Mitglied der Helmholtz-Gemeinschaft

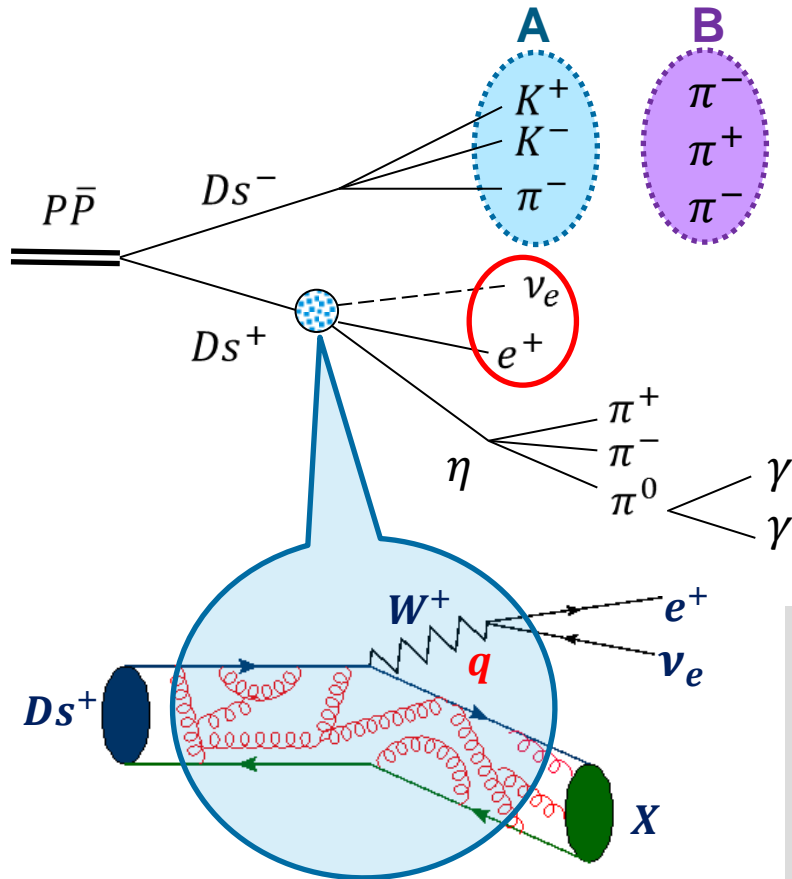# Updates on Simulating D_s Semileptonic Decay

Lu Cao

IKP1, Forschungszentrum Jülich

Sept. 9th, 2015

Outline

- Decay chain

- Reconstruction strategy

- EMC correlation & photon preselection

- Reconstruction results of Ds/eta/pi0

- Reconstructed lepton-neutrino system

- Estimate on event rate

- Summary & outlook

Decay Chain

- Single tagging D_s^-

- Tow tagging modes of D_s^-:
  - **A**: $D_s^- \rightarrow K^- K^+ \pi^-$
  - **B**: $D_s^- \rightarrow \pi^- \pi^+ \pi^-$
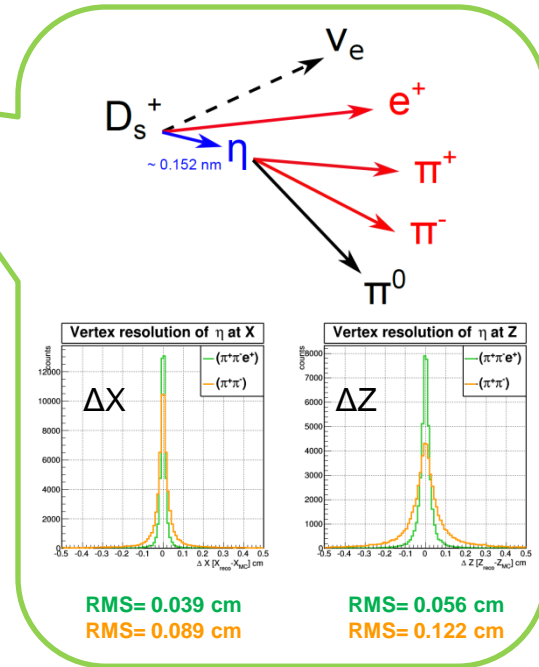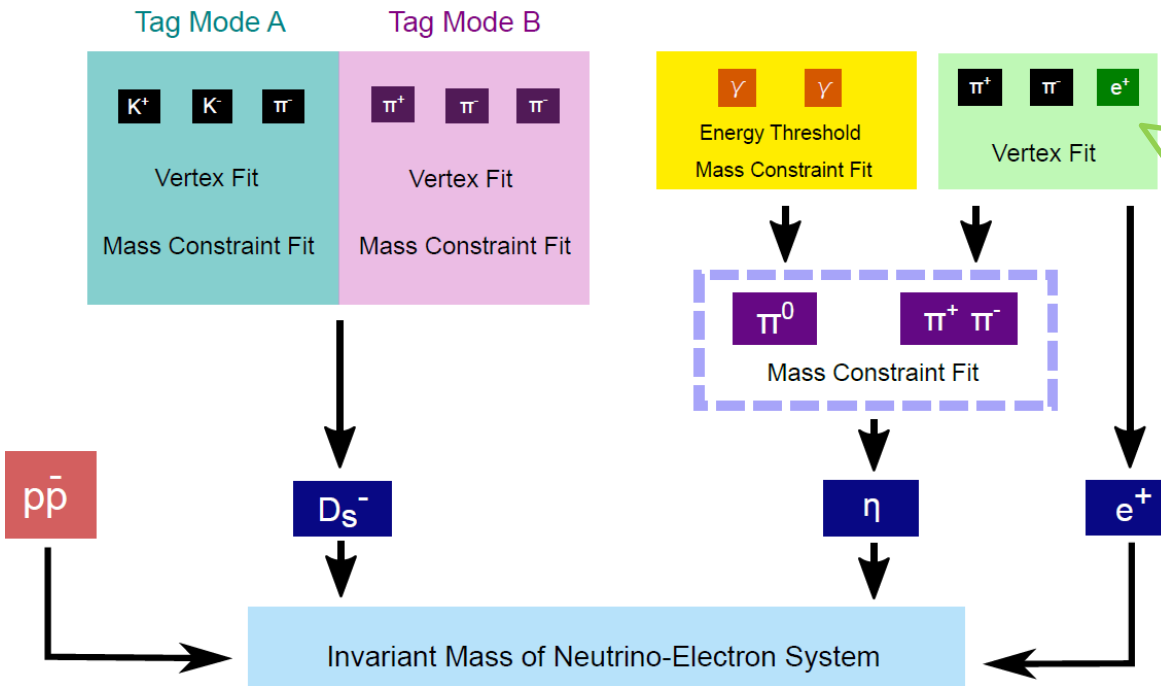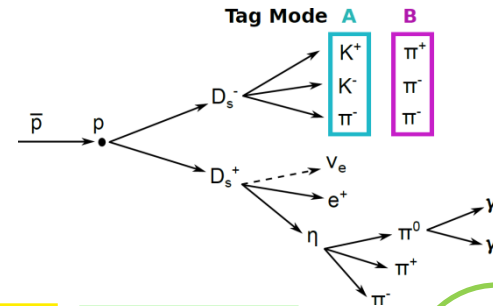
- $q^2 \equiv M^2(e^+ \nu_e)$

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

pbarpSystem

→ Ds- Ds+		$BR_{PDG2014}$	Decay Model
| |→ eta e+ nu_e		2.67%	ISGW2
| |→pi+ pi- pi0		22.92%	ETA_DALITZ
A |→ K- K+ pi-		5.39%	DS_DALTZ
B (→ pi- pi+ pi-)		1.09%	D_DALITZ

Reconstruction Strategy

- 10 million evt for each tag mode
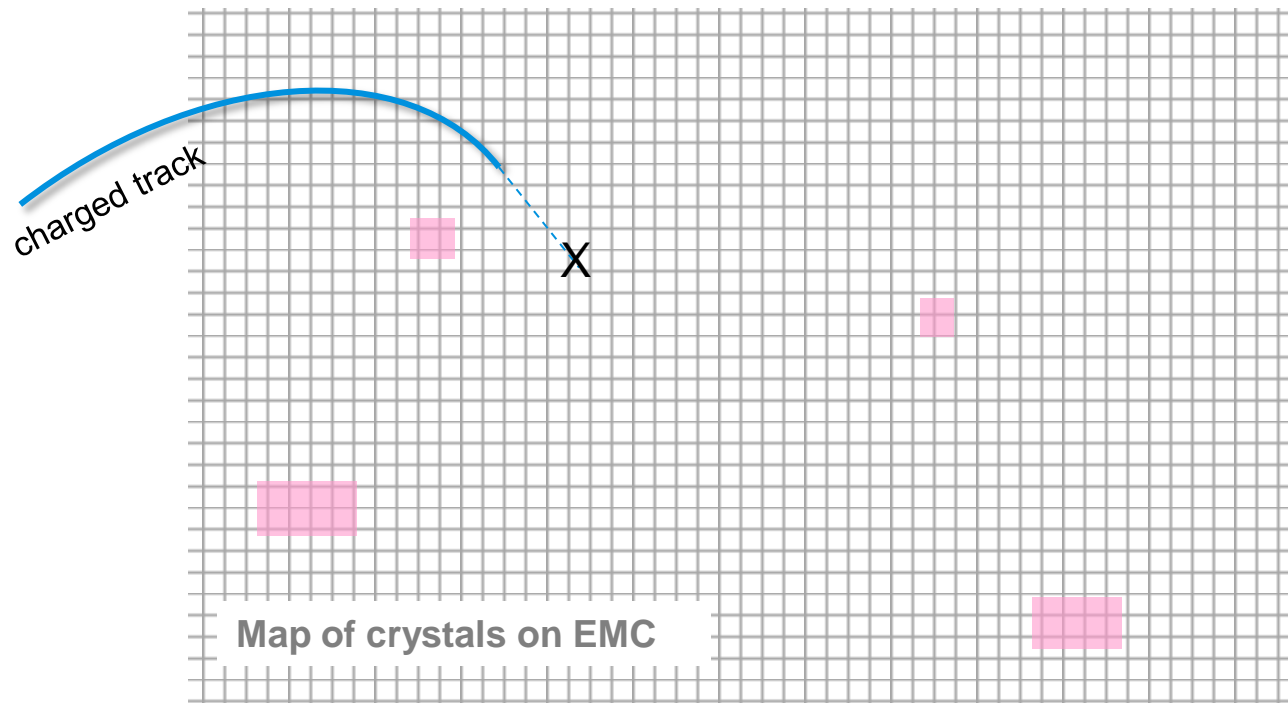- Beam mom = 8 GeV/c
- trk27806

