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LHCb pentaquark search in direct photoproduction at JLab

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The LHCb charmed "pentaquark" P_c is a **hot topic**

- **Since the CERN press release from July 14, 2015…**

HEP

HEP :: HEPNAMES :: INSTITUTIONS :: CONFERENCES :: JOBS :: EXPERIMENTS :: JOURNALS :: HELP

Information | References (55) | Citations (367) | Files

367 citations in less than 2 years!

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

Cited by: 367 records

(141) The hidden-charm pentaquark and tetraquark states - Chen, Hua-Xing *et al.* Phys.Rept. 639 (2016) 1-121 arXiv:1601.02092 [hep-ph]
(102) 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]
(88) Understanding the newly observed heavy pentaquark candidates - Liu, Xiao-Hai *et al.* Phys.Lett. B757 (2016) 231-236 arXiv:1507.05359 [hep-ph]
(88) Evidence for a $B_s^0\pi^\pm$ state - D0 Collaboration (Abazov, V.M. *et al.*) Phys.Rev.Lett. 117 (2016) no.2, 022003 arXiv:1602.07588 [hep-ex] FERMILAB-PUB-16-038-E
(85) LHCb pentaquark as a $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecular state - Roca, L. *et al.* Phys.Rev. D92 (2015) no.9, 094003 arXiv:1507.04249 [hep-ph]
more

Discovery inspired large number of theoretical work, touching our community and beyond

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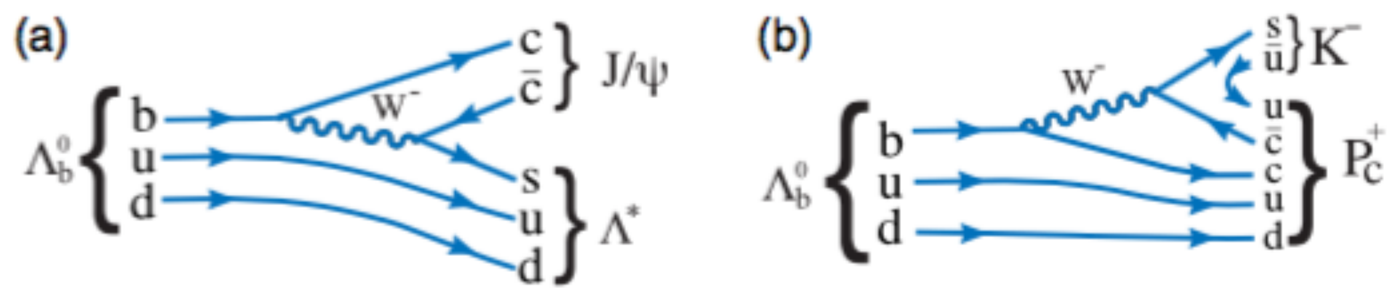
Discovery of the LHCb charmed "pentaquark" P_c

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

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

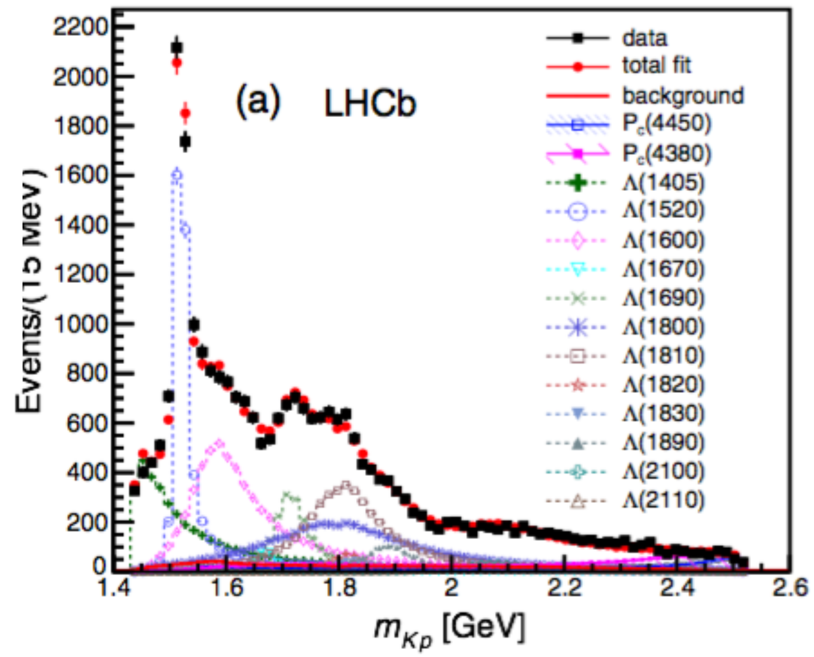


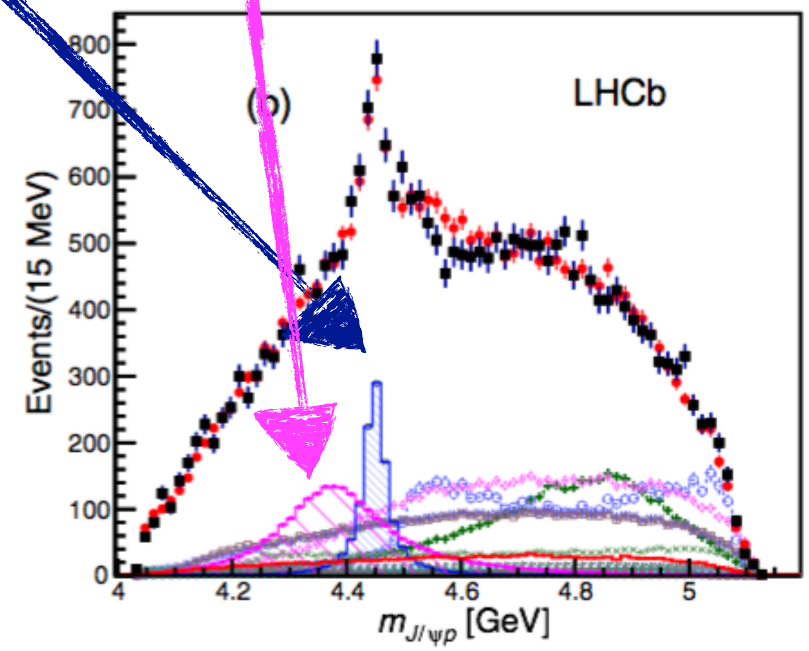
$$\Lambda_b \to \Lambda^* J/\Psi \to (K^- p) J/\Psi$$
$$\Lambda_b \to K^- P_c \to K^- (p J/\Psi)$$

- **2 P_c states** needed to describe results
  - **narrow**: P_c(4450)
  - **wide**: P_c(4380)
- spin/parity either:
  - **5/2+, 3/2- (most likely!)**
  - 5/2-, 3/2+
  - 3/2-, 5/2+

narrow: P_c(4450) (12 σ)

wide: P_c(4390) (9σ)





charmed "pentaquark" in **photo-production**

- Common explanations:
  - **LHCb**: 2 new **charmed "pentaquark"** (P_c) states
  - **alternative: kinematic enhancements** through anomalous triangle singularity **(ATS)**

    Lui X-H, *et al.*, PLB 757 (2016), p231 (and references therein)
- **Photo-production** ideal tool to **distinguish** between both explanations
  - if P_c real states, **also created in photo-production**
  - kinematic enhancement through **ATS not possible in photo-production**

    Wang Q., *et al.*, PRD 92-3 (2015) 034022-7 (and references therein)
- $P_c(4450)$ translates to **narrow peak around E_γ = 10 GeV**

JLab is the ideal laboratory for the measurement, due to luminosity, resolution and energy reach at threshold!

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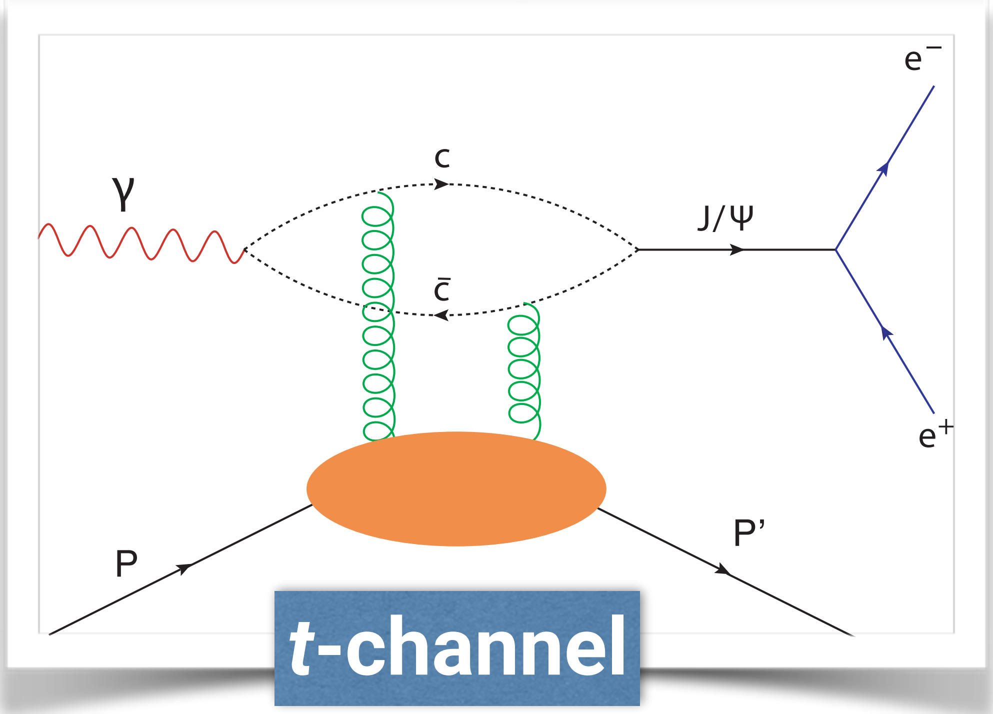
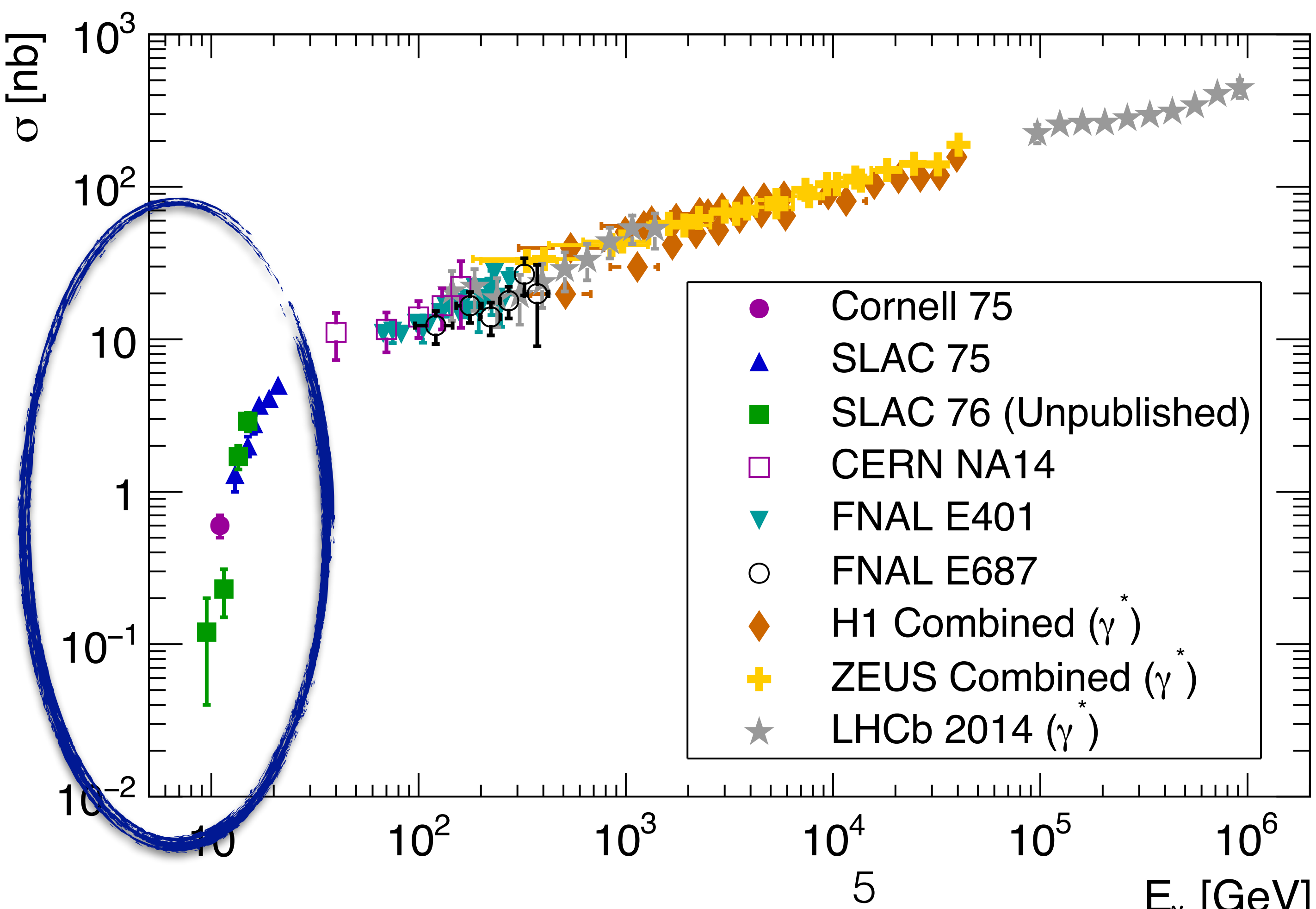
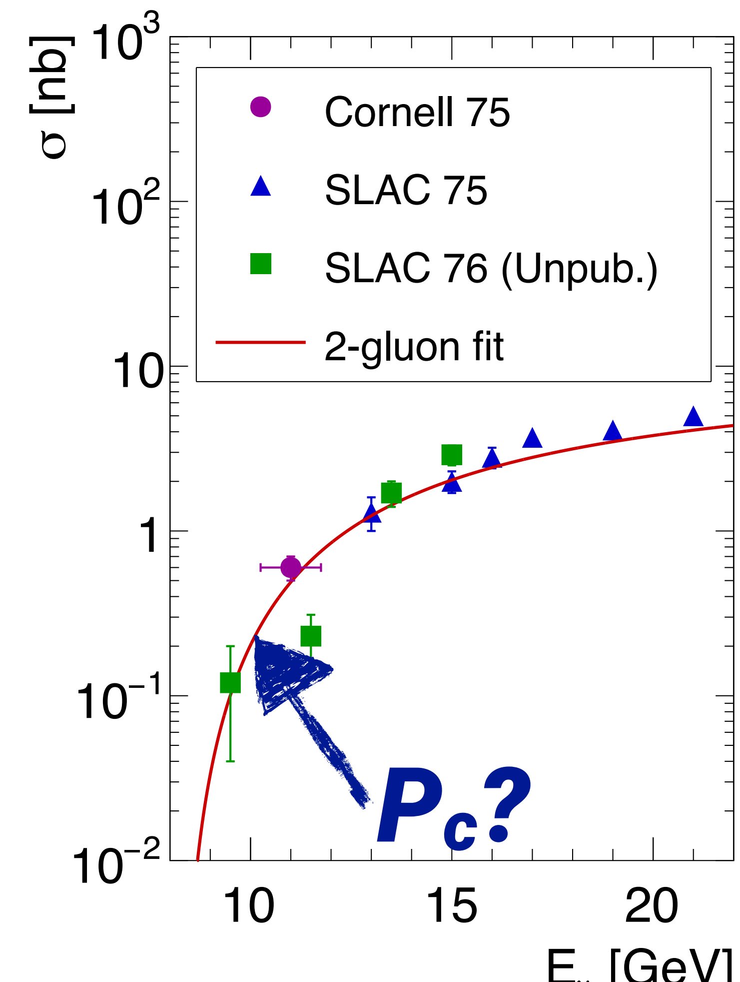
J/ψ photo-production: **what do we know?**



