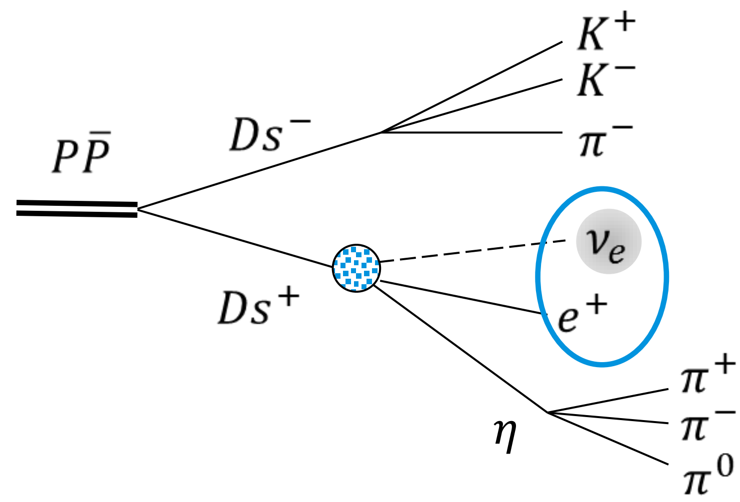
$P\bar{P}$ | Ds^-

π^+ π^-
- Vertex fit

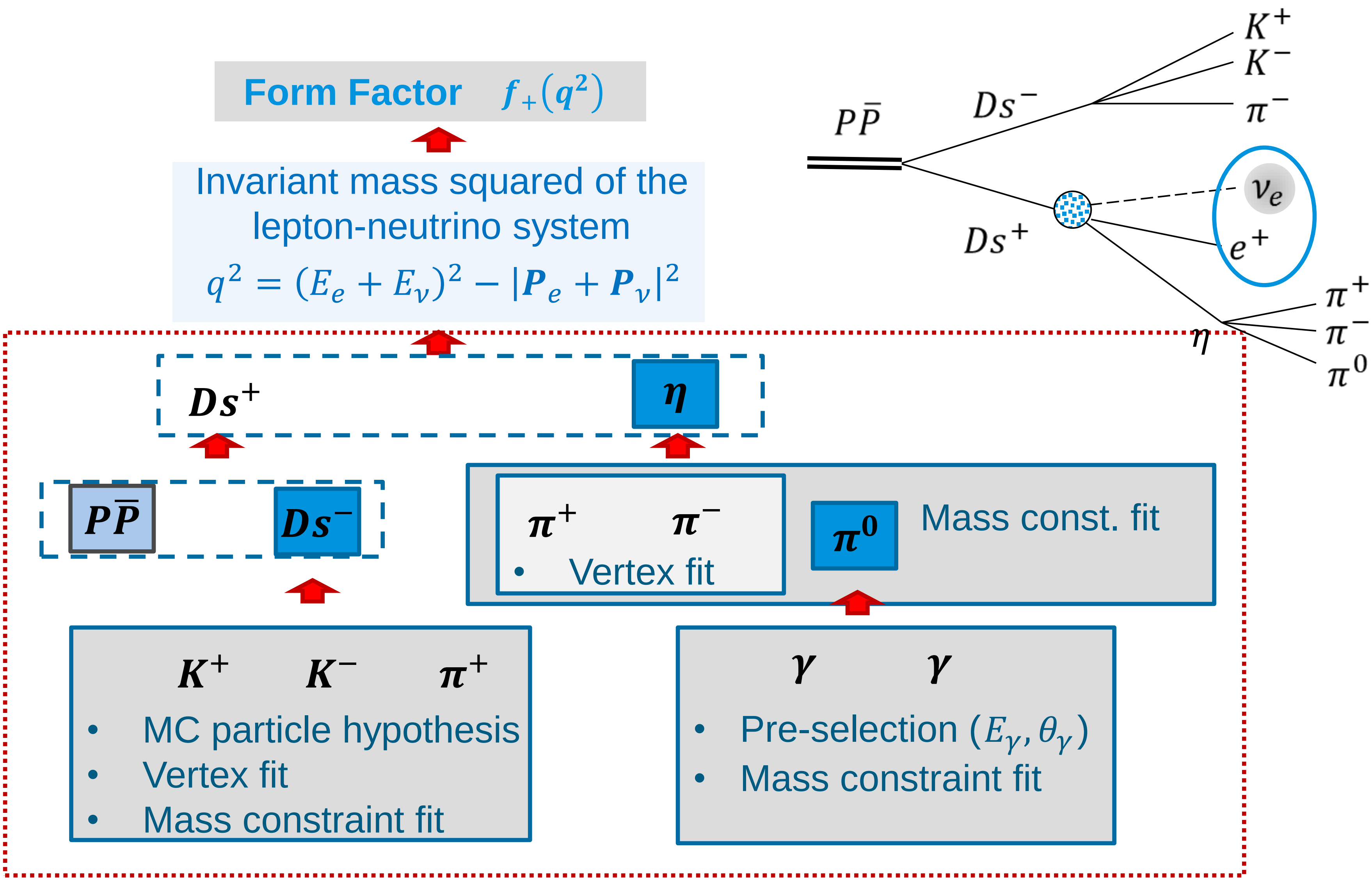
π^0 Mass const. fit

K^+ K^- π^+
- MC particle hypothesis
- Vertex fit
- Mass constraint fit

γ γ
- Pre-selection $(E_\gamma, \theta_\gamma)$
- Mass constraint fit



Reconstruction



Reconstruction

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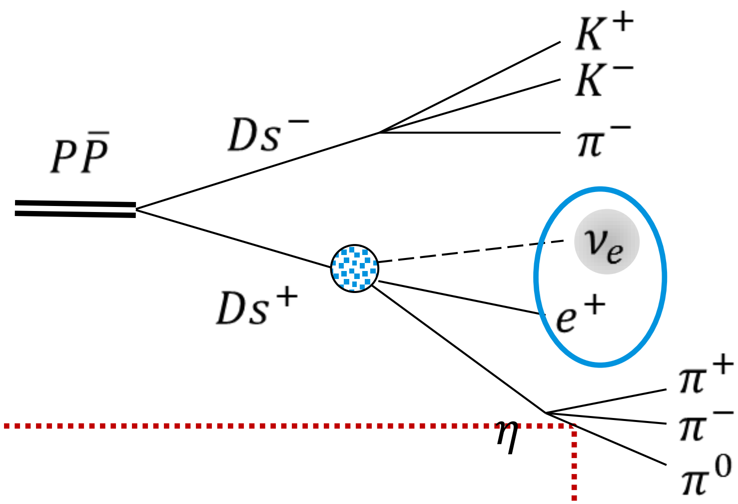


Ds^+ η

$P\bar{P}$ Ds^-

π^+ π^-
- Vertex fit

π^0 Mass const. fit

K^+ K^- π^+
- MC particle hypothesis
- Vertex fit
- Mass constraint fit

γ γ
- Pre-selection (E_γ, θ_γ)
- Mass constraint fit

Reconstruction of Ds-

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

Strategy

- Hypothesis in calculating particle propagation
- Combine the final particles ($K^+ K^- pi^-$) and filter with mass window 500 MeV/c^2
- Vertex Fitting (PndKinVtxFitter)
- Mass Constraint Fitting (PndKinFitter)
- Get resolution of selected candidates

Evt = 100,000
Mom_{pbp} = 8.0 GeV/c

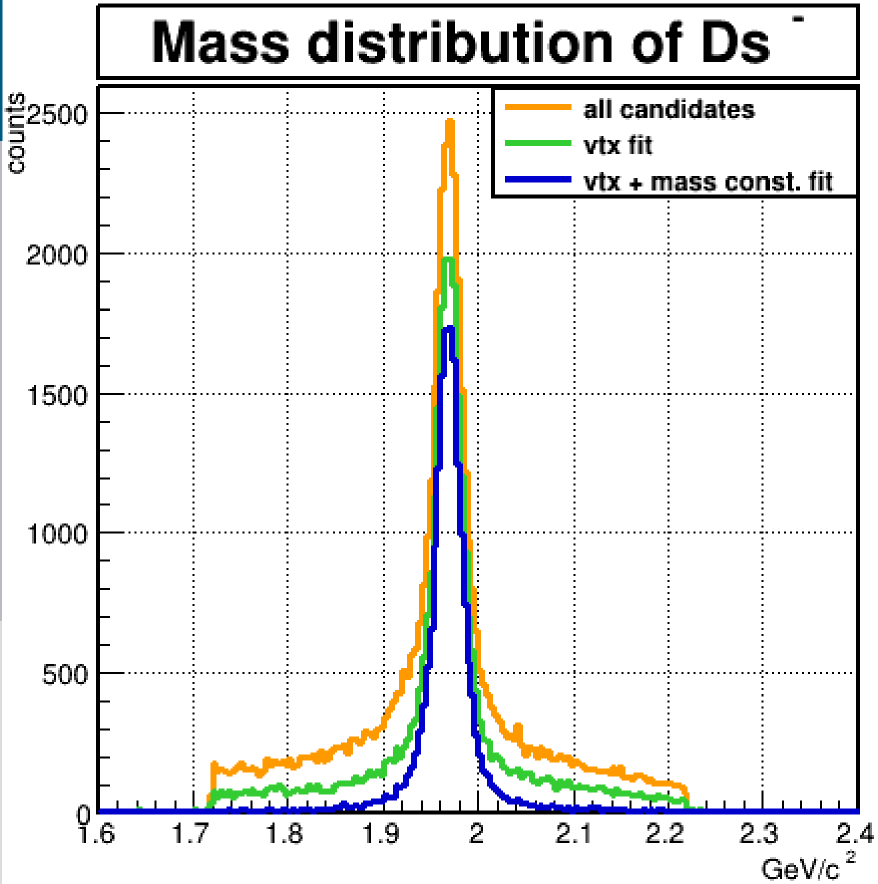
reco.C

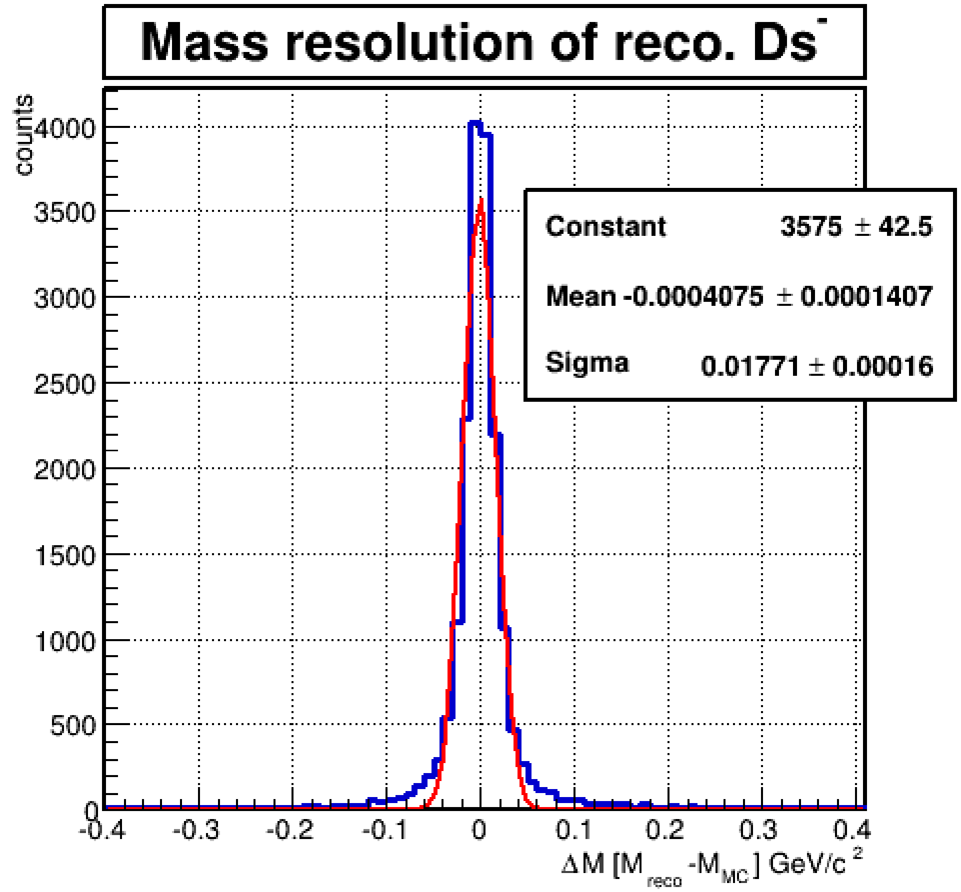
```
PndRecoKalmanTask* recoKalman = new PndRecoKalmanTask();
recoKalman->SetIdealHyp( kFALSE ); → kTRUE

PndRecoKalmanTask* recoKalmanFwd = new PndRecoKalmanTask();
recoKalmanFwd->SetIdealHyp( kFALSE ); → kTRUE
```

