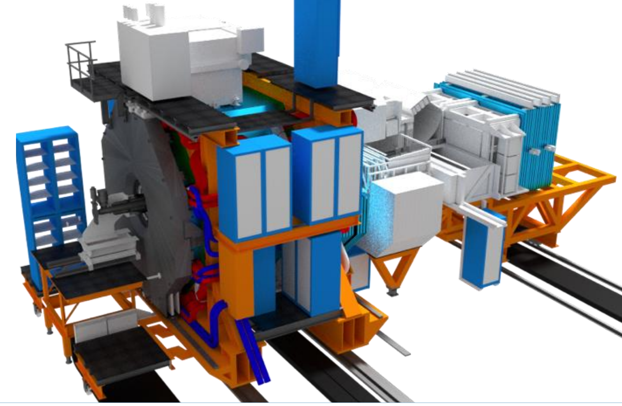
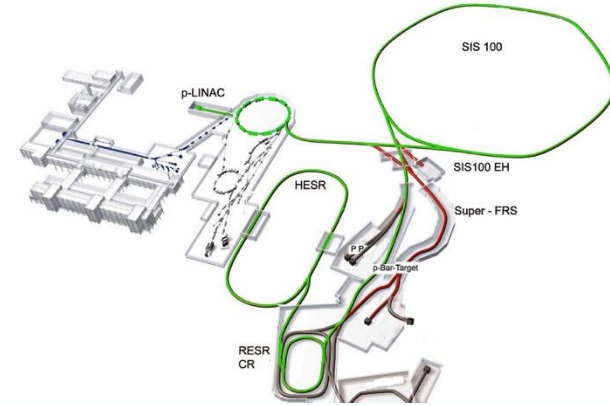




The physics program of the PANDA-Experiment at FAIR

"FAIR France"

IPN Orsay, May 17./18. 2017

Frank Maas

HI Mainz, PANDA contact person

PRiSMA

SFB 1044

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

HELMHOLTZ GEMEINSCHAFT

Helmholtz-Institut Mainz

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

GSI

PANDA Program: 2 GeV – 5.5 GeV

I: Hadron spectroscopy

light mesons, baryons, charmonium, open charm,

QCD exotics: glueballs, hybrid states, X,Y,Z-states,...

II: Electromagnetic processes

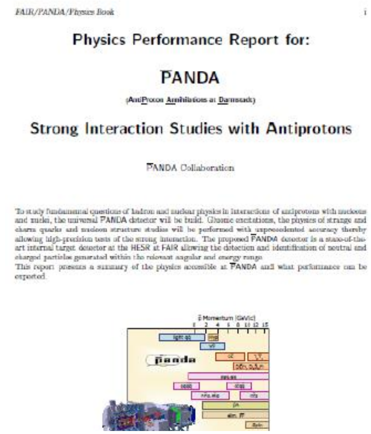
time like form factors, transition distribution

amplitudes, TMDs, ...

III:Hadronic interactions:

Hyperons, Hypernuclei,

In medium-effects


FAIR/PANDA/Physics Book i

Physics Performance Report for:

PANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

PANDA Collaboration

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal PANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed PANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at PANDA and what performance can be expected.

ArXiV:0903.3905

PANDA Objectives

HI collisions: Connecting to Quark Gluon Plasma "crossing over" through baryon resonances

HEP: interference of coupled channels

HEP: underlying elementary processes

Spectroscopy

New narrow XYZ: Search for partner states

Production of exotic QCD states: Glueballs & hybrids

Bound States of Strong Interaction

Nucleon Structure

Generalized parton distributions: Orbital angular momentum

Drell Yan process: Transverse structure, valence anti-quarks

Timelike formfactors: Low and high E, e and μ pairs

Strangeness

Strange baryons: Spectroscopy Polarisation

Astro physics: Strange n-stars

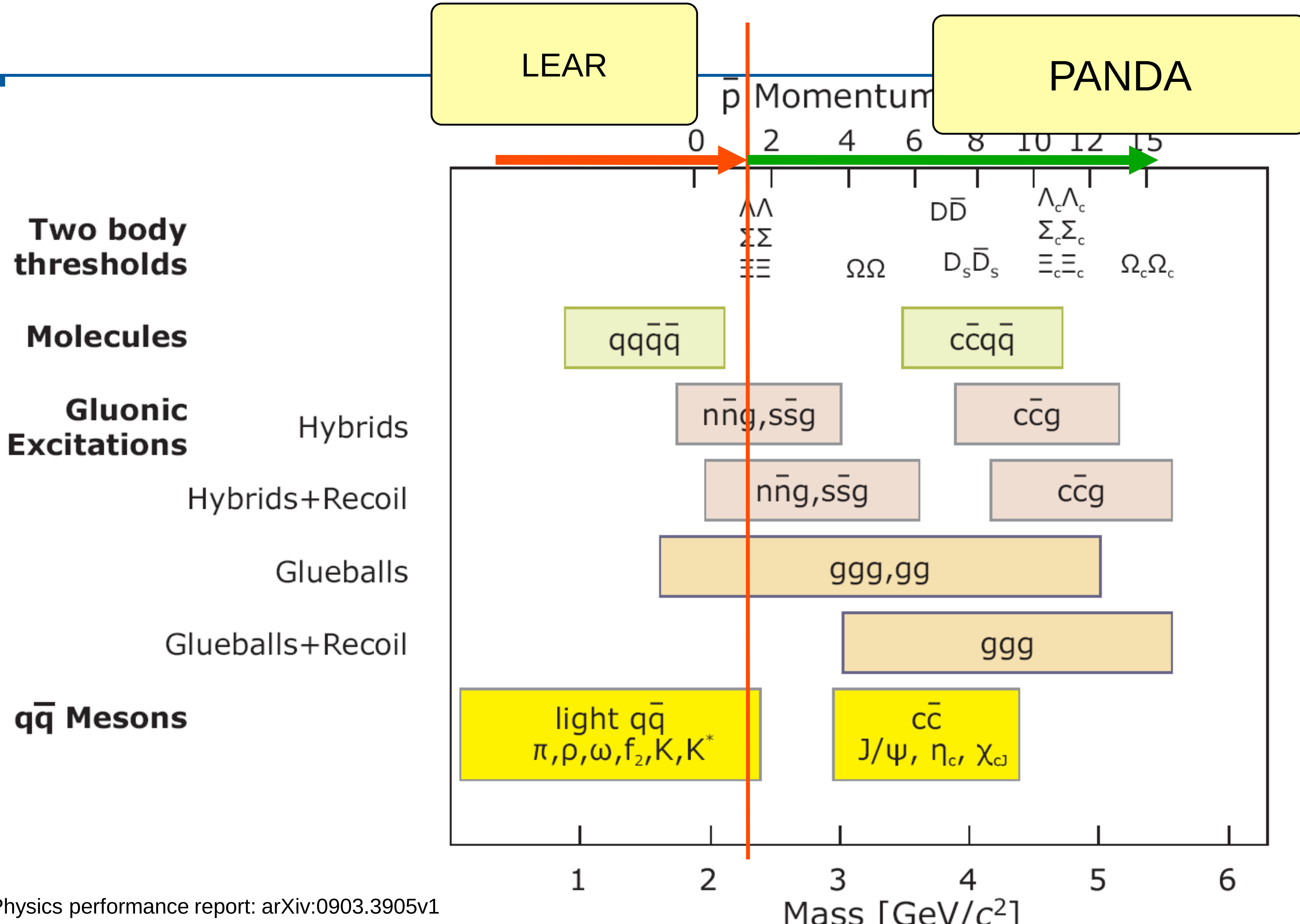
Nuclear physics: Hypernuclear spectroscopy

Nuclear Physics

Hypernuclear physics: Double Λ hypernuclei Hyperon interaction

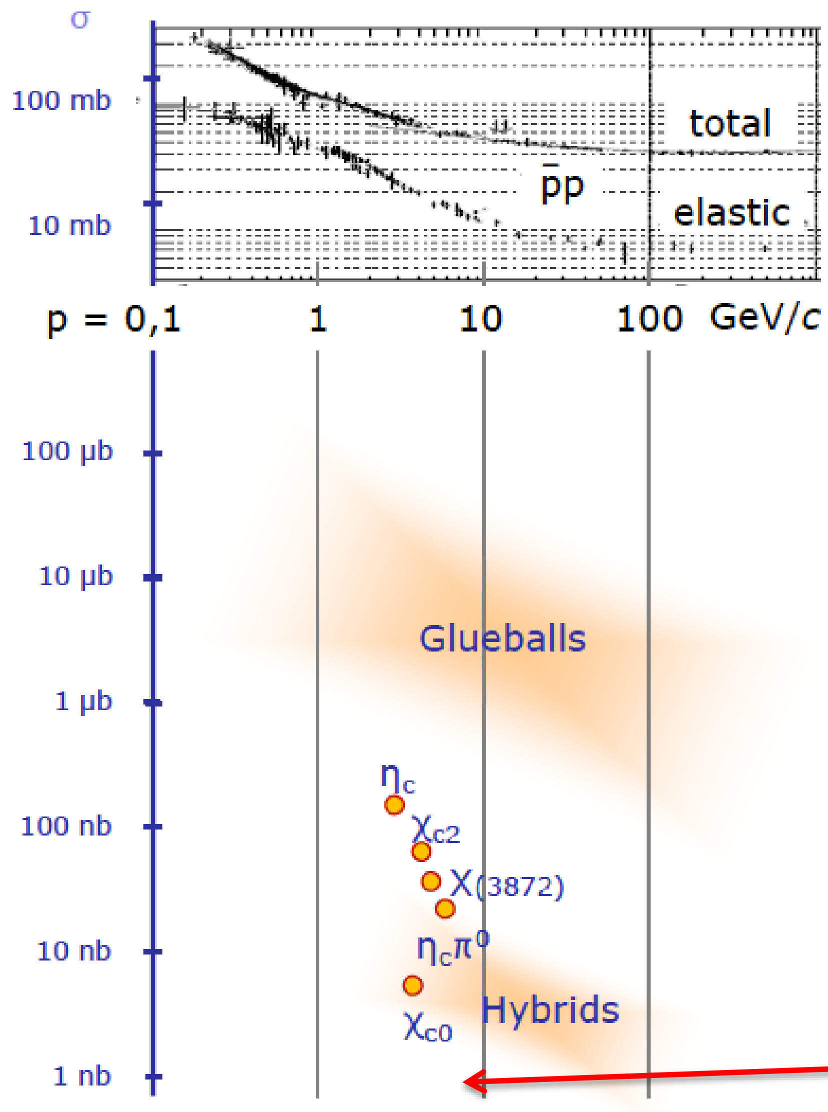
Hadrons in nuclei: Charm and strangeness in the medium

HI collisions comparing QGP to elementary reactions



Physics performance report: arXiv:0903.3905v1

Detector Requirements from Physics Case



High luminosity and hadronic cross sections

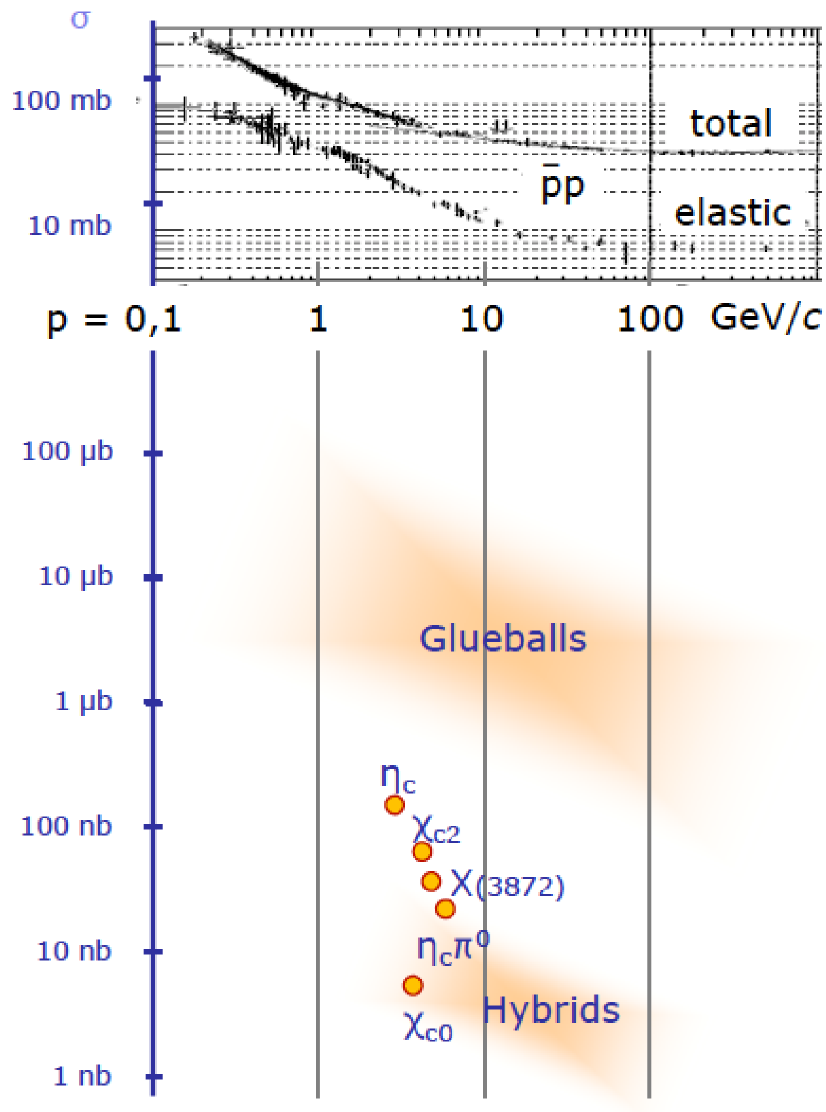
High rate capability, $2 \cdot 10^7$ s^{-1} interactions

High data rate

High degree of radiation resistance

Cross section for electromagnetic Processes

Detector Requirements from Physics Case



4π acceptance

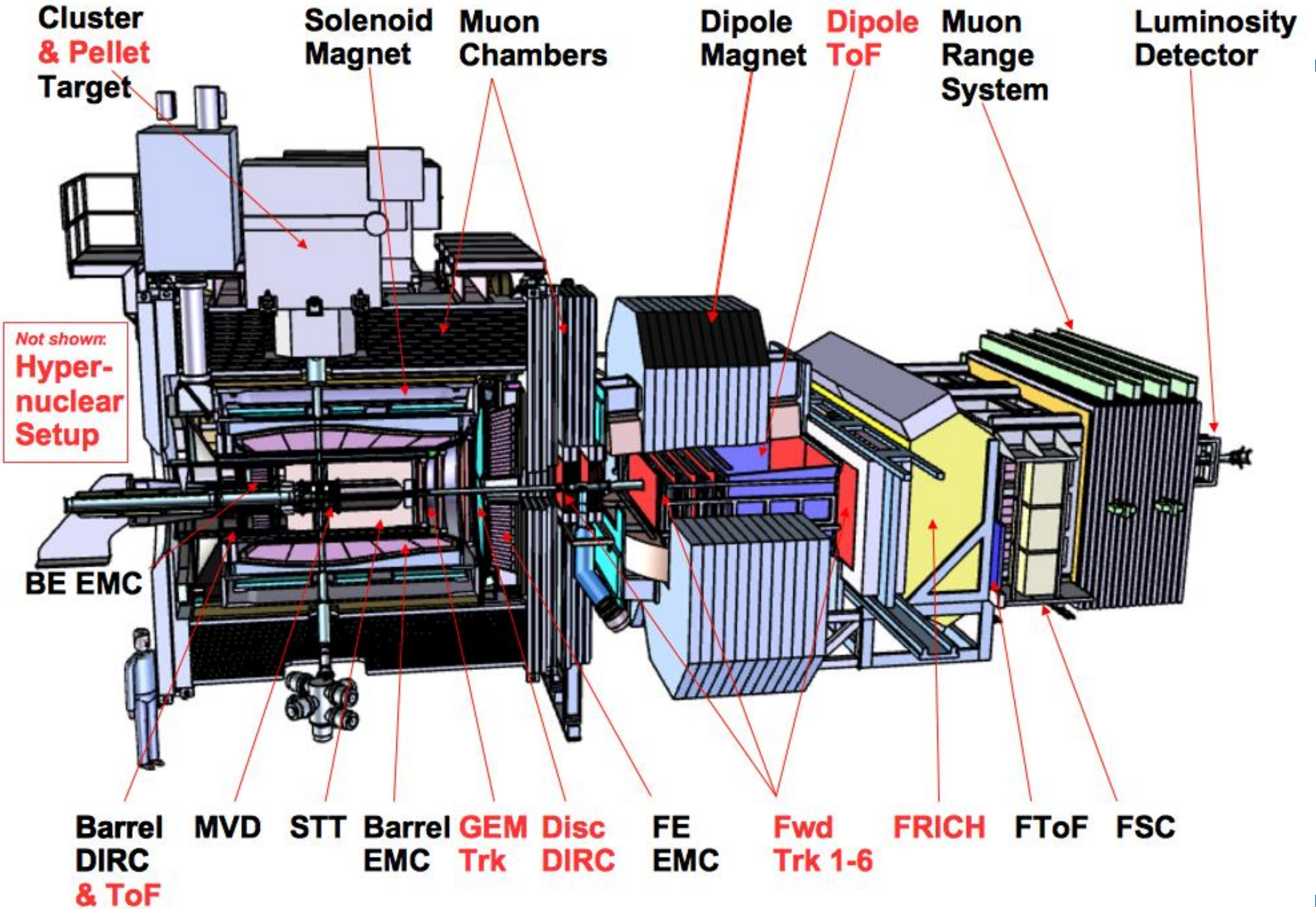
Momentum resolution: 1%
central tracker in magnetic field

