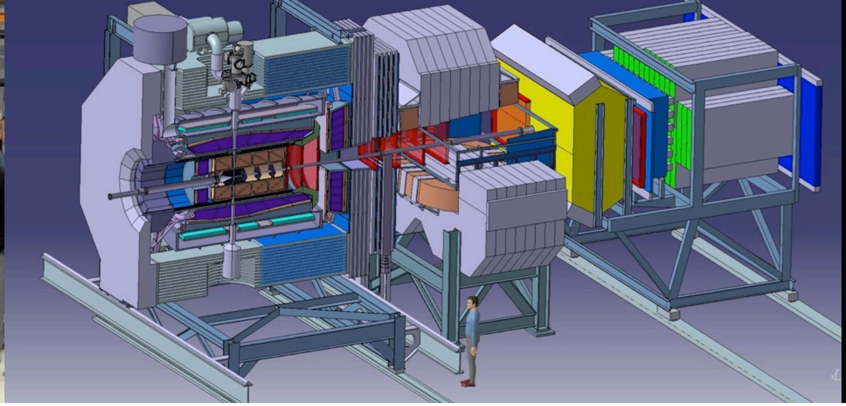
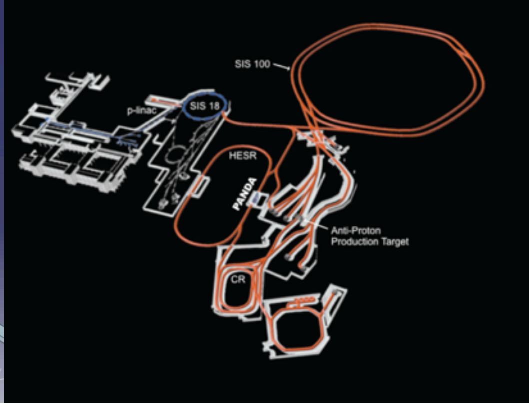




Status PANDA

KHuK Jahrestagung / Annual Meeting 2015
December, 4-5, 2015

Frank Maas
GSI / HIM / U Mainz

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

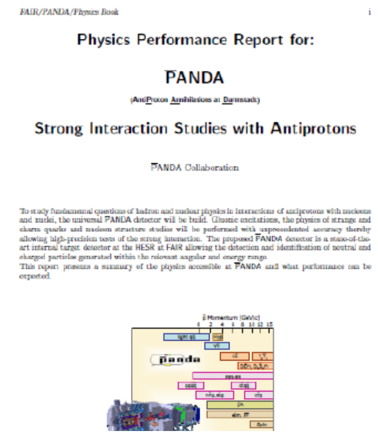
time like form factors, transition distribution

amplitudes, TMDs, …

III:Hadronic interactions:

Hyperons, Hypernuclei,

In medium-effects



FAIR/PANDA/Physics Book i

Physics Performance Report for:

PANDA

(AntiProton Annihilations at Darmstadt)

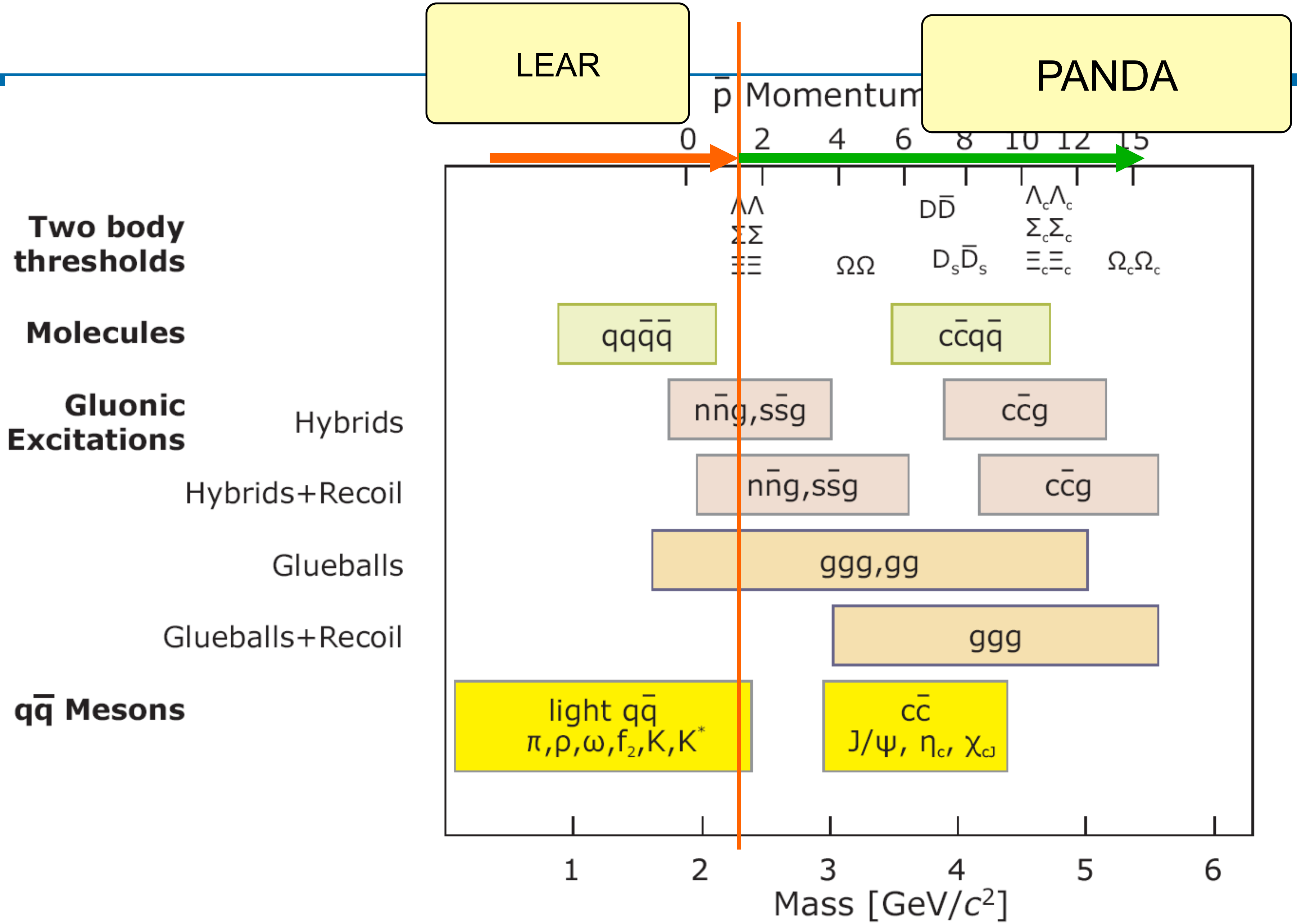
Strong Interaction Studies with Antiprotons

