Semi-inclusive XYZ production

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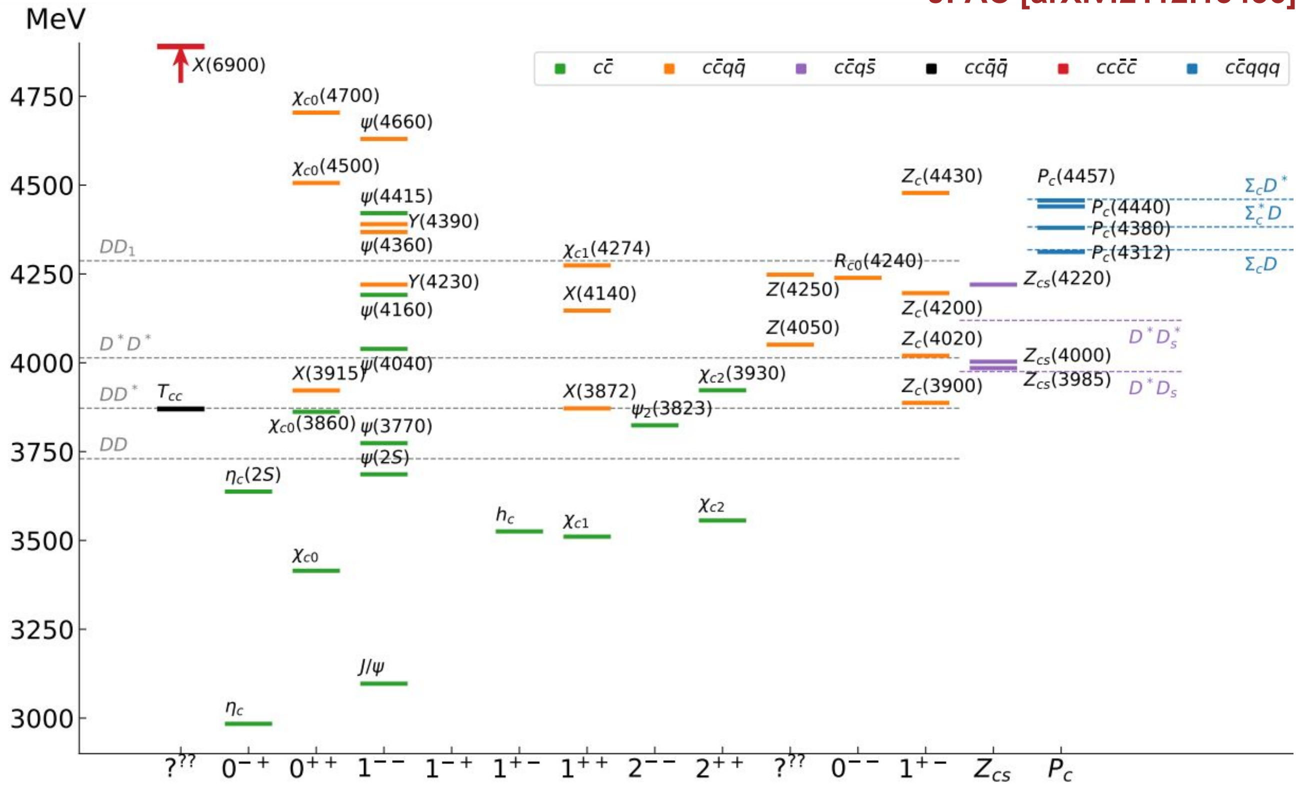
Exotic heavy meson spectroscopy and structure at EIC
16 August 2022

Exotic XYZ states

JPAC [arXiv:2112.13436]

Rich spectrum of resonance-like signals observed in heavy baryon decays and electron-positron collisions.

Seemingly consistent with structure **beyond $Q\bar{Q}$**.



Exotic XYZ states

See reviews:
JPAC [arXiv:2112.13436]
Chen et al [arxiv:2204.02649]
Brambilla et al [Phys.Rept. 873 (2020) 1-154]
Guo et al [Rev.Mod.Phys. 90 (2018) 1, 015004]
Esposito et al [Phys.Rept. 668 (2017) 1-97]

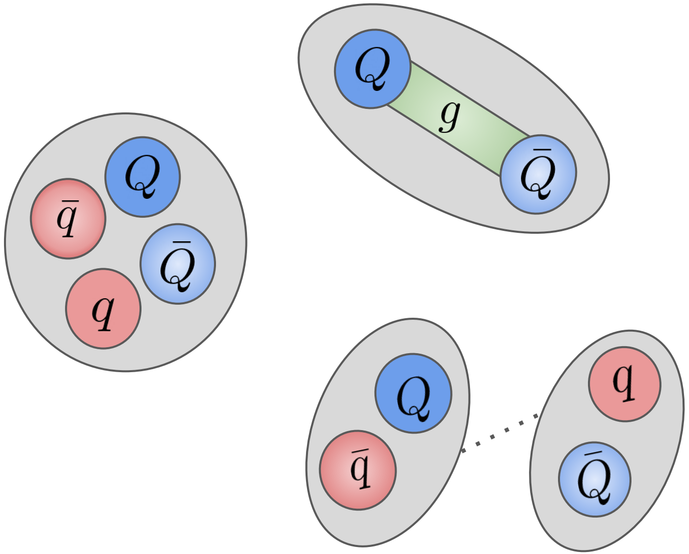
Precise microscopic nature inconclusive, with multiple possible interpretations in terms of QCD degrees of freedom.

Coincidence of nearby multiparticle thresholds may suggest important **multi-channel dynamics**.

