Open-Charm Session

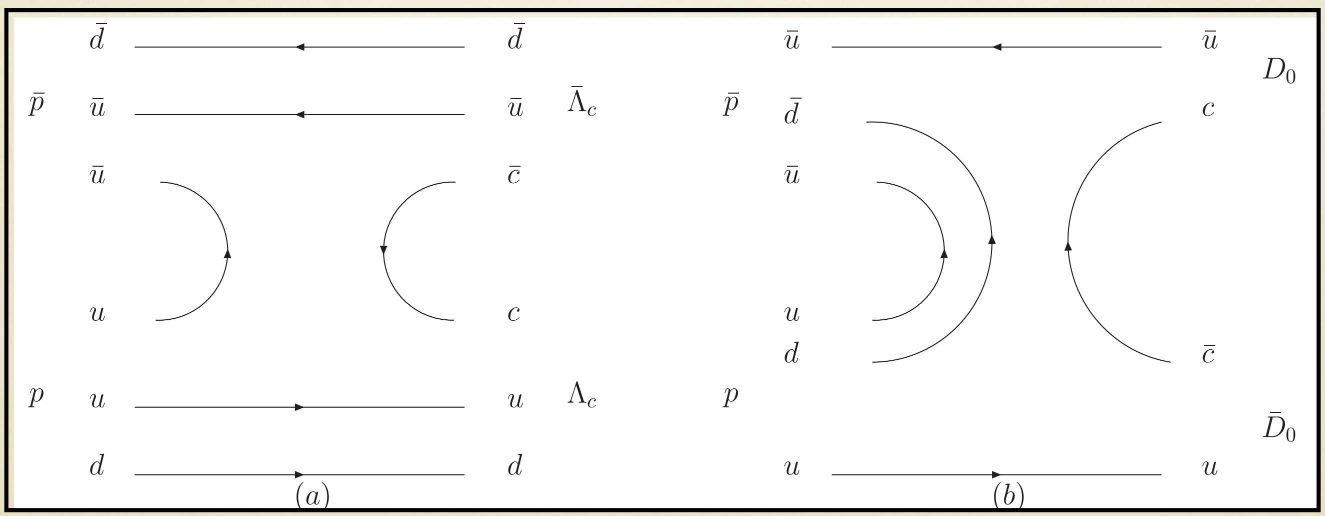
F.K.A. heavy-light+electroweak

Today's agenda

- **Sorry, no work reports today**
  - unless any ad-hoc contributions?
- **Overall status of open-charm activities**
  - physics goals?
  - who is doing what?
  - missing analysis items?
- **Looking ahead**

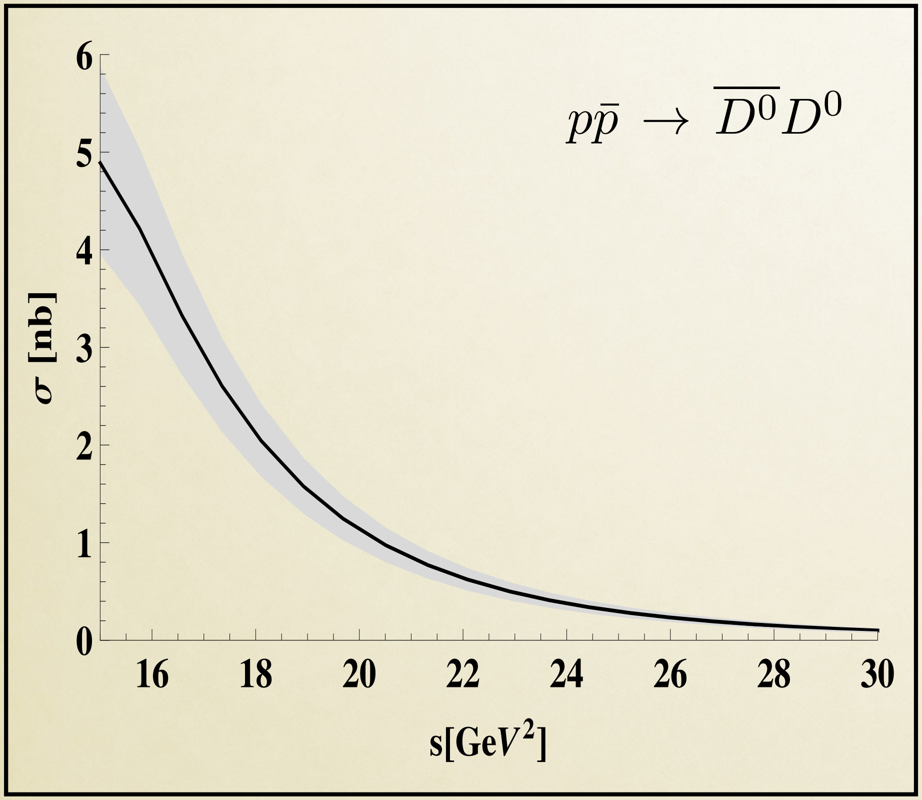
Open-charm with PANDA: "opportunities with challenges"

- **Key physics items for PANDA?**
  - fierce competition from BESIII, Belle2, LHCb, ..
  - interaction with TAG
- **Open-charm production in p-pbar?**
  - predicted cross sections vary from *nano* to *micro* barns
  - interesting physics in production mechanisms?
- **Open-charm with p-pbar far from trivial**
  - *huge* background to cope with cross section: up to ~50 mbarn
  - requires "complete" detector and over-redundancy

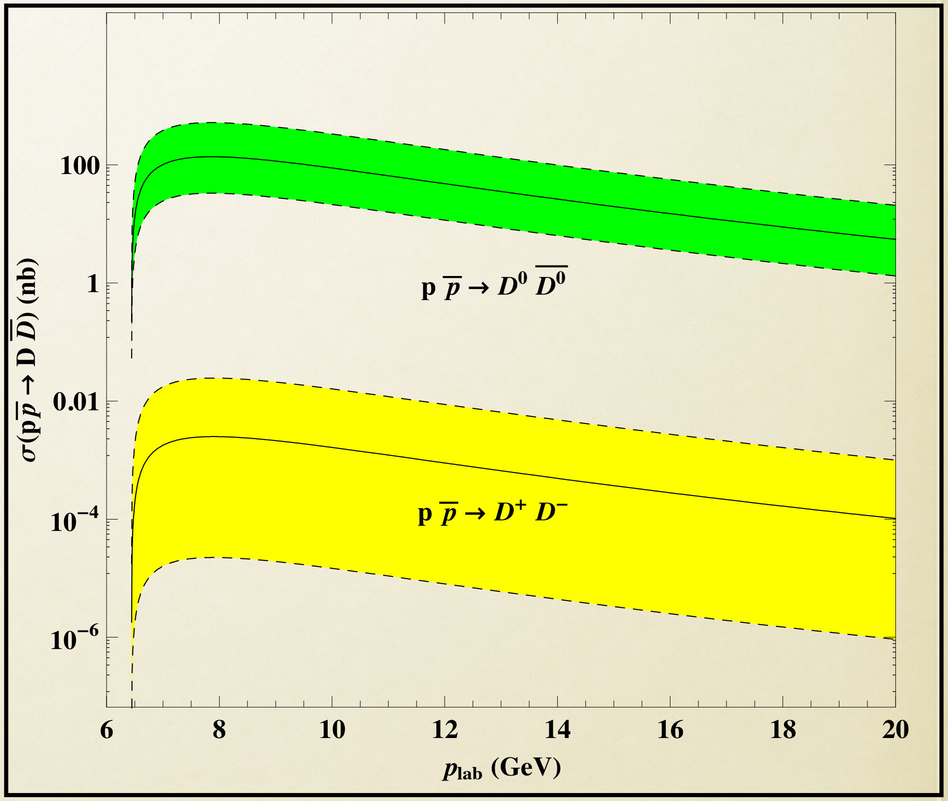


Open-charm with PANDA: "opportunities with challenges"

- **Non-resonant production**



Goritschnig,Kroll,Pire,Schweiger - EPJA42, 43 (2009), arXiv:1311.1607
(double handbag approach: pQCD motivated)

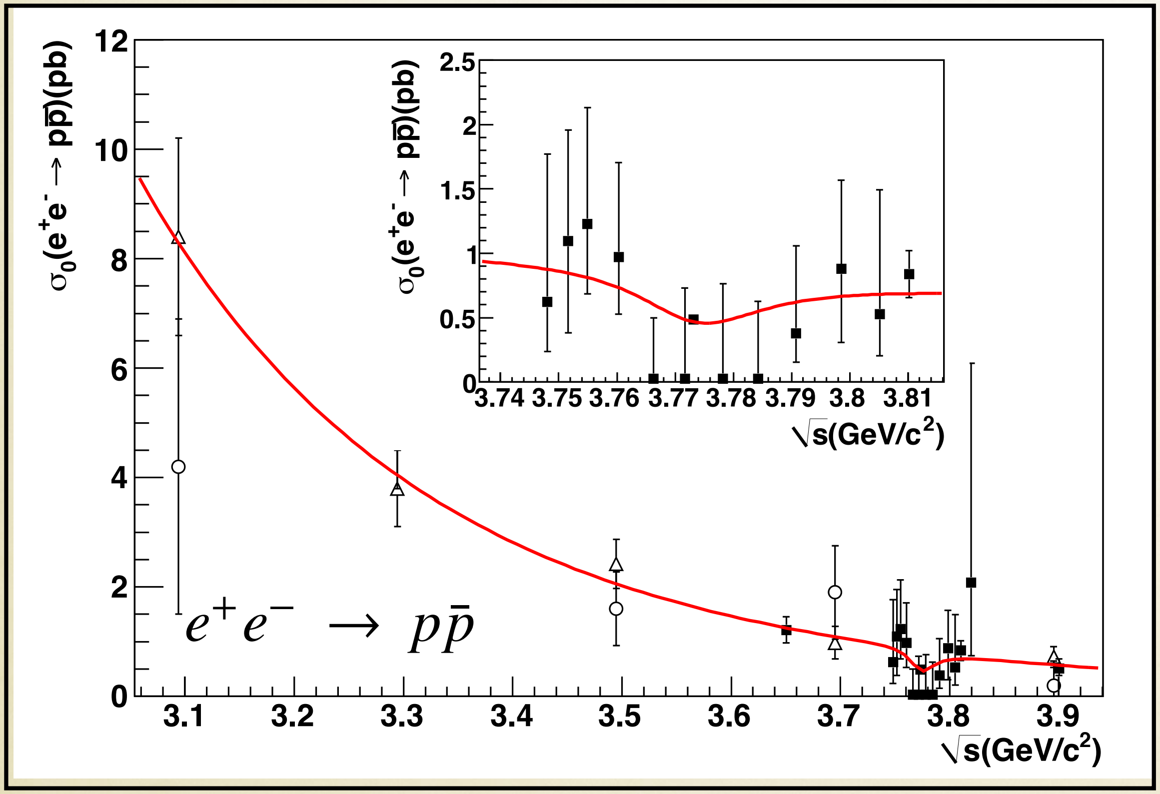


Khodjamirian,Klein,Mannel,Wang - arXiv:1111.3798
(baryon-meson couplings (light-cone sum rule) input to quark-gluon string model)

?????

