STUDY OF HADRON PROPERTIES AT PANDA

V. Mochalov (IHEP, Protvino)

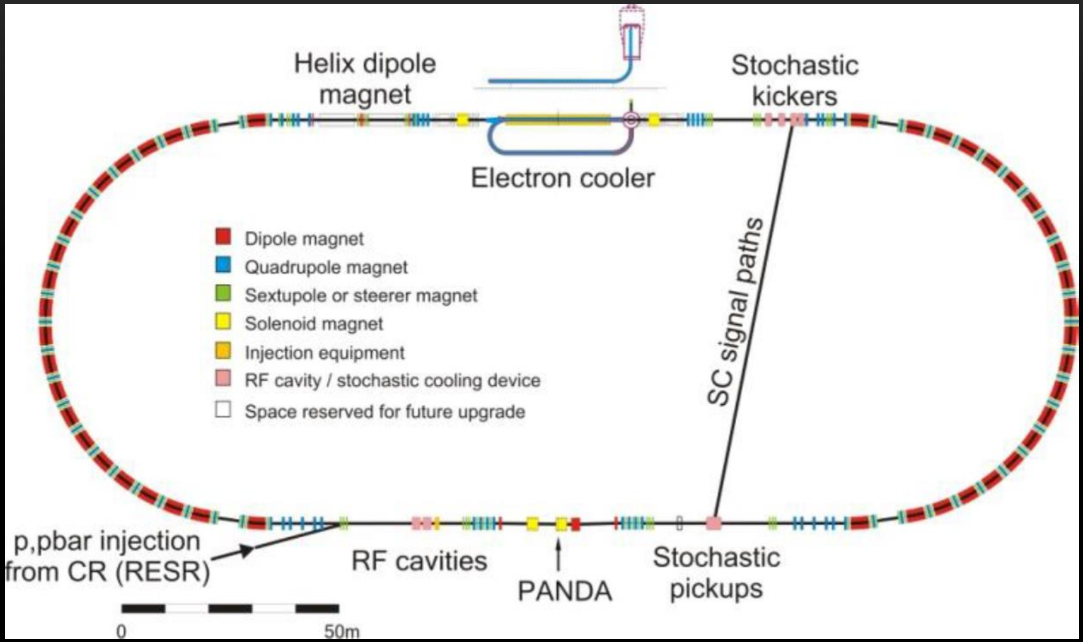
on behalf of the PANDA collaboration

CONTENT

- **Short introduction: FAIR, HESR & PANDA**
  - **(FAIR – Facility for Antiproton and Ion Research)**
  - **(HESR – High Energy Storage Ring)**
  - **(PANDA– antiProton ANnihilation at DArmstadt)**
- **Hadron Physics**
  - **PANDA experiment advantages**
  - **Charm spectroscopy**
  - **Light exotics**
  - **Baryon studies**
- **Conclusion**

FAIR FACILITY

FAIR FACILITY



$\overline{p}$ beam with momentum from 1.5 GeV/c up to15 GeV/c on a proton fixed target (or nuclear target), average interaction rate 20 MHz, √s from 2.25 up to 5.46 GeV, d<100 μ

- **High intensity mode**
  - Stochastic cooling, p≥ 3.8 GeV/c
  - 10^{11} antiprotons stored
  - Luminosity up to $2{\cdot}10^{32}$ cm^{-2} s^{-1}
  - Δ p/p = $2 \cdot 10^{-4}$
- **High resolution mode**
  - e- cooling, 1.5≤ p≤ 8.9 GeV/c
  - 10^{10} antiprotons stored
  - Luminosity up to $2 \cdot 10^{31}$ cm^{-2} s^{-1}
  - Δ p/p = $4{\cdot}10^{-5}$

MAIN DETECTOR REQUIREMENTS

- Capability to detect events with high rate (up to $2 \cdot 10^7$ s^{-1} interactions)
- Nearly 4π solid angle for large acceptance and PWA
- $p^{\pm}$, $K^{\pm}$, $p^{\pm}$, $e^{\pm}$, $\mu^{\pm}$, γ identification
- Displaced vertex detection – vertex information for D, K_S, Σ, Λ ($c\tau$ = 317 μm for $D^{\pm}$)
- Photon detection from 10 MeV to 10 GeV
- Efficient event selection & good momentum resolution
- Self-triggered electronics
- Free streaming data
- 20 MHz interaction rate
- Complete real-time event reconstruction

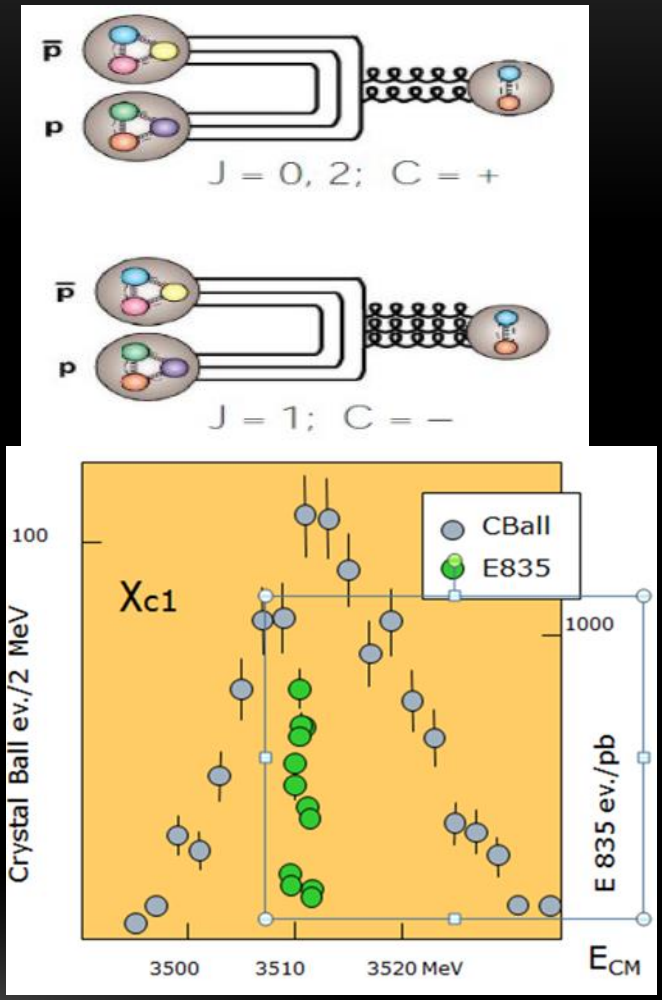
PANDA ADVANTAGES

- Possibility to produce directly all quantum numbers (only $J^{PC}=1^{--}$ are allowed in direct production at e^+e^- colliders).
- In the formation mode, masses and widths will be measured very accurately. The accuracy of mass and width measurements depends only on the beam parameters, not on the detector resolution. Detector characteristics are important for selection of a given final state and background suppression
- Typical resolution:

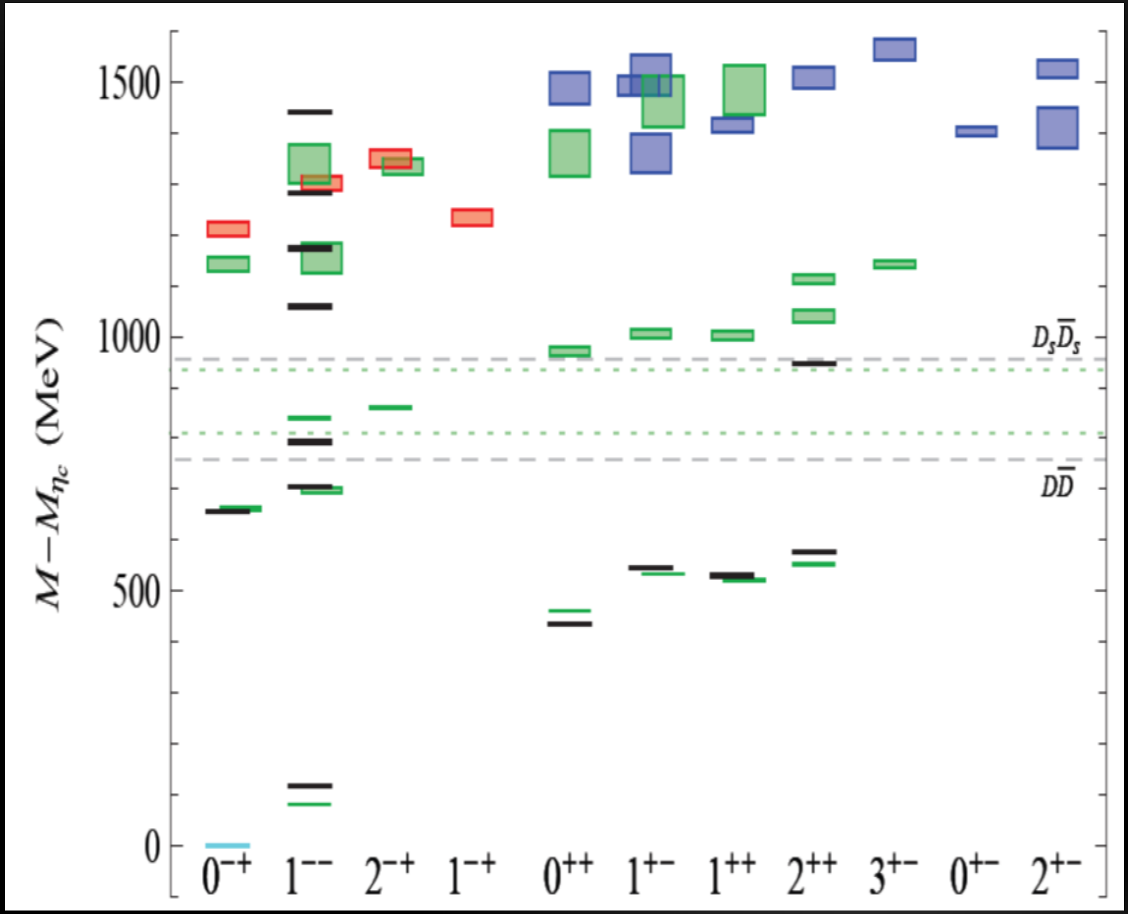
  e+e- Crystal Ball: ~ 10 MeV

  $\overline{p}$p Fermilab: 240 keV

  $\overline{p}$p PANDA: ~30-100 keV

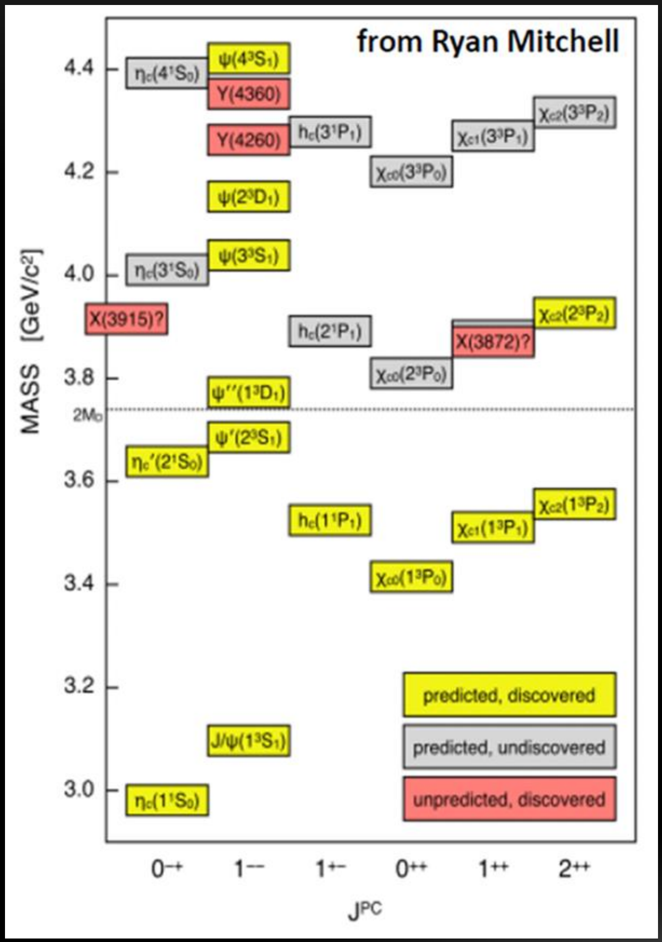


LATTICE QCD CHARMONIUM SPECTRA



- lightest supermultiplet
- first excited supermultiplet
- other states (cc)
- L. Liu et al, arXiv: 1204.5425v1 [hep-ph]

CHARM SPECTROSCOPY



- All charmonium states below open charm threshold are observed
- All charmonium 1^{--} states are observed
- Above open charm threshold:
  - many expected states are not observed
  - many unexpected ones are observed
- States with high angular momentum predicted in potential models (J>3) have to be verified for theory's confirmation(?).
- Suppressed at B factories, they may be observed at PANDA

