J/ψ polarization measurements with SBS

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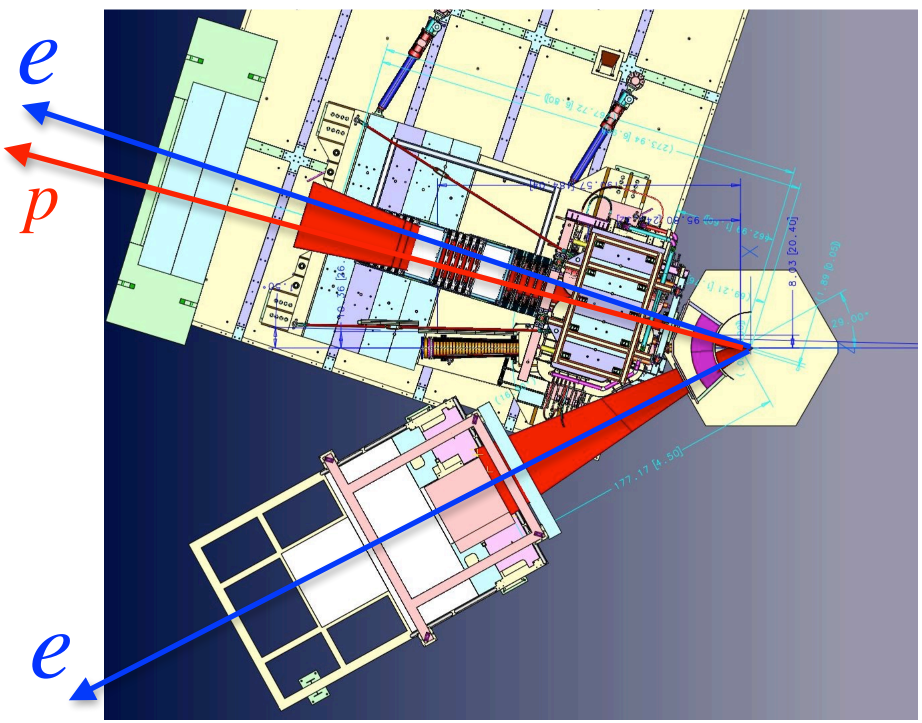
Purpose: High sensitivity search for LHCb pentaquark and other possible phenomena near J/ψ threshold, using double polarization observables.

How: Using high beam current, high SBS acceptance, proton polarimetry and/or polarized target. All three final state particles registered in the electron (e^+ or e^-) and hadron (e^+p or e^-p) arms:

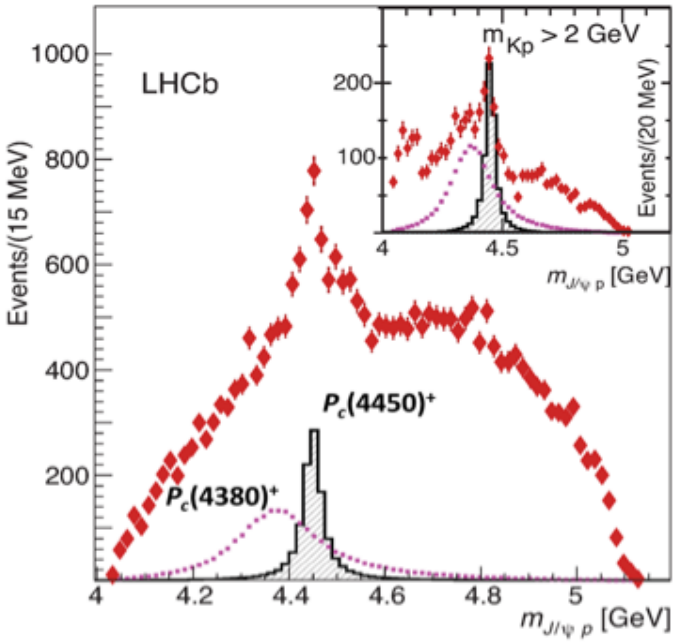
$$\vec{\gamma} p \rightarrow J/\psi \overrightarrow{p} \rightarrow e^+ e^- \overrightarrow{p} \qquad K_{LL}$$

and/or
$$\vec{\gamma} \overrightarrow{p} \rightarrow J/\psi p \rightarrow e^+ e^- p \qquad A_{LL}$$