PANDA Collaboration

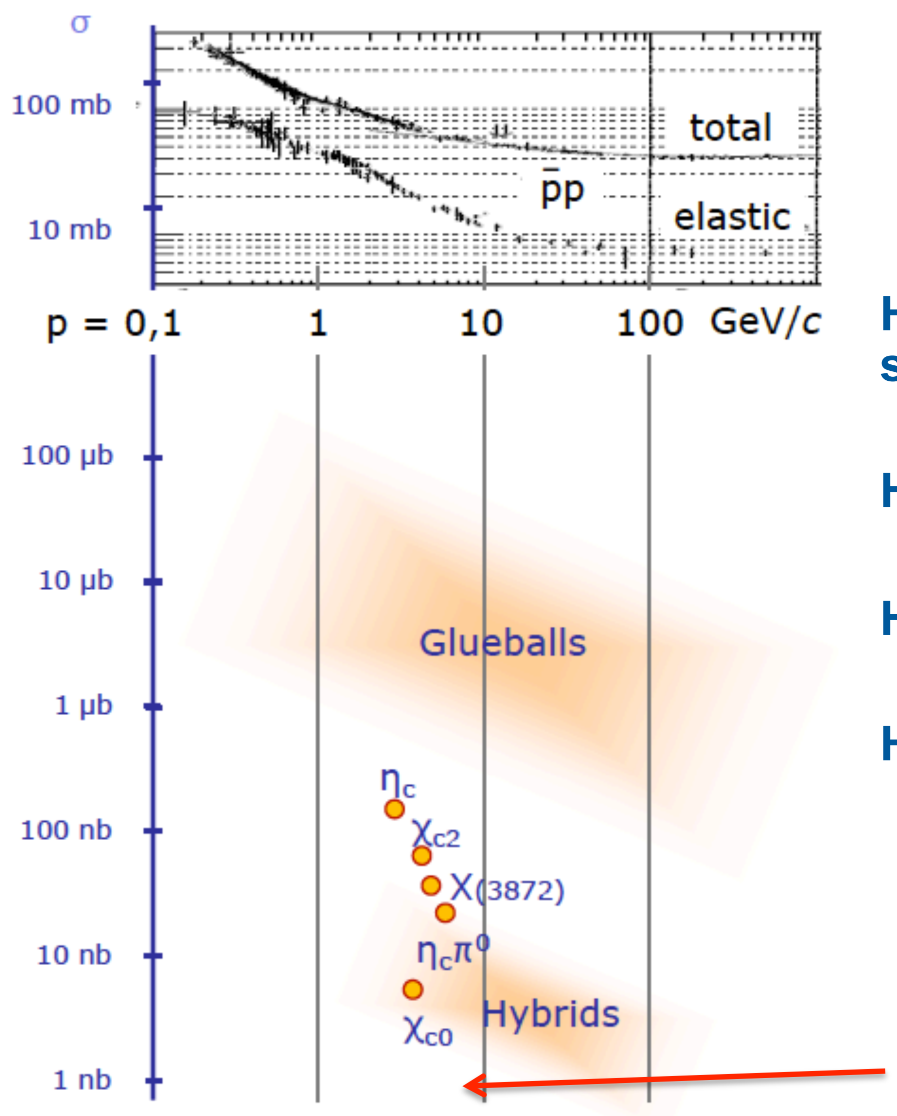
To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal PANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby 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 physics workshop in Uppsala, June 8 – 12, 2015


LEAR
PANDA
p̄ Momentum
0 2 4 6 8 10 12 15
Two body thresholds
ΛΛ
ΣΣ
ΞΞ
ΩΩ
DD̄
$D_s\bar{D}_s$
$\Lambda_c\Lambda_c$
$\Sigma_c\Sigma_c$
$\Xi_c\Xi_c$
$\Omega_c\Omega_c$
Molecules
$qq\bar{q}\bar{q}$
$c\bar{c}q\bar{q}$
Gluonic Excitations
Hybrids
$n\bar{n}g, s\bar{s}g$
$c\bar{c}g$
Hybrids+Recoil
$n\bar{n}g, s\bar{s}g$
$c\bar{c}g$
Glueballs
ggg,gg
Glueballs+Recoil
ggg
$q\bar{q}$ Mesons
light $q\bar{q}$
$\pi, \rho, \omega, f_2, K, K^*$
$c\bar{c}$
J/ψ, η_c, χ_{cJ}
1 2 3 4 5 6
Mass [GeV/c^2]

Detector Requirements from Physics Case



High luminosity and hadronic cross sections

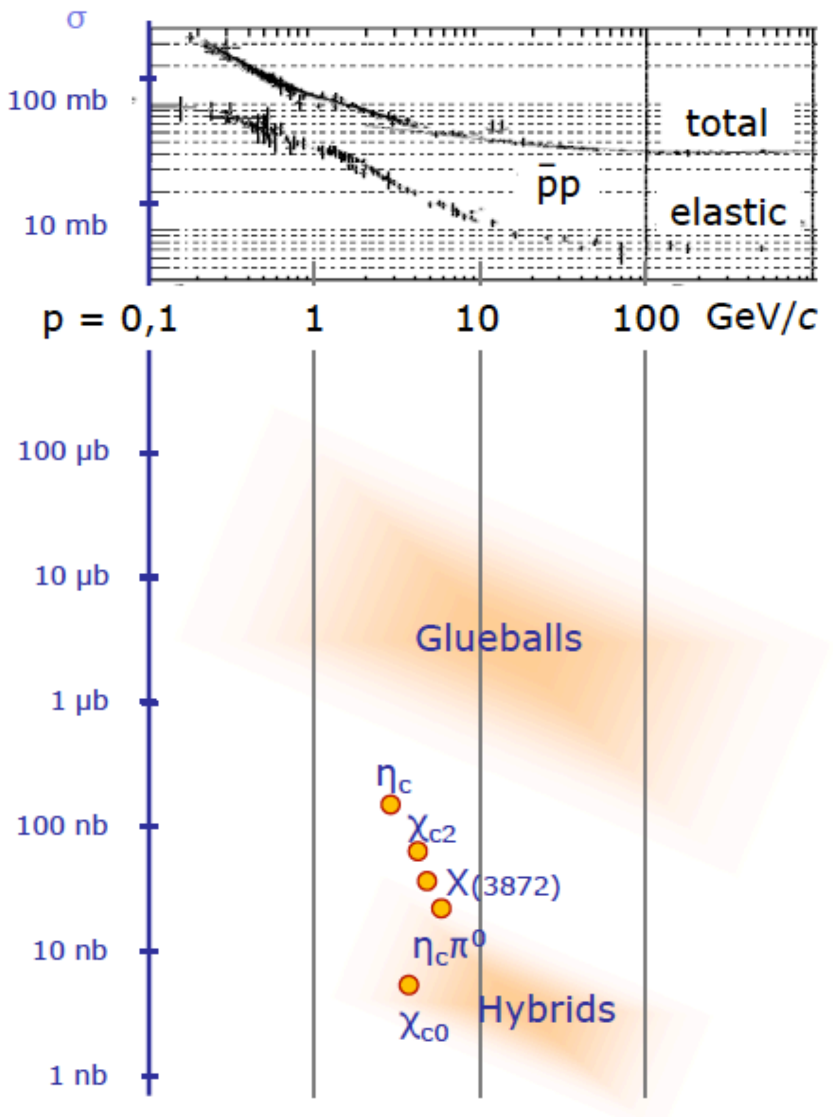
High rate capability, $2 \cdot 10^7\ s^{-1}$ interactions

