Muoproduction of exotic charmonia at COMPASS

HADRON 2017

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Salamanka
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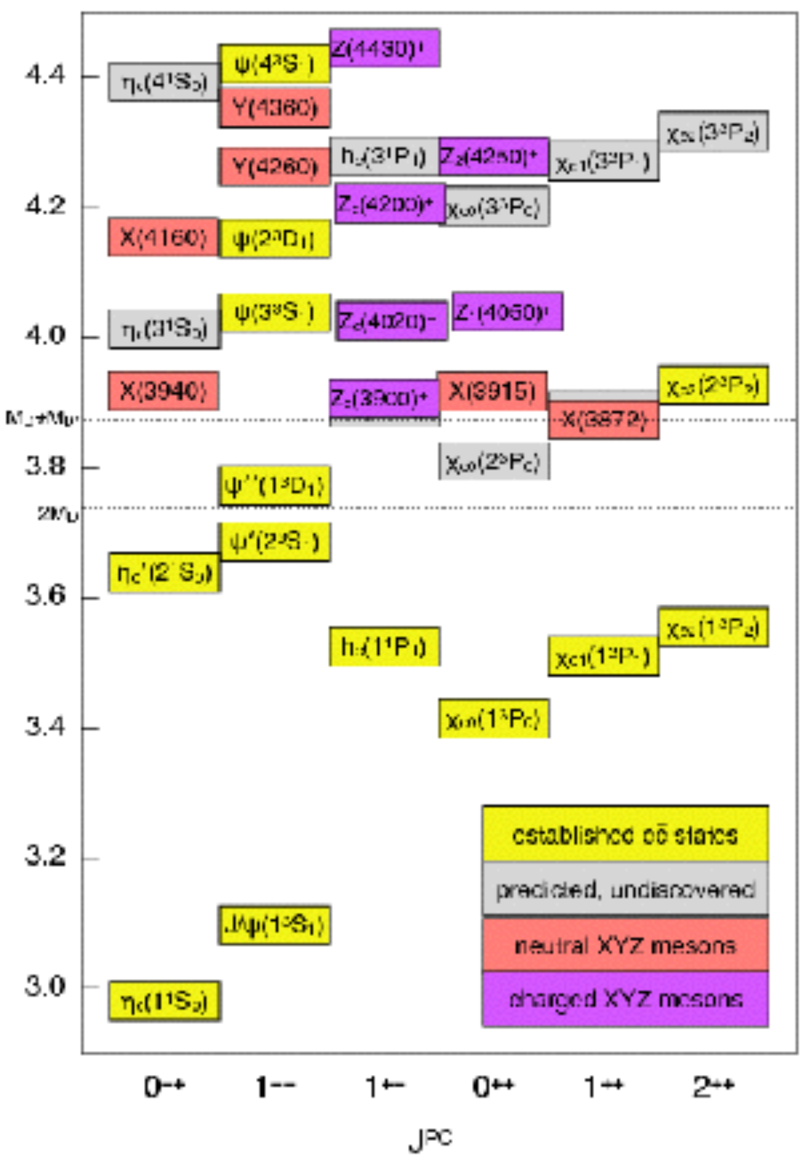
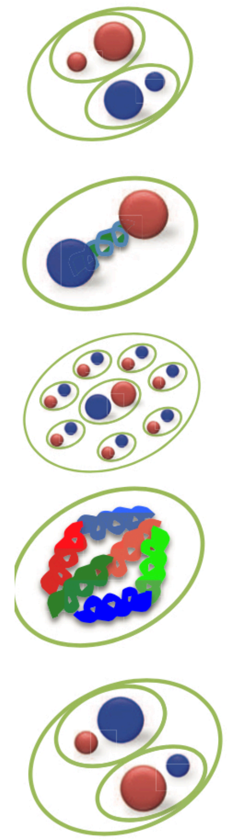
Exotic charmonia





tetraquark

hybrid meson

hadro-quarkonium

glueball

molecule

cusp

…

direct production in e+e- collisions;

direct production in hadron collisions;

B decays;

γ*γ* collisions;

Since discovery of the X(3872) in 2003 by Belle the nature of the XYZ states is still unknown

What about photoproduction?

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

$Z^{\pm}_c(3900)$ (2015)
X(3872) (2017)

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

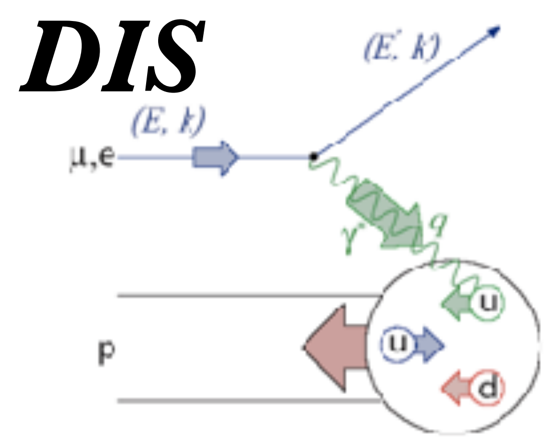
2002-now - Physical data taking

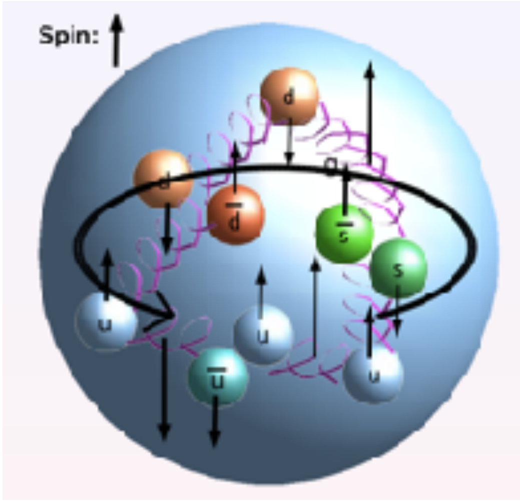
COMPASS: physics with muon and hadron beam

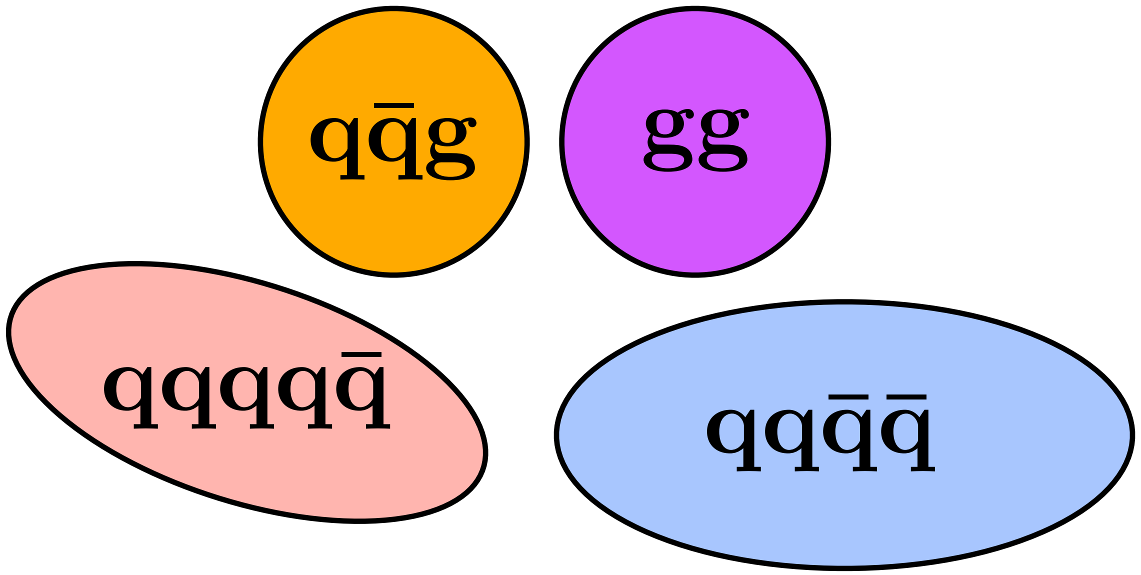
COMPASS ≈ SPIN PHYSICS + SPECTROSCOPY

Study of spin structure of nucleon with muon beam and polarized target:

- *(un)polarized and TMD PDFs and FFs*
- *Generalized PDFs*







Study of hadron structure and hadron spectroscopy with hadron beam:

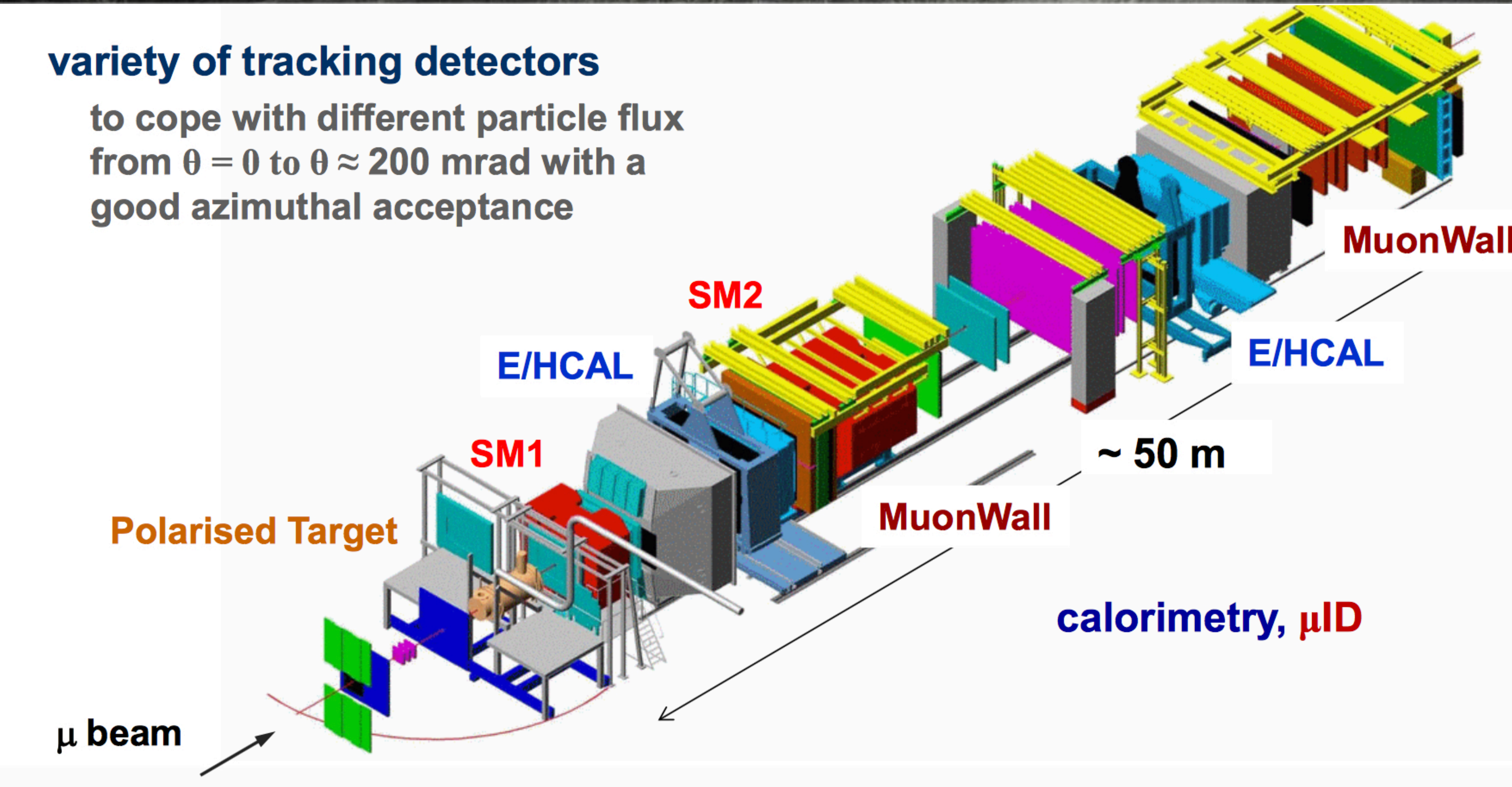
- *Primakoff reactions*
- *diffractive and central production*
- *k_T-dependent PDFs via Drell-Yan process*

