Pentaquarks

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Outline

Hidden-charm pentaquarks

Line-shape studies

Searches in photoproduction

Polarization observables

Ongoing work

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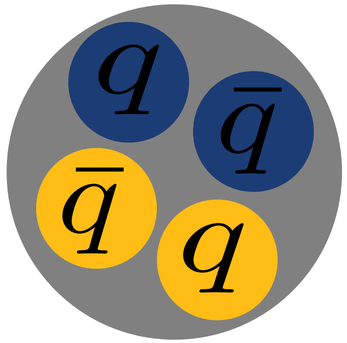
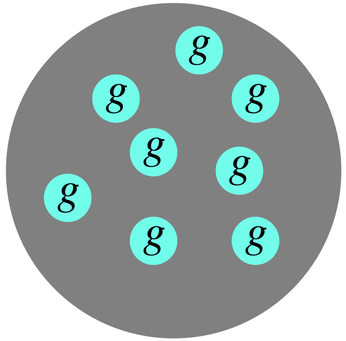
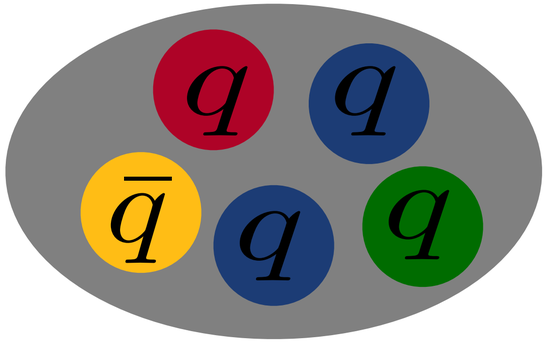
Hadrons and their mysteries

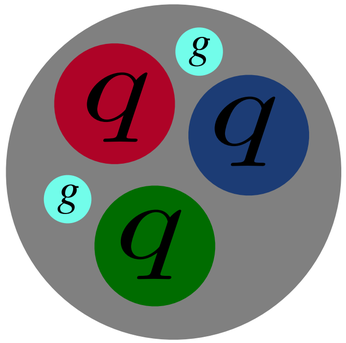


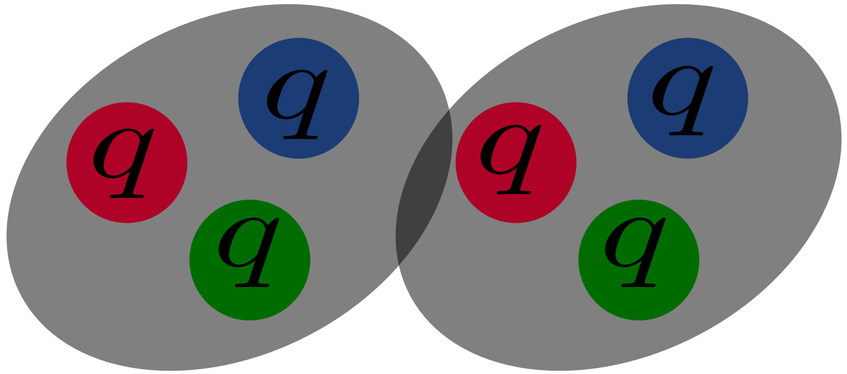
QCD describes the strong force binding the constituents,
but it behaves remarkably differently at high and low energies.



At low energies, the quarks and gluons are **confined** —
many resonances appear in the spectrum, some of them exotic!





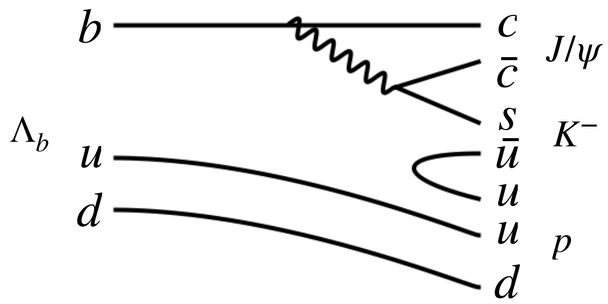


Tetraquarks and pentaquarks.
Hadron molecules.
Hybrids.
Glueballs.