Photon detection: 1 MeV - 10 GeV
high dynamic range
good energy resolution

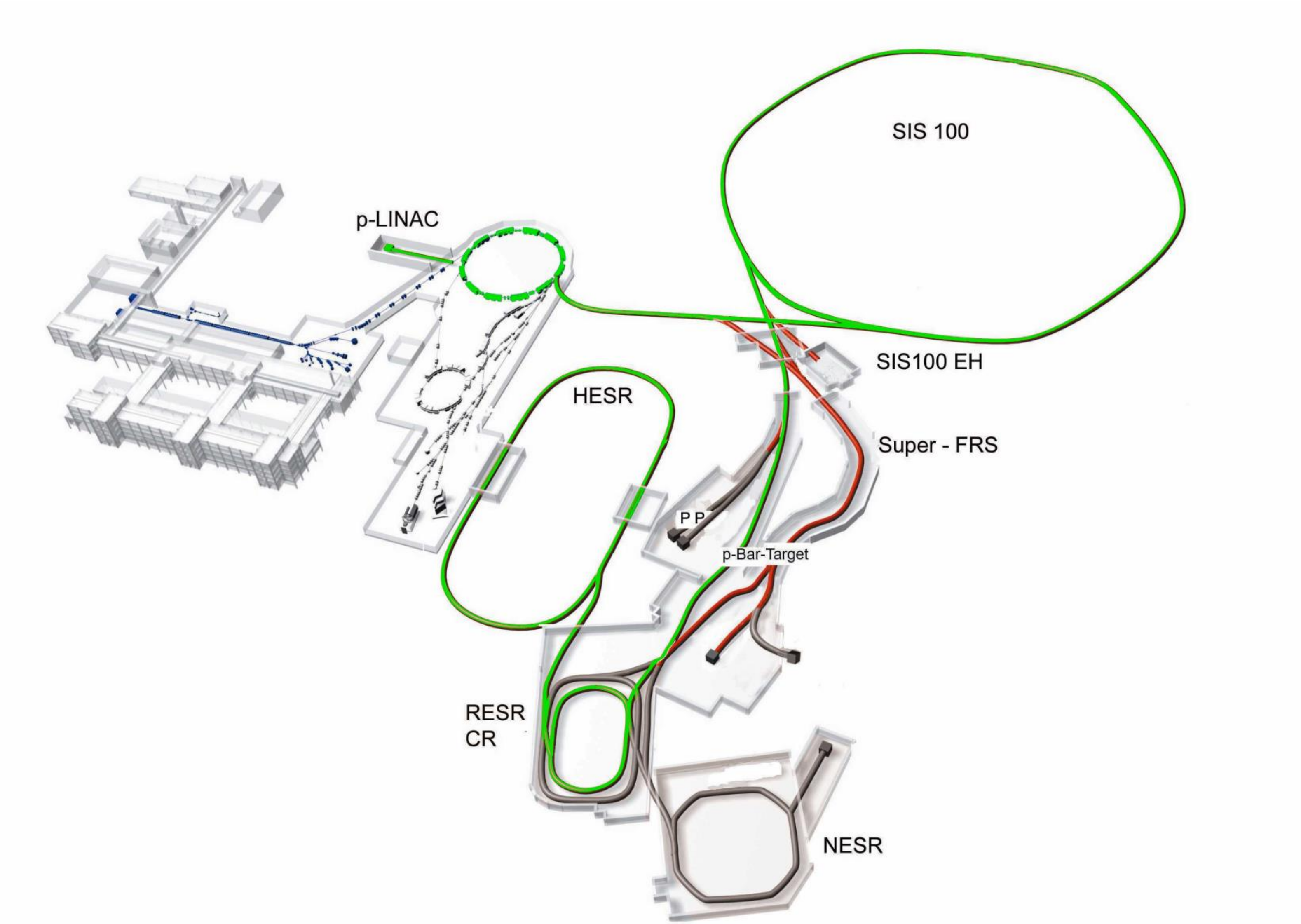
Particle identification: γ, e, μ, π, K, p
Cherenkov detector
time of flight, dE/dx, muon counter

Displaced vertex info
$c\tau$ = 317 μm for $D^{\pm}$
$\gamma\beta \approx 2$

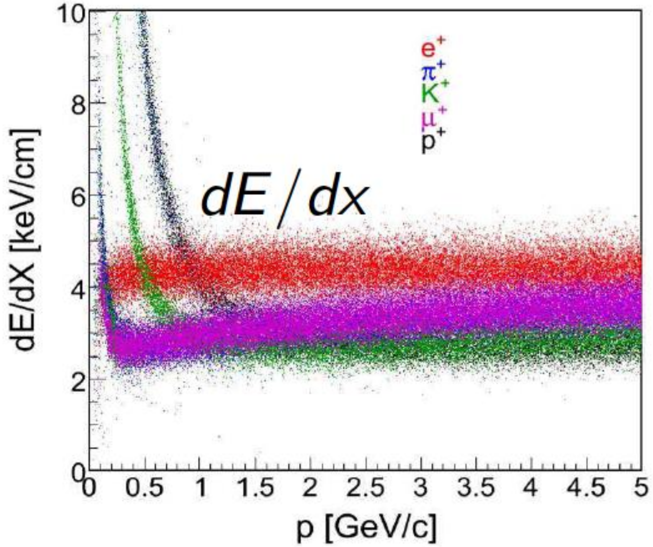
Full Setup

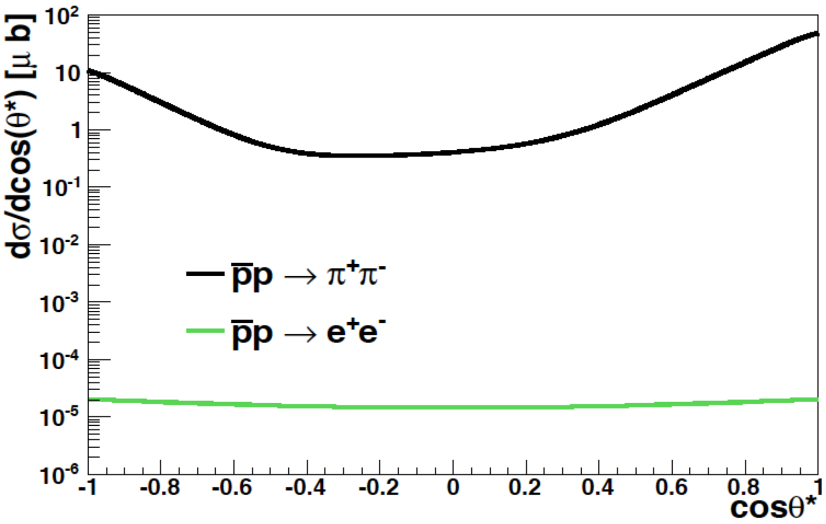

Cluster
& Pellet
Target
Solenoid
Magnet
Muon
Chambers
Dipole
Magnet
Dipole
ToF
Muon
Range
System
Luminosity
Detector
Not shown:
Hyper-
nuclear
Setup
BE EMC
Barrel
DIRC
& ToF
MVD
STT
Barrel
EMC
GEM
Trk
Disc
DIRC
FE
EMC
Fwd
Trk 1-6
FRICH
FToF
FSC

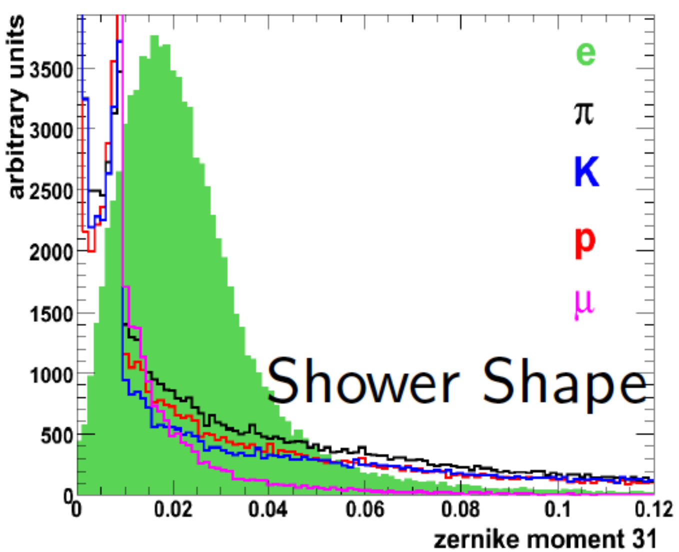
FAIR Facility Darmstadt

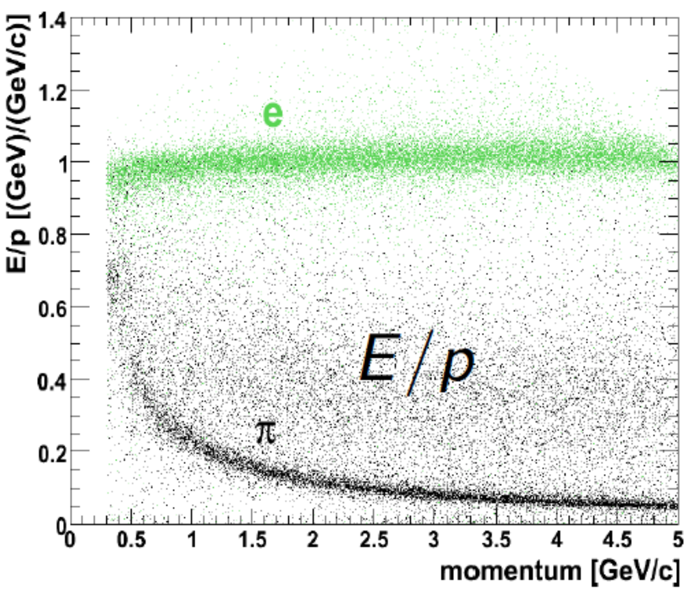


Particle Identification in PANDA







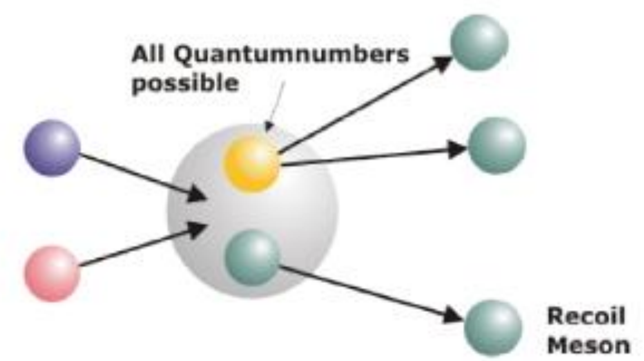


I. Spectroscopy

Antiproton annihilations: gluon rich environment

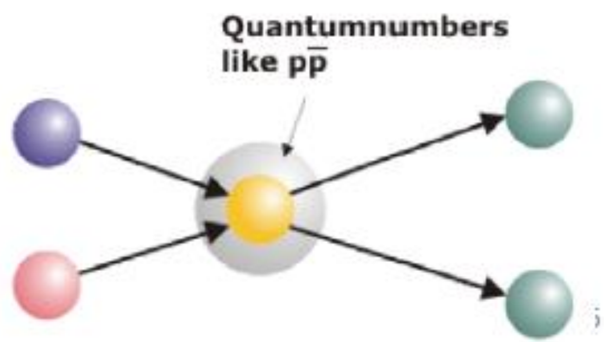
Production: all states with exotic and non-exotic quantum numbers accessible with a recoil
- high discovery potential

Associated, access to all quantum numbers (exotic)



Formation: all states with non-exotic quantum numbers accessible
- not only limited to 1^{--} as e^+e^- colliders
- precision physics of known states

Resonant, high statistics, extremely good precision in mass and width



antiproton probe unique

Comparision with other techniques

- e^+e^-
  - direct formation limited to $J^{PC} = 1^{--}$
  - limited resolution for masses and widths for non vector states
  - sub-MeV widths very difficult or impossible
  - high L not accessible
- high-energy (several TeV) hadroproduction
  - high combinatorial background makes discovery of new states very difficult
  - width measurements limited by detector resolution
- B decays (both for e^+e^- and hadroproduction)
  - limited J^{PC}
  - C cannot be determined since not conserved in weak decay

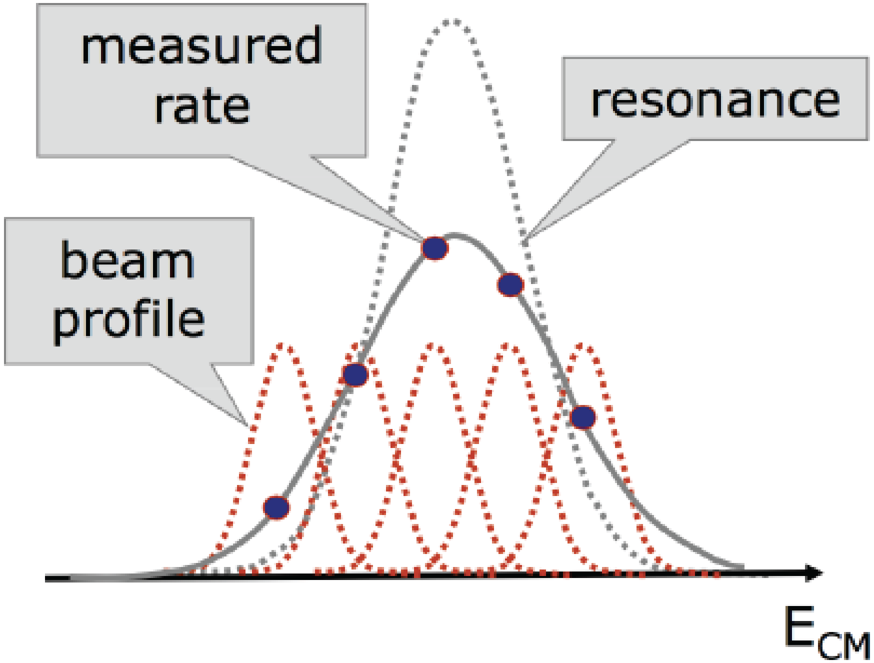
Energy scan of HESR-storage ring

High resolution mode of HESR

- Stochastic and electron cooling of beam for p < 8.9 GeV/c
- Momentum resolution: $\Delta p/p \leq 4 \times 10^{-5}$
- Peak luminosity: 10^{31} cm^{-2} s^{-1}

