Hadron Physics at PANDA

European Particle Physics Strategy Meeting

HI Mainz, Nov 20, 2018

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GSI/U Frankfurt

PANDA physics: light, strange, charm

No need for textbook motivations about the non-abelian structure of QCD and its problems

Key questions in "strong" QCD

Nucleon properties

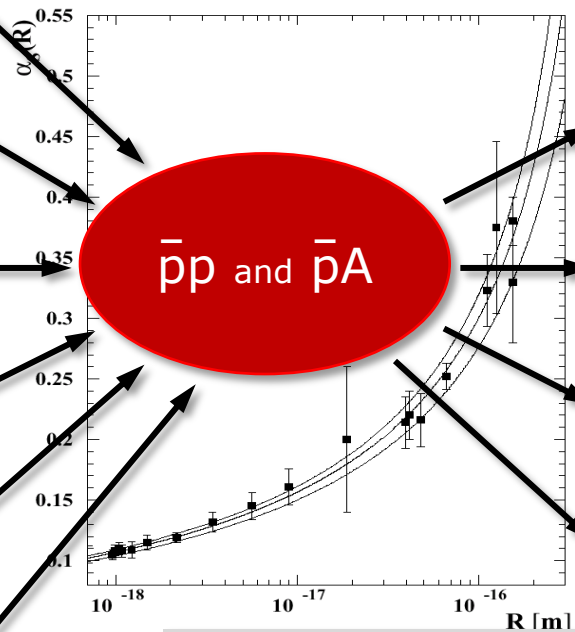
Exotics hadrons

In-medium hadron properties

Color transparency

Neutron stars

Matter-antimatter asymmetry



$\bar{p}p$ and $\bar{p}A$

PANDA Physics Pillars

Nucleon structure

Strangeness physics

Charm and exotics

Hadrons in Nuclei

Impact by precision (statistics & resolution) and uniqueness (terra incognita)

Why Antiprotons

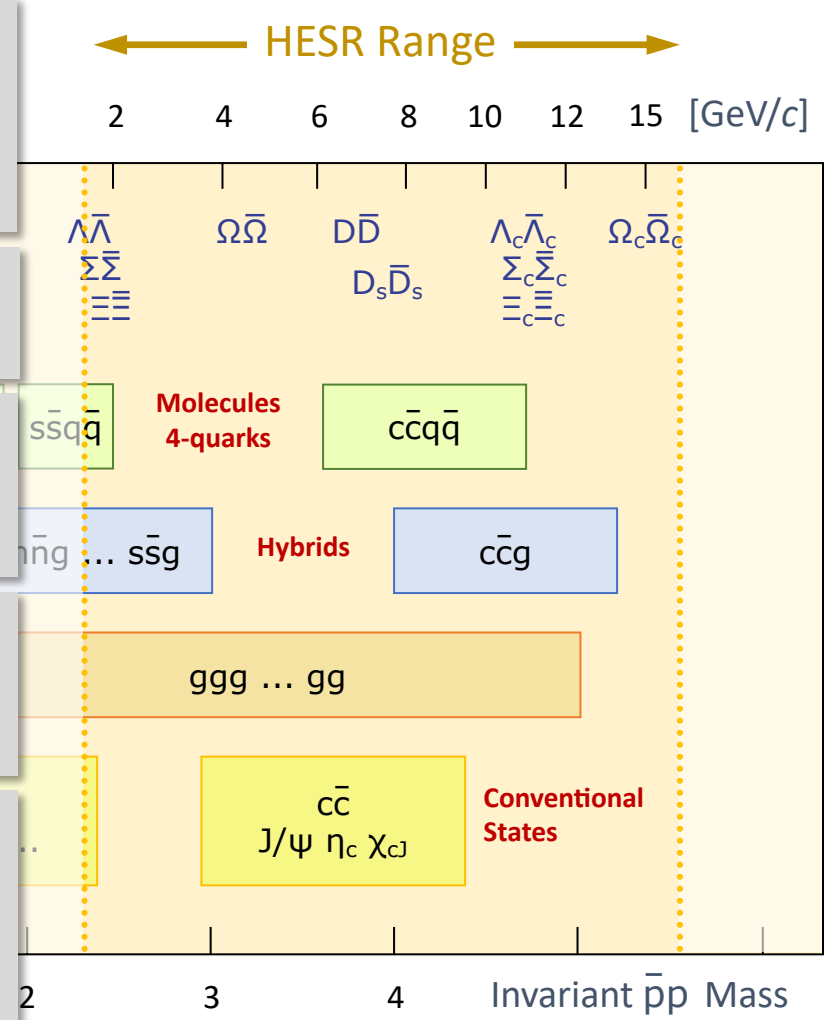
Large mass-scale coverage
- creation of mass rather than momentum
- center-of-mass energies from 2 to 5.5 GeV
- from light, strange, to charm-rich hadrons

Mass scan experiments with beam-resolution
- unique linescans → discovery by precision!

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

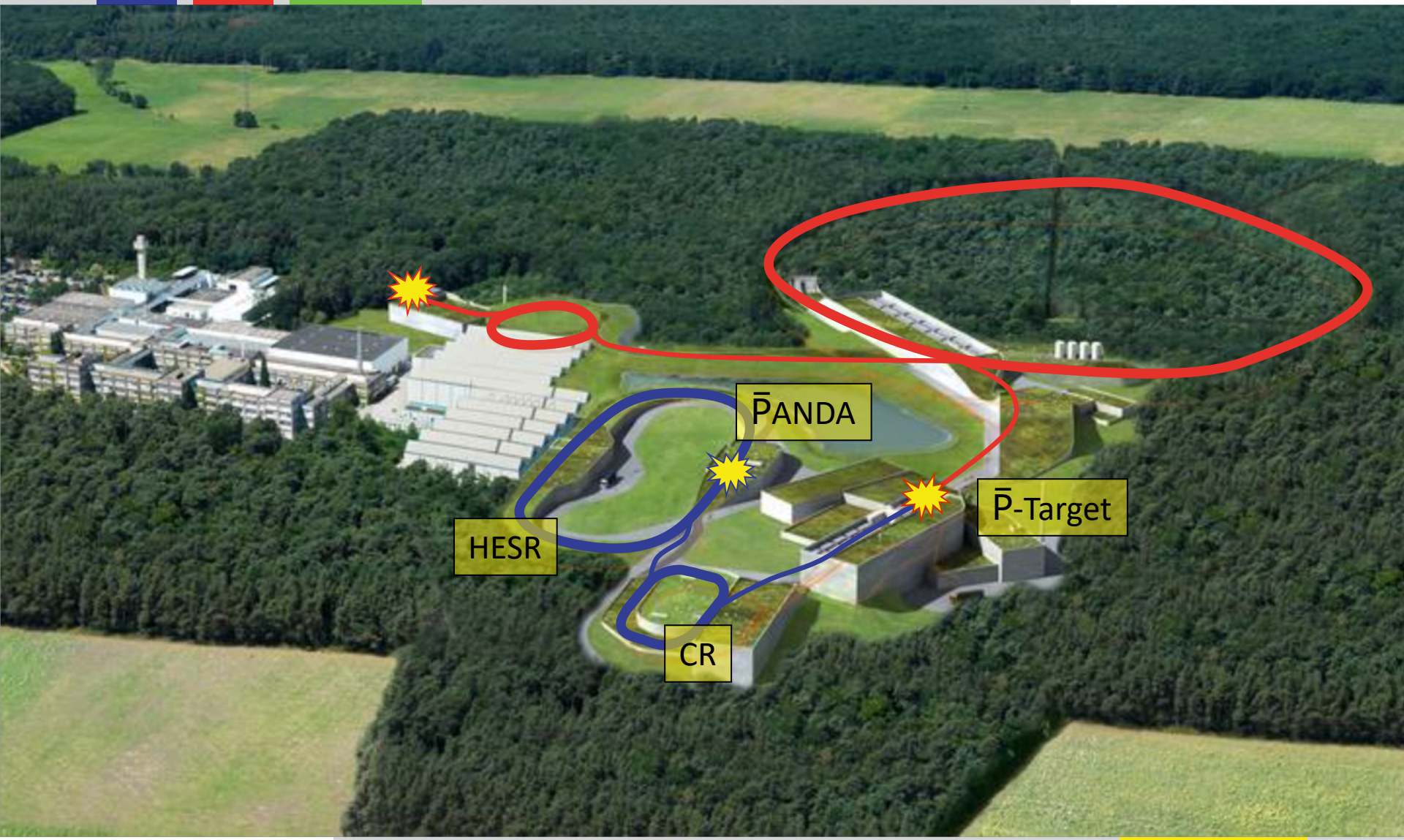
Access to large spectrum of J^{PC} states
- direct formation of *all* conventional J^{PC} states
- large sensitivity to high spin states

Associated hadron-pair production
- zero net quark content
- access to hidden-strange/charm hadrons
- tagging possibilities
- near threshold: good resolution and low background