STUDY OF HIGH

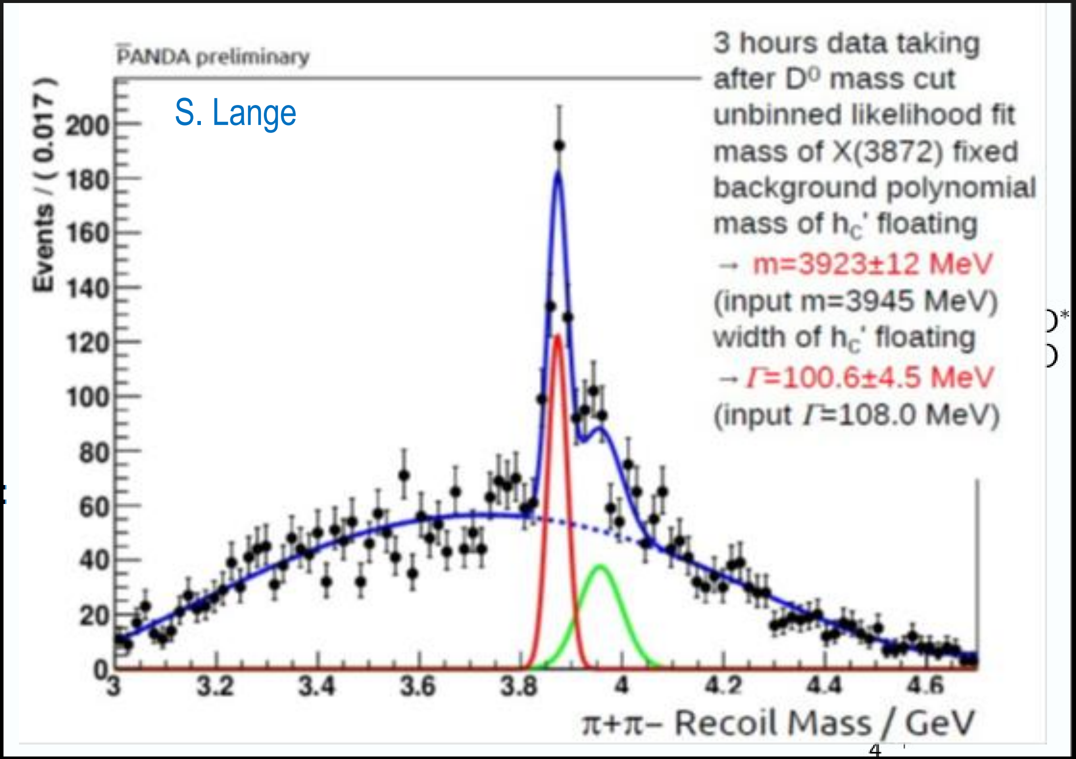
The h'_c (n=2, $^1P_1$, m=3934-3956 GeV) state with $J^{PC}=0^{-+}$ is one of the yet unobserved states

h_c (n=1) was never observed in B decays, as $0^{-+}\to 0^{-+}1^{+-}$ is forbidden

h_c (n=1) was observed at CLEO and BESIII in the isospin violating decay

$\psi^0 \to h_c \pi^0$

MC simulations were performed for the decay p(bar)p→ (π+π−)recoil+h'_c



Cross-section simulation 4.5 nb for h'_c and 50 nb for X(3872)

arXiV:1311.7597 [hep-ex]

RADIATIVE CASCADE FOR *3F4 (= 2S+1LJ) CC STATE*

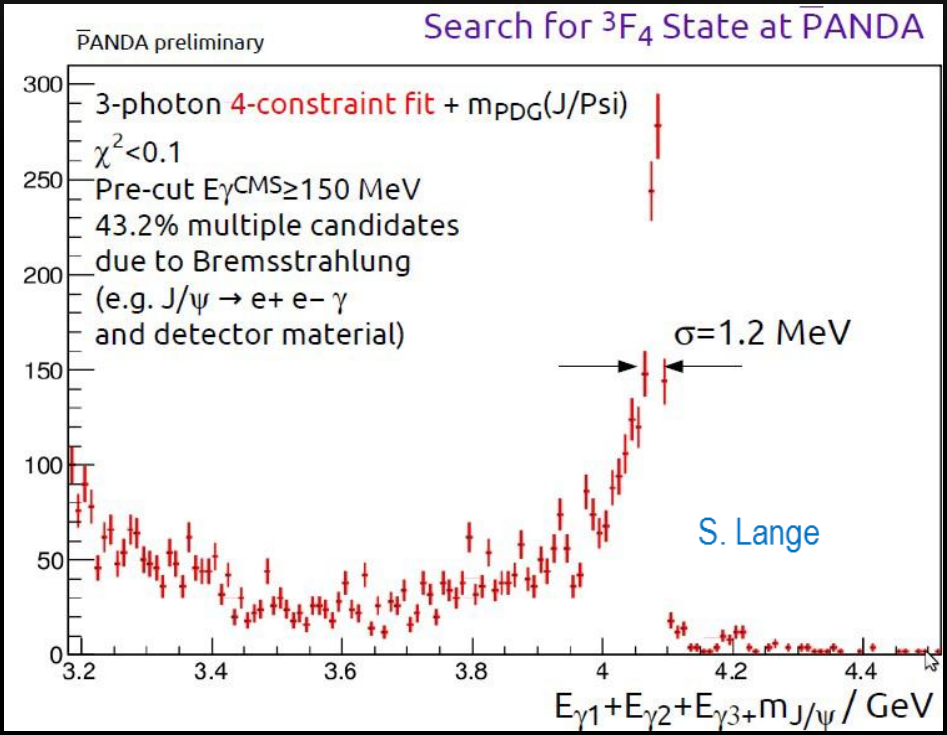
Disadvantage of using the h_c' is that the width is as large as Γ=87 MeV.

On the other hand, the yet unobserved $^3F_4$ state is more appropriate due to its very narrow predicted width of 8.3 MeV

$^3F_4$ state predicted, never seen (Suppressed search in BES III, Belle II)

PANDA can do this search

Xsection 10 nb used



Recoil mass technique is used

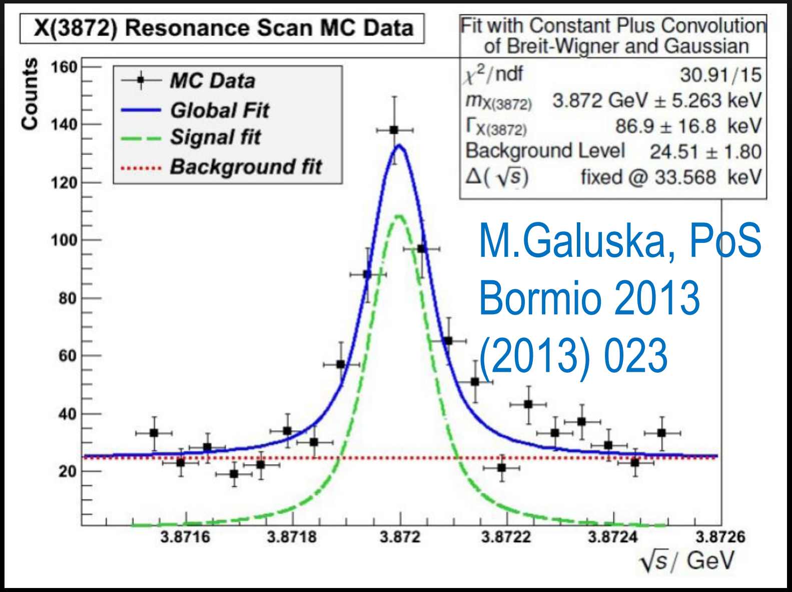
arXiV:1311.7597 [hep-ex]

X (3872) PUZZLE

- The case of X(3872): isospin violating, very narrow, known quantum numbers (LHCb), it;s nature is not clear.
- Breaks isospin in the decays $J/\psi\rho(\to\pi^+\pi^-)$ – isospin violation, $J/\psi\omega(\to\pi^+\pi^-\pi^0)$ → it is not charmonium?
- Within $\Delta m < 1$ MeV of the DD* threshold S-wave molecular state?
- Large cross-section – it is charmonium $\chi_{c1}(2P)$?- (S.S. Gershtein, A.K. Likhoded, A.V. Luchinsky Phys.Rev. D74 (2006) 016002) - For molecule should be lower by factor 10^2)
- Probably two narrow states (CDF)
- X(3872) may be a mixture of usual charmonia $\chi_{c1}(2P)$-calculated and molecule DD*

$(\bar{D}D^* + \bar{D}^*D)$ + χ_c1(2P) it is desireable to find mechanism to suppress χ_c1(2P) production.

- Charge partner? – not in the mass window neither in width found yet
- Need to measure the width and channels to understand its nature



Goal: measure the width of X(3872) to understand better its nature

In PANDA: mass resolution 20 times better than B factories

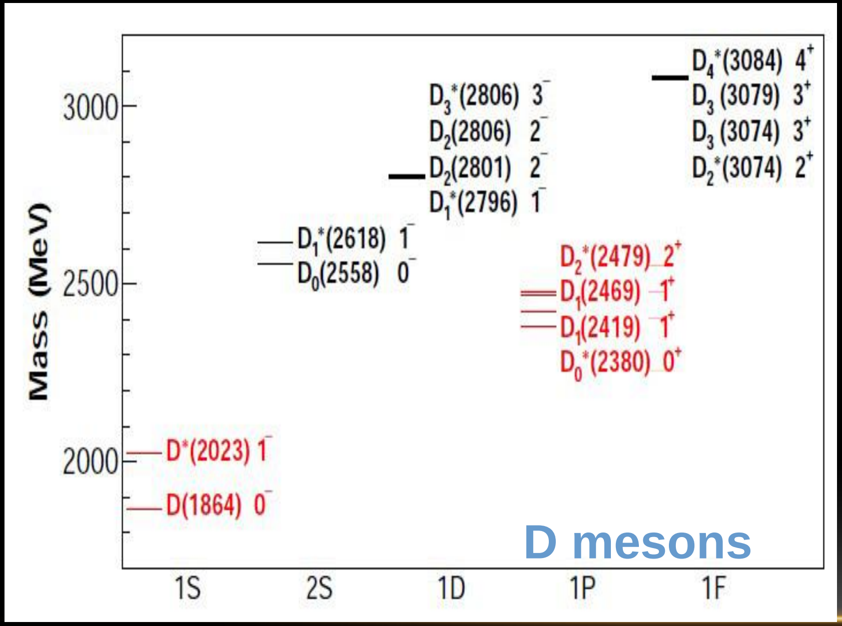
[PDG upper limit: $\Gamma<1.2$ MeV @ 90% c.l.]

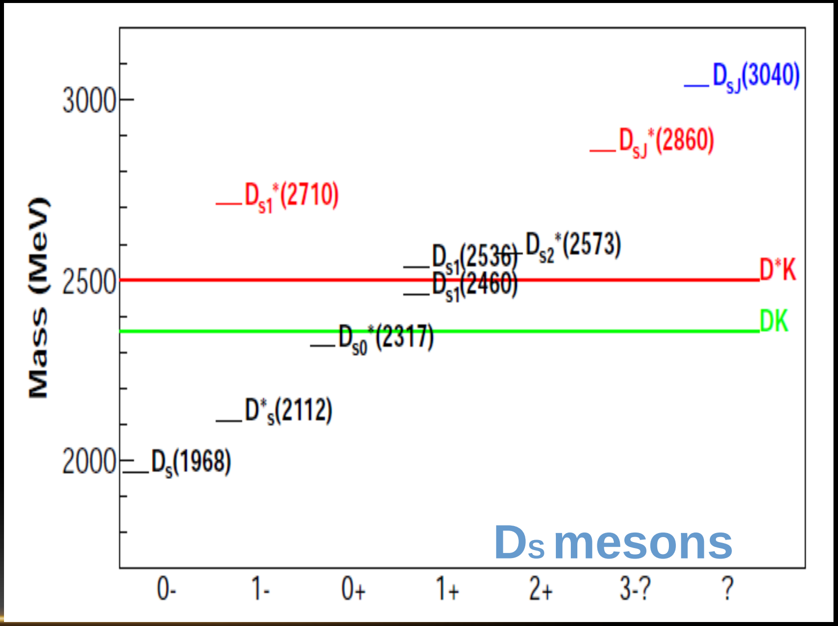
SCANNING OF D-STATES

Many new results and update recently from LHCb: width of D_S is still a challenge

PANDA will scan resonance mass to determine precisely the width of D_S

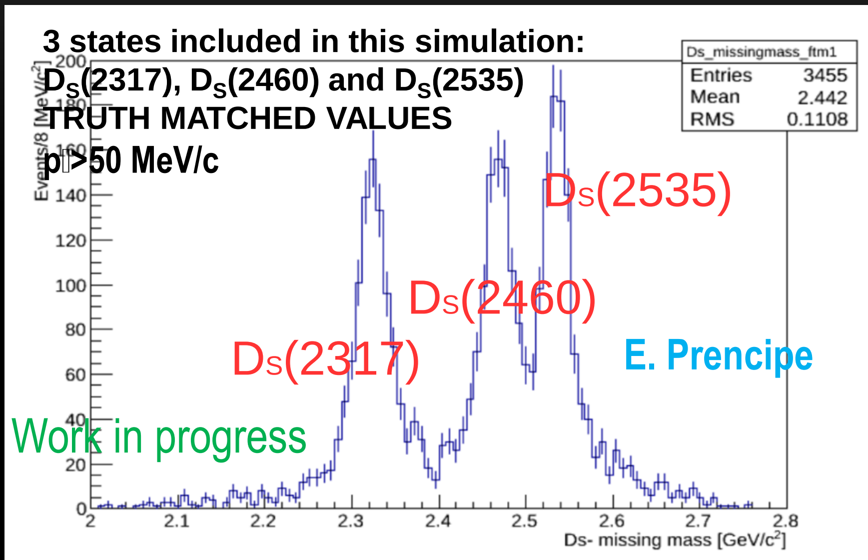
Mass resolution ~ 100 keV

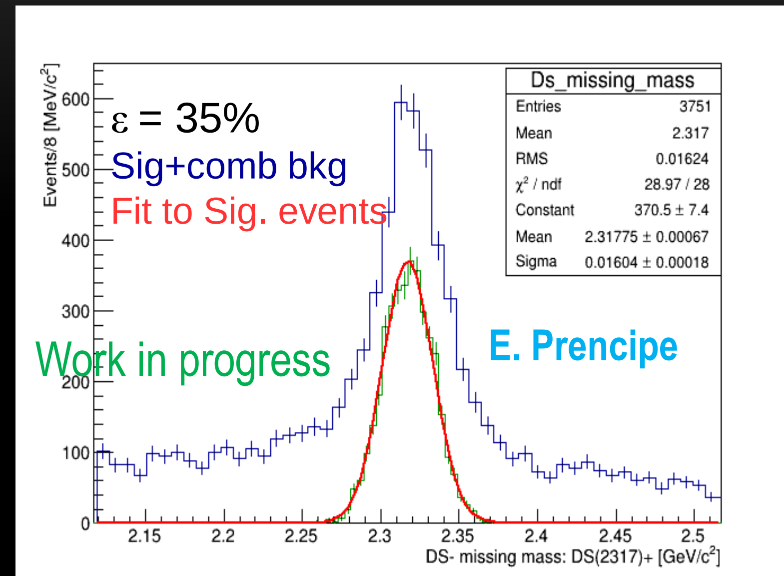




courtesy of A. Palano from CHARM 2013

CHALLENGES IN Ds MESON SPECTROSCOPY





Goals:

1. Cross section measurement in $\bar{p}\,p$ (unknown, difficult predictions: 1-100 nb)
2. Measurement of the width with mass scan and the excitation function of cross section
3. Mixing between D states with same spin, e.g. D_S(2460) and D_S(2535)
4. Chiral symmetry breaking, involving very precise mass measurement: D_S (2317) and D_S (2460) can be interpreted as chiral partners of the same heavy-light system

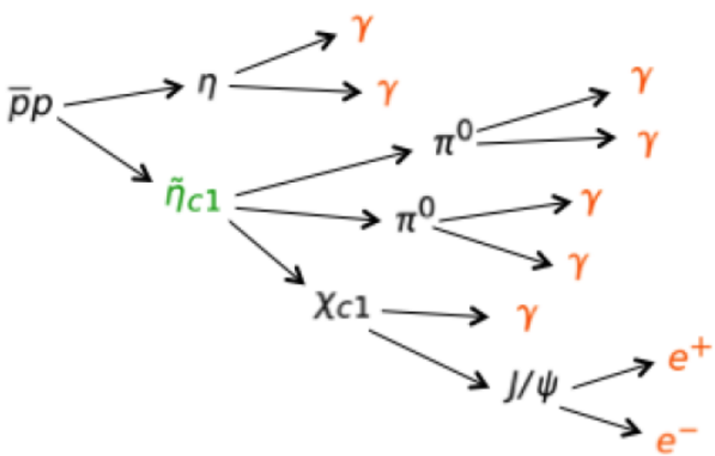
Problems – background is 1000 times higher than signal

Expected – 10^3-10^5 events/day

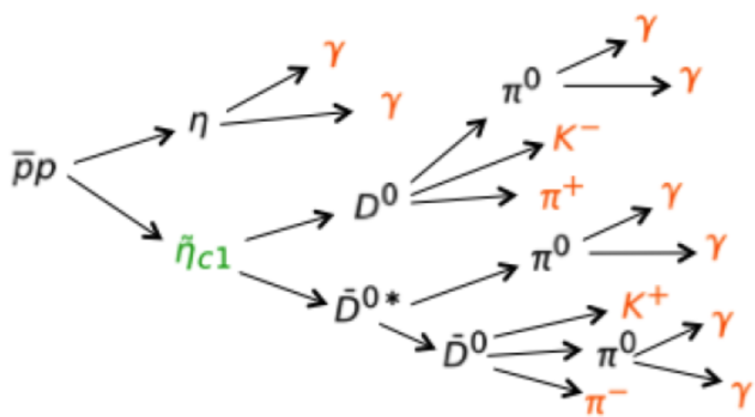
EXOTIC STATES STUDY

- exotic 1^{-+} state with mass ~4.3 GeV/c^2
  - expected to be narrow and having sizeable BF in open / hidden charm
- exclusive reconstruction at s=(5.47 GeV)^2

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



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



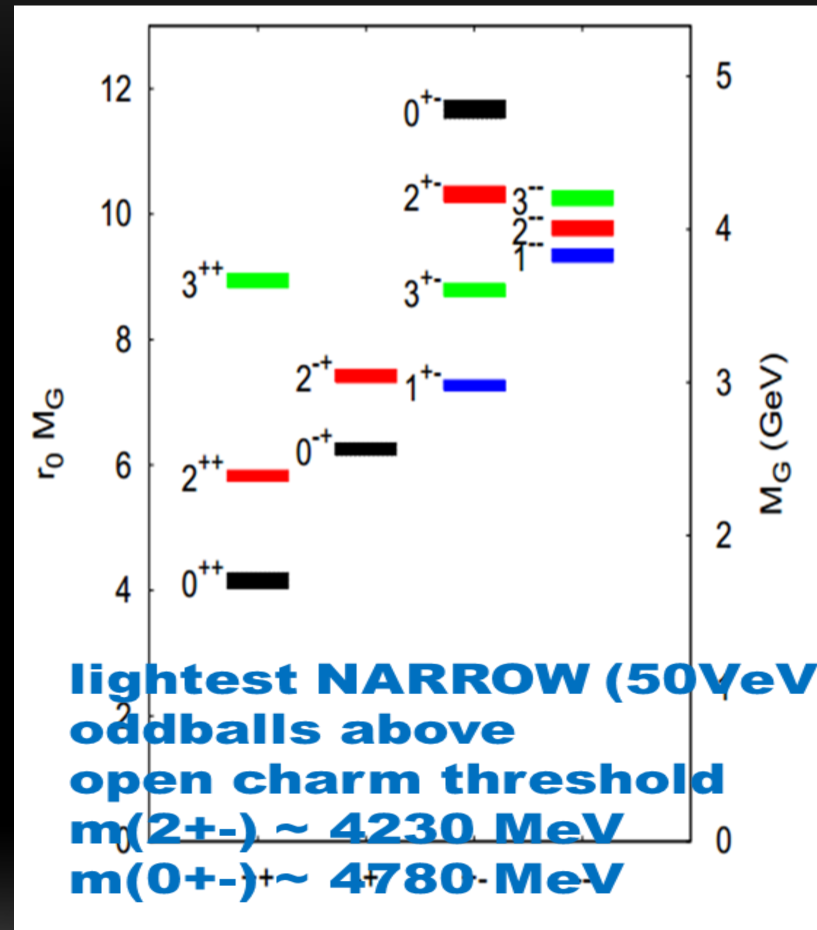
potential charm backgrounds, e.g.

$$\bar{p}p \to J/\psi\, 3\pi^0\eta,\, \chi_{c1}\pi^0\pi^0\eta$$

$$\bar{p}p \to D^0\bar{D}^{*0}\eta,\, D^0\bar{D}^{*0}\pi^0$$

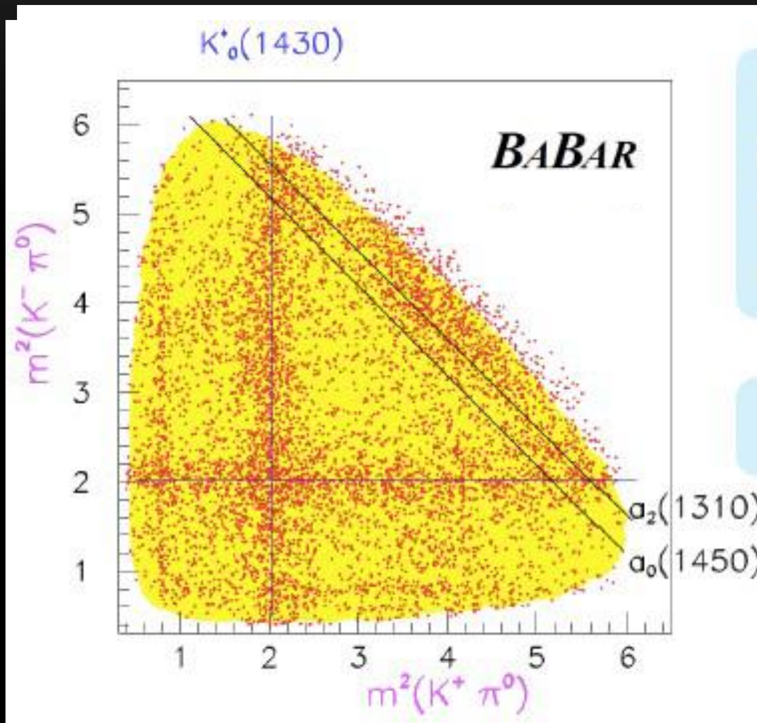
GLUEBALLS

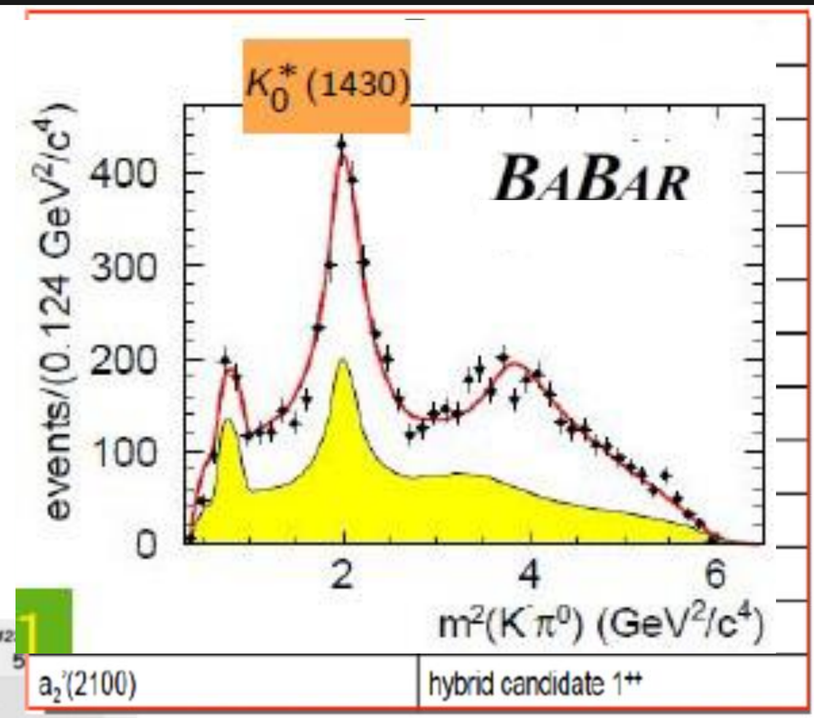
J^{PC}	$r_0 M_G$	M_G (MeV)
0^{++}	4.16(11)(4)	1710(50)(80)
2^{++}	5.83(5)(6)	2390(30)(120)
0^{-+}	6.25(6)(6)	2560(35)(120)
1^{+-}	7.27(4)(7)	2980(30)(140)
2^{-+}	7.42(7)(7)	3040(40)(150)
3^{+-}	8.79(3)(9)	3600(40)(170)
3^{++}	8.94(6)(9)	3670(50)(180)
1^{--}	9.34(4)(9)	3830(40)(190)
2^{--}	9.77(4)(10)	4010(45)(200)
3^{--}	10.25(4))(10)	4200(45)(200)
2^{+-}	10.32(7)(10)	4230(50)(200)
0^{+-}	11.66(7)(12)	4780(60)(230)

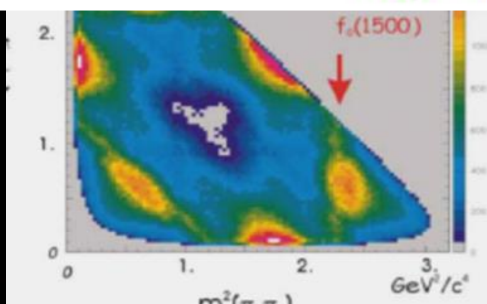


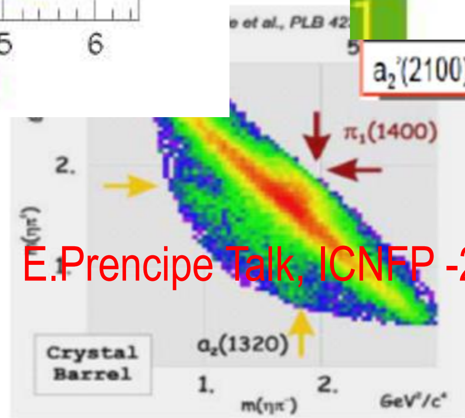
lightest NARROW (50VeV) oddballs above open charm threshold
m(2+-) ~ 4230 MeV
m(0+-) ~ 4780 MeV

LIGHT SECTOR EXOTICS









E.Prencipe Talk, ICNFP -2014, PRD 89, 112004 (2014)

LIGHT QUARK SECTOR - ISOSPIN BREAKING STUDY

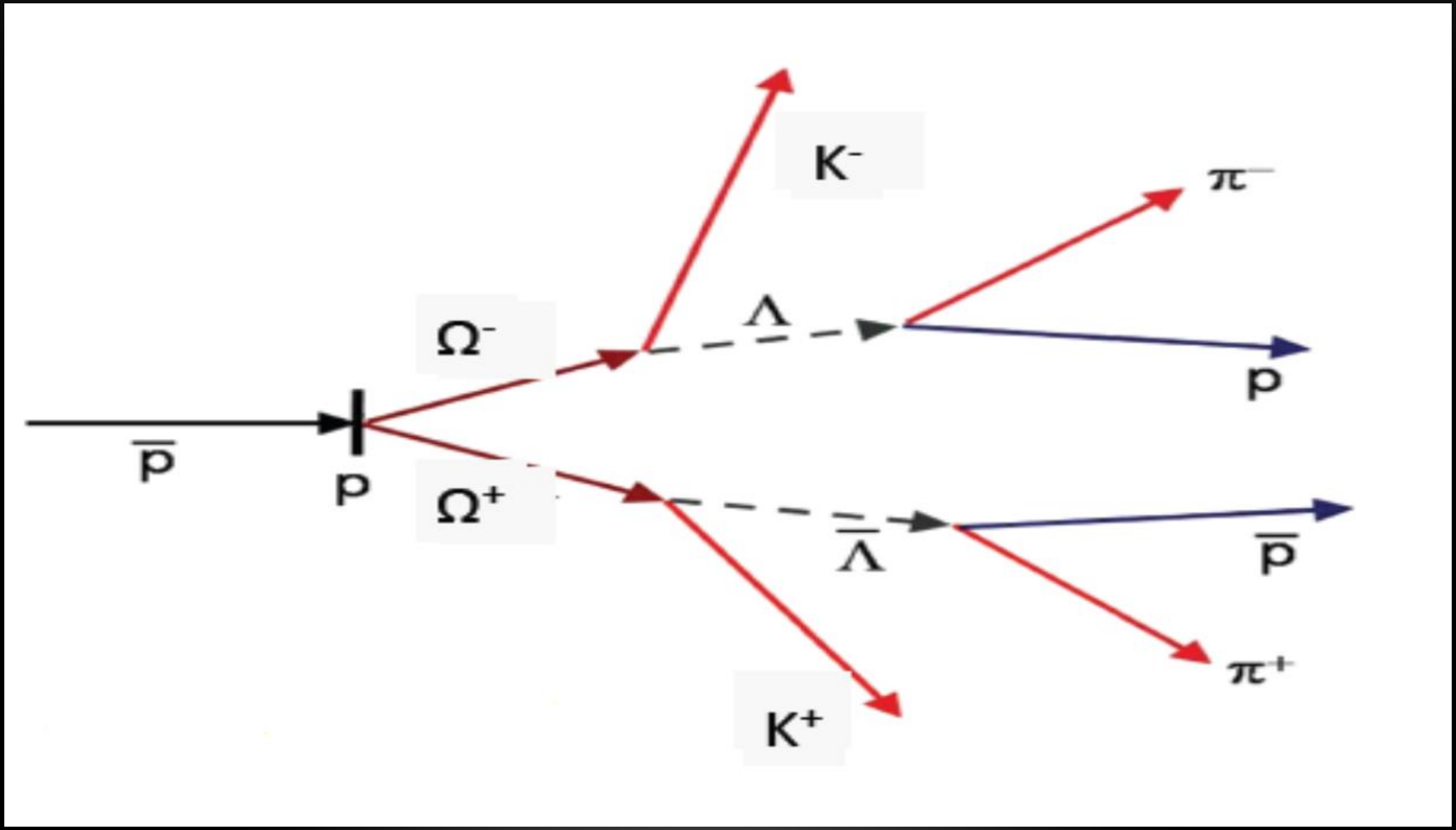
- **Study of channel: $J/\psi \to \phi\phi\gamma \to (K^+K^-)(K^+K^-)\gamma$**
- **Large isospin breaking: η(1440) and f0(980) showed incompability BESIII: PRL 108 (2012) 182001:**

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} = 0.9\%$$

But !!!

