Possible Future Hadron-Spectroscopy Measurements at COMPASS

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and
the hadron-analysis subgroup

Workshop
COMPASS Beyond 2020
CERN, 22. Mar 2016

What do we have on tape?

Large spectroscopy data sets

- 190 GeV/c beam on p target
- DT0 trigger $\Longrightarrow$ $t' > 0.1\,(\text{GeV}/c)^2$
  (event selection: in addition $t' < 1.0\,(\text{GeV}/c)^2$)
- Negative hadron beam: 97 % π^-, 2 % K^-, 1 % $\bar{p}$
  - 2008: $50 \cdot 10^6$ $\pi^-\pi^+\pi^-$ events
  - 2009: $40 \cdot 10^6$ $\pi^-\pi^+\pi^-$ events
- Positive hadron beam: 75 % p, 24 % π^+, 1 % K^+
  - $> 50 \cdot 10^6$ diffractive $p\pi^+\pi^-$ events
  - $7.5 \cdot 10^6$ centrally produced $\pi^+\pi^-$ events

Smaller spectroscopy data sets

- 190 GeV/c negative hadron beam
- Multiplicity trigger $\Longrightarrow$ all (low) t'
- Pb target
  - 2009 W43: $11 \cdot 10^6$ $\pi^-\pi^+\pi^-$ events
    ($1.8 \cdot 10^6$ events with $0.1 < t' < 1.0\,(\text{GeV}/c)^2$)
- Similar sized data sets for Ni and p targets

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What spectrometer components are essential?

Minimum-bias trigger

- Beam definition (SciFi + beam counter)
- Trigger either
  - On recoil proton (DT0)
  - Or on multiplicity of charged final-state particles > 1
- Veto
  - Beam halo
  - Final-state particles outside of spectrometer acceptance
  - Non-interacting beam particles

Tracking

- High-precision beam definition and vertexing using Si-Detectors
- Precision tracking of final-state particles over large range of momenta $\Longrightarrow$ all tracking elements used

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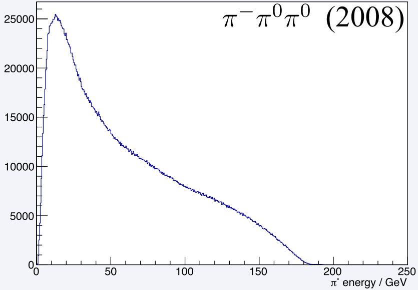

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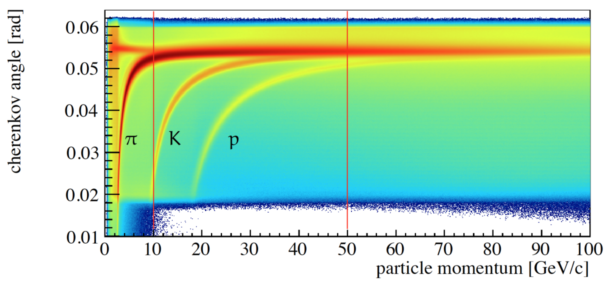
- Beam PID via CEDARs
- Final-state PID via RICH
  - **Limitation:** $K^{\pm}$ identification only for $10 < p < 50$ GeV$/c$



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Calorimetry

- ECAL1 + 2 (and 0) essential for reconstruction of neutral particles
- (HCALs not used)

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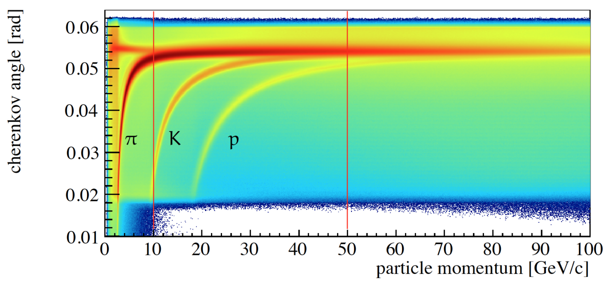

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Current knowledge of the strange-meson spectrum

- PDG lists in total 25 kaon states
- 17 kaon states above 1450 MeV/c^2
  - 12 are omitted from summary tables
  - 8 need confirmation
  - For 2 states J^P is unknown
  - All entries are older than 20 years, most older than 30 years
- Particularly interesting: $K\pi$ S-wave ($J^P = 0^+$)
  - $K_0^*(800)$ [or κ], $K_0^*(1430)$, and $K_0^*(1950)$
- Mapping out kaon excitation spectrum and decay modes
  - Helps understanding light-meson spectrum by completing $\text{SU}(3)_{\text{flavor}}$ multiplets
  - Important input for Dalitz-plot analyses of small data sets in heavy-meson decays

