Exploring the emergence of mass through XYZ photo- and electro- production

Adam Szczepaniak, August 2020, AMBER@CERN Meeting

JPAC

“XYZ spectroscopy at electron-hadron facilities: Exclusive processes”

JPAC Collaboration M. Albaladejo et al., arXiv:2008.01001

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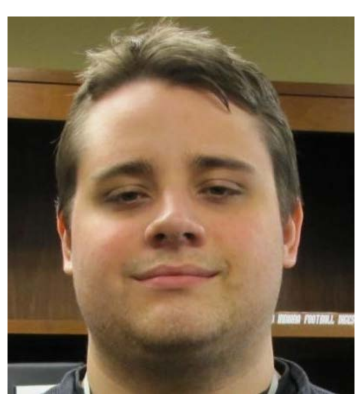
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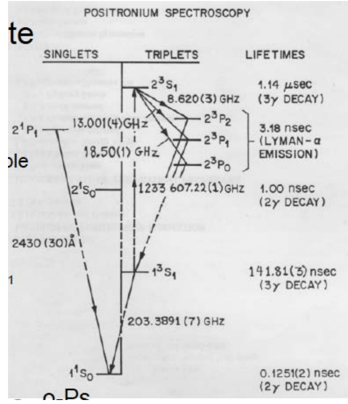
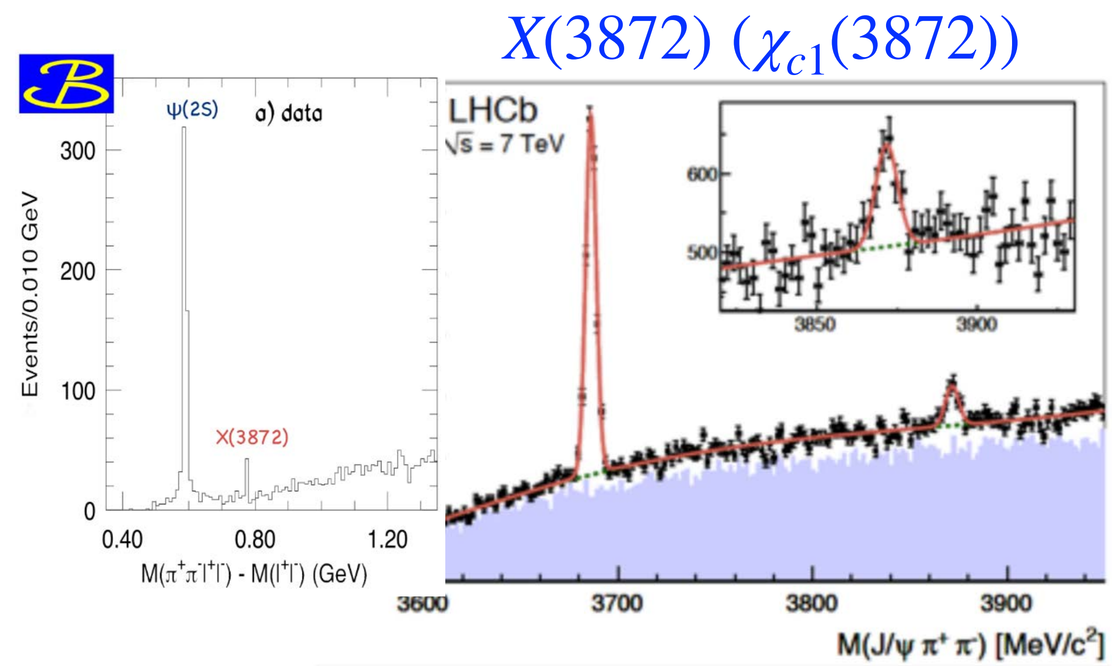
The J/ψ and its excitations were expected to follow the positronium-like spectrum

