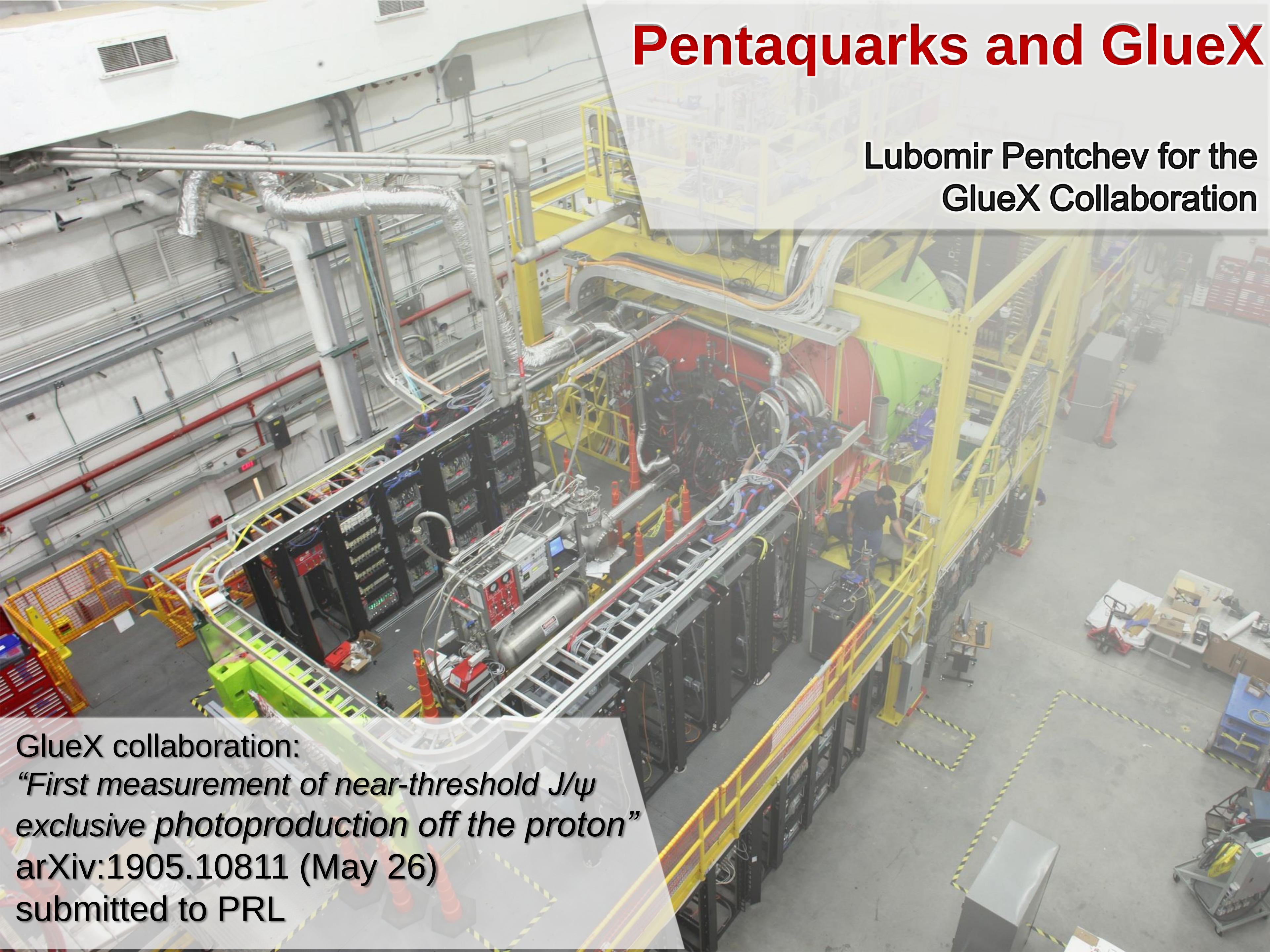
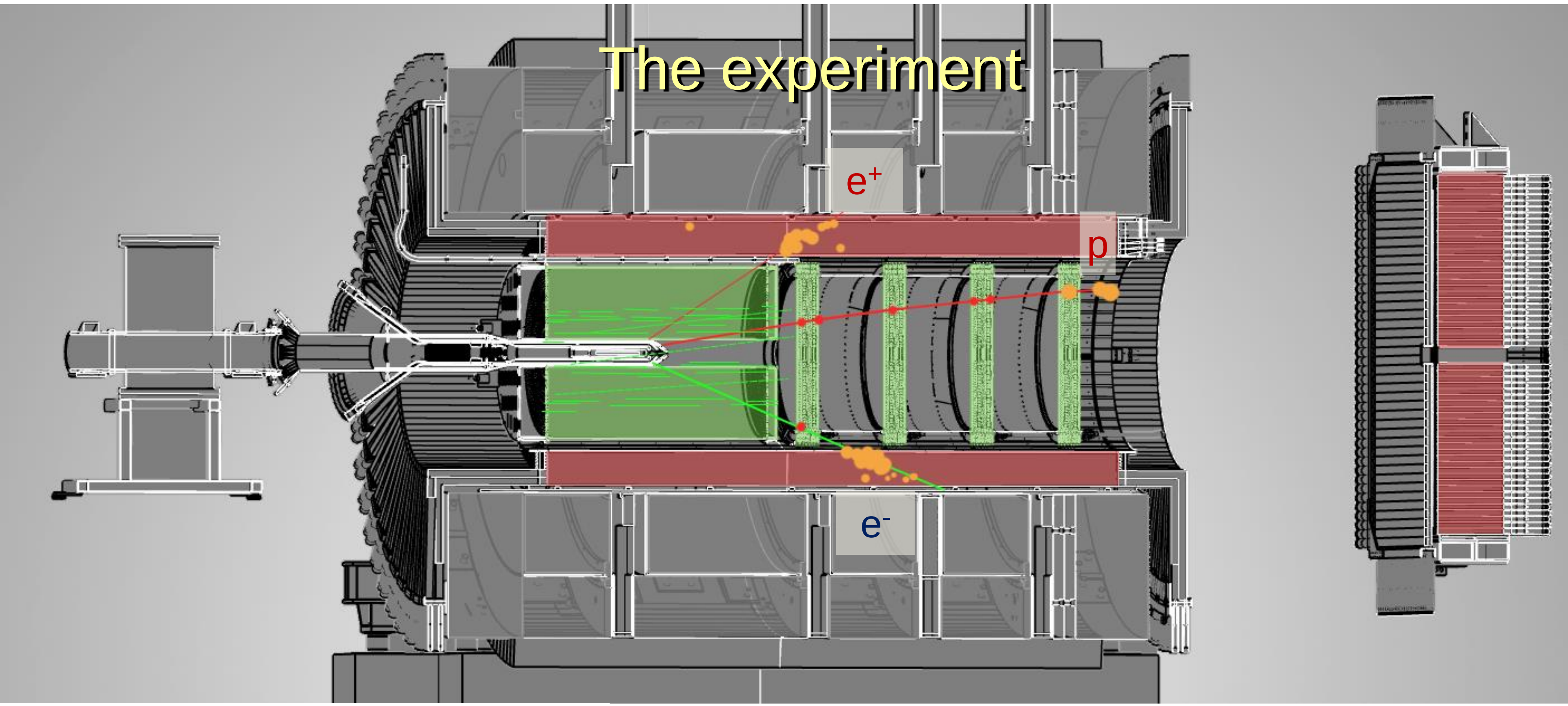
Pentaquarks and GlueX