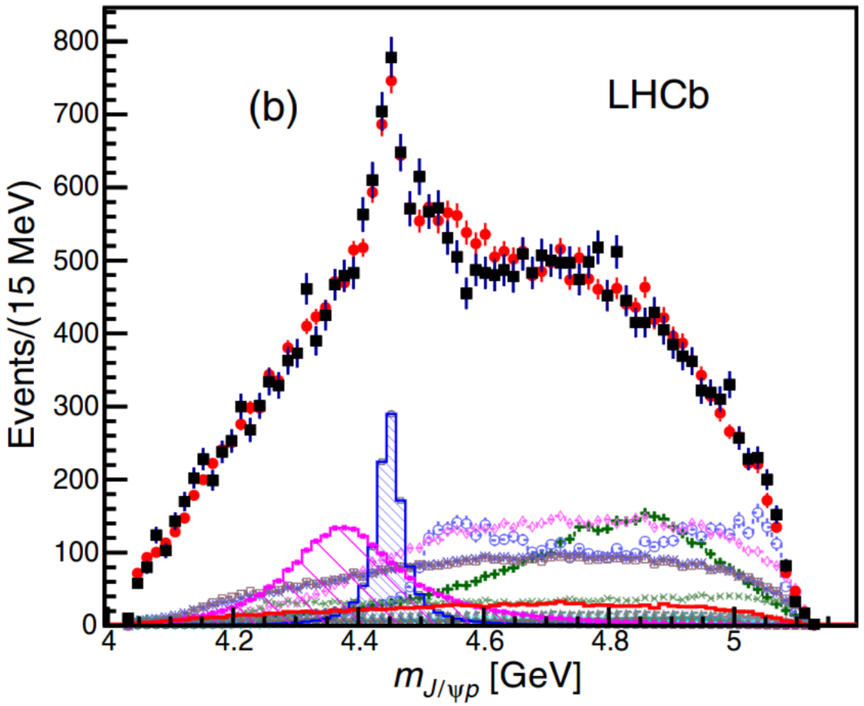
Hidden-charm pentaquark searches

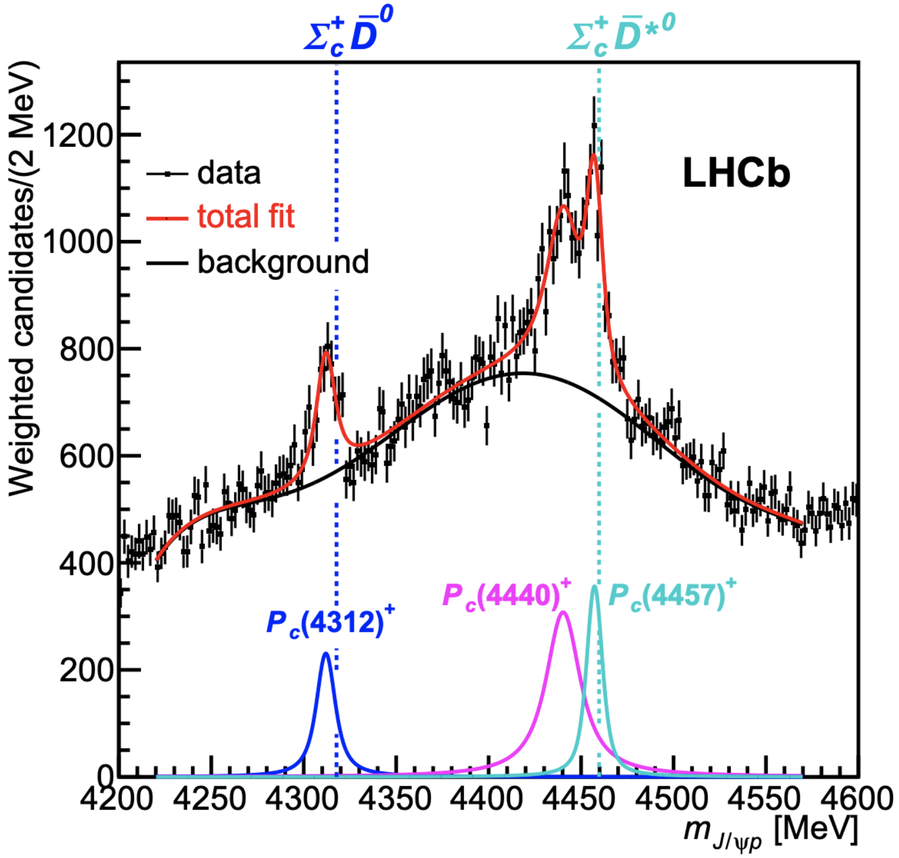
In 2015, exotic-like structures were found.

