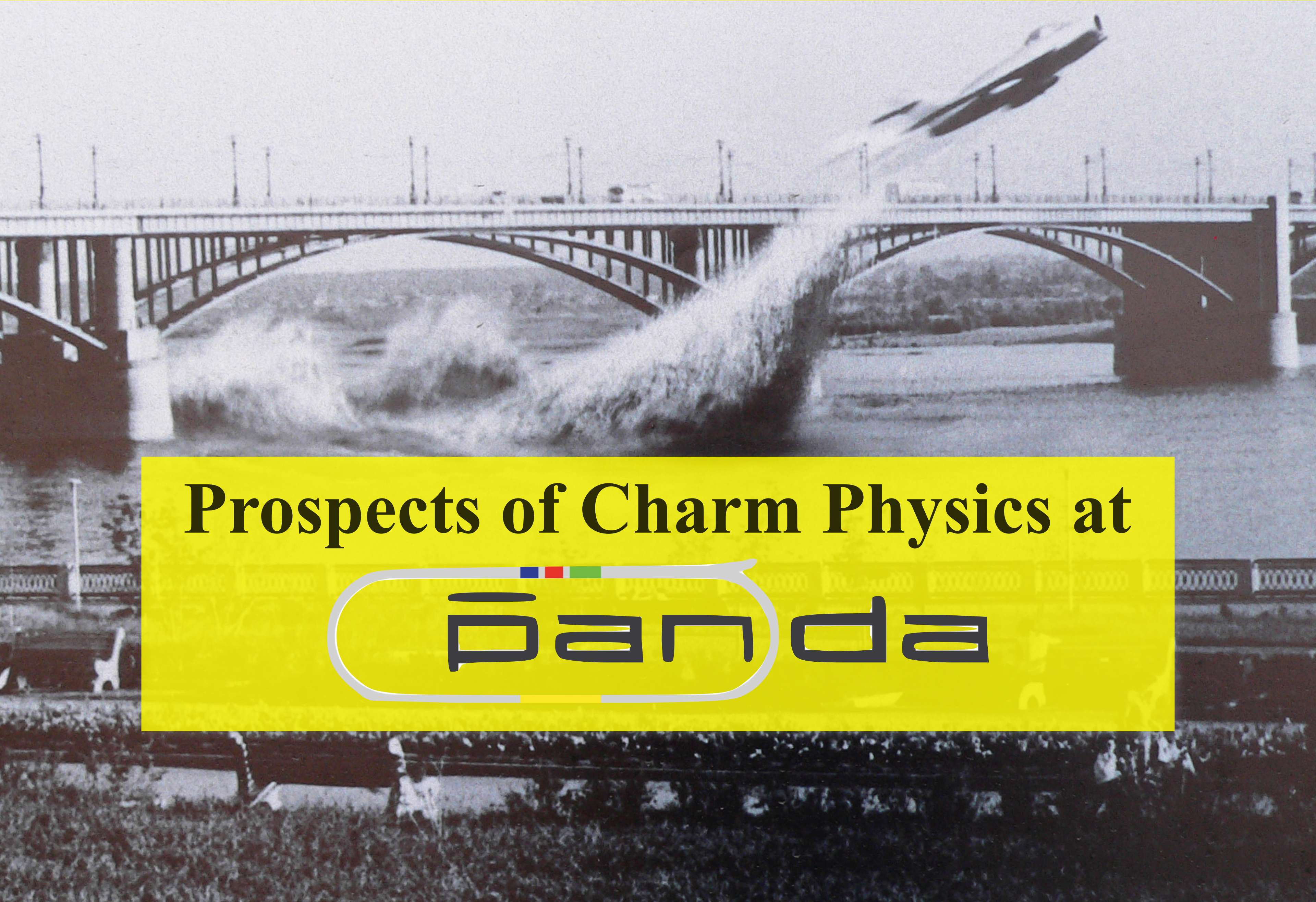
Johan Messchendorp (KVI-CART/University of Groningen) on behalf of the PANDA Collaboration
CHARM18, Novosibirsk, Russia, 21-25 May 2018



Prospects of Charm Physics at $\bar{\text{P}}$ANDA

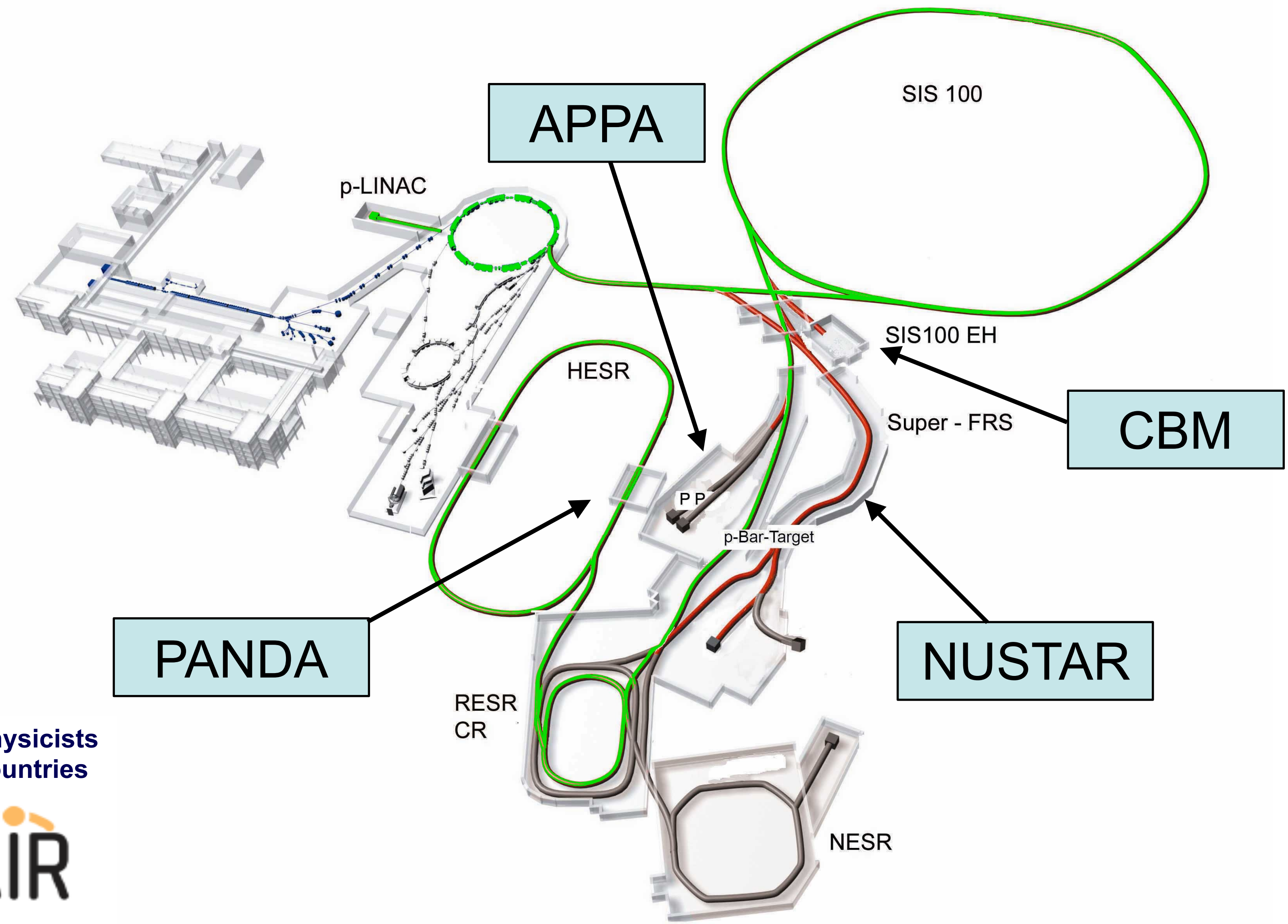
PANDA in a nutshell!

Community
- interdisciplinair: nuclear, hadron & particle physics
- international: 460 scientists from 19 countries
- strong network in other collaborations

Uniqueness
- usage of antiprotons: precision & exploration
- strange, charm, and gluon “factory”

