Feasibility studies for the measurement of electromagnetic channels with PANDA

FAIR-FRANCE meeting, 17 May 2017

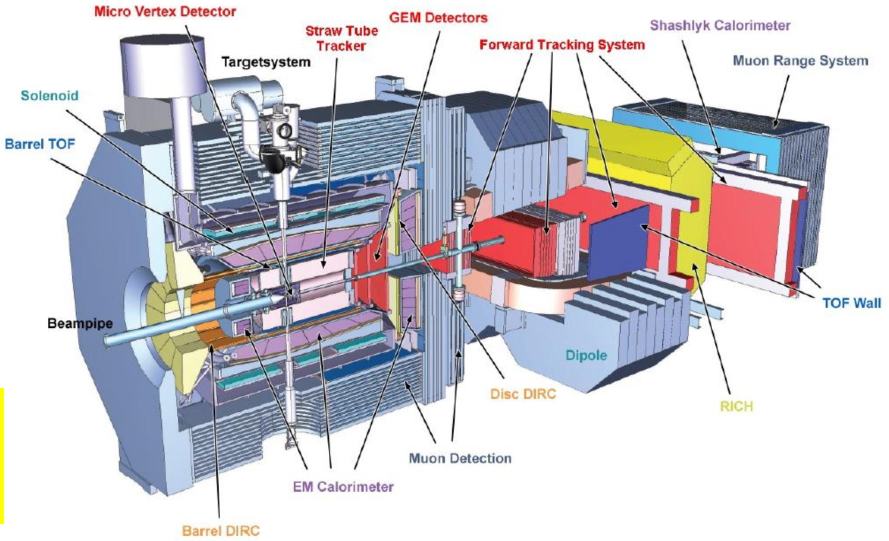
Orsay

The PANDA multipurpose detector

- Meson spectroscopy: D mesons, charmonia
- Search for exotic QCD states: glueballs, tetraquarks, hybrids, molecules…
- Single and Double hypernuclei
- Hadrons in nuclear matter
- Nucleon structure

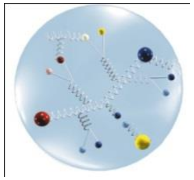
High Energy Storage Ring
Antiprotons p= 1.5-15 GeV/c
High res. mode $L_{peak}=2\times10^{31}/cm^2/s$ $\delta p/p=10^{-5}$
High lumi mode $L_{peak}=2\times10^{32}/cm^2/s$ $\delta p/p=10^{-4}$

AntiProton ANnihilation at Darmstadt



Very large overlap with research fields at IN2P3

involvment of IPNO in PANDA (I)



Start of involvment 2004

- nucleon structure studies
- R&D on the barrel calorimeter
- Contribution to the simulation and analysis code (PANDARoot)

7 permanents up to end of 2014

T. Hennino (CNRS, retired 2015)
R. Kunne (CNRS)
D. Marchand (CNRS)
E. Tomasi-Gustafsson (CEA)
S. Ong (prof. University of Amiens, retired 2015)
B. R. (CNRS)
J. Van de Wiele (CNRS, emeritus 2015),

2 Post-docs: Malgorzata Gumberidze: 2008-2012 (30% HADES from 2010 to 2012)
Ermias Atomssa (Oct. 2013-Oct. 2016, 20% HADES)

4 PhDs: Jérôme Boucher (Sept. 2011) (IPNO/Mainz)
Binsong Ma (Sept. 2014)
Alaa Dbeyssi (Sept. 2013),
Wang Ying ($\rightarrow$July 2017)

Involvment of RDD group ~ 1 FTE/year

B. Gajewski, M. Imre, C. Le Galliard, G. Minier, P. Rosier, L. Seminor
A. Maroni, C. Theneau…

involvment of IPNO in PANDA (II)

Responsibilities in PANDA

- **Collaboration Board** (2 votes) - **FAIR Ressource Review Board** (T. Hennino, D. Guillemaud-Müller) - **Technical board** (P. Rosier/R&D detectors)
- **Speakers committee** T. Hennino (2009-2011), E. Tomasi-Gustafsson (2011,chair 2012), B. R. (2013-2014)
- Coordination of the **working group on Electromagnetic processes** (D. Marchand, B. R.)

Scientific production (phenomenology, feasibility studies) :

- Phenomenology, feasibility studies:17 **Peer-reviewed journals** +14 **conf. proceedings**
- PANDA TDRs : contribution to **EMC and STT TDRs**
- 1 technical and 1 release note (RN) fully written at IPNO, 1 RN in collaboration with Mainz
- 26 talks (10 invited) ; > 37 presentations to PANDA coll. meetings , 20 audioconf.

Substantial financial support from IN2P3 (20-30 k€/year) but no recruitment.

✓ September 2014: IPN/IN2P3 decision (based on manpower and budget)

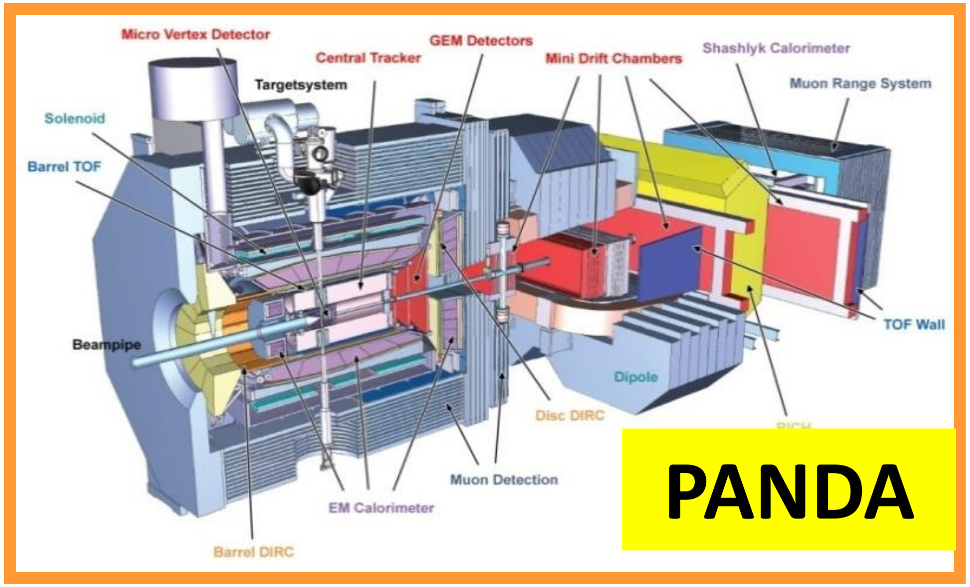
No contribution to PANDA construction/MOU