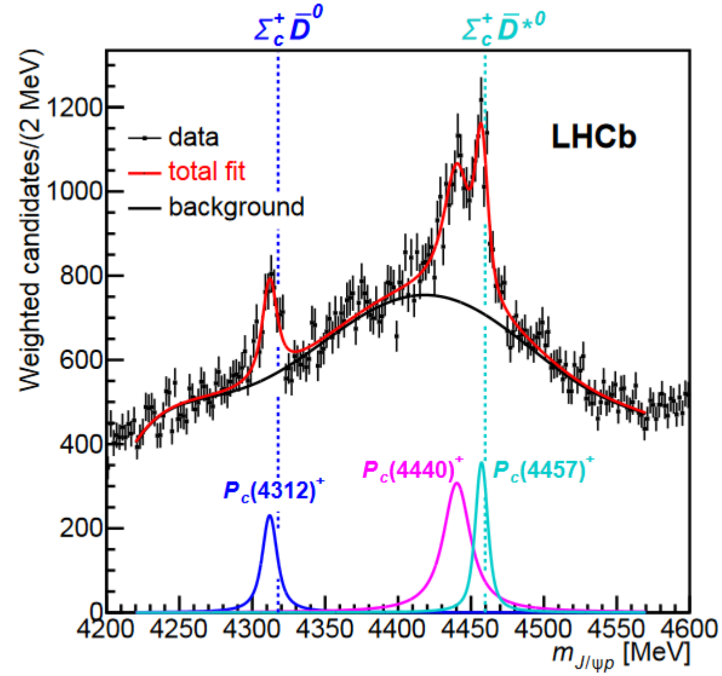


LHCb pentaquarks

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



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



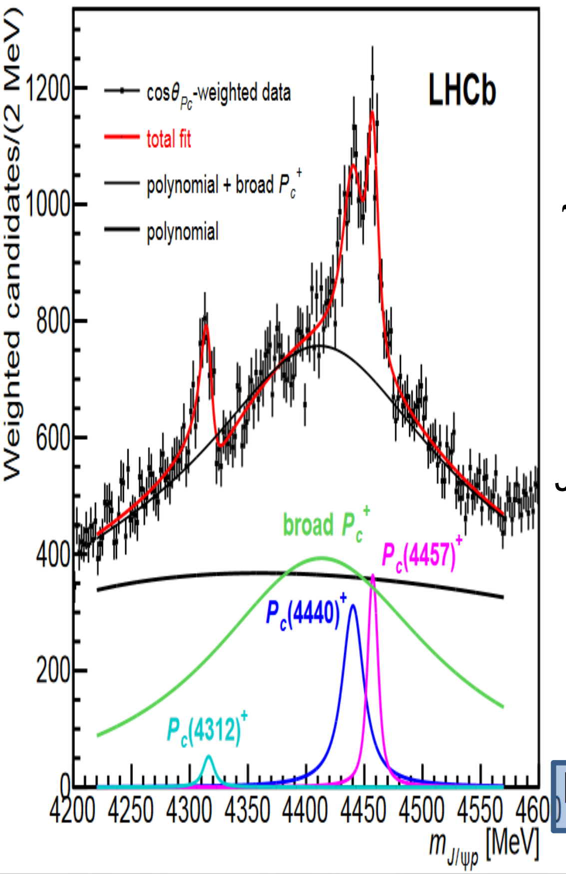
Phys. Rev. Lett. 122, 222001 (2019)

- J^P of P_c states not determined yet
- Molecules (most likely), but compact states or re-scattering 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)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

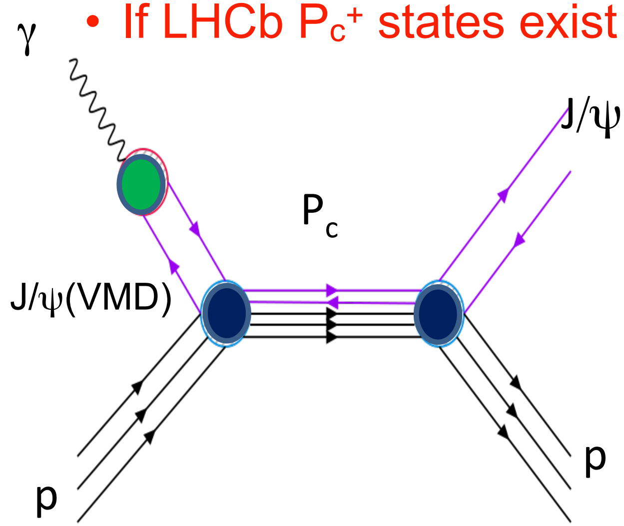
LHCb pentaquarks and J/ψ photo-production

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

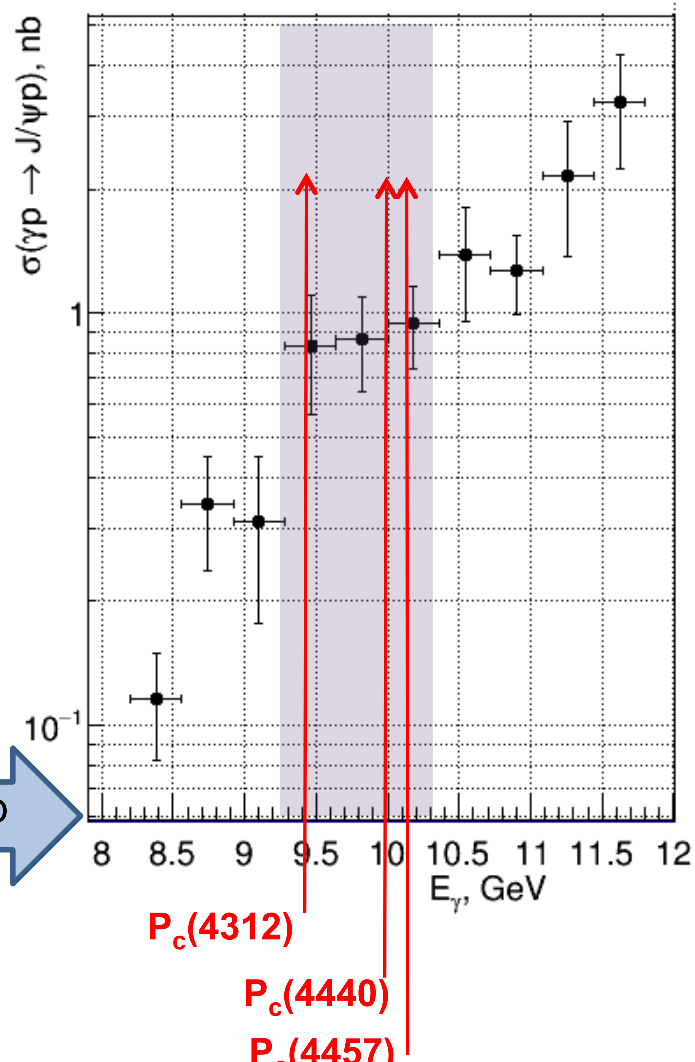


Main uncertainties:

- Br(P_c->J/ψp)
- VMD validity
- If LHCb P_c^+ states exist



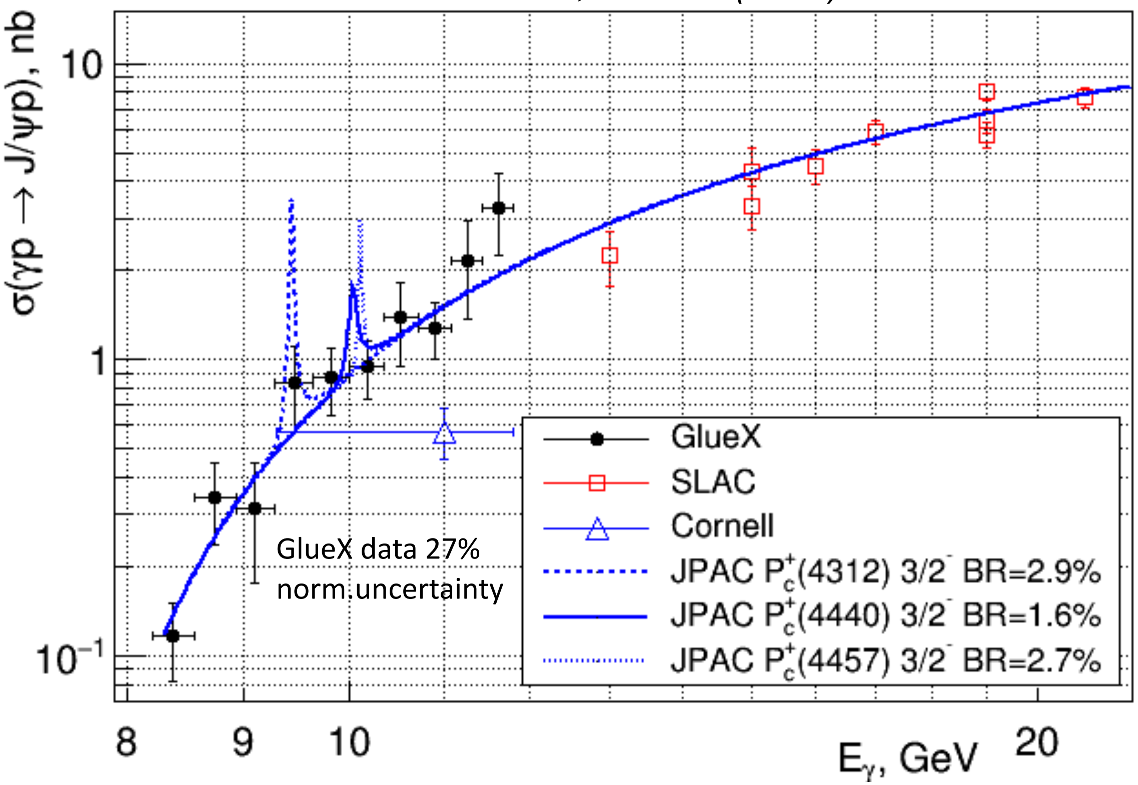
LHCb P_c related to γp ->P_c->J/ψp



- *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).*

$Br(P_c \to J/\psi p)$: J/ψ cross-section - model-dependent upper limits

GlueX: PRL 123, 072001 (2019):



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

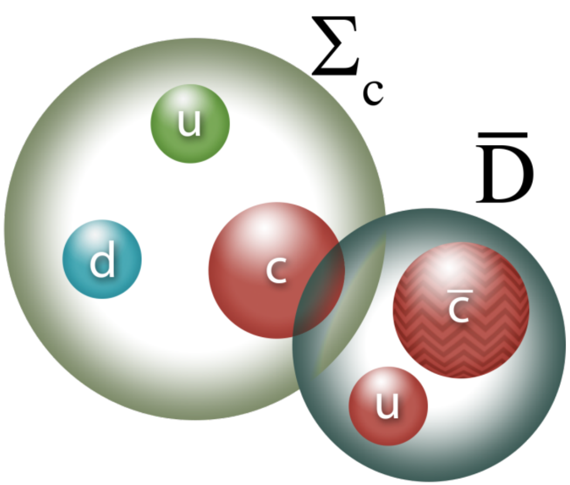
	$\mathcal{B}(P_c^+ \to J/\psi p)$ Upper Limits, %		$\sigma_{\max} \times \mathcal{B}(P_c^+ \to J/\psi p)$ Upper Limits, nb	
	p.t.p. only	total	p.t.p only	total
$P_c^+(4312)$	2.9	4.6	3.7	4.6
$P_c^+(4440)$	1.6	2.3	1.2	1.8
$P_c^+(4457)$	2.7	3.8	2.9	3.9