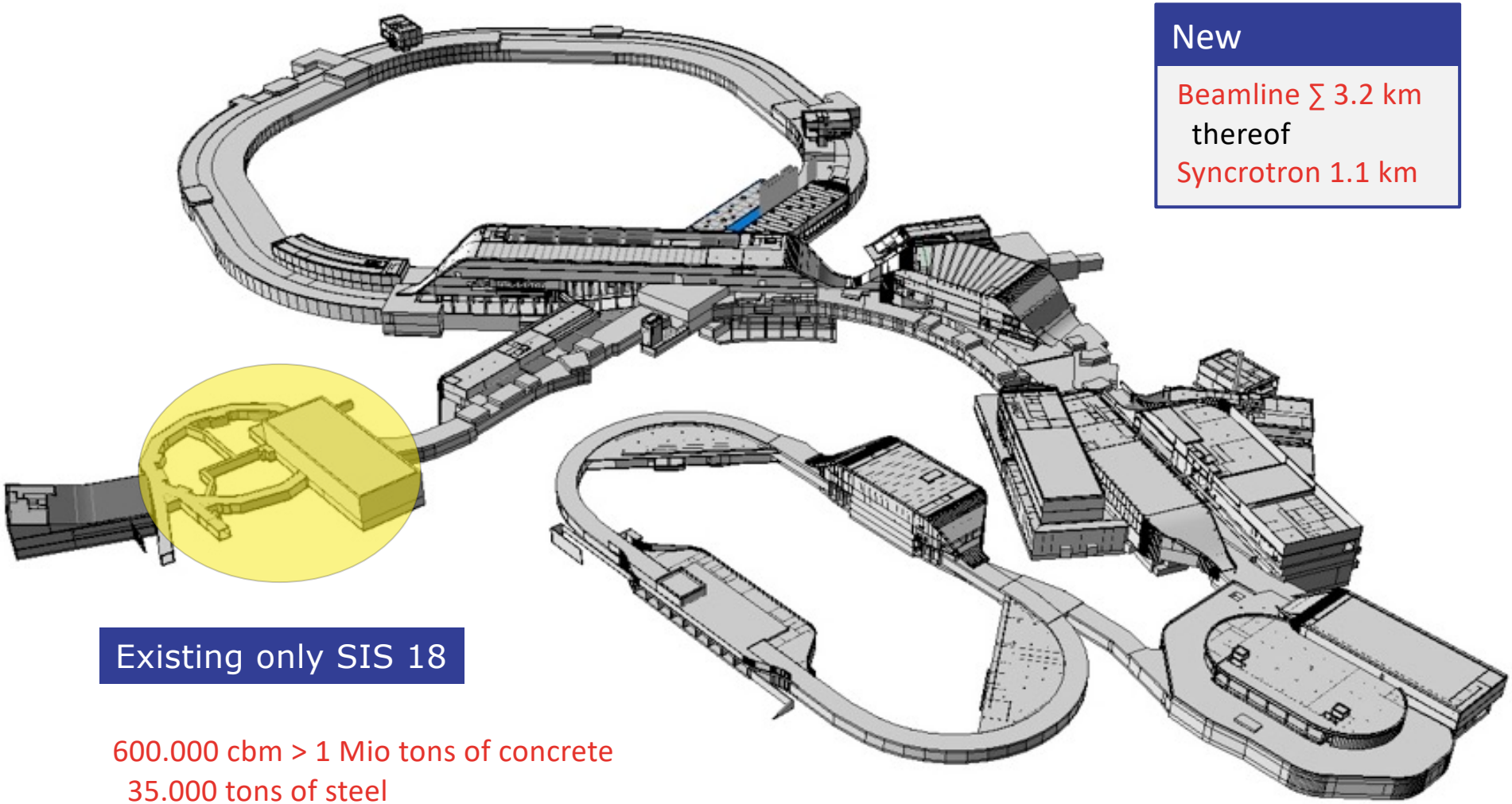


Systematic and precise tool to rigorously study the dynamics of QCD

Antiproton Chain: HESR & PANDA



Civil Engineering



New

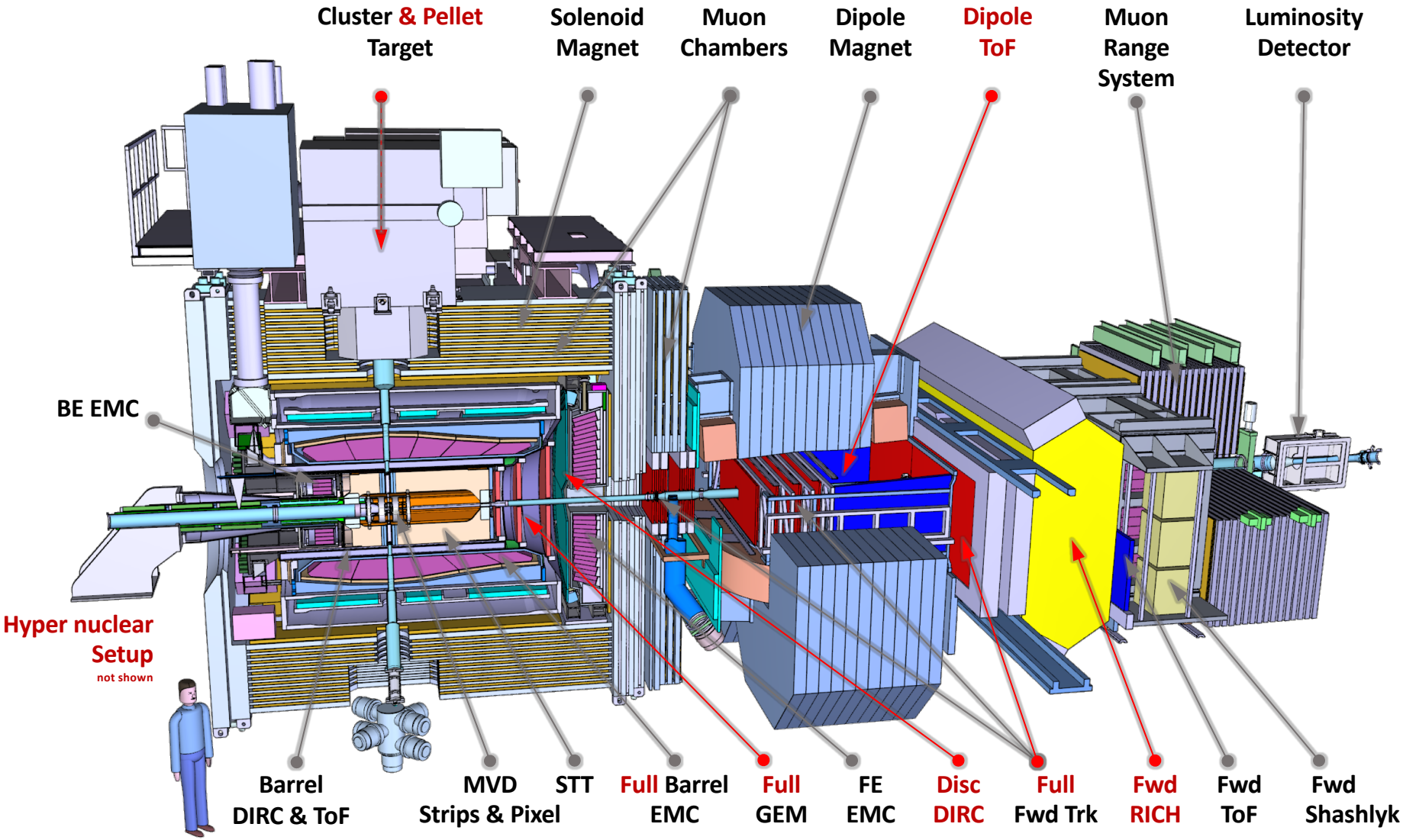
Beamline ∑ 3.2 km
thereof
Syncrotron 1.1 km