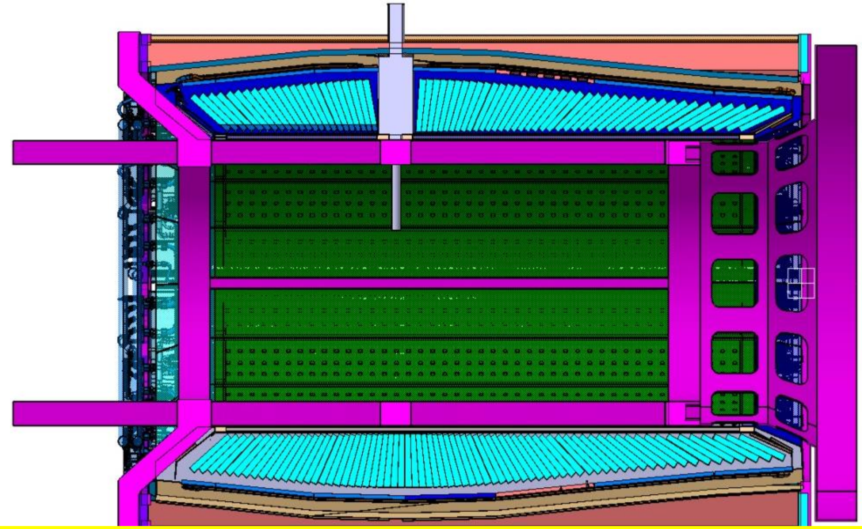
✓ 2017: finalization of the activities of the IPNO group

→ reorientation on new activities (HADES,Jlab,Prorad)

How to revive a contribution of IN2P3 to PANDA?

R & D on the barrel calorimeter





The barrel calorimeter: 11520 PbWO4 crystals

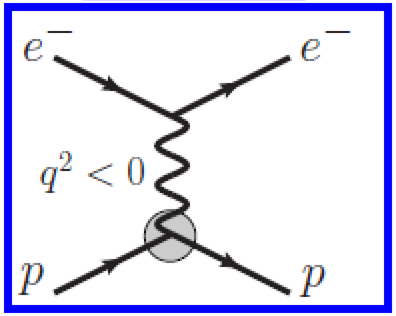
- General layout and integration (TDR)
- Optical glue studies *(A. Dbeyssi et al; NIM A722 (2013) 82)*
- Design of the cooling system (-25°C)
- Participation in construction of two prototypes and corresponding tests
- EoI (now cancelled): 300 keuros for EMC cooling
- *transfer of know-how to Bochum/Giessen in Spring 2015*

PANDA still seeks technical contributions (e.g. Forward Tracker)
is a contribution of IN2P3 a possible option ?

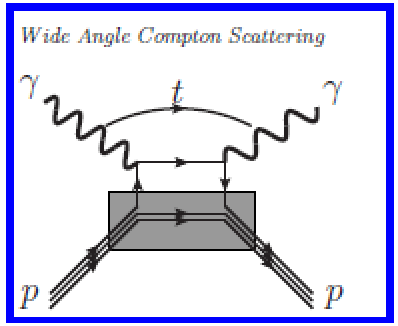
1/3 of the 120 crystal prototype

Using time-like electromagnetic processes for nucleon structure studies

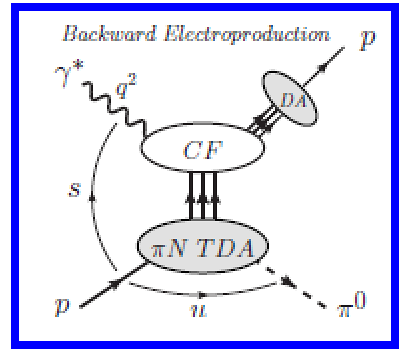
$e^- p \to e^- p$



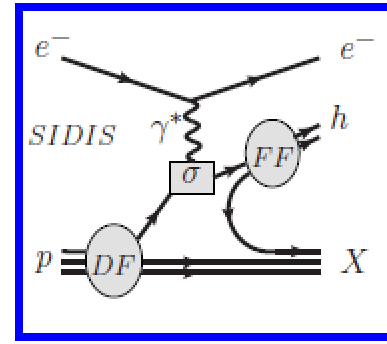
$\gamma p \to \gamma p$



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

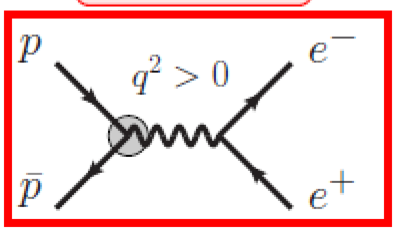


$e^- p \to e^- hX$

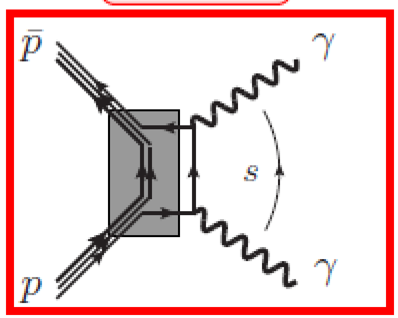


Space-Like

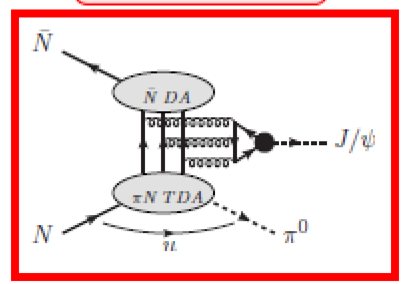
$\bar{p}p \to e^+e^-$



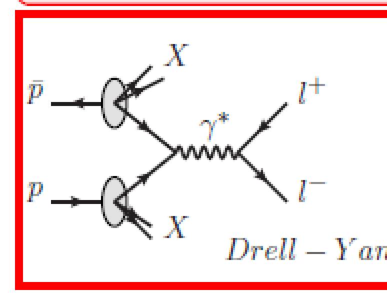
$\bar{p}p \to \gamma\gamma$



$\bar{p}p \to \pi^0 J/\psi$



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



Time-Like

Electromagnetic Form Factors (FF)

Generalized Parton Distribution (GPD)

Transition Distribution Amplitude (TDA)

Parton Distribution Functions (PDF)

- ✓ same or complementary information available in electron scattering and $\bar{p}p$ annihilation
- ✓ Only Time-like form factors measured in $\bar{p}p$ (LEAR,Fermilab)
- ✓ Novel opportunity with Panda: high precision and large kinematic coverage

Challenge of e^+e^- exit channels: pionic background !

