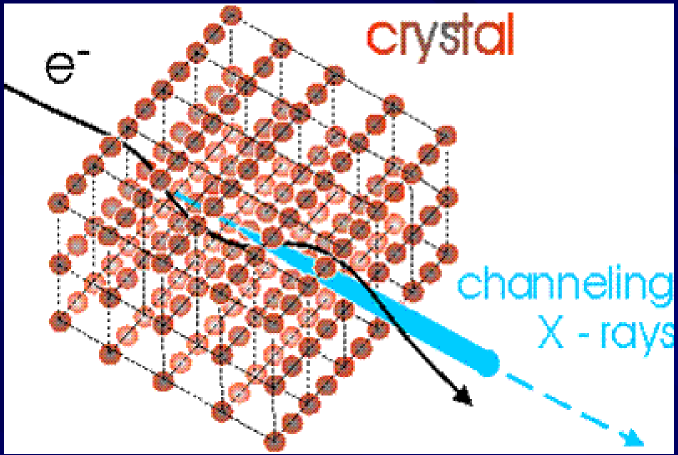

PARTICLE IDENTIFICATION BY MEANS OF CHANNELING RADIATION IN HIGH COLLIMATED BEAMS

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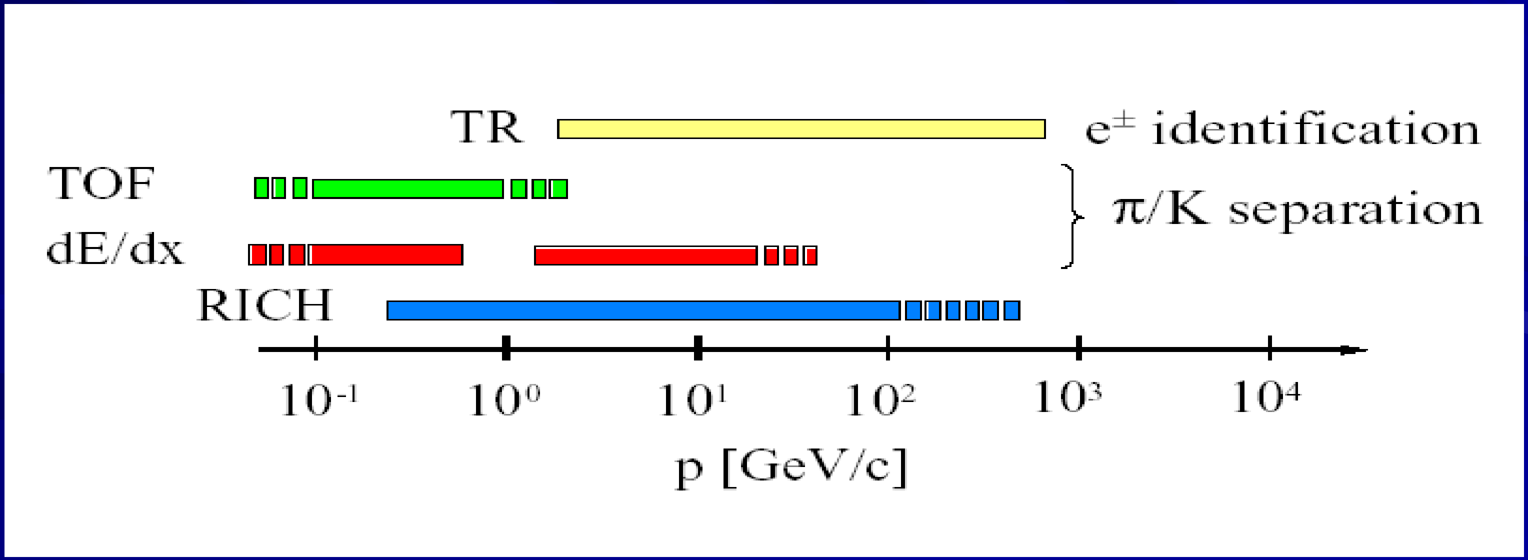
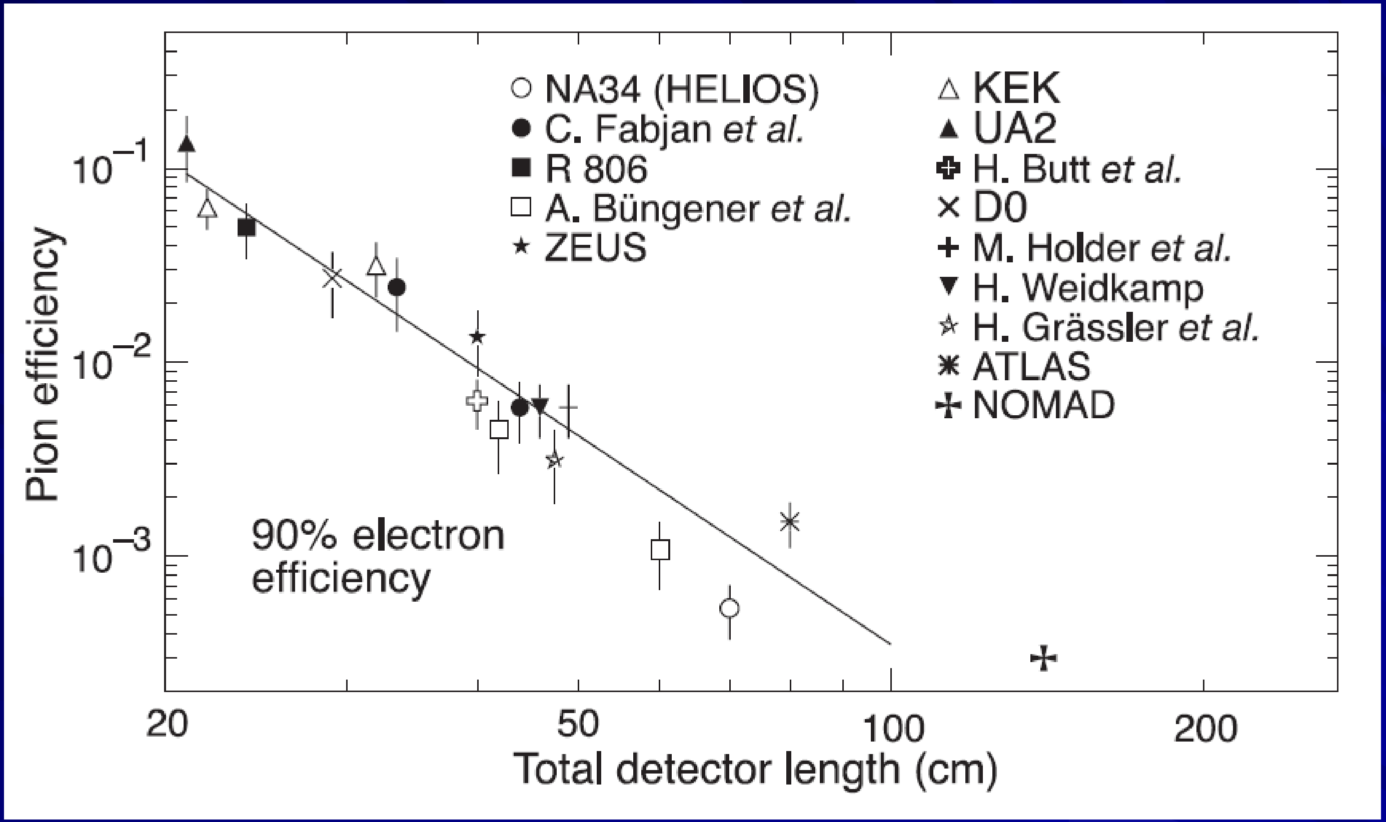
Motivation