Understanding of many as shallow bound states with prominent molecular component from open-charm

$$a = -\frac{2\,X}{1+X} R + \mathcal{O}(m_\pi^{-1}) \qquad r = -\frac{1-X}{X} R + \mathcal{O}(m_\pi^{-1})$$

Li et al [arXiv:2110.02766]
Albaladejo and Nieves [arXiv:2203.04864]

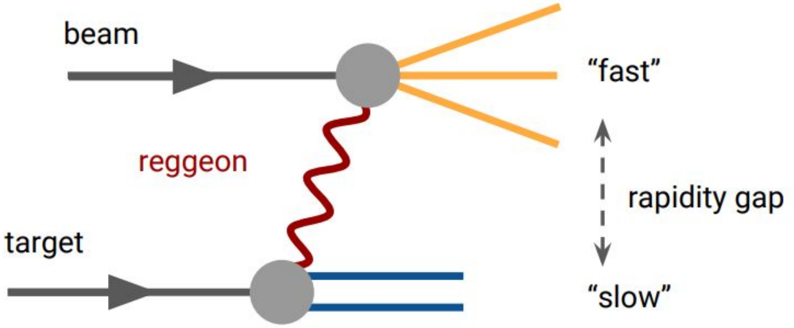


Photoproduction

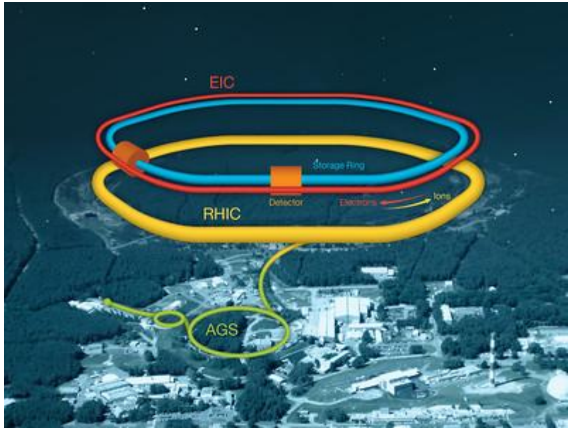
Powerful tool in spectroscopy

- Can produce any quantum-numbers
- Well understood in terms of diffractive production (**exchange physics**)
- Constrained kinematics means precise probe of production mechanism
- Polarization information gives useful insight into structure
- Minimizes role of rescattering

JPAC [Phys.Rev.D 98 (2018) 3, 034020]



EIC Yellow Report [arXiv:2103.05419]

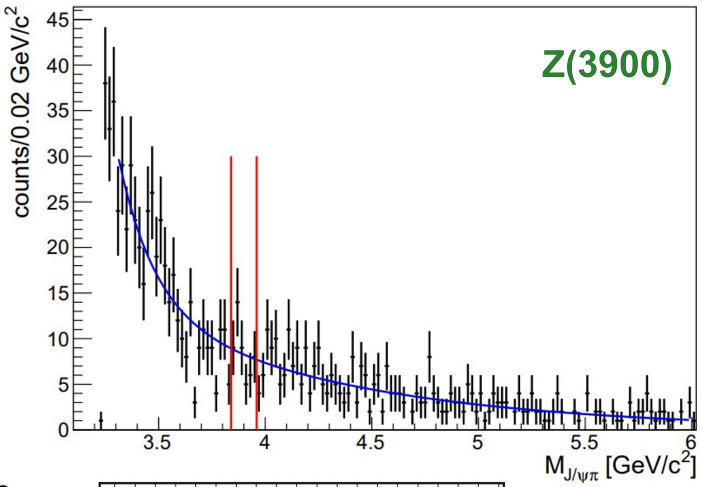


Photoproduction searches

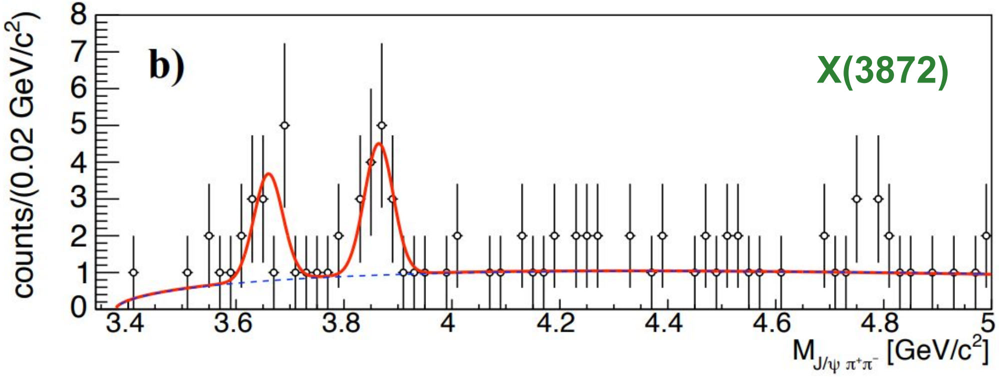
Current experimental results in electro- and muo-production limited by statistics.

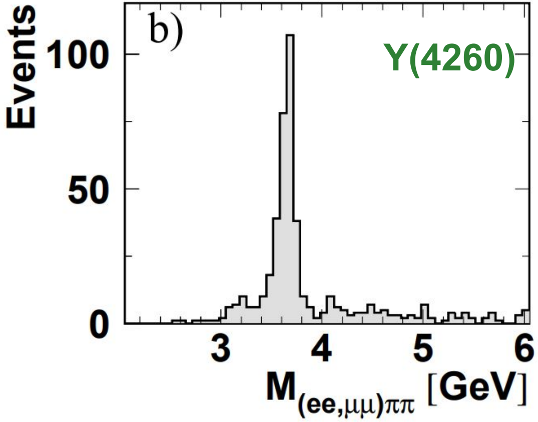
Large potential for spectroscopy program at high-luminosity photoproduction facility.