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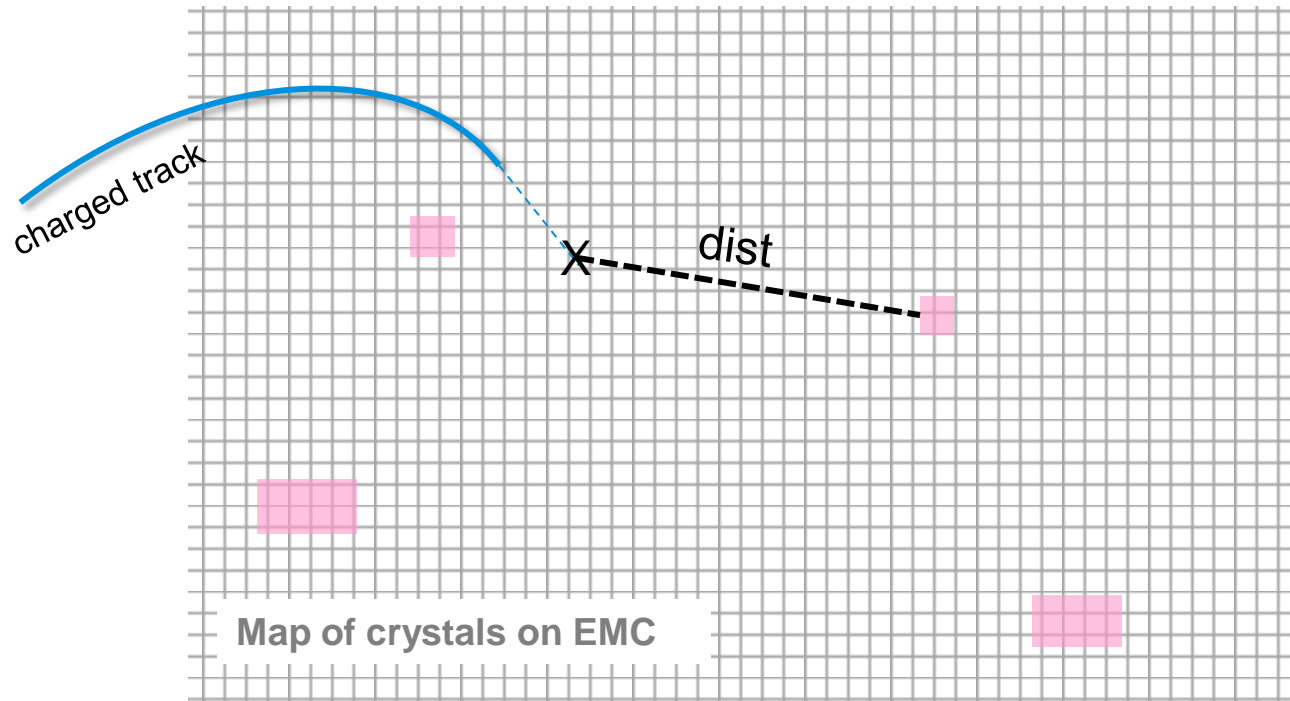
$$q^2 \equiv M^2(v_e e^+)$$

Photon Preselection

- Distance cut on EMC cluster correlation
- Energy threshold
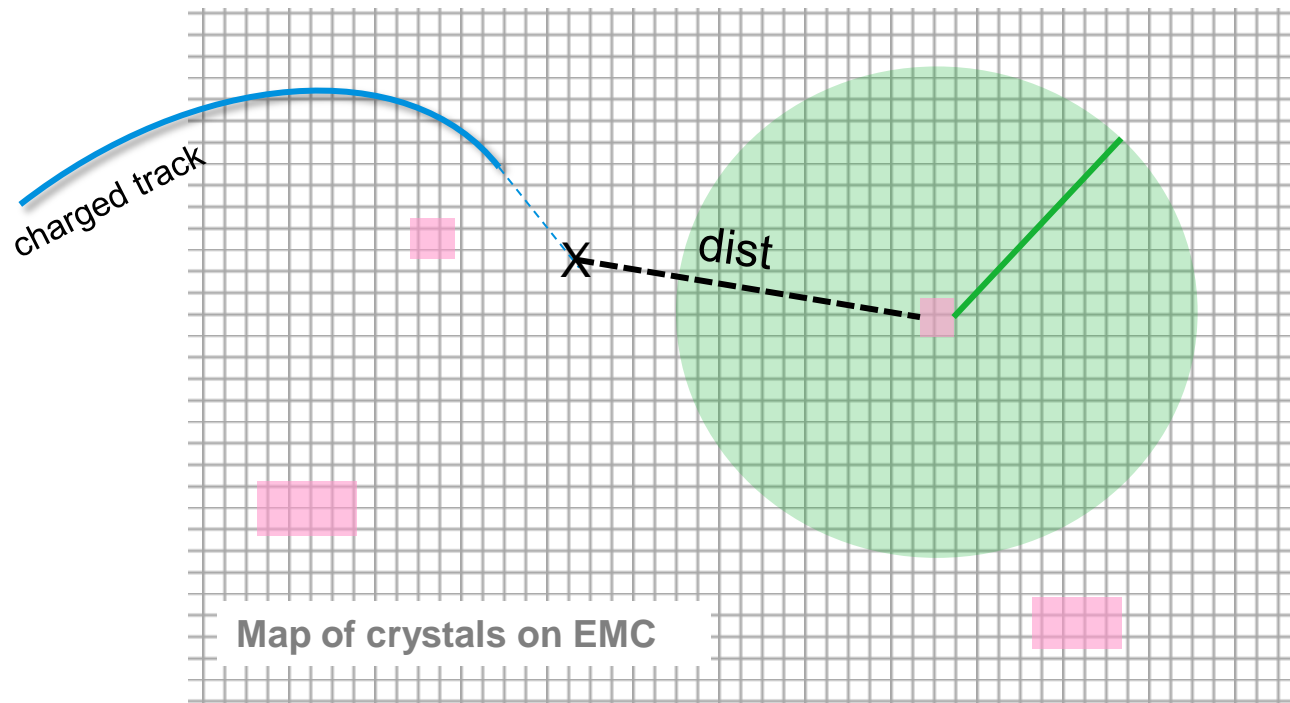- Opening angle

EMC Cluster Correlation

X   extrapolation of track

■   EMC cluster

charged track

X

Map of crystals on EMC

EMC Cluster Correlation

X   extrapolation of track

■   EMC cluster

EMC Cluster Correlation

Map of crystals on EMC

X   extrapolation of track

■   EMC cluster

— $(EmcNeutralQCut)^{1/2}$

charged track

dist

EMC Cluster Correlation

charged track

dist

X

Neutral Candidate
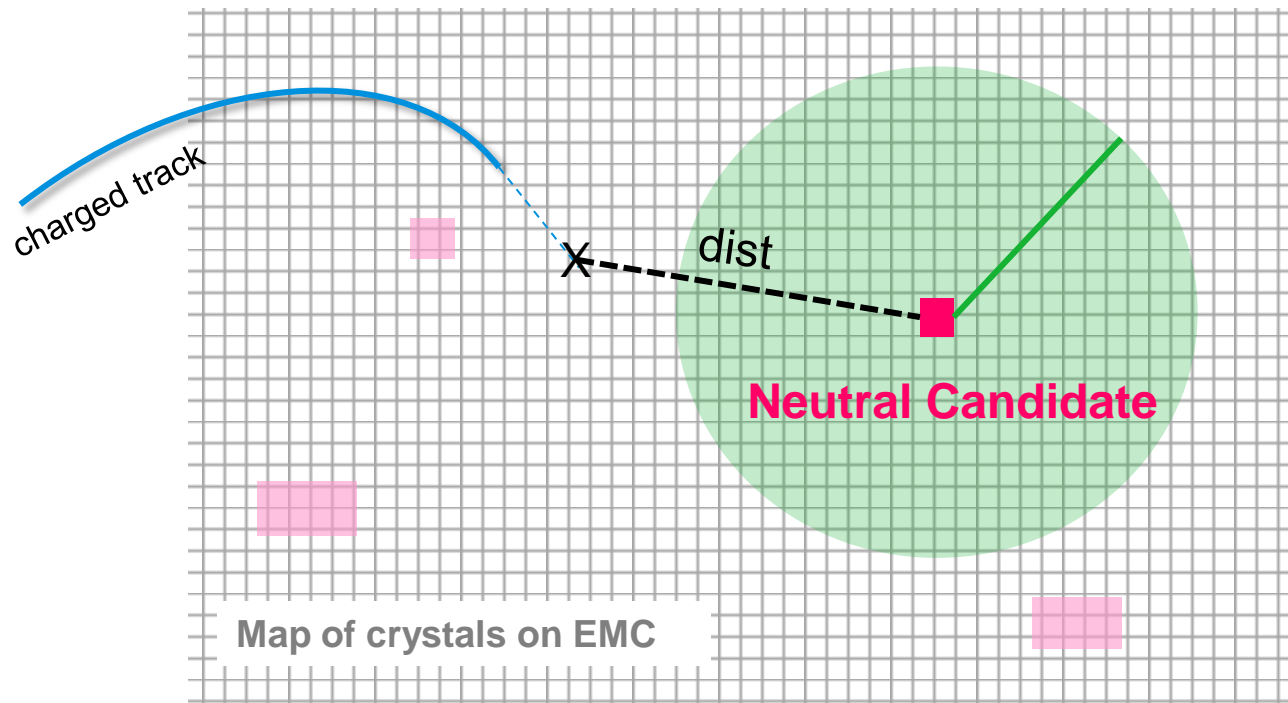
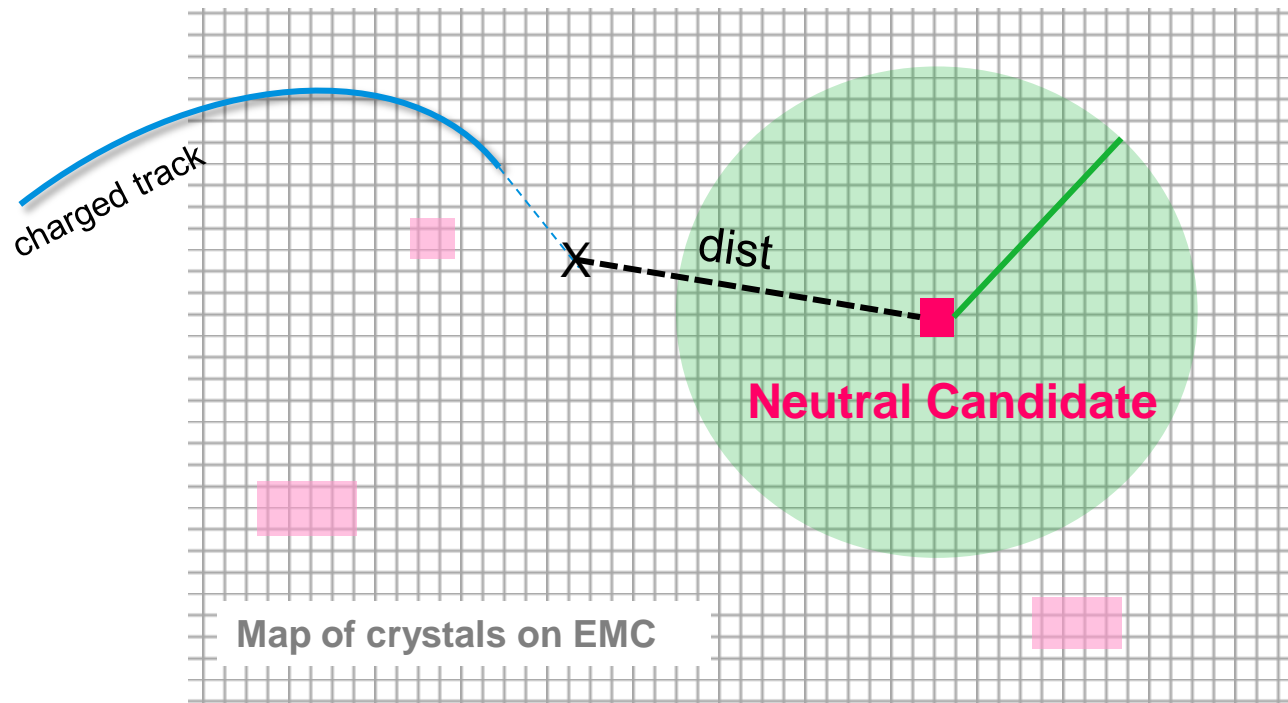Map of crystals on EMC

