Beam Energy Measurement by Synchrotron Radiation
(some first ideas)

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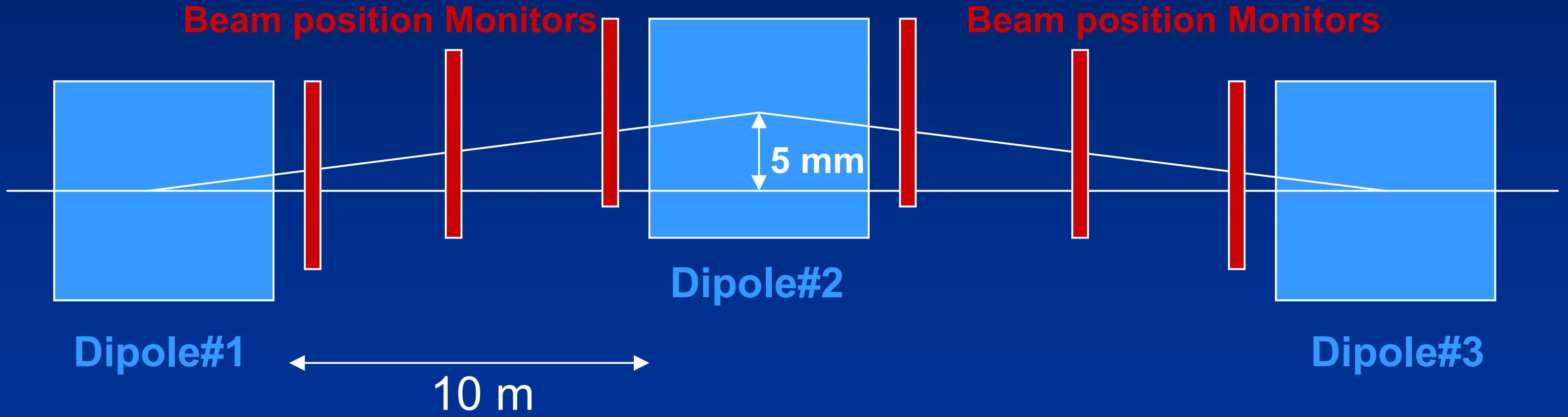
Canonical method to measure the beam energy E_b

Magnetic Spectrometer (e.g. proposed in LC-DET-2004-031)



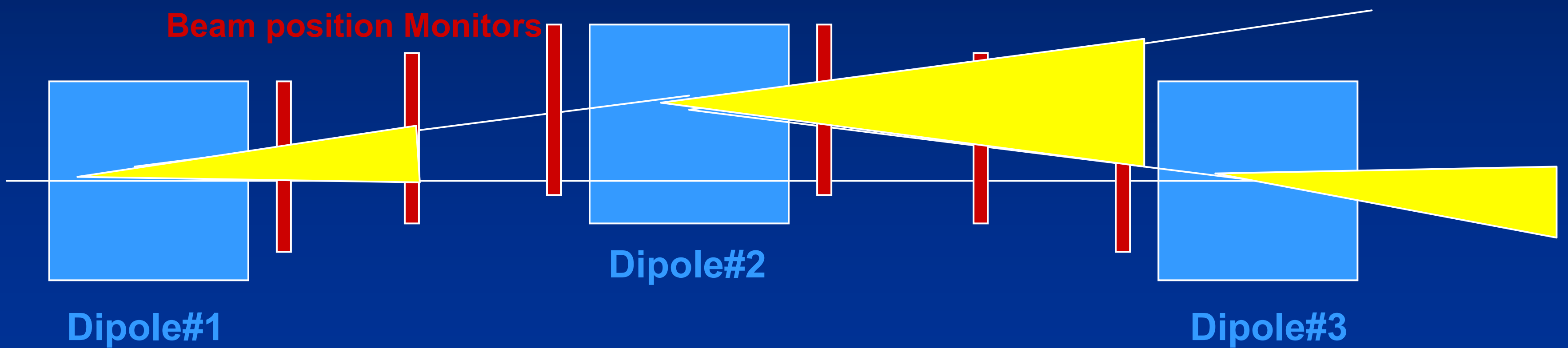
Beam energy measurement is based on precise angular measurement and on precise B-field integral of the spectrometer magnet

Example:

E_b = 250 GeV, Bl = 0.4 Tm, with $\Delta B/B = 2\ 10^{-5}$, and sigma(BPM) = 100 nm

→ $dE_b/E_b \sim 5 \times 10^{-5}$

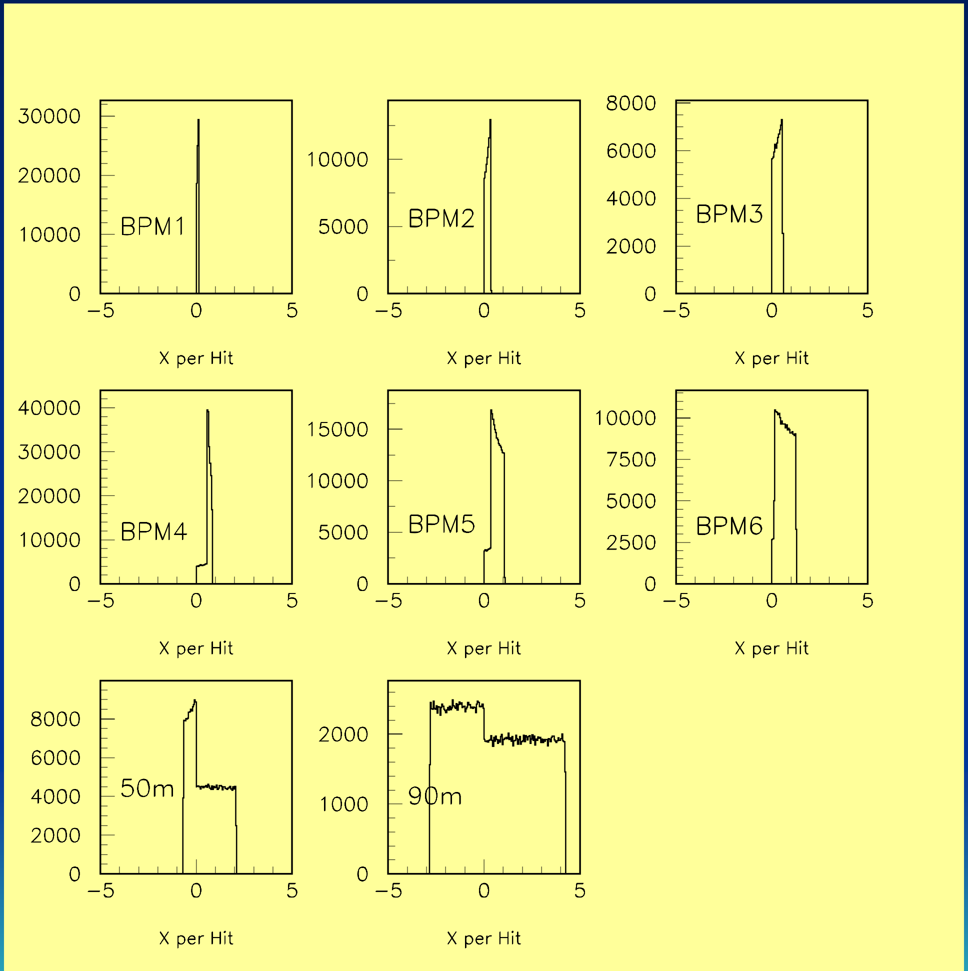
Synchrotron Radiation Fan



3 radiation fans cover exactly the electron bending angle

→Measurement the width of the fan resp. the position of both edges allows to determine E_b

Horizontal radiation Fan along the Beam



(produced by 250 GeV electrons)

