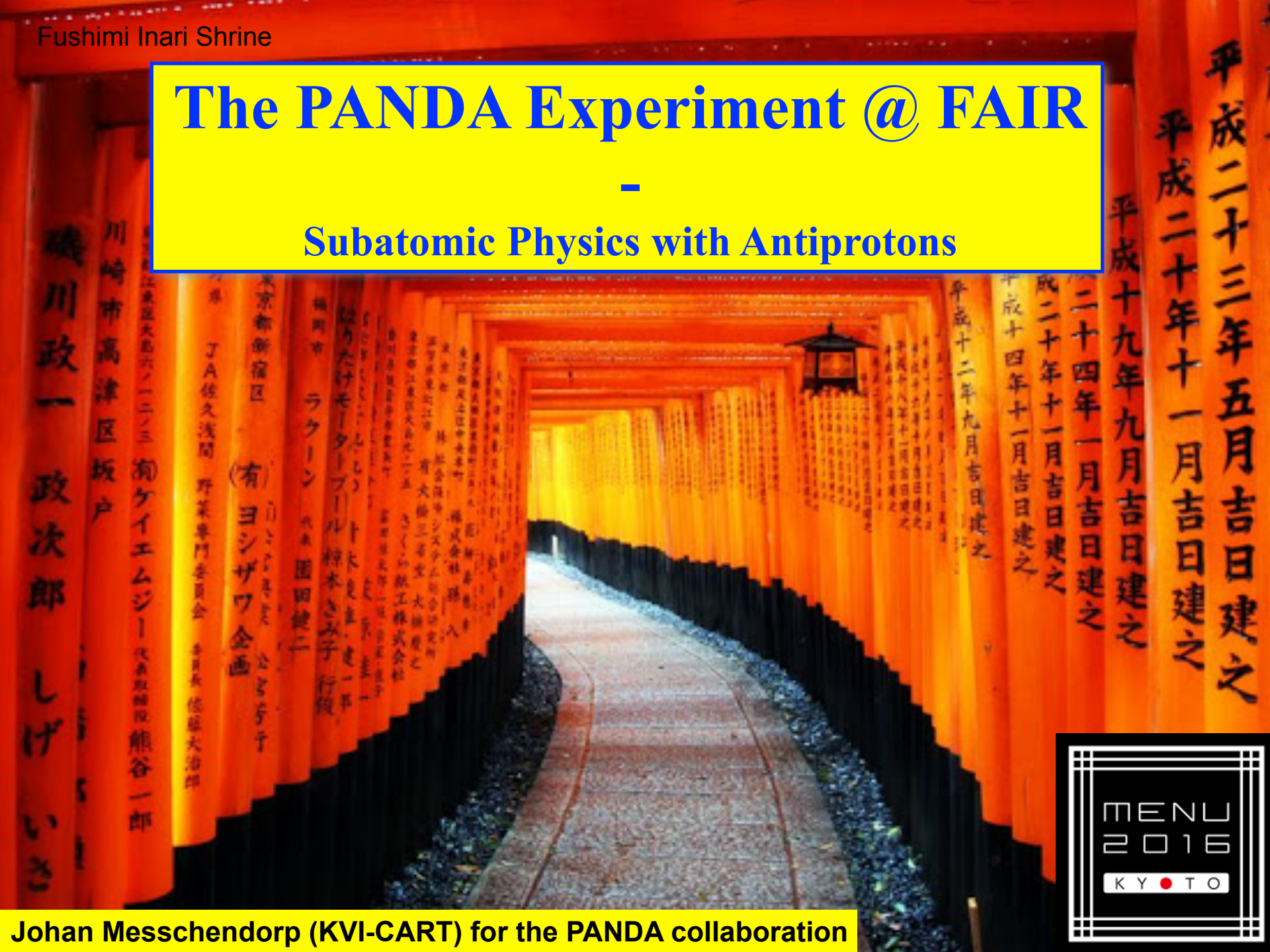
Fushimi Inari Shrine

The PANDA Experiment @ FAIR

-

Subatomic Physics with Antiprotons



Johan Messchendorp (KVI-CART) for the PANDA collaboration

MENU 2016 KYOTO

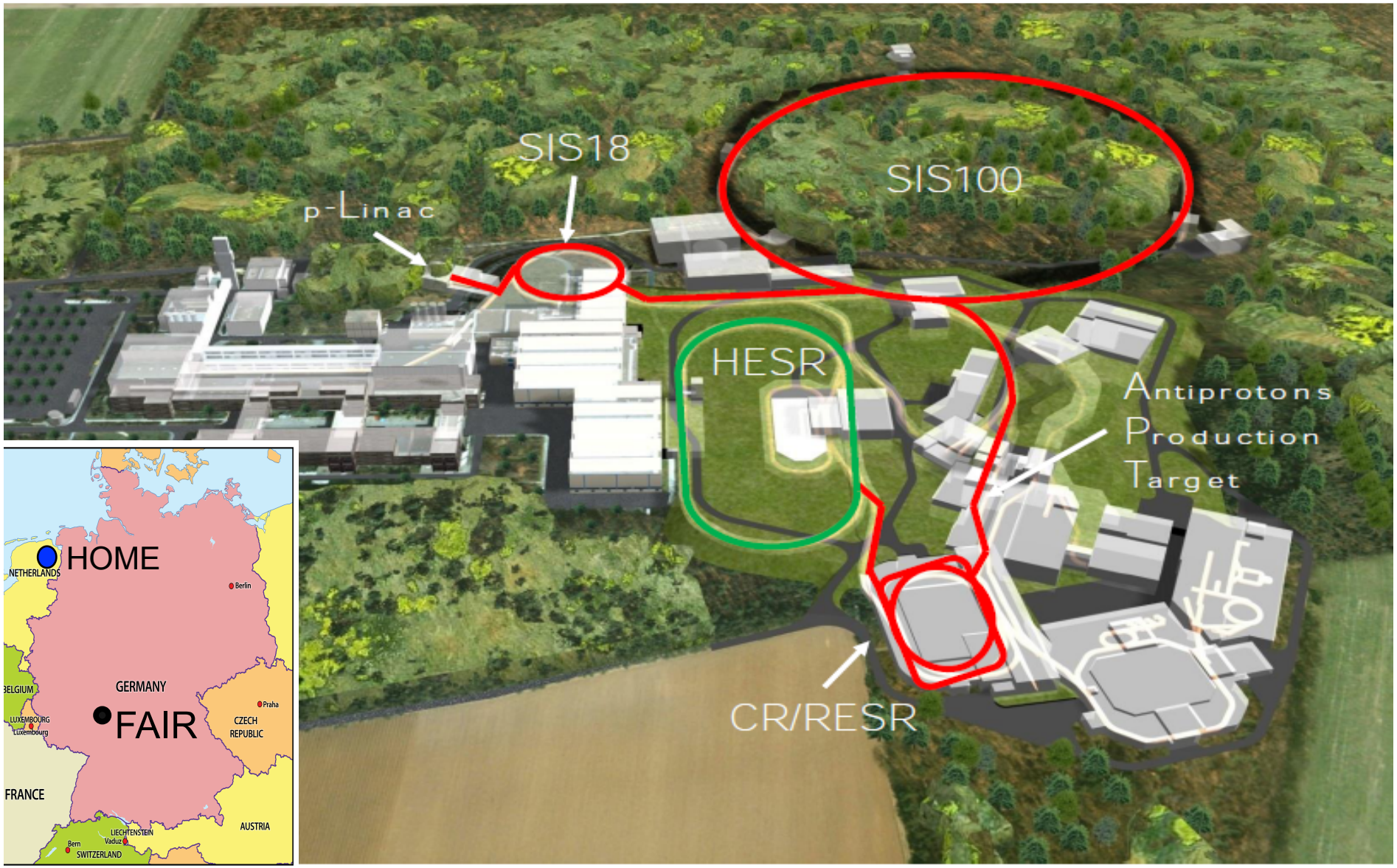
Why I joined PANDA!

Community
- interdisciplinair: nuclear, hadron & particle physics
- international: 500 scientist from 17 countries

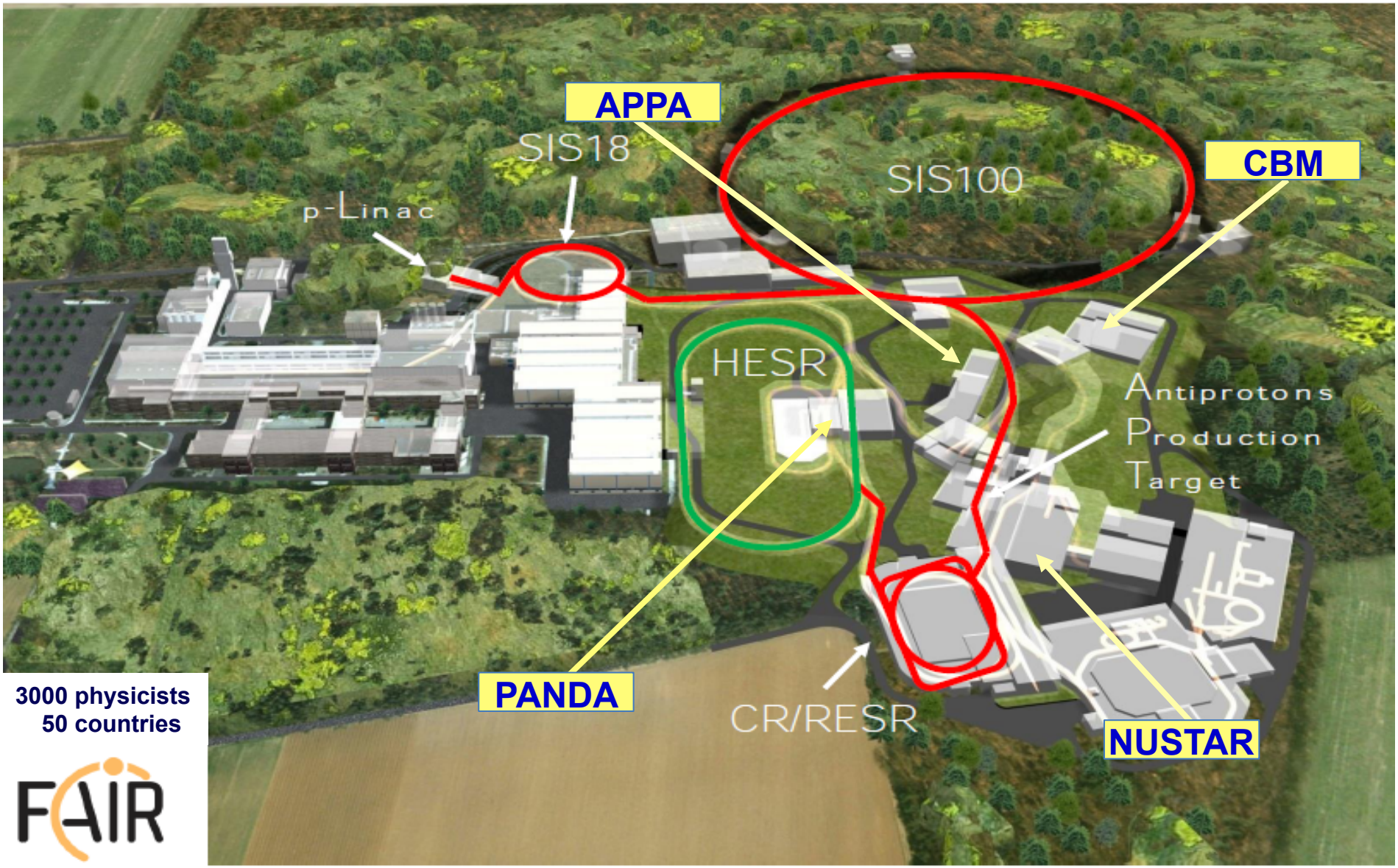
Uniqueness
- usage of antiprotons: precision & exploration
- strange and charm “factory”

Technology
- data complexity & detector developments
- versatile instrument

Facility for Antiproton and Ion Research



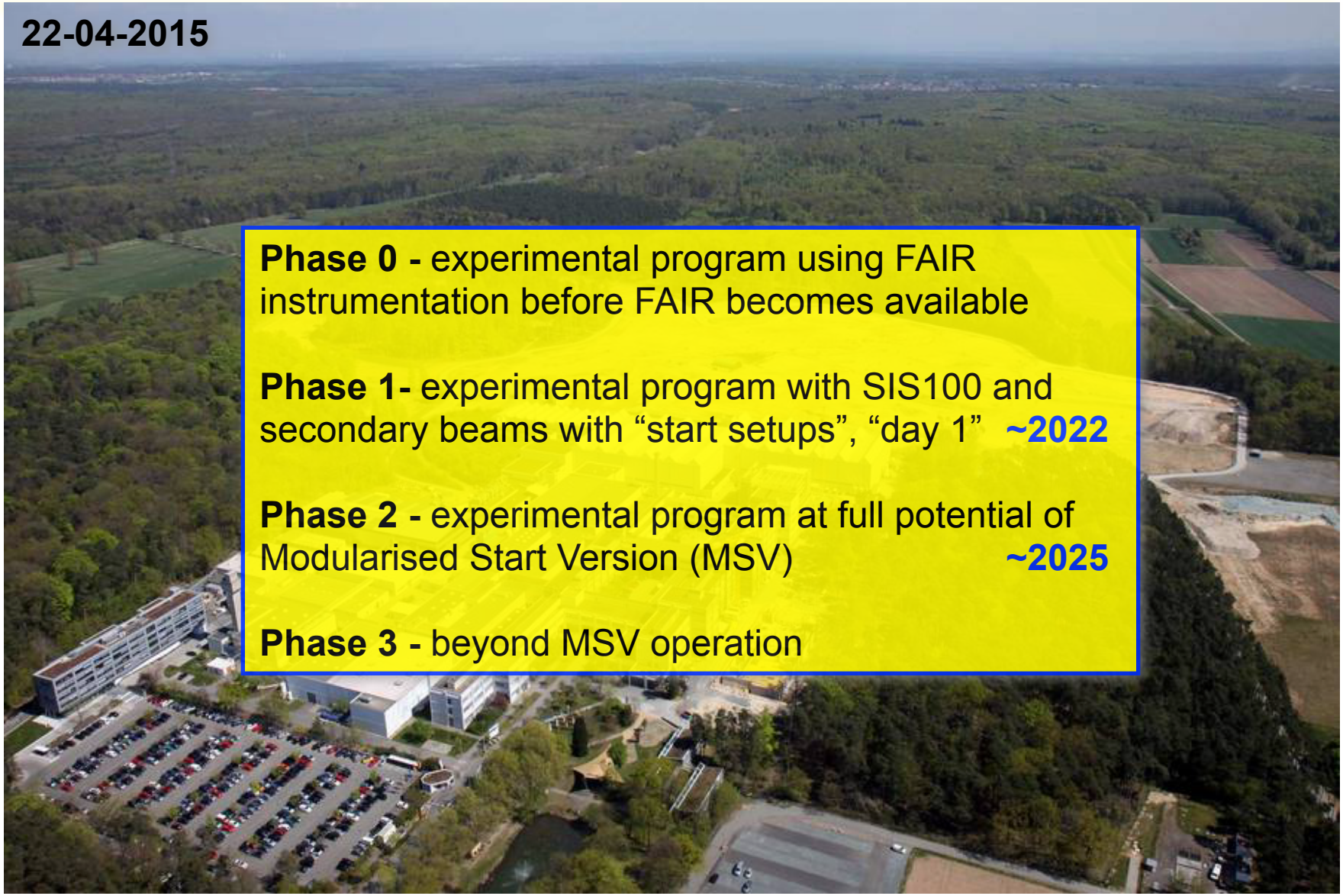
Facility for Antiproton and Ion Research



