



Readout Electronics for a Proton Computed Tomography Apparatus

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MOTIVATIONS FOR pCT

Stopping powers are the main parameters for dose calculation in proton radiotherapy.

They are derived from measured attenuation coefficients μ of conventional xCT.

The error intrinsic in this conversion (due to $\mu(\eta_e, Z)$ dependency on atomic number and electron density) is the principal cause of proton range indetermination (3%, up to 10 mm in the head)

[Schneider U. (1994), Med Phys. 22, 353]

Main aim of pCT: direct measurement of stopping power...

...and, possibly:

- a. Lower dose to the patient, with respect to xCT (according to MC simulations).
- b. Increase of low-contrast resolution
- c. Patient positioning before every treatment

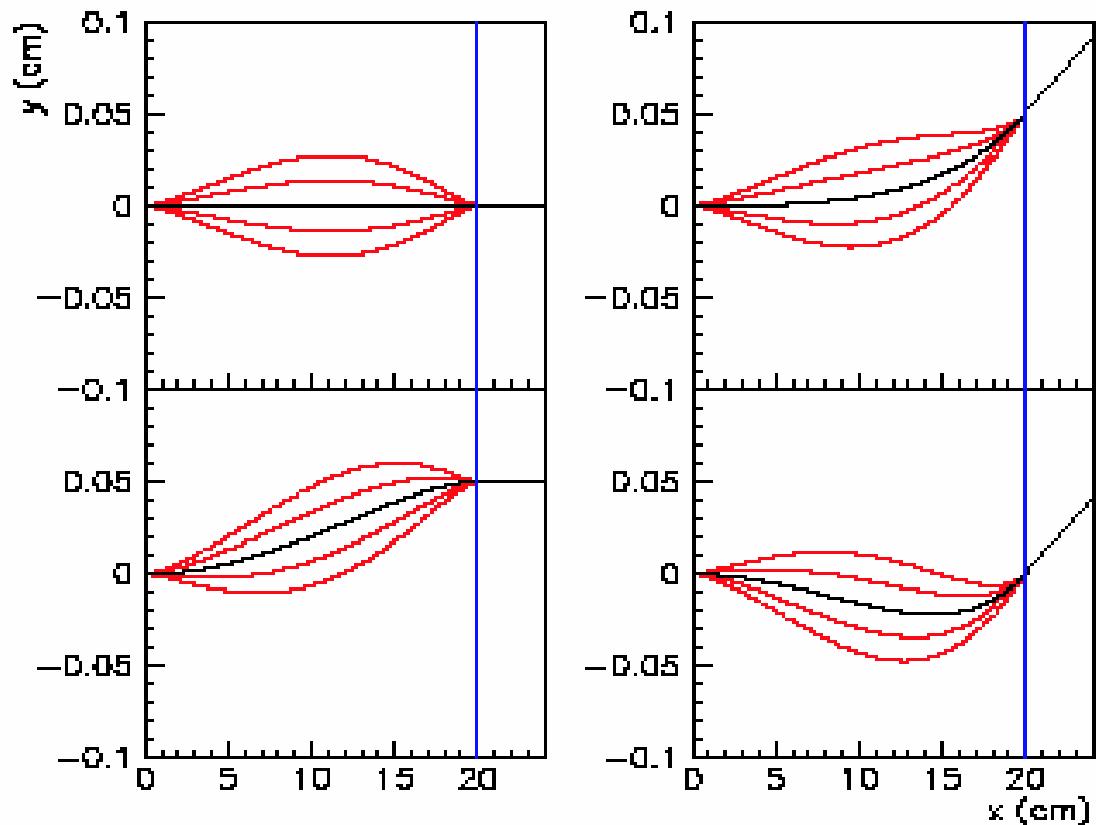
MAIN DIFFICULTY WITH pCT: multiple Coulomb scattering

To obtain high space and energy accuracy:

1. determination of protons Most Likely Path (MLP)