Spectroscopy with muon beam:
charmonium-like states

The COMPASS setup

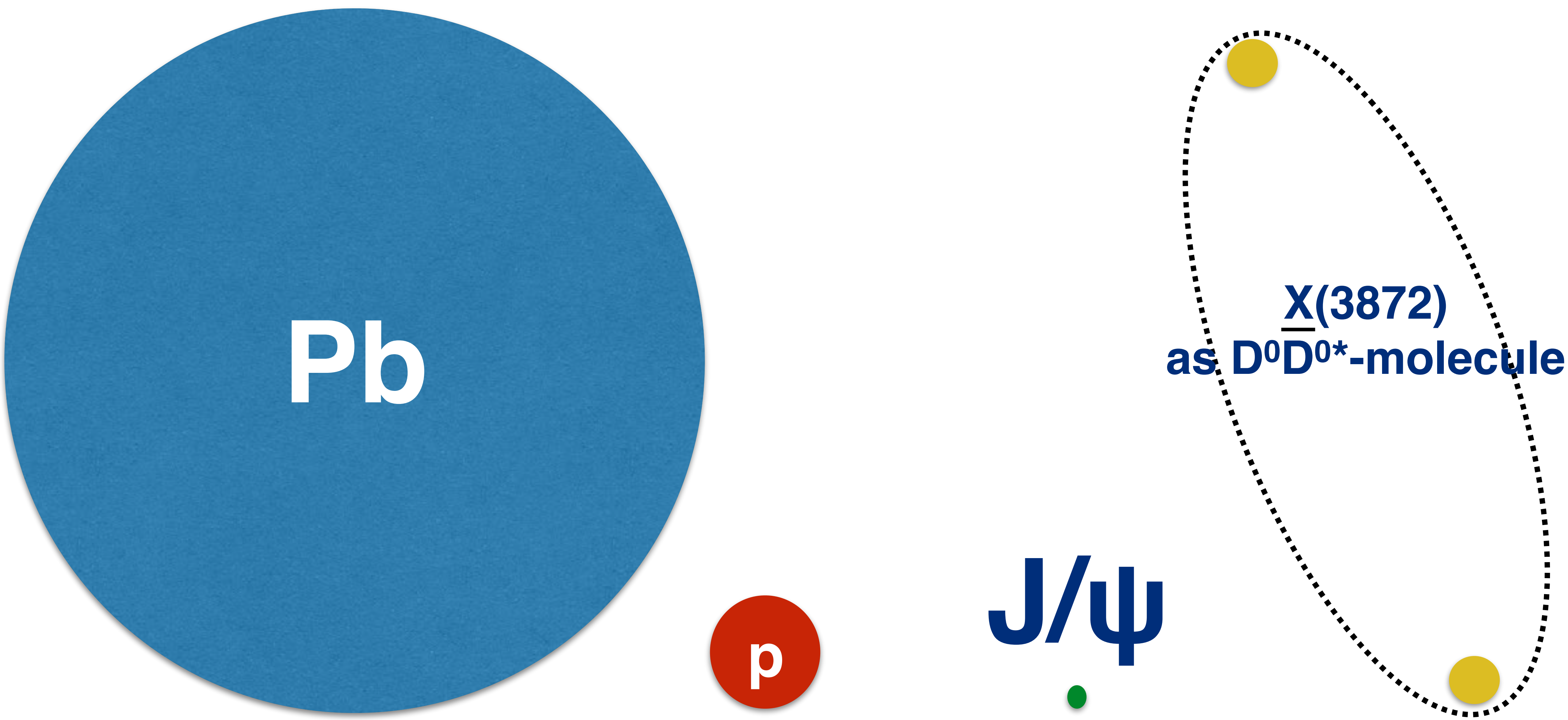
variety of tracking detectors

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



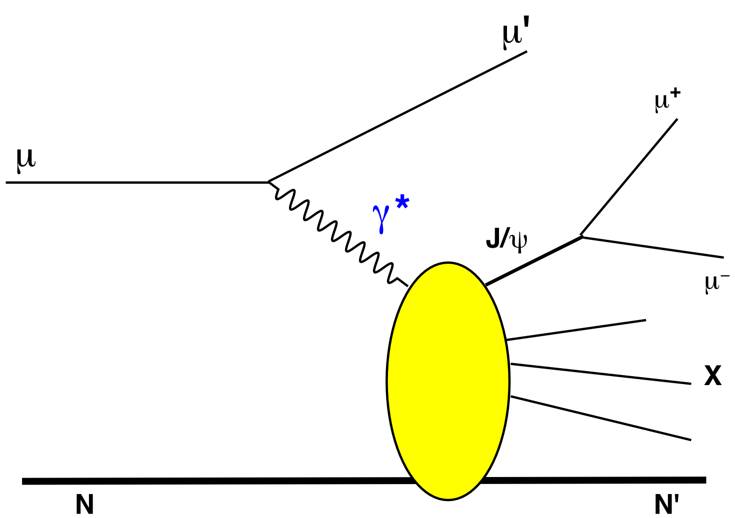
Configuration of the beam and target region depends on the particular physics programme

Charmonia and nuclear matter



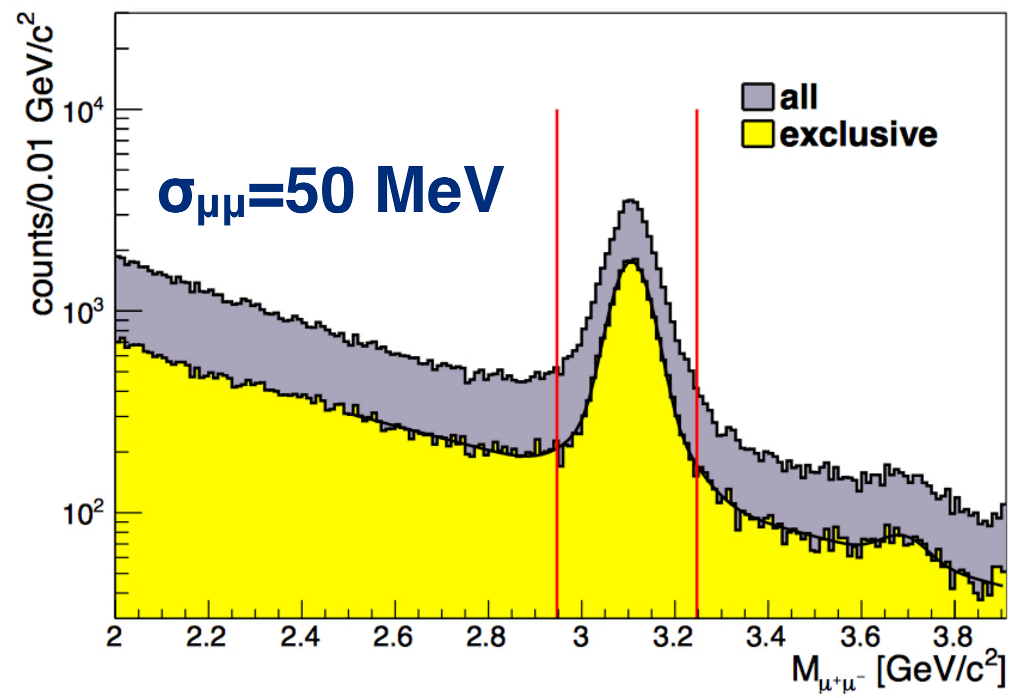
Study of charmonium production and its interaction in nuclear matter is a way to test the nature of the XYZ states

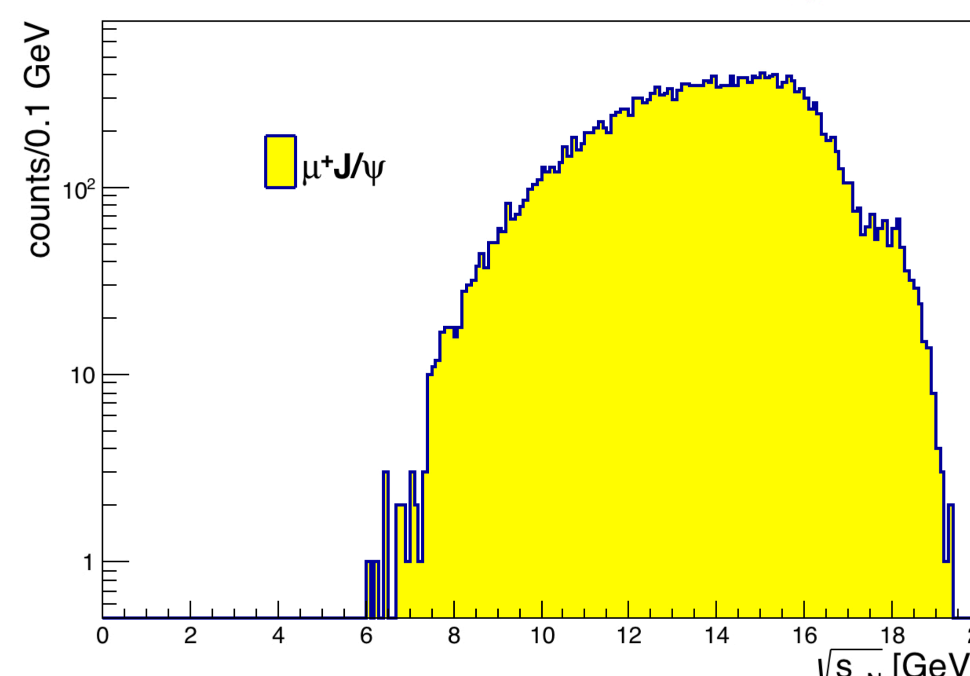
Muoproduction at COMPASS



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

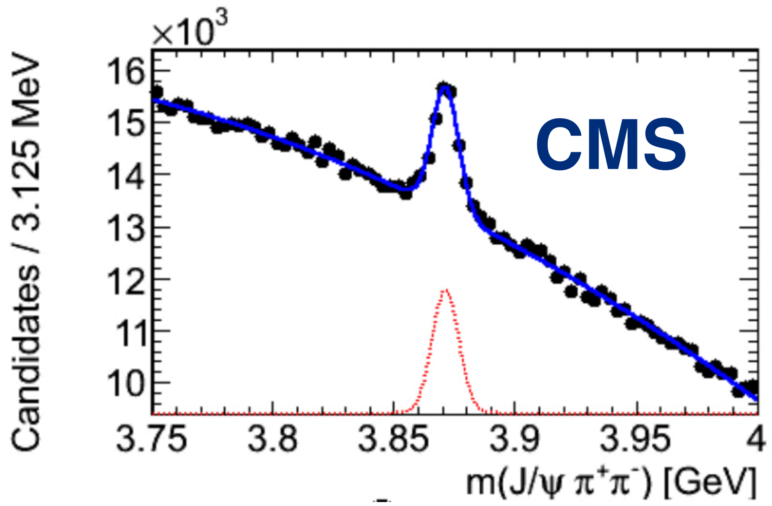
Year	am P, Ge	Target
2002	μ^+,160	^{6}LiD
2003	μ^+,160	^{6}LiD
2004	μ^+,160	^{6}LiD
2006	μ^+,160	^{6}LiD
2007	μ^+,160	NH_3
2010	μ^+,160	NH_3
2011	μ^+,200	NH_3
2016	$\mu^\pm$,160	LH_2
2017	$\mu^\pm$,160	LH_2





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

X(3872)



The first and the most mysterious exotic charmonium state discovered by Belle in 2003

Mass $m = 3871.69 \pm 0.17$ MeV

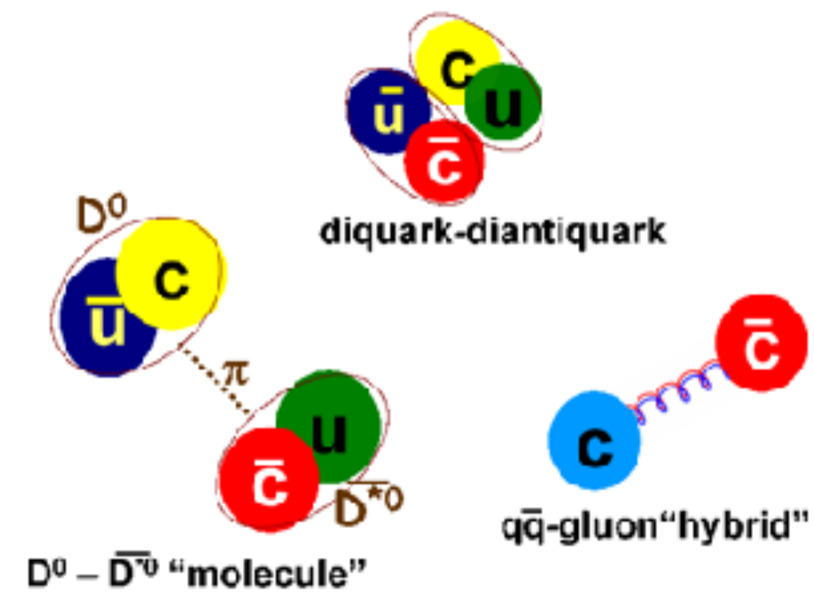
$m_{X(3872)} - m_{J/\psi} = 775 \pm 4$ MeV

Full width $\Gamma < 1.2$ MeV, CL = 90%

$m_{X(3872)} - m_{DD^*} = 0.11 \pm 0.21$ MeV

LHC-b

$I^G(J^{PC}) = 0^+(1^{++})$

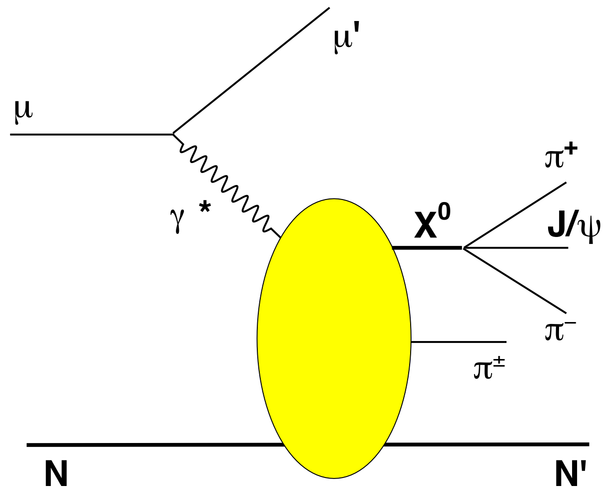


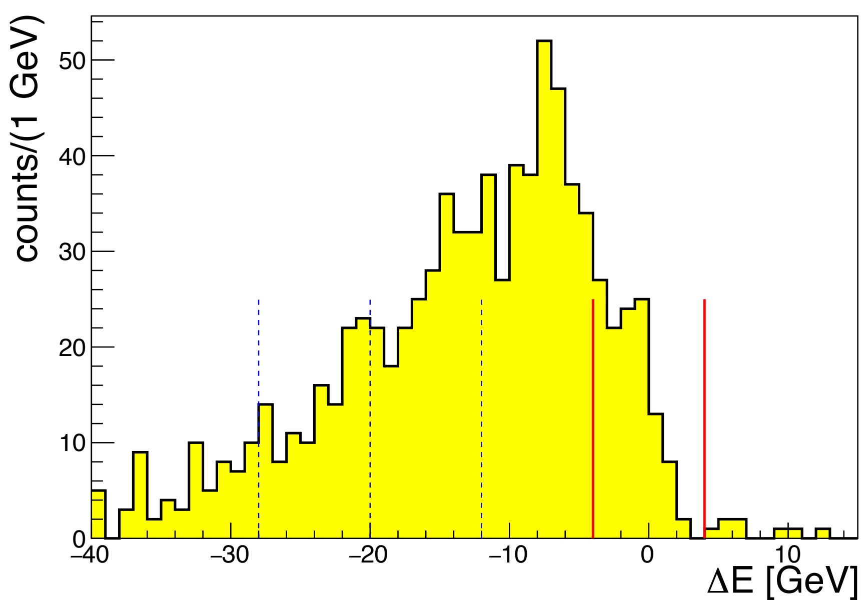
X(3872) DECAY MODES	Fraction (Γ_i/Γ)
$\pi^+\pi^- J/\psi(1S)$	> 2.6 %
$\omega J/\psi(1S)$	> 1.9 %
$D^0 \overline{D}^0 \pi^0$	>32 %
$\overline{D}^{*0} D^0$	>24 %
$\gamma J/\psi$	$> 6 \times 10^{-3}$
$\gamma \psi(2S)$	> 3.0 %
$\pi^+\pi^- \eta_c(1S)$	not seen
$\pi^+\pi^- \chi_{c1}$	not seen
$p\overline{p}$	not seen

