CHARMONIUM PHYSICS WORKING GROUP

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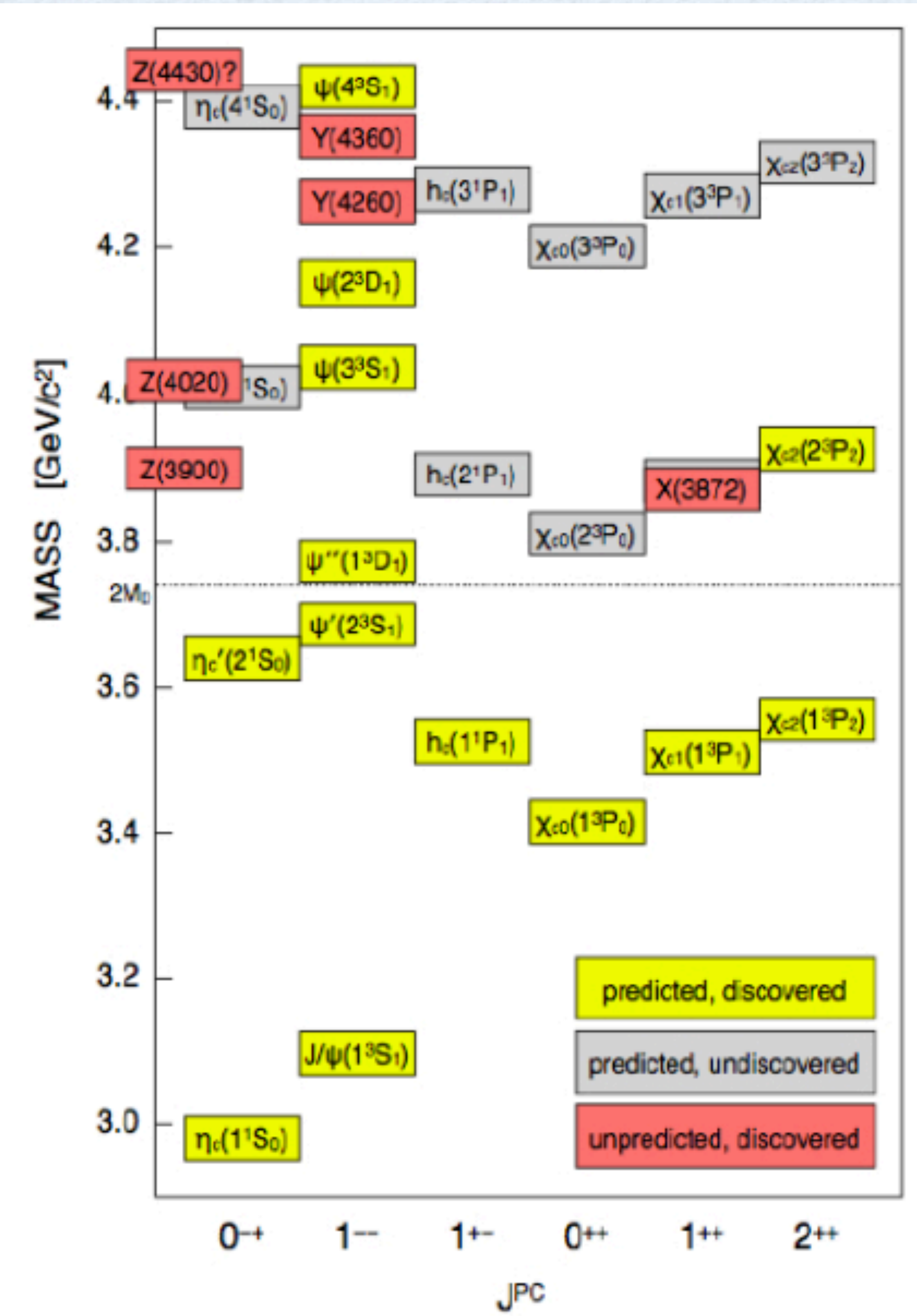
PANDA Collaboration Meeting, Nov 30 - Dec 04 2015, Vienna

Charmonium PWG

- New structure since 2014, three Physics Working Groups:
    - **Charmonium**
    - Charmonium-like Exotics
    - Light Quark Mesons
- Large overlap of interests and activities of the three groups
    - Regular joint meetings (Wed. 10.30 am)
- Manpower situation:
    - Partecipation in the joint meetings is ranging between 5 and 10 people
    - 3 analysts involved during the scrutiny process in 2014
    - At present 1 active physics analysis

Charmonium spectrum



✳ **Below the $D\bar{D}$ threshold**

- All states observed
- Precision measurements mandatory: e.g. branching fractions, masses and widths

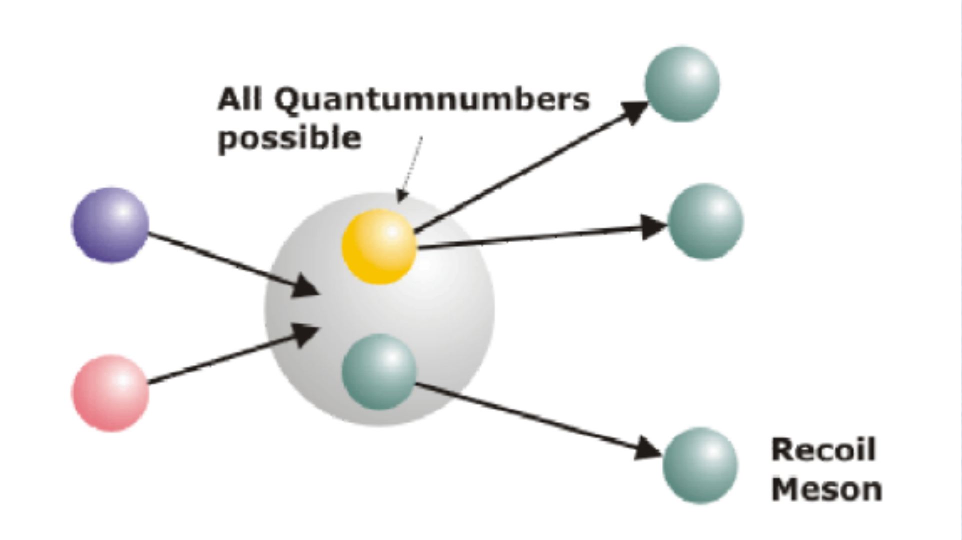
✳ **Above the $D\bar{D}$ threshold**

- Many unexpected states
- Properties not in agreement with predictions ⟶ exotic charmonium

