GamCal: a Beam-strahlung Gamma Detector for Beam Diagnostics

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GamCal Detector

- W. Morse (BNL): Coordinator
- M. Ohlerich et al. (Zeuthen): beam-strahlung simulations
- B. Parker (BNL): Machine interface issues
- M. Zeller, G. Atoian, V. Issakov, A. Poblaguev (Yale): GamCal detector design
- Y. Nosochkov (SLAC): Extraction line issues

RDR: Luminosity Feedback Detectors BeamCal and GamCal

2.7.4.2.3 Luminosity feedback Because the luminosity may be extremely sensitive to bunch shape, the maximum luminosity may be achieved when the beams are slightly offset from one another vertically, or with a slight nonzero beam-beam deflection. After the IP position and angle feedbacks have converged, the luminosity feedback varies the position and angle of one beam with respect to the other in small steps to maximize the measured luminosity.

Beam-strahlung Gammas

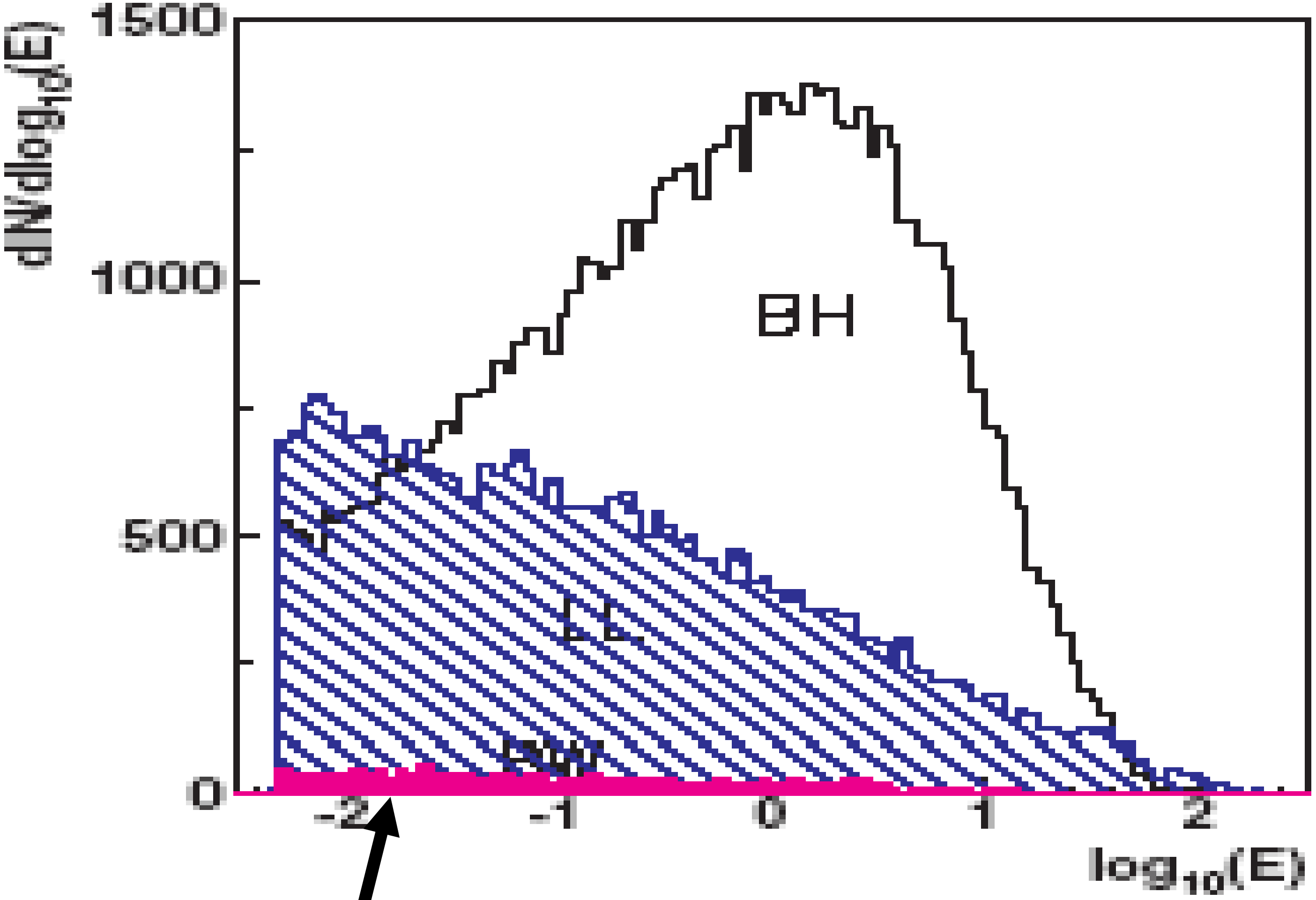
- $F = e(E + c\beta \times B)$
- $E = 0$, $B_{max} \approx 1KT$
- $P_\gamma \approx 2\%\ P_e \approx 0.3MW$
- $N_\gamma \approx 1.5N_e \approx 3\times10^{10}$ /BX

$$B_x = \frac{\mu_0 Ne\beta c}{\sigma_x \sigma_z} \frac{y}{\sigma_y} \qquad P_\gamma = \frac{2r_0\gamma^2 F^2}{3mc}$$

Beam-strahlung Pairs

- Bethe-Heitler: $\gamma e \rightarrow e\ e^+e^-$
- $\sigma_{BH} \approx 38$ mb
- $\langle E \rangle \approx 1$GeV
- Landau-Lifshitz: $ee \rightarrow ee\ e^+e^-$
- $\sigma_{LL} \approx 19$ mb
- $\langle E \rangle \approx 0.15$GeV

Beam-strahlung Pairs



≈0.1m low Z

Bethe-Heitler Pairs

- $\gamma e \rightarrow e\, e^+ e^-$

$$L \propto \frac{N_o^+ N_o^-}{\sigma_x^o \sigma_y^o}$$

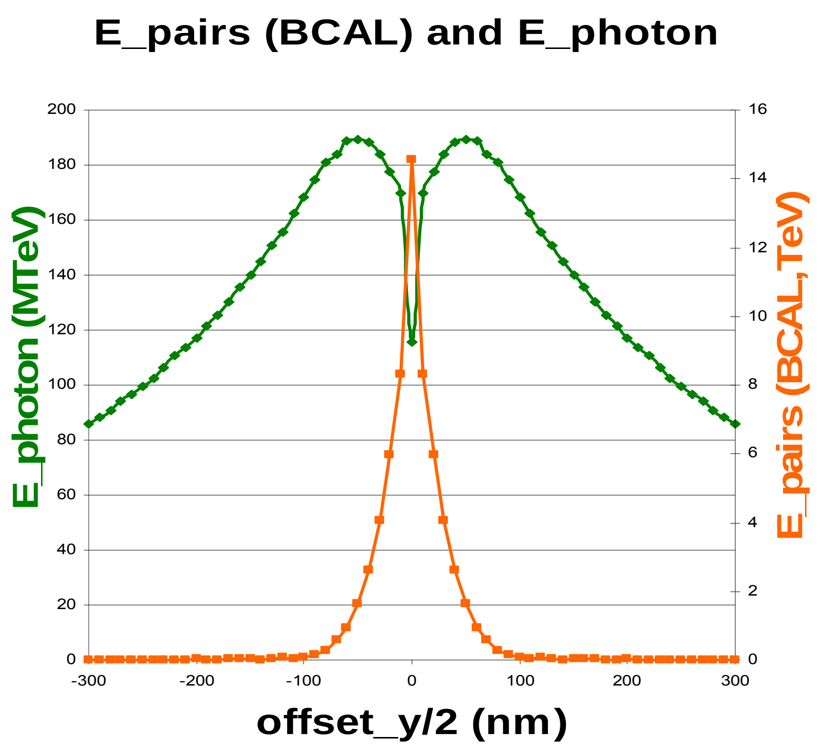
$$N_{ee} \propto \frac{\sigma_{BH} N_\gamma^o N_e^o}{\sigma_x^o \sigma_y^o}$$