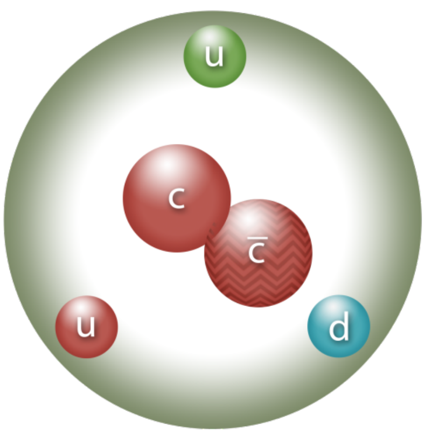
Upper limits at 90% confidence level

$Br(P_c \to J/\psi p)$ 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
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

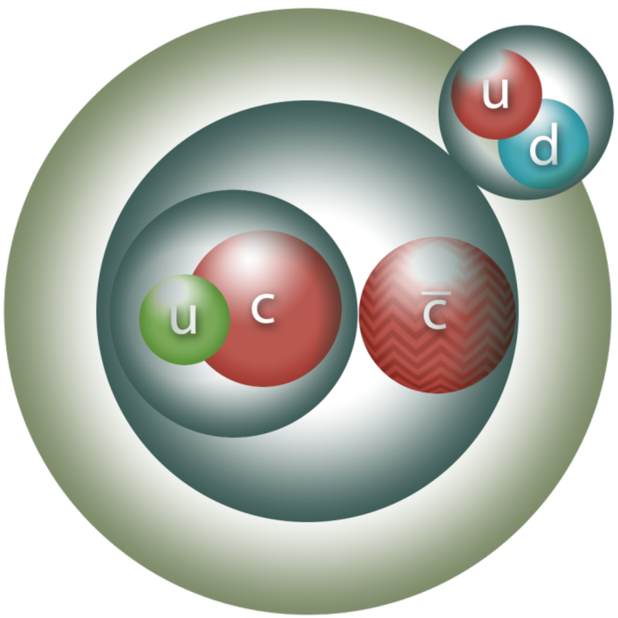
all subsystems in color singlet states





Br(P_c->$J/\psi p$) calculations: compact diquark

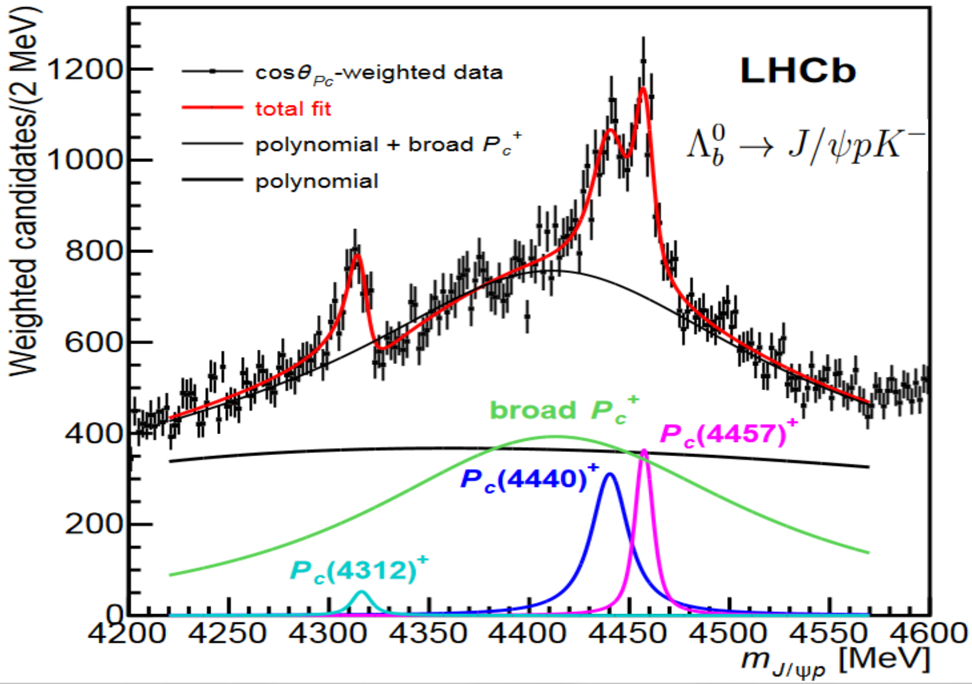
model	Γ_{P_c}, MeV	$\Gamma_{J/\psi p}$, MeV	$\mathcal{B}(P_c \to J/\psi p)$	J^P	reference
compact diquark	–	suppressed	suppressed	$3/2^-$ (4312) $3/2^+$ (4440) $5/2^+$ (4457)	A.Ali, A.Parkhomenko Phys.Lett.B793, 365



