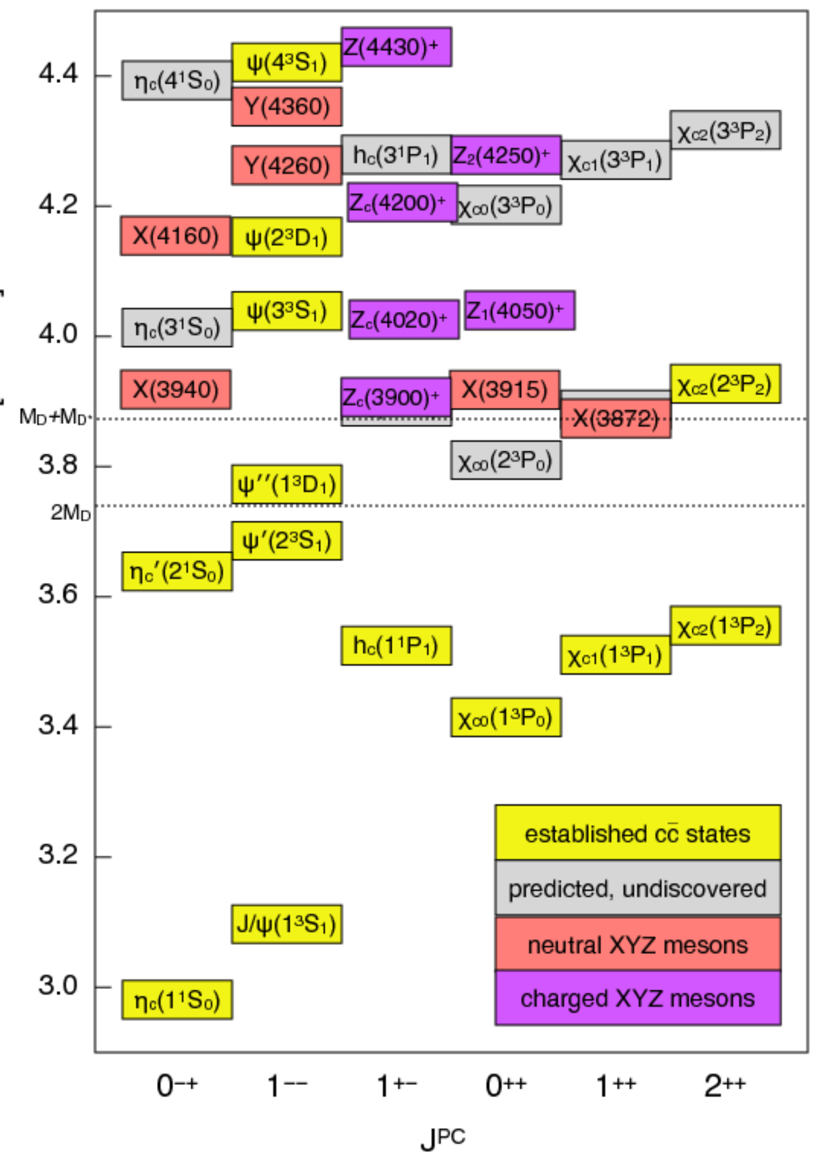
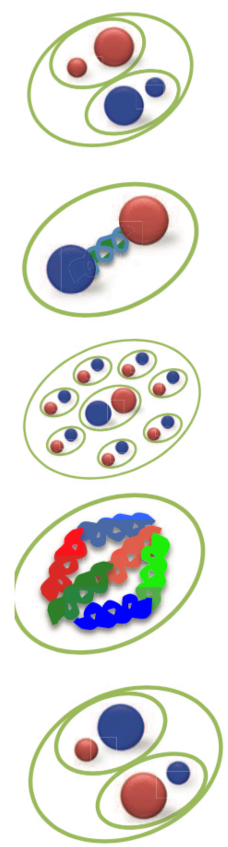
Photoproduction of charmonium: COMPASS experience

Alexey Guskov
Joint Institute for Nuclear Research (Dubna)
avg@jinr.ru
on behalf of the COMPASS collaboration

The spectroscopy program at EIC and future accelerators, Trento, 20.12.2018

Exotic charmonia





tetraquark

hybrid meson

hadro-quarkonium

glueball

molecule

cusp

...

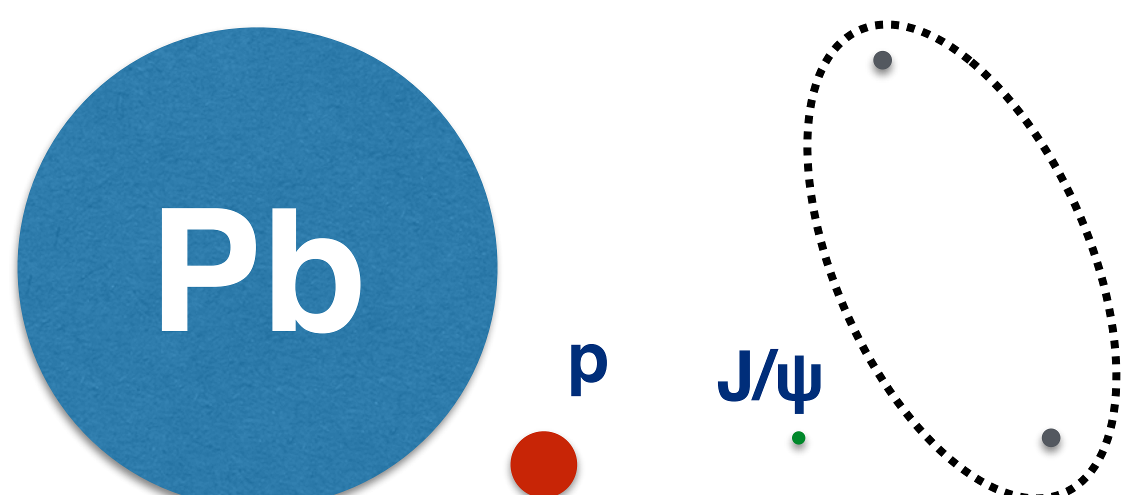
direct production in e^+e^- collisions;

direct production in hadron collisions;

B decays;

$\gamma^*\gamma^*$ collisions;

Photo(lepto)production off nuclei is the new instrument with new opportunities!



X(3872) as D^0D^{0*}-molecule

Exotic charmonia: photoproduction

Bing An Li Is $X(3872)$ a possible candidate of hybrid meson // Phys. Lett. B. 2005. V. 605. P. 306-310.

$$\gamma p \to X(3872)p \qquad \gamma p \to X(3872)n\pi^+$$

Liu X.-H. Qiang Zhao, Frank E. Close. Search for tetraquark candidate Z(4430) in meson photoproduction // Phys. Rev. D. 2008. V. 77. P. 094005

$$\gamma p \to Z_c^+(4430)n \to \psi(2S)\pi^+ n$$

He J., Liu X. Discovery potential for charmonium-like state Y(3940) by the meson photoproduction // Phys. Rev. D. 2009. V. 80. P. 114007

$$\gamma p \to Y(3940)p$$

Lin Q.-Y., Liu X., Xu H.-S. Charged charmoniumlike state $Z_c^{\pm}(3900)$ via meson photoproduction // Phys. Rev. D. 2013. V. 88. P. 114009

$$\gamma p \to Z_c^+(3900)n$$

Lin Q.-Y., Liu X., Xu H.-S. Probing charmoniumlike state X(3915) through meson photoproduction // Phys. Rev. D. 2014. V. 89. P. 034016

$$\gamma p \to X(3915)p \to J/\psi\omega p$$

Wang X.-Y., Chen X.-R., Guskov A. Photoproduction of the charged charmoniumlike $Z_c^+(4200)$ // Phys. Rev. D. 2015. V. 92. P. 094017

$$\gamma p \to Z_c^+(4360)n$$

...

COMPASS

$Z^{\pm}_c(3900)$
X(3872)

The COMPASS experiment

COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy)

is a fixed target experiment on a secondary beam of Super Proton Synchrotron at CERN

13 countries,
24 institutions,
~220 physicists

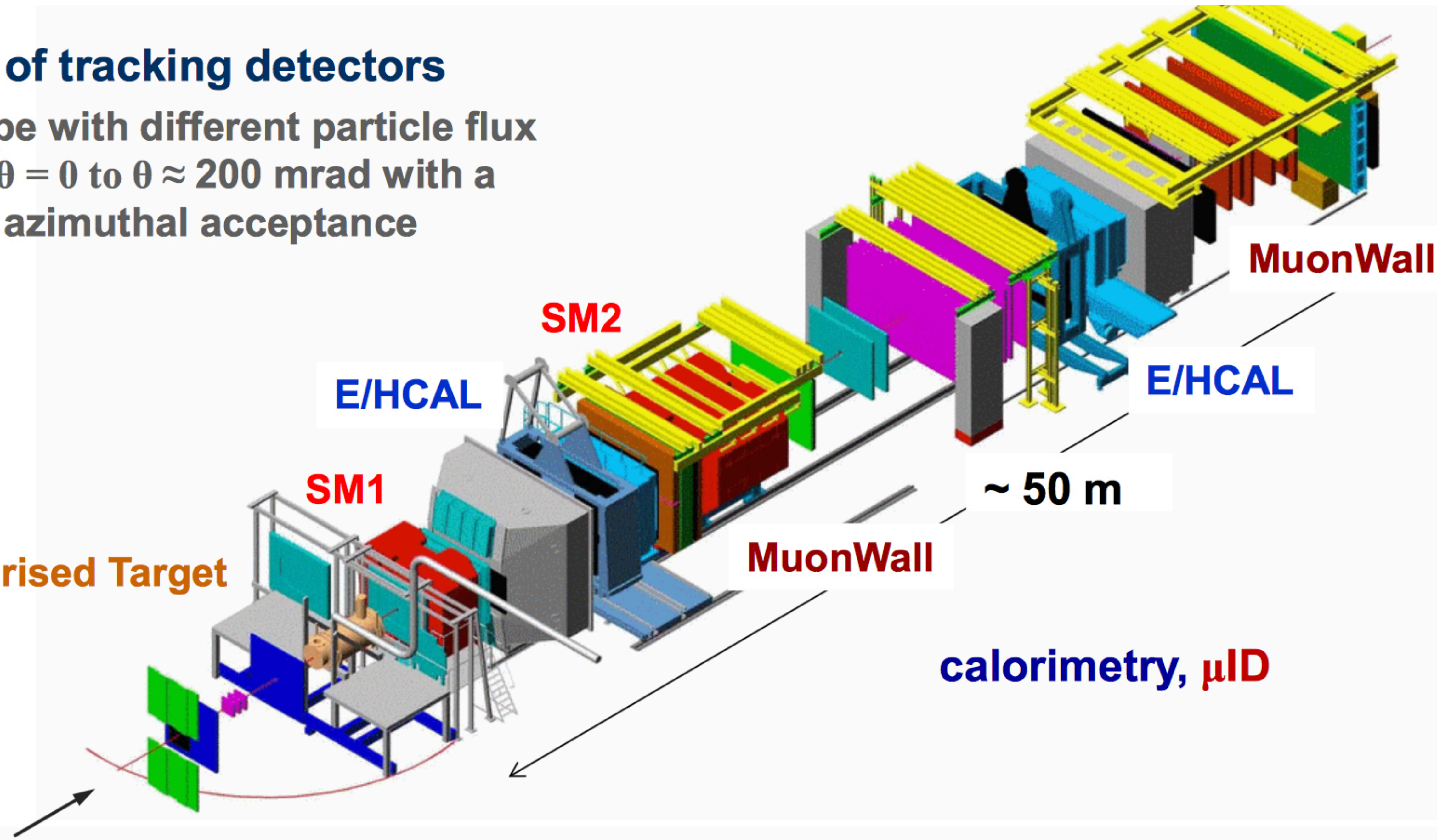
1996 - Proposal

2002-now - Physical data taking

The COMPASS setup

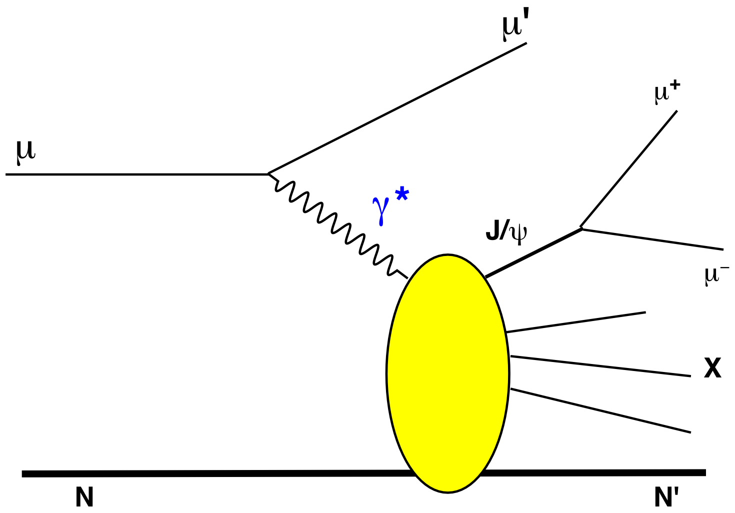
variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance

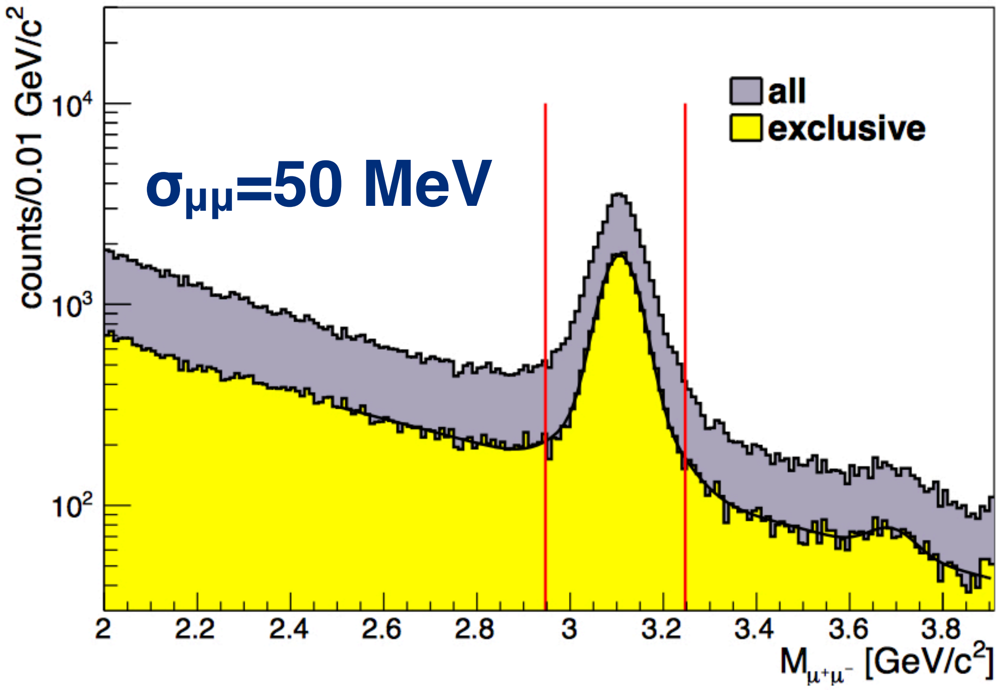


Configuration of the beam and target region depends on the particular physics programme

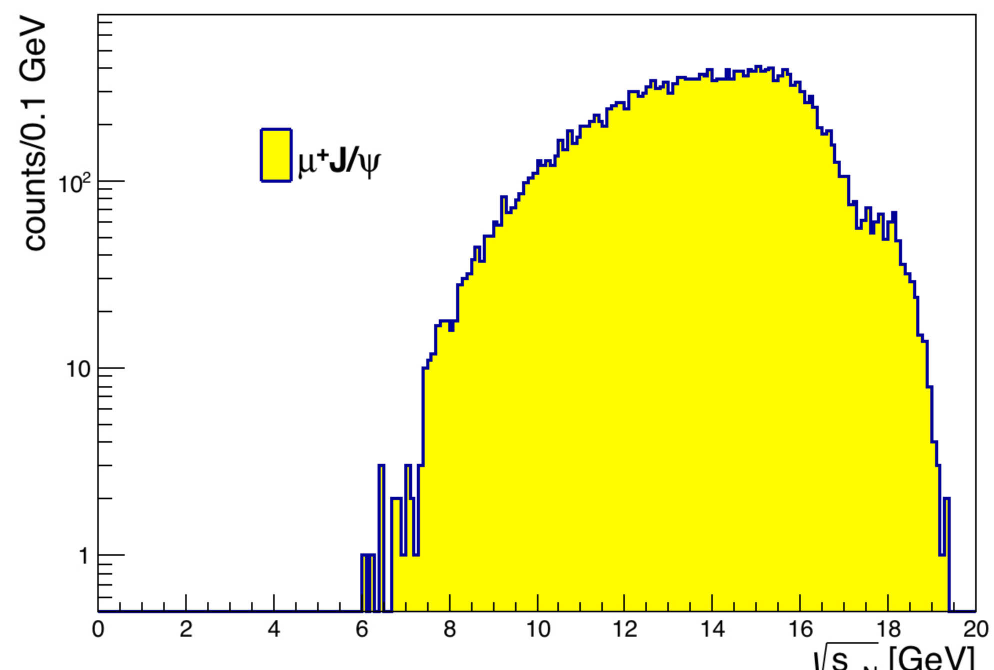
Muoproduction at COMPASS



Years	P, GeV/c	Target
2002	μ^+,160	^{6}LiD
2003	μ^+,160	^{6}LiD
2004	μ^+,160	^{6}LiD
2006	μ^+,160	^{6}LiD
2007	μ^+,160	NH_3
2010	μ^+,160	NH_3
2011	μ^+,200	NH_3
2016	$\mu^\pm$,160	LH_2
2017	$\mu^\pm$,160	LH_2

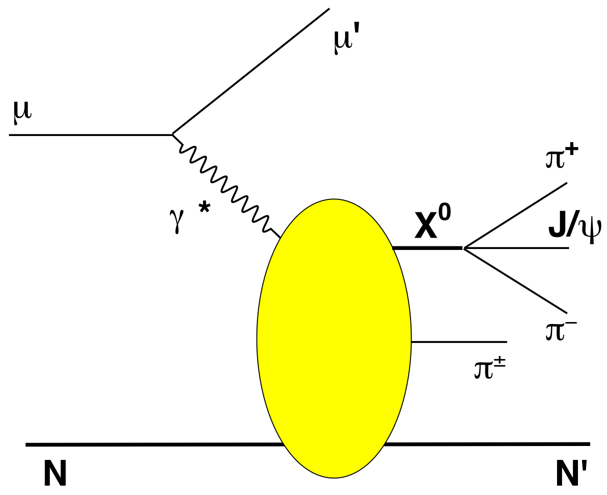


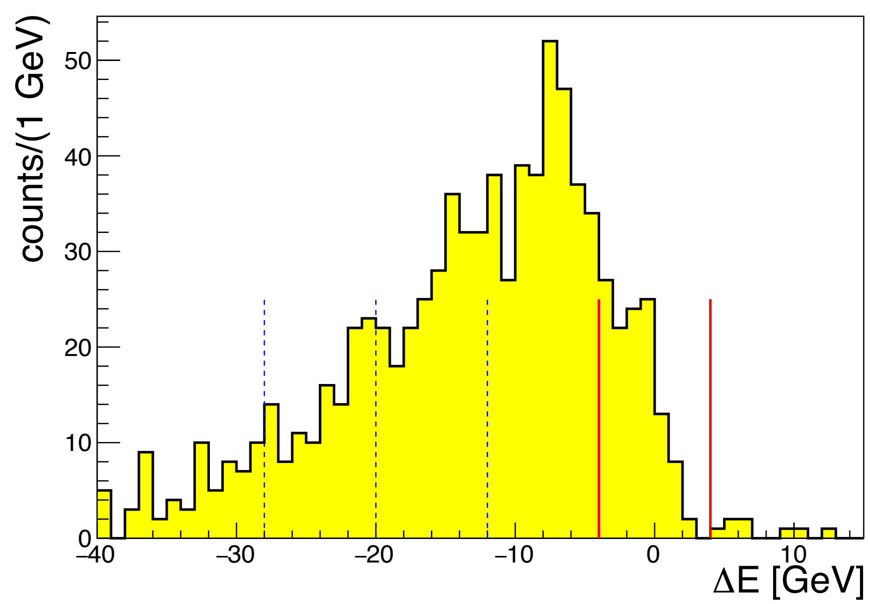
~50 000 J/ψ→ μ⁺μ⁻ events after 7 years of DIS running

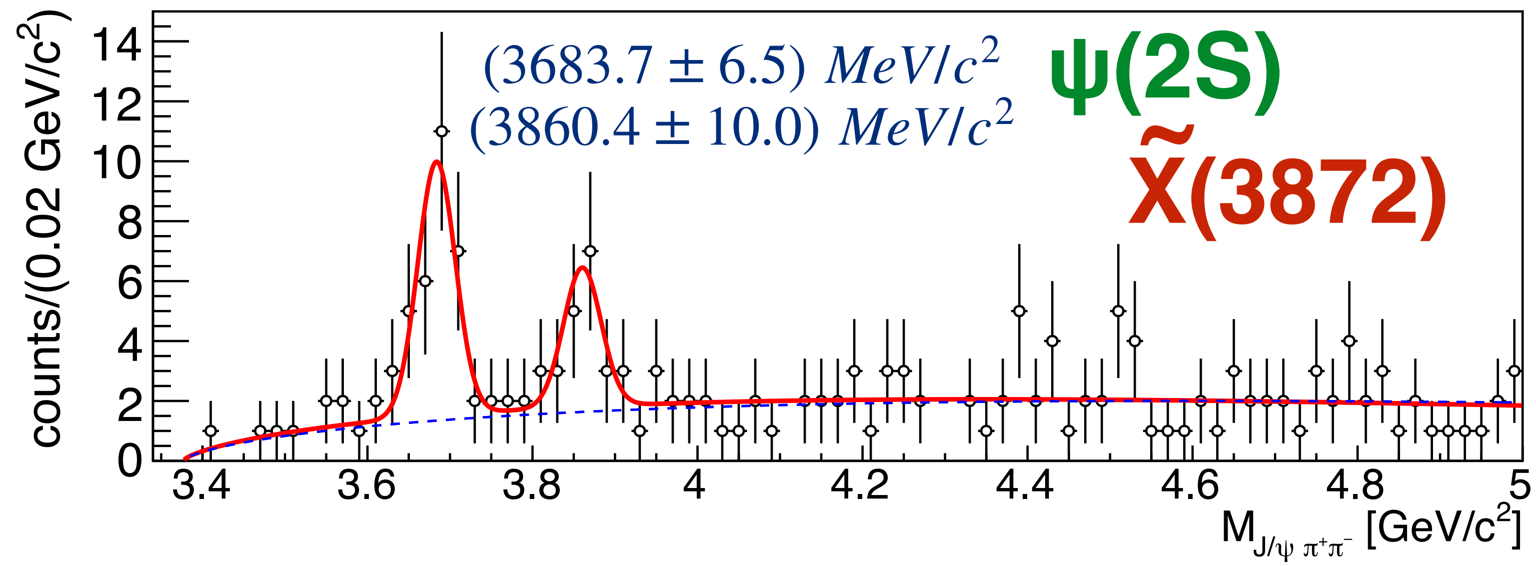


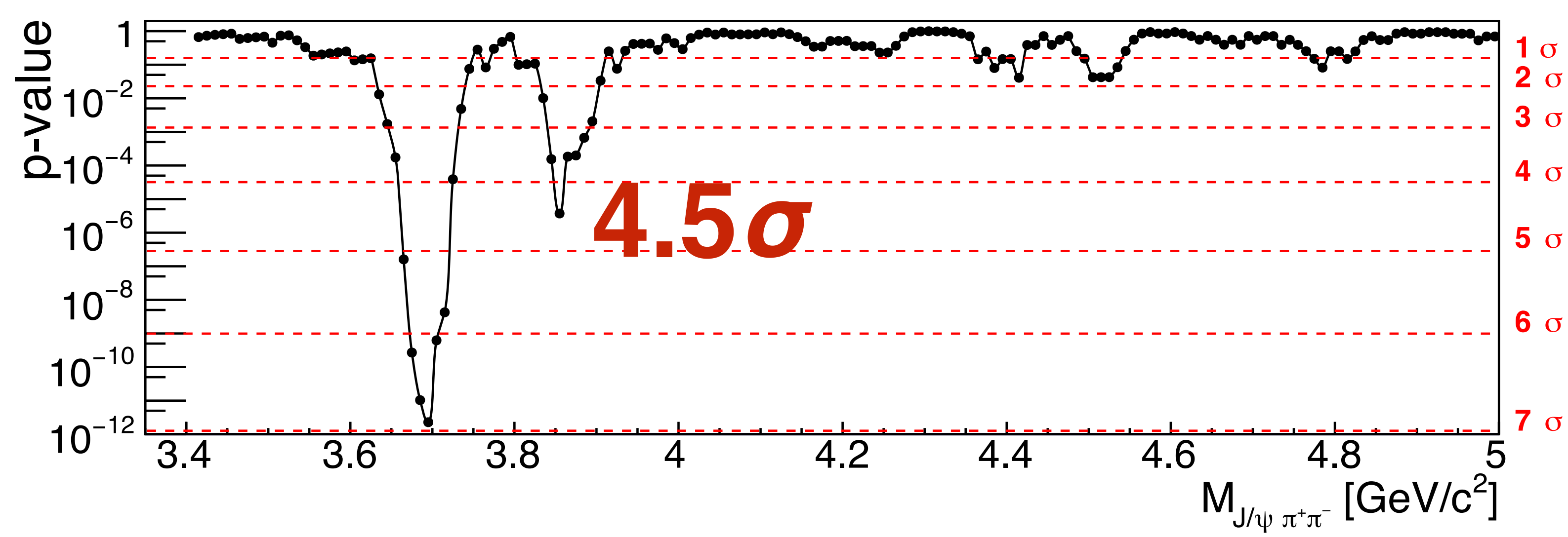
Effective γ*N statistics accumulated by COMPASS is equivalent to about L=14 pb⁻¹ of the integrated luminosity, when considering a real-photon beam of about 100 GeV incident energy scattering off free nucleons