kFALSE

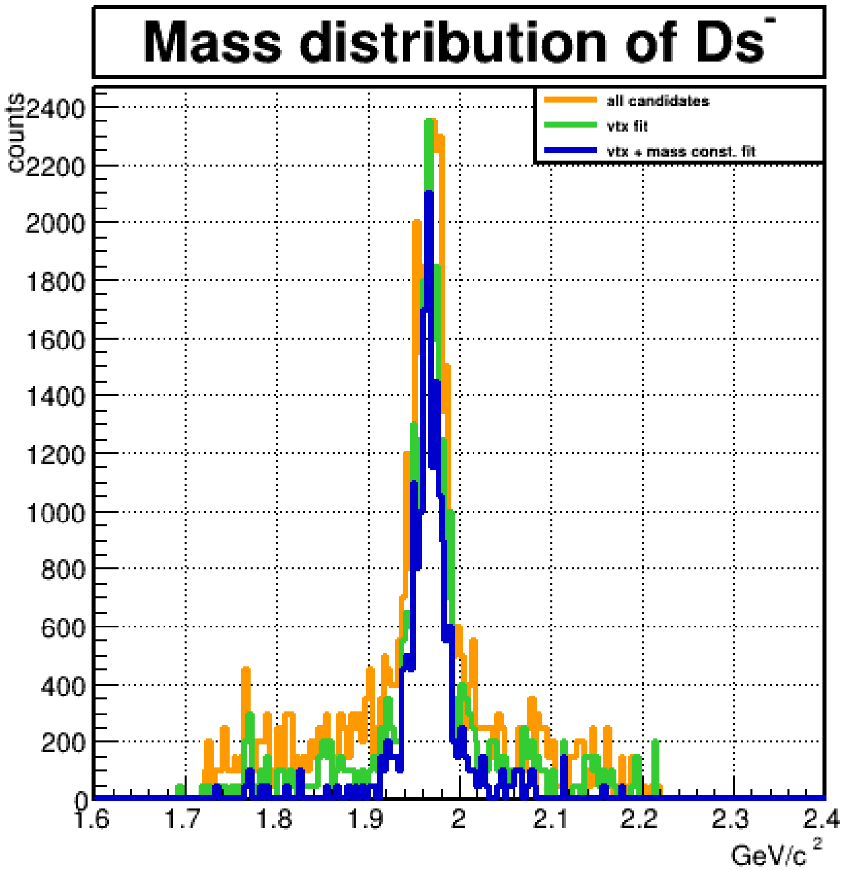
pandaroot #20993

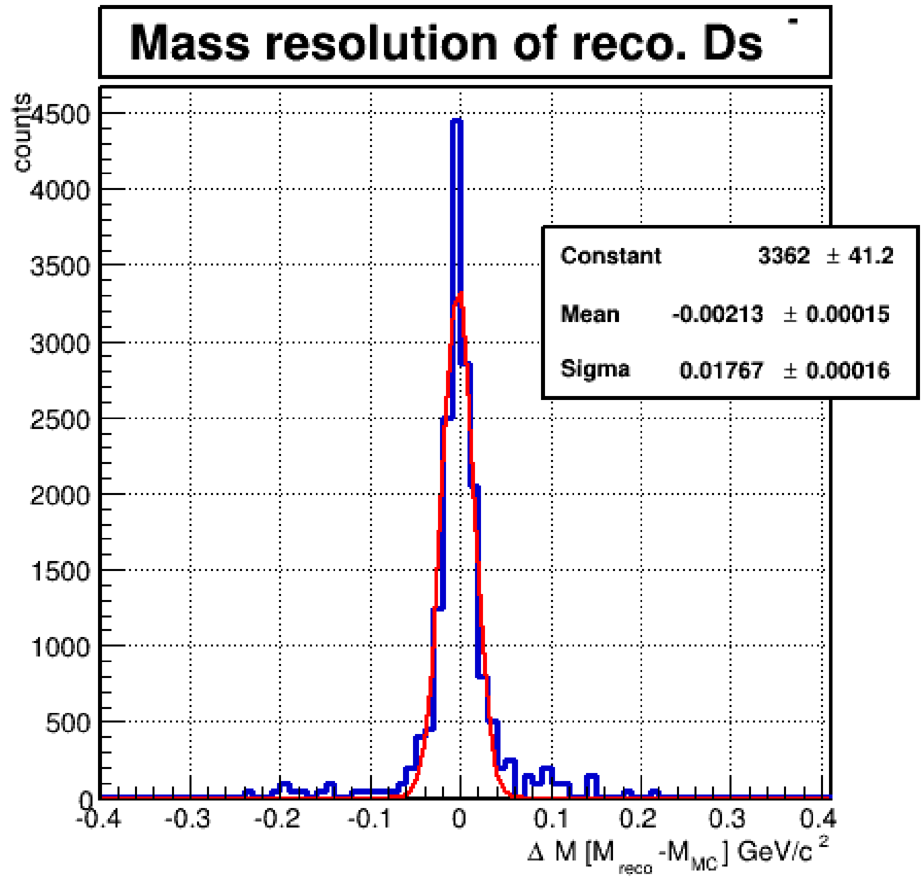




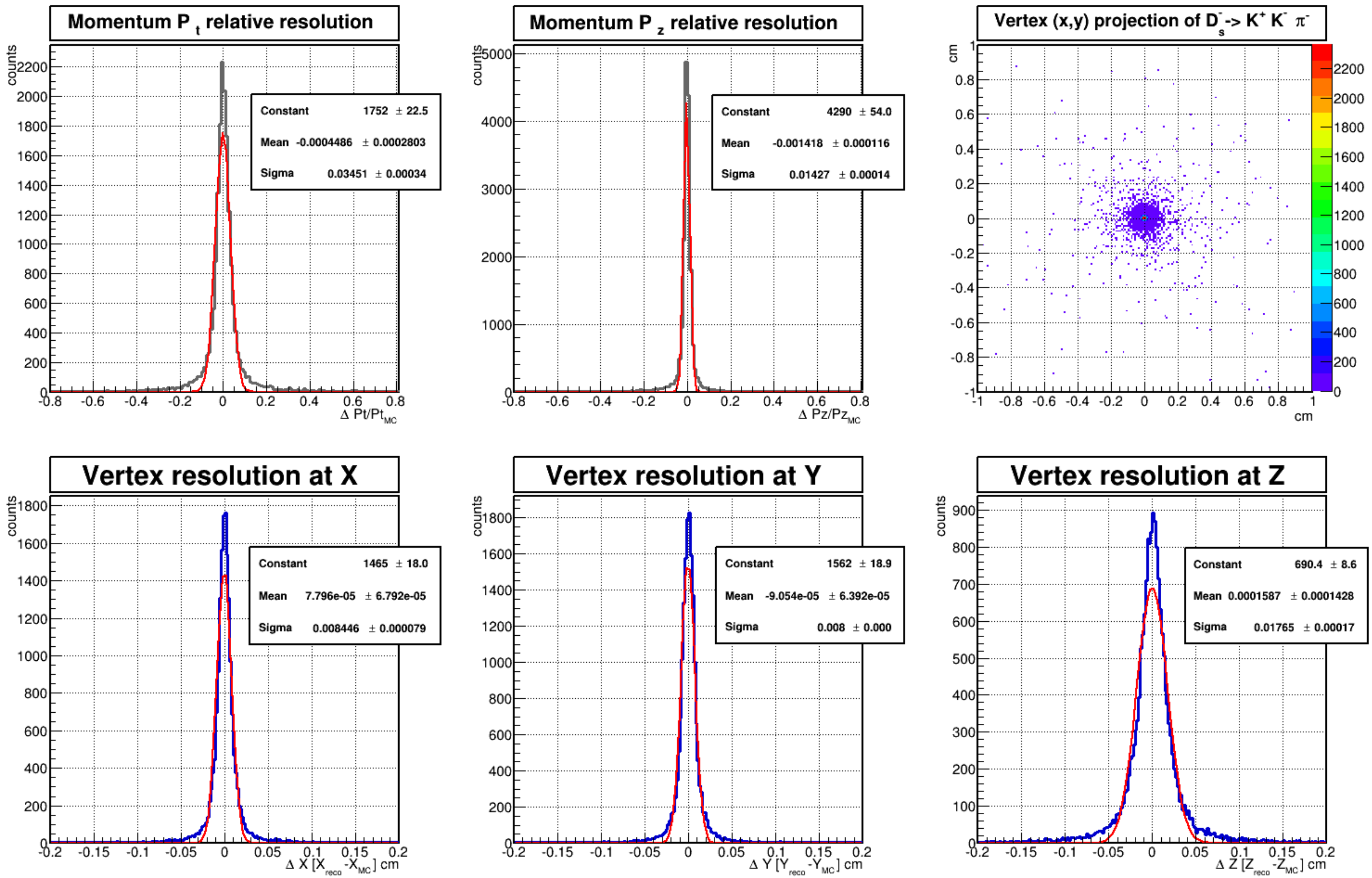
kTRUE

pandaroot #20993



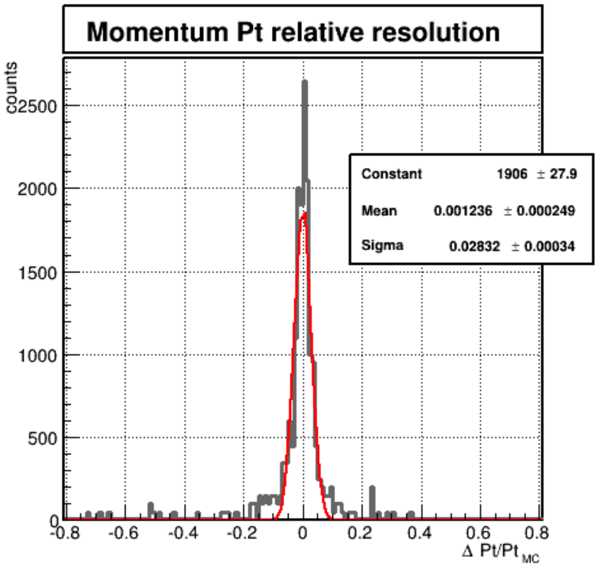


kFALSE

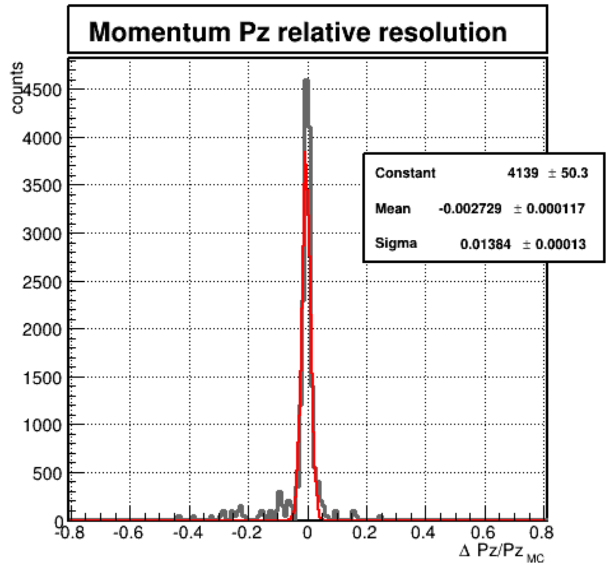


Momentum P t relative resolution
counts
Constant 1752 ± 22.5
Mean -0.0004486 ± 0.0002803
Sigma 0.03451 ± 0.00034
Δ Pt/Pt MC
Momentum P z relative resolution
counts
Constant 4290 ± 54.0
Mean -0.001418 ± 0.000116
Sigma 0.01427 ± 0.00014
Δ Pz/Pz MC
Vertex (x,y) projection of D s - -> K+ K- π-
cm
cm
Vertex resolution at X
counts
Constant 1465 ± 18.0
Mean 7.796e-05 ± 6.792e-05
Sigma 0.008446 ± 0.000079
Δ X [X reco -X MC] cm
Vertex resolution at Y
counts
Constant 1562 ± 18.9
Mean -9.054e-05 ± 6.392e-05
Sigma 0.008 ± 0.000
Δ Y [Y reco -Y MC] cm
Vertex resolution at Z
counts
Constant 690.4 ± 8.6
Mean 0.0001587 ± 0.0001428
Sigma 0.01765 ± 0.00017
Δ Z [Z reco -Z MC] cm

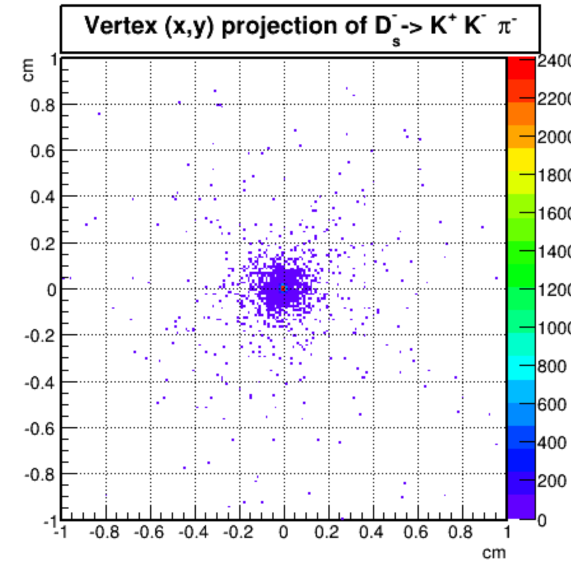
kTRUE



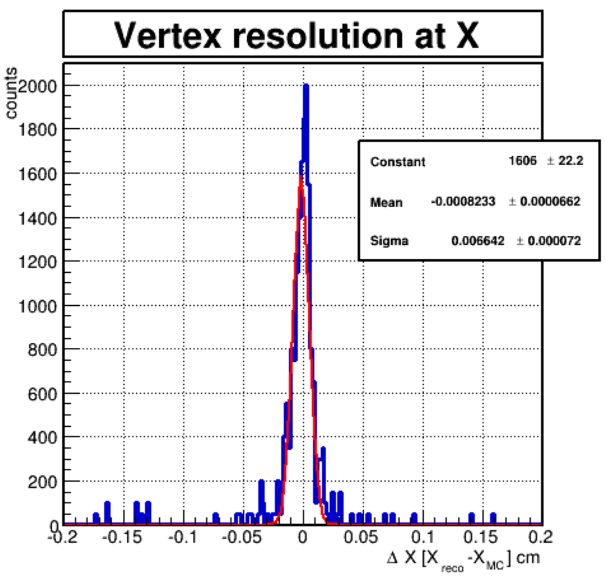
Momentum Pt relative resolution
counts
Constant 1906 ± 27.9
Mean 0.001236 ± 0.000249
Sigma 0.02832 ± 0.00034
Δ Pt/Pt MC



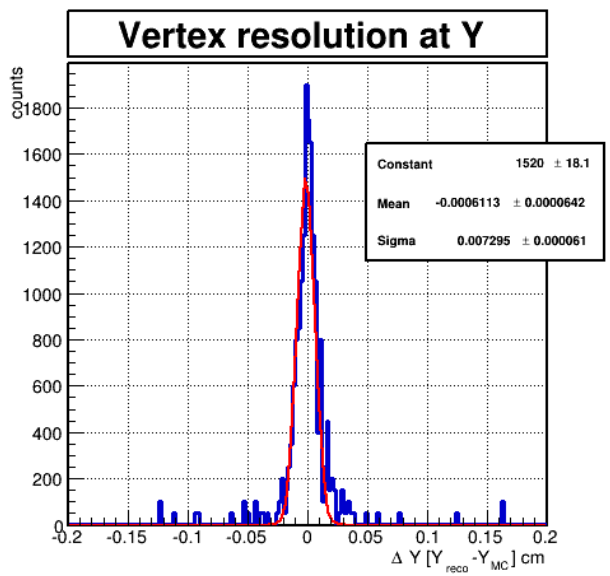
Momentum Pz relative resolution
counts
Constant 4139 ± 50.3
Mean -0.002729 ± 0.000117
Sigma 0.01384 ± 0.00013
Δ Pz/Pz MC



