Open-Charm Report

Status & perspectives

- Who is the open-charm WG?
- Why open-charm with PANDA?
- Key performance studies
- Looking ahead

Who is Open-Charm?

a.k.a. heavy-light + electroweak

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- **Participants**
  - FZJ
  - KVI-CART
  - GSI/FAIR
  - Mainz
  - Giessen
  - U. of Muenster
  - TAG (Sinead Ryan et al.)

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- **Collaborative tools**
  - Physics sessions together with charmonium/exotics/light quark/…
  - Seevogh meetings
  - Announcements: sign up on “open-charm” on forum.gsi.de
  - Documentation: see panda-wiki.gsi.de

Open-Charm binds!

QCD physics
(strong interaction)

$Q\bar{q}/Qqq/\ldots$

search “new” physics
(via weak interaction)

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hypernuclei,
hyperon interactions, …

charm in-medium,
quark-gluon plasma …

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hadron spectroscopy,
quark confinement,
“exotic” matter, …

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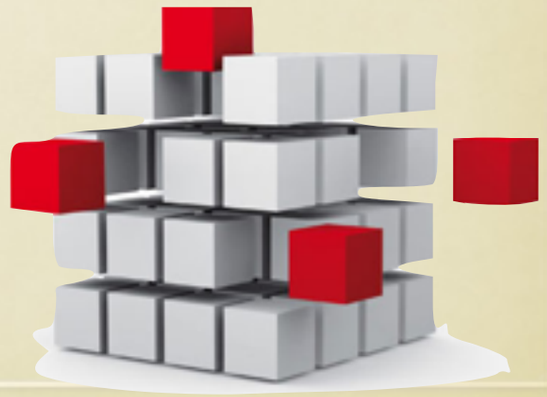
probe “new physics” (BSM),
CP violation, oscillations,
rare decays, …

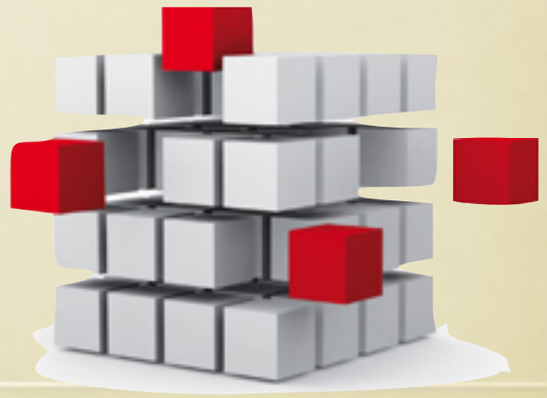
search “new” physics
(via weak interaction)

PANDA's key features



PANDA's key features

- **Precision spectroscopy**
  - sub-MeV mass and width determination
  - (near threshold) associated production



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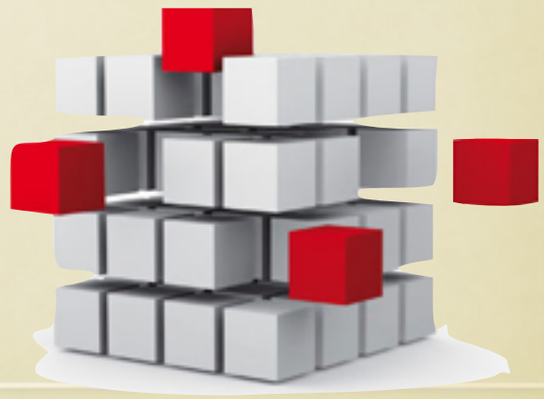
- **Energy range & p-pbar probe**
  - charm baryons production above ~4.5 GeV
  - sensitivity to D-waves in open-charm
  - complementary to e+e- machines (e.g. BESIII)



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  - sensitivity to D-waves in open-charm
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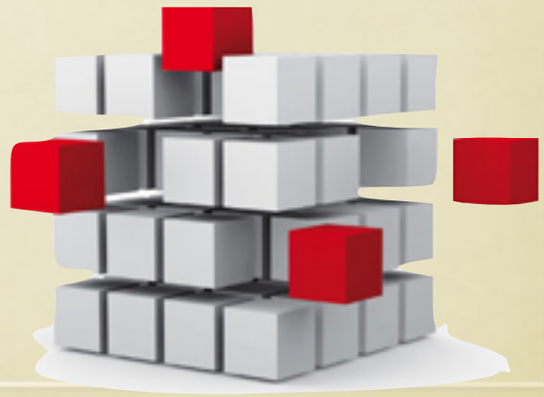
- **Vertex, track, and photon detection**
  - allows for a study of lepton/photon-rich channels
  - complementary to LHCb



PANDA's Challenges

- **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 …
  - … in particular for BSM aspects!
  - requires "complete" detector and over-redundancy
  - requires state-of-the-art reconstruction and analysis tools

- **Competition is fierce!**
  - LHCb & BelleII upgrades
  - BESIII - clean environment
  - GlueX, J-Parc - charmed baryons

Benchmark Channels

Physics	Channel (p+pbar —>)	Remark
open-charm cross sections	$D_{(s)}\bar{D}_{(s)}, Y_c\bar{Y}_c$	optimization reconstruction and analysis algorithms
nature of excited open-charm states	$\bar{D}_s D_{sJ}(2317, 2460, 2536)$	lineshape determination, l
ChPT: soft-pion couplings	$\bar{\Lambda}_c\Lambda_c(2595)(\to \pi\Sigma_c)$	precision for coupling constants?
e.m. structure of heavy baryons	$\bar{\Lambda}_c\Sigma_c(\to \Lambda_c\gamma)$	multi-pole analysis?
New Physics	$\bar{D}_0 D_0(\to \gamma\gamma)$ $\bar{D}_0 D_0(\to \pi/\rho + \ell^+\ell^-)$	sensitivity achievable?
form factors in weak decays	$D_s^- D_s^+(\to \phi/\eta/\eta' e\nu)$ $D_s \to e\mu, \bar{\Lambda}_c\Lambda_c(\to \Lambda e\nu)$	precision w.r.t FF and impact CKM?

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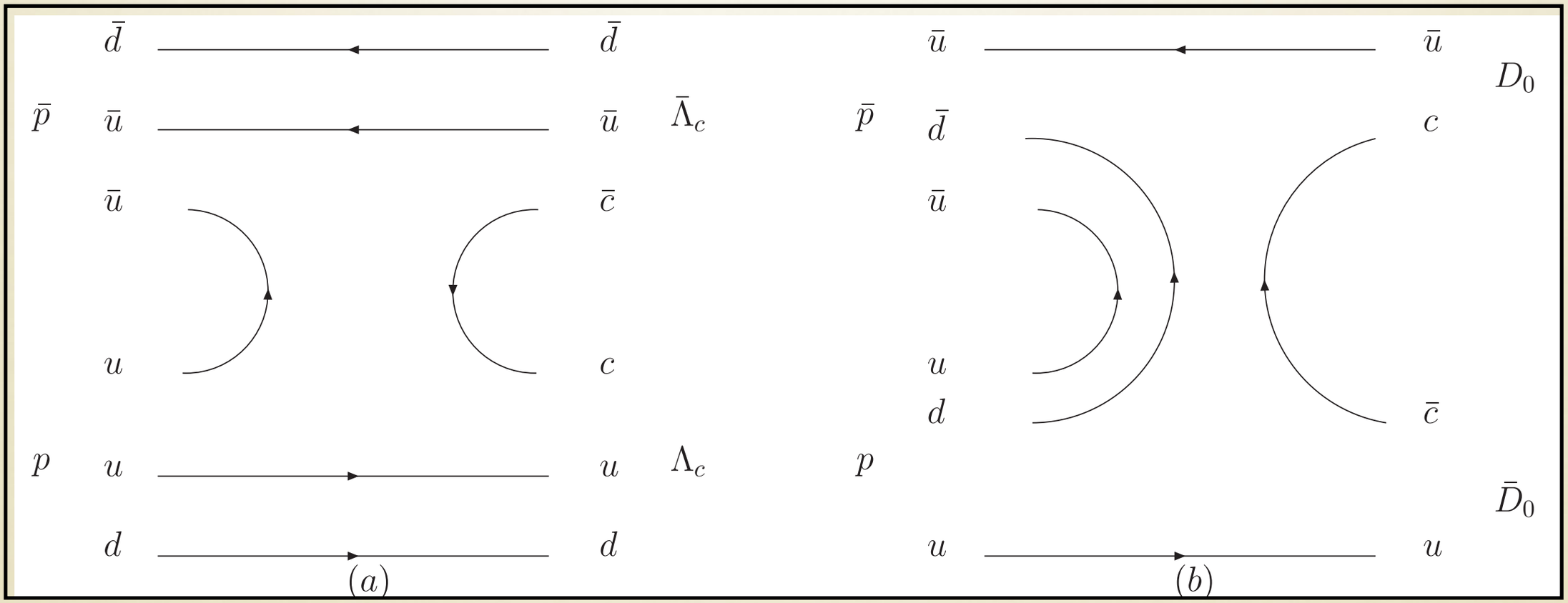
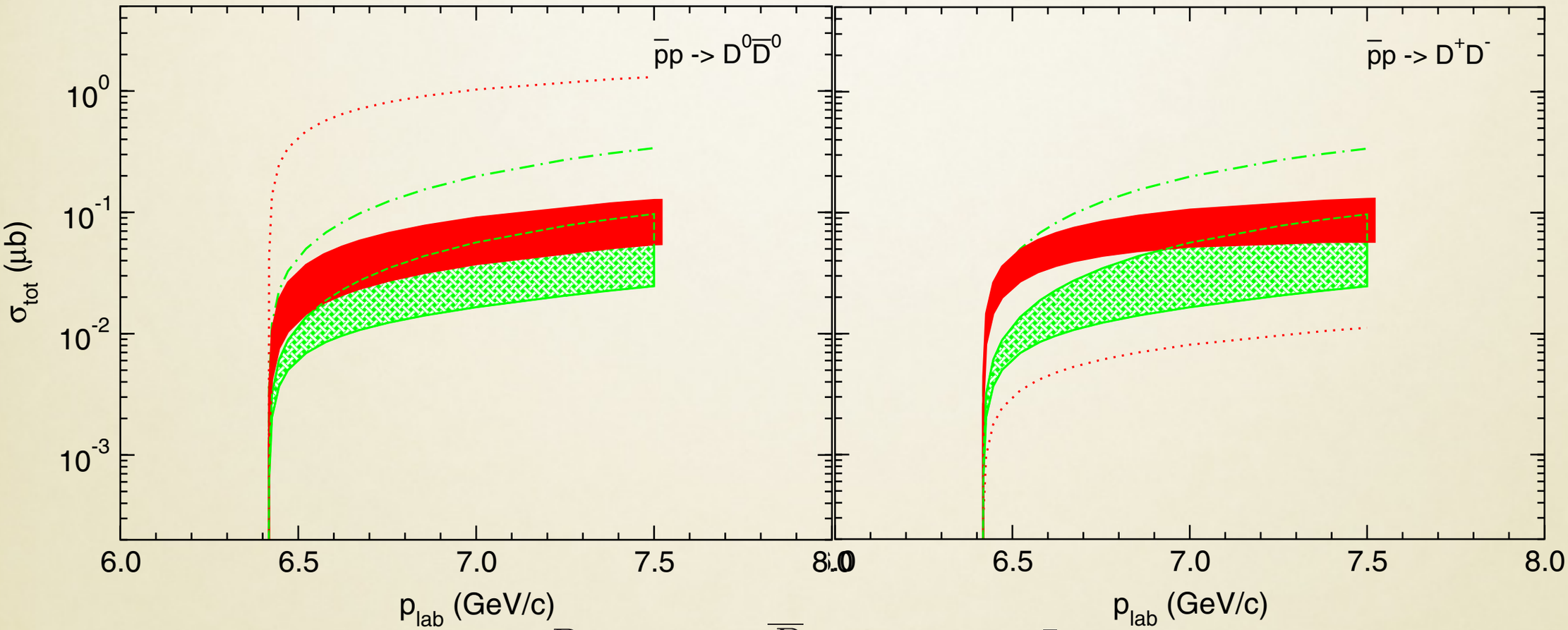
Input from you is *more* than welcome!