$\gamma^* N \to (J/\psi \pi^+ \pi^-) \pi^\pm N'$





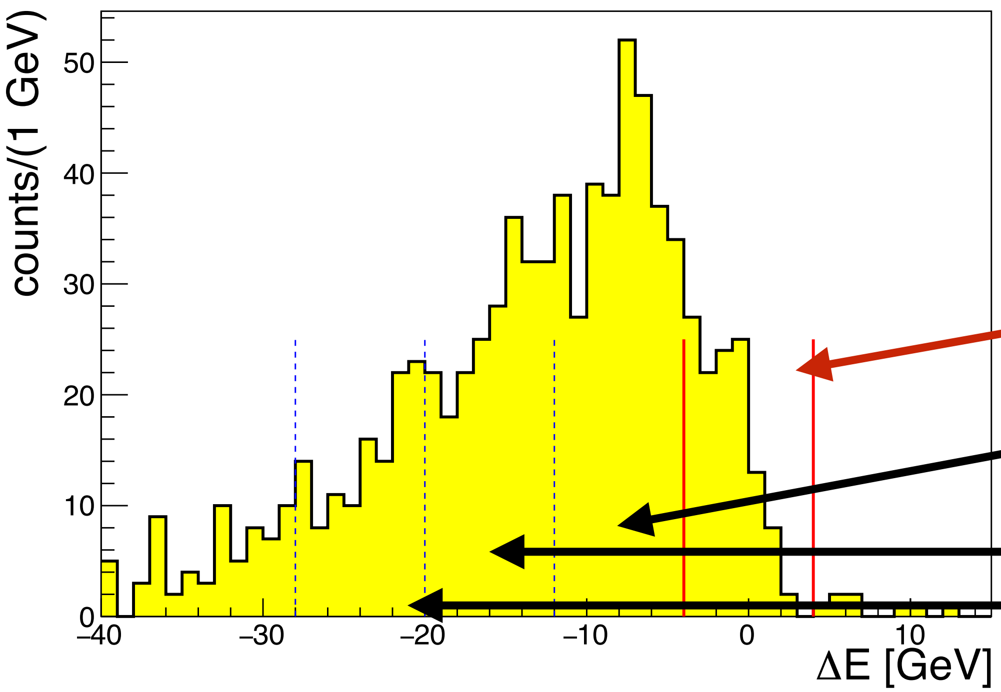


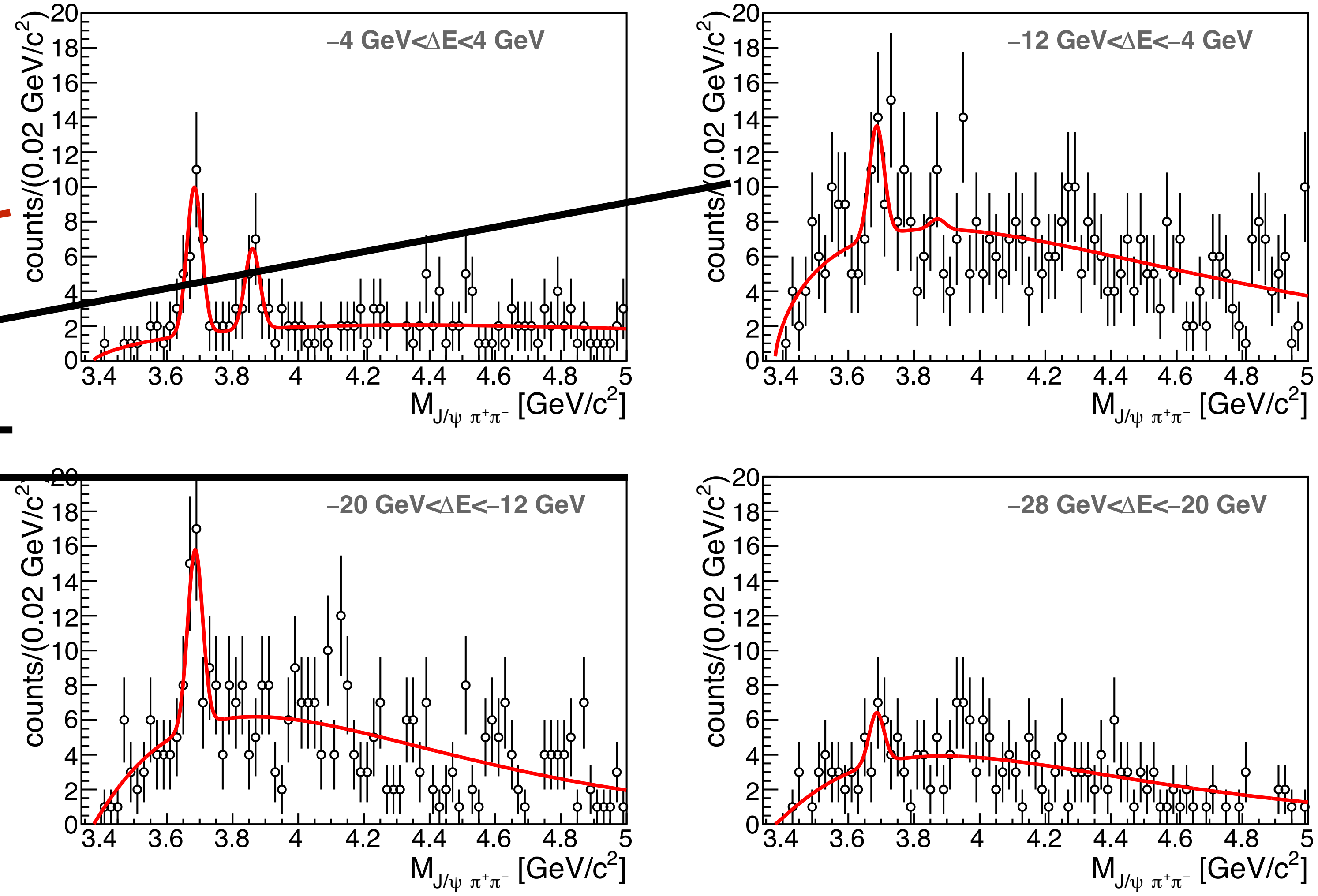


$$f(m) = \mathrm{Gauss}(N_{J/\psi(2S)}, M_{\psi(2S)}, \sigma_M) + \mathrm{Gauss}(N_{\tilde{X}(3872)}, M_{\tilde{X}(3872)}, \sigma_M) + c_1 (m - m_0)^{c_2} e^{-c_3 m}$$

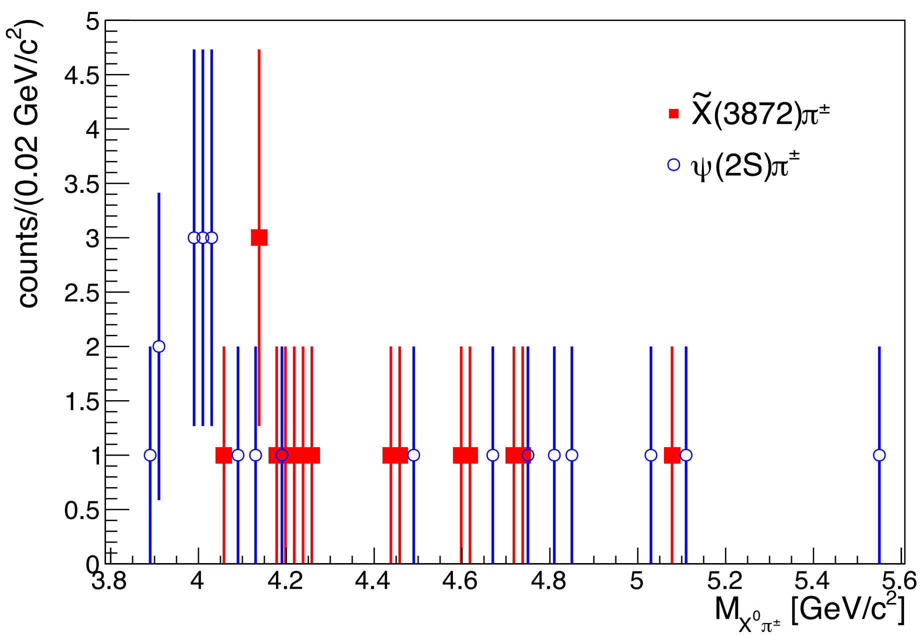
$\sigma_M = (22.8 \pm 6.9)$ MeV/c^2 **$N_{(\tilde{X}3872)} = (13.2 \pm 5.2)$ events**

More kinematics

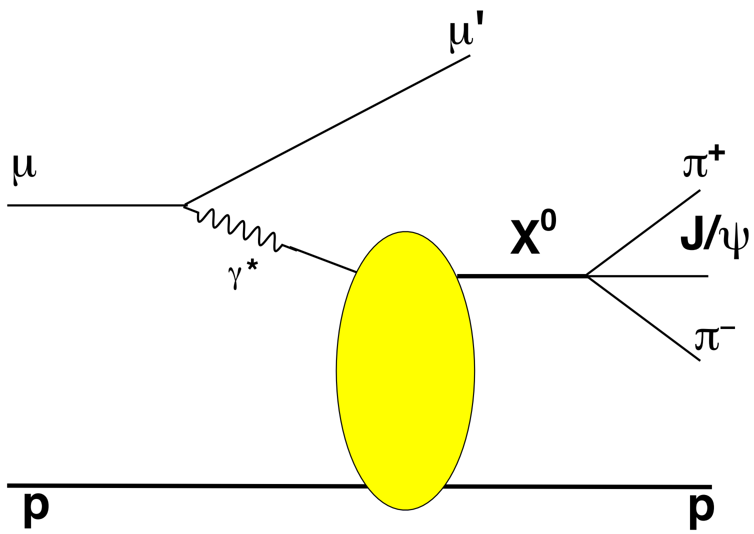




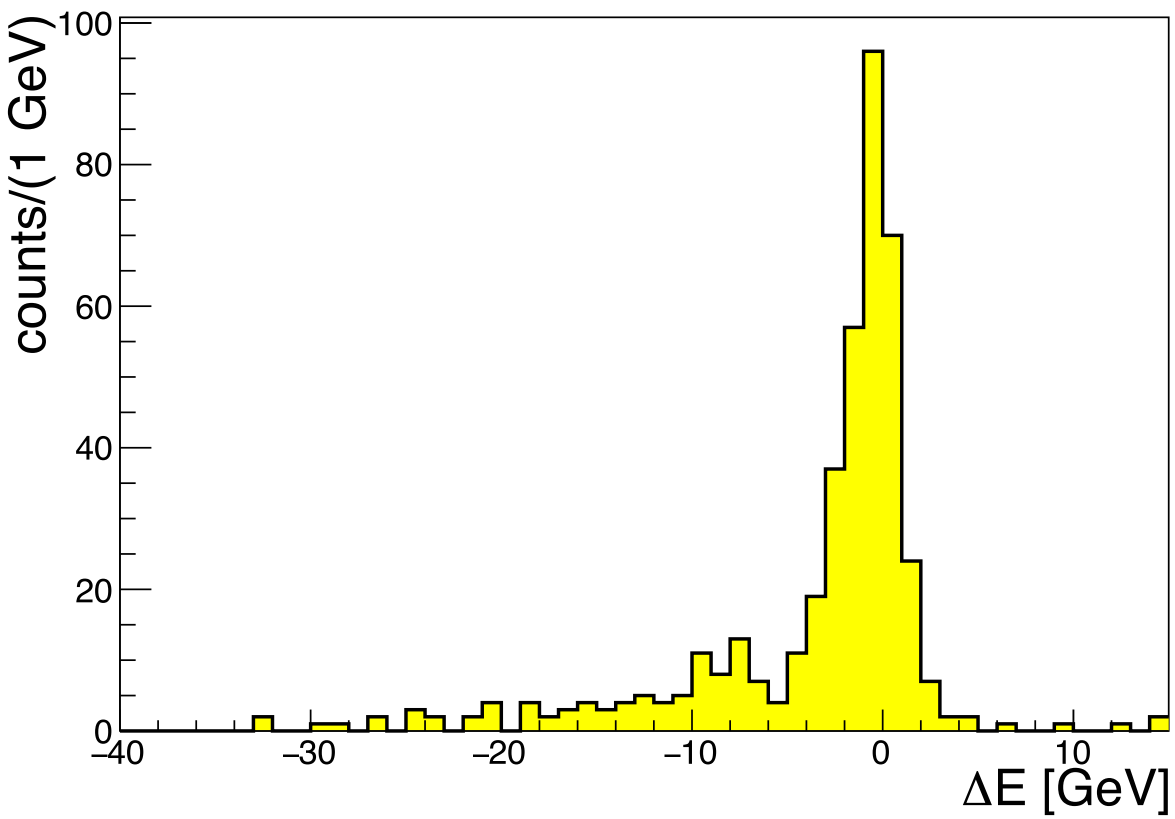
No statistically significant evidence of a peak at 3872 MeV/c^2 in our nonexclusive sample

