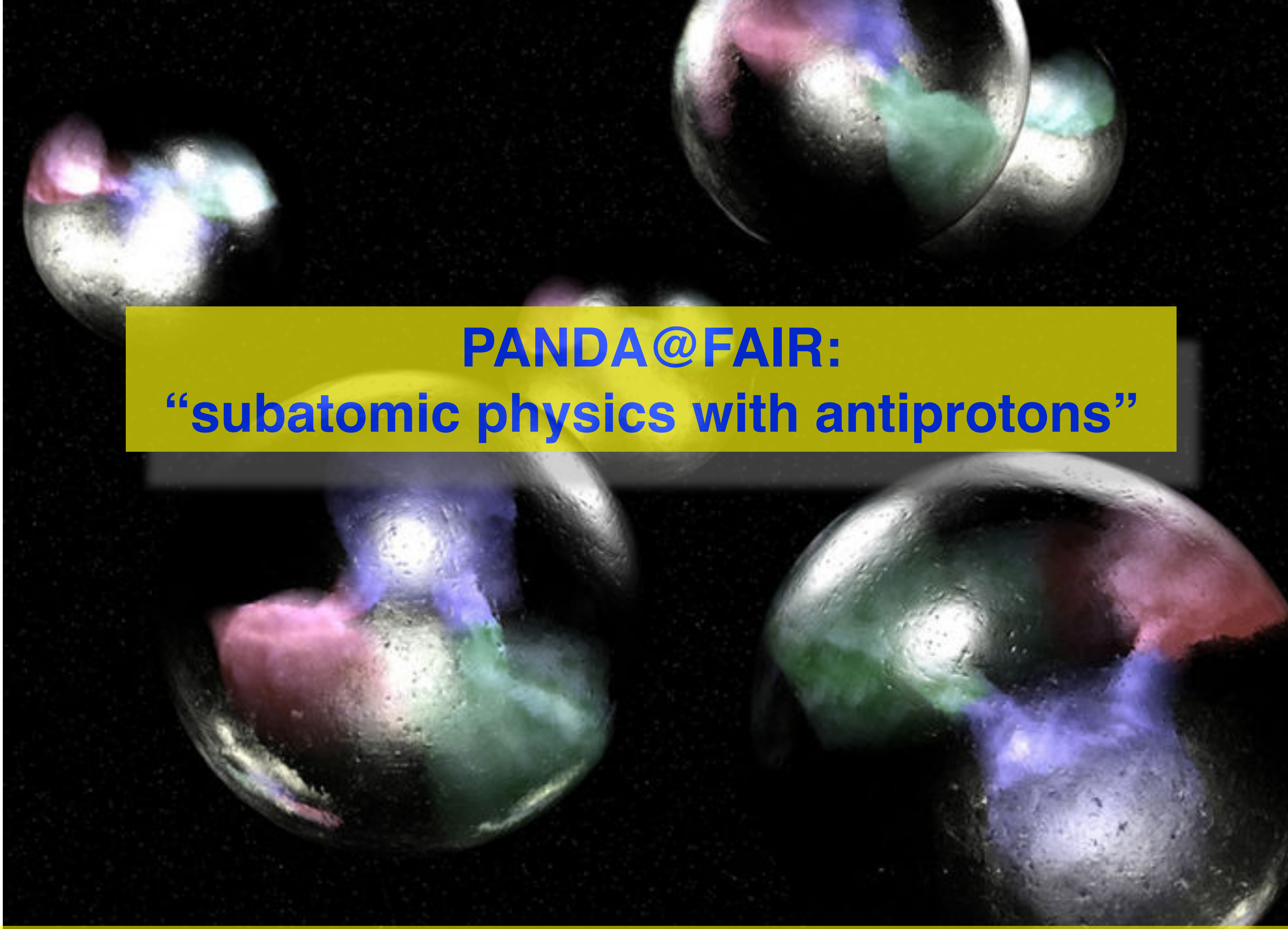
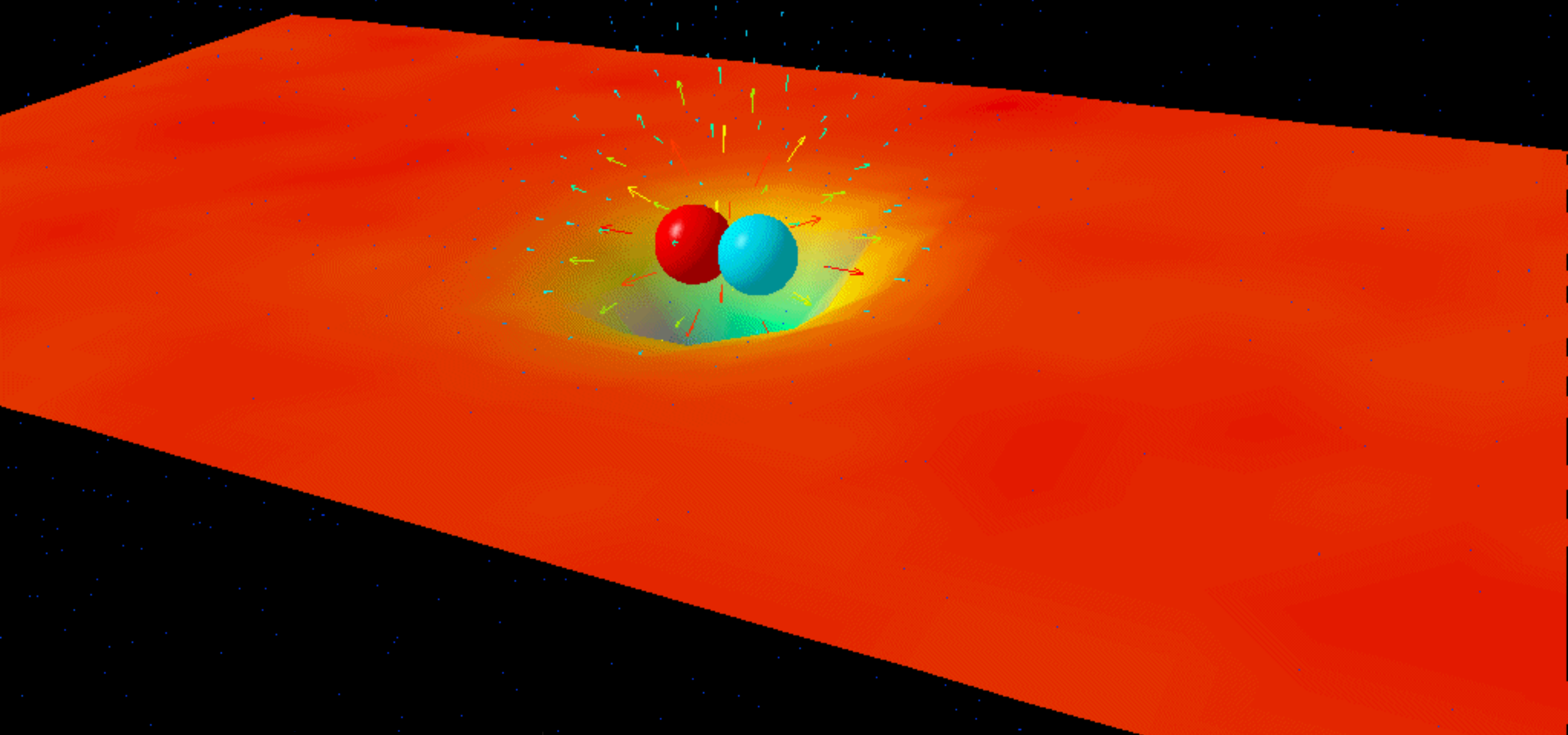


PANDA@FAIR:
“subatomic physics with antiprotons”

Johan Messchendorp (FFN-GSI) for the PANDA Collaboration
Swedish Nuclear Physicist’s Meeting, Oct 28, 2021