COMPASS [Phys.Lett.B 742 (2015) 330-334]



COMPASS [Phys.Lett.B 783 (2018) 334-340]





H1 [Phys.Lett.B 541 (2002) 251-264]

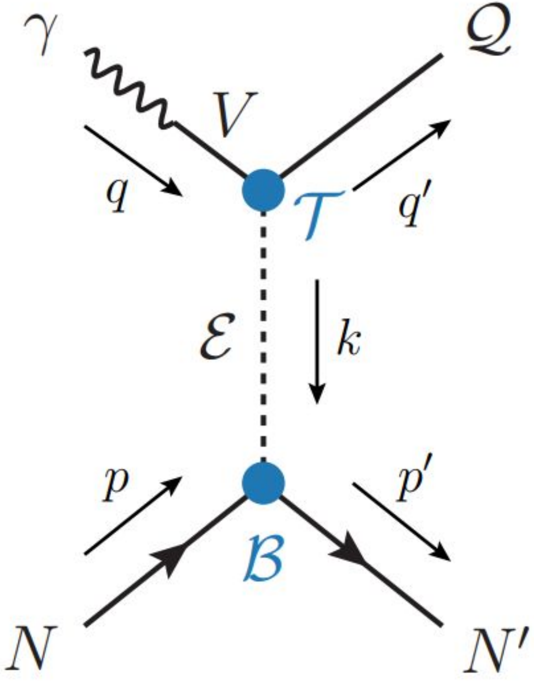
Exclusive photoproduction

Expected dominant production modes relying on measured branching fractions. Minimal assumption on microscopic nature.

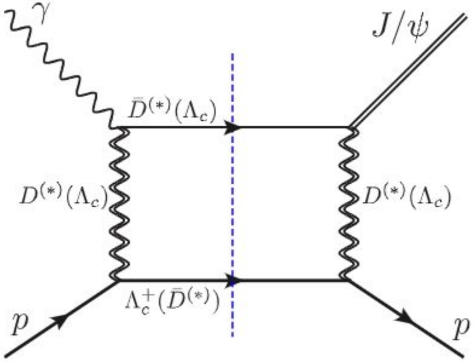
Can consider broad energy range. **Near-threshold** production dominated by meson exchanges while high-energy production proceeds through Reggeon exchanges.

Largest uncertainty comes from use of VMD.

JPAC [Phys. Rev. D 102, 114010 (2020)]



Xu et al [Eur.Phys.J.C 81 (2021) 10, 895]



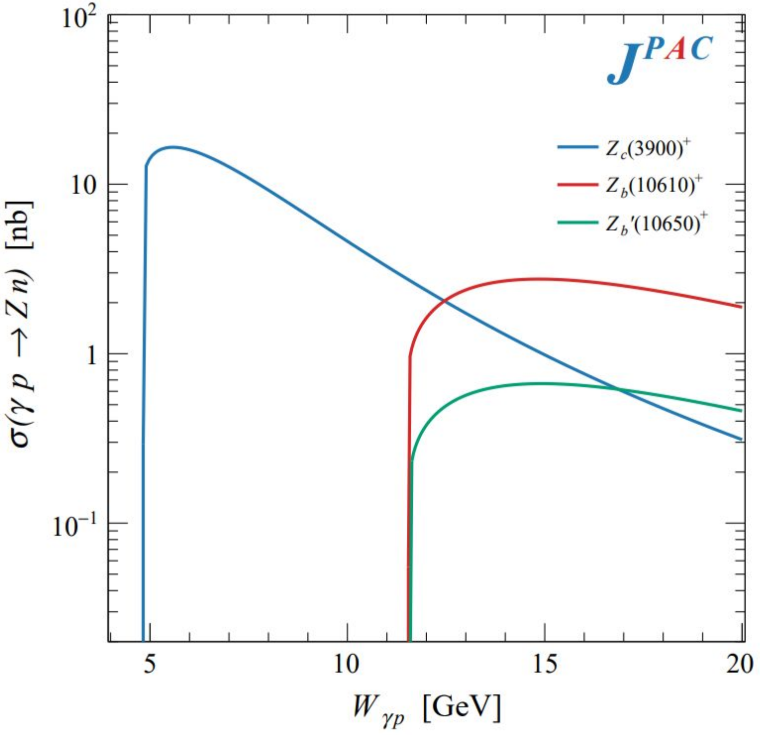
Ignores possible more complicated production modes which may contribute

