Threshold scan at $\overline{\text{P}}$ANDA

on behalf of the $\overline{\text{P}}$ANDA Collaboration.

September 29th, 2017 | Elisabetta Prencipe, Forschungszentrum Jülich | HADRON 2017 – Salamanca (ES)

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Outline

- **Introduction**
- **$\bar{p}p$ open-charm cross section estimates**
- **Possibility with the detector *$\overline{P}$ANDA* @ FAIR**
- **Example of threshold scan @ $\overline{\text{P}}$ANDA: $\bar{p}p \to D_s^+ D_{s0}^*(2317)^-$**
- **Summary**

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Introduction

Since 2003

- Unexpected observations questioning validity of potential models
- Charm (*cq*) and Charmonium ($\bar{c}c + \bar{q}q$) spectra populated by new states
- Strangeness in Charm and Charmonium physics still to be exploited
- Great contribution from past and running experiments, but:
  - ▸ spectrum still to be understood
  - ▸ different interpretations
- Excited D and D_s mesons predicted
- D_s mesons below DK threshold still of unclear interpretation:
  - ▸ limitations due to the past experiments to measure the D_s line shape;
  - ▸ limitation at LHCb to detect D_s states below the DK threshold.

→ low momentum photons

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Charm physics: why?

$D^0 = |c\bar{u}\rangle$, $D^+ = |c\bar{d}\rangle$;
$D_s^+ = |c\bar{s}\rangle$

- Why the interest in charm physics:
  - Strong interactions
    - Intermediate case between heavy and light quarks
    - Spectroscopy
    - Strong decay modes
  - Weak interactions
    - CP violation
    - Mixing
    - Possible window to search for New Physics beyond the Standard Model

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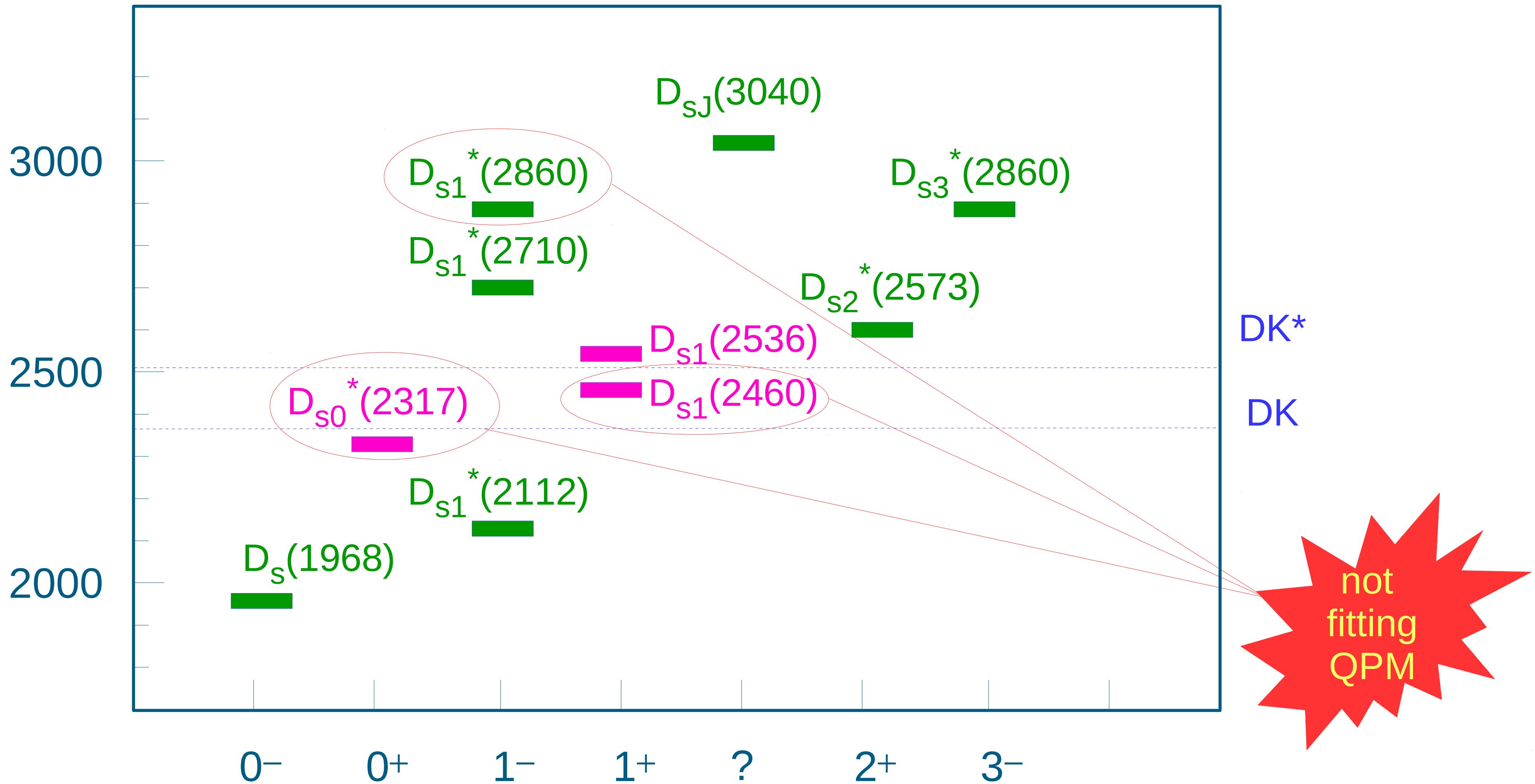
Charm-strange spectrum, today



QPM = quark potential model

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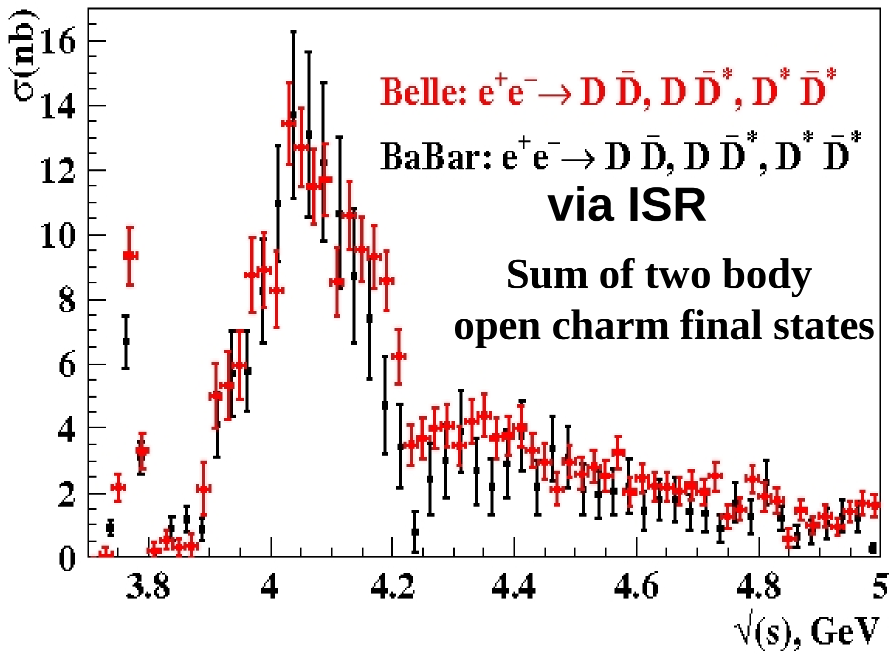
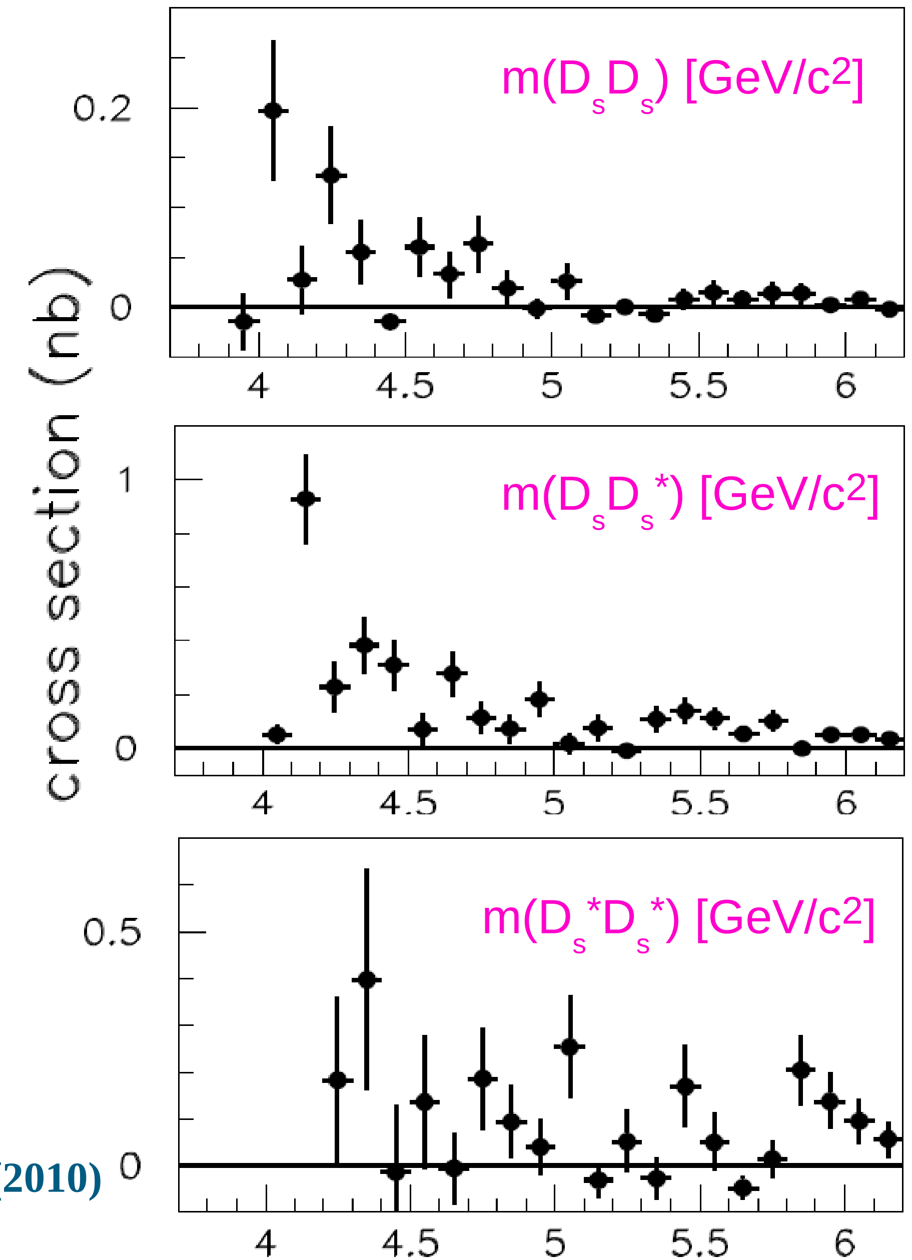
Cross section (e+e−)

Phys. Rev. Lett. 98, 092001 (2007)
Phys.Rev. D79, 092001(2009)





Phys.Rev. D82, 052004(2010)

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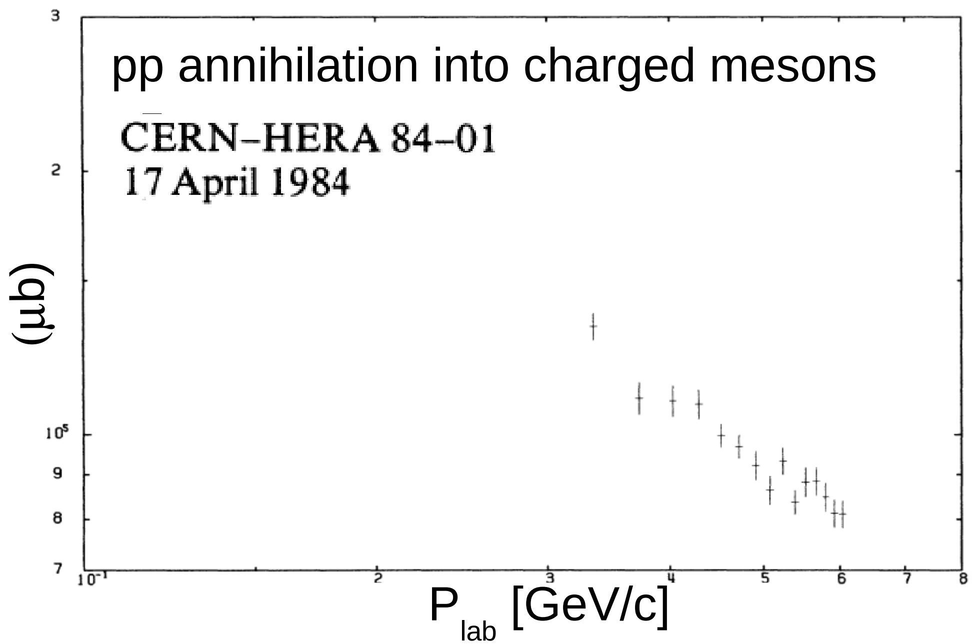
Cross section ($\bar{p}p$)

- Predictions in $\bar{p}p$ difficult due to the presence of *s*-quark in D_{sJ} mesons:
  $\sigma(\bar{p}p \rightarrow \bar{D}D)$ expected <100nb
- Inclusive search: better for cross section measurement, but higher background.
- Exclusive cross section measurement:
  difficult theoretical predictions, experimental poor knowledge

