Inclusive Decay of $D_s^+ \to \pi^+\pi^+\pi^-X$: Prospects @ BESIII

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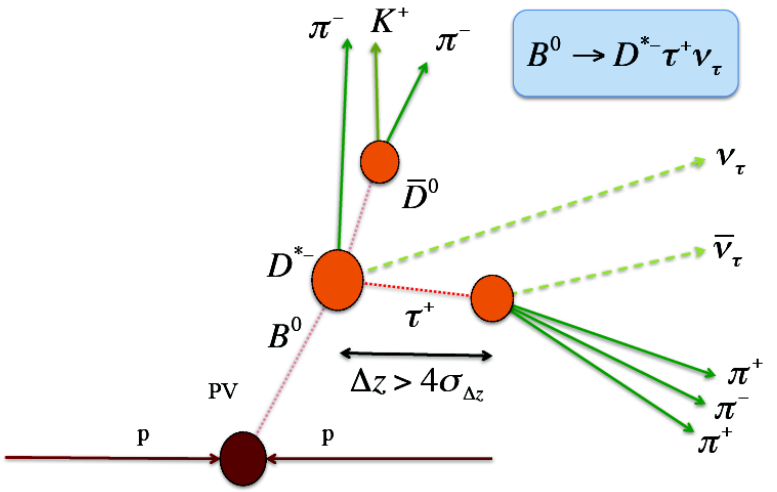
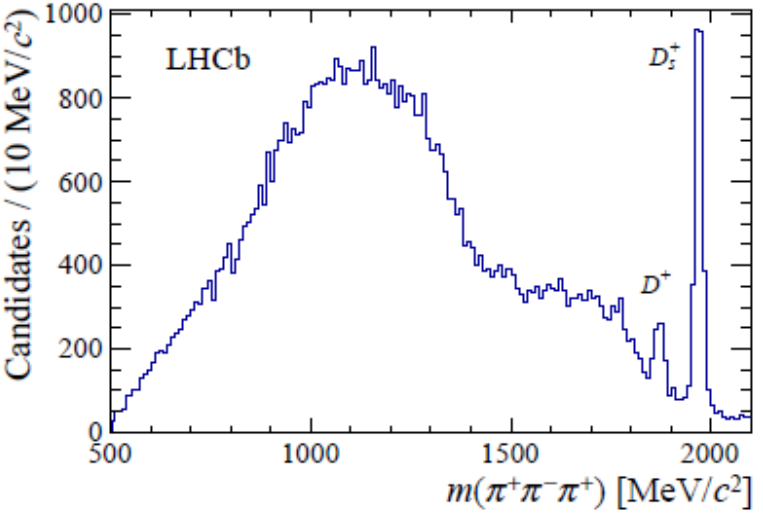
Motivation

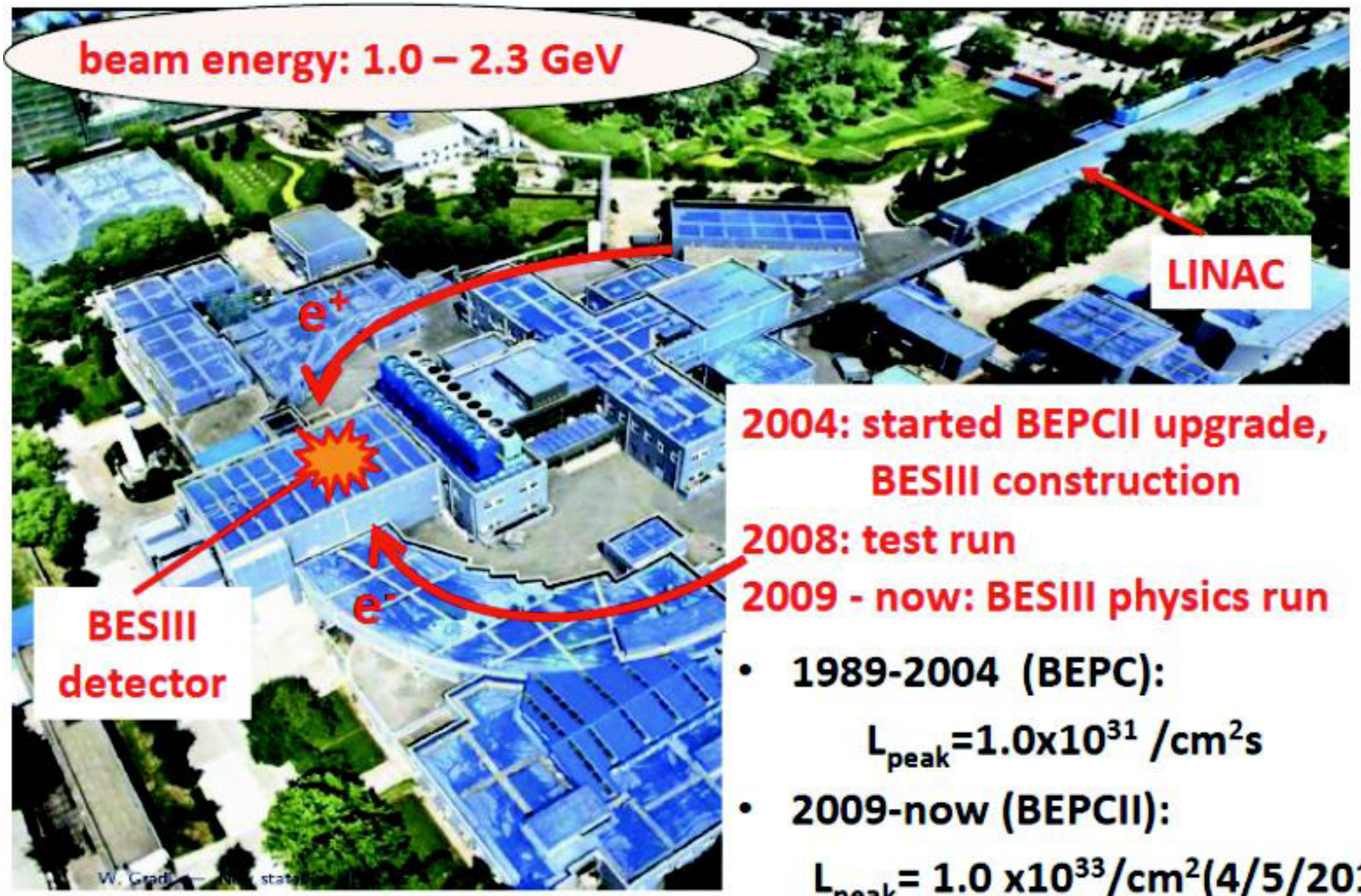
- Measuring R_{D^*} with decay $B^0 \to D^{*-}\tau^+\nu_\tau$ with τ lepton reconstructed from $\tau^+ \to \pi^+\pi^+\pi^-(\pi^0)\overline{\nu}_\tau$ in LHCb [arXiv:1708.08856, arXiv:1711.02505]
- Dominant double charm background: $B \to D^{*-} D_s(X)$ with 3 charged pions from D_s
  - Br ($D_s \to 3\pi$+X) expected to be ~30%, never measured directly
- The resonant structure of the 3π system from D_s is dominated by $\eta^{(\prime)}$, different from that in the $\tau^+ \to 3\pi X$ final states
- LHCb uses D_s enriched data to measure the inclusive $D_s \to 3\pi X$ decays
- These decays can be better understood using independent datasets from a different experiment



