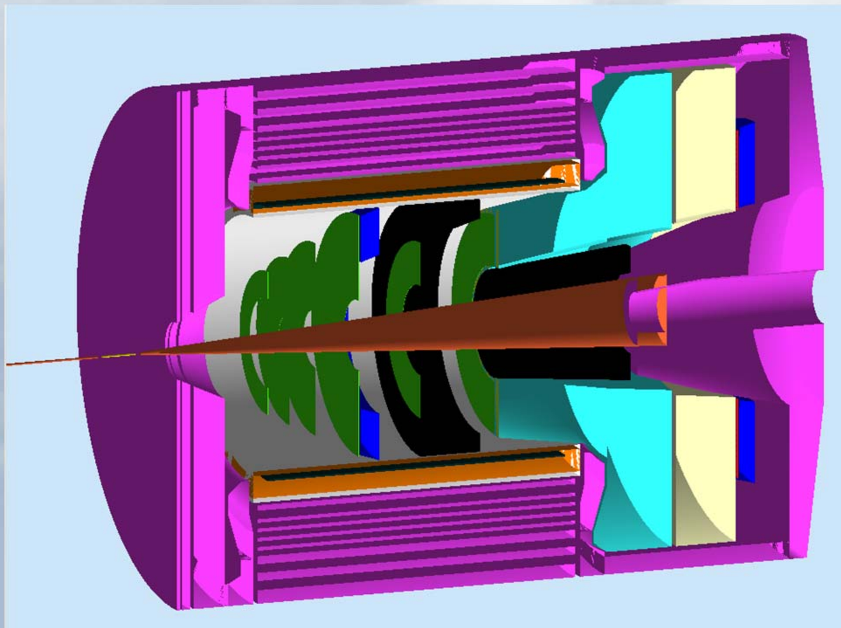
SoLID-J/ψ: Near-Threshold Electro/Photo-Production of J/ψ



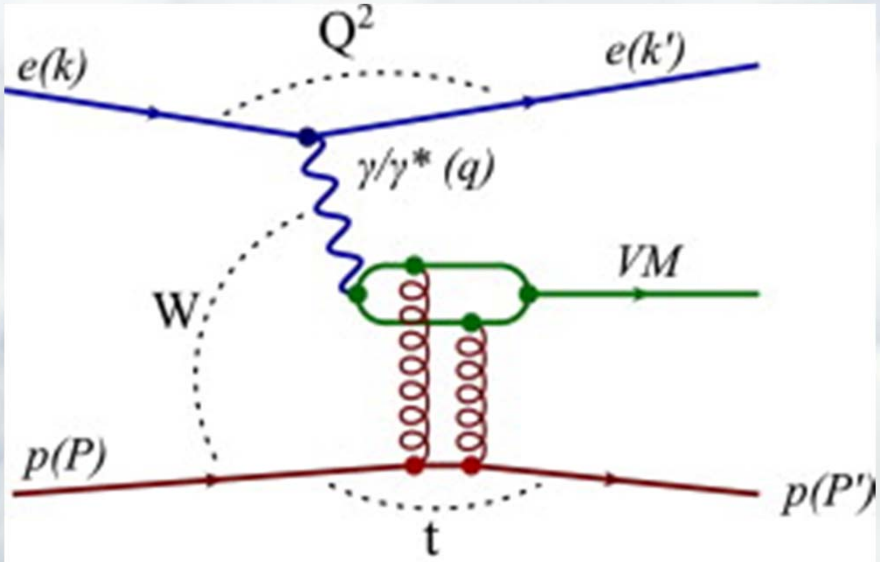
Xin Qian

Caltech

Collaboration with K. Hafidi, Z.-E. Meziani, N. Sparveris and Z. Zhao

Outline

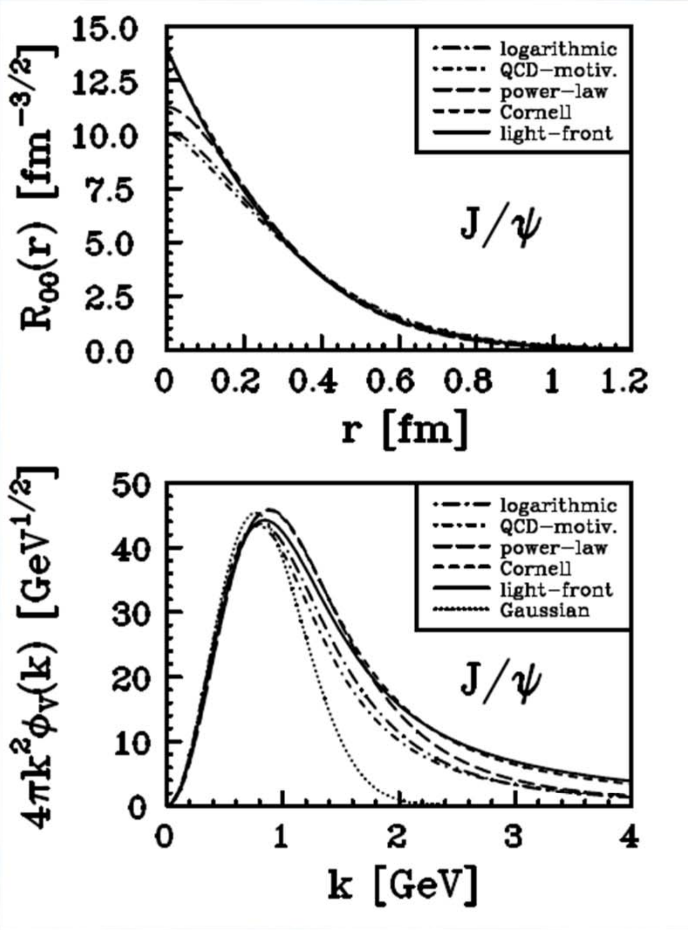
- Motivation:
  - With Proton Target
  - With Deuteron Target
- Experimental Details:
  - SoLID-J/ψ Setup
  - Backgrounds
  - Trigger Setup
- Summary/Plan/Comparison with Hall B/C



ZEUS, PLB 708, 14 2012

Introduction:

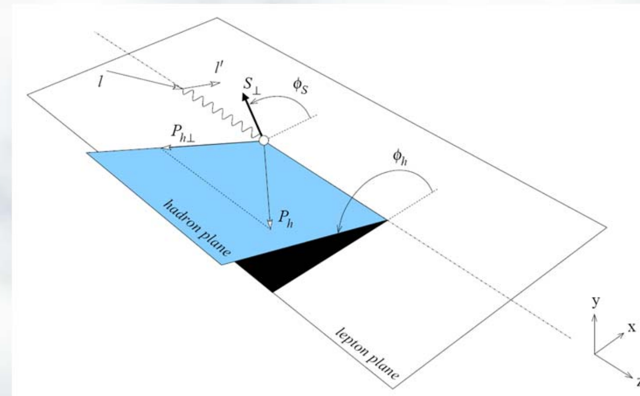
- J/ψ is a compact relativistic system.
  - Quark component ccbar
  - Typical ccbar distance 0.2-0.3 fm
- J/ψ-N interaction
  - Quark exchange are strongly suppressed
  - An unique place to study multi-gluon interactions.
- Detecting J/ ψ
  - Large BR ~ 6% to e^+e^-
  - 3.097 GeV mass → Small background
- Exclusive Channel
  - Benefit in PID/Trigger/Background

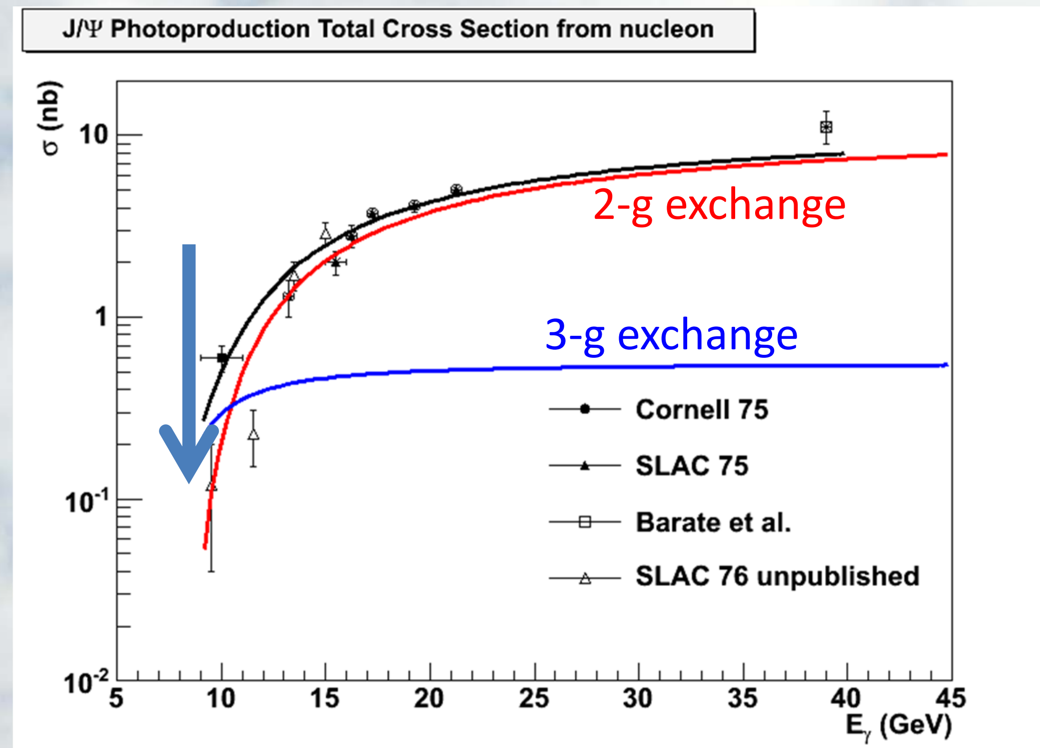


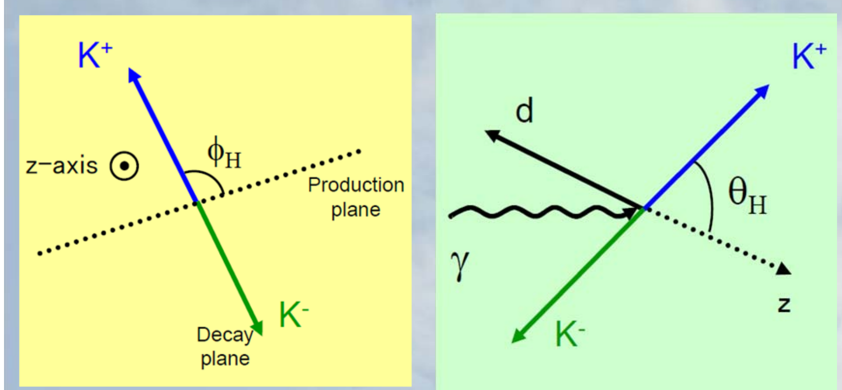
Frankfurt, Koepf and Strikman
hep-ph: 9702216

Near Threshold Production On Proton

- Motivation:
  - Search for threshold enhancement
  - Study the angular distribution of J/ψ production
  - Study the J/ ψ decay angular distribution







Change Kaon to electron for this case.