Open-charm with PANDA: "opportunities with challenges"

- **Resonant production**



BESIII, arXiv:1403.6011
(Giessen group)

"detailed balance"

$$p\bar{p} \to \Psi(3770)$$

$$\sigma < 17.2 \text{ nb}$$

or

$$\sigma = 425 \pm 43 \text{ nb}$$

?????

$$\sigma(s) = |A_{con} + A_\psi e^{i\phi}|^2$$

$$= \left| \sqrt{\sigma_{con}(s)} + \sqrt{\sigma_\psi} \frac{m_\psi \Gamma_\psi}{s - m_\psi^2 + i m_\psi \Gamma_\psi} e^{i\phi} \right|^2$$

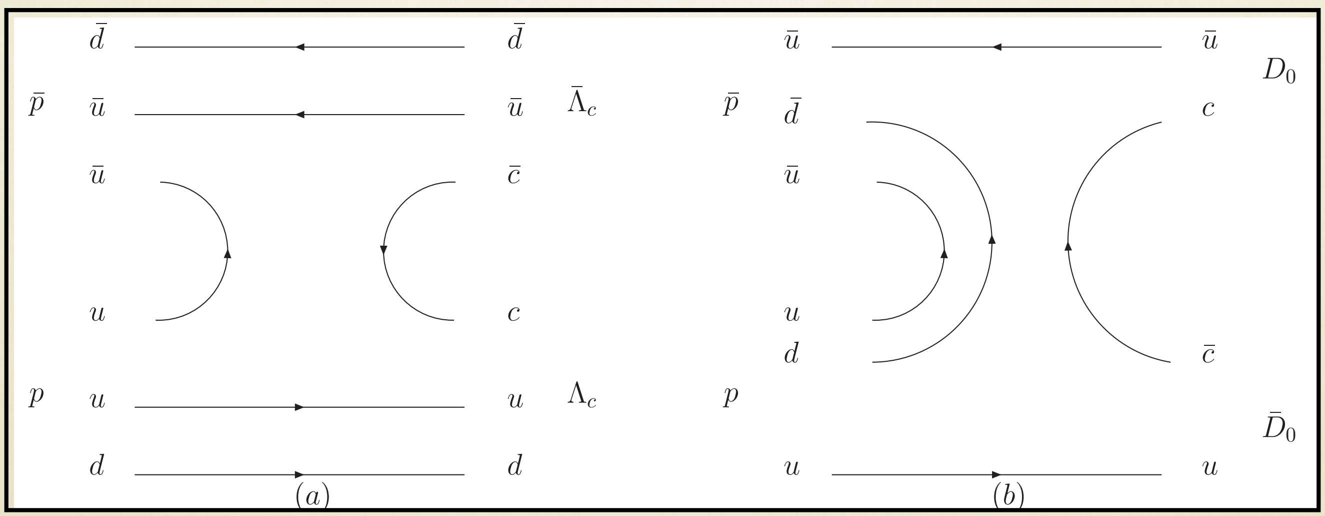
Identified Topics

- **Open-charm production in p pbar**
- **$D_{(s)}$ Spectroscopy: exotics, transitions & decays**
- $\Lambda_c/\Sigma_c/\Xi_c$ **Spectroscopy: [see above]**
- **Form Factors: (semi-)leptonic decays**
- **Electroweak: (in)direct CPV, rare decays**

