The PANDA experiment at FAIR

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On behalf of the PANDA collaboration

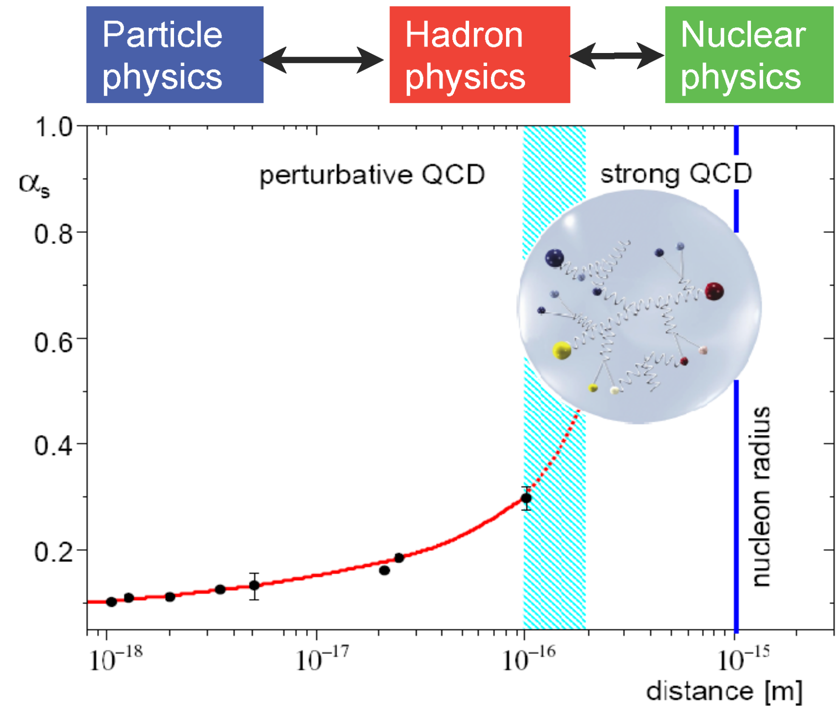
- Facility for Antiproton and Ion Research (FAIR)
- PANDA physics program
- PANDA spectrometer
- PANDA phases

MIN16 - Meson in Nucleus 2016, 31 July 2016

Physics scope

One of the open problems in the Standard Model is a full understanding of Quantum Chromodynamics (QCD):

- QCD describe well phenomena at high energies (perturbative regime).
- At low energies, QCD becomes a strongly coupled theory. Perturbation theory fails.

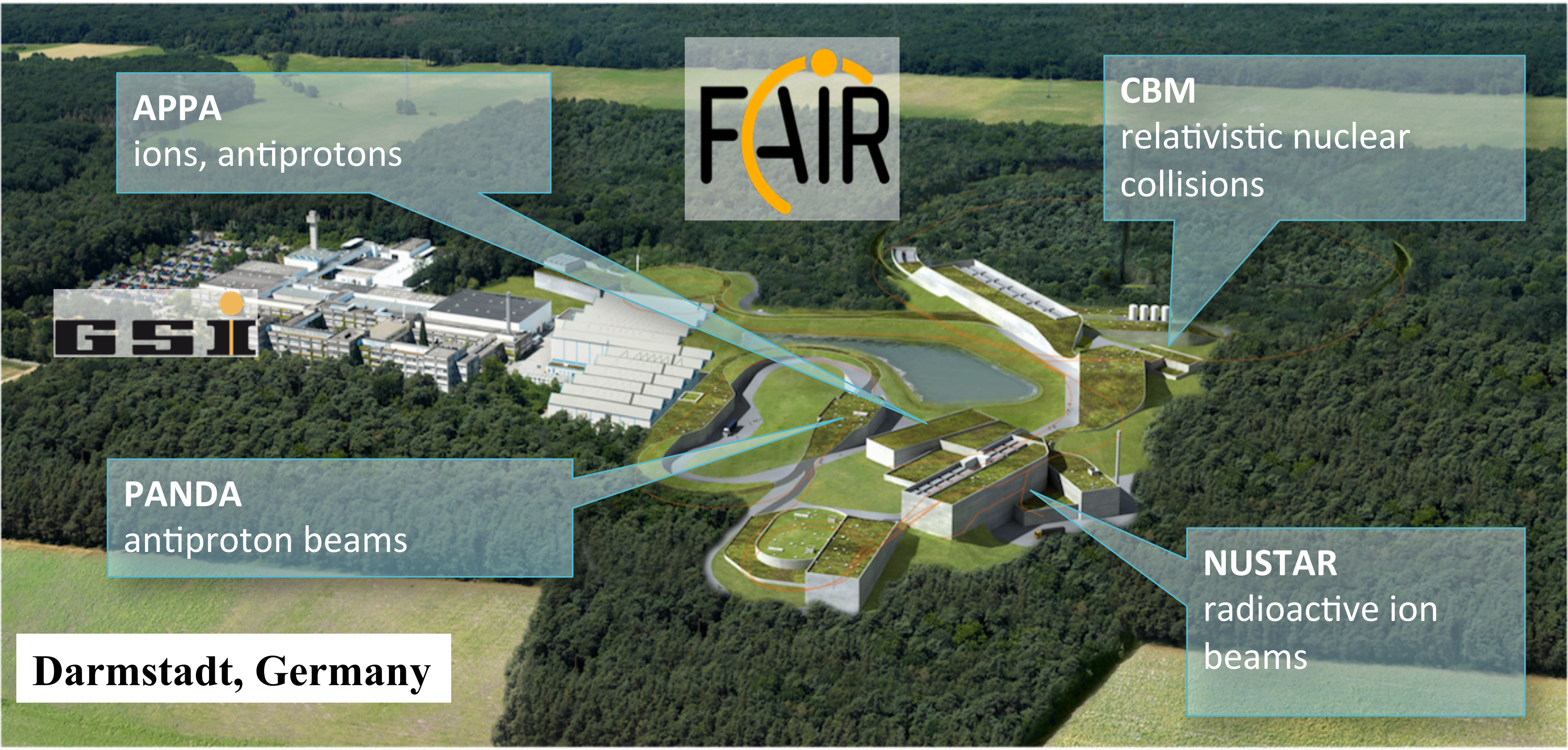


Open questions of QCD

- **Quark confinement**
- **Origin of the hadron mass**
- Establish evidence and properties of **hybrids, glueballs**
- **Hadron spectroscopy** (compare to theoretical model predictions, relevant degree of freedom)
- **Structure of the nucleon** (charge, magnetic and spin distributions)

