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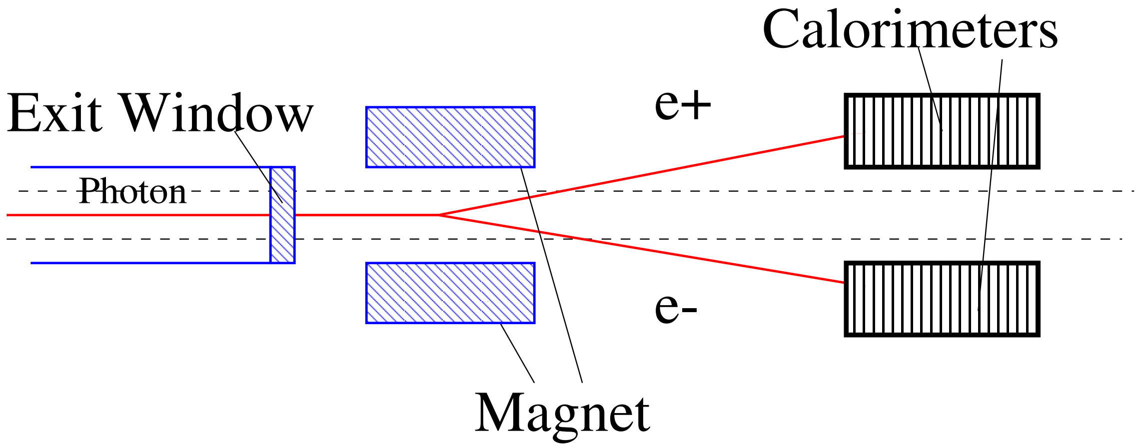
Conceptual Study for a Luminosity Spectrometer for ZEUS

- Spectrometer Characteristics.
- Spectrometer Layout.
- Spectrometer Acceptance.
- Spectrometer Performance.
- Luminosity Measurement Method.
- Systematic Errors.
- Summary.

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.

Measuring the ZEUS Luminosity

The instantaneous luminosity of ZEUS is measured using the formula:

$$L = \frac{R}{\sigma} \tag{1}$$

where R the corrected rate of $ep \to ep\gamma$ and σ is the calculated cross-section within the same photon energy window.

R is found from the coincidence rate or $e^+e^-R_0$:

1. A correction for *egas* background interaction is applied:

$$R_1 = R_0 - \frac{I_e^{tot}}{I_e^{pilot}} R^{pilot} \tag{2}$$

2. An acceptance correction is applied

$$R_2 = \frac{R_1}{\overline{a}(x_0, y_0, \sigma_x, \sigma_y)} \tag{3}$$

$$\overline{a} = C\overline{a}' = C\frac{N_{coinc}^{CORRECTED}}{N_{tags}^{CORRECTED}} \tag{4}$$

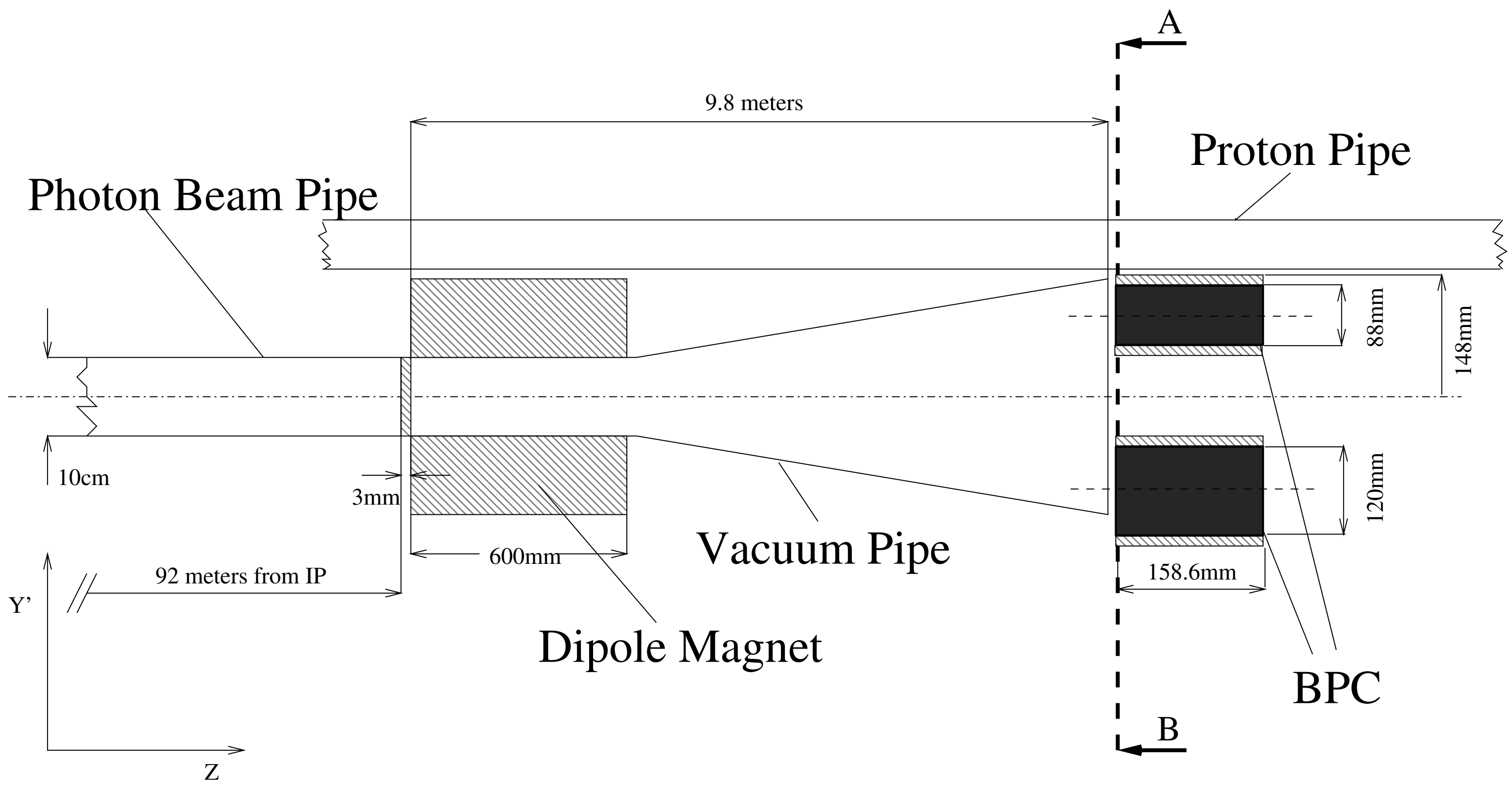
where $\overline{a}$ is the average acceptance calculated from coincidence data of the luminosity spectrometer with the 6 meter tagger.