Existing only SIS 18

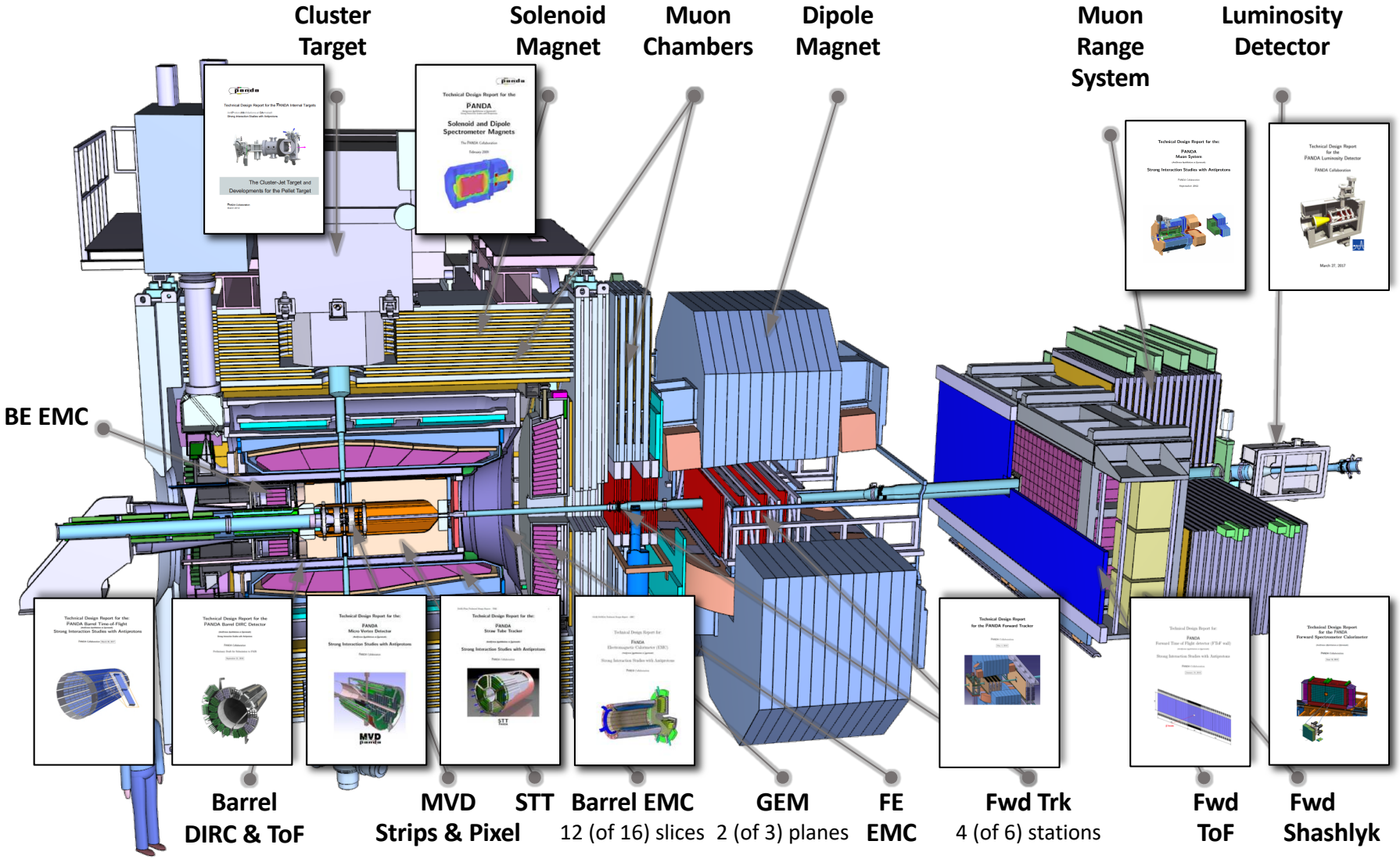
600.000 cbm > 1 Mio tons of concrete
35.000 tons of steel

Construction Site (last month)

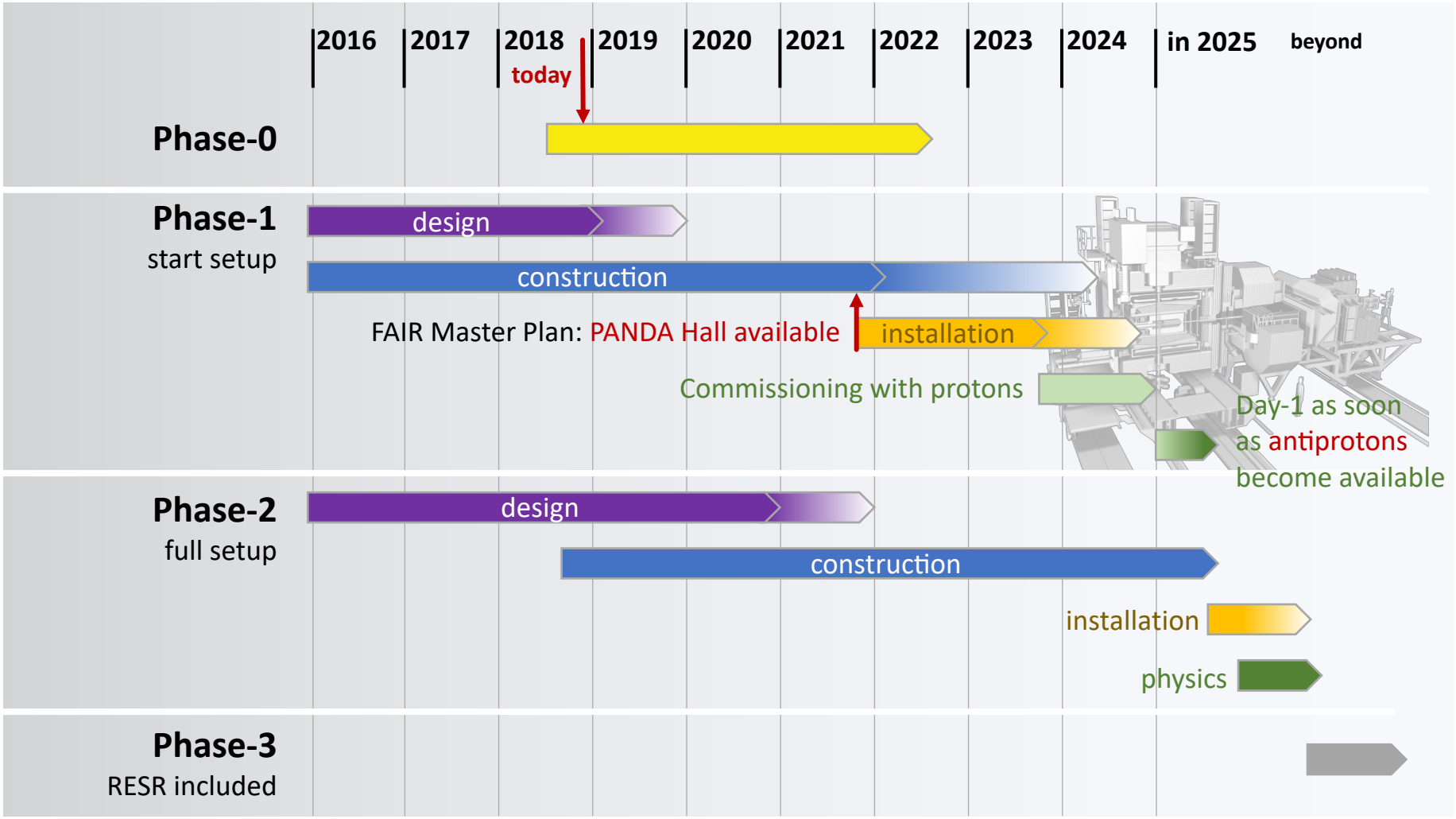
Full Setup


Cluster & Pellet Target
Solenoid Magnet
Muon Chambers
Dipole Magnet
Dipole ToF
Muon Range System
Luminosity Detector
BE EMC
Hyper nuclear Setup
not shown
Barrel DIRC & ToF
MVD Strips & Pixel
STT
Full Barrel EMC
Full GEM
FE EMC
Disc DIRC
Full Fwd Trk
Fwd RICH
Fwd ToF
Fwd Shashlyk

Day-1 Setup


Cluster Target
Solenoid Magnet
Muon Chambers
Dipole Magnet
Muon Range System
Luminosity Detector
BE EMC
Barrel DIRC & ToF
MVD Strips & Pixel
STT
Barrel EMC 12 (of 16) slices
GEM 2 (of 3) planes
FE EMC
Fwd Trk 4 (of 6) stations
Fwd ToF
Fwd Shashlyk

