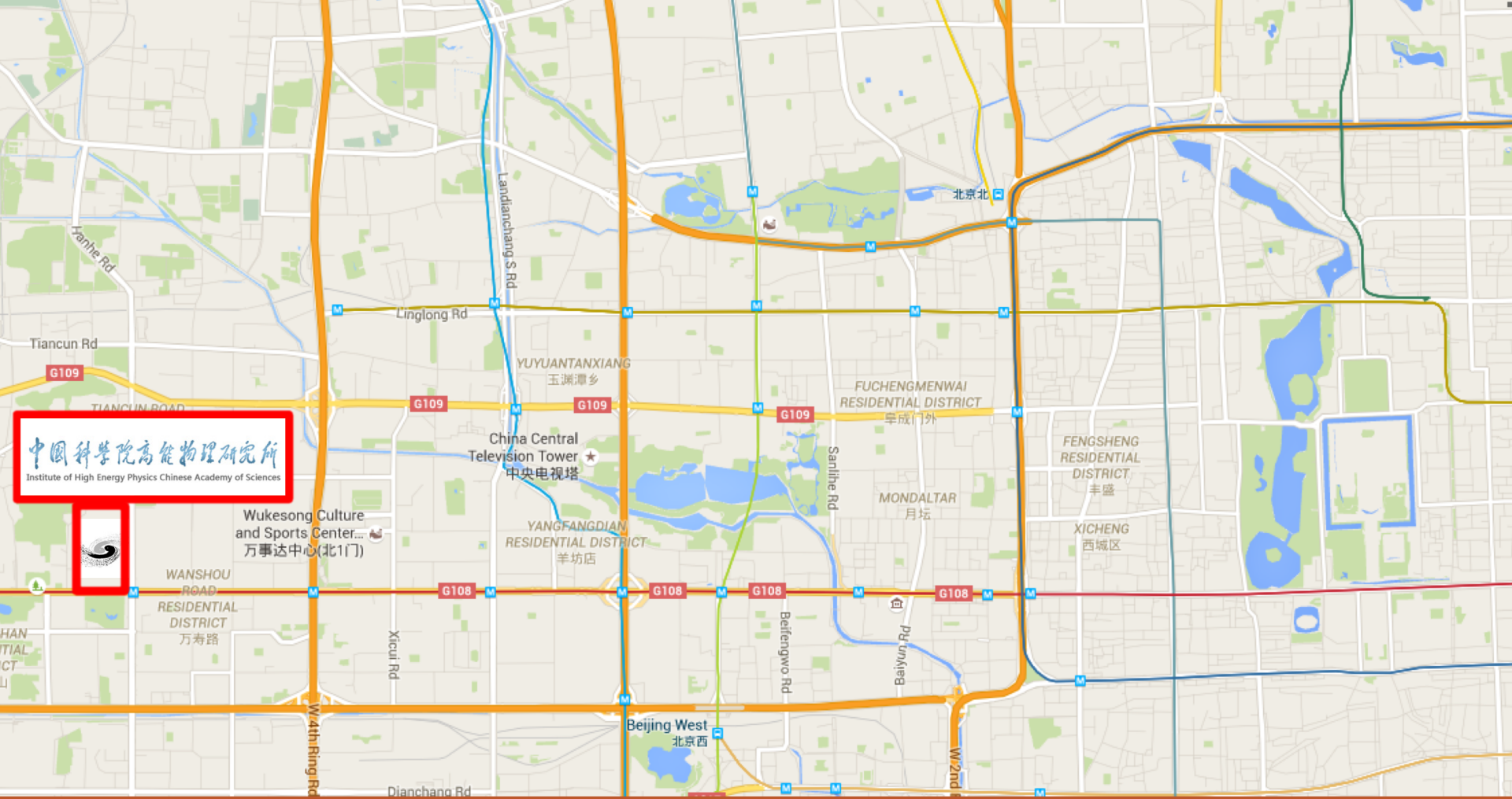
Charm meson decays @ BESIII

Peter Weidenkaff, Mainz University
on behalf of the BESIII Collaboration

CKM 2018, Heidelberg


中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences
Tiancun Rd
G109
Hanhe Rd
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Linglong Rd
YUYUANTANXIANG
玉渊潭乡
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RESIDENTIAL DISTRICT
阜成门外
China Central
Television Tower
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Sanlihe Rd
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XICHENG
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and Sports Center...
万事达中心(北1门)
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W 2nd
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Storage ring
LINAC
BESIII

- Construction phase 2004-2008
  - Upgrade from BESII und BEPC
- First physics data taking 2009
- International collaboration
  - ~450 authors

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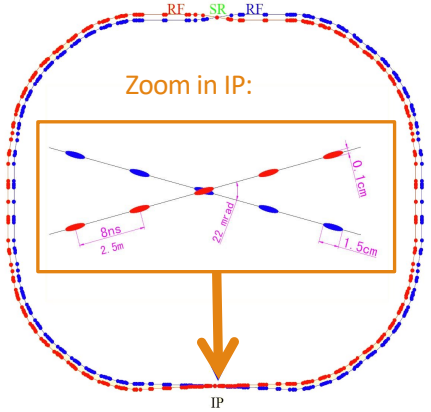
The BESIII Experiment

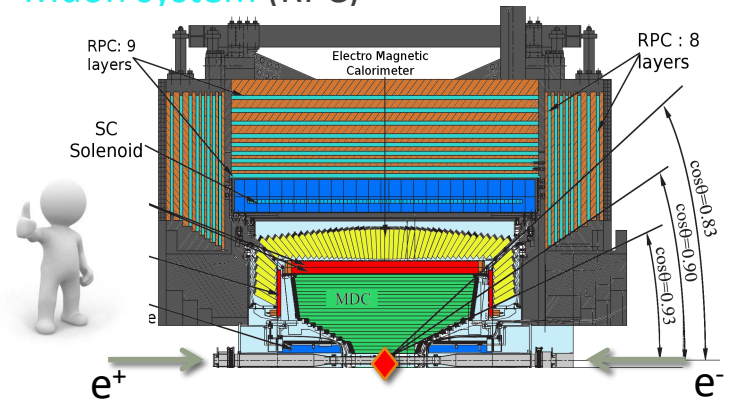
Beijing-Electron-Positron Collider II (BEPCII)