- **Development of a detector for mass tagging at high energies by means of channeling radiation**
- **Application: particle identification in high energy unseparated beams where Cerenkov counters become unpractical and TRDs cannot perform full e/h discrimination**
  - small amounts of materials (in terms of X0) along the beam lines
  - highly collimated beams required



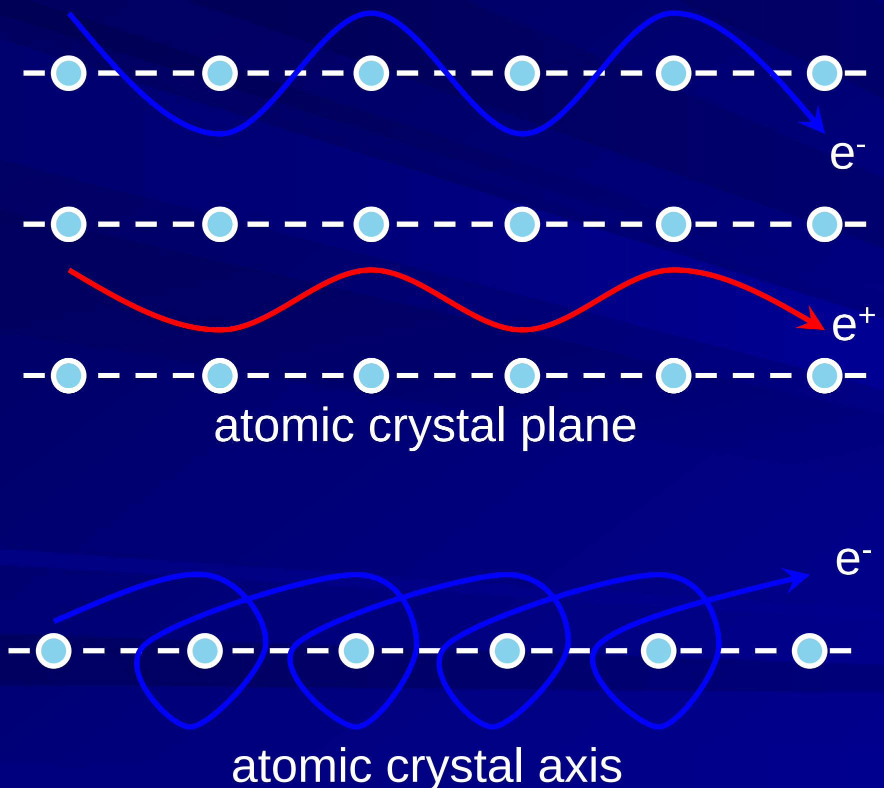
TRD performance vs length



- A good particle ID performance requires a "long" TRD:
  - large amounts of materials along the beam line
    - typically, a 50cm long TRD corresponds to ~10%X_0
    - possibility of some EM showers initiating in the TRD

Channeling Radiation (ChR)

- Channeling radiation is emitted when a charged particle crosses a crystal along a major crystal axis or plane
  - The charged particle is trapped in the potential wells due to the planes, resulting in the strong steering effect



- ChR is emitted if the incidence angle of the particle is smaller than a critical value ψ_{crit} (Lindhard angle) depending on the crystal and on the process (planar or axial channeling)
- Planar channeling: the particle is trapped between the crystal planes
- Axial channeling: the particle is channeled along a crystal axis

Features of the Channeling Radiation

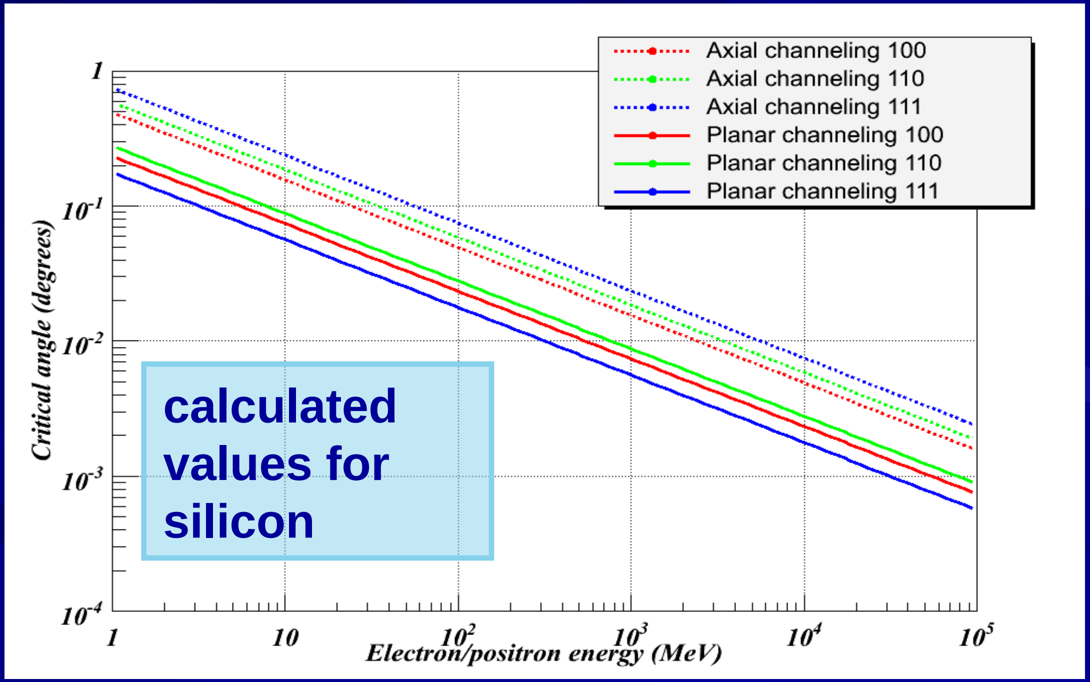
- It strongly depends on the charge sign
- It depends not only on the particle velocity, but on its energy as well
- It exhibits characteristic frequencies (peaks) depending on the particle and on the crystal
- High degree of linear polarization for planar channeling
- In the hard X-ray and γ-ray ranges it exceeds other types of radiation approximately by two orders of magnitude in spectral intensity and by three orders in luminosity

  - Emitted energy: $\Delta E \propto \gamma^2$
  - Photon energy: $\omega \propto \gamma^{3/2}$
  - Photon emission angle: $\theta \sim 1/\gamma$
  - γ is the Lorentz factor = E/m

Critical angle

$$\psi_{crit}(\text{deg}) = \begin{cases} 0.307\sqrt{\dfrac{Z_1 Z_2}{d\,E}} & \text{axial} \\ 0.545\sqrt{\dfrac{n Z_1 Z_2 a}{E}} & \text{planar} \end{cases}$$

- E = particle energy (MeV)
- d = atomic distance (Å) in a row
- n = atomic density in the planes (atoms/(Å)^2) = Nd_p/d^3
  - N = atoms per unit cell
  - d_p = interplanar distance
- a = screening length (Å)
- Z1 = Incident charge number
- Z2 = medium charge number