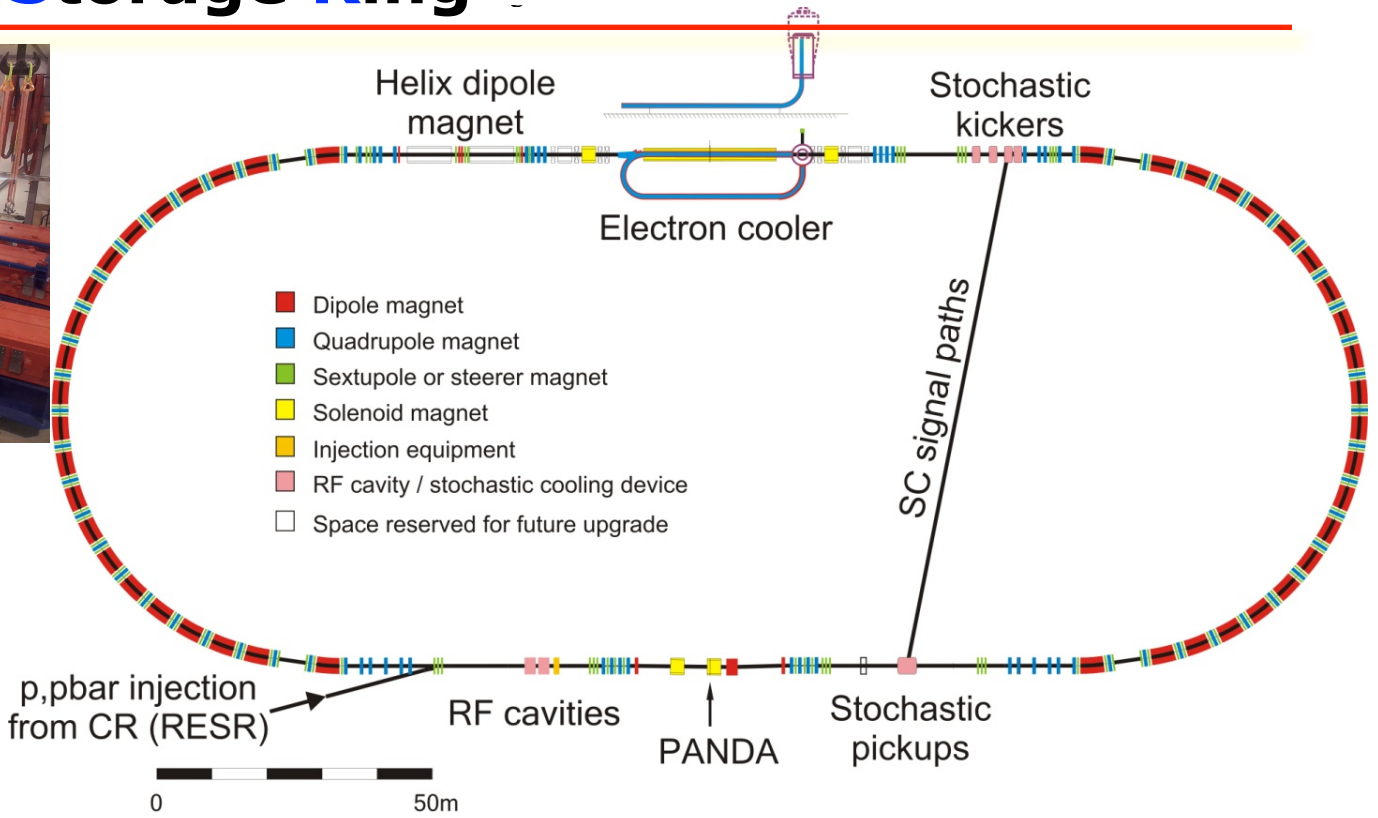
3000 physicists
50 countries

Facility for Antiproton and Ion Research

Facility for Antiproton and Ion Research



High Energy Storage Ring



High <u>resolution</u> 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 <u>intensity</u> mode:

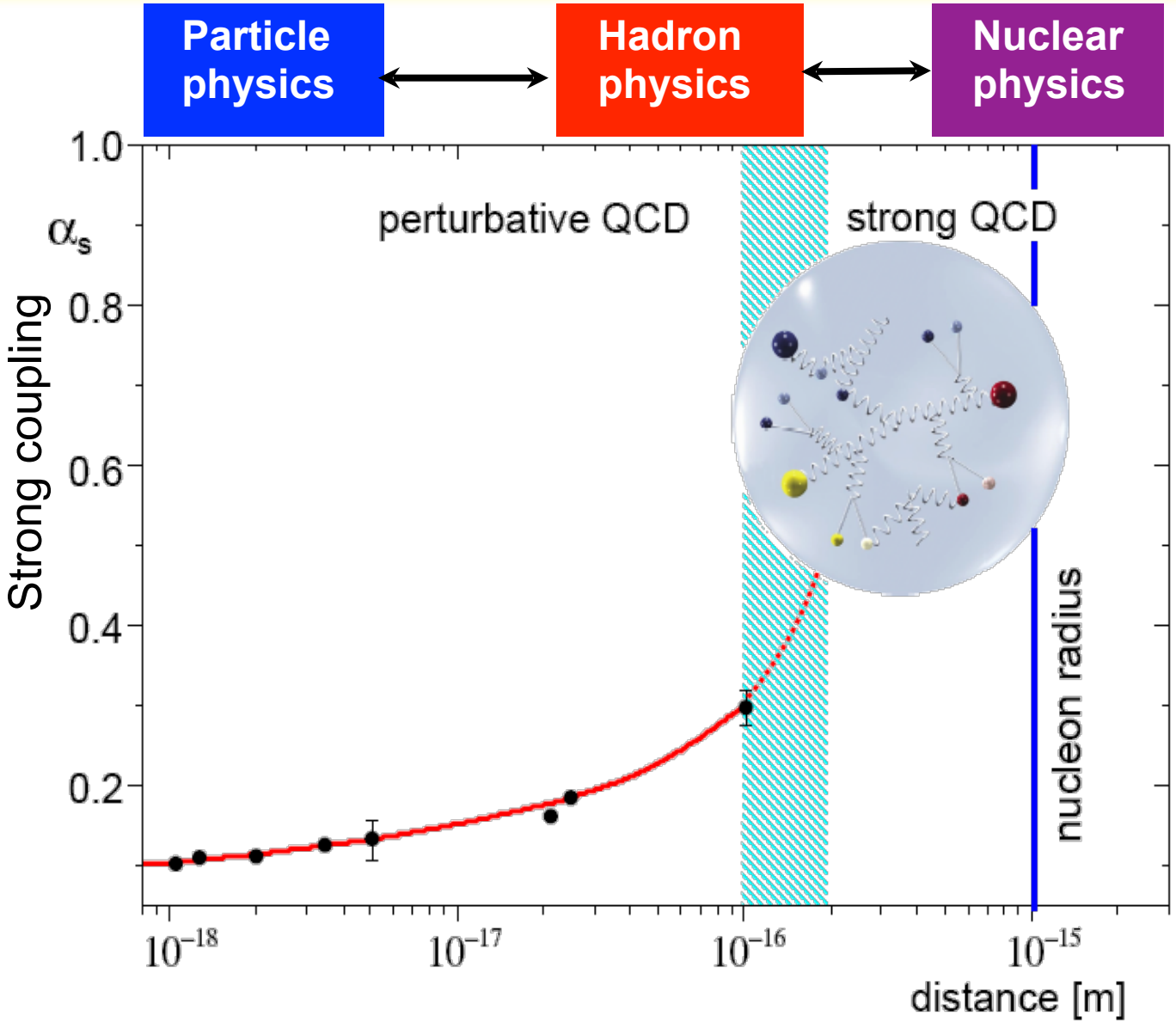
- Stochastic cooling
- 10^{11} antiprotons stored
- Luminosity up to $2x10^{32}$ $cm^{-2}s^{-1}$
- $dp/p = 2x10^{-4}$

Note: for MSV, no RESR present -> max. 10^{10} antiprotons stored

The “magic” of antiprotons

I. Versatile

Probing QCD at various distance scales

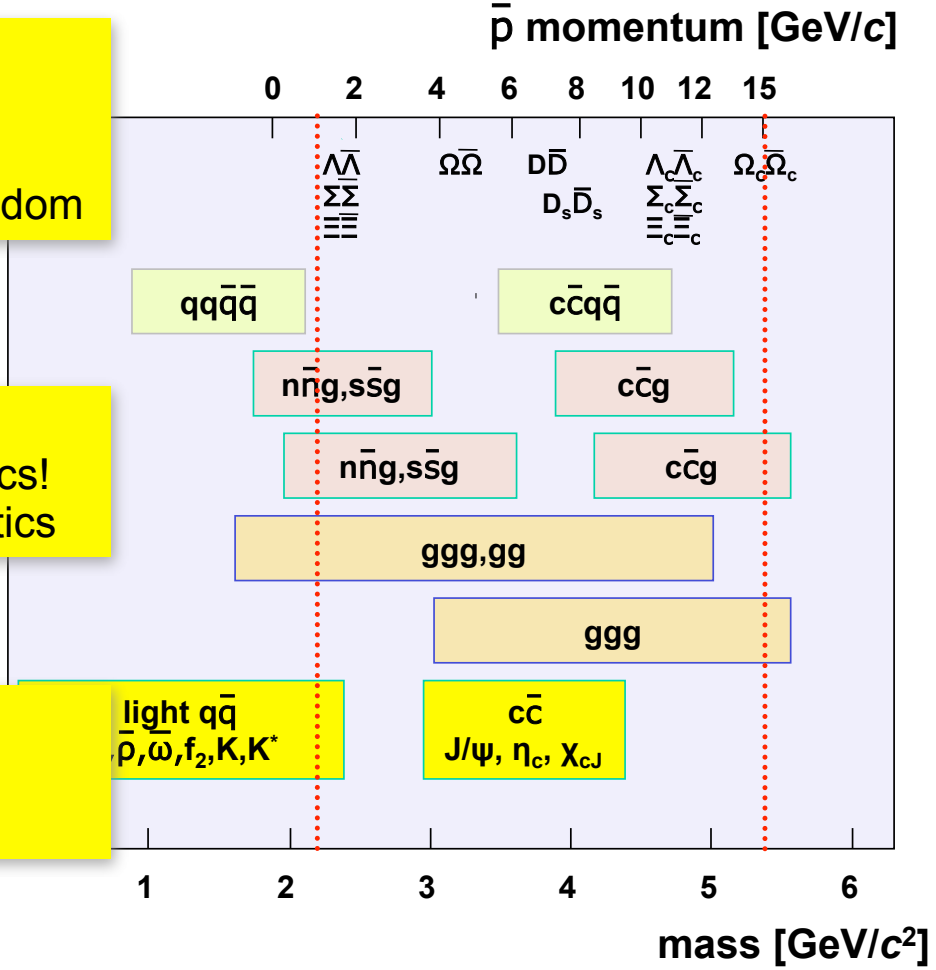


Versatility of antiprotons at PANDA

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

Study of the strong force using antiprotons

Hadron spectroscopy & dynamics
- charmonium(-like)
- gluons excitations (glueballs, hybrids, ..)
- open charm
- light meson systems

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

Hyperons & 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:

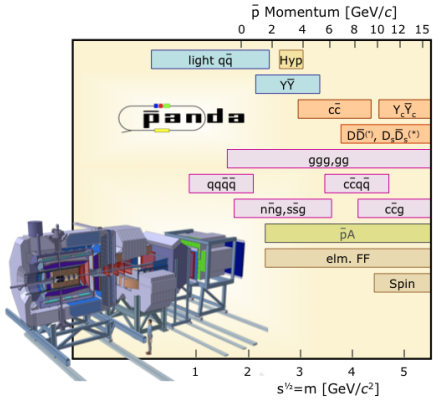
$\overline{\text{P}}$ANDA

(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.



