Study of D-wave charmonium at PANDA

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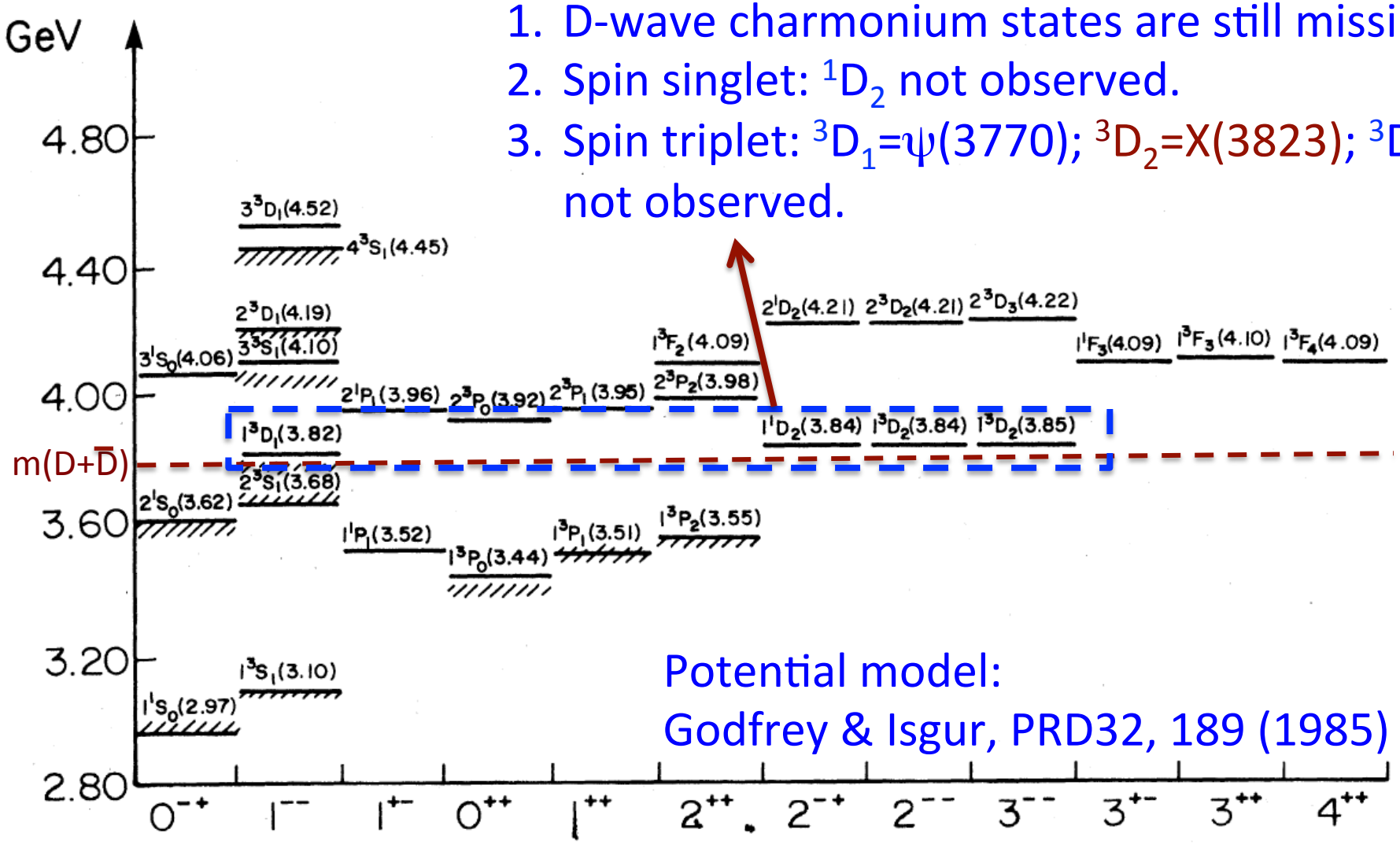
Charmonium family



1. D-wave charmonium states are still missing.
2. Spin singlet: $^1D_2$ not observed.
3. Spin triplet: $^3D_1=\psi(3770)$; $^3D_2=X(3823)$; $^3D_3$ not observed.

