A Search for the LHCb Charmed "Pentaquark" using Photoproduction of J/ψ at Threshold in Hall C at Jefferson Lab

Sylvester Joosten
sylvester.joosten@temple.edu

on behalf of the spokespeople

Eugene Chudakov
Mark Jones
Sylvester Joosten
Zein-Eddine Meziani
Michael Paolone

PAC 44, July 26, 2016

TEMPLE UNIVERSITY®

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 (221) | 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

Cited by: 221 records

(62) The hidden-charm pentaquark and tetraquark states - Chen, Hua-Xing *et al.* Phys.Rept. 639 (2016) 1-121 arXiv:1601.02092 [hep-ph]
(62) How to reveal the exotic nature of the P_c(4450 … 950 [hep-ph]
(61) LHCb pentaquark as a $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecu… 249 [hep-ph]
(59) The New Pentaquarks in the Diquark Model - …
(59) Identifying exotic hidden-charm pentaquarks - Chen, Rui *et al.* Phys.Rev.Lett. 115 (2015) no.13, 132002 arXiv:1507.03704 [hep-ph]
more

221 citations in a year!

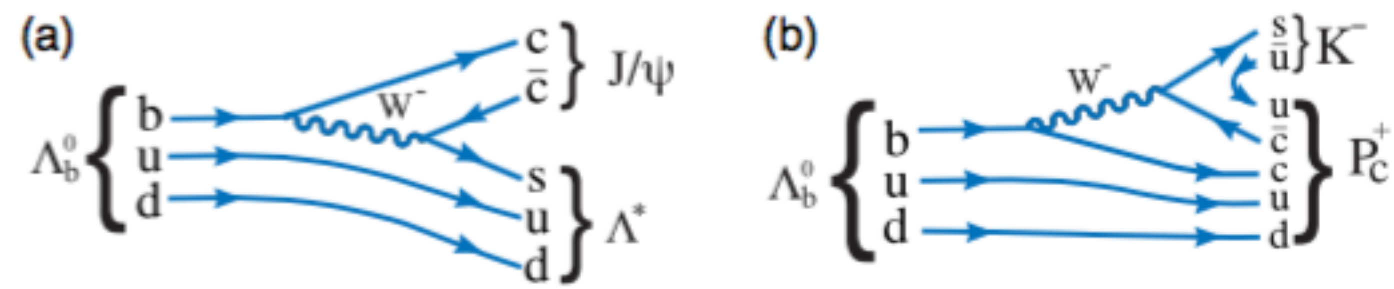
Discovery inspired large number of theoretical work, touching our community and beyond

TEMPLE UNIVERSITY

Discovery of the LHCb charmed “pentaquark” P_c

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

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

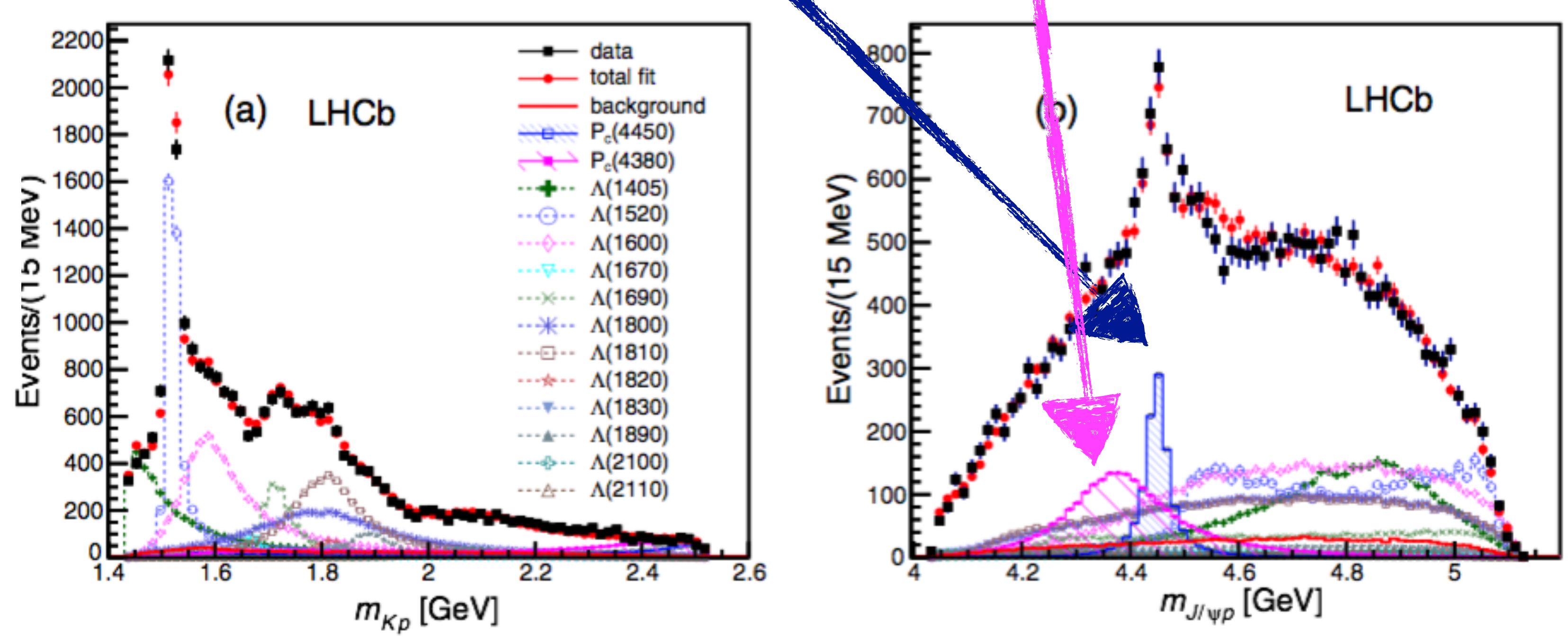


$$\Lambda_b \rightarrow \Lambda^* J/\Psi \rightarrow (K^- p) J/\Psi$$
$$\Lambda_b \rightarrow K^- P_c \rightarrow K^- (p J/\Psi)$$

- **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)

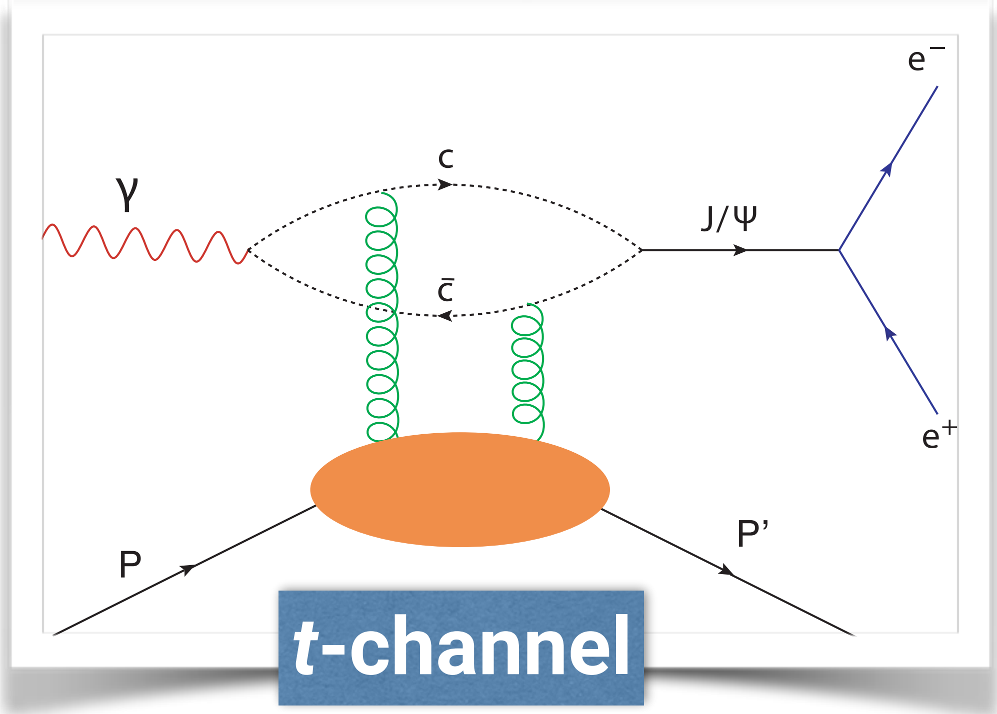
- **Photo-production** ideal tool to **distinguish** between both explanations
  - if P_c real states, **also created in photo-production**
  - kinematic enhancement through **ATS not possible in photo-production**

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**

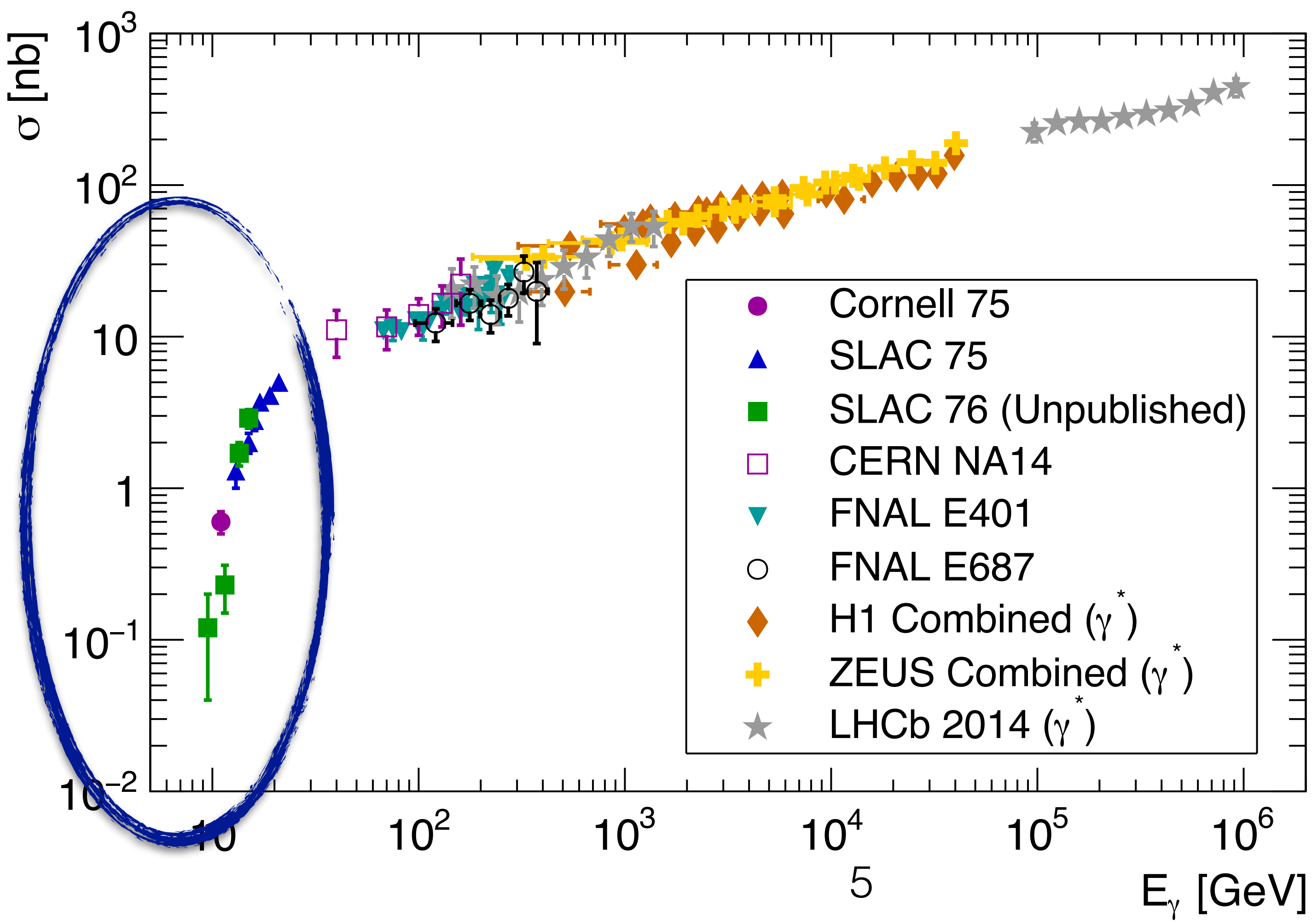
JLab is the ideal laboratory for the measurement, due to luminosity, resolution and energy reach at threshold!

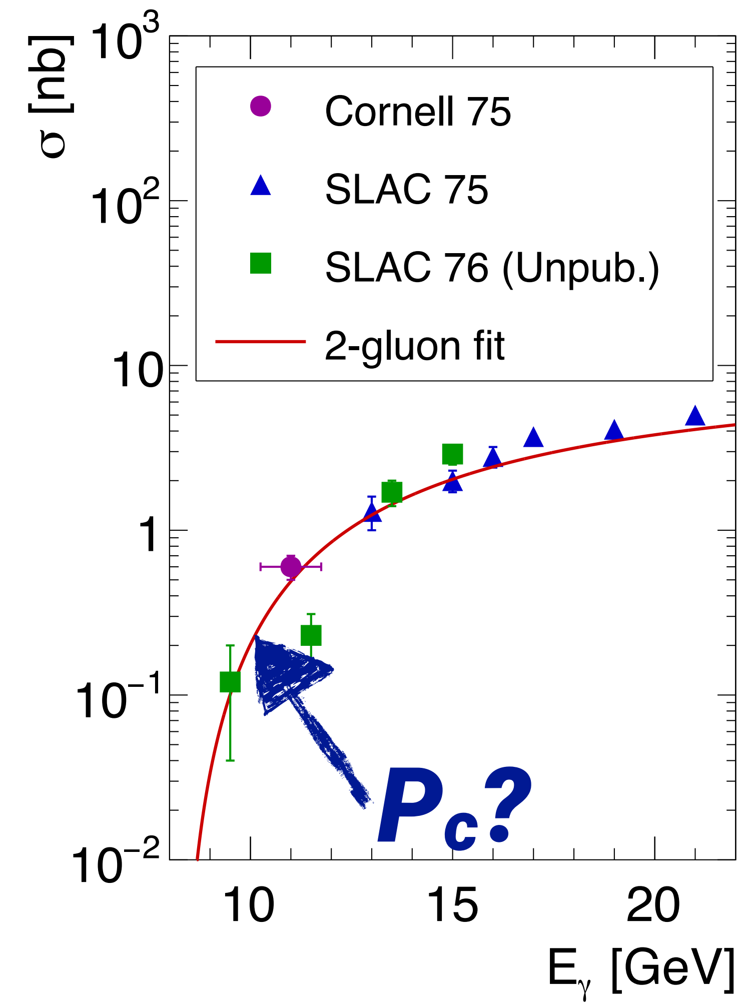
J/ψ photo-production: **what do we know?**



