The PANDA Physics Programme

International Conference on
Exotics Atoms and Related Topics
EXA20011 - Wien, September 4-9, 2011

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on behalf of the PANDA Collaboration

OUTLINE

- **Introduction**
  - **PANDA at FAIR**
  - **Antiproton's Power**
- **The Physics Programme**
  - **Charmonium and Open Charm Spectroscopy**
  - **Exotic Hadrons**
  - **Baryon-AntiBaryon Production**
  - **Proton Form Factors**
  - **Antiproton-Nucleus interactions**

THE FUTURE ANTIPROTON FACILITY @ GSI

FAIR

Facility for Antiproton and Ion Research

Primary Beams
$^{238}U^{28+}$ 10^{12}/s @ 2.7 AGeV
$^{238}U^{92+}$ 10^{10}/s @ 35 AGeV
Protons 2×10^{13}/s @ 30 GeV

Secondary Beams
- Radioactive ion beams 2 AGeV
- Antiprotons 0 –15 GeV/c
  Antiproton production target

Storage and Cooler Rings
- Rare isotope and stable ion beams
- e^- – A or pbar-A collider
- 10^{11} stored and cooled pbar 0.8—15 GeV/c
- Low Energy pbar for antiH beyond 2015
- *Future: polarized antiprotons ?*

Cost 1200 M Euros
Commissioning 2017

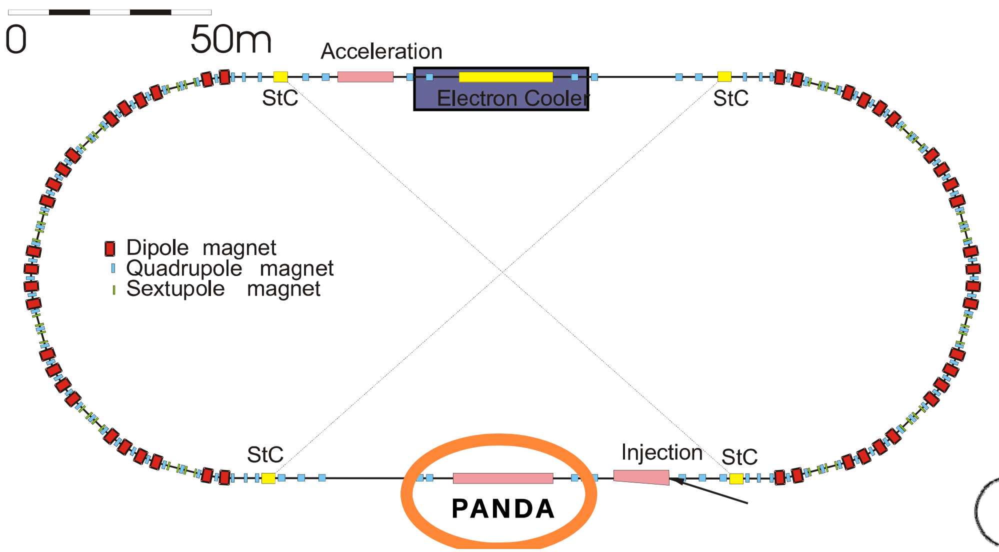
Highligths: -Atomic, Plasma & Applied Physics
-Nuclear structure & Astrophysics –Antiproton & HI Physics

High Energy Storage Ring for Antiprotons

HESR PARAMETERS

- Momentum Range 1.5 – 15 GeV/c ($2.2 < \sqrt{s} < 5.5$ GeV)
- Storage ring for internal target operation
- $N_{stored} = 5 \times 10^{10}$ antiprotons

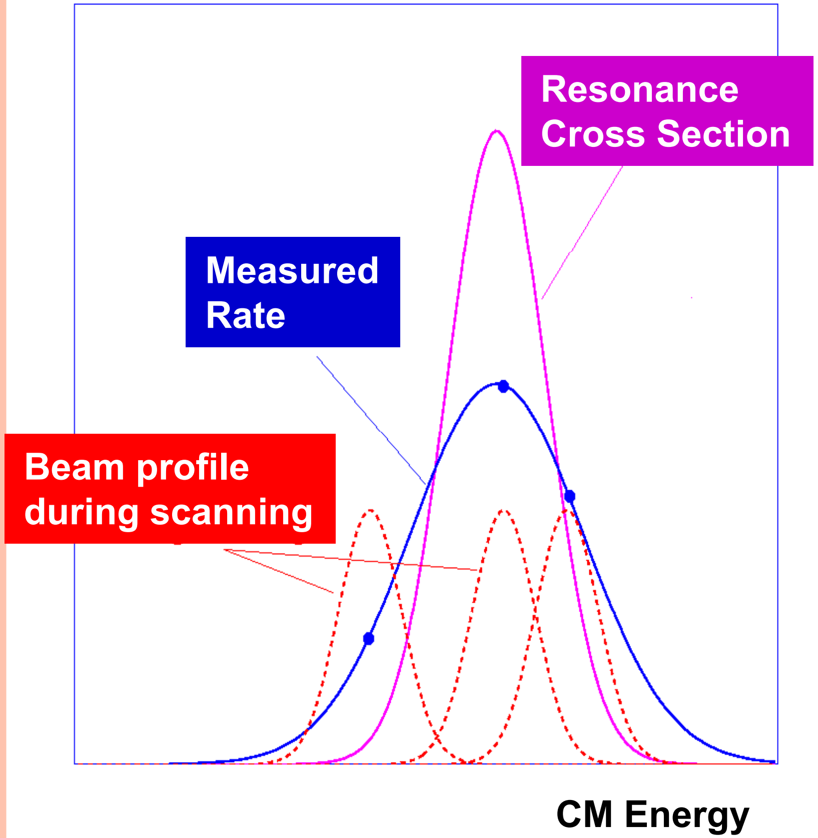
high resolution mode	high luminosity mode
$\Delta p/p \sim 10^{-5}$ $L \sim 10^{31}\ cm^{-2}\ s^{-1}$	$\Delta p/p \sim 10^{-4}$ $L \sim 2 \times 10^{32}\ cm^{-2}\ s^{-1}$
Electron cooling ≤ 8.9 GeV/c	Stochastic cooling ≥ 3.8 GeV/c



Antiproton's Power

Finite-energy spread of the beam

➡ Measured Cross Section is a convolution of the Breit-Wigner σ_{BW} and the beam energy distribution function



$$\sigma(E) = \int f(E,\Delta E_B)\,\sigma_{BW}(E)\,dE$$

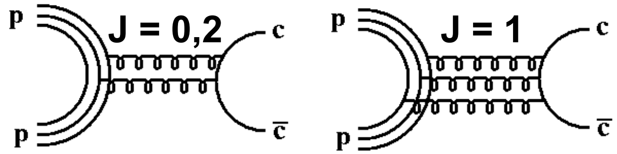
Excellent Resonance Scan

- Tune E_{CM} to probe resonance
- Get precise mass and width
- Energy resolution < 100 keV

$\bar{p}p$	E835: 240 keV
e^+e^-	Crystall Ball: 10 MeV

Optimization of the scan for every single resonance

ANTIPROTON'S POWER



p̄ p interactions

- States with **All quantum numbers** can be directly formed

  $\bar{p}p \rightarrow \chi_{c1} \rightarrow \gamma\, J/\Psi \rightarrow \gamma\, e^+e^-$
- very good mass resolution
  < 100 keV (p̄ BEAM)

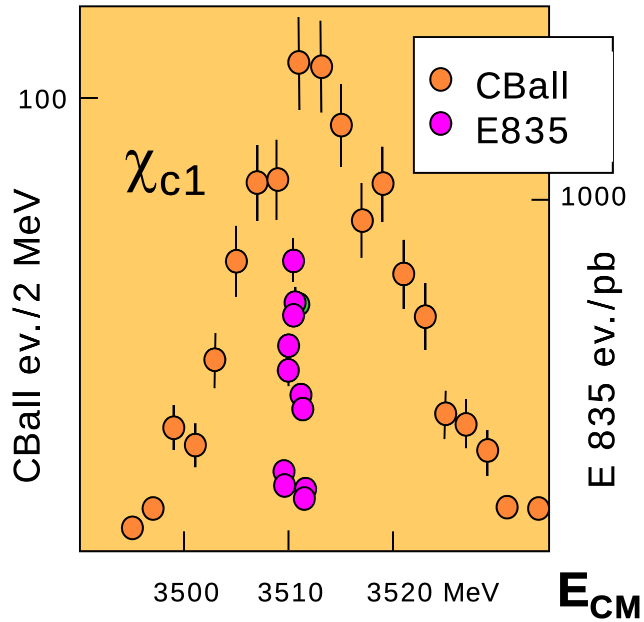
$e^+ e^-$ interactions

- **Only $J^{PC} = 1^{--}$** states are formed

  Other states only by secondary decays

  $e^+e^- \rightarrow \gamma\, \chi_{c1} \rightarrow \gamma\, \gamma\, J/\Psi \rightarrow \gamma\, \gamma\, e^+e^-$
- moderate mass resolution
  ~5 MeV (DET)

Example of χ_{c1}



CBall, PRL 48 (1982) 70
E835, PRD 62 (2000) 05202

PANDA vs E835 →

Luminosity (x 10)
Momentum resolution (x 1/10)
Angular coverage and magnetic field

Overview of PANDA Physics

Hadron Structure and Quark-Gluon Dynamics

Charmonium ($c\bar{c}$) Spectroscopy
- Unprecedented precise measurements of masses, widths and BR

Quark confinement

D meson Spectroscopy
- Precise measurement of mass and width

See Mertens' talk on D_{s0}^{*}

Exotic states
- Hybrids ($q\bar{q}g$) • Glueballs (gg or ggg) • Multi-quark systems

QCD prediction

Baryon-AntiBaryon production
- Baryon Spectroscopy • QCD dynamics

from Partons to Hadrons

Nucleon Structure
- Time-like form factors • Transverse nucleon spin • Generalised Parton Distributions