arXiv:1711.02505



Beijing Electron Positron Collider (BEPCII)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

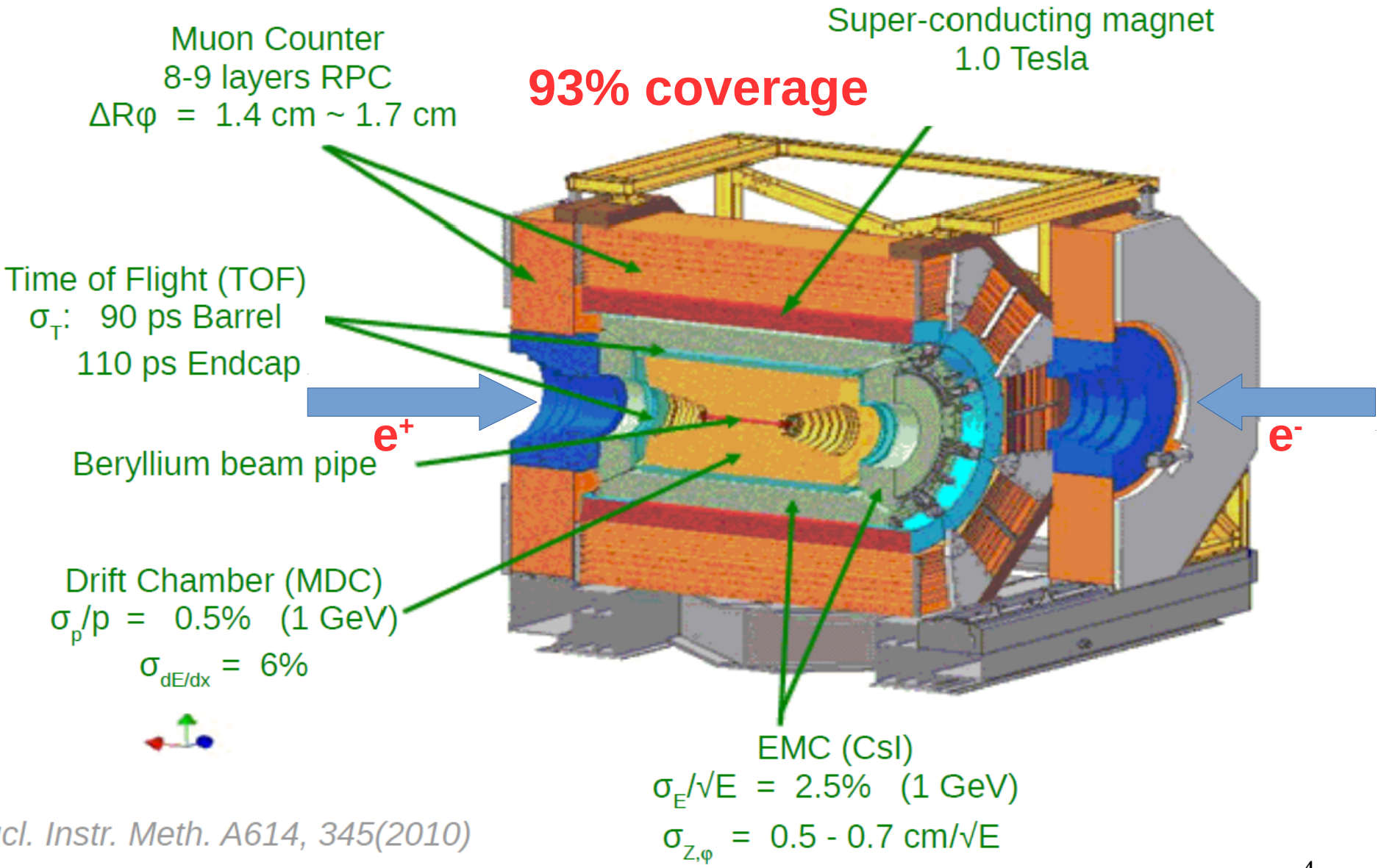
- 1989-2004 (BEPC):

  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- 2009-now (BEPCII):

  $L_{peak}= 1.0\times10^{33}$/cm^2(4/5/2016)