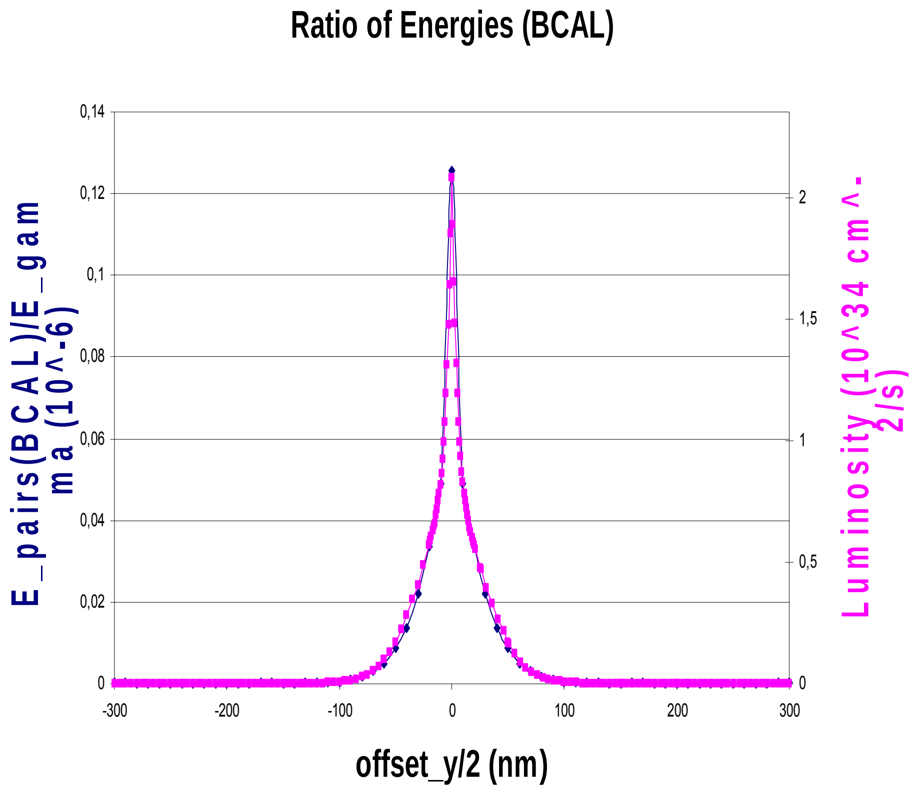
$$\frac{N_{ee}}{N_\gamma} \propto \frac{\sigma_{BH} N_e^o}{\sigma_x^o \sigma_y^o}$$

For left and right detectors separately: $N^+/\sigma_x\sigma_y$ and $N^-/\sigma_x\sigma_y$.

Vertical Offset

M.Ohlerich





complementary information from

1. total photon energy vs offset_y
2. BeamCal pair energy vs offset_y

ratio of E_pairs/E_gam vs offset_y is proportional to the luminosity

similar behaviour for angle_y, waist_y ...

see also: EUROTeV-Memo-2006-011

GamCal and BeamCal

- Measuring the beam-strahlung pairs and gammas provides robust complementary information
- Ratio of pairs to gammas is largely proportional to the instantaneous luminosity

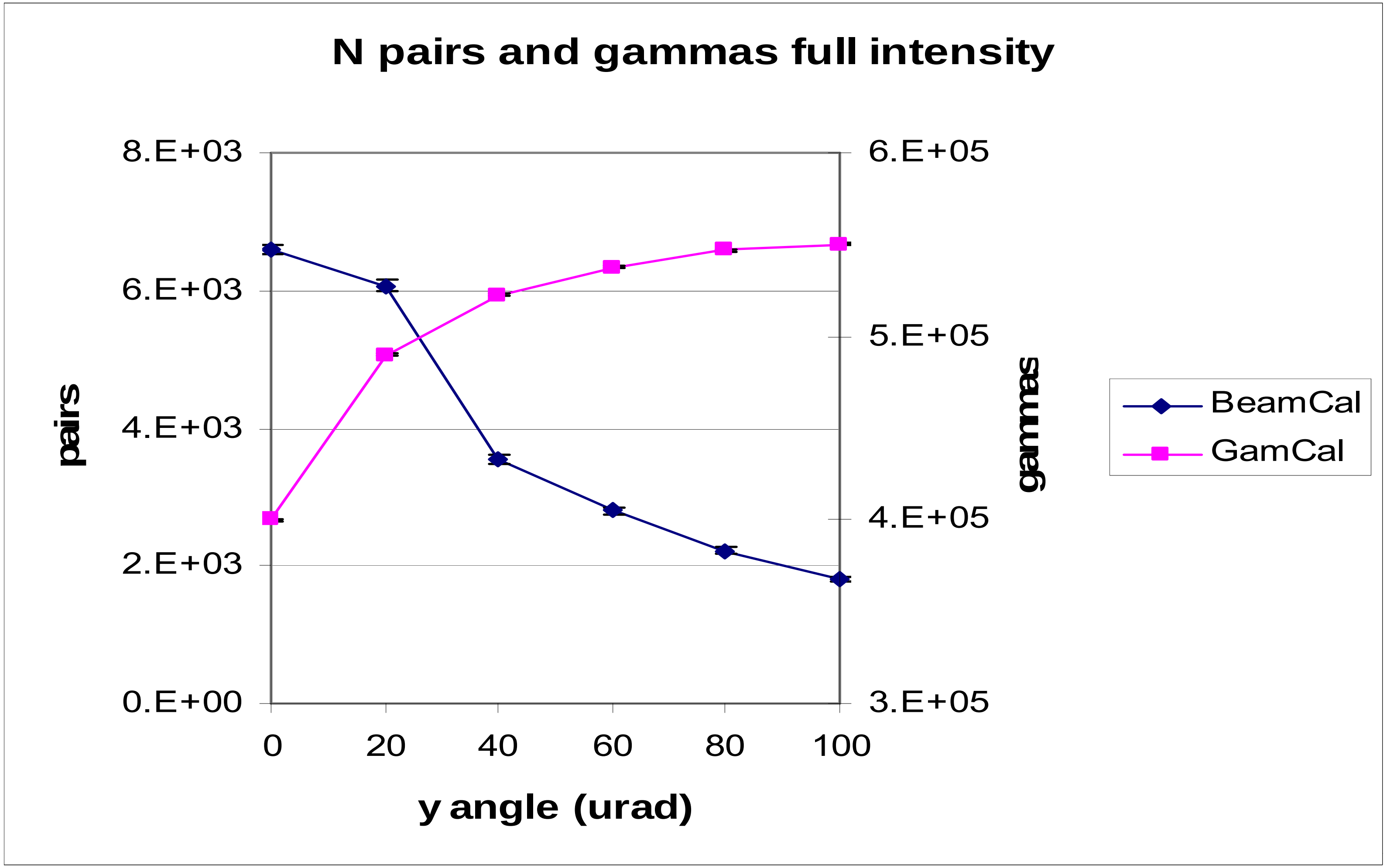
BeamCal

- $.003 < \theta < .02$ rad
- $\approx$3.5m from IR
- Pairs curl in the magnetic field
- Measure the $\approx 10^4$ beam-strahlung e^+e^- pairs/BX for beam diagnostics
- The distribution of the pairs on the BeamCal contains rich information on the beam parameters of the collision (beam sizes, emittances, etc.)