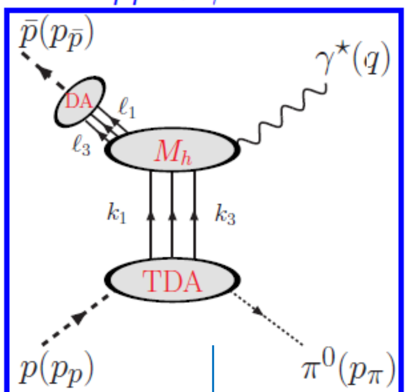
Access to p-π Transition Distribution Amplitudes

- Information on the pionic components of the nucleon wave function
- Independent of reaction type, s and q^2 - complementary to GPD
- Accessible in associated meson prod. in $\bar{p}p$ annihilation (and backw. meson electroprod.)

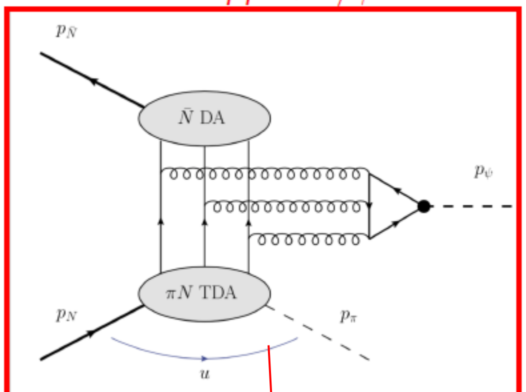
J.-P. Lansberg et al., Phys. Rev. D 76, 111502 (2007); Phys. Rev. D85, 054021 (2012)

B. Pire et al. Phys. Lett. B 724 99-107 (2013)

$\bar{p}p \to \gamma^* \pi^0$



$\bar{p}p \to J/\psi \pi^0$



Valid in the factorization regime

- large q^2
- t or u $<<q^2$ (θ_π close to 0^0 or 180^0)

$\rightarrow$ two kinematical regimes in $\bar{p}p$

$\pi\bar{p}$-TDA or πp-TDA

based on B. Ma PhD and E.Atomssa post-doctoral works

Fully written at IPNO, collab. with K. Semenov & B. Pire

B. P. Singh et al. [PANDA collaboration] Phys.Rev. D95 (2017) 032003

Analysis at Mainz

B. P. Singh et al. [PANDA collaboration]

Eur. Phys. J. A (2015) 51:107

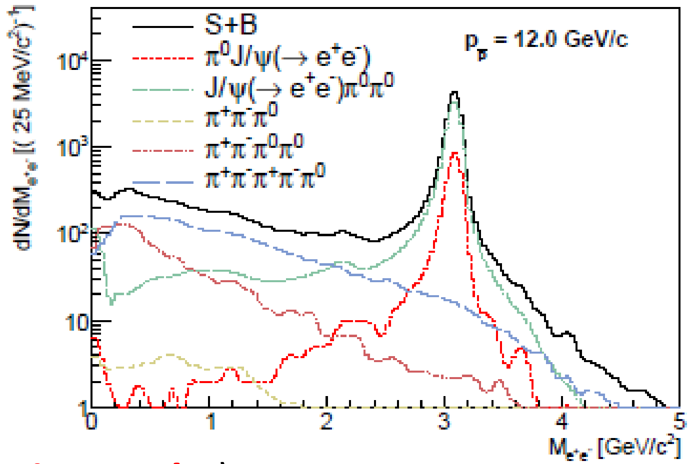
Full feasibility study of TDA in $\bar{p}p \to \pi^0 J/\psi$ ($J/\psi \to e^+e^-$)

s= 12.3, 16.9 ,24.3 GeV^2 (p_p= 5.5, 8, 12 GeV/c)

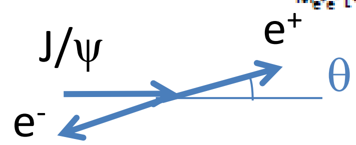
Background rejection with PID+kinematical cuts+N_γ<4

- multipion channels negligible (*side-band analysis)*
- $\bar{p}p \to J/\psi\, \pi^0\pi^0$ <2% conservative estimates, will be measured by PANDA

Signal efficiency 11% (p=5.5 GeV/c); 7% (p=12 GeV/c)



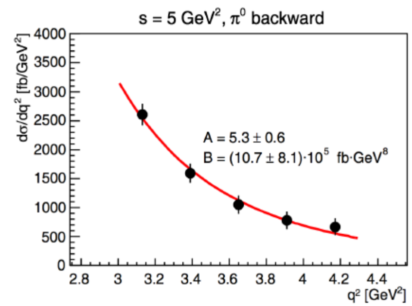
Integrated luminosity of L_{int}=2 fb^{-1} *(5 months in* ***high luminosity mode*** *)*

