JÜLICH
FORSCHUNGSZENTRUM

Update on Simulations of the Ds Semileptonic Decay Form Factor

Lu Cao

11th June， 2014

Outline

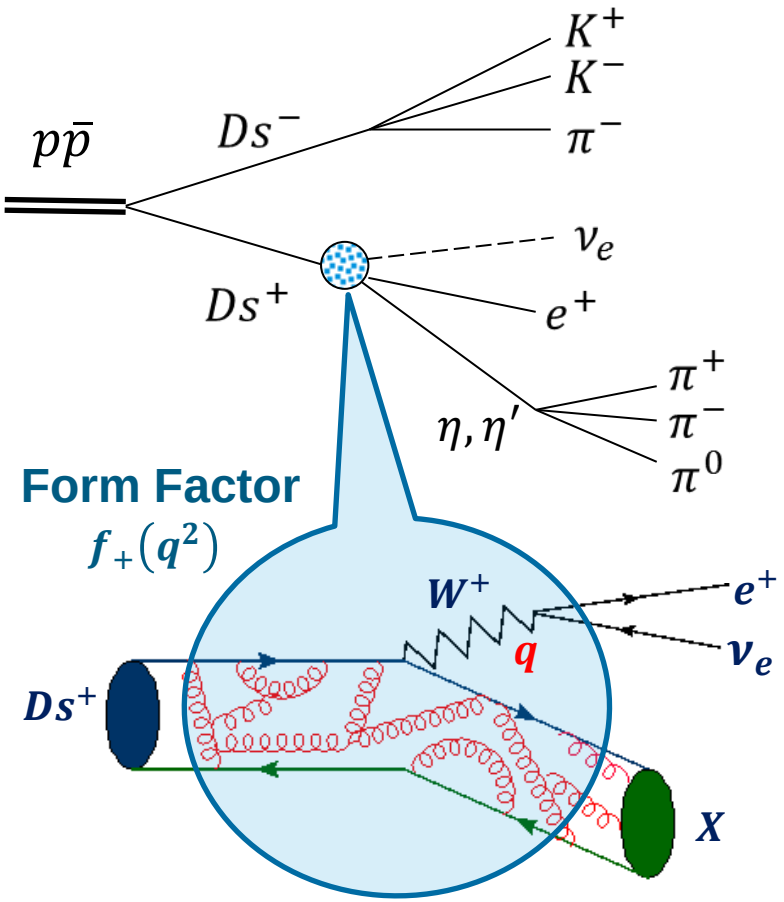
- Significance on Ds semileptonic decay
- Reconstruction of neutral pion
- Kinematics of lepton-neutrino system
- Reco. efficiency in FastSim & FullSim
- Updated reconstruction results in FullSim
- Summary & outlook

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'.



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

Reconstruction of Neutral Pion

Photon energy scaling method

Invariant mass of two-photon: $m_{\gamma\gamma} = \sqrt{2E_{\gamma_1} E_{\gamma_2}(1 - \cos\theta_{\gamma\gamma})}$

Photon energy $E_{\gamma i}$ will be scaled to $E_{\gamma i}^{REC}$: $E_{\gamma_i}^{\mathrm{REC}} = \frac{m_\pi}{m_{\gamma\gamma}} E_{\gamma_i}$

with $E_{\gamma i}^{REC}$ and angular information fixed, the 4-momenta of pi0 can be written as: $\boldsymbol{p}_\pi = \boldsymbol{p}_{\gamma_1}^{\mathrm{REC}} + \boldsymbol{p}_{\gamma_2}^{\mathrm{REC}}$

Nucl. Instr. and Meth. A 453 (2000) 606 pdf

TAPS

Reconstruction of the π° kinematics from $\gamma\gamma$ decay

K. Korzecka, T. Matulewicz*

Institute of Experimental Physics, Warsaw University, Hoża 69, PL-00-681 Warszawa, Poland

This method is appropriate when the accuracy of the angular measurements is much better compared to the energy measurements.

Otherwise, not only the photon energies have to be corrected, but also their emission angles (kinematical fit).

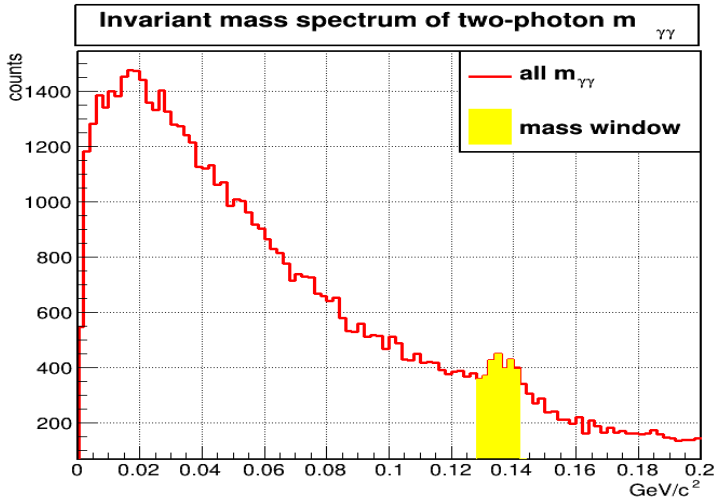
2k evt #24910

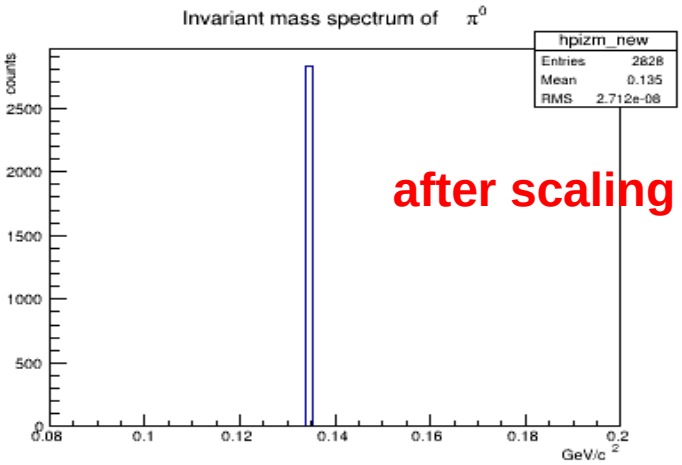
Cuttings in **energy scaling method**:

photon energy > 0.02 GeV

width of mass window on $m_{\gamma\gamma}$: 0.014 GeV/c

opening angle > 0.1 (1 evt not fulfill)





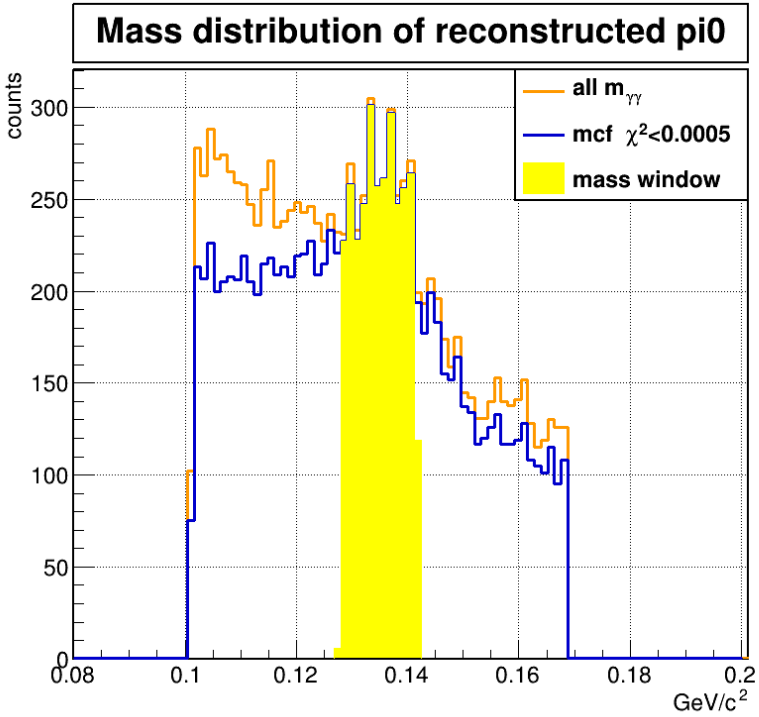
after scaling

Cuttings in **mcf method**:

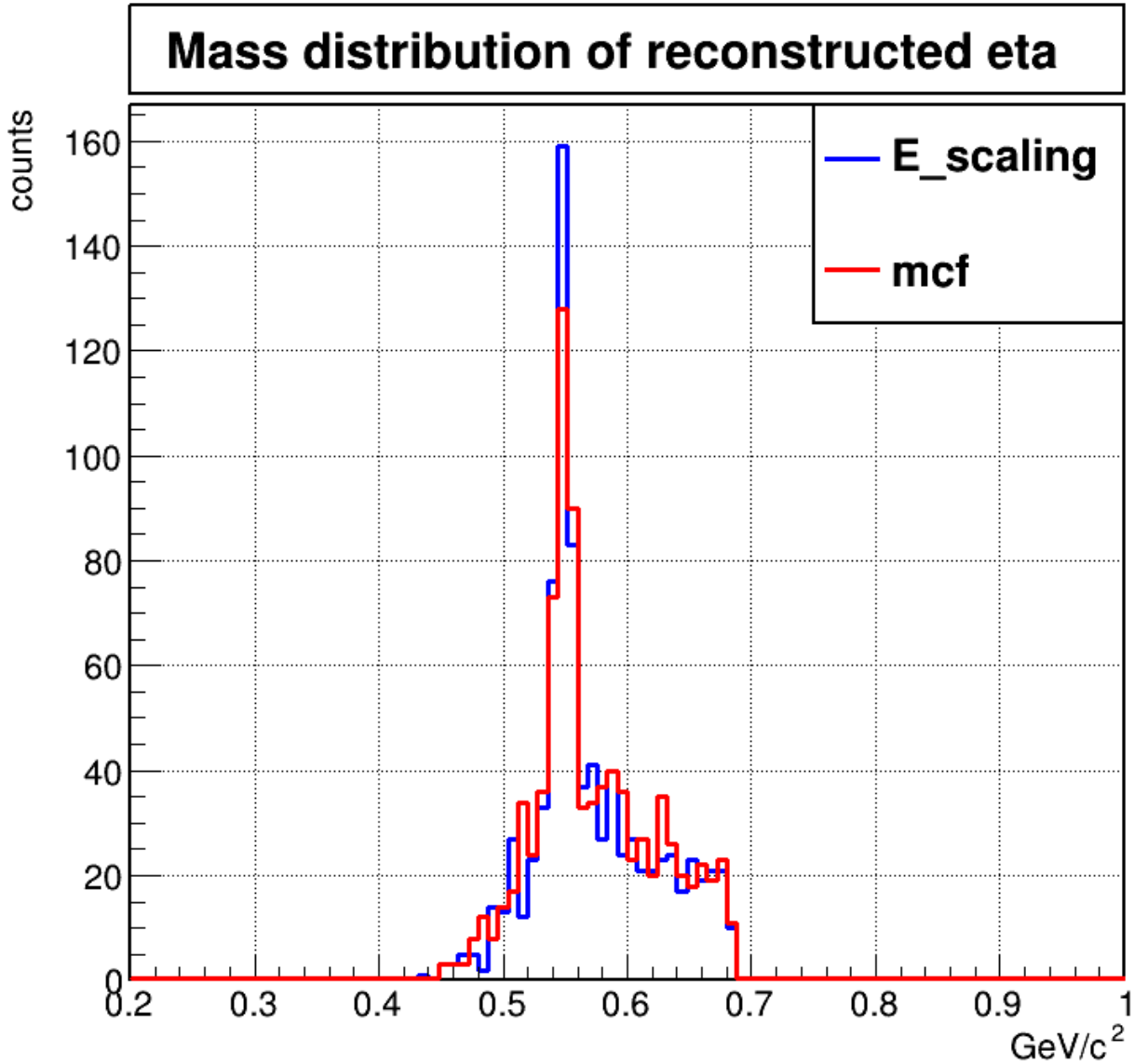
photon energy > 0.02 GeV

width of mass window: 0.014 GeV/c

mcf chi2 < 0.0005



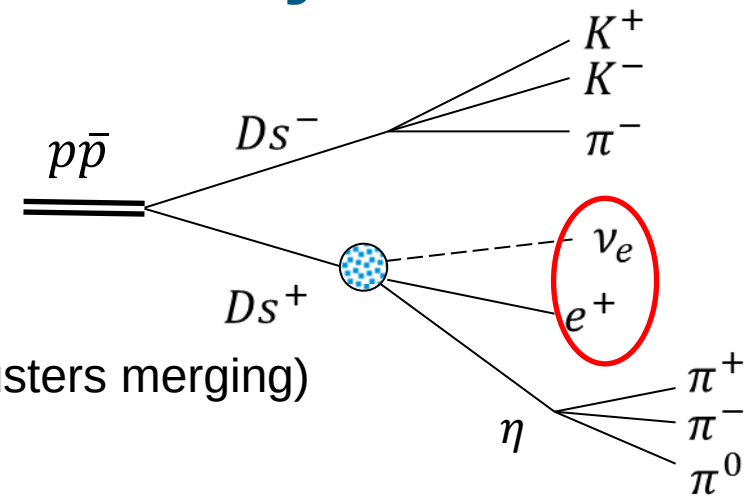
2k evt #24910


Mass distribution of reconstructed eta
counts
160
140
120
100
80
60
40
20
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
GeV/c 2
E_scaling
mcf

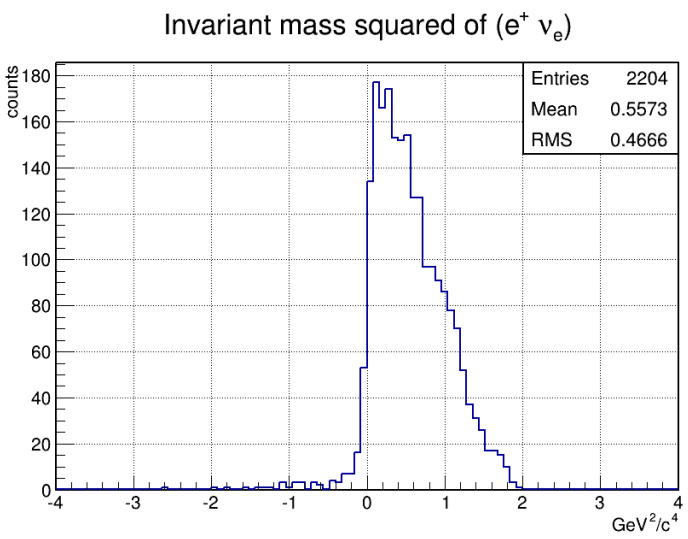
Kinematics of Lepton-neutrino System

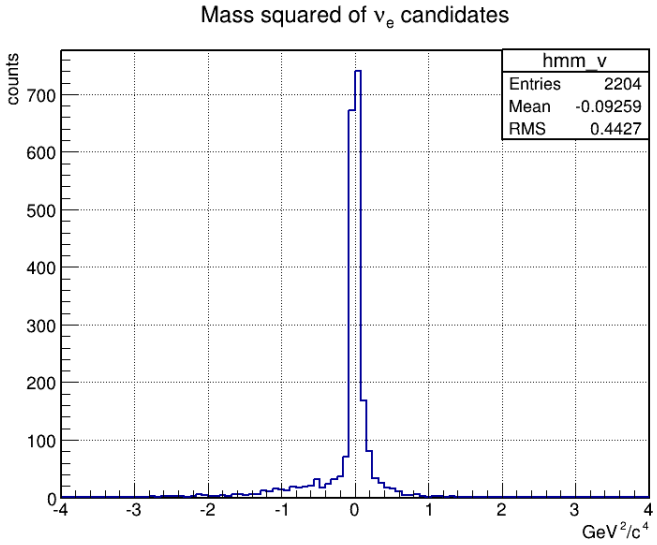
Invariant mass squared of lepton-neutrino:

$$q^2(e^+\nu_e) = \left(E_{p\bar{p}} - E_{Ds^-} - E_\eta\right)^2 - \left|\vec{P}_{p\bar{p}} - \vec{P}_{Ds^-} - \vec{P}_\eta\right|^2$$

