Proposal for J/ψ electroproduction @ JLab 12 GeV: searching for J/ψ-nucleon bound state

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Small size configuration workshop

Jefferson Lab, Newport News

March, 26th, 2011

Outline:

- Introduction: physics interest

- Experimental conditions

- Simulation

- Projected results

- Summary, perspectives

Physics interest

Ultimate goal: understand non-perturbative QCD, by observing/measuring nucleon-meson bound state.

-> significant valence-quark-exchange between nucleon and "light" meson (π, ρ, ...).

-> completely negligible with J/ψ => remains a quasi-pure gluonic contribution.

Hence, interaction between J/ψ and nucleon in a J/ψ-N bound state may be described by the exchange of several soft gluons.
=> QCD "Van der Walls" force.

Physics interest

Brodsky, Schmidt, and de Téramond (1990) discussed the existence of the interaction between quarkonia and nuclei:

- attractive (hence authorizing a binding J/ψ-A state)
- first prediction of the order of magnitude (several 100 MeV, for $A>3$);

First correction by Wasson (1991): order of magnitude of several 10 MeV, still for $A>3$;

Several corrections were then brought to this:
Luke, Mahonar, Savage, using OPE finds ~10 MeV;
Hayashigaki (1999) using QCD sum rules => 4-7 MeV;
Also found a positive binding energy for A = 1;

Physics interest

Yokokawa et al. (2006) finally made a lattice QCD calculation at low energy for J/ψ-N and found a positive binding energy;
=> need of experimental data to confront to this calculation.

The most feasible experiment is the production of J/ψ on nuclei ($\gamma^{(*)}$ A-> J/ψ p' A-1) near threshold and at high t (to minimize the J/ψ momentum, thus maximizing the probability of forming a binding state).
Discrepancy, at high t, of the t-dependences of the ($\gamma^{(*)}$ A-> J/ψ p' A-1) cross section compared to the ($\gamma^{(*)}$ p-> J/ψ p') cross section would be the experimental evidence of a J/ψ-A bound state.

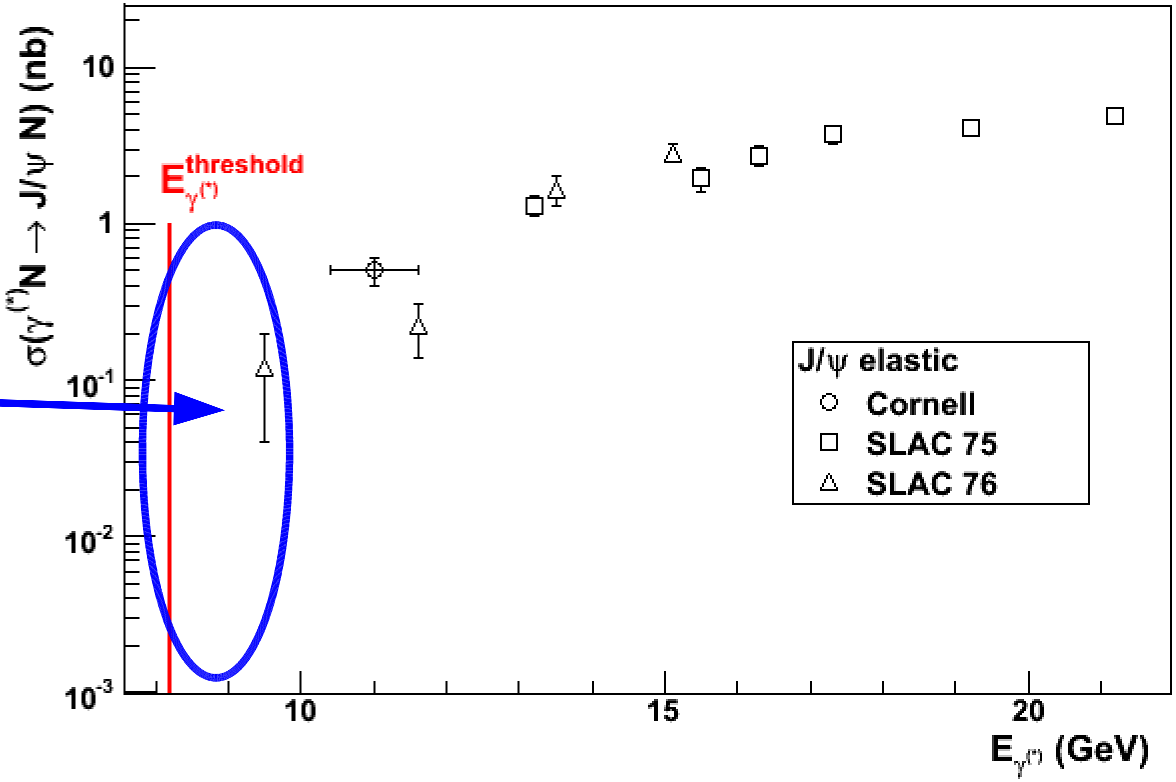
Physics interest

=> compare, at high t and near threshold, the t-dependences of the $(\gamma^{(*)}\, A \to J/\psi\, p'\, A\text{-}1)$ cross section compared to the $(\gamma^{(*)}\, p \to J/\psi\, p')$ cross section...

BUT: no (accurate) data...

A first phase of the experiment would be a precise absolute measurement of $(\gamma^{(*)}\, p \to J/\psi\, p')$ near threshold

No data !



Experimental conditions

* Experimental requirements;

* Experimental setup, kinematics;

* Further experimental constraints:
  - mechanical constraints;
  - background;

Experimental conditions: Requirements

We propose the measurement of J/ψ electroproduction cross section on proton (and deuterium in a second phase) at JLab 12 GeV.

We require full exclusivity on the measurement of the $H(e, e'p\ [J/\psi \to e^+e^-])$ reaction (necessary to constraint $A(e\to e'p\ [J/\psi \to e^+e^-])\{A\text{-}1\})$ -> "sacrifice" on the acceptance.

