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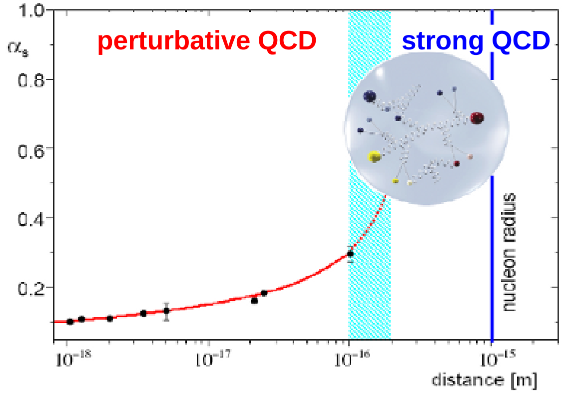
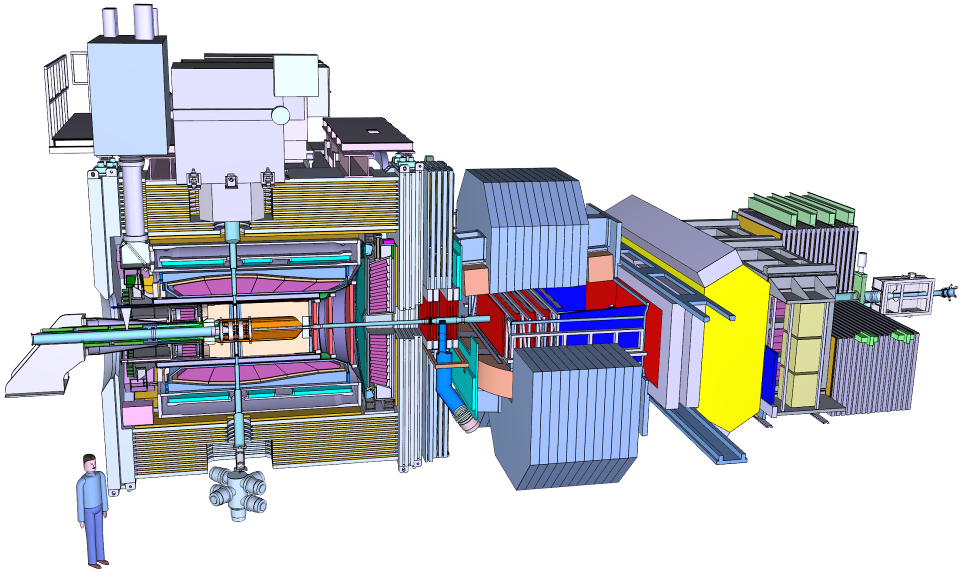
The PANDA experiment at FAIR

M. Kavatsyuk
KVI-CART, University of Groningen

for the PANDA collaboration





Quantum ChromoDynamics (QCD)

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What is the difference between QED and QCD?

$$\mathcal{L}_{\mathrm{QED}} = \bar{\psi}(x)\left[i\gamma_\mu D^\mu - m\right]\psi(x) - \frac{1}{4}F_{\mu\nu}(x)F^{\mu\nu}(x)$$

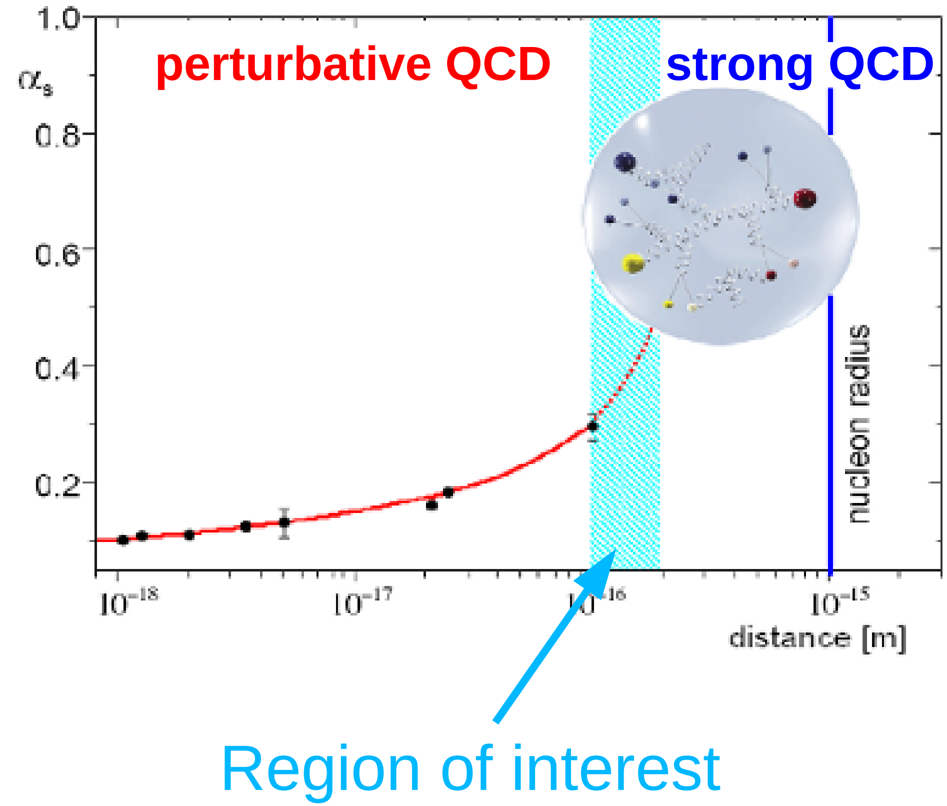
$$\mathcal{L}_{\mathrm{QCD}} = \bar{\psi}\left(i\gamma_\mu D^\mu - m\right)\psi - \frac{1}{2}\mathrm{tr}\{G_{\mu\nu}\,G^{\mu\nu}\}$$

Gluons (QCD gauge bosons) carry colour charge

⇕

Non-linear theory

Strong-interaction coupling constant



- QCD – well tested at high energies (**perturbative QCD**)
- At low energies – many aspects are *not understood* (strongly-coupled theory: **strong QCD**)

Quantum ChromoDynamics (QCD)

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What is the difference between QED and QCD?

Strong-interaction coupling constant

$\mathcal{L}_{\mathrm{QED}} =$

$\mathcal{L}_{\mathrm{QCD}}$

Gl

CD

]

Example of not resolved strong-QCD puzzle:

understanding of nucleon

- nucleon spin?
- nucleon radius?
- nucleon mass?

- QCD – well tested at high energies (**perturbative QCD**)
- At low energies – many aspects are *not understood* (strongly-coupled theory: **strong QCD**)

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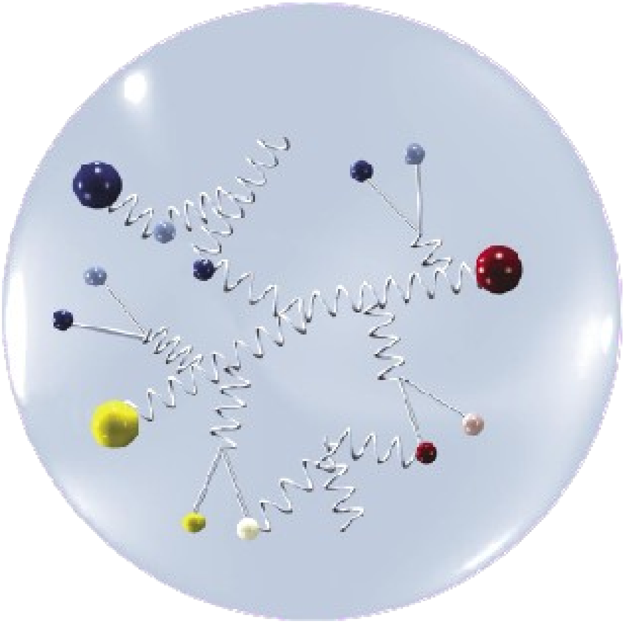
The Origin of Hadron Mass

- Elementary particles get their mass due to the …
  Higgs mechanism
- … but protons and neutrons are
  much heavier **(M_{quarks} ~ 1% of M_p)**
  than their valence quarks constituents! Why?



Most of the mass of light hadrons
is generated dynamically
by the strong interaction

How can we approach this puzzle?

Quantum ChromoDynamics (QCD)

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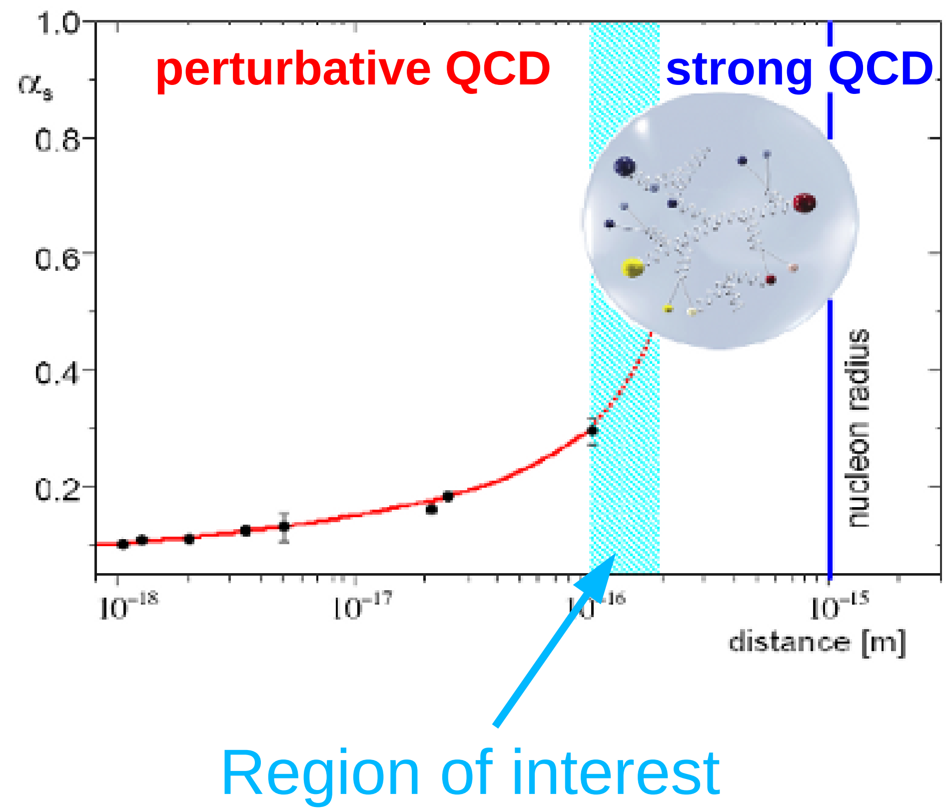
Shedding light on the hadron-mass puzzle by investigating:

- Systems with different ratio of dynamically generated mass to the Higgs mass:
  - Charmonium states ($M_{Higgs} >> M_{dynamic}$)
  - Glueballs ($M_{Higgs} = 0$)
  - strange hadrons (m_s ~ energy scale at which quarks are confined into hadrons)
- Distribution and motion of quarks in the nucleon.

Strong-interaction coupling constant



Quantum ChromoDynamics (QCD)

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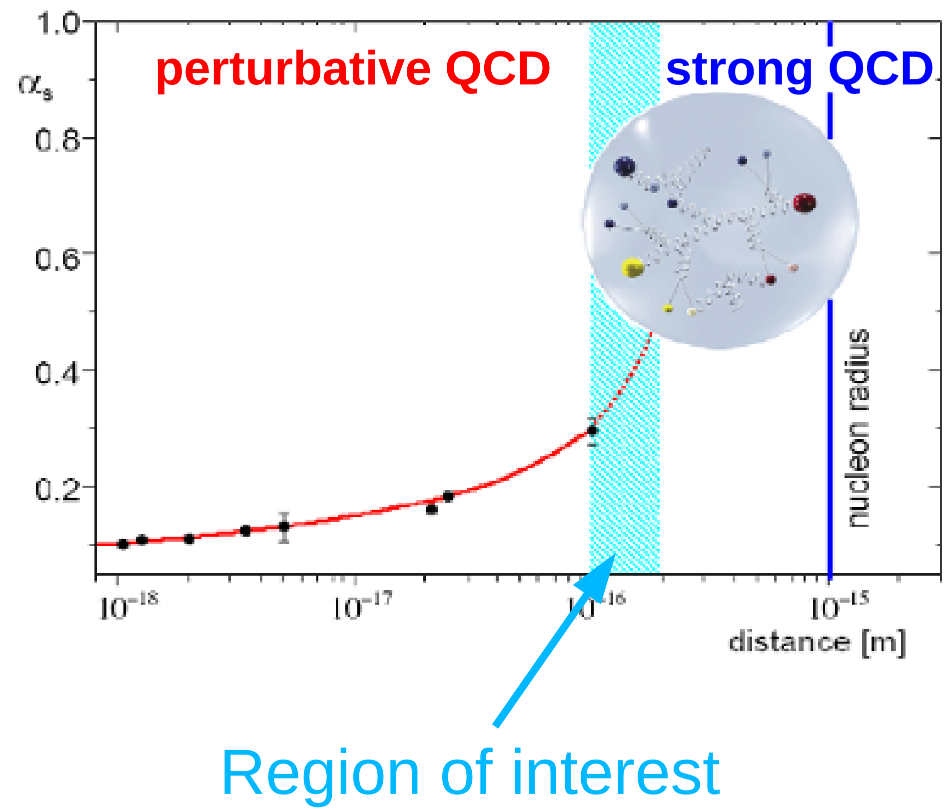

Antiprotons – the most versatile probe...

