Complete separation of deeply virtual photon and π^0 electroproduction observables of unpolarized protons

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Hall A Collaboration Meeting
Jan 5, 2007

Hall A Collaboration proposal (70+ collaborators, 20+ institutions)

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(**Jefferson Lab Hall A Collaboration PAC-31 proposal**)

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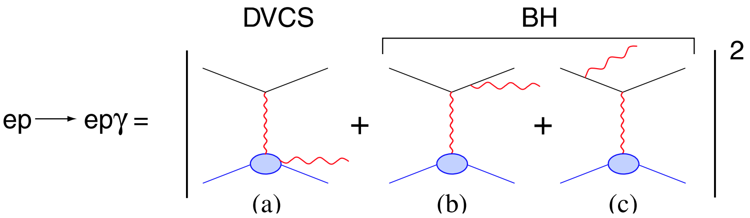
Motivation

$$\sigma(ep \to ep\gamma) = \underbrace{|BH|^2}_{\text{Known to } \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$



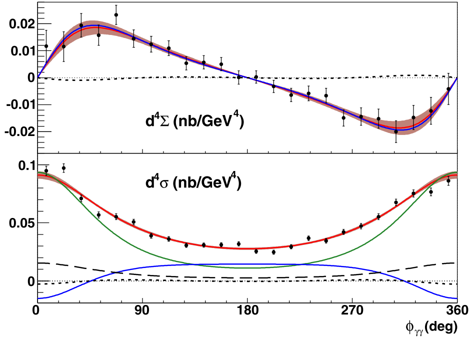
E00-110

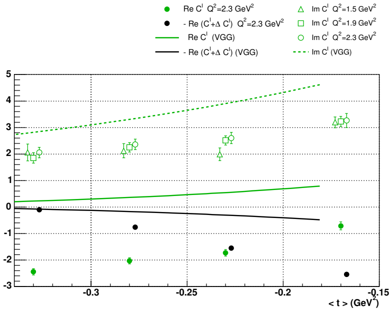
PRL**97**, 262002 (2006)

First dedicated DVCS experiment

Accurate measurement of the DVCS:

- helicity-dependent ($d^4\Sigma$) cross section for $Q^2 = 1.5$, 1.9, 2.3 GeV^2,
- helicity-independent ($d^4\sigma$) cross section for $Q^2 = 2.3$ GeV^2.





DVCS cross section

$$\frac{d^5\sigma}{d^5\Phi} = \underbrace{\frac{d^5\sigma(|BH|^2)}{d^5\Phi}}_{\text{Known from FF}} + \underbrace{\Gamma\,\eta\;\mathcal{C}^{\text{DVCS}}(\mathcal{F},\mathcal{F}^*)}_{|\text{DVCS}|^2\text{ (twist-2)}} +$$

$$\underbrace{(\Gamma_0^{\Re} - \cos(\phi_{\gamma\gamma})\Gamma_1^{\Re})\Re\text{e}\left[\mathcal{C}^I(\mathcal{F})\right] + \Gamma_{0,\Delta}^{\Re}\Re\text{e}\left[\mathcal{C}^I + \Delta\mathcal{C}^I\right](\mathcal{F}) + \cos(2\phi_{\gamma\gamma})\Gamma_2^{\Re}\Re\text{e}\left[\mathcal{C}^I(\mathcal{F}^{\text{eff}})\right]}_{\text{Interference BH-DVCS}}$$

- $$\Re\text{e}\left[\mathcal{C}^{I,\,\text{exp}}(\mathcal{F})\right] = \Re\text{e}\left[\mathcal{C}^I(\mathcal{F})\right] + \langle\eta_{c1}\rangle\,\mathcal{C}^{\text{DVCS}}(\mathcal{F},\mathcal{F}^*)$$
- $$\Re\text{e}\left[\mathcal{C}^{I,\,\text{exp}} + \Delta\mathcal{C}^{I,\,\text{exp}}\right](\mathcal{F}) = \Re\text{e}\left[\mathcal{C}^I + \Delta\mathcal{C}^I\right](\mathcal{F}) + \langle\eta_0\rangle\,\mathcal{C}^{\text{DVCS}}(\mathcal{F},\mathcal{F}^*)$$