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

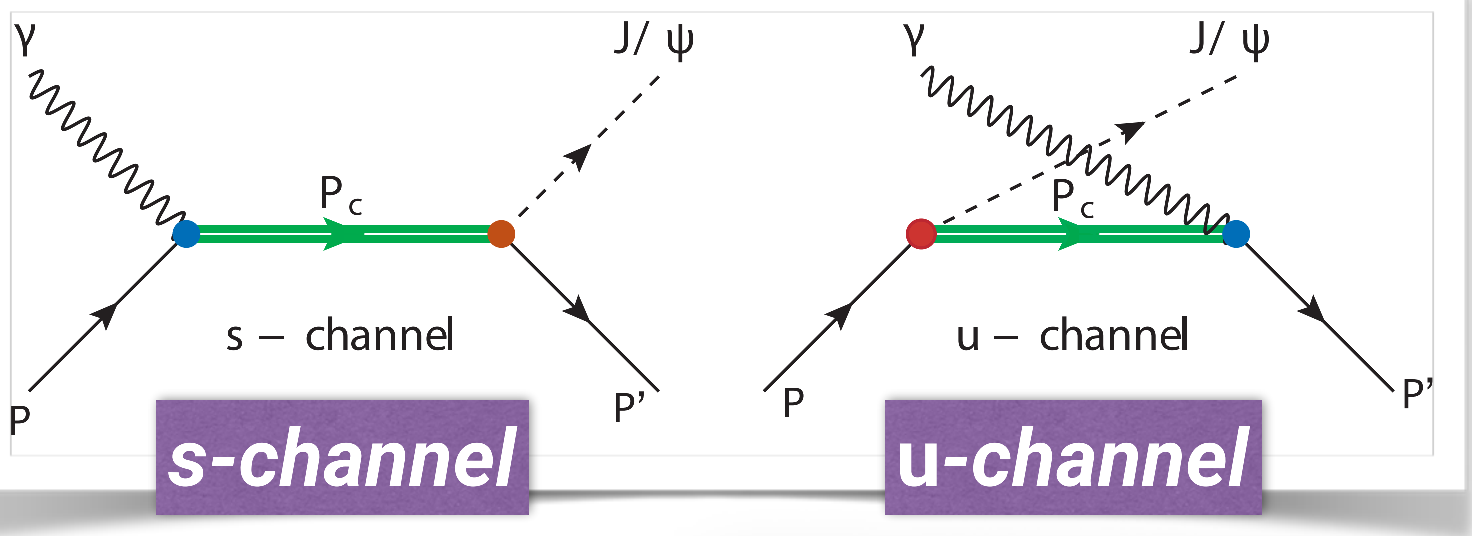
- Cross section well constrained above 100 GeV
- **Almost no data near-threshold**
- Resolution of the existing measurements too low
- 2 of the 3 lowest points unpublished!





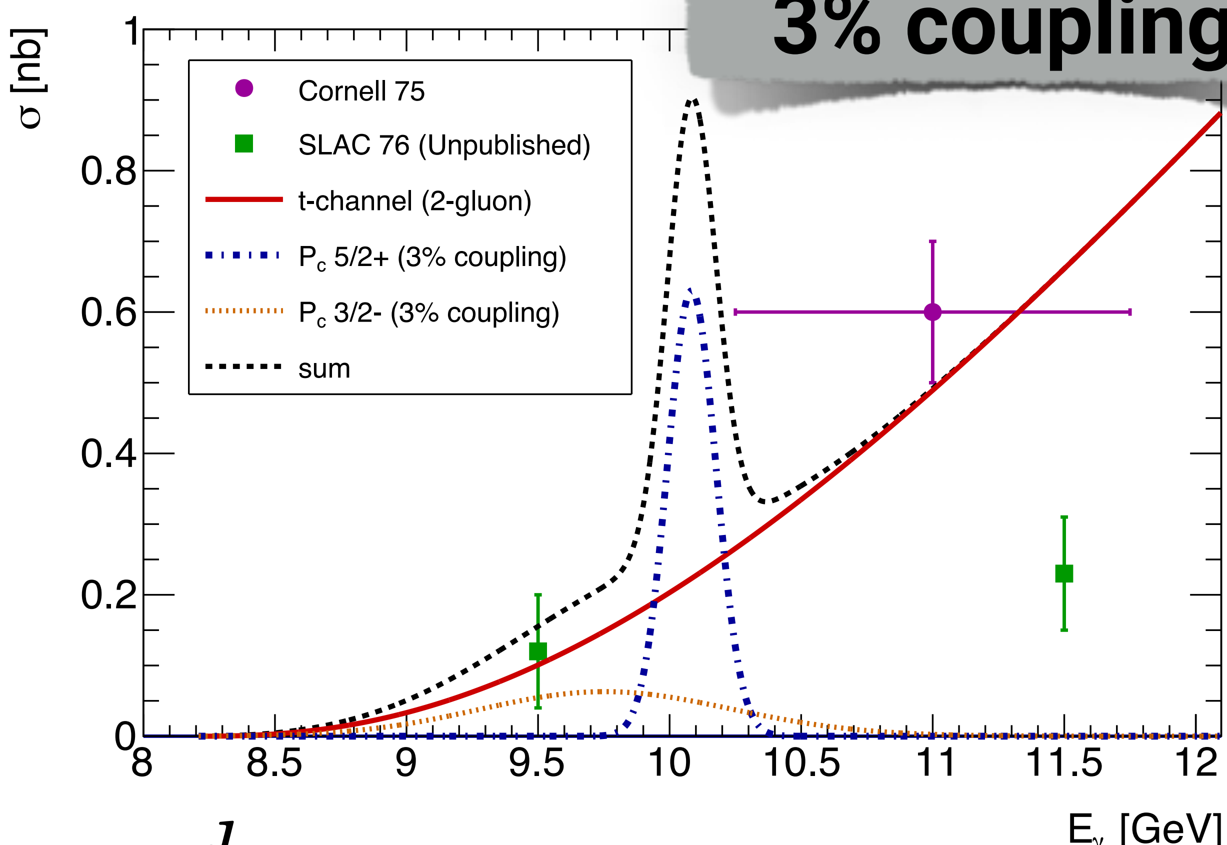
TEMPLE UNIVERSITY

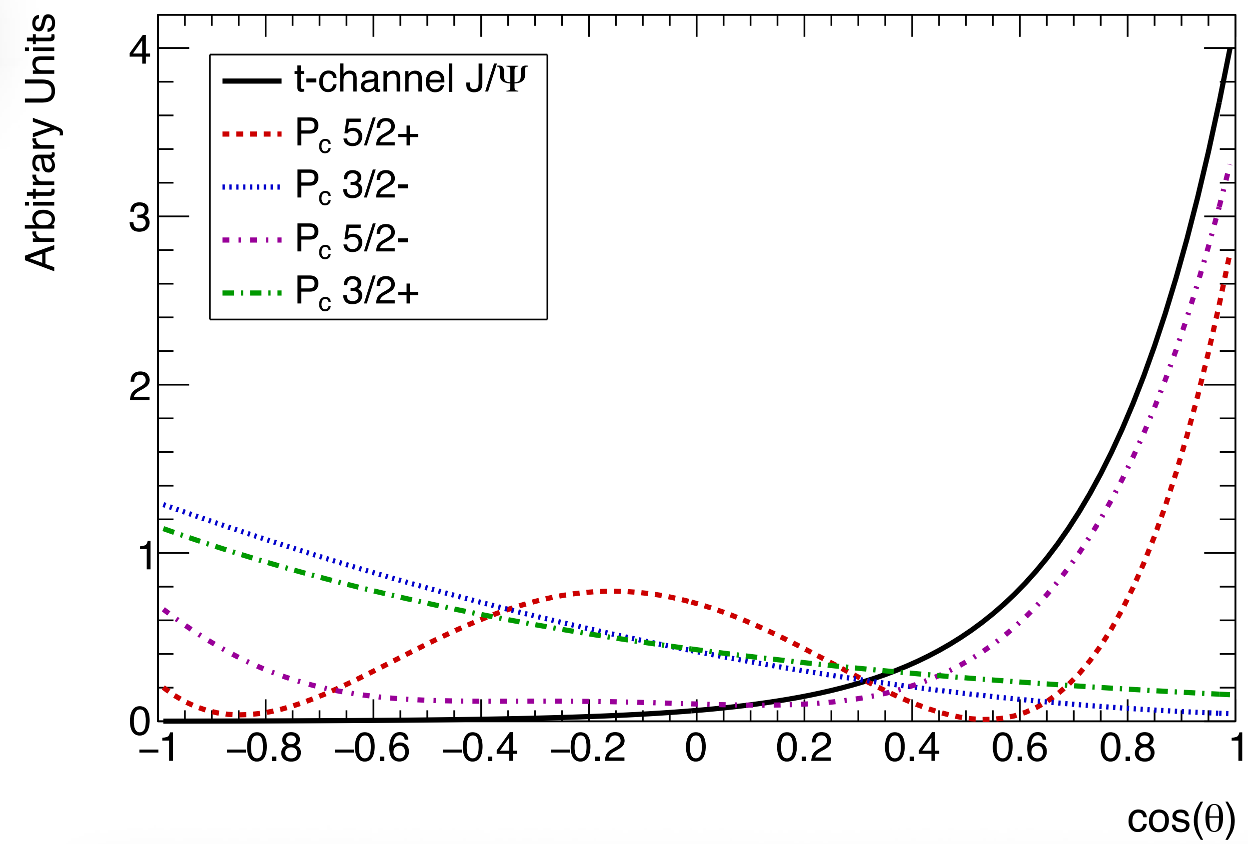
Resonant J/ψ production through P_c decay



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

3% coupling





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

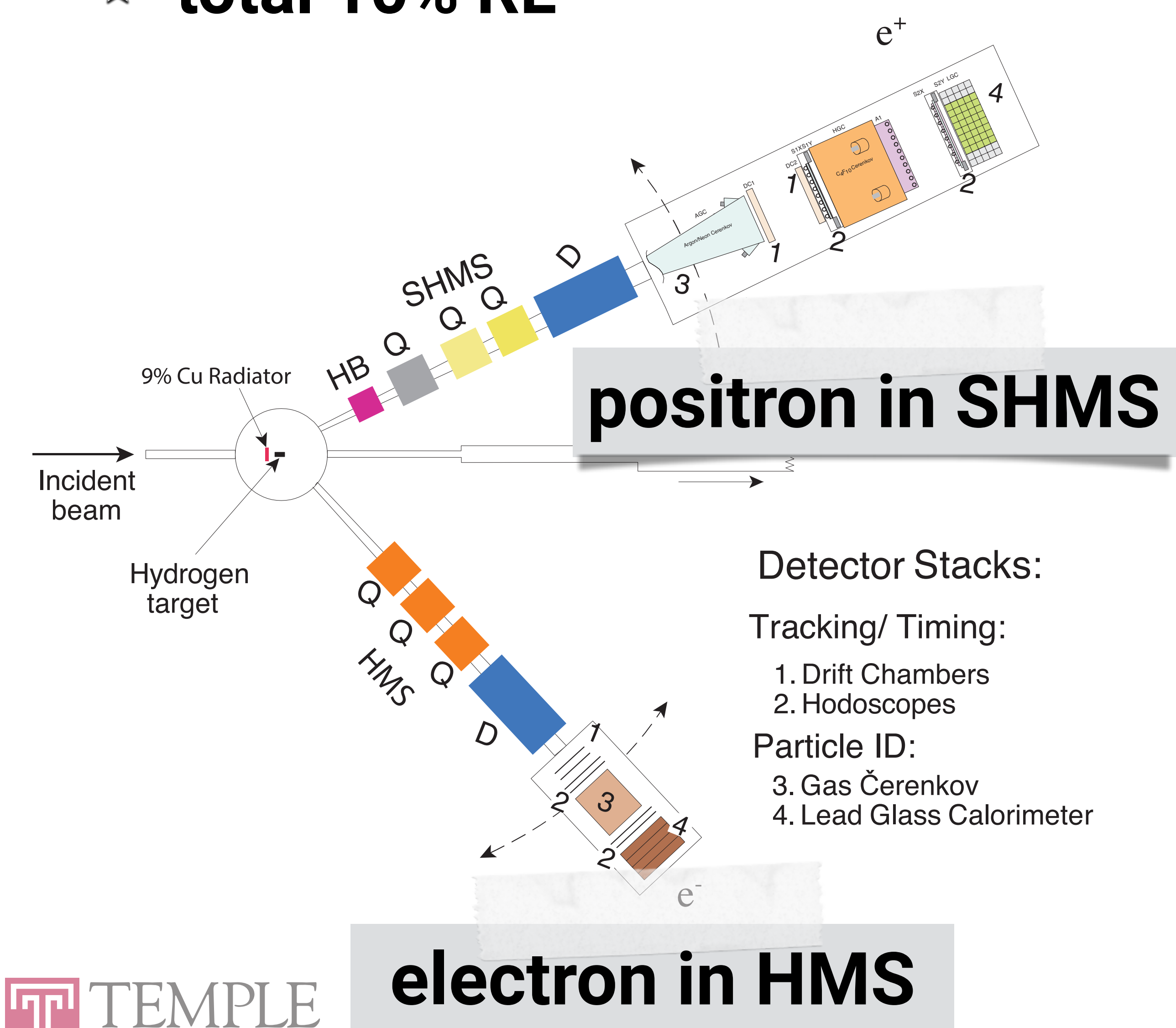
Leverage cos(*θ*) dependence to maximize S/B at low coupling!

