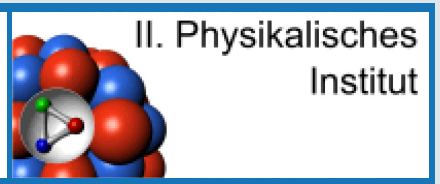
JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

K.-Th. Brinkmann, JLU Gießen & HFHF, for the $\bar{P}$ANDA collaboration



FAIR Physics With $\bar{P}$ANDA

Facility for Antiproton and Ion Research

Source: https://fair-center.de/ (Nov 26, 2021) © ion42/FAIR

Facility for Antiproton and Ion Research

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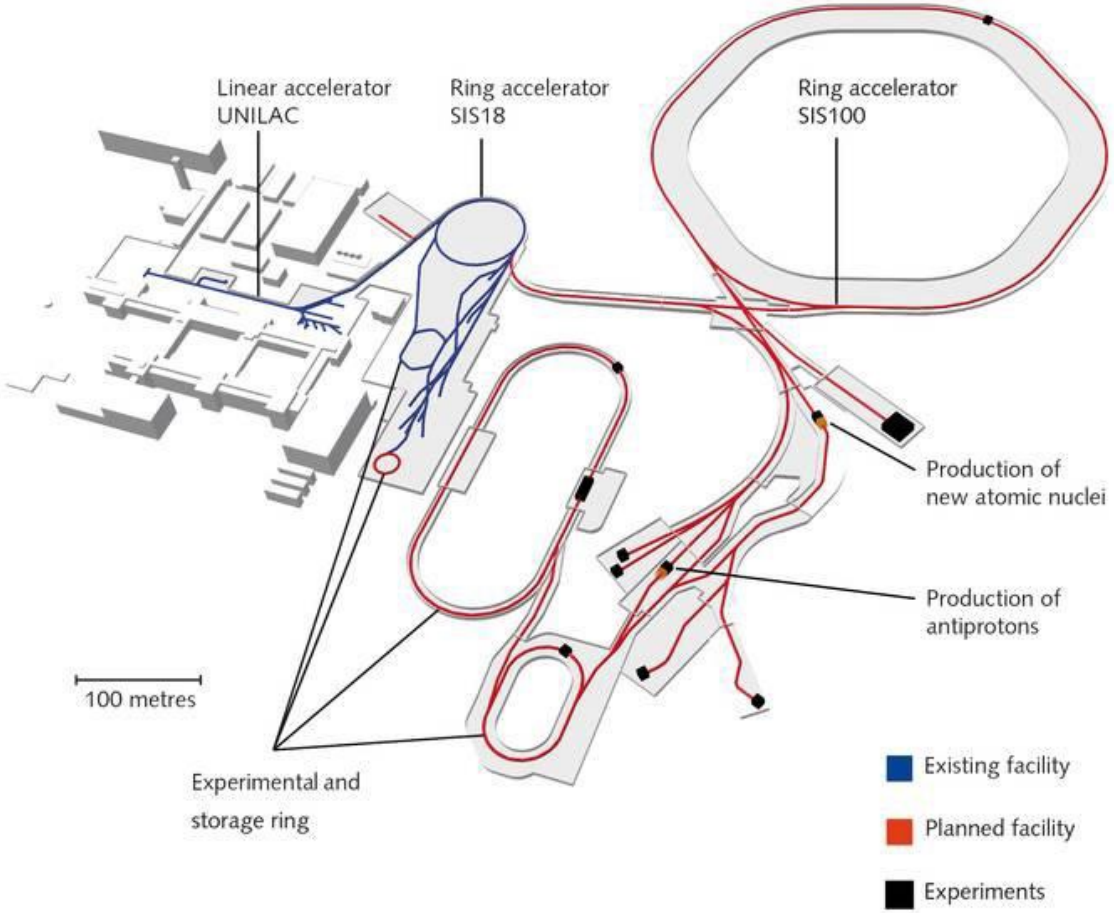
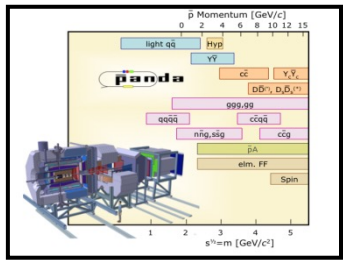
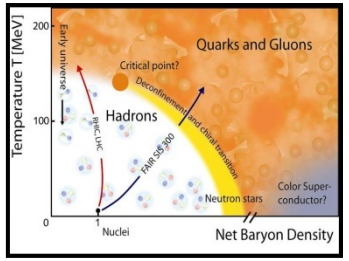
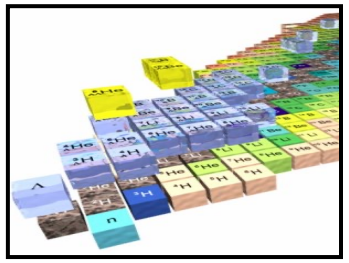


