Bundesministerium
für Bildung
und Forschung

h_c', Y(4260) and $^3F_4$-state Simulations for $\overline{\text{P}}$ANDA

Material from „New Studies of XYZ at $\overline{\text{P}}$ANDA“ Talk @

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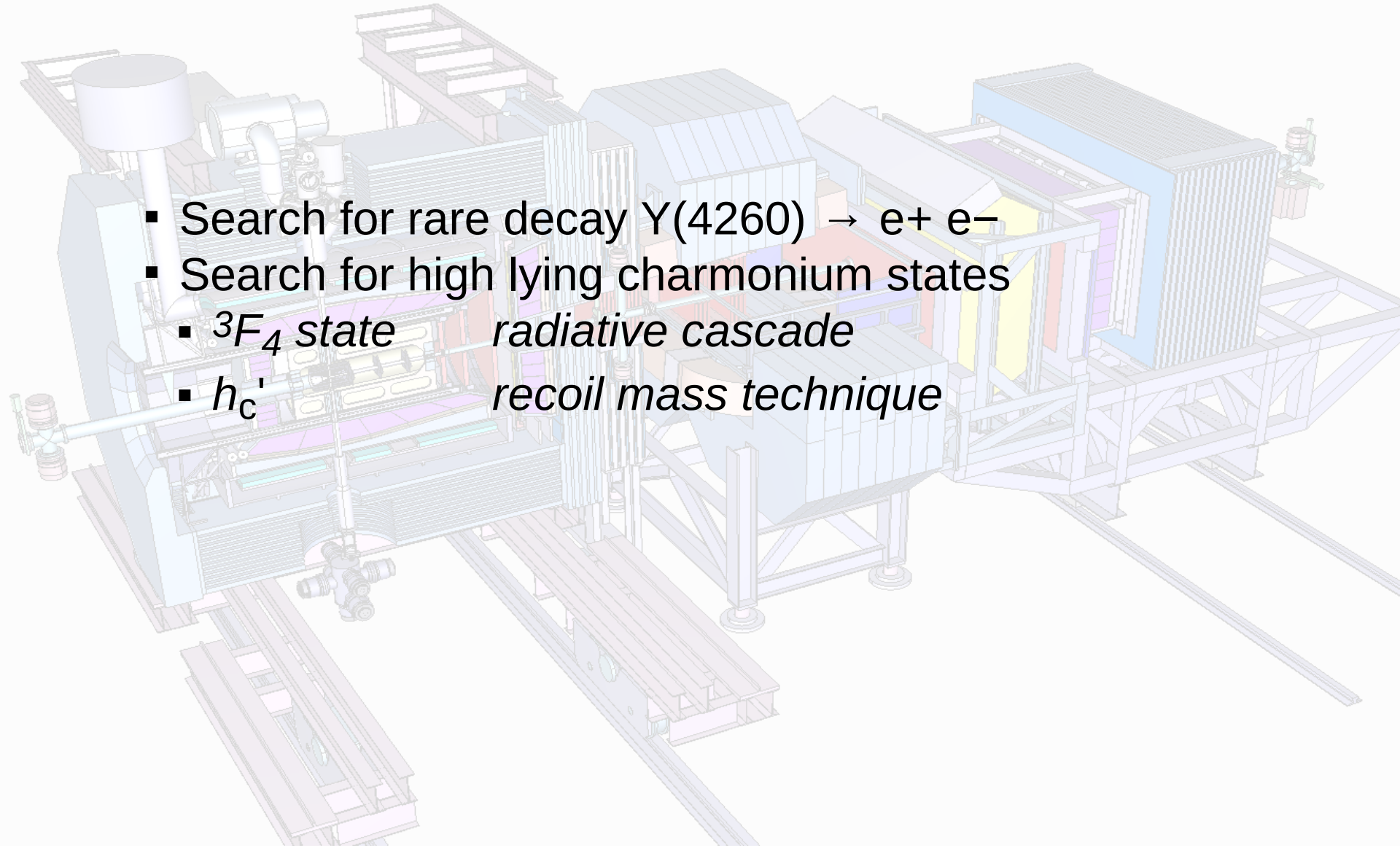
S. Spataro *(U. and INFN Torino)*

$\overline{\text{P}}$ANDA XLVI Collaboration Meeting, Bochum

Outline – New PandaRoot Simulations



- Search for rare decay Y(4260) → e+ e−
- Search for high lying charmonium states
  - $^3F_4$ *state* *radiative cascade*
  - h_c' *recoil mass technique*

Search for Rare Decay Y(4260) → e+ e–

- Y(4260) has been seen in several experiments
- $J^{PC}=1^{--}$
- BaBar measured a partial width of

$$\mathcal{B}(\pi^+\pi^- J/\psi)\Gamma_{e^+e^-} = (7.5 \pm 0.9 \ \pm 0.8)\ \mathrm{eV}$$

(total width Γ~108±12 MeV)

- Y(4260) → e+ e– is factor ≥10^7 suppressed

BaBar, arXiv:0808.1543

Formation Cross Section of Y(4260) at $\overline{\text{P}}$ANDA

- Breit-Wigner: $\sigma \leq 1300$ nb [assuming $\mathcal{B}(\text{Y}(4260) \rightarrow \text{J}/\psi\,\pi^+\pi^-)=0.1$]
  due to high upper limit $\mathcal{B}(\text{Y}(4260) \rightarrow \bar{p}p) / \mathcal{B}(\text{Y}(4260) \rightarrow \text{J}/\psi\pi^+\pi^-) < 0.13$ (90% C.L.)
  BaBar, Phys. Rev. D73(2006)012005

- **Scaling:** $\mathcal{B}(Y(4260) \rightarrow \bar{p}p) = \mathcal{B}(J/\psi \rightarrow \bar{p}p) \times \frac{\Gamma(J/\psi)}{\Gamma(Y(4260)}$

  σ=1.9±0.2 nb → 16,400 events per 1 day in high luminosity mode
  ($\mathcal{L}$=2 x 10^{32} cm^{-2} s^{-1}, planned)

- Comparison to Belle II
  - Y(4260) in *B* decays never observed
  - in ISR ≤30.000 events in 50 ab^{-1} (≥8 years)

- Comparison to BESIII
  σ=62.9±1.9±3.7 pb ($\mathcal{L}$=5.3 x 10^{32} cm^{-2} s^{-1}, achieved)
  Phys. Rev. Lett. 110, 252001 (2013)

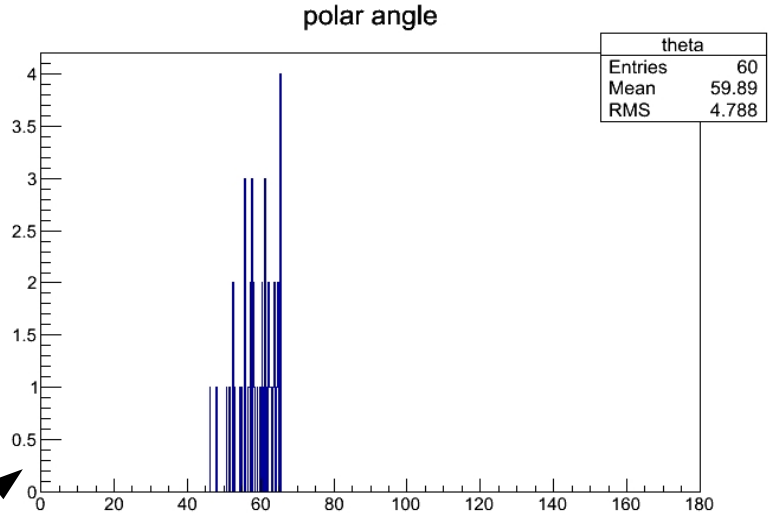
Y(4260) @ $\overline{\text{P}}$ANDA

Efficiency estimate

high >93%

only limited by

- acceptance (beampipe)
- radiative photons (Bremsstrahlung)



