JÜLICH
FORSCHUNGSZENTRUM

p a n d a

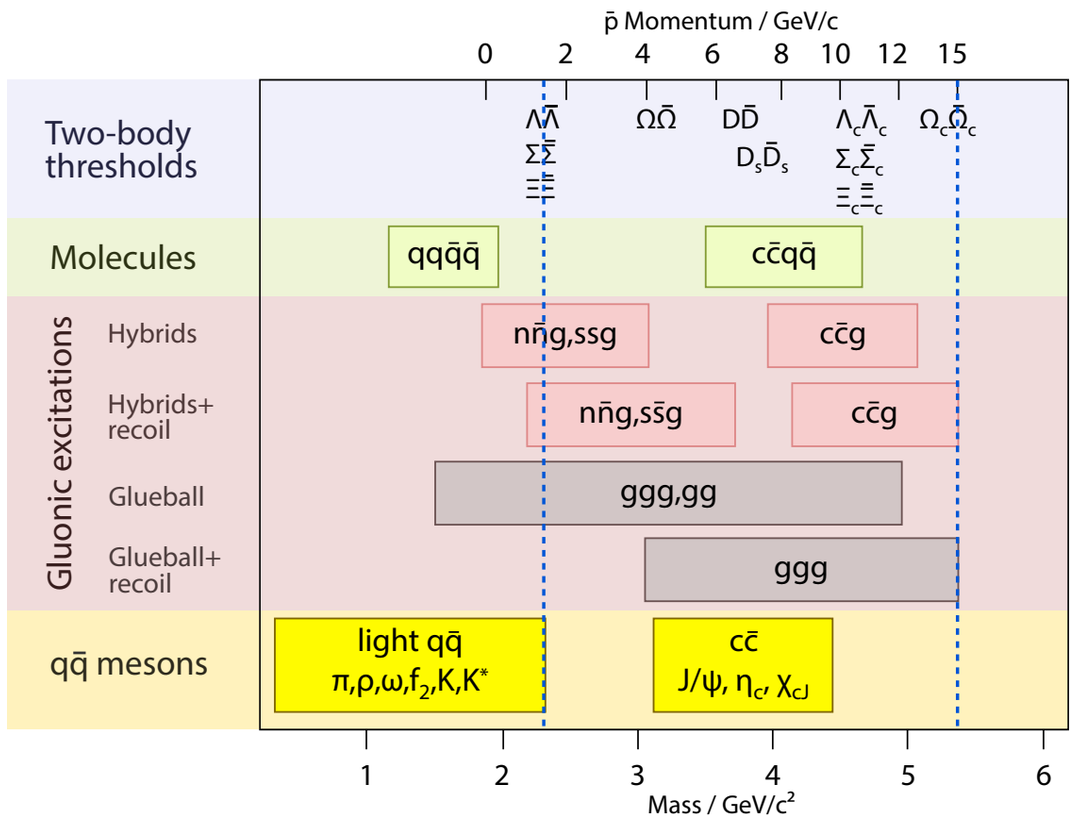
Opportunities in Open Charm Physics with P̄ANDA

3rd European Nuclear Physics Conference

1 September 2015, Groningen, Andreas Herten

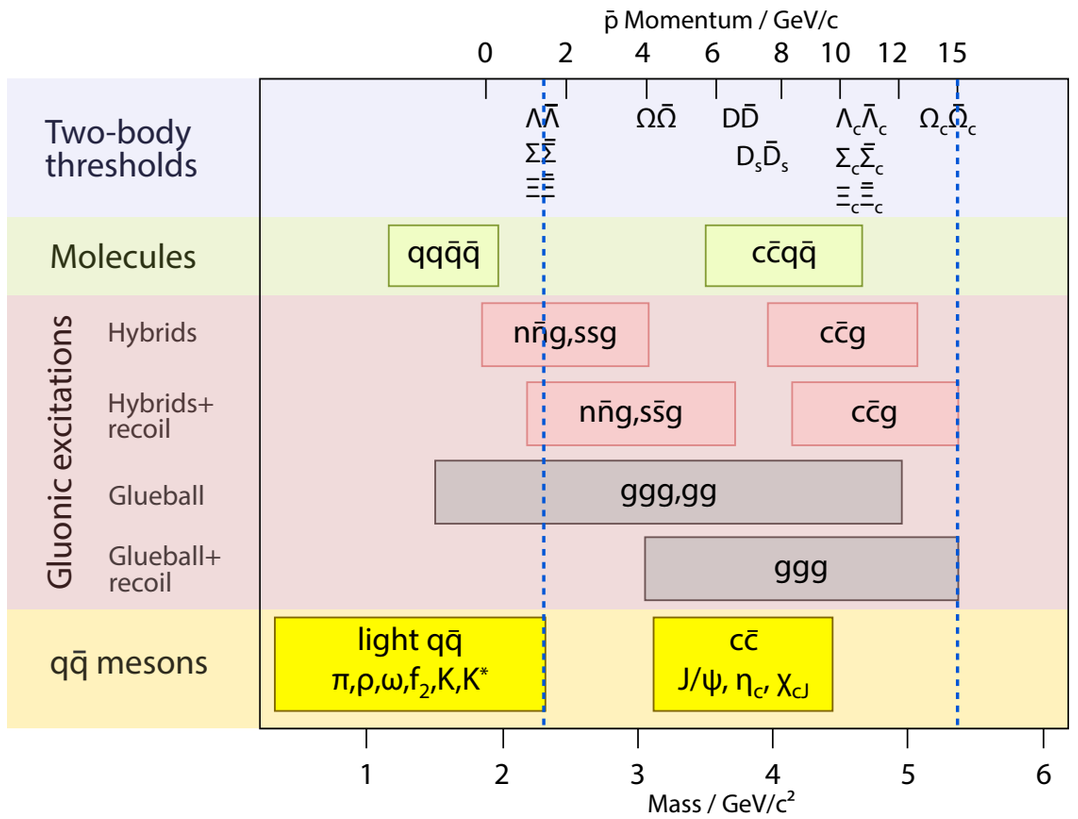
Physics with PANDA

- PANDA's physics program
  - Meson spectroscopy
    - Light mesons
    - Open charm
    - Charmonium
    - Exotic states (glueballs; hybrids)
  - Baryon spectroscopy (c, s quark content)
  - Nucleon structure & e.m. processes
  - Hadrons in matter
  - Hypernuclei
  - *more!*



Physics with PANDA

- PANDA's physics program
  - Meson spectroscopy
    - Light mesons
    - Open charm
    - Charmonium
    - Exotic states (glueballs; hybrids)
  - Baryon spectroscopy (c, s quark content)
  - Nucleon structure & e.m. processes
  - Hadrons in matter
  - Hypernuclei
  - *more!*
- PANDA's unique opportunities



Physics with PANDA

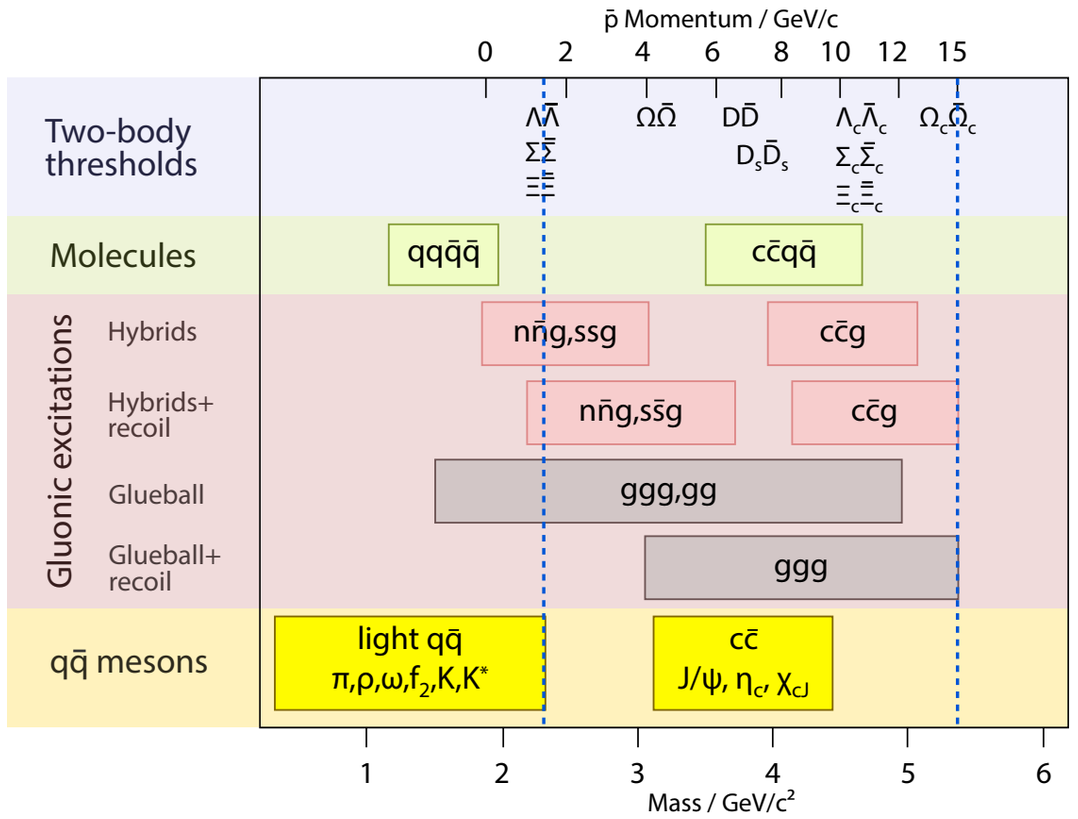
- PANDA's physics program
  - Meson spectroscopy
    - Light mesons
    - Open charm
    - Charmonium
    - Exotic states (glueballs; hybrids)
  - Baryon spectroscopy (c, s quark content)
  - Nucleon structure & e.m. processes
  - Hadrons in matter
  - Hypernuclei
  - *more!*