- e^+e^- collisions with
  $\sqrt{s} = 2.0 - 4.6 GeV$
- Direct production of charmonia
- Luminosity
  $\mathcal{L} = 1\times10^{33} cm^{-2}s^{-1}$

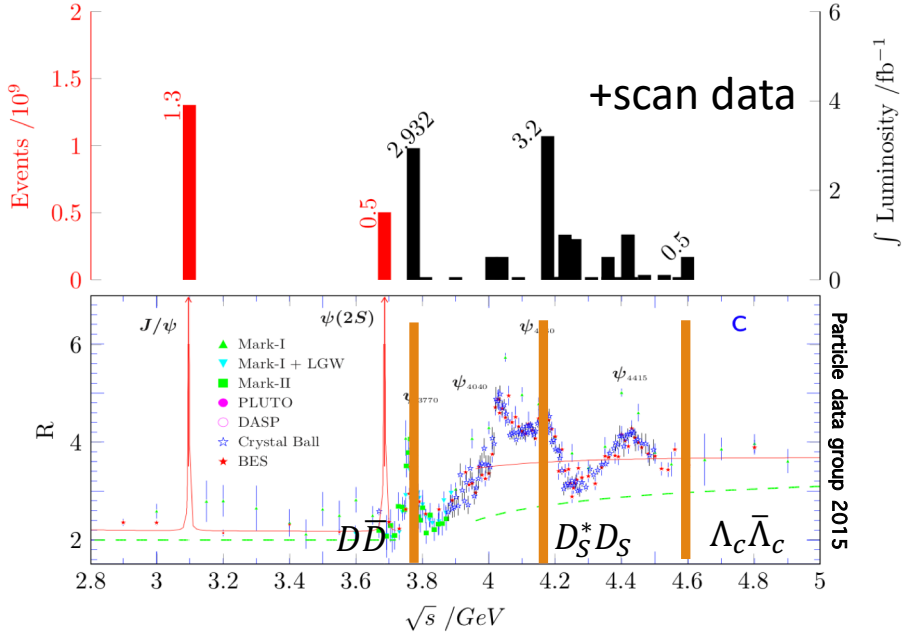


The detector

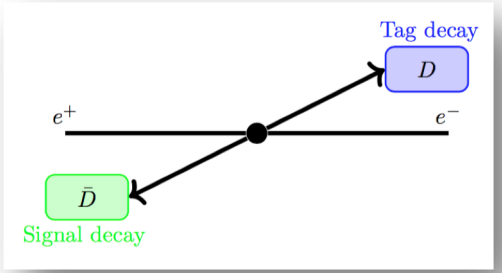
- 93% coverage of the full solid angle
- Main drift chamber $\sigma_p/p = 0.5\%@1GeV$
- Time-of-flight system $\sigma_T = 80ps$
- Elmg. Calorimeter $\Delta E/E = 2.5\%@1GeV$
- Superconducting $1T$ magnet
- Muon system (RPC)



Charm production @ threshold



- Large sample throughout the charmonium region
- Conservation laws hold for the combined decay amplitude
  - ‘Tag’ information of the signal decay



- D^0 flavour
- Charge-parity
- Predict missing track
- Normalization

Charm physics @ BESIII

- (Semi-) Leptonic D decays (WG1, now!)
- CPV and D^0 mixing (WG7, this afternoon)
- Contribution to gamma/phi (WG5, yesterday)
- Λ_c physics

Charm physics @ BESIII

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This talk:

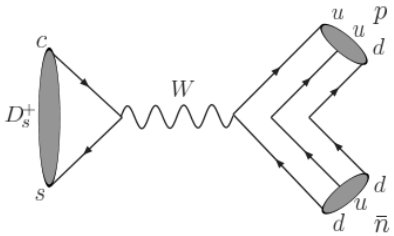
- Branching fraction measurement $D_S^+ \to p\bar{n}$
- Observation of $D \to a_0(980)e^+\upsilon_e$
- Search for ...
  - $D^+ \to D^0 e^+ \upsilon$
  - $D \to h\,(h')e^+e^-$
  - $D^+ \to \gamma e^+ \upsilon_e$

Branching fraction
$D_S^+ \to p\bar{n}$

Branching fraction $D_S^+ \to p\bar{n}$

- The only kinematically allowed baryonic D decay mode
- Help for understanding the dynamical enhancement of W-annihilation
- Evidence by CLEO-c:
  $BR = (1.30 \pm 0.36^{+0.12}_{-0.16})10^{-3}$
- Data set with high cross-section $D_S^* D_S$:
  $3.19 fb^{-1}$ @ $E_{cm} = 4.178 GeV$

Short distance $BR \sim 10^{-6}$



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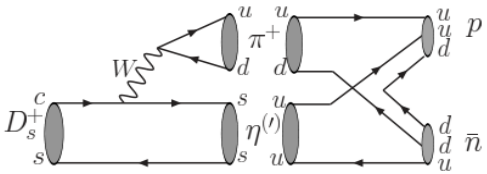

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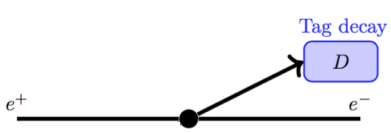
- Double tag analysis

11 tag modes



$K_S^+ K^-$
$K^+ K^- \pi^-$
$K_S^+ K^- \pi^0$
...

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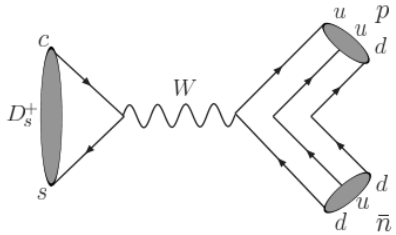

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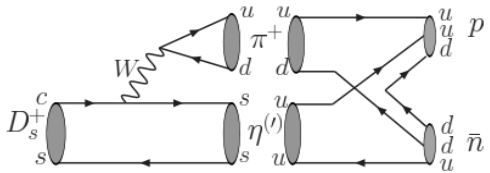

$$\mathcal{B}_{D_s \to p\bar{n}} = \frac{N_{ST}}{}$$

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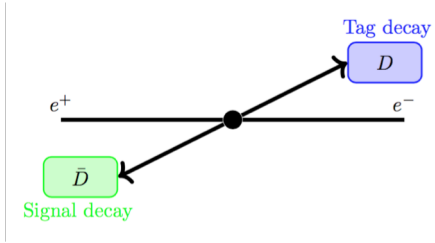