X   extrapolation of track

   EMC cluster

— $(EmcNeutralQCut)^{1/2}$
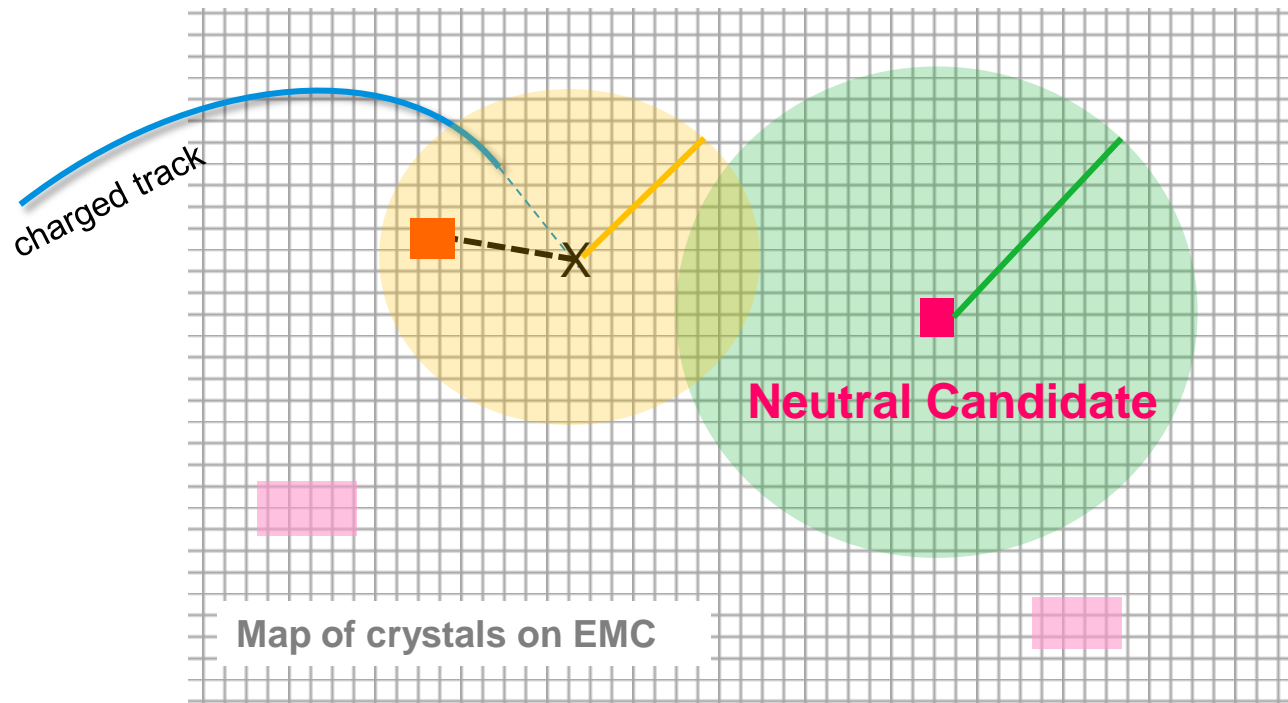
EMC Cluster Correlation

X   extrapolation of track

■   EMC cluster

—   (EmcNeutralQCut)$^{1/2}$

charged track

dist

Neutral Candidate

Map of crystals on EMC

cut = ?

EMC Cluster Correlation

charged track

Neutral Candidate

Map of crystals on EMC

X   extrapolation of track

EMC cluster

— (EmcNeutralQCut)$^{1/2}$
— (Emc12Cut)$^{1/2}$

EMC Cluster Correlation

- Efficiency Checking

10k evt single pi- with BoxGen

p = 0.5 GeV/c
θ = 30°
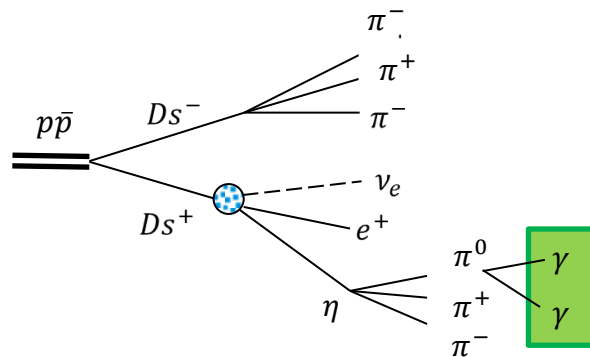φ = 0°~360°
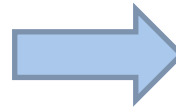
8771 trks could find cluster

23102 clusters found on EMC

~14000 neutral cand.
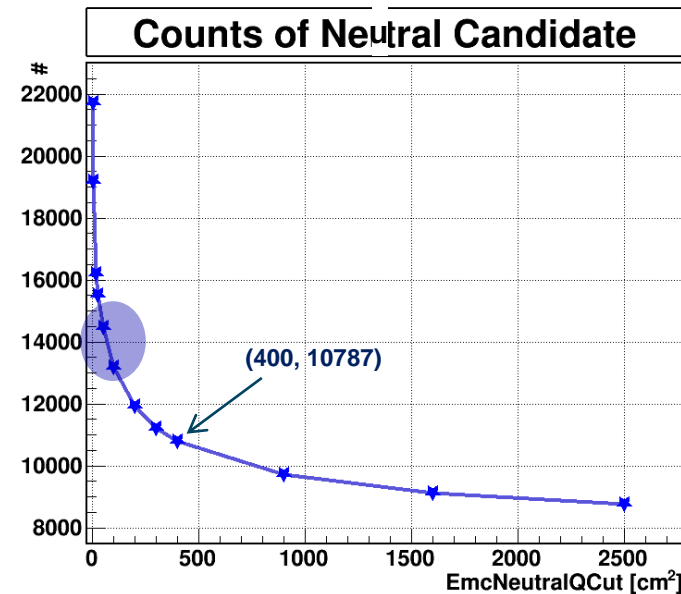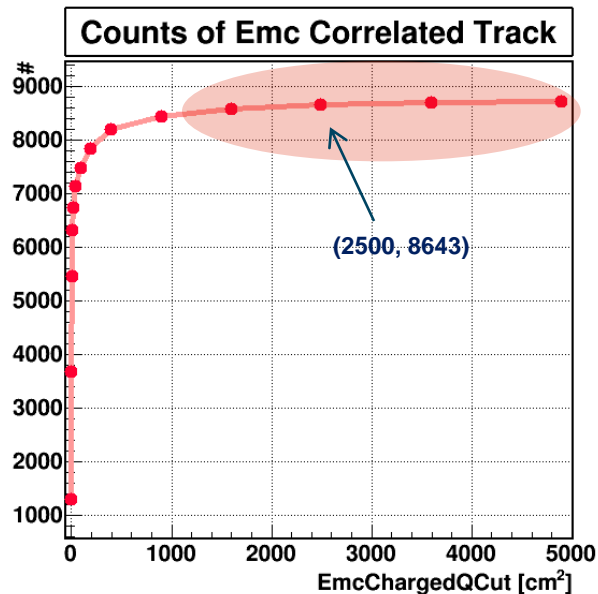
EMC Cluster Correlation