TEMPLE UNIVERSITY

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

Proposed Experiment in **Hall C**

- Setup similar to E-05-101(WACS)
  - 50μA electron beam at 10.7 GeV (or 11 GeV)
  - 9% copper radiator
  - 15cm liquid hydrogen target
  - **total 10% RL**



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

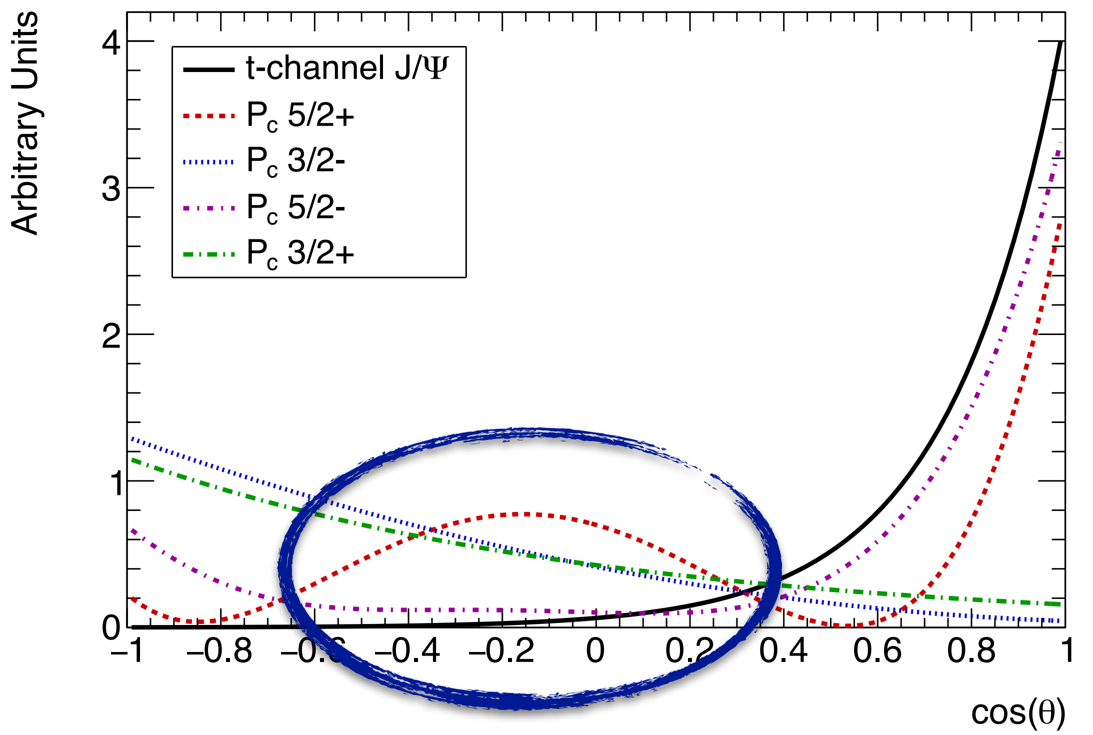
Standard Detector Package, Radiator Well Understood

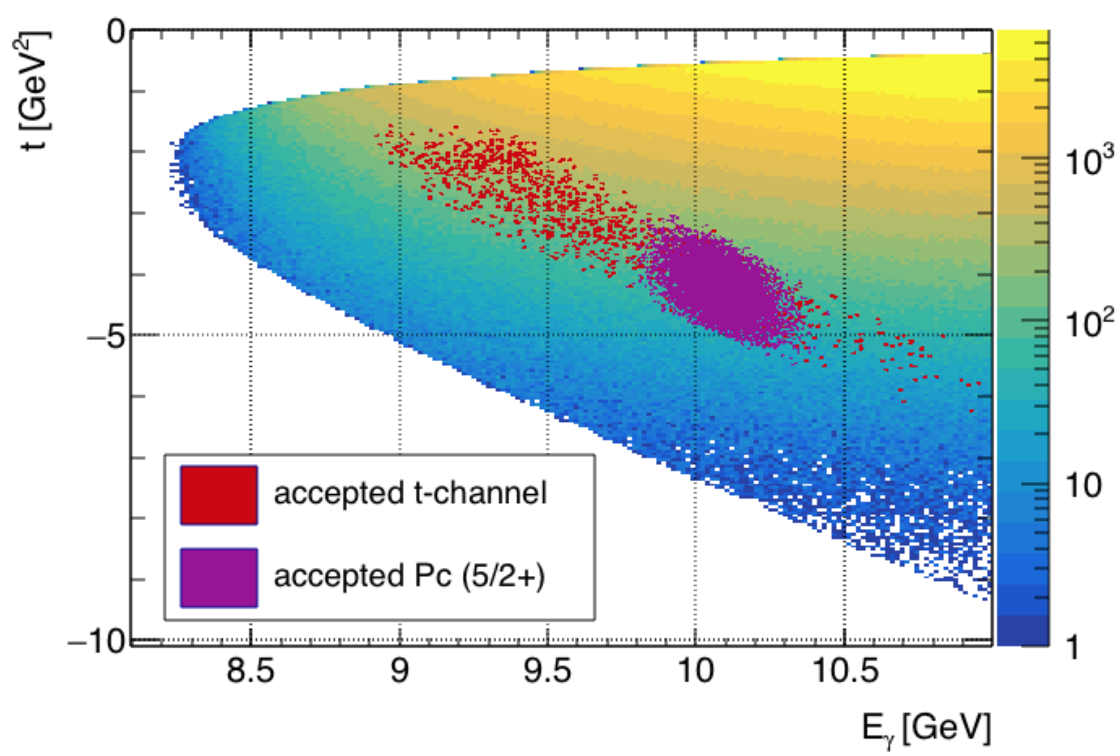
Bottom line: can run SOON and FAST

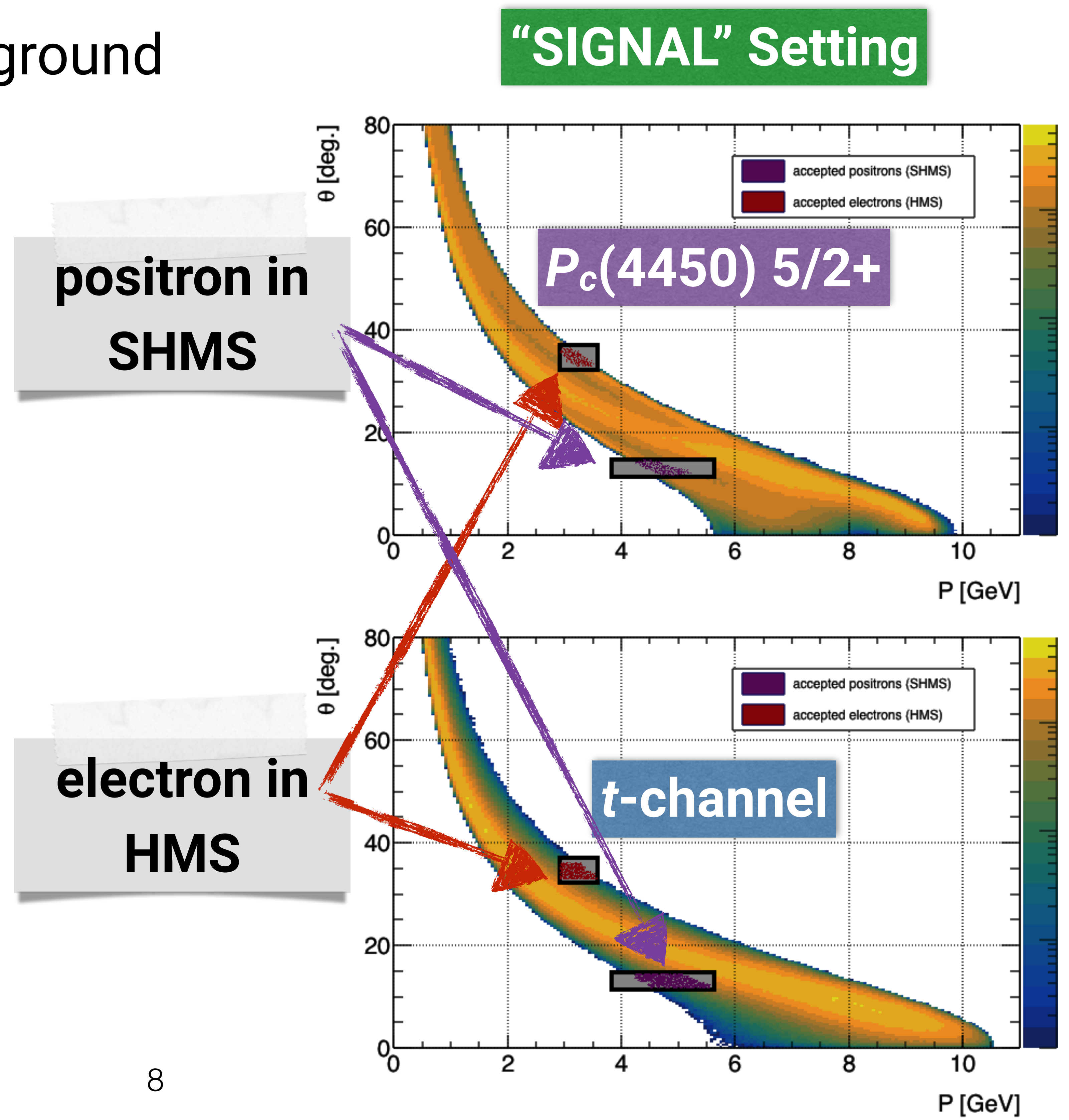
TEMPLE UNIVERSITY

Maximizing the sensitivity

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



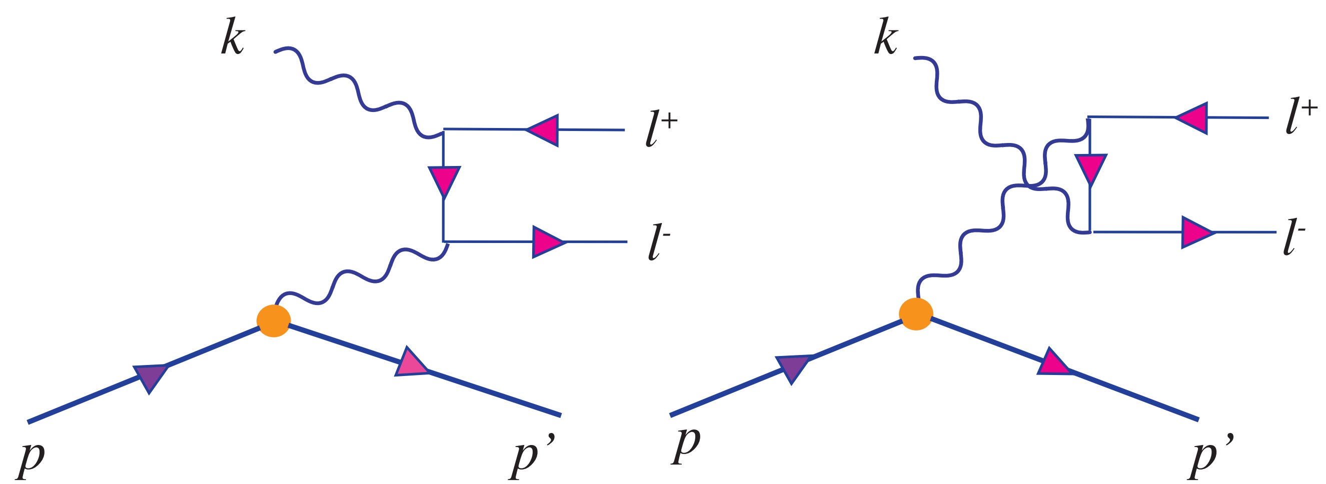




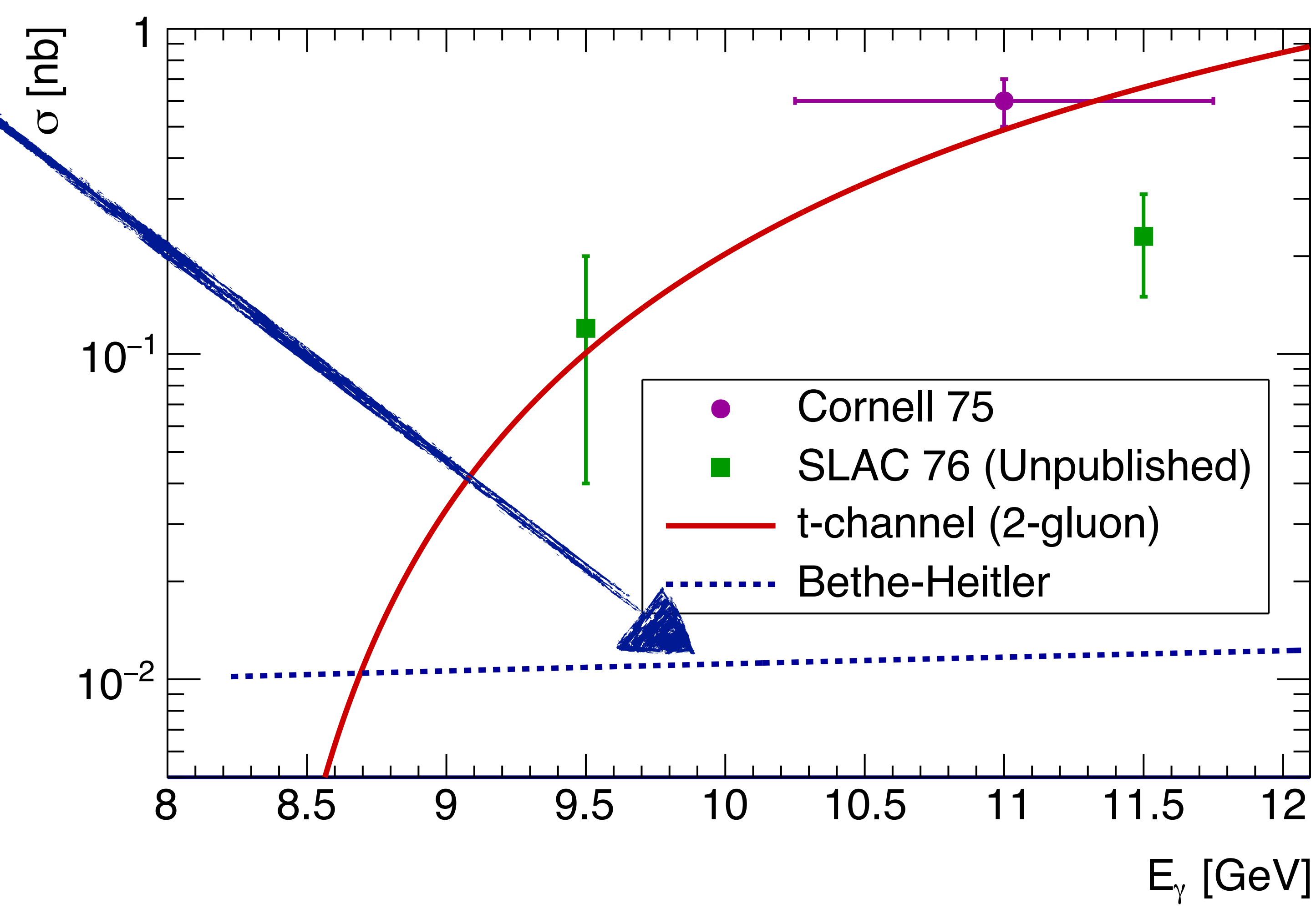
Background: **Bethe-Heitler pair production**