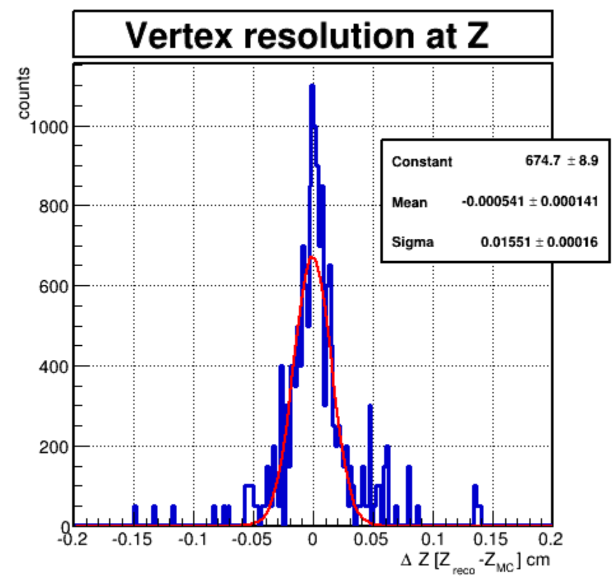
Vertex (x,y) projection of D-s -> K+ K- π-
cm
cm



Vertex resolution at X
counts
Constant 1606 ± 22.2
Mean -0.0008233 ± 0.0000662
Sigma 0.006642 ± 0.000072
Δ X [X reco -X MC] cm



Vertex resolution at Y
counts
Constant 1520 ± 18.1
Mean -0.0006113 ± 0.0000642
Sigma 0.007295 ± 0.000061
Δ Y [Y reco -Y MC] cm



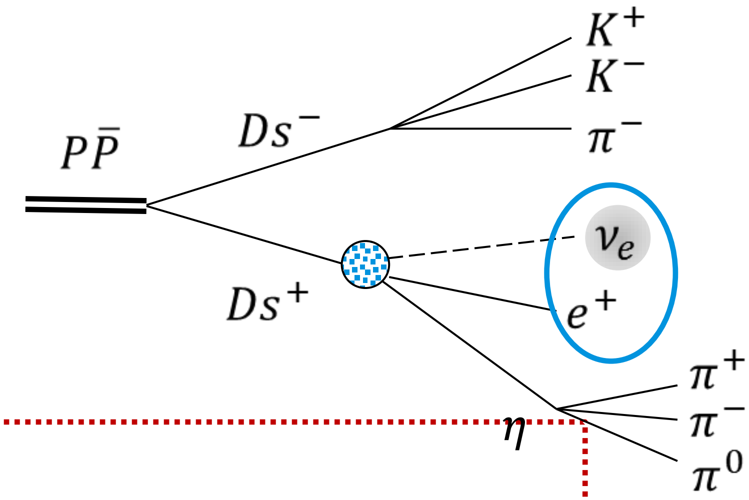
Vertex resolution at Z
counts
Constant 674.7 ± 8.9
Mean -0.000541 ± 0.000141
Sigma 0.01551 ± 0.00016
Δ Z [Z reco -Z MC] cm

Comparison of the different hypothesis in the reconstruction of $Ds^- \to K^+K^-pi^-$

SetIdealHyp()	Efficiency	Mass reso. [MeV/c^2]	Mom. reso.		Vtx reso. [µm]		
			Pt	Pz	X	Y	Z
kFALSE	18.1%	17.3	3.5%	1.4%	84	80	176
kTRUE	17.6%	16.5	2.8%	1.3%	66	73	155

The “kTRUE” enabling the ideal hypothesis brings the better reconstruction result, although the improvement is not very significant. This modification will be adopted in the coming full simulation and analysis.

Reconstruction



Form Factor $f_+(q^2)$

Invariant mass squared of the lepton-neutrino system

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

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

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

$\boldsymbol{\pi^+}$ $\boldsymbol{\pi^-}$

- Vertex fit

$\boldsymbol{\pi^0}$ Mass const. fit

$\boldsymbol{K^+}$ $\boldsymbol{K^-}$ $\boldsymbol{\pi^+}$

- MC particle hypothesis **kTRUE**
- Vertex fit
- Mass constraint fit

$\boldsymbol{\gamma}$ $\boldsymbol{\gamma}$

- Pre-selection $(E_\gamma, \theta_\gamma)$
- Mass constraint fit

Reconstruction of pi0 & eta

Pi0 candidates are all possible combinations of two photons come from the EMC components.

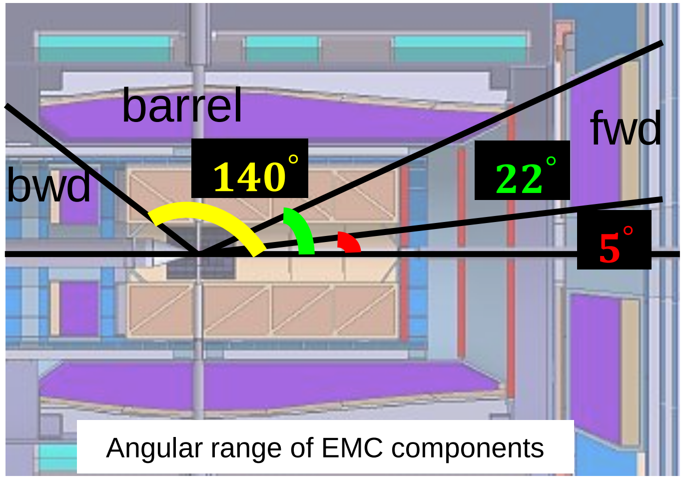
pbarp system noPhotos
-> Ds- Ds+
| |-> eta e+ nu_e PHOTOS ISGW2
| | -> pi+ pi- pi0 ETA_DALITZ
|-> K- K+ pi- DS_DALITZ

Considerations for selecting photon:

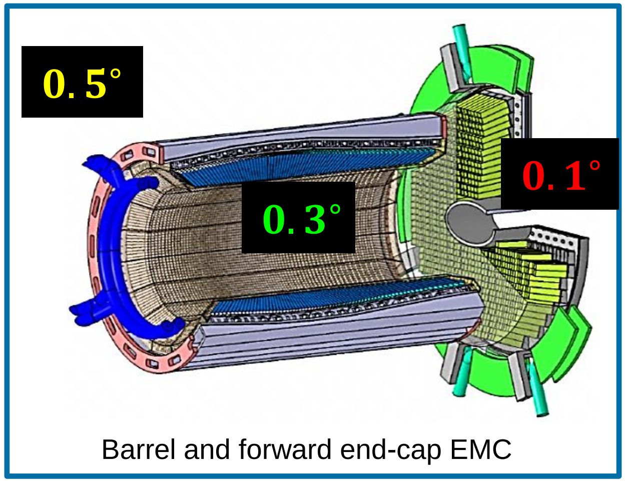
$\theta_\gamma \in [5^\circ, 175^\circ]$

$\phi_{\gamma\gamma} > \sigma_{xtl}$

$E_\gamma > ?$



Angular range of EMC components



Barrel and forward end-cap EMC

Energy threshold E_{thres}

10 MeV
(20 MeV tolerable)

Minimal energy E_{min}

- reject the radiation background
  barrel: 50 MeV
  fwd: 100 MeV
  bwd: 50 MeV

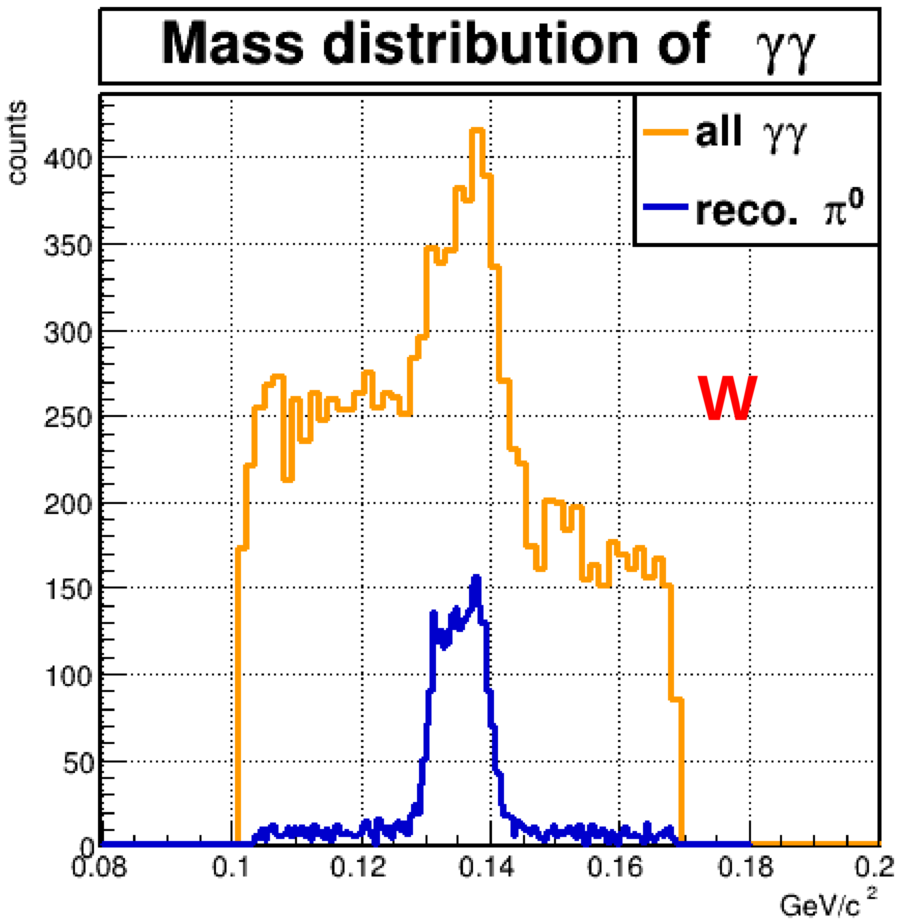
TRY

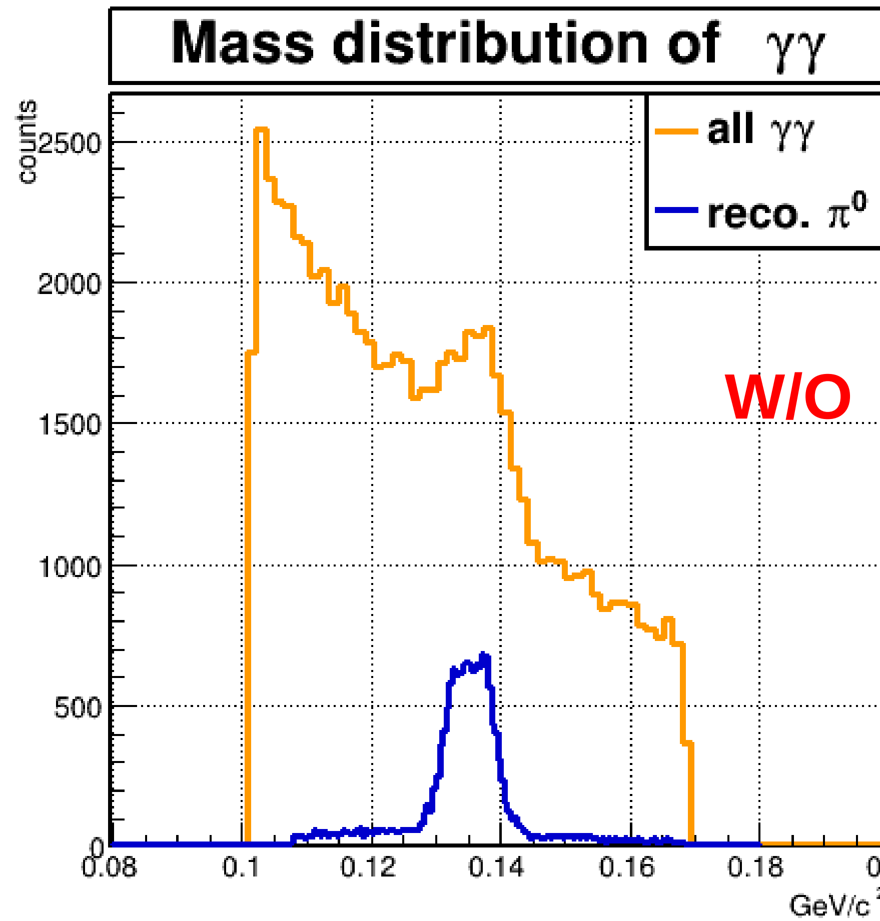
Mass window $=0.135 \pm 0.035 GeV/c^2$

Evt = 10k

Comparison of E_γ cutting: w. vs w/o $E_\gamma > E_{min}$

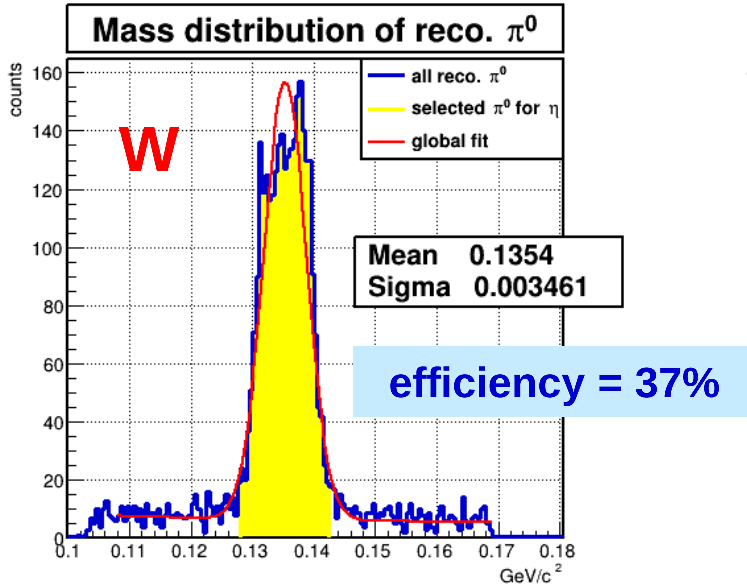
- barrel: 50 MeV
- fwd: 100 MeV
- bwd: 50 MeV

