Update on Simulation of Ds Semileptonic Decay

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PANDA LII. Collaboration Meeting @Giessen
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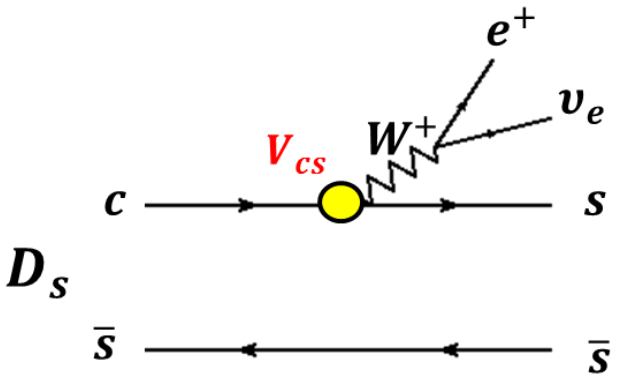
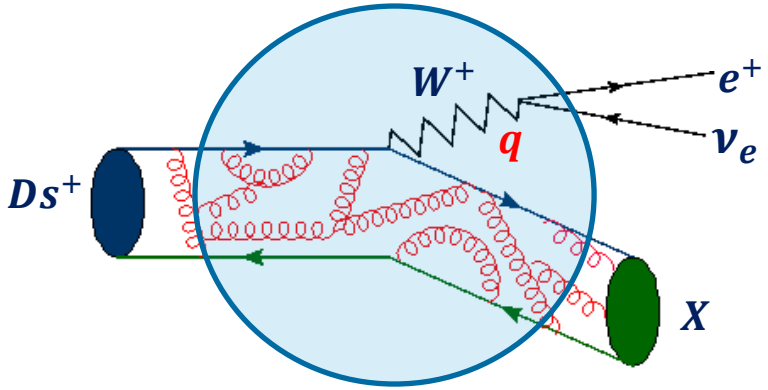
Motivation

- 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**.

Transition Form Factors: $f_+(q^2), f_0(q^2)$

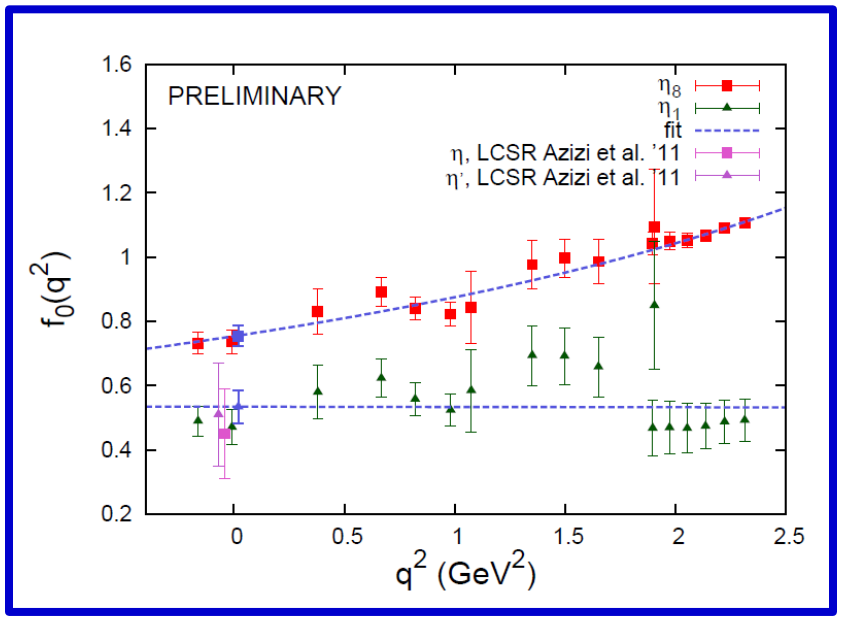


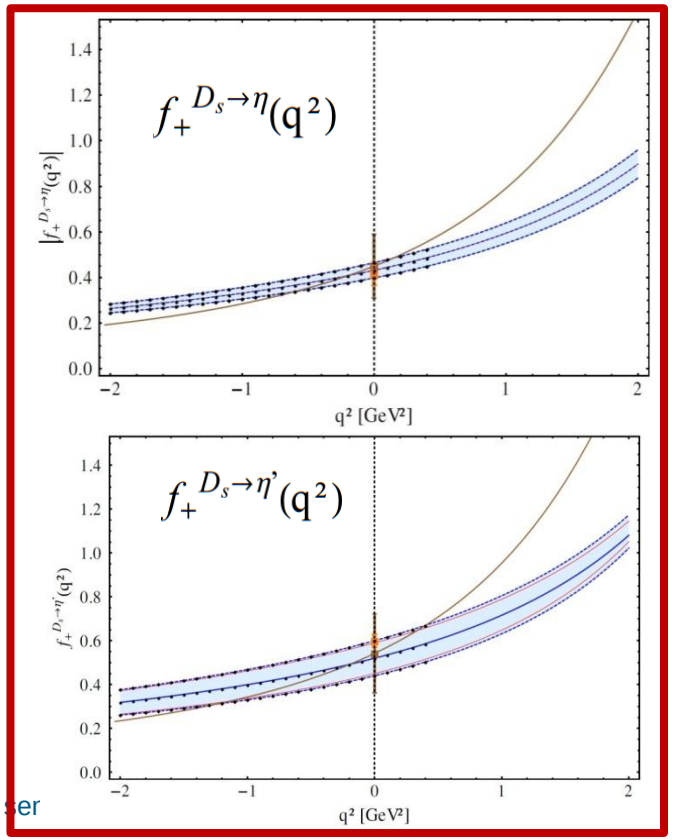
$$\frac{d\Gamma(Ds \to vlX)}{dq^2} = \frac{{G_F}^2}{24\pi^3}|V_{cx}|^2 {p_x}^3 \left|f_+(q^2)\right|^2$$

Motivation

❖ Theoretical calculations:

- **Lattice QCD**: I. Kanamori, arXiv:1302.6087[hep-lat] *etc*.
- **Light-Cone Sum Rules**: N. Offen *et al.*, PRD88 034023(2013); K. Azizi *et al.*, JPG 38 095001(2011) *etc*.
- **Effective Field Theory**: A. F. Falk *et al.*, Nucl. Phys. B343,1-13 (1990) *etc*.