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0)}{BR(\eta(1405) \to a_0(980)\pi)} \approx (17.9 \pm 4.2)\%$$

HYPERON-ANTI-HYPERON PRODUCTION



EXCLUSIVE DOUBLE HYPERON STUDY

- **Measurement of spin observables – spin density matrix (polarization) and correlation parameters**
- **CP violation**
  - **In decay width $\Gamma(Y \to B\pi)$ and conjugate decay $\Gamma(\bar{Y} \to \bar{B}\pi)$**
- **Much more with polarization:**
  - **the asymmetry parameter *α* quantifies the tendency of the decay baryon to be preferably emitted in the hyperon spin direction**
  - **With hyperon decay to another decay additional CP asymmetries can be achieved**

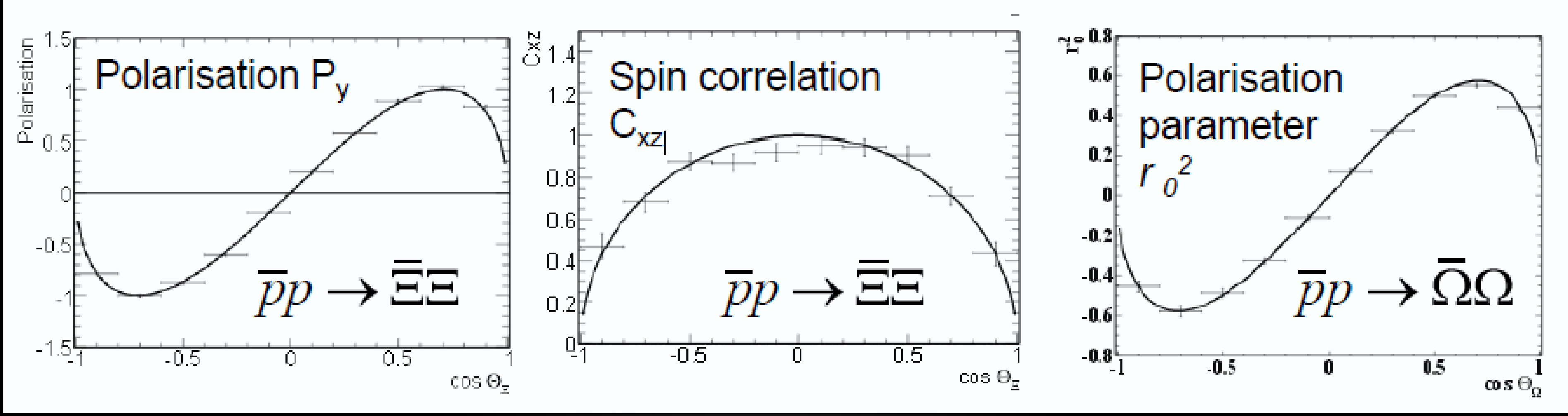
$$A = \frac{\Gamma\alpha + \bar{\Gamma}\bar{\alpha}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \simeq \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$

$$B = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\beta - \bar{\Gamma}\bar{\beta}} \simeq \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}}$$

$$B' = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \simeq \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}}$$

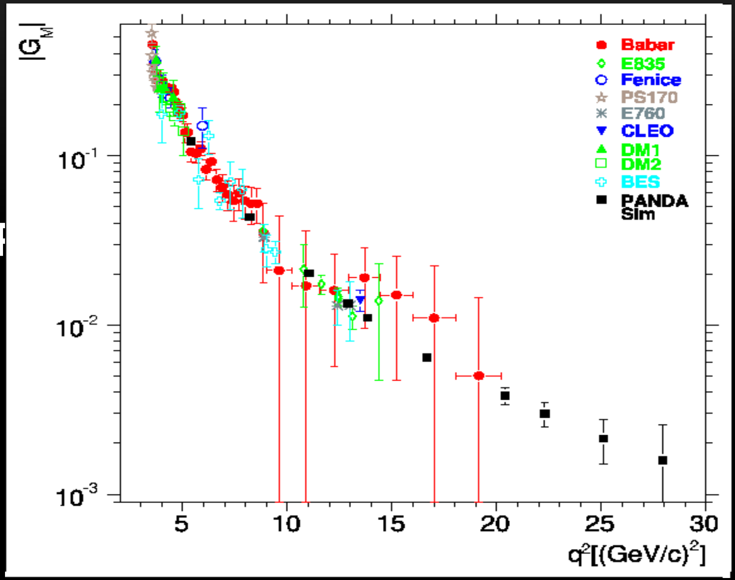
Simulations studies of polarization and spin correlations for Ξ and the recently derived polarization parameters of the Ω show excellent prospects for PANDA

Results and Plots by Erik Thomé, Ph. D. Thesis, Uppsala University (2012).



PHYSICS BEYOND THE THEME OF THE TALK

- **Nucleon Structure**
  - **Timelike Nucleon Formfactors**
  - **Transverse momentum dependent PDF** (Spin Studies in Drell-Yan Production)



Sudol et al. EPJA 44 (2010) 373

M.C. Mora Esp´ı, PhD thesis (2012)

- **Nuclear Physics**
- **Hypernuclei**:
  - Production of double Λ-hypernuclei (A.Sanches Talk 25/08)

➔ γ-spectroscopy of hypernuclei, YY interaction

- **Hadrons in Nuclear Medium**
  - **J/ψ absorption**
  - **Mass shift of charmed hadrons in nuclear matter**

Full physics program e-Print: arXiv:0903.3905 **[hep-ex]**

SUMMARY

- The PANDA experiment will have a great potential for discovery (Glueballs, hybrids, XYZ …)

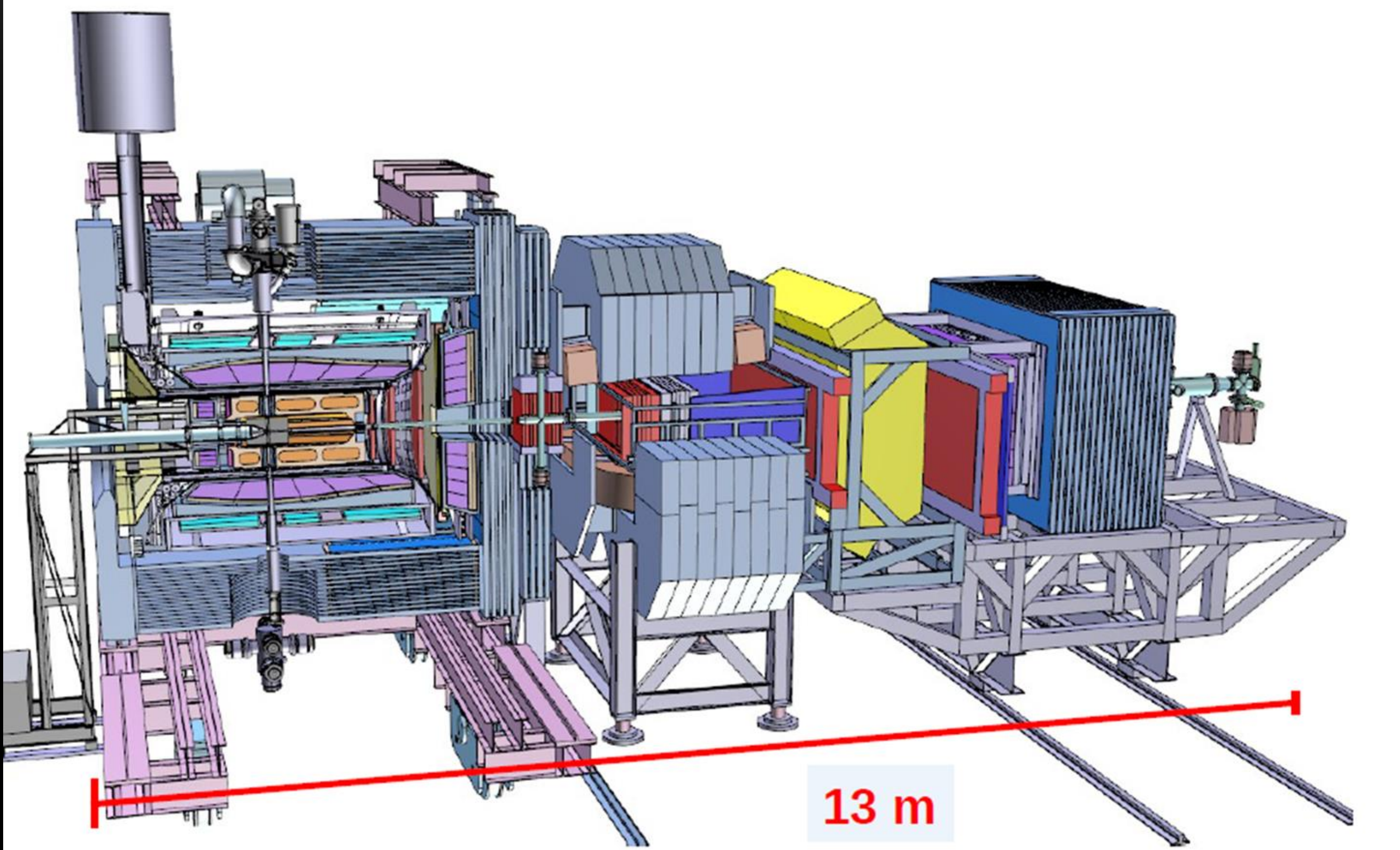
- Thanks to LHCb and electron B-factories for exciting results, but still too much left to investigate:
  - Annihilation process will give us the possibility to study directly gluon contribution and will give us unique possibility to investigate states with high spins and exotic quantum numbers.
  - The unprecendent precision of PANDA detector and FAIR antiproton beam will allow to measure masses and width of the particle at the level of 30-100 keV to understand the nature of charmonium (-like) particles and to study interference in particle production.
  - Many predicted states yet have to be observed and measured precisely at PANDA.

PANDA TEAM

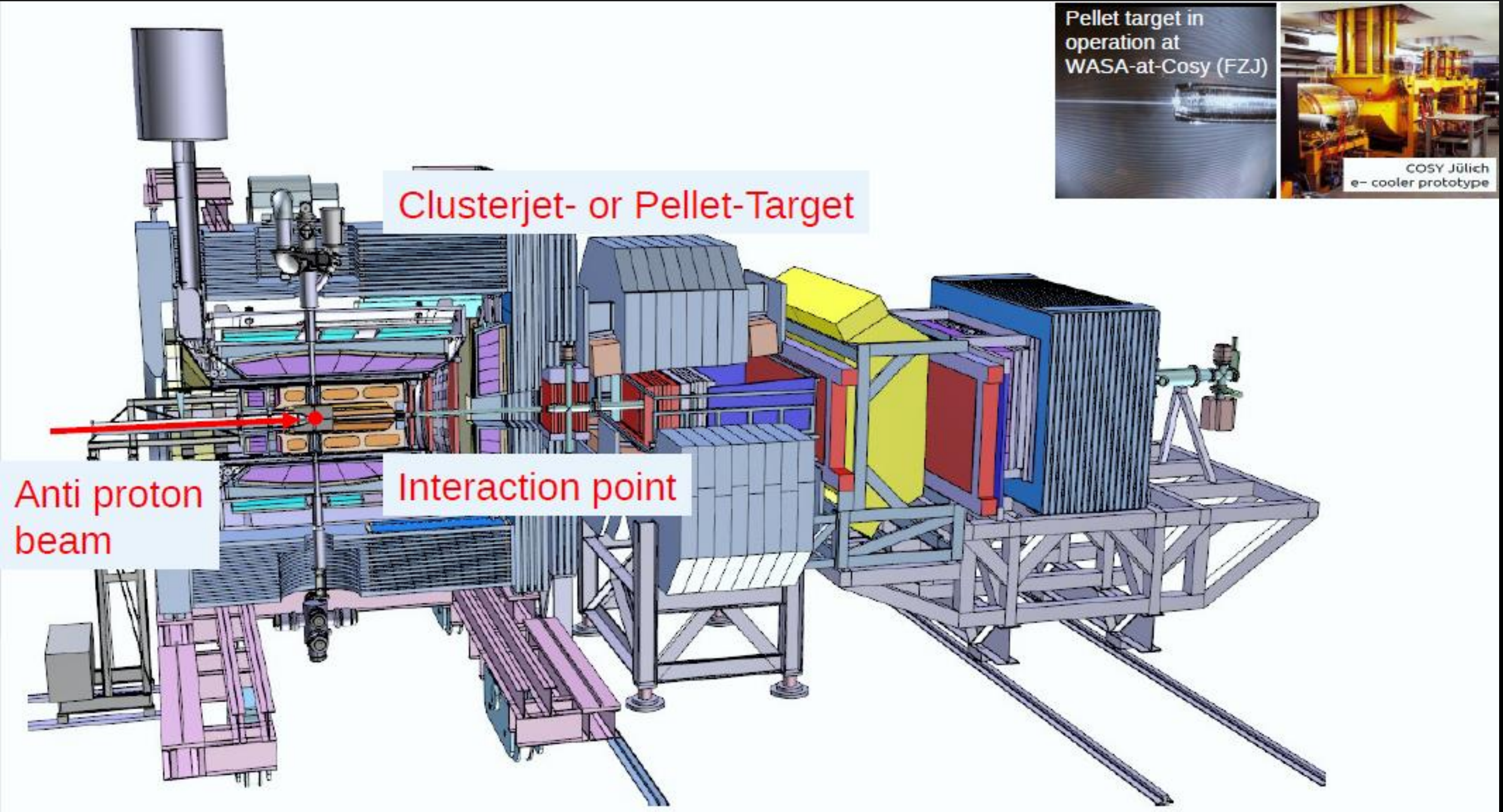
PANDA Collaboration, 520 members, 69 Institutes, 18 Countries (2014)