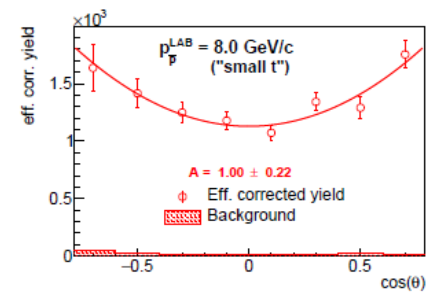


→ Differential distributions reconstructed with good precision

→ Test of collinear factorization

$$\frac{d\sigma}{d\theta_e} \sim 1+\cos^2\theta_e$$





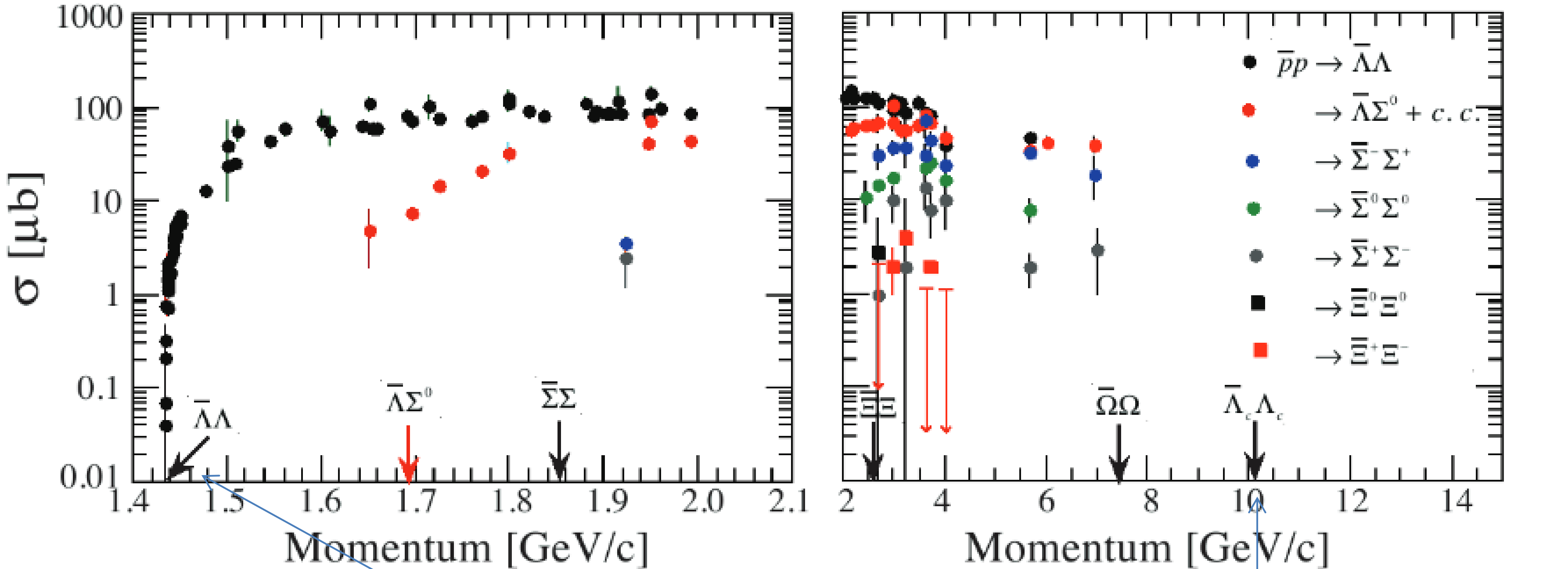
B. P. Singh et al. [PANDA collaboration] Phys.Rev. D95 (2017) 032003

Very promising results for TDA studies

N.B. Possibility of measurement in parallel with charmonium studies: X(3872), Y(4260),…

(no or rare decay to $J/\psi\, \pi^0$, $J/\psi\, \pi^0\, \pi^0$ or multipion channels)

PANDA as an hyperon factory



Day 1 luminosity
Rates including efficiency

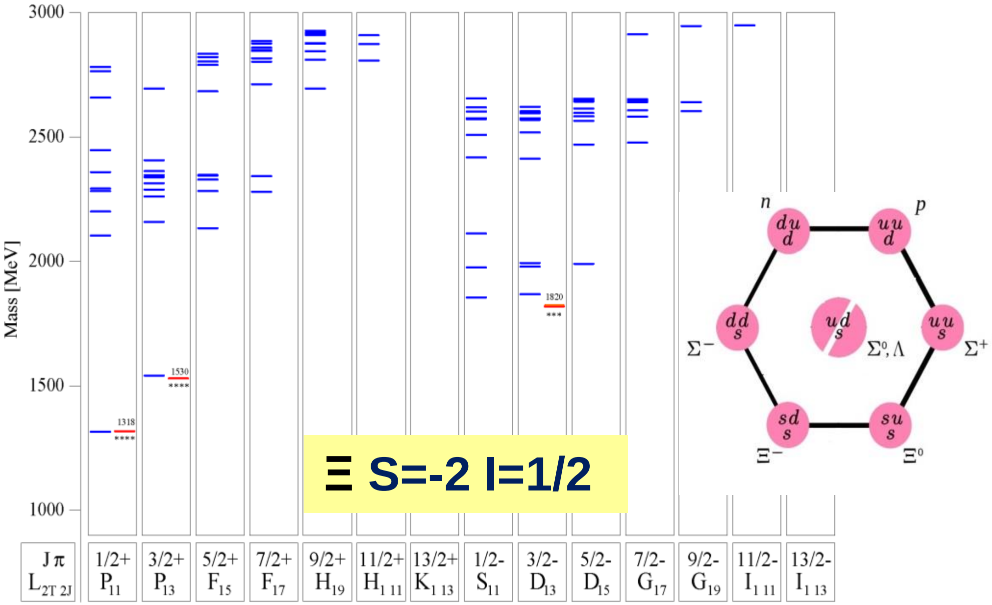
30 signal evts /s

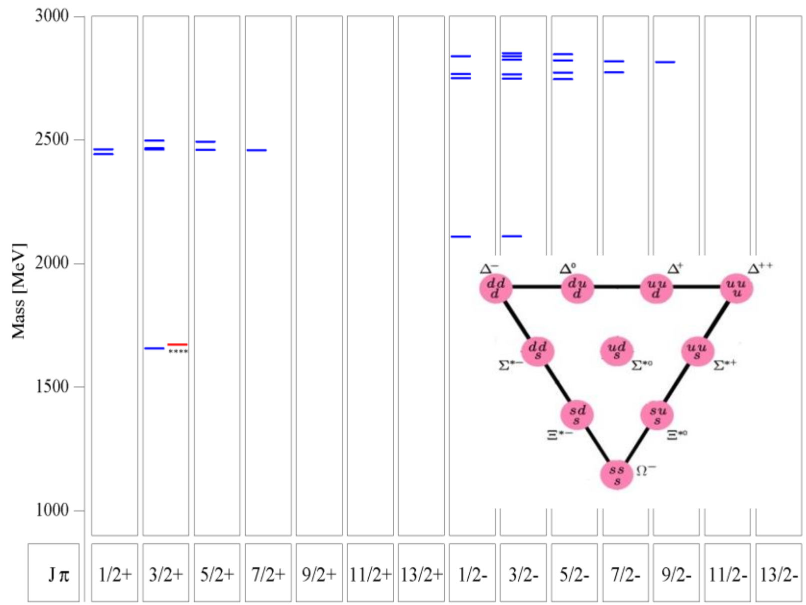
2 signal evts/day

For example: measure $\Sigma \to \Lambda e^+e^-$ Dalitz decay branching ratio unknown ·
Prediction 510^{-3}