Brodsky et al PLB 498 23 (2001)

Search for Threshold Enhancement

- Threshold enhancement has been widely observed in:

$$e^+e^- \to p\bar{p}$$

$$e^+e^- \to \Lambda\bar{\Lambda}$$

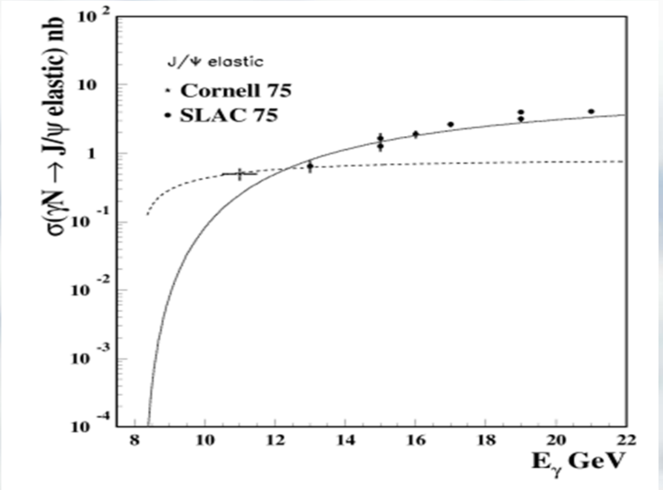
$$e^+e^- \to \Sigma^0\overline{\Sigma^0}$$

$$e^+e^- \to \Lambda\overline{\Sigma^0}$$

$$J/\psi \to \gamma p\bar{p}$$

- A threshold enhancement in J/ψ photo/electro-production would indicate existence of multi-gluon interaction (>2)
  - **Non-perturbative gluon interaction!**

- As an example:
  - Brodsky et al proposed the 3-gluon interaction:



$$\frac{d\sigma_{2g}}{dt} \sim (1-x)^2 F(t)$$

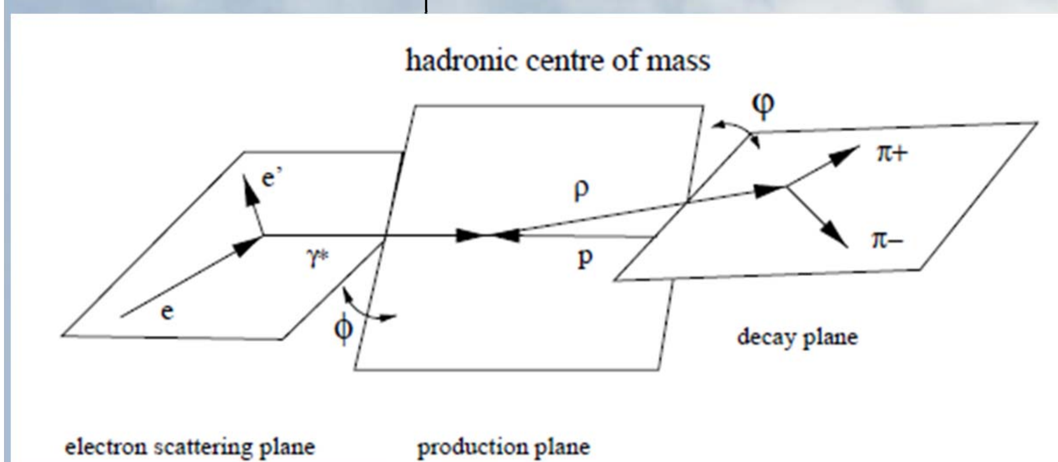
$$\frac{d\sigma_{3g}}{dt} \sim (1-x)^0 F(t)$$

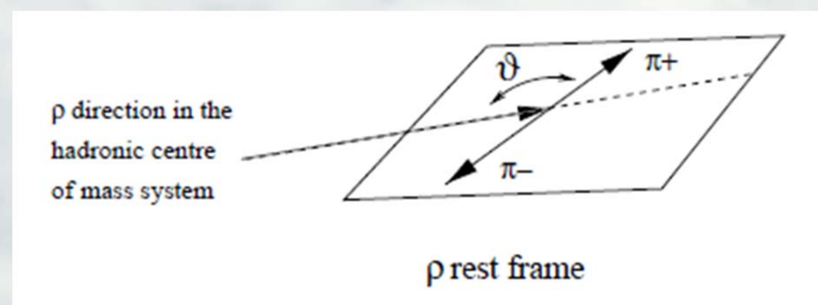
$$x = \frac{2m_p M_{J/\psi} + M_{J/\psi}^2}{s - m_p^2}$$

Study the Decay Angular Distribution of J/ψ

- The decay angular distribution of J/ψ would reveal important information of the production mechanism.
  - Test s-channel helicity conservation (SCHC) near threshold.

$$W(\cos\theta,\varphi,\phi)=\frac{3}{4\pi}\left\{\begin{array}{l}\frac{1}{2}(1-r_{00}^{04})+\frac{1}{2}(3r_{00}^{04}-1)\cos^2\theta-\sqrt{2}\,\mathrm{Re}\,r_{10}^{04}\sin 2\theta\cos\varphi-r_{1-1}^{04}\sin^2\theta\cos 2\varphi \\ -\varepsilon\cos 2\phi(r_{11}^{1}\sin^2\theta+r_{00}^{1}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\,r_{10}^{1}\sin 2\theta\cos\varphi-r_{1-1}^{1}\sin^2\theta\cos 2\varphi) \\ -\varepsilon\sin 2\phi(\sqrt{2}\,\mathrm{Im}\,r_{10}^{2}\sin 2\theta\sin\varphi+\mathrm{Im}\,r_{1-1}^{2}\sin^2\theta\sin 2\varphi) \\ +\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi(r_{11}^{5}\sin^2\theta+r_{00}^{5}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\,r_{10}^{5}\sin 2\theta\cos\varphi-r_{1-1}^{5}\sin^2\theta\cos 2\varphi) \\ +\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi(\sqrt{2}\,\mathrm{Im}\,r_{10}^{6}\sin 2\theta\sin\varphi+\mathrm{Im}\,r_{1-1}^{6}\sin^2\theta\sin 2\varphi)\end{array}\right\}$$





EPJC 13 371 (2000) change pions to electrons

Expectation: Natural Parity Exchange

Element	NPE and $T_{1-1} = T_{10} = 0$	NPE and SCHC
r^{04}_{00}	$\frac{1}{1+\epsilon R}\left(\frac{\lvert T_{01}\rvert^2}{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2} + \epsilon R\right)$	$\frac{\epsilon R}{1+\epsilon R}$
$\mathrm{Re}\ r^{04}_{10}$	$\frac{1}{2}\ \frac{1}{1+\epsilon R}\ \frac{1}{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2}\ \mathrm{Re}\ (T_{11}T^*_{01})$	0
r^{04}_{1-1}	0	0
r^{1}_{00}	$\frac{-1}{1+\epsilon R}\ \frac{\lvert T_{01}\rvert^2}{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2}$	0
r^{1}_{11}	0	0
$\mathrm{Re}\ r^{1}_{10}$	$-\mathrm{Re}\ r^{04}_{10}$	0
r^{1}_{1-1}	$\frac{1}{2}\ \frac{1}{1+\epsilon R}\ \frac{\lvert T_{11}\rvert^2}{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2}$	$\frac{1}{2}\frac{1}{1+\epsilon R}$
$\mathrm{Im}\ r^{2}_{10}$	$\mathrm{Re}\ r^{04}_{10}$	0
$\mathrm{Im}\ r^{2}_{1-1}$	$-r^{1}_{1-1}$	$-r^{1}_{1-1}$
r^{5}_{00}	$\frac{\sqrt{2R}}{1+\epsilon R}\ \frac{1}{\lvert T_{00}\rvert\sqrt{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2}}\ \mathrm{Re}\ (T_{00}T^*_{01})$	0
r^{5}_{11}	0	0
$\mathrm{Re}\ r^{5}_{10}$	$\frac{1}{2\sqrt{2}}\ \frac{\sqrt{R}}{1+\epsilon R}\ \frac{1}{\lvert T_{00}\rvert\sqrt{\lvert T_{11}\rvert^2+\lvert T_{01}\rvert^2}}\ \mathrm{Re}\ (T_{11}T^*_{00})$	$\frac{1}{2\sqrt{2}}\ \frac{\sqrt{R}}{1+\epsilon R}\ \frac{1}{\lvert T_{11}\rvert\lvert T_{00}\rvert}\mathrm{Re}\ (T_{11}T^*_{00})$
r^{5}_{1-1}	0	0
$\mathrm{Im}\ r^{6}_{10}$	$-\mathrm{Re}\ r^{5}_{10}$	$-\mathrm{Re}\ r^{5}_{10}$
$\mathrm{Im}\ r^{6}_{1-1}$	0	0

- M. Vanderhaeghen: SCHC well tested at HERA energy, no systematic tests near threshold. Natural vs. unnatural parity exchange.
- Working in progress

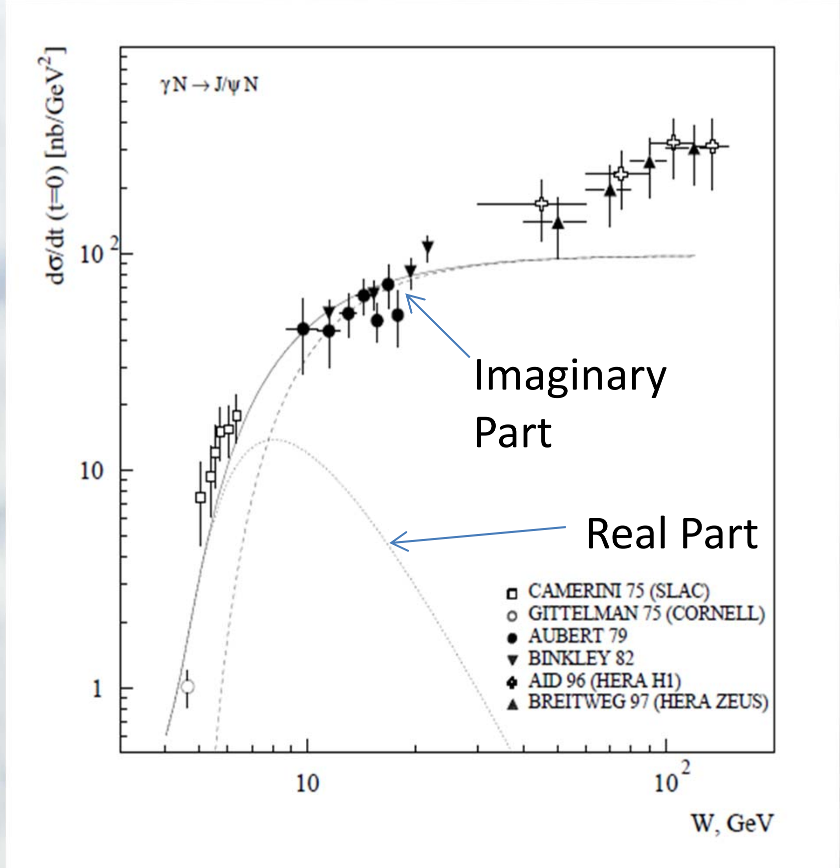
Study the Angular Distribution of J/ψ Production

$$\frac{d\sigma_{\gamma N\to J/\Psi N}}{dt}(t=0) \sim \frac{d\sigma_{J/\Psi N\to J/\Psi N}}{dt}(t=0) \sim |M_{J/\Psi N}(t=0)|^2$$

$$Re\,\mathcal{M}_{\psi N}(\lambda) = \mathcal{M}_{\psi N}(0) + \frac{2\,\lambda^2}{\pi}\int_{\lambda_0}^{\infty}\frac{d\,\lambda'}{\lambda'}\frac{Im\,\mathcal{M}_{\psi N}(\lambda')}{\lambda'^2-\lambda^2}.$$

$$\sigma_{\psi N}^{tot} = \frac{Im\,\mathcal{M}_{\psi N}}{2m_\psi\sqrt{\lambda^2-m_N^2}},$$

- Real Part Dominates near threshold
- M. Vanderhaeghen:
  - Disentangle Re/Im part using interference with Bethe-Heitler
  - Measure angular dependence (lepton vs. hadron plane)
  - Working in progress to estimate size of asymmetry