Technology
- data complexity & detector developments
- versatile instrument

Facility for Antiproton and Ion Research

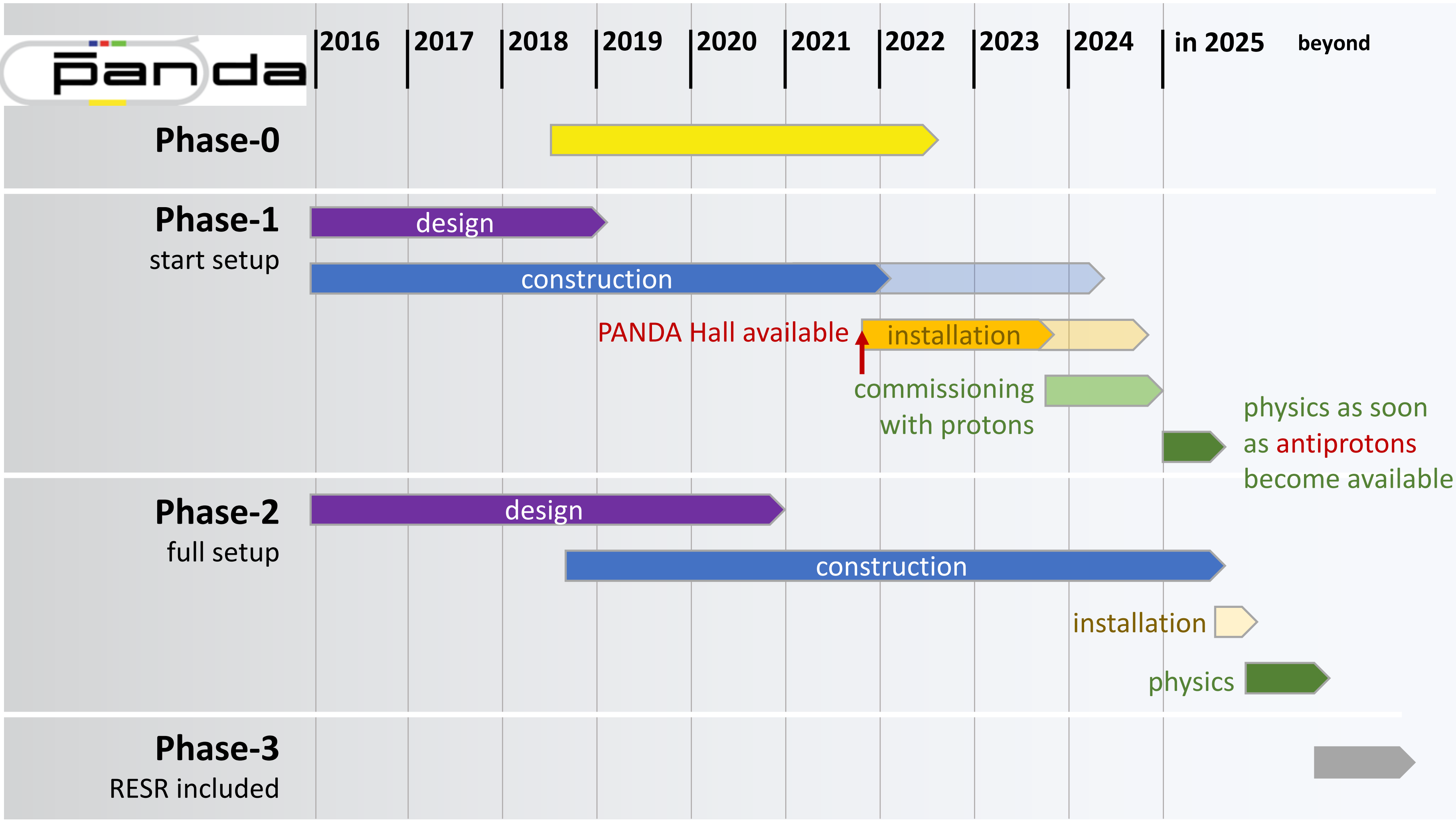


3000 physicists
50 countries

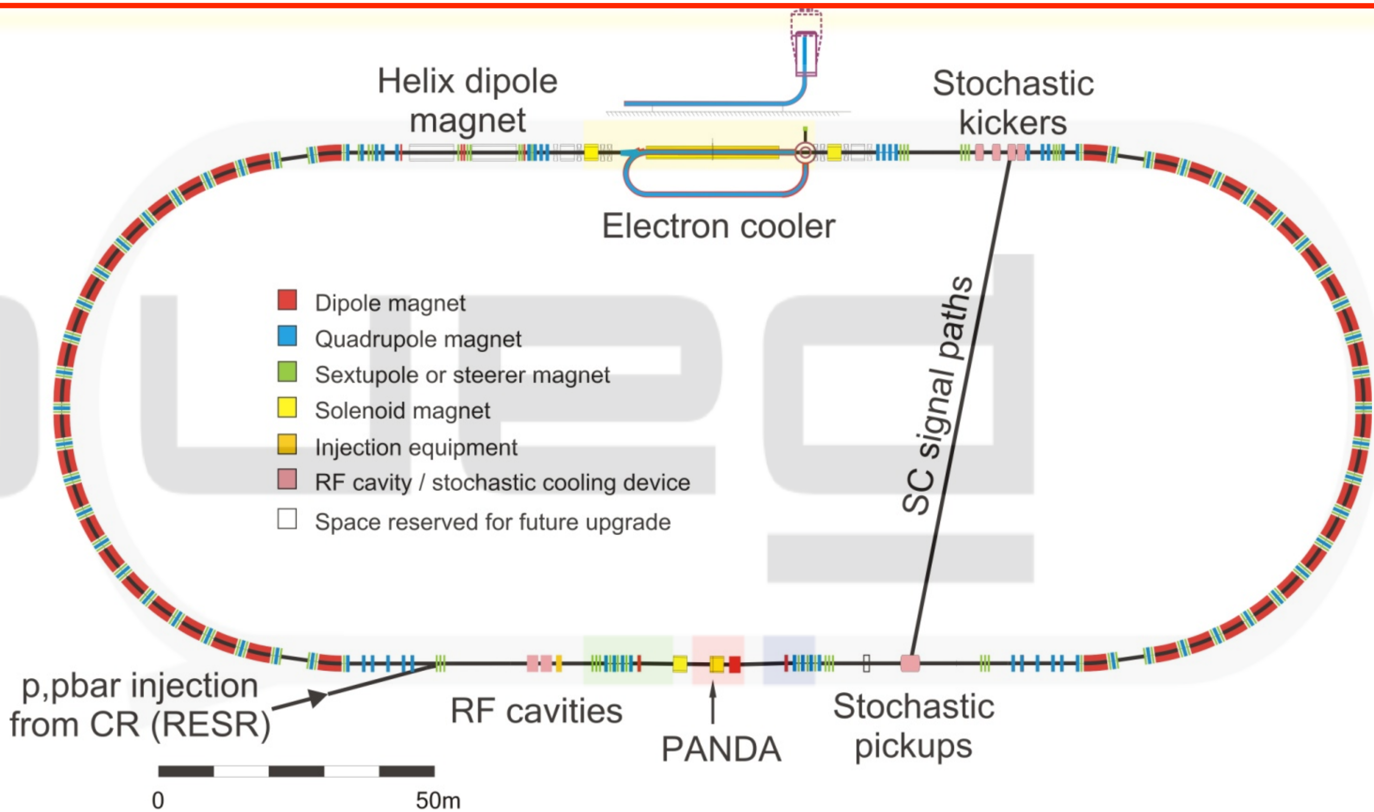
Facility for Antiproton and Ion Research

Facility for Antiproton and Ion Research

PANDA staging



High Energy Storage Ring - *precision* antiprotons



High resolution mode:

- e^- cooling : p<8.9 GeV/c
- 10^{10} antiprotons stored
- Luminosity up to $2x10^{31}$ $cm^{-2}s^{-1}$
- dp/p = $4x10^{-5}$

High intensity mode:

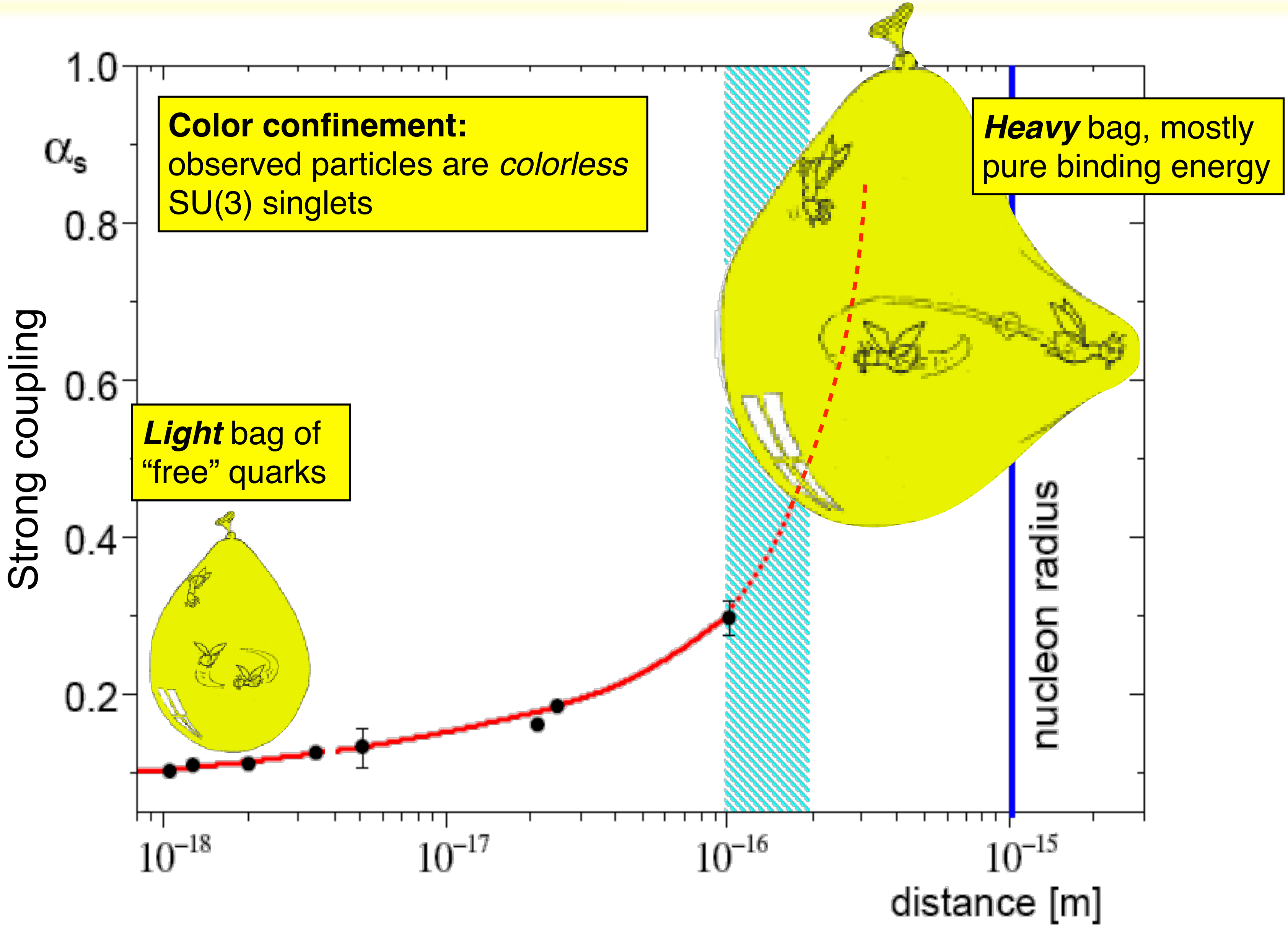
- Stochastic cooling
- 10^{11} antiprotons stored
- Luminosity up to $2x10^{32}$ $cm^{-2}s^{-1}$
- dp/p = $2x10^{-4}$

Phase 1+2: max. 10^{10} antiprotons stored

The “magic” of antiprotons

I. Versatile

Probing QCD at various distance scales

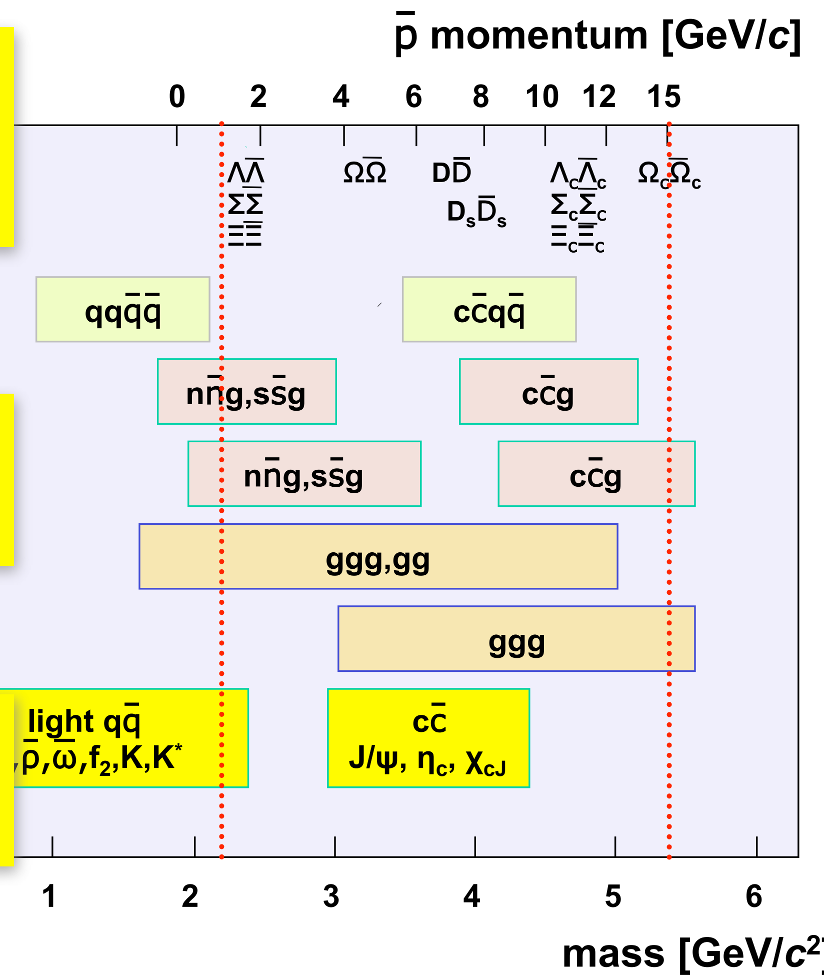


Versatility of antiprotons at PANDA

Large mass-scale coverage
- center-of-mass energies from 2 to 5.5 GeV
- from light, strange, to charm-rich hadrons
- from quark/gluons to hadronic degrees of freedom

High hadronic production rates
- charm+strange factory -> discovery by statistics!
- gluon-rich production -> potential for new exotics

Access to large spectrum of J^{PC} states
- direct formation of *all* conventional J^{PC} states
- large sensitivity to high spin states



Systematic and precise tool to rigorously study the dynamics of QCD

PANDA physics ambitions

Extensive **study of the strong force using <u>antiprotons</u>**

Hadron spectroscopy & dynamics
- open- and hidden charm
- gluonic excitations (glueballs, hybrids, ..)
- light meson systems
- hyperon spectroscopy & dynamics

Nucleon structure
- electr. magn. form factors
- TMDs, GPDs, TDAs

Hypernuclei
- $\Lambda\Lambda$ - hypernuclei
- hyperfine splitting in Ω atom
- (multi) strange baryons

Hadrons in nuclear medium
- antiproton-A collisions
- nuclear potentials of antibaryons
- charmonium-nucleon interactions

Physics Performance Report for:

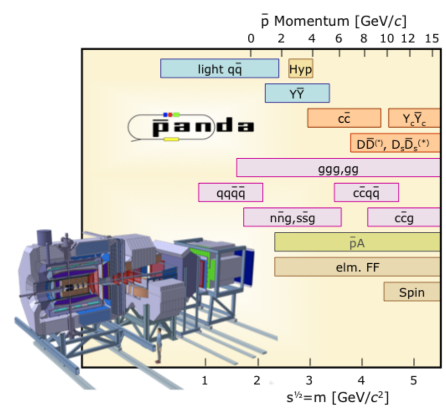
$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

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

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\text{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\overline{\text{P}}$ANDA and what performance can be expected.



arXiv:0903.3905

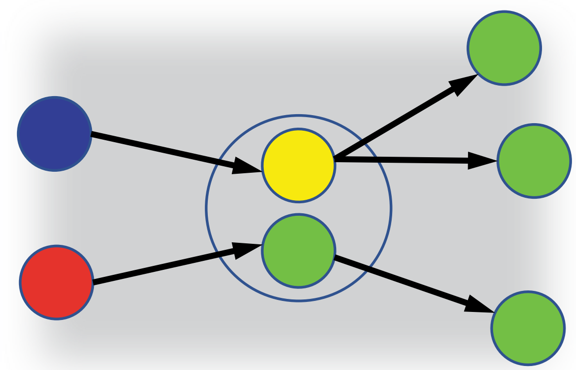
The “magic” of antiprotons

II. Discovery by precision and exploration

The “magic” of antiprotons - *spectroscopy*

Production all exotic and non-exotic quantum numbers accessible with a recoil

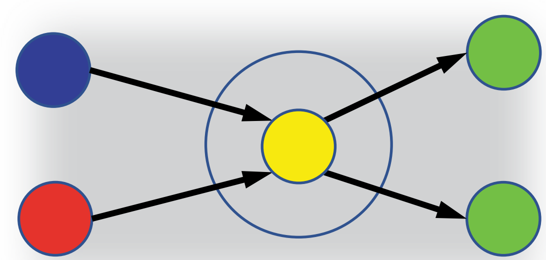
- high discovery potential
- associated, access to all quantum numbers (exotic)



all quantum numbers possible

Formation all non-exotic quantum numbers accessible

- not only limited to $J^{PC} = 1^{--}$ as e^+e^- colliders
- precision physics of known states
- resonant, high statistics, extremely good precision in mass and width