Charmonium at PANDA

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

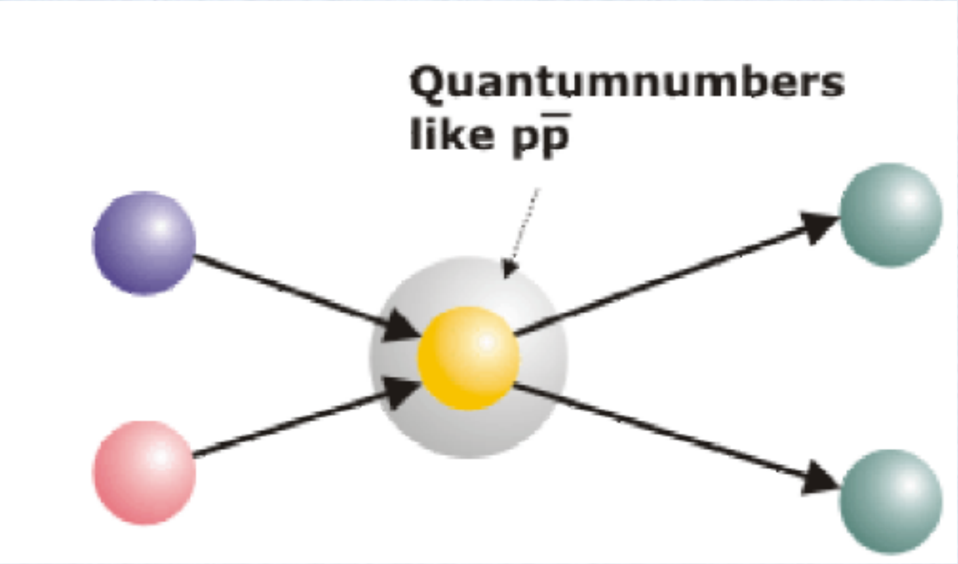
- high discovery potential



Formation: all states with non-exotic quantum numbers assessible

- not only limited to 1^{--} as e^+e^- colliders

- precision physics of known states



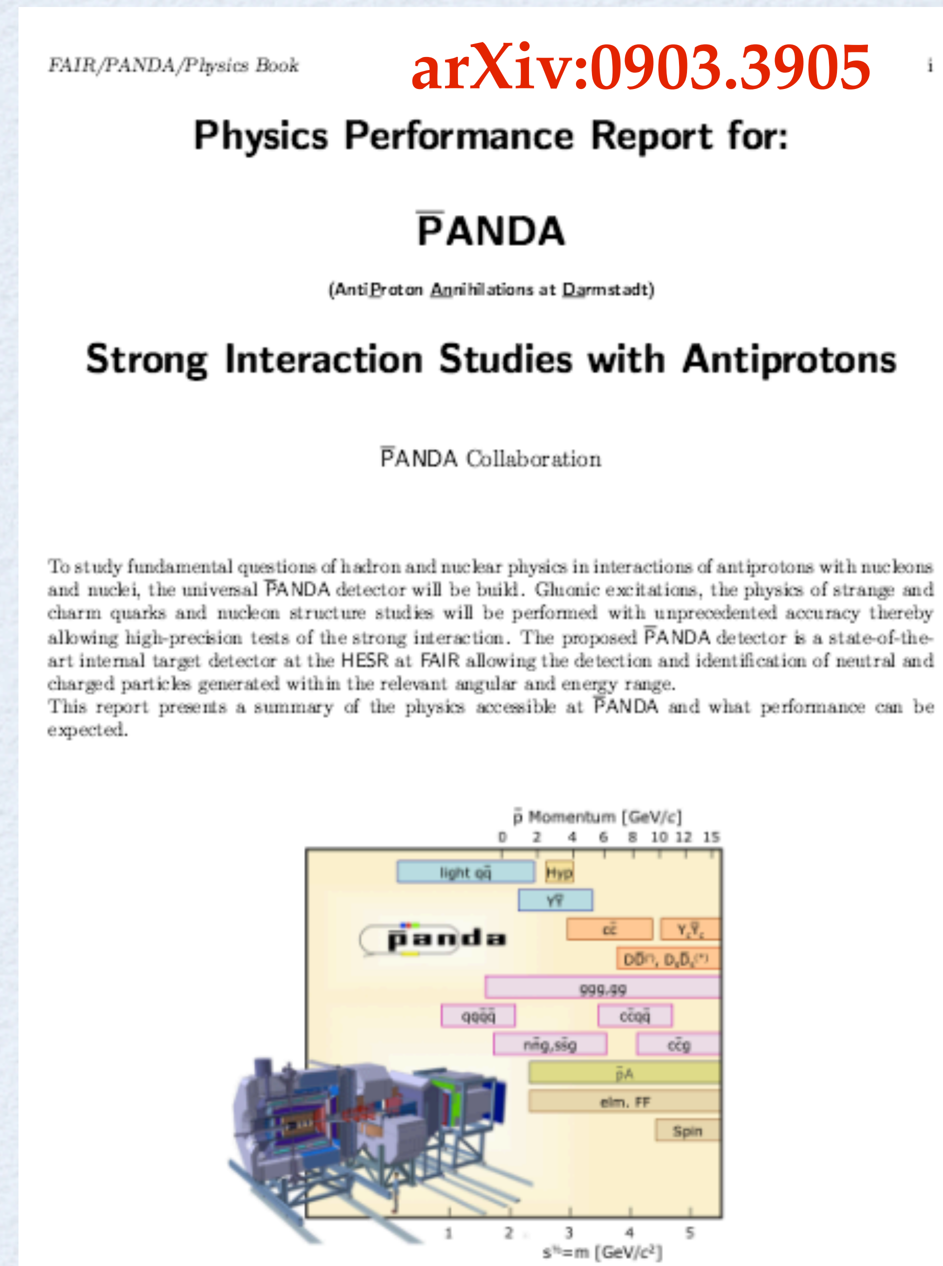
Energy scan: precise measurement of masses and widths of resonances:
- only dependent on beam momentum resolution

→ Unique at PANDA

PANDA Physics Performance Report

Several charmonium channels were analyzed and published in the PANDA Physics Book using the old analysis framework:

- $p\bar{p} \rightarrow J/\psi\eta \rightarrow e^+e^-\gamma\gamma$ (Torsten Schröder)
- $p\bar{p} \rightarrow h_c \rightarrow \eta_c\gamma$ with $\eta_c \rightarrow \gamma\gamma$ or $\eta_c \rightarrow \phi\phi$ (Dima Melnychuk)
- $p\bar{p} \rightarrow \chi_{c12}\,\gamma \rightarrow J/\psi\,\gamma\,\gamma$ (E. Fioravanti)
- $p\bar{p} \rightarrow \chi_{c12} \rightarrow J/\psi\,\gamma$ (I. Garzia)


FAIR/PANDA/Physics Book

arXiv:0903.3905

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Physics Performance Report for:

$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

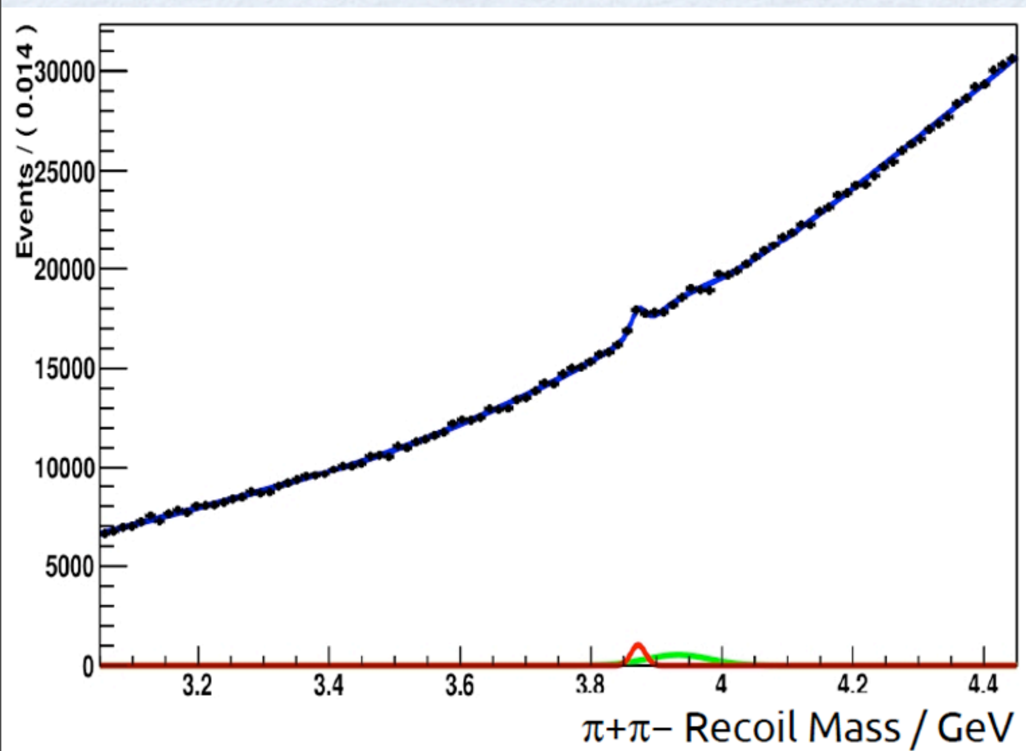
Strong Interaction Studies with Antiprotons