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

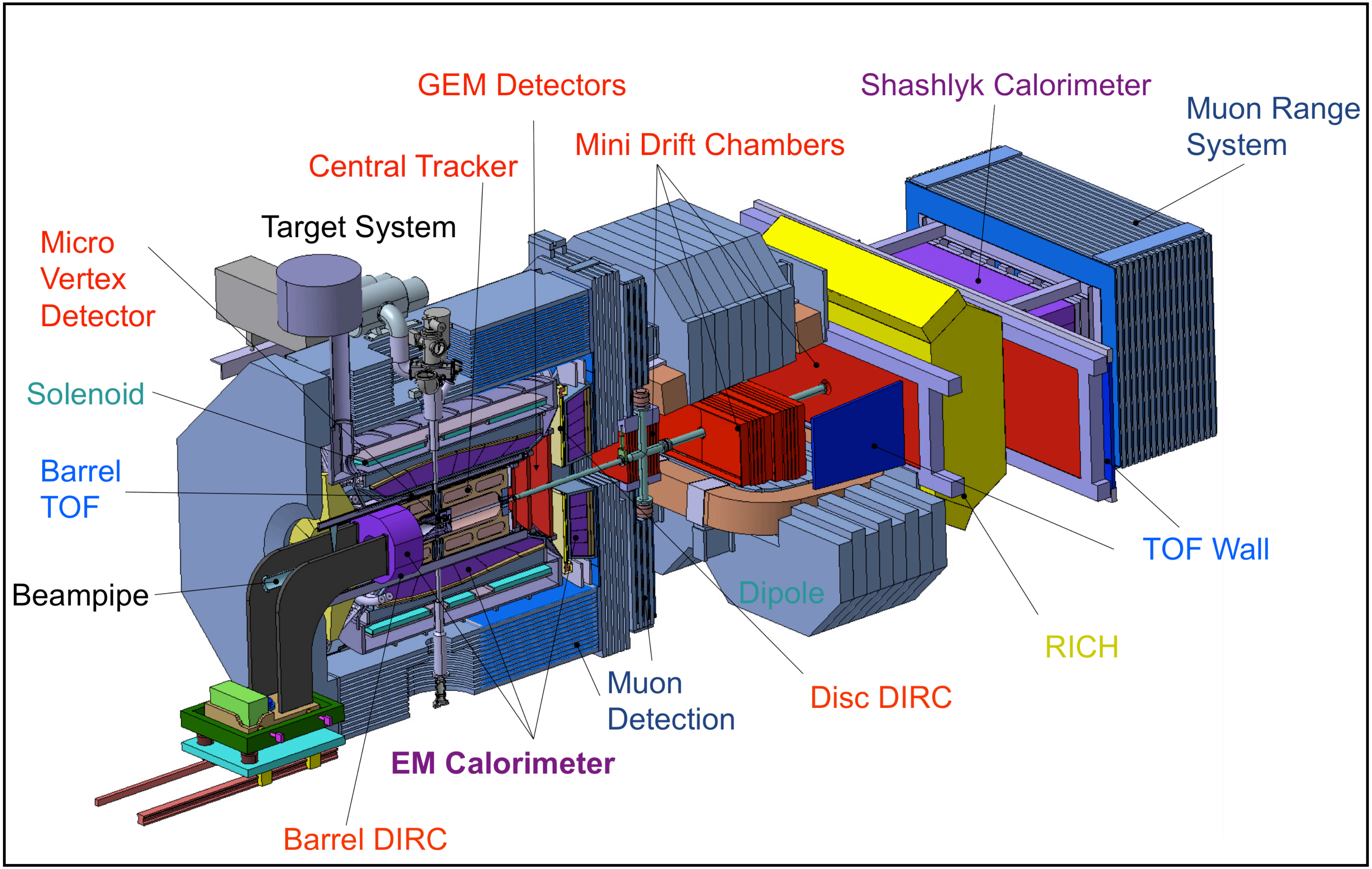
time of flight, dE/dx, muon counter

Displaced vertex info

$c\tau$ = 317 μm for $D^\pm$

$\gamma\beta \approx 2$

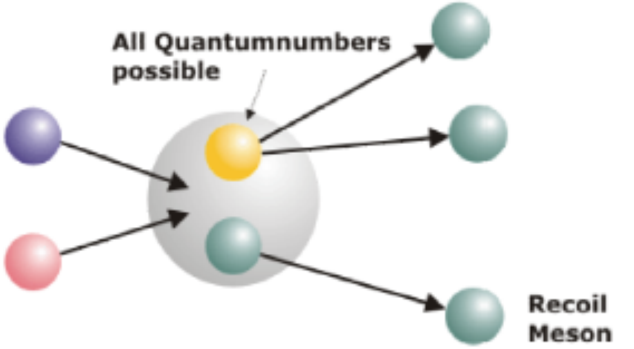
PANDA Detector



Antiproton annihilations: gluon rich environment

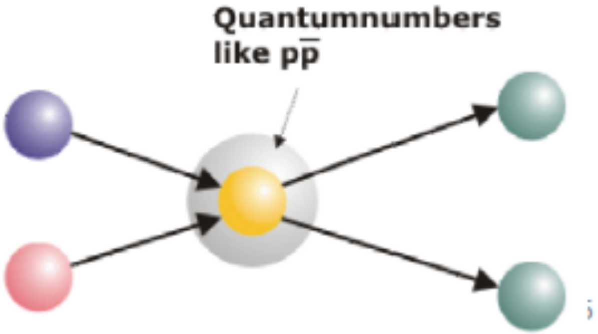
Production: all states with exotic and non-exotic quantum numbers accessible with a recoil
- high discovery potential

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

Reaction to Heuer-Review

PANDA Internal scrutiny process

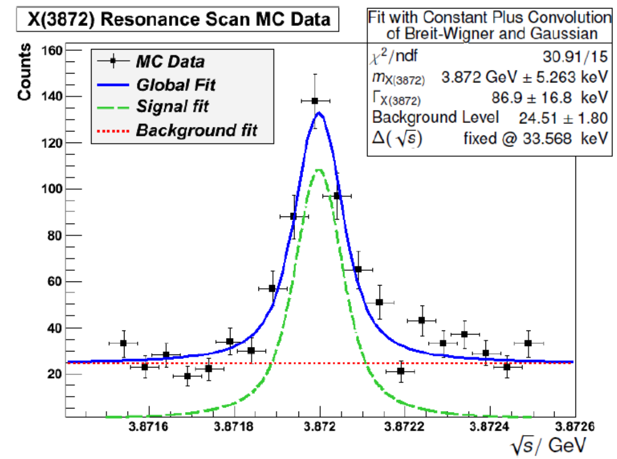
- Detector, Resources, Manpower, Science re-assessed, sharpened and day-one experiments defined (started in 2014)