BESIII detector



Nucl. Instr. Meth. A614, 345(2010)

BESIII detector

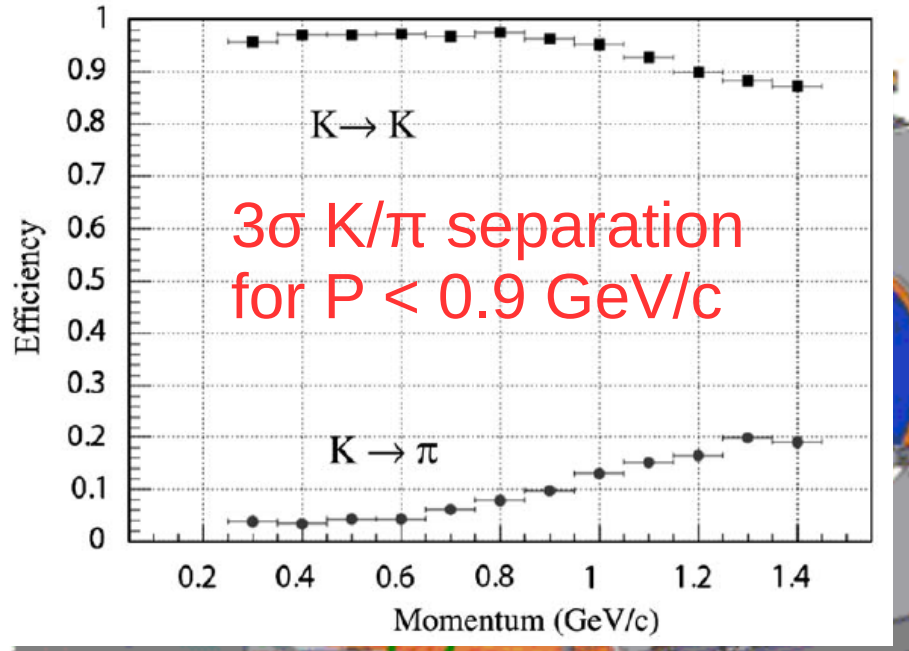
Muon Counter
8-9 layers RPC
ΔRφ = 1.4 cm ~ 1.7 cm

Time of Flight (TOF)
σ_T: 90 ps Barrel
110 ps Endcap

Beryllium beam pipe

Drift Chamber (MDC)
σ_p/p = 0.5% (1 GeV)
$\sigma_{dE/dx}$ = 6%

Super-conducting magnet
1.0 Tesla



EMC (CsI)
$\sigma_E/\sqrt{E}$ = 2.5% (1 GeV)
$\sigma_{Z,\varphi}$ = 0.5 - 0.7 cm/√E

Nucl. Instr. Meth. A614, 345(2010)

Physics objectives

- Already documented in LHCb-PUB-2016-025: "*Synergy of BESIII and LHCb physics programmes*"

5.2 Inputs required for the study of hadronic tau decays at LHCb

Table 3: A list of useful branching fractions of the D_s^+ meson to aid understanding of backgrounds to hadronic τ decays. The notation X refers to a collection of one or more neutral particles.

Decay mode	Priority	Comments
$D_s^+ \to \pi^+\pi^-\pi^+X$ inclusive	very high	See text.
$D_s^+ \to N3\pi$	high	N is any neutral meson
$D_s^+ \to \eta\pi^+X$	medium	
$D_s^+ \to \eta'\pi^+X$	medium	
$D_s^+ \to \phi\pi^+X$	medium	
$D_s^+ \to \omega\pi^+X$	medium	
$D_s^+ \to \pi^+\pi^-\pi^+\pi^-\pi^+X$ inclusive	medium	

Analysis strategy

- Top priority: branching fraction of inclusive $D_s^+ \to \pi^+\pi^+\pi^-X$
- Requiring one fully reconstructed D_s^- at the tag side, and at least three identified pions at the signal side
- First look at events tagged with $D_s^- \to K^-K^+\pi^-$
- Signal efficiency determined from cocktail MC events
- Major background source from D_s decays: fake pions & K_S contributions

Data and MC samples

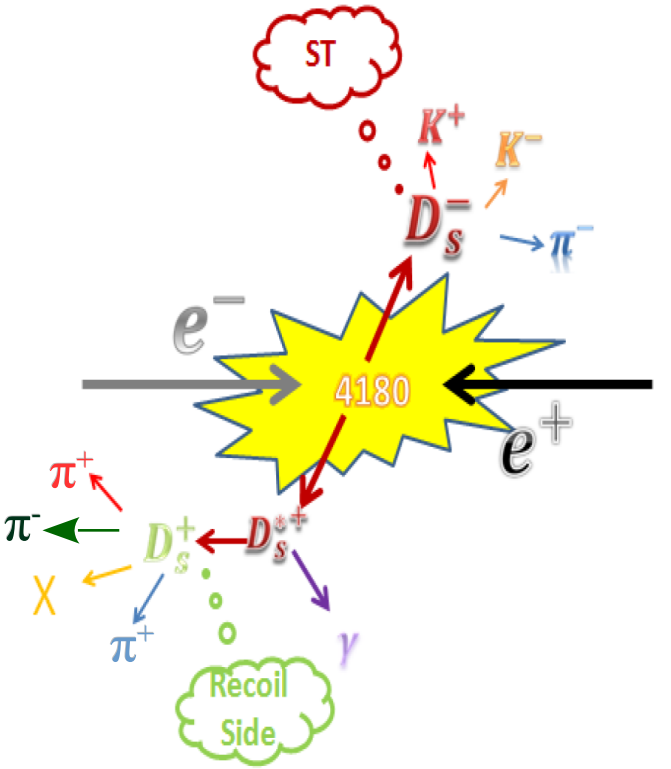
- Data: 3.19 fb^{-1} reconstructed @ $\sqrt{s}$ = 4.18 GeV
- Generic MC: ×35 data size (round01~round35)
  - Open charm ($D_{(s)}^{(*)}D_{(s)}^{(*)}$), $q\bar{q}$, etc
- Generic $D_s^{*+}D_s^-$ events that contribute to the $3\pi X$ final states are used to determine signal reconstruction efficiency