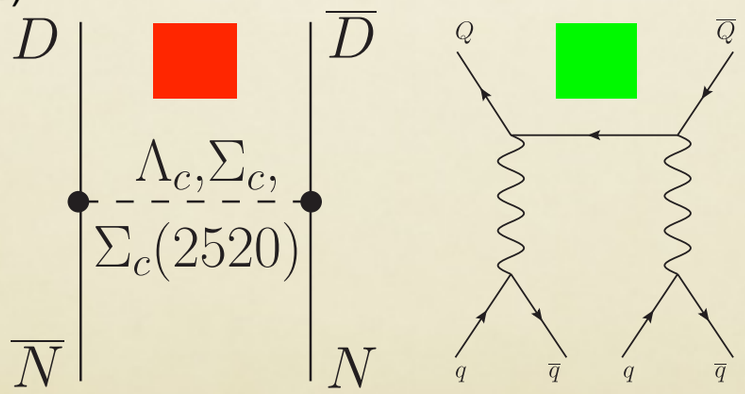
$\bar{p}p \to \bar{D}D$ Production



Open-charm Production, Theory

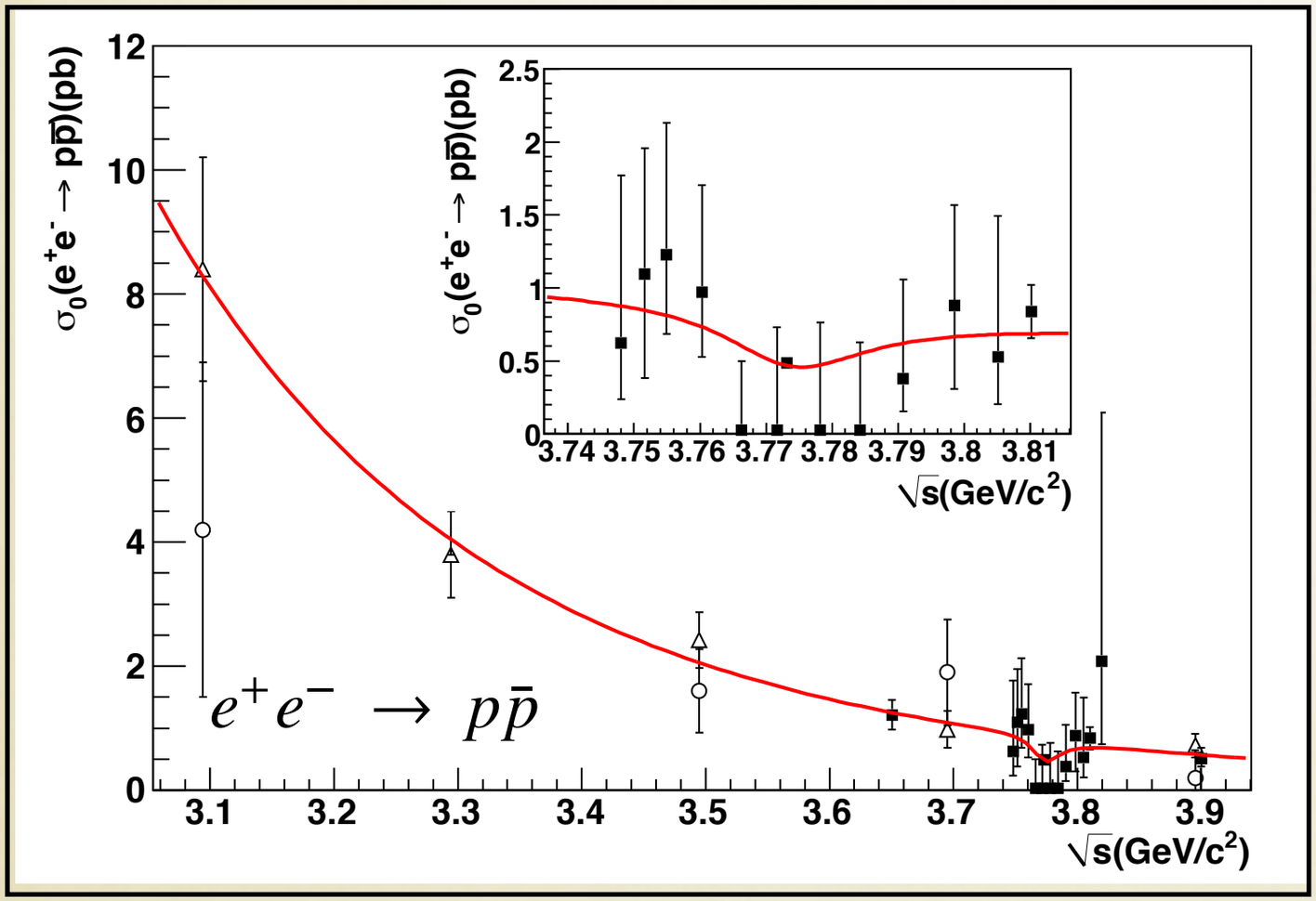
- **Non-resonant production,** Haidenbauer&Krein, PRD89, 114003 (2014)





Open-charm Production, BESIII

- **Resonant production**



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

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

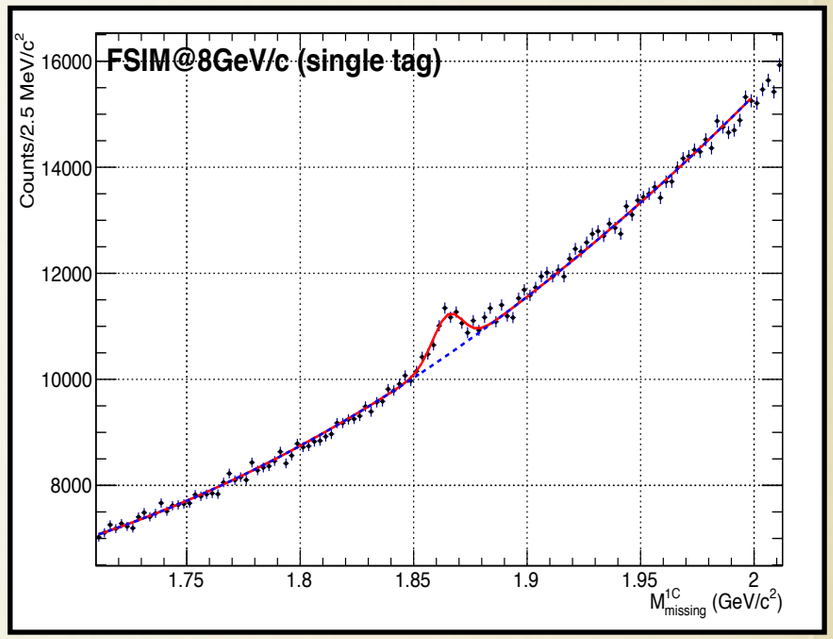
BESIII, arXiv:1403.6011
(Giessen group)

"detailed balance"

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

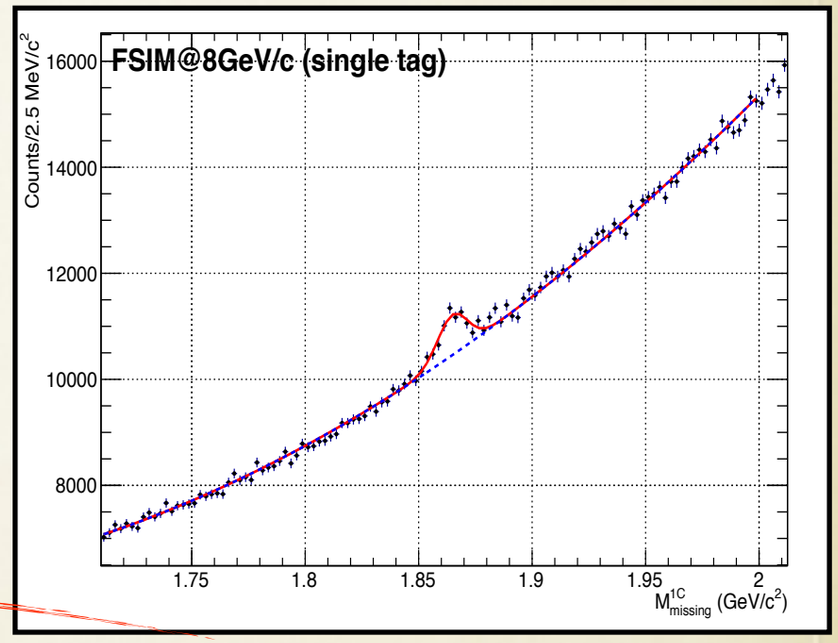
$$\sigma < 17.2 \text{ nb}$$
or
$$\sigma = 425 \pm 43 \text{ nb}$$

Open-Charm Production



- $\bar{p}p \to \bar{D}^0 D^0 \to K^- \pi^+ K^+ \pi^- / K\pi + X$
  - Alexandros Apostolou (KVI/FZJ)
  - analysis ongoing, single+double tag studies
  - benchmark results presented internally
- $\bar{p}p \to D^+ D^- \to K^- \pi^+ \pi^+ K^+ \pi^- \pi^-$
  - Andreas Herten (FZJ)
  - thesis finished, memo past referee stage
  - results presented internally and at conferences
- $\bar{p}p \to \Lambda_c^+ \Lambda_c^- \to \cdots$
  - Darius Deermann (FZJ), Solmaz Vejdani (KVI), Simone Bianco (Bonn)
  - synergy with the hyperon working group

Open-Charm Production



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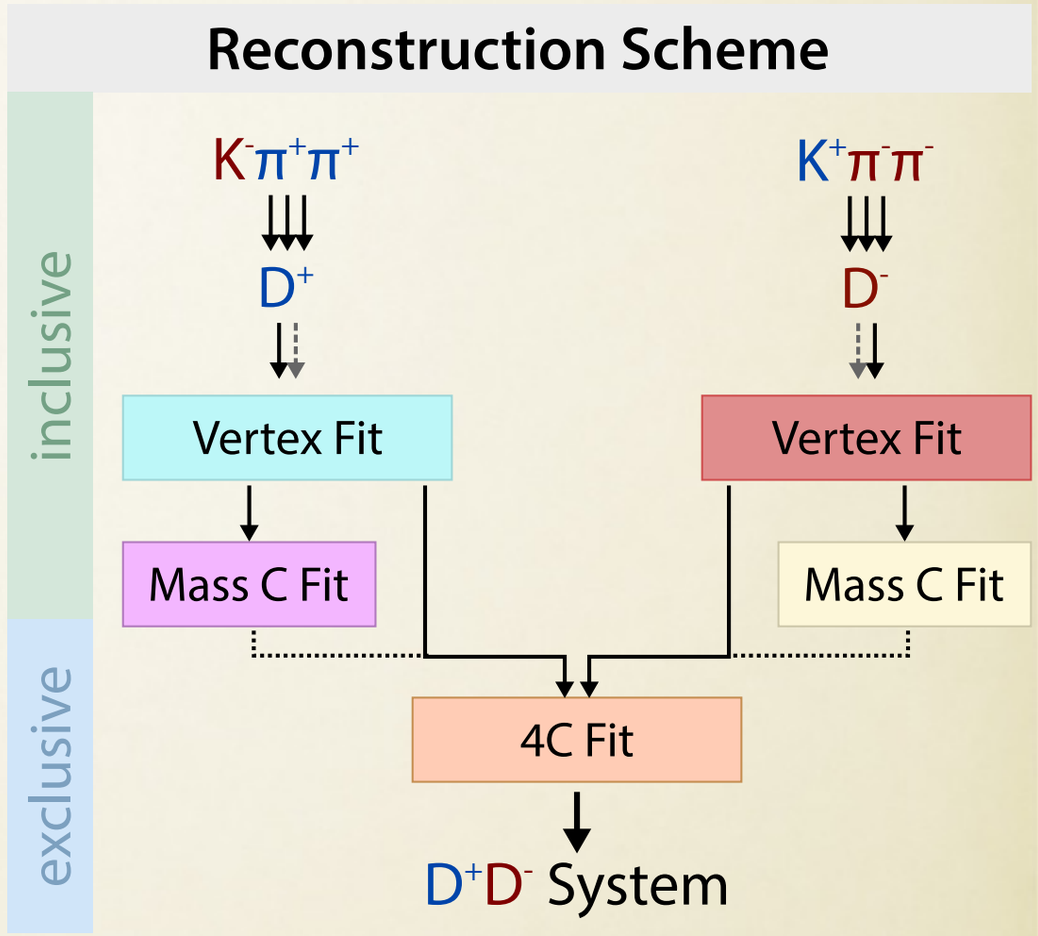
Andreas Herten (FZJ)



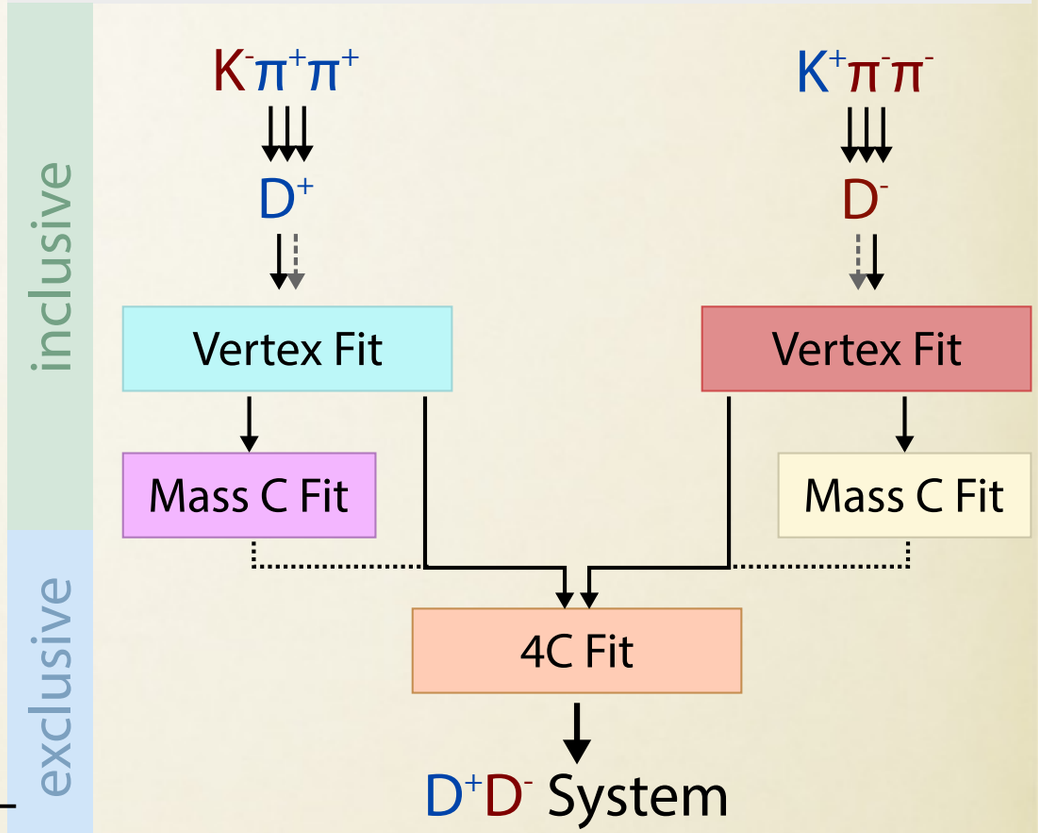
- p-beam 6.5 GeV/c (just above threshold)
- Full simulation with realistic decay model of D mesons
- Detailed performance study on reconstruction tools on physics channel
- At highest luminosity and **100 nb**: **1300/25 single/double D's/hour**
- DPM: *inclusive:* **S/B=1/10** feasible; *exclusive:* **>10^8** background suppression
- Release note ready and refereed!