Background estimation

- elastic $\bar{p}p \rightarrow \bar{p}p$

  $\sigma = 1.5 \times 10^4$ μb

  - peaking in angular distribution
  - partially identified by $\bar{p}$ annihilation in EMC

- 2-prongs $\bar{p}p \rightarrow \pi^+\pi^-$

  $\sigma = 4.6 \times 10^4$ μb

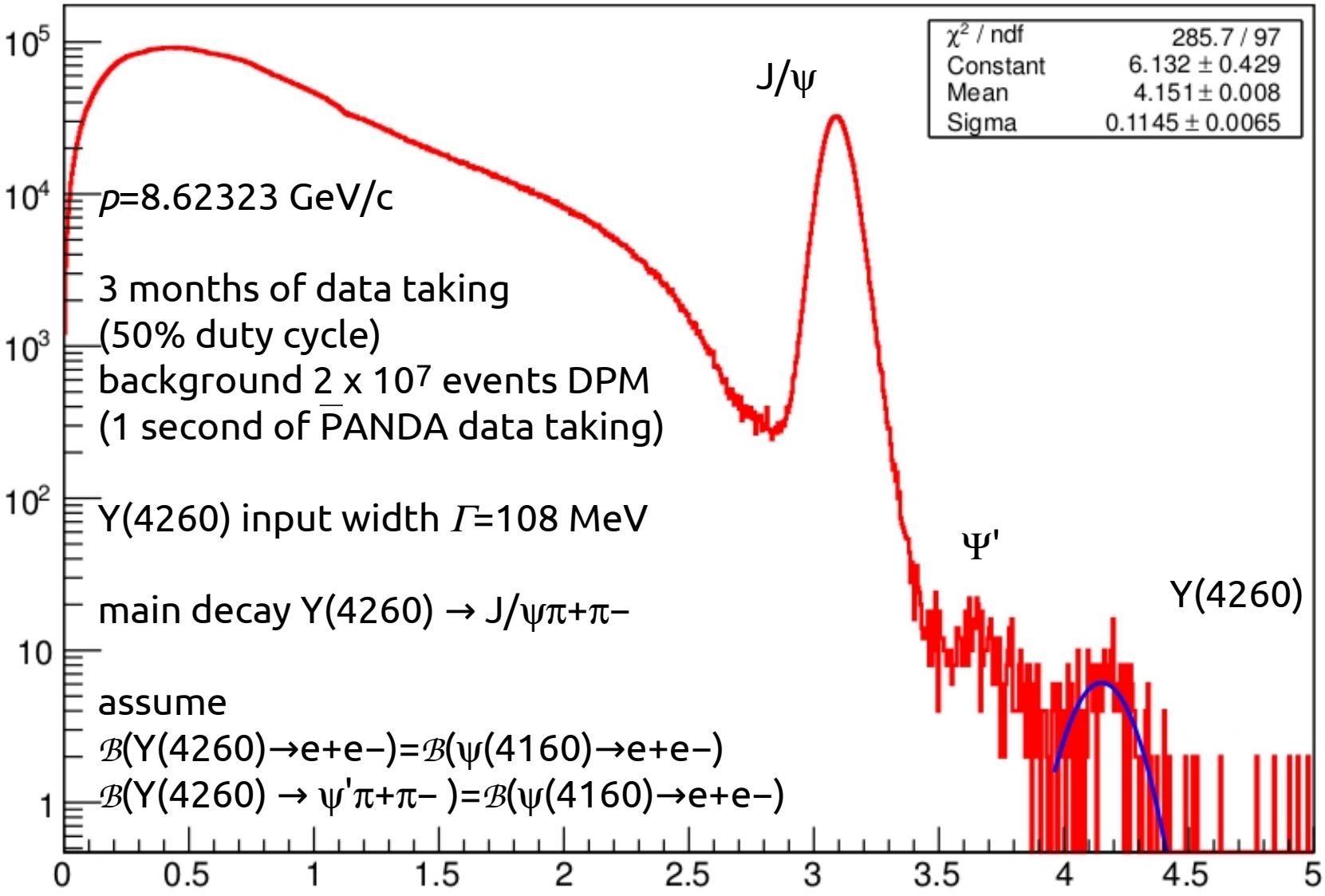
  $\geq 10^6$ suppression by PID achieved

  M. Sudol et al., EPJA 44(2010)373

} suppression $\geq 1.3 \times 10^5$ achieved

There can be interference between signal and background.

Search for Y(4260) → e+e−

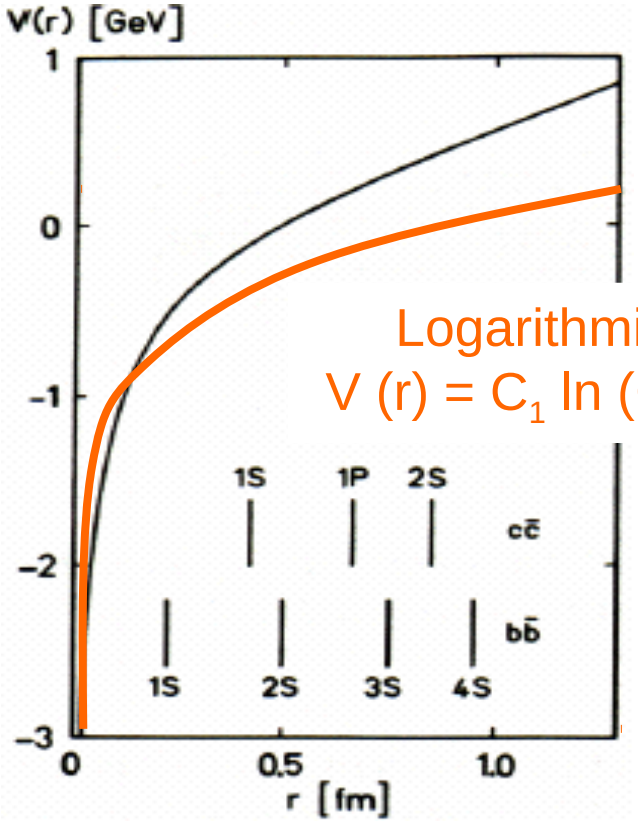


Pandaroot full simulation for Y(4260), Ψ', and part of J/Ψ.