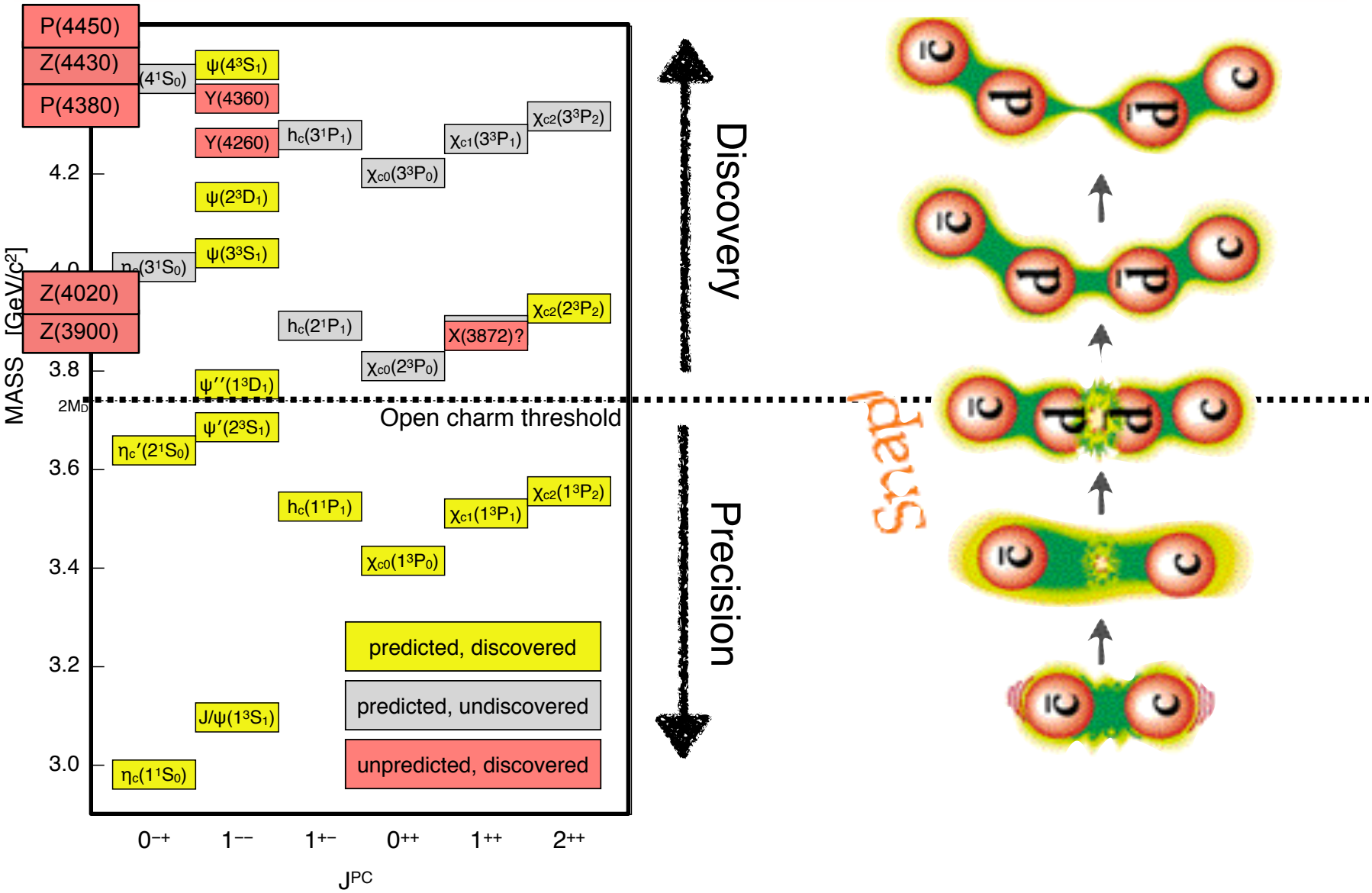
arXiv:0903.305

The "magic" of antiprotons

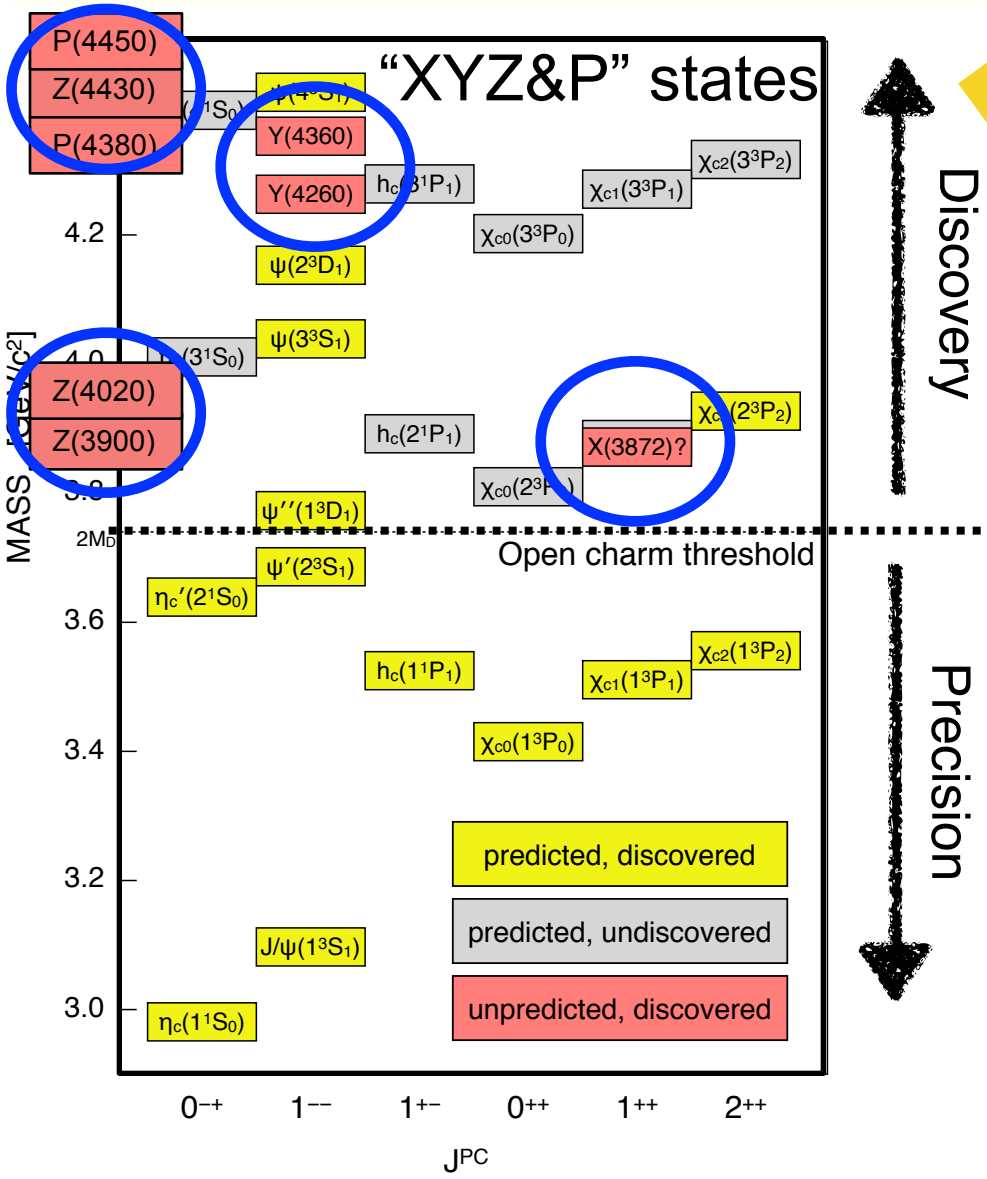
II. Discovery by precision and exploration

- a few examples

Charmonium-like spectroscopy

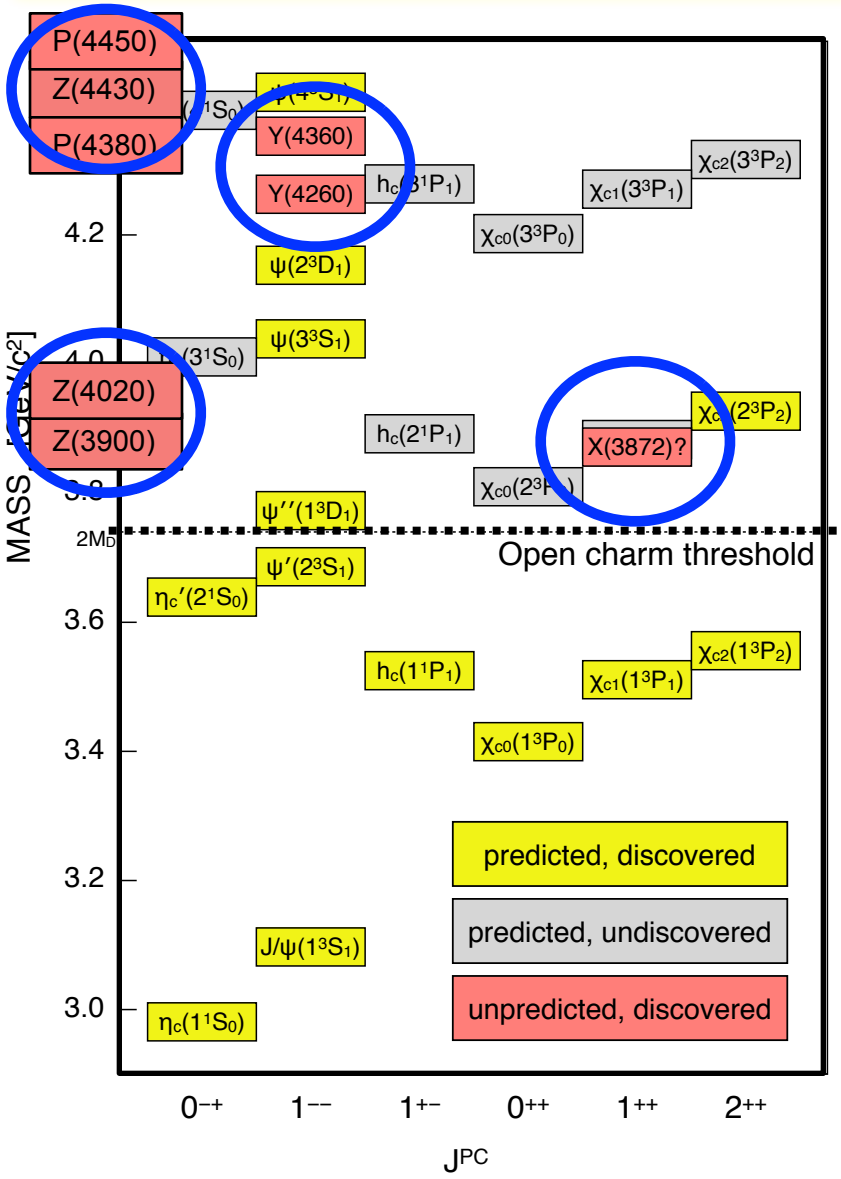


Charmonium-like spectroscopy



APS highlights

Charmonium-like spectroscopy



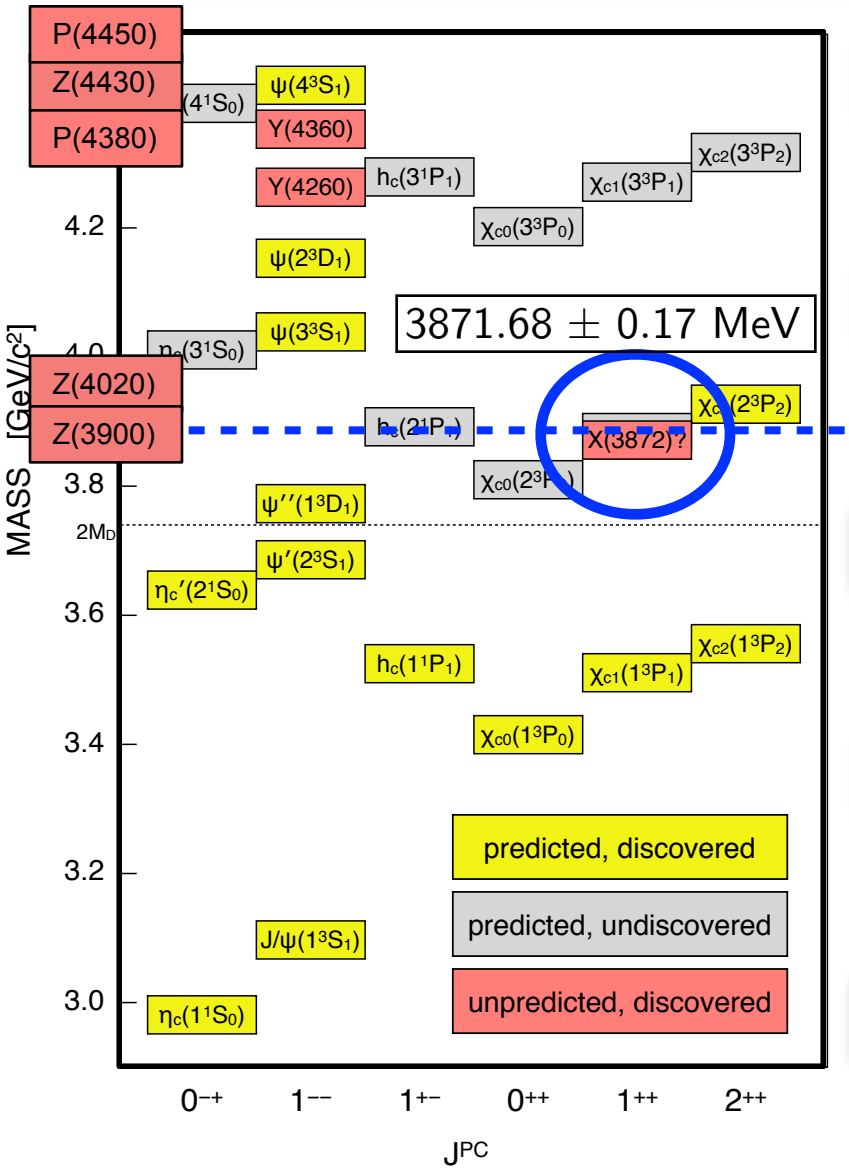
PANDA opportunities (benchmark):

- 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

arXiv:1311.7597,1410.5201

Case study: the nature of the X(3872)



Surprisingly narrow:

$$\Gamma < 1.2\,\mathrm{MeV} \quad (\Gamma(\psi'') = 27\,\mathrm{MeV})$$

Suspiciously close to DD* threshold:

$$\Delta E = -0.13 \pm 0.40\,\mathrm{MeV}$$

Large isospin breaking:

$$B(X \to \rho J/\Psi) \approx B(X \to \omega J/\Psi)$$

Spin-parity:

$$J^{PC} = 1^{++}$$

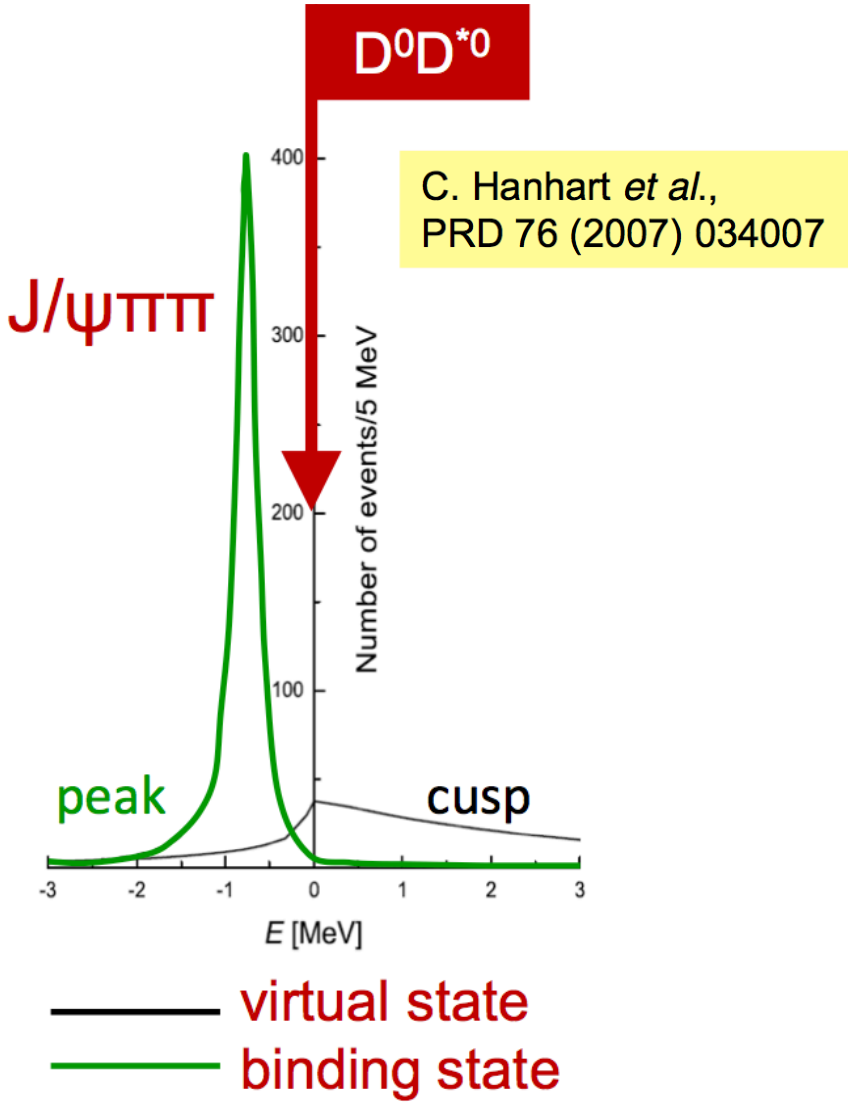
PRL110, 222001 (2013)

What is its nature?

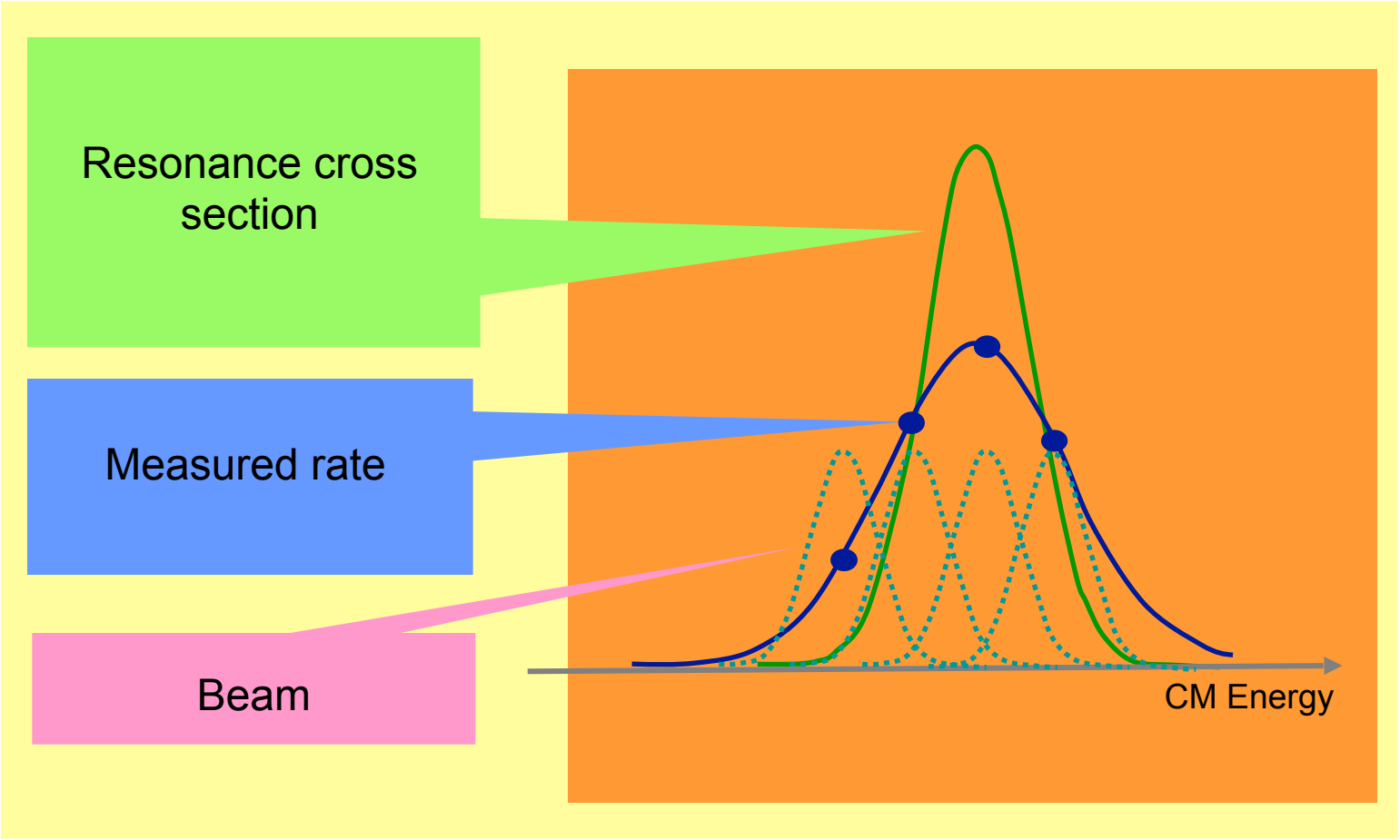
Case study: the nature of the X(3872)

Theoretical line-shape:
- depends on final state …
- … and nature of particle
-> sensitive observable!