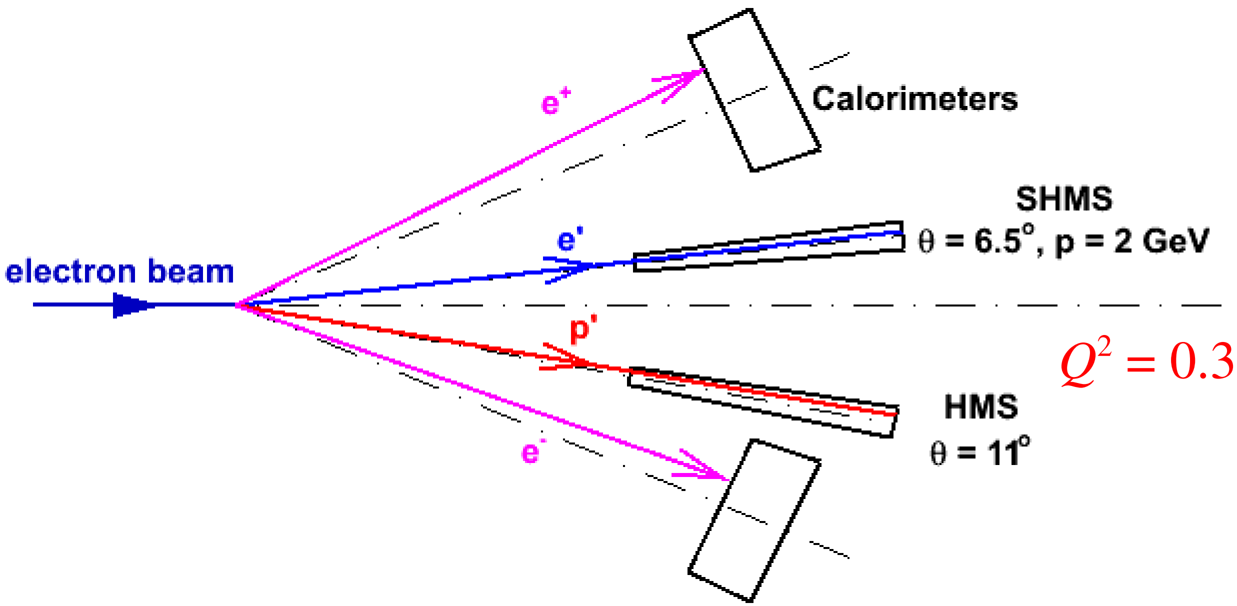
=> Need huge luminosity (several 10^{38} cm^{-2} s^{-1}).

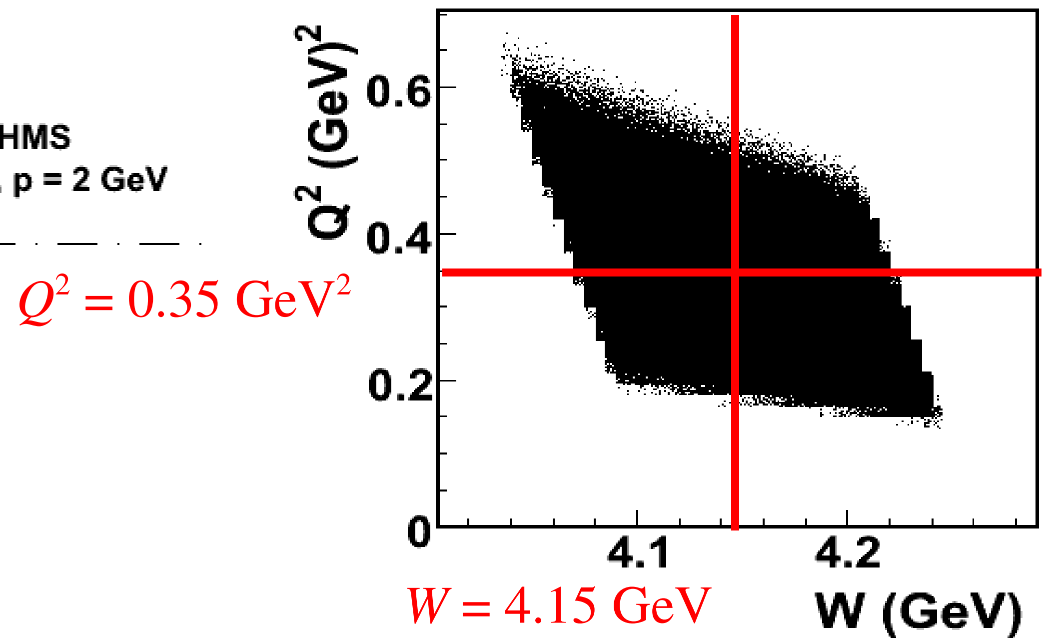
Kinematics requirements:

- highest beam energy, to be above threshold;
- lowest possible Q^2, to achieve decent counting rates.

Experimental conditions: Setup

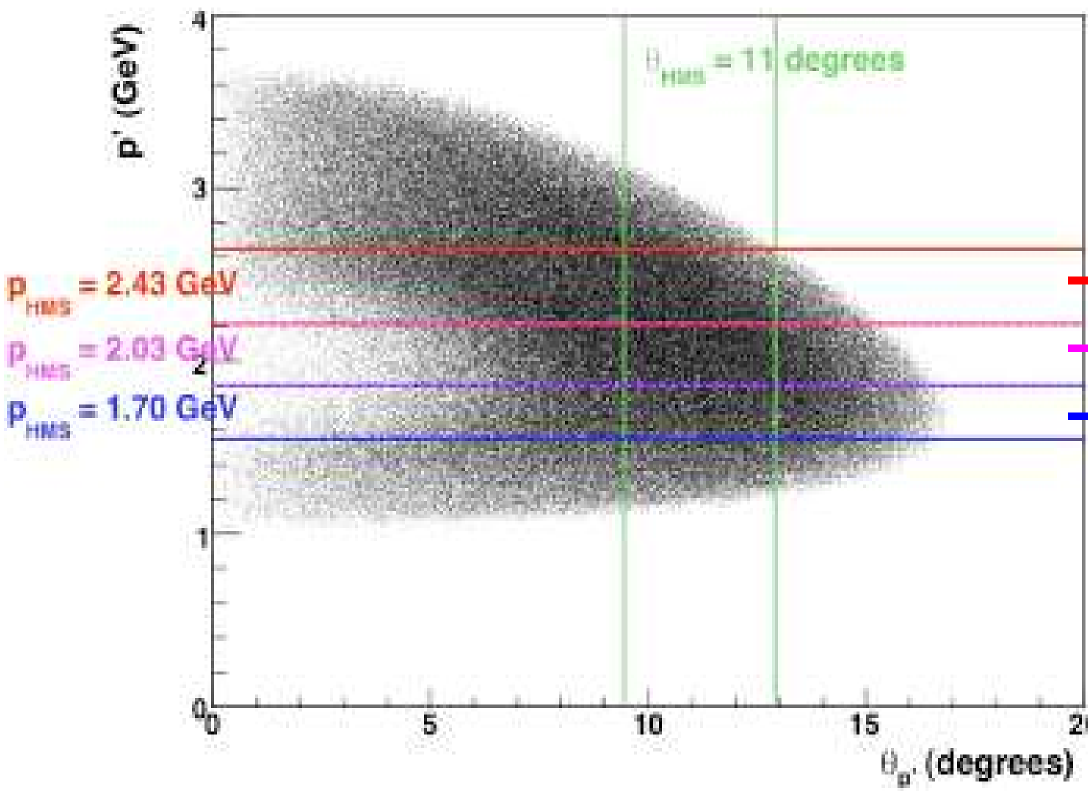
Decision has been made to propose the experiment in the Hall C, with HMS and SHMS.
Scattered electron in SHMS, recoil proton in HMS, electrons of the pair in 2 calorimeters.