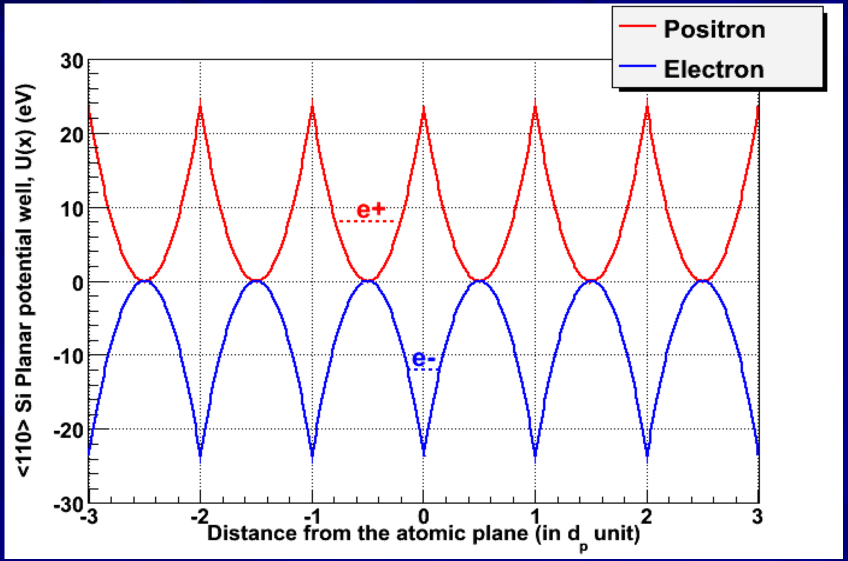


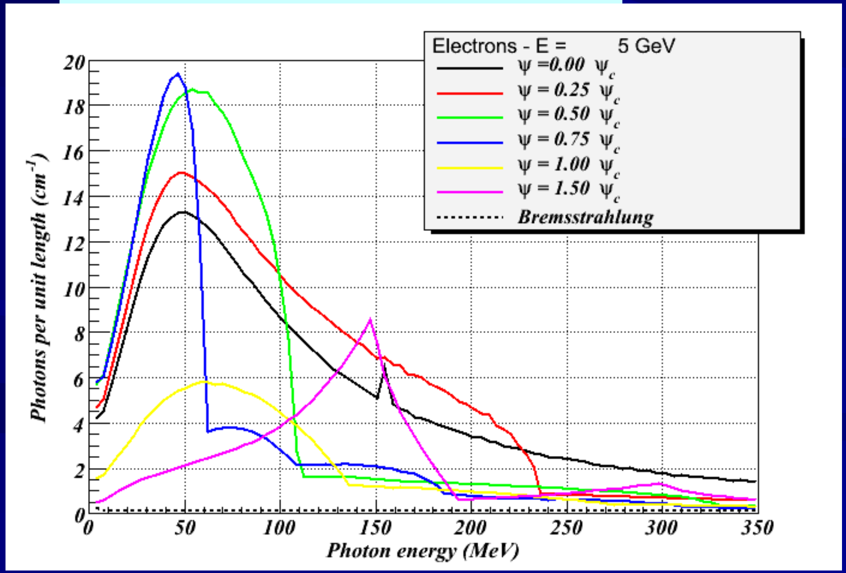
Energy spectra for <110> planar in silicon

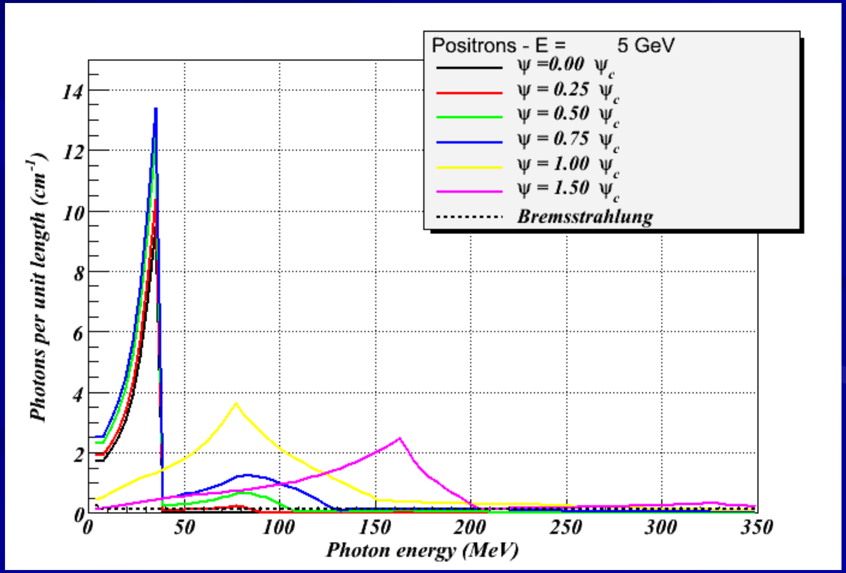
- Energy spectra can be evaluated in the framework of classical theory
- A parabolic approximation for the potential well has been assumed