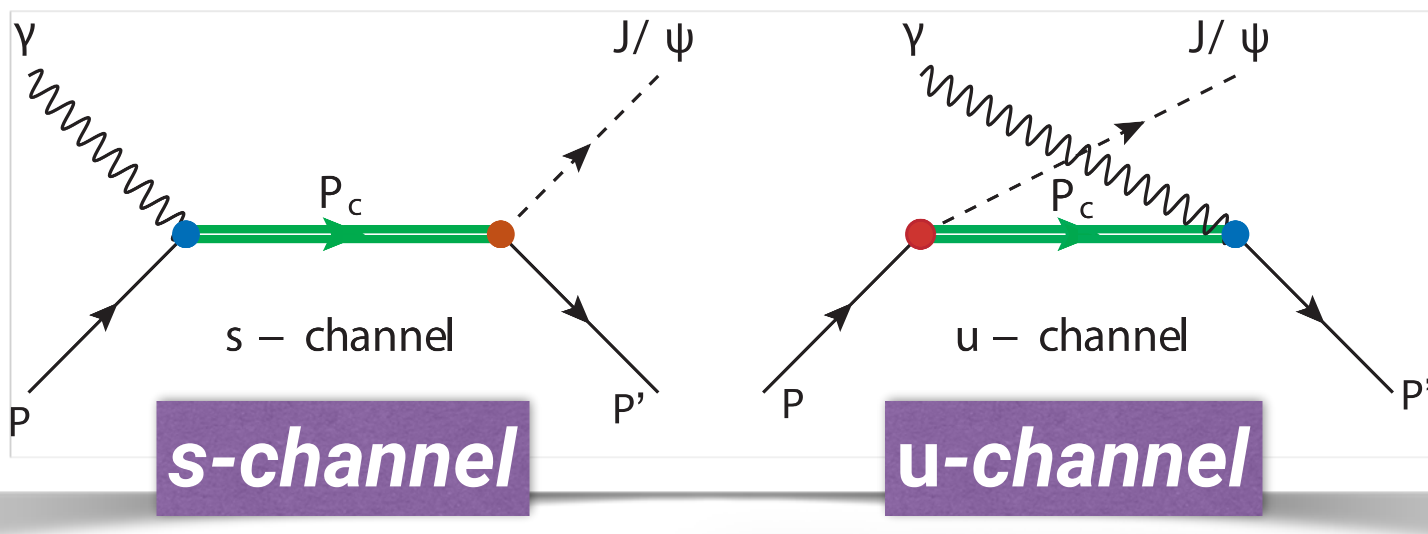
Brodsky S J, *et al.*, PLB 498-1 (2001), p23

- Cross section well constrained above 100 GeV
- **Almost no data near-threshold**
- Resolution of the existing measurements too low
- 2 of the 3 lowest points unpublished!



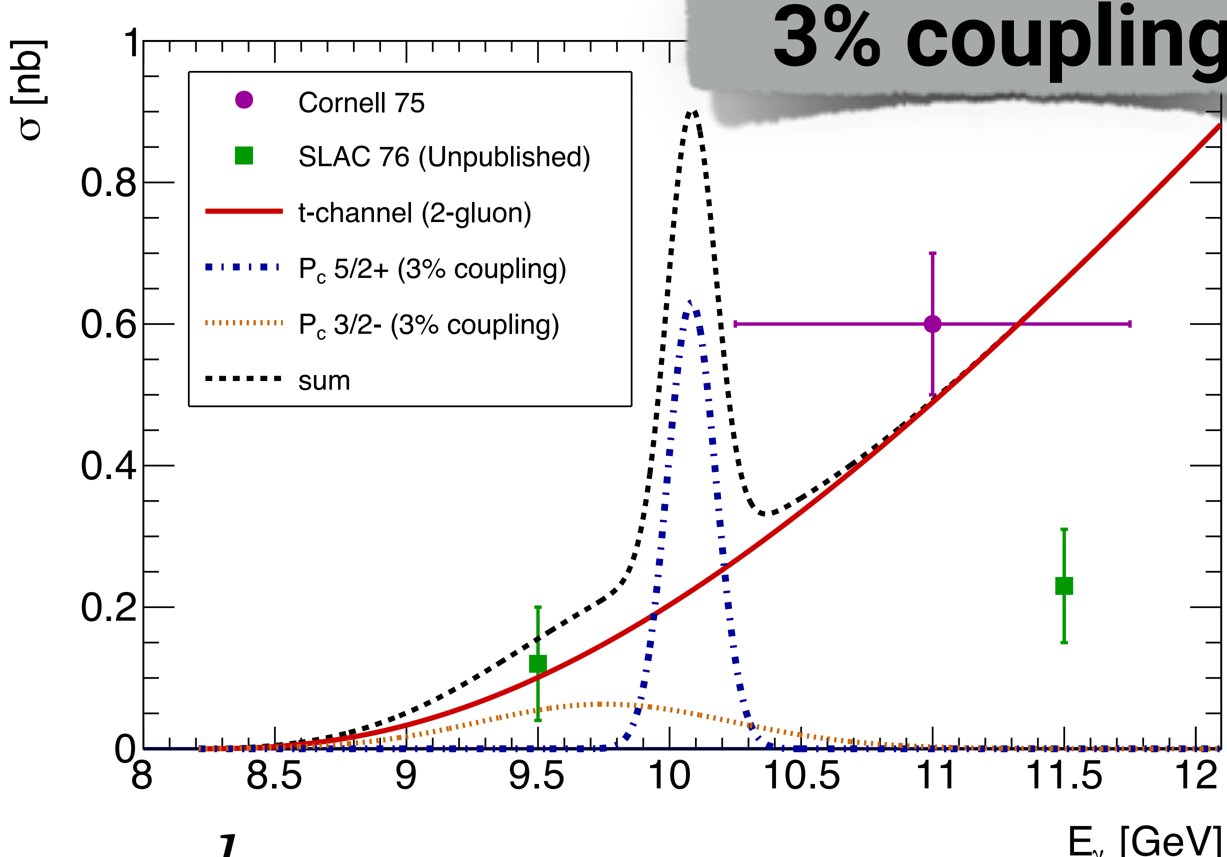


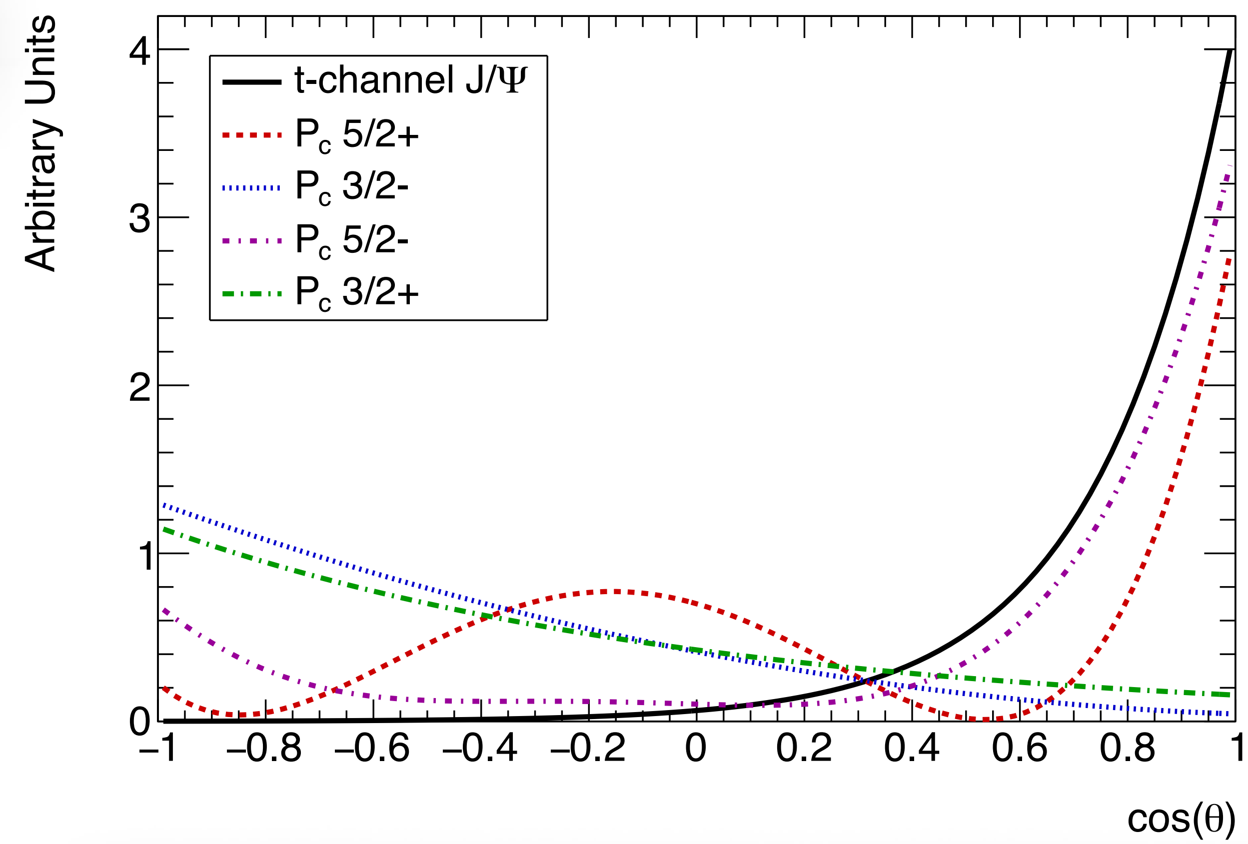
Resonant J/ψ production through P_c decay



- Cross section depends on **coupling to (J/ψ, p) channel**
- ***J/ψ* angular distribution** depends on P_c **spin/parity**

3% coupling





$$\frac{d\sigma}{d\cos\theta_{J/\psi}}(\gamma p \to P_c \to J/\psi p)$$

Leverage cos(*θ*) dependence to maximize S/B at low coupling!

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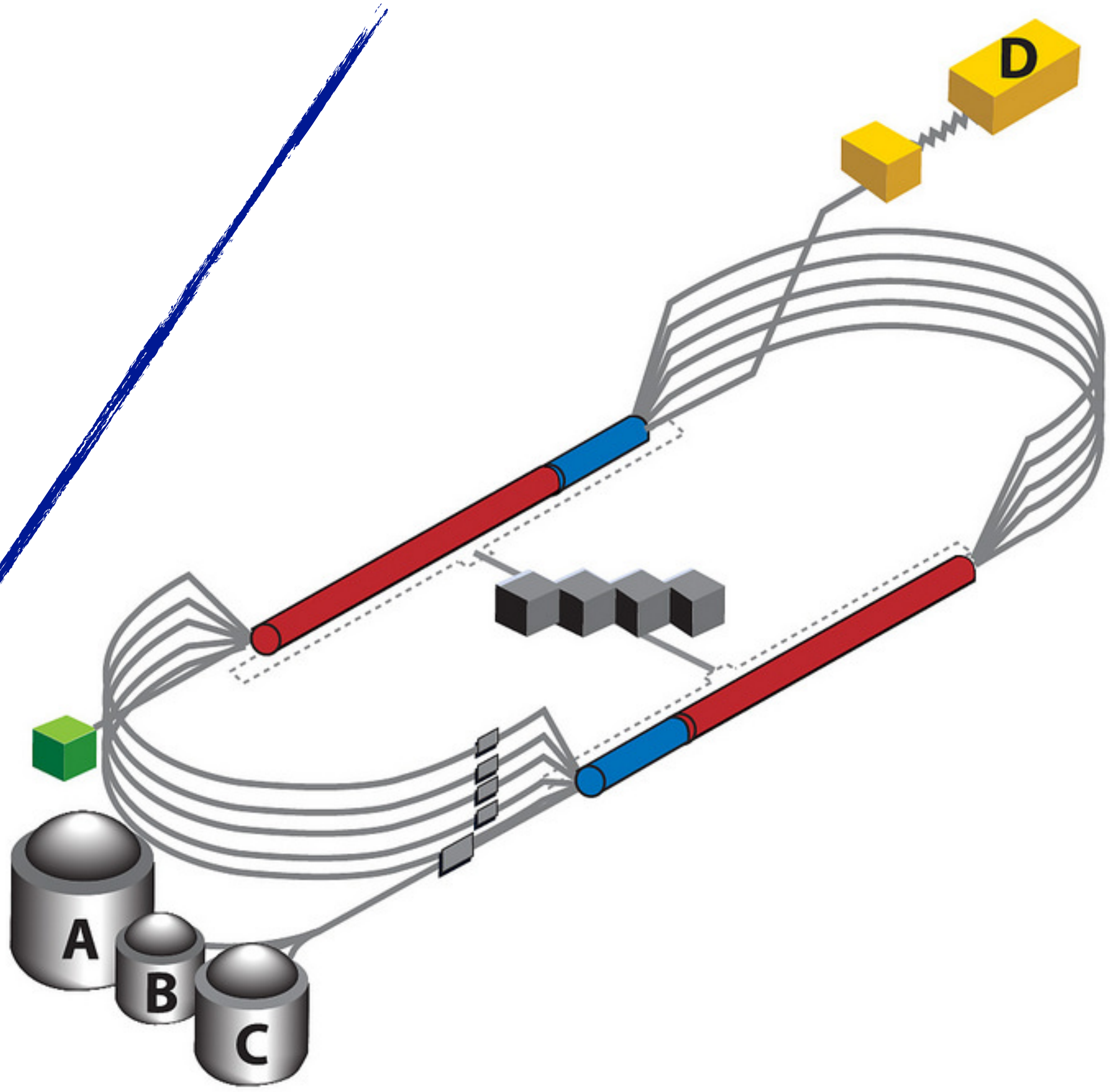
Wang Q., *et al.*, PRD 92-3 (2015) 034022-7

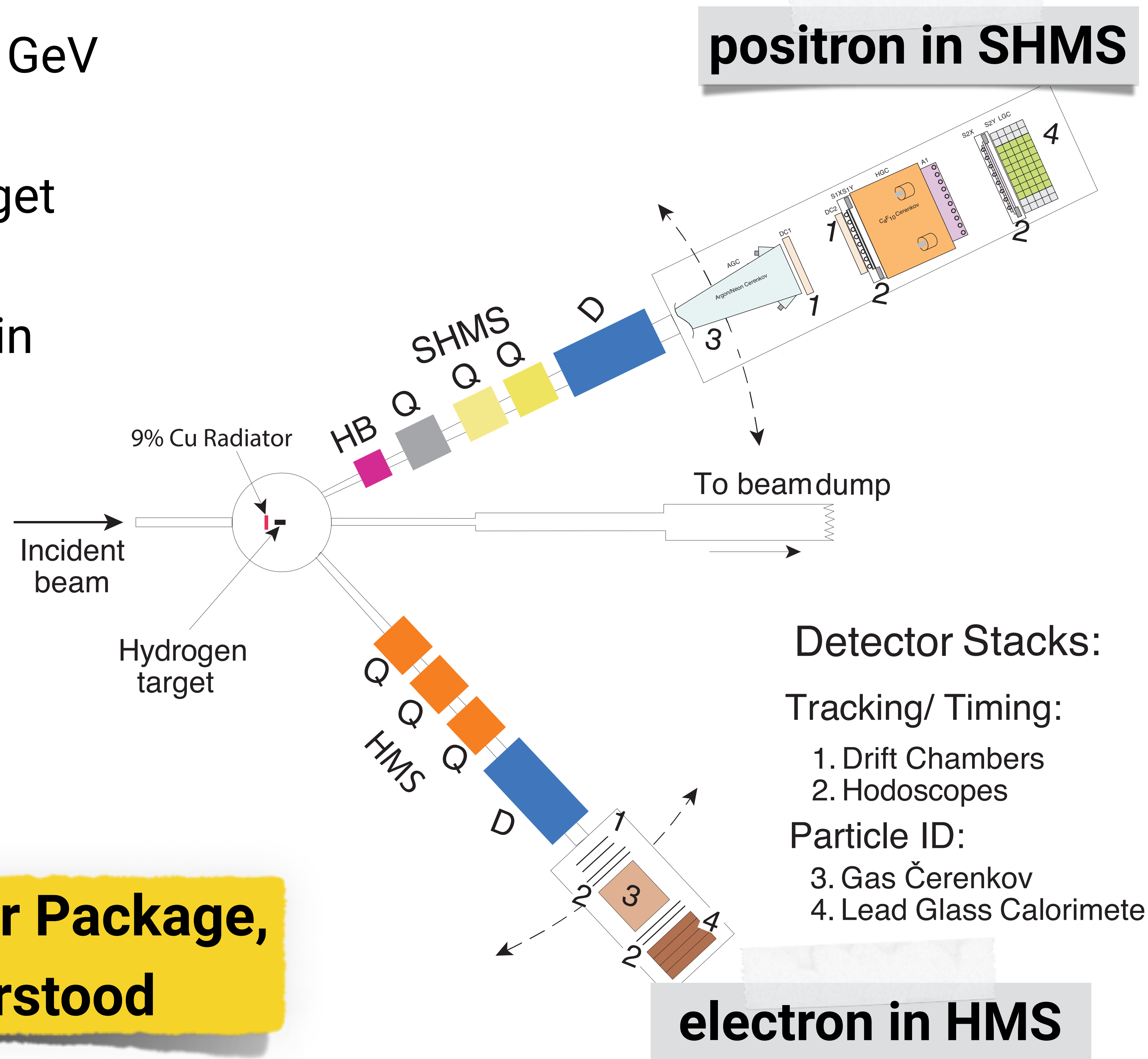
Experiment E12-16-007 in **Hall C** at JLab