PANDA:
- direct formation of X(3872)
- tagging of various final states (neutral&charged)
- access to line-shape parameters



Resonance scanning



Line shape measurement with CM energy resolution down to 50 keV

Monte Carlo studies for X(3872)

Cross sections:

$\sigma(\bar{p}p \to X(3872)) = 100\,nb$

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

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

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

Luminosity (MSV, HESRr):

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

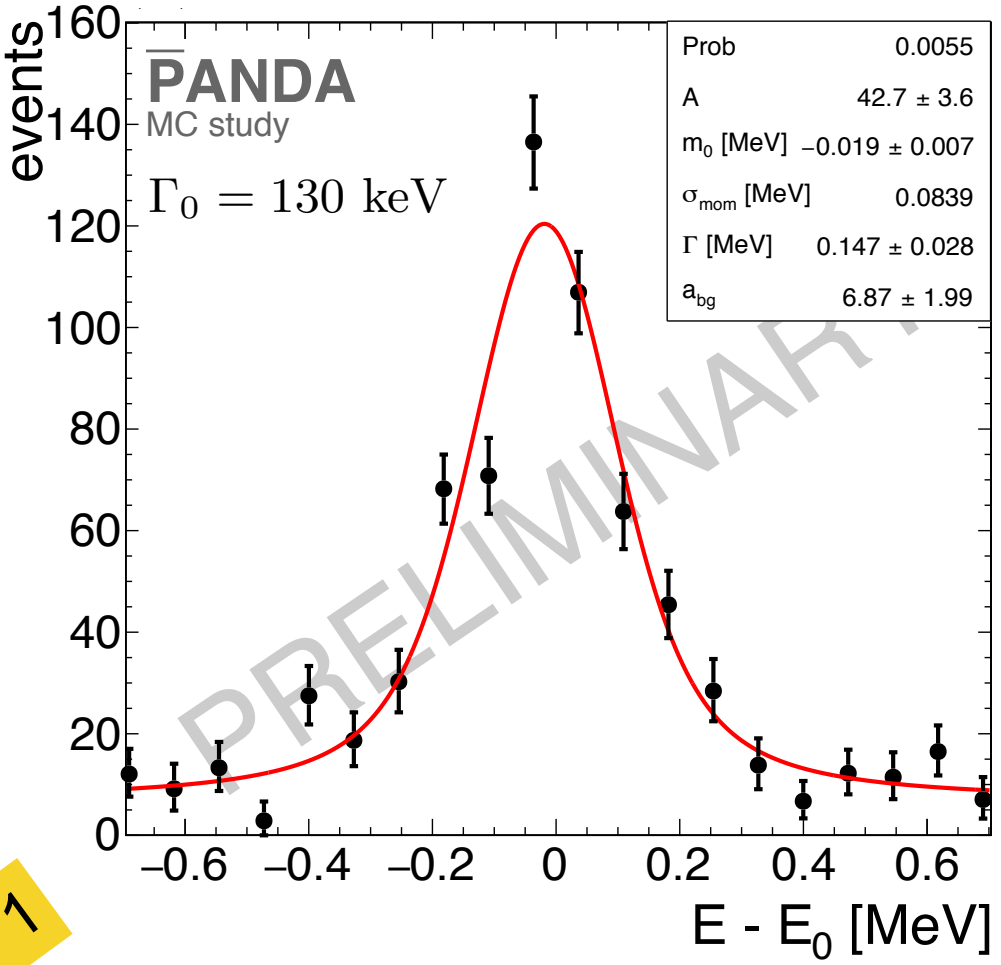
Energy resolution (HESRr):

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

20 points each 2 days data taking!

Day 1

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



Klaus Goetzen et al.

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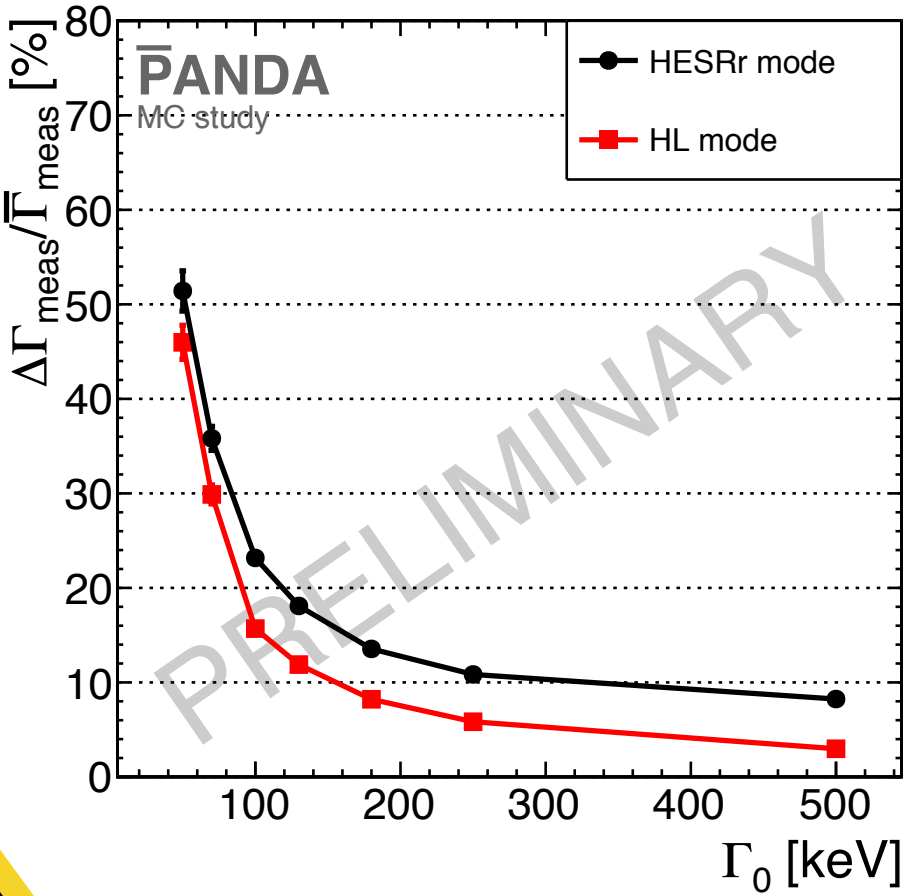


Klaus Goetzen et al.

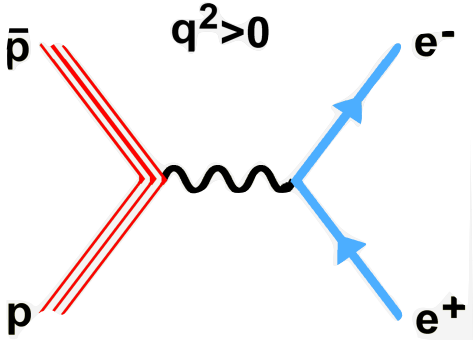
The structure of the proton

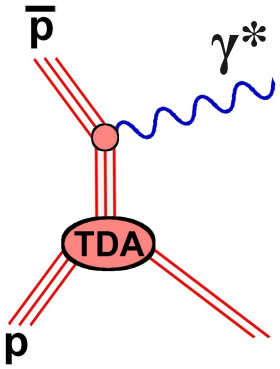
Time-like Electromagnetic Form Factors
(lepton pair production) arXiv:1606.01118

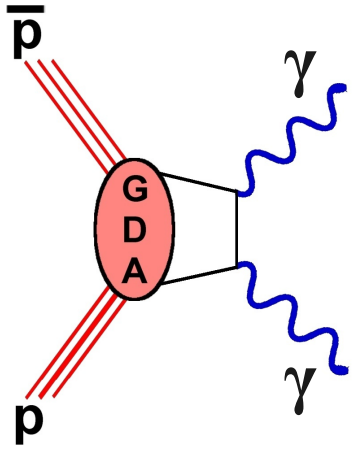
Transition Distribution Amplitudes
(meson production) arXiv:1409.0865

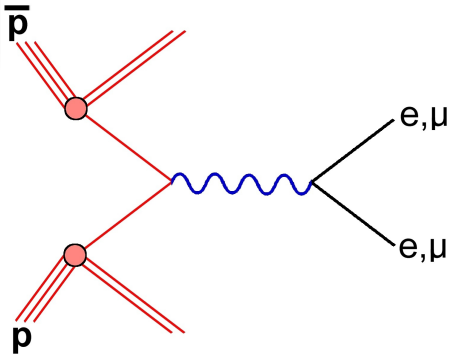
Generalised Distribution Amplitudes
(time-like Compton, hard exclusive processes)

Transverse Parton Distribution Functions
(Drell-Yan production)



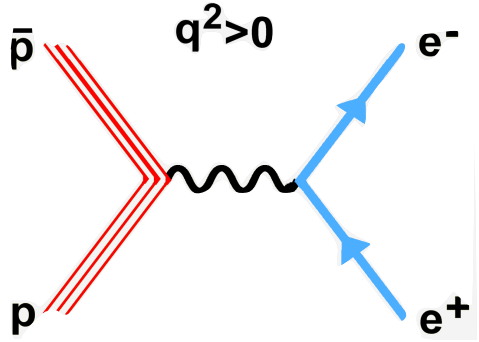






Analytical nature of form factors

Time-like Electromagnetic Form Factors
(lepton pair production) arXiv:1606.01118



$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{2\beta s}\left[(1+\cos^2\theta)|G_M|^2 + \frac{1}{\tau}\sin^2\theta|G_E|^2\right]$$

Analytical nature of form factors

Time-like Electromagnetic Form Factors
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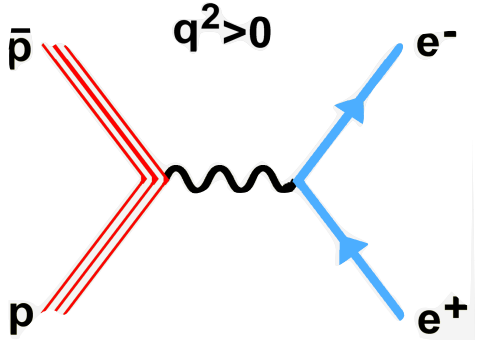
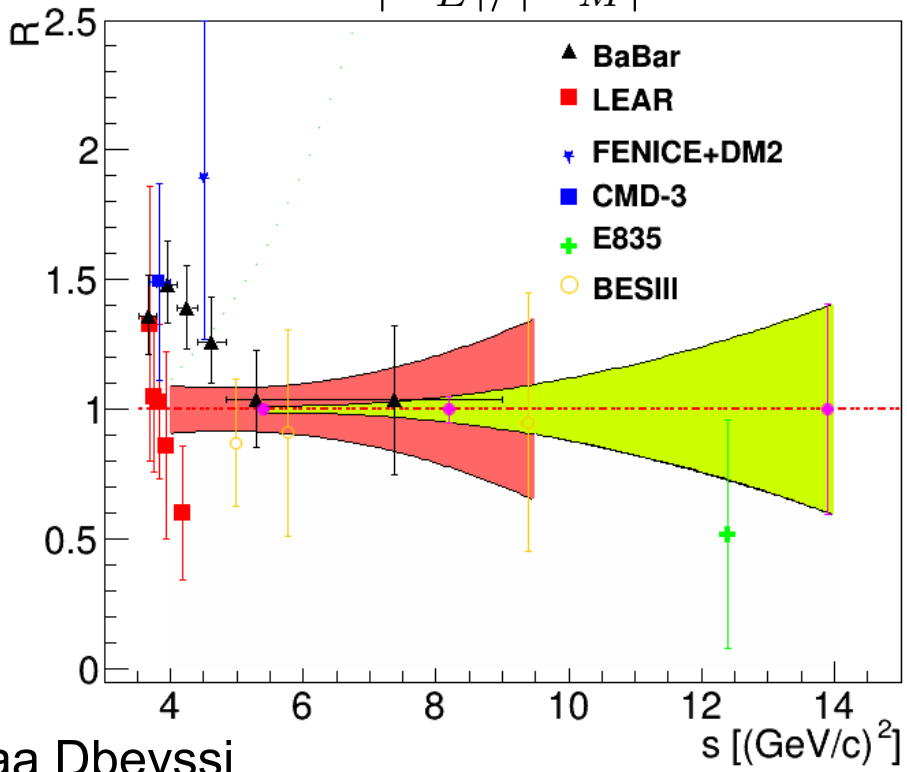


$$R = |G_E|/|G_M|$$



21 scan points 2015 (552 pb^{-1})

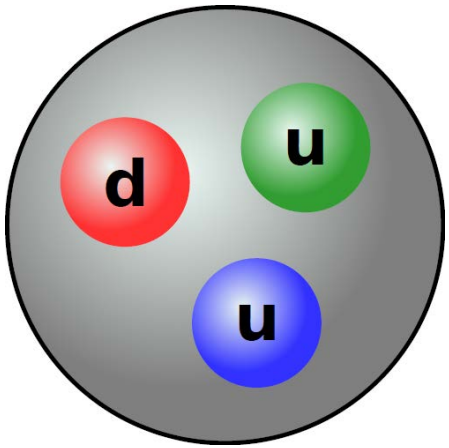
Monte Carlo Sim., R=1 (C. Morales)

L=2 fb^{-1}
2.10^{32} cm^{-2}s^{-1}

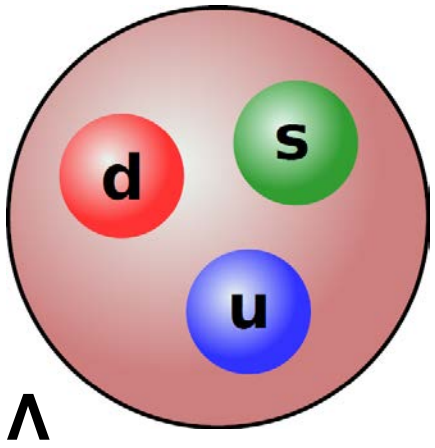
~5 months data taking /point

Exploring the hyperon sector

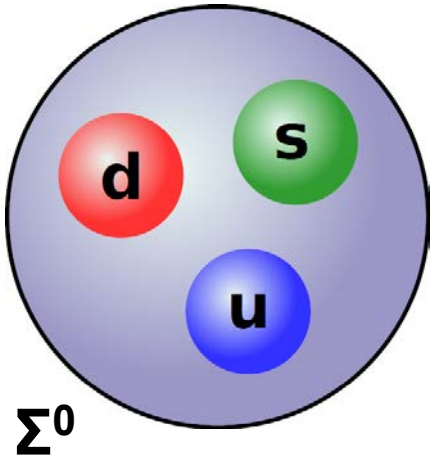
What happens if we replace one of the light quarks in the proton with one - or many - heavier quark(s)?