$$U(x) \propto U_m \left(\frac{2}{d_p} x \right)^2$$

$$U_m(\mathrm{eV}) = \frac{90.5\, N Z_1 Z_2 a}{d^2}$$





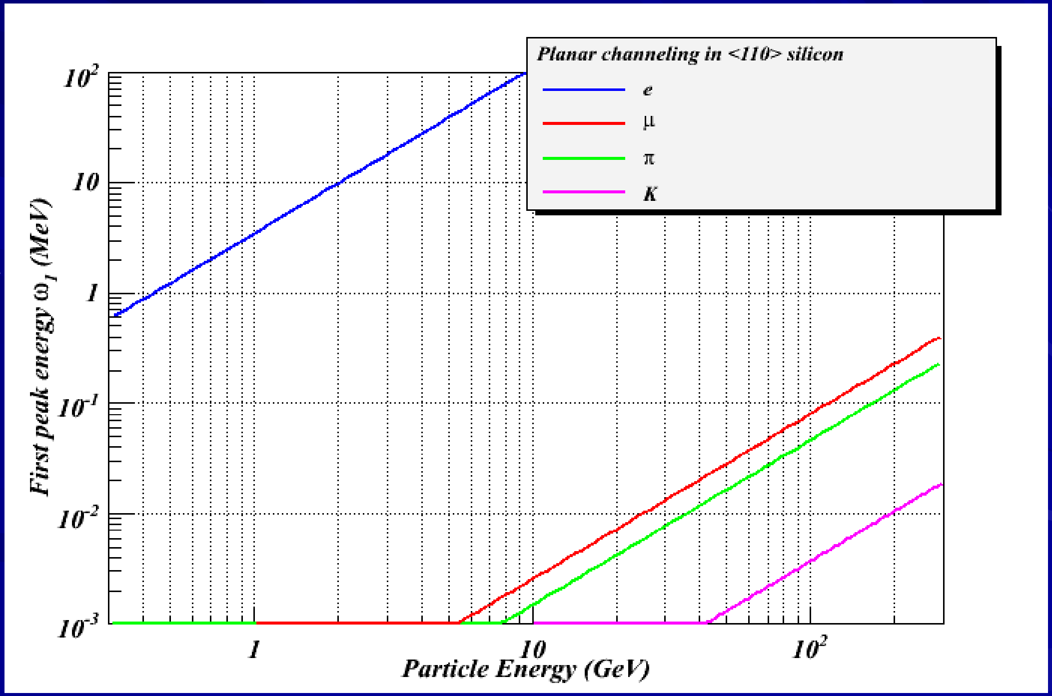


Characteristic frequencies

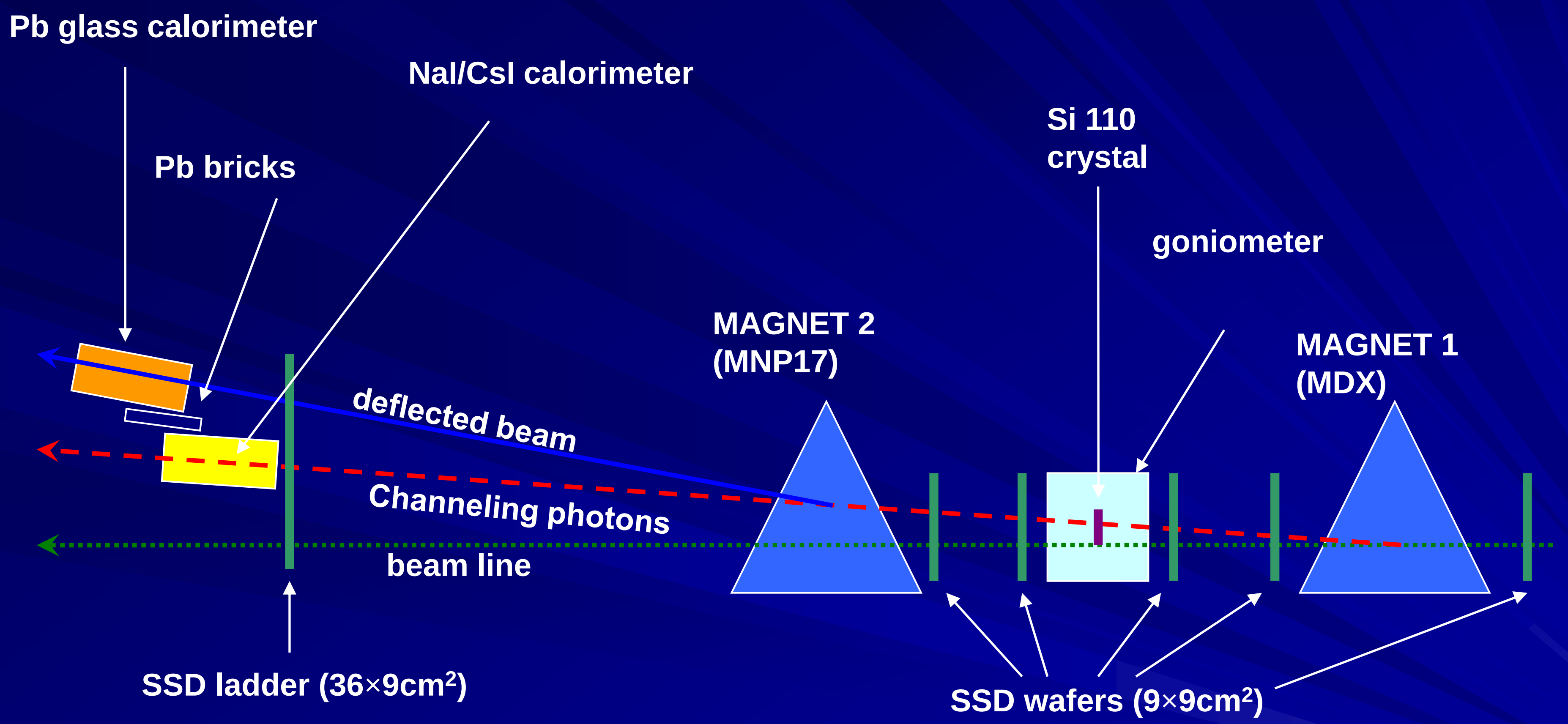
- **Intensity spectra show peaks at the frequencies $\omega_k = 2k\gamma^2\Omega$ (k=1,2,3...) where γ is the Lorentz factor of the incident particle**

$$\Omega(\mathrm{MeV}) \approx 2\frac{2\cdot 10^{-3}}{d_p(\mathrm{A})}\sqrt{\frac{2U_m}{E}} \Rightarrow \omega_1(\mathrm{MeV}) \approx 4\left(\frac{E}{m}\right)^2 \frac{2\cdot 10^{-3}}{d_p(\mathrm{A})}\sqrt{\frac{2U_m}{E}}$$

- **For energies up to a few hundreds of GeV, channeling photons produced by heavy particles are mainly in the energy region below 1MeV**
- **Channeling photons produced by electrons (positrons) have energies in the range 1-100MeV up to 10GeV beam energy**

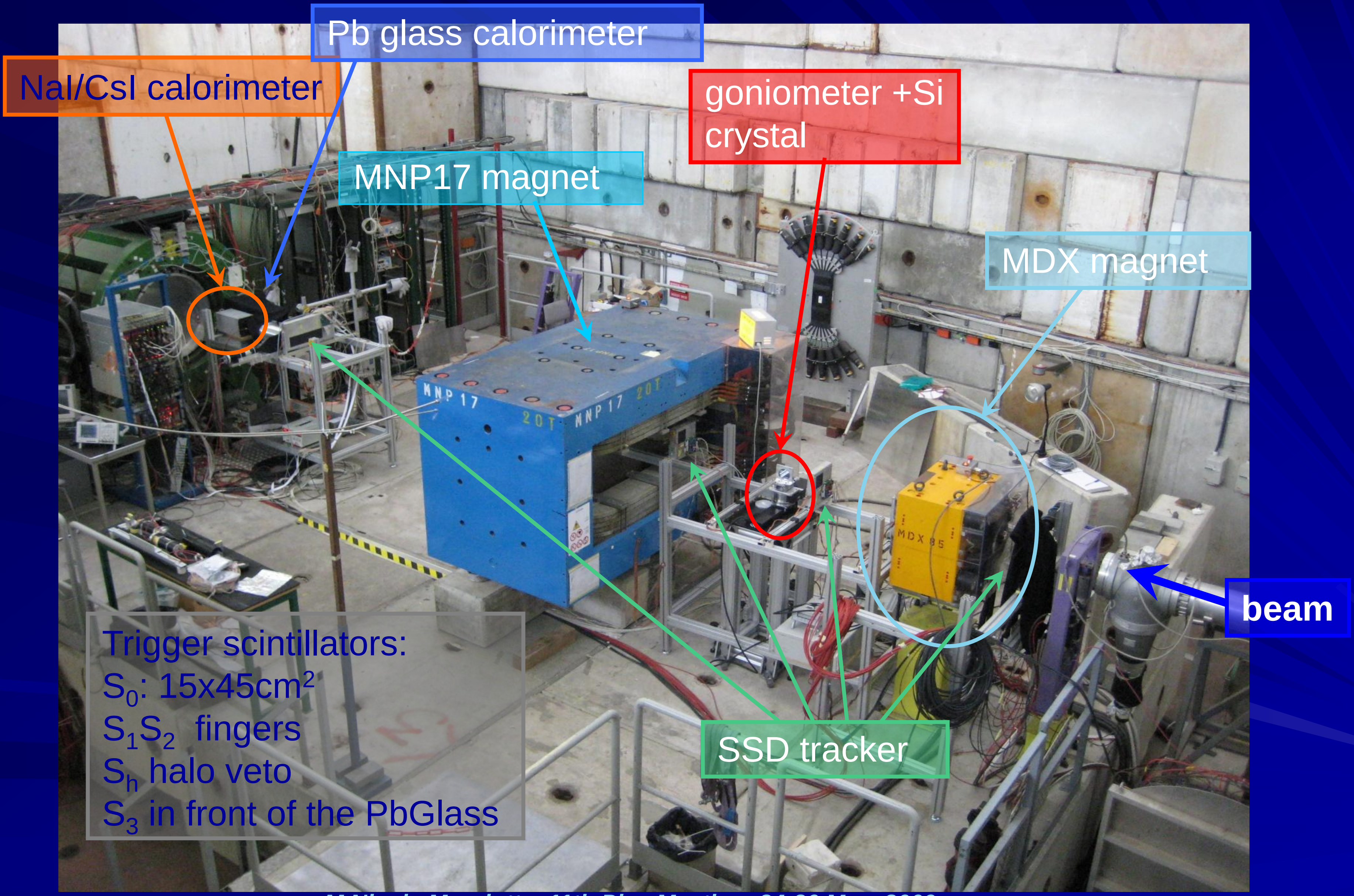


Beam test at CERN-PS T9 line (2007)

