JLU
NEUE WEGE. SEIT 1607.

JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

K.-Th. Brinkmann, JLU Gießen & HFHF, for the P̄ANDA collaboration

HFHF
Helmholtz Forschungsakademie Hessen für FAIR

II. Physikalisches Institut

Physics With P̄ANDA at FAIR

bmb+f
Großgeräte der physikalischen Grundlagenforschung

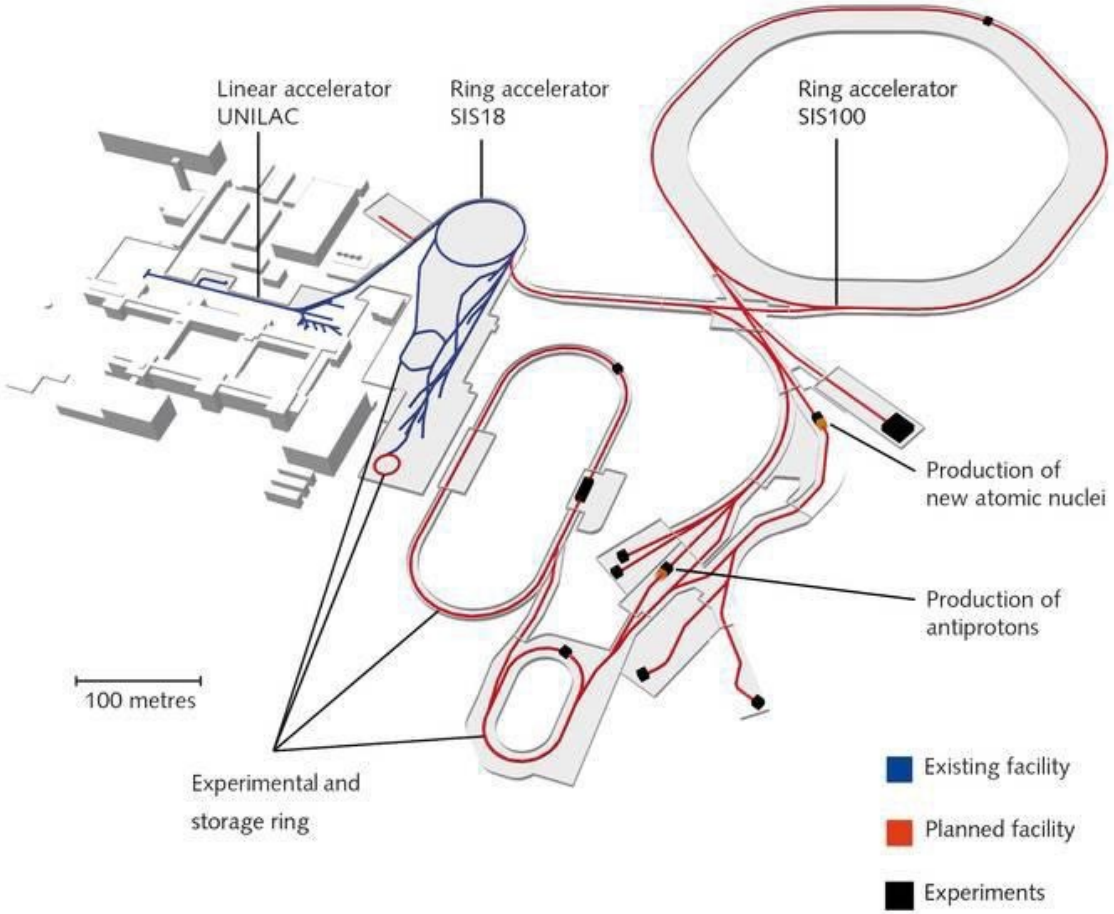
ErUM-FSP T08: P̄ANDA
05P19RGFP1/2

Facility for Antiproton and Ion Research

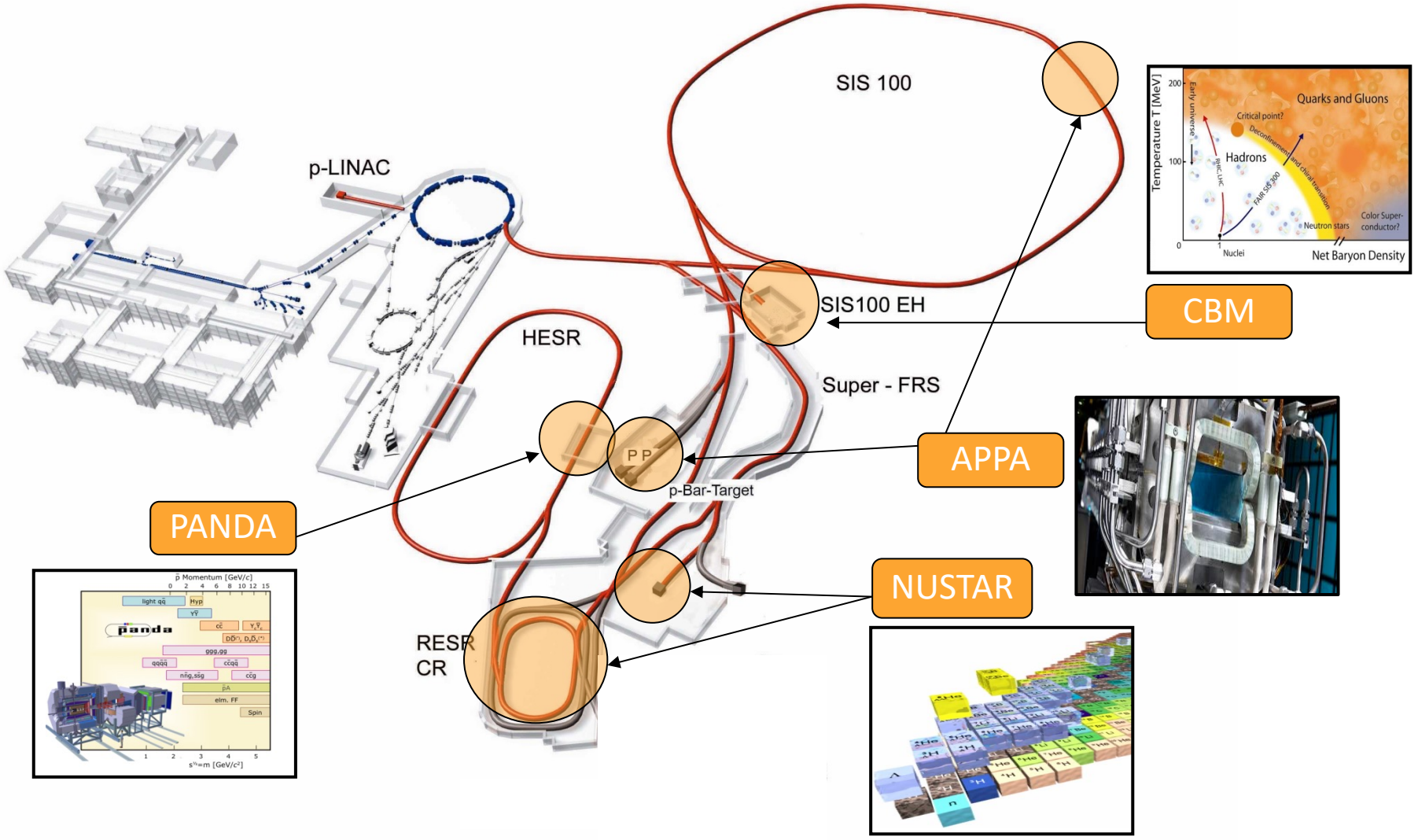
Source: https://fair-center.de/ (July 04, 2022) © ion42/FAIR

Facility for Antiproton and Ion Research

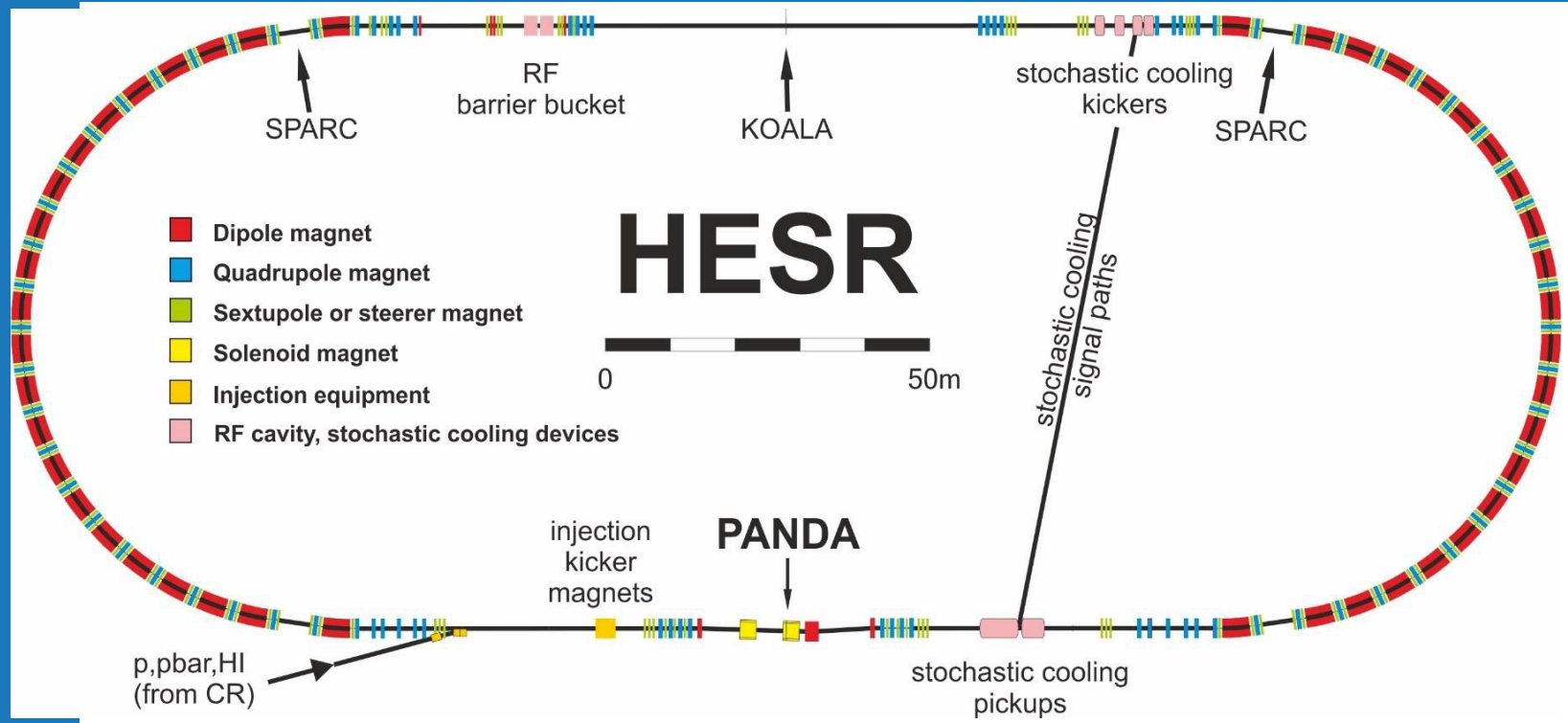
Source: https://fair-center.de/ (April 2021) © D. Fehrenz/GSI/FAIR