Experimental conditions: Setup

Scattered electron in SHMS, recoil proton in HMS, electrons of the pair in 2 calorimeters.

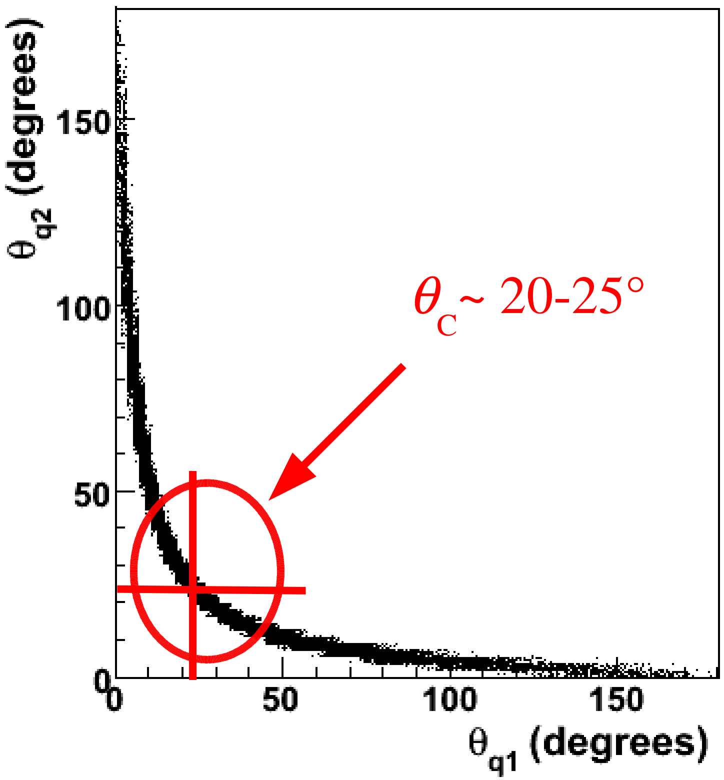


one HMS setting in angle;
three in momentum:

- higher t (Kin 13) = -3.1 GeV^2
- intermediate t (Kin 12) = -2.4 GeV^2
- lower t (Kin 11)= -1.9 GeV^2

Experimental conditions: Setup

Scattered electron in SHMS, recoil proton in HMS, electrons of the pair in 2 calorimeters.



Set symmetrically on both sides of the beam (low Q^2 favors symmetric decays). Their angle would depend on the t setting.

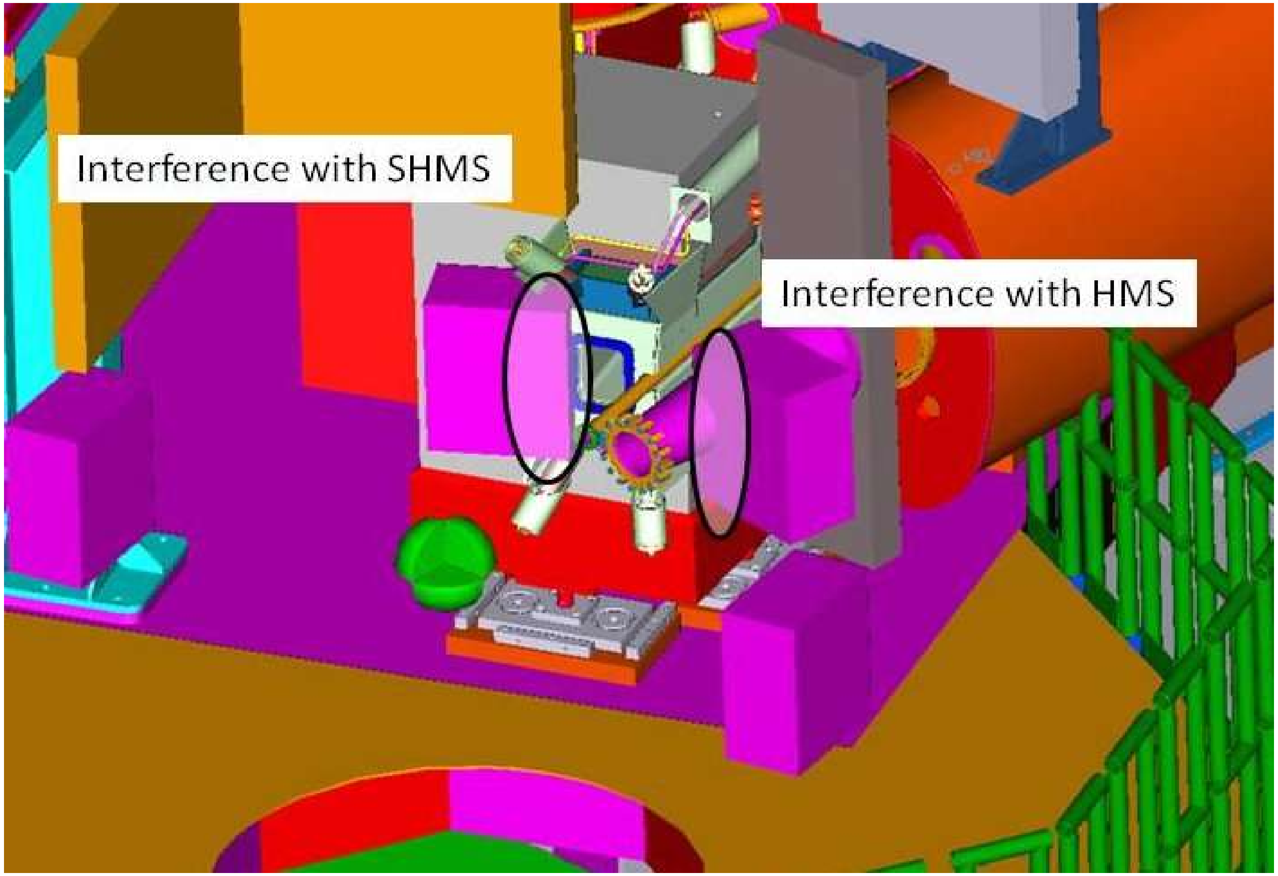
Calorimeters need to be compact, radiation resistant.