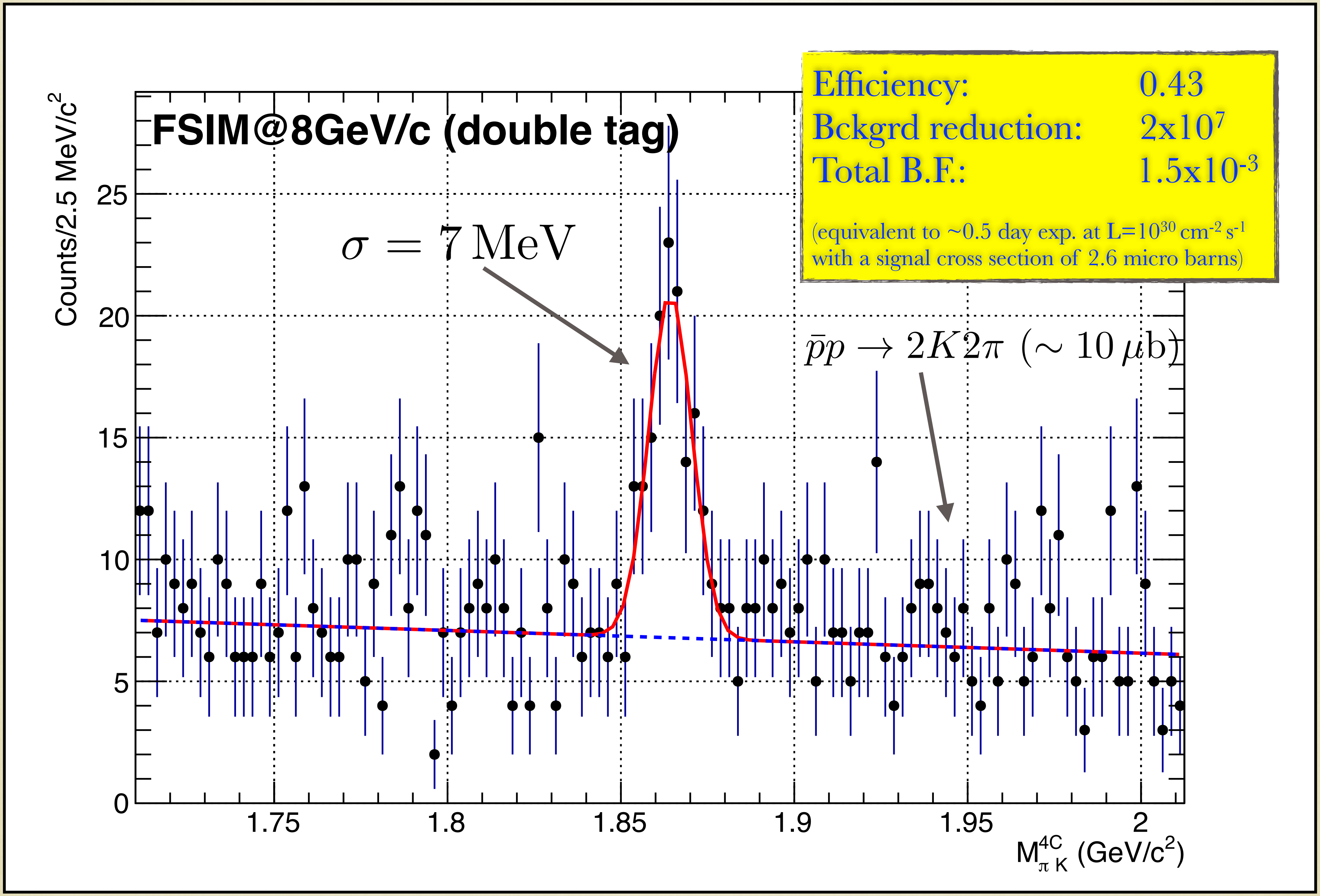
Open-charm production

Groningen, Juelich, …

Alexandros Apostolou, Andreas Herten, Solmaz Vejdani, …

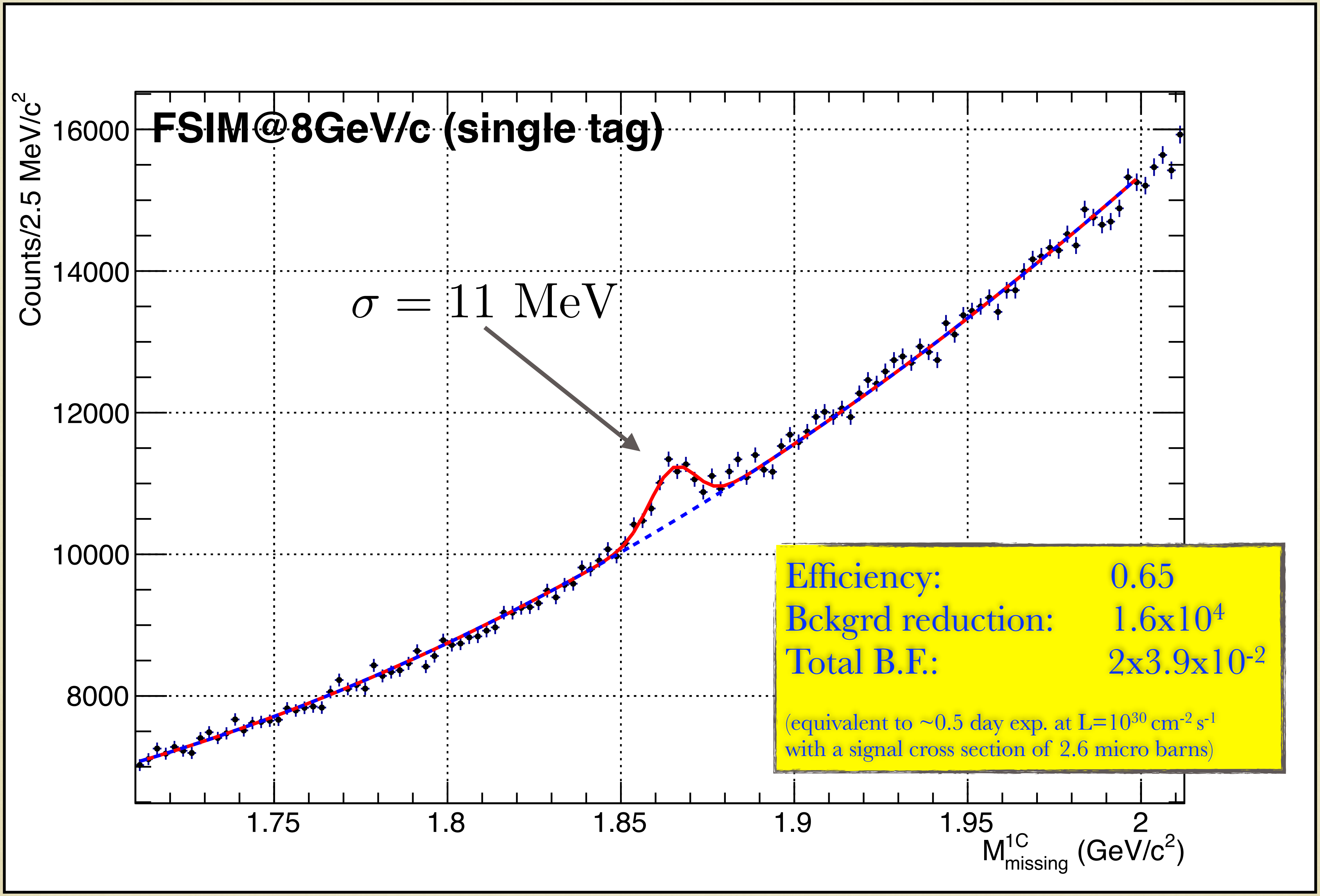


Exclusive: $p\bar{p} \rightarrow D^0\bar{D}^0 \rightarrow (K^-\pi^+)(K^+\pi^-)$ *Alexandros Apostolou, J.M. (KVI-CART)*



Only cuts on kinematics: 4C kin.fit, mass window on opposite Kpi pair

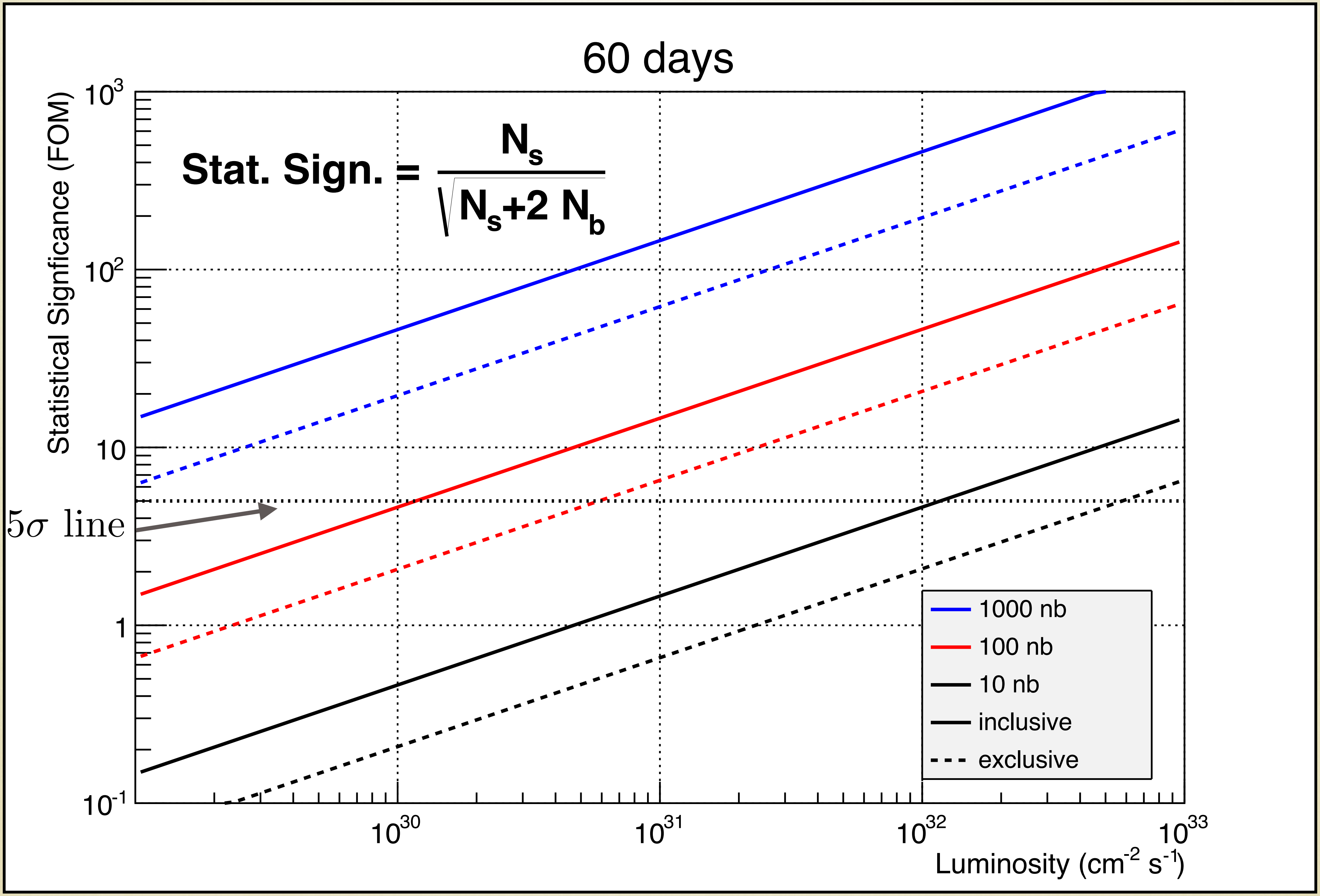
Inclusive: $p\bar{p} \to D^0 \bar{D}^0 \to (K\pi) + X$ *Alexandros Apostolou, J.M. (KVI-CART)*



Only cuts on kinematics: 1C kin.fit, mass window on tagged Kpi pair

Figure Of Merit

Alexandros Apostolou, J.M. (KVI-CART)

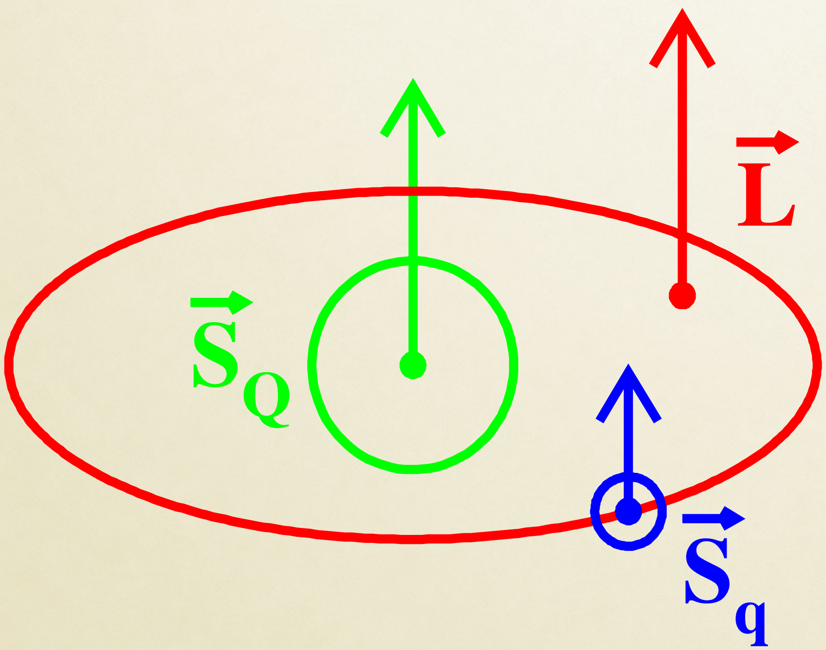


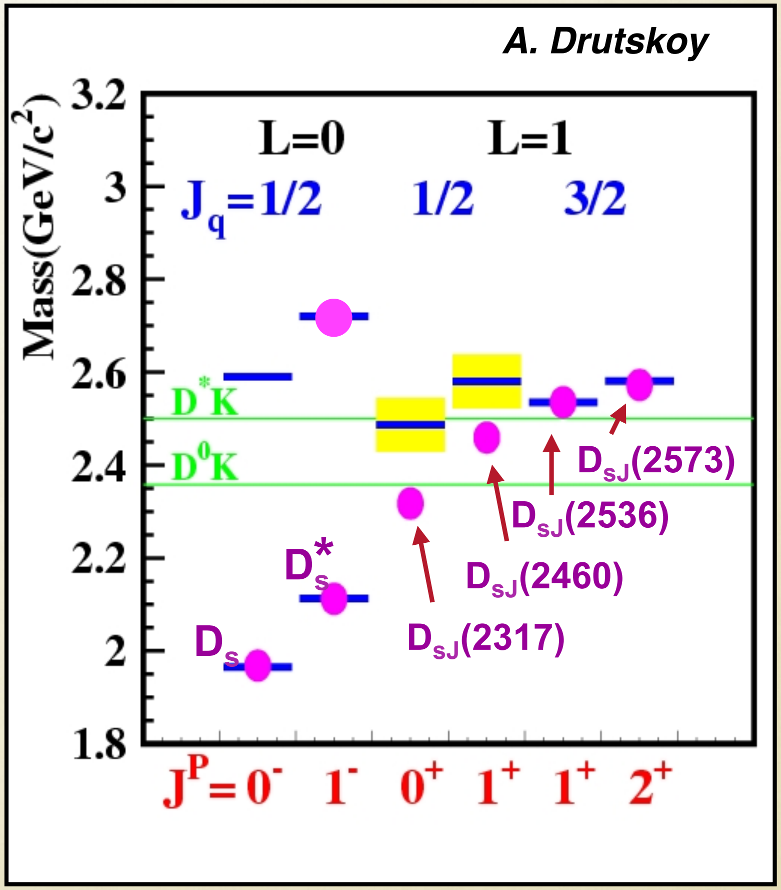
$D_{(s)}$ SPECTROSCOPY

(EXOTICS, TRANSITIONS, STRONG DECAYS, ...)