Potential model:
Godfrey & Isgur, PRD32, 189 (1985)

$\psi(^3D_2)$=X(3823)

1. D-wave charmonium: potential model predict its mass close to/above open charm threshold.

2. Belle & BESIII: X(3823)=$\psi(^3D_2)$.

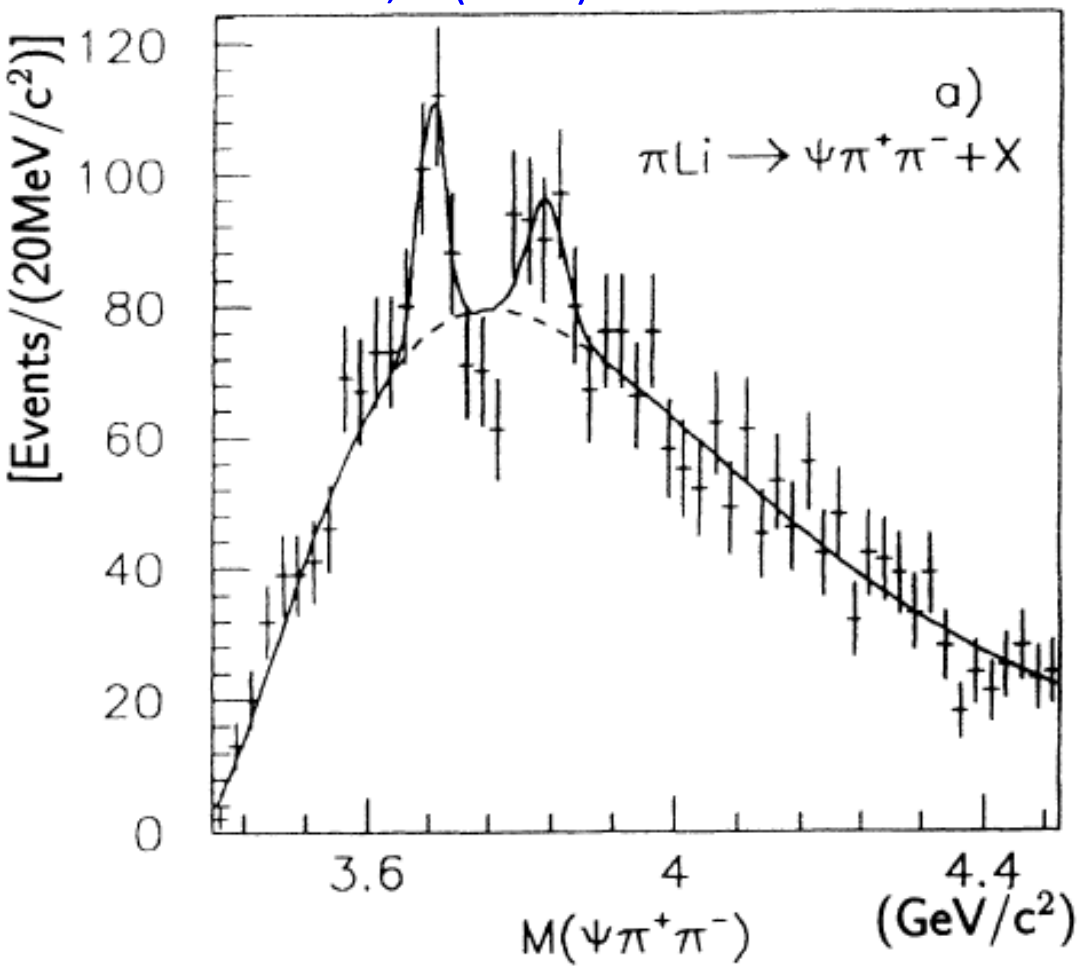
3. Mass: ~3810-3840 MeV (models…).

4. Narrow $\psi(^3D_2)$ state: $J^{PC}=2^{--}$, width ~390 keV.

5. Dominant decay: $\psi(^3D_2)\rightarrow\gamma\chi_{c1}$, Br~50%.

E705

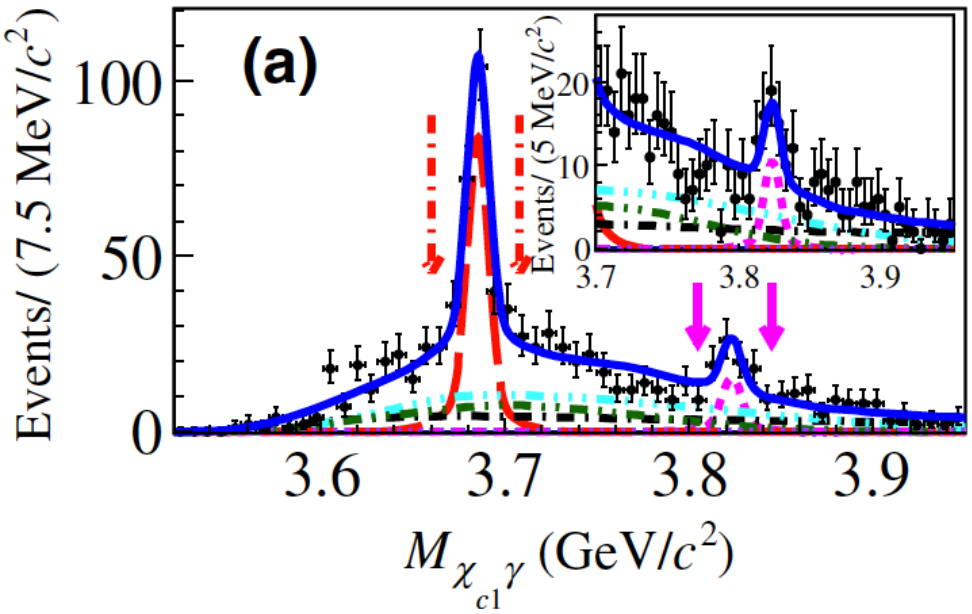
PRD 50, 7 (1994)