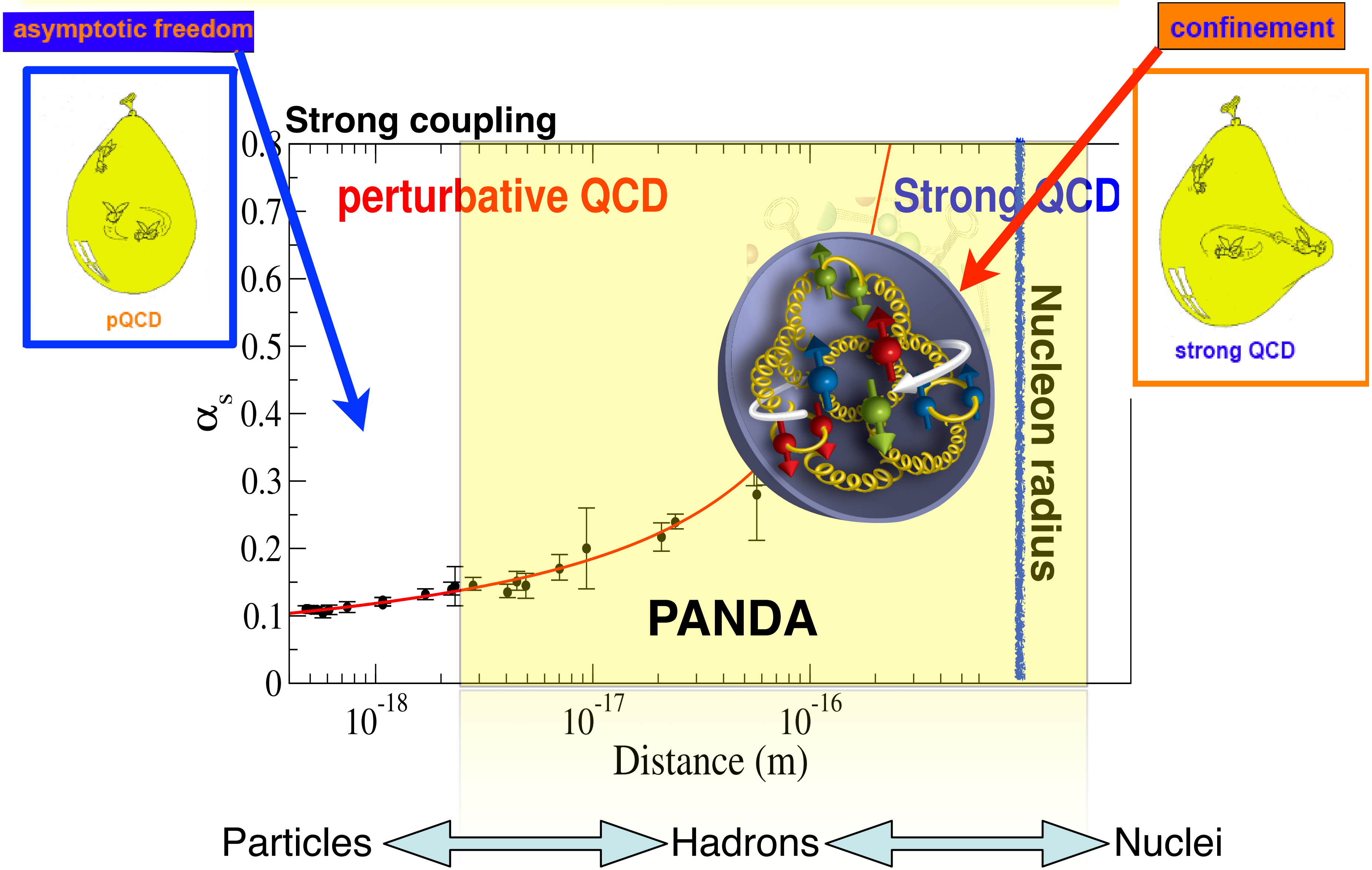
Quantum Chromo Dynamics



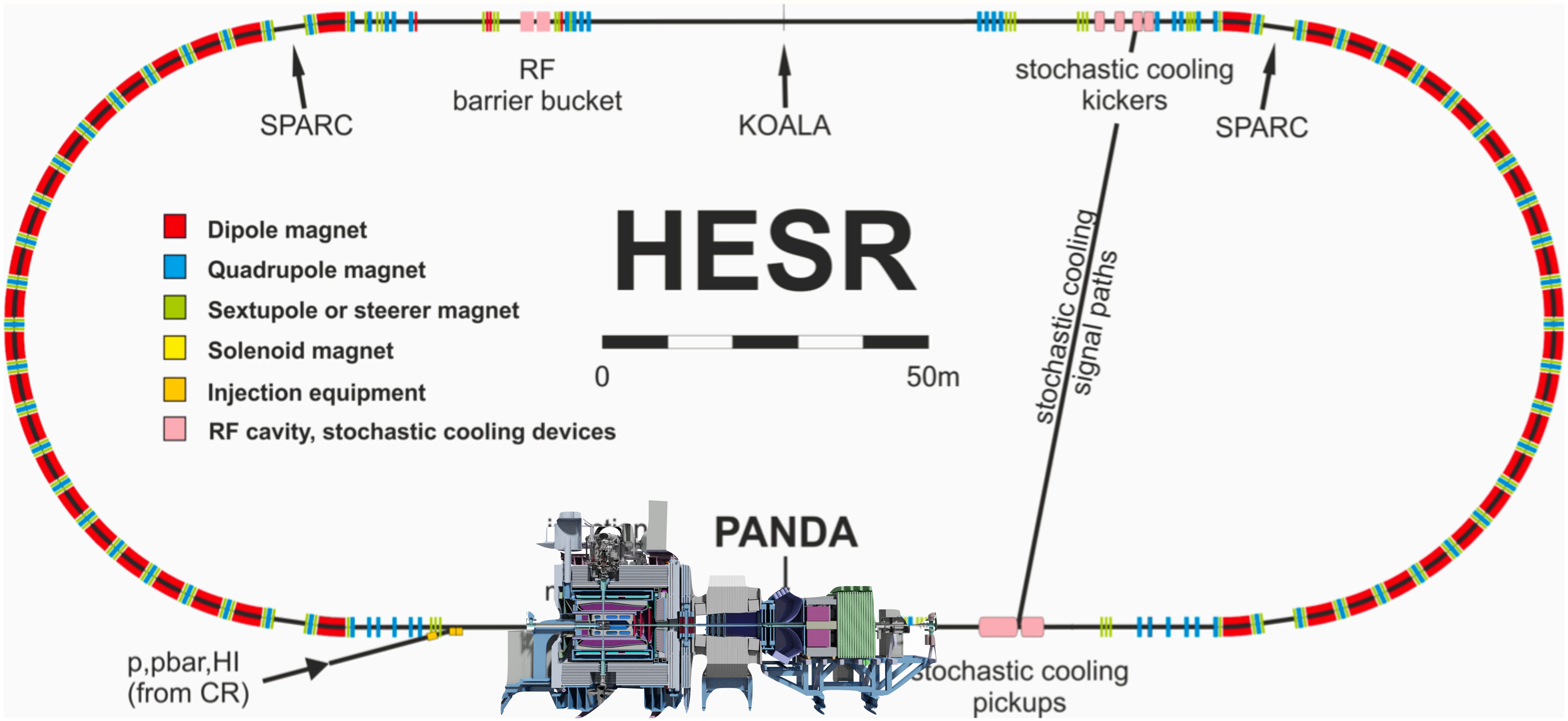
$$\mathcal{L}_{QCD} = \sum_{q=u,d,s,c,b} \bar{q} \left(i\gamma_\mu D^\mu - m_q \right) q - \frac{1}{4} G^{\mu\nu} G_{\mu\nu}$$

D.B. Leinweber, CSSM & Department of Physics, University of Adelaide

The dynamics of QCD!



High Energy Storage Ring - *precision* antiprotons



MSV-HESR mode (Phase-1+2) | **+RESR (Phase-3)**

- Energy range: 0.8-15 GeV
- Stochastic cooling: $dp/p=3x10^{-5}$
- Accumulation: 10^{10} antiprotons in 1000 s → 10^{11} antiprotons
- Luminosity up to $2x10^{31}$ $cm^{-2}s^{-1}$ → $2x10^{32}$ $cm^{-2}s^{-1}$

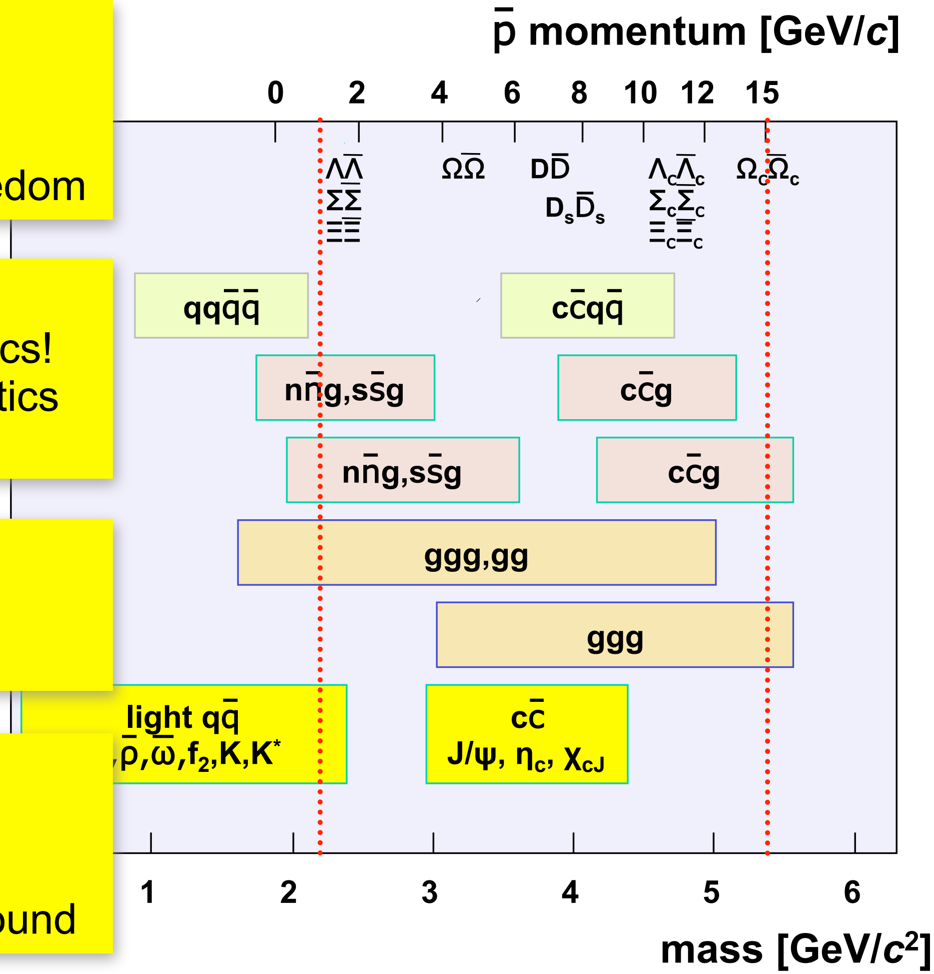
Versatility of antiprotons

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

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

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



Systematic and precise tool to rigorously study the dynamics of QCD

PANDA physics overview

CHARM — **STRANGE** — **LIGHT**

BELLEII, BESIII, COMPASS, JLAB, LHCb, …

Meson-like systems

Hidden/open-charm states

Gluon-rich QCD states

Light-meson systems

BESIII, COMPASS, EIC, JLAB, …

Nucleon Structure

Generalized parton distributions

Drell Yan process

Time-like form factors

Bound States and Dynamics of QCD

Hyperons

Strange baryon spectroscopy

Hyperon production & polarization

Hyperon transition form factors

BESIII, JLAB, JPARC, HADES, MAMI, ELSA, …

Nuclear Physics

Hadrons in nuclei

Hyperon-nucleon dynamics

Hyper-atoms and nuclei

CBM, HYPHI, JPARC, …

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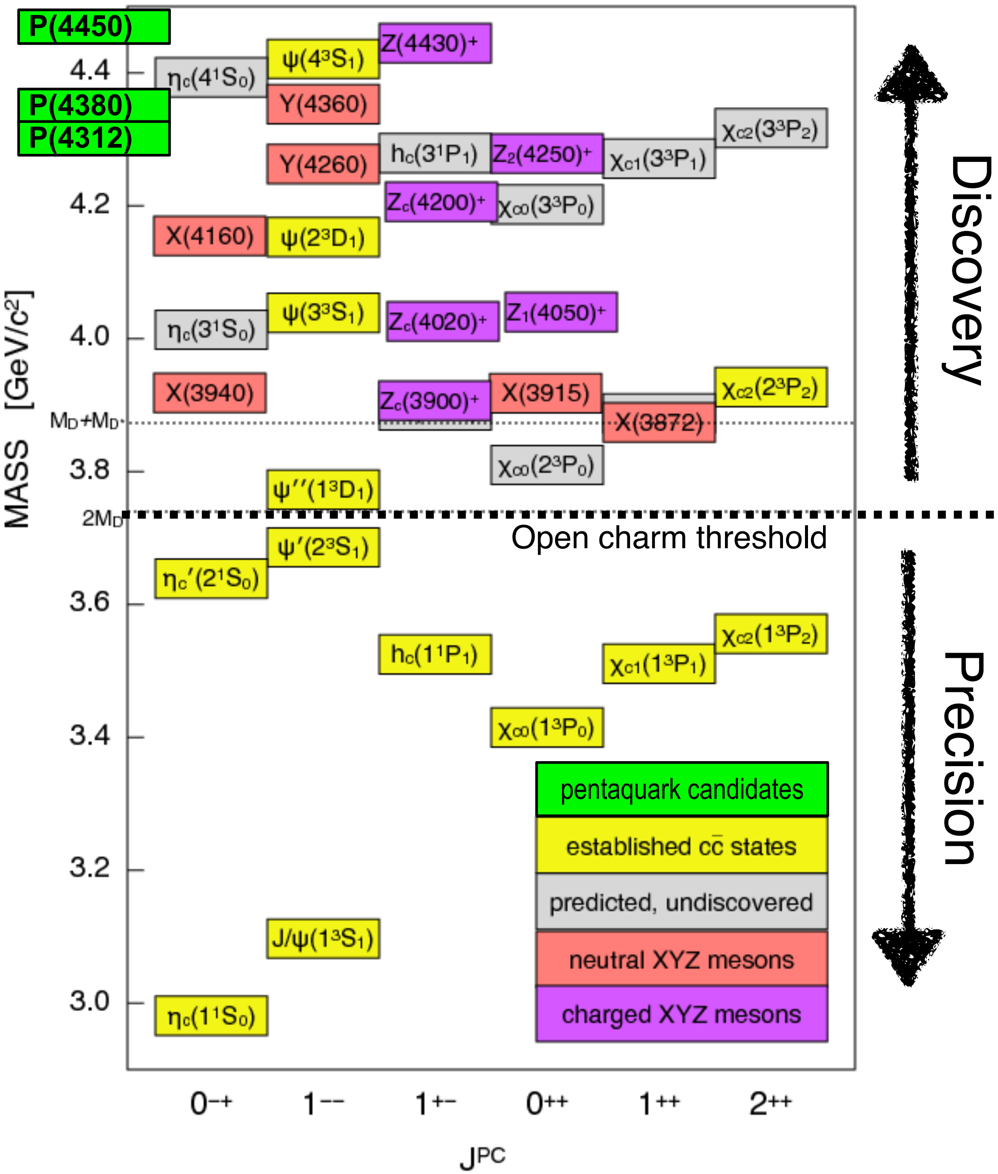
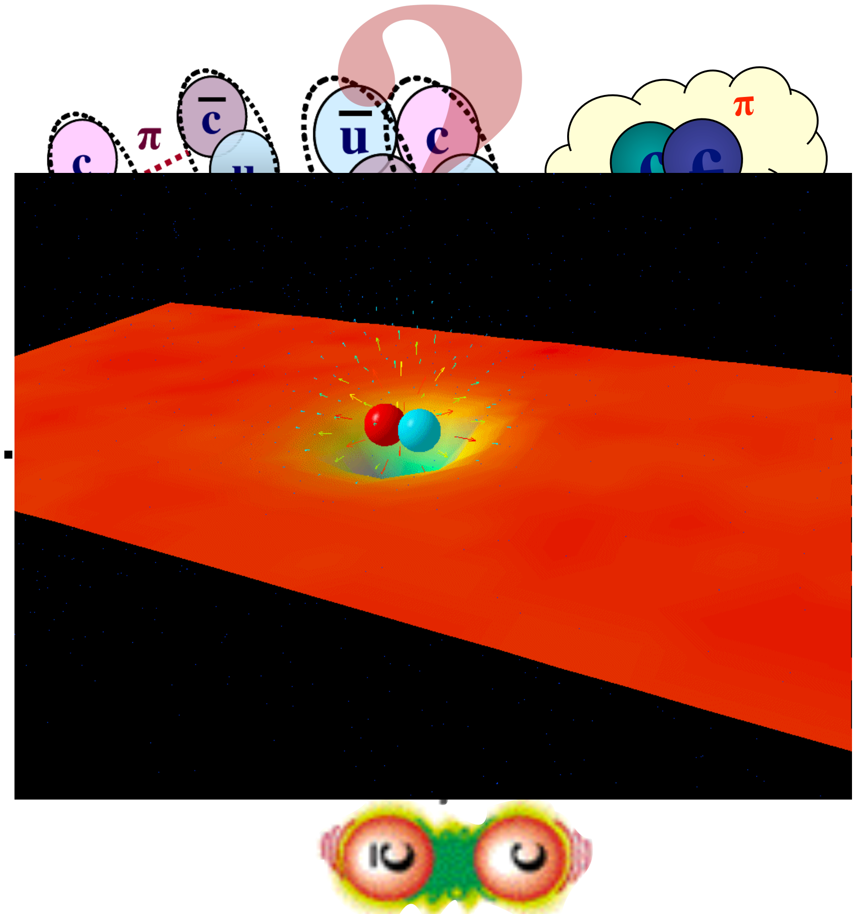
CBM, HYPHI, JPARC, ...