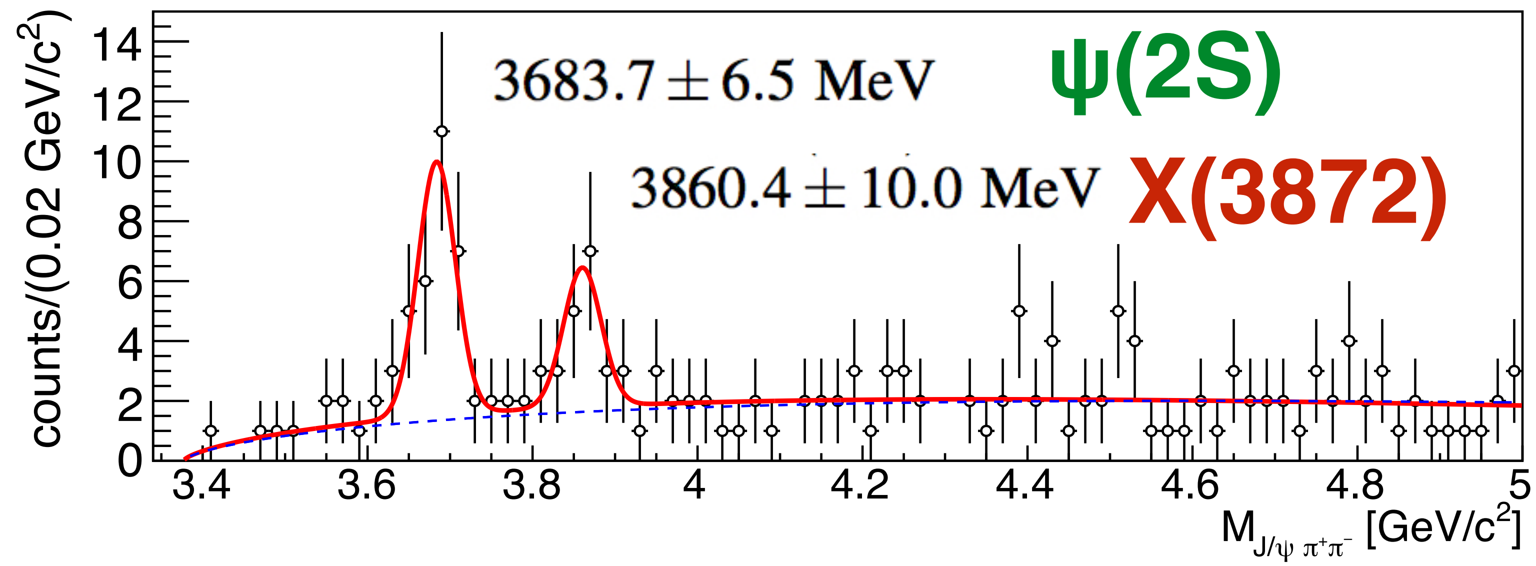
Strong isospin violation:

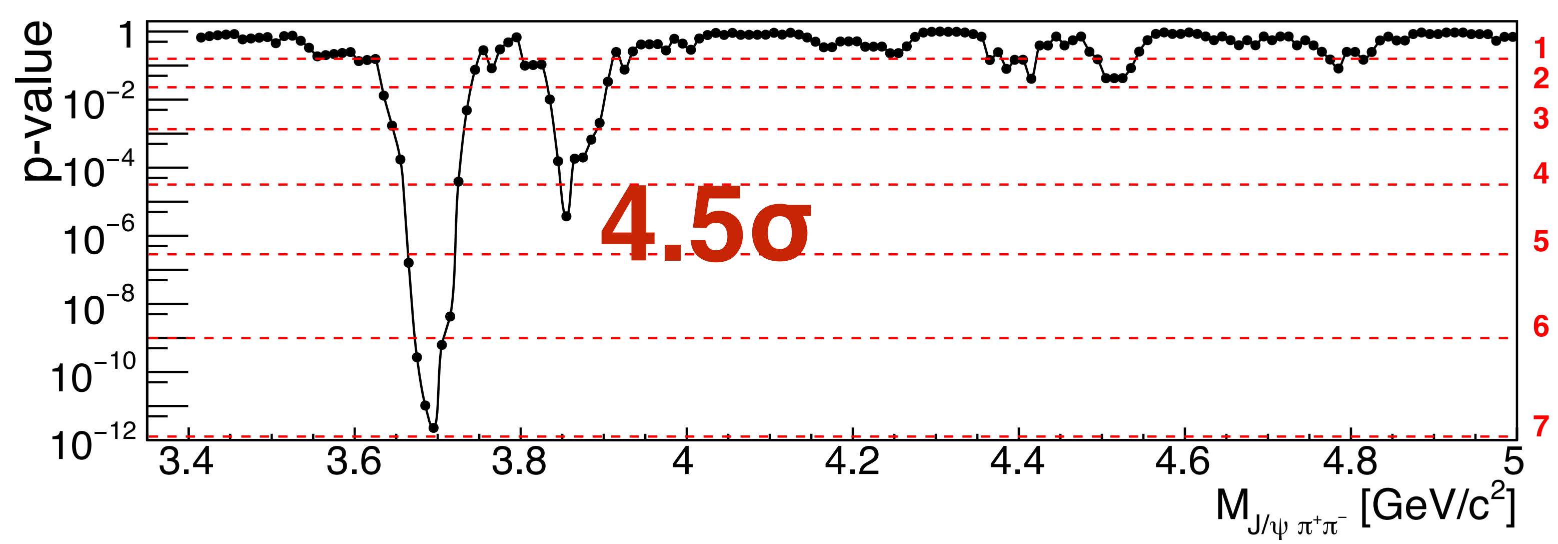
$\Gamma(\omega J/\psi(1S))/\Gamma(\pi^+\pi^- J/\psi(1S)) = \mathbf{0.8 \pm 0.3}$

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







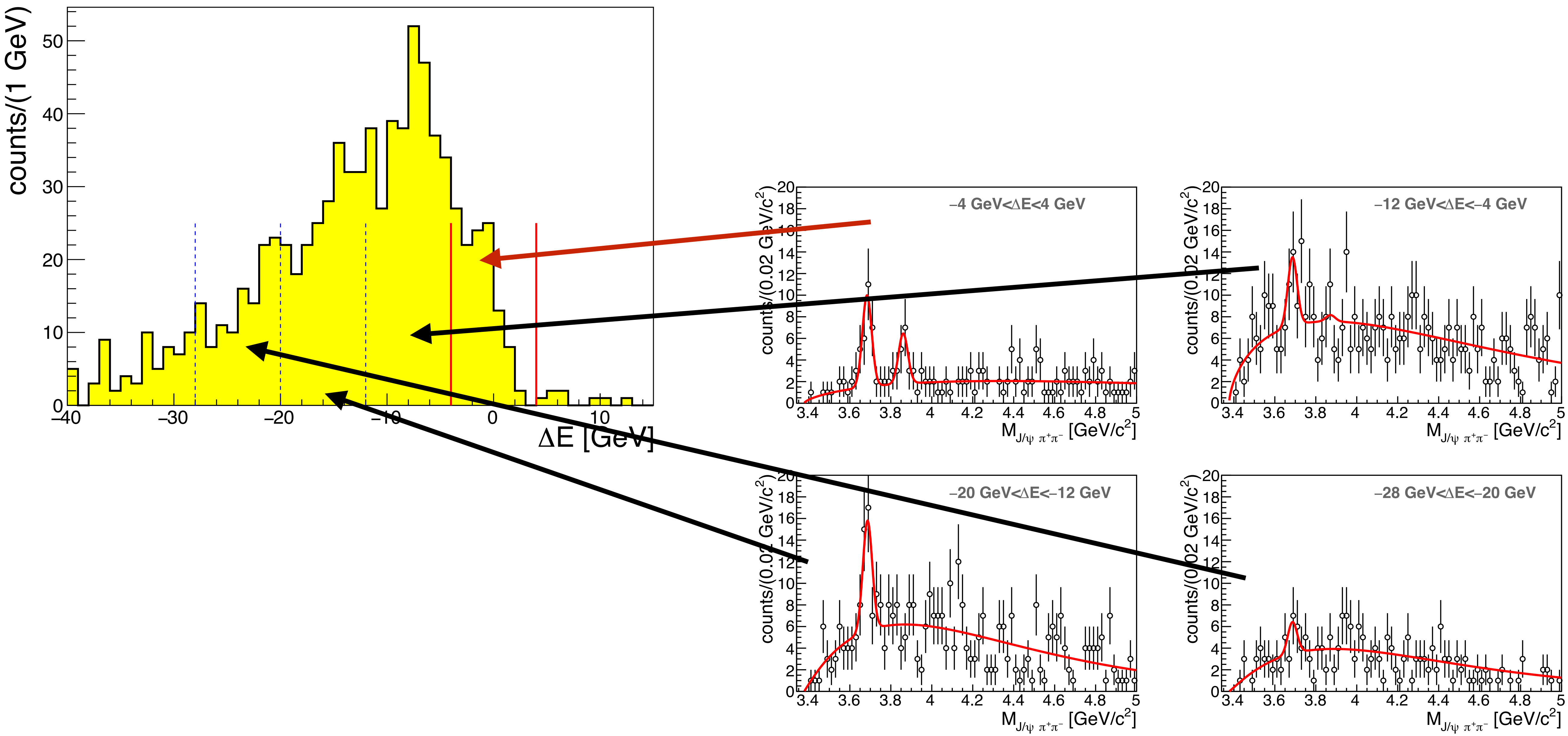


$$f(m) = Gaus(N_{\psi(2S)}, M_{\psi(2S)}, \sigma_M) + Gaus(N_{X(3872)}, M_{X(3872)}, \sigma_M) + c_1(m - m_0)^{c_2} e^{-c_3 m}.$$

σ_M=22.8±6.9 MeV

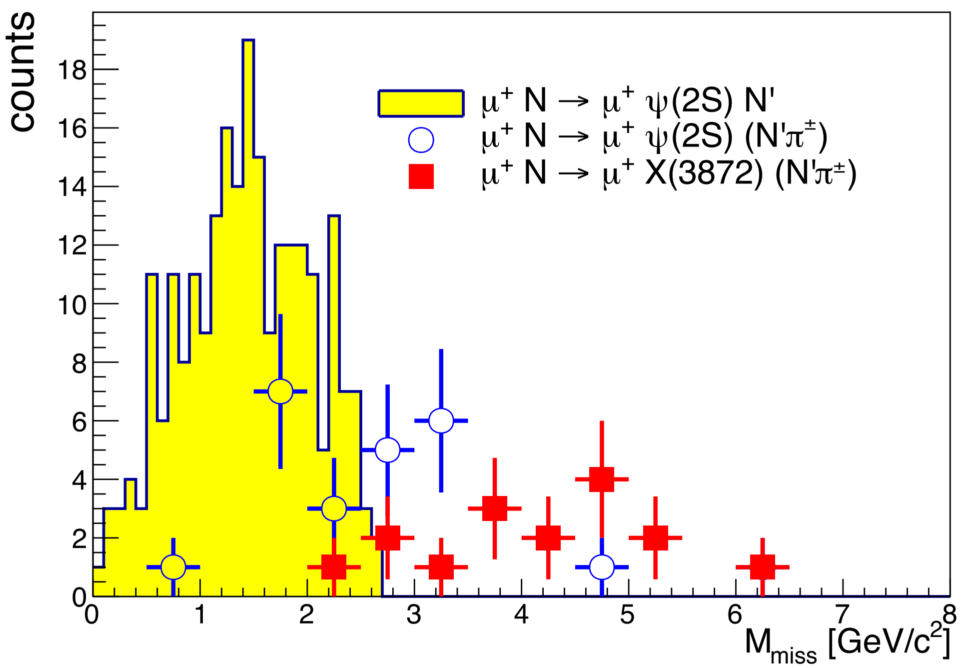
$N_{(X3872)}$=13.2±5.2 events

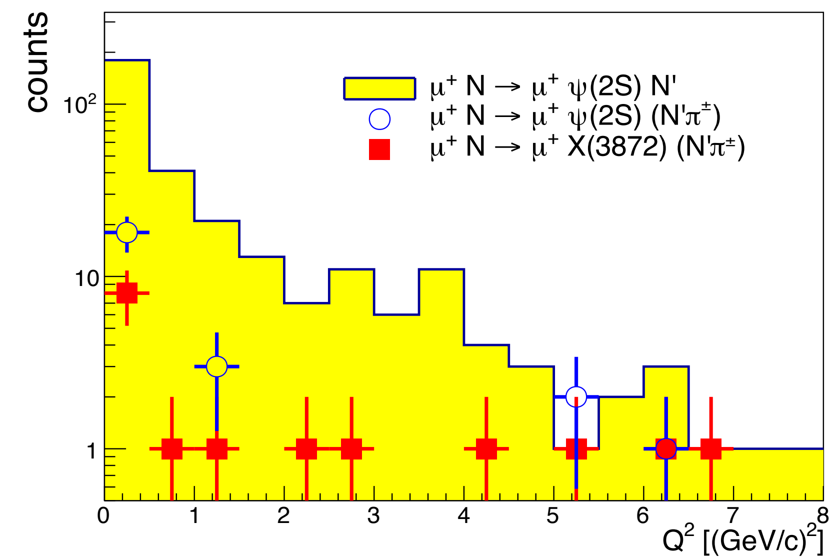
$\gamma N \rightarrow (J/\psi\pi^+\pi^-)\pi^\pm N'$