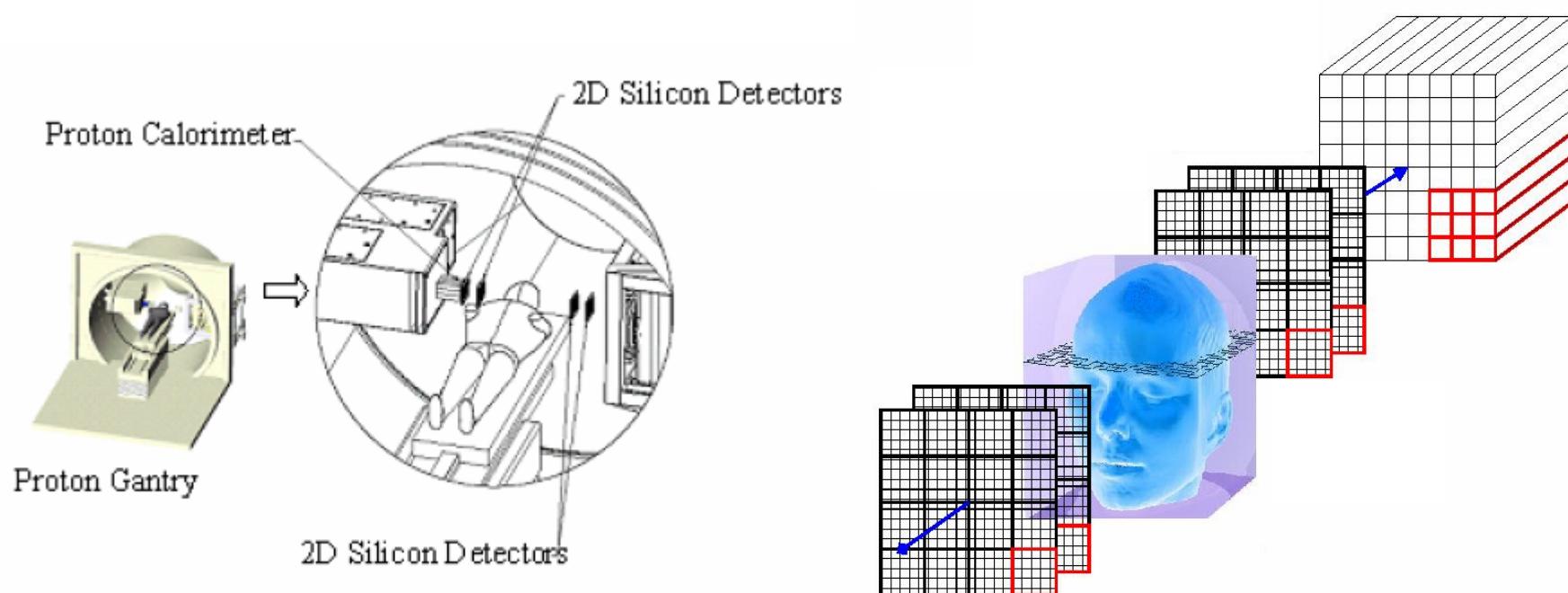
2. single proton tracking

Entrance and exit angles and positions are boundary conditions for MLP calculation.

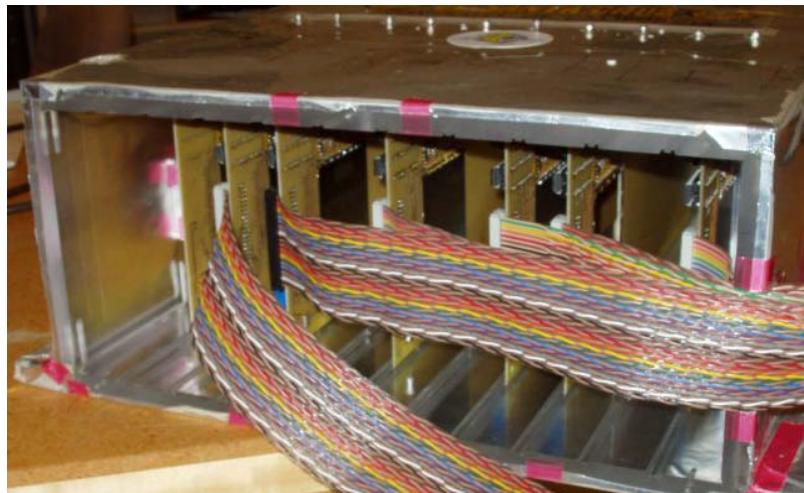
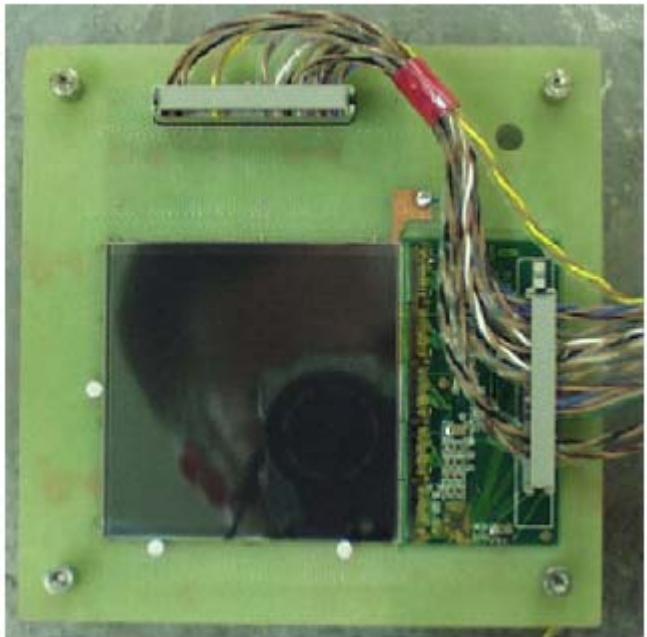


200 MeV Protons, 20 cm water
Most Likely, 1σ and 2σ path
D C Williams Phys. Med. Biol. 49 (2004) 2899–2911

CONCEPT



BACKGROUND



Initial studies with a Si single-sided strip telescope by UCSC and LLUMC.

Use of Si detectors (194 μm pitch, 400 μm thickness) to measure:
a) protons trajectory;
b) energy loss, from time over threshold (TOT).

Limits:

- 1) slow acquisition rate (1kHz).
- 2) Low energy resolution (25% at 250 MeV), improved in a later prototype by a separate calorimeter.