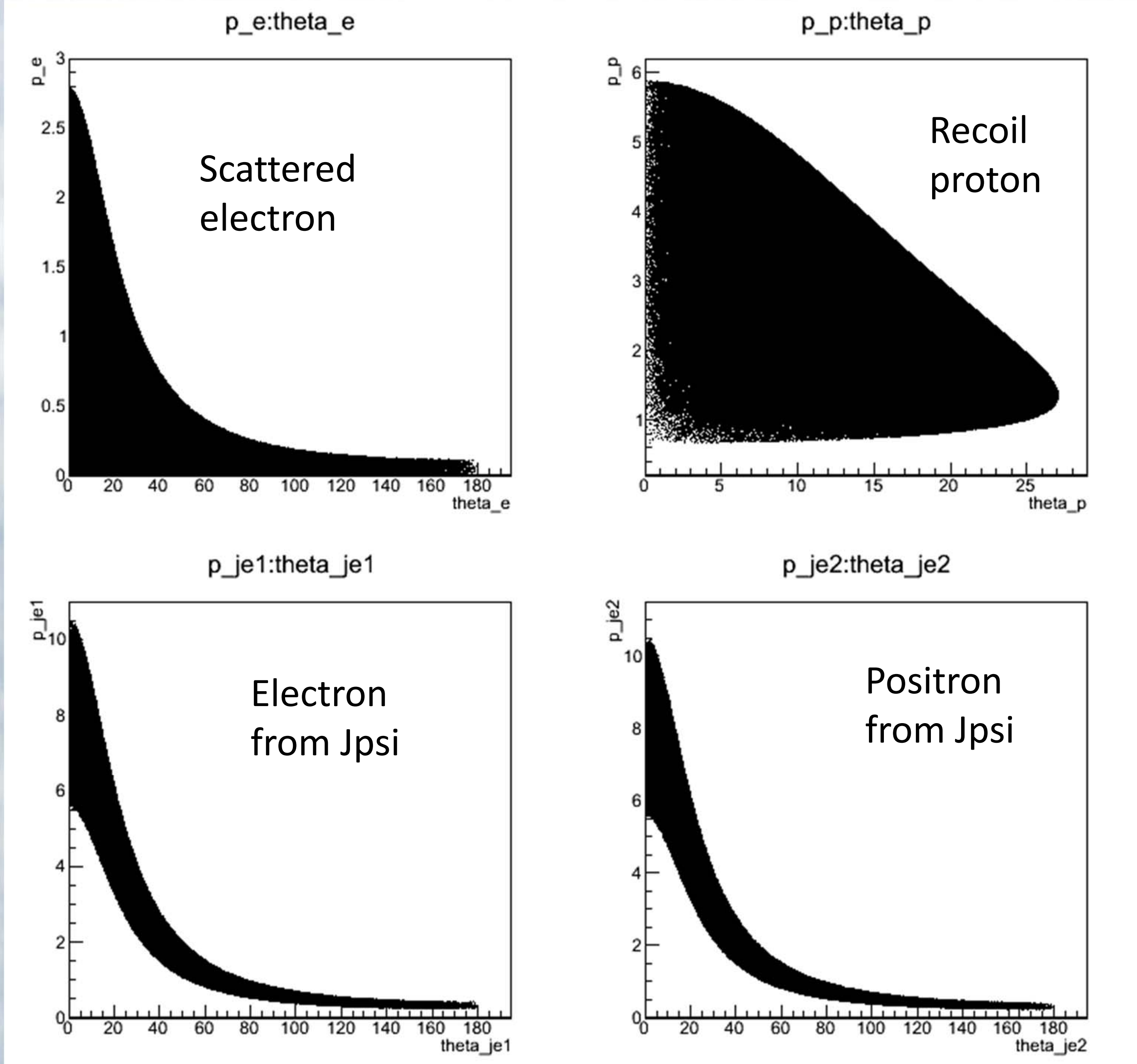
D. Kharzeev et al. EPJC 9, 459 (1999)

Looking at Phase Space @ 11 GeV

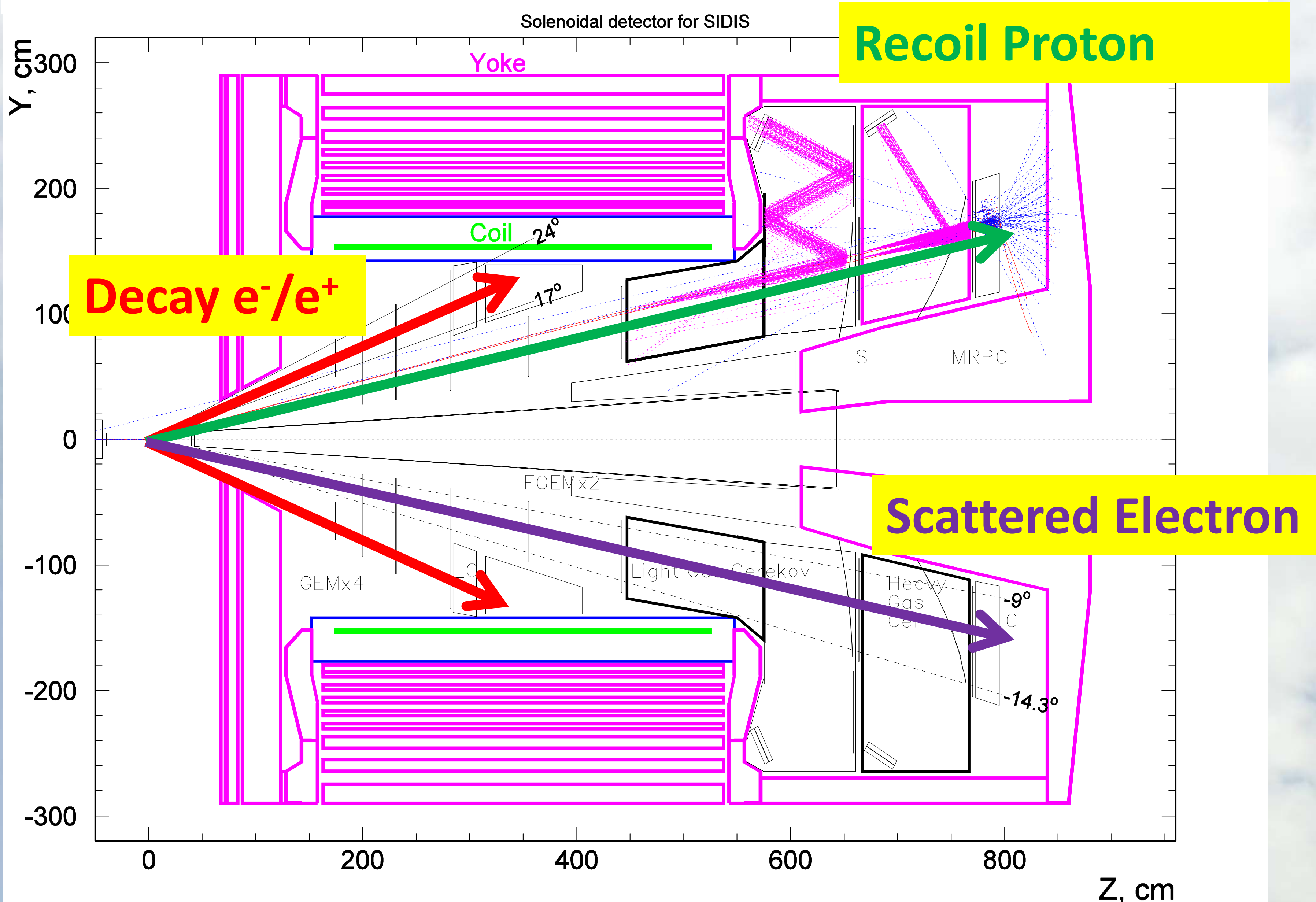
Scattered electrons at forward angle (low Q^2)

Only forward angle has the hadron PID capability

Large angle and forward angle detection for decay electrons and positrons.



Current SoLID SIDIS Setup



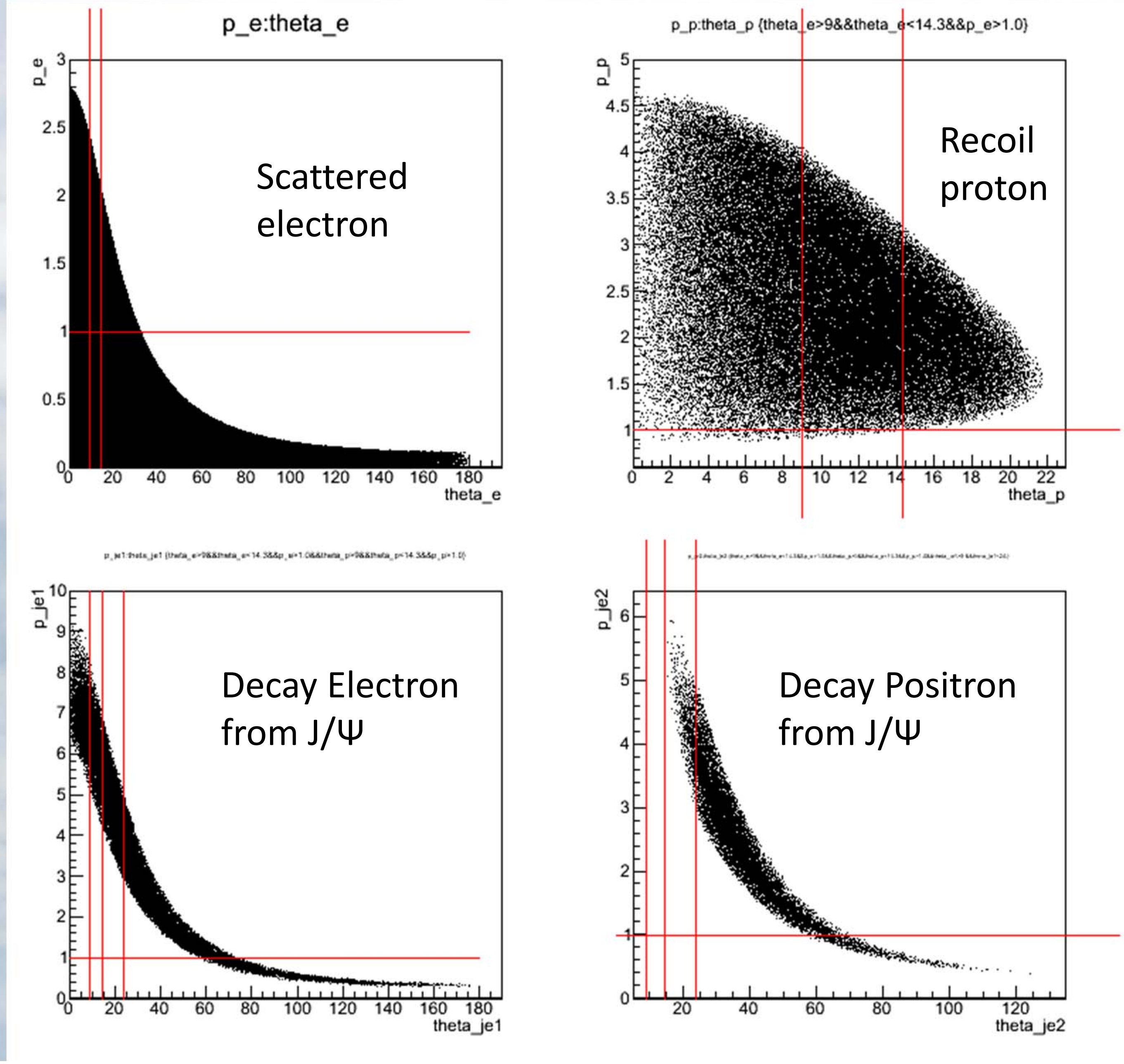
Looking at Phase Space @ 11 GeV

Scattered electrons at forward angle (low Q^2)

Only forward angle has the hadron PID capability

Large angle and forward angle detection for decay electrons and positrons.

Cuts are applied one by one.



Modification of Setup

Need larger large-angle detection for decay electron/positron:

Larger opening angle for front yoke.

Slightly more forward for large angle calorimeter and 4th layer of GEM chamber. Larger GEM Chamber would needed for 1st-3rd chamber.