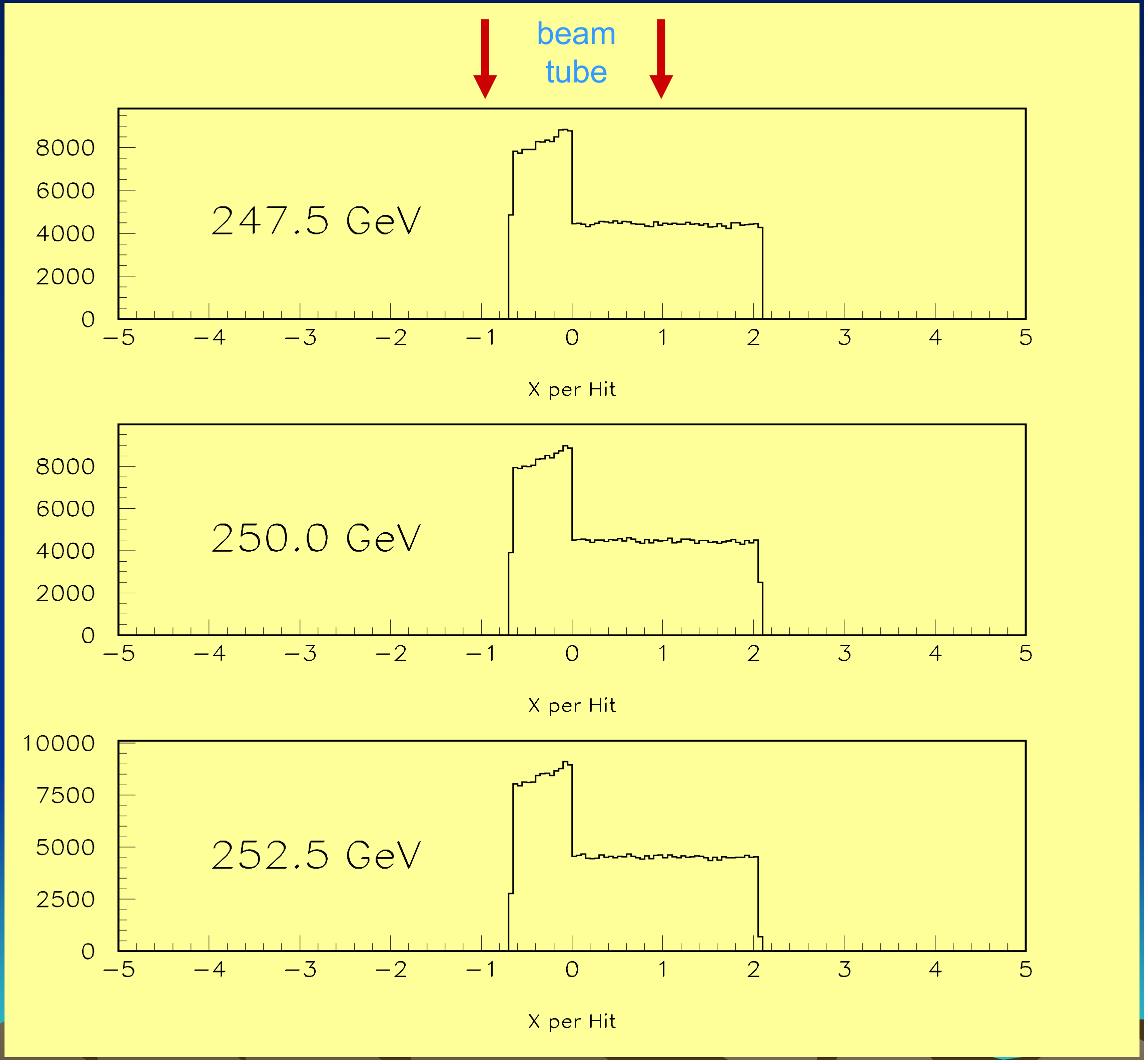
Beam tube radius 10 mm
(beam wall 2 mm steel)

→Radiation fan at all BPM positions inside tube

→Touch the steel wall downstream of ~ 40m

50 m downstream of the spectrometer magnet
SR fan width ~2.8 mm in x,
while ~0.5 mm in y,
(for photons with 20 keV energy)

Radiation Fan at 50 m

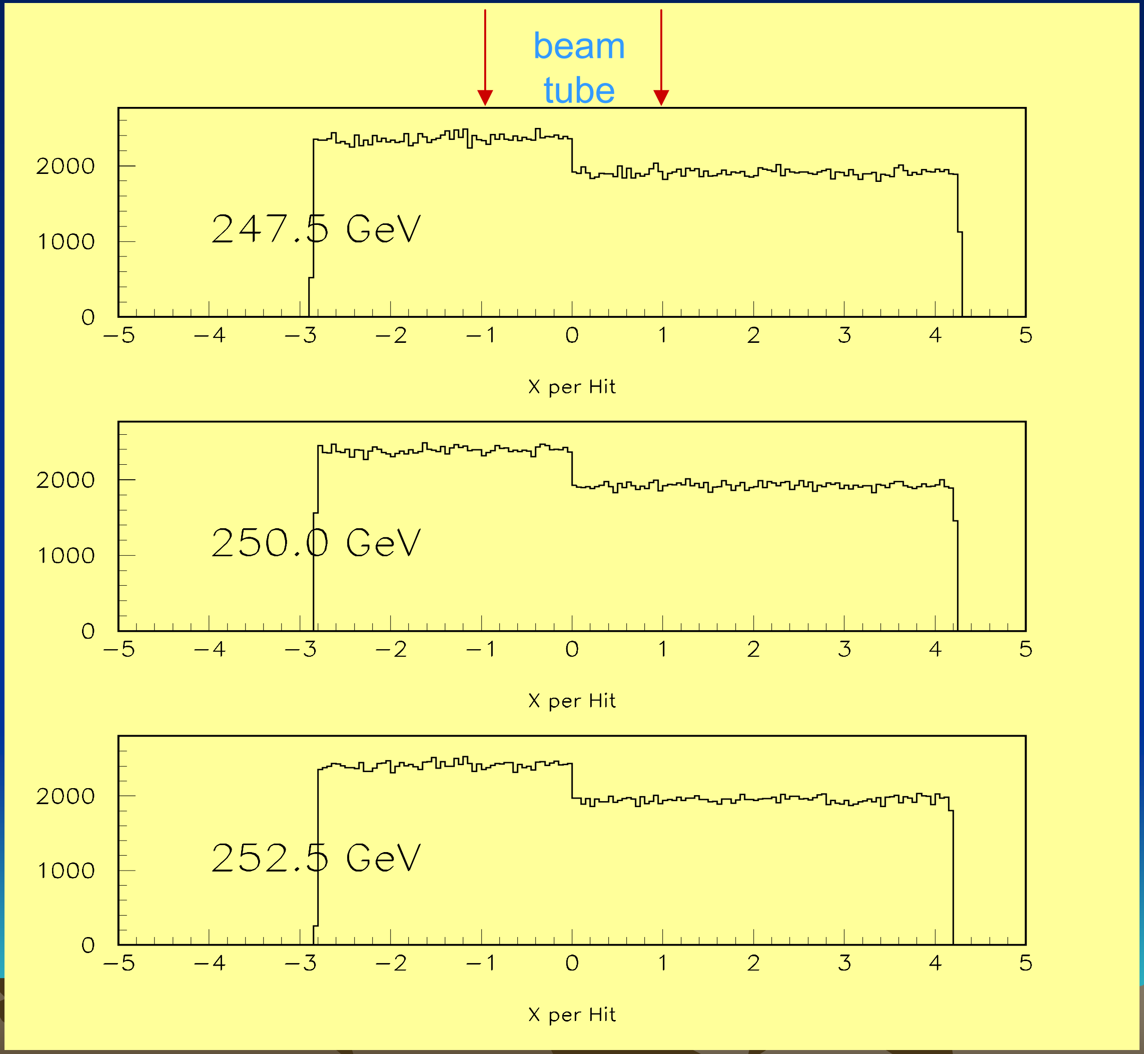


for 3 beam energies
(beam tube wall omitted
in simulations)

Most photons still
Inside the beam tube

Especially left edge
Not visible !