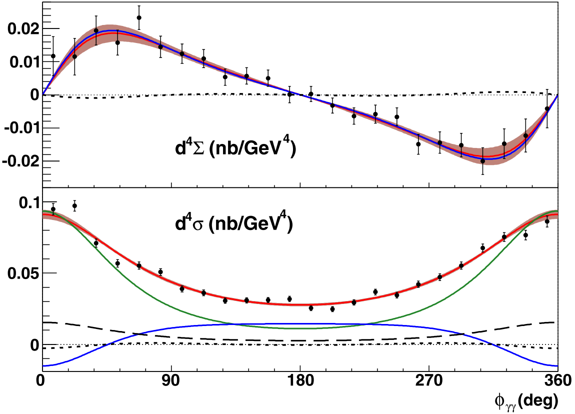
$$|\langle\eta_{0,c1}\rangle|_{E00-110} < 0.05$$

However...

$\langle\eta_{0,c1}\rangle$ depends on the *beam energy*,
which allows a Rosenbluth-like separation of BH·DVCS and DVCS^2
(**This proposal**)

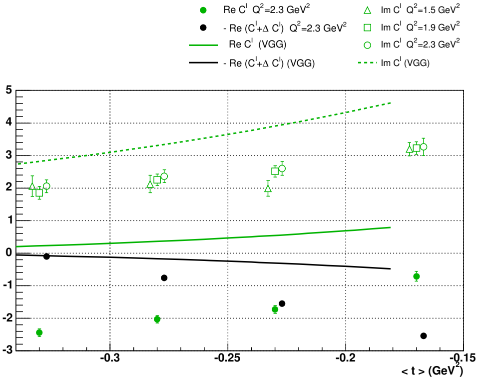
Experimental evidence of large DVCS^2 (a)

BH much smaller than total cross section $\Rightarrow$ BH·DVCS *interference alone* **cannot** explain the difference



Experimental evidence of large DVCS^2 (b)

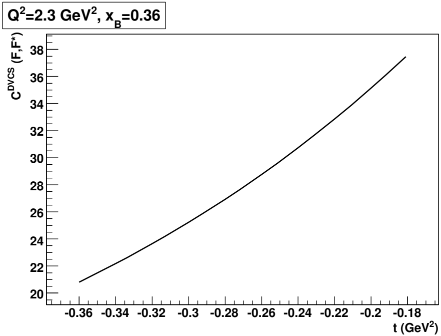
$\Delta\mathcal{C}^{\mathcal{I}}$ is kinematically suppressed wrt. $\mathcal{C}^{\mathcal{I}}$ $\Rightarrow$
$\mathcal{C}^{\mathcal{I}}$ and $(\mathcal{C}^{\mathcal{I}} + \Delta\mathcal{C}^{\mathcal{I}})$ are expected to be very similar
(unless "contaminated" by DVCS^2 terms neglected)



Theoretical prediction (VGG) for DVCS[2]

$$\Re\mathrm{e}\left[\mathcal{C}^{I,\,\mathrm{exp}}(\mathcal{F})\right] = \Re\mathrm{e}\left[\mathcal{C}^{I}(\mathcal{F})\right] + \langle\eta_{c1}\rangle\,\mathcal{C}^{\mathrm{DVCS}}(\mathcal{F},\mathcal{F}^*)$$

- $|\langle\eta_{c1}\rangle| < 0.05$
- $\Re\mathrm{e}\left[\mathcal{C}^{I,\,\mathrm{exp}}\right] \sim -2$



$\langle\eta_{c1}\rangle\,\mathcal{C}^{\mathrm{DVCS}}(\mathcal{F},\mathcal{F}^*)$ is of the same order as $\Re\mathrm{e}\left[\mathcal{C}^{I,\,\mathrm{exp}}\right]$