- Many interesting final states accessible in K^- diffraction
  - E.g. $K^-\pi^0, K^-\eta, K^-\eta', K^-\pi^+\pi^-, K^-\pi^+\pi^-\pi^0, \ldots$
  - Analog isospin-partner final states with $\bar{K}^0_S$
- Existing data
  - E.g. COMPASS (2008): 190 GeV/c K^- on p
    270 000 $K^-\pi^+\pi^-$ events for $0.07 < t' < 0.7\,(\text{GeV}/c)^2$
  - Cf. WA03 (ACCMOR) experiment (1980): 63 GeV/c K^- on p
    200 000 $K^-\pi^+\pi^-$ events for $0 < t' < 0.7\,(\text{GeV}/c)^2$

High physics potential

- Competition mainly from large B-decay data samples (LHCb, Belle II)
  - τ and charm-meson decays have only limited mass range

Interesting Future Measurements

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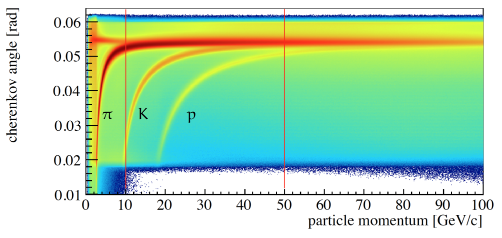
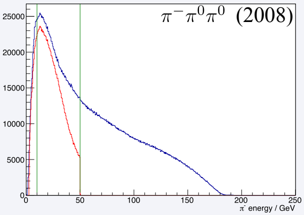
Main limitation

- Currently, kaon PID covers only $10 < p < 50$ GeV$/c$
  - More than 50% of final-state particles outside of acceptance





- Future program requires kaon PID from 10 to 90% of beam momentum
  - RICH 2 vs. photon acceptance
  - Alternatively, PID coverage could be improved by lowering beam momentum
    - Diffraction process depends only weakly on $\sqrt{s}$
    - However, lower beam energy would lead to lower photon acceptance

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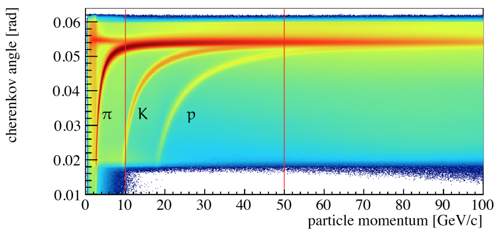

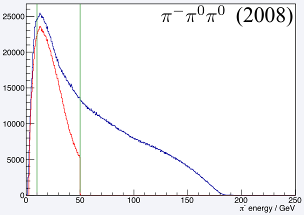

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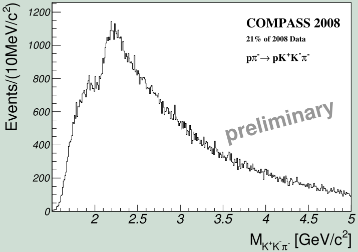
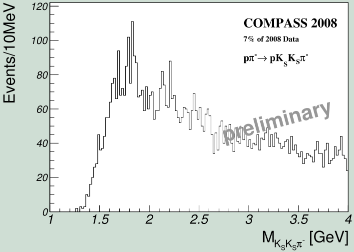
Beam requirements

- Kaon fraction $> 10\%$ required (now: $\approx 2\%$)
- Beam charge is not important
- Divergence should be small enough so that CEDARs can be used efficiently
- Intensity as high as possible
  - $\gtrsim 5 \cdot 10^6\ \mathrm{s}^{-1}$ like in 2008/9
- Pion contamination not very critical
  - If beam intensity is high enough, pions could be used to improve on existing data sets

- Interesting final states
  - E.g. $\pi K\bar{K}$ and $\pi\pi K\bar{K}$
- High physics potential, e.g.
  - $\pi K\bar{K}$: nature of $a_1(1420)$
  - $\pi\pi K\bar{K}$: spin-exotic states
- Also here, main limitation is coverage of kaon PID





- In competition with GlueX (with DIRC upgrade) and CLAS12

Interesting Future Measurements

Further Pion-Diffraction Measurements

Final states with neutral particles

- Interesting final states
  - E.g. spin-exotic waves in $\pi^-\eta, \pi^-\eta', \pi^-\pi^0\pi^0, \omega\pi^0\pi^-, \ldots$
- High physics potential
- Material budget is critical (also true for $K^-\pi^0, K^-\eta, K^-\eta', \ldots$)
  - Improved w.r.t. 2008/9 due to light RICH gas pipe
  - Possible conflict with PID requirements for final-state kaons
- In direct competition with VES and GlueX + CLAS12