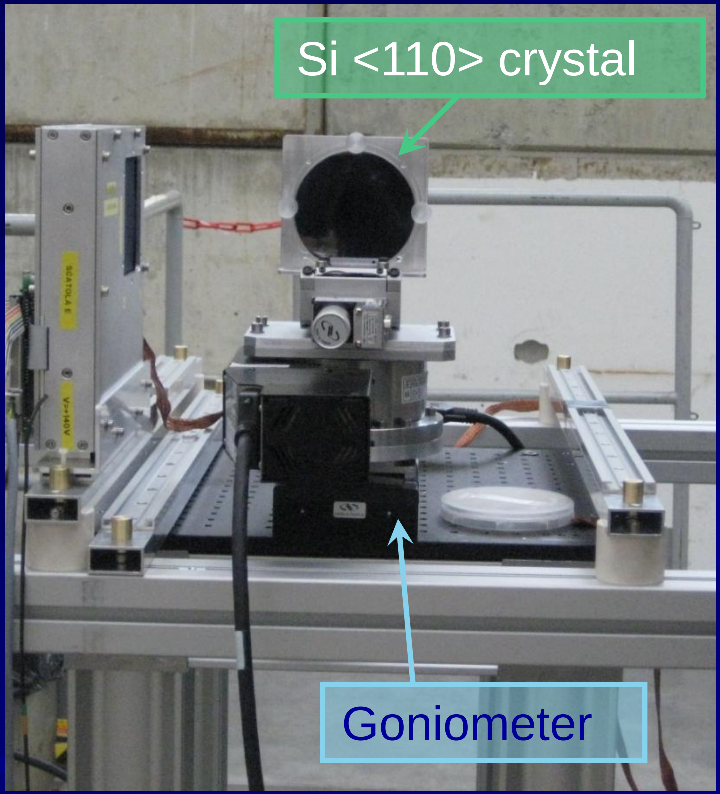


- A set of plastic scintillators were used to provide the trigger
- Two gas Cerenkov counters disposed along the beam line were used together with the Pb-glass calorimeter for particle identification
- The SSDs could be easily removed from the beam line

Beam test 2007: experimental set-up



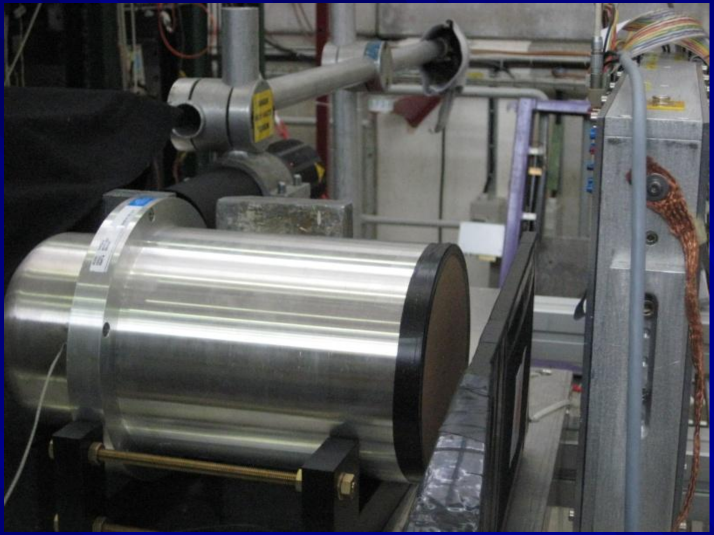
The crystal and the goniometer



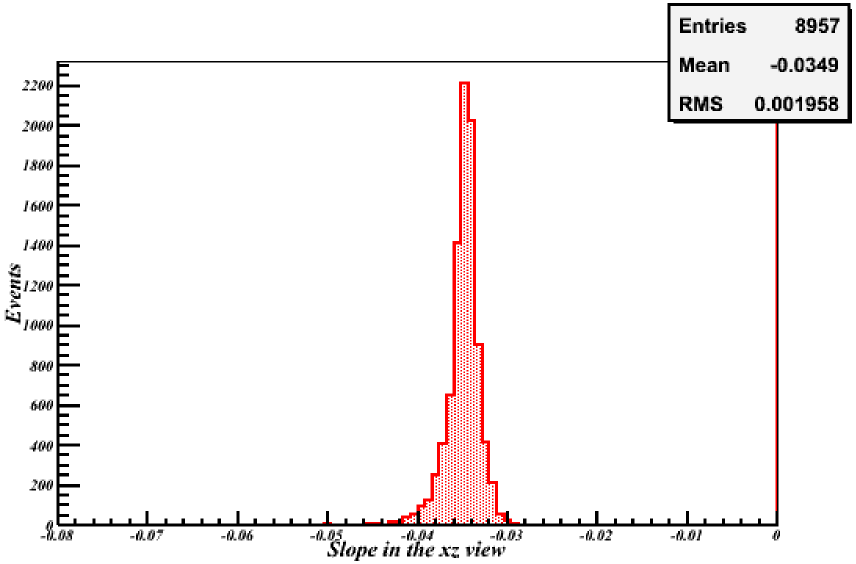
- Si <110> oriented crystal
  - thickness = 500μm (0.5%X_0)
  - miscut angle = 0.1°
- 3-axis goniometer + linear stage (Newport)
  - 0.001° angle precision
  - The linear stage allows to remove the Si crystal from the beam
  - custom control software

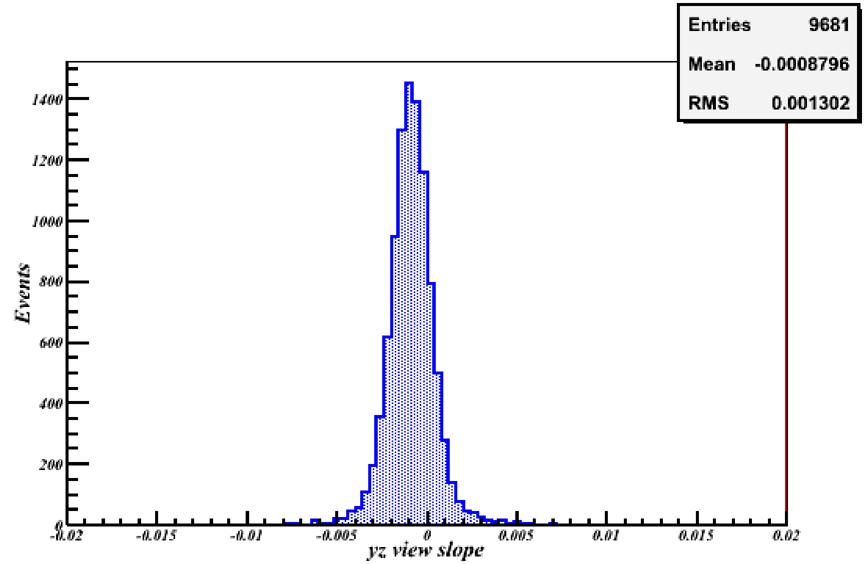
The E.M. calorimeters

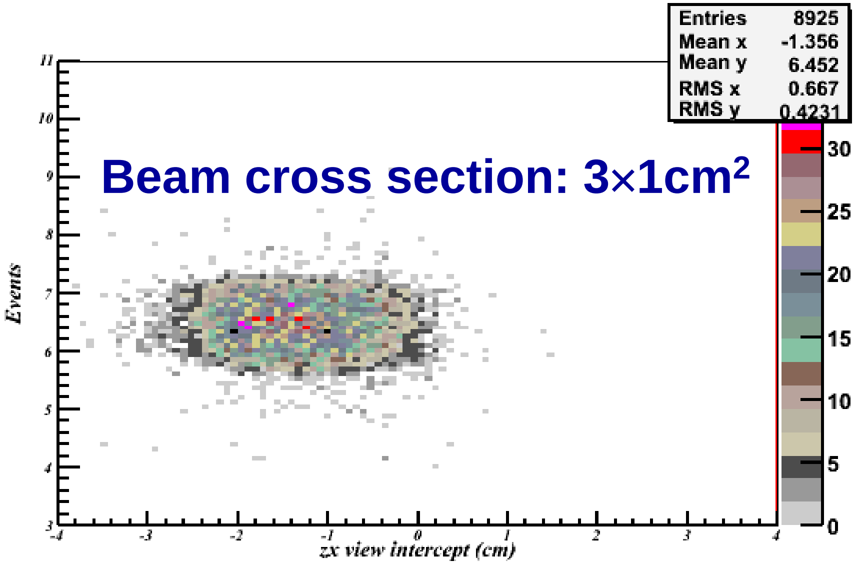
- NaI calorimeter:
  - single NaI crystal, 6'' diameter, 8'' length
  - the crystal is readout by a 5'' diameter XP3550 PMT
- CsI segmented calorimeter:
  - 7 layers (4 horizontal + 3 vertical view), each composed by 3 CsI bars, 3×3cm^2 cross section, 12cm length
  - 21cm total length
  - The bars are readout at both ends by two PIN PDs (18×18mm^2 and 10×10mm^2)
- The calorimeters have been calibrated with an electron beam with energies up to 500MeV at INFN-Frascati BTF facility



