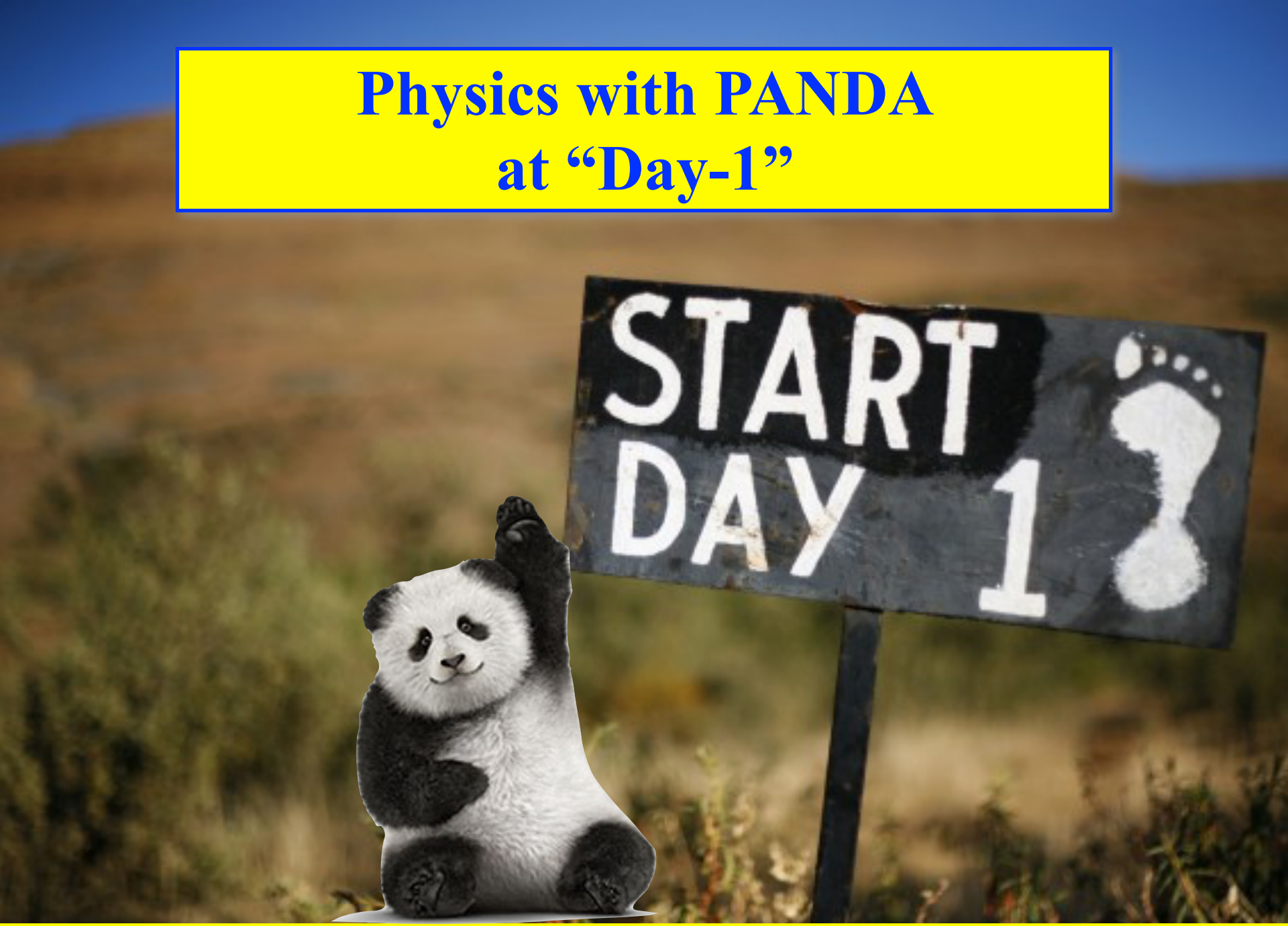
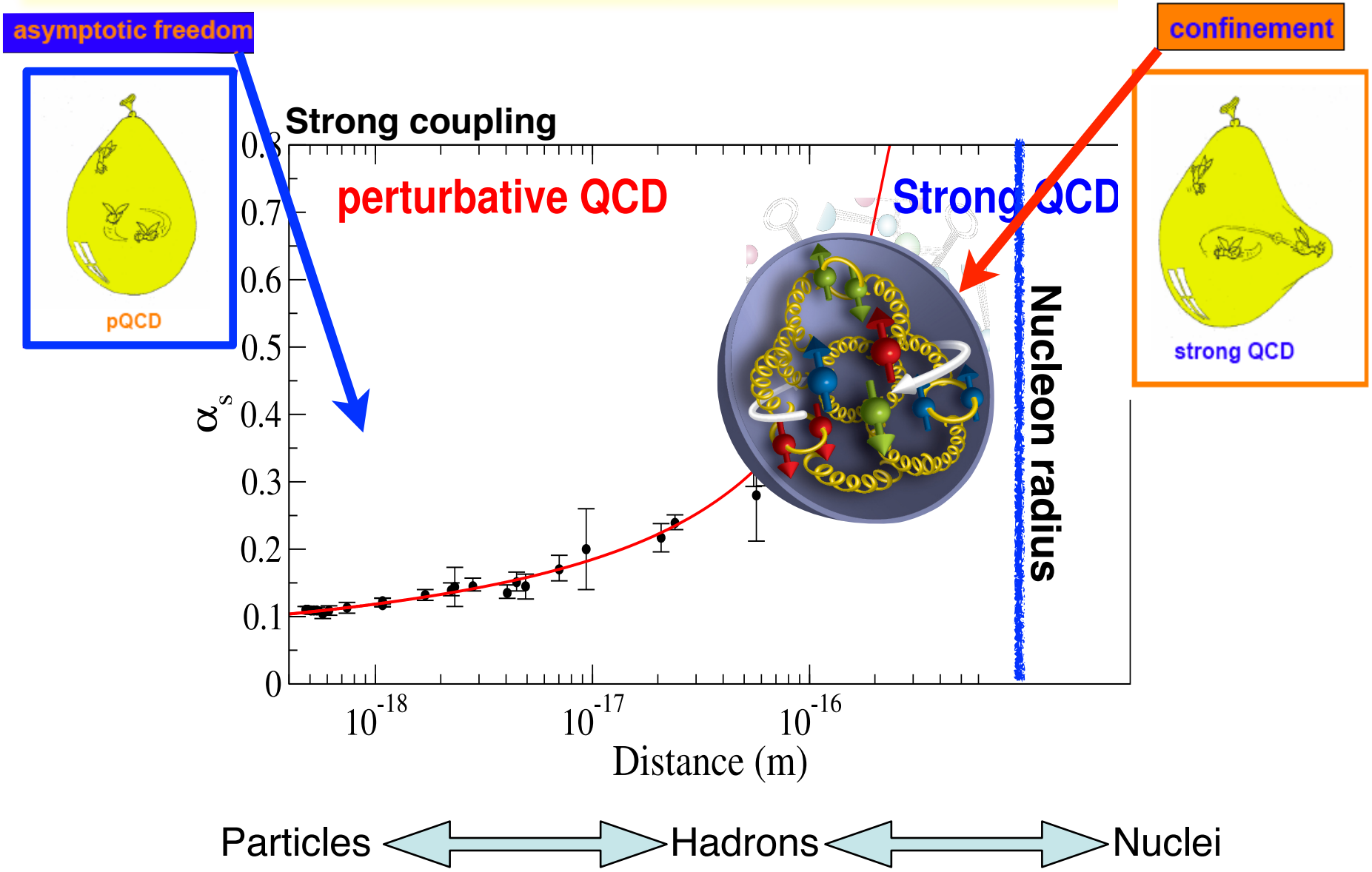
Physics with PANDA at "Day-1"

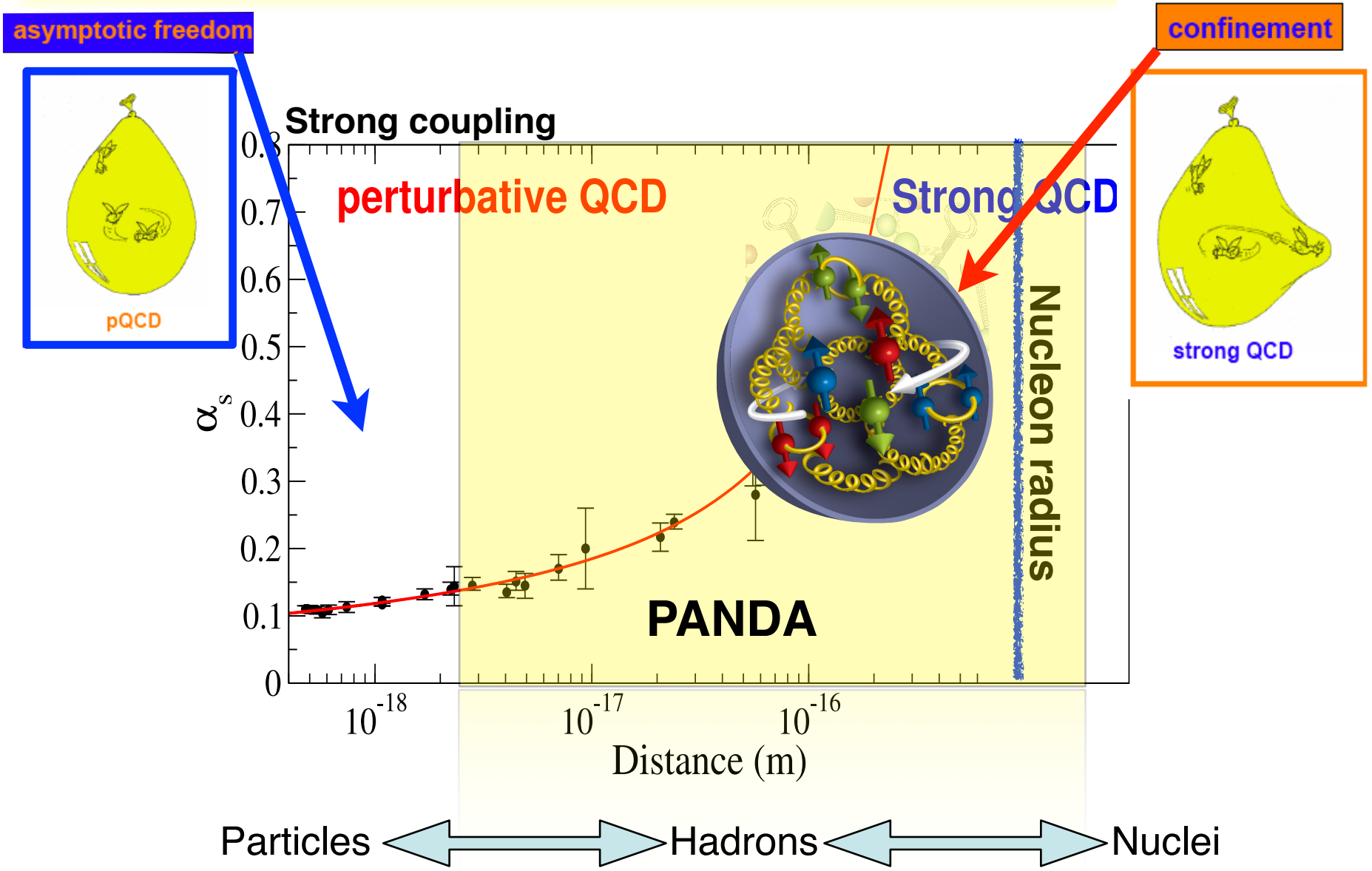


Johan Messchendorp (University of Groningen), THEIA-STRONG2020, November 25-29, 2019

The dynamics of QCD!



The dynamics of QCD!