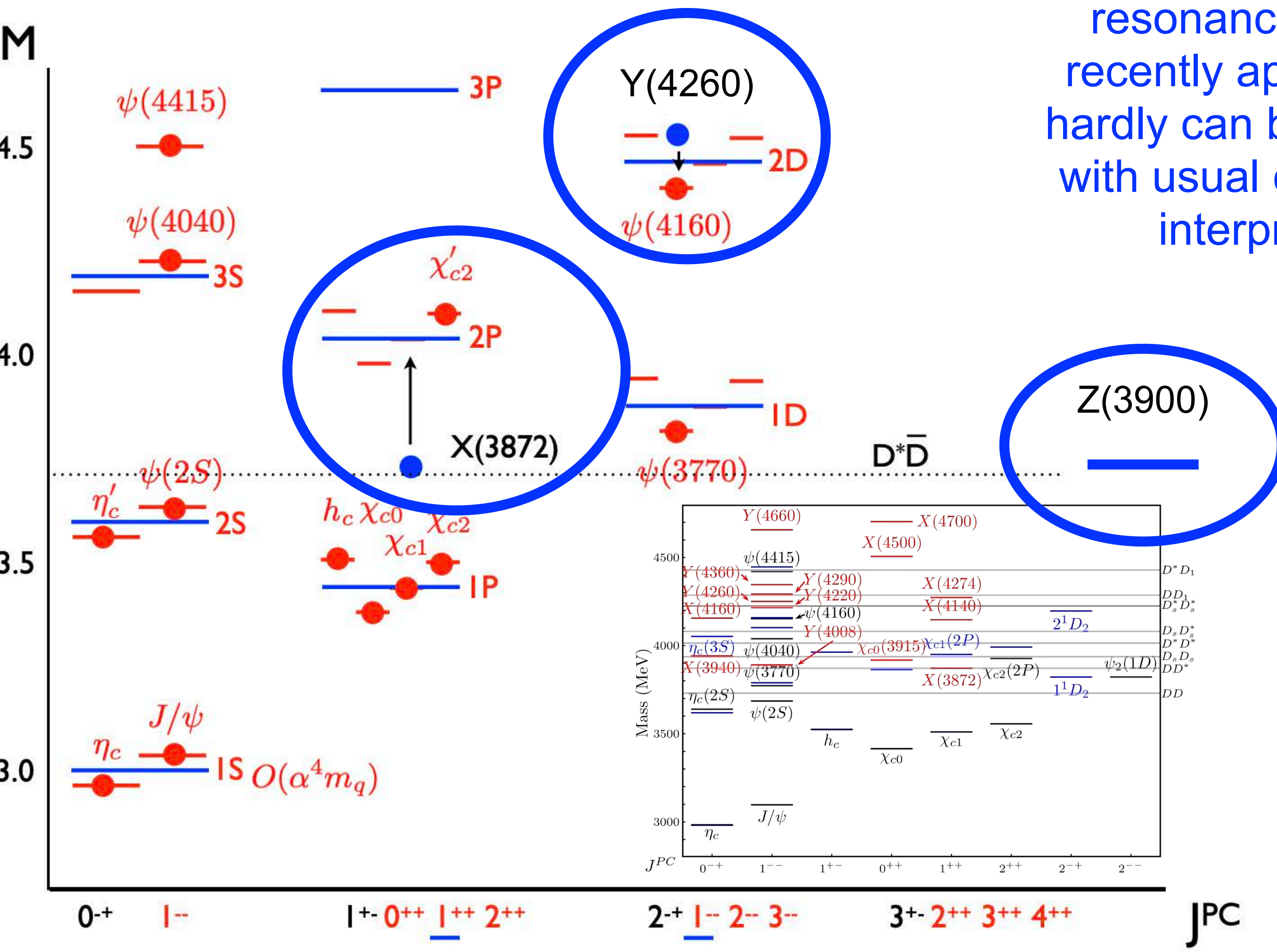


$$V(r) = -\frac{C_F \alpha_s}{r} + \sigma r$$

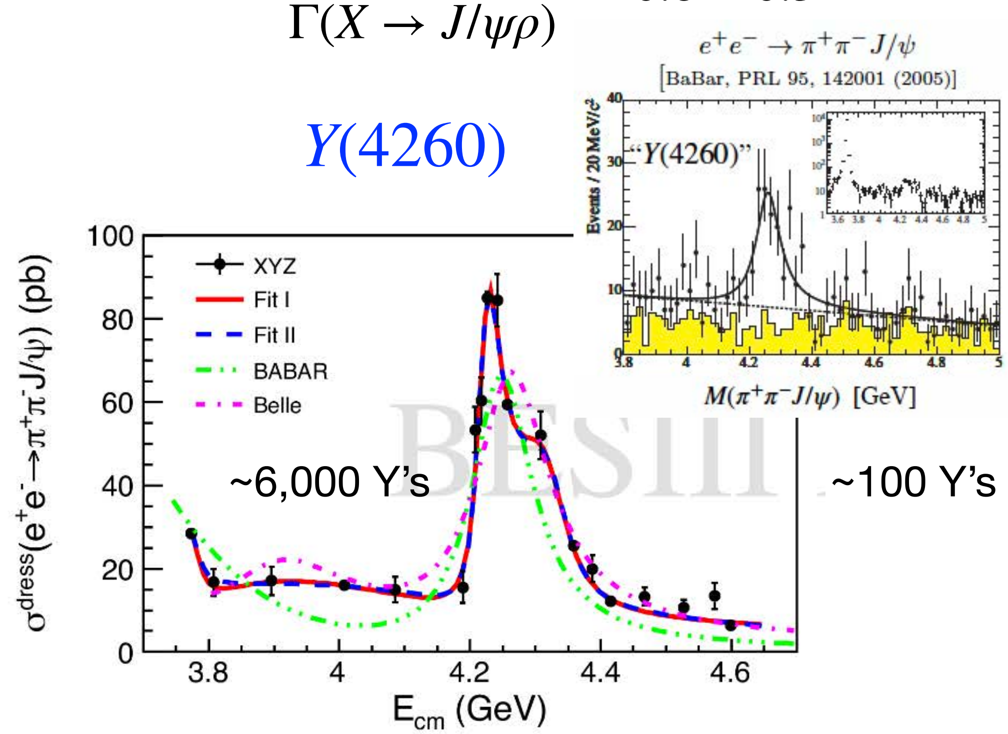


- Very close to $D\bar{D}^*$ threshold
- Isospin violation too big

$$\frac{\Gamma(X \to J/\psi\omega)}{\Gamma(X \to J/\psi\rho)} \sim 0.8 \pm 0.3$$



A few dozen resonances(?) have recently appeared that hardly can be reconciled with usual charmonium interpretation



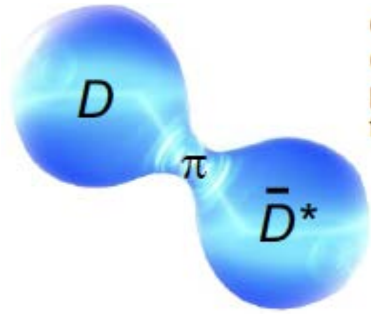
- Not seen decaying into OZI-favored open charm pairs, but seen J/ψ ππ

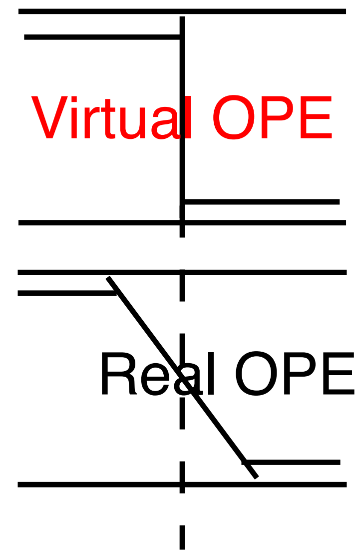
1.Residual interactions (molecules?)

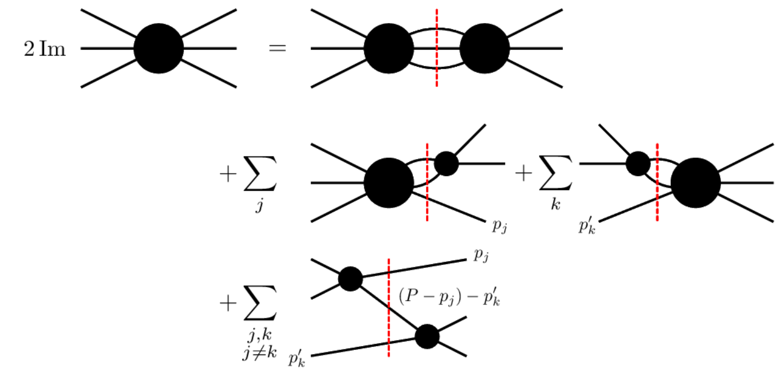
Is X(3872) a molecule ?