Study of A dependence of diffractive production

- Comparing Pb and p data in range $0.1 < t' < 1.0\,(\text{GeV}/c)^2$ shows relative enhancement of $M = 1$ over $M = 0$ waves
- May help to better understand nature of spin-exotic wave
- Requires multiplicity trigger
  - Also would extend data to low t'
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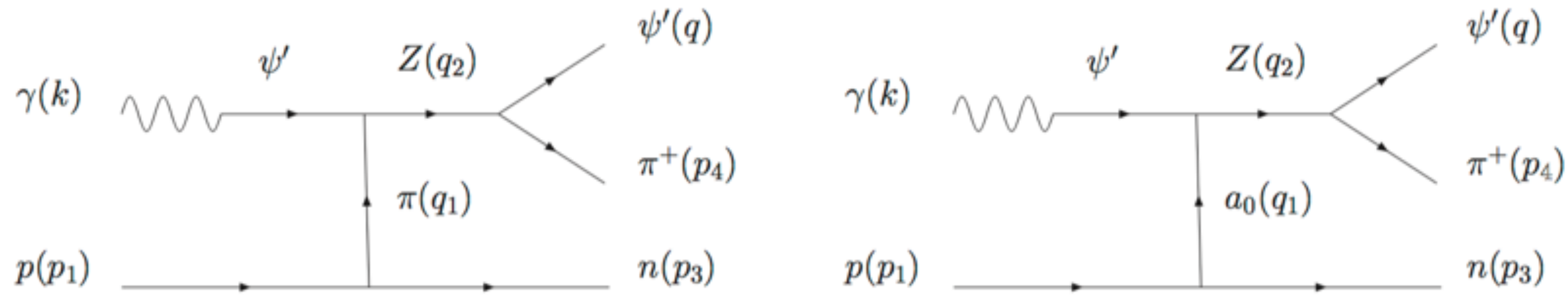
Apparatus Requirements

- Improved beam definition
  - High-precision beam-momentum measurement
    $\Delta p_{\text{beam}} \lesssim 100\ \text{MeV}/c$ (e.g. silicon detectors around BEND6)
    - Reduction of non-exclusive backgrounds
  - Improved beam PID by CEDARs (e.g. MAPMT readout?)
  - Dedicated luminosity measurement
- Improved recoil detection
  - E.g. TPC or HERMES-like (SciFis + silicon) detector
  - Reduction of non-exclusive backgrounds
- High-precision silicon vertex-detector
- Final-state kaon PID from 10 to 90% of beam momentum
- Low(er) material budget for improved photon detection efficiency
- Improved front-end electronics and DAQ
  - Record $> 80\,000$ minimum-bias trigger per second with $\lesssim 10\%$ deadtime

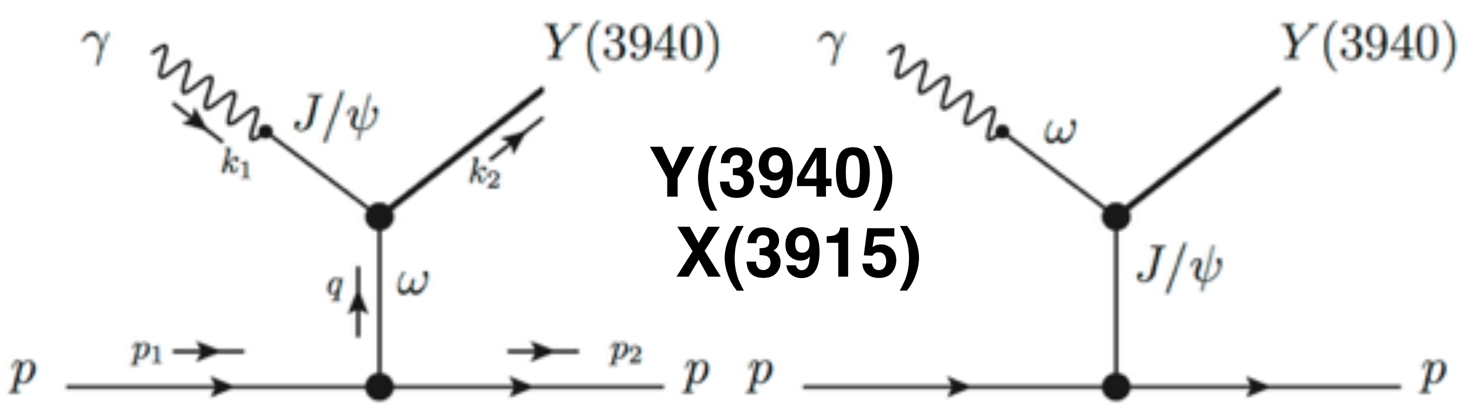
Exclusive photoproduction of exotic charmonia