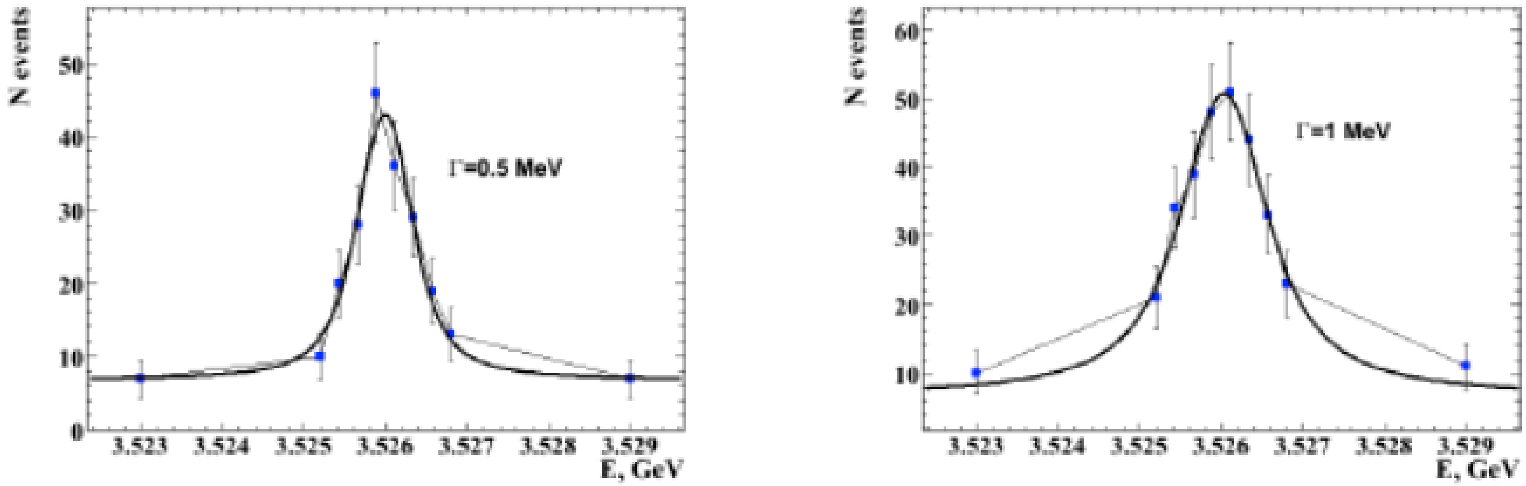
Precise measurement of masses and widths of resonances
- only dependent on beam momentum resolution

→ unique at PANDA



$h_c(1^1P_1)$ Energy Scan At PANDA

$h_c \to \eta_c\gamma \to \phi\phi\gamma \to 4K\ \gamma$



- Scan at 10 energy points around the h_c mass
- Each point corresponds to 5 days of data taking in high resolution mode

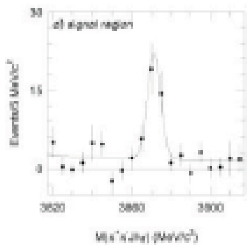
$\Gamma_{R,MC}$ [MeV]	$\Gamma_{R,reco}$ [MeV]	$\Delta\Gamma_R$ [MeV]
1	0.92	0.24
0.75	0.72	0.18
0.5	0.52	0.14

PANDA, arXiv:0903.3905 [hep-ex]

X,Y,Z

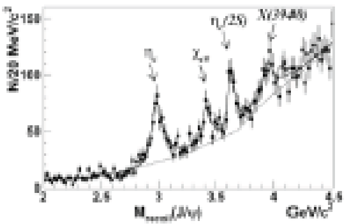
X(3872)

PRL 91,262001 (2003)



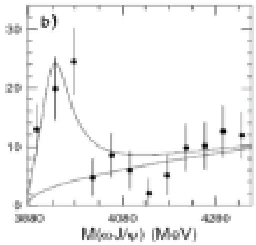
X(3940)

PRL 98,082001 (2007)



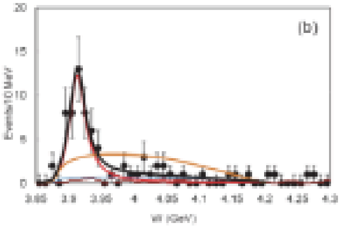
Y(3940)

PRL 94,182002 (2005)



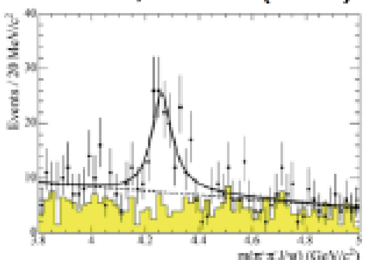
X(3915)

PRL 104,092001 (2010)



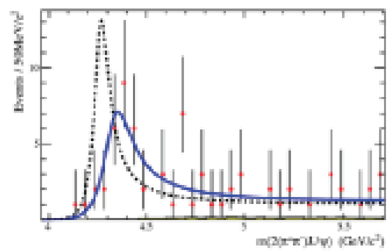
Y(4260)

PRL 95,142001 (2005)



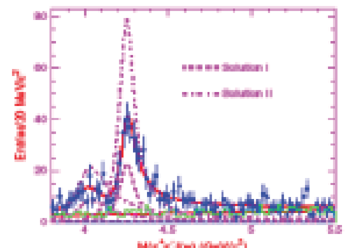
Y(4350)

PRL 98,212001 (2007)



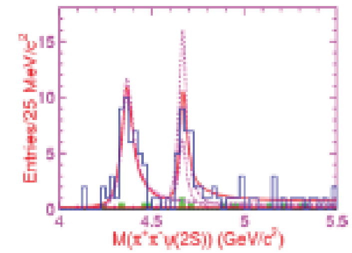
Y(4008)

PRL 99,182004 (2007)



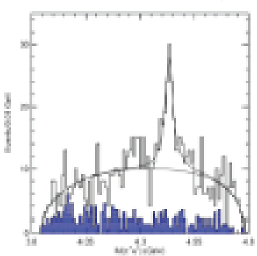
Y(4660)

PRL 99,142002 (2007)



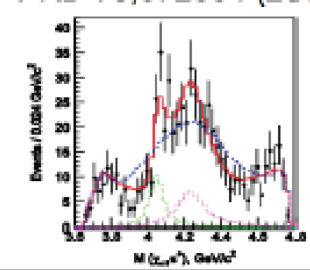
$Z(4430)^-$

PRL 100,142001 (2008)



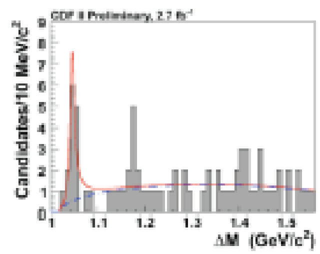
Z_1^- & Z_2^-

PRD 78,072004 (2008)



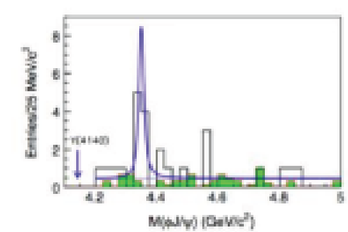
Y(4140)

PRL 102,242002 (2009)



X(4350)

PRL 104,112004 (2010)



Energy scans

HESR: average luminosity 1170 nb^{-1}/d (MSV0-3, no RESR)

- PANDA: estimate of cross section:
  σ(pbar p -> X(3872)) = 100nb i.e. 1.17×10^5 X(3872) produced per day
  X(3872) -> $J/\psi\rho^0 \to e^+e^-/\mu^+\mu^- \pi^+\pi^-$ only:
  statistics: ~120 reconstructed events per day (full simulation)
  with RESR: factor 10 more
  precise measurement of width/line shape by energy scan ~100keV,
  decisive for 4 quark states
- BELLE II:
  estimated statistics: 1500 events in 4 years
- BES III:
  statistics: ~20 events in 4 weeks

PANDA: ~120 X(3872)/day, 820 Y(4260)/day, 180 Z(3900)/day

PANDA is a X,Y,Z factory

high statistics X,Y,Z data sample

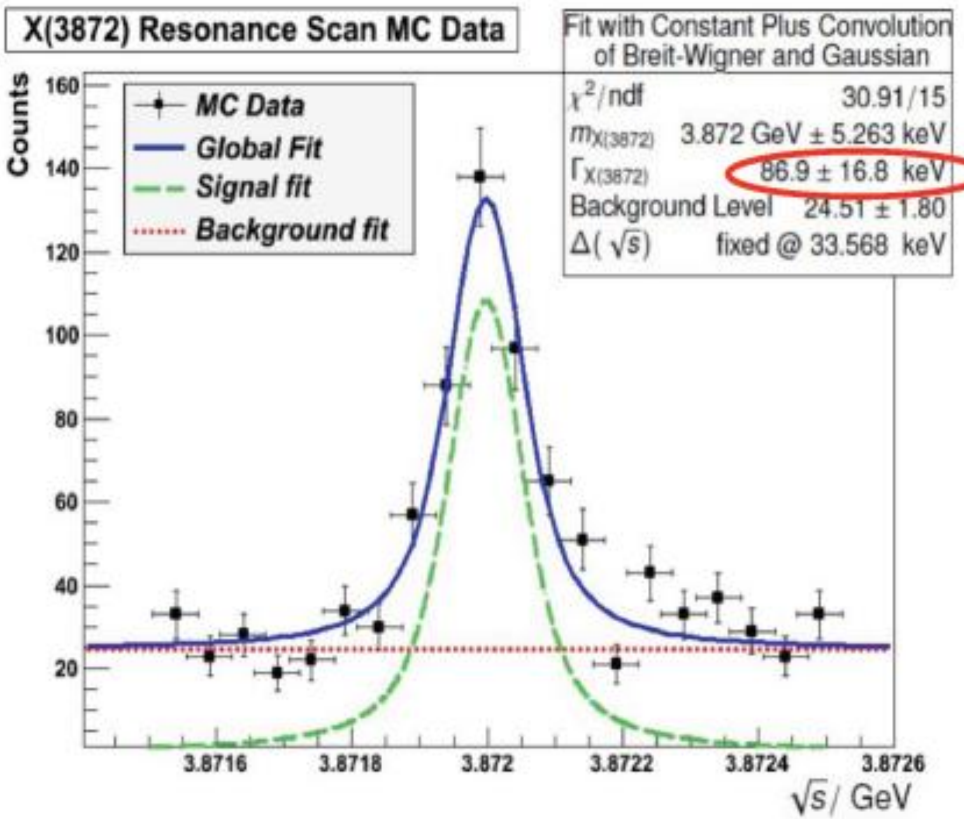
PANDA Release Note
RN-QCD-2016-002, QWG 2016

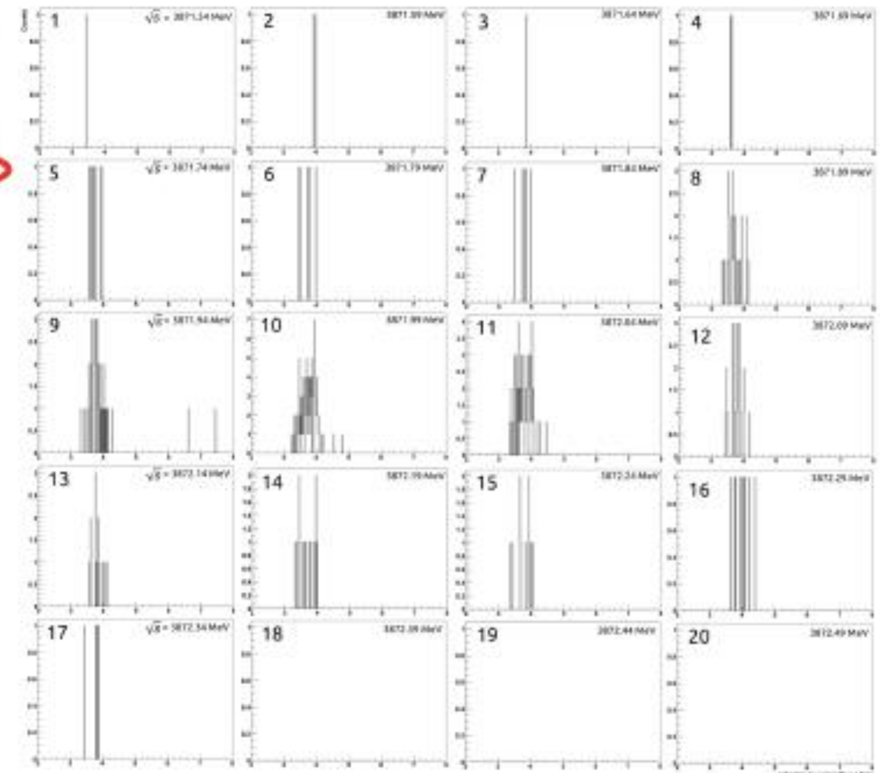
X(3872): Lineshape Scan at PANDA

- Upper limit on branching ratio by LHCb:

$BR(X \rightarrow \bar{p}p) < 0.002 * BR(X \rightarrow J/\psi \pi^{-} \pi^{+})$ → $\Gamma < 1.2$ MeV   EPJ C73 (2013) 2462

- And $BR(X \rightarrow J/\psi \pi^{-} \pi^{+}) > 0.026$ (PDG 12) => $\sigma(\bar{p}p \rightarrow X(3872)) < 67$ nb





→ 40 days of data taking

[M.Galuska, PhD thesis]

X, Y, Z Studies At PANDA

[F. Nerling, K. Goetzen, R. Kliemt]

σ_s= 10 nb, E_{cms} = 5.5 GeV

10nb	L/cms			
E_cm	detopt	Full		
	mode	t [d]	S/B	Dal QA
	Jpsi(2e) 2eta	3,8	0,57	✓
	Jpsi(2e) 2K	0,7	2,7	✓
	Jpsi(2mu) 2pi	0,6	3,1	✓
	Jpsi(2mu) 2pi0	0,6	3,0	✓
	Jpsi(2mu) 2eta	2,3	0,82	✓
	Jpsi(2mu) 2K	0,5	3,8	✓

σ_s= 1 nb, E_{cms} = 5.5 GeV

1nb	L/cms			
E_cm	detopt	Full		
	mode	t [d]	S/B	Dal QA
	Jpsi(2e) 2eta	38	0,057	✓
	Jpsi(2e) 2K	7,2	0,27	✓
	Jpsi(2mu) 2pi	6,3	0,31	✓
	Jpsi(2mu) 2pi0	6,4	0,30	✓
	Jpsi(2mu) 2eta	24	0,082	✓
	Jpsi(2mu) 2K	5,1	0,38	✓

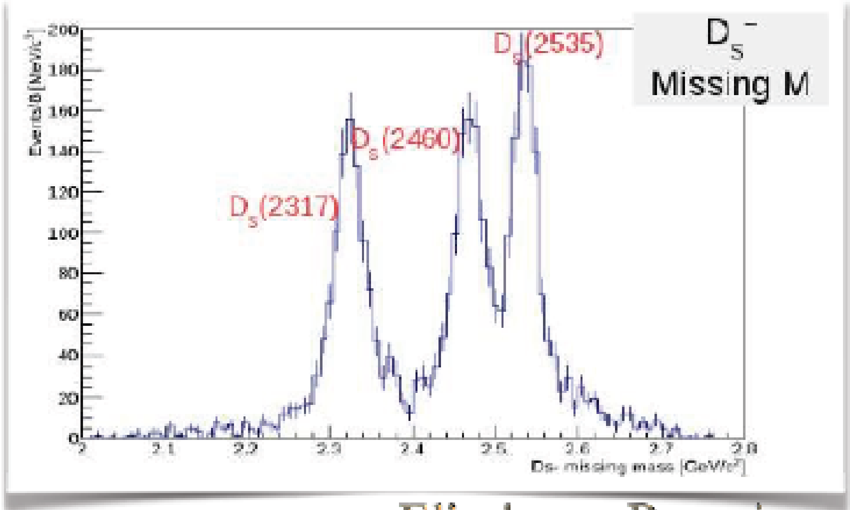
- Many more charged and neutral states predicted than observed
  - 67 among 80 ground states still to be discovered
- Only PANDA: discovery potential for high spin states *(angular momentum barrier)*
  - e.g. predicted J = 3 state
- Observation of complete multiplet pattern needed to solve X,Y,Z puzzle

