# A Search for the LHCb Pentaquark in $J/\psi$ Photo-production at Hall C

(for the $J/\psi$-007 Collaboration)

Burcu Duran

Hall C Winter Collaboration Meeting
January 29, 2019

# Discovery of the LHCb charmed (charming!) "pentaquark"

$P_c$

Information | References (55) | Citations (666) | Files | Plots

**Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays** - LHCb Collaboration (Aaij, Roel *et al.*)
Phys.Rev.Lett. 115 (2015) 072001 arXiv:1507.03414 [hep-ex] CERN-PH-EP-2015-153, LHCB-PAPER-2015-029

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(897) **Review of Particle Physics** - Particle Data Group (Tanabashi, M. *et al.*) Phys.Rev. D98 (2018) no.3, 030001
(522) **Averages of $b$-hadron, $c$-hadron, and $\tau$-lepton properties as of summer 2016** - HFLAV Collaboration (Amhis, Y. *et al.*) Eur.Phys.J. C77 (2017) no.12, 895 arXiv:1612.07233 [hep-ex] FERMILAB-PUB-16-611-ND
(352) **The hidden-charm pentaquark and tetraquark states** - Chen, Hua-Xing *et al.* Phys.Rept. 639 (2016) 1-121 arXiv:1601.02092 [hep-ph]
(345) **Test of lepton universality with $B^0 \to K^{*0} \ell^+ \ell^-$ decays** - LHCb Collaboration (Aaij, R. *et al.*) JHEP 1708 (2017) 055 arXiv:1705.05802 [hep-ex] LHCB-PAPER-2017-013, CERN-EP-2017-100
(178) **Hadronic molecules** - Guo, Feng-Kun *et al.* Rev.Mod.Phys. 90 (2018) no.1, 015004 arXiv:1705.00141 [hep-ph]
more

.. of which self-citations: 82 records

(522) **Averages of $b$-hadron, $c$-hadron, and $\tau$-lepton properties as of summer 2016** - HFLAV Collaboration (Amhis, Y. *et al.*) Eur.Phys.J. C77 (2017) no.12, 895 arXiv:1612.07233 [hep-ex] FERMILAB-PUB-16-611-ND
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(102) **Nonstandard heavy mesons and baryons: Experimental evidence** - Olsen, Stephen Lars *et al.* Rev.Mod.Phys. 90 (2018) no.1, 015003 arXiv:1708.04012 [hep-ph]
(101) **Exotics: Heavy Pentaquarks and Tetraquarks** - Ali, Ahmed *et al.* Prog.Part.Nucl.Phys. 97 (2017) 123-198 arXiv:1706.00610 [hep-ph] DESY-17-071
(89) **Amplitude analysis of $B^+ \to J/\psi \phi K^+$ decays** - LHCb Collaboration (Aaij, Roel *et al.*) Phys.Rev. D95 (2017) no.1, 012002 arXiv:1606.07898 [hep-ex] LHCB-PAPER-2016-019, CERN-EP-2016-156

Co-cited with: 25593 records

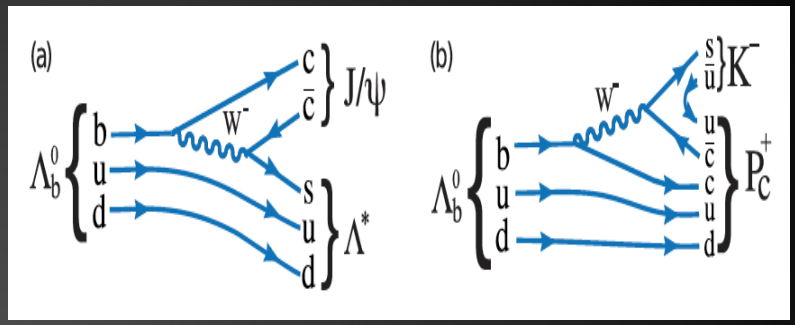
(253) **Review of Particle Physics** - Particle Data Group (Olive, K.A. *et al.*) Chin.Phys. C38 (2014) 090001
(163) **How to reveal the exotic nature of the $P_c(4450)$** - Guo, Feng-Kun *et al.* Phys.Rev. D92 (2015) no.7, 071502 arXiv:1507.04950 [hep-ph]
(147) **Review of Particle Physics** - Particle Data Group (Patrignani, C. *et al.*) Chin.Phys. C40 (2016) no.10, 100001
(140) **The hidden-charm pentaquark and tetraquark states** - Chen, Hua-Xing *et al.* Phys.Rept. 639 (2016) 1-121 arXiv:1601.02092 [hep-ph]
(139) **Identifying exotic hidden-charm pentaquarks** - Chen, Rui *et al.* Phys.Rev.Lett. 115 (2015) no.13, 132002 arXiv:1507.03704 [hep-ph]
more

*666 citations since 2015!*

# LHCb charmed (charming!) "pentaquark" $P_c$

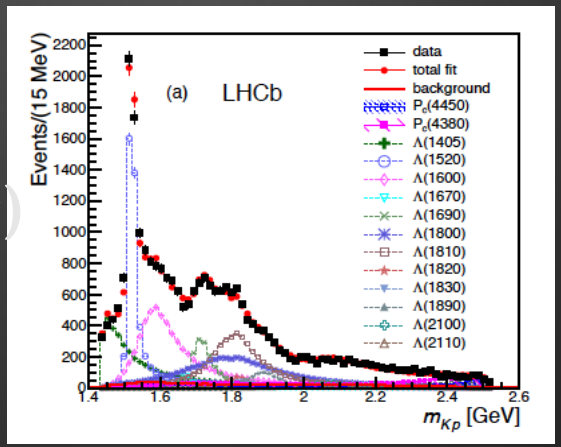
$$\Lambda_b \to K^- p J/\Psi$$

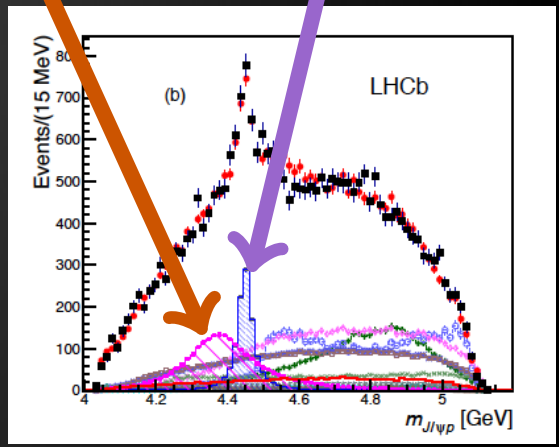
Aaij, R, et. al (LHCb) PRL 115-7 (2015)



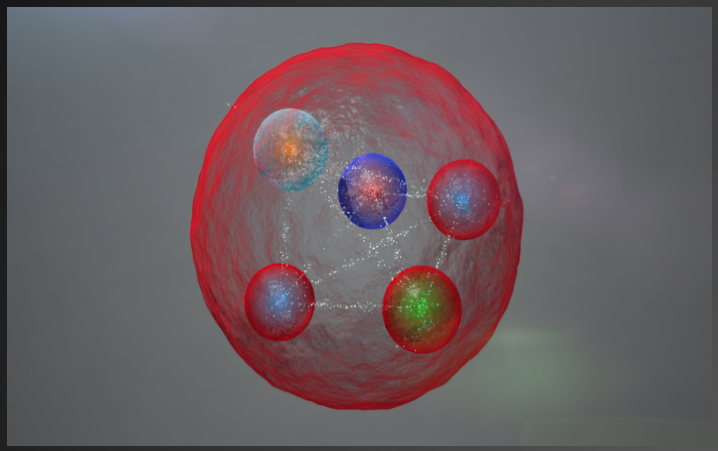

- 2 $P_c$ states needed to describe the results
  - **narrow:** $P_c(4450)$, **width:** $\sim$ 39 MeV
  - **broad:** $P_c(4380)$, **width:** $\sim$ 205 MeV
- Spin/parity either:
  - 5/2+, 3/2-(most likely)
  - 5/2-, 3/2+
  - 3/2-, 5/2+

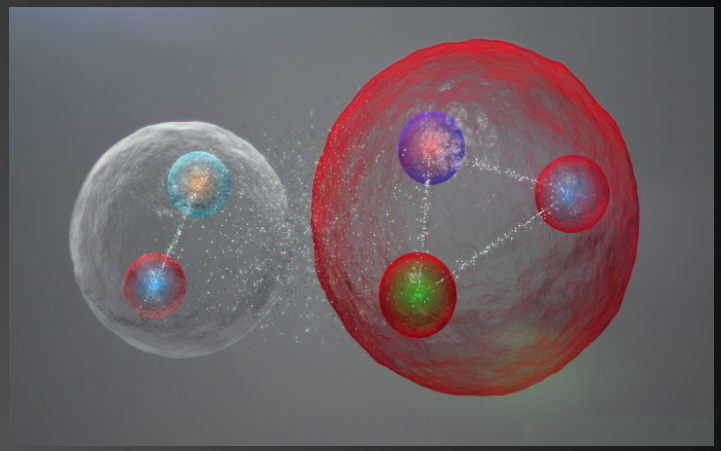
$P_c(4380)$ $P_c(4450)$



# Charmed "pentaquark" in Photo-production





- **Common Interpretations for LHCb observations**

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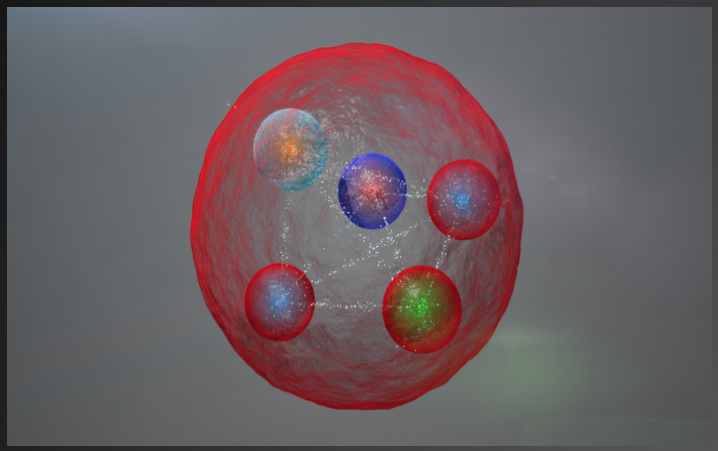