V. Flaminio, W.G. Moorhead, D.R.O. Morrison, N. Rivoire



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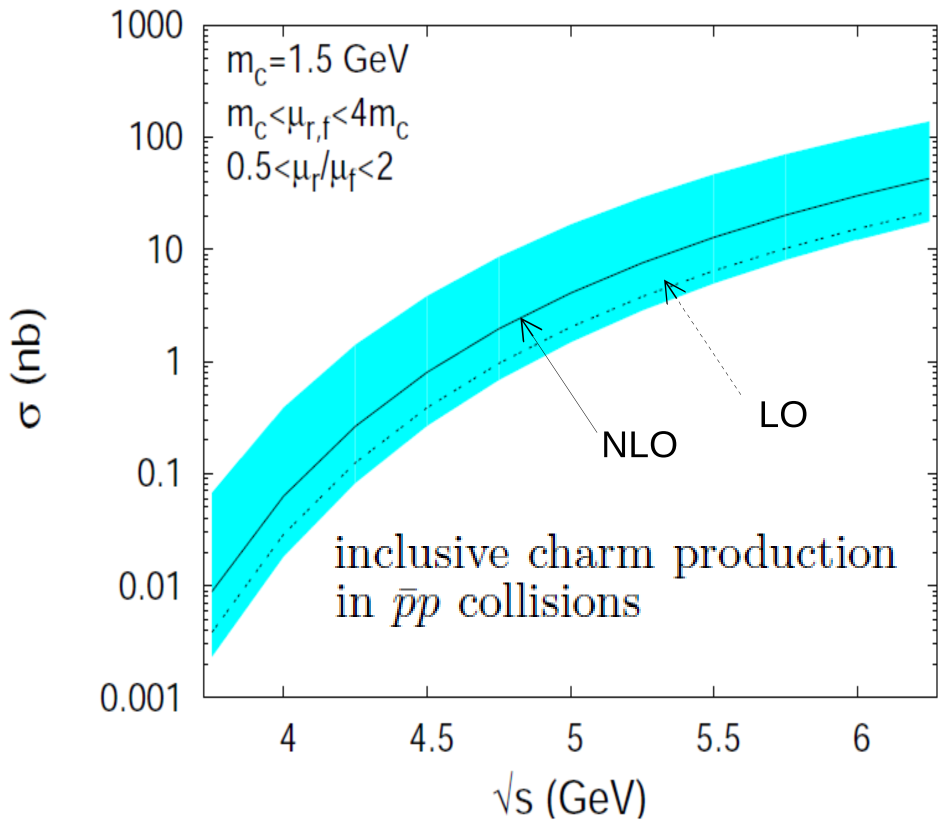
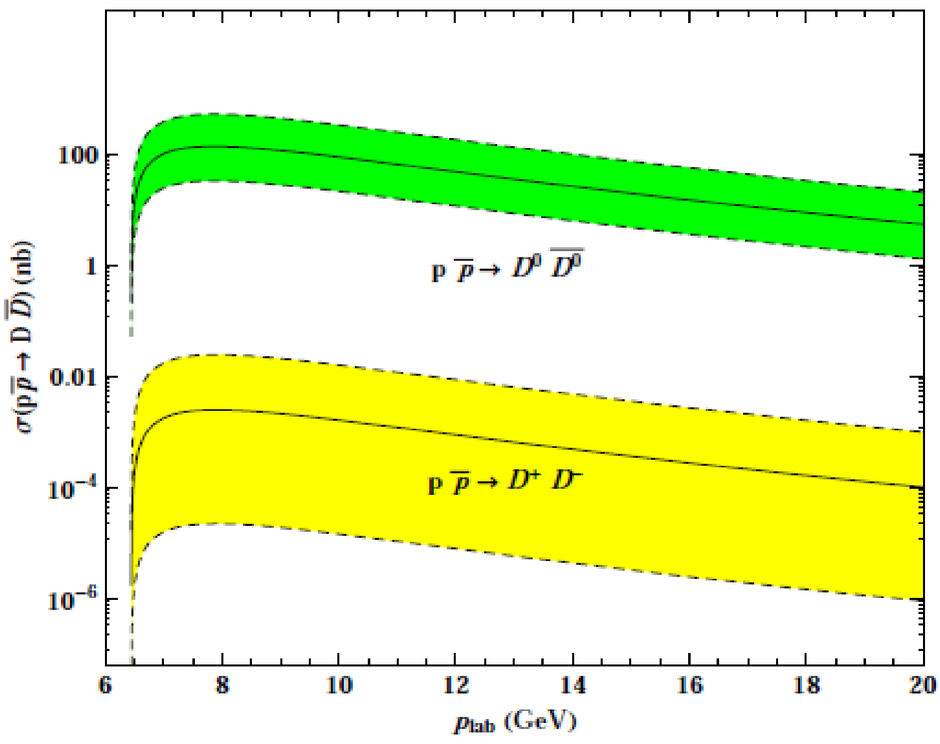
Cross section predictions ($\bar{p}p$)

- Theoretical predictions for the charmed ground states (D^+, D^0).
- Calculations for excited D states (no *s*-quark) are difficult:
  calculations in perturbative regime can under-estimate the real cross section



Phys. Rev. D 79 (2009) 114005

E. Braaten, P. Artoisenet



Eur. Phys. J. A 48 (2012) 31

A. Khodjamirian, C. Klein, T. Mannel, Y.M. Wang

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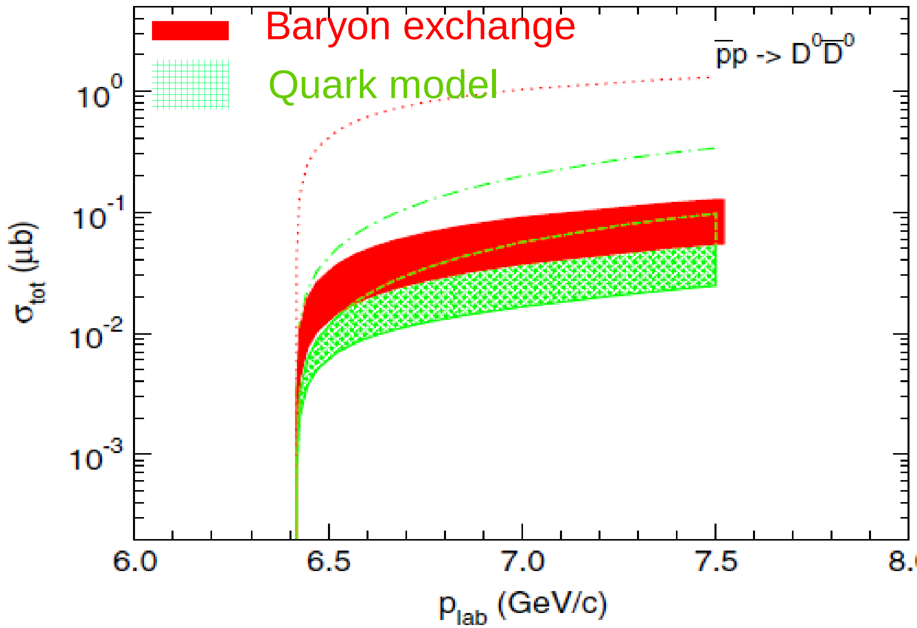
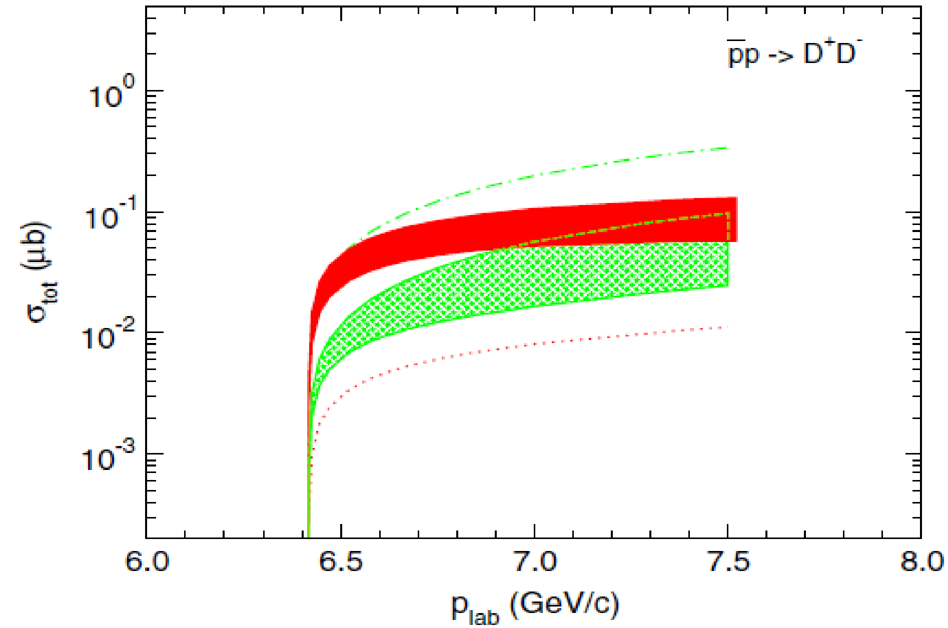
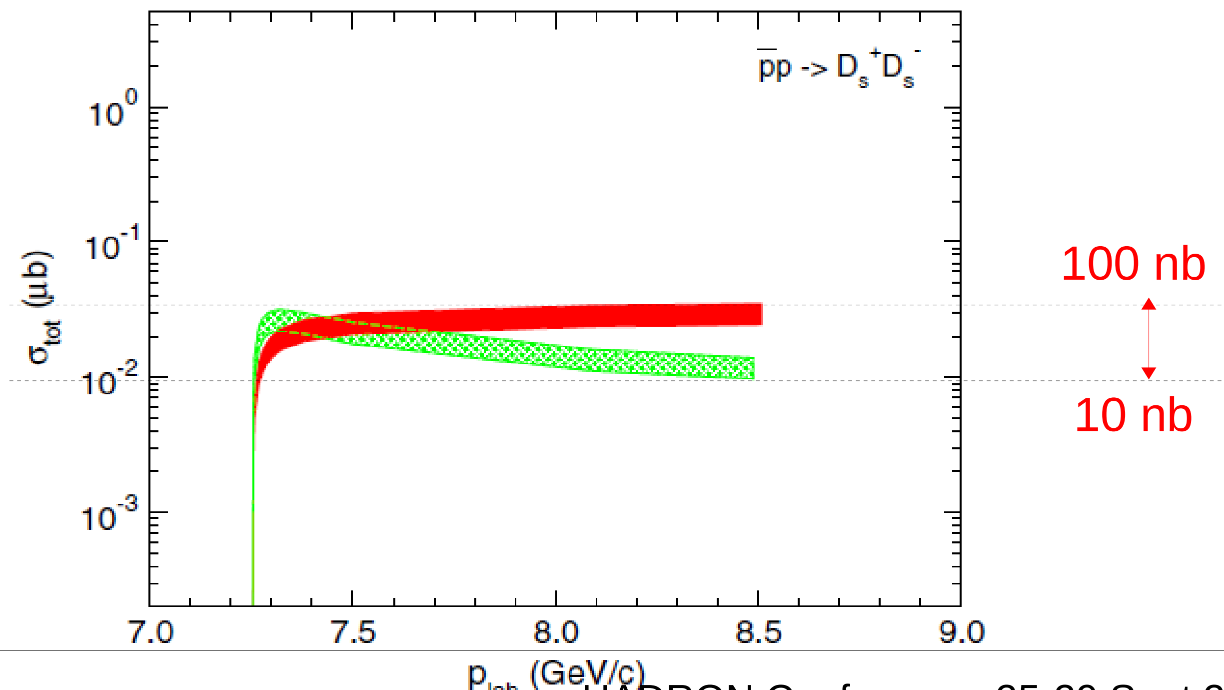
Cross section predictions ($\bar{p}p$)





Phys. Rev. D 89 (2014) 114003

J. Haidenbauer, G. Krein



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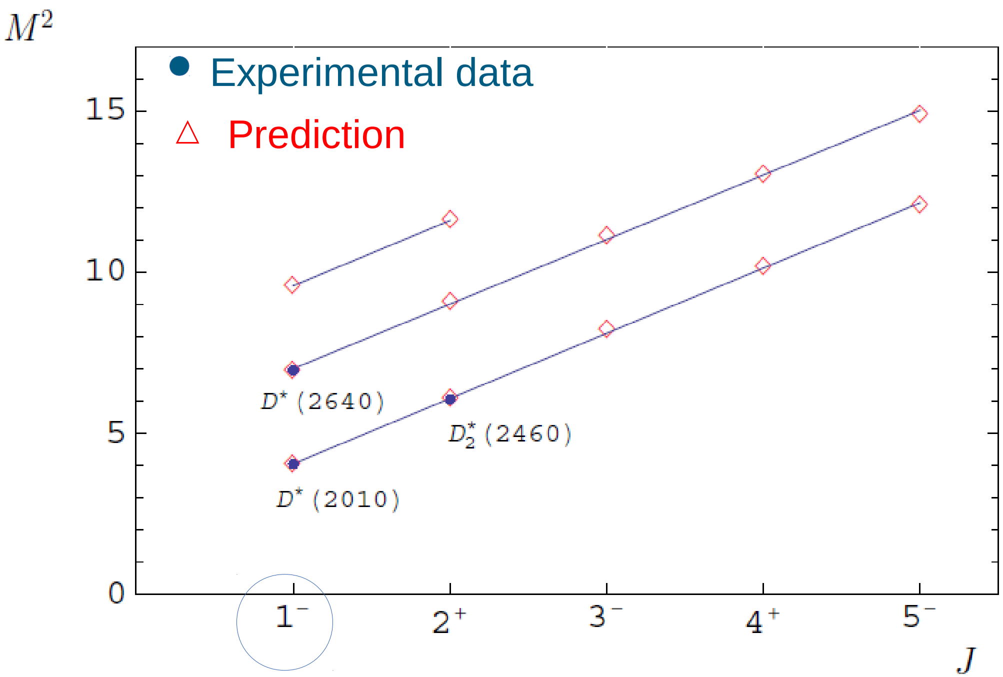
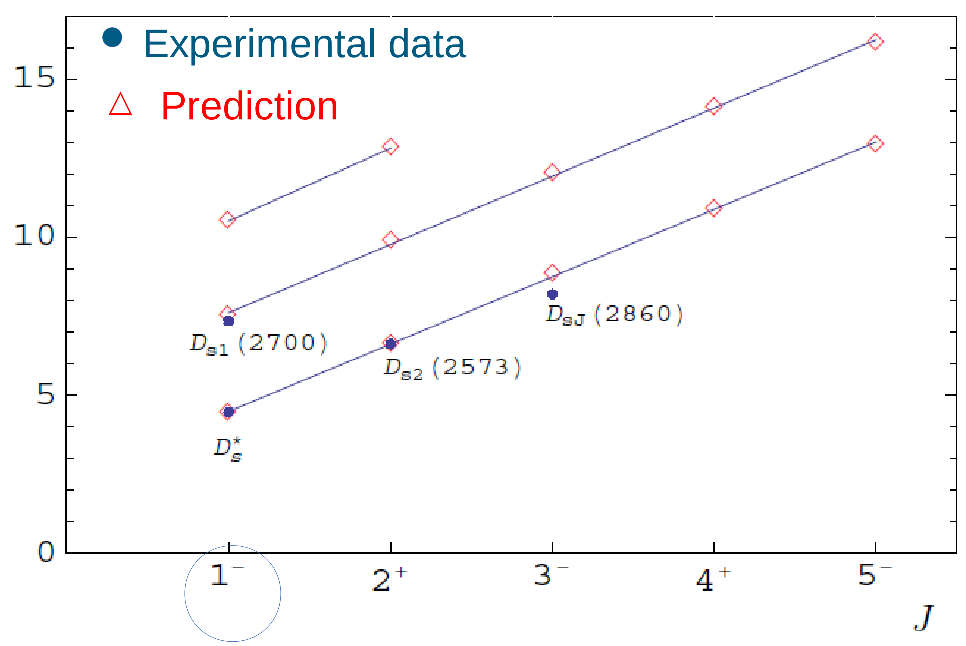
$\bar{p}p$ open-charm cross sections

- In the theoretical calculations for the $\bar{p}p \rightarrow \bar{D}D$ cross sections divergences occur which are difficult to cure.
- *Regge trajectories* are introduced for this purpose (α).