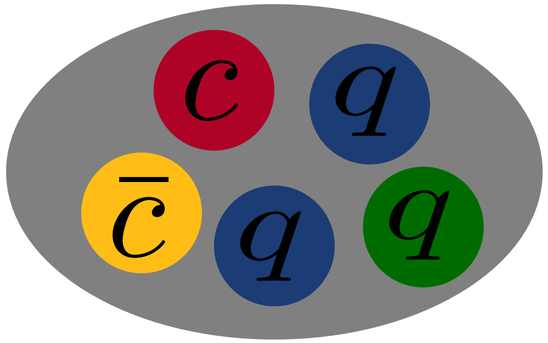
[Aaij et al. [LHCb], PRL 115 (2015) 072001;
Aaij et al. [LHCb], PRL 122 (2019) 222001]



$P_c \equiv c\bar{c}uud$





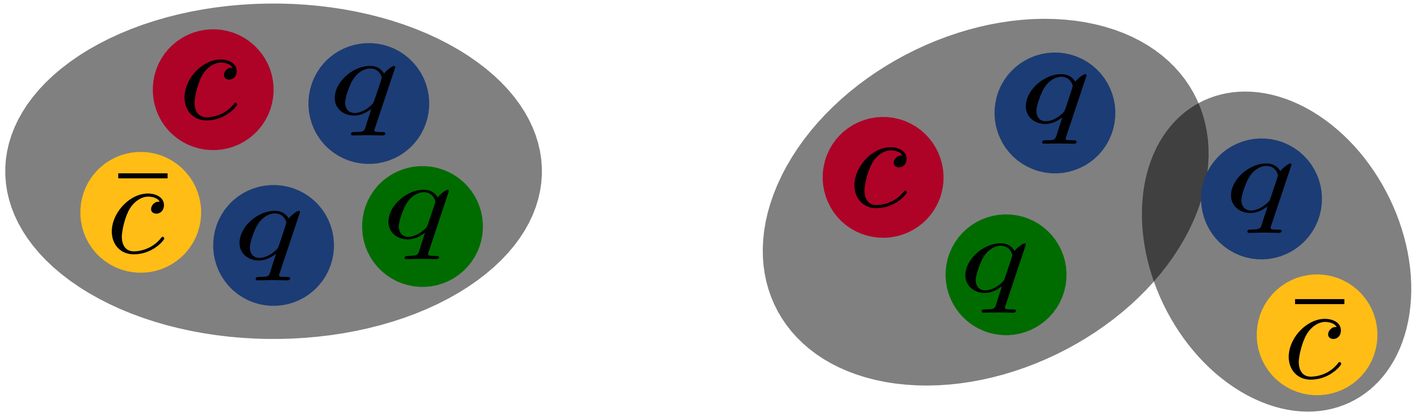


Possible interpretations

Kinematic final-state rescattering effects (triangle singularities).

