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

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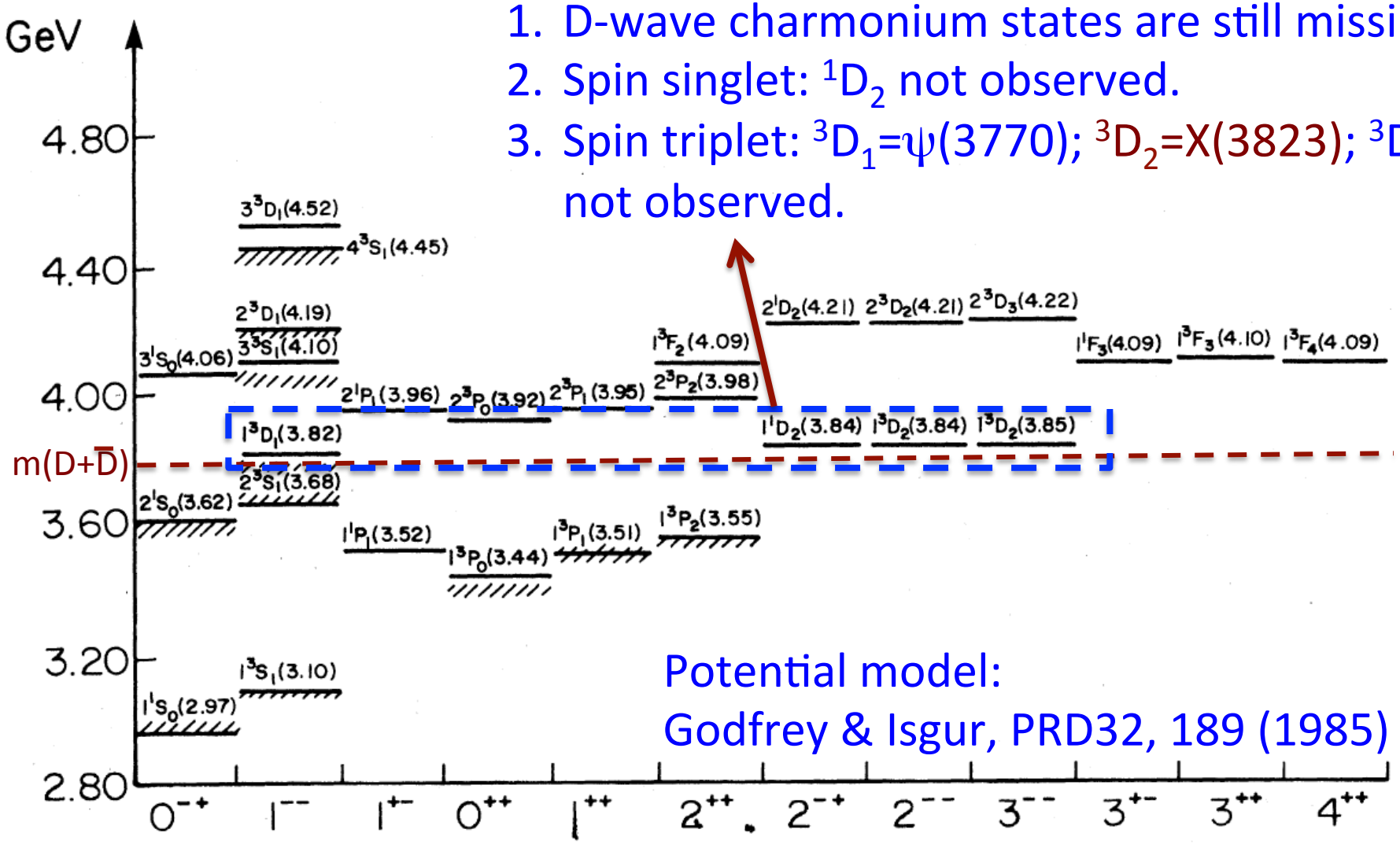
D-wave Charmonium



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)