Facility for Antiproton and Ion Research







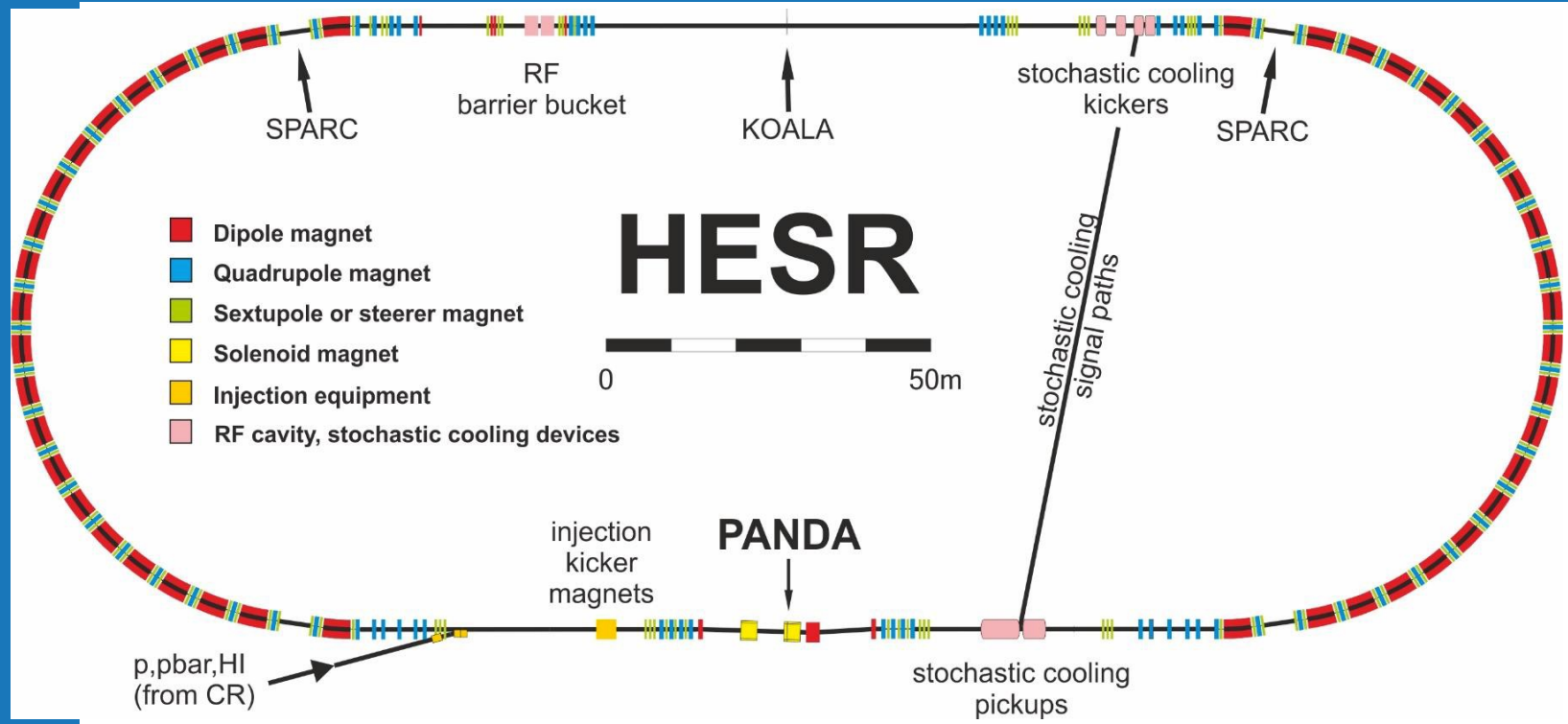
hadrons: structure and dynamics — PANDA

nuclear and quark matter — CBM

nuclear astrophysics and exotic nuclei — NUSTAR

atomic physics, plasma physics, applications — APPA

High-Energy Storage Ring for Antiprotons HESR



10^{11} **stored antiprotons**

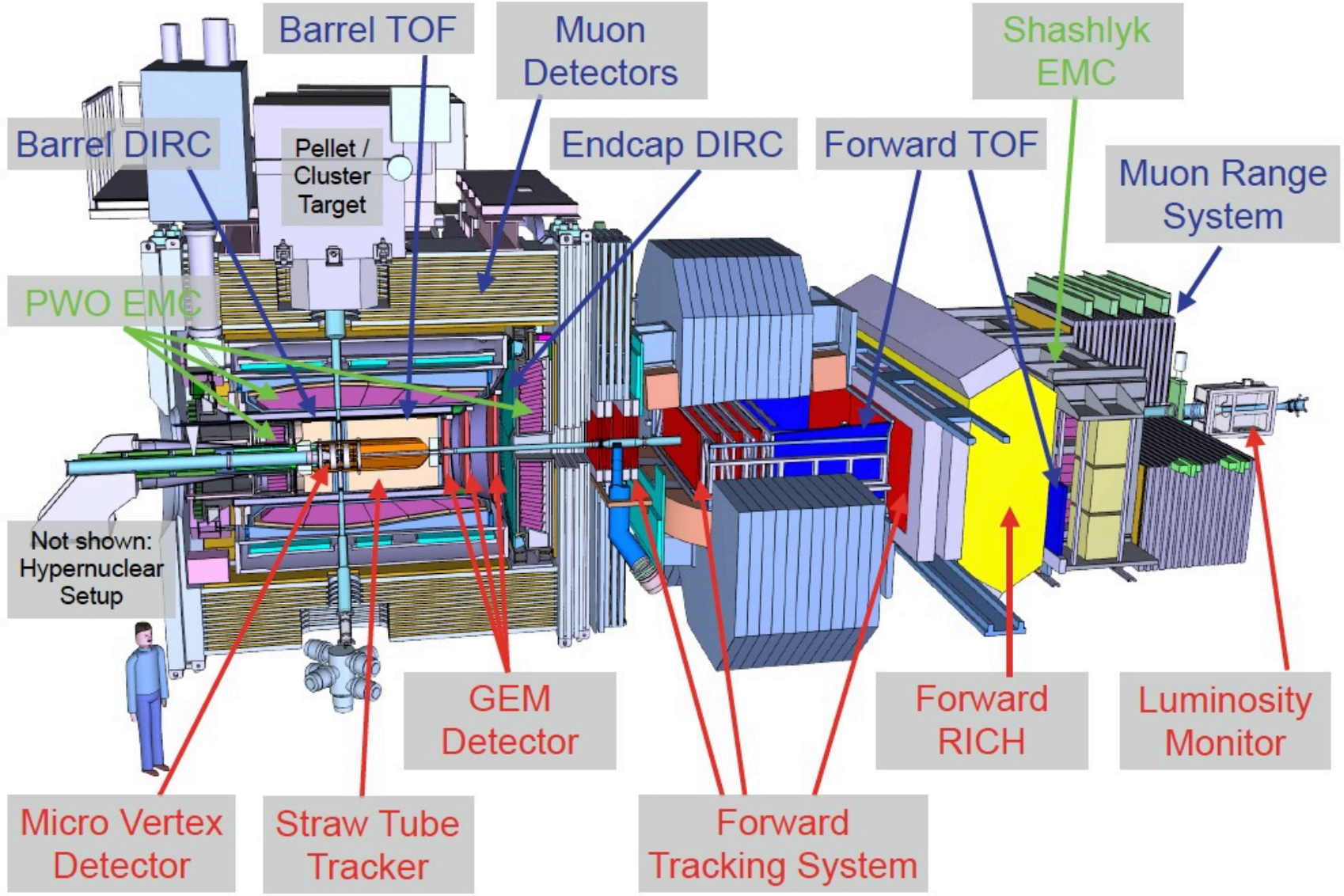
momentum range 1.5 to 15 GeV/c

internal **targets**:
cluster jet and pellet ($\bar{p}p$)
foils ($\bar{p}A$)

luminosity at **peak** intensity:
$\mathcal{L} = 2 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}$
(**Phase One**: $\mathcal{L} = 1 \cdot 10^{31}\ \mathrm{cm^{-2}s^{-1}}$)
$\delta p/p < 2 \cdot 10^{-4}$ (stochastic cooling)
interaction rate $2 \cdot 10^{7}\ \mathrm{s^{-1}}$

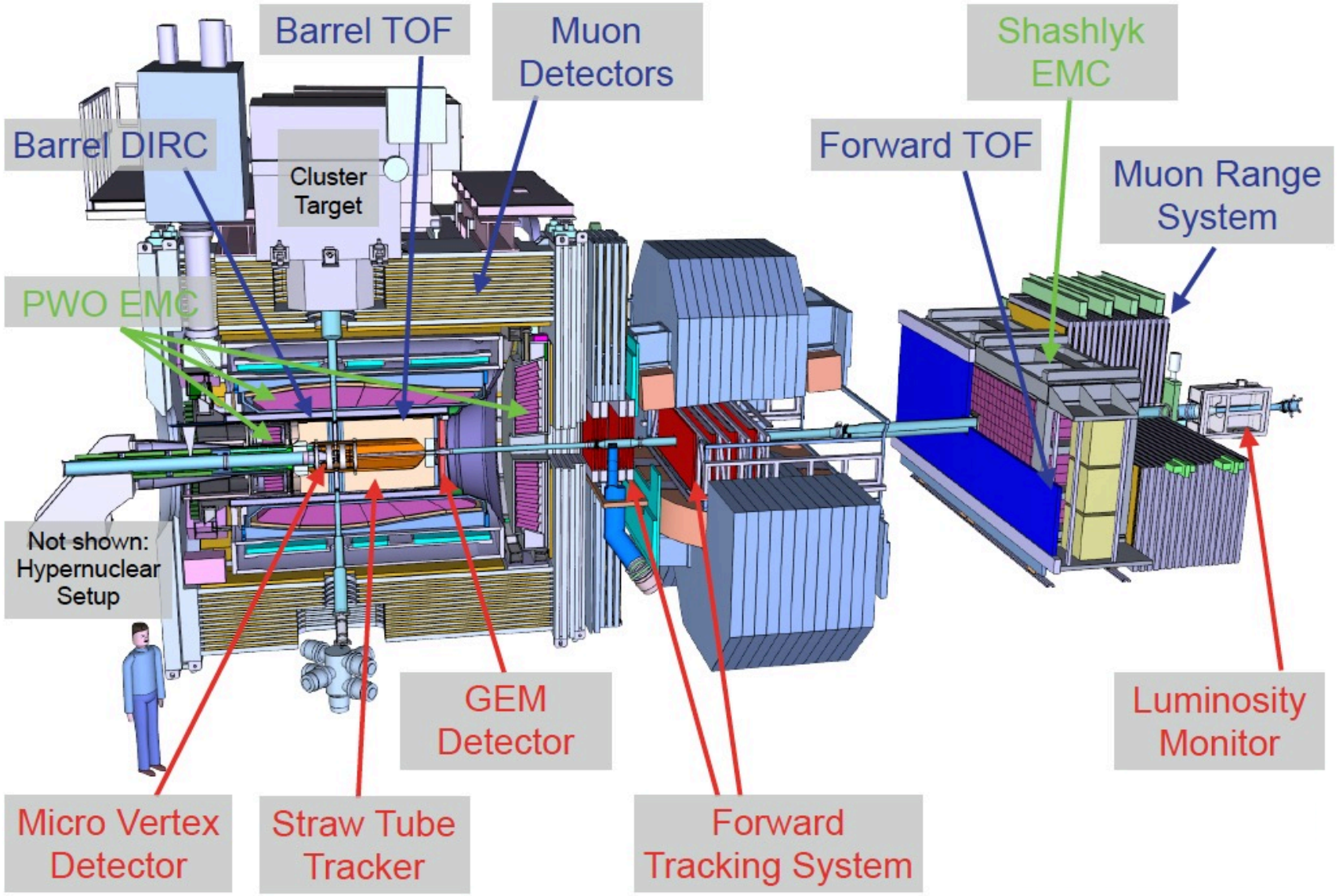
luminosity for highest **resolution**:
$\mathcal{L} = 2 \cdot 10^{31}\ \mathrm{cm^{-2}s^{-1}}$
$\delta p/p < 4 \cdot 10^{-5}$ (electron cooling)