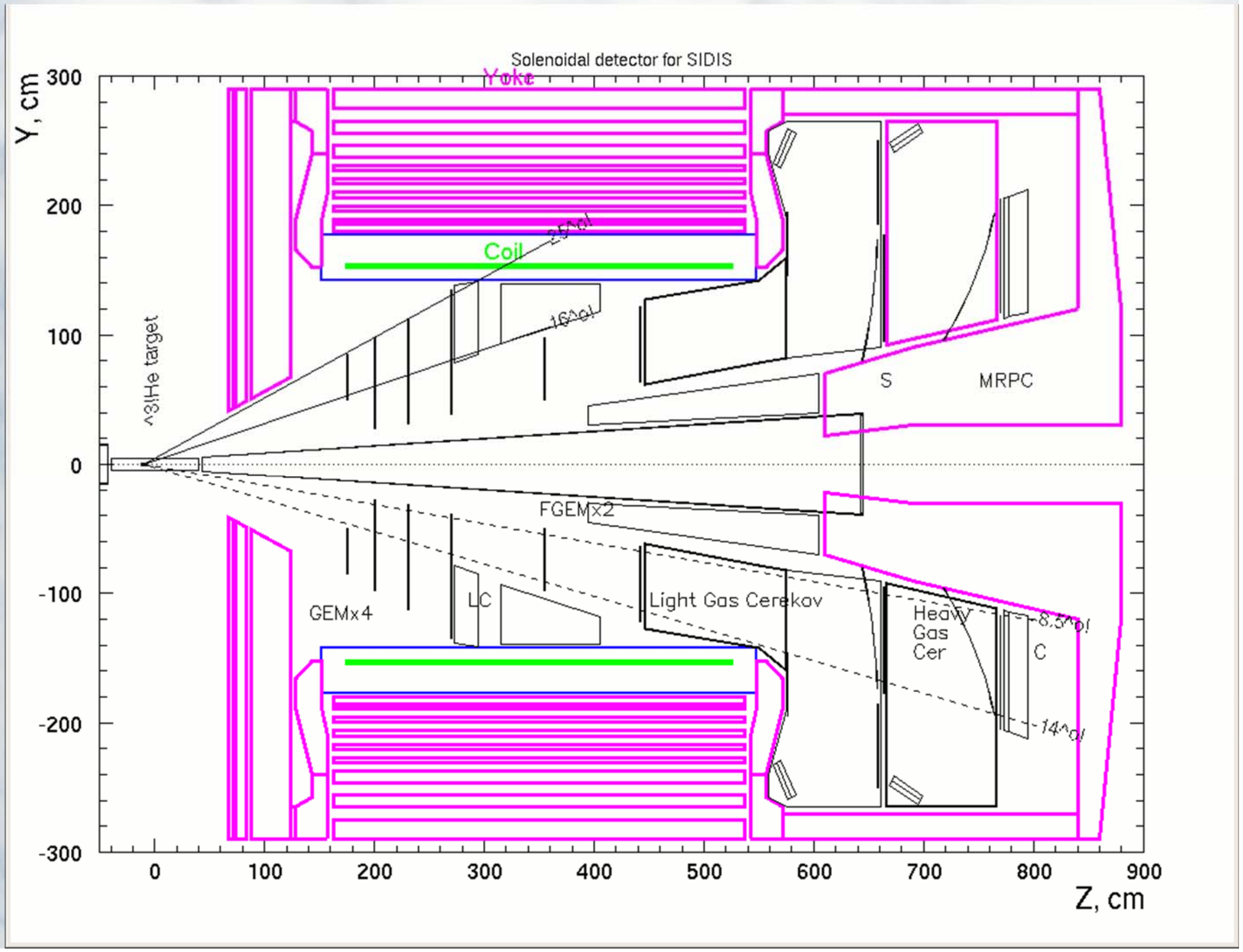
Need forward angle detection of scattered electron and recoil proton:

Move 4 cm target to -10 cm (compared to SIDIS setup.

Luminosity:

~10^{37} N/cm^2/s

~10 uA on 4 cm LH_2 target



Acceptance from GEANT3

Scattered Electron:

- GC + Calorimeter @ forward angle

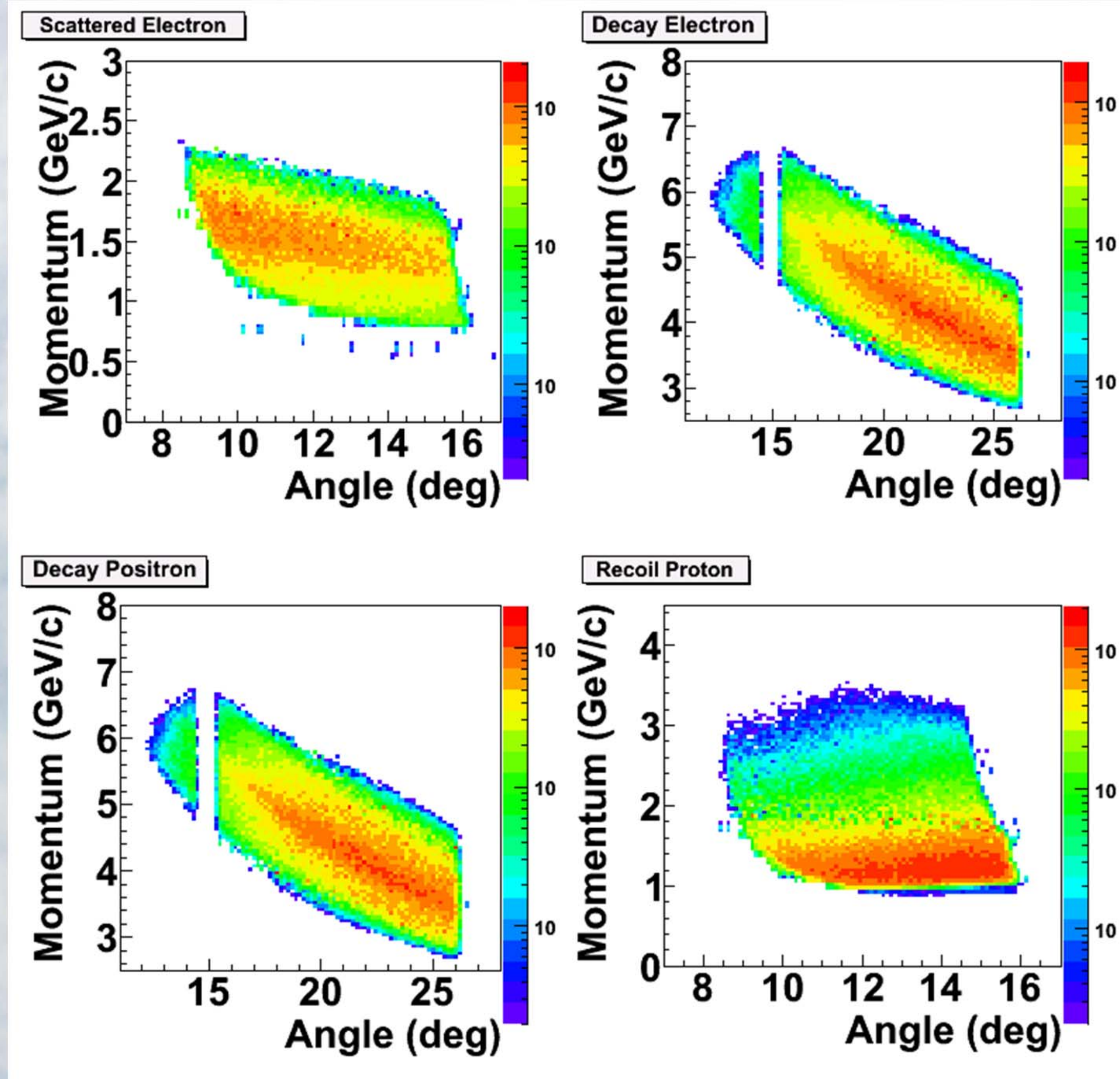
Decay Electron/Positron:

- Calorimeter only @ large angle
- GC+Calorimeter at forward angle

Recoil Proton:

- 100 ps TOF: 2 ns separation between p/K @ 2 GeV/c + 8 m

Exclusivity will further strength PID with kinematics fitting.



Strategy of SoLID-JPsi

- Map the near-threshold region:

$$e + p \to e' + e^{+} + e^{-} + p$$ 4-fold

$$e + p \to e' + e^{+} + e^{-} + (p)$$ 3-fold n.p.

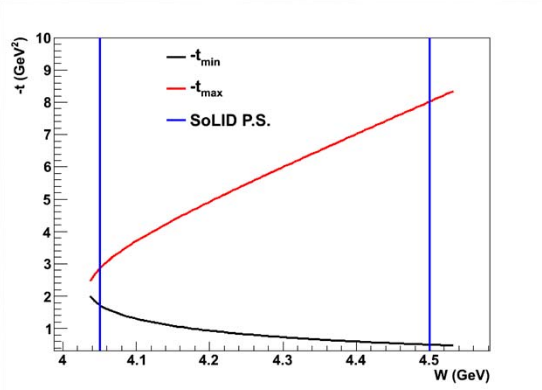
$$e + p \to (e') + e^{+} + e^{-} + p$$ 3-flod n.s.e.

- Electro-production:
  - 4-fold + 3 fold n.p.
- Photo-production:
  - 3 fold n.s.e

- Advantages of electro-production:
  - Since the scattered electron is detected, the W (thus tmin) is well determined.
  - 3-fold will have larger statistics.
  - Background can be understood with 4-fold exclusive channel
  - Also Q^2 →0.5-1 GeV^2
  - Suitable to study L-T interference and helicity-flip amplitude through J/ψ decay
  - Suitable to study B-H, J/ψ interference.

$$\delta W \sim 0.08 GeV$$

$$\sigma_{tot} = \int_{t_{\min}}^{t_{\max}} \frac{d\sigma}{dt} dt$$



- Advantages of photo-production:
  - Large statistics at Q^2 ~ 0, well suited to study t-dependence at high W.
  - Comparison between electro-production vs. photo-production.
  - Suitable to study Ratio of Longitudinal vs. Transverse Cross Section.

Rates Estimation

- Use Equivalent Photon Approximation

$$\frac{d^5\sigma}{d\Omega_e dP_e d\Omega_p} = \Gamma \frac{J}{2\pi} \frac{d\sigma}{dt}$$

$$\Gamma = \frac{\alpha}{2\pi^2} \frac{P_e}{P_e^0} \frac{K_{eq}}{Q^2} \frac{1}{1-\varepsilon}$$

$$K_{eq} = (W^2 - M_p^2)/(2M_p)$$

$$\varepsilon = (1 + \frac{2|q|^2}{Q^2} \tan^2 \frac{\theta_e}{2})^{-1}$$

$$J = Jacobian$$

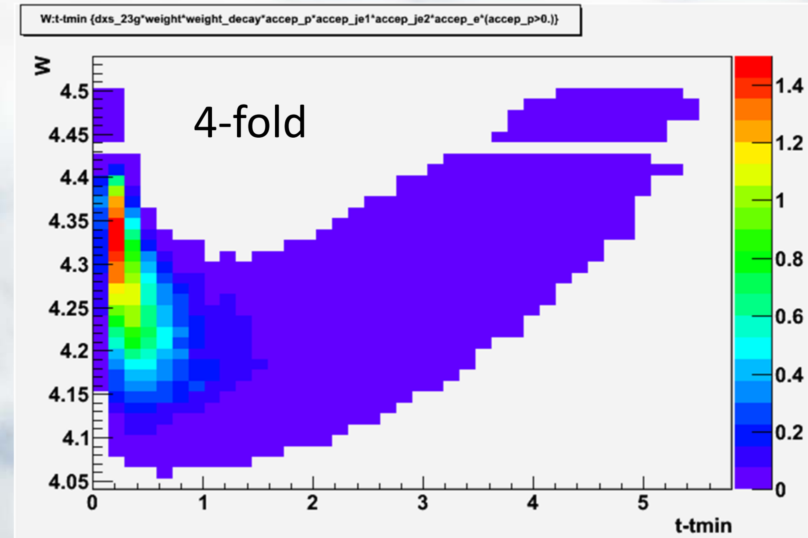
$$I : \frac{d\sigma}{dt}(nb/GeV^2) = 0.94 e^{0.97t}$$