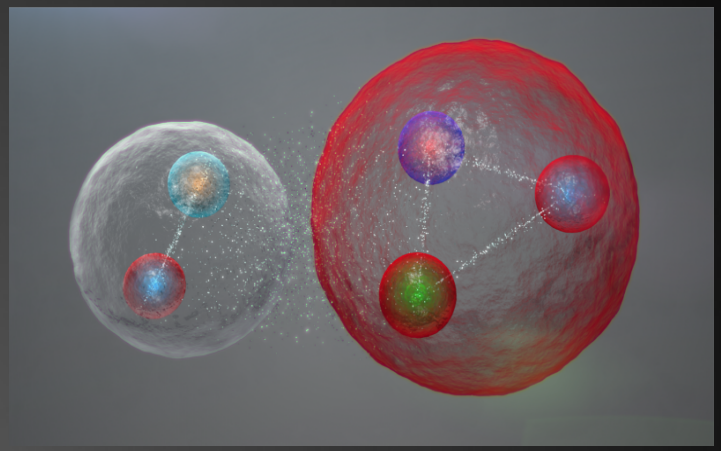

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  - **LHCb: True resonant "Pentaquark" $P_c$ states**

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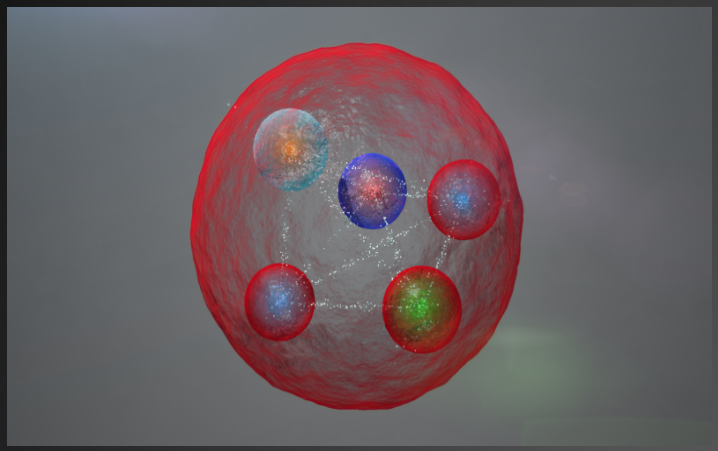

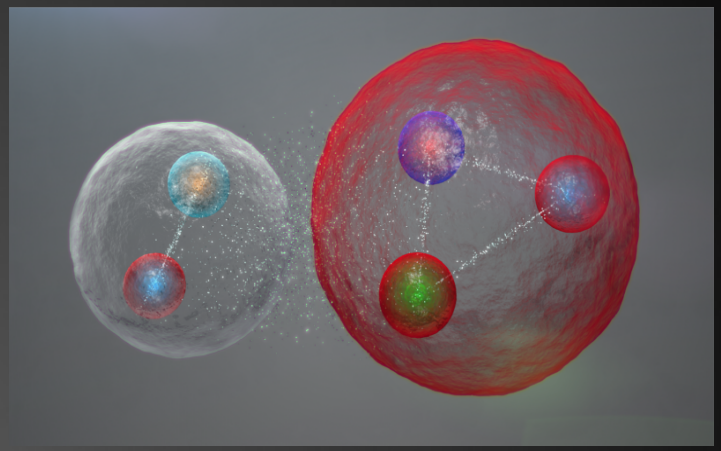

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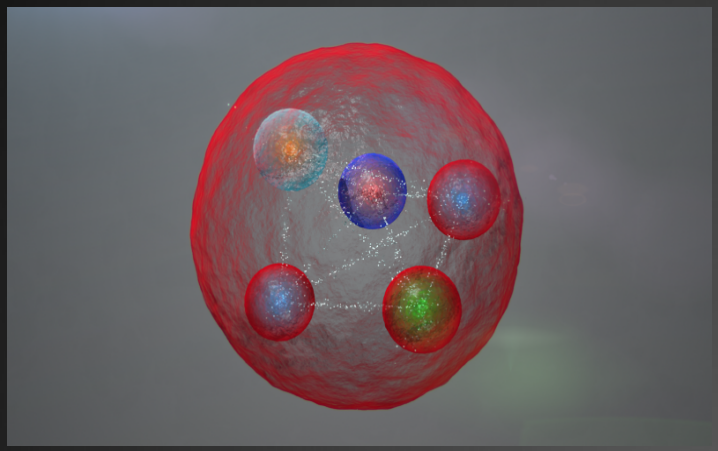

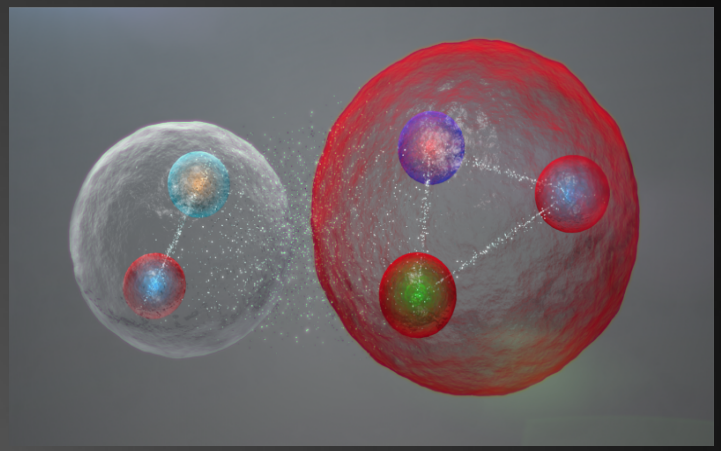

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- The **photo-production** is an ideal tool to **distinguish** between the explanations

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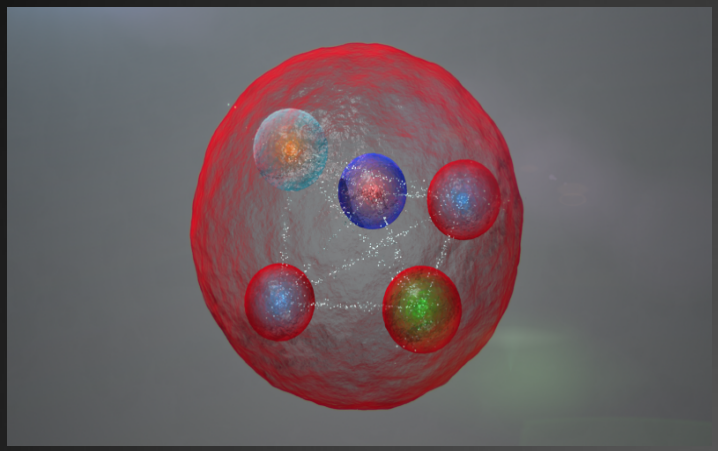

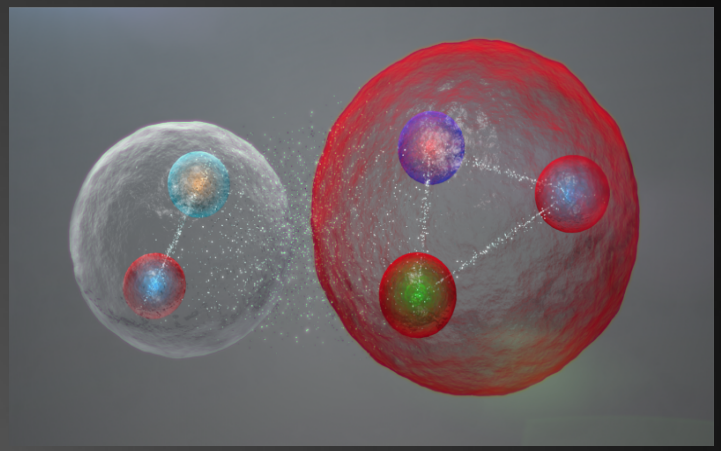

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  - if $P_c$ states are real states, should **also be created in photo-production**

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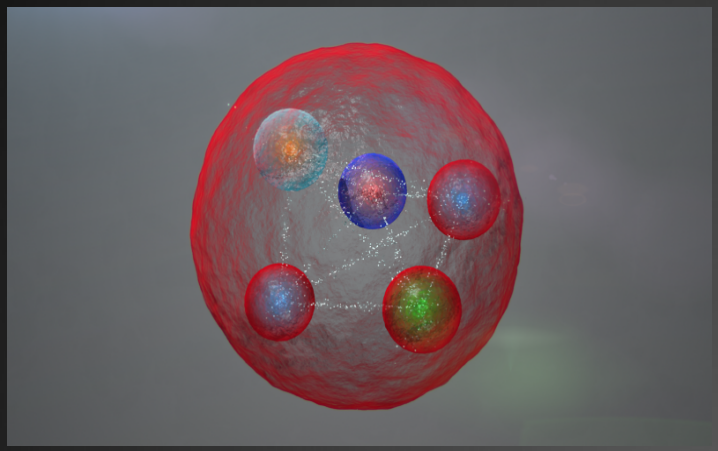

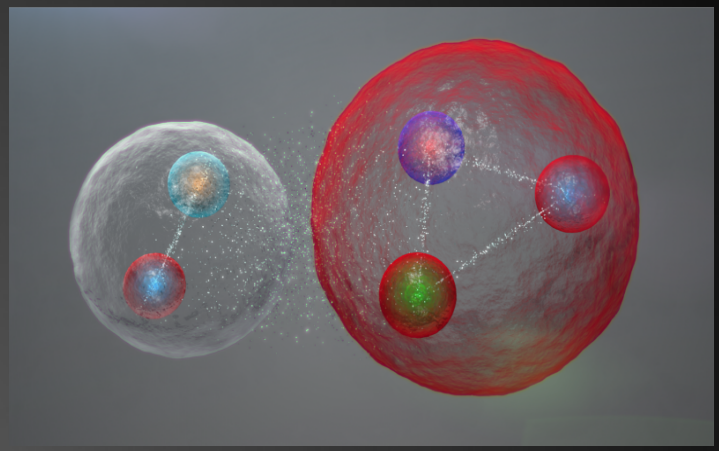

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- The **photo-production** is an ideal tool to **distinguish** between the explanations
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  - kinematic enhancement **through ATS not possible** (Wang Q., et al., PRD 92-3 (2015) 034022)