Study of the beam divergence at PS-T9





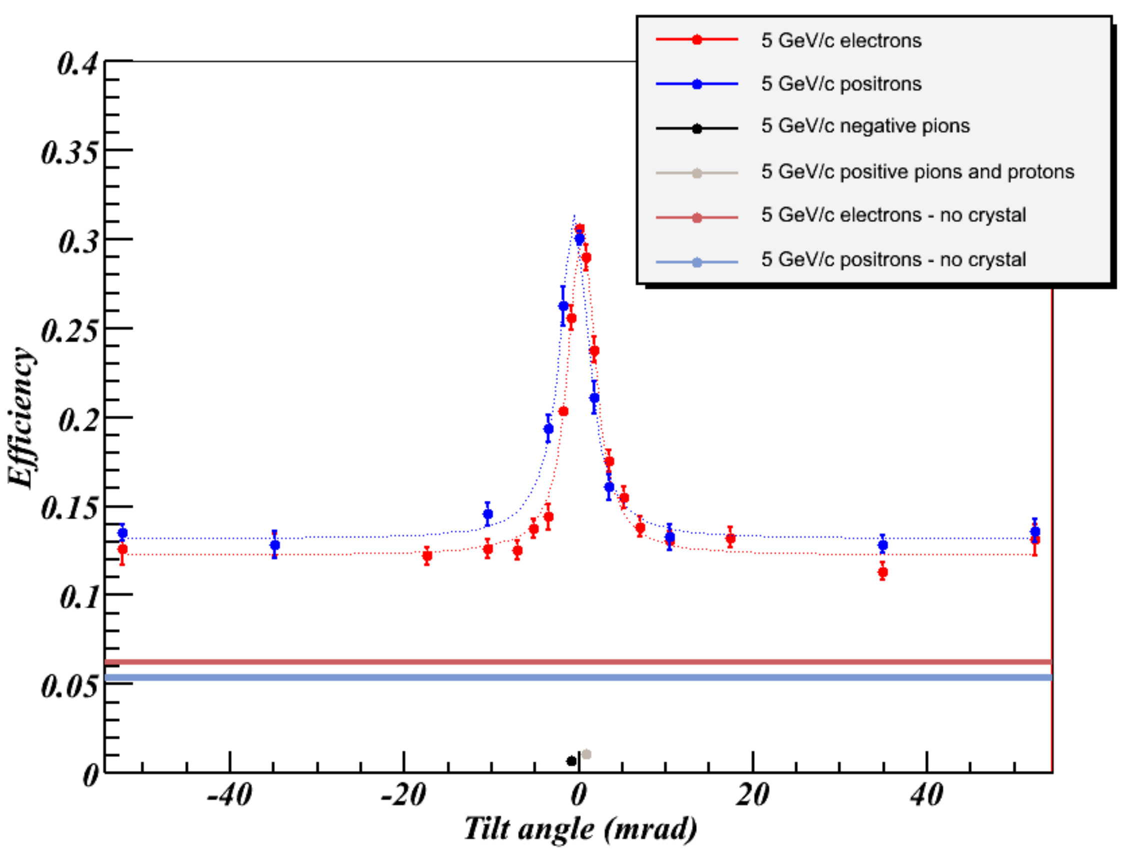


Beam cross section: $3\times1cm^2$

- **Study performed with 5 GeV/c electrons and pions**
- **Beam divergence:**
  - **2 mrad in the bending plane**
  - **1.3 mrad in the not-bending plane**
- **Electron critical angle is about 0.15 mrad (i.e. 0.1 beam divergence)**
  - **Low efficiency is expected**

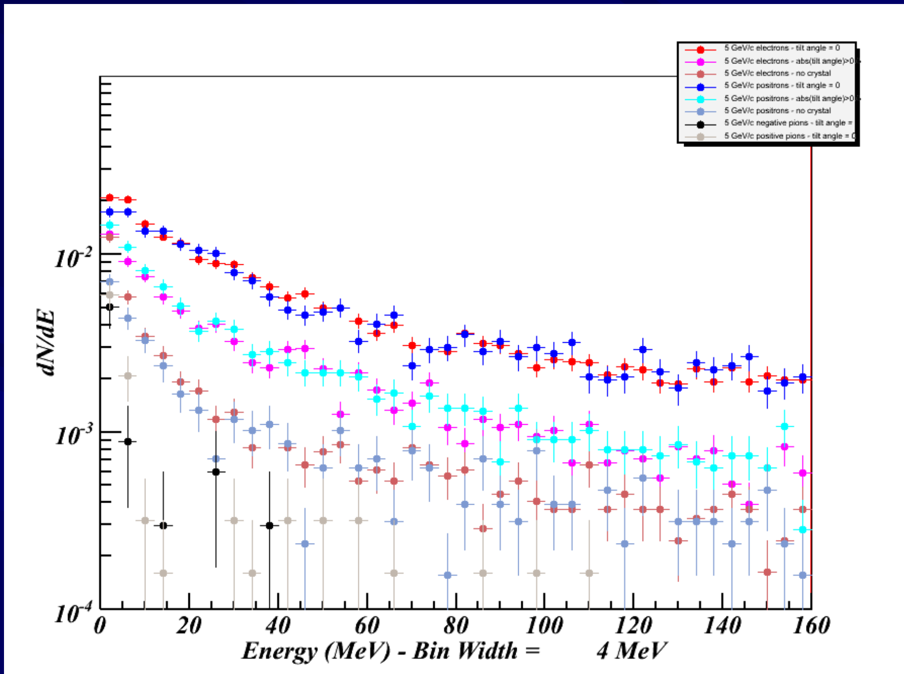
Photons Vs Si <110> tilt angle

- SSDs removed from the beam line
- No selection on incoming and outcoming particle direction
- measurement performed with the NaI calorimeter
- efficiency = fraction of events with charge > ped+3σ in the NaI calorimeter
- energy threshold: 3σ≈1.0MeV