Majority of J/ψ and background with PandaRoot fast simulation

The $Q\overline{Q}$ Potential Model and Search for New States

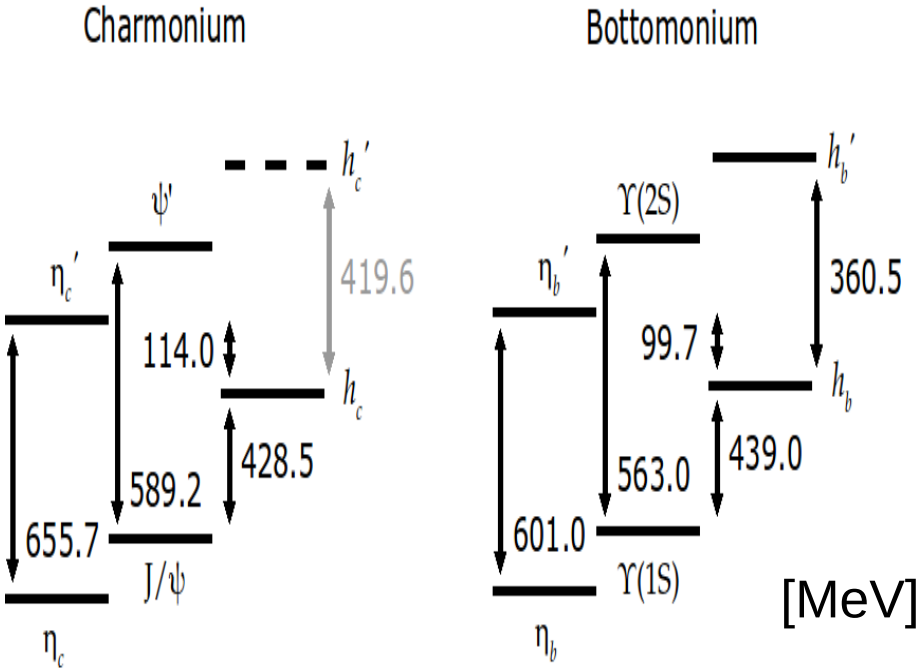
$\Delta E(c\bar{c}) = \Delta E(b\bar{b})$ is strictly true for a logarithmic potential



Logarithmic
$V(r) = C_1 \ln(C_2 r)$

C. Quigg, arXiv:hep-ph/9707493
C. Quigg, J. L. Rosner, Phys. Lett. B71(1977)153
C. Quigg, J. L. Rosner, H. B. Thacker, Phys. Rev. D21(1980) 234
C. Quigg, J. L. Rosner, Phys. Rev. D23(1981)2625

Search for Additional States



Test of flavour independence of $Q\bar{Q}$ Potential
→ Are the level spacings the same?

Search for 2 new states (yet unobserved)

2 $^1P_1$ state (h_c')

partner of h_b' (already observed by Belle)

Prediction from potential model

m=3934-3956 MeV

Prediction from flavour independence („logarithmic scaling“)

m=3887 MeV

disadvantages:

- predicted width Γ=87 MeV (decay to $\overline{D}D^*$ open)
- coupling to threshold(s)

1 $^3F_4$ state

m=4021-4095 MeV

Decay blocked by angular barrier (J^{PC}=4++)

→ narrow width Γ=8.3 MeV predicted

no bottomonium partner observed yet

no coupling to threshold(s)

Mass predictions by Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026

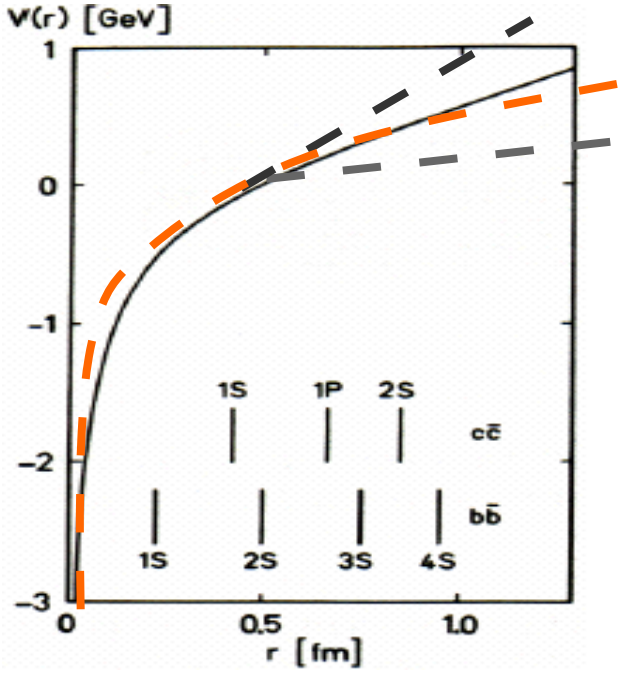
$^3F_4$

Narrow $J^{PC}=4^{++}$ state with $n=0$, $L=3$, $S=1$, $J=4$
Predicted width $\Gamma \sim 8.3$ MeV

Decay of $^3F_4$ blocked
by angular barrier
(suppressed by $2L+1$ with $L=3$)

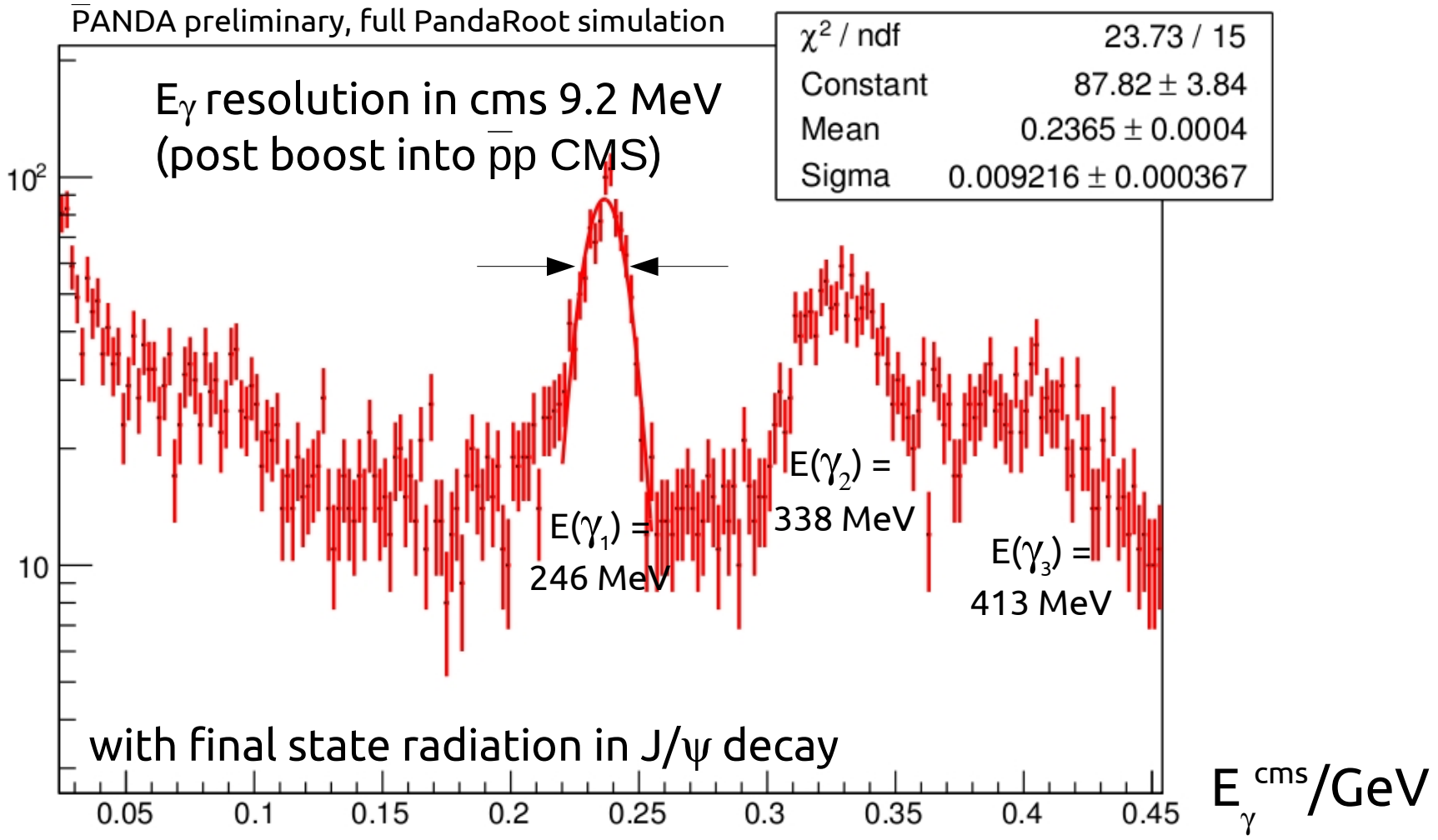
→ suppressed in B decays
→ suppressed in radiative decays
→ production in $\bar{p}p$ possible