D. Ebert, R. N. Faustov, V. O. Galkin
PRD 79 (2009) 114029





- Regge trajectories for D(s) mesons with Natural Parity
- Both light (*q* = *u*,*d*,*s*) and heavy (*Q* = *c*,*b*) quarks are treated fully relativistically without application of the heavy quark $1/m_Q$ expansion.

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$\bar{p}p$ open-charm cross sections

- In the theoretical calculations for the $\bar{p}p \rightarrow \bar{D}D$ cross sections divergences occur which are difficult to cure.
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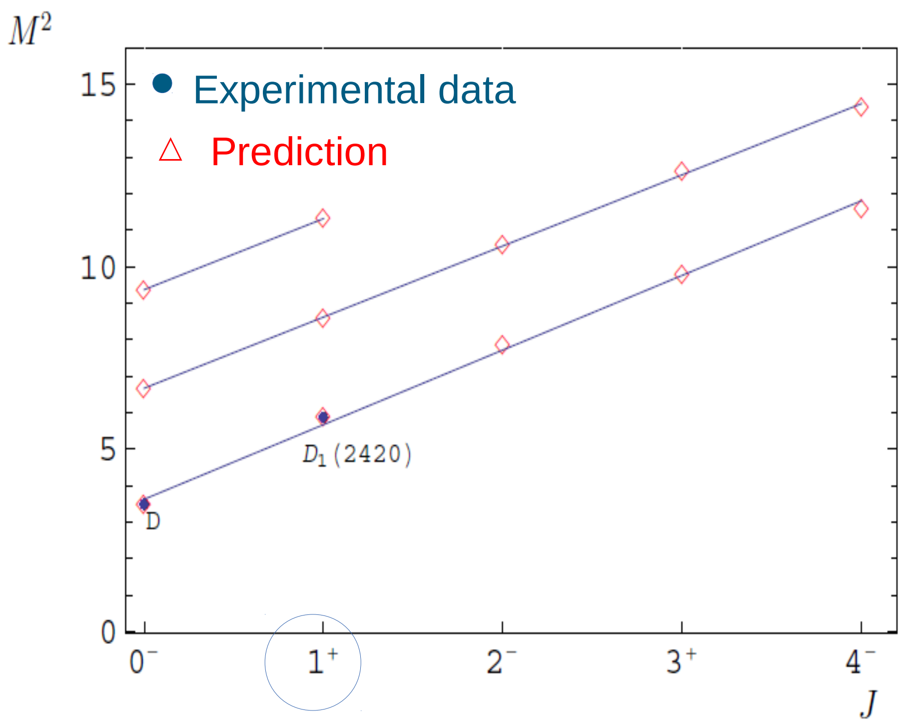

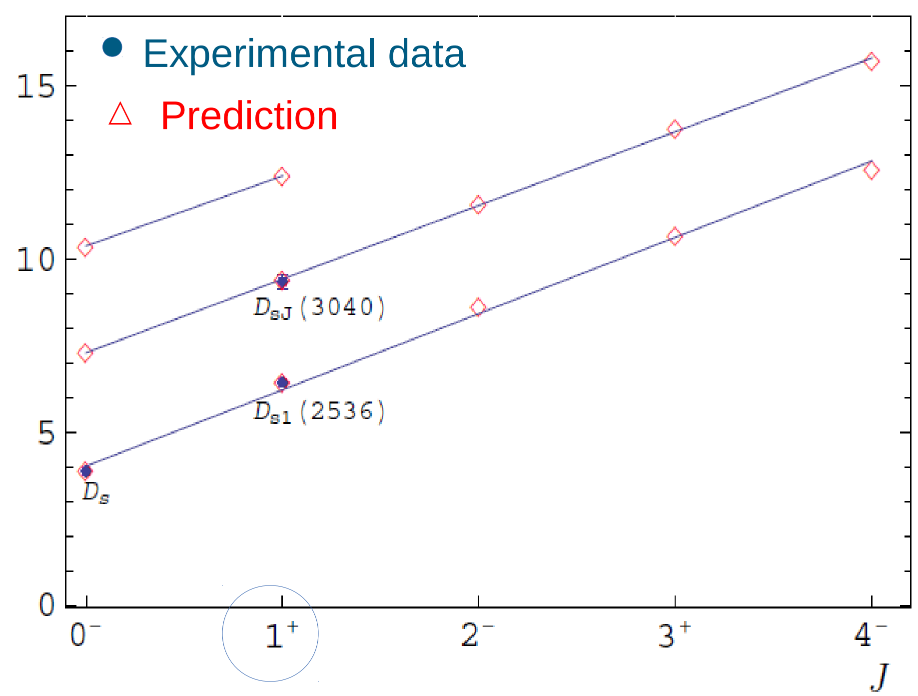

- Regge trajectories for D(s) mesons with Unnatural Parity
- Three exceptions to the model: $D_{s0}{}^*(2317)^+$, $D_{s1}(2460)^+$, $D_s(2860)^+$

$D_{s0}^*(2317)^+$ theoretical overview

Different theoretical approaches, different interpretations	$\Gamma(D_{s0}^*(2317)^+ \to D_s \pi^0)$ (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	Pure $c\bar{s}$ state
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	Tetraquark state
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	79.3 ± 32.6	DK had. molecule
M.F.M. Lutz, M. Soyeaur, Nucl. Phys. A 813, 14 (2008)	140	Dynamically gen. resonance
L. Liu, K. Orginos, F. K. Guo, C. Hanhart, Ulf-G. Meißner Phys. Rev. D 87, 014508 (2013)	133 ± 22	DK had. molecule
M. Cleven, H. W. Giesshammer, F. K. Guo, C. Hanhart, Ulf-G. Meißner Eur. Phys. J A (2014) 50 -149	Strong and radiative decays of $D_{s0}^*(2317)$ and $D_{s1}(2460)$	

- The measurement of the **narrow width** plays a leading role in the interpretation of D_s^*

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Is it feasible to perform the measurement of the open-charm cross sections in $\bar{p}p$?

Is it feasible to perform the measurement of the $D_s^*(2317)^+$ width in $\bar{p}p$?

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Is it feasible to perform the measurement of the open-charm cross sections in $\bar{p}p$?

Is it feasible to perform the measurement of the $D_s^*(2317)^+$ width in $\bar{p}p$?

YES!

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Is it feasible to perform the measurement of the open-charm cross sections in $\bar{p}p$?

Is it feasi... to perfo... ...urem...t o...

with

$\overline{\text{P}}$ANDA

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$\overline{P}ANDA$

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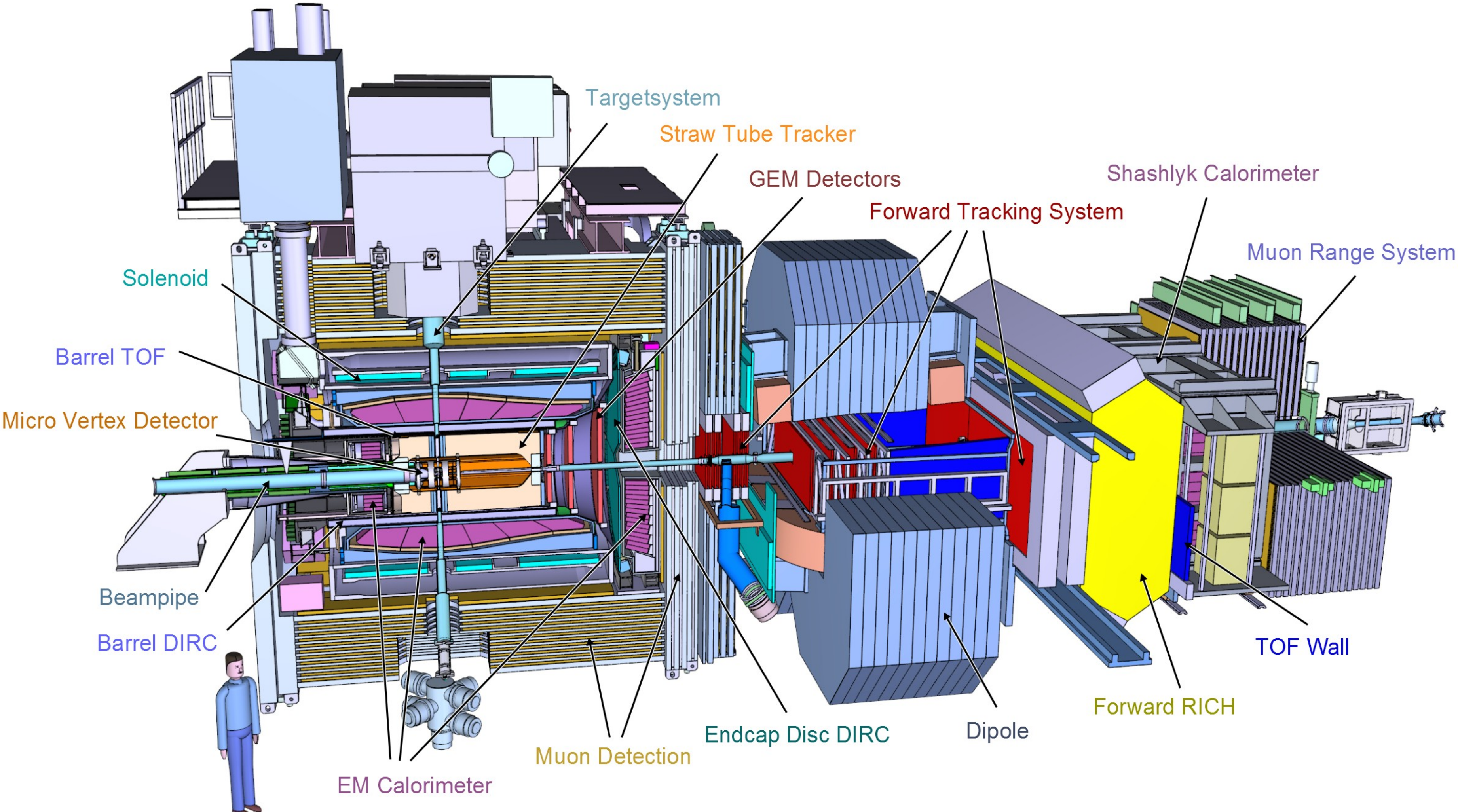

- Good tracking system
- Good particle reconstruction
- Excellent calorimeter

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The detector $\overline{\text{P}}$ANDA @ FAIR

- $\overline{\text{P}}$ANDA is a fixed target detector
  - Antiproton beam up to p = 15 GeV/*c*
  - Particles in formation and production
  - Mass resolution ~ 100 keV (beam scan)
  - $\Delta p/p$: $[10^{-4} - 10^{-5}]$
  - High boost $\beta_{cms} \geq 0.8$
  - Many tracks and photons in forward acceptance ($\theta \leq 30°$); high p_z, E_γ

- High background from hadronic reactions
  - Expected S/B ~ $[10^{-4} - 10^{-7}]$ for cross sections of ~ 100 nb
  - S (signal) and B (background) have same signature
  - Hardware trigger not possible
  - Self-triggered electronics
  - Free streaming data
  - up to 20 MHz interaction rate
  - Complete real-time event reconstruction

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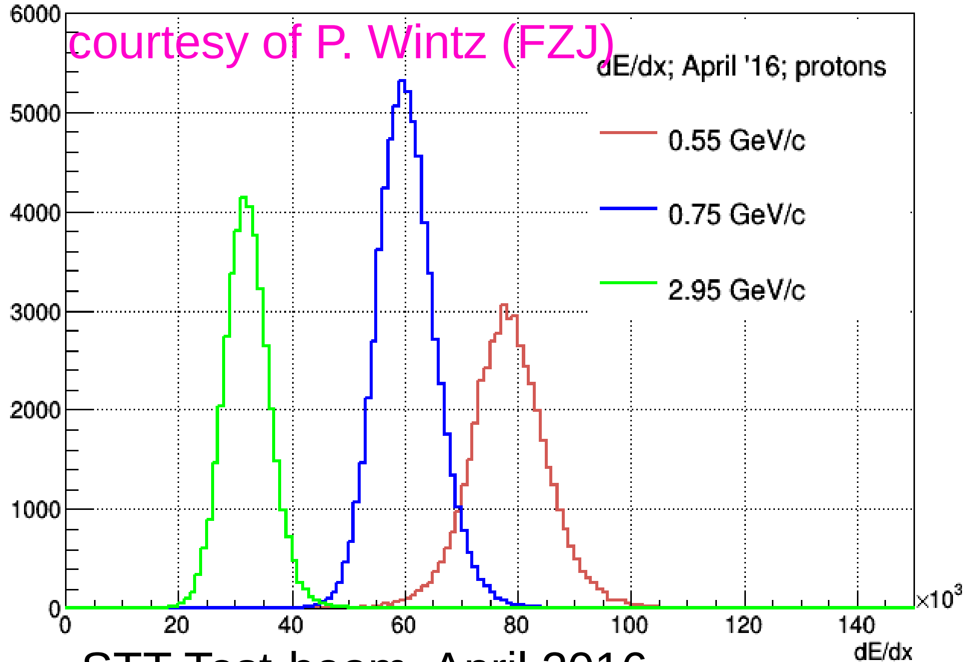
$\overline{P}$ANDA tracking performance