=> chose for model the hall A DVCS PbF_2 calorimeter:

13x16 blocks, very compact, one already exists

Experimental conditions: Constraints

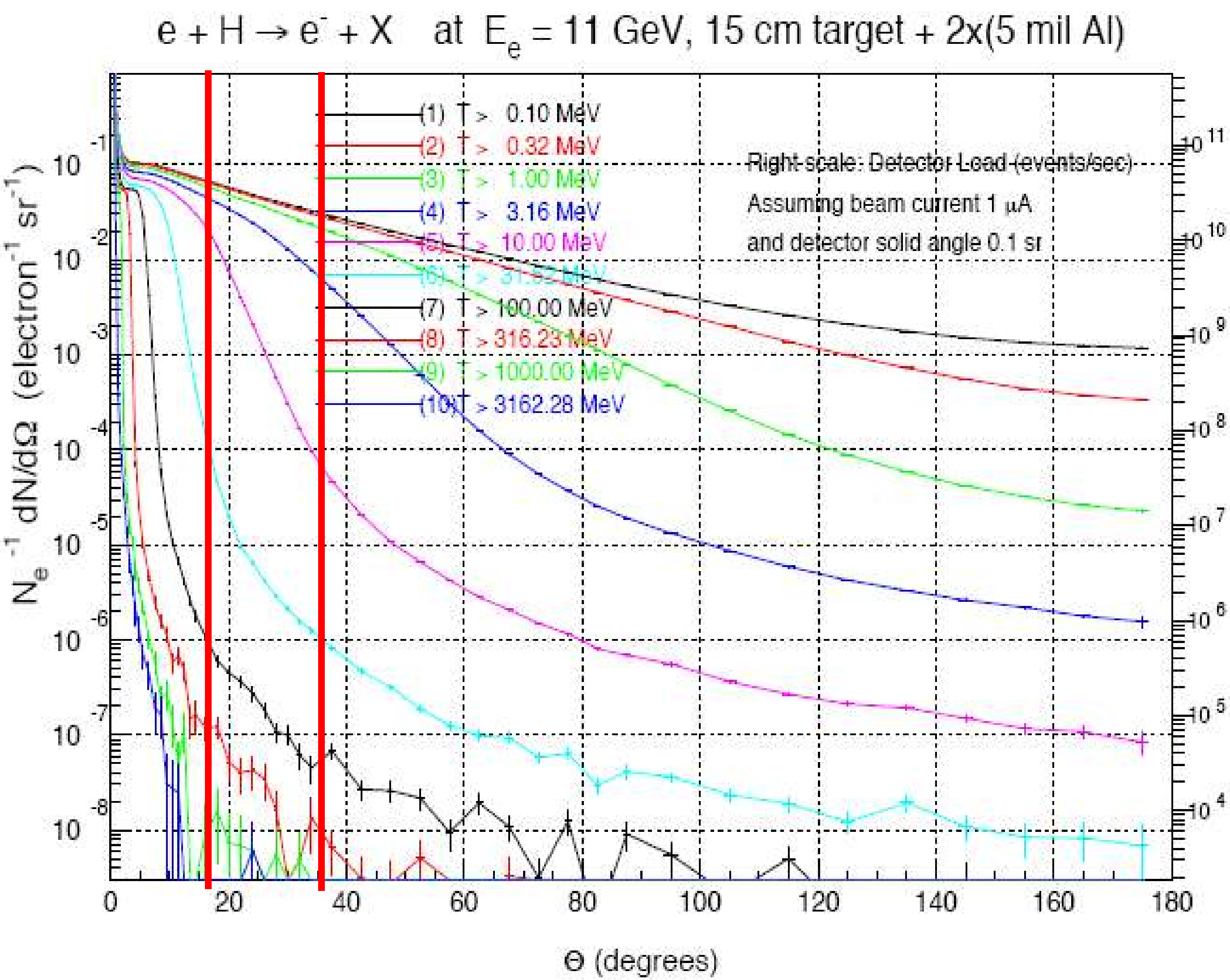
Mechanical constraints:
Calorimeter specifications submitted to the SHMS design team: =>
interferences with the spectrometers snouts at 20°.



seems
compatible at 25°
(eye estimation)