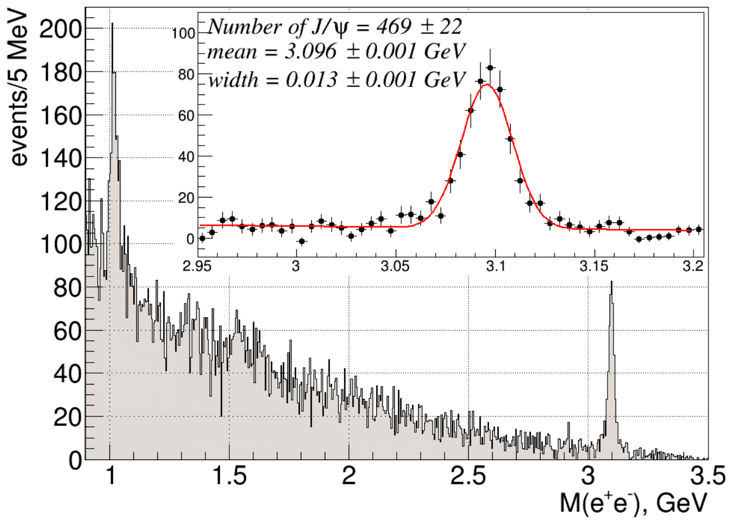
Lubomir Pentchev for the
GlueX Collaboration



GlueX collaboration:
"First measurement of near-threshold J/ψ exclusive photoproduction off the proton"
arXiv:1905.10811 (May 26)
submitted to PRL

The experiment



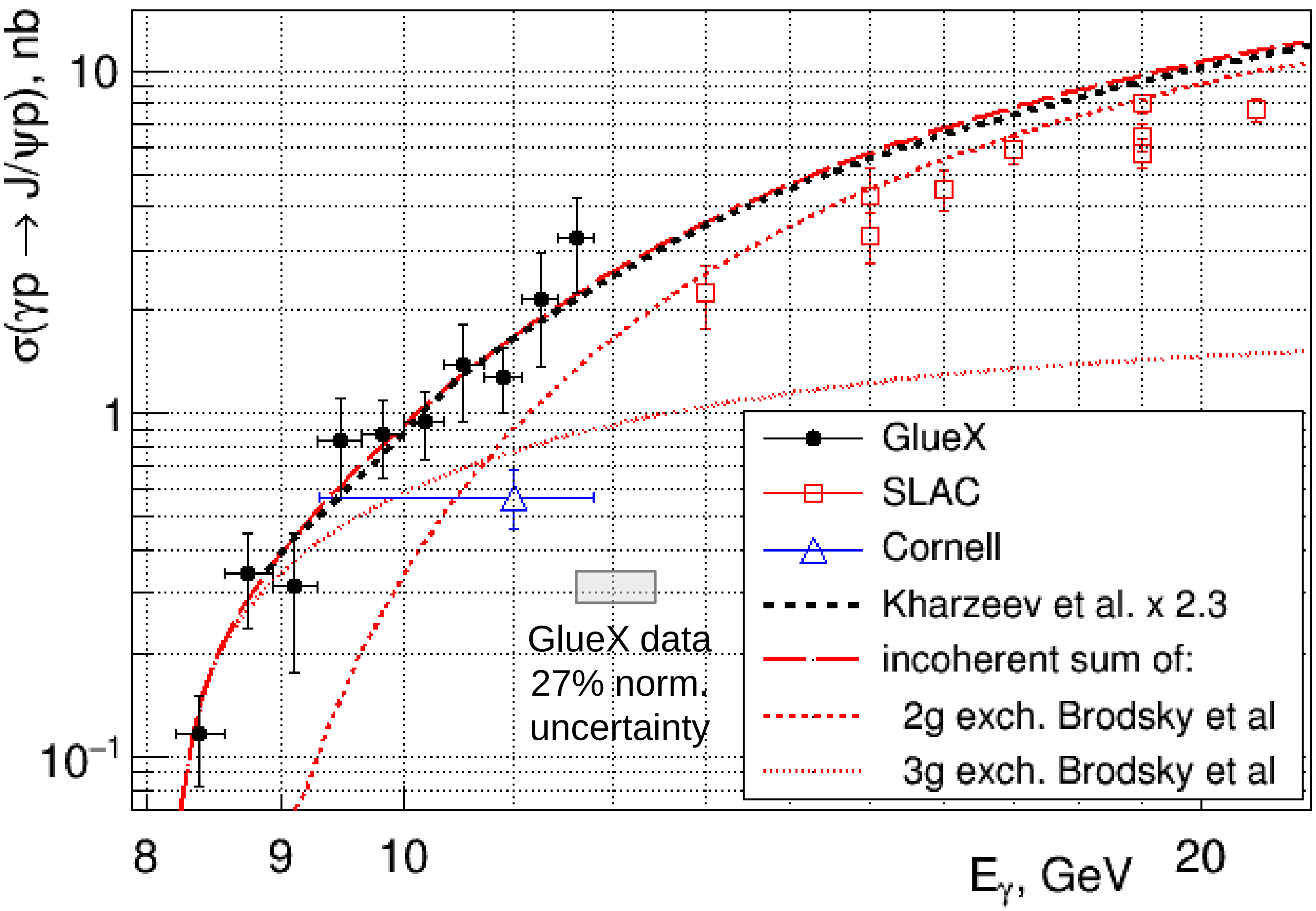


$\gamma\, p \to J/\psi\, p \to e^+e^-p$

- Tagged photon beam, 0.2% energy resolution
- Electrons identified by E/p
- Kinematic fit: 13 MeV mass resolution
- ~470 J/ψ: 25% of statistics accumulated up to date

- Using VMD ($\gamma \to J/\psi$) one can study $J/\psi\, p \to J/\psi\, p$
- Look for LHCb P_c: $\gamma\, p \to Pc \to J/\psi\, p$