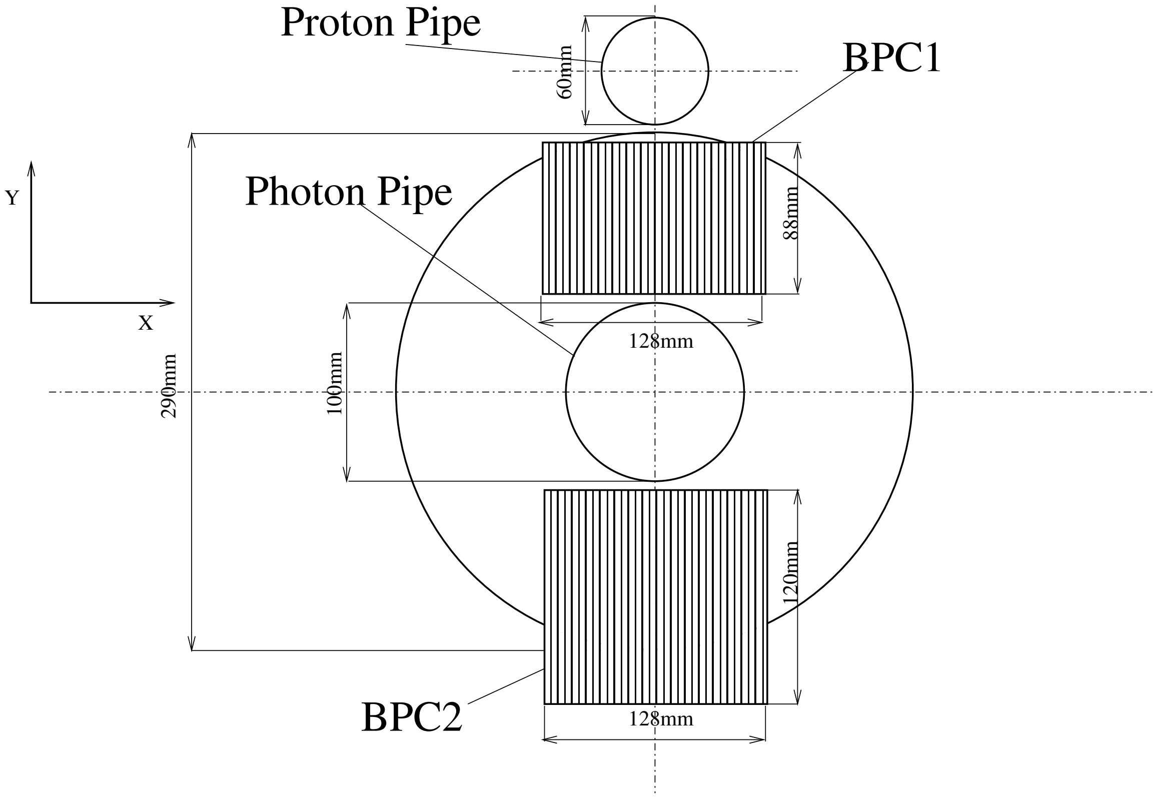
3. Multiple events (pile-up) correction is applied:

$$R = f(R_2)R_2, \tag{5}$$

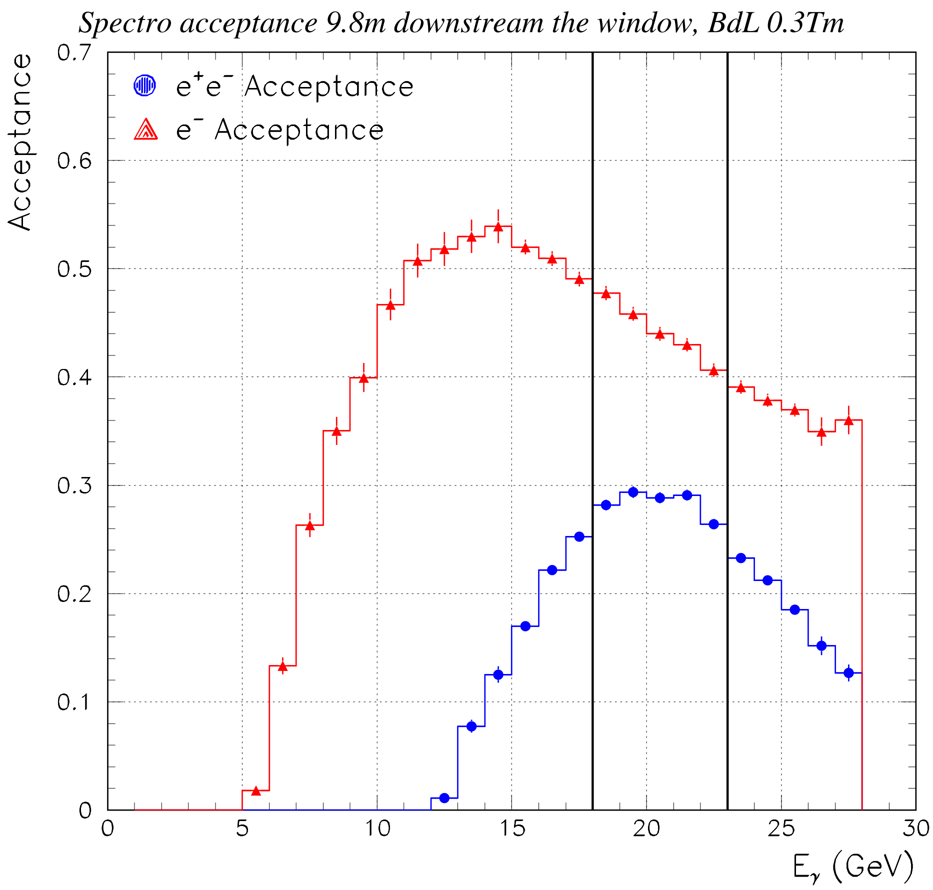
As a final step one needs the calculated cross-section :