Newly approved by PAC44
Rated A/"high impact"

Experiment E12-16-007 in **Hall C** at JLab

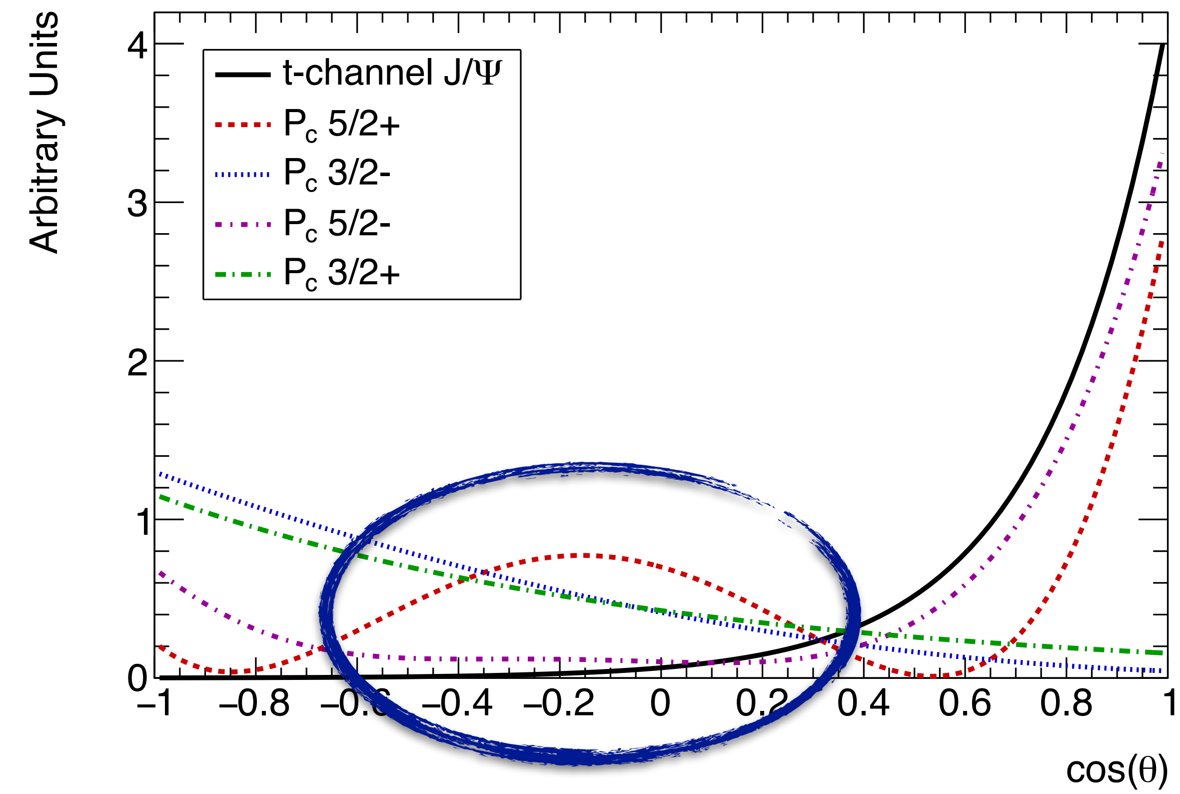
- 50μA electron beam at 11 GeV
- 9% copper radiator
- 15cm liquid hydrogen target
- **total 10% RL**
- Detect *J/ψ* decay leptons in coincidence
  - Bremsstrahlung photon energy fully constrained

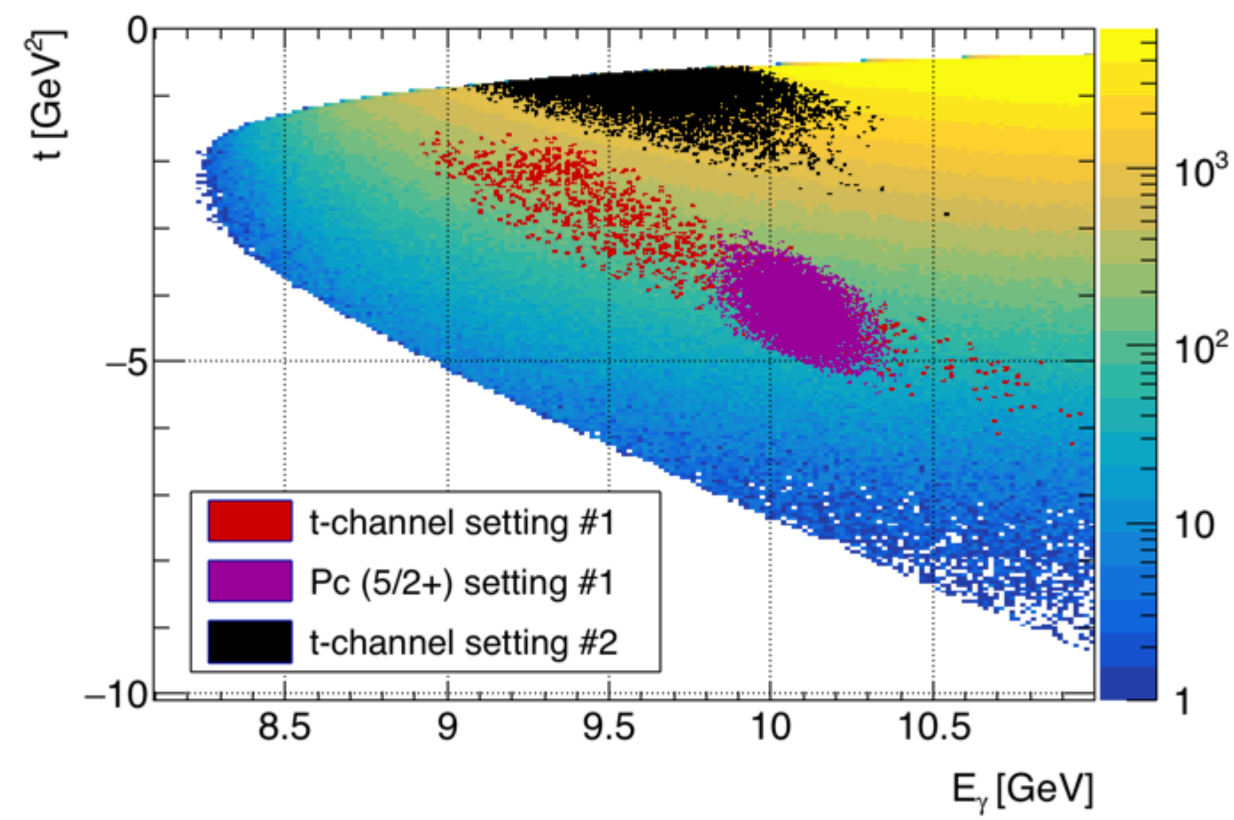


Standard Hall C Detector Package, Radiator Well Understood

Maximizing the sensitivity

- Use **HMS** and **SHMS** to maximize P_c signal over *t*-channel background
- **Run with 2 settings:**
  - **"SIGNAL" Setting** (9 days): minimizes accidentals and **maximizes signal/background**:
    - HMS: 34°, 3.25 GeV electrons
    - SHMS: 13°, 4.5 GeV positrons
  - **"BACKGROUND" Setting:** (2 days): precise determination of the ***t*-channel background**
    - HMS: 20°, 4.75 GeV electrons
    - SHMS: 20°, 4.25 GeV positrons



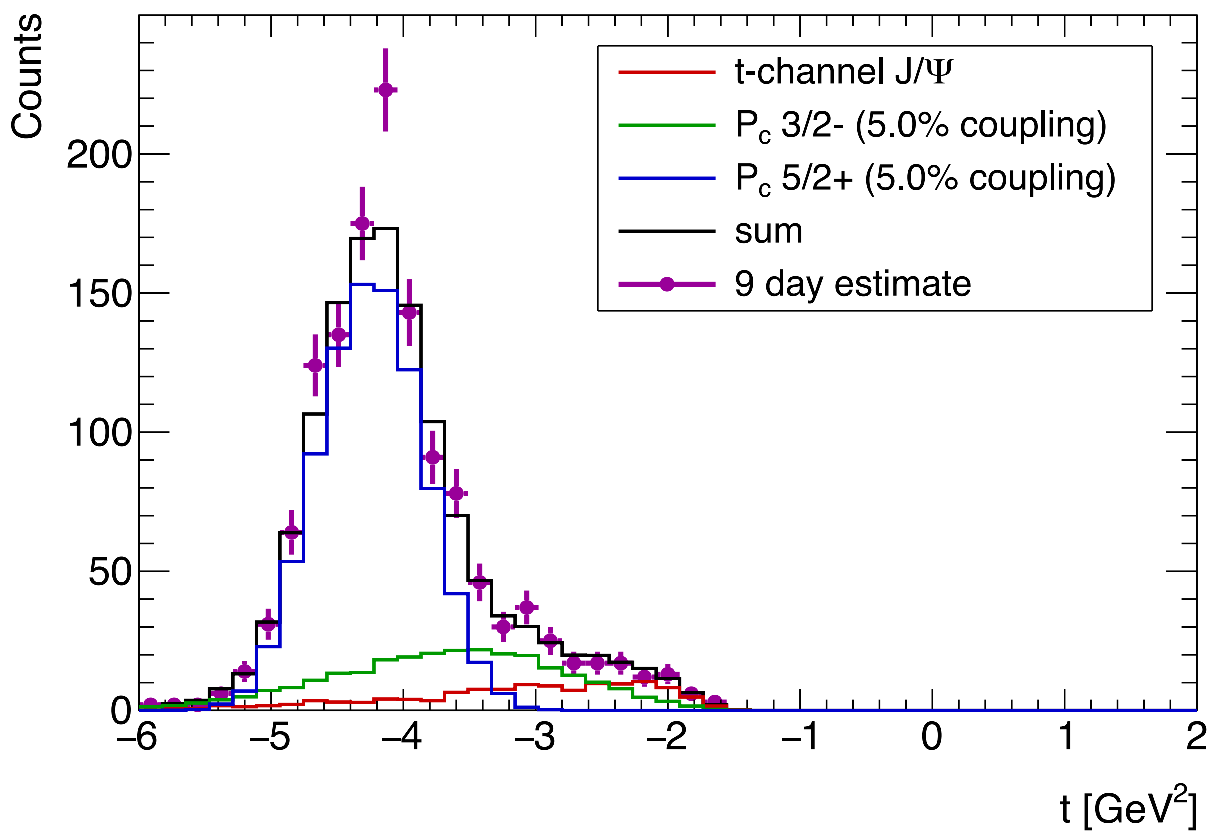


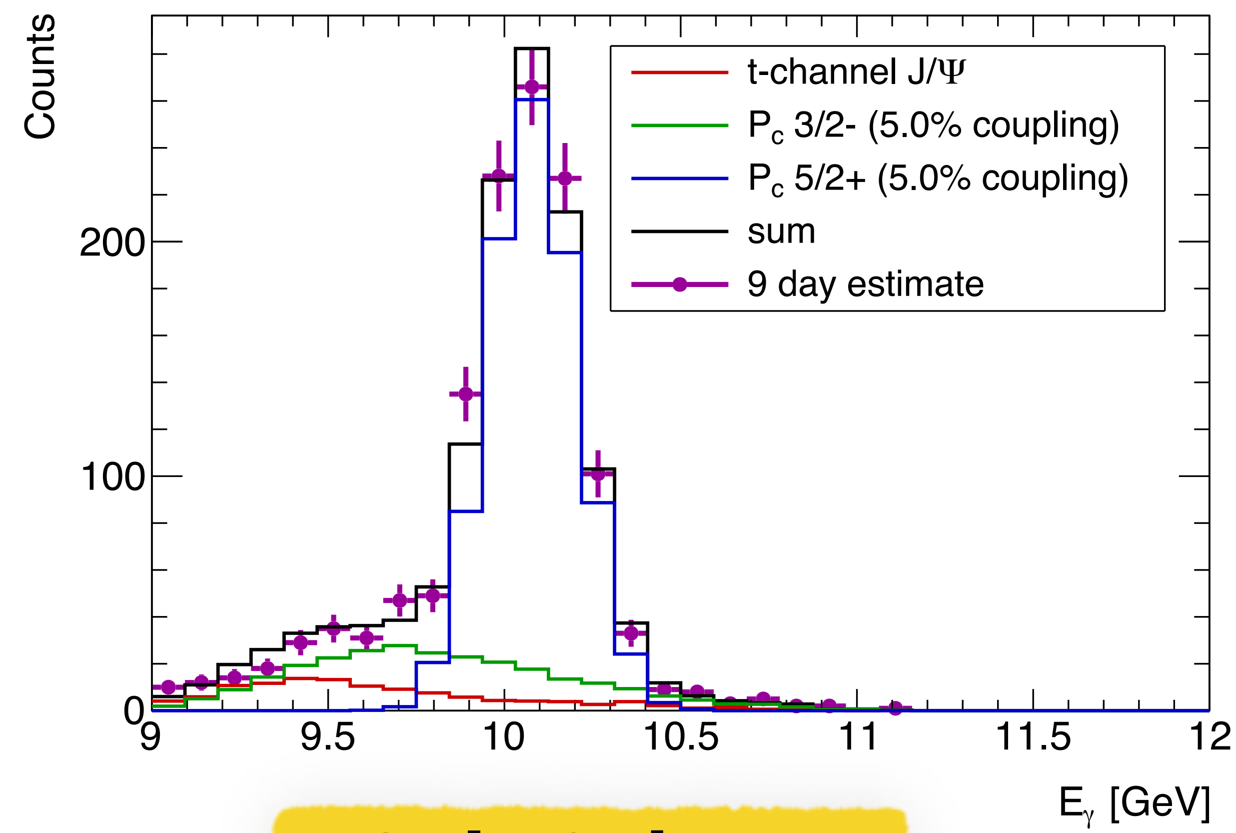
Bottom line:
can run SOON and FAST

Projected results for **"SIGNAL" Setting**

- **assuming 5% coupling** (value favored by existing photo-production data) **Wang Q., *et al.*, PRD 92-3 (2015) 034022-7**
- 9 days of beam time at 50μA
- 5/2+ peak **dominates the spectrum**

