October 2, 2000

A Luminosity Spectrometer for the ZEUS Experiment

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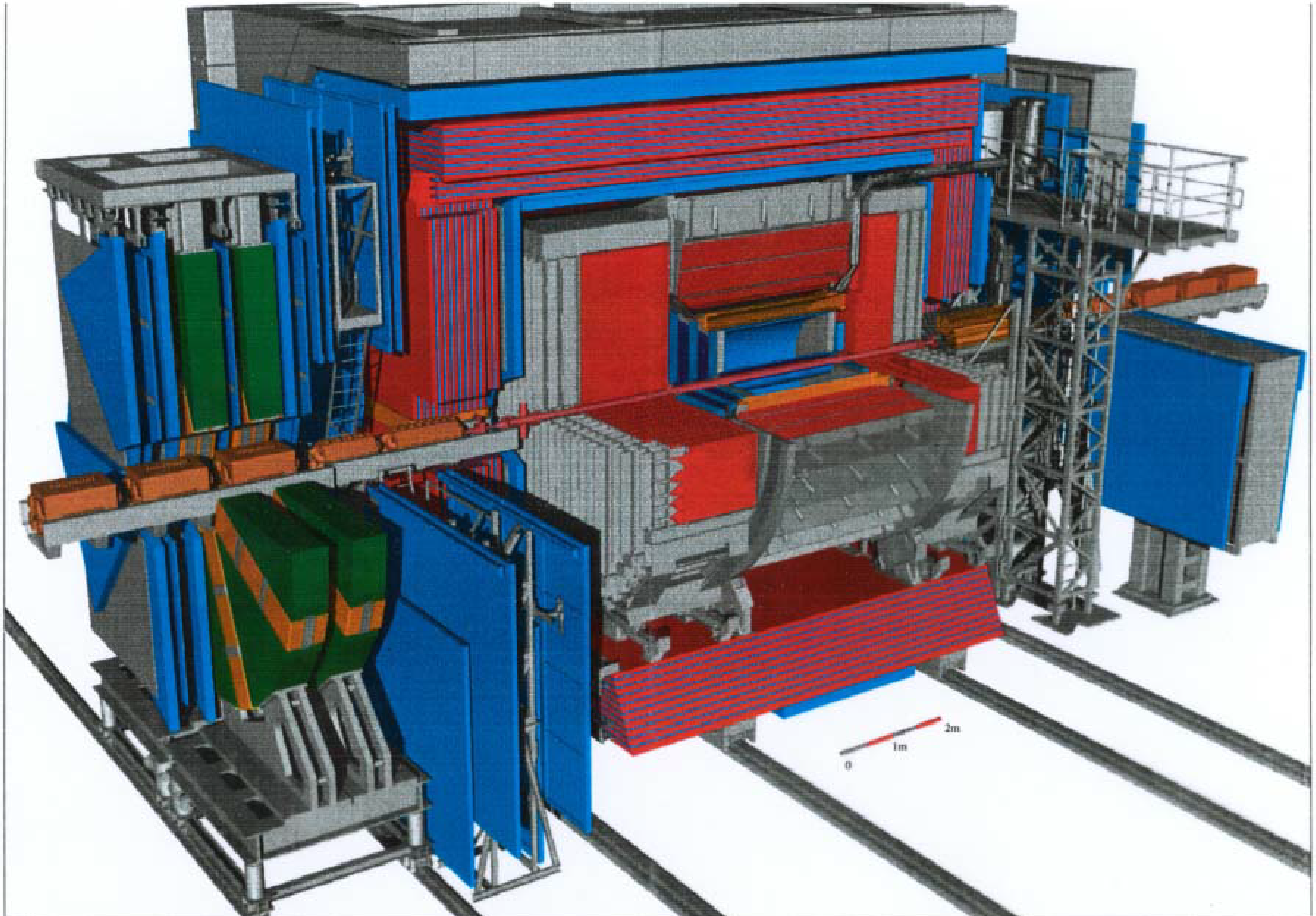
Columbia University, Nevis Laboratories
On Behalf of the ZEUS Collaboration.

- **Measuring Luminosity at ZEUS**
- **The photon Calorimeter (Cracow-DESY)**
- **The Luminosity Spectrometer (Columbia-DESY)**
- **The 6-meter Tagger (DESY-Hamburg University)**

(Ricardo Graciani, Friday)



ZEUS (HERA)

Software :SDRC-IDEAS level VI.i
Performed by : Carsten Hartmann
Status : October 1993

HERA Upgrade Schedule

Shutdown: September/00 (L$\simeq 2 \times 10^{31} cm^{-2} s^{-1}$)
Turn On : August/01 (L$\simeq 7.5 \times 10^{31} cm^{-2} s^{-1}$)

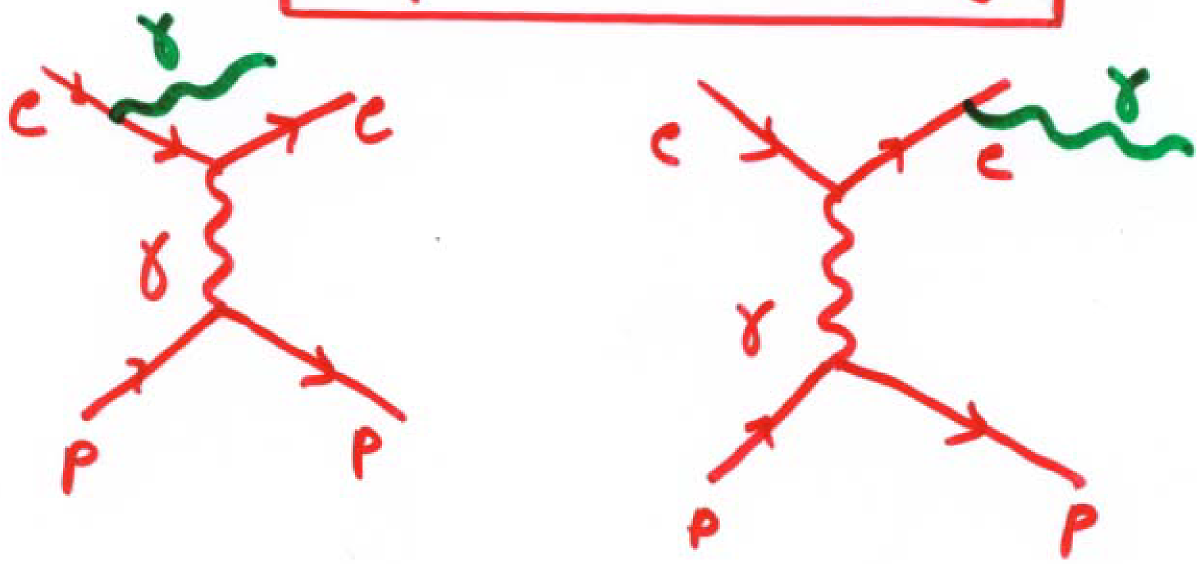
Required Luminosity Measurement Precision

- **Diffraction Group: 3%**
- **Heavy Flavor Group: 1%**
- **Hadronic Final States: 2%**
- **Structure Functions and EW Group: 1-2%**
- **Exotics Group: 5%**