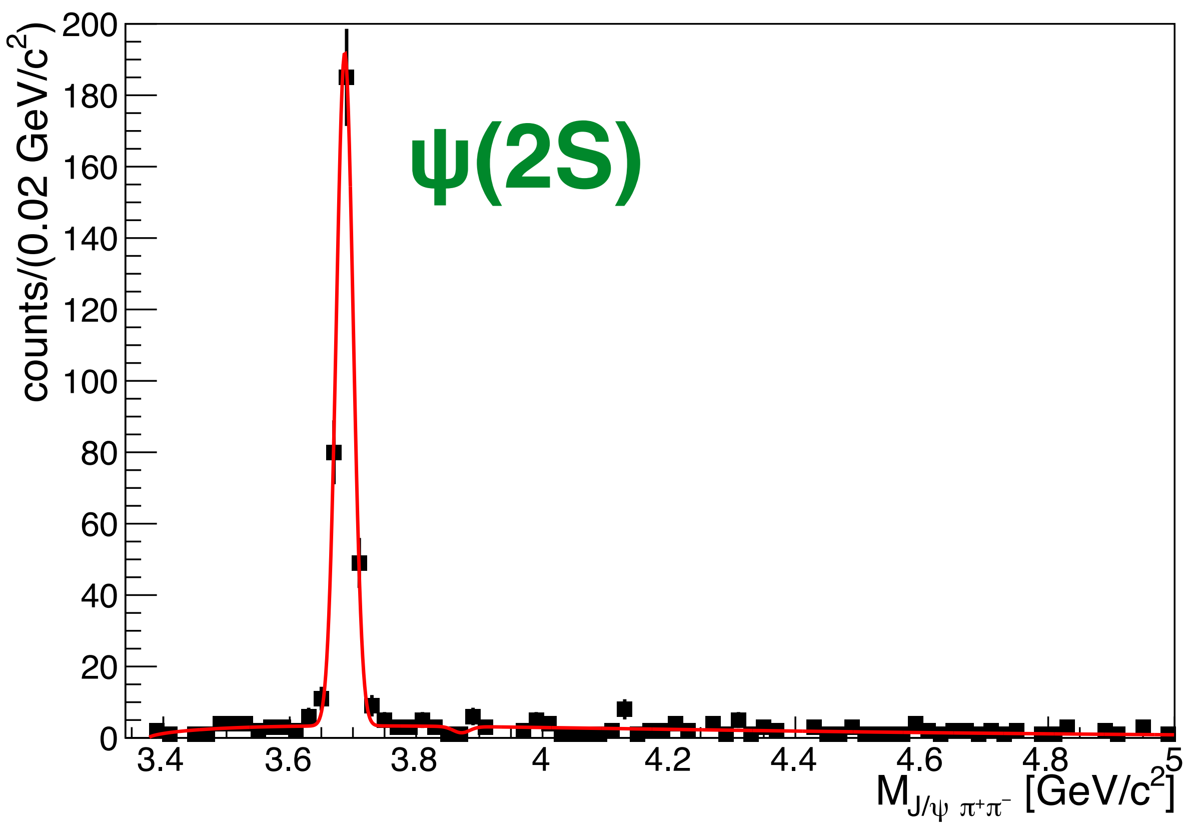


$\gamma^* N \rightarrow (J/\psi \pi^+ \pi^-) N$

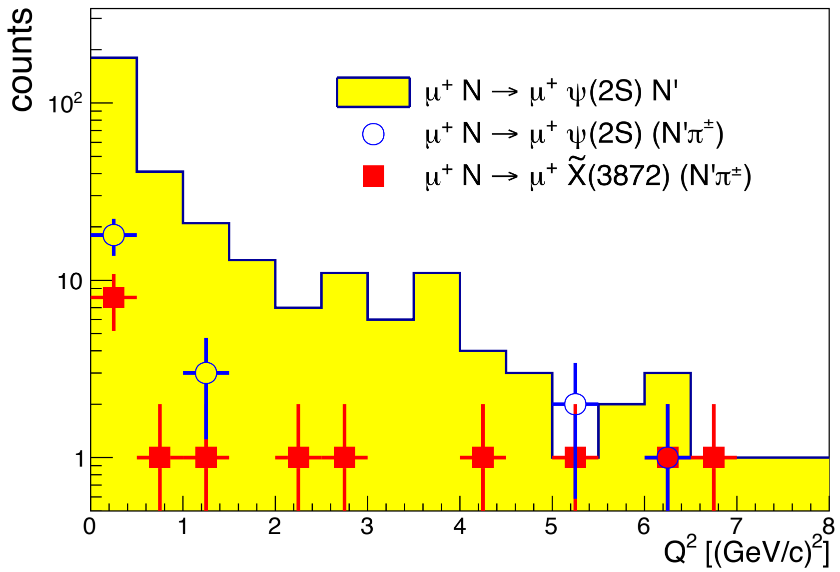


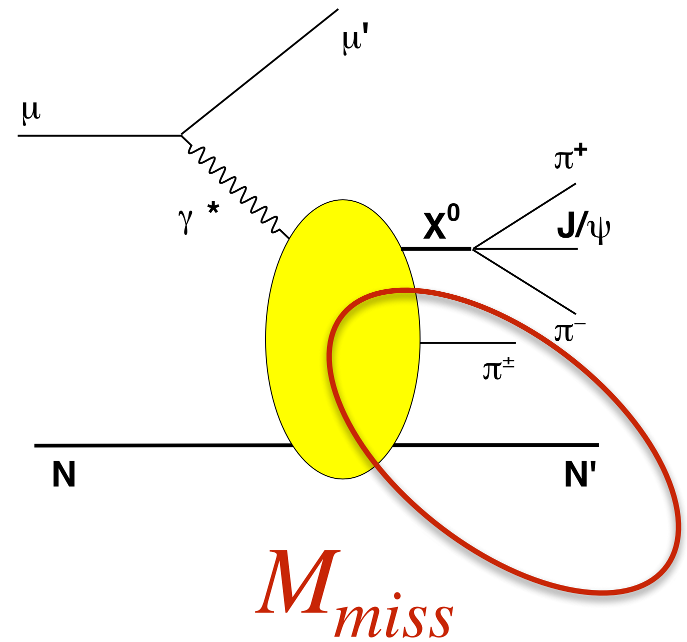
No statistically significant evidence of a peak at 3872 MeV/c^2

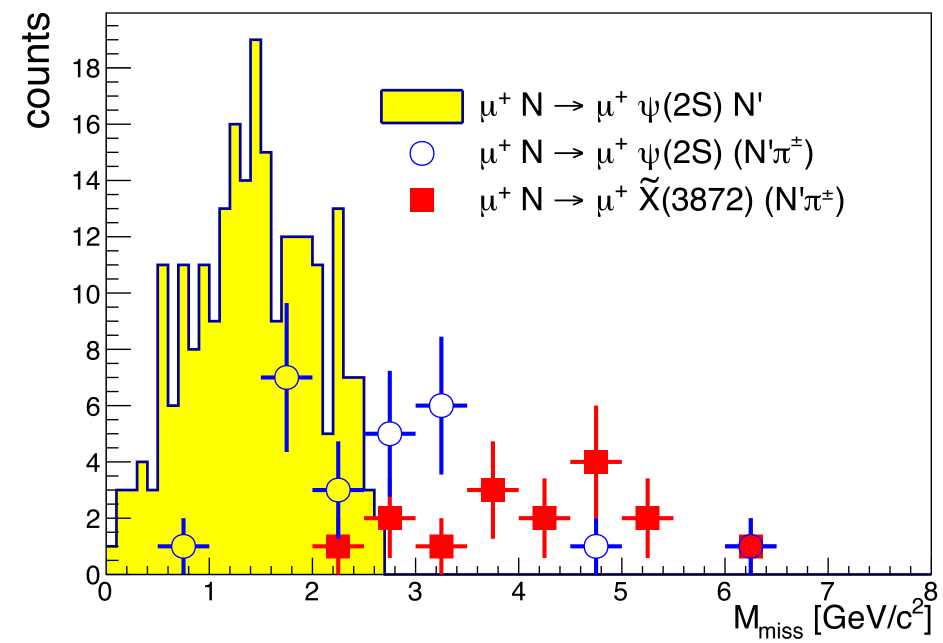


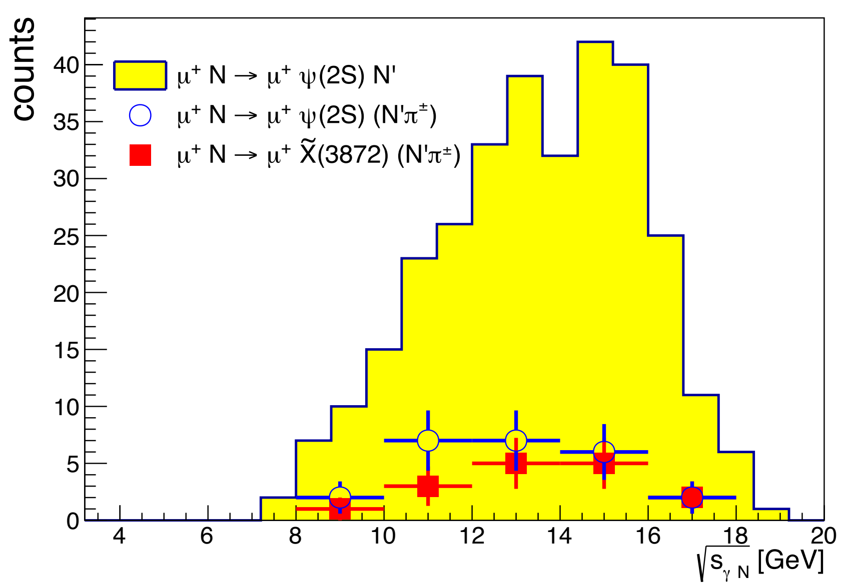


Production kinematics

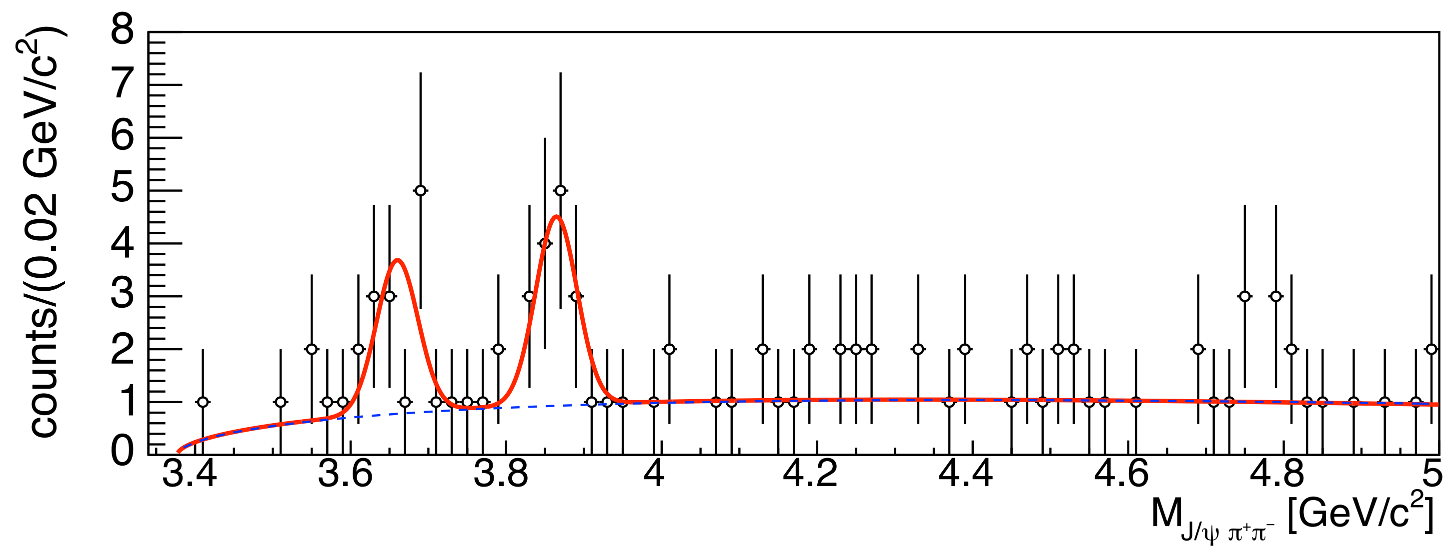






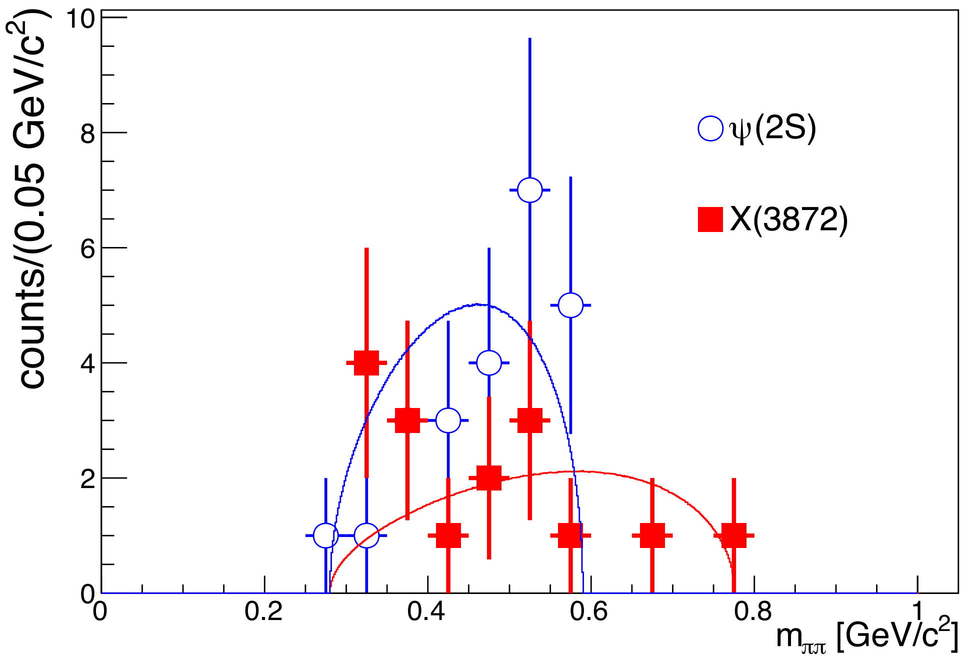


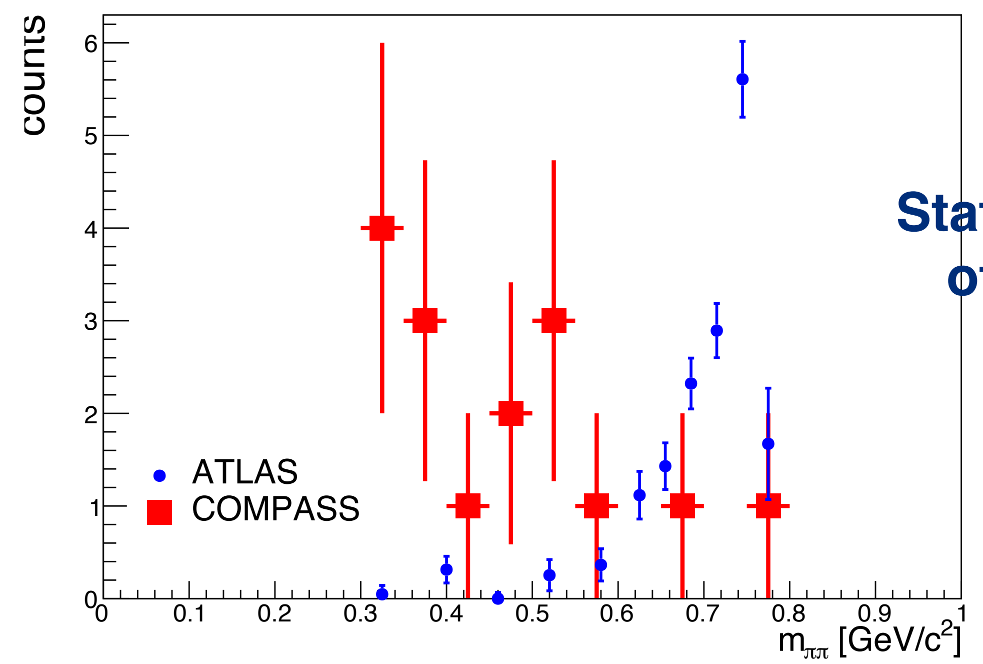
M_{miss}>3 GeV/c^2



It seems, $\tilde{X}(3872)\pi^{\pm}$ and ψ(2S) are produced via different mechanisms