- Equipment for day-one experiments
  - TDRs for Magnets, EMC, STT, MVD, Cluster-Jet Target, Muon System approved (covering 71% of **full** cost of setup)
  - Three TDRs to be submitted in the upcoming months: F-TOF, F-Tracker (reduced setup) and LumiDet, later the Bar-DIRC will be submitted
  - IT development – 2-3 years before start of operation: Detector-Controls, DAQ

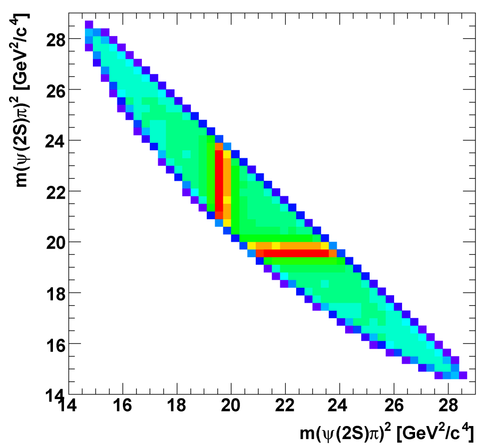
- Further components for future optimised operation
  - Full PID setup: Barrel-ToF, Disc-DIRC, FRICH
  - Higher resolution tracking: complete GEM Tracker, complete F-Tracker
  - Pellet Target
  - Higher rate DAQ

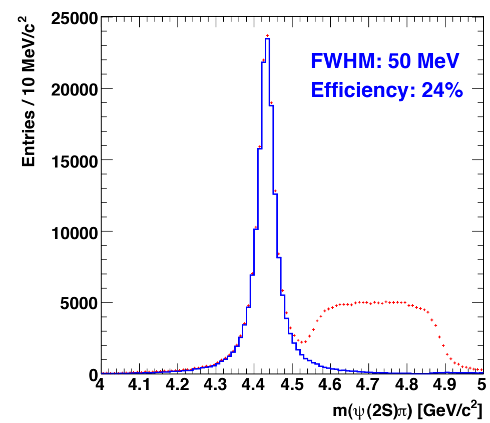
PANDA Day-One Science 2021-22

- Science re-assessed, sharpened and day-one experiments defined
  - Physics Workshop Uppsala
  - EMMI Rapid Reaction Taskforce
- Key experiments (initial cond.)
  - **Scan of narrow resonances**
    X(3872) and newly discovered narrow states and study of radiative decays
  - **Formation experiment of Z-resonances**
    (using a deuterium target?)
  - **Additional day-one measurements**
    - Time-like form factors
    - Excited hyperons, $\Lambda-\Lambda$bar
    - Precision charmonium spectroscopy e.g. $\chi_{c1,2}$
    - Delta – Delta content of Deuteron
  - Requirements: **Target**, **Tracking** and **Calorimetry**



Reconstructed width $\Gamma_{X(3872)}$ is consistent with input width of 100 keV.*





PANDA physics workshop, Uppsala, June, 2015

PANDA physics working groups

Baryons	Albrecht Gillitzer	FZ Jülich, Germany
Charmonium	Elisa Fioravanti	INFN Ferrara, Italy
Charmonium Like Exotics	Frank Nerling	HI Mainz, Germany
Drell-Yan	Marco Maggiora	INFN Torino, Italy
Electroweak Physics	Lars Schmitt	GSI Darmstadt, Germany
Hadrons in Nuclei	Albrecht Gillitzer	FZ Jülich, Germany
Hard Exclusive Processes	Frank Maas	GSI Darmstadt, Germany
Heavy-Light Systems	Johan Messchendorp	KVI Groningen, Netherlands
Hypernuclear Physics	Felice Iazzi	INFN Torino, Italy
Light Meson Exotics	Marc Pelizäus	Univ. Bochum, Germany
QCD Dynamics	Tord Johansson	Univ. Uppsala, Sweden
Timelike Form Factors	Frank Maas	GSI Darmstadt, Germany

After Heuer review: Competitiveness of PANDA physics in 2025 questioned

Confront PANDA physics with other running and future experiments:
LHCb, ATLAS, CMS, COMPASS, Jlab, BES-III, BELLE-II, J-PARC, ALICE

EMMI “rapid reaction task force”

Resonances in QCD

Matthias F. M. Lutz[a,b], Jens Sören Lange[c], Michael Pennington[d],
and,
Diego Bettoni[e], Nora Brambilla[f], Volker Crede[g], Simon Eidelman[h,i],
Albrecht Gillitzer[t], Wolfgang Gradl[j], Christian B. Lang[k], Volker Metag[c],
Takashi Nakano[l], Juan Nieves[m], Sebastian Neubert[n], Makoto Oka[o],
Steve L. Olsen[p], Marco Pappagallo[q], Stephan Paul[f], Marc Pelizäus[r],
Alessandro Pilloni[s,d], Elisabetta Prencipe[t], Jim Ritman[t], Sinead Ryan[u],
Ulrike Thoma[v], Ulrich Uwer[n], Wolfram Weise[w,f]

GSI October 12-14, 2015

Experts from international spectroscopy Community: BaBar, LHCb, BES, Belle, COMPASS, Jlab, Spring-8, ELSA, Theory
hep-ph: arXiv:1511.09353

Glueballs and hybrids:
“… Indeed PANDA complements and extends other experimental programmes ....
... the rates at PANDA will be high (10^7 candidate events per day) … “

Open Charm:
“… High precision measurements of the width are needed to scrutinize this picture.
PANDA … go down to about 100 keV by means of a threshold scan in p-bar p of
No other experiment can be that precise.”

Light baryons:
… Larger rates are foreseen with PANDA; which is expected … to search for doubly-strange baryons…

EMMI “rapid reaction task force”

Resonances in QCD

Matthias F. M. Lutz[a,b], Jens Sören Lange[c], Michael Pennington[d],
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GSI October 12-14, 2015

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hep-ph: arXiv:1511.09353

Charmonium like systems:

… One of the most important tasks is to map out the pattern of XYZ states… Angular momentum barrier effects … difficult to observe such states in B-meson decays. … have to await the running of PANDA … for the start of PANDA data taking, signfiicant numbers of X(3872), Y (4260) and Z+(3900) are expected already in year one. Cross-sections are in the order of nanobarn, compared to e+e- collisions … rare decays of the X(3872) are an opportunity for PANDA … the enormous statistics provided by 10^4 X(3872)'s produced per day, even at the start … the quest for the pattern of XYZ states can be addressed by finding partners to the presently observed states and measuring their radiative transitions …

I. Spectroscopy

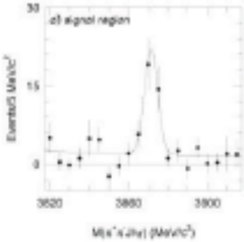
Elisa Fioravanti, Johan Meschendorp,
Frank Nerling, Marc Pelizäus