ZEUS

MEASURING LUMINOSITY

$$ep \rightarrow ep\gamma$$



(Born Level)

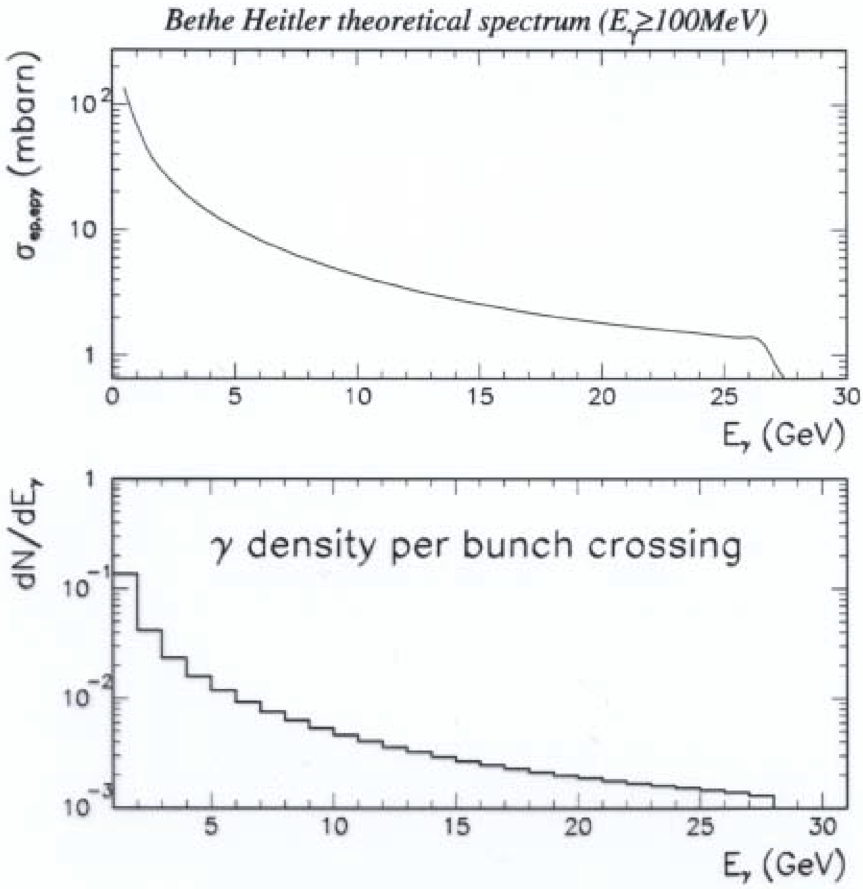
$\theta_{\gamma p} \simeq$ mrad

$$\mathcal{L} = \frac{R_\gamma}{\sigma_{ep \rightarrow ep\gamma}}$$

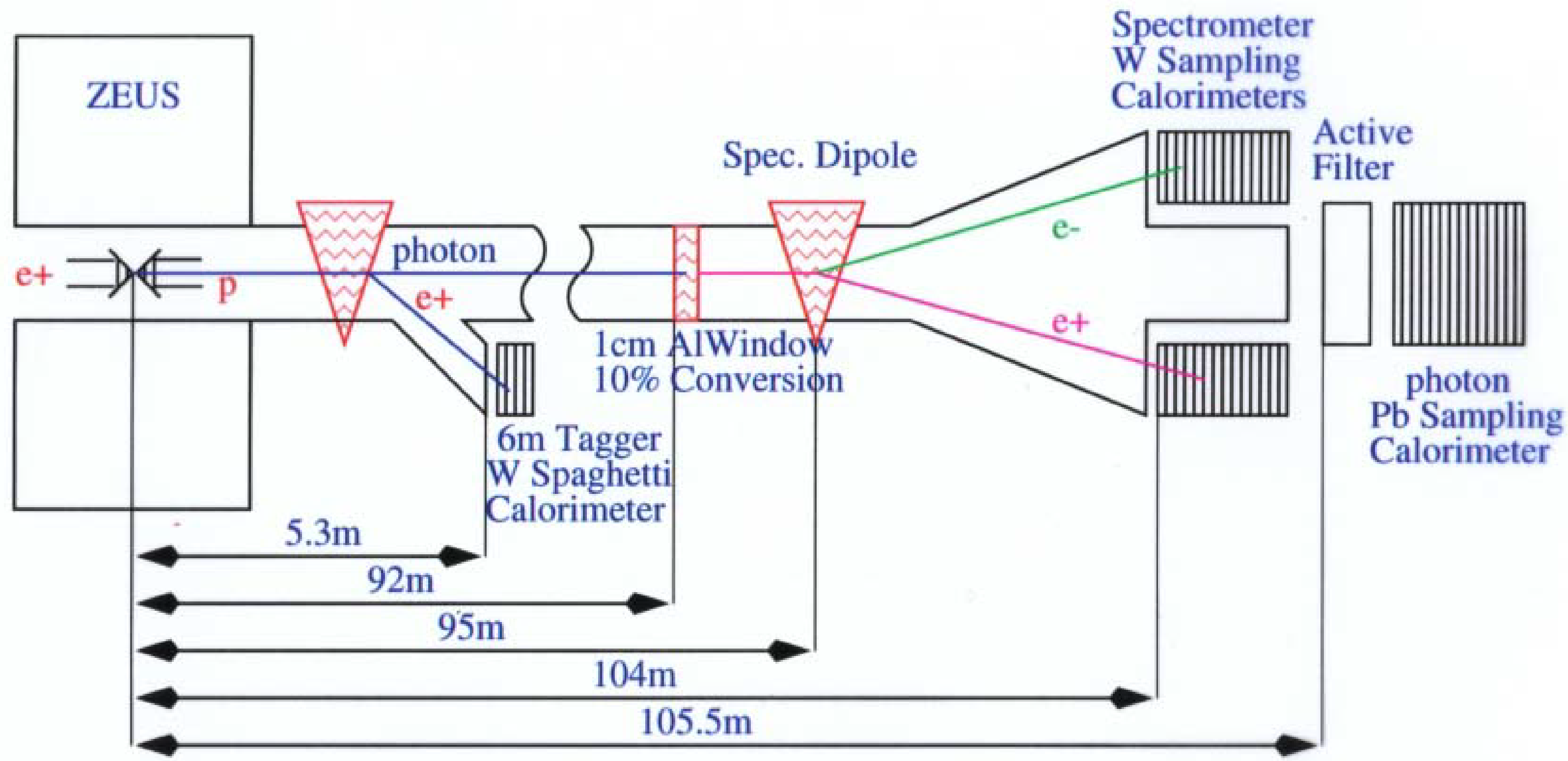
$\longrightarrow$ Corrected γ Rate

The cross-section for the process $ep \to ep\gamma$ is taken from the Bethe-Heitler formula:

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E_{e'}}{E_\gamma E_e}\left(\frac{E_e}{E_{e'}} + \frac{E_{e'}}{E_e} - \frac{2}{3}\right)\left(ln\frac{4E_p E_e E_{e'}}{MmE_\gamma} - \frac{1}{2}\right), \qquad (1)$$



Cross-section (top plot) and photon density dN/dE_γ (bottom) for the process $ep \to ep\gamma$.