Facility for Antiproton and Ion Research - FAIR

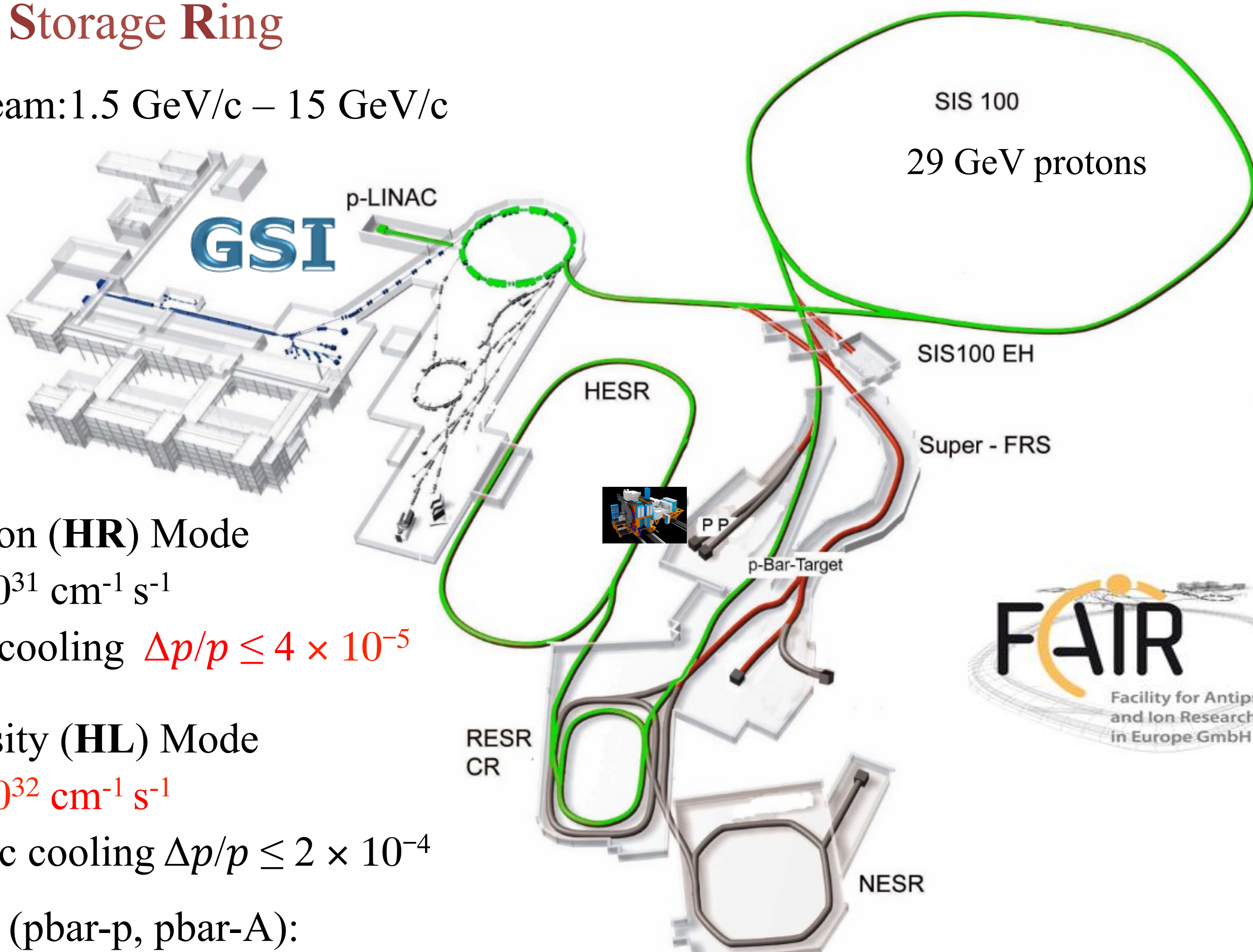
High quality antiproton beam over large energy range coupled to universal detectors and high luminosity is an ideal place to address the fundamental questions of the QCD in the non perturbative regime



Facility for **A**ntiproton and **I**on **R**esearch - FAIR

High **E**nergy **S**torage **R**ing

- Antiproton beam:1.5 GeV/c – 15 GeV/c



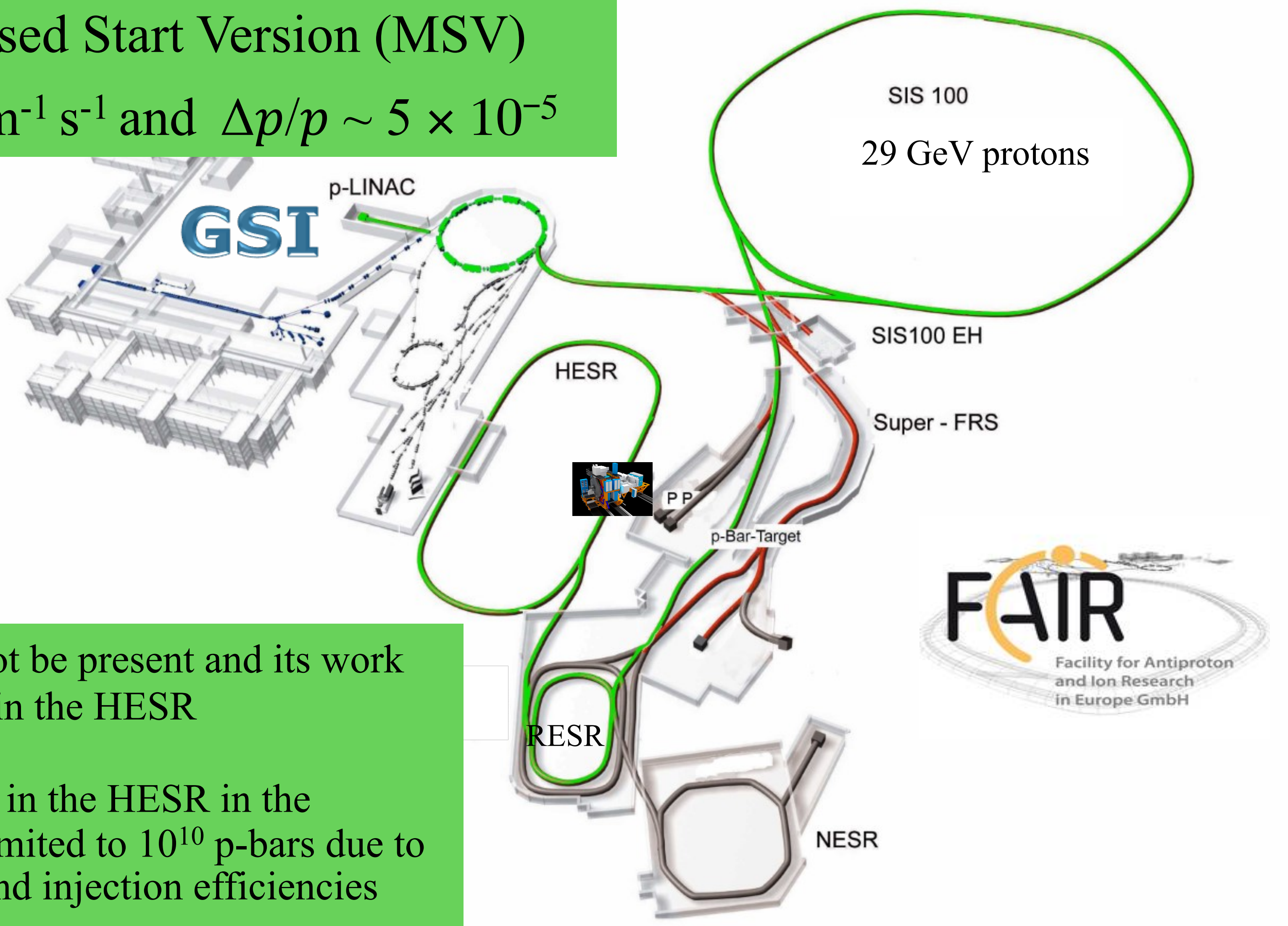
- High Resolution (**HR**) Mode
  - $L = 2 \times 10^{31}$ cm^{-1} s^{-1}
  - Electron cooling $\Delta p/p \leq 4 \times 10^{-5}$
- High Luminosity (**HL**) Mode
  - $L = 2 \times 10^{32}$ cm^{-1} s^{-1}
  - Stochastic cooling $\Delta p/p \leq 2 \times 10^{-4}$
- Internal target (pbar-p, pbar-A):
  cluster jet / pellet target; high density 4×10^{15} cm^{-2}

FAIR
Facility for Antiproton and Ion Research in Europe GmbH

FAIR-HESR (start version)

Modularised Start Version (MSV)

$L \sim 10^{31}$ cm^{-1} s^{-1} and $\Delta p/p \sim 5 \times 10^{-5}$



- RESR will not be present and its work will be done in the HESR
- The intensity in the HESR in the MSV0-3 is limited to 10^{10} p-bars due to the cooling and injection efficiencies