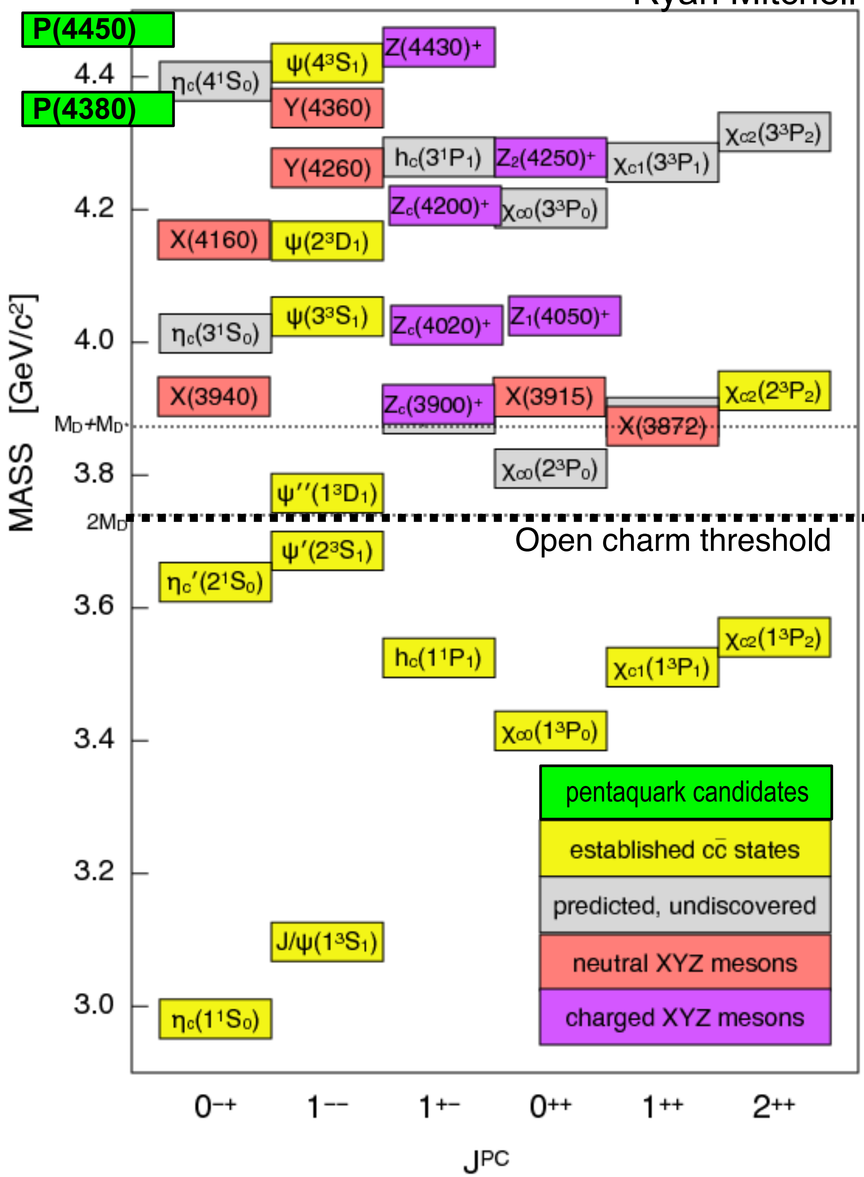


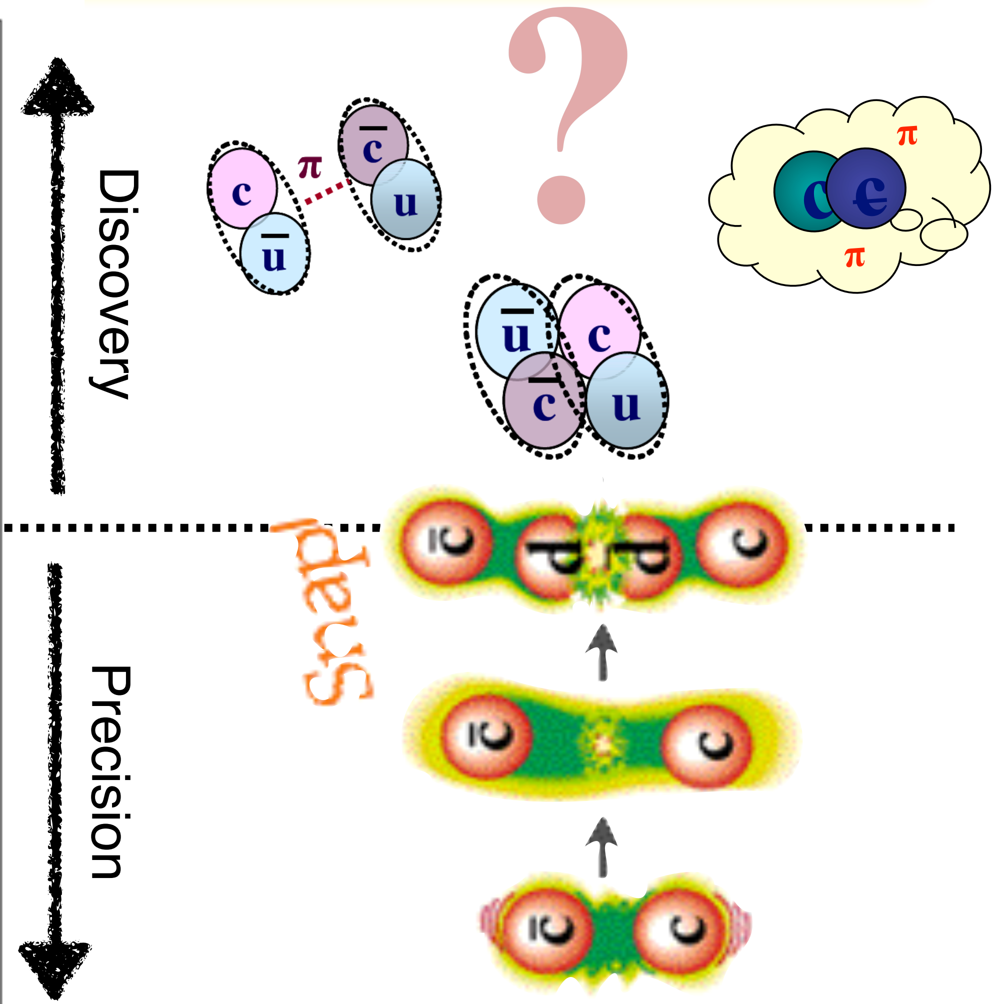
quantum numbers like $\bar{p}p$

antiproton probe unique and decisive

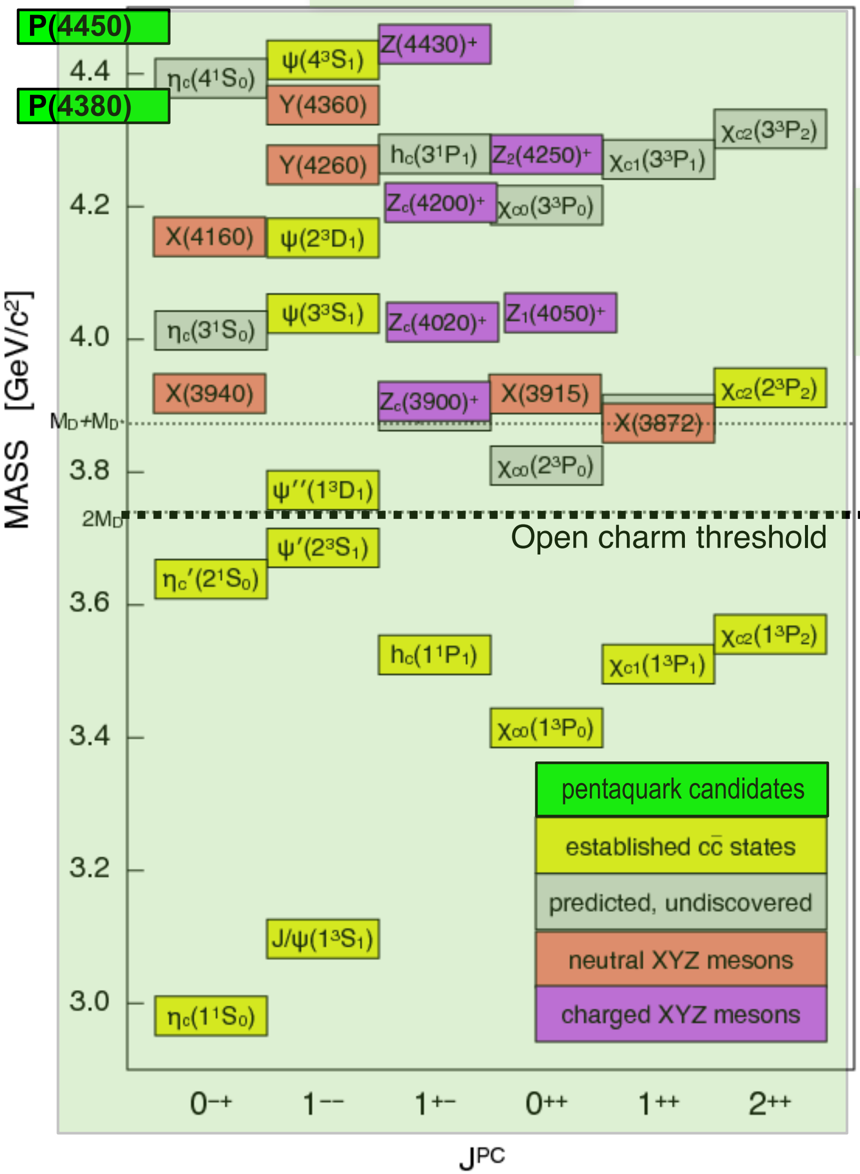
Hidden-charm spectroscopy

Ryan Mitchell





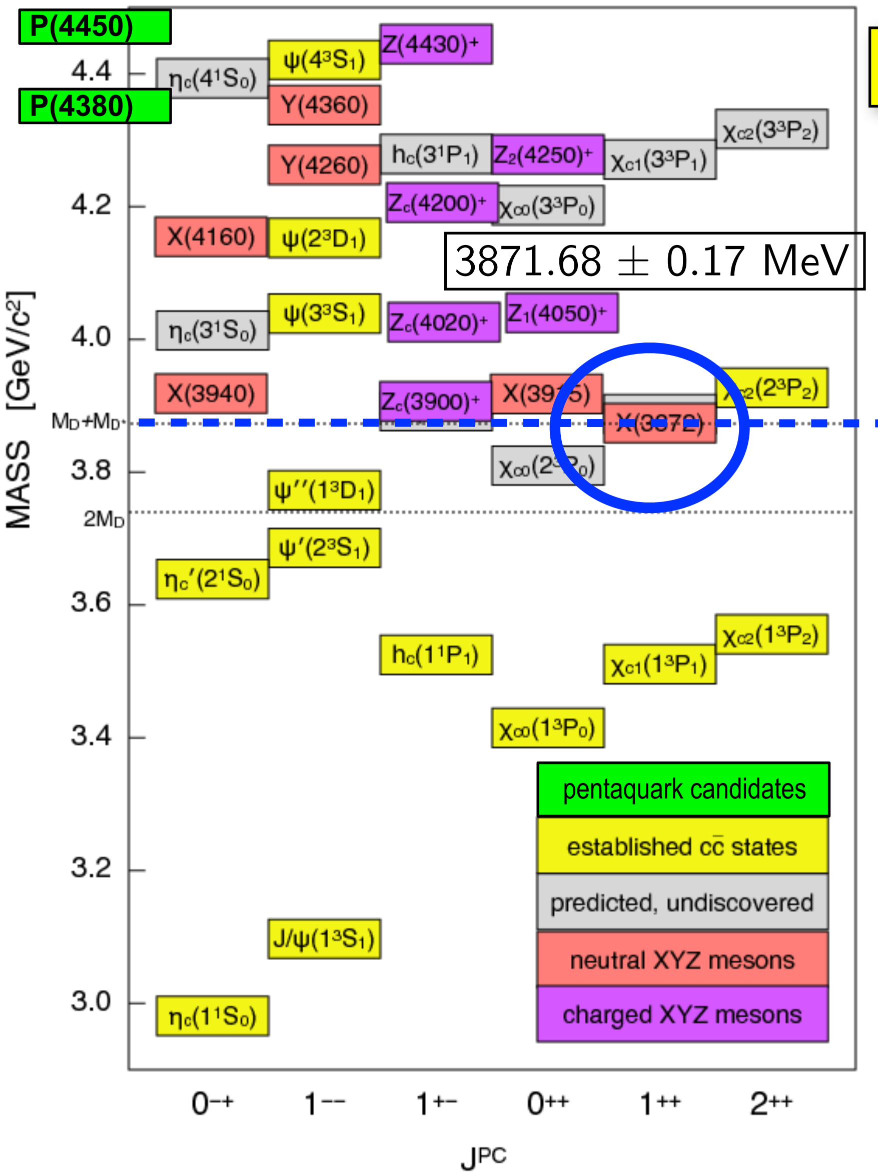
Hidden-charm spectroscopy



- line shape of X(3872)
- neutral+charged Z-states
- hidden-charm pentaquark
- X,Y,Z decays
- search for h_c', $^3F_4$, …
- spin-parity/mass&width of $^3D_2$