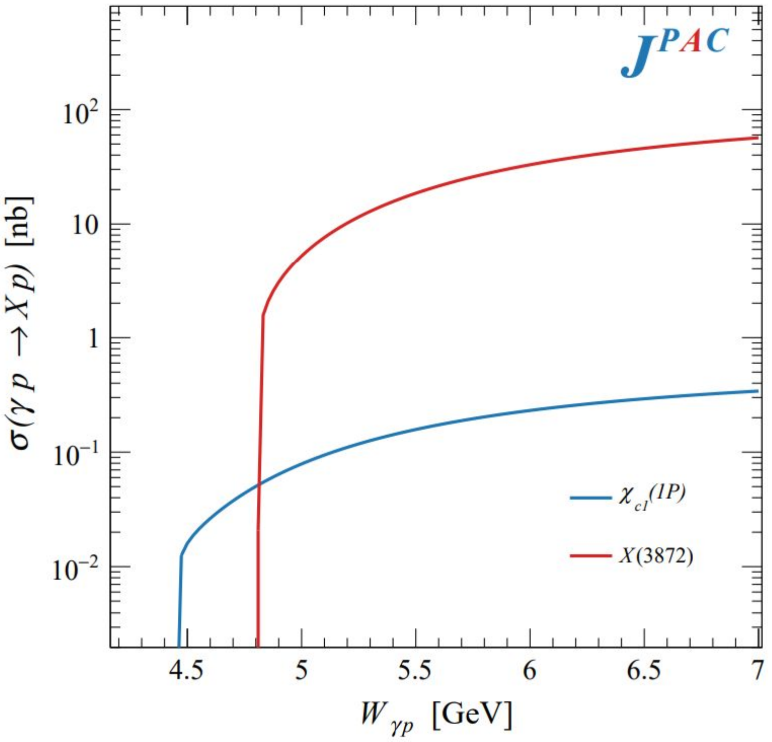
Du et al [Eur.Phys.J.C 80 (2020) 11, 1053]

JPAC [Phys. Rev. D 102, 114010 (2020)]

Exclusive photoproduction

Near-threshold production seems very promising for X(3872) and Z states





Semi-inclusive production

Expected larger cross-sections, potentially useful for **first observation**.

Inclusive cross-sections themselves may hint towards structure

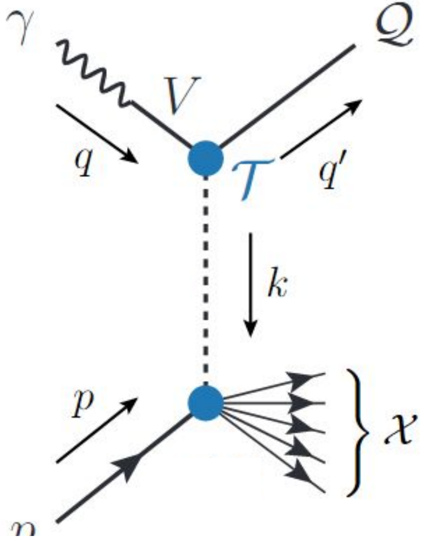
Braaten et al [Phys.Rev.D 103 (2021) 7, L071901]
Esposito et al [Eur.Phys.J.C 81 (2021) 7, 669]

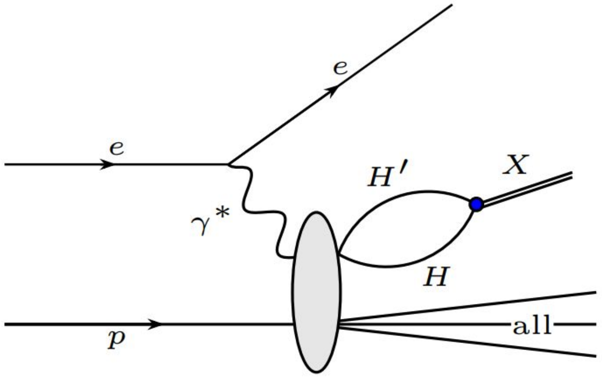
Large-pT (non-diffractive) production calculable in NRQCD

Braaten [*Phys.Rev.D* 73 (2006) 011501]

Complementary studies from rescattering of constituents in hadronic picture

Yang & Guo [Chin.Phys.C 45 (2021) 12, 123101]
Shi, Yang, & Guo [arXiv:2208.02639]





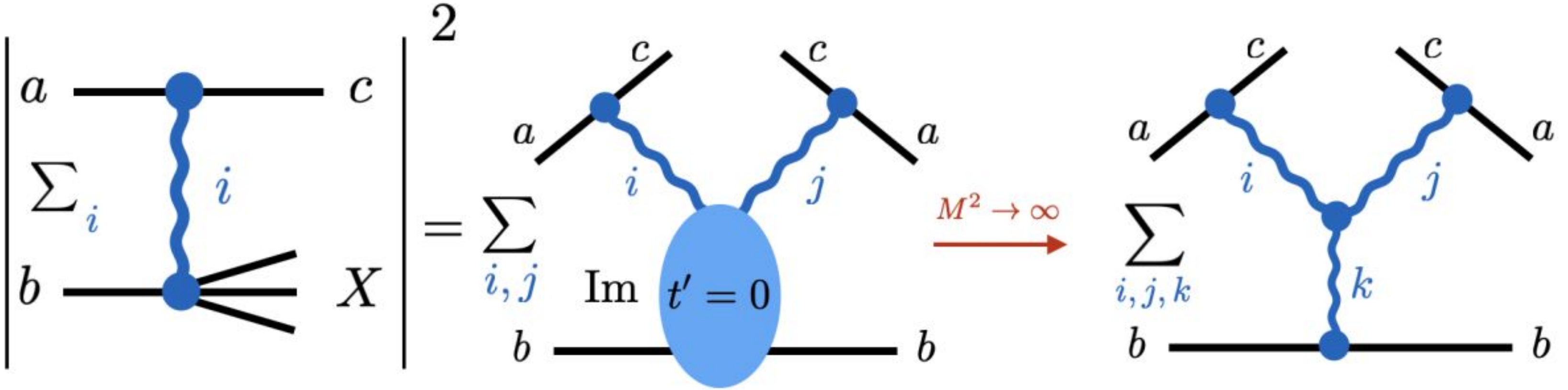
Diffractive semi-inclusive production

Diffractive processes expected to dominate in the low-pT kinematic region -- reconstructed particle observed in near-forward direction with large momentum fraction.

Can be estimated by direct extension of the amplitude approach used for exclusive production.