Facility for Antiproton and Ion Research



High-Energy Storage Ring for Antiprotons HESR



10^{11} **stored antiprotons**

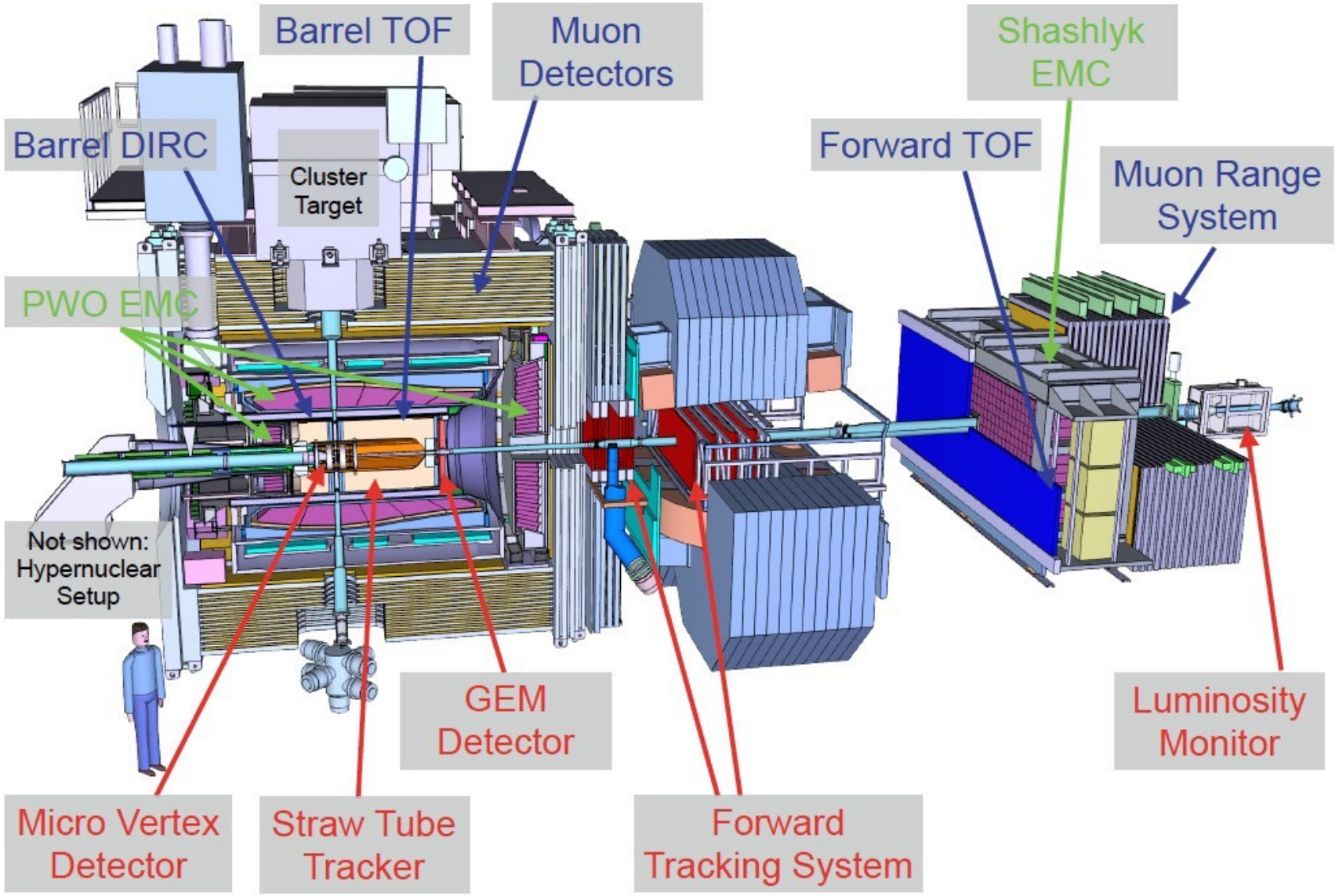
momentum range 1.5 to 15 GeV/c

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

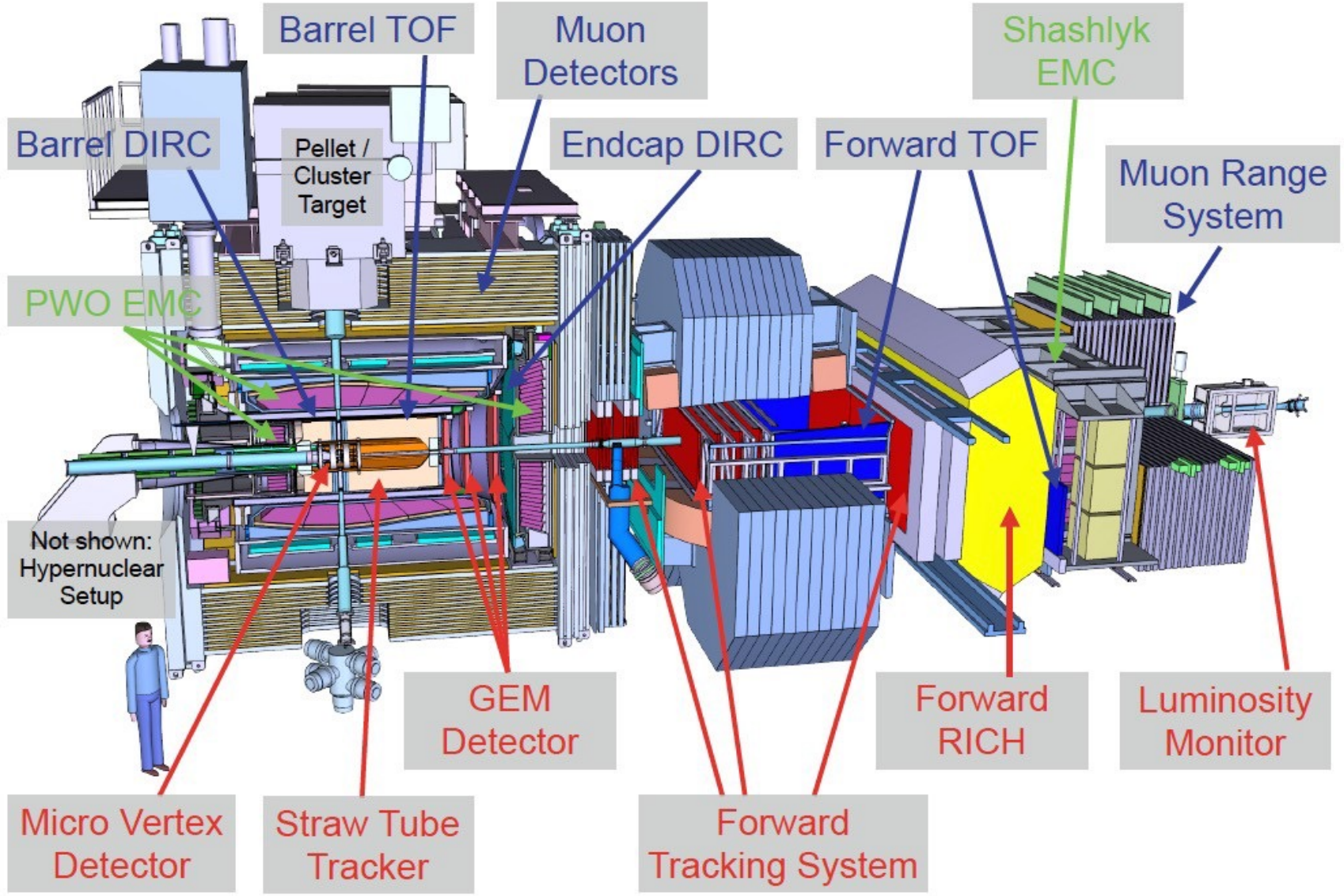
luminosity at **peak** intensity:
$\mathcal{L} = 2 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}$
(**Phase One**: $\mathcal{L} = 1 \cdot 10^{31}\ \mathrm{cm^{-2}s^{-1}}$)
$\delta p/p < 2 \cdot 10^{-4}$ (stochastic cooling)
interaction rate $2 \cdot 10^{7}\ \mathrm{s^{-1}}$

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

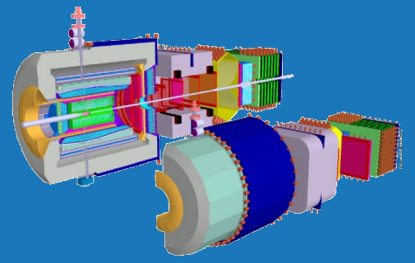


Proton-Antiproton Annihilations at Darmstadt



PANDA Technical Status, http://www-panda.gsi.de/

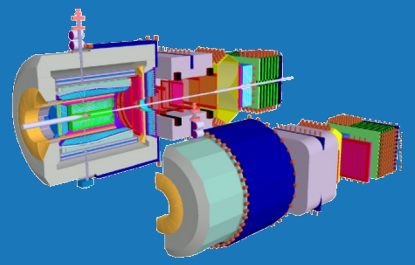
Detector Features



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 ($e^{\pm}$, $\propto^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, 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