Experimental conditions: Constraints

Background from low energy particles



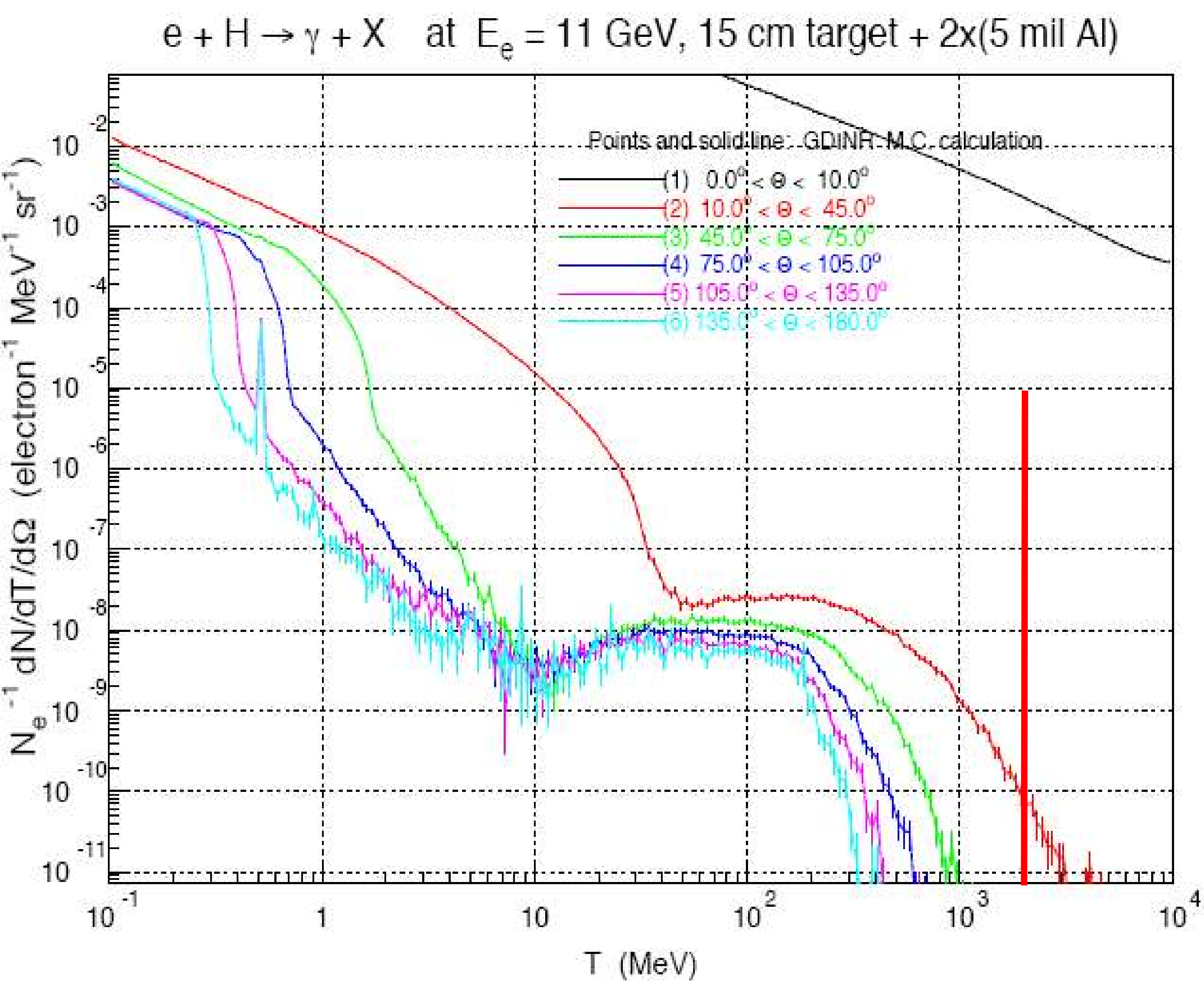
At the closest point of the calorimeter, the dose rate from electromagnetic background would be ~15 mGy/s at a beam current of 55 μA, on a 15 cm LH2 target

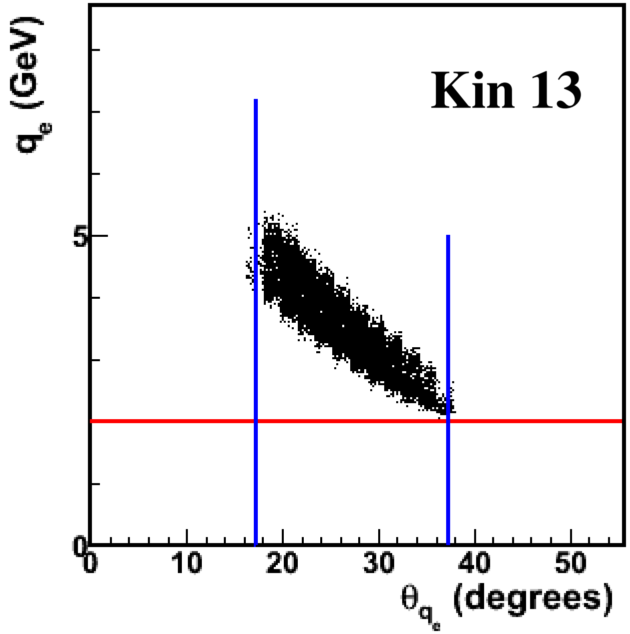
=> 40 kGy over a 720 h run.

PbF2 blocks were observed to stand 35 kGy within 4 hours.

Experimental conditions: Constraints

Rates of accidentals applying a 2 GeV threshold





The rate of > 2 GeV electromagnetic clusters (from photons and electrons) in the calorimeter is 6.5 M/s.

Simulation

* Simulation features

* Cross section model

* Simulation results

Simulation features

Simulation includes:

- Real (external and internal) radiative corrections on incident and scattered electrons;

- Spectrometers resolution effects in momentum and direction;

- Calorimeters resolution effects in momentum and position;

- Cross section model.

Simulation: cross section model

Reference: *J/ψ* photoproduction cross section from Cornell on beryllium, for $9.3\text{ GeV} < E_\gamma < 10.4\text{ GeV}$:

$$\frac{d\sigma}{dt} = A\,e^{bt}$$ (A = 0.94 nb GeV^{-2}, b = 0.97 GeV^{-2})

multiplied by the usual virtual photon flux:

$$\Gamma = \frac{\alpha_{QED}}{2\pi^2}\frac{k'}{k}\frac{k_\gamma}{Q^2}\frac{1}{1-\epsilon}$$