$\bar{p}p \to D^+D^- \to K^-\pi^+\pi^+K^+\pi^-\pi^-$

Andreas Herten (FZJ)

	D^+			D^-		
	N %	σ_E MeV	σ_m MeV/c^2	N %	σ_E MeV	σ_m MeV/c^2
inclusive						
Before Fits	35.4	31.8	15.5	41.7	31.2	15.3
Vertex Fit	21.8	31.4	15.4	25.3	30.0	15.2
Vertex Fit & cut_{mass}	18.1	30.6	15.7	21.2	29.1	15.3
Mass Fit	18.1	15.1		21.2	14.7	
Missing Mass			15.8			15.6
exclusive						
4C Fit	3.9	26.7	10.0	3.9	26.8	8.6

Reconstruction Scheme



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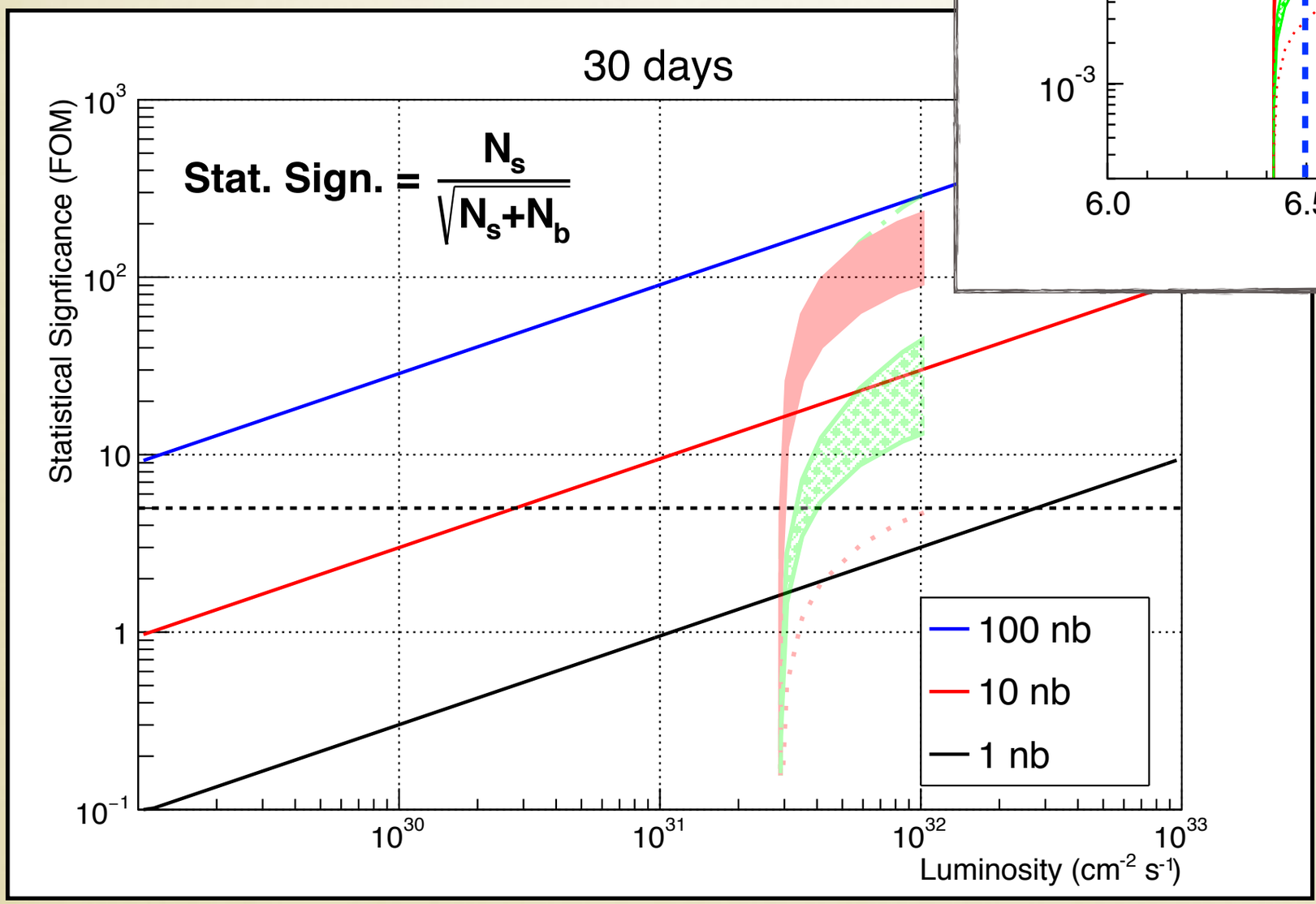
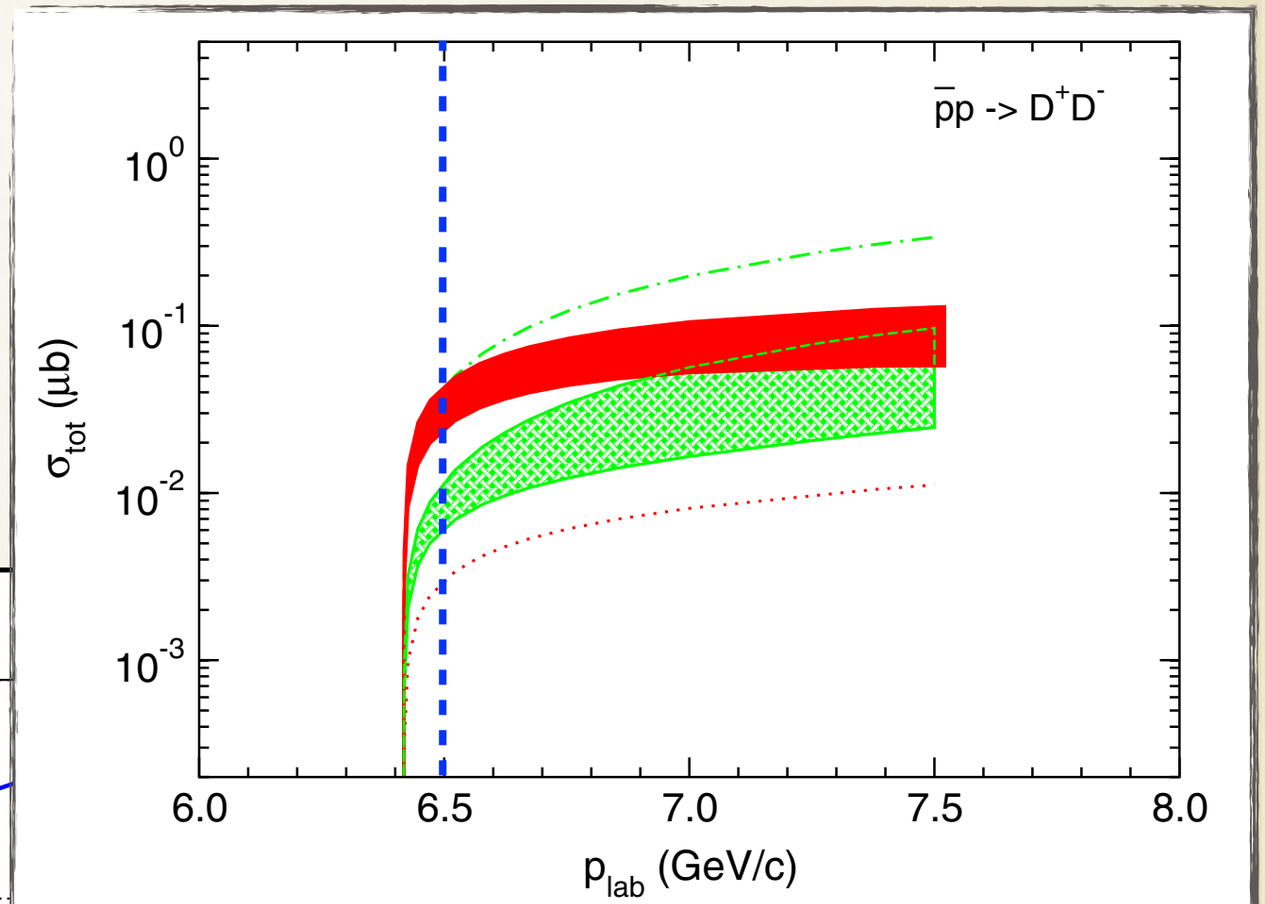
$\bar{p}p \to D^+D^- \to (K\pi\pi) + X$

Andreas Herten (FZJ), J.M.

Background model:	DPM
Efficiency:	0.18
Bckgrd reduction:	2.8×10^6
Total B.F.:	9.3×10^{-2}

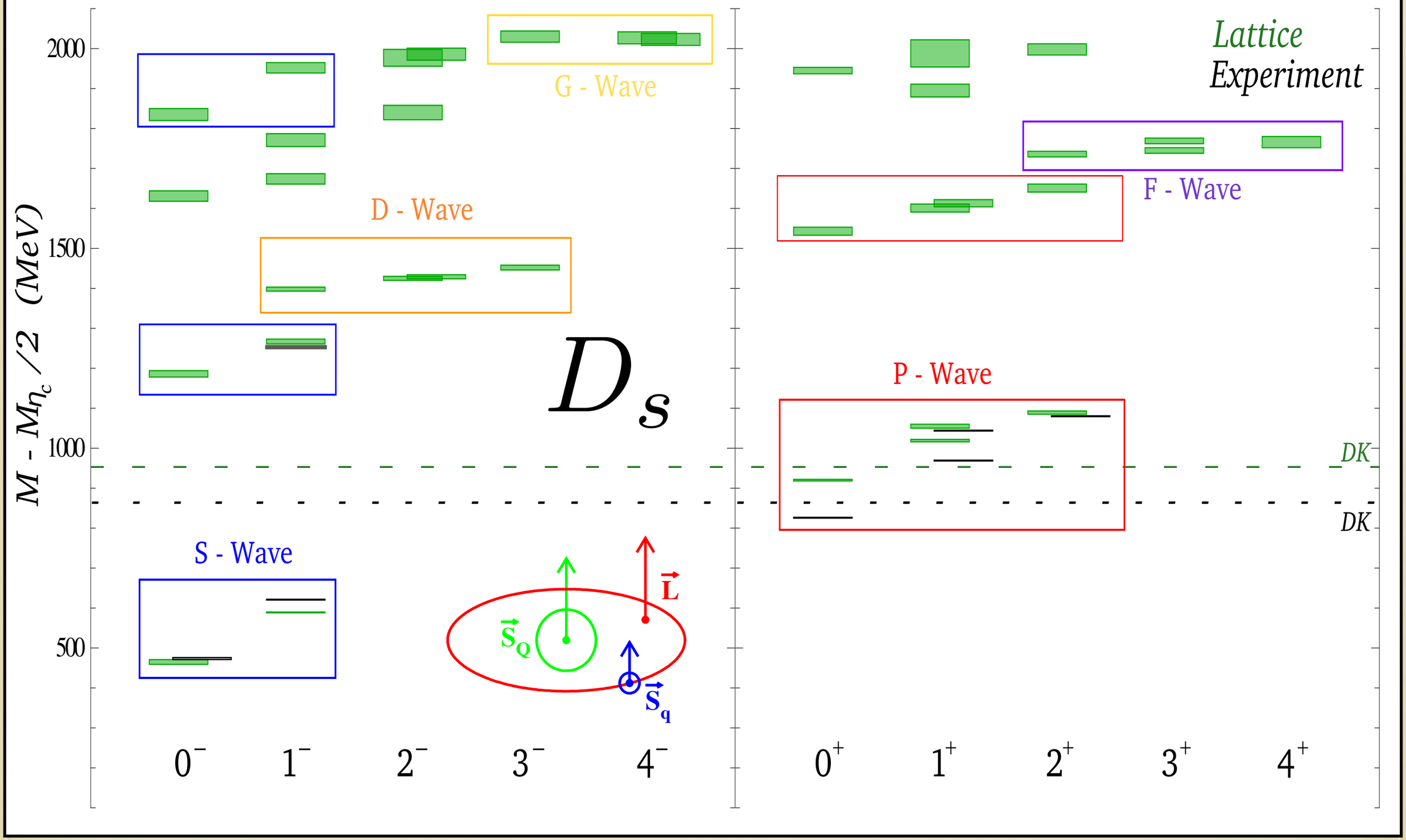
Optimized significance and
taking into account factor 2 of both tags





Further cuts?
Systematic error?
Exclusive study?
Other energies?