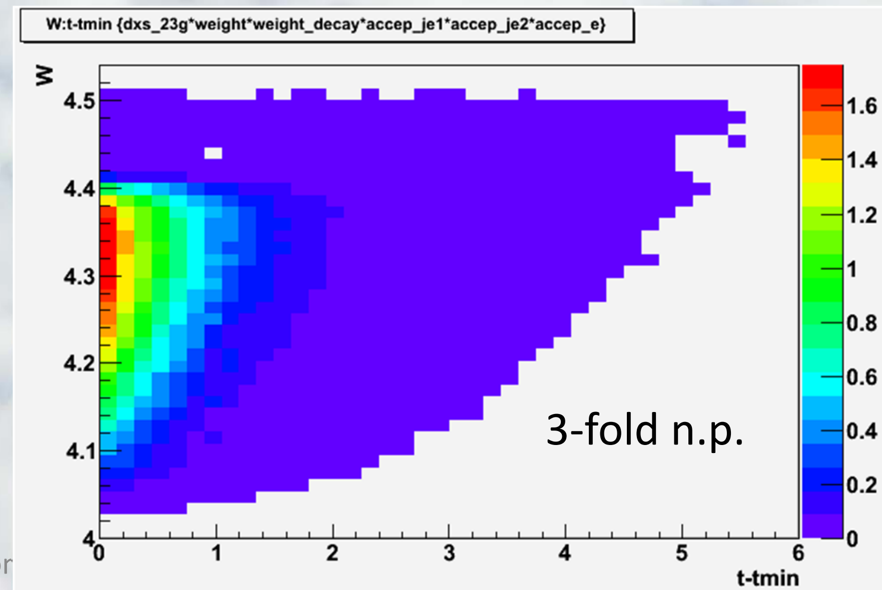
$$II : \frac{d\sigma}{dt}(nb/GeV^2) = N_{2g}(1-x)^2 e^{1.13t}$$

$$III : \frac{d\sigma}{dt}(nb/GeV^2) = N_{3g}(1-x)^0 e^{1.13t}$$

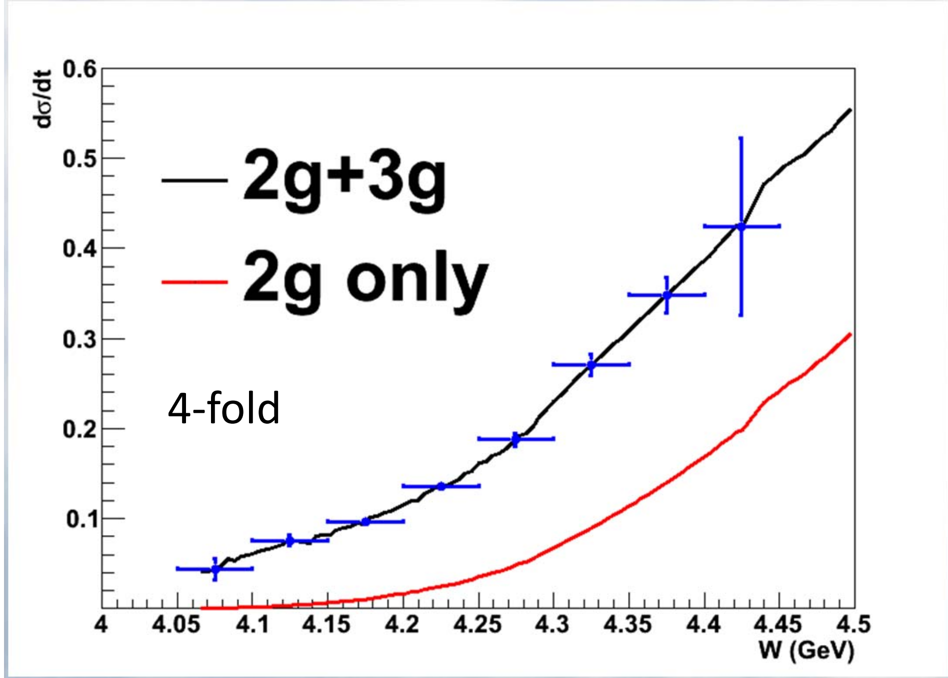
Event Rates @ 1e37 @ 50 days

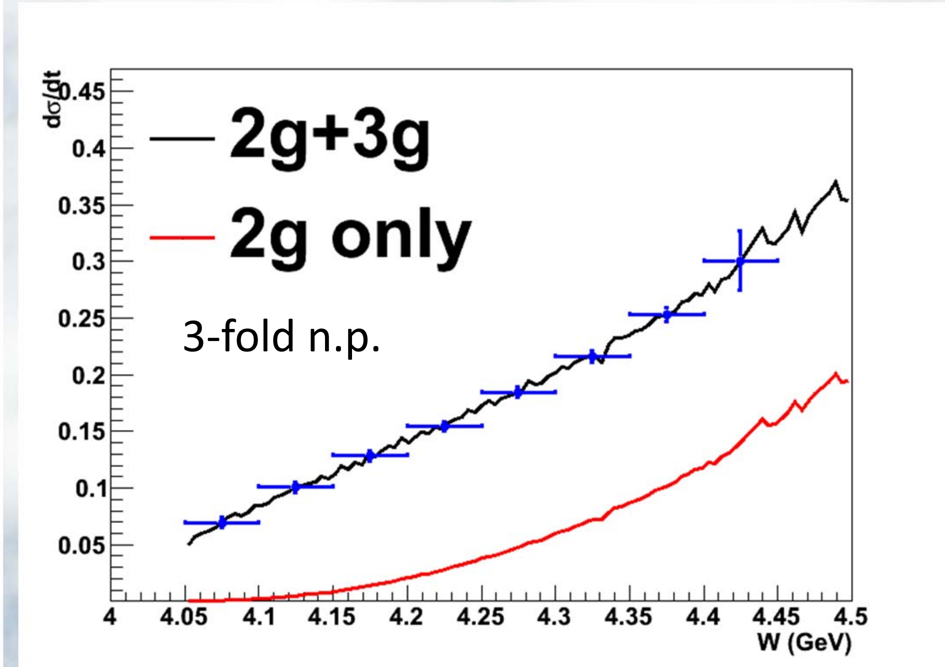
- 4-fold coincidence:
  - 0.94 * exp(0.97 t): **4.5 k**
  - 2g-only: **0.68 k** events
  - 2g + 3g: **2.9 k** events
- 3-folid n.p.:
  - 0.94*exp(0.97 t): **12 k**
  - 2g-only: **2.1 k** events
  - 2g+3g: **8.08 k** events
- Good to study a ~10% asymmetry of B-H & J/ψ interference



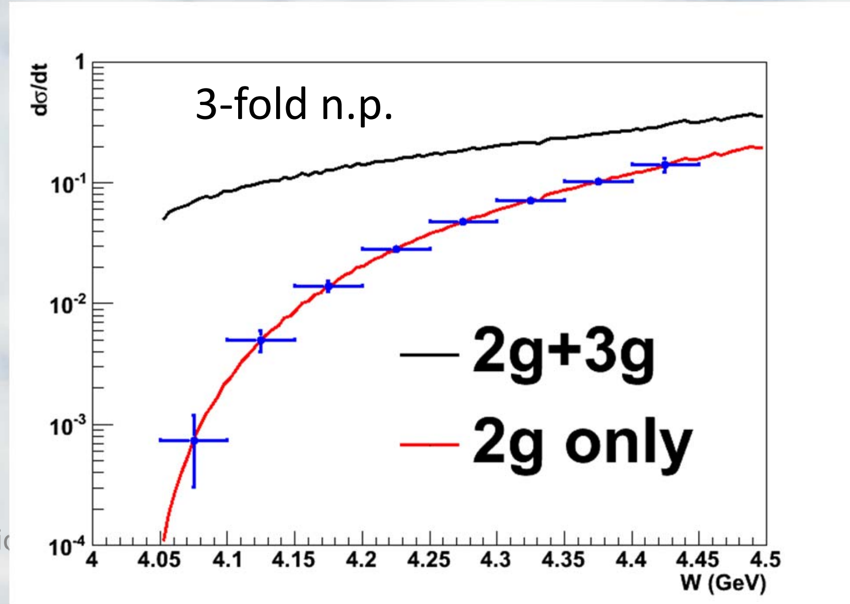


Projections

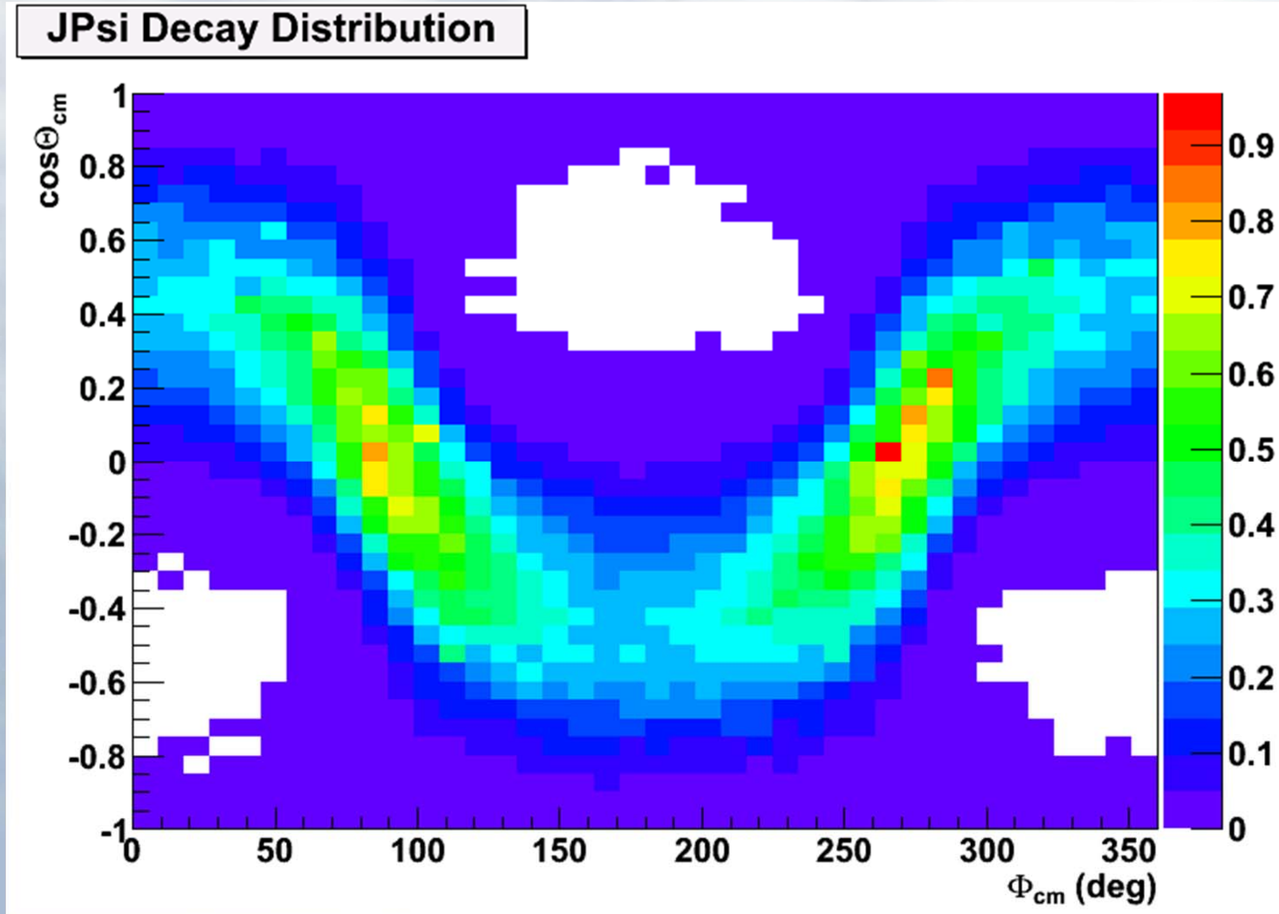




- For W < 4.12 GeV
  - 3-fold n.p.
    - 2-3g: 342 events
  - 4-fold
    - 2-3g: 50.8 events