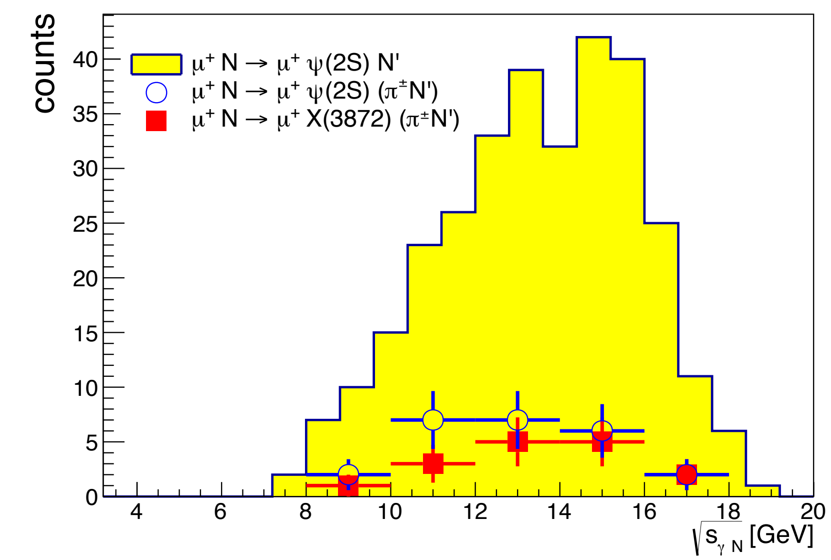


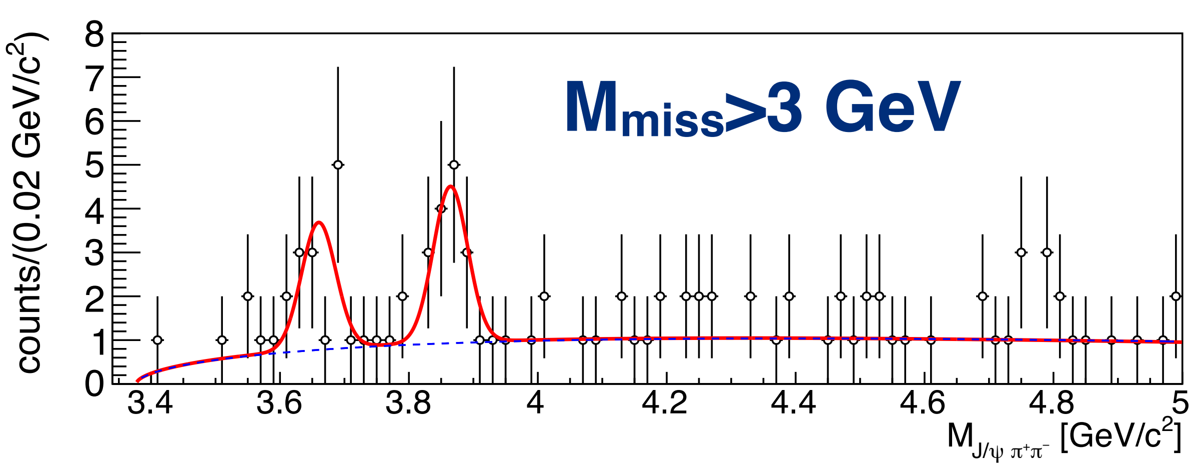
No statistically significant evidence of X(3872) in our nonexclusive sample

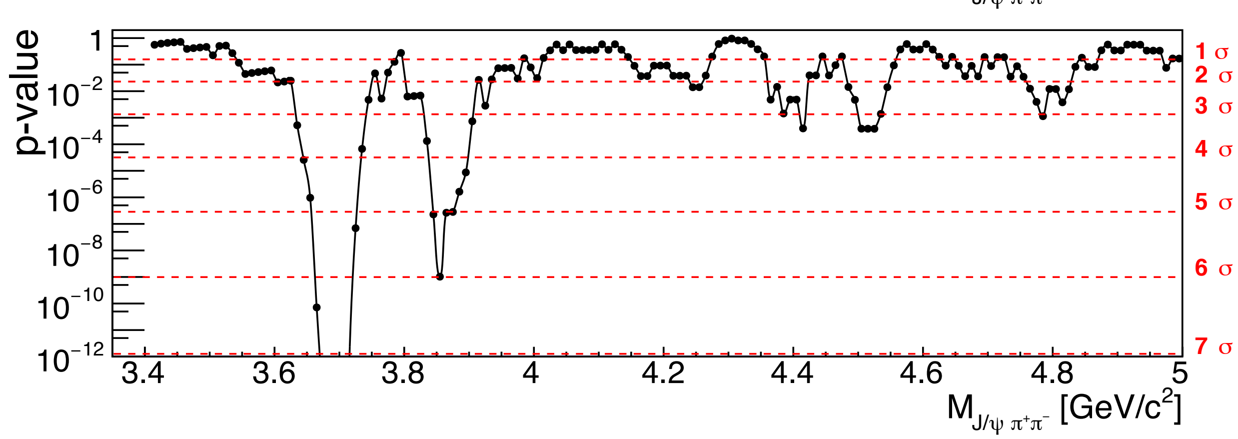
Production kinematics



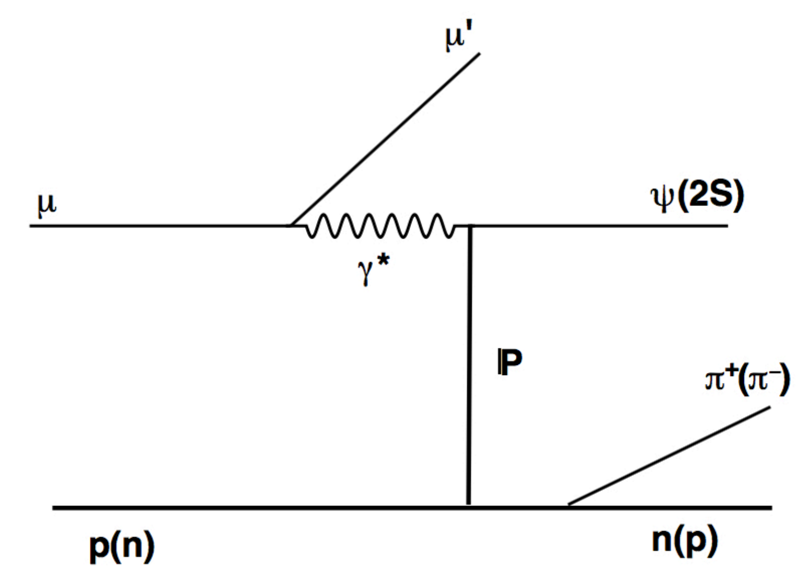






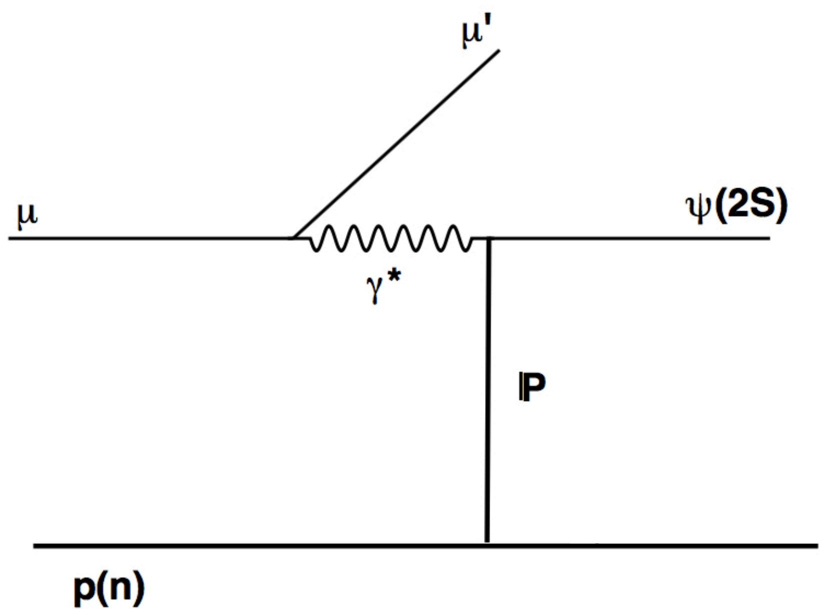


Obvious mechanism of ψ(2S) production is:

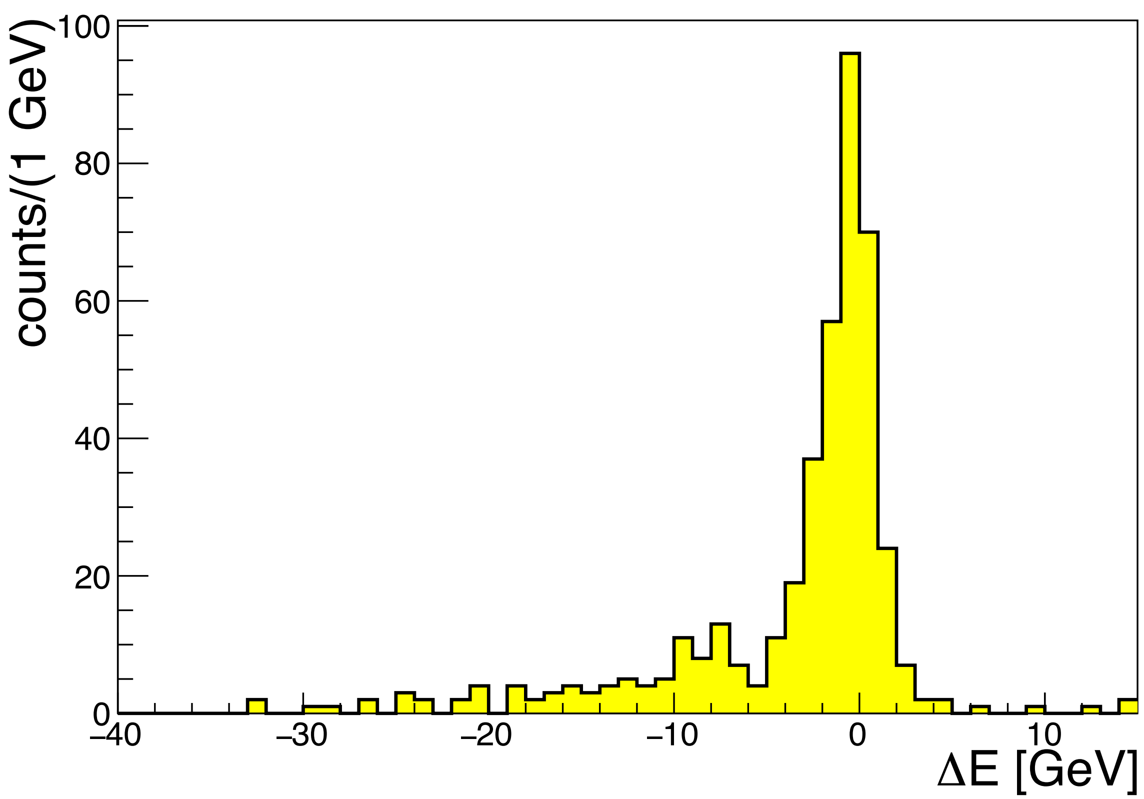


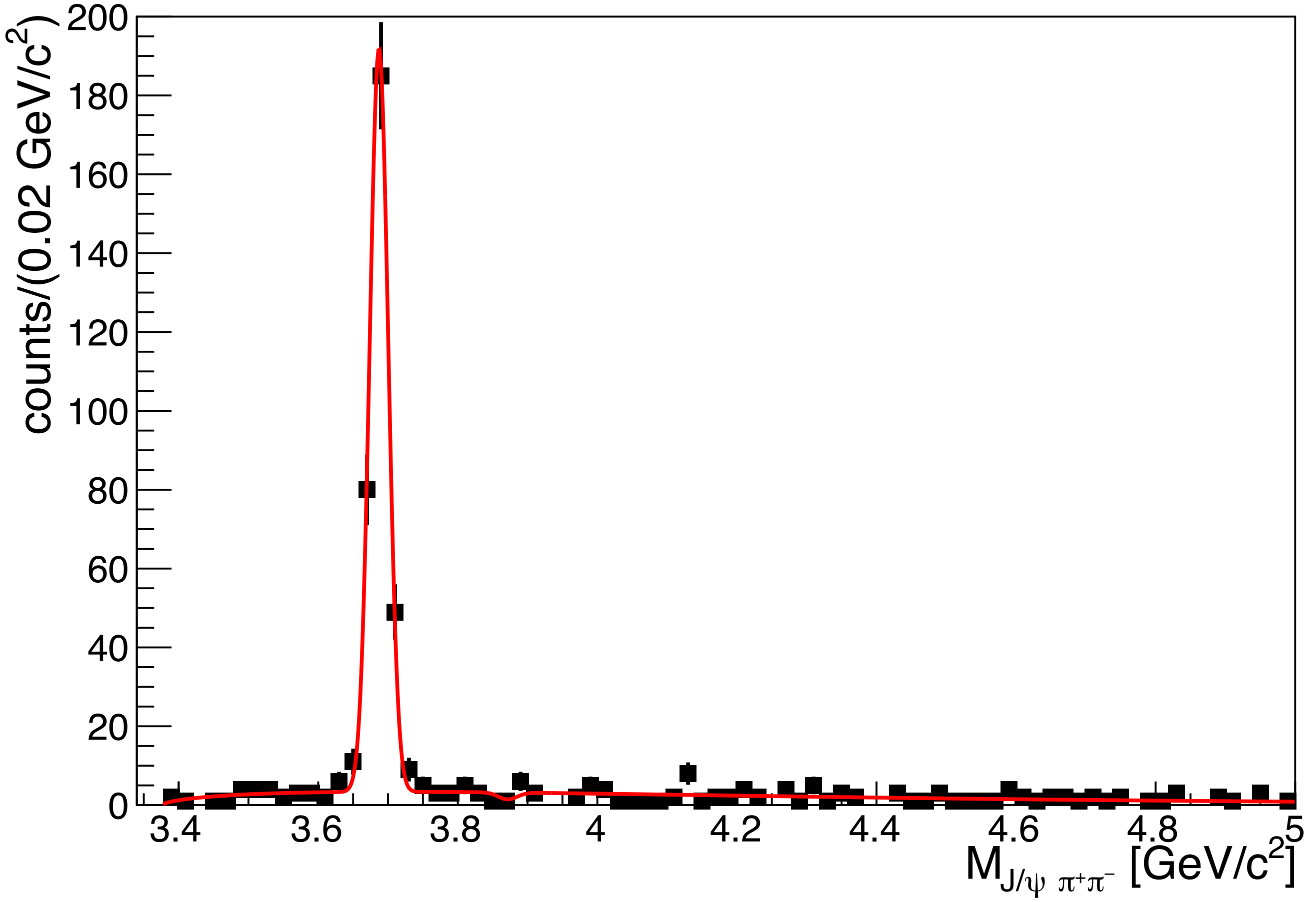
but it seems, X(3872) is produced via different mechanism…

γN→(J/ψπ⁺π⁻)N



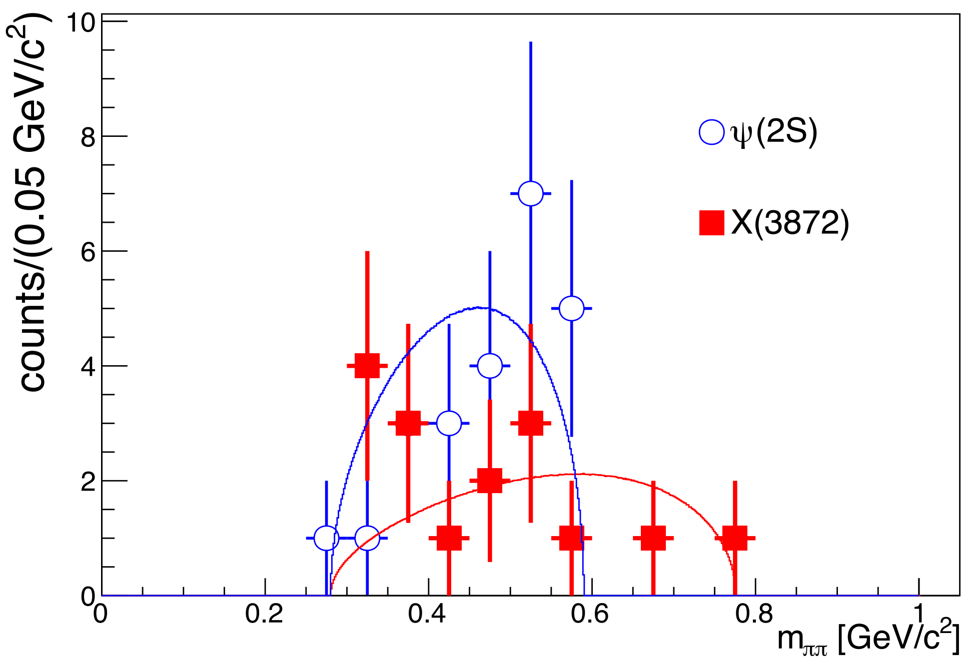
Obvious production mechanism for ψ(2S)

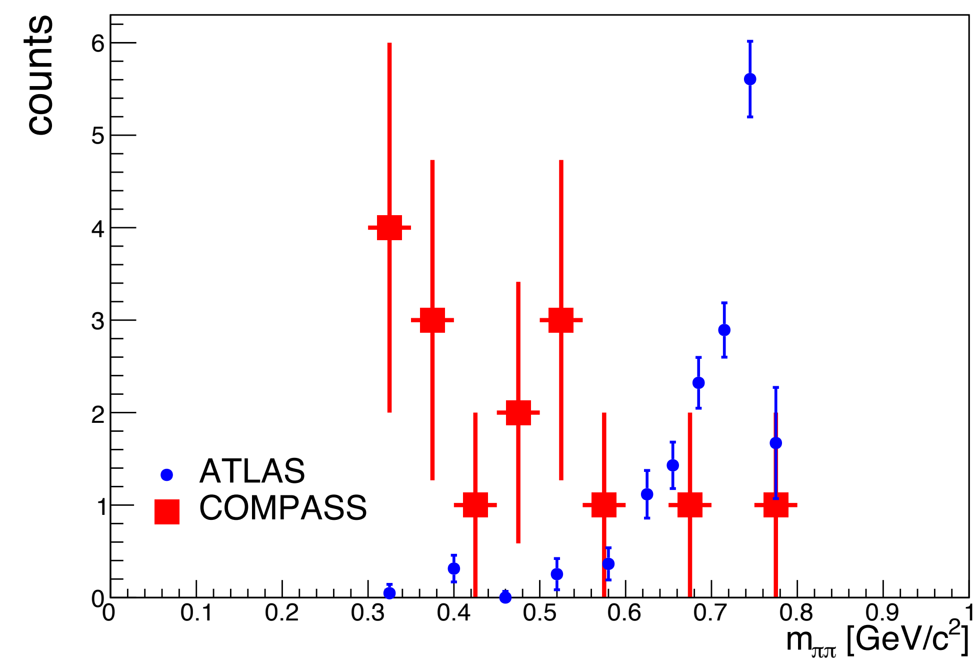




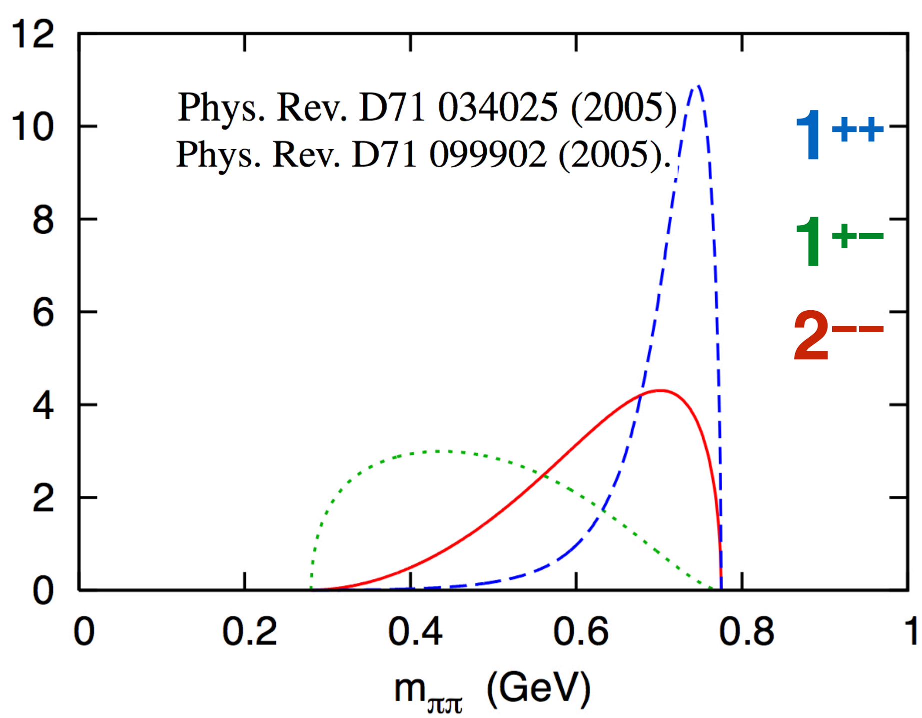
No evidence of X(3872)

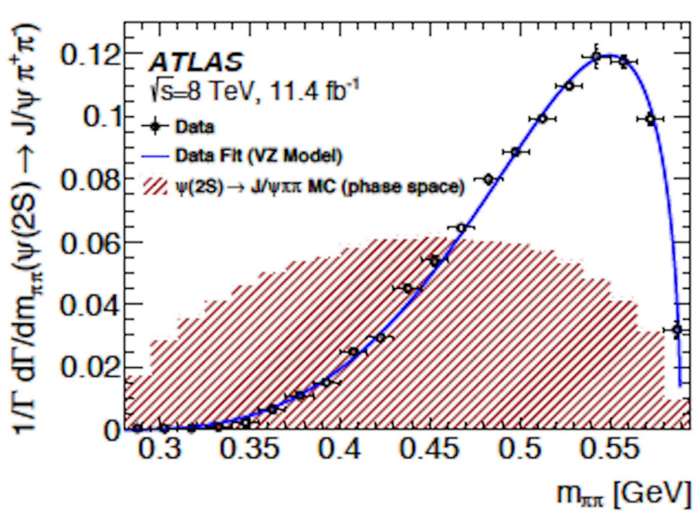
Two pion mass spectrum

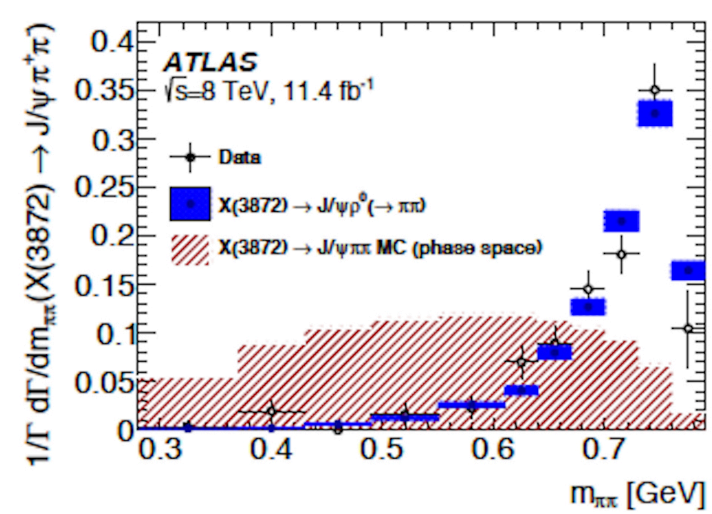




The shape of the ππ-mass spectrum observed by COMPASS for ψ(2S) is in agreement with previous results while our result for X(3872) is in tension with previous observations.