The PANDA experiment at FAIR

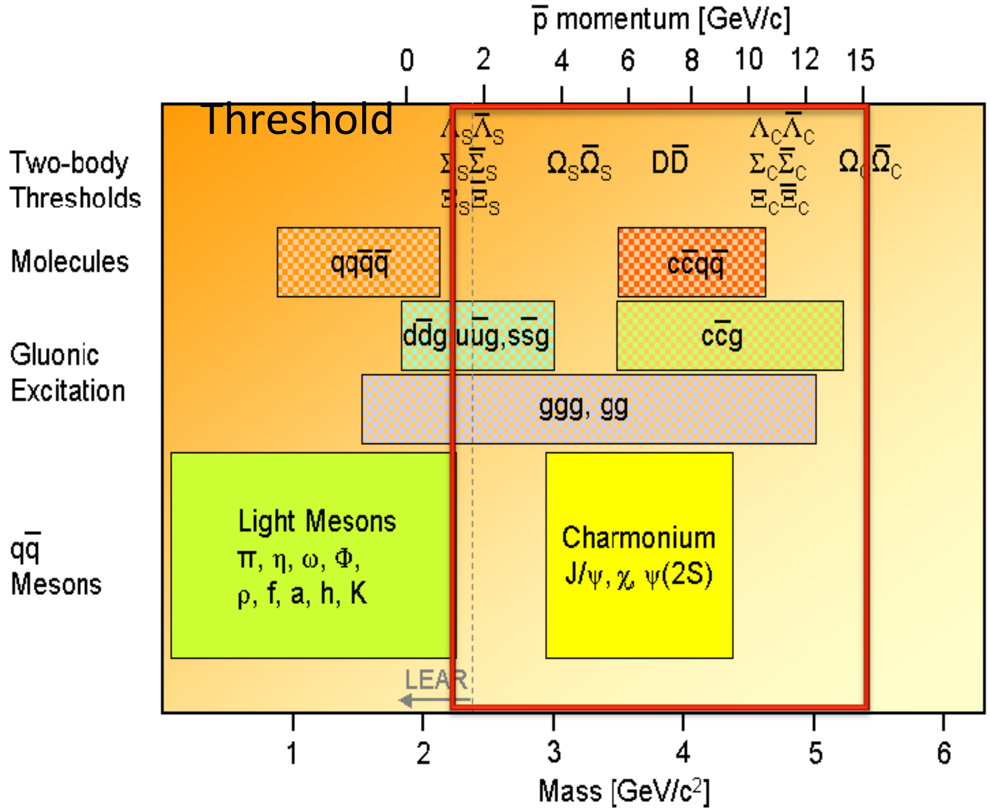
More than 520 physicists from 70 institutions in 19 countries

Hadron Spectroscopy and dynamics
- Charmonium
- Light mesons
- Gluonic exitations
- Open charm
- (Multi) strange baryons

Nucleon structure
- Electromagnetic form factors
- TMDs
- GPDs, TDAs

Hypernuclear physics

Hadrons in the nuclear medium

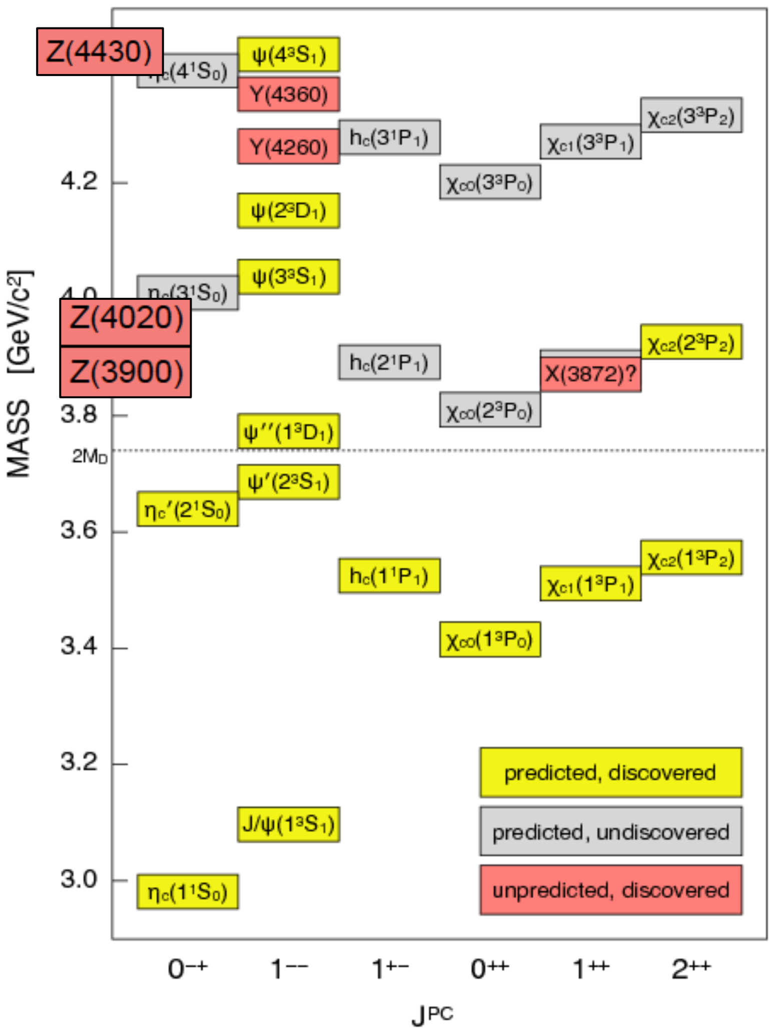


ArXiV:0903.3905

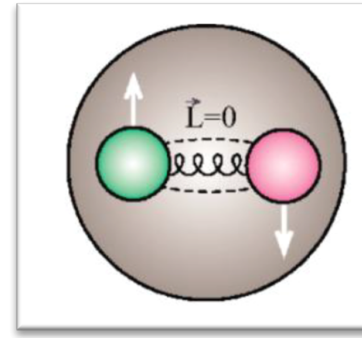
- **Charmonium (-like) spectroscopy**

Charmonium (-like) spectroscopy

Charmonium probe the perturbative, non perturbative transition regime



$c\bar{c}$ Bound state



- The mass scale is perturbative:

  $m_c \approx 1.5\ GeV >> \Lambda_{QCD}$

- The system is non relativistic:

  $v^2 \approx 0.3,\ m_c >> m_c v >> m_c v^2$

Below DD threshold:

- Good agreement between experiment and quark model prediction
- Available data on some states require more precise measurements (i.e $\eta_c(2S)$, h_c)

Above DD threshold:

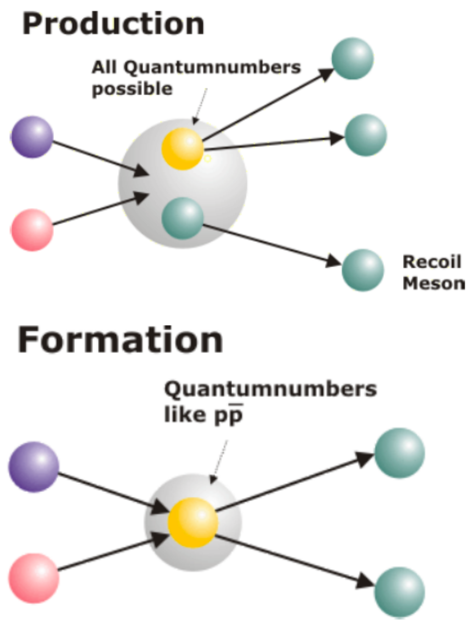
- Expected states not observed
- Unexpected states observed: their nature is not yet established (hybrids, glueball, molecule,…)

=> high precision measurements of width and line shape

Spectroscopy at PANDA: Precision and discovery

Pbar-p annihilation (PANDA)

- Access to both **exotic and non-exotic quantum numbers** via **production** and **formation** reactions
- Gluon-rich environment
- High spin (L) states can be produced
- All states with non exotic quantum numbers directly formed (only $J^{PC} = 1^{--}$ in e^+e^-)



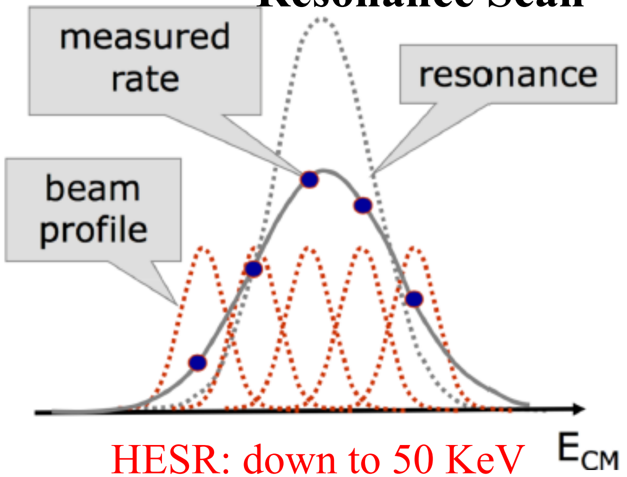
- The resonance can be extracted by measuring the formation rate for that resonance as a function of the cm energy