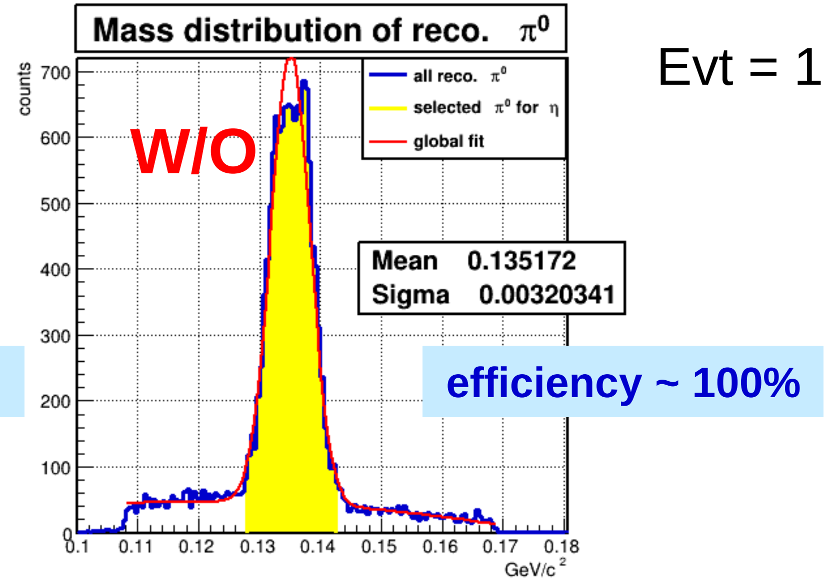




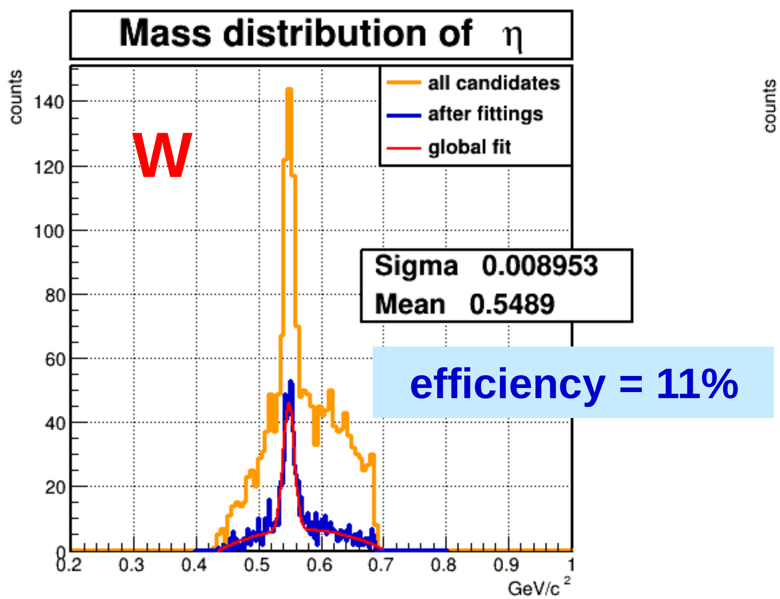
Evt = 10k

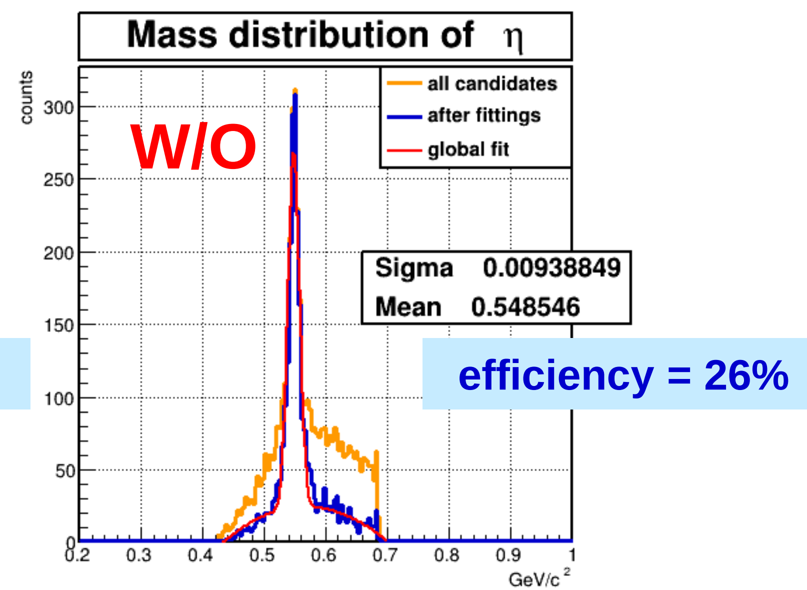
pi0



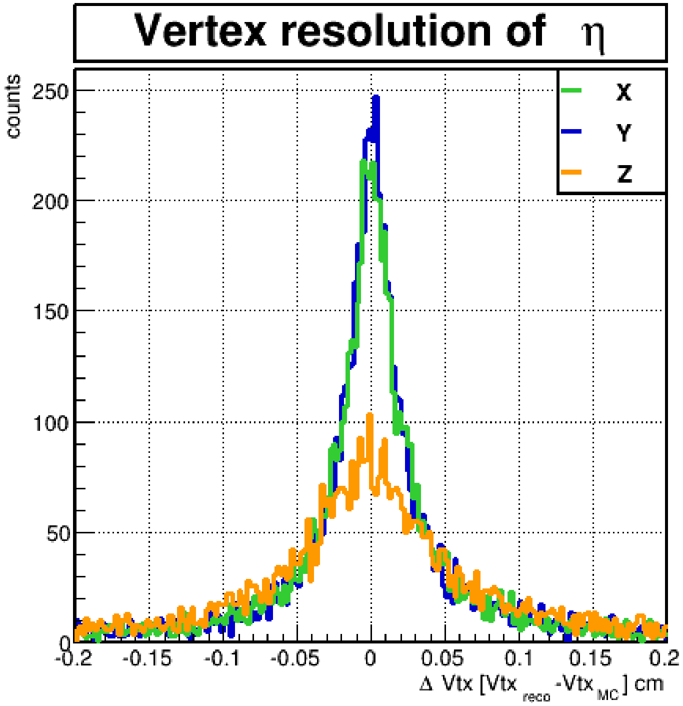


eta





pandaroot #20993

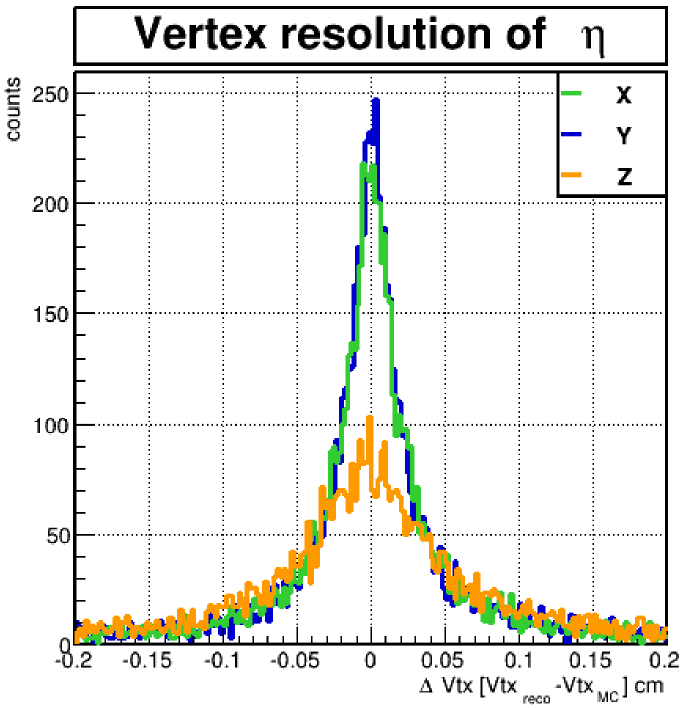


E_{min}	Efficiency [%]		Mass reso. [MeV/c²]		η Vtx reso. [μm]		
	π^0	η	π^0	η	X	Y	Z
W	37	11	3.5	9.0	318	287	675
W/O	100	26	3.2	9.4			

The charged tracks of pi+ and pi- contribute to the vertex reconstruction of eta, in which step the performance of fitter plays a great role on the efficiency and resolution.

E_γ cutting is necessary to select the “good” photons.

Then, how much & how ?



pandaroot #20993

E_{min}	Efficiency [%]		Mass reso. [MeV/c²]		η Vtx reso. [μm]		
	π^0	η	π^0	η	X	Y	Z
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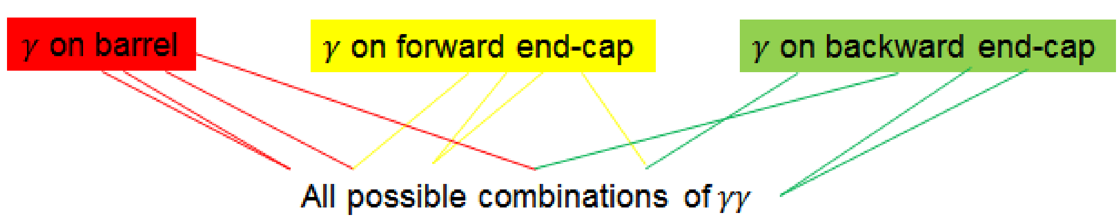
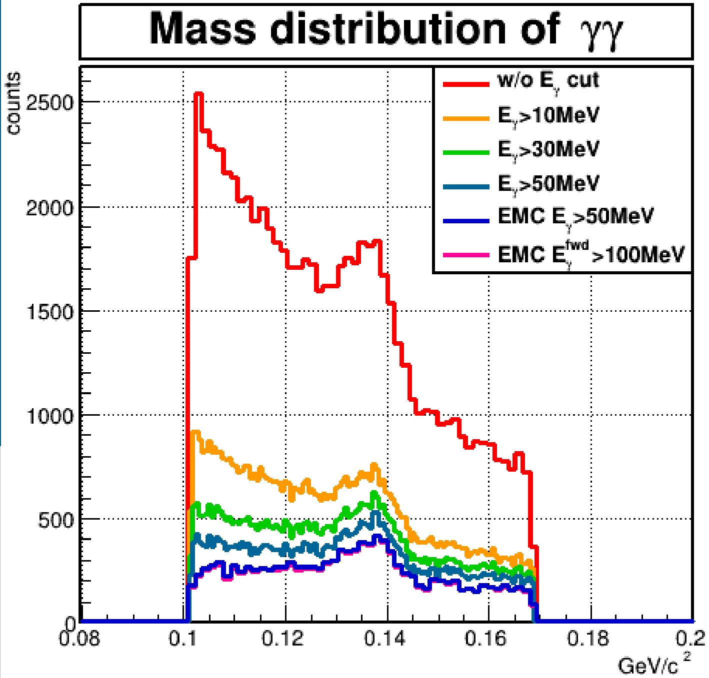
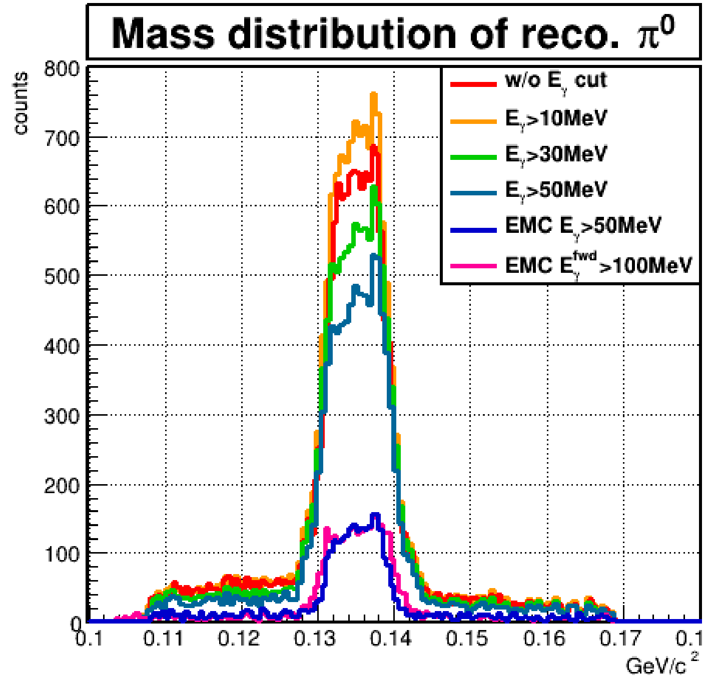


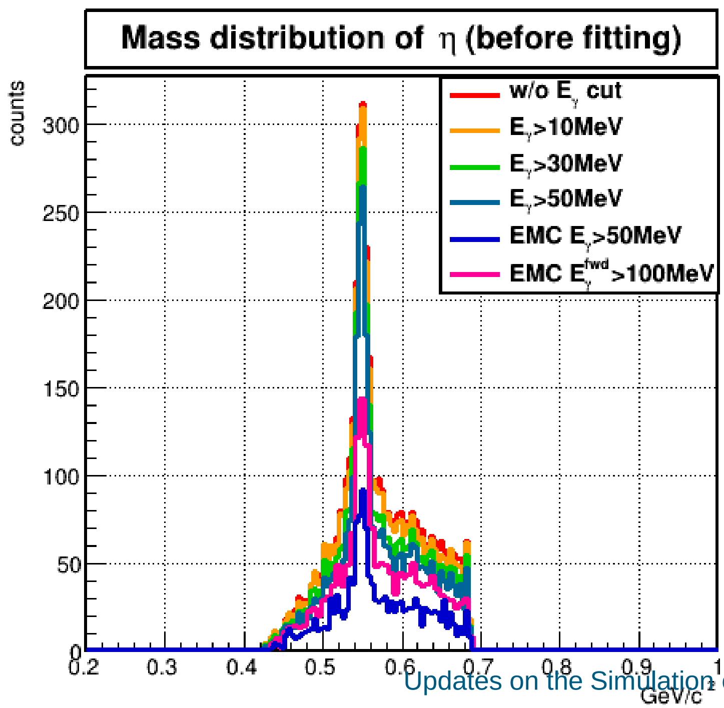
Evt = 10k



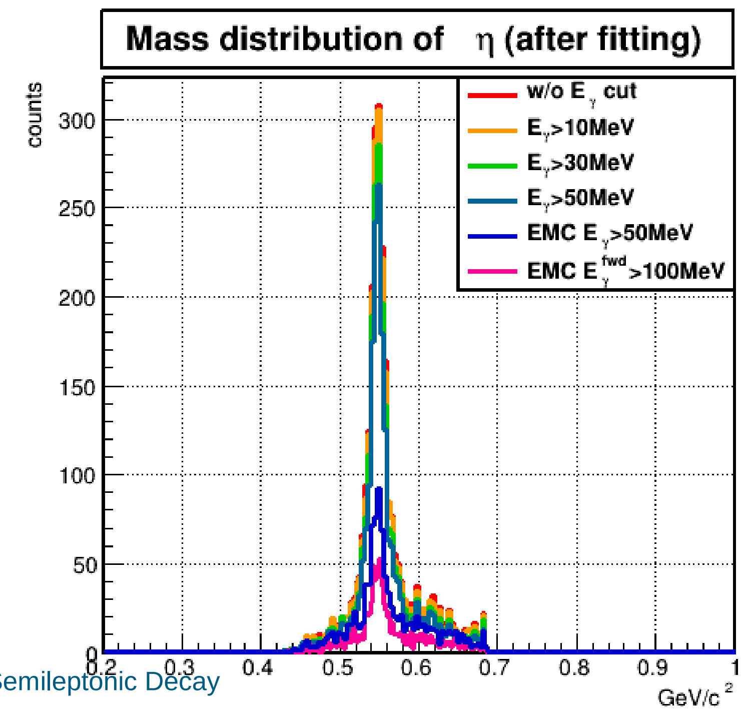
Mass distribution of γγ
counts
w/o E_γ cut
E_γ>10MeV
E_γ>30MeV
E_γ>50MeV
EMC E_γ>50MeV
EMC E_γ^fwd>100MeV
GeV/c²