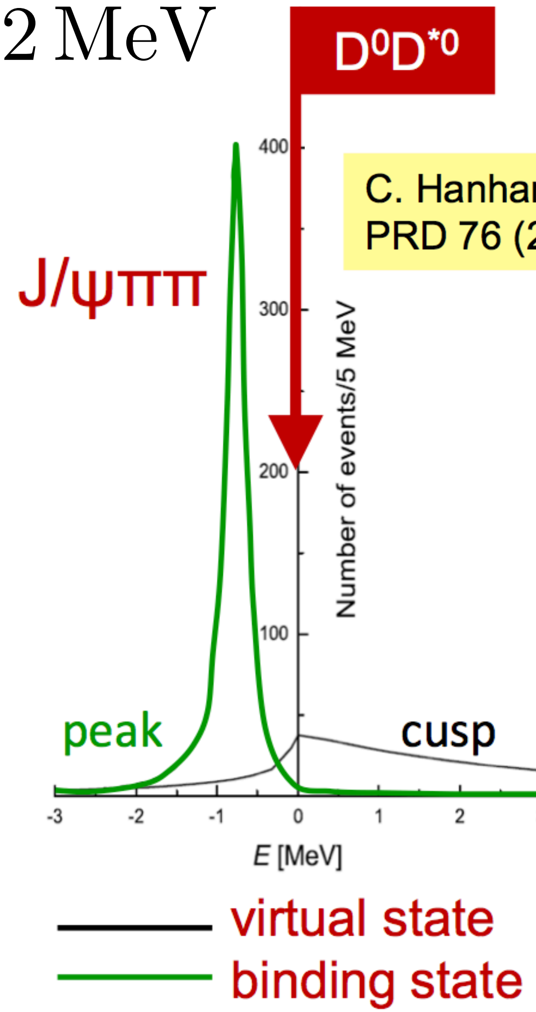
- line shape/width of the h_c
- radiative decays (multipole)
- light-quark spectroscopy

Line-shape study of the X(3872)



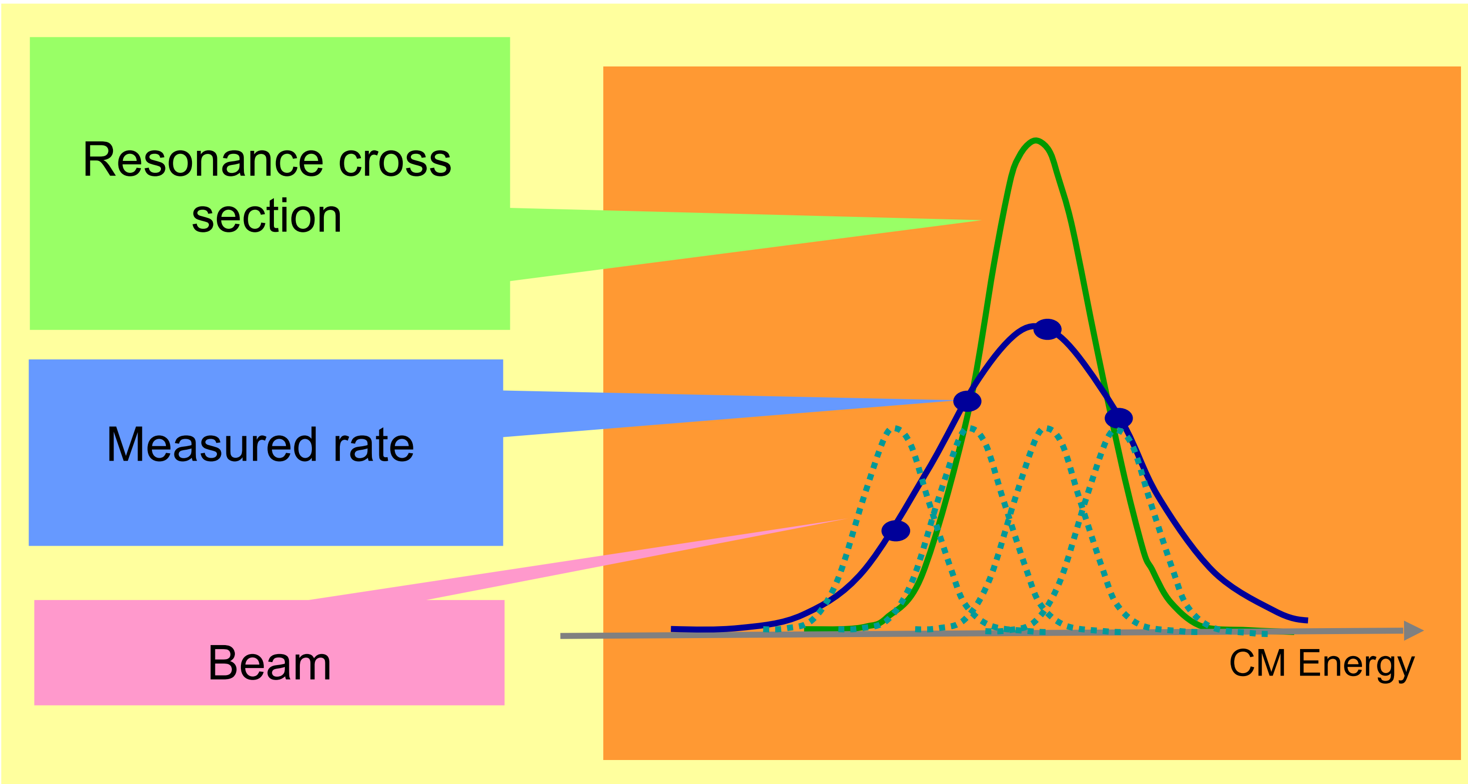
Strikingly narrow:

$$\Gamma < 1.2\,\text{MeV}$$



C. Hanhart *et al.*,
PRD 76 (2007) 034007

Resonance scanning



Energy scan with e^+e^-:	energy resolution	1-2 MeV (primarily J^{PC}=1- -)
Energy scan with $p\bar{p}$:	energy resolution	240 keV (E760/835@Fermilab)
		≈50 keV (PANDA@FAIR)

Resonance scanning

$\bar{p}p \to X(3872) \to J/\psi\pi^+\pi^-$

Klaus Goetzen et al.

Cross sections:

$$\sigma(\bar{p}p \to X(3872)) = 50\ nb$$

$$\sigma_{\mathrm{non-res}}(\bar{p}p \to J/\psi\pi^+\pi^-) = 1.2\,nb$$

$$\sigma(\bar{p}p \to \mathrm{inelastic}) = 46\,mb$$

$$B(X(3872) \to J/\psi\pi^+\pi^-) = 5\%$$

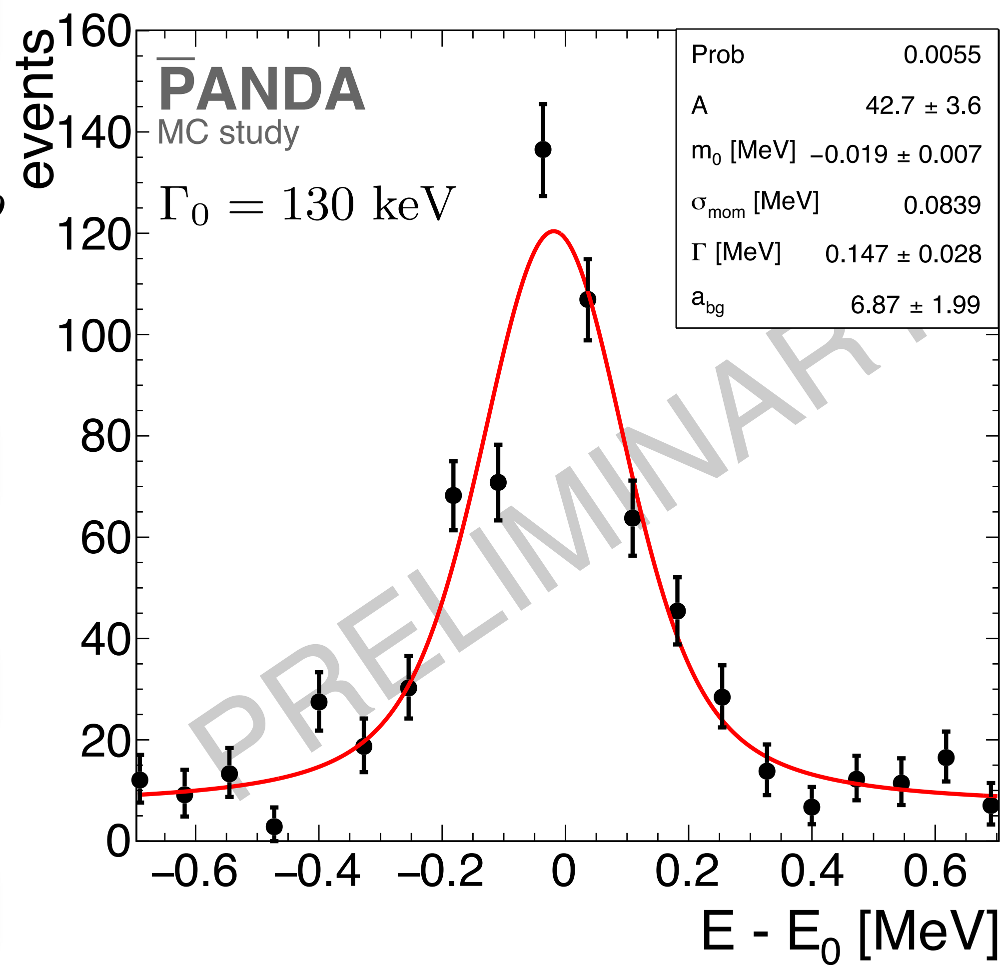
Luminosity (MSV, HESRr):

$$1170\ (\mathrm{nb} \cdot \mathrm{day})^{-1}$$

Energy resolution (HESRr):

$$\Delta E = 84\ \mathrm{keV}$$

20 points each 2 days data taking!



Resonance scanning

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Klaus Goetzen et al.