Proton-Antiproton Annihilations at Darmstadt

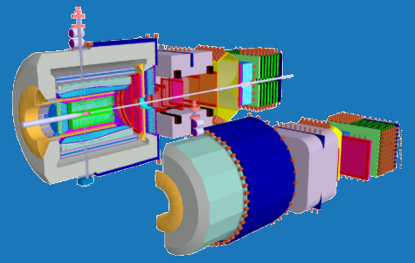


Proton-Antiproton Annihilations at Darmstadt

DAY ONE



Detector Features



PANDA is a modular multi-purpose device:

- Excellent forward acceptance and resolution
- (Moderate) backward acceptance
- Wide dynamic range: particle momenta from 0.1 to 8 GeV/c
- Momentum measurements in magnetic fields ($\Delta p/p \approx 1\%$)
- Particle ID in wide momentum range ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p, …)
- Electromagnetic calorimeter: γ, π^0, η … ($e^{\pm}$)
- High-resolution vertex detection: $D^{\pm}$, D^0 / K_s, Λ, Σ, Ω …
- High interaction rate beyond $2 \cdot 10^7\ s^{-1}$
- Intelligent trigger design for parallel data acquisition at high rates and small branching fractions

Physics Objectives

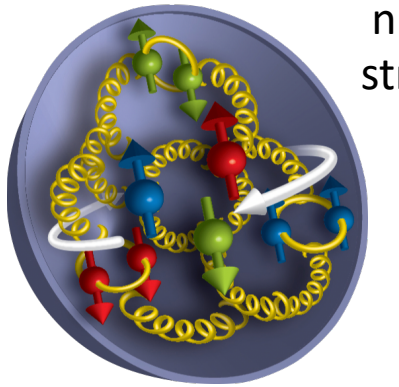
Confinement of q in hadrons

Generation of mass

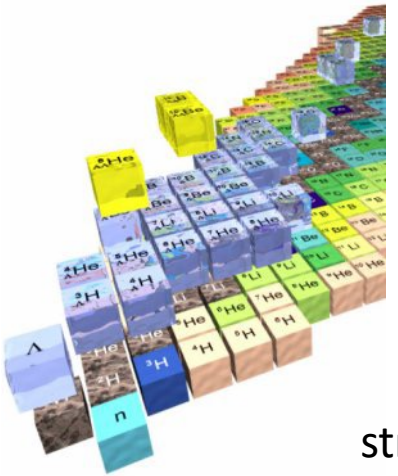
Structure of hadrons from q

Exotic bound states of q

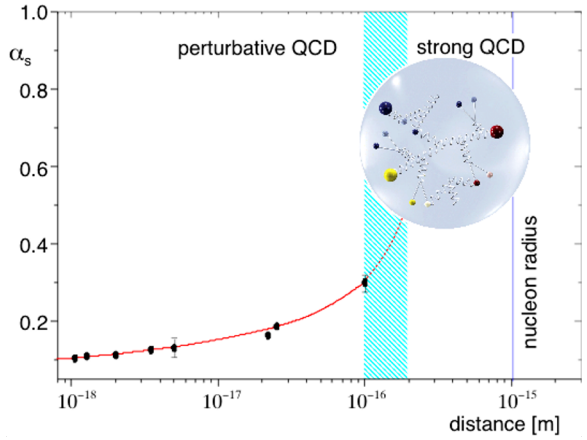
Matter-antimatter (a)symmetries

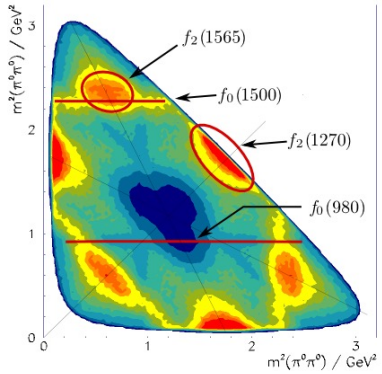


nucleon structure

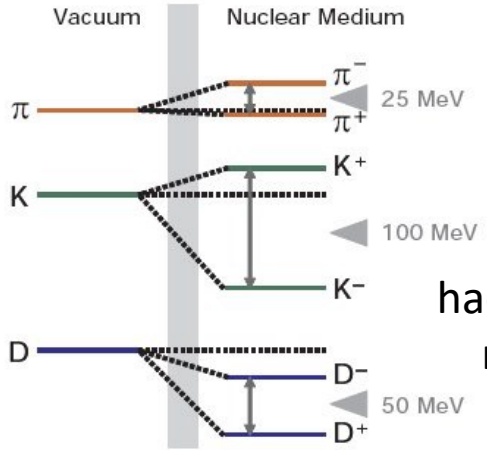


strange hadrons





charming and exotic hadrons



hadrons in nuclei

Nucleon Structure

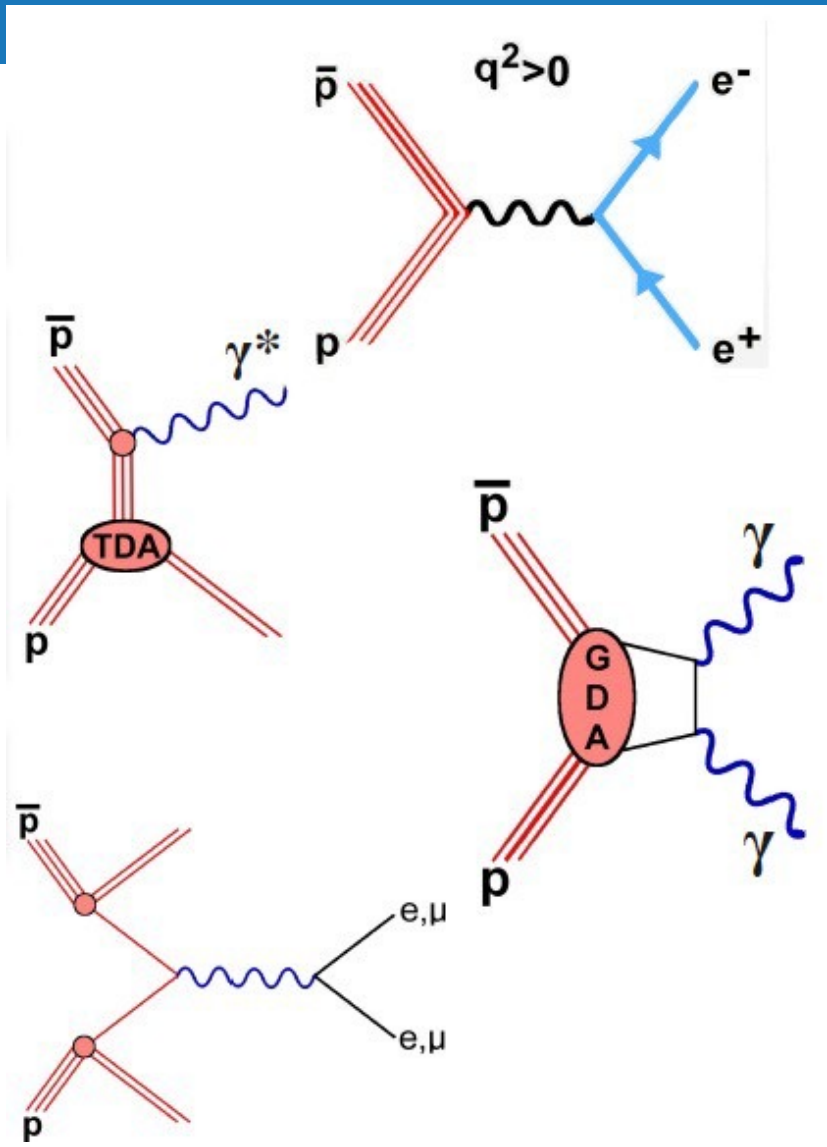
Timelike electromagnetic formfactors via lepton pair production
(arXiv:1606:01118)