- Purity Checking

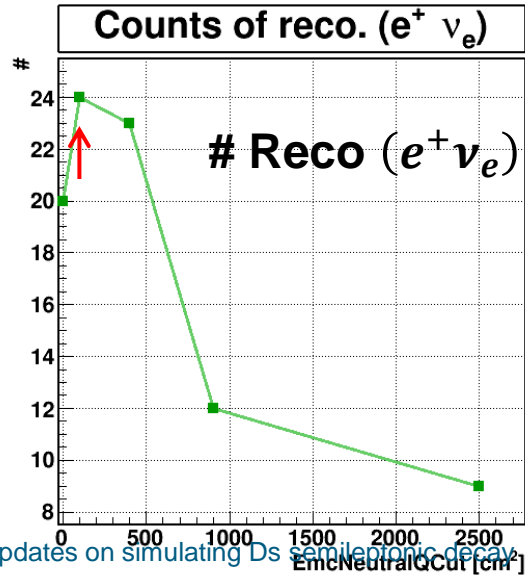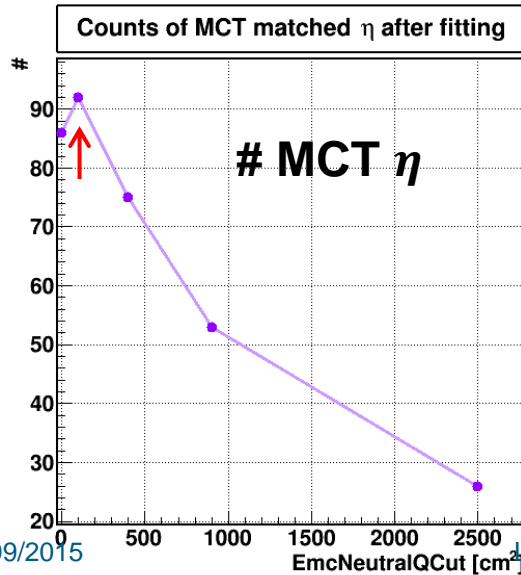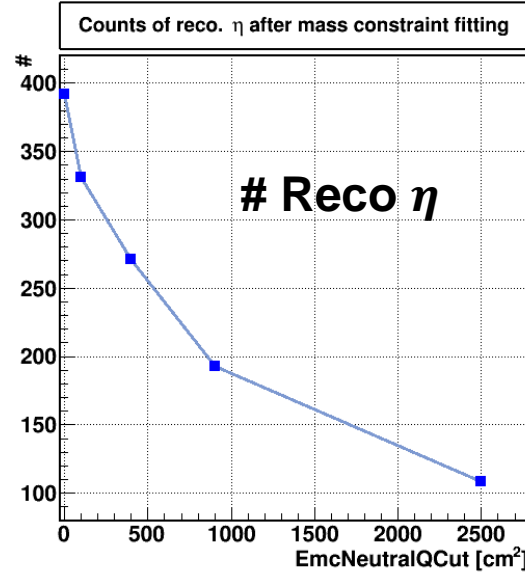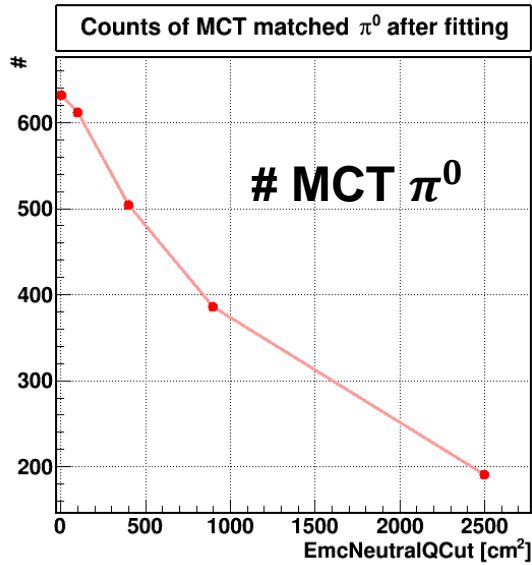2k evt   @$\sqrt{s} = 4.107$ GeV

#27806; Geant 3; GenFit 2

Photon E_thre = 20 MeV

When **EmcNeutralQCut** = **1**, **100**, **400**, **900**, **2500**,

check the reconstruction purity (**MC truth matched**) of π^0, η and efficiency of $(e^+\nu_e)$ with exactly same event data base (same output of sim, digi, reco.)

- Purity Checking

2k evt

MCT π^0

Reco η

MCT η

Reco $(e^+ \nu_e)$

Best:
EmcNeuQCut = 100

L.Cao: Updates on simulating Ds semileptonic decay

Photon Preselection

- Significance Checking

- High combinatory bkg of pi0 due to high multiplicity of photons
- Proper threshold on photon energy is requested

- **Test on 2k evt (trk27806)**

- **PidCorrelator: EmcNeutralQCut = 100,400 [cm^2]**

- **Photon energy threshold = 0~80 [MeV]**

- **Sig =** $\dfrac{N\_MCT}{\sqrt{N\_all}}$ -- counts of MC truth matched cand. after all fitting
                               -- counts of all cand.
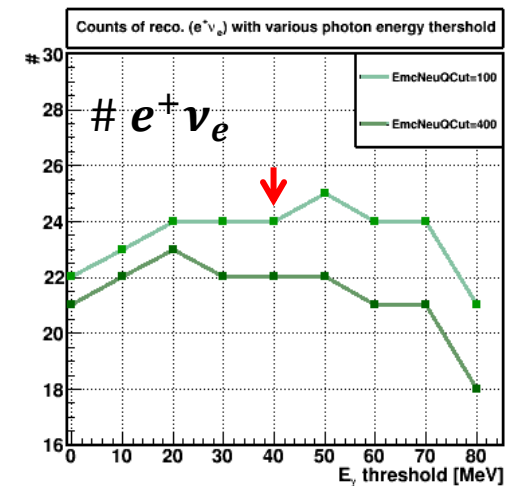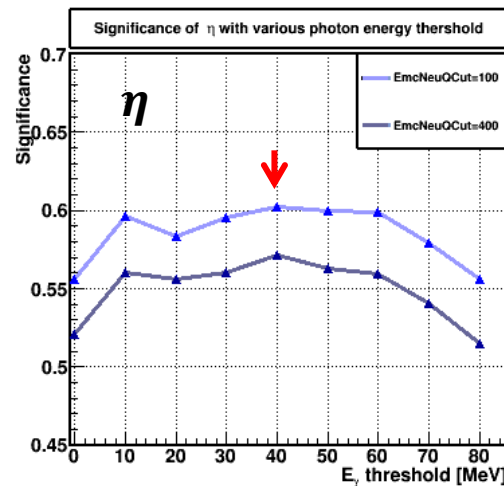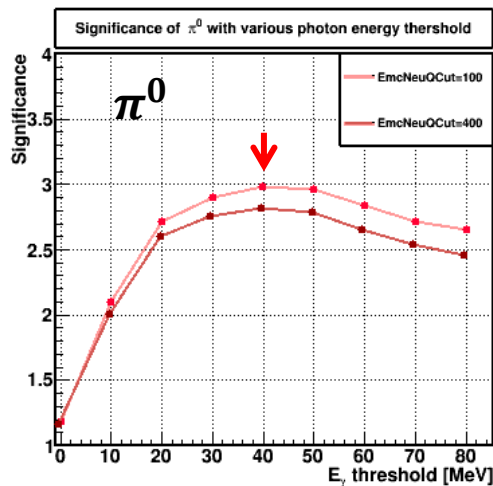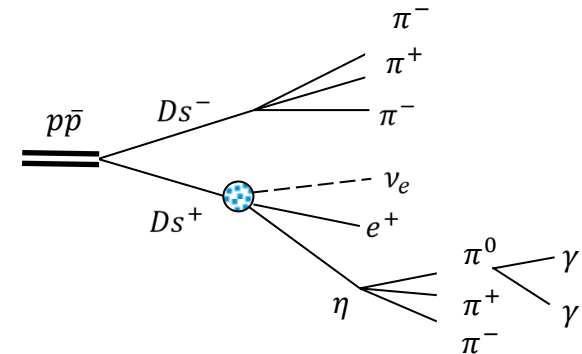
😊 **To use:**
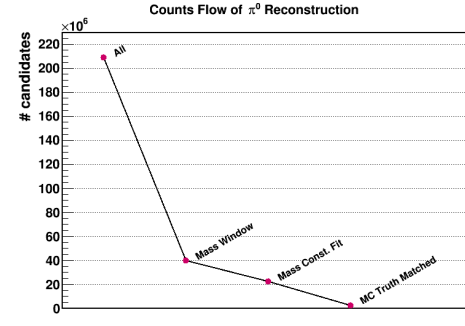- **EMC corr. dist = 10 cm (EmcNeutralQCut = 100 cm^2)**
- **E threshold = 40 MeV**

Reconstruction result of pi0

- EMC corr. dist = 10 cm
- E_gamma threshold = 40 MeV
- No cut on opening angle
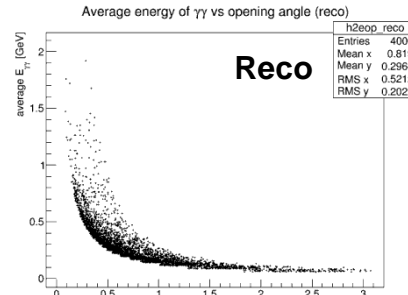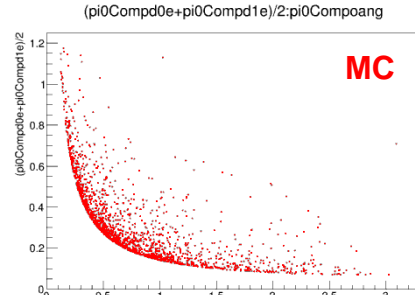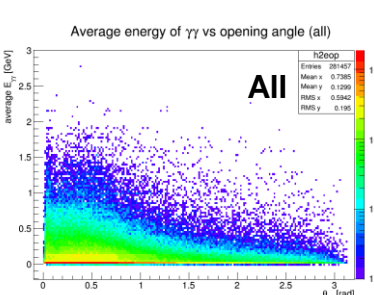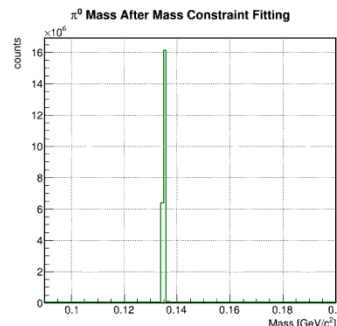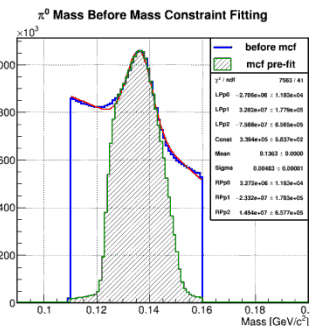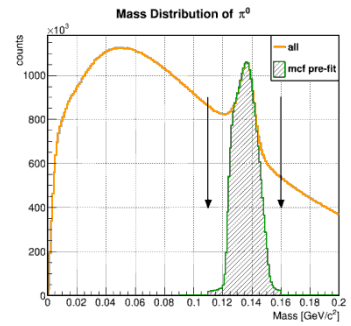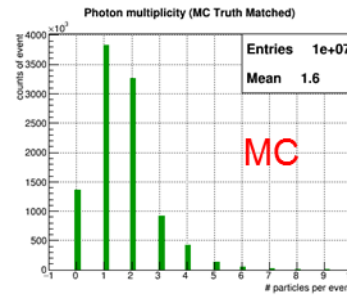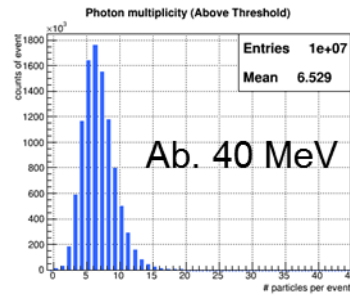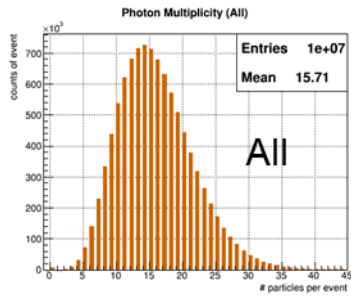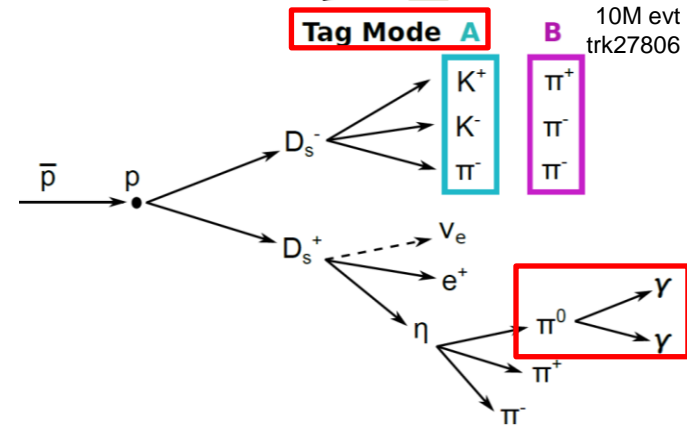
MCT eff. = 27.2%
Mass resolution = 4.9 MeV/c²

