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

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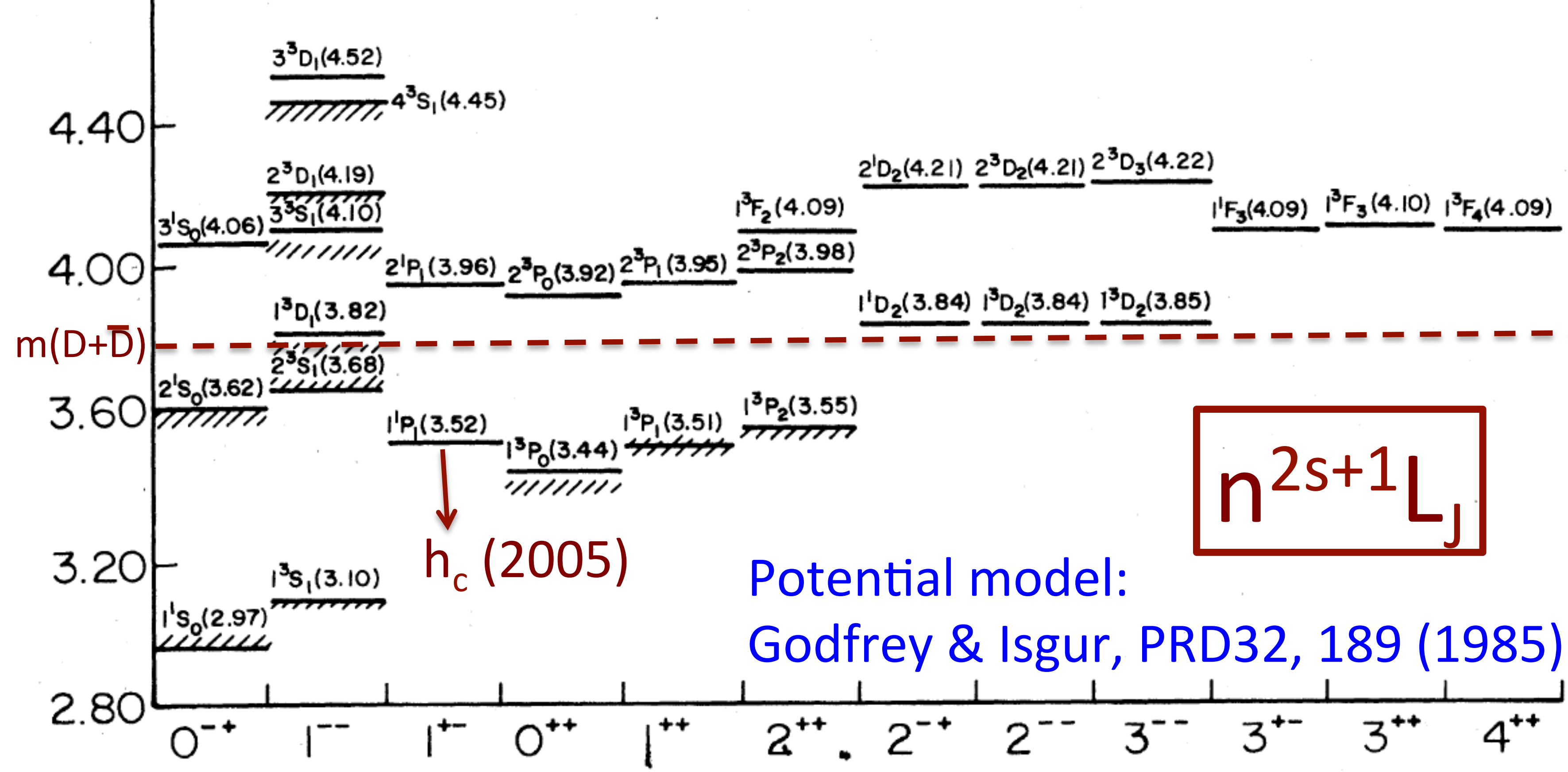
Charmonium

- States below charm threshold are all observed.
- Still many missing states above charm threshold.
- Continuously search in experiment.



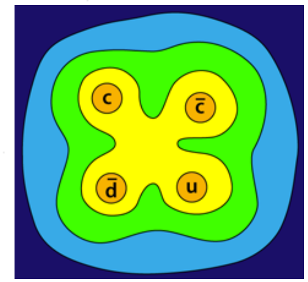
$n^{2s+1}L_J$

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

Charmonium and XYZ particles

- XYZ or charmonium-like particles
- Identify the charmonium first…then rule out possibilities…

What are they?



$Z_c(3900)$

X(3872)

Y(4260)

X(3915)

X(4160)

Y(4008)

Y(4140)

X(4350)

Y(4360)

Y(4660)