$\overline{\text{P}}$ANDA Collaboration

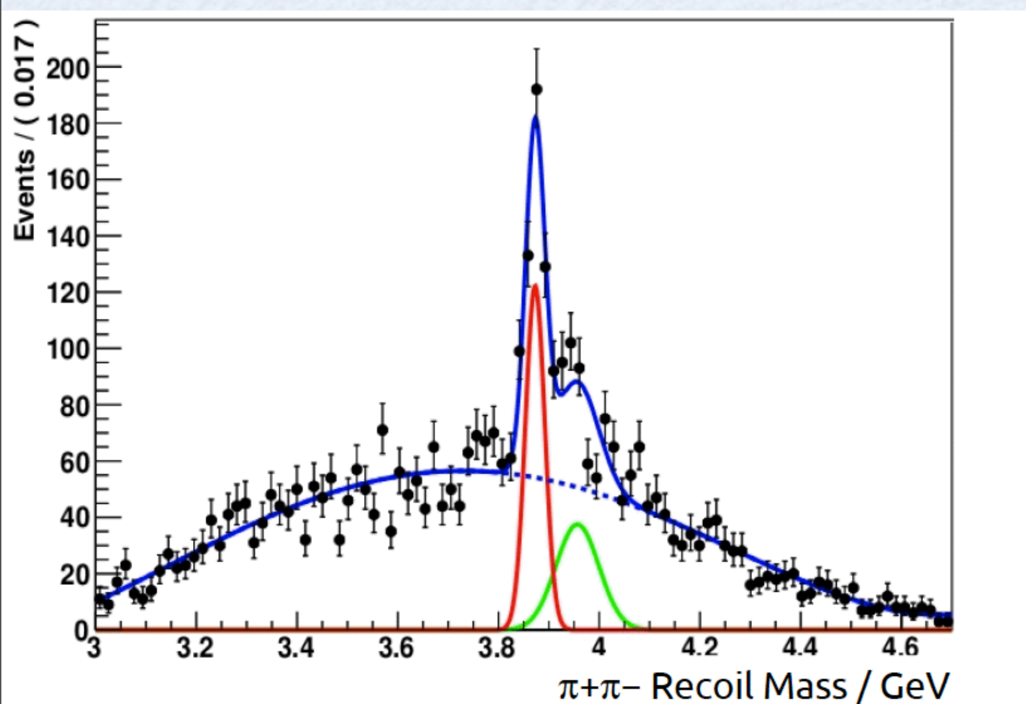
To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\text{P}}$ANDA 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 $\overline{\text{P}}$ANDA and what performance can be expected.

Detailed and dedicated PandaRoot simulation studies with a realistic detector description are needed

Prospects for h_c' at PANDA



arXiv:1311.7597; CHARM 2013 Proceedings; M. Galuska, S. Lange, E. Prencipe, S. Reiter, S. Spataro
arXiv:1410.5201; ICHEP 2014 Proceedings; E. Prencipe
S. Reiter - Bachelor Thesis (2013)



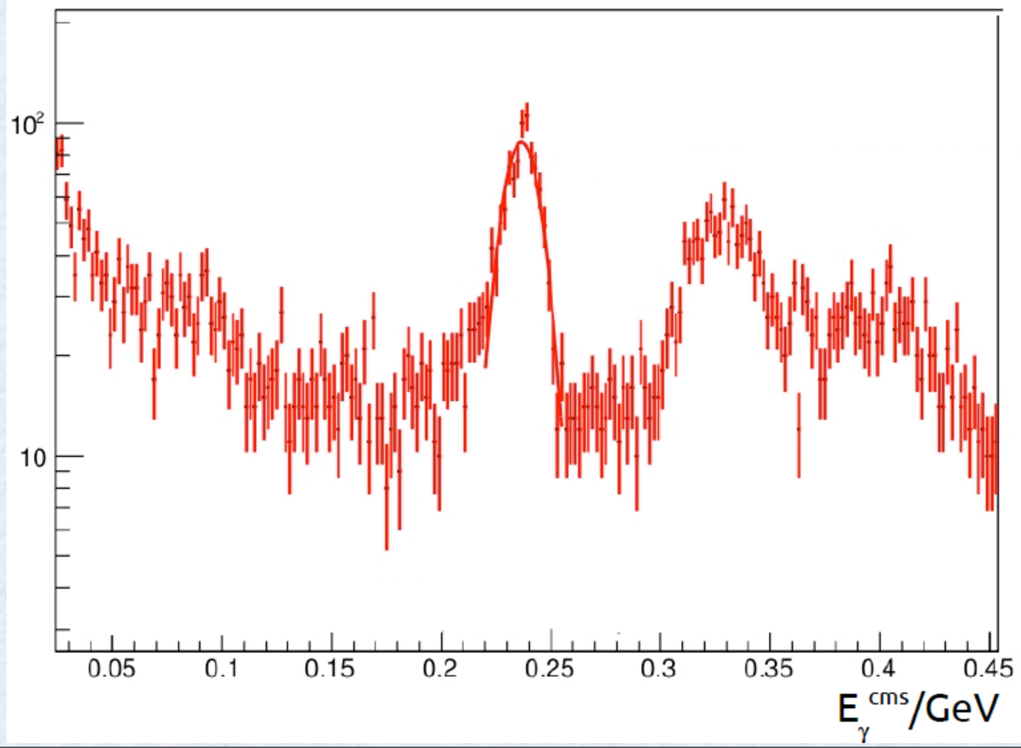
- $p\bar{p} \rightarrow (\pi^+\pi^-)_{recoil}\ h_c'$
with $h_c' \rightarrow D^0\bar{D}^{0*}$; $D^0 \rightarrow K^-\pi^+$; $\bar{D}^{0*} \rightarrow$ anything
antiproton beam of 15 GeV/c
- PandaRoot
- Signal efficiency: 8.3%
- Background efficiency: 1.6×10^{-5}
- The signal cross section of 4.5 nb is the requirement to achieve $S/\sqrt{(S+B)} \geq 10$ in 6 weeks of data taking with a duty factor of 50%.
- 3.9×10^4 h_c' per day produced at PANDA in HESR high luminosity mode.

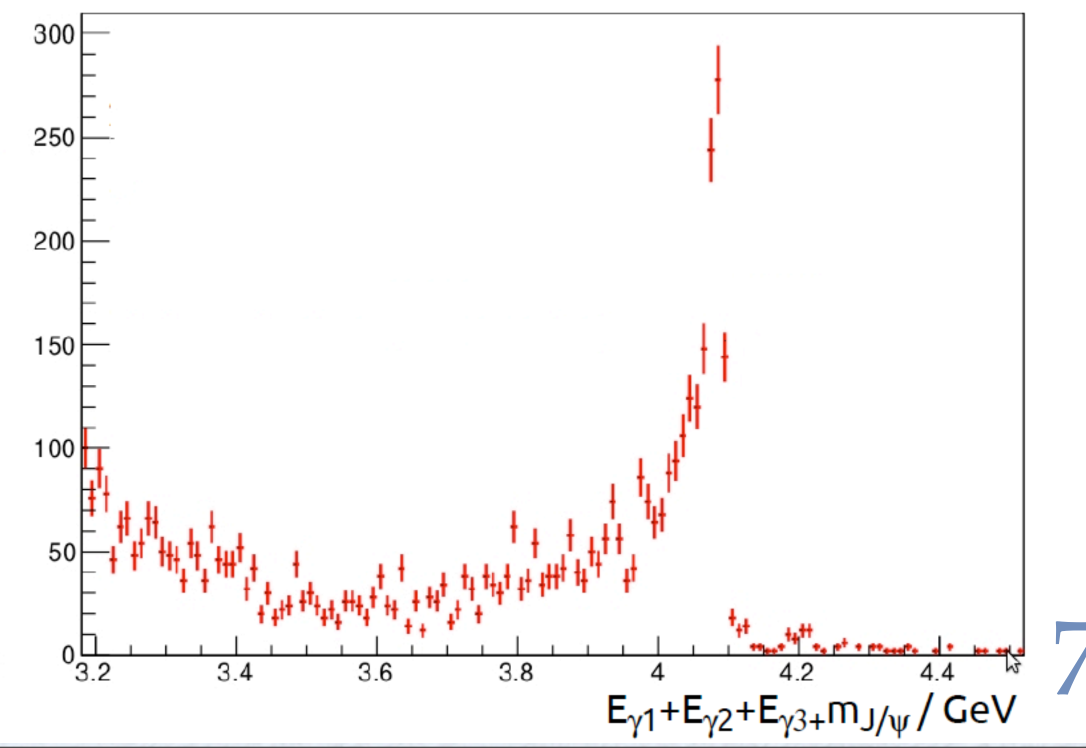
Prospects for $^3F_4$ at PANDA

1^3F_4	1^3D_3	χ_{c2}	J/ψ
$J^{PC}=4^{++}$	$J^{PC}=3^{--}$	$J^{PC}=2^{++}$	$J^{PC}=1^{--}$
4095 MeV	3849 MeV	3556 MeV	3097 MeV
Γ=8.3 MeV	Γ=0.5 MeV	Γ=2.0 MeV	Γ=0.3 MeV
$E_\gamma = 246$ MeV	$E_\gamma = 338$ MeV	$E_\gamma = 413$ MeV	

arXiv:1311.7597; CHARM 2013 Proceedings; M. Galuska, S. Lange, E. Prencipe, S. Reiter, S. Spataro
arXiv:1410.5201; ICHEP 2014 Proceedings; E. Prencipe