Transition distribution amplitudes (TDAs) through meson production
(arXiv:1409:0865) talk by Stefan Diehl on Tuesday

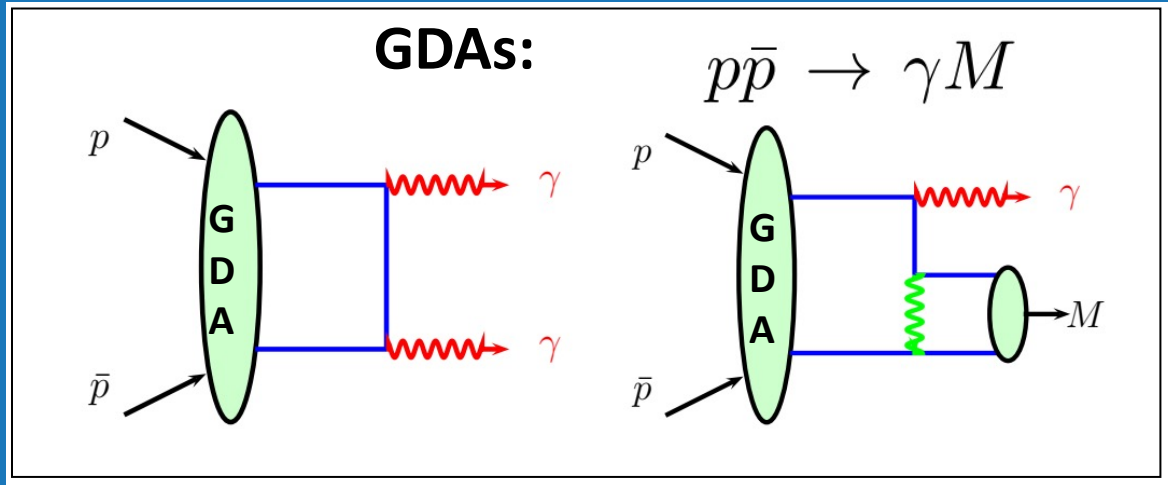
Generalized distribution amplitudes (GDAs) by timelike Compton scattering and hard exclusive processes

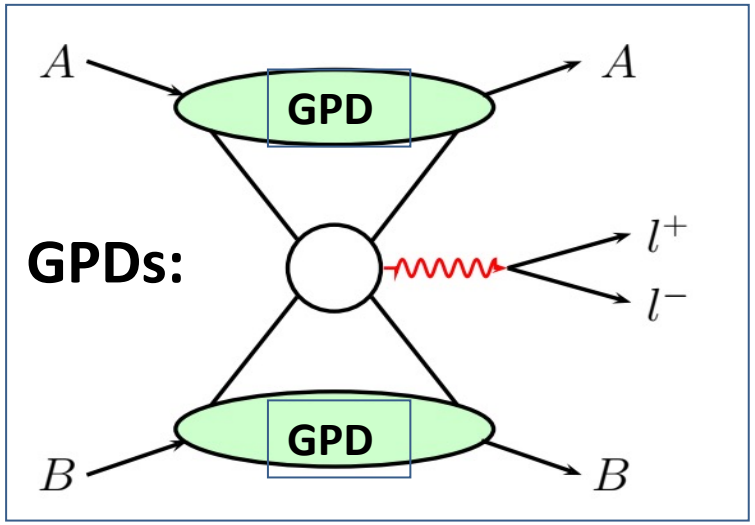
Generalized parton distributions (GPDs) via antiproton scattering

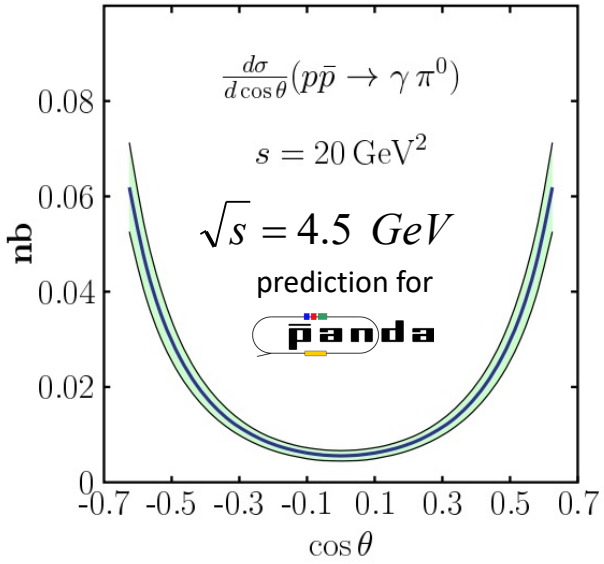
Transverse parton distribution functions in Drell-Yan



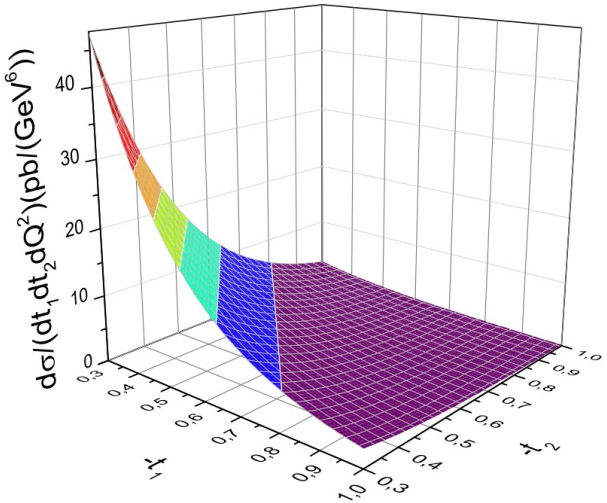
Nucleon Structure







P. Kroll, A. Schäfer, EPJ A 26, 89-98 (2005)

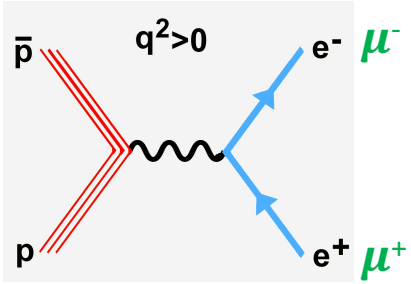


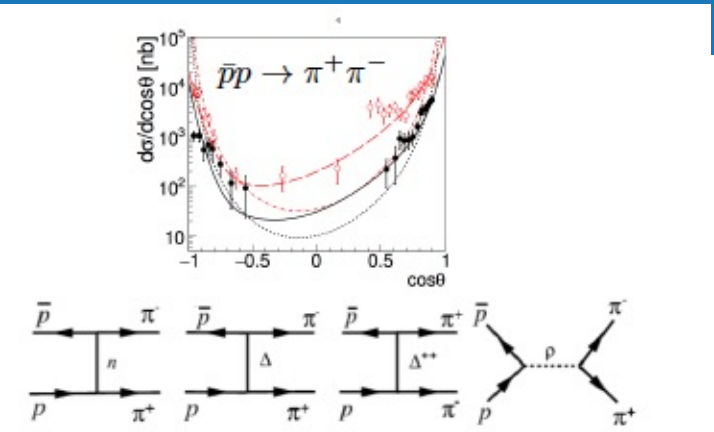
S. V. Goloskokov, P. Kroll, O. Teryaev, arXiv:2008.13594v1