Charm in nuclear medium
- In-Medium modifications of the Hadrons

See Bühler's talk on Hadrons in Matter

Chiral Symmetry Breaking

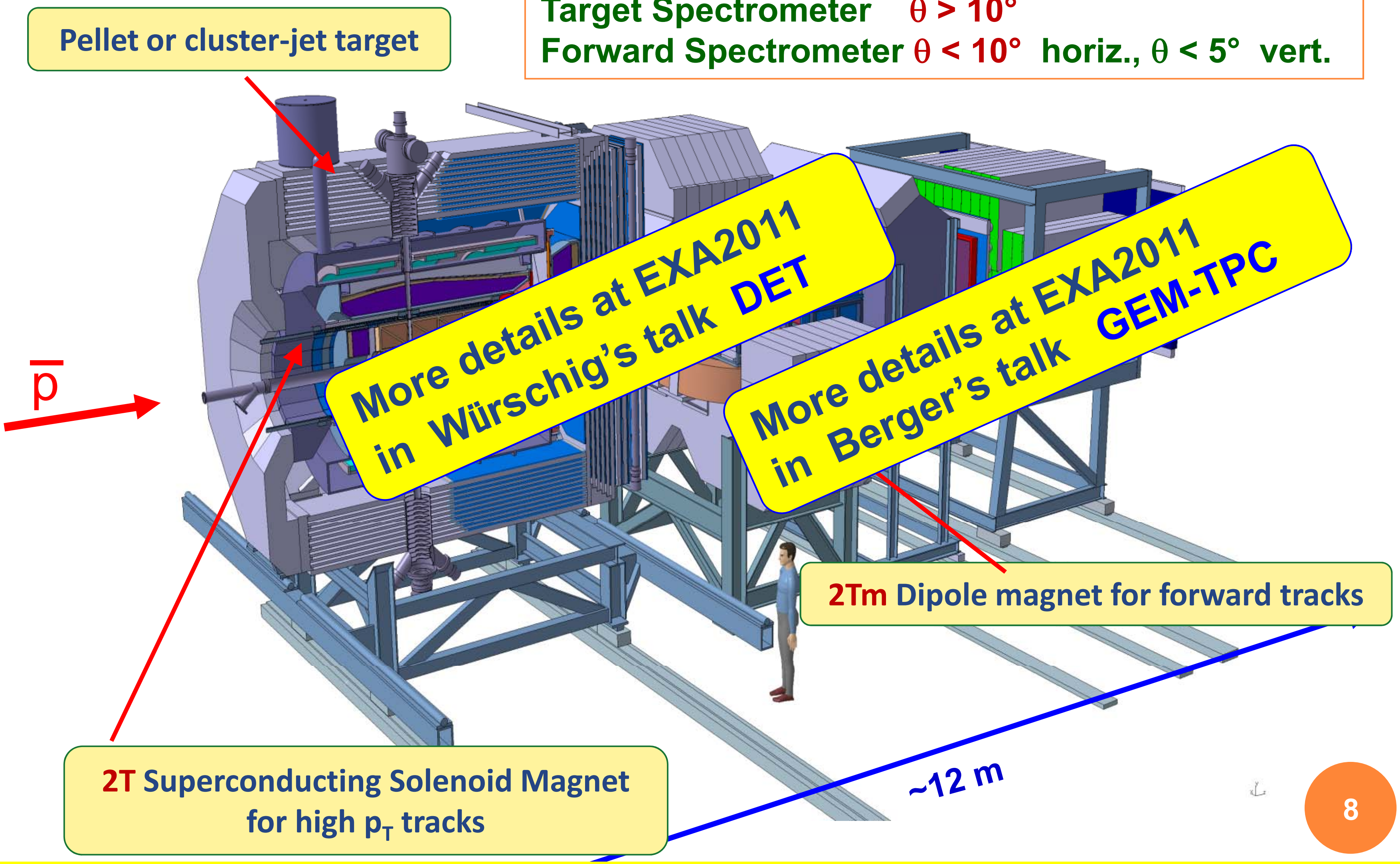
…nd Y-Y interactions

Nuclear Physics: Strangeness Sector
- Double-Λ hypernuclei (Ξ^- capture) • γ … …clear spectroscopy

See Achenbach's talk on HYP

The Spectrometer

Target Spectrometer $\theta > 10°$
Forward Spectrometer $\theta < 10°$ horiz., $\theta < 5°$ vert.

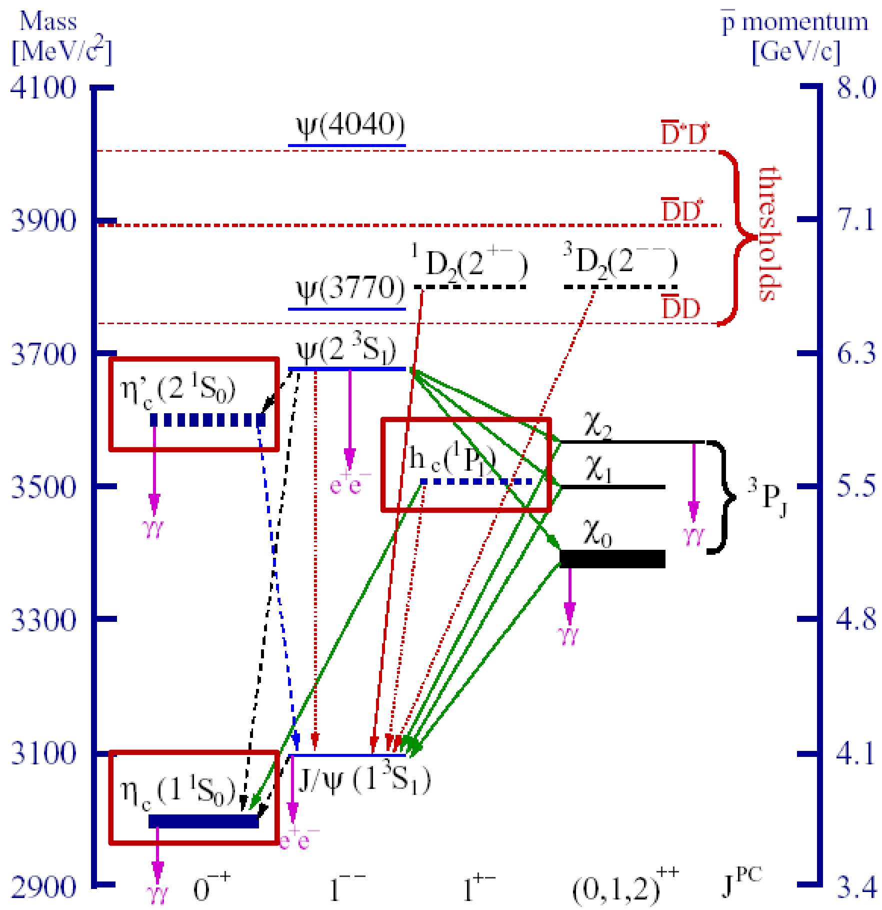


Close interplay between Machine and Detector is fundamental

CHARMONIUM SPECTROSCOPY

Spectrum more clear than in the past

- **New precise measurements of η_c Mass 2980.3 ± 1.2 MeV**
- **η'_c unambiguously observed Width 14 ± 7 keV**
- **h_{1c} Width not yet measured**
- **High *L* states: accessible in $\bar{p}p$**
- **Incomplete picture above $D\bar{D}$ threshold**
- **New "X, Y, Z" states (Belle, BaBar, CLEO, D0, CDF, ...)**



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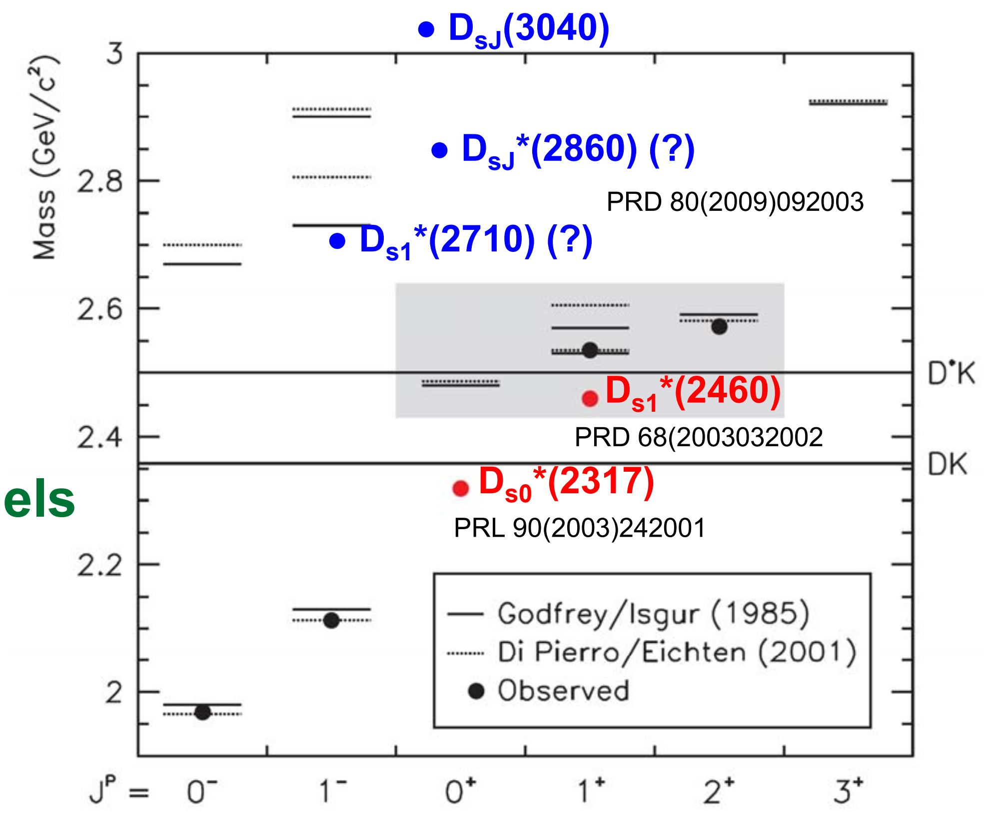
OPEN CHARM

Missing States and Unexpected States

See Mertens' talk

- New narrow states (Γ < 3.8 MeV u.l.)
  D_{s0}^* (2317) and D_{s1}^* (2460)
  BaBar, CLEO, Belle
- States just below (~ 45 MeV)
  DK and D*K thresholds
- Masses lower (<150 MeV)
  than expected by Quark models
- Recent discovery of new
  charmed-strange D_{sJ}
- Unclear interpretation
  molecules, tetraquarks, …



B. Aubert et al. (BaBar), PR D74 (2006) 032007

EXOTIC STATES

$p\bar{p}$ annihilation is a gluon rich process

Simple Constituent Quark model

Mesons: $q\bar{q}$ pairs are the constituents

$J^{PC} = 0^{-+}\ 0^{++}\ 1^{--}\ 1^{+-}\ 1^{++}\ 2^{++}$ allowed → accessible in formation