Open-Charm Spectroscopy



Graham Moir, et al. (Hadron Spectrum Collaboration), arXiv:1312.1361

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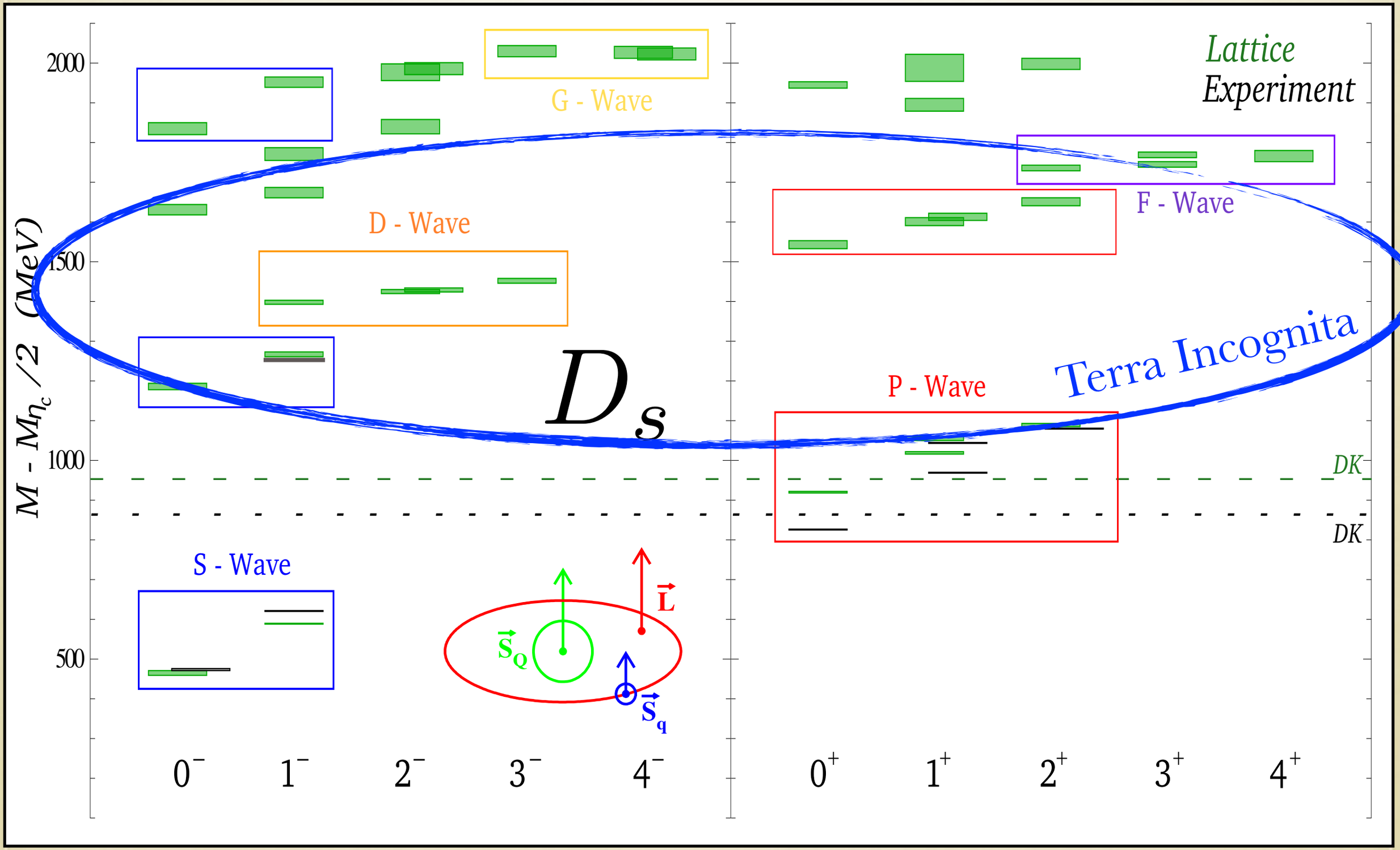

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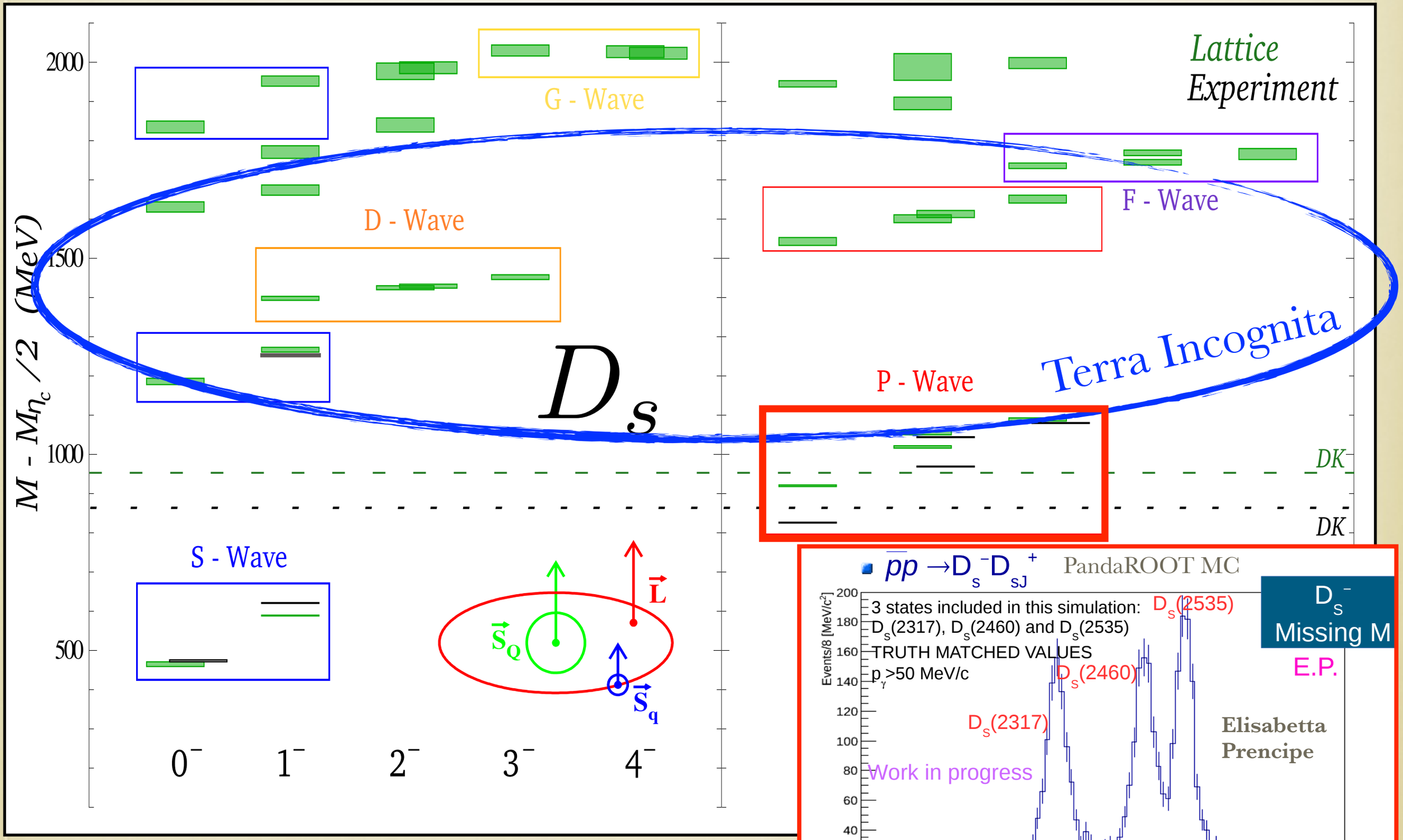


Graham Moir, et al. (Hadron Spec

$D_{s0}^*(2317)$ WIDTH

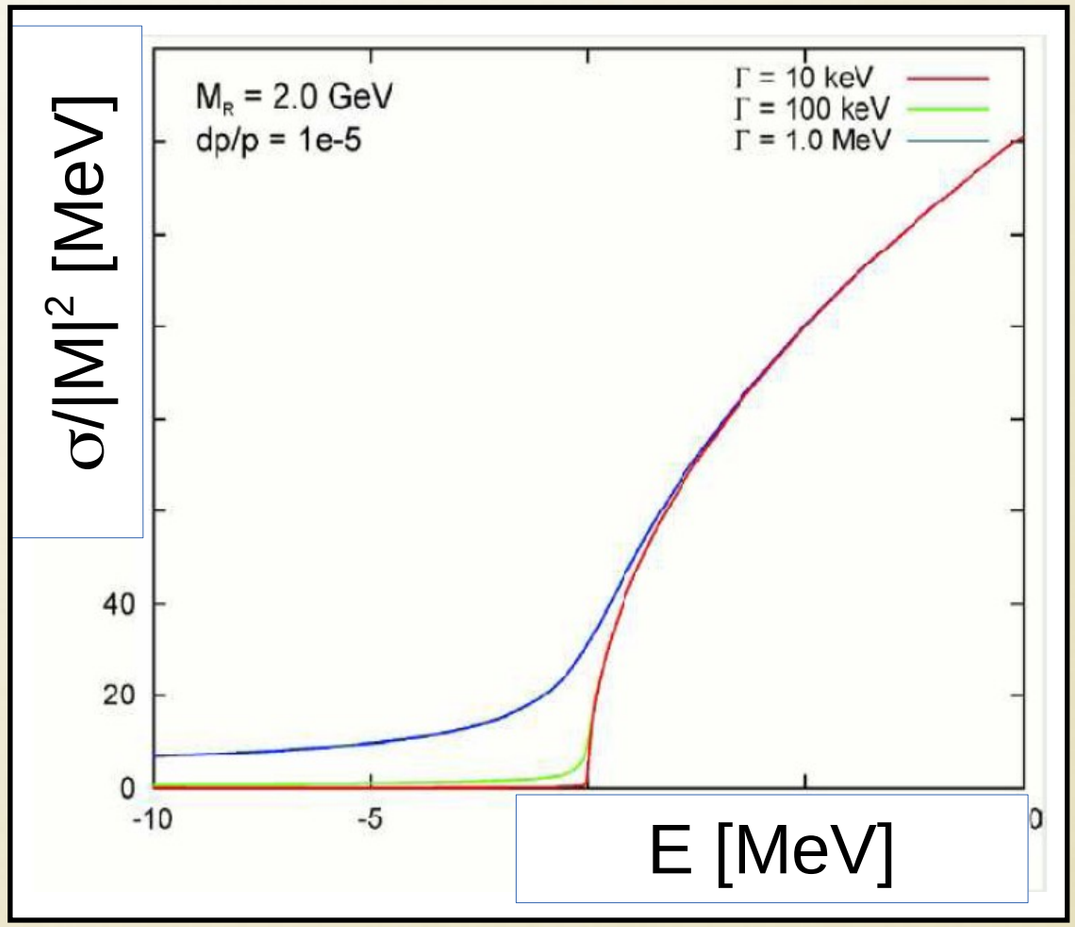
- **Nature of $D_{s0}^*(2317)$**
  - molecule/tetraquark/…?
  - deficiency quark model?
  - role chiral symmetry?

- **Model sensitivity**
  - line-shape —> nature
  - *width:* large variations 5-200 keV

- **Opportunity**
  - determine *width* by p+pbar scan in associate D_S production

- **Challenge**
  - uncertainty in prod. cross section
  - can we reach sufficient stat. sign.?
  - how far can we suppress the backgrd?
  - can we reach enough sensitivity?