***t*-channel: 120 events**
5/2+: 881 events
3/2-: 266 events





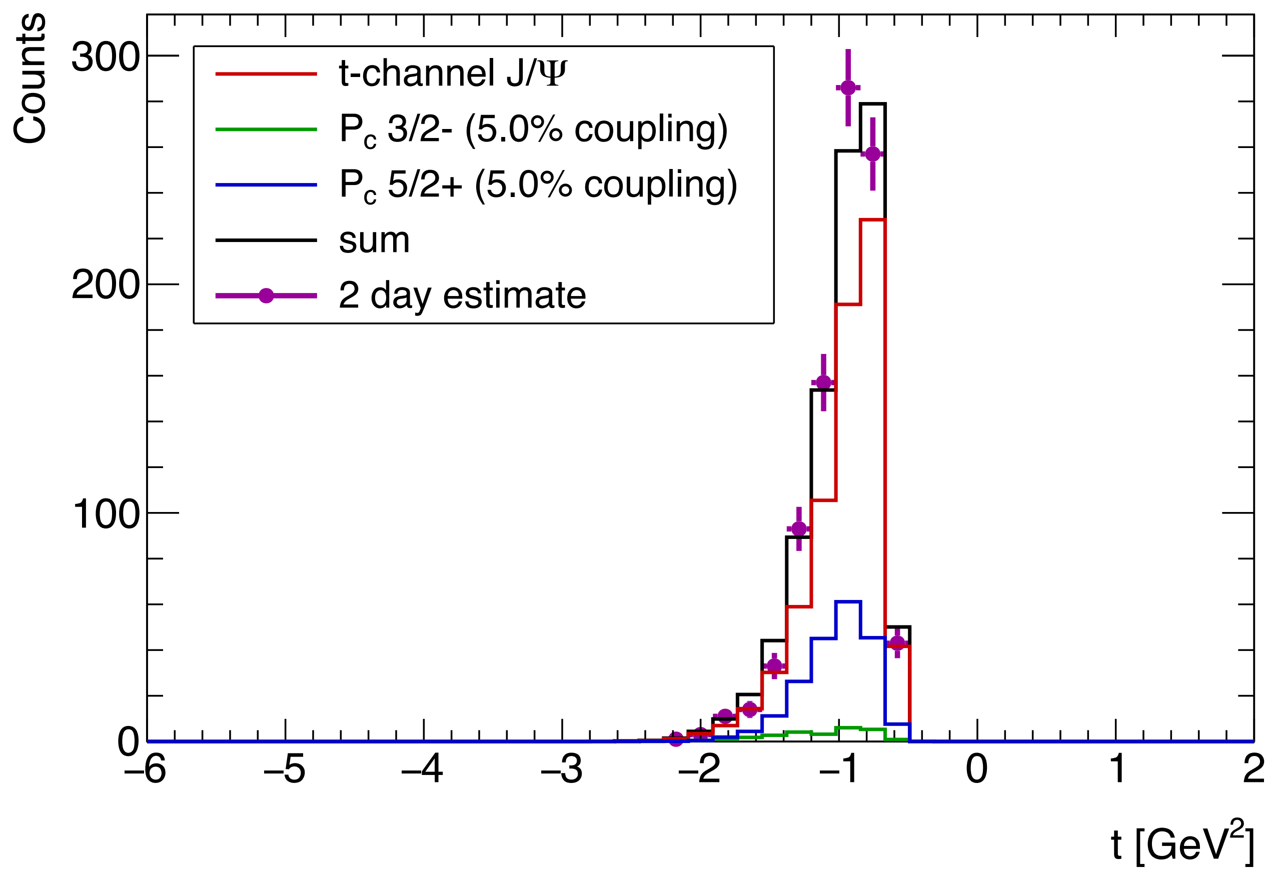
Only 9 days!

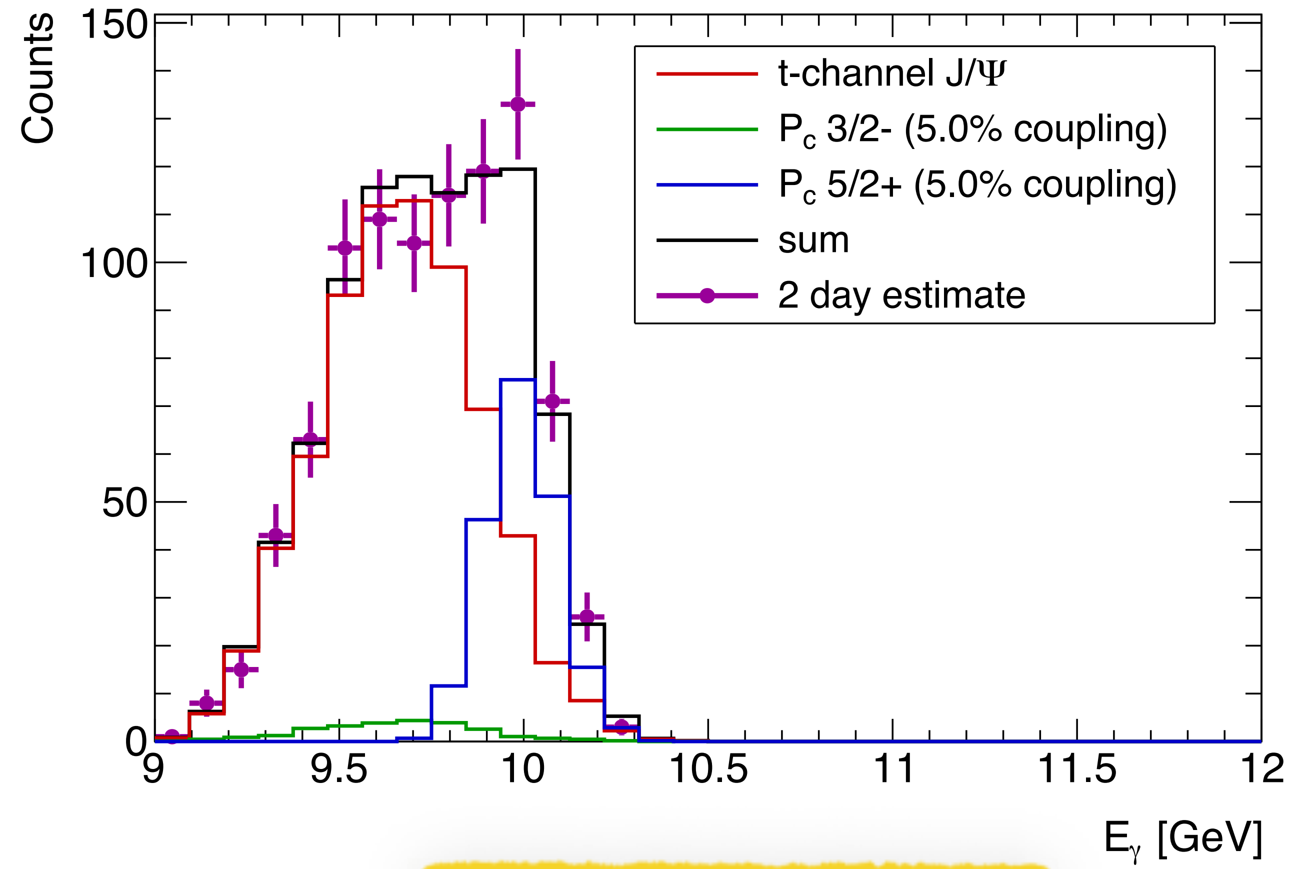
Significance > 20σ!

Projected results for **"BACKGROUND" Setting**

- 2 days of beam time at 50μA
- able to separate 5/2+ from ***t*-channel at low E_γ**
- will provide **first-hand information about *t*-channel production near threshold**
- assuming 5% coupling (value favored by existing photo-production data)

***t*-channel: 682 events**
5/2+: 204 events
3/2-: 26 events

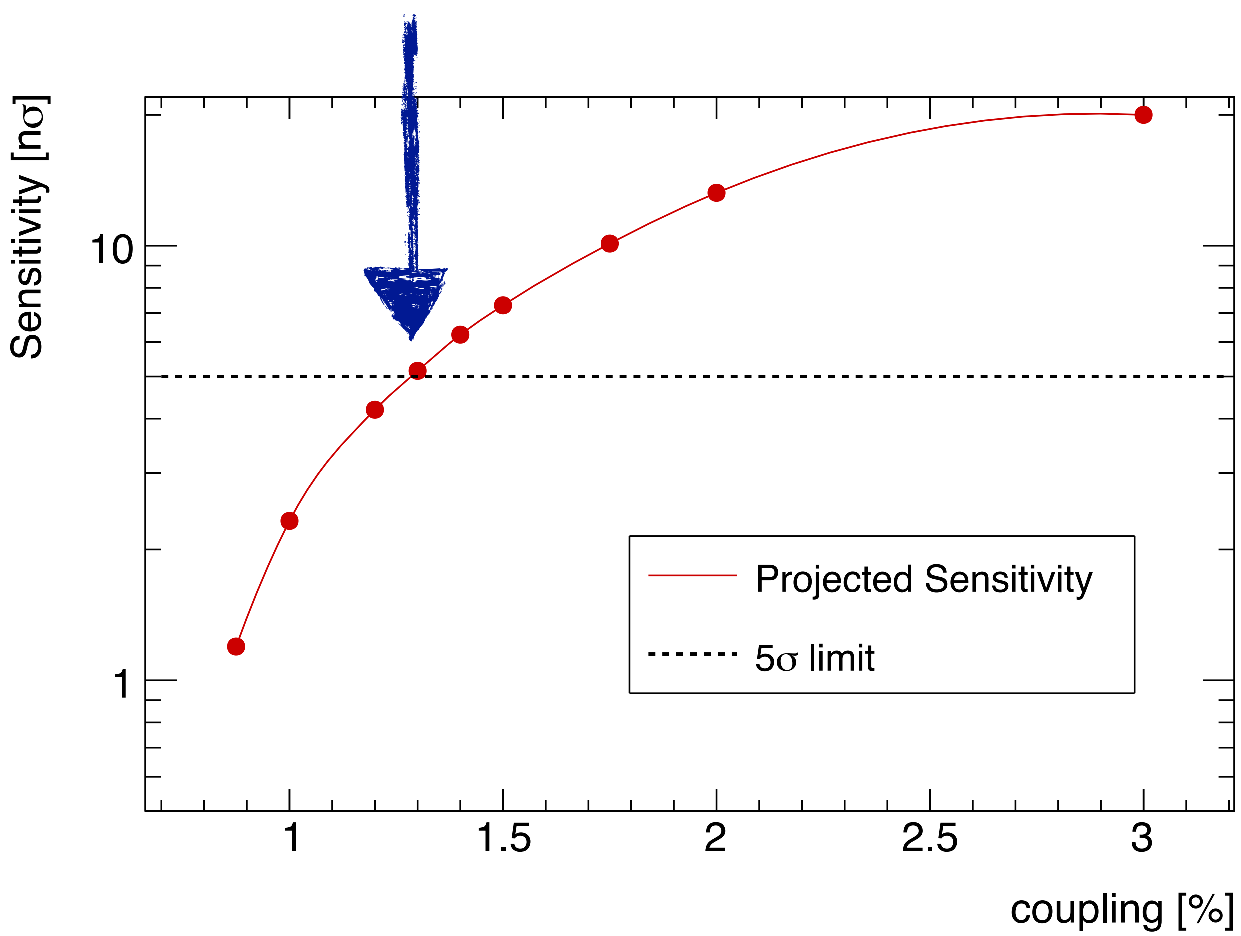


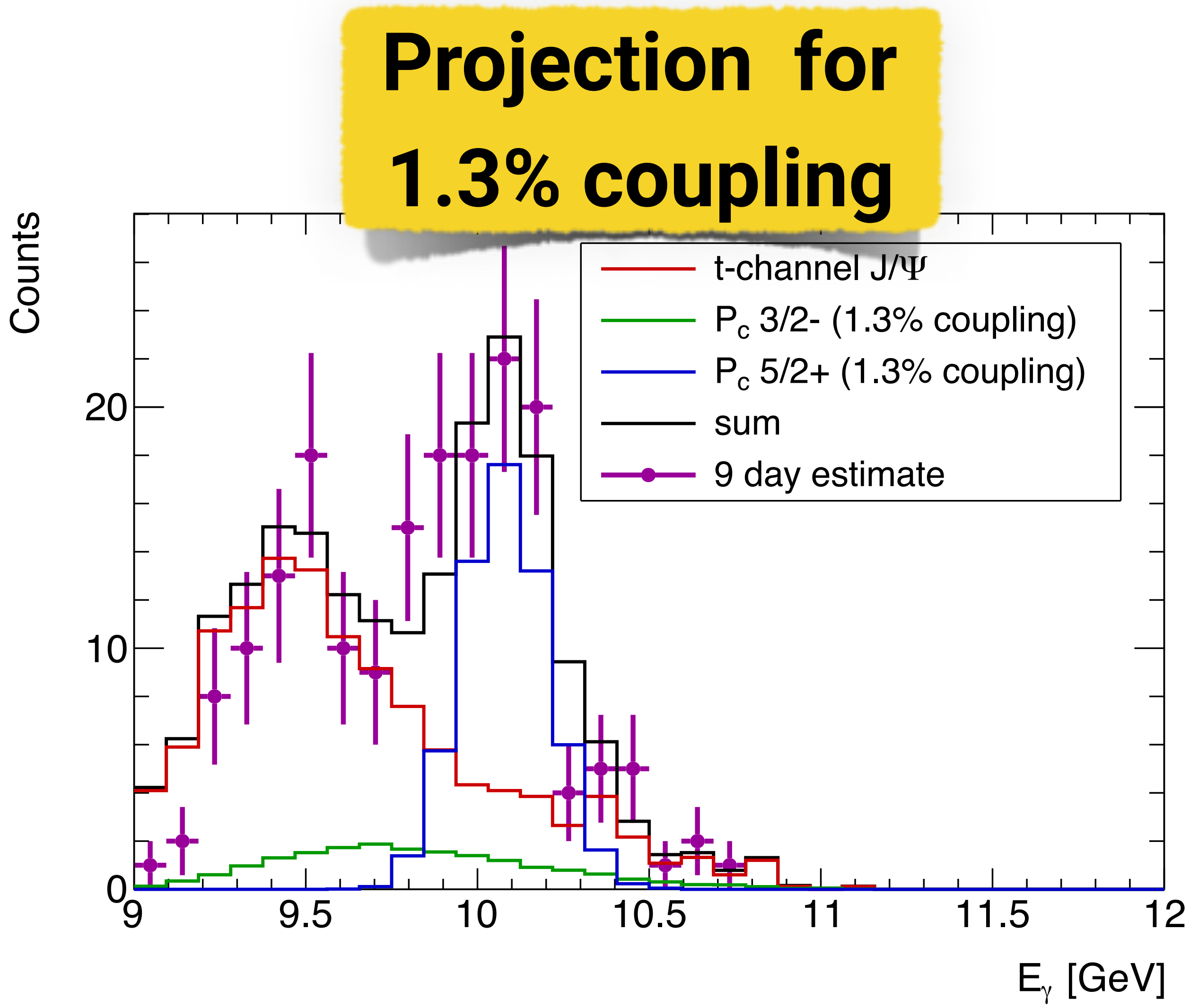


Only 2 days!