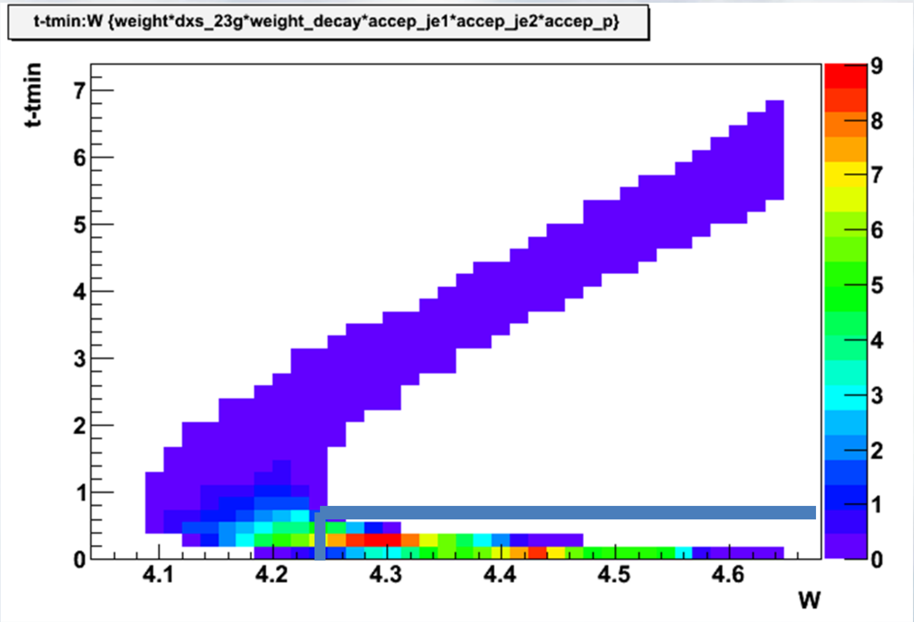
Angular Coverage



Also good coverage of azimuthal angle of J/ψ production angle due to 2π azimuthal coverage in the lab frame.

One can study the J/Ψ Decay Distributions at different kinematics.

3-fold n.s.e.



2-3g: 70 k events

2 g: 20 k events

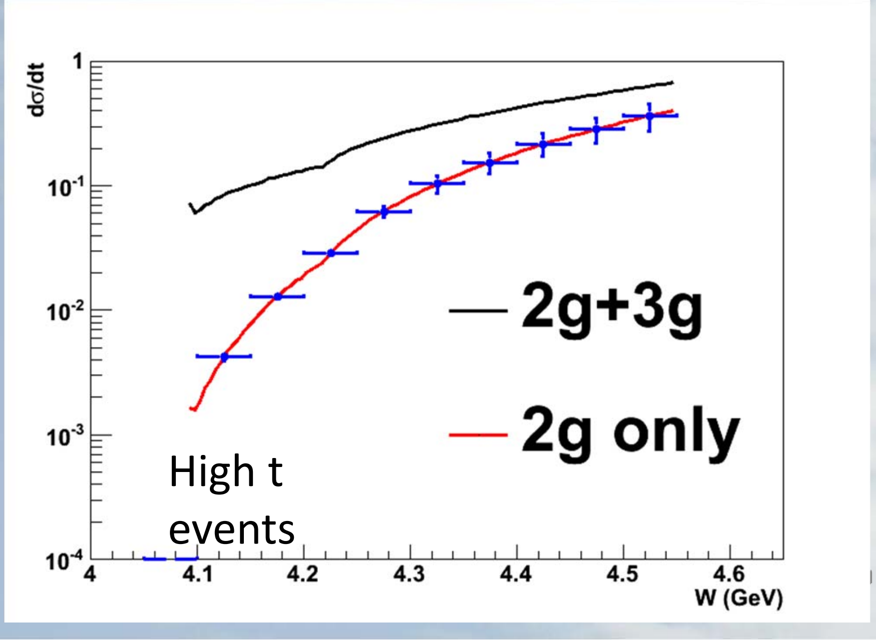
For |t-tmin|>0.5 GeV^2 or W<4.25

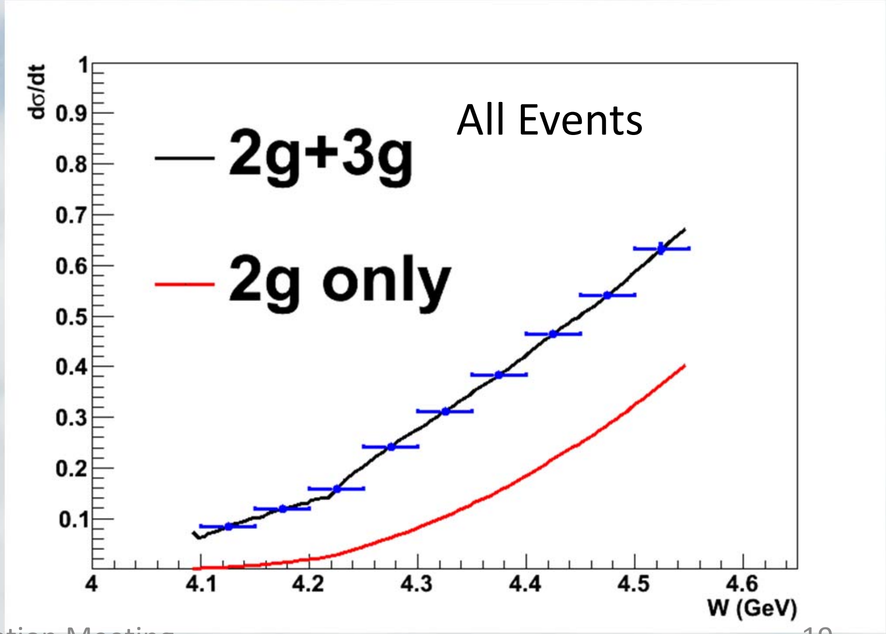
2-3g: 25.4 k events

2g: 3.8 k events

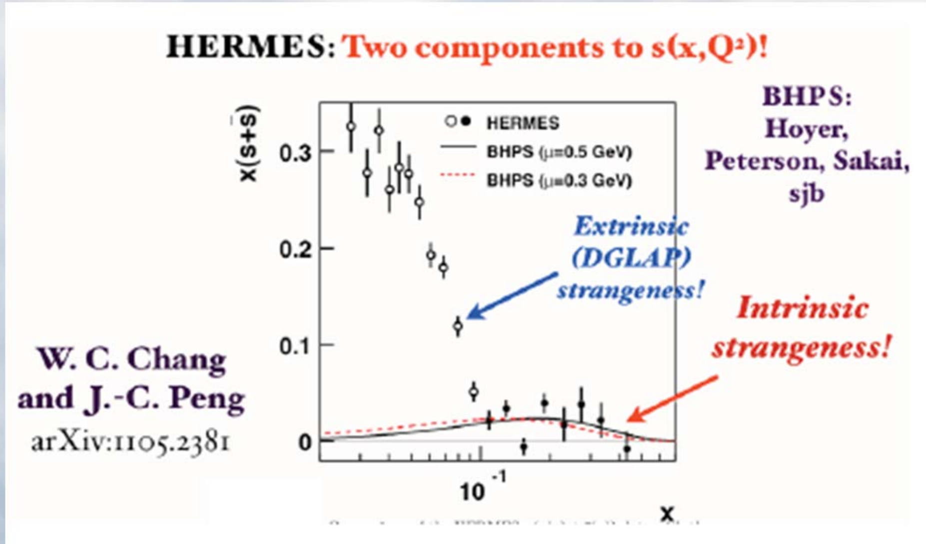
Decay Angular distribution at low t

Cross check eletro-production + threshold enhancement





Physics with Deuteron (incoherent)



- Suggest a 1% intrinsic charm.

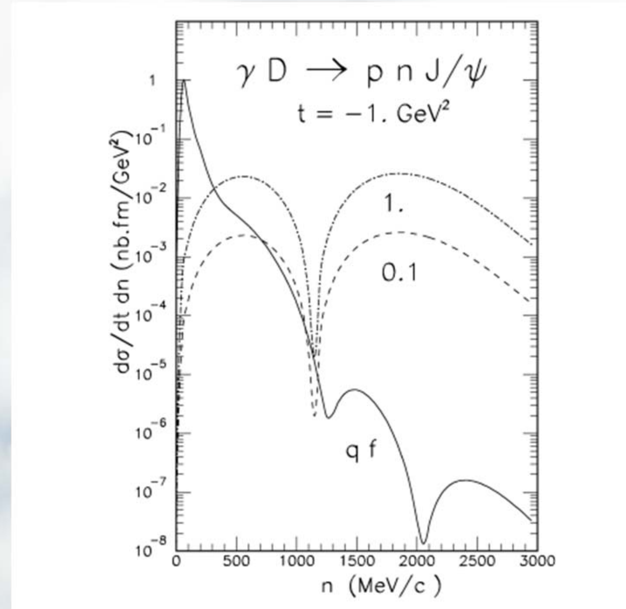
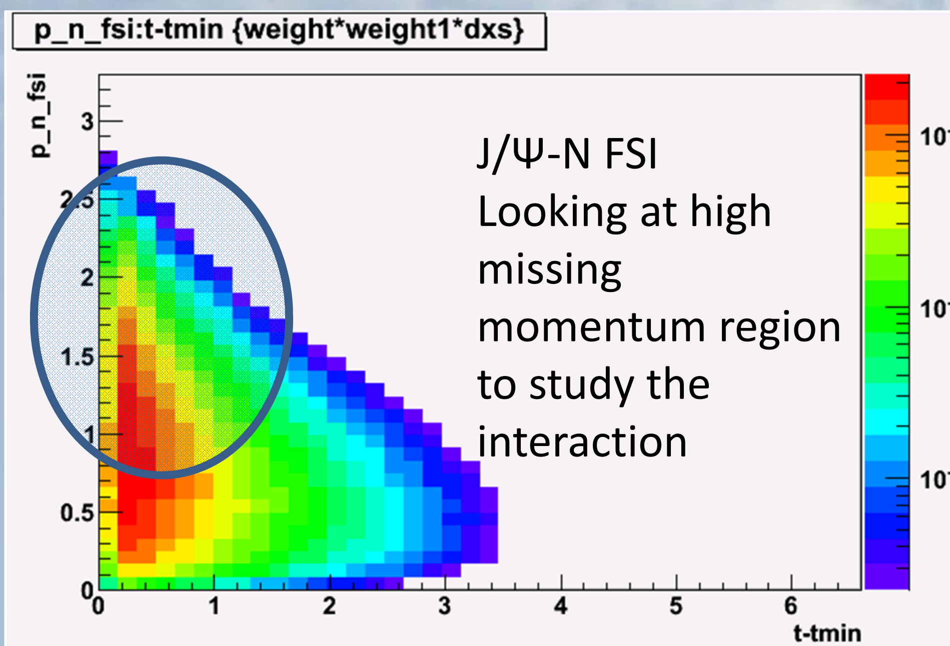


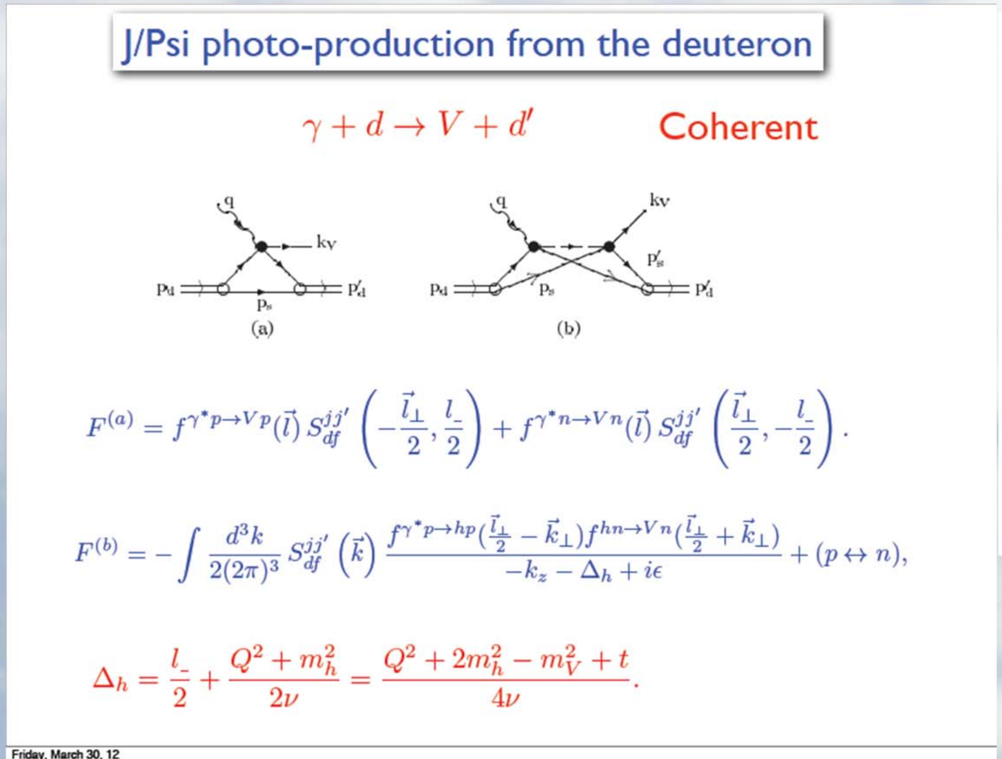
Fig. 5. The variation of the cross-section of the reaction $\gamma D \to pn J/\psi$ against the neutron momentum $|\vec{n}|$, at fixed t. Solid line: quasi-free contribution. Dashed line: contribution of a hidden-color component when its probability is 0.1%. Dash-dotted curve: the same for a probability of 1%.