- Evidence: 2.8σ
- M=3836±13 MeV
- Production cross section comparable to ψ(2S)
- Available at PANDA

Belle & BESIII

PRL 111, 032001 (2013)



772 M B mesons:

Evidence: 3.8σ

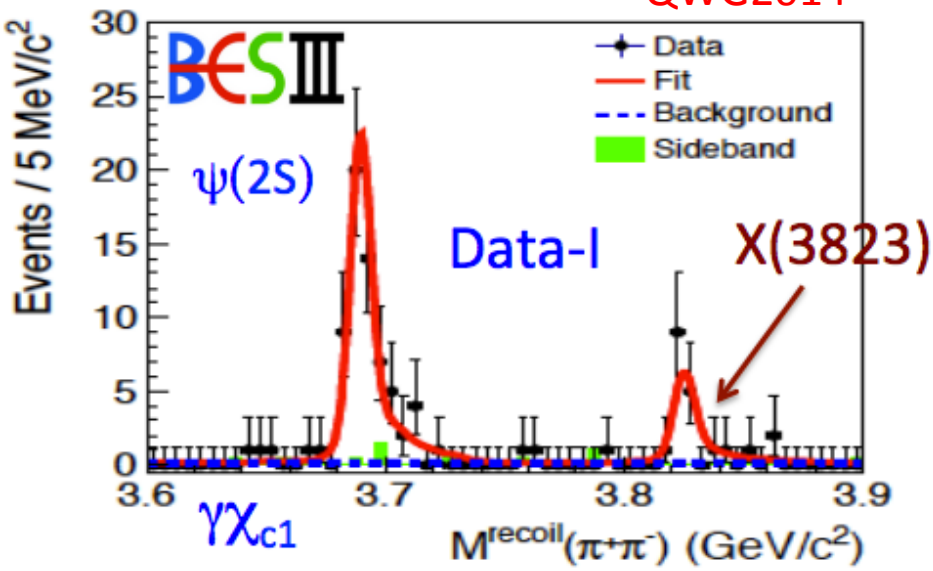
B→KX(3823)→K$\gamma\chi_{c1}$

M=(3823.1±1.8±0.7) MeV

Γ=(1.7±5.5) MeV

<24 MeV @ 90% C.L.

QWG2014



~3.8 fb^{-1} data

Observation: 6.7σ !

e+e-→$\pi^+\pi^-$X(3823)

→$\pi^+\pi^-\gamma\chi_{c1}$

M=(3821.7±1.3±0.7) MeV

Γ<16 MeV @ 90% C.L.

Mass & Width @ PANDA?

1. Both Belle & BESIII can not measure X(3823) mass and width precisely due to limited statistics.

2. Especially for width, even Belle II need several years running time (>2019).

3. PANDA has a high potential to precisely measure mass & width of X(3823).

Strategy

1. Formation experiment: $pp \rightarrow X(3823) \rightarrow \gamma\chi_{c1}$
2. Coupling calculations:

- $\Gamma(J/\psi \rightarrow pp)$=0.2 keV [PDG]
- $\Gamma(\psi(2S) \rightarrow pp)$=0.09 keV [PDG]
- $\Gamma(\chi_{c1} \rightarrow pp)$=0.06 keV [PDG]
- $\Gamma(\chi_{c2} \rightarrow pp)$=0.14 keV [PDG]
- $\Gamma[\psi(3770)=\psi(^3D_1) \rightarrow pp] \sim 0.19$ keV [BESIII: PLB735(101)]
- $\Gamma[\psi(^3D_2) \rightarrow pp] \sim 0.19$ keV ?

Strategy

1. Depends on X(3823) width: ~400 keV
   → σ[pp→X(3823)]~1100 nb.

2. o(10^2 nb) → quite large!