$D_{s0}^*(2317)$ world average (PDG)
- *Mass: 2317.8 ± 0.6 MeV/c^2*
- *Width: < 3.8 MeV/c^2*



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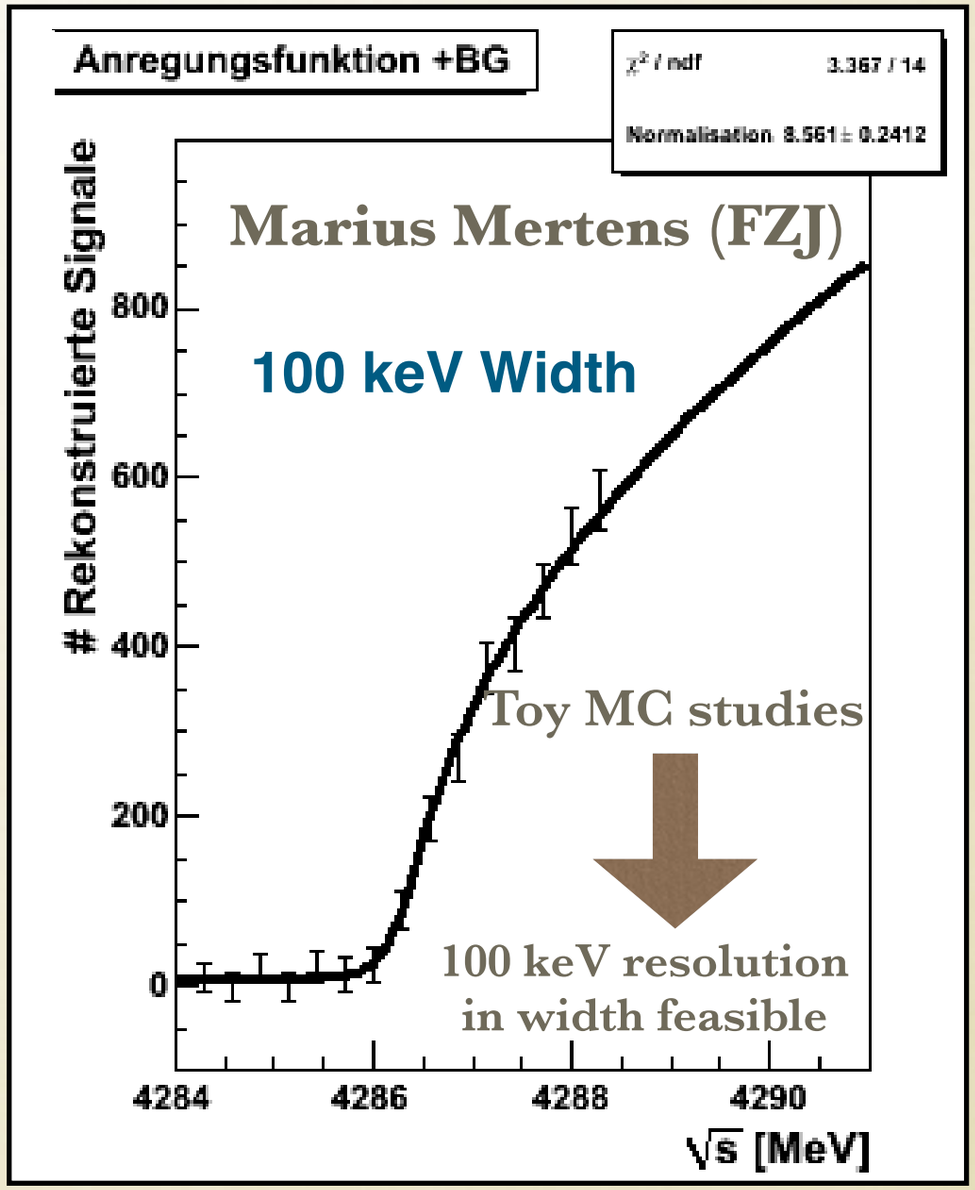
Momentum spread: $\delta p/p_0 = 10^{-4}$
Absolute positioning: $\delta p_0/p_0 = 10^{-4}$
Relative positioning: $\delta \Delta p/\Delta p = 10^{-5}$



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

(analysis note in preparation)

$D_{s0}^*(2317)$ studies

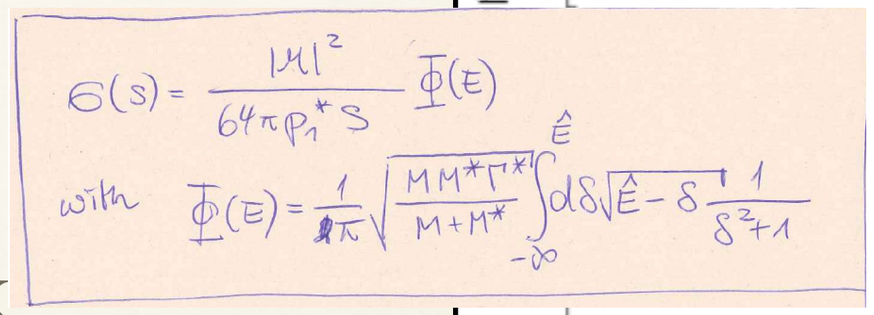
Elisabetta Prencipe (FZJ)

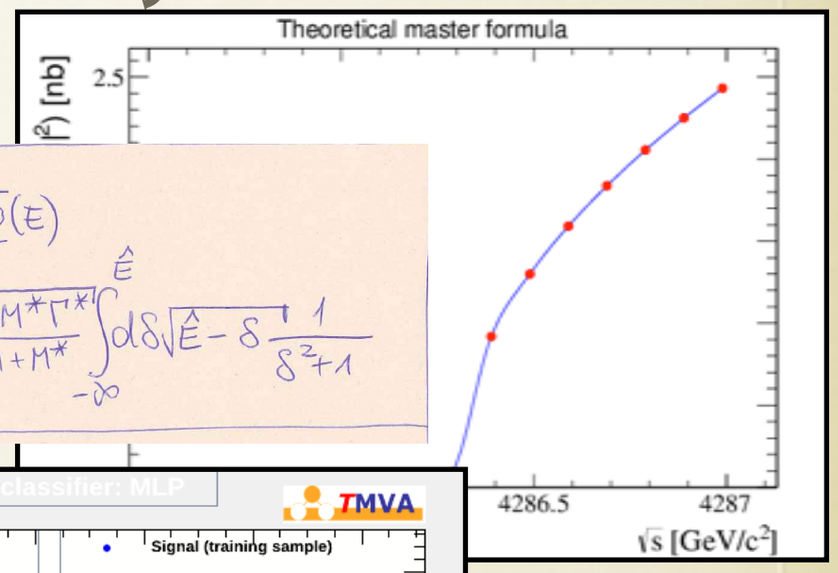
- **Collaboration with theory (Hanhart)**
  - updates in the excitation function
  - role of interferences

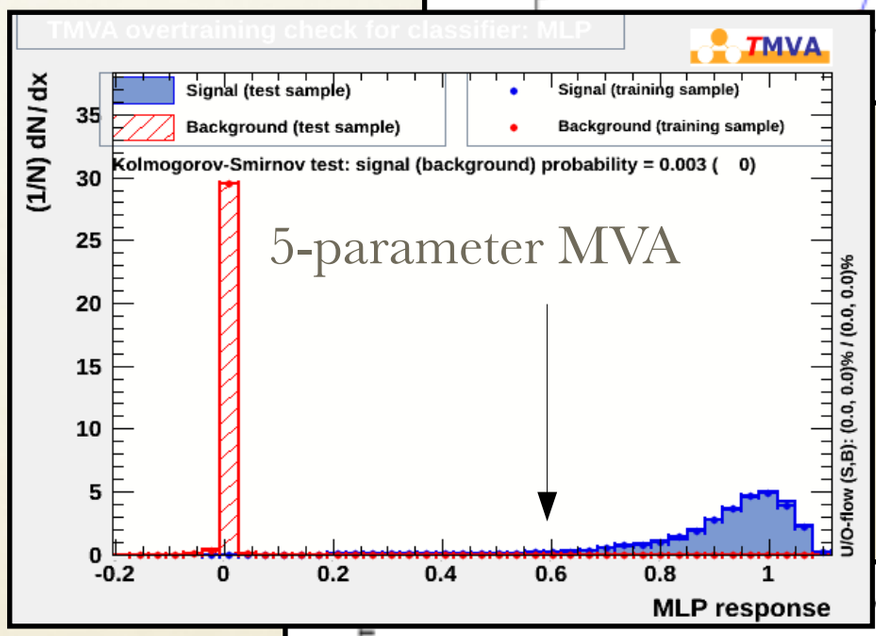
- **Full simulation**
  - focus on recoil-mass study and phi->KK
  - realistic decay model for Ds->KKpi
  - background via DPM
  - exploit MVA for background suppression
  - signal yield obtained via combined fit

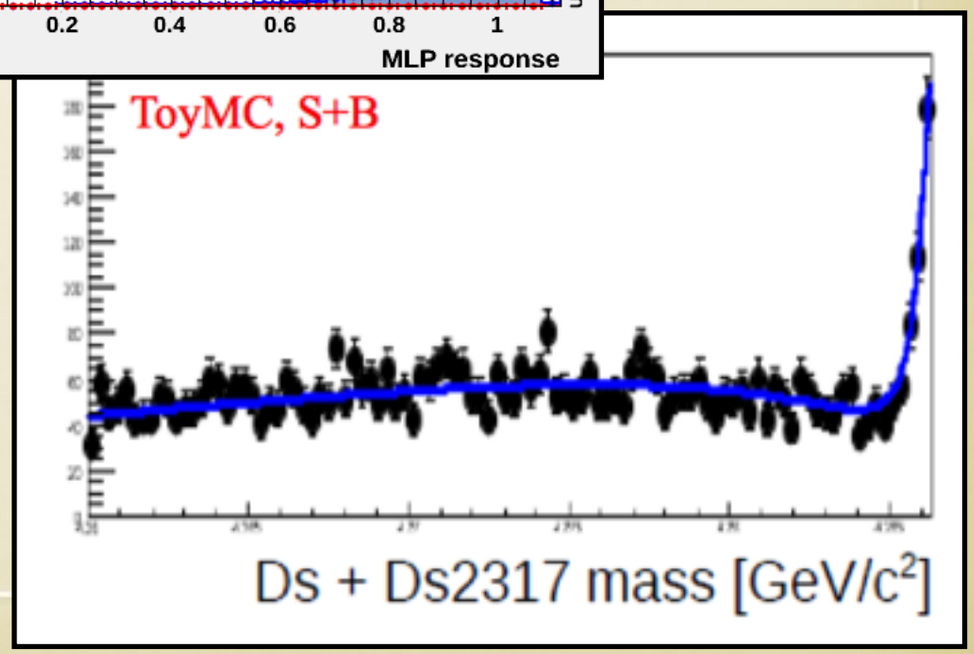
- **Preliminary results**
  - DPM backgrd suppr. of *at least* 4.5×10^7
  - … with signal efficiency of 3.2% (production rate: 864 evts/day/nb@HR)
  - memo internally discussed

- **Future items**
  - determination of background PDFs
  - systematic sensitivity studies
  - large scale simulations required
  - towards publication in 2016