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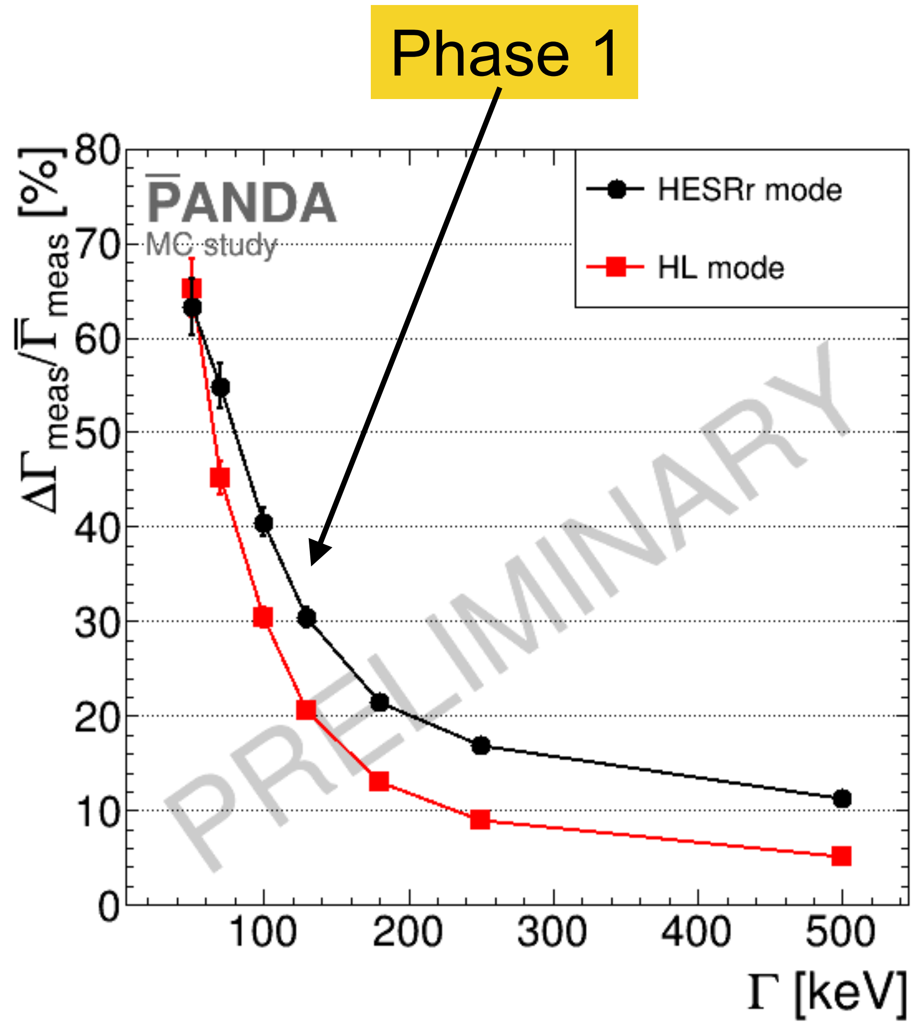
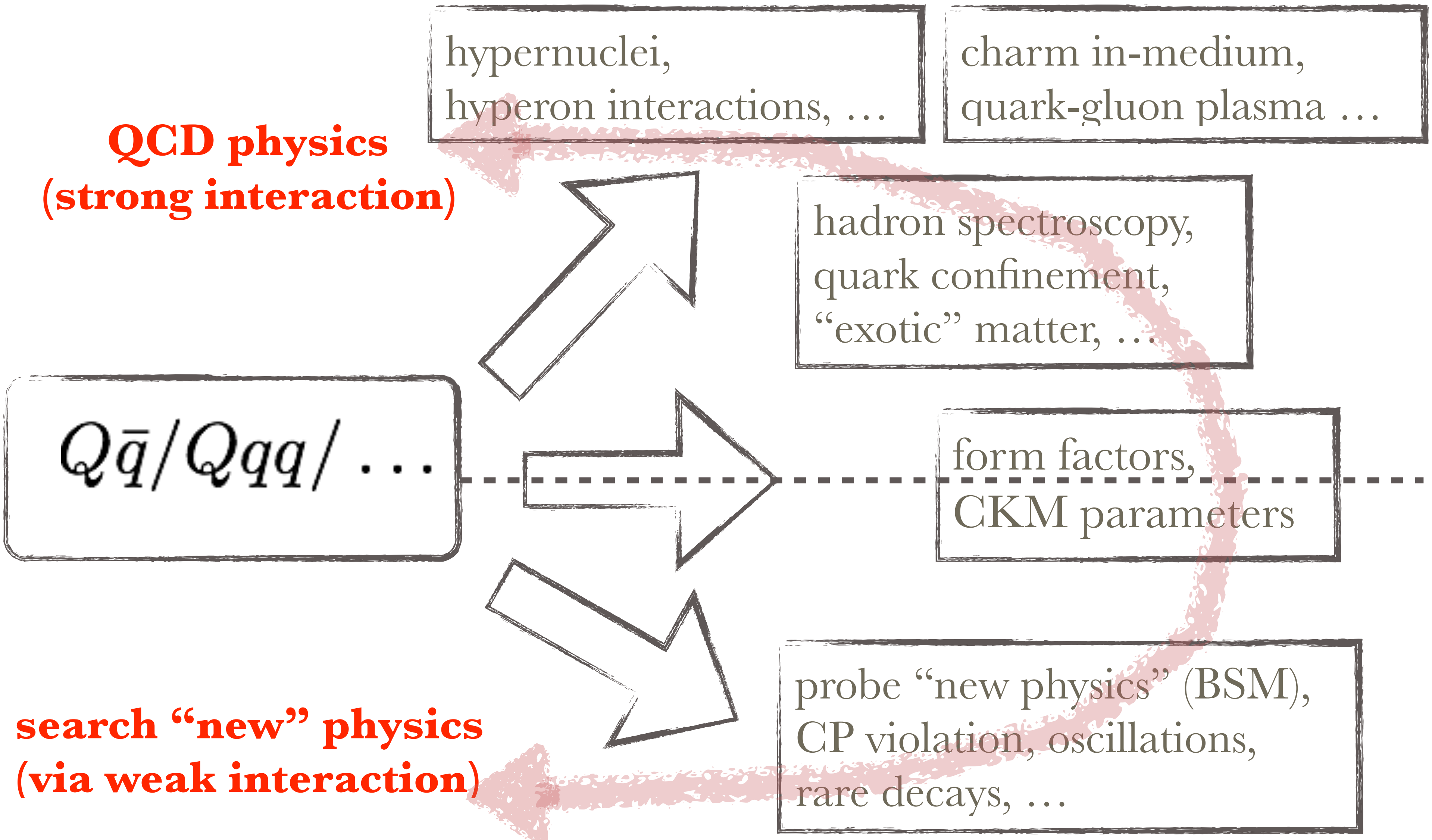
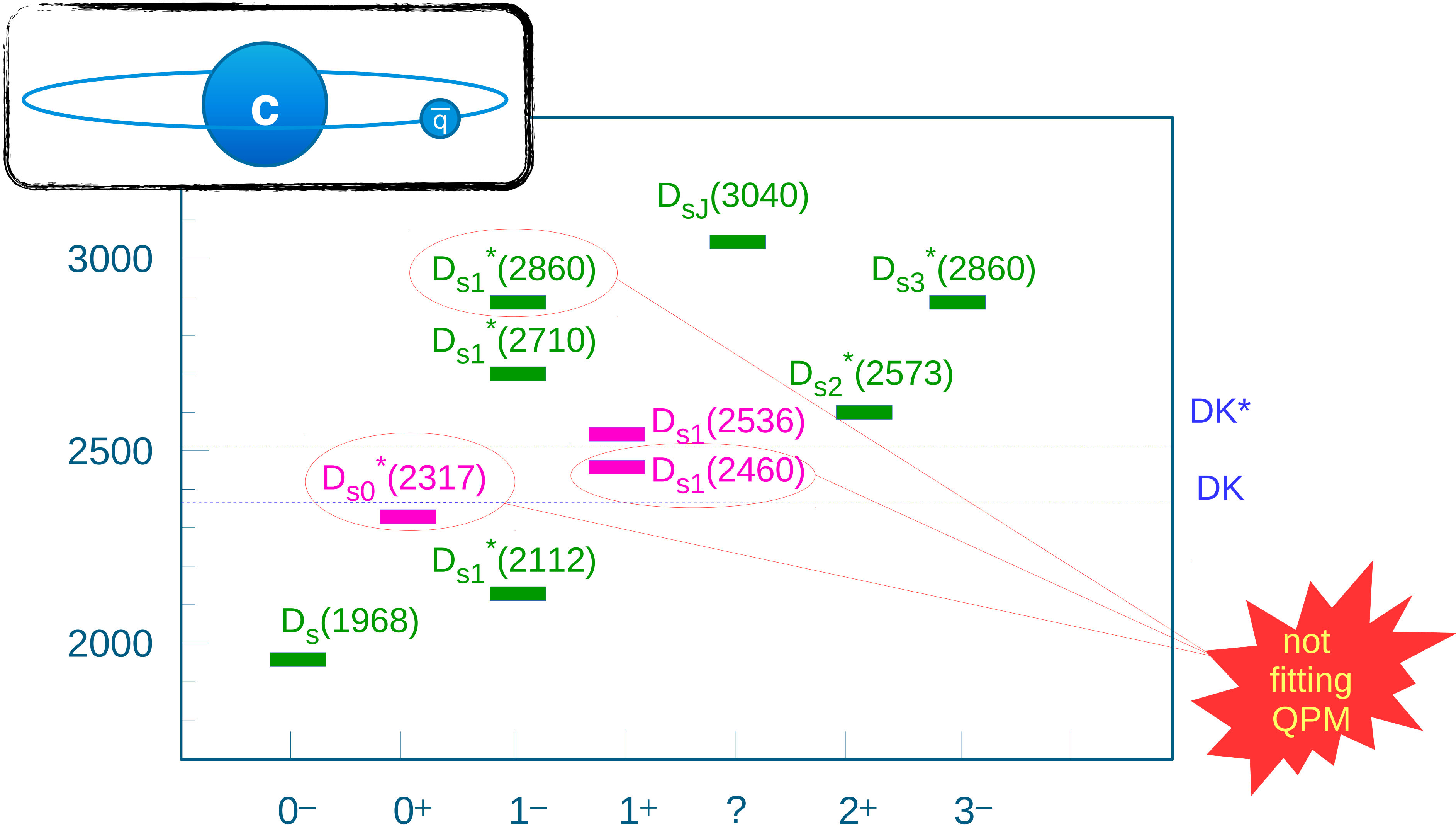


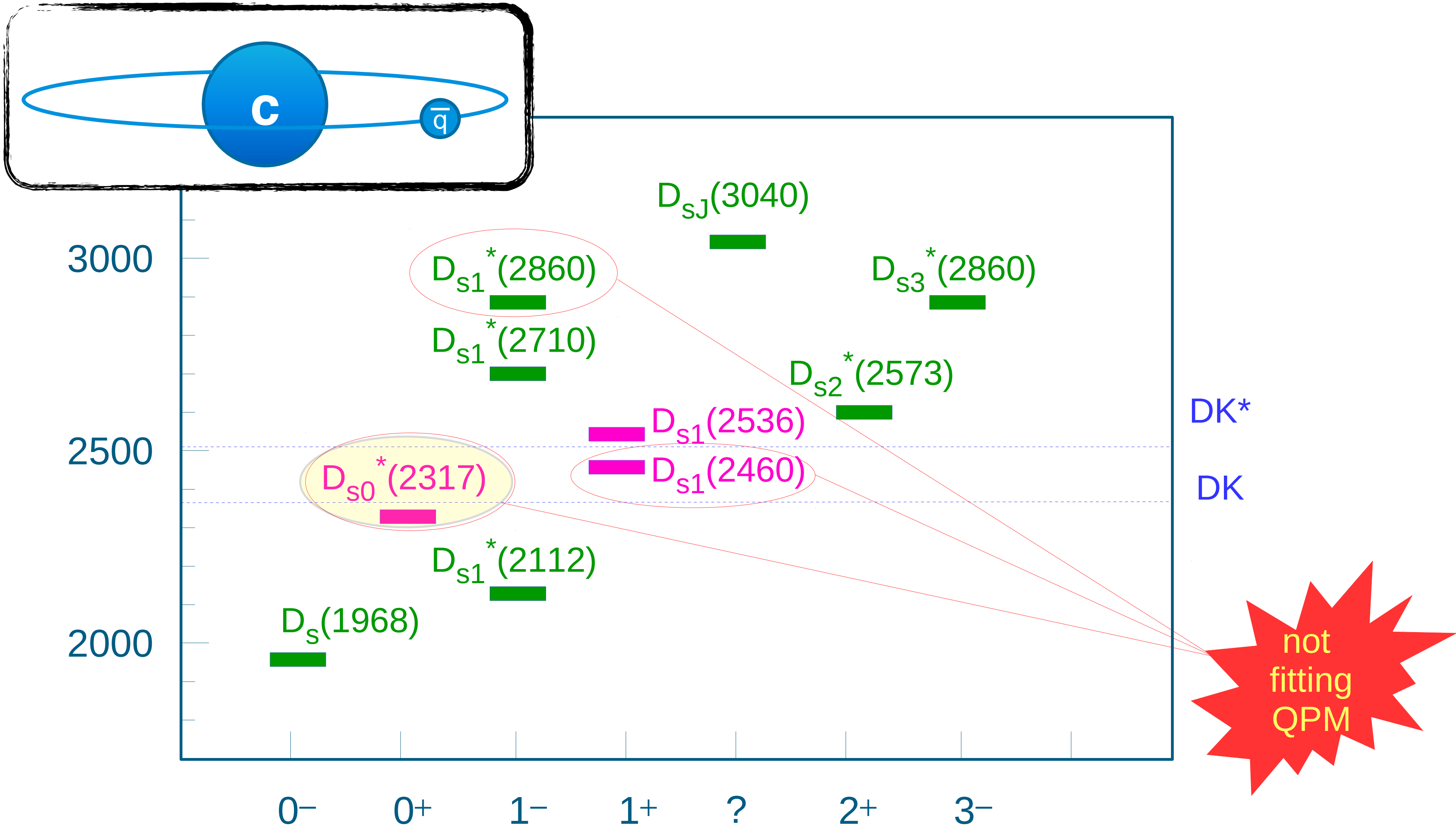
Heavy-light systems: *open-charm*



Heavy-light systems: *open-charm*



Heavy-light systems: *open-charm*



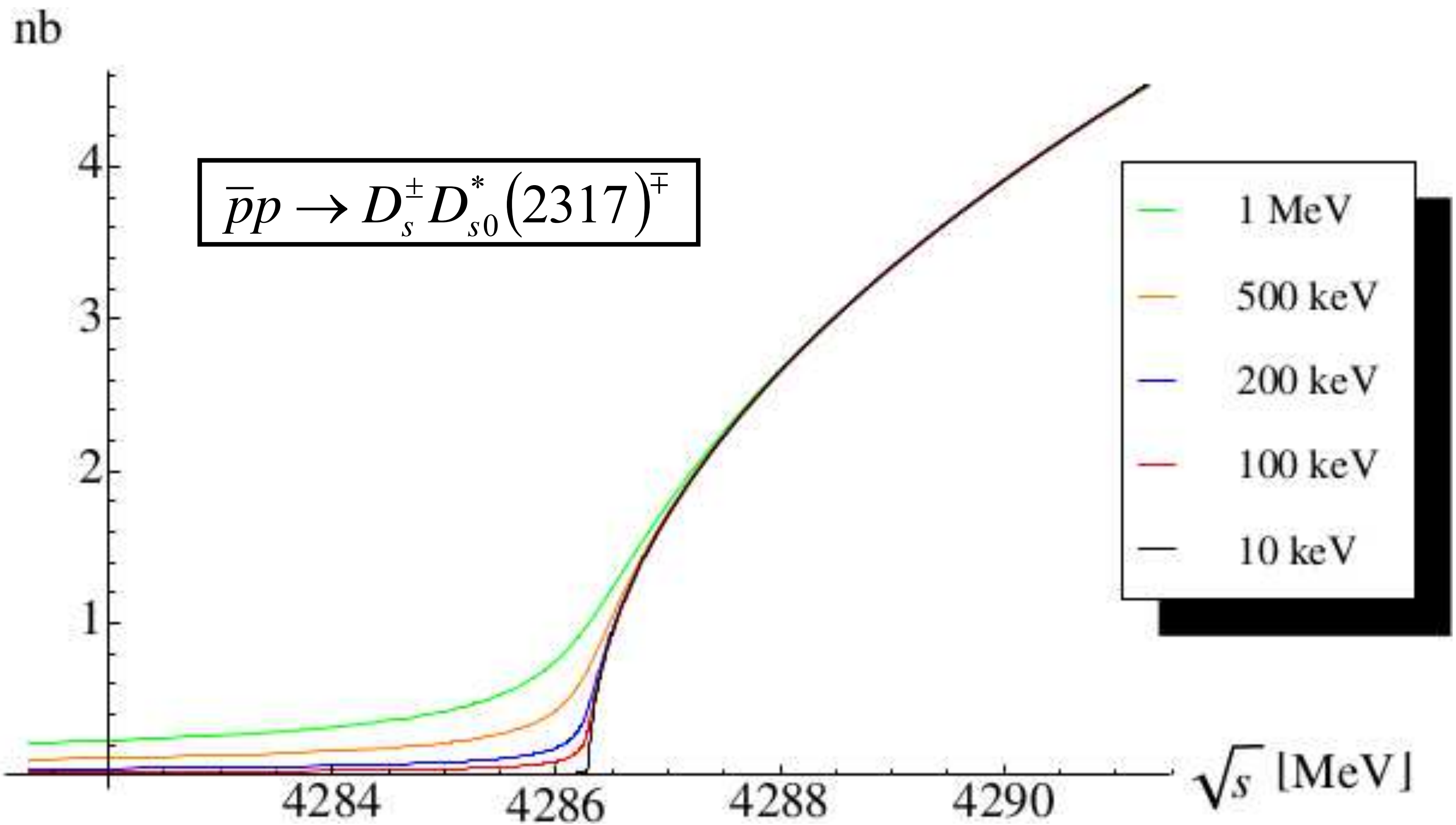
$D_{s0}^*(2317)$ theoretical predictions

Different theoretical approaches, different interpretations	$\Gamma(D_{s0}^*(2317)^+ \rightarrow D_s \pi^0)$ (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** 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	NEW! Strong and radiative decays of $D_{s0}^*(2317)$ and $D_{s1}(2460)$
Experiment:	$\Gamma_{tot} < 3.8\,\mathrm{MeV}$

A width measurement could be conclusive!