PANDA physics overview

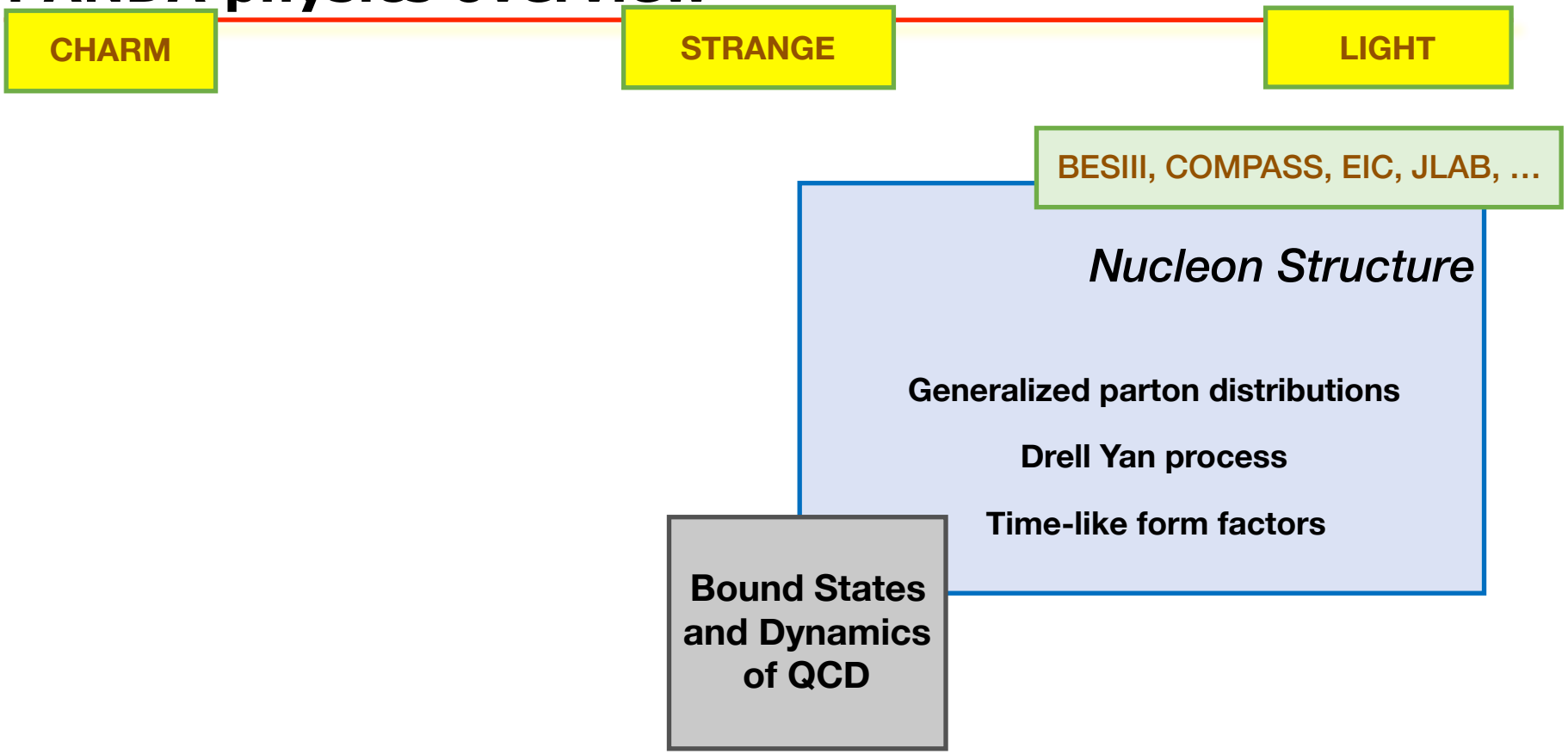
Bound States and Dynamics of QCD

PANDA physics overview

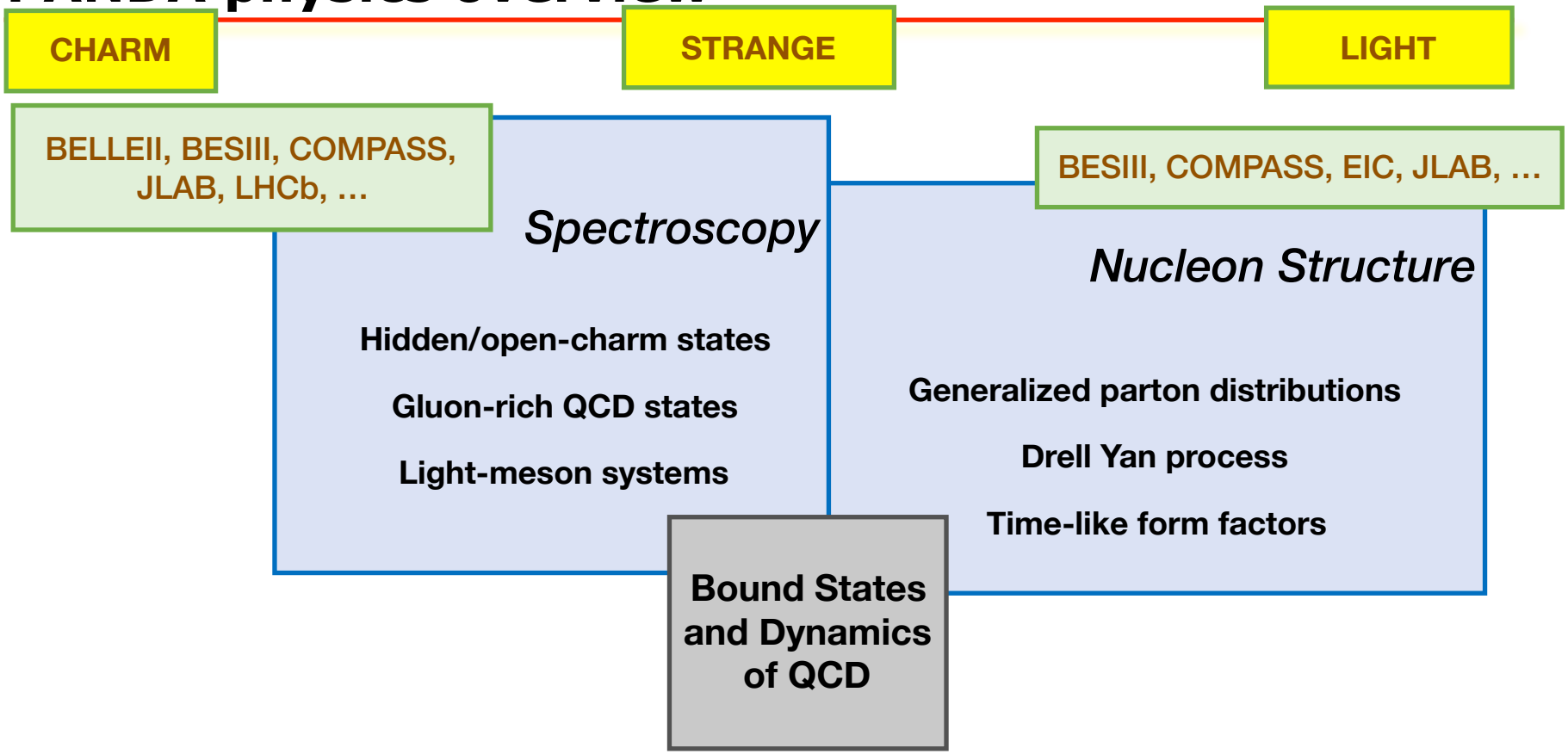
CHARM — STRANGE — LIGHT

Bound States and Dynamics of QCD

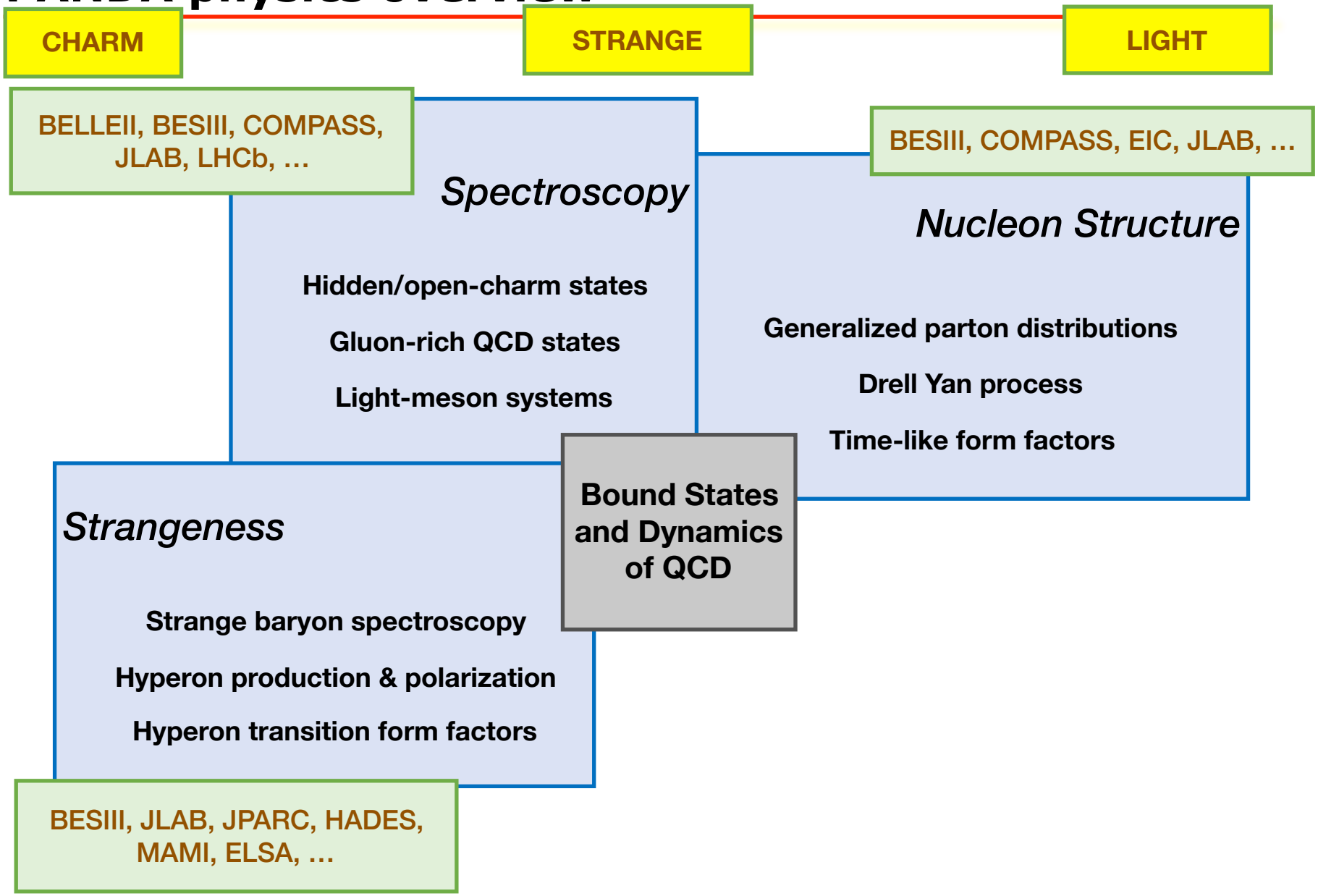
PANDA physics overview



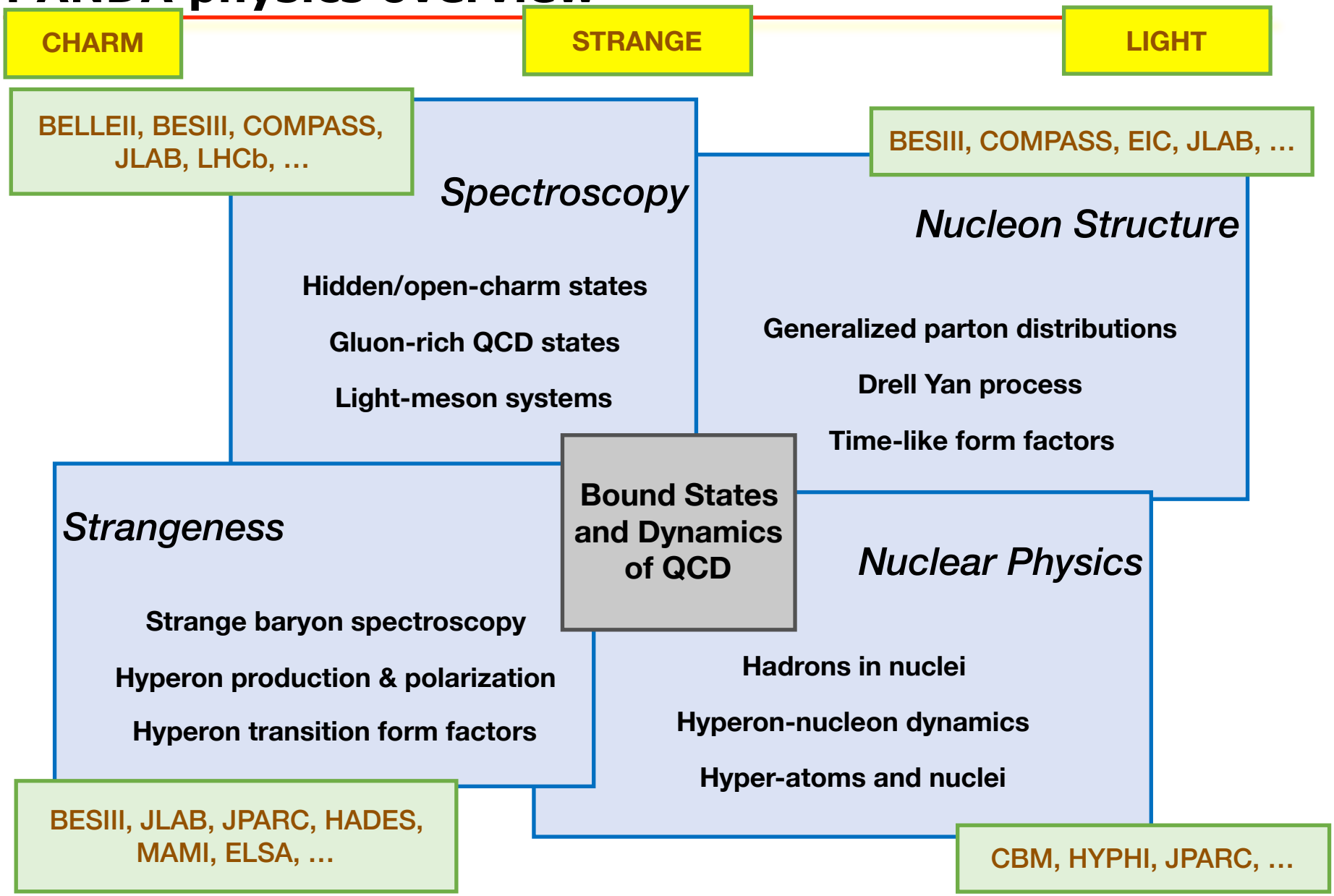
PANDA physics overview



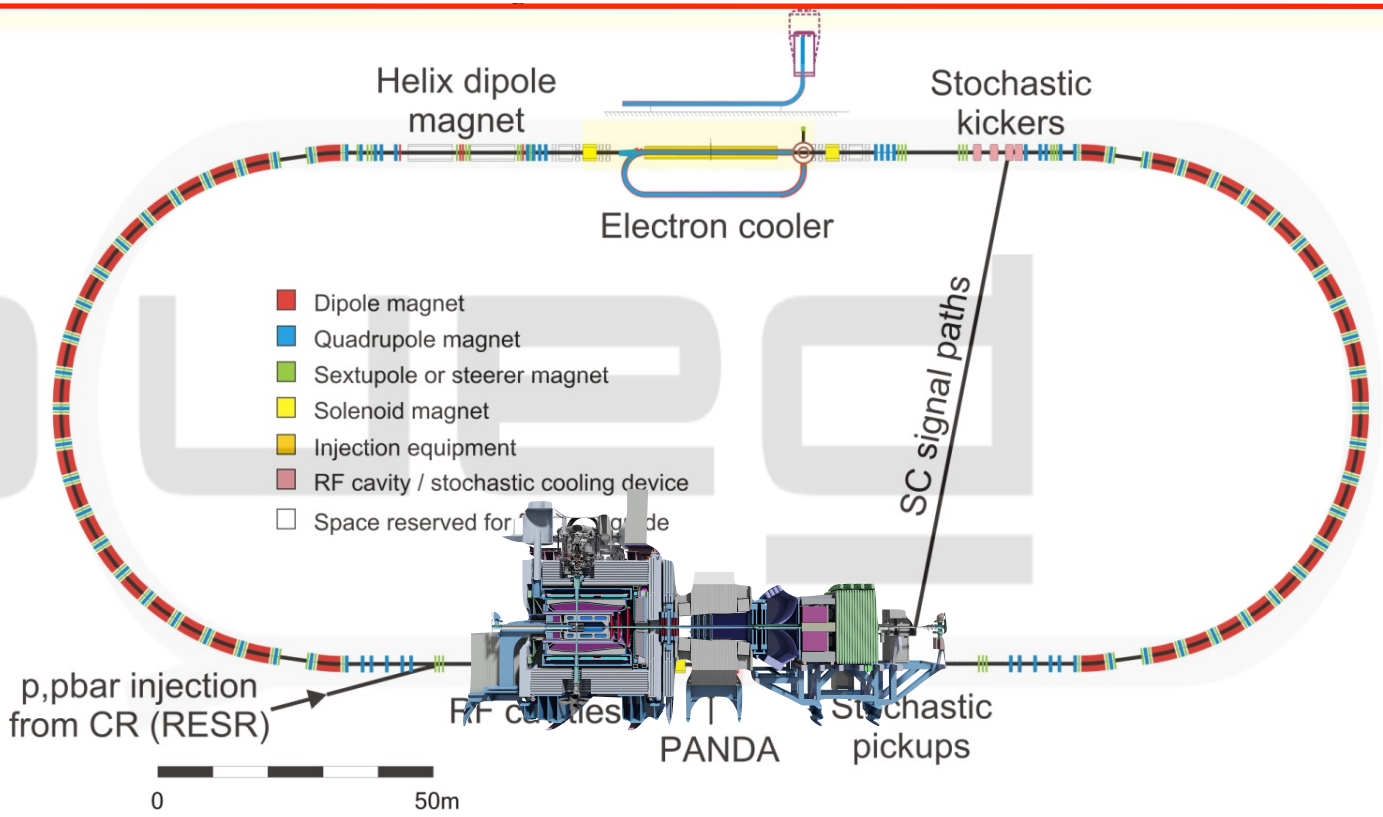
PANDA physics overview



PANDA physics overview



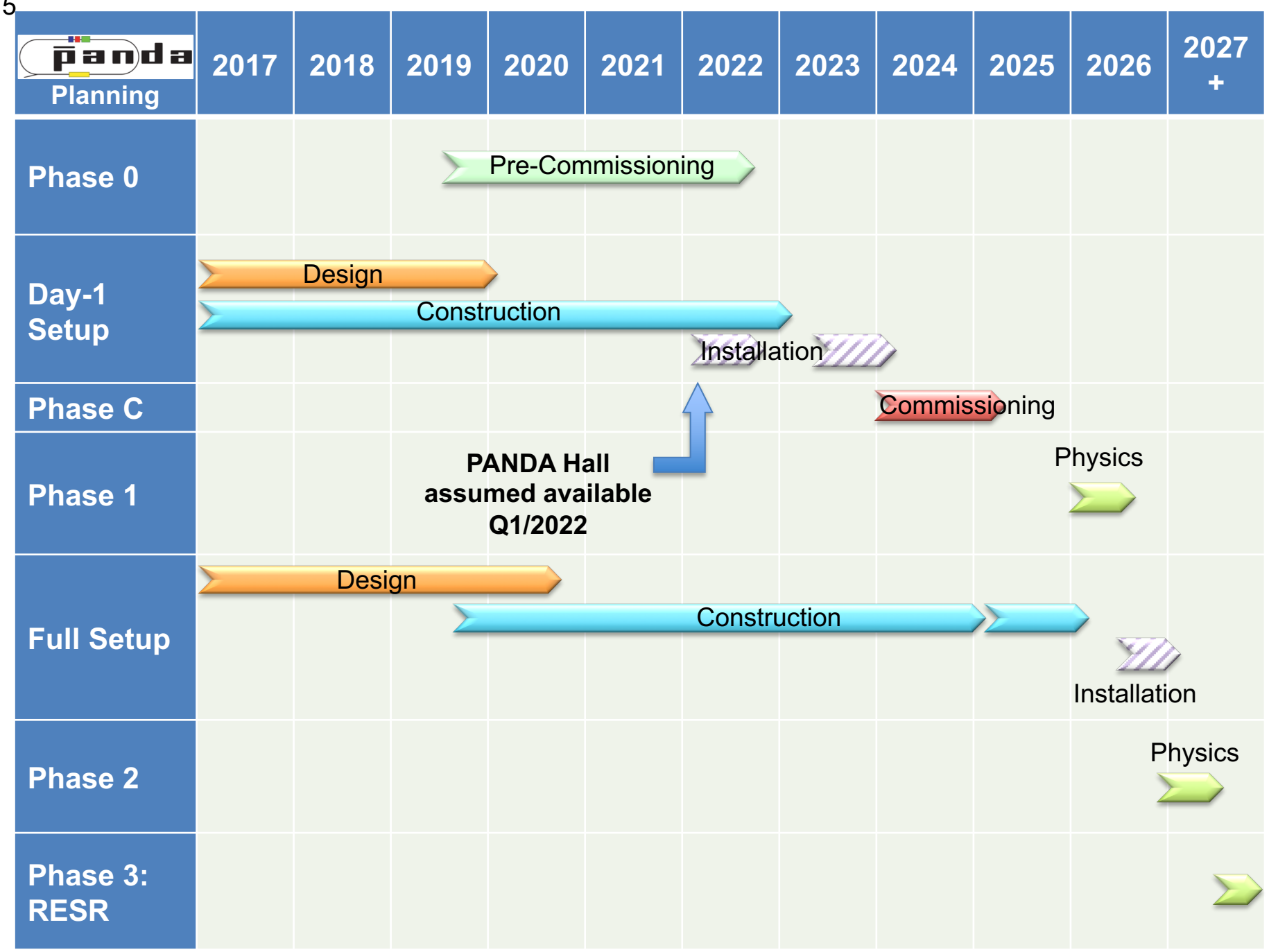
High Energy Storage Ring - *precision* antiprotons

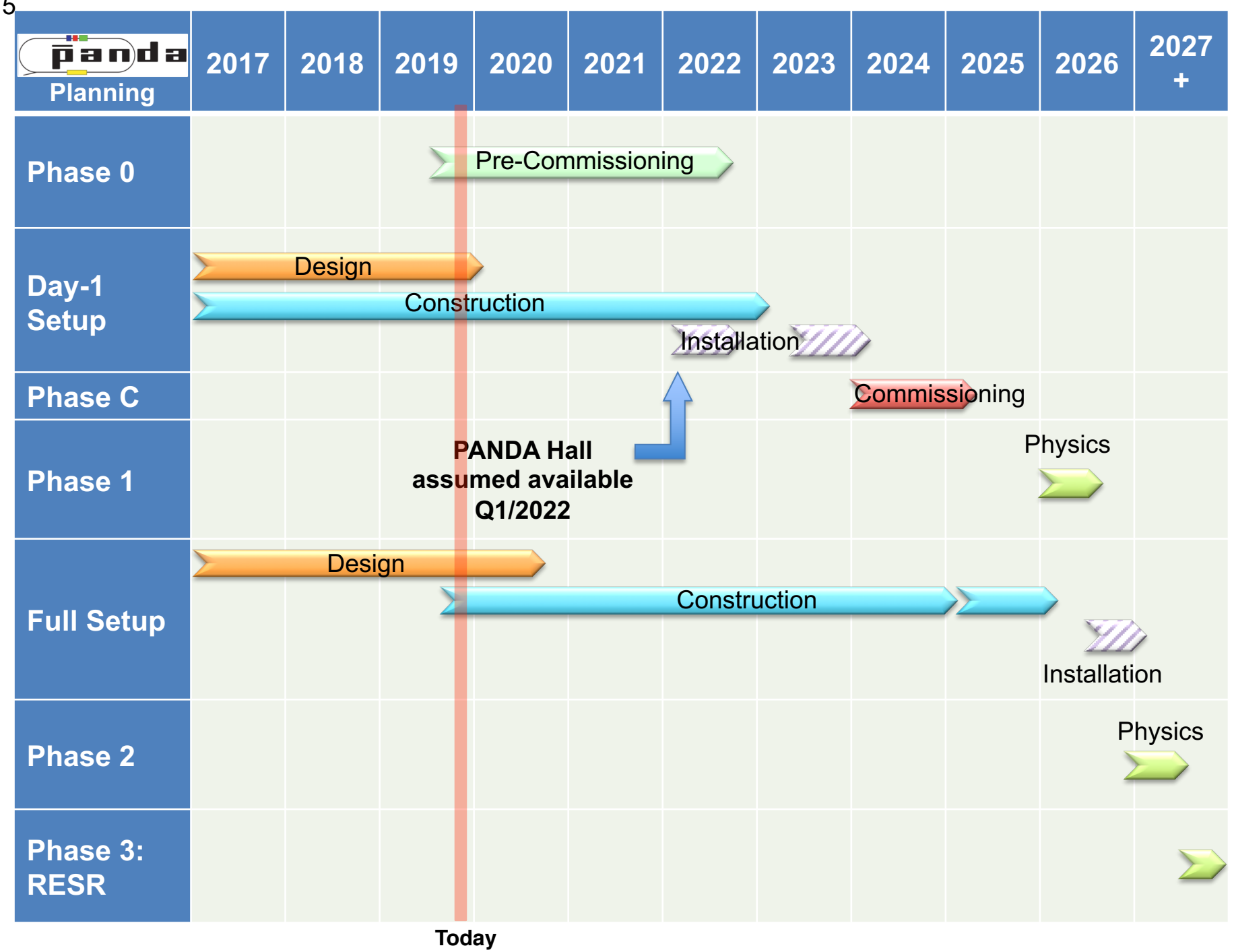


MSV-HESR mode (Phase-1+2)

- Energy range: 1.5-15 GeV
- Stochastic cooling: $dp/p=3\times10^{-5}$
- Accumulation: 10^{10} antiprotons in 1000 s → 10^{11} antiprotons
- Luminosity up to 2×10^{31} $cm^{-2}s^{-1}$ → 2×10^{32} $cm^{-2}s^{-1}$

+RESR (Phase-3)