BUT

Gluons carry colour charge and play an essential dynamical role

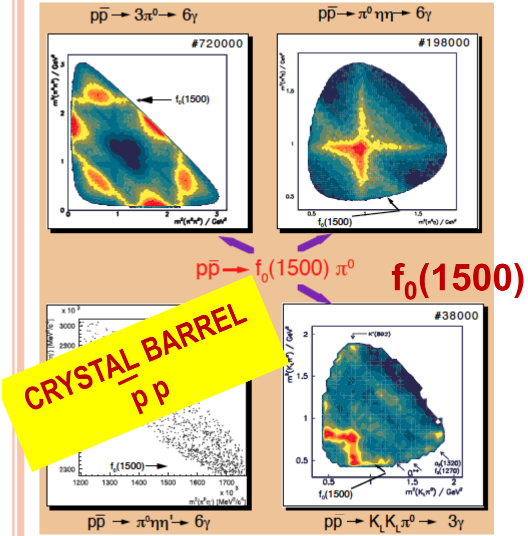
Constituents of QCD bound states (exotics)

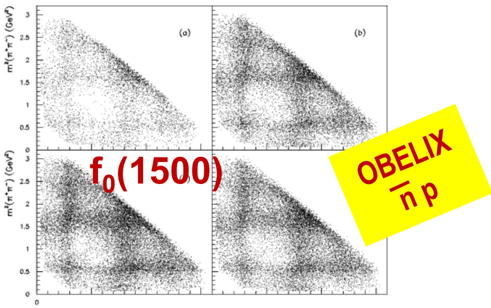
$J^{PC} = 0^{--}\ 0^{+-}\ 1^{-+}\ 2^{+-}$ forbidden → accessible in production with recoil particle

- **Cross sections for glueballs and light hybrids similar to light hadrons ~ 1-100 μb**

EXOTICS IN THE LIGHT MESON REGION

- More than 10 states classified as exotic candidates
- Most of them observed in $p\bar{p}$ interactions





Main non-$q\bar{q}$ candidates	
$f_0(980)$	4q state - molecule
$f_0(1500)$	0^{++} glueball candidate
$f_0(1370)$	0^{++} glueball candidate
$f_0(1710)$	0^{++} glueball candidate
$\eta(1410)$; $\eta(1460)$	0^{-+} glueball candidate
$f_1(1420)$	hybrid, 4q state
$\pi_1(1400)$	hybrid candidate 1^{-+}
$\pi_1(1600)$	hybrid candidate 1^{-+}
$\pi\,(1800)$	hibrid candidate 0^{-+}
$\pi_2(1900)$	hybrid candidate 2^{-+}
$\pi_1(2000)$	hybrid candidate 1^{-+}

Difficult to disentangle from conventional states

The spectrum is populated by several broad states

GLUEBALLS AND HYBRIDS

Glueballs and Hybrids with exotic quantum numbers

- **should be rather narrow (< 50 MeV)**
- **should be easier to identify**

LQCD: heavy glueballs

- M ~ 4740 MeV/c²

  $J^{PC} = 0^{+-}$

- M ~ 4140 MeV/c²

  $J^{PC} = 2^{+-}$

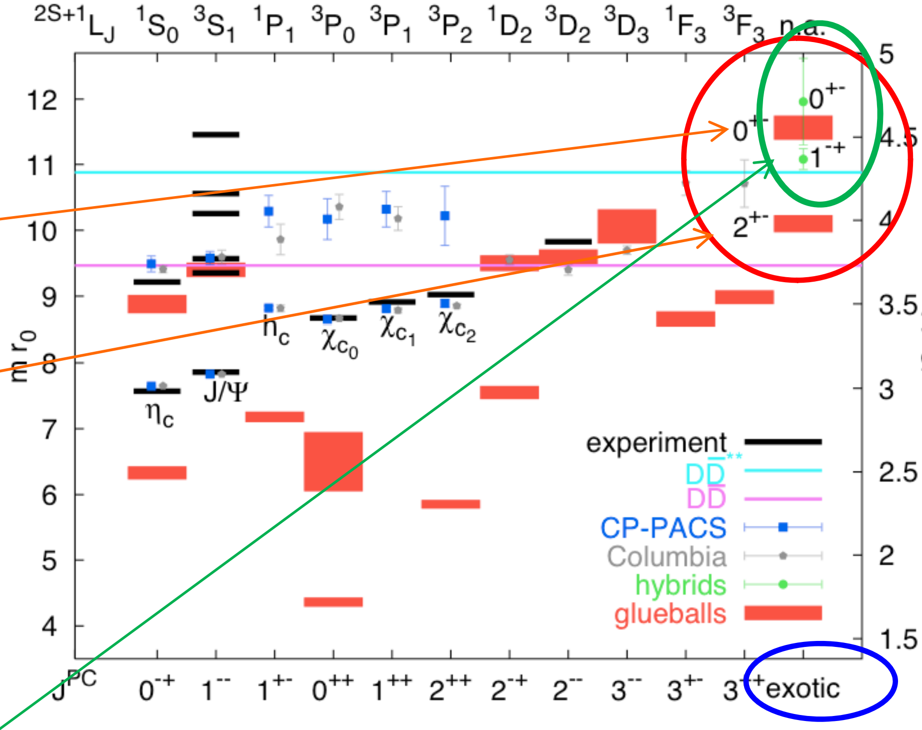
- Decay: Flavour blind

  charmed final states

Hybrid charmonium

- M ~ 4.2 – 4.5 GeV/c²

  $J^{PC} = 0^{+-}\ ,\ 1^{-+}\ ,\ 2^{+-}$



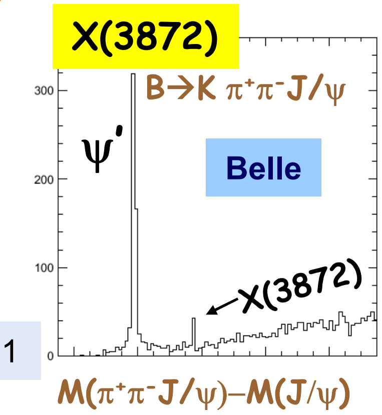
G.Bali, EPJA 1 (2004) 1

Barnes and Close, PRD 52 (1995) 5242
Lacock et al. (LQCD)

EXOTIC X Y Z STATES

In 2003 Belle first observed the X(3872)
as a narrow peak at M ~ 3872 MeV/c^2
in the invariant mass $\pi^+\pi^-J/\Psi$ in $B^- \rightarrow K^- X$ decays
Molecule or Tetraquark state ?

PRL 91 (2003)262001



Soon after a series of new hadronic structures, like Ys have been observed by different experiments (Belle, Babar, CDF, D0)
Y(4260), Y(4360), Y4660) Masses much higher than open charm threshold
Unusual decay patterns → Charmonium Hybrid or Multiquark state ?

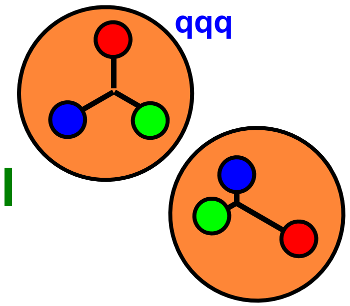
Z$^+$(4430) is unique: non zero electric charge, not possible for conventional $c\bar{c}$ or $c\bar{c}$-gluon hybrids
→ Prime candidate for a Multiquark meson (molecule or tetraquark ?)

Currently, understanding of these unusual structures is a hot topic

BARYON SPECTROSCOPY

Understanding of the Baryon excitation spectrum is one of the prime goal of pQCD

- **Quark Models, SU(3) symmetry**
  - **Most of data are available in the Nucleon sector**
  - **Some low-lying states are not at the predicted energies**
  - **Predicted higher lying states not seen experimentally**



- **Possible explanation**
  - **quark-diquark structure → reduced number of internal degrees of freedom → reduced number of states**
  - **Dinamical generatation ?**

    Excited Baryon States ↔ Meson-Baryon State ? Mixing of states?

- **Little is known about excited states of Λ and Σ, and even less about Ξ and Ω**

BARYON SPECTROSCOPY

A baryon spectroscopy program ranging from N* over multi-strange to charmed baryon physics is possible in PANDA

- $\bar{p}p \rightarrow NN^*$ or $pp \rightarrow NN^*$: no obvious advantage
- Strange and charmed Baryons $\bar{p}p \rightarrow \bar{Y}Y^*$:
  Production of K and D not required $\Rightarrow$ threshold reduced
  Pattern symmetric in baryon and antibaryon channel
- HESR up to $\sqrt{s}$ = 5.5 GeV
  Enough to study Baryons with |S|=3 and even |C|=1

	Ξ	Ω	Λ_c	Σ_c	Ξ_c
ϵ_{max} [GeV]	2.86	2.16	0.93	0.76	0.56

- Relatively large cross section for processes with strange baryon-antibaryon in final state

	$\bar{\Lambda}\Lambda$	$\bar{\Xi}\Xi$	$\bar{\Omega}\Omega$	$\bar{\Lambda}_c\Lambda_c$	$\bar{\Omega}_c\Omega_c$
σ	100μb	2 μb	2 nb	20 nb	0.1 nb

BARYON SPECTROSCOPY

$\bar{\Xi}\Xi$ cross section up to $2\mu b \Longrightarrow$ Sizeable population of excited states

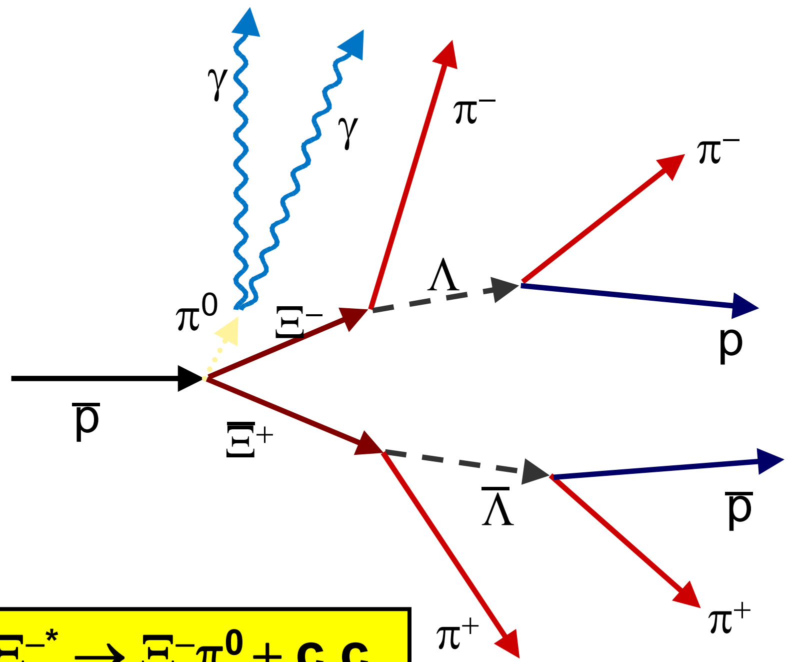
Yield ~ 10^7 Ξ /day produced at $L = 10^{32}$ $cm^{-2}s^{-1}$