- PandaRoot
- Assumed cross section: 10 nb
- HESR high luminosity mode with 8.64 pb^{-1} per day
- 14 days of data taking assuming 50% duty factor
- $^3F_4$ signal visible with a reconstructed width of 1.2 MeV
- Background suppression factor of $1.2\text{x}10^6$





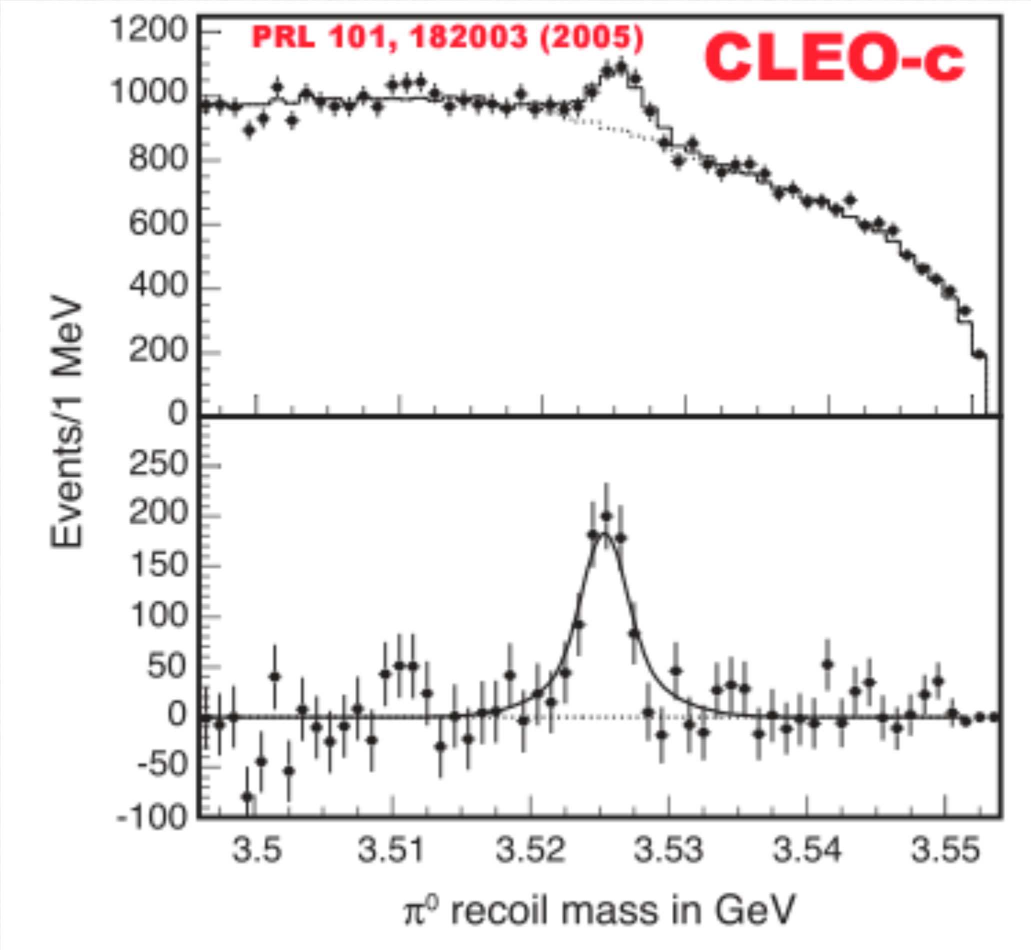
Scrutiny analysis reports

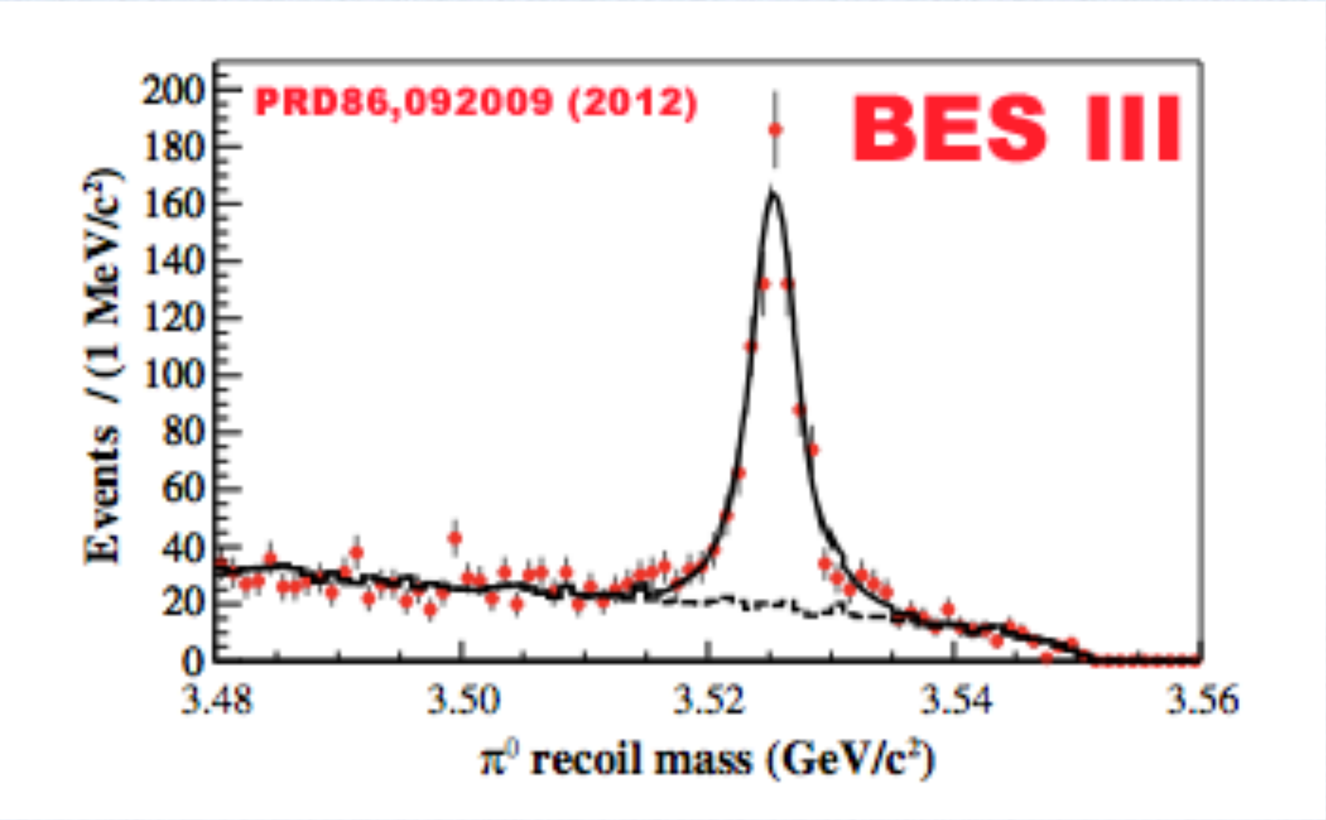
(Fast Simulations)

$h_c(1^1P_1)$ in e^+e^- collisions

Observed by CLEO-c and BESIII in
$e^+e^- \longrightarrow \psi(2S) \longrightarrow \pi^0 h_c \longrightarrow \gamma\gamma\gamma\eta_c$

$M(h_c)= 3525.31 \pm 0.11 \pm 0.14$ MeV/c^2 *
$\Gamma(h_c)=0.70 \pm 0.28 \pm 0.22$ MeV *





