ILC Beam Energy Monitoring by Synchrotron Radiation

K.Hiller, Dubna, May 2006

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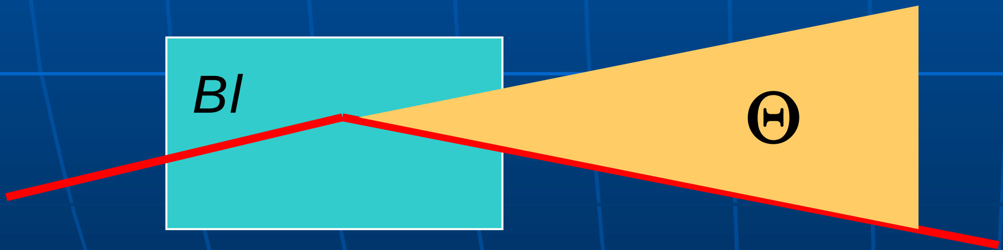
Principle

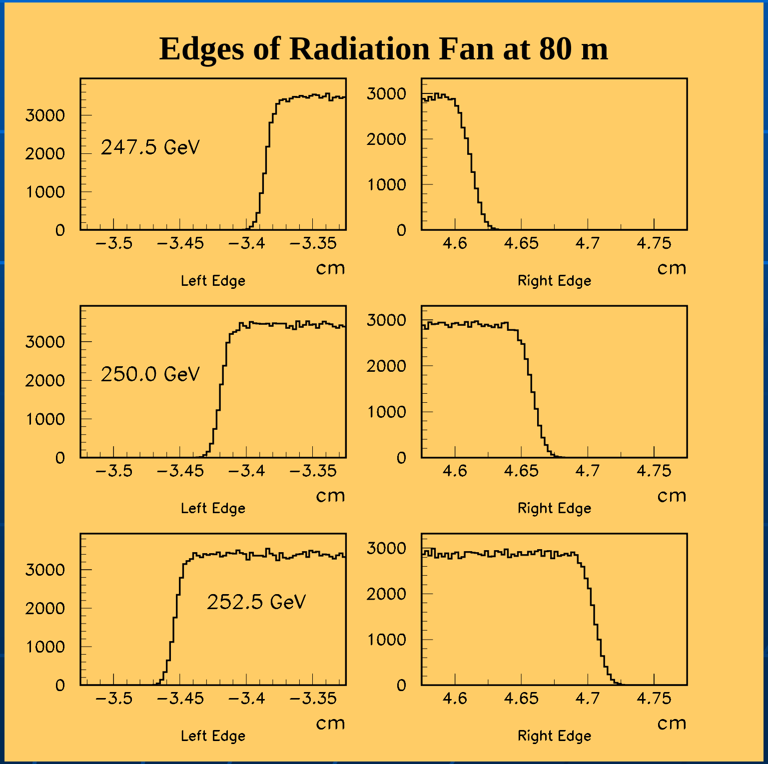
1) Beam energy is indirect proportional to the bending angle