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

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

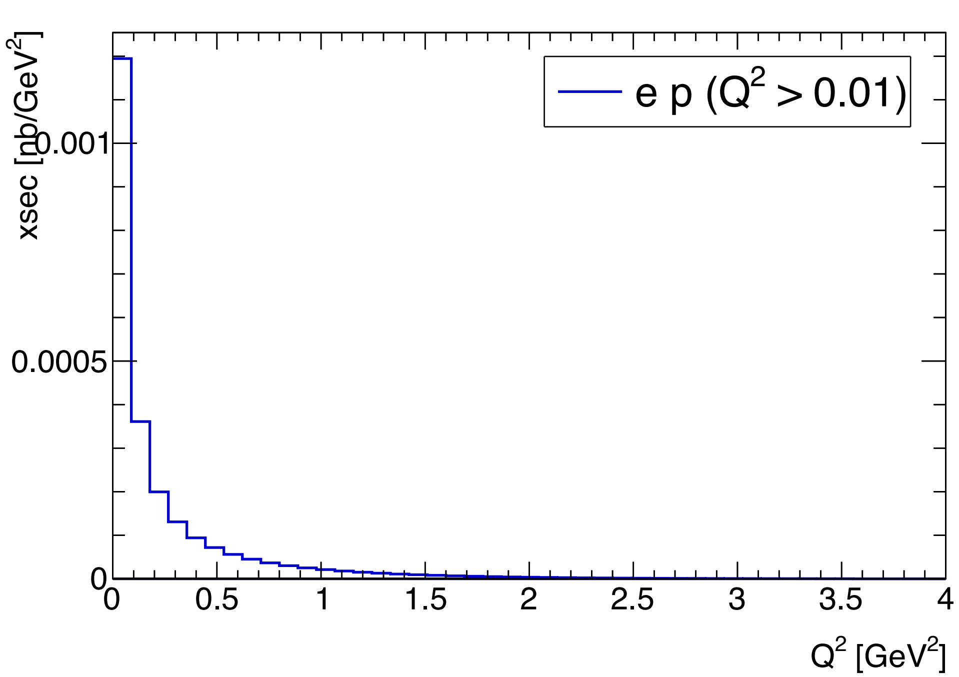


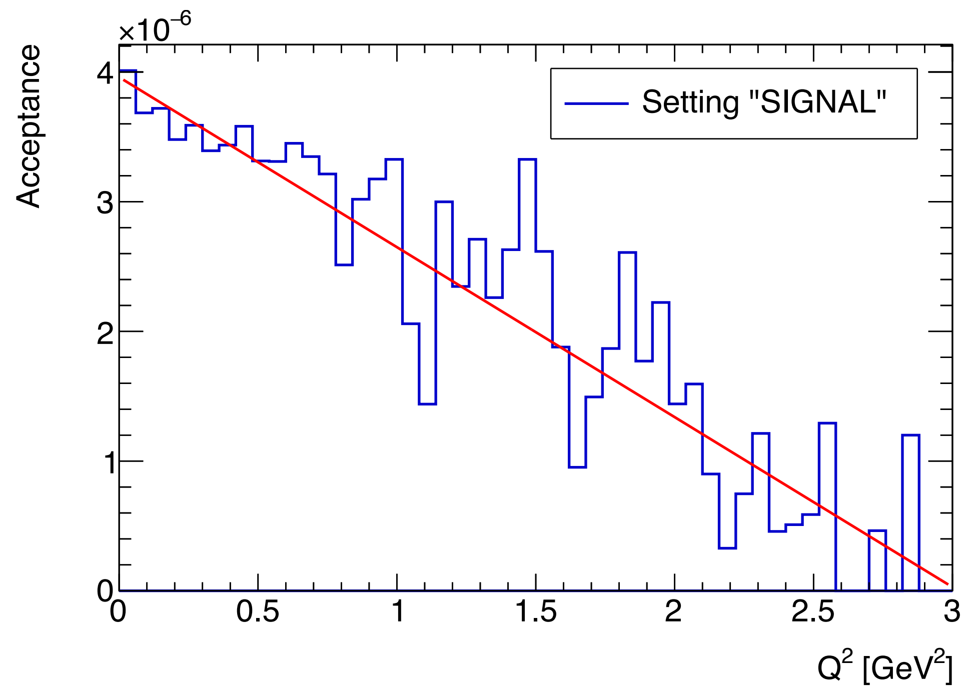
Pauk V and Vanderhaeghen M, PRL 115(22) (2015) 221804

TEMPLE UNIVERSITY

Background: **lepto-production**

- **problem: 50μA electron beam travels through target!**
- **solution: only quasi-real photons (Q^2 ~ 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

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}

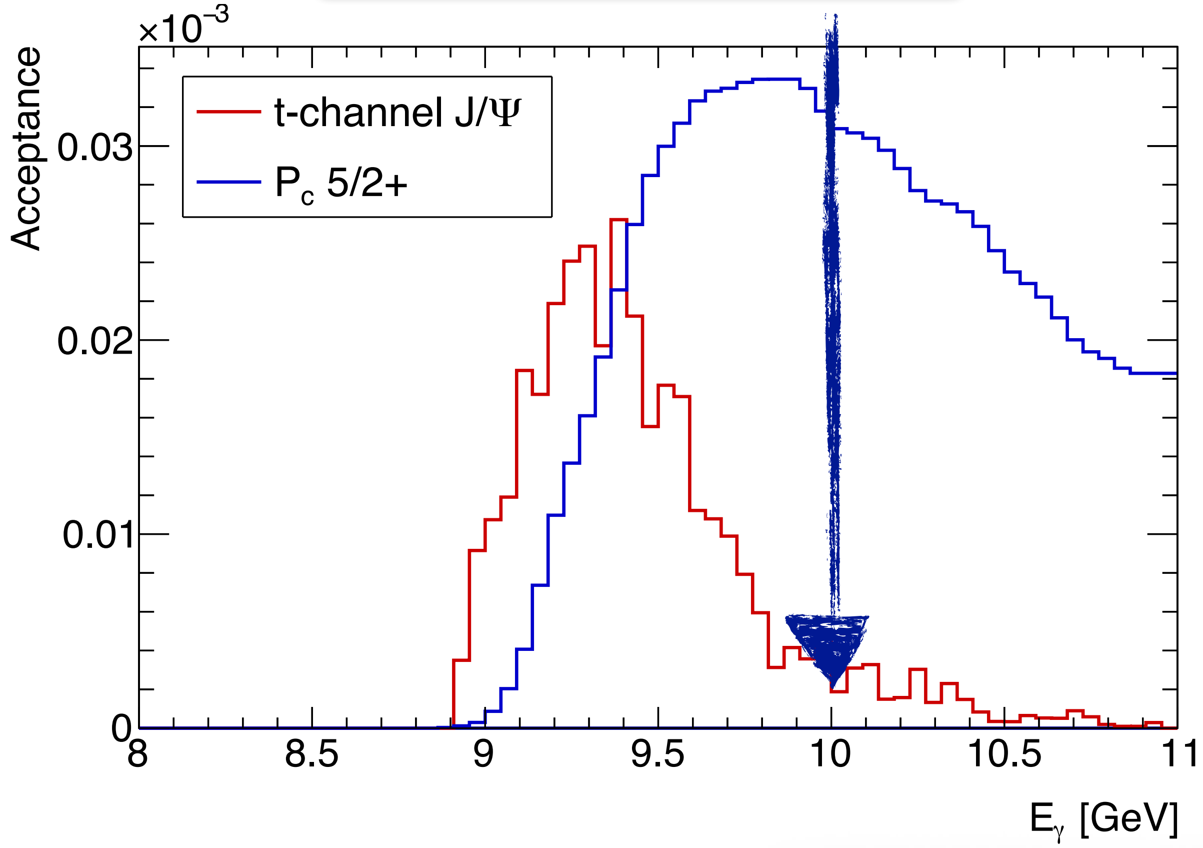
Accidental Rate < 10^{-2} x Signal Rate

NEGLIGIBLE!

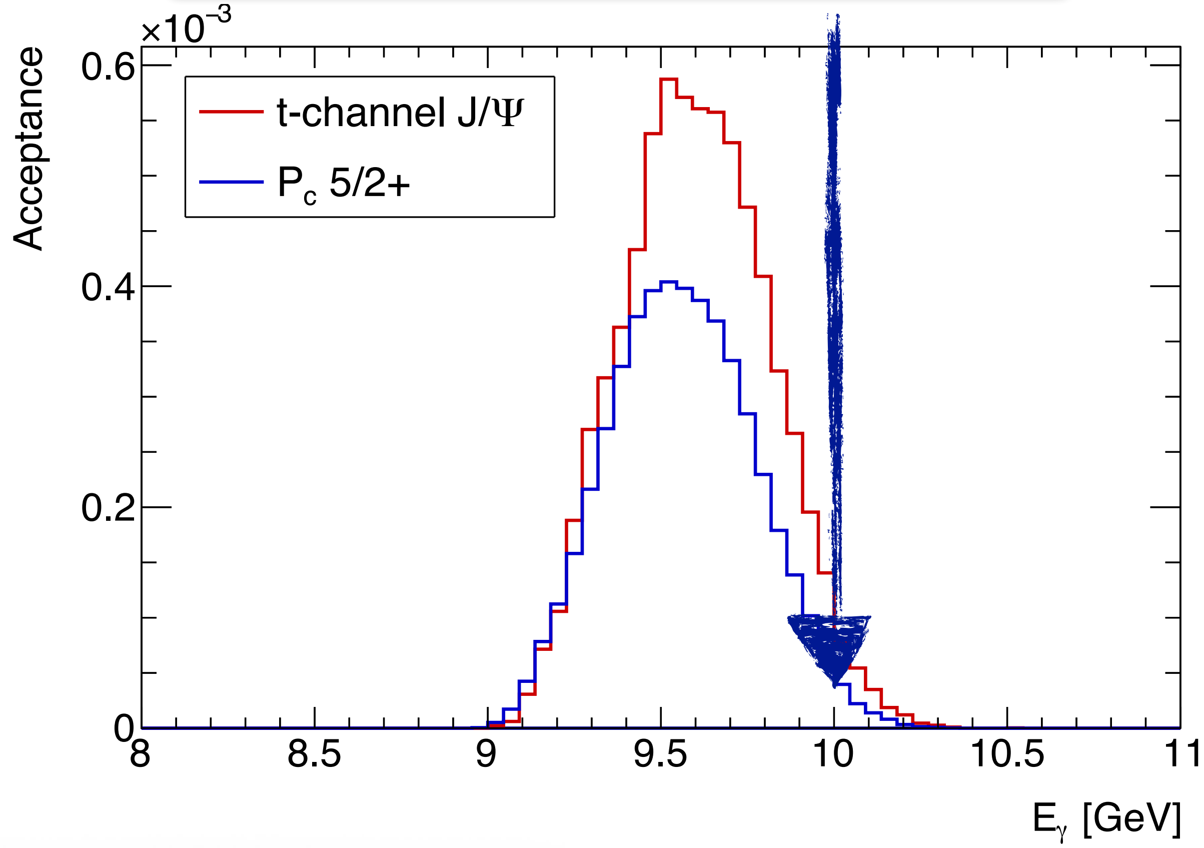
Acceptance

- **"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

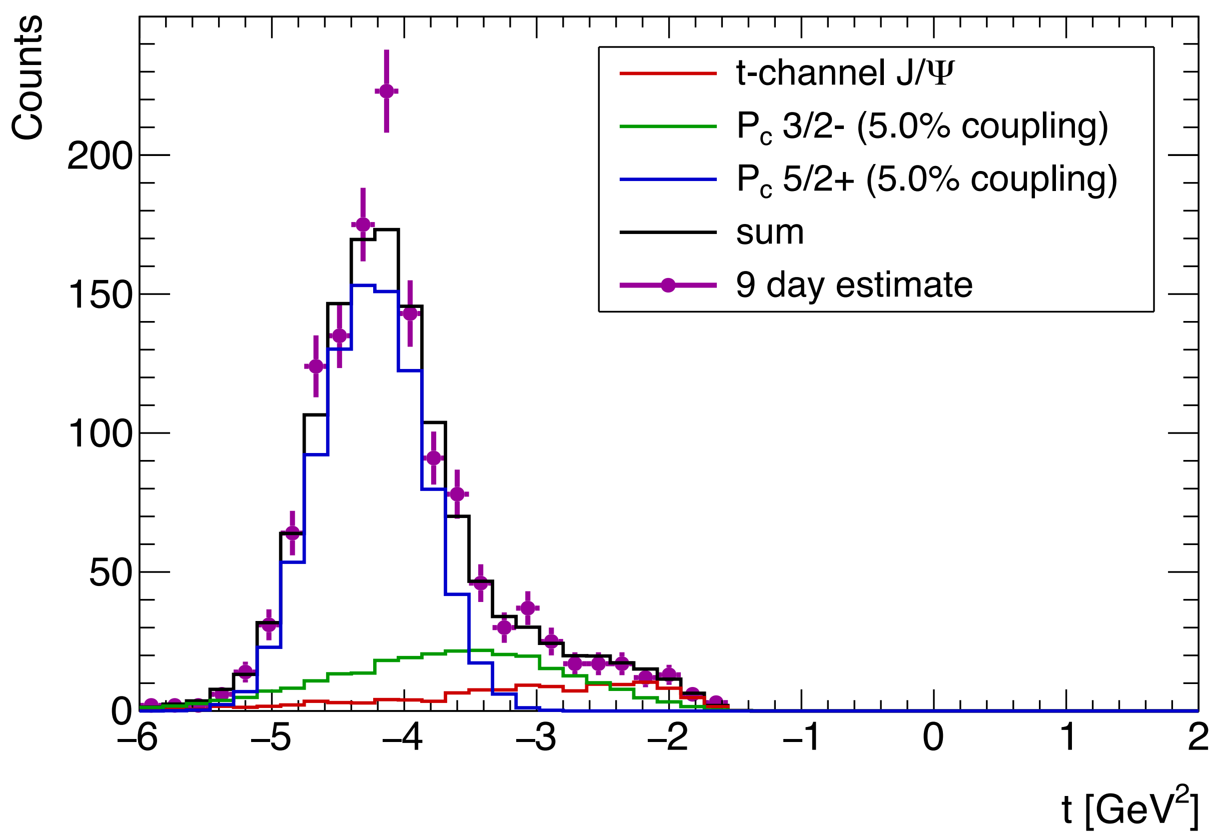


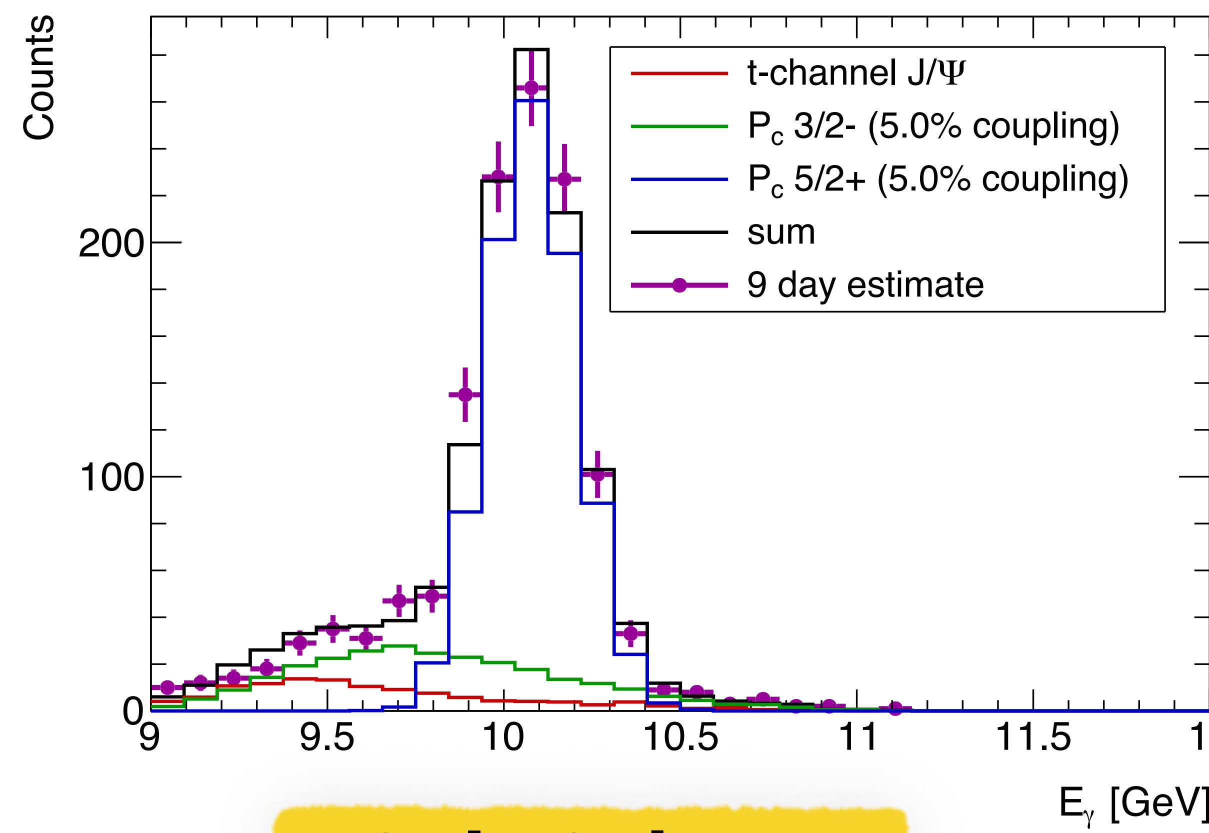
Good Acceptance over the full width of the resonance