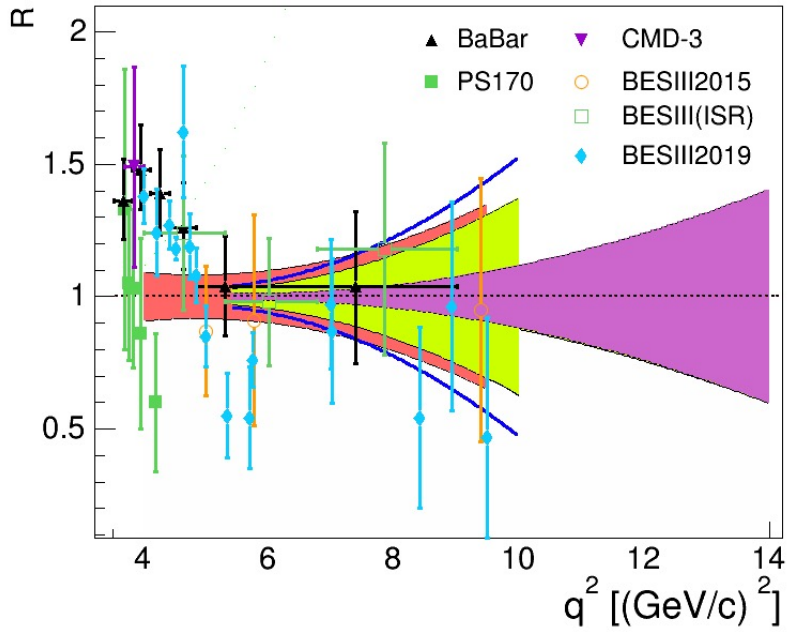
Nucleon Structure

Timelike electromagnetic formfactors

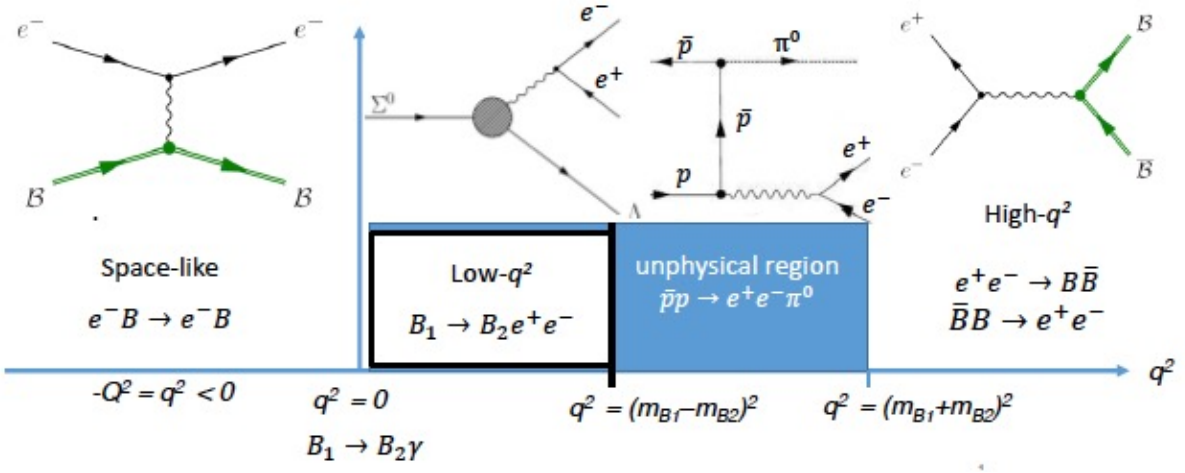
$\bar{p}p \to e^-e^+$ @ 1.5 GeV/c: ~220/day
$\bar{p}p \to e^-e^+$ @ 3.3 GeV/c: ~10/day
$\bar{p}p \to \mu^-\mu^+$ @ 1.5 GeV/c: ~170/day