$$\sigma = \int_{E_1}^{E_2} \frac{d\sigma^{BH}}{dE_\gamma} \otimes g(E_\gamma) dE_\gamma \tag{6}$$


A
9.8 meters
Proton Pipe
Photon Beam Pipe
88mm
148mm
120mm
10cm
3mm
600mm
Vacuum Pipe
158.6mm
92 meters from IP
Y'
Dipole Magnet
BPC
B
Z


Proton Pipe
60mm
BPC1
Y
X
Photon Pipe
88mm
128mm
290mm
100mm
120mm
BPC2
128mm

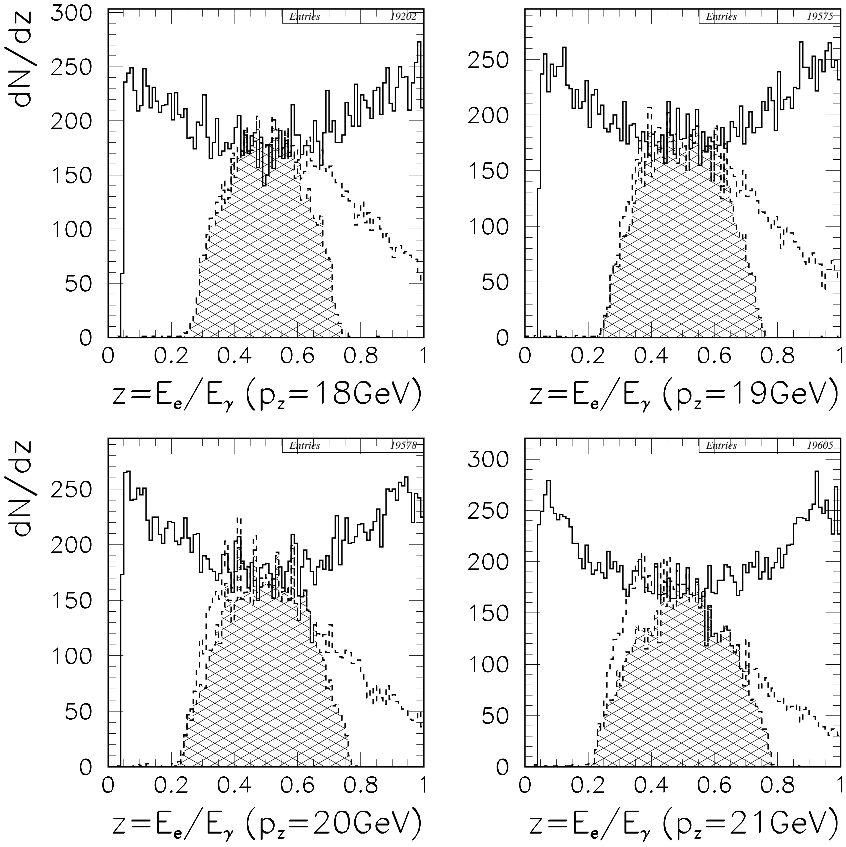
1. We Assume $\int BdL = 0.3$ Tm for standard dipole.
2. We optimize L keeping 10cm separation.



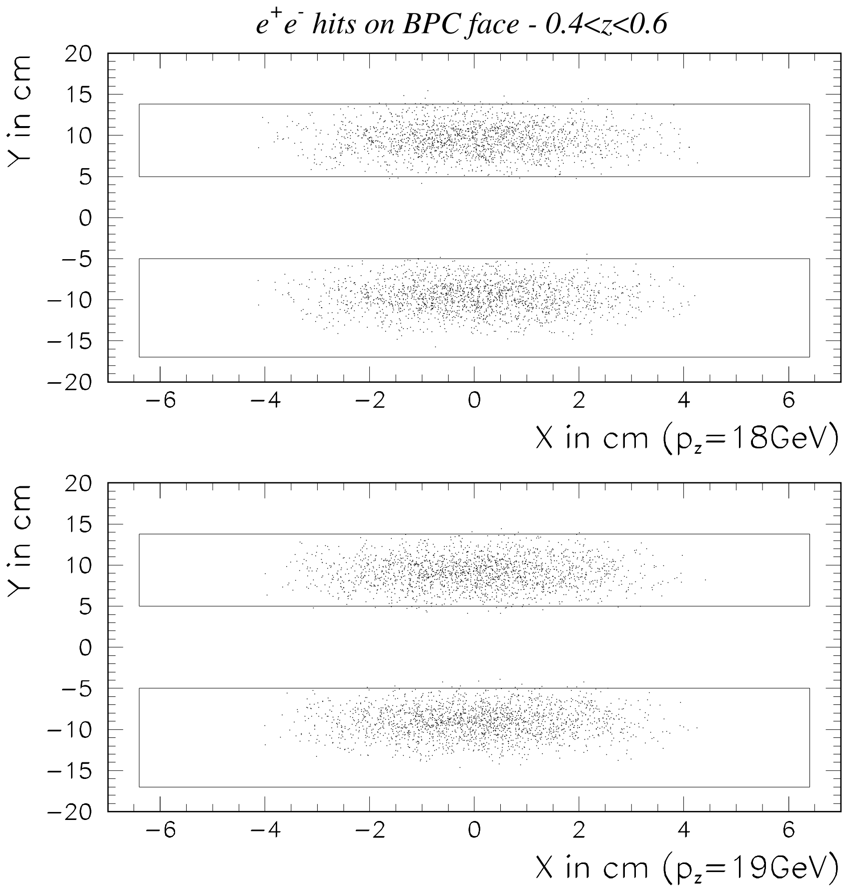
The spectrometer acceptance A is given by the formula:

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

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.