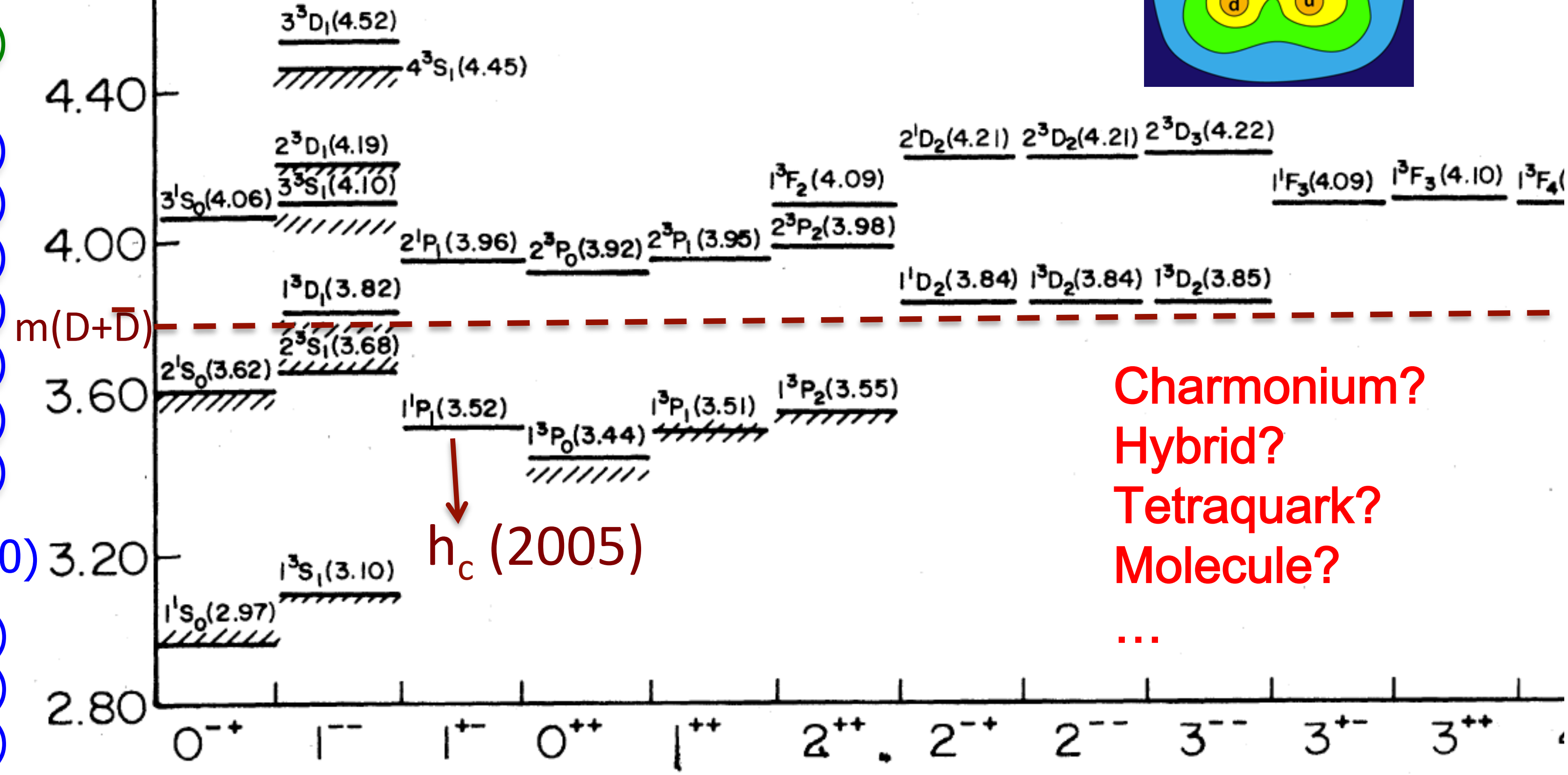
XYZ(3940)

Z(4430)

Z(4250)

Z(4050)

…



Charmonium?

Hybrid?

Tetraquark?

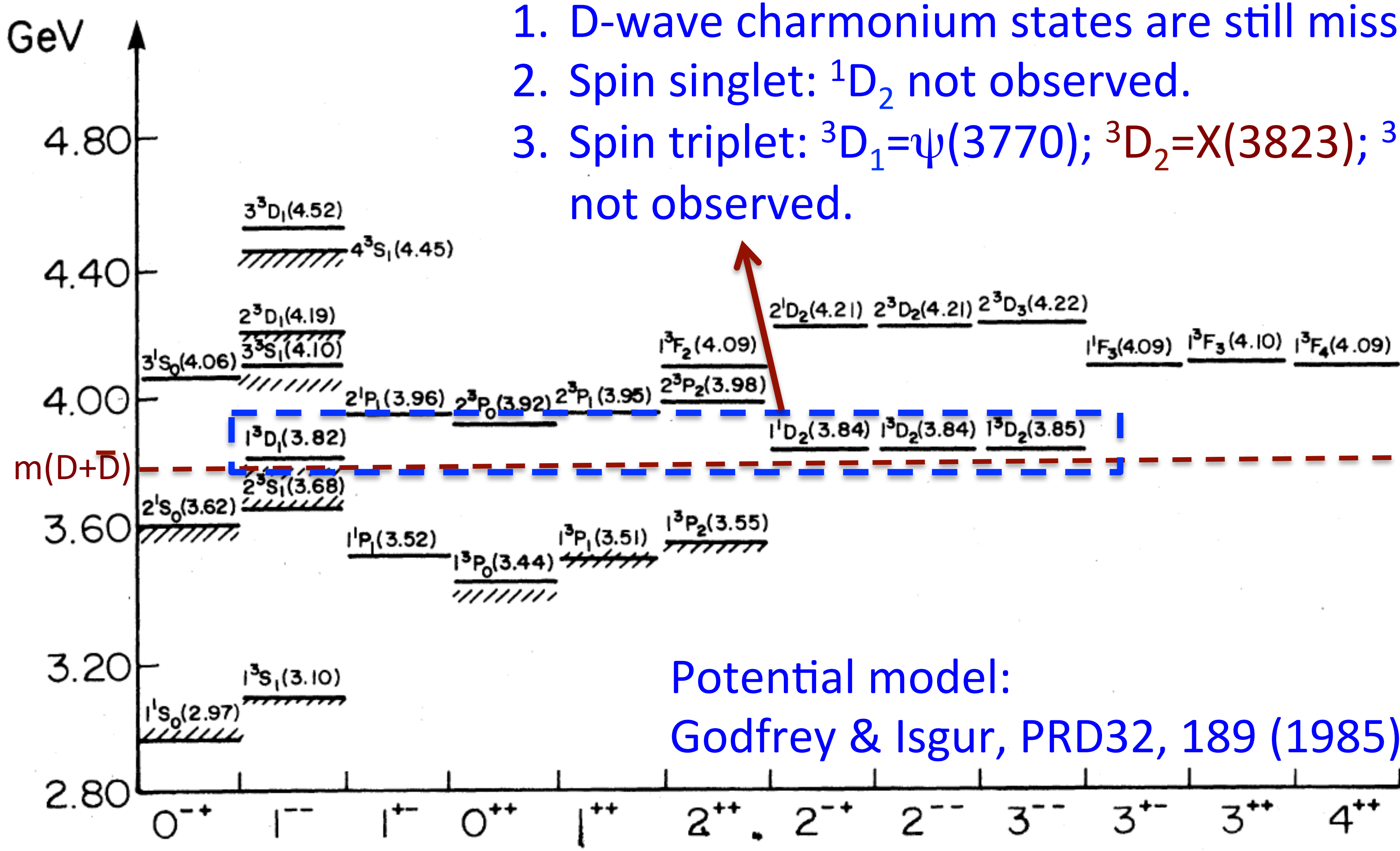
Molecule?