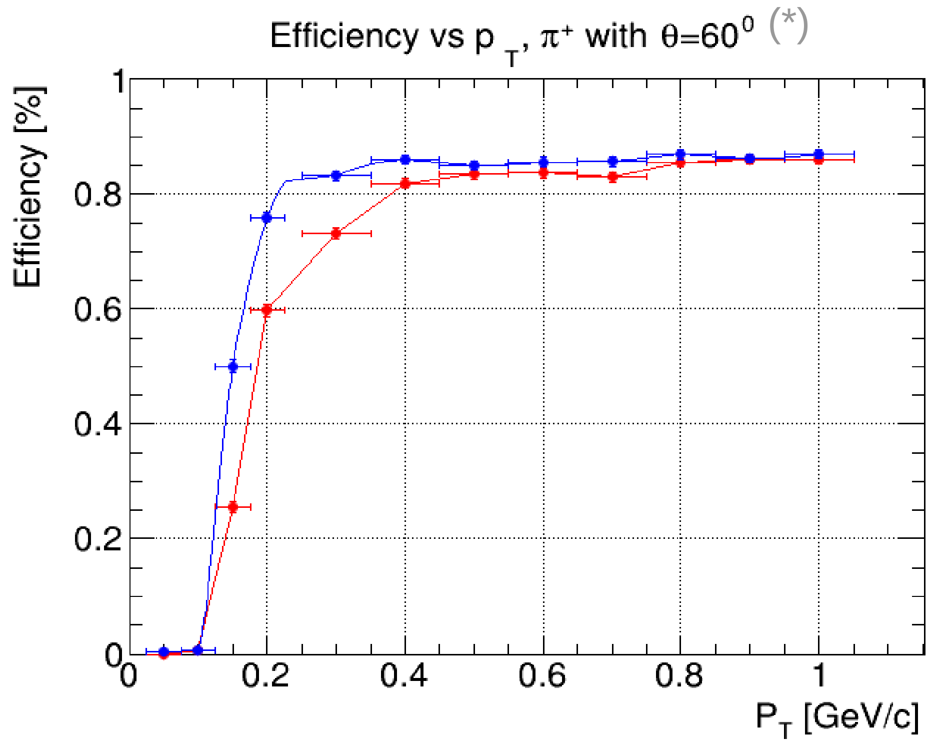
STT Test-beam, April 2016

Hardware

Software

E.P., EPJ C. 127 (2016) 00013

Good reconstruction for low momentum tracks with the GENFIT2 toolkit in PandaRoot



(*) Detector acceptance included

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$\overline{P}$ANDA construction

- $\overline{P}$ANDA will be realized in different phases:

Phase 0 : detector component commissioning and physics elsewhere (2018+);
Phase C: commissioning (proton beam, 2024+);
Phase I : start-up setup (2025+);
Phase II : complete setup (low luminosity, 2026+);
Phase III: complete setup (high luminosity, 2026+).

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$\overline{\text{P}}$ANDA construction

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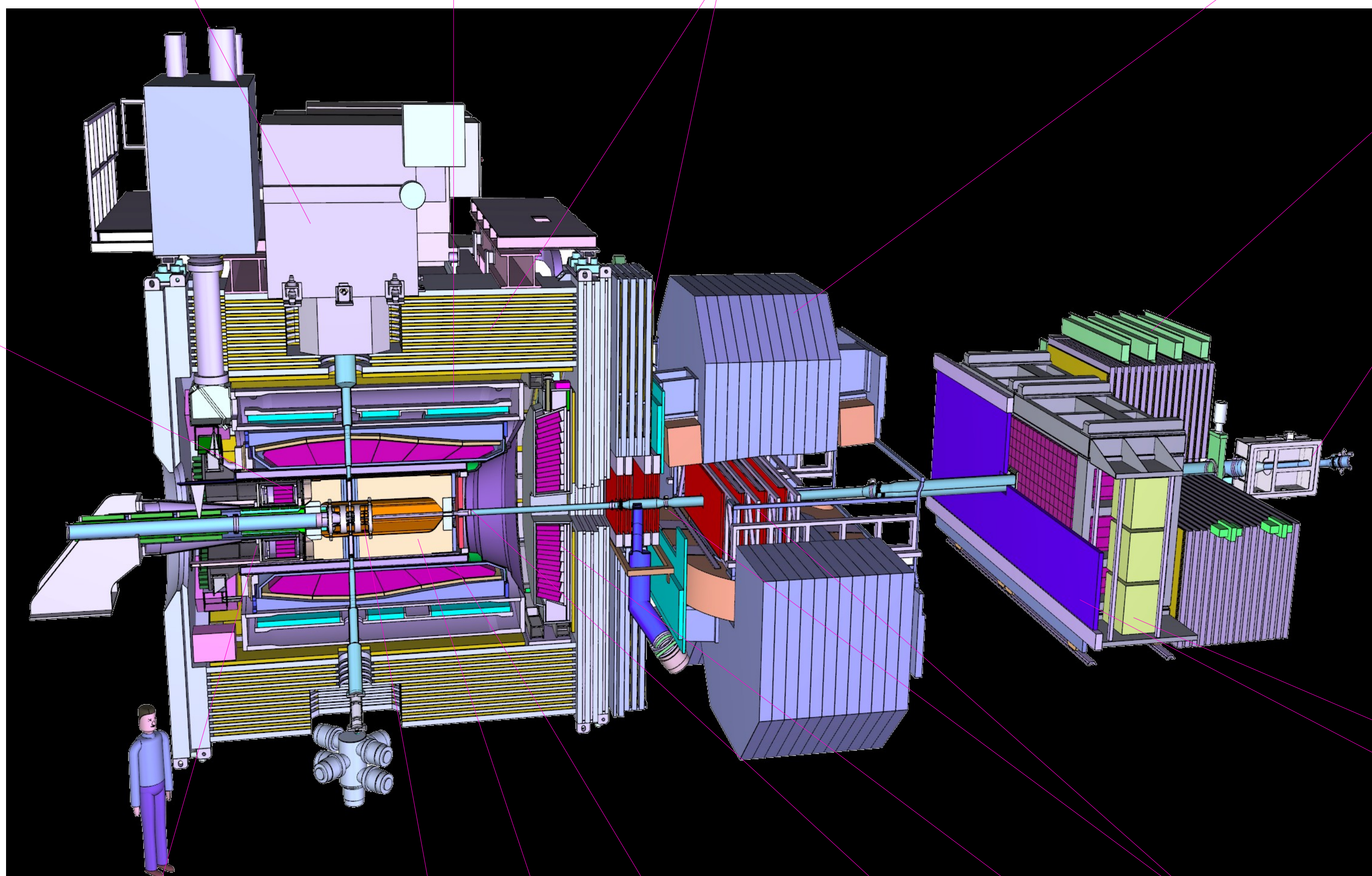
- $\overline{\text{P}}$ANDA will be realized in different phases:



Start-up:
Phase I design

Cross section measurements

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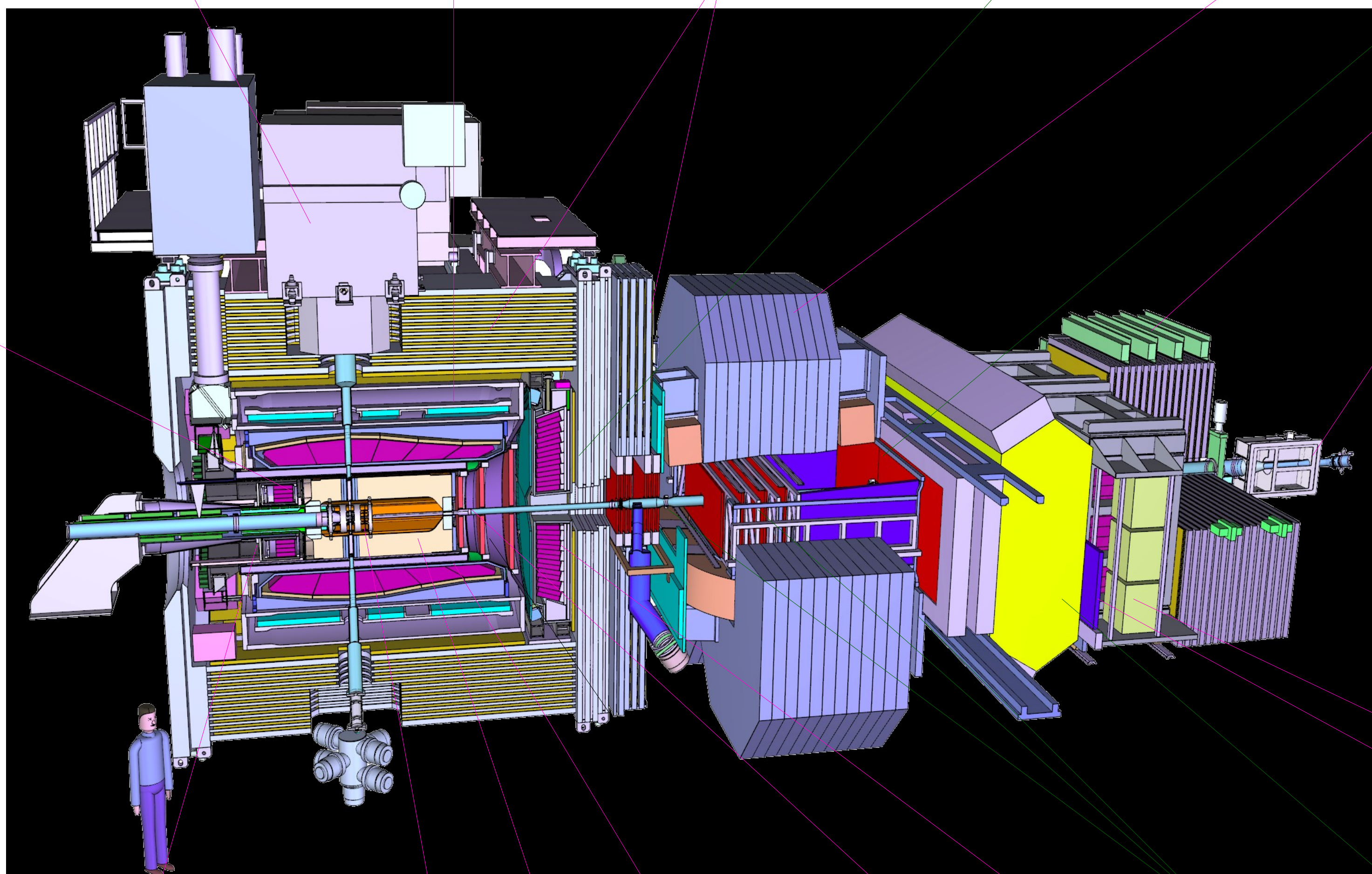
$\overline{\text{P}}$ANDA construction

- $\overline{\text{P}}$ANDA will be realized in different phases:



Complete setup:
Phase II design

↓

Open-charm energy scan

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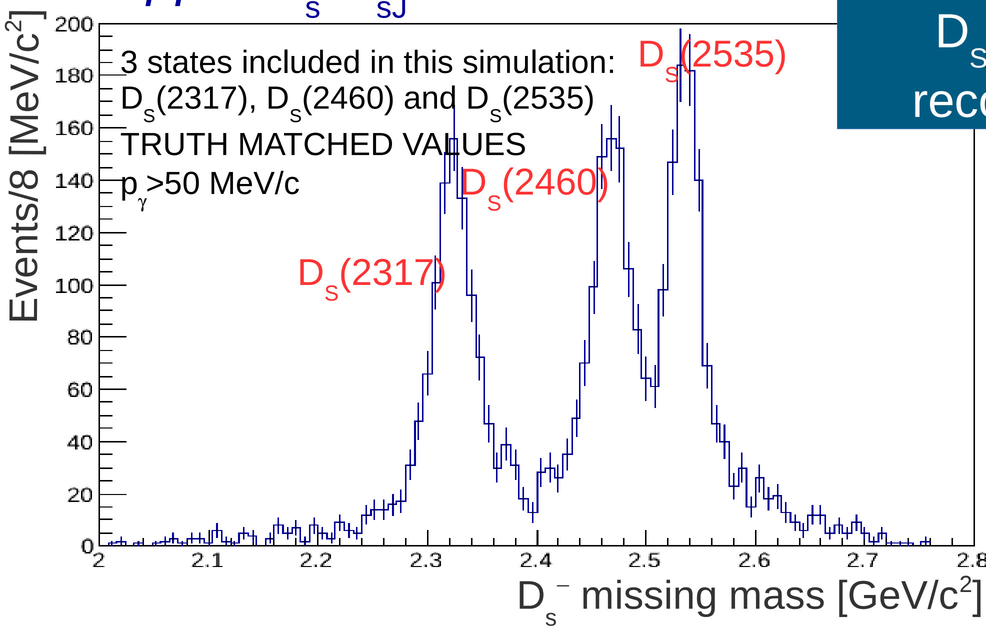
Challenges in D_s meson spectroscopy