J/ψ total cross-section



GlueX errors: quadratic sums of statistical and systematic ones

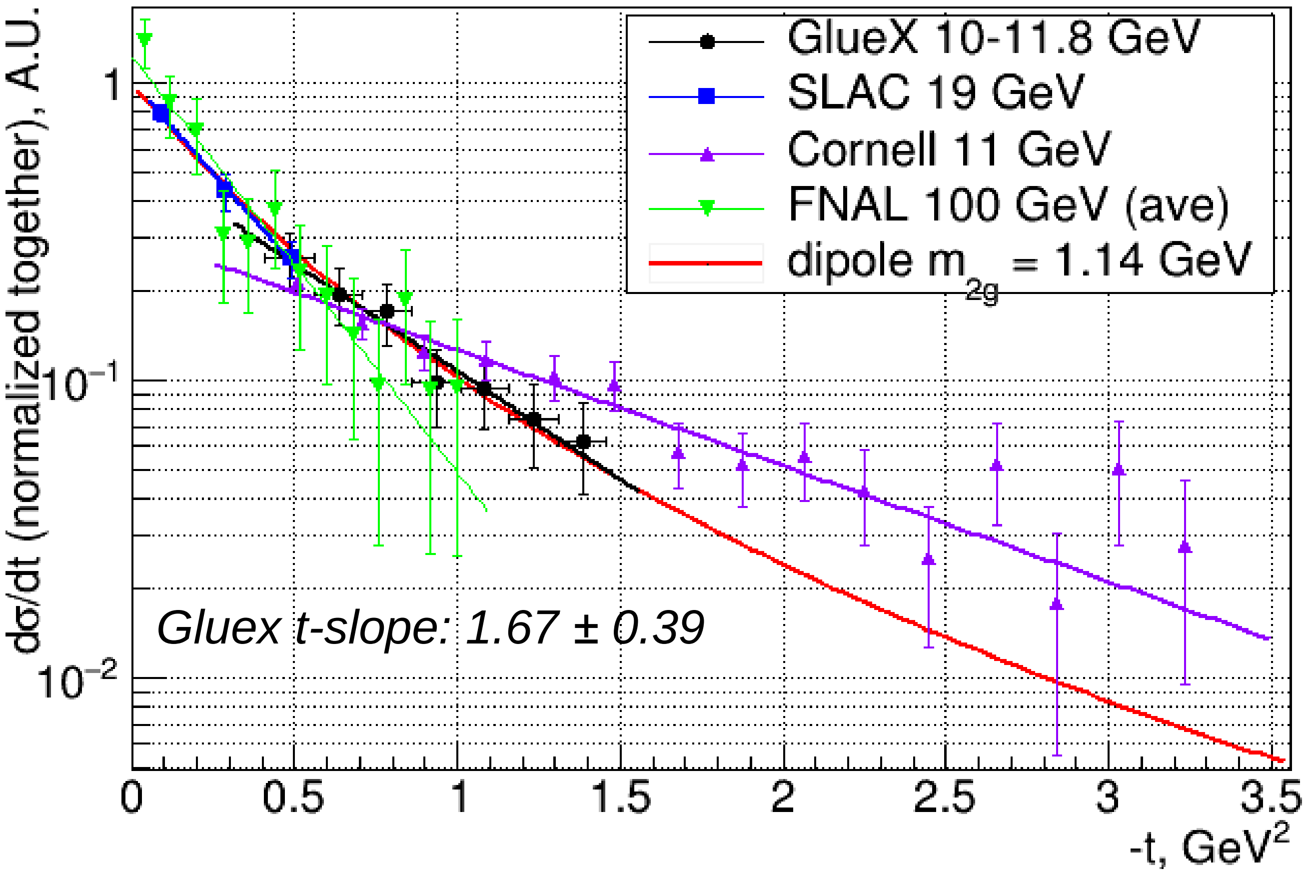
SLAC data: $\gamma d(p) \to J/\psi X$ calculated from $d\sigma/dt(t=t_{min})$ using: $F^2(t) = 1/(1-t/m_{2g}^2)^4$ m_{2g} = 1.14 GeV

Cornell data: $\gamma Be \to J/\psi X$

- *Brodsky et al*.: $\sigma(E_\gamma)$ depending on number of hard-gluons exchanged.
- *Kharzeev et al*.: real part of the amplitude dominates, contains scale anomaly term related to the mass of the proton arising from gluons.

GlueX data falls toward threshold less steeply than 2g exchange model

J/ψ differential cross-section and proton gluonic FF



gluonic form factor (dipole form in analogy with the e.-m. FF):

$$F(t) \sim 1/(1-t/m_0^2)^2$$

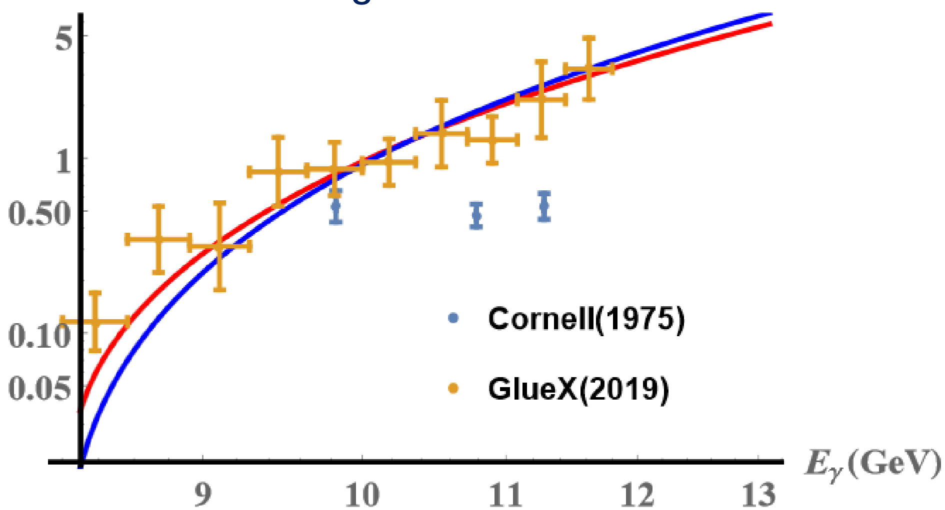
Frankfurt and Strikman PRD66 (2002)