$D_{s0}^*(2317)$ energy scan

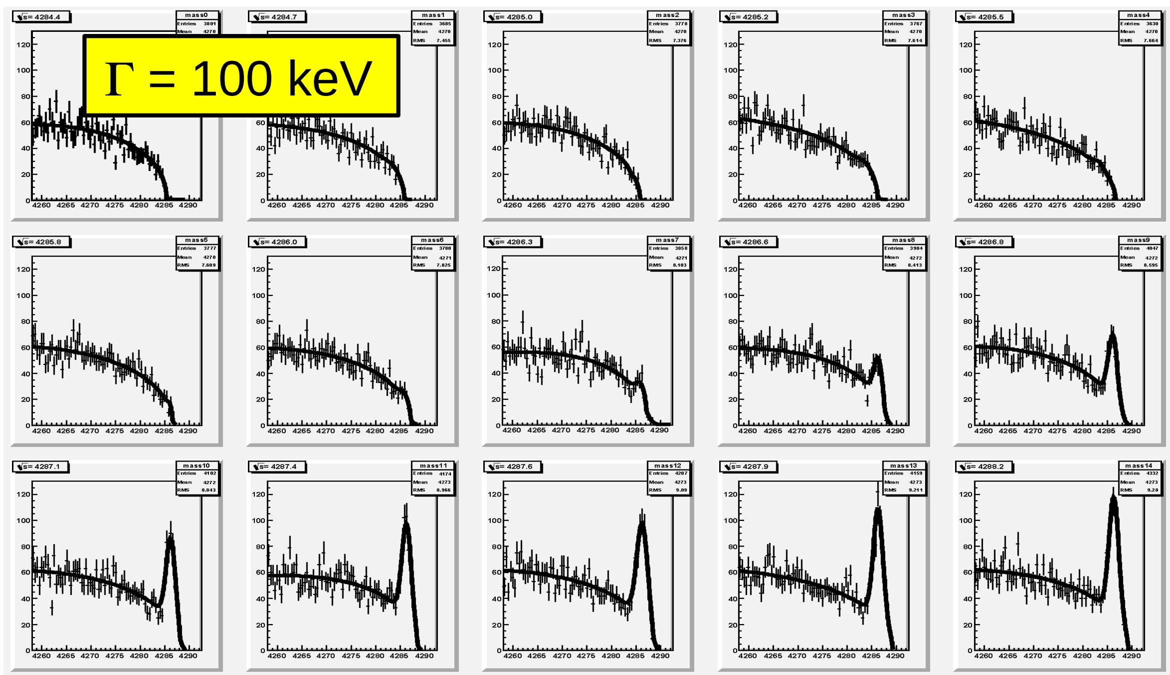
E. Prencipe, M. Mertens (FZJ)



$D_{s0}^*(2317)$ energy scan

E. Prencipe, M. Mertens (FZJ)

Toy MC study

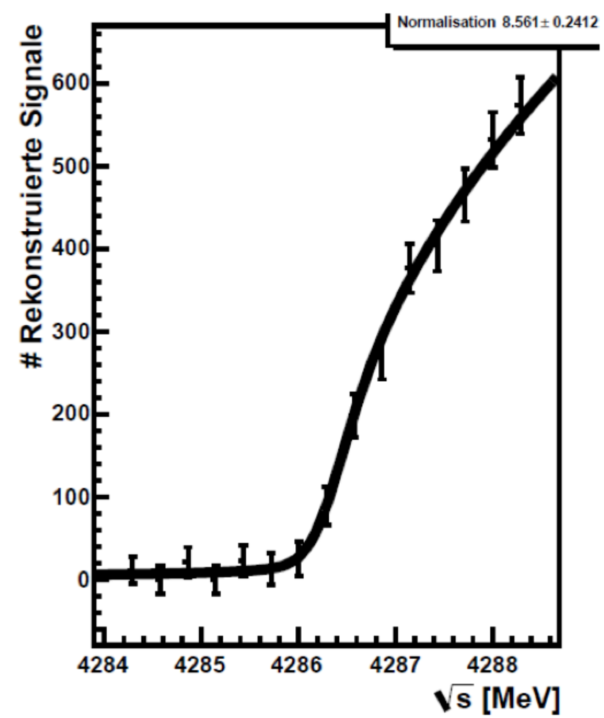


$$\bar{p}p \rightarrow D_s^{\pm} D_{s0}^{*}(2317)^{\mp}$$

$$D_s^{\pm} \rightarrow \phi\pi^{\pm}, \quad \phi \rightarrow K^+K^-$$

$$D_{s0}^{*}(2317)^{\mp} \rightarrow D_s^{\mp}\pi^0$$

Extracted excitation function

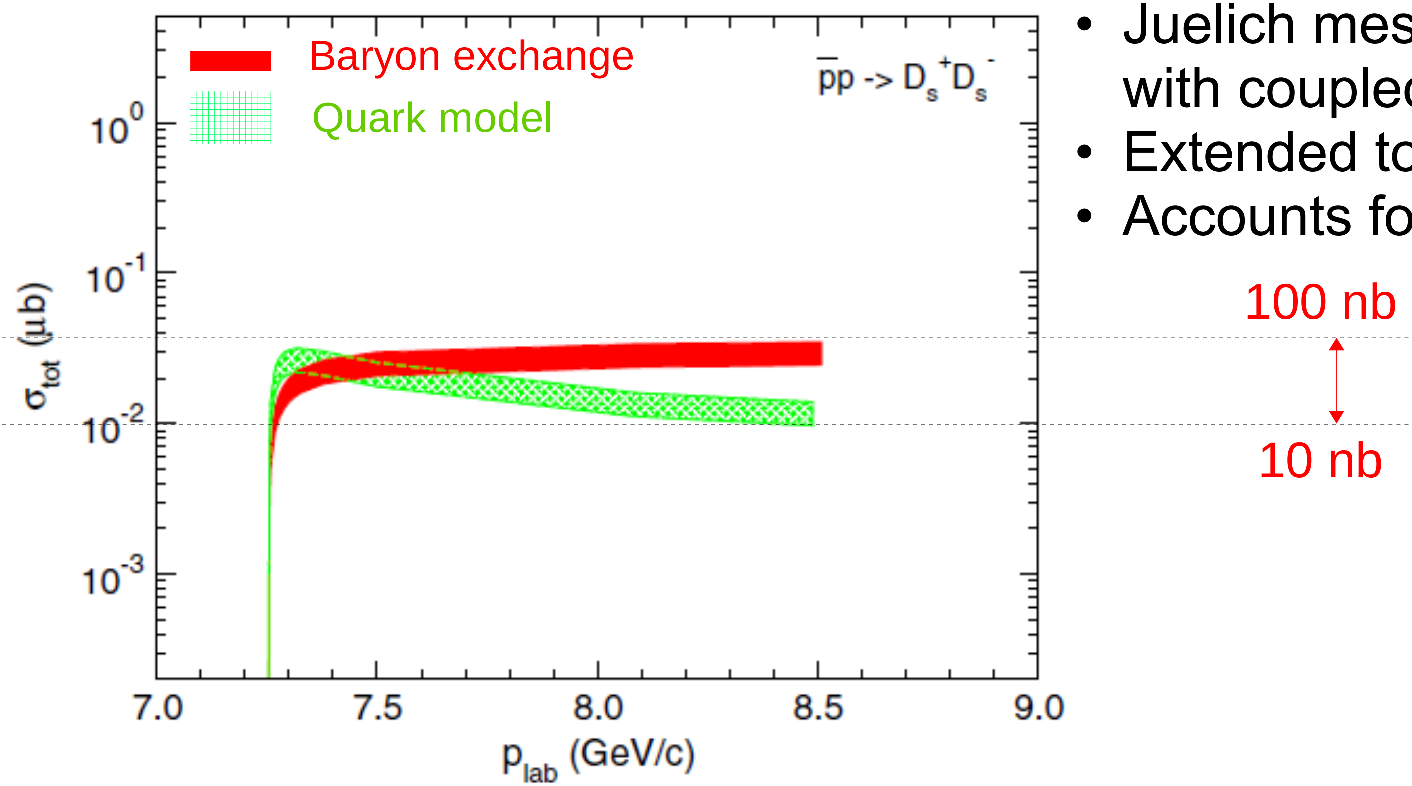


15 measurements in step of 4 MeV (L=550 pb^{-1})

Relative error less than 30% for Γ>100 keV

Open-charm production?

Haidenbauer, Krein, PRD89, 114003 (2014)



- Juelich meson-baryon model with coupled-channel approach
- Extended to SU(4)
- Accounts for ISI/FSI

Validity SU(4) approach? D.o.f. quarks+gluons or mesons+baryons?

How to extrapolate to excited open-charm states?

Cross section measurements of PANDA at *phase-one* will give insight!

Charm-baryon spectroscopy

Conceptually: heavy + light diquark system

- simplified baryonic system
- weak decay: narrow states
- heavy quark + chiral symmetry