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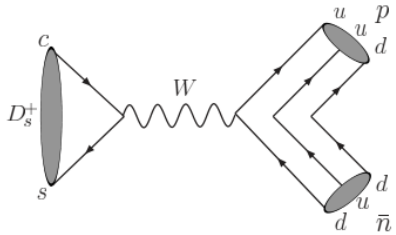

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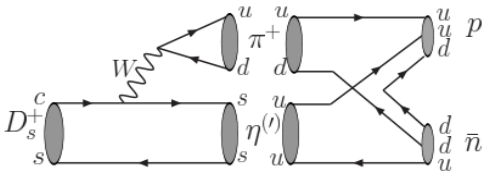

$$\mathcal{B}_{D_s \to p\bar{n}} = \frac{N_{DT}}{N_{ST}}$$

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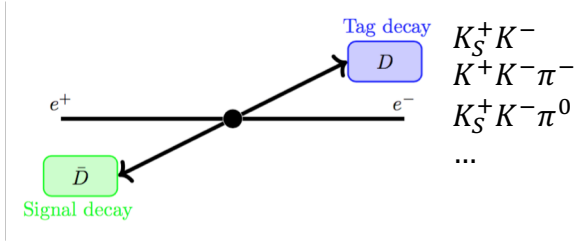

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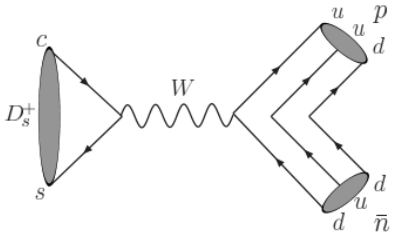

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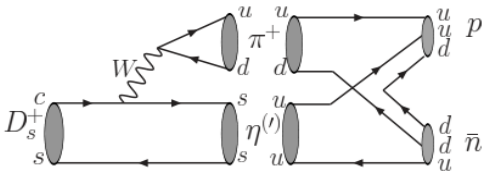

$$\mathcal{B}_{D_s \to p\bar{n}} = \frac{N_{DT}}{N_{ST}} \cdot \frac{\epsilon_{ST}}{\epsilon_{DT}}$$

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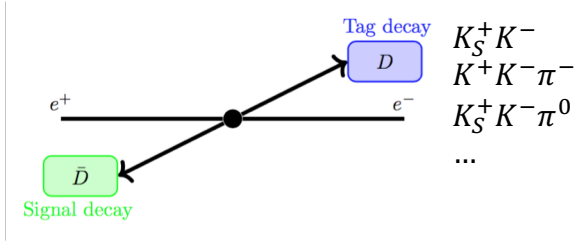

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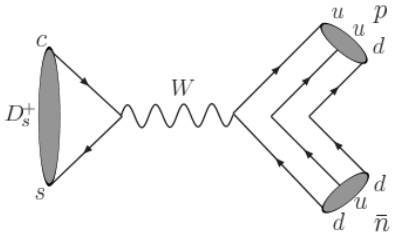

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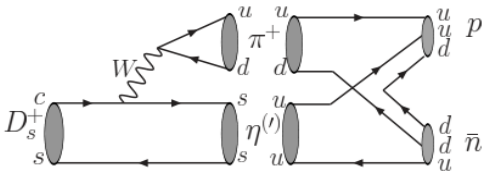

$$\mathcal{B}_{D_s \to p\bar{n}} = \frac{1}{\mathcal{B}_{D_s^* \to \gamma D_s}} \cdot \frac{N_{DT}}{N_{ST}} \cdot \frac{\epsilon_{ST}}{\epsilon_{DT}}$$

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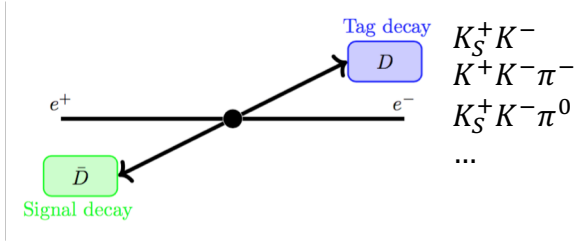

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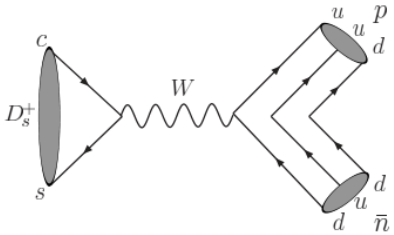

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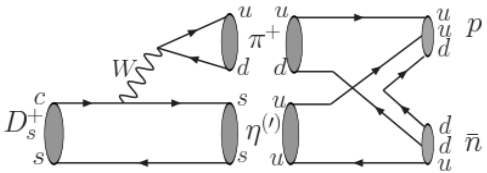
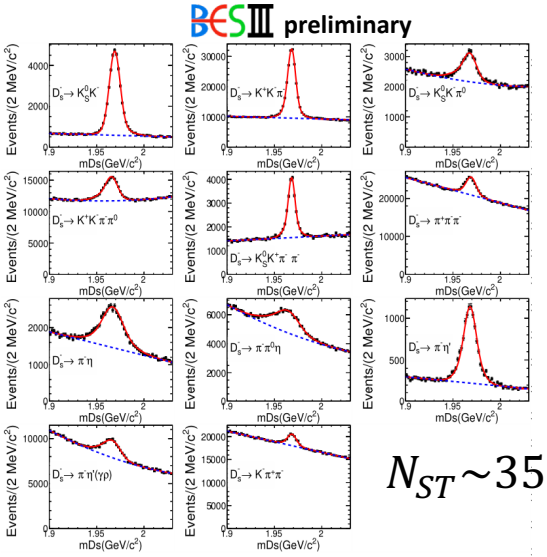