…

Godfrey & Isgur, PRD32, 189 (1985)

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)

$\psi(^3D_2)$

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

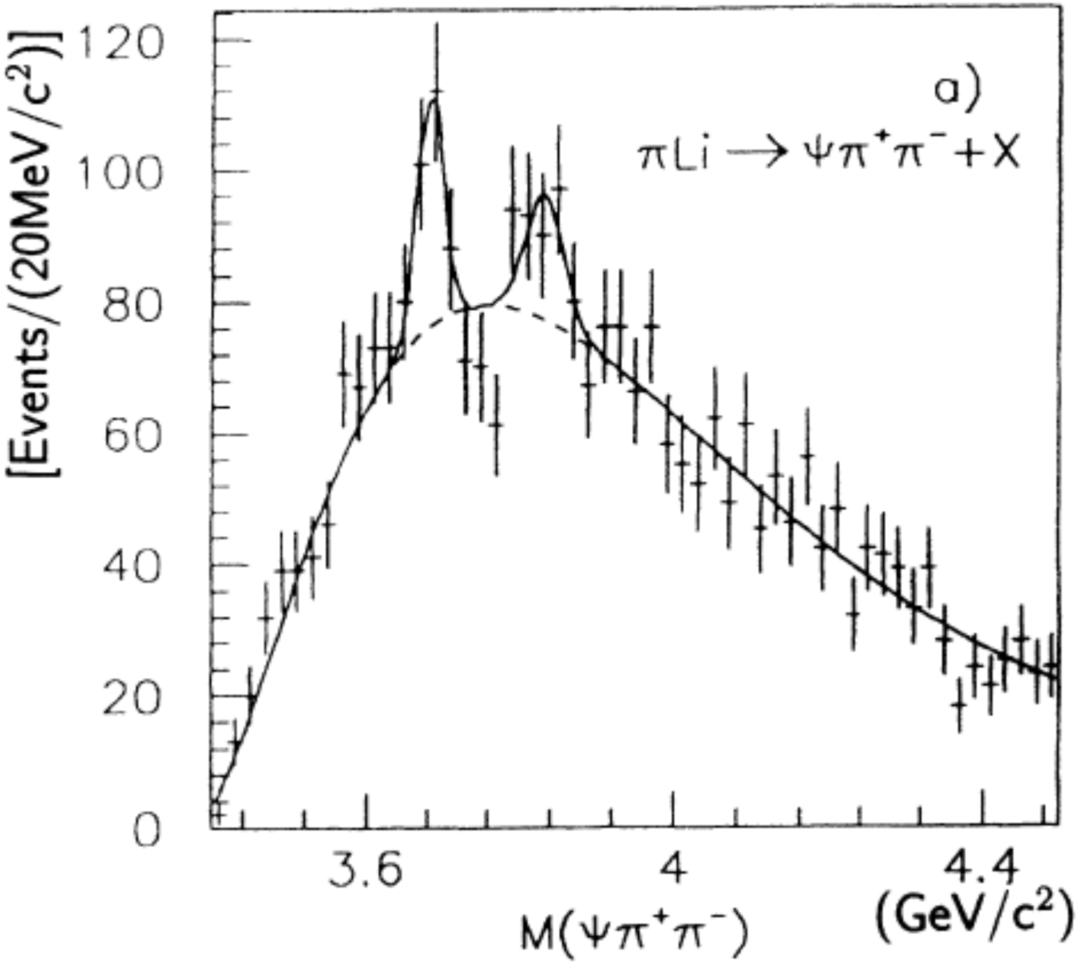
2. Mass: ~3810-3840 MeV (models…).