H. F. -W. Sadrozinsk et al., NIM A 514 (2003) 215–223.

M. Bruzzi et al. , IEEE Trans. Nucl. Sci., 54 (2007) 140 - 145.

COLLABORATION AIMS

- 1) realize a high-performance prototype for proton radiography

Proton Energy	250-270 MeV
Proton rate	$\sim 10^6$ 1/sec
Space resolution	< 1 mm
electron density resolution	< 1%
Radiation hardness	> 1000 Gy

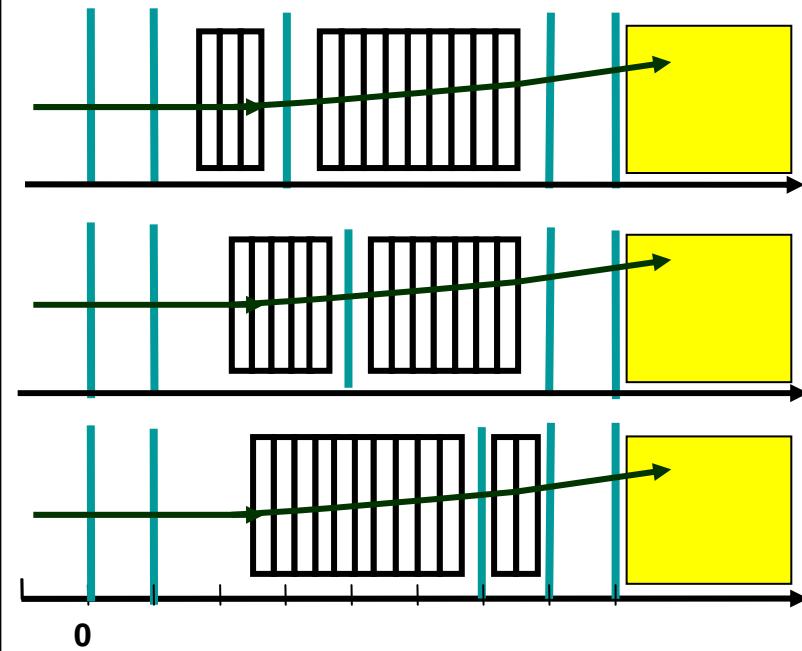
- 2) validate the prototype with pre-clinical studies
- 3) conceive a configuration for a pCT system.

Research supported by:

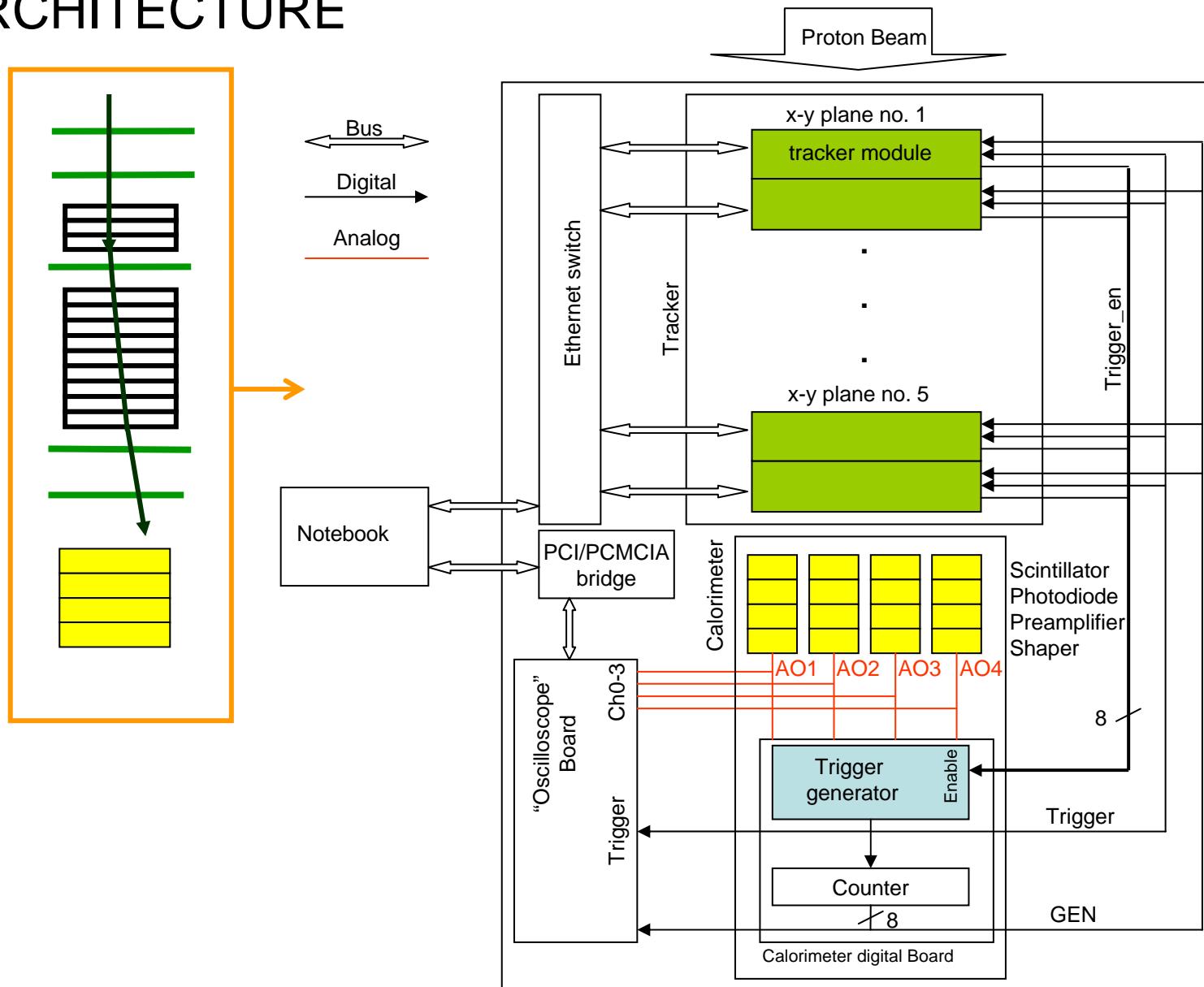
INFN (Natl. Inst. of Nucl. Phys.), "PRIMA" experiment