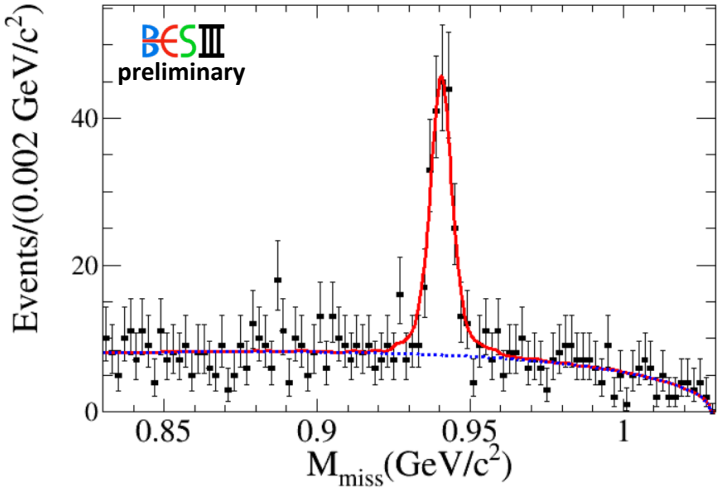
$$\mathcal{B}_{D_s \to p\bar{n}} = \frac{1}{\mathcal{B}_{D_s^* \to \gamma D_s}} \cdot \frac{N_{DT}}{N_{ST}} \cdot \frac{\epsilon_{ST}}{\epsilon_{DT}}$$

$$= \frac{1}{\mathcal{B}_{D_s^* \to \gamma D_s}} \cdot \frac{\sum N_{DT}}{\sum (N_{ST} \cdot \frac{\epsilon_{DT}}{\epsilon_{ST}})}$$

Branching fraction $D_S^+ \to p\bar{n}$



$N_{ST} \sim 350k$



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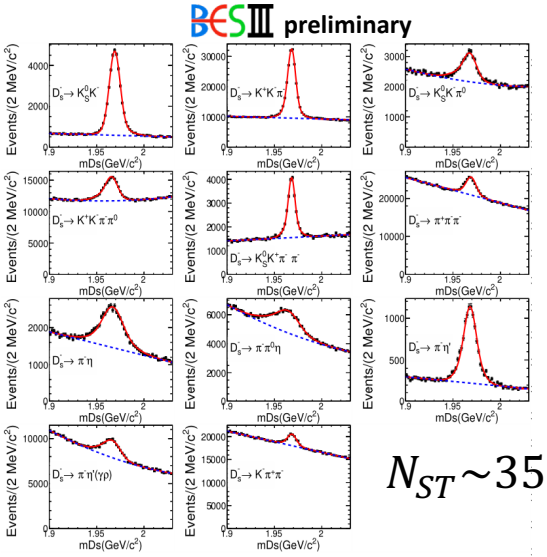

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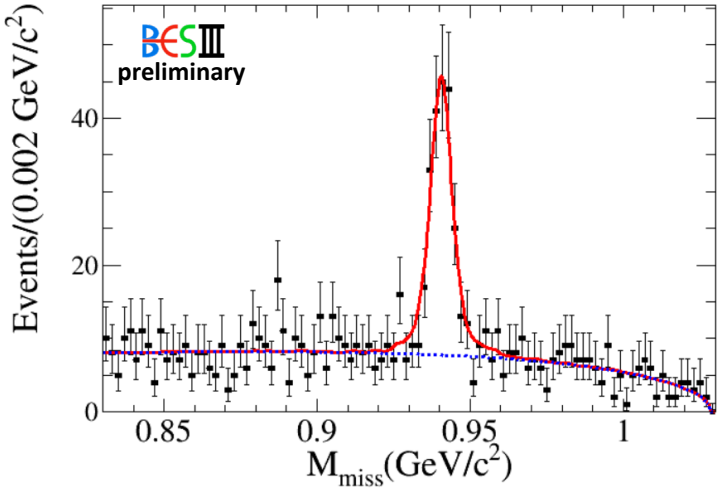


$$\mathcal{B}_{D_s^+ \to p\bar{n}} = (1.22 \pm 0.10) \times 10^{-3}$$

stat. errors only | preliminary

- Improved accuracy
- Consistent with 'long-distance' expectation
- Sys. dominated by baryon PID

Observation of $D \to a_0(980)e^+\nu_e$

Observation of $D \to a_0(980)e^+\upsilon_e$

- Nature of light scalar meson
  - $q\bar{q}$ or $K\bar{K}$ bound state

$$R \equiv \frac{B(D^+ \to f_0 l^+ \nu) + B(D^+ \to \sigma l^+ \nu)}{B(D^+ \to a_0 l^+ \nu)}$$

- Semi-leptonic D decays
  - clean production mechanism
  - limited final state interaction

- Data sample at $D\overline{D}$ threshold:
  2.93fb^{-1} @ $\sqrt{s} = 3.773GeV$

- Final state $a_0(980) \to \eta\pi$

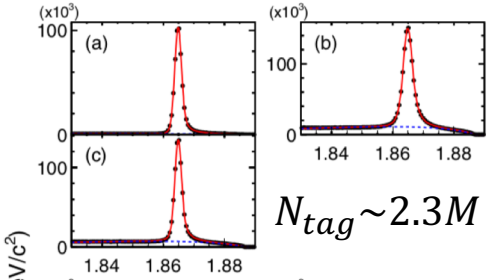
- Double tag analysis:

$$\mathcal{B}_{\text{sig}} = \frac{N_{\text{sig}}^{\text{obs}}}{\sum_\alpha N_{\text{tag}}^{\text{obs},\alpha} \epsilon_{\text{tag,sig}}^{\alpha} / \epsilon_{\text{tag}}^{\alpha}}$$