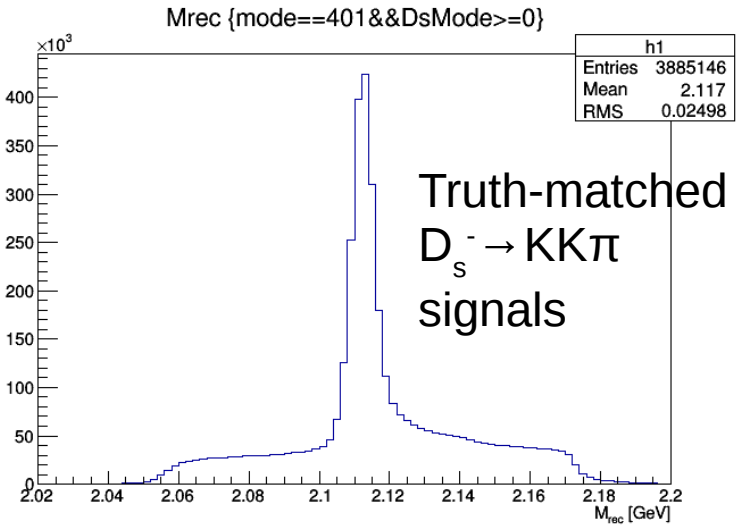
Tag selection

- For the $D_s^- \to K^+K^+\pi^-$ tag mode:
  - Charged tracks of high quality
  - Kaon PID: Prob(K) > Prob(π)
  - Pion PID: Prob(π) > Prob(K) (same for the signal side)
  - P(π) > 100 MeV to suppress D^* background (same for the signal side)
  - Selecting best candidate in the same event with recoil mass M_{rec} closest to the nominal D_s^{*+} mass

$$M_{rec} = \sqrt{\left(E_{cm} - \sqrt{|P_{D_s}|^2 + M_{D_s}^2}\right)^2 - |P_{D_s}|^2}$$

  - P_{Ds} is the reconstructed D_s momentum in the C.M. frame
  - M_{Ds} is the nominal D_s mass from PDG





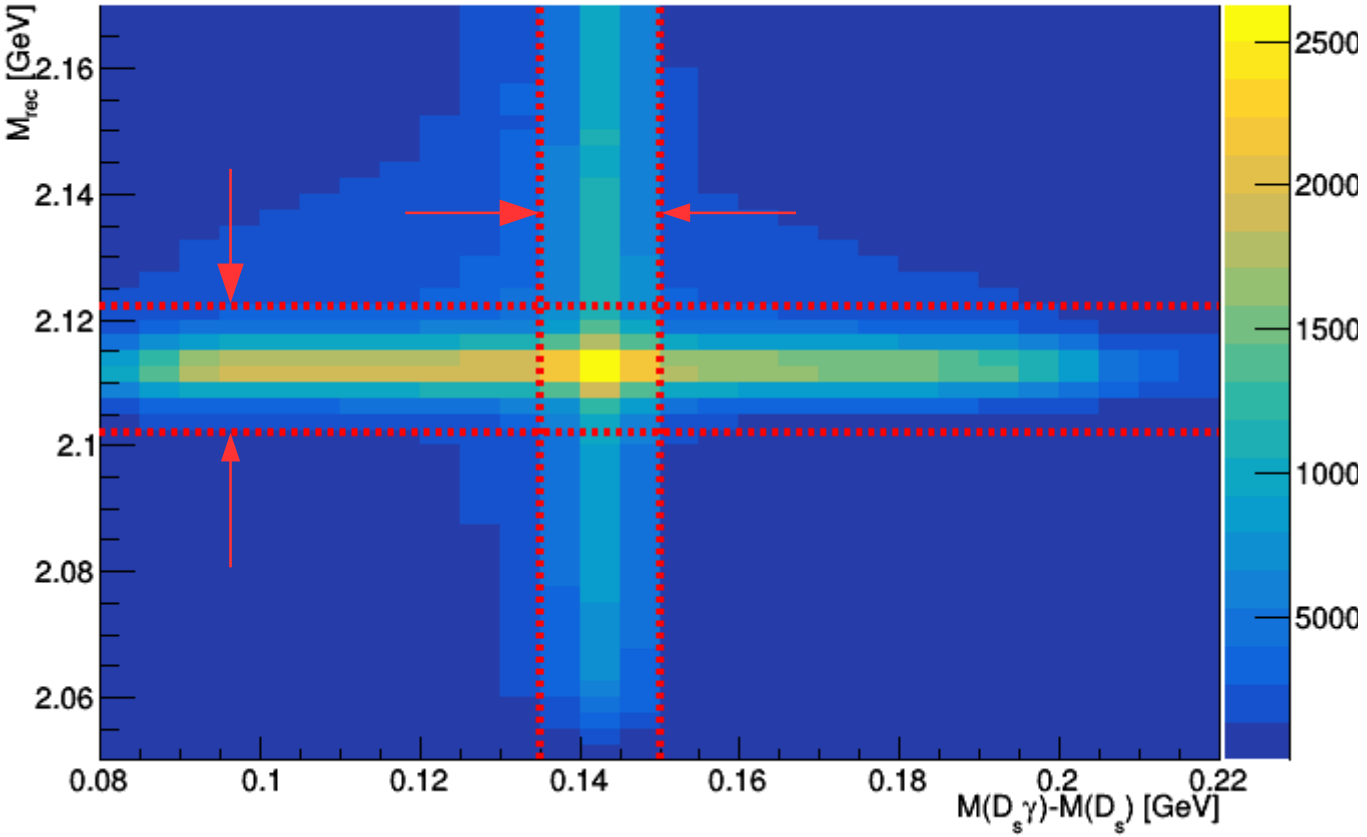
Finding photon from $D_s^{*+} \to D_s^{+}\gamma$