Hyperfine-splitting of P-wave states:

$\Delta M_{HF}(1P)=\langle M(1^3P)\rangle - M(1^1P_1)=$
$=\langle m(\chi_{cJ})\rangle - m(h_c)=$
$=-0.01 \pm 0.11 \pm 0.15$ MeV/c^2 *

Test of Lorentz-structure of confinement potential and validation of LQCD and NRQCD predictions

Errors dominated by h_c

* PRD 86, 092009 (2012) BESIII

$h_c(1^1P_1)$ at PANDA (Dima Melnychuk)

$$p\bar{p} \to h_c \to \eta_c + \gamma \to \phi\phi\gamma \to K^+K^-K^+K^-\gamma$$

Decay mode of η_c

$\eta_c \to \phi\phi$, $BR = 2.6 \cdot 10^{-3}$,
$\phi \to K^+K^-$, $BR = 0.49$

Signal cross-section

E835: $\Gamma_{p\bar{p}} B_{\eta_c\gamma} = 12$ eV
$\sigma_{p\bar{p}\to h_c \to \eta_c+\gamma} = 40nb$

E835: PRD72,032001(2005)

Background cross-section

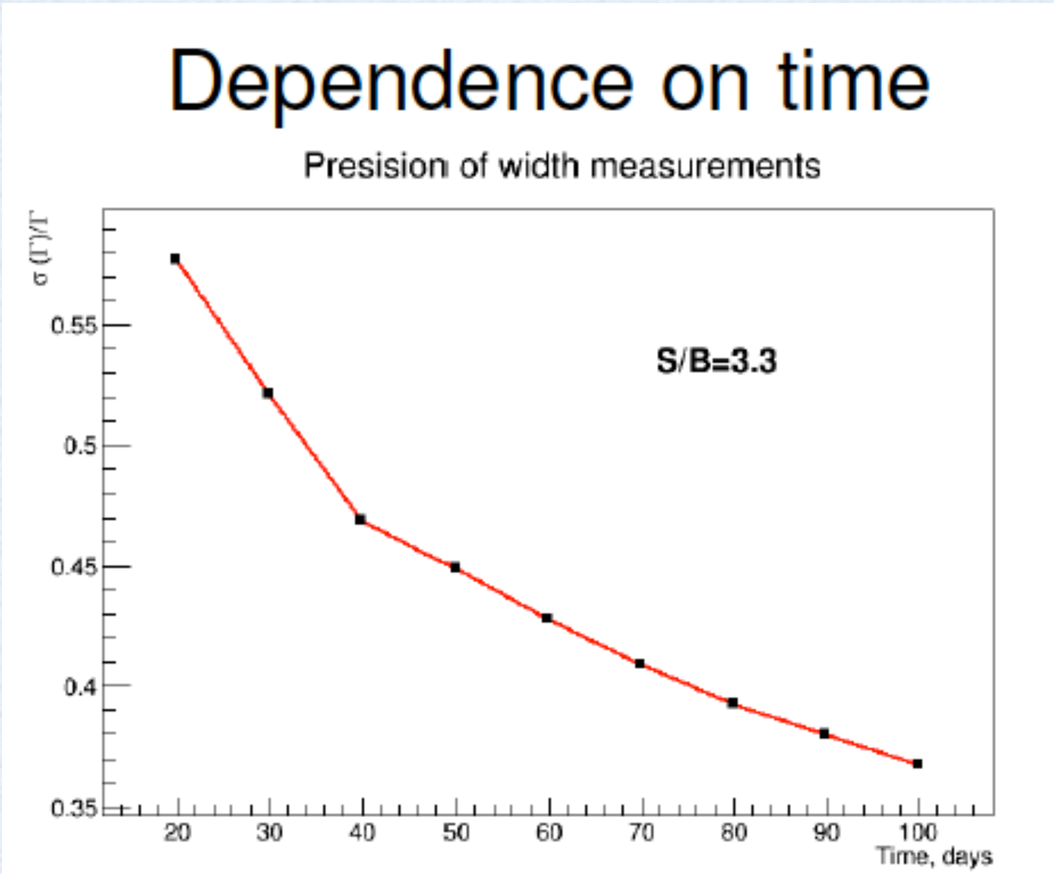
decay mode	σ
$p\bar{p} \to K^+K^-K^+K^-\pi^0$	360 nb
$p\bar{p} \to K^+K^-\phi\pi^0$	37 nb
$p\bar{p} \to \phi\phi\pi^0$	<6 nb
$p\bar{p} \to K^+K^-\pi^+\pi^-\pi^0$	30 μb