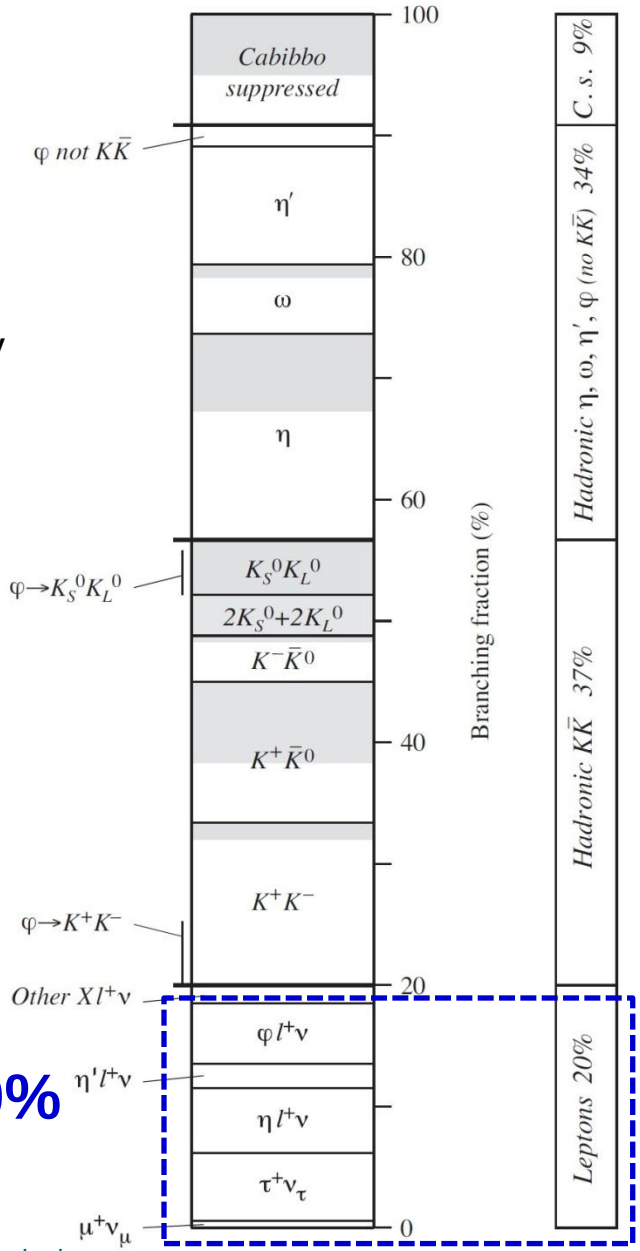




Competing measurements

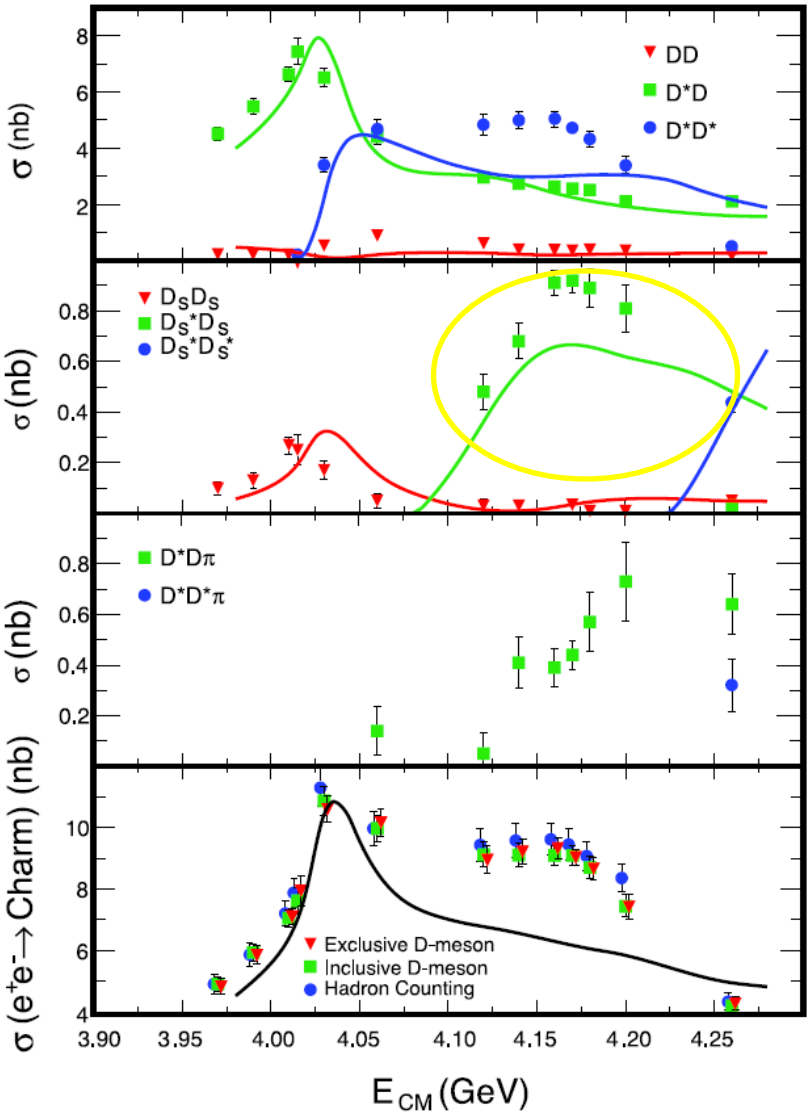
- Other experiments in this field:

- Exclusive semileptonic decays have been studied by **ARGUS**, **CLEO**, **BaBar**
- $D_s^+ \to \phi e^+ \nu_e$: **BaBar** arXiv:hep-ex/0607085
- $D_s^+ \to f_0(980) e^+ \nu_e$: **CLEO** PhysRevD.80.052009
- $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$: **BESIII** ongoing



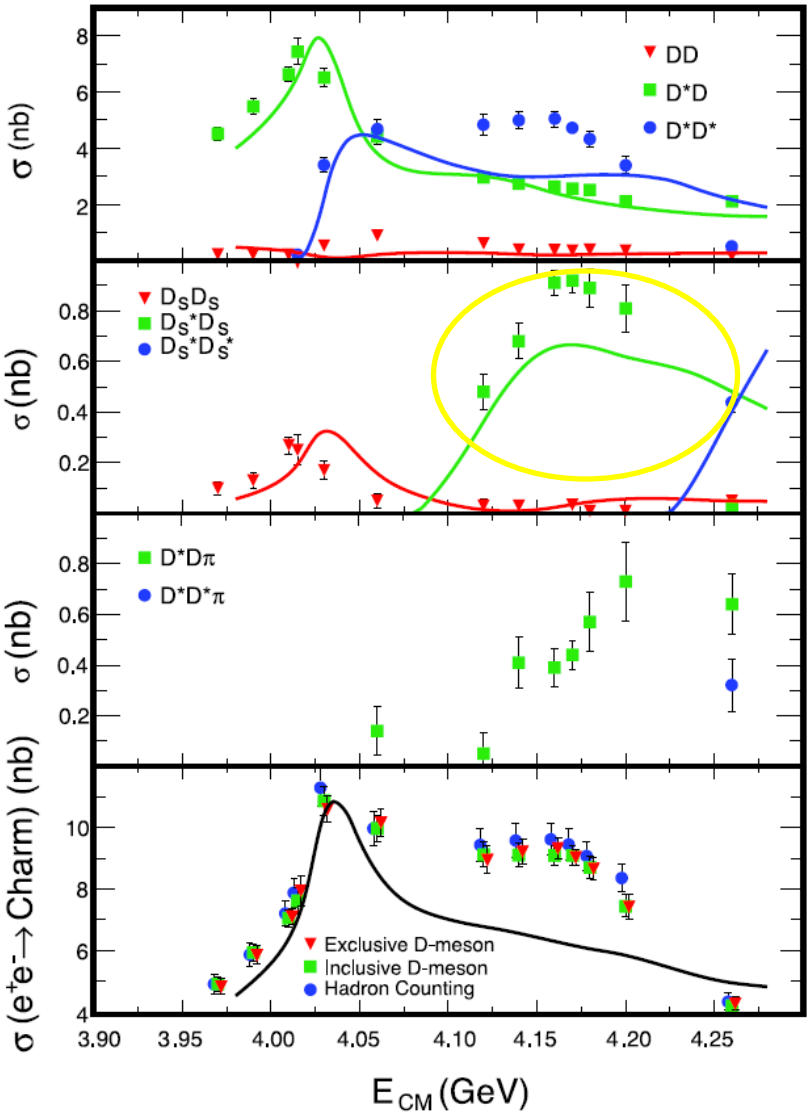
Motivation

Phys.Rev.D80:072001,2009



Motivation

Phys.Rev.D80:072001,2009

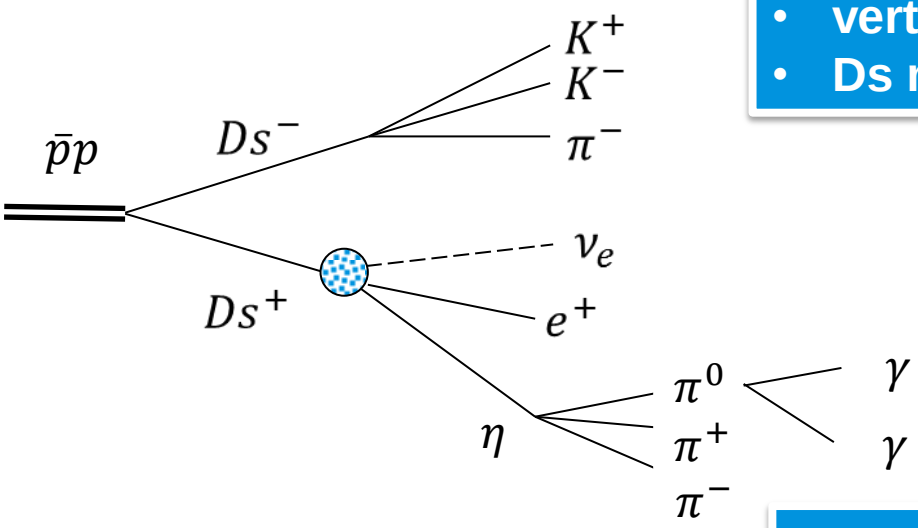


PRD 89 114003(2014)

$\sigma(\bar{p}p \rightarrow D_s^+ D_s^-) = 20$ nb

@ p_{lab} = 8.0 GeV/c

Reconstruction Strategy



- vertex fit for $(K^+K^-\pi^-)$
- Ds mass constraint fit

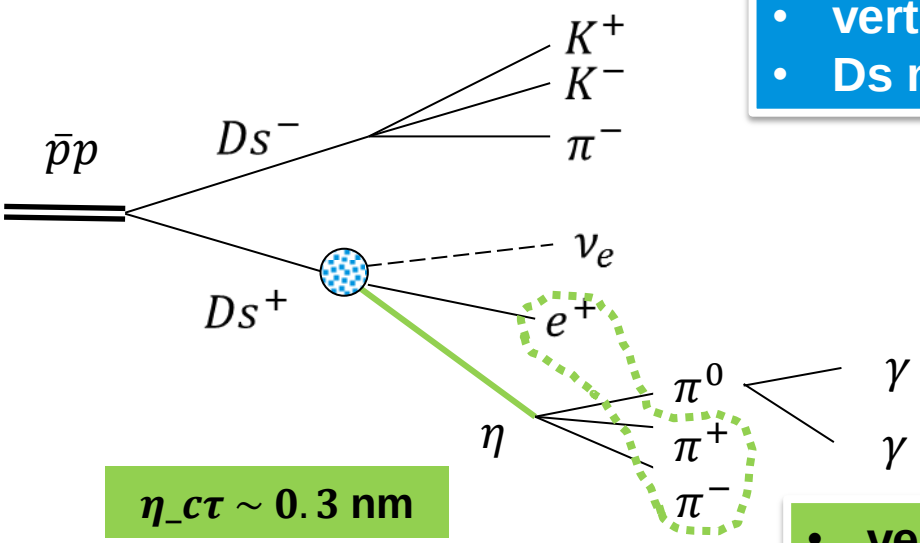
- neutral particle identification
- photon pre-selection $E_\gamma \geq 20\ MeV$
- pi0 mass constraint fit