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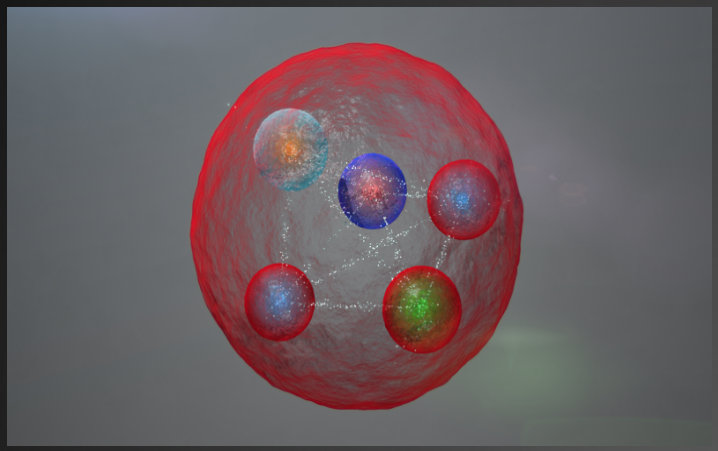

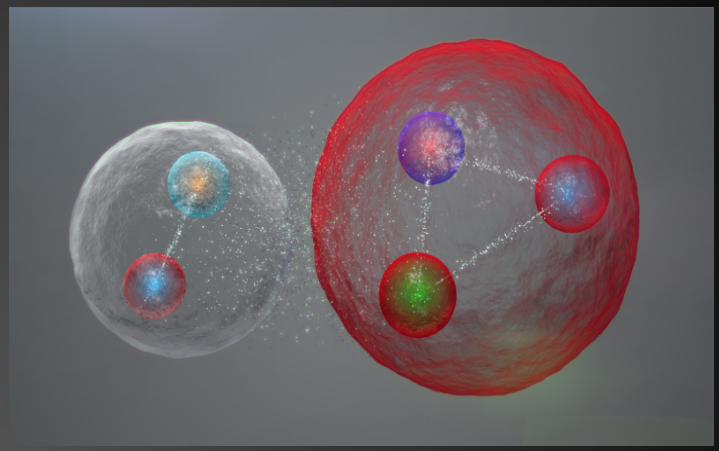

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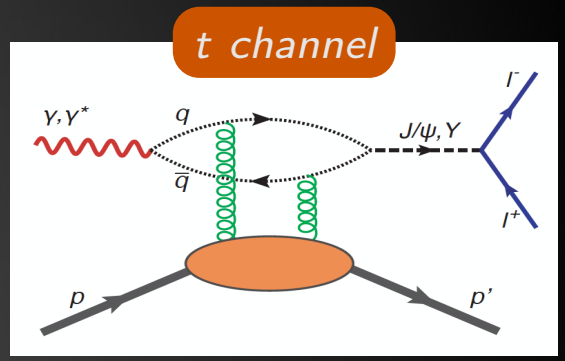
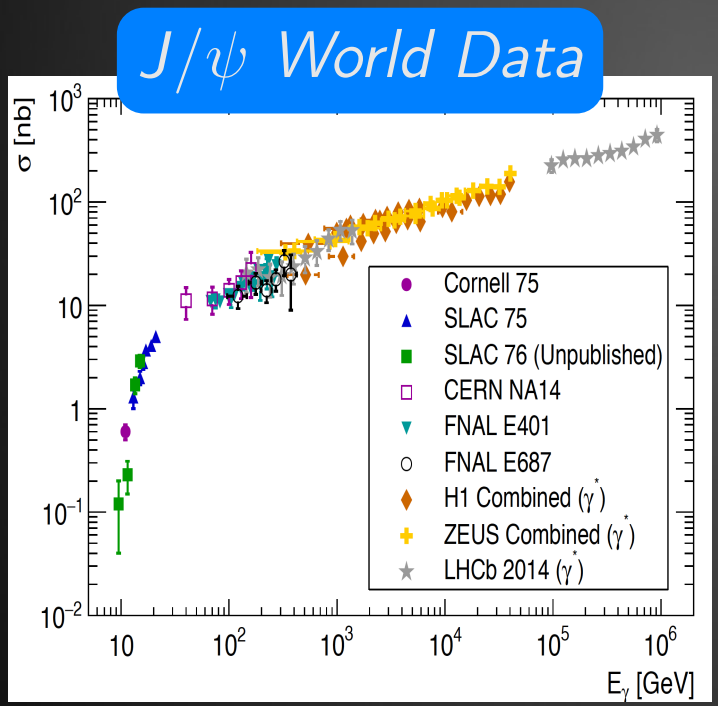
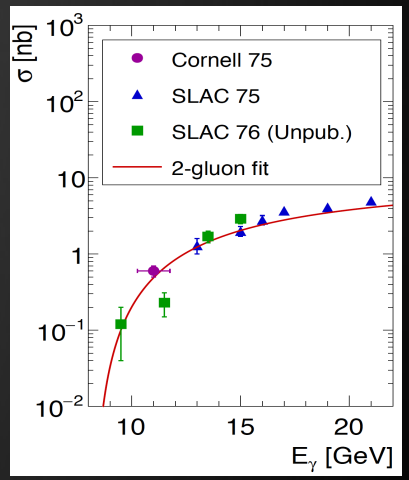
- $P_c(4450)$ creates narrow peak around $E_\gamma = 10.1$ GeV

# $J/\psi$ Photo-production: Current Data Status

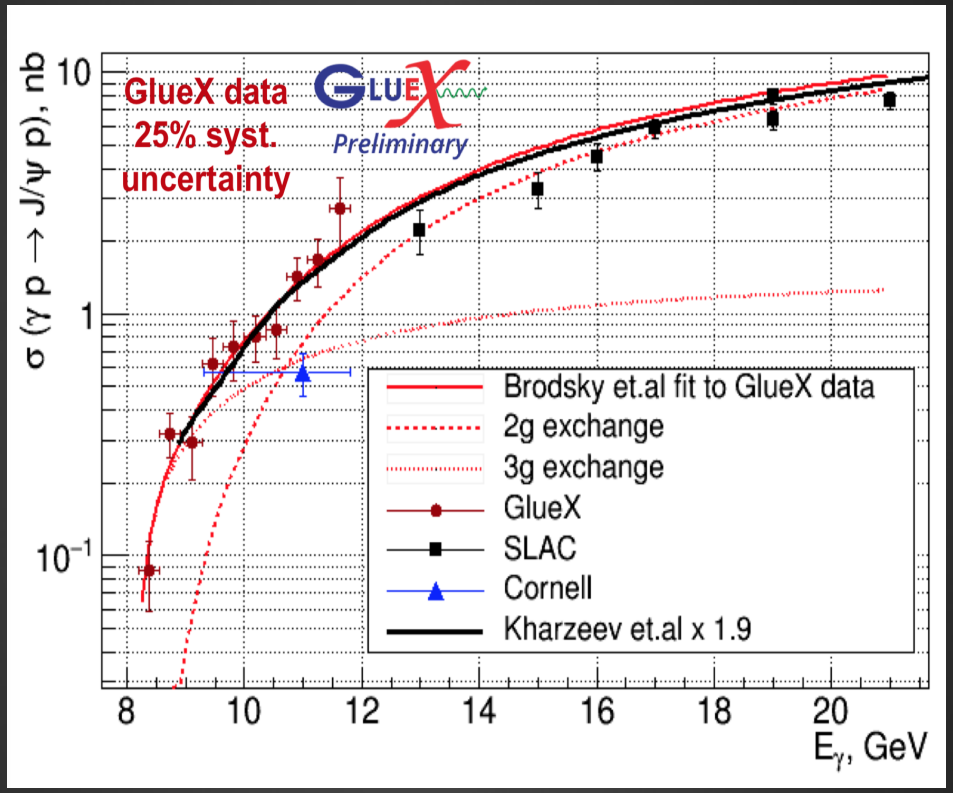
- measured in many experiments at high $W_\gamma p$
  - dominated by $t$ channel 2-gluon exchange
- almost no data in threshold region