Compact 5-quark states.

Weakly-bound molecules.



The $P_c(4312)^+$ peaks just below the threshold of $\Sigma_c^+ \bar{D}^0$.

Line-shape studies are called for insights into microscopic nature.

Minimum bias achieved through analiticity constraints from *S*-matrix theory.

[Pilloni et al., EPJC 78 (2018) 727;
Fernández-Ramírez et al., PRL 123 (2019) 092001;
Ng et al., PRD 105 (2022) L091501]

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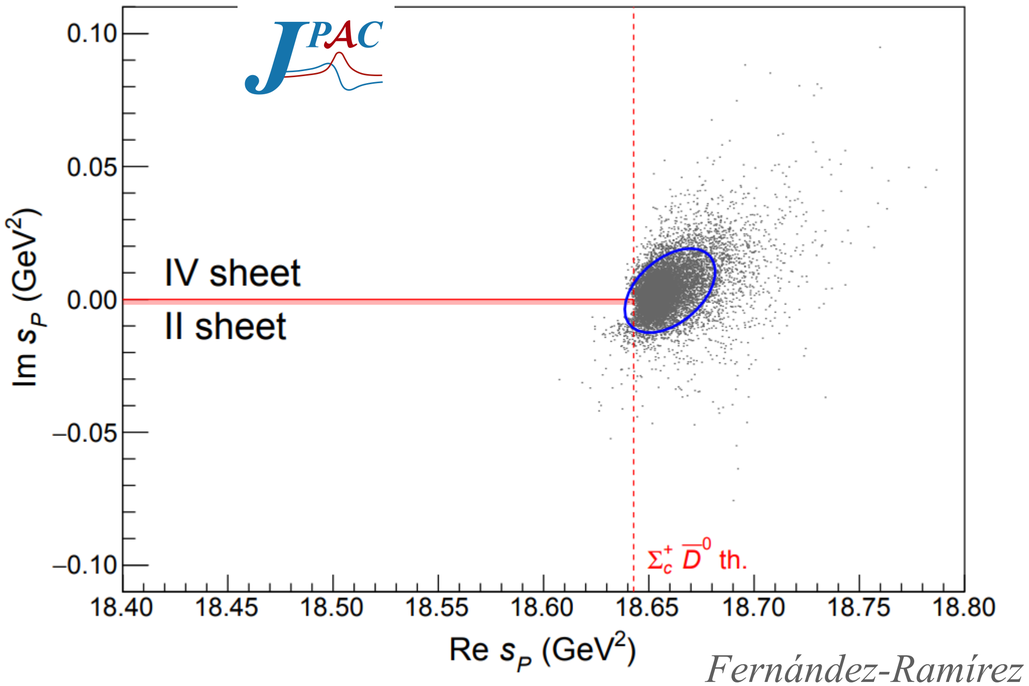