- vertex fit for $(\pi^+\pi^-)$
- eta mass constraint fit

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

$$q^2 \equiv M^2(\upsilon_e e^+)$$

Reconstruction Strategy



- vertex fit for $(K^+K^-\pi^-)$
- Ds mass constraint fit

- neutral particle identification
- photon pre-selection $E_\gamma \geq 20\ MeV$
- pi0 mass constraint fit

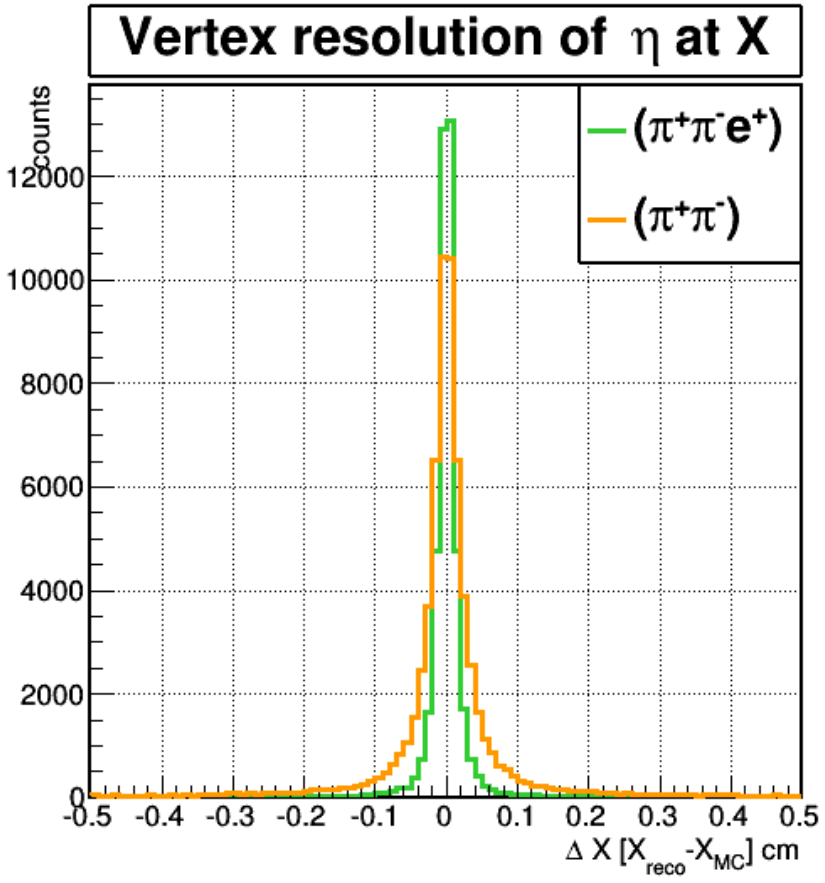
$\eta\_c\tau \sim 0.3$ nm

- vertex fit for $(\pi^+\pi^-e^+)$
- mass constraint fit for $(\pi^+\pi^-\pi^0)$

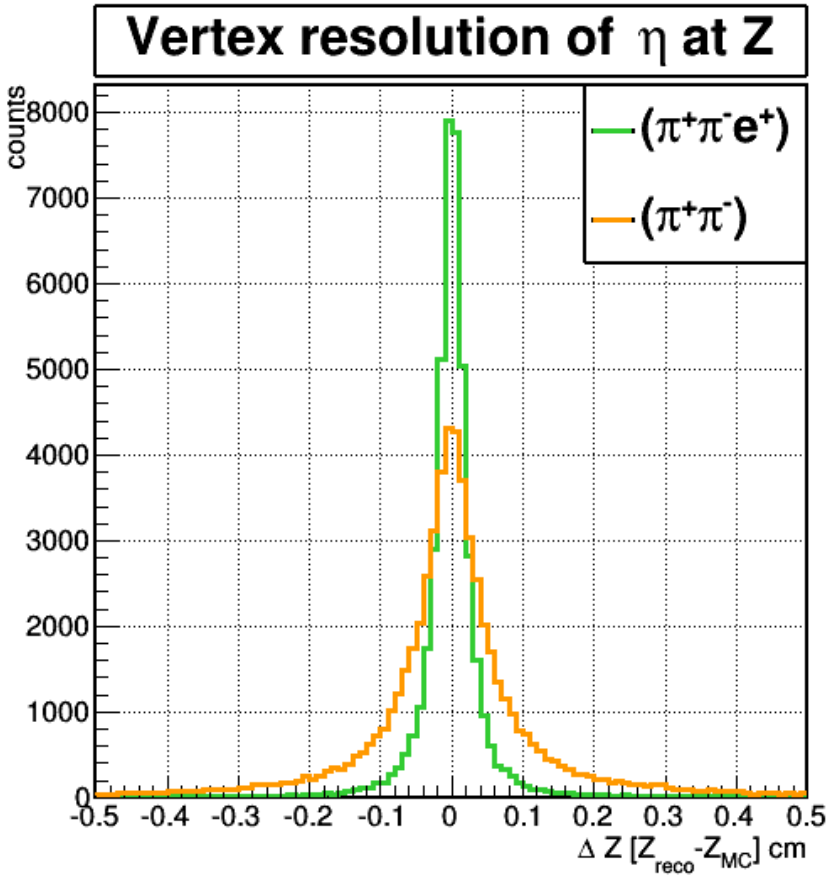
$$M^2(\upsilon_e) = \left(E_{p\bar{p}} - E_{Ds^-} - E_\eta - E_{e^+}\right)^2 - \left|\vec{P}_{p\bar{p}} - \vec{P}_{Ds^-} - \vec{P}_\eta - \vec{P}_{e^+}\right|^2$$