All quantum numbers

Precision measurement *(lineshape, width)*

Cold implantation of c in N

Double Λ-Nuclei



- PANDA's unique opportunities

Physics with PANDA

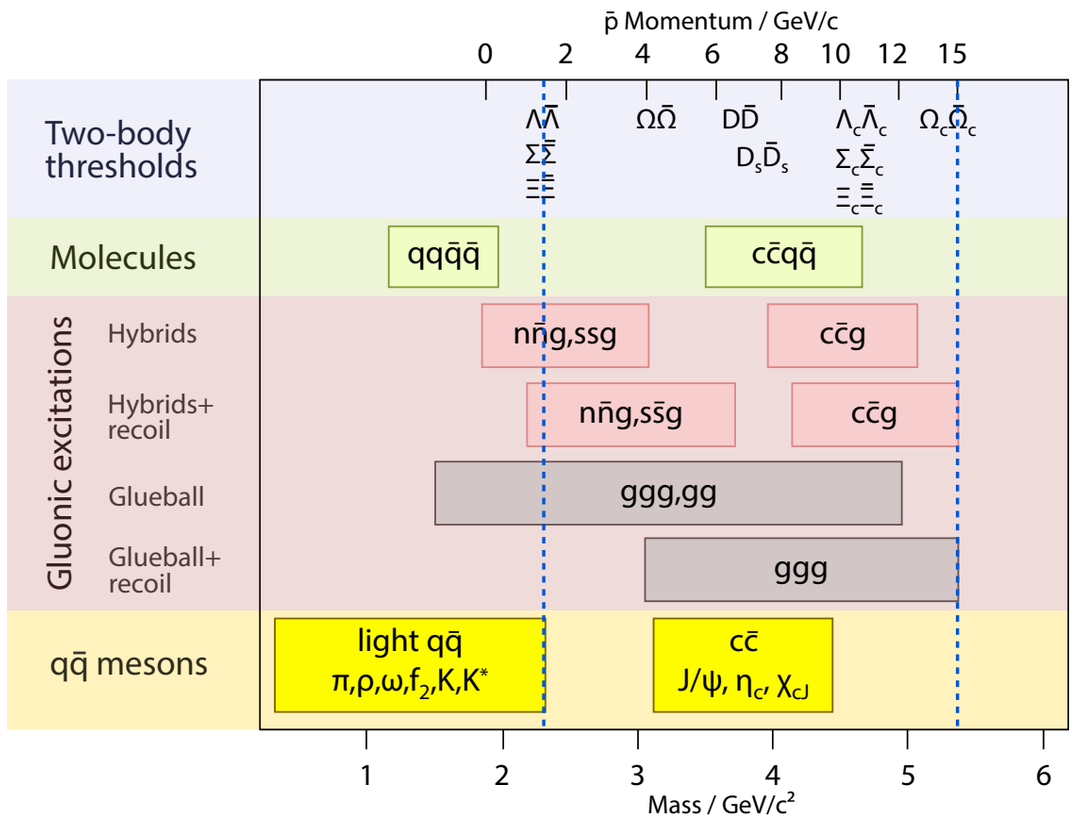
- PANDA's physics program
  - Meson spectroscopy
    - Light mesons
    - Open charm
    - Charmonium
    - Exotic states (glueballs; hybrids)
  - Baryon spectroscopy (c, s quark content)
  - Nucleon structure & e.m. processes
  - Hadrons in matter
  - Hypernuclei
  - *more!*

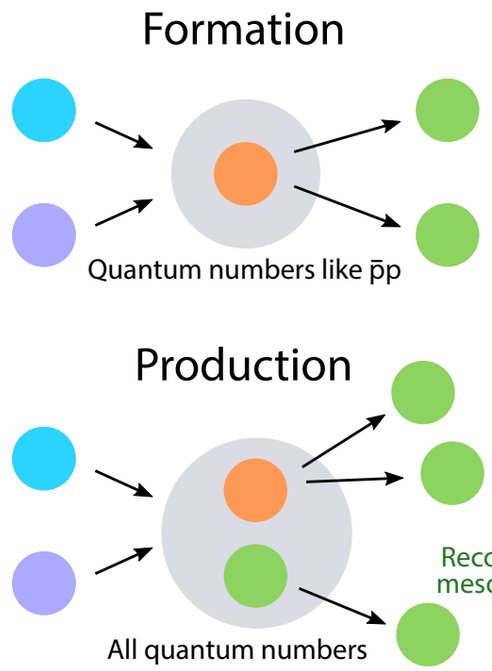
All quantum numbers

Precision measurement *(lineshape, width)*

Cold implantation of c in N

Double Λ-Nuclei





- PANDA's unique opportunities
  - All non-exotic quantum numbers directly accessible in formation *(high M & Γ resolutions)*
  - Compare production with formation for particles with exotic quantum numbers