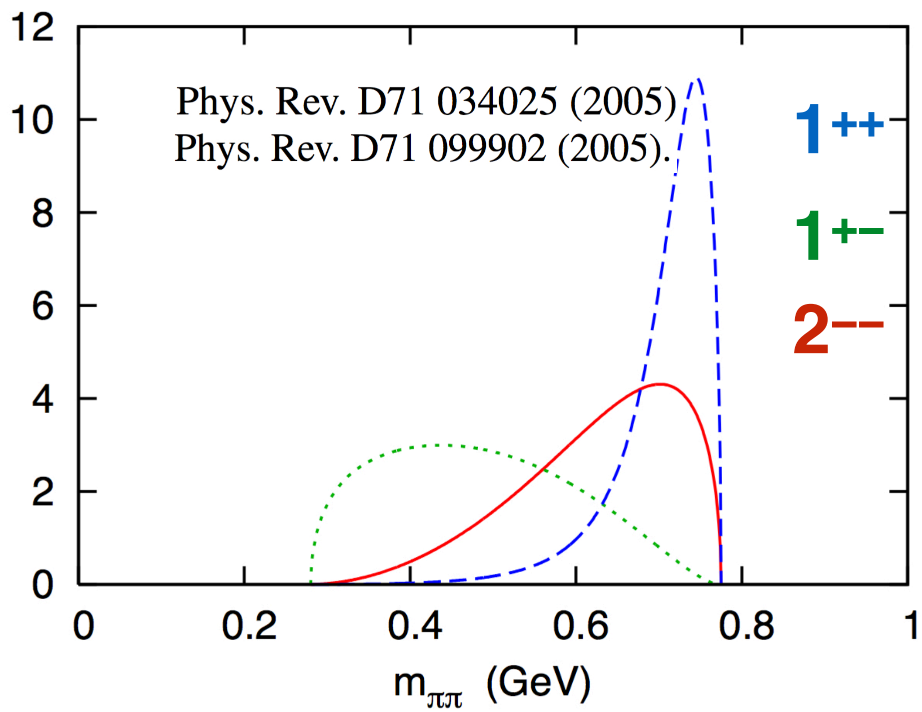
π-π mass spectrum

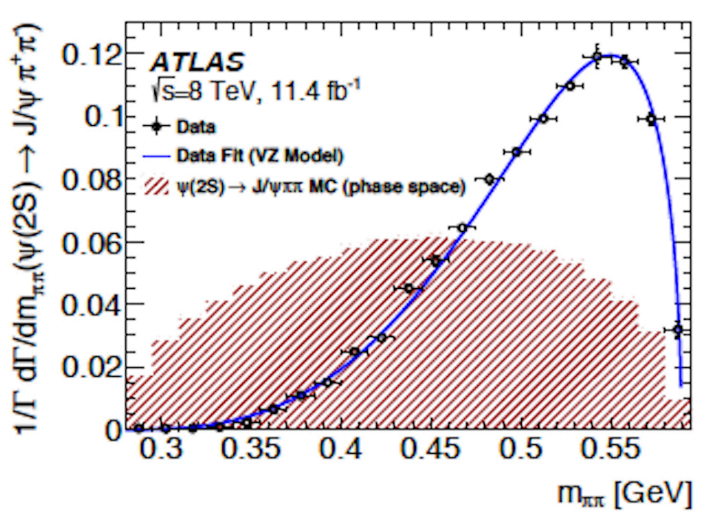


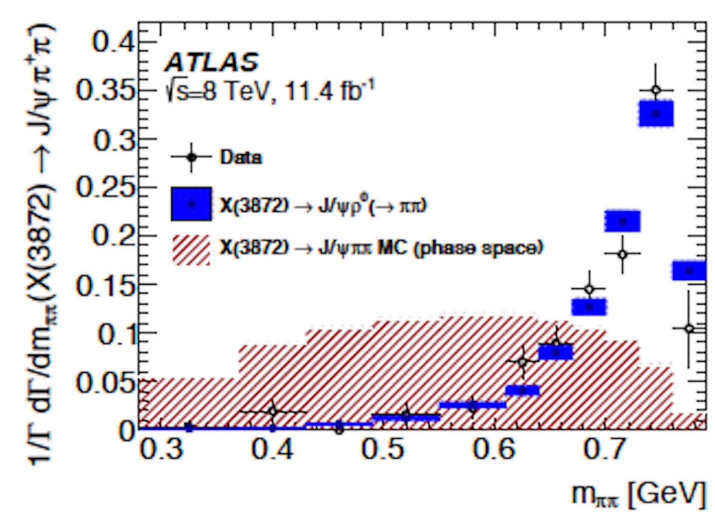


Statistical significance of the difference is (4.7–7.3)σ

The shape of the ππ-mass spectrum observed by COMPASS for ψ(2S) is in agreement with previous results while our result for $\tilde{X}$(3872) is in tension with previous observations.







our ππ-mass spectrum looks similar to 1+−

Consistency checks

COMPASS

We investigated many possible reactions which could imitate the observed $\tilde{X}(3872)$ signal:

$\gamma^* N \to \psi(2S)\pi^\pm N' \to (J/\psi\pi^+\pi^-)\pi^\pm N'$

$\gamma^* N \to \psi(2S)N^* \to (J/\psi\pi^+\pi^-)(\pi^\pm N')$

$\gamma^* N \to X(3872)\pi^\pm N' \to (J/\psi\omega)\pi^\pm N' \to (J/\psi\pi^+\pi^-\pi^0)\pi^\pm N'$

$\gamma^* N \to \chi_{cJ}\pi^\pm N' \to (J/\psi\gamma)\pi^\pm N' \to (J/\psi e^+e^-)\pi^\pm N'$

$\gamma^* N \to J/\psi\pi^+\pi^-\pi^+\pi^- N'$

$(J/\psi\eta)$, $(J/\psi\eta'(958))$, $(J/\psi\phi)$ subsystems in the final state were also considered.

But all the hypotheses were disproved.

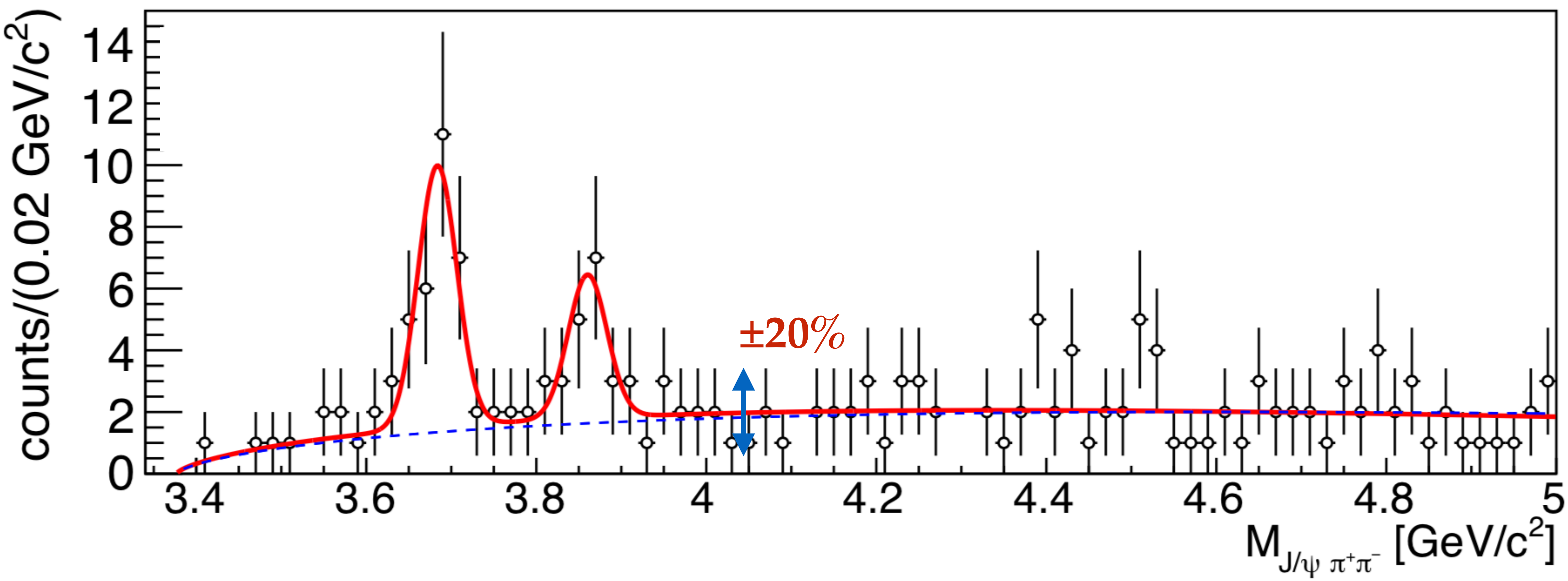
$\tilde{X}(3872)$ as a new state

$m_{\tilde{X}(3872)}$ = (3860.0±10.4) MeV/c^2

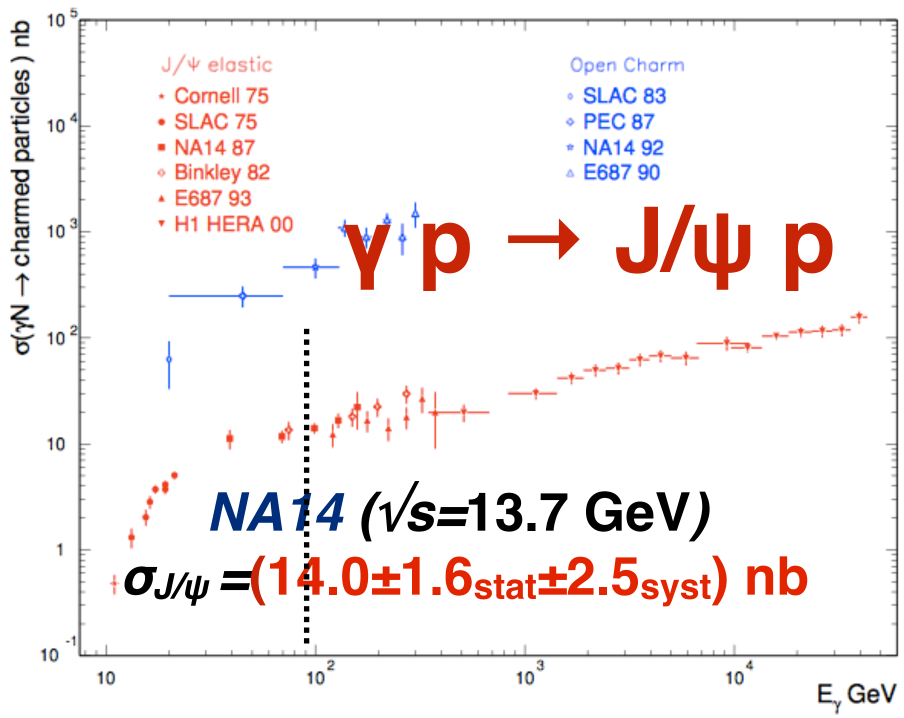
$\Gamma_{\tilde{X}(3872)}$ < 51 MeV/c^2 (CL=90%)

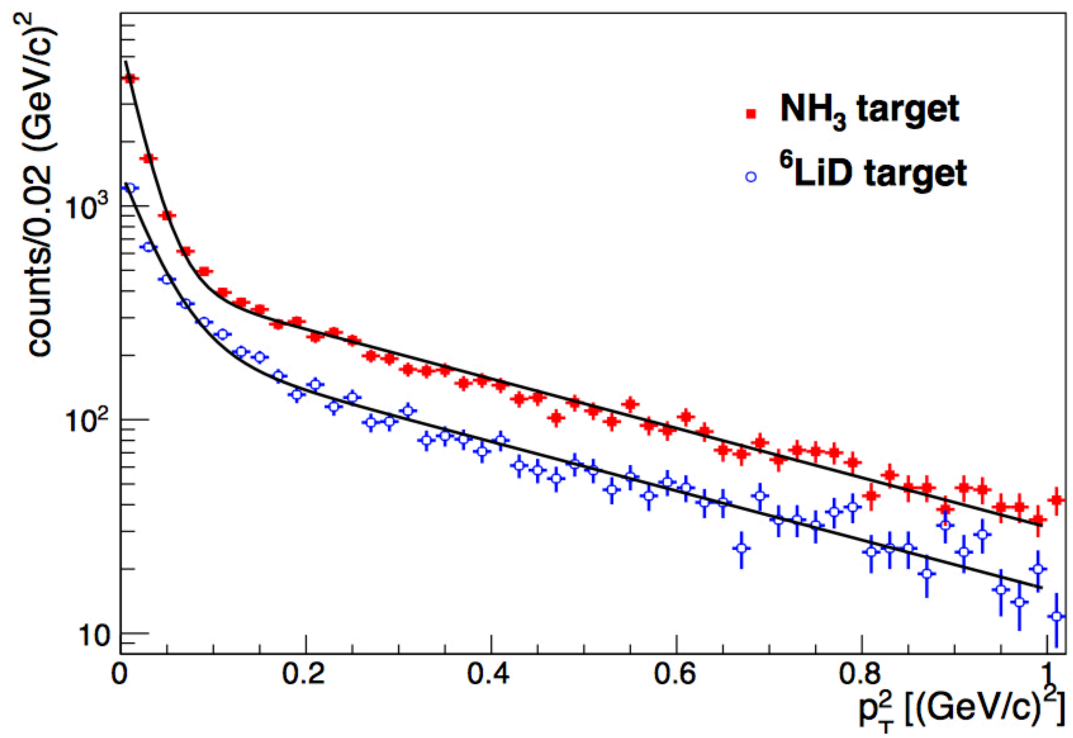
Significance (including systematics) is 4.1σ