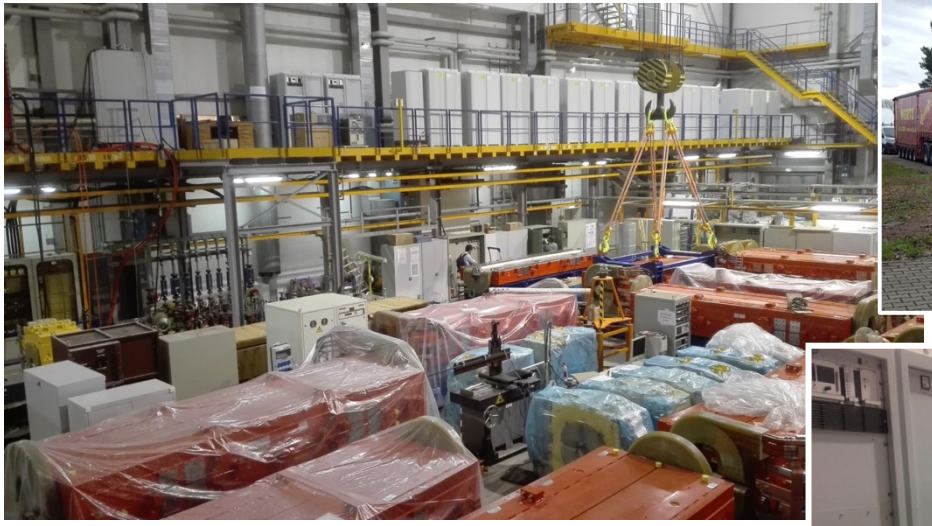
PANDA Installation Schedule

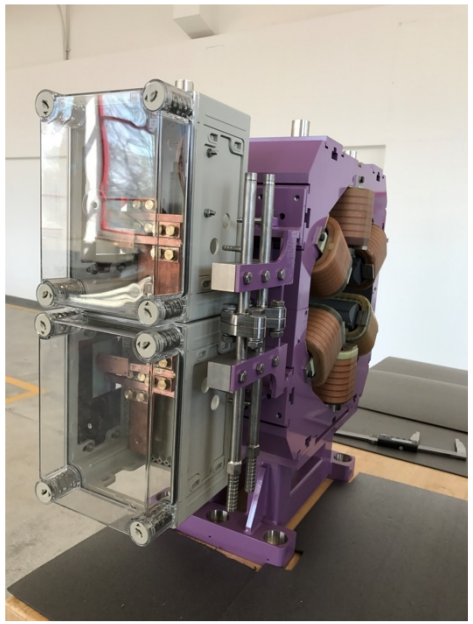


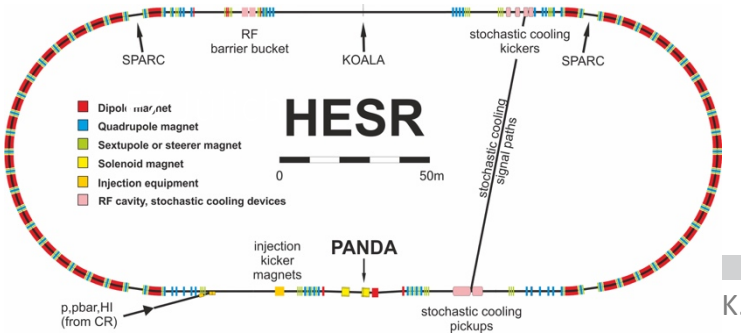
Status of HESR Dipoles and Quadrupoles complete

- 46 dipoles and 84 quadrupoles are waiting for installation
- Power converters delivered
- Sextupoles in production

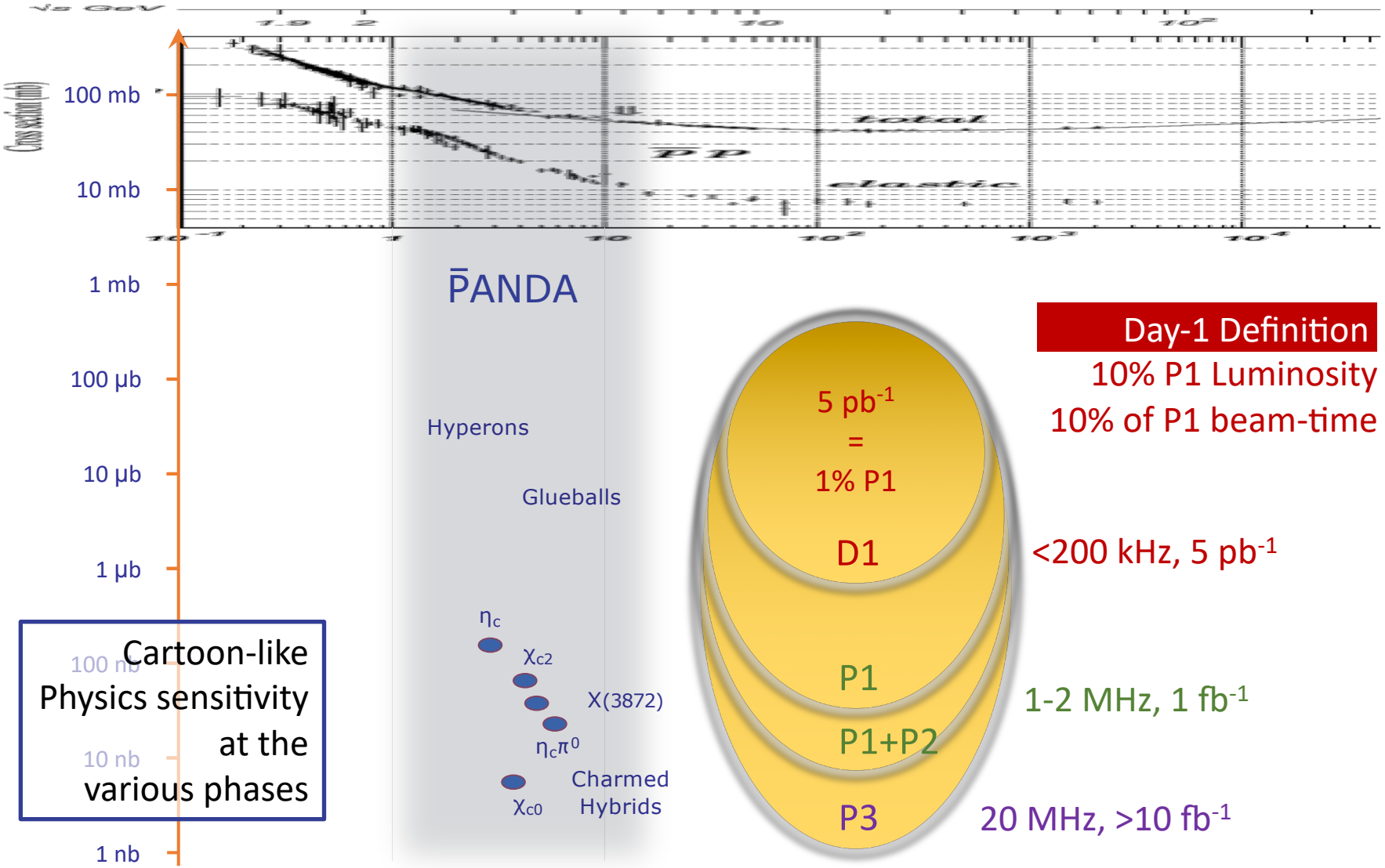
All components will be finished end of 2019







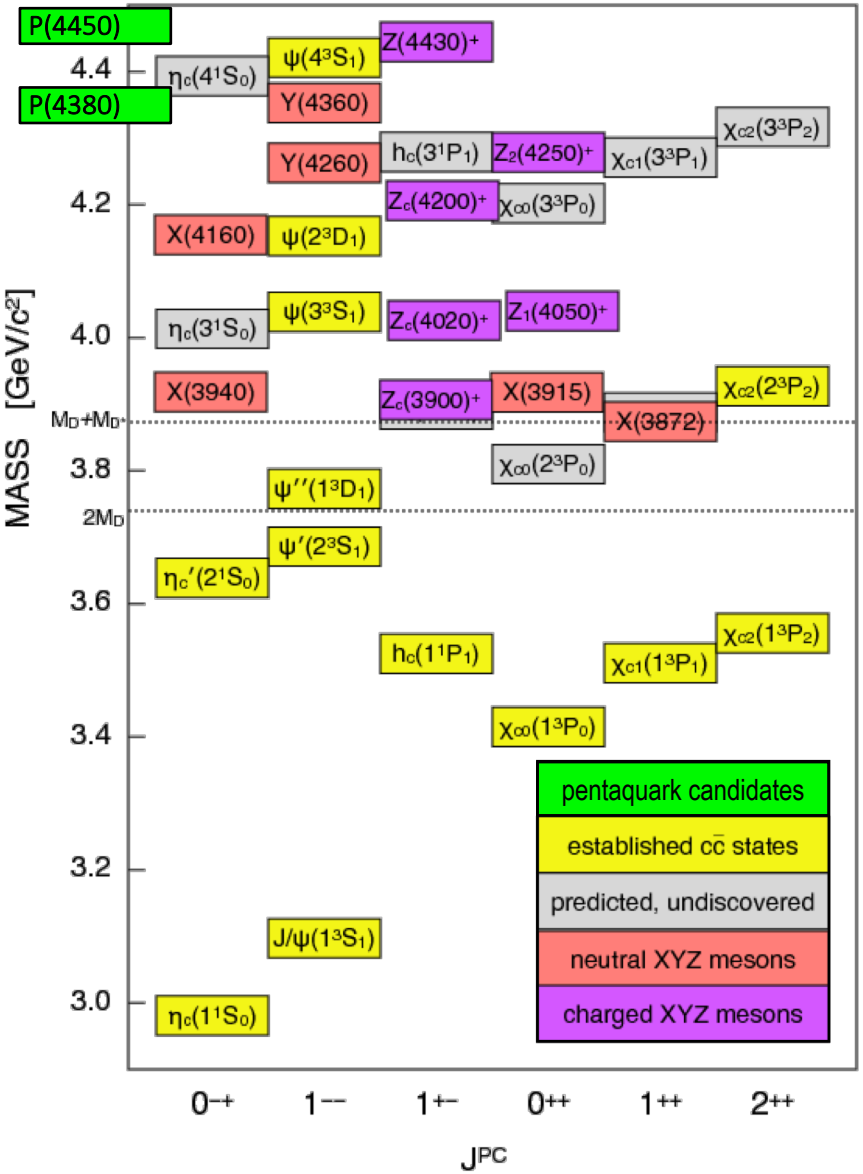
Phases of PANDA – Sensitivities in a nutshell