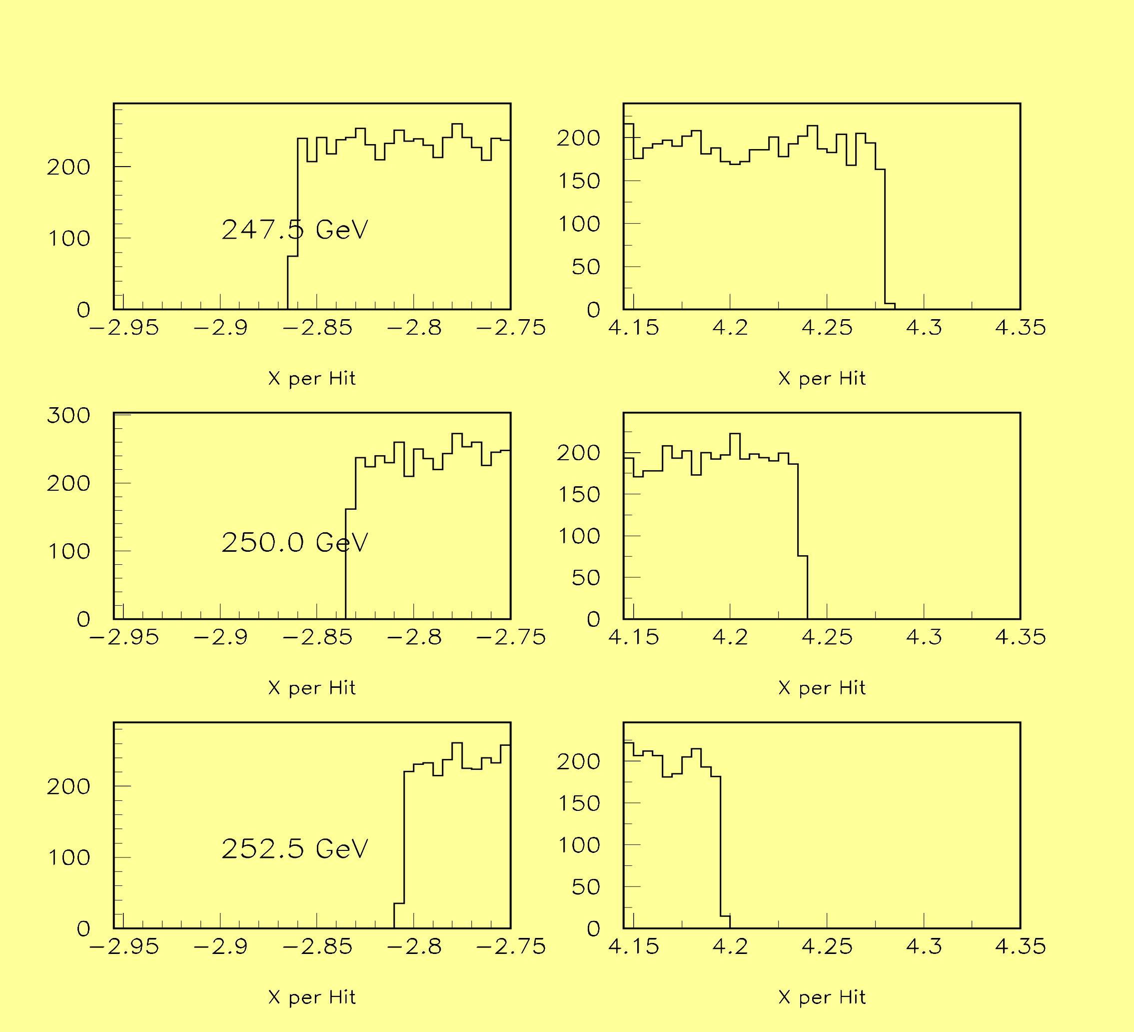
Radiation Fan at 90m



again for 3 beam energies
(beam tube wall omitted)

Both edges visible
outside the beam tube

Radiation Fan at 90m (2)

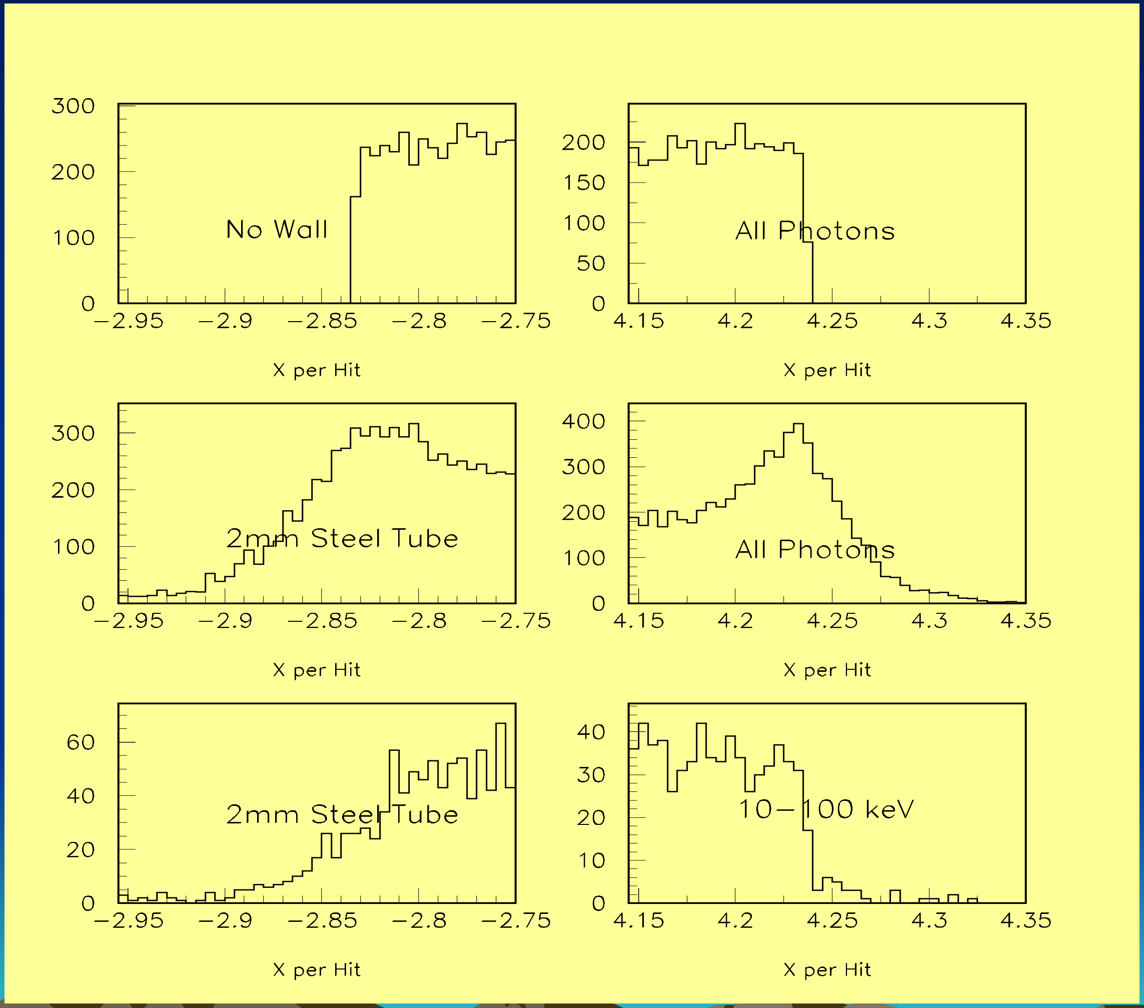


E [GeV]	Width [mm], in x
247.5	71.4
252.5	70.0

No beam tube wall !