ICHEP2014 – E.P., Nucl. Part. Phys. Proc. 273 (2016) 231

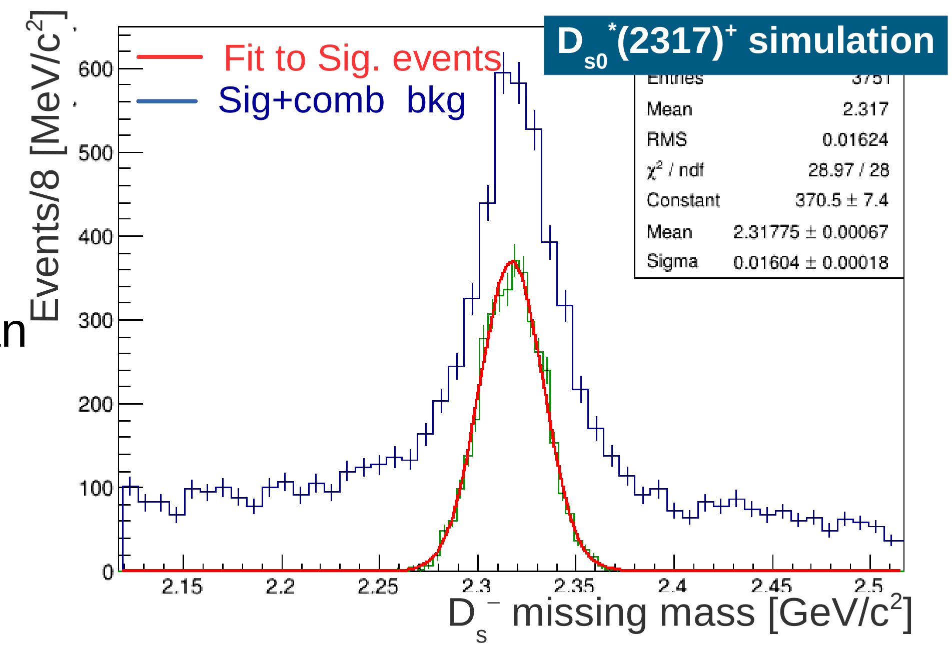
- $\bar{p}p \rightarrow D_s^- D_{sJ}^{(*)+}$

D_s^- recoil



- Missing mass of D_s^-:
- D_s reconstructed exclusively
- Bkg cross section > thousand times than expected on signal

- Goals:
  1. Cross section measurement in $\bar{p}p$
  2. Measurement of the width with mass scan
  3. Mixing between D states with same J^P
  4. Chiral symmetry breaking



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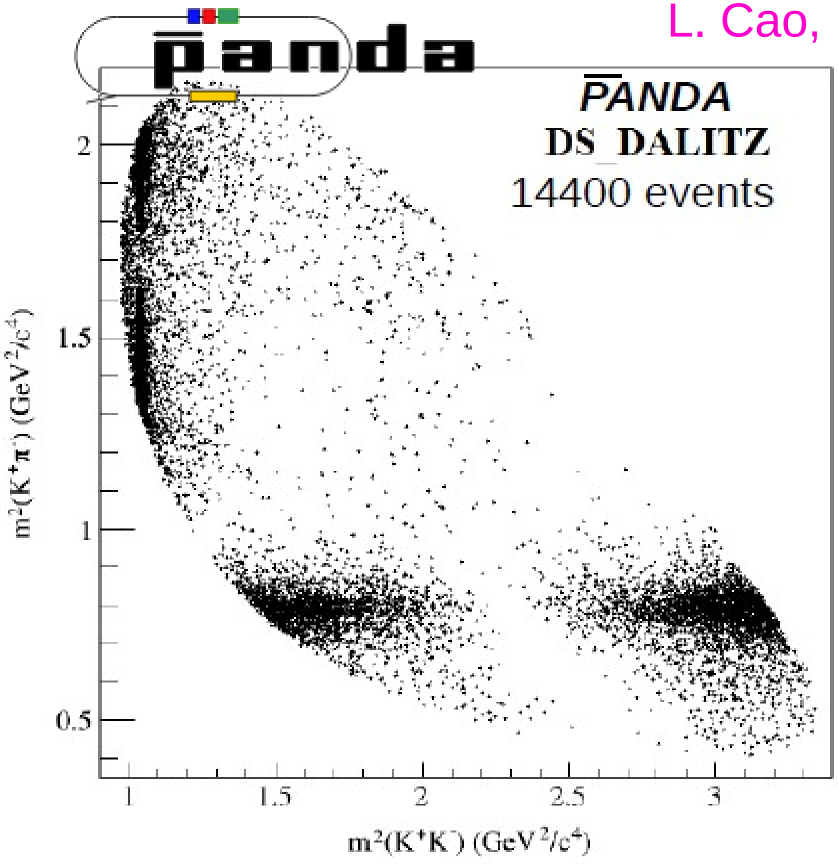
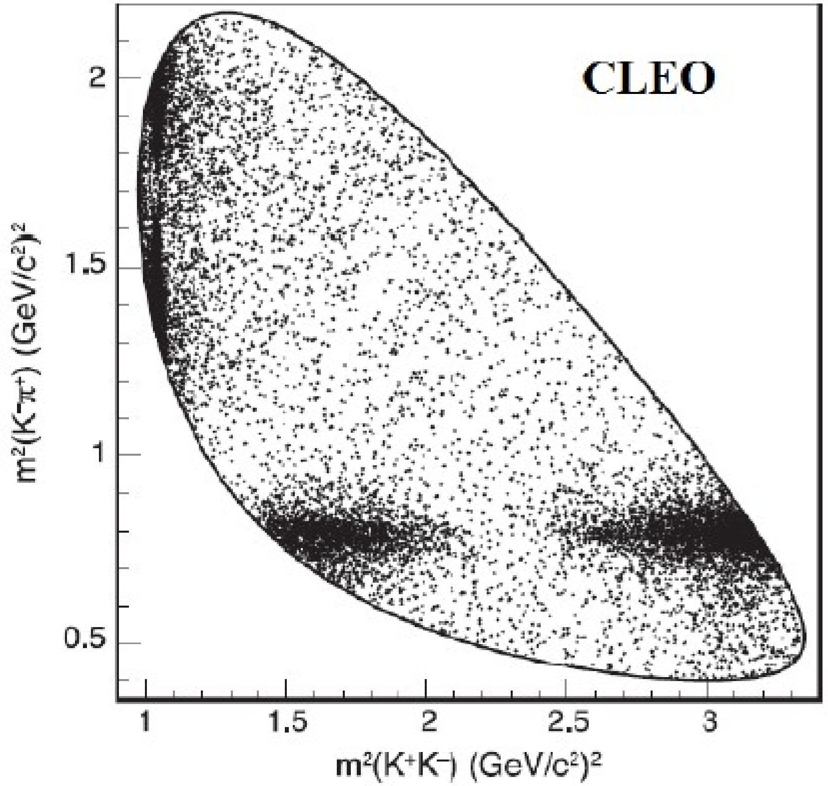
Realistic amplitude model in our simulations

L. Cao, PhD thesis (FZJ)





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Excitation function of the cross section

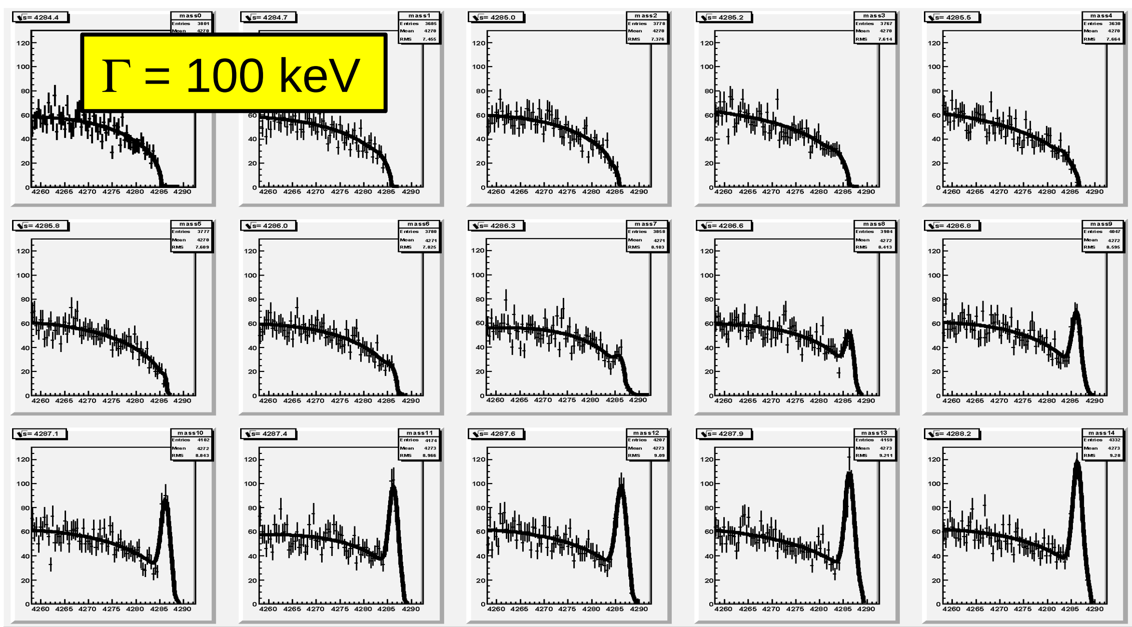
E.P, PoS Bormio2015 (2015) 044

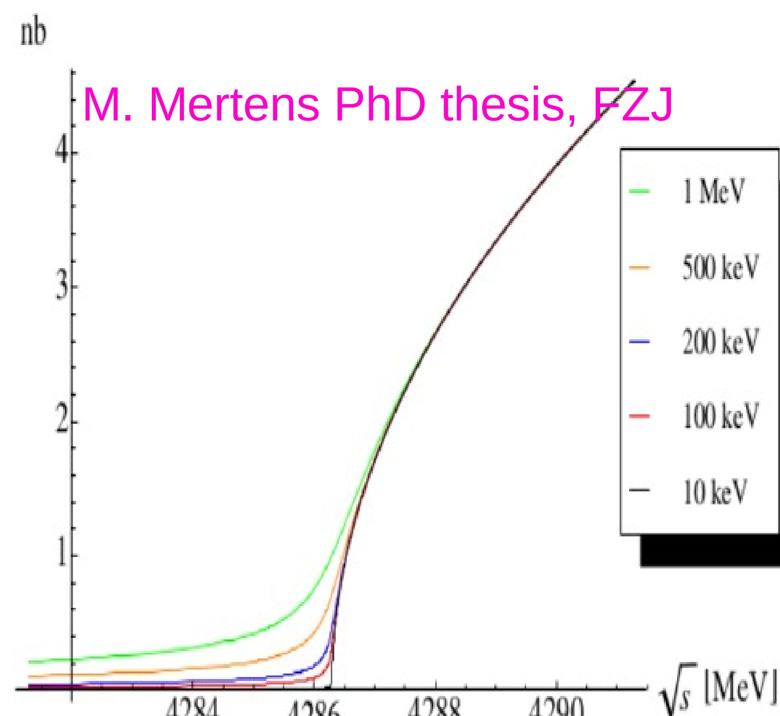
E.P., Nucl.Phys. A948 (2016) 93

$$\sigma(s) = \frac{|\mathcal{M}|^2}{64 \cdot \pi \cdot p_1^* \cdot s} \Phi(E)$$

$$\Phi(E) = \frac{1}{\pi} \sqrt{\frac{MM^*\Gamma^*}{M + M^*}} \int_{-\infty}^{\tilde{E}} d\delta \sqrt{\tilde{E} - \delta} \frac{1}{\delta^2 + 1}$$

ToyMC energy scan





- $\bar{p}p \to D_s^- D_{s0}^*(2317)^+$:
  $D_{s0}^*(2317)^+ \to D_s^+ \pi^0$, $D_s^- \to K^+K^-\pi^-$

Approximation: $m_{Ds} = m_{Ds0^*(2317)}$

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$D_s D_s$(2317) scan: expected produced events

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Input σ (nb)	$\bar{L} = 10^{31}$ cm^{-2} s^{-1} Produced events per day (Start up)	$\bar{L} = 10^{32}$ cm^{-2} s^{-1} Produced events per day (Full lumi)
20	17280	172800
10	8640	86400
5	4320	43200
2	1728	17280
1	864	8640

$\bar{p}p \to D_s^- D_s^*(2317)^+$

- Conservative range: σ [1 – 100] nb
- With **L = 10^{31} cm^{-2} s^{-1}** (average), **864** produced events/day (hyp: **σ = 1nb**)
- BR($D_s \to K^+K^-\pi^-$) = 5.34%
- $D_{s0}^*(2317)^+$ reconstructed on the D_s recoil
  efficiency = order of a few points per cent
- Comparison with B factories
  - S/B ~ 5/1, ε = 8.2% in e+e- $D_s D_{s0}^*(2317)$
  - S/B ~ 2/1, ε∈[0.42-2.75]10^{-4} through B decays

PRL 92, 012002 (2004)
PRL 91, 262002 (2003)

Belle II will collect ~ 44000 $D_{s0}^*(2317)$ in 10 years of data taking ($\mathscr{L}$ = 50 ab^{-1})

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Summary

- Still many open questions in hadron physics:

A $\bar{p}p$ machine is needed

- Open-charm physics is still of very high interest
- $\bar{\text{P}}$ANDA is in a unique position to perform such measurements
- Original measurements are expected during the *Phase-1* of data taking
- Big hardware effort: test beam started, TDRs ongoing

$\bar{\text{P}}$ANDA has lots of high profile and unique physics cases

Unique experiments are expected from *$\bar{\text{P}}$ANDA* physics program.

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"The greatest danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieve our mark." (Michelangelo, 1475 - 1564)

THANK YOU!