Interest and feasibility studies: Cracow,Jülich, Uppsala

multistrange baryons





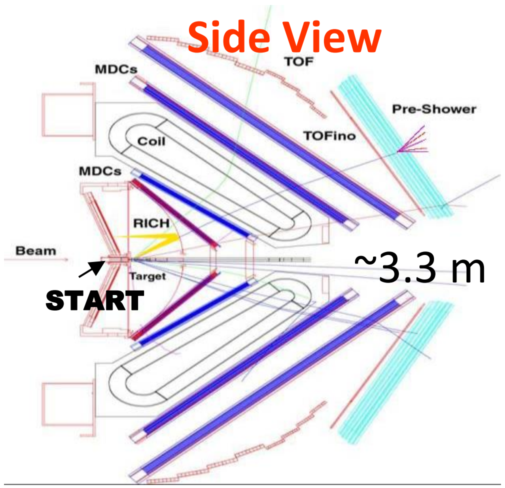
- many states predicted below 3 GeV/ very few observed
- Cross section for $\bar{p}p \to Y^*Y$ similar to $\bar{p}p \to YY$ at similar energy above threshold
- determine branching to various decay modes:

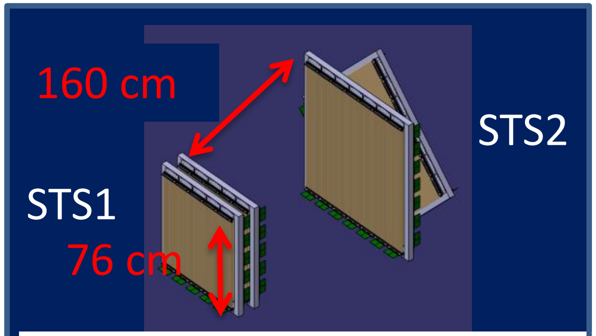
$$\Xi\pi,\ \Xi\pi^+\pi^-,\ \Xi\pi^0\pi^0,\ \ \Lambda K^-,\ \Sigma\bar{K},\ \Xi\eta,\ \Xi\eta\pi,\ \Xi\eta',\ \Xi\omega,\ \Xi\phi, \ldots$$

- On-going feasibility studies in the PANDA collaboration:
- $\bar{p}p \to \Xi^+\Xi(1521)^- \to \Xi^+\Lambda K^-$ and $\bar{p}p \to \Xi^+\Xi(1820)^- \to \Xi^+\Lambda K^-$

PANDA Phase 0 with HADES

PANDA pre-series and prototype detectors for the Forward tracker used in HADES





New Forward Detector
$0.5° < \theta < 6.5°$
Straw Tube Tracker + RPC

STS1 (Jülich) 640 tubes
(use later for FT3/4 in PANDA)
STS2 (Krakow,Orsay) 900 tubes
(same technology as FT5/6)
(4 double layers each)

- Financial contribution to construction of STS2 in Krakow
- Construction of frames and support in Orsay

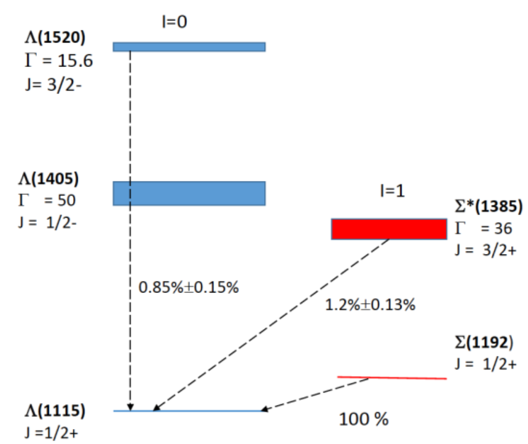
Joint HADES/PANDA interest on Time like baryon structure and Hyperon studies

Tagging via $\Lambda \rightarrow p\pi^-$

- Radiative transitions not well known $Y \rightarrow \Lambda\gamma$
- No data at all for Dalitz decay: $Y \rightarrow \Lambda e^+ e^-$

(sensitivity to timelike electromagnetic structure)

See talk on HADES



Conclusion

- Large overlap between IN2P3 and PANDA physics

(charmonium, nucleon structure, medium effects,...see F. Maas talk)

$\rightarrow$ FAIR should attract interest of French hadronic physics experts in the next years

- Urgent! Strengthen the present joint HADES-PANDA activities at SIS18 (GSI)
  - capitalize on strong IN2P3 involvment in HADES and PANDA
  - keep open the possibility of French hadronic physics activities at FAIR (HADES and PANDA)