Planning
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027 +
Phase 0
Pre-Commissioning
Day-1 Setup
Design
Construction
Installation
Phase C
Commissioning
Phase 1
PANDA Hall assumed available Q1/2022
Physics
Full Setup
Design
Construction
Installation
Phase 2
Physics
Phase 3: RESR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Full Setup
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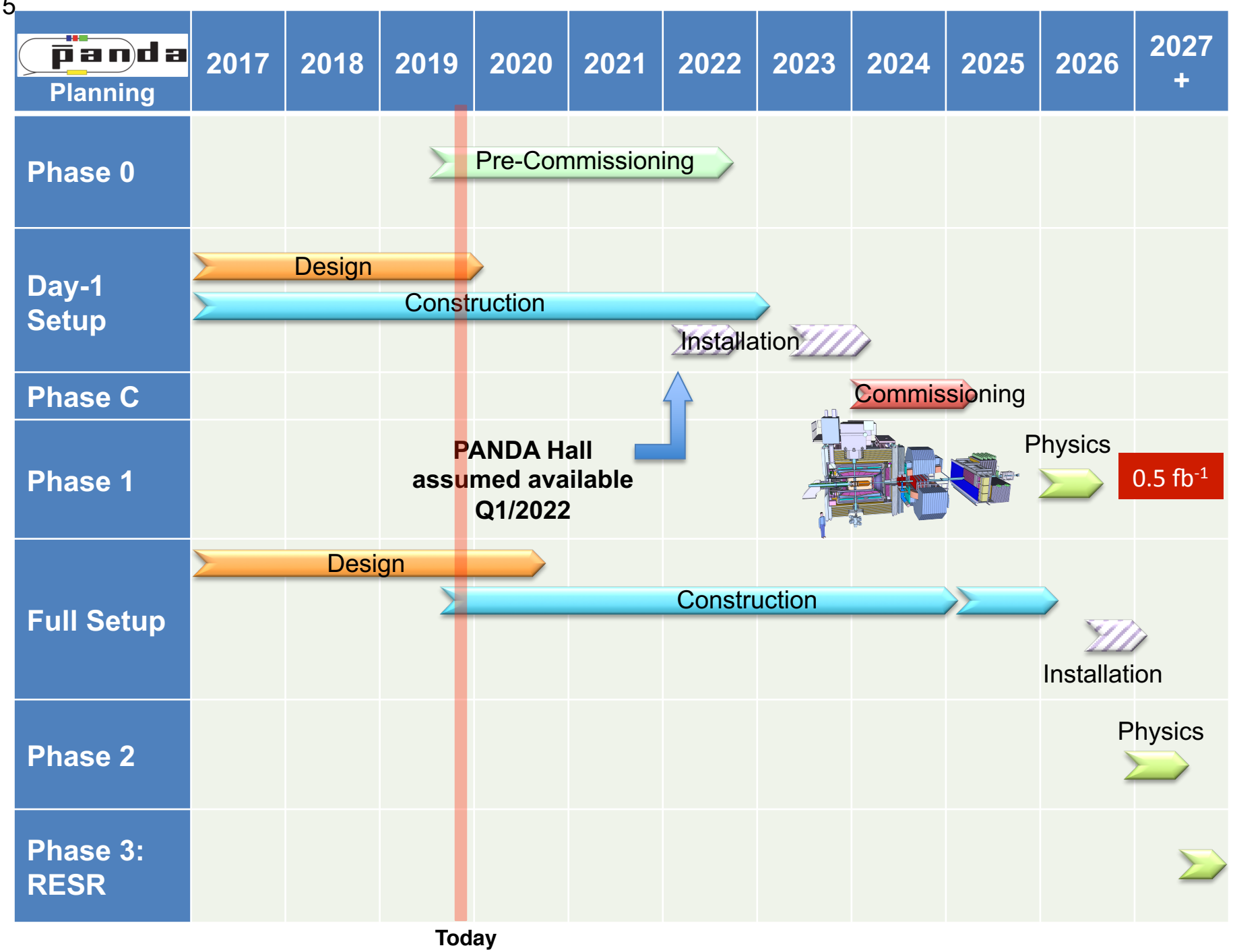
Phase 2
Physics
Phase 3: RESR
Today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Physics
0.5 fb-1
Full Setup
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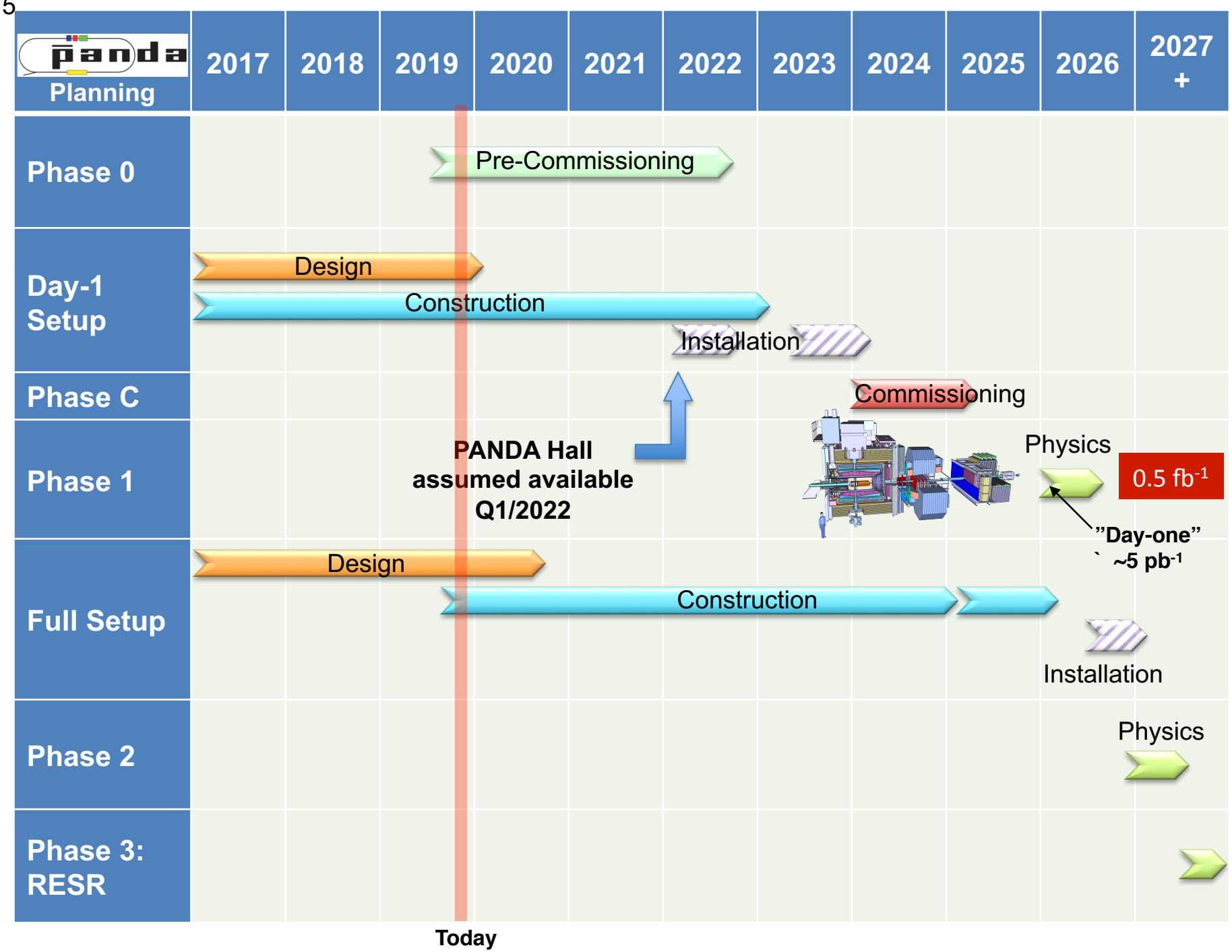
Today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Phase 1
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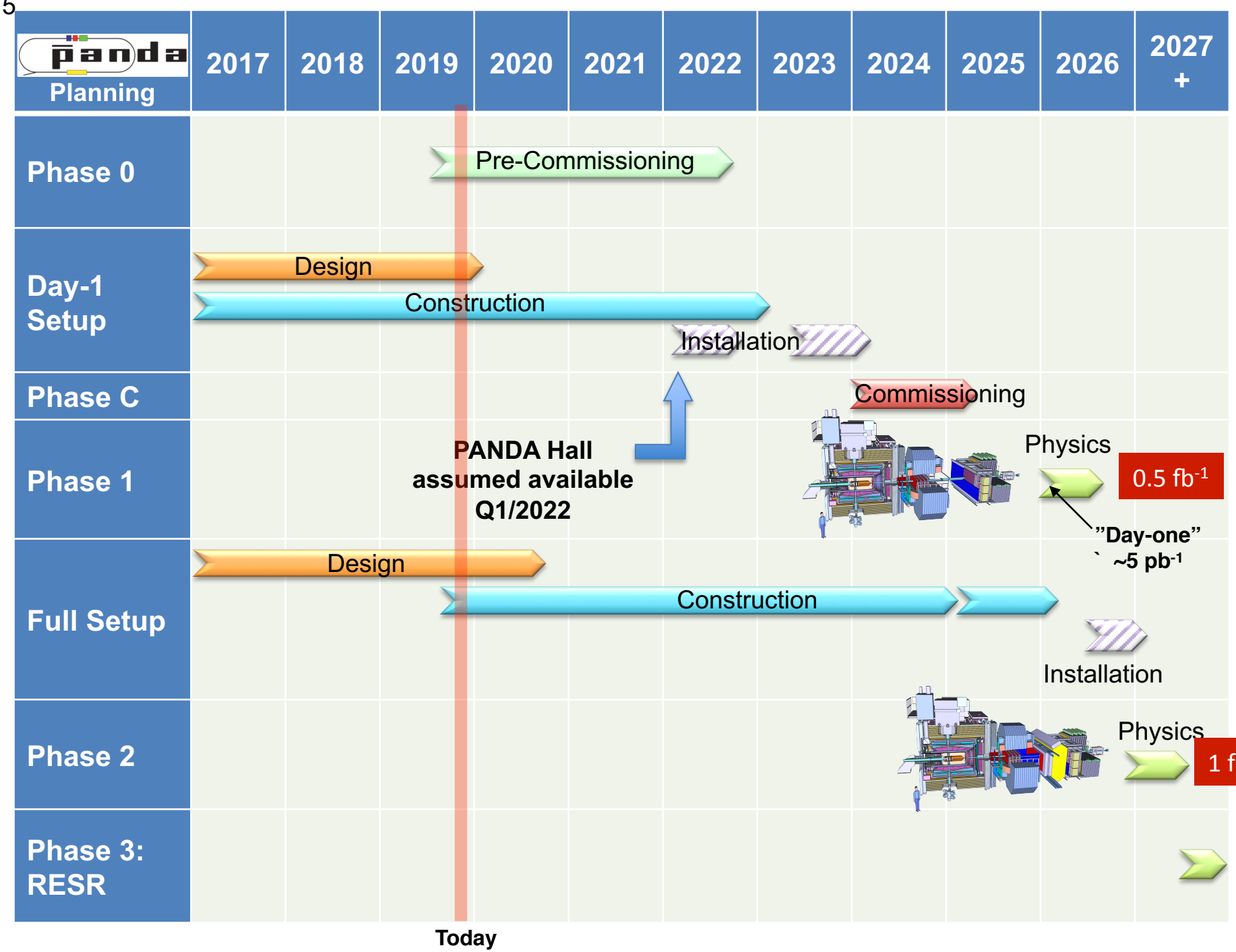
Physics
0.5 fb-1
"Day-one" ~5 pb-1
Full Setup
Design
Construction
Installation
Phase 2
Physics
Phase 3: RESR
Today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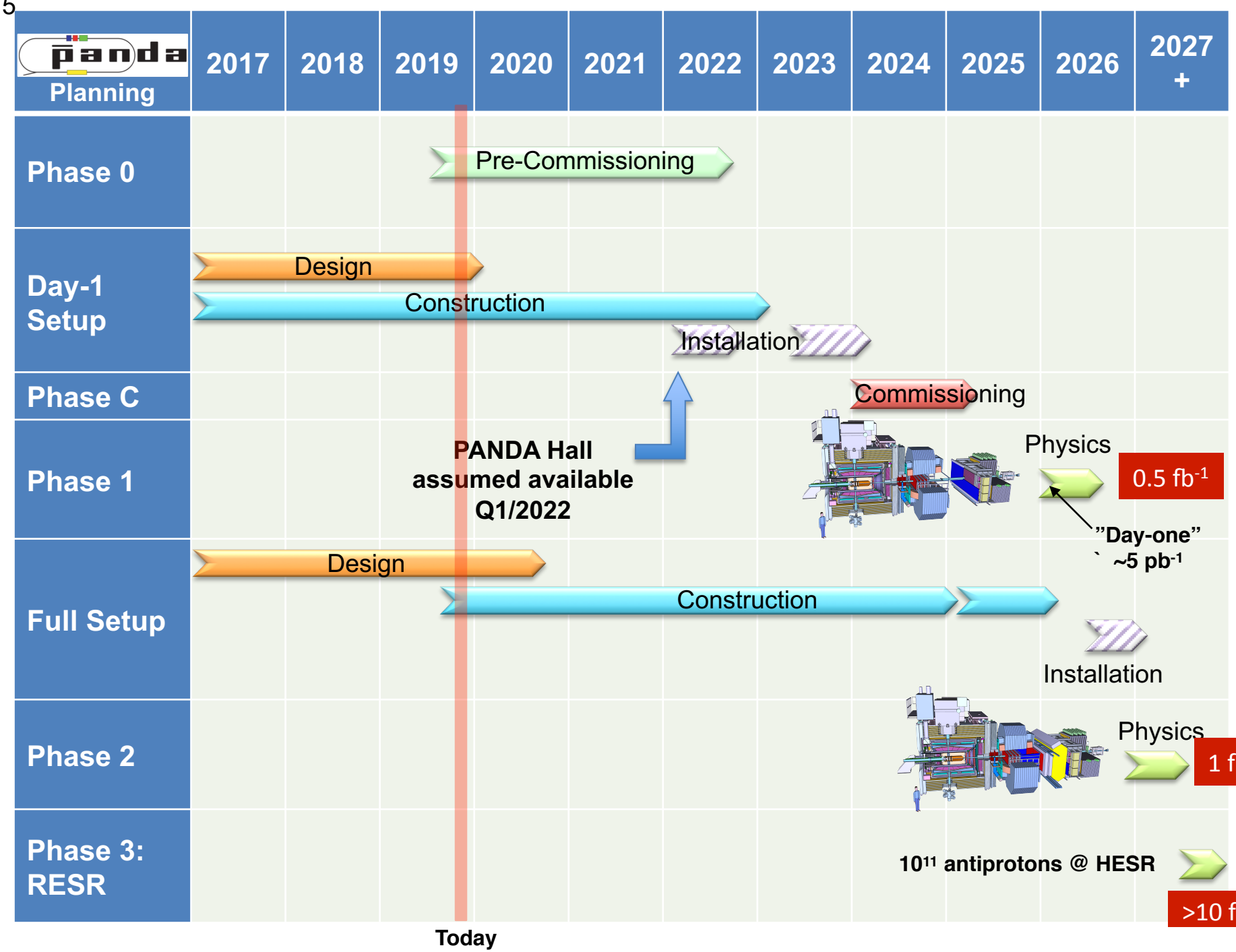
Physics
1 fb-1
Phase 3: RESR
Today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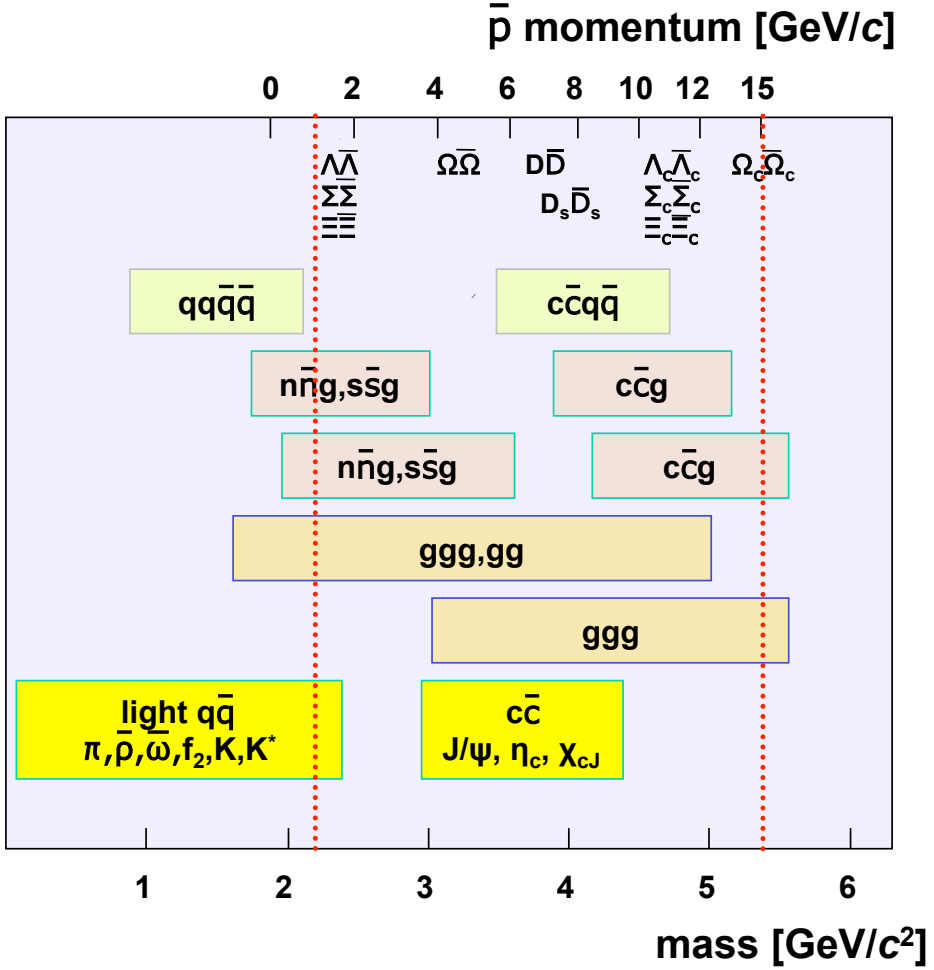
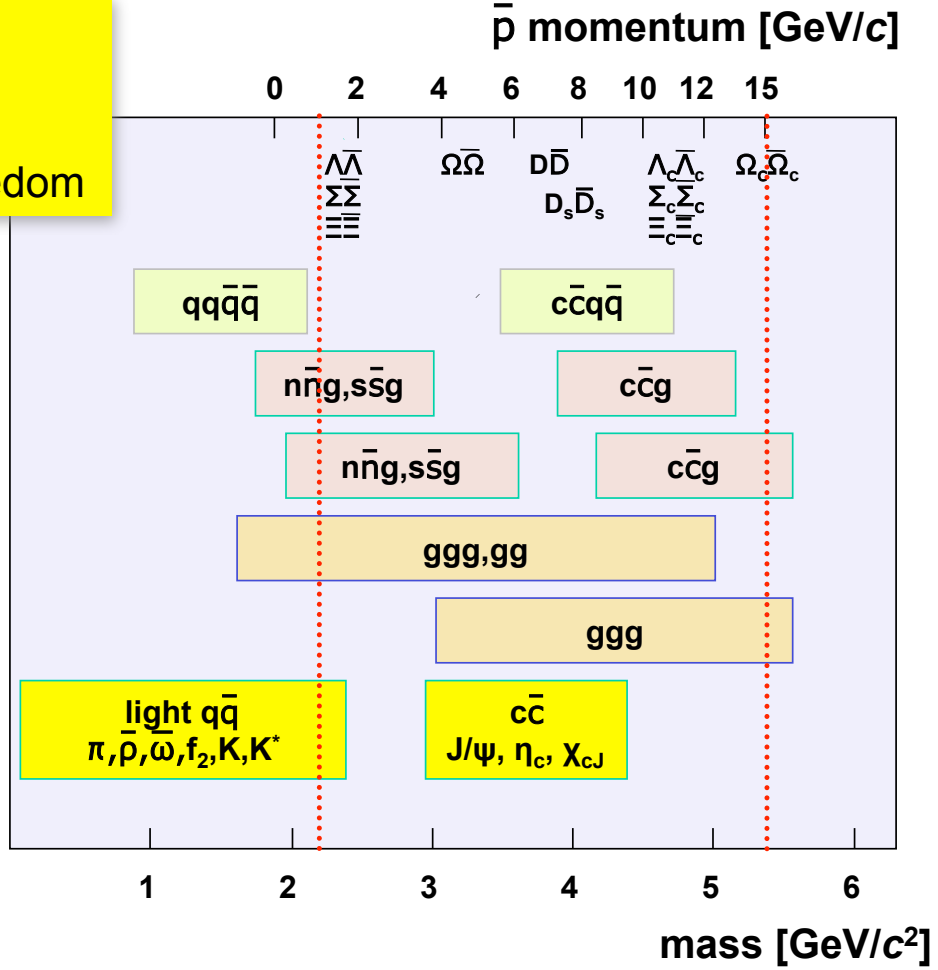
Physics
0.5 fb-1
"Day-one" ~5 pb-1
Full Setup
Design
Construction
Installation
Phase 2
Physics
1 fb-1
Phase 3: RESR
10^11 antiprotons @ HESR
>10 fb-1
Today

Versatility of antiprotons



Versatility of antiprotons

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



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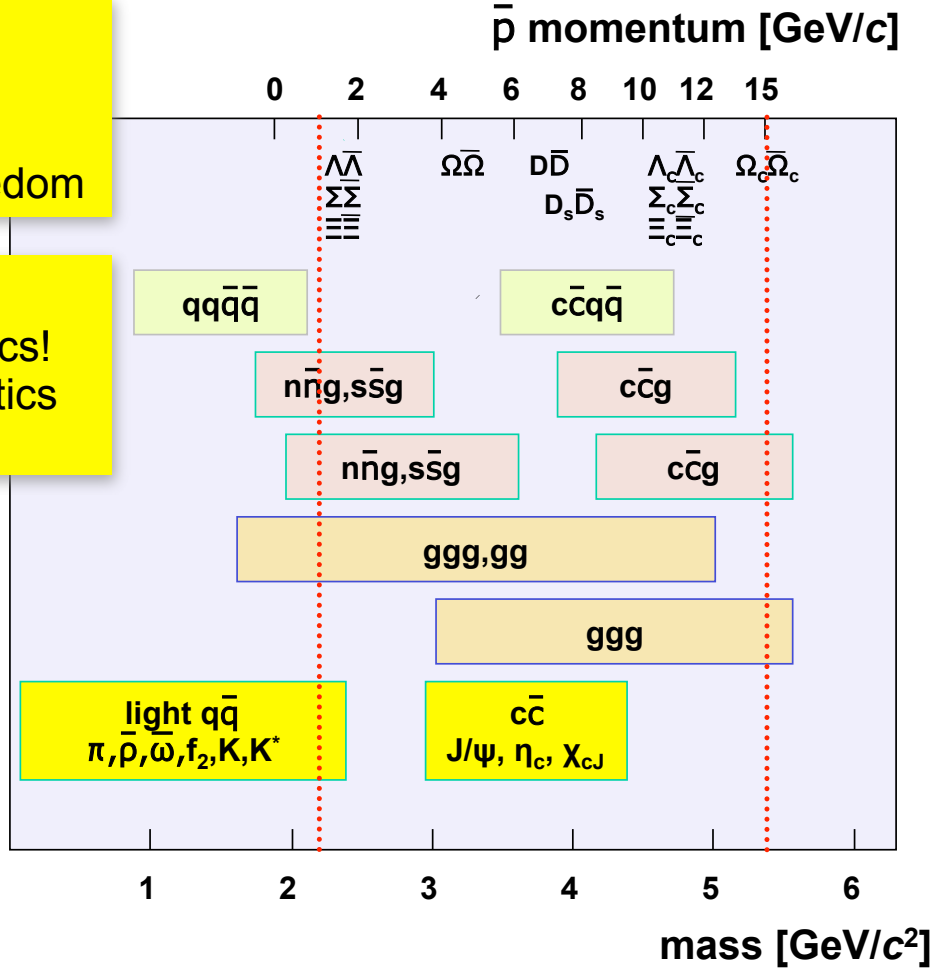
- charm+strange factory -> discovery by statistics!
- gluon-rich production -> potential for new exotics
- good perspectives already at “Day-One"!