➔ Sensitivity
1.4 mm / 5 GeV

The Influence of the Wall

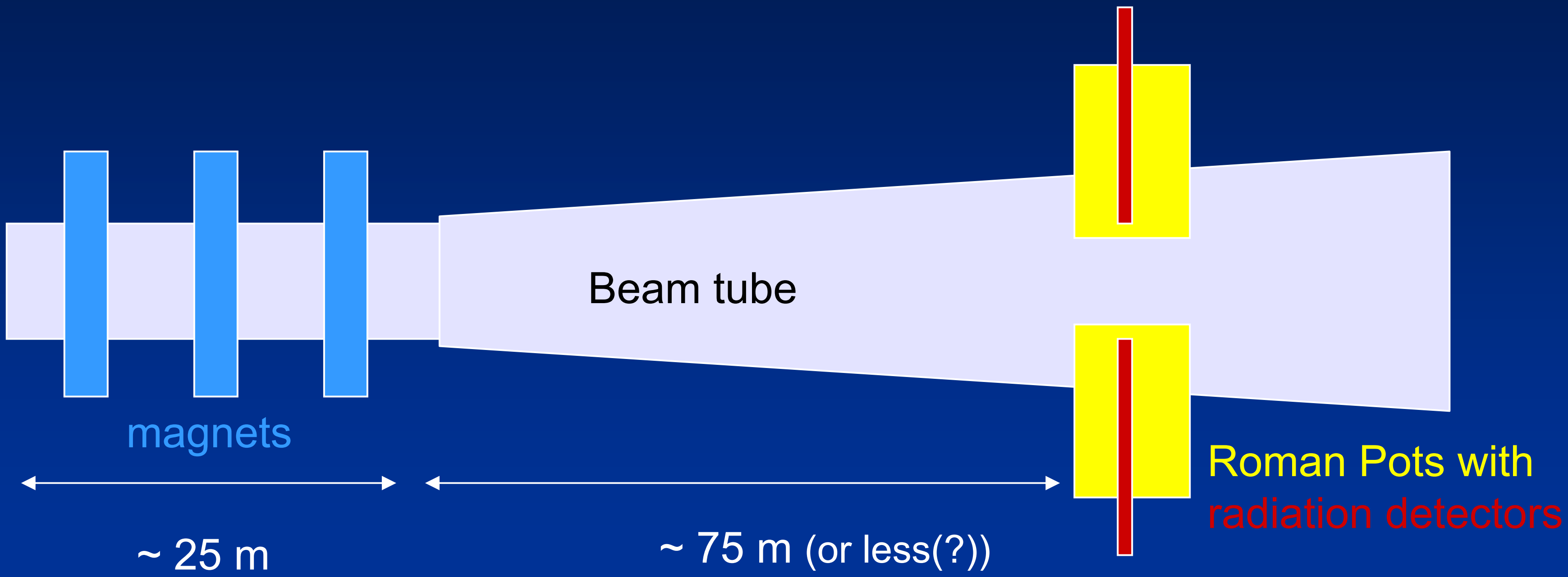


2 mm steel tube deteriorates resolution of edge positions significantly

Selection of 10 -100 keV photons changes not much

→ avoid penetration of SR through steel wall

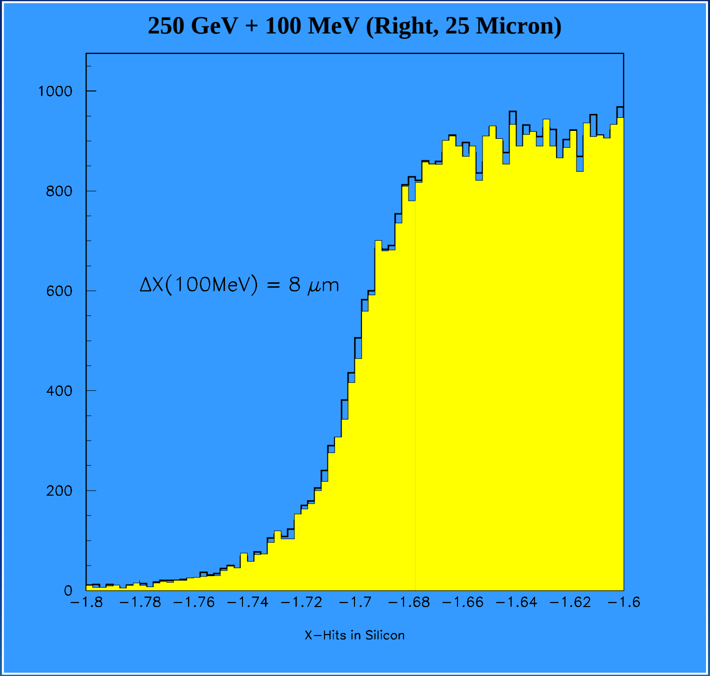
Basic Detector Layout

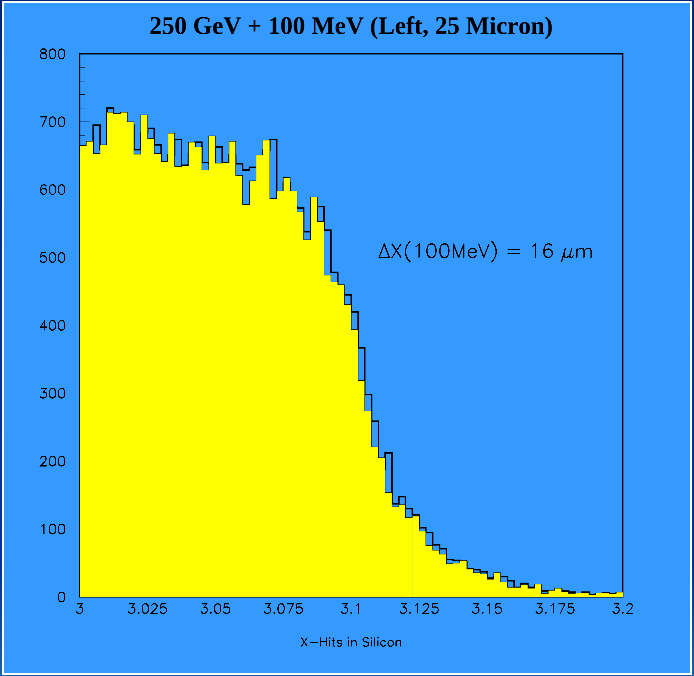


- Enlarge continuously beam tube radius R = 1cm → 3cm
- Install 2 Roman pots with thin windows for separation from vacuum
- Insert position sensitive radiation detectors

GEANT simulation (including bunch sizes, energy spread, fringe fields)
→ tracking of SR photons to the detector (Si)

In each plot, two histogram are superimposed
- one for nominal E_b = 250 GeV, the other (in yellow) for 250 GeV + 100 MeV

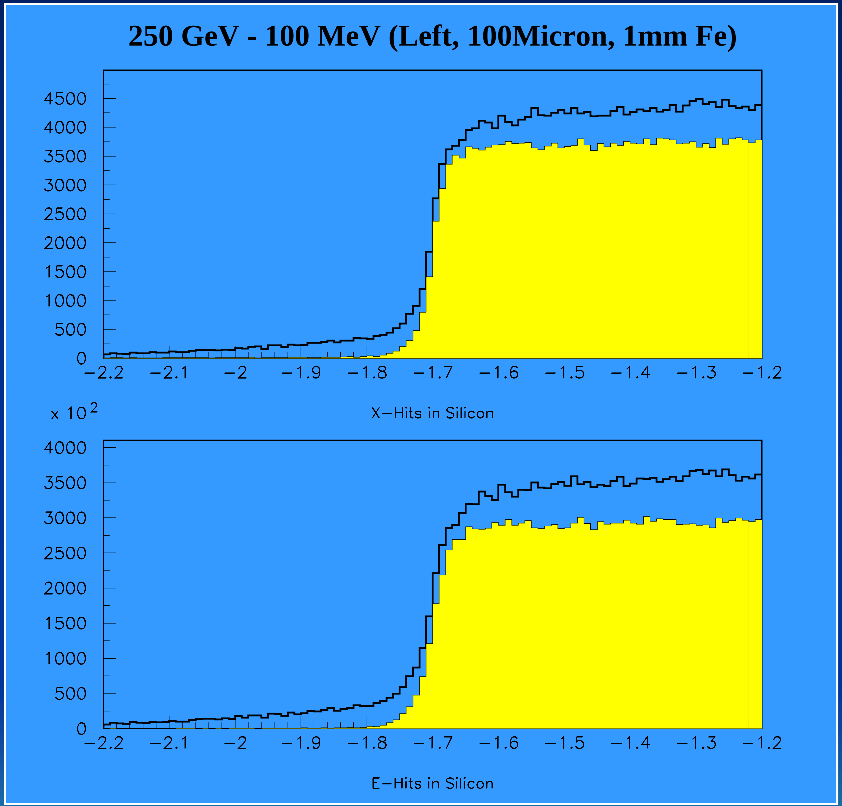


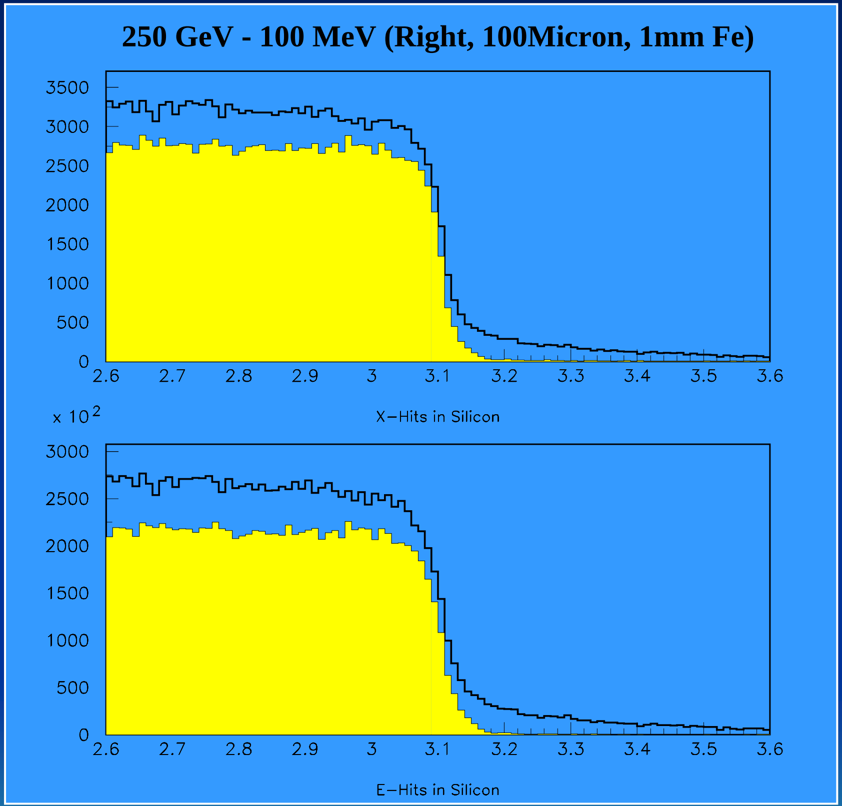


→ shift of right edge position in x = 8 μm; shift of left edge position = 16 μm
so that the total width shrinks by 24 μm