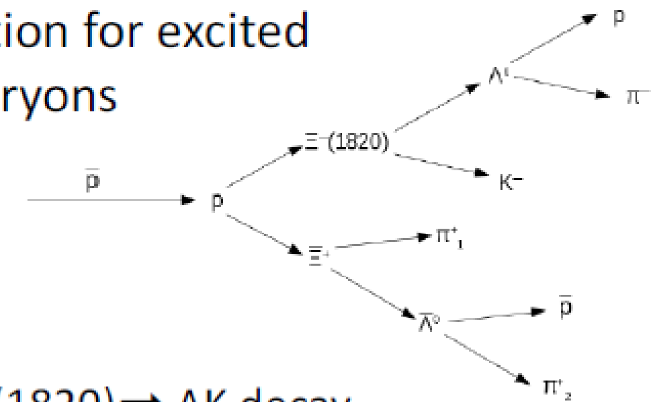
PANDA collaboration

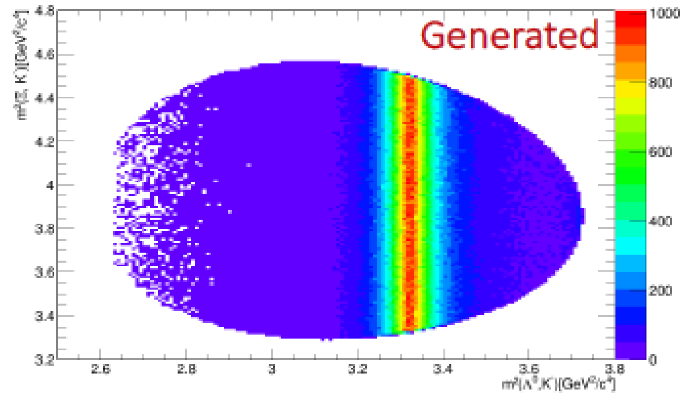
~ 520 physicists
~17 countries

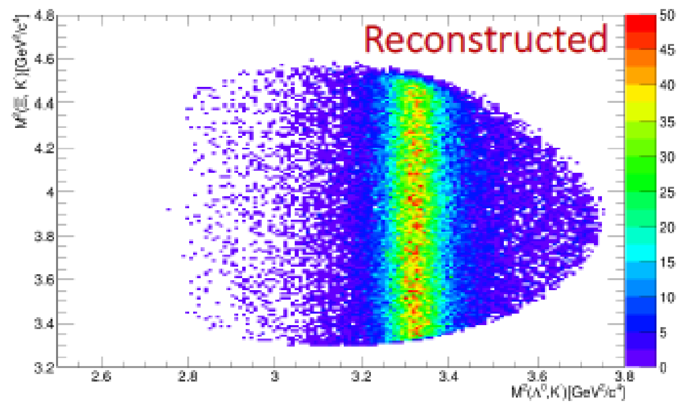
52th PANDA collaboration meeting
organized by E. Tomasi-Gustafsson and D. Marchand in 2012

Ξ(1820)

High signal rates and high background rejection for excited double strange baryons







$\bar{p}_{beam}$ = 4.6 GeV/c

- Consider the $\Xi^{*-}(1820) \rightarrow \Lambda K$ decay,
  - assume BR = 100% and σ = 1 μb
- Simplified MC framework
- Day-1 luminosity: $10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Results

- ~30 % inclusive efficiency for $\Xi^{*-}(1820)$
- ~5 % exclusive efficiency for $\bar{\Xi}^{+}\Xi^{*-}(1820)$
- Low background level → ~15000 exclusive events / day

Time Like Electromagnetic proton form factors with PANDA

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

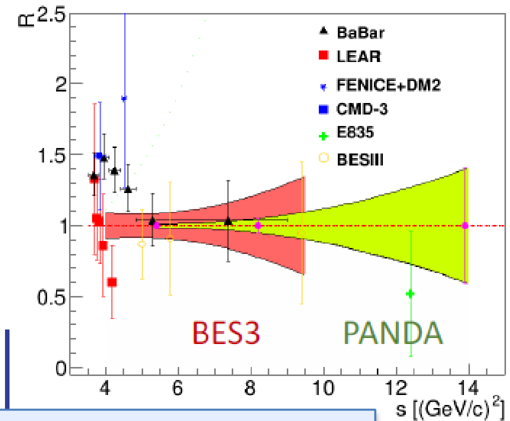
Angular distributions:

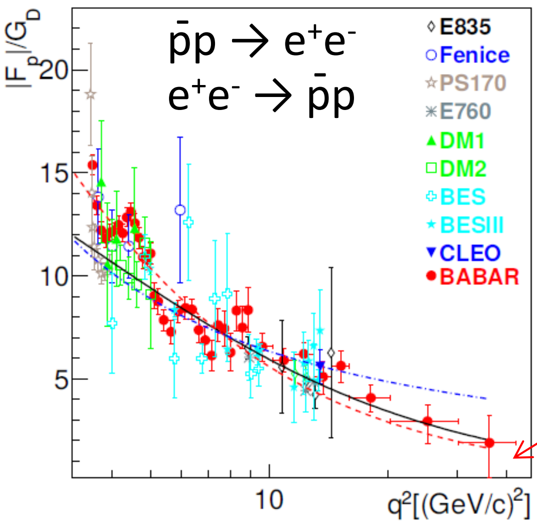
$$\frac{d\sigma}{d(\cos\theta_{CM})} = \frac{\pi\alpha^2}{8M_p^2\tau\sqrt{\tau(\tau-1)}}\left[\tau\left|G_M^{TL}\right|^2(1+\cos^2\theta_{CM})+\left|G_E^{TL}\right|^2\sin^2\theta_{CM}\right]$$

Total cross sections:

$$G_{eff}^2 = \frac{2\tau|G_M|^2+|G_E|^2}{2\tau+1} \qquad \tau = \frac{q^2}{4M_p^2}$$

$\sigma_{tot} \sim |G_{eff}|^2$





Rejection of $\bar{p}p \to \pi^+\pi^-$ 10^8-5.10^7

Efficiency for $\bar{p}p \to e^+e^-$ ~ 40%

$q^2 < 14$ GeV^2 : $|G_M|$ and $|G_E|$

$14 < q^2 < 28$ GeV^2 $|G_{eff}|$

transition towards pQCD

Full GeANT simulation

M. Sudol (Gumberidze) et al. EPJA44,373 (2010).

A. Dbeyssi 's PhD (2013) Orsay

PANDA collab: Eur.Phys.J. A52 (2016), 325

See E. Tomasi-Gustafsson's talk

Access to the unphysical region $q^2 < 4\, m_p^2$

$\bar{p}d \to ne^+e^-$ *H. Fonvieille and V.A. Karmanov EPJA42 (2009) 287-298.*

$\bar{p}p \to \pi^0 e^+e^-$ Feasibility studies by *J. Boucher , PhD University Paris-Sud, 2011).*

Further prospects for TL form factor studies with PANDA

- Measurement of $|G_E|$ and $|G_M|$ in $\bar{p}p \to \mu^+\mu^-$
  On-going PhD work I.Zimmermann (Mainz)
  Contamination by $\bar{p}p \to \pi^+ \pi^-$ S/B~1/4

- Measurements of the proton form factors in the unphysical region $q^2 < 4\, m_p^2$
  $\bar{p}d \to n e^+e^-$ *H. Fonvieille and V.A. Karmanov EPJA42 (2009) 287-298.*
  $\bar{p}p \to \pi^0 e^+e^-$ Feasibility studies by *J. Boucher , PhD University Paris-Sud, 2011).*
- Possibility to access the relative phase of G_E and G_M:
  Transverse spin asymmetry$\to$ $\mathrm{Im}(G_E G_M^*)$
  Development of a transverse polarized proton target for PANDA in Mainz
  on-going PhD work B. Fröhlich (Mainz)