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

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

E705

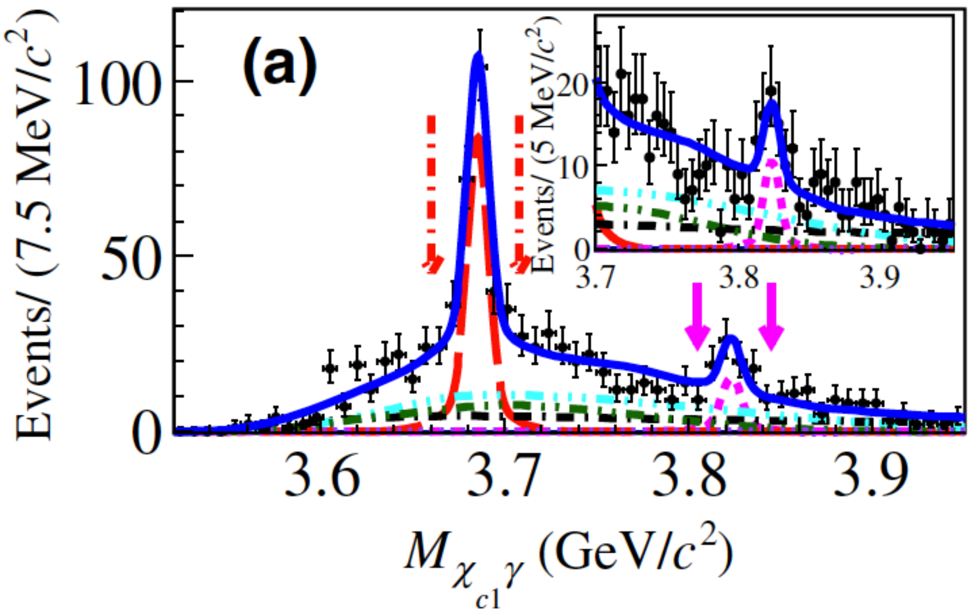
PRD 50, 7 (1994)



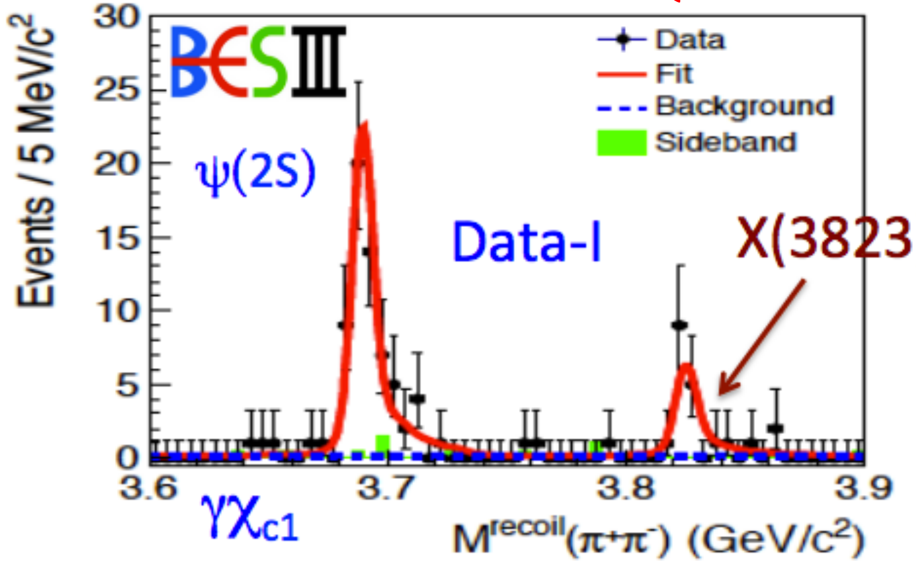
- Evidence: 2.8σ
- M=3836±13 MeV
- Production cross section comparable to ψ(2S)
- Background also controllable
- Available at PANDA

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

PRL 111, 032001 (2013)



QWG2014



772 M B mesons:
Evidence: 3.8σ
B→KX(3823)→Kγχ_{c1}
M=(3823.1±1.8±0.7) MeV
Γ=(1.7±5.5) MeV
<24 MeV @ 90% C.L.

~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.

Opportunity at PANDA

Mass & Width @ PANDA?