MIUR (Dept. of University and Research) PRIN 2006 funding

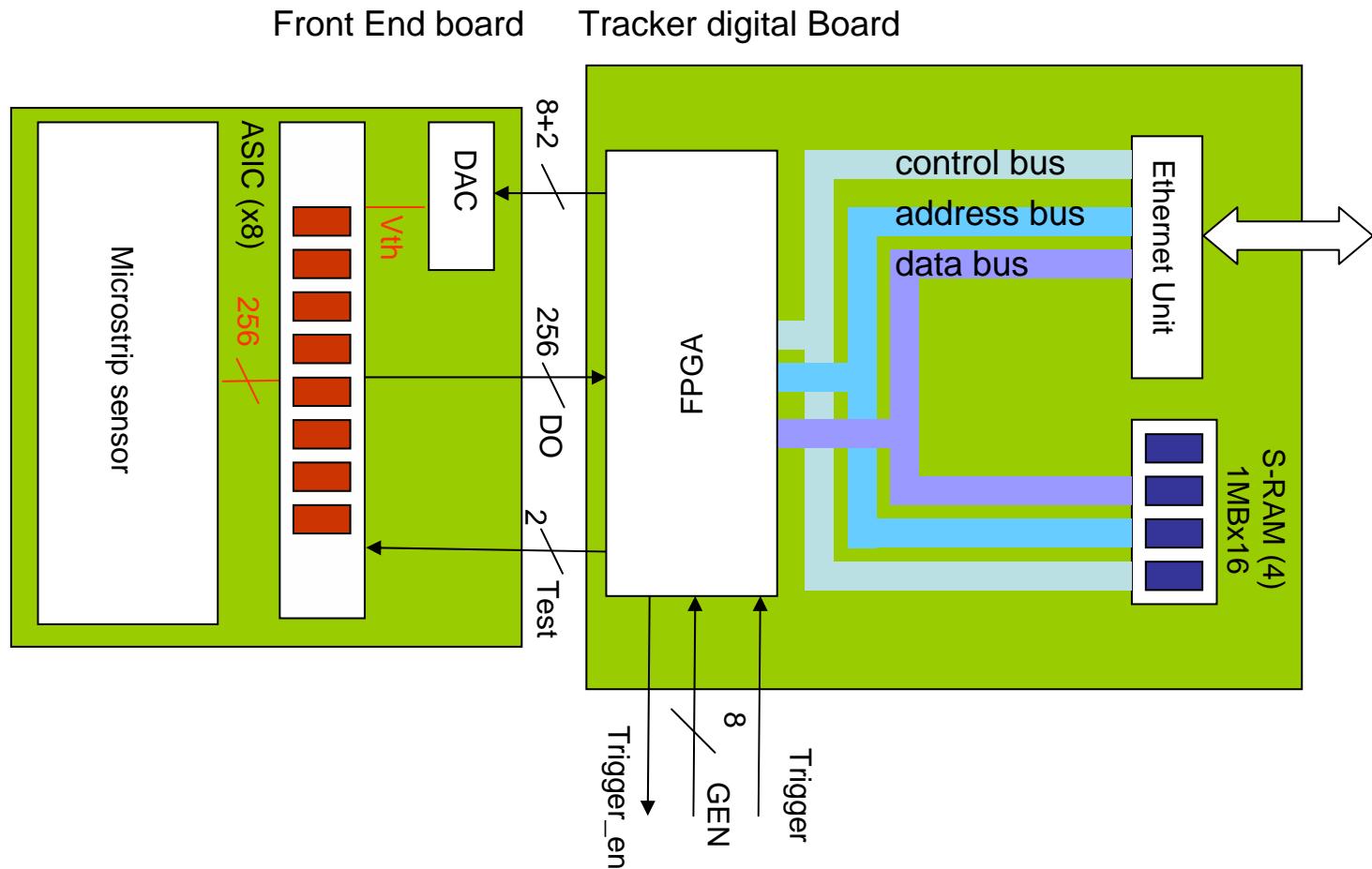
e.g.: comparison of predicted MLP with tracking measurements