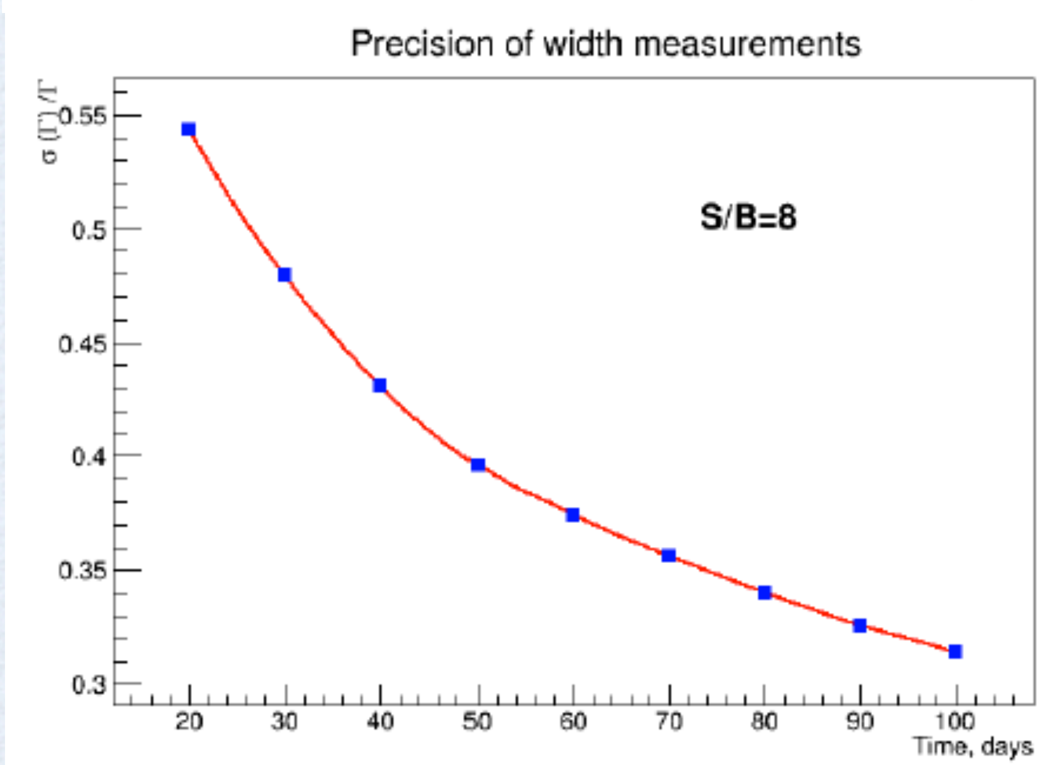
Signal to background ratio

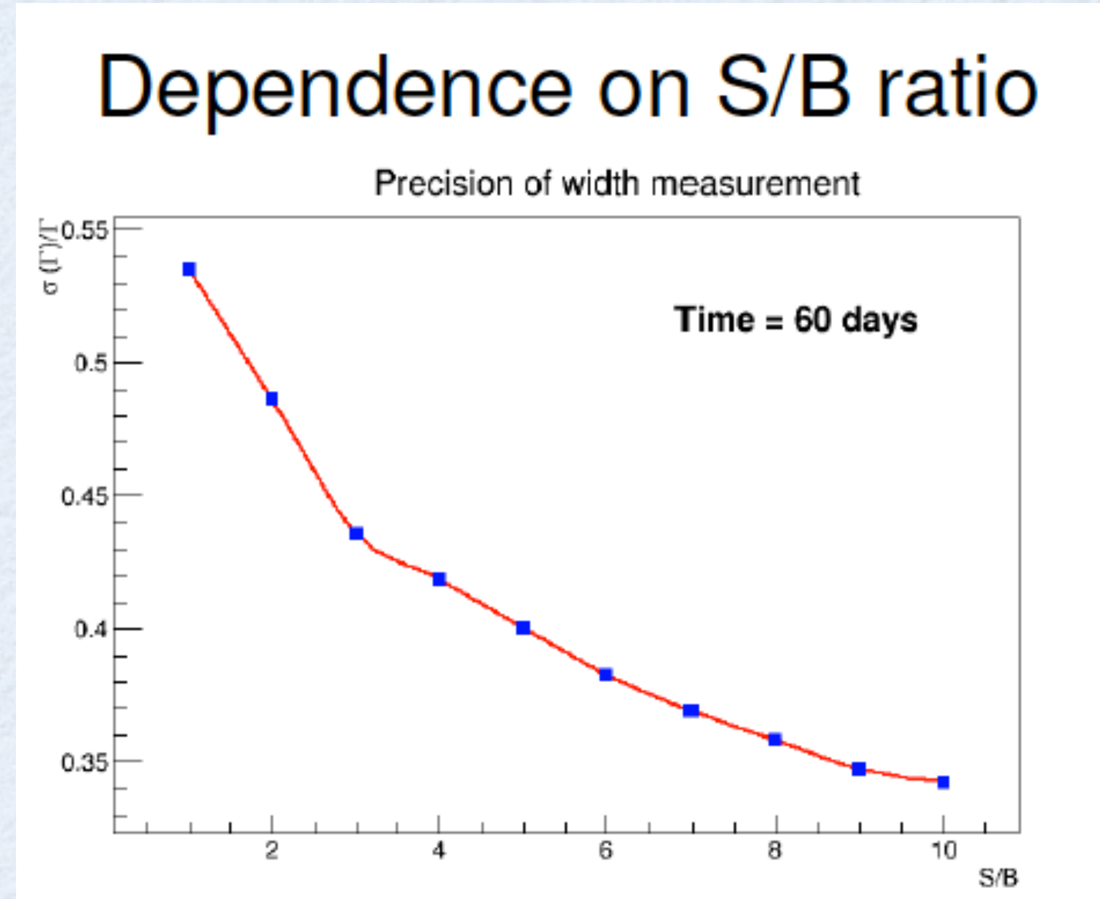
decay mode	S/B
$p\bar{p} \to K^+K^-K^+K^-\pi^0$	3.3
$p\bar{p} \to K^+K^-\phi\pi^0$	30
$p\bar{p} \to \phi\phi\pi^0$	>7
$p\bar{p} \to K^+K^-\pi^+\pi^-\pi^0$	>5

With 28.8% reconstruction efficiency and luminosity 10^{31} $cm^{-2}s^{-1}$, 6 h_c per day is expected

$h_c(1^1P_1)$ at PANDA (Dima Melnychuk)



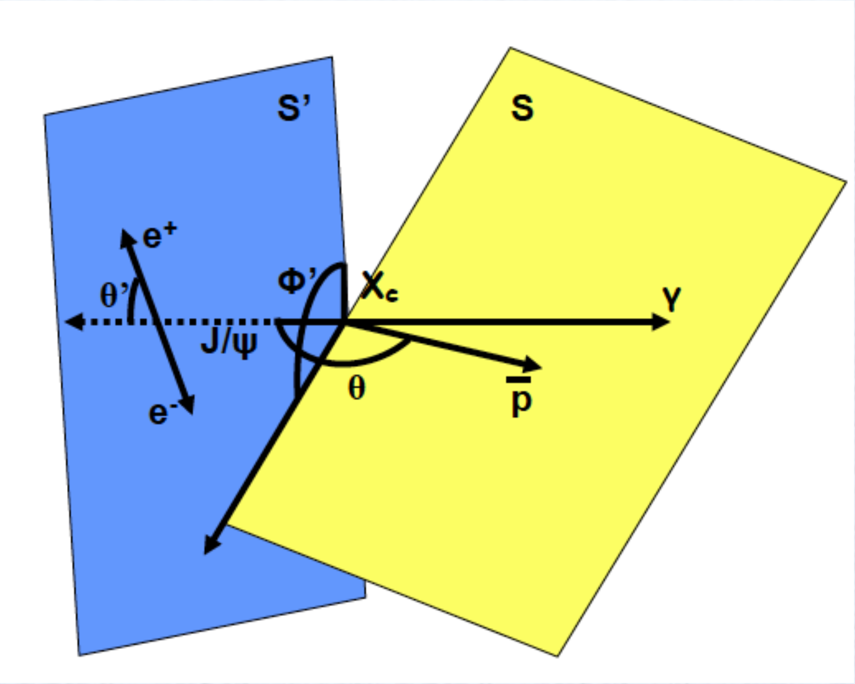




Resonable time for h_c width measurements is around 60 days with $L=10^{31}$ cm^{-2} s^{-1}

χ_{cJ} angular distributions

The measurement of the angular distributions in the radiative decays of the χ_c states provides the multipole structure of the radiative decay and the properties of the $c\bar{c}$ bound state.



Signal

$\sigma(\chi_{c1} \to J/\psi\gamma) \sim 1.7$ nbarn
$\sigma(\chi_{c2} \to J/\psi\gamma) \sim 2$ nbarn
E835 Collaboration, Nucl.Phys.B 717,34 (2005)

Background

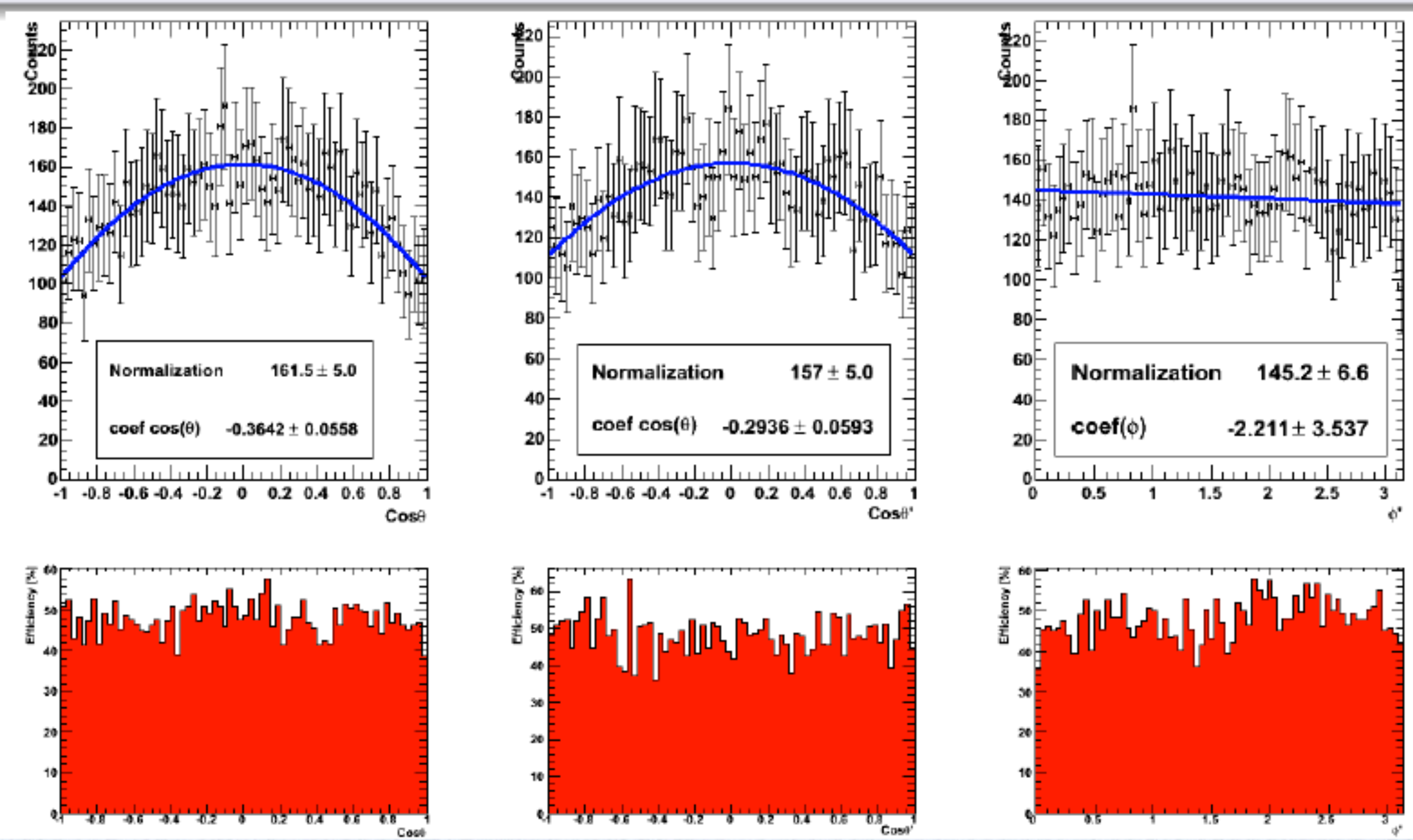
Background: $\bar{p}p \to \pi^+\pi^-\pi^0$:
$\sigma(\chi_{c2})$=0.12 mb
CERN-HERA 70-03 (1970)