Detector Features

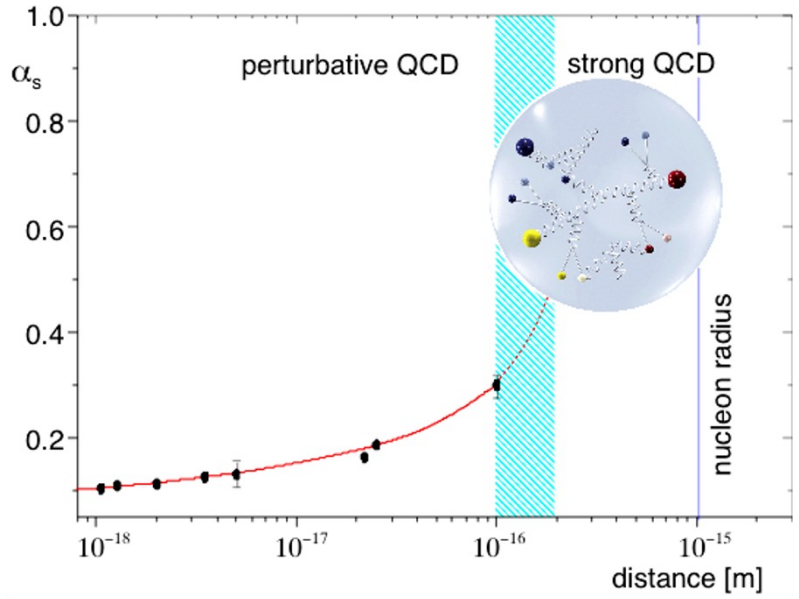


PANDA is a modular multi-purpose device:

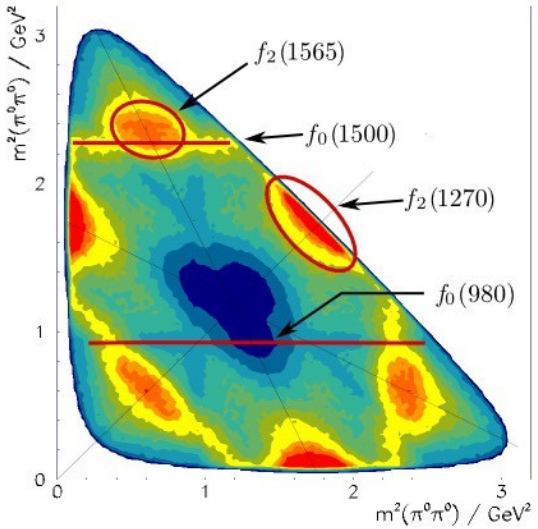
- Excellent forward acceptance and resolution
- (Moderate) backward acceptance
- Wide dynamic range: particle momenta from 0.1 to 8 GeV/c
- Momentum measurements in magnetic fields ($\Delta p/p$ better than 1%)
- Particle ID in wide momentum range ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p, …)
- 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

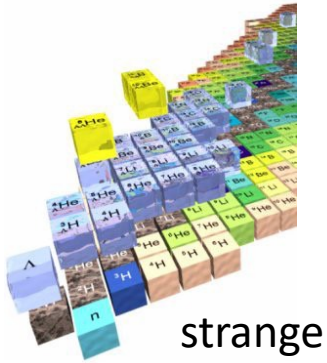
Physics Objectives

- Confinement of q in hadrons
- Generation of mass
- Exotic bound states of QCD
- Matter-antimatter (a)symmetry
- Structure of hadrons from q