The PANDA Detector

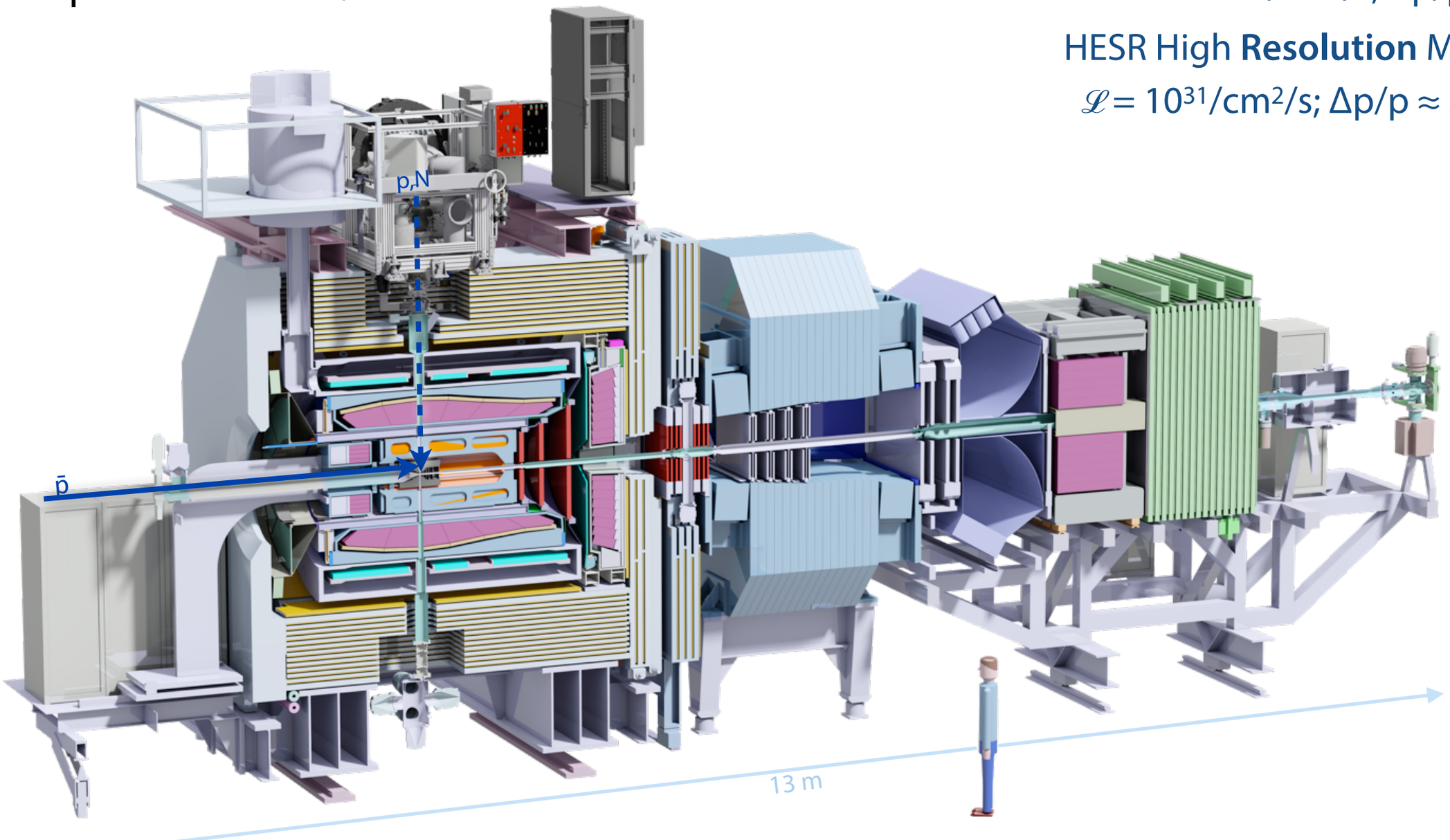
- Fixed-target experiment at FAIR, Darmstadt
  - Target spectrometer & forward spectrometer (~4π acceptance; better forward resolution)
  - Precise tracking (Δp/p ≈ 1 %); fine calorimetry (γ detection 5 MeV – 15 MeV); good PID
  - Online event reconstruction (parallel trigger lanes)
- Beam (HESR): cooled antiprotons at p = 1.5 - 15 GeV/*c*
- Up to 2×10^7 evt/s

HESR High **Luminosity** Mode:

$\mathscr{L} = 2 \times 10^{32}/cm^2/s$; $\Delta p/p \approx 10^{-4}$

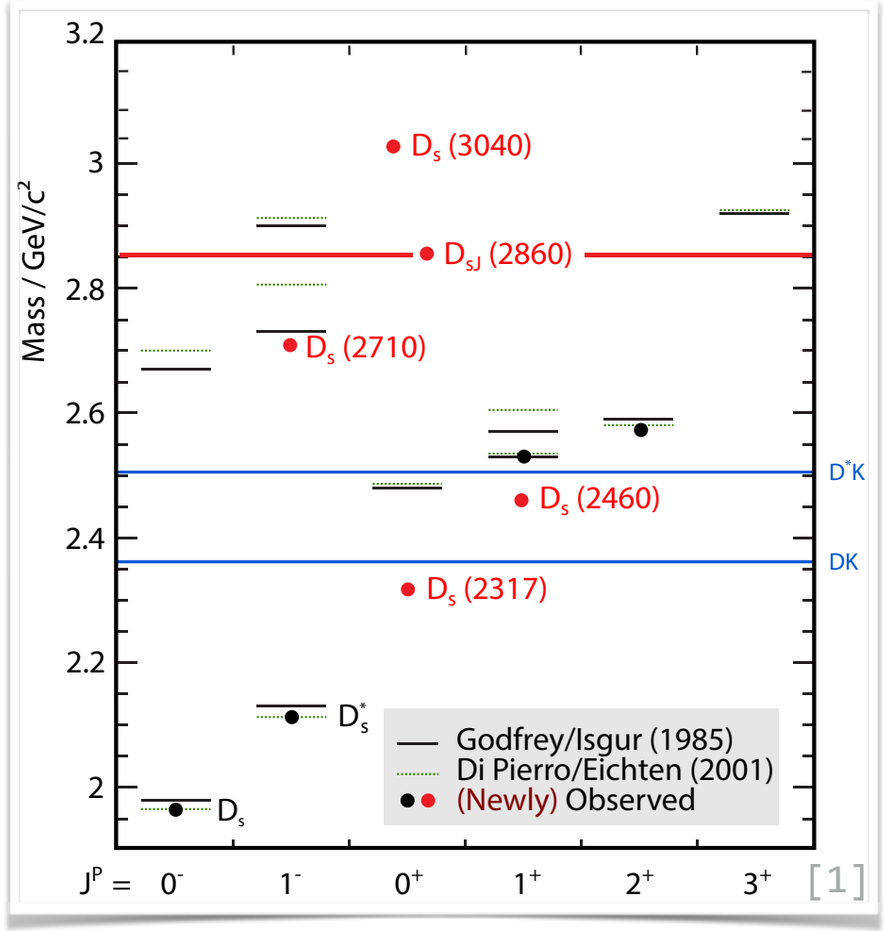
HESR High **Resolution** Mode:

$\mathscr{L} = 10^{31}/cm^2/s$; $\Delta p/p \approx 5 \times 10^{-5}$



Open Charm with PANDA

- Charm regime ideal test subject for study of different interactions
  - **Strong** interaction
    - Width characterization
    - Cross section measurements
    - New states
  - **Weak** interaction
    - D mixing
    - CP violation (e.g. D^0 $\bar{D}^0$ decay)



- High production rate of D mesons at PANDA
- Well-defined initial momentum (HESR)

PANDA Physics — $D^{\pm}$ Meson Decay

- Benchmark channel

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

  – Test of *PandaRoot*

  – Tracking, PID, Fitting, Analysis, …

- Unknown production cross section 10 nb – 100 nb

- Large branching ratio (9.13 %)

- Rate of reconstructed D mesons pairs @ PANDA:

  HL Mode, $p_{Beam} = 6.5$ GeV/c, $\sigma_{\bar{p}p \rightarrow DD} = 100$ nb

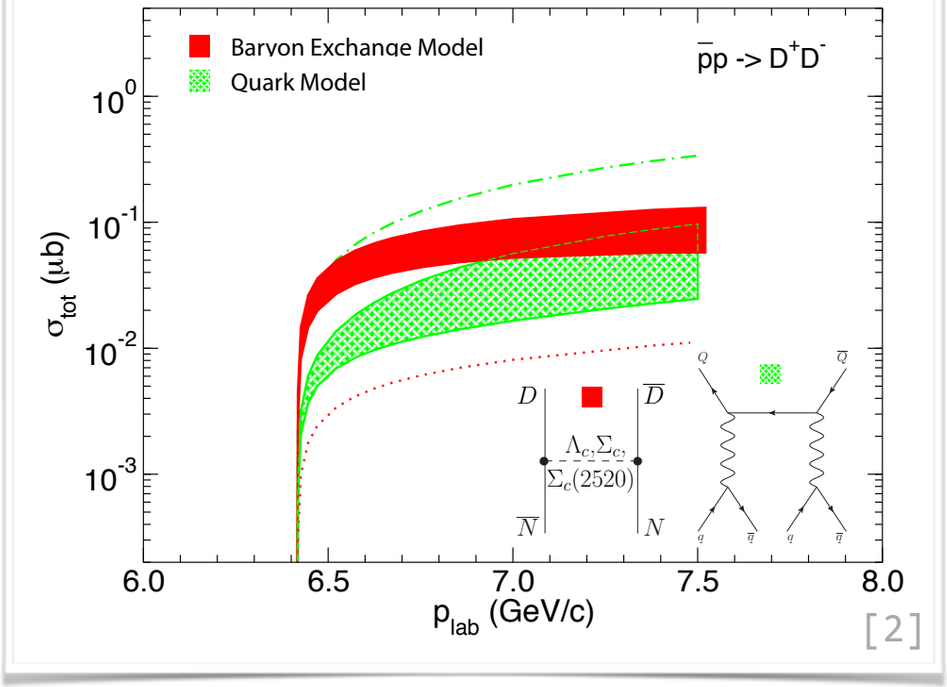
  – Inclusive: ~1300/h $D^{\pm}$ each

  – Exclusive: ~25/h D^+D^- pairs

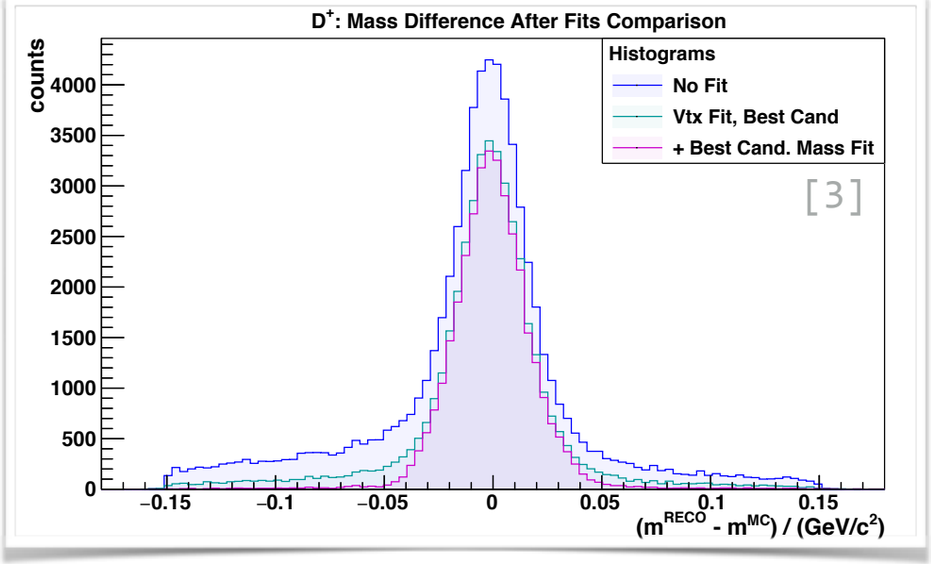
- Mass resolution:

  – Inclusive: 15 MeV/c^2

  – Exclusive: 10 MeV/c^2



[2]



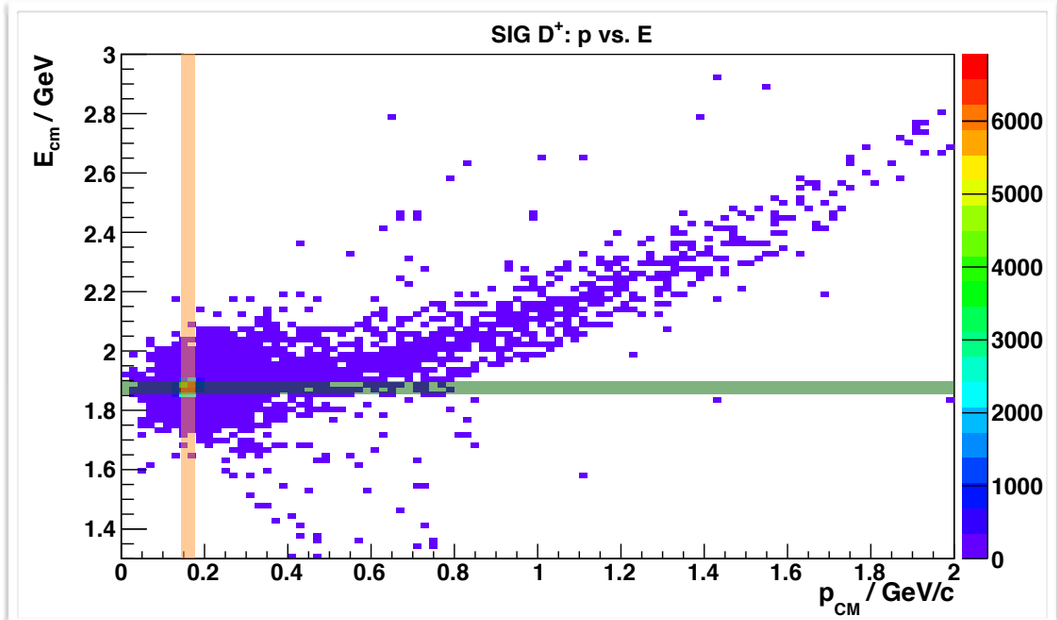
[3]

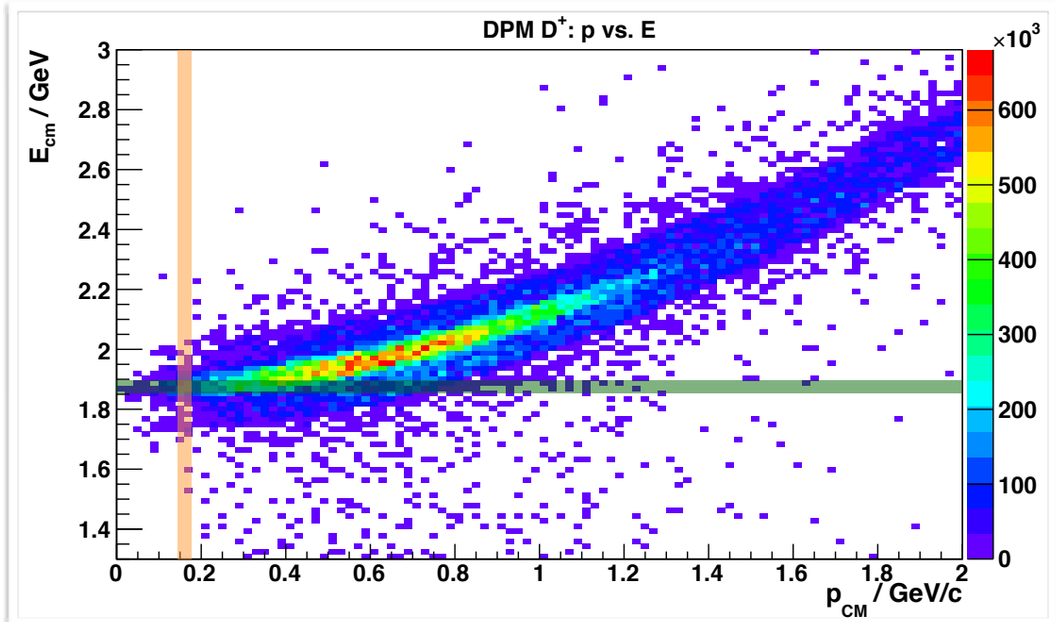
My thesis

PANDA Physics — $D^{\pm}$ Meson Decay

- Background study with DPM generator, $\bar{p}p \rightarrow q\bar{q}$
- Signal, background optimized for best significance

$$\mathcal{S} = \frac{N_{sig}^2}{N_{sig} + N_{bkg}}$$





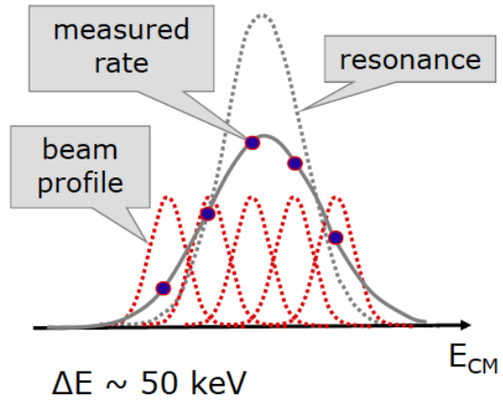
[3]

Inclusive: Challenging measurement, large background

Exclusive: Good suppression, but more background events required

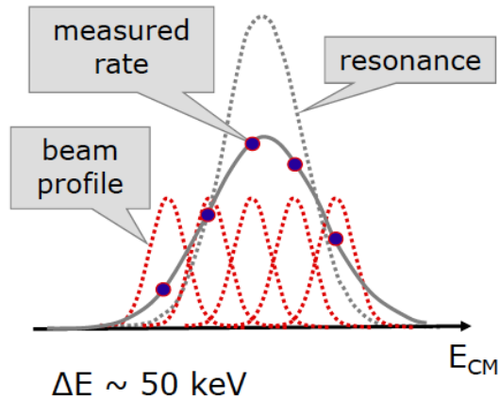
PANDA Physics — Width Measurement

- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)



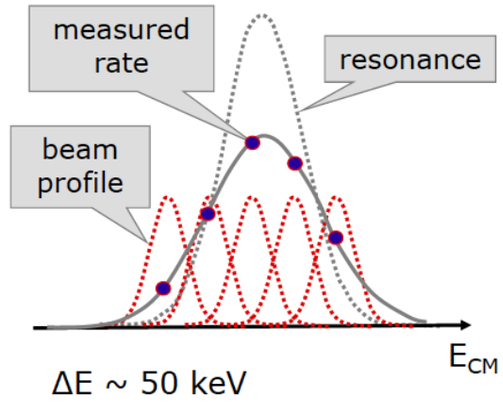
PANDA Physics — Width Measurement

- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)
- **Example:** $D_s(2317)$