π^0 electroproduction ($ep \rightarrow ep\pi^0$)

At leading twist:

$$\frac{d\sigma_L}{dt} = \frac{1}{2}\Gamma \sum_{h_N, h_{N'}} |\mathcal{M}^L(\lambda_M = 0, h'_N, h_N)|^2 \propto \frac{1}{Q^6} \qquad \sigma_T \propto \frac{1}{Q^8}$$

$$\mathcal{M}^L \propto \left[\int_0^1 dz \frac{\phi_\pi(z)}{z}\right] \int_{-1}^1 dx \left[\frac{1}{x-\xi} + \frac{1}{x+\xi}\right] \times \left\{\Gamma_1 \widetilde{H}_{\pi^0} + \Gamma_2 \widetilde{E}_{\pi^0}\right\}$$

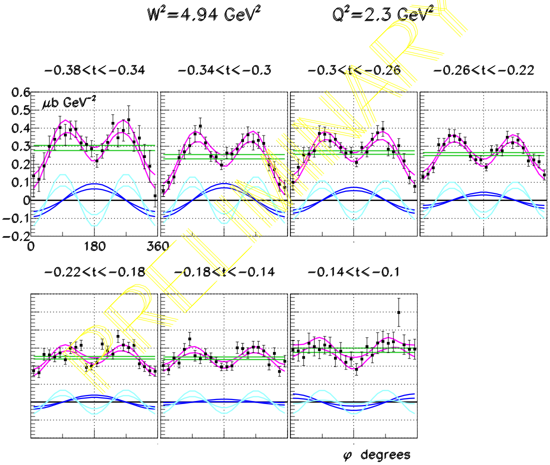
Different quark weights: flavor separation of GPDs

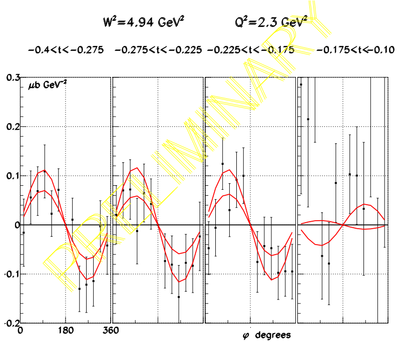
$$|\pi^0\rangle = \frac{1}{\sqrt{2}}\{|u\bar{u}\rangle - |d\bar{d}\rangle\} \qquad \widetilde{H}_{\pi^0} = \frac{1}{\sqrt{2}}\left\{\frac{2}{3}\widetilde{H}^u + \frac{1}{3}\widetilde{H}^d\right\}$$

$$|p\rangle = |uud\rangle \qquad H_{DVCS} = \frac{4}{9}H^u + \frac{1}{9}H^d$$

E00-110: π^0 electroproduction *preliminary* results

$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + \lambda\sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{dt}\sin\phi$$





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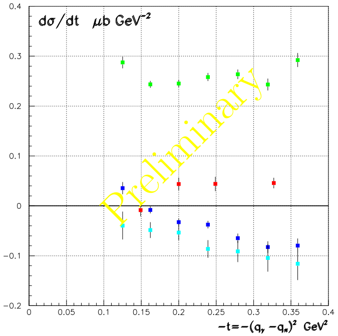
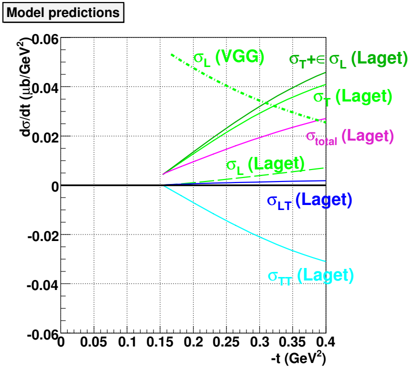




Hints that σ_L *may* be large (enough)