3. Br[X(3823)→$\gamma\chi_{c1}$]=50%, ε=40% → σ^{eff} ~0.9 - 9 nb >> $\sigma^{eff}[\eta_c \to \gamma\gamma]$ & $\sigma^{eff}[X(3872) \to \pi^+\pi^- J/\psi]$

4. Promising project, determine spin-parity !

$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

- MC simulation
- Decay chain:
- $pp \rightarrow X(3823)$ at E_{cm}=3.822 GeV
- $X(3823) \rightarrow \gamma\chi_{c1}$ with ~50% branching raito
- $\chi_{c1} \rightarrow \gamma J/\psi$ with branching ratio 33.9%
- $J/\psi \rightarrow \mu^+\mu^-$ & e^+e^- with branching raito 11.9%

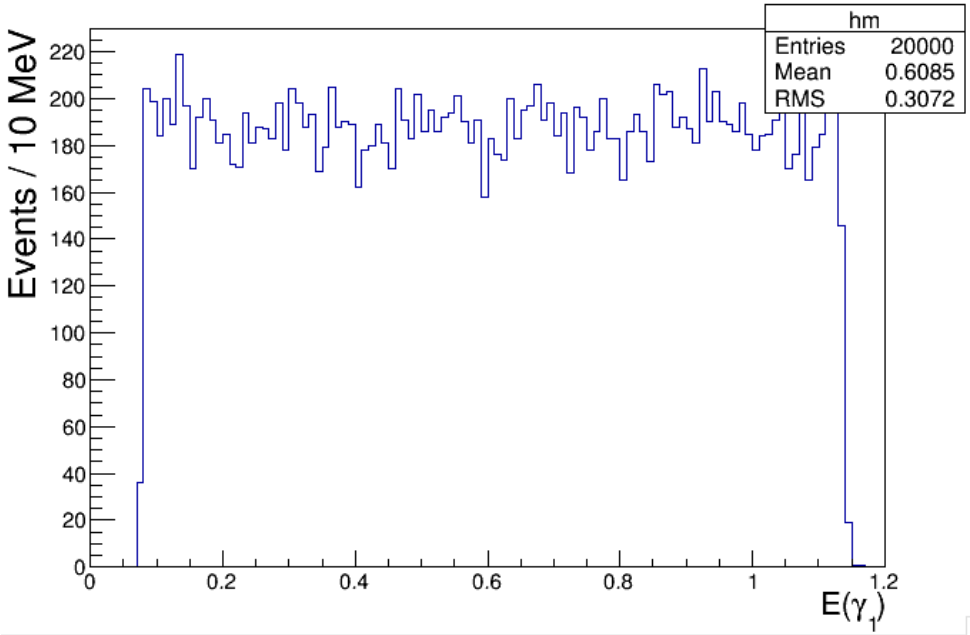
- PANDA Root:
- Full detector setup + Full simulation
- scrut14

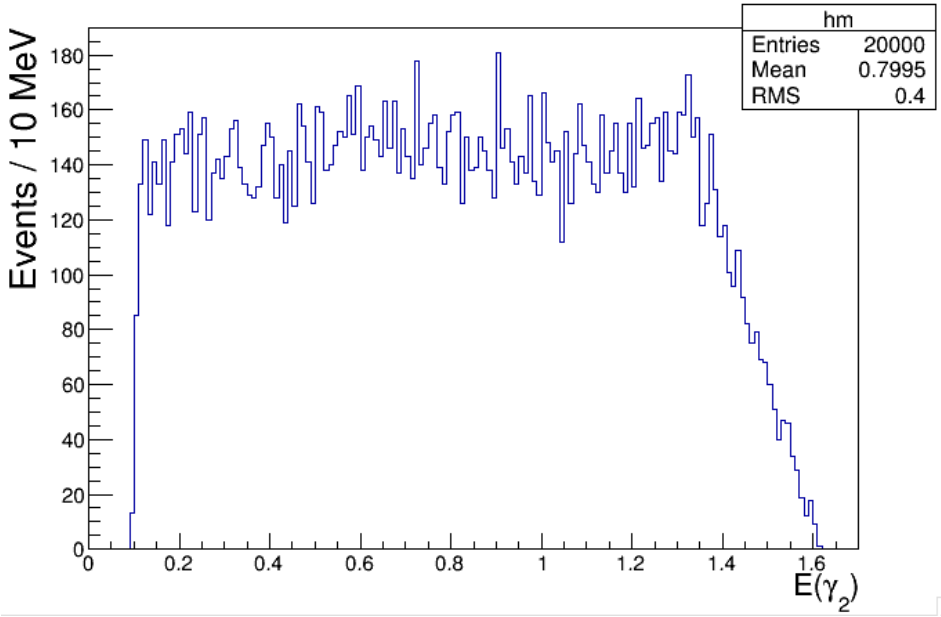
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