Appropriate test
for long-range
potential



Radiative cascade
(3-step)

$1\,^3F_4$ $J^{PC}=4^{++}$ 4095 MeV Γ=8.3 MeV E_γ=246 MeV
$1\,^3D_3$ $J^{PC}=3^{--}$ 3849 MeV Γ=0.5 MeV E_γ=338 MeV
χ_{c2} $J^{PC}=2^{++}$ 3556 MeV Γ=1.97 MeV E_γ=413 MeV
J/ψ $J^{PC}=1^{--}$



1. $\bar{p}p \rightarrow (1\ ^3F_4)$
2. $(1\ ^3F_4) \rightarrow (1\ ^3D_3)\ \gamma_1$
3. $(1\ ^3D_3) \rightarrow \chi_{c2}\ \gamma_2$
4. $\chi_{c2} \rightarrow J/\psi\ \gamma_3$
5. $J/\psi \rightarrow e+\ e-$ / $\mu+\ \mu-$

Search for $^3F_4$ at $\bar{P}$ANDA

- Cross section:
  Assume $\sigma(p\bar{p} \rightarrow {}^3F_4) = 10$ nb

- Branching fraction from $\psi' \rightarrow \chi_{c0}\gamma$ $\mathcal{B} = 9.84 \pm 0.31\%$ [PDG]
  → Assume $\mathcal{B} = 10\%$ for all 3 transitions

- High luminosity mode: 8.64 pb^{-1} per 1 day

- Background:
  DPM (dual parton model)
  → Photons from light hadron decays
  Very clean signature of [3 photons with $E_{CMS} > 150$ MeV + 1 J/ψ]
  → Suppression of 1.2×10^6 achieved

- Estimate: 14 days of data taking (50% duty factor)

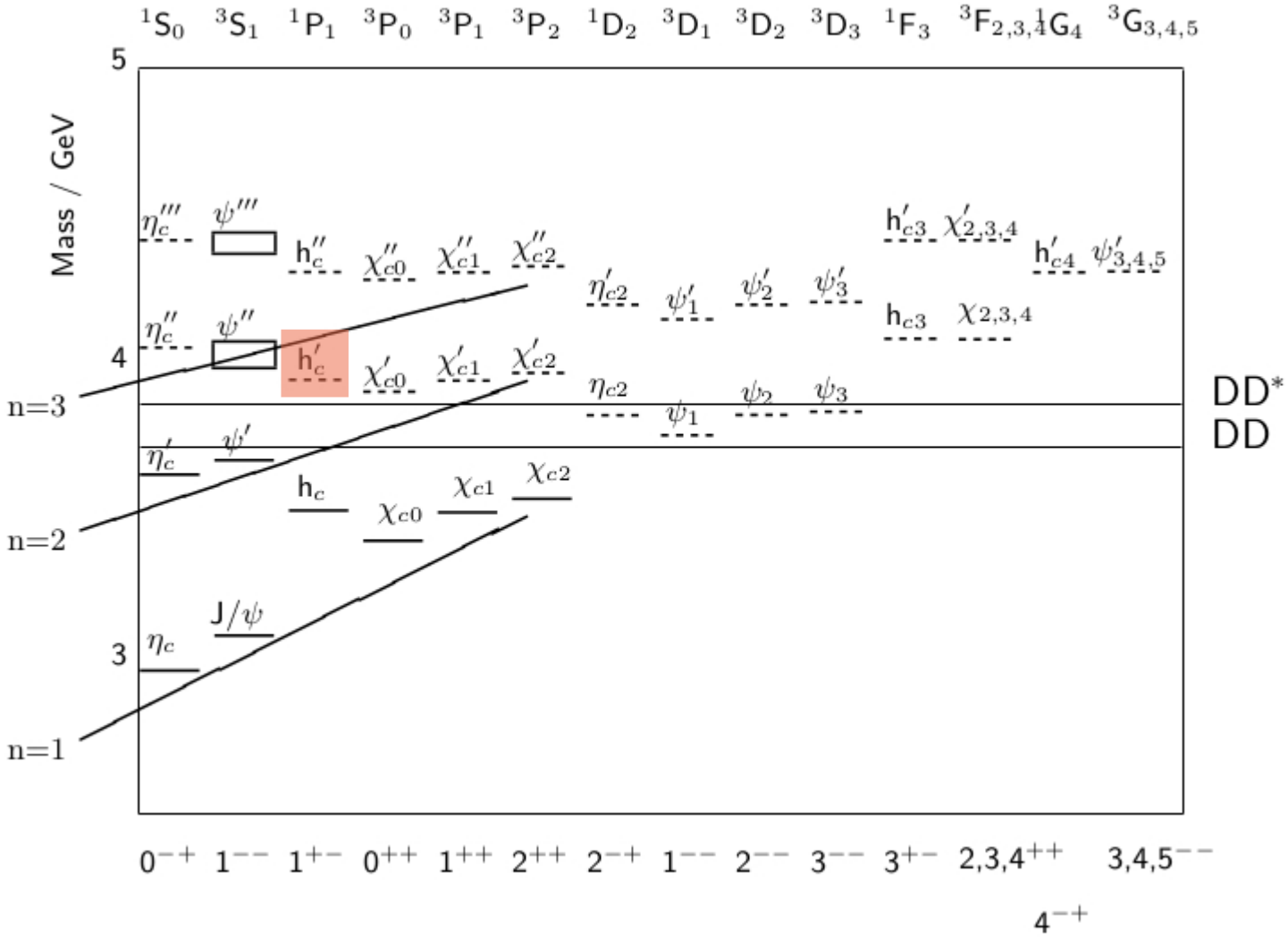
Update to talk by S. Reiter, PANDA CM 2013/06 @ GSI, Darmstadt

h_c'

$J^{PC}=1+-$ state with $n=2$, $L=1$, $J=1$
predicted mass m~3.95 GeV, width Γ~87 MeV

Mass & width prediction by Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026

$h_c'(2^1P_1)$ is the last unknown singlet $c\bar{c}$-state below 4 GeV and L<2.