AntiProton Annihilation at DArmstadt (PANDA)

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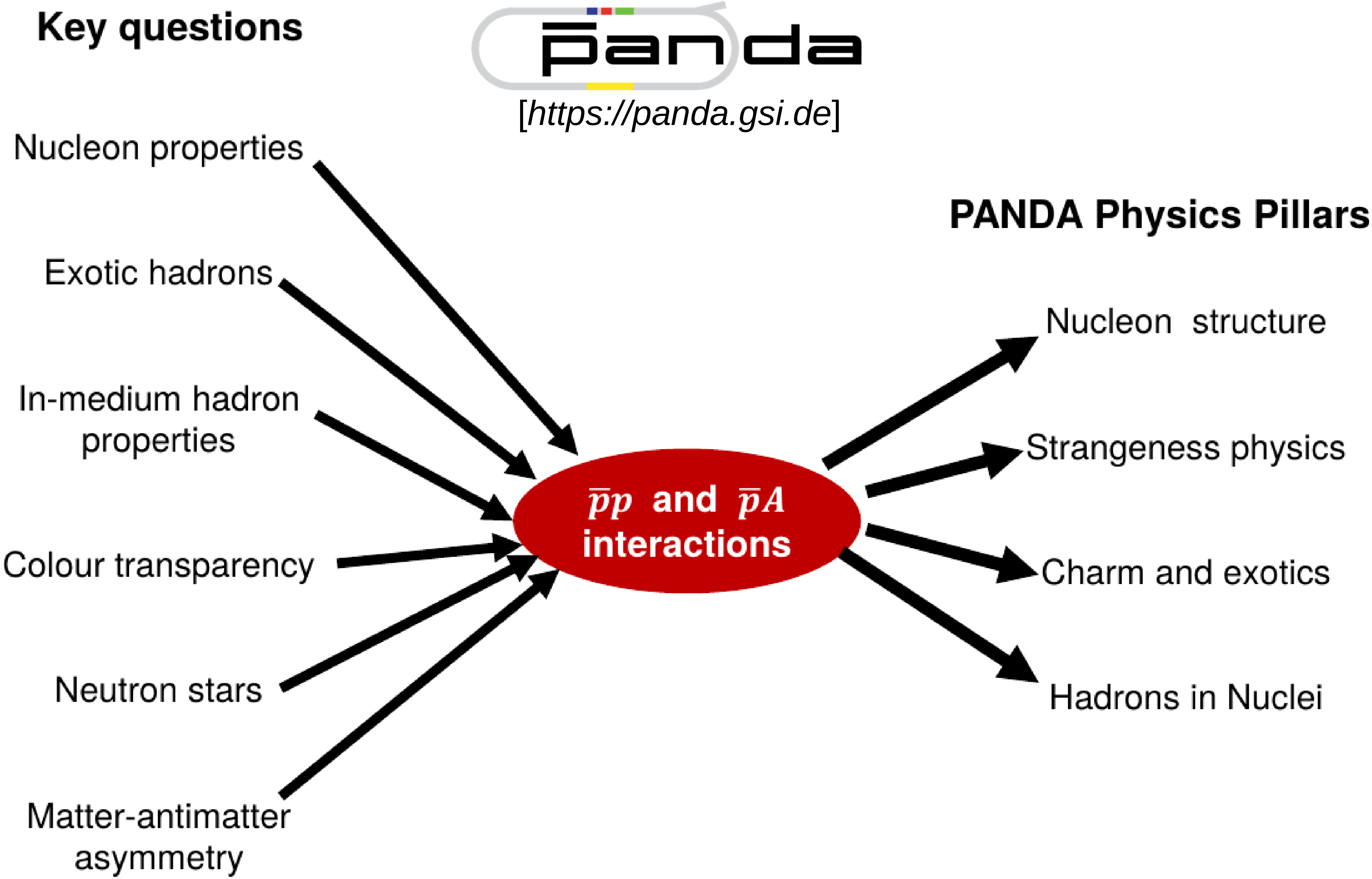
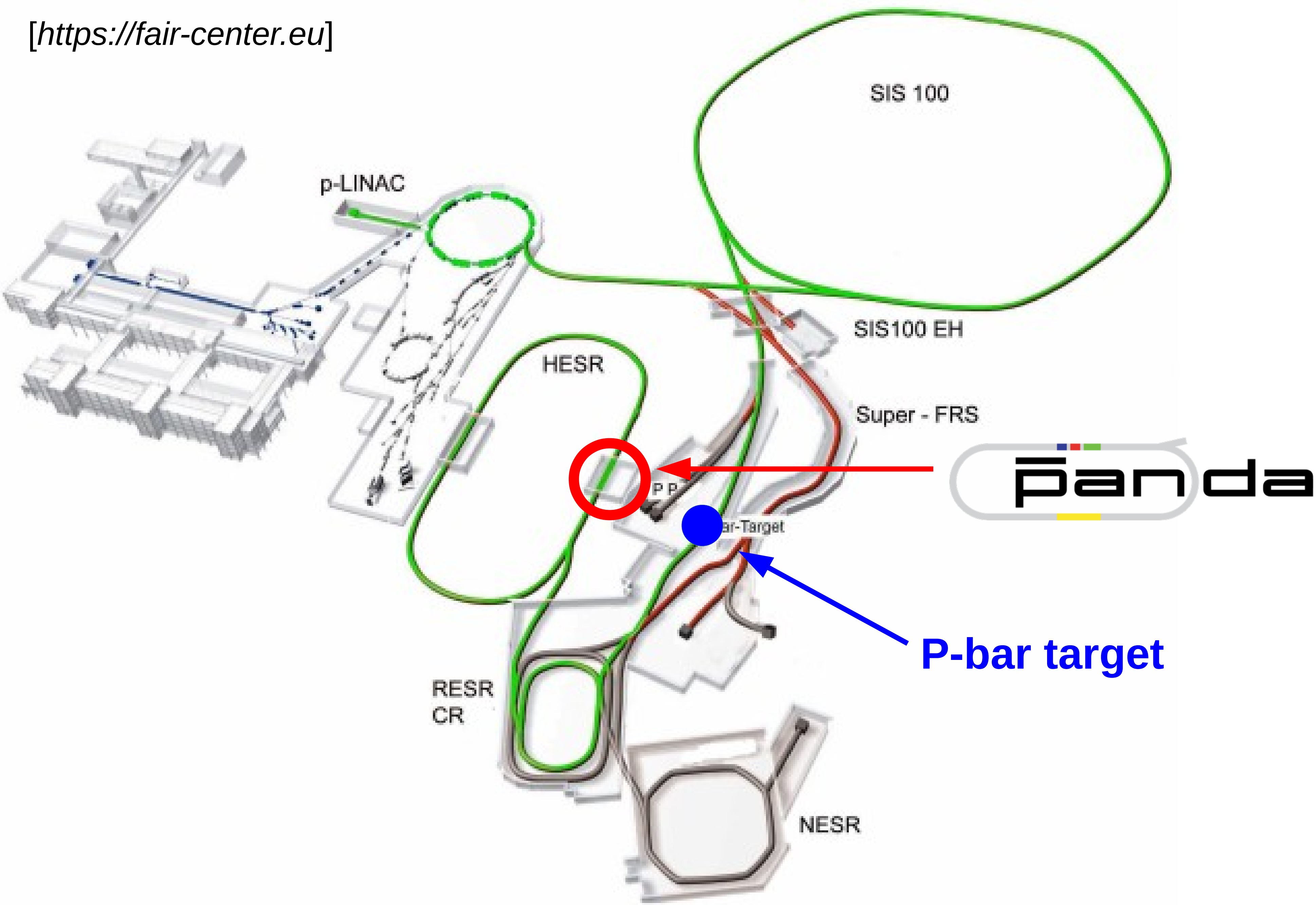


[*Karin Schoenning*]

PANDA at FAIR

[*https://fair-center.eu*]



Precision antiprotons: High Energy Storage Ring (HESR)

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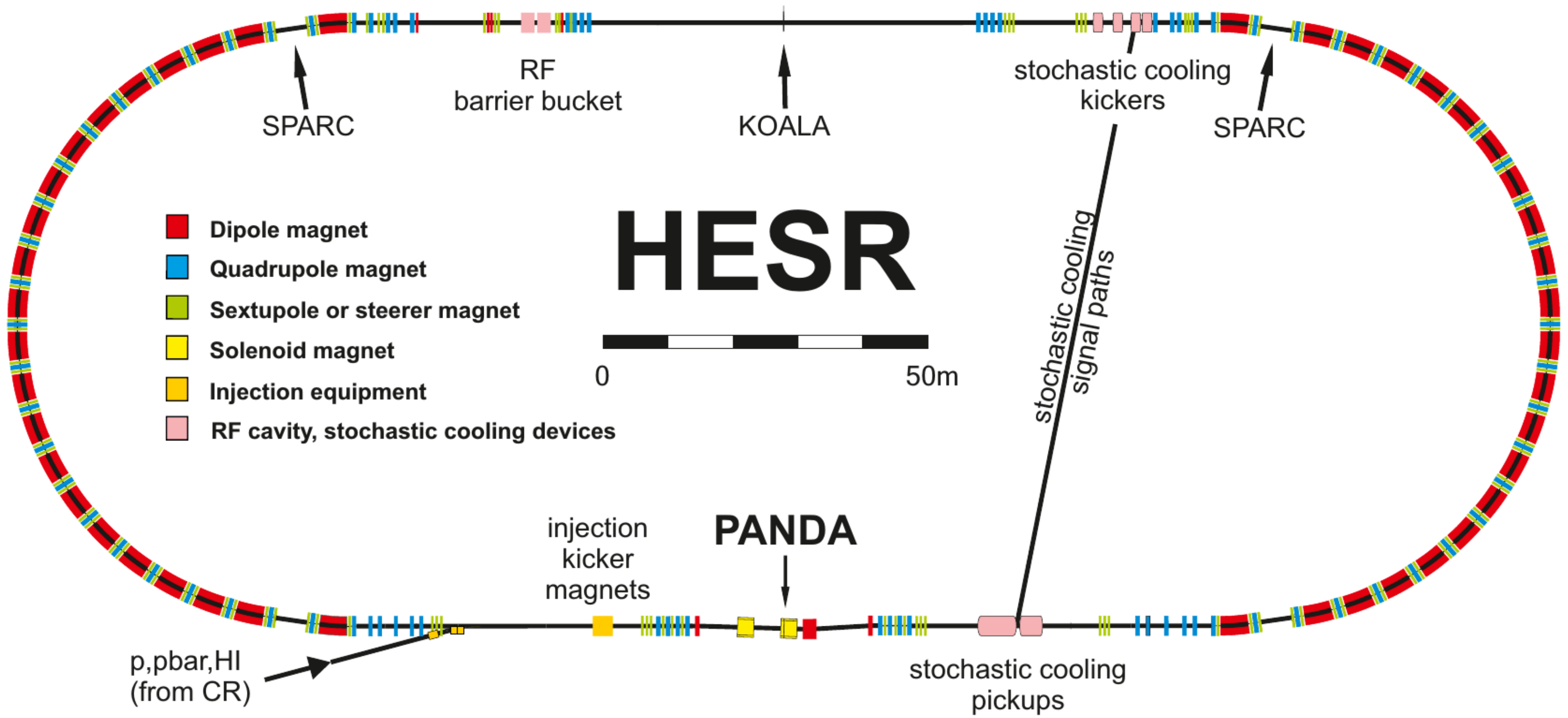


High resolution mode:

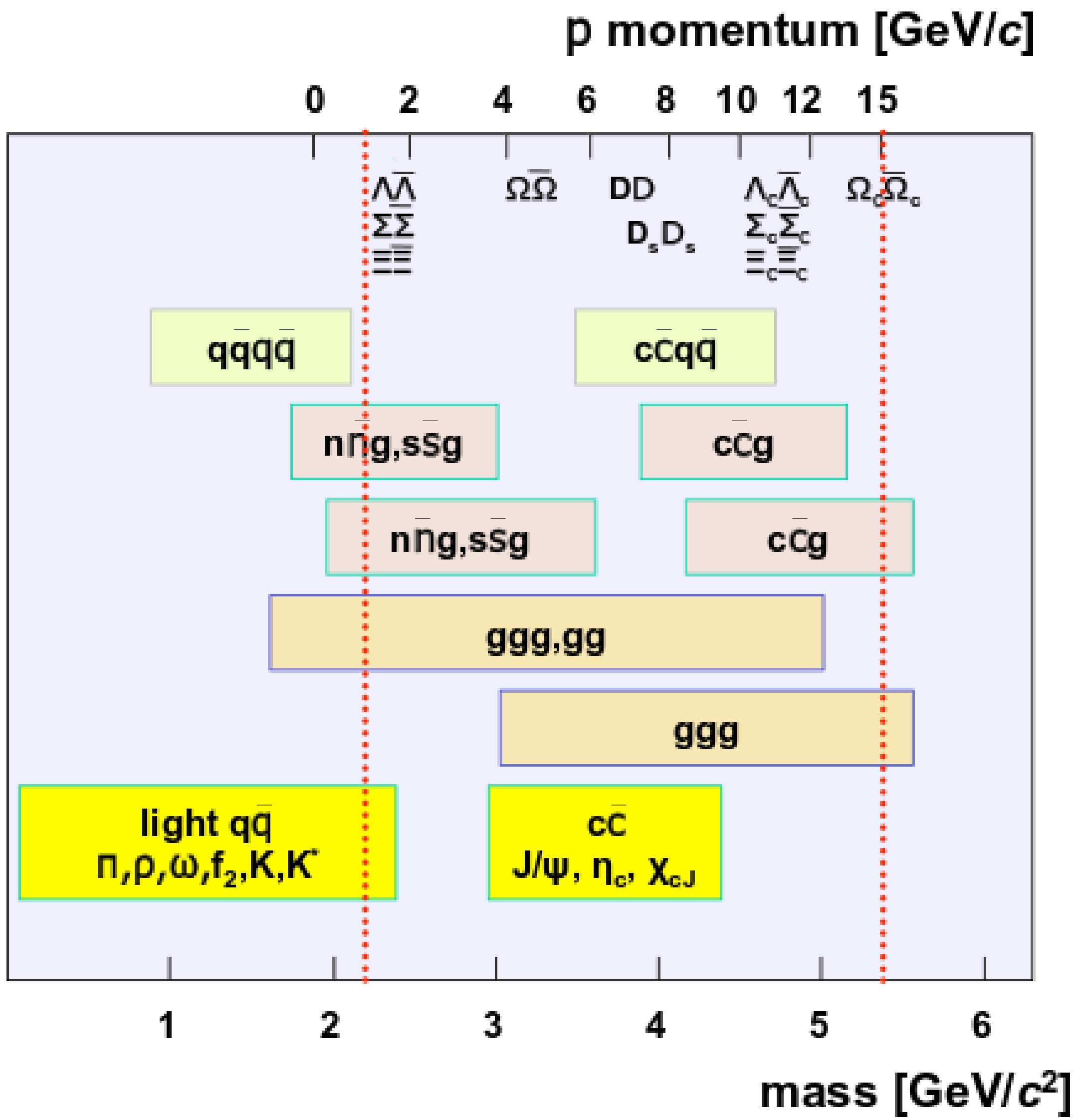
- e^- cooling: p<8.9 GeV/c
- 10^{10} antiprotons stored
- Luminosity up to 2×10^{31} cm^{-2} s^{-1}
- dp/p = 4×10^{-5}

High intensity mode:

- Stochastic cooling: p<15 GeV/c
- 10^{11} antiprotons stored (10^{10} phase 1+2)
- Luminosity up to 2×10^{32} cm^{-2} s^{-1}
- dp/p = 2×10^{-4}

Dedicated talk by Mustafa Schmidt on Monday

Antiprotons – a versatile probe!