Giessen, Juelich, ...

Andreas Herten, Andreas Pitka, Elisabetta Prencipe, ...



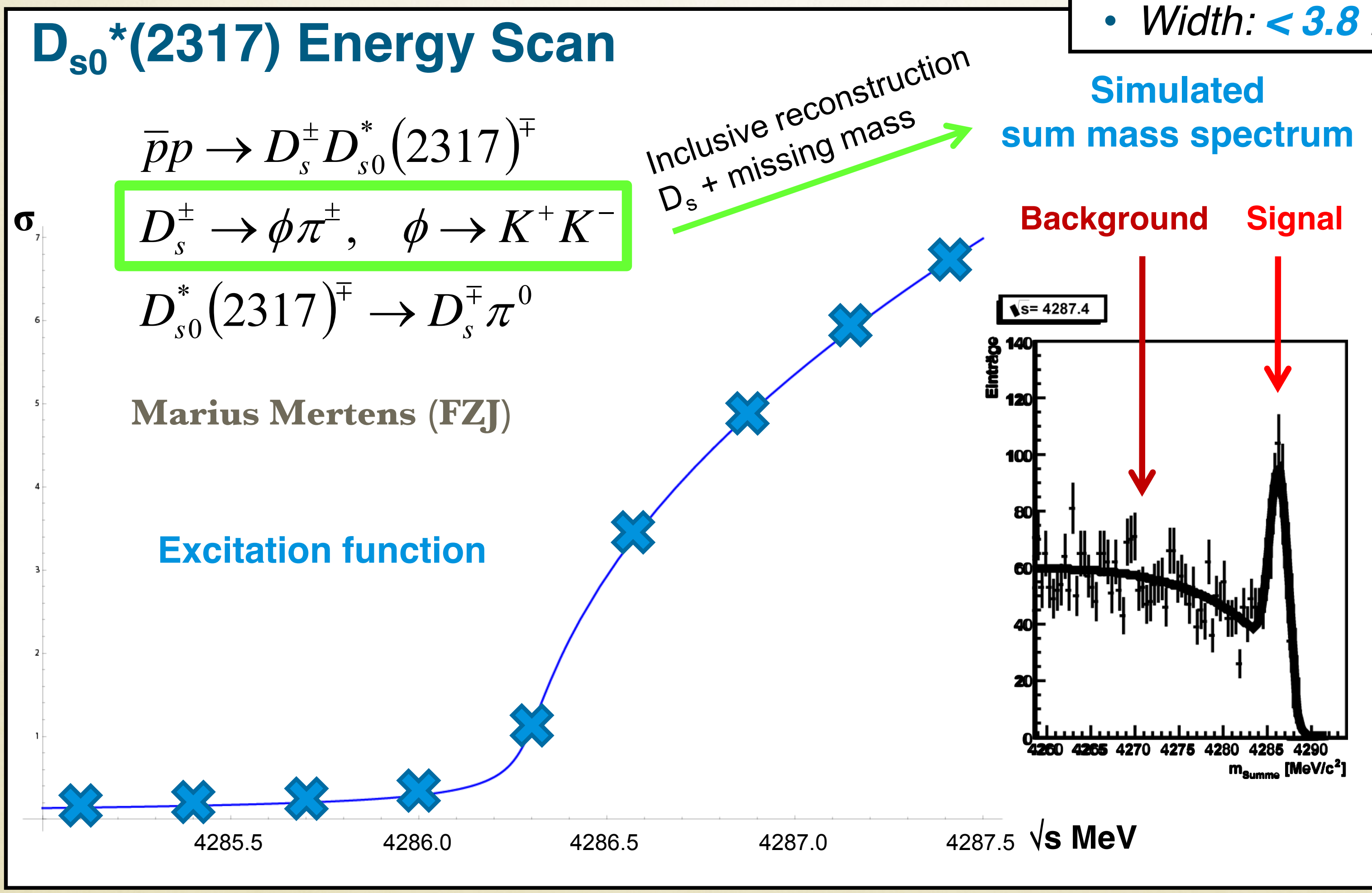


PANDA opportunities in D/D$_s$ spectroscopy

- **Mass and width determination**
  - models give large variations in width: 5-200 keV for $D_{s0}^*(2317)$
  - many upper limits for $D_{(s)}$ states

$D_{s0}^*(2317)$ world average (PDG)

- *Mass: 2317.8 ± 0.6 MeV/c²*
- *Width: < 3.8 MeV/c²*



PANDA opportunities in D/D_s spectroscopy

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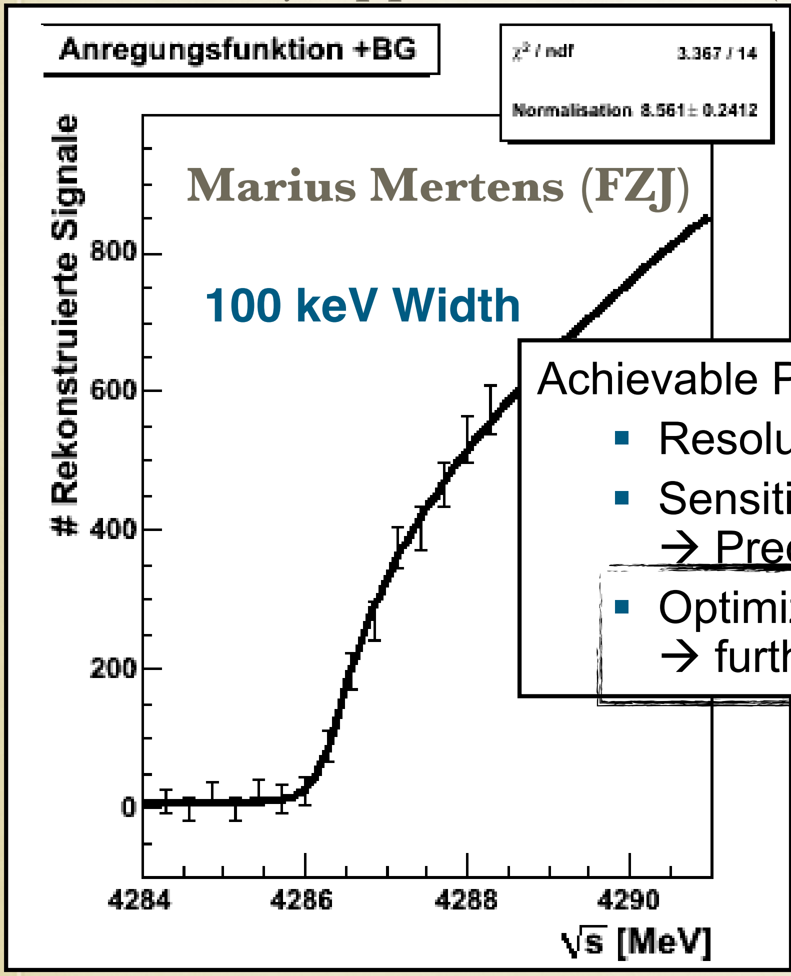


60·9000 nb^{-1}, 5 nb at 5 MeV above threshold

Momentum spread: $\delta p/p_0 = 10^{-4}$
Absolute positioning: $\delta p_0/p_0 = 10^{-4}$
Relative positioning: $\delta\Delta p/\Delta p = 10^{-5}$

Achievable PANDA performance

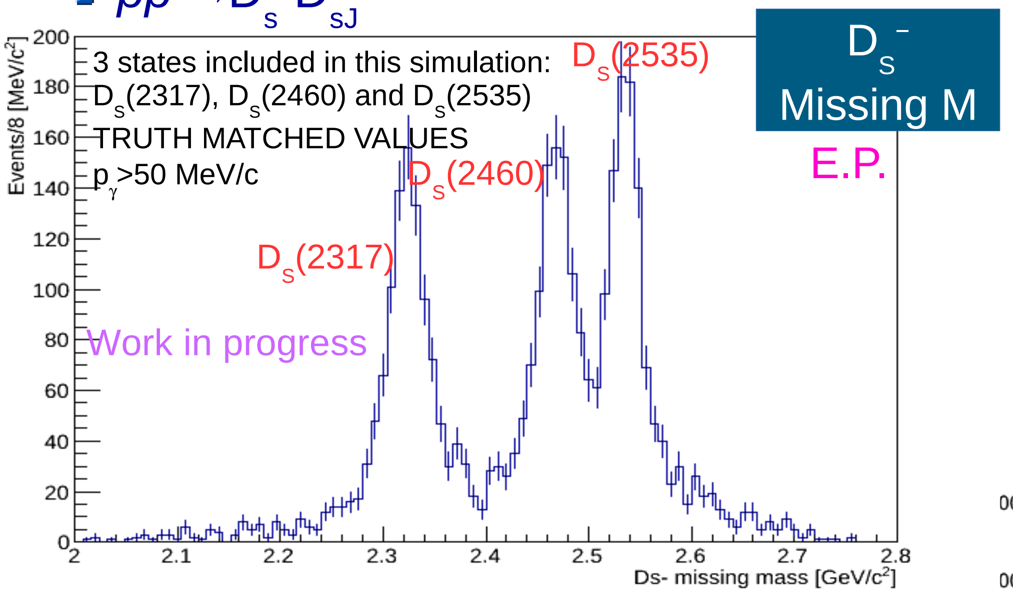
- Resolution of the width: ~ 0.1 MeV/c^2
- Sensitivity to background
  → Precision increases with higher production cross section
- Optimization of scanpoints
  → further improvement of results possible

Elisabetta Prencipe (FZJ)