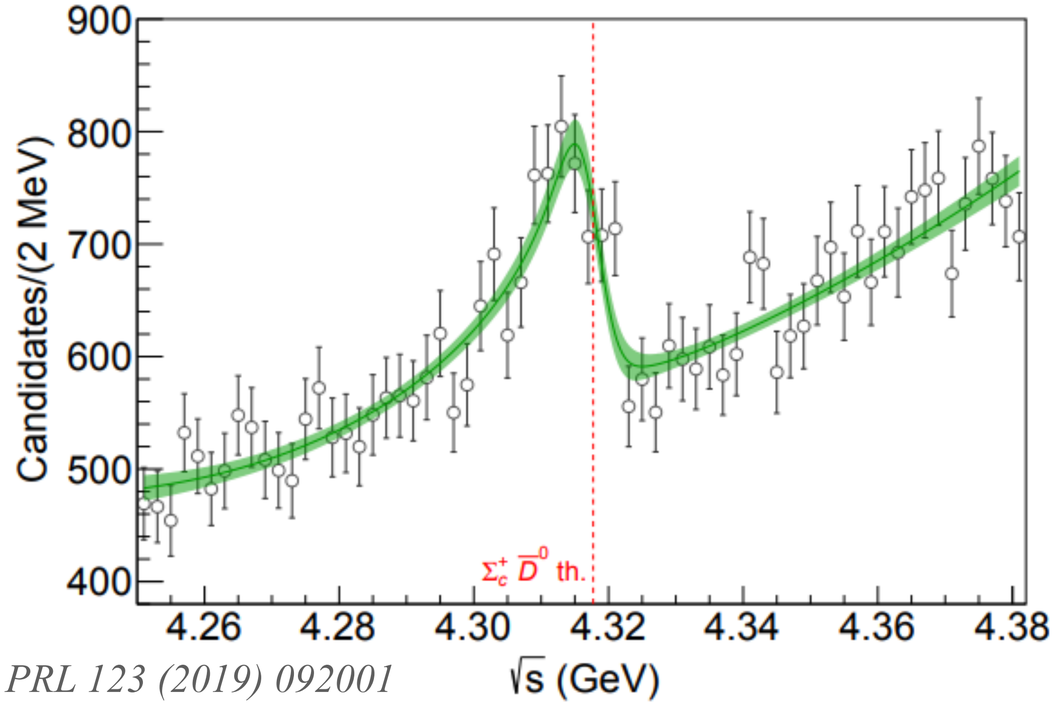

Fernández-Ramírez et al., PRL 123 (2019) 092001

We perform a local data-driven study restricting to the $P_b(4312)$ peak region.
A virtual state is favored over a bound state. Examples of other analyses in:

Du et el., Phys. Rev. Lett. 124 (2020) 072001; 1910.11846 (EFT)
Du et al., JHEP 08 (2021) 157; 2102.07159 (EFT)
Nakamura, Phys. Rev.D 103 (2021) L111503; 2103.06817 (Triangles)
Burns, Swanson, Phys.Rev.D 106 (2022) 5, 054029; 2207.00511 (Triangles)

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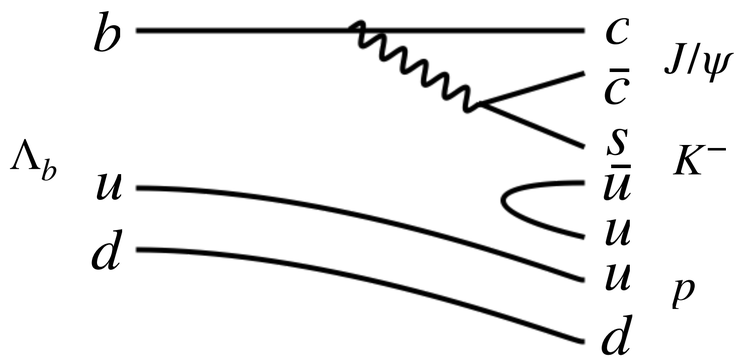
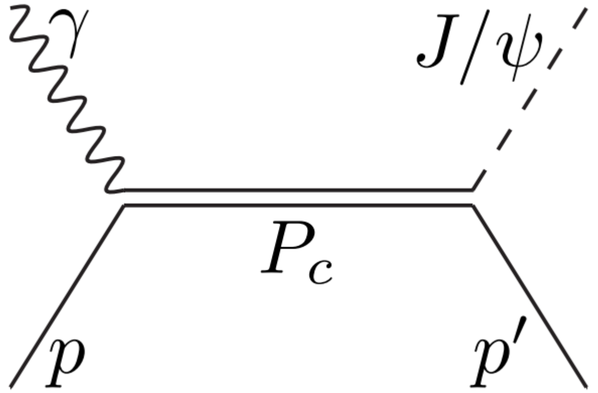
Complementary information from photoproduction



$P_c \equiv c\bar{c}uud$



Confirm resonant nature with photo-/electroproduction.