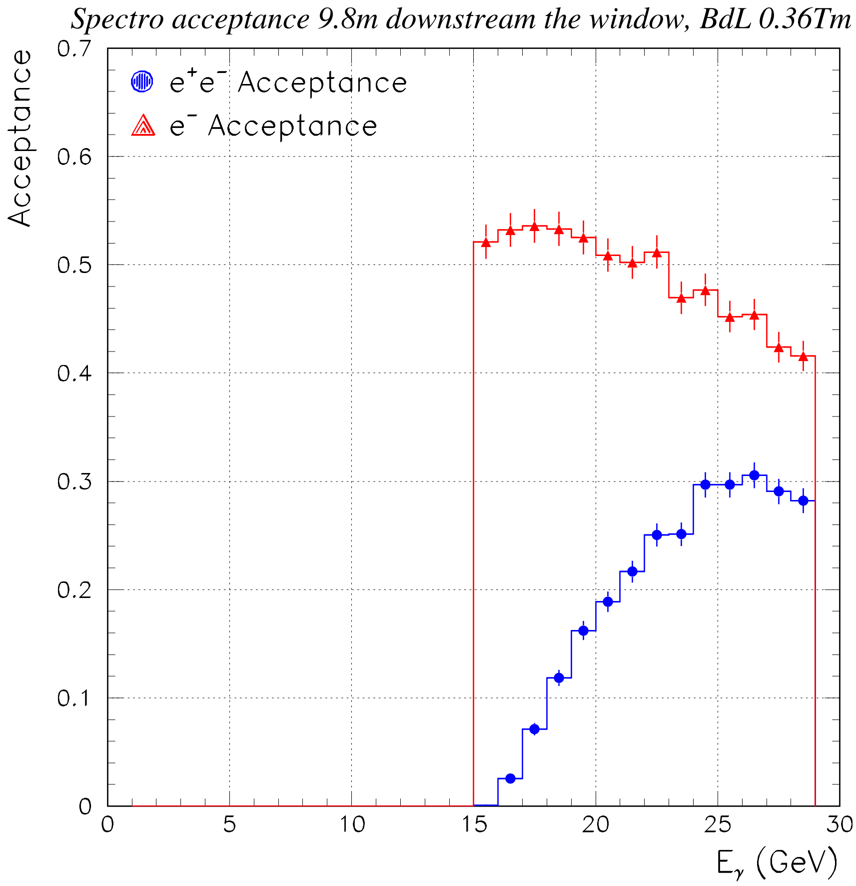


dN/dz
Entries 19202
Entries 19575
Entries 19578
Entries 19605
z=E$_e$/E$_\gamma$ (p$_z$=18GeV)
z=E$_e$/E$_\gamma$ (p$_z$=19GeV)
z=E$_e$/E$_\gamma$ (p$_z$=20GeV)
z=E$_e$/E$_\gamma$ (p$_z$=21GeV)



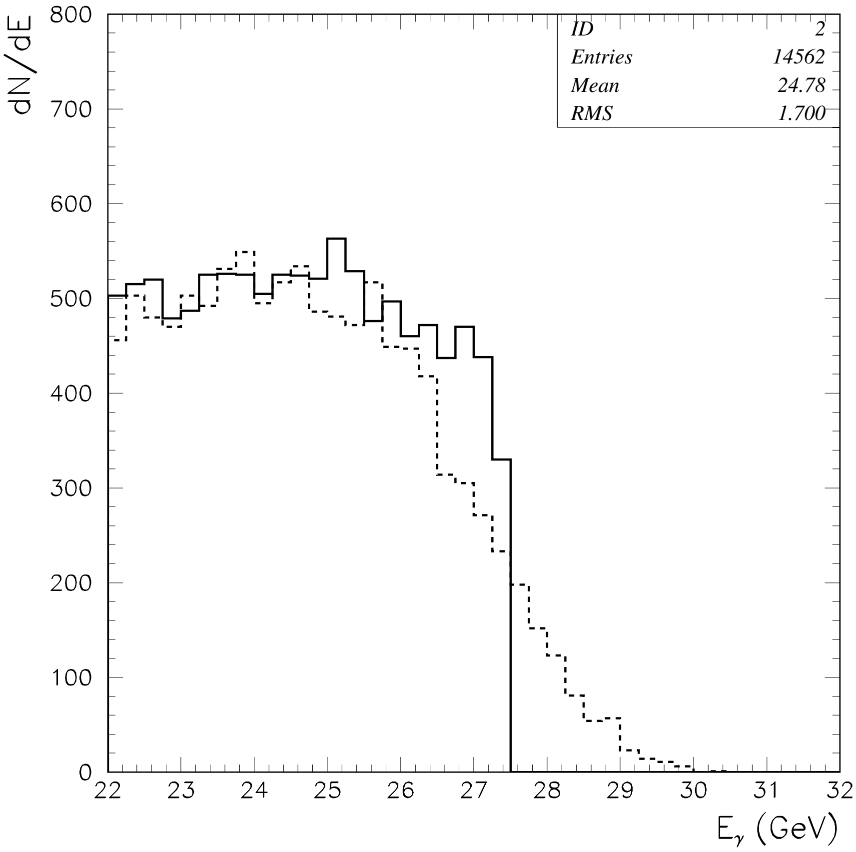
e^+e^- hits on BPC face - $0.4<z<0.6$
Y in cm
20
15
10
5
0
−5
−10
−15
−20
−6
−4
−2
0
2
4
6
X in cm (p_z=18GeV)
Y in cm
20
15
10
5
0
−5
−10
−15
−20
−6
−4
−2
0
2
4
6
X in cm (p_z=19GeV)