Sensitivity for **Discovery**

- sensitivity calculated using a Δ-log-likelihood formalism
- **5 standard deviation** level of sensitivity **starting from 1.3% coupling!**





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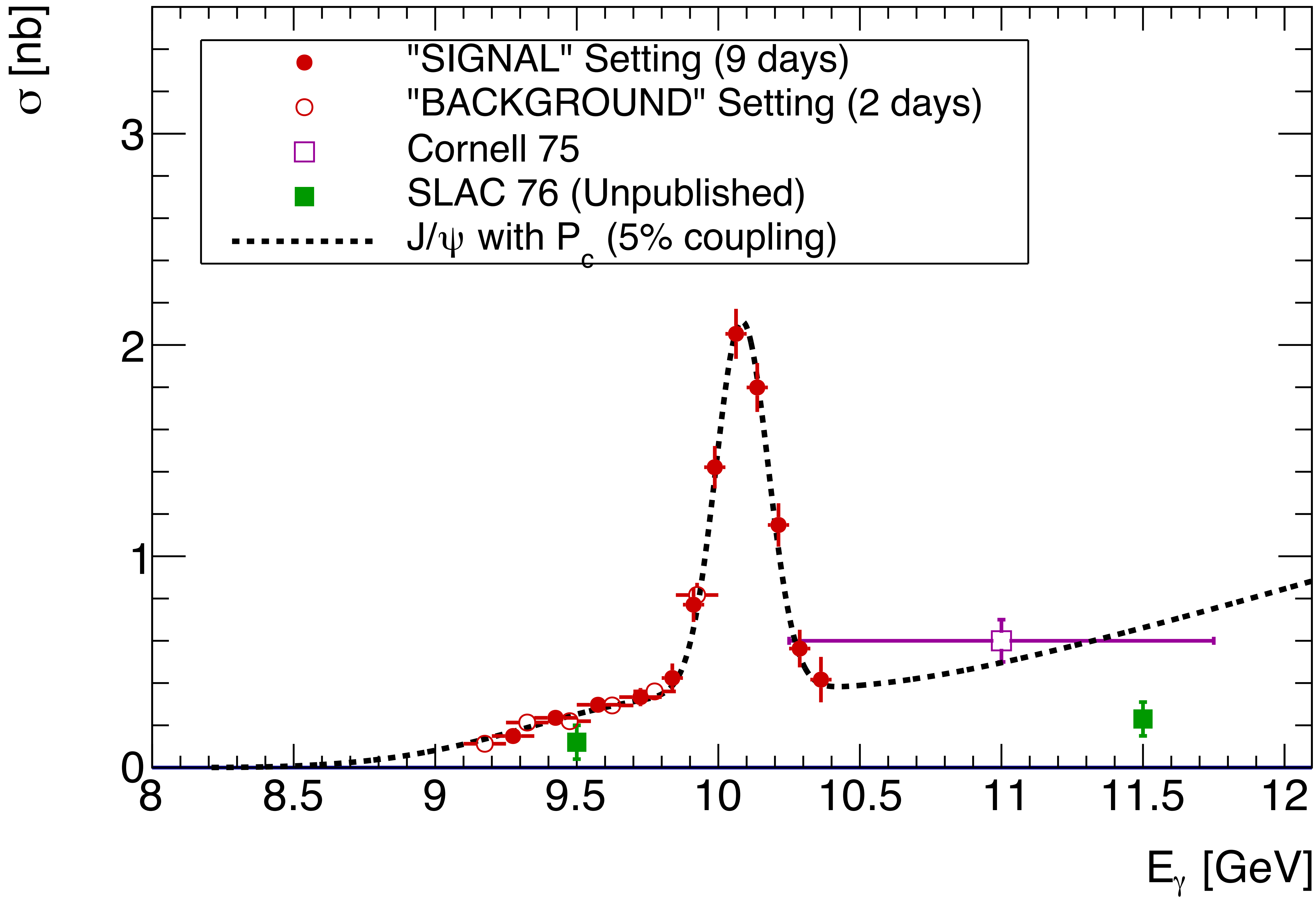
Impact on the world data for J/ψ production



Approved *J/ψ* experiments at JLab

- GlueX (**Hall D**, *γp*)
  - Luminosity: **low**
    - <100 **MHz** photon rate
  - Acceptance: **very high**
    - First access to 2D *J/ψ* cross section
    - Harder to separate P_c from *t*-channel background
  - Timeline: **ongoing!**

- E12-12-001 (**CLAS12**, HallB, *ep*)
  - Luminosity: **medium**
    - luminosity: $\mathbf{10^{35}}$ s^{-1} cm^{-2}
  - Acceptance: **high**
    - Access 2D *J/ψ* cross section
    - Harder to separate P_c from *t*-channel background
  - Timeline: **~few years**

- E12-16-007 (**Hall C**, *γp*)
  - luminosity: **very high**
    - 8000 **GHz** photon rate
    - equiv. *ep*-luminosity: >$\mathbf{10^{39}}$ s^{-1} cm^{-2}
  - Acceptance: **limited**
    - Optimized for **maximal P_c sensitivity**
    - cannot do 2D *J/ψ* cross section
  - Timeline: **soon (high-impact!)**

- E12-12-006 (**SoLID,** Hall A, *ep*)
  - Luminosity: **high**
    - luminosity: $\mathbf{10^{38}}$ s^{-1} cm^{-2}
  - Acceptance: **high**
    - Precision 2D *J/ψ* cross section
    - Good sensitivity for Pc resonance due to very high statistics
  - Timeline: **~5-10 years**

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Summary

- **High impact** result will
  - **either confirm** P_c resonance, **or strongly exclude** its existence
- **Strong sensitivity** to the coupling down to 1.3%
- Will provide **knowledge about J/ψ production (absolute cross section!) near threshold**
  - Helps future experimental endeavors at CLAS12 and SoLID
- Only need **11 days**
- **Straightforward** experiment, able to **run early** with a **standard Hall C package**

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Collaboration

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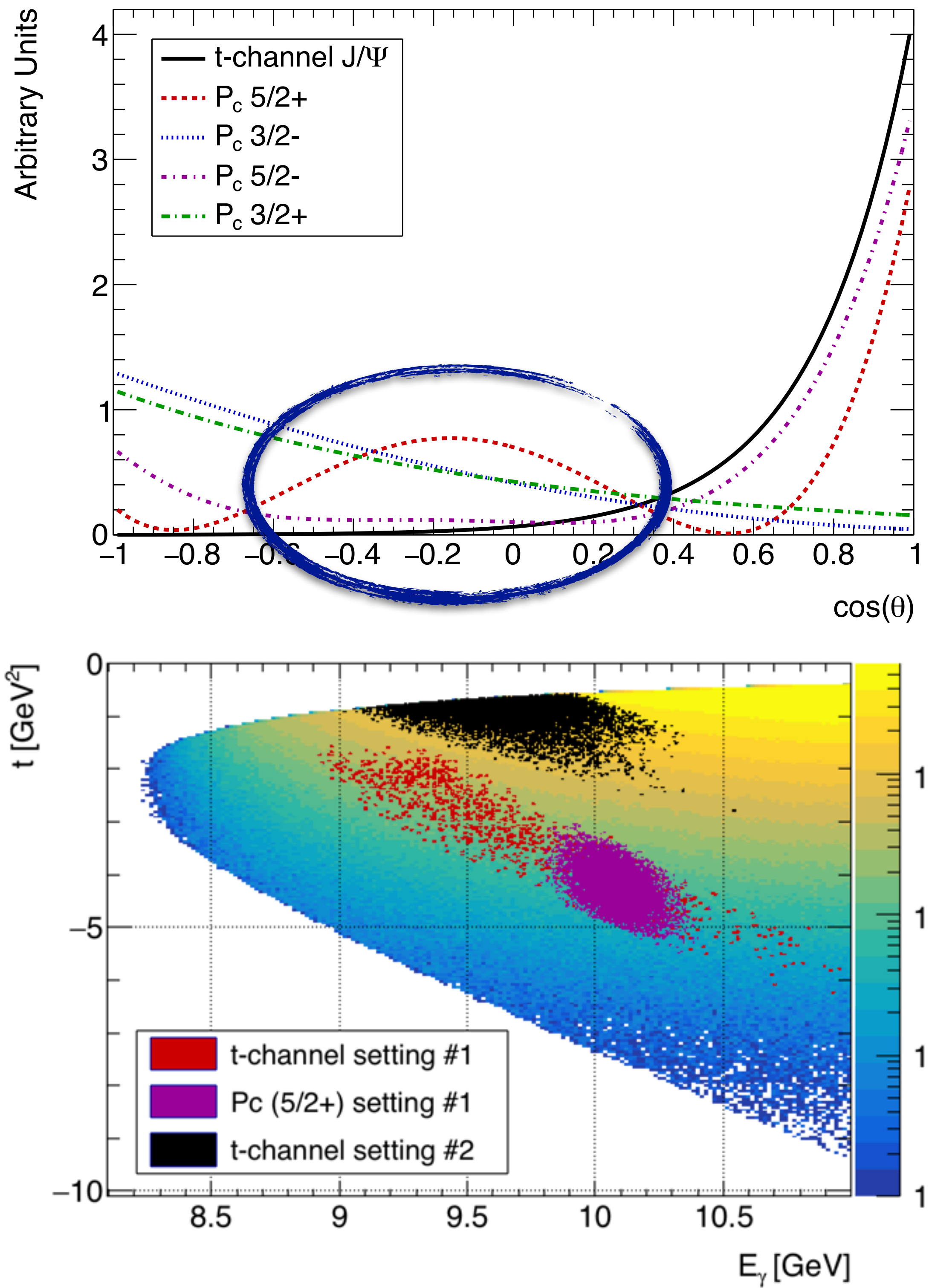
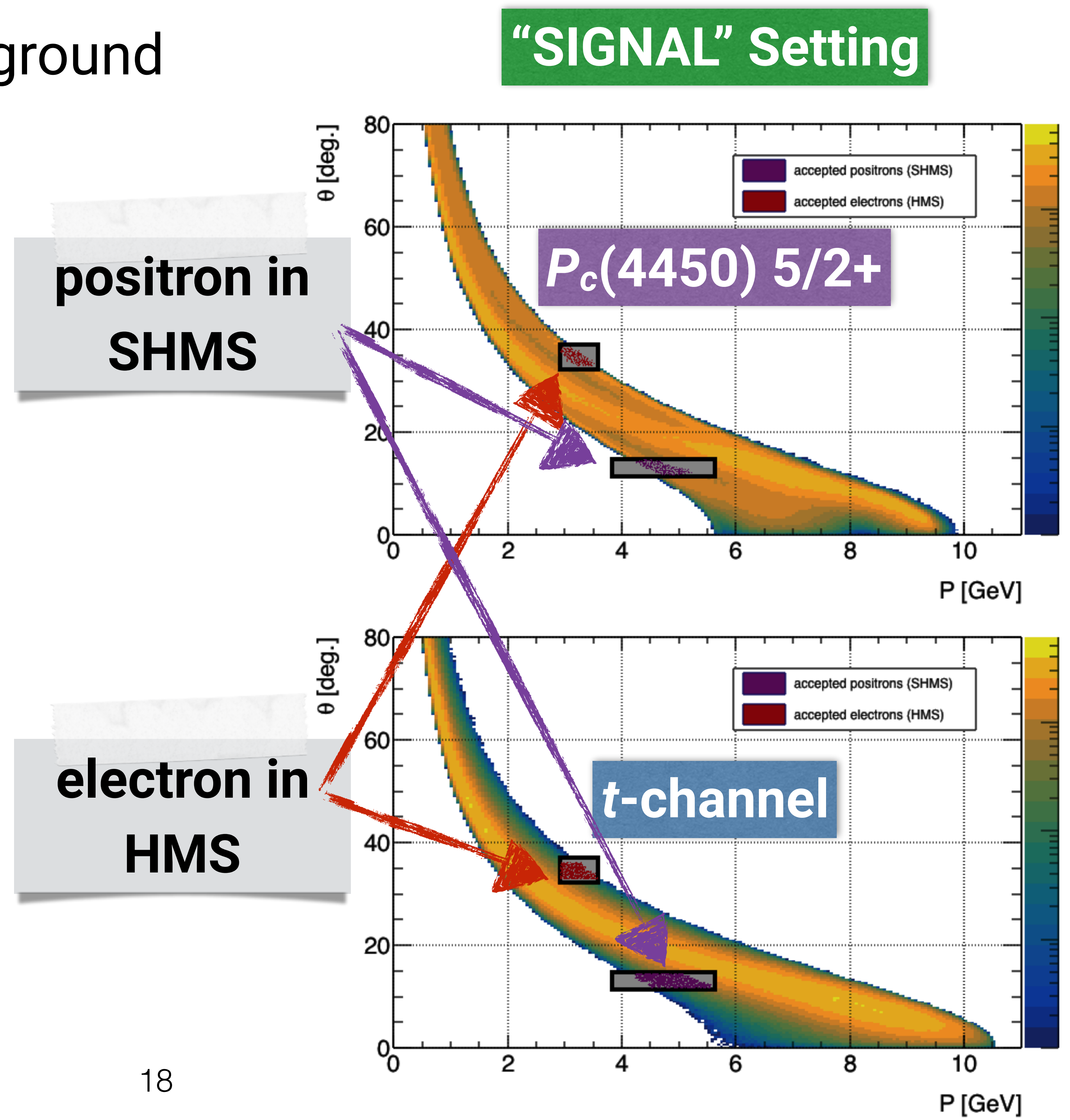
APPENDIX

BACKUP SLIDES

Maximizing the sensitivity

- Use **HMS** and **SHMS** to maximize P_c signal over *t*-channel background

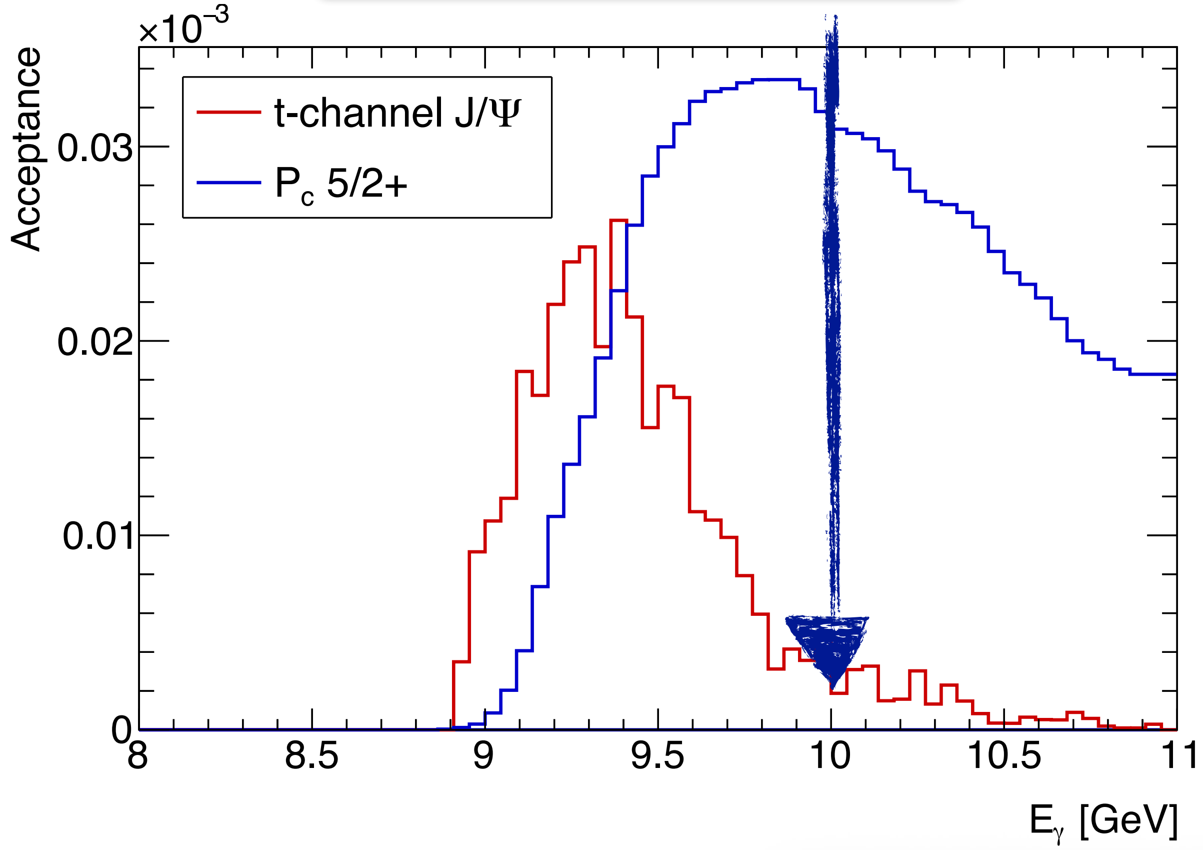




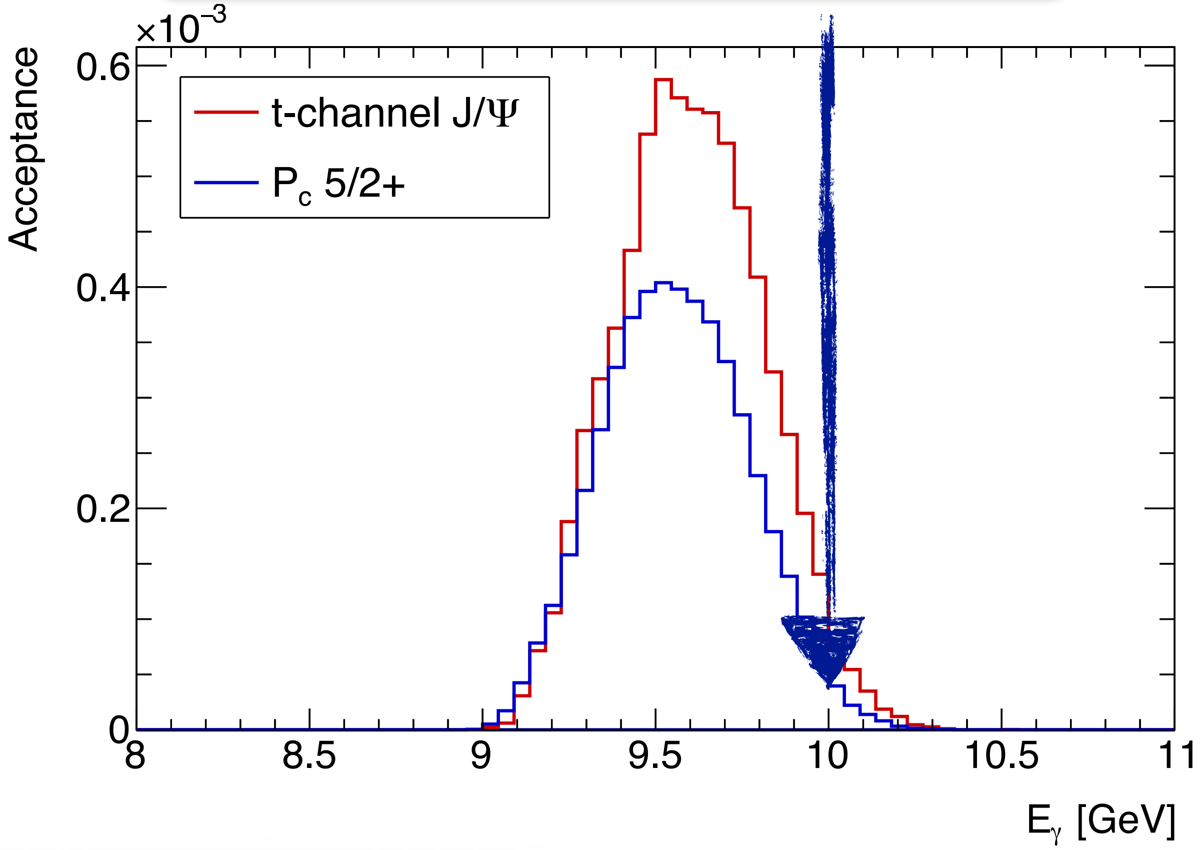
Acceptance

- **"SIGNAL" Setting:** acceptance edges far removed from P_c peak position
- **"BACKGROUND" Setting**: acceptance centered to the left of the P_c peak position