$\bar{p}p \rightarrow \bar{\Xi}\Xi^* + c.c.$

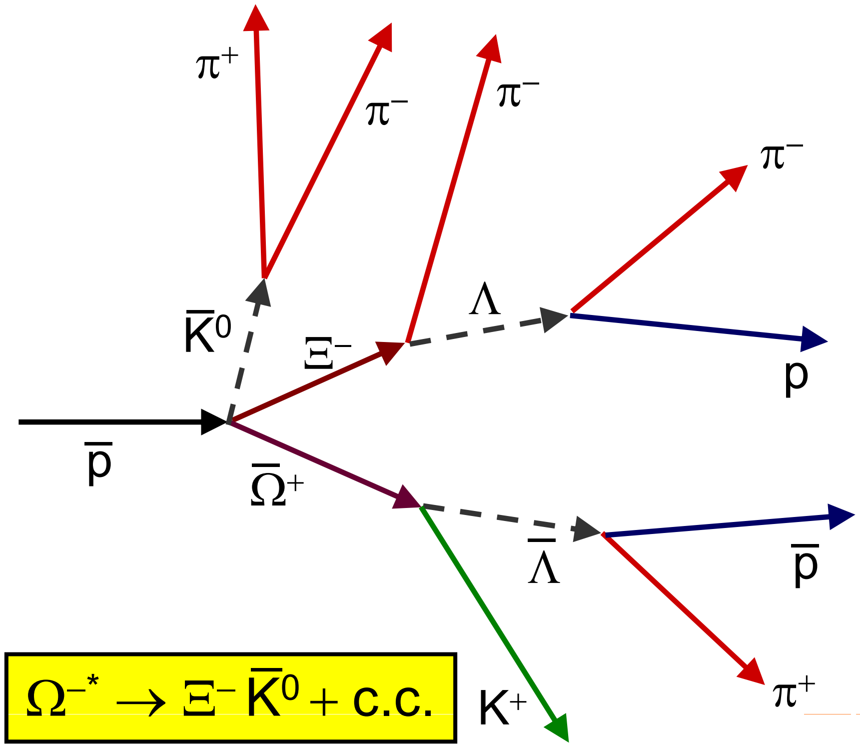
$\Xi^* \rightarrow \Xi\pi, \Xi\eta, \Lambda\bar{K}, \Sigma\bar{K}, \Xi\pi\pi, \ldots$

$\bar{p}p \rightarrow \bar{\Omega}\Omega^* + c.c.$

$\Omega^* \rightarrow \Xi\bar{K}, \Omega\pi\pi, \Lambda K^-\bar{K}^0, \ldots$



$\Xi^{-*} \rightarrow \Xi^-\pi^0 + c.c.$



$\Omega^{-*} \rightarrow \Xi^- \bar{K}^0 + c.c.$

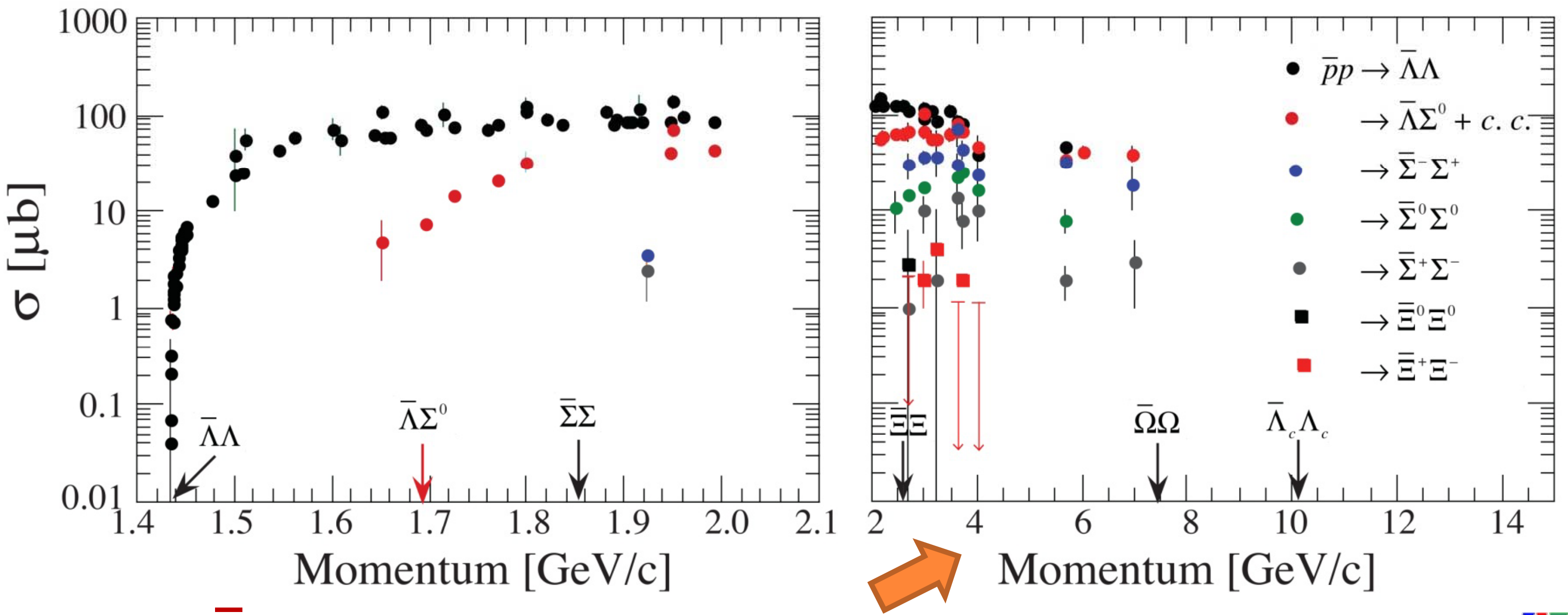
Characteristic event topology of $\bar{\Xi}\Xi^*$ and $\bar{\Omega}\Omega^*$ events

QCD Dynamics in Baryon Sector

Identification of the relevant degrees of freedom is important for an effective description of reactions in hadron physics

➢ **In the Quark Picture, Hyperon pair production involves the creation of a $\bar{q}q$ pair or the knock out of such pairs out of the nucleon sea**

Hence, the creation mechanism of $\bar{q}q$ pair and their arrangement to hadrons can be studied through $\bar{p}p \rightarrow \bar{Y}Y$ reactions



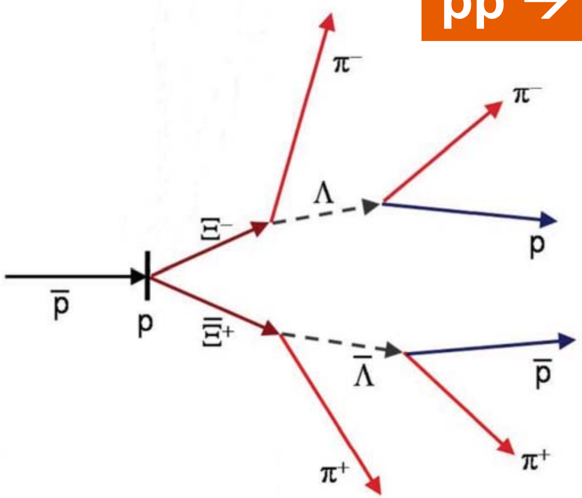
$\bar{p}p \rightarrow \bar{Y}Y$ Total cross sections in HESR momentum range

QCD Dynamics in Baryon Sector

The experimental data set is far from being complete

- **Systematic investigation of $\bar{p}p \to \bar{Y}Y$ reactions**
  - → **new information on single and multiple strangeness production**
  - → **its dependence on spin observables**
- **PANDA: High statistics and large amount of observables**
  - → **Partial Wave Analysis → Relevant quantum numbers, coupling constants and possibly new resonances**

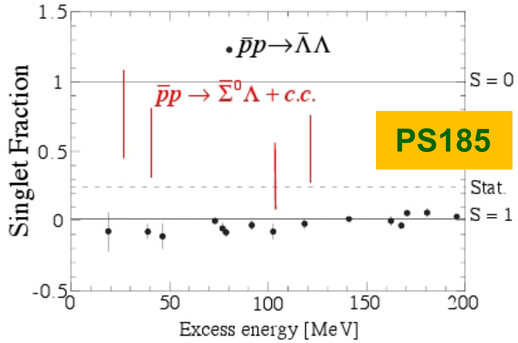
$\bar{p}p \to \Lambda\bar{\Lambda}, \Lambda\bar{\Sigma}, \bar{\Sigma}\Lambda, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}, \Lambda_c\bar{\Lambda}_c, \Xi_c\bar{\Xi}_c, \Omega_c\bar{\Omega}_c$



By comparing several reactions involving different quark flavours OZI rule and its possible violation can be tested for different levels of disconnected quark-line diagrams separately

Identification of channels → secondary vertex reconstruction for neutral Y decay and „kink" on the track for charged Y decay