Larger mass coverage:

- From light, strange, to charmed hadrons, mesons
- From quark/gluons hadronic degrees of freedom

High hadronic production rates:

- charm+strange baryons production
  → discovery by statistics!
- gluon-rich production
  → potential for new exotics

Direct formation of full J^{PC} spectrum allowed for $q\bar{q}$ systems

Challenge for PANDA

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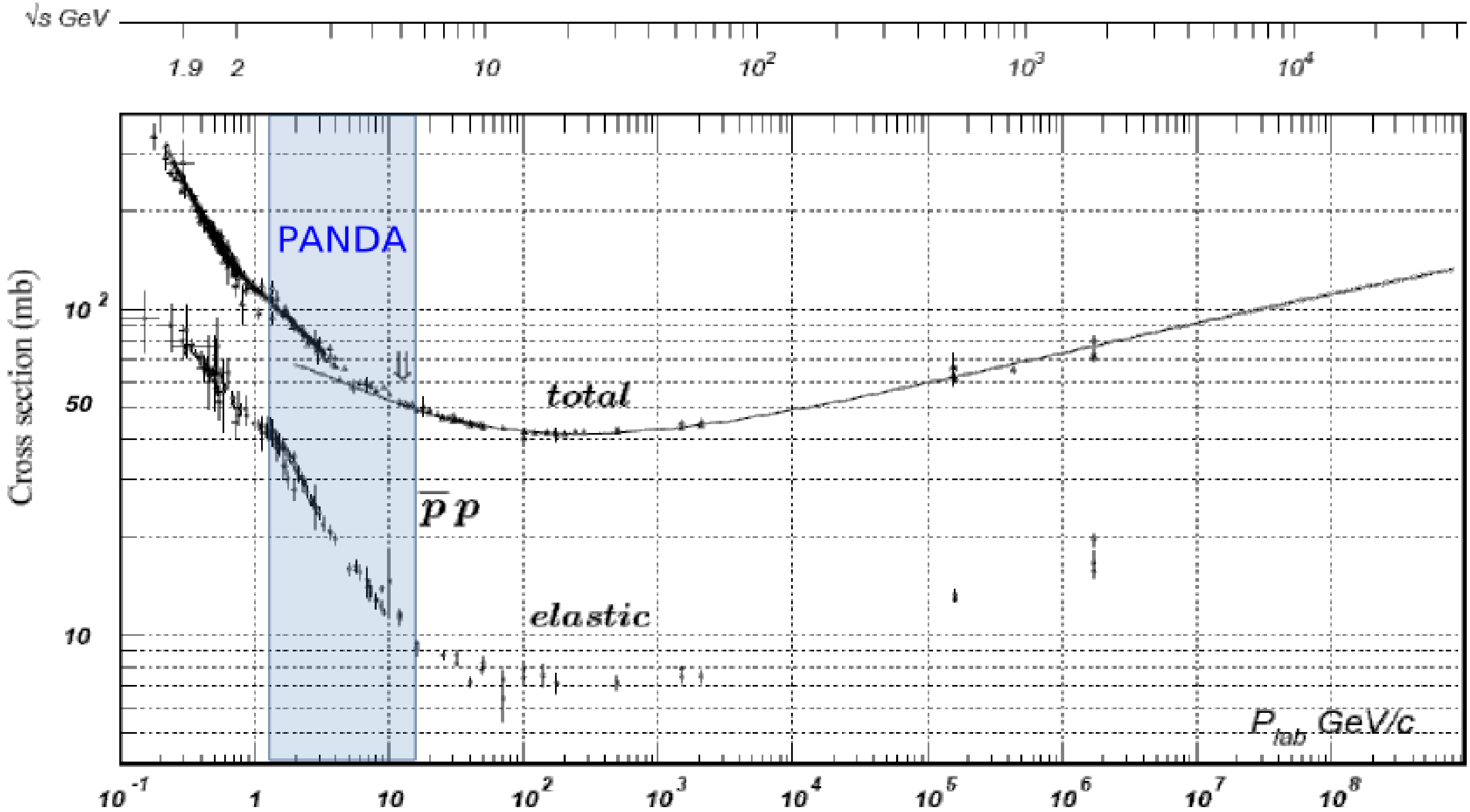
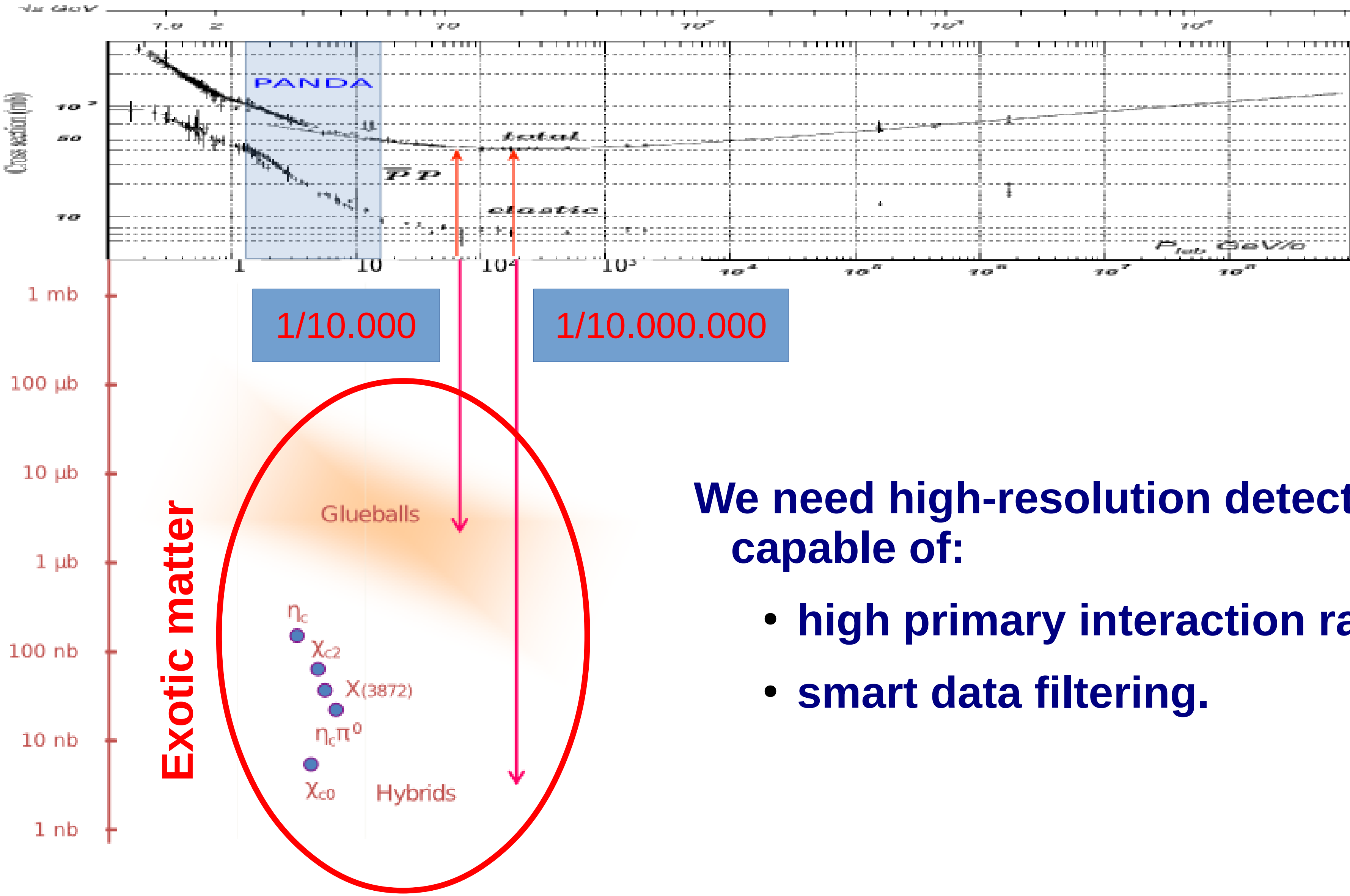
Cross section for proton-antiproton collisions



Challenge for PANDA

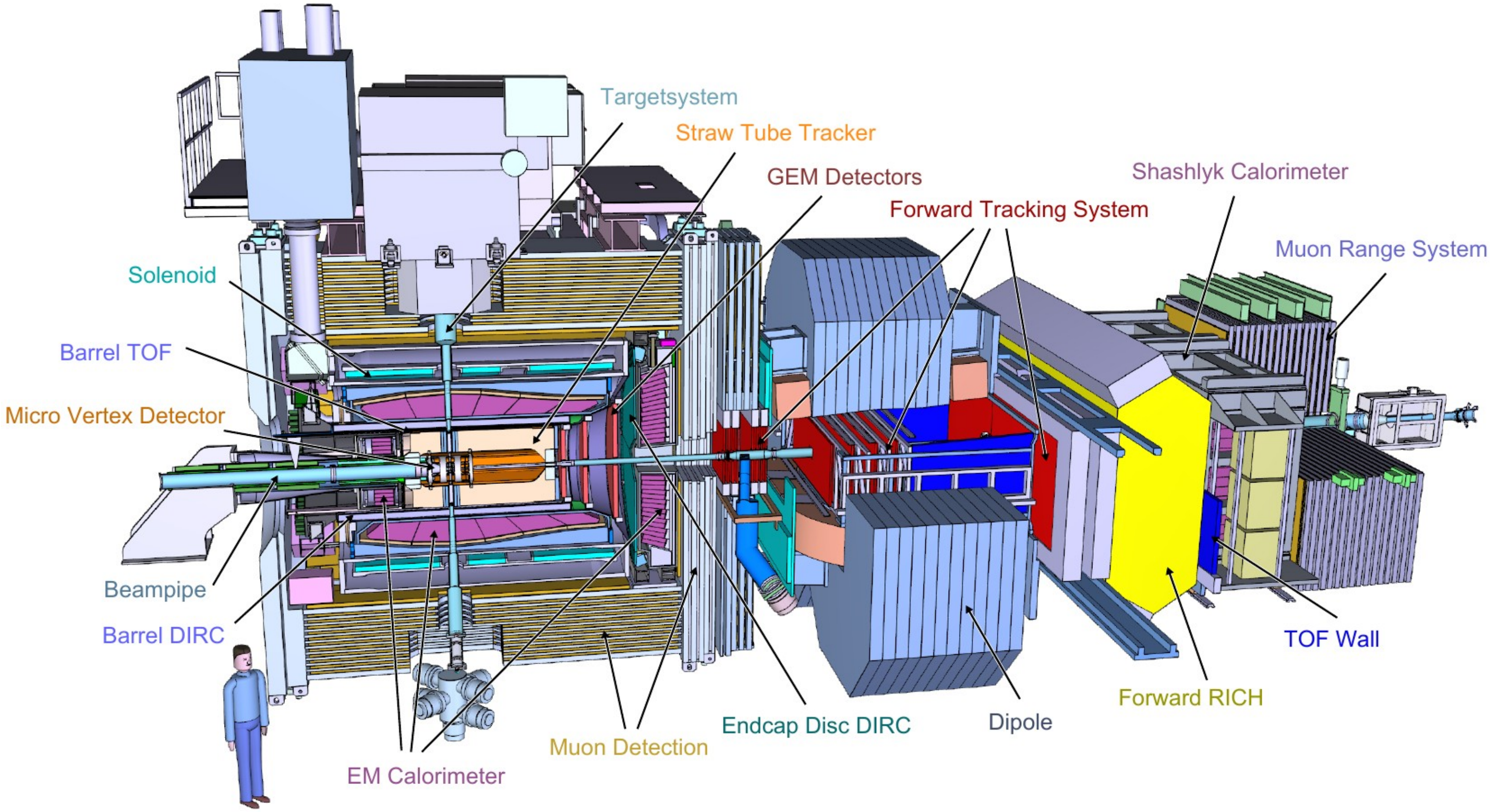
Cross section for proton-antiproton collisions