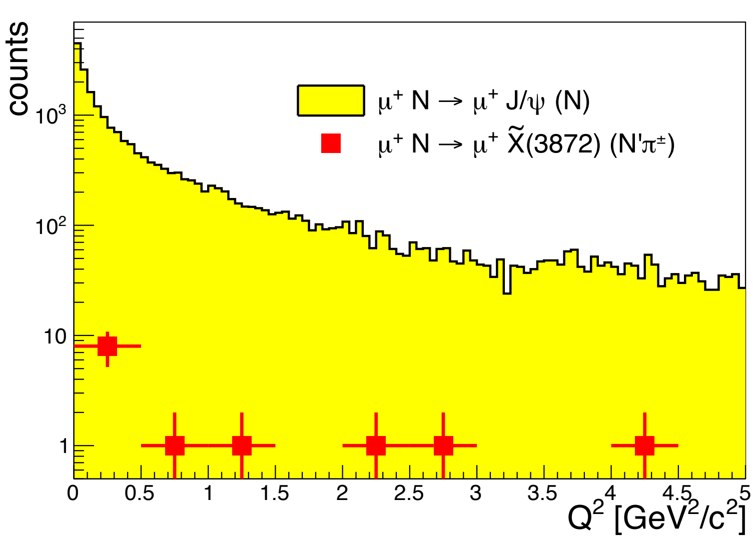
C=−1 (?)

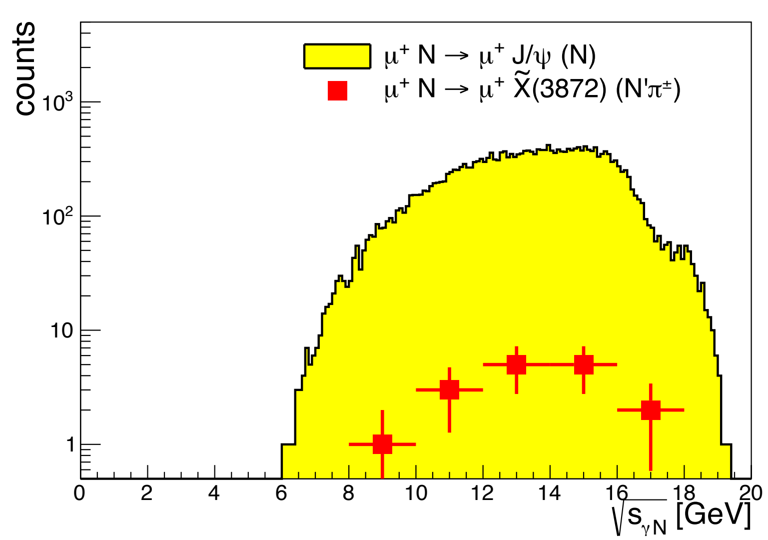


Absolute production rate









we assume the same flux of virtual photons :

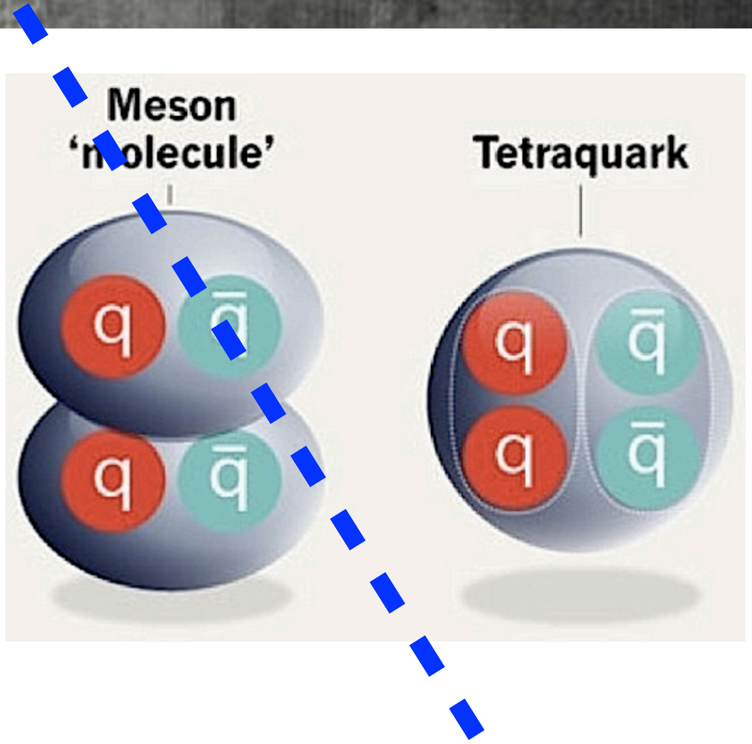
$$\frac{\sigma_{\mu\ N\to\mu\widetilde{X}(3872)\pi\ N'}}{\sigma_{\mu\ N\to\mu J/\psi\ N}} = \frac{\sigma_{\gamma\ N\to\widetilde{X}(3872)\pi\ N'}}{\sigma_{\gamma\ N\to J/\psi\ N}}$$

$$\sigma_{\gamma N\to\widetilde{X}(3872)\pi N'} \times \mathcal{B}_{\widetilde{X}(3872)\to J/\psi\pi\pi} = 71 \pm 28(\text{stat}) \pm 39(\text{syst})\ \text{pb}.$$

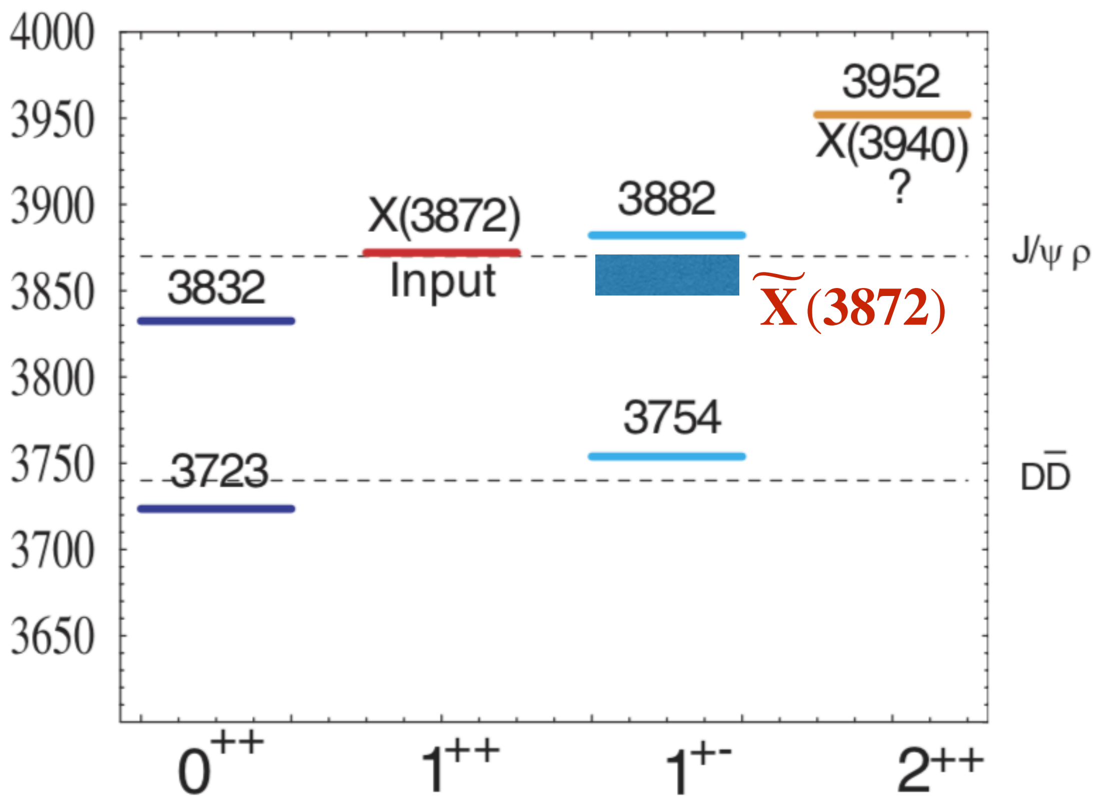
$$\sigma_{\gamma N\to X(3872)N'} \times \mathcal{B}_{X(3872)\to J/\psi\pi\pi} < 2.9\ \text{pb}\ (\text{CL} = 90\%).$$

Discussion

The $\tilde{X}(3872)$ state, whose mass is close to the X(3872) mass could be treated within the tetraquark model that predicts



L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D71 (2005) 014028.
L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D89 (2014) 114010.



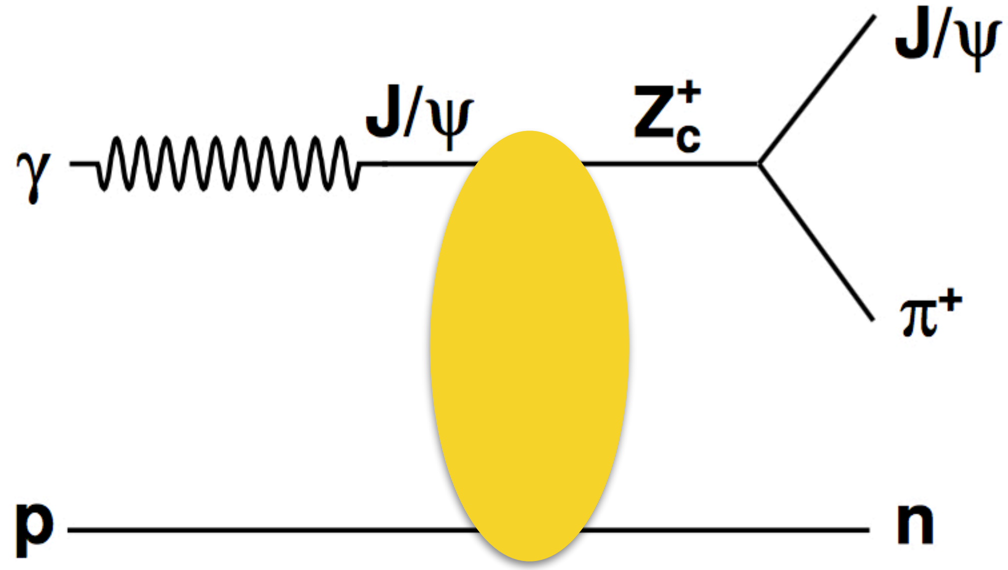
$$X_u = [cu][\bar{c}\,\bar{u}]; \qquad X_d = [cd][\bar{c}\,\bar{d}];$$

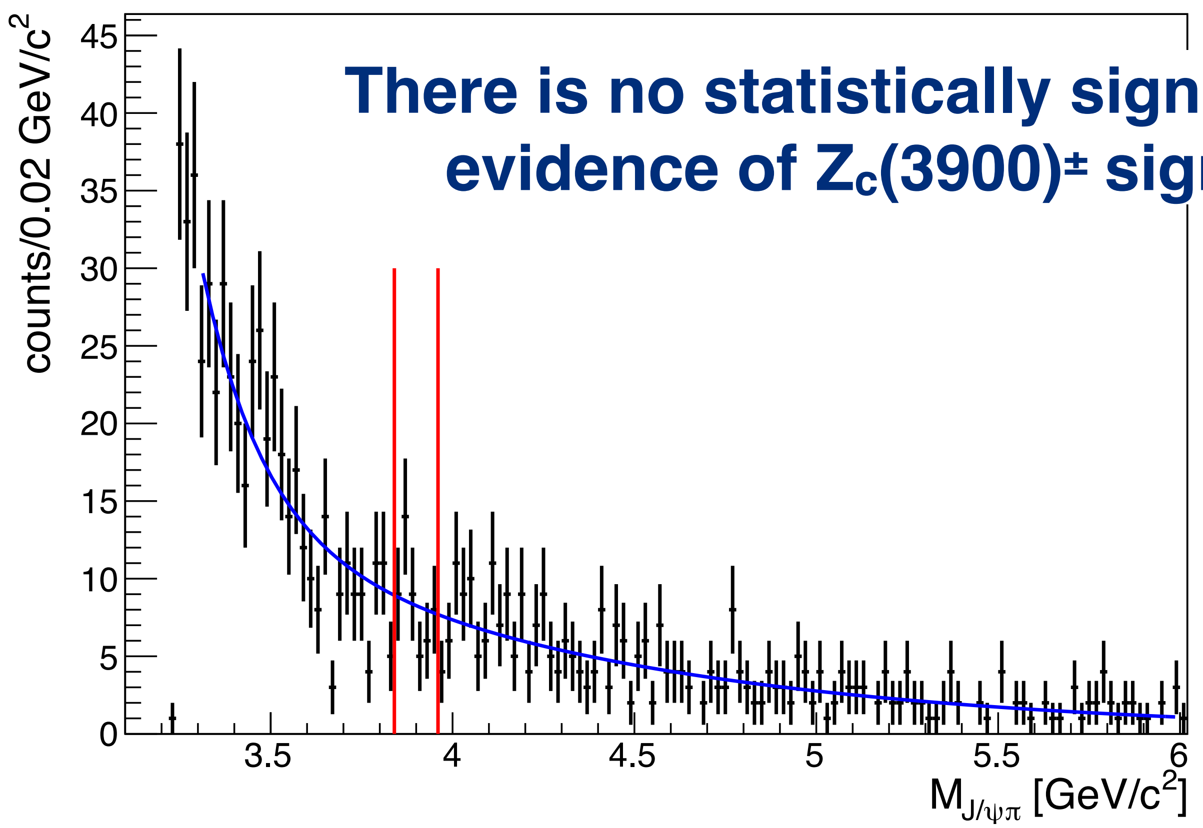
$$M(X_h) - M(X_l) = 2(m_d - m_u)/\cos(2\theta) = $$
$$= (7 \pm 2)/\cos(2\theta)\ \text{MeV}$$