PANDA physics workshop in Uppsala, June 8 – 12, 2015

X,Y,Z

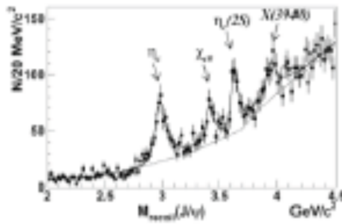
X(3872)

PRL 91,262001 (2003)



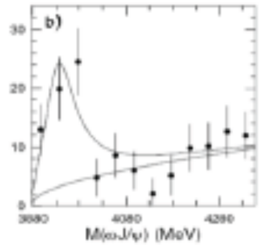
X(3940)

PRL 98,082001 (2007)



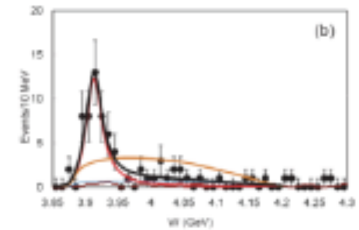
Y(3940)

PRL 94,182002 (2005)



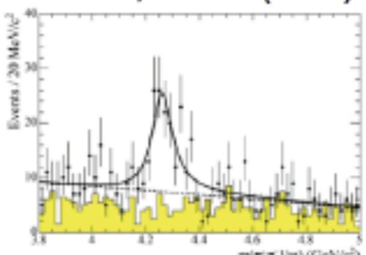
X(3915)

PRL 104,092001 (2010)



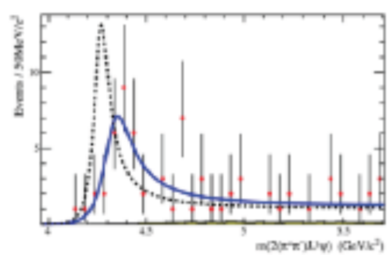
Y(4260)

PRL 95,142001 (2005)



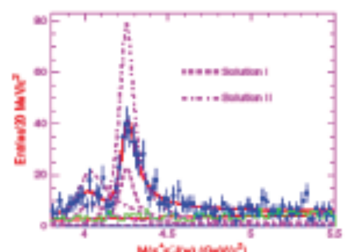
Y(4350)

PRL 98,212001 (2007)



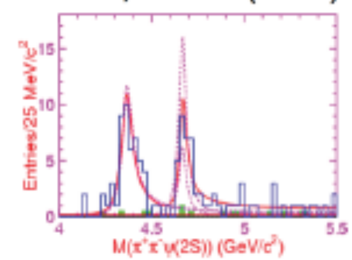
Y(4008)

PRL 99,182004 (2007)



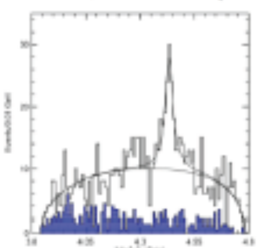
Y(4660)

PRL 99,142002 (2007)



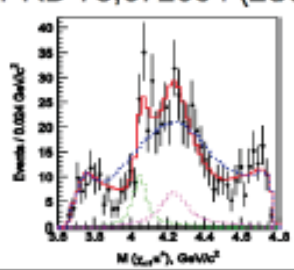
Z(4430)$^-$

PRL 100,142001 (2008)



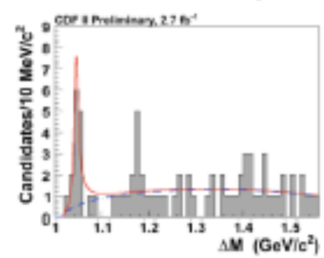
Z_1^- & Z_2^-

PRD 78,072004 (2008)



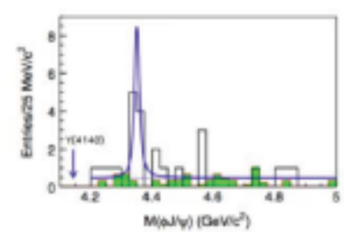
Y(4140)

PRL 102,242002 (2009)



X(4350)

PRL 104,112004 (2010)