Generalized optical theorem relates one-particle distribution to total exchange-target cross-section

Mueller [Phys. Rev. D 2, 2963]
See also textbook by P. B. Collins

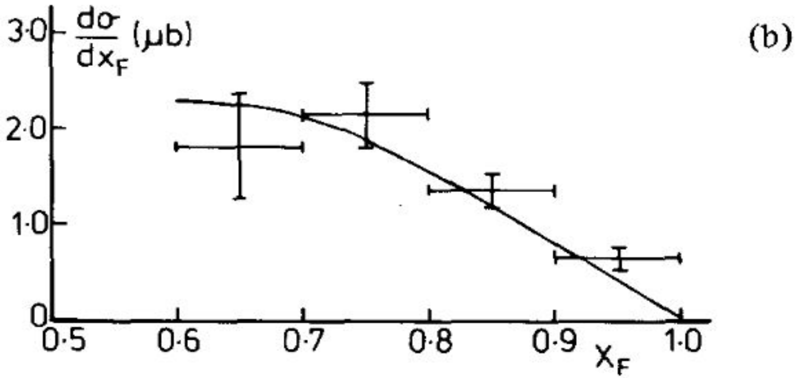


Pion exchange

Focus on the **charge exchange** process relevant for Z states as initial test of formalism.

Benchmark with available data from charged $b_1(1235)$ production from OmegaPhoton collaboration.

OmegaPhoton [Phys.Lett.B 138 (1984) 459-463]



phase-space factors

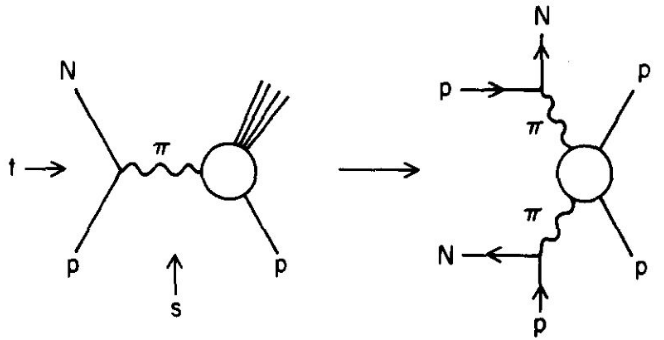
pion propagator

total hadronic cross-section

$\pi\gamma$Q coupling

$$E_Q \frac{d^3\sigma}{d^3q_f} = \frac{K}{16\pi^3}\,\frac{1}{2}\sum_{\lambda_\gamma\lambda_Q} |\mathcal{T}_{\lambda_\gamma\lambda_Q}|^2\,\mathcal{P}_\pi^2\,\sigma_{\text{tot}}^{\pi^* N}$$

Field & Fox [Nuclear Physics B80 (1974) 367-402]



Apart from parameterization for the (virtual) pion-nucleon cross-section no additional parameters or model dependence

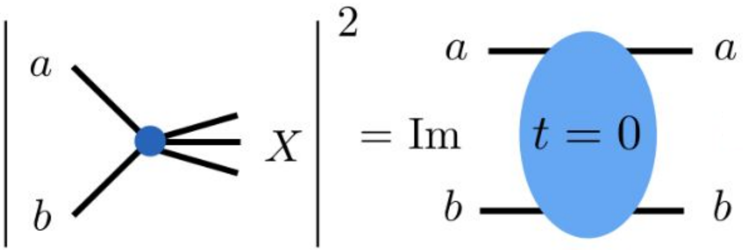
πN total cross-section

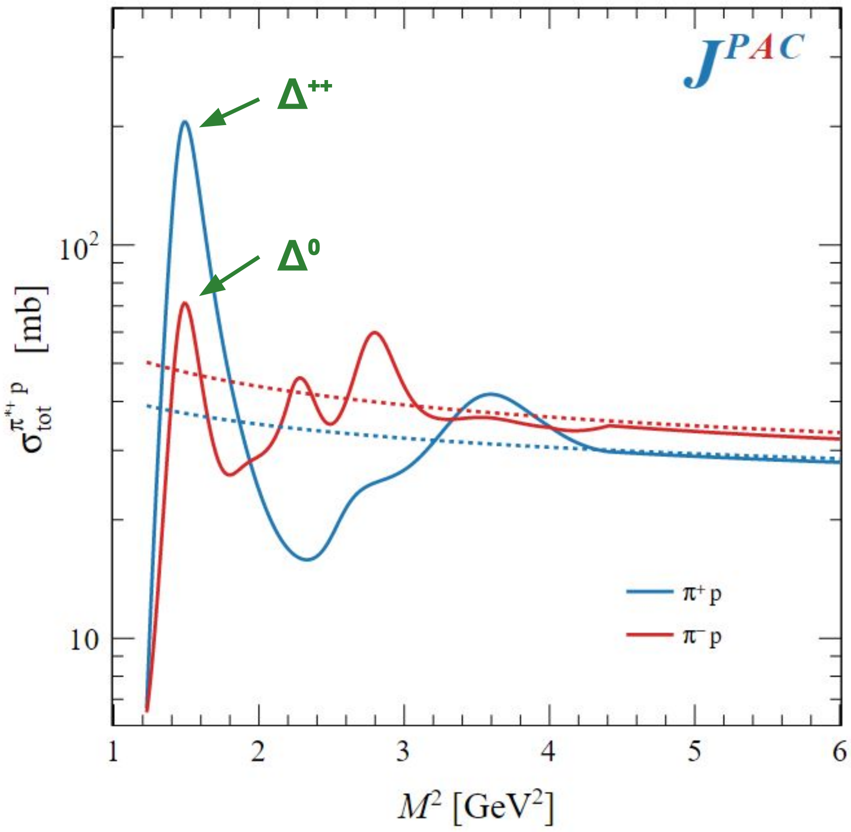
Missing mass dependence enters through total hadronic cross-section at the bottom vertex (πN $\rightarrow$ anything)

The on-shell pion total cross-section known very well in broad energy range.