PANDA Physics — Width Measurement

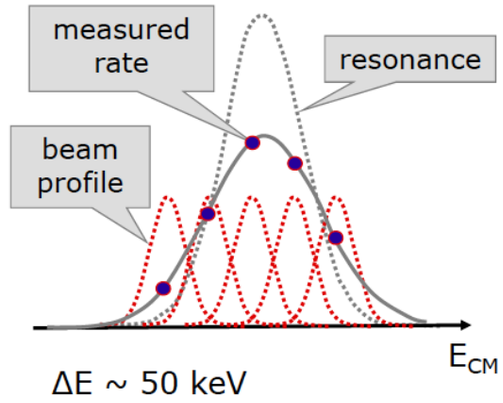
- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)
- **Example:** $D_s(2317)$



Theoretical Approach	$\Gamma(D_{s0}^*(2317) \to D_s\pi^0)$ keV
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10
Fayyazuddin and Riazuddin, Phys. Rev. D 69, 114008 (2004)	16
W. A. Bardeen, E. J. Eichten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
J. Lu, X. L. Chen, W. Z. Deng and S. L. Zhu, Phys. Rev. D 73, 054012 (2006)	32
W. Wei, P. Z. Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Yamauchi, AIP Conf. Proc. 717, 716 (2004)	15 - 70
H. Y. Cheng and W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	79.3 ± 32.6
Y. I. Azimov and K. Goeke, Eur. Phys. J. A 21, 501 (2004)	129 ± 43 (109 ± 16)
M.F.M. Lutz, M. Soyeur, arXiv: 0710.1545 [hep-ph]	140
Feng-Kun Guo, Christoph Hanhart, Siegfried Krewald, Ulf-G. Meißner Phys Lett. B 666 (2008) 251-255	$180 \pm 40 \pm 100$

PANDA Physics — Width Measurement

- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)
- **Example:** $D_s(2317)$

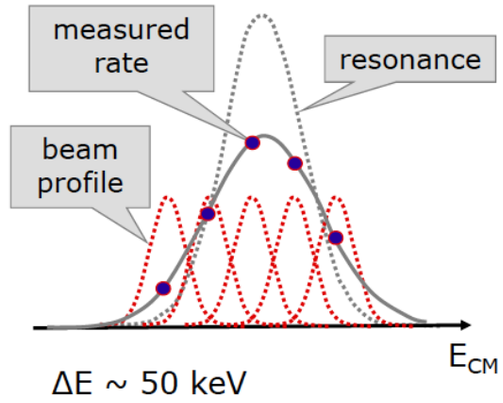


Theoretical Approach	$\Gamma(D_{s0}^*(2317) \to D_s\pi^0)$ keV
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10
Fayy… …uddin, Phys. Rev. D 69, 114008 (2004)	16
…nten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
…eng and S. L. Zhu, Phys. Rev. D 73, 054012	32
…Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Yamauchi, AIP Conf. Proc. 717, 716 (2004)	15 - 70
H. Y. Cheng and W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	79.3 ± 32.6
Y. I. Azimov and K. Goeke, Eur. Phys. J. A 21, 501 (2004)	129 ± 43 (109 ± 16)
M.F.M. Lutz, M. Soyeur, arXiv: 0710.1545 [hep-ph]	140
Feng-Kun Guo, Christoph Hanhart, Siegfried Krewald, Ulf-G. Meißner Phys Lett. B 666 (2008) 251-255	$180 \pm 40 \pm 100$

Decay width of $D_s(2317)$ is criterion for testing nature

PANDA Physics — Width Measurement

- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)
- **Example:** $D_s(2317)$



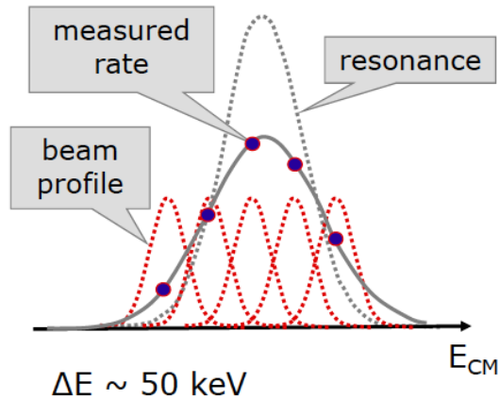
Theoretical Approach	$\Gamma(D_{s0}^*(2317) \to D_s\pi^0)$ keV
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10
Fayy…uddin, Phys. Rev. D 69, 114008 (2004)	16
…nten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
…eng and S. L. Zhu, Phys. Rev. D 73, 054012	32
…Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Ya… P Conf. Proc. 717, 716 (2004)	15 - 70
…nd W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100
…Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007)	79.3 ± 32.6
…and K. Goeke, Eur. Phys. J. A 21, 501 (2004)	129 ± 43 (109 ± 16)
M.F.M. Lutz, M. Soyeur, arXiv: 0710.1545 [hep-ph]	140
Feng-Kun Guo, Christoph Hanhart, Siegfried Krewald, Ulf-G. Meißner Phys Lett. B 666 (2008) 251-255	$180 \pm 40 \pm 100$

Decay width of $D_s(2317)$ is criterion for testing nature

Only possible at PANDA!

PANDA Physics — Width Measurement

- Production at **B factories**: mass resolution depends on detector resolution (~ MeV)
- Formation in **PANDA**: resonance scan *(like in E760)*, use good beam resolution (~ 30 - 50 keV)
- **Example:** $D_s(2317)$
- $\bar{p}p \rightarrow D_s^- D_{s0}^*(2317)^+$
  $D_s(2317)$ reconstructed as D_s^- recoil



Theoretical Approach	$\Gamma(D_{s0}^*(2317) \rightarrow D_s\pi^0)$ keV
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10
Fayy…uddin, Phys. Rev. D 69, 114008 (2004)	16
…nten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
…eng and S. L. Zhu, Phys. Rev. D 73, 054012	32
…Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Y… P Conf. Proc. 717, 716 (2004)	15 - 70
…nd W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100
…Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007)	79.3 ± 32.6
…nd K. Goeke, Eur. Phys. J. A 21, 501 (2004)	129 ± 43 (109 ± 16)
M.F.M. Lutz, M. Soyeur, arXiv: 0710.1545 [hep-ph]	140
Feng-Kun Guo, Christoph Hanhart, Siegfried Krewald, Ulf-G. Meißner Phys Lett. B 666 (2008) 251-255	$180 \pm 40 \pm 100$