- Better background suppression can be achieved if the photon from D_s^* is identified
- Requiring photons not coming from any reconstructed π^0
- Finding the "best" photon by selecting the mass of the rest of the event closest to the nominal D_s mass:

$$\vec{P}_{rest} = \vec{P}_{beam} - \vec{P}_{D_s^{tag}} - \vec{P}_{\gamma}$$

Additional mass cuts

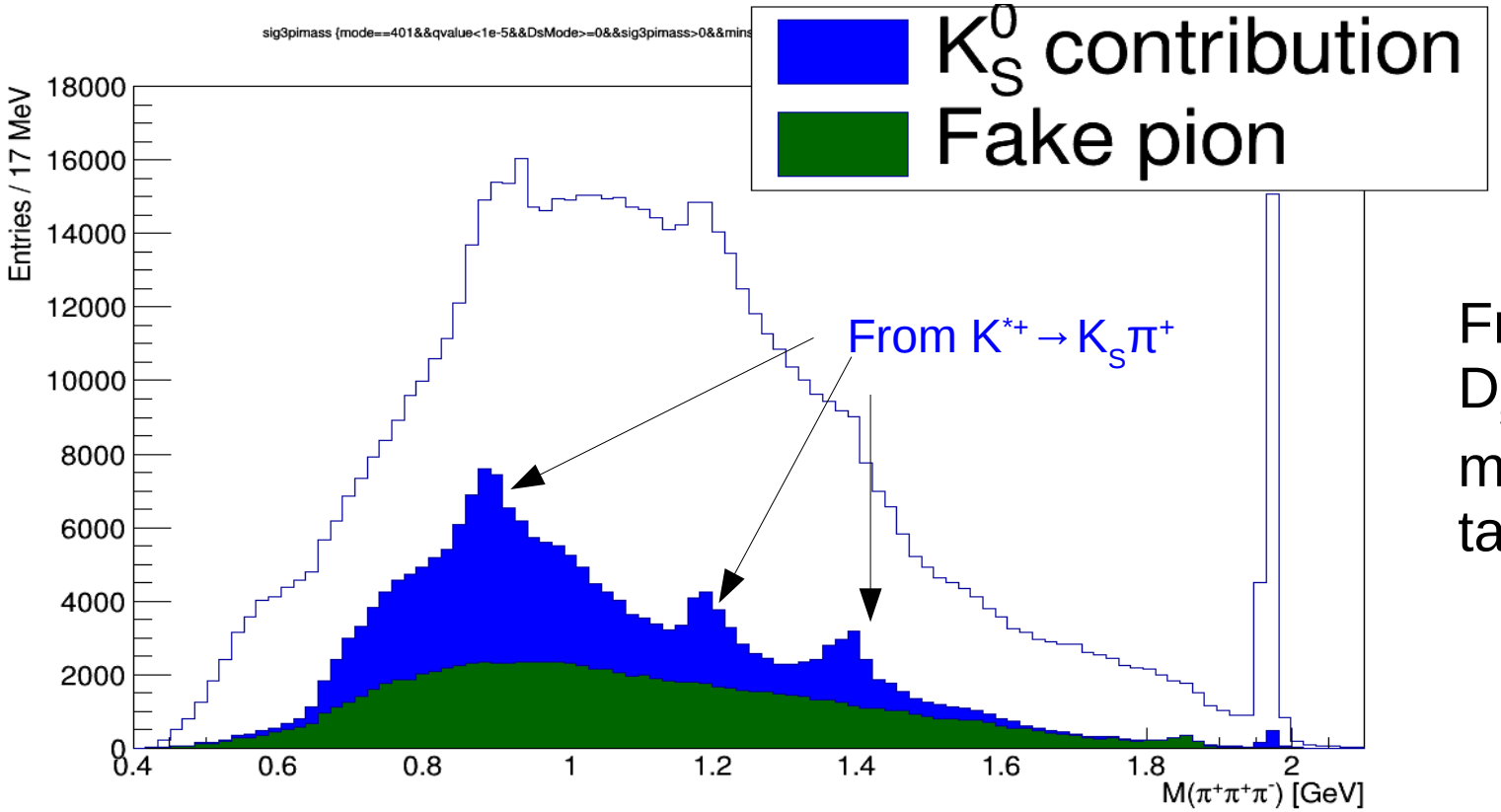
- As we are dealing with two different types of tagged events, direct D_s, or D_s from D_s^*, a selection on the following 2D plane is made:



Truth-matched $D_s^- \rightarrow KK\pi$ signals

Fake pions & K_s

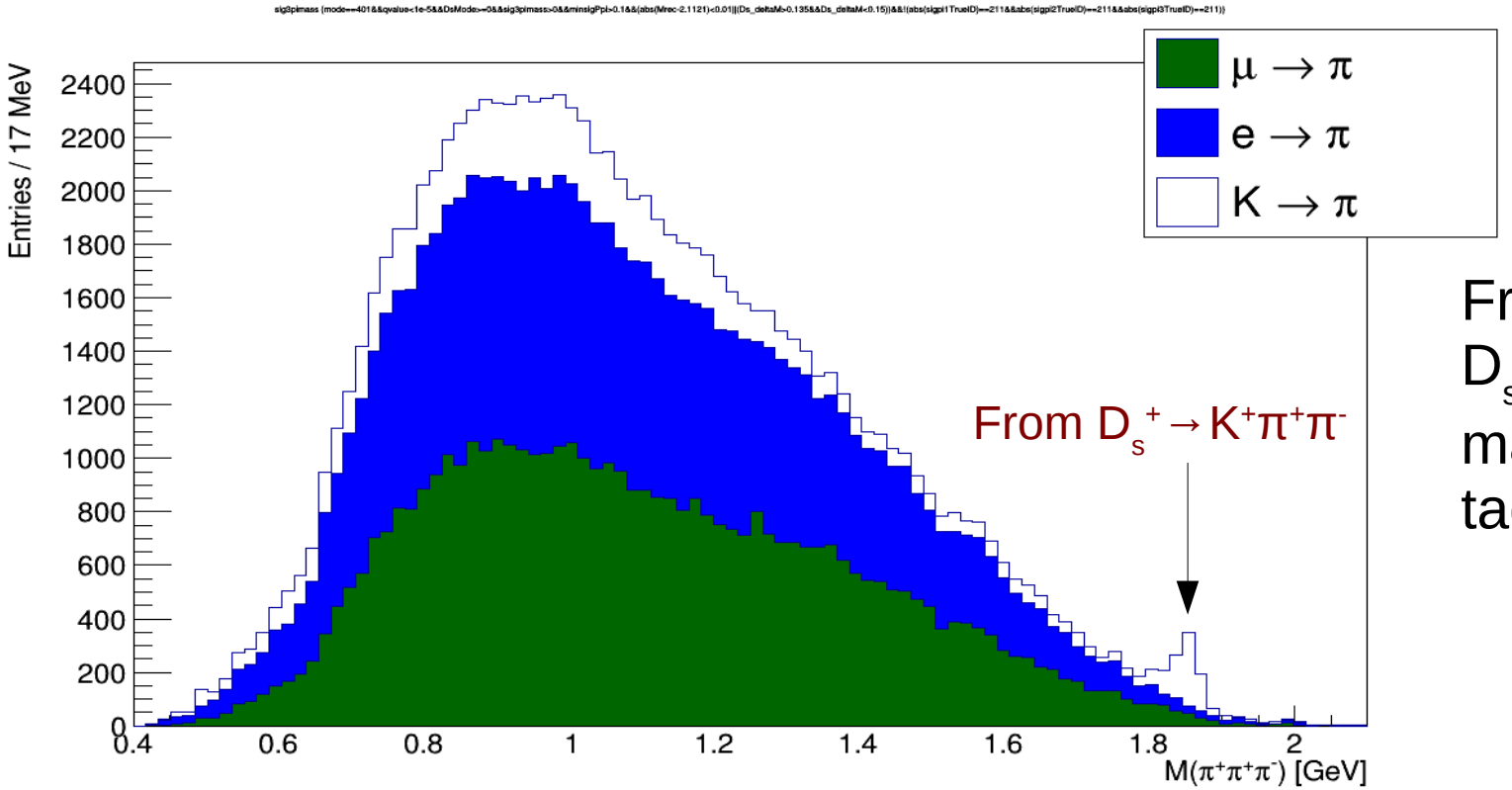
- Shown is the invariant mass spectrum of the three most energetic pions at the signal side:



From generic $D_s^* D_s$ MC, truth-matched at the tag side

Origins of fake pions

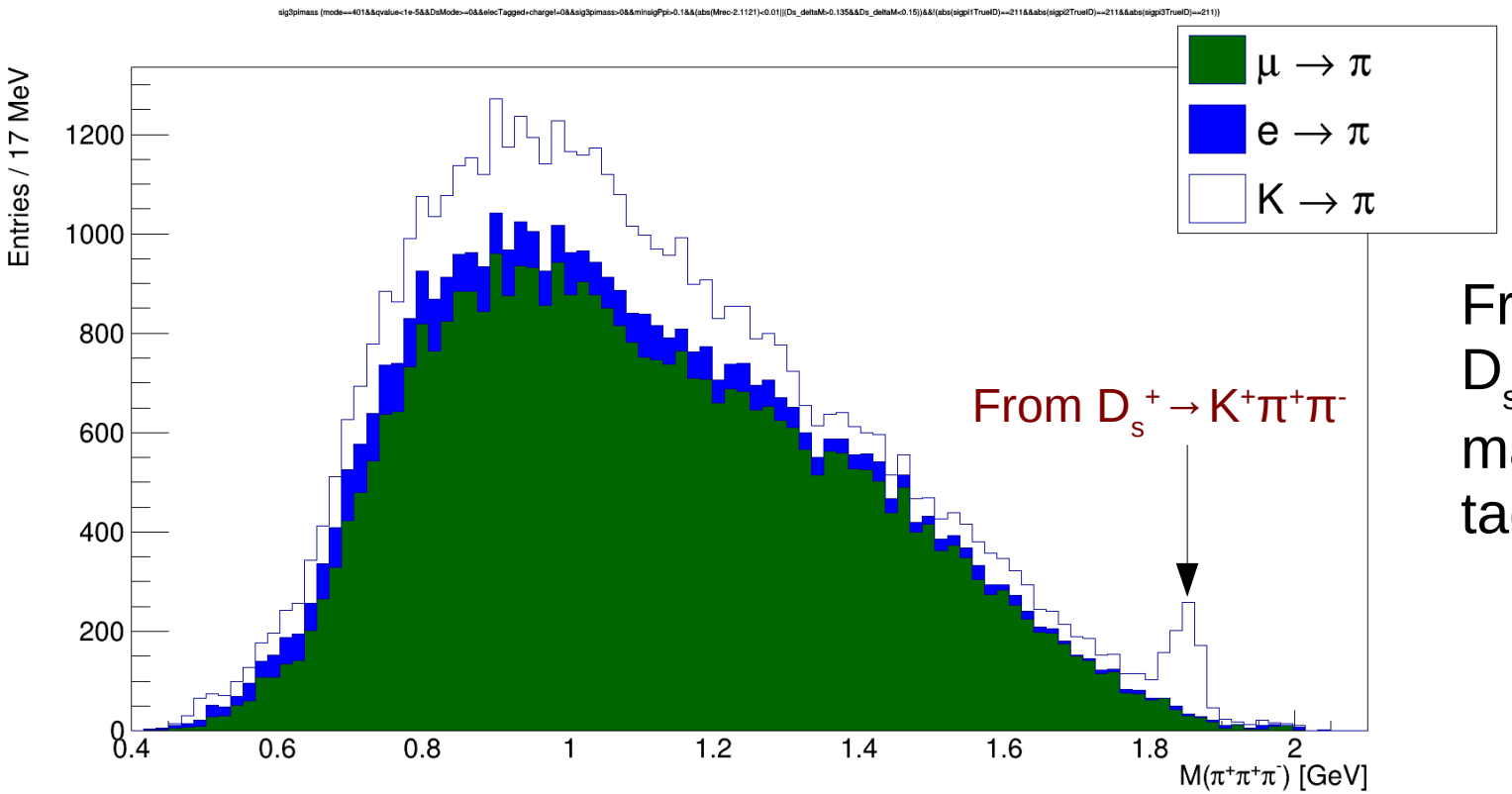
- Different misidentification scenarios:
  - Dominating contributions from $D_s^+ \to X\ell^+\nu$ with BF ~6% for either electron or muon mode