Day-1 Definition
10% P1 Luminosity
10% of P1 beam-time

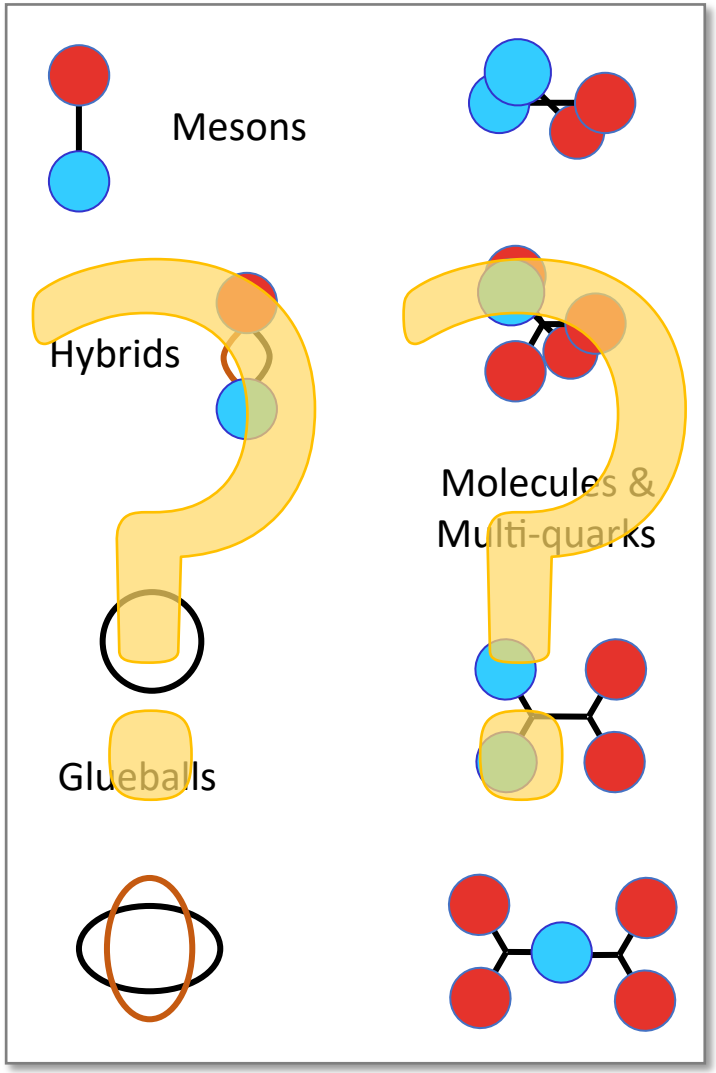
Cartoon-like Physics sensitivity at the various phases

Charmonium-like particles – a mystery

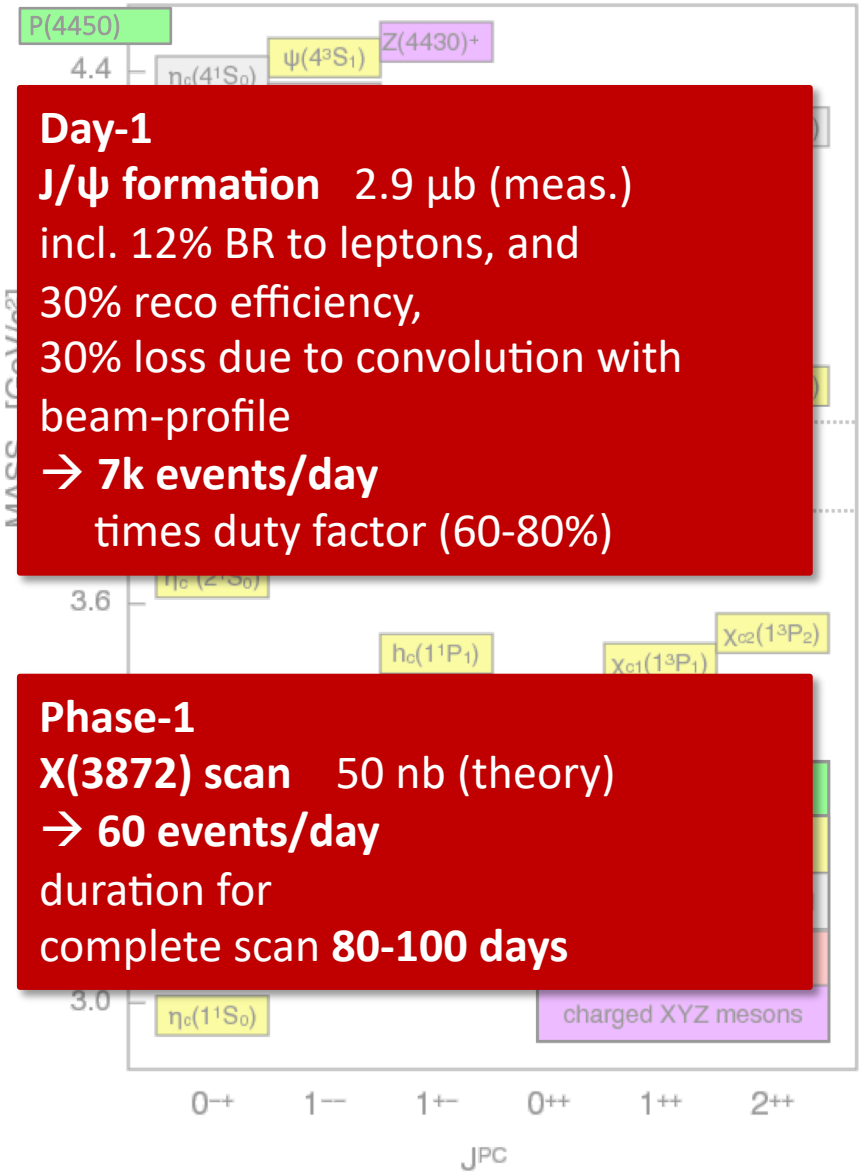


Discovery

Precision



Charmonium-like particles – a mystery



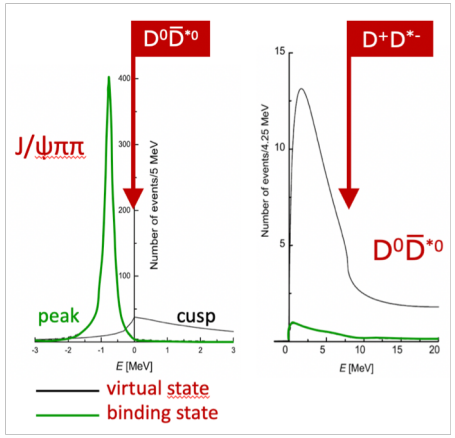
Day-1
J/ψ formation 2.9 µb (meas.)
incl. 12% BR to leptons, and
30% reco efficiency,
30% loss due to convolution with beam-profile
→ **7k events/day**
times duty factor (60-80%)

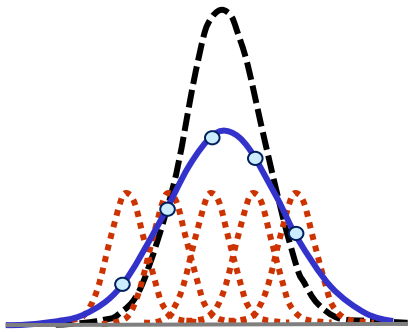
Phase-1
X(3872) scan 50 nb (theory)
→ **60 events/day**
duration for
complete scan **80-100 days**

Day-1

Exploratory search of new Z states using direct formation in antiproton neutron

Line-scan proof-of-principle with narrow conventional charmonium





Phase-1

Line-scan of "exotic" candidates such as X(3872)

Search for high-spin states with hidden-charm

Light Quark/Meson Spectroscopy

Kaon spectrum

- every SU(3) meson nonet contains kaons but most of them have not been found
- their properties remain unclear and how well we really understand light mesons

(Strangeonium) hybrids

- predicted in the mass region of abo
- spin-exotic quantum numbers signa
- efforts will be continued and exten

Glueballs

- $f_0(1500)$ discovered at LEAR/CB 199
- LQCD predicts also 2^{++}, 0^{-+} below 2.
- mixing with $q\bar{q}$ states complicates c
- BES III rad. J/ψ for masses below 2.5 GeV/c^2 in (not conclusive so far)
- 4-5 GeV/c^2 region unexplored, where spin-exotic states are predicted

Multiquarks/Molecules

- Where are the strange/strangeonium counterparts to the Zc's
- Is the recent $a_1(1420)$ finding by Compass a hint to that area?