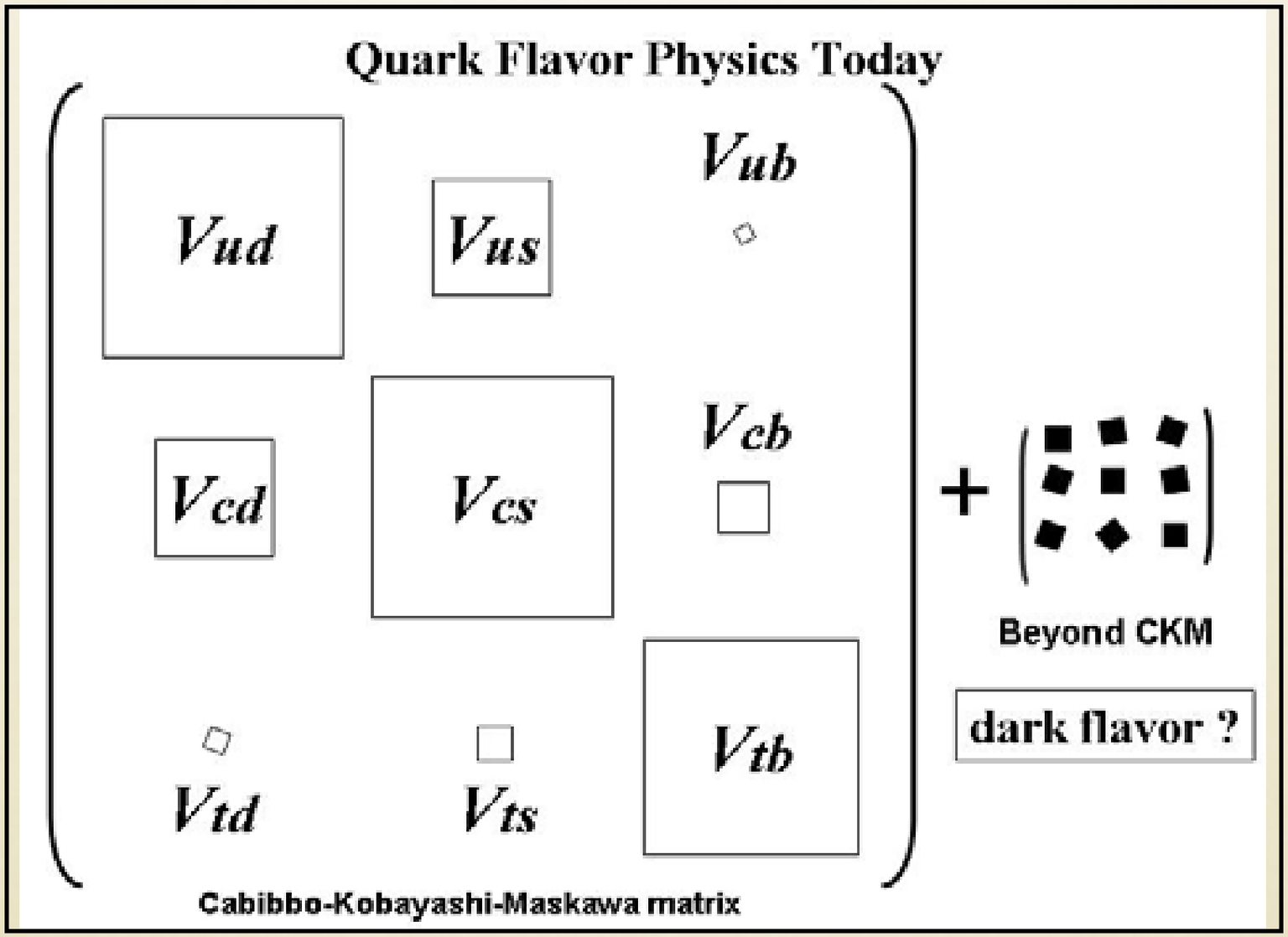






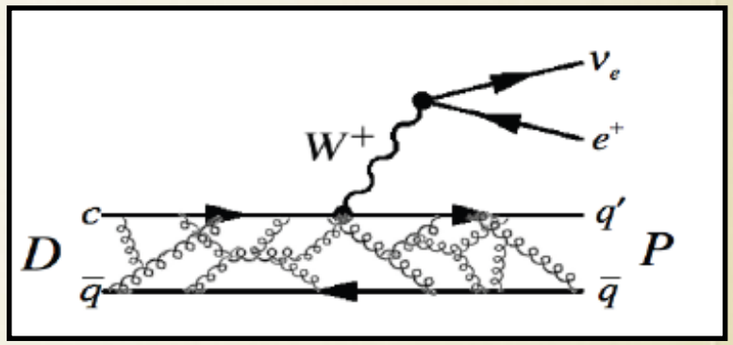


Open-Charm: weak decays

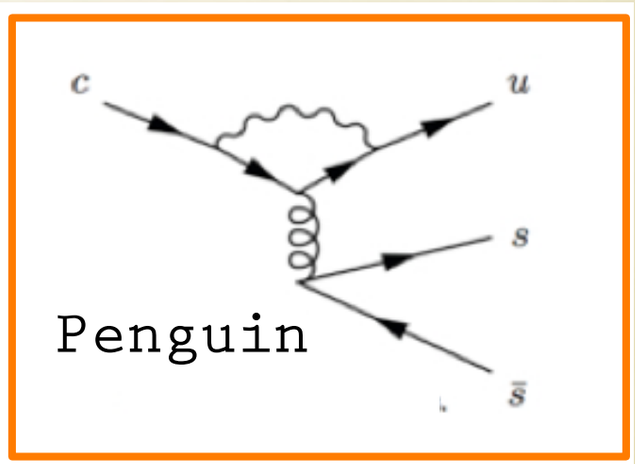


Open-Charm: weak decays

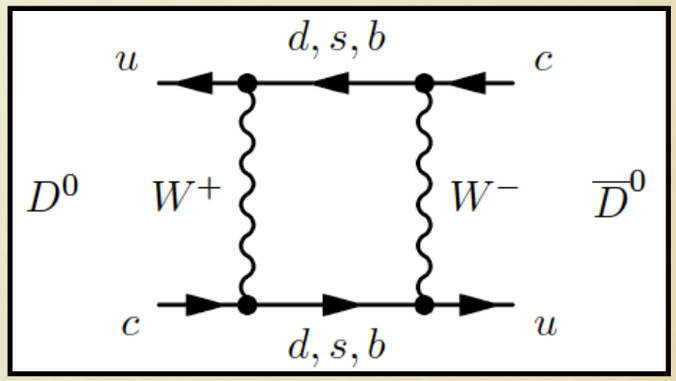
- $\bar{p}p \to D_s^- D_s^+ \to KK\pi/3\pi + \eta e^+ \nu_e$
  - Lu Cao (FZJ)
  - Semi-leptonic Ds decay: *weak* meets *strong* physics!
  - Thesis/memo in progress



- $\bar{p}p \to D^0 \bar{D}^0 \to (\gamma\gamma) + (K\pi/K2\pi/K3\pi)$
  - Donghee Kang (Mainz)
  - Search for enhancement c—>ug transition (BSM)
  - Internal note available on doc-server



- $\bar{p}p \to D^0 \bar{D}^0 \to (K_S \pi^+ \pi^-)(K^+ \pi^-)$
  - Andreas Pitka (Giessen)
  - Study decay time differences in D0/D0bar decays
  - Time resolution of 612 fs achieved
  - Continuation (background studies etc.)?



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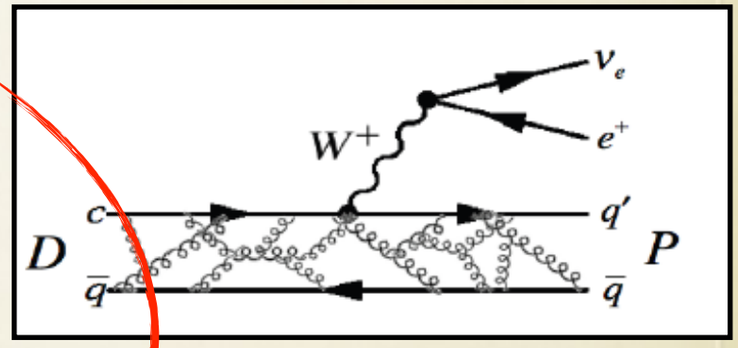
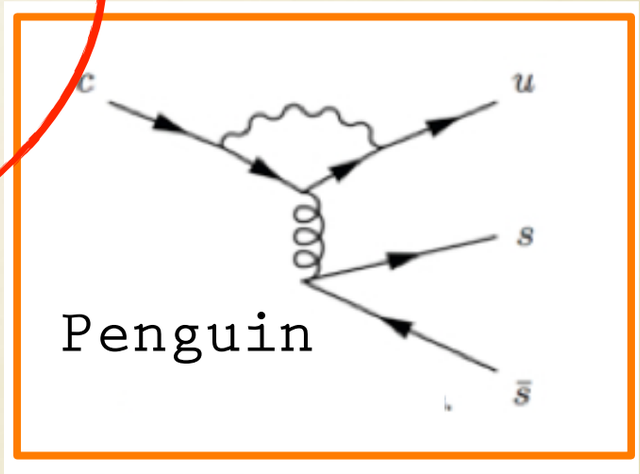
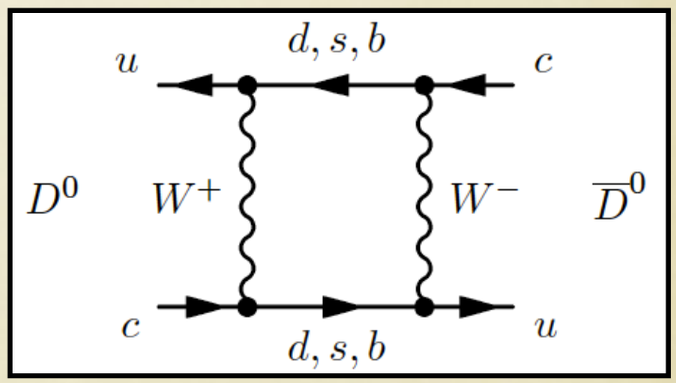
  - Semi-leptonic Ds decay: *weak* meets *strong* physics!
  - Thesis/memo in progress



- $\bar{p}p \to D^0 \bar{D}^0 \to (\gamma\gamma) + (K\pi/K2\pi/K3\pi)$
  - Donghee Kang (Mainz)
  - Search for enhancement c—>ug transition (BSM)
  - Internal note available on doc-server



- $\bar{p}p \to D^0 \bar{D}^0 \to (K_S\pi^+\pi^-)(K^+\pi^-)$
  - Andreas Pitka (Giessen)
  - Study decay time differences in D0/D0bar decays
  - Time resolution of 612 fs achieved
  - Continuation (background studies etc.)?



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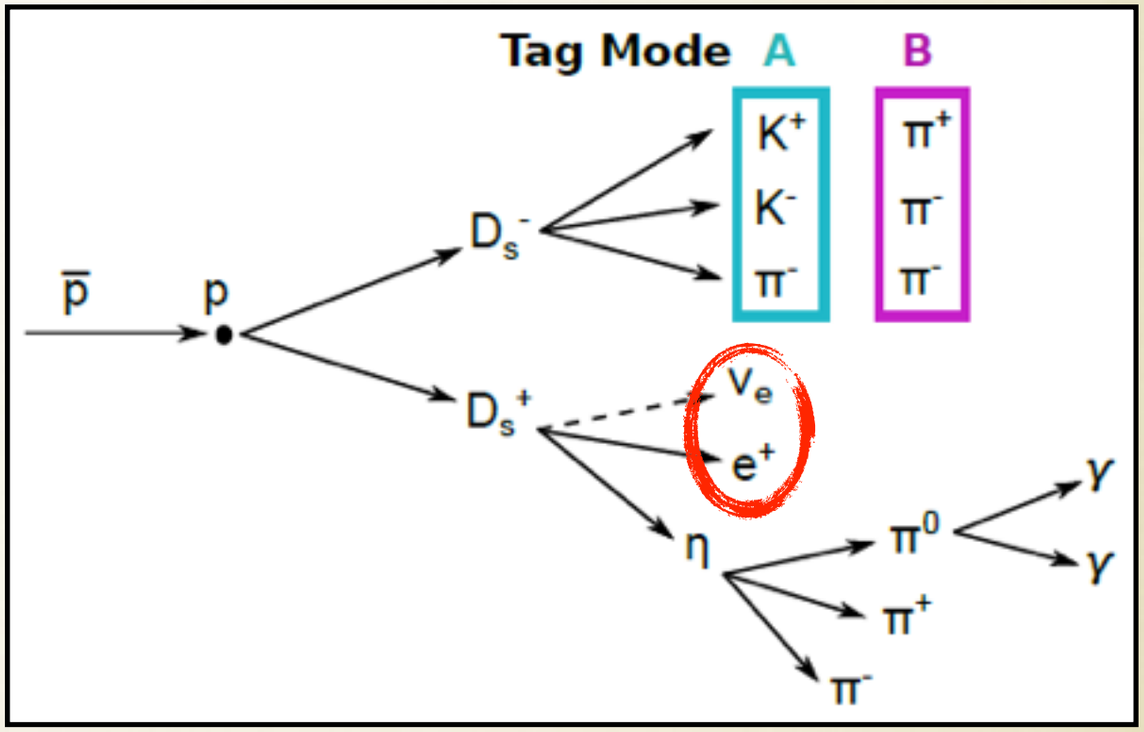

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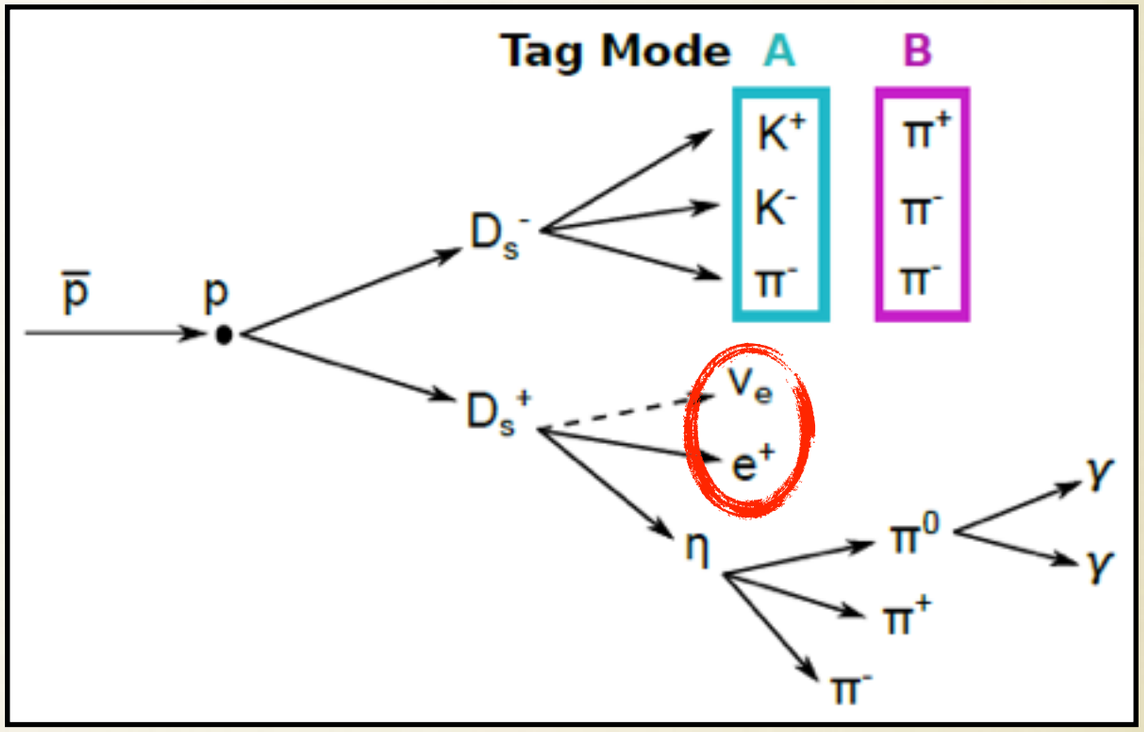