- Antiproton beam can be efficiently cooled $\Delta p/p \sim 10^{-5}$

High-precison measurement of masses and widths

unique at PANDA: Lineshape measurement

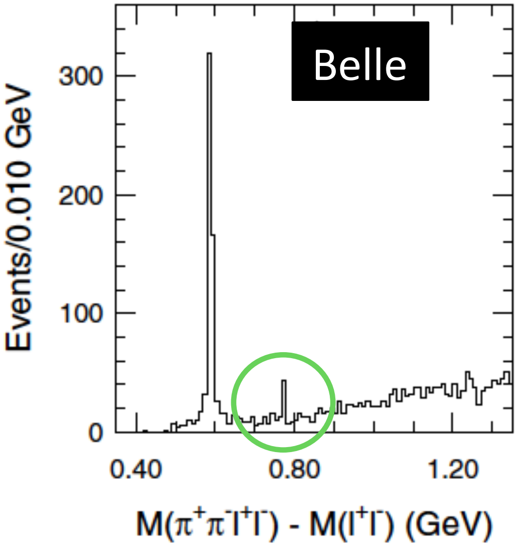
Resonance Scan



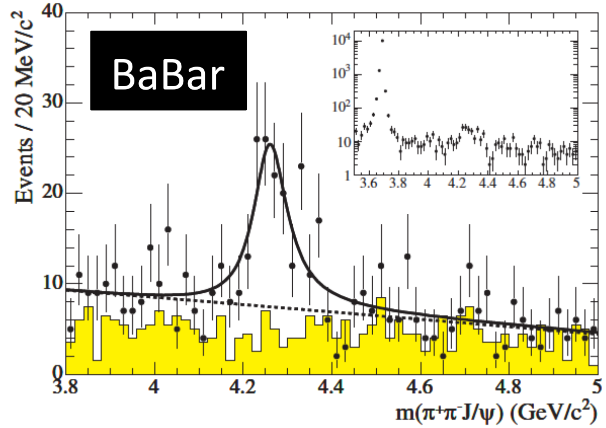
HESR: down to 50 KeV

X,Y, Z states

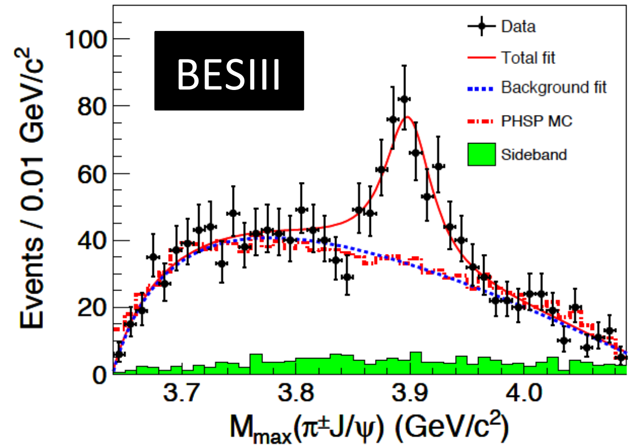
X(3872)



Y(4260)



$Z_c(3900)$



Case X(3872) -> $J/\psi\rho^0$ -> $e^+e^-/\mu^+\mu^-\ \pi^+\pi^-$

- PANDA (**MSV0-3, no RESR**): ~120 reconstructed events per day
- BELLE II: ~1500 events in 4 years
- BESIII: ~20 events in 4 weeks

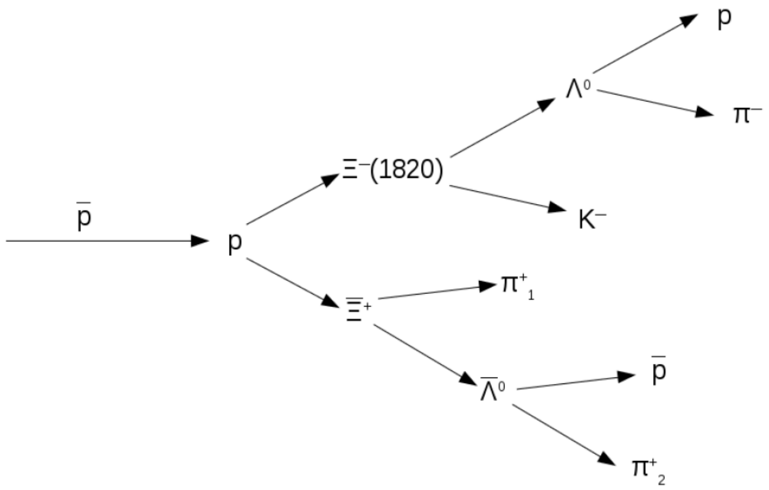
PANDA *1170 nb^{-1}/d (MSV0-3, no RESR)*

~120 X(3872)/day, 820 Y(4260)/day, 180 Z(3900)/day

PANDA is a X,Y, Z factory: high statistics X,Y,Z data sample

- **Baryon spectroscopy and dynamics**

Strange and charmed baryons

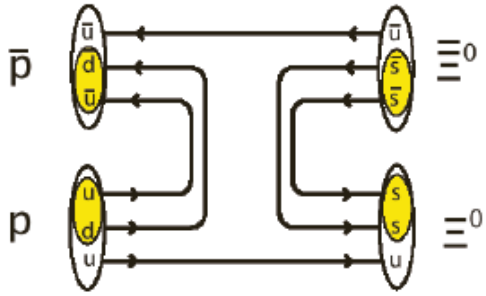


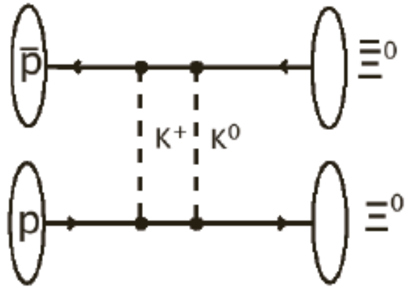
~ 5000 inclusive events/day (Lumi 10^{31} cm^{-2} s^{-1})

Baryon Spectroscopy

- Relevant degrees of freedom?
- New baryon states ?
- Properties of already known states
- Symmetries in observed spectrum

PANDA is a Strangeness Factory



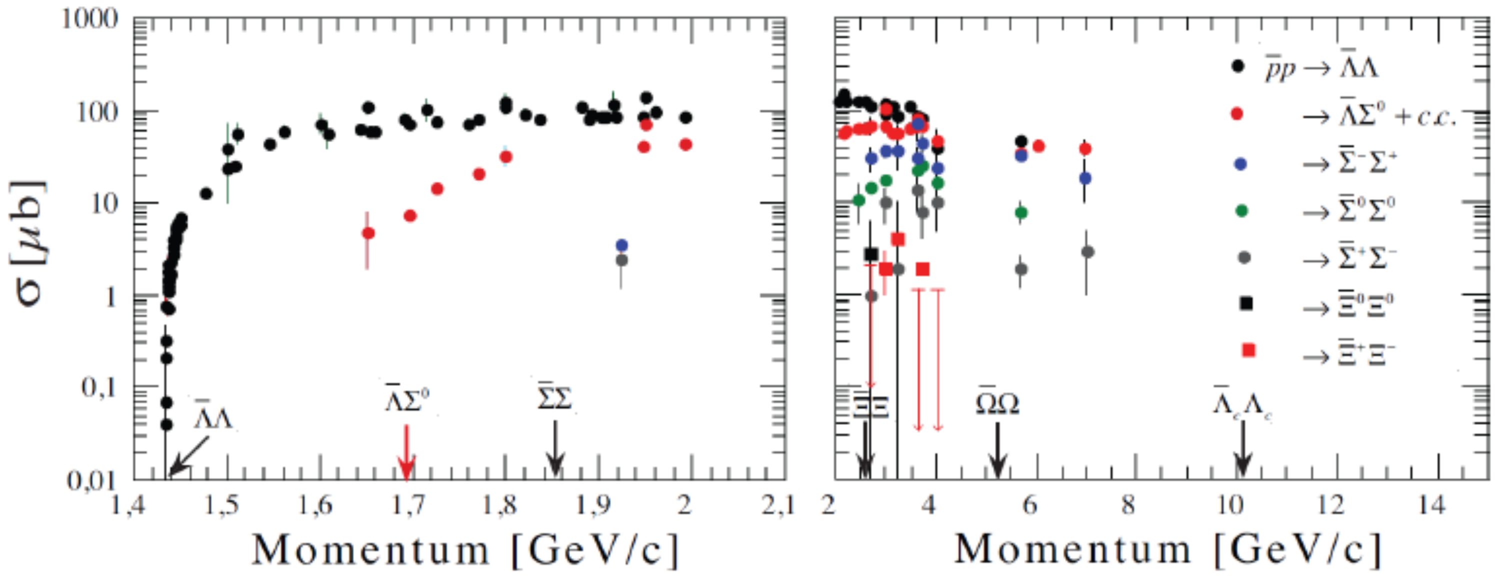


Spin Observables in baryon production / decay

- Reaction mechanism at different energy scales
- The role of spin in the production of heavy quarks
- CP violation