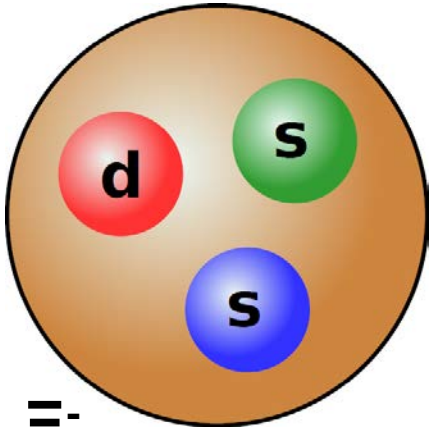
proton



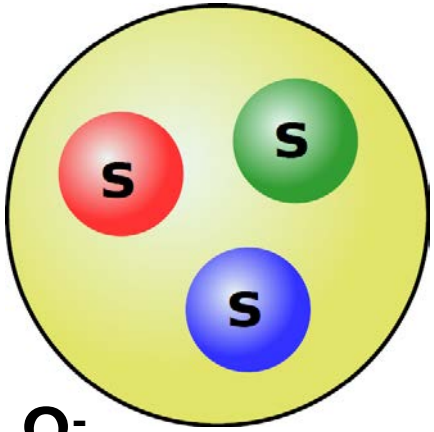
Λ



Σ^0

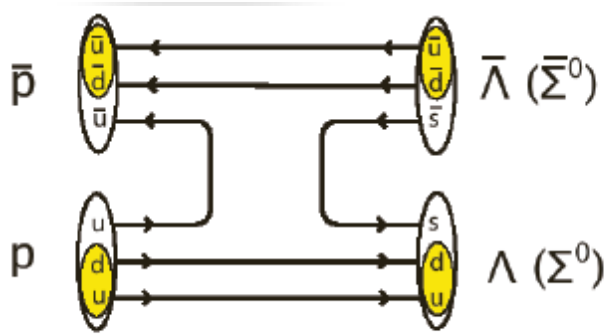


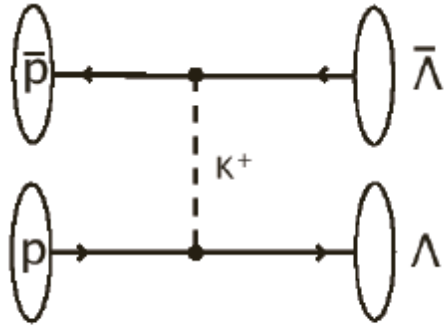
Ξ^-

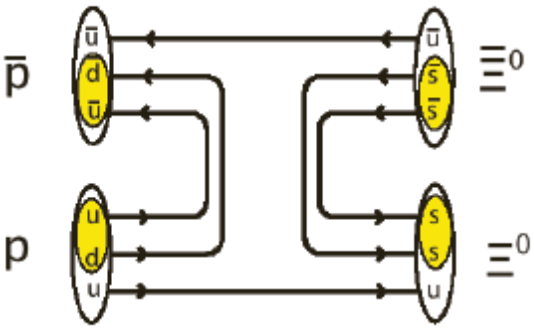


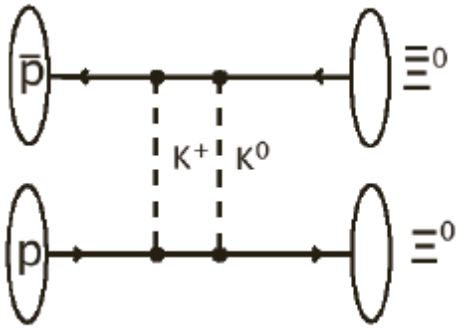
Ω^-

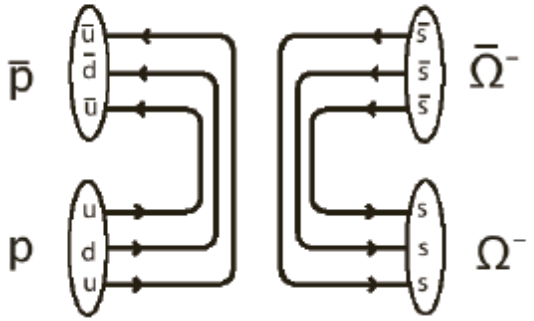
Exploring the hyperon sector

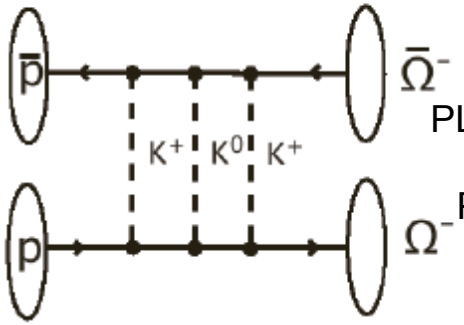












Models based on

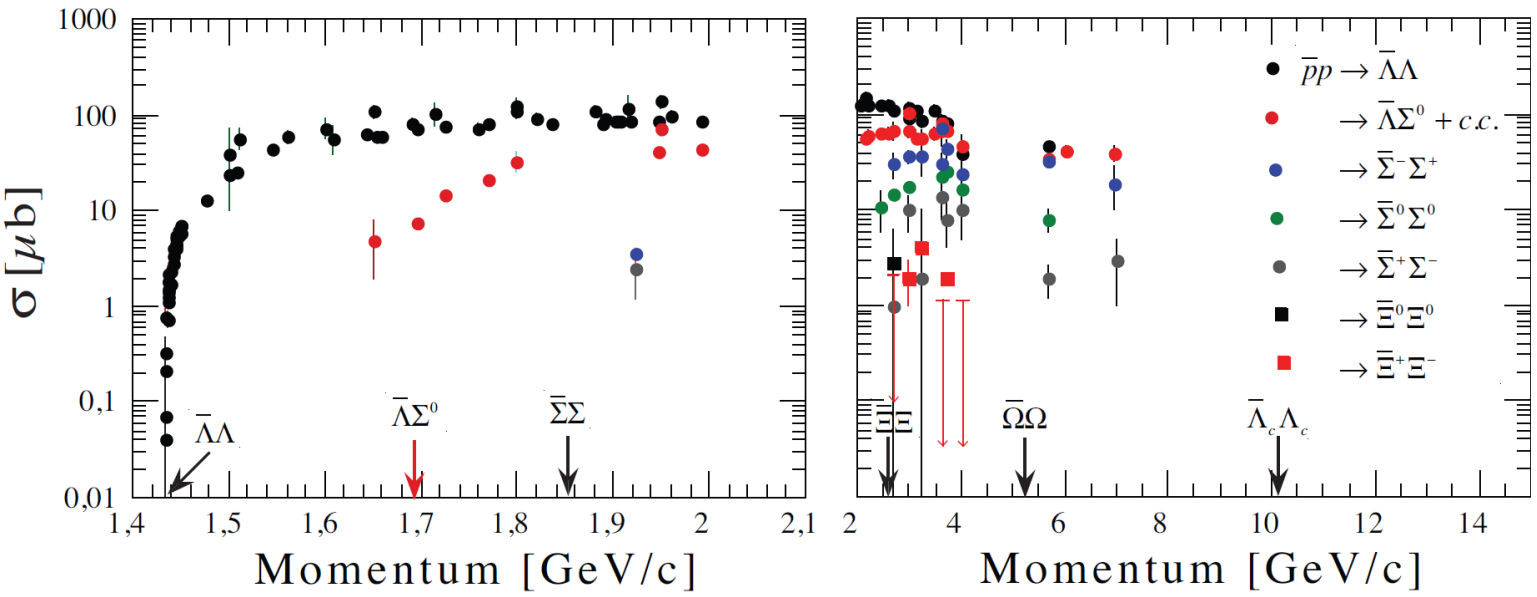
1) quark-gluon picture*

2) the hadron picture**

3) a combination of 1) and 2) ***

PL**B** 179 (1986) 15; PLB 165 (1985) 187;
NPA 468 (1985) 669;
PRC 31(1985) 1857; PLB179 (1986) 15;
PLB 214 (1988) 317;
*** PLB 696 (2011) 352.

PANDA is a hyperon factory!



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

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

PANDA is a hyperon factory!

$$\bar{p}p \to \bar{\Lambda}\Lambda,\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Sigma}^{0}\Sigma^{0},\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Xi}^{0}\Xi^{0},\ \bar{\Xi}^{+}\Xi^{-},\ \bar{\Omega}^{+}\Omega^{-},\ \bar{\Lambda}_{c}^{-}\Lambda_{c}^{+}$$

$$\downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow \qquad \downarrow$$

$$p\pi^{-} \quad p\pi^{0} \quad \Lambda\gamma \quad n\pi \quad \Lambda\pi^{0} \quad \Lambda\pi \quad \Lambda K \quad \Lambda\pi$$

$$64\% \quad 52\% \quad \approx 100\% \quad \approx 100\% \quad \approx 100\% \quad \approx 100\% \quad 68\% \quad \approx 1\%$$

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

Day 1

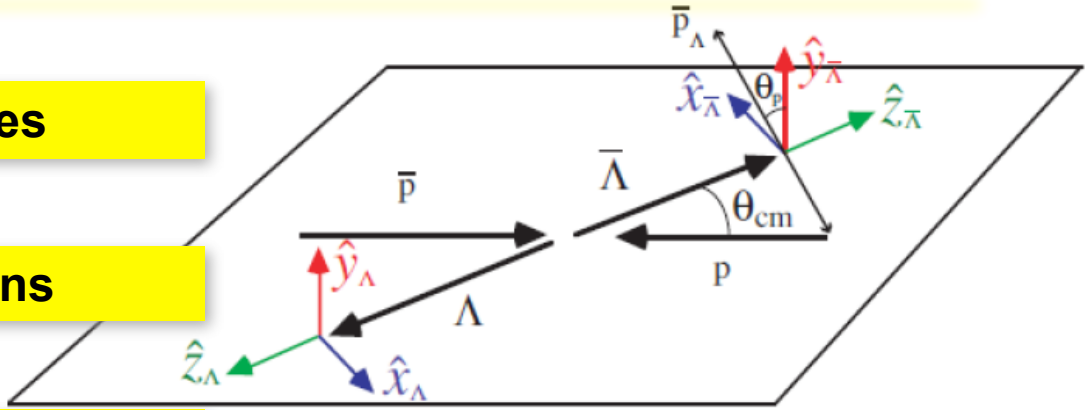
Karin Schoenning

PANDA is a hyperon factory!

Rich set of polarisation observables

(double) strange and charm baryons

Explore hyperon dynamics above 4 GeV



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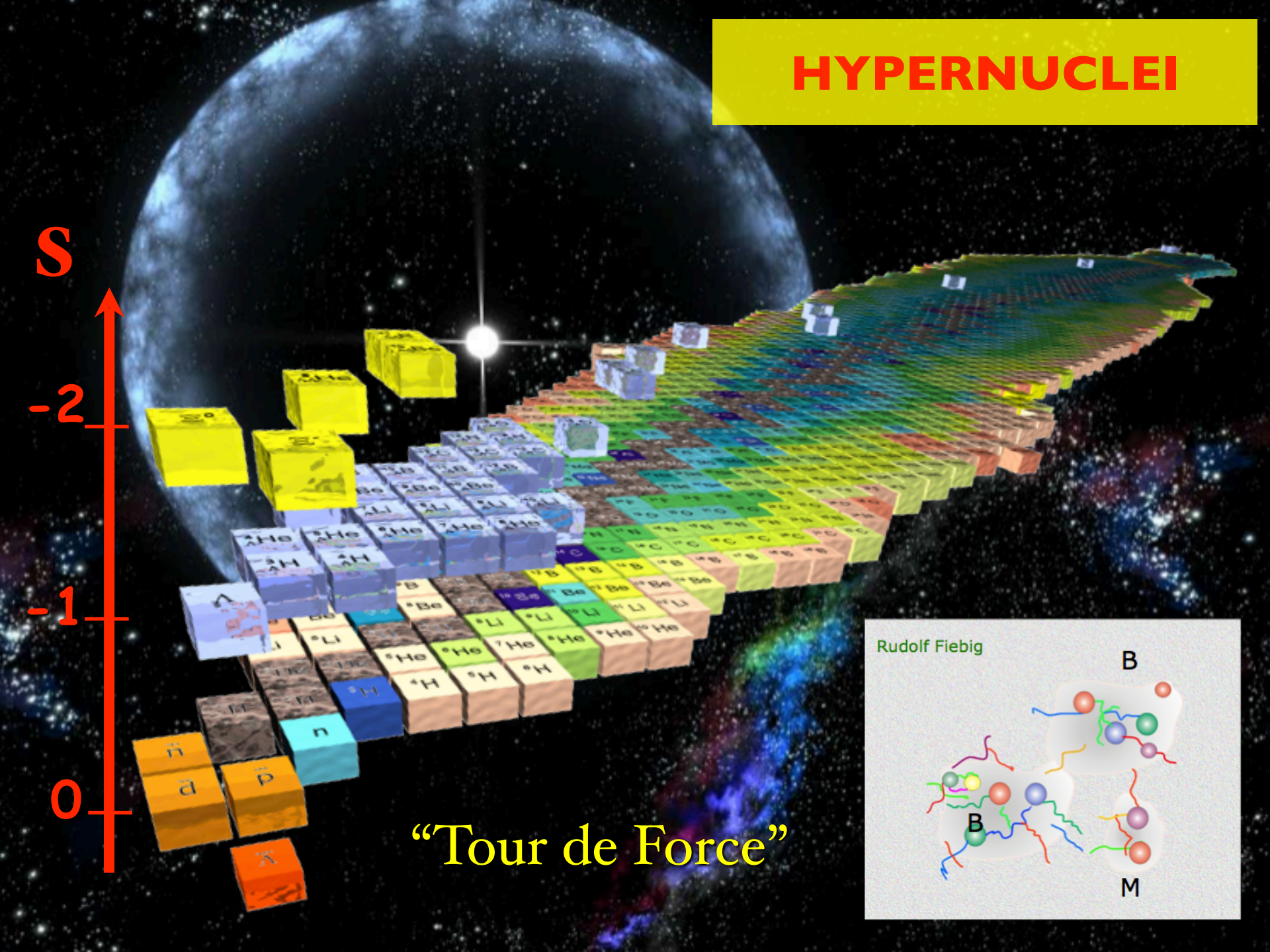
12	$\bar{p}p \to \bar{\Lambda}_c^-\Lambda_c^+$	~0.1	~35	~2 day^{-1}