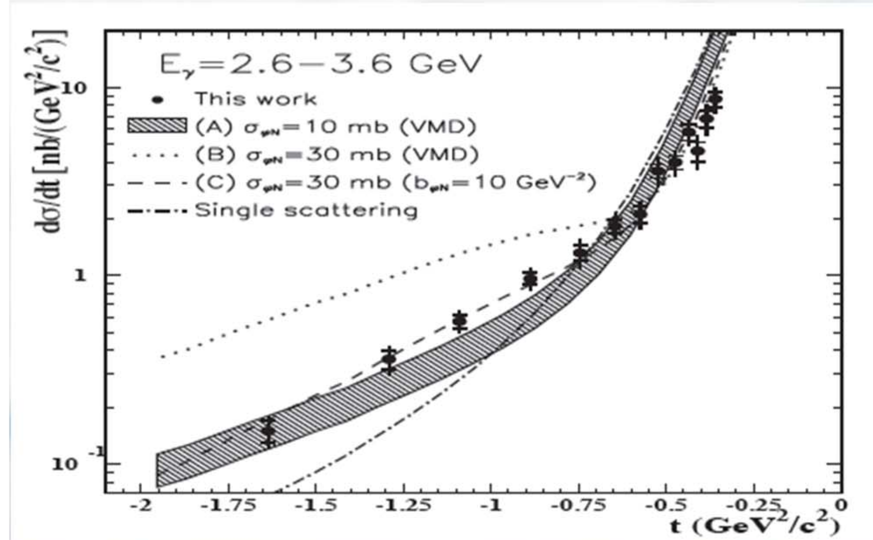
Brodsky et al PLB 498 23 (2001)



- Also $$\frac{d^2\sigma}{dt\,dP_n} \; vs. \; \frac{d\sigma}{dt}$$

Physics with Deuteron (Coherent)





- Also Physics with nuclear target
- Medium propogation of J/ψ (existing Hall C proposal)
- Eugene: SoLID is the ideal device to do this study.

- Search for the change of slope in coherent deuteron production
- Enough Rate?
- Work in progress

Backgrounds

- Random Coincidence
  (e.g. $e^- p + e^+ e^-$)
  - Multiple combinations
  - Suppressed by exclusive condition (detector resolution)
- Physics Backgrounds
- Single rate
  - Rate comparison with Pythia
  - Design of trigger and DAQ
- Background Rate on Detectors @ 1e37 $N/cm^2/s$

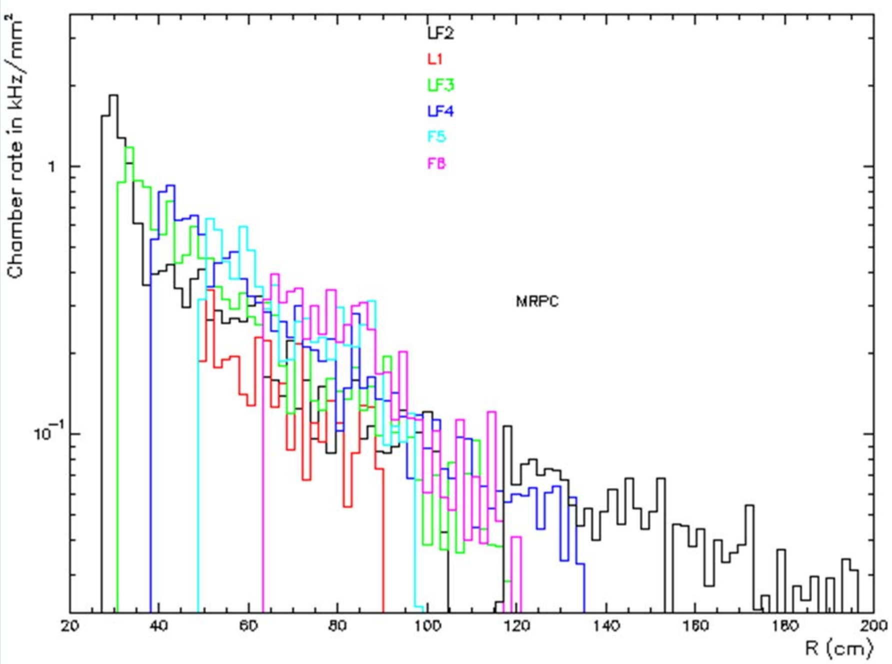
Pythia

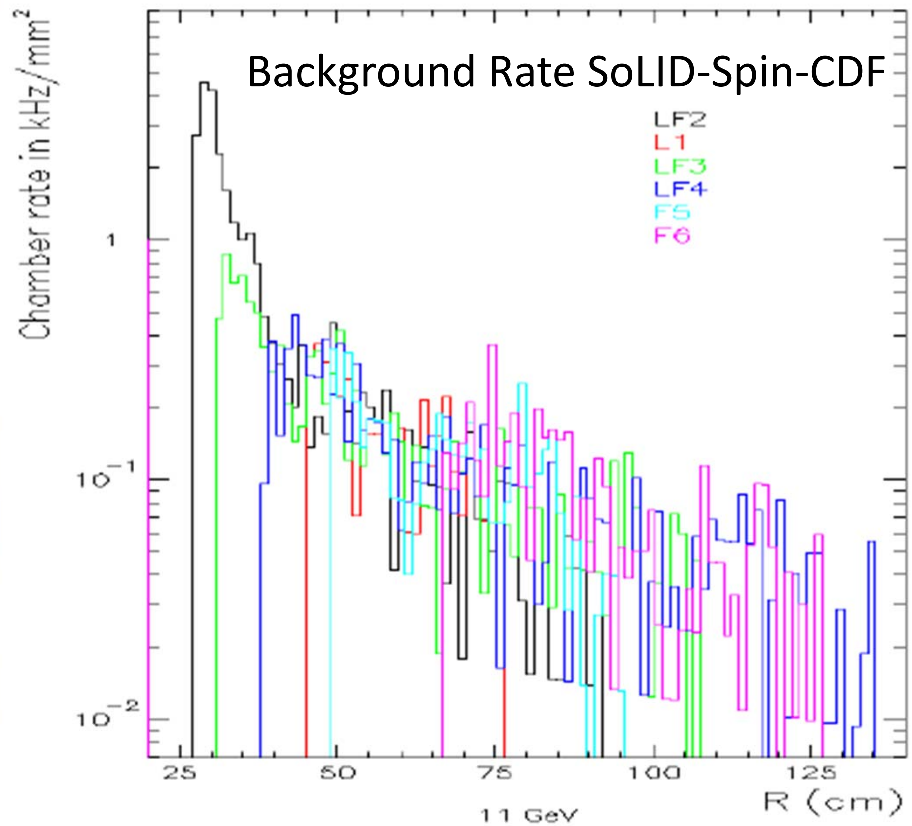
Wiser/QFS

GEANT3

Backgrounds (GEM + MRPC)

Background Rate SoLID-J/Ψ-CLEO

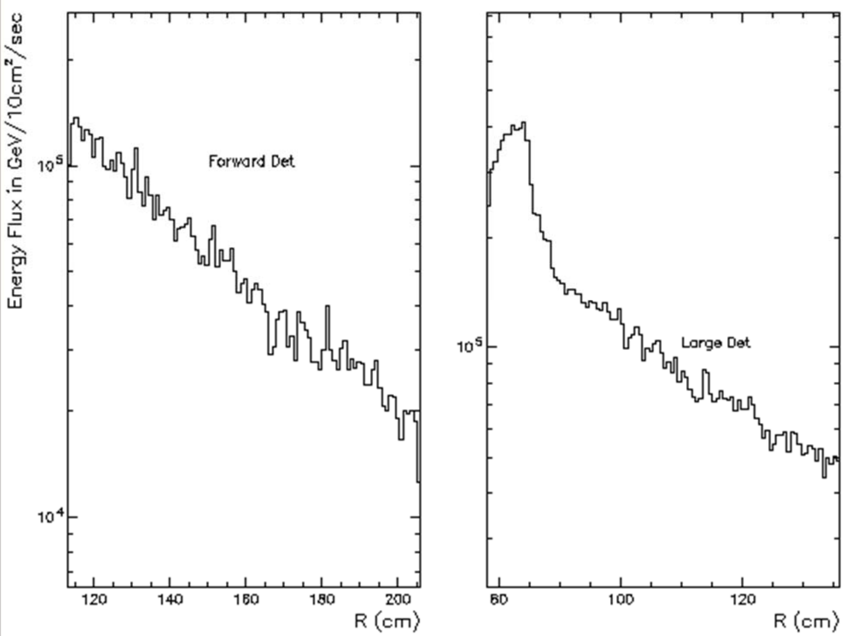




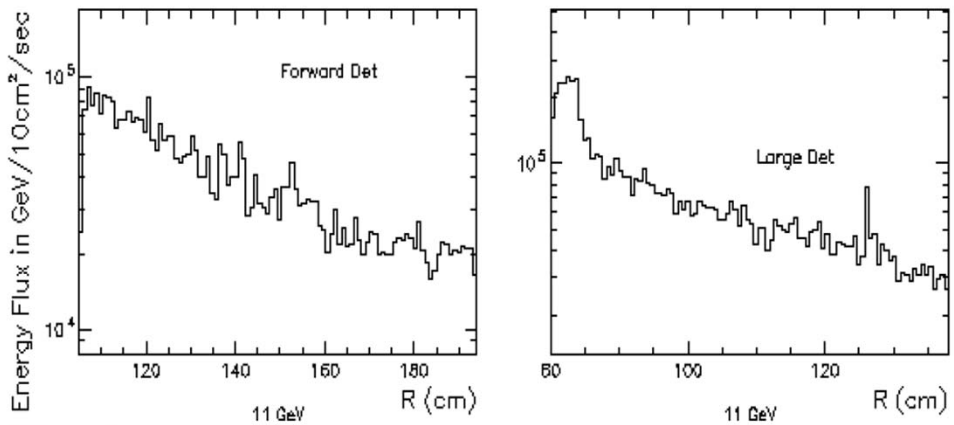
Background rates on GEM are very close to the SoLID-Spin Setup.

Backgrounds (Calorimeter)

Background Rate SoLID-J/Ψ-CLEO



Background Rate SoLID-Spin-CDF



Background rates on Calorimeter are slightly higher without the target collimator.