Decay width of $D_s(2317)$ is criterion for testing nature

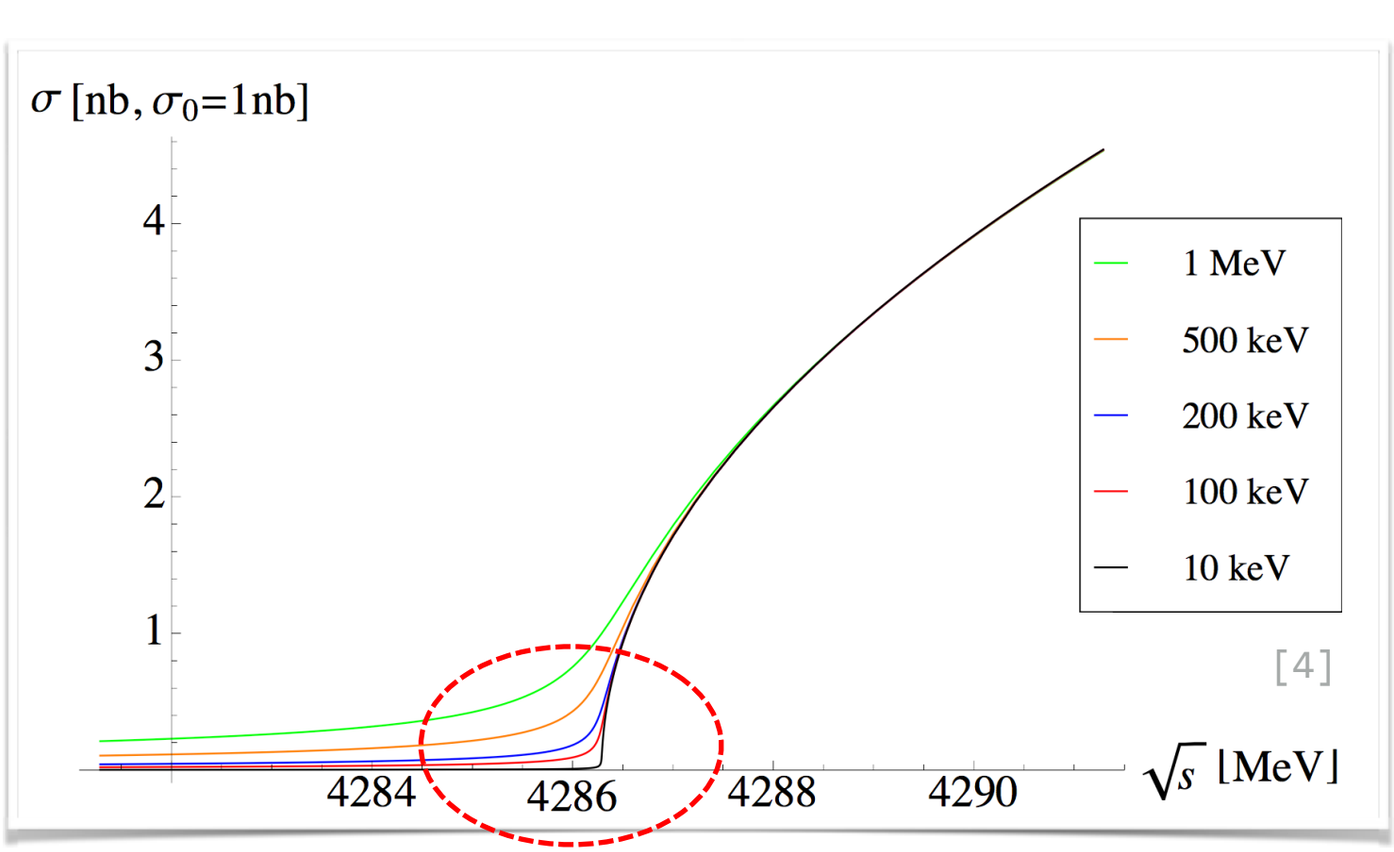
Only possible at PANDA!

PANDA Physics — Threshold Scan

- Reaction: $\bar{p}p \to D_s^{\pm} D_{s0}^{*}(2317)^{\mp}$
- Excitation function:

$$\frac{\sigma(s)}{|M^2|} = \frac{\Gamma}{4\pi\sqrt{s}} \int_{-\infty}^{\sqrt{s}-m_{D_s}} \mathrm{d}m \frac{\sqrt{\left(s-(m+m_{D_s})^2\right)\left(s-(m-m_{D_s})^2\right)}}{\left(m-m_{D(2317)}\right)^2+(\Gamma/2)^2}$$

  - Depends on m and Γ of $D_s(2317)$
  - Experimental accuracy determined by **beam quality**, not detector resolution



Thesis of M. Mertens

PANDA Physics — Threshold Scan

JÜLICH FORSCHUNGSZENTRUM

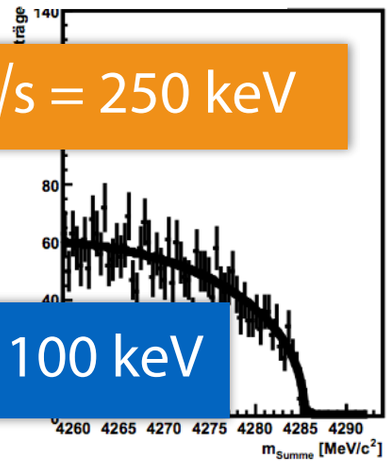
panda

$\Delta\sqrt{s} = 250$ keV

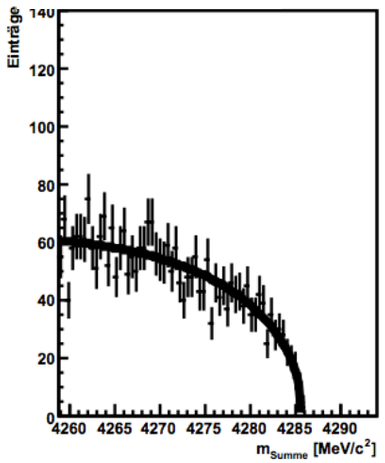
$\Gamma = 100$ keV

~60 days beam time
(HL Mode)