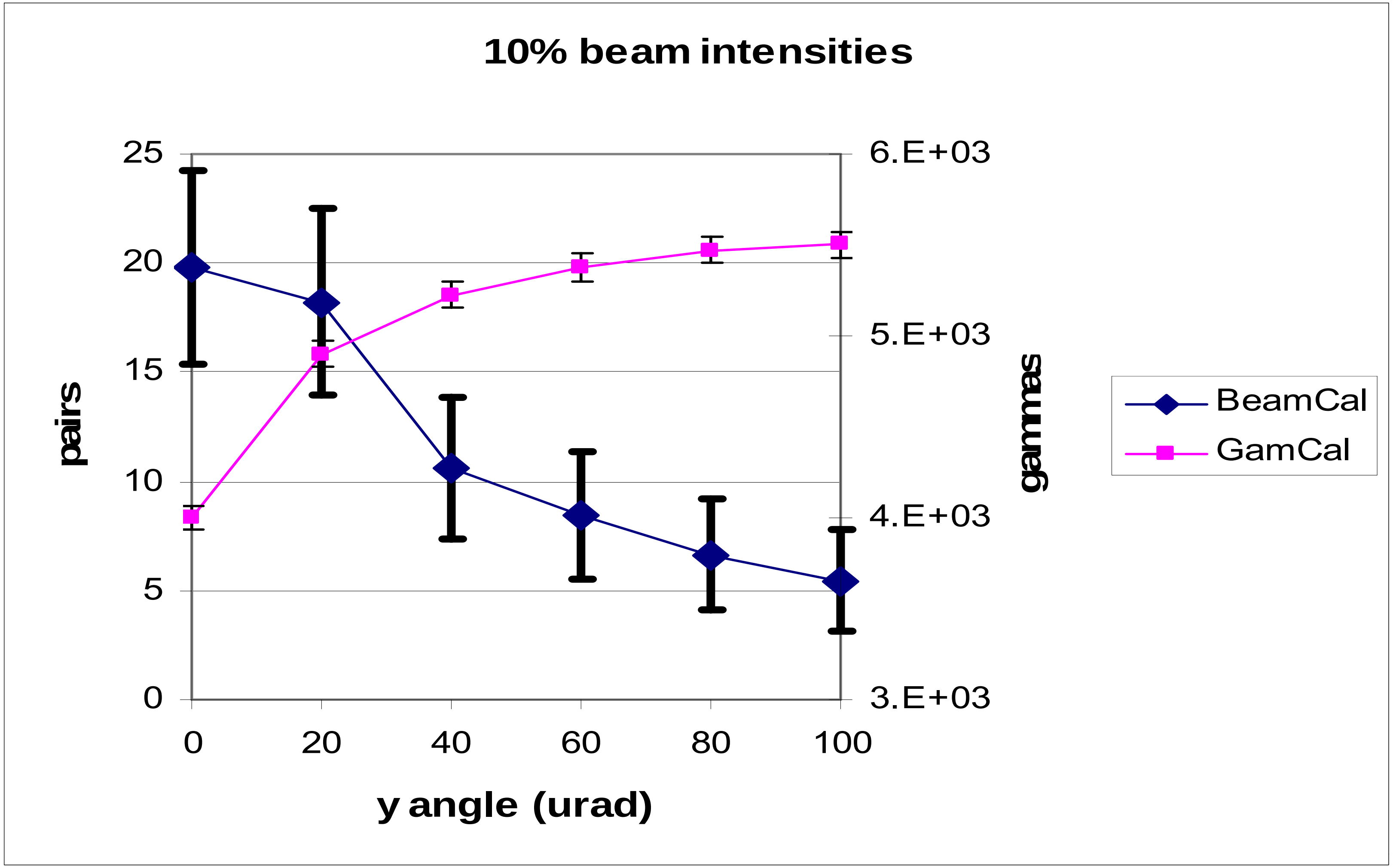
GamCal Detector

- ≈180m from IR
- ≈10^{-4} X_0 to convert beam-strahlung gammas into e^+e^- pairs
- Converter could be gas jet or a thin solid converter
- Dipole magnet with P_T kick 0.25 GeV/c separates the pairs from beam electrons
- Calorimeters outside vacuum after magnet measure the 1-10 GeV positrons

Statistical Error for BX

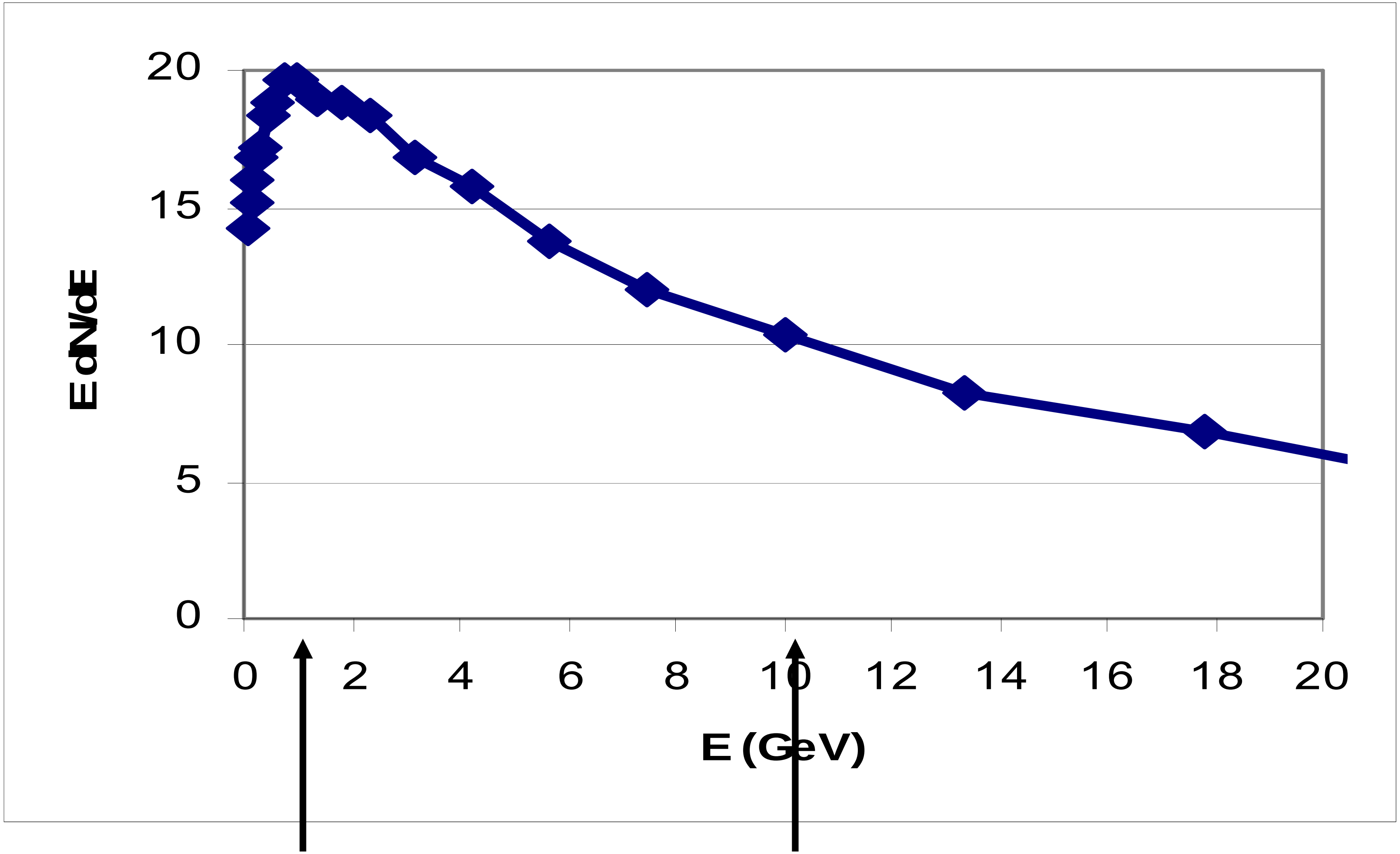


Start-up?



10% beam intensities
25
20
15
10
5
0
pairs
6.E+03
5.E+03
4.E+03
3.E+03
gammas
0
20
40
60
80
100
y angle (urad)
BeamCal
GamCal