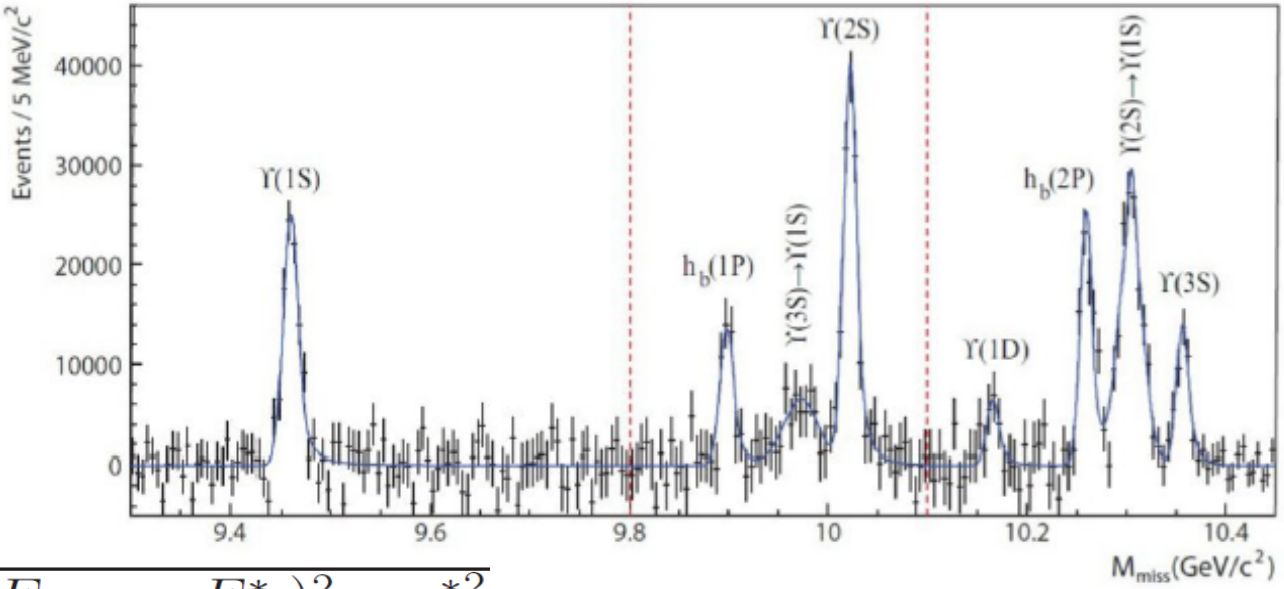


Why $\bar{P}$ANDA?

- similar precise states of Bottomonium were already found with recoil mass method at Belle
- h_c', h_c suppressed at B-Factories:

$$0^{-+} \to 0^{-+}1^{+-}(B \to K\ h_c')$$

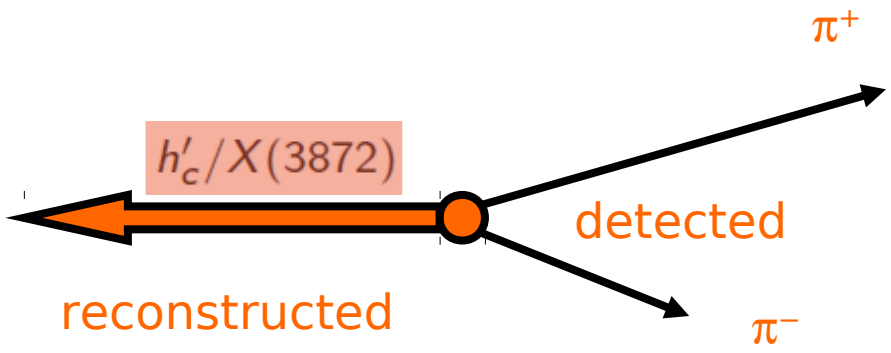
  is forbidden in factorisation limit
- h_c', h_c suppressed at BESIII:
  in 1^{--} decays, 1^{+-} can only be produced by $1^{--} \to 1^{+-}\ \pi^0$, but this is isospin-violating (BR $\sim 10^{-3}$ or less)



$$M_{\mathrm{miss}}(X) = \sqrt{(E_{\mathrm{c.m.}} - E_X^*)^2 - p_X^{*2}}$$

Simulation

- Full PandaRoot simulation with release apr13 and external packages sep12
- Barrel: SttMvdGemGenTrack; Forward: FtsIdealGenTrack
- Momentum of $\bar{p}$ beam: 15 GeV/c
- $p\bar{p} \to h_c' + \pi^+ + \pi^-$
- $h_c' \to D^0 + \bar{D}^{0*}$
- $p\bar{p} \to X(3872) + \pi^+ + \pi^-$
- $X(3872) \to D^0 + \bar{D}^{0*}$
- $D^0 \to K^- \pi^+$
- $\bar{D}^{0*} \to$ anything

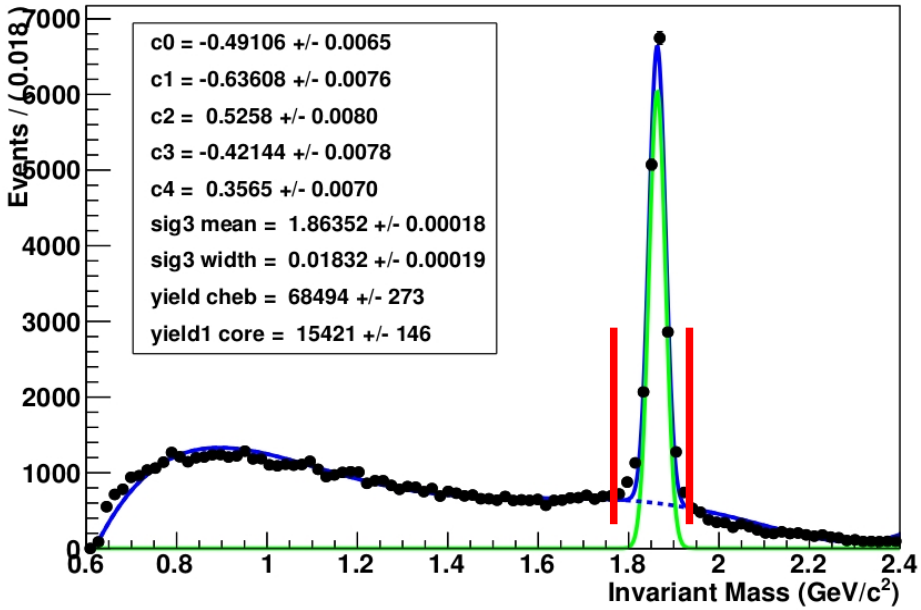


Background Rejection for h_c'

	Cross section	Reconstruction efficiency
Signal	4.5 nb	8.3%
Background	43 mb	1.6×10^{-5}

Signal cross section is required to achieve $S/\sqrt{(S+B)} \geq 10$ in 6 weeks

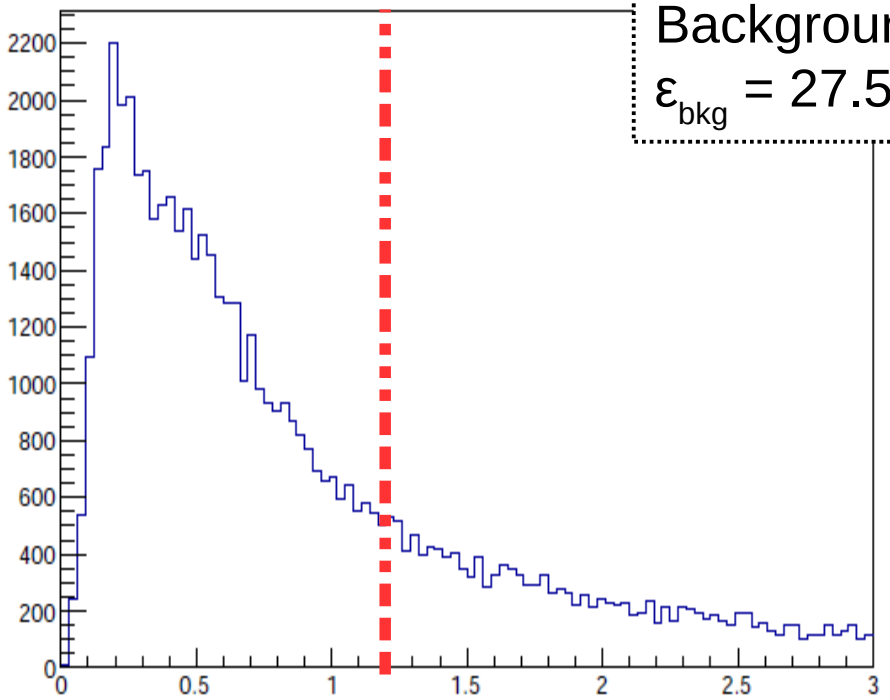
→ Background suppression:
- Realistic PID
- π+ K– invariant mass
- Cut on D^0 mass range
- $p_{lab}(\pi\pm)$>1.2 GeV
- vertex cut
  ±0.1 cm (z)