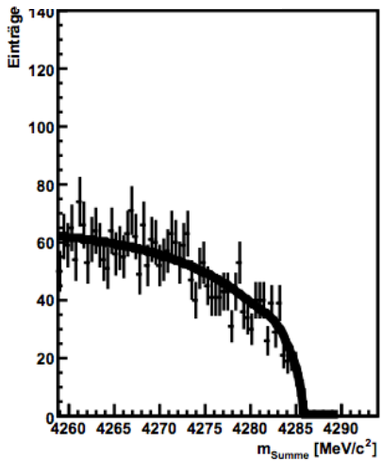
√s = 4284.4 MeV



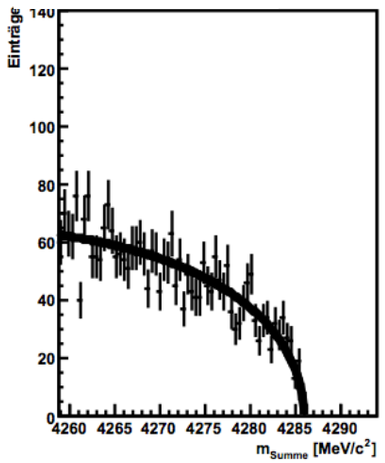
√s = 4284.7 MeV



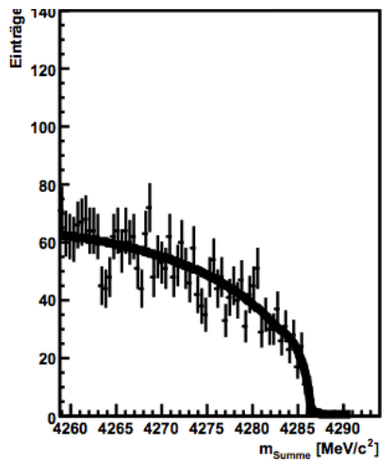
√s = 4285 MeV



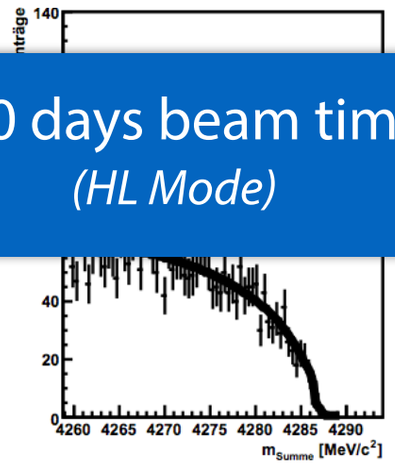
√s = 4285.2 MeV



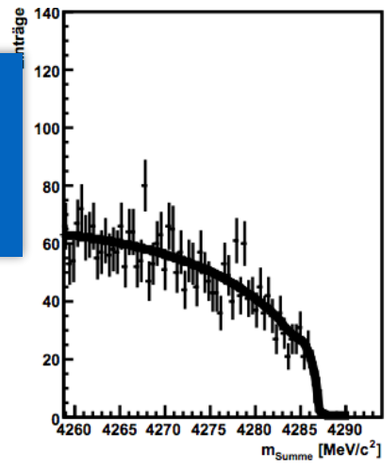
√s = 4285.5 MeV



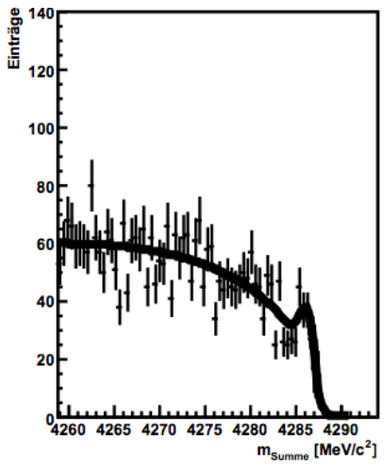
√s = 4285.8 MeV



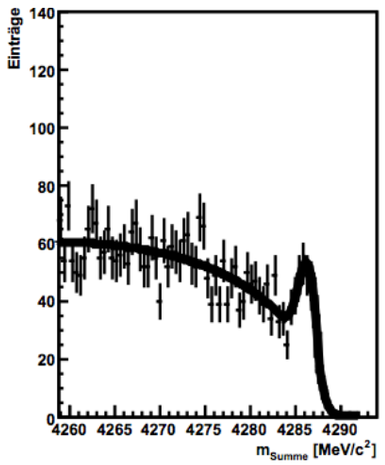
√s = 4286 MeV



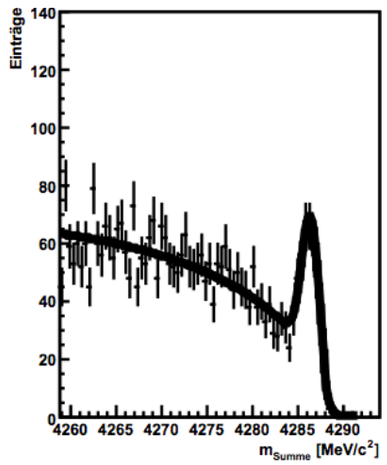
√s = 4286.3 MeV



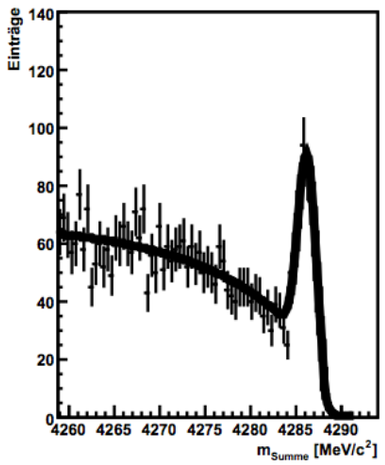
√s = 4286.6 MeV



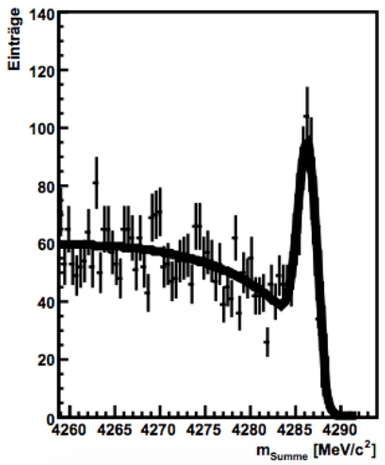
√s = 4286.8 MeV



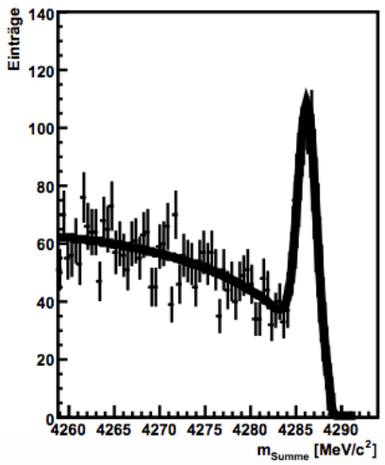
√s = 4287.1 MeV



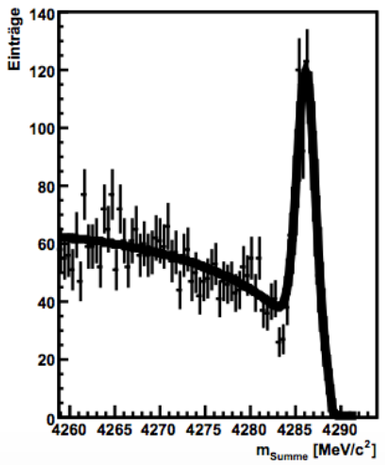
√s = 4287.4 MeV



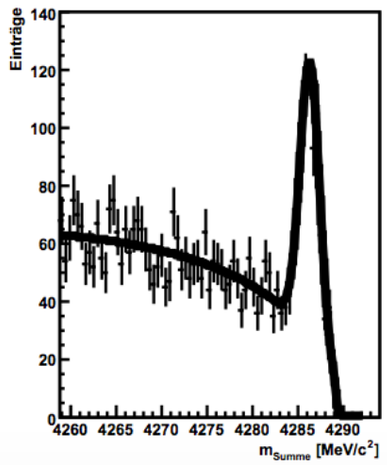
√s = 4287.6 MeV



√s = 4287.9 MeV

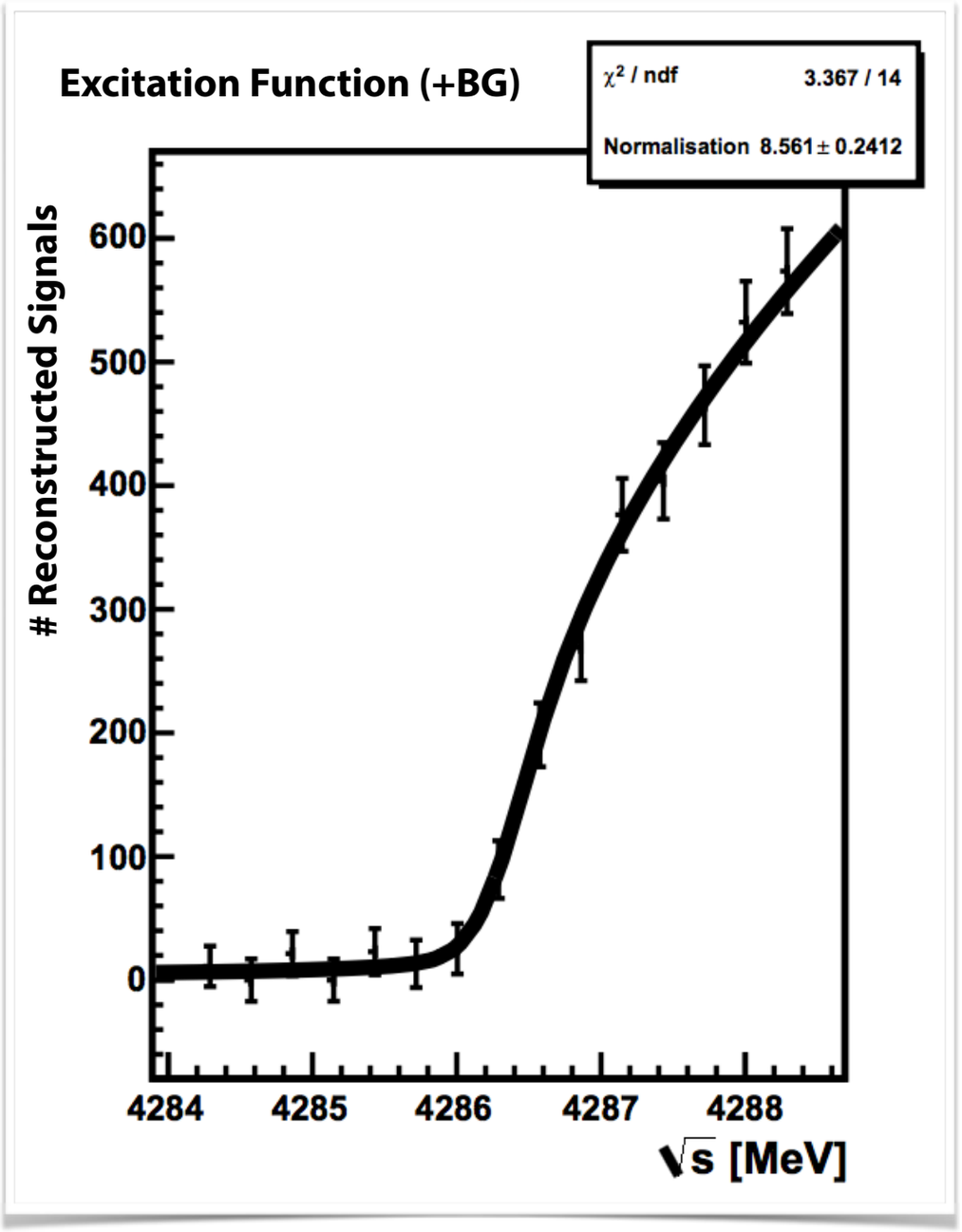


√s = 4288.2 MeV



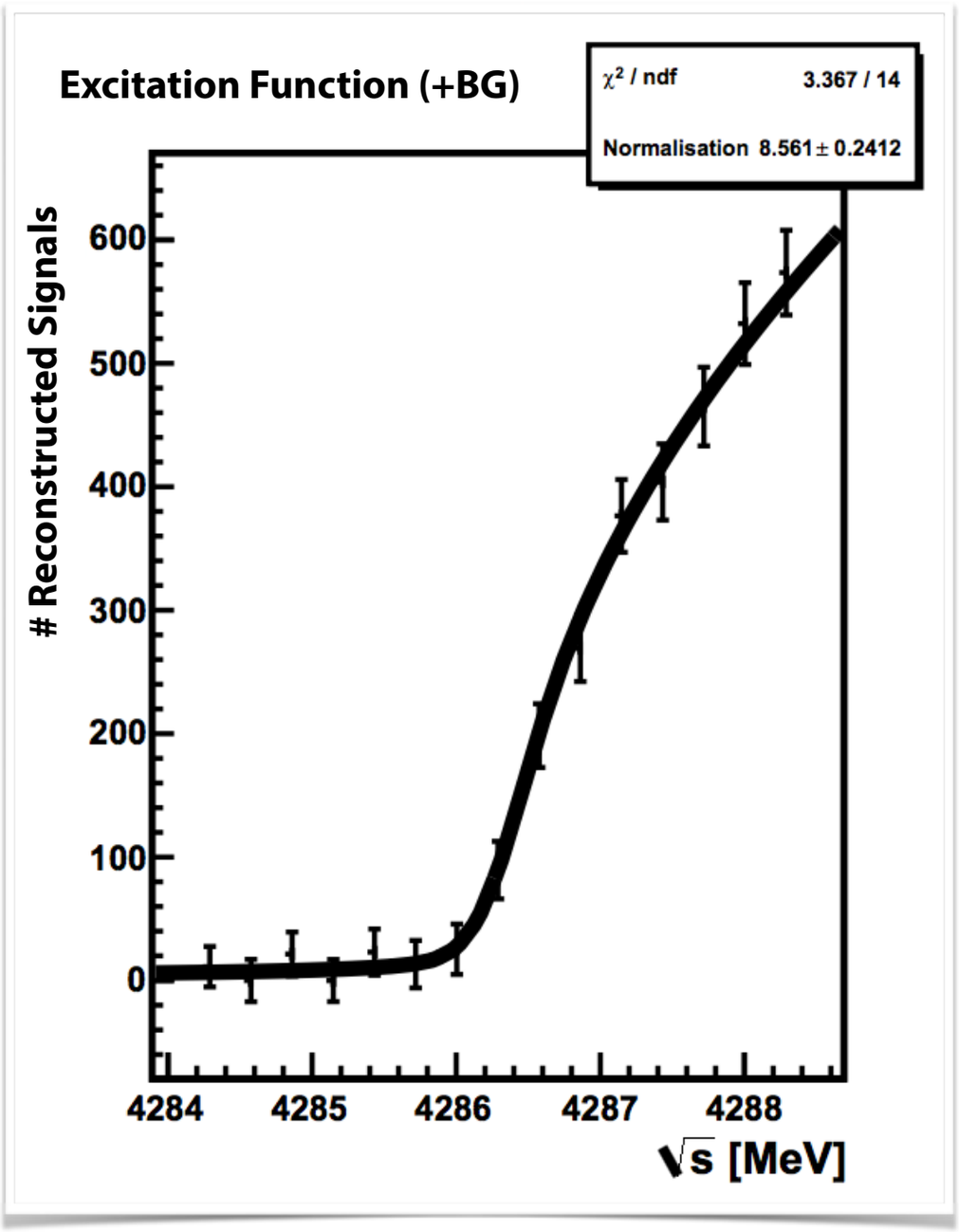
[4]

PANDA Physics — Threshold Scan



[4]

PANDA Physics — Threshold Scan



Width resolution of σ(Γ) ≈ 100 keV possible!

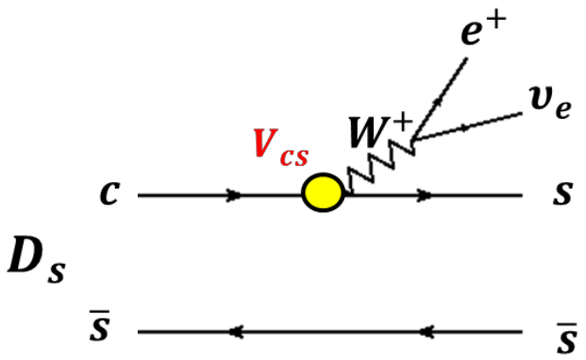
Cross section: 10 nb

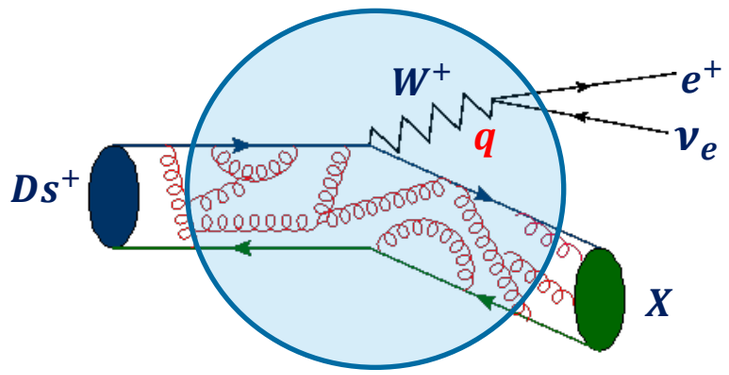
[4]

PANDA Outlook — D_s Analysis

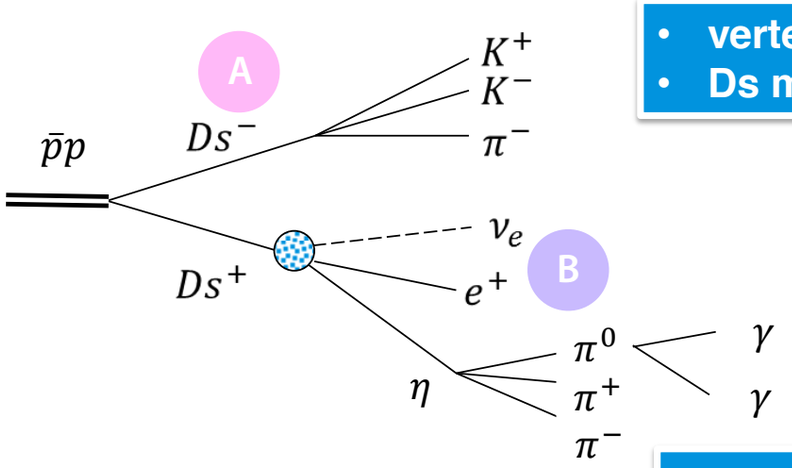
- $D_s^+ \rightarrow e^+ \nu_e \eta/\eta'$
  - Access V_{cs} and form factor
  - Validation of theoretical calculations
  - η–η' mixing

- Analysis still ongoing





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



- 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

[5]

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

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

Thesis of L. Cao

Summary & Conclusion