Access to spin observables even with unpolarised beam/target

Hyperon physics

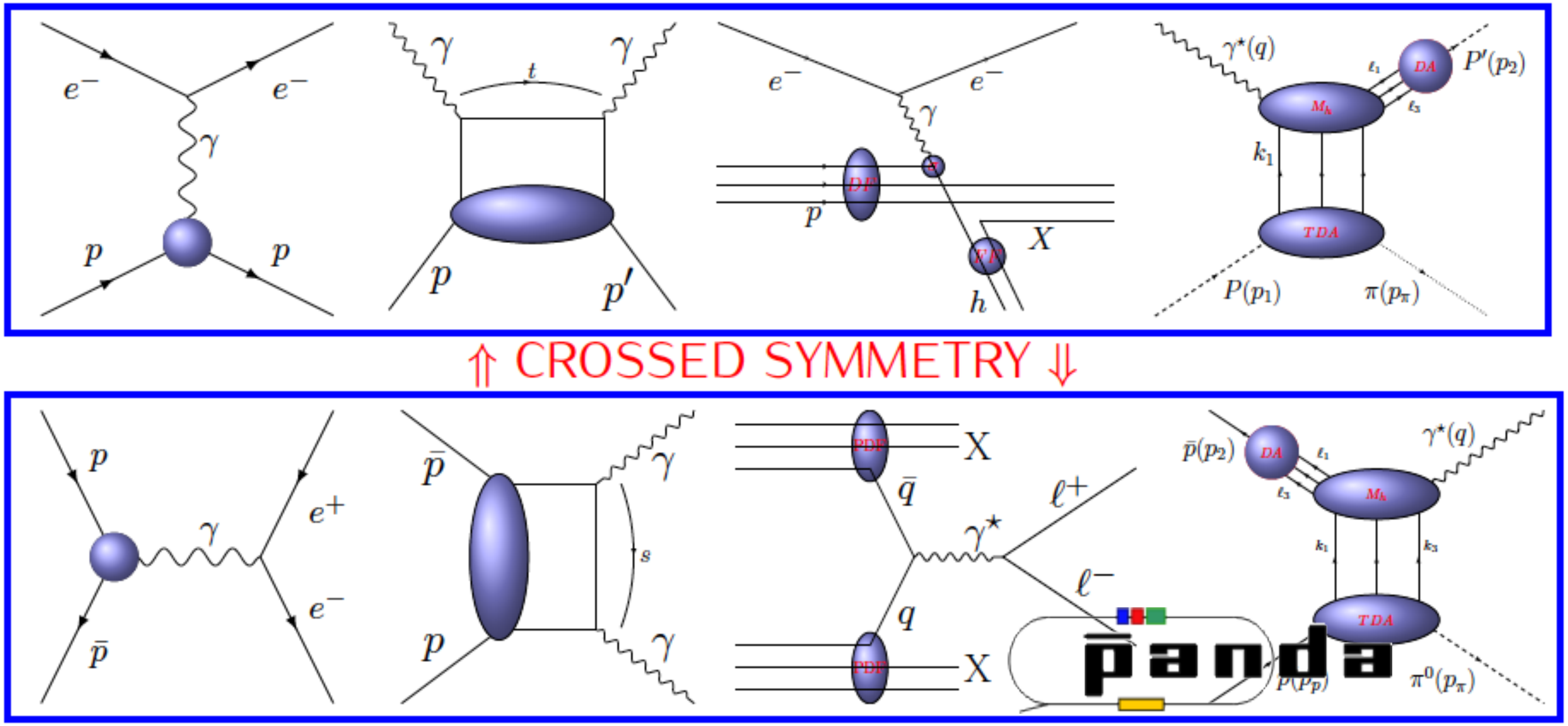


S=2 hyperons (Ξ)
S=0 baryons (N)
S=1 hyperons (Λ)
S=3 hyperons (Ω)
Charmed (Λc, Σc)
Hidden charm (N_{ccbar})

PANDA is a Strangeness Factory

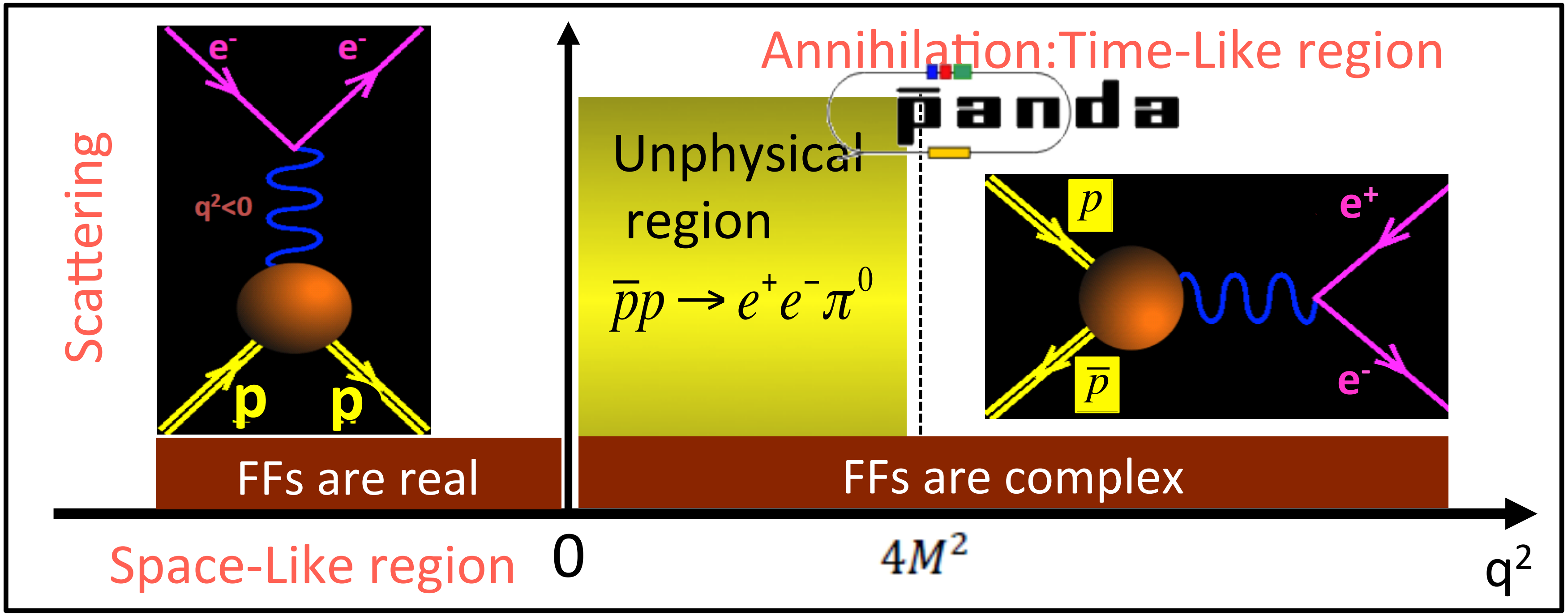
- Large cross section s for pbarp → YbarY
  - pp → ΞΞ ≈ μb
  - pp → ΩΩ ≈ 0.002 ÷ 0.06 μb
- No extra mesons in final state needed for strangeness or charm conservation
- Symmetry in hyperon and antihyperon

- **Nucleon structure**



- Proton Electromagnetic Form Factors (FFs)
- Generalized Distribution Amplitudes (GDAs)
- Transverse Momentum Dependent Parton Distribution Functions (TMD-PDFs)
- Transition Distribution Amplitudes (TDAs)