Mass distribution of reco. π⁰
counts
w/o E_γ cut
E_γ>10MeV
E_γ>30MeV
E_γ>50MeV
EMC E_γ>50MeV
EMC E_γ^fwd>100MeV
GeV/c²



Mass distribution of η (before fitting)
counts
w/o E_γ cut
E_γ>10MeV
E_γ>30MeV
E_γ>50MeV
EMC E_γ>50MeV
EMC E_γ^fwd>100MeV
GeV/c²



Mass distribution of η (after fitting)
counts
w/o E_γ cut
E_γ>10MeV
E_γ>30MeV
E_γ>50MeV
EMC E_γ>50MeV
EMC E_γ^fwd>100MeV
GeV/c²

Summary & outlook

- ✓ Check/develop the decay models: ETA_DALITZ, ISGW2, DS_DALITZ
- ✓ Access MC truth for comparing
- ■ Use ideal hypothesis in the reconstruction of Ds-
- ■ Improve the selection of photon and the reconstruction of neutral particles
- ☐ Extract the information of the missing neutrino
- ☐ Evaluate transiton form factor and total reco. efficiency
- ☐ Extension to Ds-> e + ν + η'(958)

Thank you

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):

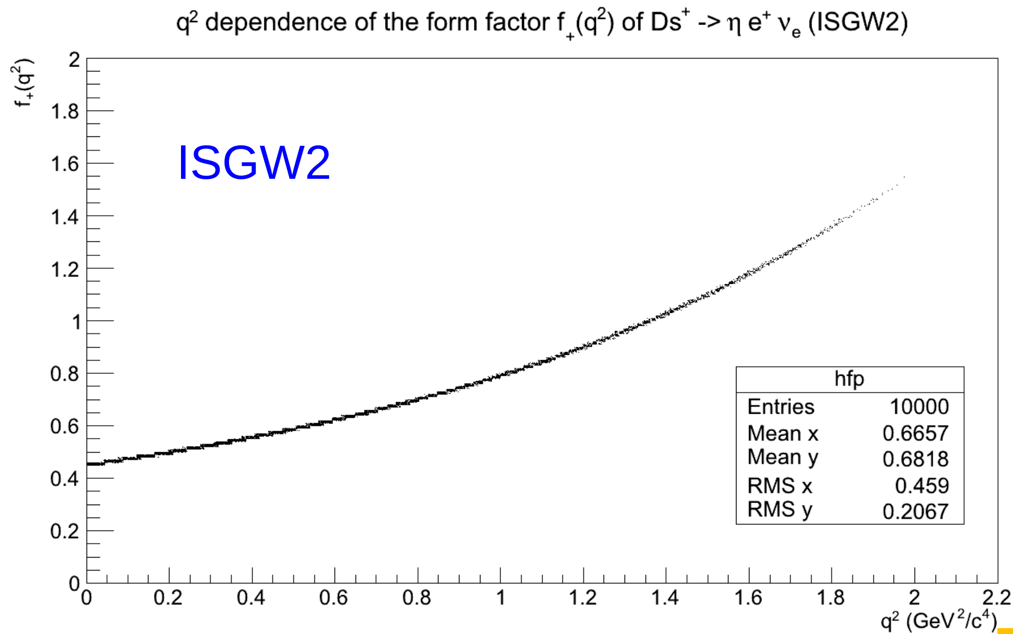
$$\frac{d\Gamma}{dq^2}(D_s \to (\eta,\eta')l\nu_l) = \frac{G_F^2|V_{cs}|^2}{192\pi^3 m_{D_s}^3}\left[(m_{D_s}^2 + m_{\eta^{(\prime)}}^2 - q^2)^2 - 4m_{D_s}^2 m_{(\eta,\eta')}^2\right]^{3/2} |f_+^{D_s\to\eta^{(\prime)}}(q^2)|^2$$

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



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

$$\hat{q} = q^2/m^2_{D_s}$$

Light cone QCD sum rules

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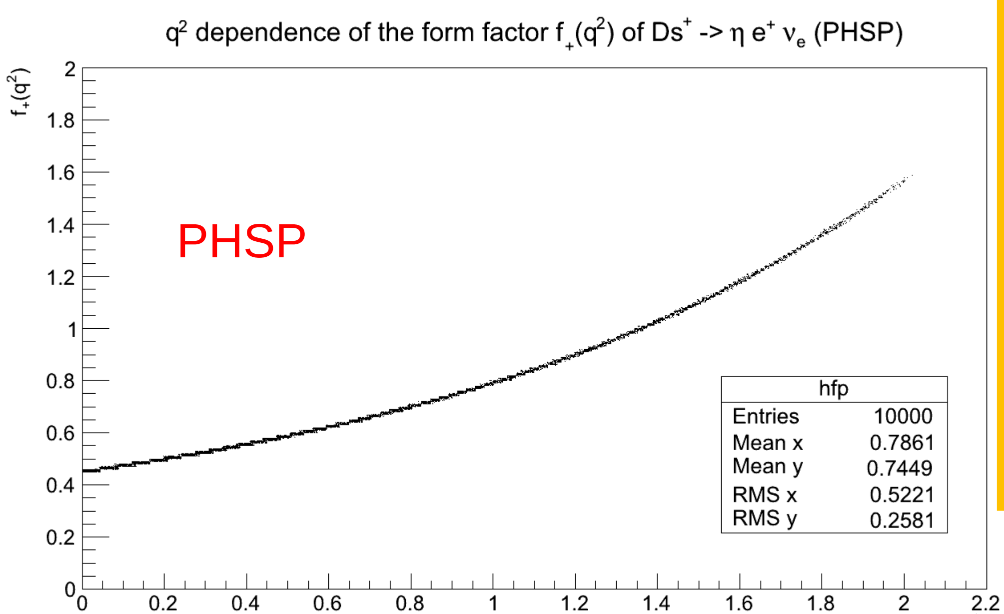
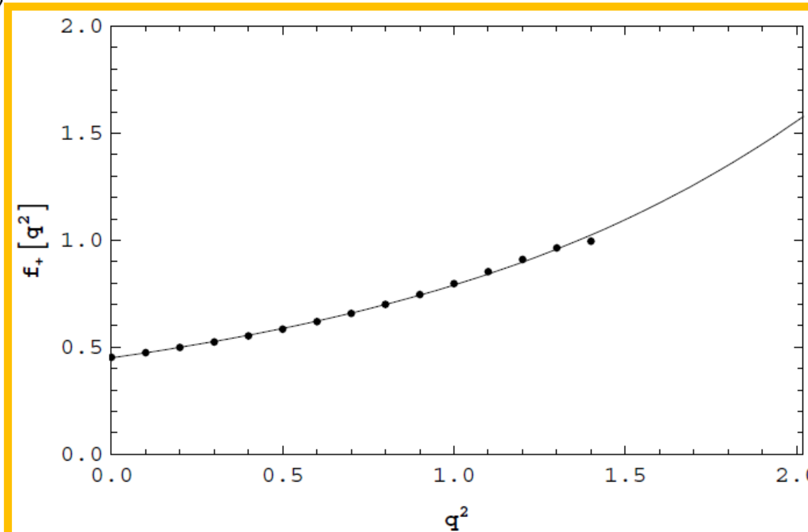
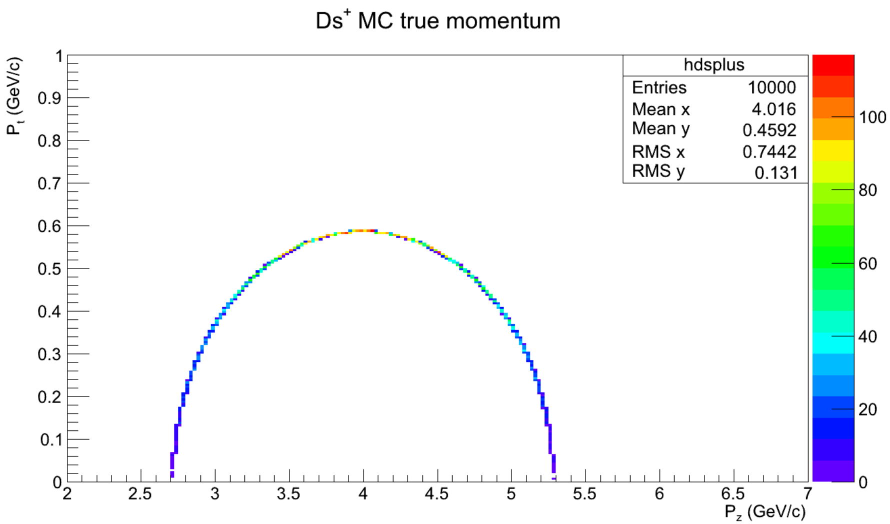
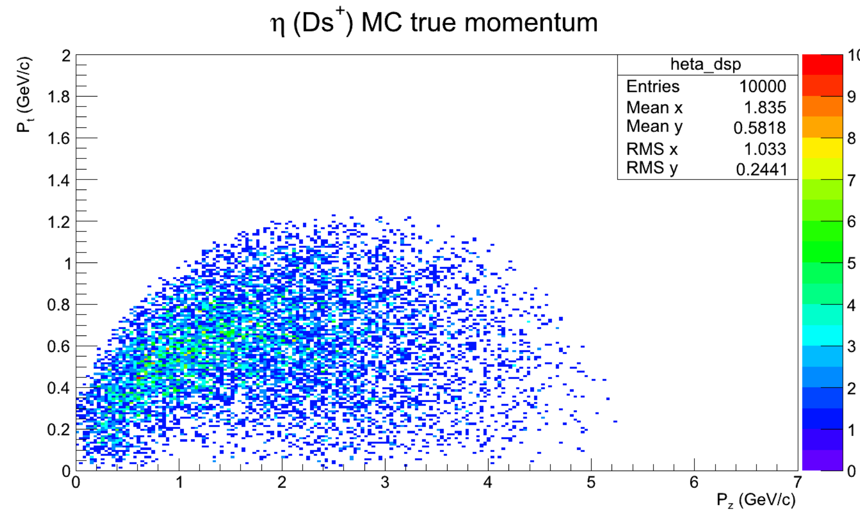
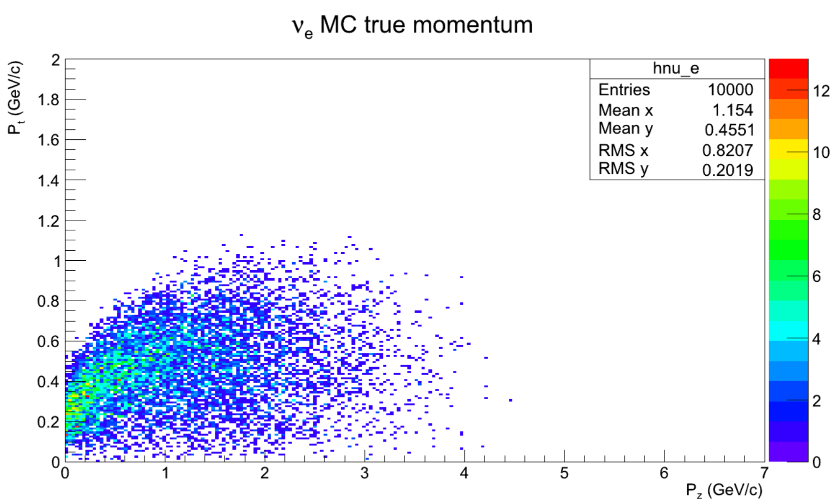