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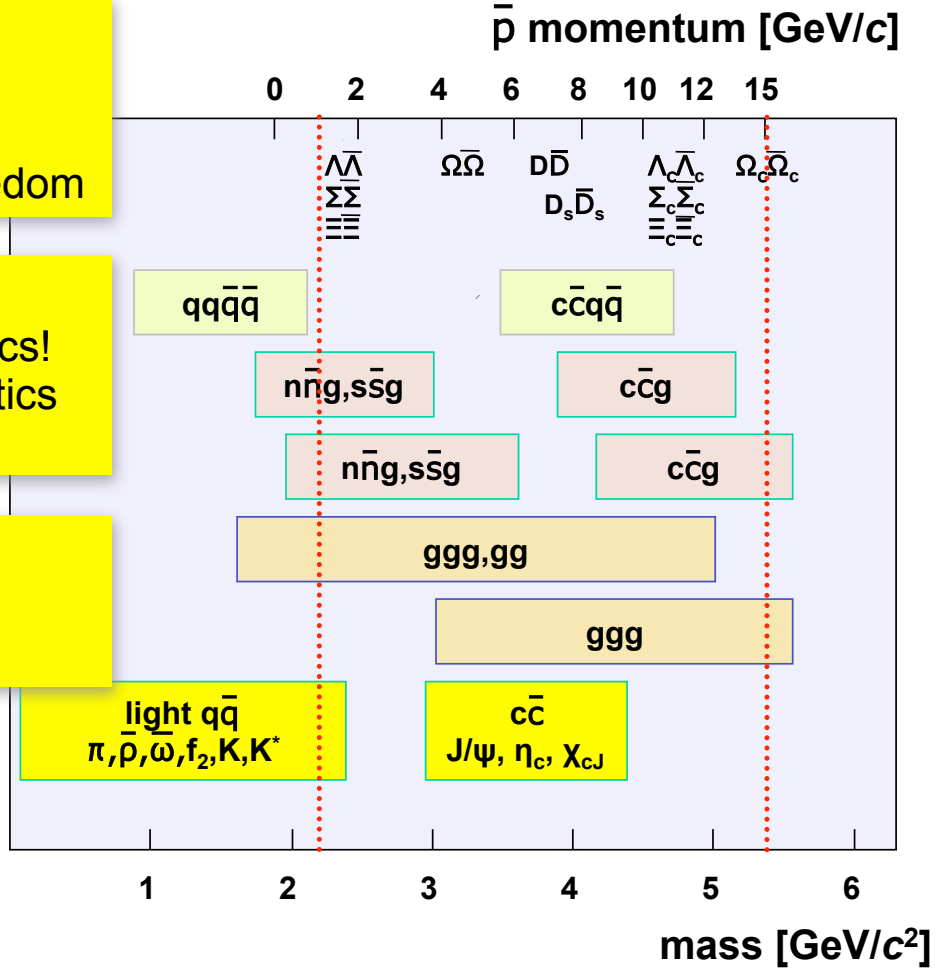
Access to large spectrum of J^{PC} states
- direct formation of *all* conventional J^{PC} states
- large sensitivity to high spin states



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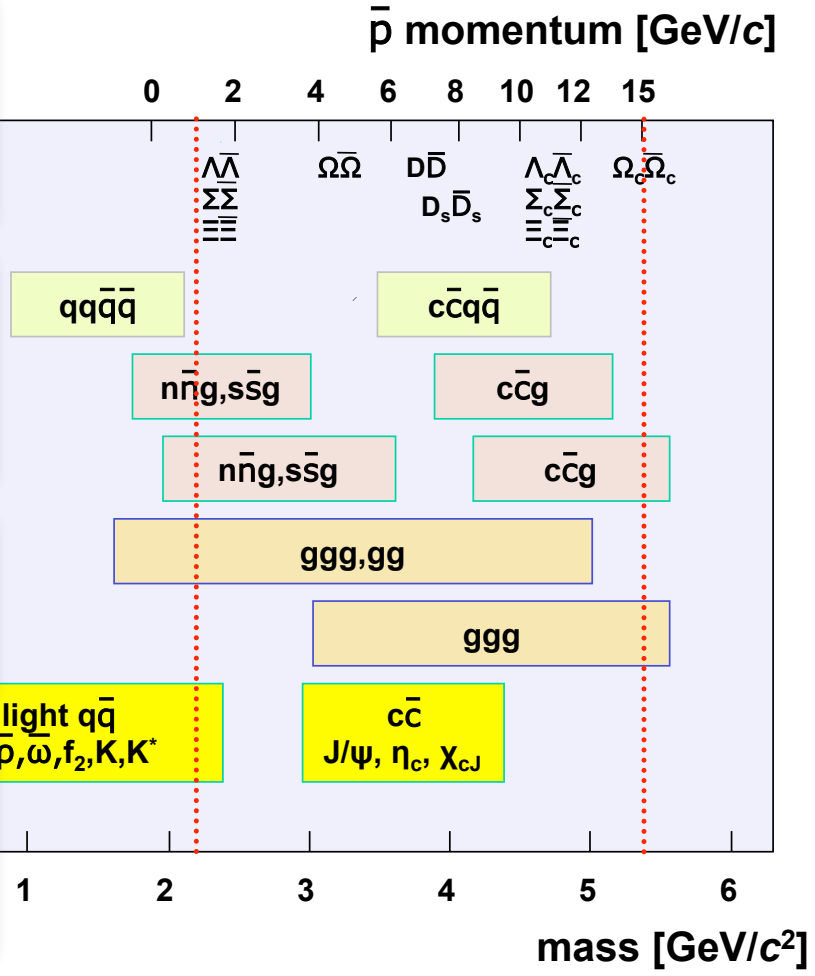
Associated hadron-pair production
- access to hidden-strange/charm hadrons
- tagging possibilities
- near thresh.: good resolution and low background



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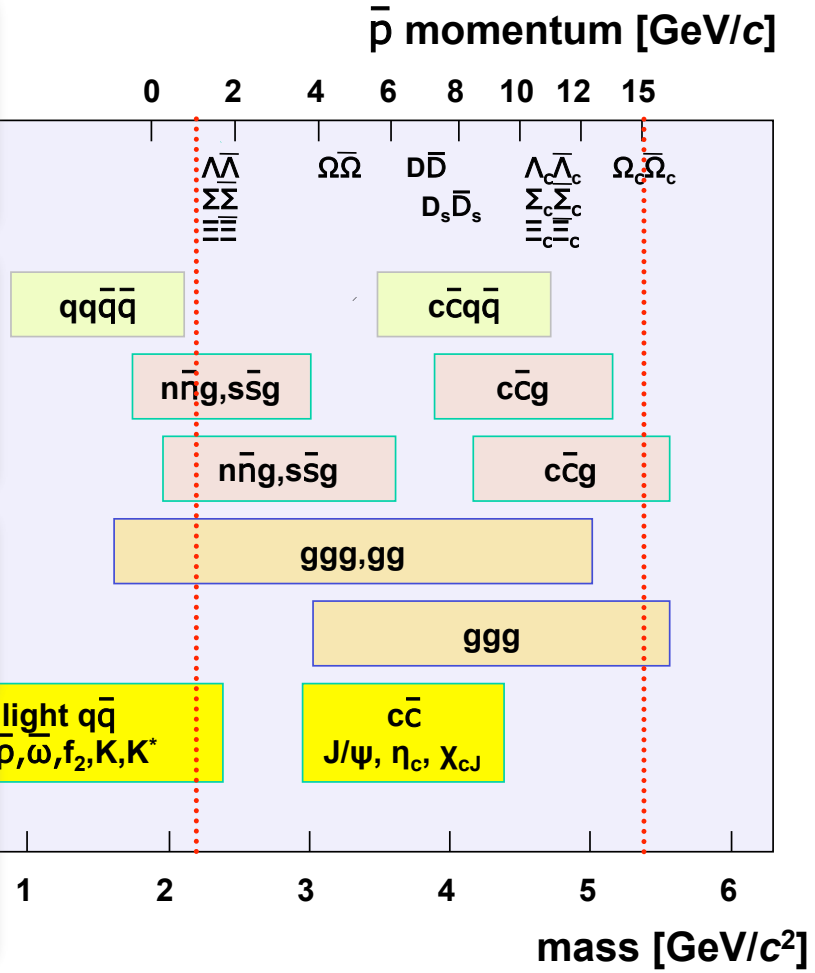
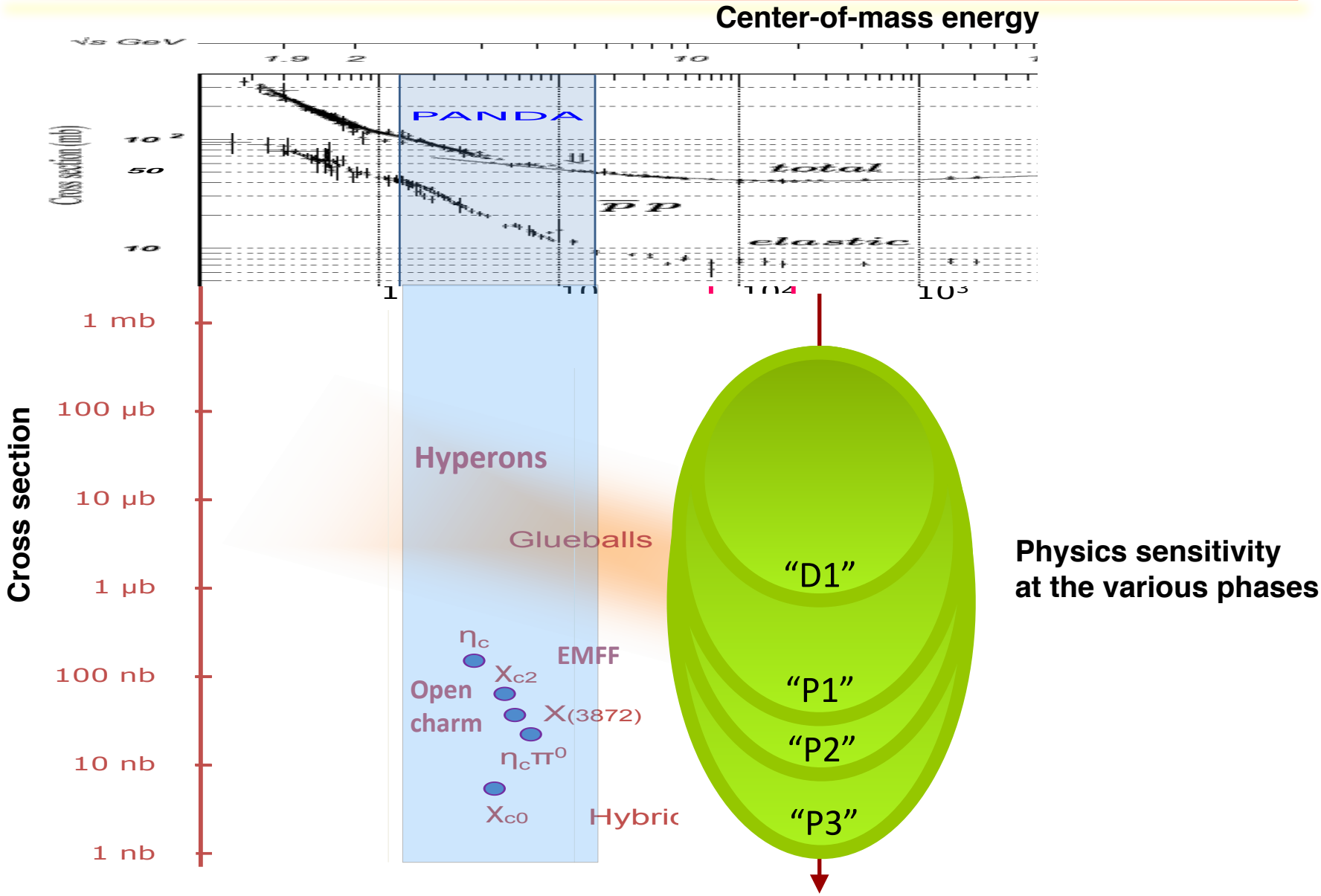


Systematic and precise tool to rigorously study the dynamics of QCD

Physics staging at PANDA



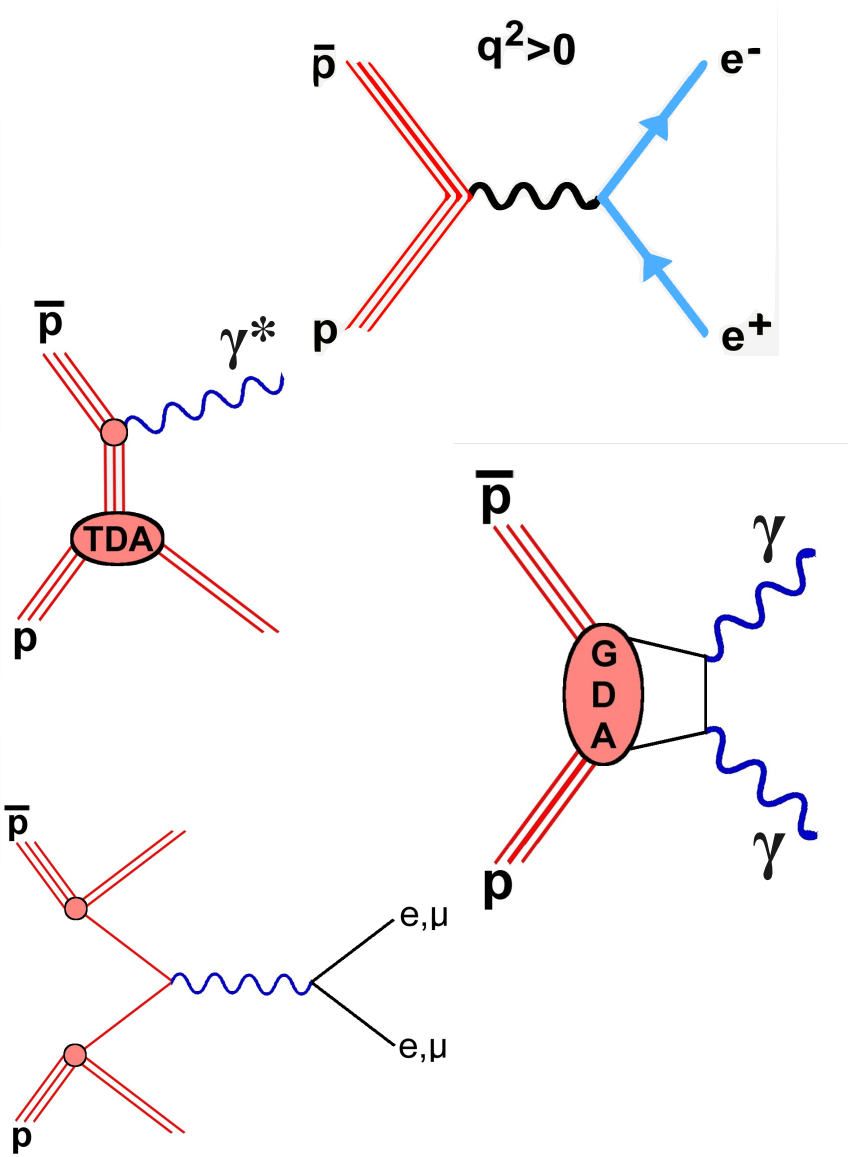
PANDA- the structure of the proton

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
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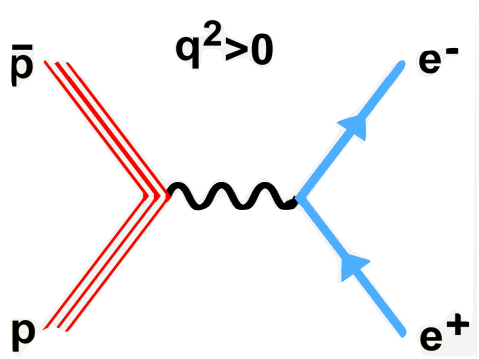

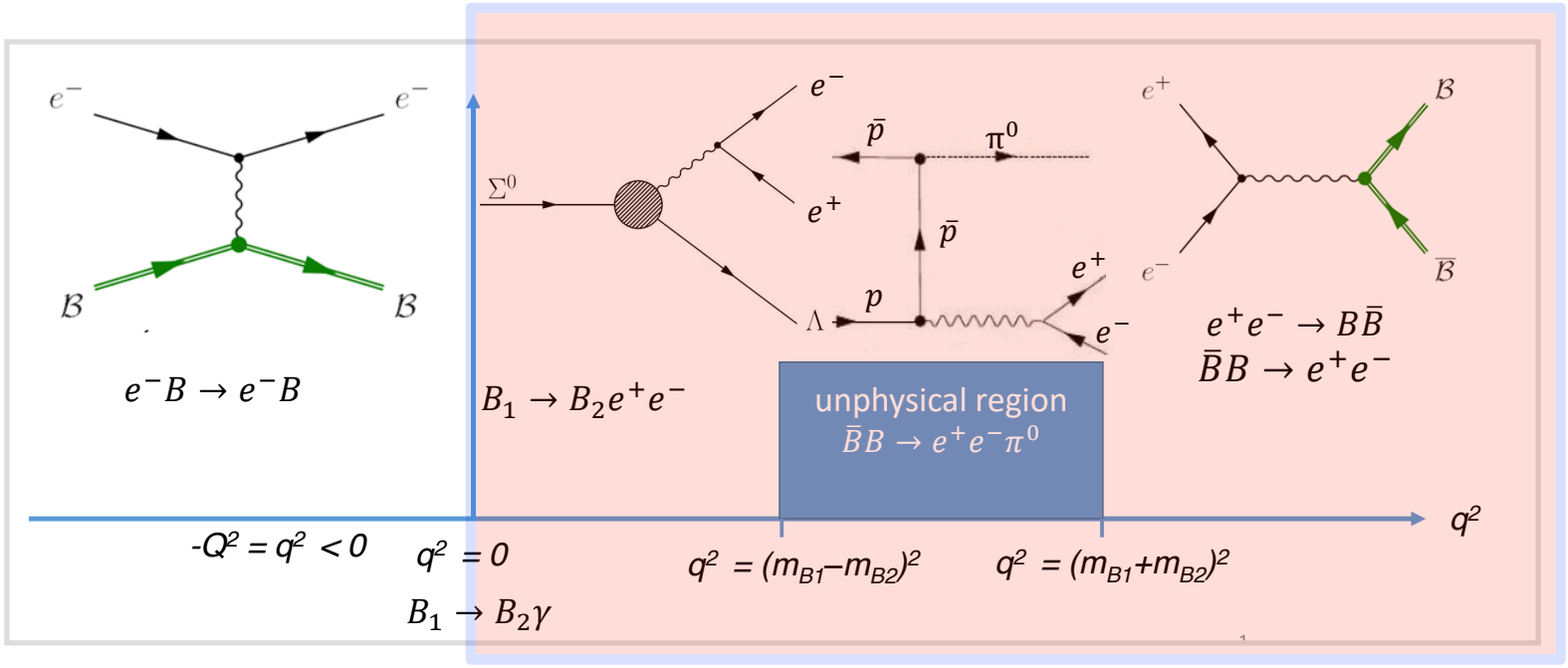

Analytical nature of form factors

EPJA 52 325 (2016)