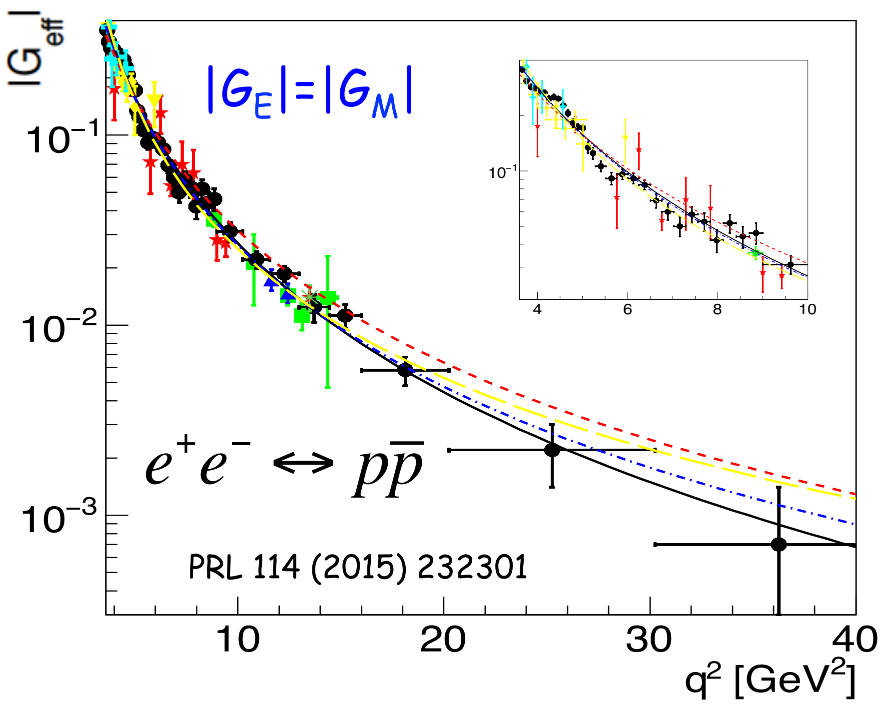
Proton electromagnetic form factor: the analyticity

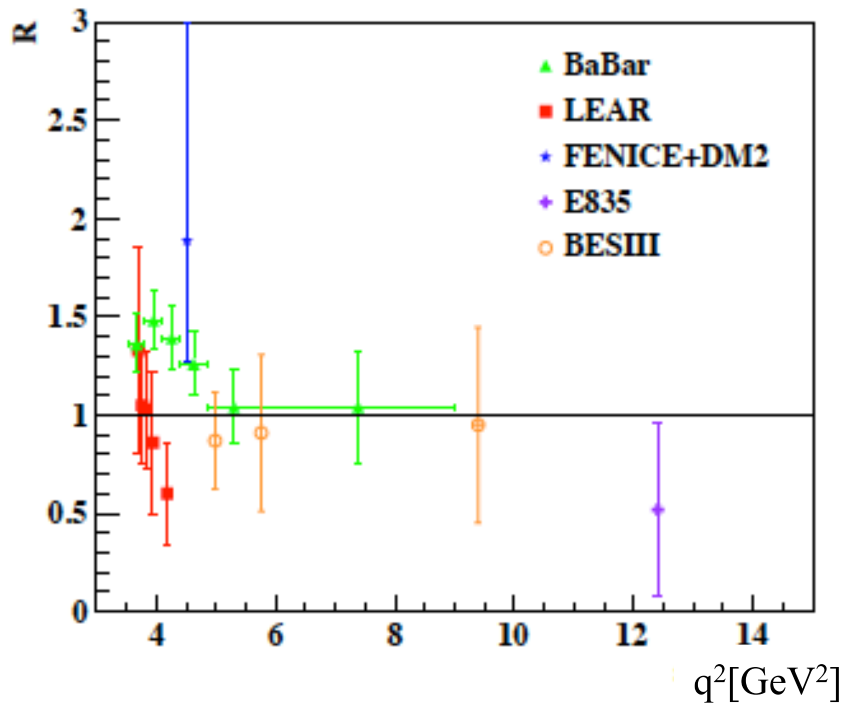


- **Electric G_E and magnetic G_M** proton FFs are analytical functions of the momentum transfer squared q^2

- Playground for theory and experiment:
  - at low q^2, probe the size of the nucleus,
  - at high q^2, test QCD scaling

Time-Like proton electromagnetic form factors

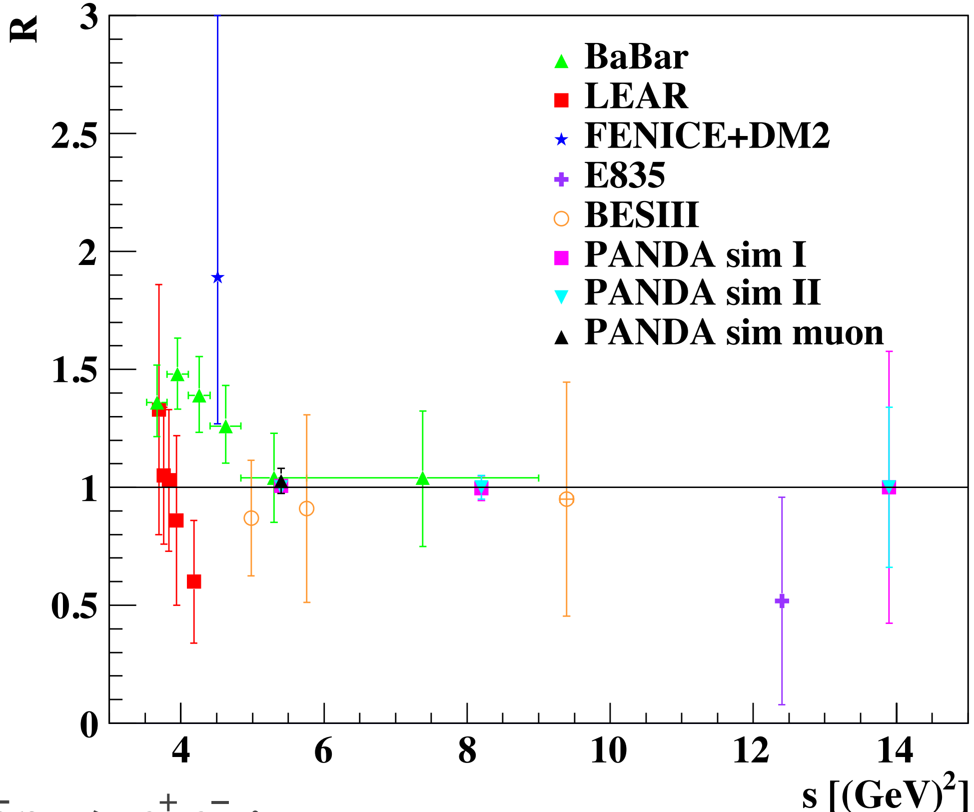




- No individual determination of G_E and G_M
- Steep behaviour of the **effective form factor (G_{eff})** at threshold
- Structures appeared in BaBar data (PRD 87 (2013) 092005)?
  - Resonances (PRD 92 (2015) 034018)
  - Rescattering processes between few coherent sources (PRL 114 (2015) 232301)
- **Form factor ratio (R)**: discrepancy between LEAR (NPB 411 (1994) 3) and BaBar data

Time-Like proton electromagnetic form factors

$\bar{p}p \rightarrow e^+e^-$ $\bar{p}p \rightarrow \mu^+\mu^-$



$\bar{p}p \rightarrow e^+e^-$:

Study of the systematic effects (sim I and sim II): Effects of the event generator model on the efficiency determination, effect of fluctuations and fit function

- Measurement of effective form factor over wide q^2 range (28 GeV^2)
- Individual measurement of $|G_E|$ and $|G_M|$ and their ratio R
- First measurement of form factors with muons.
- Measurement of FFs in the TL unphysical region
- Longer range goal: measurement of relative phase of $|G_E|$ and $|G_M|$ via polarisation observables.