ZEUS
e+
p
photon
e+
Spec. Dipole
Spectrometer
W Sampling
Calorimeters
Active
Filter
e-
e+
1cm AlWindow
10% Conversion
6m Tagger
W Spaghetti
Calorimeter
photon
Pb Sampling
Calorimeter
5.3m
92m
95m
104m
105.5m

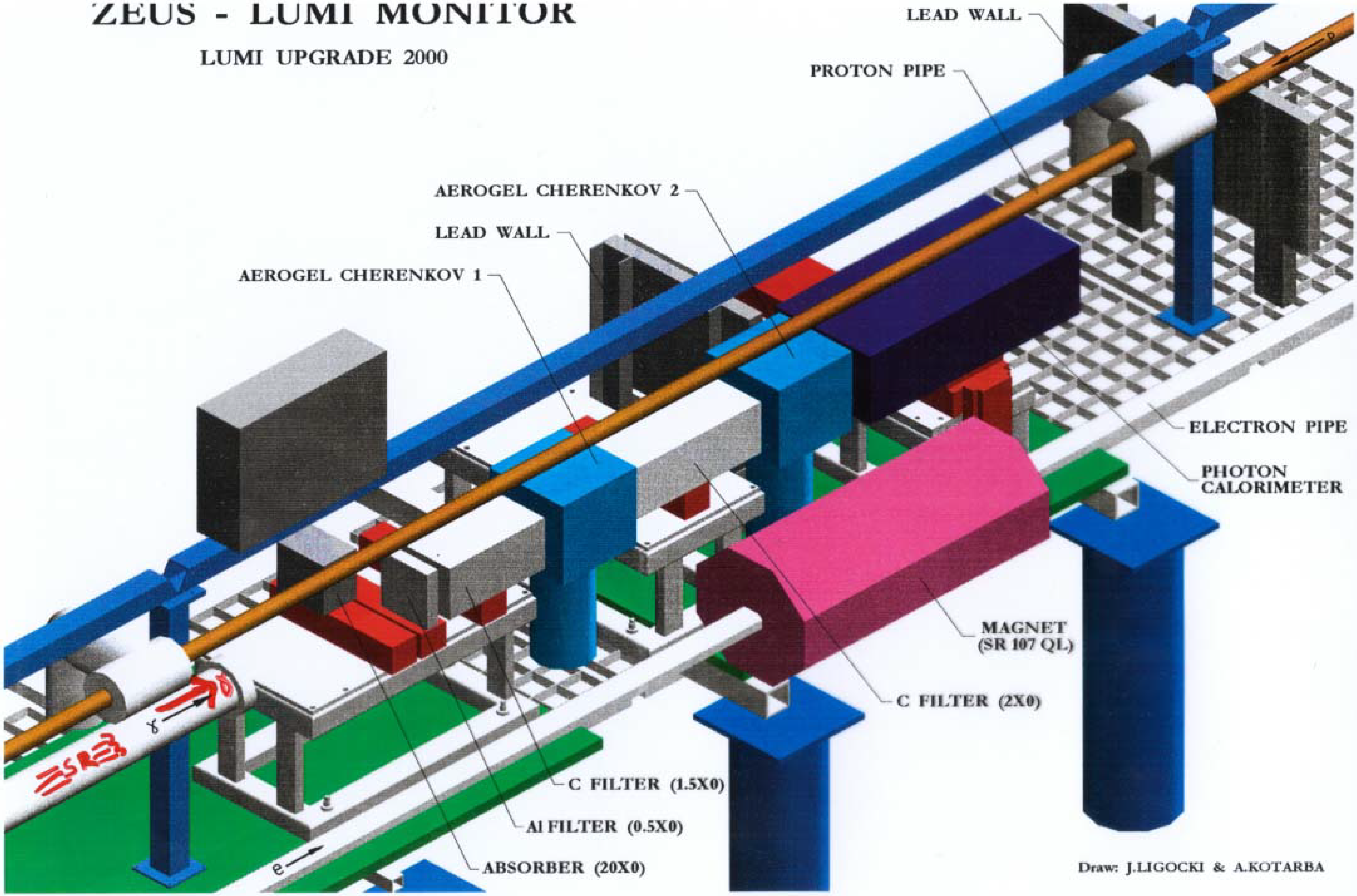
Problems associated with the Lumi Measurement after the HERA upgrade

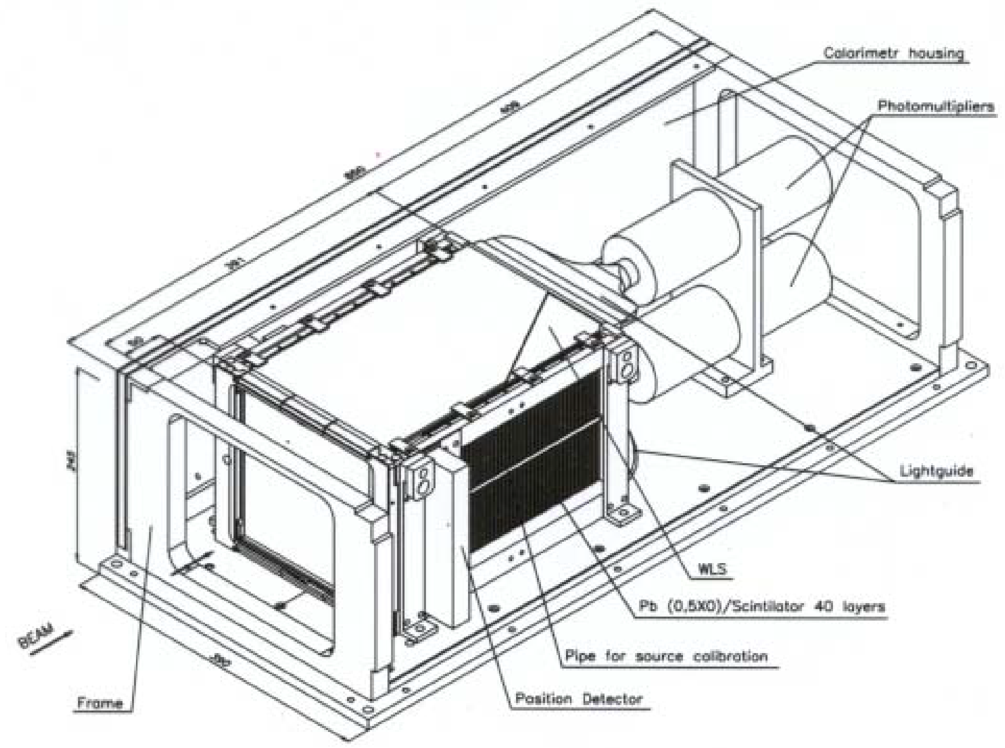
- **Direct and Scattered Synchrotron Radiation**
- **Bremsstrahlung Photon Pile-up**
- **Bremsstrahlung Photon Acceptance**
- **Energy Scale Calibration**