Ds SPECTROSCOPY WITH PANDA

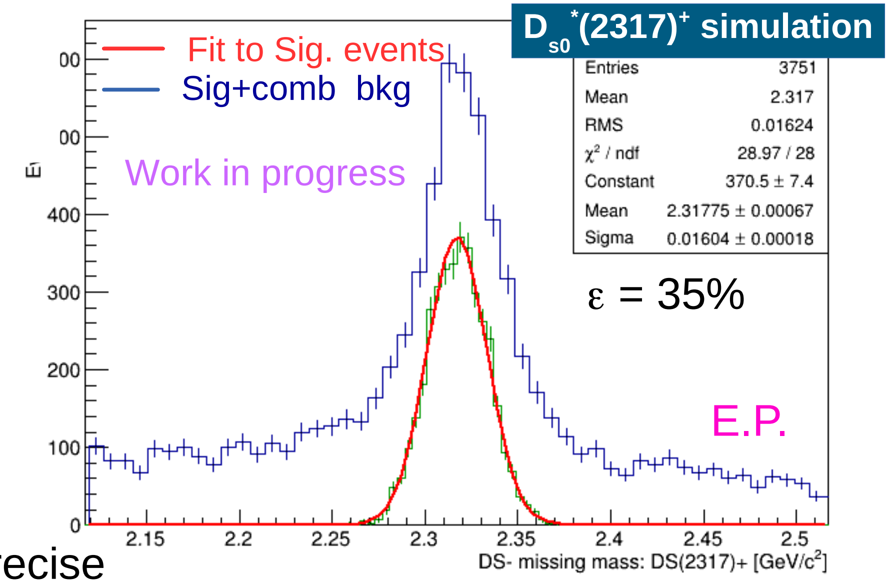
Challenges in D_s meson spectroscopy

- $\bar{p}p \rightarrow D_s^- D_{sJ}^+$



- Missing mass of D_s^-: improve mass resolution and efficiency
- D_{SJ} reconstructed exclusively to evaluate the width
- Bkg cross section > thousand times than expected on signal
- Expected ~$(10^3$-$10^5) \cdot \varepsilon$ events/day

high res. mode



- Goals:

1. Cross section measurement in $\bar{p}p$ (unknown, difficult predictions: 1-100 nb)
2. Measurement of the width with mass scan and the excitation function of cross section
3. Mixing between D states with same spin, e.g. $D_{S1}(2460)$ and $D_{S1}(2535)$
4. Chiral symmetry breaking, involving very precise mass measurement: $D_{S0}(2317)$ and $D_{S1}(2460)$ can be interpreted as chiral partners of the same heavy-light system

PANDA opportunities in D/D_s spectroscopy

- **Radiative transitions**
  - limited data available
  - model sensitive and calculable as well!
- **Soft pion transitions**
  - isospin breaking mechanism in D_s
  - low-energy with Goldstone bosons
  - mixing of 1+ states: f.e, D_{sJ}(2460,2536)—>D*pi
- **Search for D-waves and "exotics"**
  - expect higher production rate in p-pbar than in e+e-
  - determine spin-parity of existing candidates
  - *new* discovery from LHCb: D^*_{s1}(2860) mixture with D^*_{s3}(2860) - arXiv:1407.7574
- **Light quark spectroscopy**
  - study light (strange) meson spectrum in hadron decays (PWA)
  - ideal $J^P=0^-$ beacons

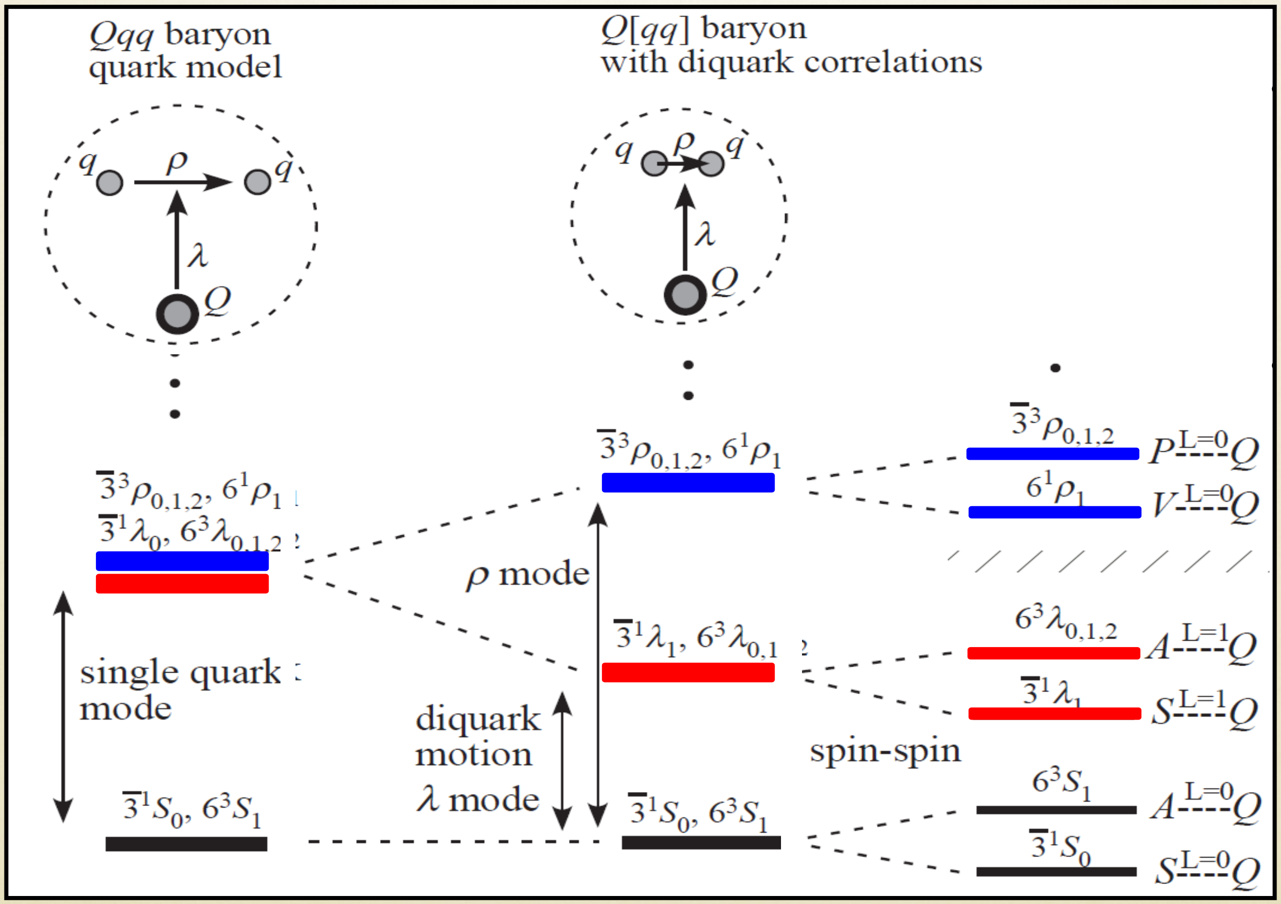
*Many opportunities for *you* to join the efforts!*

CHARM BARYON SPECTROSCOPY

Groningen, Juelich, …

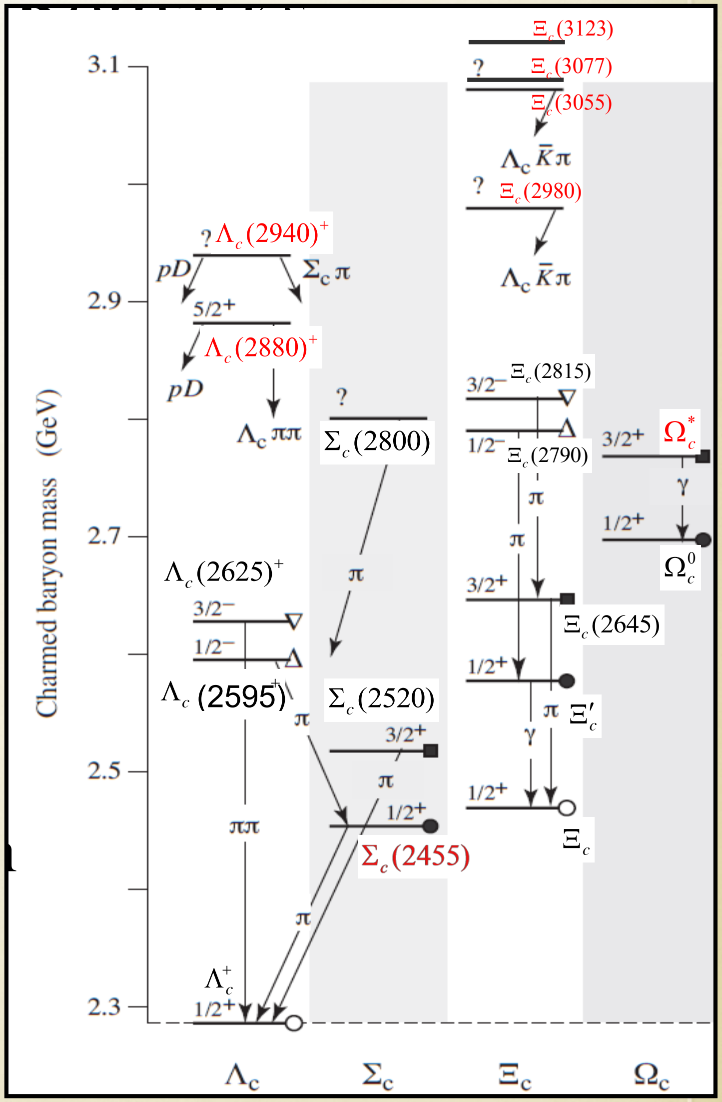
You??…

(strong overlap with Baryon working group)