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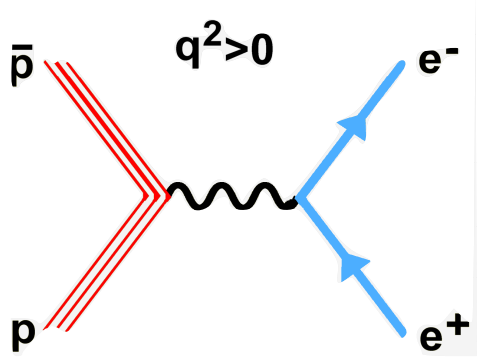

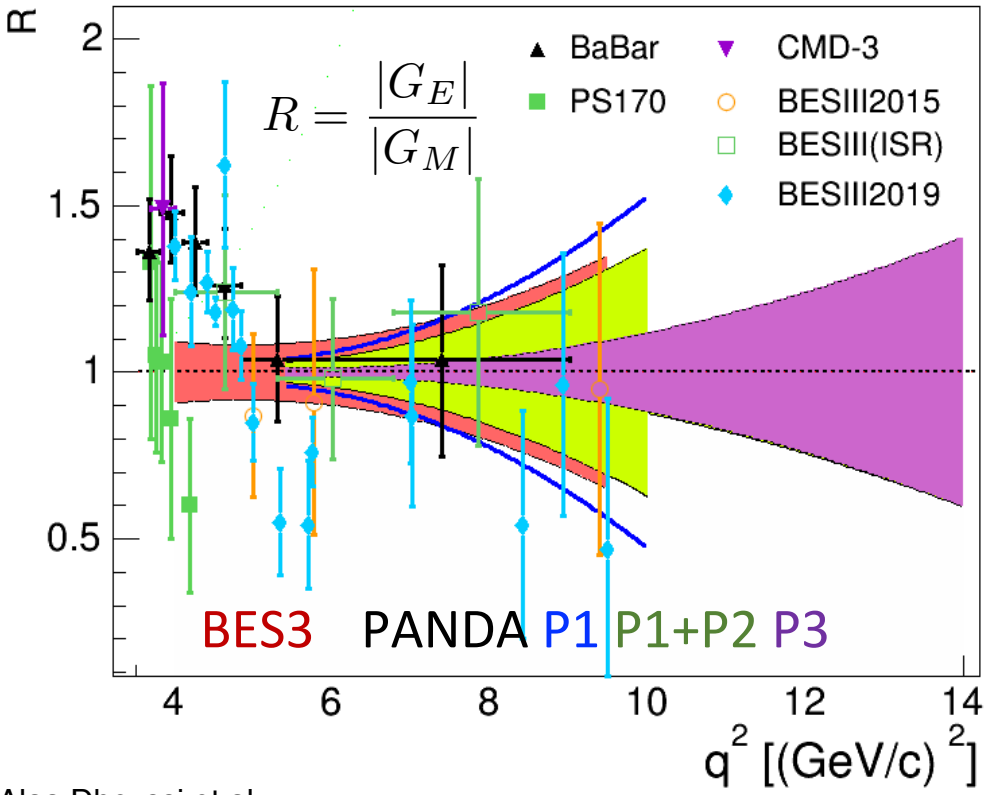

Phase-1
pp → e^+e^- @1.5 GeV/c ~ 220/day
pp → e^+e^- @3.3 GeV/c ~ 10/day

Analytical nature of form factors

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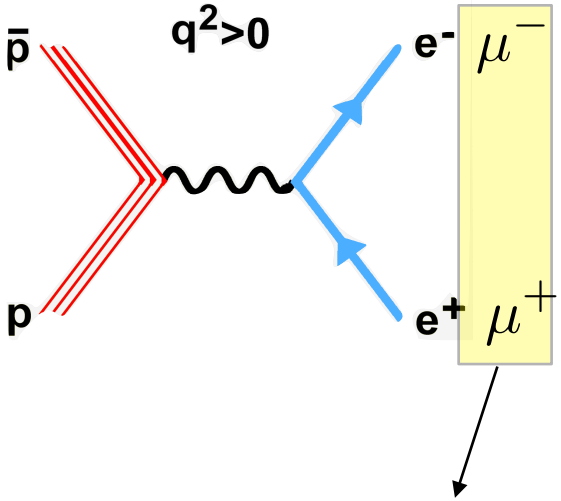
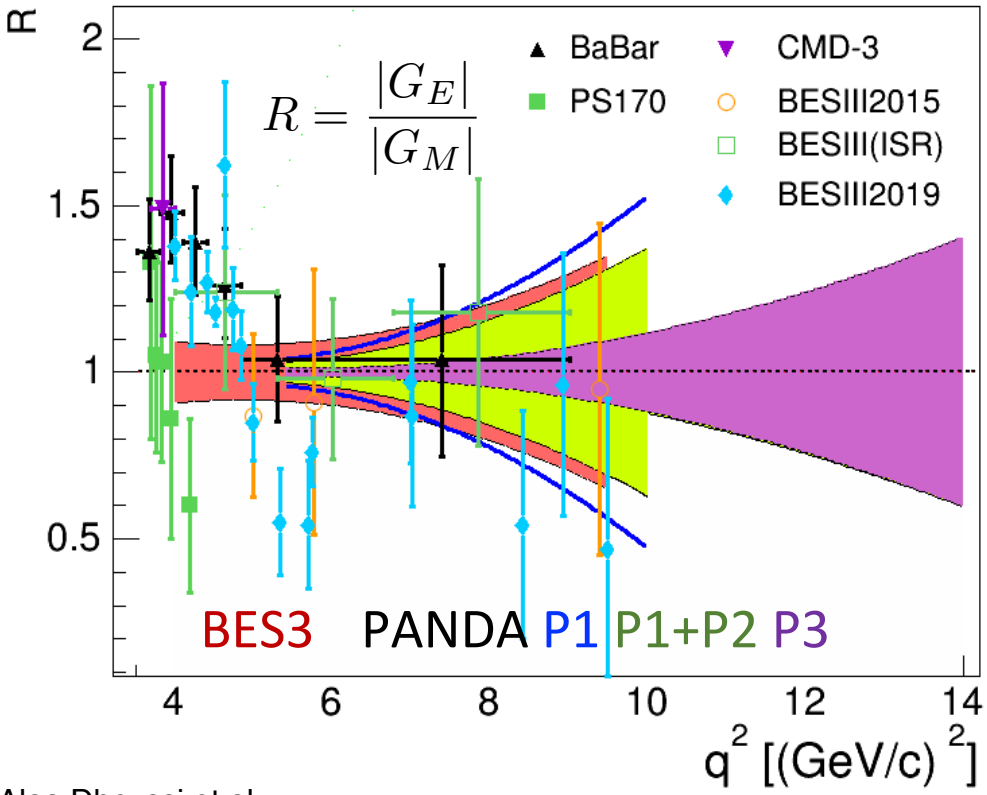


Unique for PANDA:
proton-radius puzzle
radiative corrections



Phase-1

pp → e^+e^-	@1.5 GeV/c	~ 220/day
pp → e^+e^-	@3.3 GeV/c	~ 10/day
pp → $\mu^+\mu^-$	@1.5 GeV/c	~ 170/day

Alaa Dbeyssi et al.

Analytical nature of form factors

EPJA 52 325 (2016)

Time-like Electromagnetic Form Factors
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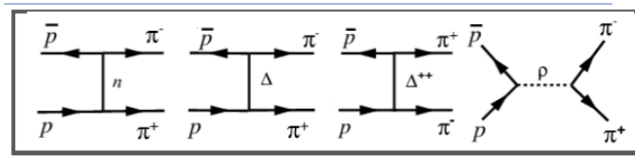
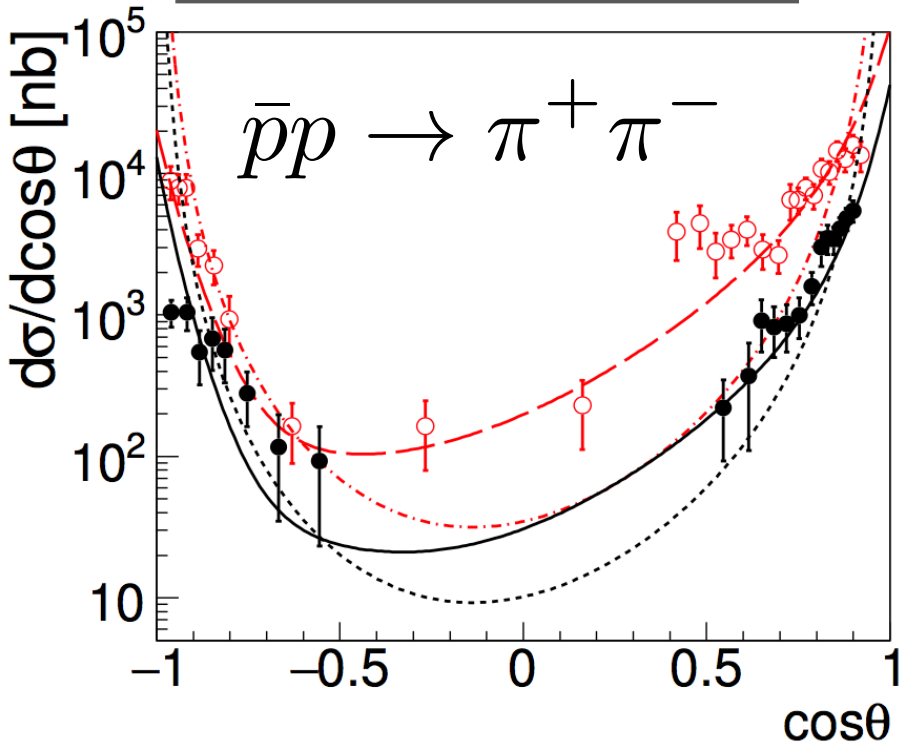
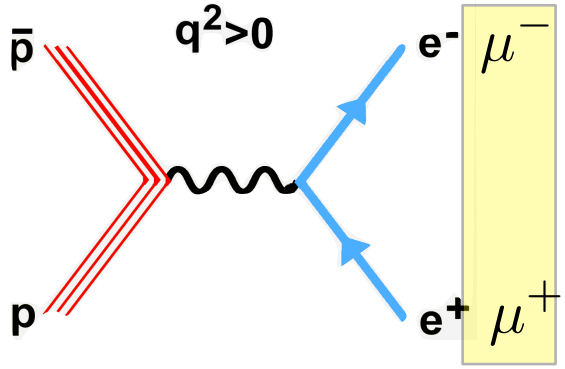






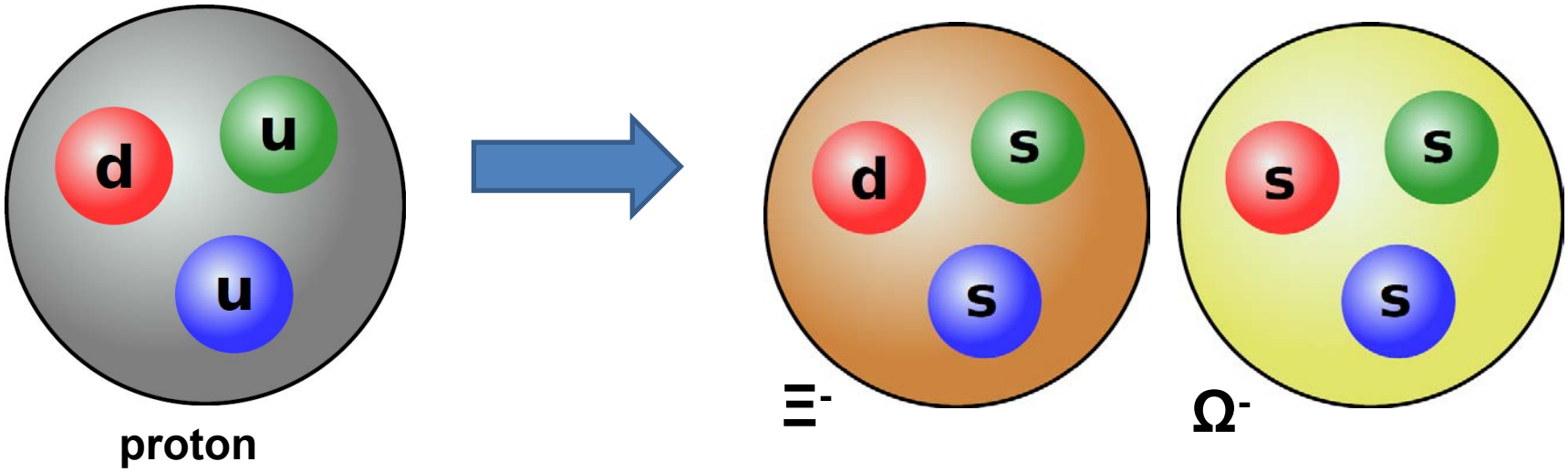
Day-1 activities:

1) Build *database* on *multi-pion production* in p+pbar as input to QCD calculations

2) *Demonstrate* the feasibility to identify di-lepton (+pi0) channels

Exploring the hyperon sector

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

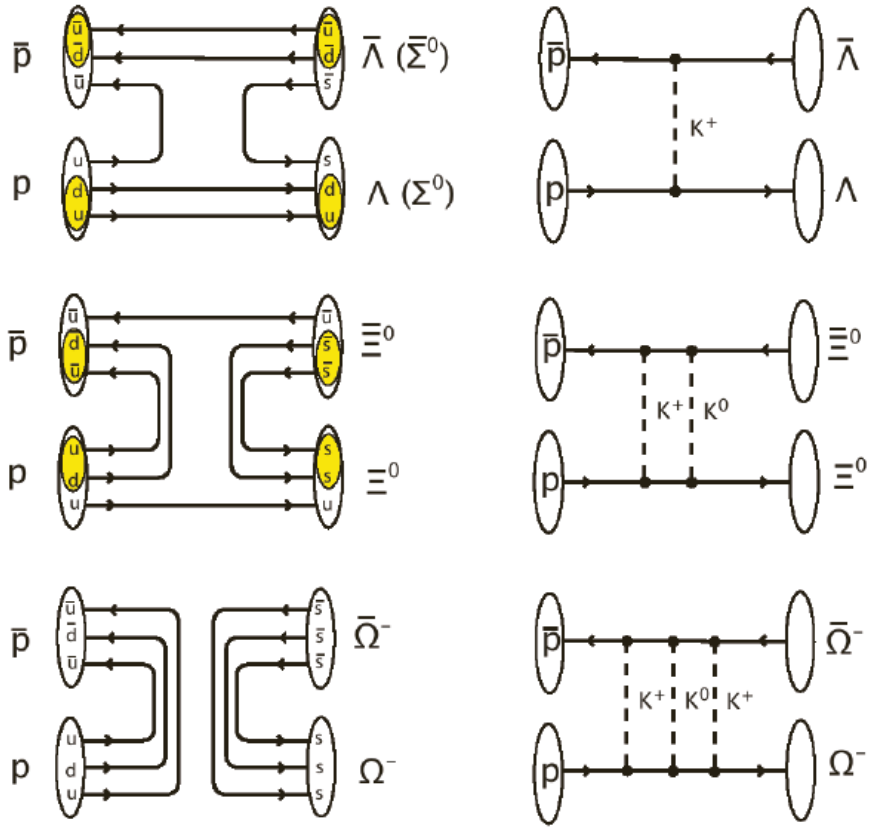


Courtesy: Karin Schoenning

Exploring the hyperon sector

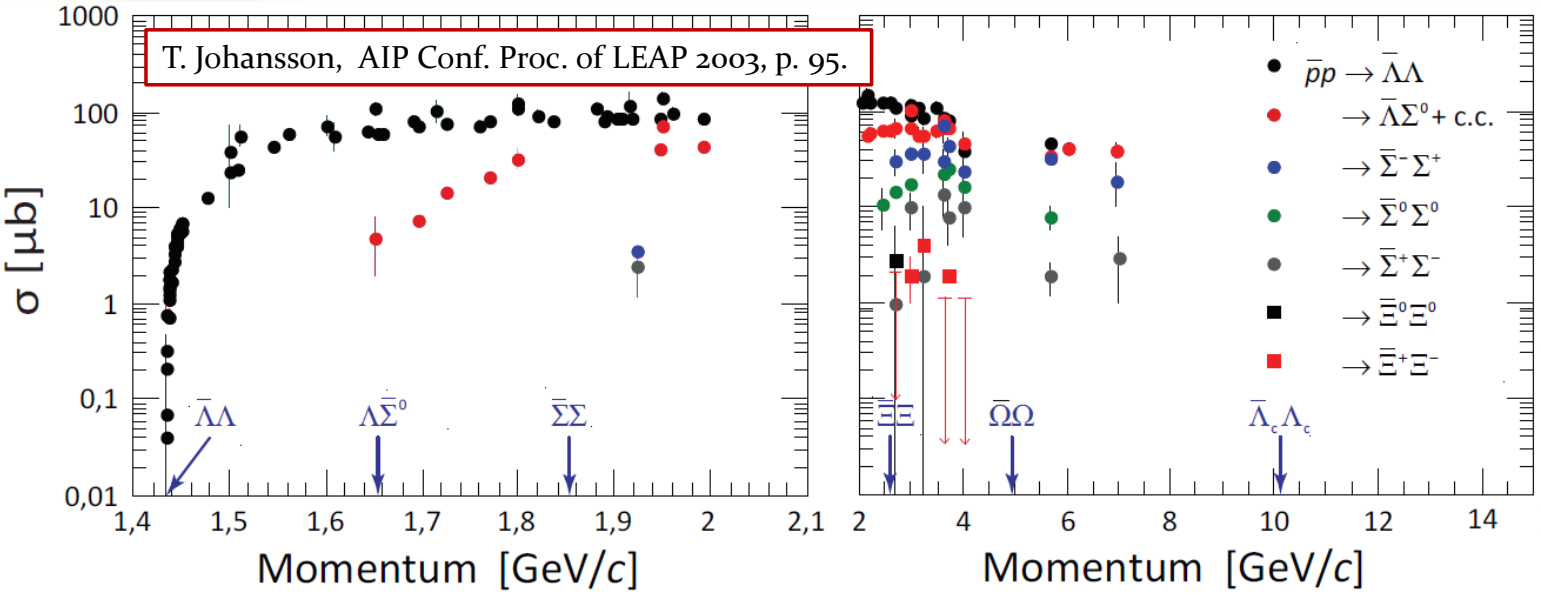
Strong production dynamics

- Relevant degrees of freedom?
- Strange *versus* charm sector?
- Role of spin?



Courtesy: Karin Schoenning

PANDA is a hyperon factory!