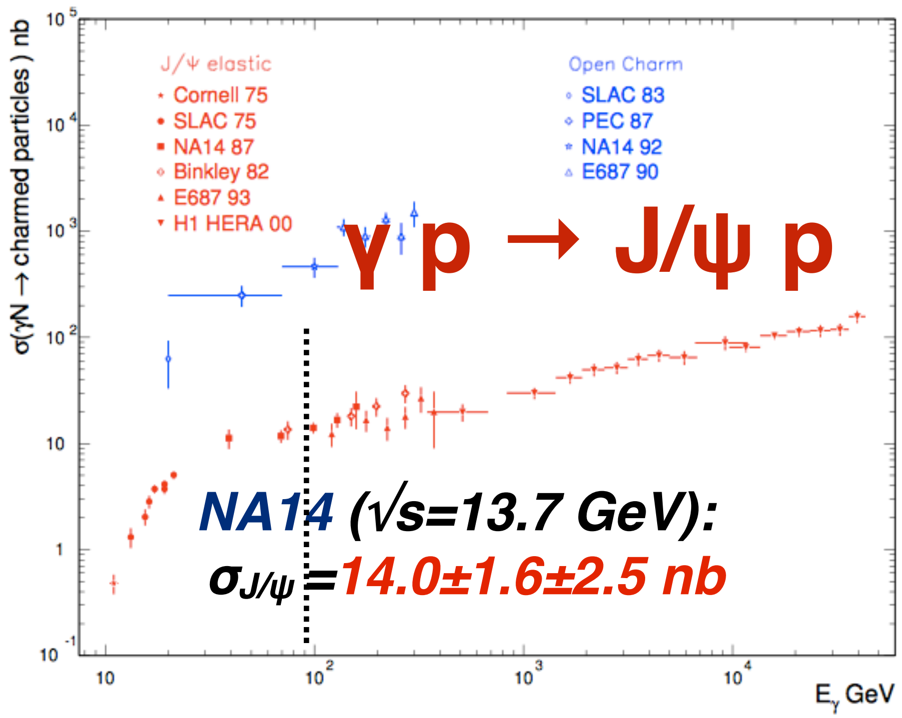


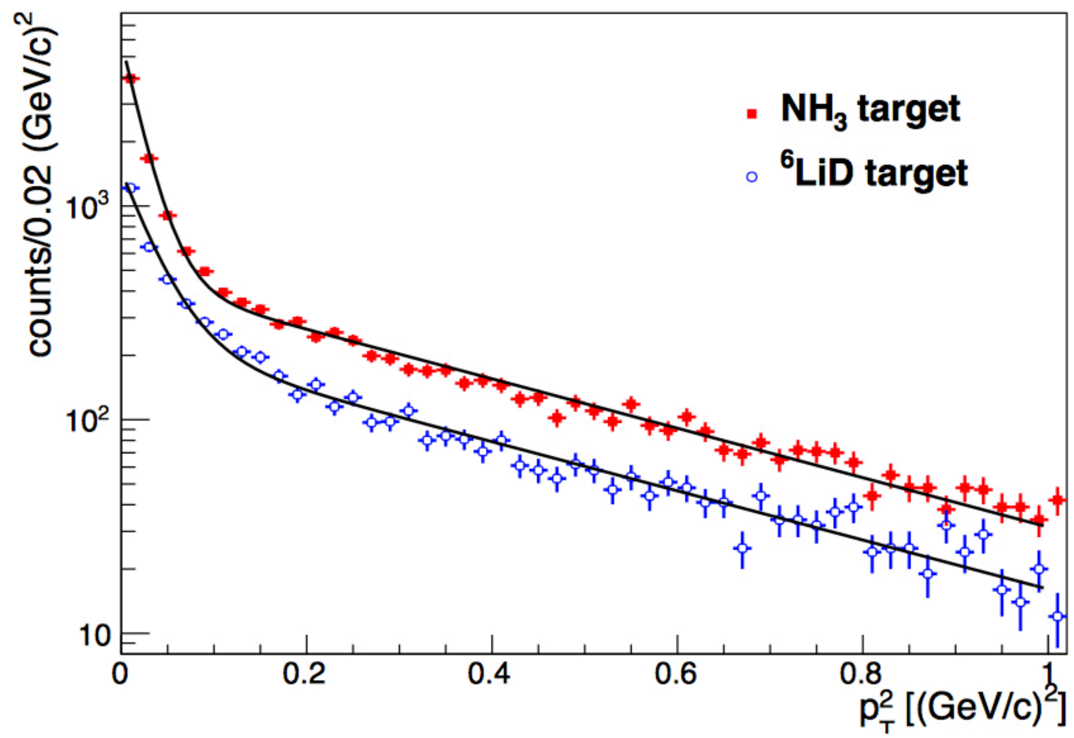


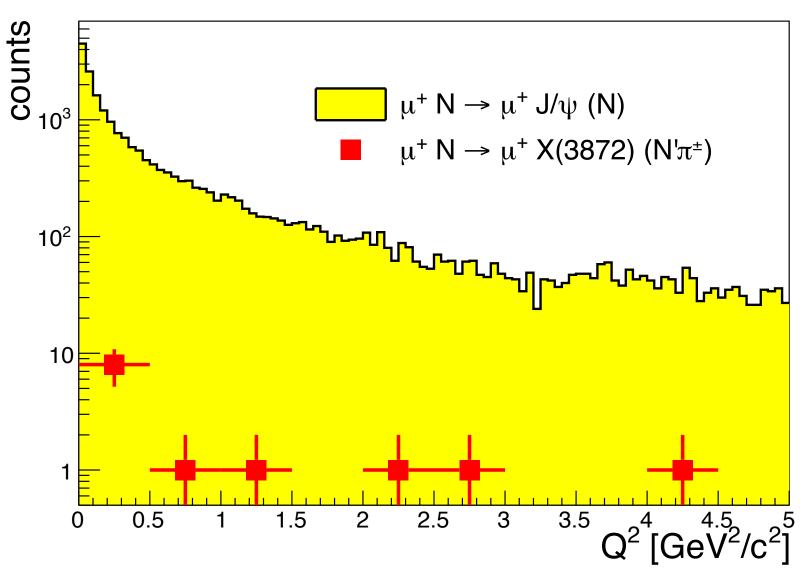


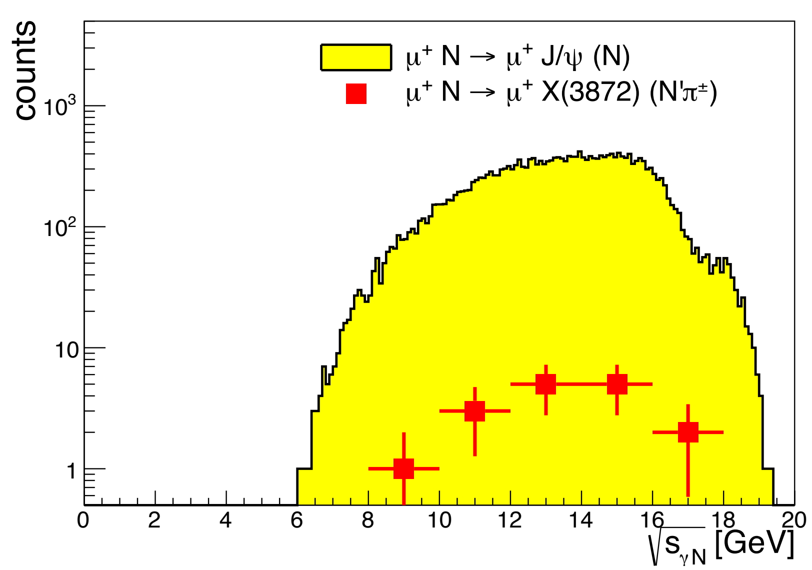
It looks like an evidence of a component in X(3872) different from 1^{++}

Absolute production rate for X(3872)









we assume the same flux of virtual photons :

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

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

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

X(3872): summary

We observed muoproduction of exotic hadron X(3872) with a significance up to 6σ in the reaction $\gamma N \to (J/\psi \pi^+ \pi^-) \pi^\pm N'$.

Absolute production rate is determined.

Our observation for the two-pion mass spectrum shows disagreement with previous experimental results.

It could be an indication that the *X*(3872) object could contain a component with quantum numbers different from 1^{++}.

$Z_c(3900)^{\pm}$

X(3900)

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 3886.6 \pm 2.4$ MeV (S = 1.6)
Full width $\Gamma = 28.1 \pm 2.6$ MeV

	Mode	Fraction (Γ_i/Γ)
Γ_1	$J/\psi\pi$	seen
Γ_2	$h_c\pi^{\pm}$	not seen
Γ_3	$\eta_c\pi^+\pi^-$	not seen
Γ_4	$(D\overline{D}^*)^{\pm}$	seen
Γ_5	$D^0 D^{*-}$ + c.c.	seen
Γ_6	$D^- D^{*0}$ + c.c.	seen
Γ_7	$\omega\pi^{\pm}$	not seen
Γ_8	$J/\psi\eta$	not seen
Γ_9	$D^+ D^{*-}$ + c.c	seen
Γ_{10}	$D^0 \overline{D}^{*0}$ + c.c	seen

$\Gamma((D\overline{D}^*)^{\pm})/\Gamma(J/\psi\pi)$

VALUE
6.2±1.1±2.7

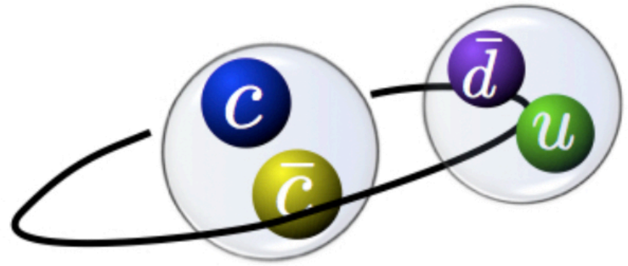
What is $Z_c(3900)$?

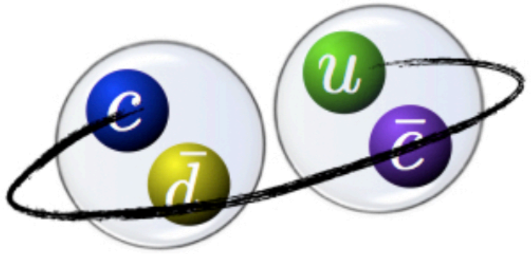
tetraquark

$D\overline{D}^*$ molecular state

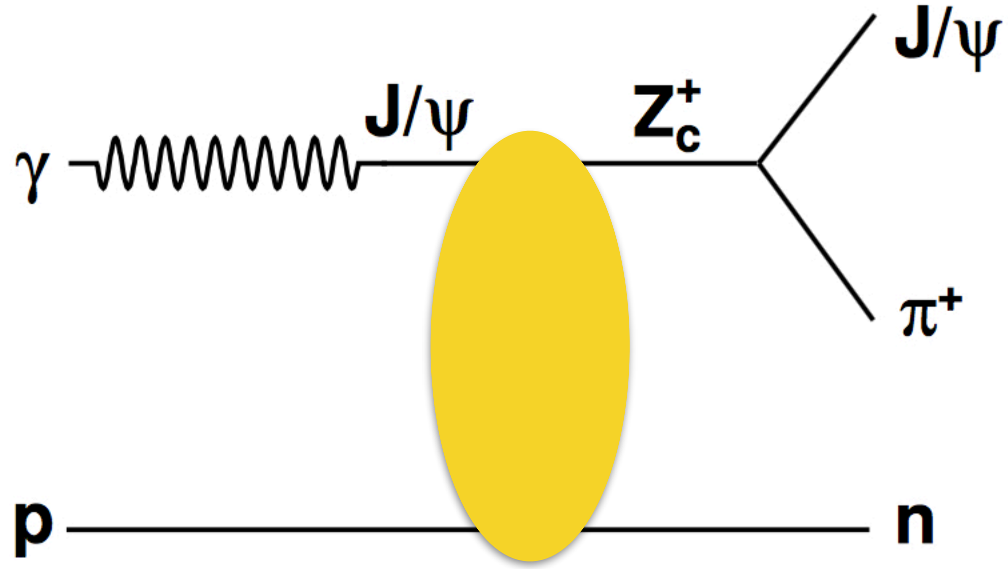
cusp effect

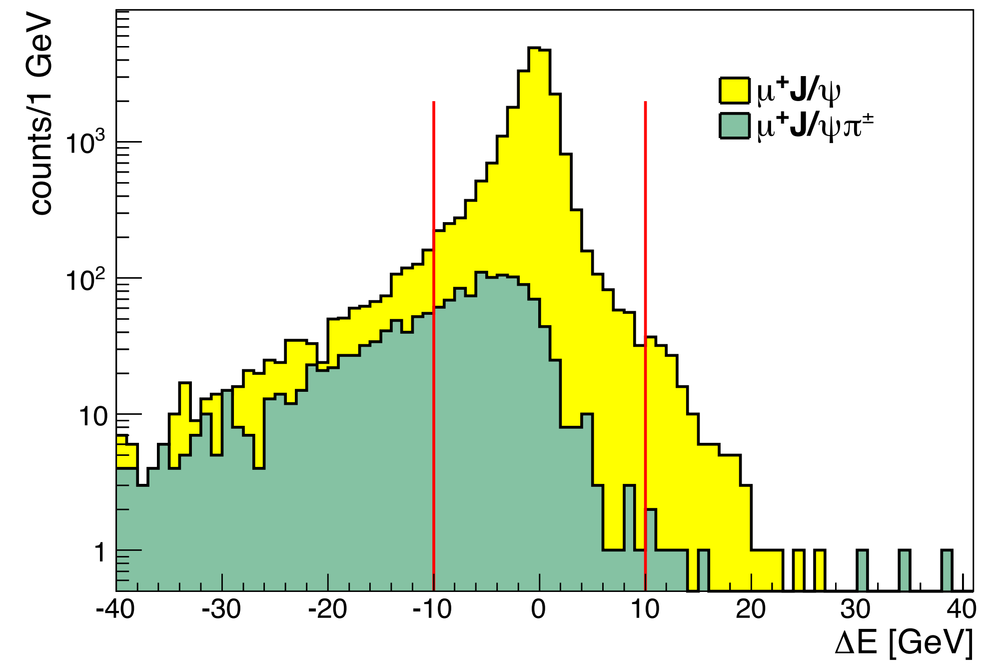
...