JPAC [Phys. Rev. D 92, 074004 (2015)]

Nucleon resonances in low-mass squared region could potentially boost production rates!





π*N total cross-section

Need to incorporate pion virtuality in a minimal way. Luckily resonance region well described on the level of individual partial-waves.

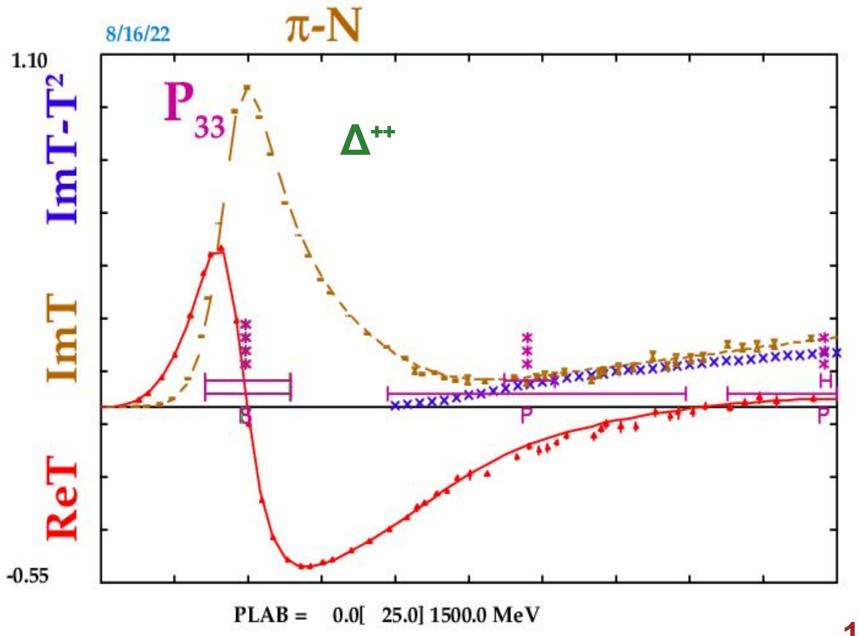
Workman et al [Phys.Rev.C 86 (2012) 035202]

These can be rescaled by the ratio of angular-momentum barrier factors such that pion virtuality enters only through phase-space

$$\sigma_{\text{tot}}^{\pi^{*\pm}p}(t, M_{\mathcal{X}}^2) = \sum_L R_L^{\pi^*}(t, M_{\mathcal{X}}^2)\, \sigma_L^{\pi^\pm p}(M_{\mathcal{X}}^2)$$

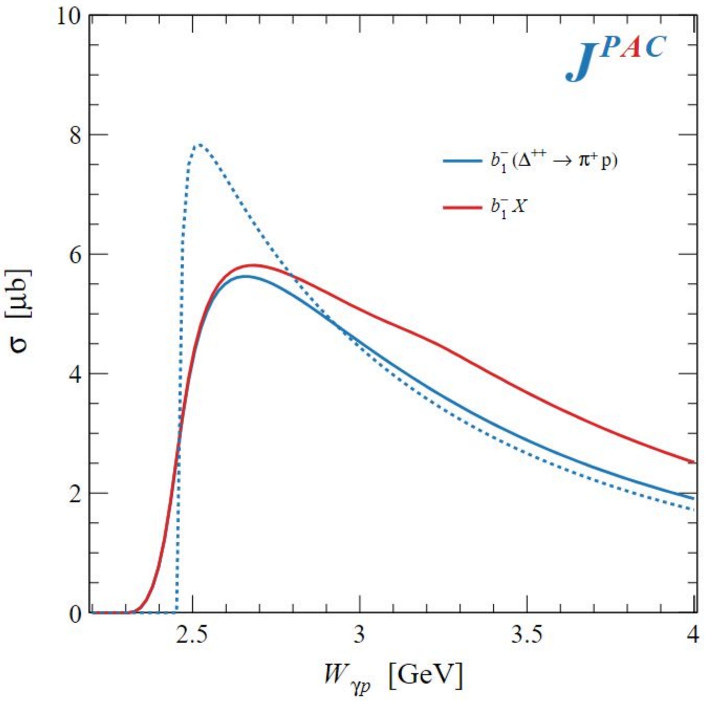
Rescaling factors scales each partial-wave differently and tends to unity in the large missing mass limit (triple Regge limit)

$$R_L^{\pi^*}(t, M_{\mathcal{X}}^2) = \left(\frac{p_{\pi^*}}{p_\pi}\right)^{2L}$$