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





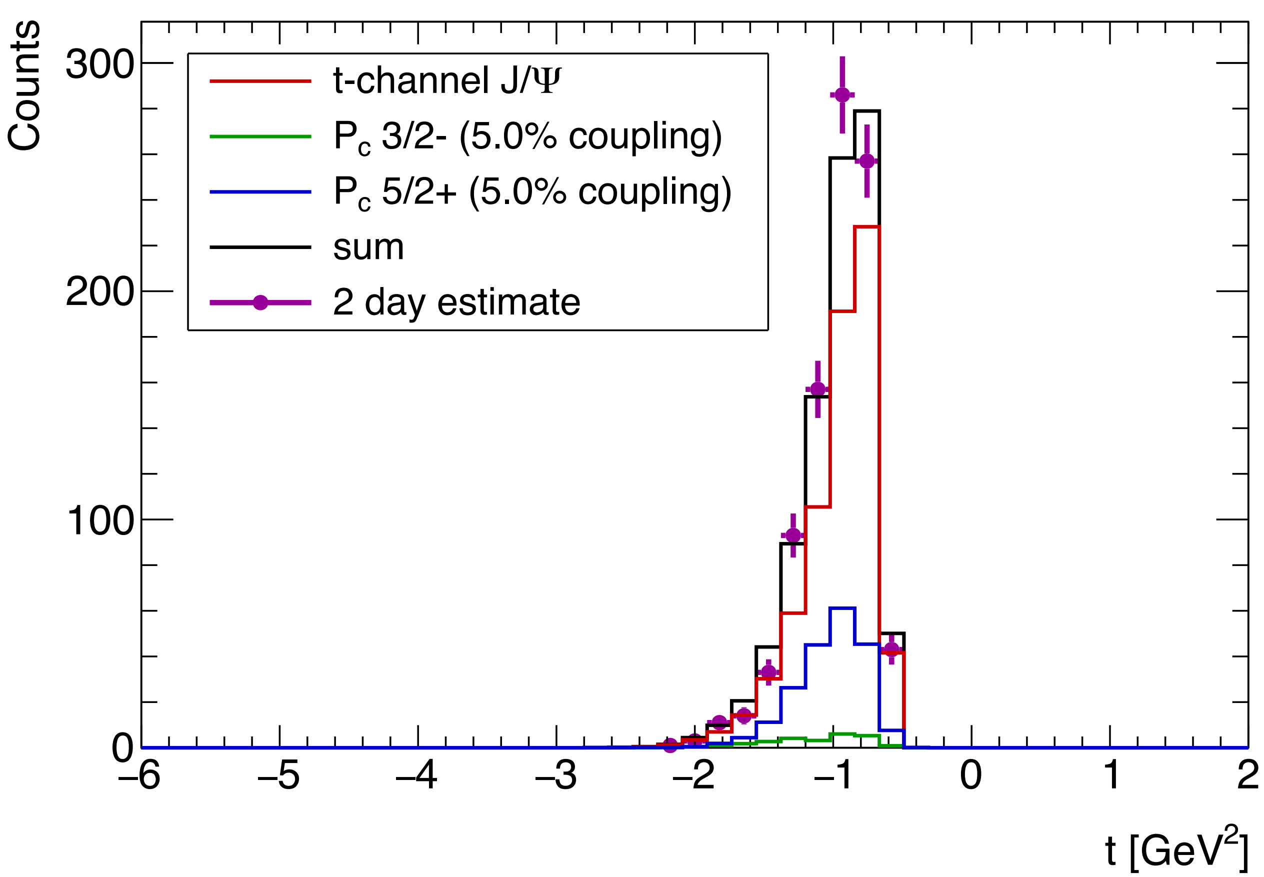
Only 9 days!

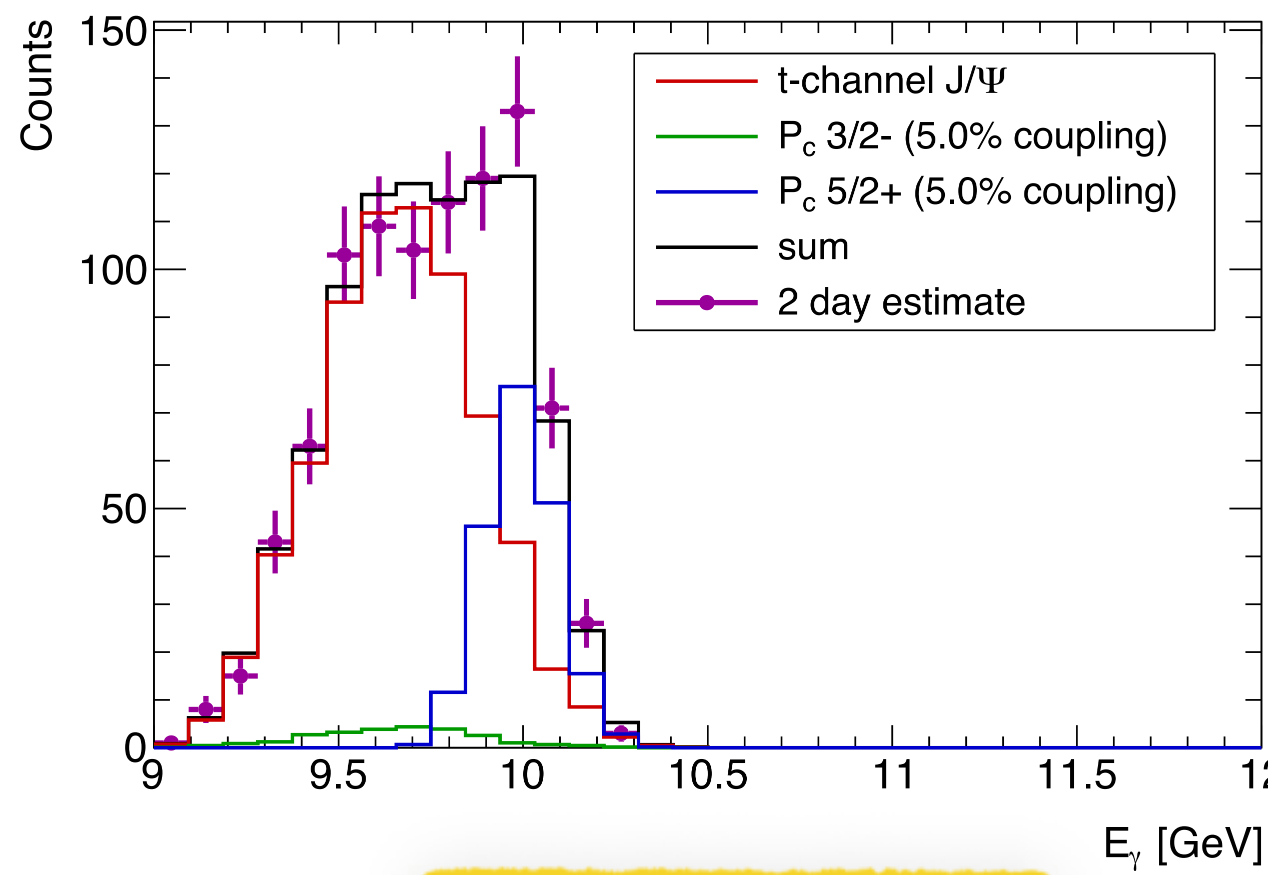
Significance > 20σ!

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



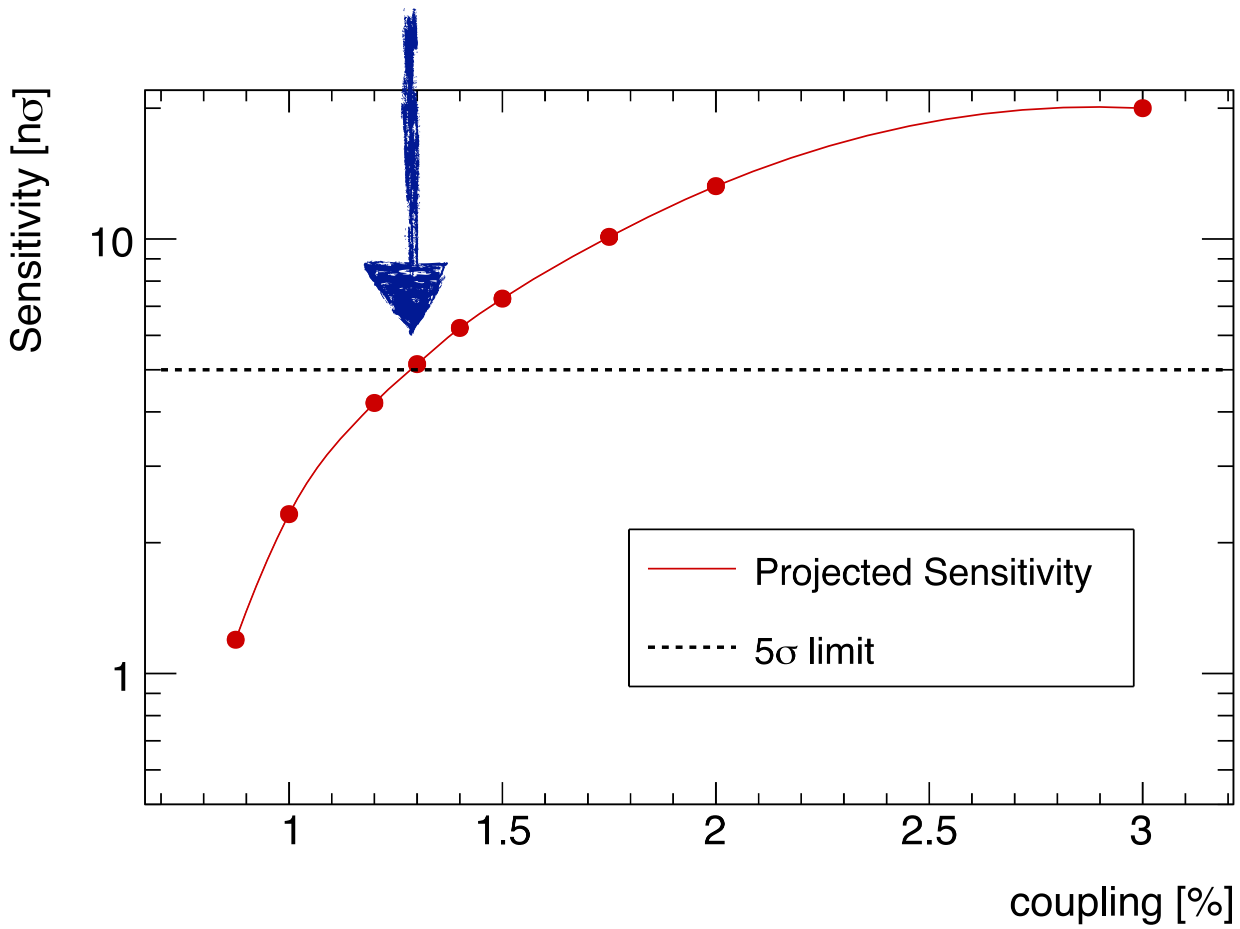


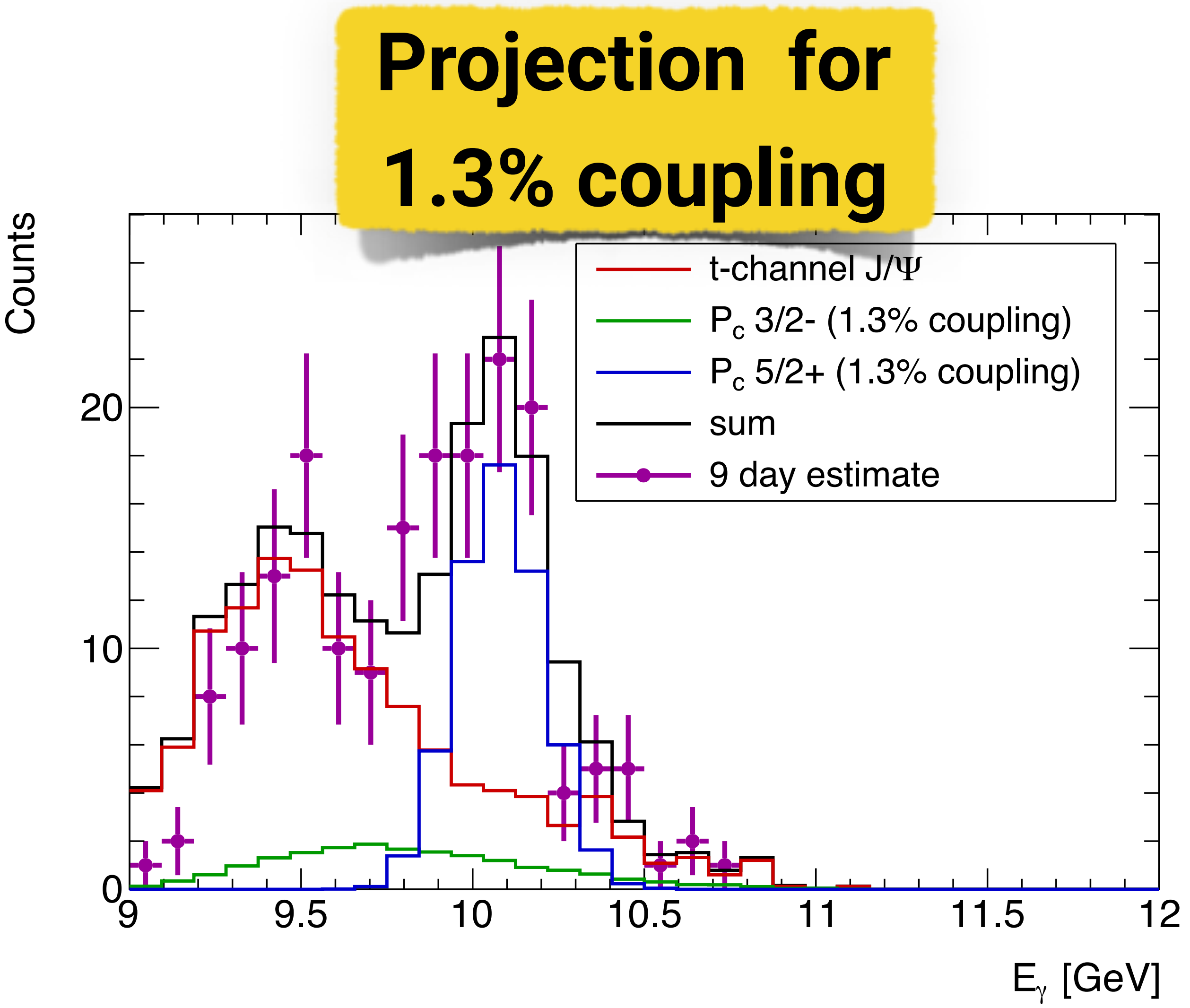
Only 2 days!