We need high-resolution detector capable of:

- **high primary interaction rate;**
- **smart data filtering.**

The PANDA detector



- 4π acceptance
- high rate capability (average interaction rate 20 MHz)
- excellent tracking capabilities, momentum resolution 1%
- Vertex reconstruction for D, K_s, hyperons

- good PID (e, μ, π, K, p)
  → Čerenkov, ToF, dE/dx
- γ detection 10 MeV- 15 GeV
  → PWO crystal calorimeter
- no hardware trigger, intelligent on-line event selection

Dedicated talk by Mustafa Schmidt on Monday

PANDA physics

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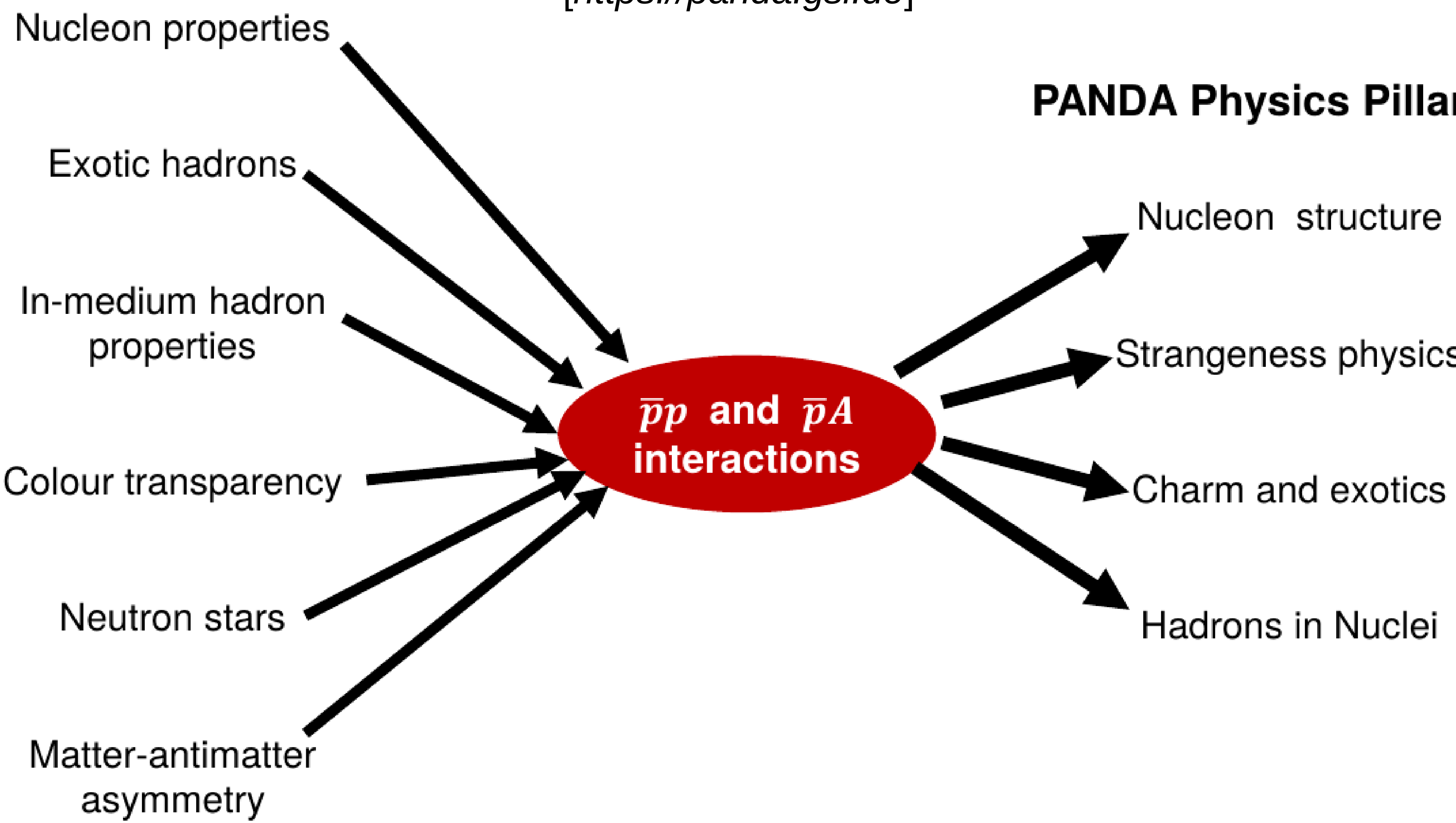
Key questions

PANDA Physics Pillars



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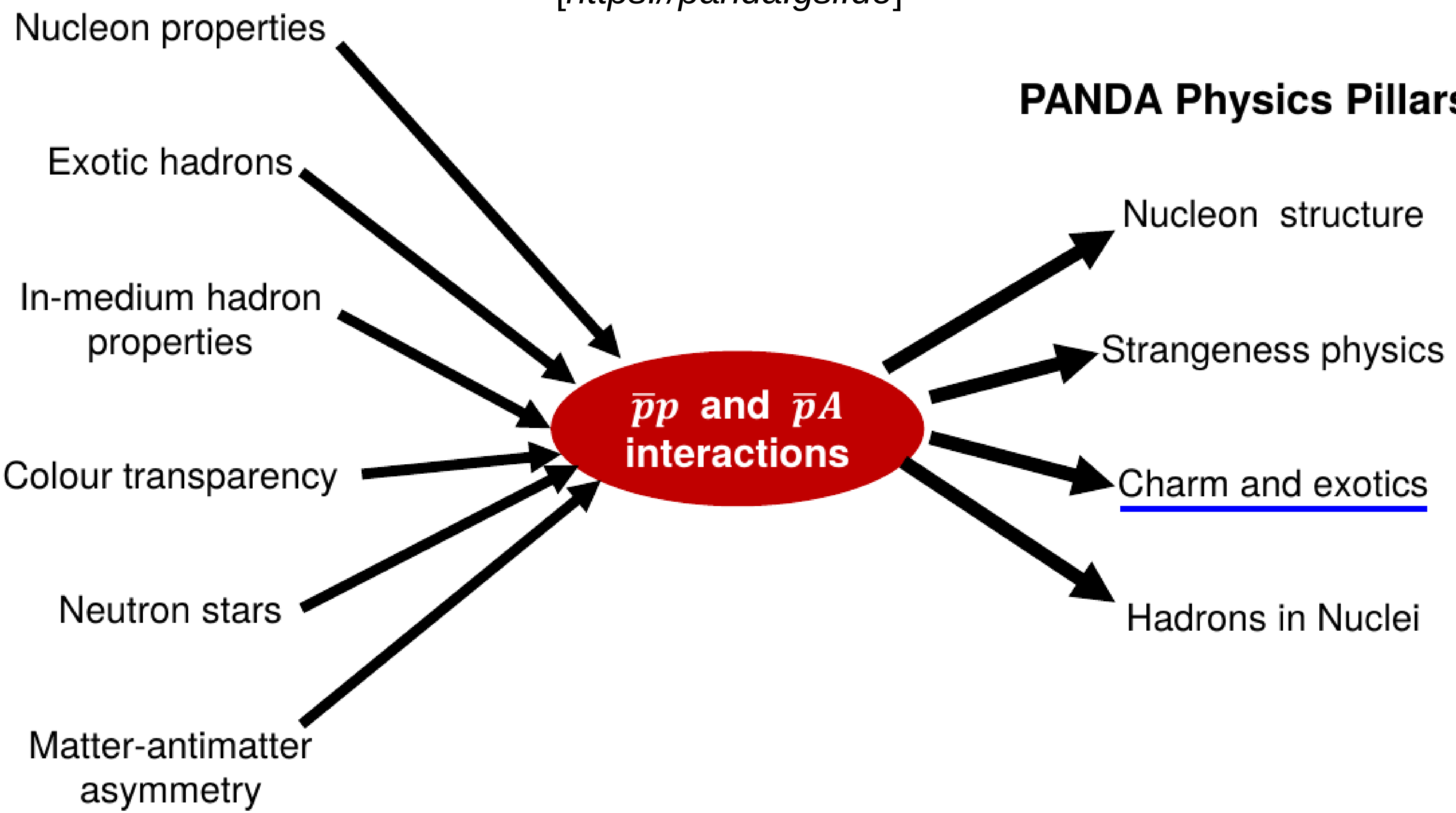
Key questions

PANDA Physics Pillars



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Charmonium

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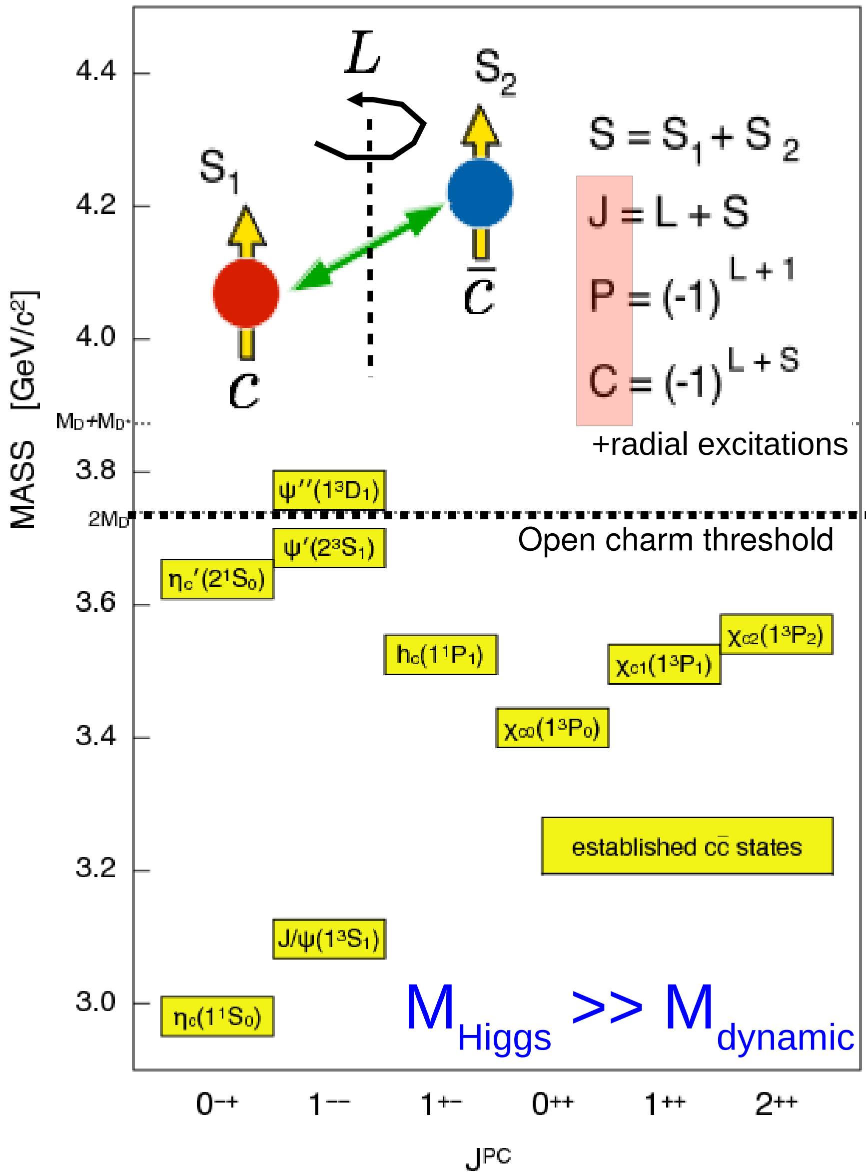

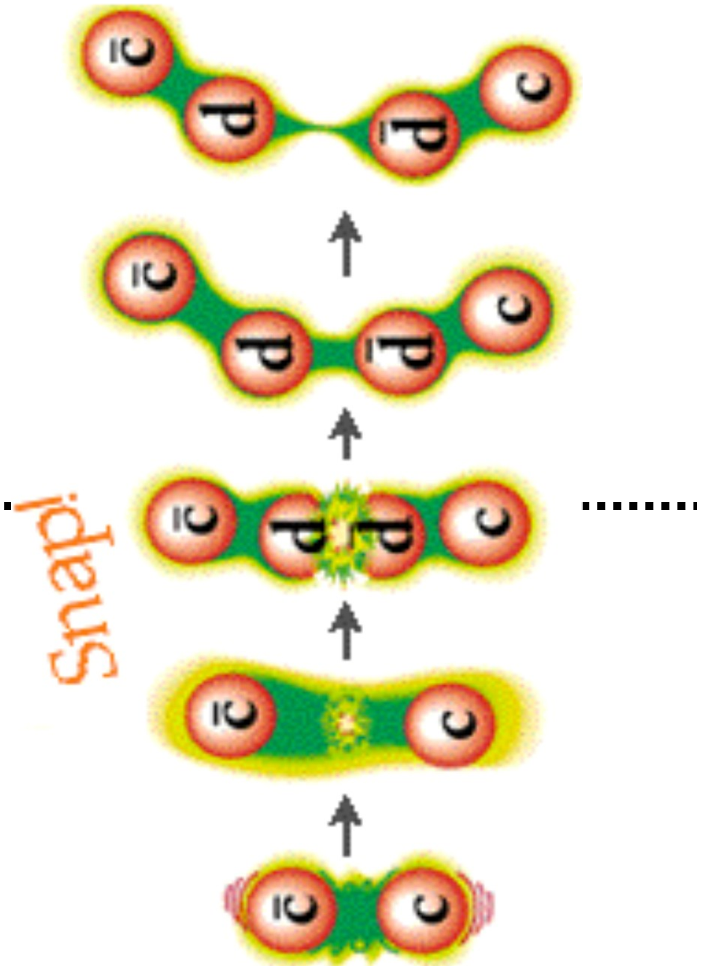

<u>Precise</u> data on the key states and <u>transitions</u> → Insight into the strong interactions at long-distance scales