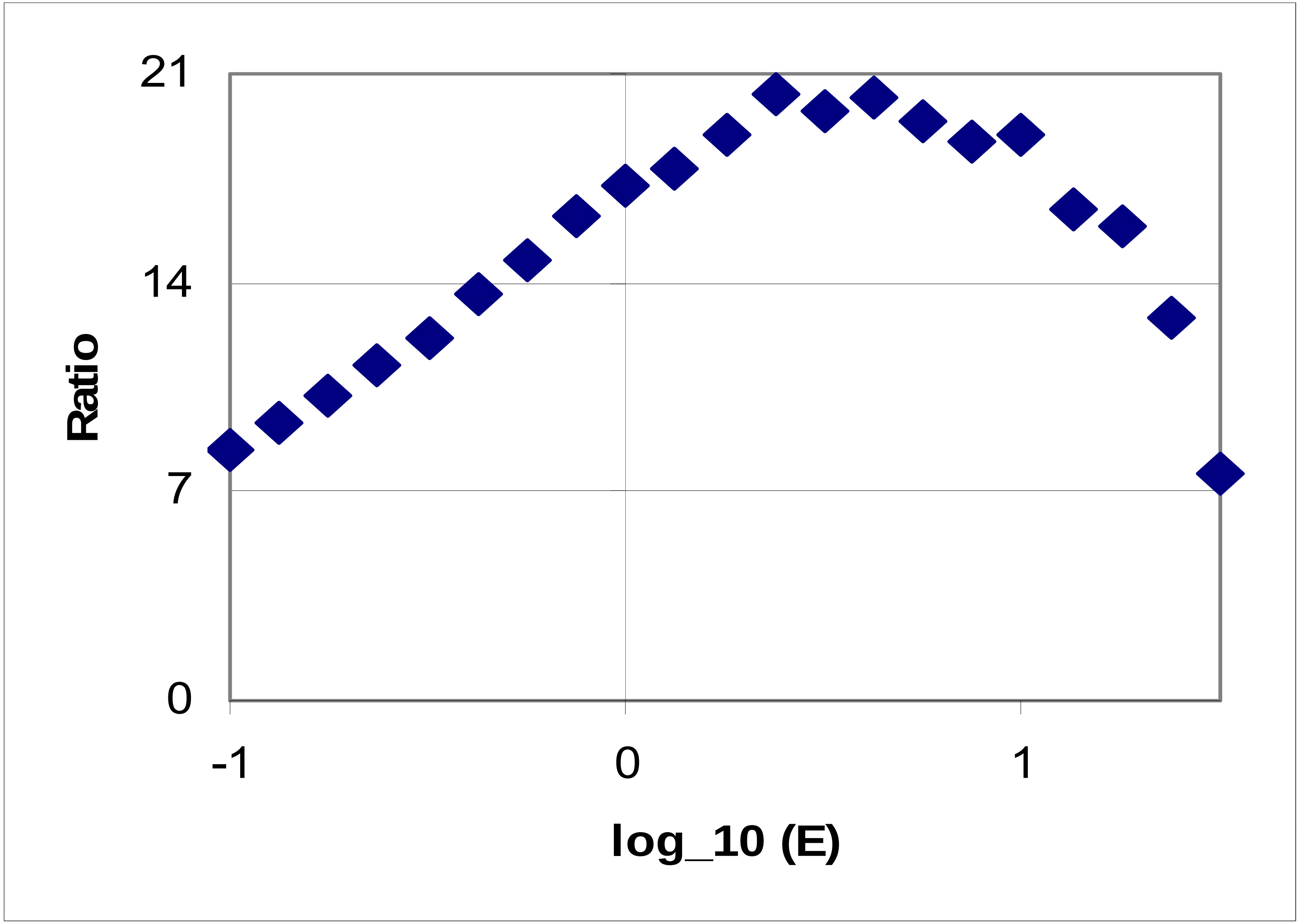
Beam-strahlung $\gamma Z \rightarrow e^+e^-Z$



GamCal Backgrounds from Beam Electrons

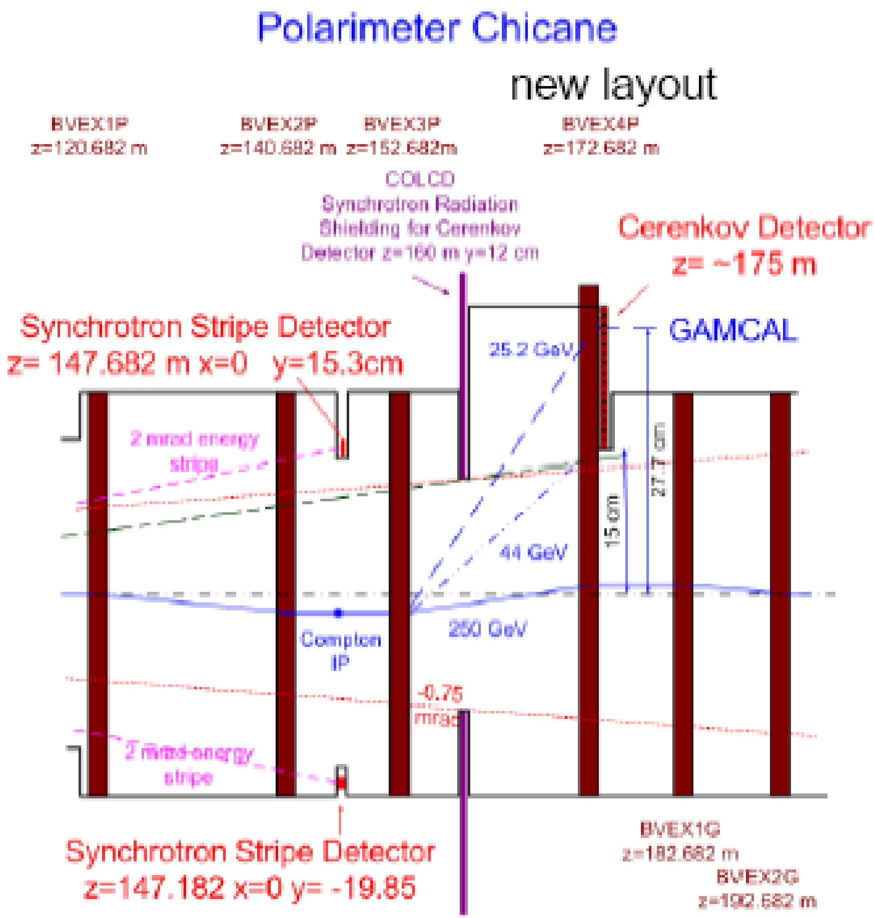
Process	Background/signal
Bremsstrahlung	<1%
Delta rays	<1%
Landau-Lifshitz	≈6%
π production	<0.1%

Ratio of $\gamma Z \rightarrow eeZ$ vs. $eZ \rightarrow eZee$

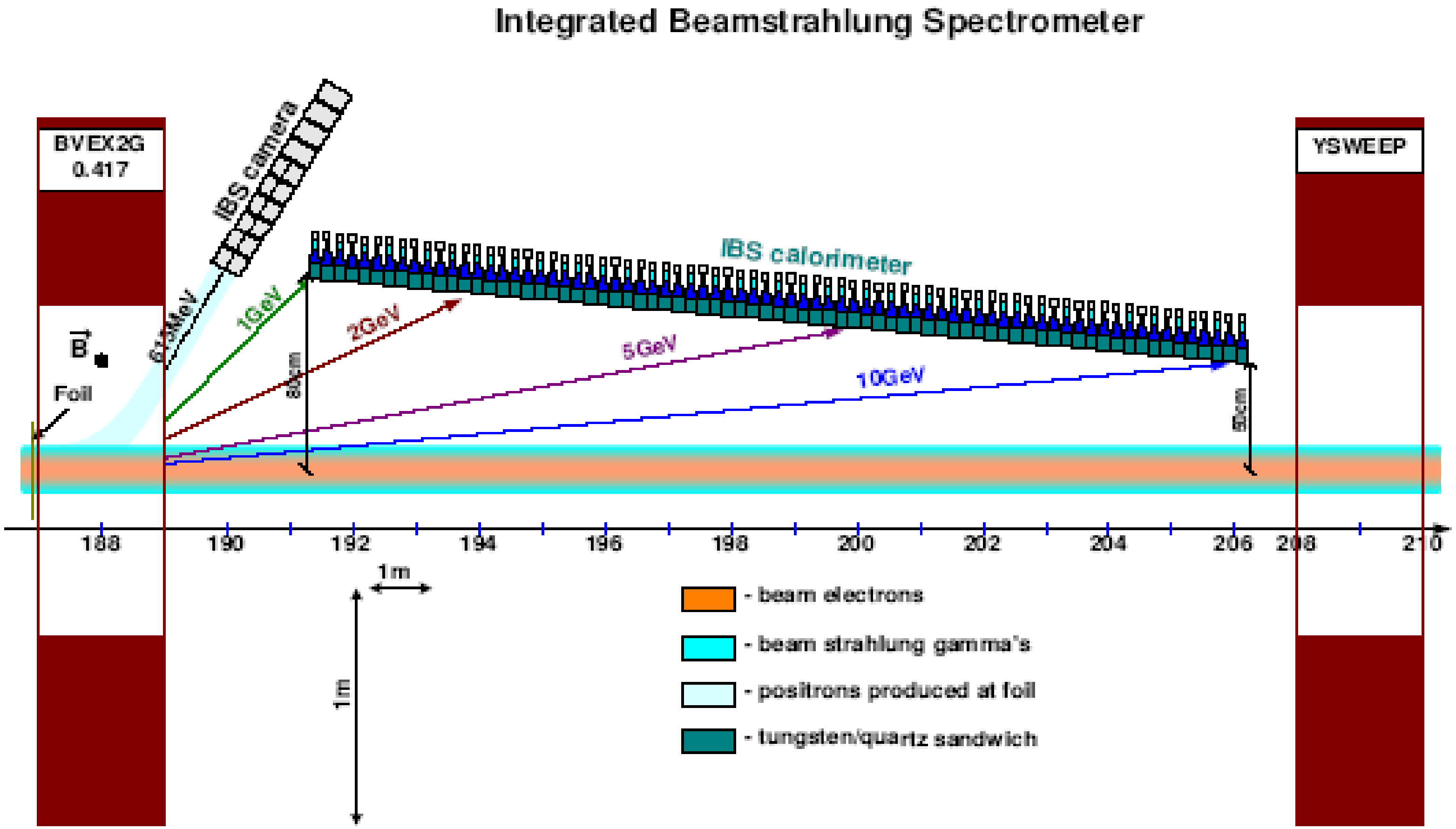


Modification of polarimeter chicane (CCR oncoming)