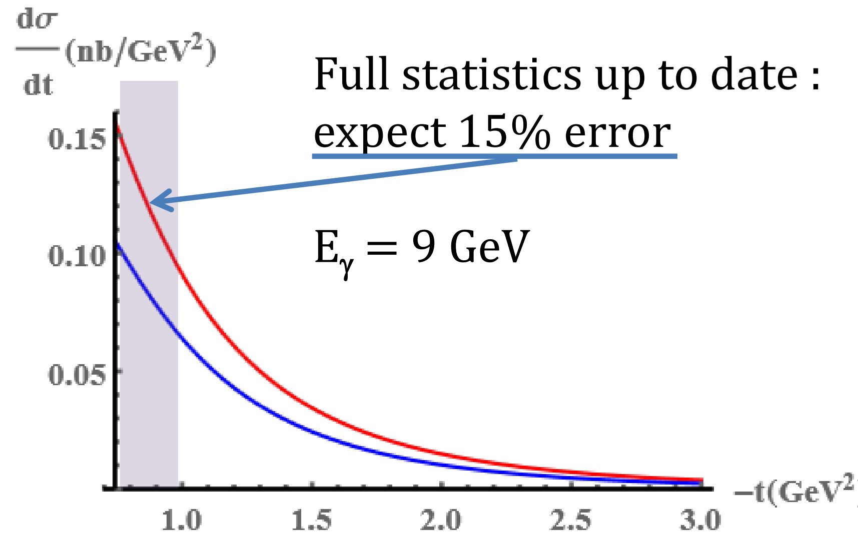
	e.m. FF	gluonic FF
reaction	$ep \to ep$	$J/\psi p \to J/\psi p$
transverse size of probe	0	$<<\ 1\ fm$
effective mass scale m_0	0.84 GeV (vector meson)	$\sim 1.1\ GeV$ (two-gluon mass)

Near-threshold J/ψ cross-sections and gluonic contribution to the mass of the proton

Red – maximal contribution from gluons, favored by GlueX data

Blue – no gluonic contribution





Y. Hatta, A. Rajan, and D.-L. Yang, arXiv:1906.00894:

Proton gluonic FF: *"..these are nothing but the gravitational form factors* $A_g, B_g, C_g, \bar{C}_g$"

$$\langle P'|(T_g)^\mu_\mu|P\rangle = \langle P'|\left(\frac{\beta(g)}{2g}F^a_{\mu\nu}F^{\mu\nu}_a + m\gamma_m\bar\psi\psi\right)|P\rangle$$

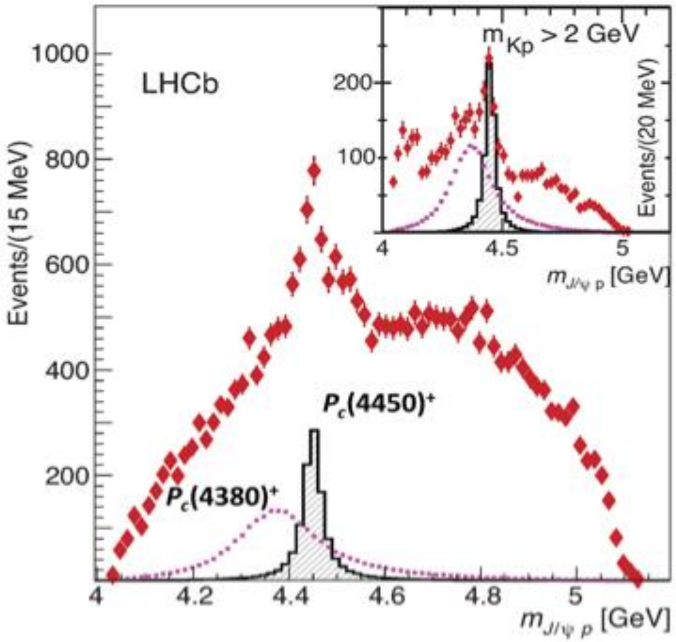
$$= \bar{u}(P')\left[A_g M + \frac{B_g}{4M}\Delta^2 - 3\frac{\Delta^2}{M}C_g + 4\bar{C}_g M\right]u(P)$$

A_g, B_g, C_g were recently calculated on lattice:

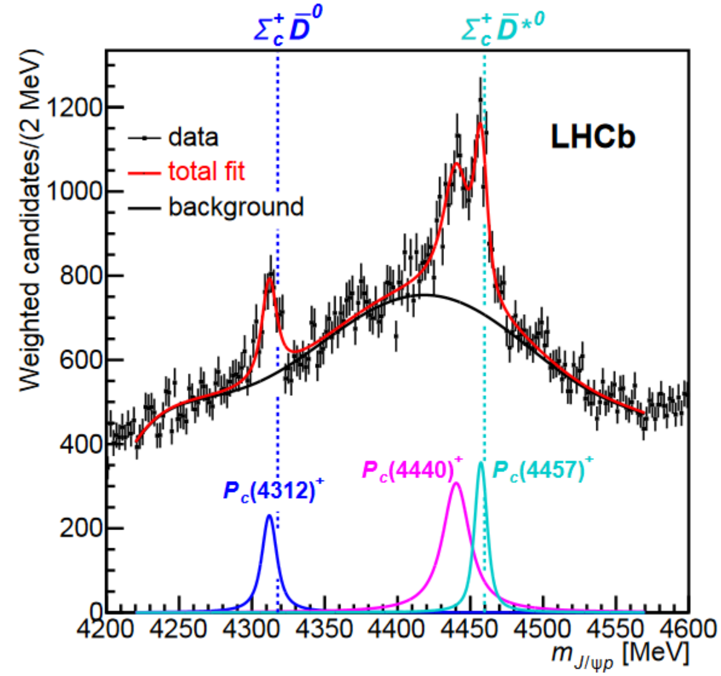
P. E. Shanahan and W. Detmold, arXiv:1810.04626

LHCb pentaquarks

$$\Lambda_b^0 \to J/\psi p K^-$$



Phys. Rev. Lett.,115,072001 (2015)



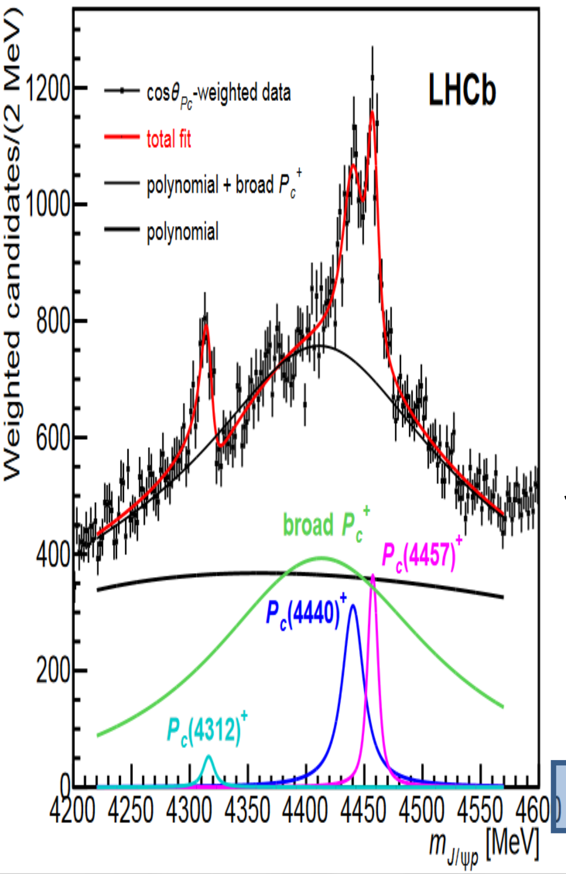
Phys. Rev. Lett. 122, 222001 (2019)