"SIGNAL" Setting



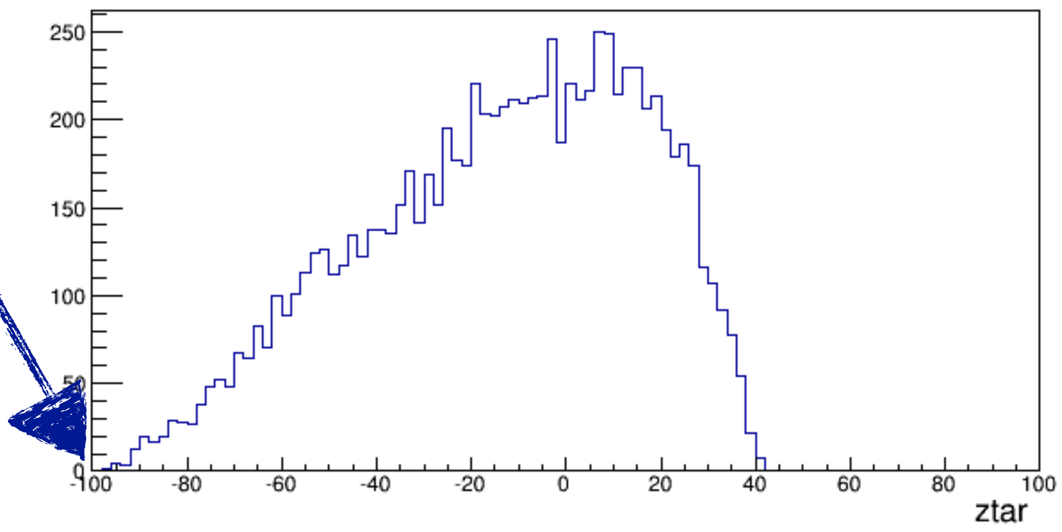
"BACKGROUND" Setting



Good Acceptance over the full width of the resonance

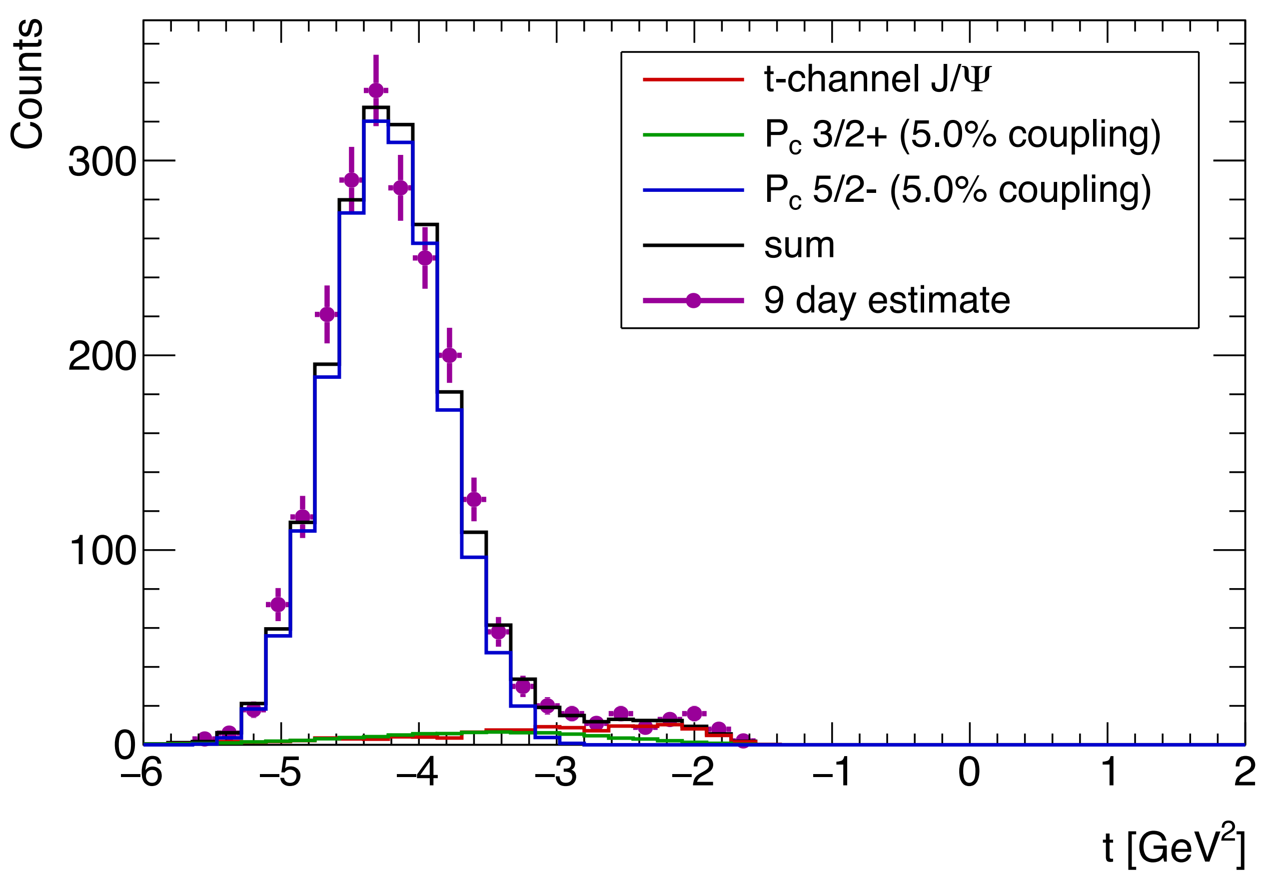
Radiator (Answer to TAC)

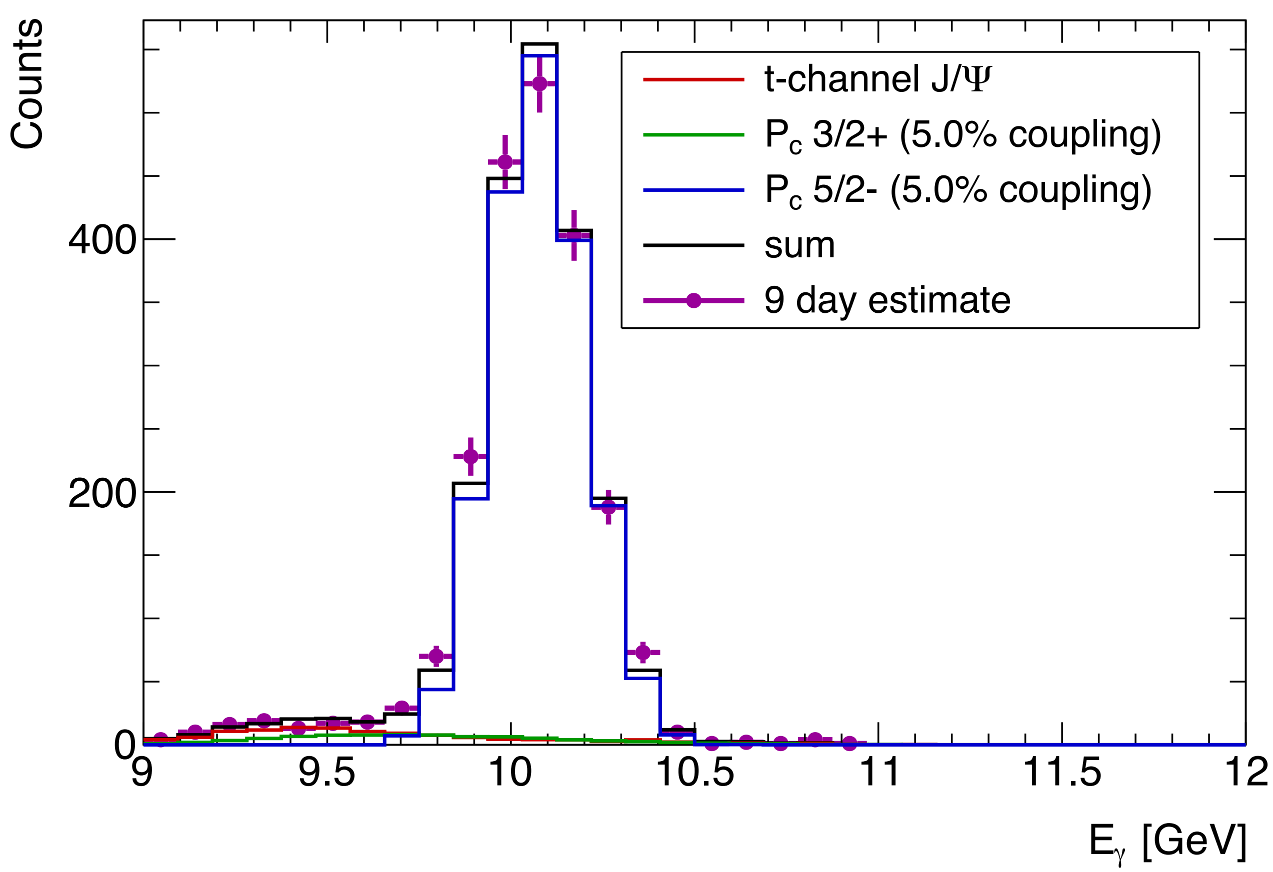
- SHMS upstream acceptance to almost 100 cm at 13^o
  - radiator needs to be upstream by >1m (outside of the target chamber), no additional shielding needed
  - ensure we don't hit flow diverters of the target and entrance cylinder to the target (0.5 in opening)
  - Assuming a raster of ± 1 mm, multiple scattering of ±2.35 mm (within current target parameters)



Alternate P_c Assumption (Setting "SIGNAL")

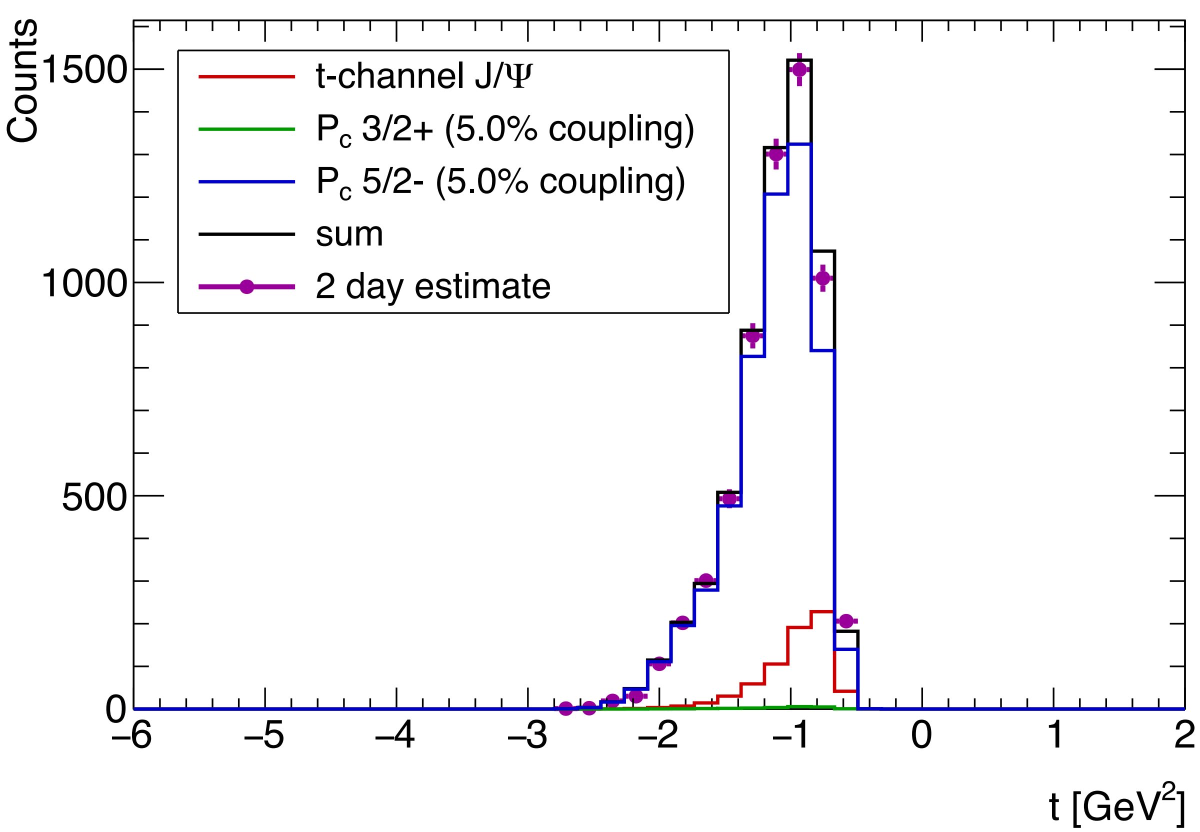
- **Alternate (5/2-, 3/2+) P_c assumption**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption
- 9 days of beam time at 50μA
- 5/2- peak **dominates the spectrum** (even larger than the 5/2+ peak!)