Required Beam Time (days)
green < 30 yellow < 365 red >= 365

Signal / Background
green > 1 yellow > 0.1 red <= 0.1

Homogeneity of Dalitz plot
ok < 1.5

PANDA Opportunities



Elisabetta Prencipe

- **Radiative transitions**
  - limited data available
  - model sensitive and calculable as well!
- **Soft pion transitions**
  - isospin breaking mechanism in D_s
  - low-energy with Goldstone bosons
  - mixing of 1+ states: f.e, $D_{sJ}(2460,2536)$—>D*pi
- **Search for D-waves and "exotics"**
  - expect higher production rate in p-pbar than in e+e-
  - determine spin-parity of existing candidates
  - *new* discovery from LHCb: $D^*_{s1}(2860)$ mixture with $D^*_{s3}(2860)$ - arXiv:1407.7574

Light Mesons in $\bar{p}p$ Annihilation at PANDA

- Light meson production cross sections in $\bar{p}p$ are huge
  - 100 nb … 10 μb

- Neutral resonances with $m>2.25$ GeV/c^2 and non-exotic quantum numbers accessible in formation
  - all others accessible in production with at least one recoil meson and variable center-of-mass energy (→ tuneable phasespace)

- Many broad and overlapping states
  - requires (often) partial wave analysis techniques to identify resonances

Y(2175) Studies at PANDA

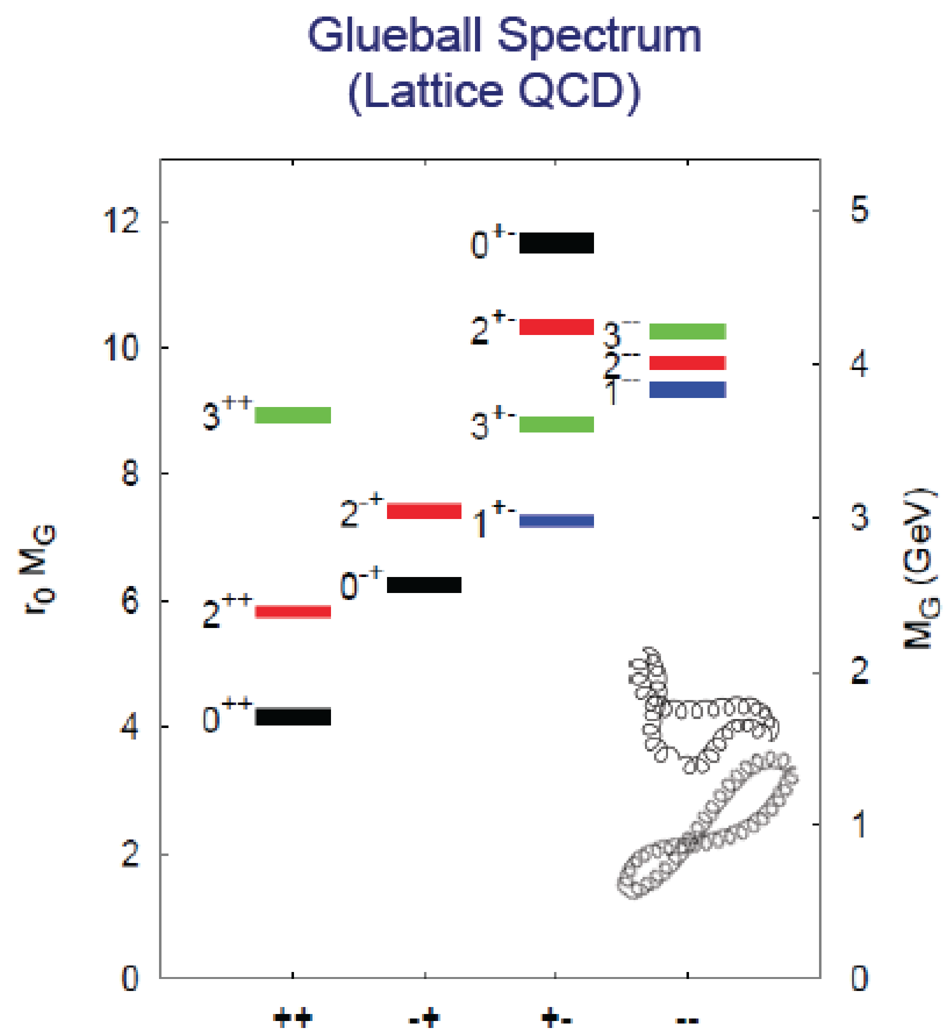
- $\bar{p}p \rightarrow Y(2175)\pi\pi, Y(2175)\pi^0$ at E_{CMS}= 3 GeV
  - Y(2175) reconstructed in $\Phi\pi^+\pi^-$ and $\Phi\pi^0\pi^0$
  - assumed signal cross section: 100 nb
  - background cross section: 70 mb

Beam-time to record 1000 reconstructed events in the $\Phi\pi^+\pi^-\pi^0$ decay mode

	$f_{BR} = 5\,\%$	$f_{BR} = 10\,\%$	$f_{BR} = 30\,\%$
$L = 2 \cdot 10^{30}$	99.5 d	24.9 d	2.8 d
$L = 2 \cdot 10^{31}$	9.95 d	2.49 d	0.28 h
$L = 2 \cdot 10^{32}$	0.995 d	0.249 d	0.028 h

[Ch. Motzko]

Glueballs



Higher spin Glueballs only accessible with PANDA

C. Morningstar, M. Peardon, Phys. Rev. D60, 34509 (1999)
C. Morningstar, M. Peardon, Phys. Rev. D56, 4043 (1997)

Glueball Studies at PANDA

- Study of glueball production in $K^+K^-\pi^0$, $K^+K^-\pi^0\pi^0$, and $\Phi\Phi\pi^0$
  - assuming cross section of 10 nb (including decay to final state)
  - background cross sections 50 to 80 mb

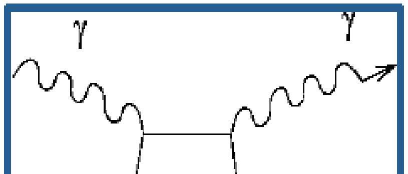
- "Light" glueball m = 2400 MeV/c^2 (could be 2^{++} or 0^{-+})
  - E_{CMS} = 2.57 GeV and 5.47 GeV
  - could be broad, study final states w/o intermediate resonances

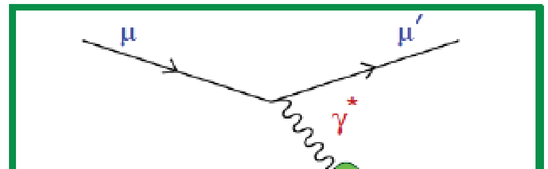
- "Heavy" glueball m = 3900 MeV/c^2
  - E_{CMS} = 5.47 GeV
  - could be narrow, assume Γ=10 MeV
  - search for narrow signal in production followed by detailed studies in formation [unique at PANDA]

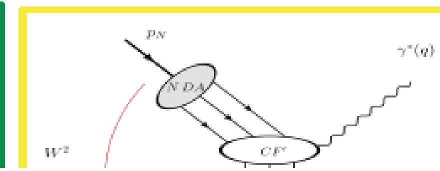
II. Electromagnetic Processes

Alaa Dbeyssi

(Virtual) photon in intermediate state

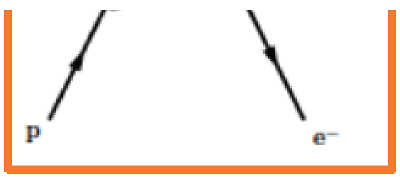


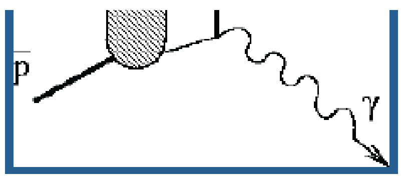


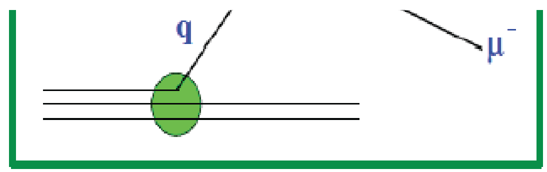


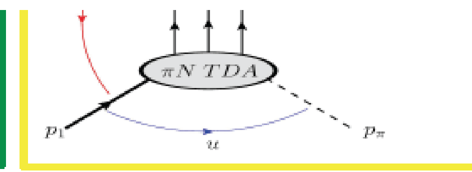
Crossing symmetry: - different kinematical regions
- observables are counterparts

A high quality and energy antiproton beam will be an excellent tool for a complementarity study of the nucleon structure with electron or photon experiments



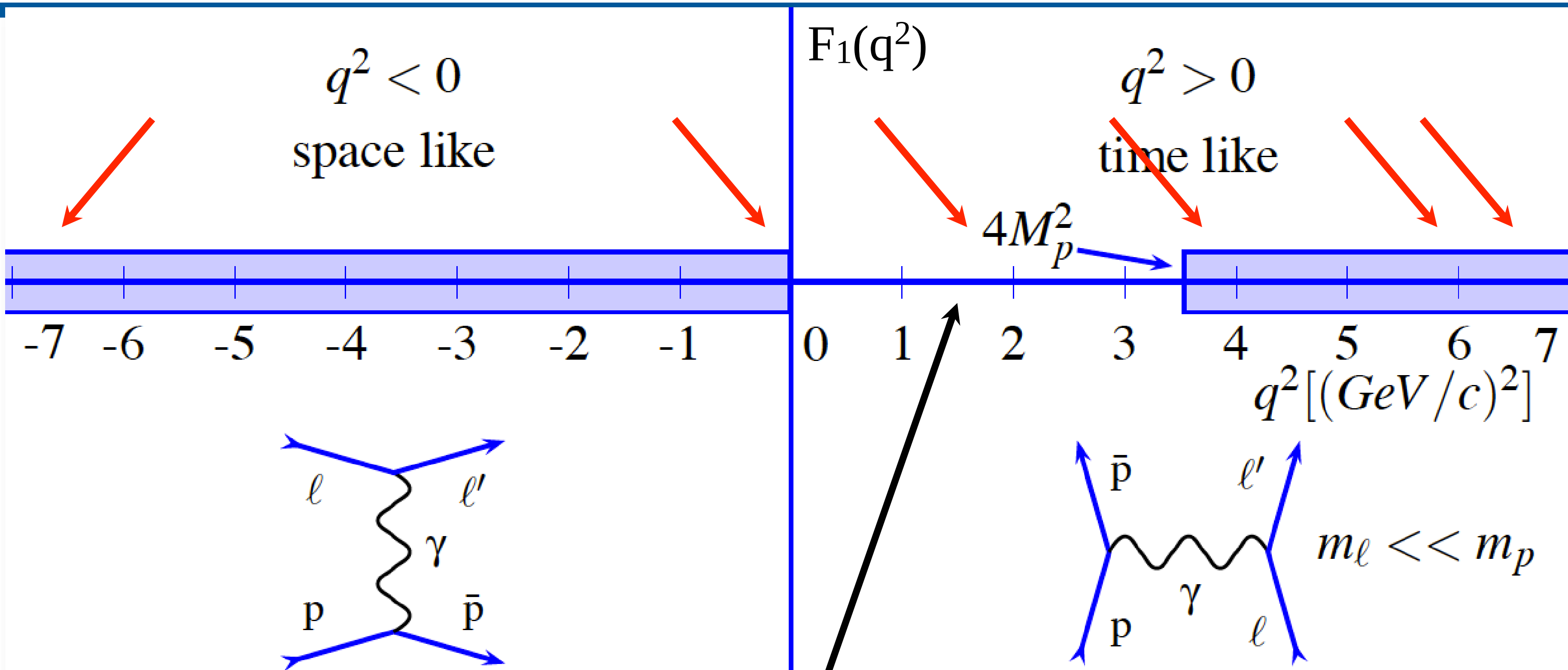






Extended feasibility studies in simulations based on present PANDA design

Electromagnetic Form factors of the Nucleon



unphysical region

Form Factor real

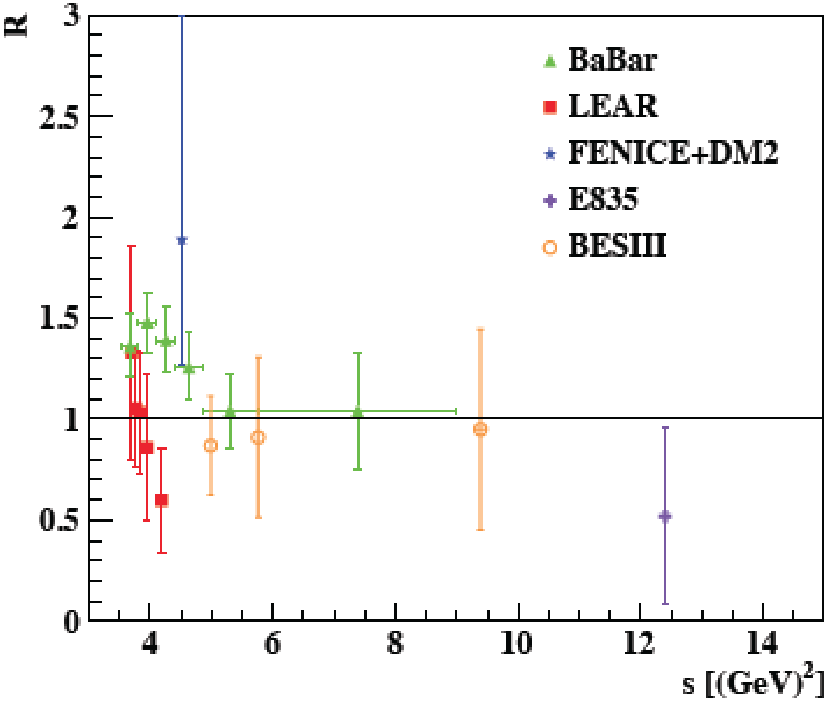
cross section (Rosenbluth)
no single spin observables
double spin observables

Form Factor complex

cross section (angular Distr.)
single spin observables (P_y)
double spin observables

connected by dispersion relations

Data on the time-like proton form factor ratio $R=|G_E|/|G_M|$



@ BaBar (SLAC): $e^+e^- \rightarrow \bar{p}p\gamma$

- data collection over wide energy range
- 10%-24% statistical uncertainties

@ PS 170 (LEAR): $\bar{p}p \rightarrow e^+e^-$

- data collection at low energies

Data from BaBar & LEAR show inconsistencies

@ BESIII: $e^+e^- \rightarrow \bar{p}p$

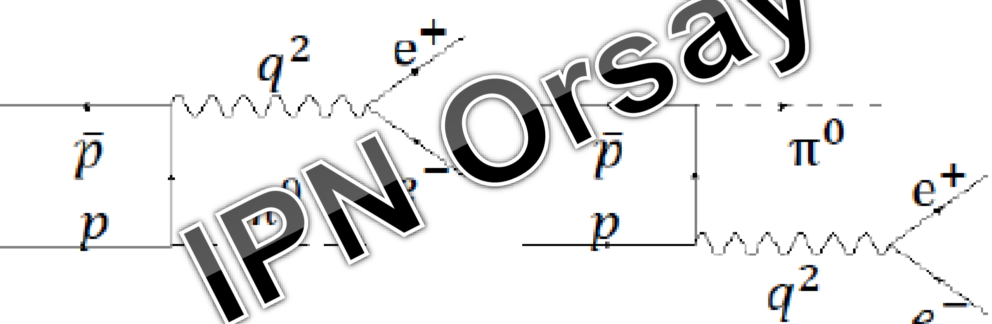
- Measurement at different energies
- Uncertainties comparable to previous experiments

BaBar: Phys. Rev. D88 072009
LEAR: Nucl.Phys.J., B411:3-32. 1994
BESIII: arXiv:1504.02680. 2015