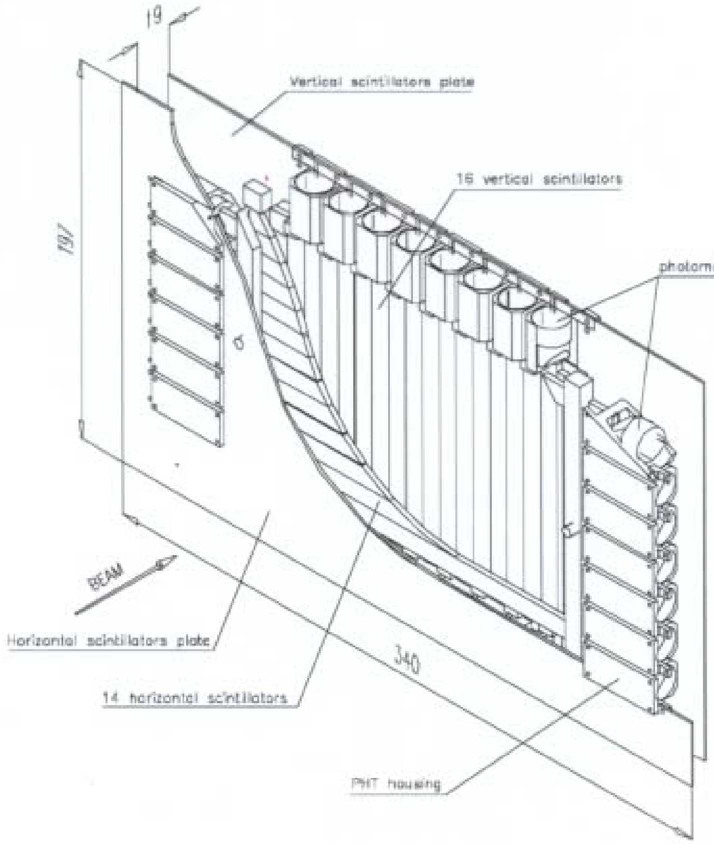
ZEUS

ZEUS - LUMI MONITOR

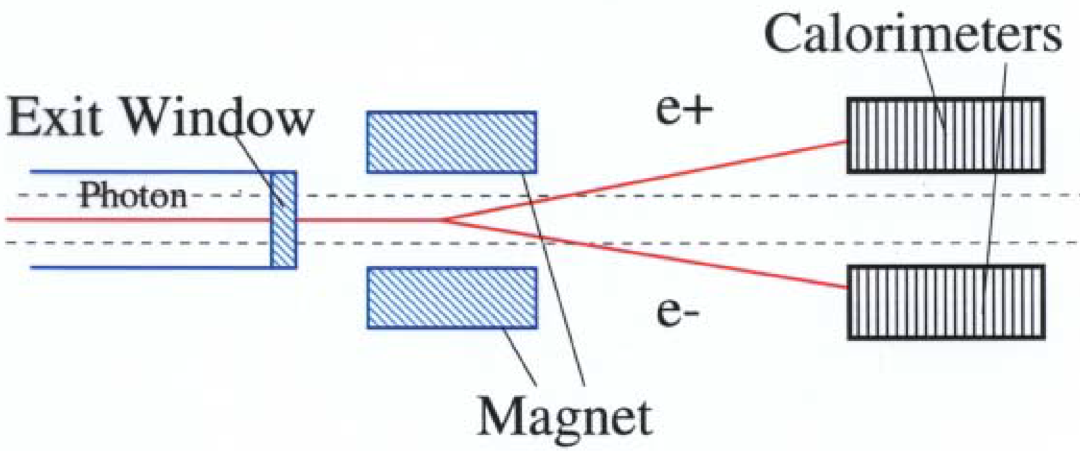
LUMI UPGRADE 2000




Colorimetr housing
Photomultipliers
Lightguide
WLS
Pb (0,5X0)/Scintilator 40 layers
Pipe for source calibration
Position Detector
Frame
BEAM


19
197
Vertical scintillators plate
16 vertical scintillators
photomultiplier
BEAM
Horizontal scintillators plate
14 horizontal scintillators
340
PMT housing

Lumi Spectrometer Characteristics



- Small systematic errors due to pile-up. With acceptance $A \simeq 3\%$, the chances of confusion from a second photon are reduced by two orders of magnitude.

- Accurate knowledge of the acceptance ($\Delta A/A < 1\%$) in a window of width $\Delta E_\gamma \simeq 3GeV$, as determined with the use of the 6m tagger.

- No radiation damage issue due to synchrotron radiation.

- Small errors from energy scale uncertainty due to the good BPC resolution and clean spectrum end point.

- Good photon beam profile reconstruction at the exit window. Shifts of the profile mean values smaller than $\simeq 1mm$ can be measured every 10 seconds.