Day 1

Karin Schoenning

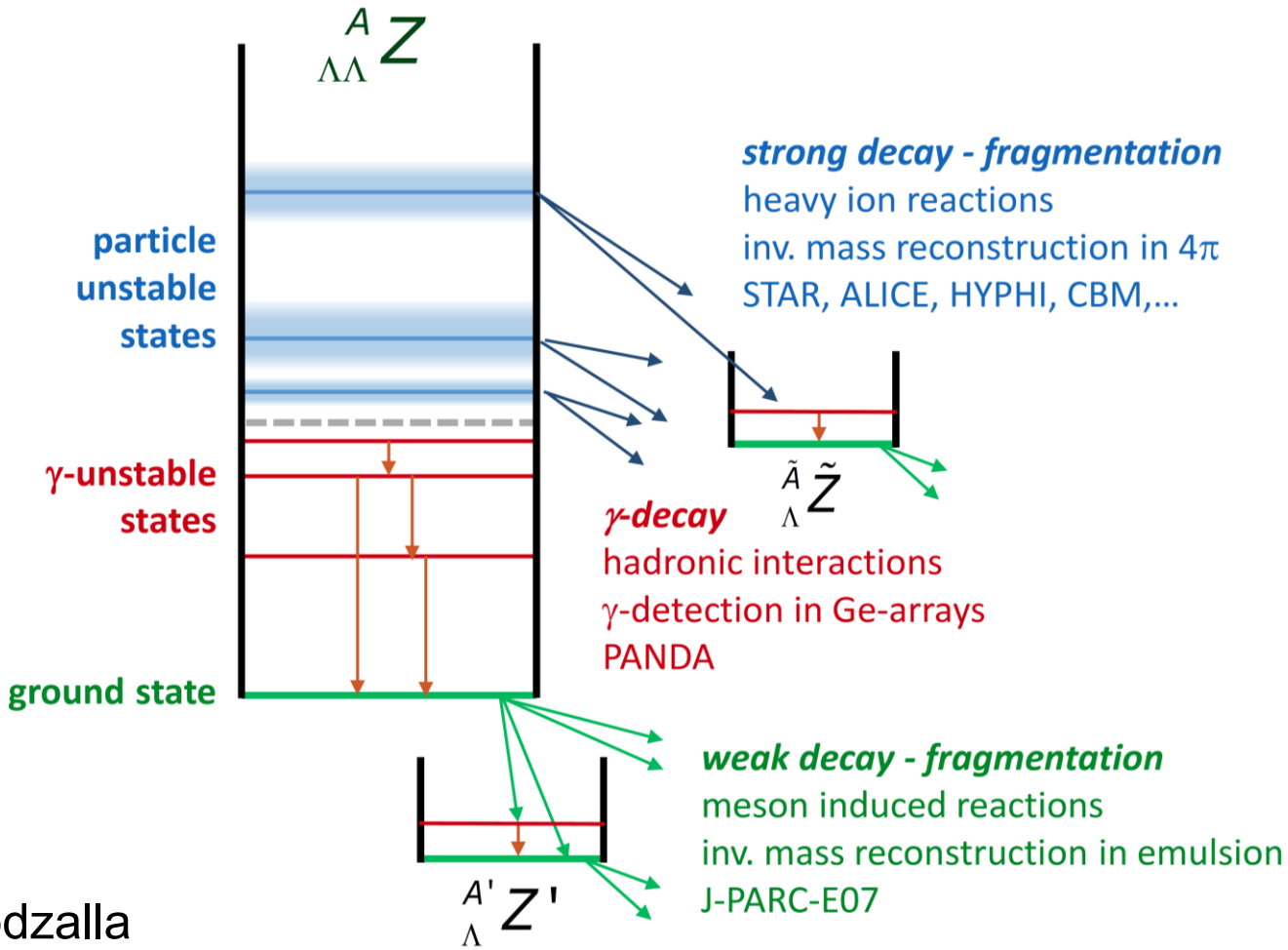
HYPERNUCLEI



S=-2 systems

NPA 954, 323 (2016)

- missing mass (K^-,K^+) reactions ⇒ Ξ bound state J-PARC
- Ξ capture ⇒ Ξ atoms J-PARC, FAIR
- Ξ capture and $\Xi^- p \to \Lambda\Lambda$ ⇒ ΛΛ hypernuclei J-PARC, FAIR,HI



Ξ^- production

$\bar{p}N \rightarrow \Xi^- \bar{\Xi}$

rescattering in primary target nucleus

deceleration in secondary target

capture of Ξ

atomic cascade of Ξ^-

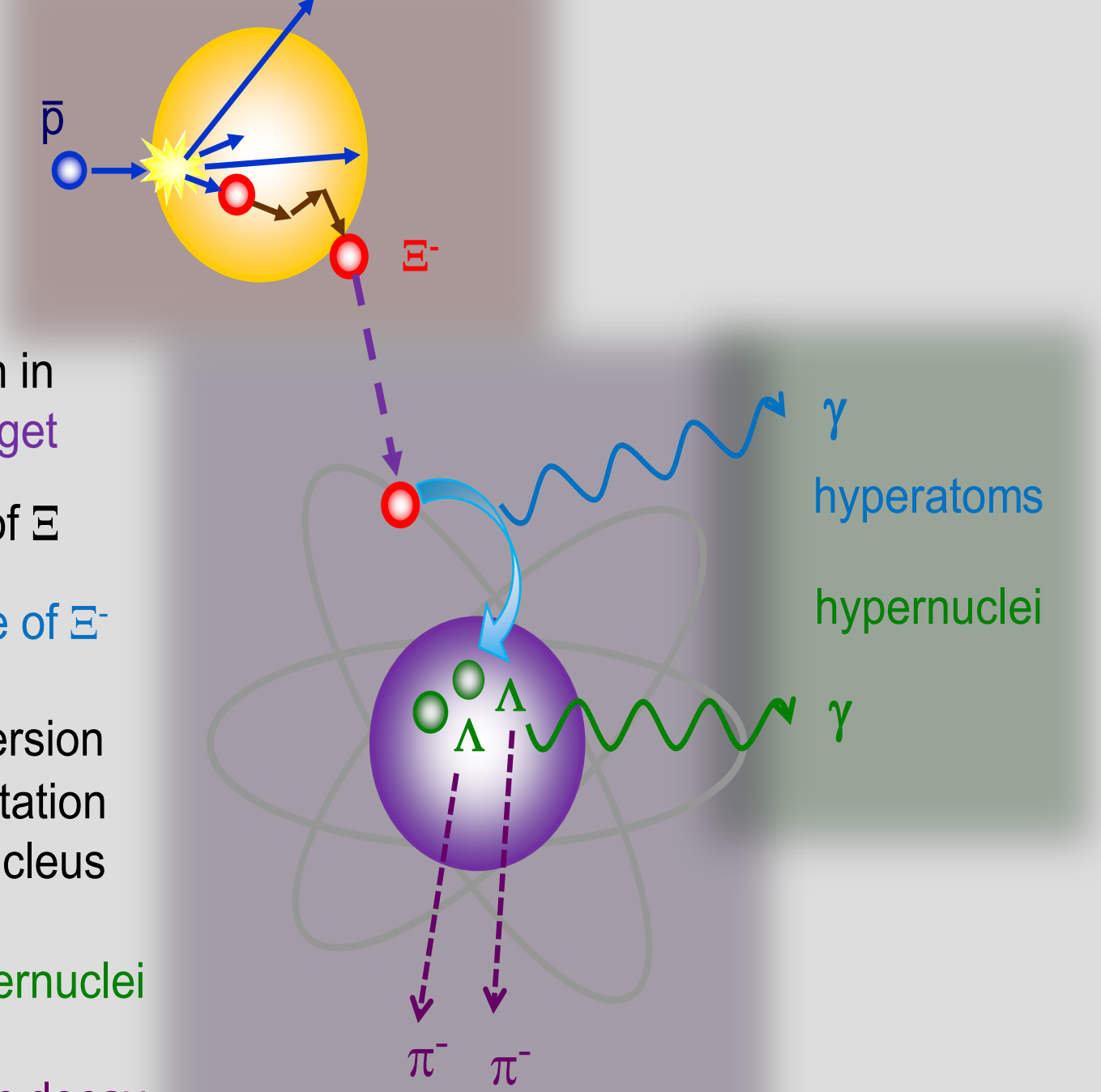
$\Xi^- p \rightarrow \Lambda\Lambda$ conversion

fragmentation

$\rightarrow$ excited $\Lambda\Lambda$-nucleus

γ-decay of $\Lambda\Lambda$ hypernuclei

weak pionic decay



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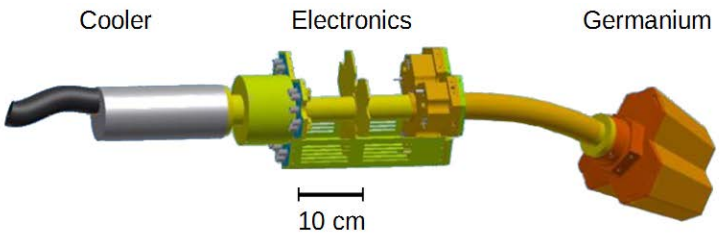
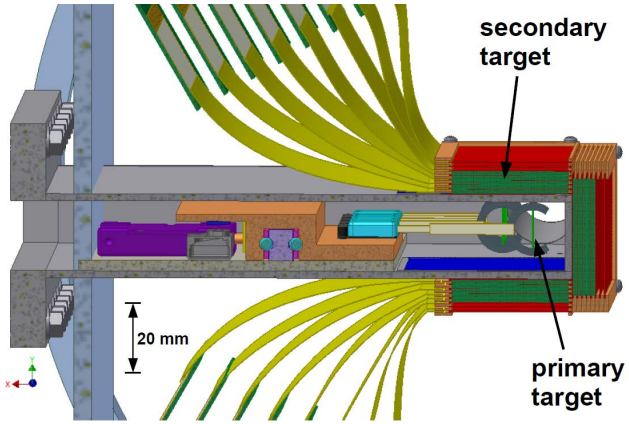
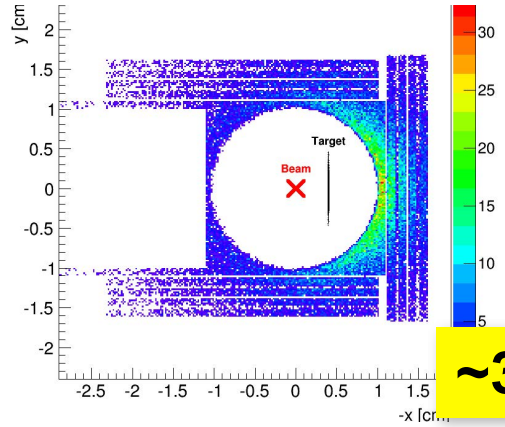
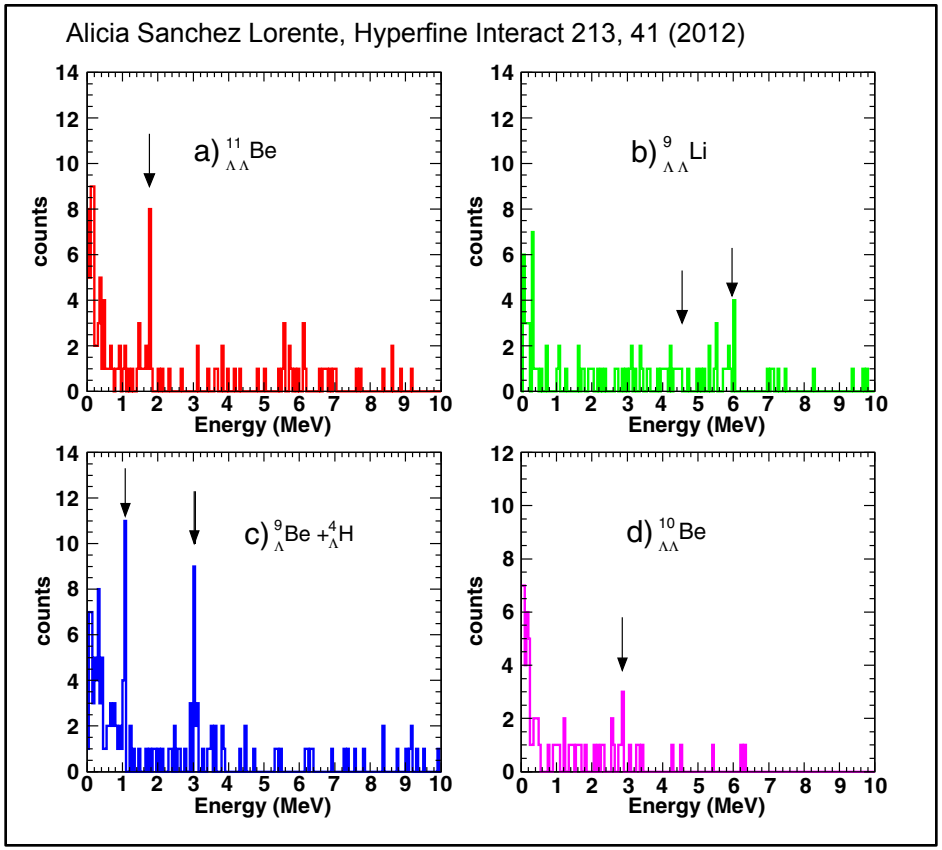
Double Λ hypernuclear spectroscopy









~33.000 stopped Ξ^-'s per day

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Quadrupole moment of hyperatoms

- reaching for the unthinkable!

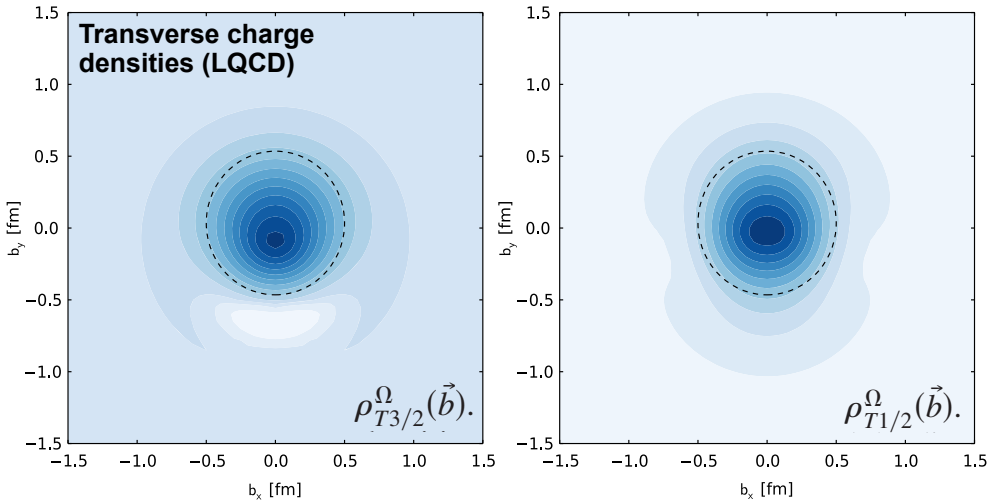
NPA 954, 323 (2016)

"The precision measurements of X-rays from Ω^--Pb atoms will certainly require a future generation of accelerators and probably also physicists." - C.J. Batty (1995)

Study "shape" of spin 3/2, |S|=3 Ω^-

Complementary to nucleon structure

Meson cloud correction expected small



Alexandro et al., PRD82, 034504 (2010)

Model	Q_Ω [e·fm^2]	Reference
NRQM	0.02	NP33,772 (1981)
NRQM	0.004	ZPC12,369 (1982)
NRQM	0.031	PRD25,2395 (1982)
SU(3) Bag model	0.052	NP45,109 (1987)
NRQM with mesons	0.0057	PRD41,924 (1990)
NQM	0.028	PRD43,3763 (1991)
Lattice QCD	0.0.005	PRD46,3067 (1992)
HBχPT	0.009	PRD49,3459 (1994)
Skyrme	0.024	PLB334,287 (1994)
Skyrme	0.0	PLA10, 1027 (1995)
QM	0.022	ZN52a, 877 (1997)
χQM	0.026	JPG26,267 (2000)
GP QCD	0.024	PRD65,073017 (2002)
QCD-SR	0.1	EPJC61,311 (2009)
χPT+qlQCD	0.0086	PRD80,034027 (2009)
Lattice QCD	0.0096±0.0002	PRD83,054011 (2011)