diquarks in color anti-triplet states

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

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



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

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

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

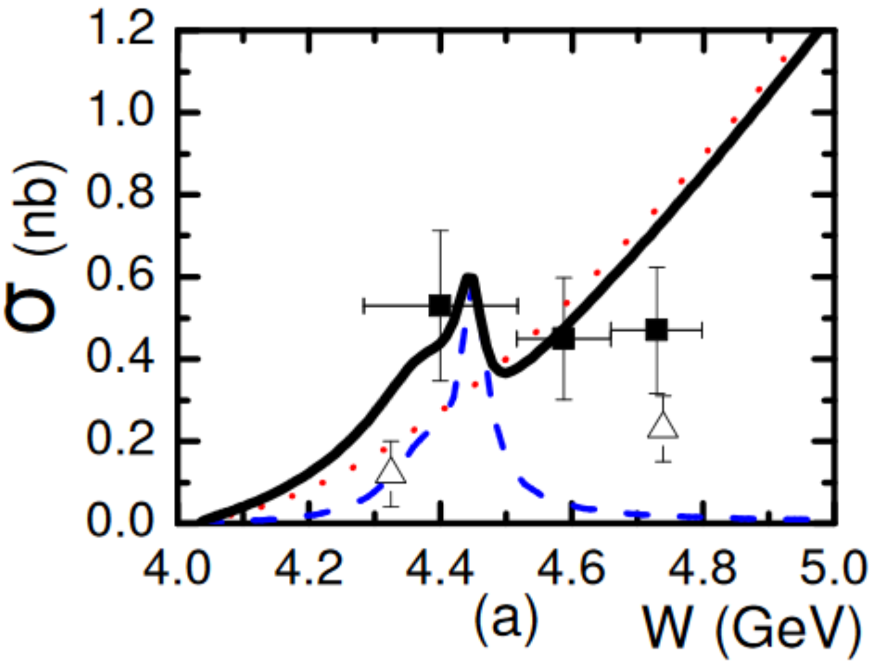
$\mathcal{B}(\Lambda_b \to P_c^+ K^-) < 10^{-3}$ at the level of $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^-)$ and $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-)$

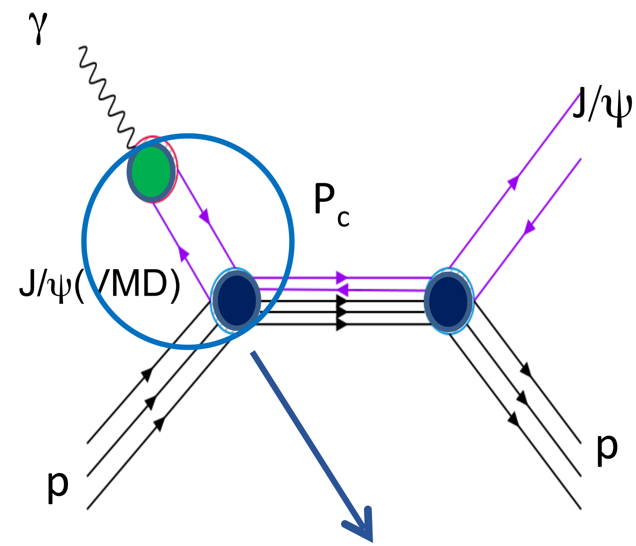
(model dependent 2-4%) $> \mathcal{B}(P_c^+ \to J/\psi p) > 0.05\%$

GlueX

Attempts to suppress VMD coupling

J.-J. Wu, T.-S. Lee, B-S. Zou, Phys. Rev. C 100, 035206 (2019)