$$E = 0.3Bl / \Theta$$

2) Edges of the synchrotron radiation fan measure the bending angle

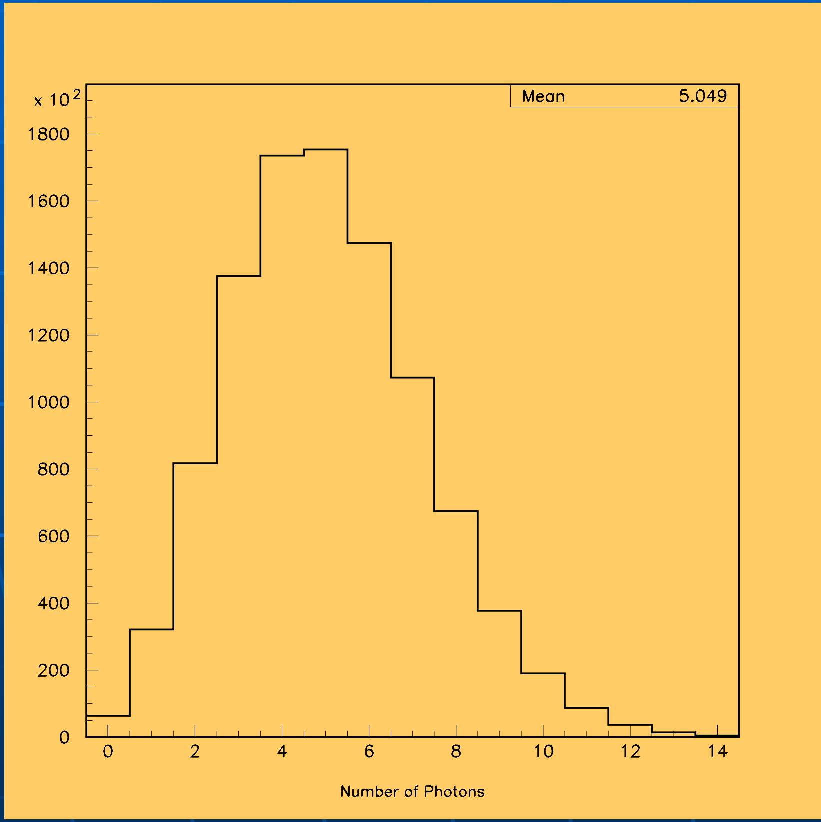


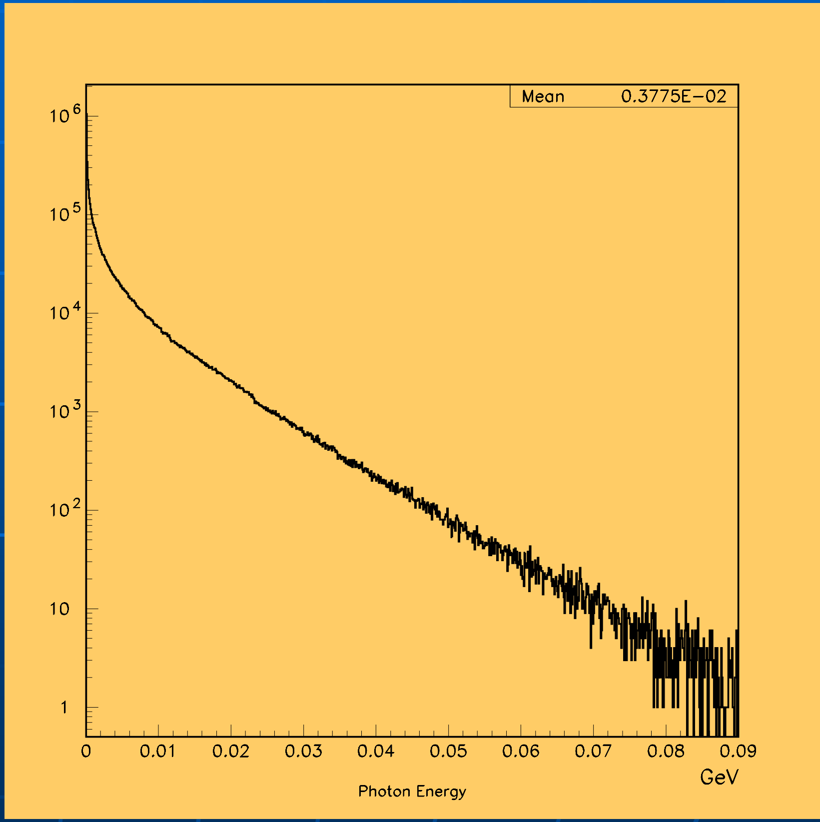
Example:
E = 250, +- 2.5 GeV



Synchrotron Radiation at ILC

e+/e- 250 GeV, magnet B = 0.28 T, L = 3m, Θ = 1 mrad



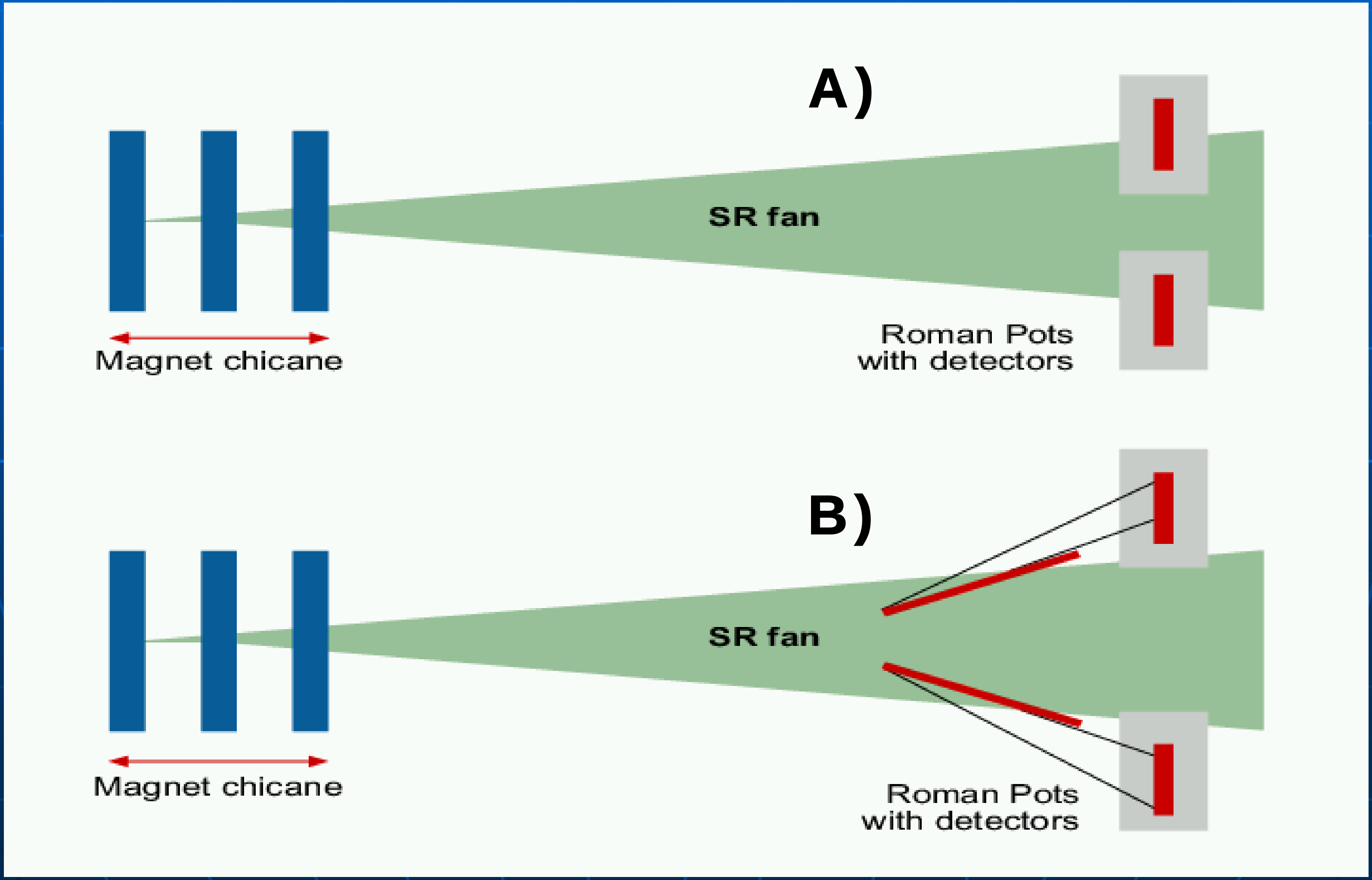