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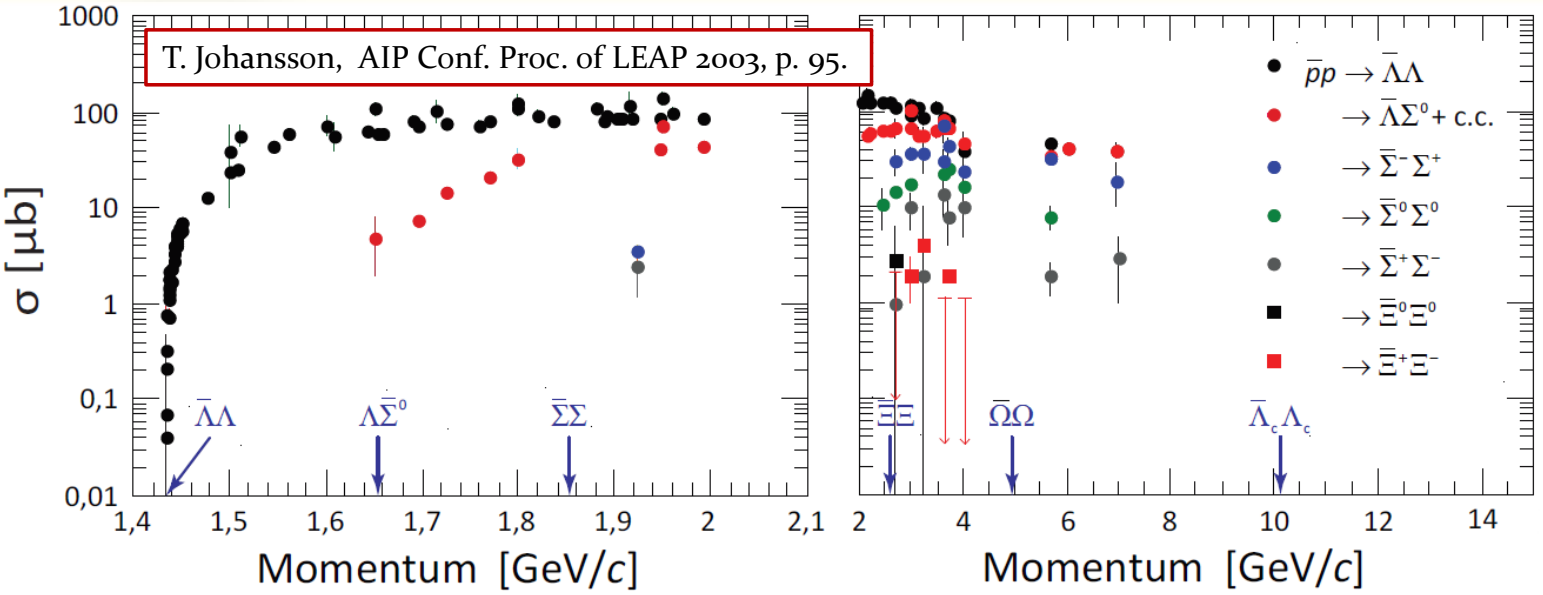
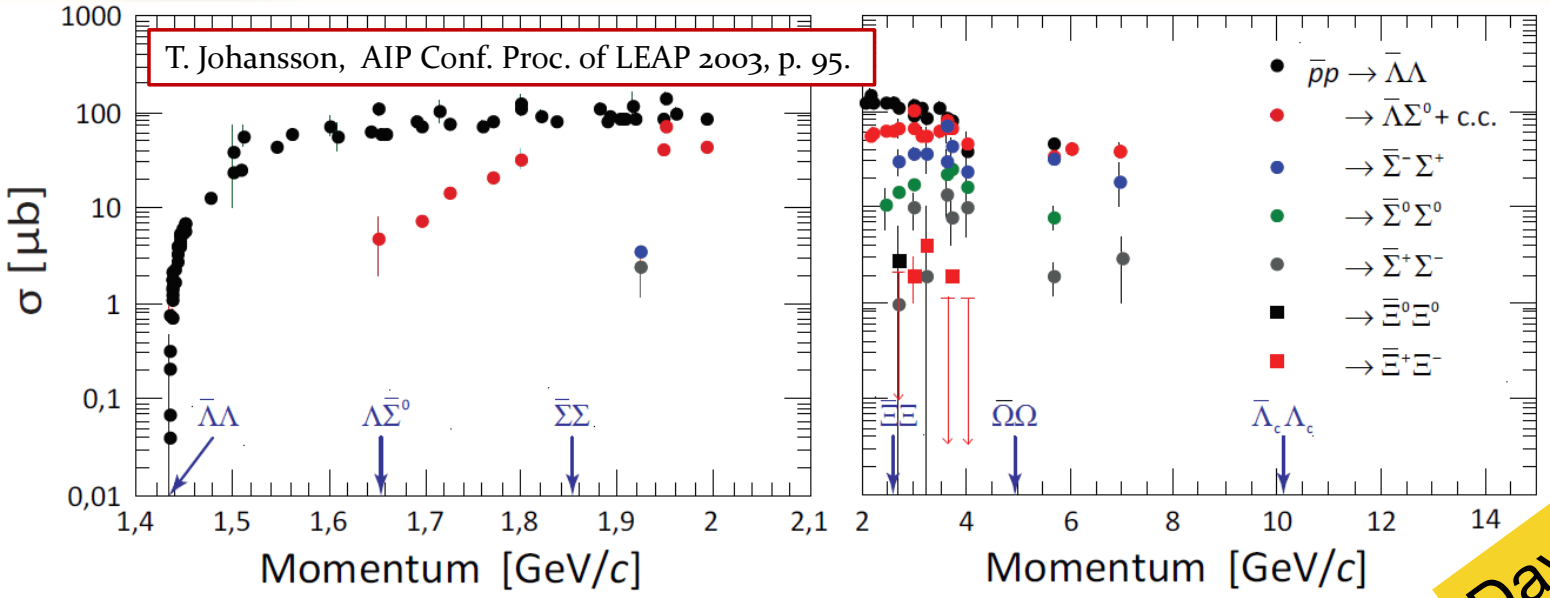


p_{beam} (GeV/c)	Reaction	σ (μb)	ε (%)	Rate @ 10^{31} $cm^{-2}s^{-1}$	S/B	Events /day
1.64	$\bar{p}p \to \bar{\Lambda}\Lambda$	64.0	16.0	44 s^{-1}	114	$3.8 \cdot 10^6$
1.77	$\bar{p}p \to \bar{\Sigma}^0\Lambda$	10.9	5.3	2.4 s^{-1}	>11**	207 000
6.0	$\bar{p}p \to \bar{\Sigma}^0\Lambda$	20	6.1	5.0 s^{-1}	21	432 000
4.6	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	~1	8.2	0.3^{-1}	274	26000
7.0	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	~0.3	7.9	0.1^{-1}	65	8600

Courtesy: Karin Schoenning

** 90% C.L.

PANDA is a hyperon factory!



Day-1

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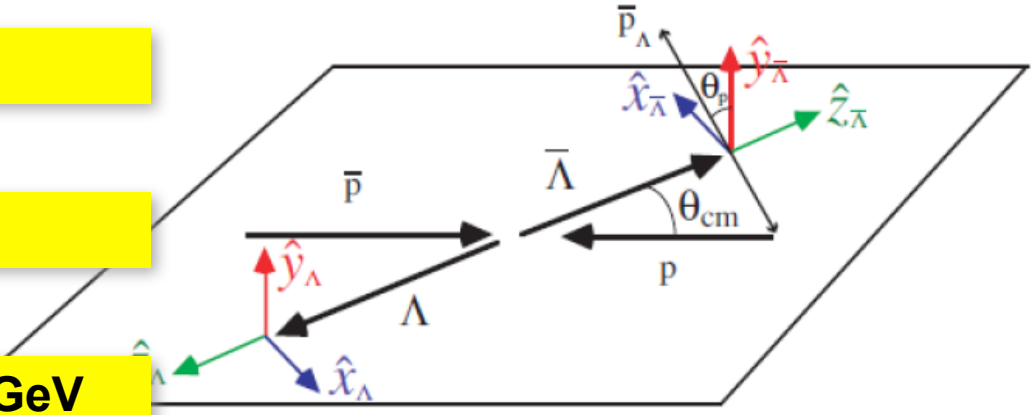
PANDA is a hyperon factory!

Rich set of polarisation observables

(double) strange and charm baryons

Explore hyperon dynamics above 4 GeV



$$I(\cos\theta_B) = \frac{1}{4\pi}(1 + \alpha_Y P_y \cos\theta_B)$$

Day-1

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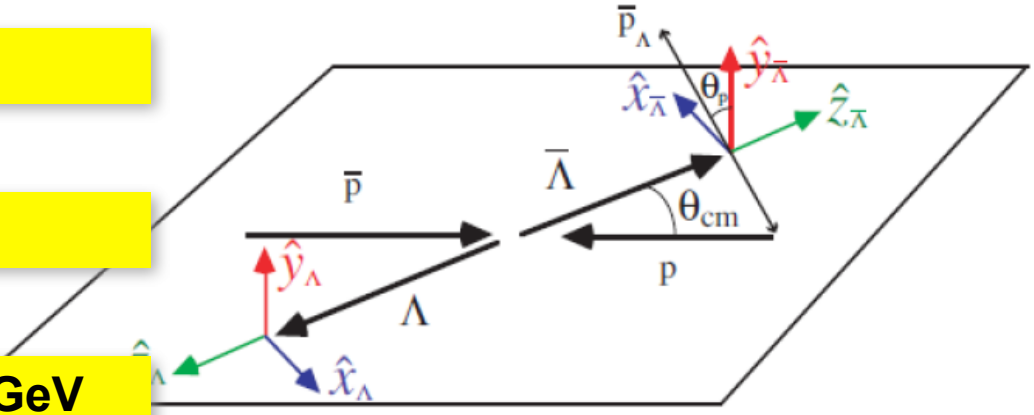
(double) strange and charm baryons

Explore hyperon dynamics above 4 GeV



Day-1:

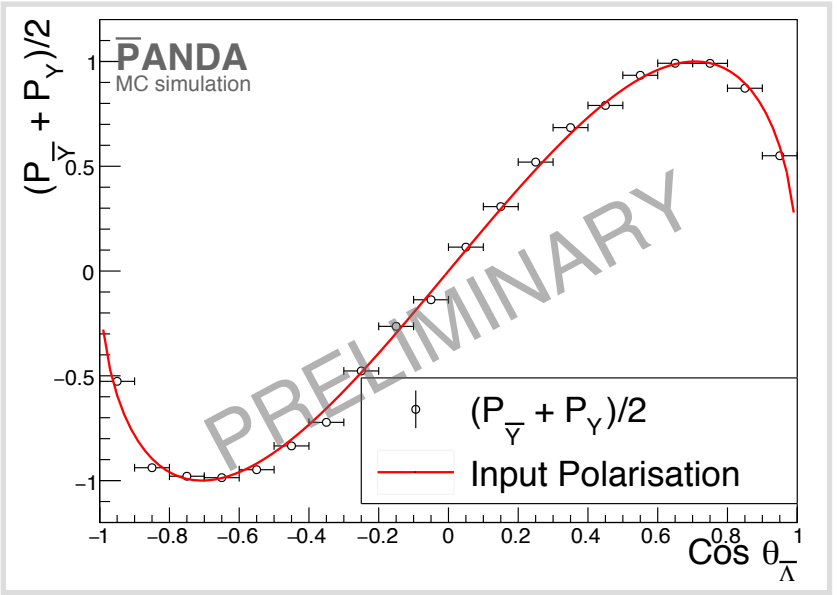
Reproduce LEAR studies @1.64 GeV/c

Extend at 4 GeV/c and for |S|=2 hyperons

Phase-1:

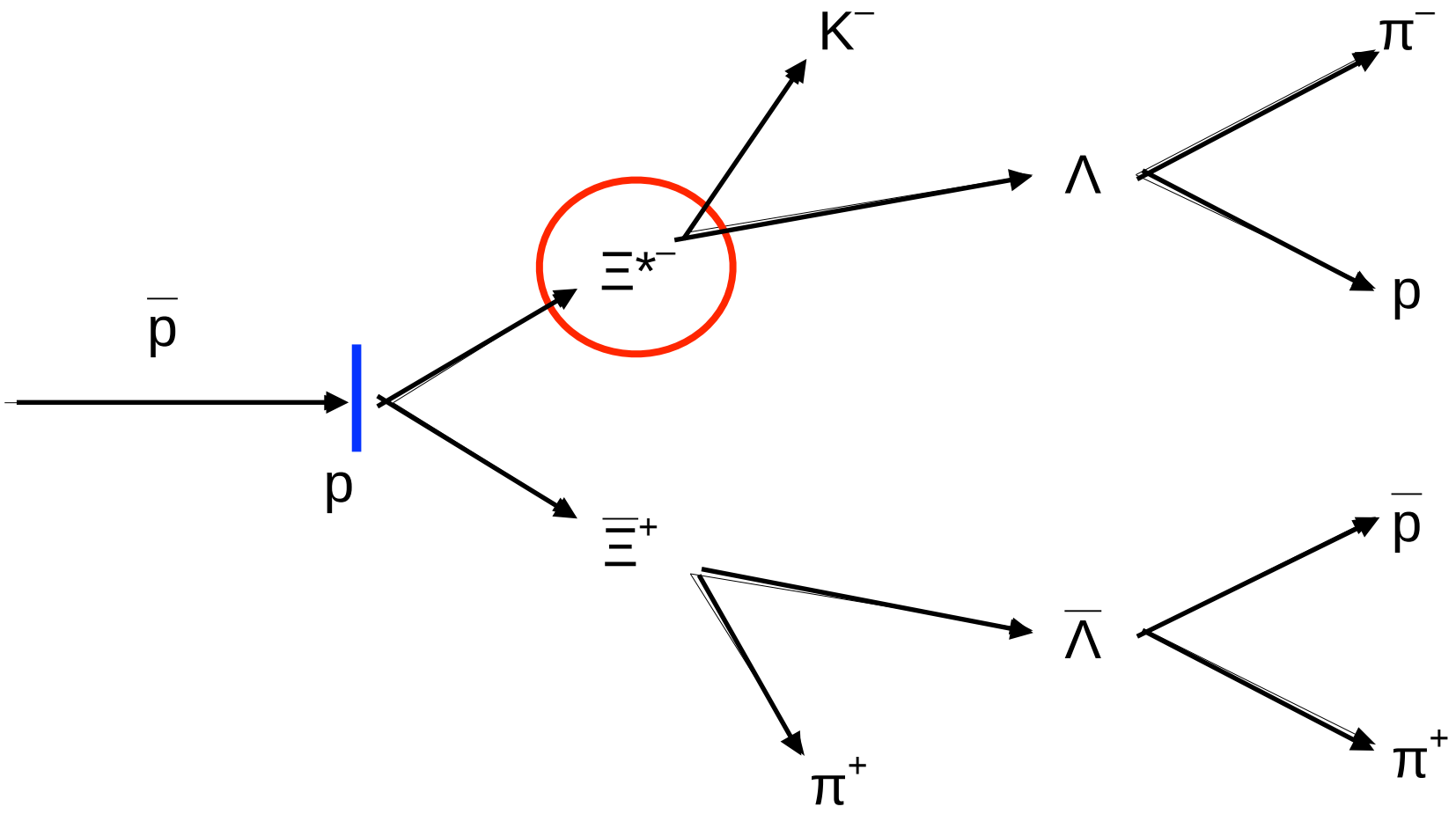
Spin correlations in |S|=1,2

Extend to |S|=3 and charm hyperons



Hyperon spectroscopy

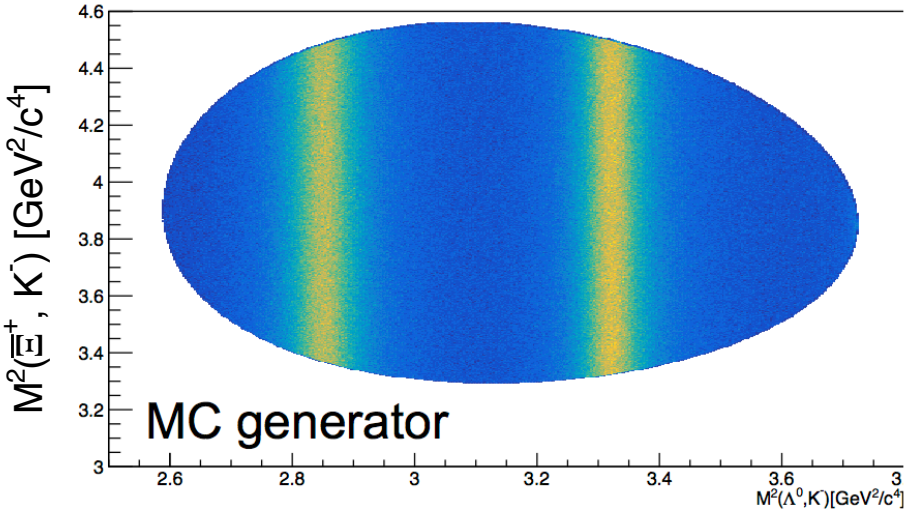
Map out the |S|=2 excited baryon spectrum

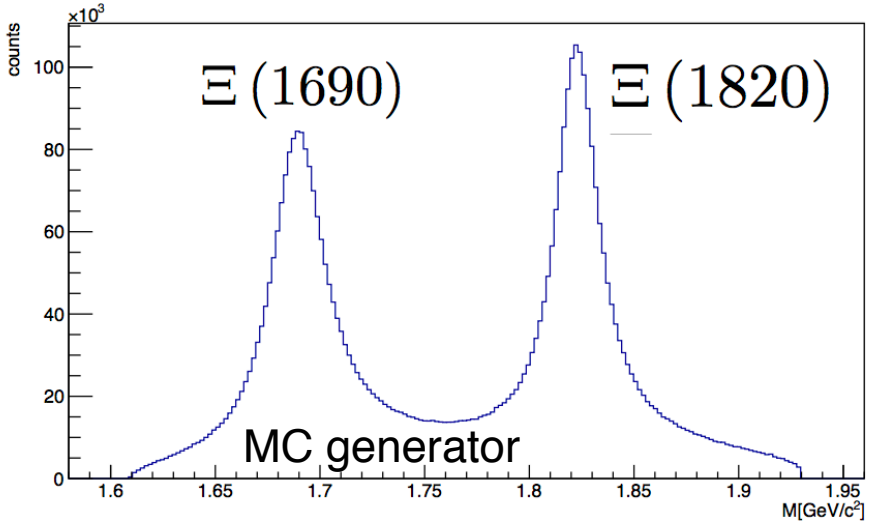


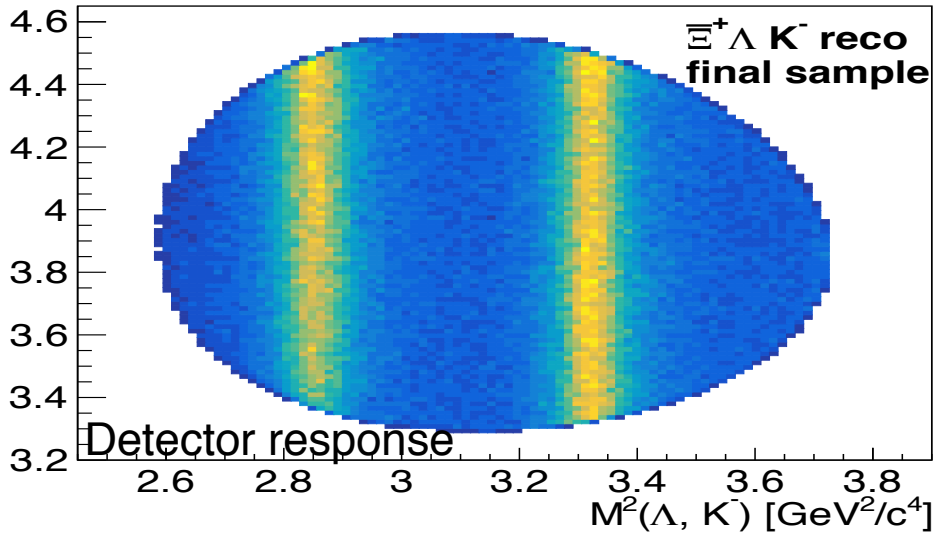
Hyperon spectroscopy

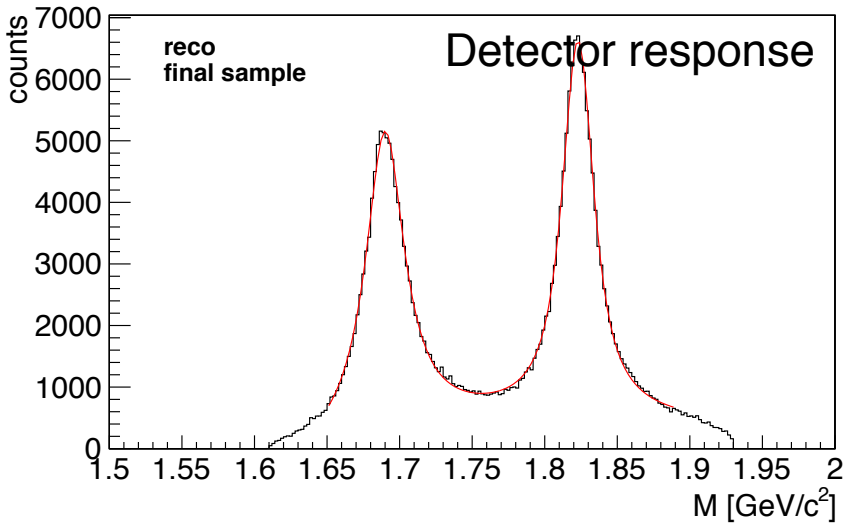
Albrecht Gillitzer et al.