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

2. Especially for width, BESIII/Belle II need an order of magnitude more data.

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

Coupling

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

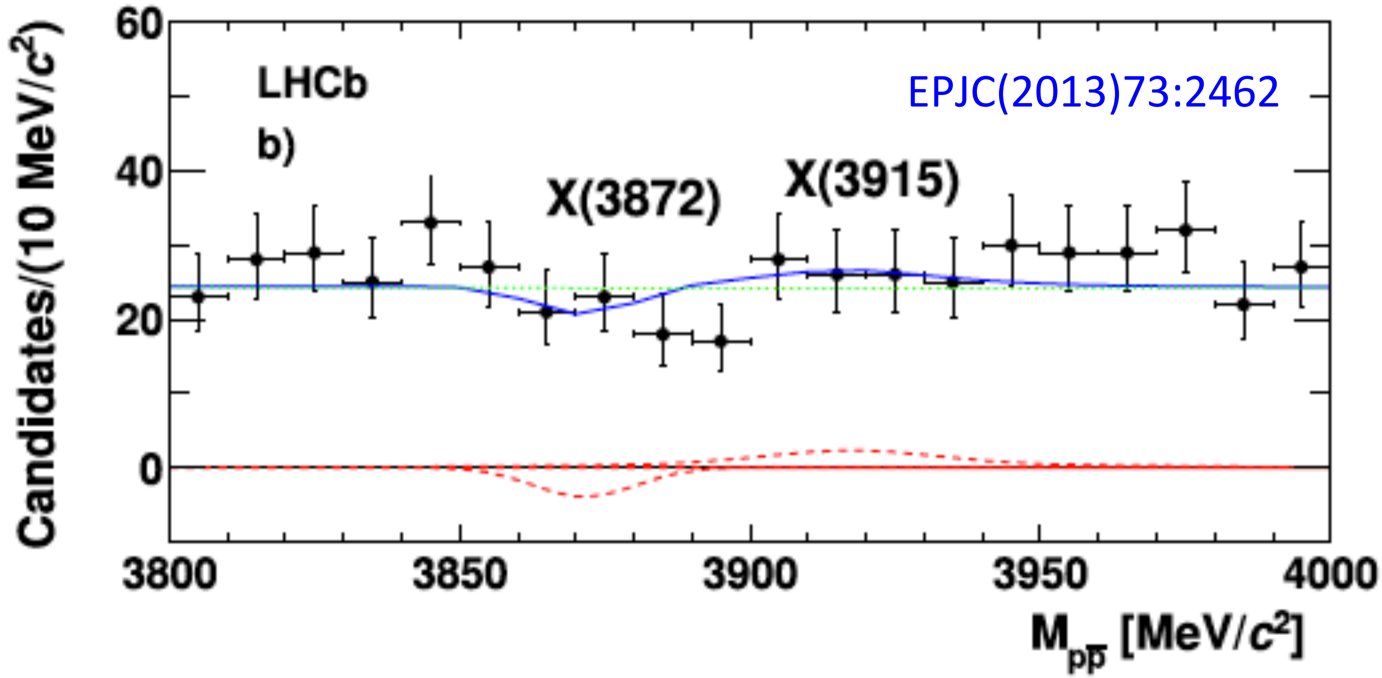
$X(c\bar{c})$	$\mathcal{B}(X \to \bar{p}p)$	$\Gamma(X \to \bar{p}p)$ (keV)
$\eta_c(1^1S_0)$	$(1.52 \pm 0.16) \times 10^{-3}$	48.9
$J/\psi(1^3S_1)$	$(2.120 \pm 0.029) \times 10^{-3}$	0.2
$\chi_{c0}(1^3P_0)$	$(2.25 \pm 0.09) \times 10^{-4}$	2.36
$\chi_{c1}(1^3P_1)$	$(7.72 \pm 0.35) \times 10^{-5}$	0.06
$\chi_{c2}(1^3P_2)$	$(7.5 \pm 0.4) \times 10^{-5}$	0.14
$\psi(2S) = \psi(2^3S_1)$	$(2.80 \pm 0.11) \times 10^{-4}$	0.08
$\psi(3770) = \psi(1^3D_1)$ [12]	$7.1^{+8.6}_{-2.9} \times 10^{-6}$	0.19

Conservative solution from BESIII

Coupling

1. Partial width: Γ[X(3823)→pp]~0.06 – 0.2 keV
2. Depends on X(3823) width: ~400 keV
   →σ[pp→X(3823)]~331 - 1103 nb
   →o(10^2) nb (model dependent width)
3. Br[X(3823)→$\gamma\chi_{c1}$]=50%, ε~40%
   →σ^{eff} ~2.67 – 8.90 nb
   > σ^{eff}[η_c→$\gamma\gamma$]~50 pb (E835, PLB566,45-50)
   > σ^{eff}[X(3872)→$\pi^+\pi^-$J/ψ]<0.3 nb @ 90% C.L.
4. Promising project, determine spin-parity !

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

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%

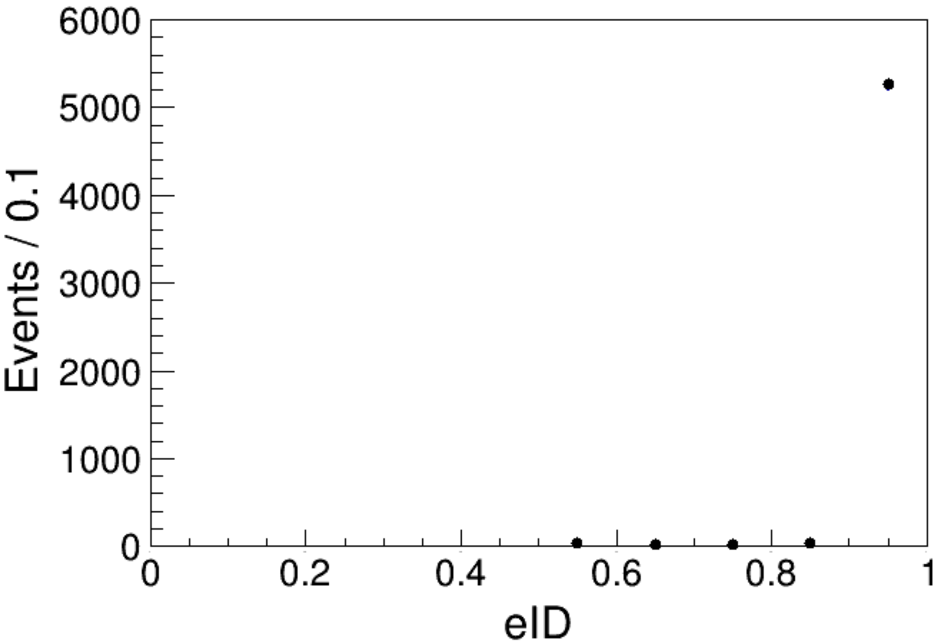
- PANDA Root:
- Full detector setup + Full simulation
- scrut14