With 48% reconstruction efficiency and luminosity 10^{31} cm^{-2}s^{-1}
χ_{cJ} angular distribution with 5σ:
- χ_{c1}: 13 days (only e^+e^-)
- χ_{c2}: 36 days (only e^+e^-)

$p\bar{p} \rightarrow \chi_{c1} \rightarrow J/\psi\gamma$ angular distributions

The angles distributions corrected with the efficiency, which is presented in the lower part.
The angular distributions for the three angles can be approximately written as:

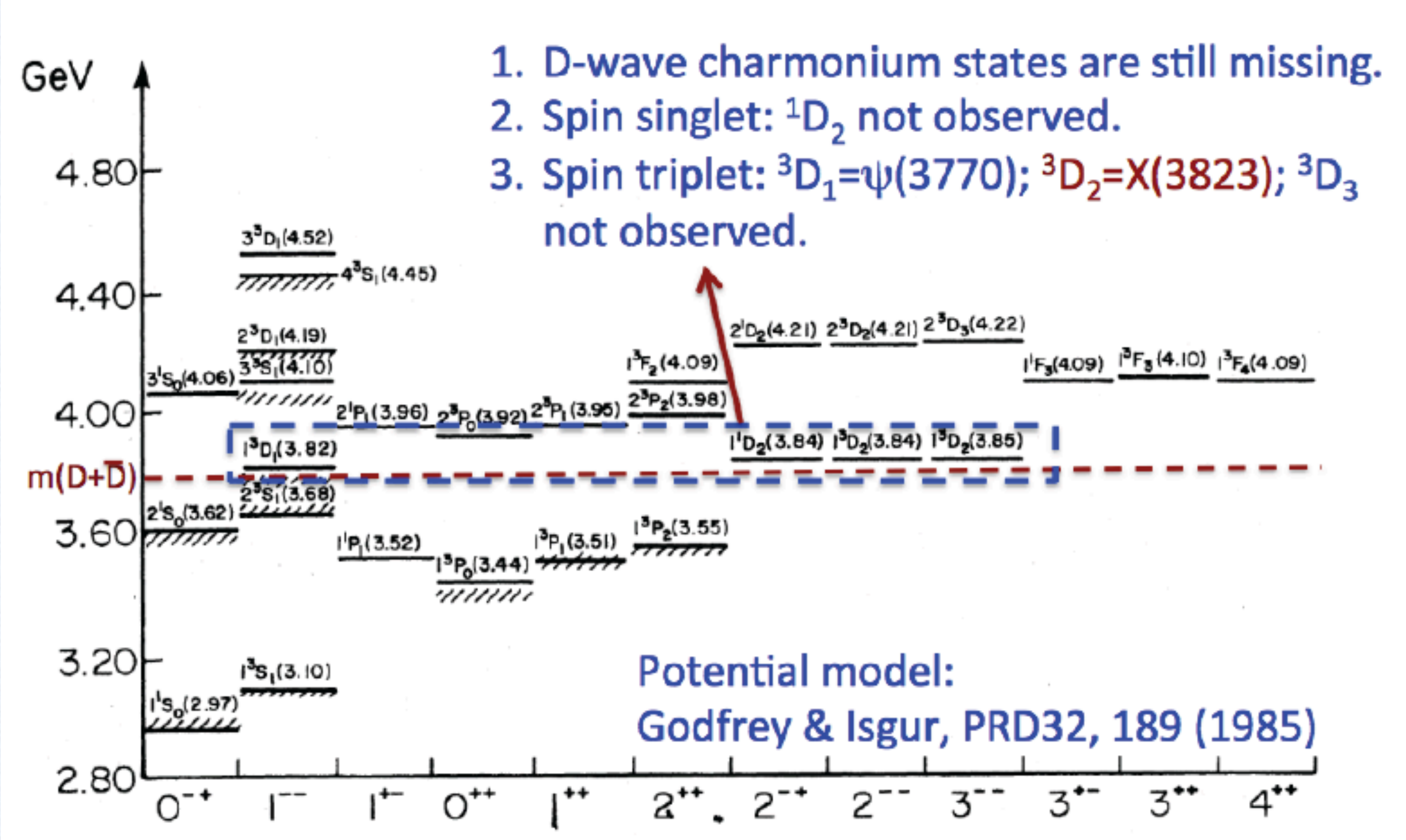
$$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta; \quad W(cos\theta') = 1 - \frac{1}{3}cos^2\theta'; \quad W(\phi) = \text{flat}$$



Recent activities

Study of $\psi(1^3D_2)$ charmonium state at PANDA (Zhiqing Liu)

One of the topics of the PANDA physics program is the search for D wave $c\bar{c}$ states.



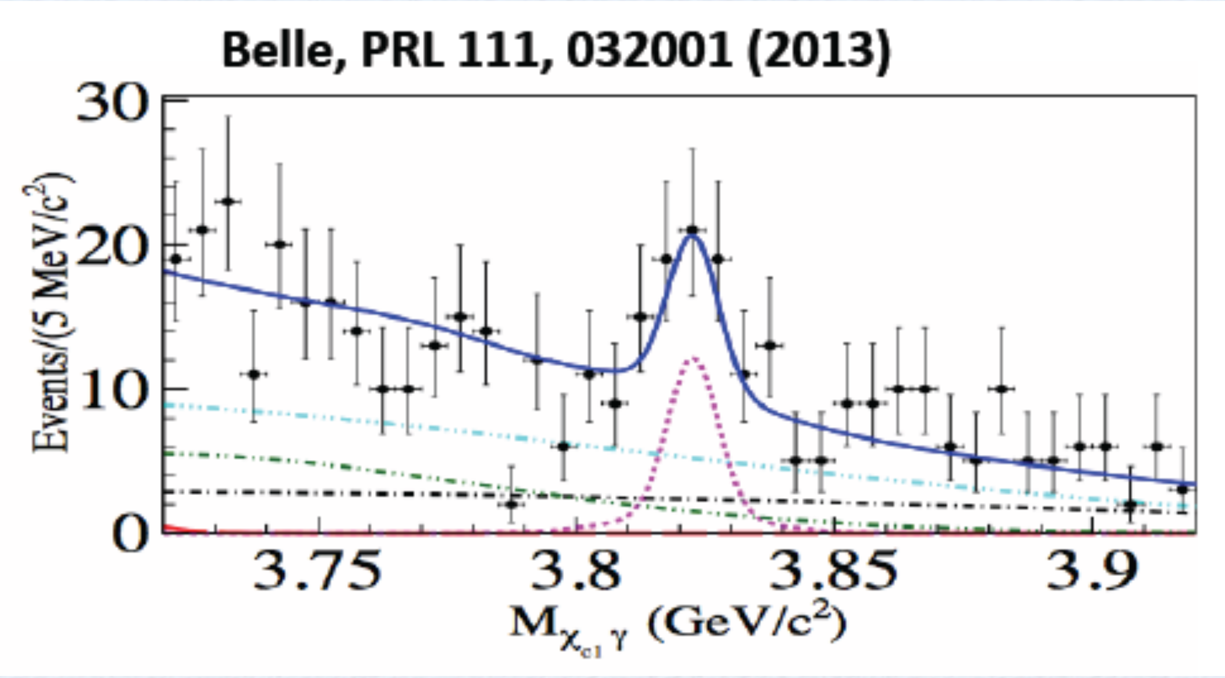
Study of $\psi(1^3D_2)$ charmonium state at PANDA (Zhiqing Liu)