Mean Photons per e+/e- ~ 5

Mean photon energy ~ 3.7 MeV

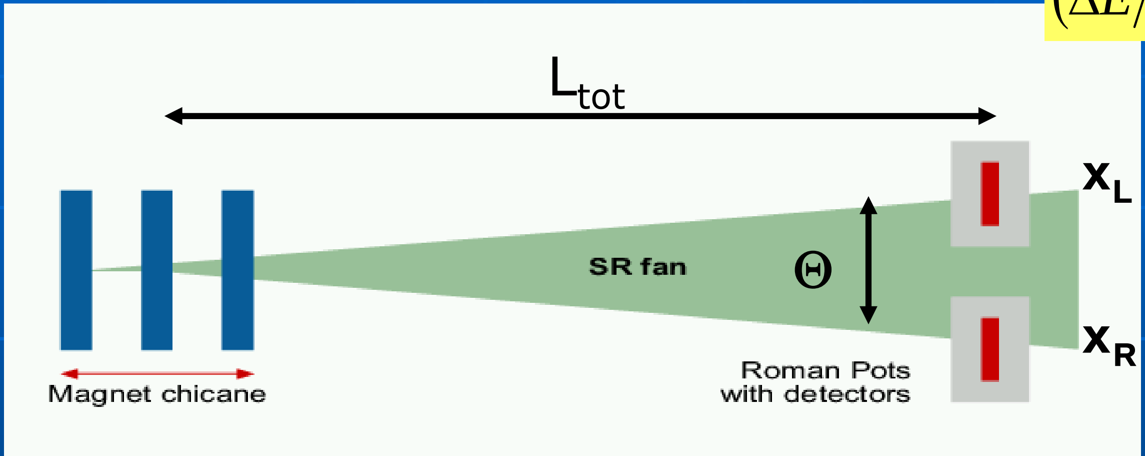
Two Measurement Schemes

A) Direct edge measurement
B) Mirrored edge measurement



Energy Resolution – Direct Scheme

$$(\Delta E/E) = \sqrt{(\Delta Bl/Bl)^2 + (\Delta\Theta/\Theta)^2}$$



Ignoring $\Delta Bl \sim \Delta L \sim 0$:

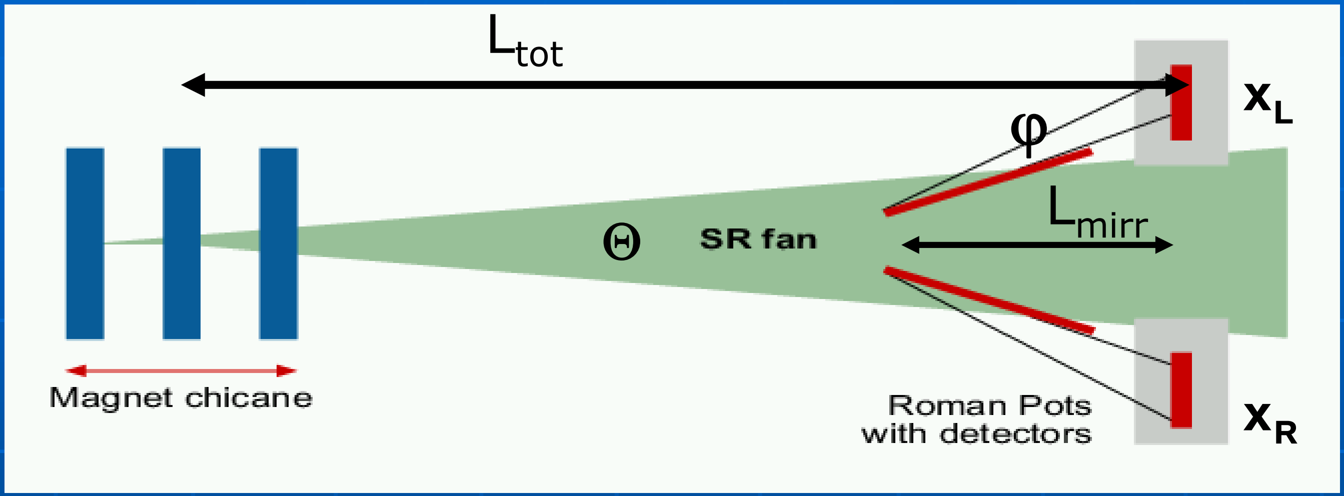
$$\begin{aligned} \Delta E / E &= \Delta\Theta / \Theta \\ &= 2\Delta x / (x_L + x_R) \\ &= 2\Delta x / \Theta\, L_{tot} \end{aligned}$$

For L_{tot} = 80m, Θ = 1mrad :
→ $(x_L + x_R)$ = 80 mm

Δx / μm	$\Delta E/E$ / 10^{-4}
10	2.5
4	1.0
2	0.5

For the goal of $\Delta E/E = 0.5\ 10^{-4}$
one needs ~ 2 μm spatial resolution

Energy Resolution with Mirrors



Angular difference
$\beta = \varphi - \Theta/2$

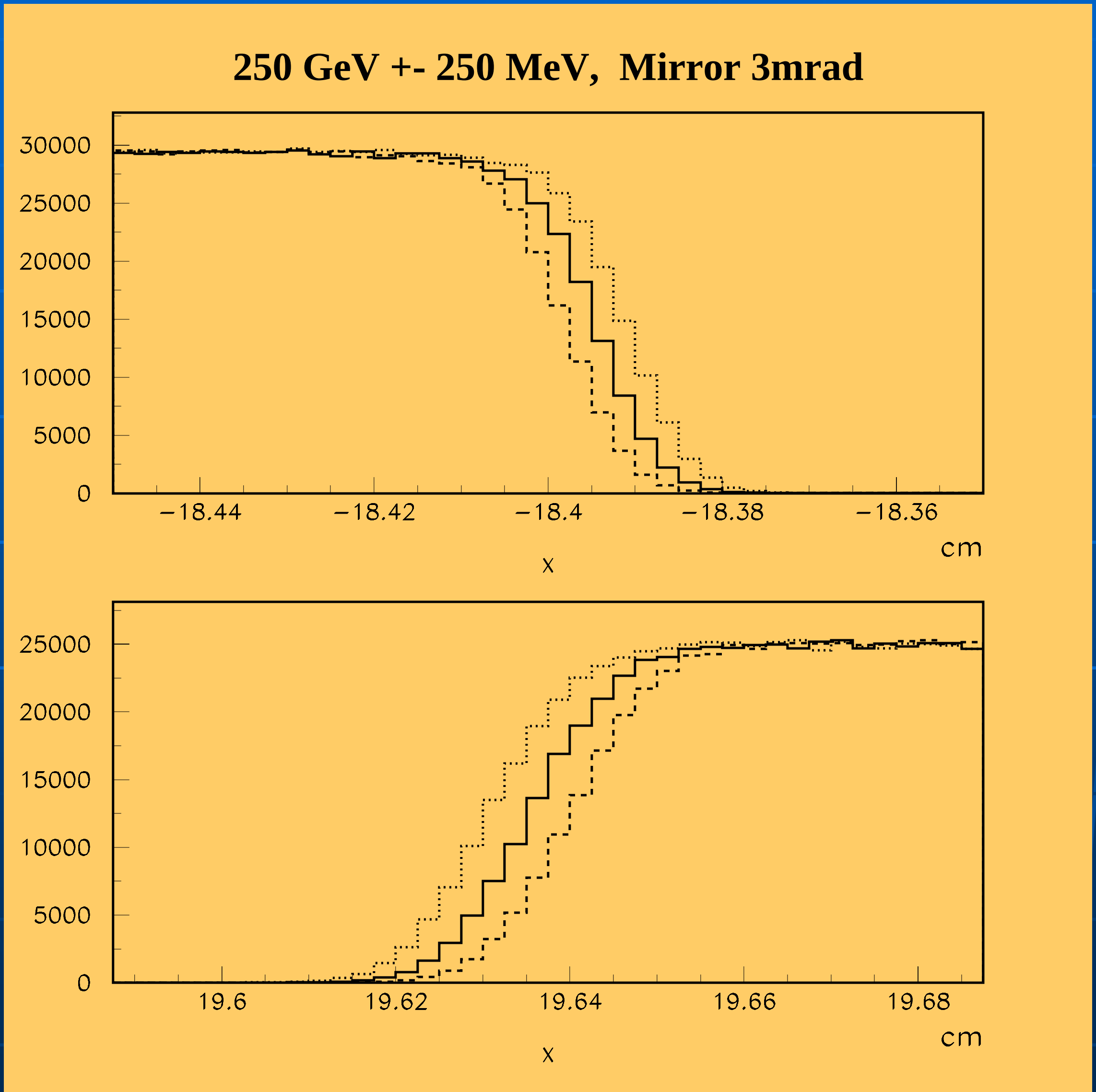
1)