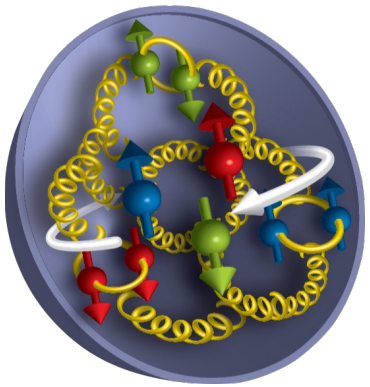
charming and exotic states

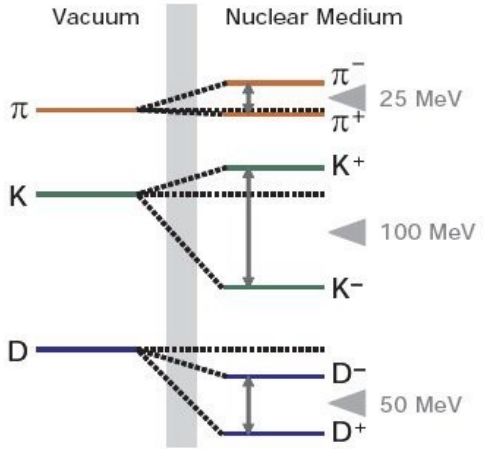




strange hadrons

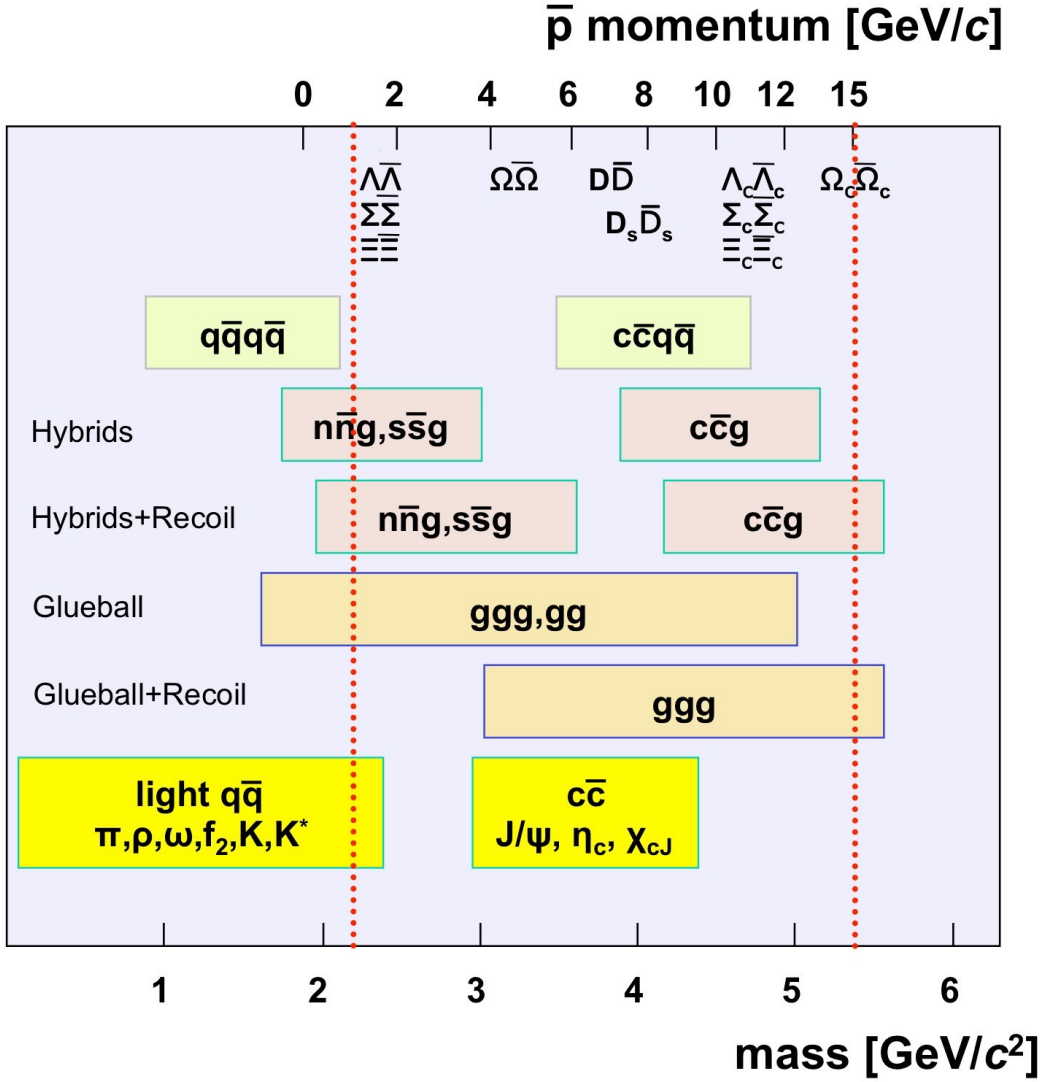
nucleon structure





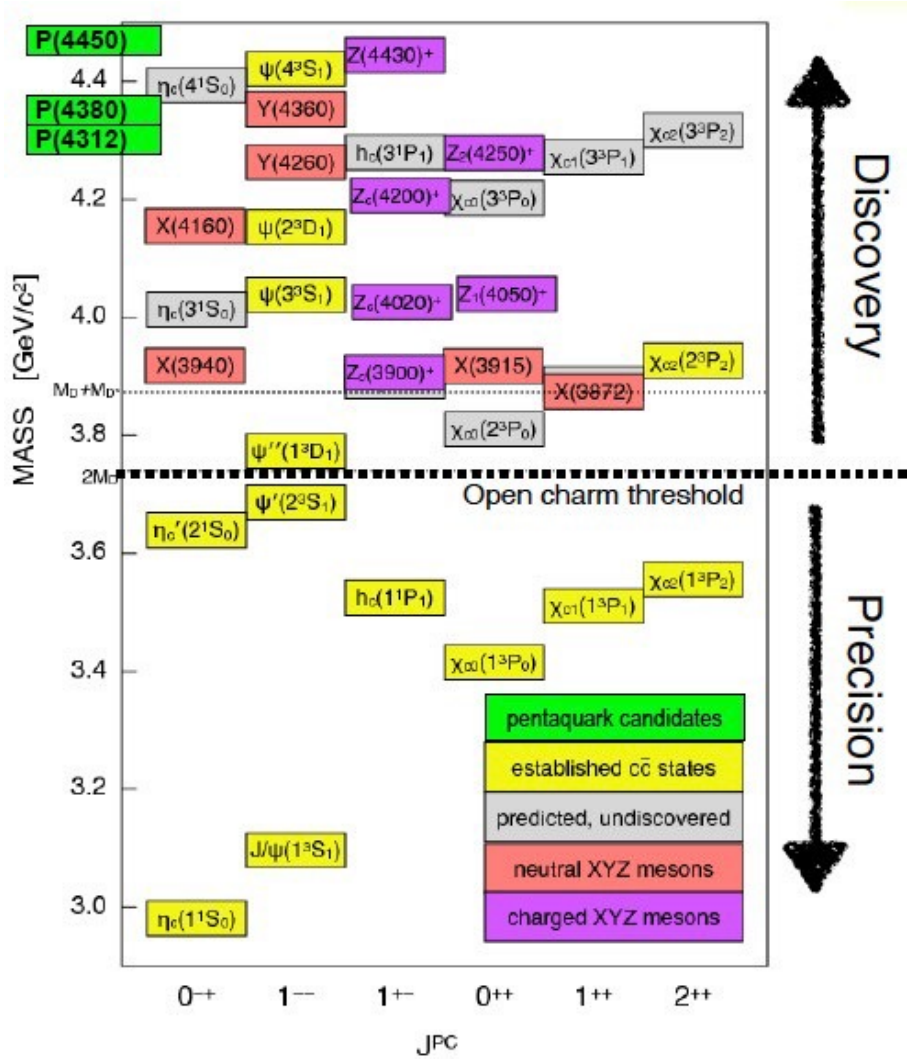
hadrons in matter

Hadron Spectroscopy

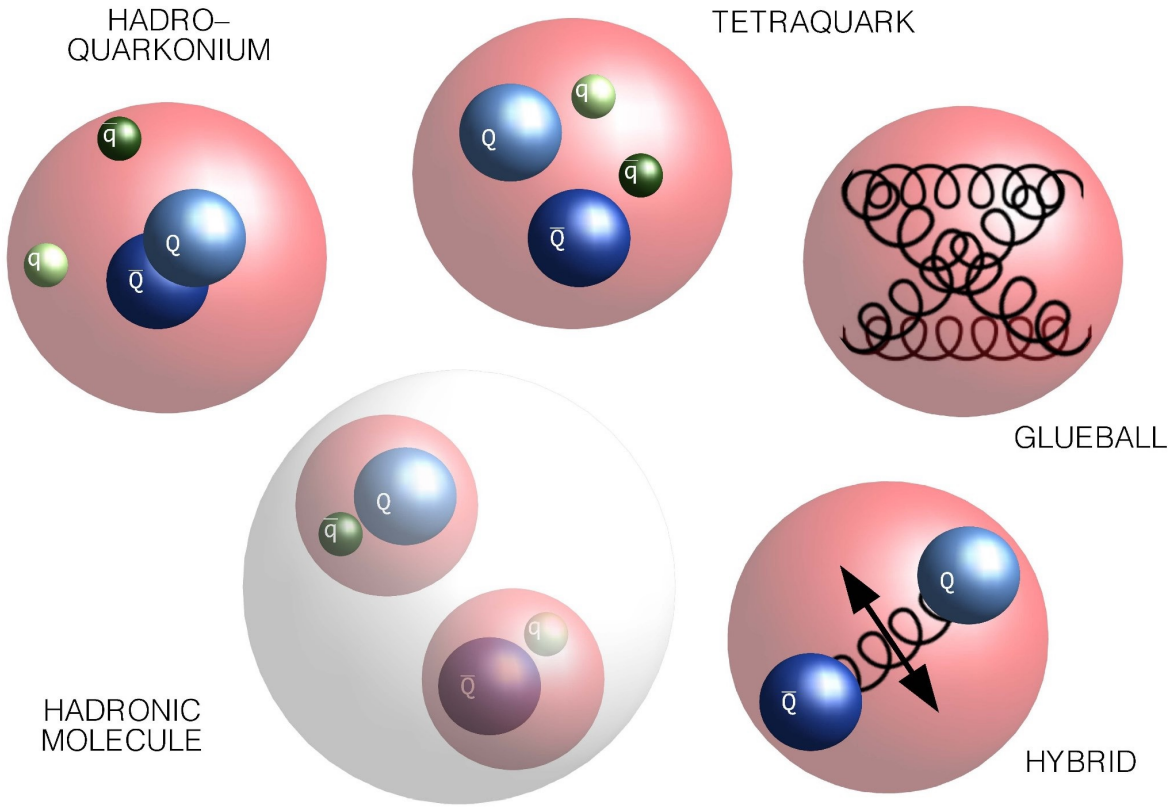


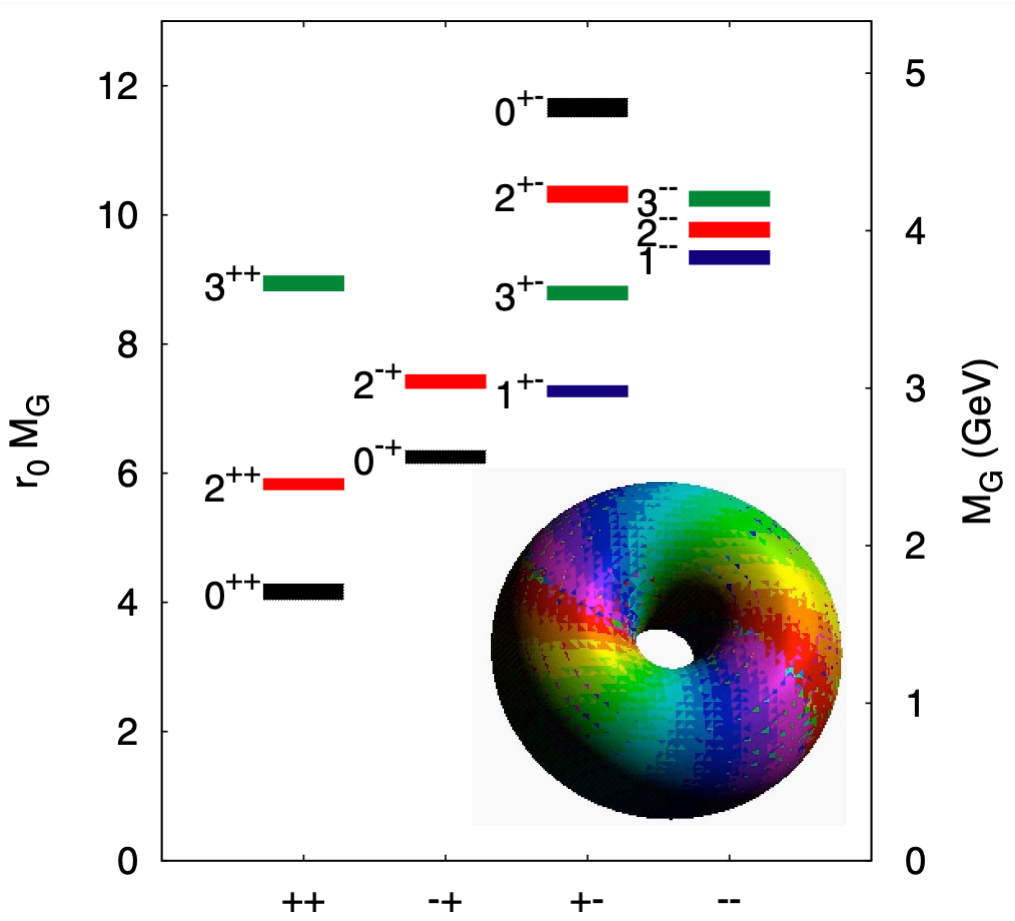
P̄ANDA:

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



Hadron Spectroscopy



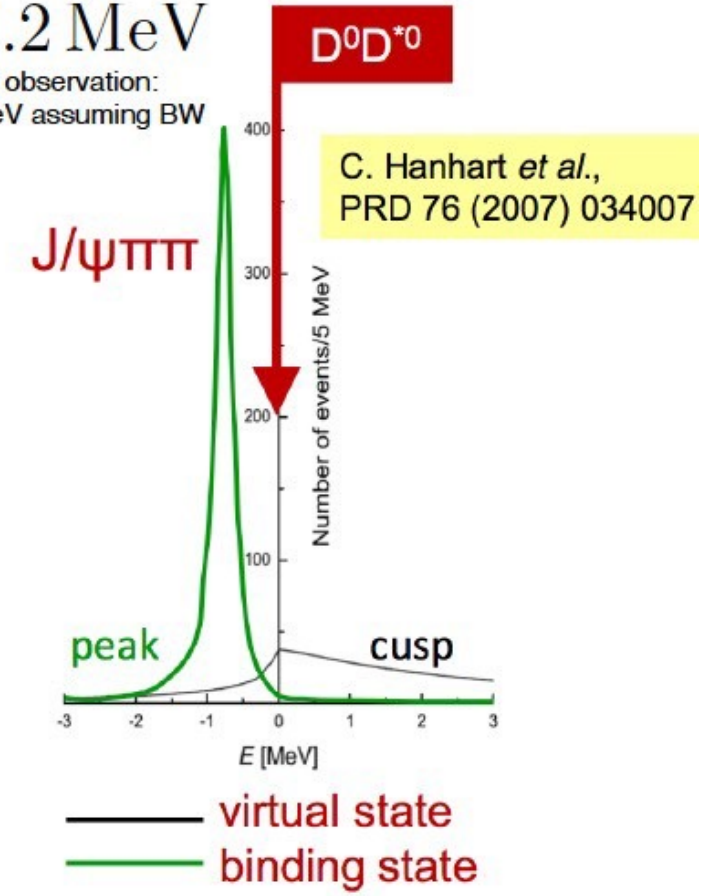


Hadron Spectroscopy: Lineshape of $\chi_{c1}(3872)$

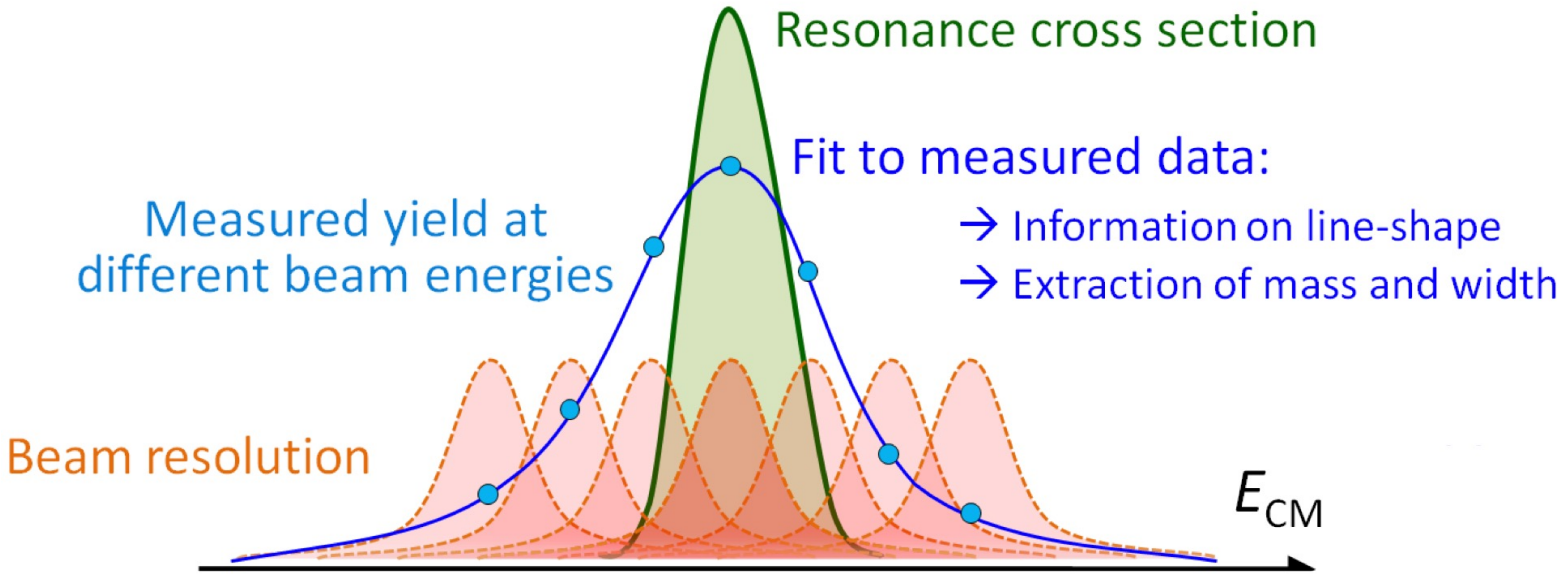
Strikingly narrow:

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

*recent LHCb observation: width=1.4 MeV assuming BW

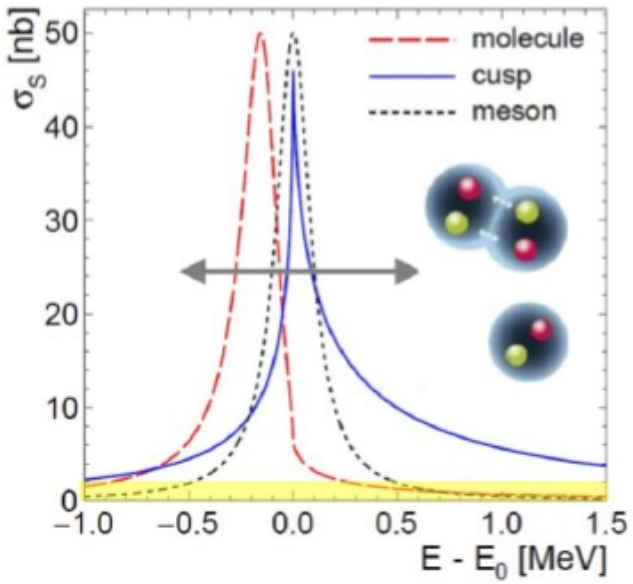


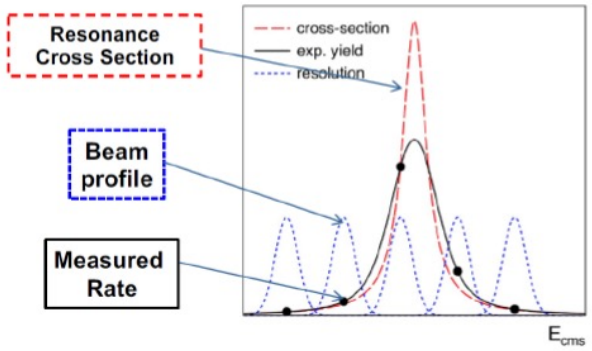
Energy scan with e^+e^-:	energy resolution	1-2 MeV (primarily $J^{PC}=1^{--}$)
Energy scan with $p\bar{p}$:	energy resolution	240 keV (E760/835@Fermilab)
		≈50 keV (PANDA@FAIR)

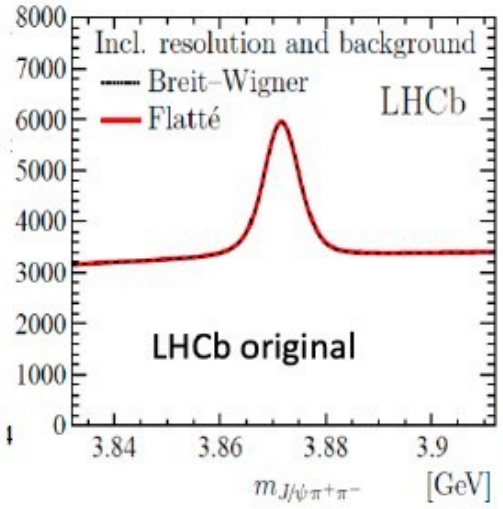


July 14, 2022 KTB, APCTP Jeju 2022 13

Hadron Spectroscopy: Lineshape of $\chi_{c1}(3872)$

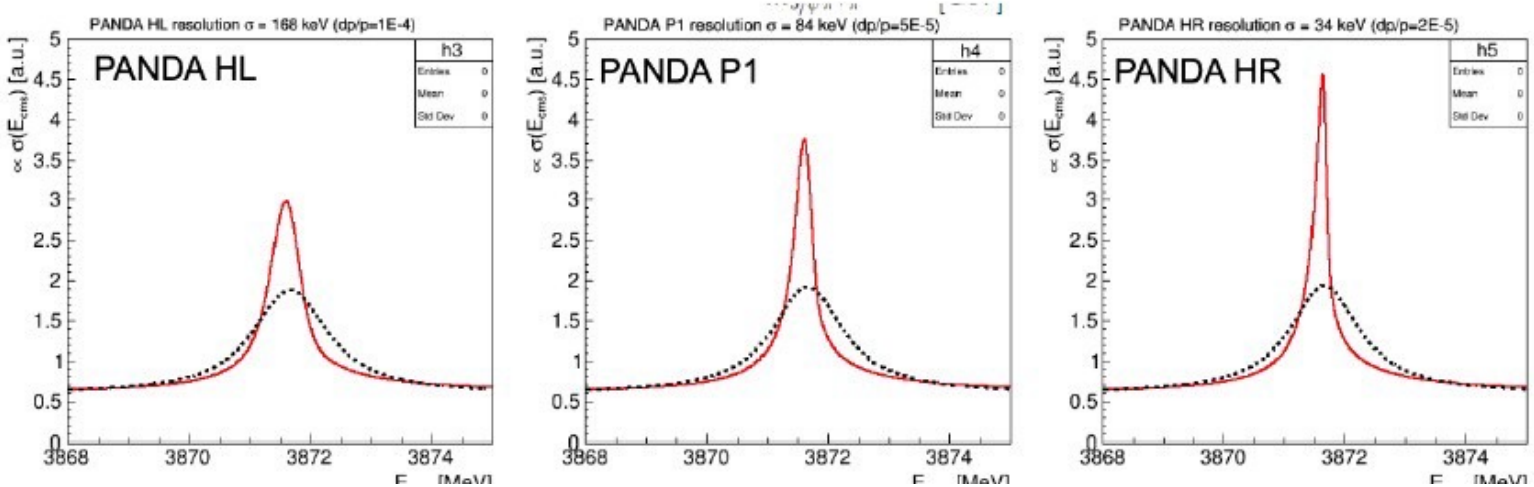






LHCb:
PRD102, 092005 (2020), arXiv:2005.13419

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

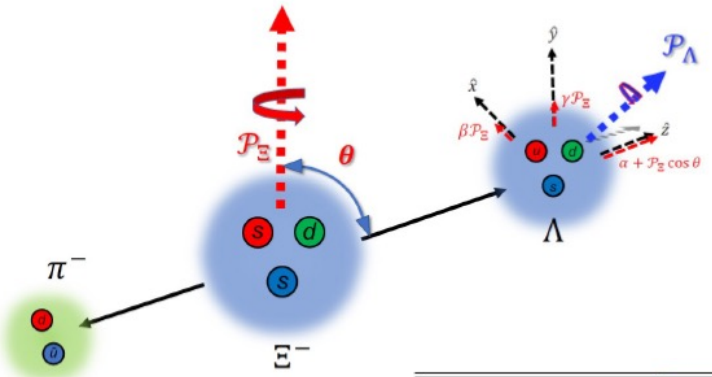


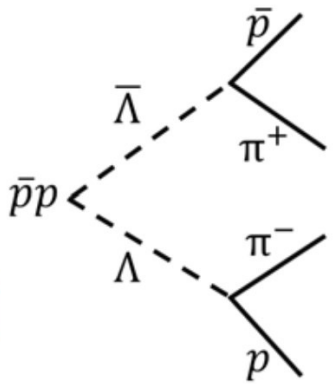
Hadron Spectroscopy: Hyperons

P̄ANDA:
Strangeness and spin in strong interaction
Multi-strange spectra
CP violation in the baryon sector

- Ample production of strangeness
- Self-analyzing weak decays

- Rich set of polarization observables
- Double- and triple-strange baryons
- Excitation spectra of Ξ and Ω