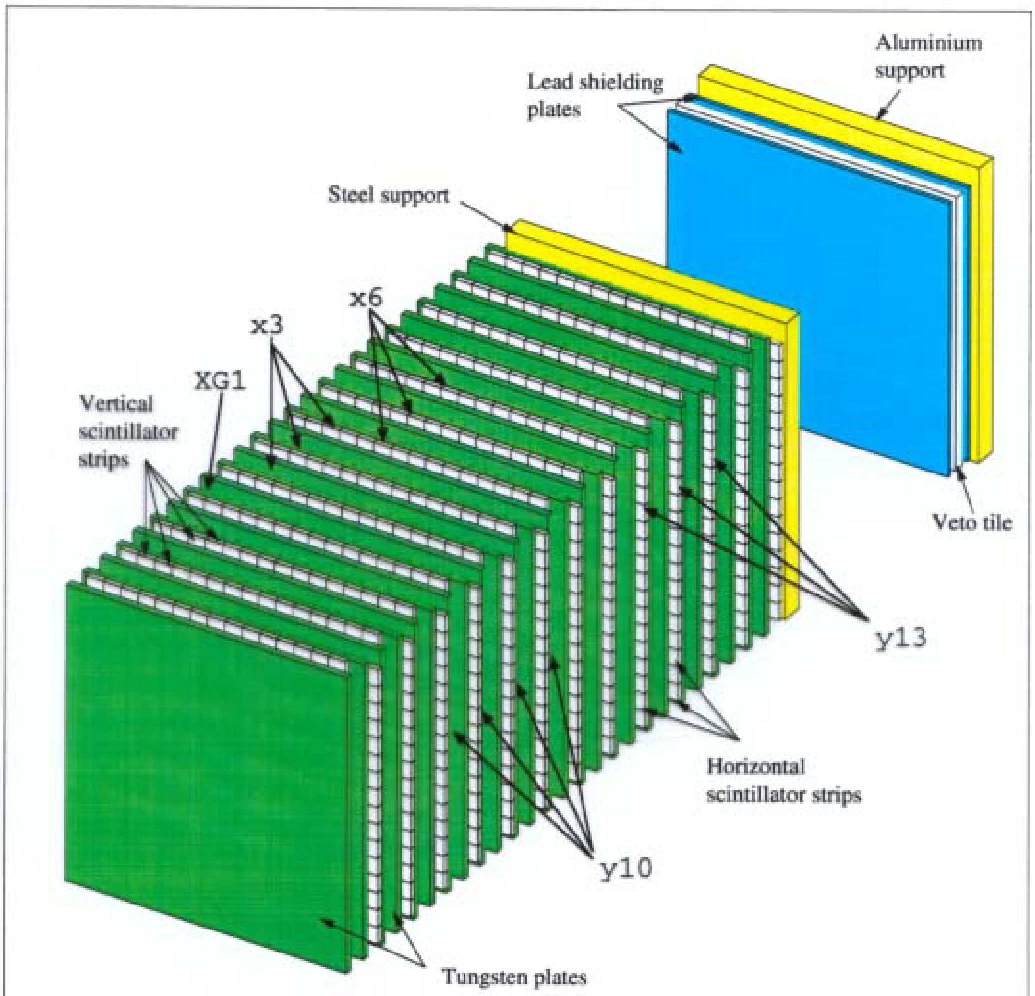
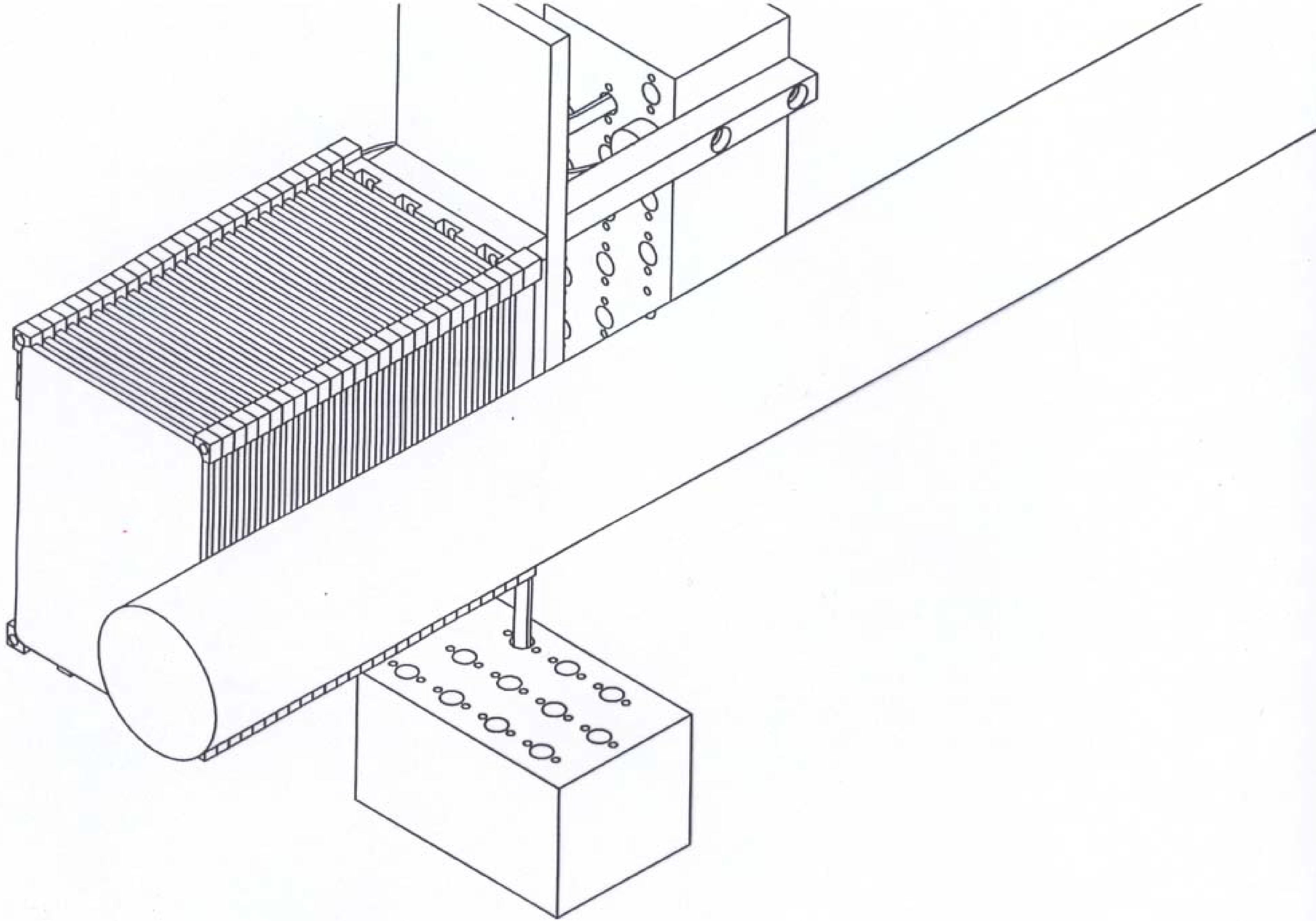
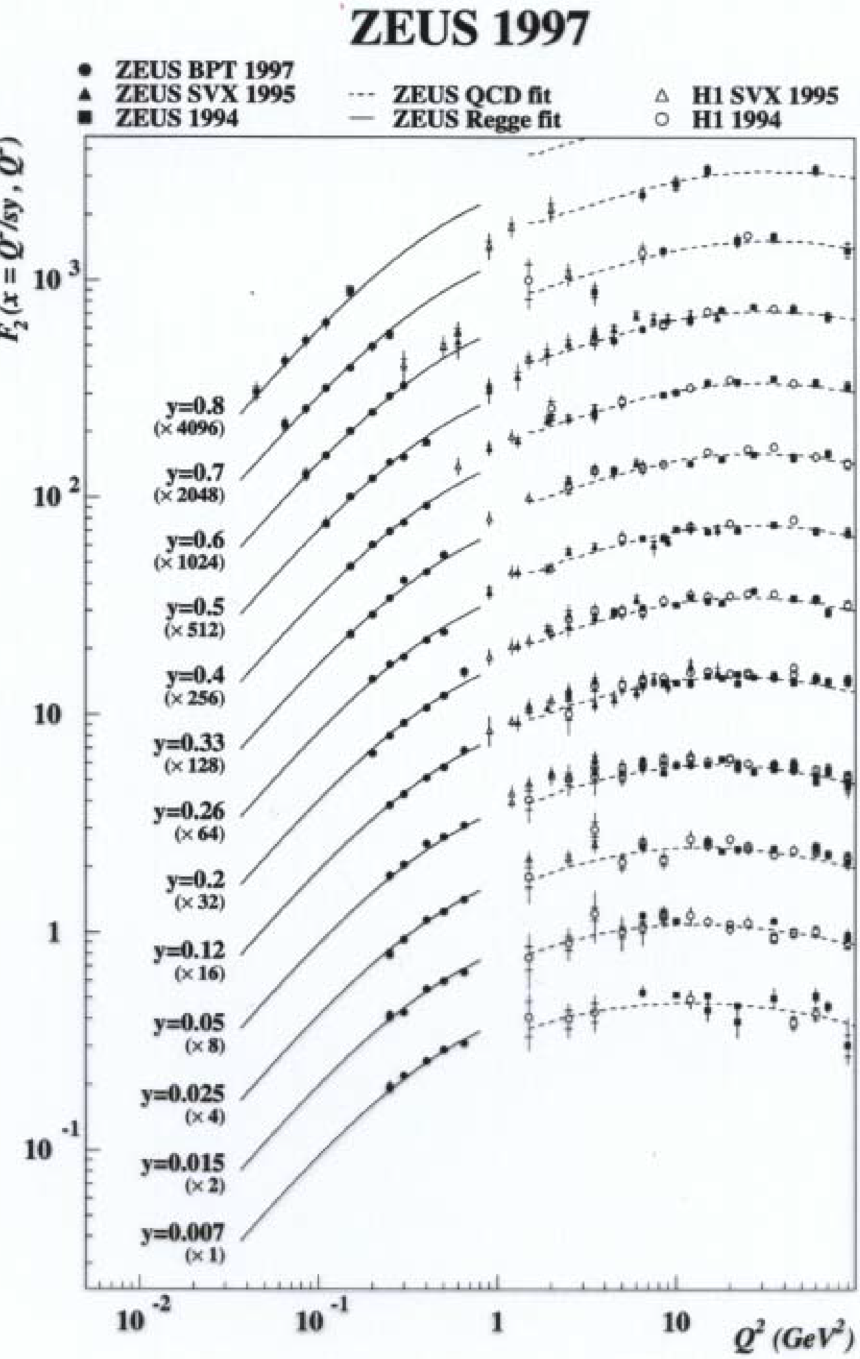