BACKUP SLIDES

PANDA DETECTOR

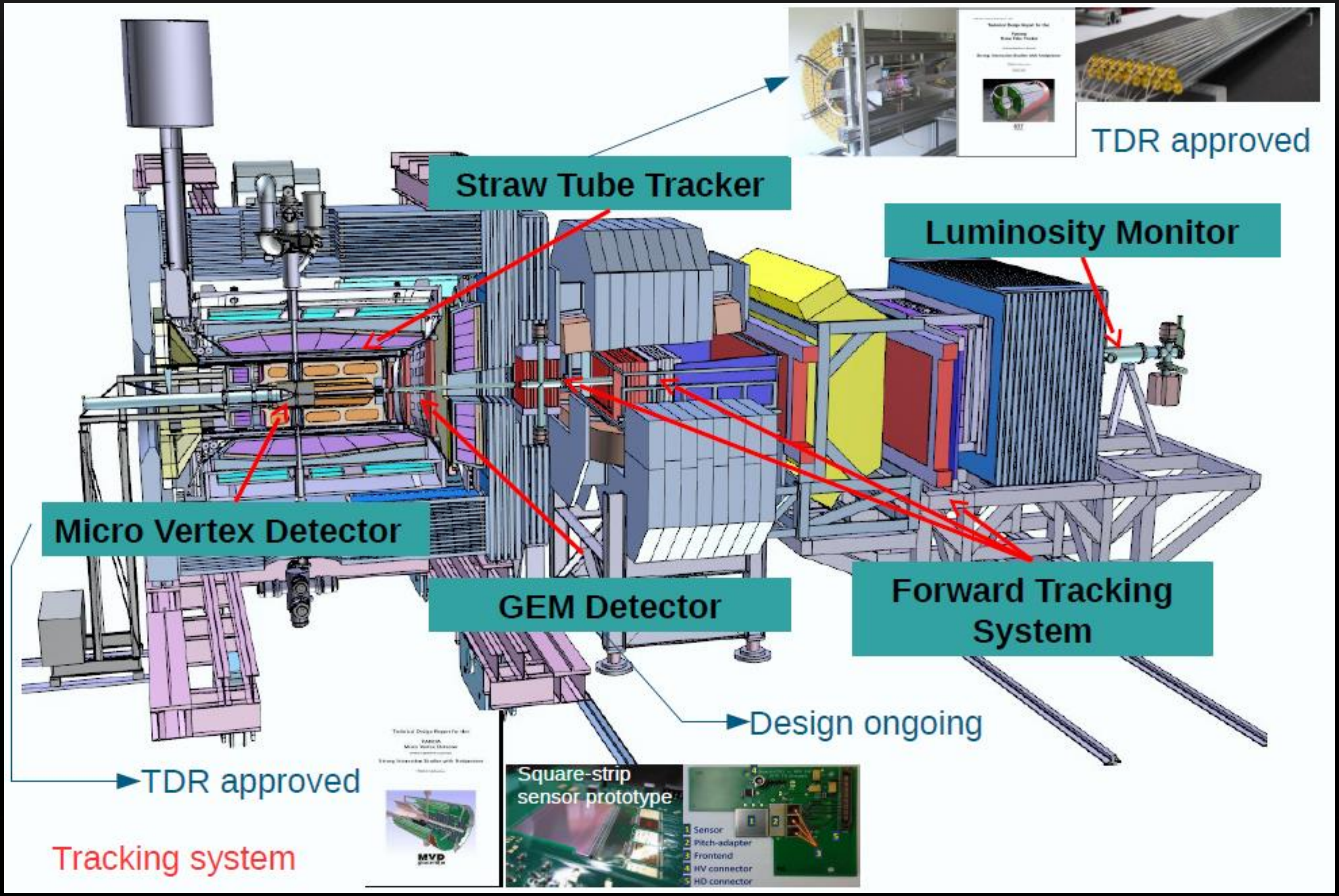


- 2013-2017: pre-assembling at COSY, Jülich
- Summer 2017: $\overline{\text{P}}$ANDA hall accessible at FAIR