Exotic matter

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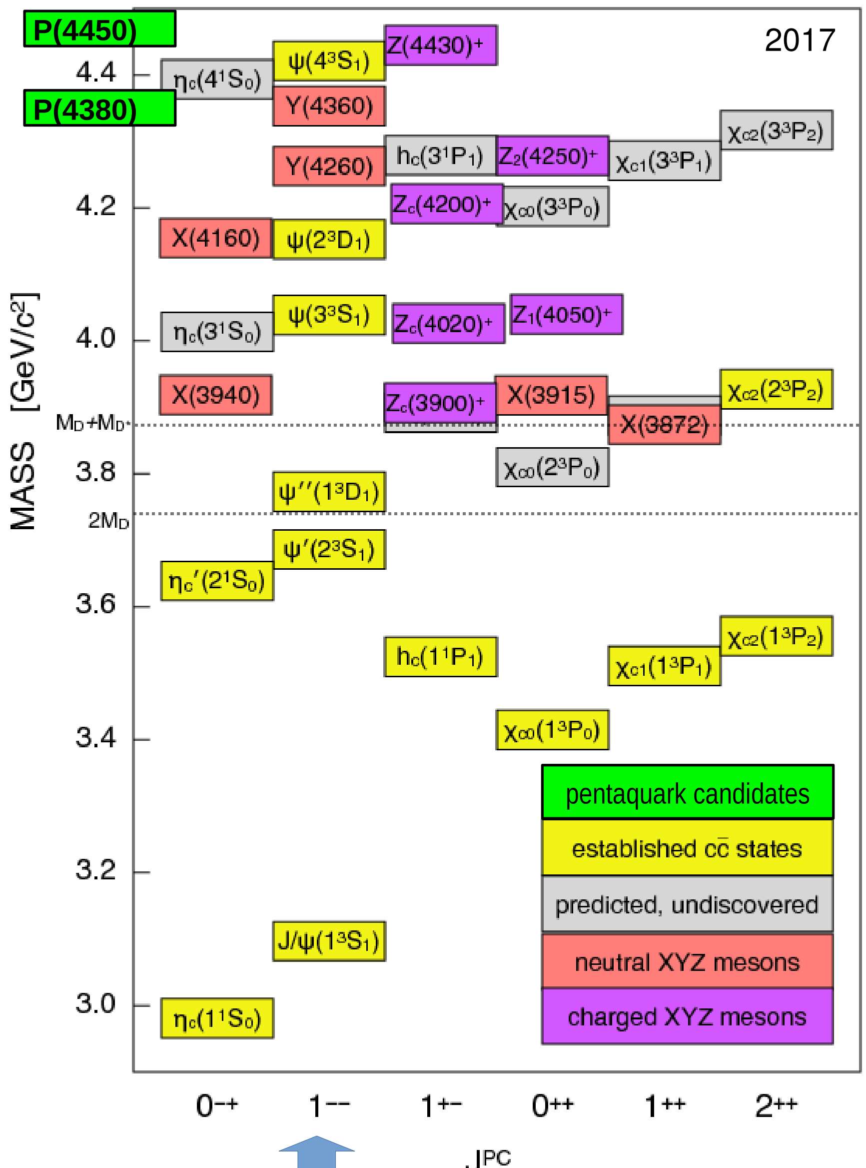
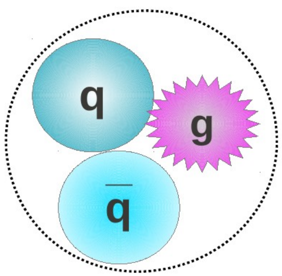


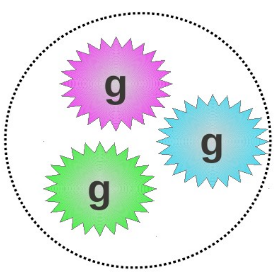
States can be directly populated in annihilation e^+e^-

Lattice QCD predicts exotic matter (hybrids, glueballs) which have spin-symmetries forbidden for mesons

Can be unambiguously identified
(no mixing with conventional states)



Hybrid



Glueball

$M_{Higgs} = 0$

Exotic matter

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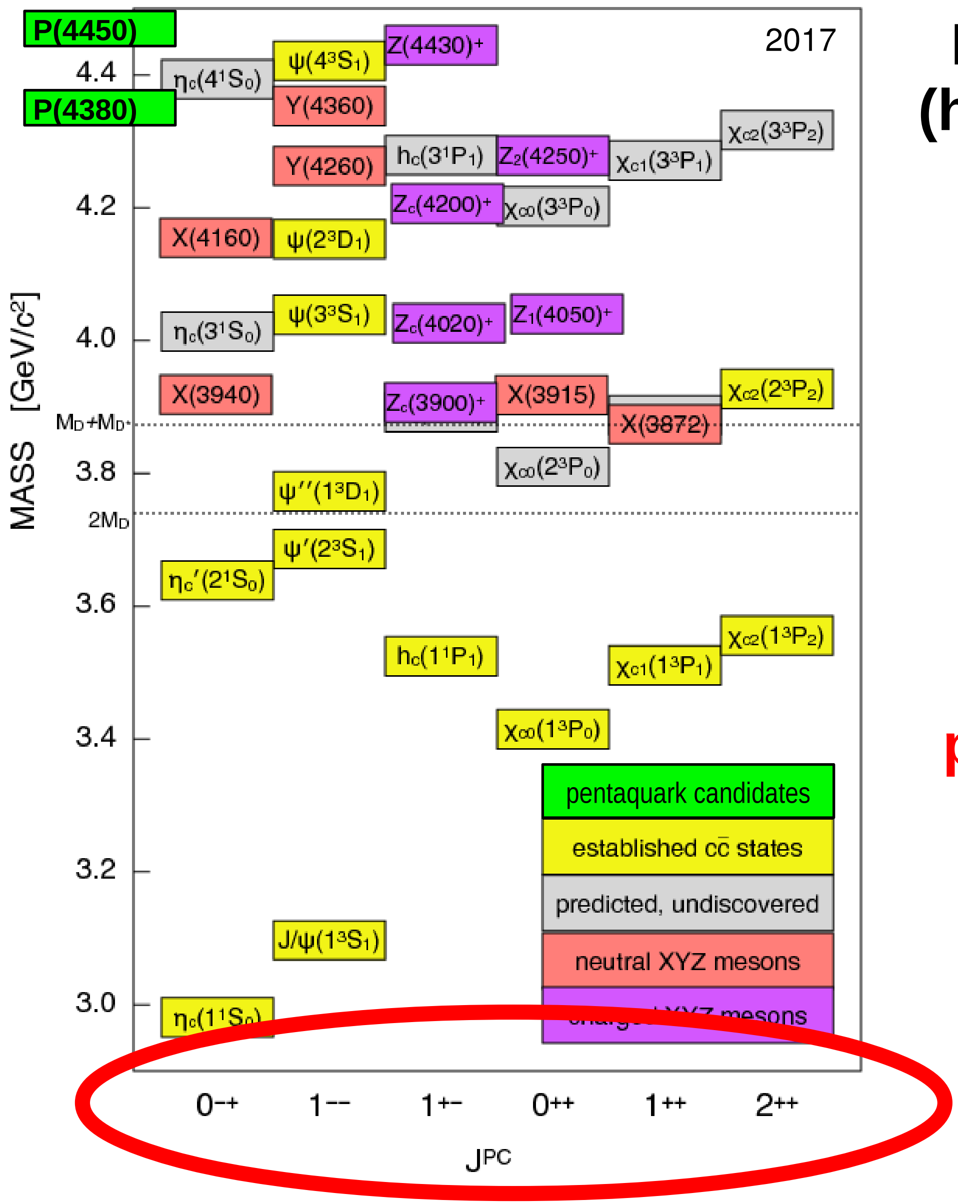


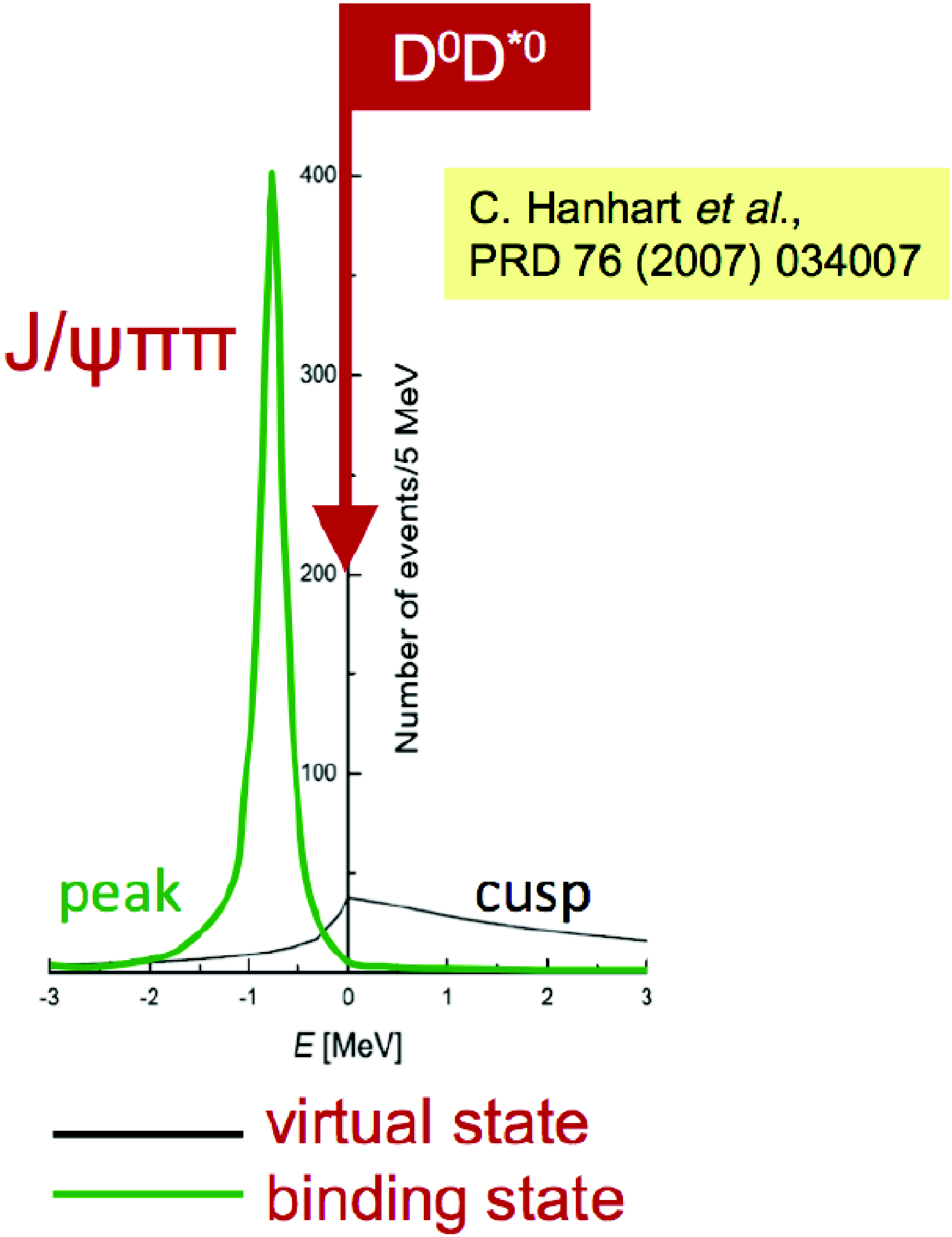
Lattice QCD predicts exotic matter (hybrids, glueballs) which have spin-symmetries forbidden for mesons

Can be unambiguously identified
(no mixing with conventional states)

In proton-antiproton annihilation all possible conventional and high-spin states are directly formed!

Antiprotons – a versatile probe!

Revealing Nature of X(3872)?