- Event Reconstruction:

- Two photons and two leptons from J/ψ.
- Tight lepton identification: eID>0.5; muID>0.5.
- Vertex fit: leptons from the original vertex.
- 4C fit: leptons + photons (best χ^2 combination).
- In ppbar CM frame, high energy gamma +J/ψ

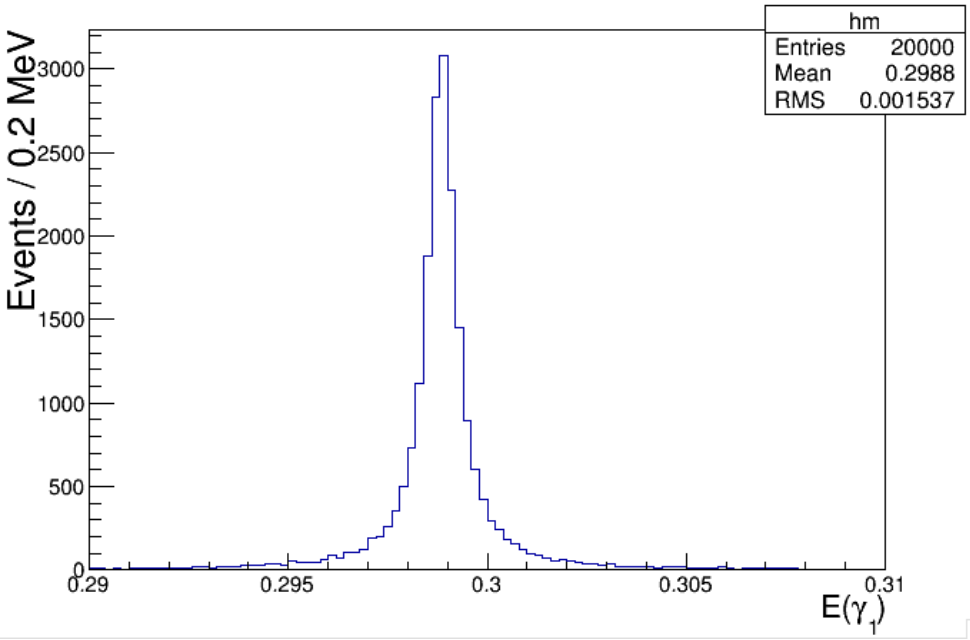
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma_1 \chi_{c1} \rightarrow \gamma_1 \gamma_2 J/\psi$

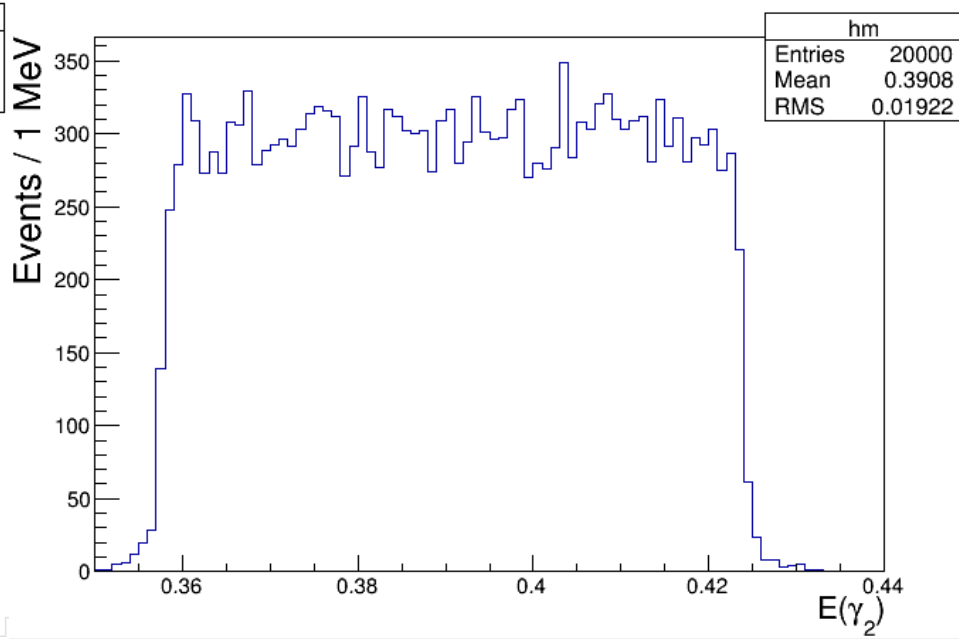




- In lab-frame:
- MC-Truth level energy distributions of two photons.
- Threshold: >50 MeV for all photon candidates.