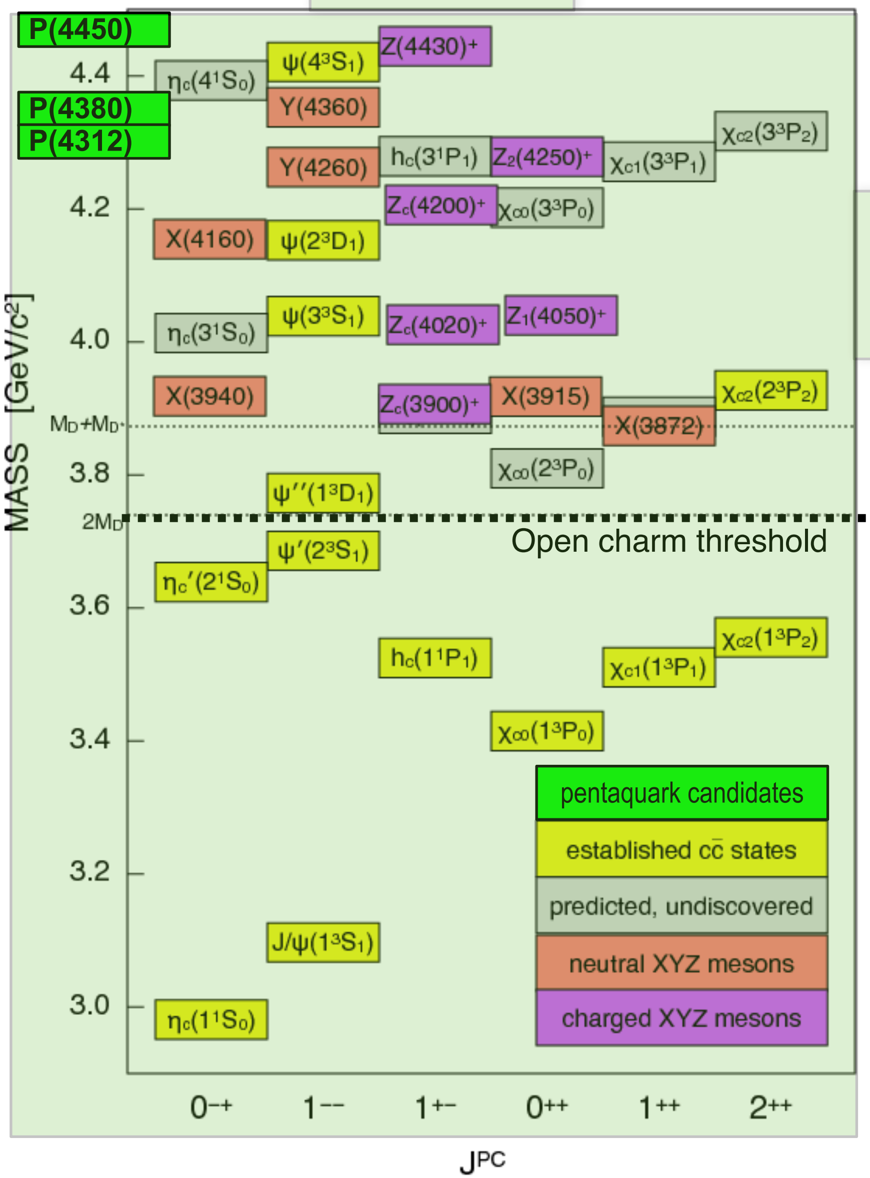
Charmonium-like particles - terra incognita





- Positronium of QCD
- Narrow states
- Heavy charm quarks

Charmonium-like particles - PANDA opportunities

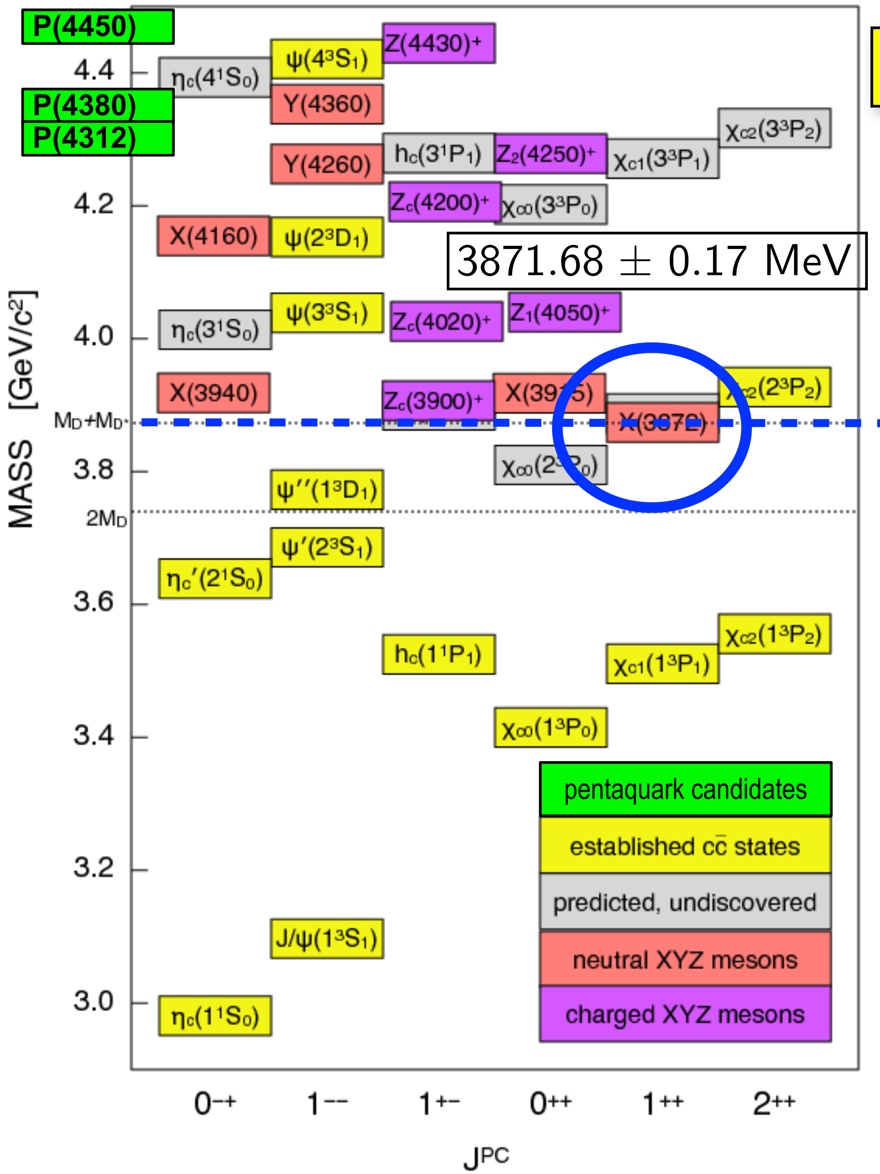


- line shape of, f.e., X(3872)
- neutral+charged Z-states
- X,Y,Z decays
- search for h_c', $^3F_4$, …
- spin-parity/mass&width of $^3D_2$
- Search for pentaquarks

- line shape/width of the eta_c, h_c
- radiative transitions
- hadronic transitions
- light-quark spectroscopy

Note: LHCb discovery of $^3D_3$ candidate: [arXiv:1903.12240]

Lineshape study of the X(3872)

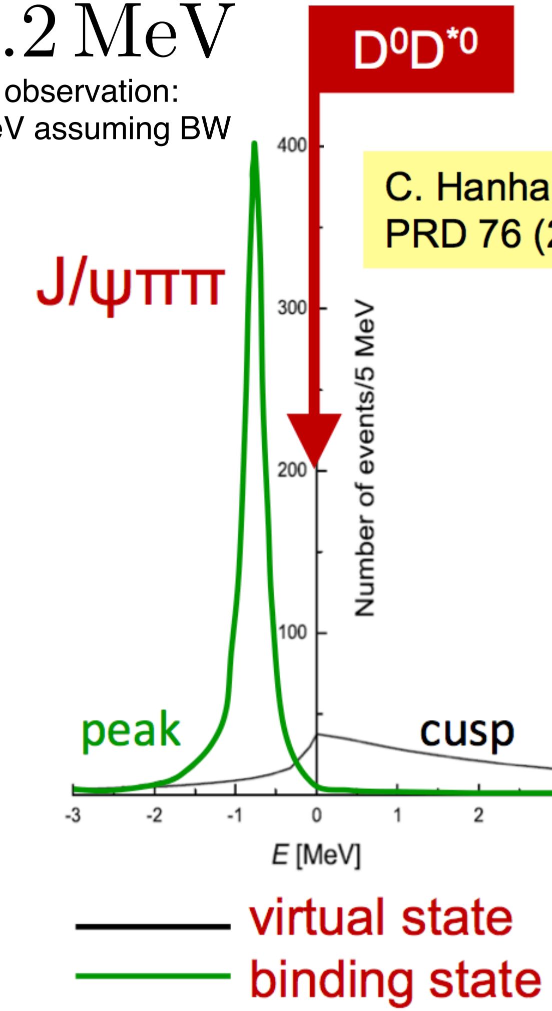


Strikingly narrow:

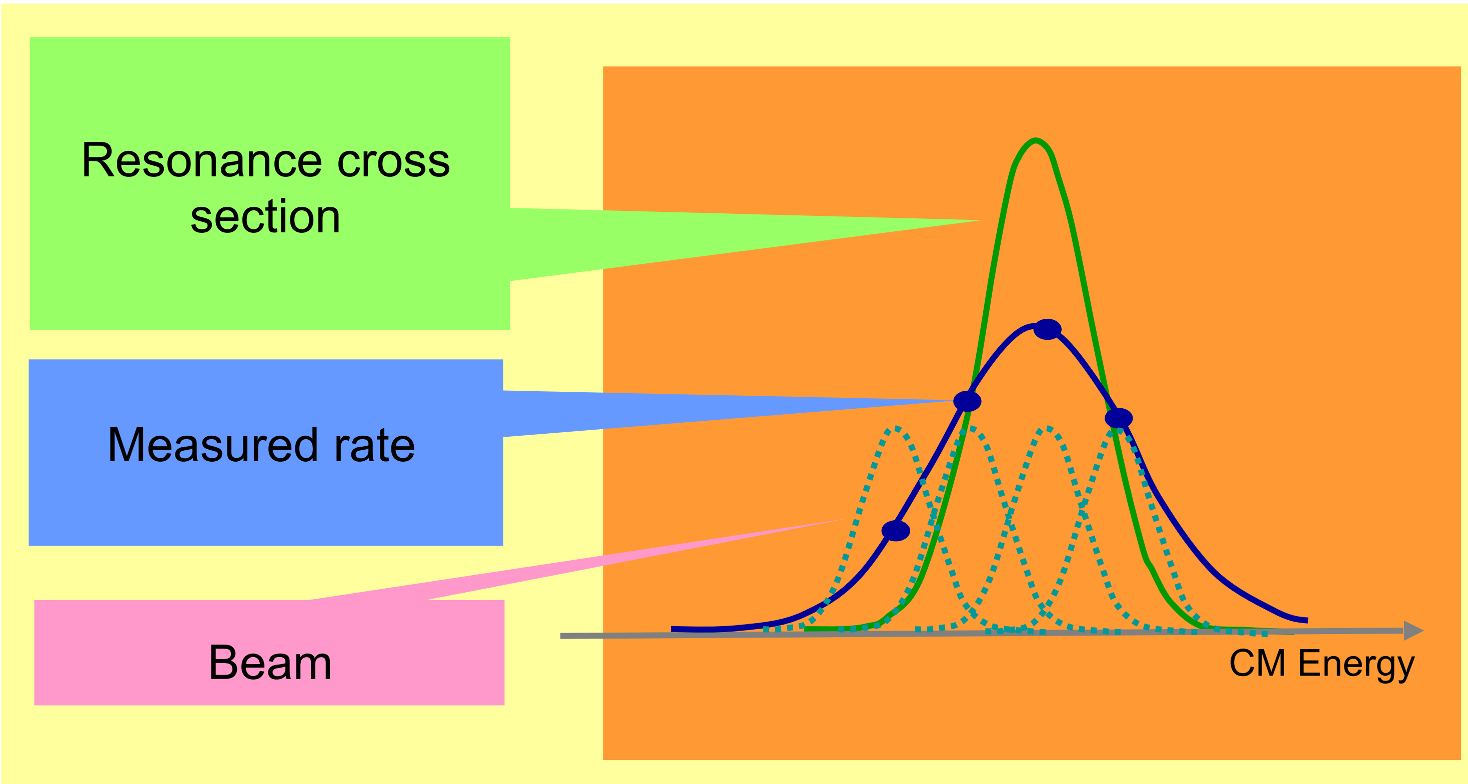
$$\Gamma < 1.2\,\mathrm{MeV}$$

*recent LHCb observation: width=1.4 MeV assuming BW

C. Hanhart *et al.*, PRD 76 (2007) 034007

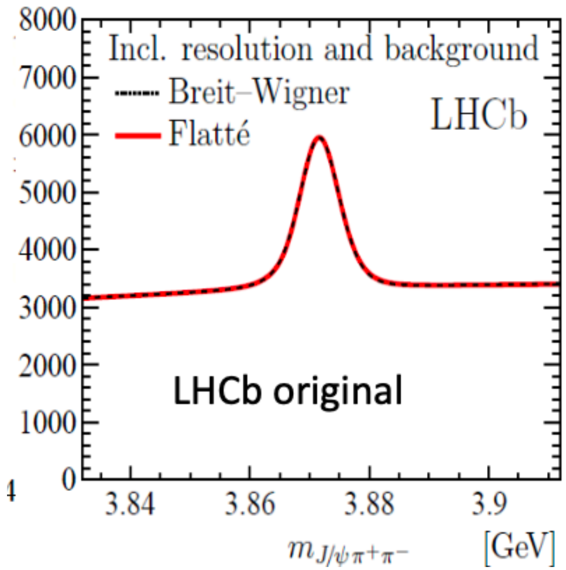


Resonance scanning



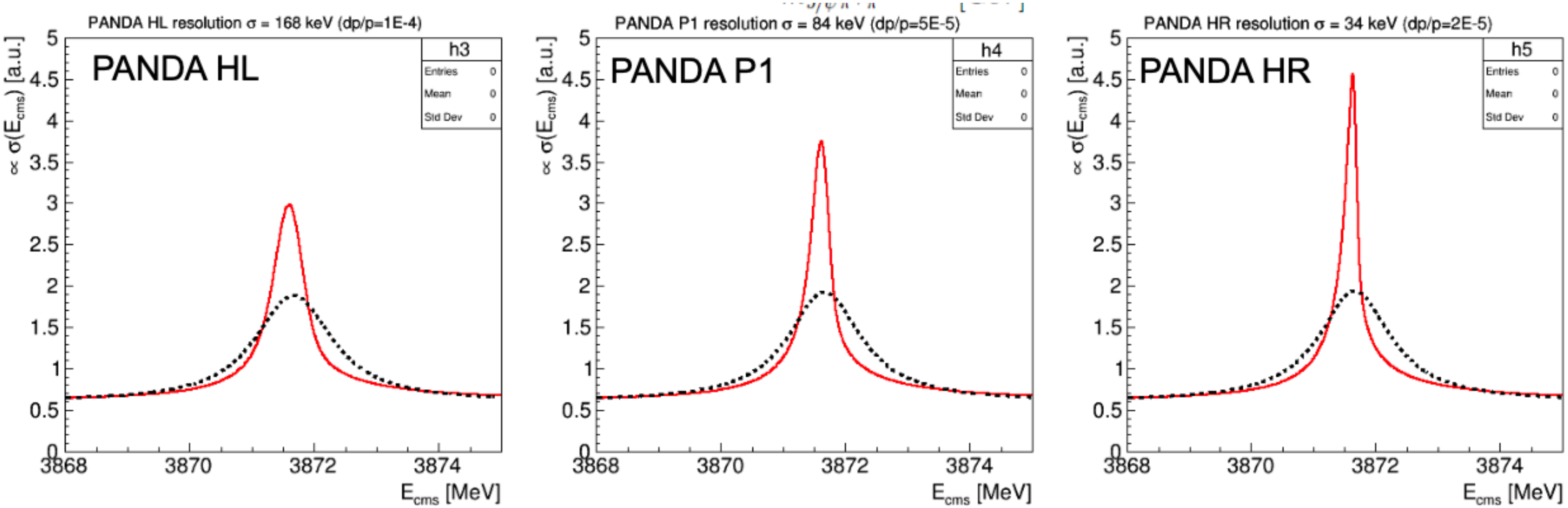
Energy scan with e^+e^-:	energy resolution	1-2 MeV (primarily $J^{PC}=1^{--}$)
Energy scan with $p\bar{p}$:	energy resolution	240 keV (E760/835@Fermilab)
		≈50 keV (PANDA@FAIR)

Lineshape study of the X(3872)



LHCb:
PRD102, 092005 (2020), arXiv:2005.13419

PANDA perspectives:
EPJA55, 42 (2019), arXiv:1812.05132



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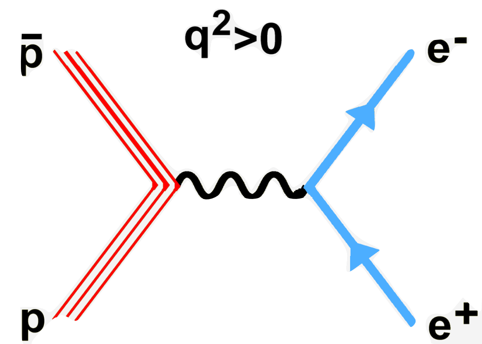
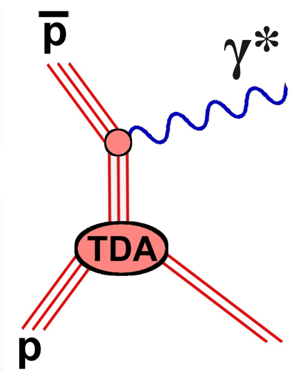
PANDA- the structure of the proton

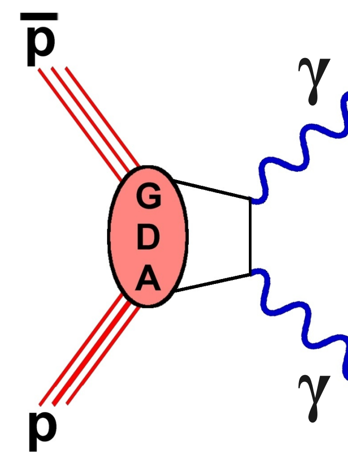
Time-like Electromagnetic Form Factors
(lepton pair production) arXiv:1606.01118



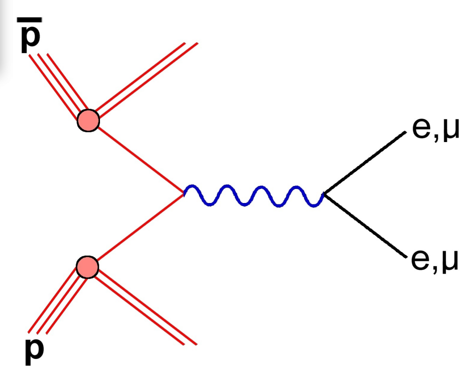
Transition Distribution Amplitudes
(meson production) arXiv:1409.0865



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



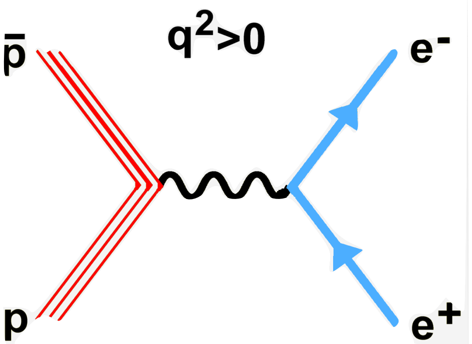
Transverse Parton Distribution Functions
(Drell-Yan production)



Analytical nature of form factors

EPJA 52 325 (2016)