Reconstruction result of η

- **Get vtx fitted π^+, π^-**
- **Combine (π^+, π^-, π^0) $\rightarrow \eta$ mass**
- **Select "best fitted cand." in each event**

10M evt
trk27806

Tag Mode A   B
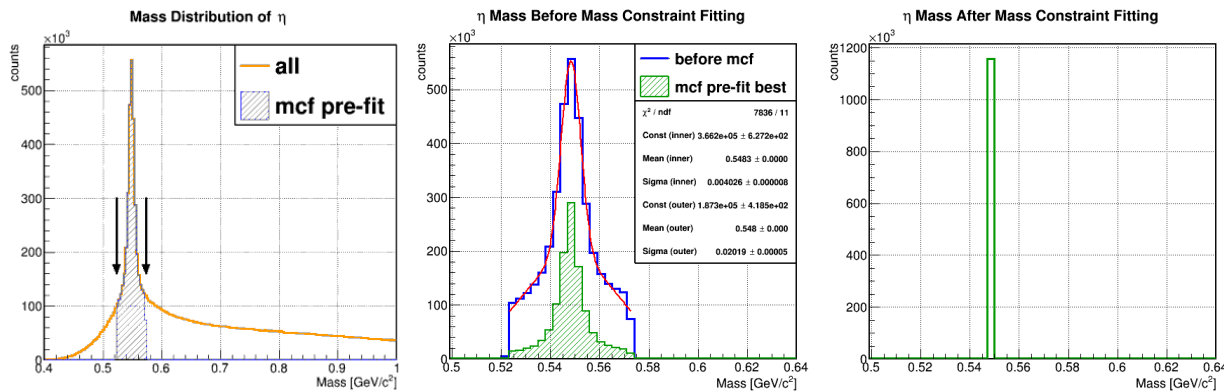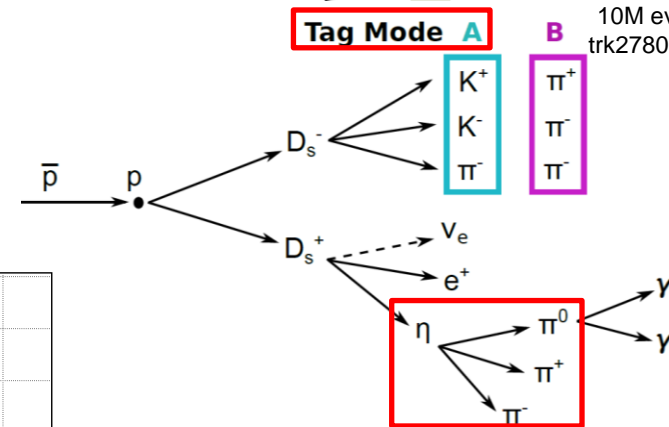
- **Different distributions of prob in mass constraint fitting between oct14 and mar15** post on forum

oct14

mar15

Counts Flow of η Reconstruction (Zoom in)
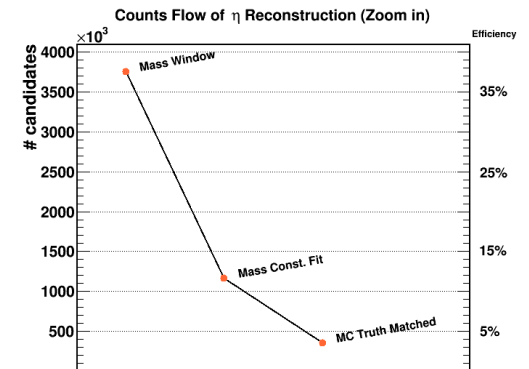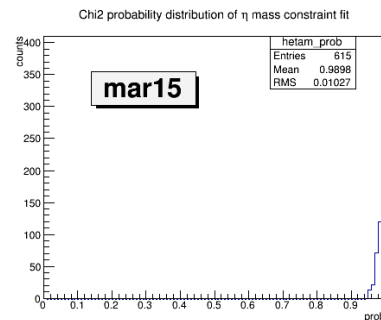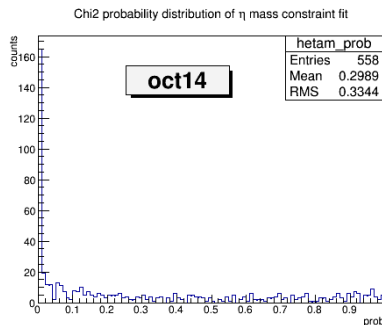
Reco Eff.	MCT Eff.	σ_{mass} [MeV/c^2]	σ_{vtx} [μm]			σ_{mom}	
			X	Y	Z	P_t	P_z
11.6%	3.6%	4.0	90	87	169	1.4%	1.1%

Reconstruction result of D_s^- (mode A)

- Vtx fit and mass constraint fit for (K^+, K^-, π^-): cut off prob < 0.01
- Select "best fitted cand." in each event

10M evt
trk27806

Mass Distribution of Ds⁻

Ds⁻ Mass Before Mass Constraint Fitting

Ds⁻ Mass After Mass Constraint Fitting

Counts Flow of D⁻s Reconstruction
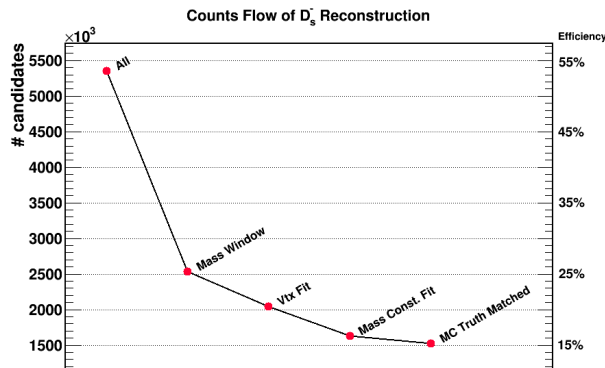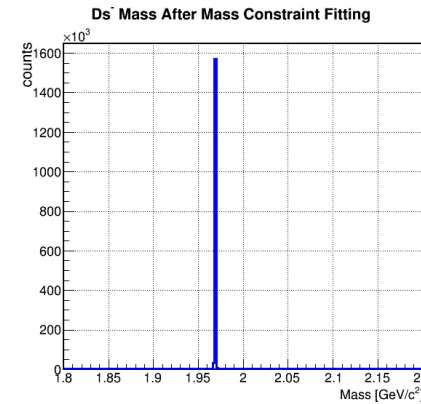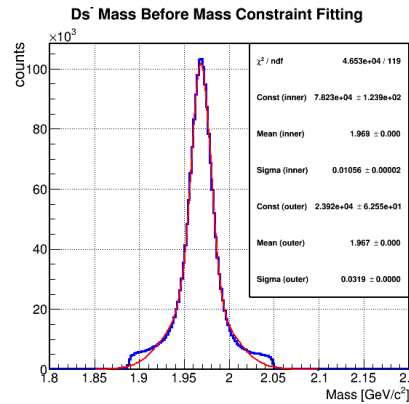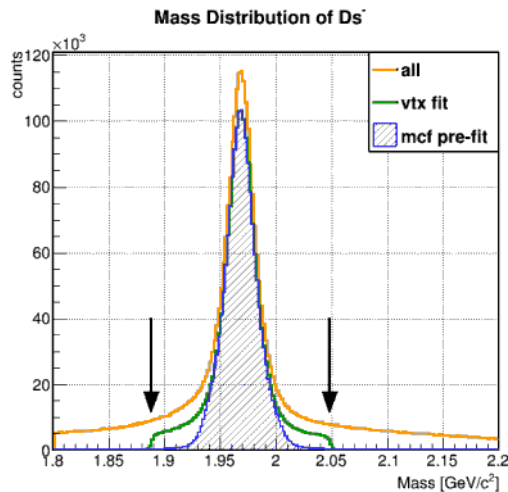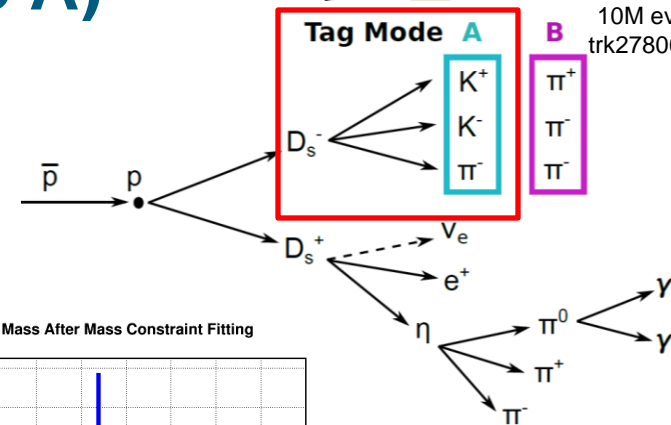
Reco Eff.	MCT Eff.	σ_{mass} [MeV/c^2]	σ_{vtx} [μm]			σ_{mom}	
			X	Y	Z	P_t	P_z
16.4%	15.3%	10.6	57	56	121	2.0%	0.7%

Reconstruction result of D_s^- (mode B)

- Higher combinatory bkg than mode A
- Vtx fit and mass constraint fit for (π^+, π^-, π^-): cut off prob < 0.01
- Select "best fitted cand." in each event

Mass Distribution of Ds-

Ds- Mass Before Mass Constraint Fitting

χ^2 / ndf	1.926e+05 / 144
Const (inner)	1.272e+05 ± 2.102e+02
Mean (inner)	1.969 ± 0.000
Sigma (inner)	0.0125 ± 0.0000
Const (outer)	1.126e+05 ± 1.517e+02
Mean (outer)	1.965 ± 0.000
Sigma (outer)	0.03209 ± 0.00001