- PANDA has broad and ambitious physics program; charm & charmonium sector of high interest
  - Unique position to study nature of old and new charm states
  - Good mass resolutions (about 20 × better than B factories)
  - Cross section measurements
- Detector and software still in development

→ PANDA essential tool *(not only)* for understanding charm physics sector!

Summary & Conclusion

- PANDA has broad and ambitious physics program; charm & charmonium sector of high interest
  - Unique position to study nature of old and new charm states
  - Good mass resolutions (about 20 × better than B factories)
  - Cross section measurements
- Detector and software still in development

→ PANDA essential tool *(not only)* for understanding charm physics sector!

Thank you!

Andreas Herten
a.herten@fz-juelich.de

Table Of Contents

References

- [1] (p5): P. Gianotti (2012); *Results and perspectives in hadron spectroscopy;* Phys. Scr. 2012 014014
- [2] (p6): J. Haidenbauer, G. Krein (2014); *Production of charmed pseudoscalar mesons in antiproton-proton annihilation*; arXiv:1404.4174
- [3] (p6,p7): A. Herten (2015); *GPU-based Online Track Reconstruction for PANDA and Application to the Analysis of $D \rightarrow K\pi\pi$*; PhD Thesis
- [4] (p9,p10,p11): M. Mertens (2012); *Der PANDA Mikro Vertex Detektor: Entwicklung eines Labormesssystems, Simulation der MVD-Betriebsparameter sowie Untersuchungen zur Auflösung der Breite des Ds0(2317)*; PhD Thesis
- [5] (p13): L. Cao (2014); *Simulated Measurements of the Ds Semileptonic Decay Form Factor with the PANDA Detector*; Poster at ICHEP Valencia 2014