$$\Delta E/E = \sqrt{\frac{(2\Delta x)^2}{(x_L + x_R - 4L_{mirr}\beta)^2} + \frac{(4L_{mirr}\Delta\beta)^2}{(x_L + x_R - 4L_{mirr}\beta)^2}}$$

1) The mirror angular dispersion Δβ enlarges ΔE/E
2) For β→0 the energy resolution is identical with direct scheme

3) Since $(x_L + x_R - 4L_{mirr}\beta) = L_{tot}\,\Theta$:
   → ΔE/E is for any β the same in both schemes
   → L_{mirr} has no influence on ΔE/E

What is visible at 80 m ?

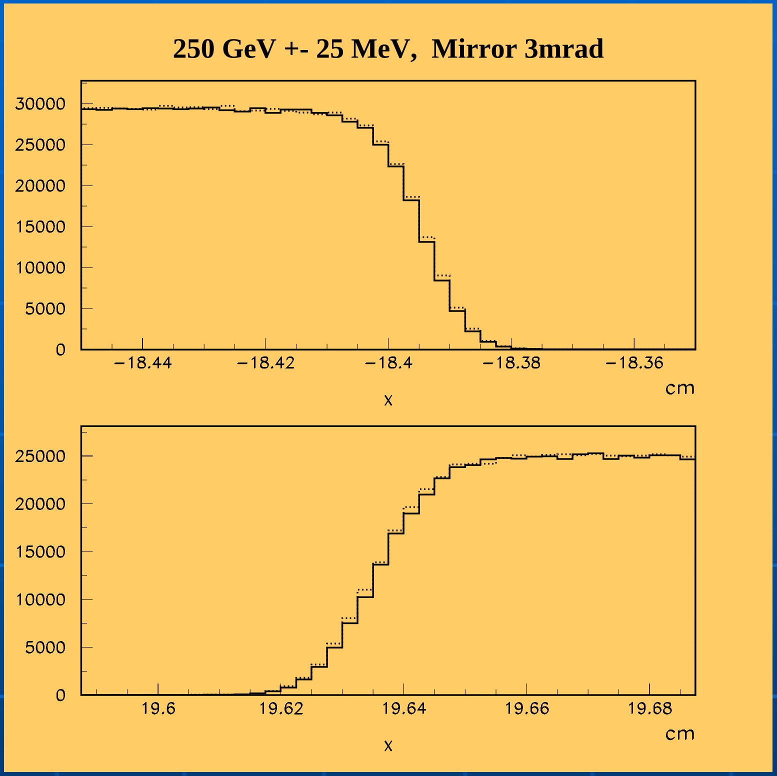


Mirrors: φ = 3mrad
No dispersion $\Delta\beta = 0$

"Silicon-Detector"
Pitch/binning = 25 µm

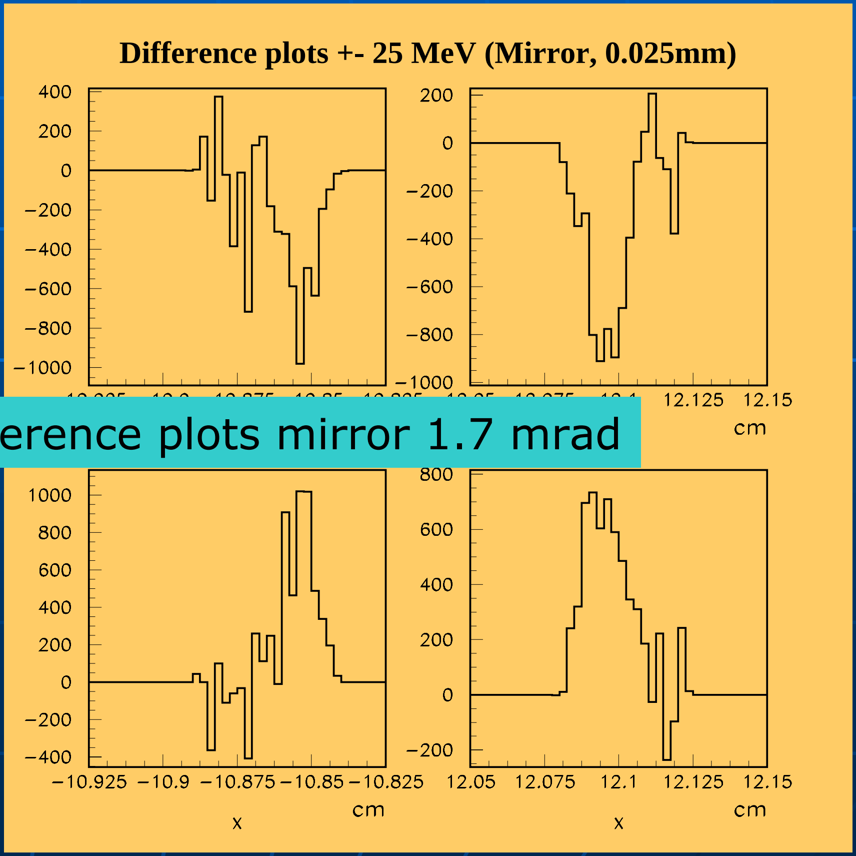
Conclusion:
$\Delta E / E = 10^{-3}$
clearly visible