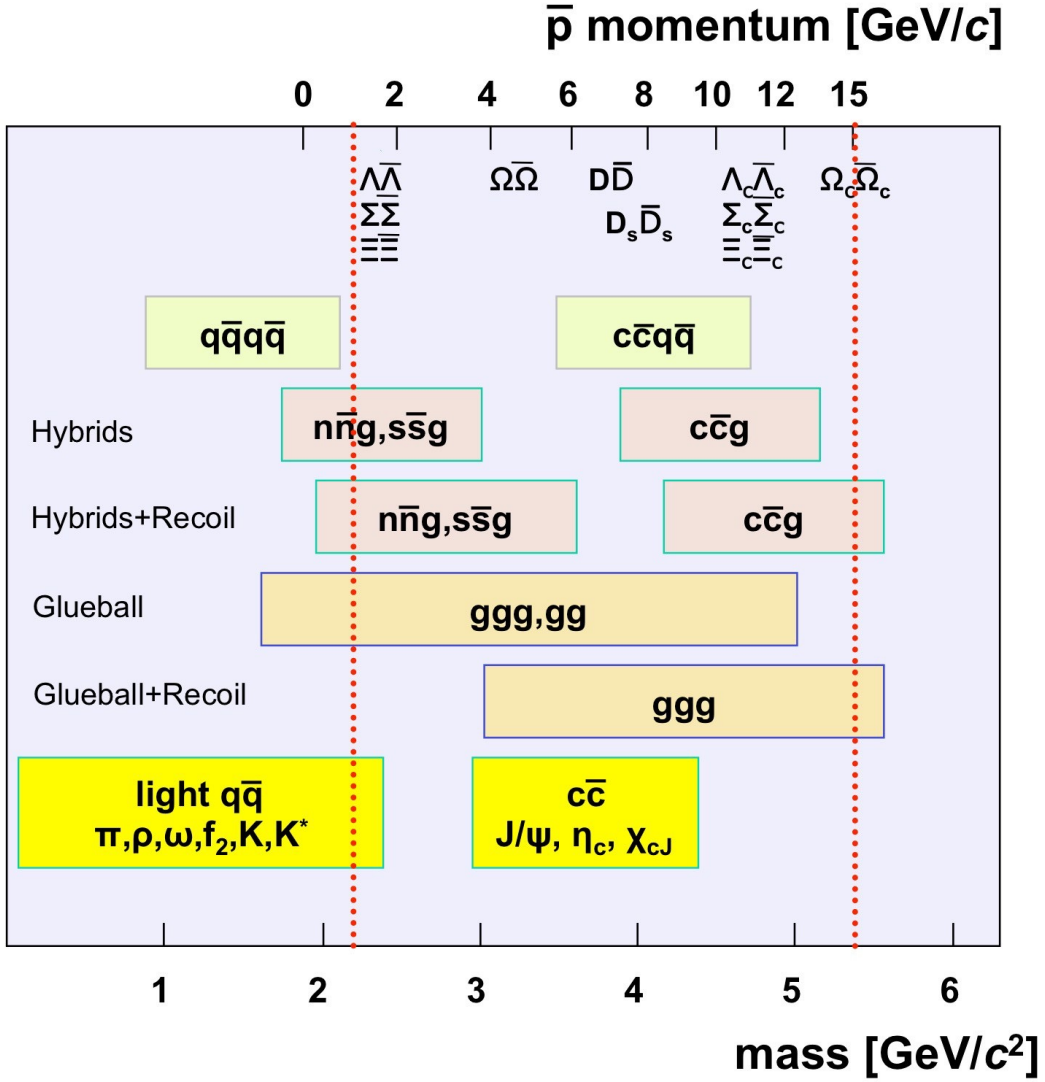




Access to unphysical region of formfactors $\bar{p}p \to e^-e^+\pi^0$

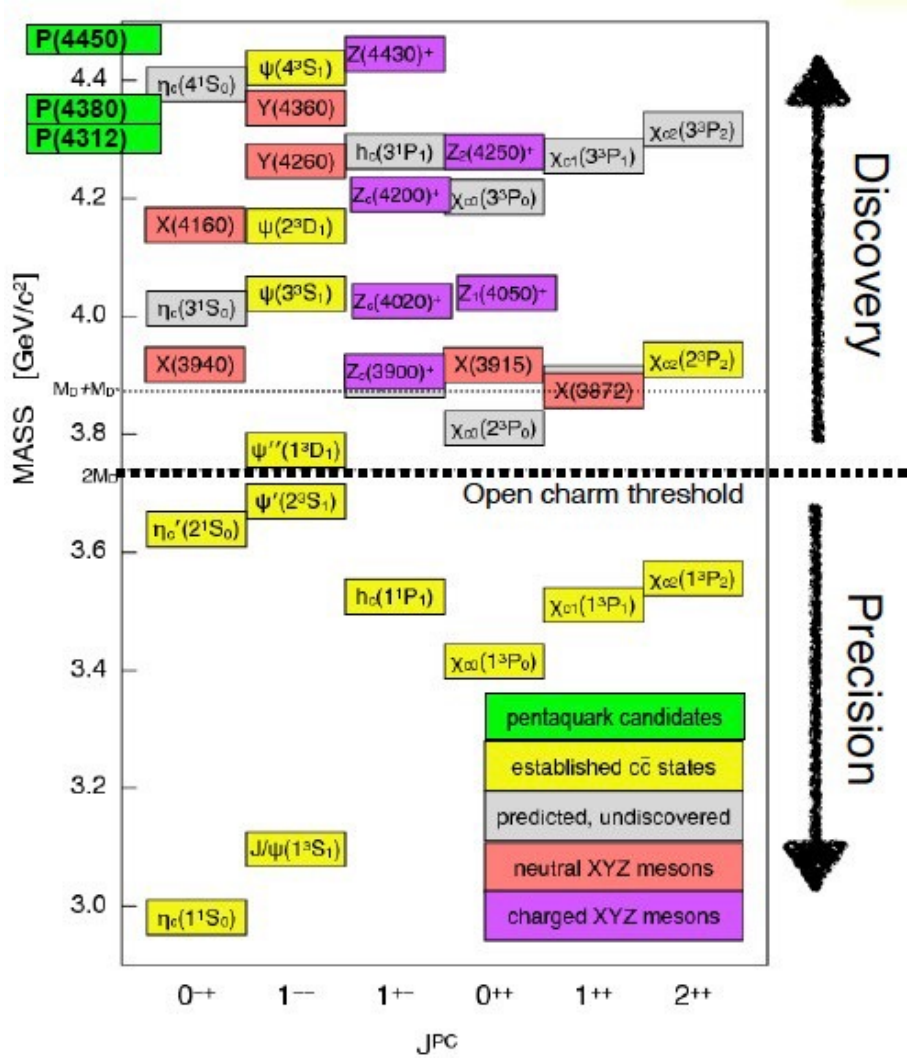


Hadron Spectroscopy



P̄ANDA:

- Tuned to charmonium.
- High-resolution spectroscopy through resonance energy scans in formation.
- Line shapes, widths and masses.
- Branching ratios.

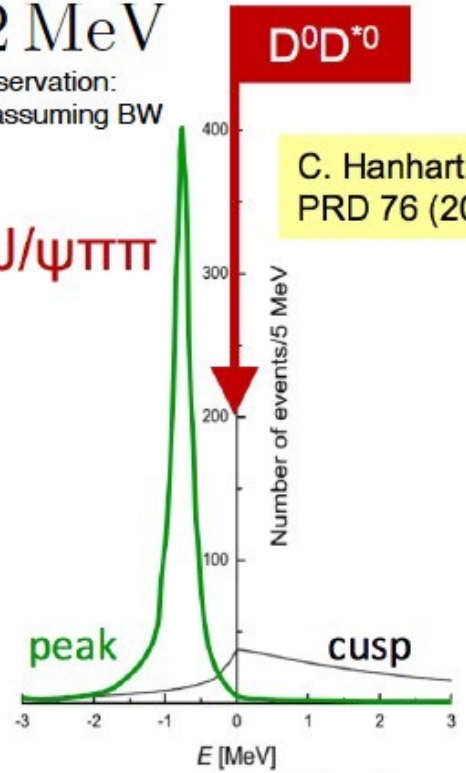


Hadron Spectroscopy: Lineshape of X(3872)

Strikingly narrow:

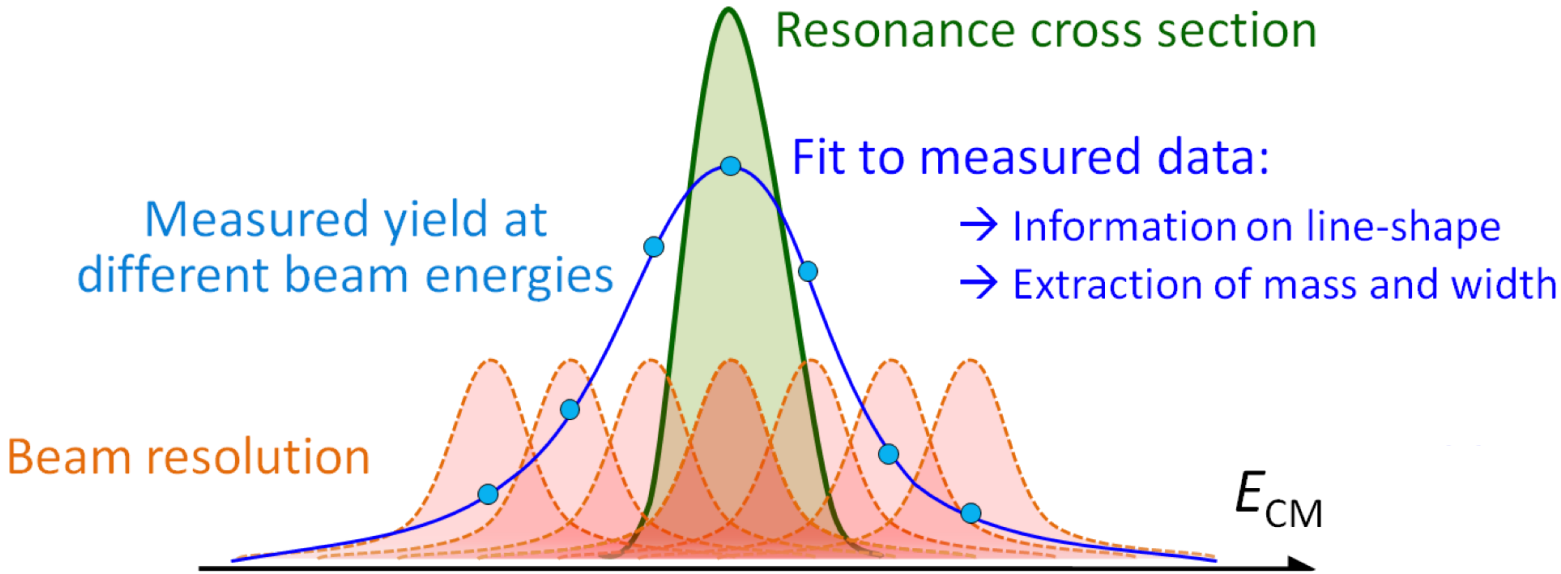
$\Gamma < 1.2\,\mathrm{MeV}$

*recent LHCb observation: width=1.4 MeV assuming BW



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

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)



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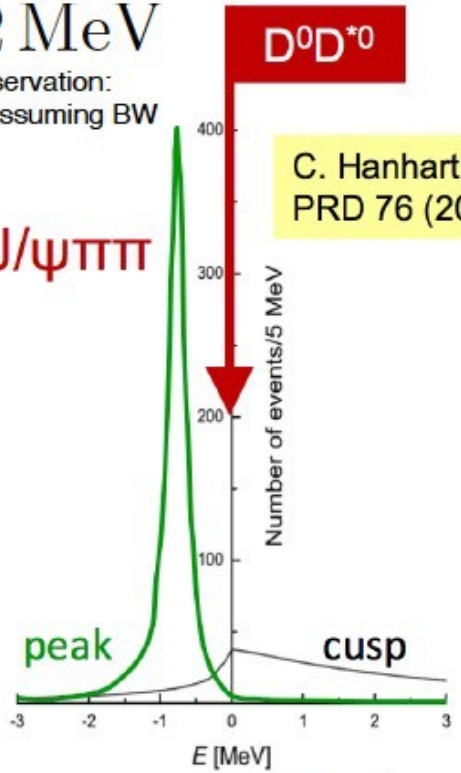
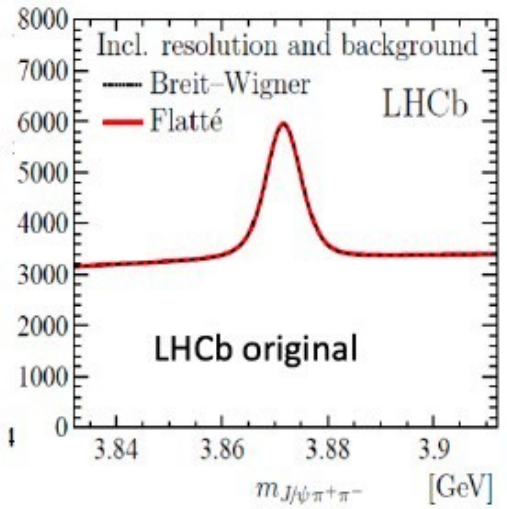


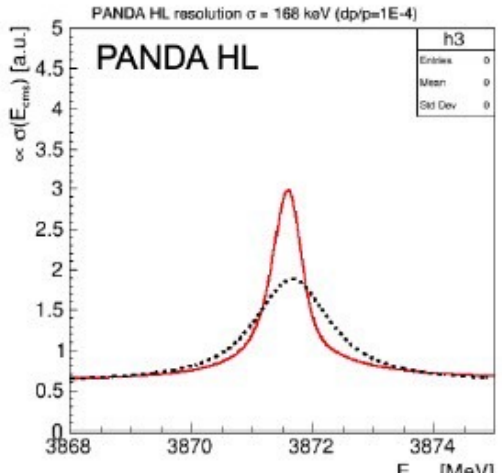
C. Hanhart *et al.*,
PRD 76 (2007) 034007