PANDA: Measurement up to large q^2 with unprecedented precision

Electro magnetic form factors in the time like regime in PANDA

- Measurements of the proton effective form factor in the TL region over a large kinematical region through: $\bar{p}p \to e^+e^-$ $\bar{p}p \to \mu^+\mu^-$
- Individual measurement of $|G_E|$ and $|G_M|$ and their ratio
- Possibility to access the relative phase of proton TL FFs
  - Polarization observables (**Born approximation**) give access to $G_E G_M^*$
  - Development of a transverse polarized proton target for PANDA in Mainz
- Measurement of proton FFs in the unphysical region: $\bar{p}p \to e^+e^-\pi^0$



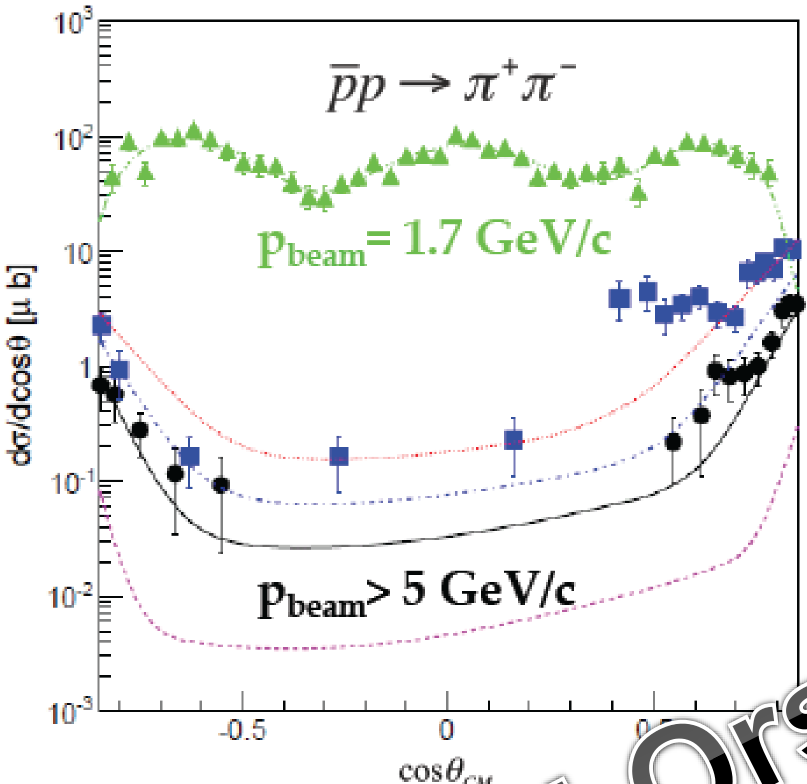
- M.P. Rekalo. Sov. J. Nucl. Phys., 1:760, 1965
- Adamuscin, Kuraev, Tomasi-Gustafsson and F. Maas, Phys. Rev. C 75, 045205 (2007)
- C. Adamuscin, E.A. Kuraev, G. I. Gakh, …
- Feasibility studies (J. Boucher, M. C. Mora-Espi PhD)

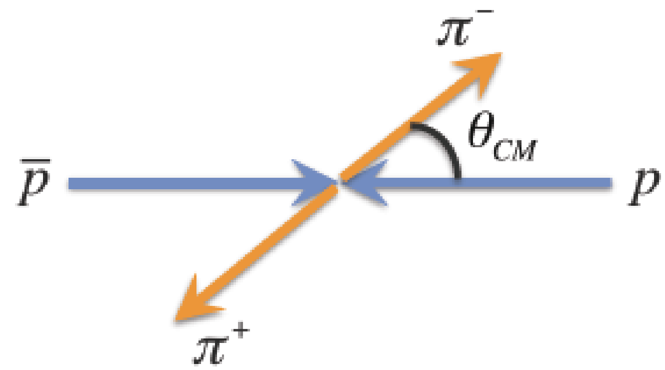
Feasibility studies: time-like proton form factors @ PANDA

Background studies

$$\boxed{\bar{p}p \rightarrow \pi^+\pi^-}$$

- **New event generator** developed by Mainz working group (M. Zambrana et al.)





$$\frac{\sigma(\bar{p}p \rightarrow \pi^+\pi^-)}{\sigma(\bar{p}p \rightarrow l^+l^-)} \propto [10^5 - 10^6]$$

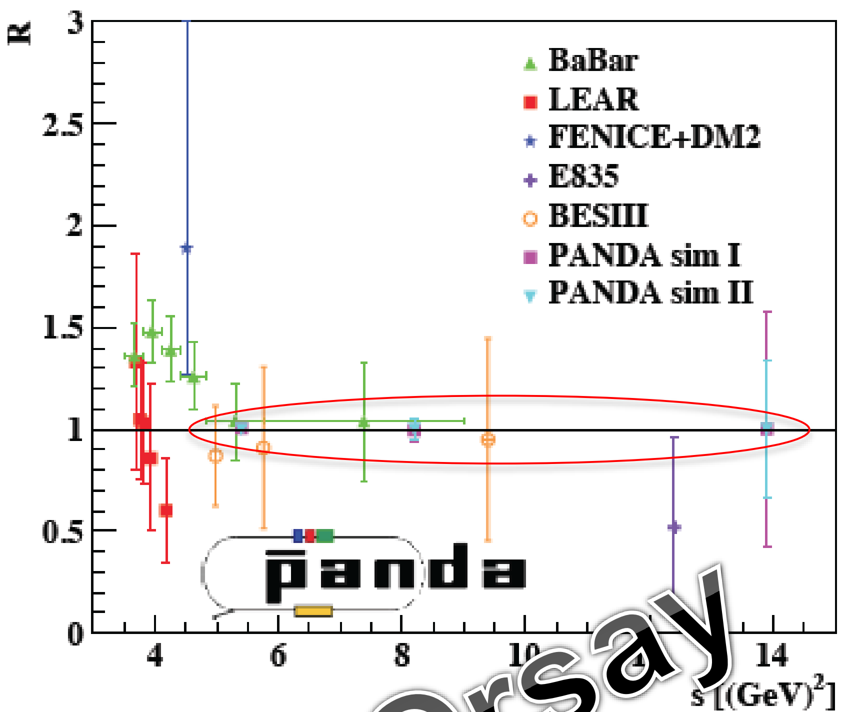
- J. Van de Wiele and S. Ong: Eur.Phys.J. A46, 291-298 (2010)
- M. Sudol et al. EPJA44, 373 (2010)
- A. Dbeyssi, D. Khaneft, M. Zambrana et al.: Paper will be published soon (2015)

- **Background rejection ~10^{-8} needed: Pollution < 1%**
- **For e^+e^-: A background rejection** of the order of 10^{-8} will be achieved @ PANDA
- **For $\mu^+\mu^-$: background rejection** of the order of ~10^{-6} will be achieved @ PANDA

(I) Feasibility studies: time-like proton form factors @ PANDA

Precision of $|G_E|$, $|G_M|$ and R

$$\boxed{\bar{p}p \rightarrow e^+e^-}$$



Sim. I: Determination precision

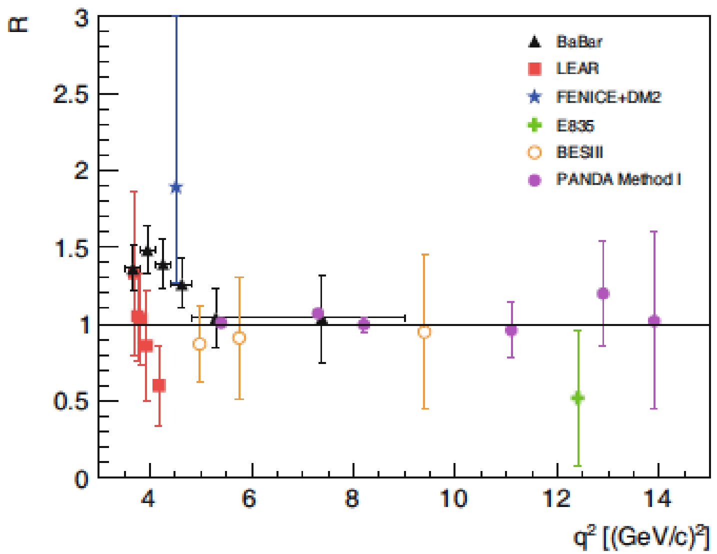
s (GeV)²	5.4	8.2	13.9
$R=\lvert G_E\rvert/\lvert G_M\rvert$	1.5 %	5.3 %	57 %
$\lvert G_E\rvert$	3.3 %	6.8%	45%
$\lvert G_M\rvert$	1.7%	2.3 %	9%

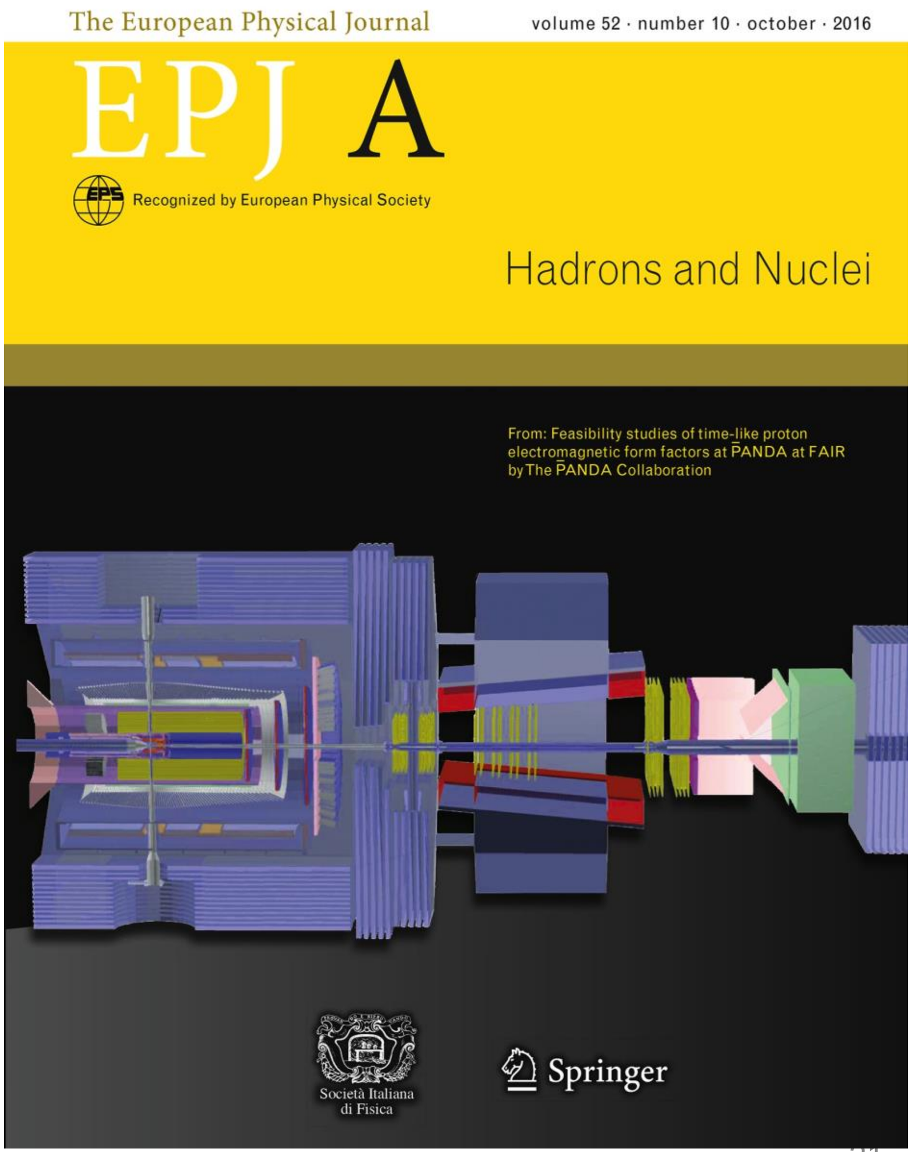
- Integrated luminosity of $L=2\ fb^{-1}$ $2{*}10^{32}\ cm^{-2}\,s^{-1}$-> 4 months data taking
- The determination precisions obtained at 5.4 GeV^2 and 8.2 GeV^2 are compatible between sim I & sim II
- At 13.9 GeV^2 the error of R was studied.

- The effective FF can be measured with good precision ranging from 0.3% up to 62.4% at q^2 ~28 GeV^2)

Electro magnetic form factors in the time like regime in PANDA

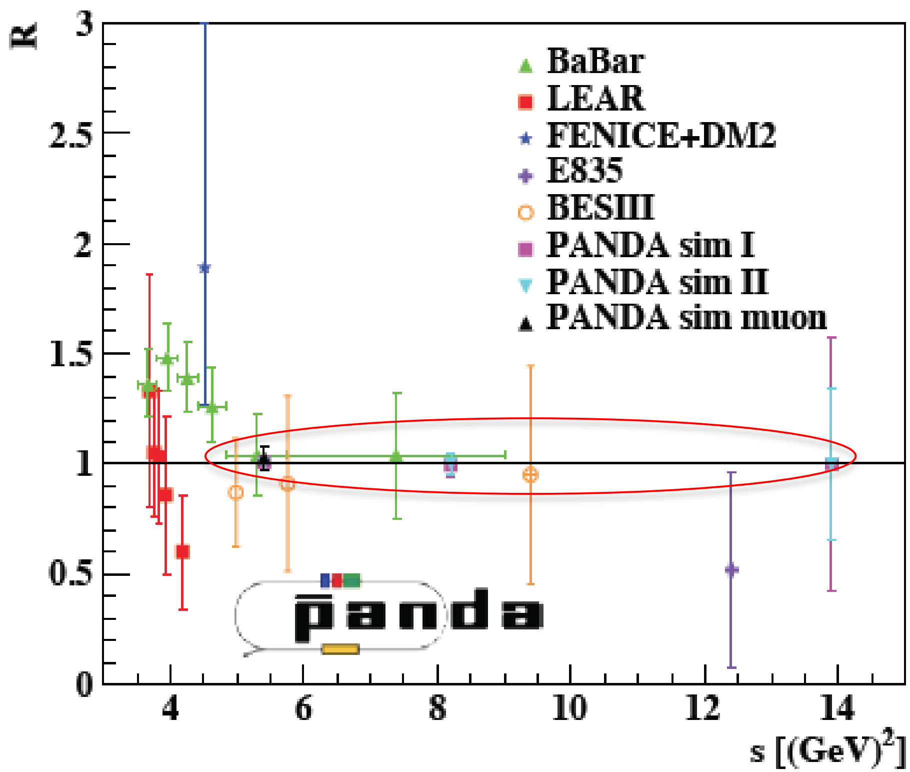
EPJ A Highlight
COVER EPJA October issue (2016)
"Feasibility studies of time-like proton electromagnetic form factors at PANDA at FAIR"
Corresponding author:
D. Khaneft (PhD-Student HIM)
A. Dbeyssi (Helmholtz-Postdoc HIM)





(II) Feasibility studies: time-like proton form factors @ PANDA

Precision of $|G_E|$, $|G_M|$ and R

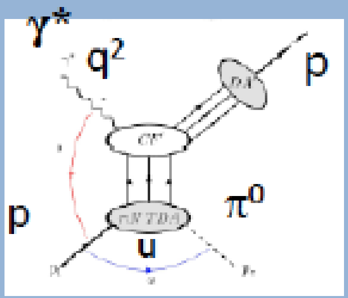


s (GeV)²	5.4	8.2	13.9
sim I $\bar{p}p \rightarrow e^+e^-$			
$R=\vert G_E\vert/\vert G_M\vert$	1.5 %	5.3 %	57 %
$\vert G_E\vert$	3.3 %	6.8%	45%
$\vert G_M\vert$	1.7%	2.3 %	9%
MVA $\bar{p}p \rightarrow \mu^+\mu^-$			
$R=\vert G_E\vert/\vert G_M\vert$	**5.1%**	-	-
$\vert G_E\vert$	**8.6%**	-	-
$\vert G_M\vert$	**4.1%**	-	-

Transition Distribution Amplitudes (TMDs)