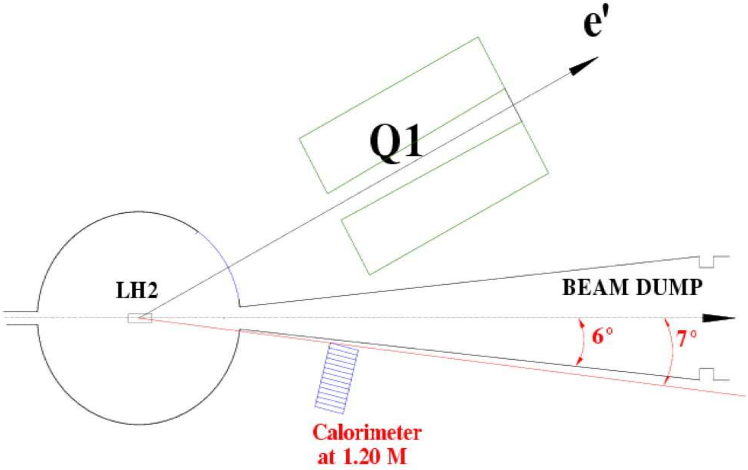
PR-07-007

We propose:

1. To use the beam energy dependence of the BH and DVCS amplitudes to **isolate the BH·DVCS interference term from the pure DVCS^2** contribution (as a function of Q^2):
   - Extraction of both *linear* and *bilinear* combination of GPDs
   - Additional test of DVCS scaling (unpolarized cross section)

2. To measure the **5 response functions of the deep virtual π^0 channel**, in particular $d\sigma_L$ and $d\sigma_T$ by a Rosenbluth separation (as a function of Q^2):
   - First test of factorization in $ep \to ep\pi^0$
   - If positive, valuable complementary (flavor) information on GPDs

Experimental setup

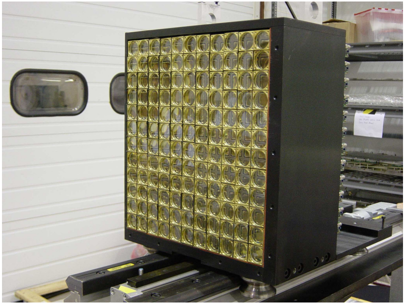


Electromagnetic calorimeter

Array of 13×16 PbF_2 blocks

- 3×3 cm^2. Total size 39×48 cm^2.
- 18 cm long ($\sim$20 radiation lengths).
- Hamamatsu 5900U PMTs.

E00-110 calorimeter



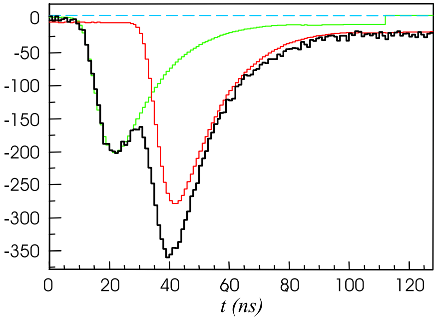
- Energy resolution: 2.4% at 4.2 GeV
- Position resolution: 2 mm at 1.1 m

Upgrade (from E00-110):

- 76 additional blocks

DAQ: *Analog Ring Sampler* (ARS) and upgraded trigger

Calorimeter pile-up limits *instantaneous* **luminosity**



Upgraded calorimeter trigger:

- Lower threshold on 2-cluster events: more statistics for π^0

Calorimeter optical curing

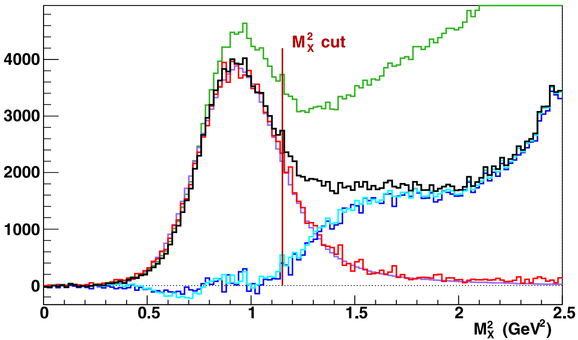
Calorimeter radiation damage limits *integrated* **luminosity**