$\psi(1^3D_2)$

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

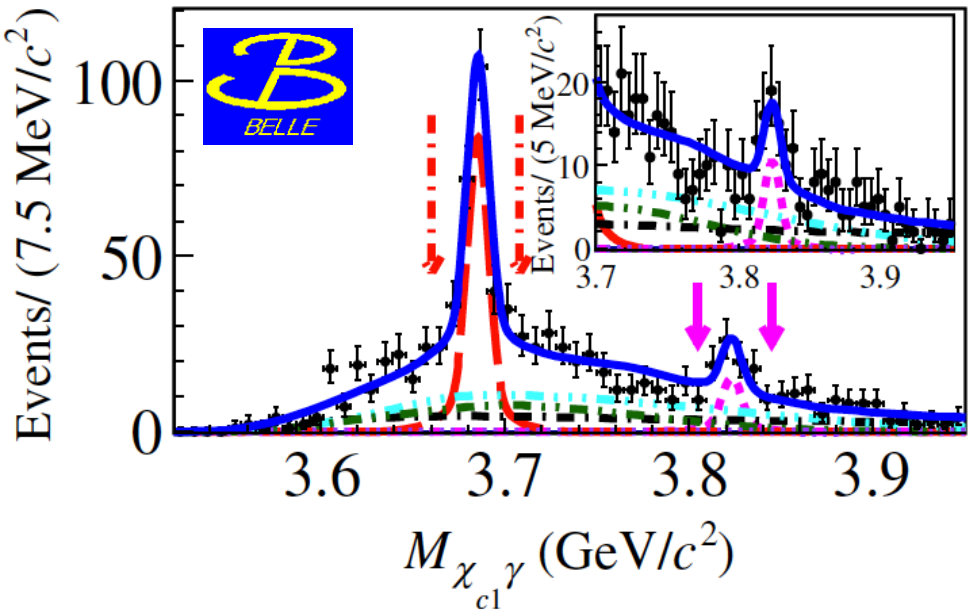
2. Mass: ~3810-3840 MeV (models…).

3. Narrow $\psi(^3D_2)$ state: $J^{PC}=2^{--}$, width ~400 keV.

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

Belle & BESIII: X(3823)=$\psi(1^3D_2)$

PRL 111, 032001 (2013)



Evidence: 3.8σ

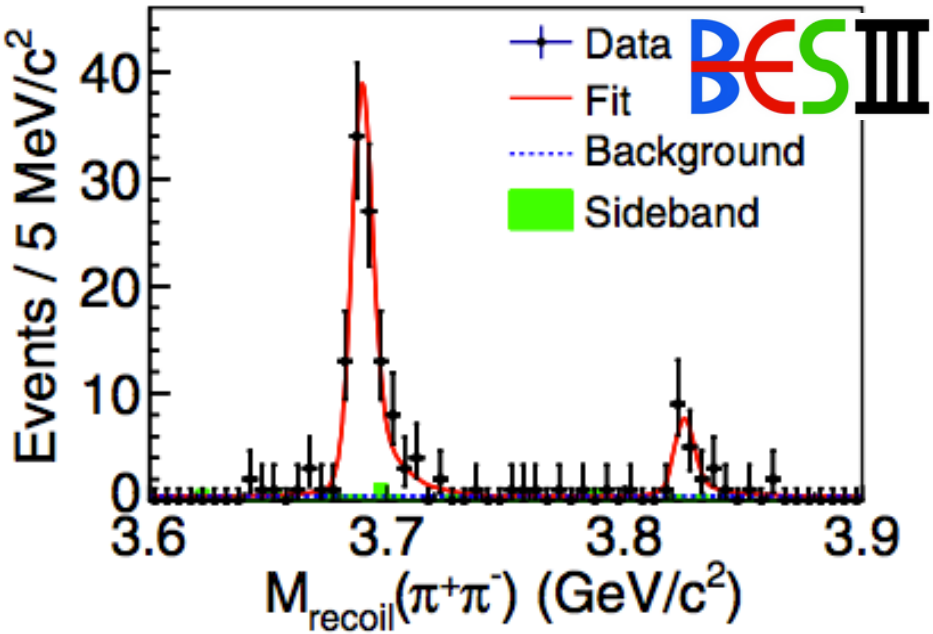
B→KX(3823)→K$\gamma\chi_{c1}$

M=(3823.1±1.8±0.7) MeV

Γ=(1.7±5.5) MeV

<24 MeV @ 90% C.L.

PRL 115, 011803 (2015)



~3.8 fb^{-1} data

Observation: 6.2σ !

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.