$e^-p \to e^-p\pi^0$ Bwd

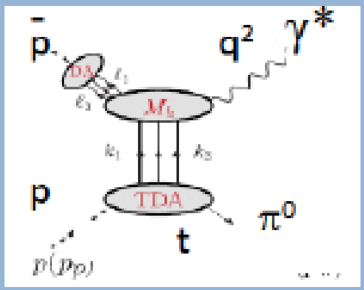
electroproduction



Large q^2
small u

Transition Distrib.
Amplitudes

$\bar{p}p \to e^+e^-\pi^0$ Fwd/bwd



Large q^2
small t or u

Transition Distrib.
Amplitudes

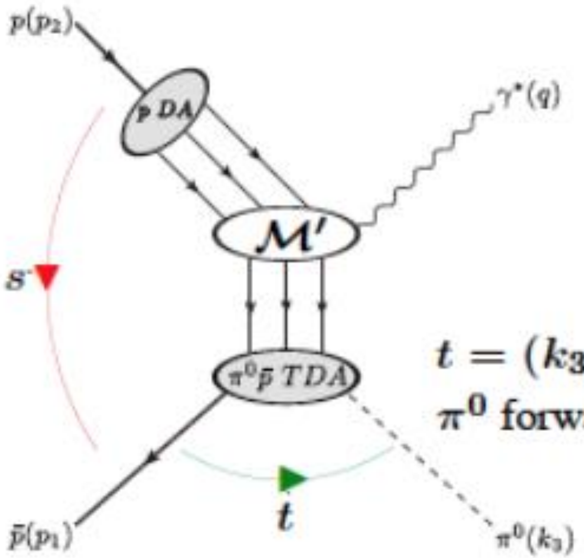
Transitions Distribution Amplitudes:

$\bar{p}p \to e^+e^-\pi^0, e^+e^-\rho^0, e^+e^-\eta, \ldots$

- Describe the transition between two particles
- Explore pionic components in the nucleon wave function
- Transverse picture of the pion cloud
- Universality: the same TDA could be measured in different kinematics or different reactions

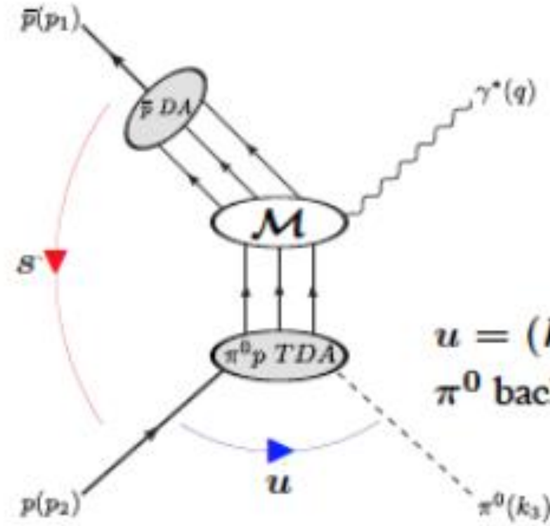
Transition Distribution Amplitudes (TMDs)

Signal channel: $\bar{p}p \rightarrow \gamma^* \pi^0 -> e^+ e^- \pi^0$



$t = (k_3 - p_1)^2$

π^0 forward



$u = (k_3 - p_2)^2$

π^0 backward

$$\mathcal{M}(\bar{p}p \rightarrow \gamma^* \pi^0) = \mathcal{M}_{\text{parton, parton}} \otimes \text{distribution amplitude (DA) and TDA}$$

B. Pire et al. PRD 76, 111502 (2007)

- Admits a factorized description when:
  - q^2 is large ($q^2 \approx s$)
  - *t* is small (forward kinematics, pi-N TDAs) , or *u* is small (backward, pi-Nbar TDAs)
    [check the symmetry violation between proton and antiproton]
- TDAs are related to the proton FFs by integration over all variables but q^2.

Transition Distribution Amplitudes (TMDs)

Feasibility studies of measuring $\bar{p}p \rightarrow \gamma^{*}\pi^{0} -> e^{+}e^{-}\pi^{0}$ at PANDA

$$\text{i) } s = 5\,\mathrm{GeV}^2 \quad \rightarrow \quad 3.0 < q^2 < 4.3\,\mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$$

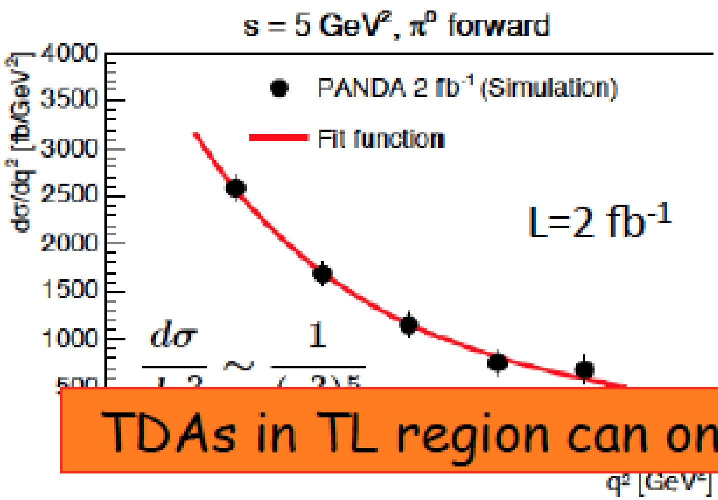
$$\text{ii) } s = 10\,\mathrm{GeV}^2 \quad \rightarrow \quad 5 < q^2 < 9\,\mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$$

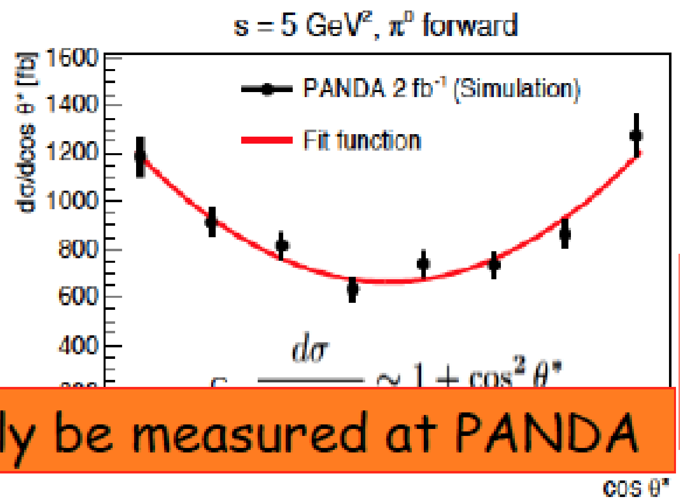
- Background suppression of the $\bar{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ and measurement precision:

s = 5 GeV^2: 5 . 10^7 (1 . 10^7) $\quad \Delta\sigma/\sigma \sim 12\%$

s = 10 GeV^2: 1 . 10^8 (6 . 10^6) $\quad \Delta\sigma/\sigma \sim 24\%$

- Test of the QCD factorization/access TDAs





TDAs in TL region can only be measured at PANDA

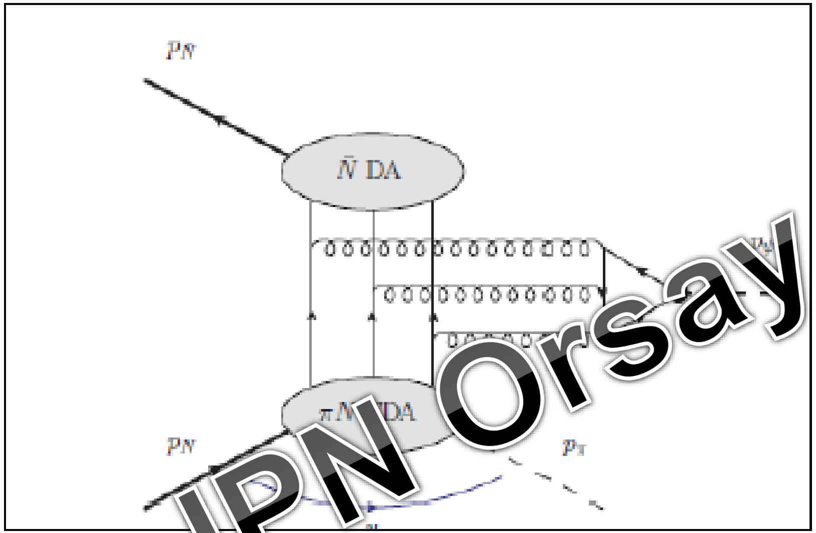
M. Carmen Mora Espi *et al.* (HIM). Submitted to EPJA

PANDA Collaboration (B.P. Singh et al.) Eur.Phys.J. A51 (2015) 8, 107

Transition Distribution Amplitudes (TMDs)

Signal channel: $\bar{p}p \rightarrow J/\psi\pi^0 -> e^+e^-\pi^0$

- High signal cross section
- Large q² fixed to $M^2_{J/\psi}$ (facorization theorem is likely reached)
- Reduces uncertainty on DAs by using the data on the $J/\psi -> pp$ partial decay modes
- Test of universality of TDAs by comparing to $\bar{p}p \rightarrow \gamma^*\pi^0 -> e^+e^-\pi^0$ at different q²



Feasibility studies for PANDA @ p=5.513, 8.0 and 12.0 GeV/c:

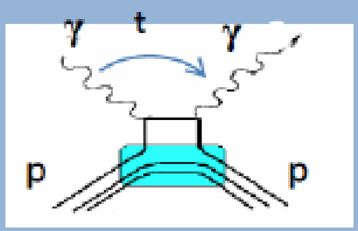
S/B> 8, 70, 600

Binsong Ma, PhD thesis, IPNO 2014
Ongoing work by Ermias Atomsa et al. (IPNO)

Generalized Distribution Amplitudes (GDAs)

(SL)

$\gamma p \to \gamma p$ Wide Angle Compton Scattering



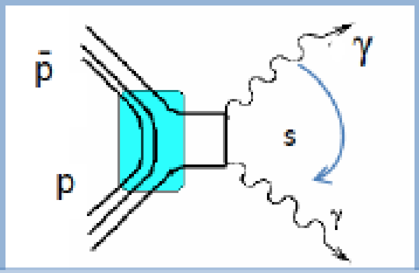
Large p_t

Generalized Parton Distributions

(TL)

$\bar{p}p \to \gamma\,\gamma$

Large p_t



Generalized Distrib. Amplitudes

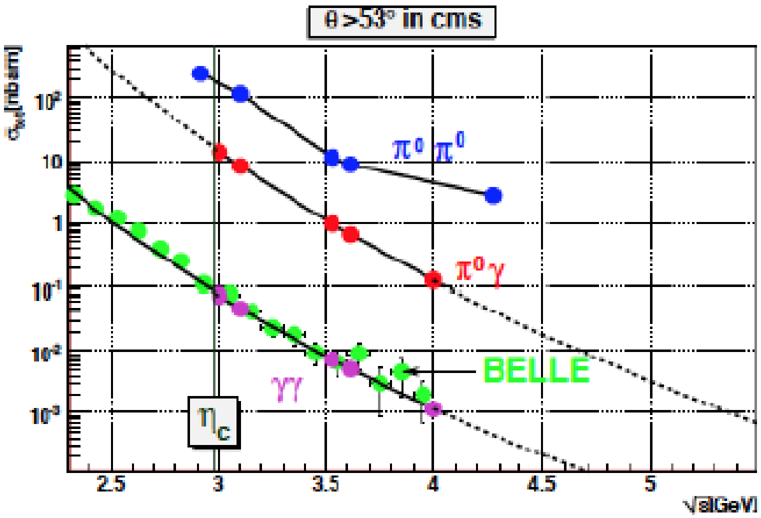
Time-like Wide Angle Compton Scattering (WACS)

The QCD factorization theorem allows us to calculate hign energy cross sections separating short-distance process with long-distance non perturbative functions

Hard scale is defined by the large transverse momentum of the final state photon

WACS process: give access to the GDAs, the counterpart of the GPDs

Feasibility studies for $\bar{p}p \to \gamma\gamma$ and $\bar{p}p \to \pi^0\gamma$ at PANDA

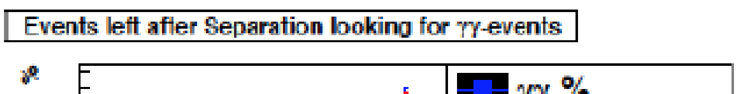


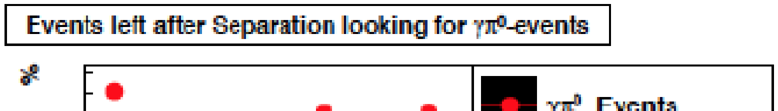
PANDARoot simulations:

- 4 different CM energies
- Main background channels:

$\bar{p}p \to \pi^0\pi^0$ (for both signals)

$\bar{p}p \to \pi^0\gamma$ (for signal1: $\bar{p}p \to \gamma\gamma$)





Time-like wide angle Compton scattering and hard exclusive meson production can be measured at PANDA

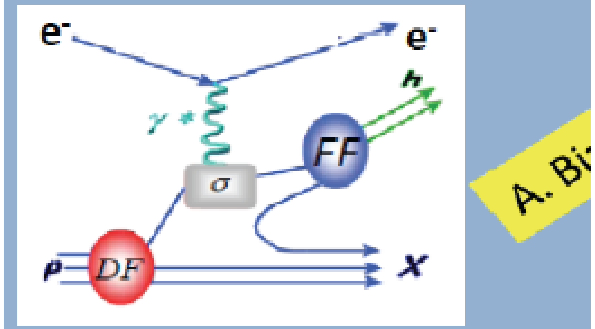
S/B~1 for $\bar{p}p \to \gamma\gamma$ (25% efficiency)
S/B~2 for $\bar{p}p \to \pi^0\gamma$ (50% efficiency)

Further studies are required for precise predictions

Drell-Yan Process

$e^-p \to e^-hX$

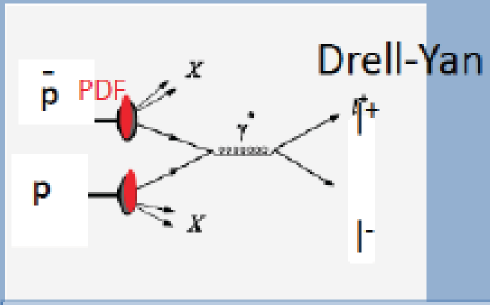
SIDIS



Parton Distribution Functions

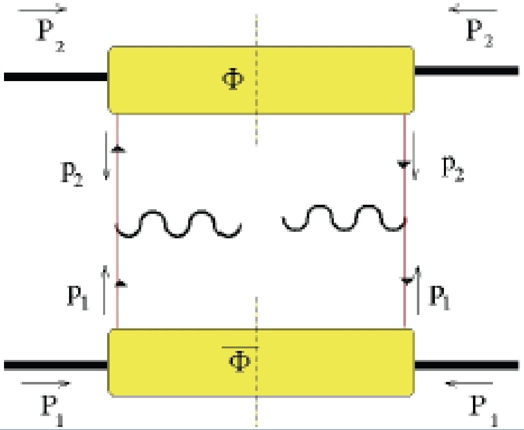
PDFs are convoluted with the fragmentation functions

$\bar{p}p \to \mu^+\mu^-X/e^+e^-X$



Parton Distribution Functions

Handbag diagram: $s \gg M_h^2$



@ FAIR unique energy range
up to s~30 GeV2 with PANDA
up to s~200 GeV2 with PAX

@ much higher energies
→ big contribution from sea-quarks

@ppbar annihilation each valence quark contribute to the diagram

Feasibility measurement of DYs at PANDA

Feasibility studies using Monte-Carlo simulation:

- Signal: $\bar{p}p \rightarrow \mu^+\mu^- X$ Unpolarized DY

  $\bar{p}p^{\uparrow} \rightarrow \mu^+\mu^- X$ Single-polarized DY

- Main background: $\bar{p}p \rightarrow n(\pi^+\pi^-)X$, required rejection factor ~10^7
- Simulations @ s=30 GeV^2 and $1.5 \leq M_{\gamma^*} \leq 2.5$ (non resonance region, large cross section)

  N_{gen}=480 . 10^3, 5 months with L=2 . 10^{32} cm^{-2} s^{-1} PANDA Physics Performance Report arXiv:0903.3905