Optical curing with UV blue light
(Tests to be performed during Summer 2007 at the FEL/JLab)

- We will run at 10 μA (maximum instantaneous luminosity of E00-110)
- We will cure the calorimeter every time we lose 20% transparency
  - This will require 3 curing cycles (1 day of time each)

Exclusivity

Missing mass squared $ep \to e\gamma X$ (E00-110)



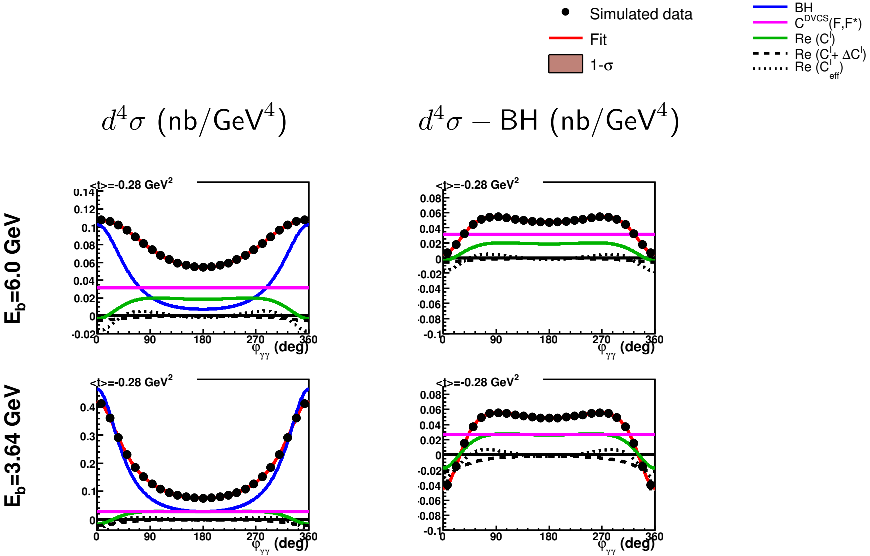
Exclusivity ensured by missing mass technique

Beam time request

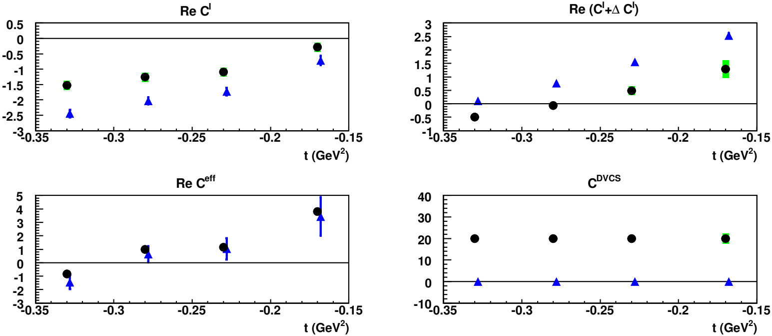
$$400\,\text{h} + 72\,\text{h (calibration)} + 72\,\text{h (calorimeter curing)} = 544\,\text{h}$$

	KIN I		KIN II		KIN III	
Q^2 (GeV^2)	1.5		1.9		2.3	
x_B	0.36		0.36		0.36	
W^2 (GeV^2)	3.78		4.26		4.96	
q' (GeV)	2.14		2.73		3.32	
k (GeV)	6.00	3.64	6.00	4.82	6.00	4.82
ϵ	0.873	0.566	0.792	0.652	0.683	0.473
k' (GeV)	3.78	1.42	3.19	2.01	2.59	1.41
θ_e (deg)	14.77	31.26	18.13	25.60	22.16	32.22
θ_q (deg)	-22.3	-16.89	-18.45	-16.07	-15.22	-12.18
θ_{Calo} (deg)	-22.3	-16.89	-18.45	-16.23	-16.23	-16.23
$\Gamma\Delta k'$	$5.3\ 10^{-4}$	$3.9\ 10^{-5}$	$2.3\ 10^{-4}$	$6.7\ 10^{-5}$	$9.9\ 10^{-5}$	$2.2\ 10^{-5}$
$d\sigma_{DIS}$ (nb)	69.1	12.5	26.2	11.9	11.0	4.32
Beam time (h)	**20**	**60**	**30**	**90**	**50**	**150**