(access to partial width of decays)

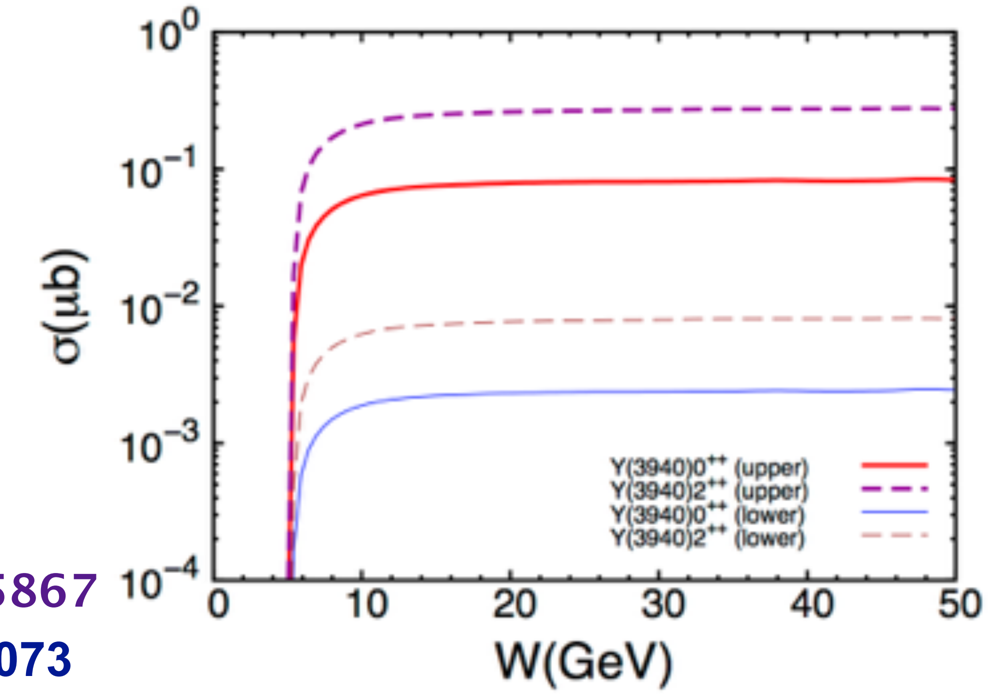


Z(4430)

X. Liu *et al.* Phys. Rev. D 77 094005 (2008) arXiv:0802.2648

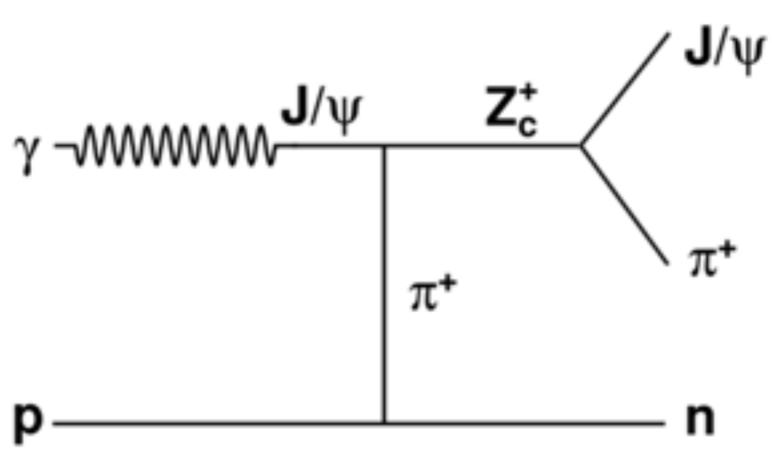


Y(3940)
X(3915)