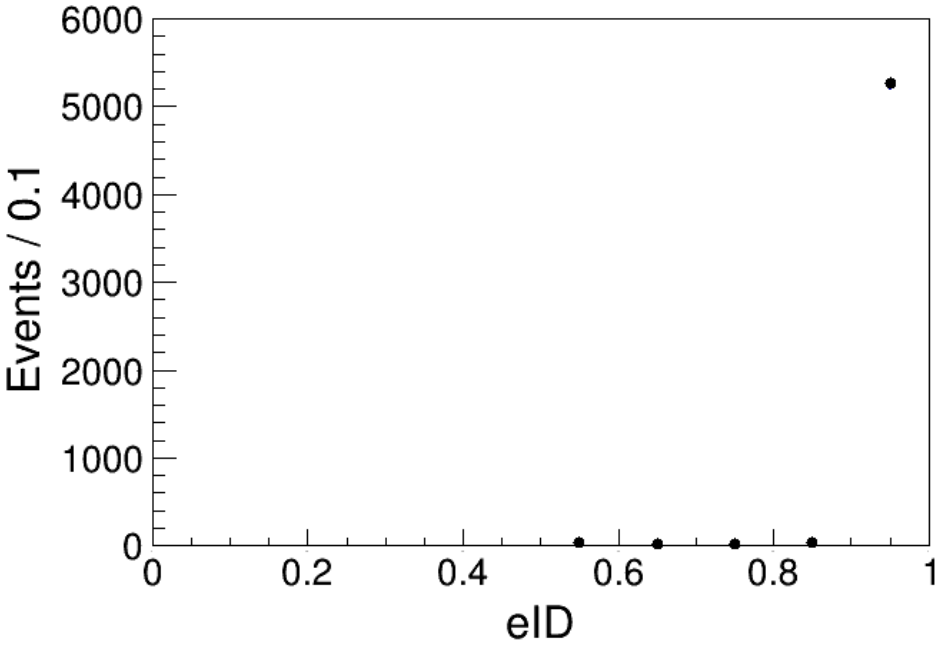
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma_1 \chi_{c1} \rightarrow \gamma_1 \gamma_2 J/\psi$

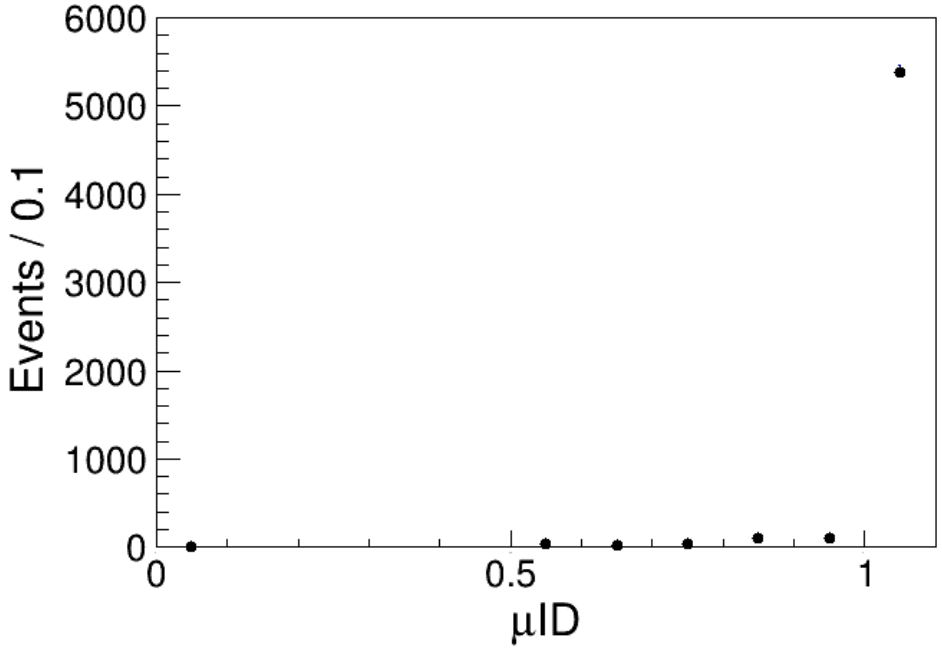




- Boost to $p\bar{p}$ central-of-mass (CM) frame:
- Low energy: γ_1 have good energy resolution.
- High energy: γ_2 was wide due to Lorentz boost effect.
- $E(\gamma_2) > E(\gamma_1)$