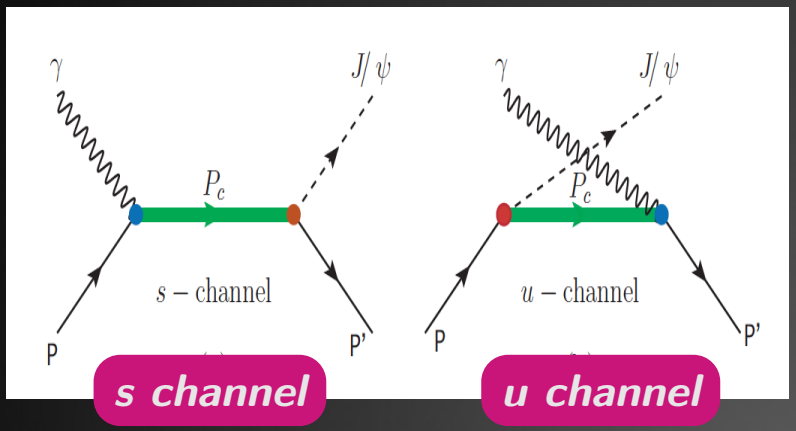



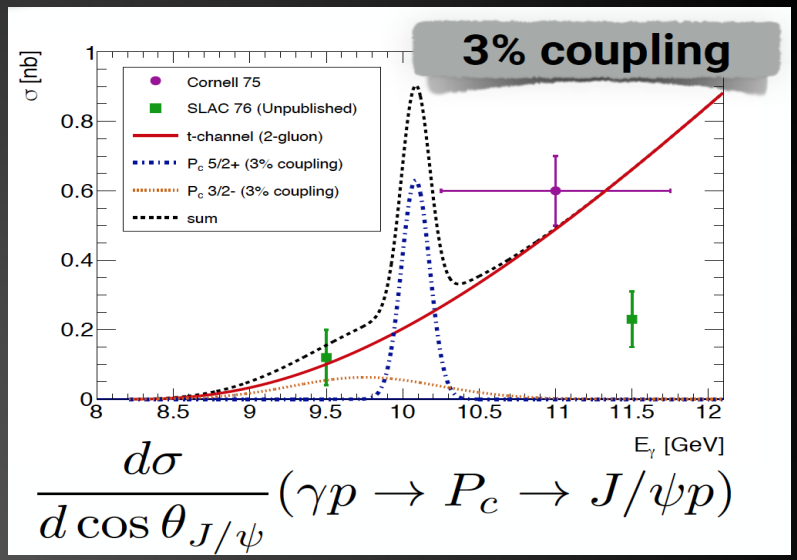
# Unpublished GLUEX data




*from Lubomir Pentchev's slide*

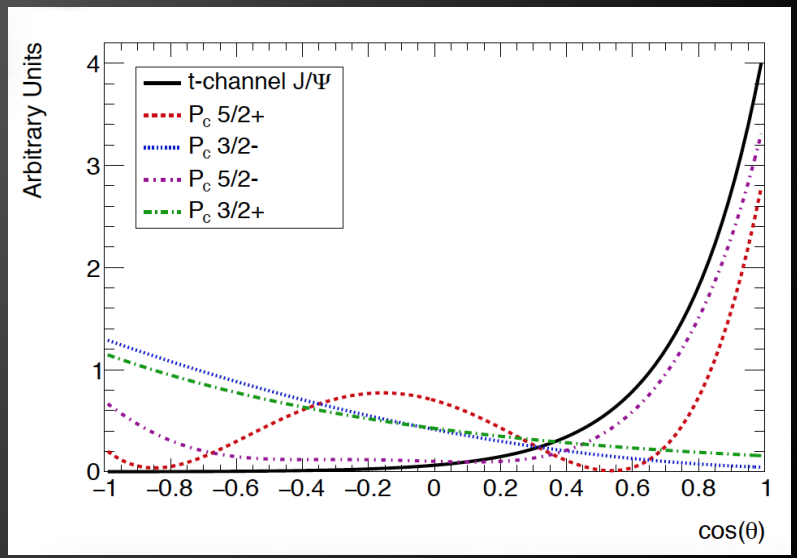
# Resonant $J/\psi$ production through $P_c$ decay



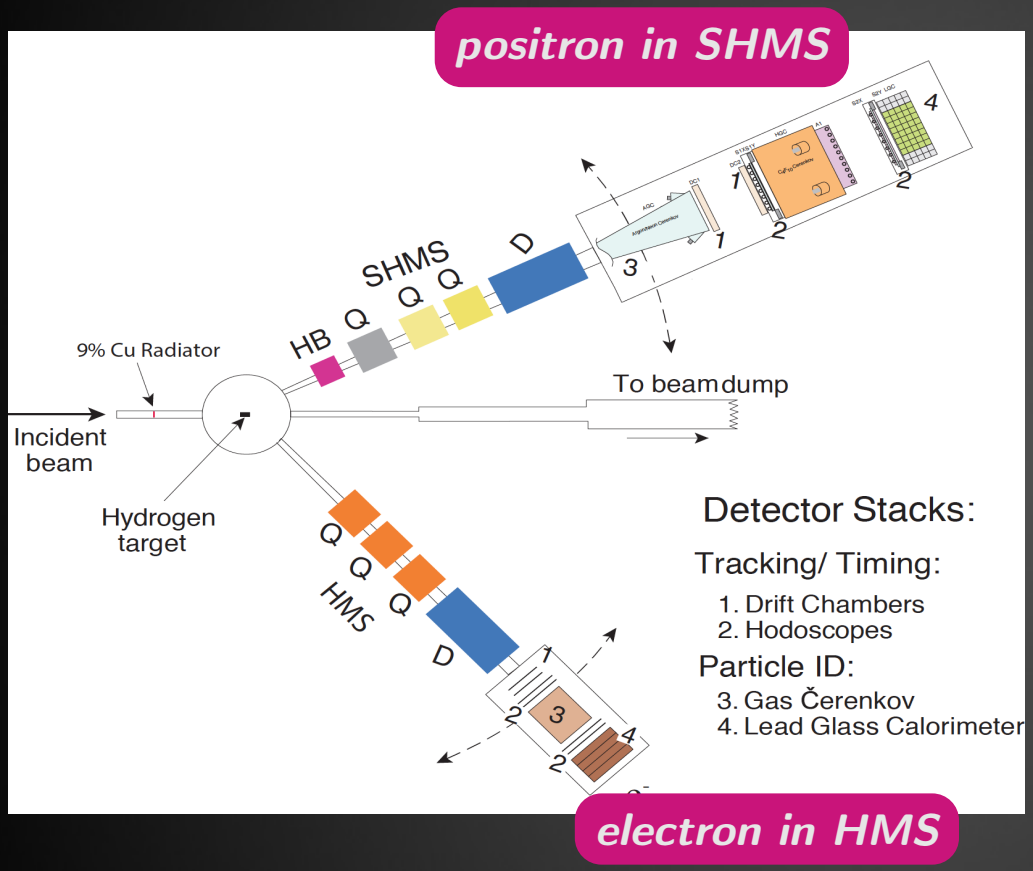




- cross section depends on coupling to $(J/\psi p)$ channel
- $J/\psi$ angular distribution depends on $P_c$ spin/parity

(Wang Q., et al., PRD 92-3 (2015)) 034022-7)



# Pentaquark Search with E12-16-007 Experiment in Hall C




- Experimental Setup (PAC)
  - 11 GeV beam energy
  - 50 $\mu$A
  - 9% copper radiator
  - LH2 15 cm target
  - total 10% RL
- Experimental Setup (NEW)
  - 10.6 GeV beam energy
  - 70 $\mu$A
  - 9% copper radiator
  - LH2 10 cm target
  - total 10% RL

# E12-16-007 SETTINGS

- $t$ channel (BG) Setting 1: low $E\gamma$, low $t$
- precise determination of the $t$ channel background

- HMS: 4.95 GeV, 19.1°
- SHMS: 4.835 GeV, 17°

- $t$ channel (BG) Setting 2: high $E\gamma$, low $t$
- precise determination of the $t$ channel background

- HMS: 4.08 GeV, 19.9°
- SHMS: 3.5 GeV, 20.1°

- Signal ($P_c$) Setting:
- minimizes accidentals and maximizes S/B

- HMS: 4.6 GeV, 16.4°
- SHMS: 4.3 GeV, 30°

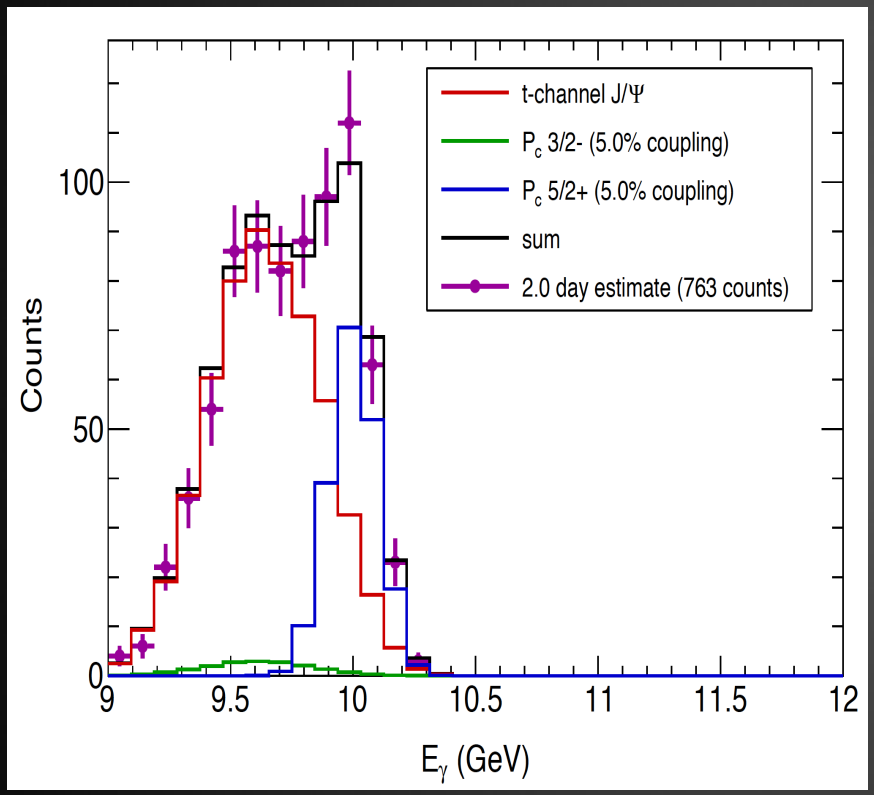
# Photon Energy Reconstruction

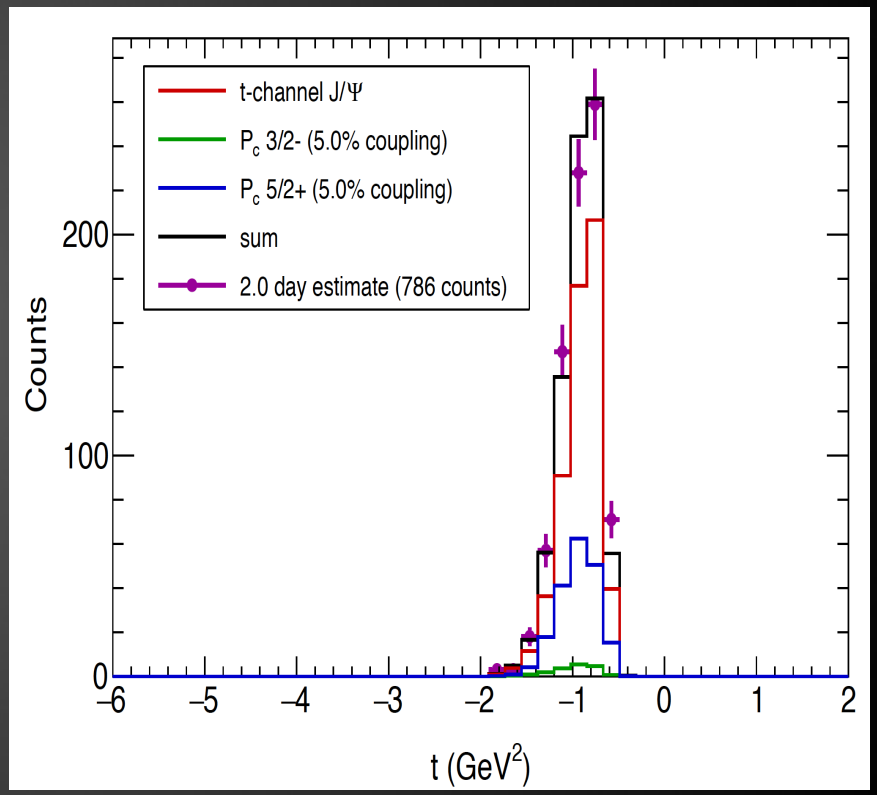
- Initial photon energy can be unambigously reconstructed from the reconstructed $J/\psi$ momentum and energy
  - **Assumptions**
    - ★ proton target at rest
    - ★ photon beam along the z axis
    - ★ proton and $J/\psi$ are the two final state particles

$$E_\gamma = \frac{M_\psi^2 - 2E_J M_P}{2(E_\psi - M_p - P_\psi \cos\theta_\psi)}$$