Day-1

> 500k $\bar{p}p \rightarrow f_0(1500)\pi^0$/day

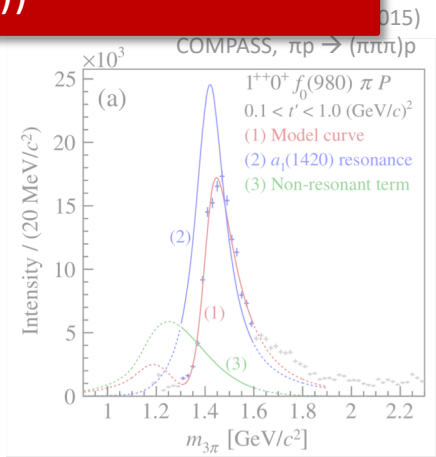
> 100k $\bar{p}p \rightarrow f_0(1500)\eta$/day

reconstructed, duty factor of 80% included

$\bar{p}p$ **dominated by resonance production !!**

LEAR: exotics yield is similar to ordinary mesons

$f_0(1500) \sim O(f_2(1270))$



φφ Resonances - Light Glueball Search

series of 2^{++}states with weak evidence by Etkin et al.

Jetset (1998):

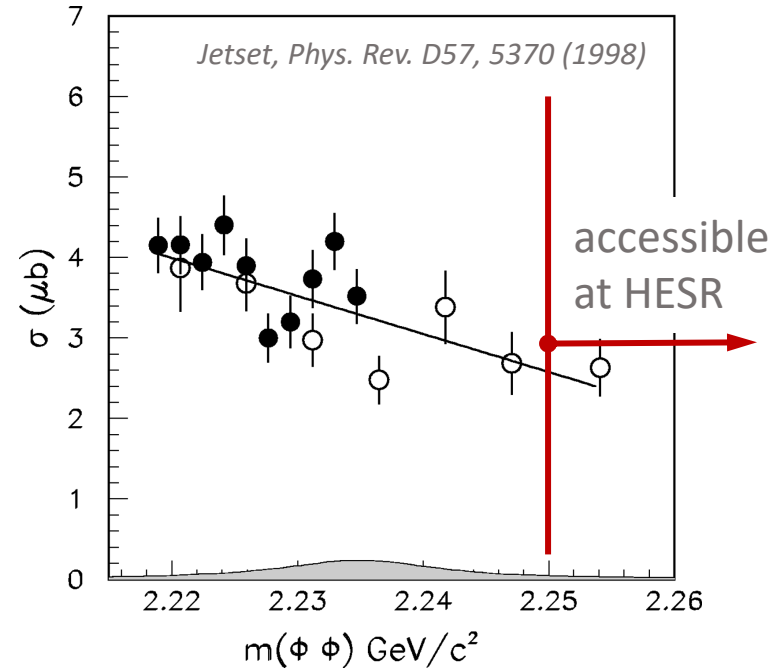
- cross section 100x larger than expected from OZI
- large gluonic component?
- glueball candidate?
- limited phase space, low rates

tensor states in this mass region seen by BESIII
in J/ψ → γφφ (13k events in 2^+ wave in 1.3B J/ψ)
γφφ lacks crossing interferences in Dalitz plot → J^{PC} biased

PANDA (2025):

- scan above 2.25 GeV: terra incognita
- physics studies at reduced luminosities feasible
- accesses 2^{++} and 0^{-+}
- conventional mesons are suppressed due to OZI

$\bar{p}p$ → φφ cross section

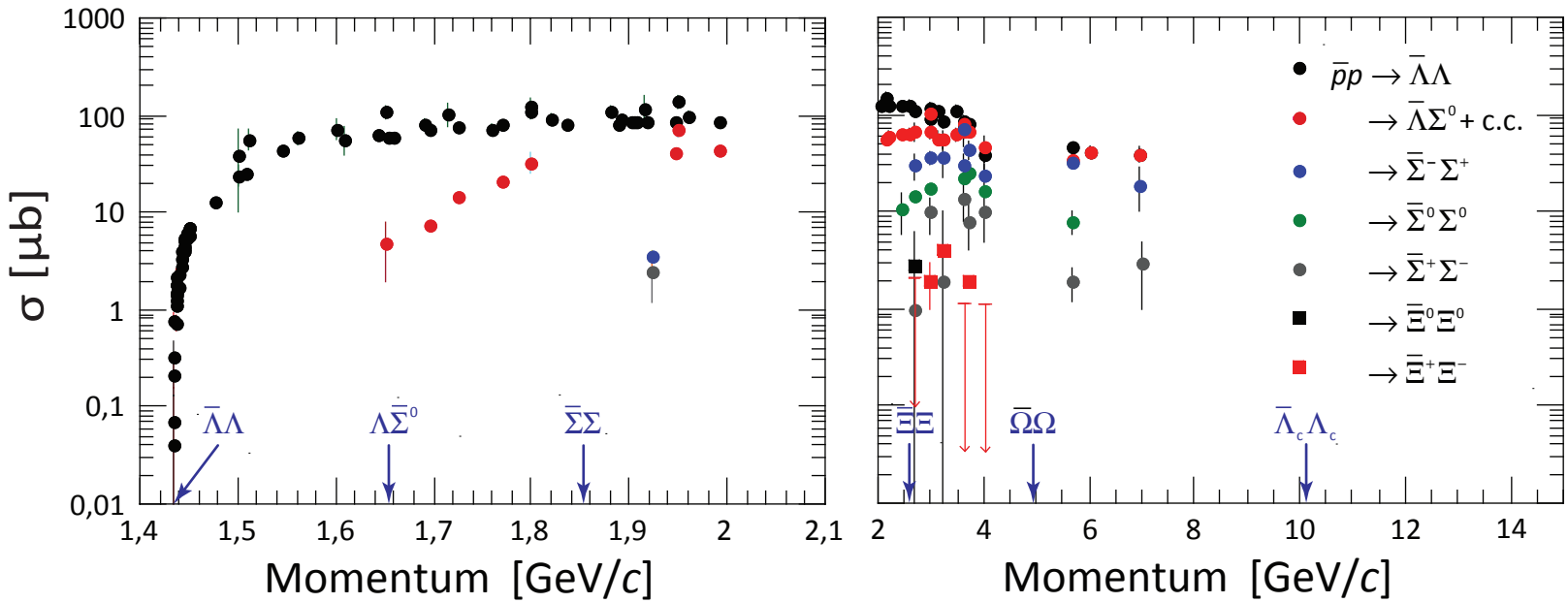


Phase-1
> 500k $\bar{p}p$ → φφ/day

Day-1
> 50k $\bar{p}p$ → φφ/day

reconstructed
(duty factor of 80% included)

Previous measurements of $\bar{p}p \rightarrow \bar{Y}Y$



A lot of data on $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ near threshold, mainly from PS185 at LEAR

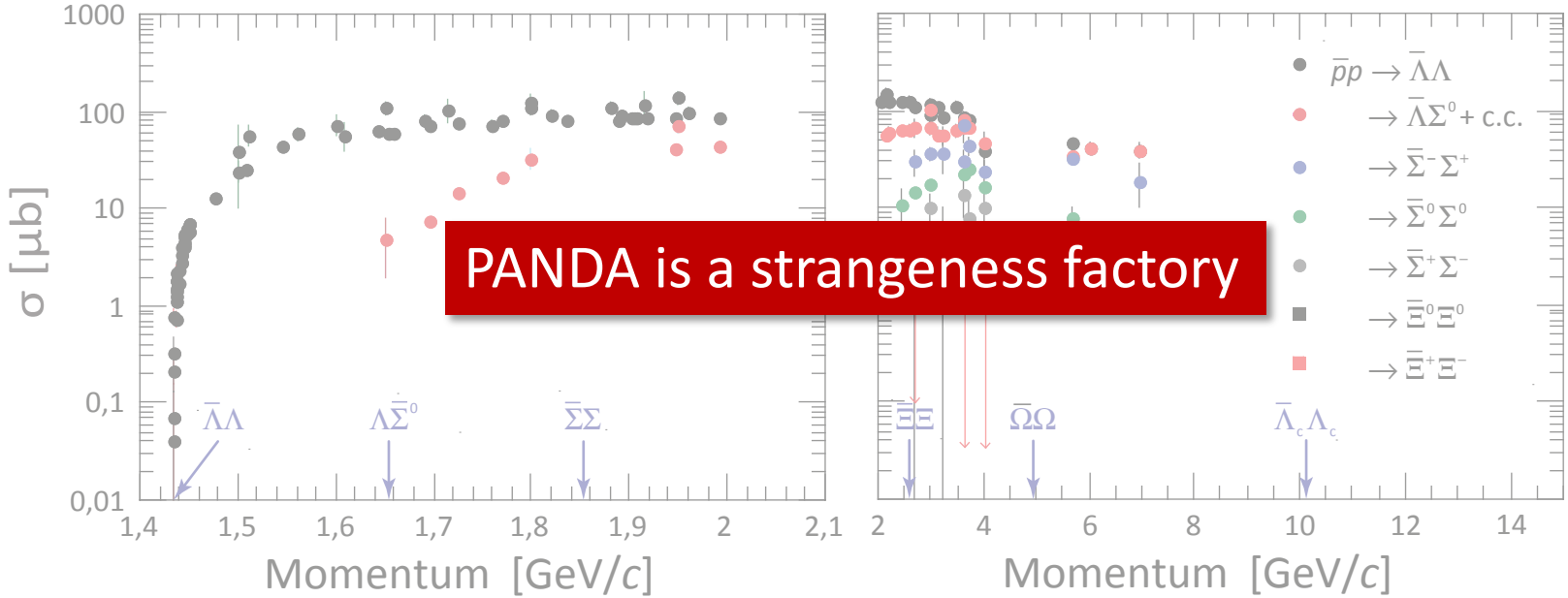
Very scarce data bank above 4 GeV/c

High event rates & low background for Λ and Σ

No data on $\bar{p}p \rightarrow \bar{\Omega}\Omega$ nor $\bar{p}p \rightarrow \bar{\Lambda}_c\Lambda_c$