From generic $D_s^* D_s$ MC, truth-matched at the tag side

Origins of fake pions (cont.)

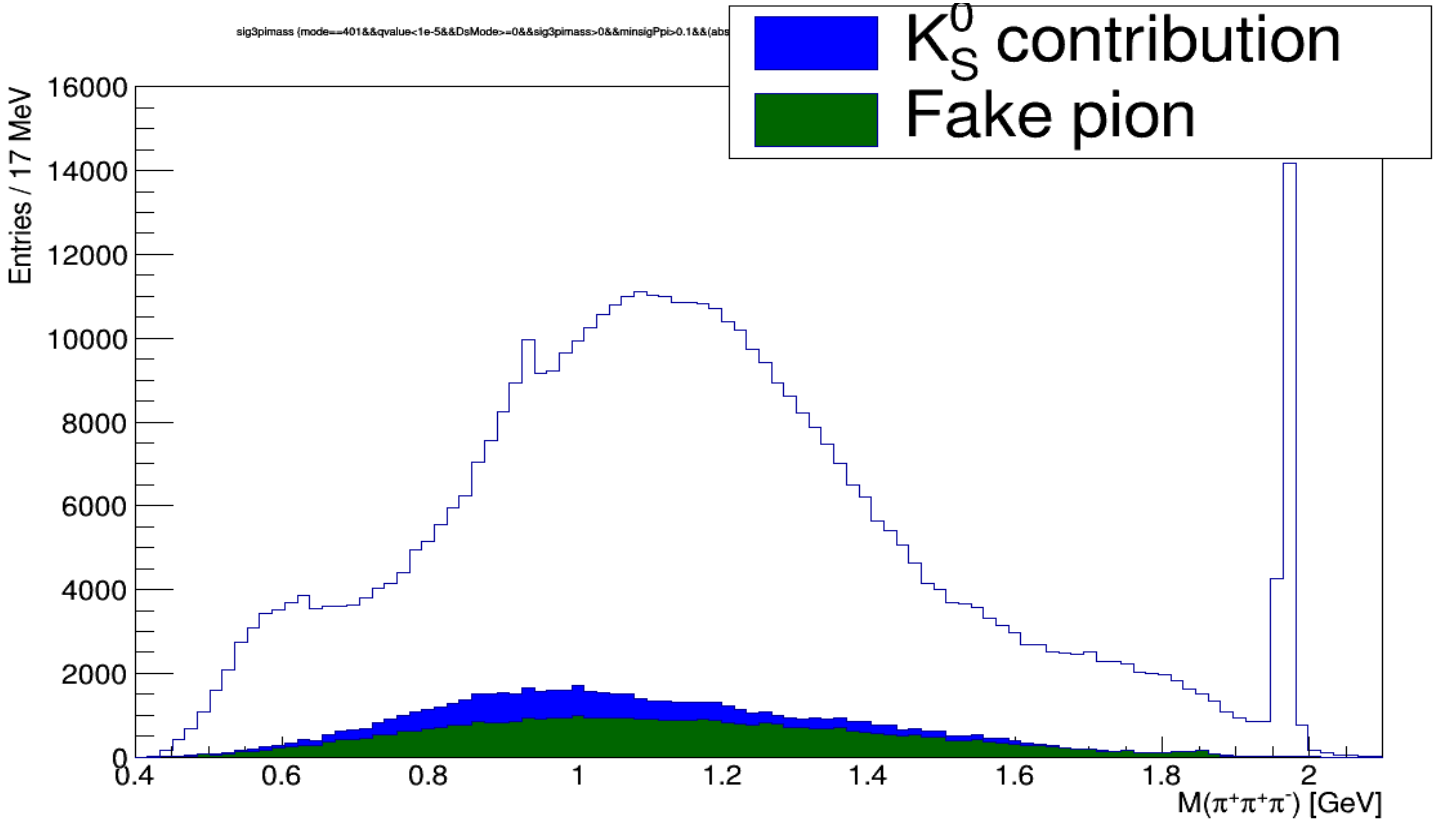
- Electron background can be largely removed by rejecting events with the identification of at least one **e^+** at the signal side
  - Removal of 90% electron background at the cost of ~5% real signals