# Projected results for "background" setting 1

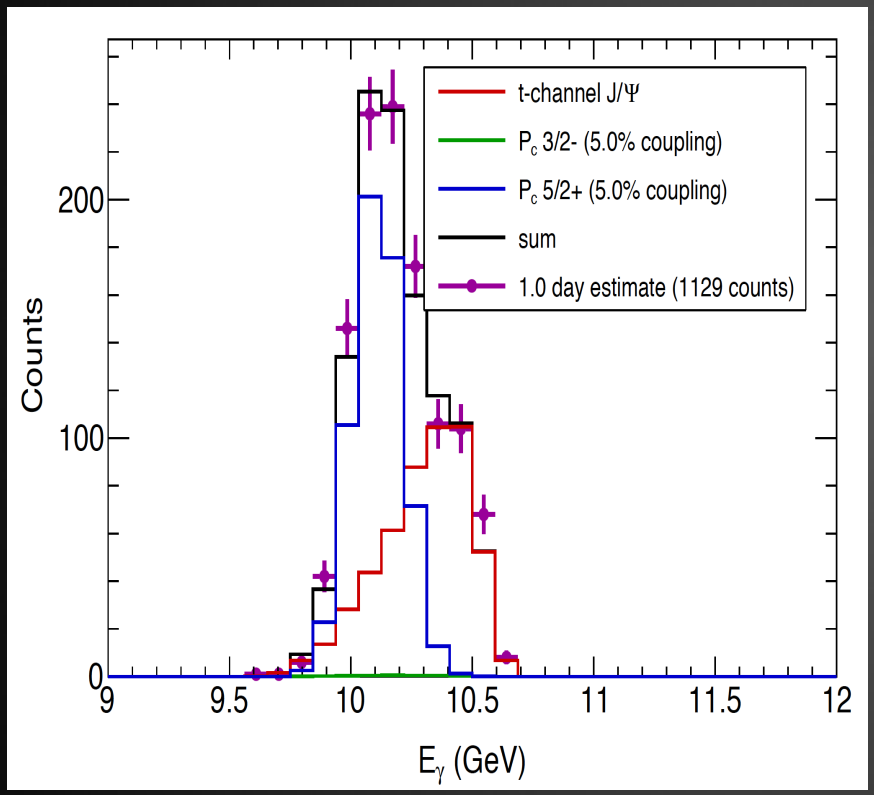
## low $E\gamma$, low $t$

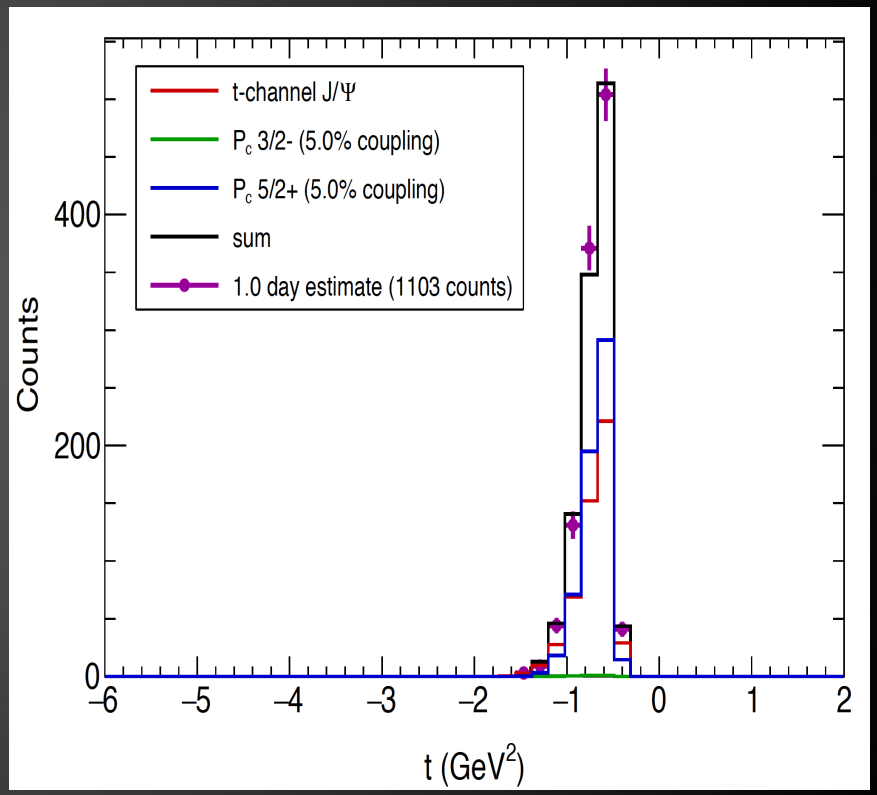


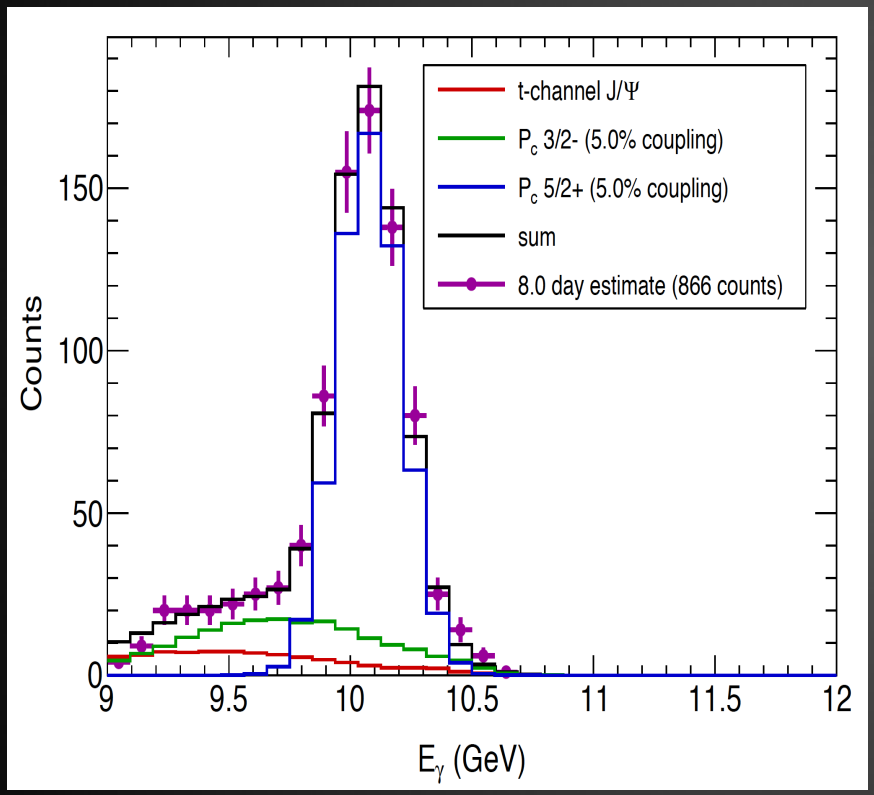
# Projected results for "background" setting 2