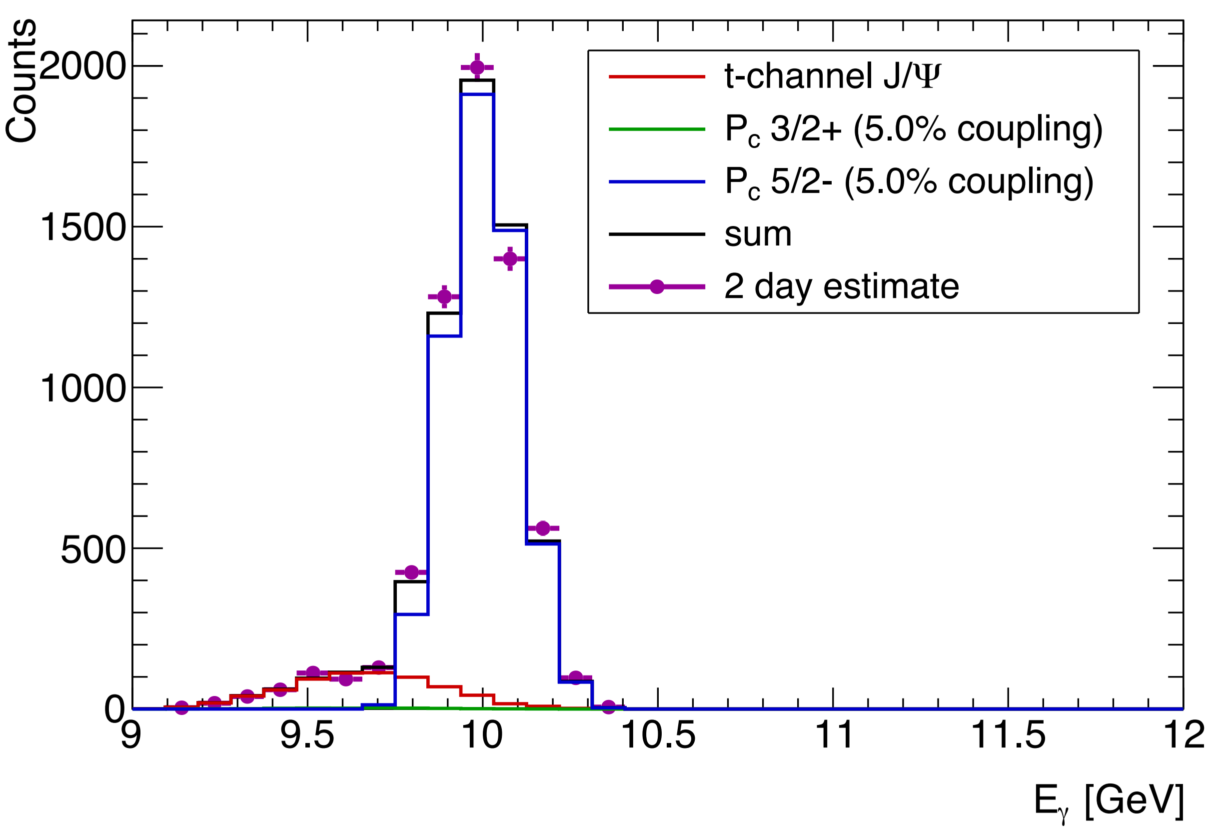




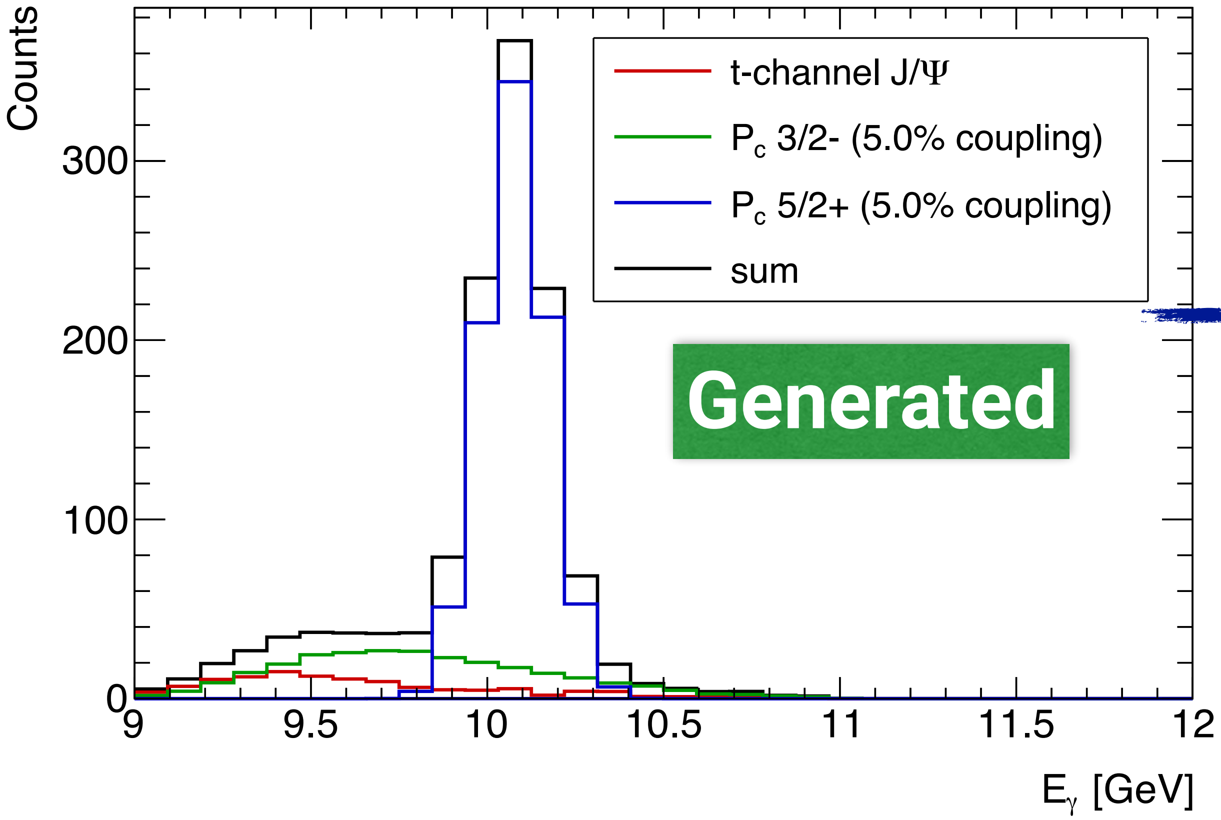
Alternate P_c Assumption ("BACKGROUND" Setting)

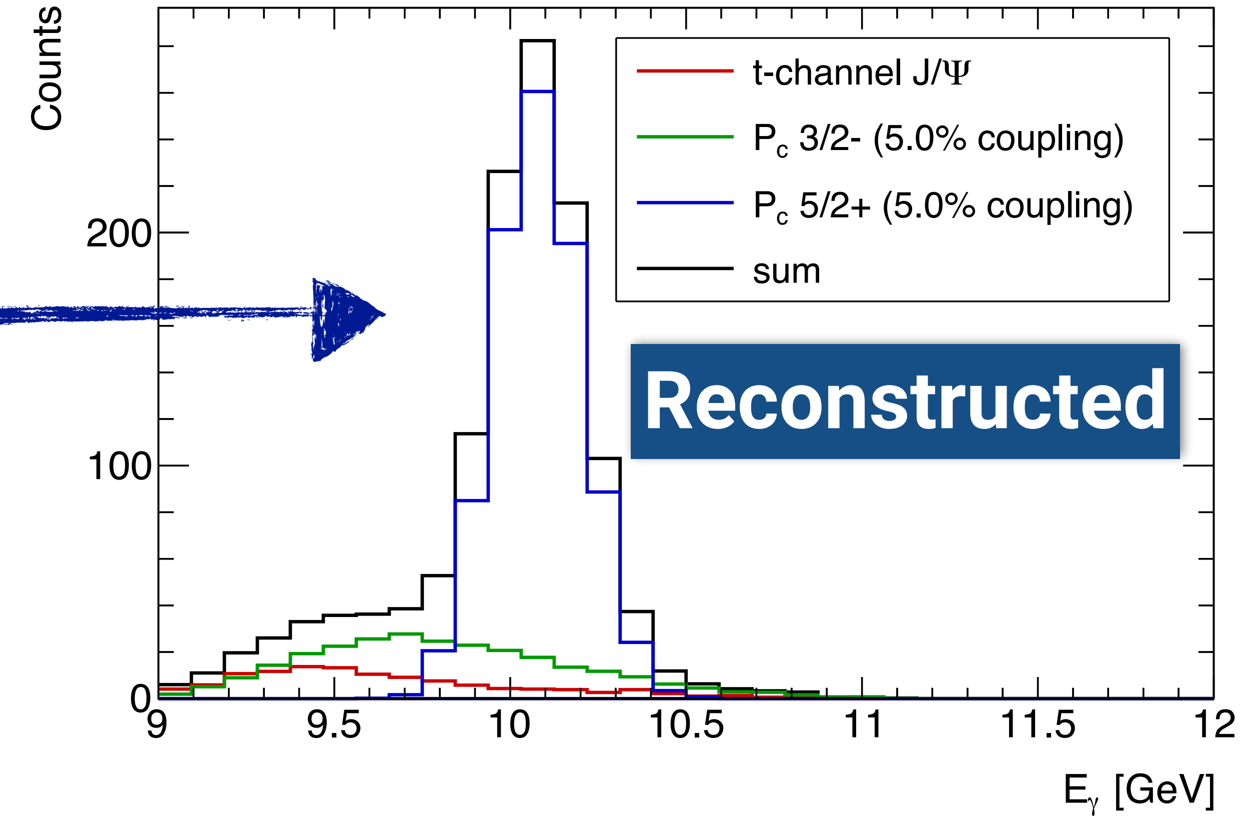
- **Alternate (5/2-, 3/2+) *P_c* assumption**
- 2 days of beam time at 50μA
- able to **separate** 5/2- from ***t*-channel at low E_γ**
- will provide **first-hand information about *t*-channel production near threshold**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption

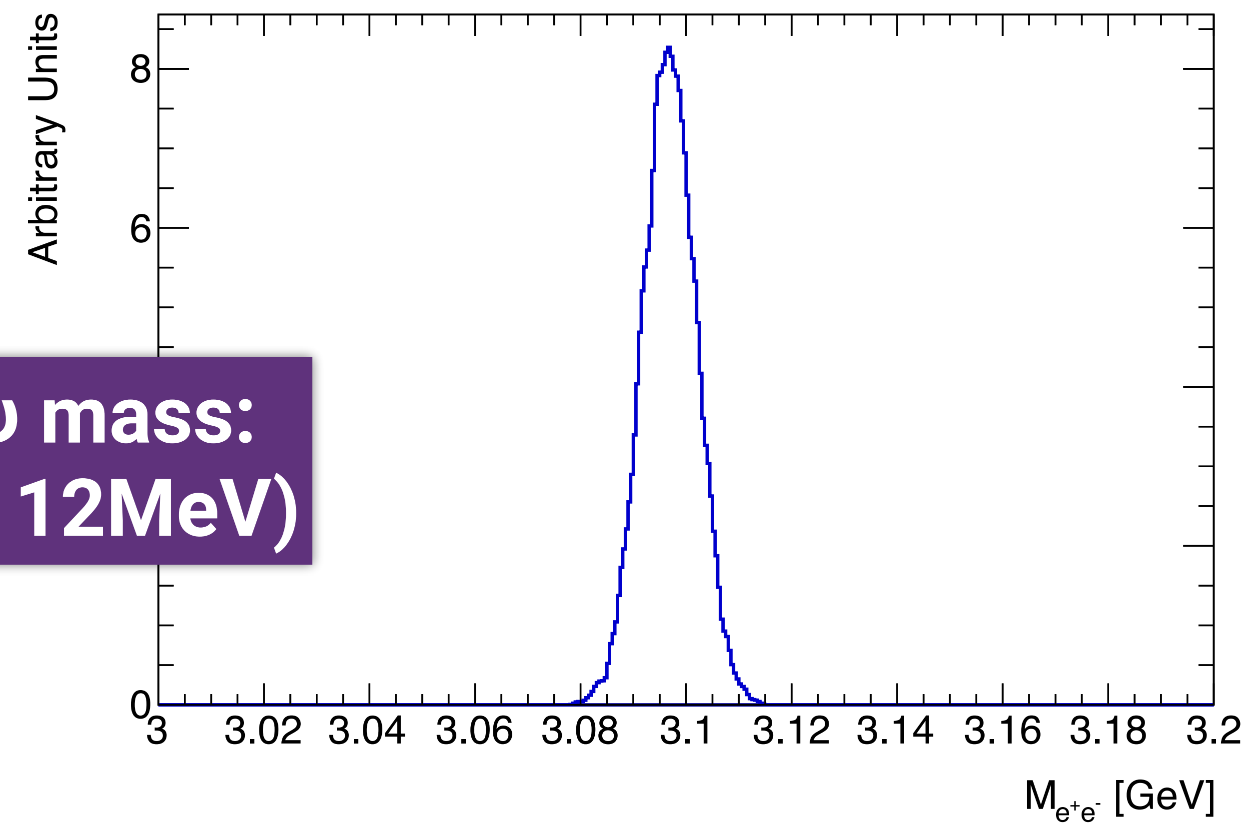




Energy Resolution



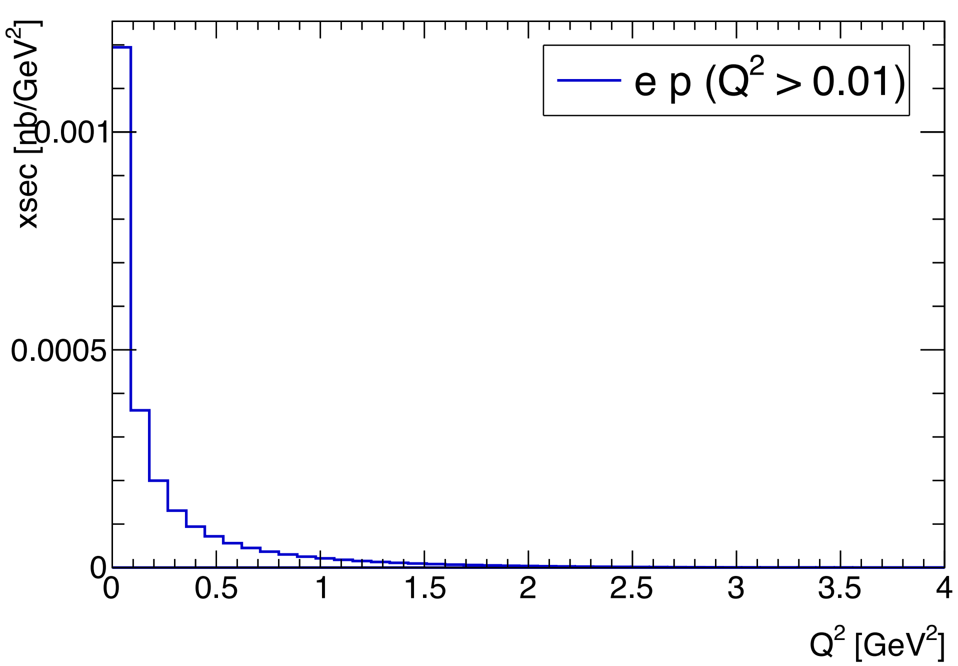


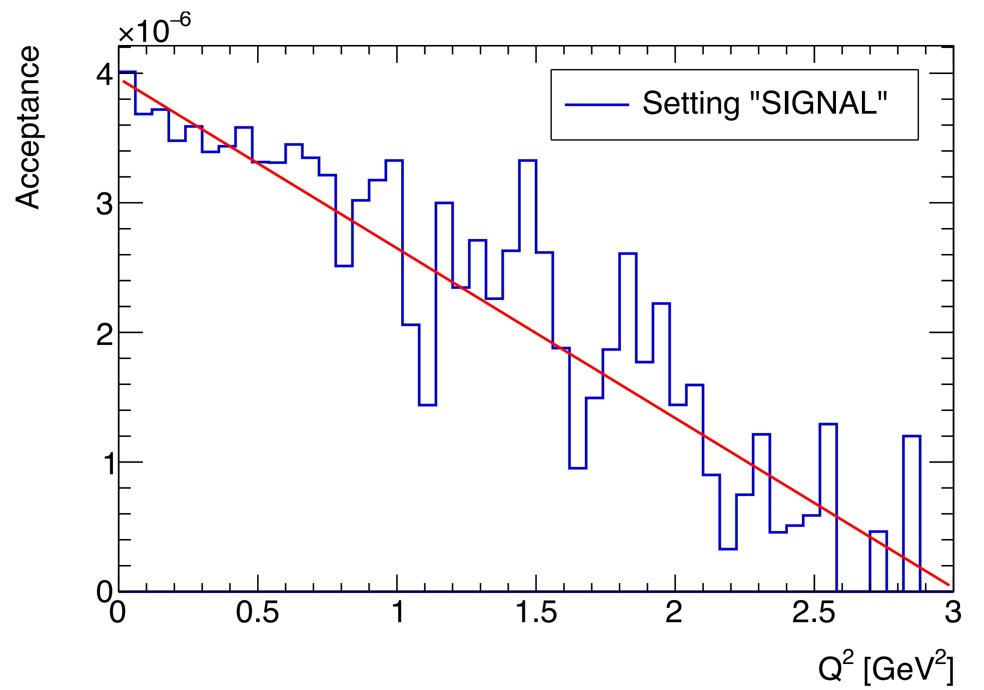


reconstructed J/ψ mass:
σ = 5 MeV (FWHM: 12MeV)