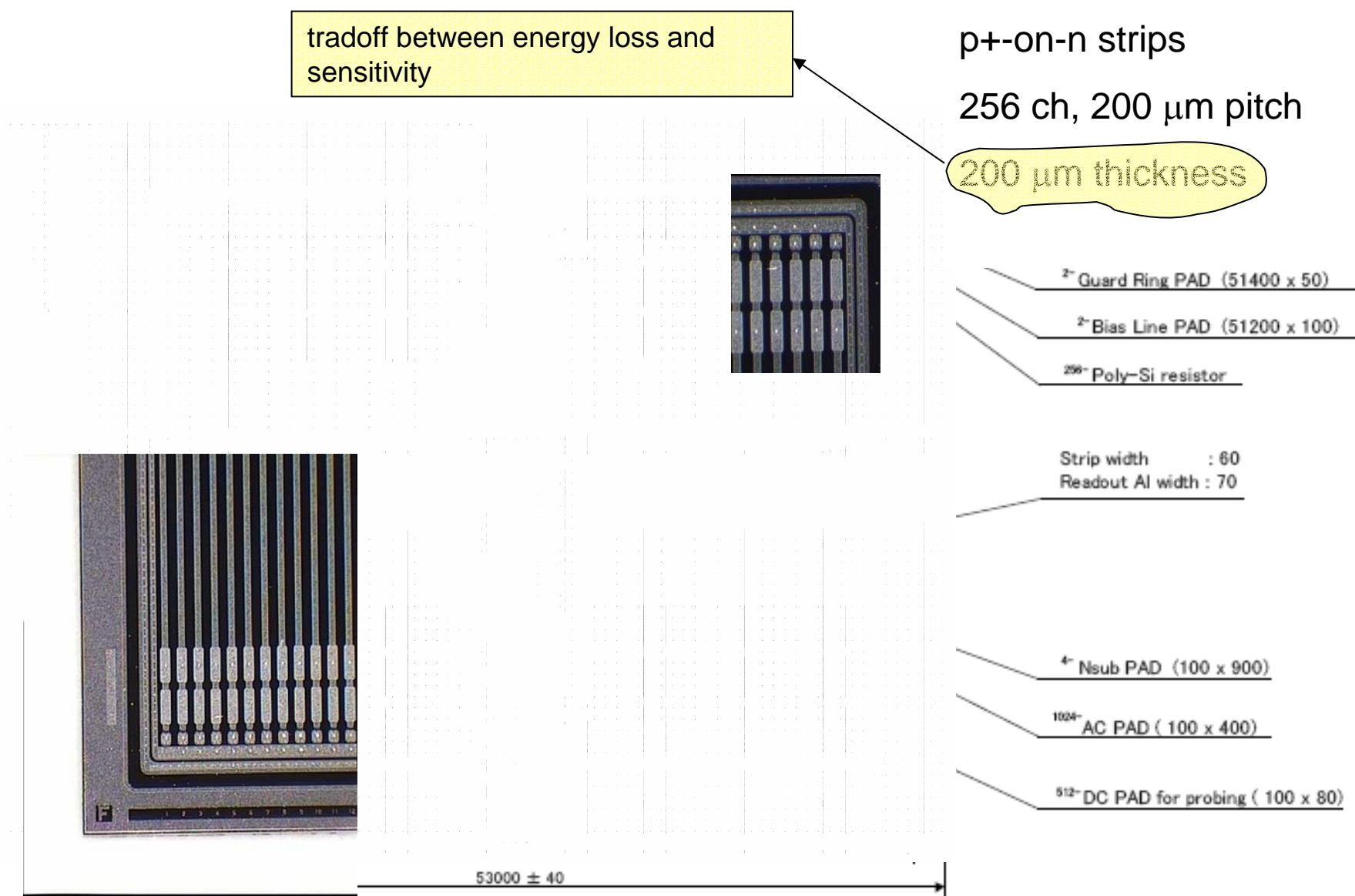
ARCHITECTURE



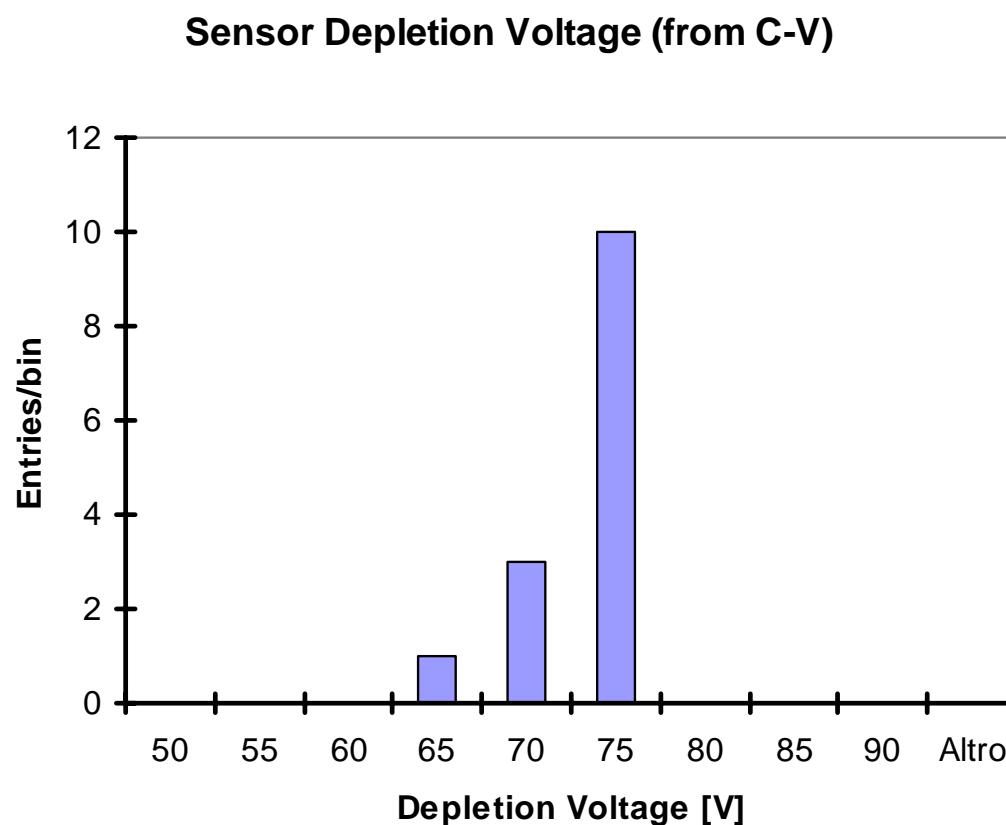
TRACKER MODULE



Si SENSOR

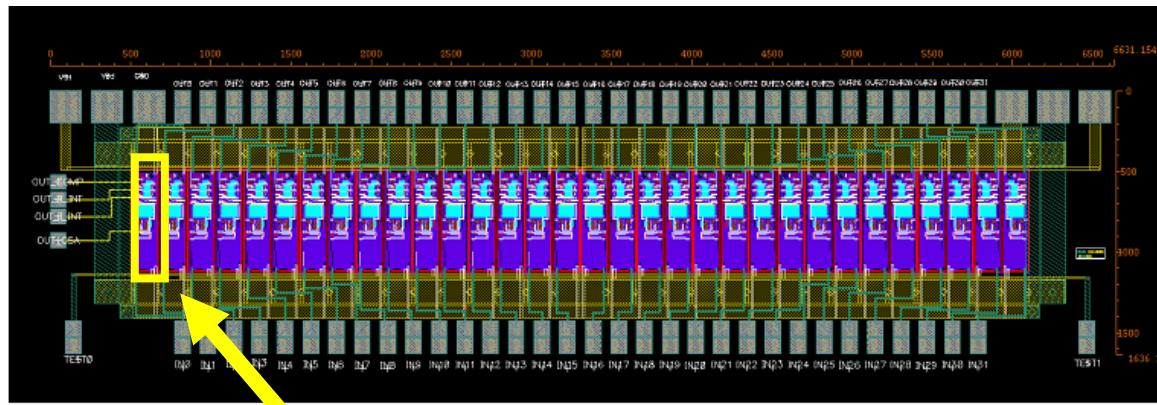


Si SENSOR PERFORMANCES



$V_{fd} < 75 \text{ V}$
 $i(100\text{V}) < 1 \mu\text{A}$
 $i(200\text{V}) < 3 \mu\text{A}$
 $C = 54 \text{ pF/cm}$ (coupling)
 $C = 1.5 \text{ pF/cm}$ (interstrip)