TEMPLE UNIVERSITY

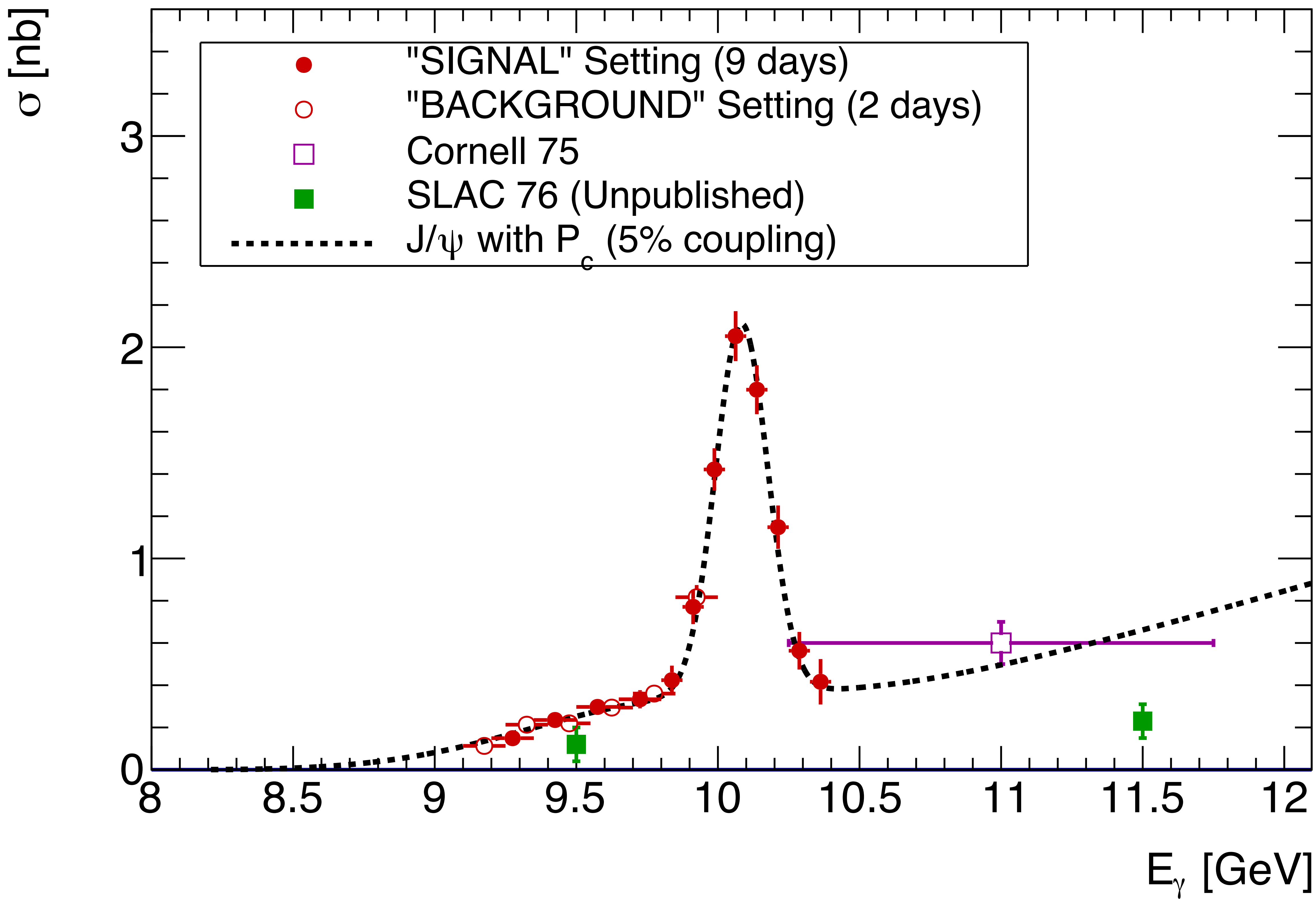
Sensitivity for **Discovery**

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





Impact on the world data for J/ψ production



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!

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**

Collaboration

A. Asaturyan, H. Mkrtchyan, V. Tadevosyan, S. Zhamkochyan
Alikhanyan National Science Laboratory (YerPhI), Yerevan, Armenia

J. Arrington, W. Armstrong, K. Hafidi, M. Hattawy, Z. Ye
Argonne National Laboratory, Chicago, IL

K. Aniol
California State University, Los Angeles, CA

H. Gao, Z. Zhao, T. Liu, X. Yan, C. Gu, C. Peng, X. Li, W. Xiong
Duke University, Durham, NC

P. Markowitz
Florida International University, Miami, FL

K. Adhikari, H. Bhatt, D. Bhetuwal, J. Dunne, D. Dutta, L. El-Fassi, L. Ye
Mississippi State University, Starkville, MS

F. R. Wesselmann
Old Dominion University, Norforlk, VA

X. Chen, Q. Fu, R. Wang, Y. Zhang, F. Zhao
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China.

R. Dupré
Institut de Physique Nuclaire d'Orsay, Orsay, France

G. M. Huber, W. Li, A. Zafar
University of Regina, SK, Canada

S. Bae, H. Choi, S. Choi, H. Go, J. Ha
Seoul National University, Seoul, Korea

H. Atac, B. Duran, S. Joosten[1],
Z.-E. Meziani[2], M. Paolone[3], M. Rehfuss, N. Sparveris
Temple University, Philadelphia, PA

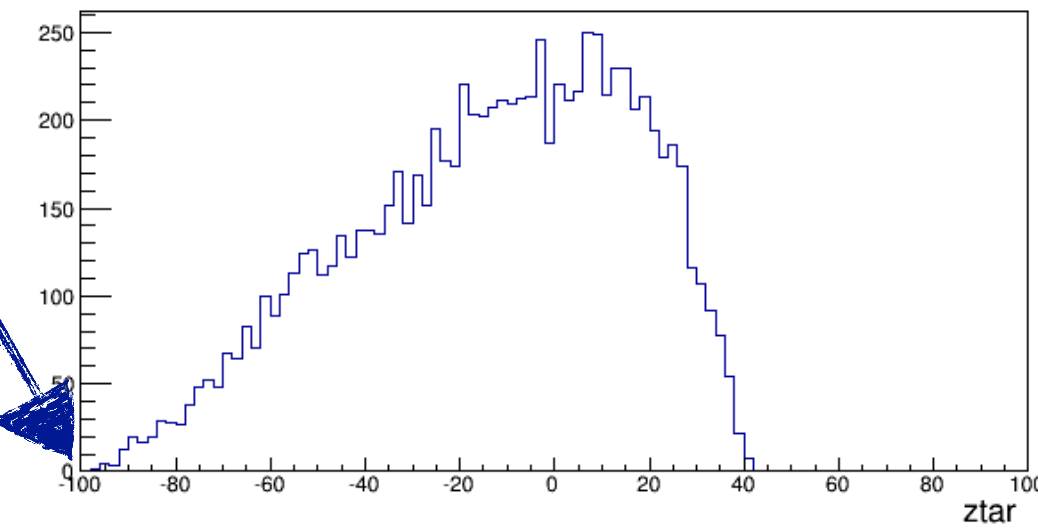
J.-P. Chen, E. Chudakov[4], M. Diefenthaler, O. Hansen, D. Higinbotham, M. Jones[5], D. Meekins, L. Pentchev, E. Pooser, S. Wood
Thomas Jefferson National Accelerator Facility, Newport News, VA

APPENDIX

BACKUP SLIDES

Radiator (Answer to TAC)

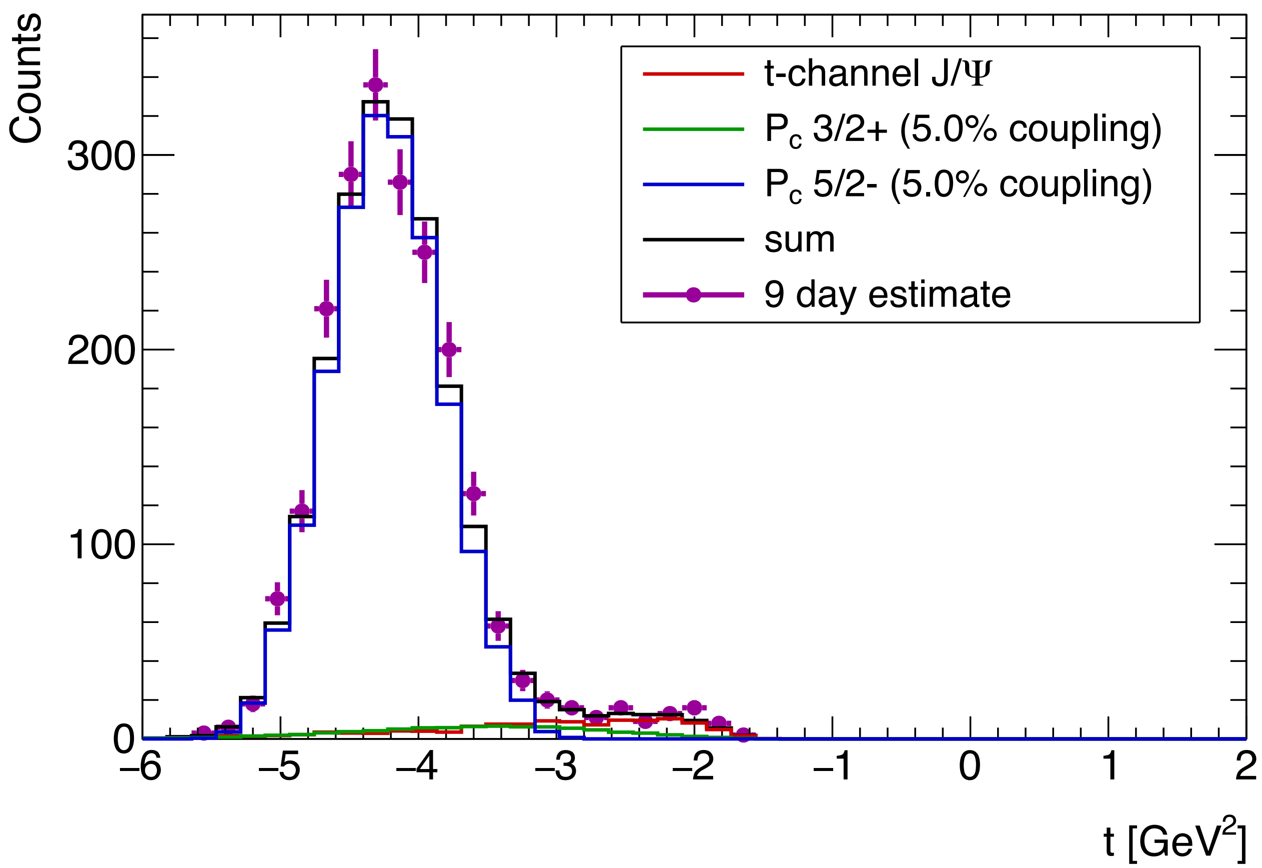
- SHMS upstream acceptance to almost 100 cm at 13°
  - radiator needs to be upstream by >1m (outside of the target chamber), no additional shielding needed
  - ensure we don't hit flow diverters of the target and entrance cylinder to the target (0.5 in opening)
  - Assuming a raster of ± 1 mm, multiple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