- J^P of P_c states not determined yet
- Molecules (most likely), but compact states or rescattering effects not excluded

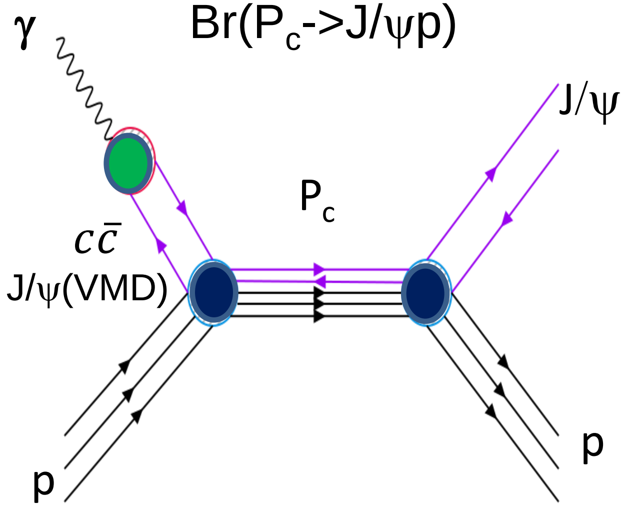
State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

LHCb pentaquarks and J/ψ photo-production

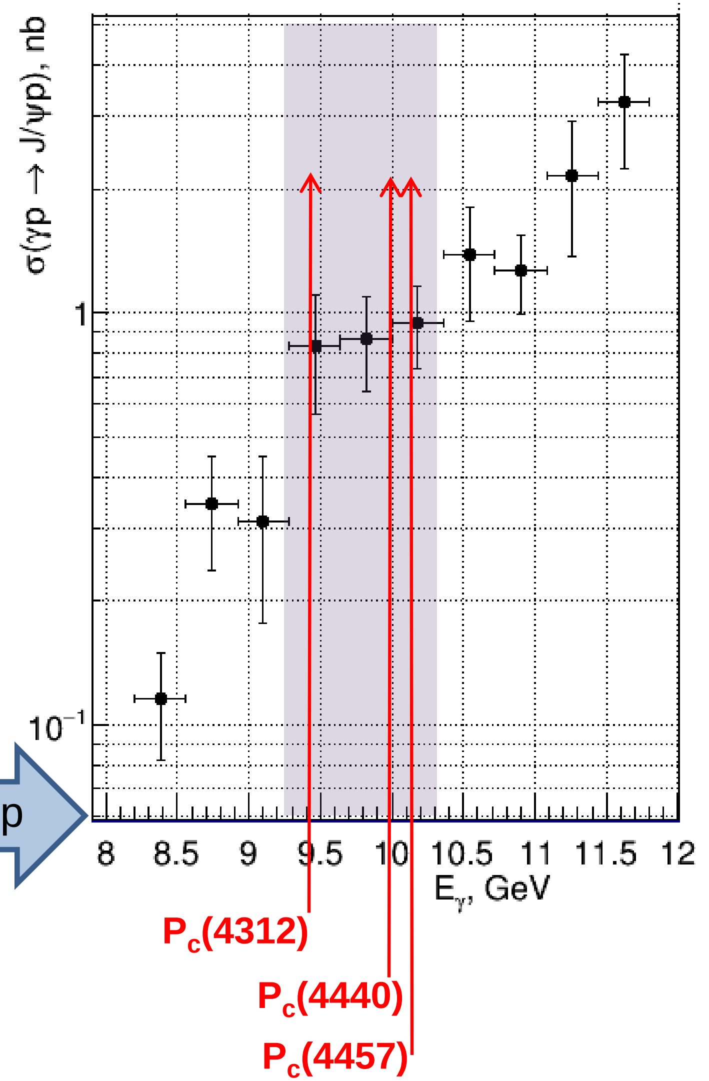
- If LHCb pentaquarks exist they should be seen in s-channel photoproduction (free of rescattering effects in the final state):



Main uncertainty
Br(P_c->J/ψp)

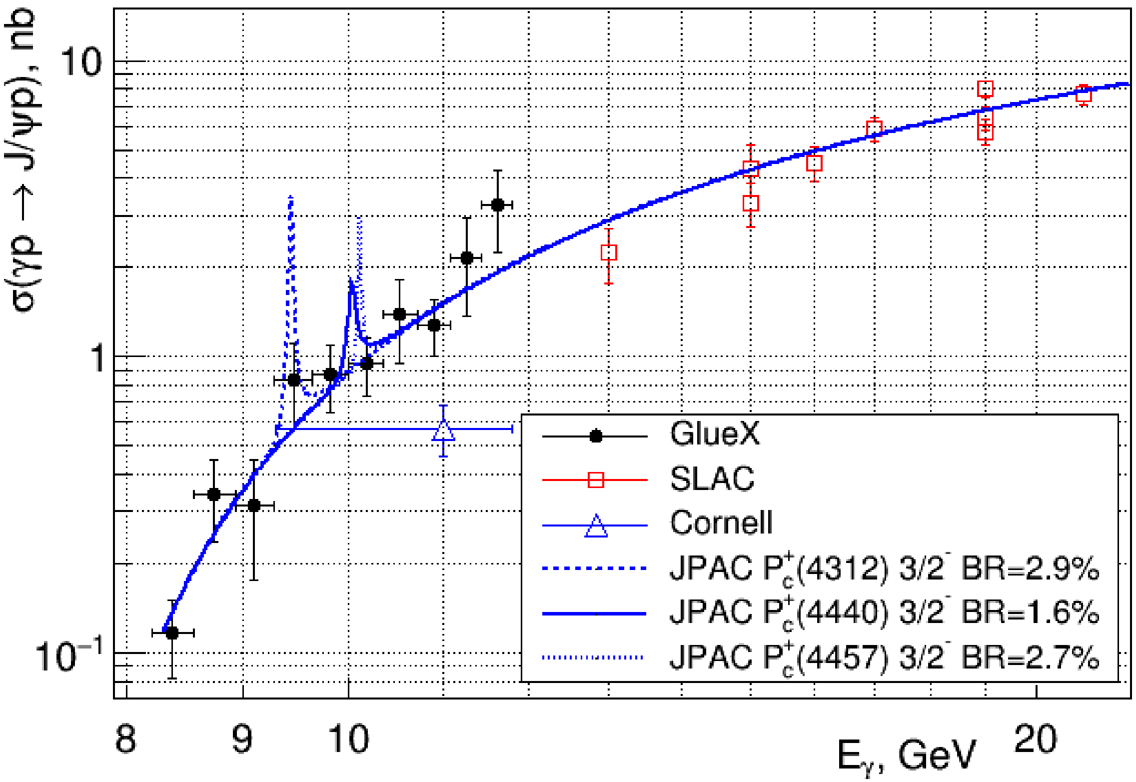


LHCb P_c related to γp ->P_c->J/ψp



- *V.Kubarovsky and M.B.Voloshin, PRD 92.031502 (2015).*
- *M.Karliner and J.Rosner, arXiv: PLB 752, 329 (2016).*
- *A.Blin, C.Fernandez-Ramirez, A.Jackura, V.Mathieu, V.Mokeev, A.Pilloni, and A.Szczepaniak, PRD 94,034002 (2016).*