- Study of hadronic channels: background for electromagnetic channels and reaction mechanisms *on-going PhD work Wang Ying (Orsay)*

PANDA EMP @ "phase one" (P1)

Signal	Physics	Comments on the process or the physics	Phase
$\bar{p}p \to e^+e^-$	FFs	High precision Large momentum range	1 (competition from BESIII)
$\bar{p}p \to \mu^+\mu^-$	FFs	The process is unique for PANDA	1 (Limited precision)
$\bar{p}p \to e^+e^-\pi^0$	FFs below threshold	Unique for PANDA	1
$\bar{p}p \to \gamma^*\pi^0$ $\bar{p}p \to J/\psi\pi^0$	TDAs	The processes are unique for PANDA	3
$\bar{p}p \to \gamma\gamma$ $\bar{p}p \to \pi^0\gamma$	GDAs	The process (with pi0) Is unique for PANDA	1 (Lack of person power)
$\bar{p}p \to \mu^+\mu^-X$	TMD PDFs		3

Phenomenological works related to TL form factors

- Radiative Corrections

  J. Van de Wiele and S. Ong, EPJ A 49 (2013) 18.
  E. Tomasi-Gustafsson et al, PRC83 (2011) 04520.

- Heavy leptons and Polarisation

  E. Tomasi-Gustafsson et al, NPA 894 (2012) 20 and PRC83 (2011) 025202.

- Crossed channels and TL-SL Unification

  E. Tomasi-Gustafsson et al, PLB 712 (2012) 240.

- Reaction mechanisms

  E. Tomasi-Gustafsson et al, NPA 920 (2013) 45.

- Hadronic channels

  E. Tomasi-Gustafsson et al, EPJA 46 (2011) 91.
  J. Van de Wiele and S. Ong, EPJA 46 (2010) 291 and EPJ C73 (2013) 2640.
  W. Ying et al. arXiv:1512.05520, subm. to Phys. Lett. B
  W. Ying JPCS 742 ,012021

Competitiveness

- **LHCb**
  - large number of Ξ and Ω observed
  - spectroscopy in the light quark sector, J^P determination?
  - neutrals in final state difficult
- **Belle 2**
  - small Υ and B branching to baryon-antibaryon final states
- **GlueX, CLAS-12**
  - small production cross section, no state seen above $\Xi(1530)$
- **J-PARC**
  - K^- beam, but so far focussed on missing mass experiments

➢ **PANDA is the best experiment for hyperon spectroscopy !**

Key-Experiments of the Start Phase

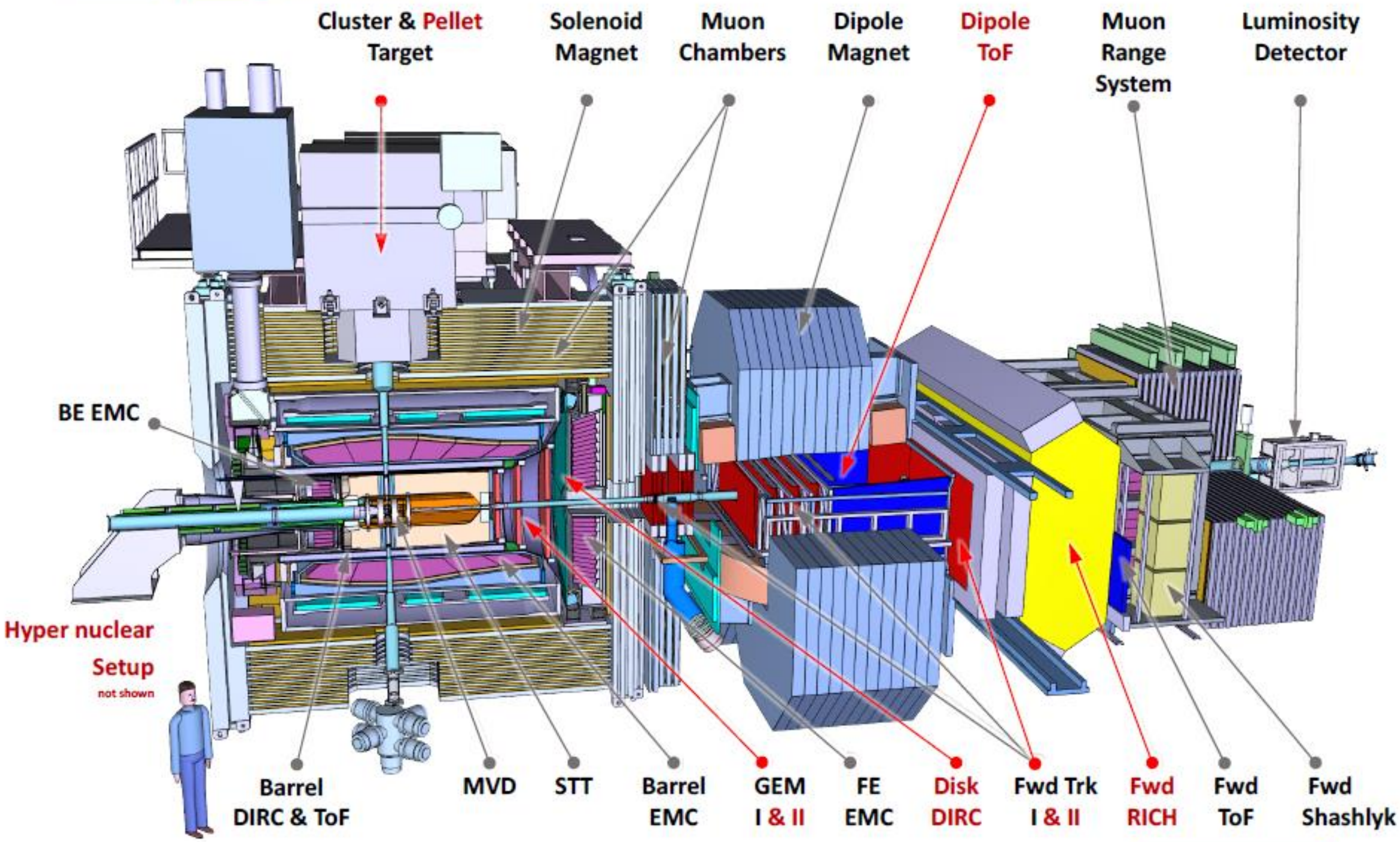
Concentration on unique and forefront physics topics