$$q^2 \equiv M^2(\upsilon_e e^+)$$

Vertex Resolution of η

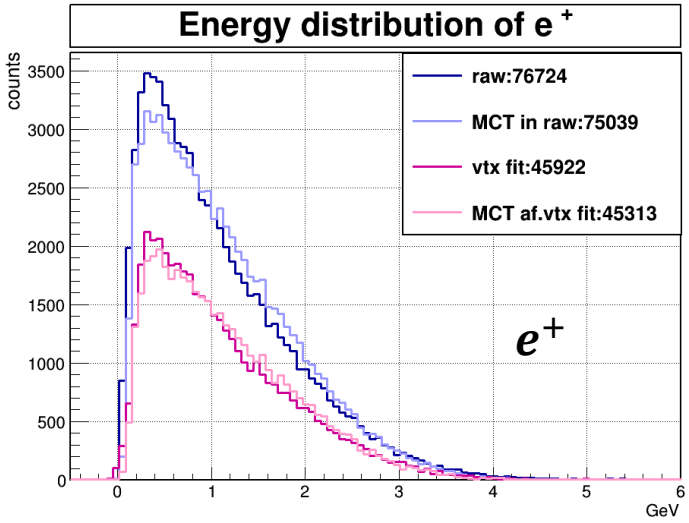


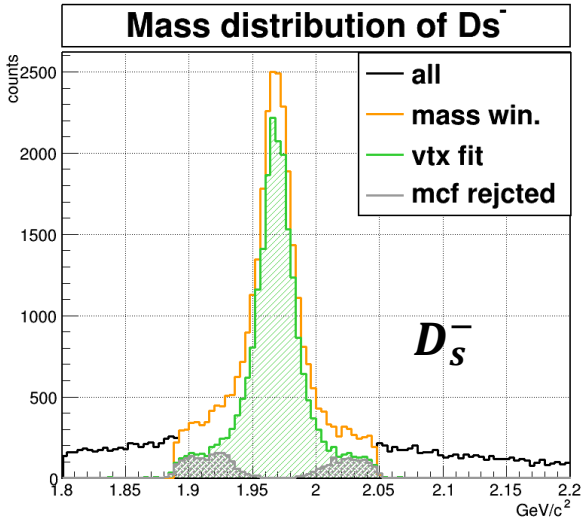
ΔX **RMS= 0.039**
RMS= 0.089

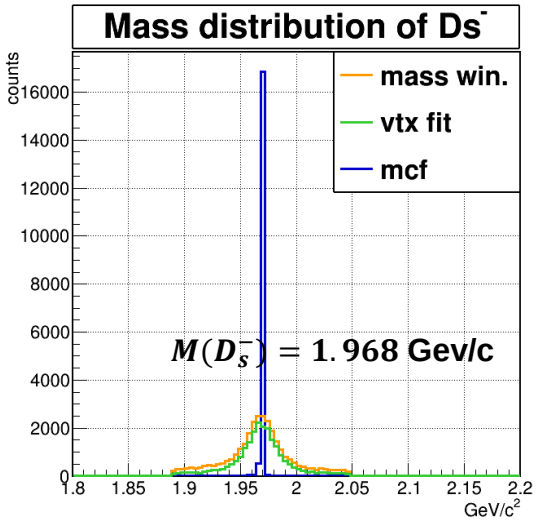


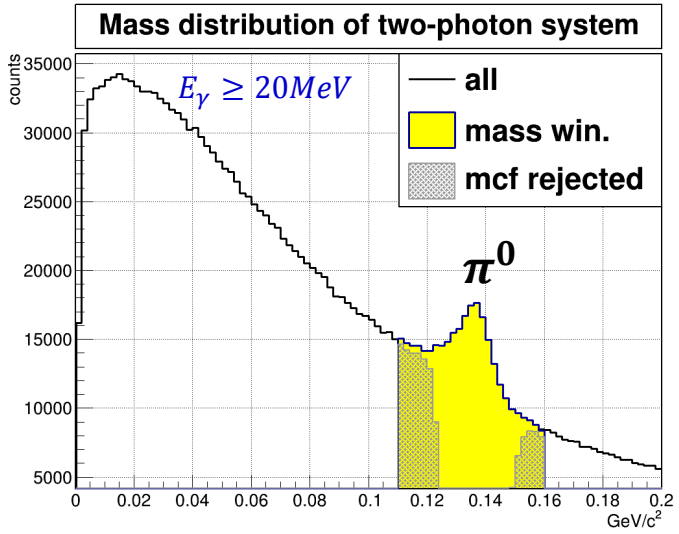
ΔZ **RMS= 0.056**
RMS= 0.122

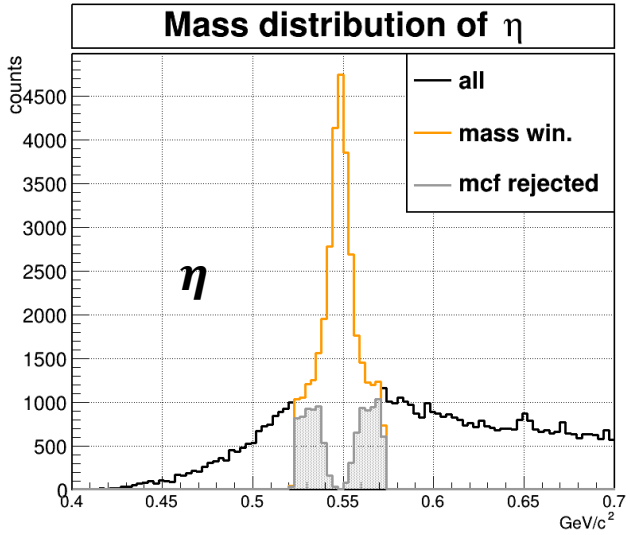
Results of Efficiency & Resolution









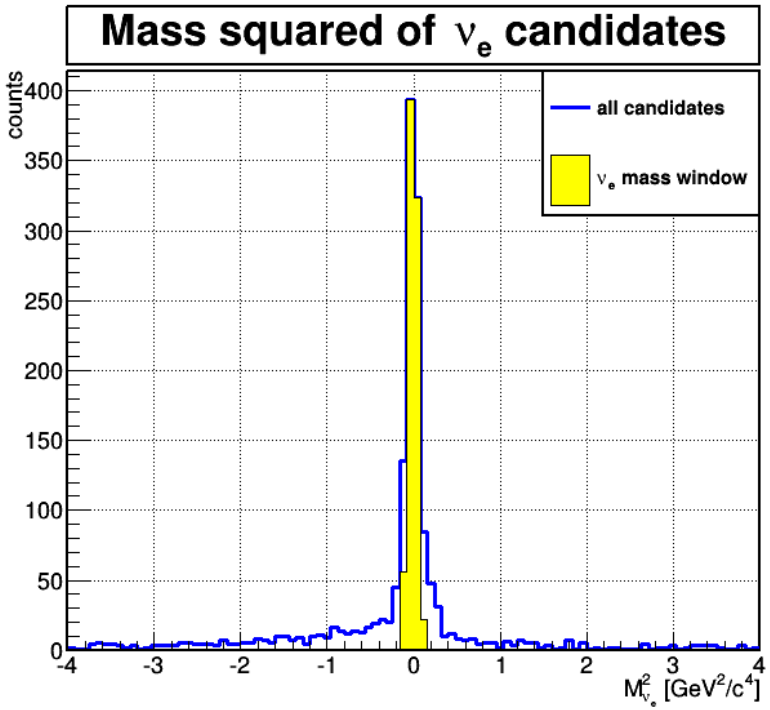


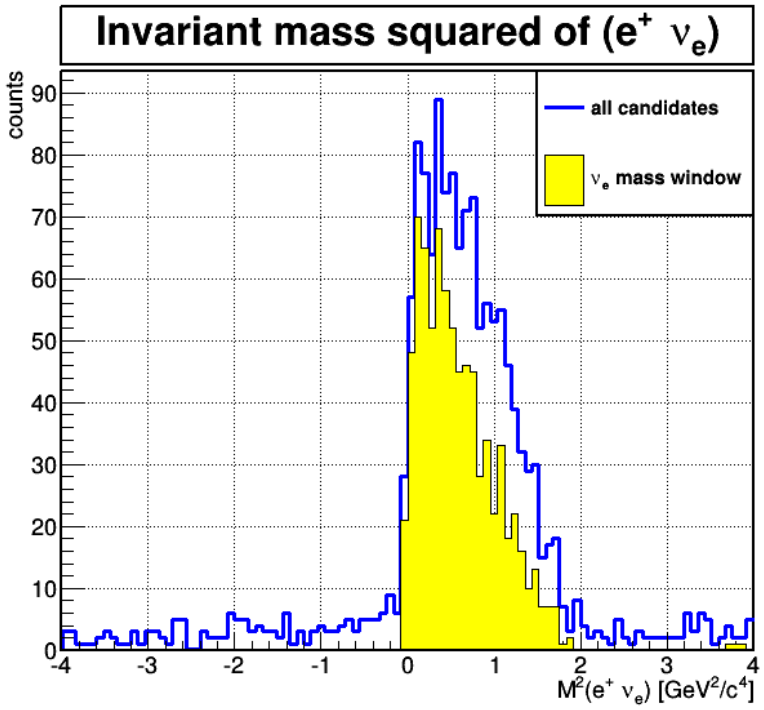
100k evt
p_{lab} = 8.0 GeV/c

#26514
Ideal PID

Invariant Mass of Leptons System

100k evt
#26514



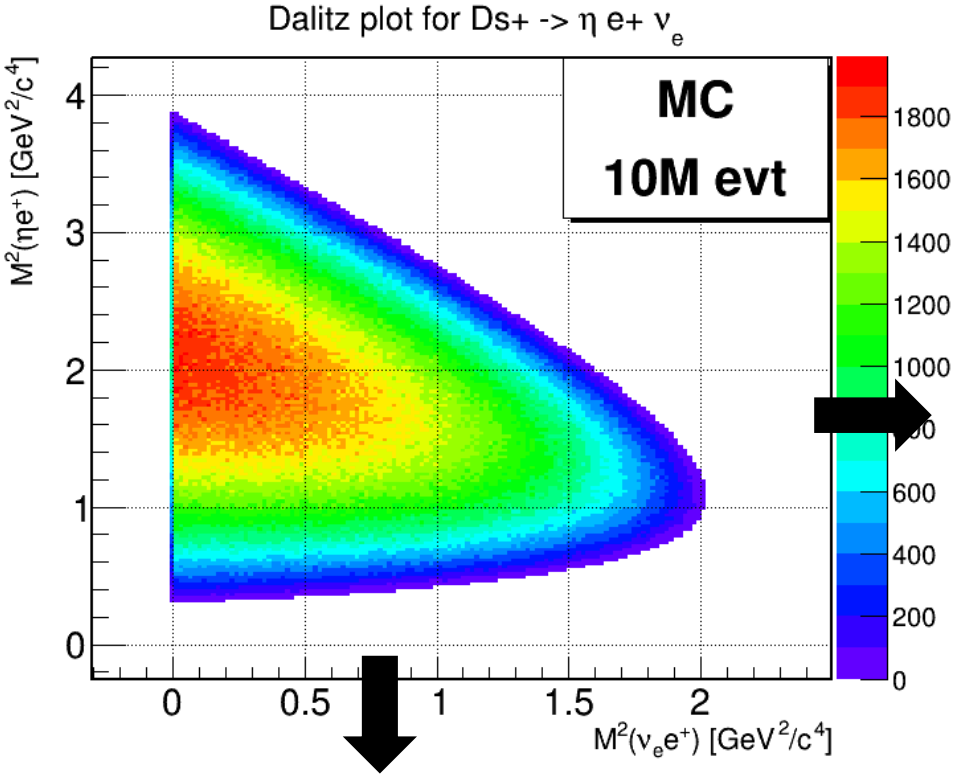


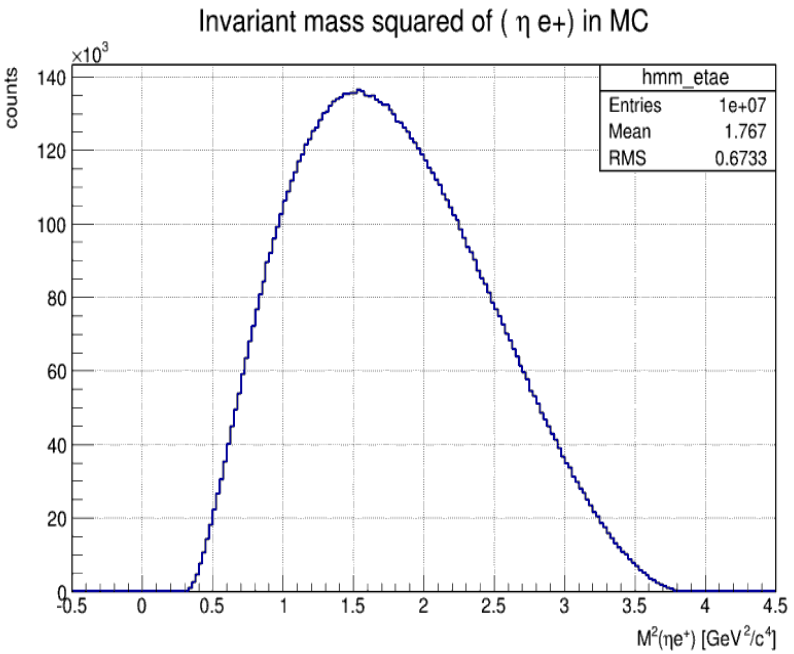
Results of Efficiency & Resolution

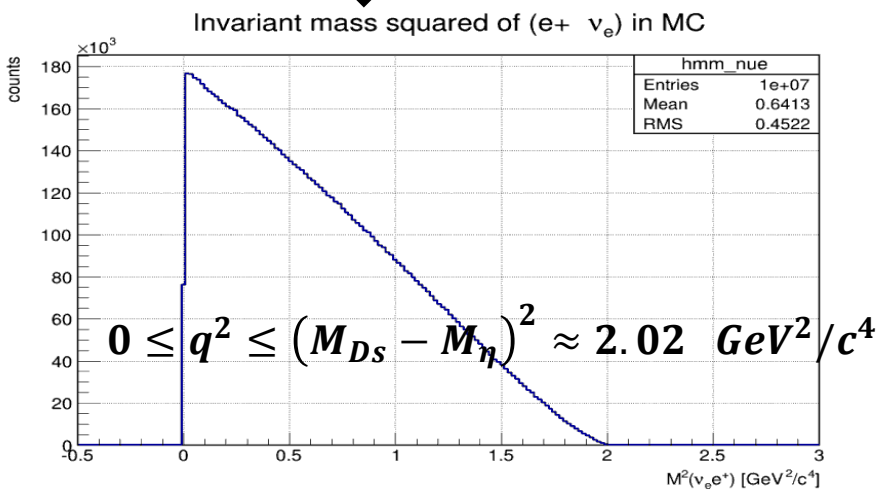
100k evt

		efficiency	Mass resolution [MeV/c^2]	Vertex resolution [μm]			Momentum rel. resolution [%]		# $(e^+\nu_e)$
				X	Y	Z	Pt	Pz	
Ds		17.7%	18.7	69	68	151	2.6	1.1	-
η	$\pi^+\pi^-$	6.9%	10.8	265	246	691	1.9	1.4	878