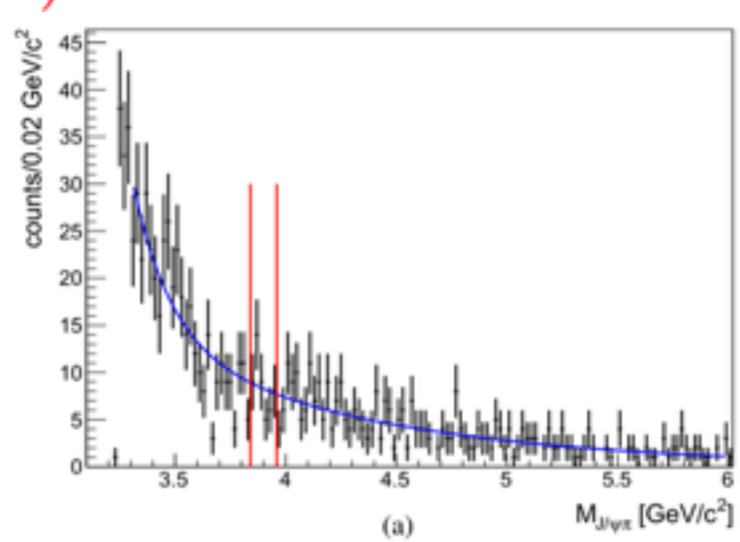


J. He, X. Liu, Phys. Rev. D 80 114007 (2009) arXiv:0910.5867

Q. Lin *et al.* Phys. Rev. D 89 034016 (2014) arXiv:1312.7073

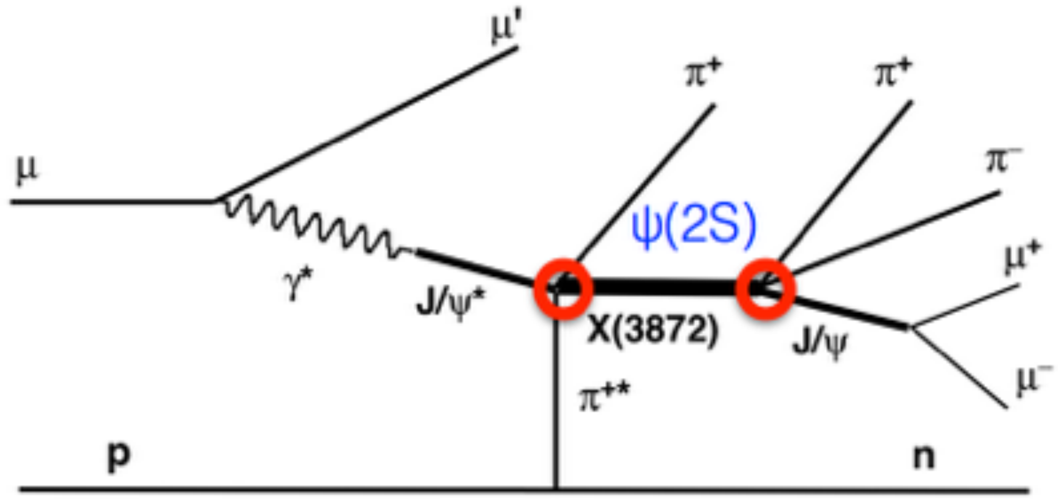


Z(3900)
Z(4200)



C. Adolph et. al. "Search for exclusive photoproduction of Zc±(3900) at COMPASS" PLB 742 (2015) 330

Associative photoproduction X(3872)