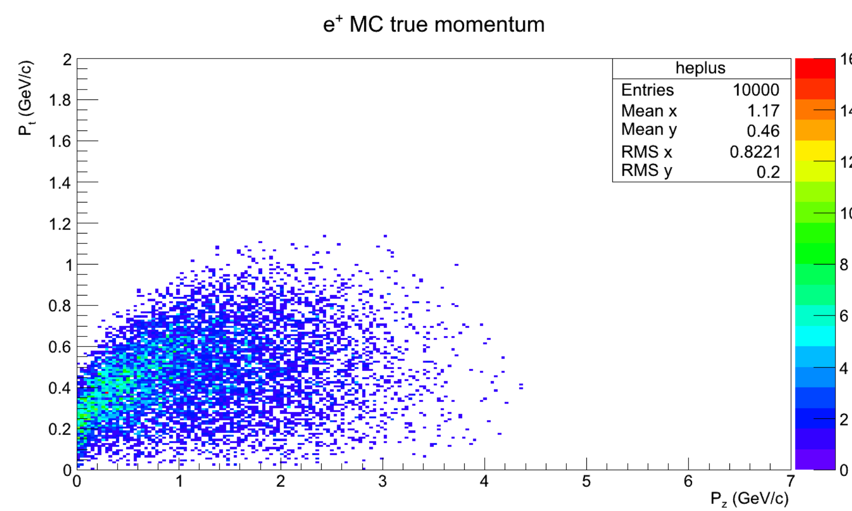


MC Truth of Ds^+ decay chain

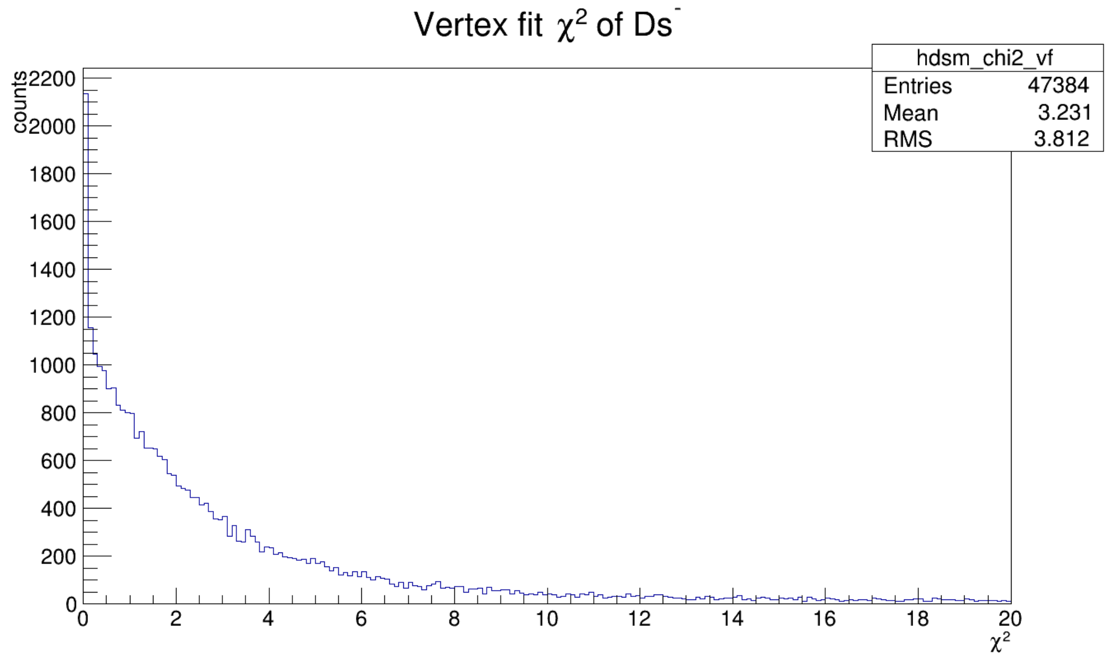




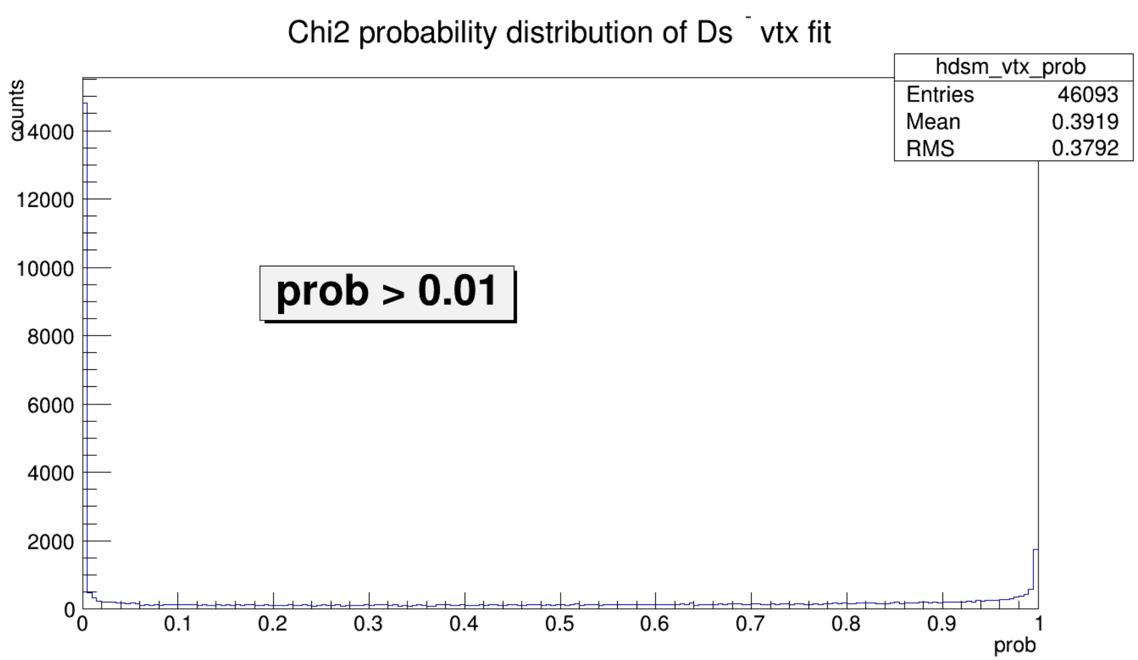




Evt = 100,000

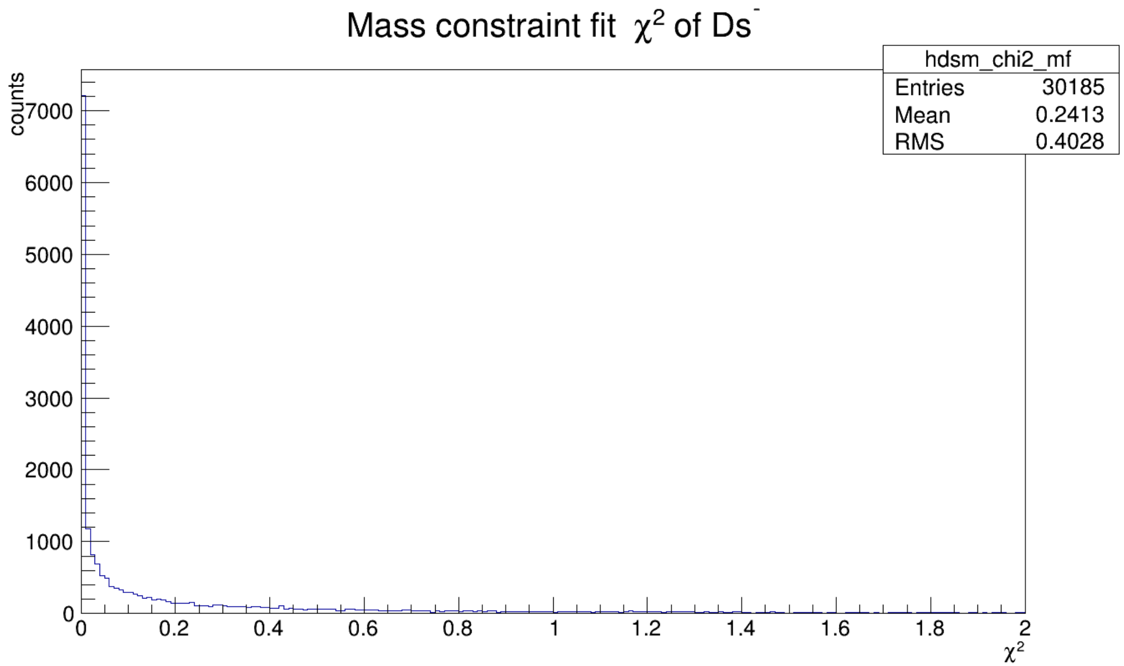


Vertex fit χ^2 of Ds$^-$
hdsm_chi2_vf
Entries 47384
Mean 3.231
RMS 3.812
counts
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
0
2
4
6
8
10
12
14
16
18
20
χ^2

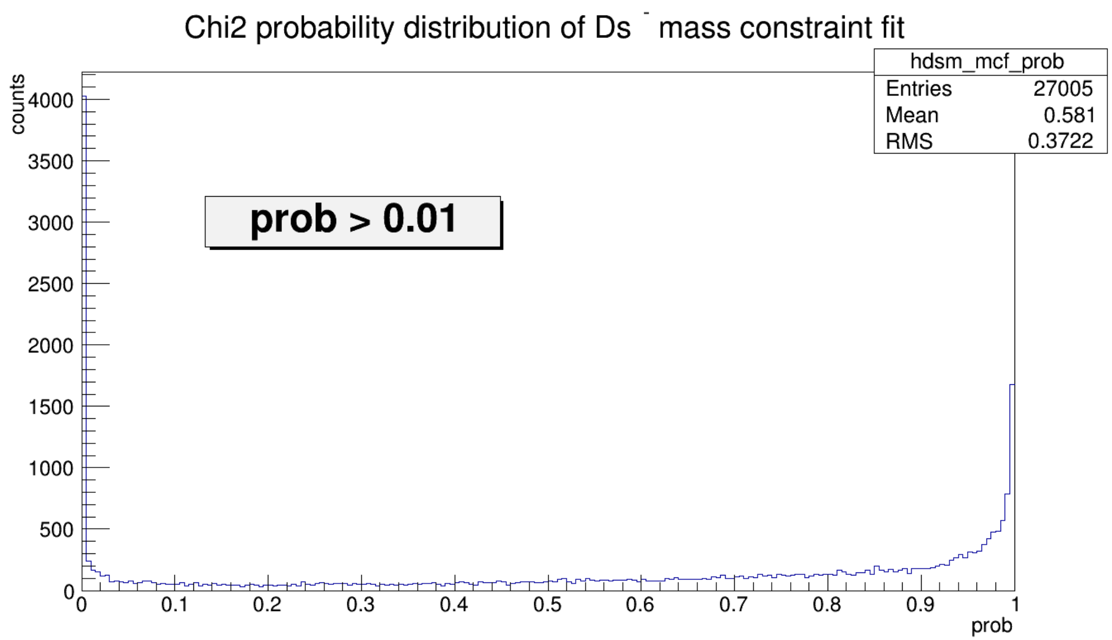


Chi2 probability distribution of Ds $^-$ vtx fit
hdsm_vtx_prob
Entries 46093
Mean 0.3919
RMS 0.3792
counts
0
2000
4000
6000
8000
10000
12000
14000
prob > 0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
prob

Evt = 100,000



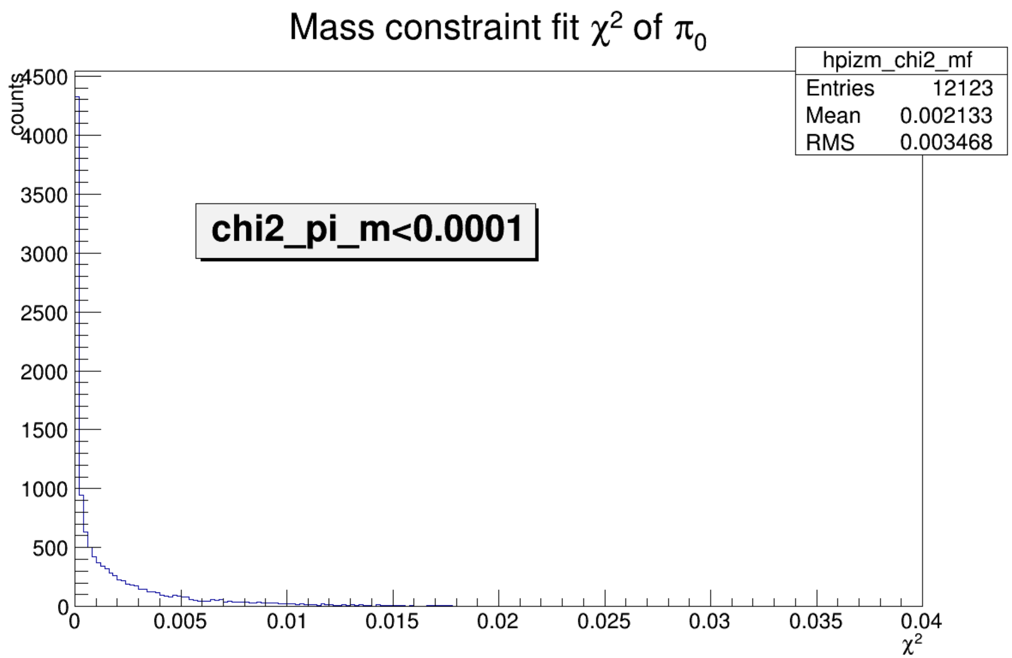
Mass constraint fit χ² of Ds⁻
hdsm_chi2_mf
Entries 30185
Mean 0.2413
RMS 0.4028
counts
χ²

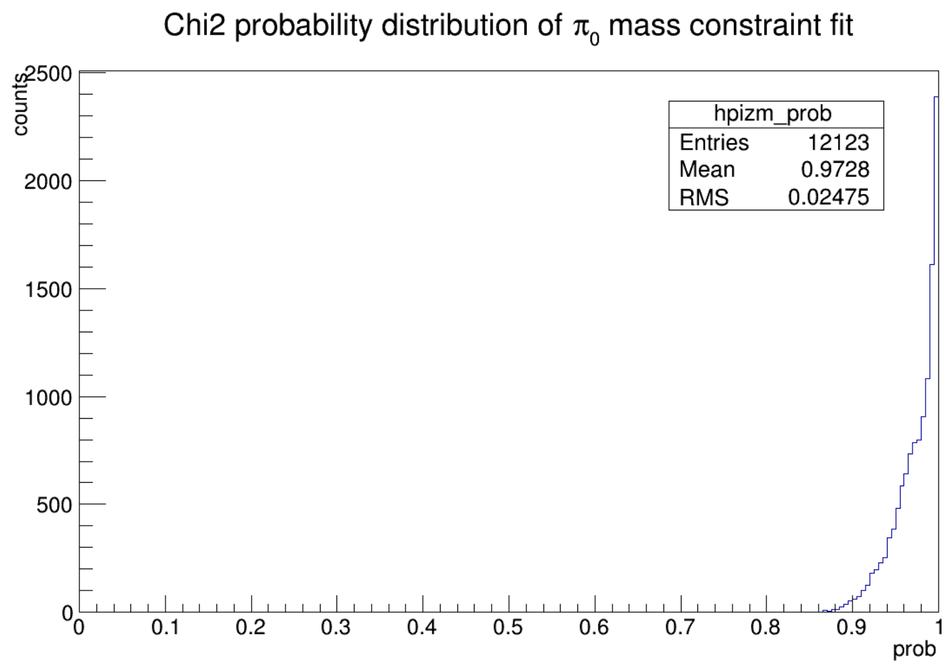


Chi2 probability distribution of Ds⁻ mass constraint fit
hdsm_mcf_prob
Entries 27005
Mean 0.581
RMS 0.3722
prob > 0.01
counts
prob