From generic $D_s^* D_s$ MC, truth-matched at the tag side

Suppression of K_S contribution

- K_S background can be largely removed by searching among pions at the signal side for pairs with invariant mass consistent with being a K_S (within 10 MeV)
  - Removal of 80% K_S background at the cost of ~10% real signals



From generic $D_s^* D_s$ MC, truth-matched at the tag side

Sum of fake pion & K_S background estimated to be **~14%** of real signals

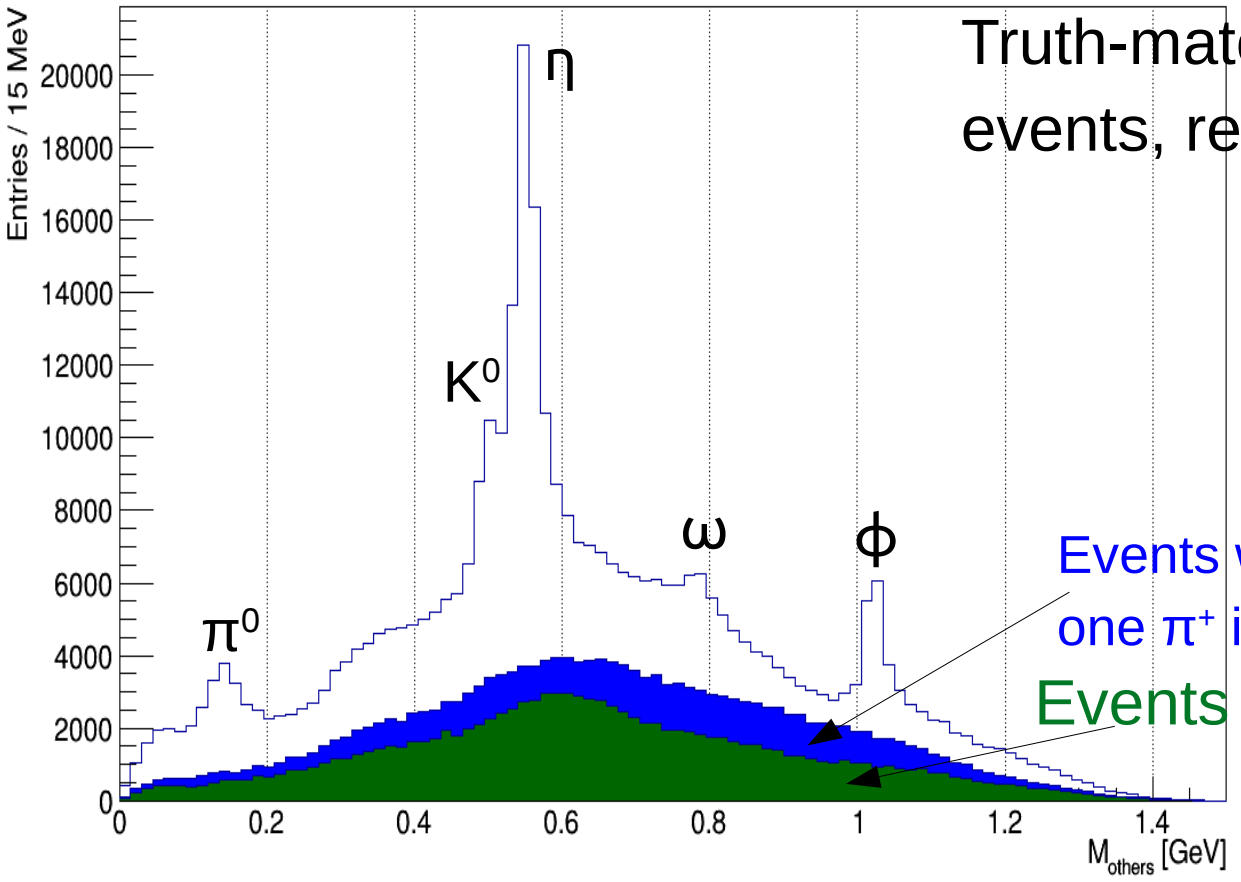
Efficiency estimation

$$N_{tag} = 2N_{D_s D_s^*}\mathcal{B}_{tag}\epsilon_{tag}$$
$$N_{sig} = 2N_{D_s D_s^*}\mathcal{B}_{tag}\mathcal{B}_{sig}\epsilon_{sig|tag}$$
$$\mathcal{B}_{sig} = \frac{N_{sig}\epsilon_{tag}}{N_{tag}\epsilon_{sig|tag}}$$
$$N_{sig} = N'_{sig} - N_{misID} - N_{K_S}$$

- From generic MC, based on 10M $D_s \rightarrow KK\pi$ events, we have:
  - ε_{tag} = 25.7%, $\varepsilon_{sig|tag}$ = 12.9%
- N'_{sig} ~ 14k as estimated from MC scaled to data luminosity, indicating a statistical sensitivity < 1%

$D_s \to \pi\pi\pi N$

$$\vec{P}_{other} = \vec{P}_{beam} - \vec{P}_{D_s^{tag,-}} - \vec{P}_{\gamma} - \vec{P}_{\pi^+\ \pi^+\ \pi^-}$$



Truth-matched $D_s^+ \to \pi^+\pi^+\pi^-X$ MC events, requiring $M(3\pi) < 1.9$ GeV

Events with γ from D_s^*, but at least one π^+ is either misIDed or from K_s

Events with γ not coming from D_s^*

Summary

- The analysis is in a good state to move forward, within a limited time scale
- Expected statistical uncertainty on inclusive 3π rate is ~1%, for one single KKπ tag mode
- A major missing piece is the suppression & determination of fake pion & K_S contributions
- A large range of physics topics, such as $D_s \to \pi\pi\pi N$, are within reach
- Also stay tuned for inclusive $D \to \pi\pi\pi X$ results from BESIII