When including a window between vacuum of beam pipe and Roman Pots

- 300 µm of steel → yellow to black histograms





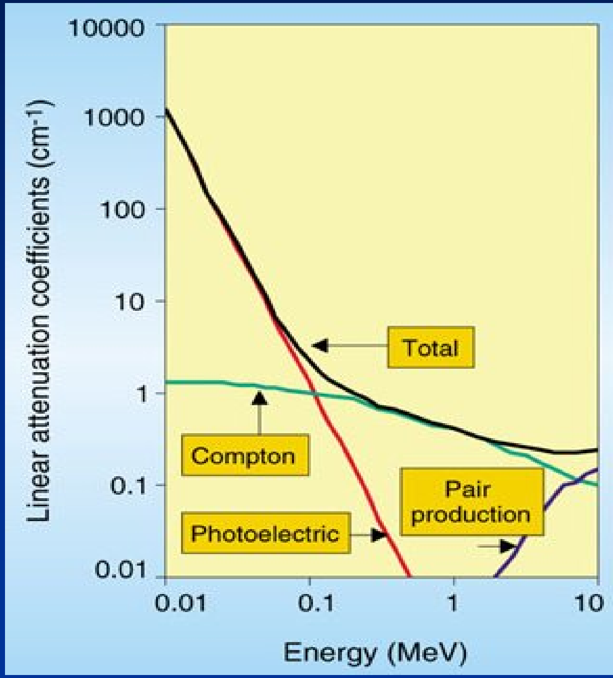
→The edges become somewhat less sharp, but still good recognizable and the shift of edge positions is not altered

Detection of X-Rays

X-rays have no electric charge and cannot directly detected:

→1) use scintillators to get low energetic photons of 200 – 1000 nm wavelengths which match sensitivity of PMT or photodiode

→2) convert X-rays into electrons/positrons which produce electron-hole pairs by Coulomb interaction, and collect their charge

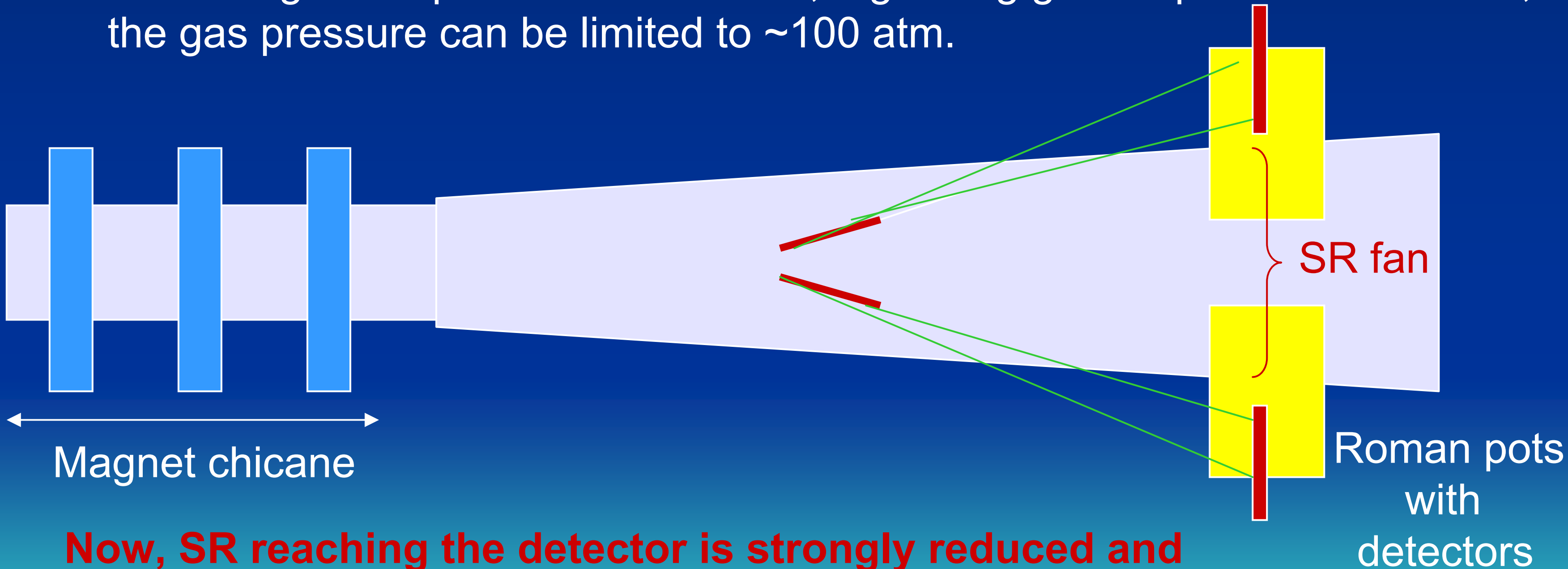


	Photoelectric	Compton	Pair Production
interacts with	bound electron	"free" electron	atomic nucleus
energy range	<100 keV	~100 keV - 10 MeV	>1.02 MeV (pred >10 MeV
energy variation	$1/E^3$	$1/E$	E
Z variation	$\sim Z^3$	none	Z

Due to the ***large radiation dose*** expected in the detector

→ set-up is supplemented by Rh **mirrors** (somewhere after the last magnet)

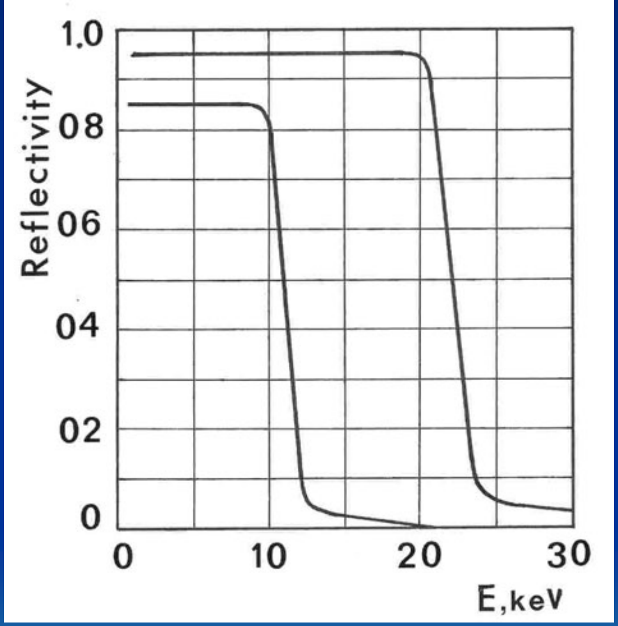
- reflection of only photons < 20 keV,
  (with total reflection only below critical angle $\varphi_{max} \sim [0.08/E_\gamma(\text{keV})] = 0.4$ mrad)
- improve of position resolution of incident gammas (to 1-3 μm)
- sensitive area of the detector reduced to few millimeter (3-5 mm)
- if some signal amplification is needed, e.g. using gas-amplification detector, the gas pressure can be limited to ~100 atm.



Now, SR reaching the detector is strongly reduced and limited to photons with energies < 20 keV

Separation of SR at low energy from hard radiation

The background hard radiation component is much greater than the number of useful γ-quanta.
A highly selective reflecting mirror separates γ-quanta with energy $E_\gamma \sim 1 – 20$ keV,
for mirrors with a large Z



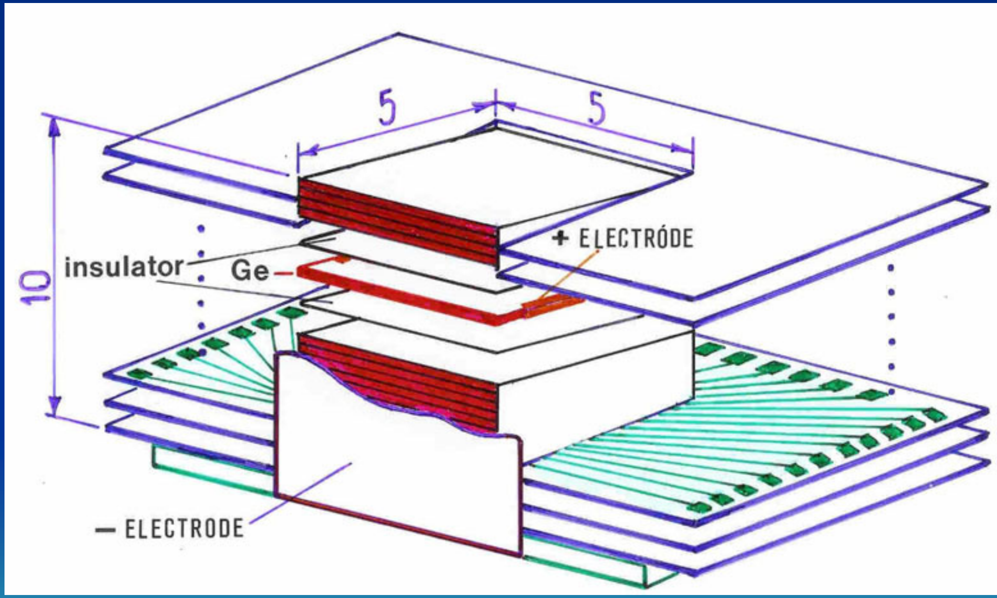
Reflection efficiency for Rh mirror vs. E_γ, keV

Detector (proposed)

Sensitive region contains N_x Ge layers 2 μm thick.
The layers are separated with dielectric 0.05 μm thick.
To read out information, each layer is surrounded with a gold contact 10 μm wide and 0.9 μm thick .