X(3872) → J/ψ ρ → J/ψ $\pi^+\pi^-$: C=+1

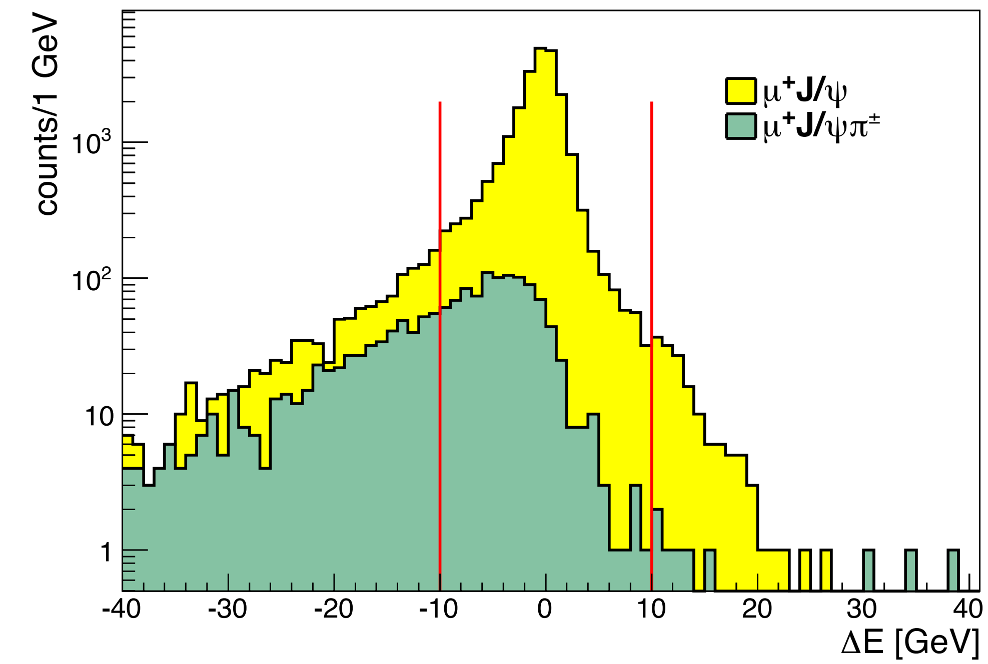
$\tilde{X}$(3872)→ J/ψ σ → J/ψ $\pi^+\pi^-$: C=−1

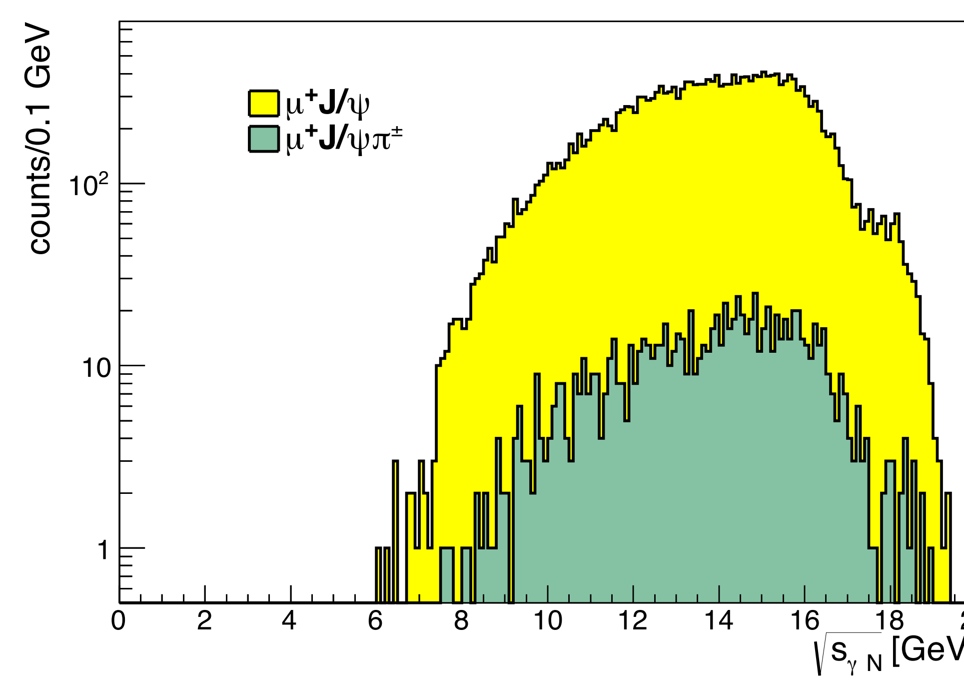
$\gamma N \to (J/\psi\pi^{\pm})N'$





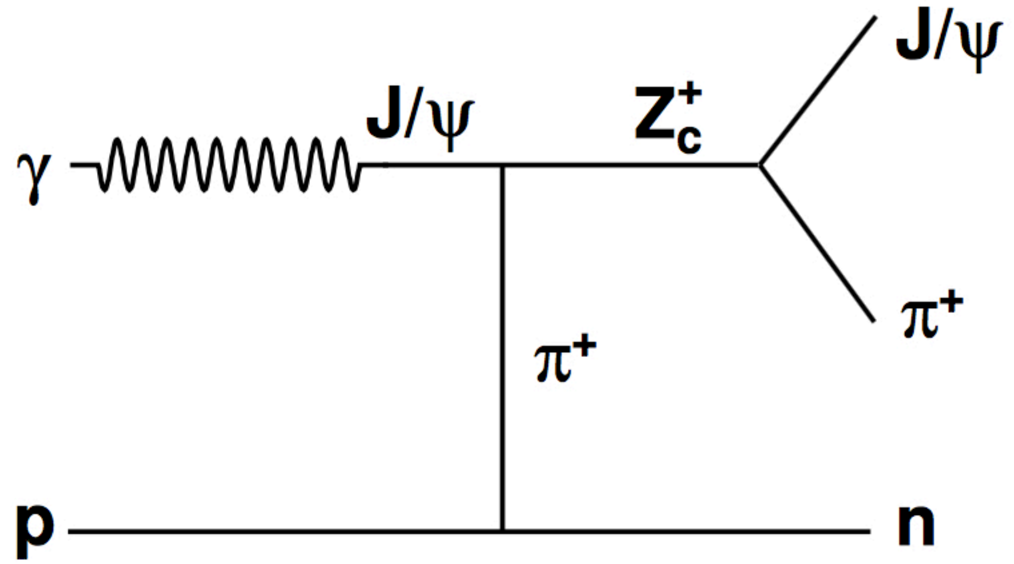
There is no statistically significant evidence of $Z_c(3900)^{\pm}$ signal

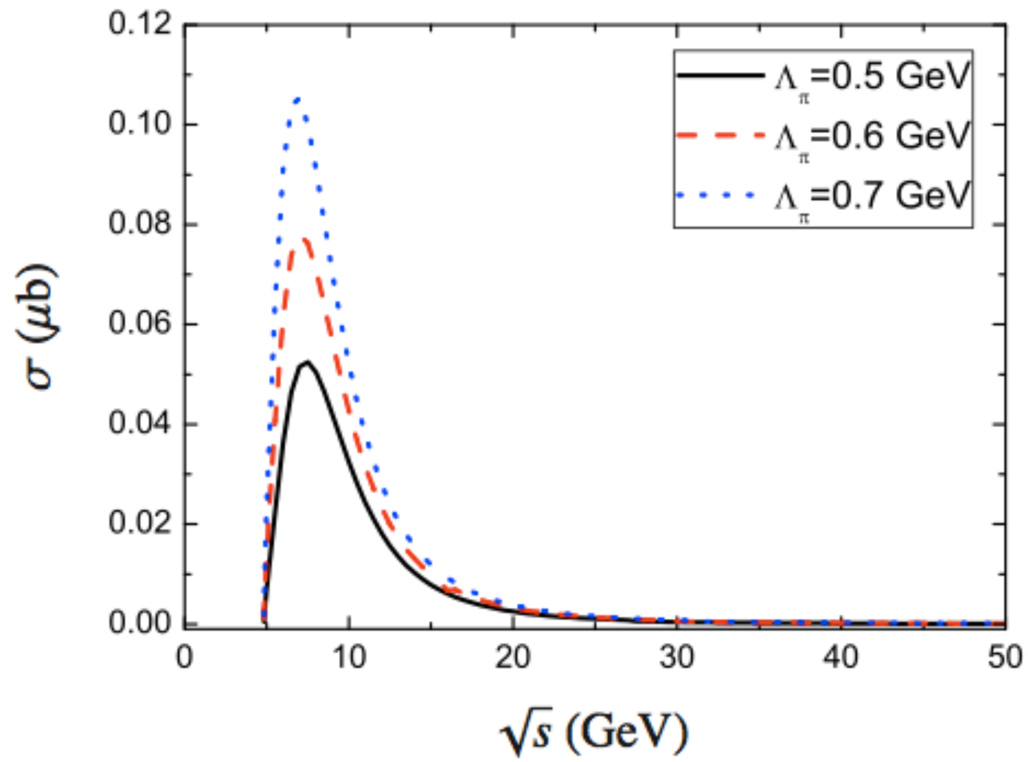


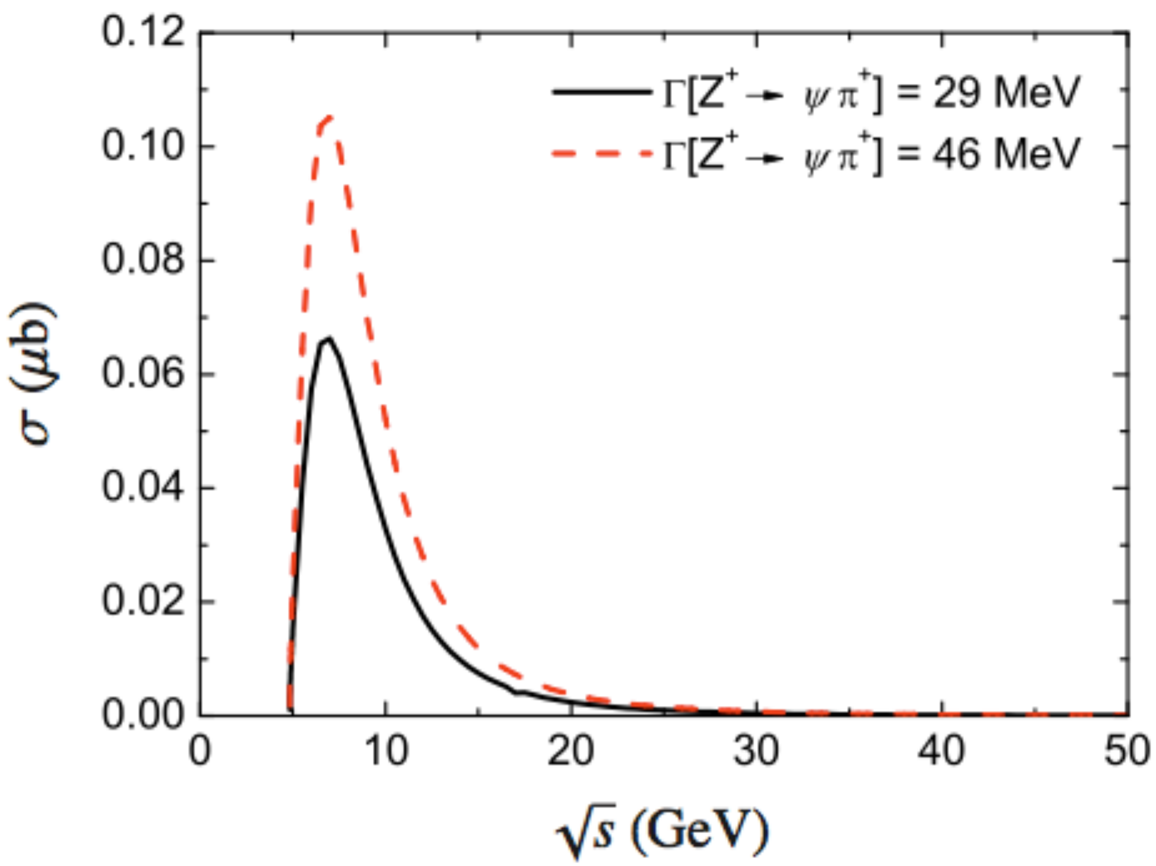


$$BR(Z_c^{\pm}(3900) \to J/\psi\pi^{\pm}) \times \sigma_{\gamma\ N \to Z_c^{\pm}(3900)\ N}\Big|_{\langle\sqrt{s_{\gamma N}}\rangle = 13.8\ \text{GeV}} < 52\ \text{pb}.$$