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



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

Analytical nature of form factors

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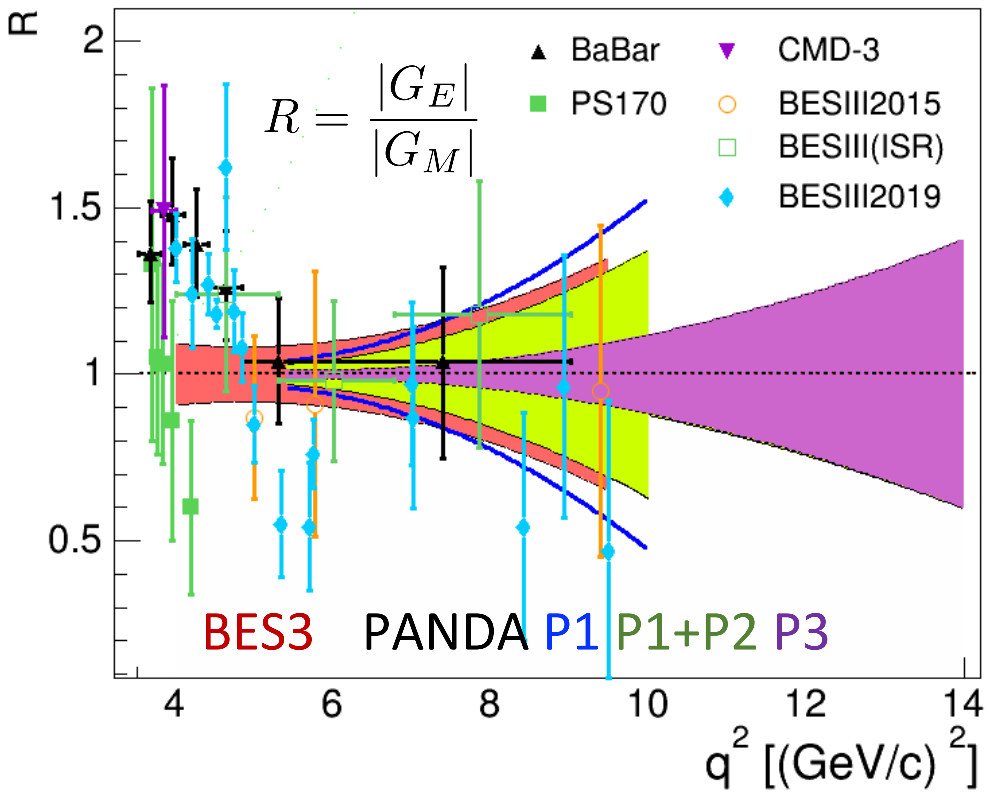
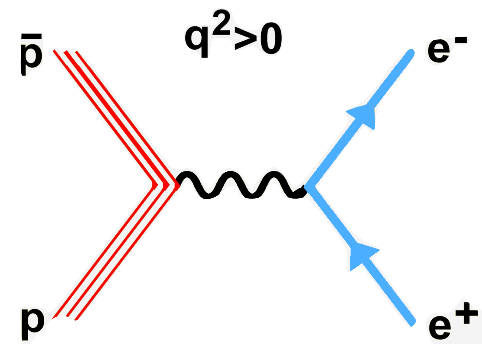




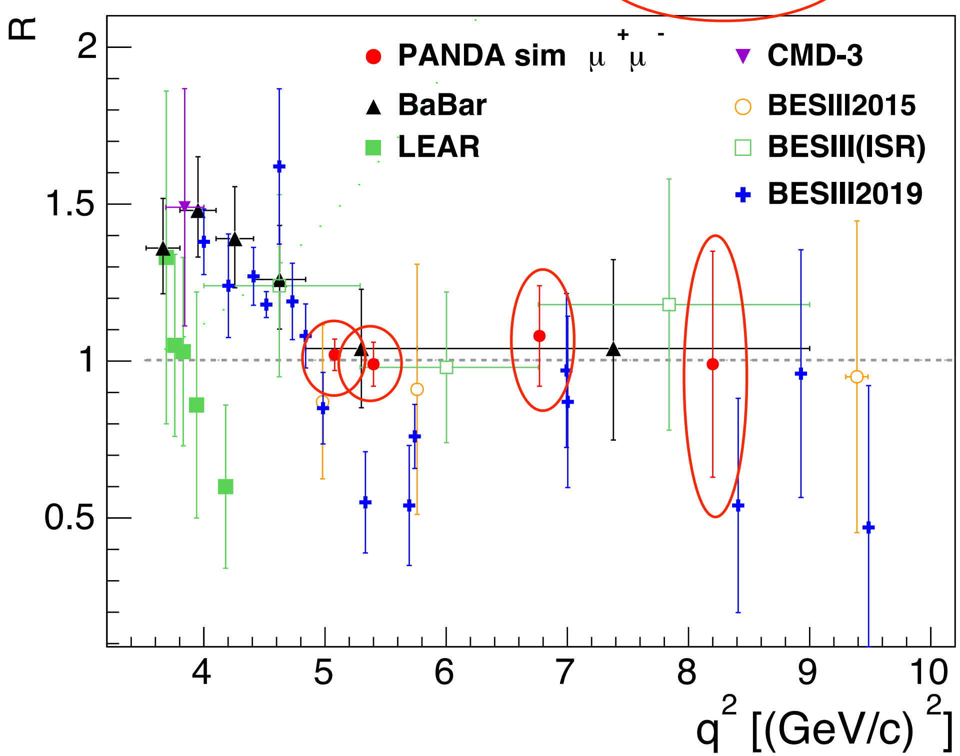
Phase-1

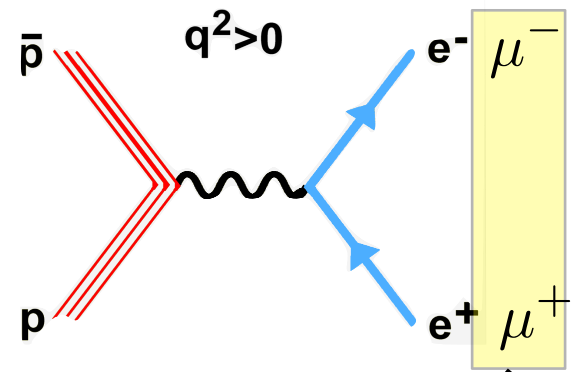
$\bar{p}p \rightarrow e^+e^-$	@1.5 GeV/c	~ 220/day
$\bar{p}p \rightarrow e^+e^-$	@3.3 GeV/c	~ 10/day

Analytical nature of form factors

Time-like Electromagnetic Form Factors
(lepton pair production)

Results for Phase-3 (L=2 fb⁻¹)

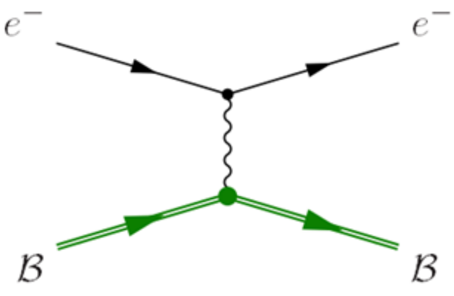




Unique for PANDA

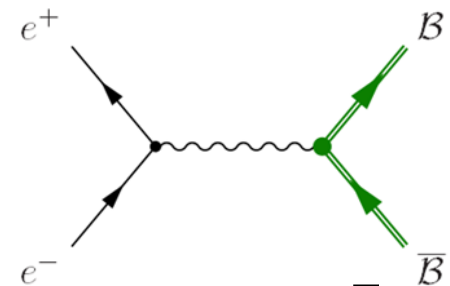
EPJA57, 30 (2021), arXiv:2006.16363

Form factors from space to time-like region



$e^- B \rightarrow e^- B$

e.g. JLAB



$e^+ e^- \rightarrow B \bar{B}$

$\bar{B} B \rightarrow \ell^+ \ell^-$

BES III

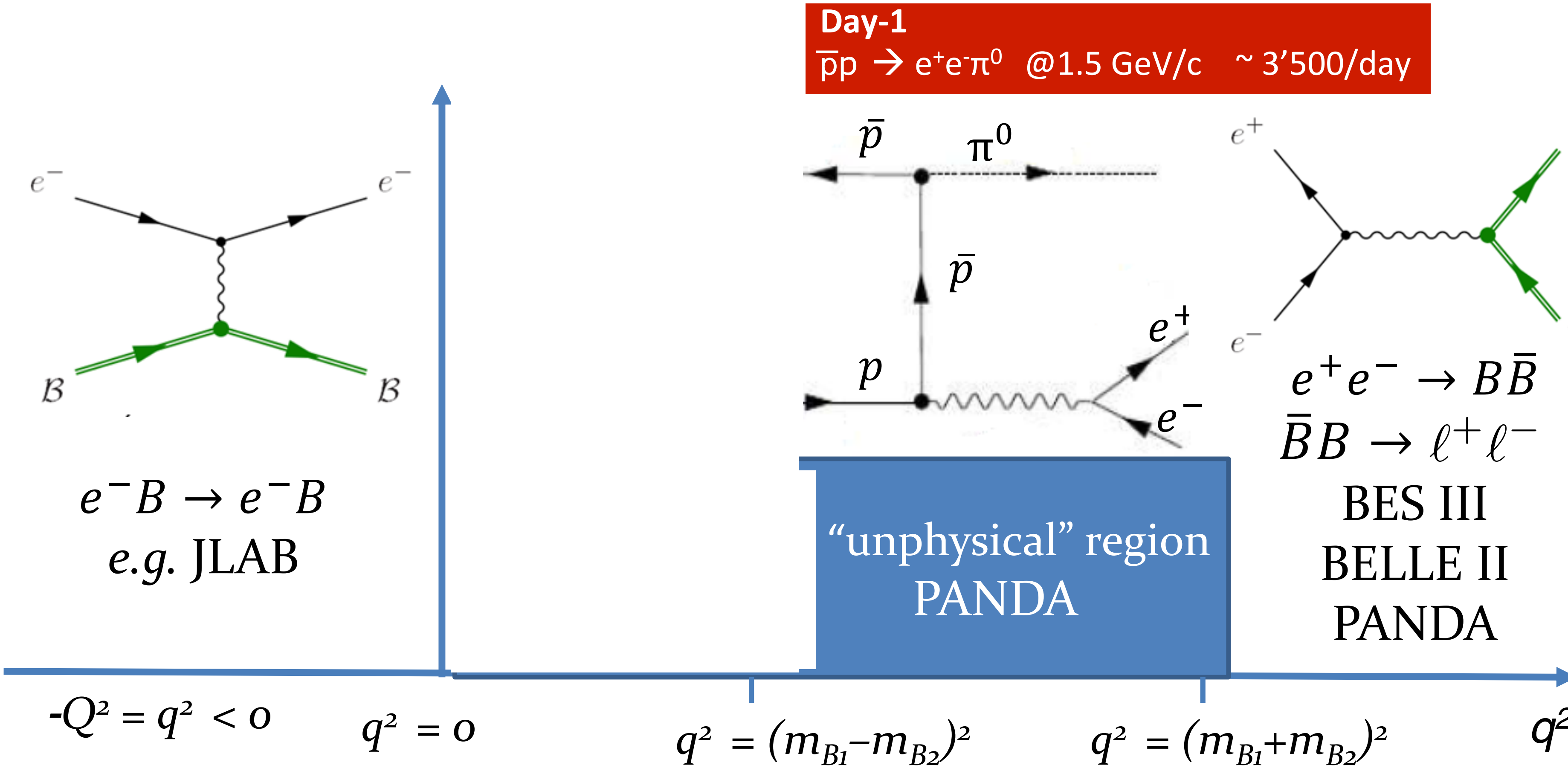
BELLE II

PANDA

$-Q^2 = q^2 < 0$ $q^2 = 0$ $q^2 = (m_{B_1} - m_{B_2})^2$ $q^2 = (m_{B_1} + m_{B_2})^2$ q^2

Space-like and time-like are related by dispersion theory!