dfasdfaf

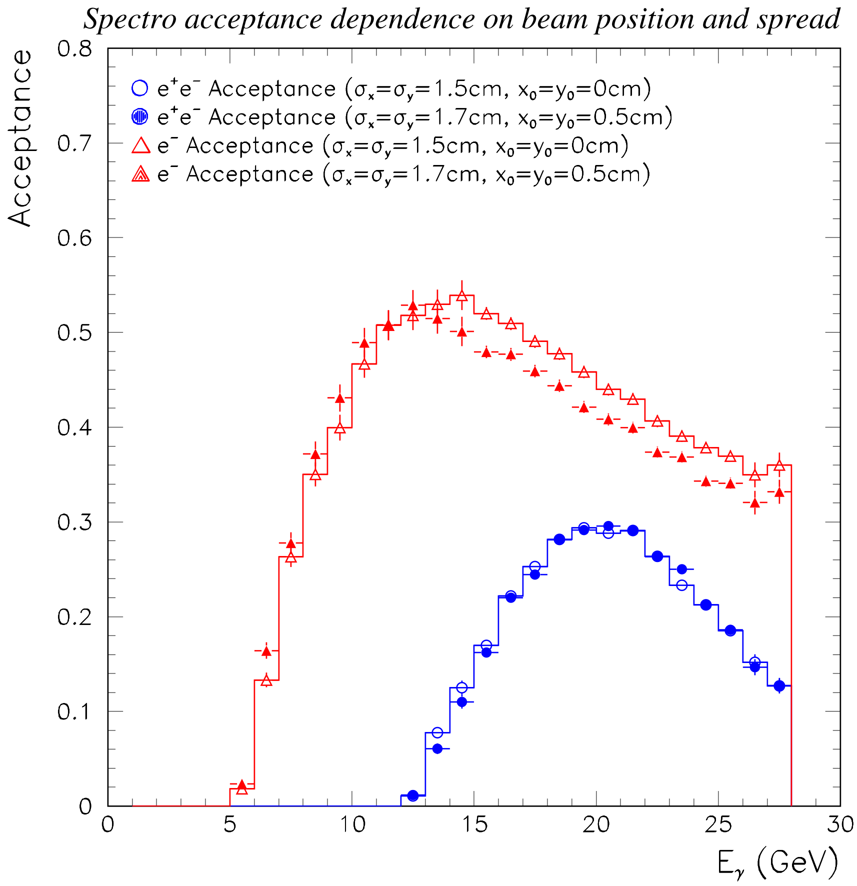


Spectro acceptance 9.8m downstream the window, BdL 0.36Tm
Acceptance
e+e− Acceptance
e− Acceptance
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
5
10
15
20
25
30
Eγ (GeV)

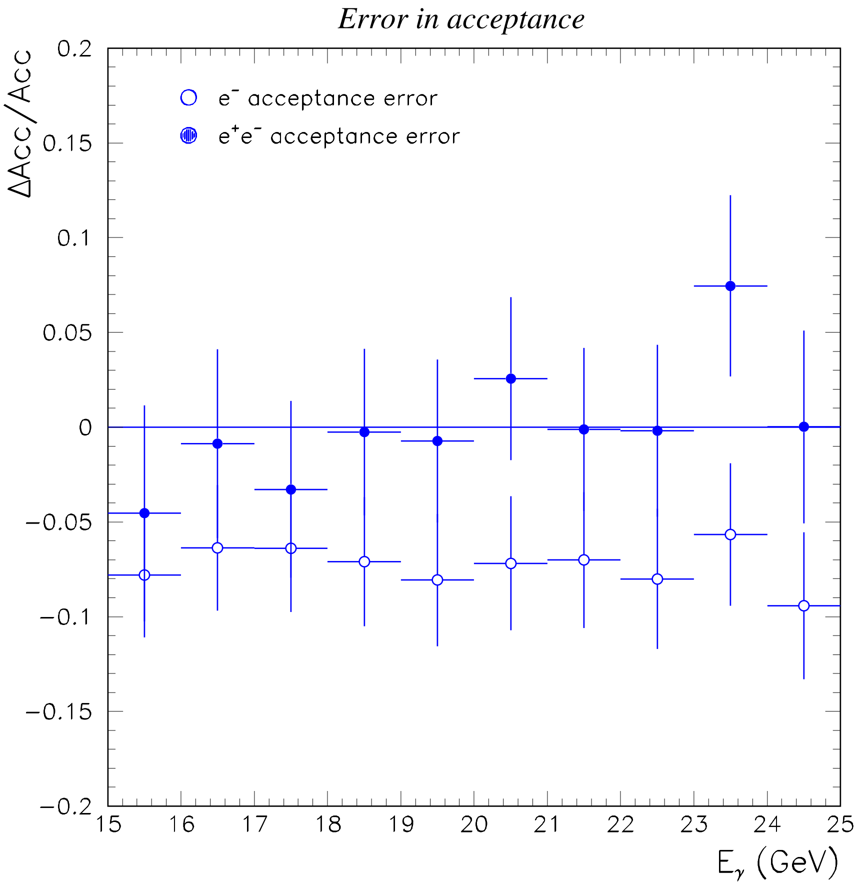
Photon Energy Spectrum Distribution as measured by the lumi spectrometer



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



Spectro acceptance dependence on beam position and spread
Acceptance
e+e− Acceptance (σx=σy=1.5cm, x0=y0=0cm)
e+e− Acceptance (σx=σy=1.7cm, x0=y0=0.5cm)
e− Acceptance (σx=σy=1.5cm, x0=y0=0cm)
e− Acceptance (σx=σy=1.7cm, x0=y0=0.5cm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
Eγ (GeV)



Error in acceptance
ΔAcc/Acc
e⁻ acceptance error
e⁺e⁻ acceptance error
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
15
16
17
18
19
20
21
22
23
24
25
Eγ (GeV)