Figure 5: *Principle structure of the BPC*



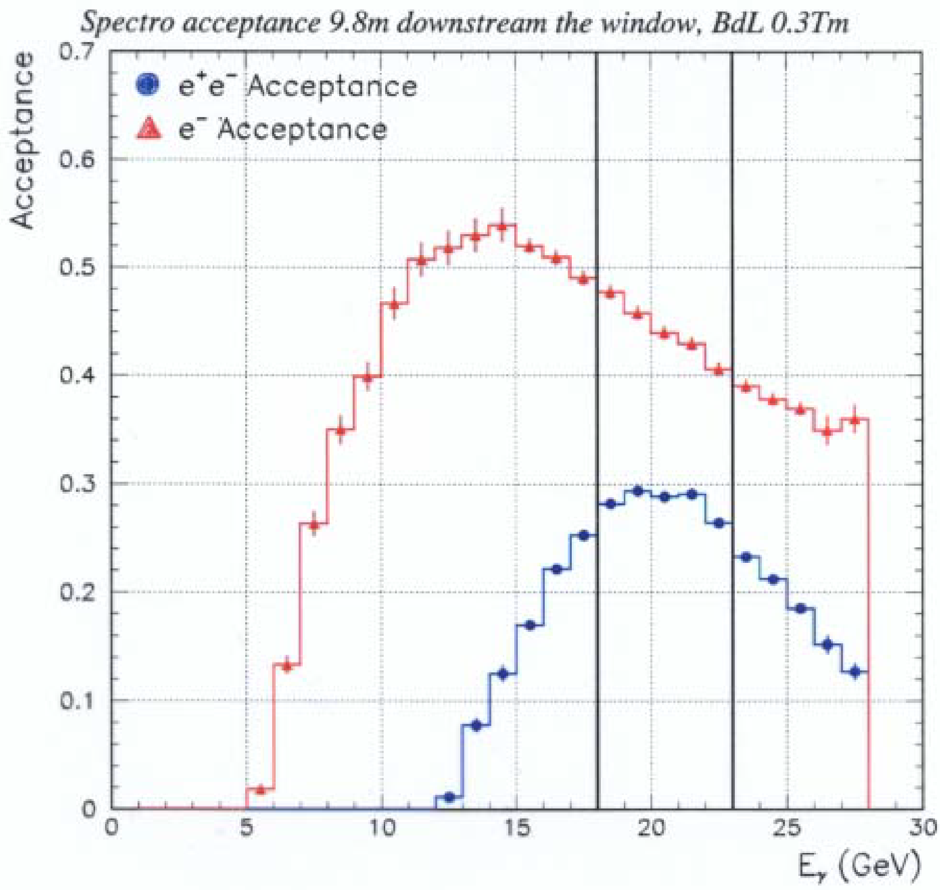
BPC specification	BPC performance
Depth	$24X_0$
Moliere radius	$13mm$
Energy resolution	$17\%/\sqrt{E}$ (stochastic term)
Energy scale calibration	$\pm0.5\%$ → 0.3%
Energy uniformity	$\pm0.5\%$
Linearity	$\leq 1\%$
Position resolution	$< 1mm$
Time resolution	$< 1ns$

The Beam Pipe Calorimeters (BPCs) have been used during the last 5 years to measure ep cross sections at very low Q^2.



ZEUS 1997
ZEUS BPT 1997
ZEUS SVX 1995
ZEUS 1994
ZEUS QCD fit
ZEUS Regge fit
H1 SVX 1995
H1 1994
F_2(x = Q^2/sy, Q^2)
y=0.8 (× 4096)
y=0.7 (× 2048)
y=0.6 (× 1024)
y=0.5 (× 512)
y=0.4 (× 256)
y=0.33 (× 128)
y=0.26 (× 64)
y=0.2 (× 32)
y=0.12 (× 16)
y=0.05 (× 8)
y=0.025 (× 4)
y=0.015 (× 2)
y=0.007 (× 1)
Q^2 (GeV^2)

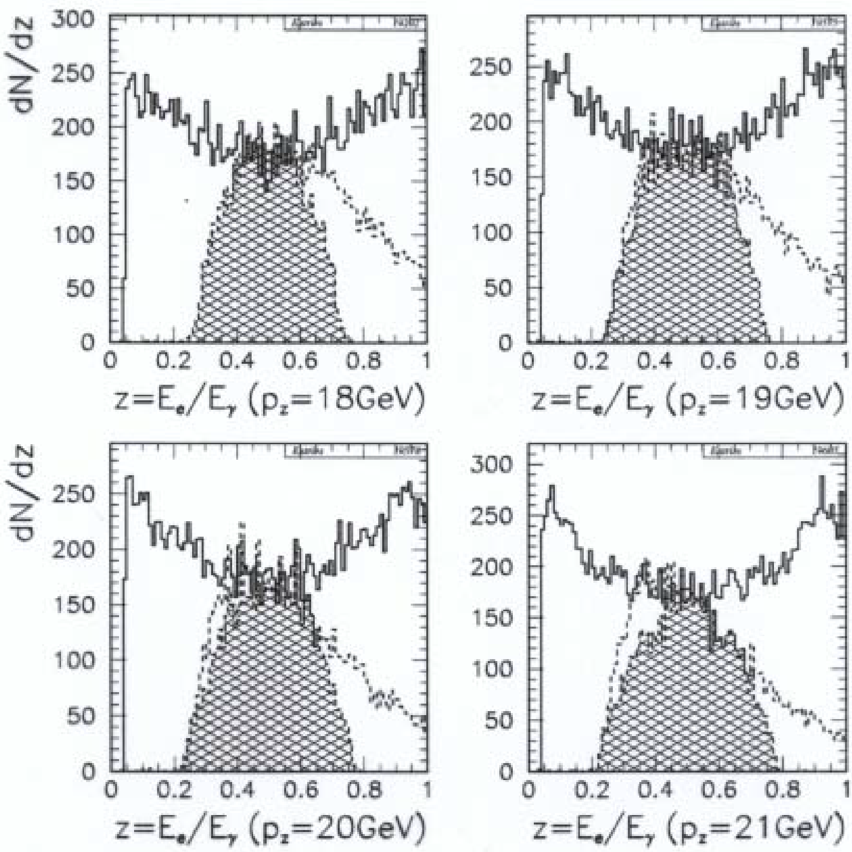
1. We Assume $\int BdL = 0.3$ Tm for standard dipole.
2. We optimize L keeping 10cm separation.