QCD Dynamics in Baryon Sector



PS185

Charmed $Y\bar{Y}$-pairs
are accessible in PANDA for masses < 2740 MeV/c^2

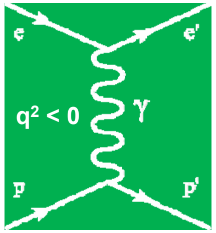
Hyperon	Quarks	Mass [Mev/c^2]	cτ [cm]	α	Decay channel	B.R. [%]
Λ	uds	1116	8.0	+0.64	$p\pi^-$	64
Σ^+	uus	1189	2.4	-0.98	$p\pi^0$	52
Σ^0	uds	1193	2.2×10^{-9}	-	$\Lambda\gamma$	100
Σ^-	dds	1197	2.4	-0.07	$n\pi^-$	100
Ξ^0	uss	1315	8.7	-0.41	$\Lambda\pi^0$	99
Ξ^-	dss	1321	4.9	-0.46	$\Lambda\pi^-$	100
Ω^-	sss	1672	2.5	-0.03	ΛK^-	68
Λ_c^+	udc	2285	6.0×10^{-3}	-.98(19)	$\Lambda\pi^+$	1
Σ_c^{++}	uuc	2453	.		$\Lambda_c^+\pi^+$	100
Σ_c^+	udc	2455	.		$\Lambda_c^+\pi^0$	100
Σ_c^0	ddc	2452	.		$\Lambda_c^+\pi^-$	100
Ξ_c^+	usc	2466	1.3×10^{-2}			
Ξ_c^0	dsc	2472	2.9×10^{-3}	-0.6(4)	$\Xi^-\pi^+$	seen
Ω_c^0	ssc	2697	1.9×10^{-3}			

Same spin analysis
for $\bar{p}p \to \Lambda_c\bar{\Lambda}_c$
as $\bar{p}p \to \bar{\Lambda}\Lambda$

σ ~ 20 nb
1 year of data taking
L_{int} ~ 1-2 fb^{-1}
~ 10^7 events into $\Lambda\pi$

Proton Form Factors

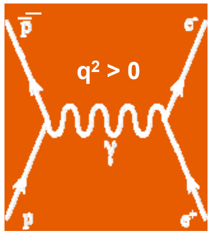
Measurement of the Cross Sections allows to access FF moduli



Space-like
FF real

e p → e' p

- Major progress recently achieved using polarised beam or target
- New data show different electric and magnetic distributions for the p
- $\mu G_E/G_M$ deviates linearly from a constant at least up to $q^2 \sim 6\ (\mathrm{GeV}/c)^2$
- Discrepancy between polarised and unpolarised measurements due to radiative correction, as Two Photon Exchange, suppressed by a factor of α_e, it could be important at high q^2



Time-like
FF complex

$\bar{p}p \leftrightarrow e^+e^-$

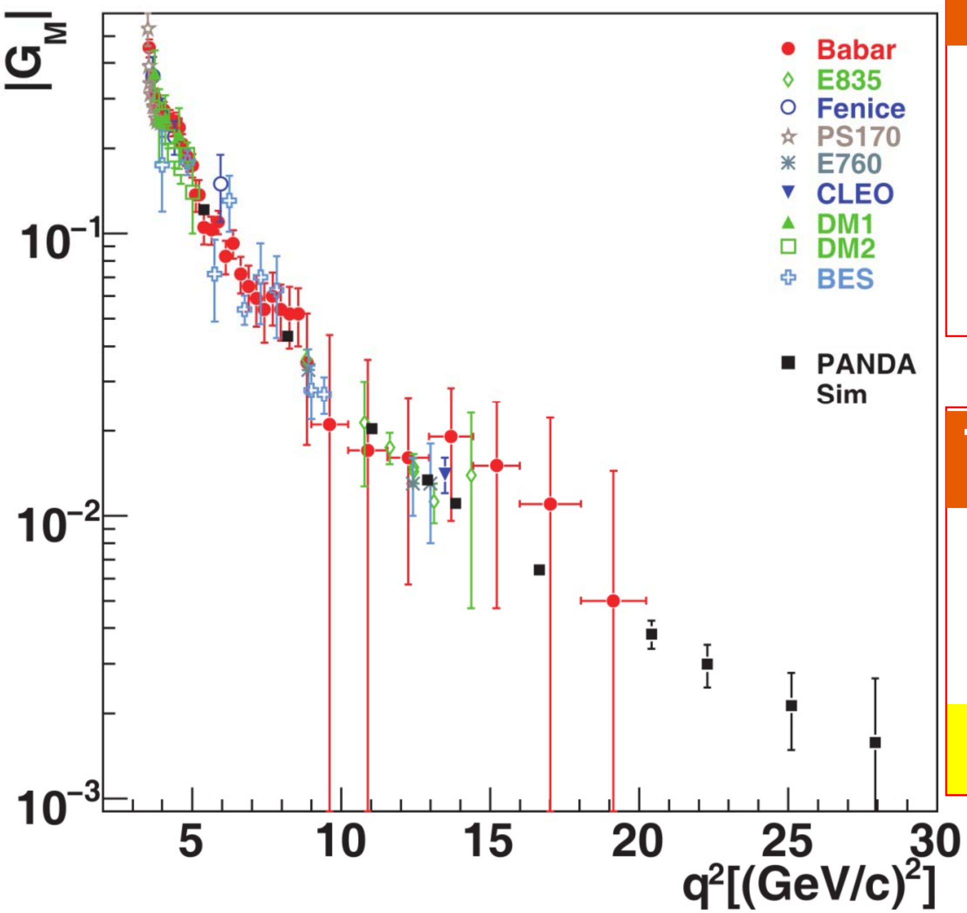
- Scarce data and large errors
- Time-like ← Analiticity → Space-like continuous transition predicted and equality at asymptotic $|q^2|$
- Determination of $|G_E|$ and $|G_M|$ requires angular distributions of outgoing leptons
- $R = |G_E| / G_M|$ sensitivity decreases at increasing q2

In the approximation of One Photon Exchange

$$d\sigma/d\Omega \propto [\ |G_M|^2 (1+\cos^2\theta) + (4m_N^2/q^2)\ |G_E|^2 \sin^2\theta]$$

$$\sigma_{TOT} \propto [\ |G_M|^2 + (4m_N^2/q^2)\ |G_E|^2]$$

TIME-LIKE FF : WORLD DATA



e^+e^-	$\mathcal{L}$ ($cm^{-2}\ s^{-1}$)	$q^2(GeV/c)^2$
FENICE	1.2×10^{29}	3.6 – 6
BABAR	3×10^{33}	3.5 – 20
BES II	$< 10^{31}$	4 – 9.4

$\bar{p}\ p$	$\mathcal{L}$ ($cm^{-2}\ s^{-1}$)	$q^2(GeV/c)^2$
PS170	3×10^{30}	3.5 – 4.2
E835	2×10^{31}	8.8 – 18.4
PANDA	2×10^{32}	5 – 28

PANDA simulations
Sudol et al. EPJA4482010) 373

PROTON TIME-LIKE FF IN PANDA

- Measurement of $|G_M|$ up to $q^2 = 28\ (\text{GeV}/c)^2$ for $R \sim 1$ (QCD)

  Large dynamic range allows to study transition from soft to hard scattering mechanisms (domain of pQCD)

  High energy to verify asymptotic behaviour

- Independent measurement of $|G_E|$ and $|G_M|$ up to $q^2 = 14\ (\text{GeV}/c)^2$

- Measurement of $R = |G_E| / |G_M|$ up to $q^2 = 14\ (\text{GeV}/c)^2$

  For $R \sim 1$ $\Delta R/R$ < 5% up to $q^2 = 8\ (\text{GeV}/c)^2$ → ~ 40% BaBar through ISR reaction

  $\Delta R/R \sim 50\%$ at $q^2 \sim 14\ (\text{GeV}/c)^2$

- Test of the One Photon Exchange hypothesis

  Information fully contained in angular distribution

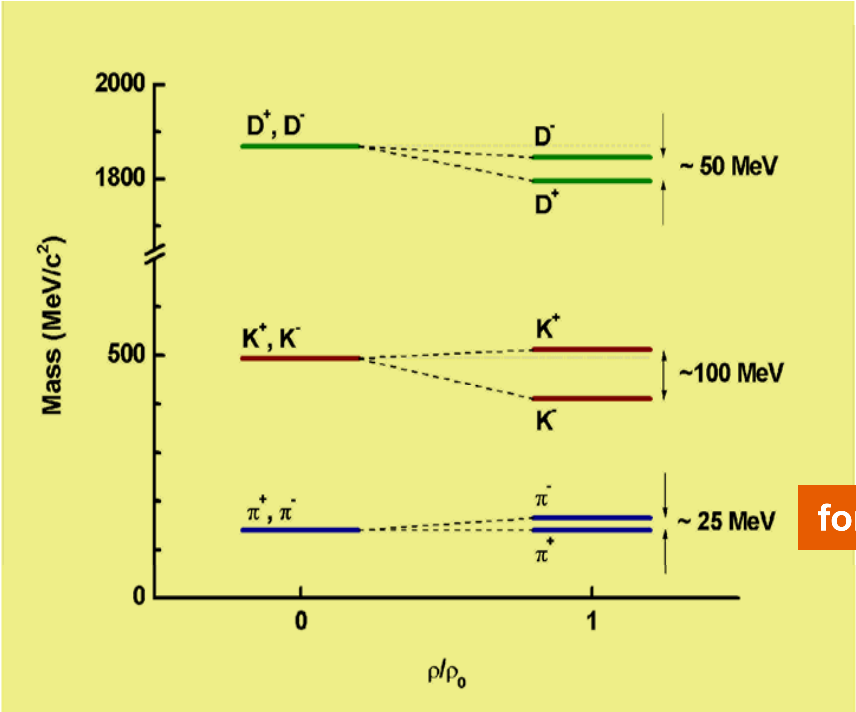
  Sensitivity of ~5% for the Two Photon Exchange

- Measurement of real and imaginary parts of FF and relative phase needs polarised beam or target