ASIC design

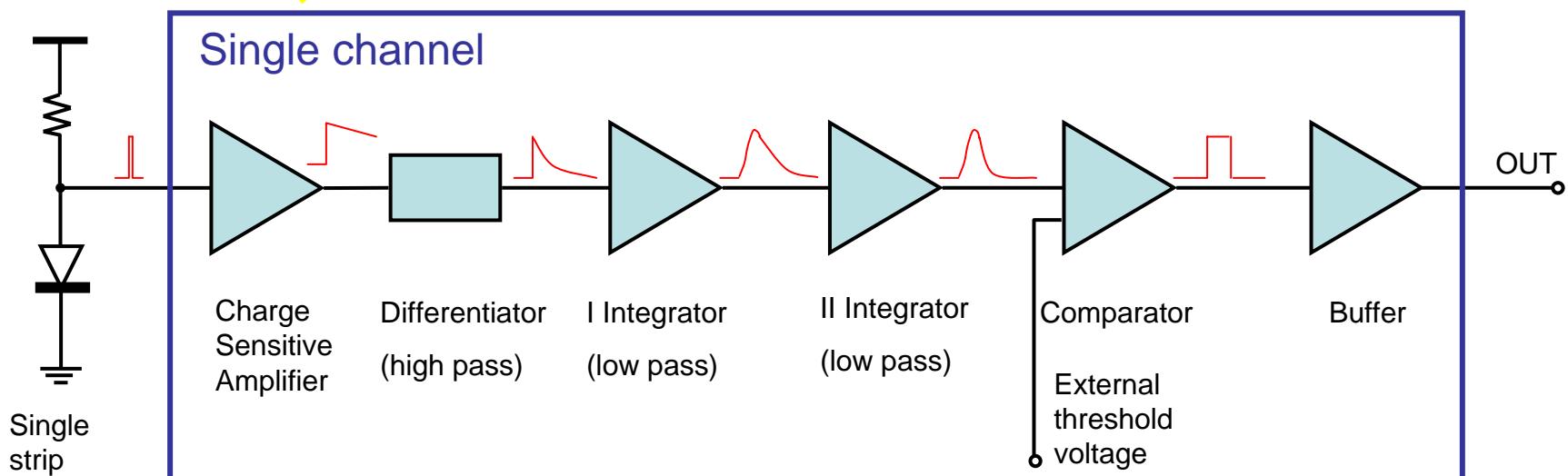


6.6 x 1.6 mm²

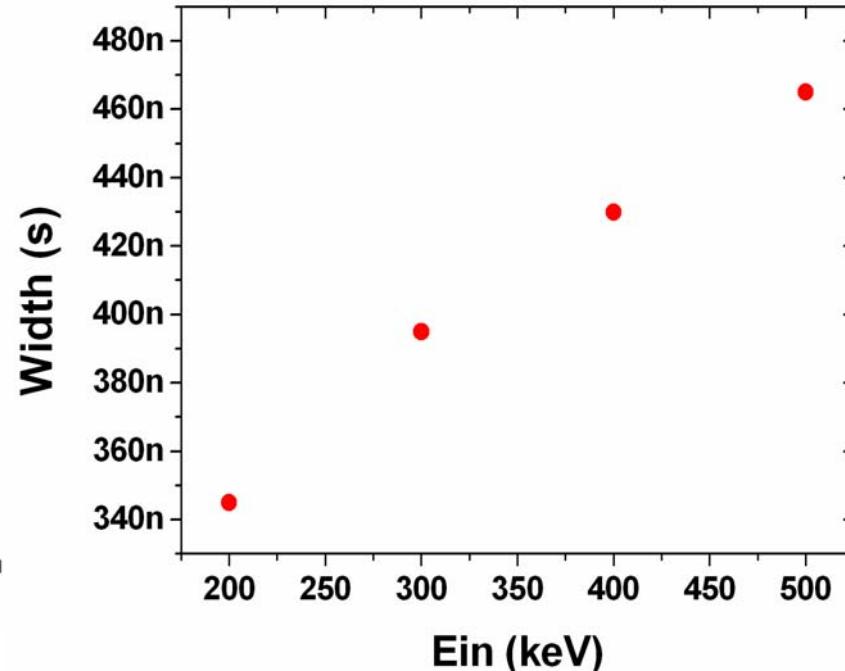
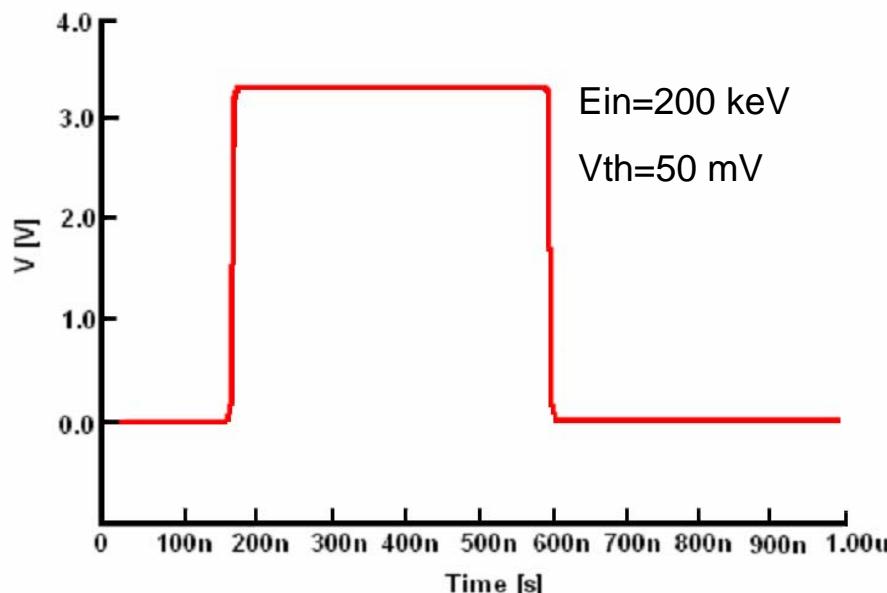
32 inputs - 32 outputs