$$M_{X(3872)} - M_{D^0} - M_{\bar{D}^{*0}}$$

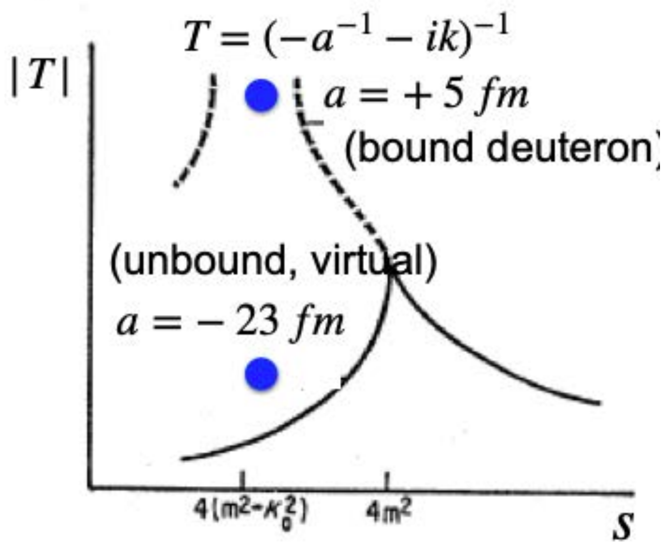
$$= -0.01 \pm 0.14 MeV$$



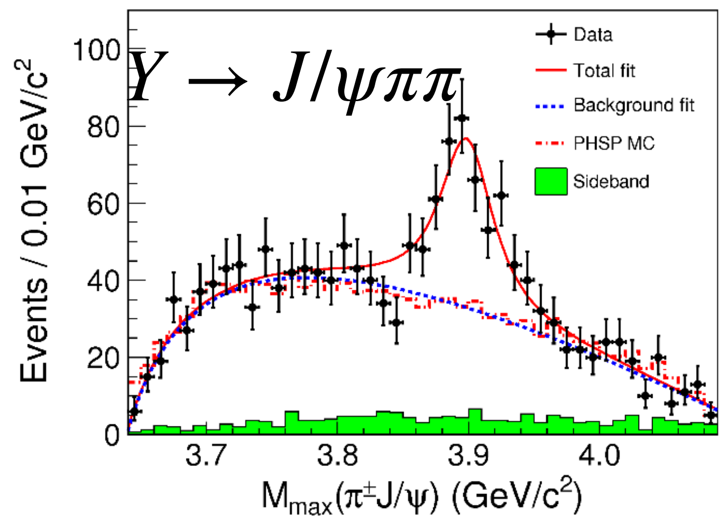


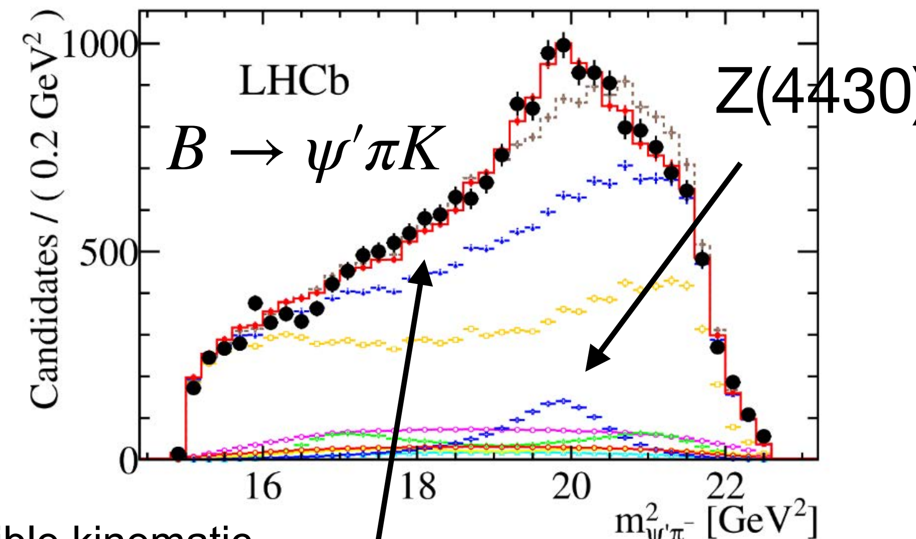


[JPAC, EPJ,C79('19),56]
[JPAC, PR,D100('19),034508]
[JPAC, JHEP08('19),080]



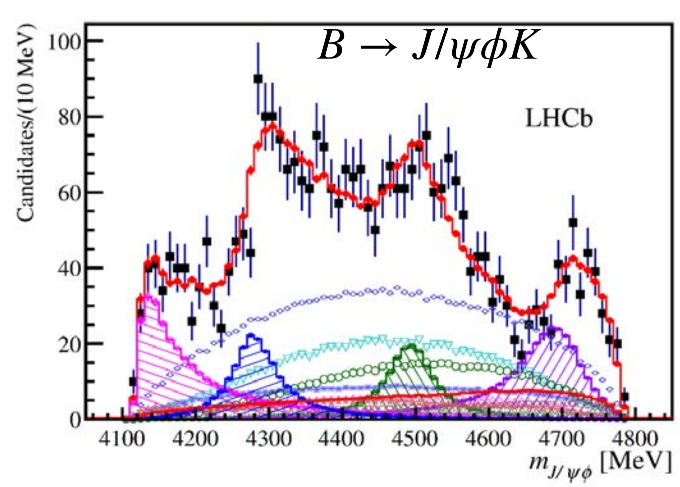
2. Z's A kinematic effect ?

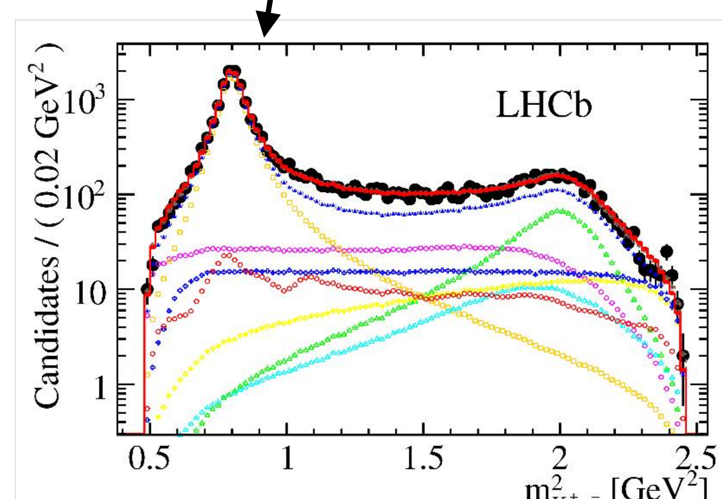




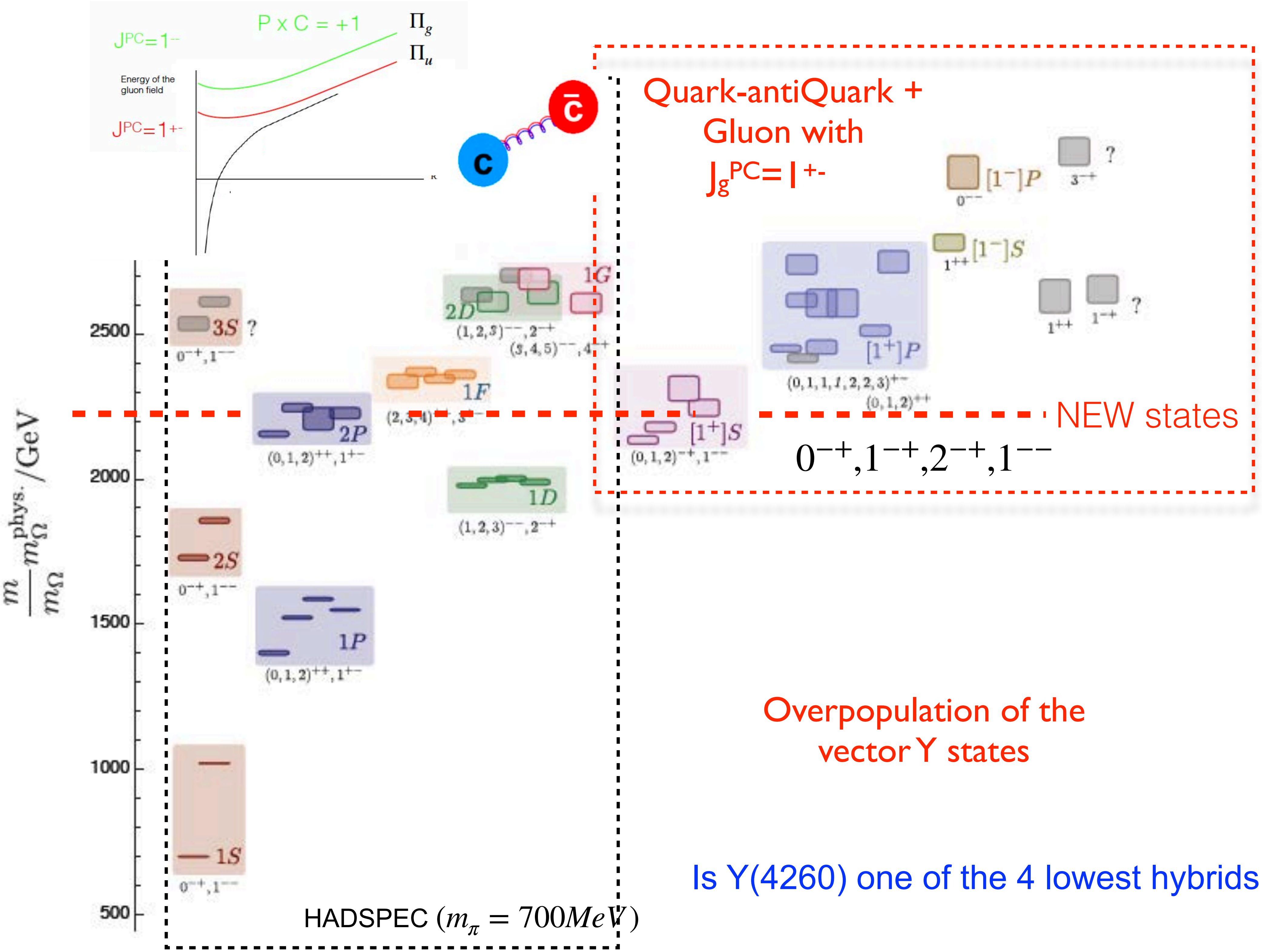
Possible kinematic effects from K* decays