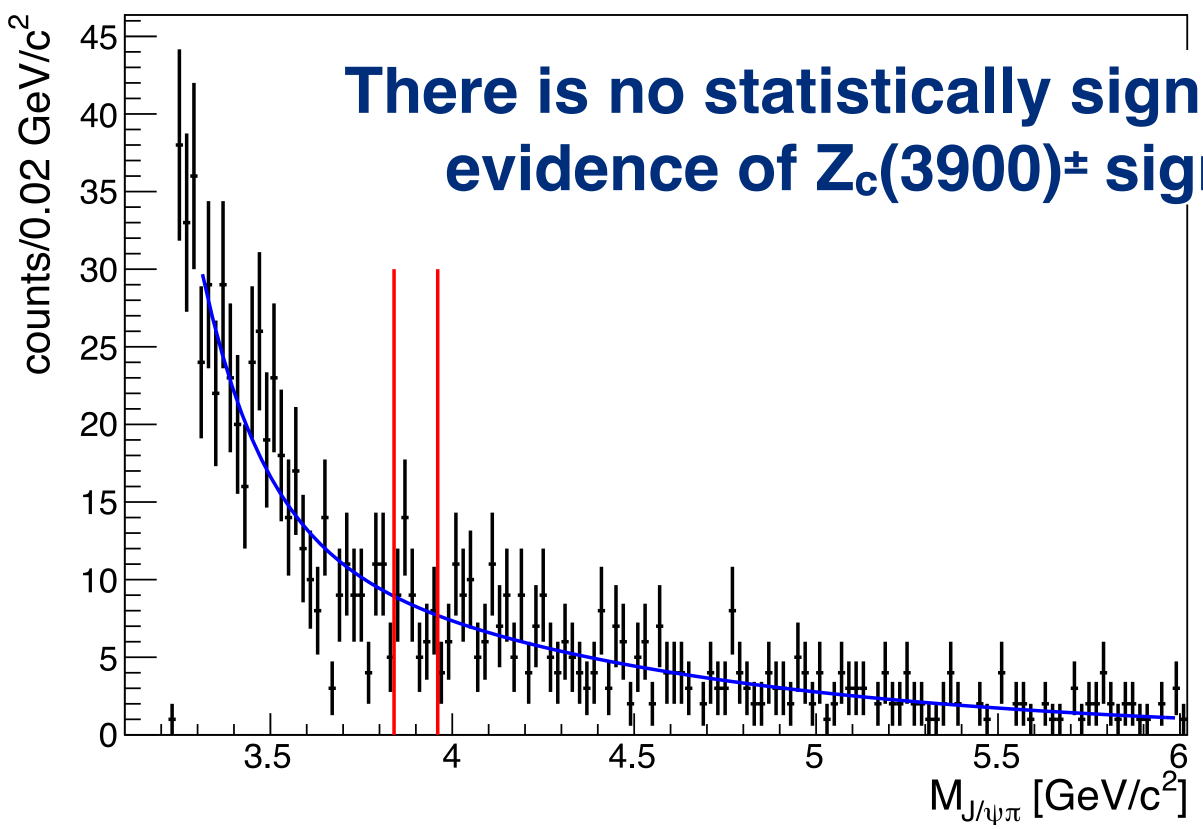




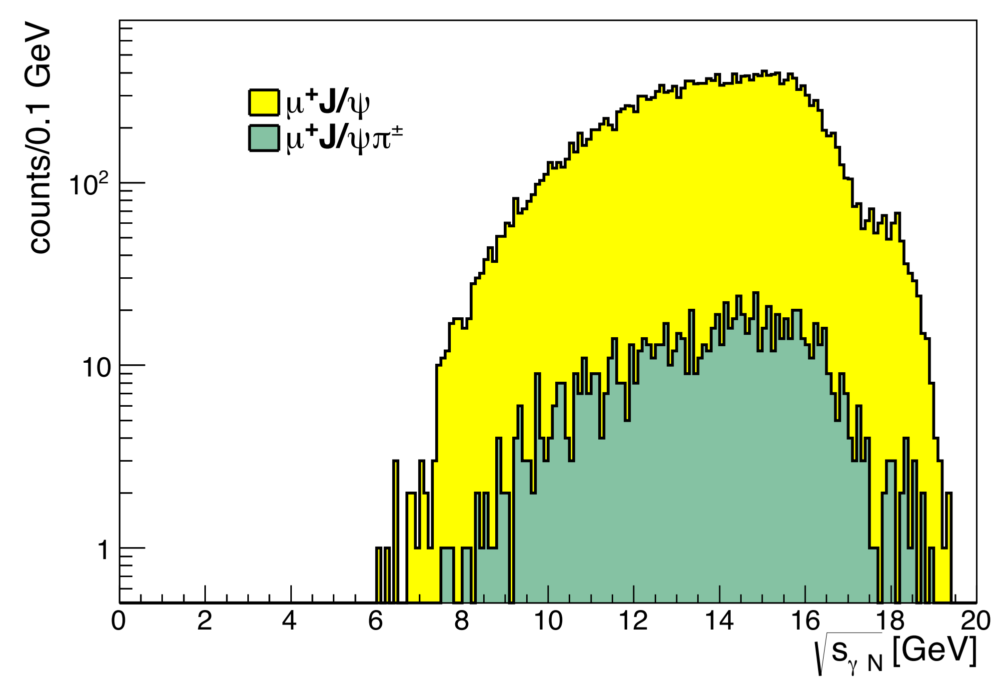
$\gamma N \rightarrow (J/\psi\pi^{\pm})N'$





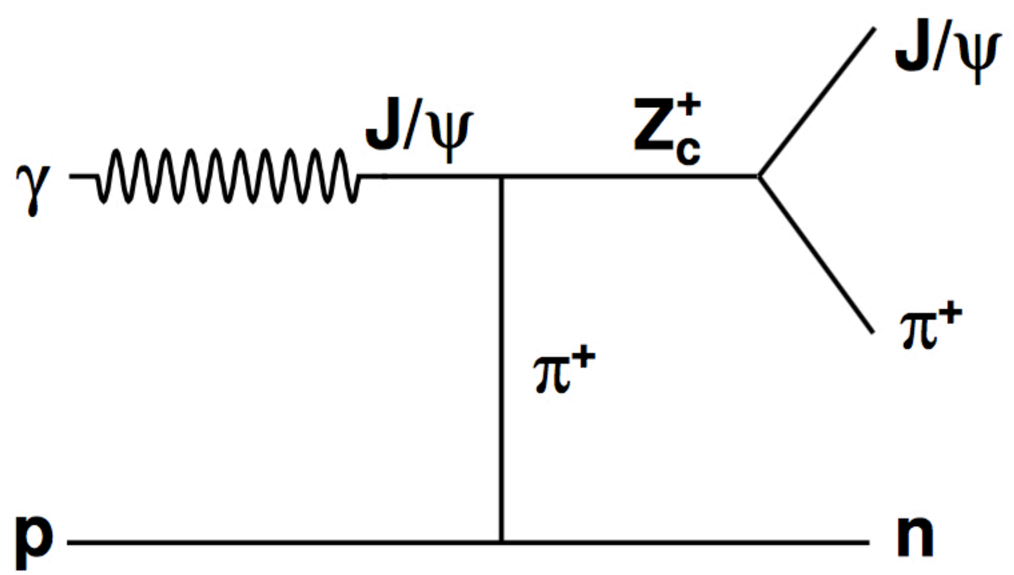


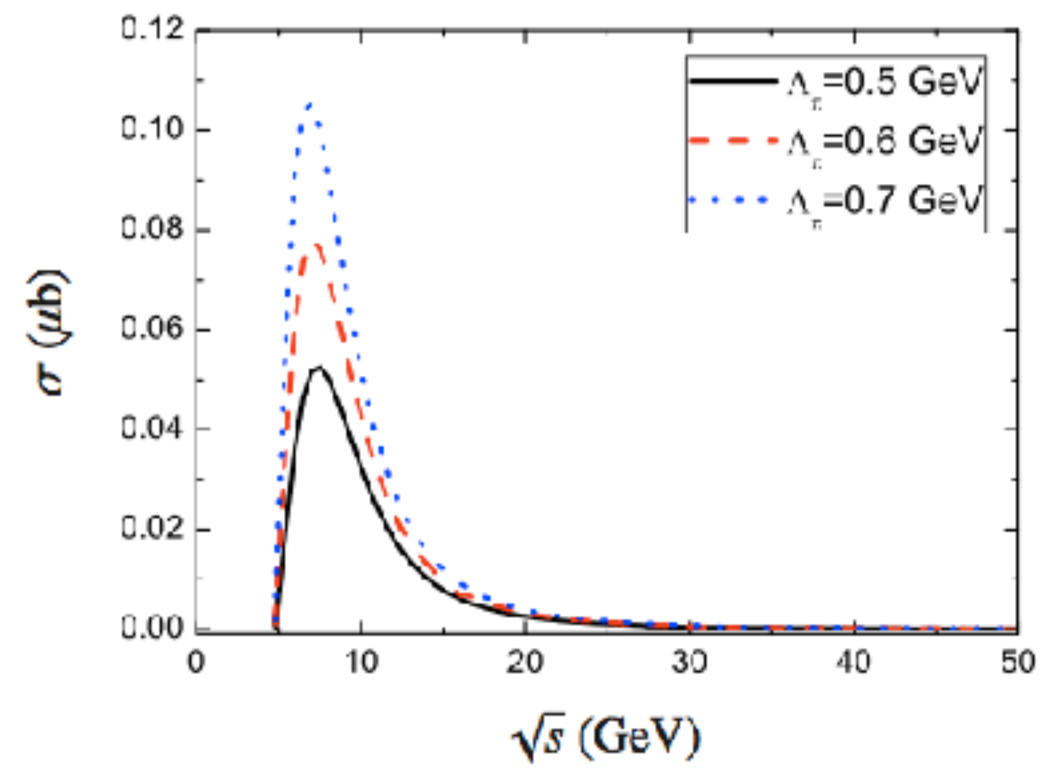
There is no statistically significant evidence of $Z_c(3900)^{\pm}$ signal

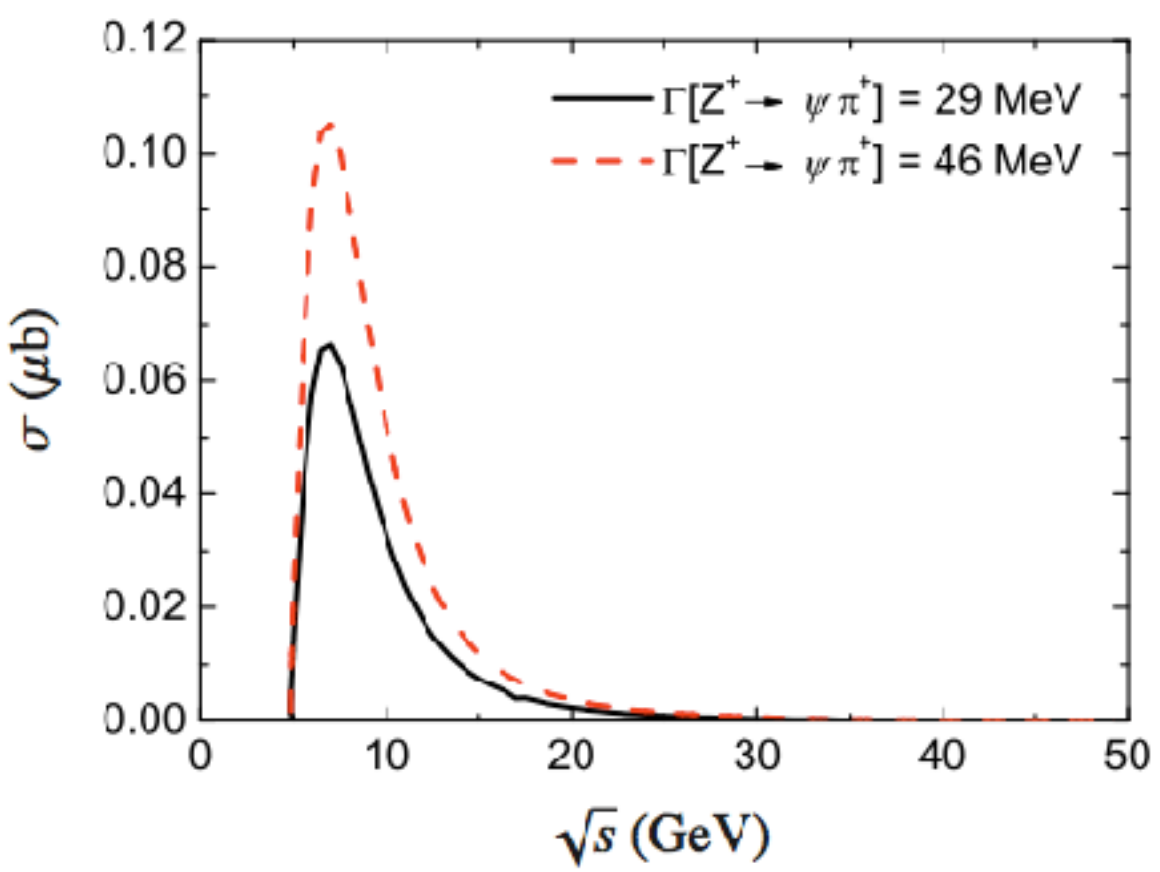


$$BR(Z_c^{\pm}(3900) \rightarrow J/\psi\pi^{\pm}) \times \sigma_{\gamma\ N \rightarrow Z_c^{\pm}(3900)\ N}\Big|_{\langle\sqrt{s_{\gamma N}}\rangle = 13.8\ \mathrm{GeV}} < 52\ \mathrm{pb}.$$

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 $Z_c(3900) \to J/\psi\pi$ is not a dominant decay channel