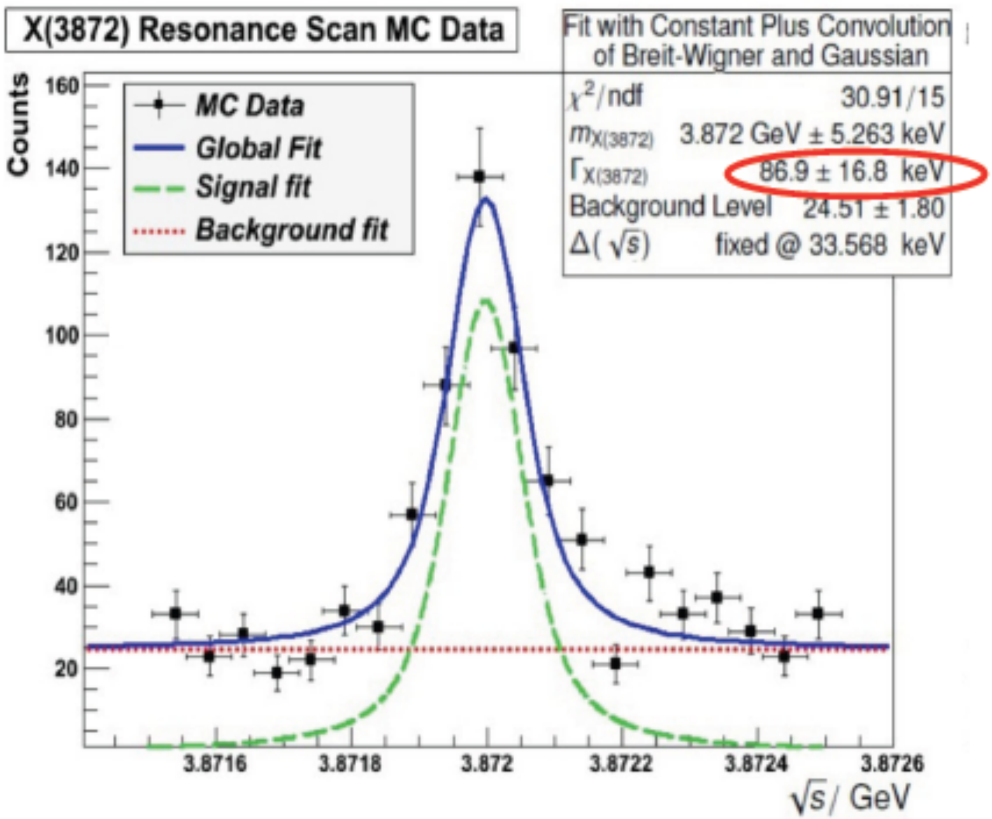


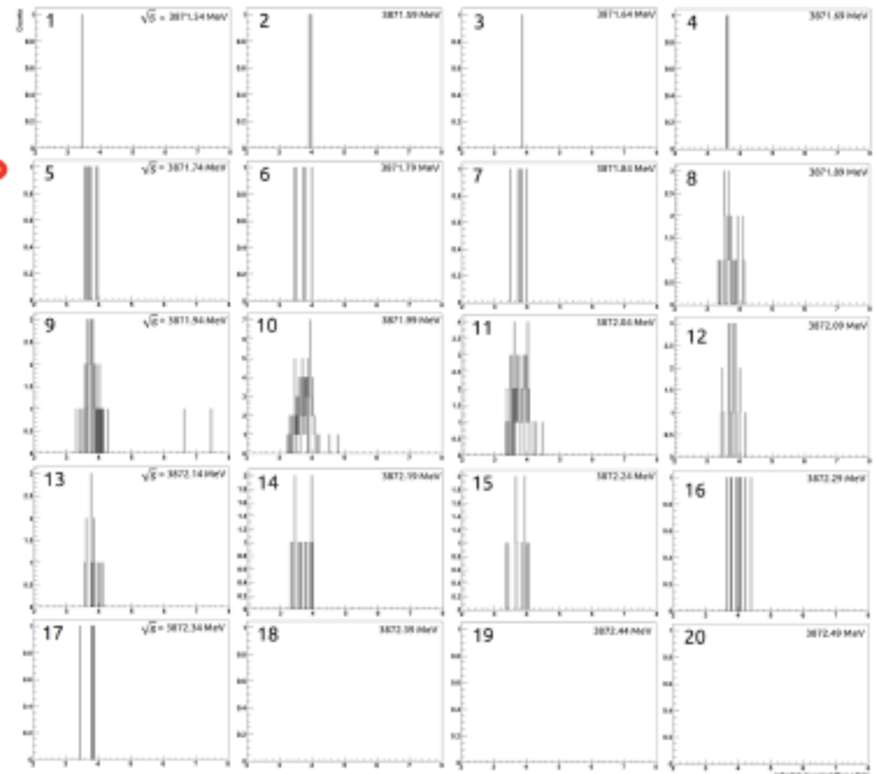
X(3872): Lineshape Scan at PANDA

- Upper limit on branching ratio by LHCb:

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

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





→ 40 days of data taking

[M.Galuska, PhD thesis]

X(3872): PANDA vs. Belle II And BES III

Some numbers, considering $J/\psi\, \pi^+\pi^-$ decay mode only:

- PANDA, assume $\sigma(p\bar{p} \to X(3872))$=50 nb
  statistics ~130 (1300) per day on peak for $\mathcal{L}$=2 x 10^{31} (10^{32}) $cm^{-2}\, s^{-1}$
  efficiency ~50% (4 charged, exclusive)
  high boost β ... =0.89 (fixed target) → $\beta\gamma$=1.95
  mass
- Belle
  statis
  effien
  small boost $\beta\gamma$=0.43 (Belle), $\beta\gamma$=0.28 (Belle II)
  mass resolution ~10-20 MeV (unfitted)

350 X(3872)/day
820 Y(4260)/day
176 Z(3900)/day

P̄ANDA is an
X Y Z factory

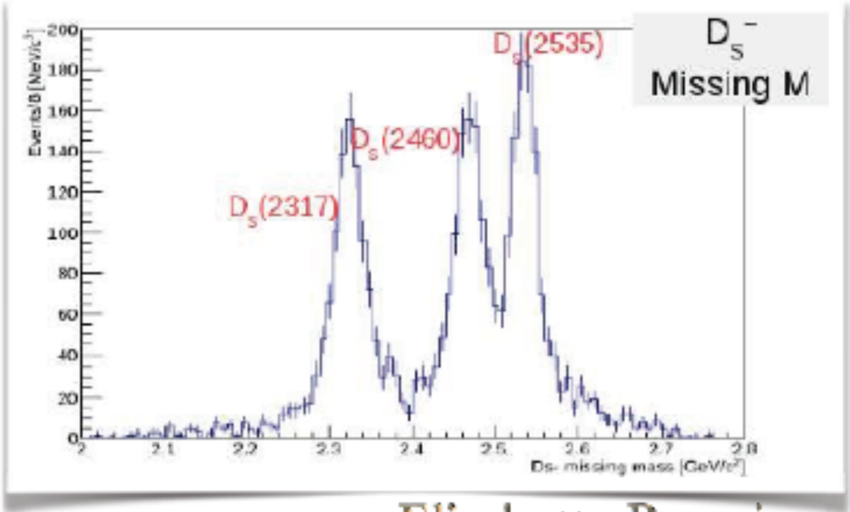
) measurement
e X(3872),
lineshape!

- BESIII
  $e^+e^- \to Y(4260) \to \gamma X(3872)$ BESIII, Phys. Rev. Lett. 112(2014)092001
  ≃1200 Y(4260) per day (σ≃60 pb, integrated luminosity ≃20 pb^{-1}/day)
  but branching fraction small, only ≃0.5% (≃20 events in ~4 weeks)
  rare

[S.Lange, Worms 2014]