Complicated final states (interactions), require amplitude analyses (care of reflections kinematical effects)





3.Multiquarks : QCD strings and its excitations: hybrids, tetraquarks, pentaquarks

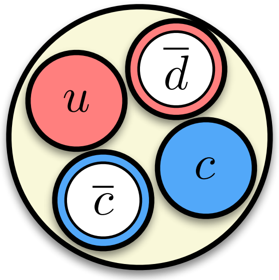


Muti quark states needed in order to “fill in" gaps in arguments based on duality (large-N_c, QCD strings)

G.Rossi G. Veneziano Phys. Rep.1982

Overpopulation of the vector Y states

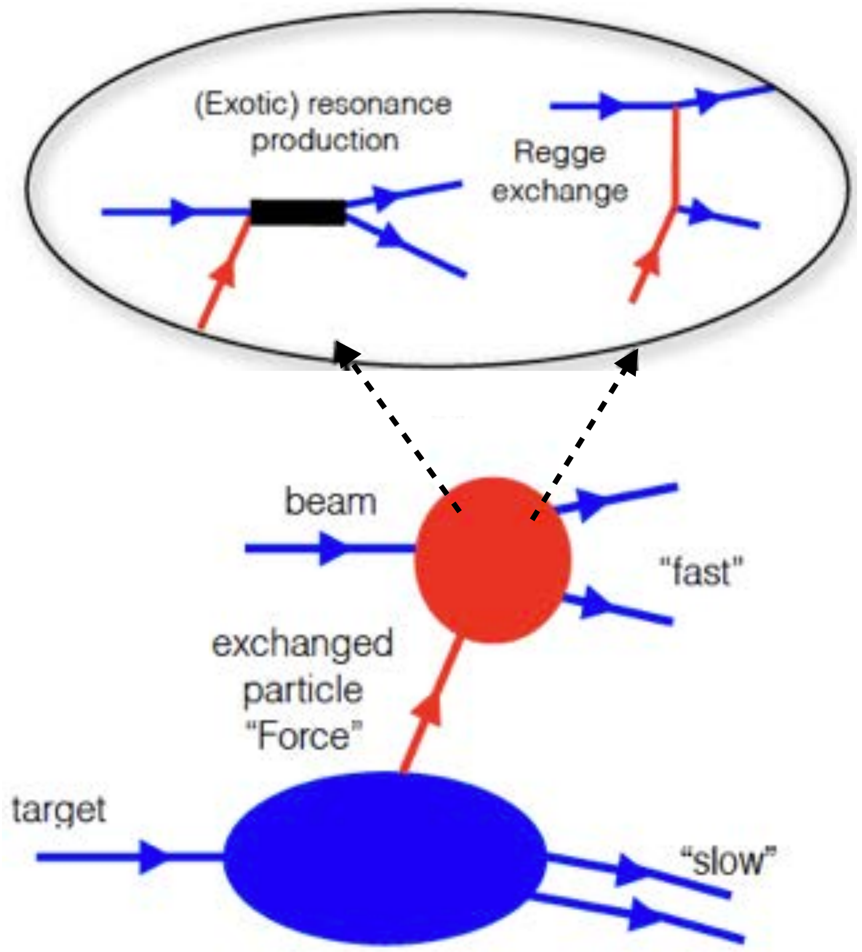
Is Y(4260) one of the 4 lowest hybrids

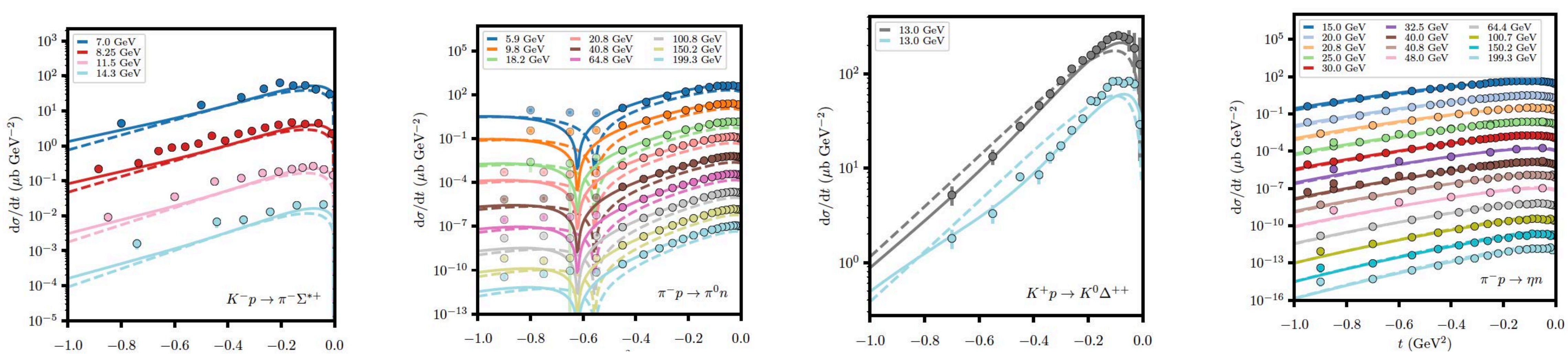


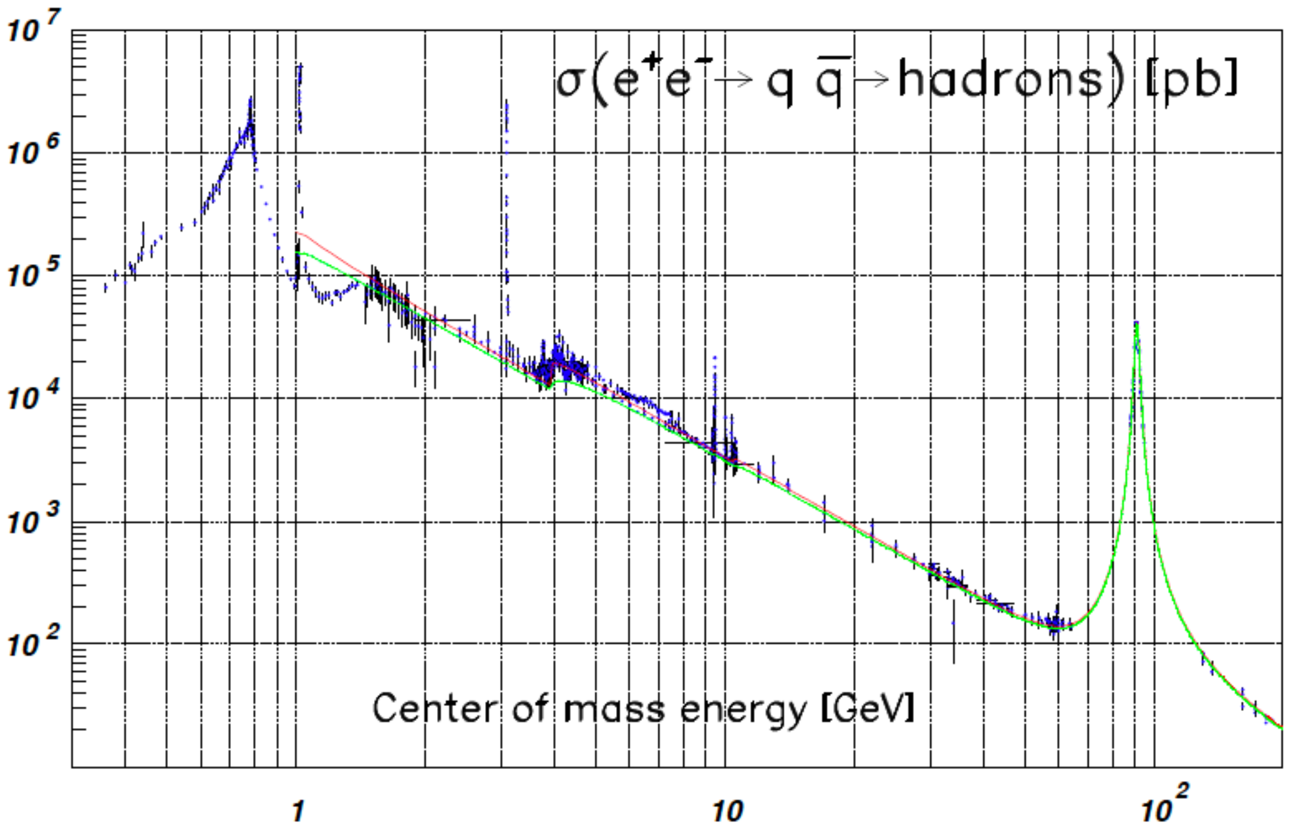