What about $\Delta E / E = 10^{-4}$?



This seems to be the limit for detection by human eyes !

Since fitting is complicated
→ check difference plots !!!!

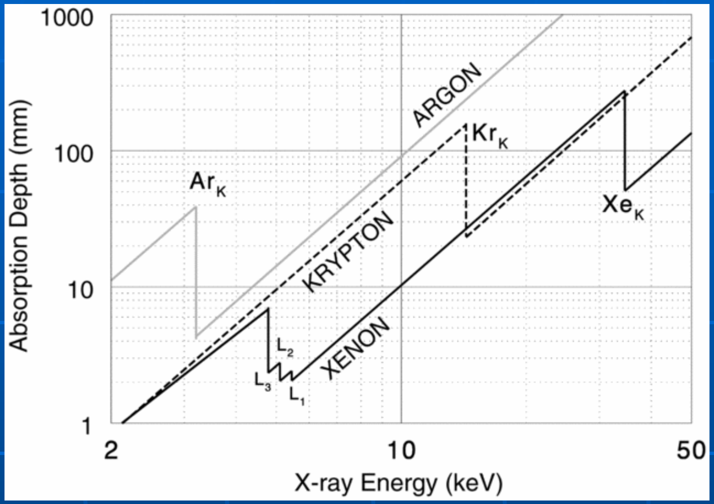


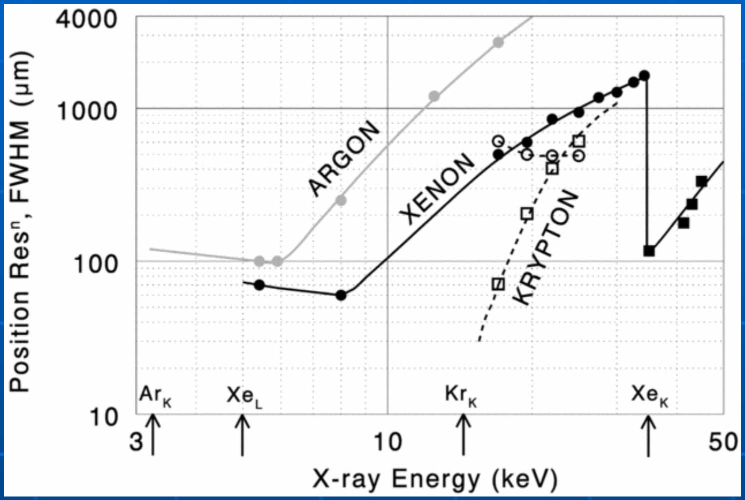
Difference plots mirror 1.7 mrad

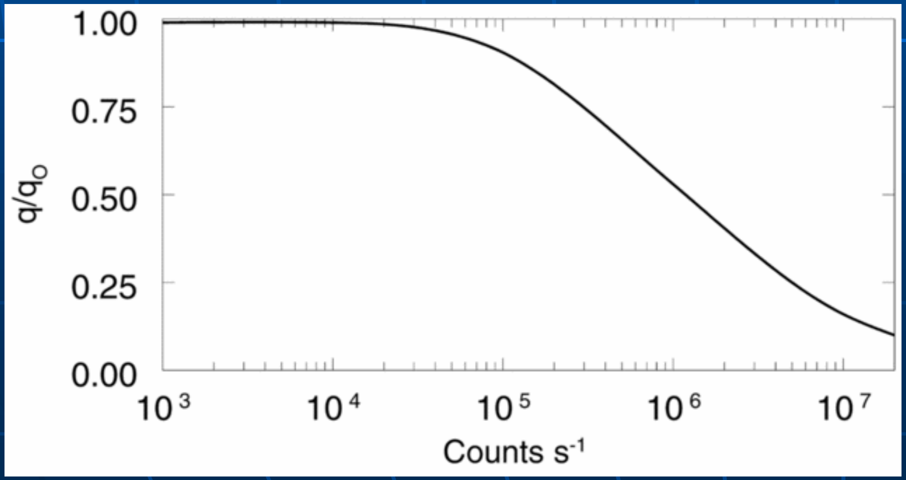
$\Delta E / E = 10^{-4}$ clearly visible, may be even better values …