- Some increase of cost, improved performance
- More suitable for GamCal
- Ratio of energy in Gammas/Pairs ~ Lumi signal



Yale IBS Design



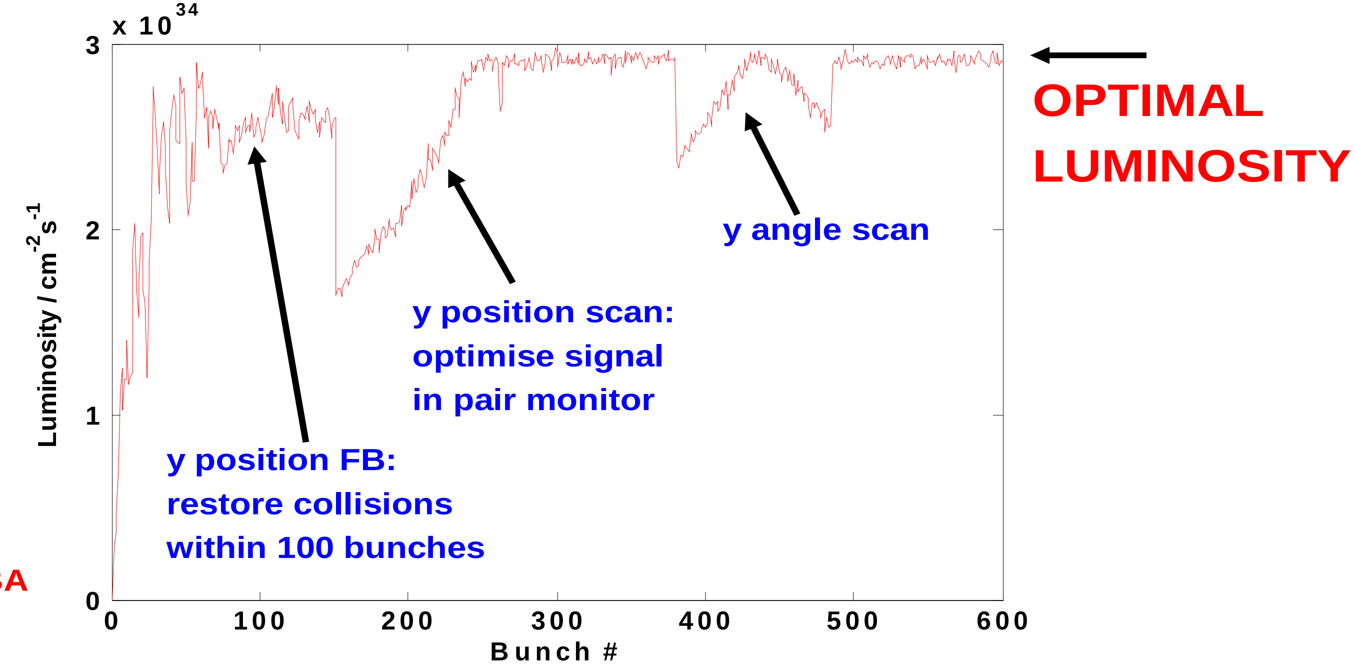
Beam Diagnostics Detectors Conclusions

- BeamCal and GamCal provide robust complimentary information.
- GamCal backgrounds look OK – needs simulations.
- Can measure, and then subtract, the GamCal background by accelerating only one beam.
- Ratio of the beamstrahlung pairs (BeamCal) to gammas (GamCal) is largely proportional to the instantaneous luminosity.
- There is much rich information from pair distributions on BeamCal and IBS camera, which we are studying.

Extra Slides

Feed-back with Luminosity Detectors

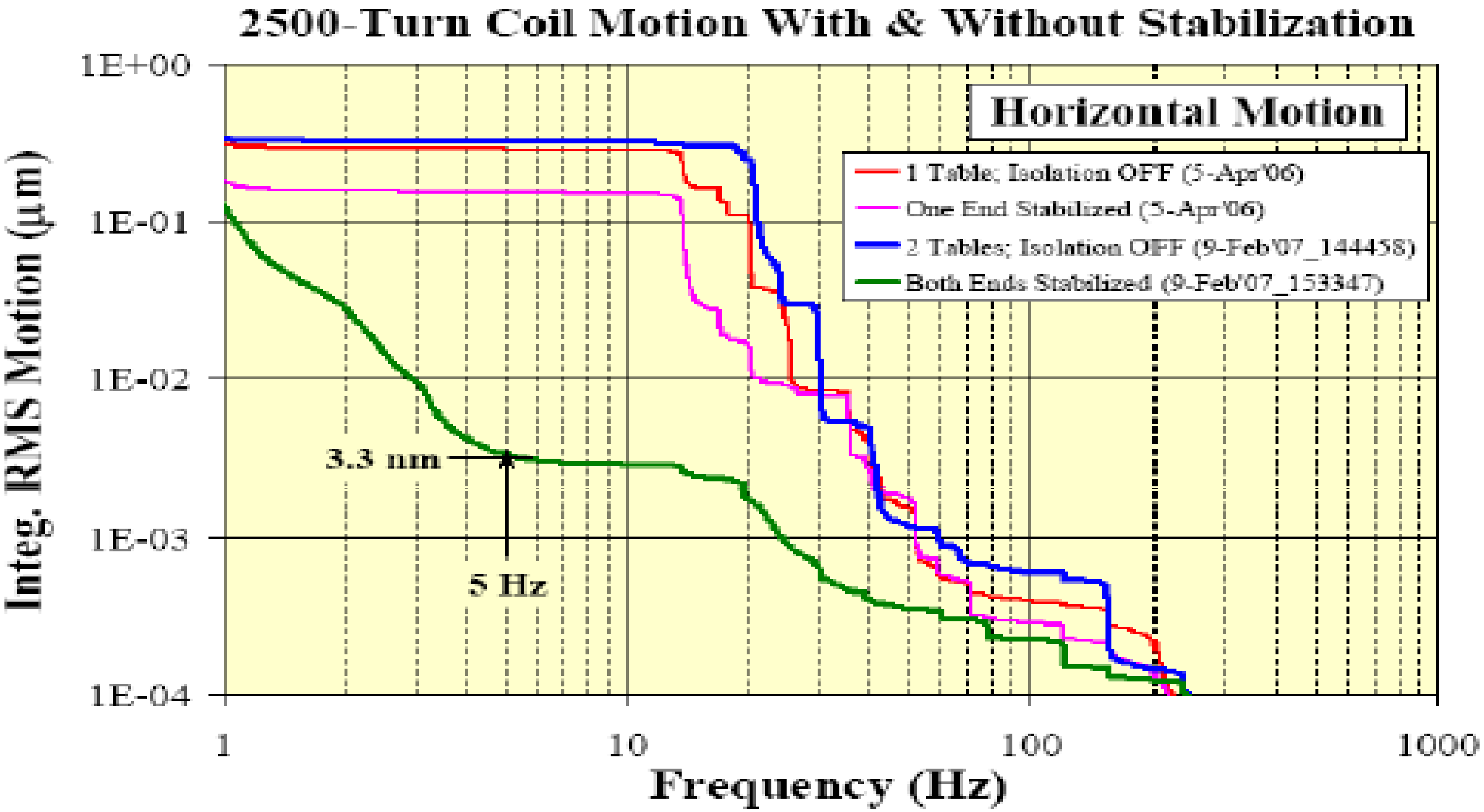
Intra-train y + y’ IP feedback simulations