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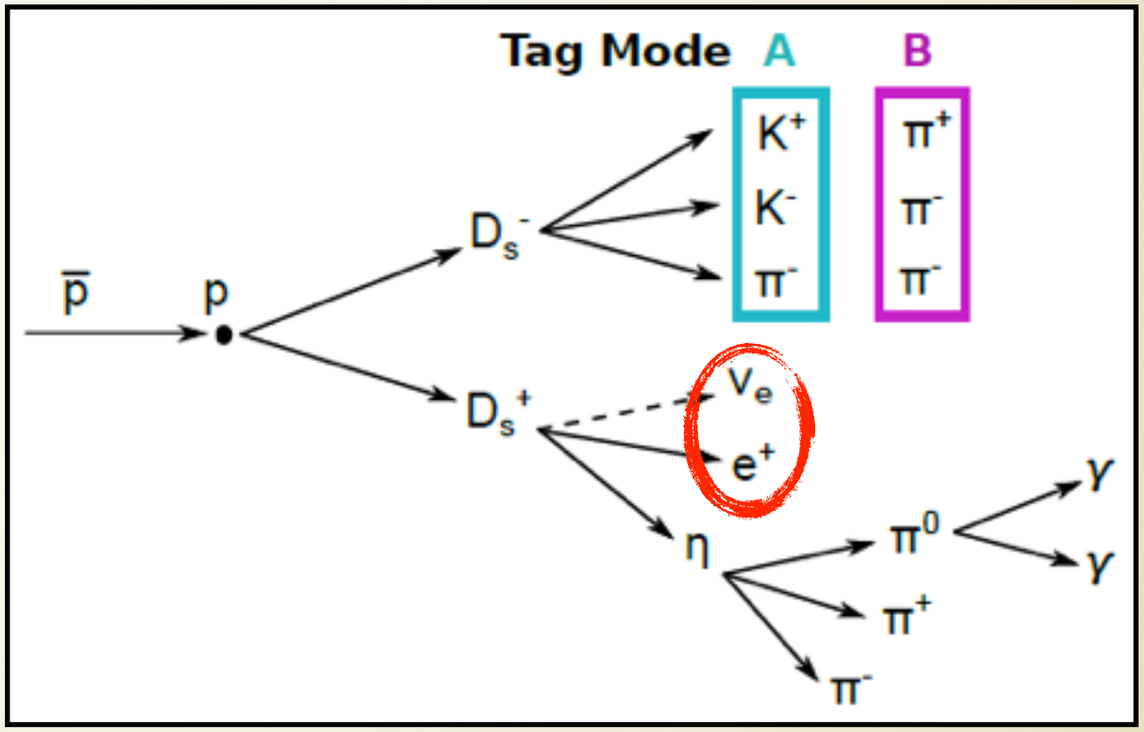

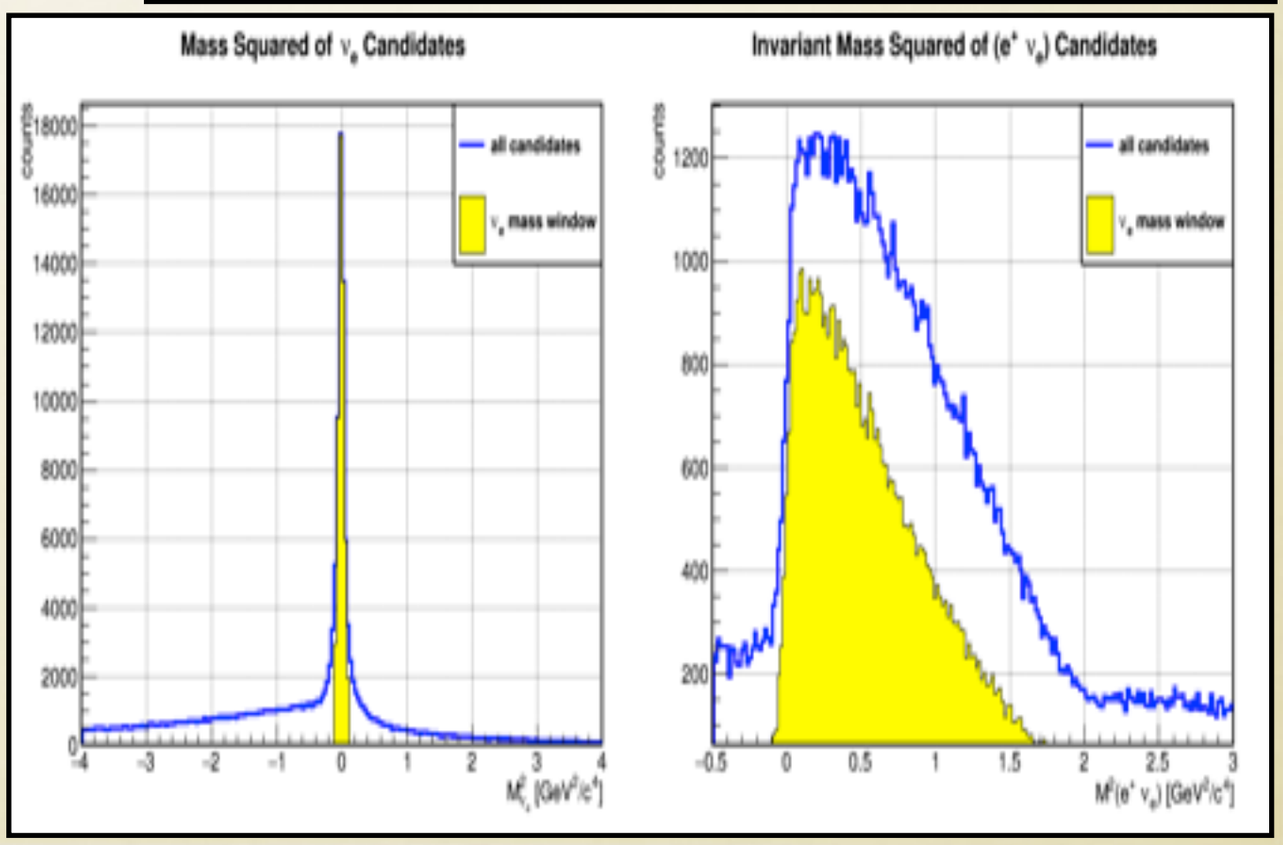

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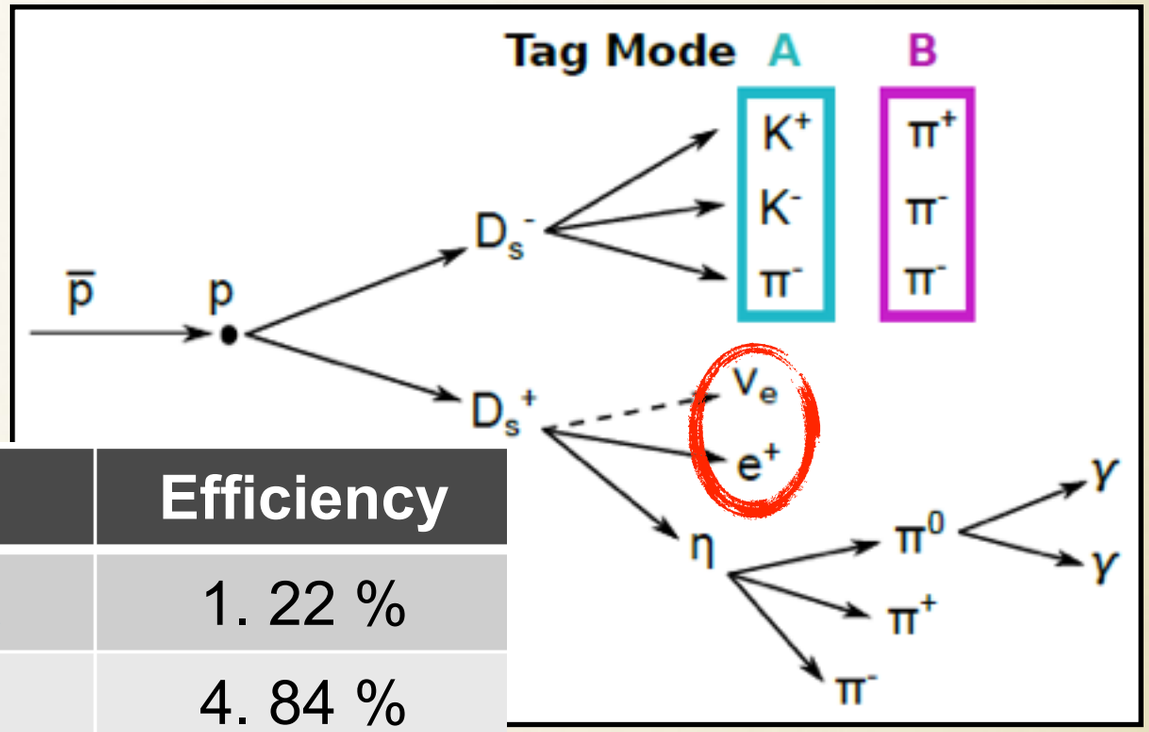

	Efficiency
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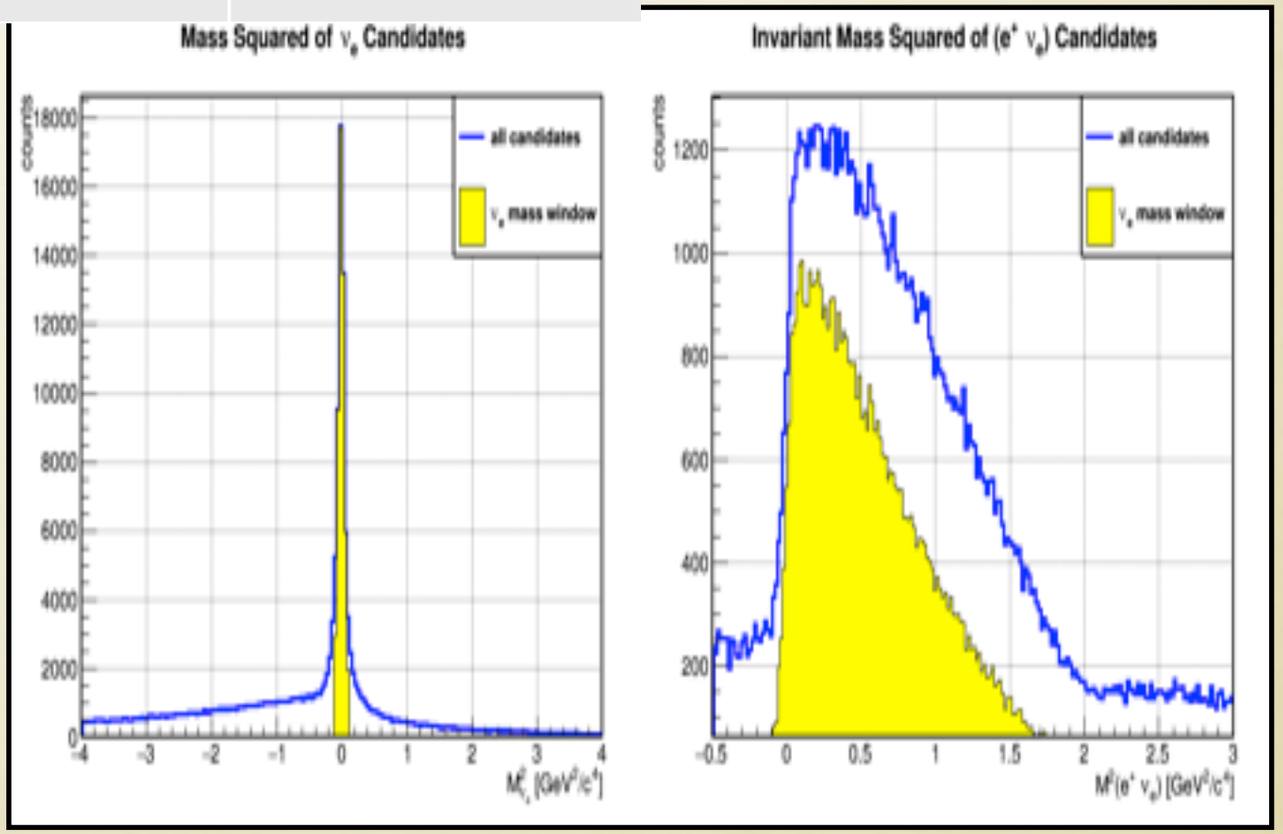