Acceptance, efficiency corrections, background rejection are still
Under unvestigation: expectation: 130. 10^3 DY/month

One year data taking: azimuthal asymmetries with uncertainties of
The order of the presented one

Torino group, Marco Maggiora

Electromagnetic processes in PANDA

Feasibilty study for the measurement of many electromagnetic processes at PANDA are done

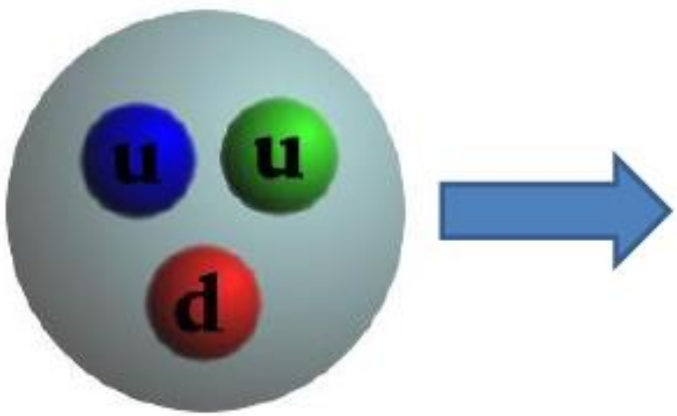
Signal	Physics	s [Gev²]	S/B	Status
$\bar{p}p \rightarrow e^+e^-$	FFs	5.4, 8.2, 13.9	>100	Feasibile IPN Orsay
$\bar{p}p \rightarrow \mu^+\mu^-$	FFs	5.4	¼	Feasibile
$\bar{p}p \rightarrow \gamma^*\pi^0$	TDAs	5.0 10.0	$5 . 10^7$ ($1 . 10^7$) $1 . 10^8$ ($6 . 10^6$)	Feasibile IPN Orsay
$\bar{p}p \rightarrow J/\psi\pi^0$	TDAs	P=5.513 P=8.0 P=12.0	>8 >70 >600	Feasibile IPN Orsay
$\bar{p}p \rightarrow \gamma\gamma$ $\bar{p}p \rightarrow \pi^0\gamma$	GDAs	2.5, 3.5, 4.0, 5.5	1 2	Feasibile
$\bar{p}p \rightarrow \mu^+\mu^-X$	TMD PDFs	30	in progress	Feasibile

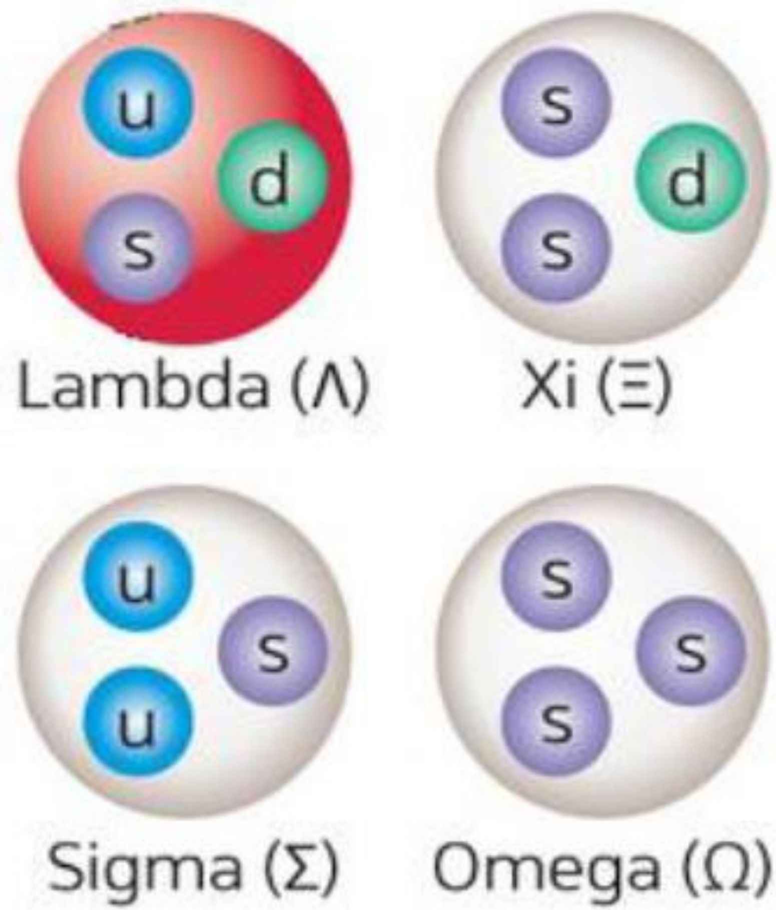
III. Hyperons, Hypernuclei, In-medium effects

Karin Schöning (Uppsala)
Alicia Sanchez (HI Mainz)

Strange (and charmed) hyperons

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





Strange hyperons

Excited strange hyperon spectrum:

- PANDA can fill the gap in the strange sector

→ the full Ξ and Ω spectra are accessible with PANDA!

strangeness

- Octet Ξ* partners of *N** ?
  - Only a few found
- Decuplet Ξ* and Ω* partners of Δ*?
  - Nothing found

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	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
$9/2^+$	$(56,4_4^+)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	

Decuplet members

J^P	(D, L_N^P)	S				
$3/2^+$	$(56,0_0^+)$	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	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

Baryon spectroscopy subtopics with PANDA

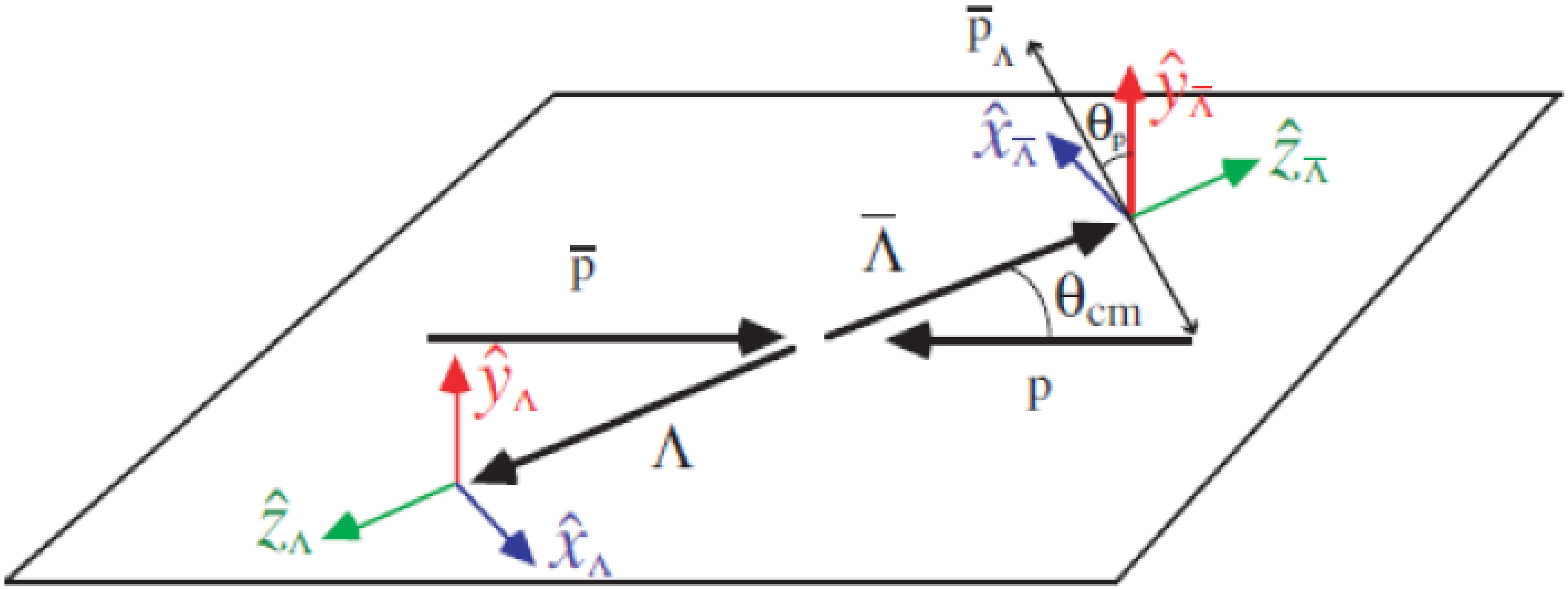
Study excited states of

PANDA is a strangeness factory!

- hidden-charm nucleons ($N_{c\bar{c}}$)
- non-strange baryons (N^*)
- single-strange hyperons (Λ^*, Σ^*)

Spin observables in hyperon production

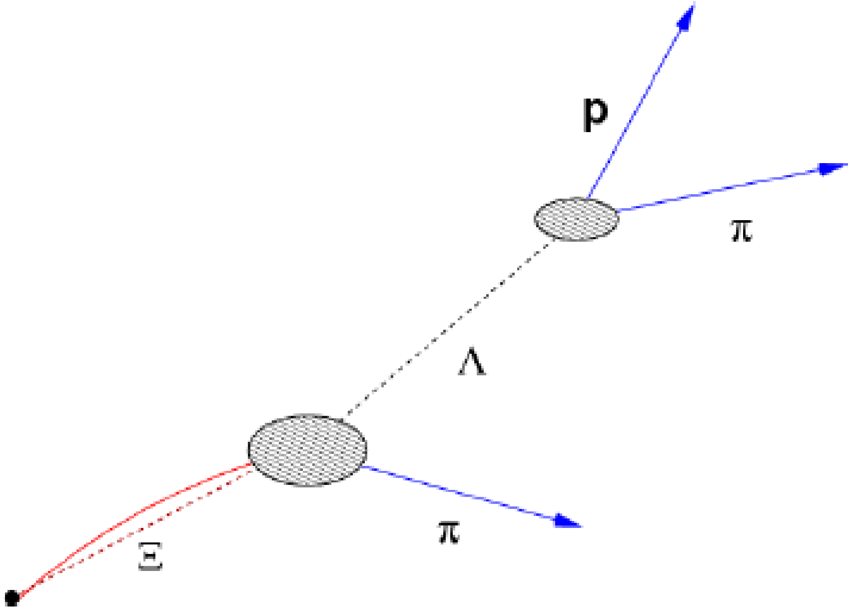
- *Vector polarisation* P the most straight-forward observable for spin $\frac{1}{2}$ hyperons.
- Strong interactions: normal to the production plane (y-direction)



Spin observables in hyperon production

If the decay product of the hyperon is a hyperon, *e.g.* $\Xi \rightarrow \Lambda\pi$, then also β and γ can be obtained from the decay protons of the Λ.

$$I(\theta_p,\phi_p)=\frac{1}{4\pi}\left[1+\alpha_\Xi\alpha_\Lambda\cos\theta_p+\frac{\pi}{4}\alpha_\Lambda P\sin\theta_p(\beta_\Xi\sin\phi_p-\gamma_\Xi\cos\phi_p)\right]$$



α, β, γ decay parameters.
related to the decay amplitudes T_s and T_p

Spin observables in hyperon production

$$\bar{p}p \to \bar{\Lambda}\Lambda,\ \bar{\Sigma}^-\Sigma^+,\ \bar{\Sigma}^0\Sigma^0,\ \bar{\Sigma}^-\Sigma^+,\ \bar{\Xi}^0\Xi^0,\ \bar{\Xi}^+\Xi^-,\ \bar{\Omega}^+\Omega^-,\bar{\Lambda}_c^-\Lambda_c^+$$

	$\bar{\Lambda}\Lambda$	$\bar{\Sigma}^-\Sigma^+$	$\bar{\Sigma}^0\Sigma^0$	$\bar{\Sigma}^-\Sigma^+$	$\bar{\Xi}^0\Xi^0$	$\bar{\Xi}^+\Xi^-$	$\bar{\Omega}^+\Omega^-$	$\bar{\Lambda}_c^-\Lambda_c^+$
	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
	$p\pi^-$	$p\pi^0$	$\Lambda\gamma$	$n\pi$	$\Lambda\pi^0$	$\Lambda\pi$	ΛK	$\Lambda\pi$
BR:	64%	52%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	68%	$\approx$ 1%

- Simulation studies using a simplified MC framework (smearing and acceptance included)
- Quoted rates are valid for day one luminosity of the HESR (10^{31} cm^{-2} s^{-1}).
- Cross sections of $\bar{p}p \to \bar{\Lambda}\Lambda$ and $\bar{p}p \to \bar{\Lambda}\Sigma^o$ known near threshold, the $\bar{p}p \to \bar{\Xi}^+\Xi^-$ measured with large uncertainty.
- Only theoretical predictions of $\bar{p}p \to \bar{\Omega}^+\Omega^-$ and $\bar{p}p \to \bar{\Lambda}_c^-\Lambda_c^+$

Spin observables in hyperon production

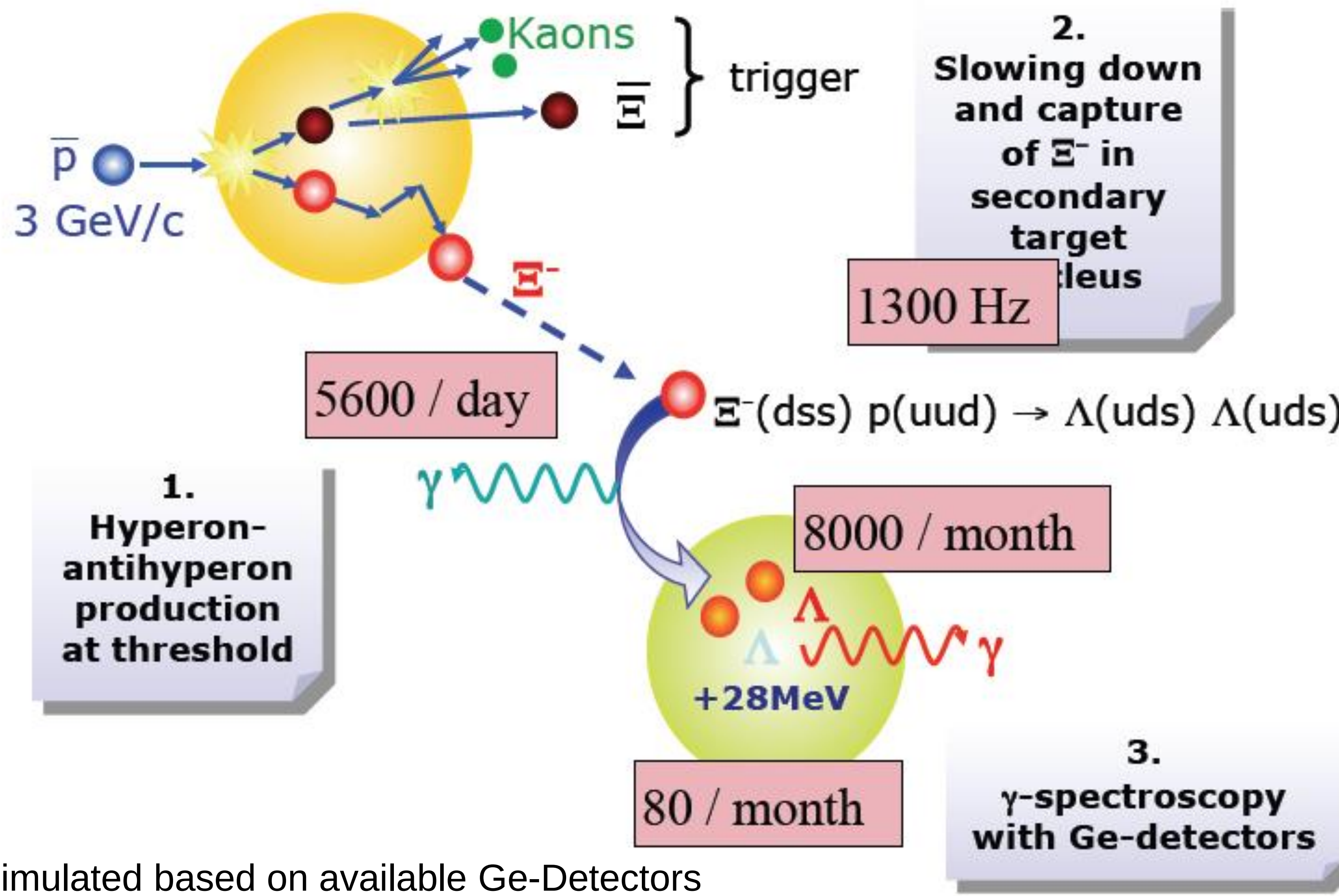
Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate (with 10^{31} $cm^{-1}s^{-1}$)
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	10	28 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^{o}$	~40	30	30 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$	~2	20	1.5 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}^{+}\Omega^{-}$	~0.002	30	~4 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c^{-}\Lambda_c^{+}$	~0.1	35	~2 day^{-1}

Gain a factor of 100 with inclusive measurement

- High event rates for Λ and Σ *.
- Low background for Λ and Σ *.
- Ω channel feasible
- Λ_c requires high luminosity **
- New efficiencies obtained with a more sophisticated MC framework are underway.