Not affected by 3-body dynamics: confirmation of resonant nature.

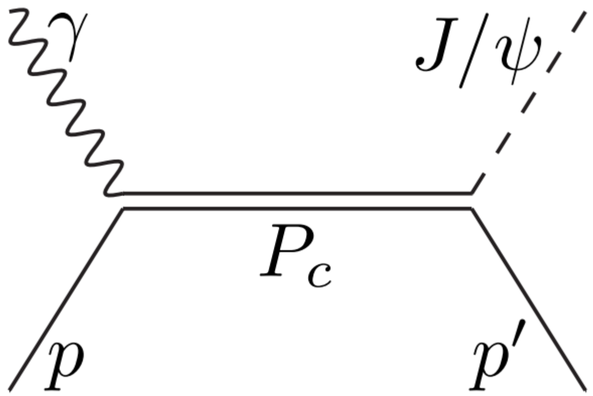
[Wang et al., PRD 92 (2015) 034022;
ANHB et al., Phys. Rev. D 94 (2016) 034002;
Huang et al., Chin.Phys.C 40 (2016) 124104;
LoI12-18-001 (PAC 46);
Wang et al., PRD 99 (2019) 114007;
Winney et al., PRD 100 (2019) 034019;
Wu et al., PRC 100 (2019) 035206;
Cao and Dai, PRD 100 (2019) 054033;
Cao et al., PRD 101 (2020) 074010]

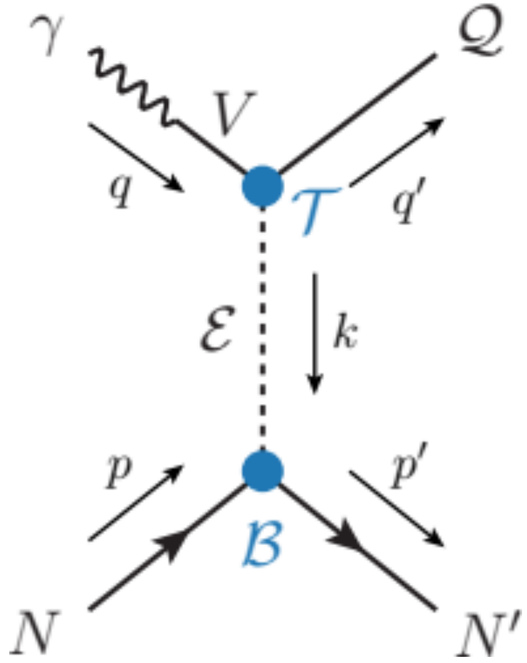
Photoproduction dynamics

So far, exotics have not been seen in photo-/electroproduction: independent confirmation.

Jefferson Lab an EIC: promising high-luminsotiy experiments in the appropriate energy range.

Background is parametrized as diffractive production.