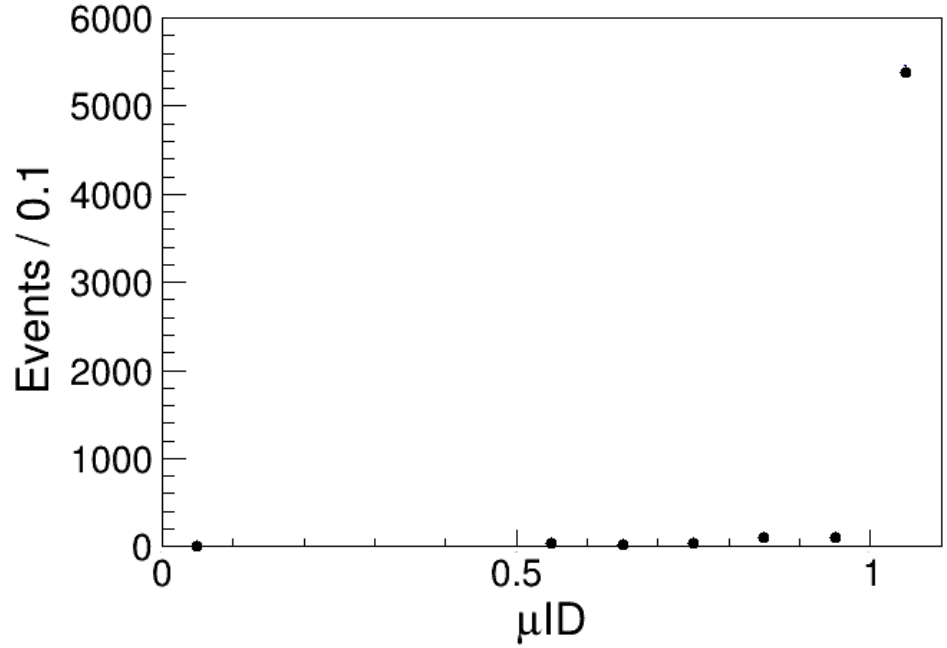
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$

- 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

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



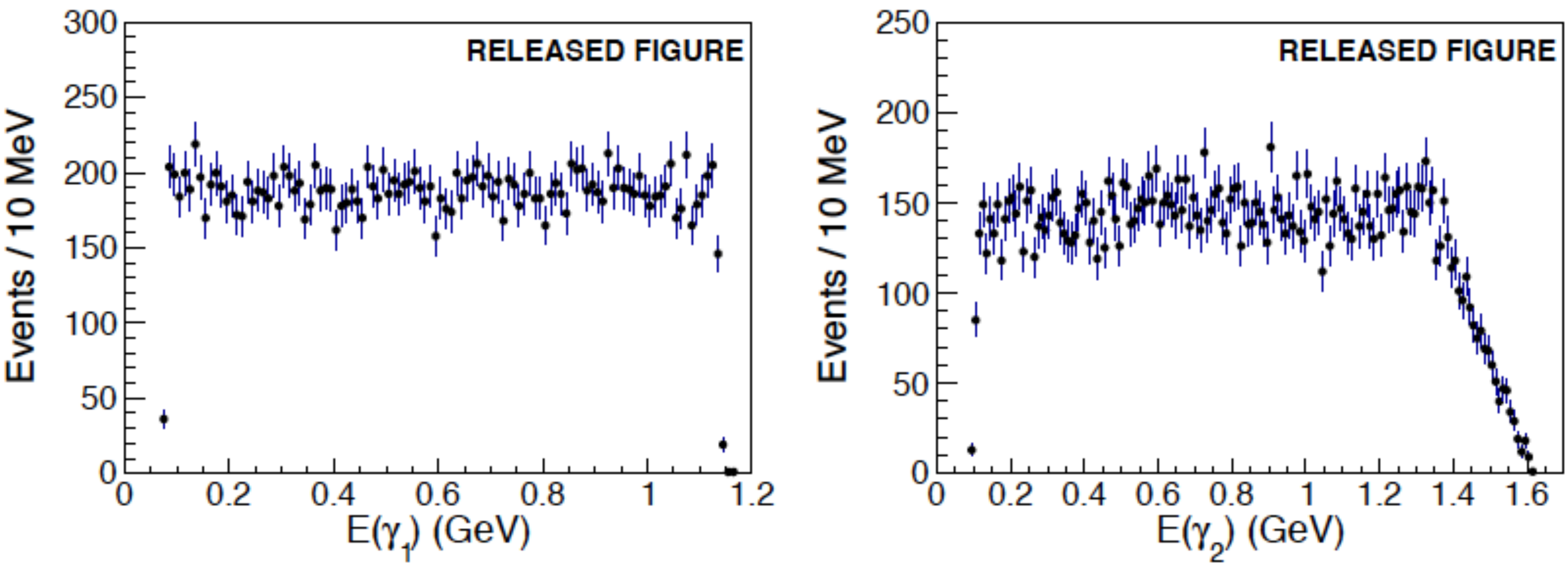


PID: all sub-detector combined p-value (EMC:Drc:Disc:Stt:Mdt:Mvd)