Advantage of photo- electro-production

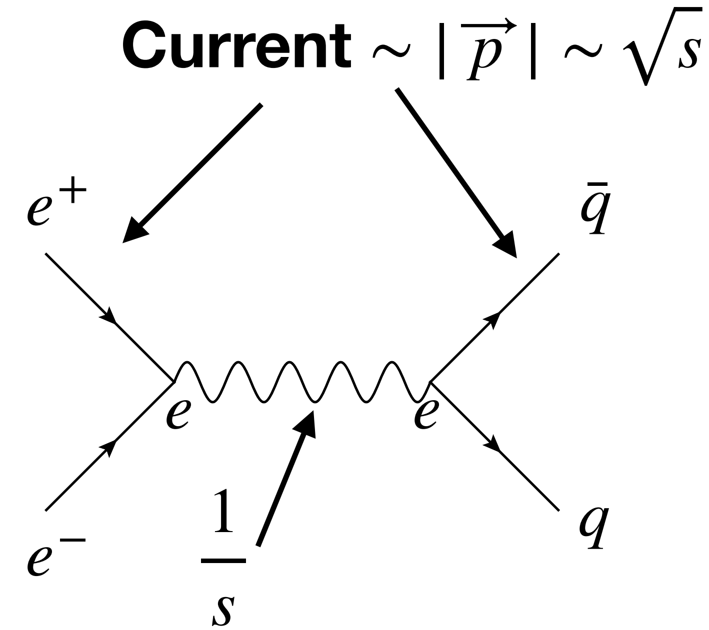
- XYZ’s and P’s can be directly produced from beam (meson) or target fragmentation

- Based on a global analysis to establishes dominance of leading Regge poles, we think we understand production mechanisms.









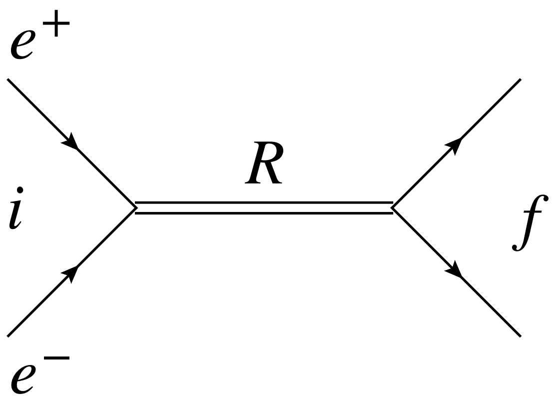
$$A \sim \sqrt{s} \times e \times \frac{1}{s} \times e \times \sqrt{s} \sim \alpha_{em}$$

$$\sigma_{tot} = P.S. \times |A|^2$$

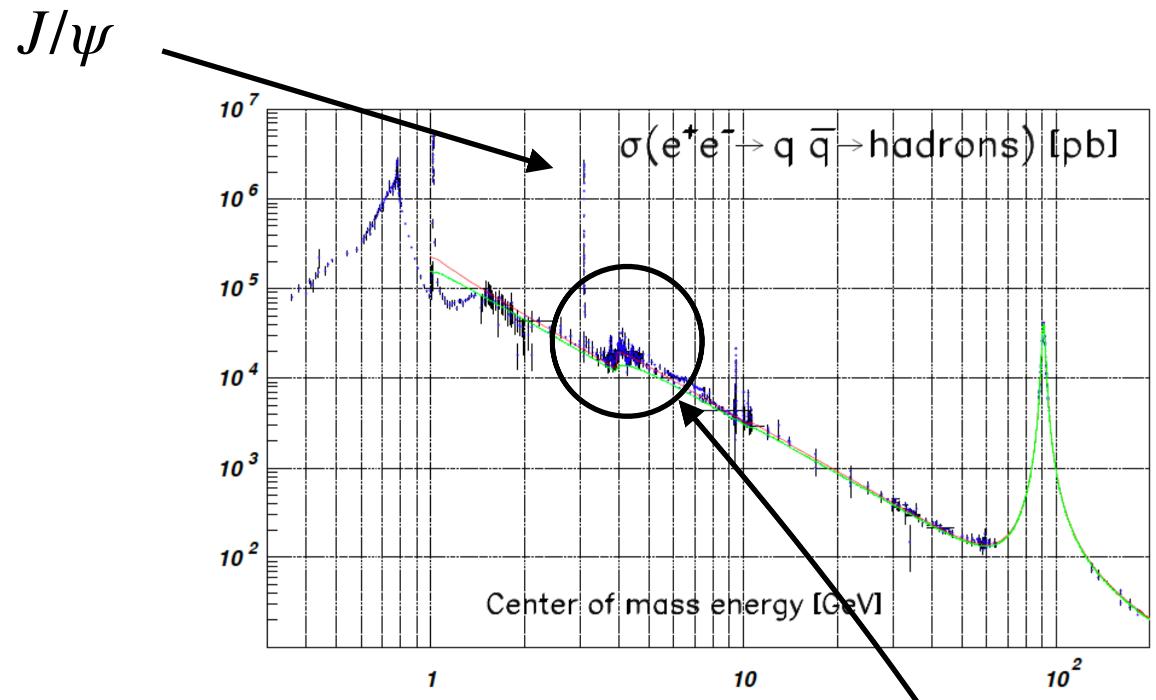
$$\sigma_{tot} = \frac{4\pi\alpha_{em}^2}{s} = \frac{26\,nb}{(s/10GeV^2))}$$

- nb cross sections are not a problem !