Background: **lepto-production**

- **problem: 50µA electron beam travels through target!**
- **solution: only quasi-real photons ($Q^2 \sim 0.01$ GeV^2) play a role!**
  - virtual photon flux drops with Q^2
  - higher Q^2 means lower W^2 for fixed ν and
    - t-channel cross section drops for lower W^2
    - phase space drops **rapidly** for lower W^2
  - acceptance drops with Q^2





Quasi-real photons ENHANCE the count rate

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Background: **single $e^{\pm}$ and $\pi^{\pm}$ tracks**

- **electron** rate estimated using CTEQ5, cross checked with F1F209
- **positron** rate estimated using EPC combined with a background program from E94-010
- **coincidence rate < 10^{-5} Hz** (50ns trigger window)
- **pion** rates estimated using Wiser
- Assuming a pion rejection > 10^3 from the Cherenkov + Calorimeter, **coincidence rate ~ 10^{-5} Hz**

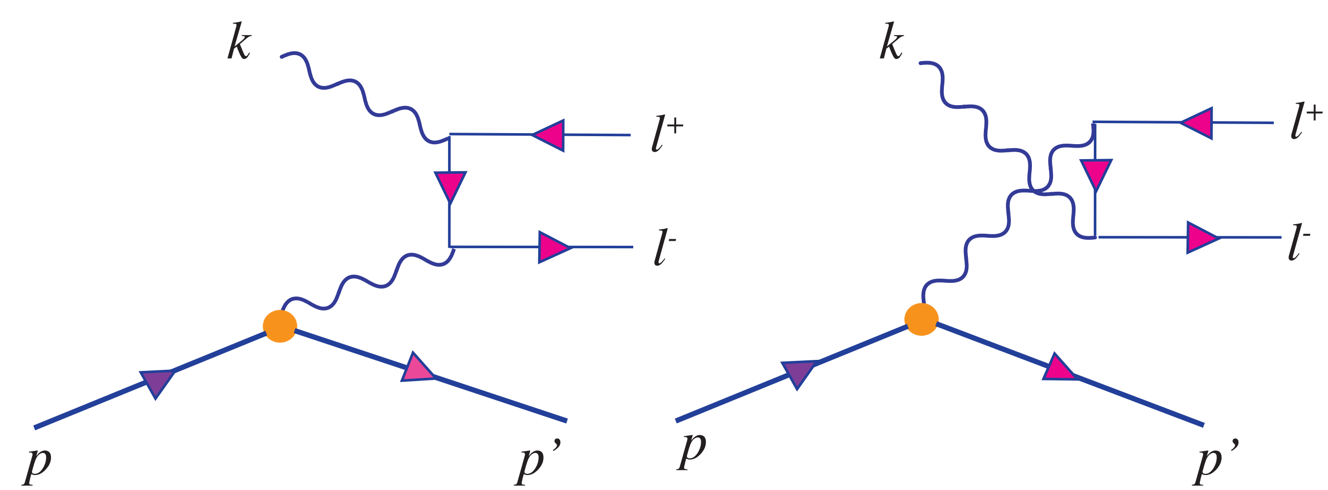
	HMS		SHMS	
Setting	e^- (kHz)	π^- (kHz)	e^+ (kHz)	π^+ (kHz)
#1	6.9×10^{-3}	7.5×10^{-2}	6.5×10^{-4}	1.95×10^{2}
#2	9.7×10^{-1}	2.2×10^{0}	7.5×10^{-4}	10.5×10^{0}

Accidental Rate < 10^{-2} x Signal Rate
NEGLIGIBLE!

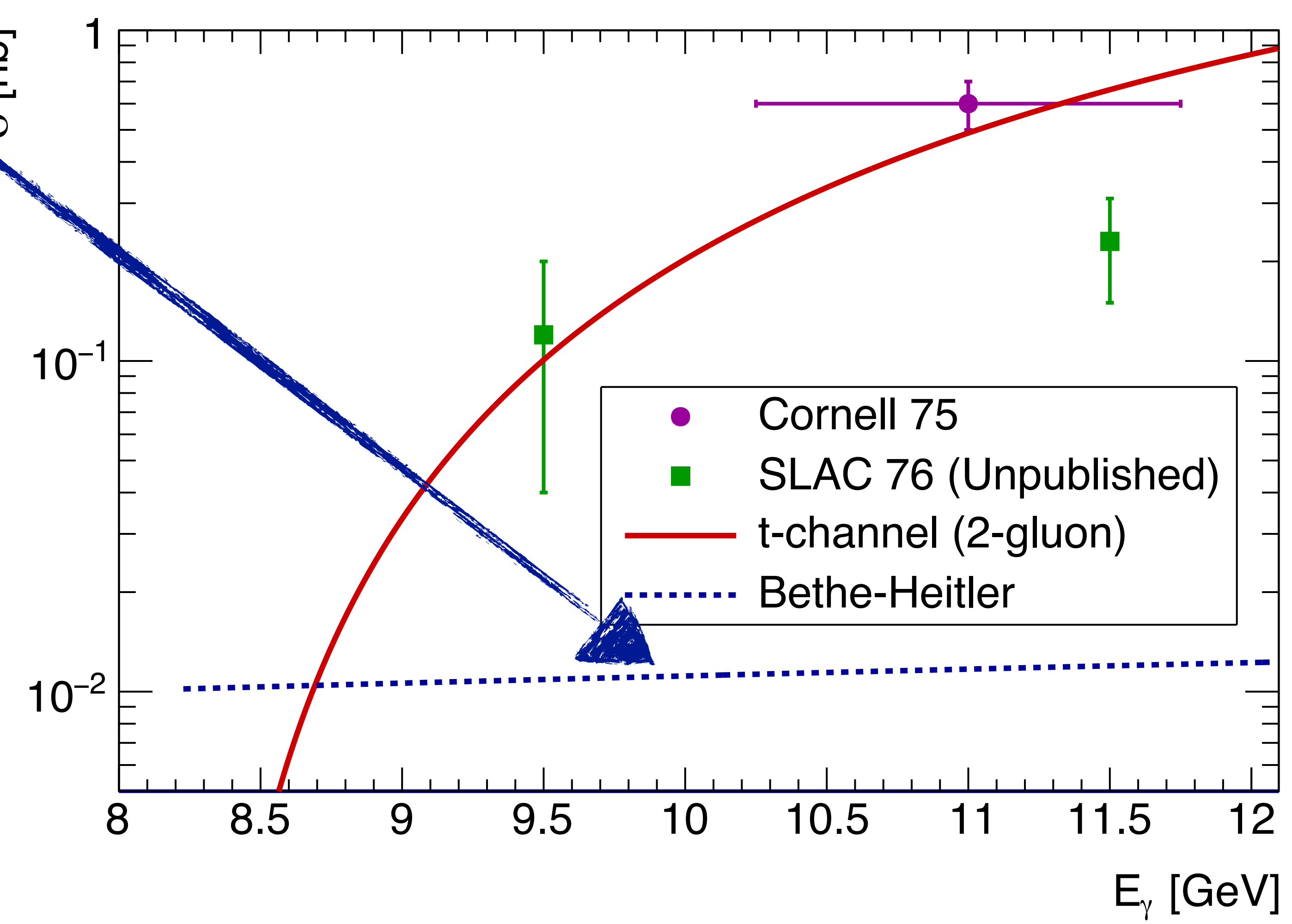
Background: **Bethe-Heitler pair production**

$$\gamma p \rightarrow e^+ e^- p$$

Not an issue!



- Estimated using calculations from Pauk and Vanderhaeghen
- Constant background < 10% of the *t*-channel J/ψ
- Can be **exactly calculated** and controlled for
- Interference negligible at the $P_c(4450)$ peak



Pauk V and Vanderhaeghen M, PRL 115(22) (2015) 221804

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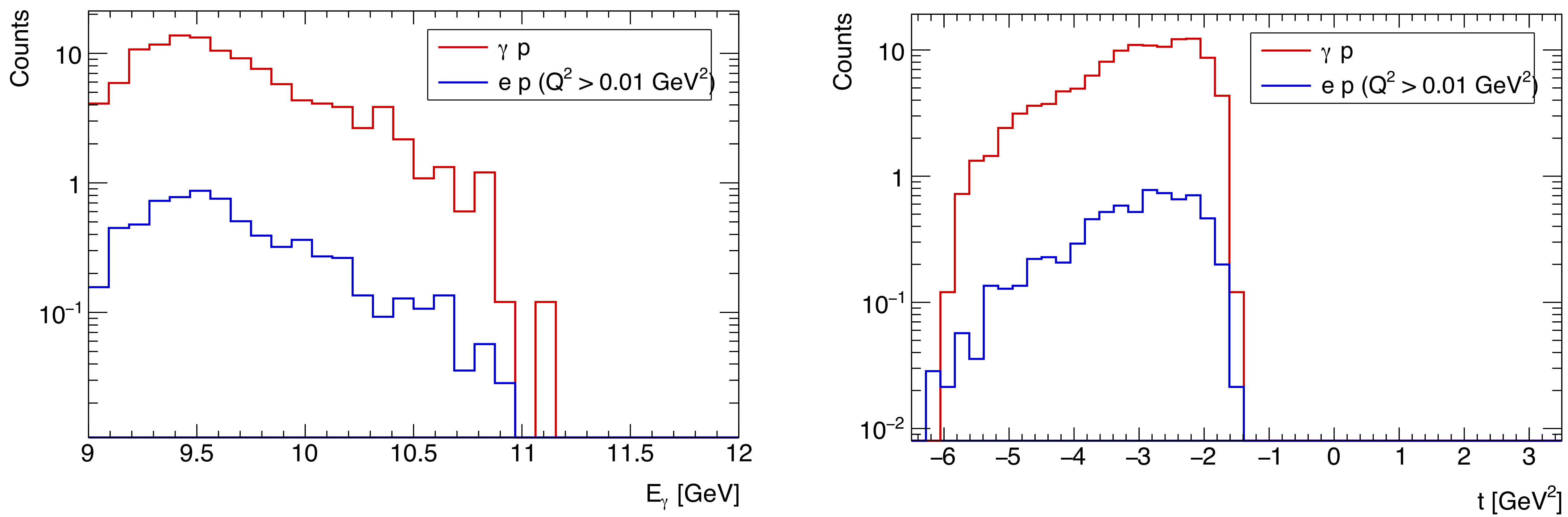
lepto-production vs photo-production

- **only quasi-real photons (Q^2 ~ 0.01 GeV) play a role!**

t-channel projected counts



Quasi-real photons ENHANCE the count rate

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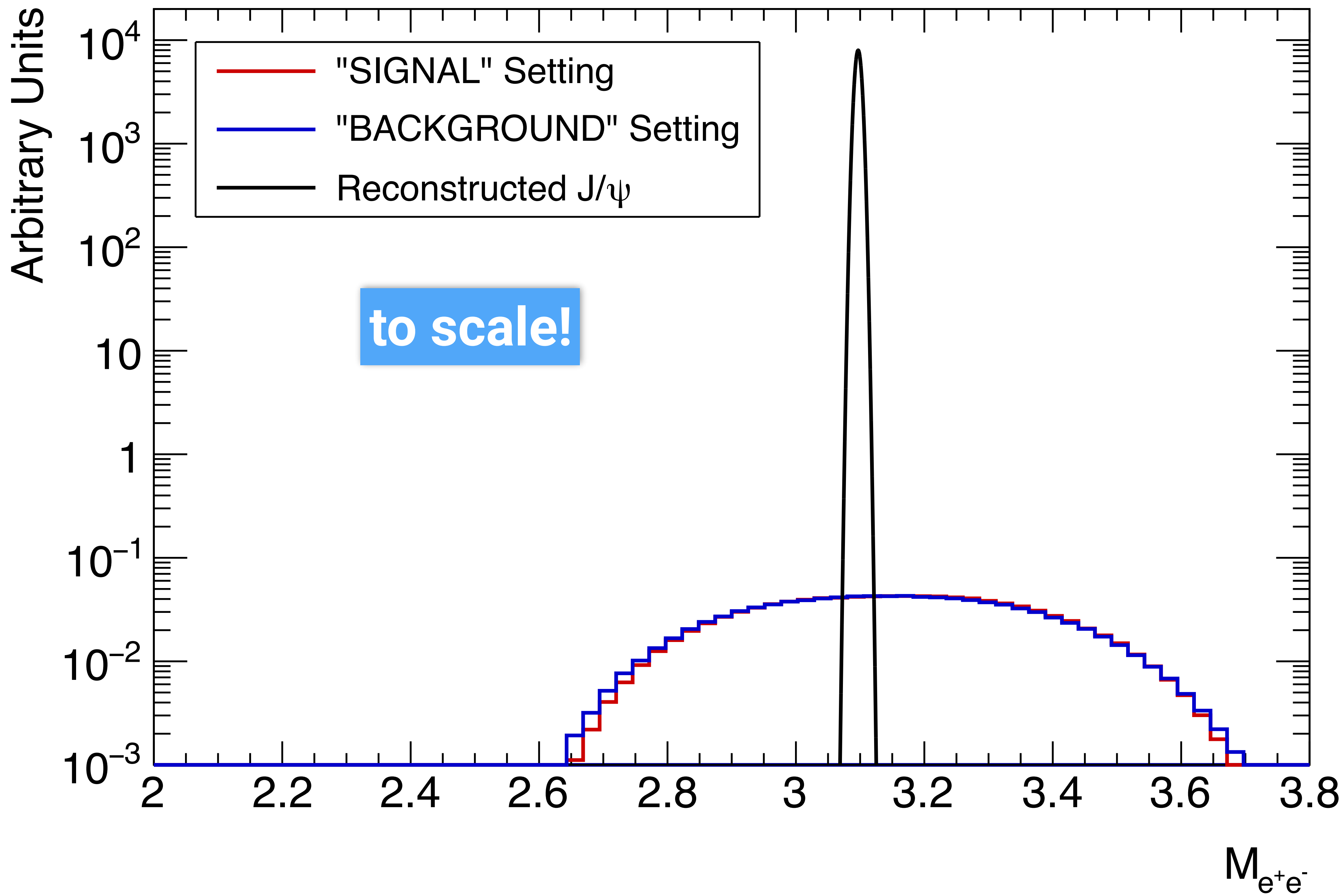
Invariant Mass Acceptance for Accidentals

- Reconstructed invariant mass **range for accidentals much wider** than J/ψ mass resolution



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Background: **inelastic *t*-channel** ($\gamma p \rightarrow J/\psi p \pi$)

- Threshold at 9 GeV
- Reconstructed photon energy $\underline{E}_{rc}$ is ~1 GeV too low
- **less than 30% of the elastic *t*-channel** background
- Contaminates the **8 GeV < $\underline{E}_{rc}$ < 9.7 GeV** range for a photon end-point energy of 10.7 GeV
  - **not an issue for the P_c(4450) ($\underline{E}_{rc}$ > 9.7GeV)!**

not an issue for the P_c!

Photon Energy Reconstruction

- Can **unambiguously** reconstruct the initial photon energy from the reconstructed J/ψ momentum and energy
- Assumptions:
  - photon beam along the *z*-axis
  - proton target at rest
  - 2 final state particles: a proton and a *J/ψ*

$$E_\gamma = \frac{M_J^2 - 2E_J M_P}{2(E_J - M_p - P_J \cos\theta)}$$

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Properties of the Hall C Spectrometers

	P GeV/c	$\Delta P/P$ %	$\sigma P/P$ %	$\theta^{\rm in}$	$\Delta\theta^{\rm in}$ mrad	$\Delta\theta^{\rm out}$ mrad	$\Delta\Omega$ msr	$\sigma\theta^{\rm in}$ mrad	$\sigma\theta^{\rm out}$ mrad
HMS	0.4-7.4	-10 +10	0.1	10.5°-90°	$\pm$24	$\pm$70	8	0.8	1.0
SHMS	2.5-11.	-15 +25	0.1	5.5°-25°	$\pm$20	$\pm$50	4	1.0	1.0

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Run Plan

- **Total Beam Time Request:**
  - 11 days (264h), 10.7 GeV (or 11 GeV), 50μA, Hall C
- **Run Plan:**
  1. ***t*-channel "BACKGROUND": 40 hours**
  2. **radiator out: 8 hours (longer if needed)**
  3. **main "SIGNAL" measurement: 216 hours**

11 days,
standard equipment!