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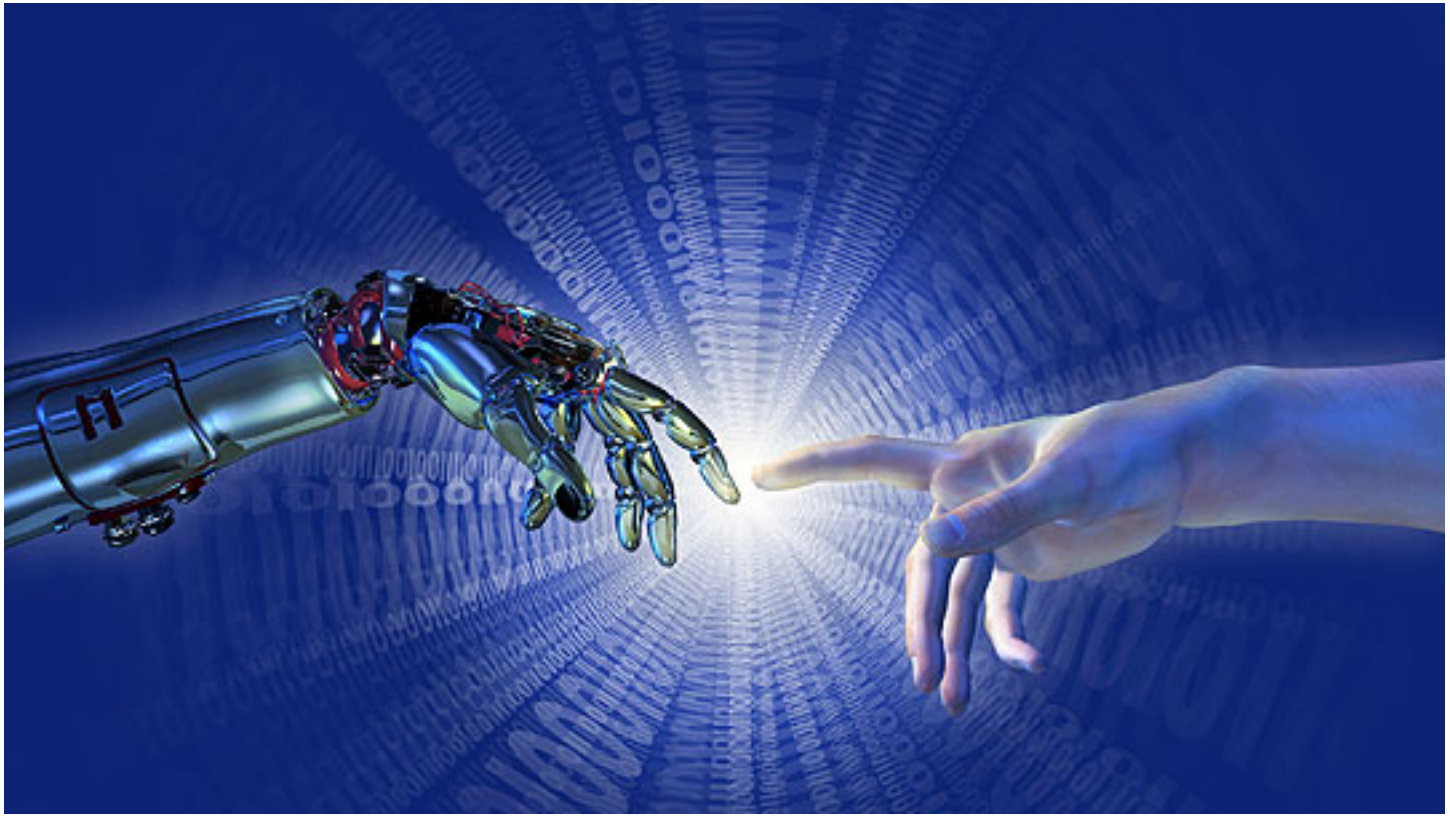
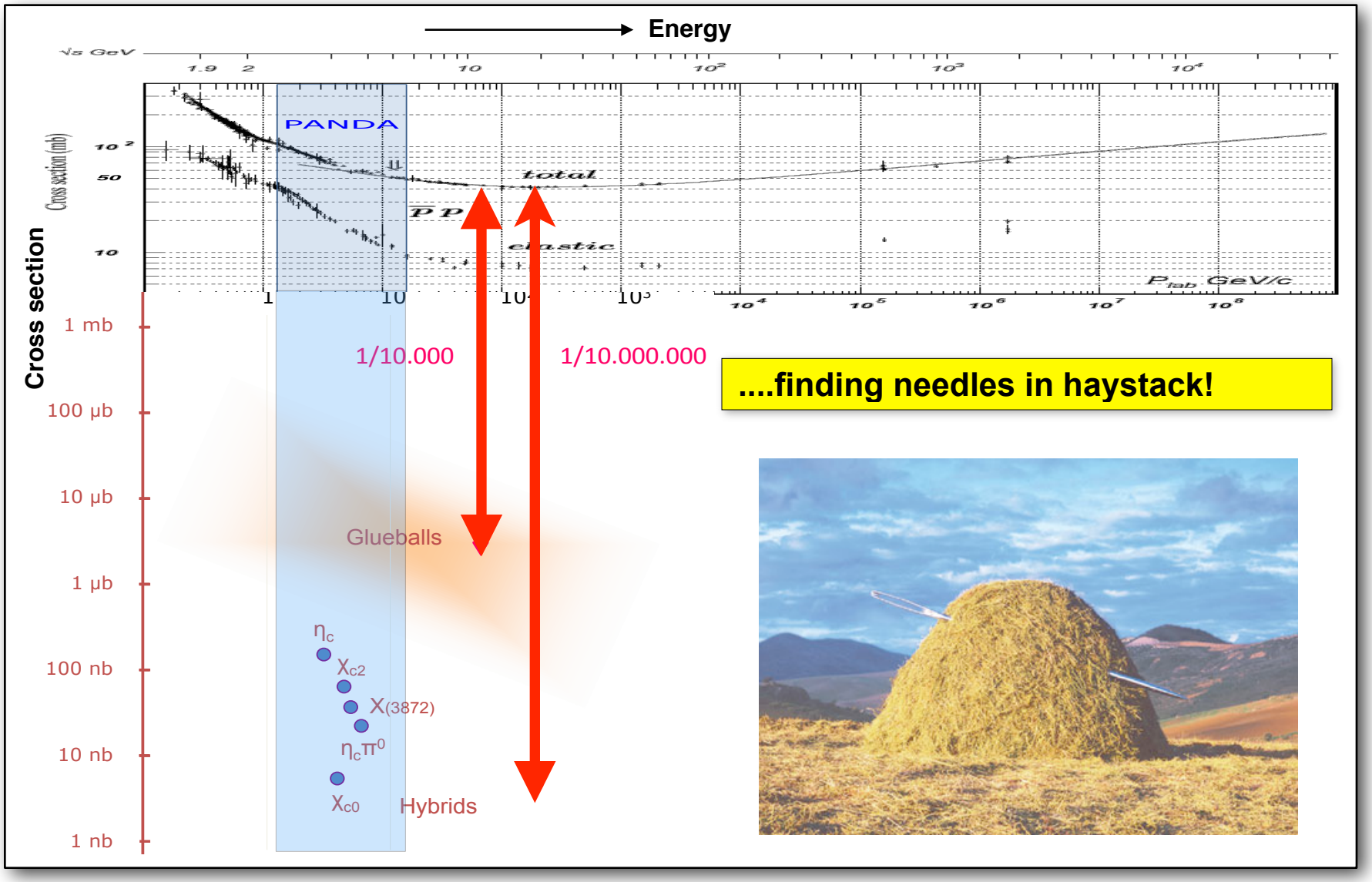
The “magic” of antiprotons