The dominant background should be pions

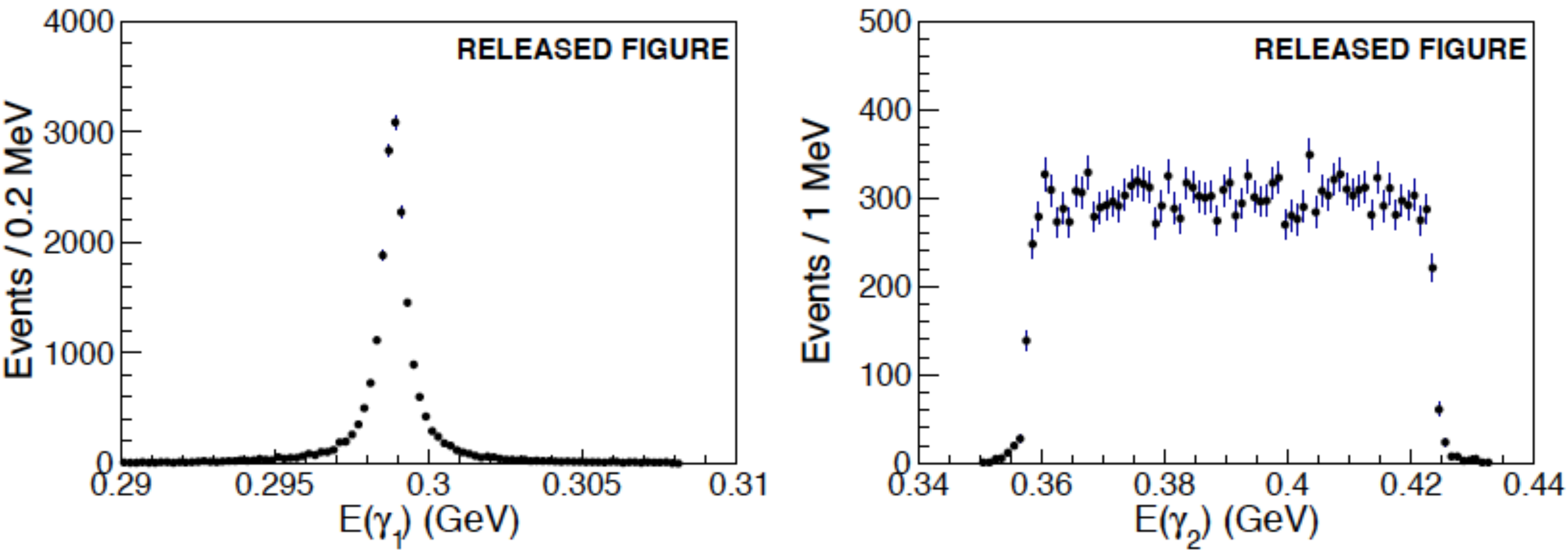
1. Tight PID ($p>0.5$) for electrons
2. Tight PID ($p>0.5$) for muons

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



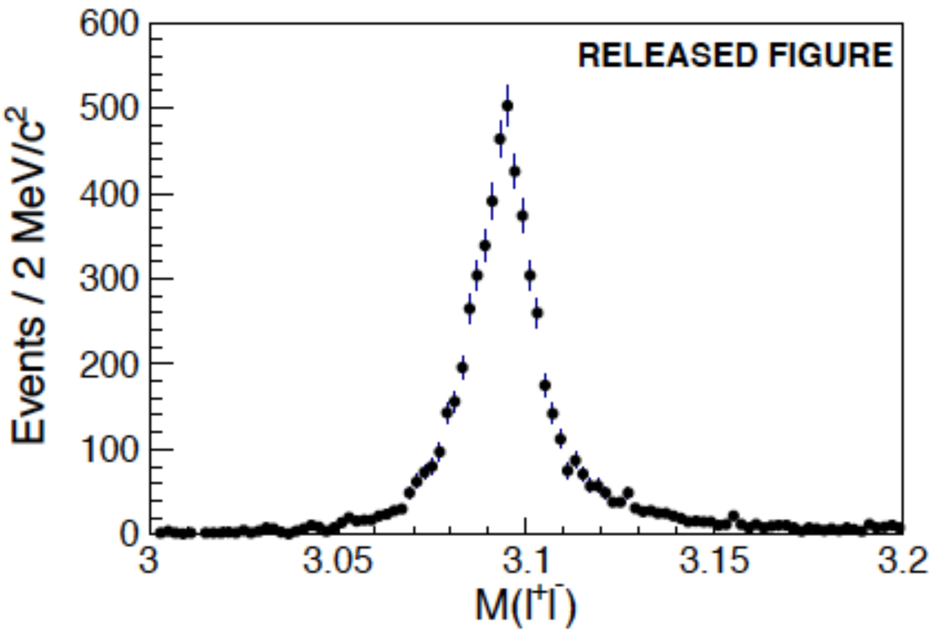
- In lab-frame:
- MC-Truth level energy distributions of two photons.
- Threshold: >50 MeV for all photon candidates.

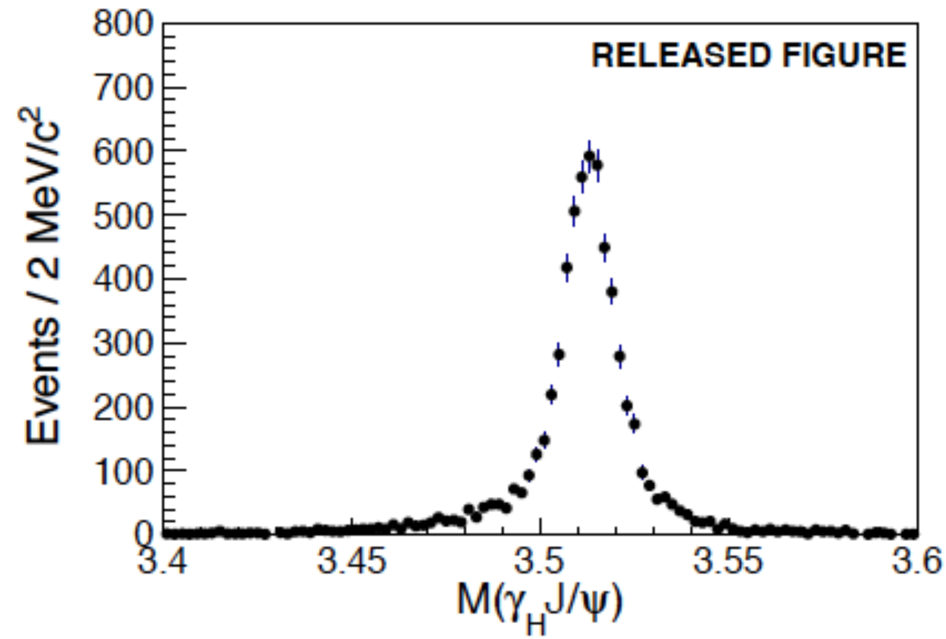
$p\bar{p} \rightarrow X(3823) \rightarrow \gamma_1 \chi_{c1} \rightarrow \gamma_1 \gamma_2 J/\psi$