Resonance production



$f\,(\rho\pi, K\bar{K}, \ldots)$ at the peak of a resonance



$$A \sim i \frac{\sqrt{\Gamma_{R\to e^+e^-}}\sqrt{\Gamma_{R\to hadrons}}}{\Gamma_{total}}$$

$|A| \sim 1$ vs $|A| \sim \alpha_{em}$

- J/psi is very narrow (decays are OZI suppressed) and the decay to l^+l^- (12%=2x6%) is comparable to hadronic.

$$\sigma(R = J/\psi) = \frac{4\pi(2J+1)}{m_\psi^2}(6\%)(90\%) \sim 88\mu b$$

vs

$$\sigma_{background}(\sqrt{s} = m_{J/\psi}) = 28nb$$

- For other resonances $\mathscr{B}(R \to l^+l^-) \sim 10^{-5} - 10^{-4}$

Hypothetical luminosity estimates
Based on a GlueX-like facility

We consider a photon flux of $10^8\ \gamma/s$ (cfr. HL-Gluex is 2×10^7)
We consider a typical LH_2 target, $\rho L = 1\ \mathrm{g/cm^2}$
For a 24/7 run, we get $1.9\ \mathrm{fb^{-1}\ yr^{-1}}$
We divide by a factor of 4 to take into account the spread in energy,
and approximate the photon beam as having a fixed 20 GeV energy

$$470\ \mathrm{pb^{-1}\ yr^{-1}}$$

BESIII Data Sets (primary):
(e+e- collisions at E_{CM} between 2.0 and 4.7 GeV)

2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 $\mathrm{pb^{-1}}$ at $\psi(3770)$
2011: 2.9 $\mathrm{fb^{-1}}$ *(total)* at $\psi(3770)$
482 $\mathrm{pb^{-1}}$ at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 $\mathrm{pb^{-1}}$ at 4.23 GeV
826 $\mathrm{pb^{-1}}$ at 4.26 GeV
540 $\mathrm{pb^{-1}}$ at 4.36 GeV
10×50 $\mathrm{pb^{-1}}$ scan 3.81 — 4.42 GeV
2014: 1029 $\mathrm{pb^{-1}}$ at 4.42 GeV
110 $\mathrm{pb^{-1}}$ at 4.47 GeV
110 $\mathrm{pb^{-1}}$ at 4.53 GeV
48 $\mathrm{pb^{-1}}$ at 4.575 GeV
567 $\mathrm{pb^{-1}}$ at 4.6 GeV
0.8 $\mathrm{fb^{-1}}$ R-scan 3.85 — 4.59 GeV
2015: R-scan 2 — 3 GeV + 2.175 GeV
2016: ~3$\mathrm{fb^{-1}}$ at 4.18 GeV (for D_s)
2017: 7×500 $\mathrm{pb^{-1}}$ scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
8×500 $\mathrm{pb^{-1}}$ scan 4.13, 4.16, 4.29 — 4.44 GeV
2020: 5×500 $\mathrm{pb^{-1}}$ scan 4.63 — 4.70 GeV *(+ extra)*

From R.Mitchell

X(3872)

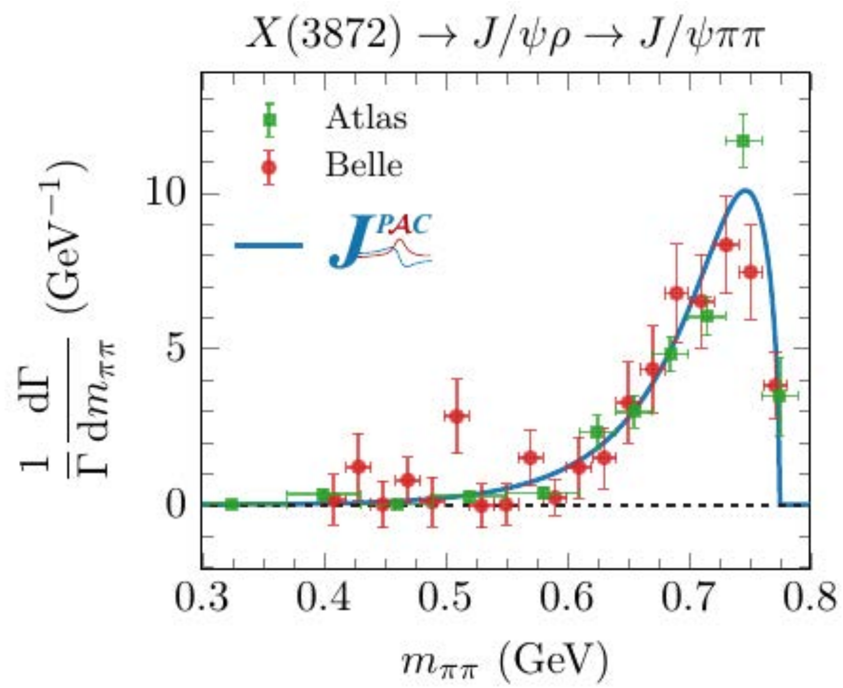
For production/detection, its main decay channels are $J/\psi\rho$ and $J/\psi\omega$ with Br=4.1% and 4.4%, respectively.

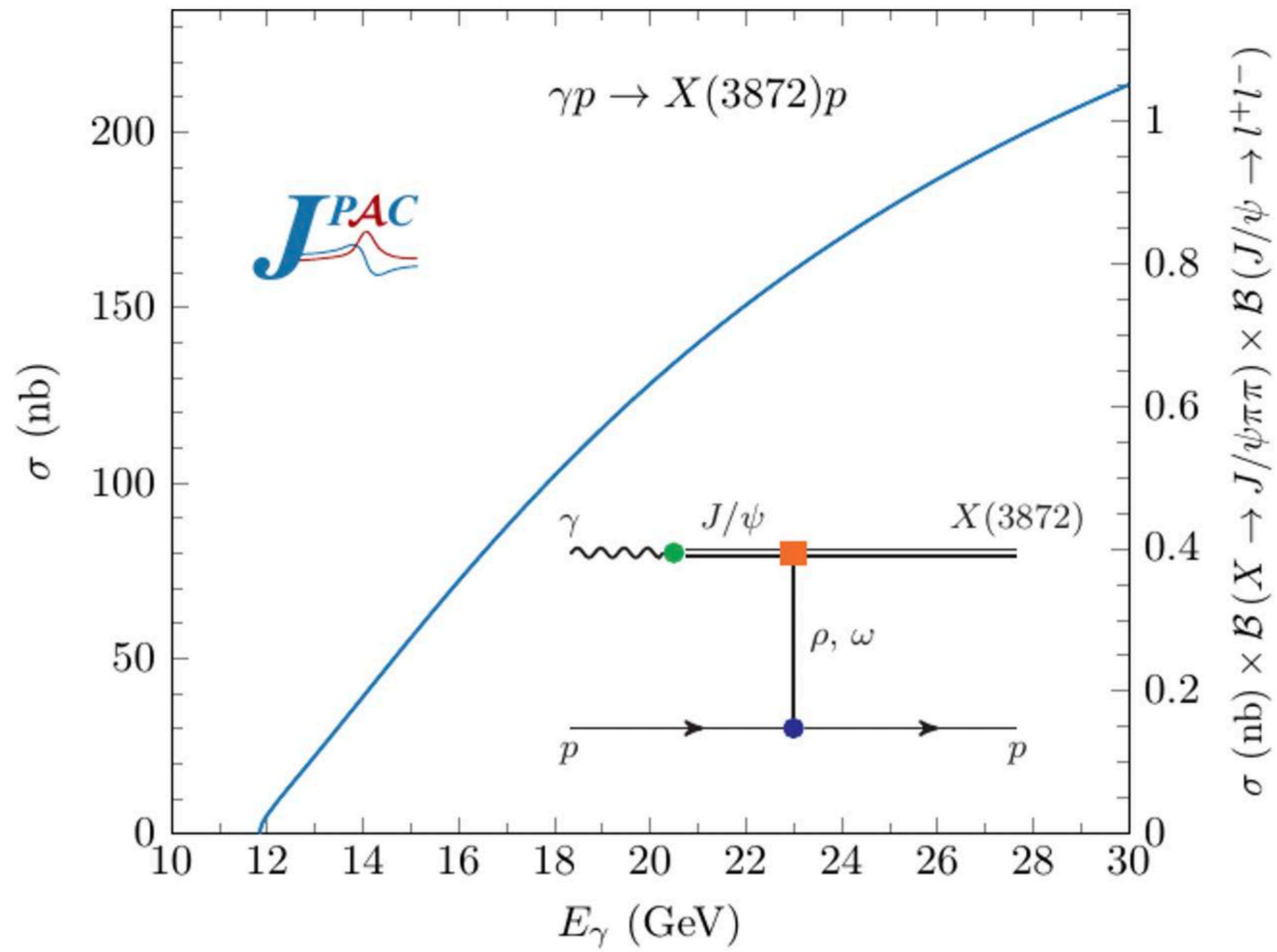
The couplings $J/\psi\rho$ and $J/\psi\omega$ are determined from the branching ratios and assuming a width 1.2 MeV.