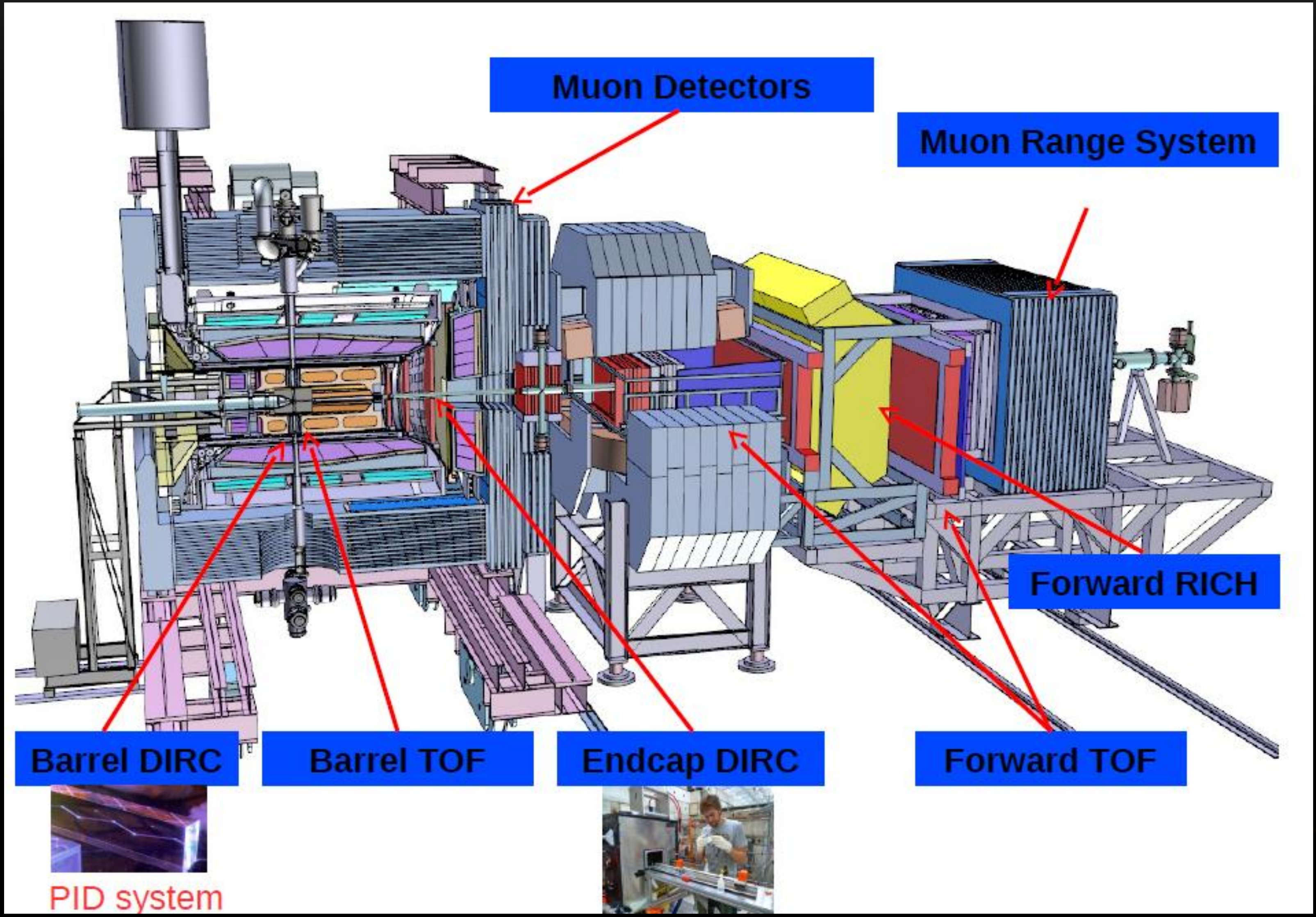


Target system: TDR approved
Under construction

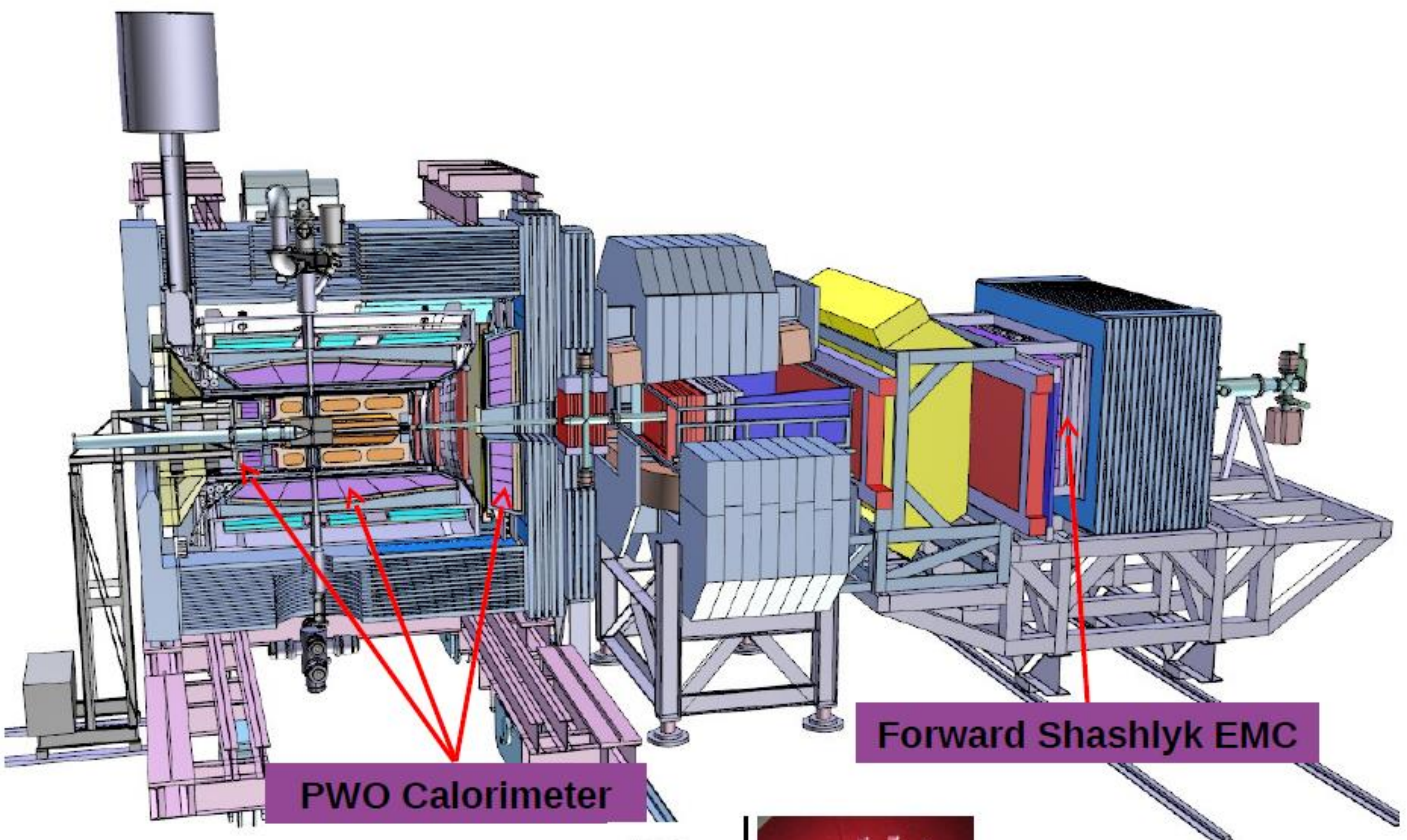
PANDA TRACKING



PANDA IDENTIFICATION



PANDA CALORIMETERS

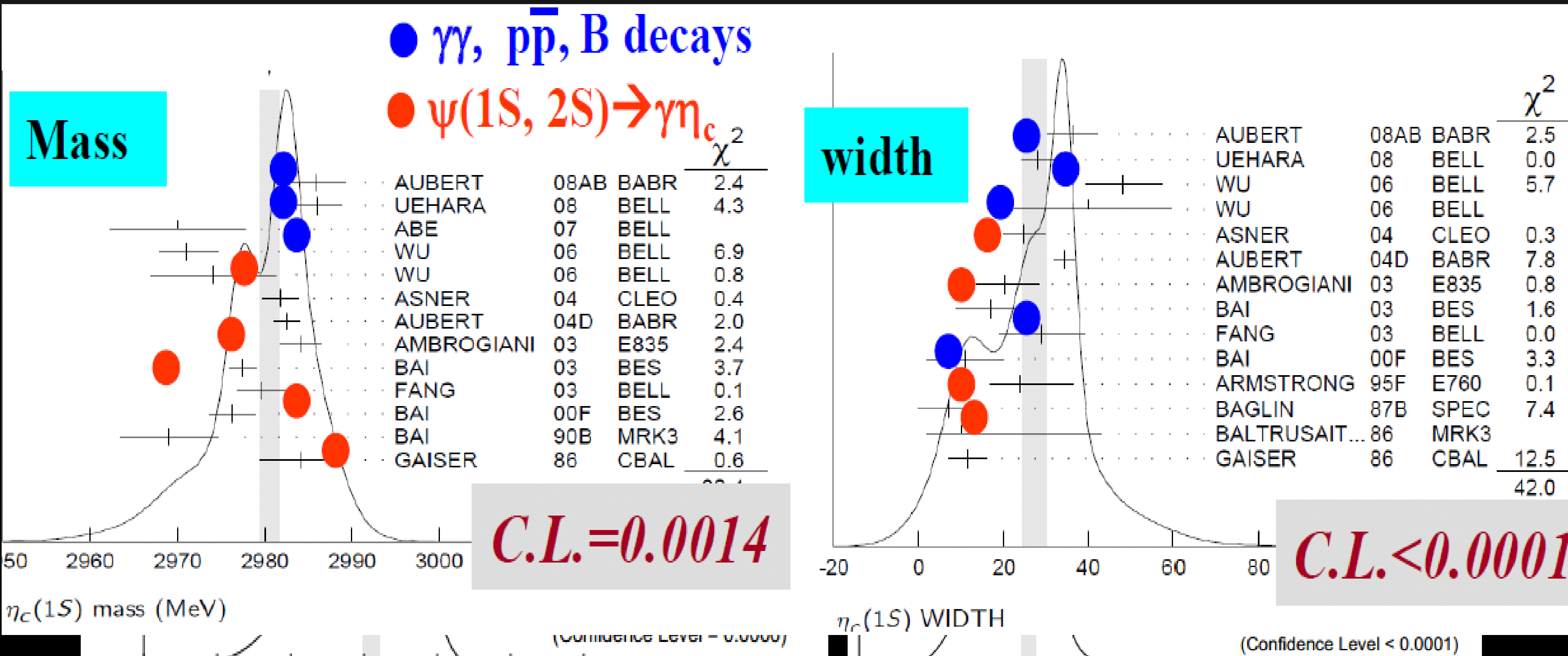


Calorimeters:
all endcap crystals produced
TDR approved

PDG 2012 STATES – CONVENTIONAL STATES

n	L	J^{PC}	$n^{2S+1}L_J$	Name	Mass(MeV)	Width(MeV)
1	0	0^{-+}	1^1S_0	$\eta_c(1S)$	2981.0 ± 1.1	29.7 ± 1.0
1	0	1^{--}	1^3S_1	J/ψ	3096.916 ± 0.011	92.9 ± 2.8keV
1	1	0^{++}	1^3P_0	$\chi_{c0}(1P)$	3414.75 ± 0.31	10.4 ± 0.6
1	1	1^{++}	1^3P_1	$\chi_{c1}(1P)$	3510.66 ± 0.07	0.86 ± 0.05
1	1	2^{++}	1^3P_2	$\chi_{c2}(1P)$	3556.20 ± 0.09	1.98 ± 0.11
1	1	1^{+-}	1^1P_1	$h_c(1P)$	3525.41 ± 0.16	< 1
1	2	1^{--}	1^3D_1	$\psi(3770)$	3773.15 ± 0.33	27.2 ± 1.0
2	0	0^{-+}	2^1S_0	$\eta_c(2S)$	3638.9 ± 1.3	10 ± 4
2	0	1^{--}	2^3S_1	$\psi(2S)$	$3686.109^{+0.012}_{-0.014}$	304 ± 9keV
		$?^{?+}$		$X(3872)$	3871.68 ± 0.17	< 1.2
		$?^{?+}$		$X(3915)$	3917.5 ± 2.7	27 ± 10
2	1	2^{++}	2^3P_2	$\chi_{c2}(2P)$	3927.2 ± 2.6	24 ± 6
3	0	1^{--}	3^3S_1	$\psi(4040)$	4039 ± 1	80 ± 10
2	2	1^{--}	2^3D_1	$\psi(4160)$	4153 ± 3	103 ± 8
		1^{--}		$X(4260)$	4263^{+8}_{-9}	95 ± 14
		1^{--}		$X(4360)$	4361 ± 13	74 ± 18
4	0	1^{--}	4^3S_1	$\psi(4415)$	4421 ± 4	62 ± 20
		1^{--}		$X(4660)$	4664 ± 12	48 ± 15

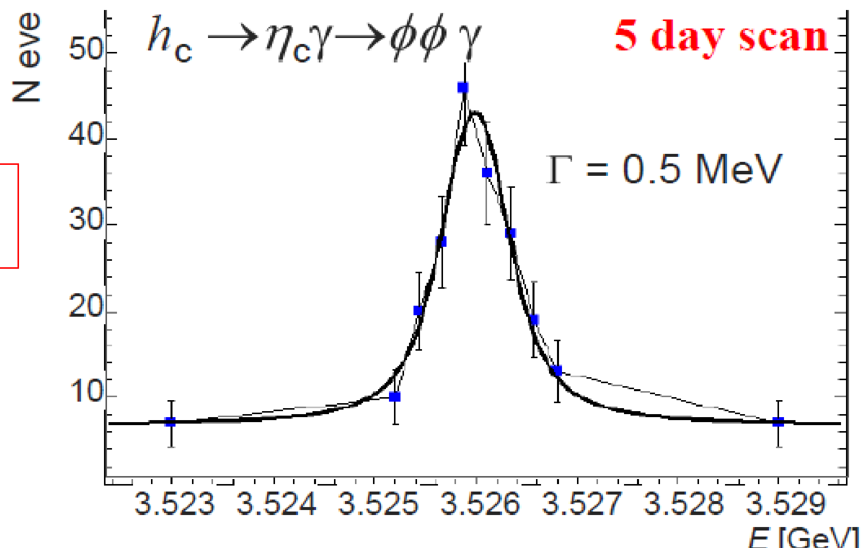
Conventional states: masses and width of η_c



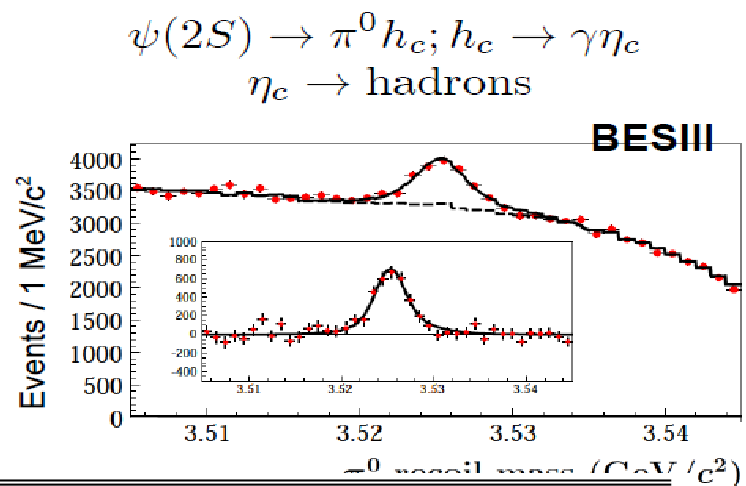
Data from Xiaoyan SHEN Talk at PANDA-meeting

Conventional states: h_c width

- exclusive reconstruction $\bar{p}p \to h_c \to \eta_c\gamma; \eta_c \to \phi\phi \to 2(K^+K^-)$
- good background suppression, e.g. $\bar{p}p \to 2(K^+K^-)\pi^0, K^+K^-\pi^+\pi^-\pi^0$
- simulation for high resolution mode (sys. uncertainty O(10 keV))



arXiv:0903.3905v1 [hep-ex]



$\Gamma_{R,MC}$ [MeV]	$\Gamma_{R,reco}$ [MeV]	$\Delta\Gamma_R$ [
1	0.92	0.2
0.75	0.72	0.1
0.5	0.52	0.1

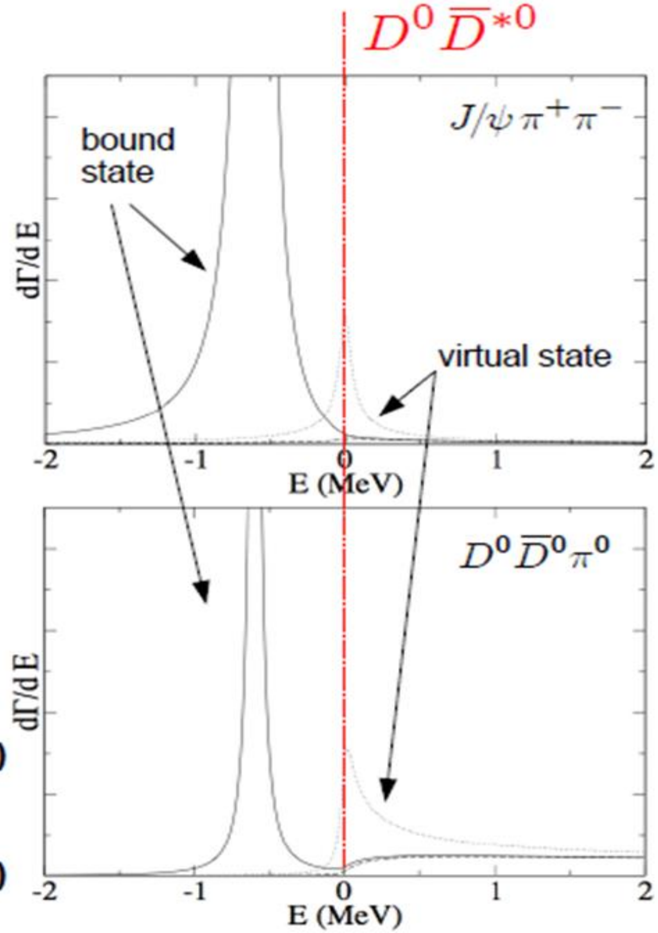
channel	Signal/Background
$\bar{p}p \to K^+K^-K^+K^-\pi^0$	8
$\bar{p}p \to \phi K^+K^-\pi^0$	8
$\bar{p}p \to \phi\phi\pi^0$	> 10
$\bar{p}p \to K^+K^-\pi^+\pi^-\pi^0$	> 12

t. 104

X(3872) SCAN

- determining lineshape in $D^0 \overline{D}^0 \pi^0$ and $D^0 \overline{D}^0 \gamma$ may help to understand if X(3872) is D$\overline{\text{D}}$* bound state or virtual state

- PANDA: scan with simultaneously measurement of
  $J/\psi\, \pi\pi,\, D^0 \overline{D}^0 \pi^0,\, D^0 \overline{D}^0 \gamma$



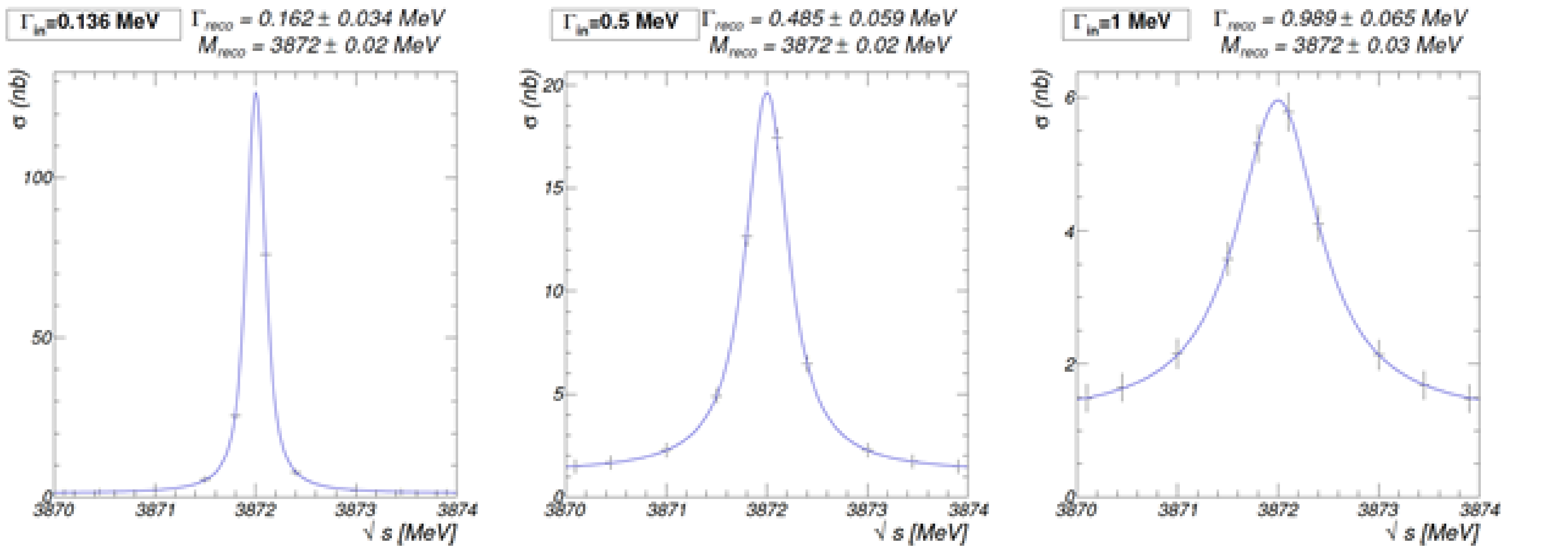
E. Braaten, M. Lu, Phys. Rev. D 77, 014029 (2008) and references therein

see also C. Hanhart et al, Phys. Rev. D 76, 034007 (2007)

X(3872) PUZZLE

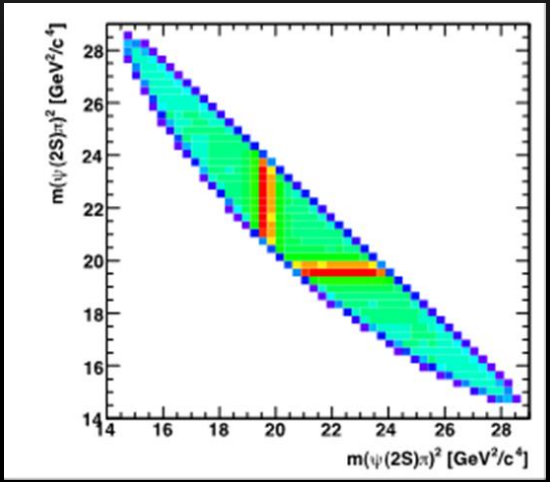
The mass value of M = 3871.68 ± 0.17 MeV is .05±0.27 MeV lower than the sum of masses of the D^0 and D^{*0}

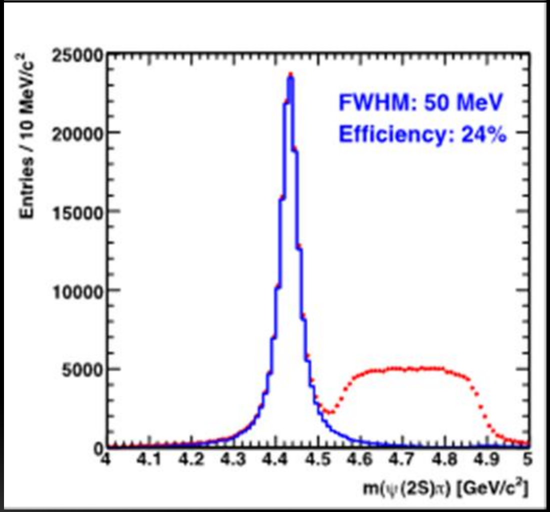
PANDA will measure width at the level of 0.1 MeV with 20 keV accuracy.