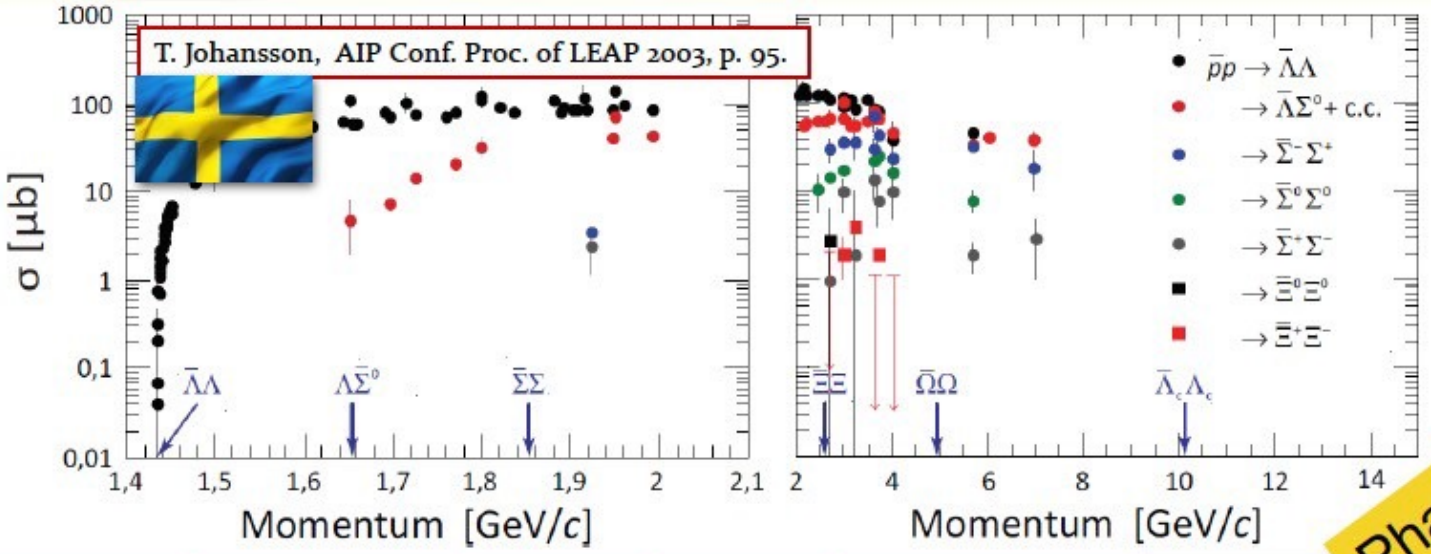




J^P	(D, L_N^P)	S	Octet members			Singlets
$1/2^+$	$(56,0_0^+)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$ $\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$ $\Xi(?)$	
$1/2^-$	$(70,1_1^-)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$ $\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$ $\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$ $\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(?)$ $\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$ $\Xi(?)$	
$1/2^+$	$(70,0_2^+)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$ $\Xi(?)$	$\Lambda(?)$
$3/2^+$	$(56,2_2^+)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$ $\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$ $\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$ $\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$ $\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$ $\Xi(?)$	

			Decuplet members			
$3/2^+$	$(56,0_0^+)$	3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
$3/2^+$	$(56,0_2^+)$	3/2	$\Delta(1600)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$1/2^-$	$(70,1_1^-)$	1/2	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$3/2^-$	$(70,1_1^-)$	1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$5/2^+$	$(56,2_2^+)$	3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$7/2^+$	$(56,2_2^+)$	3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$
$11/2^+$	$(56,4_4^+)$	3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

Hadron Spectroscopy: Hyperon Factory



EPJA57, 184 (2021) arXiv:2101.11877

PANDA:

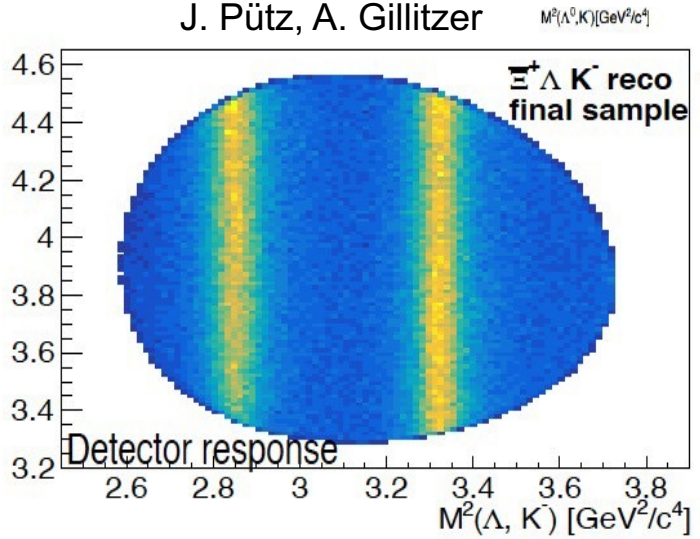
- Rich set of polarization observables
- Double- and triple-strange baryons
- Excitation spectra of Ξ and Ω

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.

J. Pütz, A. Gillitzer



Nucleon Structure

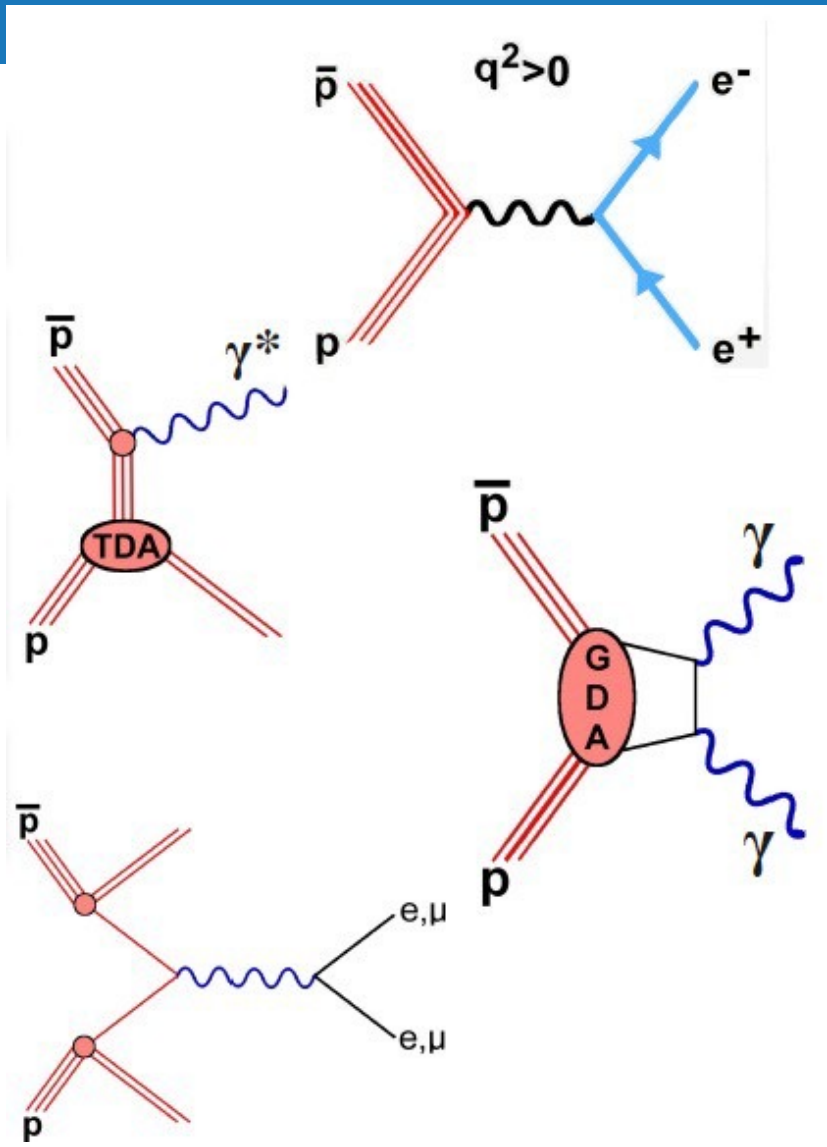
Timelike electromagnetic formfactors via lepton pair production (arXiv:1606:01118)

Transition distribution amplitudes (TDAs) through meson production (arXiv:1409:0865)

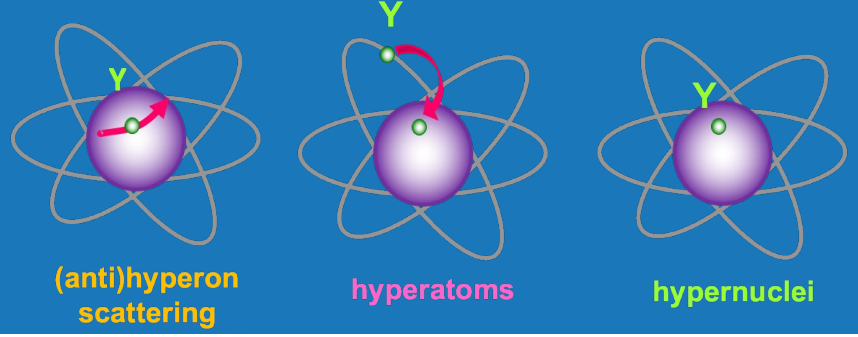
Generalized distribution amplitudes (GDAs) by time-like Compton scattering and hard exclusive processes

Generalized parton distributions (GPDs) via antiproton scattering

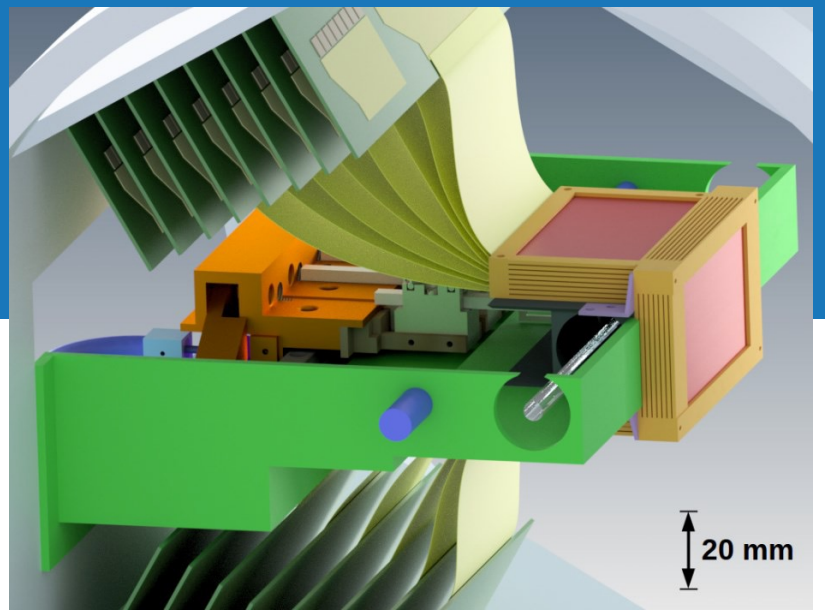
Transverse parton distribution functions in Drell-Yan