Opportunity at PANDA

Coupling

Eq. (1)

$$\sigma_X(s) = \frac{4\pi(2J+1)}{s-4m_p^2}\frac{\mathcal{B}_{\rm in}\mathcal{B}_{\rm out}}{1+[2(\sqrt{s}-M)/\Gamma]^2}$$

J=2

B_{out}=100%

$X(c\bar{c})$	$\mathcal{B}(X\to\bar{p}p)$	$\Gamma(X\to\bar{p}p)$ (keV)
$\eta_c(1^1S_0)$	$(1.52\pm0.16)\times10^{-3}$	48.9
$J/\psi(1^3S_1)$	$(2.120\pm0.029)\times10^{-3}$	0.2
$\chi_{c0}(1^3P_0)$	$(2.25\pm0.09)\times10^{-4}$	2.36
$\chi_{c1}(1^3P_1)$	$(7.72\pm0.35)\times10^{-5}$	0.06
$\chi_{c2}(1^3P_2)$	$(7.5\pm0.4)\times10^{-5}$	0.14
$\psi(2S)=\psi(2^3S_1)$	$(2.80\pm0.11)\times10^{-4}$	0.08
$\psi(3770)=\psi(1^3D_1)$ [12]	$7.1^{+8.6}_{-2.9}\times10^{-6}$	0.19

Final value !