Technology studies
in Dubna;

Prototype production
of few layers
also envisaged



Estimate of Signal Size

At 70 m the fan width ~70 mm

and the # of gammas (<20 keV) is ~2 10^6 → 4 10^4 within 1mm Ge.

A photon needs some 10 eV to generate an electron

→ # of electrons within 1 mm Ge ~8 10^7

and $\boxed{N_e \approx 10^5}$ per 1μm of Ge.

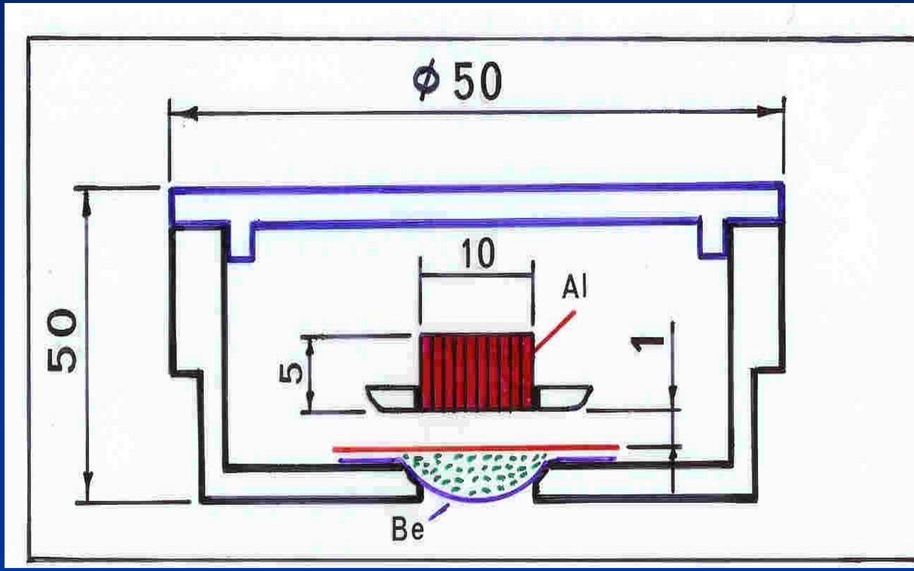
An amplifier conversion factor of 15mV/fC with
with an input charge of 10^5 electrons
produces an output signal with an amplitude of ~30 mV

If for some reasons the number of γ-quanta in the range 1 – 20 keV is not sufficient for a detectable signal

→ alternative proposal for the detector:

a plan-parallel avalanche detector with gas amplification 10-100 and a linear resolution of 1μm

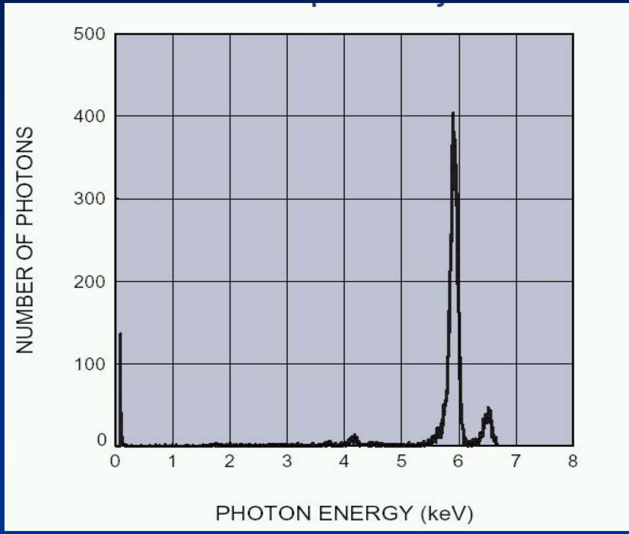
Detector is a flat capacitor filled with Xe at 100-150 atm; anode plane comprises about 1000 Al layers 0.9μm thick, separated by dielectric.

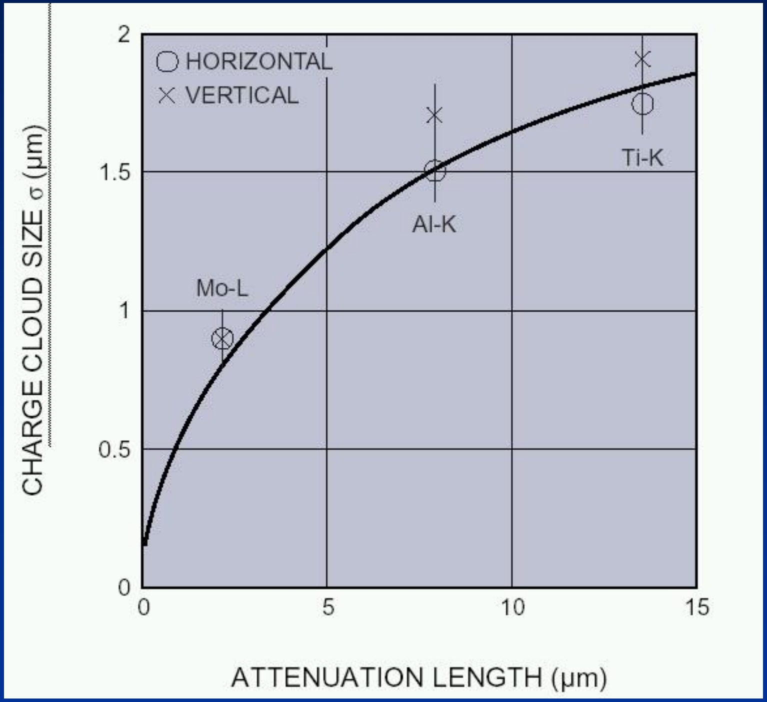


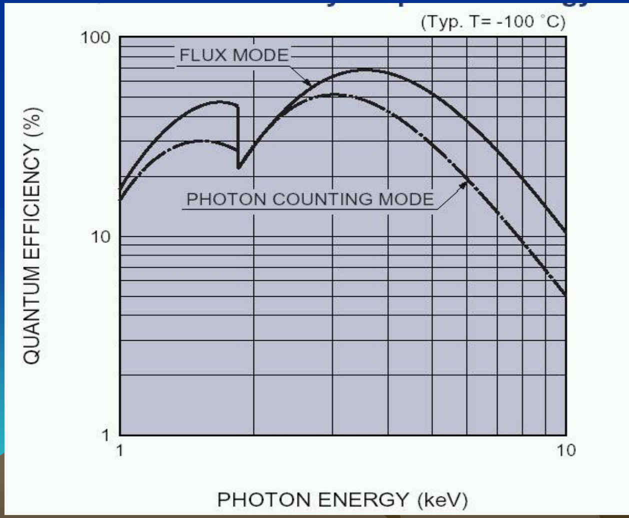
High voltage is applied to the carbon-coated mylar cathode plane 20μm thick. The 10 x10 mm^2 entrance windows made of 1 mm thick beryllium.

Position of the device in a magnetic field to avoid resolution degradation due to electron diffusion ?

CCD (back-up solution)







- dE = 109 eV at 5.9 keV (Fe55)
- quantum efficiency > 10% at E < 10 keV
- 12 x 12 μm^2 plus micro-mesh plate gives
  1 … 2 μm spatial resolution
- drawback - **slow readout** in msec

Summary (preliminary)

- SR has the potential to monitor the beam energy with high precision
- based on a concrete magnetic chicane
  → sensitivity 1.4 mm/5 GeV
- challenging task: high position resolution detector (1-3 μm) for low energy gammas within large radiation background
- scaling the 1.4 mm/5 GeV sensitivity
  → $\Delta E_b/E_b \sim (1\text{-}3)\ 10^{-5}$
- the concept needs some 70m dedicated beam line free of further magnets
- simple scheme using well-proven Roman Pot technology
- radiation detectors easy to exchange (radiation damage !)
- width of the radiation fan insensitive to changes of beam position and inclinations

- the detectors should withstand a high counting rate (~ 10^9 cm^{-2} sec^{-1}) and has to have adequate radiation resistance

- detector production should be simple and may be carried out by methods used in the microelectronic industry

- calibration (e.g. Z mass) → absolute beam energy measurement (?)