	$\pi^+\pi^- e^+$	5.8%	10.9	121	115	232	1.9	1.5	796

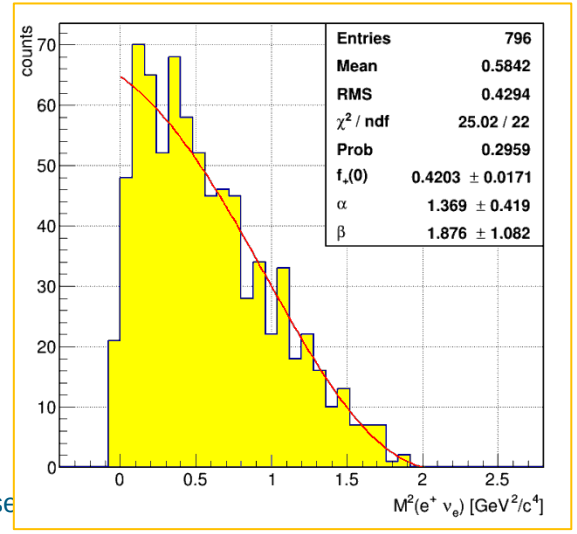
MC Truth







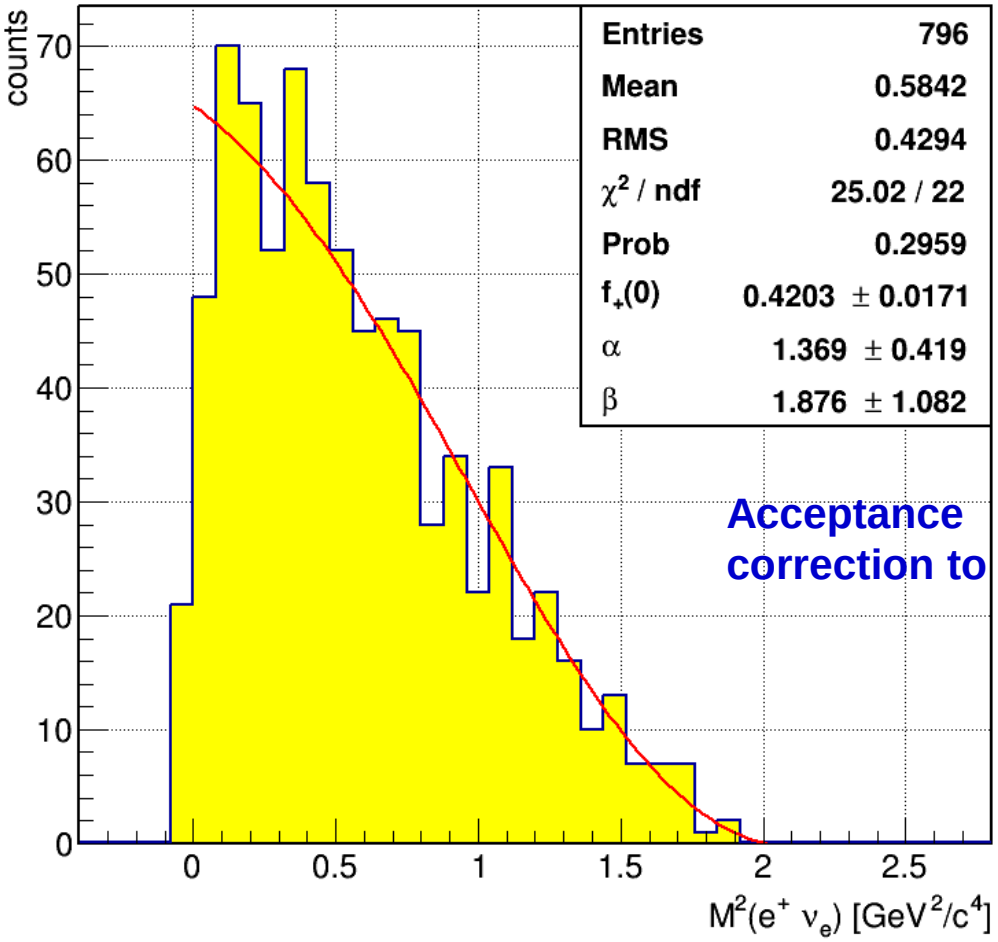
$$0 \leq q^2 \leq \left(M_{Ds} - M_{\eta}\right)^2 \approx 2.02 \;\; GeV^2/c^4$$



of Ds se

Fitting Parameters in Form Factor

100k evt
#26514



Acceptance correction to be done!

Modified pole:

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

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

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

$$f_{\pm}(0) = 0.45 \pm 0.14$$

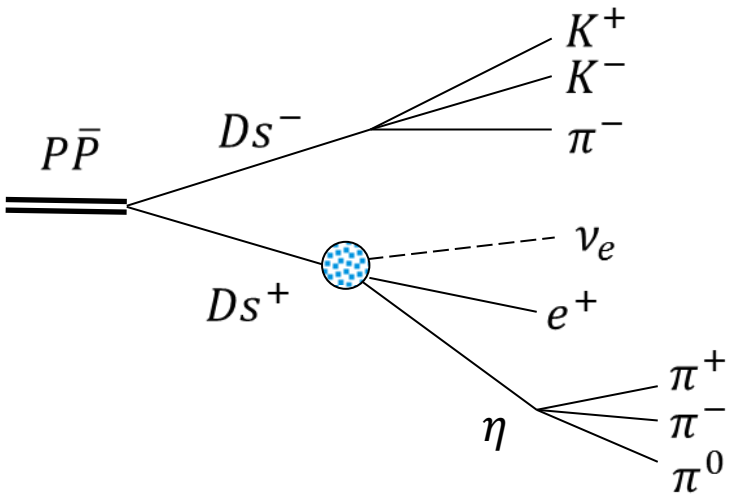
$$\alpha = 1.96 \pm 0.63$$

$$\beta = 1.12 \pm 0.36$$

Estimated Event Rate

pbarpSystem

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



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

$$= 2 \times 10^{32}(cm^{-2}s^{-1}) \cdot \mathbf{20}(nb) \times 10^{-24}(cm^2/b) \cdot 1\% \cdot 3 \times 10^6(s) \cdot 2.67\% \times 5.49\% \times 22.74\%$$