1 seed:
post-BBA
+ GM
+ wakes

P.N. Burrows *GDE/MDI Vancouver 19/7/06*

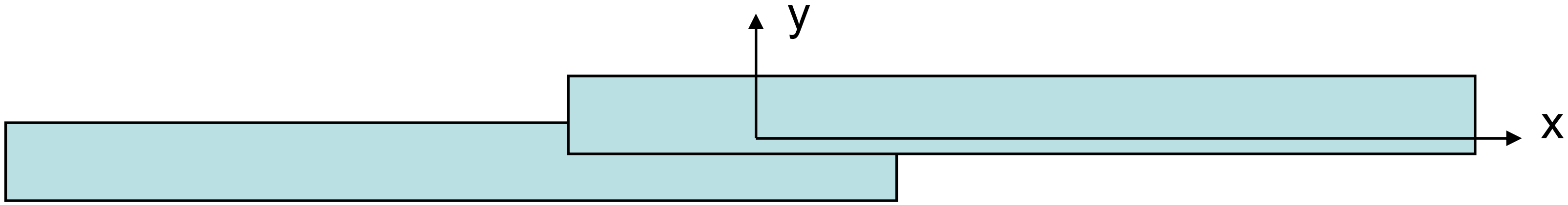
BNL Magnet Division Position Stability



Achieving the ILC Luminosity Will Be a Challenge

- Bunch $P_-(t)$ $\{N, \sigma_x, \sigma_y, \sigma_z, \sigma_{xy}, \psi_x, \psi_y\}$
- Bunch $P_+(t)$ $\{N, \sigma_x, \sigma_y, \sigma_z, \sigma_{xy}, \psi_x, \psi_y\}$
- Instantaneous Luminosity:

$$L(t) \propto \frac{N_+^o N_-^o}{\sigma_x^o \sigma_y^o}$$



IBS Camera

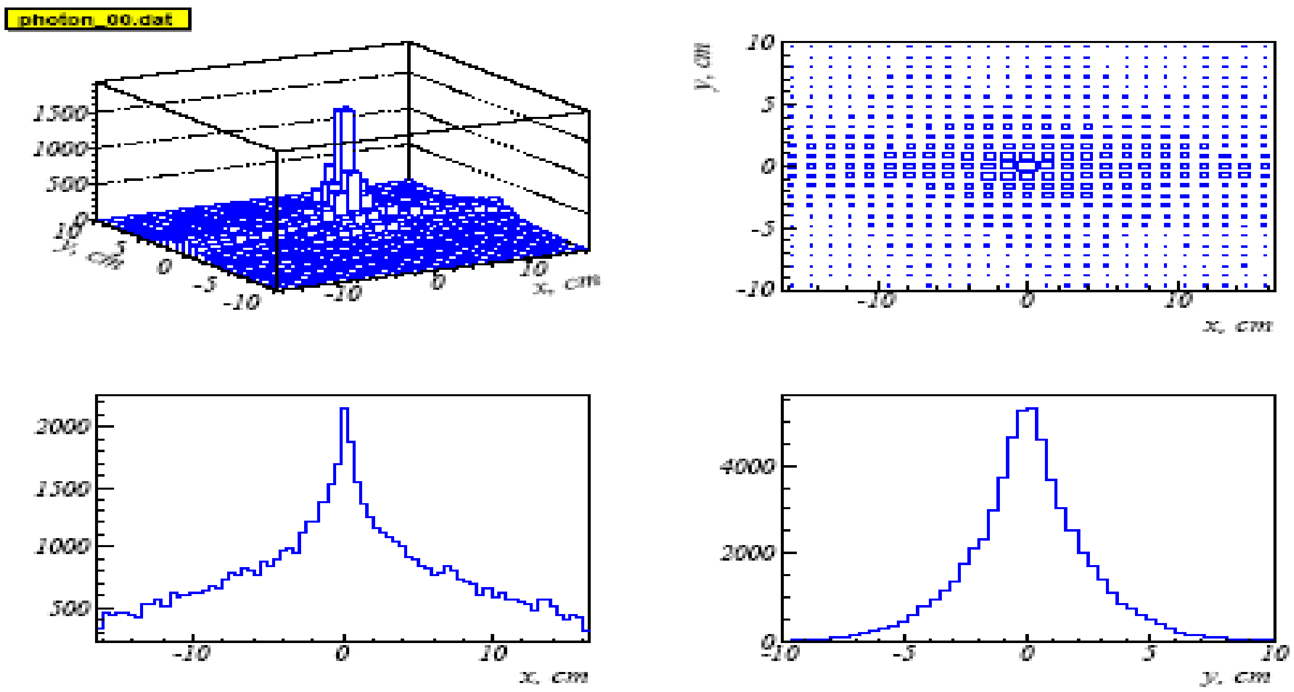


Figure 3: Distributions as seen by the IBS camera from head-on collisions at the IP. Upper left is a plot of positron intensity vs. horizontal (x) and vertical (y) directions transverse to the beamstrahlung beam. Upper right is the the same as seen in the $x - y$ plane. Lower left and right are projected intensity distributions in x and y, respectively.

IBS Camera

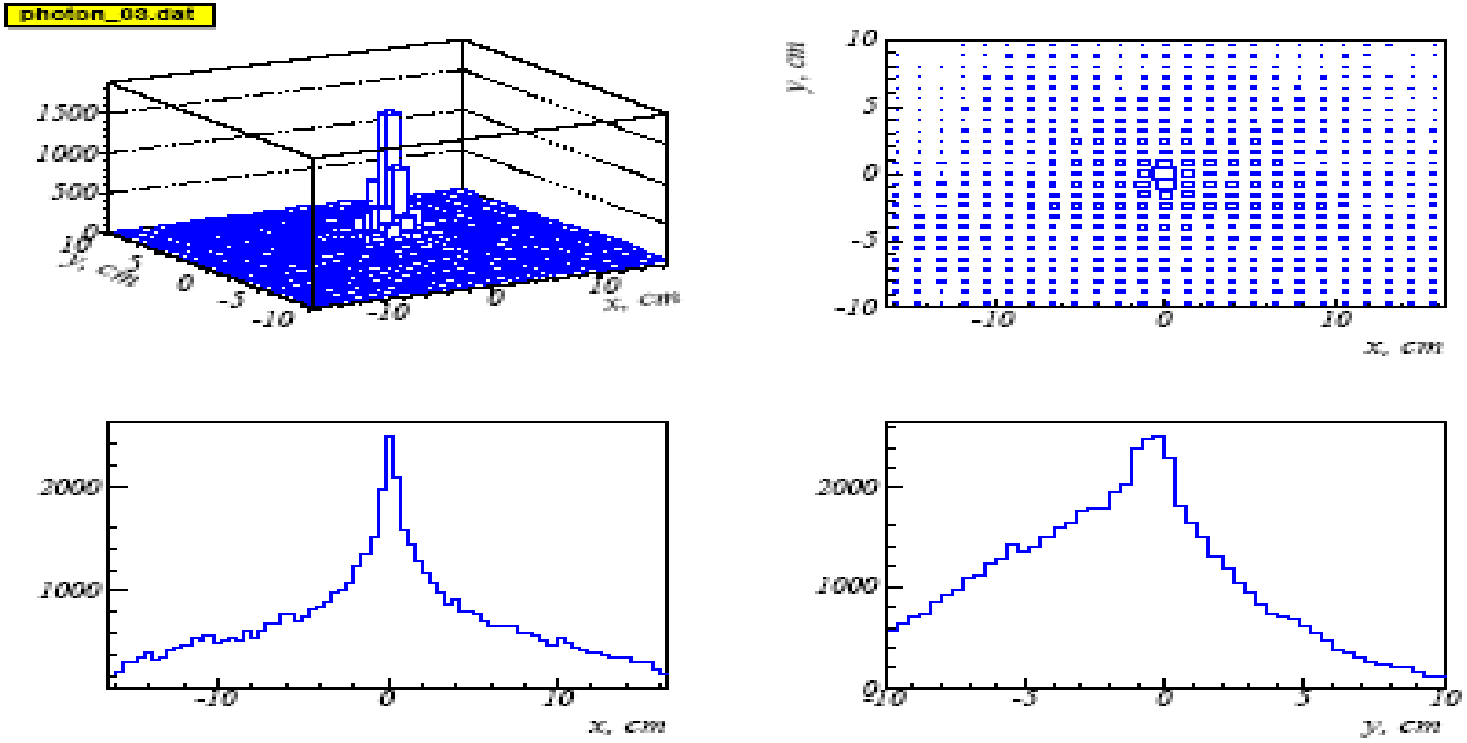
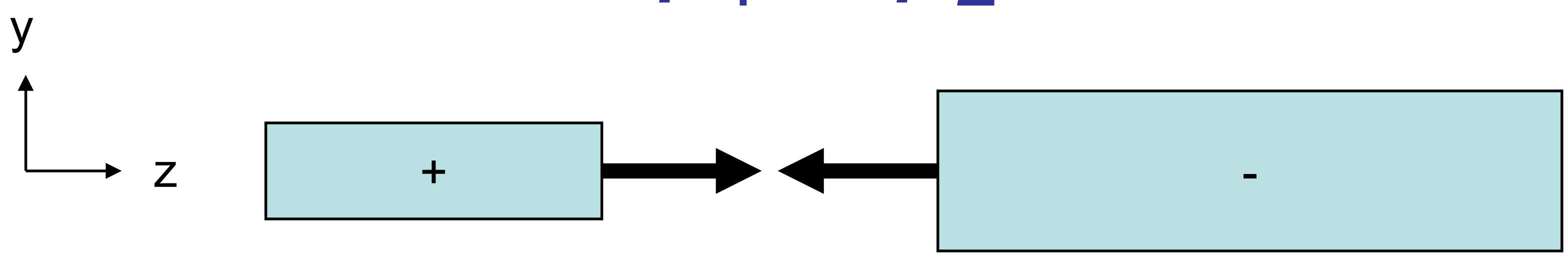