Ds- Mass After Mass Constraint Fitting

Counts Flow of D_s^- Reconstruction (Zoom in)
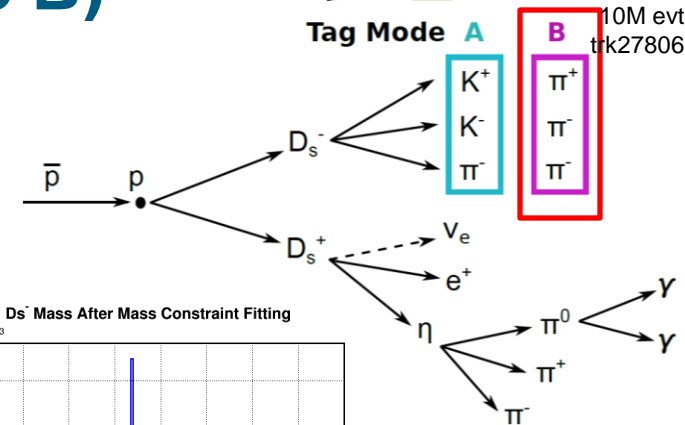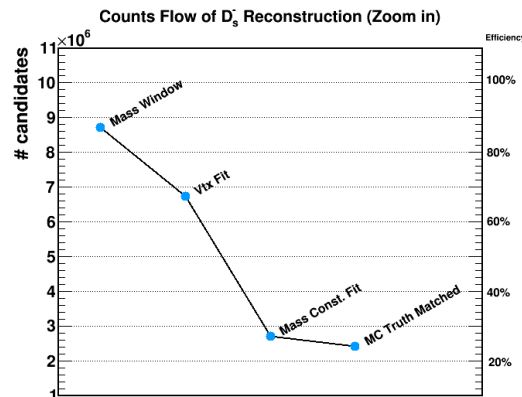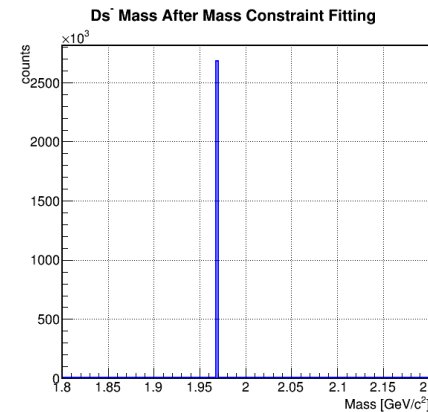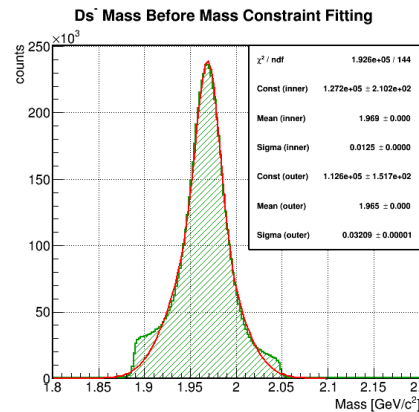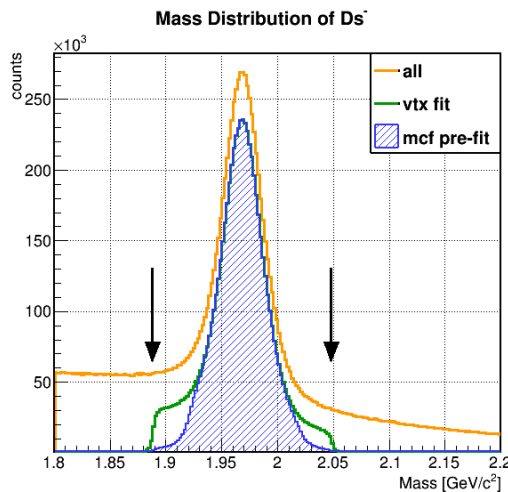
Reco Eff.	MCT Eff.	σ_{mass}	σ_{vtx} [μm]			σ_{mom}	
		[MeV/c^2]	X	Y	Z	P_t	P_z
27.1%	24.1%	12.5	47	46	81	2.0%	0.6%

Reconstruction results

- 10 million evt for each tag mode
- Beam mom = 8 GeV/c
- trk27806
- EmcNeutraQCut = 100
- Photon E threshold = 40 MeV
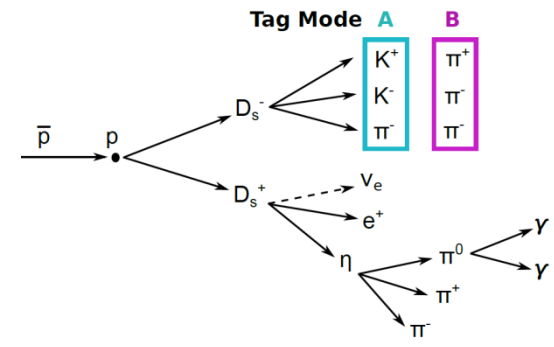
Mode	Particle	Reco Eff.	MCT Eff.	σ_{mass} [MeV/c^2]	σ_{vtx} [μm] x	y	z	σ_{mom} p_t	p_z
A	D_s^-	16.4%	15.3%	10.6	57	56	121	2.0%	0.7%
	π^0	-	27.7%	4.8				1.9%	1.8%
	η	11.6%	3.6%	4.0	90	87	169	1.4%	1.1%
B	D_s^-	27.1%	24.1%	12.5	47	46	81	2.0%	0.6%
	π^0	-	27.2%	4.9				1.9%	1.8%
	η	11.6%	3.5%	4.1	78	75	152	1.4%	1.1%

Reconstructed Lepton-neutrino System

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

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

physical range: $\quad 0 \leq \boldsymbol{q^2} \leq \left(M_{Ds} - M_\eta\right)^2 \approx 2.02 \ \text{GeV}^2/c^4$

Mass Squared of ν_e Candidates

— all candidates

ν_e mass window

$$M^2(\nu_e)$$

$M^2_{\nu_e}$ [GeV^2/c^4]
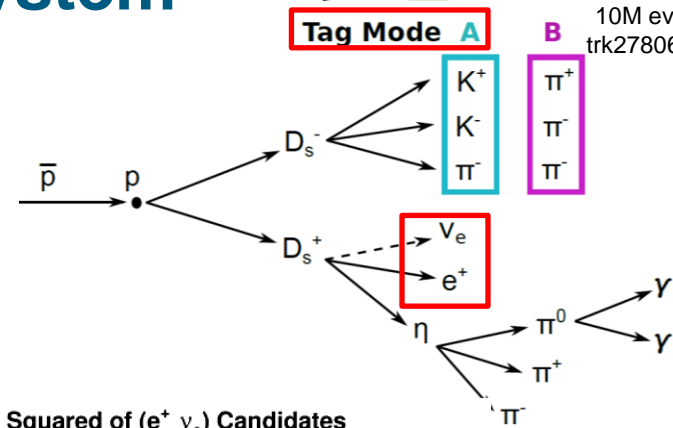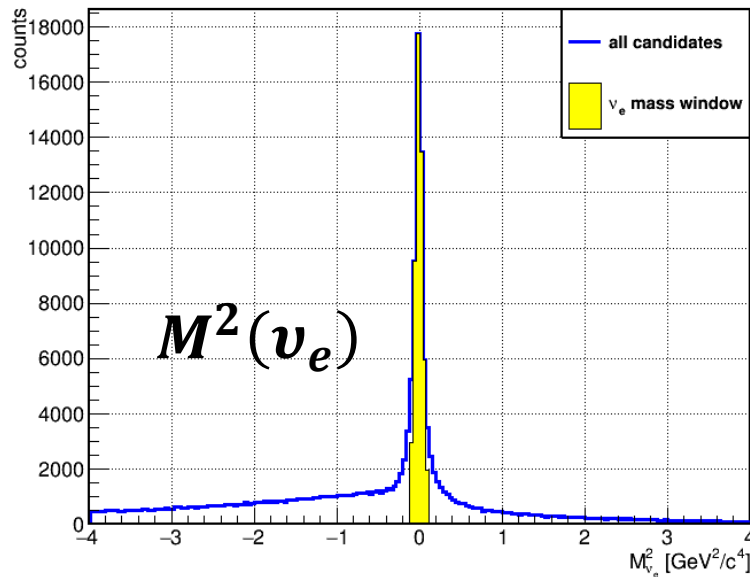
Invariant Mass Squared of (e^+ ν_e) Candidates
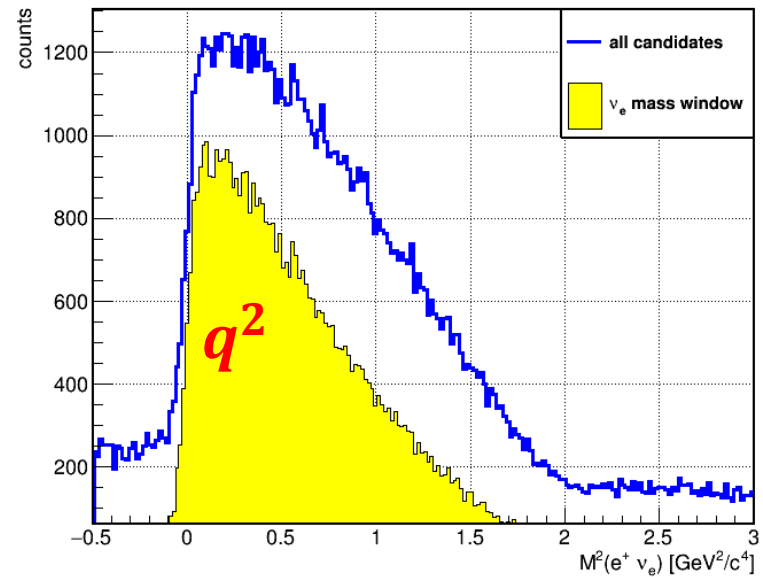
— all candidates

ν_e mass window

$$q^2$$

$M^2(e^+ \nu_e)$ [GeV^2/c^4]