$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

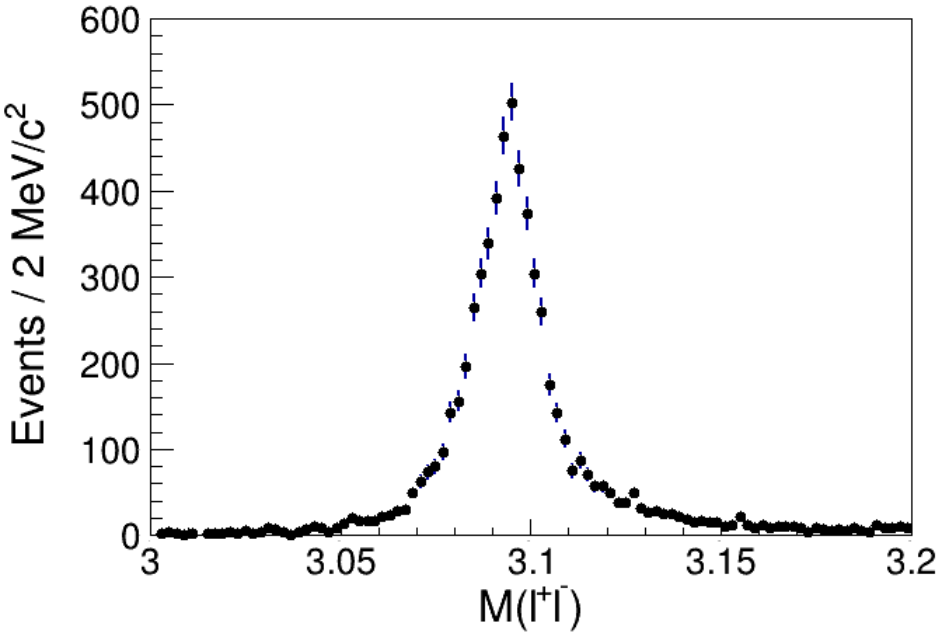


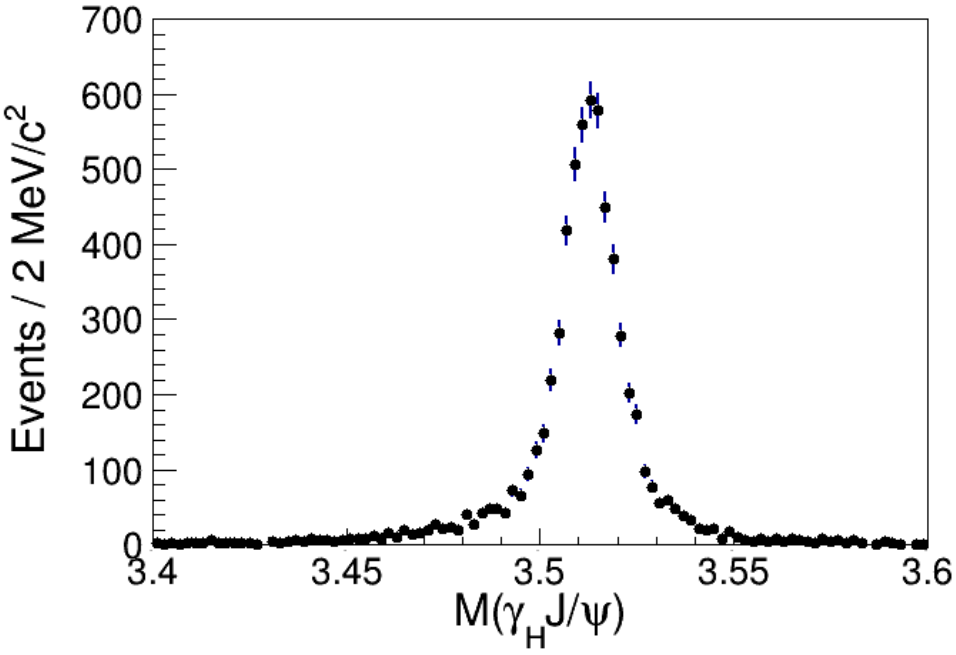


PID: all sub-detector combined p-value (EMC:Drc:Disc:Stt:Mdt:Mvd)