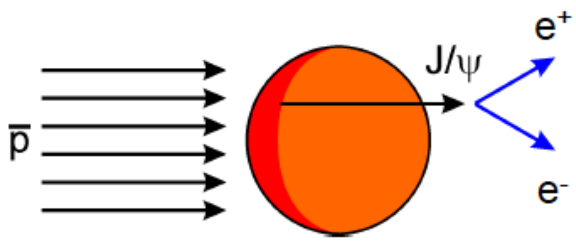
- **Hadrons in nuclear medium**

Hadrons in the nuclear medium

The PANDA detector setup allows using heavy nuclear targets, giving access to the study of antiproton-nucleus collisions:

- Charmonium nucleon interaction

J/ψ N dissociation cross section with Pbar-A at 4.5 GeV



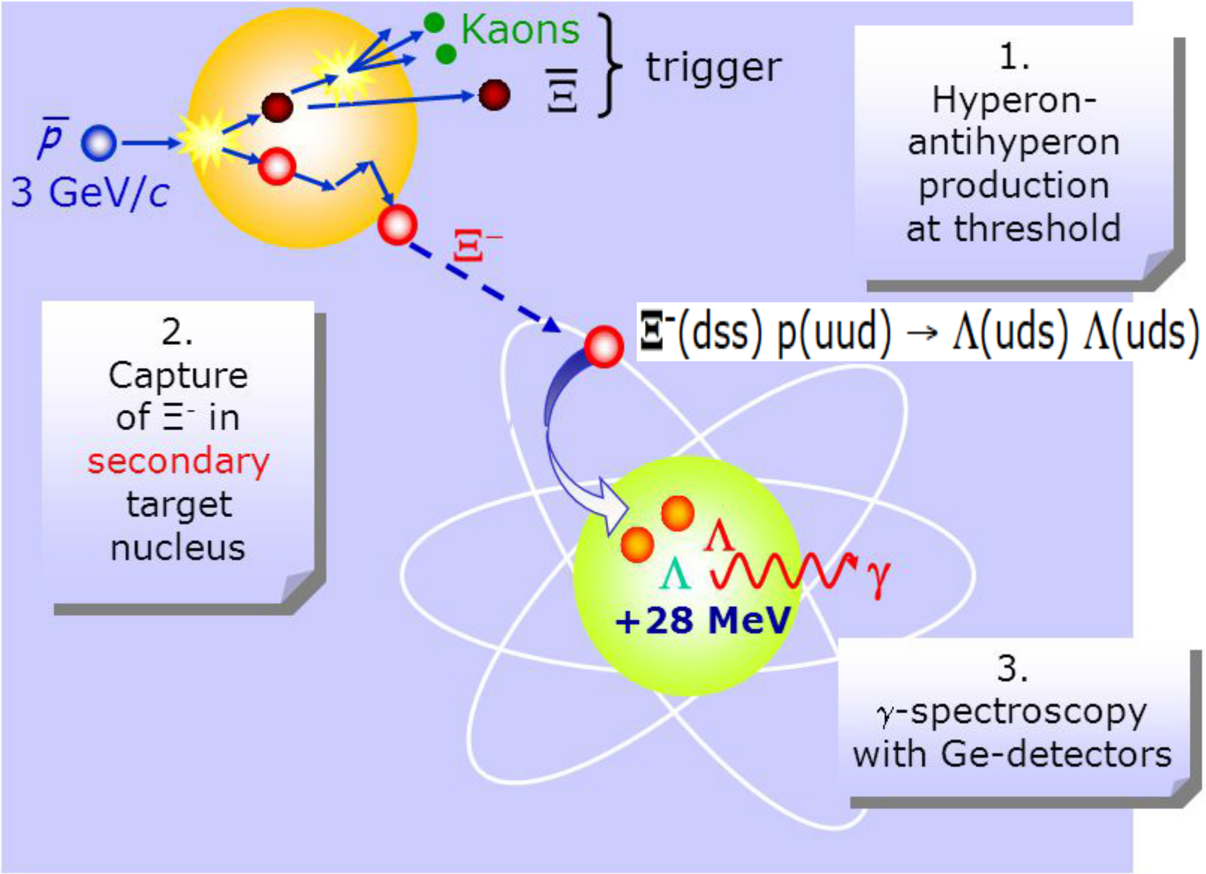
- well-defined conditions: exclusive resonant J/ψ formation on target proton at rest at 4.05 GeV/c
- antiproton mean free path sufficiently known

- Nuclear potential of hadrons (antibaryons, K, …)
- Color transparency
- Short range nucleon correlations
- High resolution γ-Spectroscopy of ΛΛ hypernuclei

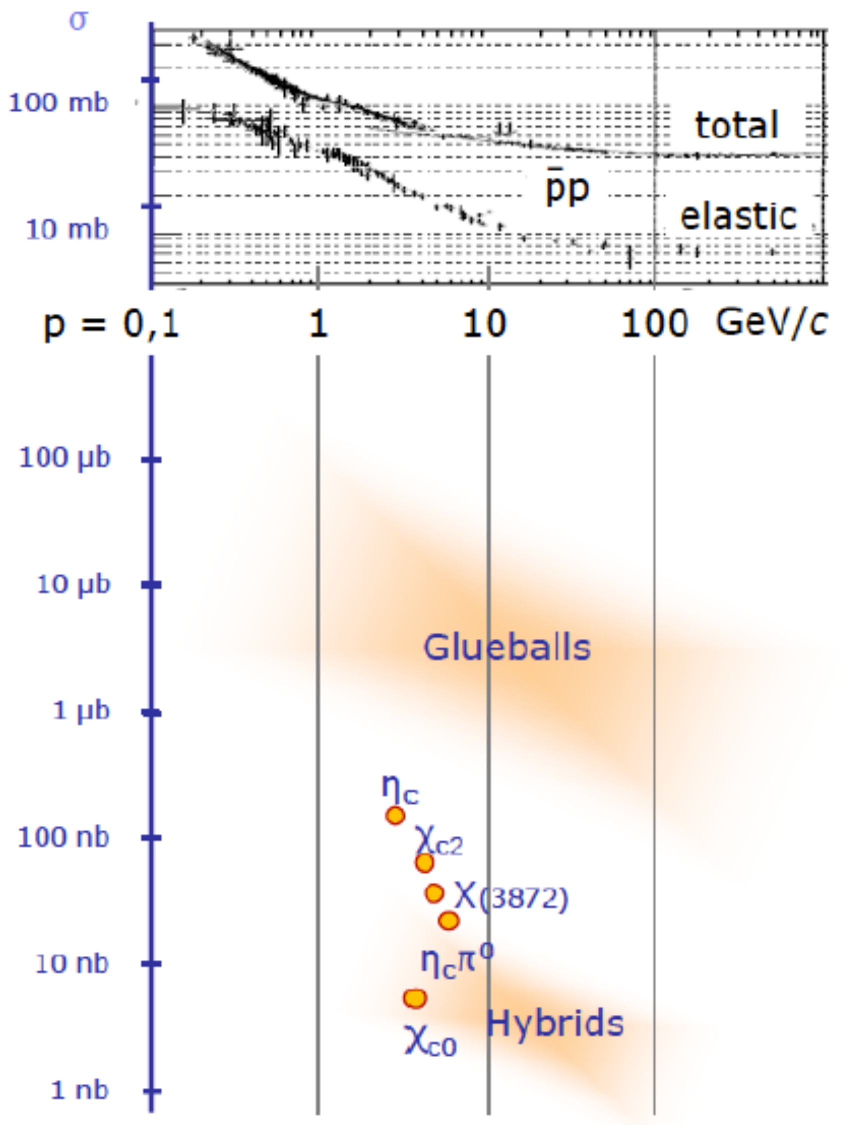
Hadrons in the nuclear medium

ΛΛ−hypernucleus production @ PANDA

- High production rate;
- Many hypernuclear systems at the same time
- High acceptance/resolution magn. Spect. for neutral and charged
- Ge-detectors for X-.-ray transitions