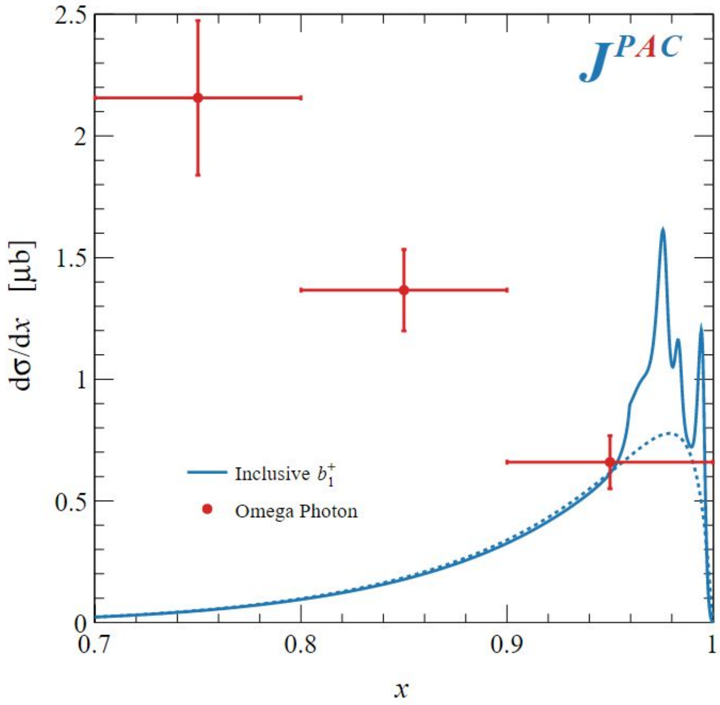


$b_1(1235)$ benchmarks

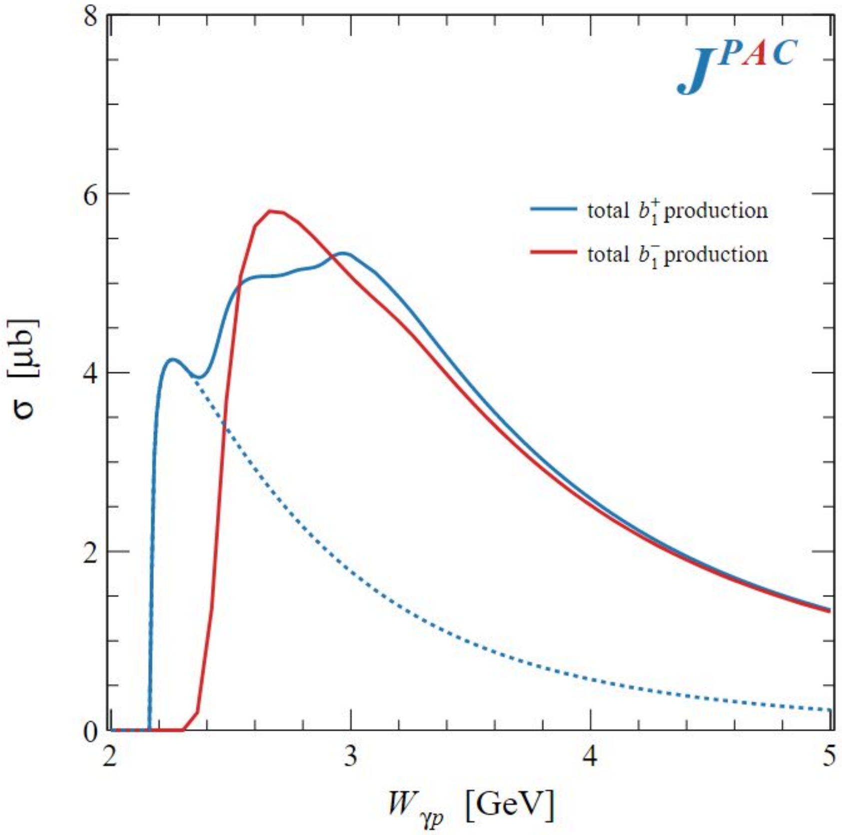
Compare with exclusive production with Δ^{++}
(near-threshold, small missing mass)



Compare with OmegaPhoton data
(high-energy, large missing mass)