EMC E_{γ} >50MeV

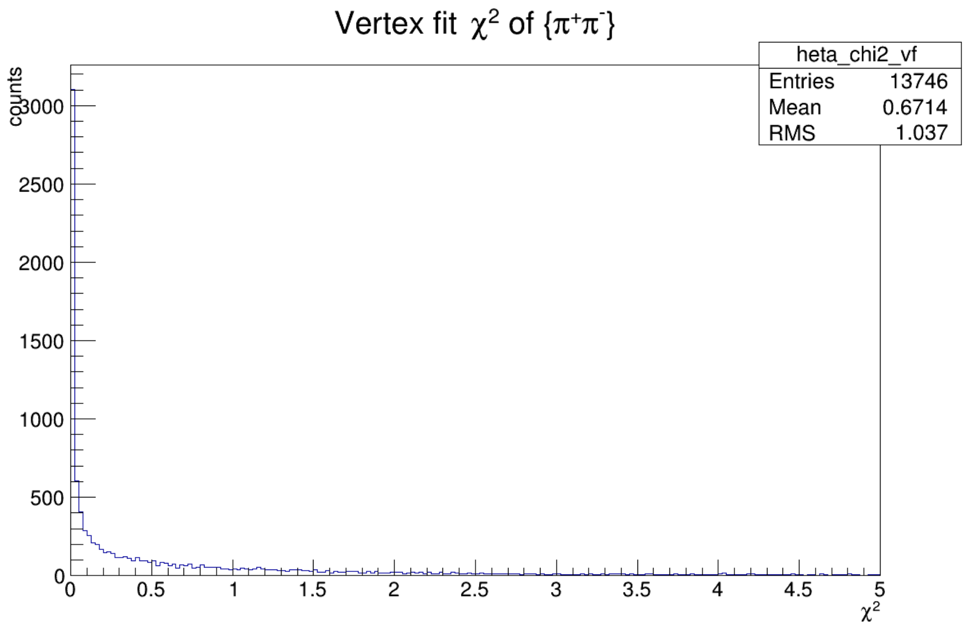
Evt = 10k

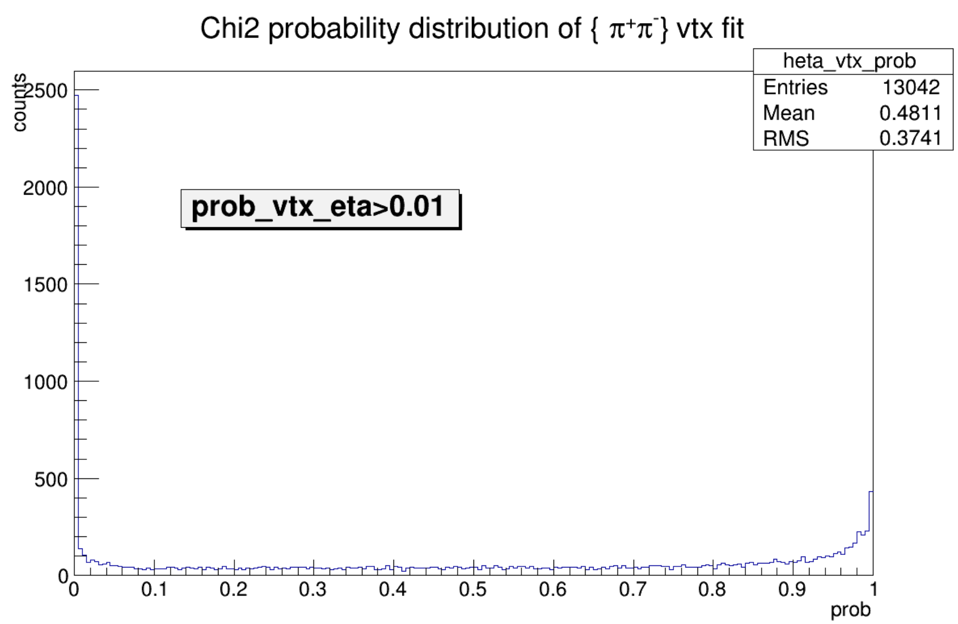




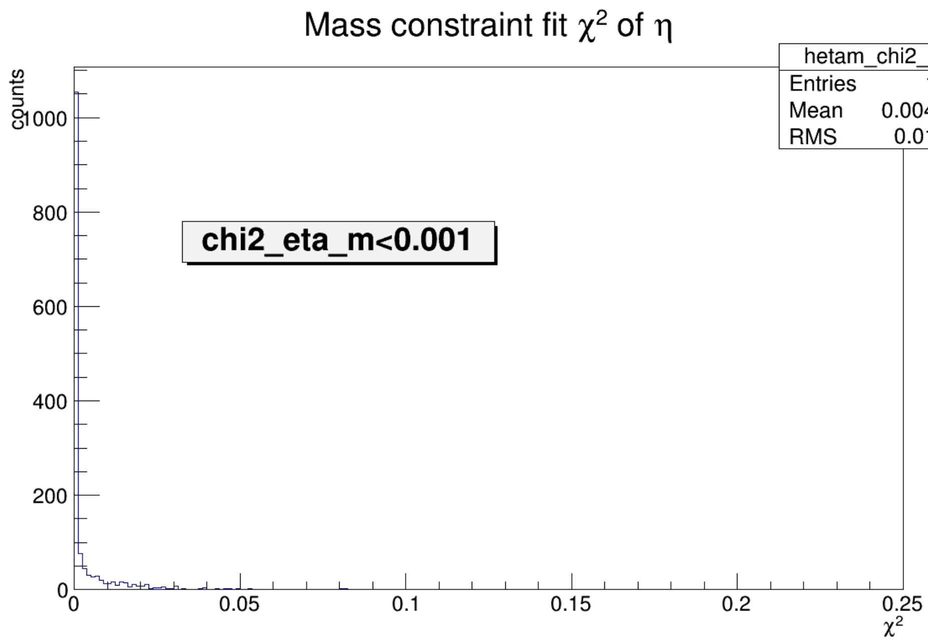
?!

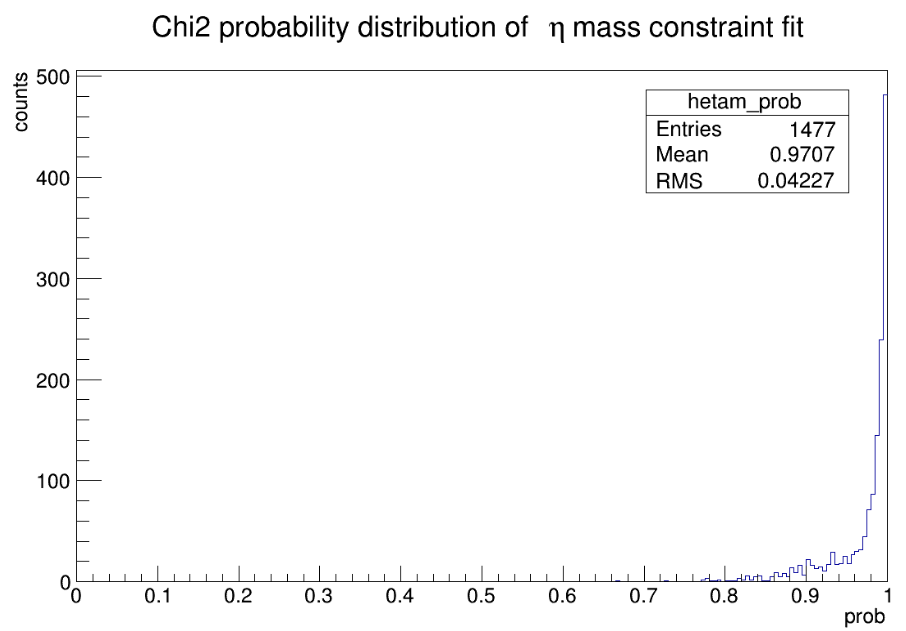
EMC E_γ >50MeV
Evt = 10k





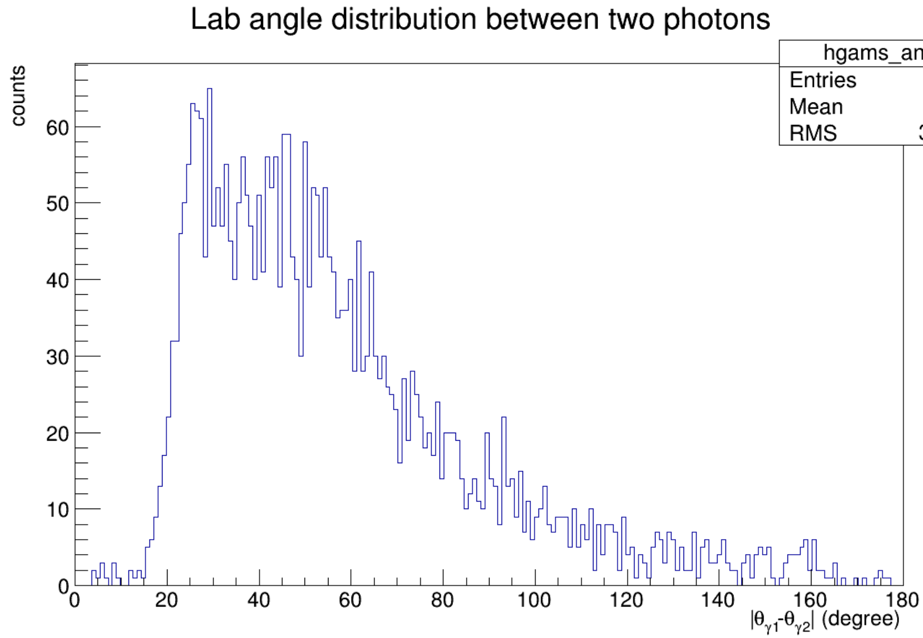
EMC E_γ >50MeV
Evt = 10k

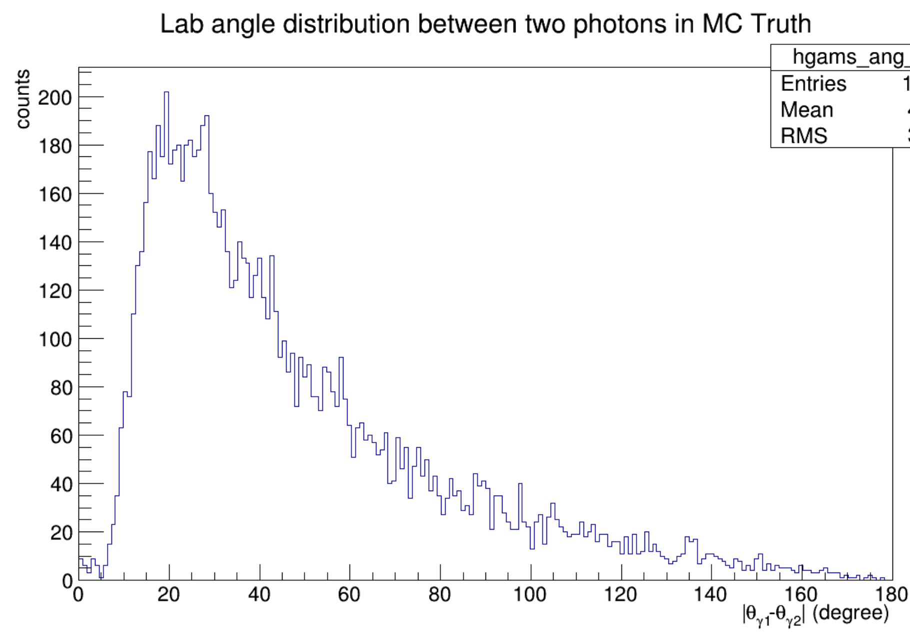




?!

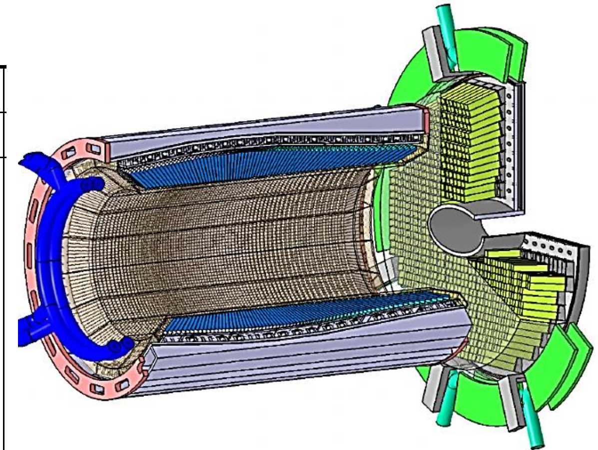
EMC E_{γ} >50MeV
Evt = 10k





Main requirements for EMC

	Required performance value		
Common properties			
energy resolution σ_E/E	$\leq 1\,\% \oplus \frac{\leq 2\,\%}{\sqrt{E/\mathrm{GeV}}}$		
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 $\%\,4\pi$	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