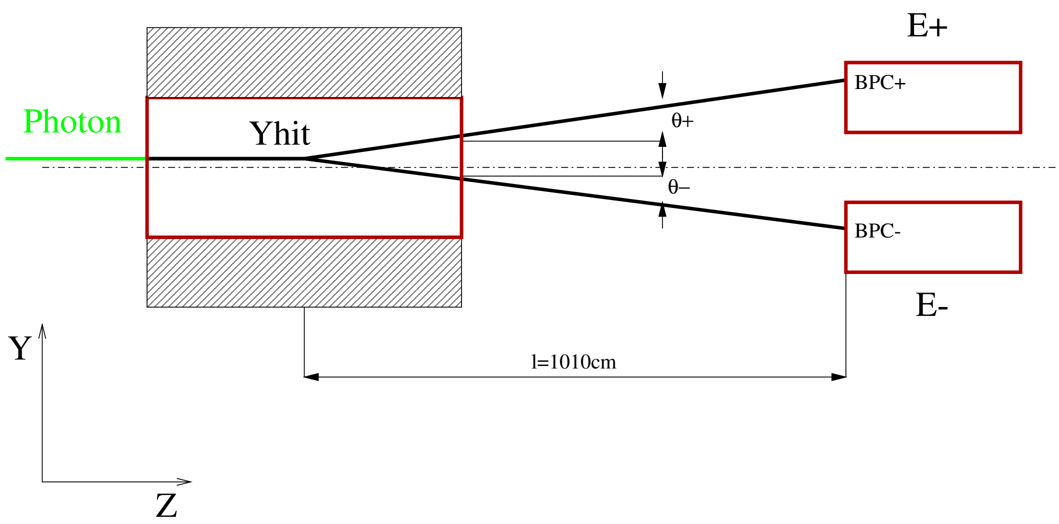
Description	$L = 10^{31} cm^{-2} s^{-1}$	$L = 7.10^{31} cm^{-2} s^{-1}$
e^- per bunch crossing (large BPC)	3.62×10^{-3}	$\times 7$
e^- per bunch crossing (small BPC)	2.65×10^{-3}	$\times 7$
e^+e^- per bunch crossing	8.13×10^{-4}	$\times 7$
Fake e^+e^- per bunch crossing	9.59×10^{-6}	$\times 49$
Overlayed e^- per bunch crossing	2.55×10^{-6}	$\times 49$
$\mathrm{Bgnd}_{e^-}/\mathrm{Signal}_{e^+e^-}$	0.31%	2.17%
Description (5 GeV window)	$L = 10^{31} cm^{-2} s^{-1}$	$L = 7.10^{31} cm^{-2} s^{-1}$
e^+e^- per bc in E_γ window	3.12×10^{-4}	$\times 7$
Fake e^+e^- per bc in E_γ window	2.68×10^{-6}	$\times 49$
$\mathrm{Bgnd}_{e^+e^-}/\mathrm{Signal}_{e^+e^-}$ (window)	0.86%	6.02%
$\mathrm{Bgnd}_{e^+e^-}/\mathrm{Signal}_{e^+e^-}$ (z-cut)	0.67%	4.73%
Rates of e^+e^- (5 GeV window)	3.12 kHz	21.84 kHz
Probability of an overlay in window	10.07%	
Migrations in window per bc	2.72×10^{-7}	$\times 49$
$\mathrm{Bgnd}_{IN}/\mathrm{Signal}_{e^+e^-}$ (window)	0.087%	0.61%
Migrations out of window per bc	2.55×10^{-6}	$\times 49$
$\mathrm{Bgnd}_{OUT}/\mathrm{Signal}_{e^+e^-}$ (window)	0.81%	5.72%

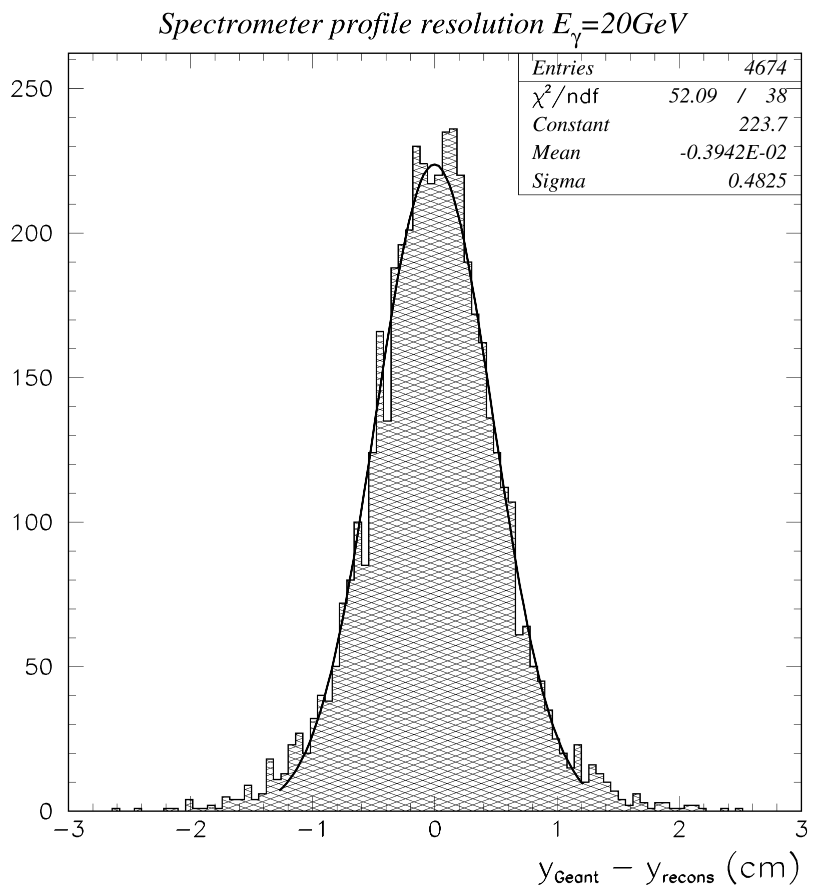
Table 1: Luminosity spectrometer rates.