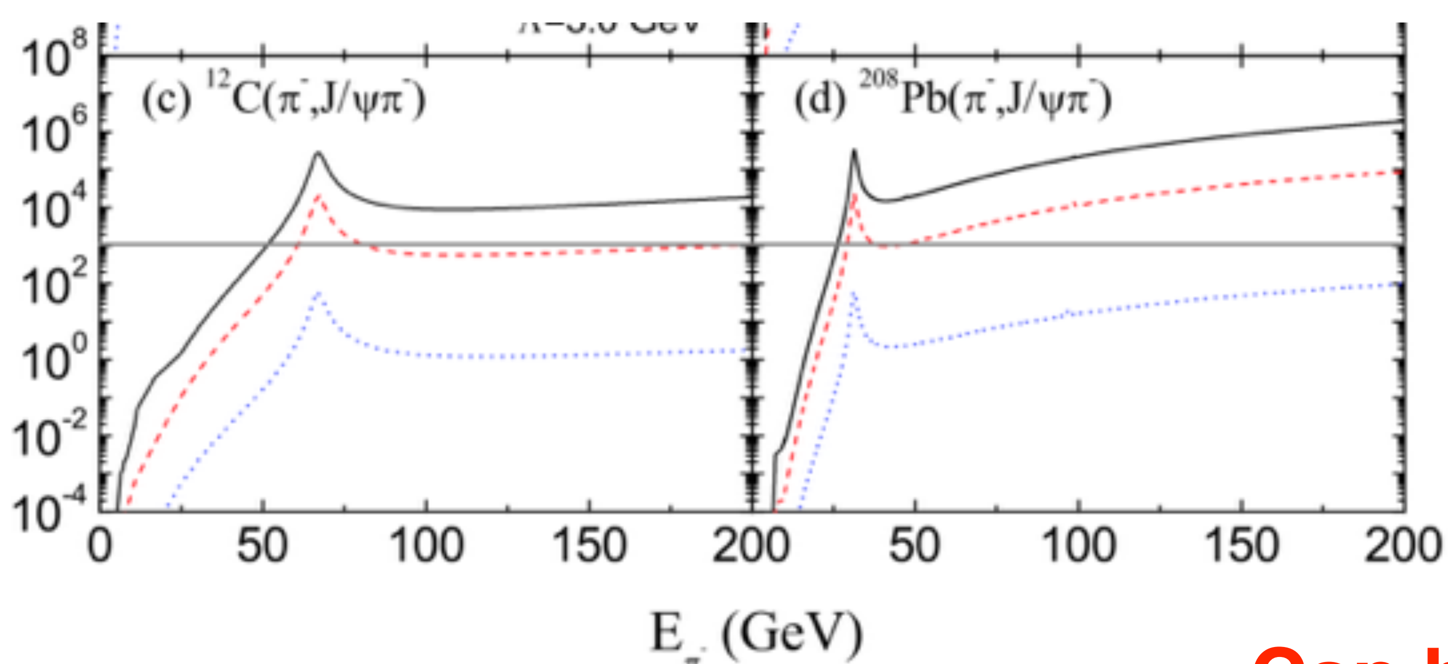


Access to the lower limit for the full width of X(3872)

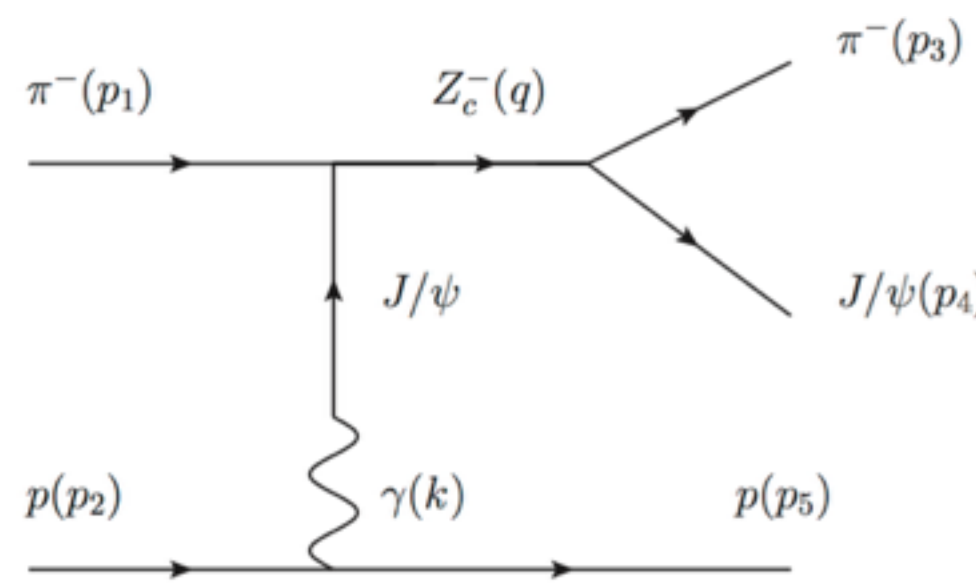
$$\Gamma_{X(3872)} = \frac{N_{X(3872)}}{N_{\psi(2S)}} \frac{\Gamma_{\psi(2S)\to J/\psi\pi\pi} BR_{\psi(2S)\to J/\psi\pi\pi}}{BR^2_{X(3872)\to J/\psi\pi\pi}}$$

Primakoff-like production of Z(3900)