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

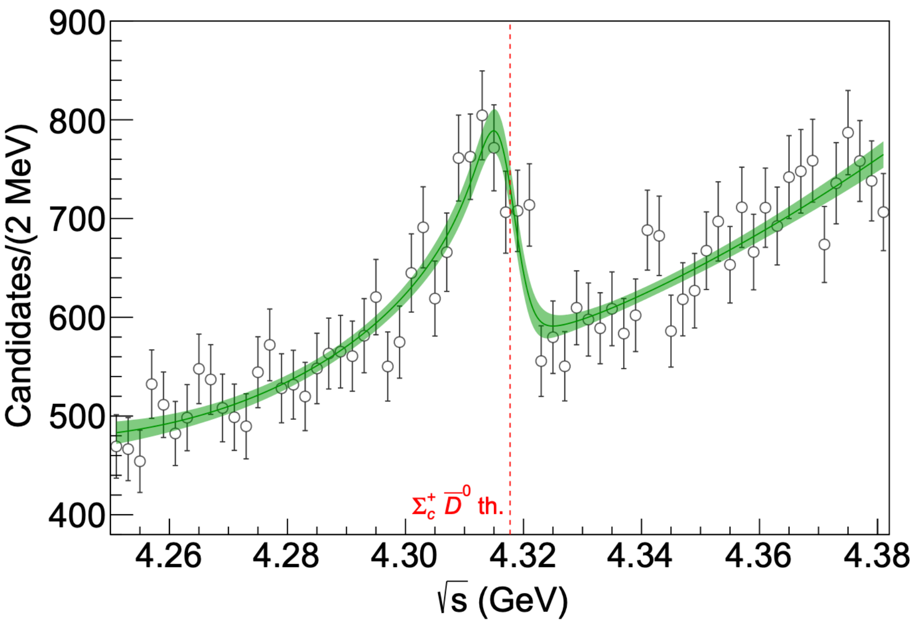
$$\Lambda = 0.55 \text{ GeV}$$

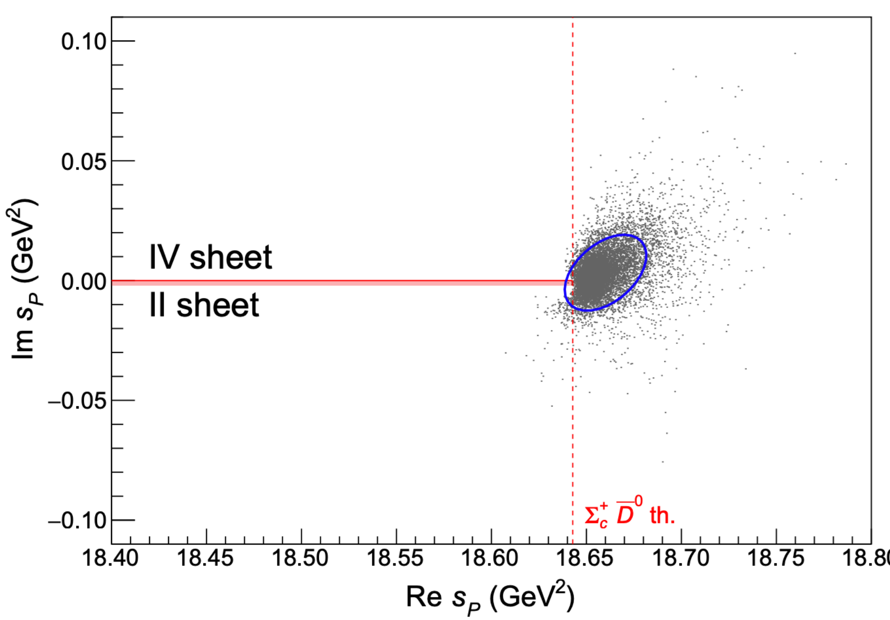
- J/ψ is suppressed by 10^{-3}, VMD coupling dominated by ρ and ω
- How to explain J/ψ photoproduction at high energies with such suppression???
- Other papers (*K. G. Boreskov and B. L. Ioffe, Sov. J. Nucl. Phys. 25, 331 (1977); Phys. G4 (1978) 989; Phys. Rev. Lett. 38 (1977) 263)* suggest some moderate suppression (factor of 2-5)

If LHCb P_c^+ states exist: bound (virtual) state, or kinematic effect?

- Expecting J^{PC} parameters from ongoing analysis by LHCb
- JPAC analysis: Pc(4312) - virtual (unbound) state, i.e. attractive forces not strong enough to form bound state (pole not in the physical region)
- Nevertheless, even virtual state should produce some structure in the photo-production cross section.

JPAC: PRL 123, 092001 (2019)





J/psi polarization measurements with SBS

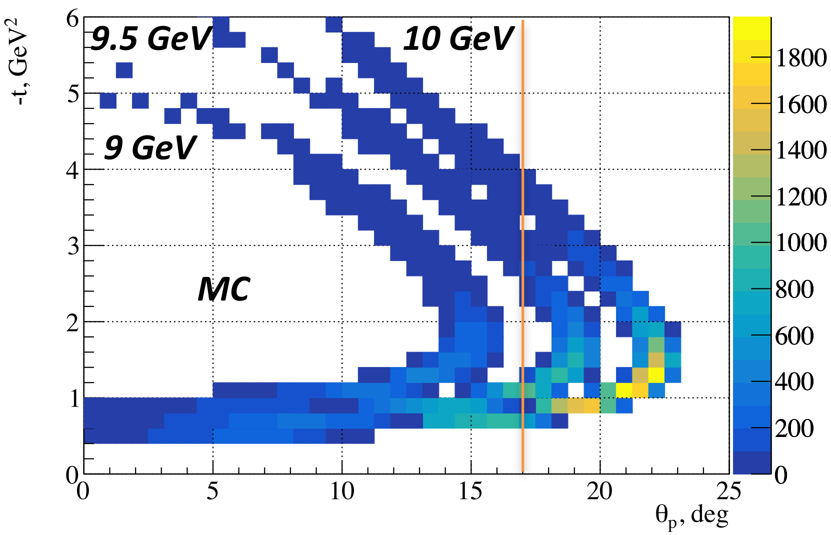
LOI 12-18-001 submitted in 2018:
"*Measurement of the parameters of the LHCb pentaquark states through double polarization asymmetries with SBS in Hall A*" C.Fanelli, L.P., B. Wojtsekhowski.

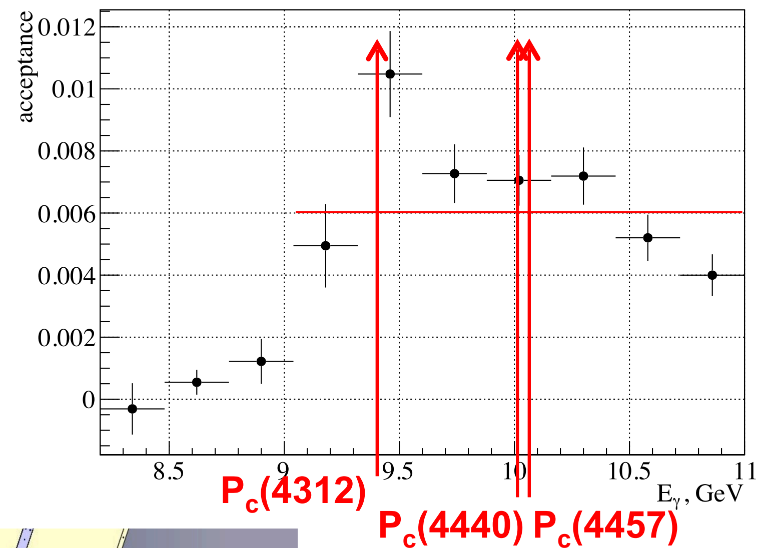
PAC46:
"*The measurement of polarization observables will be a novel and innovative way to probe the parameters of the newly discovered pentaquark states. The PAC encourages submission of a full proposal after observation through photoproduction is confirmed by an approved JLAB experiment.*"