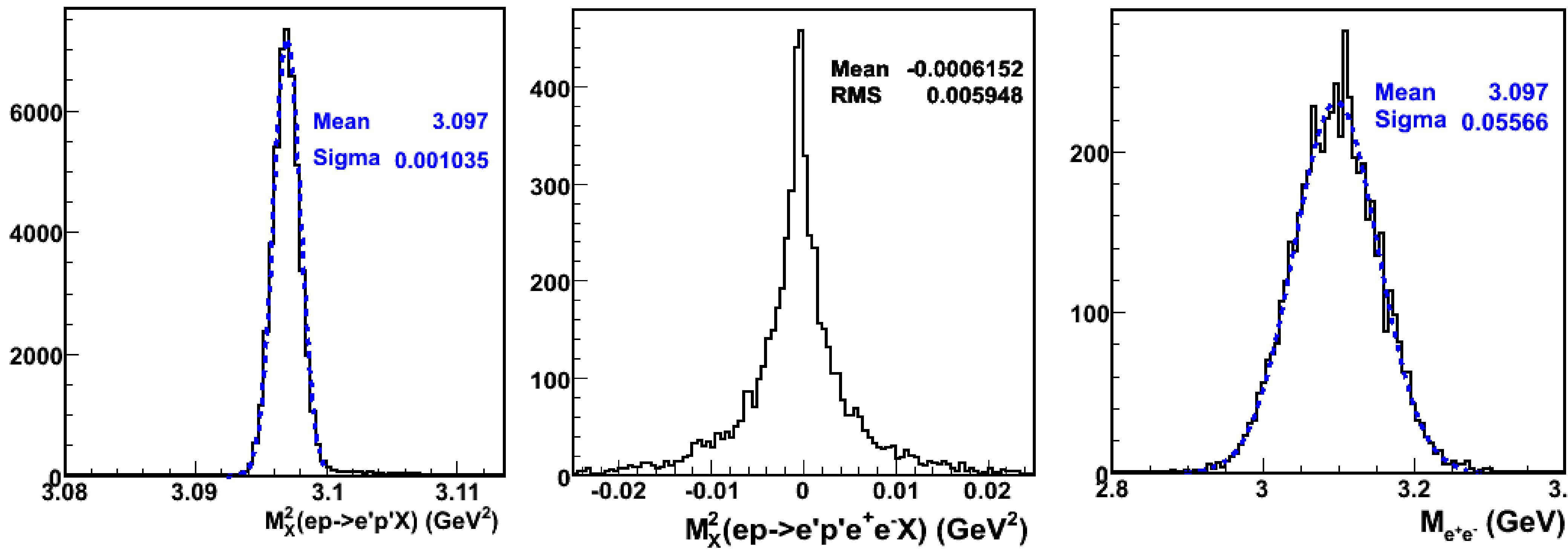
and weighted with the leading term of the vector meson angular distribution (Schilling and Wolf):

$$W(\cos\theta) = \frac{3}{8\pi}\left(1 - r_{00}^{04} + (3r_{00}^{04} - 1)\cos\theta\right)$$

with $r_{00}^{04} = \frac{\epsilon R}{1+\epsilon R}$ and $R = \frac{d\sigma_L}{d\sigma_T} = \left(\frac{a\,m_{J/\psi}^2 - Q^2}{a\,m_{J/\psi}^2}\right)^n - 1$ parameterized by Fiore *et al.* (*a = 2.164*, *n = 2.131*)

Simulation results

Plots of missing masses *ep-> e'p'X* , *ep-> e'p'e⁺e⁻X* , and e^+e^- invariant mass.
No cross section weight.



Projected results

* Projected counting rates

* Projected error bars

Projected counting rates

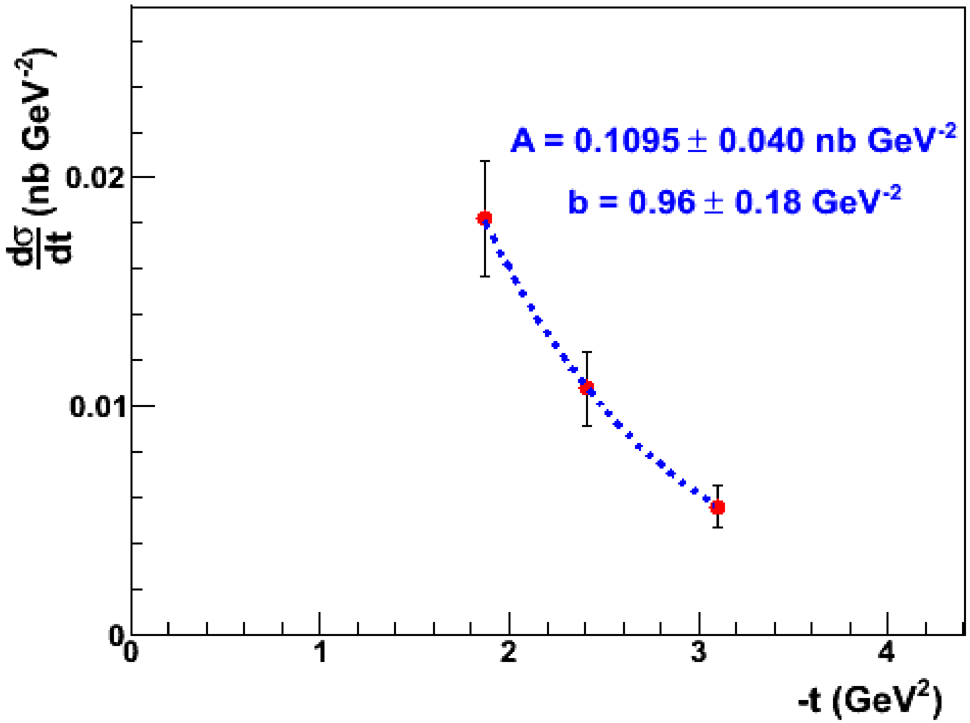
Counting rates for each kinematics, assuming 20 days per setting, and at a current of 55 μA on a 15 cm liquid H_2 target ($\mathcal{L} = 2.10^{38}$ cm^{-2} s^{-1}):

Kin	p_{HMS} (GeV)	θ_C (°)	$\int d\sigma$ $(10^{-11}\text{nb})^{-1}$	Counts
11	1.70	25.0	29.20	50
12	2.03	25.0	26.86	46
13	2.43	25.0	20.28	35
total Kin1			76.34	131

(θ_{SHMS} = 6.5°, p_{SHMS} = 2 GeV, θ_{HMS} = 11 °)