Strong Z-dependence of the cross section

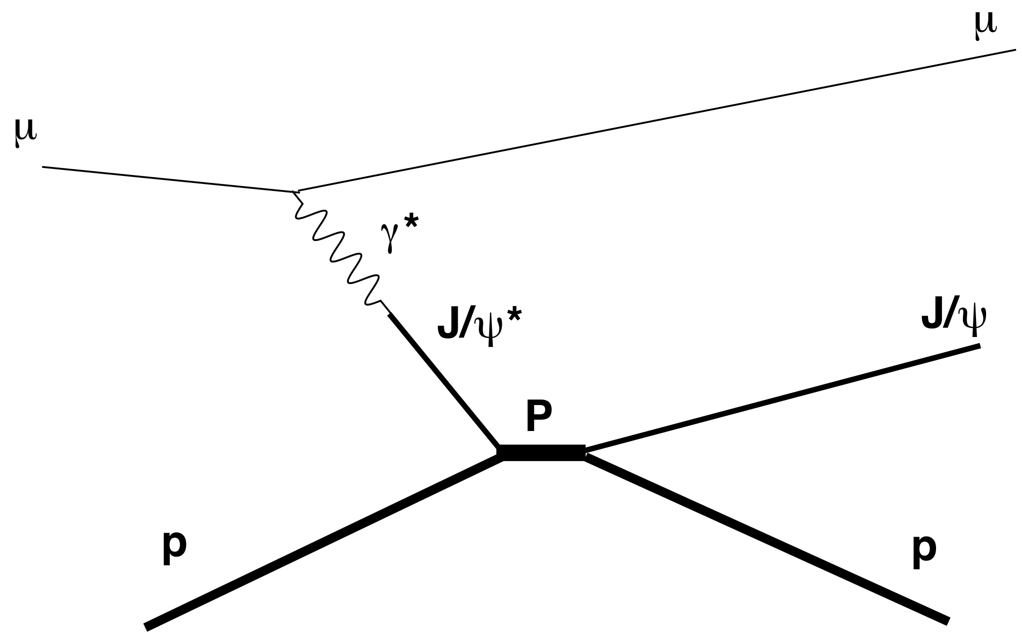


Phys.Rev. D93 (2016) 034022



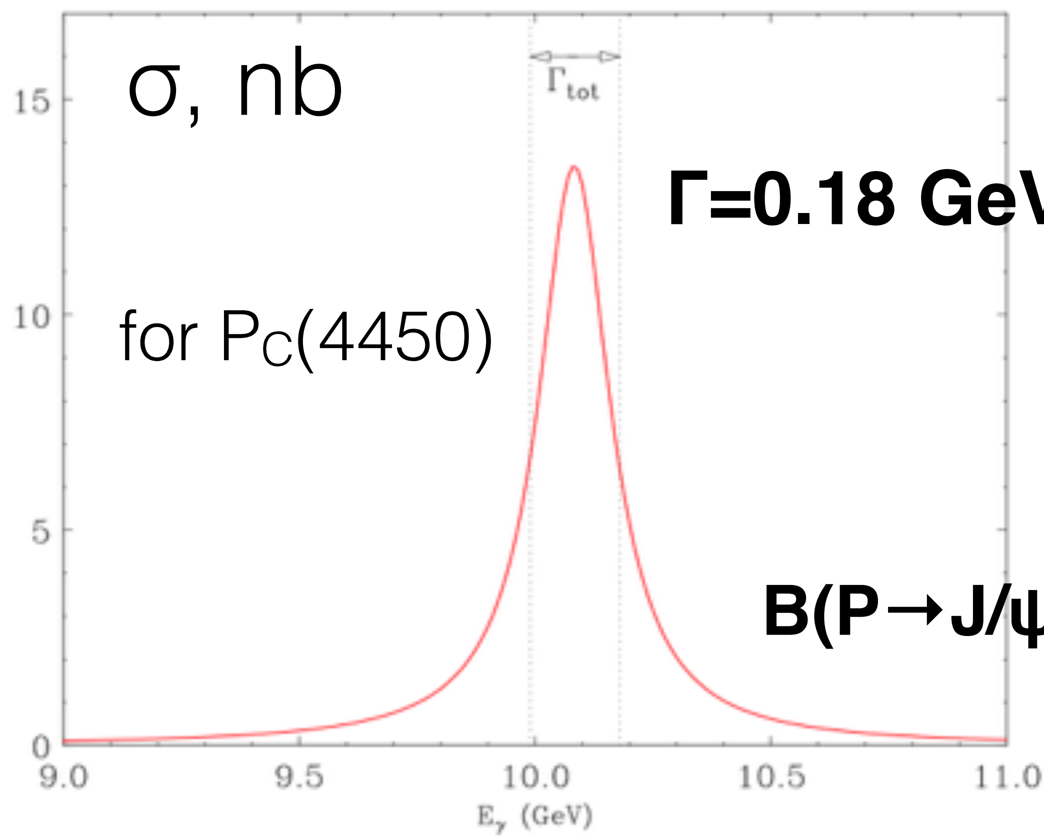
Can be observed even in DY run with absorber