Model-dependent result



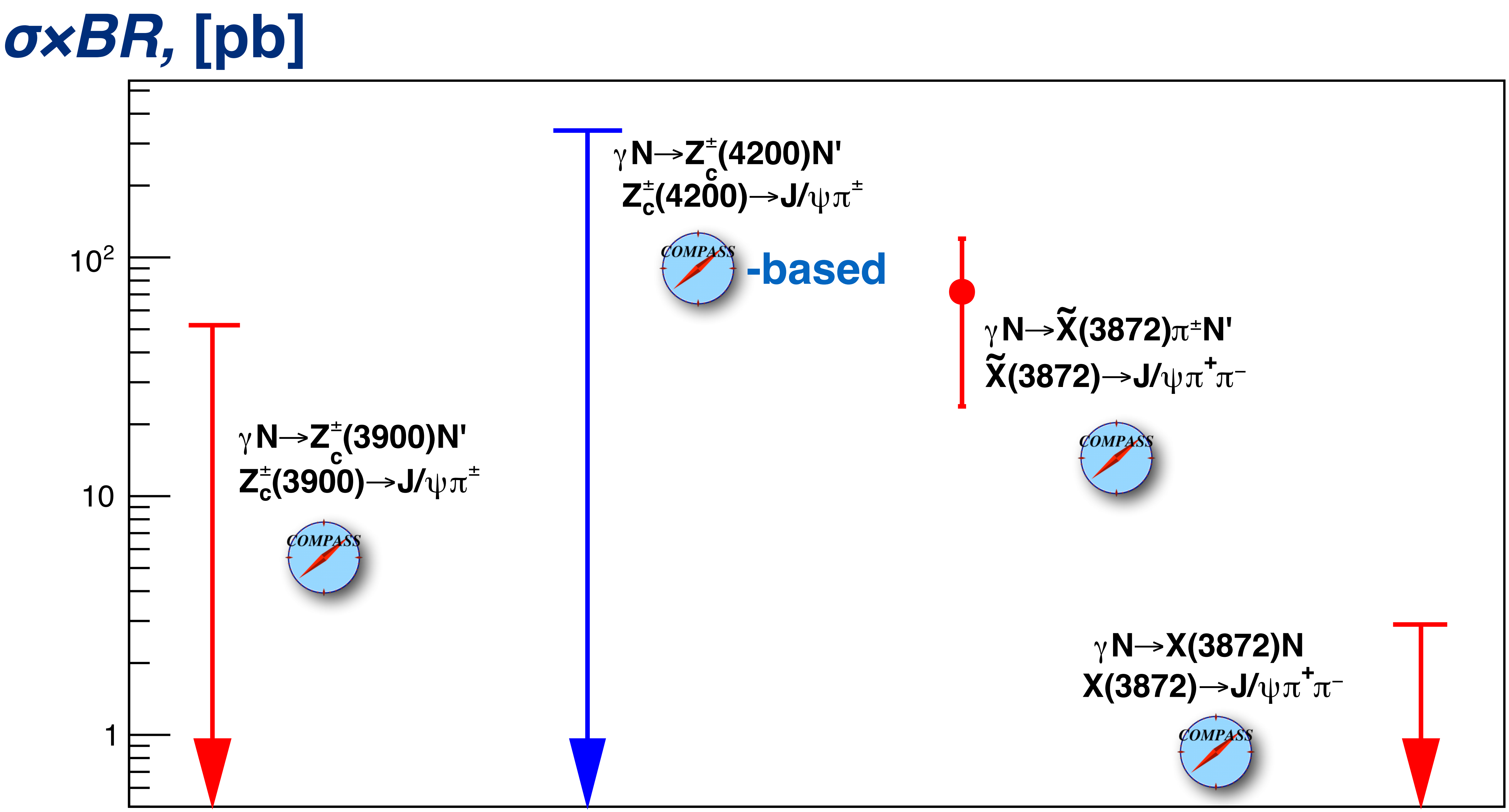




Assuming : Λ_π=0.6 GeV/c, Γ_{tot}=46 MeV we obtained $\Gamma_{J/\psi\pi}$<2.4 MeV that is in agreement with the fact that Z_c(3900)→J/ψπ is not a dominant decay channel

Phys.Lett. B742 (2015) 330-334

Photoproduction results for exotic charmonia



Phys.Lett. B742 (2015) 330

Phys.Rev. D92 (2015) 094017

Phys.Lett. B783 (2018) 334

COMPASS run 2016-2017: new opportunities

Years	P, GeV/c	Target
2002	μ^+,160	^{6}LiD
2003	μ^+,160	^{6}LiD
2004	μ^+,160	^{6}LiD
2006	μ^+,160	^{6}LiD
2007	μ^+,160	NH_3
2010	μ^+,160	NH_3
2011	μ^+,200	NH_3
2016	$\mu^\pm$,160	LH_2
2017	$\mu^\pm$,160	LH_2
2021	μ^+,160	^{6}LiD

Data presently used

COMPASS

COMPASS II

COMPASS++ / AMBER
(Apparatus for Meson and Baryon Experimental Research)
Hard reactions with muon beam, proton radius, charmonia spectroscopy with low-energy antiproton beam, physics with RF-separated kaon beam etc…

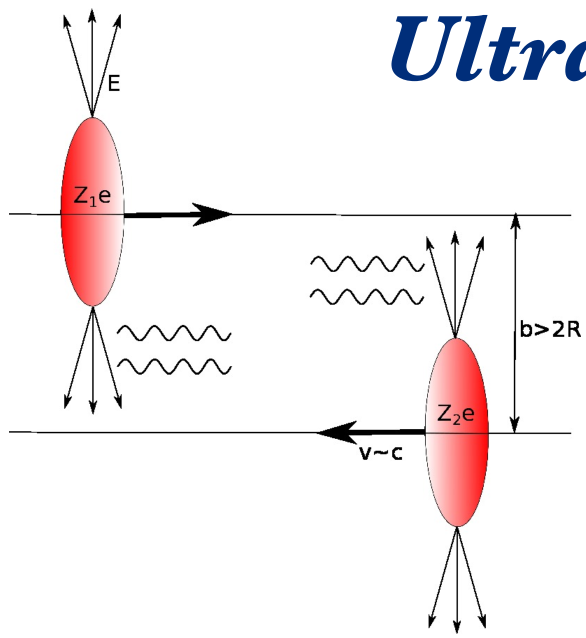
Possibility to search for and study of XYZ hadrons decaying to final states with photons like $J/\psi\pi^0$, $J/\psi\eta$, $J/\psi\omega$, $\chi_{c0,1,2}$ etc.

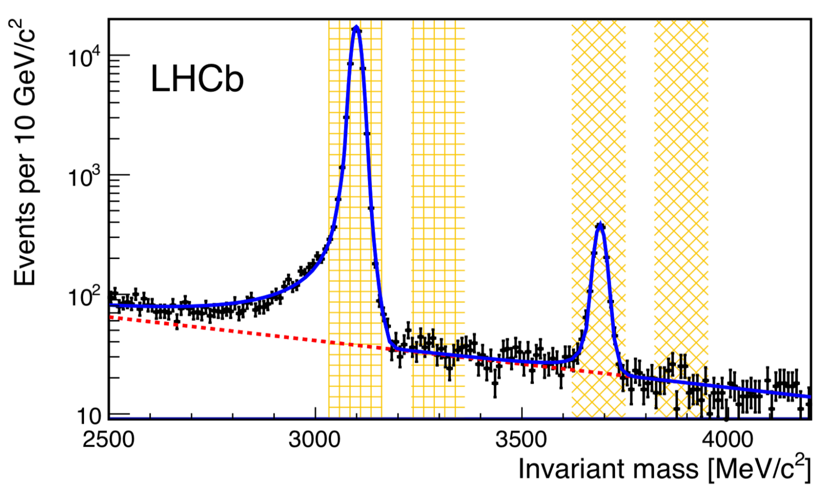
- *2.5 m long liquid hydrogen target transparent for photons ($0.27X_0$) surrounded by a recoil proton detector;*
- *3 electromagnetic calorimeters covering a large aperture.*

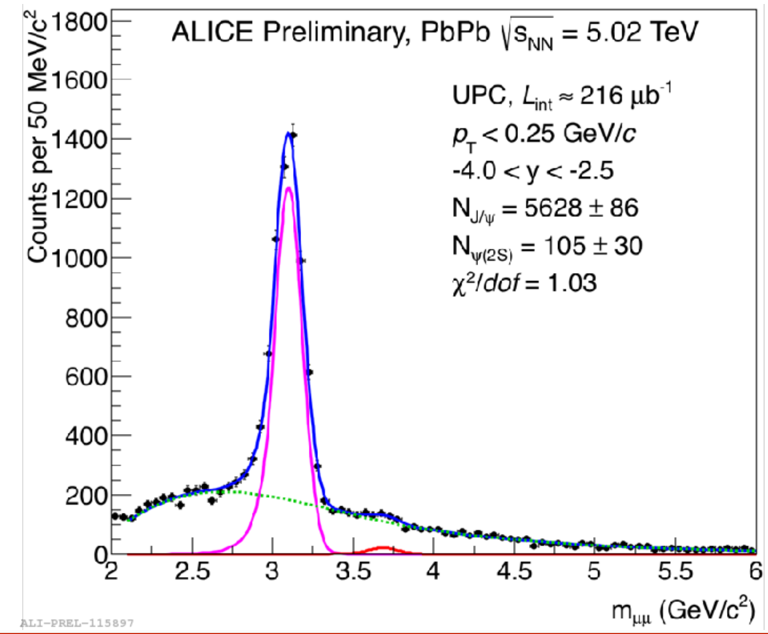
COMPASS is able to increase statistics of photoproduced charmonia to 30-50% only

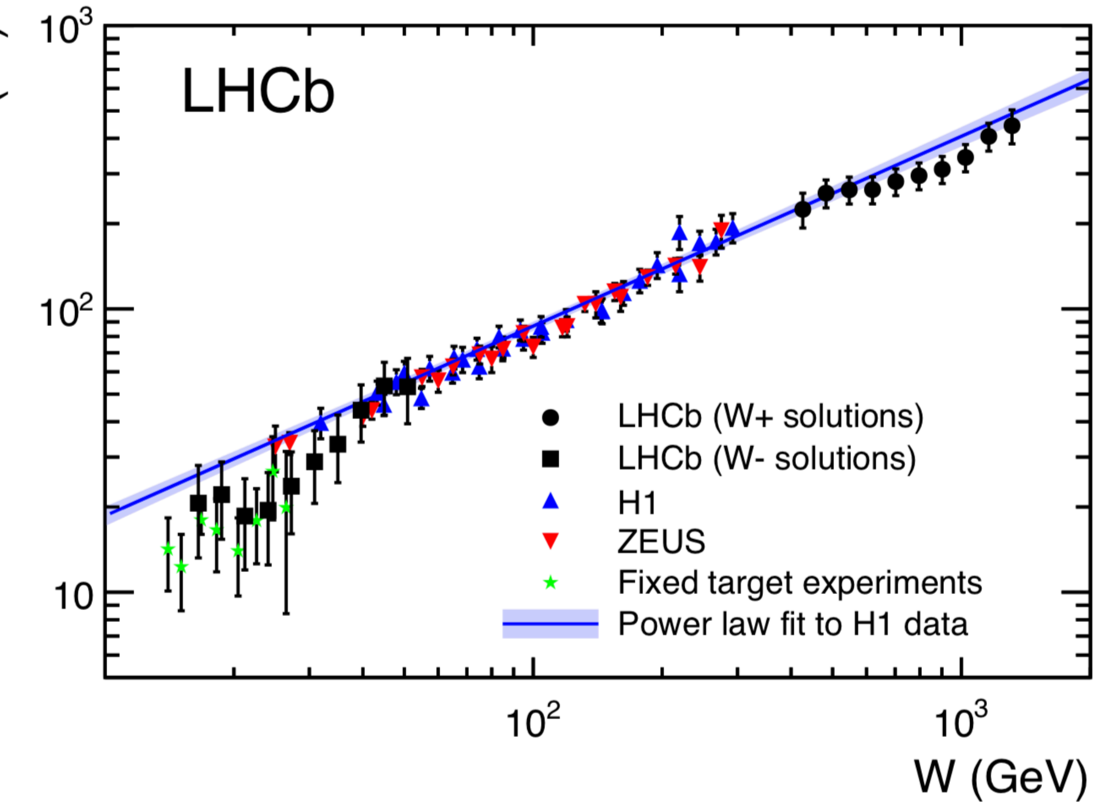
Possibilities at other exps.

Ultraperipheral hadronic collisions at LHC









At COMPASS conditions:

$\sigma_{\mu N} \approx \sigma_{\gamma N} / 300$

EIC $L=10^{34}\ cm^{-2}\ s^{-1}$

$$e^- N \to e^- \widetilde{X}(3872)\pi^\pm N' \to$$

$$\to e^- J/\psi \pi^+\pi^-\pi^\pm N' \to e^-\mu^+\mu^-\pi^+\pi^-\pi^\pm N'$$

~10 events per day

SUMMARY

Indeed exclusive photoproduction of exotic charmonia off a nuclear target is a new opportunity to clarify nature of the XYZ states.

Basing on 7 years of data taking with muon beam COMPASS performed:

- ***first observation of exclusive photoproduction of the X(3872)***
- ***first search for exclusive photoproduction of the $Z_c(3900)^{\pm}$.***

New results from runs 2016-2017 for reactions with photons in the final state are expected.

The next step in study of exotic charmonia photoproduction could be performed using ultraperipheral hadron collisions at LHC (especially at LHC-b) and electron-ion collisions at EIC.