Photon Beam Profile Reconstruction

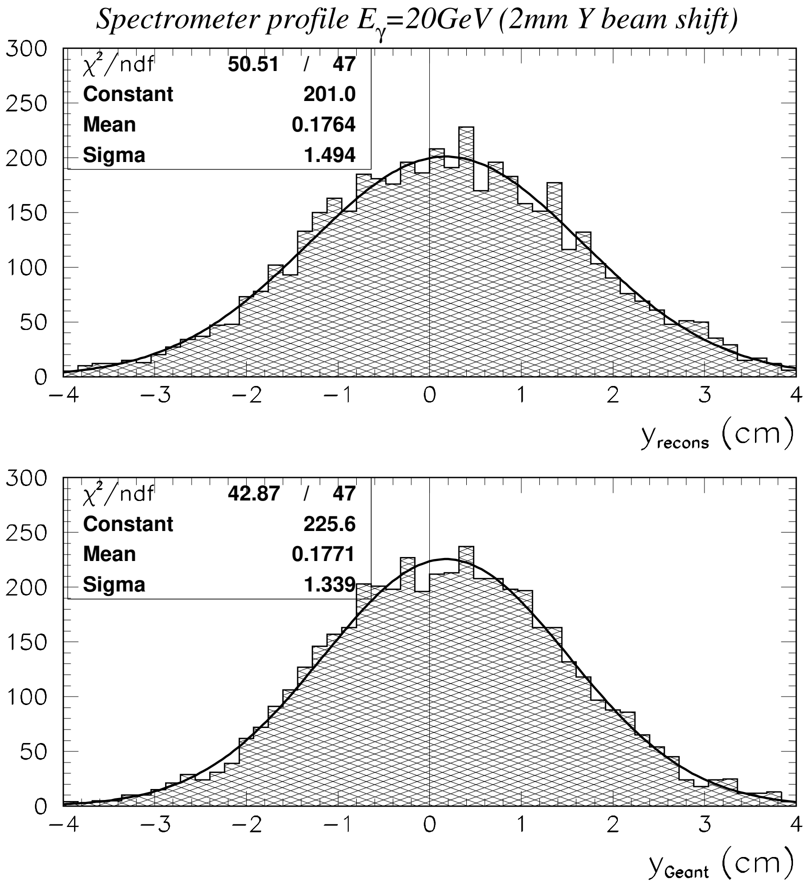
The position of the photon (projected to the BPC Z location) is approximated as the energy-weighted position of the two electrons as measured in the BPC.

$$Y_{hit} = \frac{E^+ BPC^+ + E^- BPC^-}{E^+ + E^-} \tag{8}$$





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


Spectrometer profile E_γ=20GeV (2mm Y beam shift)
χ²/ndf 50.51 / 47
Constant 201.0
Mean 0.1764
Sigma 1.494
y_recons (cm)
χ²/ndf 42.87 / 47
Constant 225.6
Mean 0.1771
Sigma 1.339
y_Geant (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.**

Energy Scale and resolution uncertainties in the cross section determination

To calculate this error we parametrize the BPC resolution as follows:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E_{e^\pm}}} \oplus b \tag{9}$$

The total bremsstrahlung cross section is:

$$\sigma^{BH} = \int_{E_1}^{E_2} \frac{d\sigma^{BH}}{dE_\gamma} \otimes g(E_\gamma) dE_\gamma \tag{10}$$

The convolution with the detector response $g(E_\gamma)$ gives in detail:

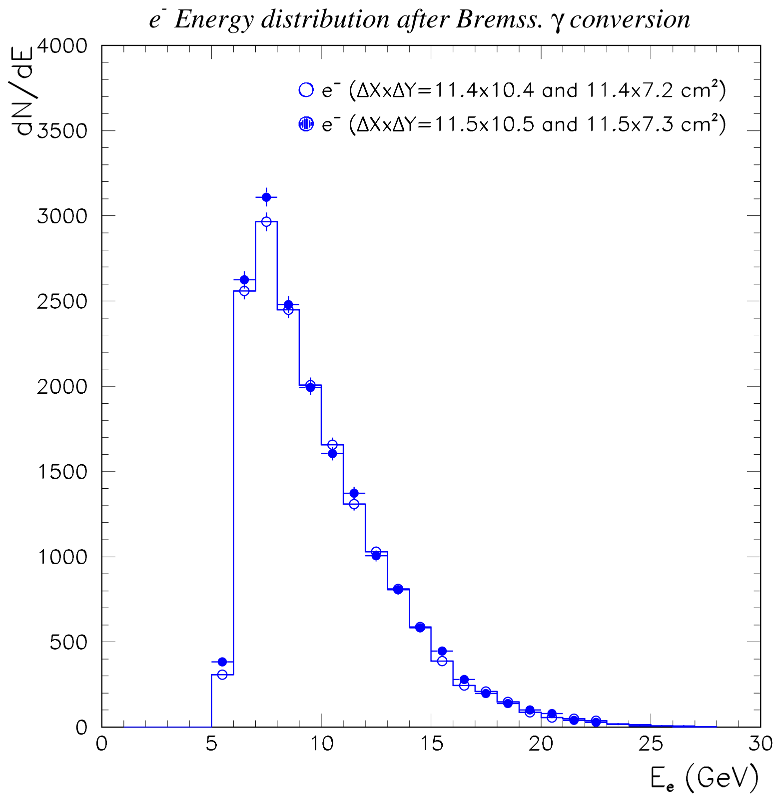
$$\sigma^{BH} = \int_{E_1}^{E_2} [\int \frac{d\sigma^{BH}}{dE'_\gamma} \frac{1}{\sqrt{2\pi}\sigma} e^{-(E'_\gamma - E_\gamma)^2/2\sigma^2} dE'_\gamma] dE_\gamma \tag{11}$$

Test	a	b	Boundary Shift	σ^{BH} (mb)	Total Error
Test 1	0.	0.	0.%	8.908826	0.
Test 2	0.2	0.01	0.%	8.908762	0.001%
Test 3	0.2	0.01	0.5%	8.865372	0.4878%
Test 4	0.2	0.02	0.5%	8.865236	0.4893%
Test 5	0.17	0.02	0.5%	8.865623	0.4850%
Test 6	0.2	0.02	1%	8.822408	0.97%

In summary, the total systematic error due to energy scale in the cross section determination is about 0.5% or less.