1. Tight PID for electrons need
2. Tight PID for muons also need

$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

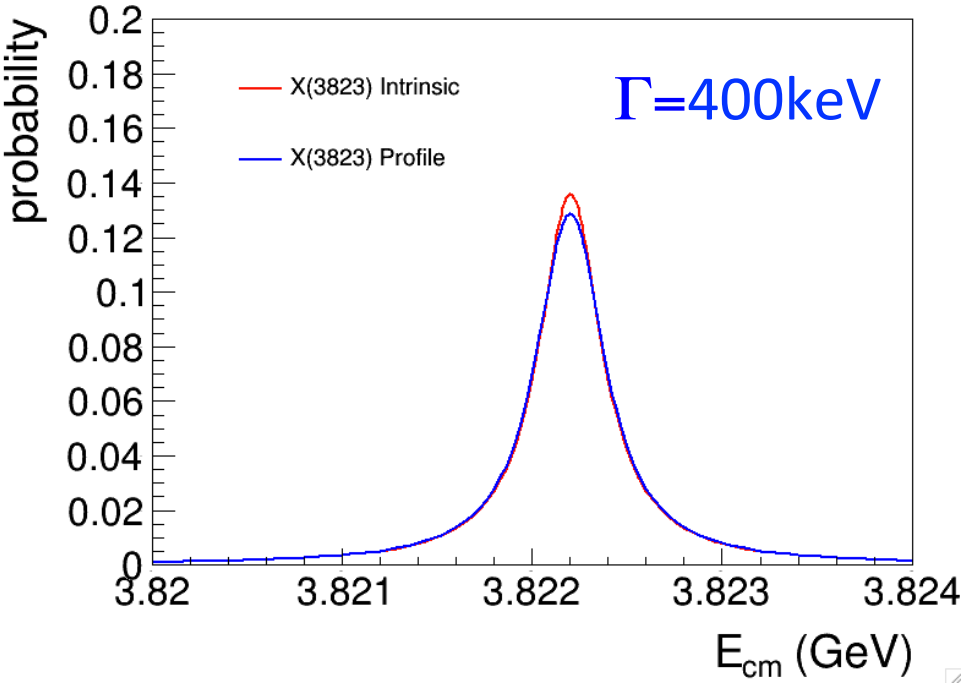


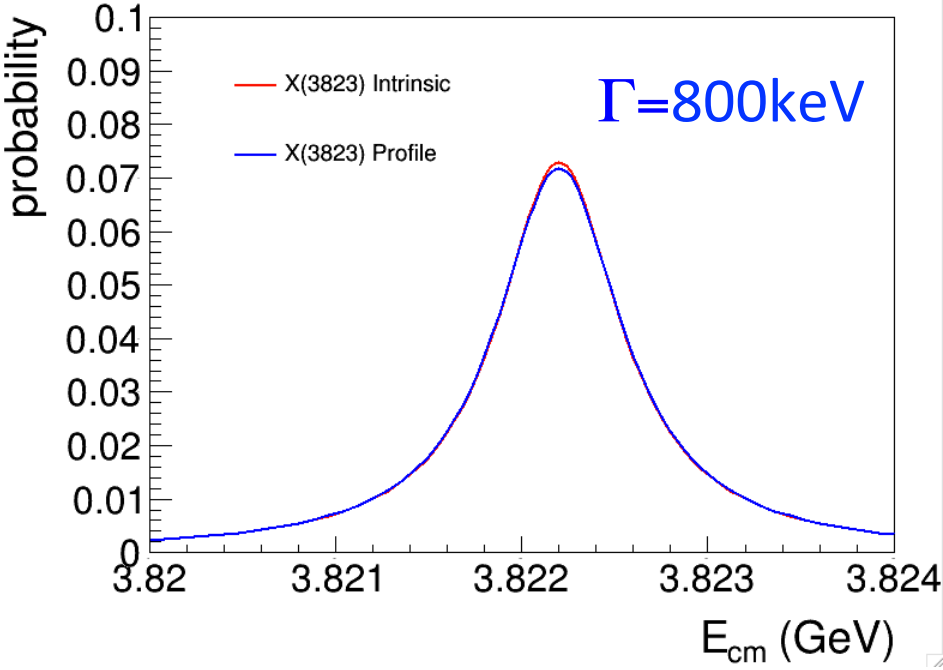


1. (Left) lepton pairs invariant mass distribution, (right) High energy photon combined with J/ψ candidate
2. Signal efficiency: ~40%
3. Background: no events surviving in 10 M DPM MC sample

Thanks Donghee for generating DPM MC background samples.

Beam Spread:





In high resolution mode:

- Beam energy spread is expected ~50 keV
- Beam spread effect is not large compared with psi($^3D_2$) intrinsic width.

Data taking proposal:

1. Mass: 3822.2±1.1 MeV (BESIII+Belle)

2. Width: ~400 keV & 800 keV

3. Beam spread: 50 keV

4. Find the peak postition→Scan 15 points with 0.5 MeV step: m, m±0.5, m±1.0 , m±1.5 MeV… with 500 nb^{-1}/point (~1 day)

5. Add 5 – 7 point for fine scan to measure m & Γ; and further determine spin-parity.

Summary

1. D-wave charmonium state still need to be investigated.

2. PANDA has a high potential to study D-wave charmonium [even at early stage].

3. More competitive than BESIII, Belle II and LHCb.

Thanks (谢谢)!