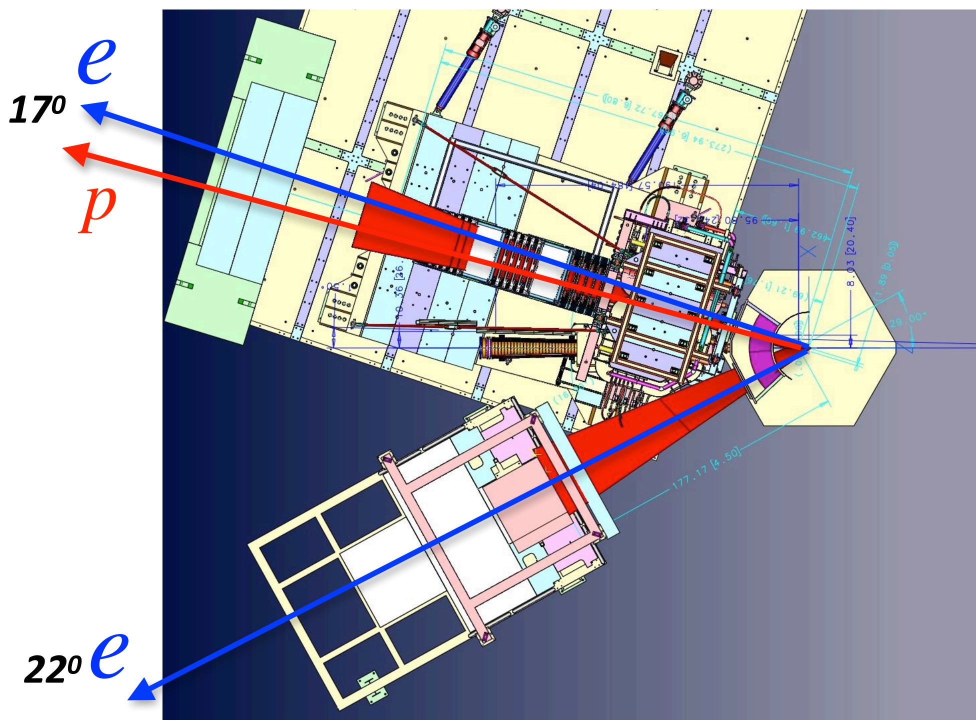
Most likely if P_c exists, cross-section small:
- GlueX set model dependent upper limit on $Br(P_c \to J/\psi p)$ of few percent, which doesn't exclude molecular interpretation.
- Expect additional suppression of the P_c cross-section up to a factor of 5 (VMD suppression).
- Cross-section experiment would hardly be sensitive to $Br(P_c \to J/\psi p) < 1\%$ due to t-channel background.

However, still chance to observe effects of P_c states in the photo-production:
- Conservative lower limit (data-driven) $Br(P_c \to J/\psi p) > 0.05\%$
- Amplitude analysis of $P_c(4312)$: virtual state, should be seen in photo-production.
- Only polarization measurements can disentangle t- and s-channel for such low P_c yields.
- The $P_c(4380)$ state has ~1 GeV width in photon energy, such wide state can only be identified with polarization measurements.