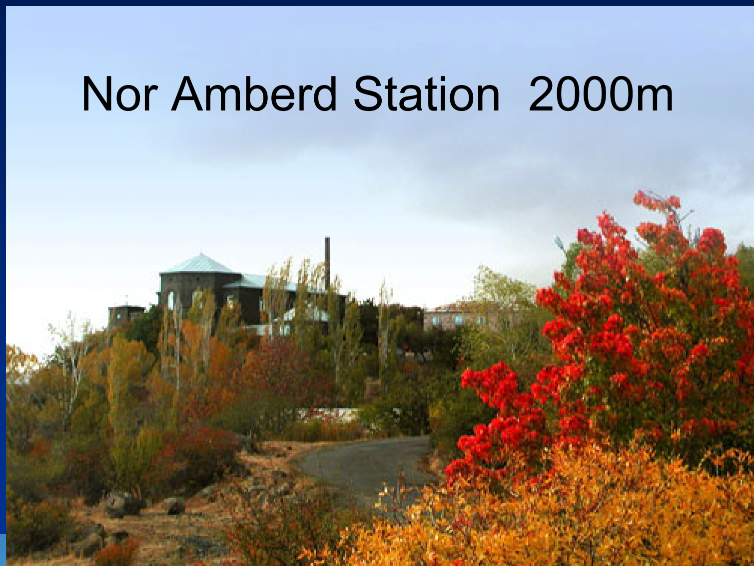
Conclusions

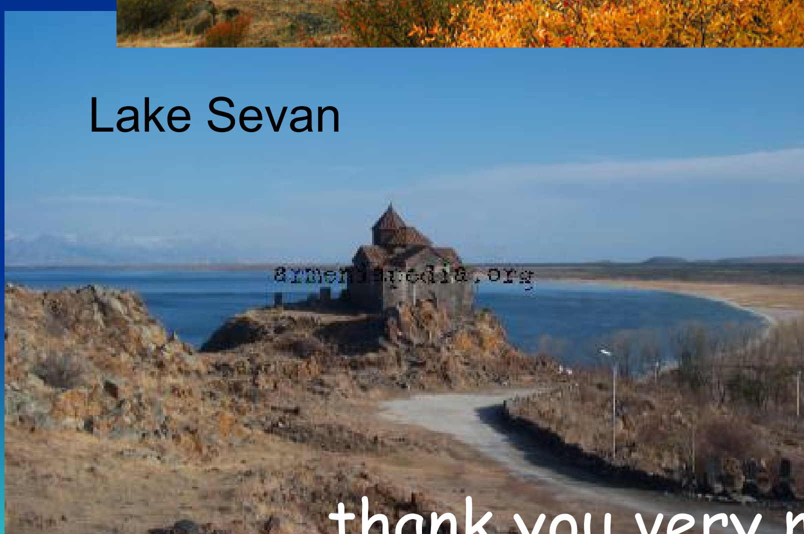
- **Energy resolution : spatial resolution / sensitivity**

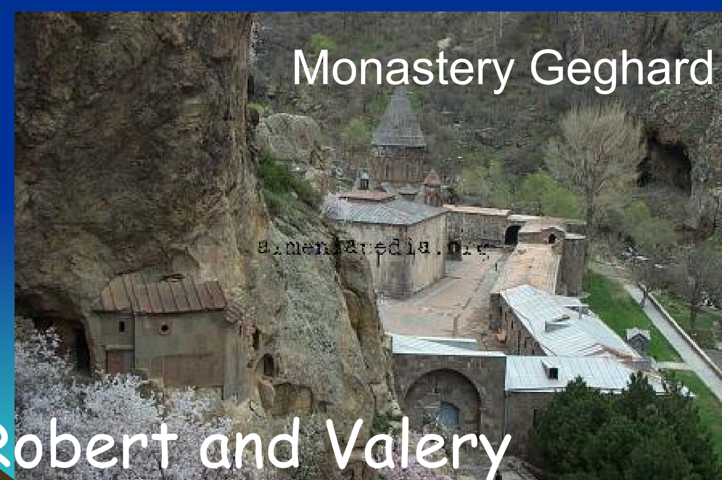
dX	dE	dE / E	Feasibility
100 μm	357 MeV	1.4 10^{-3}	→ possible with existing detectors
10 μm	36 MeV	1.4 10^{-4}	→ in reach with some detector R&D
1 μm	4 Mev	1.4 10^{-5}	→ probably a dream

- **needs some 100m dedicated beam line free of magnets**
- **simple scheme using well-proven Roman Pot technology**
- **radiation detectors easy to exchange (radiation damage !)**
- **width of the radiation fan insensitive to changes of beam offsets and inclinations**
- **without calibration good for relative beam energy changes**

Acknowledgement



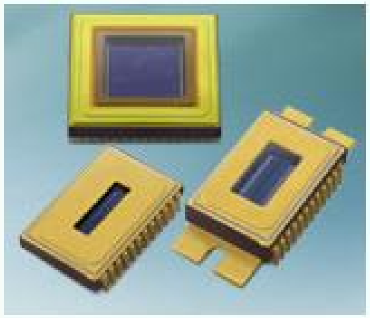




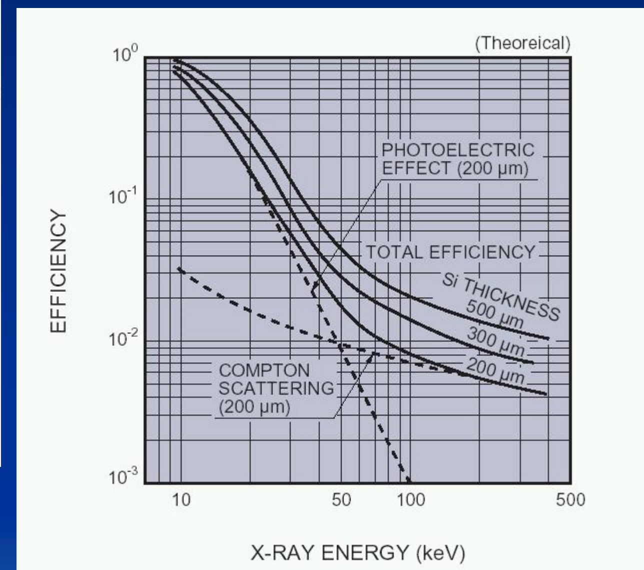
… thank you very much Robert and Valery
for the meeting in such great surroundings.

Hamamatsu CCD

CCD



Charged-Coupled Devices (CCDs) are solid-state image sensors that provide low light level detection, with high signal-to-noise ratio and wide dynamic range. The vast majority of our CCDs are full frame transfer devices with 100% fill factor. We offer scientific grade CCDs including a unique back-thinned (BT-CCD) device featuring 90% quantum efficiency (QE). The back-thinned CCD has high QE from the near infrared to the vacuum UV region of the spectrum and it can even directly detect X-rays with energy below 0.5 keV. Front-illuminated CCDs can be used to directly detect X-rays up to 10 keV and X-rays over 100 keV can be imaged using fiber optic scintillators (FOS). Our CCD detectors are used in low light level imaging, raman spectroscopy, microscopy, non-destructive inspection, dental X-ray imaging and medical imaging.



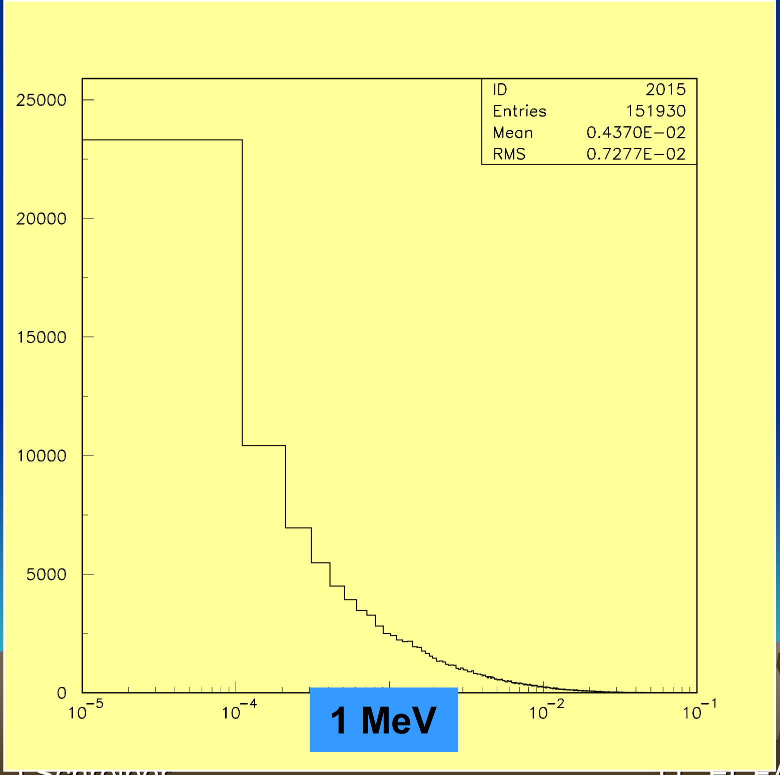
→ CCDs or other (thin) solid state detectors measure in the range < 100 keV