DVCS^2 separation: $Q^2 = 1.5$ GeV^2

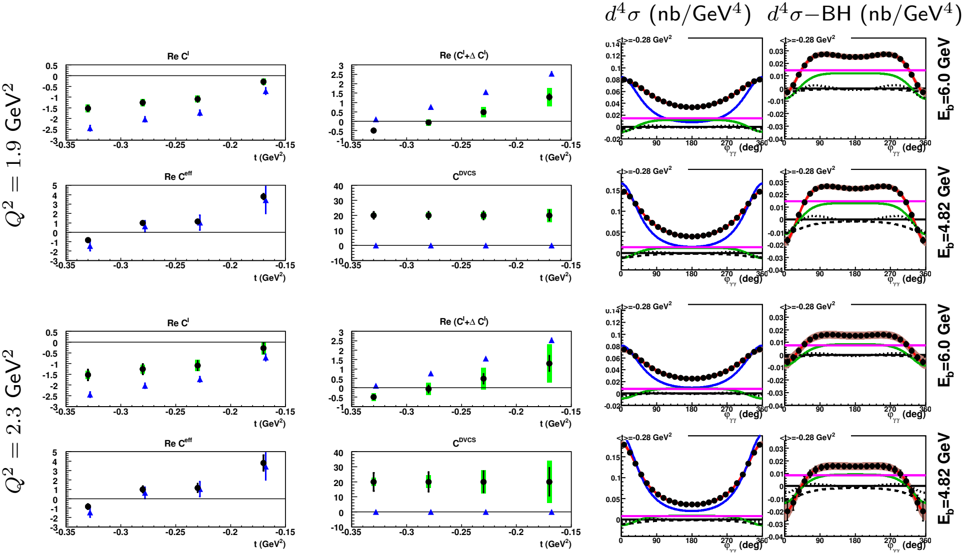


DVCS^2 separation: $Q^2 = 1.5$ GeV^2



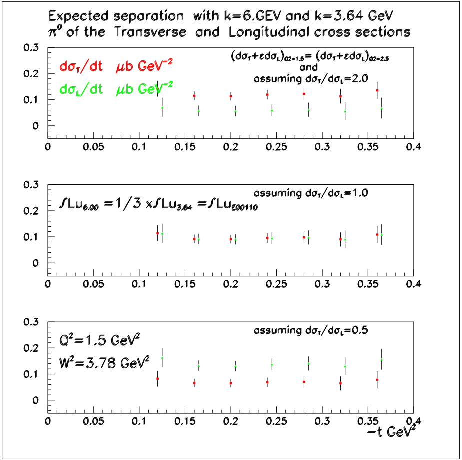
DVCS^2 separation: $Q^2 = 1.9$ GeV^2 and $Q^2 = 2.3$ GeV^2

$d^4\sigma$ (nb/GeV^4) $d^4\sigma$−BH (nb/GeV^4)