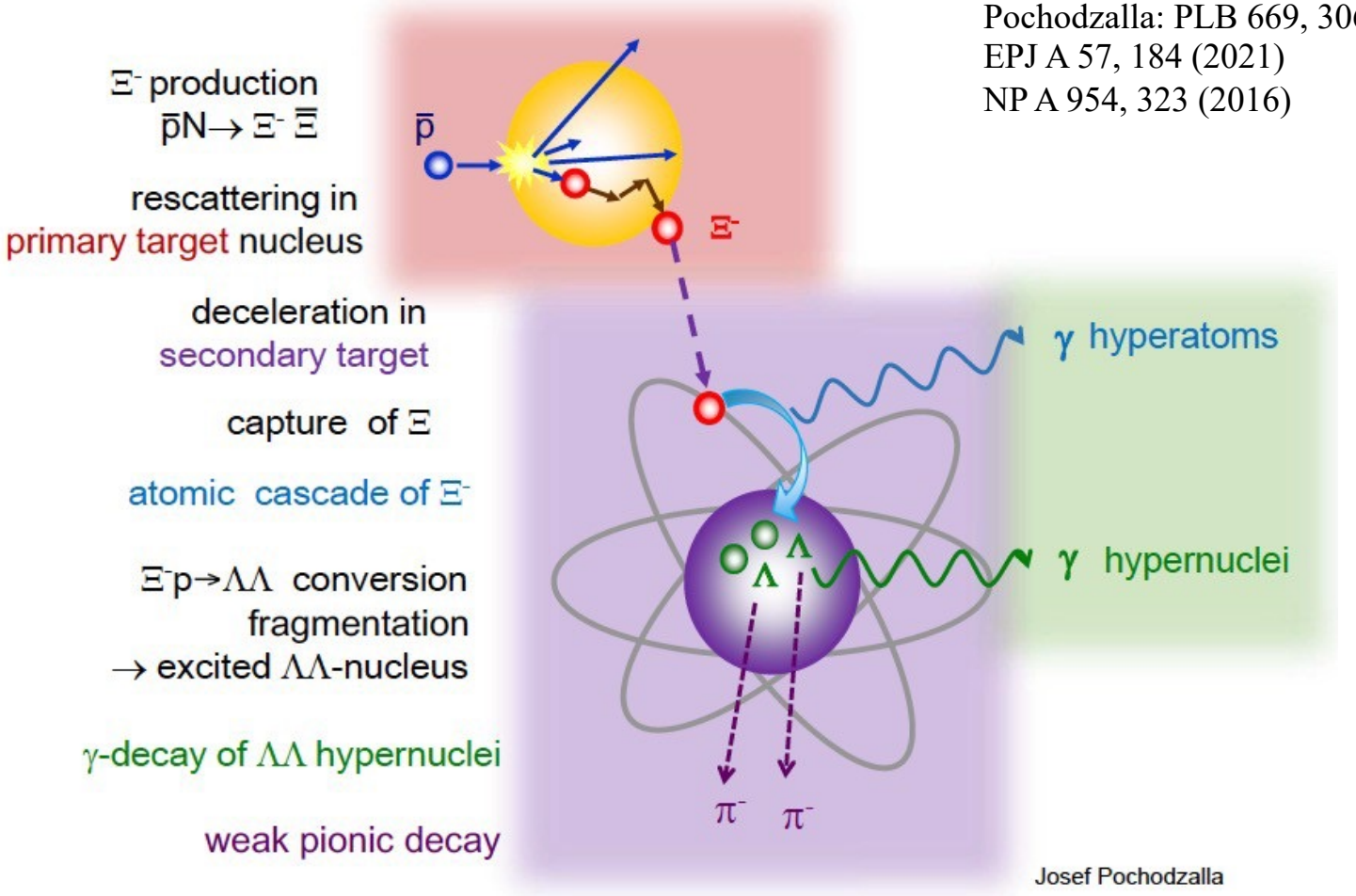
Hyperons

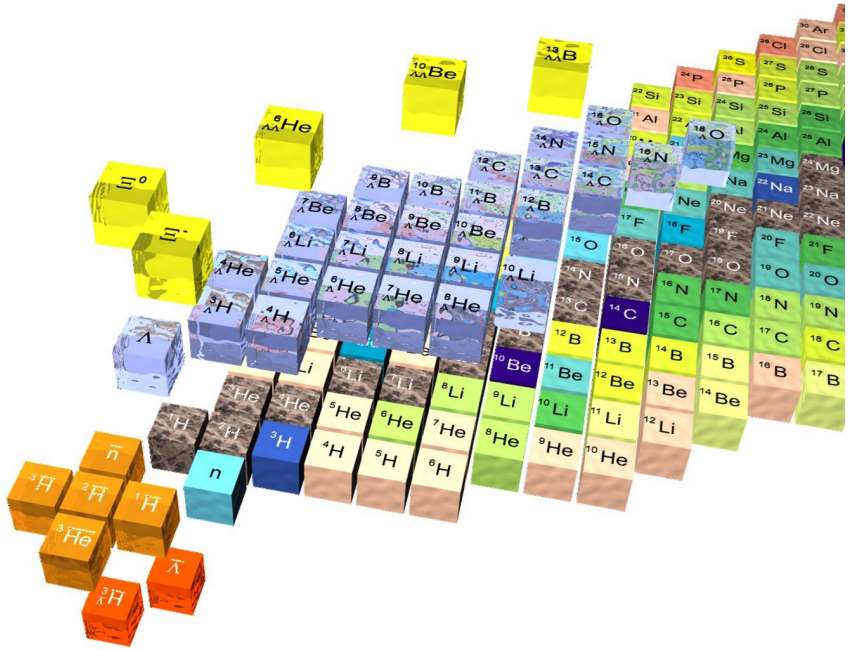


(anti)hyperon scattering | hyperatoms | hypernuclei



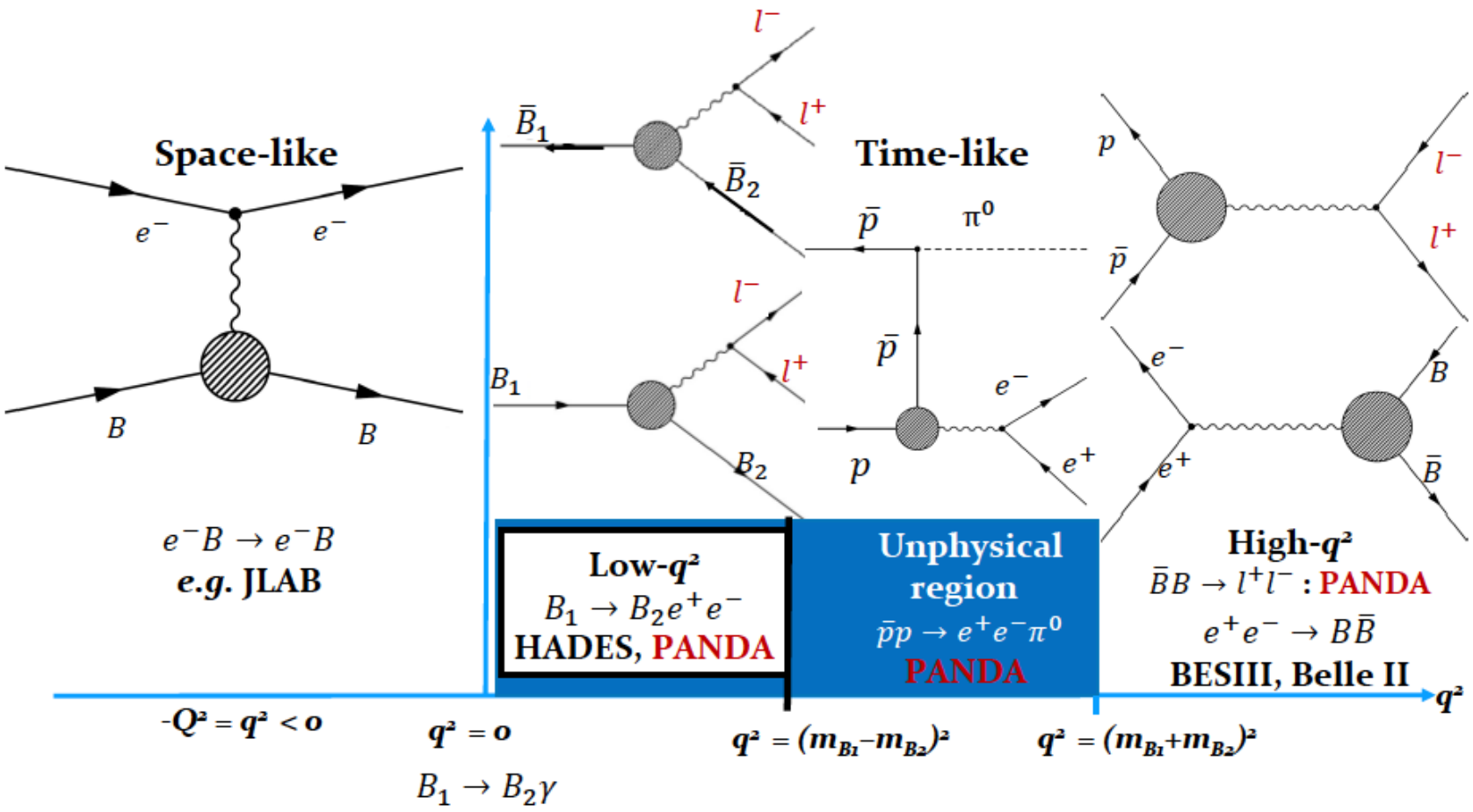
Pochodzalla: PLB 669, 306 (2008)
EPJ A 57, 184 (2021)
NP A 954, 323 (2016)