J/ψ cross-section: model-dependent upper limits



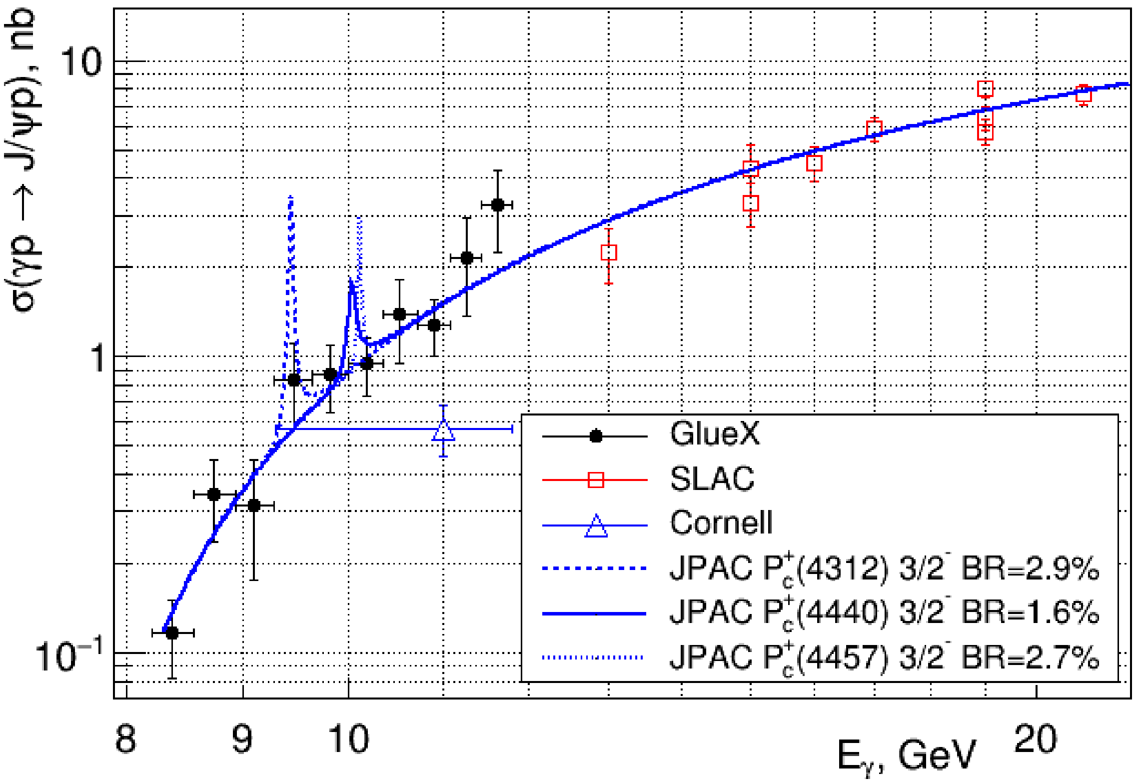
Assuming:

- all P_c independent $J^P = 3/2^-$
- s-channel model:
  $$\sigma(\gamma p \to P_c \to J/\psi p) \approx 0.35\ \mu b\ Br^2(P_c \to J/\psi p)\ (2J+1)$$
- JPAC model for t-channel: Pomeron and tensor part extracted at high energies

	$\mathcal{B}(P_c^+ \to J/\psi p)$ Upper Limits, %		$\sigma_{max} \times \mathcal{B}(P_c^+ \to J/\psi p)$ Upper Limits, nb	
	p.t.p. only	total	p.t.p only	total
$P_c^+(4312)$	2.9	4.6	3.7	4.6
$P_c^+(4440)$	1.6	2.3	1.2	1.8
$P_c^+(4457)$	2.7	3.8	2.9	3.9

Upper limits at 90% confidence level

J/ψ cross-section: model-dependent upper limits



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Upper limits at 90% confidence level

Br($P_c \to J/\psi p$) calculations: pentaquark models

model	Γ_{P_c}, MeV	$\Gamma_{J/\psi p}$, MeV	$\mathcal{B}(P_c \to J/\psi p)$	J^P	reference
molecular	21.7 (4450)	0.03 (4450)	0.14% (4450)	$1/2^-$ (4312)	M.Eides and V.Petrov
(OPE)				$1/2^-$ (4440)	Phys.Rev.D98, 114037
$\Sigma_c \bar{D}^{(*)}$				$3/2^-$ (4457)	
hadro-	– (4312)	suppr.(4312)	suppr. (4312)	$1/2^+$ (4312)	same as above
charmonium	44.8 (4440)	11 (4440)	25% (4440)	$1/2^-$ (4440)	and M.Eides, V.Petrov
	16.2 (4457)	11 (4457)	68% (4457)	$3/2^-$ (4457)	M.Polyakov,arXiv:1904.1161
compact	–	suppressed	suppressed	$3/2^-$ (4312)	A.Ali, A.Parkhomenko
diquark				$3/2^+$ (4440)	Phys.Lett.B793, 365
				$5/2^+$ (4457)	
molecular	9.8* (4312)	6.5	66%	$1/2^-$ (4312)	Z.-H. Guo and J.Oller
(ERE)	20.6* (4440)	16.3	79%	$1(3)/2^-$ (4440)	Phys.Lett.B793, 144
$\Sigma_c \bar{D}^{(*)}$	6.4* (4457)	3.5	55%	$1(3)/2^-$ (4457)	
molecular	15.2 (4306)	4**	26%	$1/2^-$ (4306)	C.Xiao, J.Nieves, E.Oset,
(DSE)	23.4 (4453)	18**	77%	$1/2^-$ (4453)	arxiv:1904.01296
$\Sigma_c \bar{D}^{(*)}$	3.0(4453)	2**	67%	$3/2^-$ (4453)	Phys.Rev.D88, 056012

* The total width measured by LHCb has been used.