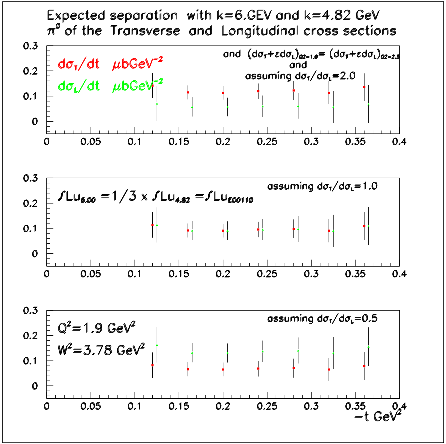
σ_L Rosenbluth separation

$$Q^2 = 1.5 \text{ GeV}^2$$

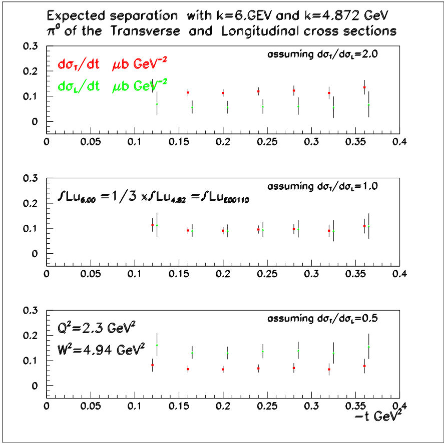


σ_L Rosenbluth separation

$Q^2 = 1.9$ GeV^2



$Q^2 = 2.3$ GeV^2



Systematic uncertainties

Type		Relative errors (%) E00-110	Relative errors (%) proposed
Luminosity	target length and beam charge	1	1
HRS-Calorimeter	Drift chamber multi-tracks	1.5	1.5
	Acceptance	2	2
	Trigger dead-time	0.1	0.1
DVCS selection	π^0 subtraction	3	1
	e(p,e'γ)πN contamination	2	2
	radiative corrections	2	2
Total cross section sum		4.9	4.0

Summary

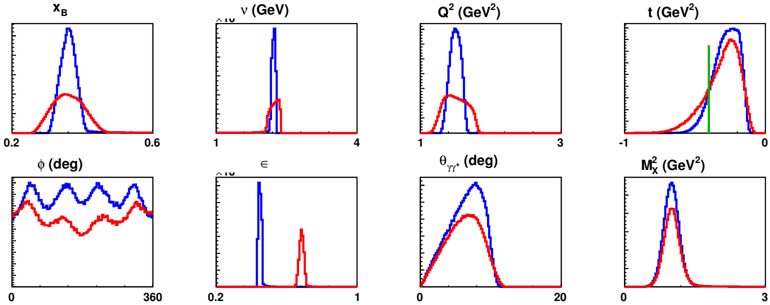
We propose:

- **Accurate separation of BH·DVCS interference and DVCS^2 terms** in the $ep \to ep\gamma$ cross section:
  - New GPDs observables: *linear* + *bilinear* combinations of GPDs
  - Additional tests of DVCS *scaling* from unpolarized cross section
- σ_L **Rosenbluth separation in** $ep \to ep\pi^0$ (*vs.* Q^2):
  - *First* test of factorization in this most important channel
  - *If scaling observed*, most interesting complementary (flavour) information on GPDs

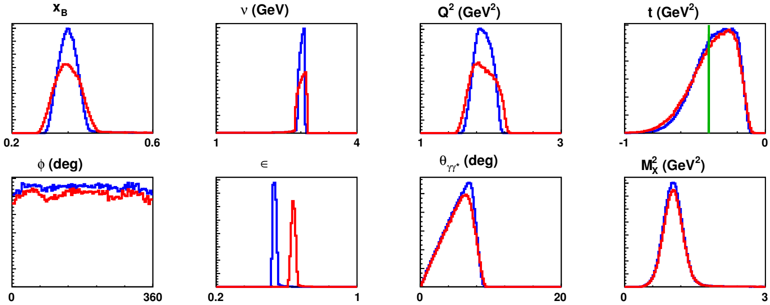
We request:

$$400 + 72 + 72 = 544 \text{ h beam time}$$

Kinematic distributions ($Q^2 = 1.5$ GeV^2)



Kinematic distributions ($Q^2 = 1.9$ GeV^2)



Kinematic distributions ($Q^2 = 2.3$ GeV^2)