Exclusive photoproduction of pentaquarks P_c in s-channel



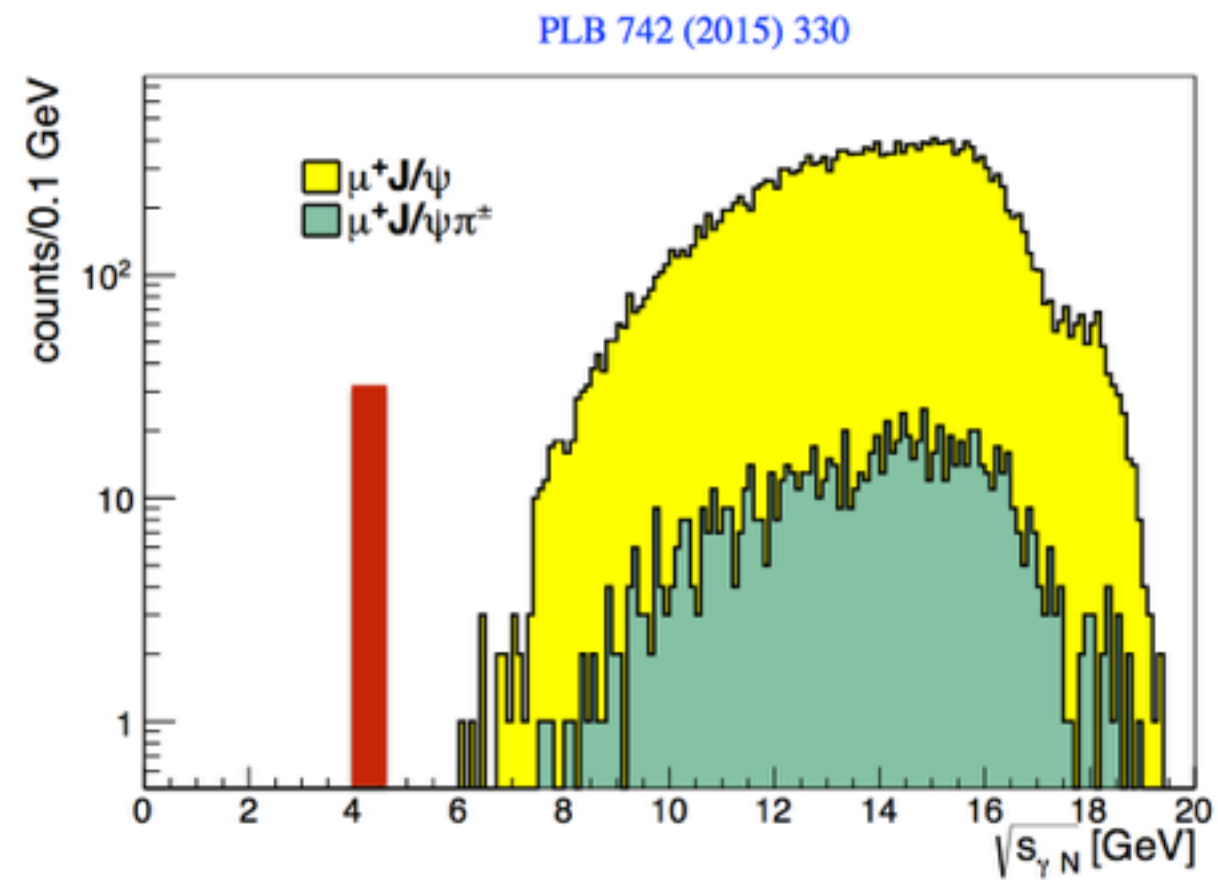
$$\gamma\, p \to X \to J/\psi\, p$$

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



B(P→J/ψp)=0.1

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



For 160 GeV muon beam we need for trigger at small Q^2 and Y=0.05-0.06

Conclusions

Light-meson spectroscopy

- High-intensity hadron beam with kaon fraction $\gtrsim 10\%$
- Kaon-spectroscopy data sample that supersedes any existing one by at least factor 5
  - COMPASS could rewrite PDG for states above 1.5 GeV/c^2 (like LASS and WA03 did 20+ year ago)
  - Precision study of $K\pi$ S-wave
- Pion fraction of beam can be used to improve on existing data sets
  - Clarify nature of $a_1(1420)$ signal

Heavy-meson spectroscopy

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  - Extraction of partial and full decay widths
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