~ 40 events **with high luminosity mode in 35 days**

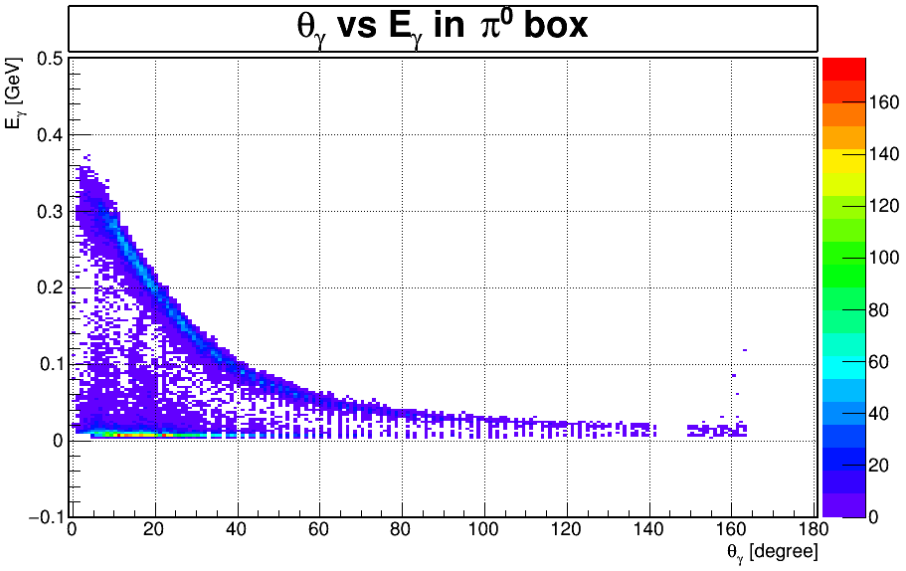
too low ☹
under investigate…

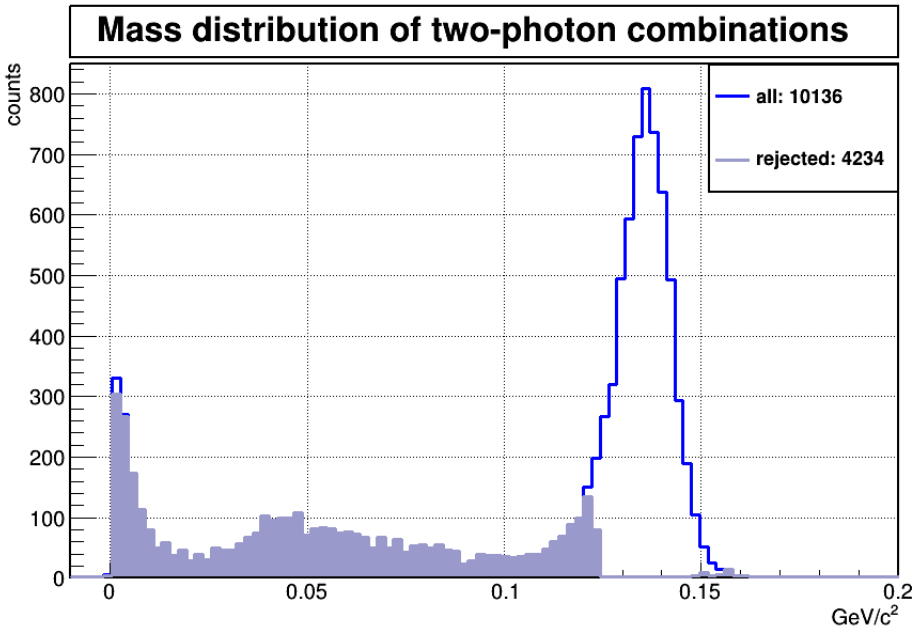
Photons in π^0 Box

10k evt single pi0:

p = 0.3 GeV/c
θ = 0°
φ = 0°~360°

pandaroot #26514
default parameters in PidCorr





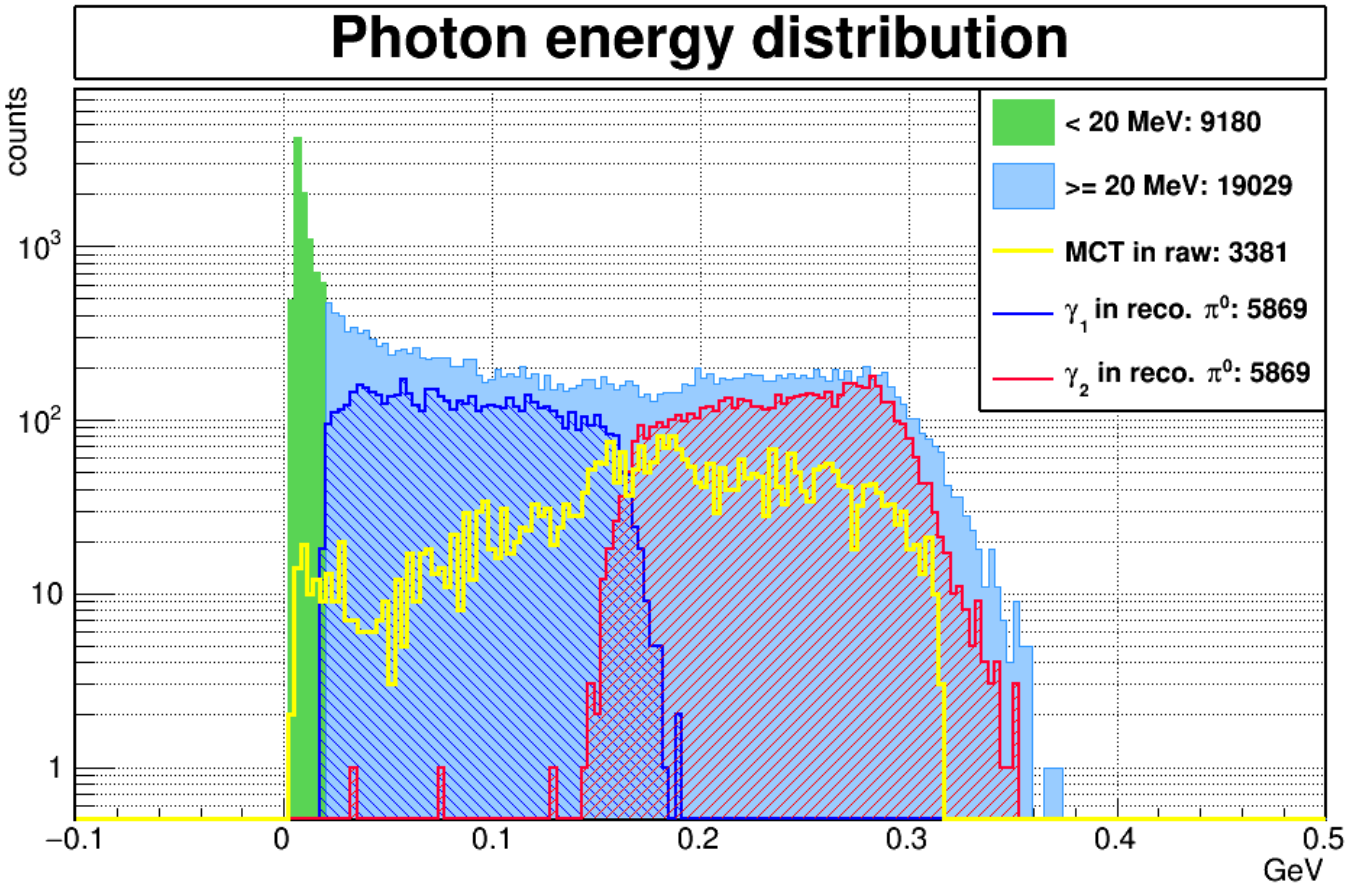
- 101.4% seen
- 42.3% rejected (χ^2prob<0.01in mass constraint fit)
- 59.1% accepted in mcf
- 16.0% MC truth matched

Photons in π^0 Box

10k evt single pi0:

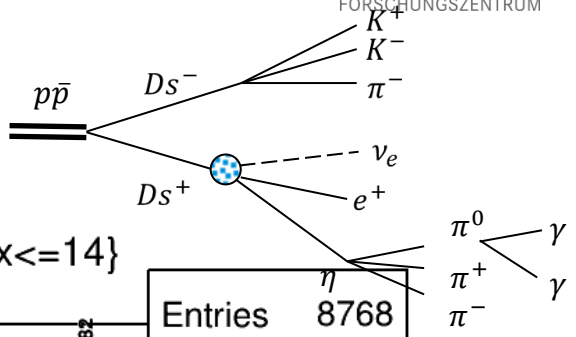
p = 0.3 GeV/c
θ = 0°
φ = 0°~360°

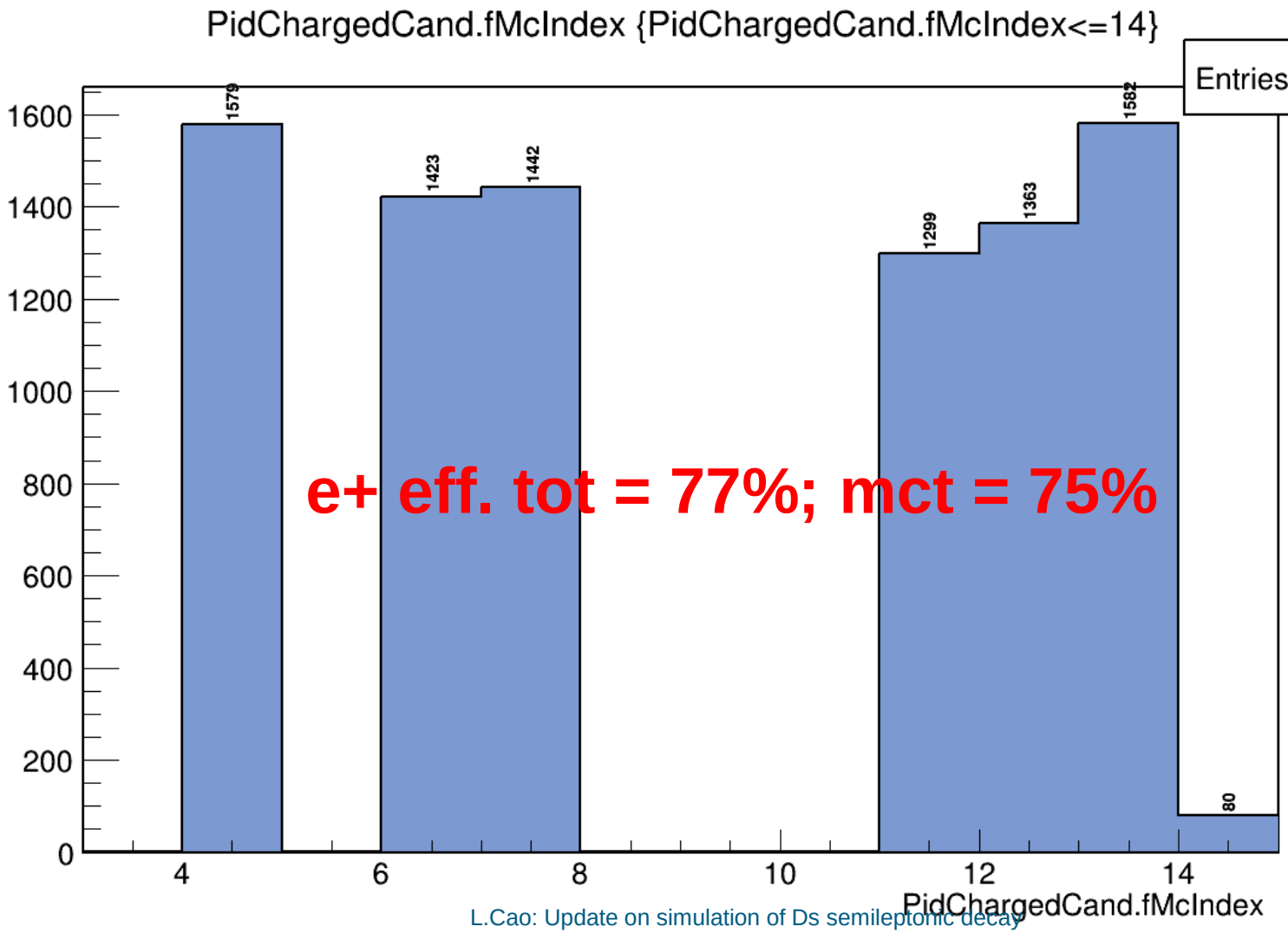
#26514
default parameters in PidCorr



e^+ Efficiency

MC Idex	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Particle	$P\bar{P}$	D_s^+	D_s^-	η	e^+	ν_e	π^+	π^-	π^0	γ	γ	K^+	K^-	π^-

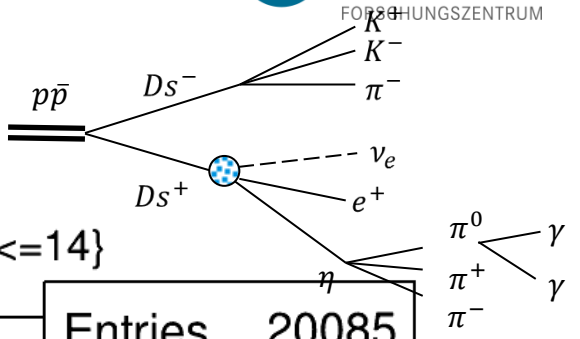


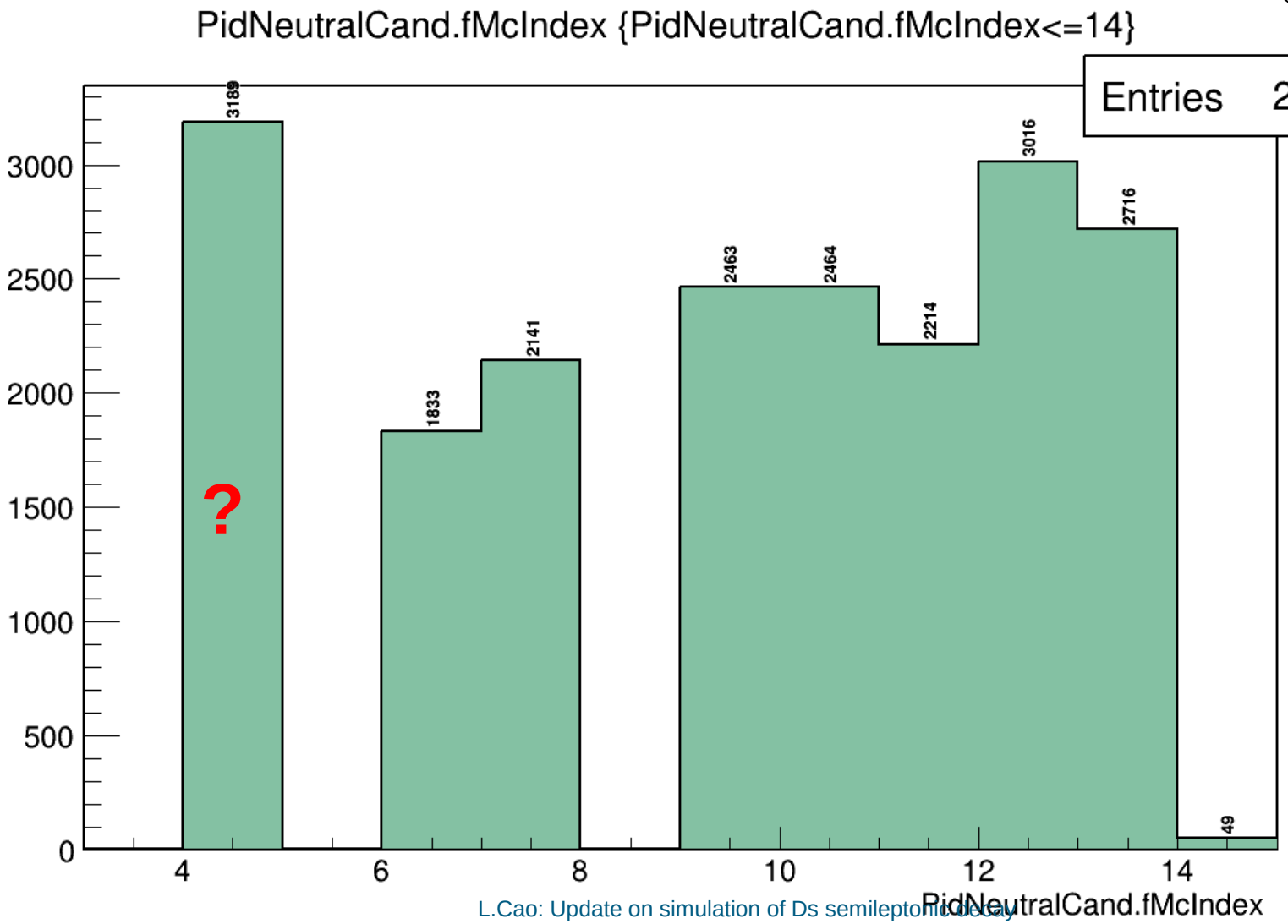


e+ eff. tot = 77%; mct = 75%

2k evt
#26514

MC Idex	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Particle	$P\bar{P}$	D_s^+	D_s^-	η	e^+	ν_e	π^+	π^-	π^0	γ	γ	K^+	K^-	π^-





2k evt
#26514

Summary & Outlook

- ✓ Decay chain reconstructed and resolution improved
- ✓ Expand kinematic fit for unmeasured neutrino
- ✓ Preliminary efficiency and production rate obtained
- ✓ Estimate precision on determining form factor

- ❑ Improve present simulation if possible
- ❑ Consider more tagging channels for D_s^-
- ❑ Investigate background events
- ❑ Simulation with different beam momenta

Picture cited from internet

Thank you !