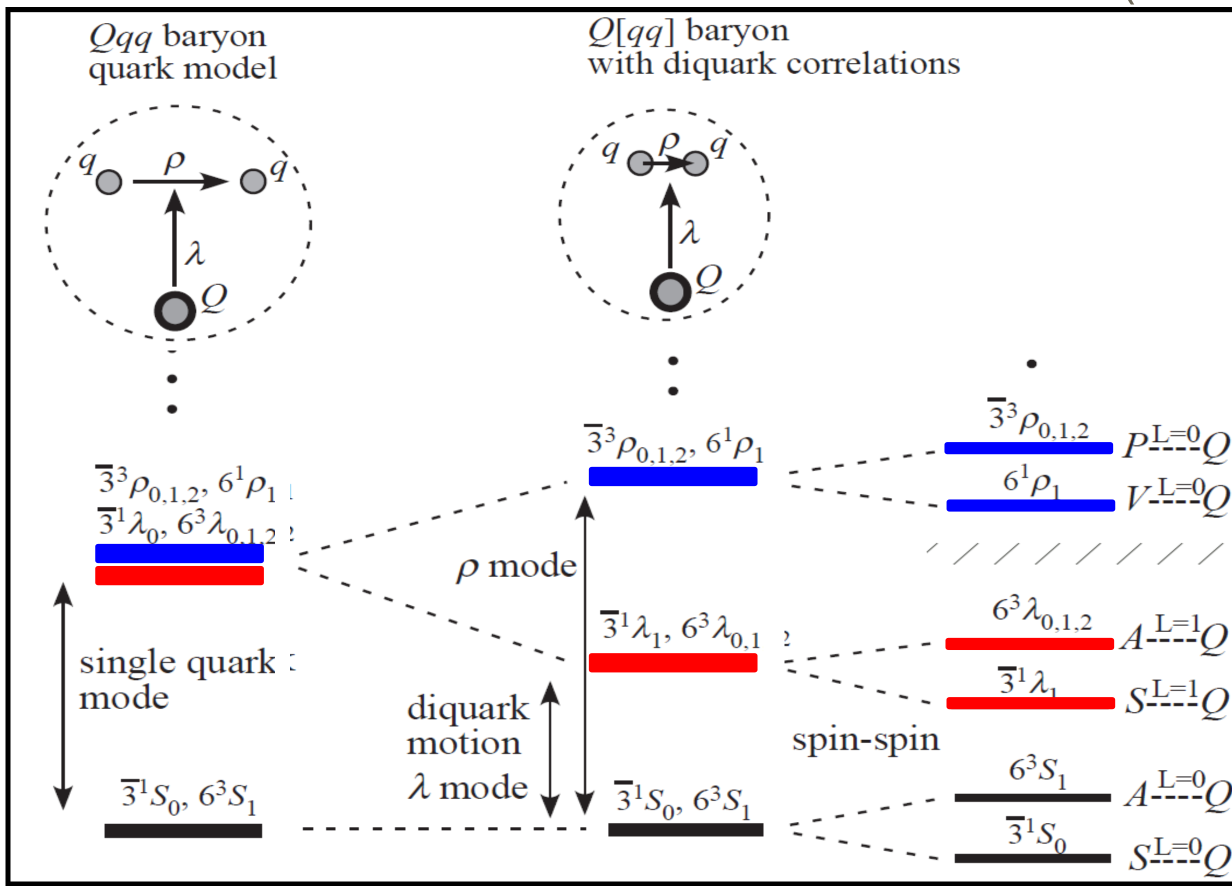
Charm-baryon spectroscopy

Conceptually: heavy + light diquark system

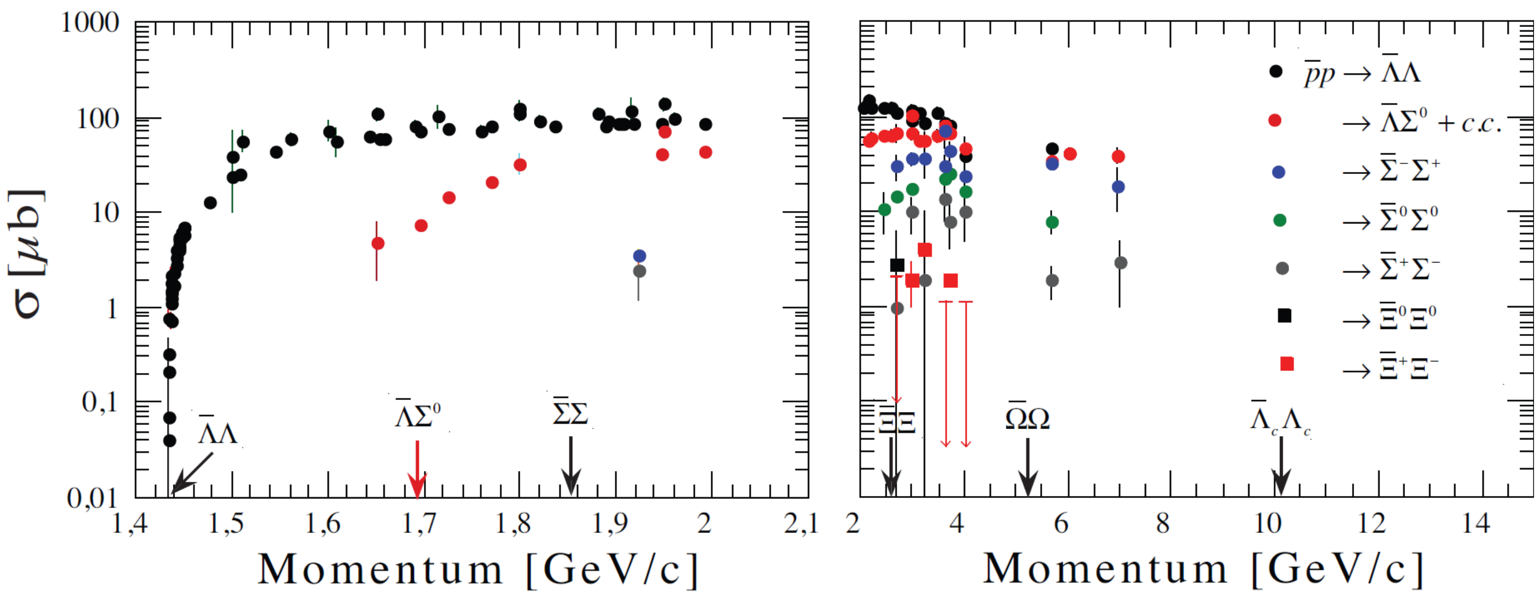
- simplified baryonic system
- weak decay: narrow states
- heavy quark + chiral symmetry

K. Ozawa (KEK)

probing di-quark correlations in baryons



PANDA is a hyperon factory!



- A lot of data on $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ near threshold, mainly from PS185 at LEAR*
- Very scarce data bank above 4 GeV
- Only a few bubble chamber events on $\bar{p}p \rightarrow \bar{\Xi}\Xi$
- No data on $\bar{p}p \rightarrow \bar{\Omega}\Omega$ nor $\bar{p}p \rightarrow \bar{\Lambda}_c\Lambda_c$

* See e.g. T. Johansson, AIP Conf. Proc. of LEAP 2003, p. 95

PANDA is a hyperon factory!

$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda,\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Sigma}^{0}\Sigma^{0},\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Xi}^{0}\Xi^{0},\ \bar{\Xi}^{+}\Xi^{-},\ \bar{\Omega}^{+}\Omega^{-},\ \bar{\Lambda}_c^{-}\Lambda_c^{+}$$

Λ	Σ^{+}	Σ^{0}	Σ^{-}	Ξ^{0}	Ξ^{-}	Ω^{-}	Λ_c^{+}
$\downarrow p\pi^{-}$	$\downarrow p\pi^{0}$	$\downarrow \Lambda\gamma$	$\downarrow n\pi$	$\downarrow \Lambda\pi^{0}$	$\downarrow \Lambda\pi$	$\downarrow \Lambda K$	$\downarrow \Lambda\pi$
64%	52%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	68%	$\approx$ 1%

Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate (with 10^{31} $cm^{-2}s^{-1}$)
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	11	29 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^{o}$	~40	~30	50 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$	~2	~20	1.5 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}^{+}\Omega^{-}$	~0.002	~30	~4 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c^{-}\Lambda_c^{+}$	~0.1	~35	~2 day^{-1}

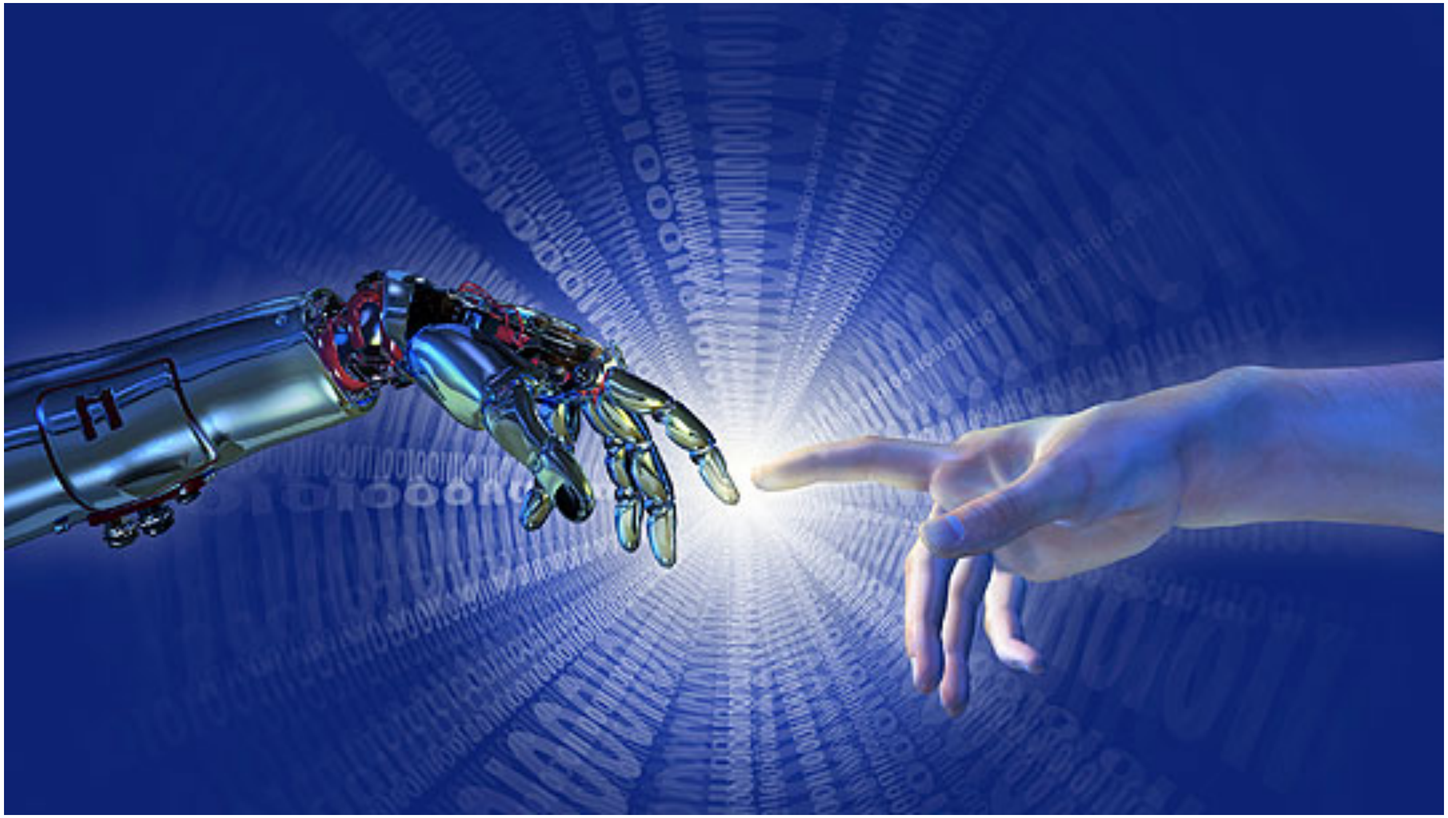
Phase 1

Gain factor 100 in inclusive mode;
Feasibility studies are underway!