$M^2(\nu_e) \ window = \pm \ 0.1 \ \text{GeV}/c^2$

Reconstructed Lepton-neutrino System

Reconstructed Lepton-neutrino System

10M evt
trk27806
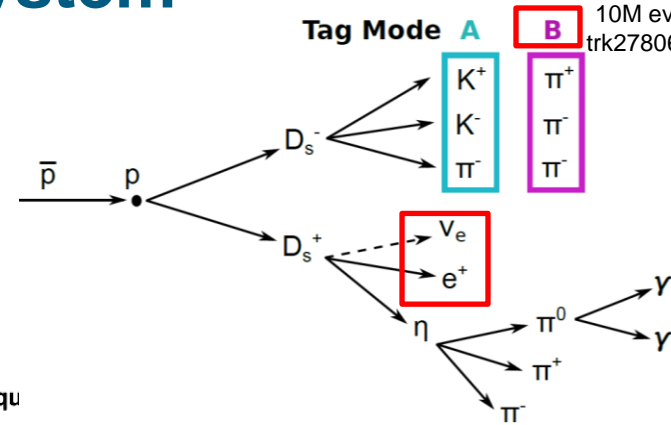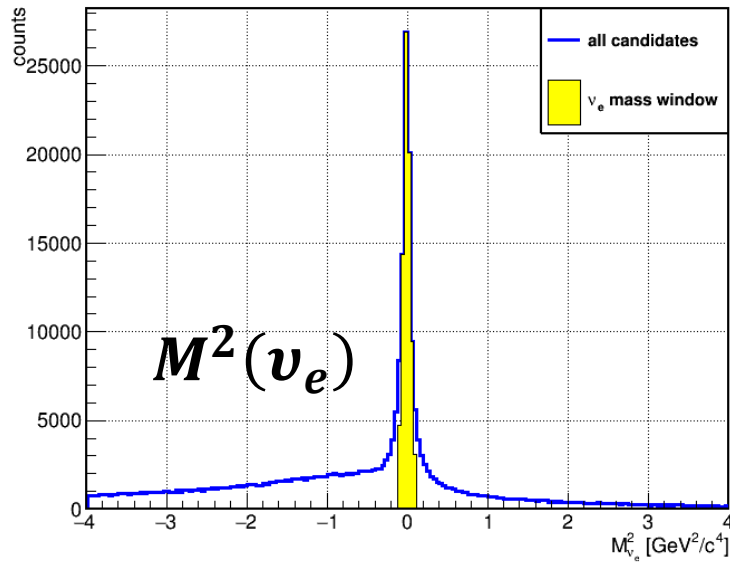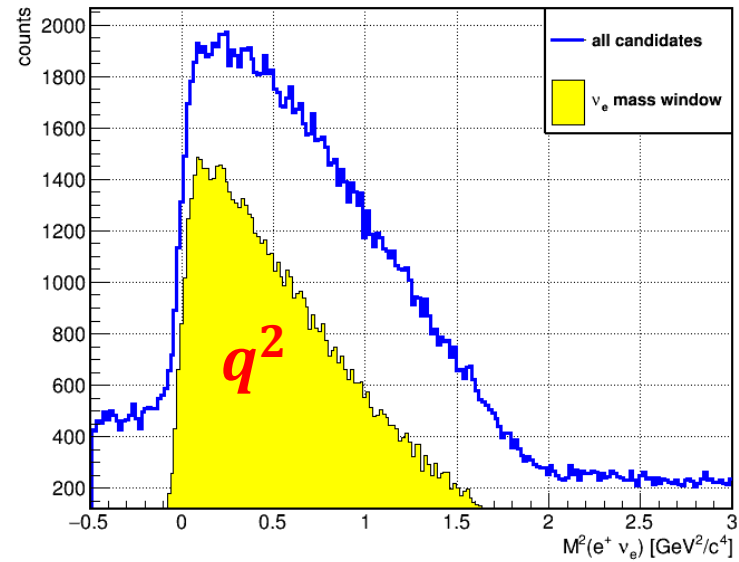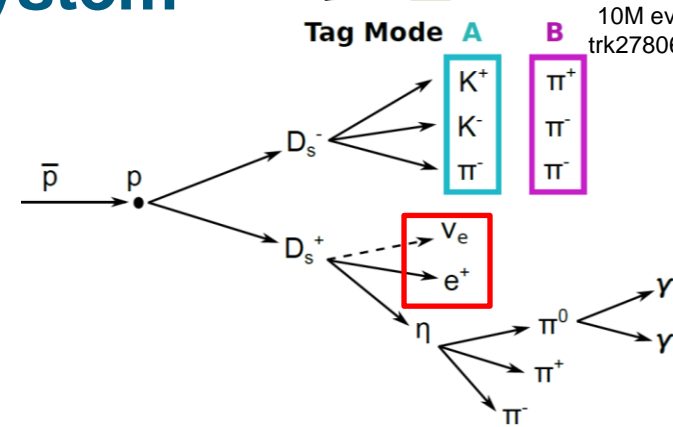
Tag Mode	# $(e^+ \nu_e)$	Efficiency
A	48798	0.49%
B	73921	0.74%

Mode A

Mode B
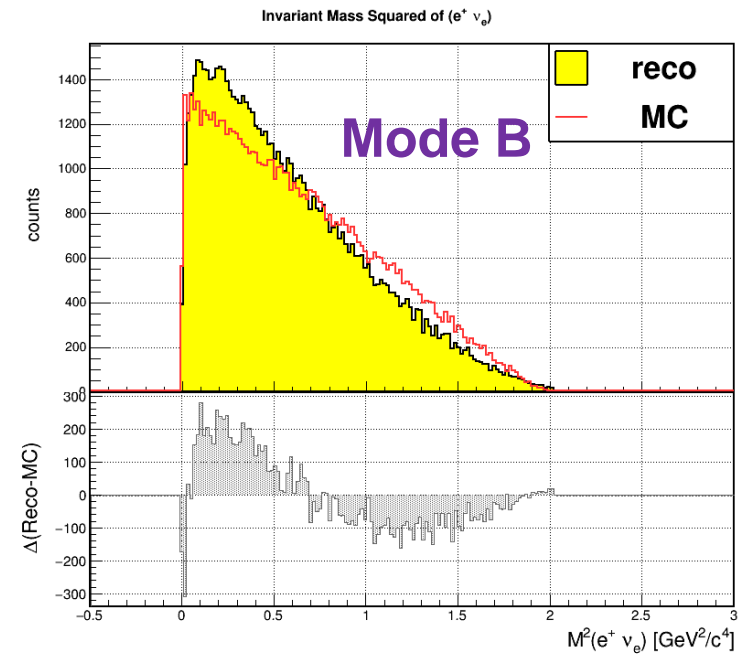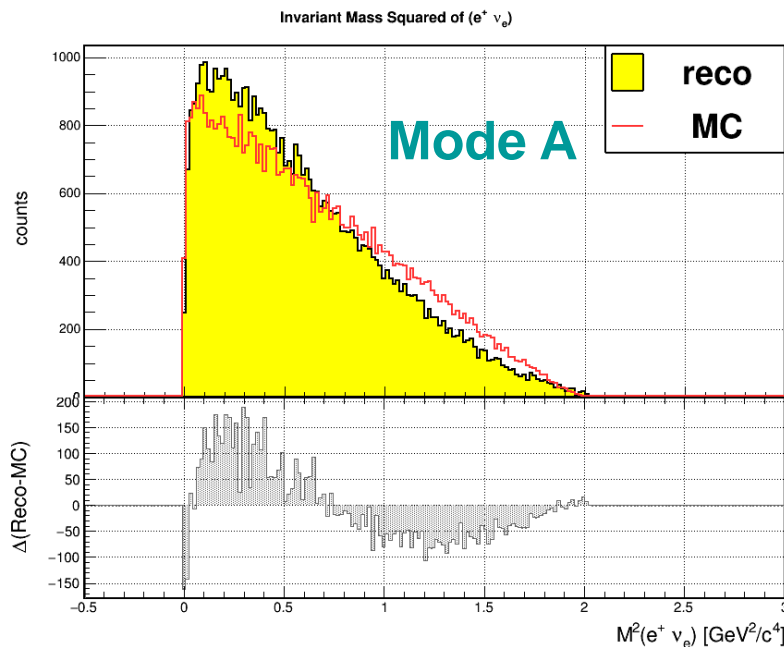
Estimate on Event Rate

pbarpSystem	
→ Ds- Ds+	$BR_{PDG2014}$
| |→ eta e+ nu_e	**2.67 %**
| |→pi+ pi- pi0	**22.92 %**
| |-> 2 gamma	**98.8 %**
|→ K- K+ pi-	**5.39 %**
(→ pi- pi+ pi-)	**1.09 %**
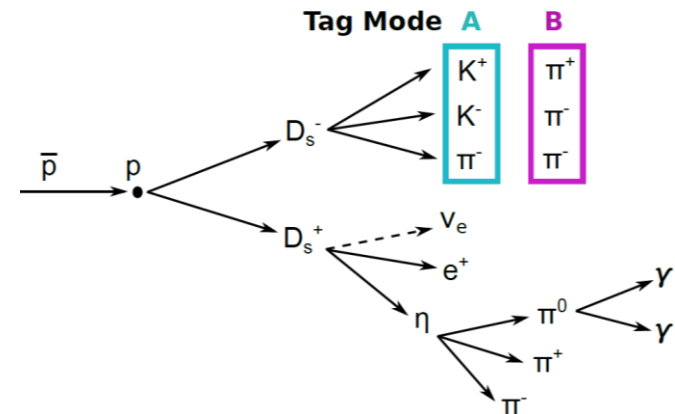
$$R(e^+\nu_e) = \mathcal{L} \cdot \sigma \cdot \varepsilon \cdot t \cdot \mathcal{BR}$$

$$= 2 \times 10^{32}(cm^{-2}s^{-1}) \cdot \mathbf{20}(nb) \times 10^{-24}(cm^2/b) \cdot 3 \times 10^6(s) \cdot 2.67\% \times 22.92\% \times 98.8\%$$
$$\times (\mathbf{0.49\%} \times \mathbf{5.39\%} + \mathbf{0.74\%} \times \mathbf{1.09\%}) + \text{c.c.}$$

$\sim$ **60** useful events

with high luminosity mode in 35 days

Summary & Outlook

- ✓ Decay chain reconstructed and resolution improved

- ✓ Two singly tagging modes considered

- ✓ Efficiency and production rate obtained

- ➤ Improve efficiency if possible

- ➤ Study background events (ongoing)

- ➤ Simulate with variant beam momenta (e.g. 7.3 Gev/c, 9 GeV/c)

Picture cited from internet
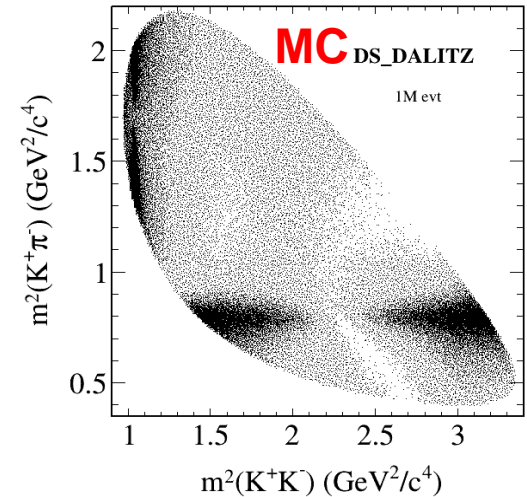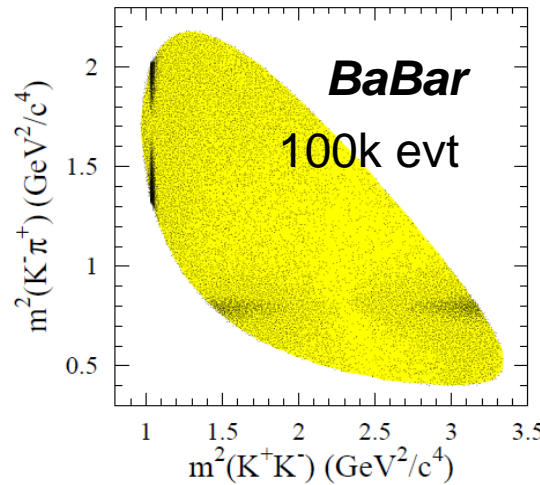
Thank you !