The other parts of the amplitude, $\gamma \to J/\psi$ given by VMD, and VNN (bottom vertex) also well known. [1]

[1] Phys. Rev. D 96, 093008 (2017)

The $X \to J/\psi\rho$, $\rho \to \pi\pi$ distribution also agrees with data.



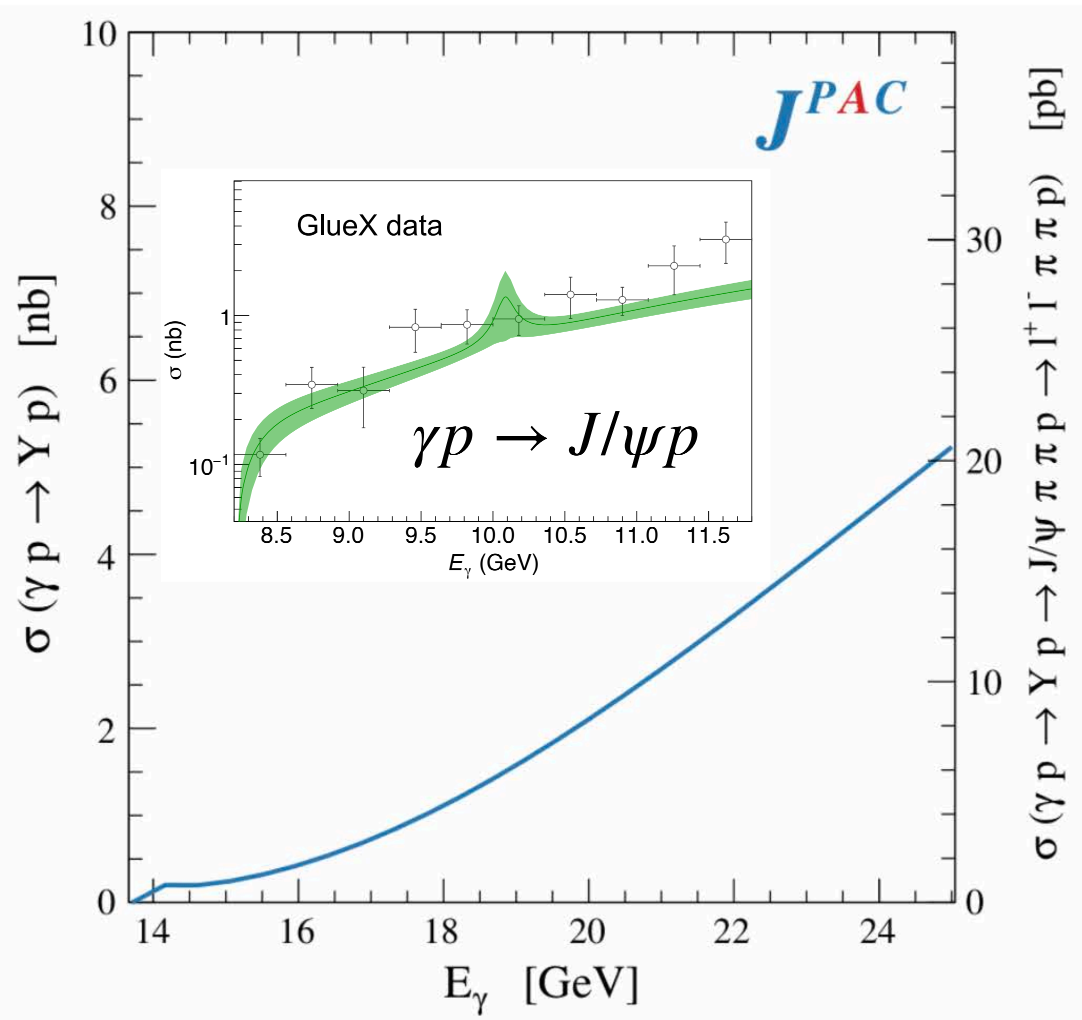


$\mathscr{L} \sim 500 pb^{-1}/yr$ (at $E_\gamma = 20 GeV$) with 1% eff.

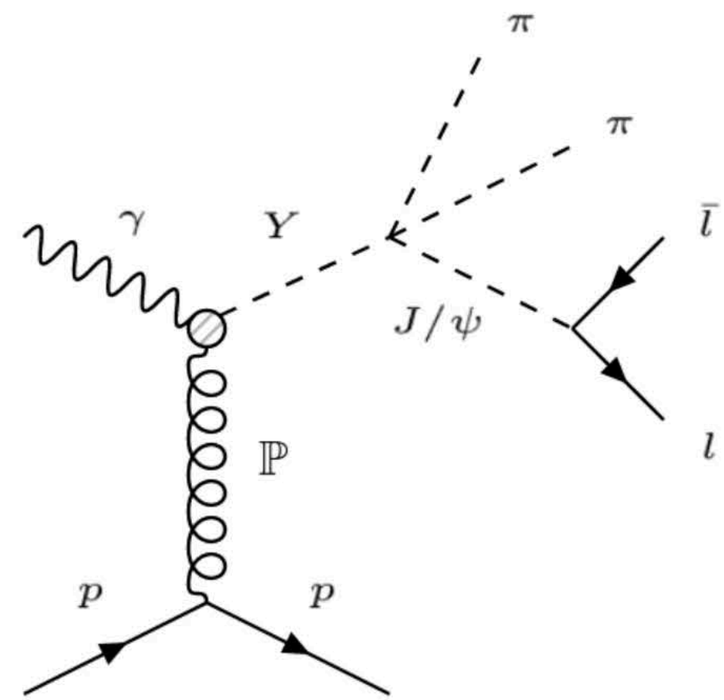
Number of events ~3000 events/yr

BESIII efficiency ~50% due to enhanced acceptance of the symmetric detector — thus our efficiency estimate of 1% is probably conservative

Y(4260)



J/ψ photoproduction near threshold by Pomeron exchange studied by JPAC in [1, 2]



Same bottom ($g_{\mathbb{P}pp}$) coupling. Top couplings ($g_{\mathbb{P}\gamma\psi}/g_{\mathbb{P}\gamma Y}$) related by [3] (omitting phase space factors):

$$\frac{g_{\mathbb{P}\gamma Y}}{g_{\mathbb{P}\gamma\psi}} = \frac{g_{Y\to\gamma gg}}{g_{\psi\to\gamma gg}} = \sqrt{4\pi\alpha}\,\frac{f_\psi}{m_\psi}\sqrt{\frac{\Gamma_Y}{\Gamma_{\psi(1S)}}\,\frac{\mathcal{B}(Y\to\psi(1S)\pi\pi)\,\mathcal{B}(\psi(2S)\to\psi gg)}{\mathcal{B}(\psi(1S)\to\gamma gg)\,\mathcal{B}(\psi(2S)\to\psi\pi\pi)}}$$

$$\frac{g_{\mathbb{P}\gamma Y}}{g_{\mathbb{P}\gamma\psi}} \sim 1.5$$

[1] Phys. Rev. D 94, 034002 (2016)
[2] Phys. Rev. D 100, 034019 (2019)
[3] Phys. Rev. Lett. 45, 688 (1980)