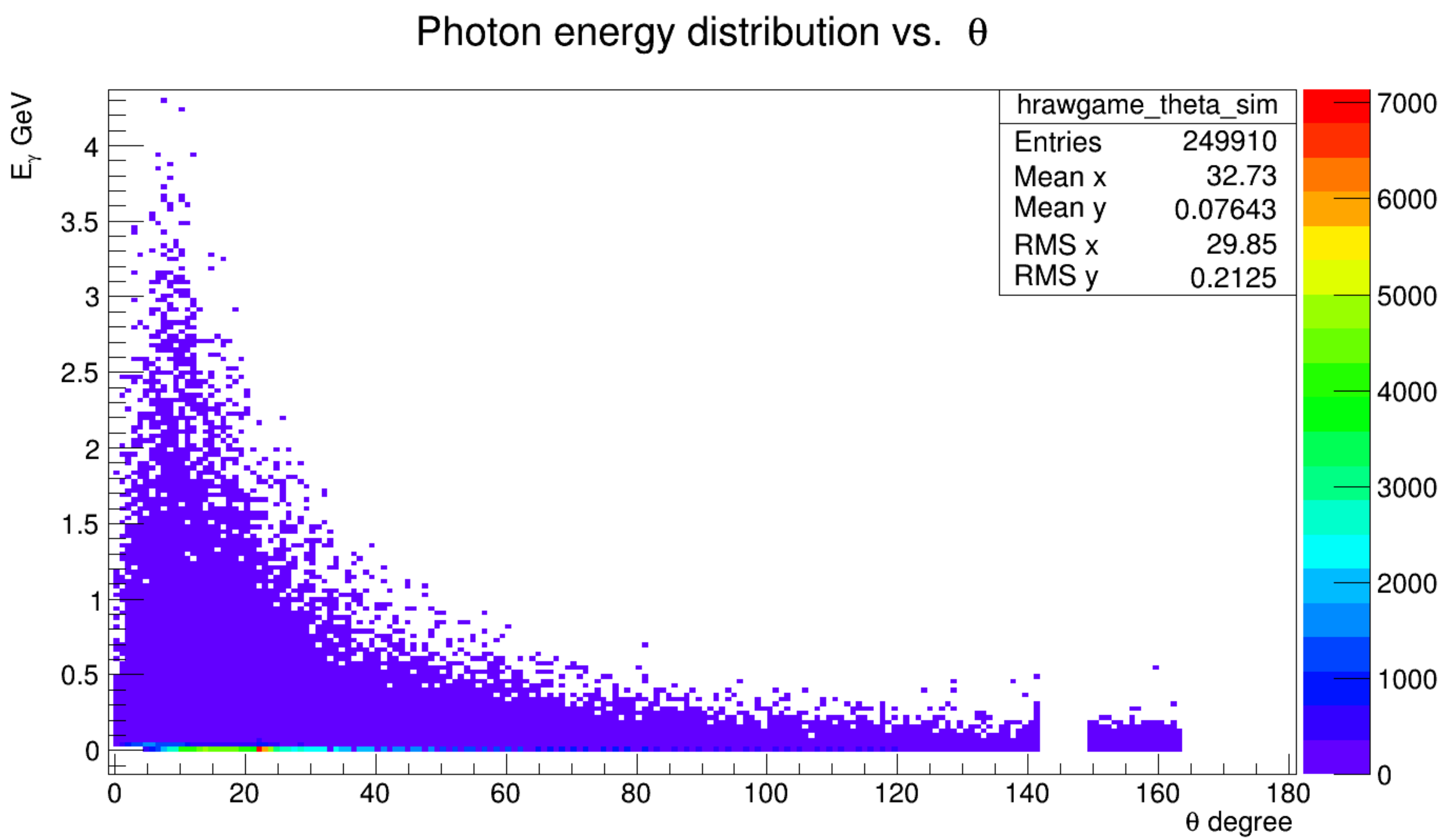
Barrel and forward end-cap EMC

Reconstruction thresholds

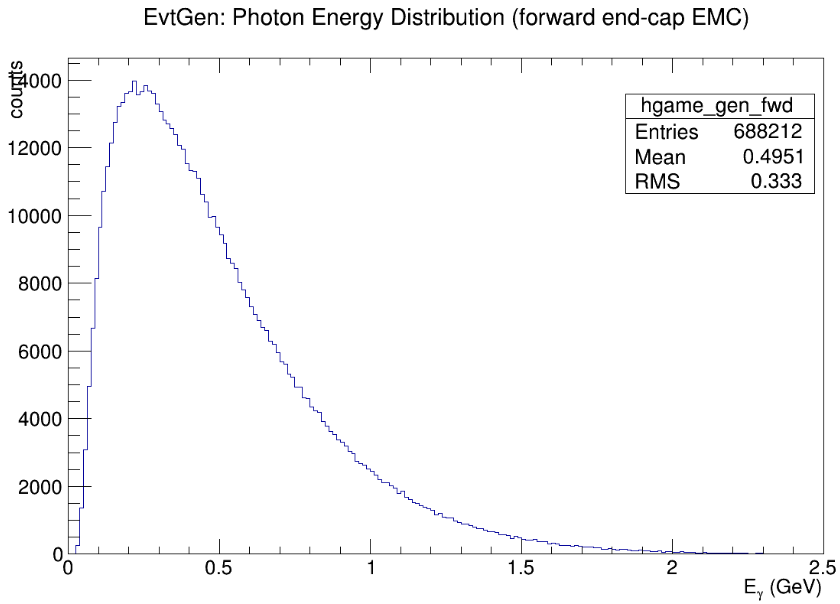
- $E_{xtl} = 3\,\mathrm{MeV}$
- $E_{cl} = 10\,\mathrm{MeV}$
- $E_{max} = 20\,\mathrm{MeV}$

Dynamical Energy Range

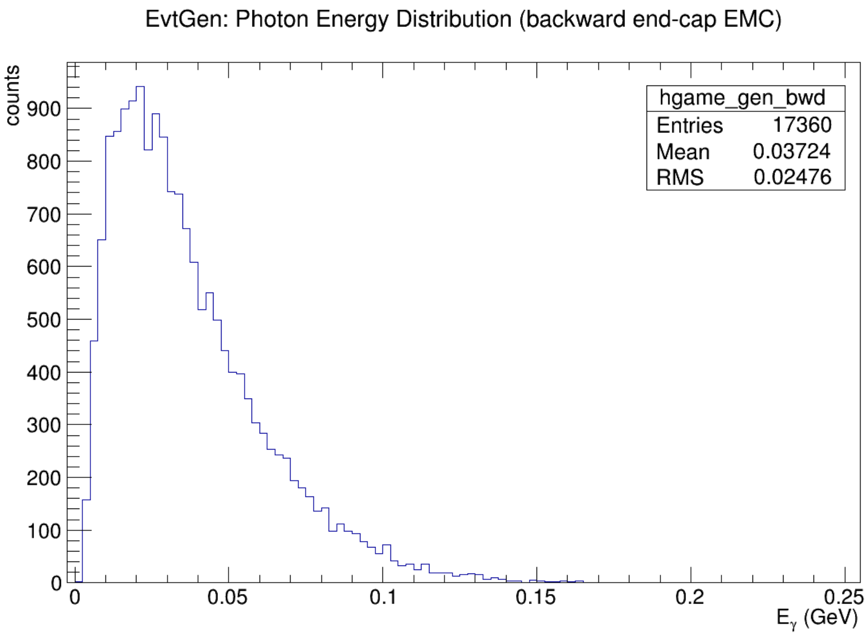
- backward endcap EMC: 10(20) MeV- 0.7 GeV
- barrel EMC: 10(20) MeV- 7.3 GeV, and
- forward endcap EMC: 10(20) MeV- 14.6 GeV.


Photon energy distribution vs. θ
hrawgame_theta_sim
Entries 249910
Mean x 32.73
Mean y 0.07643
RMS x 29.85
RMS y 0.2125
E_γ GeV
θ degree
0
0.5
1
1.5
2
2.5
3
3.5
4
0
20
40
60
80
100
120
140
160
180
0
1000
2000
3000
4000
5000
6000
7000

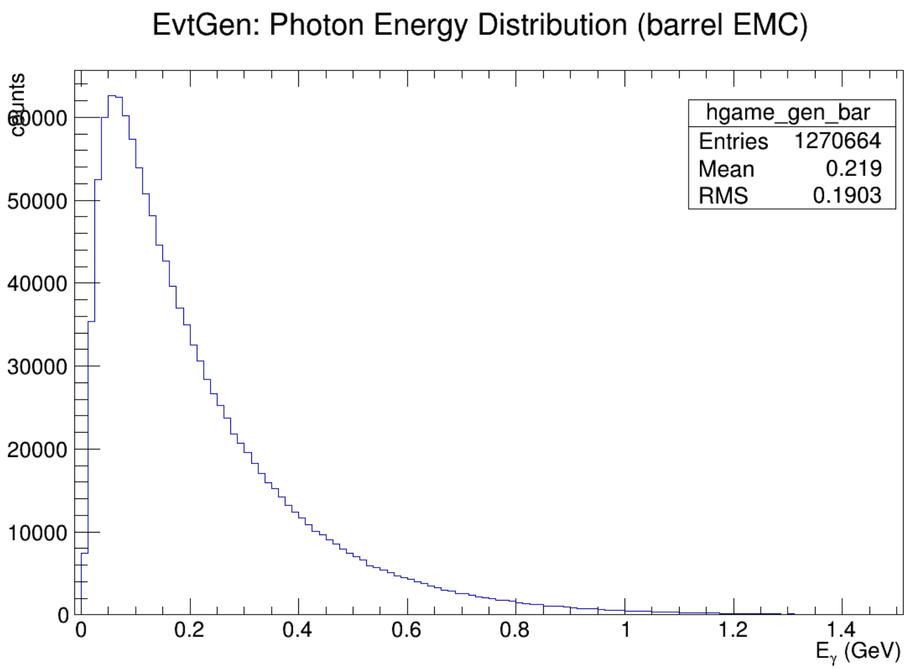
Photon Energy Distribution (EvtGen)

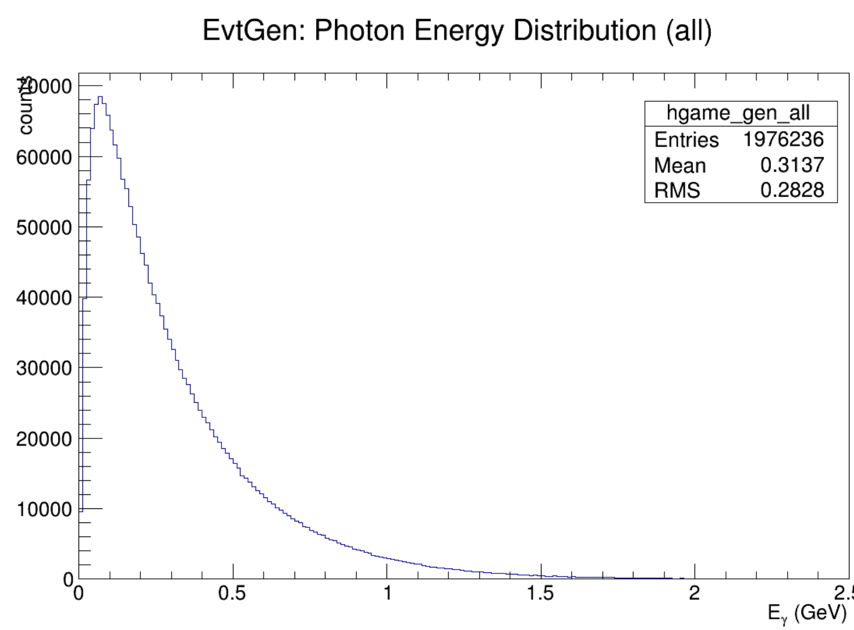


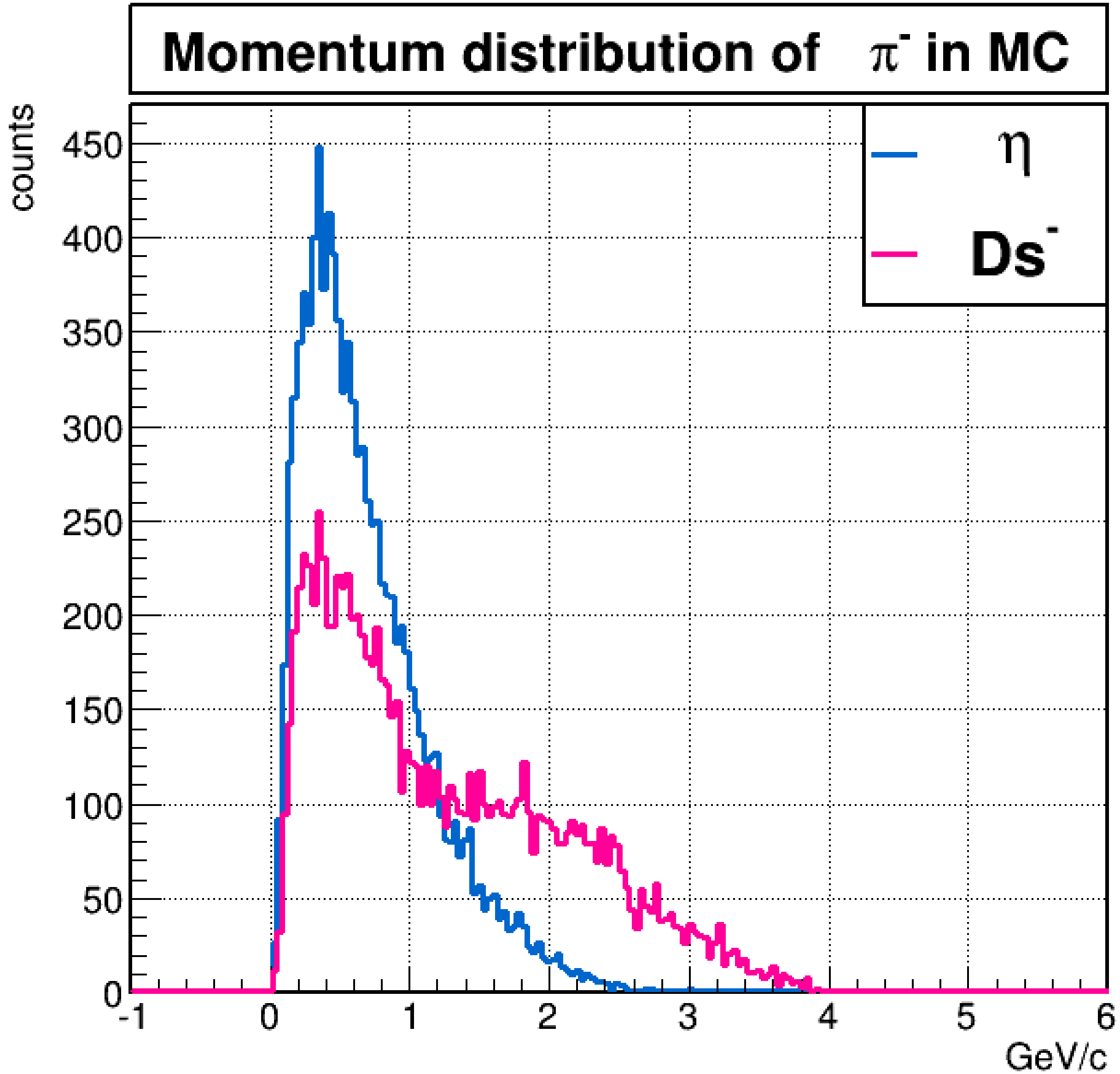
1 M evt
Generator: EvtGenDirect
Sim. via SimpleEvtGenRO



Photon Energy Distribution (EvtGen)



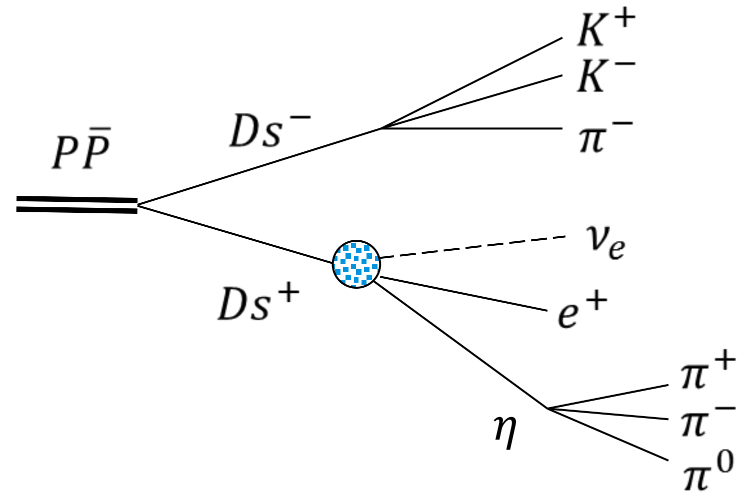




Momentum distribution of π⁻ in MC
counts
450
400
350
300
250
200
150
100
50
0
-1
0
1
2
3
4
5
6
GeV/c
η
Ds⁻

pbarpSystem

-> Ds- Ds+	***BR*$_{PDG}$**
| |-> eta e+ nu_e	**2.67%**
|-> K- K+ pi-	**5.49%**



Production Rate of Ds pair

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

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

$$\backsimeq 220$$

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