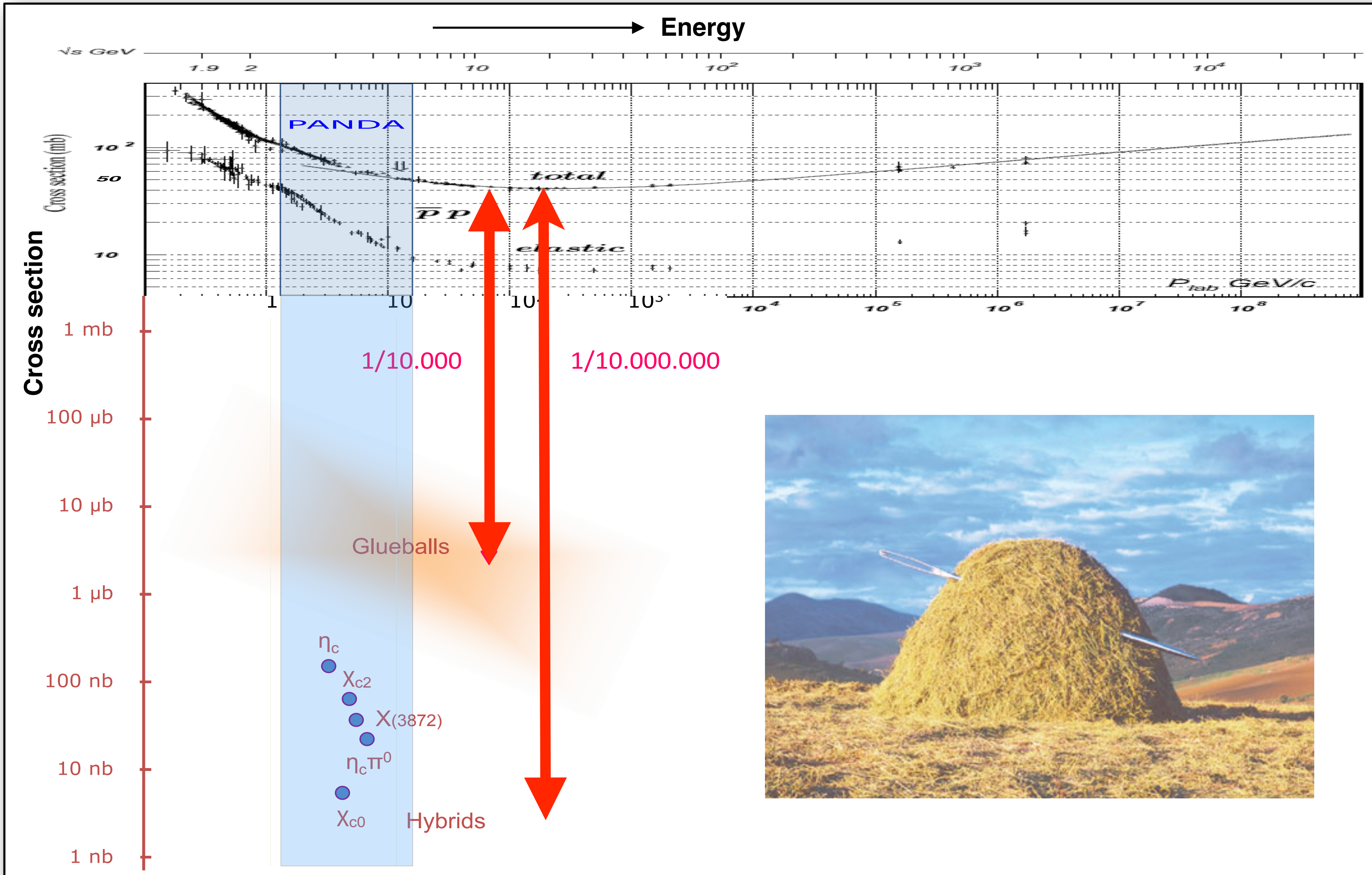
Karin Schoenning

The “magic” of antiprotons

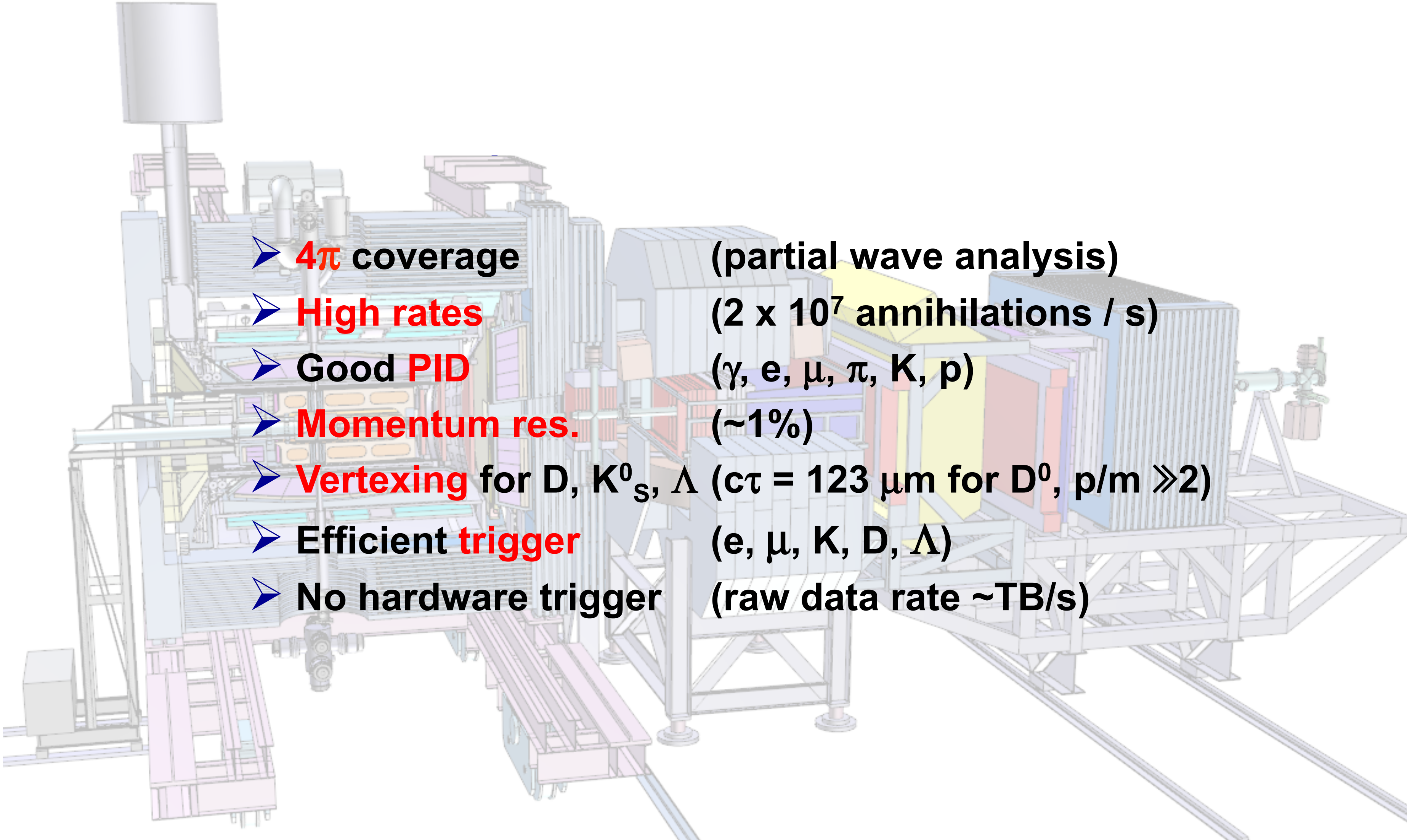
III. Technological innovation



Needle-in-a-haystack

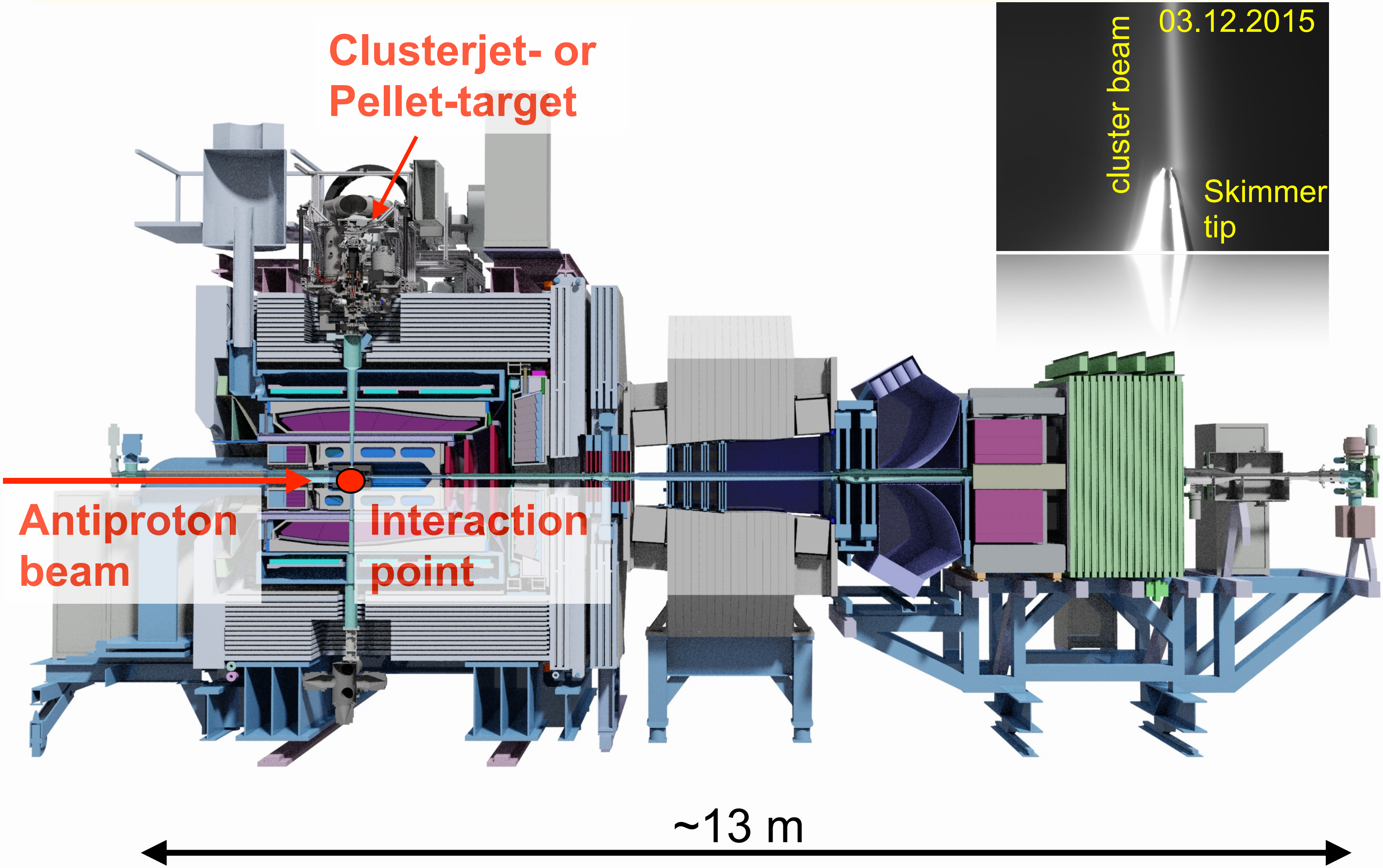


Detector capabilities

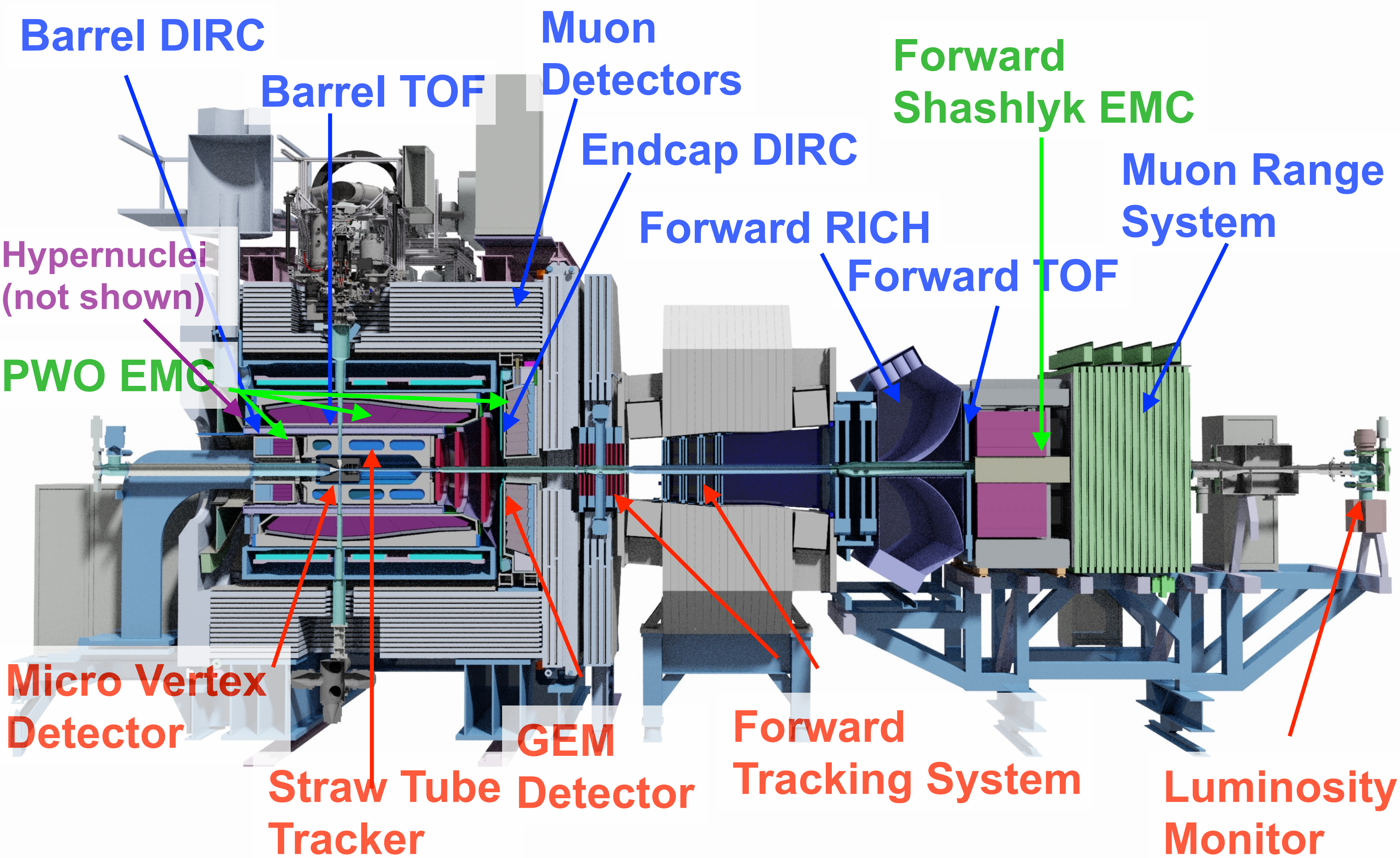


- **4π coverage** (partial wave analysis)
- **High rates** (2 x 10^7 annihilations / s)
- **Good PID** (γ, e, μ, π, K, p)
- **Momentum res.** (~1%)
- **Vertexing for D, K^0_S, Λ** (cτ = 123 μm for D^0, p/m ≫2)
- **Efficient trigger** (e, μ, K, D, Λ)
- **No hardware trigger** (raw data rate ~TB/s)

The PANDA detector



The PANDA detector



Prospects of Charm Physics at PANDA

http://www-panda.gsi.de/

j.g.messchendorp@rug.nl

Prospects of Charm Physics at PANDA

To take away, PANDA …

… offers a versatile program in hidden/open-charm using *antiprotons*.

… aims to start in 2025 (phase-one) with a reduced luminosity.

… with the potential to perform unique studies of "exotic" states.

… and to study the production dynamics of charm hadrons.

… needs help in finding reliable estimates of antiproton-p couplings.

http://www-panda.gsi.de/
j.g.messchendorp@rug.nl

Collaboration

UniVPM Ancona
U Basel
IHEP Beijing
U Bochum
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
U Cracow
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara

FIAS Frankfurt
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
U Glasgow
BITS Pilani KKBGC, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
FH Iserlohn
FZ Jülich
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz

U Mainz
INP Minsk
ITEP Moscow
MPEI Moscow
BARC Mumbai
U Münster
Nankai U
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U Wisconsin, Oshkosh
U & INFN Pavia
Charles U, Prague
Czech TU, Prague
IHEP Protvino
Irfu Saclay
U of Sidney

PNPI St. Petersburg
West Bohemian U, Pilzen
KTH Stockholm
U Stockholm
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Uppsala
U Valencia
SMI Vienna
U Visva-Bharati
SINS Warsaw

more than 460 physicists from
from 75 institutions in 19 countries