- 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.
- $E(\gamma_2) > E(\gamma_1)$

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





1. 4C kinematic fit is performed to the leptons and photons
2. (Left) lepton pairs invariant mass distribution, (right) High energy photon combined with J/ψ candidate
3. Signal efficiency: 42.5%
4. Background: no events surviving in 10 M DPM MC sample, total hadron events about 60 mb*0.5 $pb^{-1}=3*10^{10}$

Data taking proposal

Data taking plan

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

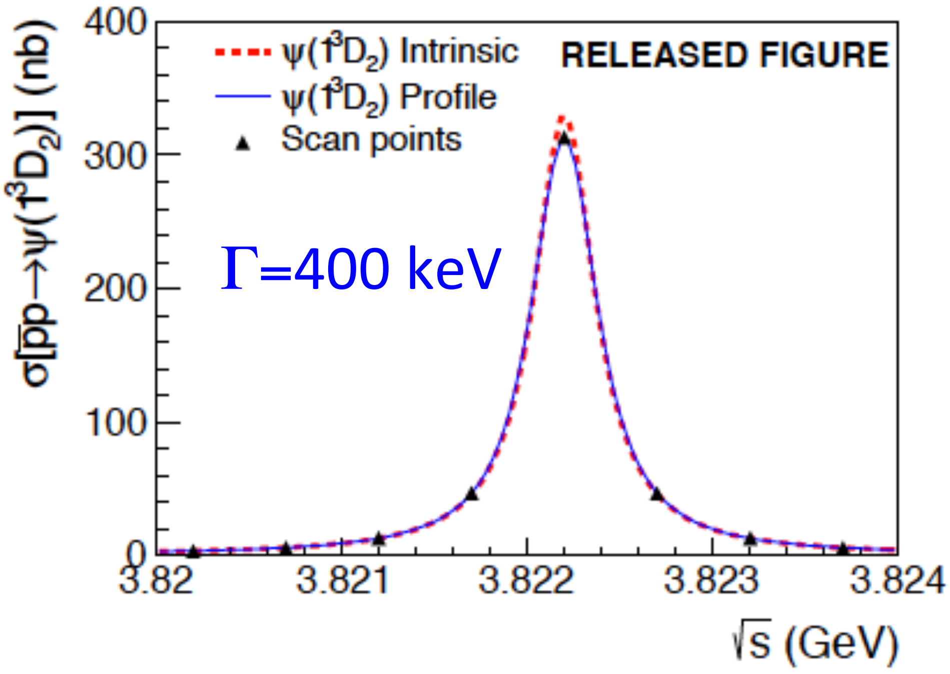
2. High resolution mode, beam spread: 50 keV

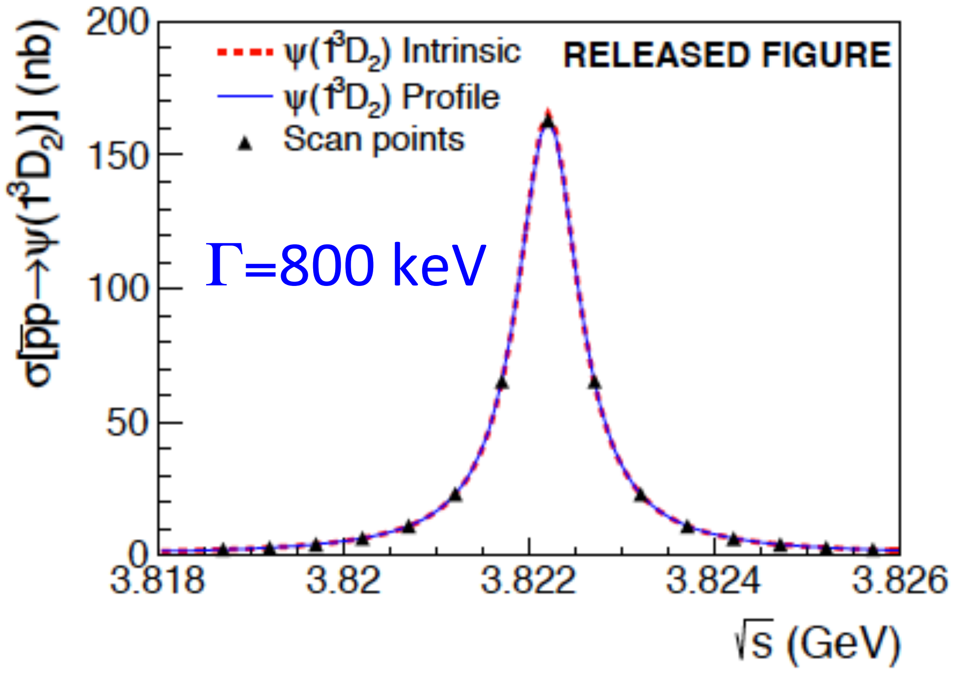
3. Find the peak position → Scan 15 points with 0.5 MeV step: m, m±0.5, m±1.0 , m±1.5 MeV… with 0.5 pb^{-1}/point (~7 days)

4. Add 5 – 7 point for fine scan (100 keV step) to measure m & Γ (spin-parity)

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

Beam Spread





In high resolution mode:

- Beam energy spread is ~50 keV
- Beam spread effect is small compared with $\psi(^3D_2)$ intrinsic width.

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) [even at early stage].

3. More competitive than BESIII, Belle and LHCb.

Thanks (谢谢)!