Theoretical line-shape:

- depends on final state …
- … and nature of particle

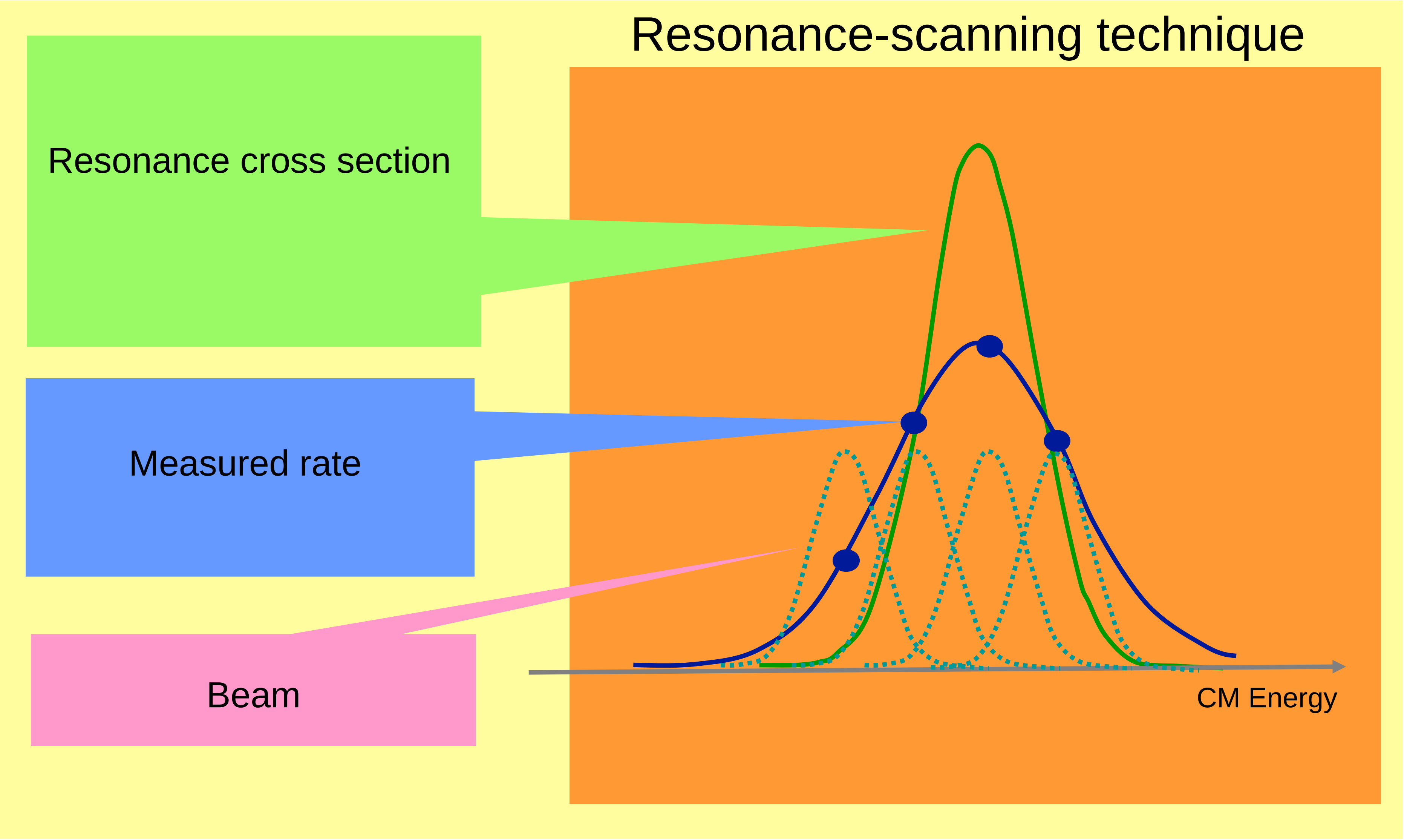
Sensitive observable!

What can be achieved with PANDA?

Line-Shape Measurement

Momentum spread of the cooled antiproton beams: $< 4 \cdot 10^{-5}$

Line shape measurement with CM energy resolution down to 50 keV



Line-Shape scan of X(3872)

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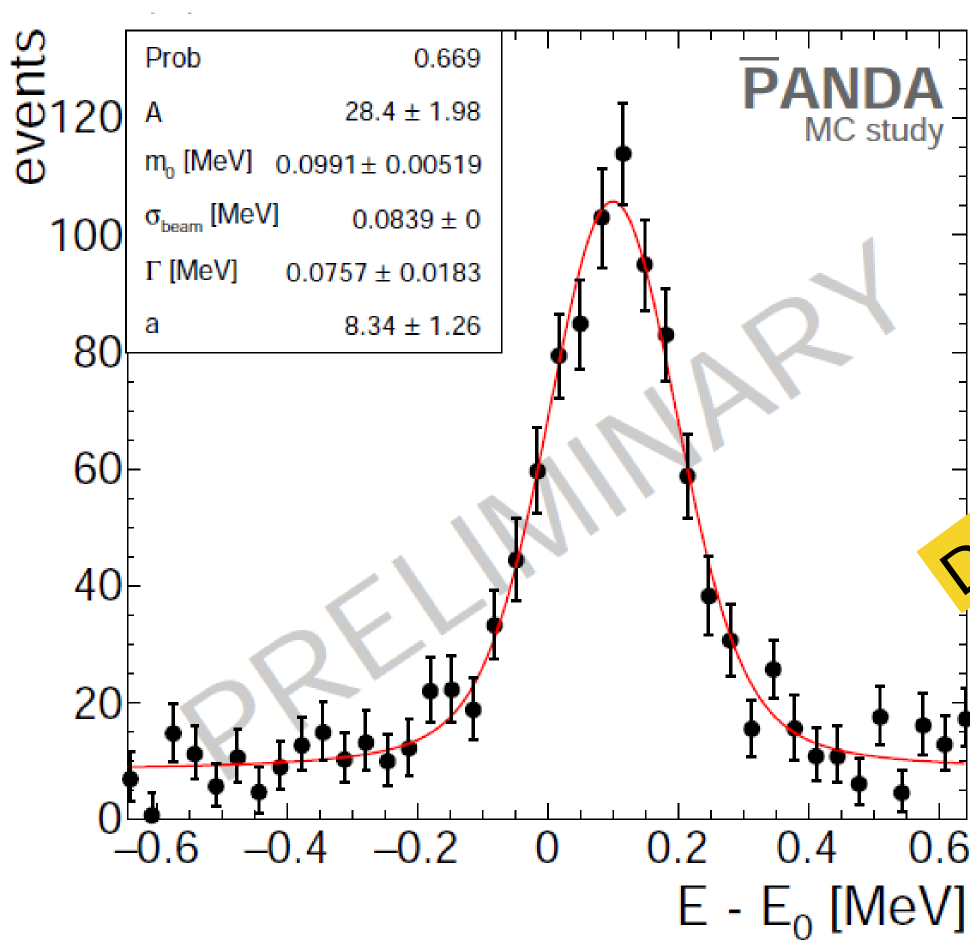
$$\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^-$$

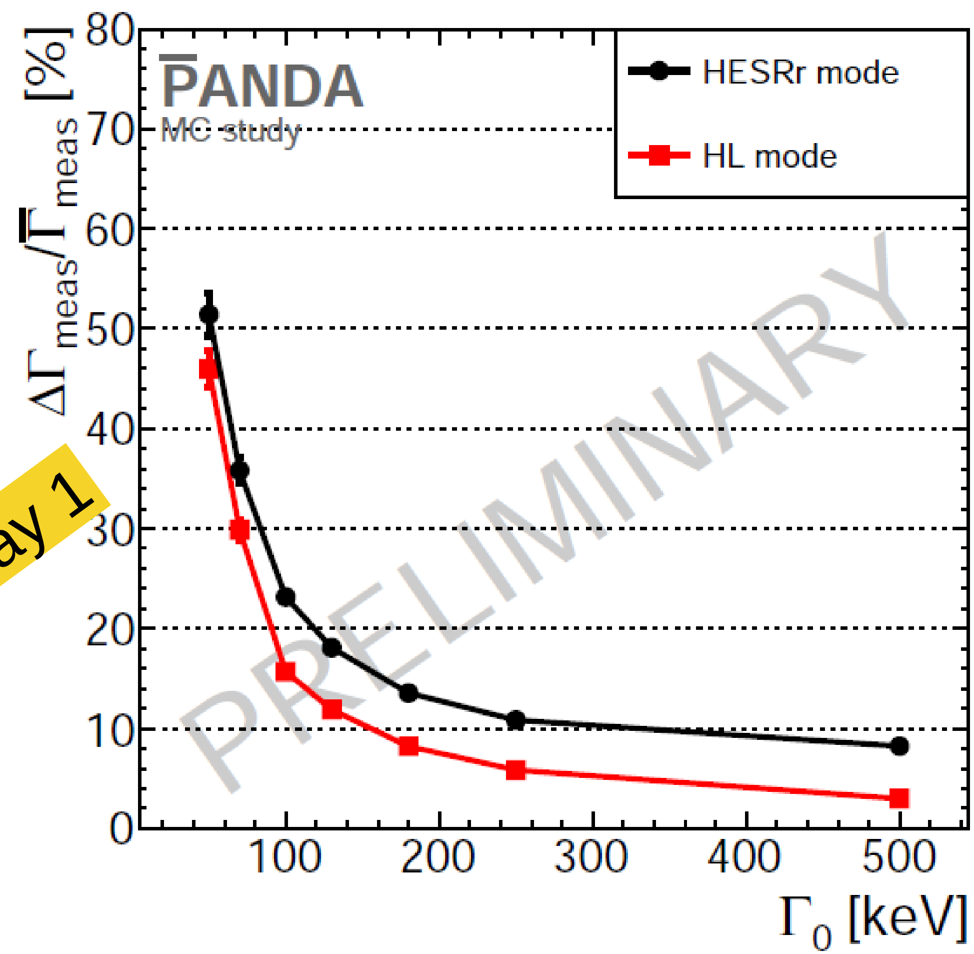
PANDA will be able to provide crucial information on X(3872)!

MC Simulations of the X(3872) scan (assumed Γ=100 keV)



Day 1

Achievable resolution of Γ for different assumed width of X



Klaus Goetzen et al.

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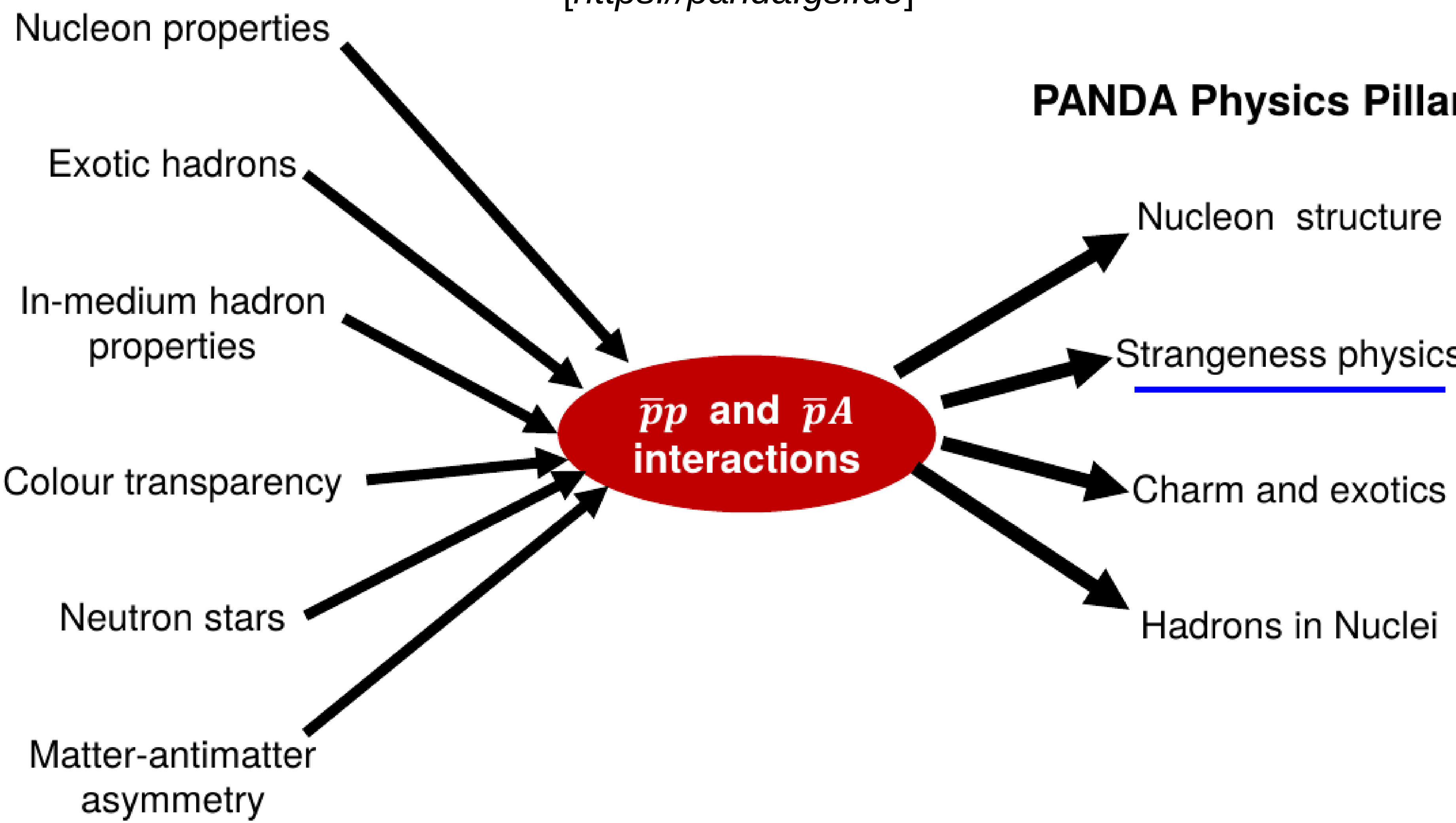
PANDA physics

Key questions

[*https://panda.gsi.de*]

PANDA Physics Pillars



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Strangeness as diagnostic tool

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- Hyperons – a new access to the nucleon puzzle (strange quark light enough to be able to relate knowledge on hyperon to nucleon); which degrees of freedom are relevant?

Strangeness as diagnostic tool

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- Hyperons – a new access to the nucleon puzzle (strange quark light enough to be able to relate knowledge on hyperon to nucleon); **which degrees of freedom are relevant?**

There are multiple attempts to describe $p\bar{p} \rightarrow Y\bar{Y}$ process in:

- quark-gluon picture,
- hadronic meson-exchange picture,
- or both?..

Which picture represents nature the best?

Strangeness as diagnostic tool

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- Hyperons – a new access to the nucleon puzzle (strange quark light enough to be able to relate knowledge on hyperon to nucleon); which degrees of freedom are relevant?

Missing resonances:
What do we know about excited states of multistrange baryons?

Ξ should have as many excited states as N* and Δ together!