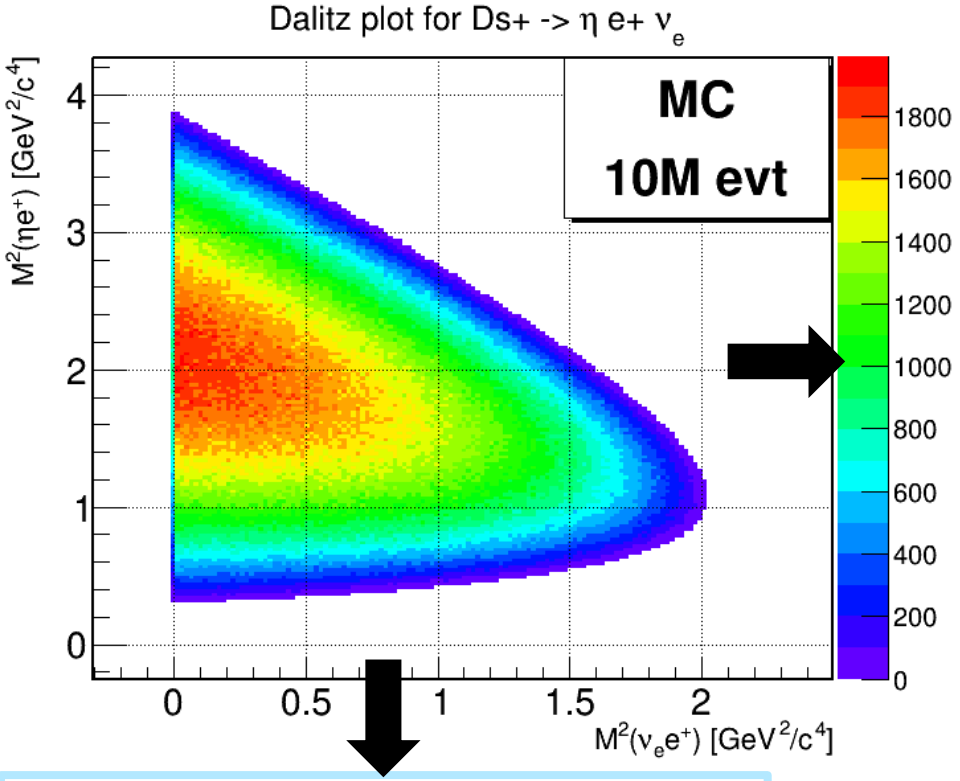


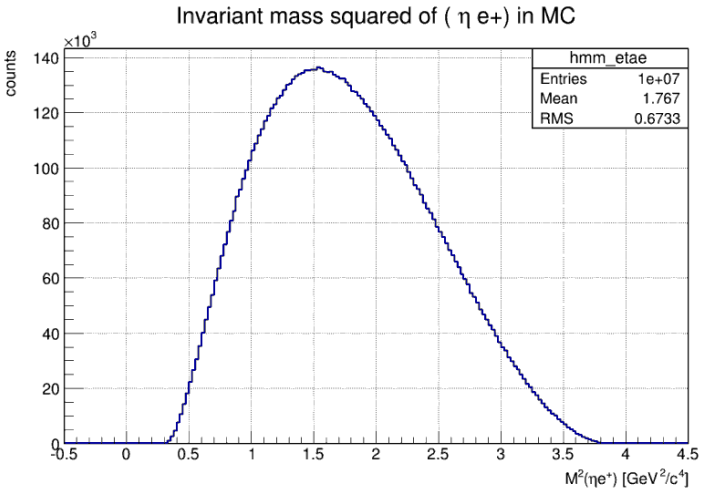
- FaSim (enable bremsstrahlung and neutral clusters merging)
- 10k evt at $\sqrt{s} = 4.108$ GeV
- Ideal PID (#25009)

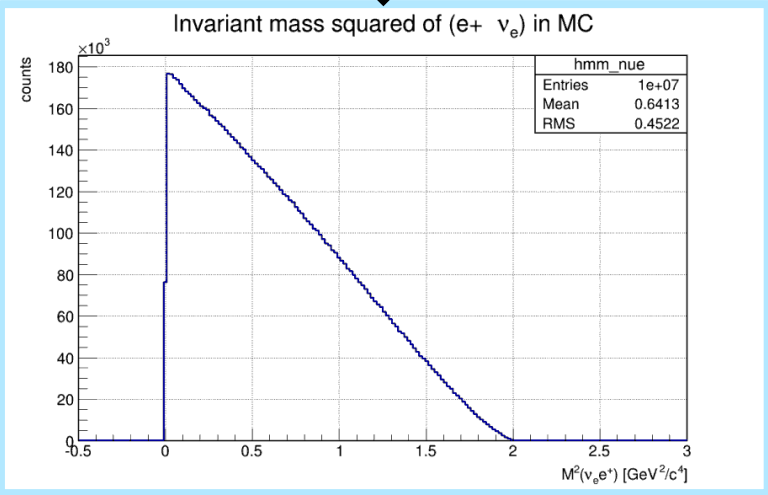




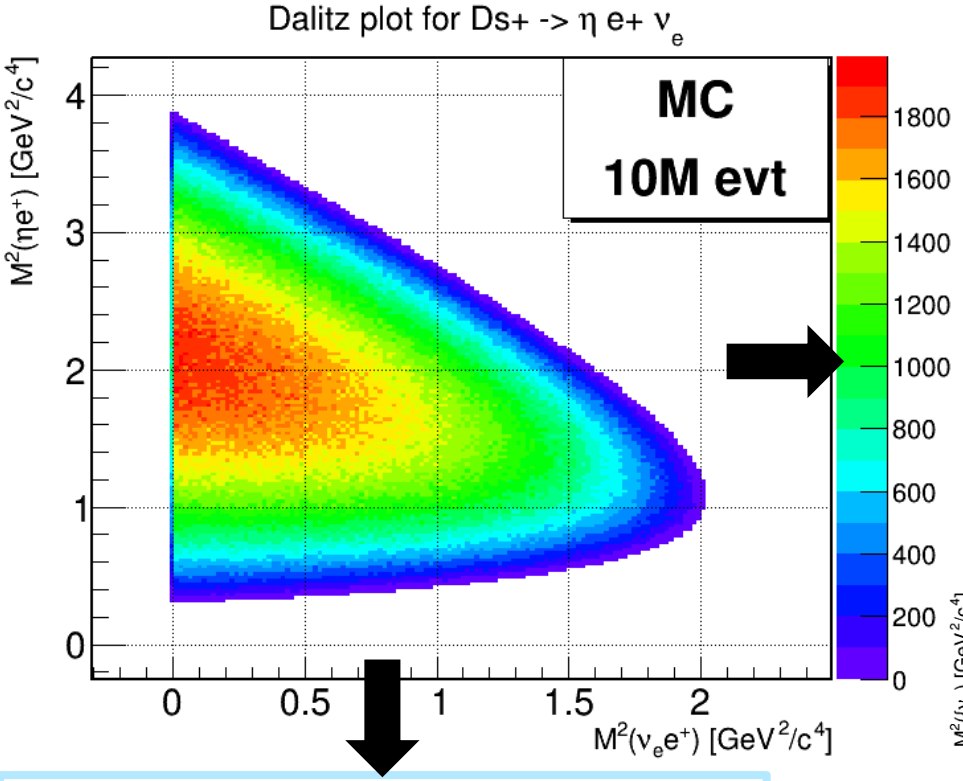
MC Truth

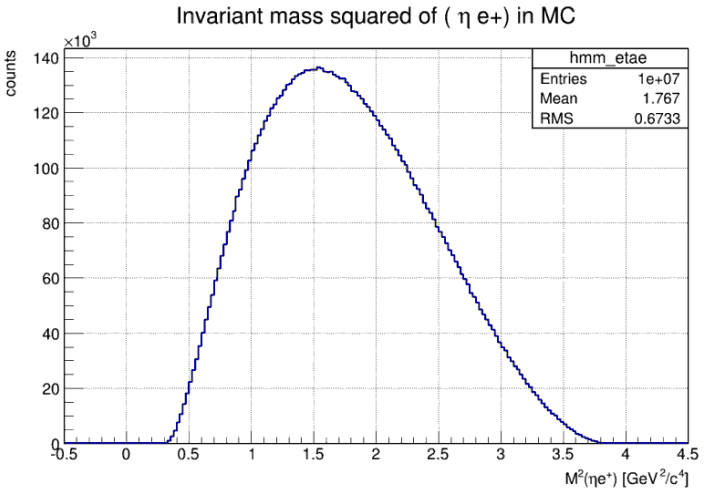

Dalitz plot for Ds+ -> η e+ ν_e
MC
10M evt
M²(ηe⁺) [GeV²/c⁴]
M²(ν_e e⁺) [GeV²/c⁴]