Phys.Lett. B742 (2015) 330-334

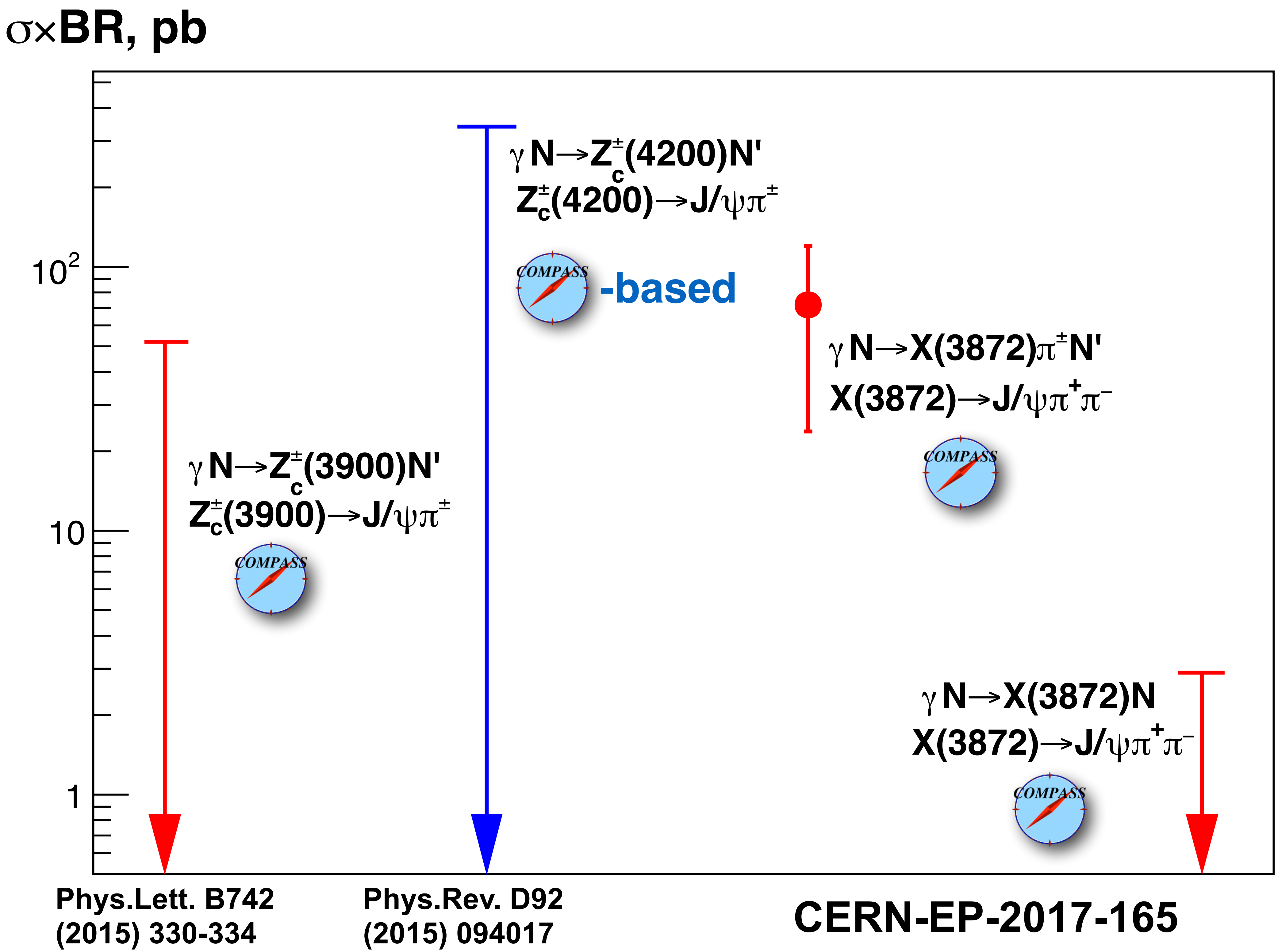
$Z_c(3900)^{\pm}$: summary

No statistically significant evidence of $Z_c^{\pm}(3900)$ production in the reaction $\gamma N \rightarrow (J/\psi\pi^{\pm})N'$ was found.

Upper limit for the absolute production rate is determined.

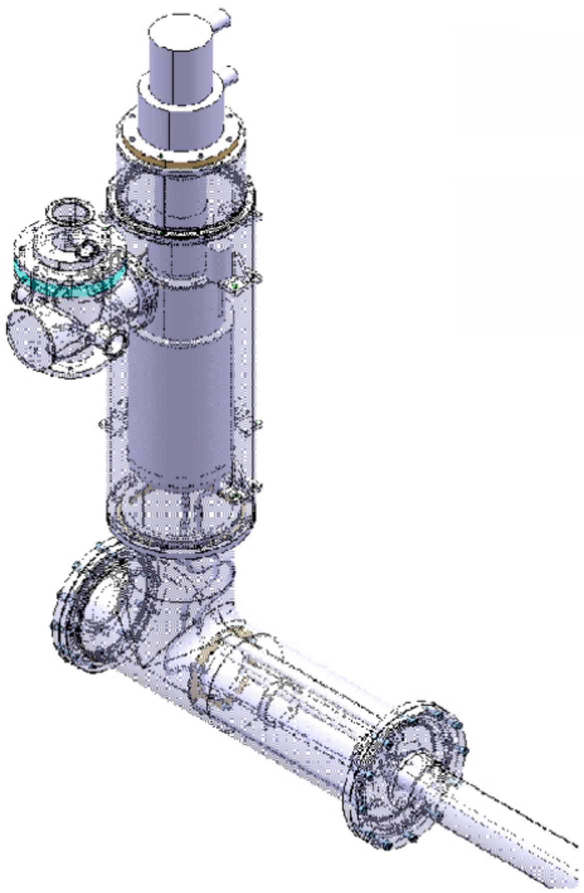
Model-dependent upper limit for the partial width $\Gamma_{J/\psi\pi}$ was established.

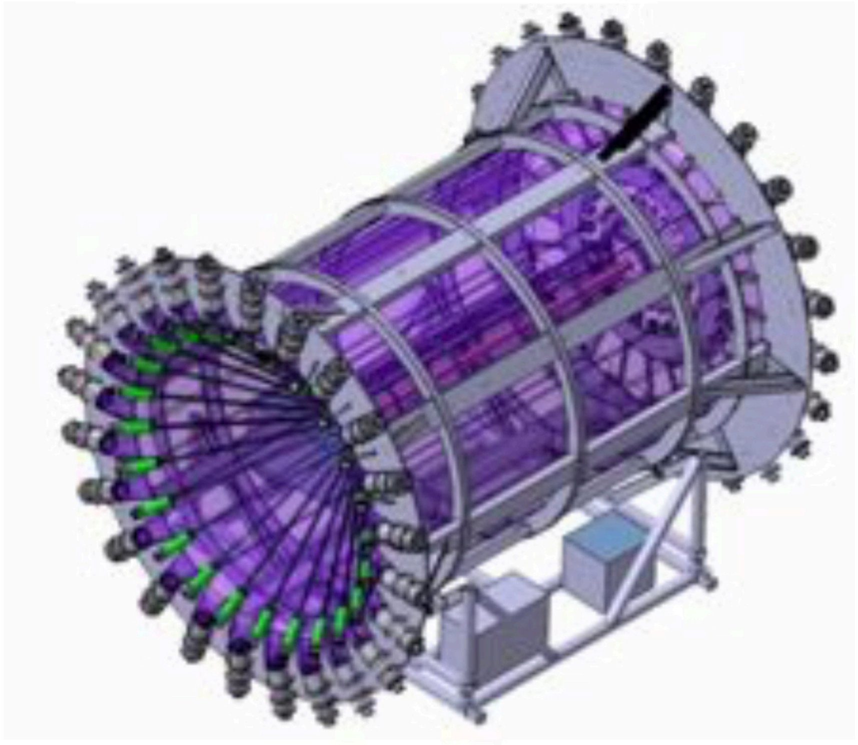
Photoproduction results for exotic charmonia



COMPASS run 2016-2017: new opportunities

- ***New 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.***



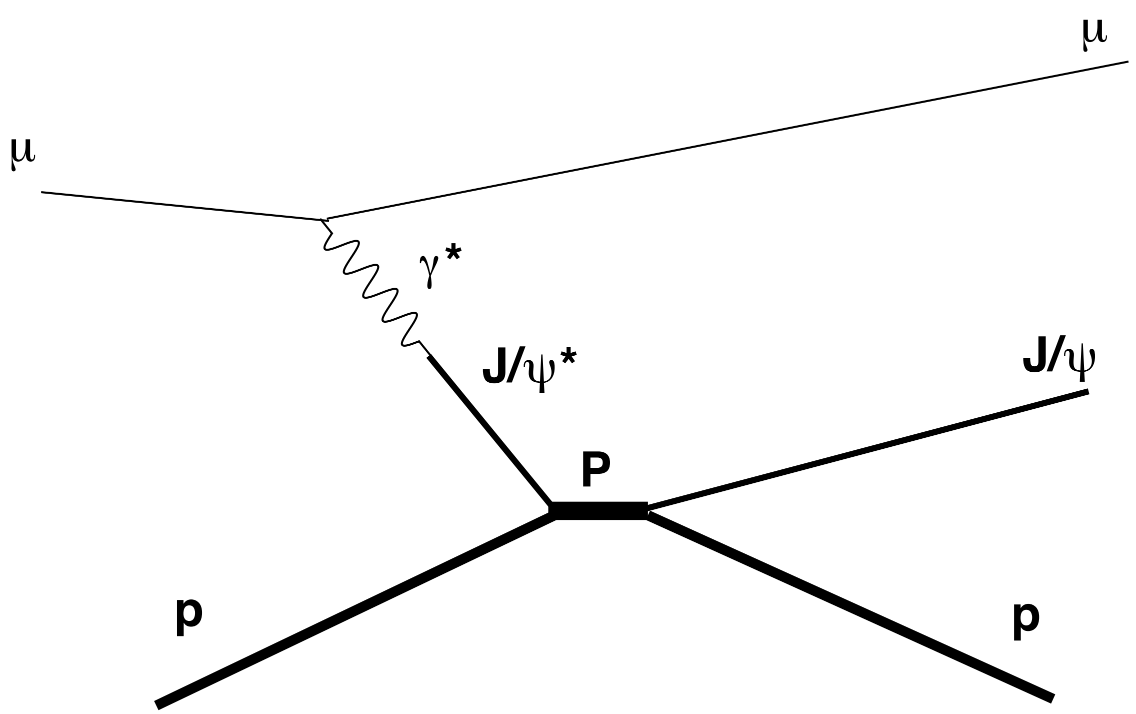


Possibility to search for and study of XYZ hadrons decaying to final states with photons like $J/\psi\pi^0$, $J/\psi\eta$, $J/\psi\omega$, $\chi_{c0,1,2}$ etc.

Exclusive photoproduction of pentaquarks P_c in s-channel

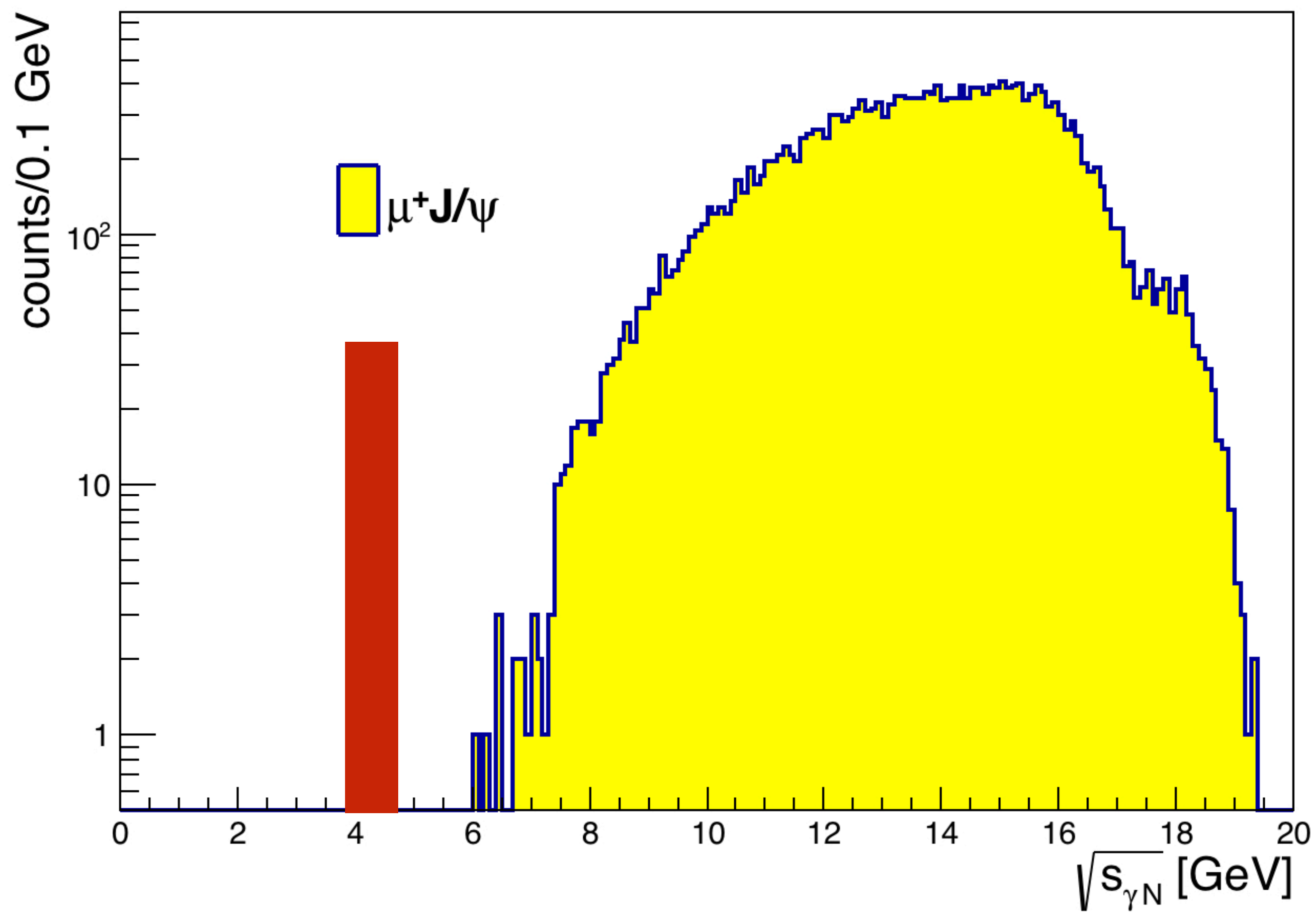
$P_c^+(4380)$ and $P_c^+(4450)$ were discovered by LHC-b in 2015 in the decay $\Lambda_b \rightarrow (J/\psi\ p)\ K^-$

$$\gamma p \rightarrow X \rightarrow J/\psi p$$



M. Karliner et. al. PLB 752 329 (2016)
arXiv:1508.01496v3

Q. Wang *et al.* Phys. Rev. D 92 034022 (2015)
arXiv:1508.00339



In present COMPASS data this process is out of trigger coverage

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.

What about facilities with high-intensity photon beams like Glue-X and CLASS ?

Backup

We also investigated the next processed as possible source of observed signal:

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

$\gamma N \to \chi_c\, x^{\pm} \to J/\psi \gamma x \to J/\psi e^+ e^- x^{\pm}$

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

...