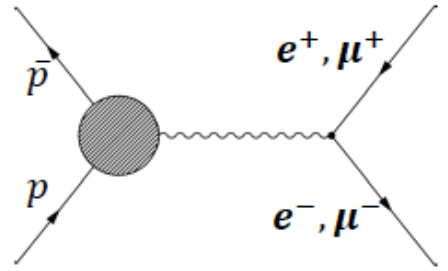


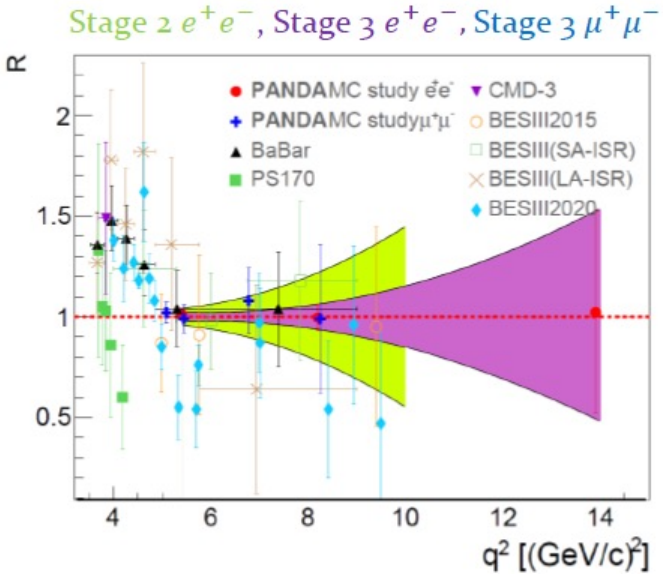


Nucleon Structure: Form Factors

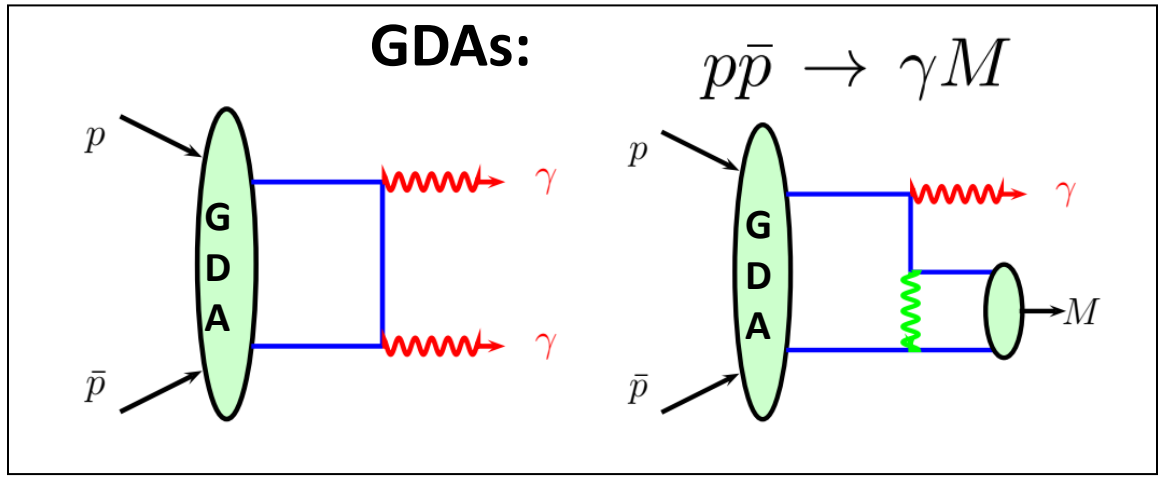
EPJ A 57:30 (2021)
EPJ A 57:184 (2021)
EPJ A 52:10 (2016)

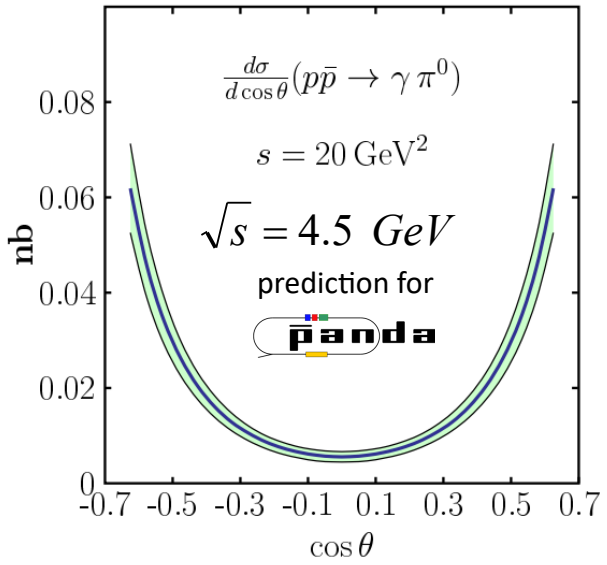






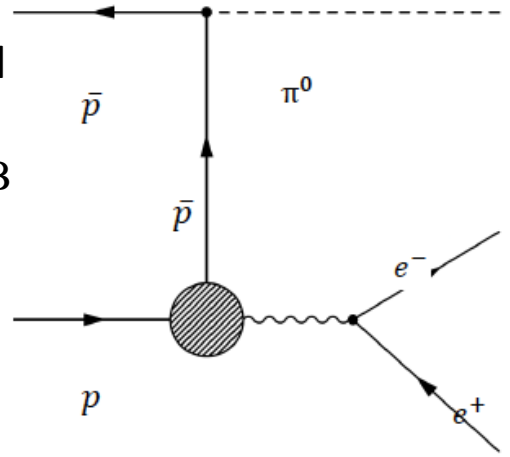
Nucleon Structure: $\bar{p}p \longrightarrow \pi\gamma$



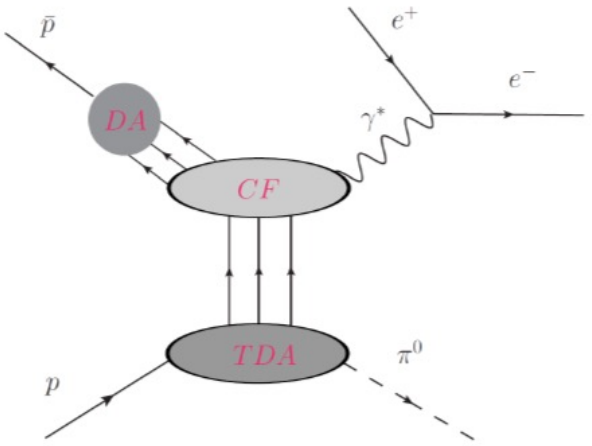


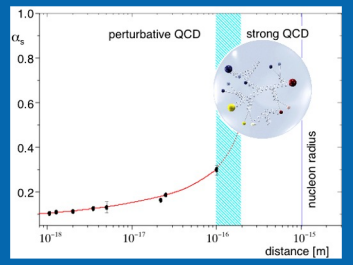
P. Kroll, A. Schäfer, EPJ A 26, 89-98 (2005)

Low e^+e^- mass:
Form factors in the unphysical region accessible
(Guttmann&Vanderhaeghen, PL B 719 (2013))
→Phase between proton G_E and G_M

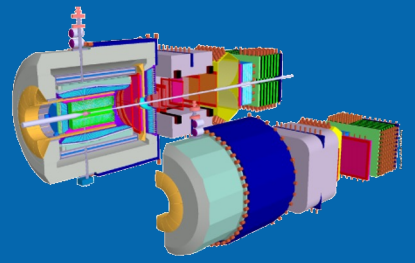


High e^+e^- mass:
TransitionDistribution Amplitudes(TDAs)
(PRD 51 (2015), PRD95 (2017))





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.
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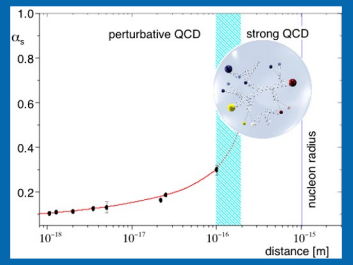
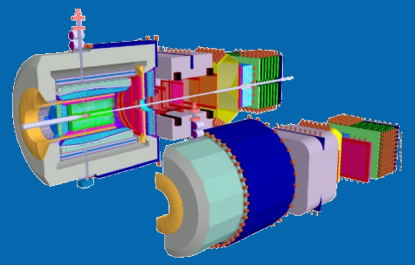


Summary



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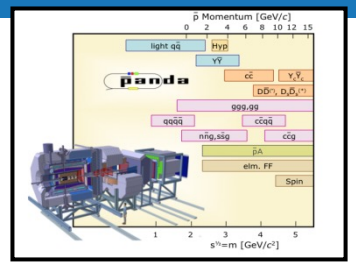
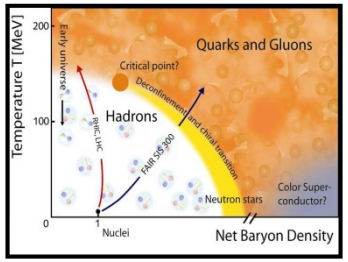
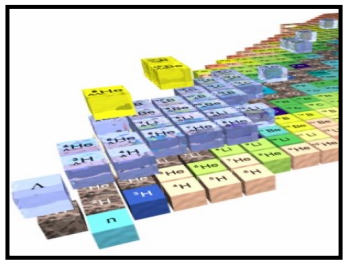
- Backup -

Facility for Antiproton and Ion Research







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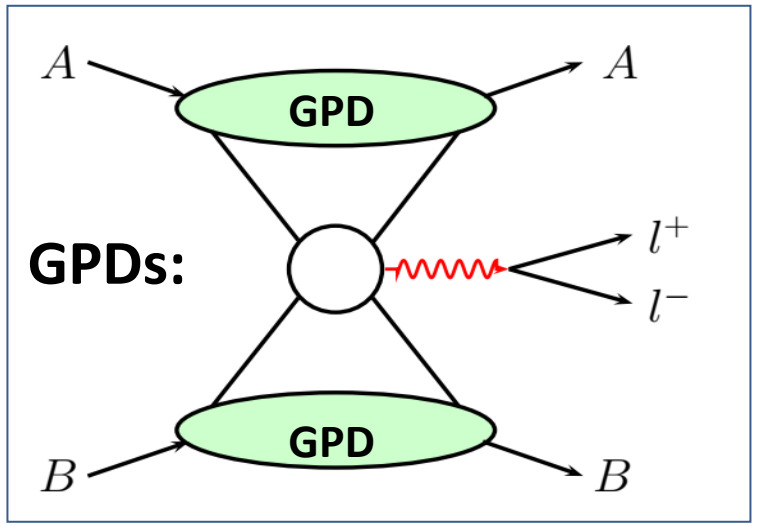
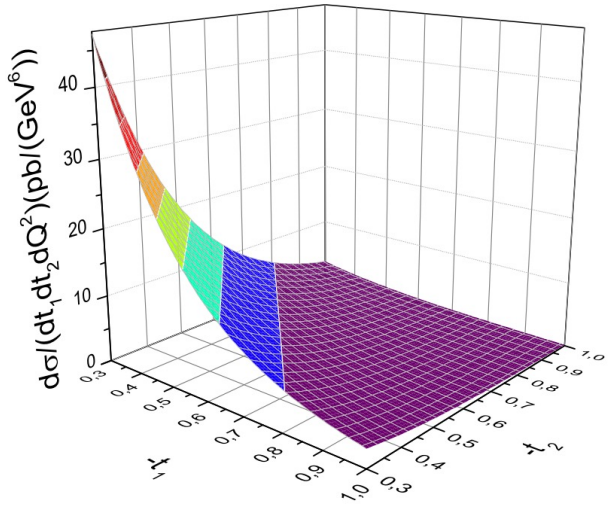
Nucleon Structure: GPDs

EPJ A 57:30 (2021)
EPJ A 57:184 (2021)
EPJ A 52:10 (2016)





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