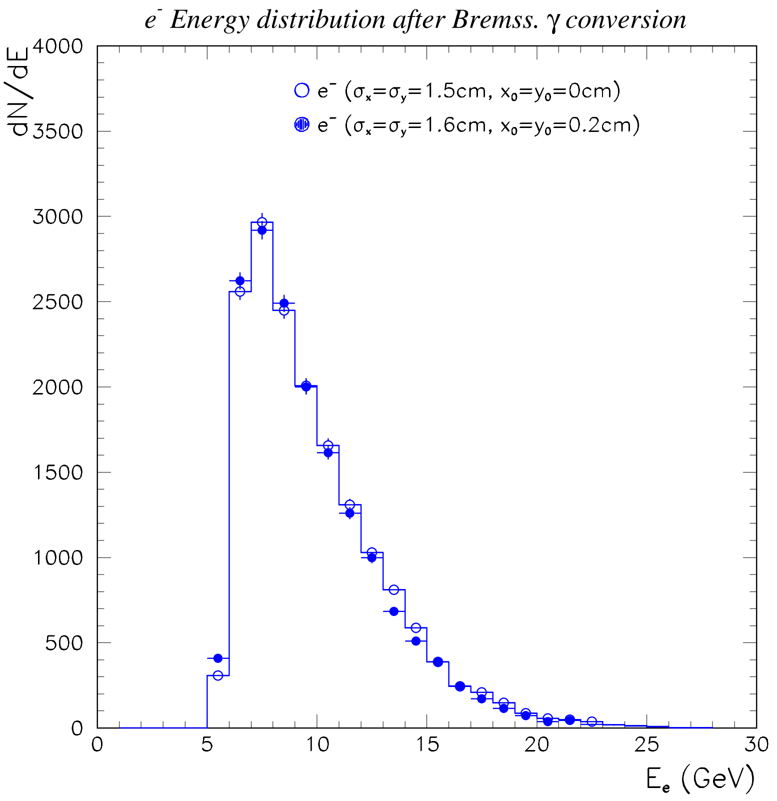
Multiple events correction errors (pile-up)

Uncertainty in the BPC fiducial volume



Pile-up corr.	est. error	syst. err. $L = 10^{31}$	syst. err. $L = 7 \times 10^{31}$
Fake Coincid.	0.1%	small	small
Migrations in	2%	small	small
Migrations out	2%	small	0.11%

Uncertainty in the photon beam position and distribution



Pile-up corr.	est. error	syst. err. $L = 10^{31}$	syst. err. $L = 7 \times 10^{31}$
Fake Coincid.	4.1%	0.028%	0.2%
Migrations in	7%	small	0.04%
Migrations out	7%	0.057%	0.4%

In summary, the total systematic error due to pile-up is about 0.5% or less.

Acceptance Correction Errors

$$\overline{a} = \frac{\int_{E_1}^{E_2} a(E_\gamma)\frac{dN}{dE_\gamma}dE_\gamma}{\int_{E_1}^{E_2} \frac{dN}{dE_\gamma}dE_\gamma} \tag{12}$$

BPC energy scale uncertainties (0.5 %)

egas background correction error (<0.5 %)

$$R_1 = R_0 - \frac{I_e^{tot}}{I_e^{pilot}} R^{pilot} \tag{13}$$

Off momentum beam electrons correction error (<0.5 %)

Off momentum beam electrons may generate a background in the interesting energy window of the tagger :

$$N_{tags}^{CORRECTED} = N_{tags}^{MEAS} - N_{tags}^{OFFMOM} - N_{tags}^{EGAS}. \tag{14}$$

This correction is measured in a way similar to the *egas* background correction.

Multiple events correction uncertainties (<0.5 %)

$$N_{coinc}^{CORRECTED} = N_{coinc}^{MEAS} - N_{coinc}^{PILEUP} - N_{coinc}^{EGAS} \tag{15}$$

6 meter tagger energy scale and resolution uncertainties

Acceptance Correction Errors

$$a = C\overline{a}' \tag{16}$$

$$\overline{a}' = \frac{N_{coinc}^{CORRECTED}}{N_{tags}^{CORRECTED}} \tag{17}$$

where

$$C = \frac{\frac{\int_{E_1}^{E_2} a(E_\gamma)\frac{dN}{dE_\gamma}dE_\gamma}{\int_{E_1}^{E_2}\frac{dN}{dE_\gamma}dE_\gamma}}{\frac{\int_{E_1^{6m}}^{E_2^{6m}} P_6(E_\gamma)a(E_\gamma)\frac{dN}{dE_\gamma}dE_\gamma}{\int_{E_1^{6m}}^{E_2^{6m}} P_6(E_\gamma)\frac{dN}{dE_\gamma}dE_\gamma}} \tag{18}$$

The tagger resolution is given by:

$$\frac{\sigma_E}{E} = \frac{a^{6m}}{\sqrt{E_e}} + b^{6m} \tag{19}$$

Test	a^{6m}	b^{6m}	Boundary Shift	Factor C	Total Error
Test 1	0.	0.	0.%	1.0	0.
Test 2	0.2	0.01	0.%	0.999994	6×10^{-6}
Test 3	0,	0.	0.5%	1.005173	0.517%
Test 4	0.2	0.01	0.5%	1.005194	0.519%

In summary, the total systematic error due to the acceptance calculation is about 1% or less.

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%