331 nb

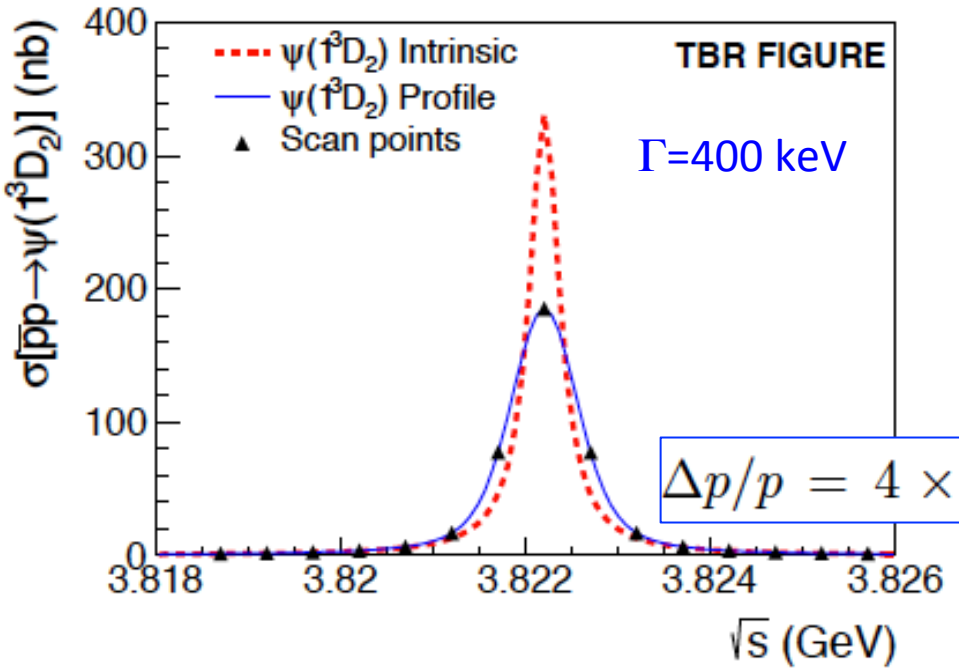
$1/(2L+1)^2$ ~1/3

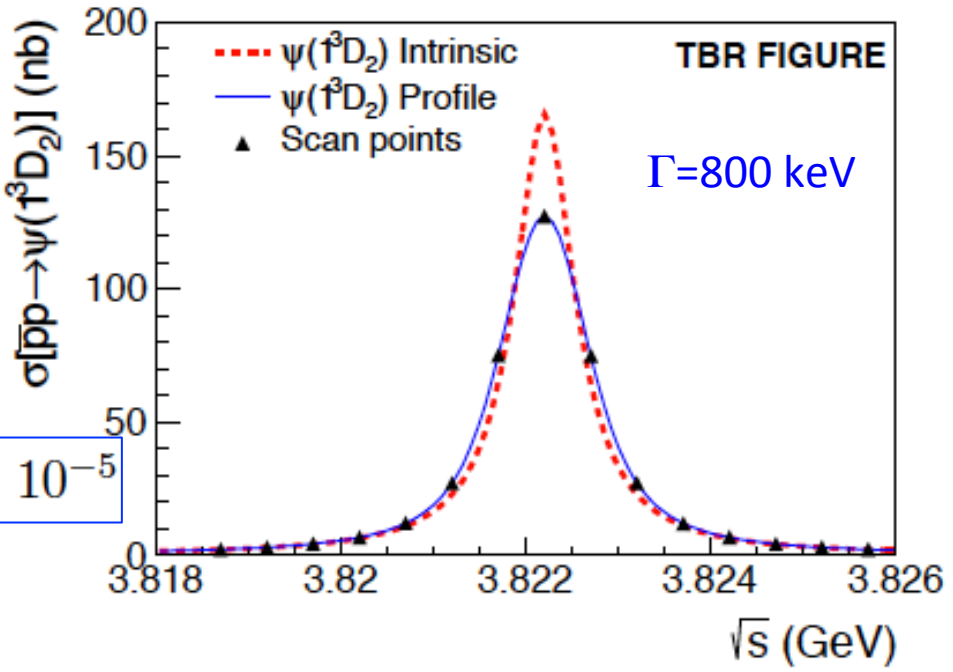
1048 nb

- Interference effect: two identical solutions
- Conservative solution from BESIII

Coupling

1. Br[X(3823)→$\gamma\chi_{c1}$]=50%, Br[χ_{c1}→γJ/ψ]=33.9% Br[J/ψ→l+l-]=11.9% and ε~34% →σ^{eff} ~2.27 nb





$$\Delta p/p = 4 \times 10^{-5}$$

σ^{eff} ~o(1) nb

2. > σ^{eff}[η_c→$\gamma\gamma$]~50 pb (E835, PLB566,45-50)
   > σ^{eff}[X(3872)→$\pi^+\pi^-$J/ψ]~0.07 nb

MC simulation @ PANDA

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

- MC simulation
- Decay chain:
- $pp \rightarrow X(3823)$ at E_{cm}=3.8222 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%

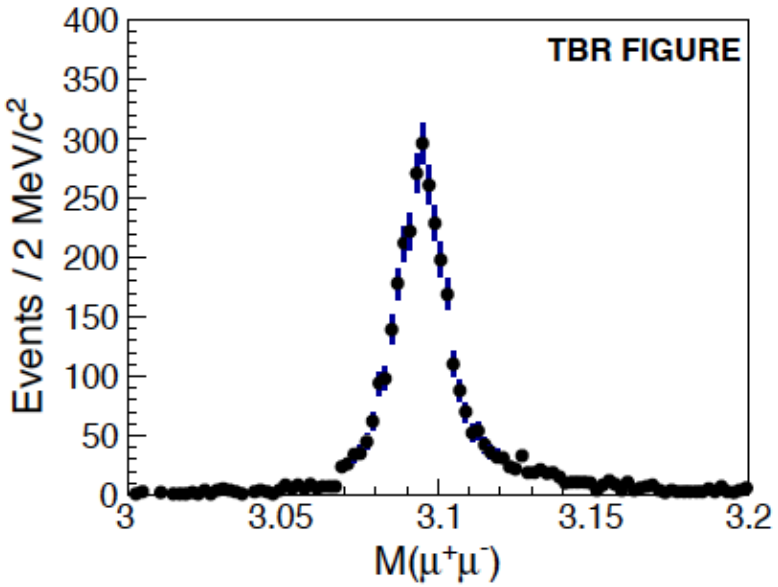
- PANDA Root:
- Full detector setup + Full simulation (Geant 3)
- scrut14

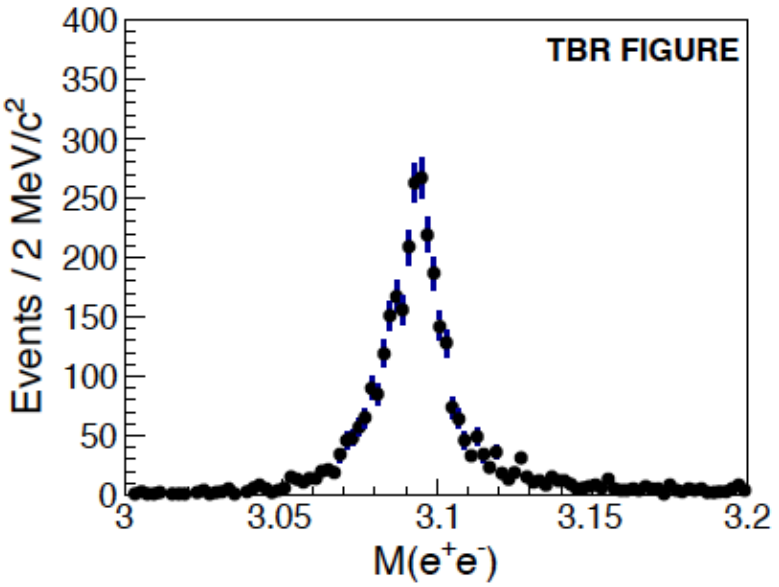
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