Figure 4: Same as fig. 3 but for a vertical offset of the colliding beams of 35 nm.

ρ₁ ≠ ρ₂



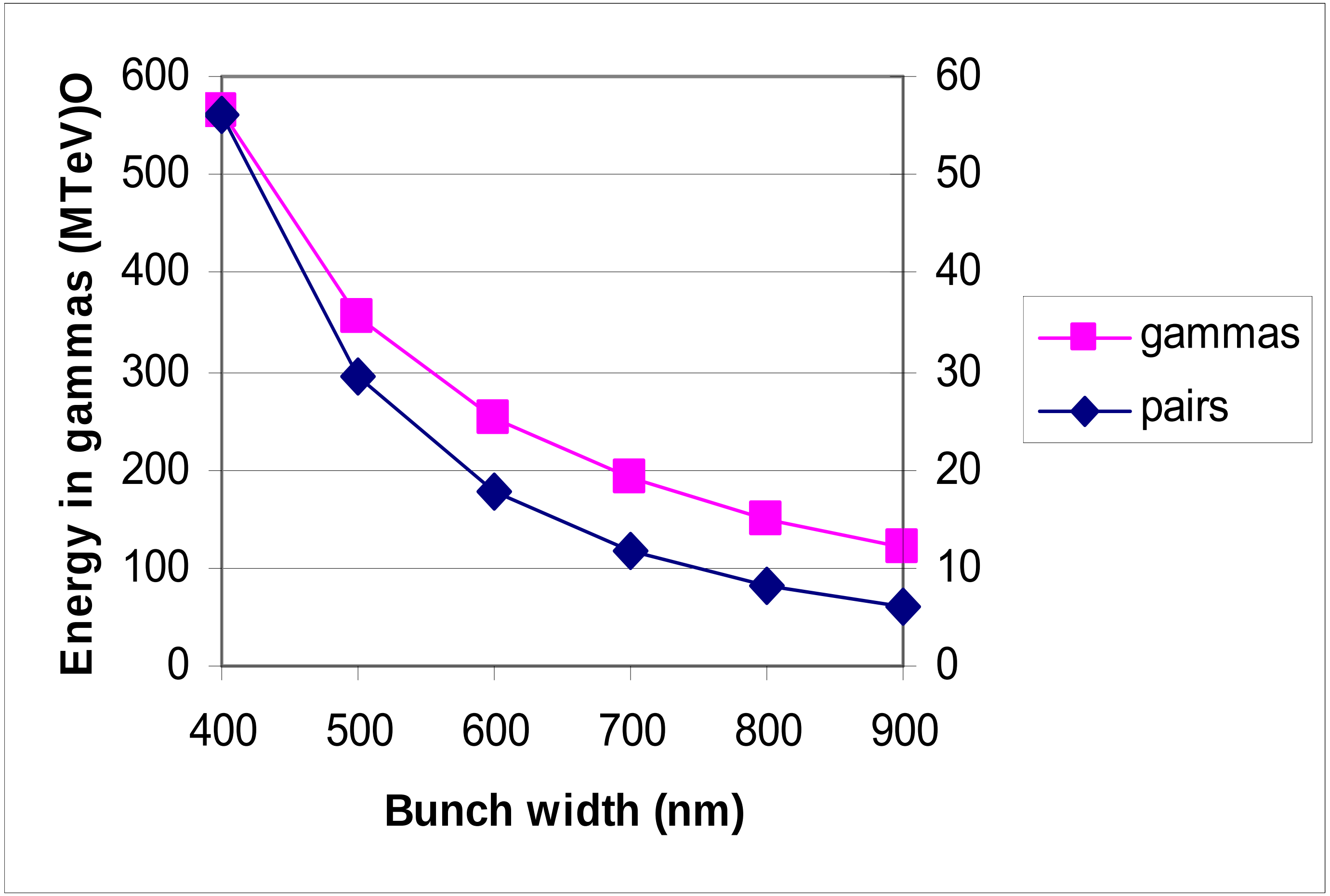
$$F_1 = \frac{ey}{\varepsilon_0}\left(\rho_2 - \rho_1 + \beta^2\left(\rho_1 + \rho_2\right)\right) \approx \frac{2\rho_2 ey}{\varepsilon_0}$$

$$E = \frac{\left(\rho_1 - \rho_2\right)y}{\varepsilon_0} \qquad B = \frac{\beta\left(\rho_1 + \rho_2\right)y}{\varepsilon_0}$$

Perfect Collisions

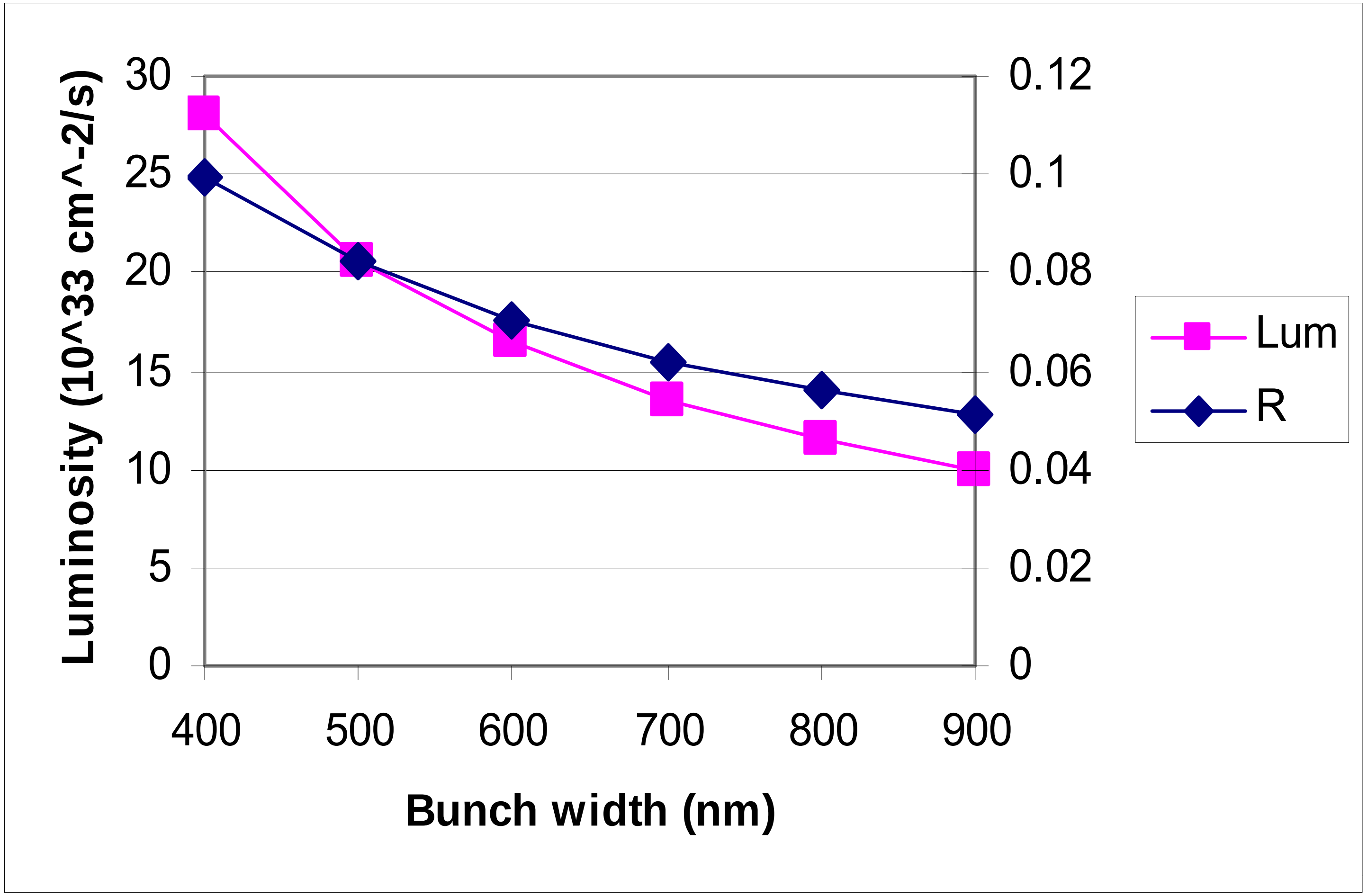
$$E_{\gamma} \propto \frac{N^2}{\sigma_x^2 \sigma_z} \qquad E_{ee} \propto \frac{N^3}{\sigma_x^3 \sigma_y \sigma_z}$$