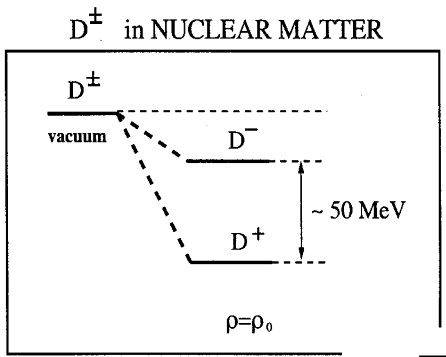
Medium modification of D Mesons

In-Medium studies limited to light and strange sector

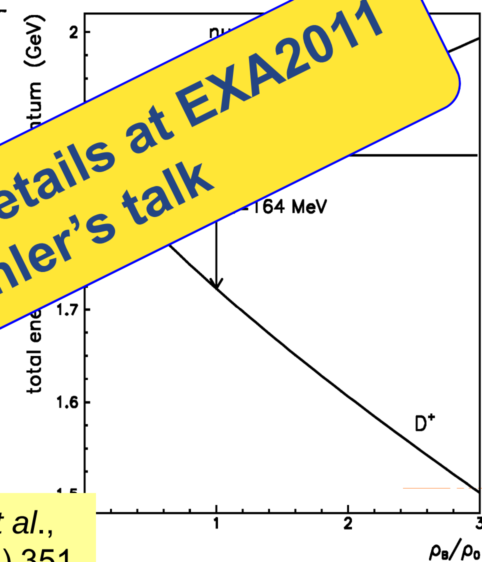
Extension to the charm sector in $\bar{p}$-Nucleus collision



for N > Z



W. Weise,
Proc. Hirschegg 2001



A. Sibirtsev *et al.*,
EPJA 6 (1999) 351

More details at EXA2011 in Bühler's talk

Mass Shifts caused by potential in Nuclear Mat

K potential: still controversial
D potential: large uncertainties
K, D will have large width

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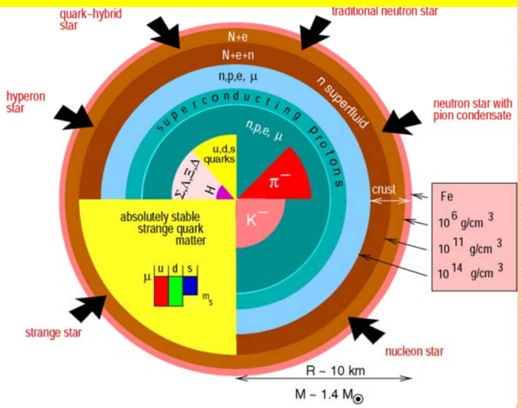
HYPERNUCLEAR PHYSICS

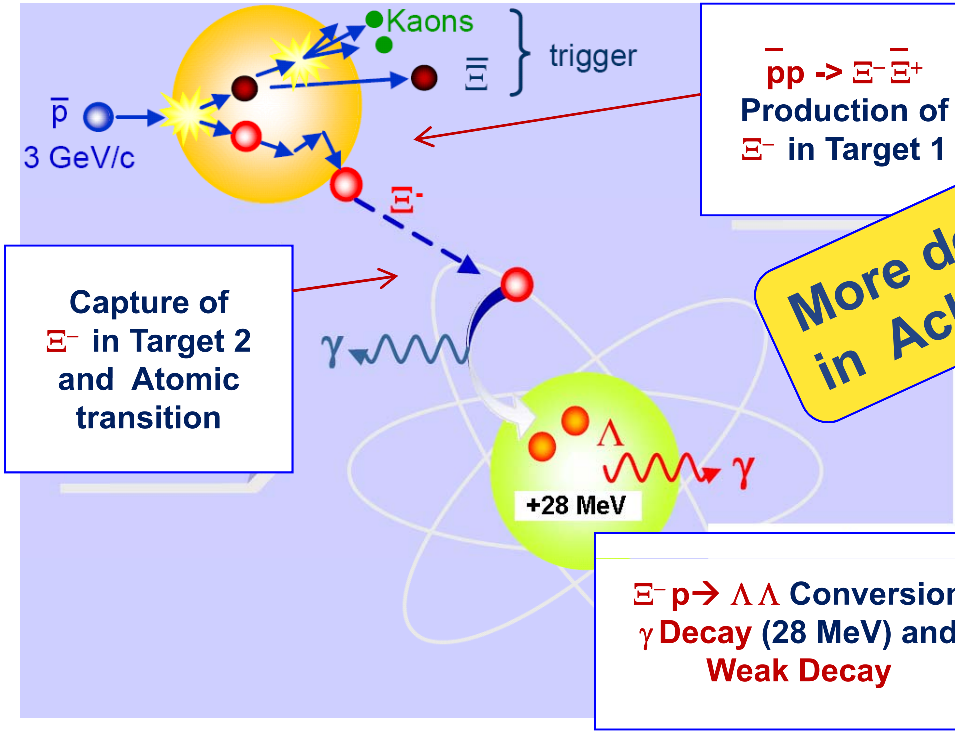
Double Λ Hypernuclei

- YY Interaction
- Mesonic and Non Mesonic Weak Decays

Neutron Stars or Hyperon Stars ?



Knowledge on *YN* and YY interaction is fundamental to understand high-density nuclear matter inside Neutron Stars



$\bar{p}p \to \Xi^-\bar{\Xi}^+$ Production of Ξ^- in Target 1

Capture of Ξ^- in Target 2 and Atomic transition

$\Xi^- p \to \Lambda\Lambda$ Conversion
γ Decay (28 MeV) and Weak Decay

More details at EXA2011 in Achenbach's talk

Expected
~ 2000 captured Ξ^-/day
~ 10 ΛΛ-Hyp/day

to be compared with
~ 6000 captured Ξ^- / day
at J-PARC

PANDA TIMESCALE

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 →

Experiment

Commissioning

Installation at FAIR

Pre-Assembly
at FZ Juelich

mass production

R&D

TDR

The overall time scale is driven by civil construction and infrastructures

TDR — Magnet and EMC TDR's already approved

FAIR — Legal Foundation of FAIR signed in October 2010

Conclusions

PANDA is well equipped to achieve many physics goals

The high intensity and high resolution $\bar{p}$ beam available at HESR will offer unique opportunities, complementary to e+e- machines, to study

- **Charmonium and Open Charm Spectroscopy ☺ high resolution**
- **Exotic non $\bar{q}q$ states ☺ Production technique**

Antiproton-proton interactions

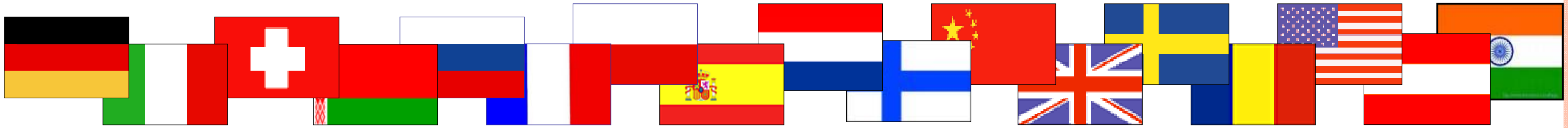
- **Spectroscopy of strange Baryons looks promising ☺ high statistics**
- **Study of QCD dynamics in the Baryon sector with many observables**
- **Unique possibility to measure Time-like FF up to $q^2 = 28\ (\mathrm{GeV}/c)^2$**

Antiproton-Nucleus interactions

- **Extension to the charm sector of Medium modifications of mesons**
- **Hypernuclear Physics**

PANDA looks promising to understand Strong Interaction

PANDA COLLABORATION

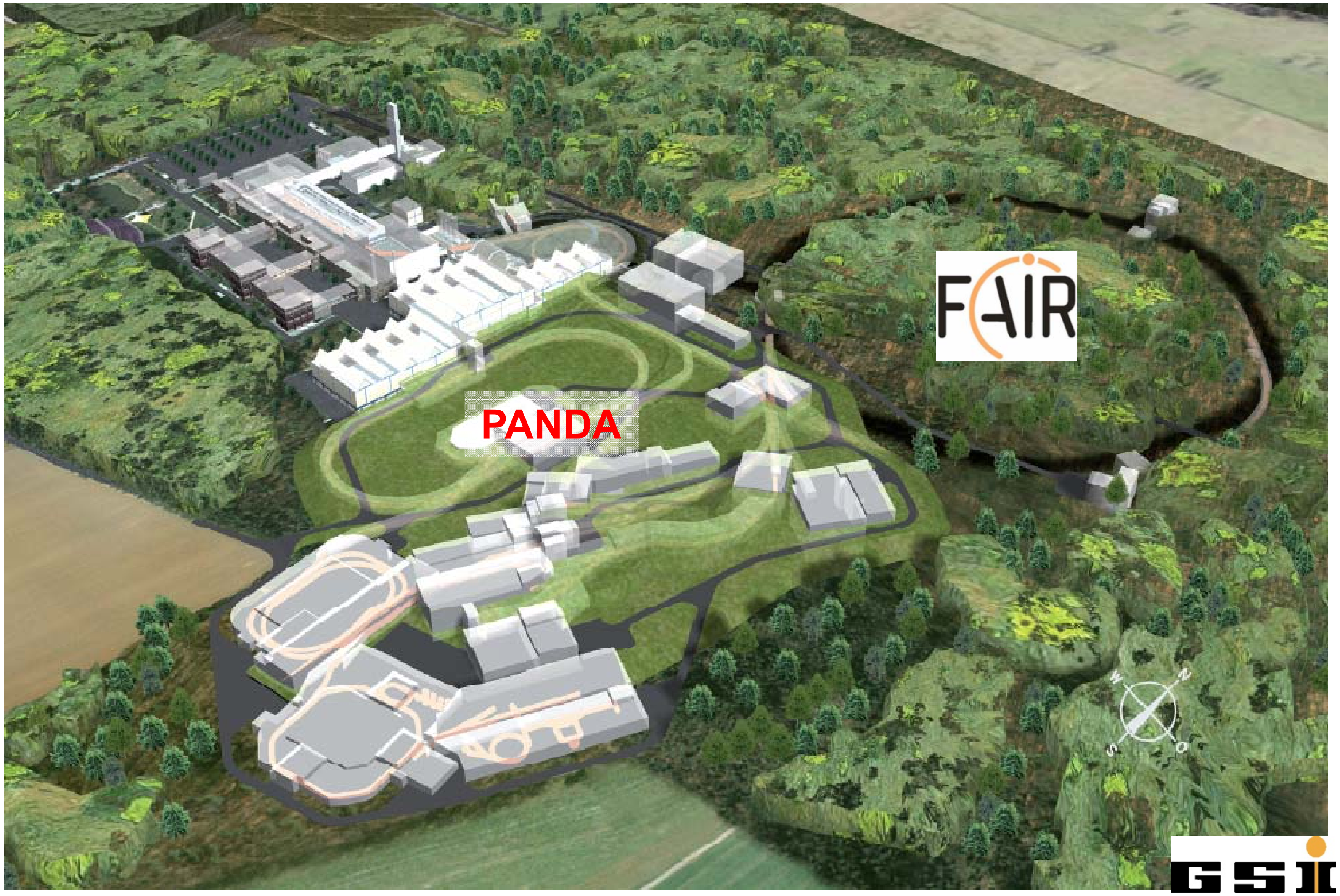


At present 460 physicists from 54 institutions of 16 countries

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

Basel, Beijing, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, Catania, Cracow, IFJ PAN Cracow, Cracow UT, Dresden, Edinburgh, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, INFN LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow, TU München, Münster, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, Piemonte Orientale, IHEP Protvino, PNPI St.Petersburg, KTH Stockholm, Stockholm, INFN Torino, Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, SMI Wien

http://www.gsi.de/panda


FAIR
PANDA
GSI

PHYSICS PERFORMANCE REPORT

Published in March 2009

arXiv:0903.3905v1

Feasibility study for the major channels of interest

$1.3x10^9$ Monte Carlo events

More than 20 Institues contributed to the simulations

Physics Performance Report for:

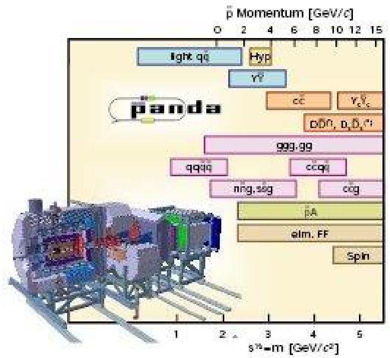
P̄ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

P̄ANDA Collaboration

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal P̄ANDA 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 P̄ANDA 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 P̄ANDA and what performance can be expected.