The PANDA detector



4π acceptance

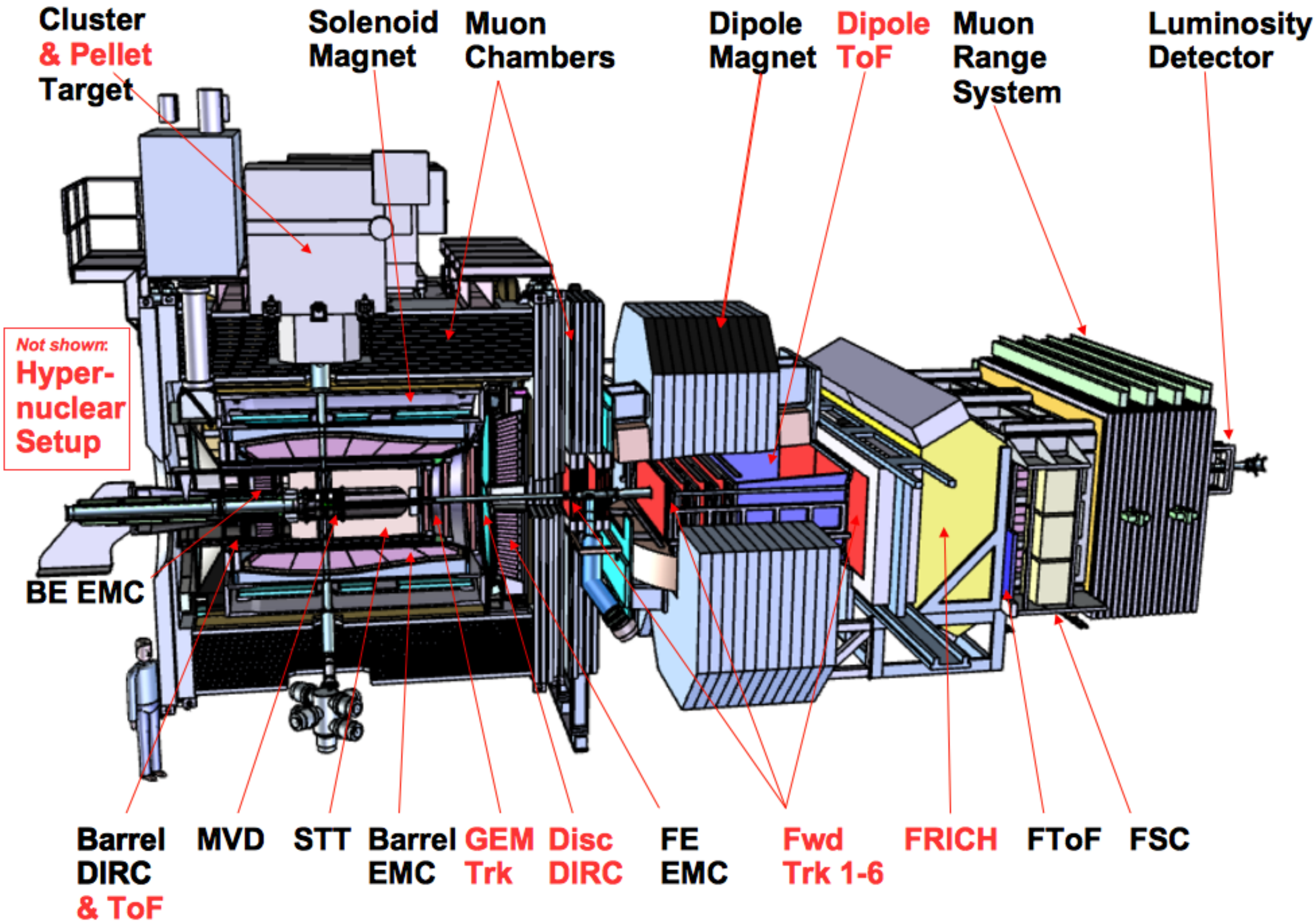
Momentum resolution: 1%
central tracker in magnetic field

Photon detection: 1 MeV - 10 GeV
high dynamic range
good energy resolution

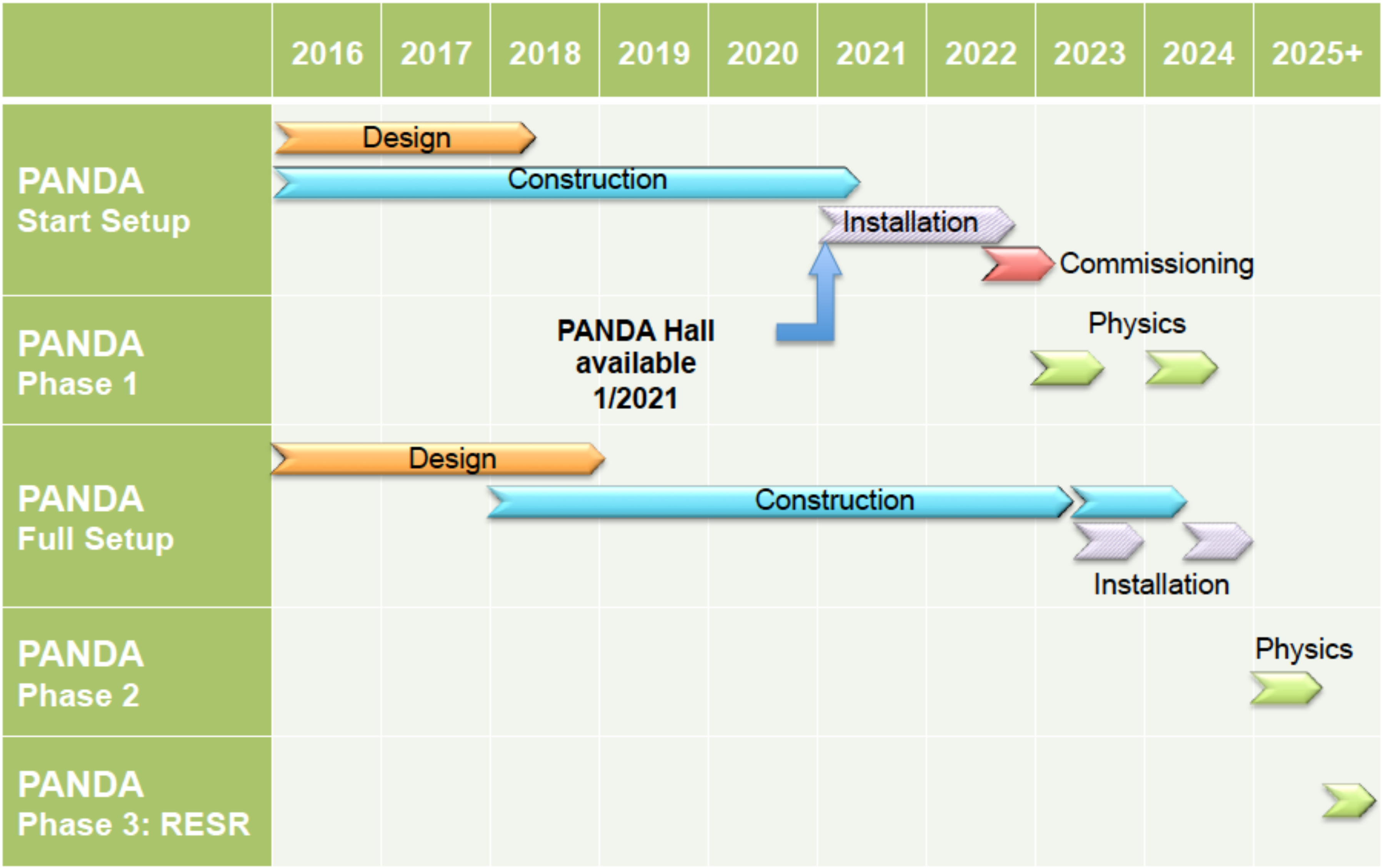
Particle identification: γ, e, μ, π, K, p
Cherenkov detector
time of flight, dE/dx, muon counter

Displaced vertex info
$c\tau = 317$ μm for D±
$\gamma\beta \approx 2$

The PANDA detector (start and full setup)



PANDA Phases



EMMI Rapid Reaction Task Force meeting

“ Resonances in QCD ” - GSI October 12-14, 2015

Experts from international spectroscopy Community: BaBar, LHCb, BES, Belle, COMPASS, Jlab, Spring-8, ELSA & Theory accepted in NPA, hep-ph: arXiv:1511.09353

Glueballs and hybrids:
“… Indeed PANDA complements and extends other experimental programmes ....
... the rates at PANDA will be high (10^7 candidate events per day) … “

Open Charm:
“… High precision measurements of the width are needed to scrutinize this picture. PANDA … go down to about 100 keV by means of a threshold scan in p-bar p of
No other experiment can be that precise.”

Light baryons:
… Larger rates are foreseen with PANDA; which is expected … to search for doubly-strange baryons…

Summary

- The high quality antiproton beams of FAIR between 1.5 and 15 GeV/c allows the PANDA experimental program to cover the three pillars of hadron physics

  – hadron spectroscopy
  – hadron structure
  – hadron interaction

- PANDA is unique in combining the potential for discoveries with the ability to carry out precise and systematic measurements

Thank you for your attention