Detectors: 1)gas-based

MWPCs, image plate chambers, micro-hole structures (GEM),…







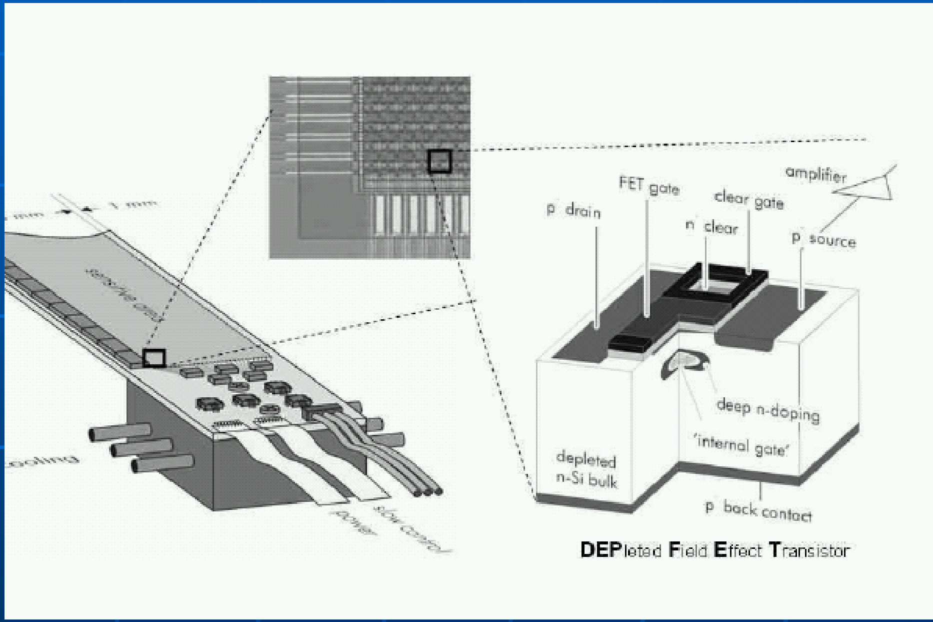
Resolution 0.1 … 1 mm,
count rate limitations …
➔ Not what we need.

Detectors: 2)silicon pixels

LHC: Hydrid pixel technology, 50 x 400 / 100 x 150 μm2
→ 20 μm resolution

ILC : needs 20 x 20 μm2, d << 1 X0 ~ 50 μm, high rates
fast readout > 10 – 20 MHz

Ongoing R & D:
- Diamond pixels
- 3D silicon sensors
- monolithic silicon detectors →



At 6 GeV beam energy the spatial residuals are still multiple scattering dominated. Residuals on the order of 10μm are obtained, while with the large S/N value of 144 true space resolutions in the order of 2μm should be possible.

Fits better our needs.

Silicon problem: Radiation Damage

Literature

BELLE: 10% gain drop at 100krad
H1: 300 krad for 5 years – to survive
CLEO: no damage for 10 krad/year
LHC: pixel detectors must survive 50 Mrad in 10 years

Dose estimate for 200 days ILC running ...

Dose = energy/mass

Mass = 80mm x 1mm x 0.3 mm X 2.3 g/cm3
= 0.055g

energy: from GEANT we know:
interaction/photon = 8.5 10^{-3}
E-loss / interaction = 70 keV

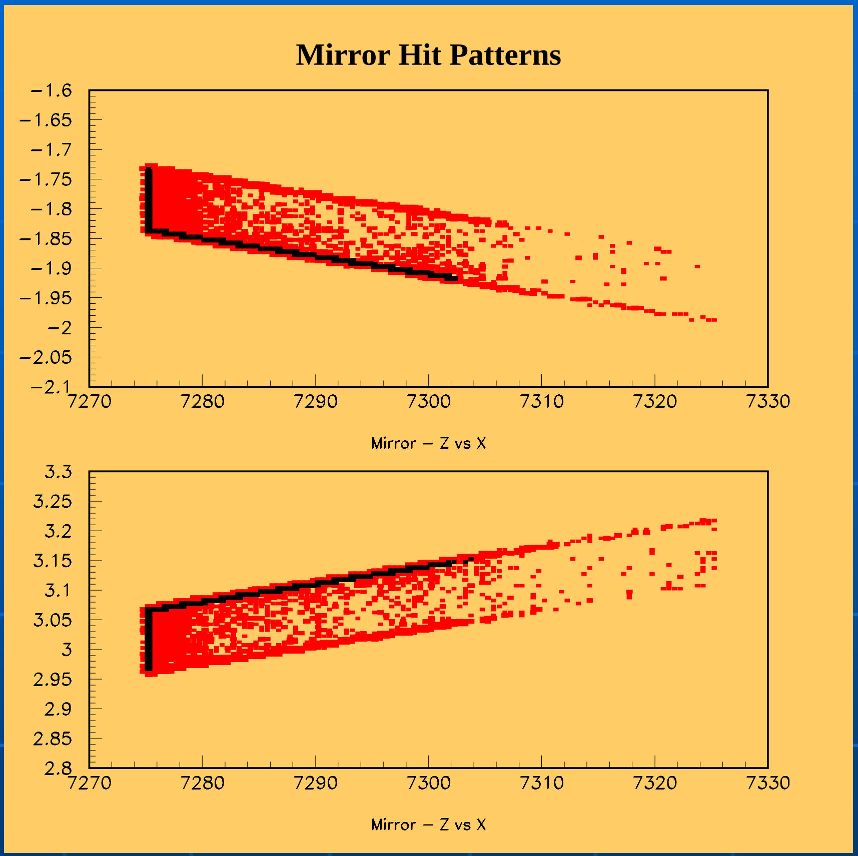
ILC bunch 2 10^{+10} e,
full train = 2820 bunches with 5 Hz
data taking 200 days