Trigger Design

- We potentially have the following physics topics:

$$e^- + p \rightarrow e^- + J/\psi(e^- + e^+) + "p"$$

$$e^- + D \rightarrow e^- + p + J/\psi(e^- + e^+) + "n"$$

$$e^- + D \rightarrow e^- + J/\psi(e^- + e^+) + "D"$$

- A triple coincidence of scattered electron, decay electron and positrons from J/Ψ will be good enough for both channels.
- **Trigger Rate < 1 kHz @ 1e37 N/cm^2/s**
- Compare to SIDIS ~50 kHz L2 rate

Backgrounds (Random Coincidence)

$$e^- + p \rightarrow e^- + p + J/\psi(e^- + e^+)$$

We used **e** (scattered electron), **p** (recoil proton), Je (decay electron from J/Ψ) and Jp (decay positron from J/Ψ).

2-fold coincidence includes: (e,p)+(Je,Jp), (e,Je)+(p,Jp), (e,Jp)+(Je,p) and (e,Je,Jp)+(p), (e,Je,p)+(Jp), (e,Jp,p)+(Je), (p,Jp,Je)+(e)

3-fold coincidence includes: (e,p)+(Je)+(Jp), (e,Je)+(p)+(Jp), (e,Jp)+(p)+(Je), (Je,Jp)+(e)+(p), (Je,p)+(e)+(Jp), (Jp,p)+(e)+(Je)

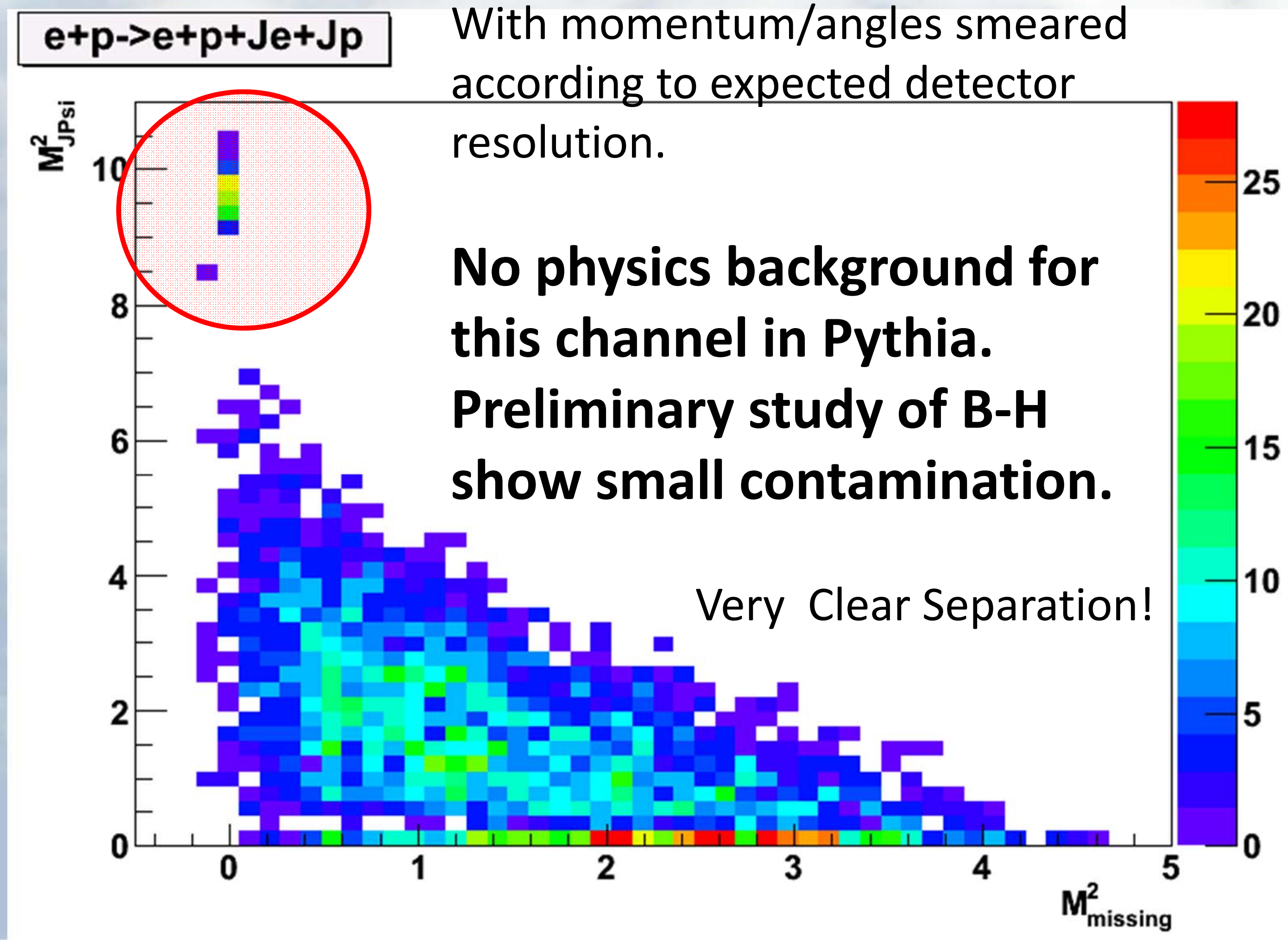
4-fold coincidence is (e)+(p)+(Je)+(Jp)

Pythia (11 GeV e+p)

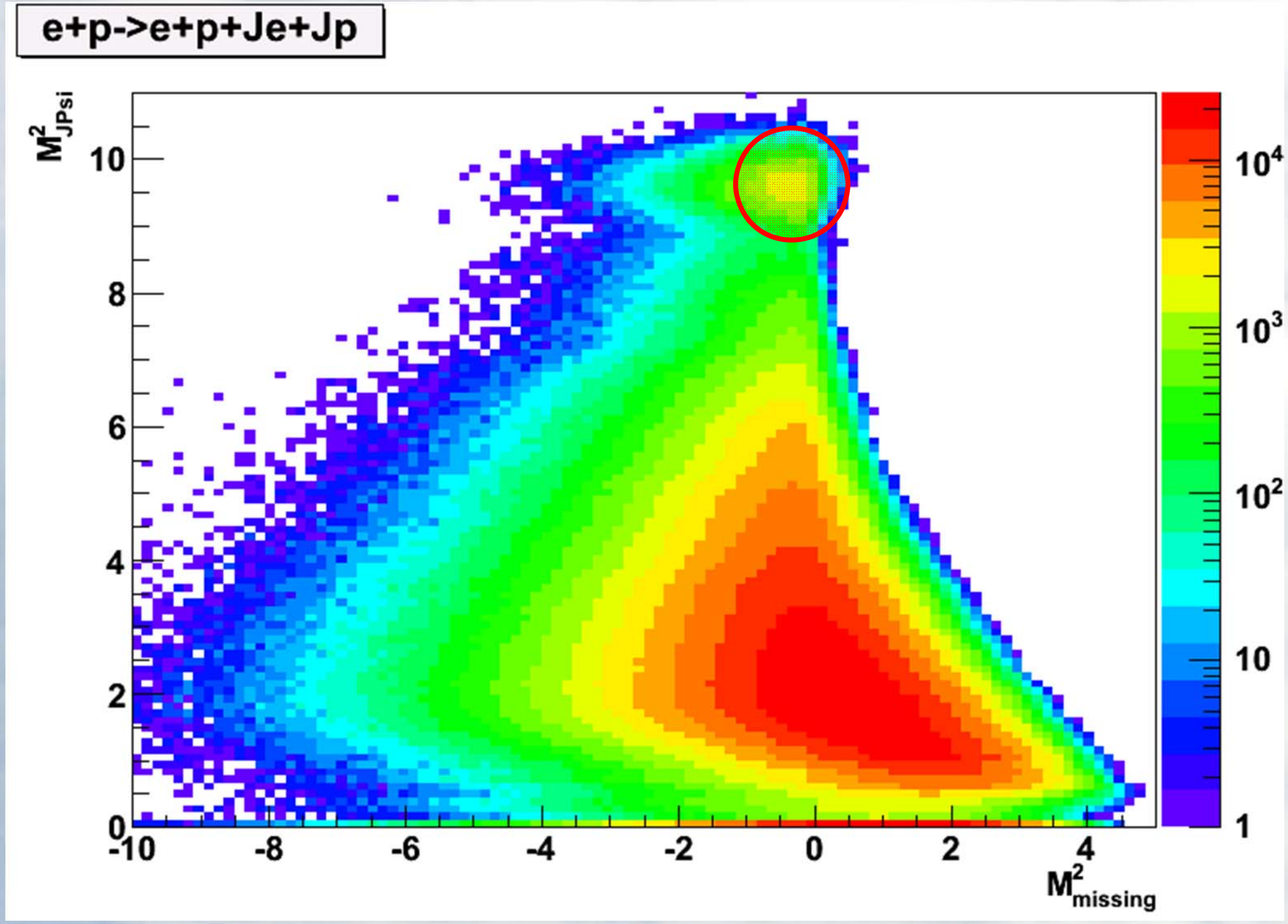
- Use PYTHIA exclusive event generator.
  - Input file (HERMES tuned, from H. Avakian)
  - SIDIS (e,eπ) rates are in reasonable agreement with data/calculations.
  - Event range
    - $0.05 < y < 0.95$ and $0.1 < Q^2 < 1500$ GeV^2
  - Event Selection (mimic SoLID acceptance):
    - Recoil Proton: P > 1 GeV, 8→15 degrees
    - Scattered Electron: 2.5 > P > 1 GeV, 8→ 15 degrees
    - Decay Electron: P > 2.5 GeV 8→25 degrees
    - Decay Positron: P > 2.5 GeV 8→25 degrees

$$e^- + p \to e^- + p + J/\psi(e^- + e^+)$$

- This channel is selected using invariant mass of J/Ψ, and missing mass.



Suppression Factor is 8e-5 for (e,p) + (Je,Jp)



- Random Coincidence Rate is then: 4.3 e-7 Hz
- Physics Rate is 0.015 Hz in Pythia

2-Fold Random Coincidence (Subtractable)

Channel	Rate of first	Rate of second	Suppression Factor	Effective Rate (Hz)
(e,Je)+(Jp,p)	0.28 kHz	67 kHz	3e-7	3.4e-8
(e,Jp)+(Je,p)	0.035 kHz	67 kHz	5e-8	7.0e-10
(e,p)+(Je,Jp)	22.3 kHz	0.04 kHz	8e-5	4.3e-7
(e,Je,Jp)+(p)	0.01 kHz	306 kHz	9.3e-5	1.7e-6
(e,Je,p)+(Jp)	0.04 kHz	0.13 kHz	1.3e-8	4e-13
(e,Jp,p)+(Je)	0.0037 kHz	460 kHz	4.7e-7	4.8e-9
(Je,Jp,p)+(e)	0.0048 kHz	165 kHz	**1.75e-3**	8.3e-6

Physics Rate is 0.015 Hz in Pythia, 1.2e-3 in our calculation

The background is expected to be **< 1%** level for (e,Je,Jp,p).

Long extended target at low beam current would help.

Random Coincidence should not be a problem.

Comparison

- SoLID-Jpsi will emphasize the electro-production and related mechanism.
- Complementary to other Halls
  - Hall B will only do photo-production of J/ψ
    - SoLID will win in luminosity (x50), probably ran later though.
  - Hall C will have 1 or 2 points in W (100→200 events with 2-3 g)
    - SoLID will do a thorough scan in the near-threshold W range.
- We shoot to finish draft proposal by 24^{th} this month. We will circulate draft proposal in SoLID collaboration shortly after that.

Summary

- Near-threshold electro/photo J/ψ production would reveal the role of the non-perturbative gluon interaction.
  - Search for threshold enhancement.
  - J/ψ Decay angular distribution
  - Measure interference with B-H (real vs. imaginary part of amplitude)
  - Also physics with deuteron/nuclei (hidden color, Jpsi-N interaction etc.) to be carefully studied
- SoLID is a near ideal device for this study
  - High luminosity + Large acceptance → Rare signal.