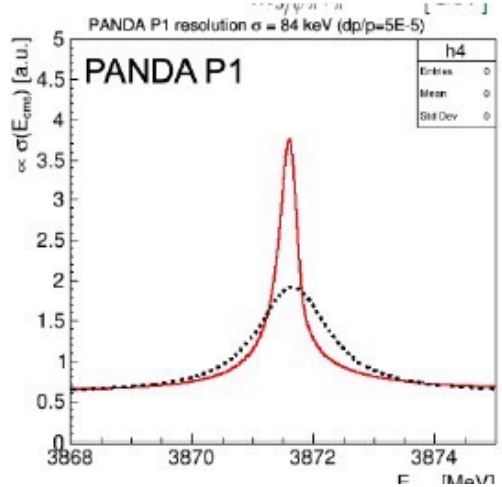
virtual state
binding state

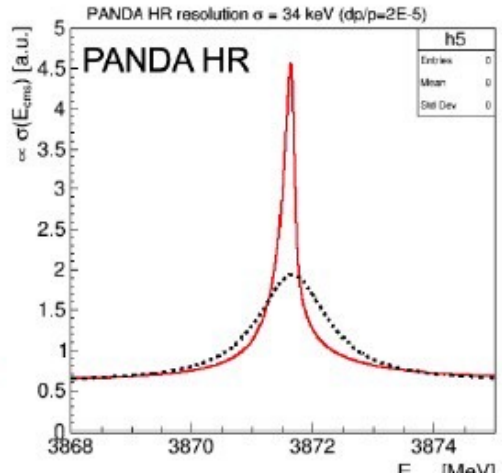


LHCb:
PRD102, 092005 (2020), arXiv:2005.13419

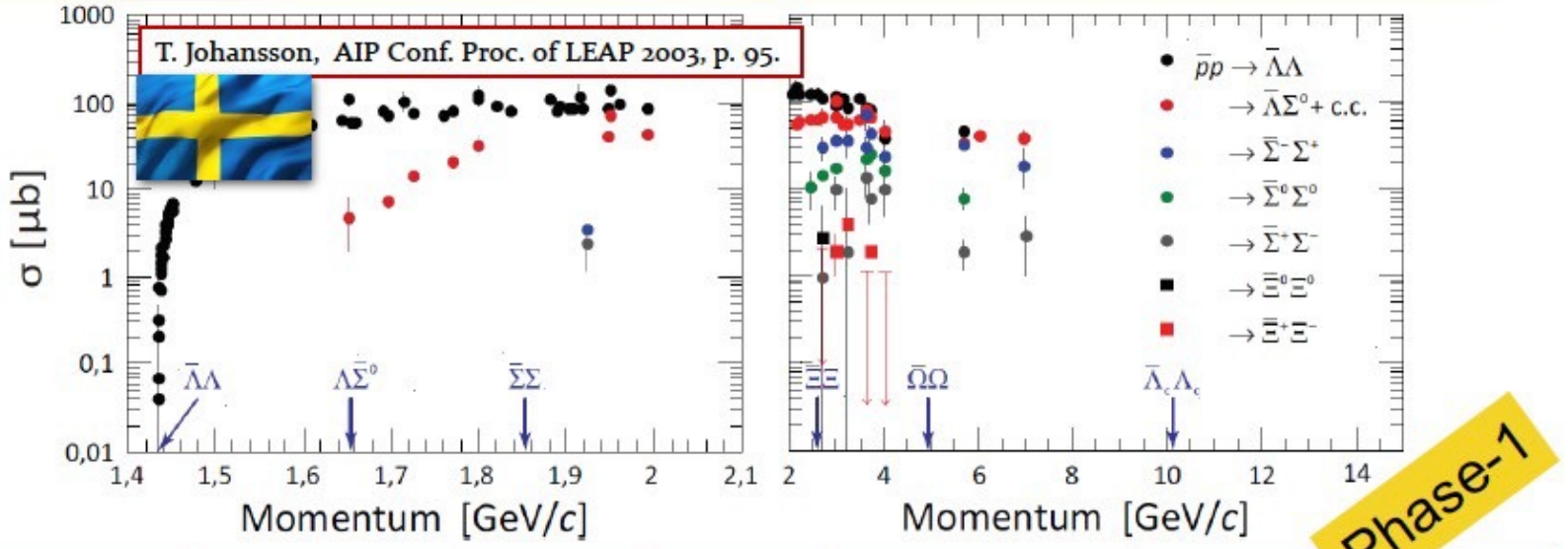
PANDA perspectives:
EPJA55, 42 (2019), arXiv:1812.05132







Hadron Spectroscopy: Hyperon Factory



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

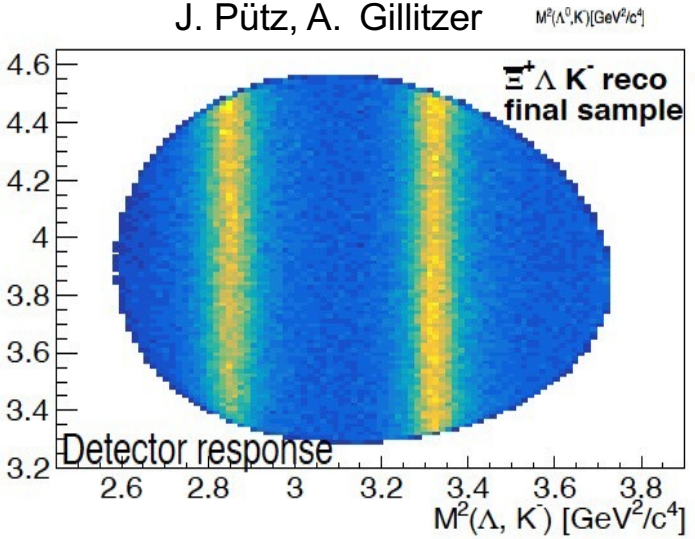
** 90% C.L.

EPJA57, 184 (2021) arXiv:2101.11877

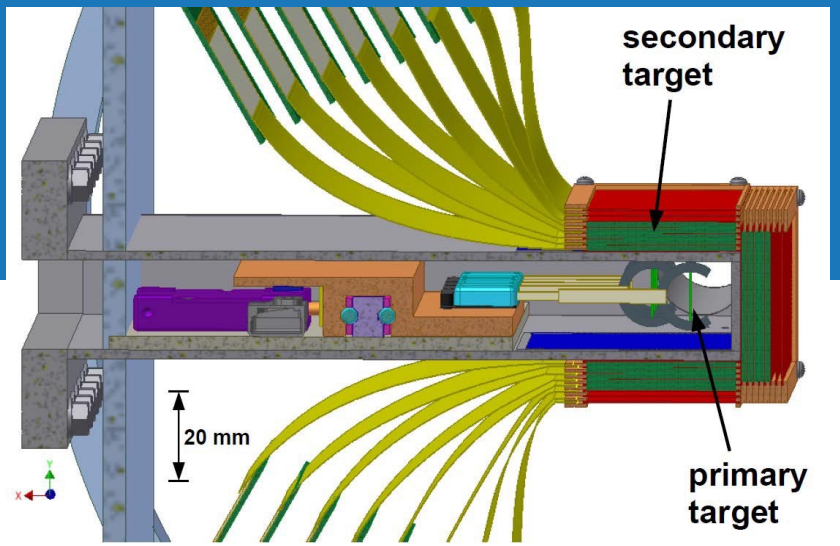
PANDA:

- Rich set of polarization observables
- Double- and triple-strange baryons (e.g. excitation spectrum of Ξ and Ω states)