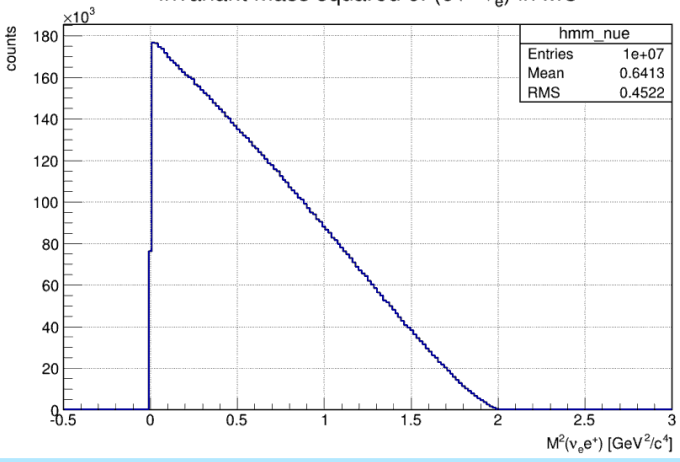

Invariant mass squared of (η e+) in MC
hmm_etae
Entries 1e+07
Mean 1.767
RMS 0.6733
counts
M²(ηe⁺) [GeV²/c⁴]

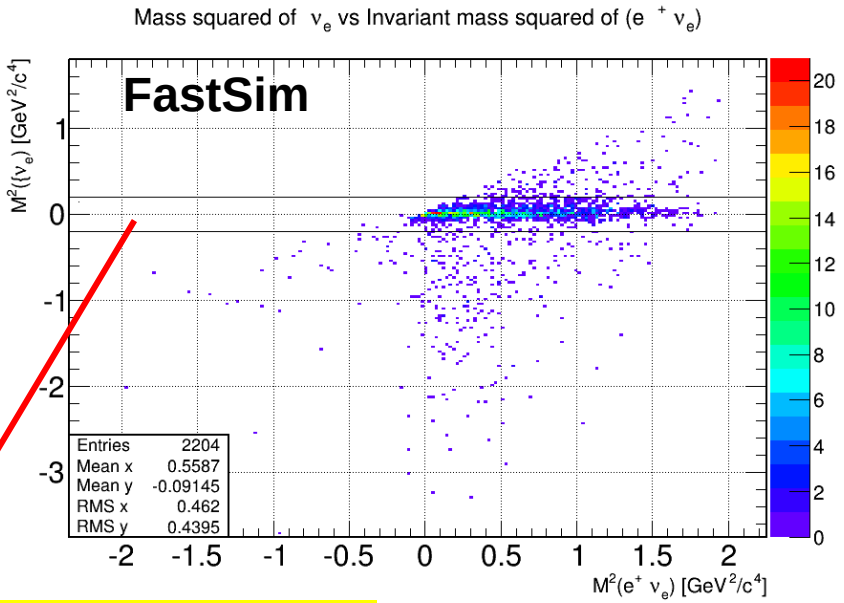

Invariant mass squared of (e+ ν_e) in MC
hmm_nue
Entries 1e+07
Mean 0.6413
RMS 0.4522
counts
M²(ν_e e⁺) [GeV²/c⁴]