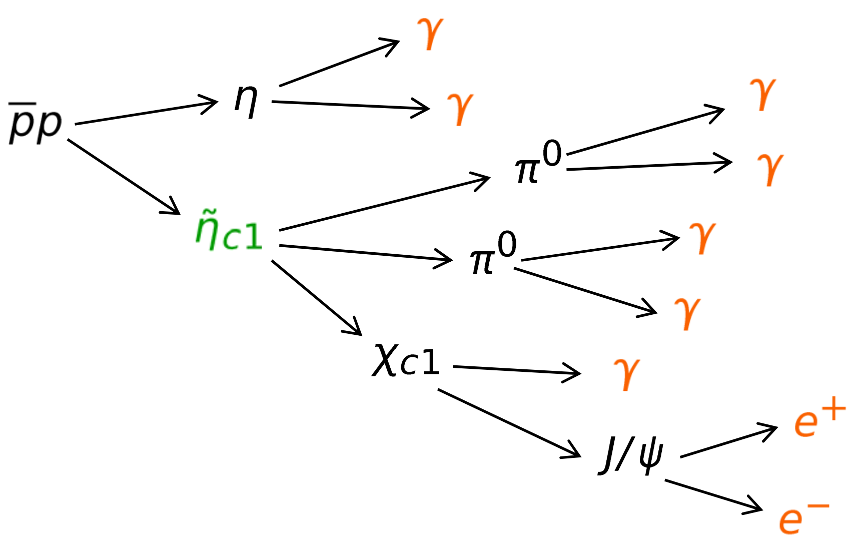
Backup Slides

EXOTIC STATES, CHARM HYBRIDS

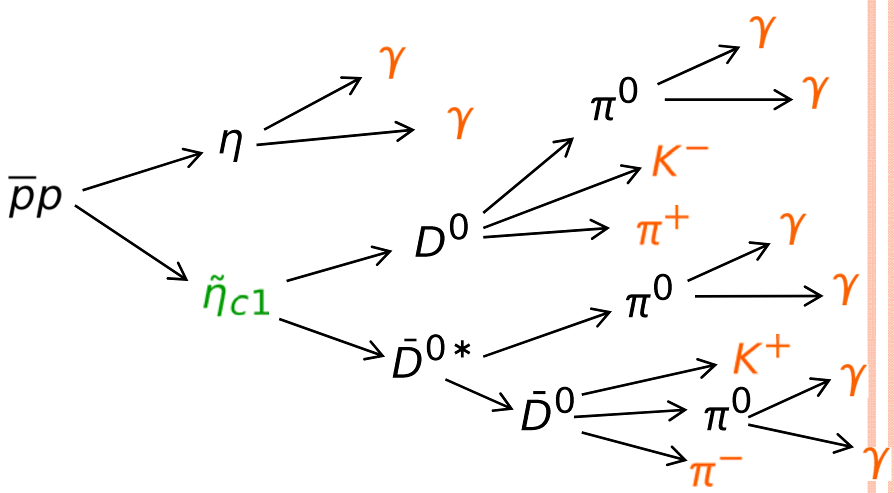
from LQCD calculations, $\tilde{\eta}_{c1}$ with m ~ 4.3GeV/c^2, $J^{PC} = 1^{-+}$

reconstruction possible in PANDA in exclusive channels like

$$\bar{p}p \rightarrow \tilde{\eta}_{c1}\eta \rightarrow \chi_{c1}\pi^0\pi^0\eta$$



$$\bar{p}p \rightarrow \tilde{\eta}_{c1}\eta \rightarrow D^0\bar{D}^{0*}\eta$$

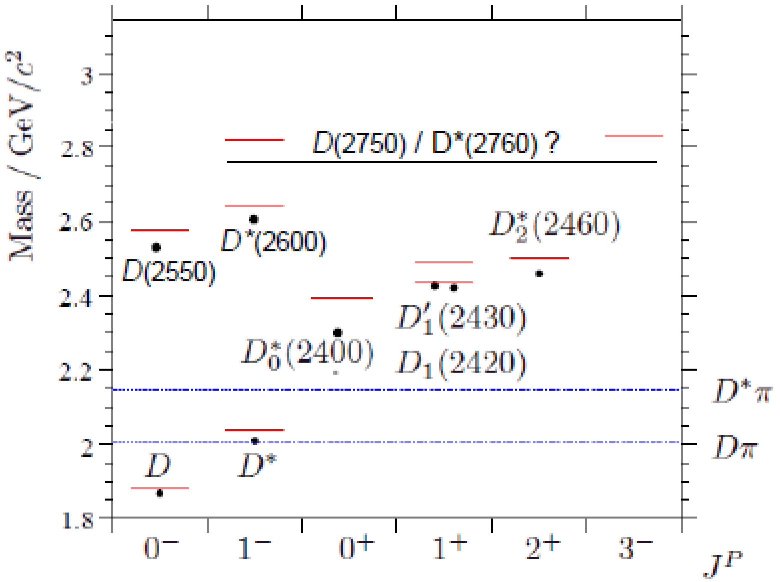


requires:

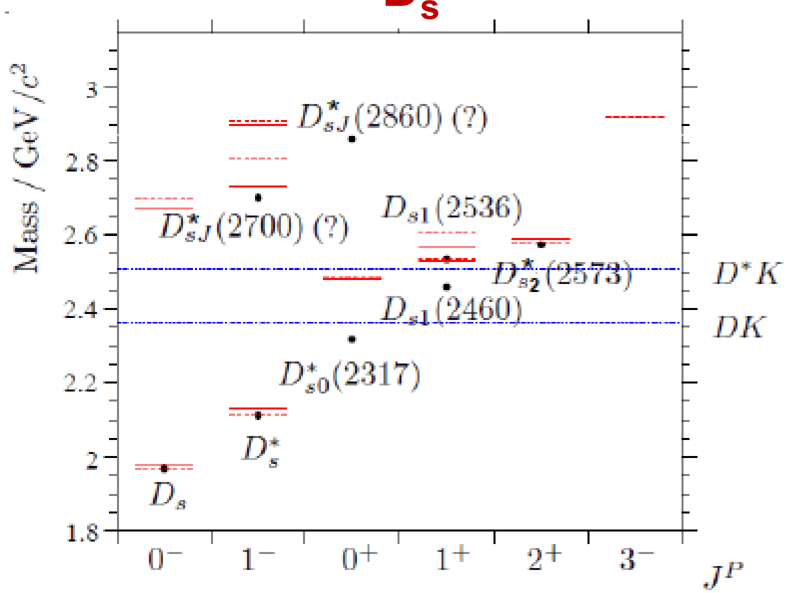
high-resolution electromagnetic calorimeter (γ reconstruction)
and excellent charged particle identification

Open Charm

D



D_s



— [S. Godfrey and N. Isgur PRD **32**, 189 (1985)] ---- [M. Di Pierro, E. Eichten, PRD **64**, 114004 (2001)]

New D_J states

D(2550), D*(2600),

D(2750), D*(2760)