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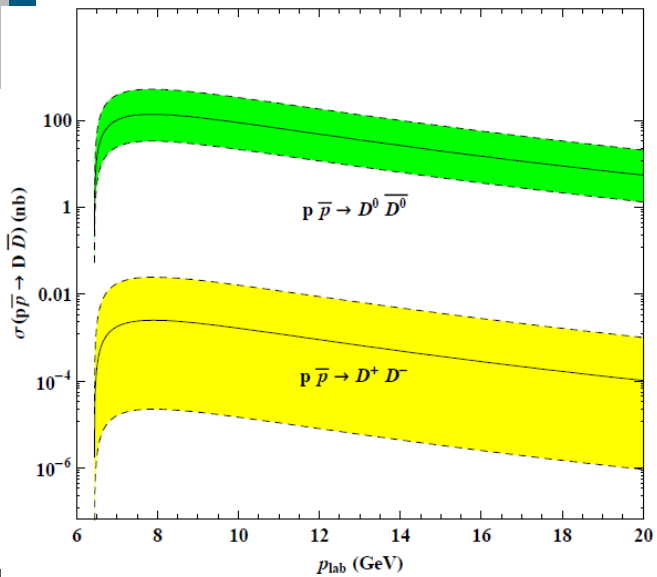
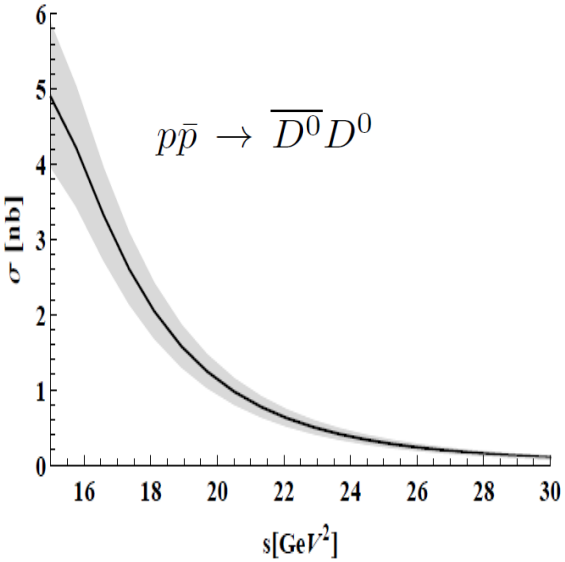
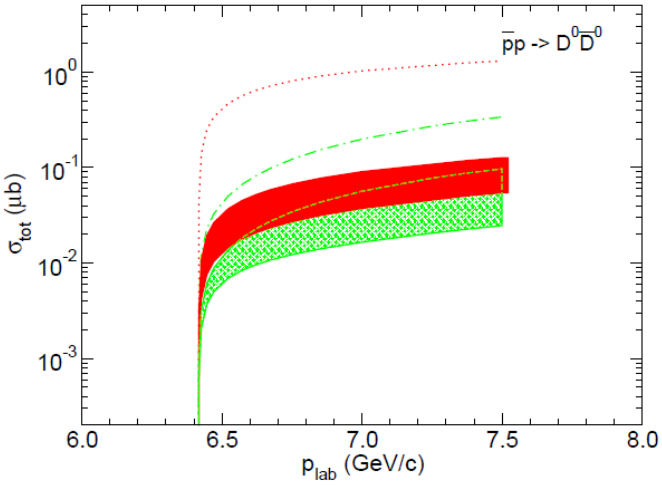
Backup Slides

Charm Production Cross Section in $\bar{p}p$







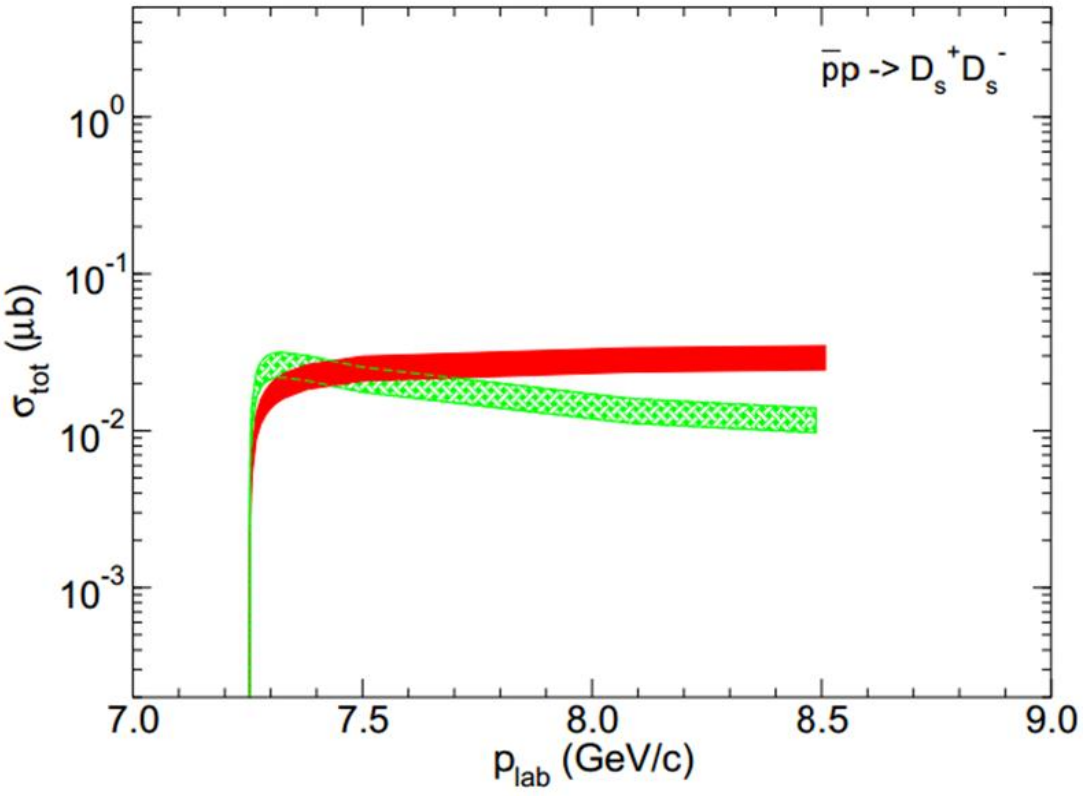
EPJA 48, 31(2012), arXiv:1111.3798v2
- quark-gluon string (QGS) model
- uncertainties introduced by the strong couplings obtained from LCSR

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

Charm Production Cross Section in $\bar{p}p$

The direct $\bar{p}p \to D_s^+ D_s^-$ transition requires the annihilation of three (up or down) quark-antiquark pairs and a creation of two (s and c) quark-antiquark pairs and is, therefore, OZI suppressed.



PRD 89, 114003(2014), arXiv:1404.4174

- Two-step processes:
  $$\bar{p}p \to D\bar{D} \to D_s^+ D_s^-$$
- hadronic interaction model
- baryon exchange (shaded band)
- quark model (grid)

In this simulation:

$$\sigma(\bar{p}p \to D_s^+ D_s^-) = 20 \text{ nb}$$

@ p_{lab} = 8.0 GeV/c

Simulated Decay Chain

pbarpSystem

-> Ds- Ds+	BR_{PDG}
| |-> eta e+ nu_e	2.67%
| |->pi+ pi- pi0	22.74%
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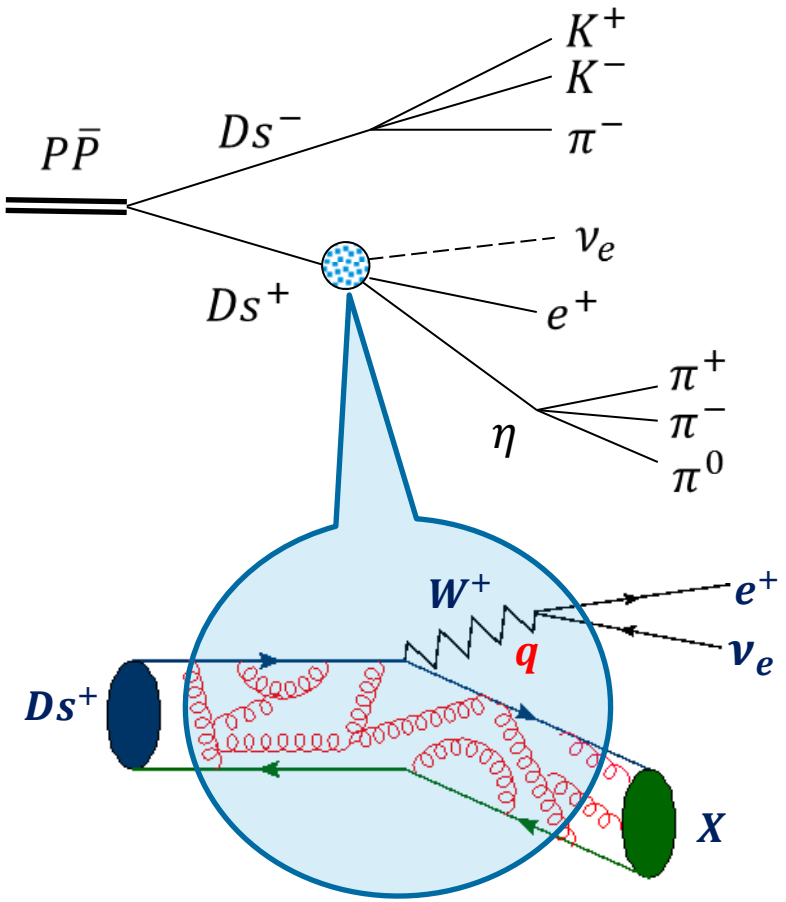
Decay models:

ISGW2

ETA_DALITZ

DS_DALITZ



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

FF Parameterization

- **Lattice QCD**: I. Kanamori, arXiv:1302.6087[hep-lat] *etc*.
- **Light-Cone Sum Rules**: N. Offen *et al.*, Phys. Rev. D88,034023 (2013) *etc*.

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

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

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

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

$$\begin{aligned}\langle P(p)|\bar{q}\gamma_{\mu}c|D_{(s)}(p+q)\rangle &= 2f^{+}_{D_{(s)}P}(q^2)p_{\mu} \\ &+ \left(f^{+}_{D_{(s)}P}(q^2) + f^{-}_{D_{(s)}P}(q^2)\right)q_{\mu}\end{aligned}$$

$$f^{0}_{D_{(s)}P}(q^2) = f^{+}_{D_{(s)}P}(q^2) + \frac{q^2}{m^2_{D_{(s)}} - m^2_{\eta^{(\prime)}}}f^{-}_{D_{(s)}P}(q^2)$$