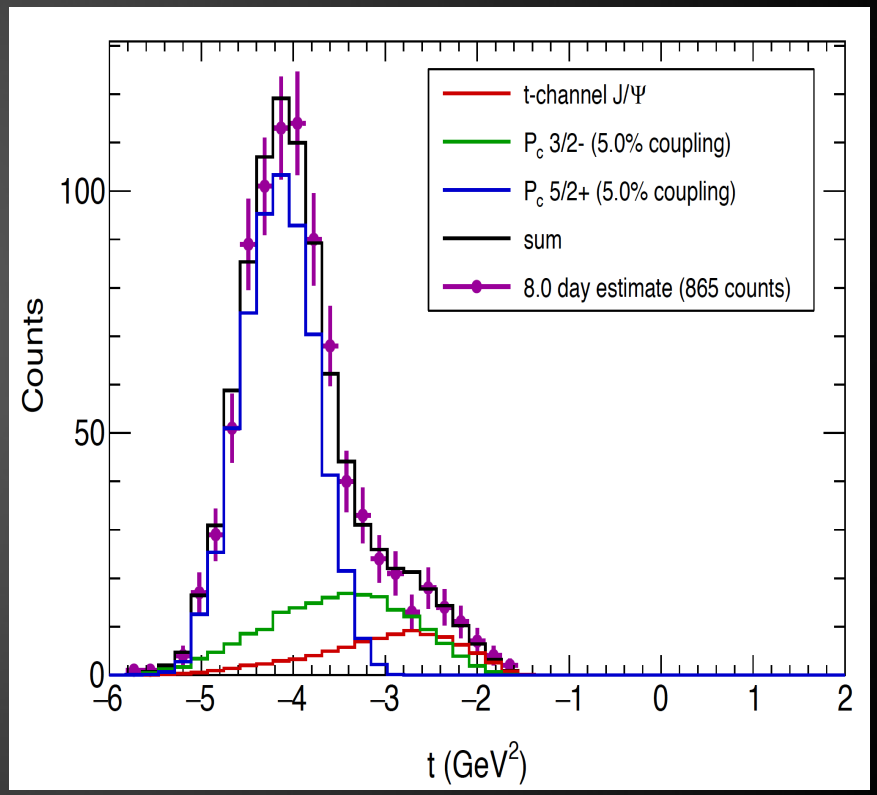
## high $E\gamma$, low $t$



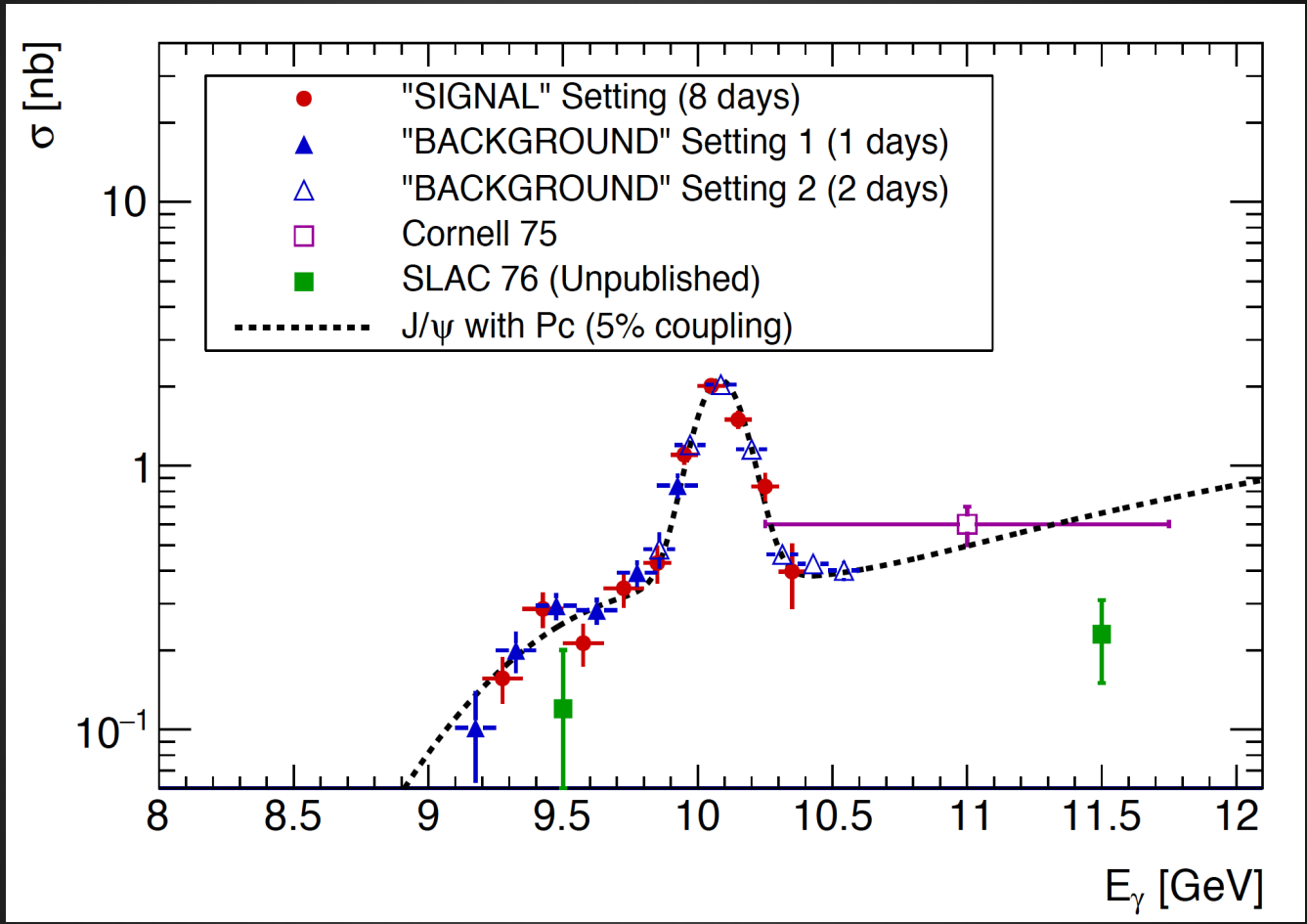



# Projected results for "signal" setting

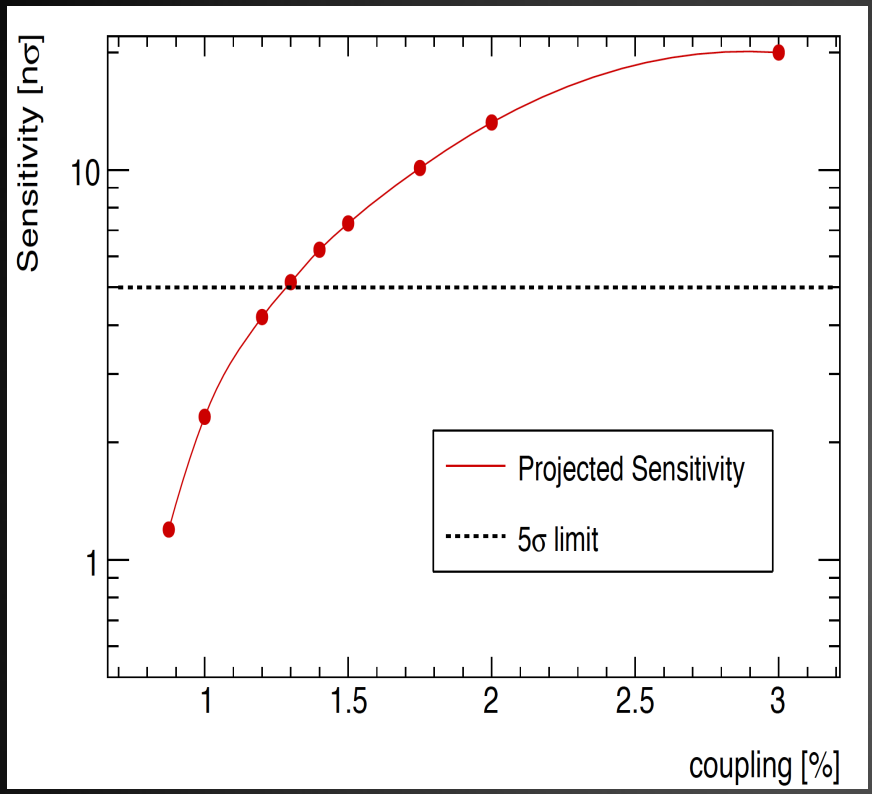


# Impact on $J/\psi$ World Data



# Sensitivity for Discovery

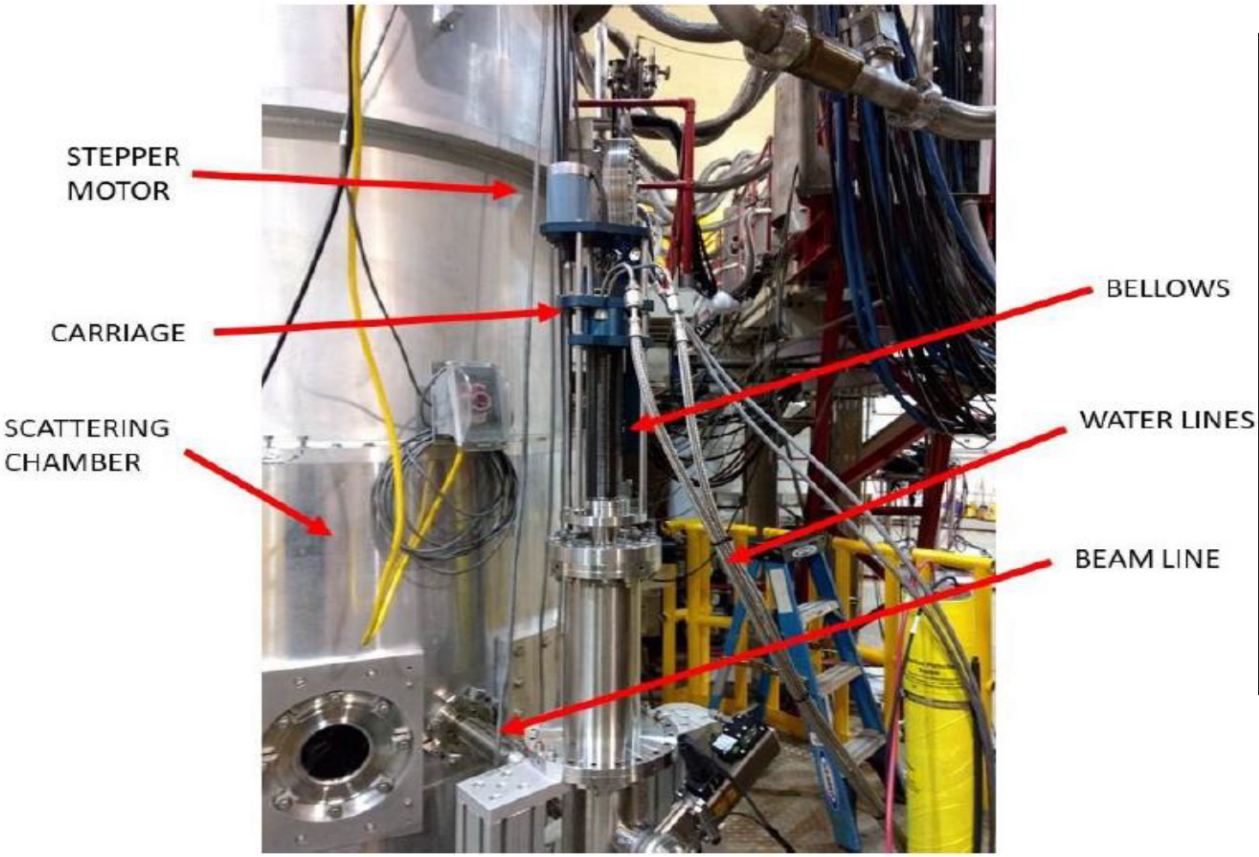



- Δ-log-likelihood formalism

- $5\sigma$ discovery sensitivity can be reached starting from 1.3%

# Hall C Bremsstrahlung Radiator (Jan. 2019)

- Link to water-cooled radiator operating procedure TGT-PROC-19-001:
  - https://misportal.jlab.org/jlabDocs/version.seam?docVersionId=121970
  - Copy of