** The width calculated from coupling constants.

Br(Pc → J/ψp) calculations: molecular vs hadrocharmonium

model	Γ_{P_c}, MeV	$\Gamma_{J/\psi p}$, MeV	$\mathcal{B}(P_c \to J/\psi p)$	J^P	reference
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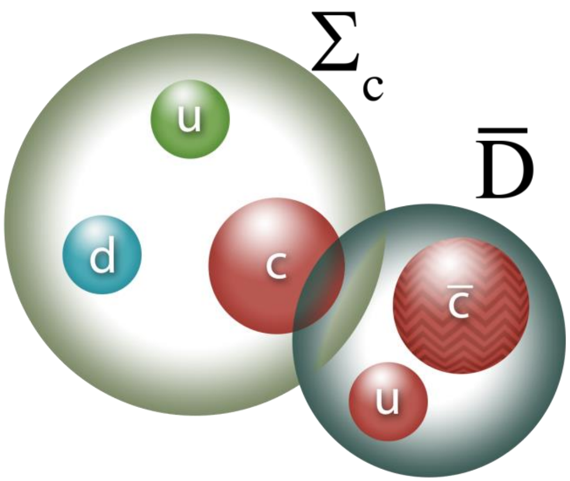
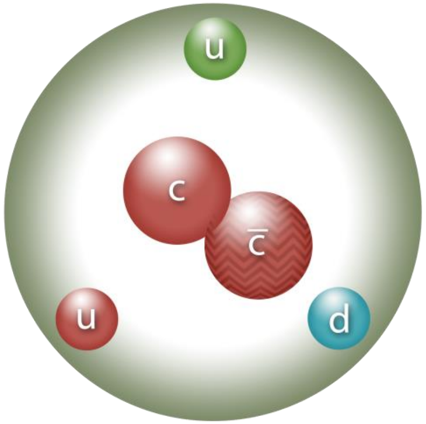
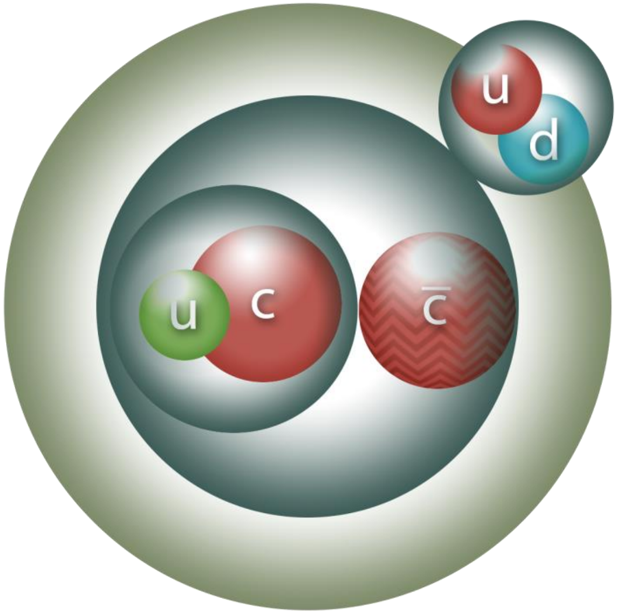
all subsystems in color singlet states





Br(Pc → J/ψp) calculations: compact diquark

model	Γ_{P_c}, MeV	$\Gamma_{J/\psi p}$, MeV	$\mathcal{B}(P_c \to J/\psi p)$	J^P	reference
compact diquark	–	suppressed	suppressed	$3/2^-$ (4312) $3/2^+$ (4440) $5/2^+$ (4457)	A.Ali, A.Parkhomenko Phys.Lett.B793, 365



diquarks in color anti-triplet states

The bound-state effect in (uC)-diquark
reduces the probability to form $C\overline{C}$ -state

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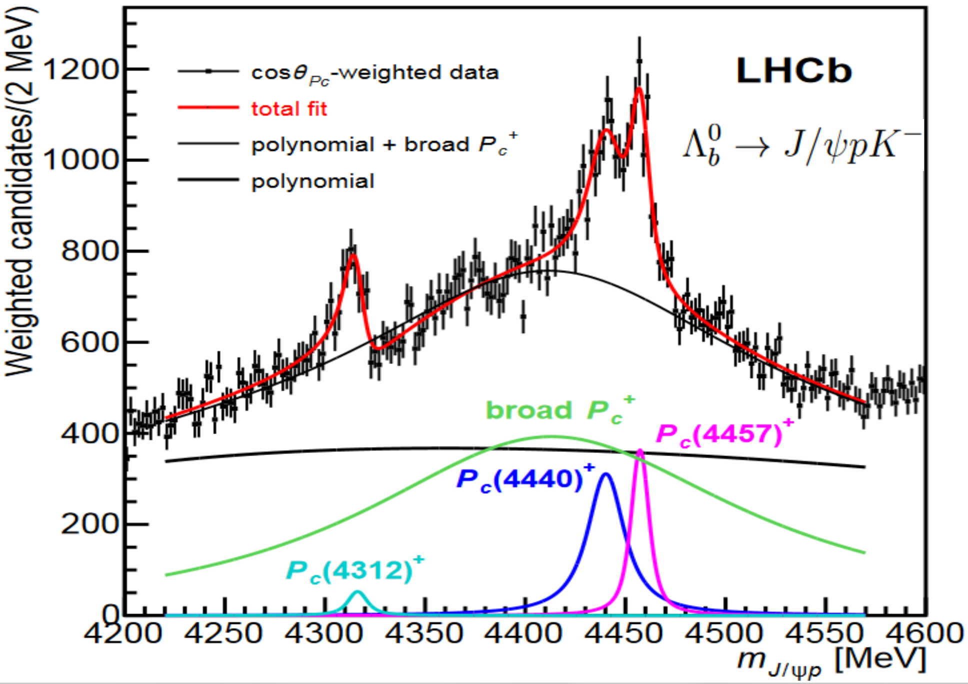
Lower limits on Br($P_c \to J/\psi p$) from data?