The spectrometer acceptance A is given by the formula:

$$A = A_{geom} \cdot A_{conv} \cdot A_z \qquad (7)$$

A_{geom} is the acceptance of the photon beam exit window (90-95%), A_{conv} is the conversion rate ($A_{conv} \simeq 10\%$), and A_z describes the $z = E_e/E_\gamma$ dependent part of the acceptance.


dN/dz
z=E_e/E_γ (p_z=18GeV)
z=E_e/E_γ (p_z=19GeV)
z=E_e/E_γ (p_z=20GeV)
z=E_e/E_γ (p_z=21GeV)

R. Graciani (Friday)

MEASURE SPECTRO ACCEPTANCE USING Gmt:

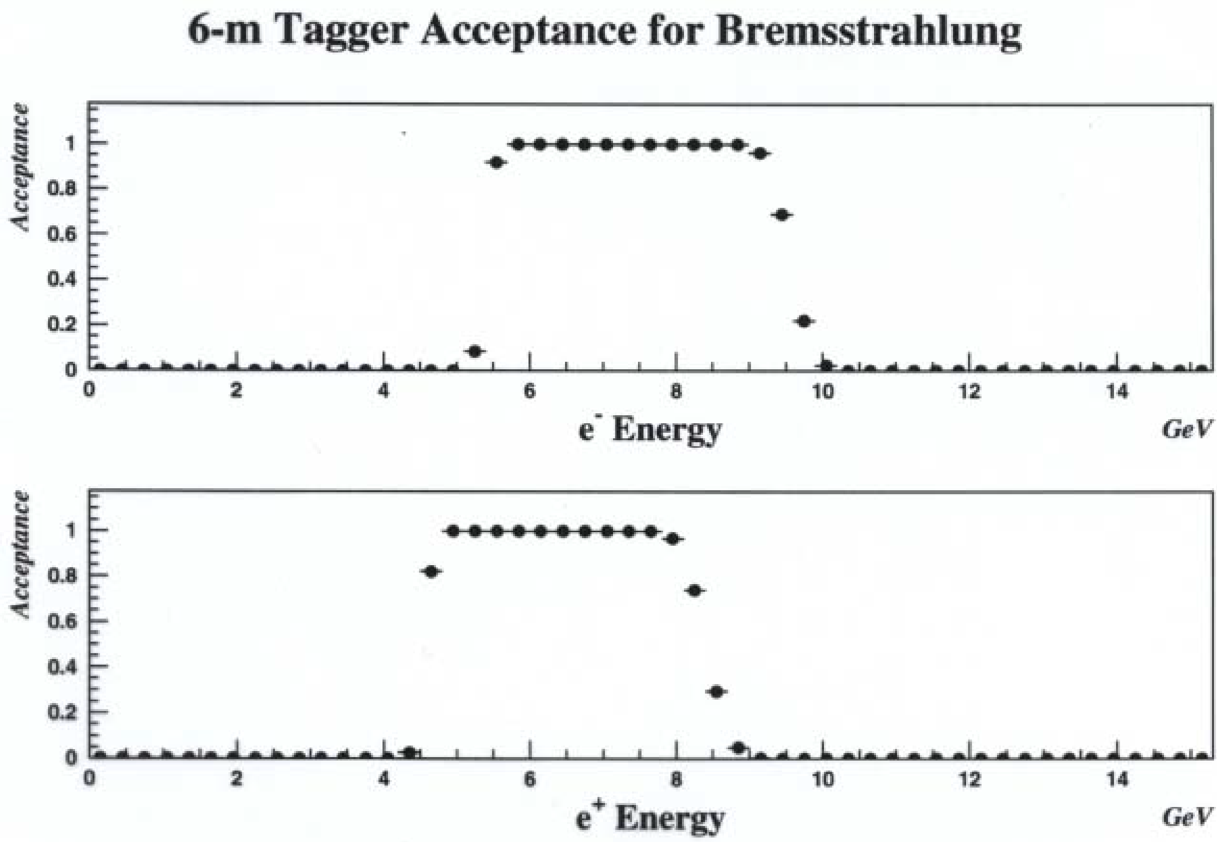


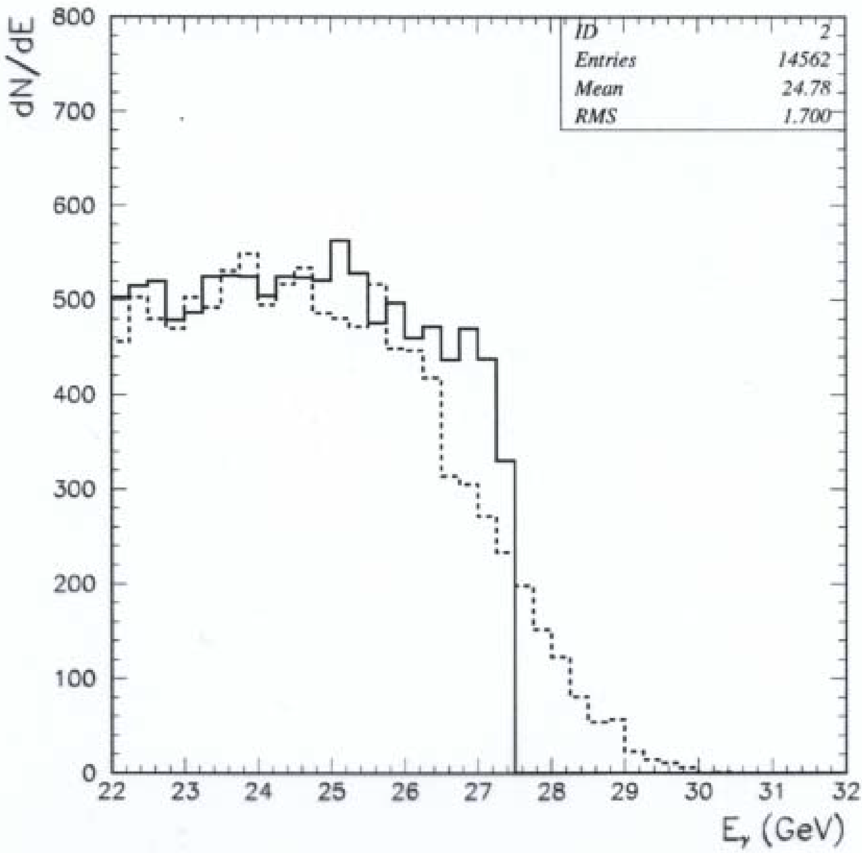
Figure 6: Acceptance of exit window for bremsstrahlung electrons (top) and positrons (bottom).