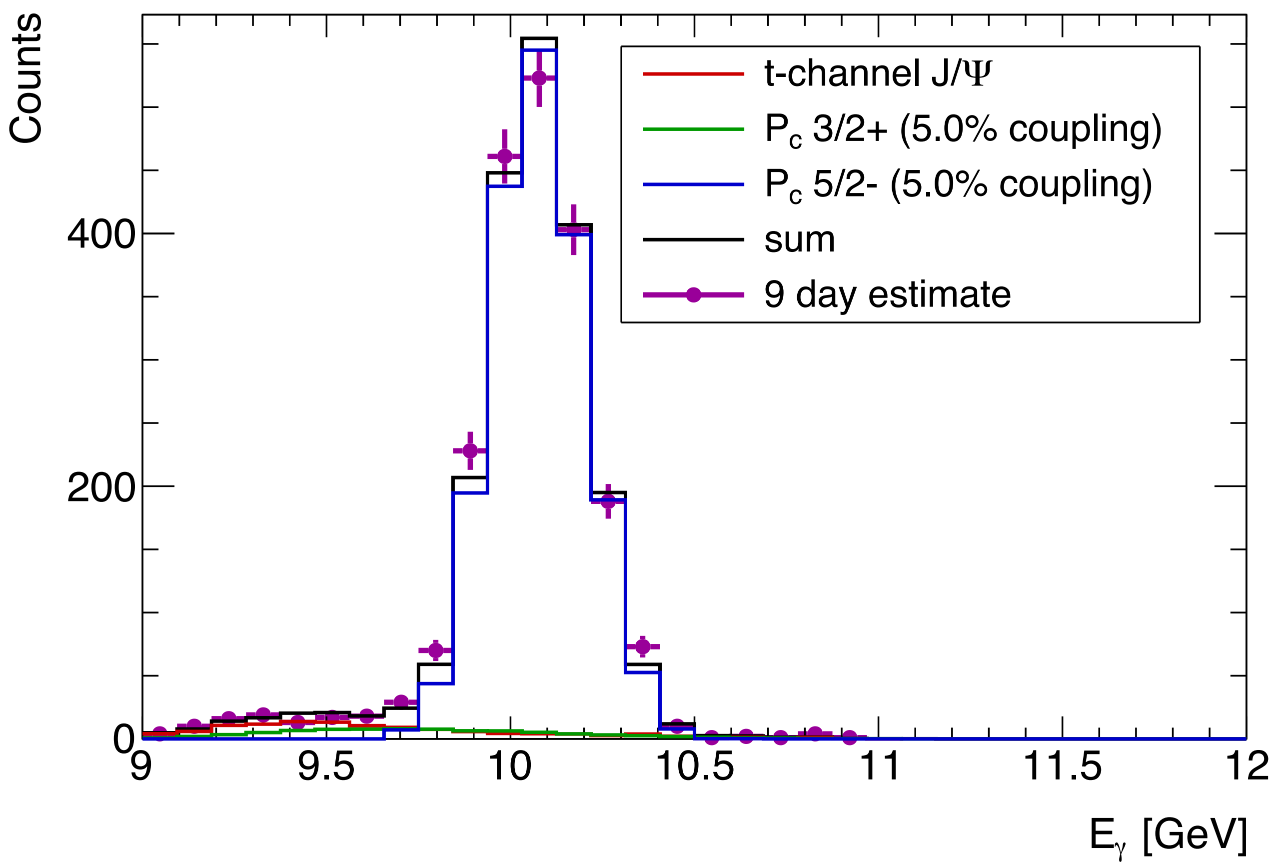


TEMPLE UNIVERSITY

Alternate P_c Assumption (Setting "SIGNAL")

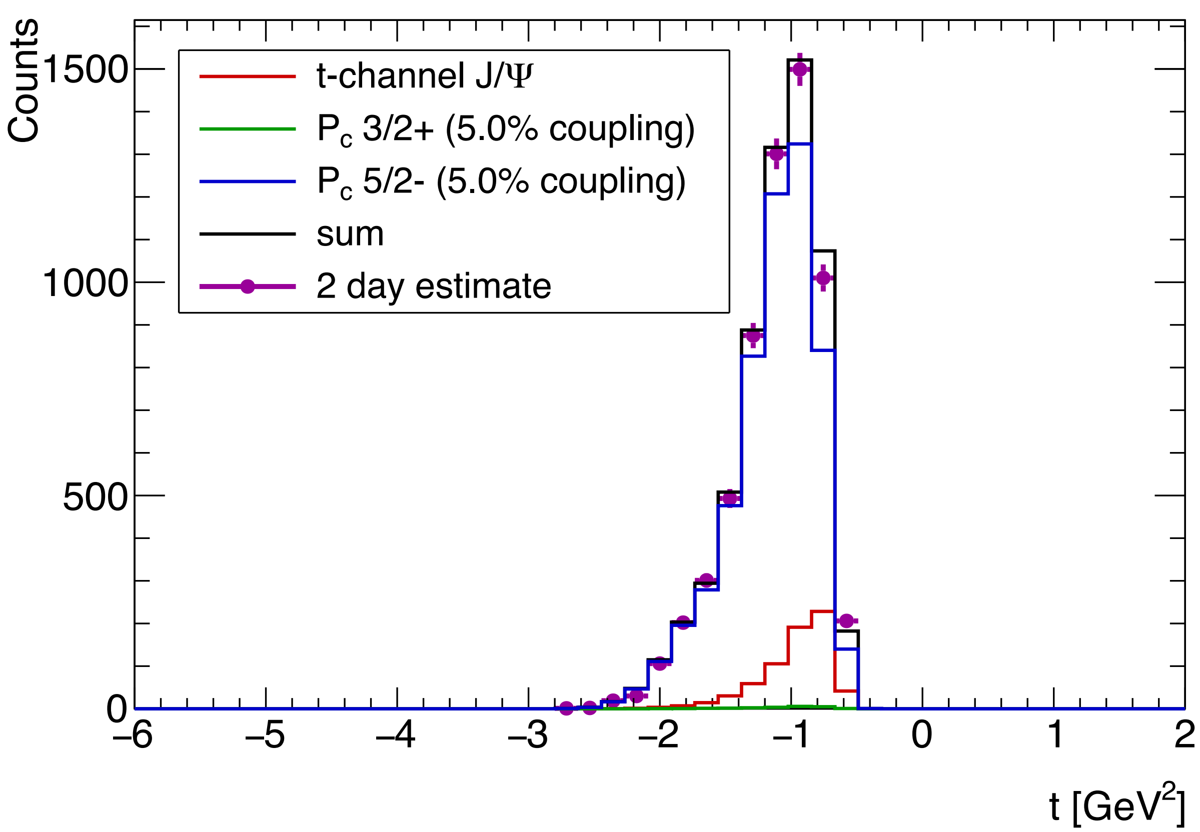
- **Alternate (5/2-, 3/2+) P_c assumption**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption
- 9 days of beam time at 50μA
- 5/2- peak **dominates the spectrum** (even larger than the 5/2+ peak!)

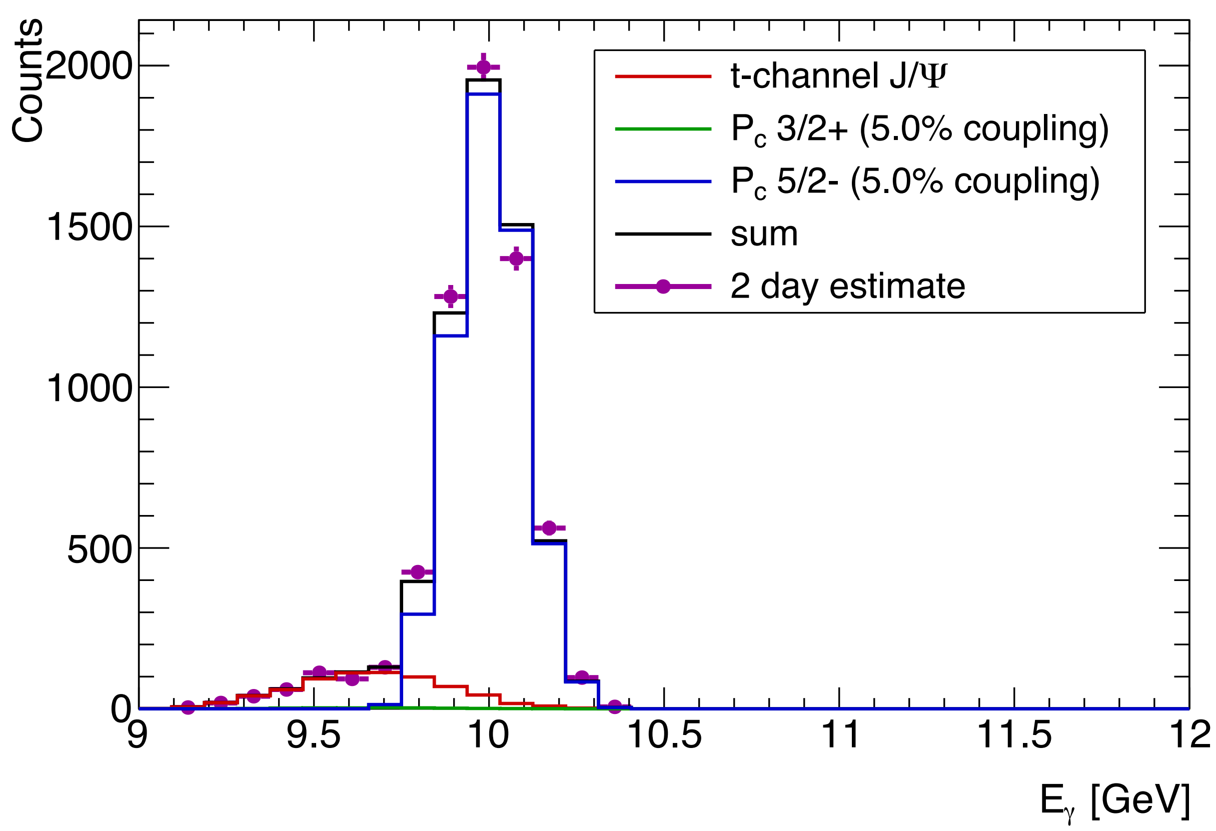




Alternate P_c Assumption ("BACKGROUND" Setting)

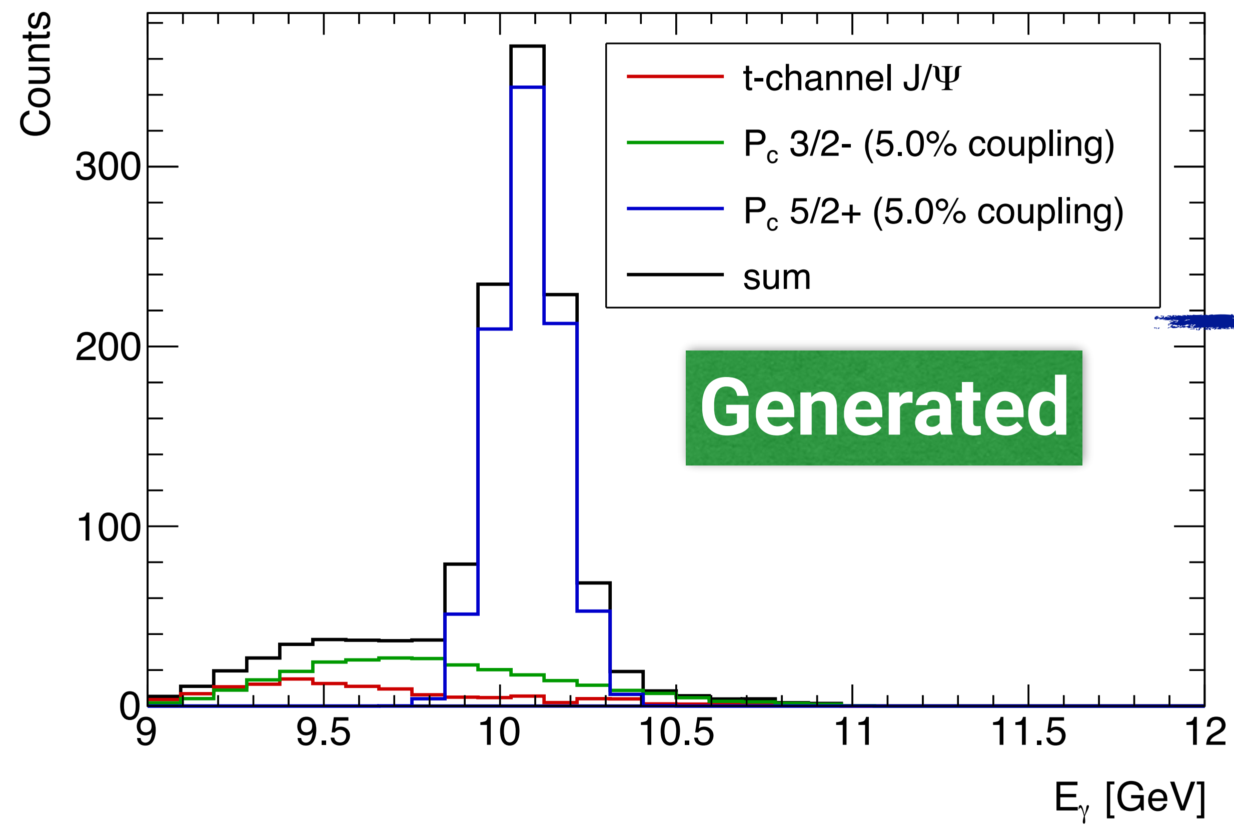
- **Alternate (5/2-, 3/2+) P_c assumption**
- 2 days of beam time at 50μA
- able to **separate** 5/2- from ***t*-channel at low E_γ**
- will provide **first-hand information about *t*-channel production near threshold**
- assuming 5% coupling for the (5/2-, 3/2+) P_c assumption