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Backup slides

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Charm spectrum

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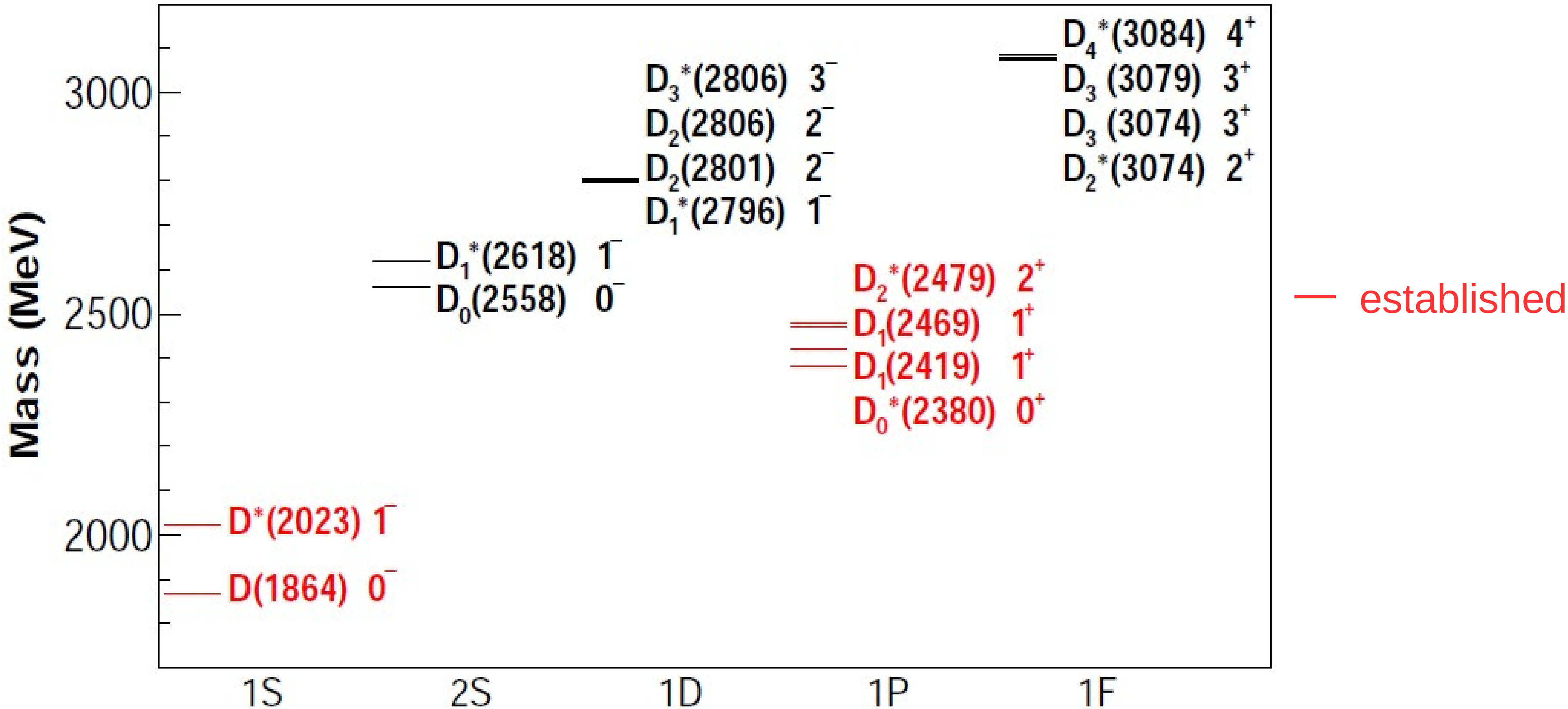

- States having $J^P = 0^+, 1^-, 2^+, 3^-, \ldots$ are defined as having "Natural Parity"
- States having $J^P = 0^-, 1^+, 2^-, \ldots$ are defined as having "Unnatural Parity"
- A resonance decaying to $D\pi$ has "Natural Parity" (labeled D^*)
- The $D^*\pi$ system can access to both "Natural Parity" and "Unnatural Parity", except for $J^P = 0^+$ (forbidden)
- Access via inclusive $e^+e^- \rightarrow D_J X$ (BaBar, Belle) and $pp \rightarrow D_J X$ (LHCb)

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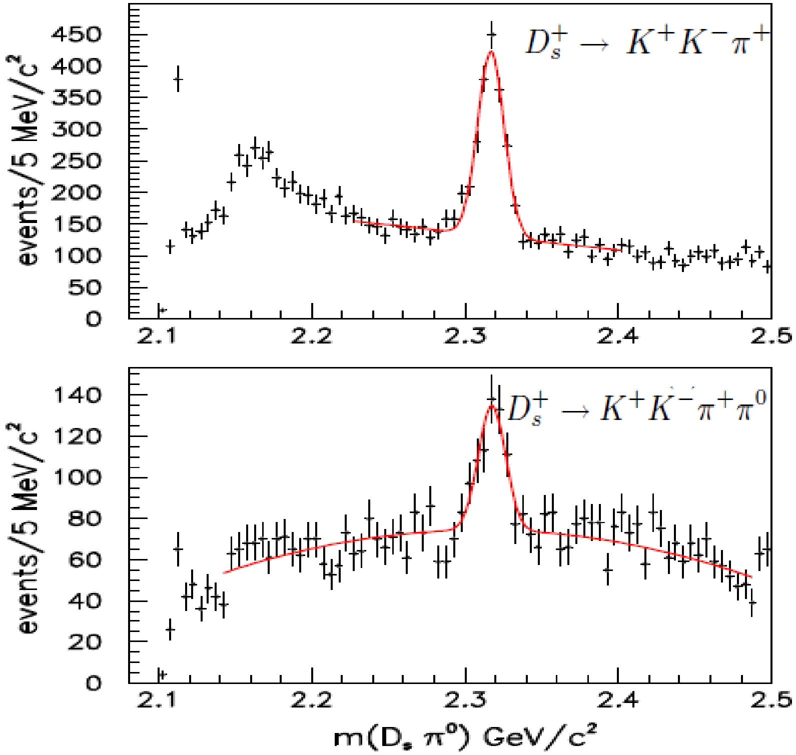
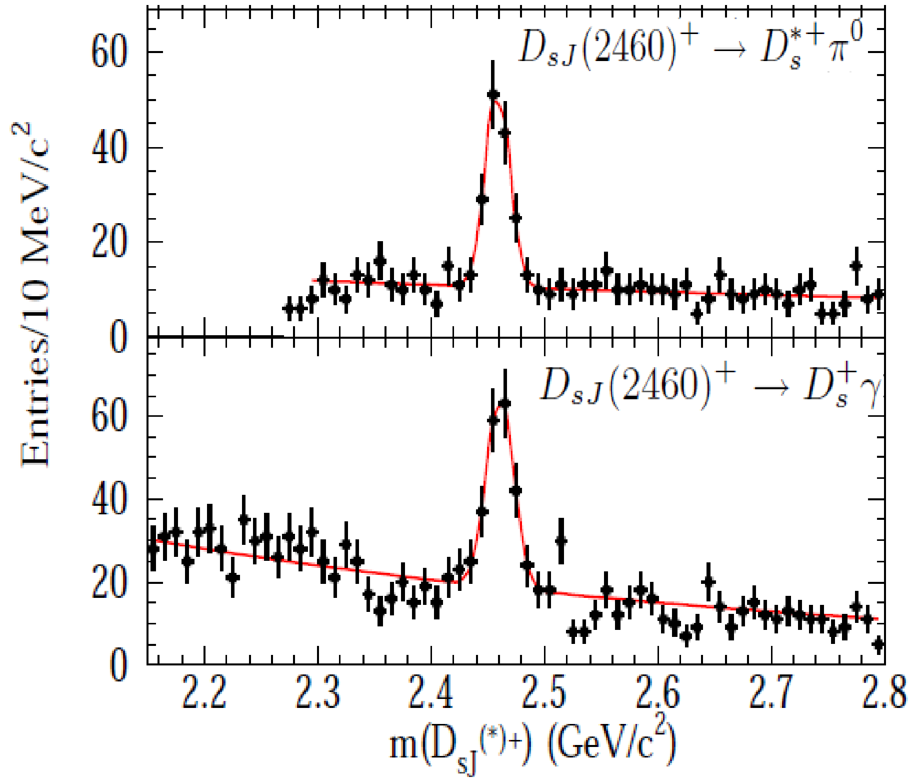
Observation of $D_{s0}^*(2317)$ and $D_{s1}(2460)$

BABAR, PRL 90 (2003) 242001



BABAR, PRL 93 (2004) 181801



$m(D_{s0}^*(2317)^+) = (2317.7 \pm 0.6)$ MeV/c^2

$m(D_{s0}^*(2317)^+ - m(Ds^+)) = (349.4 \pm 0.6)$ MeV/c^2

$\Gamma < 3.8$ MeV CL=95.0%

$m(D_{s1}(2460)^+) = (2459.5 \pm 0.6)$ MeV/c^2

$m(D_{s1}(2460)^+ - m(D_s^{*+})) = (347.3 \pm 0.7)$ MeV/c^2

$m(D_{s1}(2460)^+ - m(D_s^+)) = (491.2 \pm 0.6)$ MeV/c^2

$\Gamma < 3.5$ MeV CL=95.0%

- What did we learn after 14 years?

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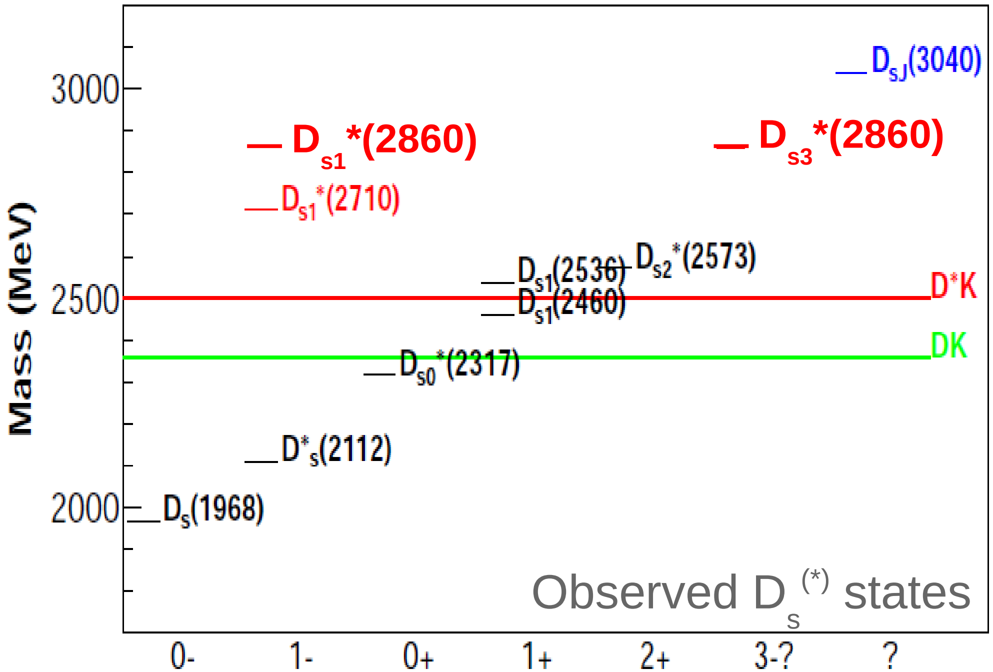
D_s spectroscopy, today: remarks



D mesons: $|c\bar{u}\rangle$, $|c\bar{d}\rangle$

D_s mesons: $|c\bar{s}\rangle$

Predicted from Godfrey-Isgur (1985);
Update: Di Pierro- Eichten (2001)

- Many excited D_s states have been found:
  some of these not in agreement with potential models (→below the DK threshold);
  the identification of $D_{s0}^*(2317)$ and $D_{s1}(2460)$ states as 0^+ or 1^+ *cs* states is difficult to accommodate in the potential models.

- LHCb recently performed amplitude analyses:
  $D_{s2}(2573)$ confirmed with J=2;
  $D_{s1-3}^*(2860)$: for the first time a heavy flavored J=3 state is observed.

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Experimental overview of D_{s0}*(2317) and D_{s1}(2460)

Decay Channel	$D^*_{sJ}(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\pi^0$	Forbidden	Seen
$D^*_{sJ}(2317)^+\gamma$	—	Seen
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

(a) Non-resonant only

- Most of theoretical works treat *cs-systems* as the hydrogen atom (potential models, *c* = heavy quark):
- $D_{s1}(2317)^+$ and $D_{s2}(2460)^+$ are predicted, found with good accuracy <u>but</u>:

m(D_{s0}*$(2317)^+$) found 160 MeV/c^2 lower

m($D_{s1}(2460)^+$) found 120 MeV/c^2 lower

than predicted by potential models

- $D_{s0}^*(2317)^+$ is found below the DK threshold:
- $D_{s0}^*(2317)^+$ can in principle decay
  - electromagnetically (no exp. evidence); or
  - through isospin-violation $D_s^+\pi^0$ strong decay

Is D_{s0}^* the missing 0^+ state of the *cs-spectrum*?

- $D_{s1}(2460)^+$ is found in the inv. mass $D_s^+\gamma$
- Spin <u>at least</u> 1
- We can exclude the hypothesis 0^+, because $D_{s1}(2460)^+ \rightarrow D_s^+\gamma$

Is D_{s1} the missing 1^+ of the *cs-spectrum*?

Do these 2 particles belong to the same family of exotics?

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D_{S0}^* and D_{s1} theoretical overview: Hadronic width

M. Cleven, H. W. Griesshammer, F.-K. Guo, C. Hanhart, Ulf-G. Meissner, Eur. Phys. J. A(2014) 50, 149

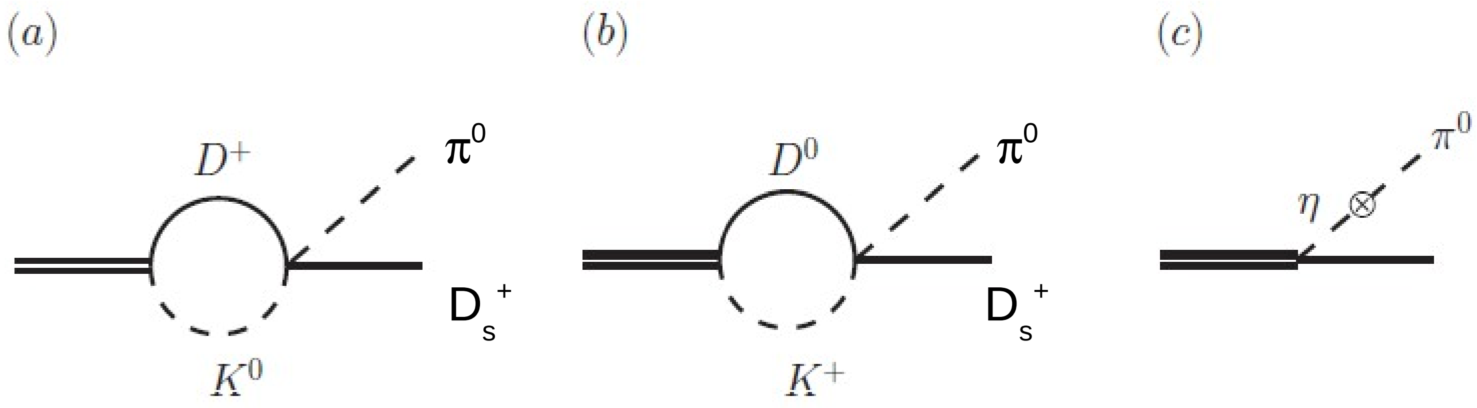

Figure 2: The two mechanisms that contribute to the hadronic width of the D_{s0}^*. (a) and (b) represent the nonvanishing difference for the loops with D^+K^0 and D^0K^+, respectively. (c) depicts the decay via π^0-η mixing.