~50 events/yr

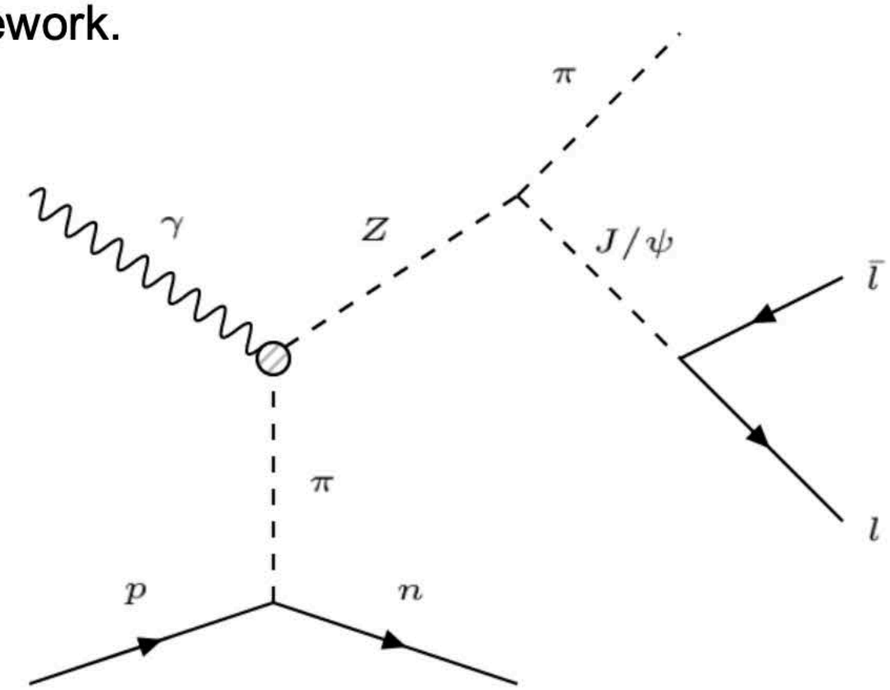
The reason why J/ψ photo production is larger is due to the small $Y \to J/\psi\pi\pi$ branching ratio of 3%

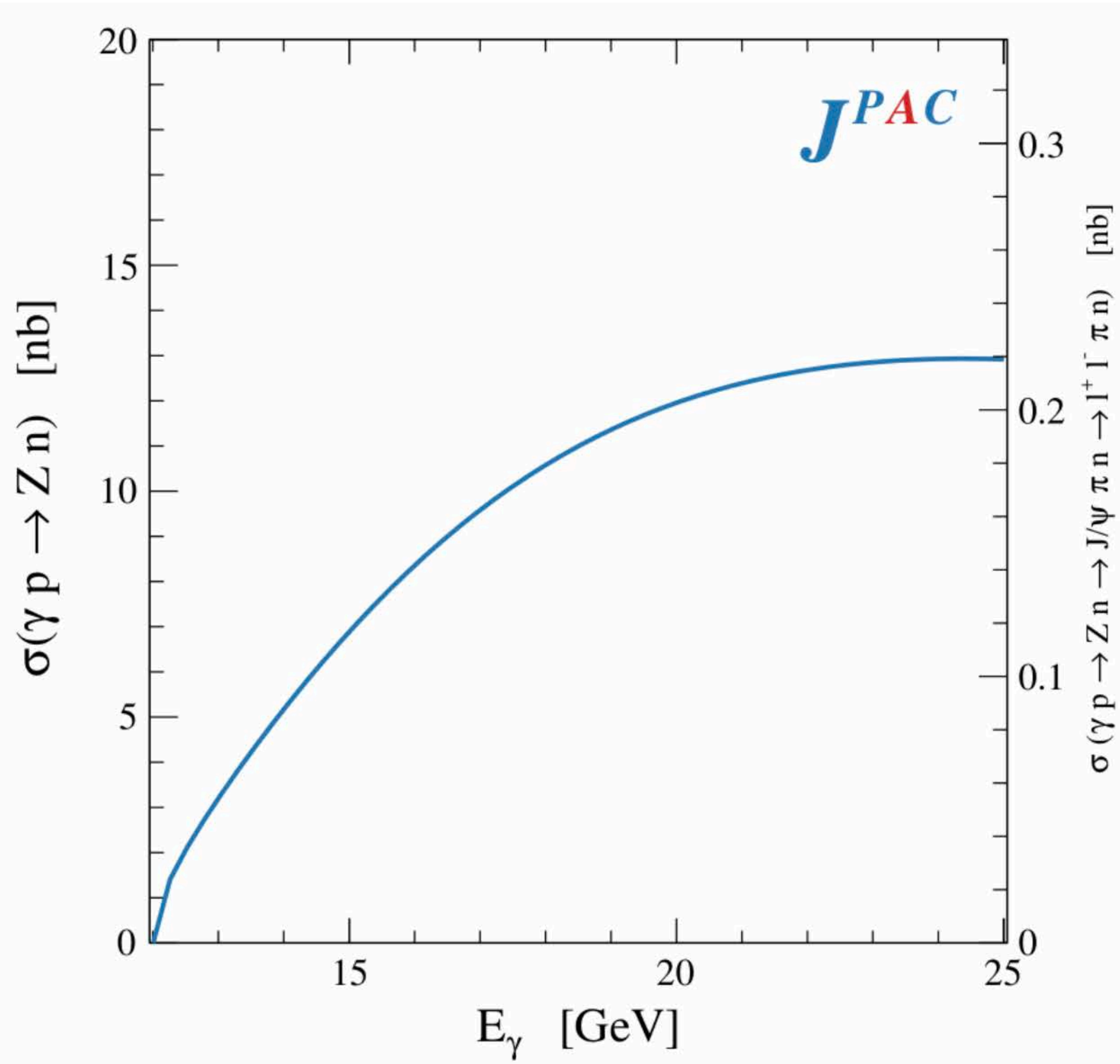
Y production increases with energy : AMBER

Z(3900)

Photoproduction by charged pion exchange considered in [1] but decay widths were largely unknown.

BESIII determination [2] of $\Gamma(Z \to D\bar{D}^*)/\Gamma(Z \to J/\psi\pi)$ allows more accurate estimation of the coupling within VMD framework.





[1] Phys. Rev. D 88, 114009 (2013)
[2] Phys. Rev. Lett. 112, 022001 (2014)

~1000 events/yr

Branching ratio $Z \to J/\psi\pi$ is larger than that of $Y \to J/\psi\pi\pi$

Summary

Hypothetical photo production at 20GeV, 500 pb^{-1} assuming 1% efficiency

- X(3872) : about 3000 events
- Y(4260) : about 50 events with
- Z(3900) : about 1000 events

BESIII

- X(3872) : about 20 events with 3000 pb^{-1} (2013)
- Y(4260) : about 6k events with 3000 pb^{-1} (2016)
- Z(3900) : about 300 events with 525 pb^{-1} (2013)
  About 1200 events with 1900pb^{-1} (2017)

- There is room to use a more intense beam, if the trigger is optimized for charmonium final states; Moreover quasi-real electro production Is likely more efficient at higher energies.
- Direct production vs indirect (BESIII, Belle, LHCb) which involve more complicated final states, particularly true for the Z's which so far seen only in 3body final states. Null results are as important as observations !
- Variable photon energy is important, it probes different production mechanisms : Y production at higher energies W>10 GeV, XZc , at lower W < 10 GeV
- If of interest specific estimates can be made.