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  - additional eta' study
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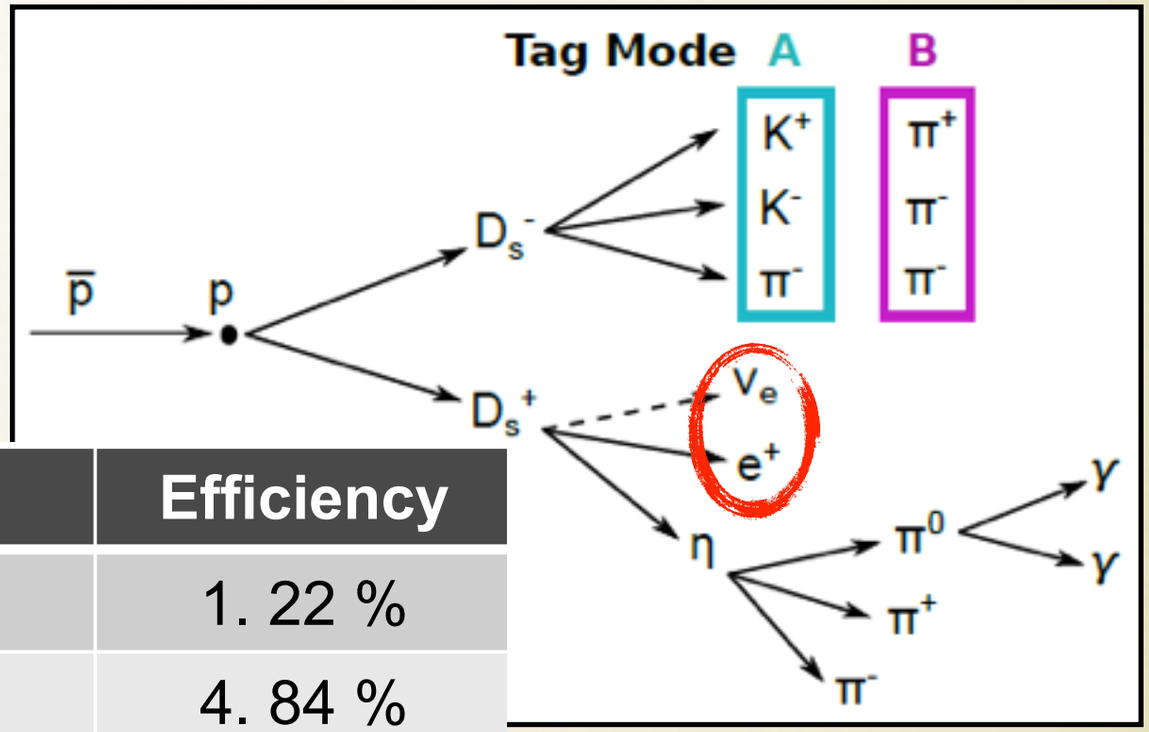

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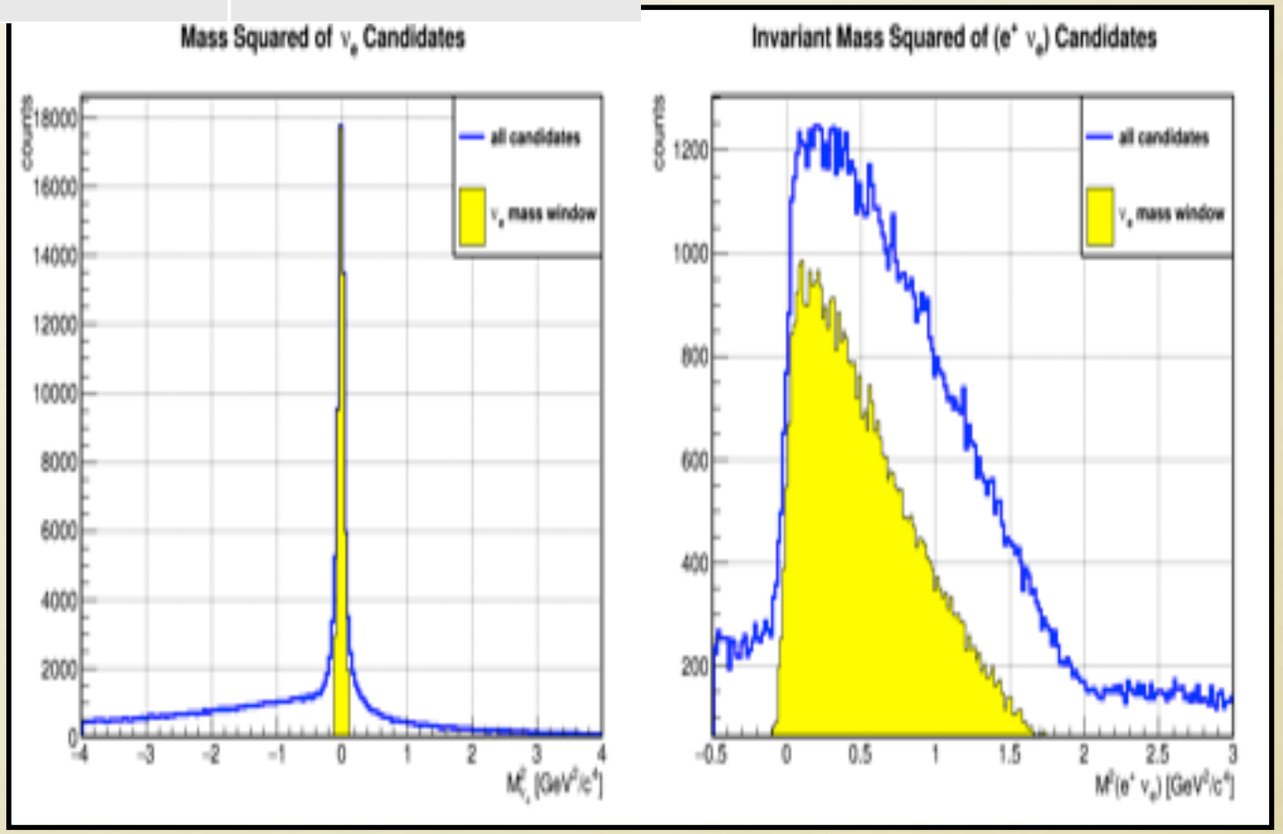

FCNC DECAYS

$\bar{p}p \to D^0\bar{D}^0 \to (\gamma\gamma) + (K\pi/K2\pi/K3\pi)$

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Mode : $E_{CM} = 3.77$ GeV	Efficiency	$N_{expected}$	comments
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$D^0\bar{D}^0 \to \gamma\gamma K^+\pi^-$	14.85%	61.5	
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Open charm background			
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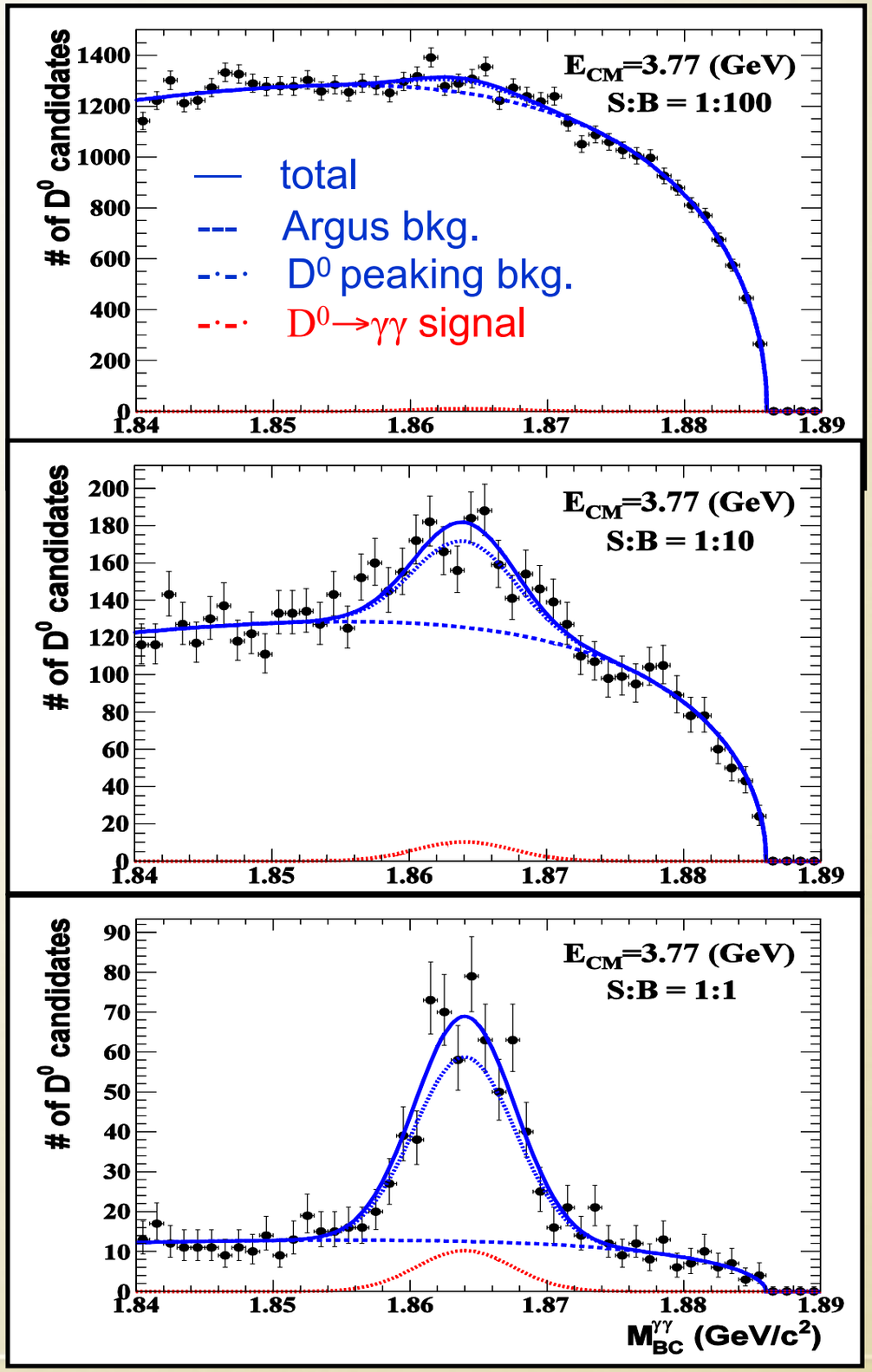

Open-Charm: Looking Ahead

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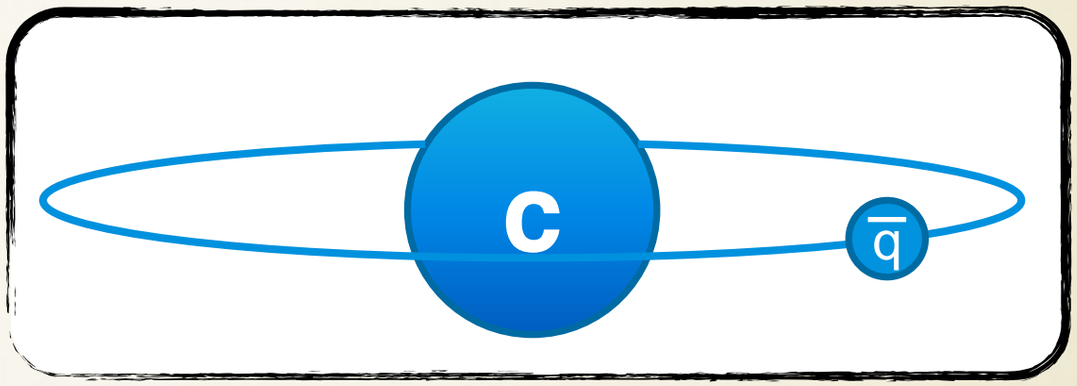
  - Funding limitations, career changes, …

Open-Charm "goodies"



- **Hadrons with narrow widths/long lifetimes**
  - ideal experimental signatures
  - perfect probes to study weak and strong forces
  - well suited for PANDA precision ambitions

- **Hydrogen-like system**
  - close to heavy-quark symmetry (HQS)
  - flavour (mass) and spin independent strong interaction
  - "tethered" constituent light quarks

- **Theoretically controllable (QCD based)**
  - HQS: heavy-quark effective theory and expansions
  - lattice QCD: model independent and moving forward!
  - b-sector: possibly precise;
  - c-sector: systematic *probe* of non-perturbative effects!

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