J. Pütz, A. Gillitzer



Hypernuclei



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

rescattering in
primary target nucleus

deceleration in
secondary target

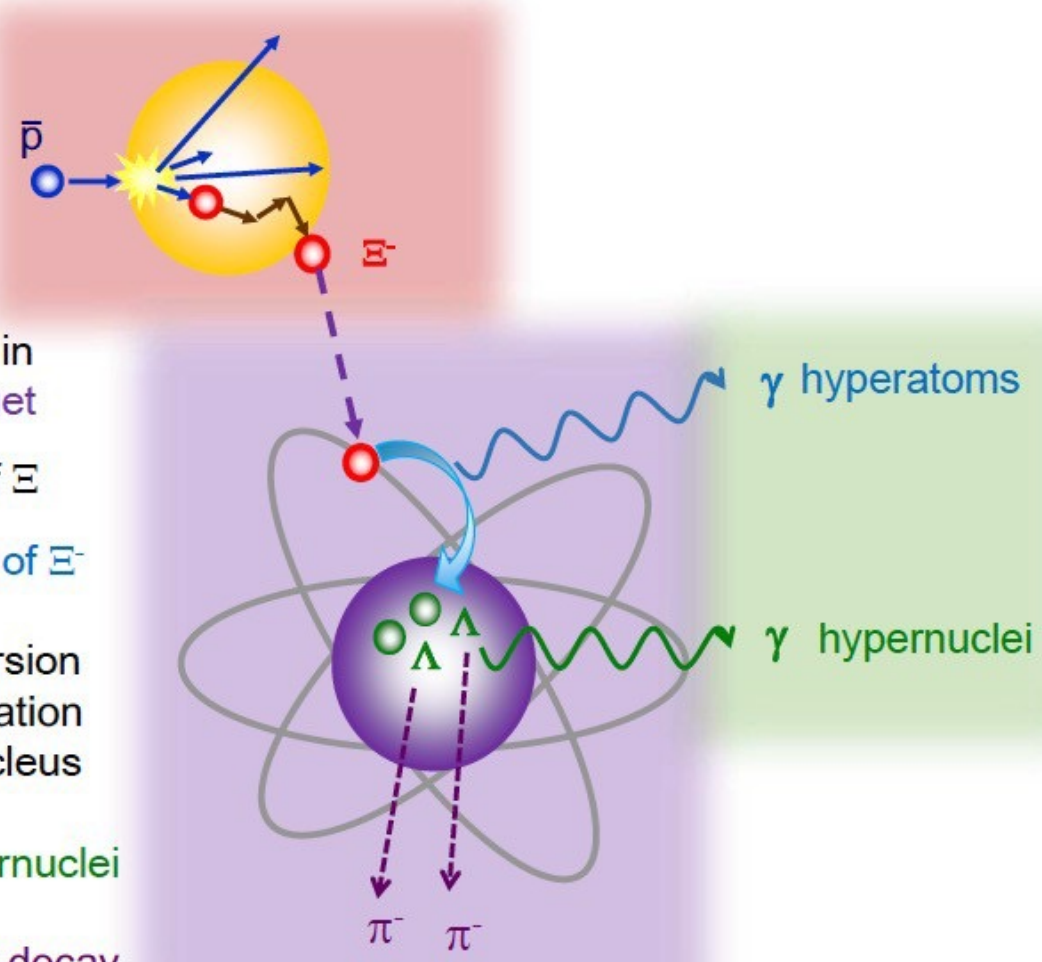
capture of Ξ

atomic cascade of Ξ⁻

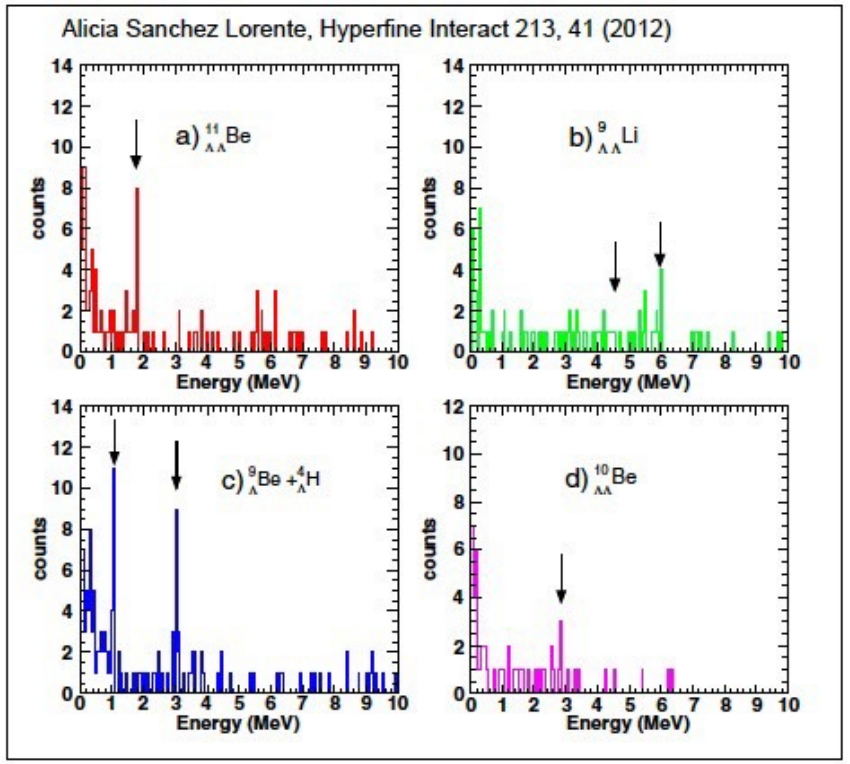
$\Xi^- p \rightarrow \Lambda\Lambda$ conversion
fragmentation
→ excited ΛΛ-nucleus

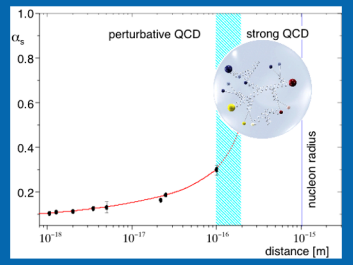
γ-decay of ΛΛ hypernuclei

weak pionic decay

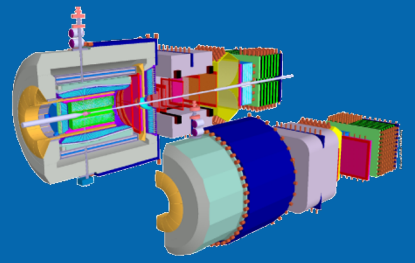


Josef Pochodzalla





Summary



$\bar{P}$ANDA …

- is a unique facility featuring a broad physics program employing antiprotons.
- is therefore complementary to running and future experiments.
- enlists modern detector technologies.

$\bar{P}$ANDA physics book,
arXiv.org/pdf/0903.3905
also: NPA 948 (2016) 93
Phase 1: arXiv:2101.11877

The experimental program at $\bar{P}$ANDA …

- covers aspects of nuclear, hadron and particle physics across the transition from elementary nucleons to elementary quarks.
- puts precision spectroscopy alongside high discovery potential.

Members of the PANDA collaboration

UP Marche Ancona
U Basel
IHEP Beijing
U Bochum
Abant Izzet Baysal
U Golkoy, Bolu
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
Cracow UT
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Erlangen
NWU Evanston
U Frankfurt
LNF-INFN Frascati
U & INFN Genova

U Gießen
Giresun U
U Glasgow
KVI Groningen
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
Doğuş U, Istanbul
Okan U, Istanbul
FZ Jülich
IMP Lanzhou
INFN Legnaro
Lund U
HI Mainz
U Mainz
RINP Minsk
ITEP Moscow
MPEI Moscow
U Münster
BINP Novosibirsk
Novosibirsk State U

IPN Orsay
U Wisconsin, Oshkosh
U & INFN Pavia
PNPI St. Petersburg
Wet Boh. U, Pilzen
Charles U, Prague
Czech TU, Prague
IHEP Protvino
Irfu Saclay
KTH Stockholm
Stockholm U
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U Uppsala
SMI Vienna
NCBJ Warsaw
U York

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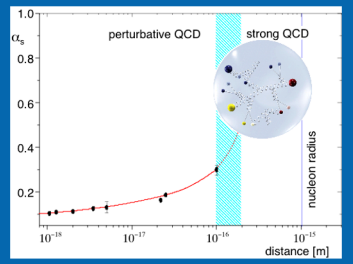
Thank you, stay healthy and safe!



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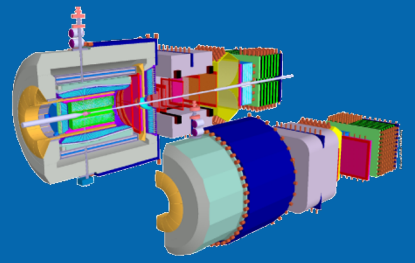

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