CHARGE STUDY: Z(4430) AND OTHERS

- **Charge states Z(4430), Z(4020,4025) - are observed (Neutral Z(4020) is also observed), they can not be charmonium (charged)**
- **They must contain a cc-bar pair due to its decay into $\psi'\pi^+$.**
- **Decay into $J/\psi\pi^+$ is not observed**
- **The $\psi(2S)\pi$ Dalitz plot for the reaction $\bar{p}p \rightarrow Z^{\pm} + \pi^{\mp}$ with Z decaying into $\psi(2S)\pi$ (up picture)**
- **The $\psi(2S)\pi$ invariant mass (blue). Combinatorics background in red**





SEARCH FOR Z(4430) PARTNERS

- PANDA can investigate the $Z^+(4430)$ even further by switching to studies of the $Z^+(4430)$ in formation mode.
- Due to the charge of the Z, this is only possible by annihilating the antiprotons on a neutron in a deuterium target. Experimentally it is no problem to replace the hydrogen gas, for example in a pellet target, with deuterium. The reaction to look for in would then be:

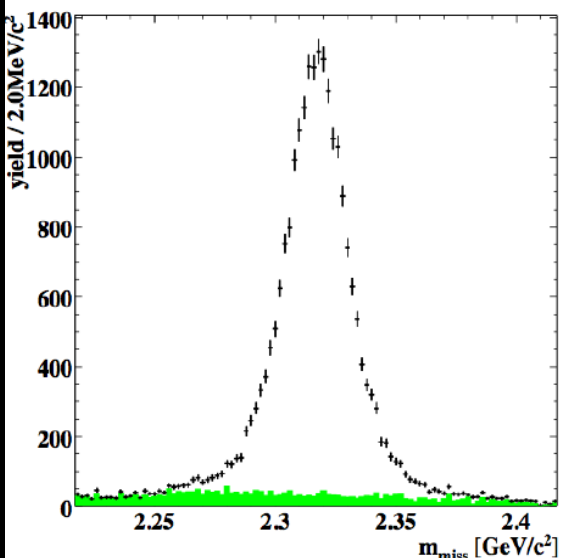
$$\bar{p}d \rightarrow Z^- + p_{spectator}$$

With decay $Z^- \rightarrow \psi(2S)\pi^- \rightarrow J/\psi\pi^+\pi^-\pi^-$

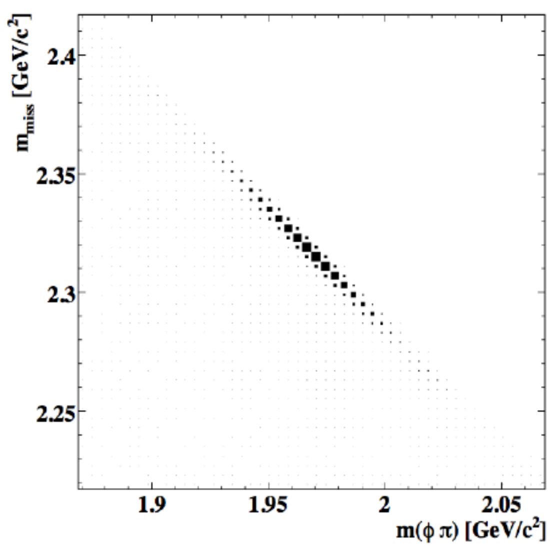
OPEN CHARM IN PANDA $\overline{p}p \to D^+{}_s D^*{}_{s0}(2317)$

- reconstruct one side $D_s^+ \to \phi\pi^+$
- identify recoil $D_{s0}^*(2317)^-$ in missing mass
- charm background channels, e.g. $\bar{p}p \to D_s^+ D_s^- \pi^0$
- 10M generic background events

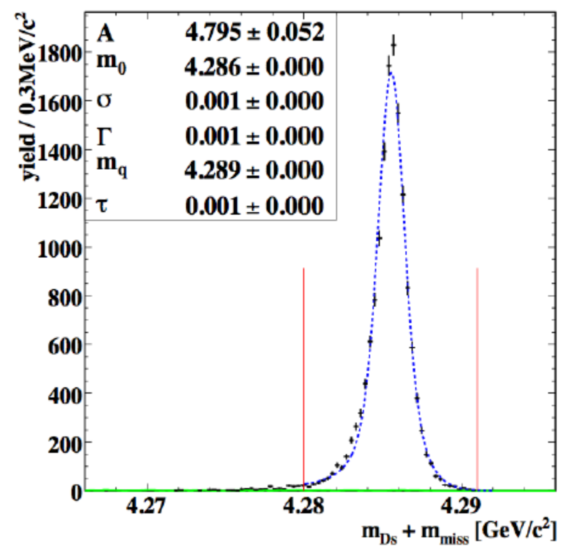
missing mass



missing vs rec. mass

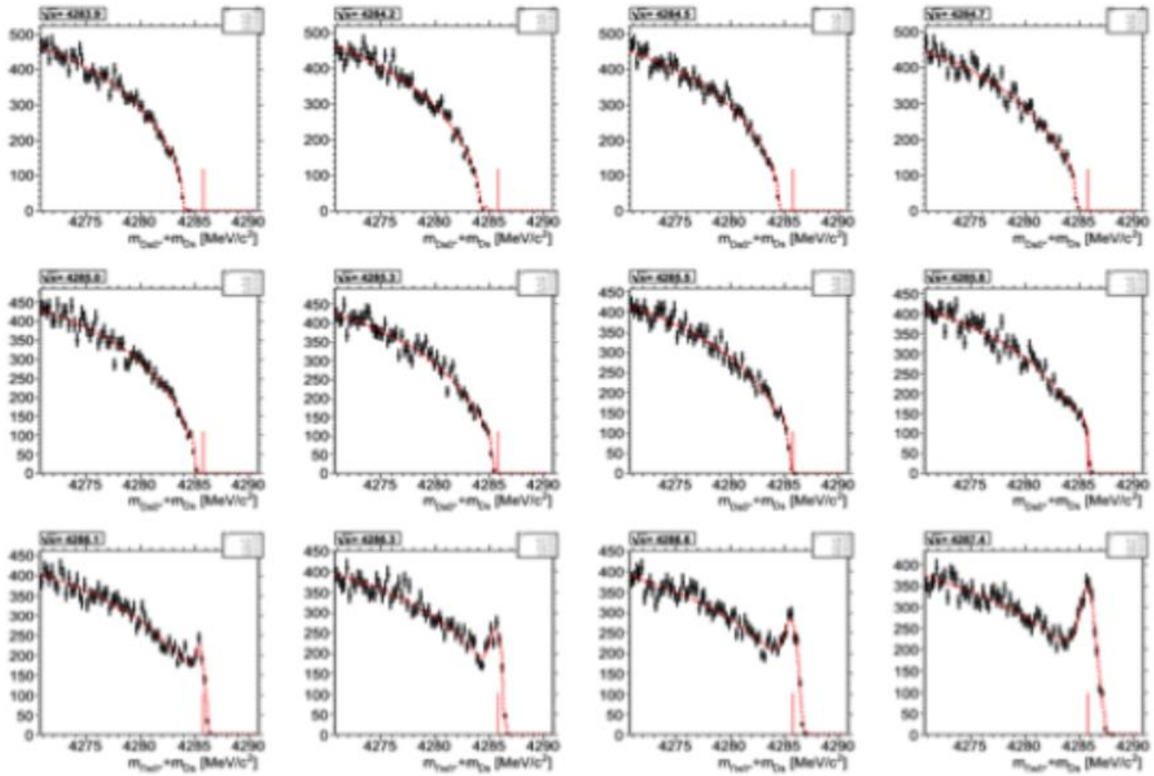


missing + rec. mass

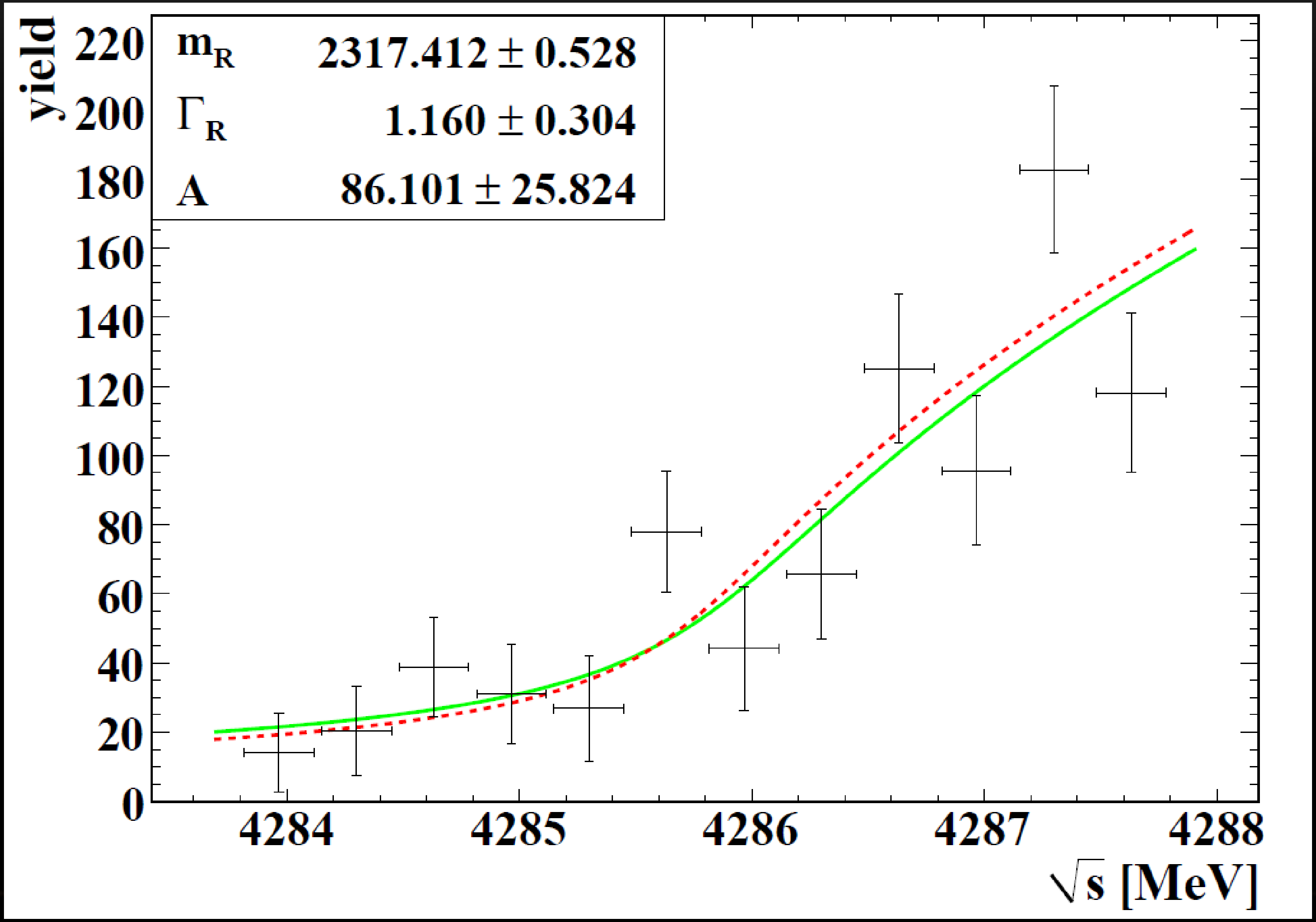


$D_s(2317)^*$ Threshold Scan

- simulation with S/N=3; 14 d data taking; Γ=1 MeV
- signal extraction for 12 scan points +/-2 MeV around threshold (not optimized!)