Branching fraction $D \to a_0(980)e^+\nu_e$

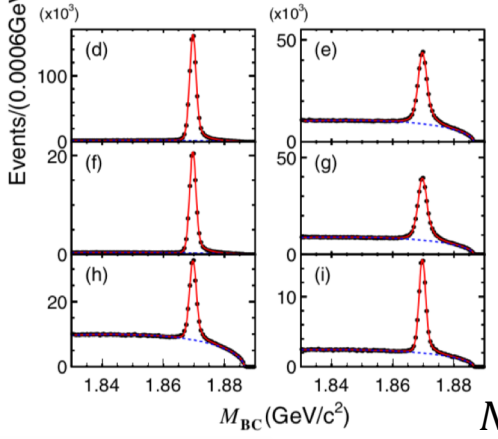
Single tag yield

D^0



N_{tag}~2.3M

D^+



N_{tag}~1.6M

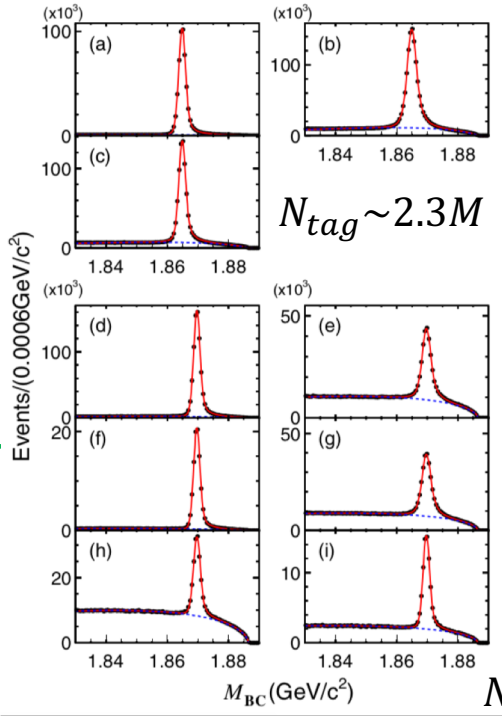
Branching fraction $D \to a_0(980)e^+\nu_e$

Single tag yield

Double tag yield

D^0

D^+



N_{tag}~2.3M

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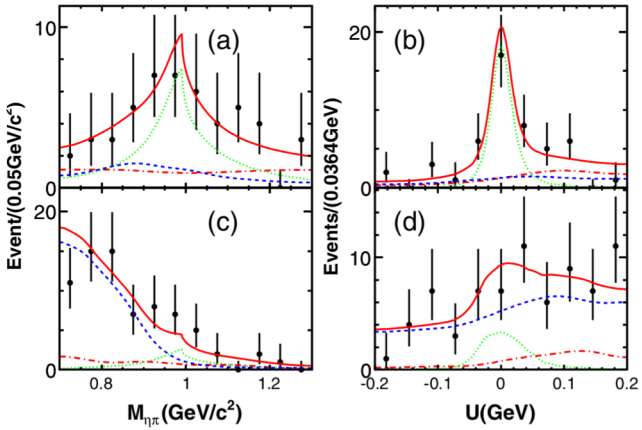

Missing energy:

$U_{miss} = E_{miss} - c|\vec{p}_{miss}|$

Branching fraction $D \to a_0(980)e^+\nu_e$

Single tag yield

Double tag yield

D^0

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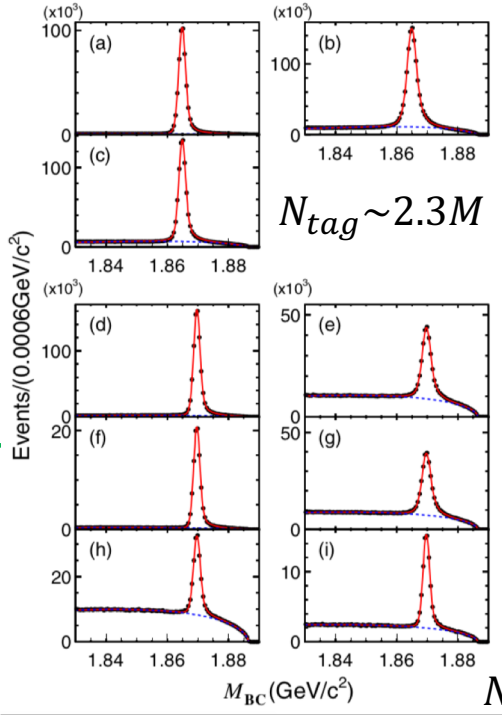

N_{tag}~2.3M

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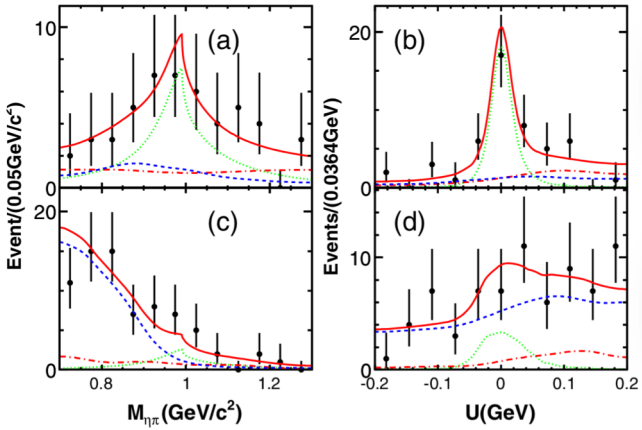

Missing energy:

$U_{miss} = E_{miss} - c|\vec{p}_{miss}|$

$$\mathcal{B}(D^0 \to a_0(980)^- e^+ \nu_e) \times \mathcal{B}(a_0(980)^- \to \eta\pi^-) = (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$$ 6.4σ

$$\mathcal{B}(D^+ \to a_0(980)^0 e^+ \nu_e) \times \mathcal{B}(a_0(980)^0 \to \eta\pi^0) = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4},$$ 2.9σ

$$\frac{\Gamma(D^0 \to a_0(980)^- e^+ \nu_e)}{\Gamma(D^+ \to a_0(980)^0 e^+ \nu_e)} = 2.03 \pm 0.95 \pm 0.06$$

Consistent with isospin sym.

Phys. Rev. Lett. 121, 081802 (2018)

Search for
$D^+ \to D^0 e^+ \upsilon$

Search for $D^+ \to D^0 e^+ \upsilon$

- Heavy quark does not change
- Decay via light quark process
- Theoretical prediction: $\mathrm{BR} \sim 2.77 \cdot 10^{-13}$
  Flavour SU(3) symmetry of light quark
  Eur. Phys. J. C 59, 841 (2009)
- Double tag method
- Data sample at $D\bar{D}$ threshold:
  $2.93\mathrm{fb}^{-1}$ @ $\sqrt{s} = 3.773 GeV$