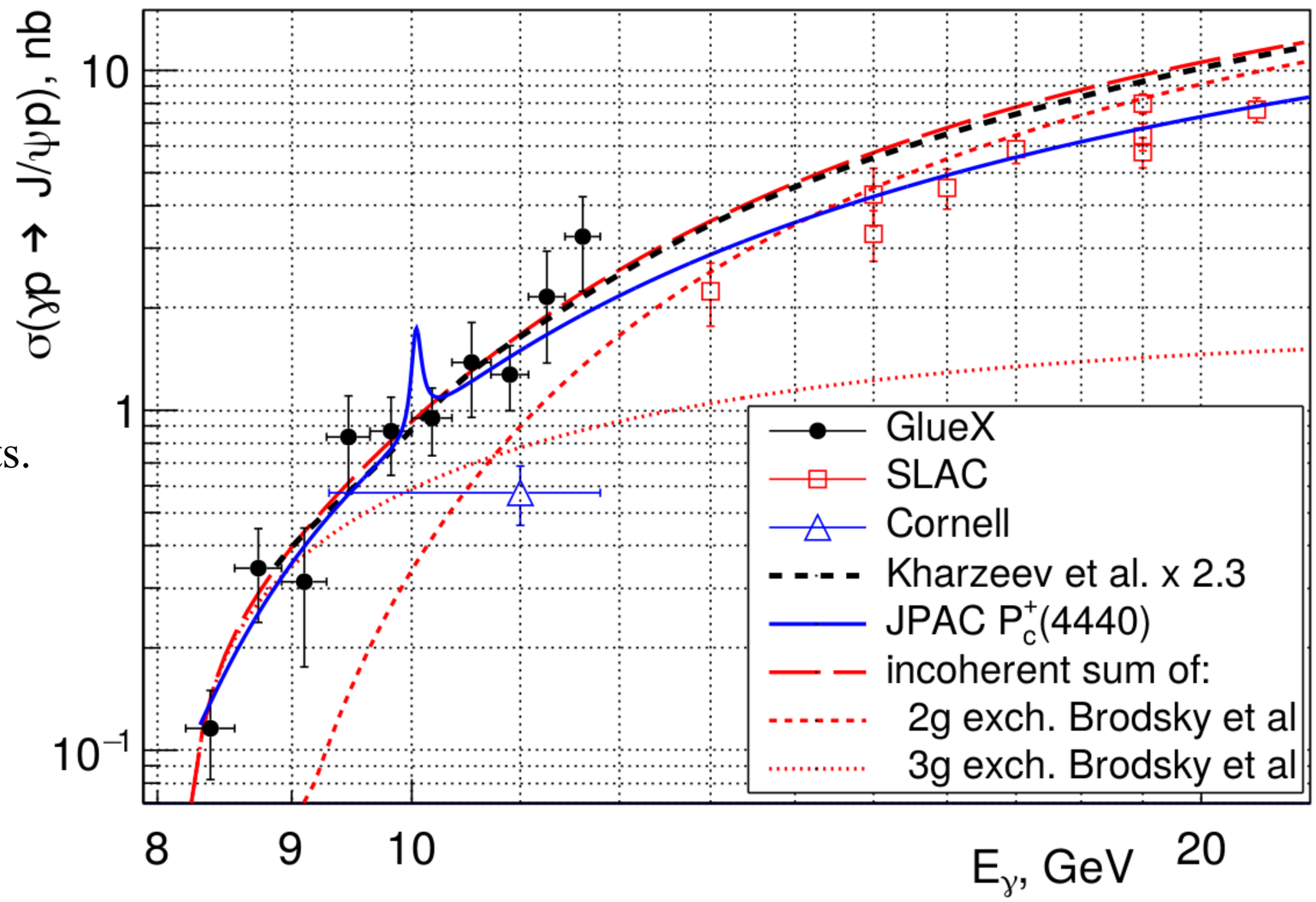
Photoproduction data so far

GlueX set upper limits to branching fractions.
[Ali et al., PRL 123 (2019) 072001;
ANHB et al., PRD 94 (2016) 034002;
Winney et al., PRD 100 (2019) 034019]

Differential cross sections soon, with more statistics.

Hall C results have been presented – order of magnitude more stringent limits.
[See S. Joosten's talk at DNP2021]

Challenges several theory models, but still allows for many others.