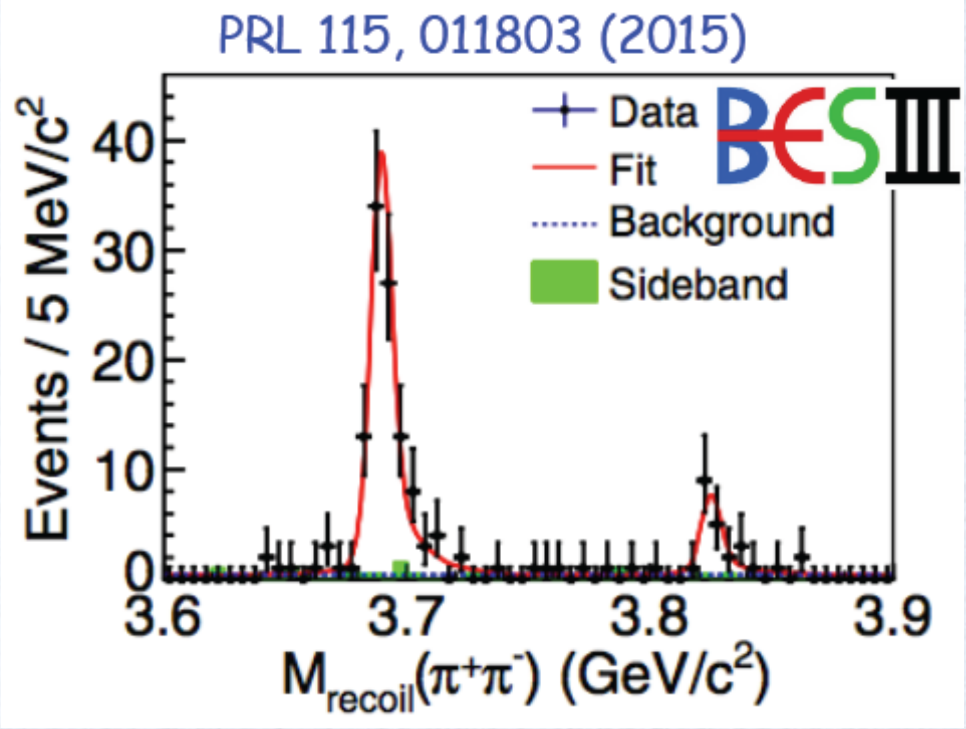
- Recent evidence of X(3823) $\rightarrow \gamma X_{c1}$ at Belle in B $\rightarrow$ XK decays and observation at BESIII in $e^+e^- \rightarrow \pi^+\pi^- X$ production

- M=3821.7 ± 1.3 ± 0.7 MeV/c^2; Γ < 16 MeV (PRL 115, 011803 (2015) BESIII)

- J^P unknown; C = -1

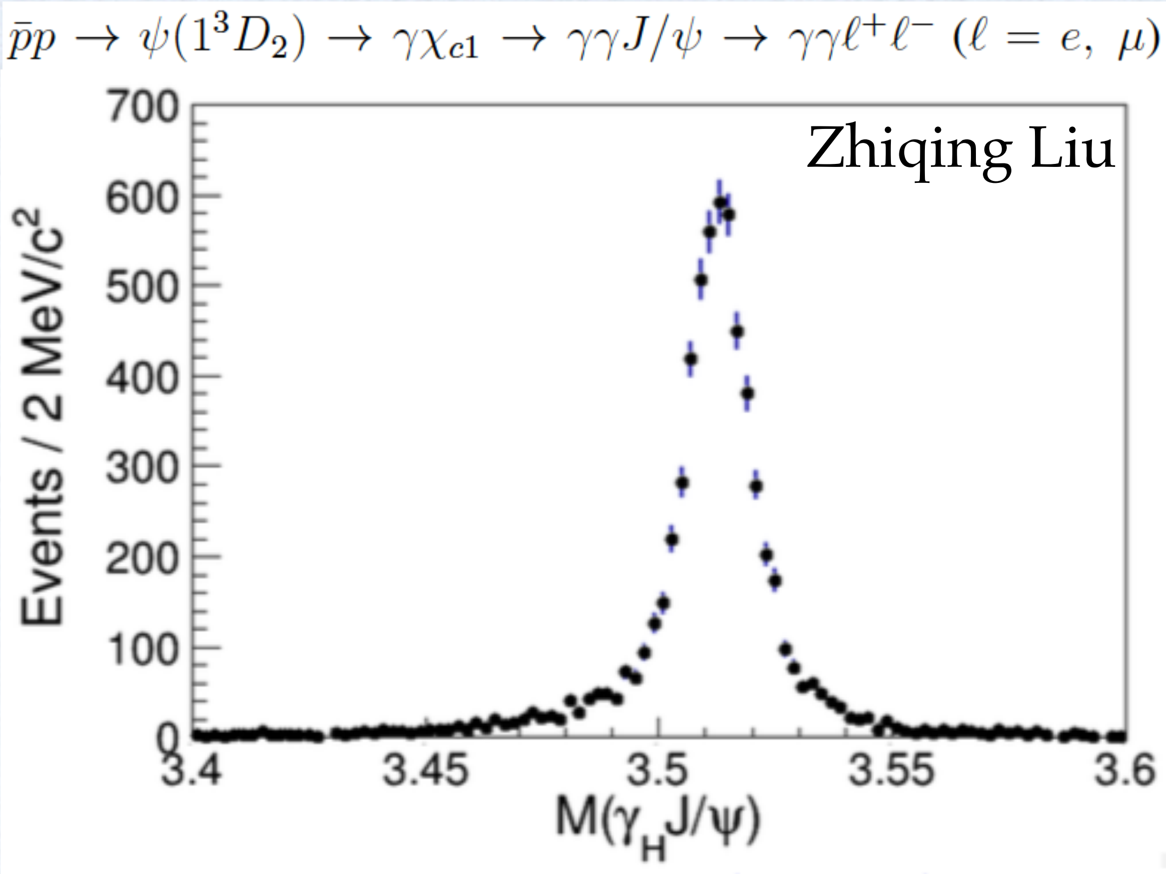
- Candidate for 1^3D_2 charmonium state





Study of $\psi(1^3D_2)$ charmonium state at PANDA (Zhiqing Liu)

- Goals of analysis: precise mass and width measurement of $\psi(1^3D_2)$, spin-parity measurement.
- PandaRoot version: scrut 14
- Full detector setup and full simulation
- 15 scan points with 0.5 MeV step with 0.5 pb^{-1} / point (≈15 days)
- Add 5-7 points for fine scan (150 KeV step) to measure mass and width (spin-parity)
- Total beam time ≈3 weeks ($L=10^{31}\ cm^{-2}s^{-1}$)
- Challenge: high statistics (10^9) background MC samples



Release note RN-QCD-2015-005 started inside the PWG

Future plans

✳ h_c width measurement using full simulation

✳ χ_{cJ} angular distribution using full simulations

✳ h_c in hadrons using full simulation:

- ✳ BR($\pi^+ \pi^- \pi^0$) < 2.2×10^{-3} (PDG)
- ✳ BR($2\pi^+ 2\pi^- \pi^0$) < $2.2^{+0.8}_{-0.7}$ % (PDG)
- ✳ BR($3\pi^+ 3\pi^- \pi^0$) < 2.9% (PDG)

Any other idea is welcome!

Anyone is welcome!

Summary

✳ **Charmonium spectroscopy at PANDA:**

- Precision measurements mandatory: e.g. branching fractions, masses and widths

✳ Scutiny Group merged proposals made by the various PWGs to a **two year early physics proposal**

Charmonium spectroscopy:

- 13 days at 5.55 GeV/c for χ_{c1} angular distribution studies
- 36 days at 5.73 GeV/c for χ_{c2} angular distribution studies
- 60 days at 5.61 GeV/c for h_c width measurement

✳ **Future plans:**

- Full simulation of the analysis done during the scrutiny process

✳ **Limited manpower:**

- like in Charmonium-like Exotic and Light Mesons PWGs - Anyone is welcome!