PANDA Opportunities

- **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



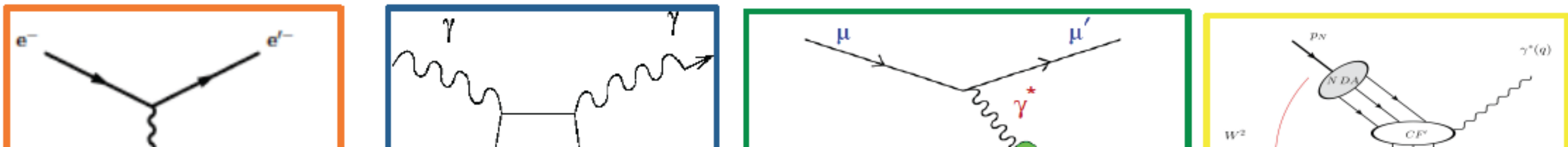
Elisabetta Prencipe

II. Electromagnetic Processes

PANDA physics workshop in Uppsala, June 8 – 12, 2015

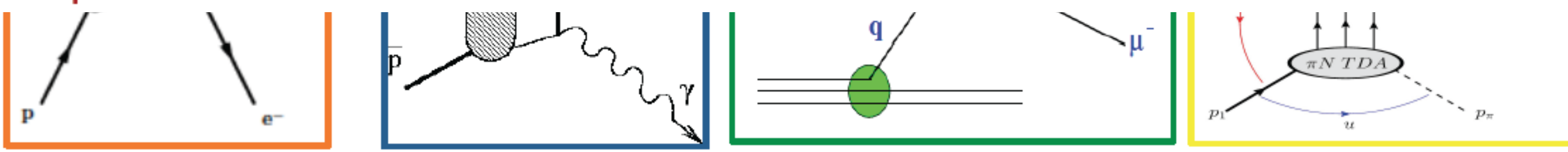
Alaa Dbeyssi

(Virtual) photon in intermediate state

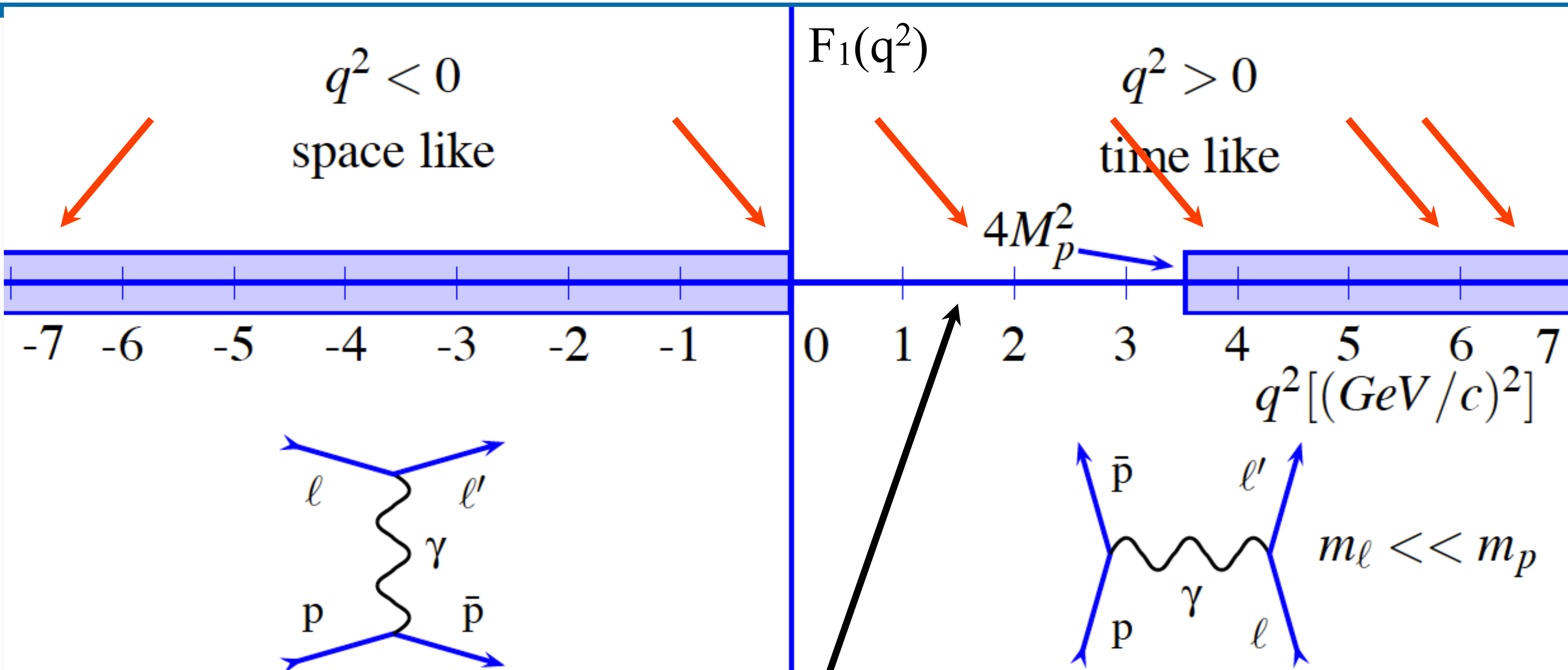


Crossing symmetry: - different kinematical regions
- observables are counterparts

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



Electromagnetic Form factors of the Nucleon



unphysical region

Form Factor real

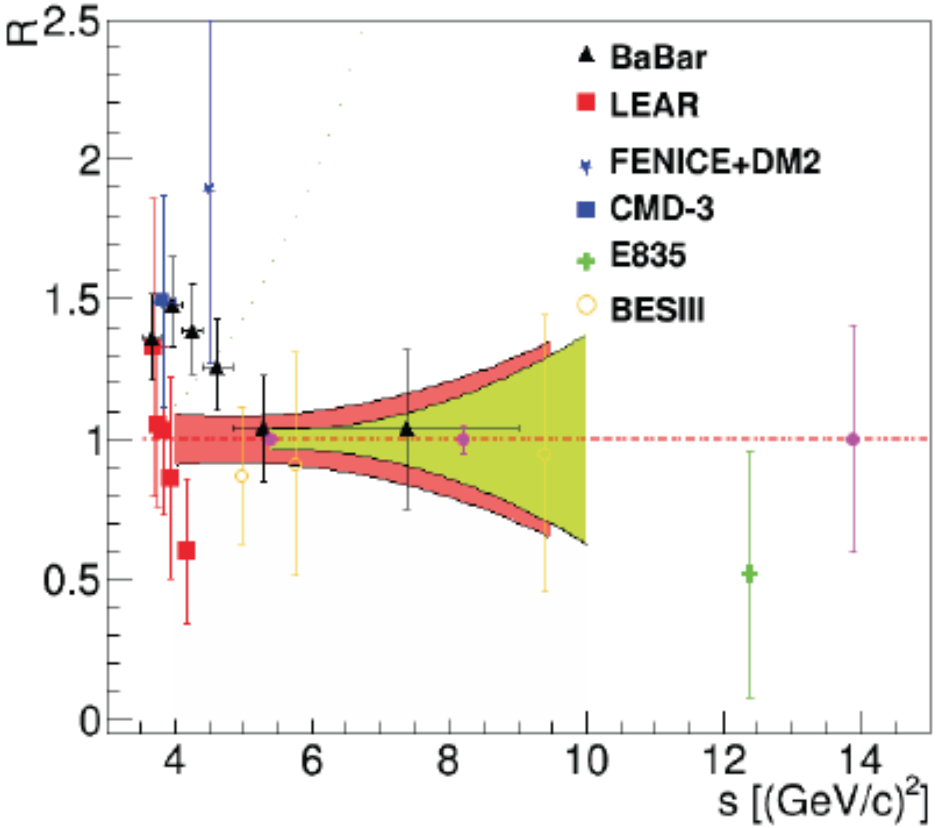
cross section (Rosenbluth)
no single spin observables
double spin observables

Form Factor complex

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

connected by dispersion relations

Current/future experiments: BESII-PANDA



21 scan points 2015 (552 pb^{-1})

Monte Carlo Sim., R=1 (C. Morales)