Even with conservative cross section estimates, Ω / Λ_c channels are feasible

Previous measurements of $\bar{p}p \rightarrow \bar{Y}Y$



PANDA is a strangeness factory

A lot of d … hold, r
Very sca
High eve … or Λ ar
No data … Λ_c
Even wit … estima … ble

Phase-1

|S| = 1	~ 7M $\Lambda\bar{\Lambda}$/day
	~ 4M $\Lambda\bar{\Sigma}^0$/day
|S| = 2	~ 90k $\Xi\bar{\Xi}$/day
|S| = 3	~ 100 $\Omega\bar{\Omega}$/day

duty factor of 80% included

Day-1

|S| = 1	~ 700k $\Lambda\bar{\Lambda}$/day
	~ 400k $\Lambda\bar{\Sigma}^0$/day
|S| = 2	~ 9k $\Xi\bar{\Xi}$/day
|S| = 3	~ 10 $\Omega\bar{\Omega}$/day excl.

more w/incl. studies

Antihyperons in Nuclei

Antiprotons sensitive tool to study **antihyperon potential in nuclei** !

Exploit abundantly produced **hyperon-antihyperon pairs near threshold**

Benchmark data to test theoretical concepts to describe dynamics of (anti)hyperons in heavy-ion collisions

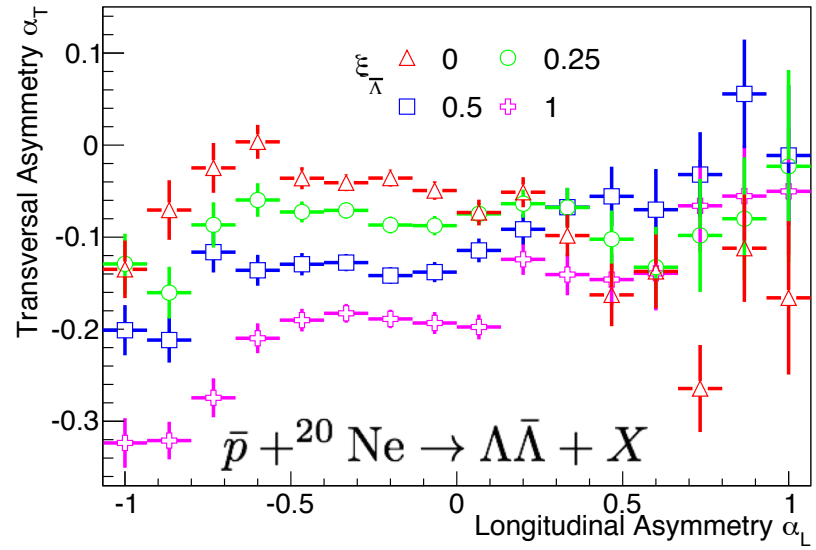
Important **first step** towards the |S|=2 **hypernuclei program** of PANDA

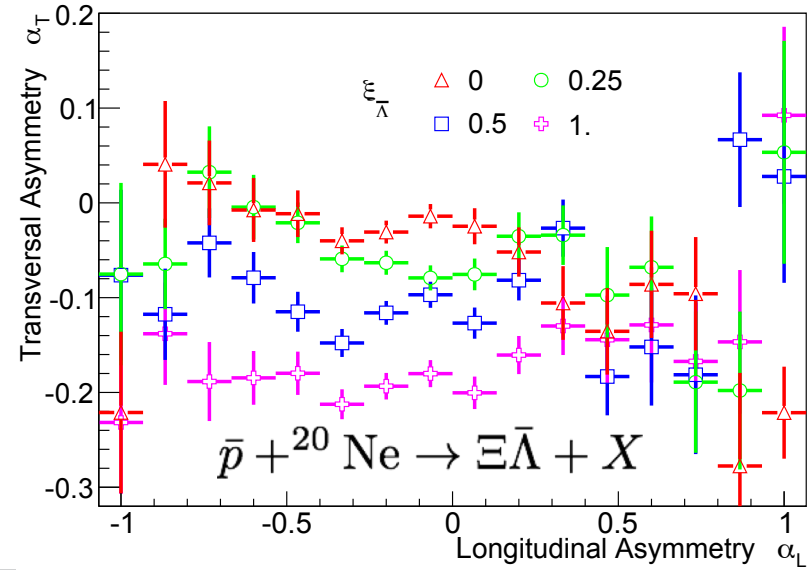
Need ~10^6 $Y\bar{Y}$ pairs for unique physics (polarization, planarity and everything)

Phase-1
→ ~10 d for $\bar{\Lambda}$-Potentia & ~75 d $\bar{\Xi}$-Potential

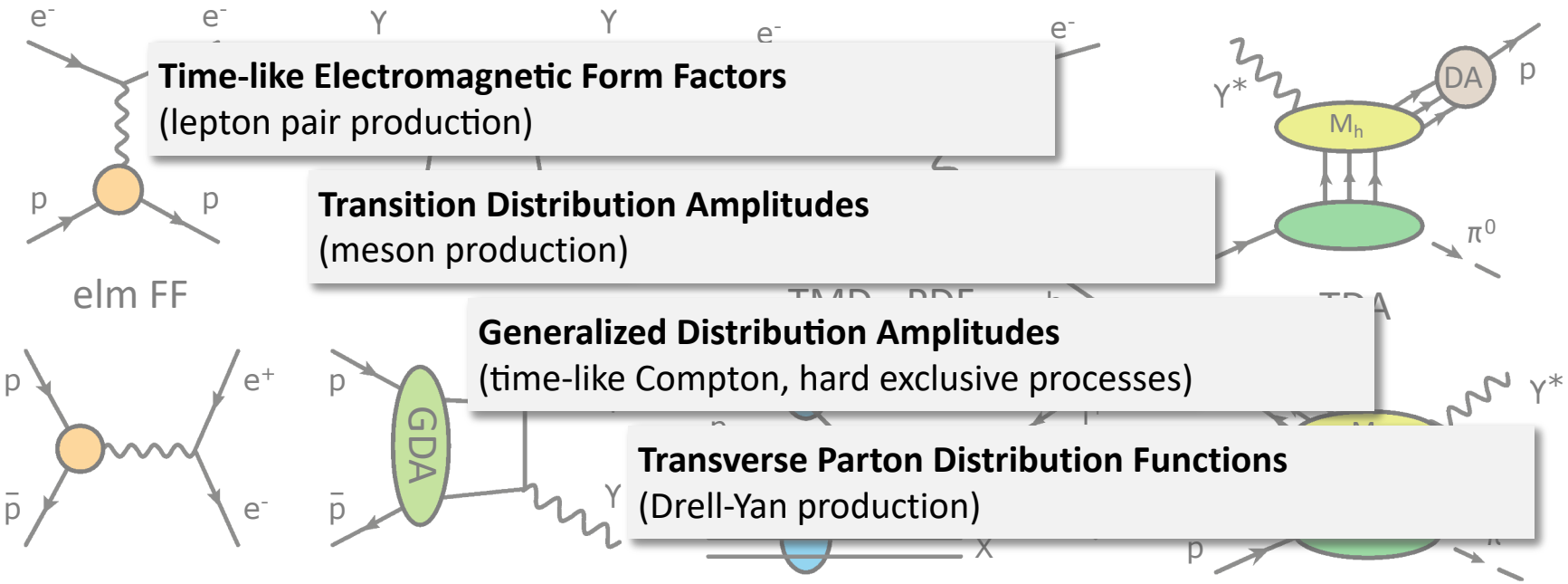
Day-1
→ 1 day for 10^5 for $\bar{\Lambda}$-Potential (12x simu)

PANDA, NPA954, 323 (2016)





Nucleon Electromagnetic Final States



Time-like Electromagnetic Form Factors
(lepton pair production)

Transition Distribution Amplitudes
(meson production)