l.cao@fz-juelich.de

Decay Models for D_s^-

A: $D_s^- \rightarrow K^- K^+ \pi^-$

DS_DALITZ
/ D_DALITZ

B: $D_s^- \rightarrow \pi^- \pi^+ \pi^-$

D_DALITZ

PRD 83:052001 (2011)

PRD79:032003 (2009)
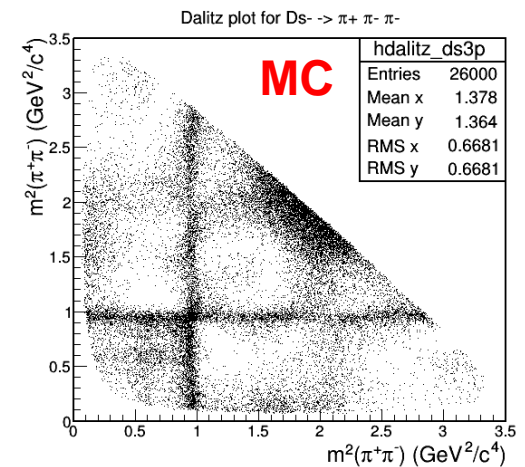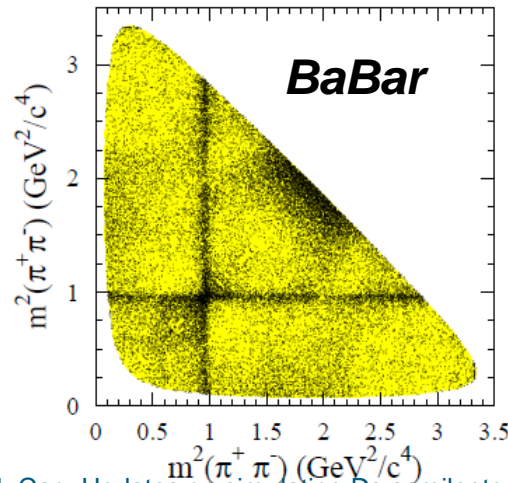
backup slides

- **Lattice QCD**: I. Kanamori, arXiv:1302.6087[hep-lat] *etc.*

- **Light-Cone Sum Rules**: N. Offen *et al.*, Phys. Rev. D88,034023 (2013) *etc.*

$$\langle \eta^{(')}(k)|V^{\mu}(q^2)|D_s(p)\rangle = f_+(q^2)\left[(p+k)^{\mu} - \frac{M_{D_s}^2 - M_{\eta^{(')}}^2}{q^2}q^{\mu}\right] + f_0(q^2)\frac{M_{D_s}^2 - M_{\eta^{(')}}^2}{q^2}q^{\mu},$$

$$\eta_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s}), \qquad \eta_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s}). \qquad (2.1)$$

The physical η and η' should be a mixing of the above octet state (η_8) and the singlet state (η_1):

$$\eta = \cos\theta\,\eta_8 - \sin\theta\,\eta_1, \qquad \eta' = \sin\theta\,\eta_8 + \cos\theta\,\eta_1. \qquad (2.2)$$

$$\langle P(p)|\bar{q}\gamma_{\mu}c|D_{(s)}(p+q)\rangle = 2f_{D_{(s)}P}^{+}(q^2)p_{\mu}$$
$$+ \left(f_{D_{(s)}P}^{+}(q^2) + f_{D_{(s)}P}^{-}(q^2)\right)q_{\mu}$$

$$f_{D_{(s)}P}^{0}(q^2) = f_{D_{(s)}P}^{+}(q^2) + \frac{q^2}{m_{D_{(s)}}^2 - m_{\eta^{(')}}^2}f_{D_{(s)}P}^{-}(q^2)$$

Parameters in Form Factor

$$\frac{dN}{dq^2} = \frac{1}{const} \times \frac{G_F^2 \left|V_{cs}\right|^2}{192\pi^3 m_{D_s}^3} \left[\left(m_{D_s}^2 + m_\eta^2 - q^2\right)^2 - 4m_{D_s}^2 m_\eta^2\right]^{3/2} \left|f_+^{D_s \to \eta}(q^2)\right|^2$$

form factor

Normalization:

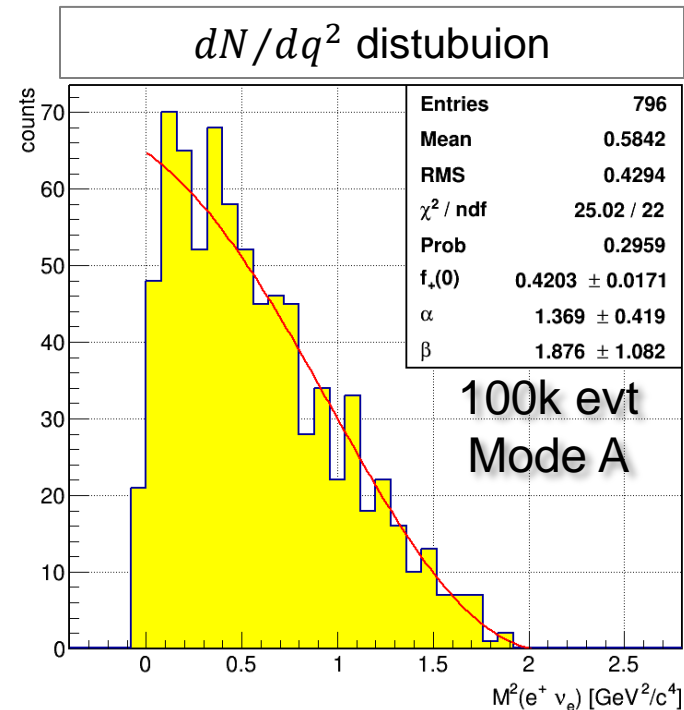$$const = \frac{\Gamma_{D_s^+ \to \eta e^+ \nu_e}}{N_{D_s^+ \to \eta e^+ \nu_e}}$$

Modified pole parameterization:

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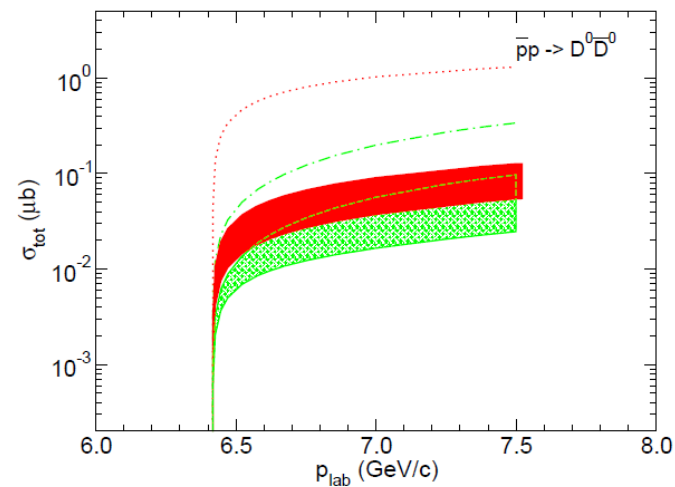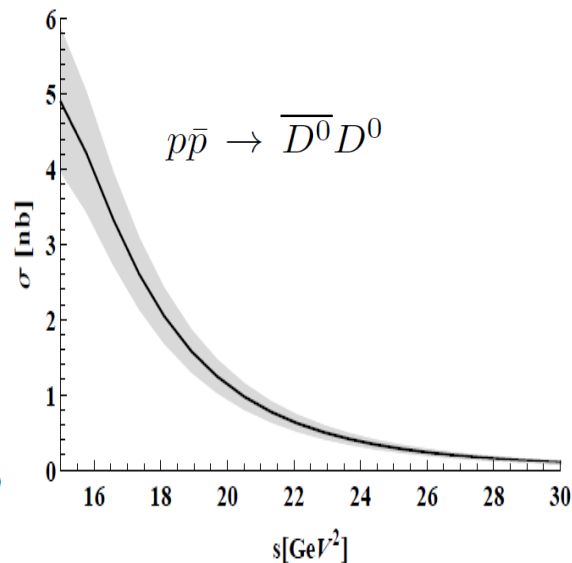
$$\hat{q} = q^2/m_{D_s}^2$$

Theoretical calculation from J.Phys.G 38 (2011) 095001]

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

dN/dq^2 distubuion

Entries	796
Mean	0.5842
RMS	0.4294
χ^2 / ndf	25.02 / 22
Prob	0.2959
$f_+(0)$	0.4203 ± 0.0171
α	1.369 ± 0.419
β	1.876 ± 1.082

100k evt
Mode A

100k evt
#26514

Charm Production Cross Section in $\overline{p}p$
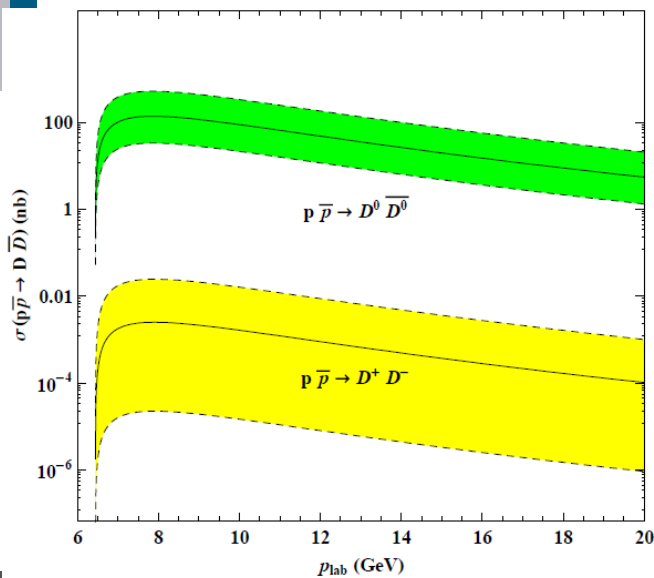
EPJA 48, 31(2012), arXiv:1111.3798v2
- quark-gluon string (QGS) model
- uncertainties introduced by the strong couplings obtained from LCSR

JPCS 503, 012012(2014), arXiv:1311.1607
- double handbag approach
- in accordance with NPB 316, 373(1989) using a quark-diquark model

PRD 89, 114003(2014), arXiv:1404.4174
- hadronic interaction model
- baryon exchange (shaded band)
- quark model (grid)
- Results obtained in Born approximation are indicated by the dotted (baryon exchange) and dash-dotted (quark model) lines