$$E_e + E_\gamma = E_{e,BEAM} = 27.5$$

E_e ↓ Gmt

E_γ ↓ Spectro

Photon Energy Spectrum Distribution as measured by the lumi spectrometer

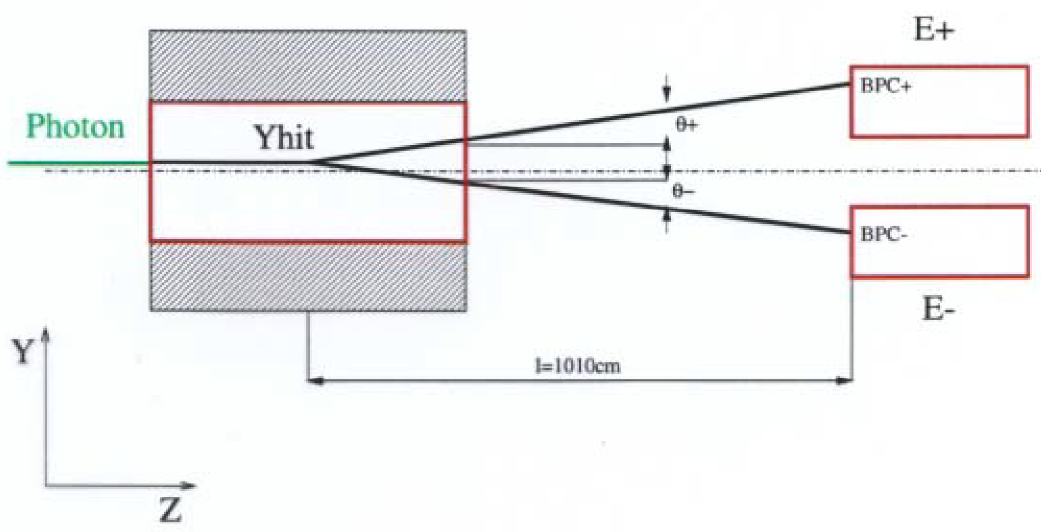


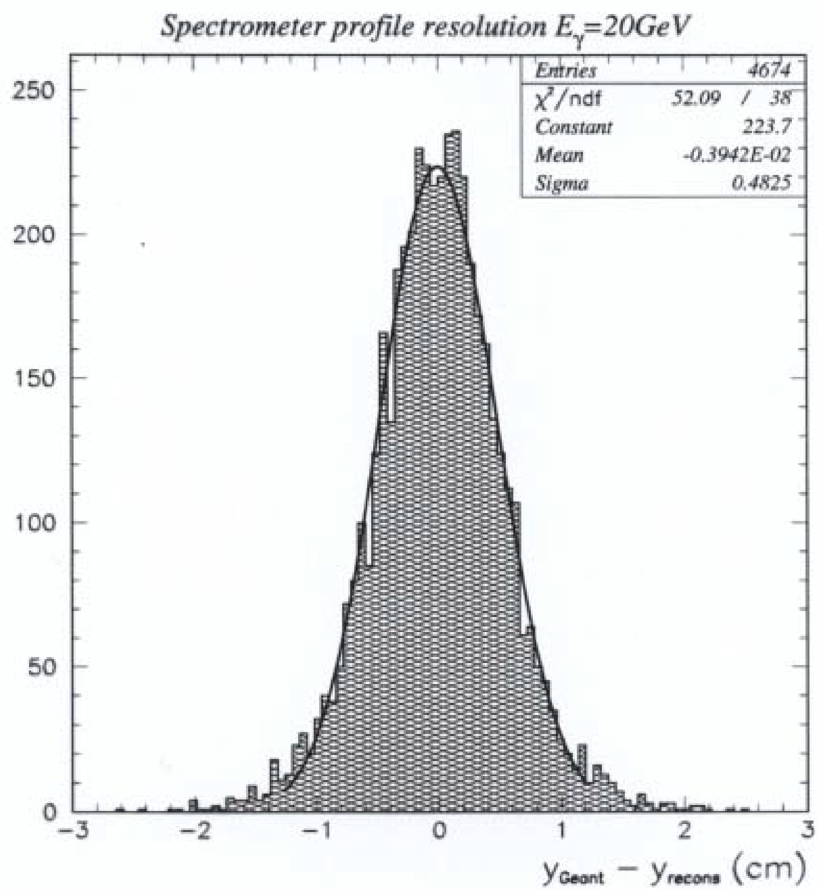
Solid Line: Spectrum of coincidences without detector resolution folded. Dash line: Spectrum of coincidences with detector resolution folded.

Photon Beam Profile Reconstruction

The position of the photon (projected to the BPC Z location) is approximated as the energy-weighted position of the two electrons as measured in the BPC.

$$Y_{hit} = \frac{E^{+}BPC^{+} + E^{-}BPC^{-}}{E^{+} + E^{-}} \quad (8)$$




Spectrometer profile resolution E_γ=20GeV
Entries 4674
χ^2/ndf 52.09 / 38
Constant 223.7
Mean -0.3942E-02
Sigma 0.4825
250
200
150
100
50
0
-3
-2
-1
0
1
2
3
$y_{Geant} - y_{recons}$ (cm)

Systematic Errors

1. **Energy Scale and resolution uncertainties in the cross section determination.**

2. **Theoretical cross section error.**

3. **Multiple events correction errors (pile-up).**

4. **Acceptance correction errors.**

Error Type	$L = 7.10^{31} cm^{-2} s^{-1}$
Multiple event correction	$\leq 0.5\%$
egas bgnd subtraction	$\leq 0.5\%$
Total Acceptance error	$\leq 1.0\%$
Energy Scale errors	$\leq 0.5\%$
Cross-section Calculation	$\leq 0.5\%$
Total systematic error	$\leq 1.4\%$

Table 2: Systematic Error in luminosity.

Summary of Systematic Errors

The counting, thermal γ background and p-beam background errors are currently expected to be relatively low so they are not taken into account. The theoretical calculation of the cross section error was taken as 0.5%. The total systematic error is calculated by summing all errors in quadrature.
KEY POINT: escale calibration of the spectrometer. Current BPC escale resolution 0.3%. We expect to do better using the photon spectrum end point. Spectro calibration sets the 6m tagger escale error at 0.5%.

The total systematic error is expected to be below 1.4%

CONCLUSIONS

The ZEUS Luminosity measurement after the HERA upgrade has two difficulties: synchrotron radiation and pile-up (two Bremss. photons per bunch crossing).

The old method can still be used after appropriate modification of the current setup: measure directly the photons using filters to block the SR and counters to correct for energy loss in the filters. The challenge for this method is the pile-up correction and energy scale calibration.

A new method will be used: luminosity spectrometer. Photons are measured indirectly by counting e^+, e^- coincidences in two small well understood calorimeters. The calorimeters are away from the SR plane and pile-up is a secondary effect. The spectrometer acceptance is measured using an independent device, the 6m e-tagger. The tagger has almost 100% acceptance in Bremss. electrons in an energy window where the spectrometer acceptance is maximized. The electron and photon energy sum equals the electron beam energy $(27.5GeV)$.

Detailed calculations show that the new ZEUS luminosity monitor will measure luminosity with an accuracy better than 2%.