X. Cao, J-P. Dai *arXiv:1904.06015*

$$\mathcal{R} = \frac{\mathcal{B}(\Lambda_b^0 \to P_c^+ K^-)\mathcal{B}(P_c^+ \to J/\psi p)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)}$$

$$\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-) = (3.2^{+0.6}_{-0.5}) \times 10^{-4}$$

$\mathcal{B}(\Lambda_b \to P_c^+ K^-) < 10^{-3}$ at the level of $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)$ and $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-)$

(model dependent 2-4%) $> \mathcal{B}(P_c^+ \to J/\psi p) > 0.05\%$
GlueX

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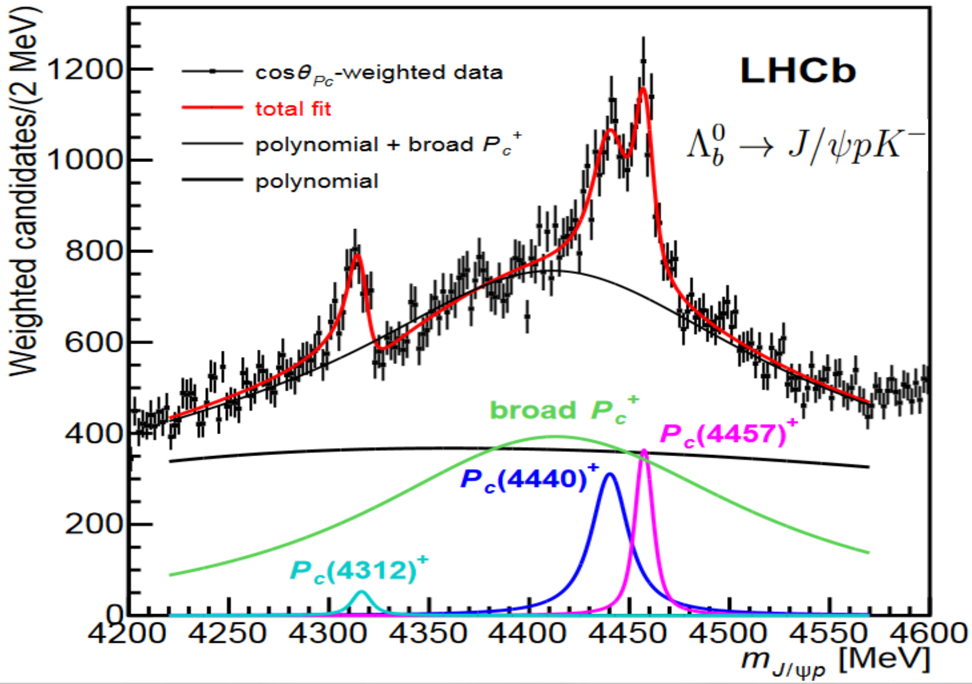

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(model dependent 2-4%) $> \mathcal{B}(P_c^+ \to J/\psi p) > 0.05\%$

GlueX

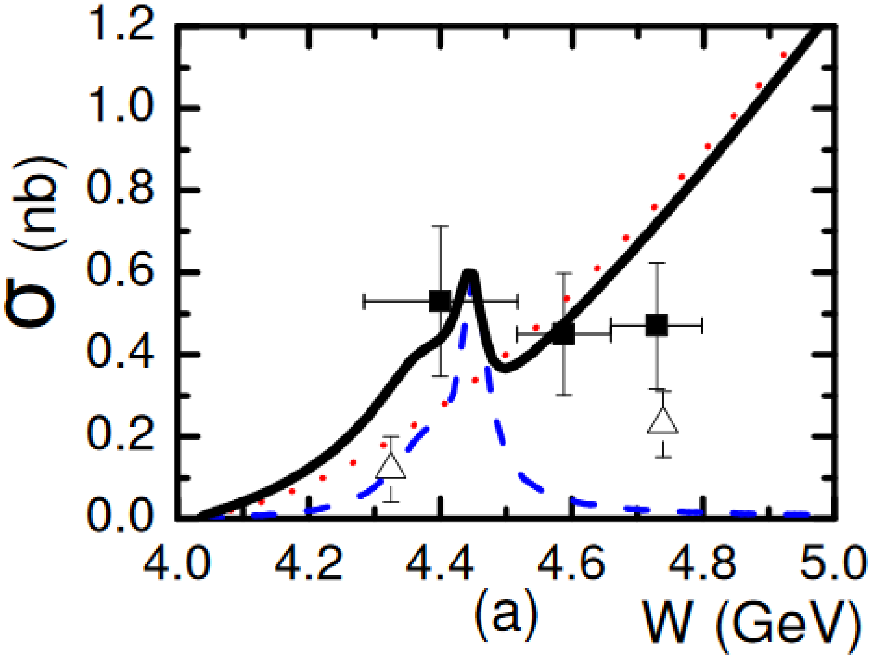
Conclusions

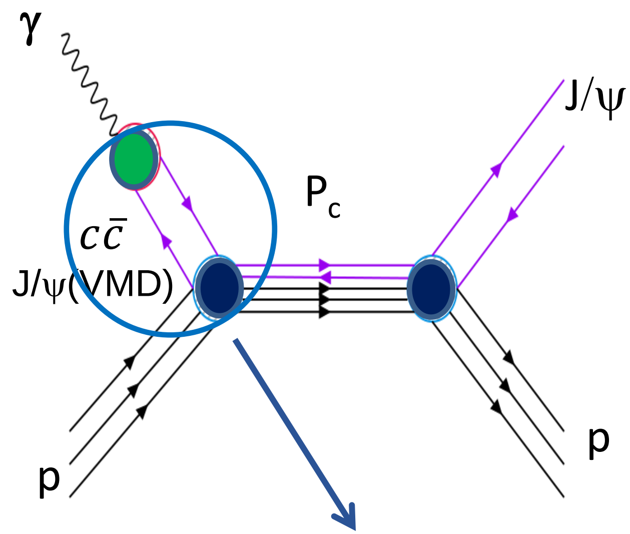
- JLab 12GeV accelerator has unique opportunity (high intensity, correct energy, polarized beam) to study J/ψ photo-production right above the threshold (E_γ=8.2 GeV) up to 12 GeV
- Do not see evidence for LHCb pentaquarks and set model-dependent limits on $Br(P_c \rightarrow J/\psi p)$ at several percent level,
  and limits on the $\sigma_{max}(gp \rightarrow Pc) x Br(P_c \rightarrow J/\psi p)$ at nb level
- This allows us to discriminate between different pentaquark models
- Extraction of the J^P numbers of the penaquark states (by LHCb) will certainly reduce many ambiguities in their interpretation
- Expect results with higher statistics (x4) from GlueX and the other Halls: will allow to reduce the upper limits or find positive signals

Back-ups

Attempts to suppress VMD coupling

J.-J. Wu, T.-S. Lee, B-S. Zou arXiv:1906.05375





$$F_V(q) = \frac{\Lambda_V^4}{\Lambda_V^4 + (q^2 - m_V^2)^2}$$

$$\Lambda = 0.55\ \text{GeV}$$

- J/ψ is suppressed by 10^{-3}, VMD coupling dominated by ρ and ω
- How to explain J/ψ photoproduction at high energies with such suppression???
- Other papers (*J. Phys. G4 (1978) 989, Phys. Rev. Lett. 38 (1977) 263)* suggest some moderate suppression (factor of *2-3*)