Map out the |S|=2 excited baryon spectrum

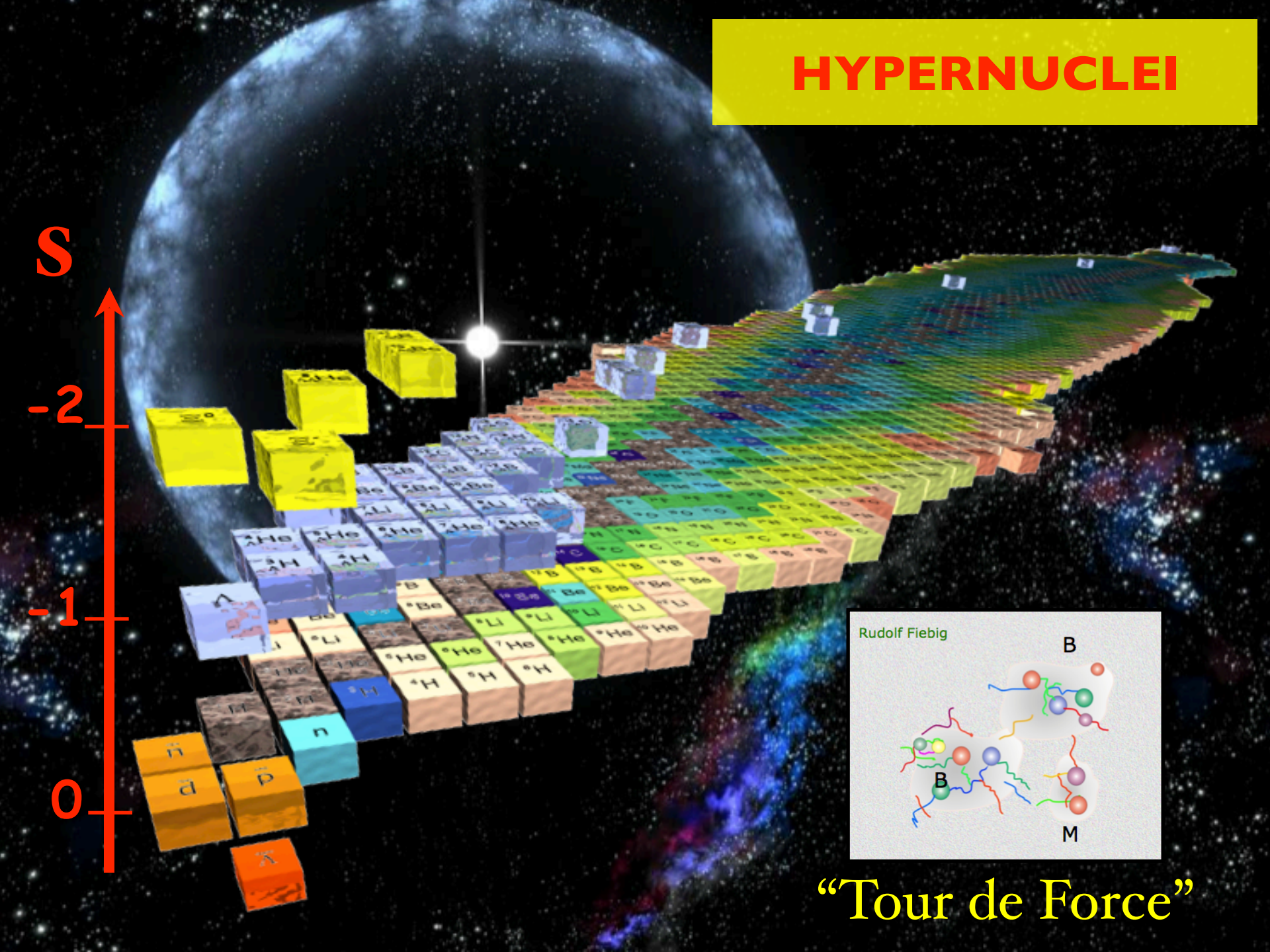






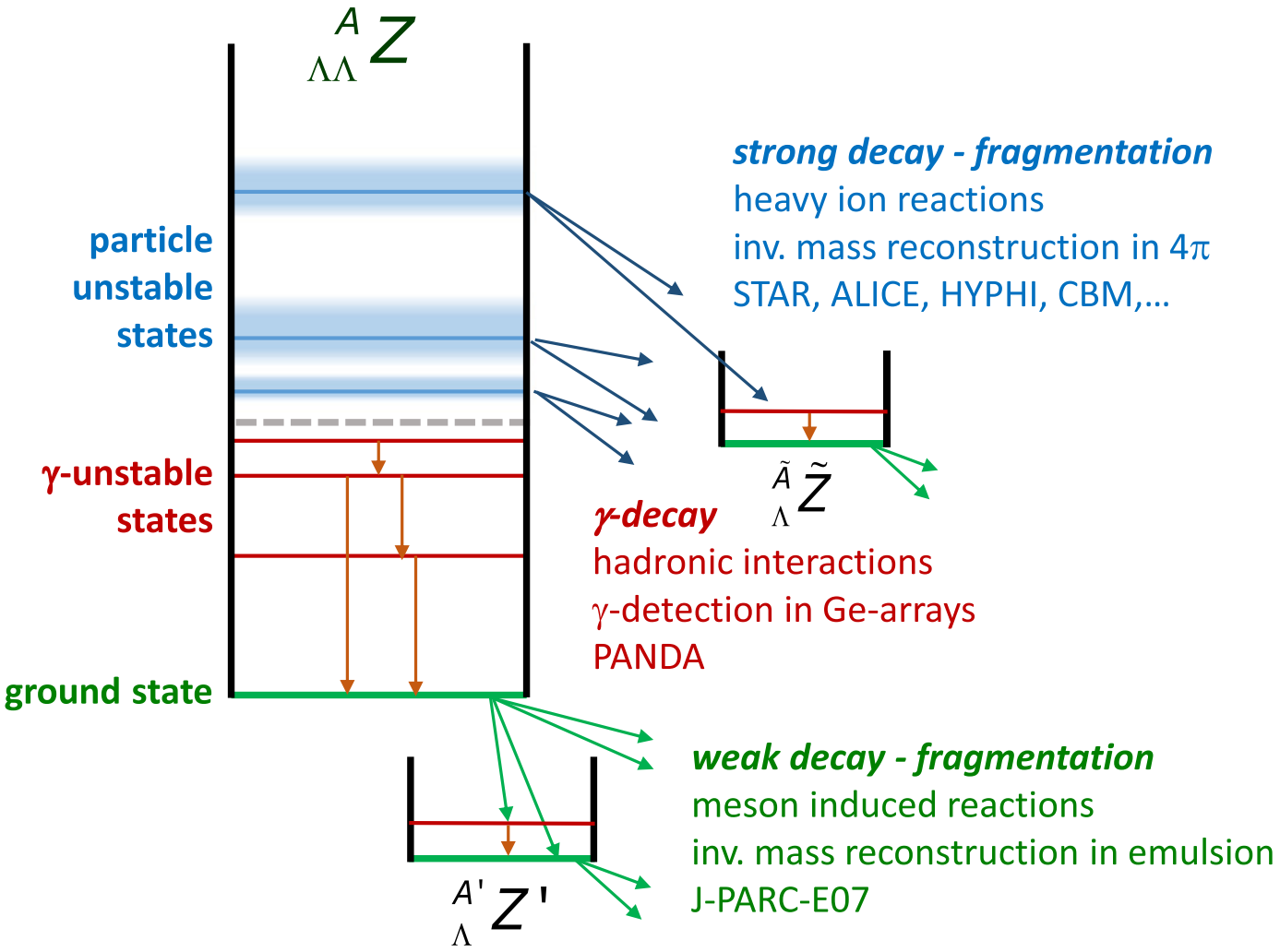


HYPERNUCLEI



"Tour de Force"

Double hypernuclear spectroscopy



Courtesy: Josef Pochodzalla

HYPERNUCLEI

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

rescattering in
primary target nucleus

deceleration in
secondary target

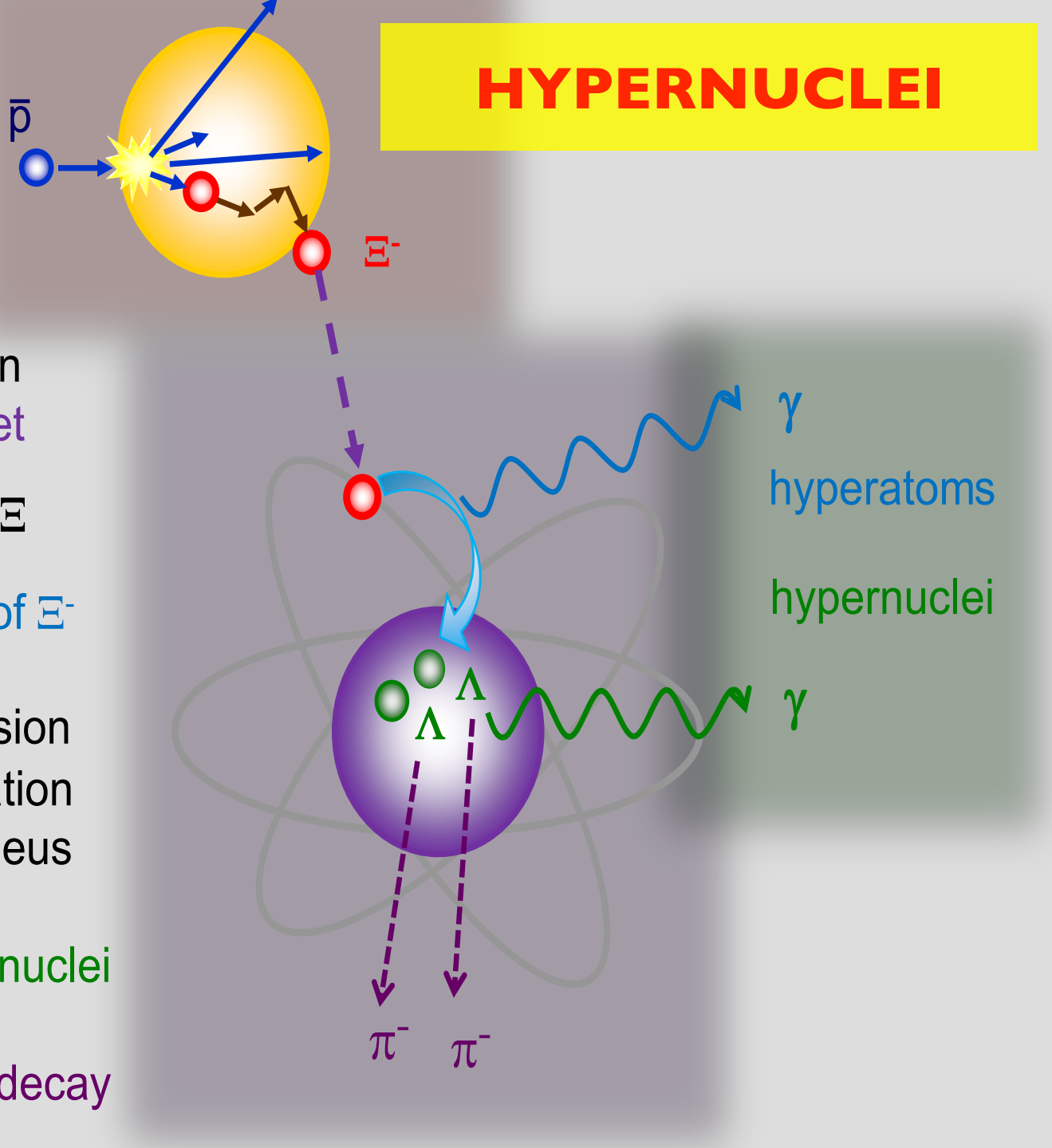
capture of Ξ

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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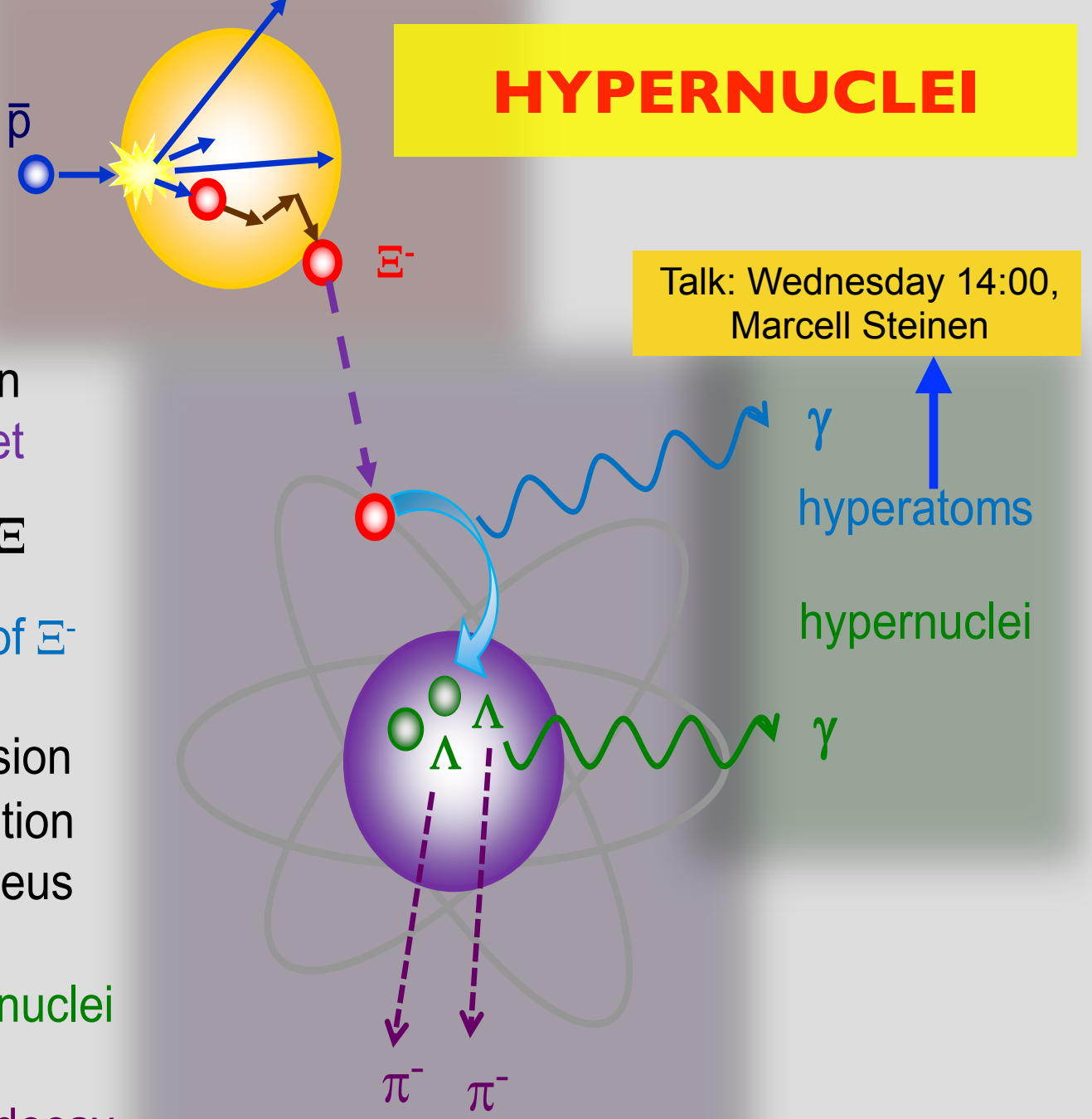
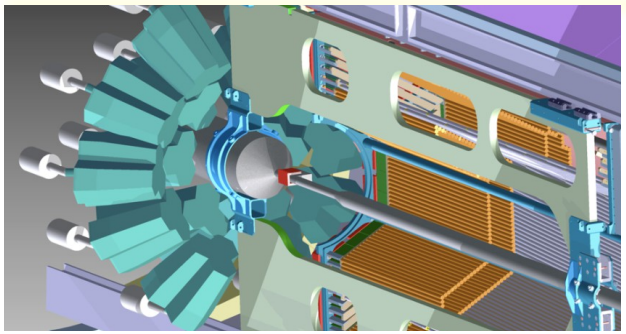
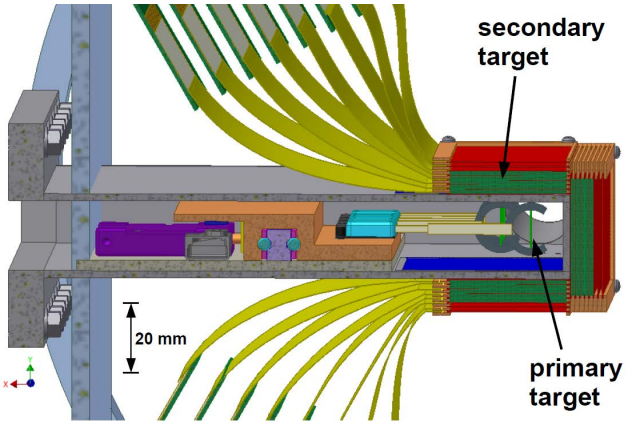
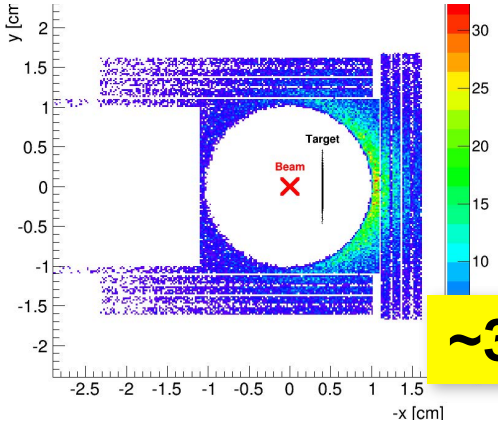


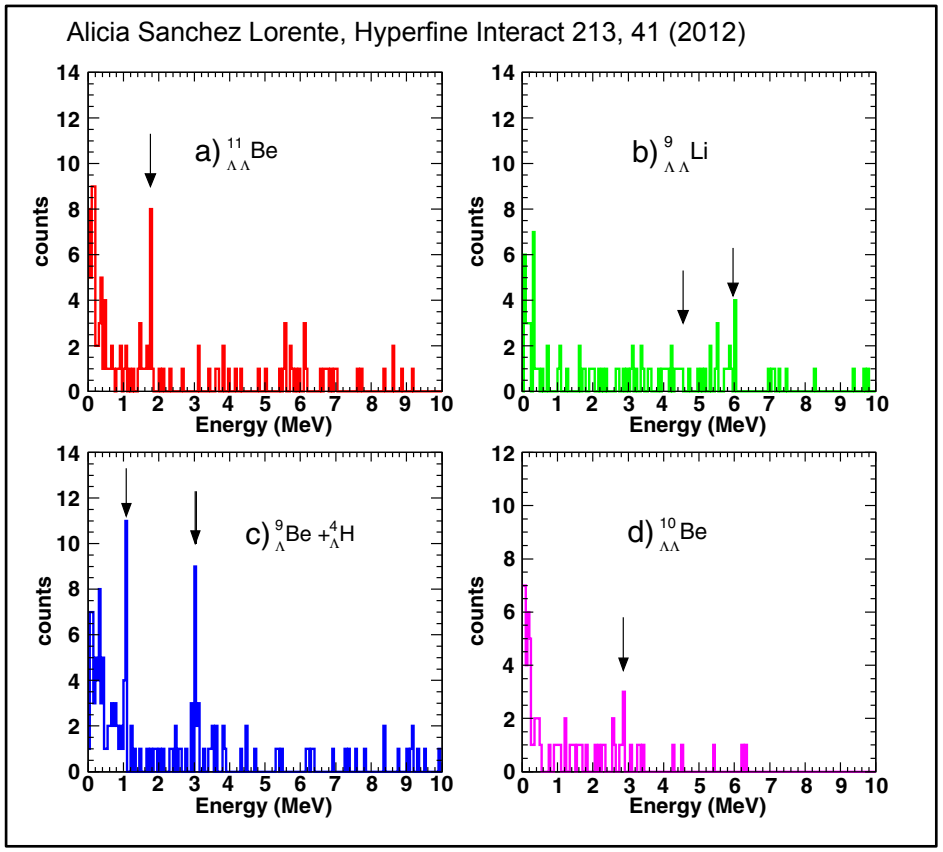
Talk: Wednesday 14:00,
Marcell Steinen

Double hypernuclear spectroscopy









~30.000 stopped Ξ^-'s per day

Josef Pochodzalla et al.