Some estimates for SBS: K_{LL} and A_{LL}

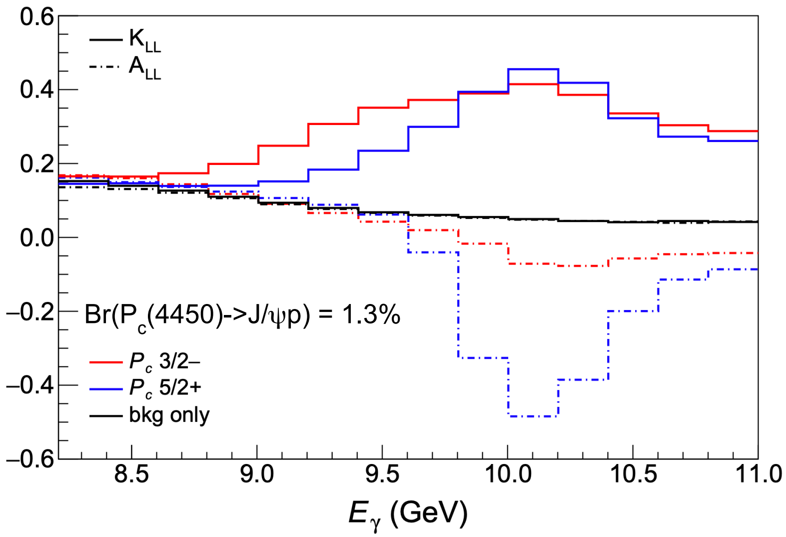


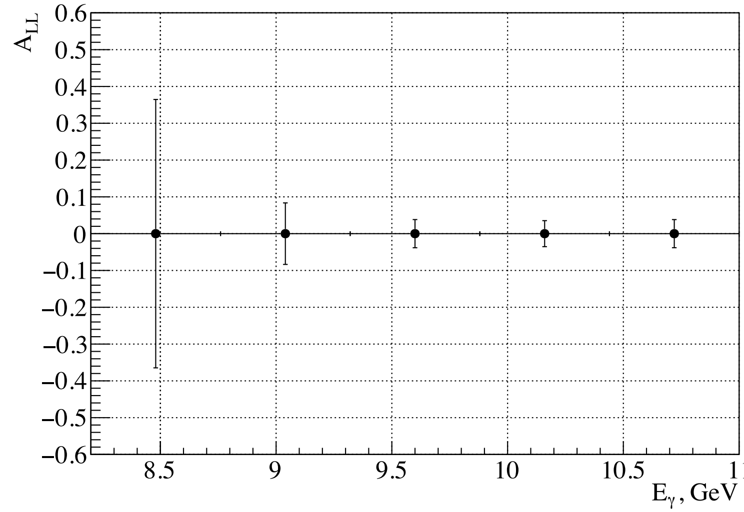


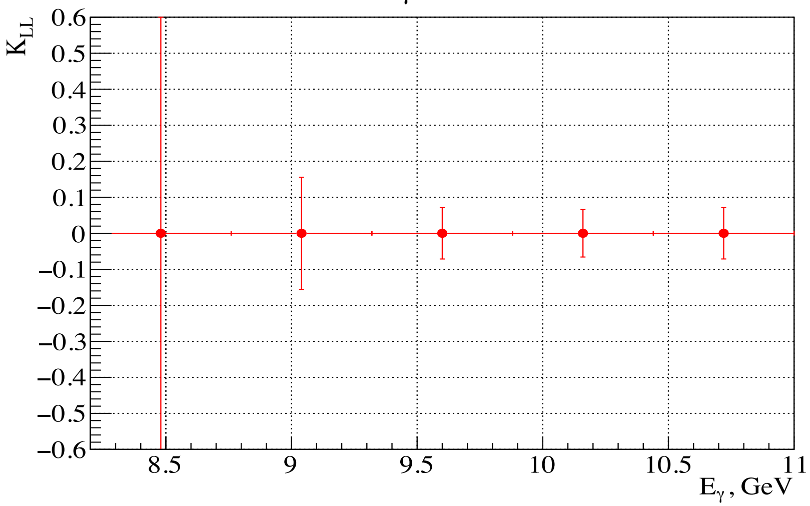


Some estimates for SBS: K_{LL} and A_{LL}

*JPAC: Phys. Rev. D **100**, 034019 (2019)*







Toy MC assuming: using CPS and 75% polarized target for A_{LL}, 2% radiator for K_{LL}, and:

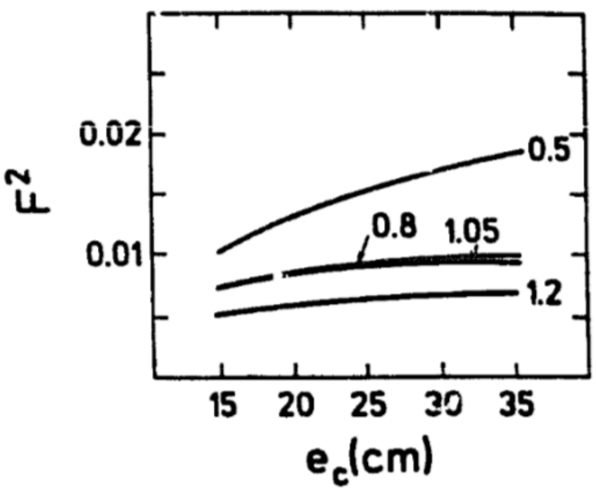
observable	$I\ [\mu A]$	$\mathscr{L}\ [cm^{-2}s^{-1}]$	*FOM*	*days*
A_{LL}	2.7	$3.2\ 10^{35} dE/E$	0.525	20
K_{LL}	60	$10^{37} dE/E$	0.056	20

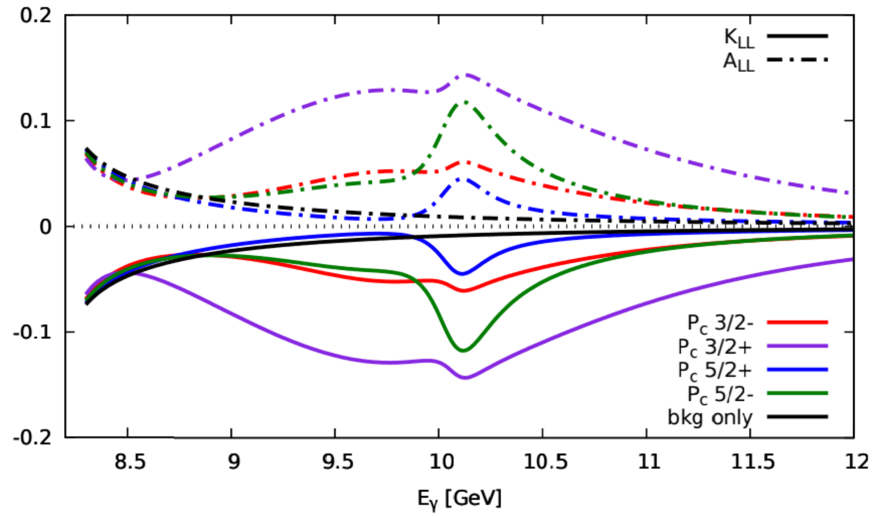
Conclusions

- LHCb pentaquarks still not confirmed by other experiments; possibilities: molecular, virtual state, or kinematic effect.
- Extraction of the J^P numbers of the penaquark states (by LHCb) will certainly reduce many ambiguities in their interpretation.
- For low P_c yields, $Br(P_c \rightarrow J/\psi p) < 1\%$, and/or wide resonances, only polarization measurements could find some structures related to LHCb pentaquarks.
- SBS (high intensity, high acceptance, polarimetry) is in a good position to contribute in solving this puzzle.

Back-ups

Back-ups





- B. Bonin et al., NIM A288 p.379 (1990)

FOM on Carbon

labels: proton KINETIC energy

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

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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.