MC Truth

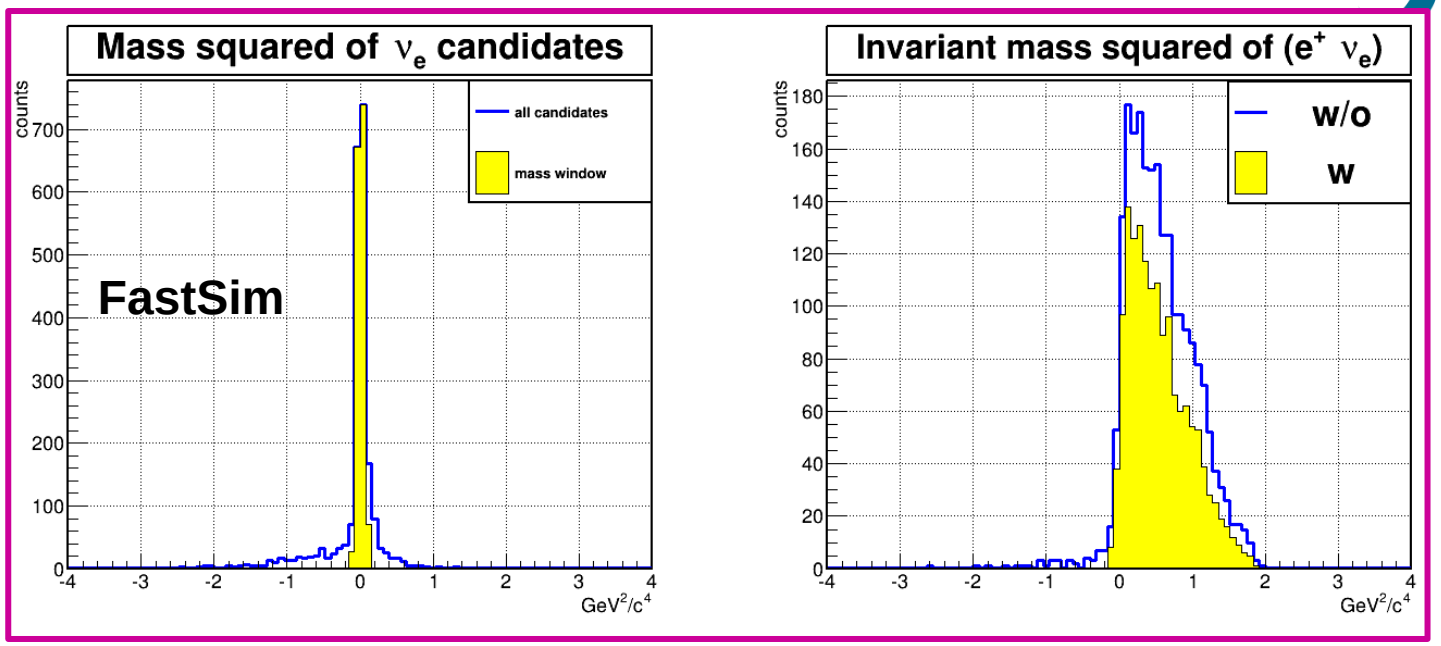


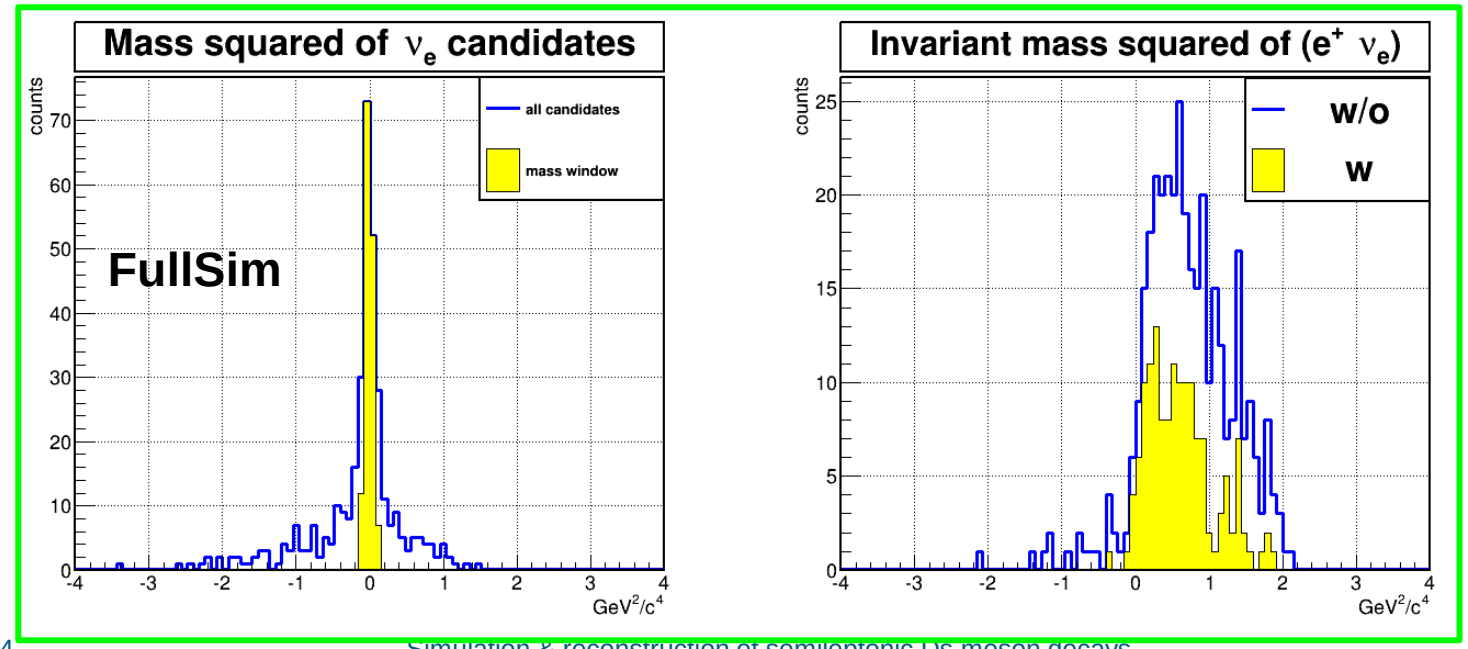






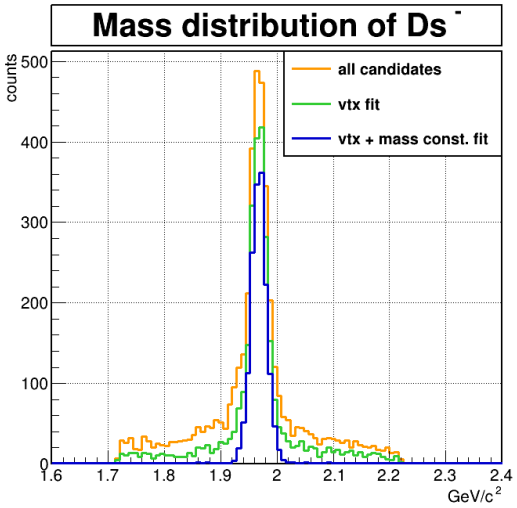
$|M^2(\nu_e)| < 0.1$ GeV/c²


Mass squared of ν_e candidates
counts
all candidates
mass window
FastSim
GeV^2/c^4
Invariant mass squared of (e^+ ν_e)
w/o
w
GeV^2/c^4

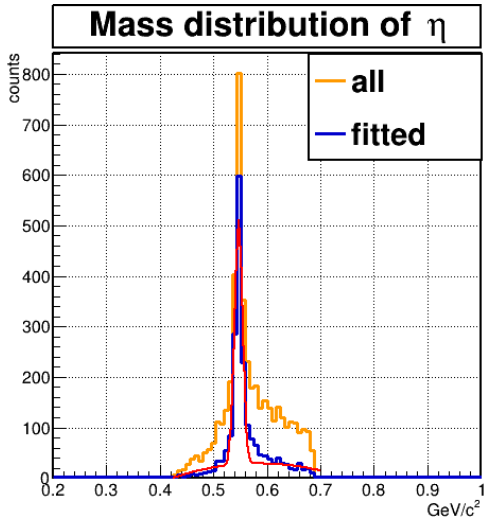

Mass squared of ν_e candidates
counts
all candidates
mass window
FullSim
GeV^2/c^4
Invariant mass squared of (e^+ ν_e)
w/o
w
GeV^2/c^4

Updated Reconstruction Results in FullSim

- 10k evt $\sqrt{s} = 4.108$ GeV (ideal PID， #25009)
- photon energy scaling in pi0 reconstruction
- photon energy threshold: 20 MeV
- $\gamma\gamma$ minimum opening angle: 0.1 rad
- $\gamma\gamma$ mass window: 135 ± 7 MeV/c²
- D_s^- mass window: 1968 ± 250 MeV/c²
- η mass window: 548 ± 270 MeV/c²



Ds Resolution	M [MeV/c²]	Vx [μm]	Vy [μm]	Vz [μm]	Pt [%]	Pz [%]
	14	75	73	160	3.0	1.4



eta Resolution	M [MeV/c²]	Vx [μm]	Vy [μm]	Vz [μm]	Pt [%]	Pz [%]
	7.5	363	319	943	2.1	1.8

Reco. efficiency in FastSim & FullSim

10k evt (ideal PID， #25009)

Full Sim

paritcle		entries	eff.
e^+		7315	**73%**
D_s^-	all	4302	
	vtx	2849	
	mcf	1590	**16%**
η	$\pi^+\pi^-$ all	9952	
	$\pi^+\pi^-$ vtx	7434	
	eta all	4526	
	eta mcf	2021	**20%**
π^0	all	360034	
	mass win.	14351	
	$\theta_{\gamma\gamma} > 0.1$	14346	
$(e^+\nu_e)$	w/o cut	374	**3.7%**
	w. cut	151	**1.5%**

Fast Sim

paritcle		entries	eff.
e^+		8023	**80%**
D_s^-	all	6845	
	mcf	5288	**53%**
η	eta all	5348	
	eta mcf	4127	**41%**
π^0	all	15342	
	mass win.	8543	
	$\theta_{\gamma\gamma} > 0.1$	8543	
$(e^+\nu_e)$	w/o cut	2204	**22%**
	w. cut	1511	**15.1%**

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$(e^+\nu_e)$	w/o cut	2204	**22%**
	w. cut	1511	**15.1%**

Summary and outlook

- Use photon energy scaling method in pi0 reconstruction
- Reconstructions in FastSim & FullSim are compared
- Efficiency lepton-neutrino system is ~3.7% (80 evt/mon)

- Improve eff. in FullSim (eg. vtx reso., tracking eff.)
- Include η' decay in present simulation
- Investigate background channels

Picture cited from internet

Thank you

l.cao@fz-juelich.de

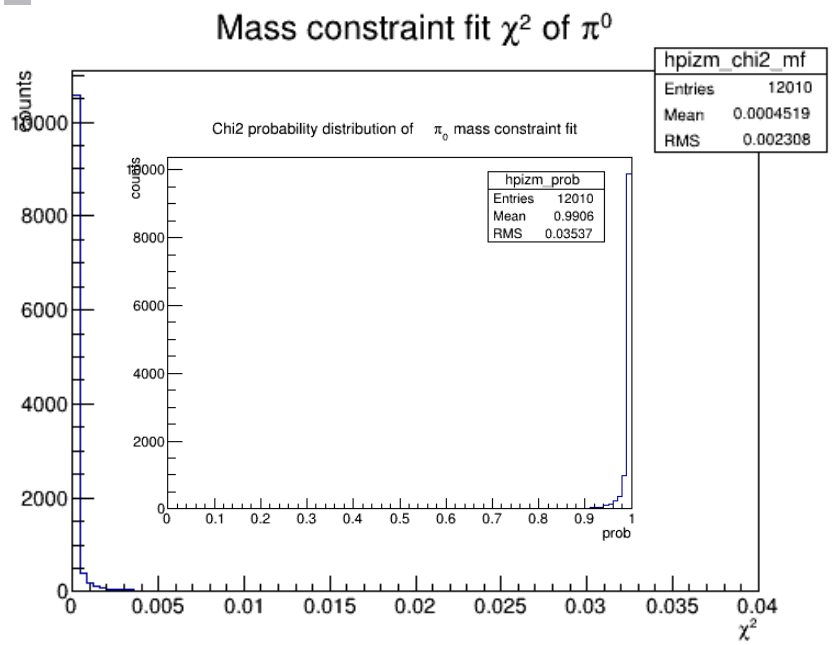
Backup Slides

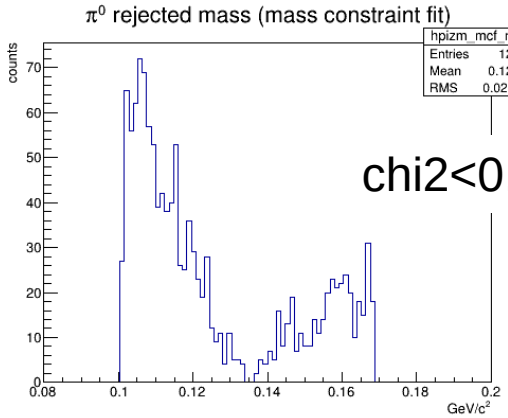
Reconstruction of neutral pion

Two ways:

- mass constraint fit for two photons (PndKinFitter in PandaRoot) *fitter fixed since #24893*
- photon energy scaling method *Nucl. Instr. and Meth. A 453 (2000) 606*

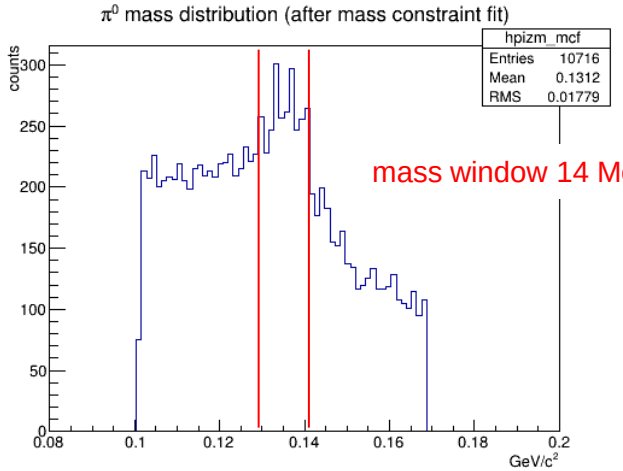
mass constraint fit





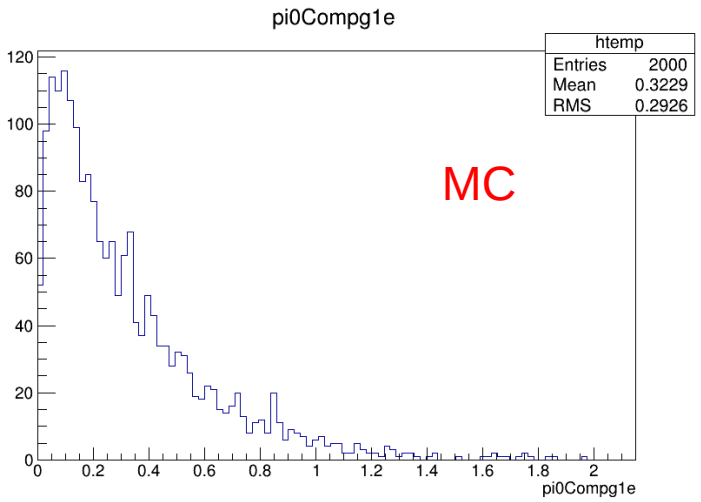
chi2<0.0005

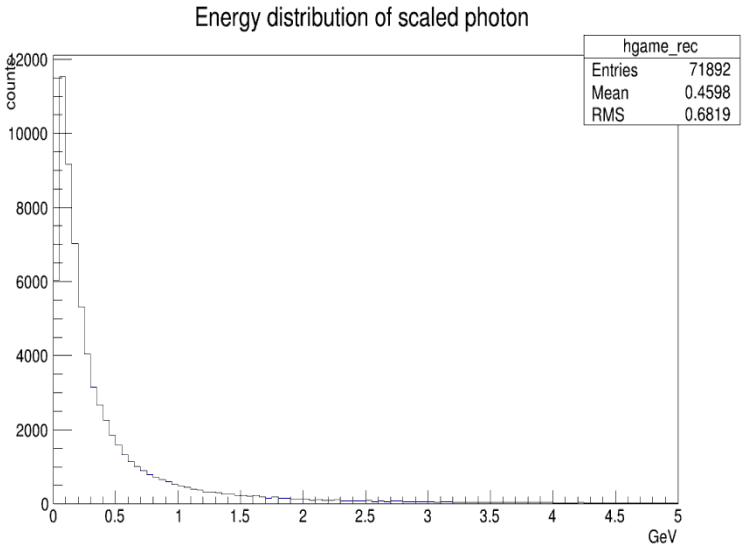
2k evt
#24910



mass window 14 MeV/c

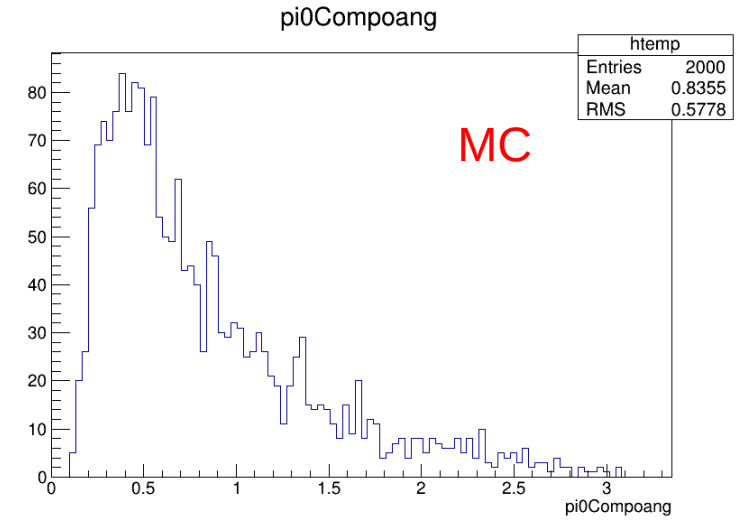
Cutting 1: photon energy > 0.02 GeV

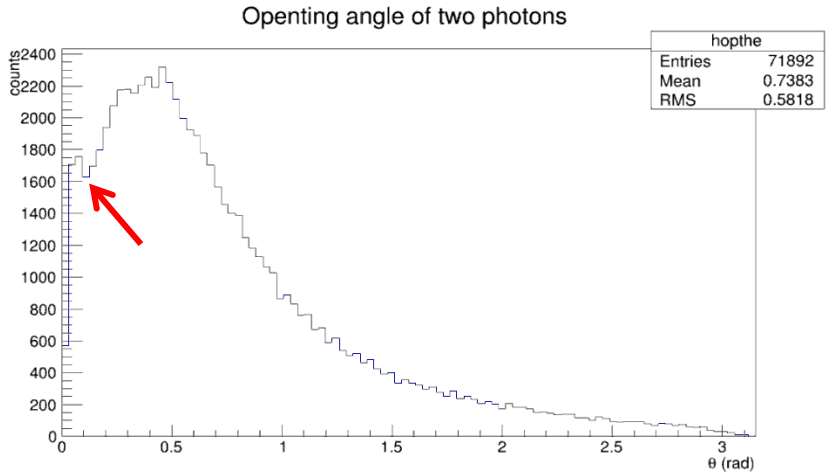




Cutting 2: opening angle > 0.1 rad

2k evt
#24910



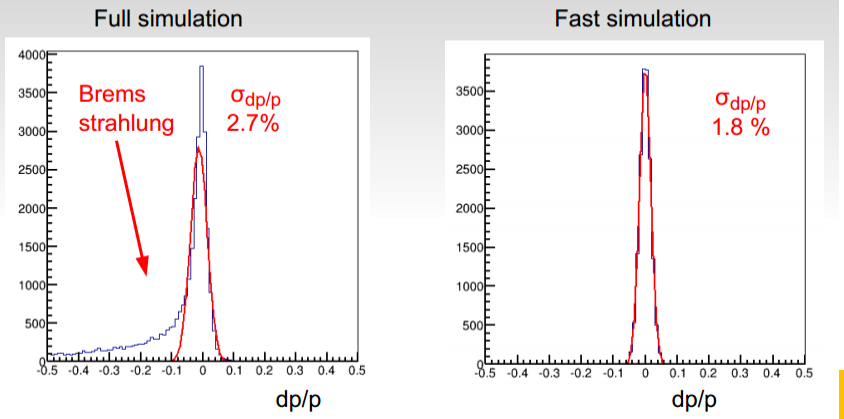


FastSim：bremsstrahlung and neutrals merging

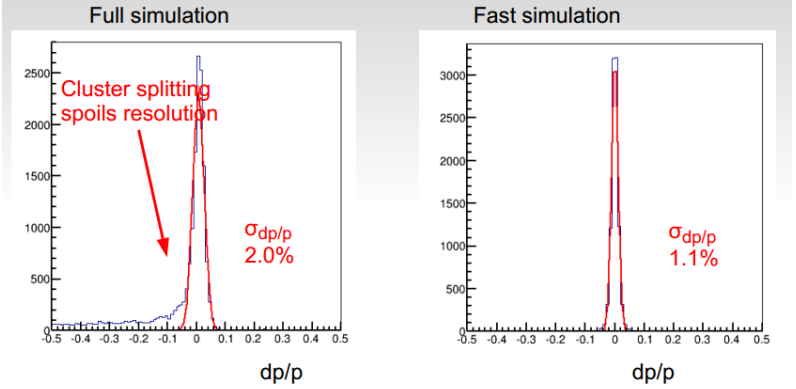
Talk by Ronald Kunne:

- $\bar{p}p \rightarrow J/\psi\,\pi^0$ PHSP
  $J/\psi \rightarrow e^+e^-$ VLL
- π^0 box simulation 0.2 – 10 GeV

Electron resolution



Pizero resolution



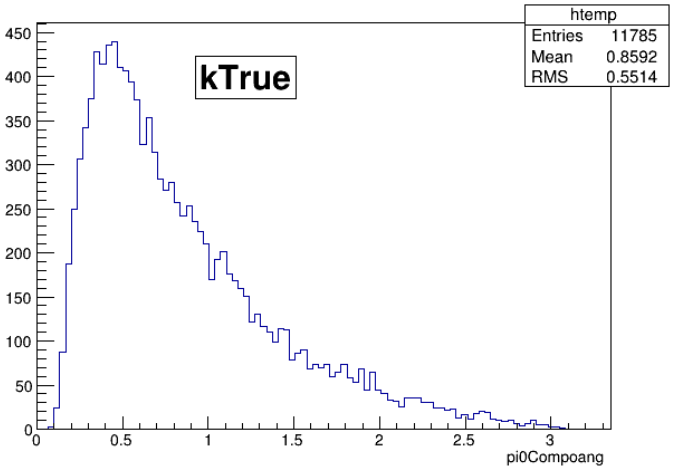
Implements in fast sim macro

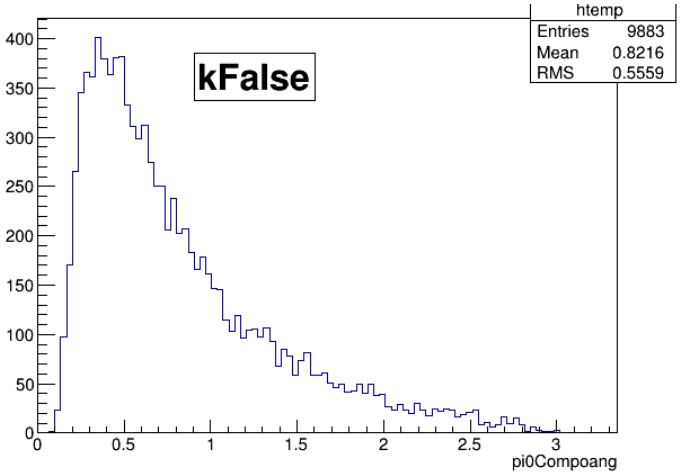
```
// enable the merging of neutrals if they have similar direction
fastSim->MergeNeutralClusters();

// enable bremsstahlung loss for electrons
fastSim->EnableElectronBremsstrahlung();
```

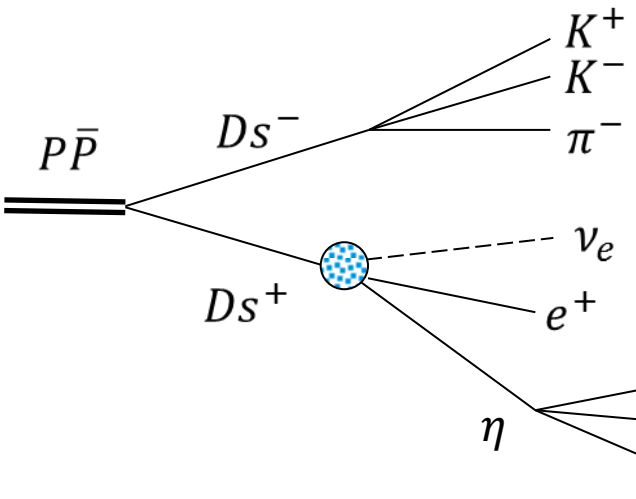
default value is kfalse now;
will be enabled after checking

Test with my decay chain

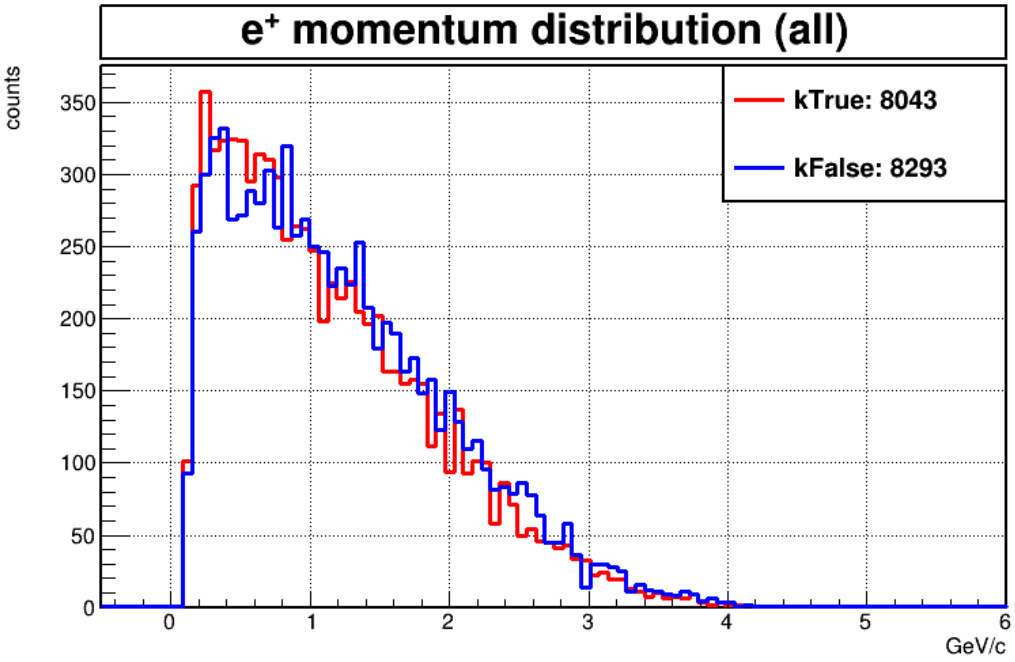
Opening angle of two-photon(pi0)







10k evt
#25009
Ideal PID



Form factor 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):

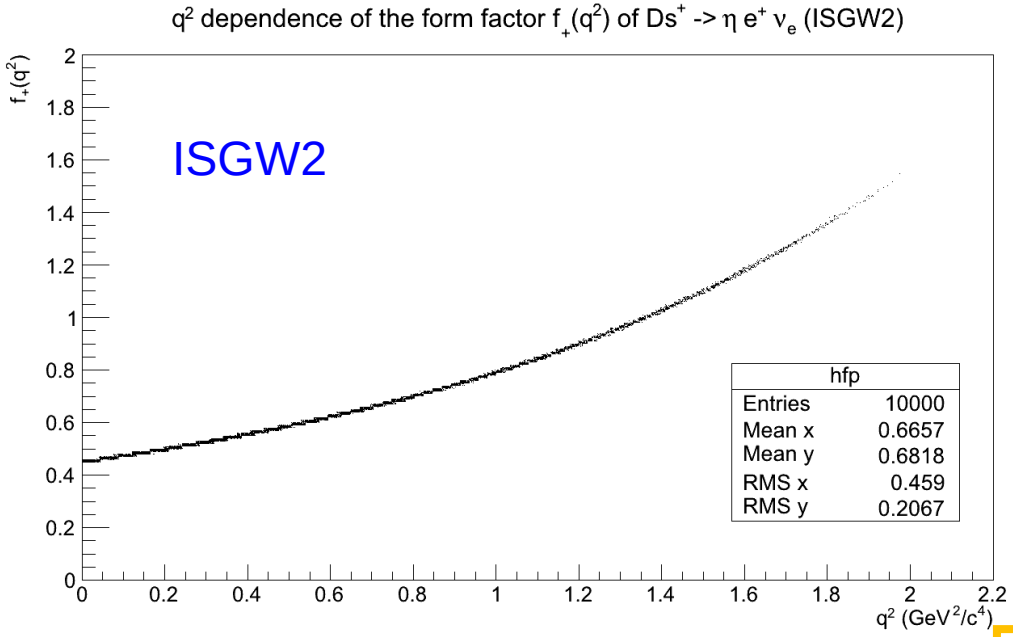
$$\frac{d\Gamma}{dq^2}(D_s \to (\eta,\eta')l\nu_l) = \frac{G_F^2|V_{cs}|^2}{192\pi^3 m_{D_s}^3}\left[(m_{D_s}^2 + m_{\eta^{(\prime)}}^2 - q^2)^2 - 4m_{D_s}^2 m_{(\eta,\eta')}^2\right]^{3/2}|f_+^{D_s\to\eta^{(\prime)}}(q^2)|^2$$