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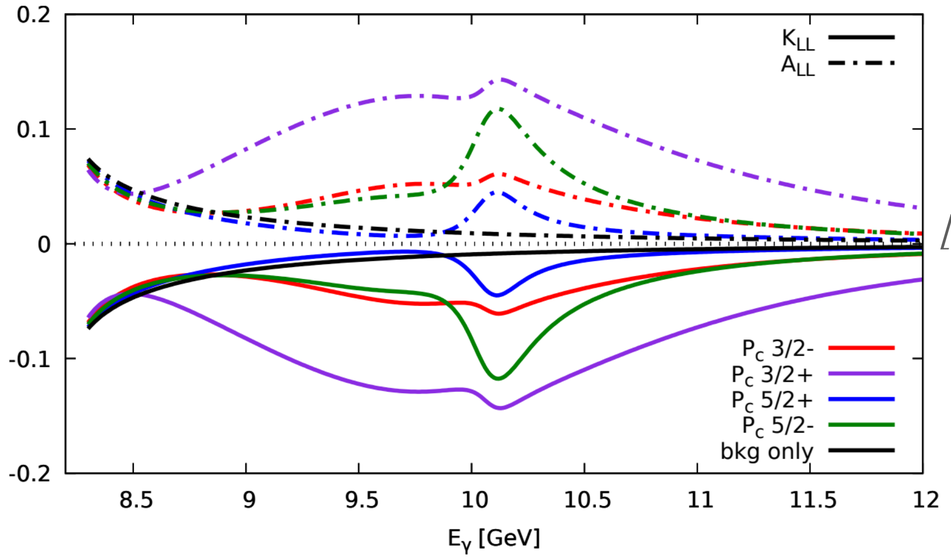
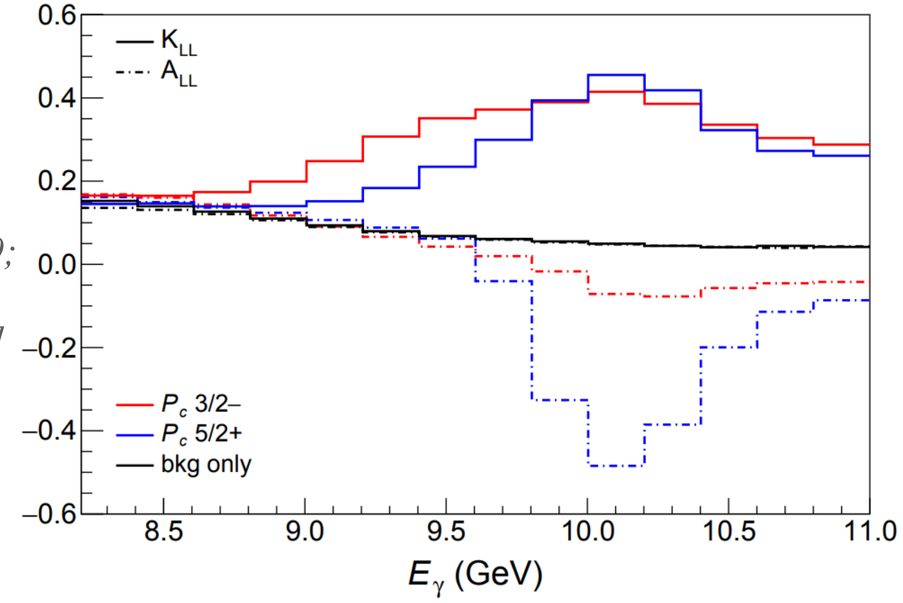
Double polarization observables



[Winney et al., PRD 100 (2019) 034019;
LoI12-18-001 (PAC 46);
https://github.com/dwinney/jpacPhoto]



Moving forward, measurement of **polarization observables:**
sensitive even to broader and overlapping signals.

Open-charm production, and **hidden-bottom** searches promising at the EIC.
[Cao and Dai, PRD 100 (2019) 054033;
Du et al., EPJC 80 (2020) 1053]

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Ongoing work and summary

We are currently scrutinizing:

beam **asymmetries**;
new fits to most recent (yet unpublished) **GlueX** data;
open-charm thresholds as additional backgrounds.

Moving forward we will:

give **predictions for EIC** searches;
provide further scrutiny of the pentaquark nature with **deep neural networks**.

In summary, since the JPAC review in 2016, we have:

provided first **bounds** on pentaquark **couplings**;
performed **feasibility studies and simulations** for Jefferson Lab experiments,
making all codes available, and leading to successful experimental proposals and analyses;
given **minimum-bias line-shape** studies.