- Production of multi-strangeness baryons
  (unexplored, new territory, „Strangeness-Factory")
- 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, goal is the nature of the states)
- Measurement of the electromagnetic form factors of the proton in the time-like domain with electrons and muons in the final state
- Production of high spin charmonia
  (only possible in proton–antiproton)
  light mesons, baryons and production of hybrids und glueballs

XYZ-, Hyperon Factory

PANDA@FAIR / K. Peters 52

Full Setup (Phase-2)



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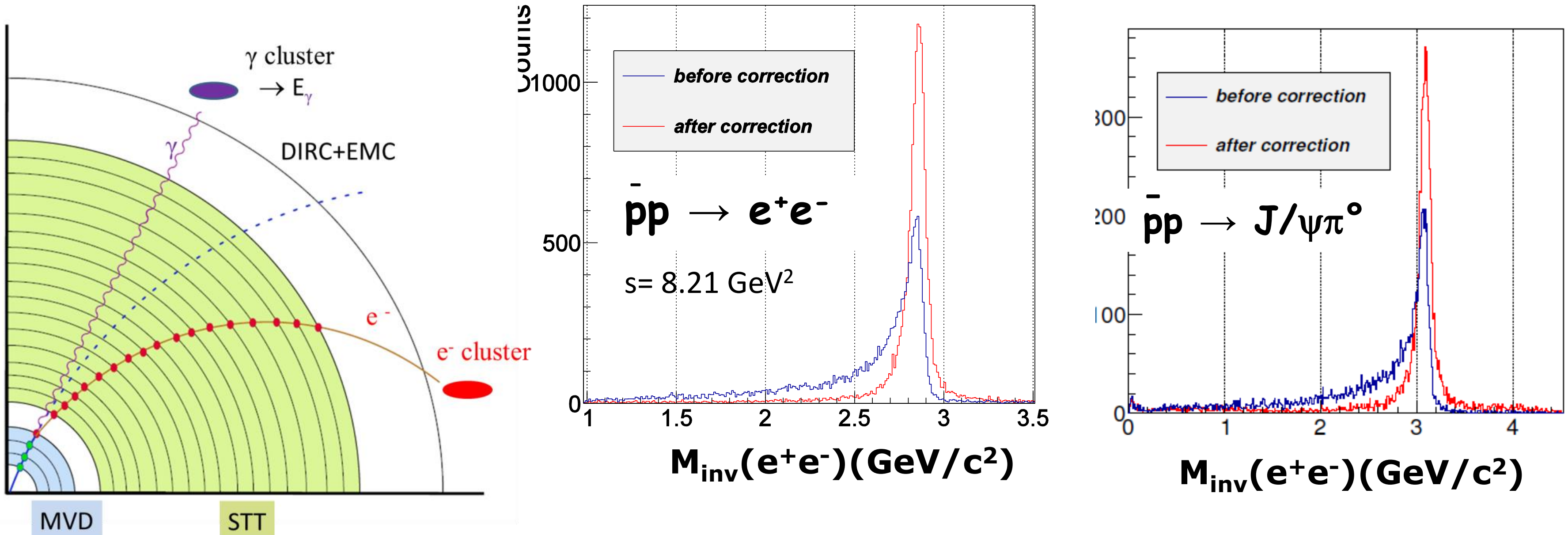
PANDA Schedule

Simulation and analysis code developments for PANDA

- **Particle IDentification** (Bayesian methods/ GEANT hadronic models sensitivity)

- **Bremsstrahlung correction** using photon detection in EMC
  B. Ma, PhD, Univ. Paris-Sud. Sept 2014.



- **Event Filtering** (trigger): fast selection of em channels/suppression of hadronic channels

Status of Ξ^* Resonances: RPP 2014

Chin. Phys. C 38 (2014) 090001

$\Xi(1820)$:

Teodoro78 favors $J = 3/2$, but cannot make a parity discrimination. Biagi 87c is consistent with $J = 3/2$ and favors negative parity for this J value.

Table 1. The status of the Ξ resonances. Only those with an overall status of $***$ or $****$ are included in the Baryon Summary Table.

			Status as seen in —				
Particle	J^P	Overall status	$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	$1/2+$?	$****$					Decays weakly
$\Xi(1530)$	$3/2+$	$****$	$****$				
$\Xi(1620)$		$*$	$*$				
$\Xi(1690)$		$***$		$***$	$**$		
$\Xi(1820)$	$3/2-$?	$***$	$**$	$***$	$**$	$**$	
$\Xi(1950)$		$***$	$**$	$**$		$*$	
$\Xi(2030)$		$***$		$**$	$***$		
$\Xi(2120)$		$*$		$*$			
$\Xi(2250)$		$**$					3-body decays
$\Xi(2370)$		$**$					3-body decays
$\Xi(2500)$		$*$		$*$	$*$		3-body decays

$****$ Existence is certain, and properties are at least fairly well explored.

$***$ Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.

$**$ Evidence of existence is only fair.

$*$ Evidence of existence is poor.

SU(6) x O(3) Classification

RPP 2014: Chin. Phys. C 38 (2014) 090001

„Assignments for …

Ξ(1820) and Ξ(2030), are merely

educated guesses.“

Phys.Rev. D95 (2017) 032003

?

Ξ(1690), Ξ(1950):

T. Melde *et al.*, PRD 77 (2008) 114002

decuplet: no Ξ*, no Ω*

“… nothing of significance on Ξ resonances has been added since our 1988 edition.”

J^P	$(D, L_N^P)\,S$		Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	$1/2$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	$1/2$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1_1^-)$	$1/2$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$ $\Sigma(1560)^\dagger$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	$1/2$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	$3/2$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$ $\Sigma(1620)^\dagger$	$\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	$3/2$	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	$3/2$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0_2^+)$	$1/2$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2_2^+)$	$1/2$	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	$1/2$	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	$1/2$	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	$3/2$	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	$1/2$	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	
			Decuplet members				
$3/2^+$	$(56,0_0^+)$	$3/2$	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$	
$3/2^+$	$(56,0_2^+)$	$3/2$	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$	
$1/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$	
$3/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$5/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$7/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$	
$11/2^+$	$(56,4_4^+)$	$3/2$	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	