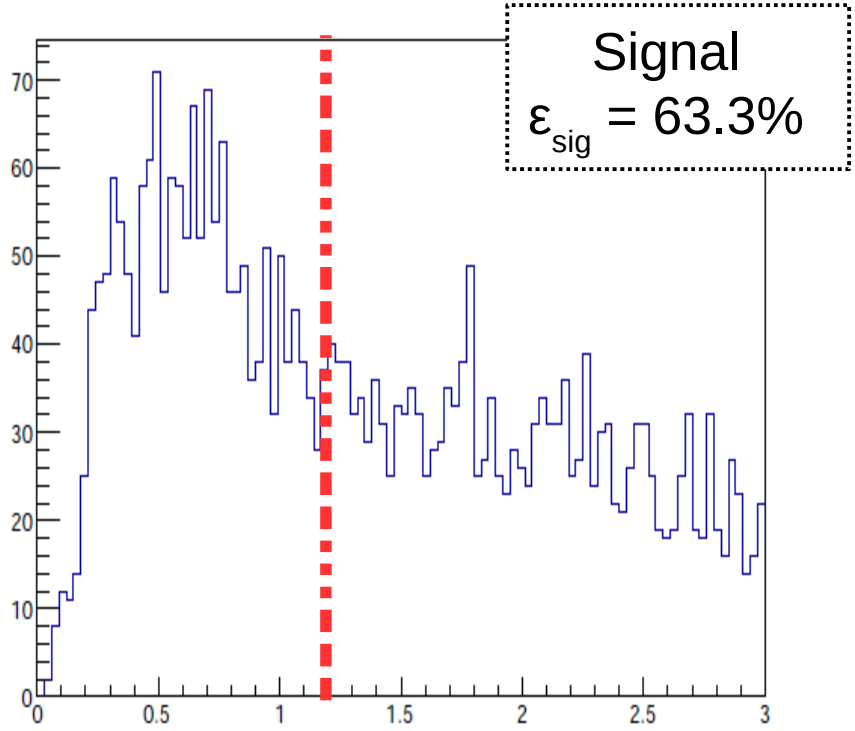


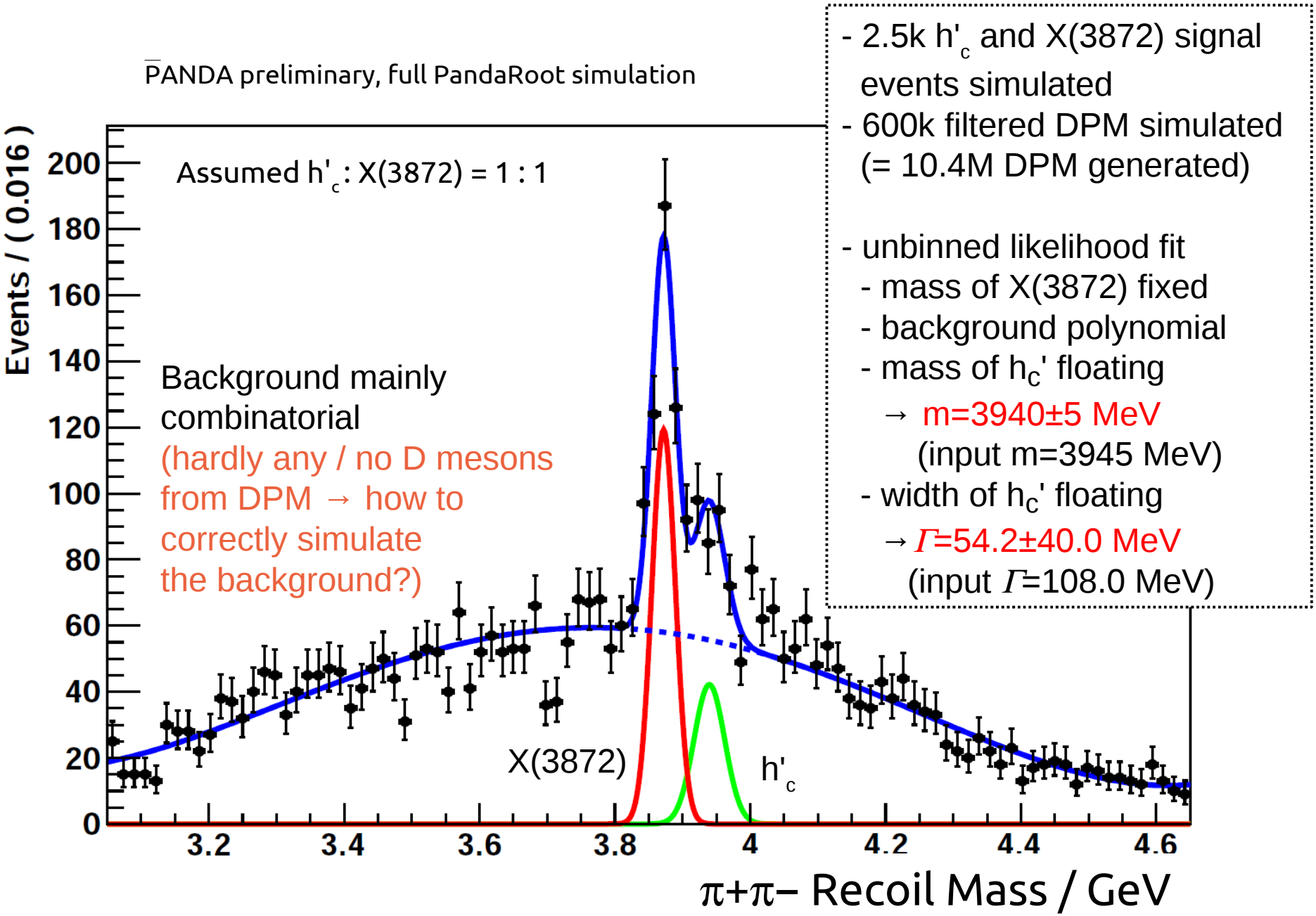
$p_{lab}(\pi\pm) > 1.2$ GeV Cut

Efficiencies for p_{lab} cut only

- Cut on invariant mass already applied
- Signal are $\pi\pm$ from $p\bar{p}$ interaction
- Background from DPM generator
- Cut value determined by maximizing $(1-\varepsilon_{bkg})/(1-\varepsilon_{sig})$







- 2.5k h'_c and X(3872) signal events simulated
- 600k filtered DPM simulated (= 10.4M DPM generated)

- unbinned likelihood fit
  - mass of X(3872) fixed
  - background polynomial
  - mass of h_c' floating
    → m=3940±5 MeV
    (input m=3945 MeV)
  - width of h_c' floating
    → Γ=54.2±40.0 MeV
    (input Γ=108.0 MeV)

Summary

- Search for rare decay
- Search for yet unobserved states
  - high mass (for charmonium-like states)
  - high J^{PC} (suppressed in B-decays and e^+e^-)
    - Recoil mass
    - Radiative cascade

Outlook

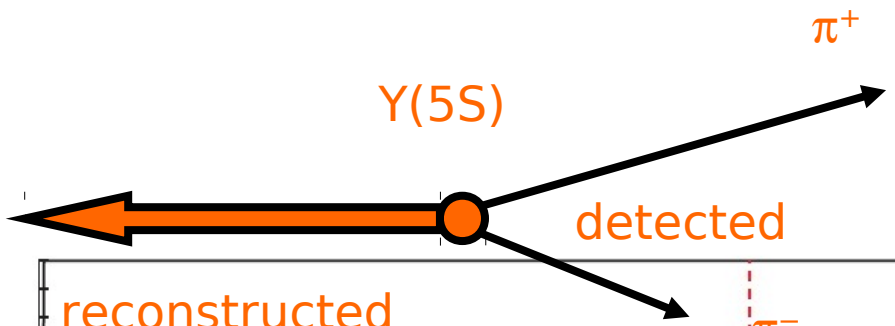
- Plots for 1 week data + background
- Study best p_{beam} for h'_c study

Thank you.