*Sophie Grape, Ph. D. Thesis, Uppsala University 2009
** Erik Thomé, Ph. D. Thesis, Uppsala University 2012

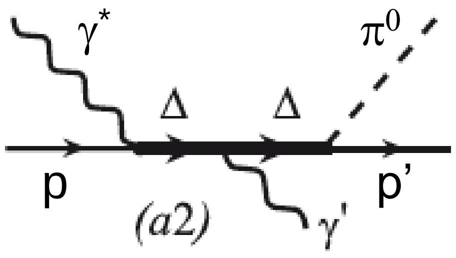
Production of Double Hypernuclei



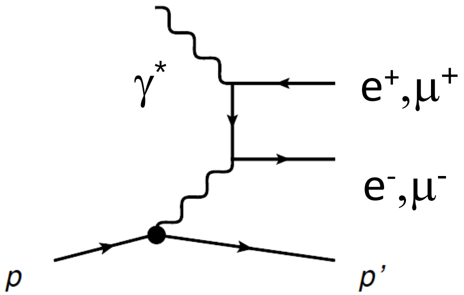
Fully simulated based on available Ge-Detectors

Phase 0: BEMC@MAMI

- Magnetic Moment of $\Delta(1232)$-Resonance by
  - e p -> e p $\pi^0 \gamma$
  - Additional calorimeter for π^0 and γ detect.
  - Virtual photon flux higher in e-production
  - S_{11}-Resonance

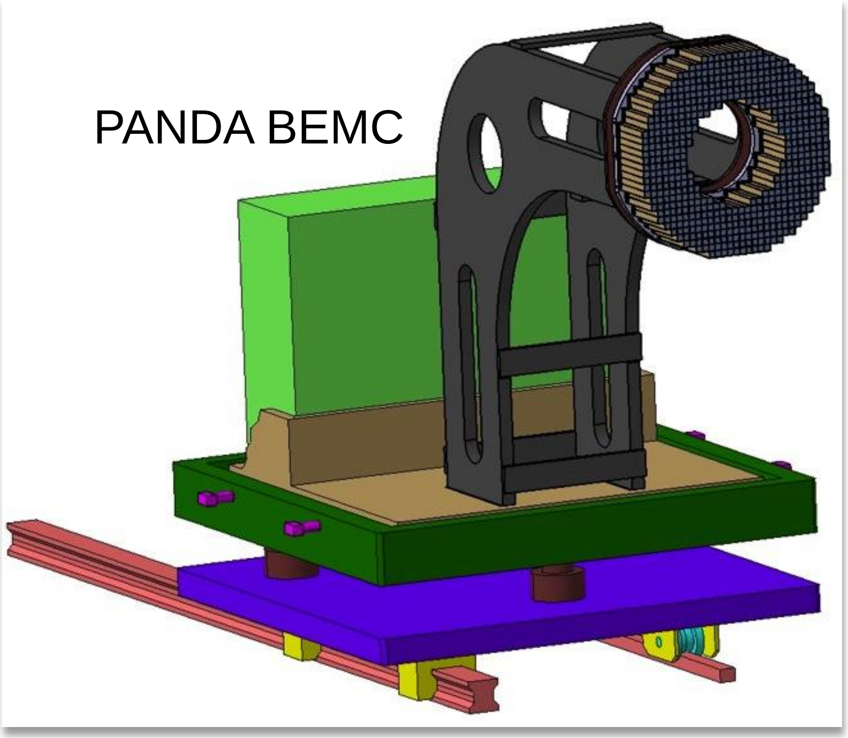


- Electron-Muon-Universality (Proton Radius Puzzle)
  - e p -> e p l^+l^- below/above $\mu^+\mu^-$ pair threshold
  - Additional calorimeter for forward angles



- Multi-π^0-Production
  - e p -> e p $\pi^0 \pi^0$ etc.
  - Unknown transition amplitudes, calibration and commissioning of calorimeter

Phase 0: BEMC@MAMI



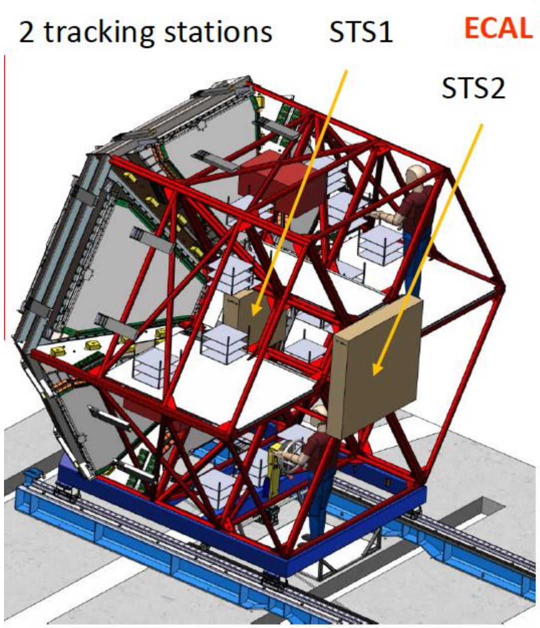
- A1: 3 Magnetic Spectrometer setup
- Momentum Resolution: $\Delta p/p < 10^{-4}$ in each spectrometer
- Conincident detection of three charged particles.
- MAMI: 180 MeV – 1.6 GeV electron accelerator

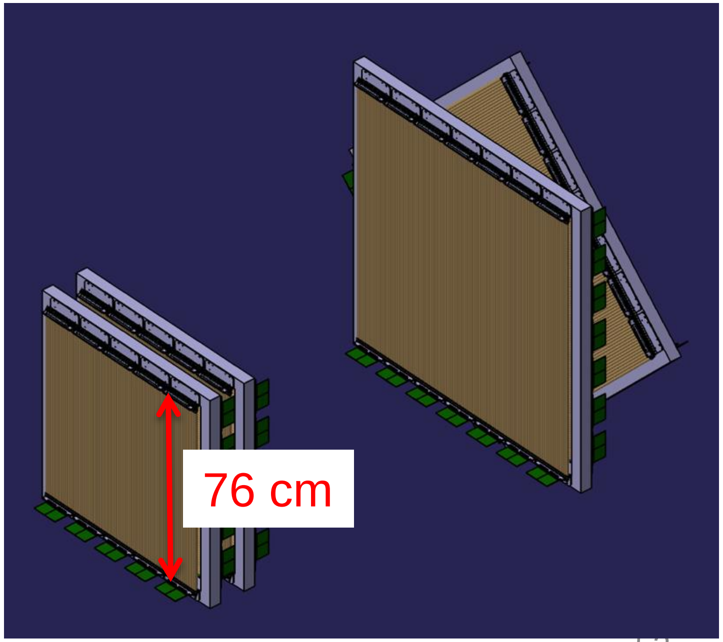
PANDA Phase 0 Experiments with HADES *Detectors*

PANDA pre-series and prototype detectors for STS1/2

– HADES measures the dileptons & mesons

– PANDA Straw Trackers for the baryon (Θ<7˚)





PANDA: Excellent Physics-Opportunity

FAIR will be the main national laboratory for strong interaction Studies at all length scales: PANDA-experiment 1 of 4 Pillars

Antiproton beams for spectroscopy: X,Y,Z-factory, open charm, light mesons, baryons, glue-balls, hybrids, …
precision studies with large data samples, measurement of width and cross section

Explore electromagnetic probe in antiproton annihilation: many channels and reactions studied in detailed simulations, so far all accessible and measurable with high precision

Study of hyperon spectrum and hypernuclei with strangeness S=2

Backup Slides

PANDA Collaboration

- At present a group of **500 physicists** from 62 institutions and 16 countries

Austria – Belaruz – China – France – Germany – India – Italy – The Netherlands – Poland – Romania – Russia – Spain – Sweden – Switzerland – U.K. – U.S.A.

AMU Aligarh, Basel, Beijing, BITS Pillani, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, IIT Chicago, AGH-UST Cracow, JGU Cracow, IFJ PAN Cracow, Cracow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Gauhati, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, Legnaro, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow, TU München, Münster, BARC Mumbai, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, South Gujarat University, SVNIT Surat, Sadar Patel University, KTH Stockholm, Stockholm, FH Südwestfalen, Suranaree University of Technology, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, NCBJ Warsaw, TU Warsaw, AAS Wien

http://www.gsi.de/panda

“Review 15.02.2015”

Recommendations by the

International Review Committee for the FAIR Project

concerning the ranking of the science pillars

Introduction

An ad hoc expert group comprising independent scientists and experienced project managers was set up by the *Aufsichtsrat* of the GSI *Helmholtzzentrum für Schwerionenforschung GmbH* to inter alia evaluate the scientific relevance of the Facility of Antiproton and Ion Research (FAIR) project. Given the delayed schedule in the construction of the facility a clearly prioritized ranking of the experiments in comparison with other existing or planned future facilities should be recommended.

Consequently, the Committee reviewed the science cases of the four scientific pillars in the context of the worldwide progress in the field as well as the delayed start-up and cost increases of the FAIR Modularised Start Version (MSV). Extensive input was provided by the FAIR/GSI managements, the experiments and by the scientific committees of GSI and FAIR.

The emphasis was placed on the availability of scientific data and the competitiveness of FAIR experimental pillars around 2025.

“Review 15.02.2015”

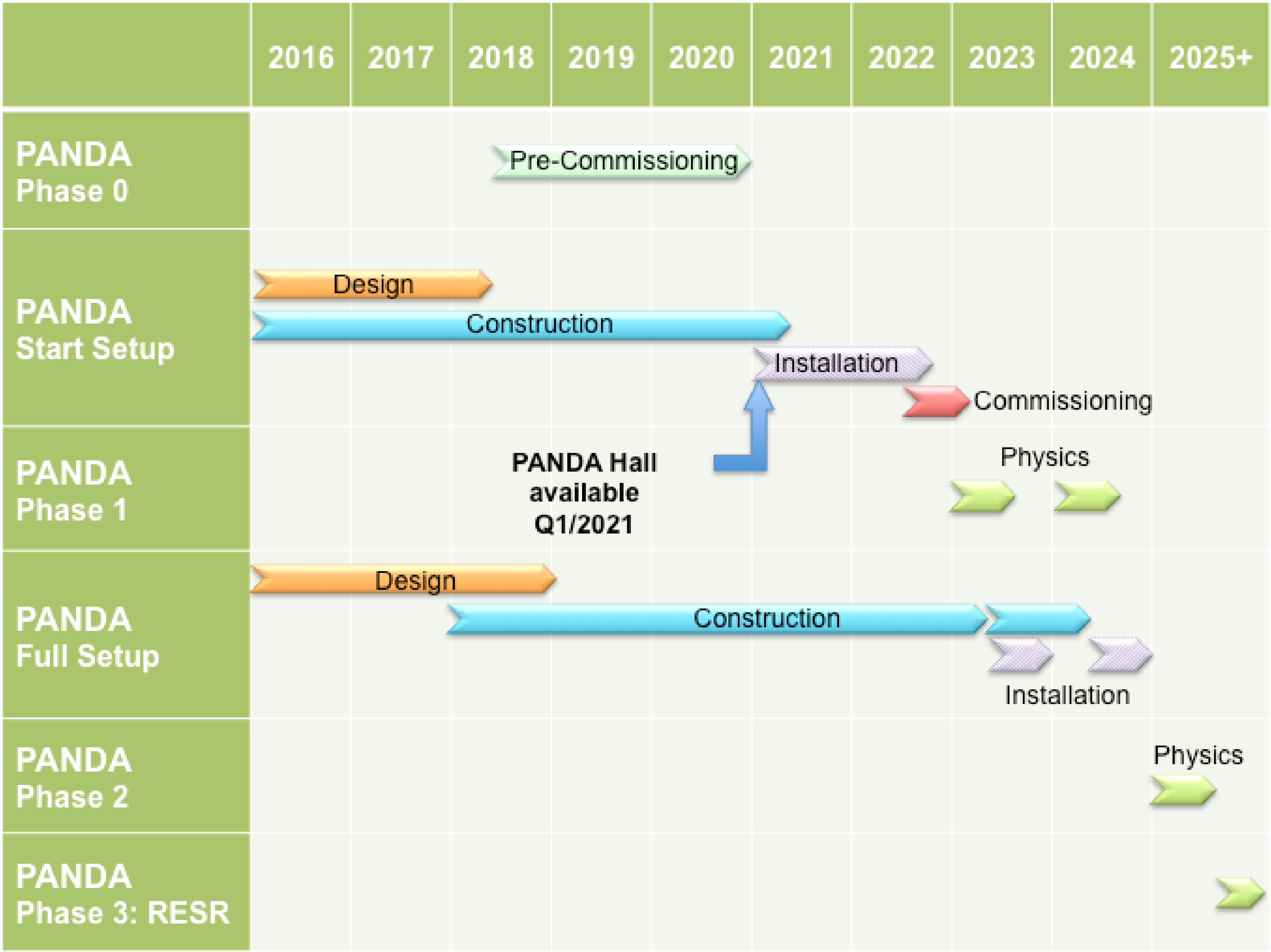
PANDA offers unique capabilities to measure properties of hadronic states not readily accessible at other facilities. However, due to the delay of the FAIR facility a substantial part of the *discovery* potential, e.g. for new resonances and exotic states, will have been lost to operating facilities where the current experiments have made remarkable progress in their capabilities (e.g. LHCb) or to facilities coming online well before FAIR (e.g. Belle-II, GlueX). The remaining physics program is still attractive but viewed in the context of the large incremental cost to implement the antiproton target, HESR, and PANDA, the priority is judged to be lower than the other science pillars.

Reactions by the PANDA Collaboration

- PANDA internal scrutiny process (March 2014, Final report September 2015)
- PANDA physics workshop in Uppsala, 8. - 12. Juni 2015
- EMMI rapid reaction task force, 12.-14. Oktober 2015

- Results:
  - Definition of key experiments with high impact in Phase 1
  - Definition of reduced setup for Phase 1
  - Proposals for PANDA Phase 0

- Present activities on the way to FAIR
  - Development of dedicated analysis methods at ELSA, MAMI, BESIII, Jlab, COMPASS to ensure a quick start of PANDA.
  - Cutting edge physics results, education of young scientists
  - Application of modern PANDA technologies at present and future facilities Cherenkov (DIRC), EMC, Photonreadout, Readout electronics,


2016
2017
2018
2019
2020
2021
2022
2023
2024
2025+
PANDA Phase 0
Pre-Commissioning
PANDA Start Setup
Design
Construction
Installation
Commissioning
PANDA Phase 1
PANDA Hall available Q1/2021
Physics
PANDA Full Setup
Design
Construction
Installation
PANDA Phase 2
Physics
PANDA Phase 3: RESR

Key-Experiments of the phase 1

Concentration on unique and forefront physics topics

- 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, clarification of the nature of the states)

- (Parasitic) production of multi-strangeness baryons
  (unexplored, new territory, „Strangeness-Factory")

- Parasitic production of high spin charmonia (only possible in proton–antiproton)
  light mesons, baryons and production of hybrids und glueballs

- Measurement of the electromagnetic form factors of the proton in the time-like domain with electrons and muons in the final state

XYZ-, hyperon factory