Form factors from space to time-like region



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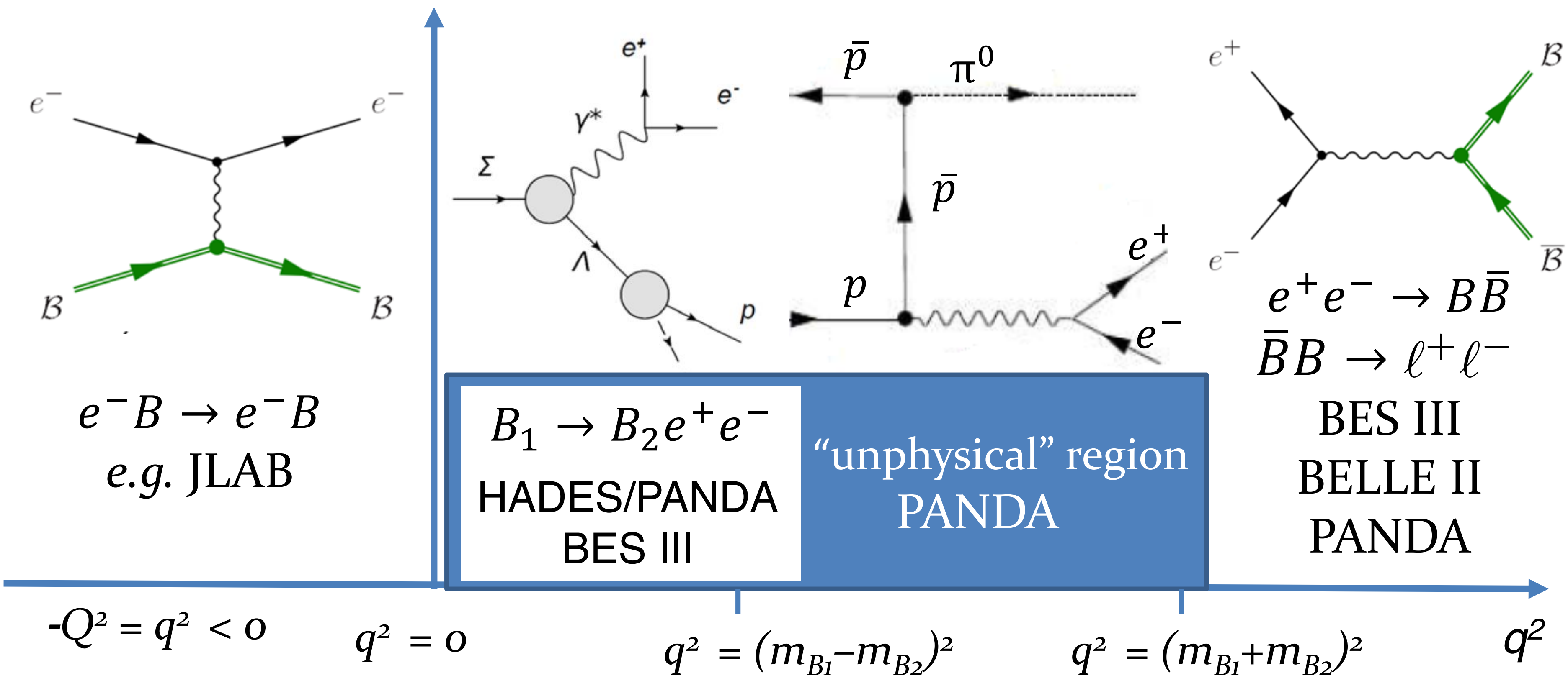
Form factors from space to time-like region



Space-like and time-like are related by dispersion theory!

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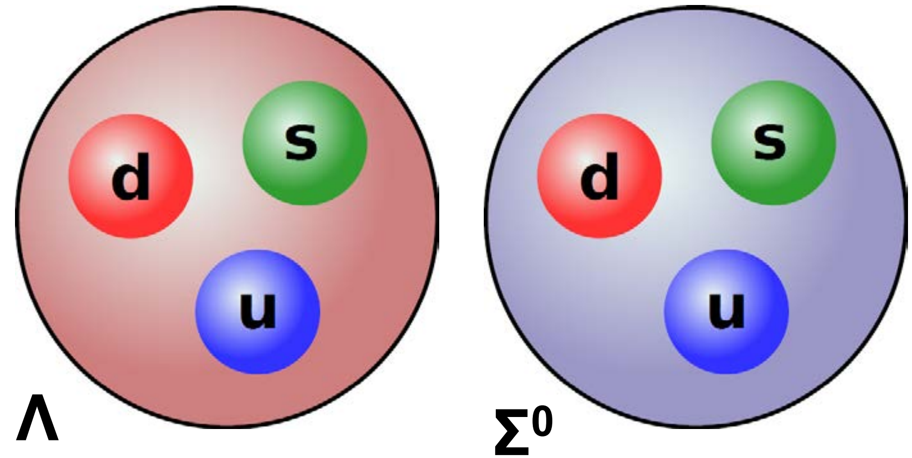
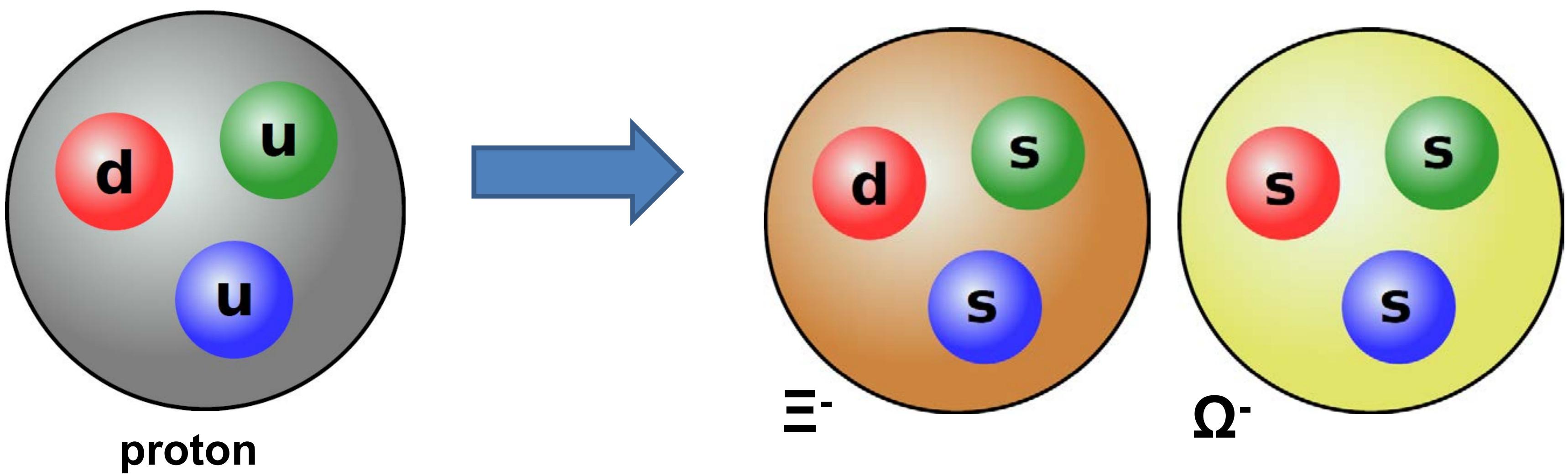
CBM, HYPHI, JPARC, …

Exploring the hyperon sector

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



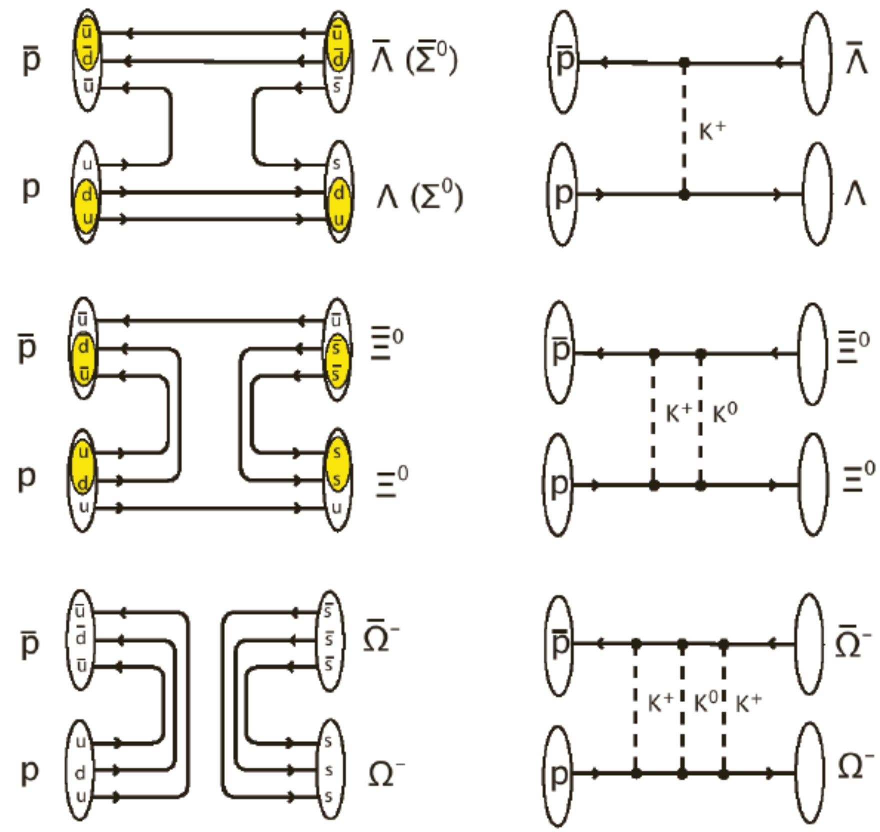


Courtesy: Karin Schoenning

Hyperon *dynamics*

Strong production dynamics

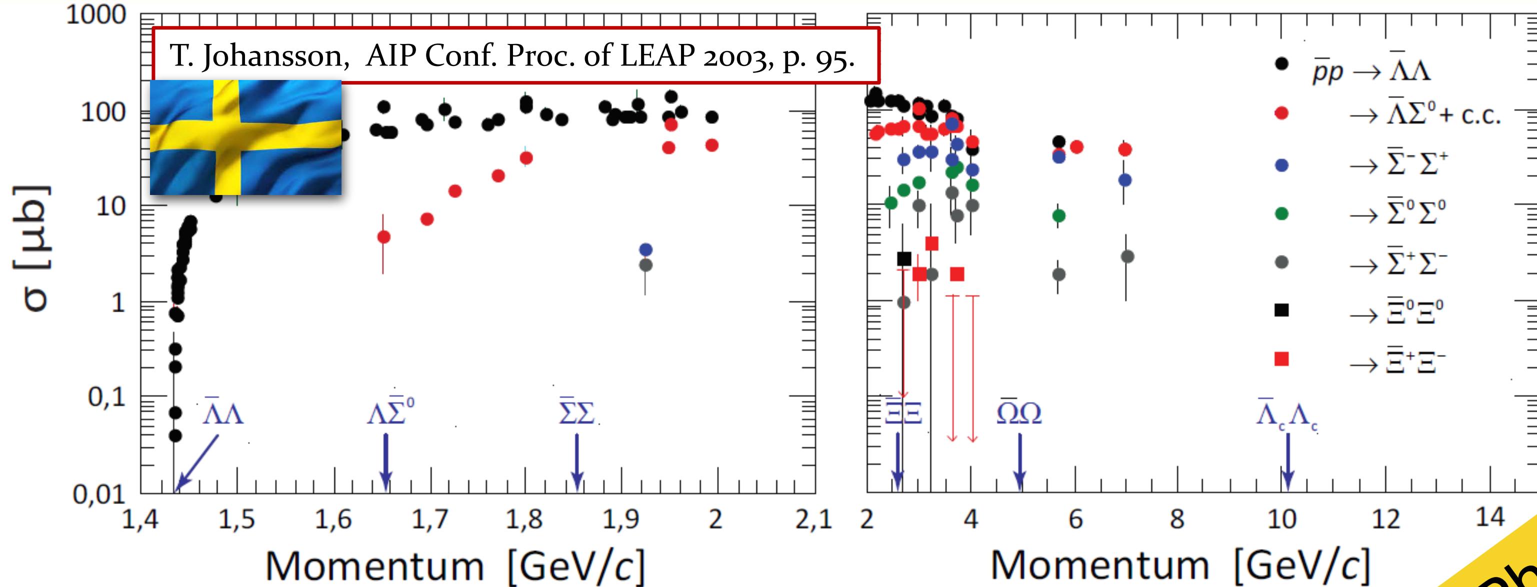
- Relevant degrees of freedom?
- Strange *versus* charm sector?
- Role of spin?