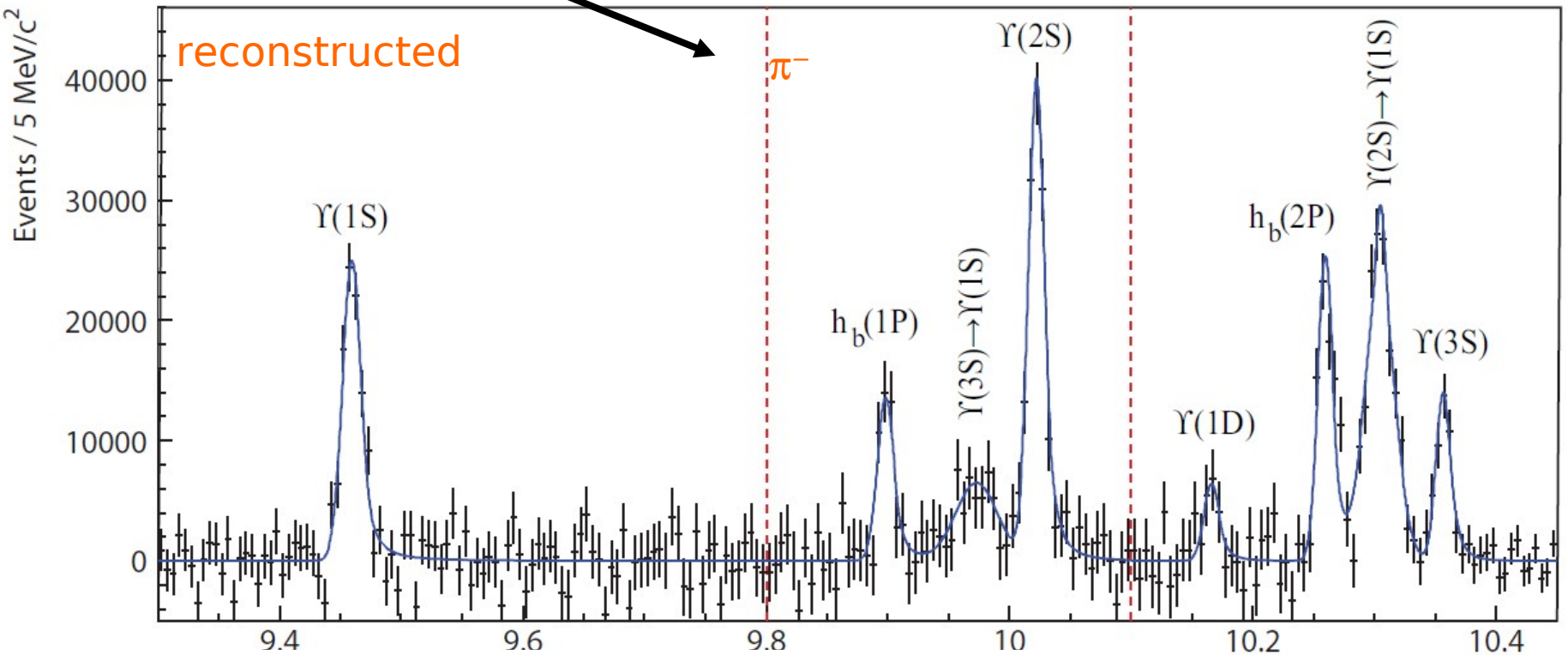
BACKUP

Technique of $\pi^+ \pi^-$ recoil („missing“) mass

pioneered by CLEO-c for h_c, Phys. Rev. Lett.107(2011)041803



Belle, 121.4 fb^{-1}
Phys. Rev. Lett 108(2011)032001
arXiv:1103.3419



$$M_{\mathrm{miss}}(X) = \sqrt{(E_{\mathrm{c.m.}} - E_X^*)^2 - p_X^{*2}}$$

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

- Charmonium(-like) states with high masses

  $p_{beam} \leq 15$ GeV/c → $m_{c\bar{c}} \leq 5.5$ GeV

- Charmonium(-like) states with high quantum numbers

  up to L = 15

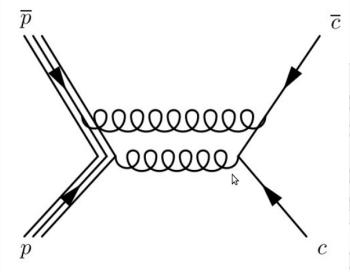
- High statistics

  $\sigma_{\bar{p}p \to c\bar{c}} = 50$ nb → 4.3 x 10^5 events per 1 day (high luminosity mode)

- Good √s resolution

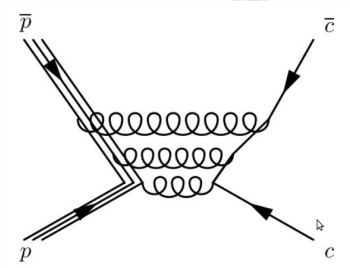
  FWHM = 160 keV @ $m_{c\bar{c}} = 4$ GeV (high resolution mode)

- Formation of states with any (non-exotic) quantum number



2 gluons: 0^{-+}, 0^{++}, 2^{++}, ...

3 gluons: 1^{--}, 1^{+-}, ...