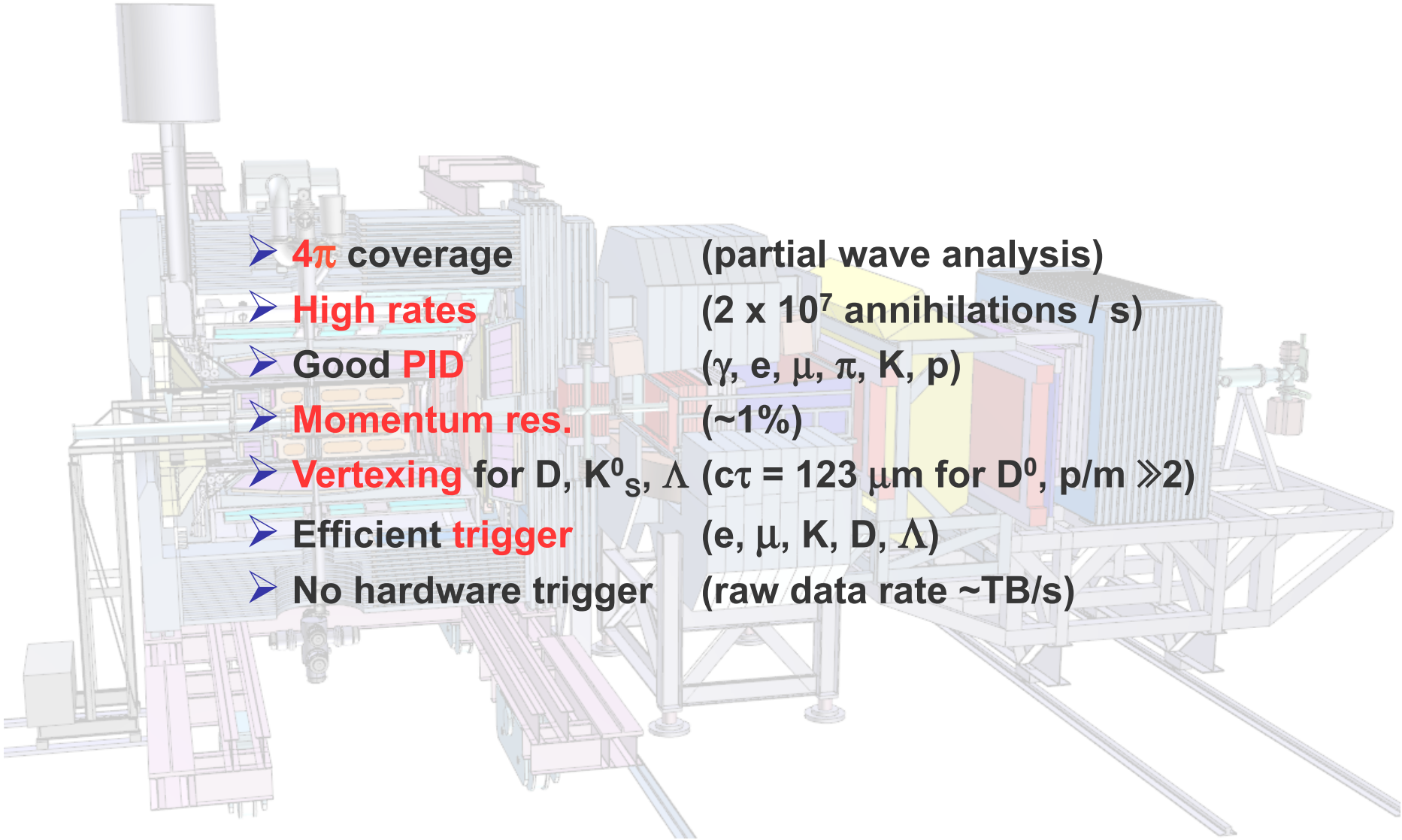
III. Technological innovation



Needle-in-a-haystack

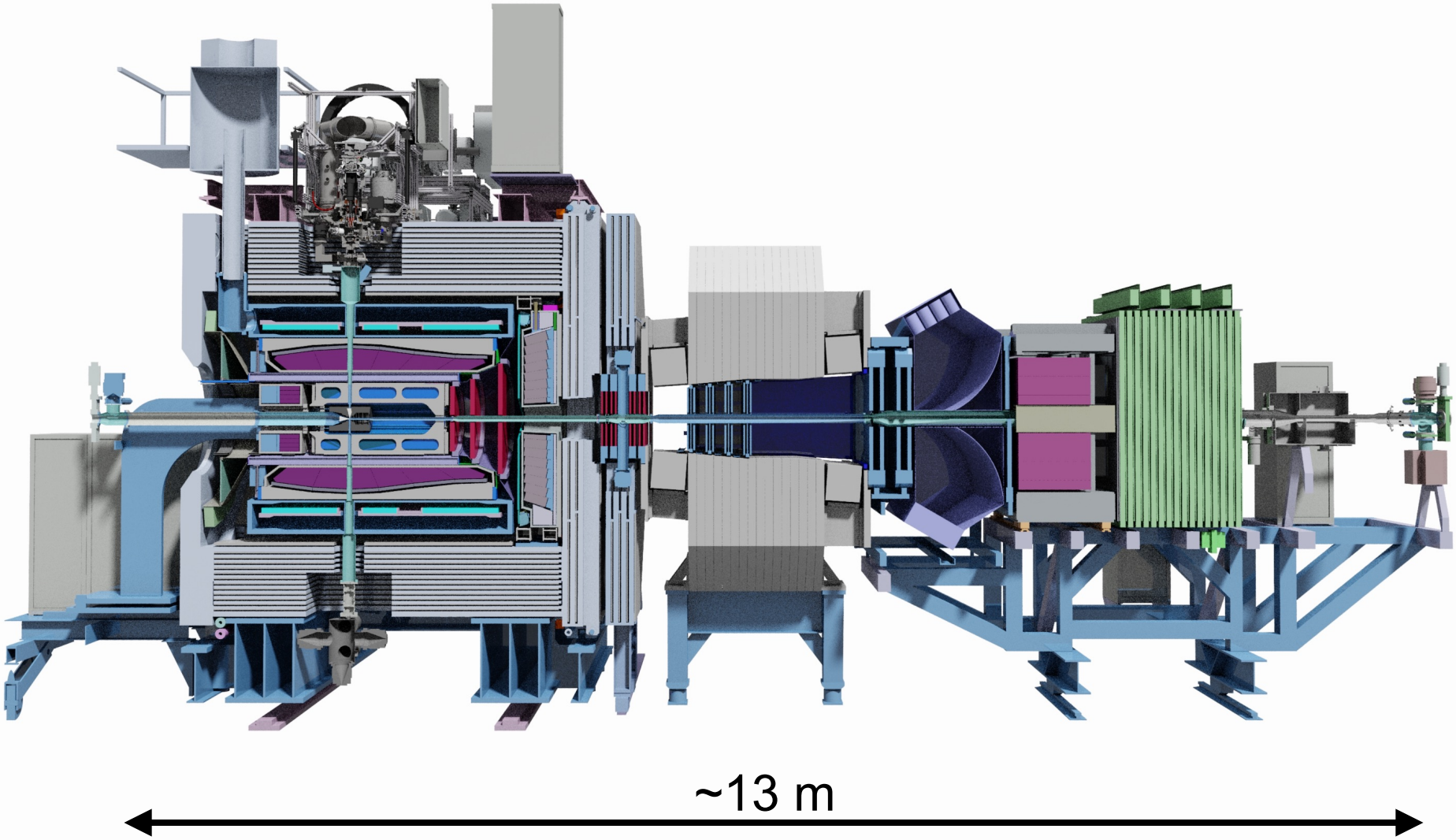


Detector requirements

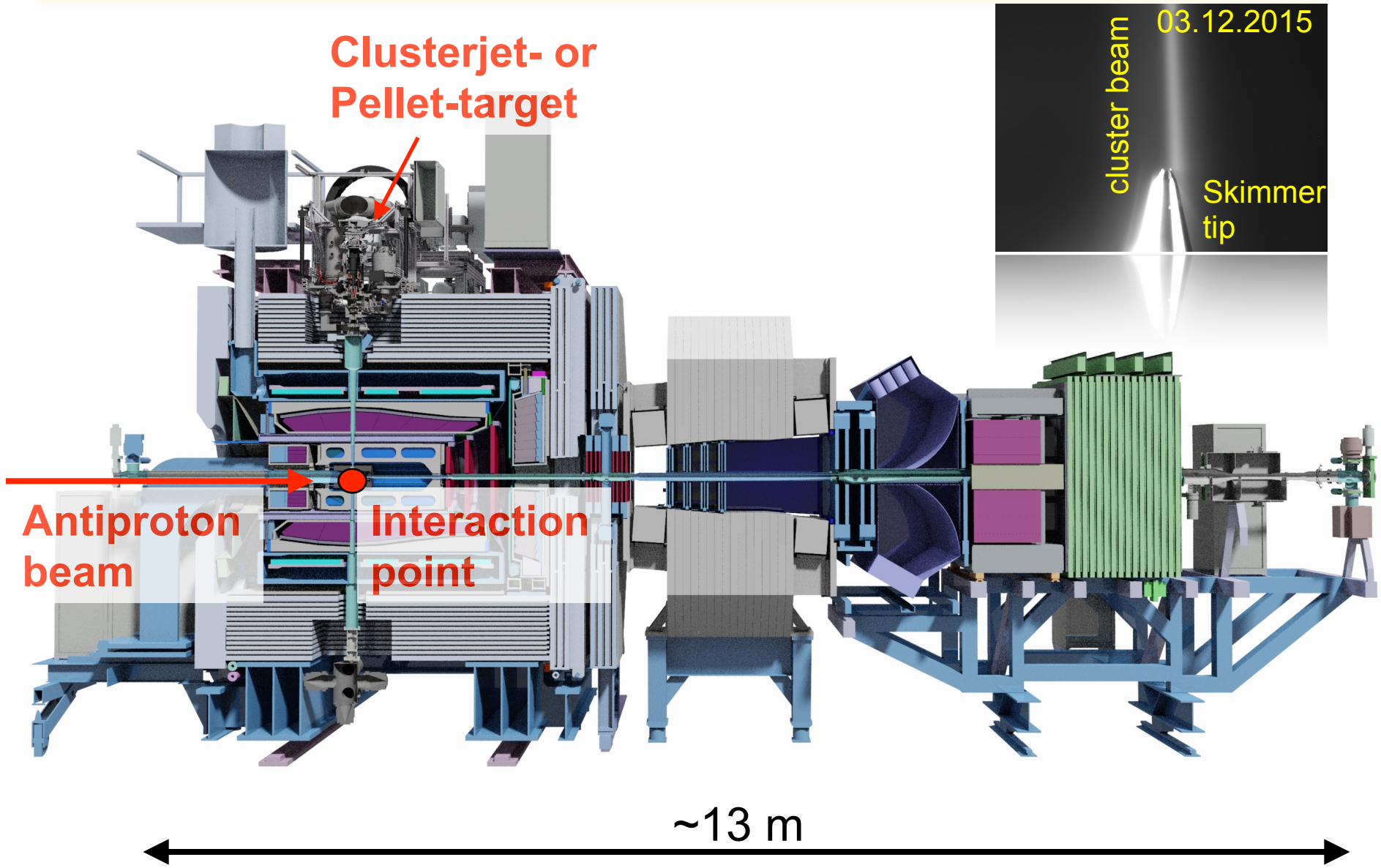


- 4π coverage (partial wave analysis)
- High rates (2×10^7 annihilations / s)
- Good PID (γ, e, μ, π, K, p)
- Momentum res. (~1%)
- Vertexing for D, K^0_S, Λ ($c\tau$ = 123 μm for D^0, p/m $\gg$2)
- Efficient trigger (e, μ, K, D, Λ)
- No hardware trigger (raw data rate ~TB/s)

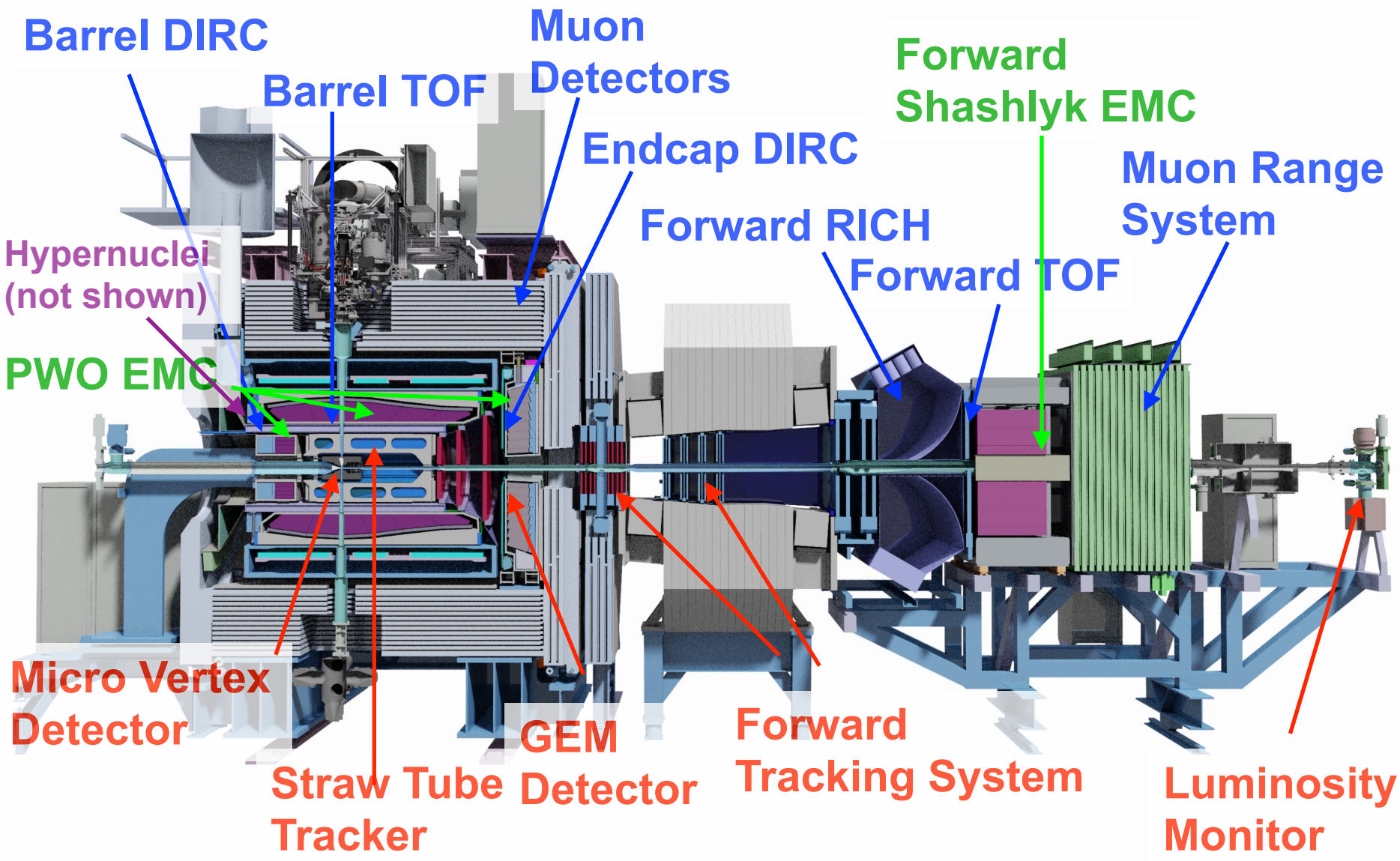
The PANDA detector



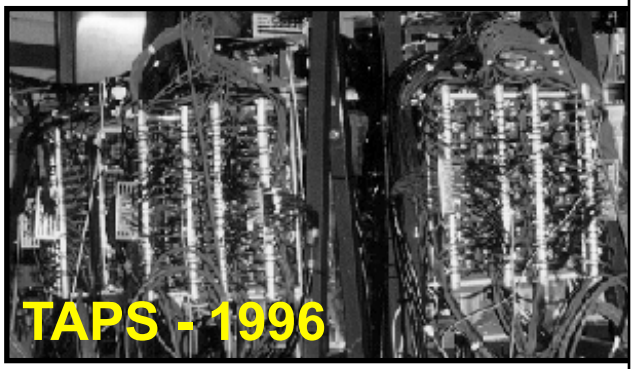
The PANDA detector



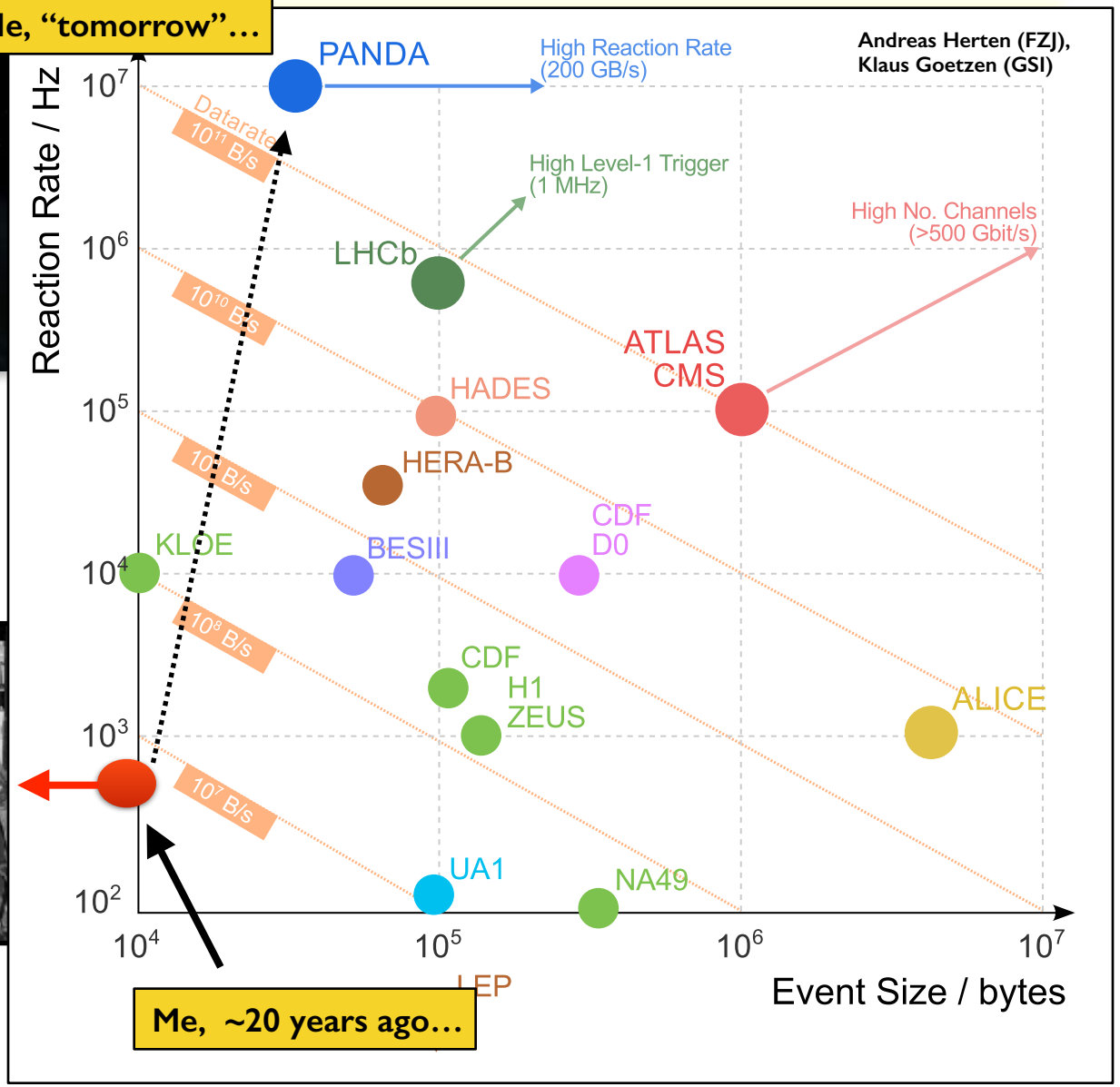
The PANDA detector



QCD physics - the next generation computing

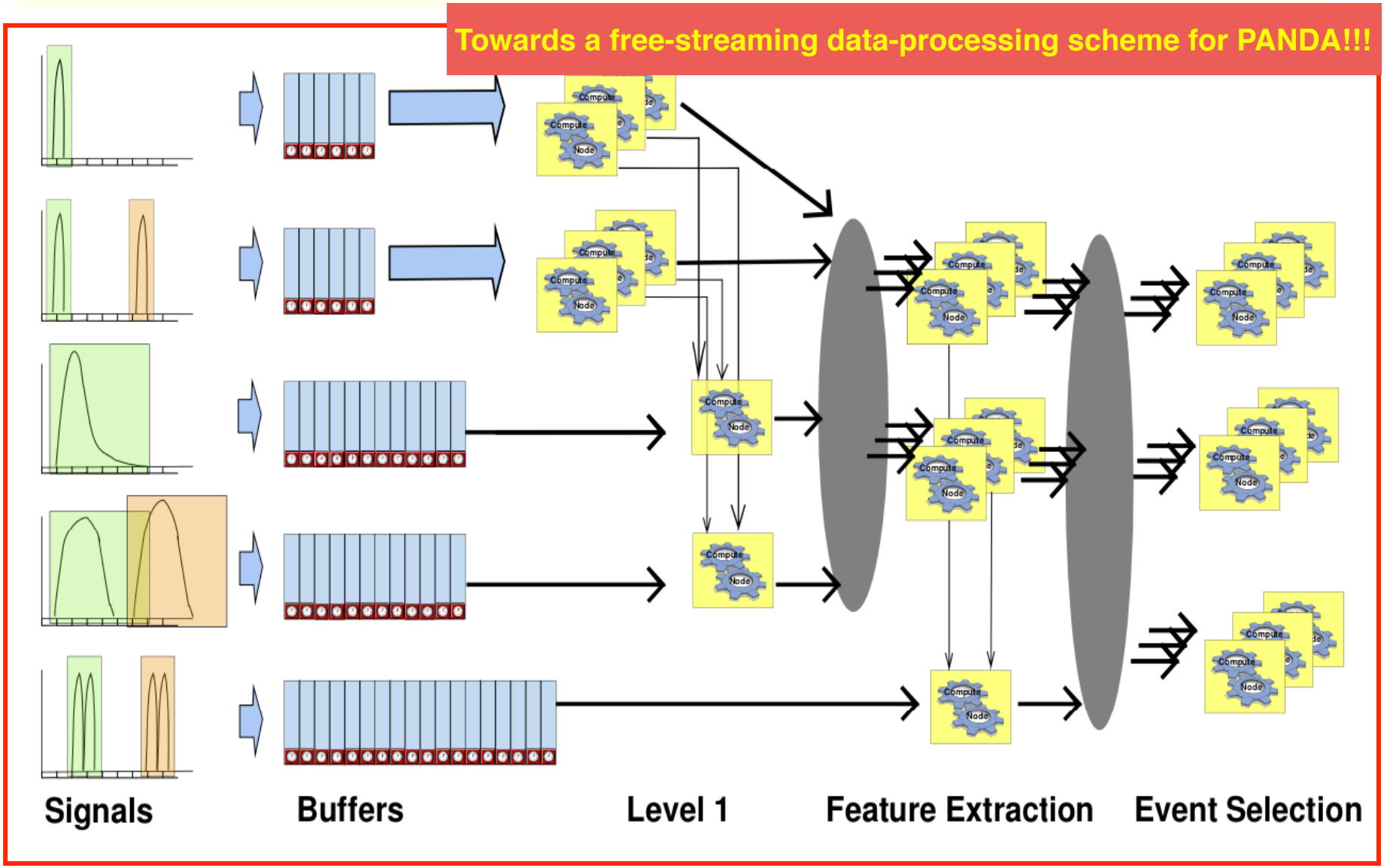


Me, "tomorrow"…



Me, ~20 years ago…

New paradigm in data processing



The PANDA experiment at FAIR …

… offers a unique environment to study QCD in its many facets.

… is working on a long-term program for todays and the next generation physicists.

… with key experiments already at “day one”.

Thanks for your attention and for all the support to PANDA!!

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Last Updated: Friday, 24 August 2007, 14:27 GMT 15:27 UK

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New optimism for panda survival

The giant panda has a better chance of survival than previously thought, scientists have discovered.

The Wolong Giant Panda Research Centre helped with the fieldwork

The fear had been that their bamboo diet, slow reproduction rate and isolated habitat made them unable to adapt as a species in the modern world.

But research by Cardiff University and scientists in Beijing shows they are more capable of evolving than believed.