			Decuplet members			
$3/2^+$	$(56,0_0^+)$	$3/2$	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
$3/2^+$	$(56,0_2^+)$	$3/2$	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$
$1/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$
$3/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$5/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$7/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$
$11/2^+$	$(56,4_4^+)$	$3/2$	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

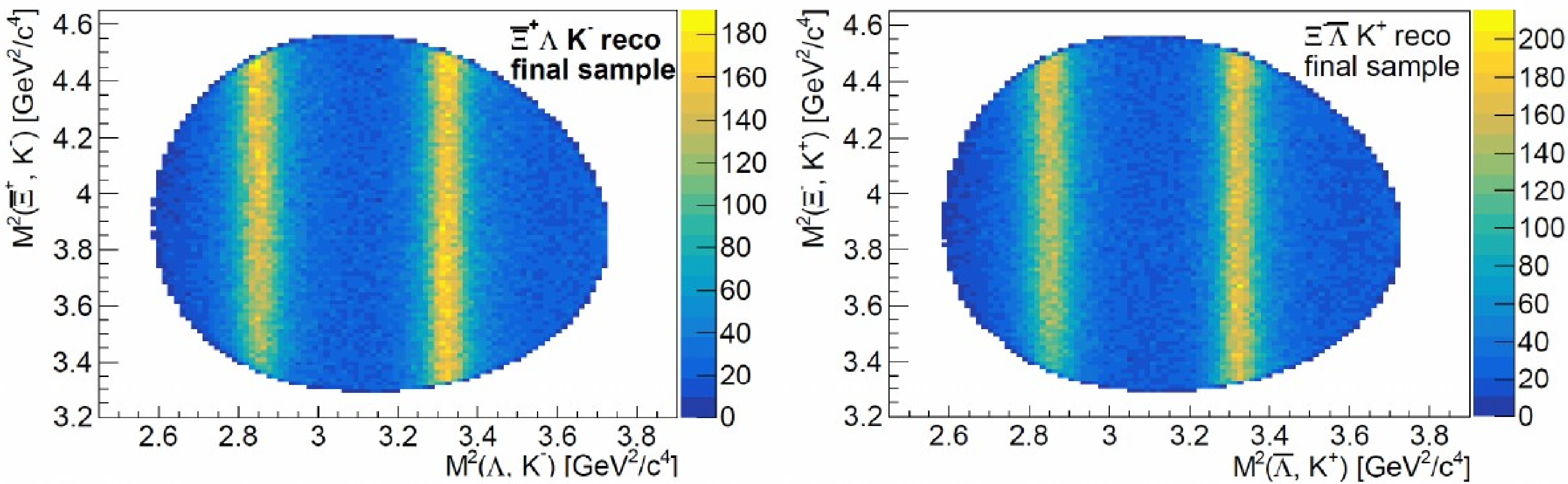
J^P	$(D, L_N^P)\,S$		Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	$1/2$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	$1/2$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1_1^-)$	$1/2$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$ $\Sigma(1560)^\dagger$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	$1/2$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	$3/2$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$ $\Sigma(1620)^\dagger$	$\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	$3/2$	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	$3/2$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0_2^+)$	$1/2$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2_2^+)$	$1/2$	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	$1/2$	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	$1/2$	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	$3/2$	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	$1/2$	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	

Strangeness as diagnostic tool

- Hyperons – a new access to the nucleon puzzle (strange quark light enough to be able to relate knowledge on hyperon to nucleon); which degrees of freedom are relevant?

Missing resonances:
What do we know about excited states of multistrange baryons?

MC studies for PANDA: $\overline{\Xi}^+\Lambda K^-$ and $\Xi^-\overline{\Lambda}K^+$



High discovery potential of PANDA **[Jennifer Pütz]**

Strangeness as diagnostic tool

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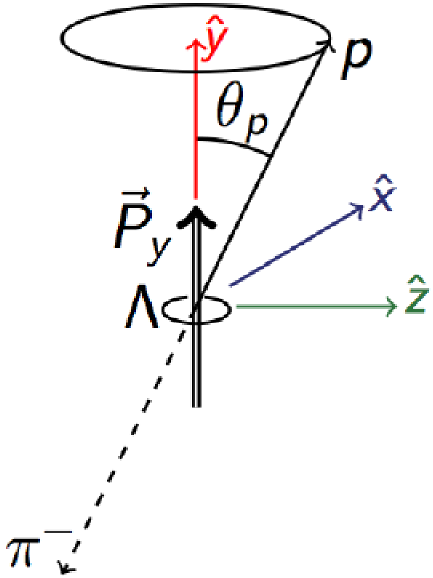
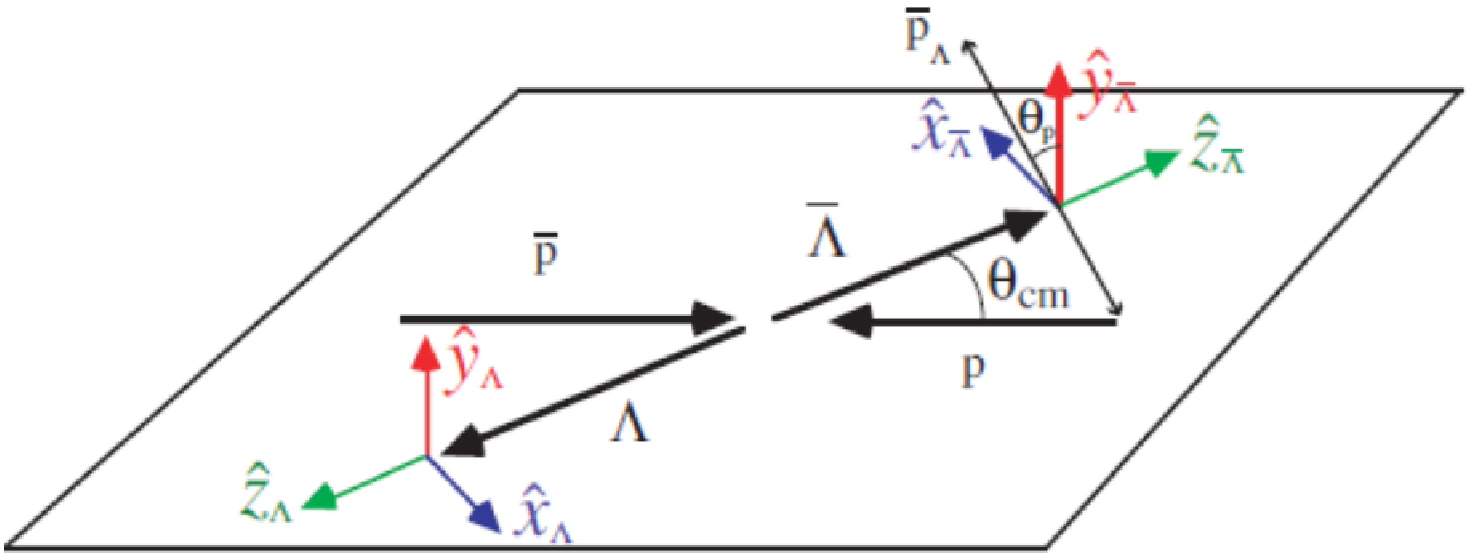
- In hyperon decays spin is easily traceable – improve the existing limits on CP violation





Strangeness as diagnostic tool

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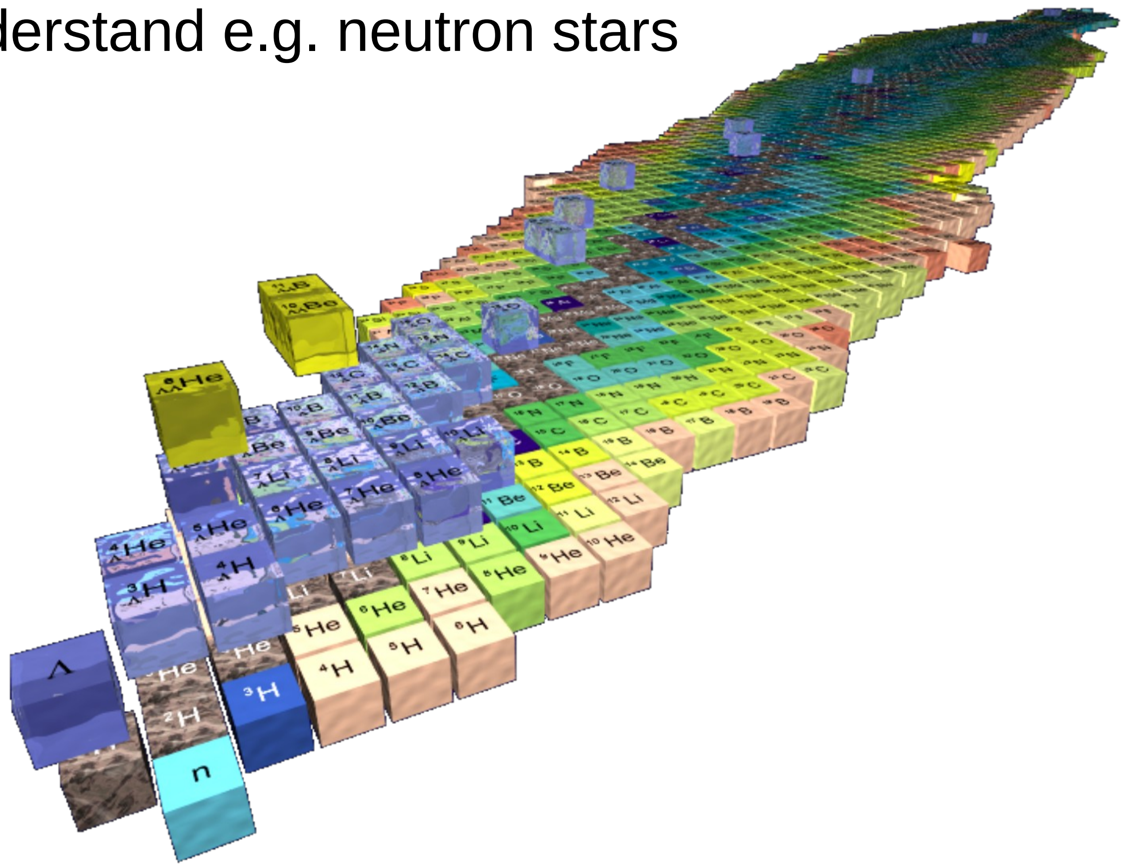
- In hyperon decays spin is easily traceable – improve the existing limits on CP violation
- Hyperon in nuclei (hypernuclei) – additional degree of freedom, crucial to understand e.g. neutron stars



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$p_{\overline{p}}$ (GeV/c)	Reaction	σ (μb)	Eff (%)	Decay	Rate at 10^{31}cm^{-2}s^{-1}
1.64	$\overline{p}p \rightarrow \Lambda\Lambda$	64	14	$\Lambda \rightarrow p\pi^-$	39 s^{-1}
4	$\overline{p}p \rightarrow \overline{\Xi}^+\Xi^-$	≈2	20	$\Xi^- \rightarrow \Lambda\pi^-$	2 s^{-1}
12	$\overline{p}p \rightarrow \overline{\Omega}^+\Omega^-$	≈0.002*	≈30	$\Omega \rightarrow \Lambda K^-$	≈4 h^{-1}
12	$\overline{p}p \rightarrow \overline{\Lambda}_c^-\Lambda_c^+$	≈0.1*	≈30	$\Lambda_c \rightarrow \Lambda\pi^+$	≈2 d^{-1}

PANDA – is a hyperon factory!

PANDA physics

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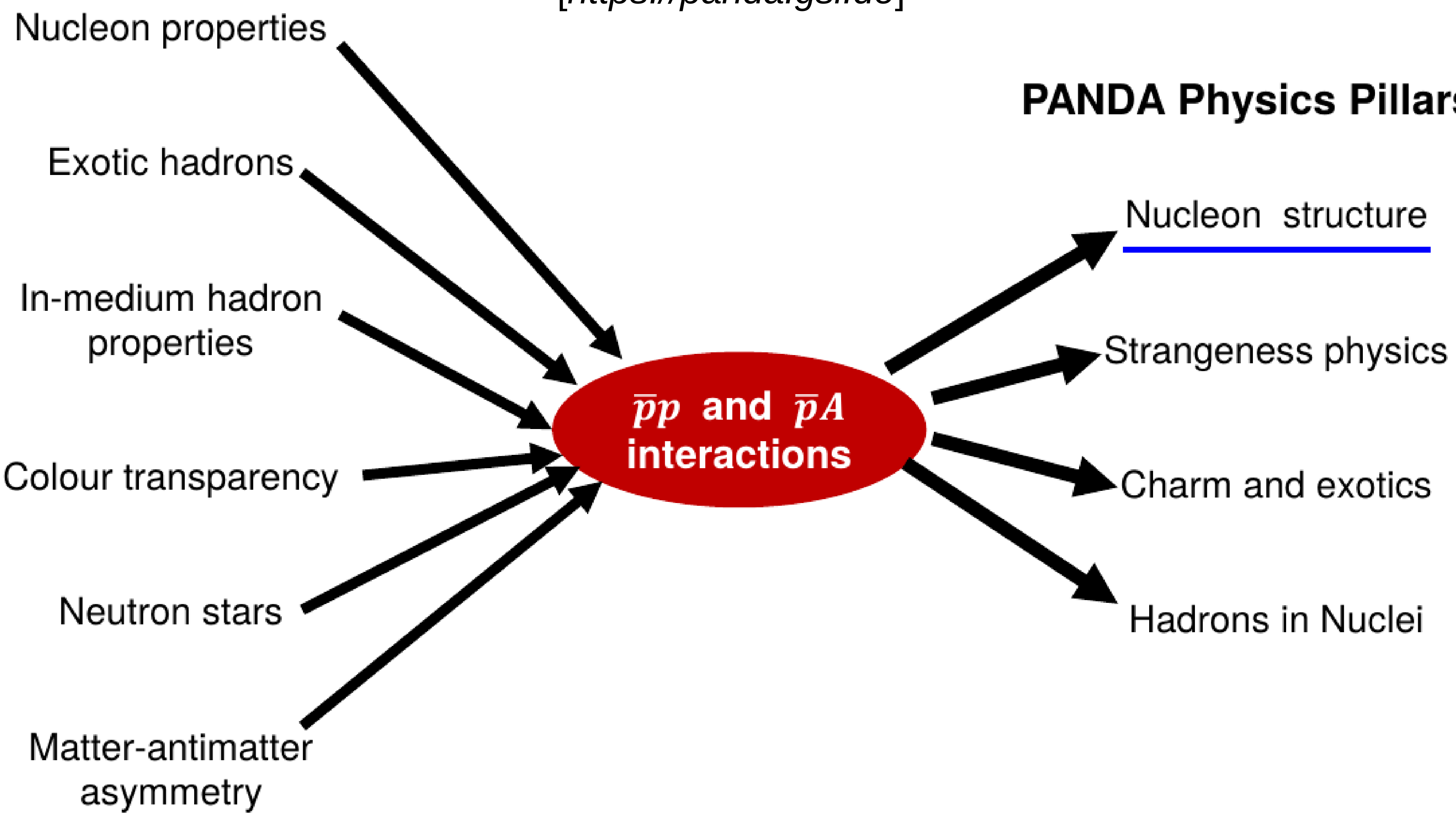
Key questions