BaBar, PRD 82 (2010) 111101

New D_{sJ} states

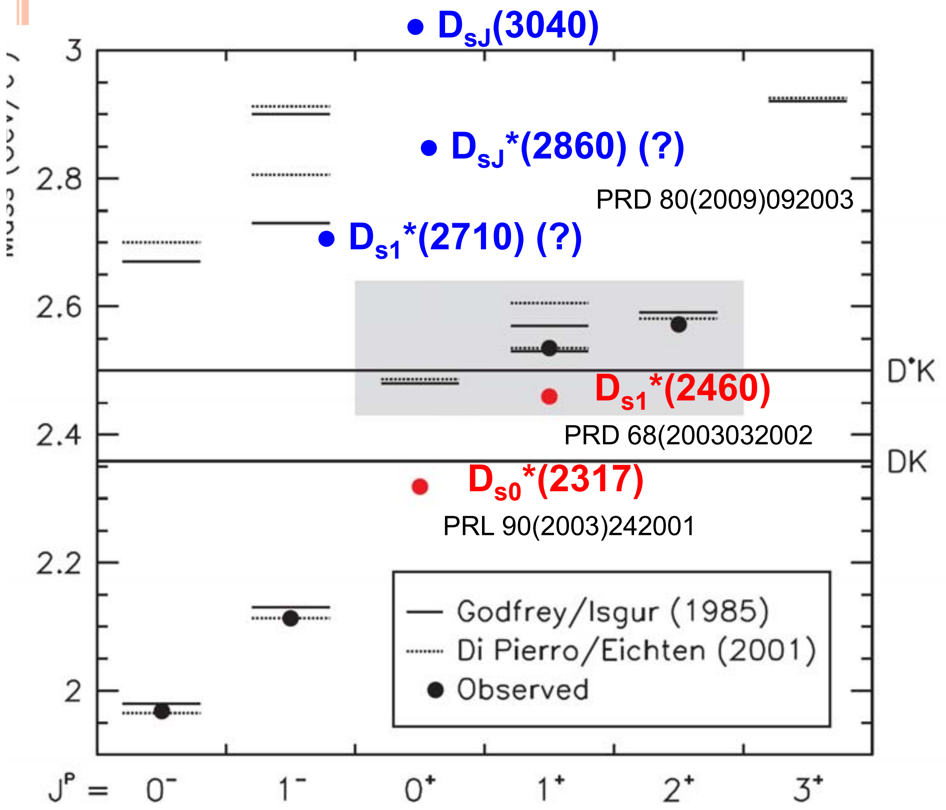
$D_{s0}(2317)$, $D_{s1}(2460)$

$D_{s1}^*(2710)$, $D_{sJ}^*(2860)$, $D_{sJ}(3040)$

BaBar, PRD 80 (2009) 092003

Many states need to be confirmed

Open Charm



E.S.Swanson, Physics Reports 429 (2006) 243

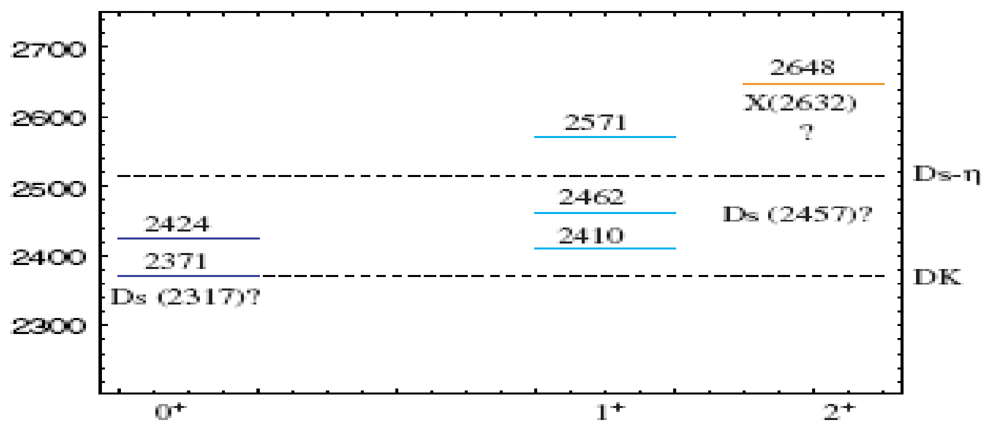


Fig. 32. $c\bar{s}$ tetraquark spectrum [49].

Tetraquark spectrum

Open Charm
Benchmark Channels Analysis

Following reactions were chosen to demonstrate the physics performance of the PANDA detector

- $\bar{p}p \to \psi(3770) \to D^+ D^- \to K^- \pi^+ \pi^+ + c.c.$
- $\bar{p}p \to \psi(4040) \to D^{*+} D^{*-} \to D^0 \pi^+ \overline{D}^0 \pi^-,$

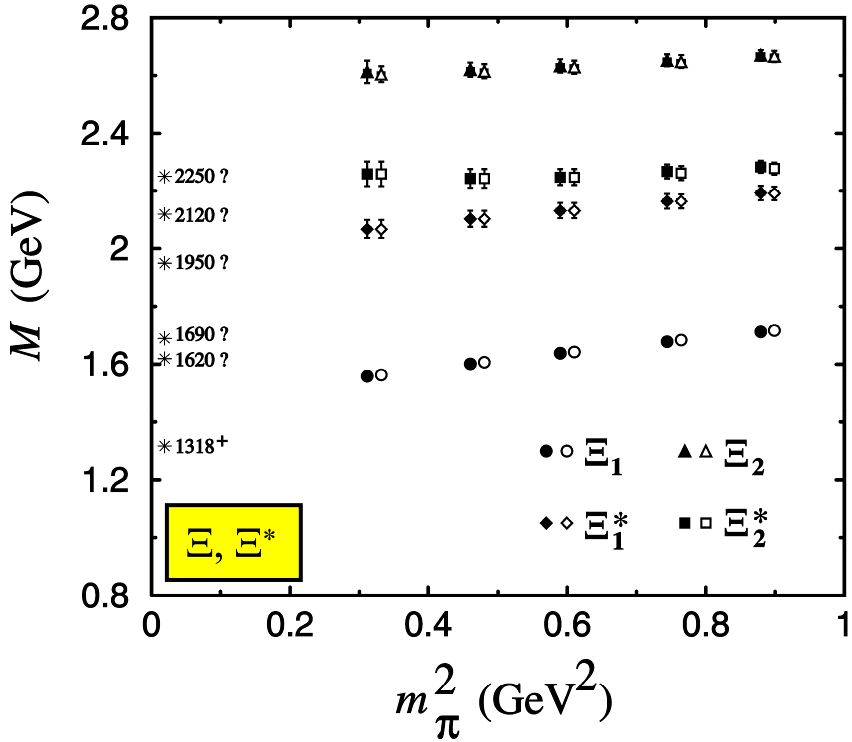
  $\mapsto D^0 \to K^- \pi^+$ or $K^- \pi^+ \pi^- \pi^+$
-
- $\bar{p}p \to D^*_{sJ}(2317)^+ D^*_{sJ}(2317)^- \to D_s^+ \pi^0 D_s^- \pi^0 \to K^- K^+ \pi^+ \gamma\gamma + c.c.$

  $\bar{p}p \to D_{sJ}(2460)^+ D_{sJ}(2460)^- \to D_s^+ \gamma D_s^- \gamma \to K^- K^+ \pi^+ \gamma + c.c.$

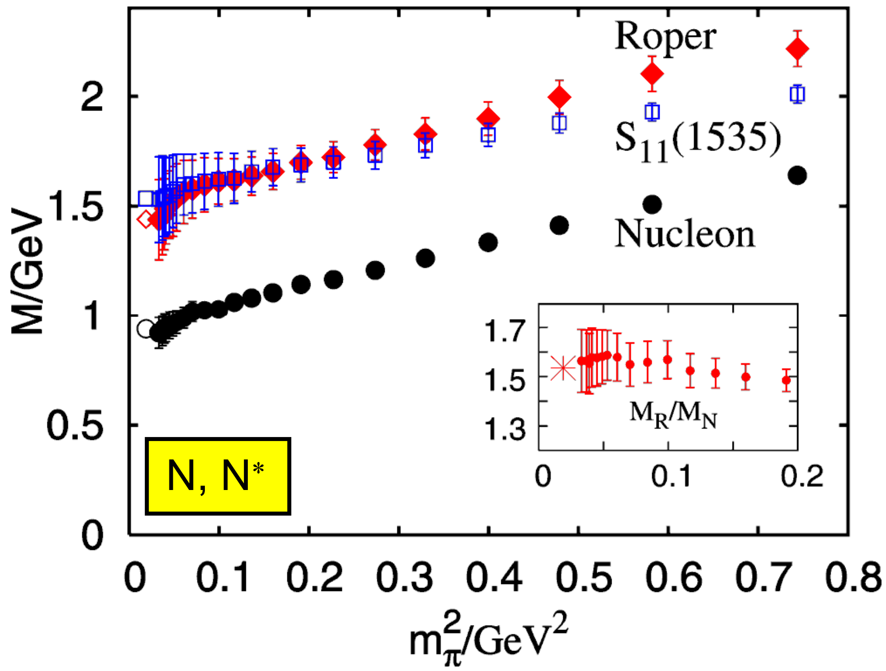
Baryon Spectroscopy

Predictions: Lattice QCD

Recent results - improvements expected



CSSM: W. Melnitchouk *et al.*,
Phys. Rev. D 67 (2003) 114506



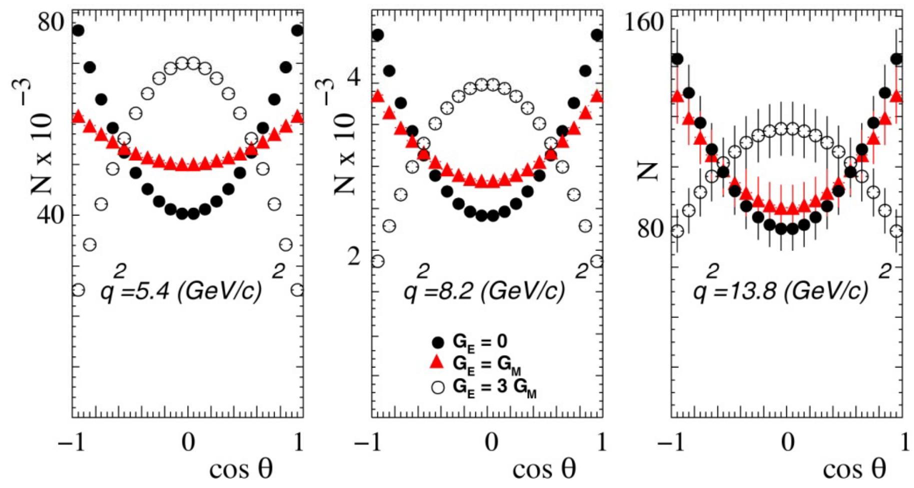
G. Bali, Nucl. Phys. A 755 (2005) 7c

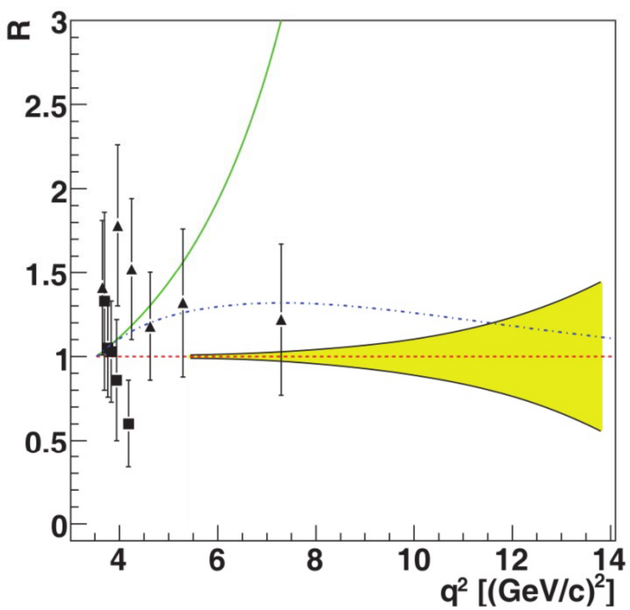
PROTON TIME-LIKE FF IN PANDA

$R = |G_E| / |G_M|$

CM Angular distributions from event generator

- ● R = 0
- ▶ R = 1
- o R= 3





Expected statistical precision for ratio R

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■ PS170