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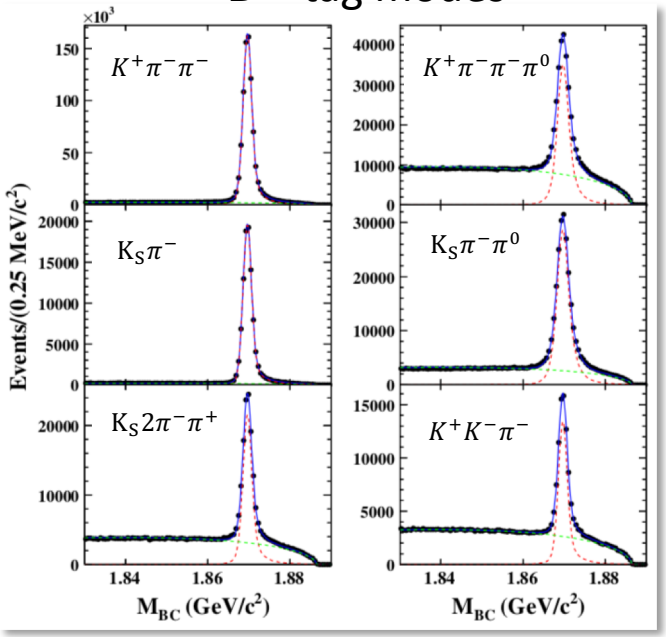
D^- tag modes



$N_{ST} \sim 1.5 \cdot 10^6$

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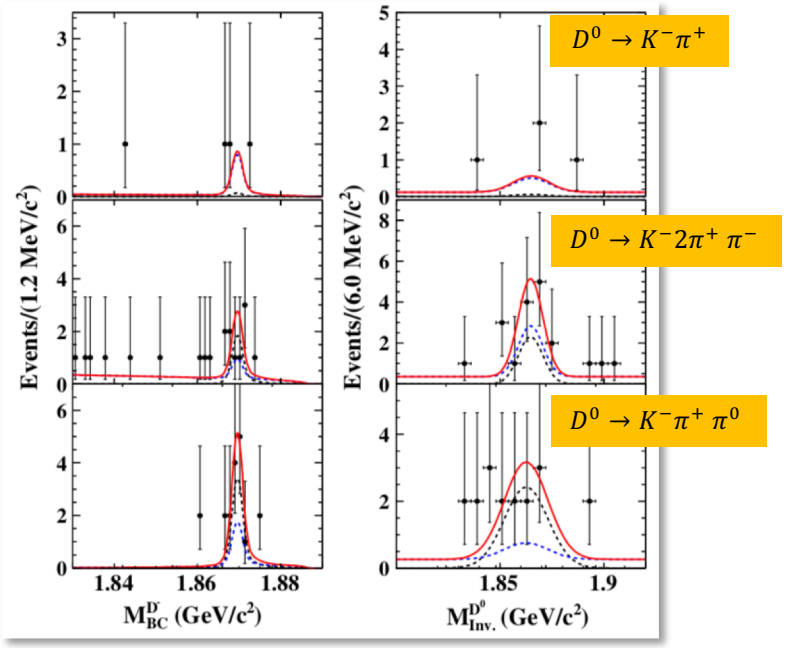

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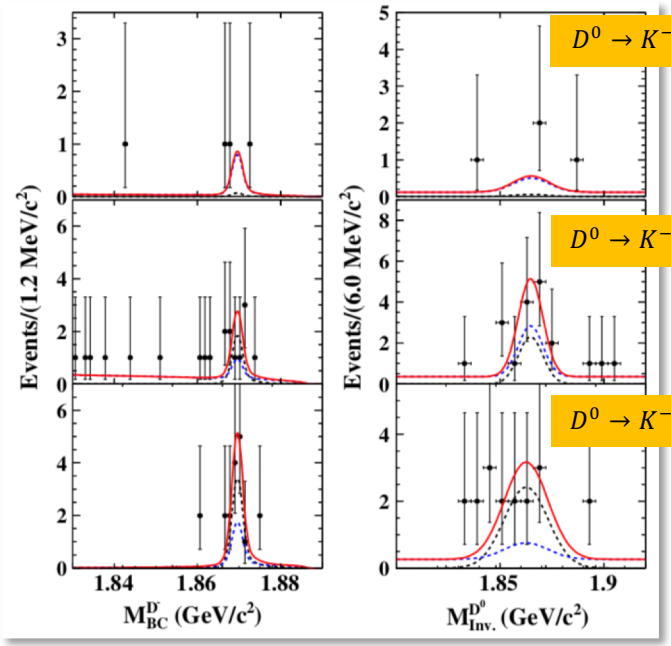
D^0 decay modes



Combined UL:

$$BR(D^+ \to D^0 e^+ \upsilon) < 3.0 \times 10^{-5}$$

@ 90% C.L.

PHYSICAL REVIEW D 96, 092002 (2017)

Search for

$$D \to h\,(h')e^+e^-$$

Search for $D \to h\,(h')e^+e^-$

- FCNC transition $c \to ul^+l^-$ forbidden on tree level
- Short distance: Loop level $BF \sim 10^{-9}$
  - ➢ Contributions from new physics models
- Long distance: $BF \sim 10^{-6}$

  $$D \to hV^{(*)} \to hl^+l^-$$

  - ➢ overshadow FCNC processes
- Recent observations of $D^0 \to h\,(h')\mu^+\mu^-$
- Yet, no observations in e^+e^- final states

- Data sample at $D\overline{D}$ threshold:

  $$2.93\text{fb}^{-1}\ @\ \sqrt{s} = 3.773GeV$$

- Single tag yields:
  $D^+ \sim 1.5 \cdot 10^6$, $D^0 \sim 2.2 \cdot 10^6$

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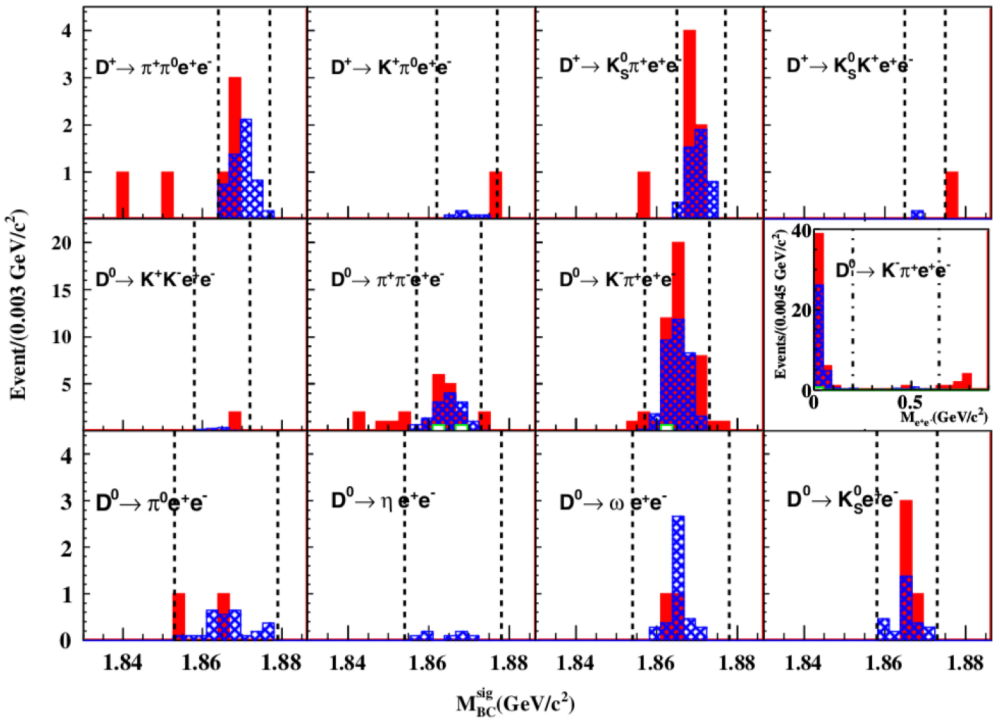