CHARM BARYON SPECTROSCOPY PANDA OPPORTUNITIES

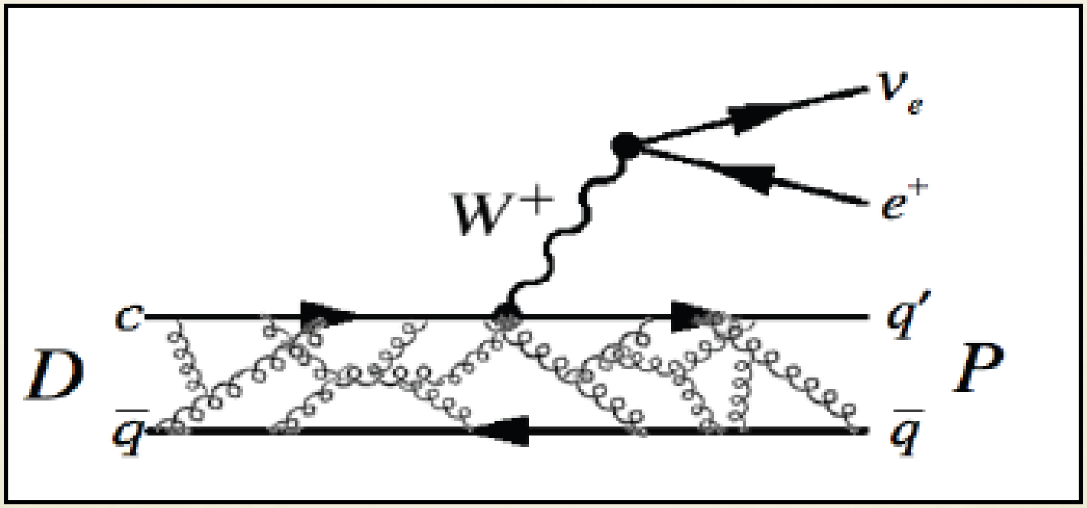
- **Strong decays of charm baryons**
  - soft pion transitions —> HHChPT
  - direct determination of pion couplings:
  - g_1-g_2 (s to s-wave) and h_2-h_{18} (p to s-wave)
  - requires measurements of partial widths
- **Electromagnetic decays of charm baryons**
  - test role of heavy quark and chiral symmetry (HHChPT)
  - f.e. g_1 determination via $\Gamma(\Xi_c'^{*0} \to \Xi_c^0\gamma)$
  - exp. challenging, BF are expected to be tiny
- **Molecular states & heavy baryons?**
  - many predictions of molecular states from coupled-channels models



Form factors/decay constants: (semi)leptonic decays

Juelich, Mainz, Muenster, …

Lu Cao, …

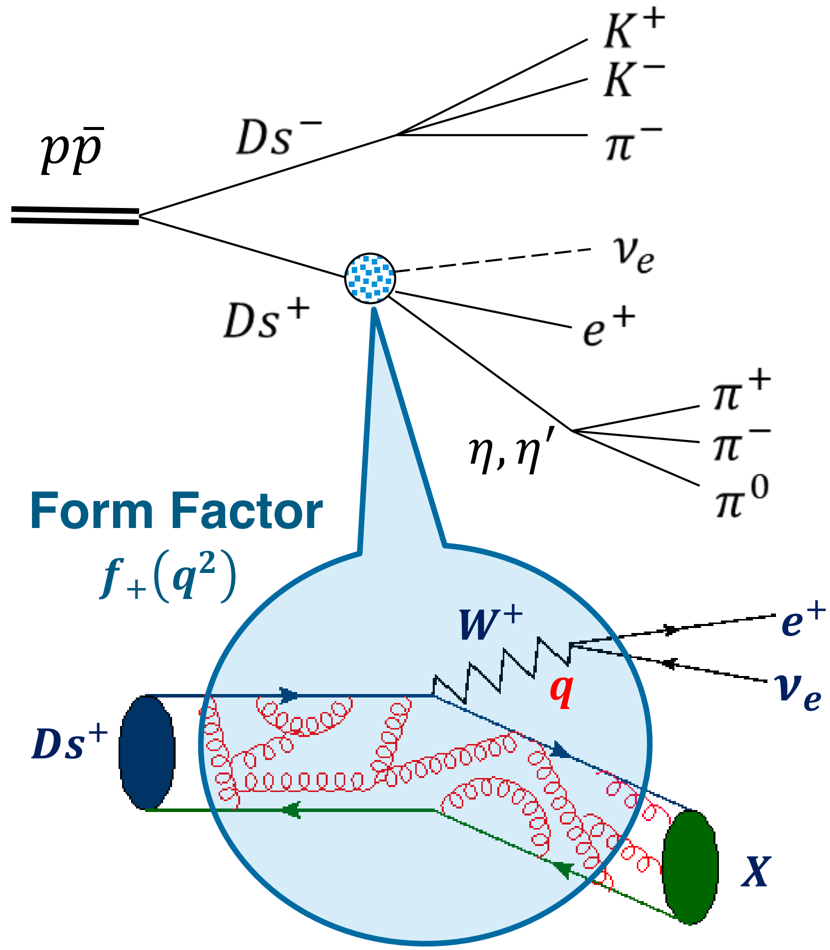


$$\frac{d\Gamma\left(D \to K(\pi) e\nu\right)}{dq^2} = \frac{G_F^2 \left|V_{cs(d)}\right|^2 P_{K(\pi)}^3}{24\pi^3} \left|f_+\left(q^2\right)\right|^2$$

D_s SEMI-LEPTONIC DECAY

Lu Cao (FZJ)

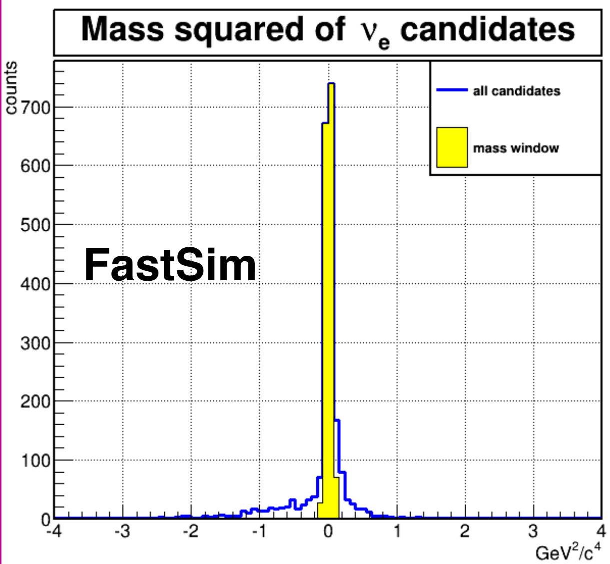
- Semileptonic decays Ds-> e + v + η,η' are an excellent environment for precision measurements of the CKM matrix elements $|V_{cd}|$ and $|V_{cs}|$.
- Form factor encapsulates QCD bound-state effects; relates to the probability of forming final state at given invariant mass squared of the lepton-neutrino system q^2.
- The investigation opens a new approach to improve the measurement of mixing angle for η and η'.

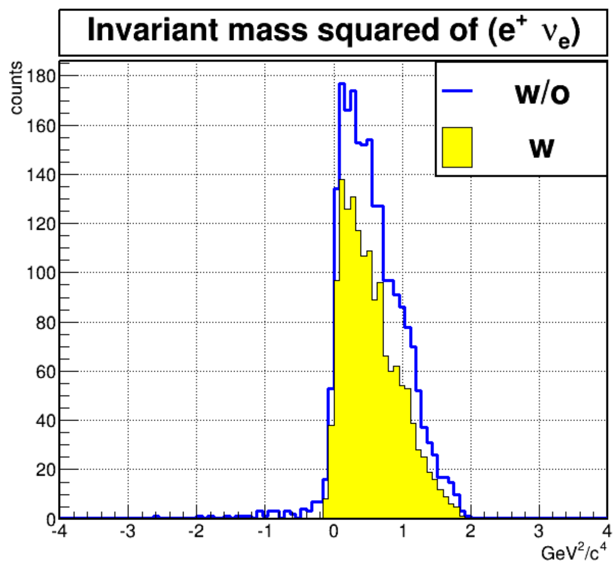


$$\frac{d\Gamma(Ds \to \nu l X)}{dq^2} = \frac{{G_F}^2}{24\pi^3} |V_{cx}|^2 {p_x}^3 |f_+(q^2)|^2$$

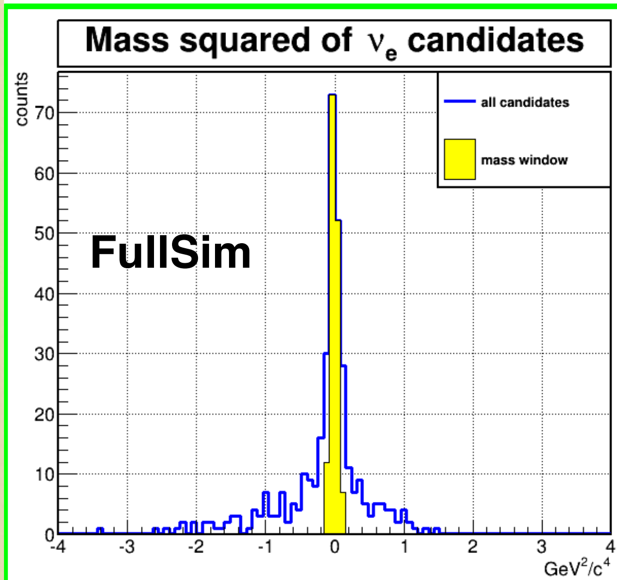
D_s semi-leptonic decay

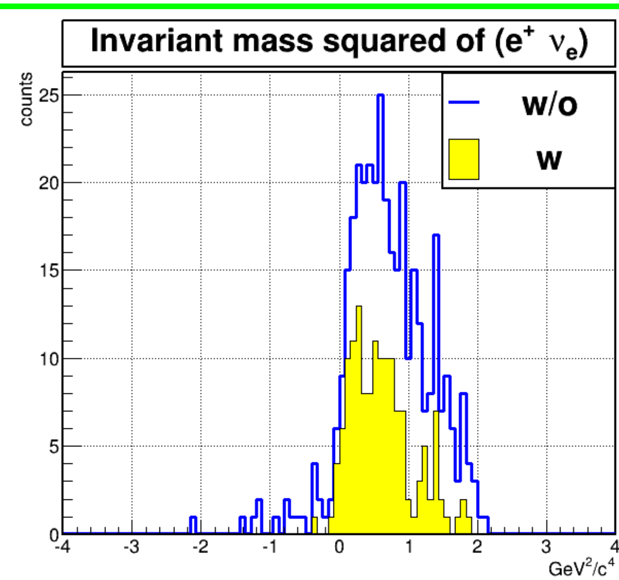
Lu Cao (FZJ), June Collaboration meeting