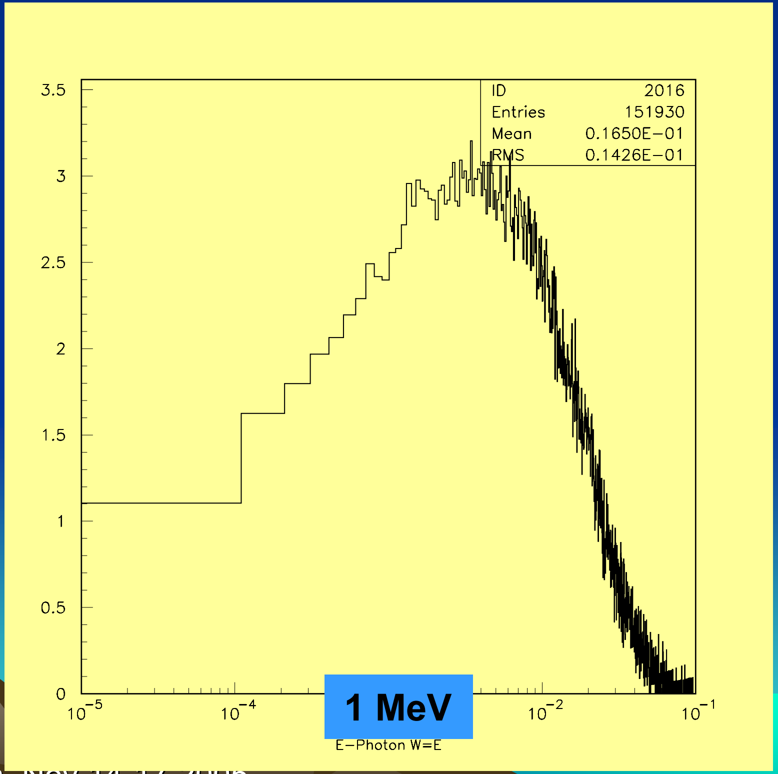
Synchrotron Radiation Spectrum

Critical energy:
50% of power

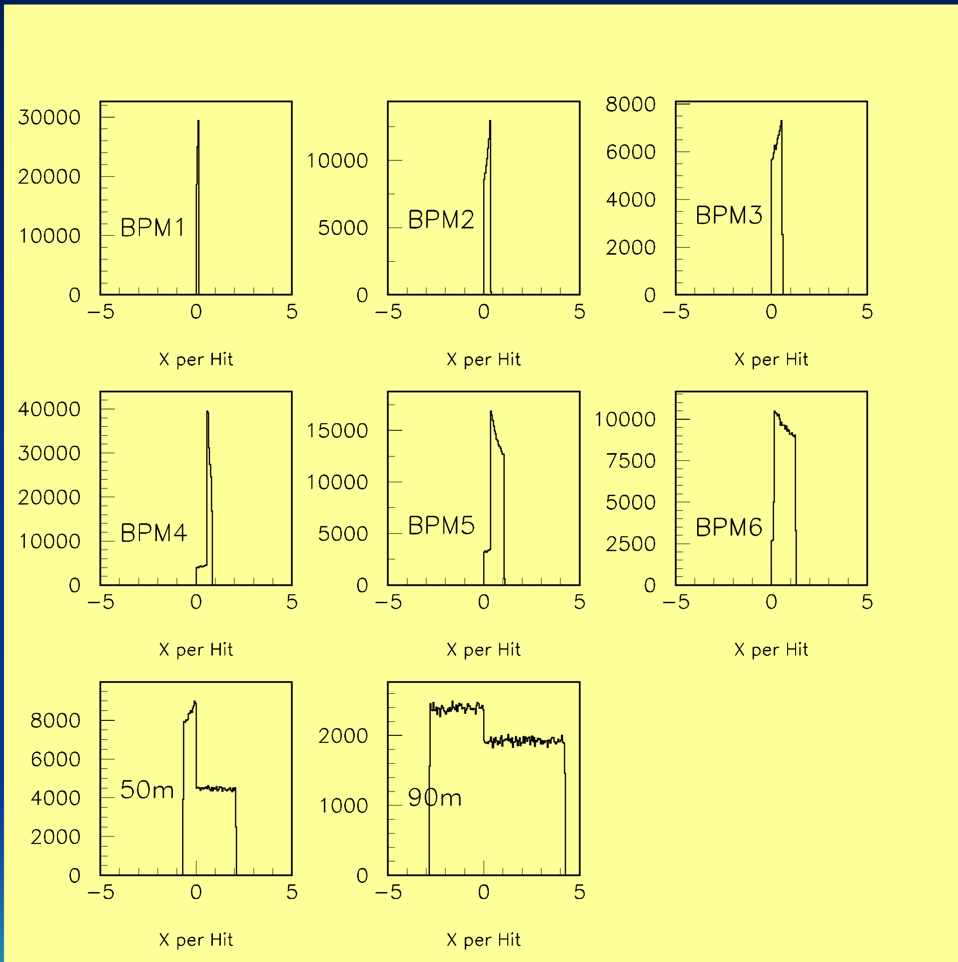
$$E_{crit}[keV] = 0.665 \cdot B[T] \cdot E^2[GeV]$$

250 GeV, 0.5 mrad or 0.4 Tm → E_{crit}= 16.6 MeV





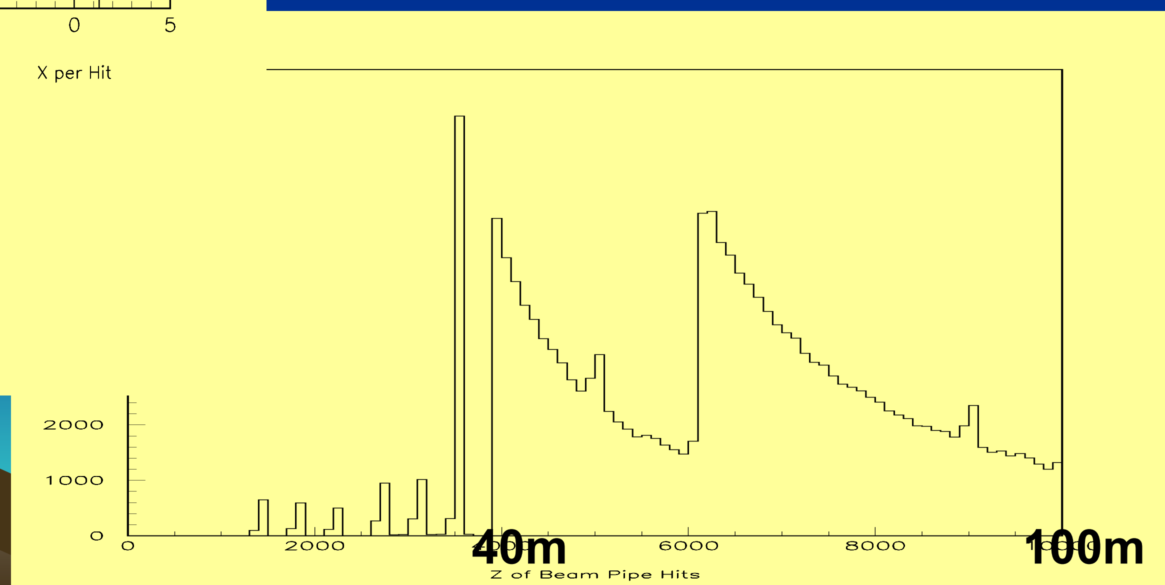
Radiation Fan along the Beam



Beam tube radius R = 10 mm
Beam wall 2 mm steel

→Radiation fan at all BPM positions inside tube

→Touch the steel wall downstreams of ~ 40m



DETECTOR SIGNAL

Assume, **300 tracks enter the detector within a sensitivity range of 1 mm and each track generates about q ~ 105 electrons, about N_e~ 3 10^7 electrons are produced inside the detector**

At the amplifier conversion factor 15 mV/fC the input charge of 10^5 e will produce an output signal with the amplitude ~ 30 mV.

GAS AMPLIFICATION DETECTOR

Low detector signal can be increased by factor 10-100 by gas amplification in detector at linear resolution of 1 μm

Detector is filled with Xe at 100 – 150 atm.
The anode plane comprises about 1000 Al layers 0.9 μm thick and separated from each other by dielectric.
High voltage is applied to the carbon-coated mylar cathode plane 20 μm thick.

Detector is placed in the magnetic field to remove the diffusion of electrons upon the detector resolution.