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

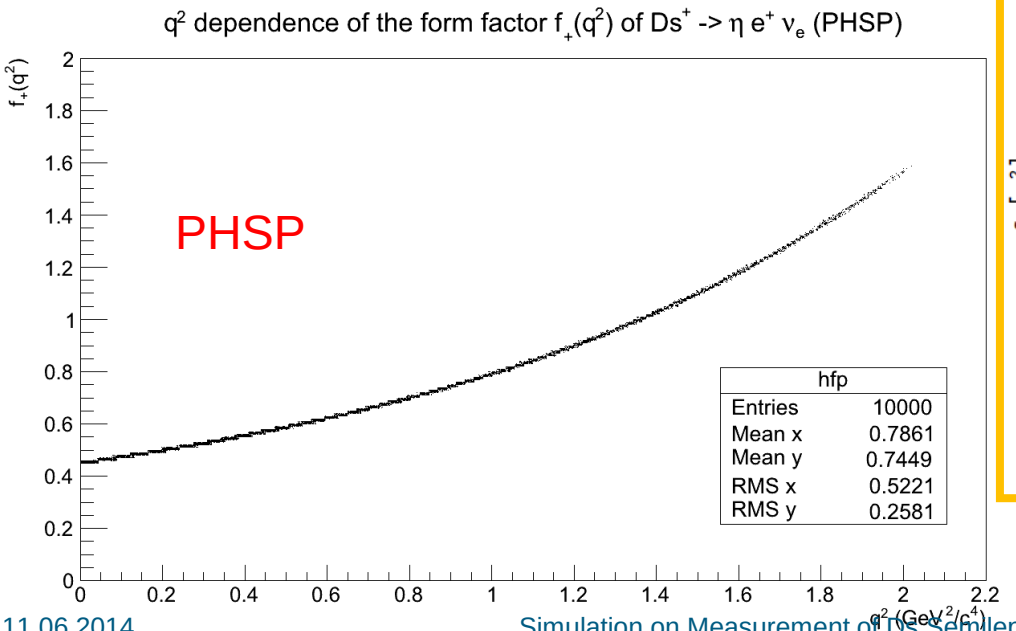


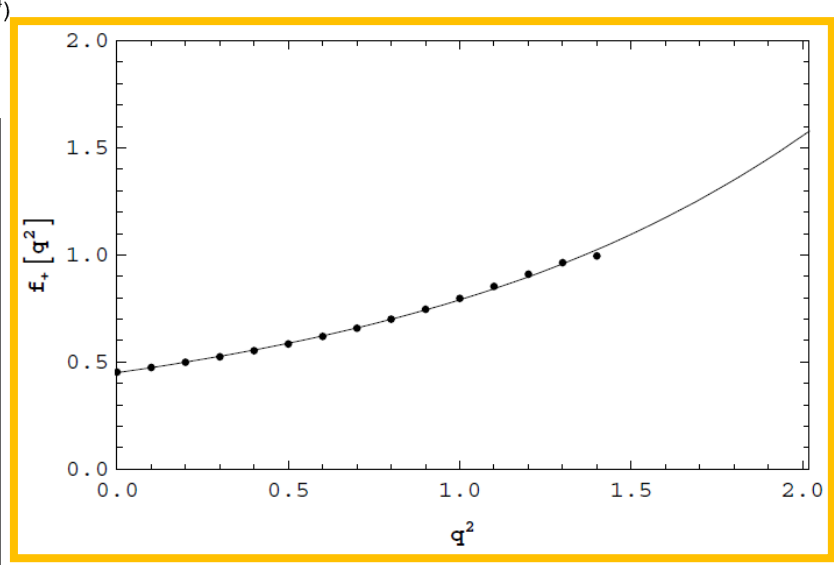
$$f_\pm(q^2) = \frac{f_\pm(0)}{1 - \alpha\hat{q} + \beta\hat{q}^2}$$

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

Light cone QCD sum rules

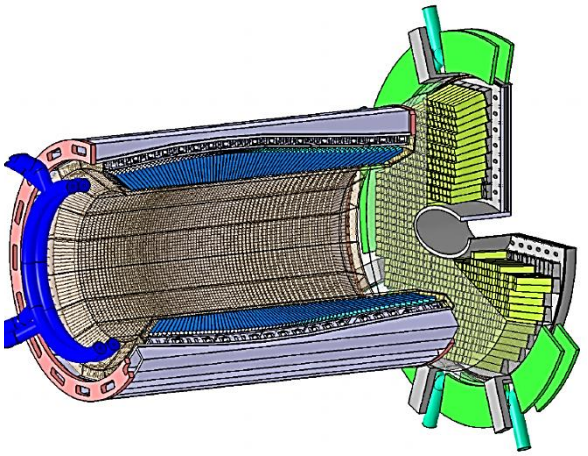
J.Phys.G 38 (2011) 095001
arXiv:1011.6046[hep-ph]





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
($\mathrm{p\bar{p}}$-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	0.15 Gy	7 Gy	125 Gy
(maximum annual dose $\mathrm{p\bar{p}}$-events)			
radiation hardness (maximum annual dose from all events)	10 Gy		125 Gy



Barrel and forward end-cap EMC

Reconstruction thresholds

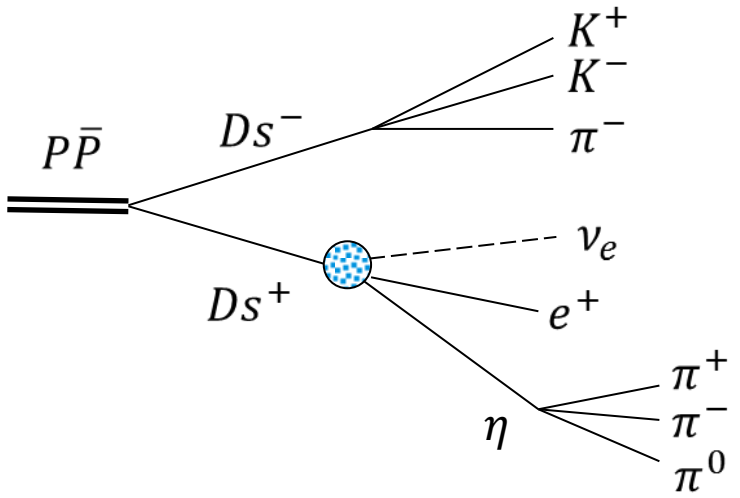
- $E_{xtl} = 3\,\mathrm{MeV}$
- $E_{cl} = 10\,\mathrm{MeV}$
- $E_{max} = 20\,\mathrm{MeV}$

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.

pbarpSystem

-> Ds- Ds+	BR_{PDG}
| |-> eta e+ nu_e	2.67%
| |->pi+ pi- pi0	22.74%
|-> K- K+ pi-	5.49%



Production Rate of Ds pair

with high luminosity mode in 35 days

$$R = \mathcal{L} \cdot \sigma \cdot \varepsilon \cdot t \cdot \mathcal{BR} \qquad \sigma = A\ nb = A \times 10^{-9}\ b \qquad \varepsilon = B\%$$

$$= 2 \times 10^{32}(cm^{-2}s^{-1}) \cdot \boldsymbol{A}(nb) \times 10^{-24}(cm^2/b) \cdot \boldsymbol{B} \times 10^{-2} \cdot 3 \times 10^{6}(s) \cdot 2.67\% \times 5.49\% \times 22.74\%$$

$$\sim 2\boldsymbol{AB} = \mathbf{2 \times 20 \times 3.7 = 148}$$