~22% efficiency

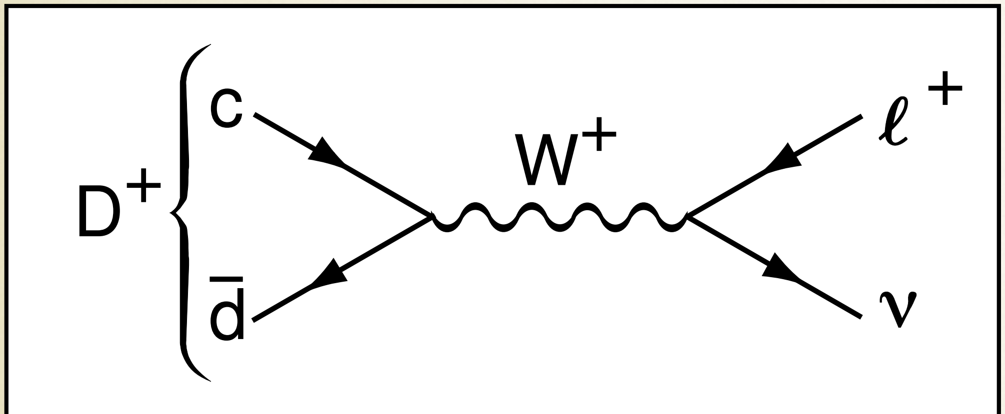




~3.7% efficiency
(=80 evts/month)

D/D$_s$ LEPTONIC DECAYS

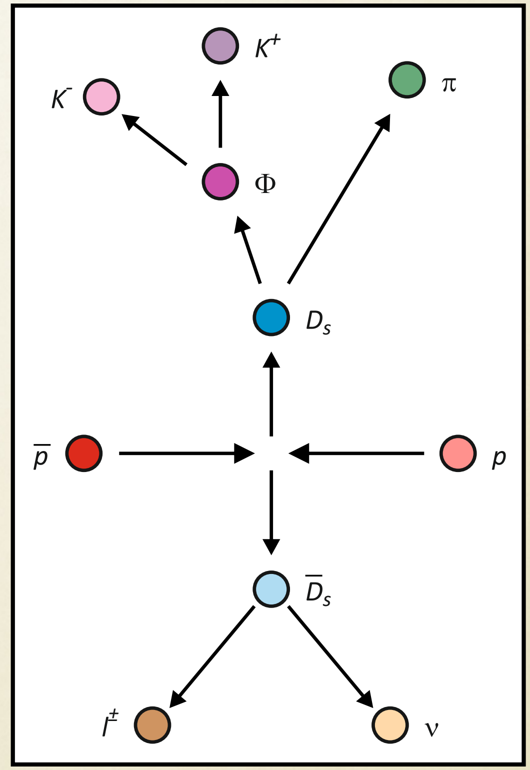
Interest from Muenster group (Jochen Heitger, Alfons Khoukaz)



$$\Gamma(D \to \ell\nu) = \frac{G_F^2}{8\pi} m_\ell^2 m_D \left(1 - \frac{m_\ell^2}{m_D^2}\right) f_D^2 |V_{cq}|^2 \qquad q = d, s$$

Model	$f_{D_s^+}$(MeV)	f_{D^+}(MeV)	$f_{D_s^+}/f_{D^+}$
Experiment (our averages)	257.5 ± 4.6	204.6 ± 5.0	1.258 ± 0.038
Lattice (HPQCD) [22]	$246.0 \pm 0.7 \pm 3.5$	$208.3 \pm 1.0 \pm 3.3$	$1.187 \pm 0.004 \pm 0.012$
Lattice (FNAL+MILC) [23]	$246.4 \pm 0.5 \pm 3.6$	$209.2 \pm 3.0 \pm 3.6$	1.175 ± 0.019
PQL [24]	244 ± 8	197 ± 9	1.24 ± 0.03
QCD sum rules [25]	205 ± 22	177 ± 21	$1.16 \pm 0.01 \pm 0.03$
QCD sum rules [26]	$245.3 \pm 15.7 \pm 4.5$	$206.2 \pm 7.3 \pm 5.1$	$1.193 \pm 0.025 \pm 0.007$
QCD sum rules [27]	246 ± 6	204 ± 6	1.21 ± 0.04
QCD sum rules [28] (I)	241 ± 12	208 ± 11	1.16 ± 0.07
QCD sum rules [28] (II)	258 ± 13	211 ± 14	1.22 ± 0.08
QCD sum rules [29]	238^{+13}_{-23}	201^{+12}_{-13}	$1.15^{+0.04}_{-0.05}$
Field correlators [30]	260 ± 10	210 ± 10	1.24 ± 0.03
Light front [31]	268.3 ± 19.1	206 (fixed)	1.30 ± 0.04

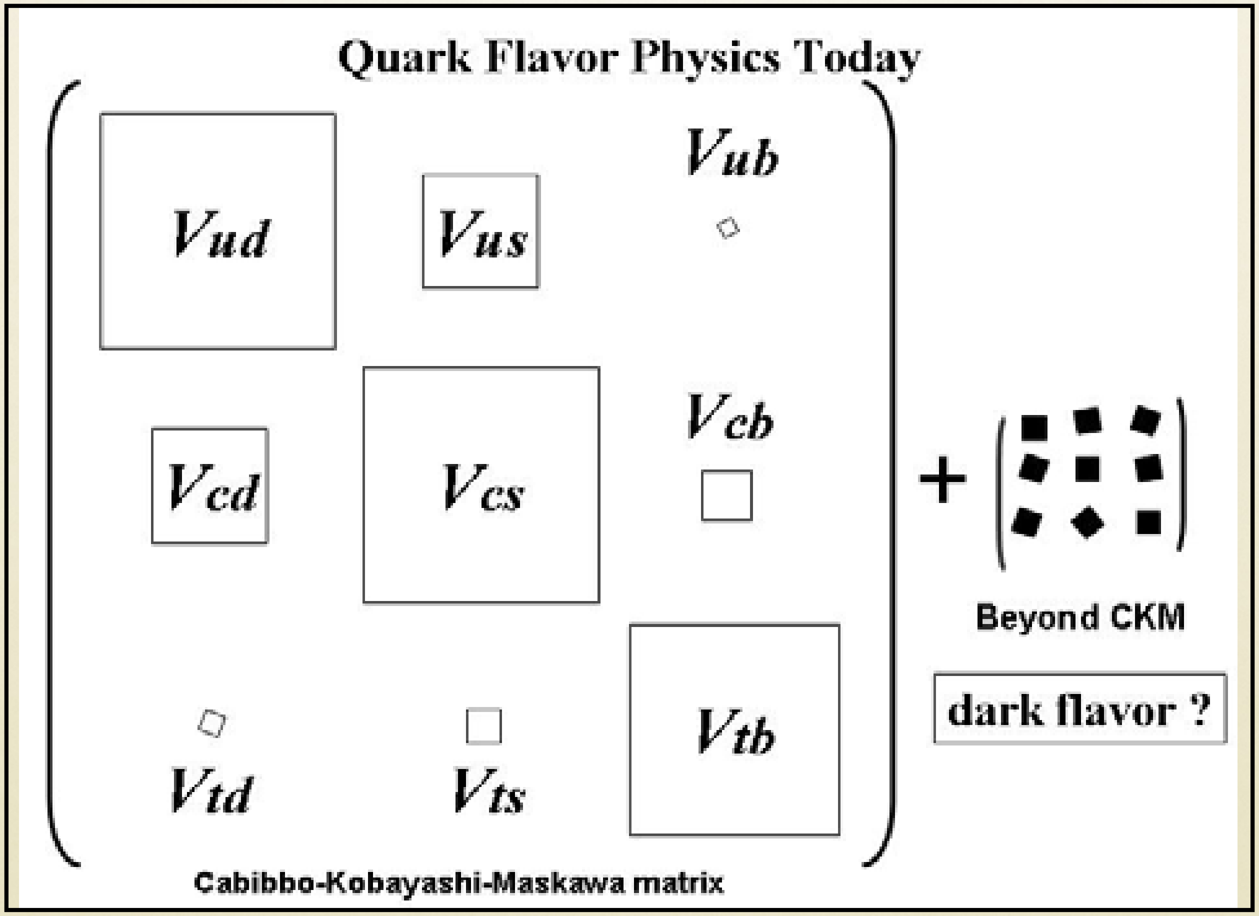
PANDA:



Detailed simulations urgently needed!