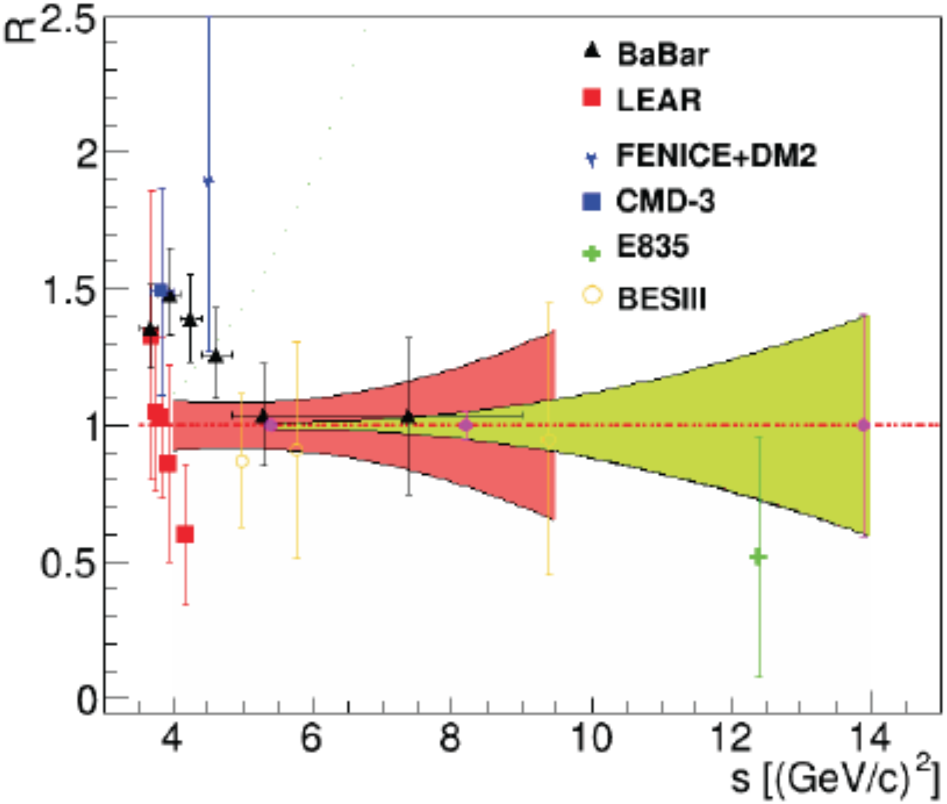
L=0.2 fb^{-1}

2.10^{31} cm^{-1} s^{-1}

~5 months data taking /point

	BESIII	PANDA (e^+e^-)	PANDA (mu^+mu^-)
s [(GeV/c)^2]	4 - 9.5	5 - ~10	@ 5.4
$R=\|G_E\|/\|G_M\|$	9 % - 35 %	3.5 % - 38 %	13.3 %

Current/future experiments: BESII-PANDA



BESIII

21 scan points 2015 (552 pb^{-1})

Monte Carlo Sim., R=1 (C. Morales)

panda

L=2 fb^{-1}

2.10^{32} cm^{-1} s^{-1}

~5 months data taking /point

	BESIII	PANDA (e^+e^-)	PANDA (mu^+mu^-)
s [(GeV/c)^2]	4 - 9.5	5 - 14	5 - ~9
$R=\|G_E\|/\|G_M\|$	9 % - 35 %	1.4 % - 41 %	5 % - 18.7 %

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
$\bar{p}p \rightarrow \mu^+\mu^-$	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
$\bar{p}p \rightarrow J/\psi\pi^0$	TDAs	P=5.513 P=8.0 P=12.0	>8 >70 >600	Feasibile
$\bar{p}p \rightarrow \gamma\gamma$ $\bar{p}p \rightarrow \pi^0\gamma$	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)

PANDA physics workshop in Uppsala, June 8 – 12, 2015

Strange hyperons

Excited strange hyperon spectrum:

• F … ctor

→ the f … PANDA!

PANDA is a strangeness factory!

strangeness

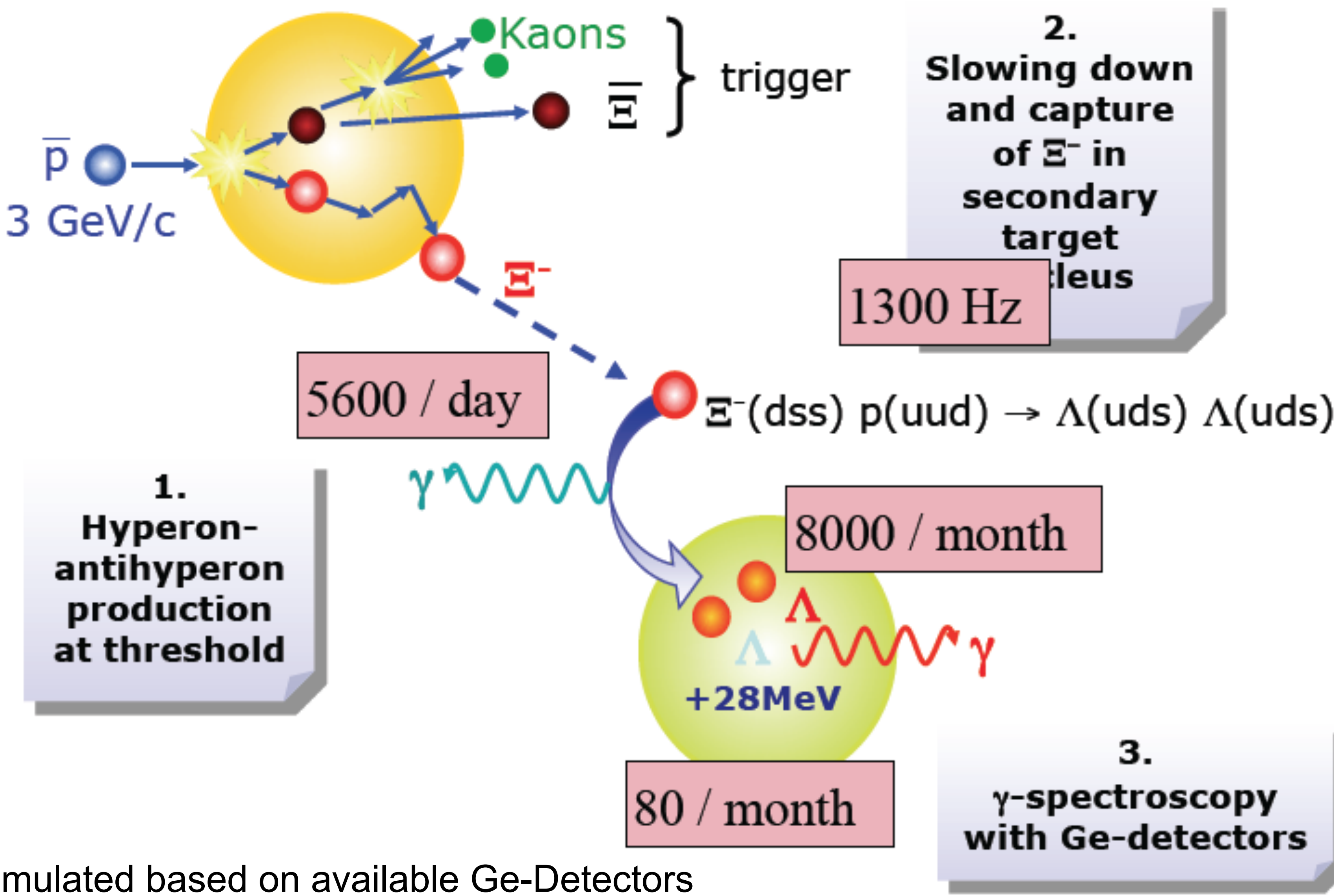
- Octet Ξ* partners of *N** ?
  - Only a few found
- Decuplet Ξ* and Ω* partners of Δ*?
  - Nothing found

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	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

Production of Double Hypernuclei



Fully simulated based on available Ge-Detectors

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