Bunch width



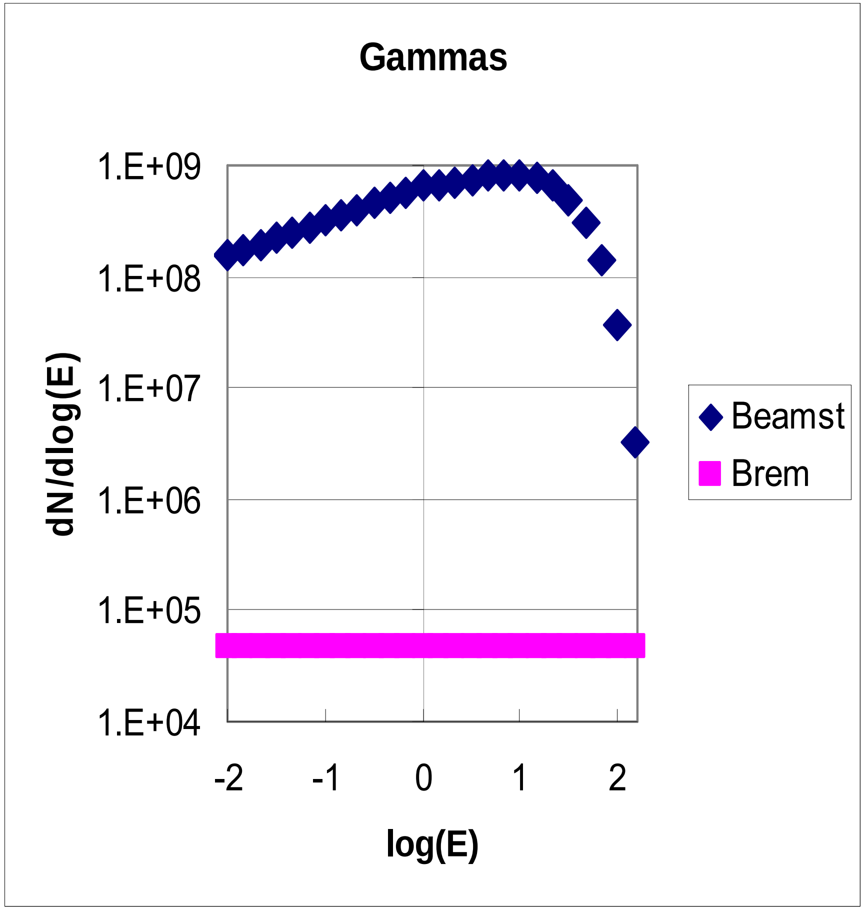
Energy in gammas (MTeV)O
600
500
400
300
200
100
0
60
50
40
30
20
10
0
400
500
600
700
800
900
Bunch width (nm)
gammas
pairs

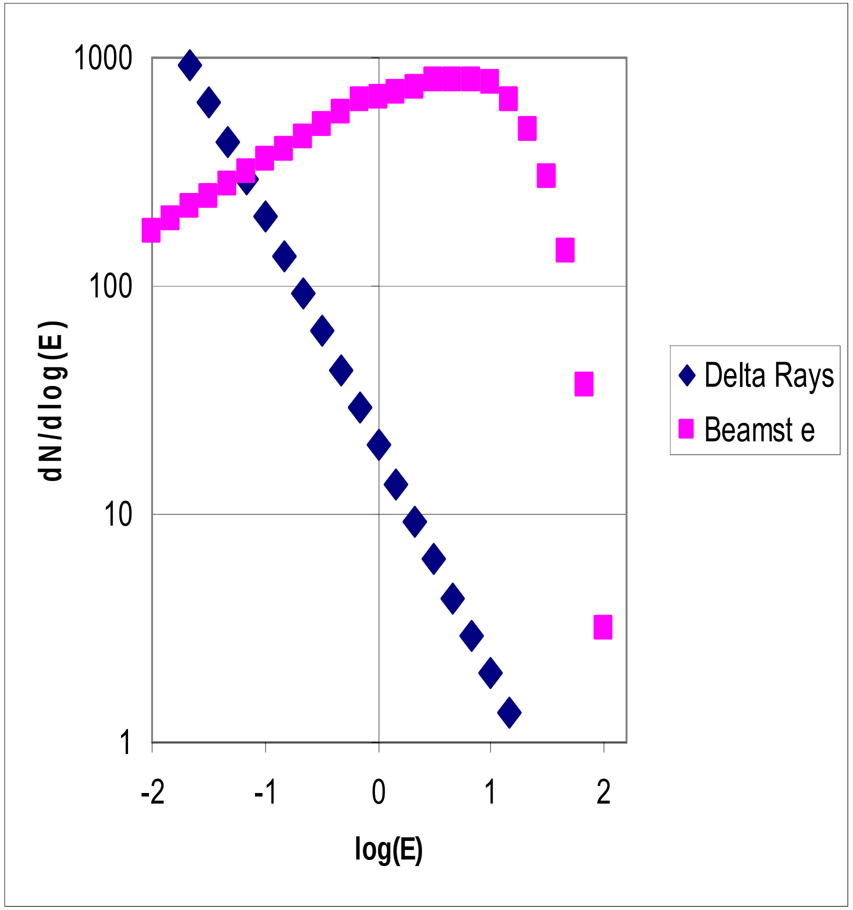
Bunch Width



Luminosity (10^33 cm^-2/s)
30
25
20
15
10
5
0
0.12
0.1
0.08
0.06
0.04
0.02
0
400
500
600
700
800
900
Bunch width (nm)
Lum
R

GamCal Backgrounds





$\gamma Z \rightarrow eeZ$ vs. $eZ \rightarrow eZee$

- Electron carries virtual gammas
- Landau Lifshitz conversion of virtual gammas

$$\frac{dN}{d\omega} = \frac{2\alpha}{\pi} \frac{1}{\omega} \left[\ln \frac{1.1\gamma c}{\omega b_{\min}} - \frac{1}{2} \right]$$

π Production Compared to ee

- $\gamma p \to eep \quad \sigma \approx 10$ mb
- $\gamma p \to \pi N \quad \sigma \approx 0.5$ mb on peak of Δ resonance
- $\gamma p \to \pi N \quad \sigma \approx 0.1$ mb $\quad E > 4$GeV
- $ep \to e \pi N \quad \sigma \approx 10^{-3}$ mb
- Thus $ep \to e \pi N$ is negligible