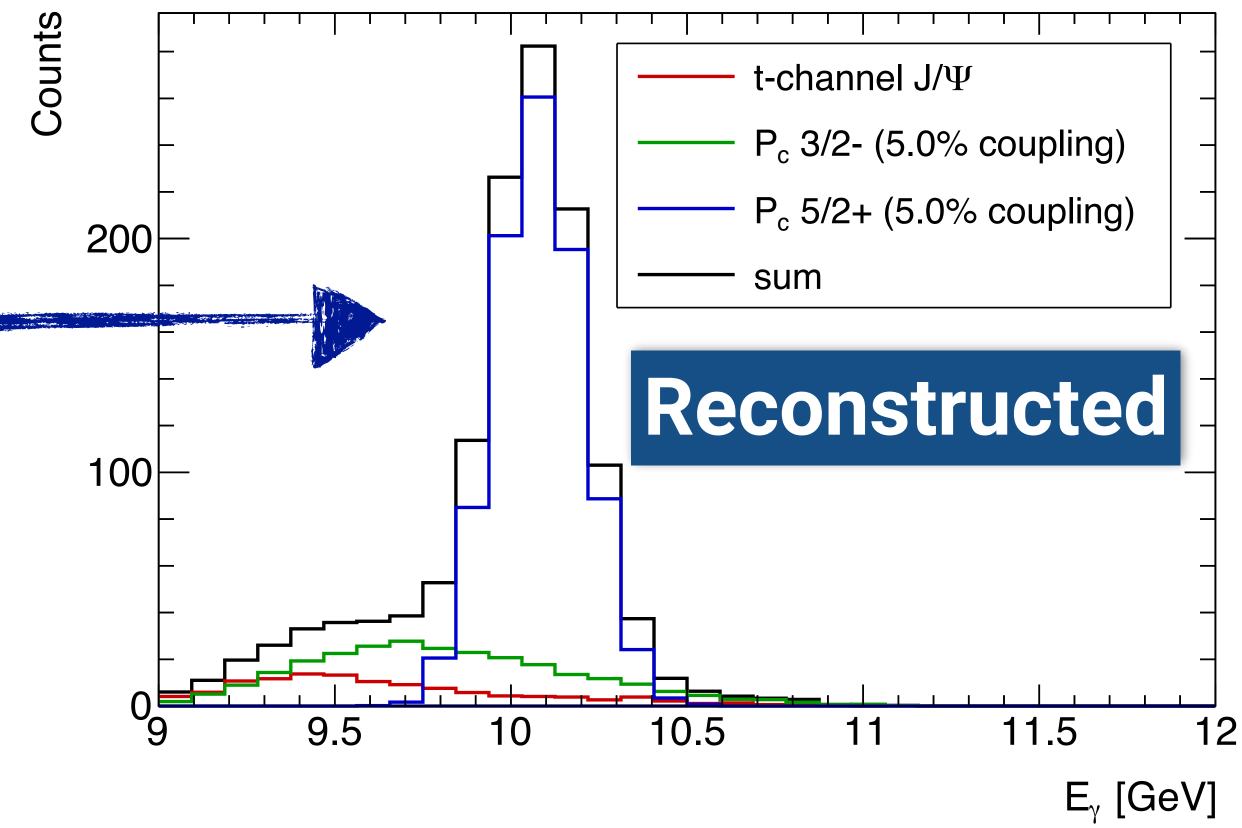


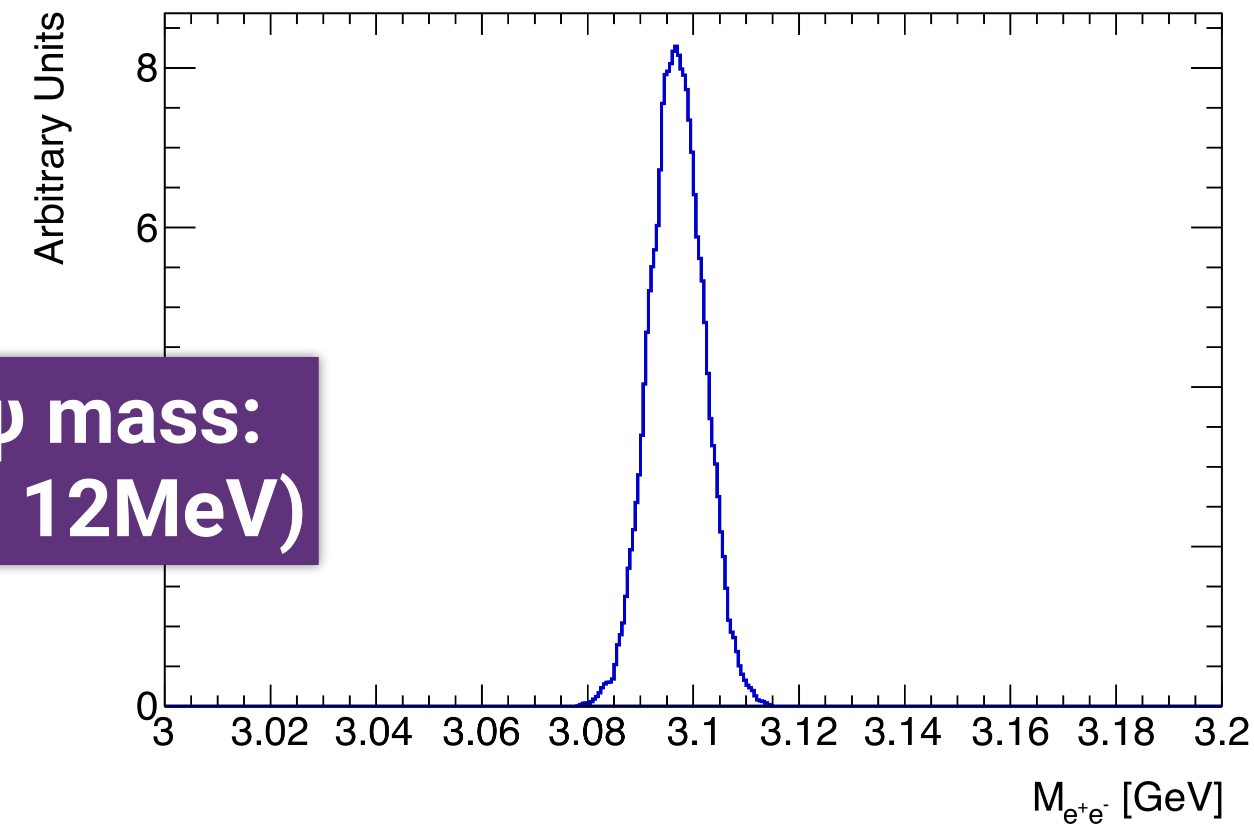


TEMPLE UNIVERSITY

Energy Resolution







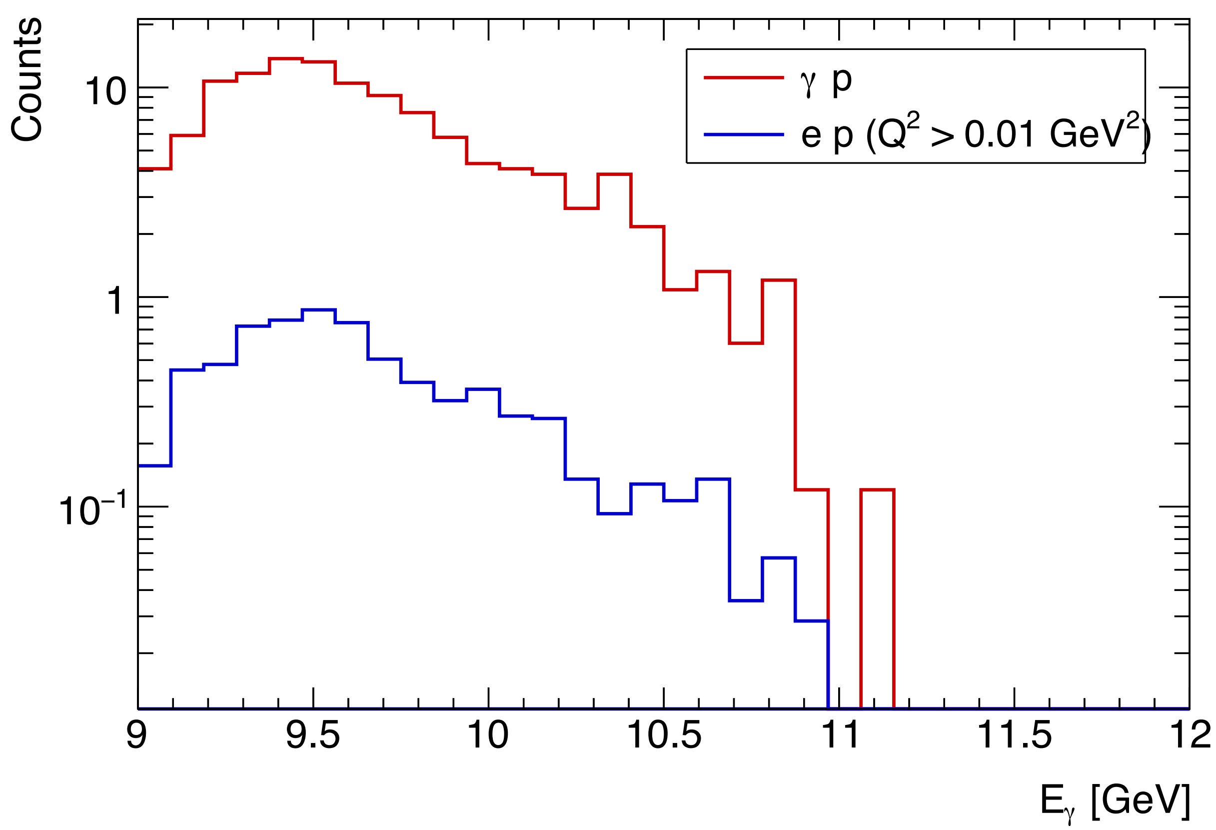
reconstructed J/ψ mass:
σ = 5 MeV (FWHM: 12MeV)

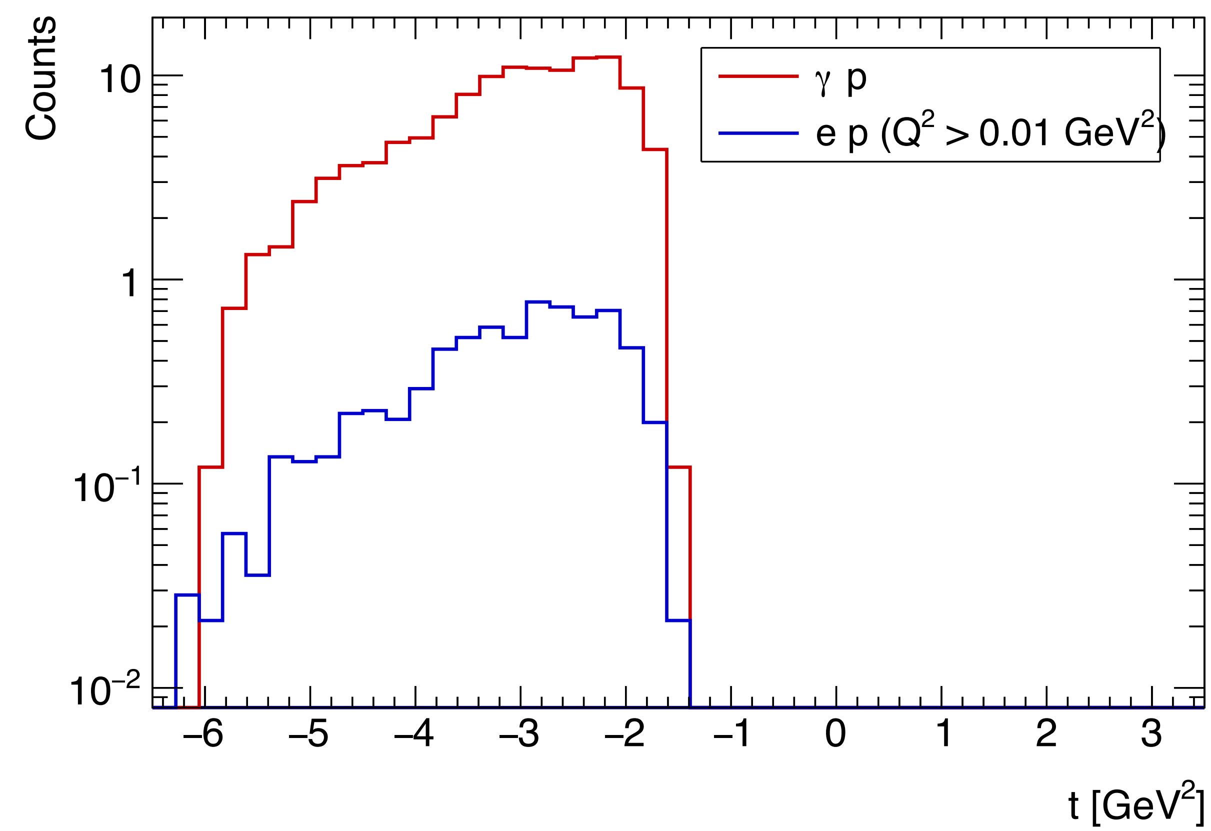
TEMPLE UNIVERSITY®

lepto-production **vs** **photo**-production

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

t-channel projected counts



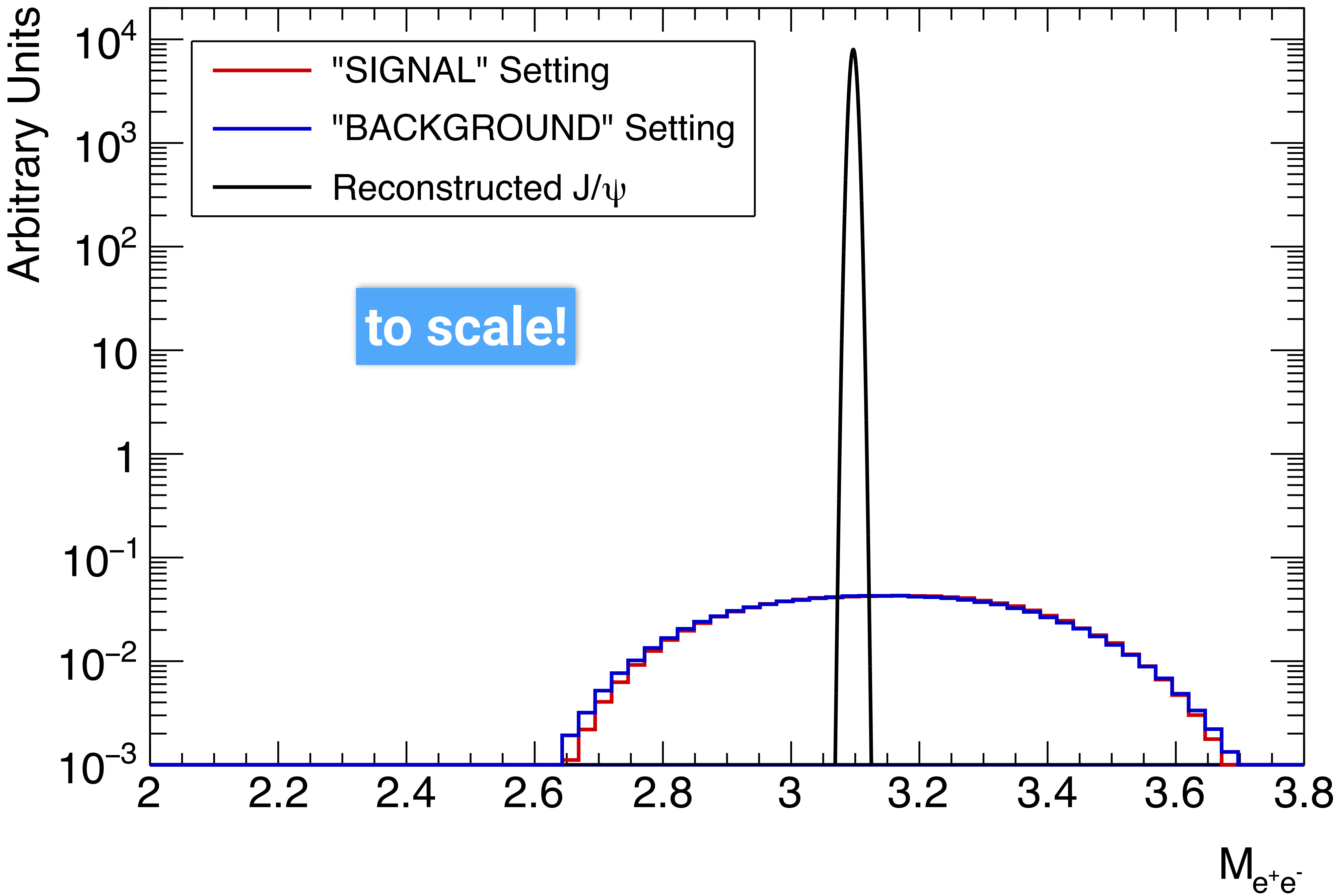


Quasi-real photons ENHANCE the count rate

TEMPLE UNIVERSITY

Invariant Mass Acceptance for Accidentals

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



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

- 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!

TEMPLE UNIVERSITY

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*

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

Properties of the Hall C Spectrometers

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