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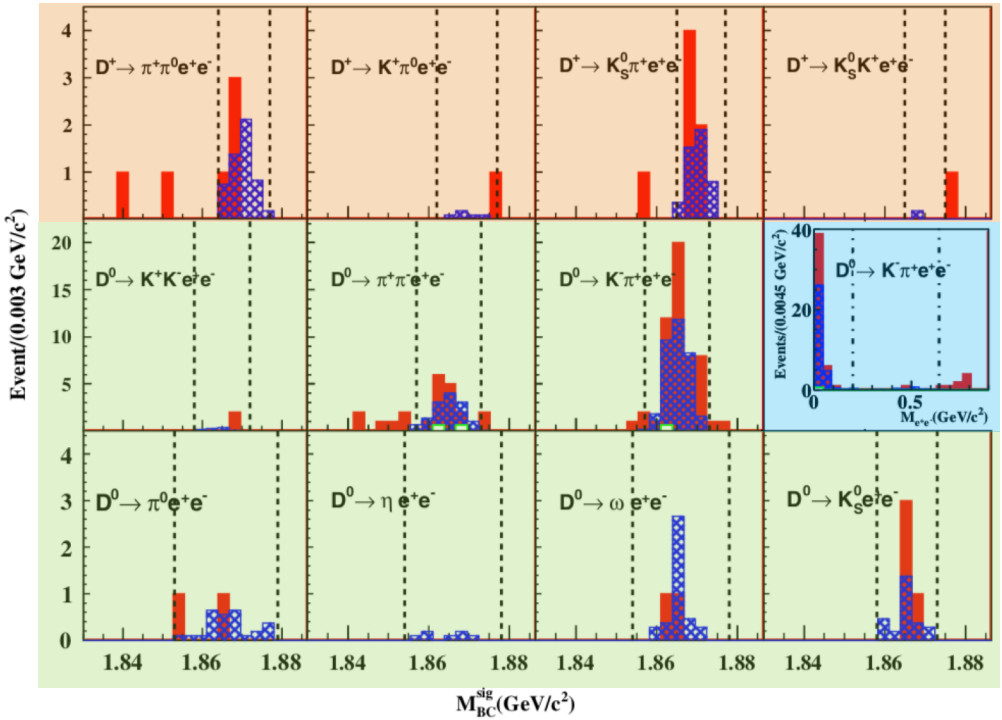

Signal decays	$\mathcal{B}$ ($\times 10^{-5}$)	PDG [9] ($\times 10^{-5}$)
$D^+ \to \pi^+\pi^0 e^+e^-$	<1.4	···
$D^+ \to K^+\pi^0 e^+e^-$	<1.5	···
$D^+ \to K^0_S\pi^+ e^+e^-$	<2.6	···
$D^+ \to K^0_S K^+ e^+e^-$	<1.1	···
$D^0 \to K^-K^+e^+e^-$	<1.1	<31.5
$D^0 \to \pi^+\pi^-e^+e^-$	<0.7	<37.3
$D^0 \to K^-\pi^+e^+e^-$ †	<4.1	<38.5
$D^0 \to \pi^0 e^+e^-$	<0.4	<4.5
$D^0 \to \eta e^+e^-$	<0.3	<11
$D^0 \to \omega e^+e^-$	<0.6	<18
$D^0 \to K^0_S e^+e^-$	<1.2	<11
† in $M_{e^+e^-}$ regions:		
$[0.00, 0.20)$ GeV/c^2	$<3.0\ (1.5^{+1.0}_{-0.9})$	···
$[0.20, 0.65)$ GeV/c^2	<0.7	···
$[0.65, 0.90)$ GeV/c^2	$<1.9\ (1.0^{+0.5}_{-0.4})$	···

- UL $\mathcal{O}(10^{-5} \sim 10^{-6})$
- Significant improvements in UL

Phys.Rev.D97, 072015 (2018)

Search for

$$D^+ \to \gamma e^+ \nu_e$$

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- Strong interaction effects theoretically simple
- SM predictions range from 10^{-6} to 10^{-4}
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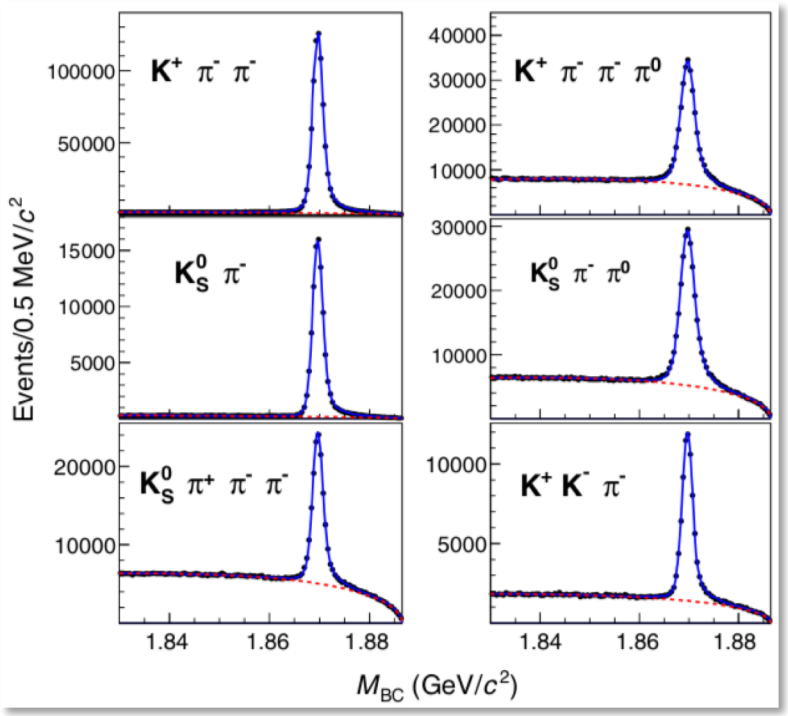