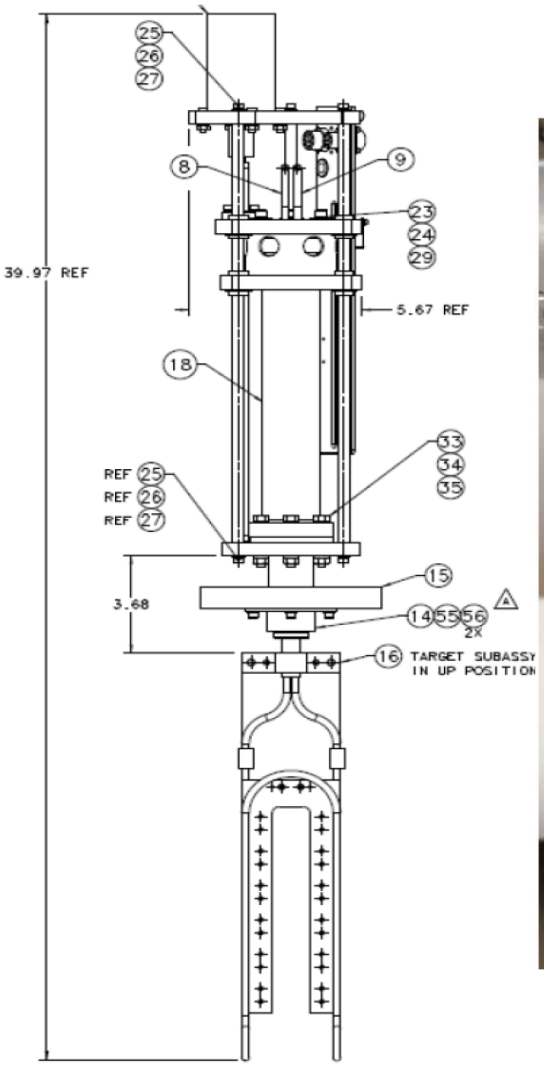

- Just upstream of target scattering chamber
- Water-cooled
- Upper (=home) & Lower limit switches
- Stepper motor controlled
- No motion FSD for radiator
  - Can move in/out of beam while beam is on after calling MCC
- But there is an FSD on water flow

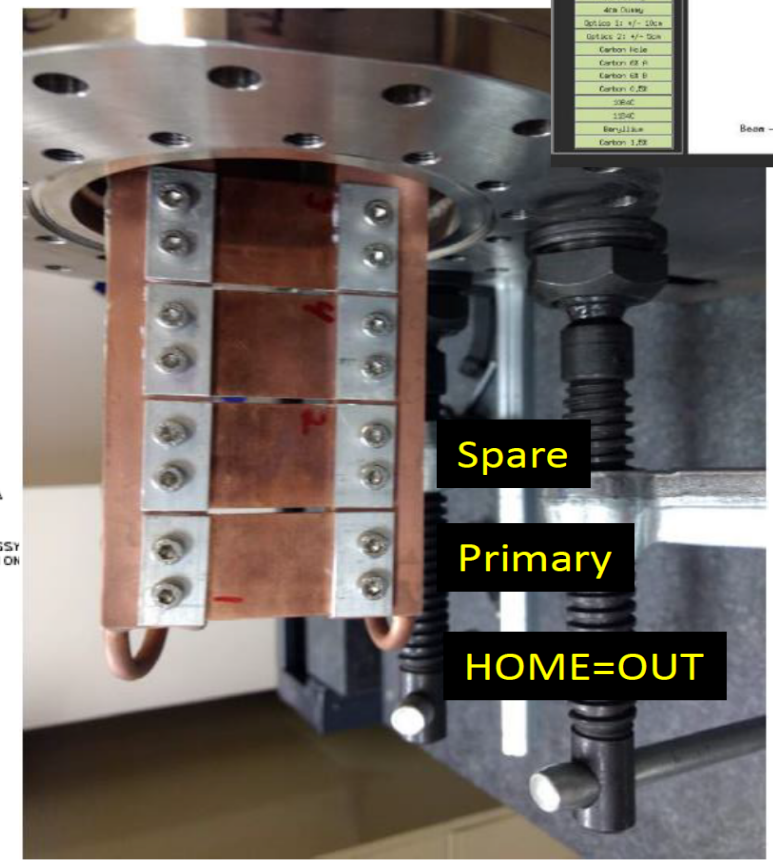
Jan 18, 2019 Bremsstrahlung Radiator

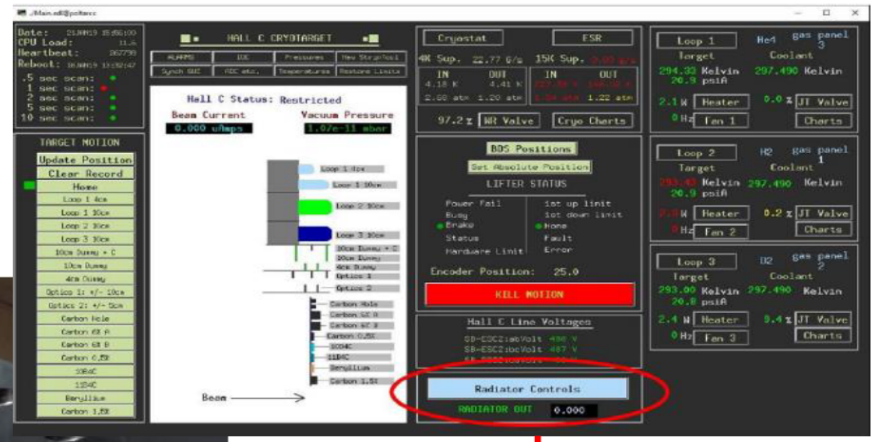
Greg Smith's slide

# E12-16-007 Experiment: Radiator for photon beam

## Setup & GUI





Bremsstrahlung Radiator

Greg Smith's slide

# Particle Identification

- HMS Momentum Settings
  - 4.6 GeV, 4.95 GeV, 4.08 GeV
- SHMS Momentum Settings
  - 4.835 GeV, 4.3 GeV, 3.5 GeV
- PID for HMS:

  HMS Cherenkov + Calorimeter

- PID for SHMS

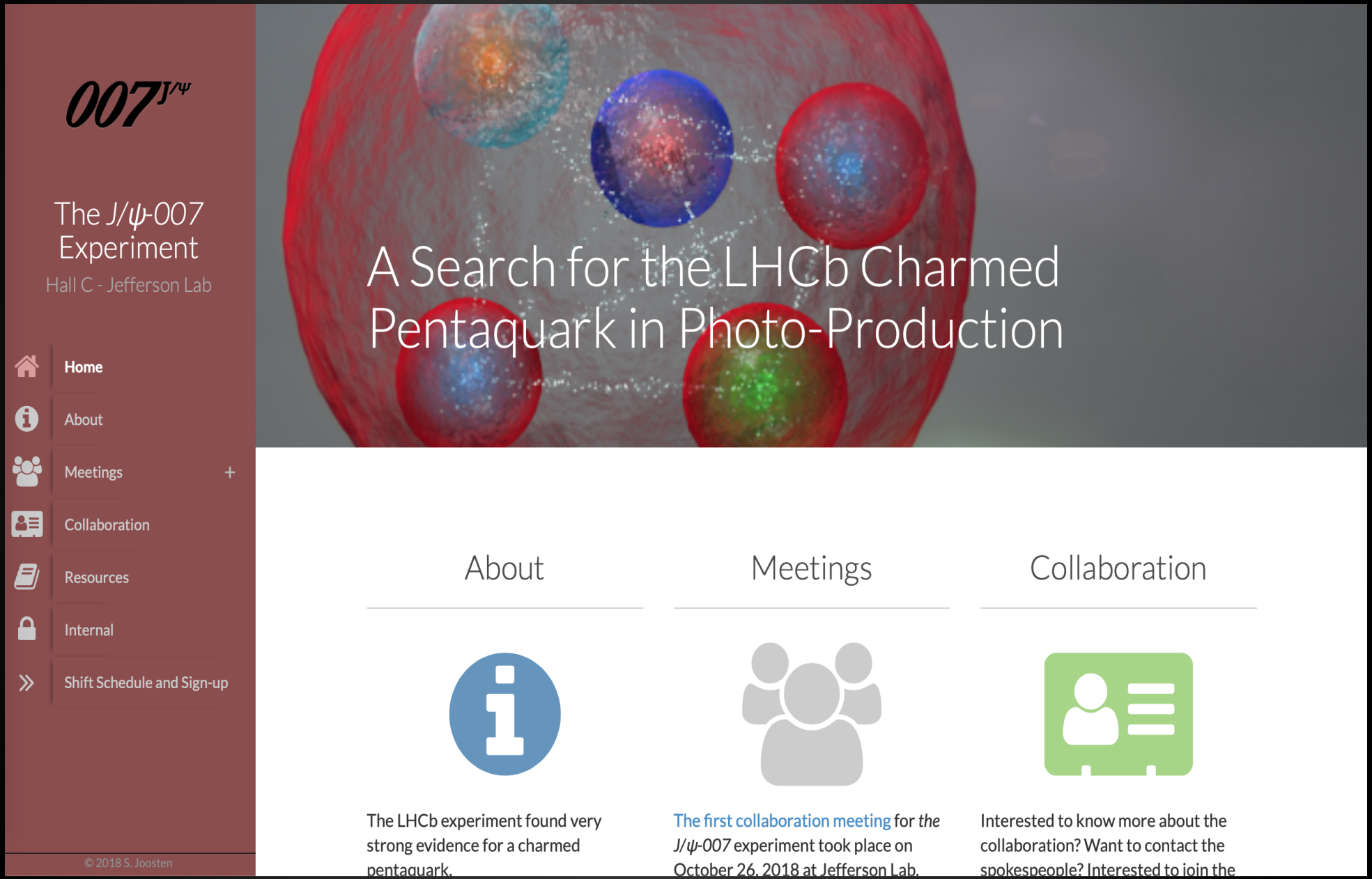
  SHMS Noble Gas Cherenkov + Calorimeter