Antihyperons in nuclei

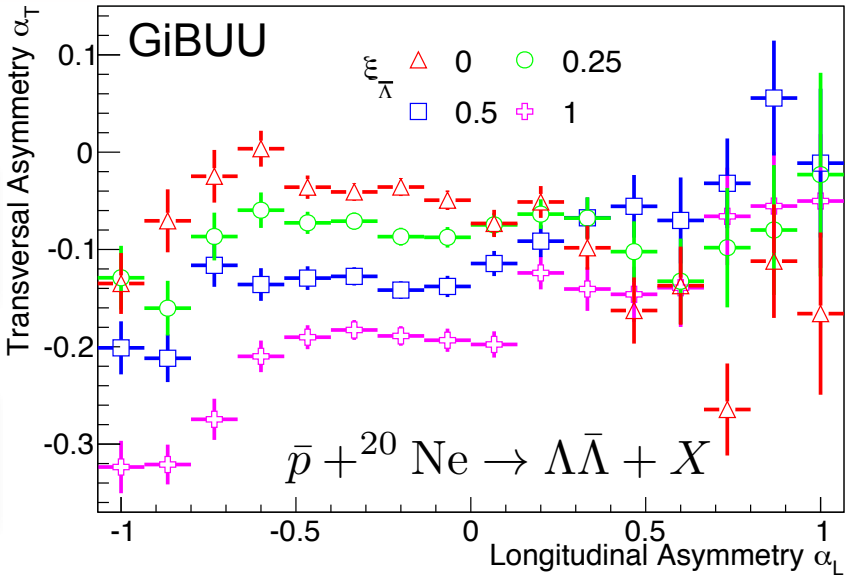
Josef Pochodzalla et al.

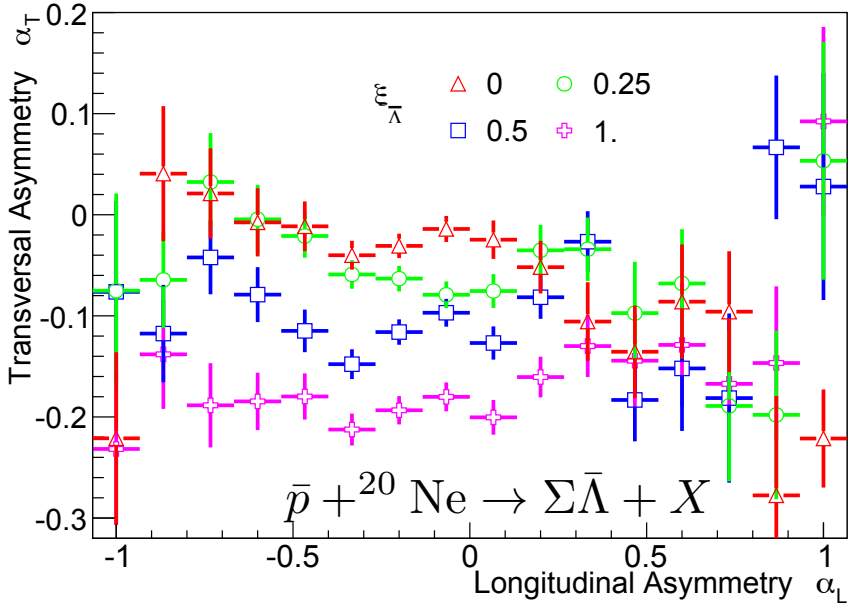
Antiprotons sensitive tool to study antihyperon potential in nuclei!!!

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





PANDA, NPA954, 323 (2016)

Antihyperons in nuclei

Josef Pochodzalla et al.

Talk: Friday 11:00, Josef Pochodzalla

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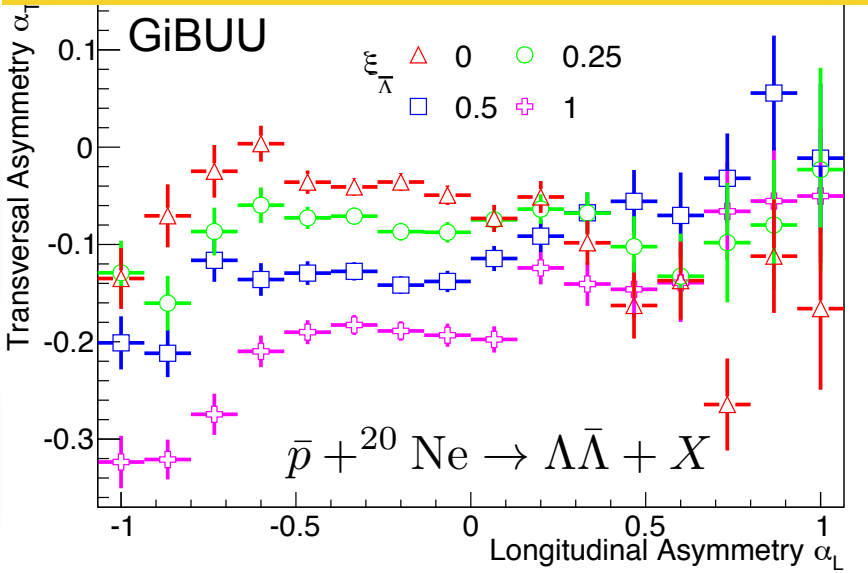
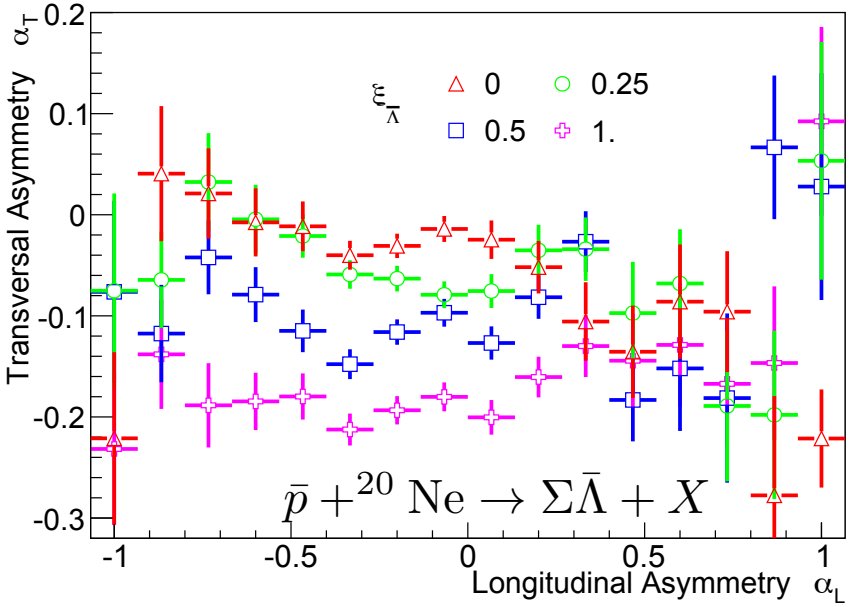
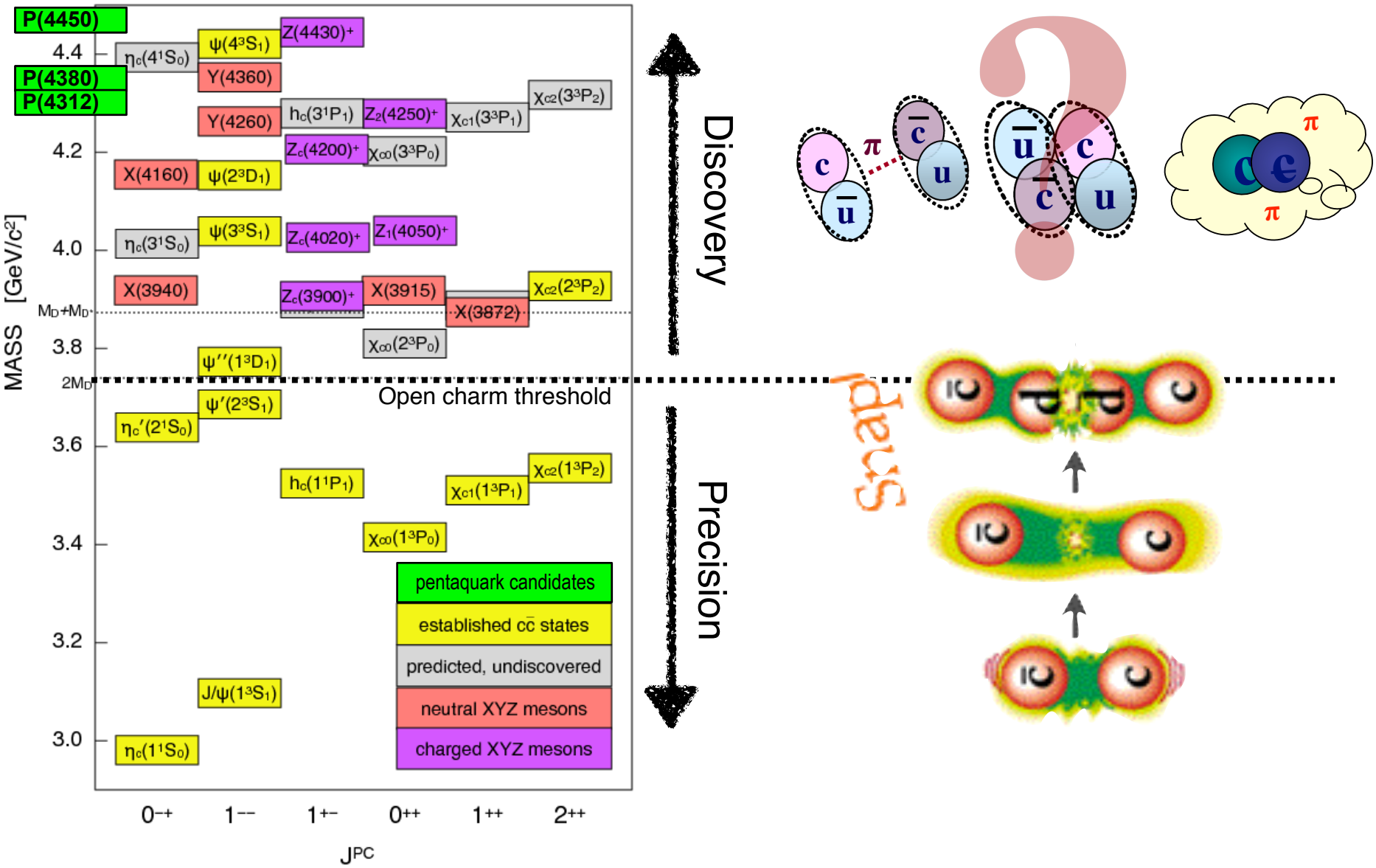


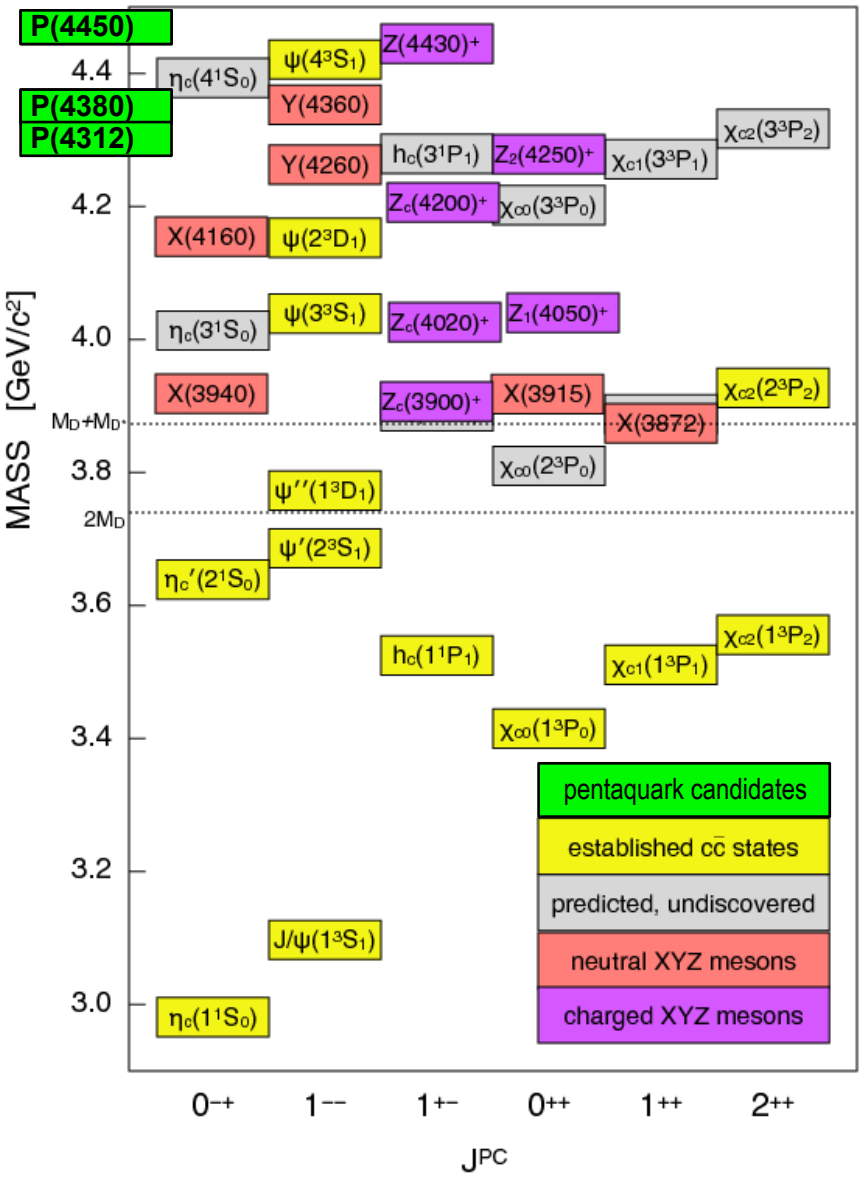


PANDA, NPA954, 323 (2016)

Charmonium-like particles - terra incognita



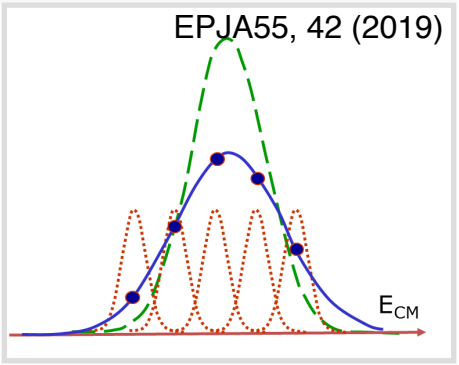
Charmonium-like particles - terra incognita



Day-1:

Exploratory search of new Z states using direct formation in pbar-n

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

Frank Nerling, Klaus Goetzen, et al.

Glueball searches in light-meson sector

Day-1

Marc Pelizaeus et al.

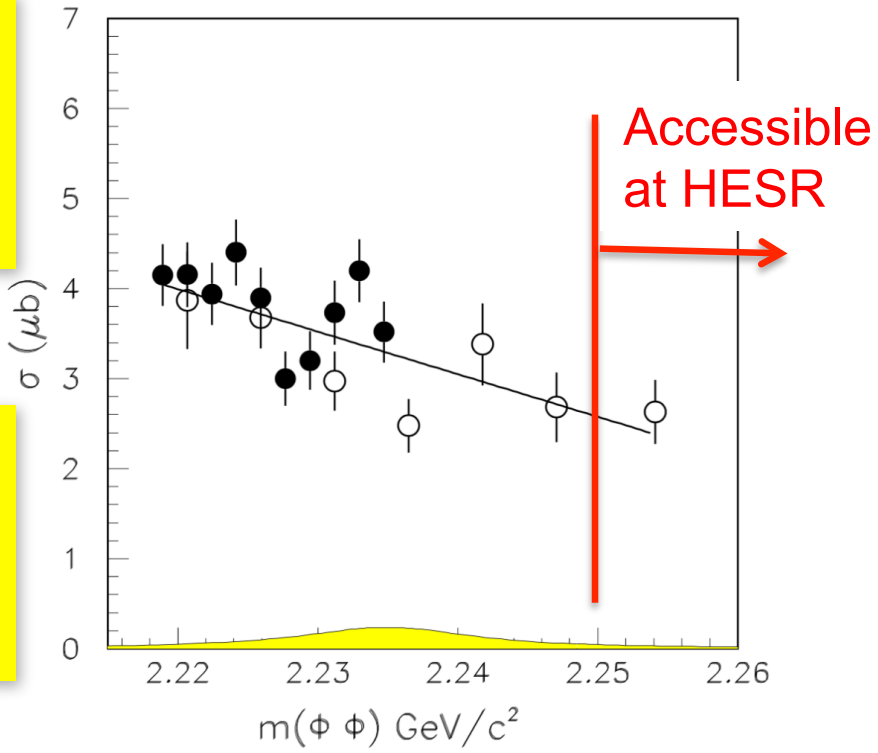
Jetset (1998):

- fine scan around 2230 MeV
- cross section 100x larger than expected from OZI
- large gluonic component? LQCD: tensor glueball?

PANDA (2026):

- scan above 2.25 GeV: terra incognita
- 5×10^4 reconstructed events/day at $L=10^{31}$ $cm^{-2}s^{-1}$
- physics studies at reduced luminosities feasible

$\bar{p}p \rightarrow \Phi\Phi$ Cross Section



Jetset, Phys. Rev. D 57, 5370 (1998)

Glueball searches in light-meson sector

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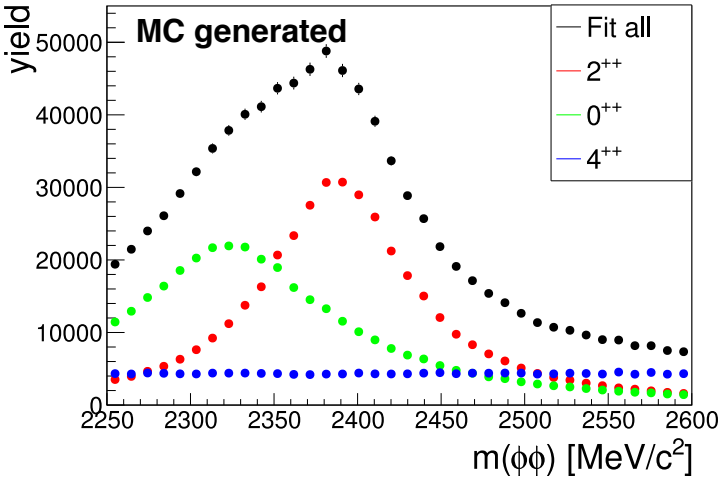
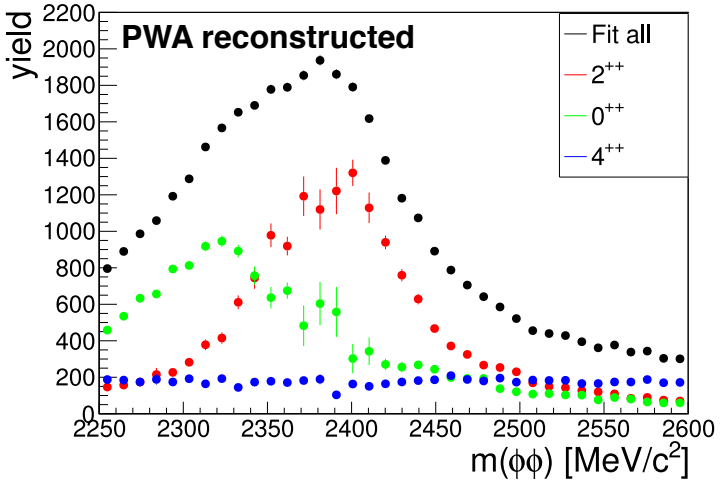
Iman Keshk (RUB), preliminary





Physics with PANDA at "Day-1"

Flagship studies:

- Strangeness (|S|=1,2) *production* in pbar-p and pbar-A.
- Spectroscopy in light-meson sector: search for gluon-rich matter.

Feasibility studies with discovery potential:

- |S|=2 baryon spectroscopy.
- Search for new unconventional hidden-charm states.

Development studies:

- Database on multi-pion production: tune QCD models for electromagnetic form factor studies etc..
- Line-scan performance studies on conventional hidden-charm states.

… as a first step of phase-1

j.g.messchendorp@rug.nl