(IN)DIRECT CPV/RARE DECAYS

Mainz, GSI…
Donghee Kang, …



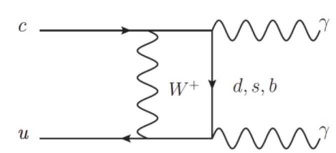
Feasibility study rare decays

$$D^0 \to \gamma\gamma / \mu^+\mu^-$$

Donghee Kang (Mainz), June Collaboration meeting

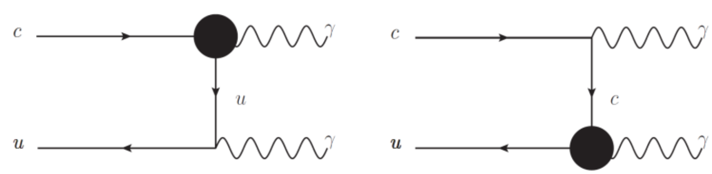
Branching fraction of rare decay $D^0 \to \gamma\gamma$

Short distance contribution

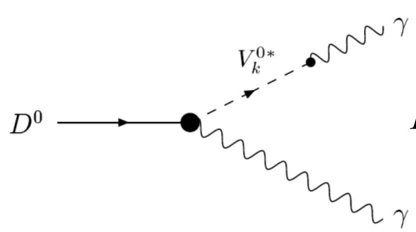


$$Br^{SD}_{D^0\to\gamma\gamma} = 3\times10^{-11}$$

[PhysRev D66 014009 (2002)]



Long distance contribution

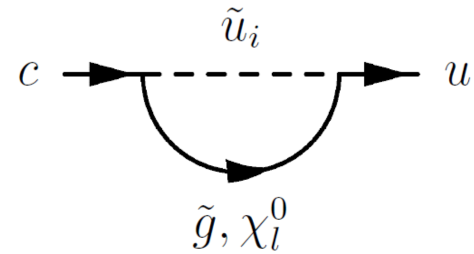


$$Br^{VMD}_{D^0\to\gamma\gamma} = (3.5^{+4.0}_{-2.6})\times10^{-8}$$

[PhysRev D66 014009 (2002)]

New Physics

c→uγ transition can be enhanced by NP, e.g. some NP models can allow at sizeable levels



$$Br^{MSSM}_{D^0\to\gamma\gamma} = 6\times10^{-6}$$

[Phys.Lett.B500 304-312 (2001)]

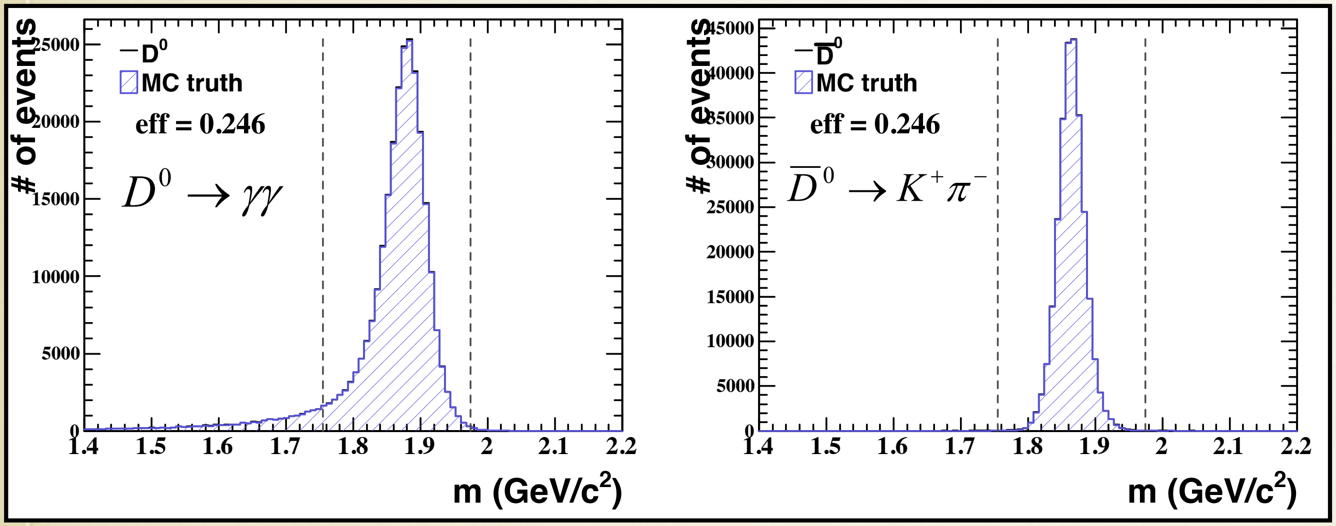
$$Br^{SM,HQ\chi PT}_{D^0\to\gamma\gamma} = (1.0\pm0.5)\times10^{-8}$$

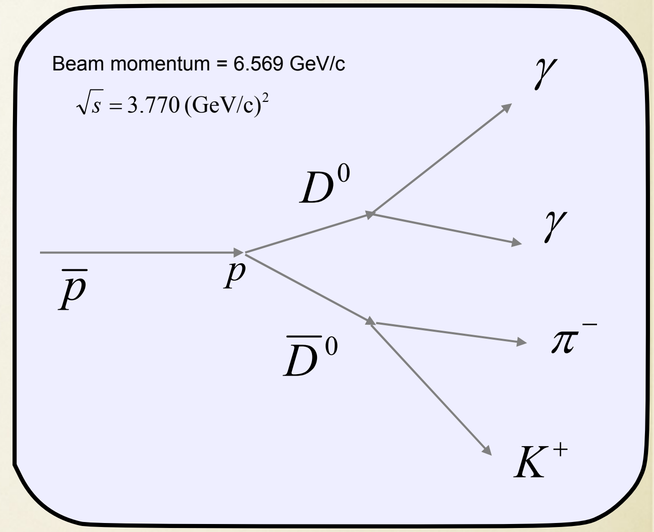
[PhysRev D64 074008 (2001)]

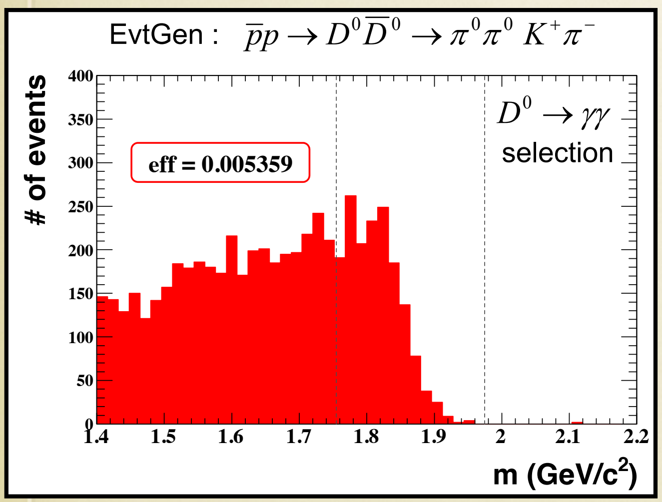
Feasibility study rare decays

$$D^0 \to \gamma\gamma / \mu^+\mu^-$$

Donghee Kang (Mainz), June Collaboration meeting







FSIM: DPM background reduction possible up till a level of $\sim 10^{-9}$

Feasibility study rare decays

$$D^0 \to \gamma\gamma/\mu^+\mu^-$$

Donghee Kang (Mainz), June Collaboration meeting

$D^0 \to \gamma\gamma$ signal data	$D^0 \to \pi^0\pi^0$ background data
$N_{D\to\gamma\gamma} = 2\ \text{fb}^{-1} \times 100\ \text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$	$N_{D\to\pi^0\pi^0} = 2\ \text{fb}^{-1} \times 100\ \text{nb} \times \Sigma(Br_i) \times \varepsilon_{tag} \times 2$
$= 8.4$ events	$= 70$ events
$Br(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$	$Br(D^0 \to \pi^0\pi^0) = 8.4\times10^{-4}$[BABAR(2012)]
$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$	$Br(\overline{D}^0 \to K^+\pi^-) = 0.0389$
$\varepsilon_{tag} = \varepsilon_{D^0\to\gamma\gamma \& \overline{D}^0\to K^+\pi^-} = 0.246$	$\varepsilon_{tag} = \varepsilon_{D^0\to\pi^0\pi^0 \& \overline{D}^0\to K^+\pi^-} = 0.005359$

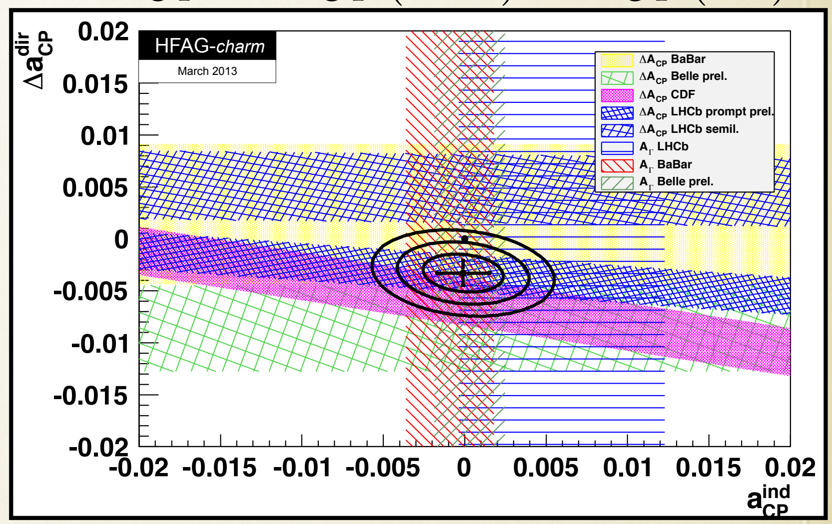
On the edge of feasibility!

(let's hope the cross section is larger than 100 nb)

Other electroweak opportunities?

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

$$\Delta A_{CP} = A_{CP}(KK) - A_{CP}(\pi\pi)$$



- **NP searches via mixing/decays?**
  - (in)direct CPV studies
  - CPV "excitement" in charm from LHCb
- **Additional FCNC transitions:**
  - forbidden at tree level, possibly sensitive to NP
  - dominated by long-distance effect
  - f.e. $D_0 \to \pi/\rho + \ell^+\ell^-$ (SM ~10^{-6}, PDG <10^{-4}-10^{-5}), q^2 distributions could help!
- **Weak decays from charm baryons?**
  - Λ_c, Ξ_c
  - maybe higher production rate?

*Many opportunities for *you* to join the efforts!*

- **We are making progress!**
  - Many tools in simulation framework have become available (thanks to the nice developments by software group)
  - Results are becoming more-and-more conclusive

- **But there are bottlenecks and to-dos…**
  - figure-of-merits not always available (for good reasons)
  - Open charm analyses are complex and require a detailed understanding and improvement of the underlying software and algorithms
  - request for analysis memos: better start right-away!
  - manpower remains limited, although many open physics channels to study
  - communication with TAG: room for improvement!

- **Looking forward to this week's workshop**
  - Sinead Ryan: "Open-charm meson sector"
  - Antimo Palano: "Open-charm, an experimental overview"
  - Alexei Pivovarov: "Electroweak physics"