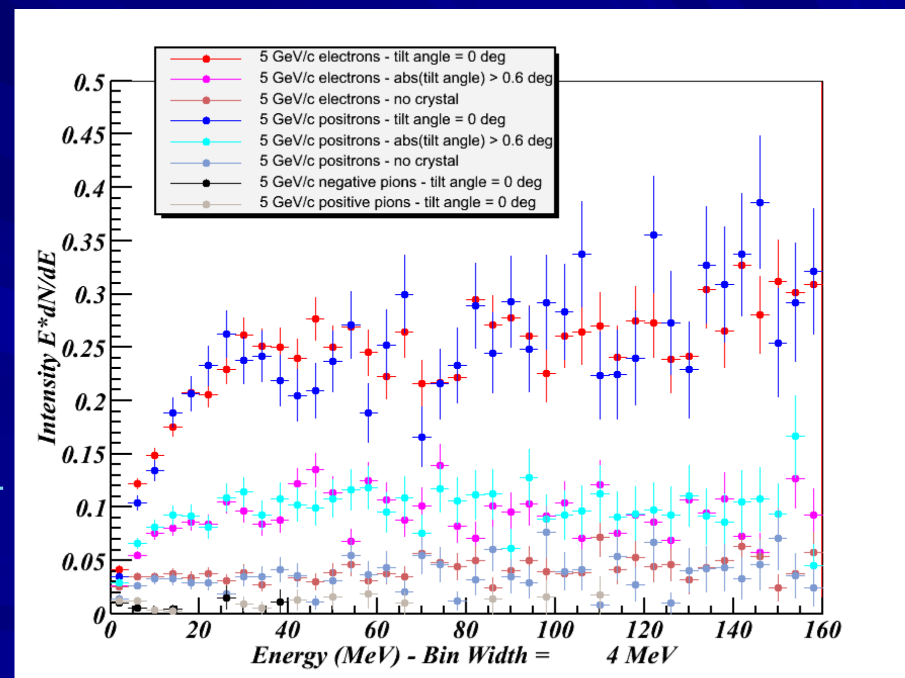


- **An efficiency peak is found for both electrons and positrons with SNR≈4**
- **The FWHM of the peak is about 4 mrad (i.e. the beam divergence)**
- **Pion background → photon detection efficiency ≈ 0.01**

Energy and intensity spectra



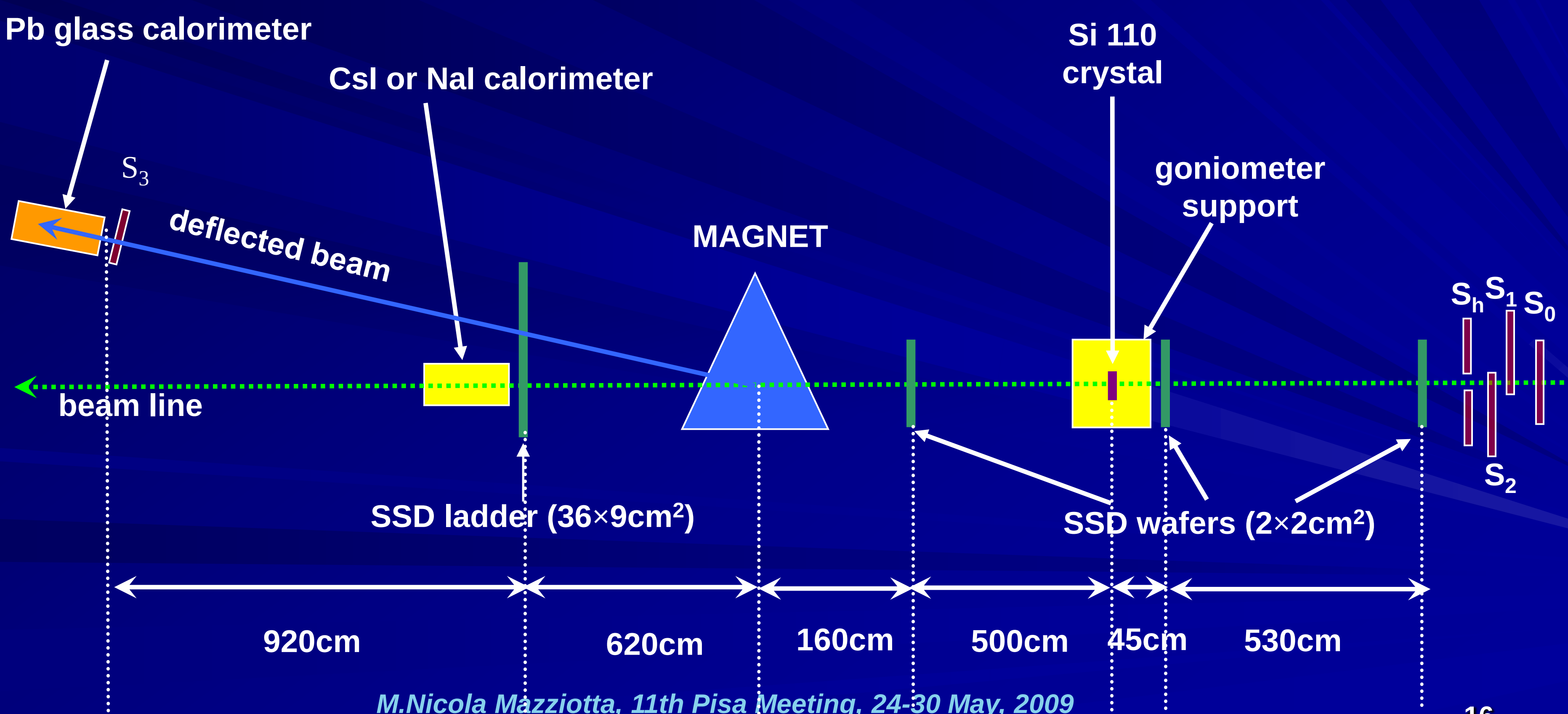
Energy spectra measured with the NaI calorimeter



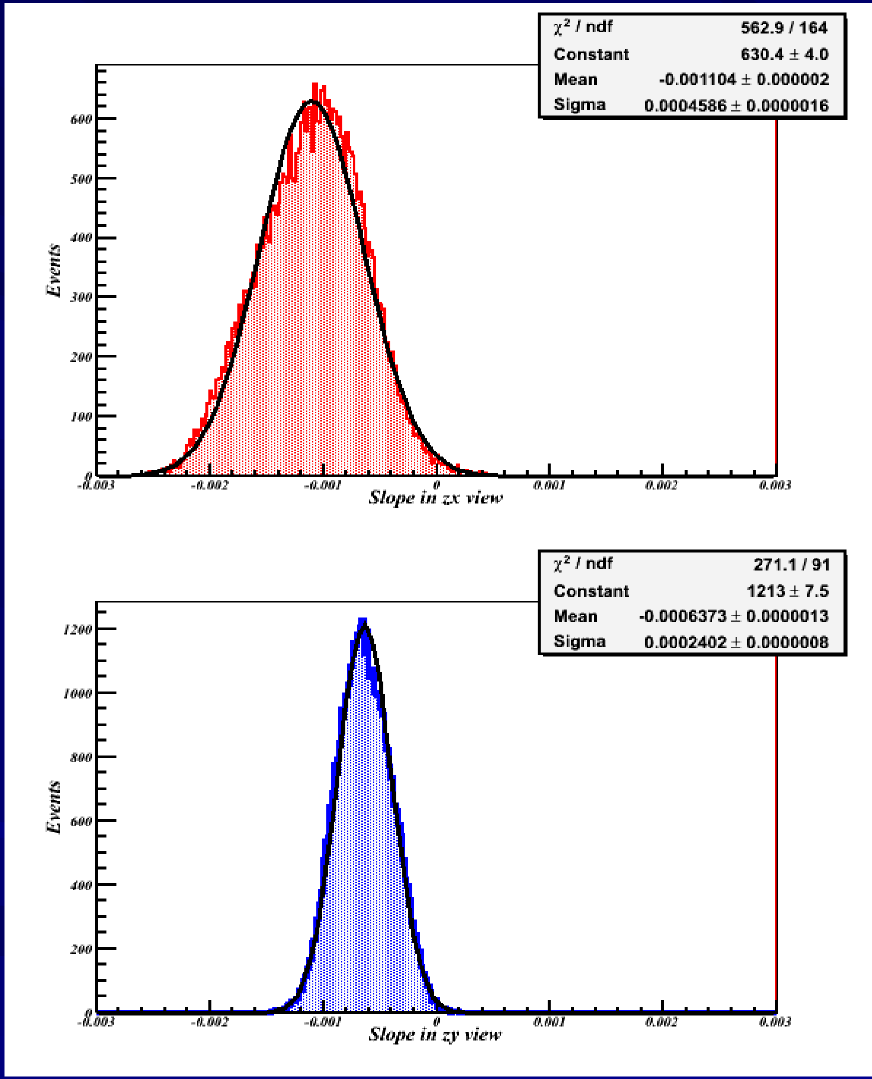
- **Photon intensity spectra at channeling angle exhibit a peak at 30 MeV, consistent with the expected value of ω_1**
- **Intensity spectra at angles far from the channeling peak are almost flat**
- **A flat background of ≈0.03 photons/beam particle is observed**