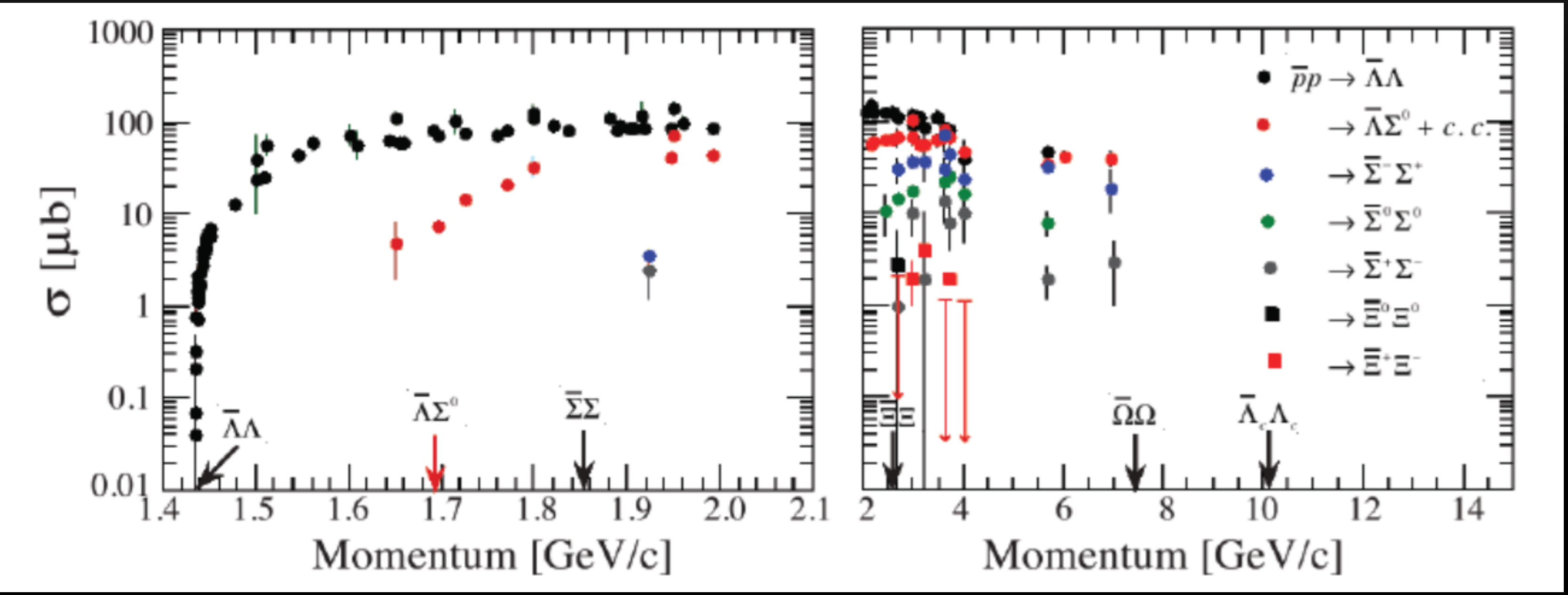
D_S*(2317) THRESHOLD SCAN



THEORY PREDICTIONS OF Ds WIDTH

Different theoretical approaches, different interpretations	$\Gamma(D_{s0}^*(2317)^+ \to D_s \pi^0)$ (keV)
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10 Pure $c\bar{s}$ state
Fayyazuddin and Riazuddin, Phys. Rev. D 69, 114008 (2004)	16
W. A. Bardeen, E. J. Eichten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
J. Lu, X. L. Chen, W. Z. Deng and S. L. Zhu, Phys. Rev. D 73, 054012 (2006)	32
W. Wei, P. Z. Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Yamauchi, AIP Conf. Proc. 717, 716 (2004)	15 - 70
H. Y. Cheng and W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100 Tetraquark state
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	79.3 ± 32.6 DK had. molecule
M.F.M. Lutz, M. Soyeaur, Nucl. Phys. A 813, 14 (2008)	140 Dynamically gen. resonance
L. Liu, K. Orginos, F. K. Guo, C. Hanhart, Ulf-G. Meißner Phys. Rev. D 87, 014508 (2013)	133 ± 22 DK had. molecule
M. Cleven, H. W. Giesshammer, F. K. Guo, C. Hanhart, Ulf-G. Meißner hep-ph: arXiV 1405.2242 (2014)	NEW! Strong and radiative decays of $D_{s0}^*(2317)$ and $D_{s1}(2460)$

PAIR HYPERON PRODUCTION

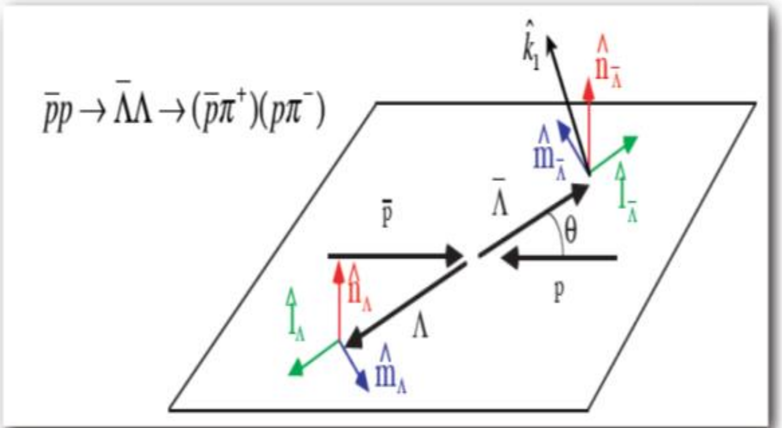


Almost full symmetry for the particles an anti-particles gives unique possibility to measure CP effects minimizing systematics

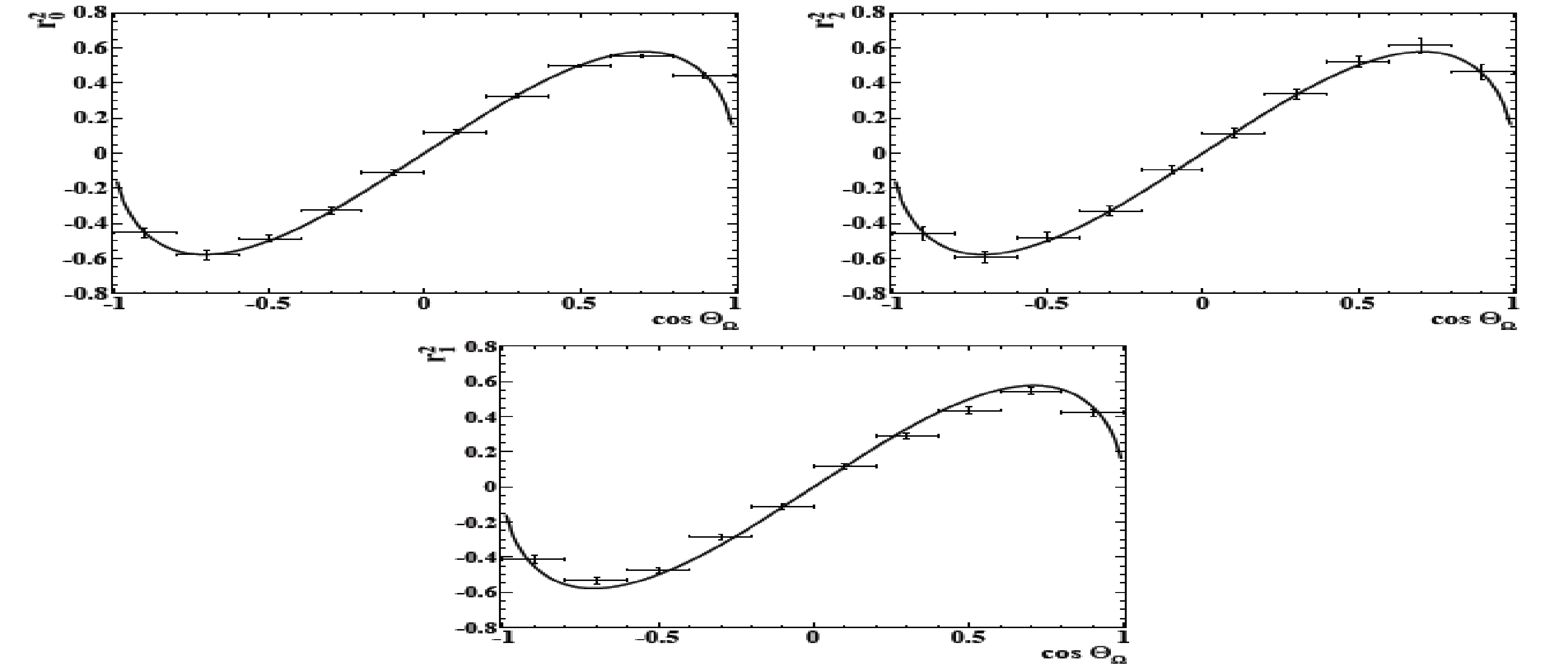
BARYON SPECTROSCOPY (ERIK THOMÉ PHD)

- The weak hyperon decay gives access to polarisation and spin correlations.
  - Access to spin degrees of freedom in $\overline{s}s$ and $\overline{c}c$ quark-pair creation.
  - Many observables
    - PWA of the data to extract relevant quantum numbers (resonances)
    - high discriminating power between models (hadron or quark-gluon based)
  - High x-sec for $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$: CP-violation tests
  - Powerful reactions for Baryon Spectroscopy

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



POLARIZATION STUDY IN $\bar{p}p \rightarrow \bar{\Omega}^{+}\Omega^{-}$



Expressions for extracting polarisation parameters derived using the spin density formalism. 7 non-zero parameters:
3 parameters from the $\Omega \rightarrow \Lambda K$ decay
4 parameters from combined $\Omega \rightarrow \Lambda K$ and $\Lambda \rightarrow p\pi$ angular distributions.

The total Ω polarisation can be obtained by summing the square of these 7 parameters.

PERSPECTIVES FOR PANDA (2-HYPERON)

Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate at $2*10^{32}$ cm^{-2} s^{-1}
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	11	580 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	~50	23	980 s^{-1}
15	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	~10	14	120 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^o$	~40	31	600 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	~2	19	30 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}^+\Omega^-$	~0.002	~30	~80 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c^-\Lambda_c^+$	~0.1	~35	~25 day^{-1}

Table prepared by Karin Schönning (BEACH 2014, Birmingham), based on

*Sophie Grape, Ph. D. Thesis, Uppsala University 2009

** Erik Thomé, Ph. D. Thesis, Uppsala University 2012

OTHER PHYSICS

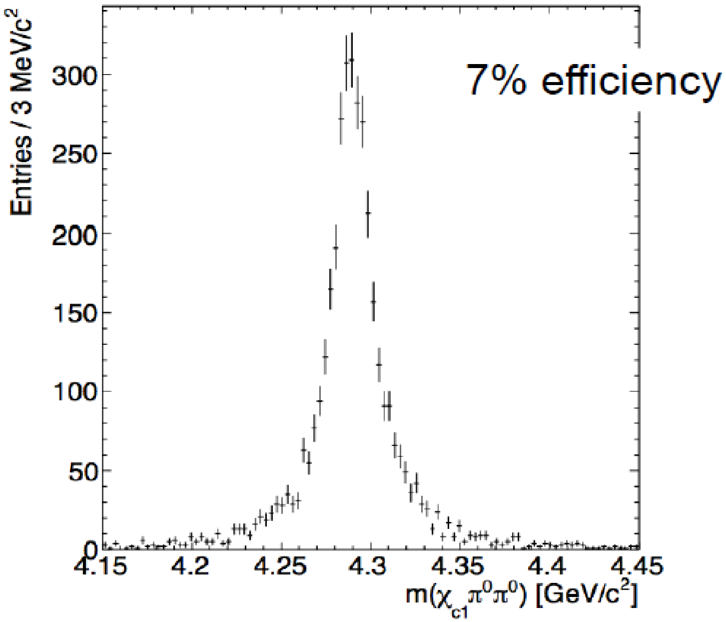
- **Nucleon Structure from electromagnetic processes**
  - **The extension of form factor measurements to the so called time-like region separating the magnetic and electric components can be performed with an order of magnitude improvement**
  - **clean identification of dileptons can be used to measure a whole series of other electromagnetic processes like for example Drell-Yan in order to get access to the transverse spin structure functions.**
- **Study hyper-nuclei (including - double) and charm-nuclei, when the strange (one or two) or charmed particle "implanted" into the nuclei instead of the usual nucleon**
- **Hadrons in nuclear matter**

Production of Exotic Charmonium Hybrid

- background under control
  - due to 9C / 11C kinematic fit (mass, energy and momentum constraints)

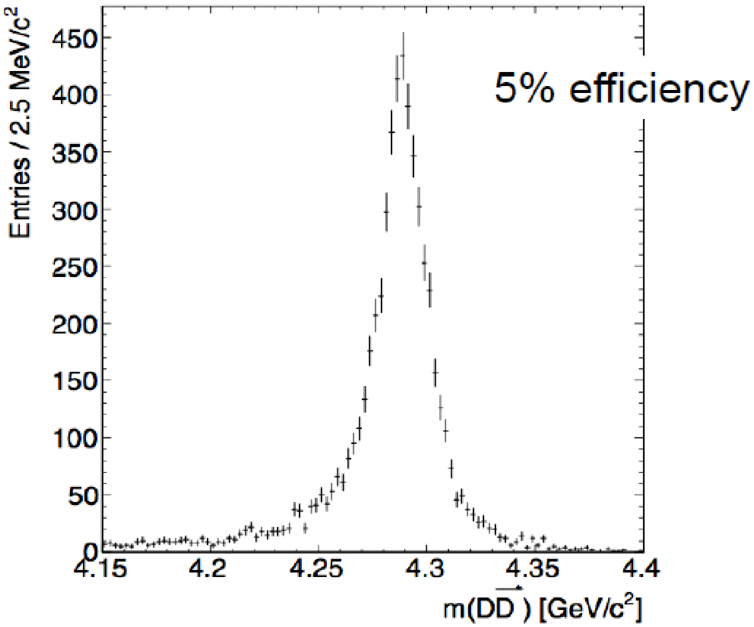
$$\bar{p}p \to \tilde{\eta}_{c1}\eta \to \chi_{c1}\pi^0\pi^0\eta$$

$$\frac{S}{N} > 250\mathcal{B}(\tilde{\eta}_{c1} \to \chi_{c1}\pi^0\pi^0)^*$$



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

$$\frac{S}{N} \approx 2900\mathcal{B}(\tilde{\eta}_{c1} \to D^0\overline{D}^{*0})^*$$



* assume same cross sections for signal and charm background

EXPECTED MASS SHIFT IN NUCLEAR MATTER

	η_c	J/ψ	$\chi_{c\,0,1,2}$	$\psi(3686)$	$\psi(3770)$
Expected Mass shift	-5 MeV to -8 MeV	-7 MeV to -10 MeV	-40 MeV to -60 MeV	-100 MeV to -130 MeV	-120 MeV to -140 MeV
Observation through	$\gamma\gamma$	$e^+e^-/\mu^+\mu^-$	$J/\psi\,\gamma$	$e^+e^-/\mu^+\mu^-$	$e^+e^-/\mu^+\mu^-$