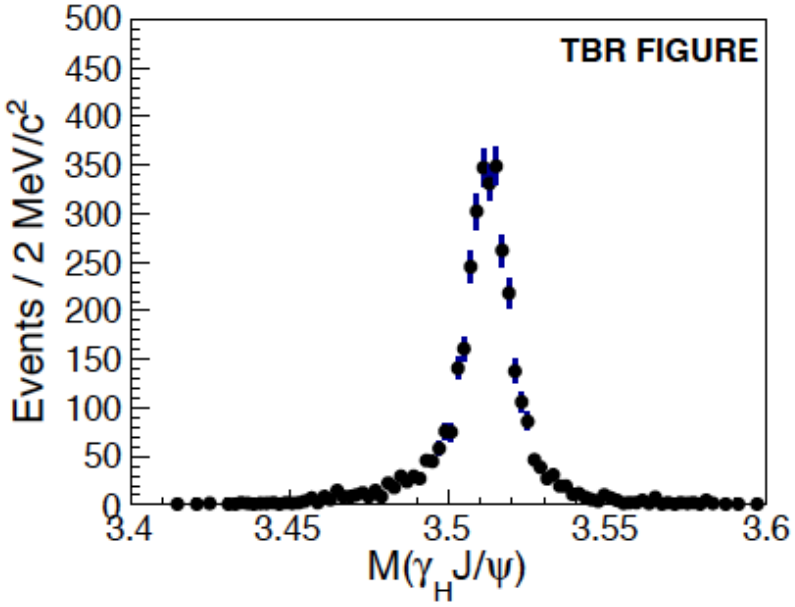
- Event selection:

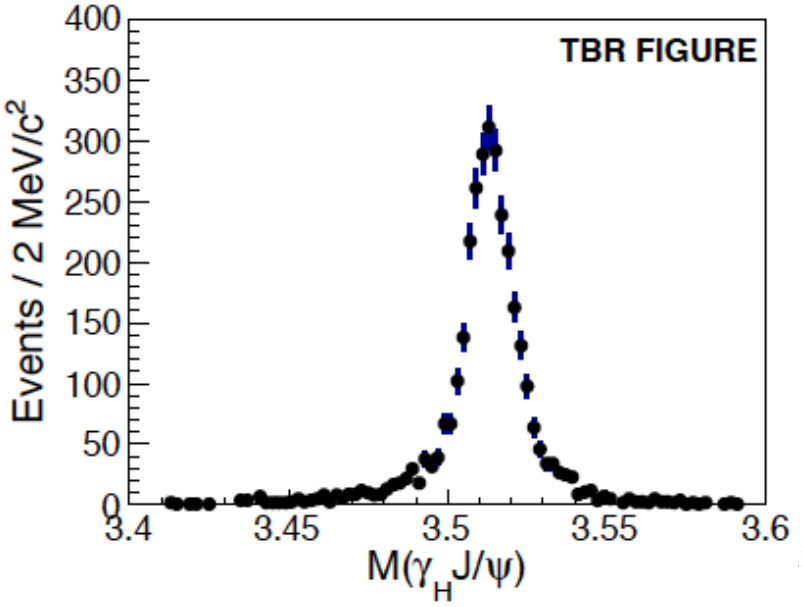
- Two photons and two leptons from J/ψ.
- Tight lepton identification: eID>0.5; muID>0.5.
- Vertex fit: leptons from the original vertex.
- 4C fit: leptons + photons (best χ^2 combination).
- In ppbar CM frame, high energy gamma +J/ψ

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









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

1. 4C kinematic fit is performed to the leptons and photons

2. Signal efficiency: 34.3% (average muon & electron channel).

3. Background: no events surviving in 10 M DPM inelastic MC sample, 3 events left for 10 M $\pi^+\pi^-\pi^0\pi^0$ background MC events (about 374 μb*0.5 pb^{-1}=187 M).

4. Not enough computing power.

Simulation of J=2 particle

```
242 Decay pbarpSystem
243 1.0   psi(3823)   PHSP;
244 Enddecay
245
246 Decay psi(3823)
247 1.0   gamma   chi_c1    PHSP;
248 Enddecay
249
250 Decay chi_c1
251 1.0   J/psi   gamma     VVP 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0;
252 Enddecay
253
254 Decay J/psi
255 0.5   mu+ mu-           PHOTOS  VLL;
256 0.5   e+  e-            PHOTOS  VLL;
257 Enddecay
258
259 End
```

- PHSP may be not perfect
- Not affect M & Γ measurement too much
- Angular distribution related with spin-parity info.