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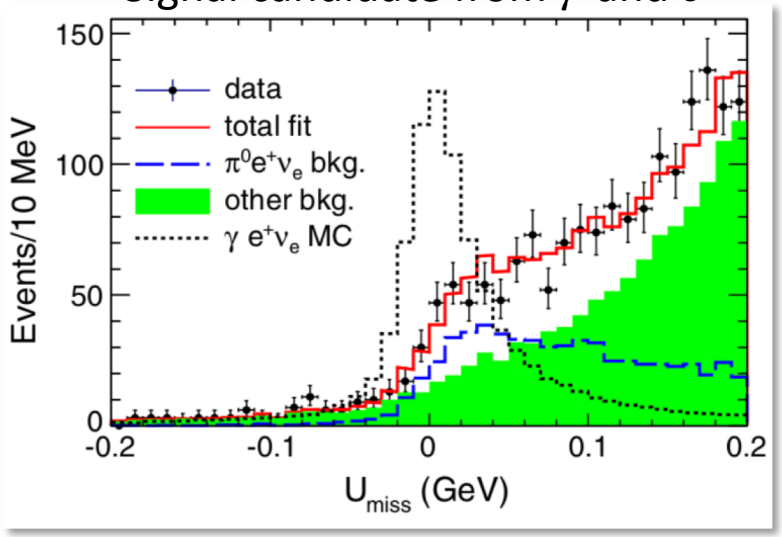
Signal candidate from γ and e^+



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@ 90% C.L.

- Largest systematic from EMC shower model
- More data needed to discriminate th. models

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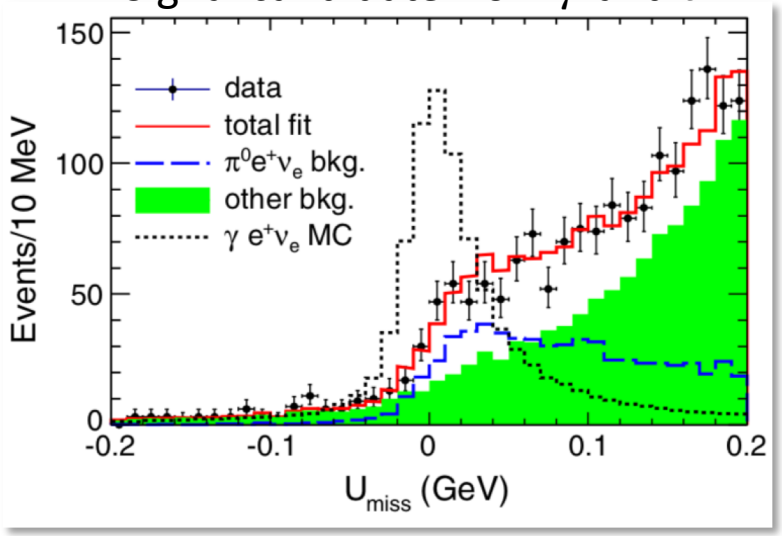
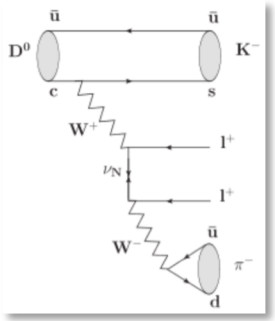


Phys. Rev. D. 95, 071102 (2017)

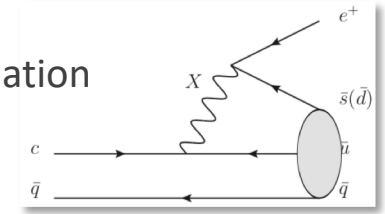
Outlook … ongoing analyses

- $D \to K\pi e^+ e^+$ search for LNV
  - Previous limits 10^{-4} … 10^{-5} **PRL 86, 3969(2001)**
  - Expected BESIII precision 10^{-6}
  - close to publication



- Search for $D \to \pi^0 \upsilon\bar{\upsilon}$
  - Theoretically clean
  - Long distance effects suppressed

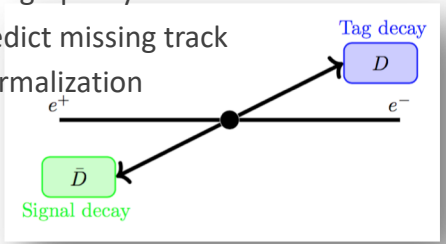
- Baryon/Lepton number violation in $D^+ \to \Lambda(e^+)$ and $\Sigma(e^+)$



- …

Summary

- BESIII provides large data samples close to charm related thresholds
- Correlated $D\overline{D}$ production offers unique opportunities
  - D^0 flavour
  - Charge-parity
  - Predict missing track
  - Normalization



- Improved $\mathcal{BF}\ D_S^+ \to p\bar{n}$
- Observation of $D \to a_0(980)e^+\upsilon_e$
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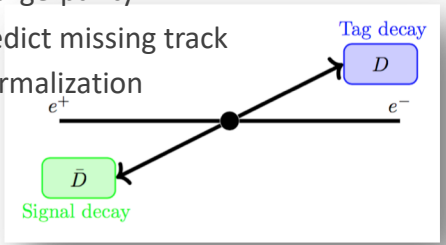

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$$D\overline{D} \quad 2.93fb^{-1} \to 20fb^{-1}$$
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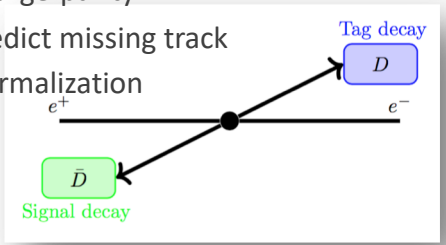

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Thank you for your attention!