[*https://panda.gsi.de*]

PANDA Physics Pillars



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Electromagnetic Form Factors

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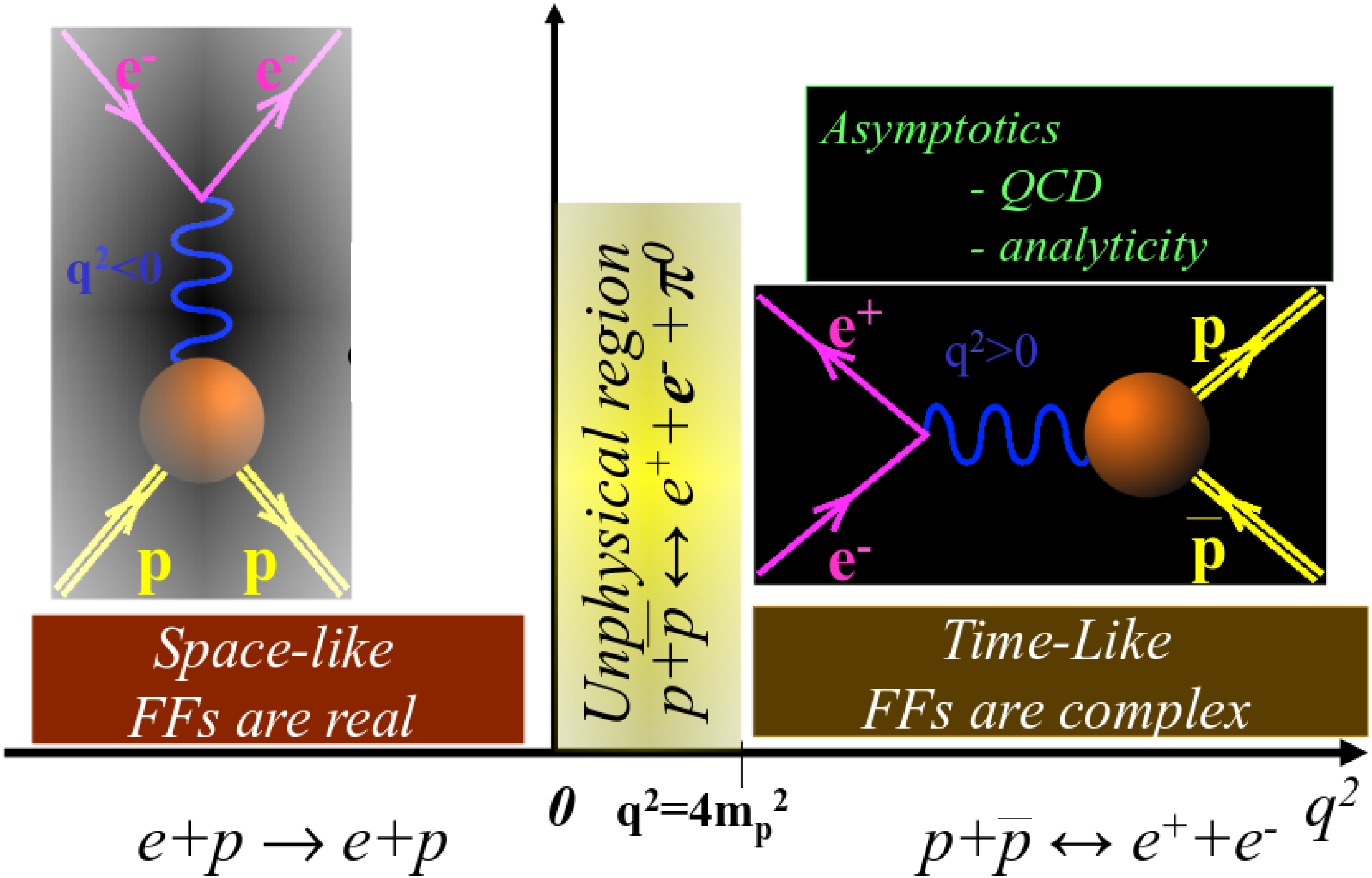

PANDA physics

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Key questions

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PANDA Physics Pillars

We are looking forward for the first results!

[*Karin Schoenning*]

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
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PNPI St. Petersburg
West Bohemian U, Pilzen
KTH Stockholm
U Stockholm
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
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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

Thank you for your attention!

Planning

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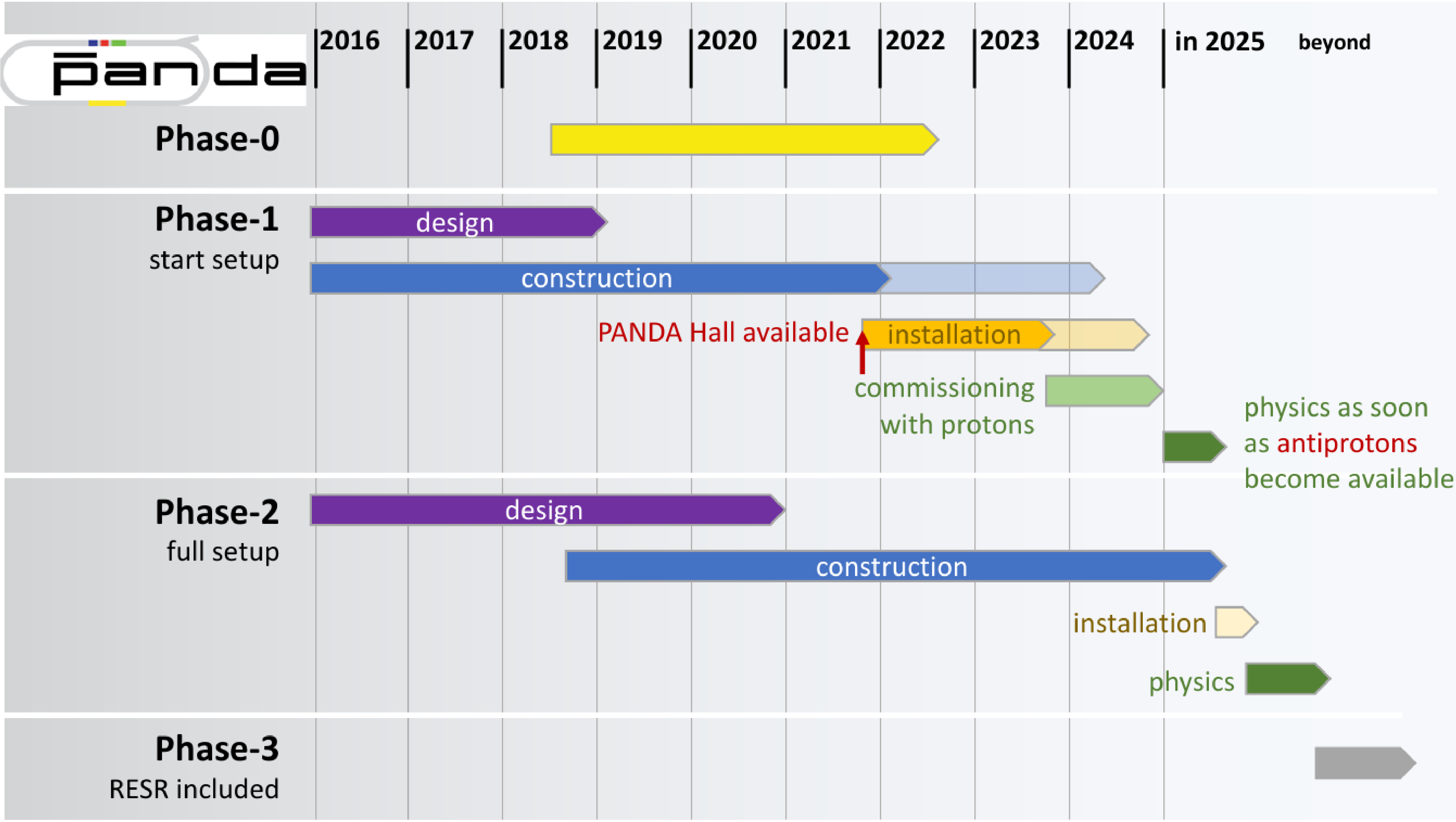

Dedicated talk by Mustafa Schmidt on Monday

PANDA phases

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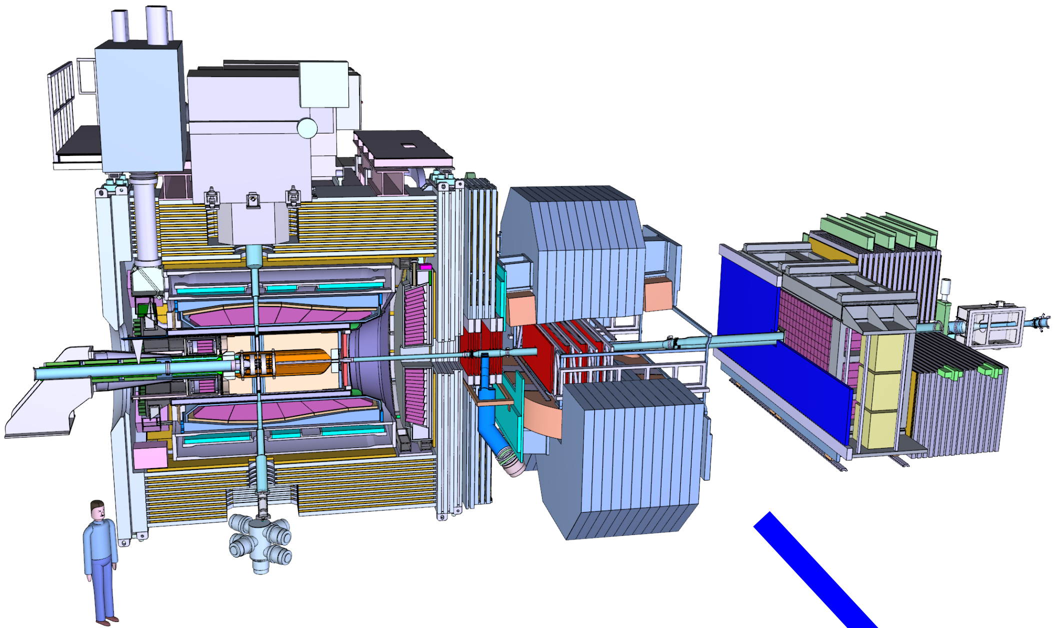
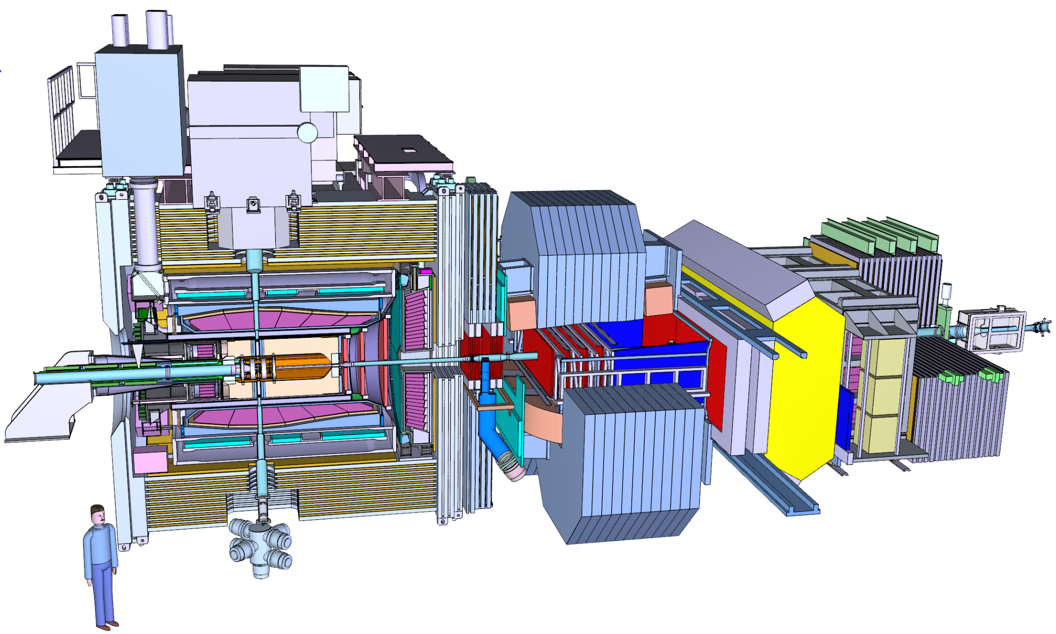


PANDA start set-up
(phase 1, reduced luminosity)

PANDA full set-up
(phase 2, full luminosity)



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