Data taking proposal

Data taking plan

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

2. High resolution mode, beam spread: ~270 keV

3. Find the peak position → Scan 15 points with 0.5 MeV step: m, m±0.5, m±1.0 , m±1.5 MeV… with 0.5 pb^{-1}/point (~15 days)

4. Add 5 – 7 point for fine scan (150 keV step) to measure m & Γ (spin-parity)

5. Total beam time ~3 weeks ($L=1*10^{31}$ /cm^2/s)

Summary

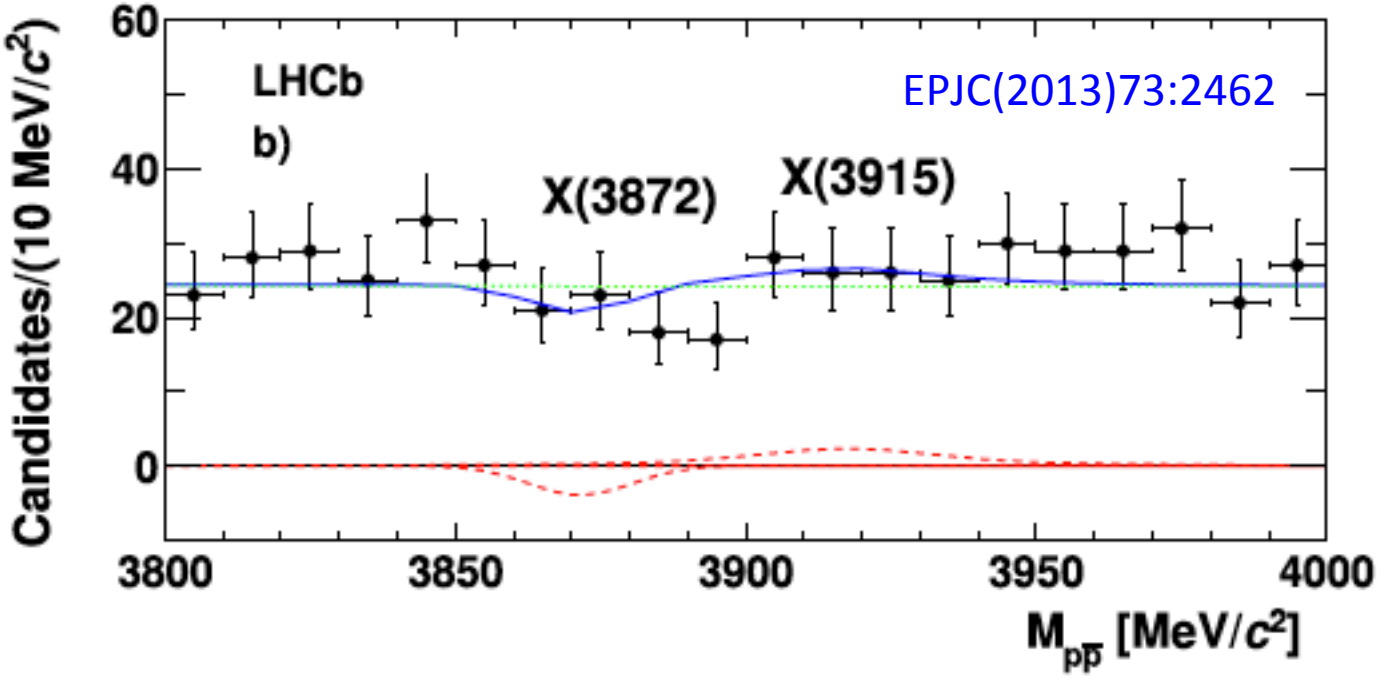
1. 1^3D_2 charmonium state need to be further investigated.

2. PANDA has a high potential to study 1^3D_2 charmonium (m & Γ) at early stage.

3. More competitive than BESIII, Belle and LHCb.

Thanks (谢谢)!

LHCb's measurement



$$\frac{\mathcal{B}(B^+ \to X(3872) K^+ \to p\bar{p}K^+)}{\mathcal{B}(B^+ \to J/\psi K^+ \to p\bar{p}K^+)} < 0.017$$ similar for X(3823)

Belle's measurement: PRL111,032001(2013).
→Br[B→KX(3823)]~$2*10^{-5}$

Considering LHCb's measurement:
→Br[X(3823)→pp]<$2*10^{-3}$@90% C.L. >> (0.06 – 0.2) keV/400 keV