# Summary

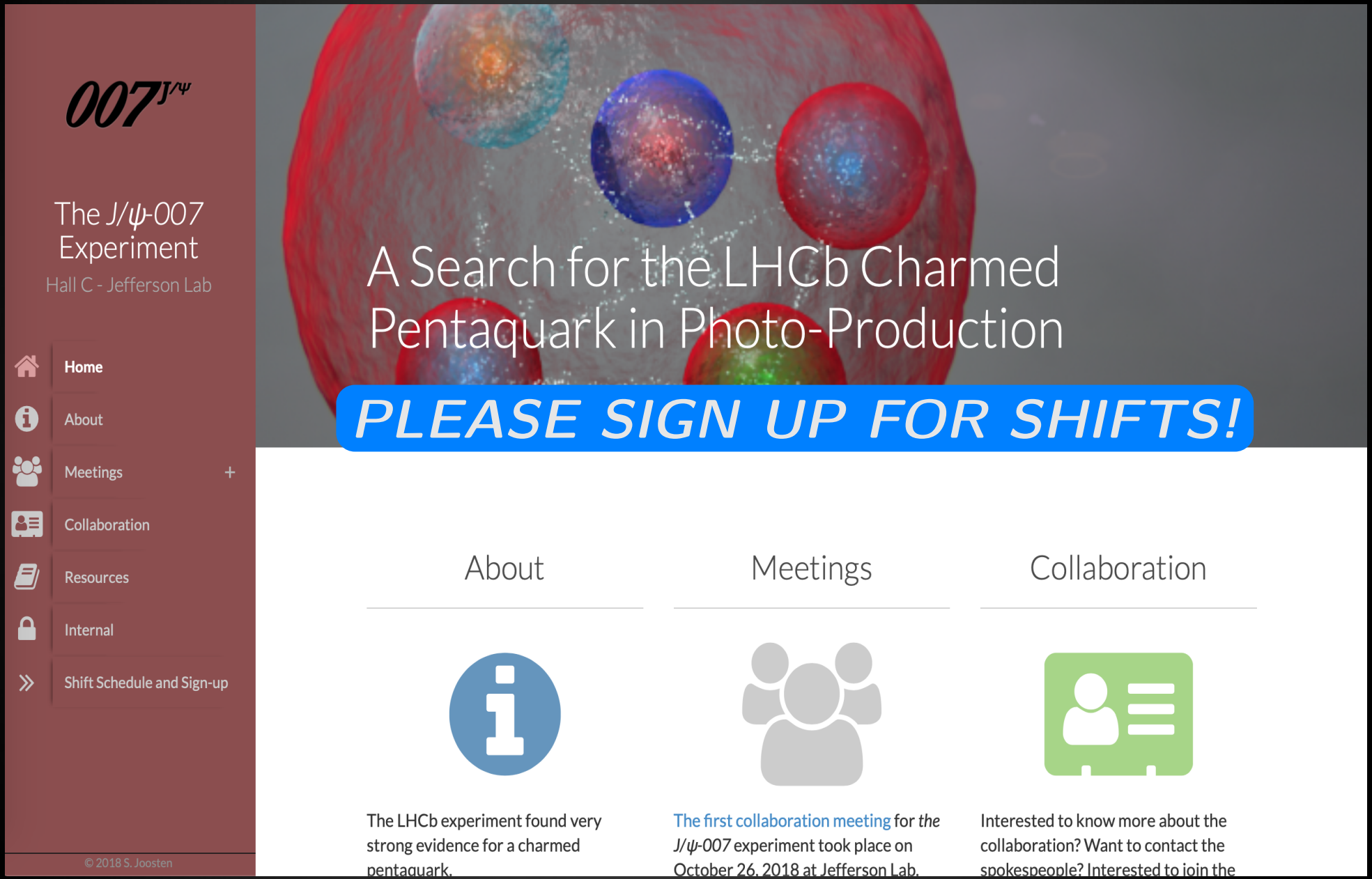
High impact experiment

- true nature of the LHCb "pentaquark" $P_c$
- Strong sensitivity to the coupling 1.3%
- Contribution to the knowledge of the threshold region of the $J/\psi$ photo-production (absolute cross section)

# Experiment website: https://jpsi-007.sly2j.com



# Experiment website: https://jpsi-007.sly2j.com



# BACKUP SLIDES

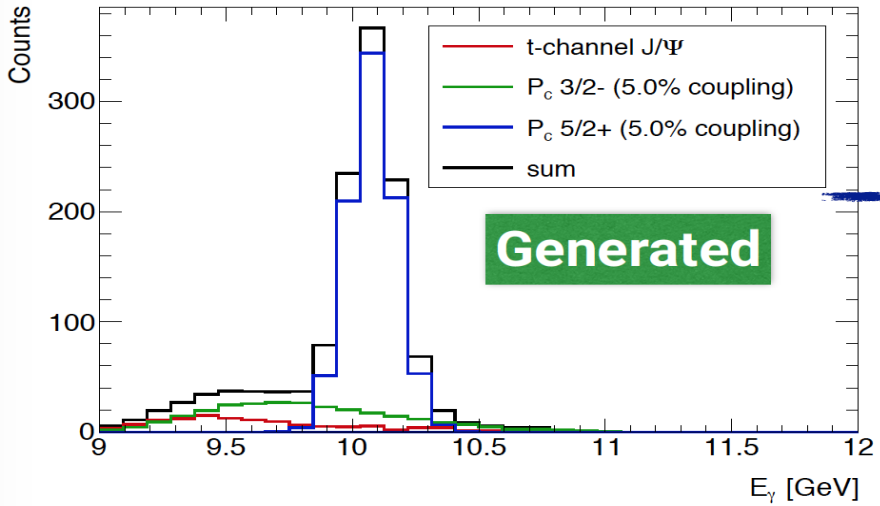
# Background: Inelastic $t$ Channel $\gamma$p -> $J/\psi$p$\pi$

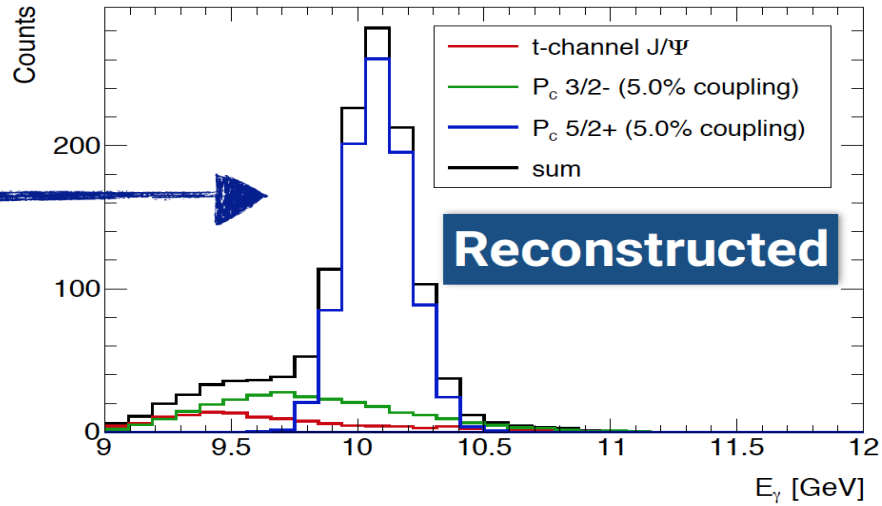
- **Threshold at 9 GeV**
- **Reconstructed photon energy Erc is 1 GeV too low**
- Contribution to the **Contaminates the 8 GeV $<$ Erc $<$ 9.7 GeV range for a photon end-point energy of 10.7 GeV**
  - **not an issue for the Pc(4450) (Erc $>$ 9.7GeV)!**

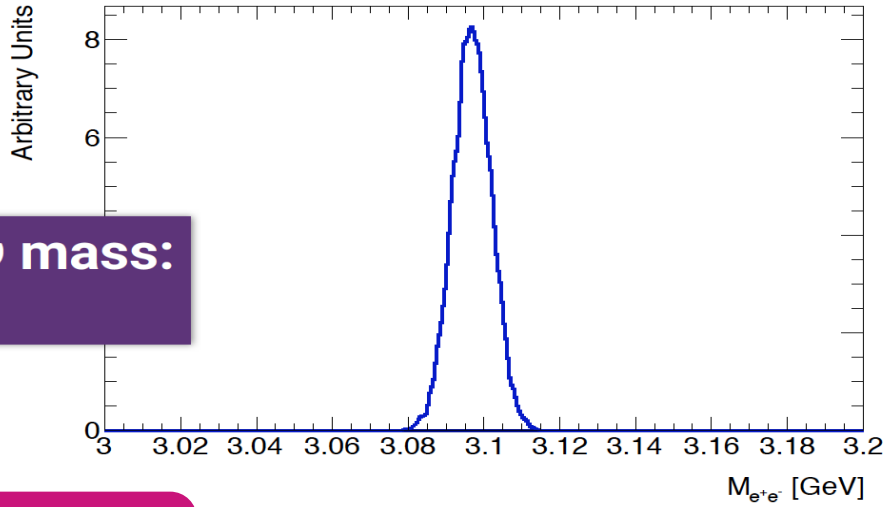
# Background: single electron/pion tracks

- **electron rate estimated using CTEQ5, cross checked with F1F209**
- **positron rate estimated using EPC combined with a background program from E94-010**
- Contribution to the **coincidence rate $<$ 10-5 Hz**
- **pion rates estimated using Wiser**
  - **Assuming a pion rejection $>$ 103 from the Cherenkov + Calorimeter coincidence rate $\sim$ 10-5 Hz**

# Resolution




**reconstructed *J/ψ* mass:**
**σ = 5 MeV**

*from Sylvester Joosten's slide*