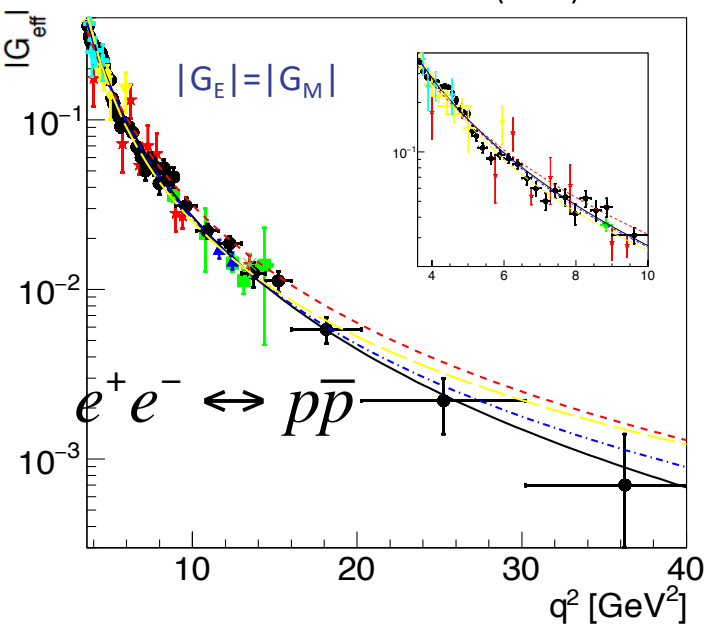
Generalized Distribution Amplitudes
(time-like Compton, hard exclusive processes)

Transverse Parton Distribution Functions
(Drell-Yan production)

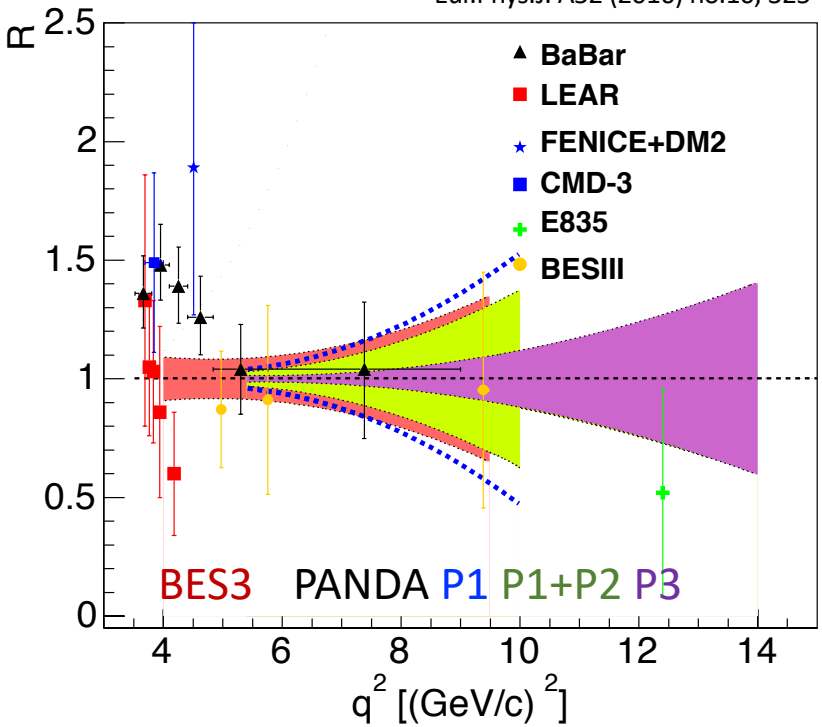
Time-Like proton electromagnetic FFs

The effective FF can be measured
up to q^2 ~30 GeV^2
no individual determination
of G_E and G_M so far

PRL 114 (2015) 232301



Eur.Phys.J. A52 (2016) no.10, 325



Outlook with transversely polarized target

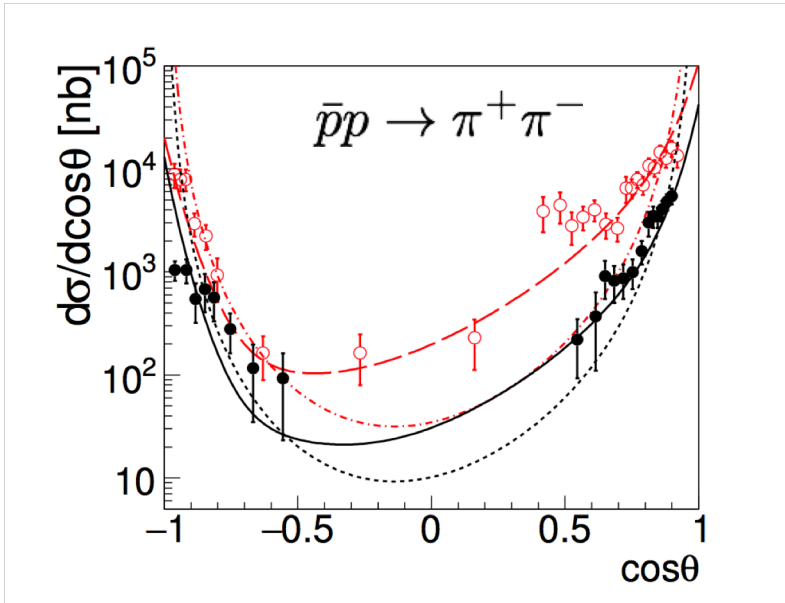
$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{1,y} \propto \sin 2\Theta \, \mathrm{Im}\left(G_M G_E^*\right)$$

Analytical Structure of the Formfactor

Time-like Electromagnetic Form-factors
(lepton pair production)
Integrated luminosity (Phase-1)

$$L = 75\ \mathrm{pb}^{-1}\ @\, p_{\mathrm{lab}} = 1.5\,\mathrm{GeV}/c$$

$$L = 97\ \mathrm{pb}^{-1}\ @\, p_{\mathrm{lab}} = 3.3\,\mathrm{GeV}/c$$

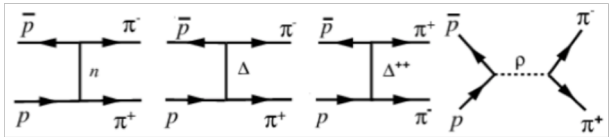


Phase-1

$\bar{p}p \to e^+e^-$	@1.5 GeV/c	~ 220/day
$\bar{p}p \to e^+e^-$	@3.3 GeV/c	~ 10/day
$\bar{p}p \to \mu^+\mu^-$	@1.5 GeV/c	~ 170/day

Day-1

$\bar{p}p \to e^+e^-\pi^0$	@1.5 GeV/c	~ 3'500/day



Day-1 activities:

Build database on multi-pion production in $\bar{p}p$ as input to QCD calculations

Demonstrate the feasibility to identify di-lepton ($+\pi^0$) channels

Key-Experiments of the Start Phase

Concentration on unique and forefront physics topics

- Production of (multi-)strangeness baryons
  (unexplored, new territory, „Strangeness-Factory“)
- Precise measurement of the line shape of narrow XYZ-states,
  e.g. X(3872) (only possible in proton–antiproton, counting experiment, clarification of the nature of the states)
- Resonant formation of the
  negative and uncharged partners of the Z-States
  (only possible in proton–antiproton, goal is the nature of the states)
- Measurement of the electromagnetic form factors of the proton in the time-like domain with electrons and muons in the final state
- Production of high-spin charmonia
  (only possible in proton–antiproton)
  light mesons, baryons and production of hybrids und glueballs

XYZ-, Hyperon Factory

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Concentration on unique and forefront physics topics

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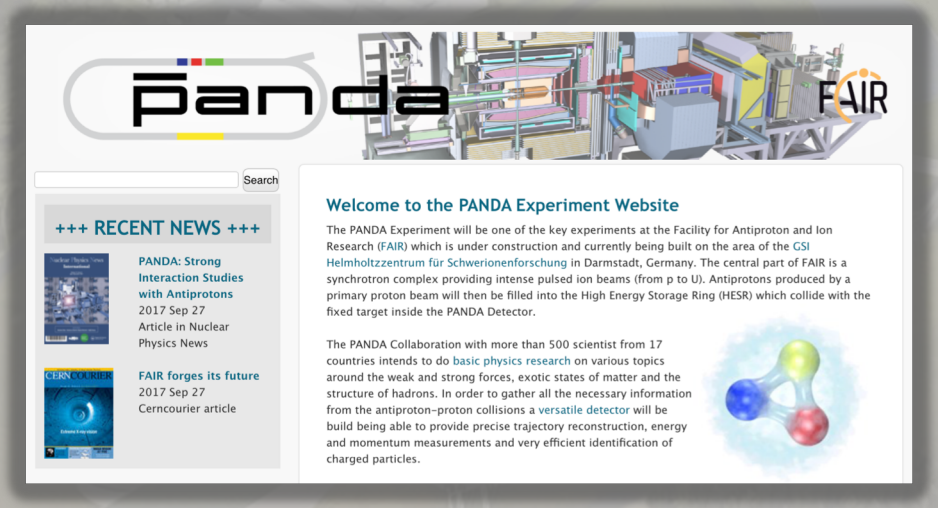
Please stay tuned for start
of proton beam 2024
and anti-proton beam 2025
with interesting results already on Day-1

XYZ-, Hyperon Factory

panda.gsi.de



Thank you