Projected error bars

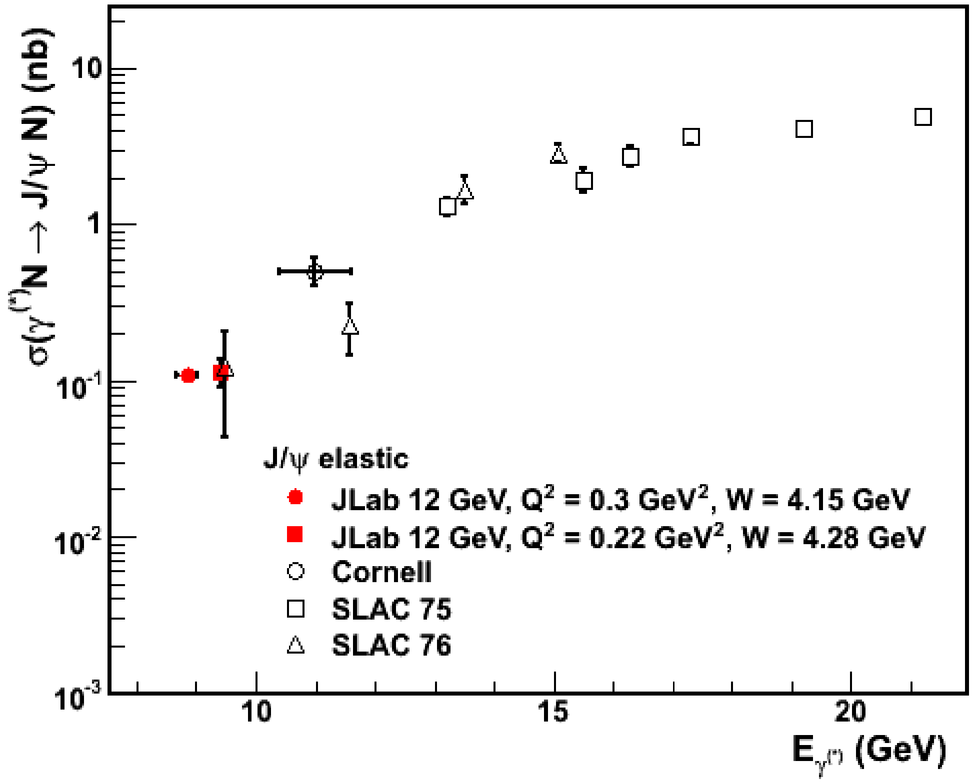
Projected $d\sigma/dt$ and error bars:



compatible with model input.

$A/\langle W(\cos\theta)\rangle = 0.92$ nb GeV^{-2}

Total projected cross section:



the relatively low counting rates already allows to achieve unprecedented statistical precision.

Summary

Projected counting rates would allow to set a new level of statistical precision to J/ψ electroproduction.

In the actual design status, most of the apparatus is already available, so the experiment would be affordable.

A letter of intent about J/ψ electroproduction in Hall C has already be submitted to PAC37. This letter received encouragements.

Perspectives

Still, work remains to do, mainly about the background issues :

- A Geant 4 simulation of the background is of course underway, to improve the understanding/handling of the background;

- Other instrumental prospects are underway, such as the addition of GEMs to the calorimetric system.

Back-up

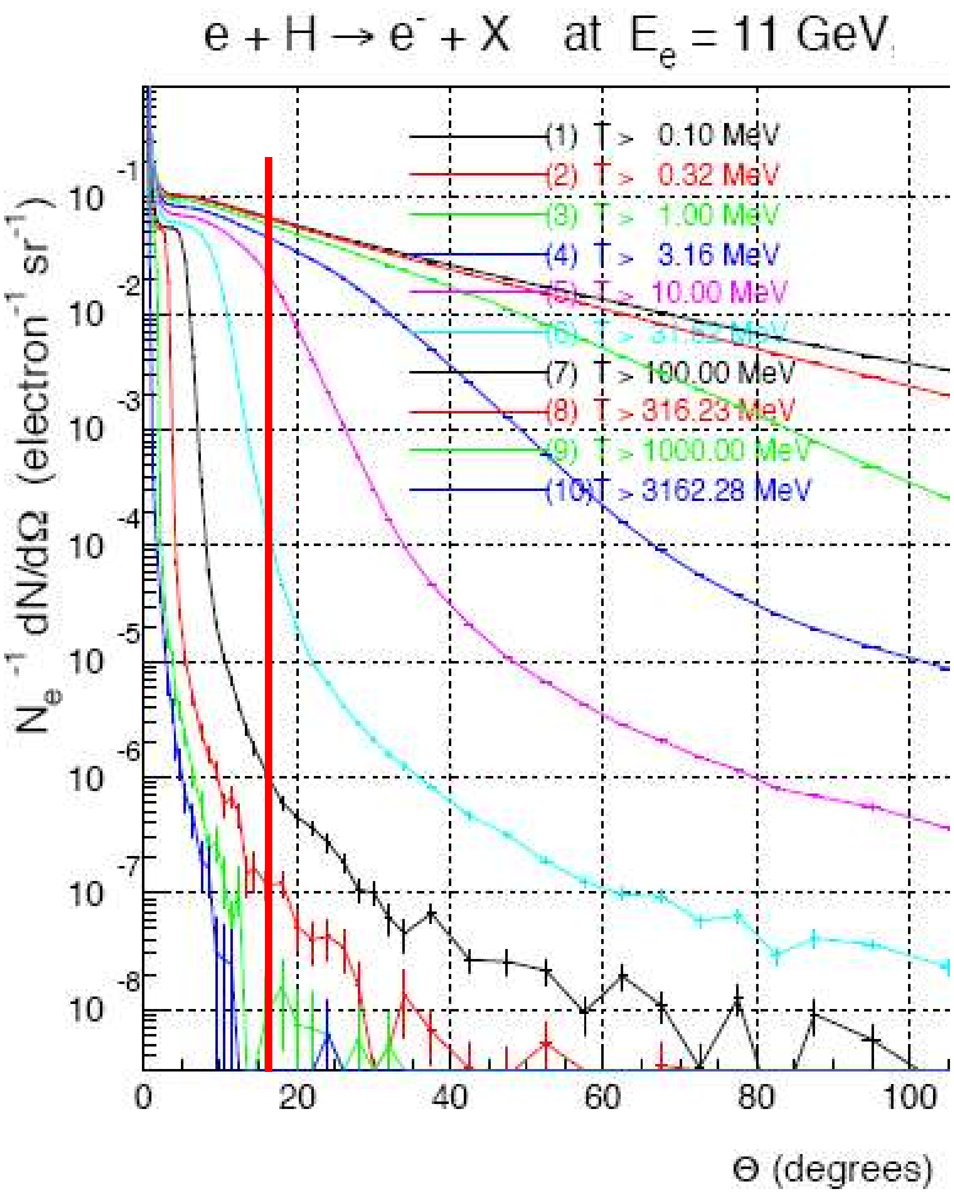
Hall C Spectrometers specifications:

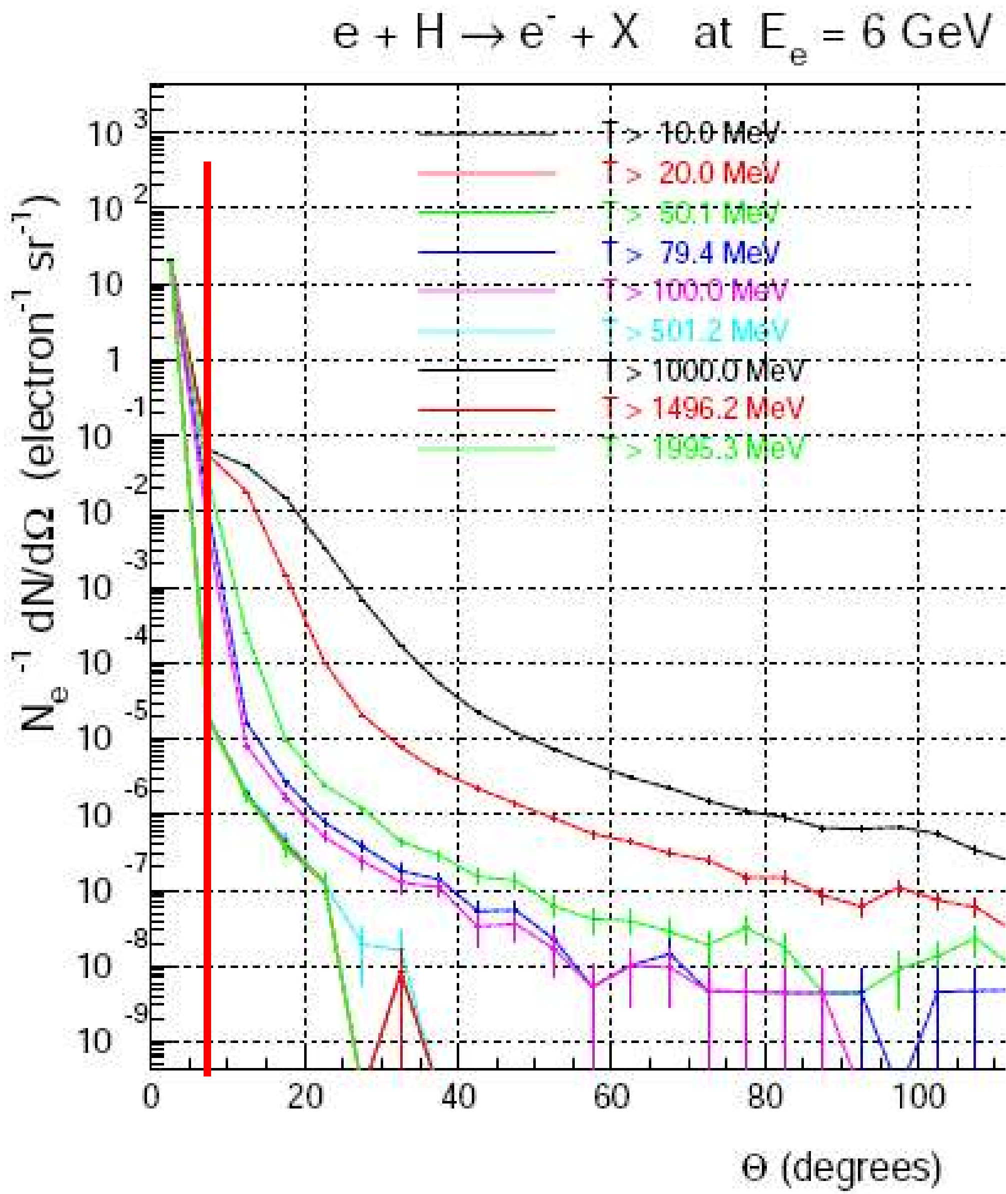
	p range (GeV)	$\delta p/p$ min/max (%)	σ_p/p (%)	θ_{in} range* (°)	$\Delta\theta_{in}$ (mrad)	$\Delta\theta_{out}$ (mrad)	σ_θ (mrad)	$\sigma_v/\sin\theta$ (mm)
HMS	1-7.3	$\pm$ 9	0.1	11-90	24	70	1	1
SHMS	2-11	-10/+22	0.1	5.5-25	24	50	1	3

Calorimeters specifications:

Material	distance from target (m)	width (cm)	height (cm)	depth (cm)	channel (block) size (cm $\times$ cm)	$\delta E/E$ (%)	$\delta x/x$ (mm)
PbF_2	1.1	39	48	18.5	3×3	< 2.5	< 3

Background: comparison between *J/ψ* electroproduction and DVCS





ep -> ep J/ψ cross section model: full formalism

$$\frac{d^7\sigma}{dk'\,d\cos\theta_{k'}\,d\phi_{k'}\,dt\,d\phi_{qq'}\,d\cos\theta_{q'q_1}\,d\phi_{q'q_1}} = \Gamma\,\frac{d\sigma}{dt}\,W(\cos\theta_{q'q_1})$$

$$\frac{d\sigma}{dt} = A\exp(bt)$$ A = 0.94 nb GeV^{-2}, b = 0.97 GeV^{-2}

$$\Gamma = \frac{\alpha_{QED}}{2\pi^2}\,\frac{k'}{k}\,\frac{k_\gamma}{Q^2}\,\frac{1}{1-\epsilon} \qquad k_\gamma = \frac{W^2-M^2}{2M} \qquad \epsilon = \left(1+2\frac{\vec{q}^{\,2}}{Q^2}\tan^2\theta_{k'}\right)^{-1}$$

$$W(\cos\theta_{q'q_1}) = \frac{3}{8\pi}\left(1-r_{00}^{04}+(3r_{00}^{04}-1)\cos\theta_{q'q_1}\right)$$

$$r_{00}^{04} = \frac{\epsilon R}{1+\epsilon R} \qquad R = \frac{d\sigma_L}{d\sigma_T} = \left(\frac{a\,m_{J/\psi}^2 - Q^2}{a\,m_{J/\psi}^2}\right)^n - 1$$ a = 2.164, n = 2.131

Counting rates determination

The number of events for each kinematics is given by:

$$N = \sum_{i \in 4-coinc} \frac{d^7\sigma}{d\Phi^7}(\Phi_i^n)$$ Integrated cross section over accepted events of the uniform simulation

$$\times \frac{\Delta\Phi_{gen}}{N_{gen}}$$ Generation normalization

$$\times \int \mathcal{L}\, dt$$ Experimental integrated luminosity

$$\times BR_{J/\psi \to ee}$$ Branching ratio of J/ψ decay in electron pair

$$\times \eta^2_{spectro}$$ Spectrometer global inefficiency (set to 0.5, likely overestimated)