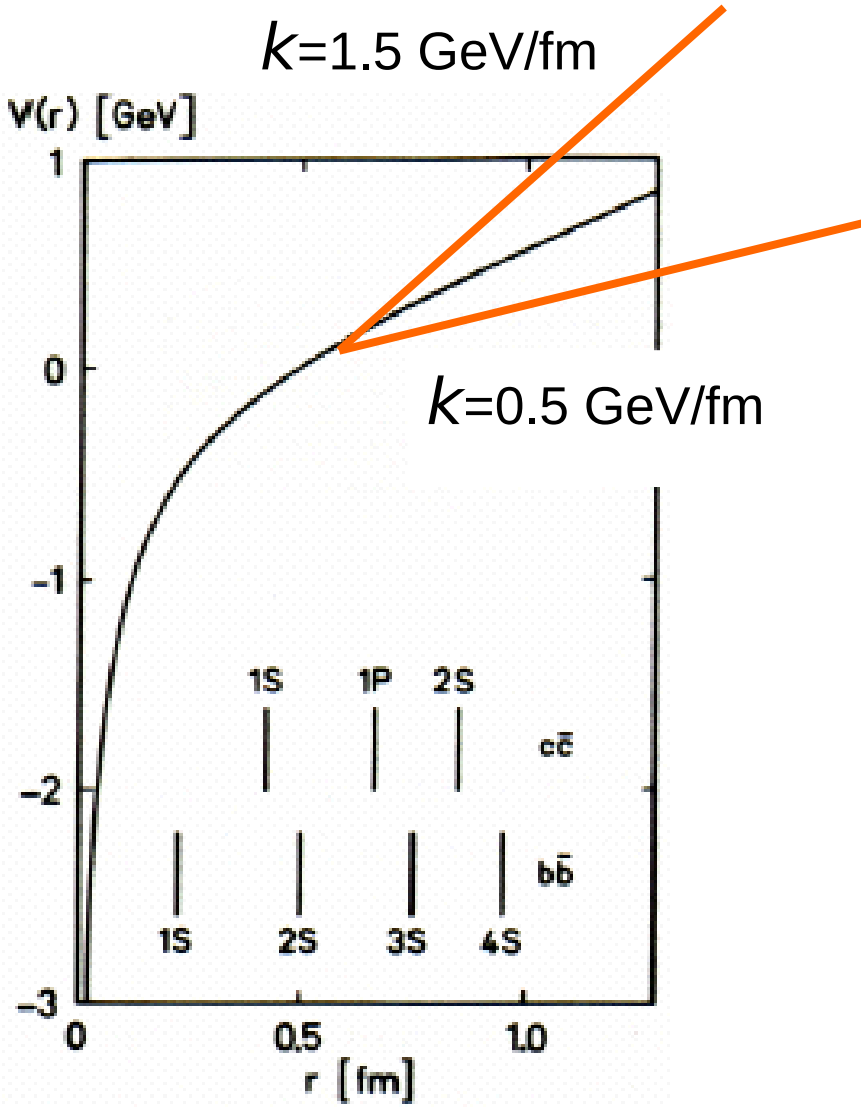


Potential Model

linear confinement term

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + \frac{32\pi\alpha_s}{9m_c^2}\delta_r \vec{S}_c\vec{S}_{\bar{c}} + \frac{1}{m_c^2}\left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{L}\vec{S} + \frac{1}{m_c^2}\frac{4\alpha_s}{r^3}\left(\frac{3\vec{S}_c\vec{r}\cdot\vec{S}_{\bar{c}}\vec{r}}{r^2} - \vec{S}_c\vec{S}_{\bar{c}}\right)$$

E. Eichten, K. Gottfried, T. Kinoshita,
K. D. Lane, T.-M. Yan,
Phys. Rev. D17(1978)3090



$\Delta E(c\bar{c}) = \Delta E(b\bar{b})$ is mathematically only strictly true for a logarithmic potential

C. Quigg, arXiv:hep-ph/9707493
C. Quigg, J. L. Rosner,
Phys. Lett. B71(1977)153
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Phys. Rev. D21(1980) 234
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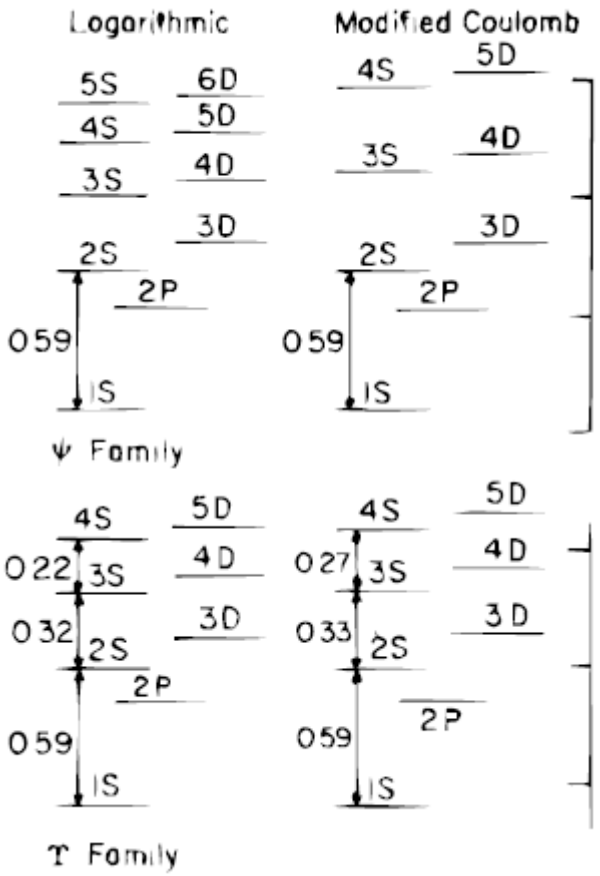
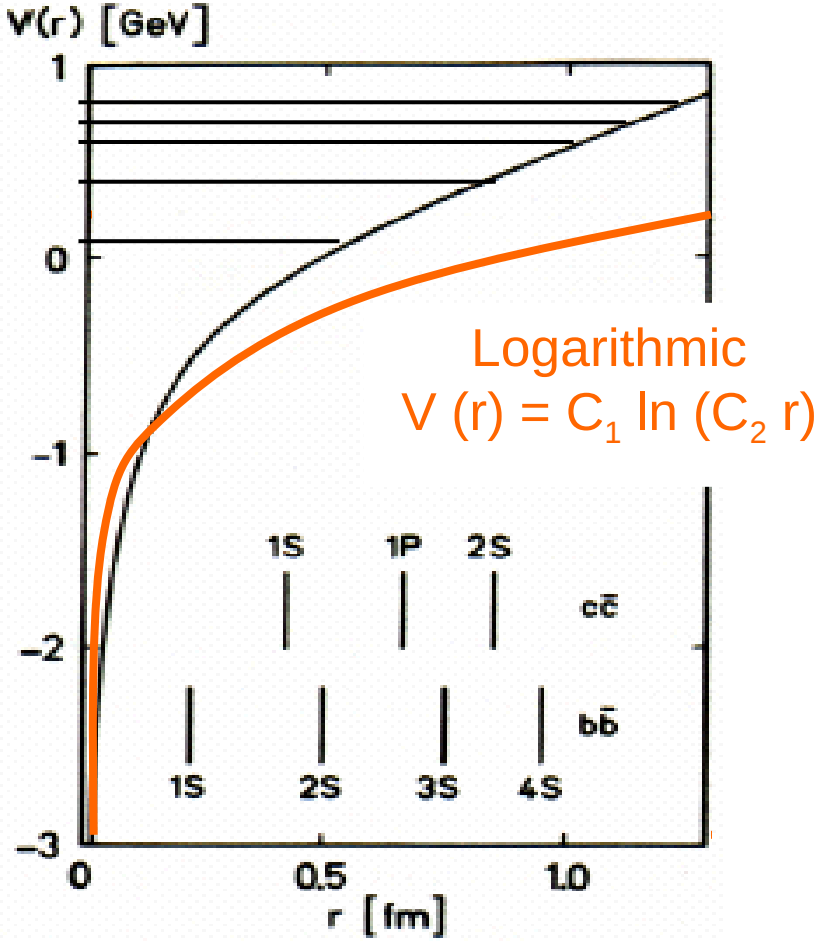
Phys. Rev. D23(1981)2625





Logarithmic
$V(r) = C_1 \ln(C_2 r)$

EvtGen Decay File for Search for $^3F_4$ at $\overline{\text{P}}$ANDA

```
Decay pbarpSystem
1.0 psi(4415) PHSP;
Enddecay

Decay psi(4415)
1.0000 psi(4160) gamma VVP 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0;
Enddecay

Decay psi(4160)
1.0000 chi_c2 gamma VVP 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0;
Enddecay

Decay chi_c2
1.0000 J/psi gamma VVP 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0;
Enddecay

Decay J/psi
0.5 e+ e- VLL;
0.5 mu+ mu- VLL;
Enddecay

End
```