- Contribution (a) – (b) non-zero for $m_{D+} \neq m_{D0}$, $m_{K+} \neq m_{K0}$; this applies to molecular states

Table 2: Hadronic decay widths from different mechanisms.

Decays	loops	π^0-η mixing	full result
$D_{s0}^* \to D_s\pi^0$	(26 ± 3) keV	(23 ± 3) keV	(96 ± 19) keV
$D_{s1} \to D_s^*\pi^0$	(20 ± 3) keV	(19 ± 3) keV	(78 ± 14) keV

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D_{s0}^* and D_{s1} theoretical overview: Radiative width

M. Cleven, H. W. Griesshammer, F.-K. Guo, C. Hanhart, Ulf-G. Meissner, Eur. Phys. J. A(2014) 50, 149

Table 3: The decay widths (in keV) calculated only from the coupling to the electric charge (EC), from the magnetic moments (MM) and from the contact term (CT), respectively, compared to the total (including interference). The CT strength for the transitions to odd parity mesons is fixed to data, while that to even parity states, marked as '?', is undetermined and part of the uncertainty.

Decay Channel	EC	MM	CT	Sum	[1]	[2]	[3,4,5]
$D_{s0}^* \to D_s^* \gamma$	2.0	0.03	3.3	9.4	4 – 6	1.94(6.47)	0.55-1.41
$D_{s1} \to D_s \gamma$	4.2	0.2	11.3	24.2	19 – 29	44.50(45.14)	2.37-3.73
$D_{s1} \to D_s^* \gamma$	9.4	0.5	10.3	25.2	0.6 – 1.1	21.8(12.47)	–
$D_{s1} \to D_{s0}^* \gamma$	–	1.3	?	1.3	0.5 – 0.8	0.13(0.59)	–

[1] P. Colangelo, F. De Fazio, A. Ozpineci. PRD 72, 074004 (2005);
[2] M. F. M. Lutz, M. Soyeur, Nucl. Phys. A 813, 14 (2008);
[3] A. Faessler, T. Gutsche, V. E. Lyubovitskij and Y. L. Ma, PRD 76, 014005 (2007);
[4] A. Faessler, T. Gutsche, V. E. Lyubovitskij and Y. L. Ma, PRD 76, 114008 (2007);
[5] A. Faessler, T. Gutsche, V. E. Lyubovitskij and Y. L. Ma, PRD 77, 114013 (2008).

- **Only hadronic decays are sensitive to a possible molecular component of D_{s0}^* and D_{s1}**
- **Hadronic width of ≥ 100 keV: unique feature for molecular state**
- **Demand for a new generation machine: Δm ~100 keV, 20 times better than attained at B factories**

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Excitation function of the cross section

- Excitation function of the cross section for $\bar{p}p \rightarrow D_s^- D_{s0}^*(2317)^+$:

$$\sigma(s) = \frac{|\mathcal{M}|^2}{64 \cdot \pi \cdot p_1^* \cdot s} \, \Phi(E)$$

$$\Phi(E) = \frac{1}{\pi} \sqrt{\frac{MM^*\Gamma^*}{M + M^*}} \int_{-\infty}^{\tilde{E}} d\delta \sqrt{\tilde{E} - \delta} \, \frac{1}{\delta^2 + 1}$$

$$\sqrt{\tilde{E}} \cdot \int d\delta \, / \, (\delta^2+1) = \pi$$

$$\Phi(E) \rightarrow \sqrt{2E/\Gamma^*} \cdot p^{cm}_{Ds2317}, \quad \text{for } \tilde{E} >> 1$$

$M = M(D_s^-)$
$M^* = M(D_s^*(2317)^+)$
$\Gamma^* = \Gamma(D_s^*(2317)^+)$
s = square energy in the center-of-mass system
p_1^* = momentum of the antiproton beam
$E = \sqrt{s} - M - M^*$
$\tilde{E} = 2 E/\Gamma^*$

Many thanks to Christoph Hanhart for his extremely useful help!

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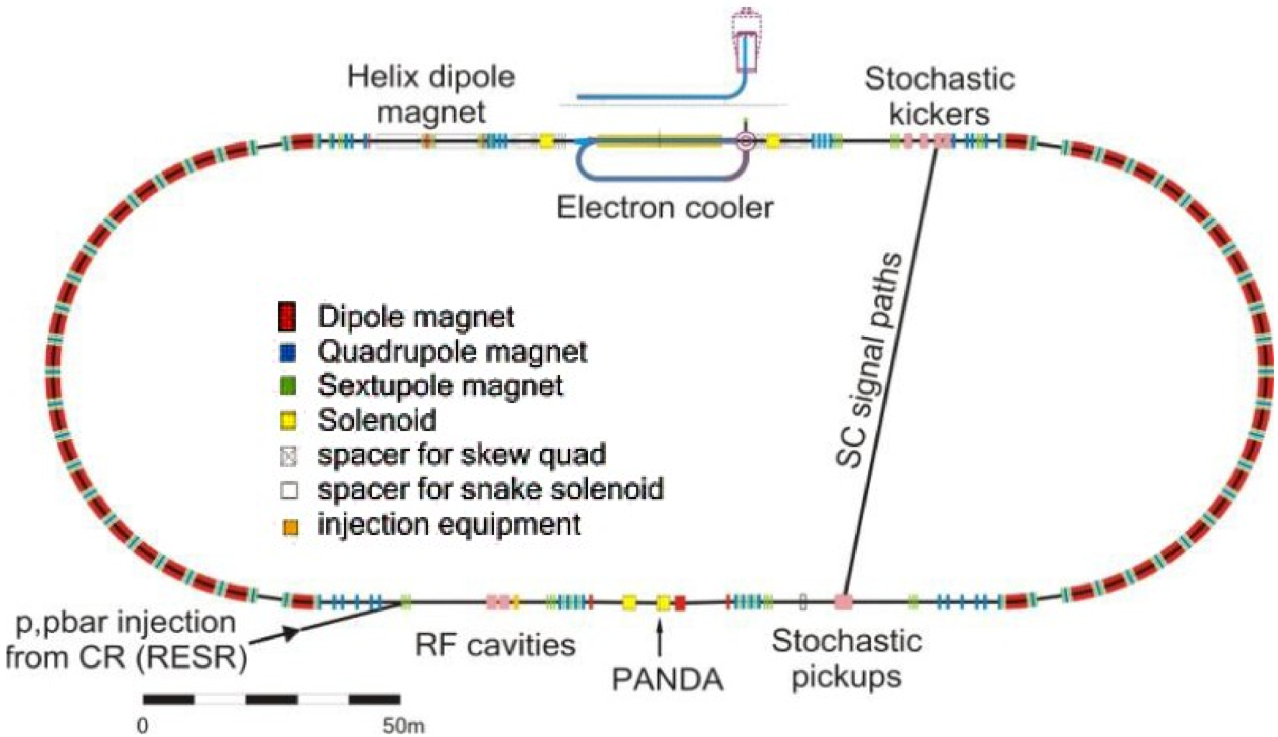
HESR with $\overline{P}$ANDA



HESR	
575 m	Circumference
1.5 – 15 GeV/c	Momentum
up to 9 GeV/c	Electron Cooling
Full range	Stochastic Cooling

- Thick target: 4 $\cdot 10^{15}$ cm^{-2}
- Beam life time >30 min

High resolution mode

- e^{-} cooling, 1.5≤ p≤ 8.9 GeV/c
- 10^{10} antiprotons stored
- Luminosity up to 2 $\cdot 10^{31}$ cm^{-2} s^{-1}
- $\Delta p/p = 4 \cdot 10^{-5}$

High intensity mode

- Stochastic cooling, p≥ 3.8 GeV/c
- 10^{11} antiprotons stored
- Luminosity up to 2 $\cdot 10^{32}$ cm^{-2} s^{-1}
- $\Delta p/p = 2 \cdot 10^{-4}$

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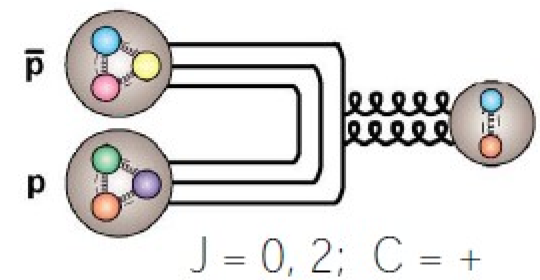
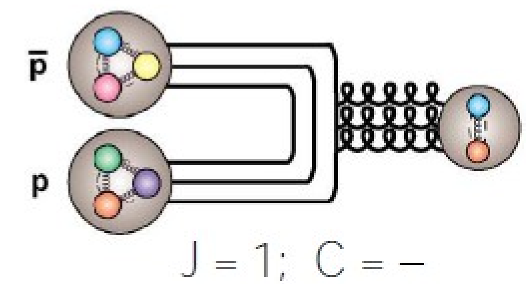
Why antiprotons in $\bar{\text{P}}$ANDA?

- Annihilation is a gluon rich process



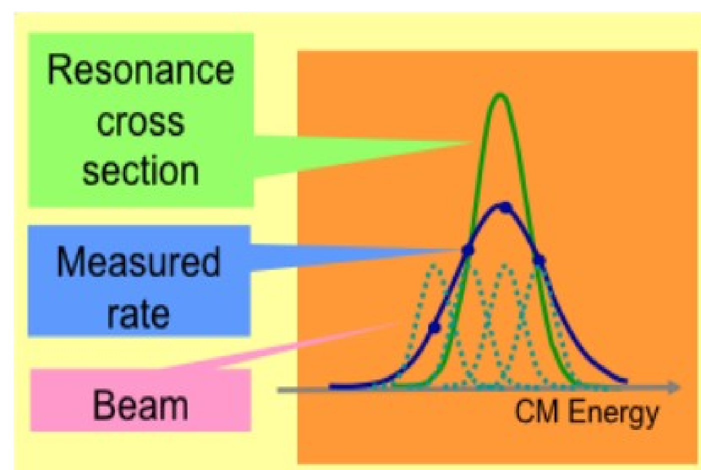
- In production:
all quantum numbers accessible in *$\bar{p}p$* reactions

- High mass / width resolution in formation



- High angular momentum accessible

- Resonance scan technique:
invariant mass resolution depends
on the beam resolution



- *$\bar{\text{P}}$ANDA* is in an unique position to
perform such a study!
Charm and Charmonium resonance mass scan

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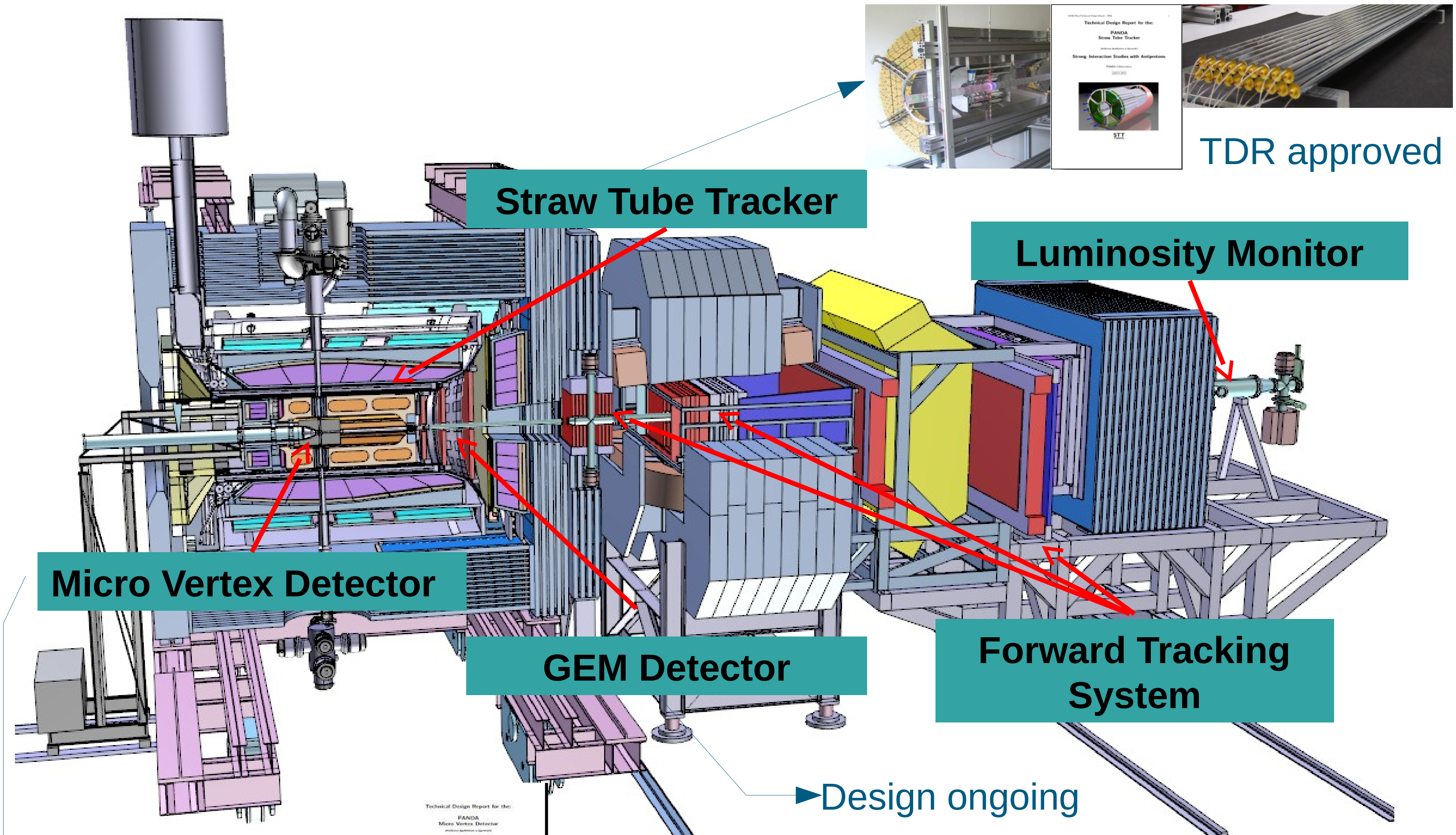
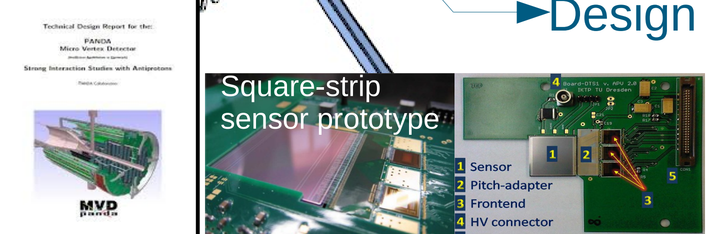