5.2 10^{+19} GeV/kg

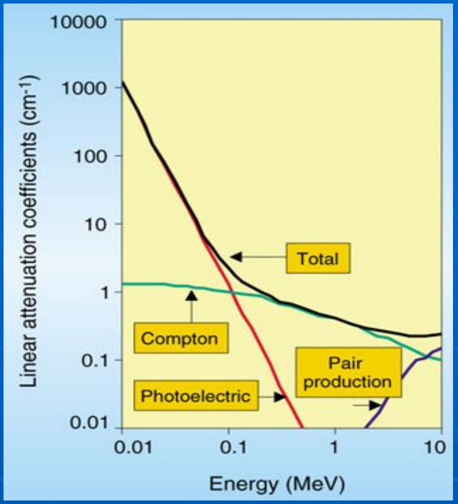
~ 10^{+6} Mrad

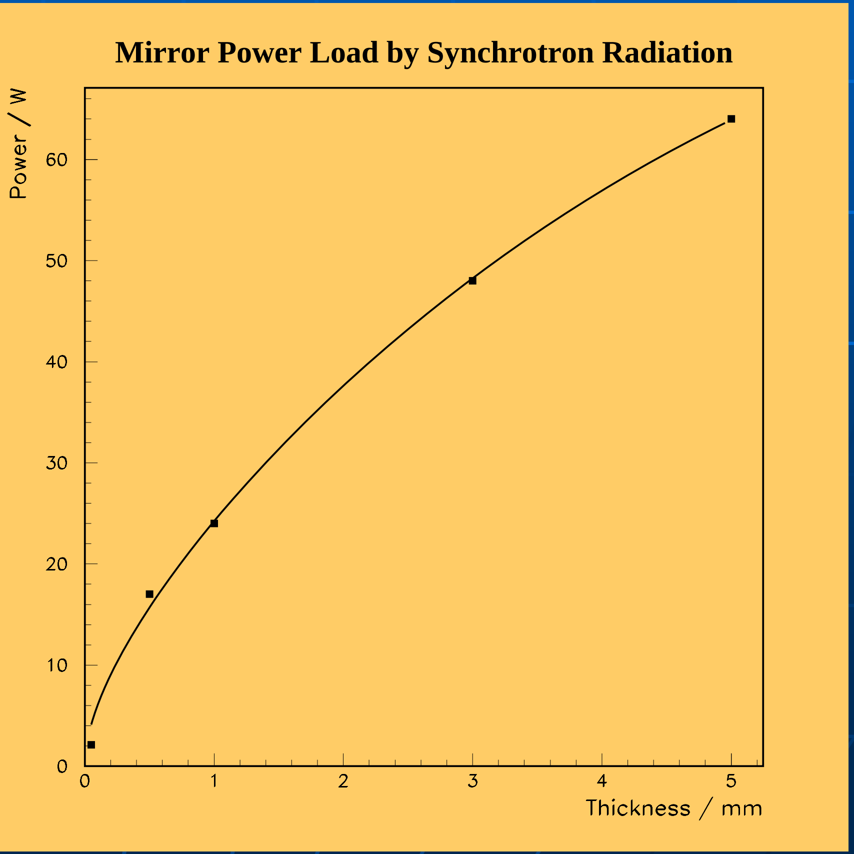
1) Impossible to use silicon in the direct synchrotron fan
2) Filter and scale by ... mirrors ?

Mirror Heat Load



E-loss of e+/e- heats the mirror





Few 10 W seems manageable for mirror of few mm steel

Summary

1) If dose < 1 Mrad Silicon detectors can be used for $\Delta E/E = 10^{-4}$

2) More radiation hard detectors can relax the situation …
→ special Dubna Ge/Si layer detector.

3) Mirrors useful to filter/reduce radiation dose for detectors.

4) Mirror problems: dispersion, angular precision, surface quality, stability … → experience needed.

Launch special R&D program for synchrotron radiation detectors and mirrors used for ILC beam energy measurement