Courtesy: Karin Schoenning

PANDA is a hyperon factory!

EPJA57, 184 (2021), arXiv:2101.11877



Phase-1

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

** 90% C.L.

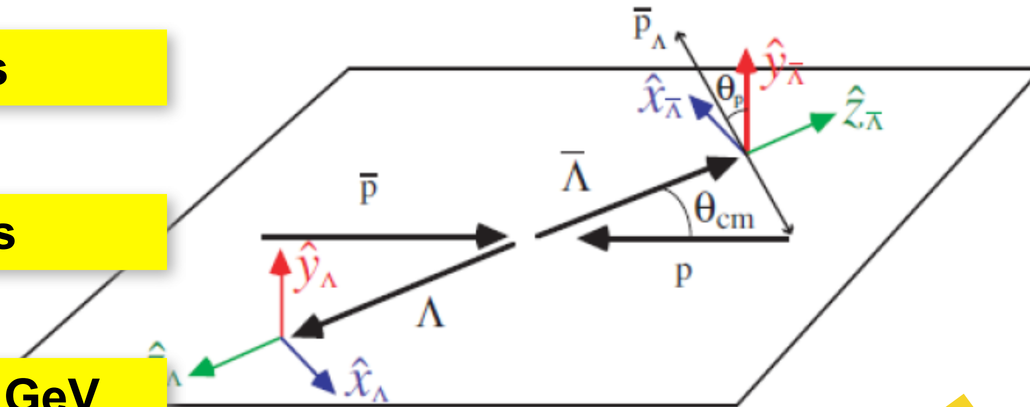
PANDA is a hyperon factory!

EPJA57, 184 (2021), arXiv:2101.11877

Rich set of polarisation observables

(double) strange and charm baryons

Explore hyperon dynamics above 4 GeV



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

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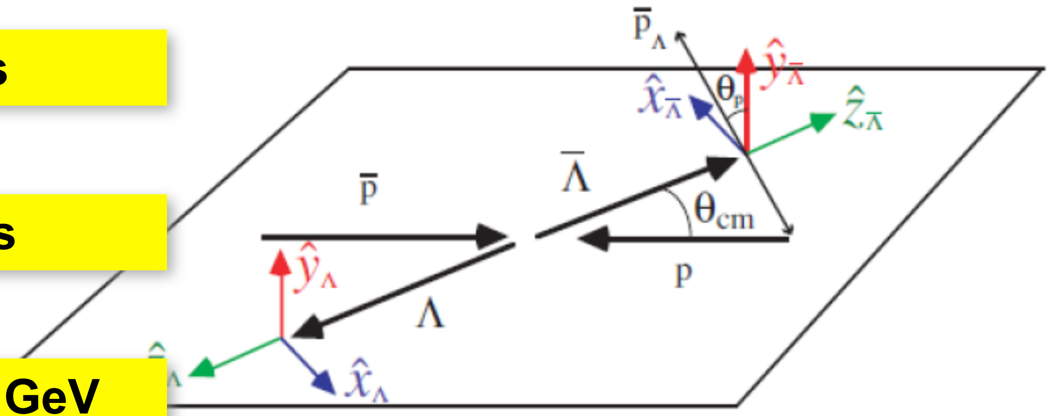


Day-1:

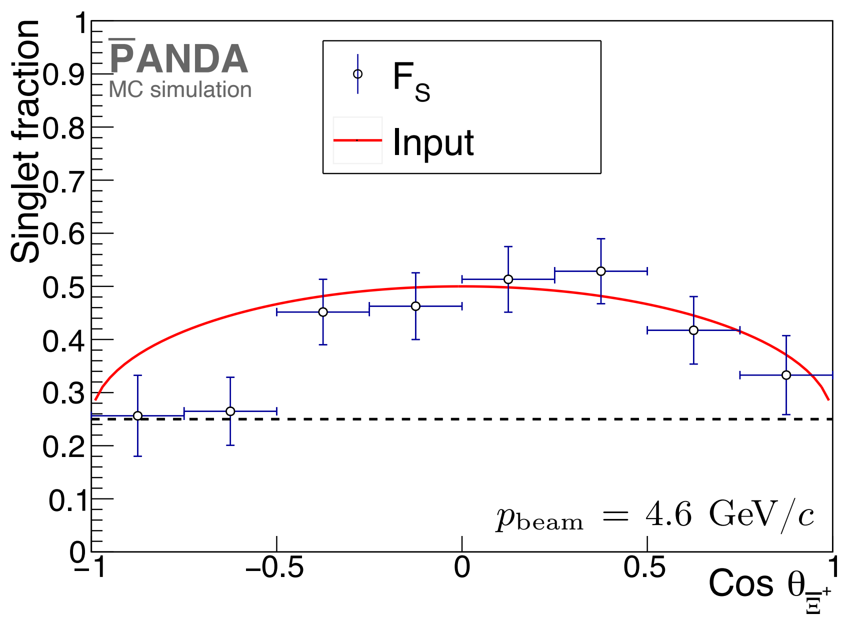
Reproduce LEAR studies @1.64 GeV/c

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

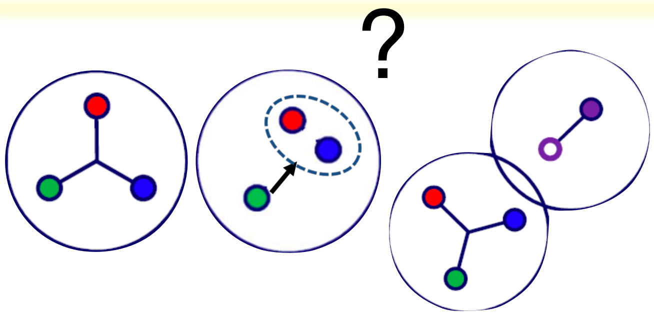
Phase-1:

Spin correlations in |S|=1,2

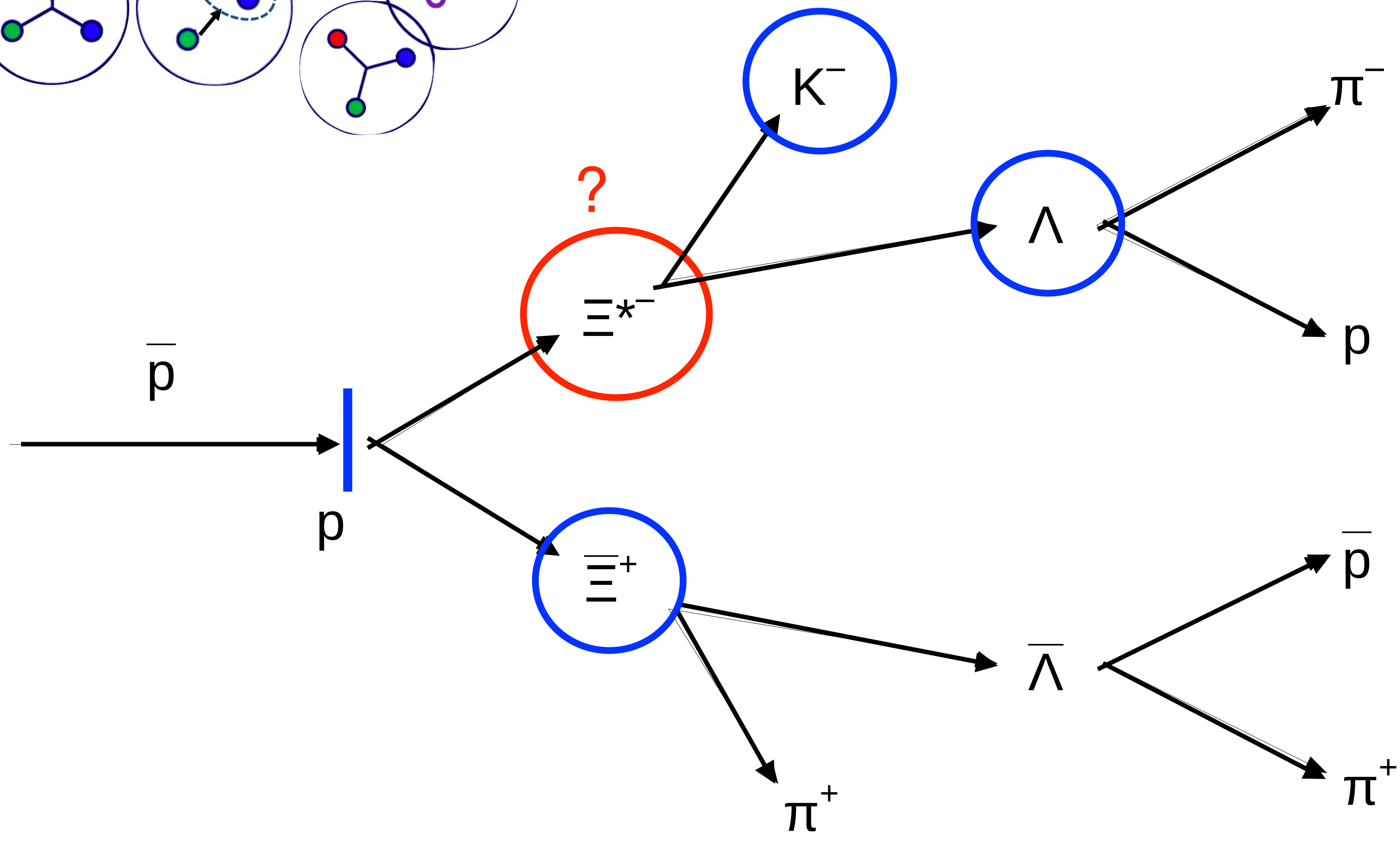
Extend to |S|=3 and charm hyperons



Hyperon *spectroscopy*



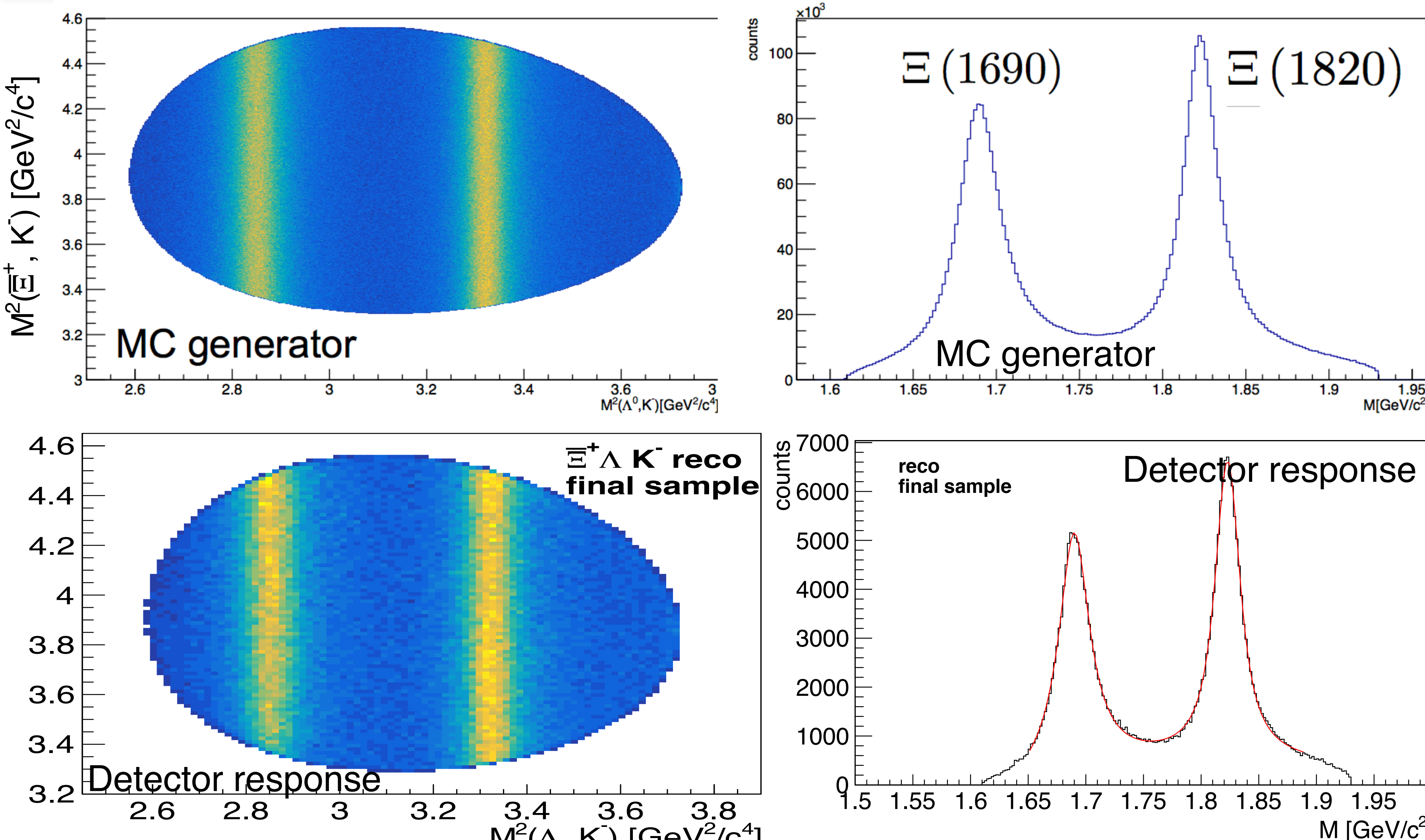
Map out the |S|=2 excited baryon spectrum



Hyperon spectroscopy

Map out the |S|=2 excited baryon spectrum

EPJA 57, 149 (2021), arXiv:2012.01776



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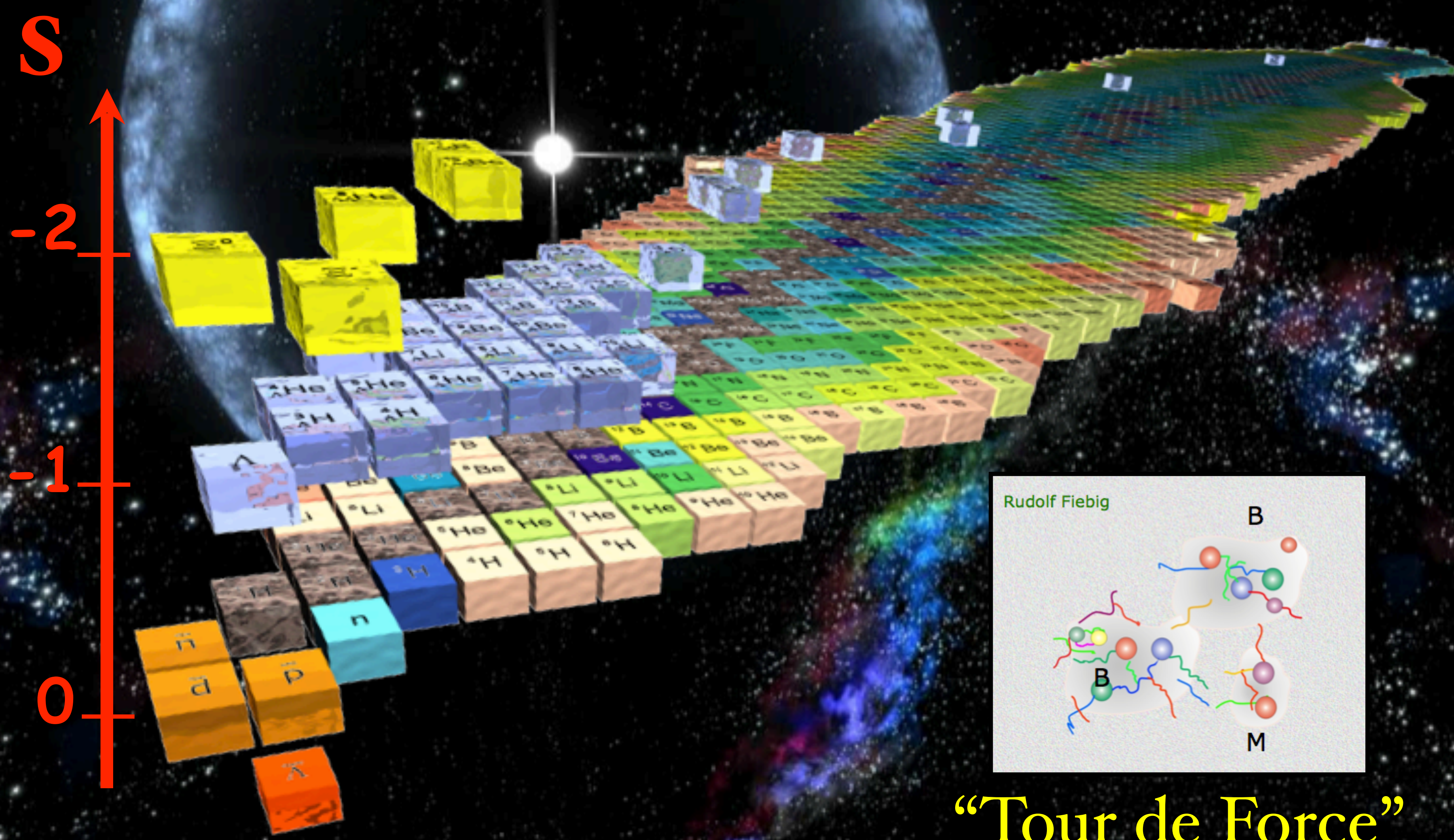
HYPERNUCLEI



“Tour de Force”

Ξ^- production

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

rescattering in
primary target nucleus

deceleration in
secondary target

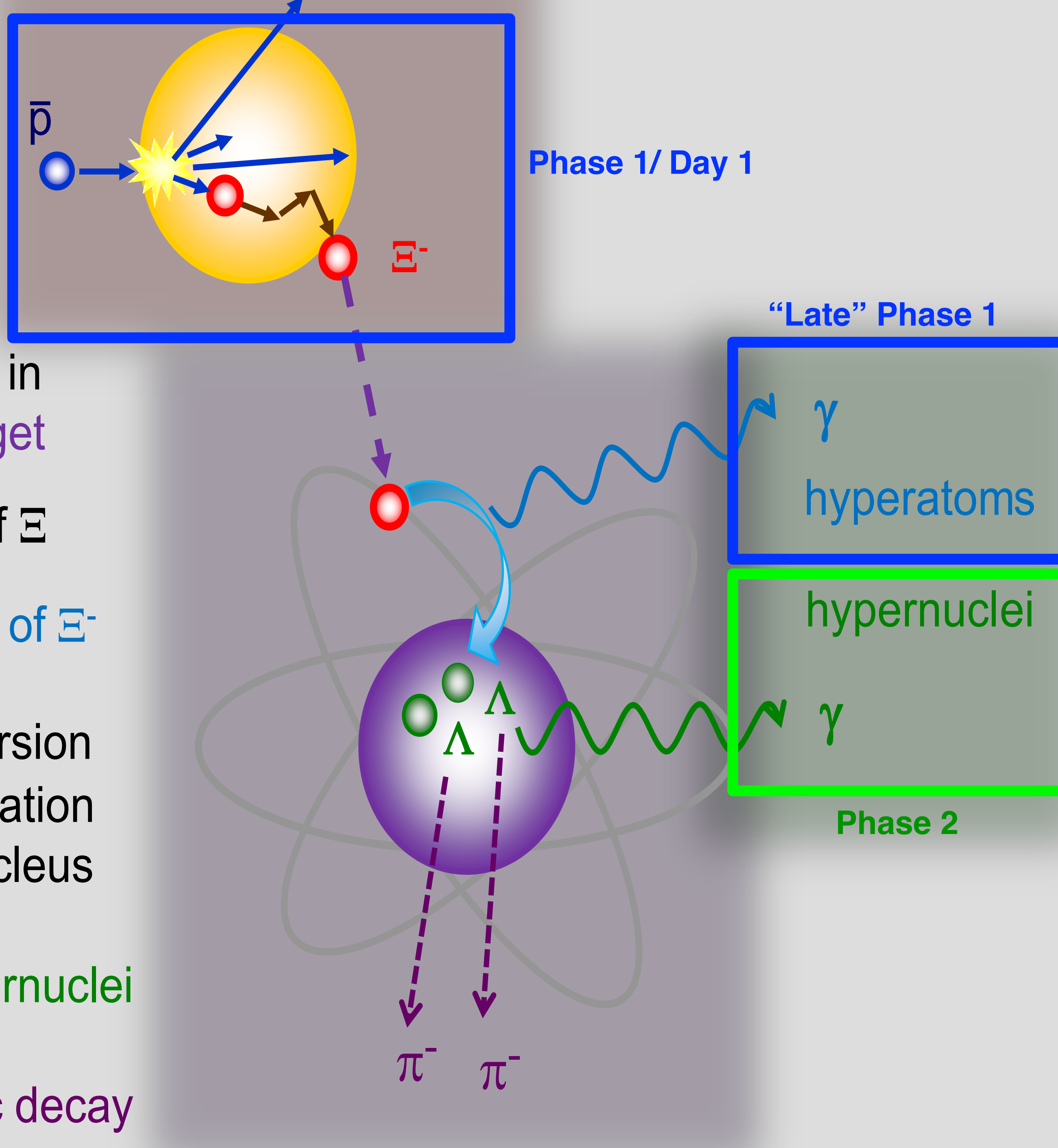
capture of Ξ

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



PANDA@FAIR:
"subatomic physics with antiprotons"

GSI+FAIR April 2021

… covers particle, hadron, and nuclear aspects

- quark d.o.f.: from light to heavy
- gluon d.o.f.: glueballs, hybrids, etc.
- meson-baryon d.o.f.: B-B interaction in SU(3)-flavor

… is complementary and competitive

- *unique* antiproton facility
- versatile detector

… with excellent contributions from Sweden

… you are welcome to join the endeavour!

j.messchendorp@gsi.de