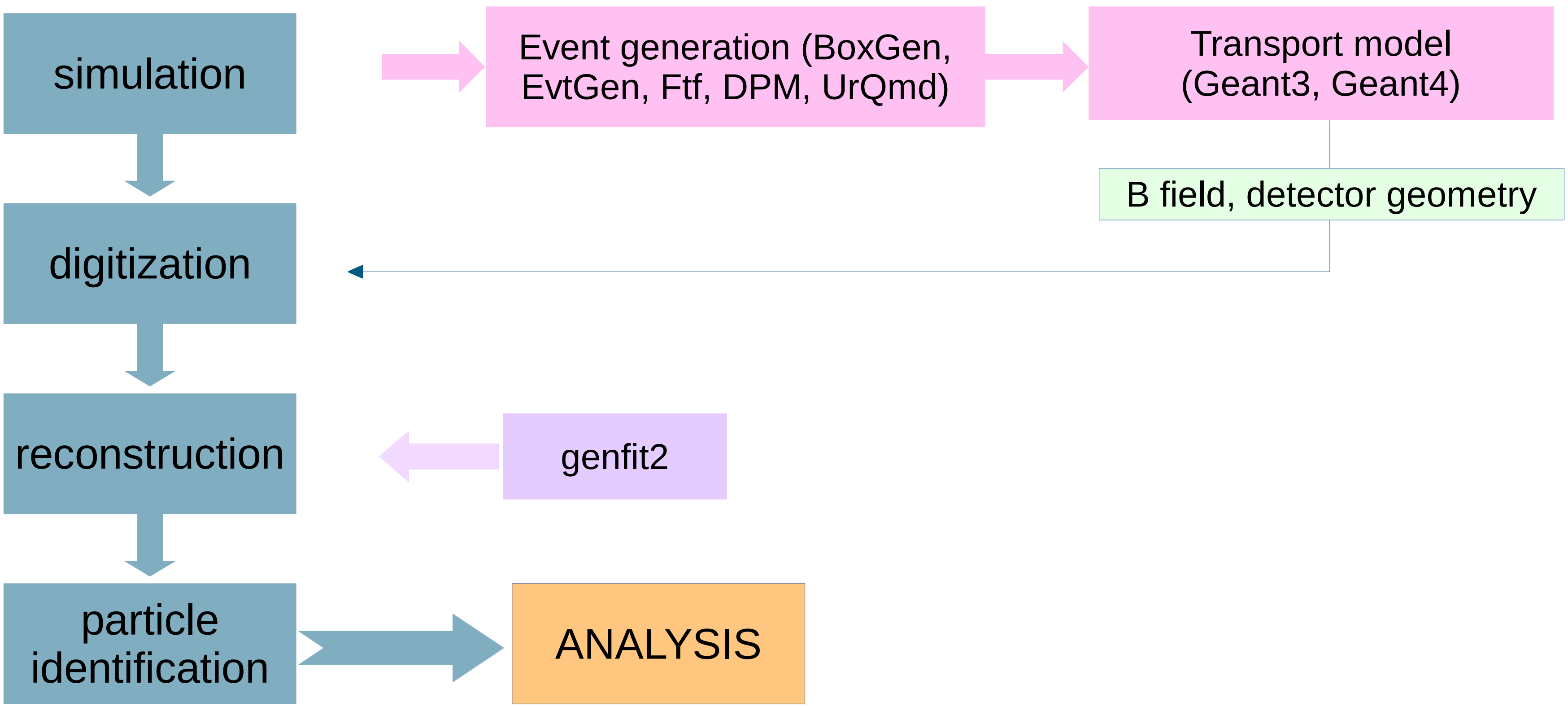
Tracking system

PandaRoot: official $\bar{\text{P}}$ANDA framework

- **PandaRoot**: code inside the FAIRRoot project, based on Root;
  code for simulation and analysis;
  working on many Linux distributions, and OS X.

D. Bertini, M. A-Turany, I. Koenig and F. Uhlig , Journal of Phys: Conf. Series 119 (2008) 032011; S. Spataro, Journal of Phys: Conf. Series 396 (2012) 022048

E.P., EPJ C. 127 (2016) 00013



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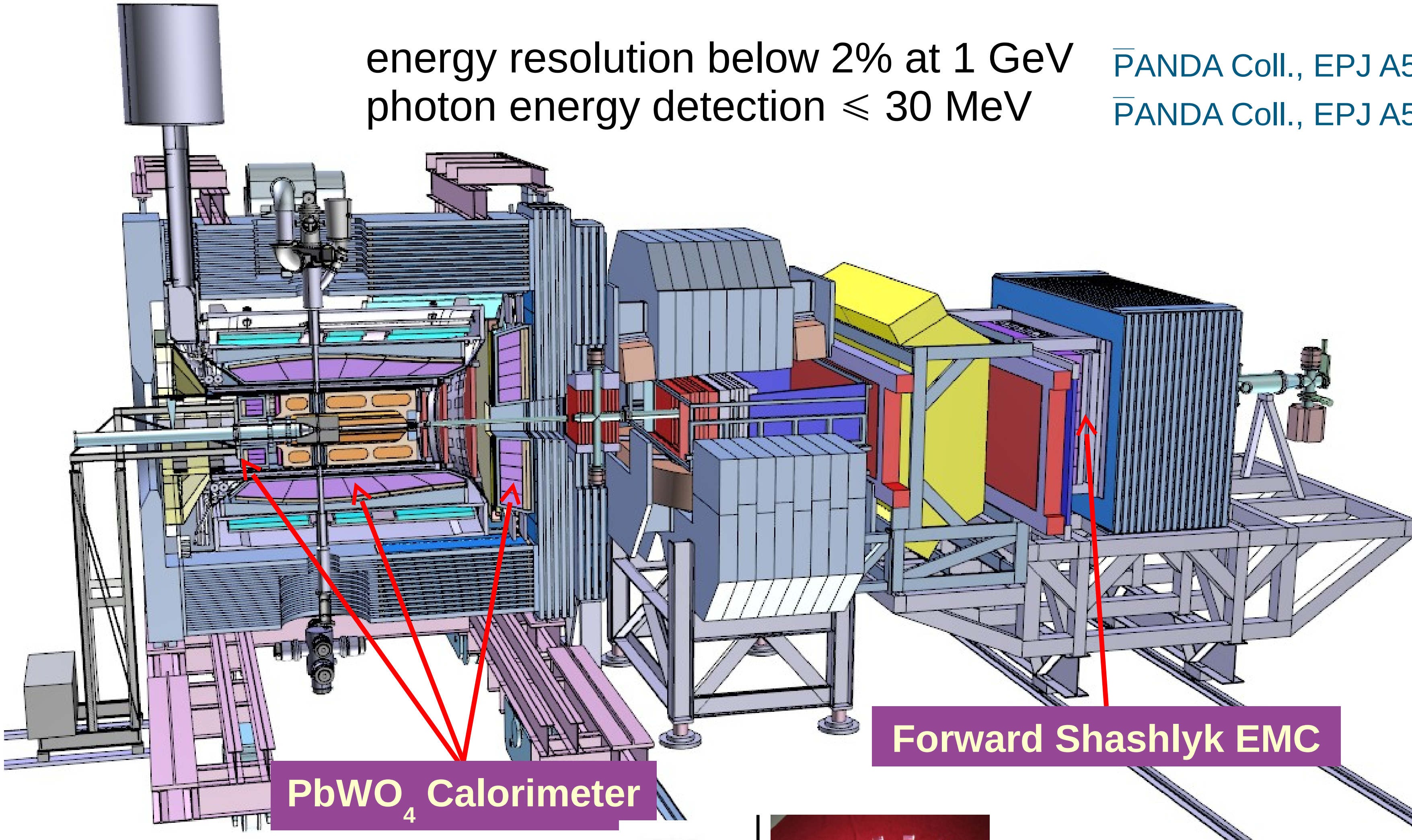
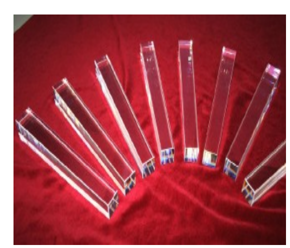
energy resolution below 2% at 1 GeV
photon energy detection ⩽ 30 MeV

$\overline{\text{P}}$ANDA Coll., EPJ A51 (2015), 107
$\overline{\text{P}}$ANDA Coll., EPJ A52 (2016), 325



Calorimeters:
All endcap crystals produced
TDR approved



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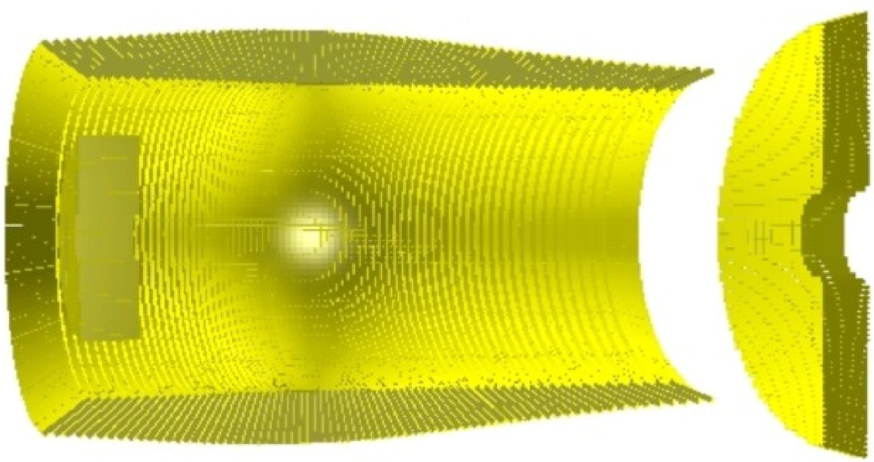
$\overline{P}$ANDA calorimeter

$\overline{P}$ANDA EMC (Electromagnetic Calorimeter)

17,200 crystals
$PbWO_4$ (radiation hard, fast τ_{Decay}~6 ns)
28 X_0
dE/dx=13.0 MeV/cm



operated at −25° C

- Crystal length: 20 cm = 22X_0
- Increase of light yield:
  - PbWO II~x2 CMS $PbWO_4$ Crystals
  - Operation with 2 APDs (1 cm^2 each) increase effic. ~ x4 compared to CMS
  - Operation at -25 °C increases light yield compared to +18 °C ~x4 times

⇩

<u>big improvement compared to CMS</u>

Barrel Calorimeter
- 11360 $PbWO_4$ Crystals
- LAAPD readout, 2x1 cm^2
- σ(E)/E ~ `.5% E = const

Forward Calorimeter
- 3600 $PbWO_4$ Crystals
- High occupancy in center
- LAAPD or VPT

Backward endcap
- 524 $PbWO_4$ Crystals

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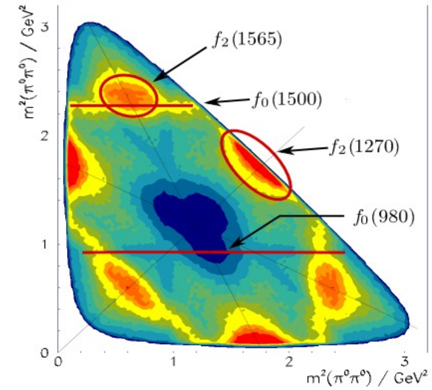
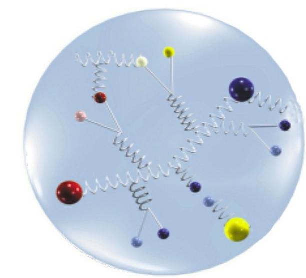
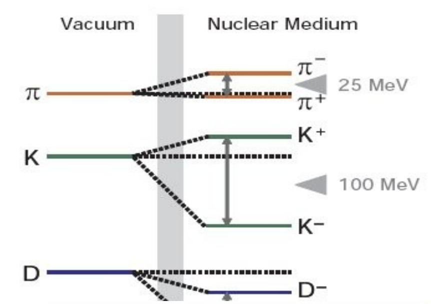
$\overline{\text{P}}$ANDA physics program



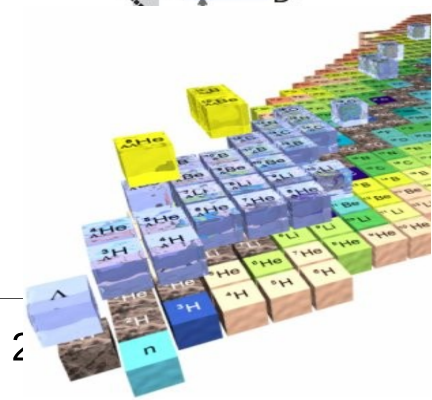
- **Hadron spectroscopy**:
  search for particles and measurement of hadron properties



- **Nucleon structure**:
  generalized parton distribution, Drell-Yan processes and time-like form factor of the proton



- **Hadrons in matter**:
  study in medium effects of hadronic particles



- **Hypernuclei**:
  measurement of nuclear properties with an additional strangeness degree of freedom

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