Beam test at CERN-SPS H4 line (2008)

- A single magnet has been used in the set-up
  - Large background expected due to the interaction of the beam with upstream materials
- The H4 line provides clean beams (electron/positron/hadron)
  - A Pb-glass calorimeter has been used to improve the electron/hadron identification



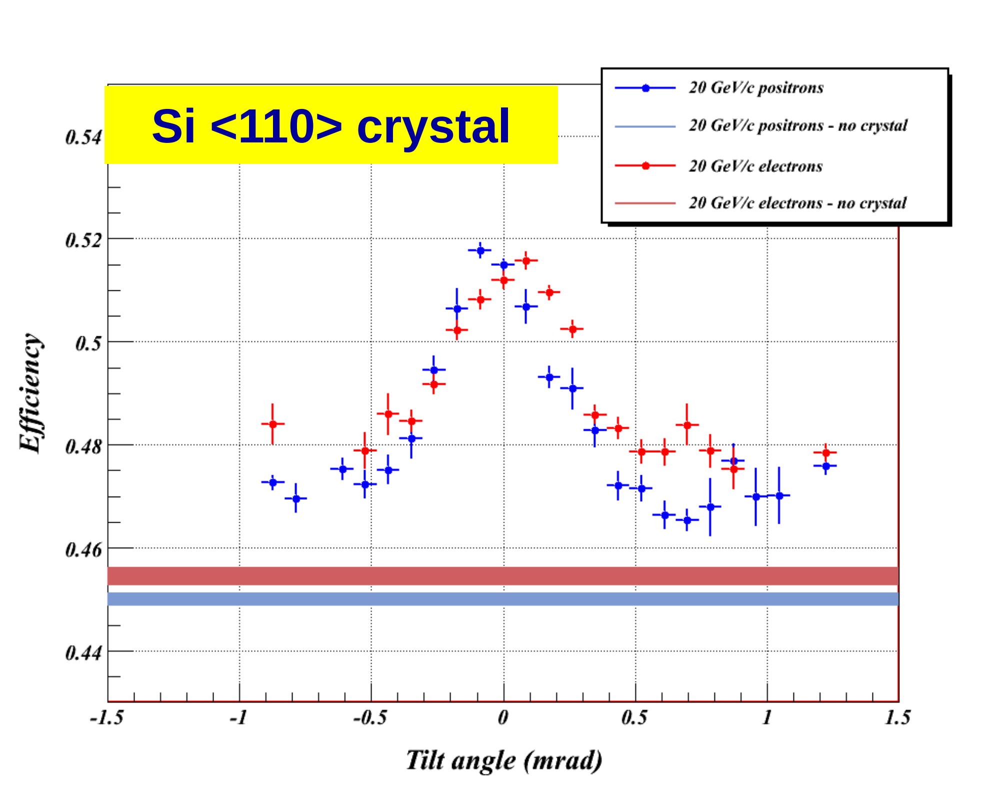
Study of the beam divergence at SPS-H4



- Study performed at 20 GeV/c
- Beam divergence:
  - 0.46 mrad in the bending plane
  - 0.24 mrad in the perpendicular plane
- Electron critical angle is about 0.06 mrad (i.e. 0.1 beam divergence)
  - Low efficiency is excepted

Photon Efficiency vs tilt angle at 20 GeV

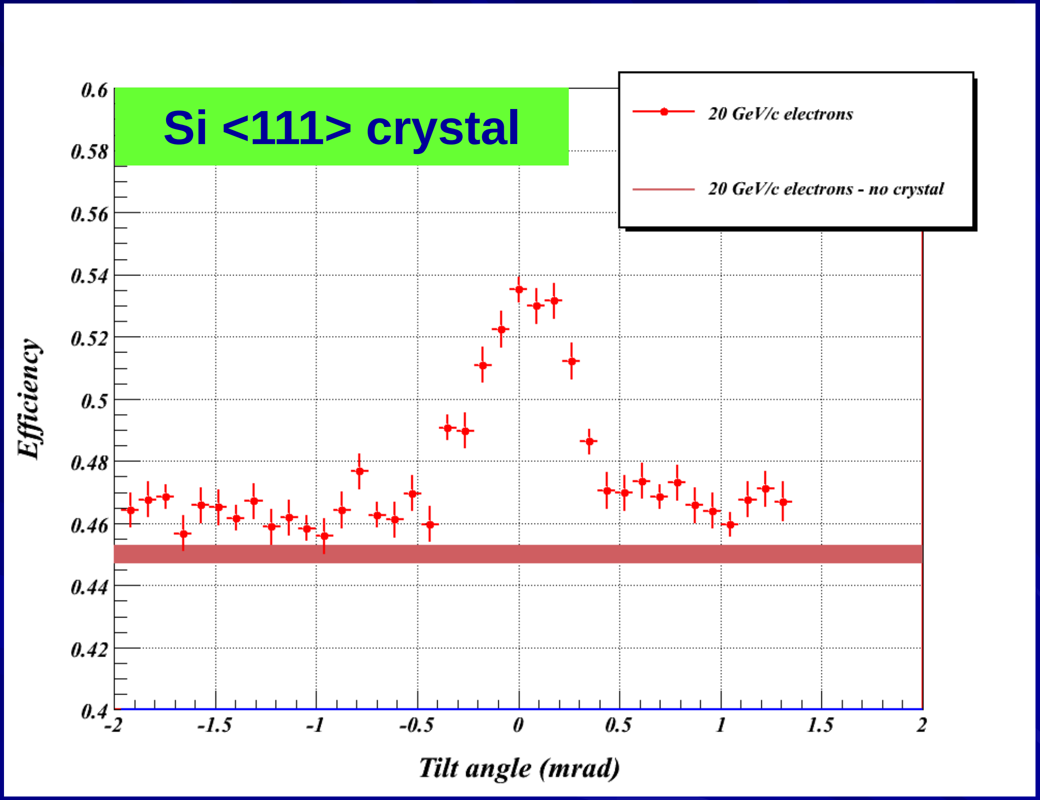
- SSDs removed from the beam line
- No selection on incoming and outcoming particle direction
- measurement performed with the NaI calorimeter
- efficiency = fraction of events with charge > ped+3σ in the NaI calorimeter
- energy threshold: 3σ≈1.0MeV



- An efficiency peak is found for both electrons and positrons with SNR≈4
- The FWHM of the peak is about 0.5mrad (i.e. the beam divergence)
- Pion background → photon detection efficiency < 10^{-3}

Photon Efficiency vs tilt angle at 20 GeV

- SSDs removed from the beam line
- No selection on incoming and outcoming particle direction
- measurement performed with the NaI calorimeter
- efficiency = fraction of events with charge > ped+3σ in the NaI calorimeter
- energy threshold: 3σ≈1.0MeV



- An efficiency peak is found for electrons with SNR≈4
- The FWHM of the peak is about 0.5mrad (i.e. the beam divergence)
- Pion background → photon detection efficiency < 10^{-3}

Conclusions

- A measurement has been performed of the channeling radiation emitted by electrons and positrons crossing a 500μm thick (0.5%X_0) <110> and <111> silicon crystals
  - the channeling peak has been found, even though the beam divergence was ~10 times larger than the expected channeling angle
    - a SNR~4 has been observed at the channeling peak
  - no significant differences found between e^+/e^- because of the large beam divergence
  - significant background from the materials along the beam line
- A new beam test campaign is planned at the CERN SPS H4 beam line