Total $b_1(1235)$ production

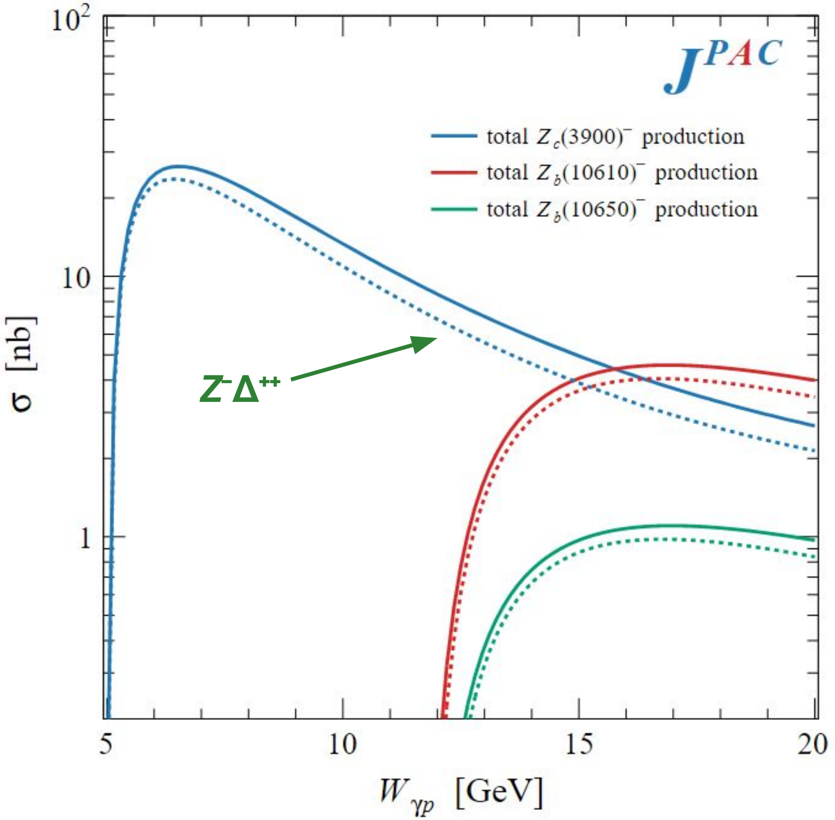


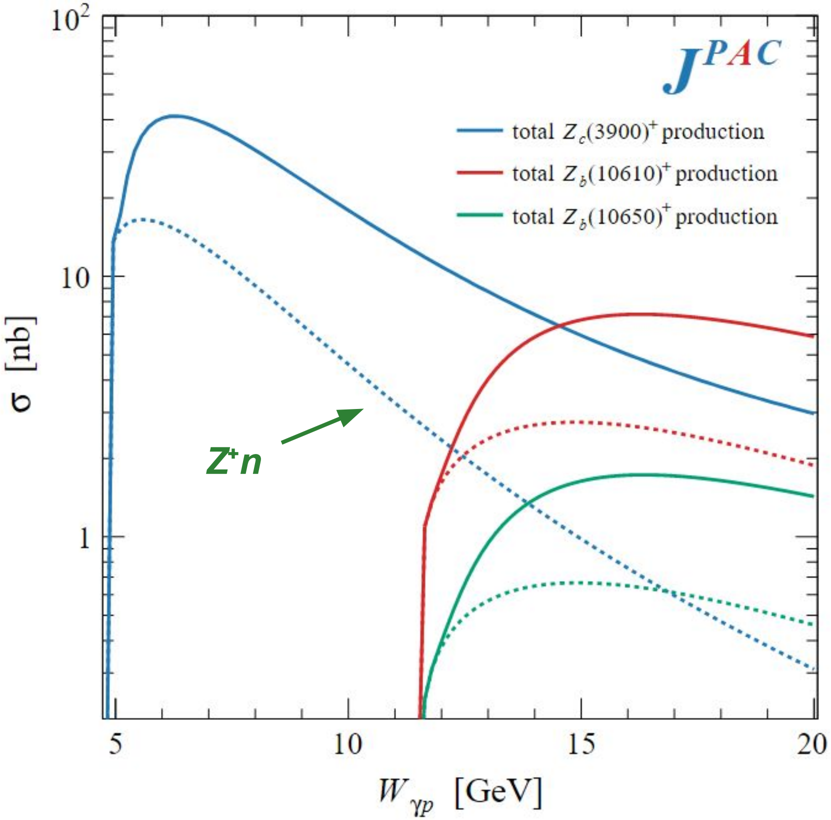
The positive charge channel allows the exclusive reaction which corresponds to the **nucleon pole** contribution of the πN cross-section.

$$\gamma\, p \to \mathcal{Q}^+\, n$$

Can investigate double differential cross-section with respect to momentum transfer and missing mass dependence

Charged Z production





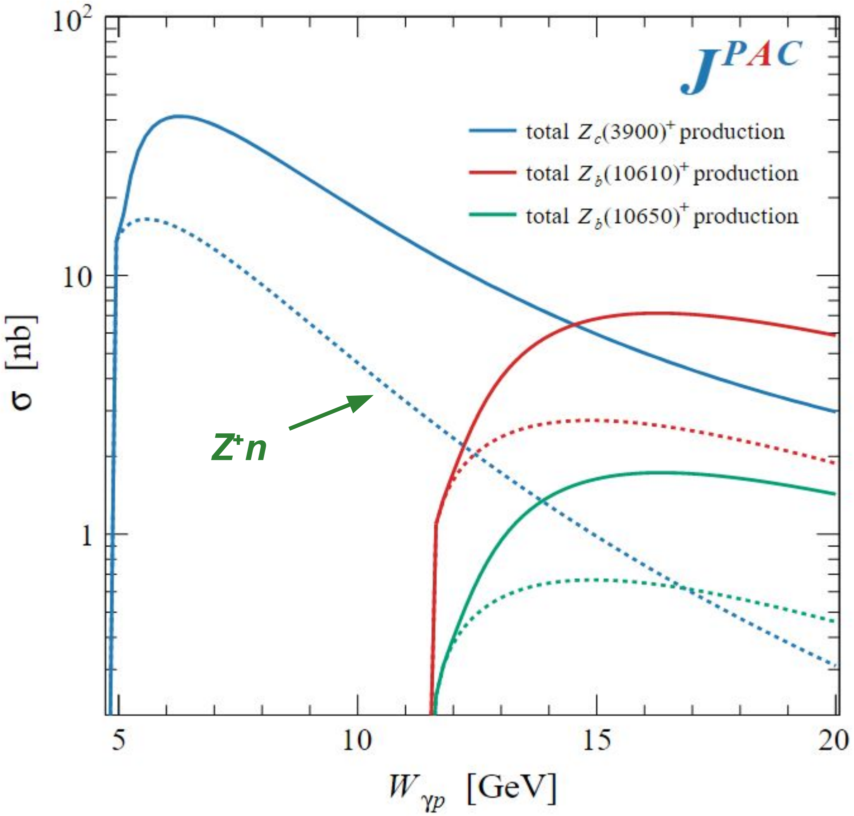
Summary and outlook

Restriction to small-momentum transfer kinematics allows reliable estimation of semi-inclusive rates using exchange (Regge) physics.

Estimates tens of nanobarn for inclusive production near threshold, substantial effect from baryon resonances. This likely a conservative **lower-bound**.

Formalism extendable to more complicated exchanges:

Pc states	- Proton	pp scattering
X(3872)	- ϱ/ω	γp scattering / Reggeon-Reggeon
Y(4260)	- Pomeron	triple Pomeron coupling



Thank you!