670 mW power consumption

V_{cc}=+3.3 V



ASIC CAD SIMULATION: output signal



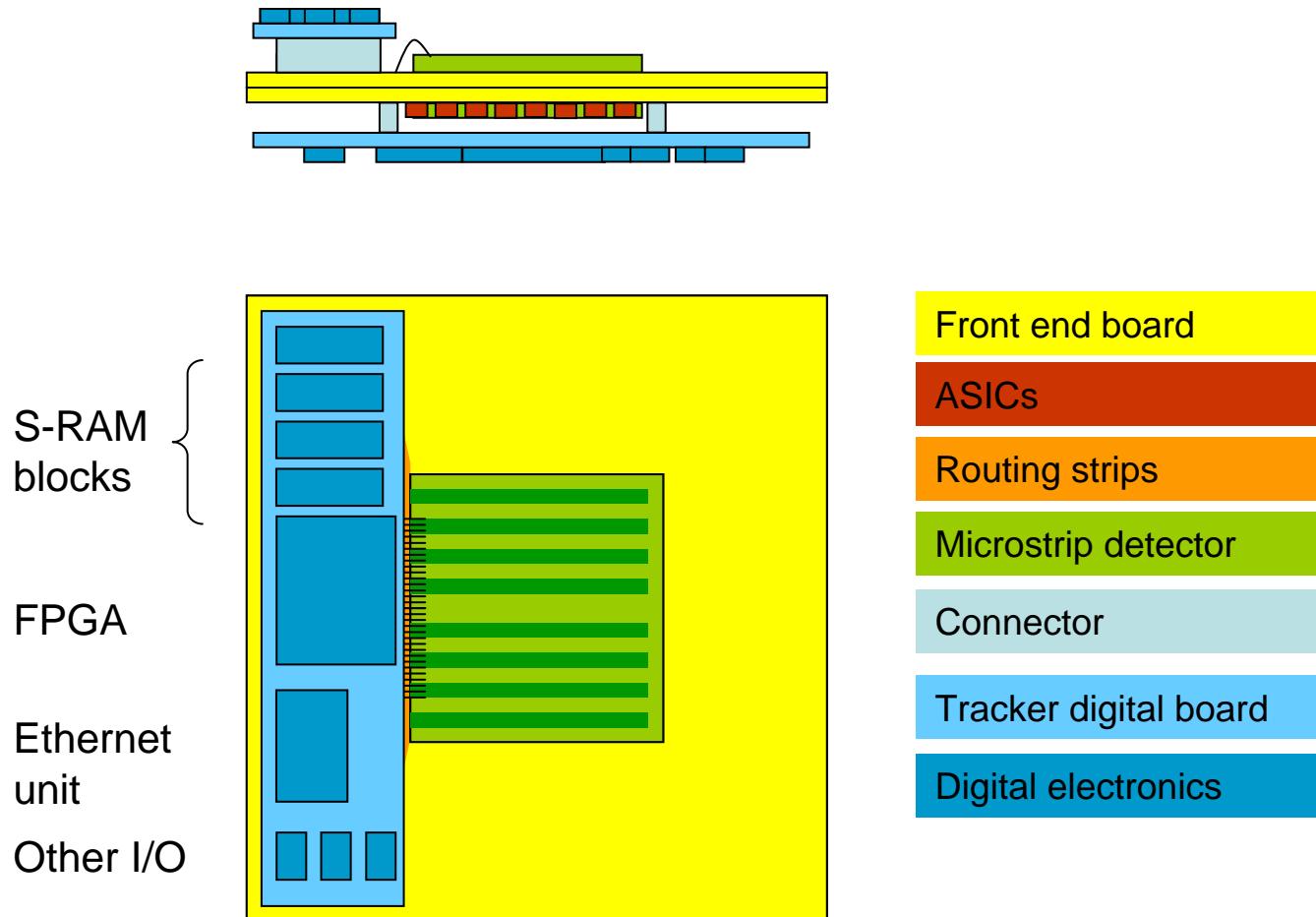
Rise time = 12ns @ CL = 30pF

Fall time = 13ns @ CL = 30pF

Width ~ [250 + 0.50×E(keV)] ns

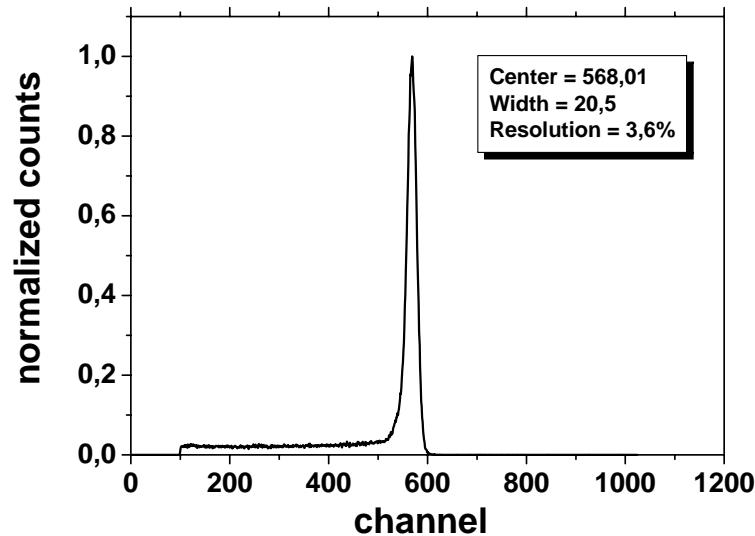
Dynamic range ~ 3 MeV

X-Y PLANE ASSEMBLY

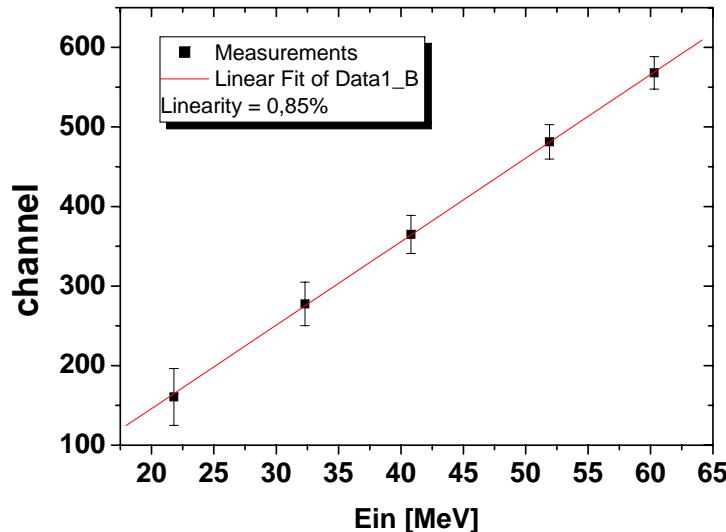


Calorimeter

Charge spectra for 62 MeV proton beam

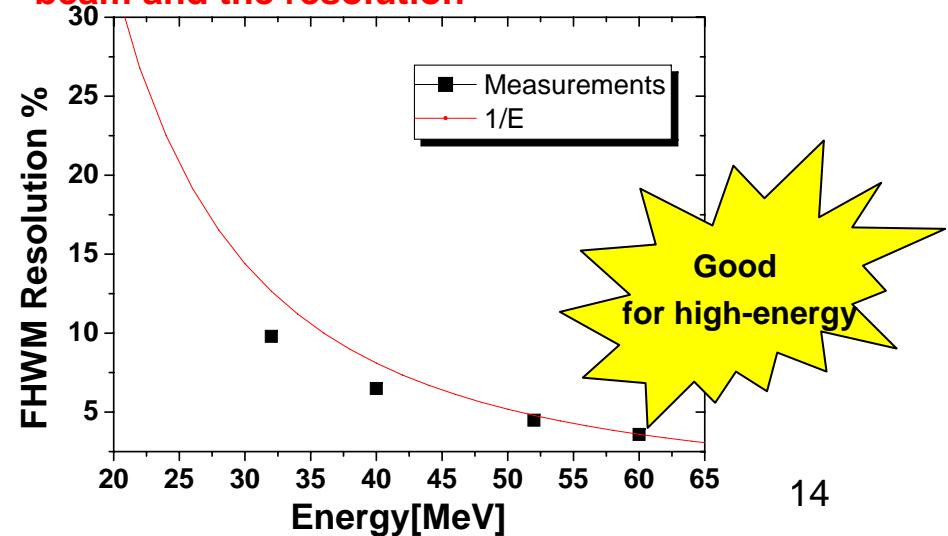


The relationship between the input energy beam and the peak position

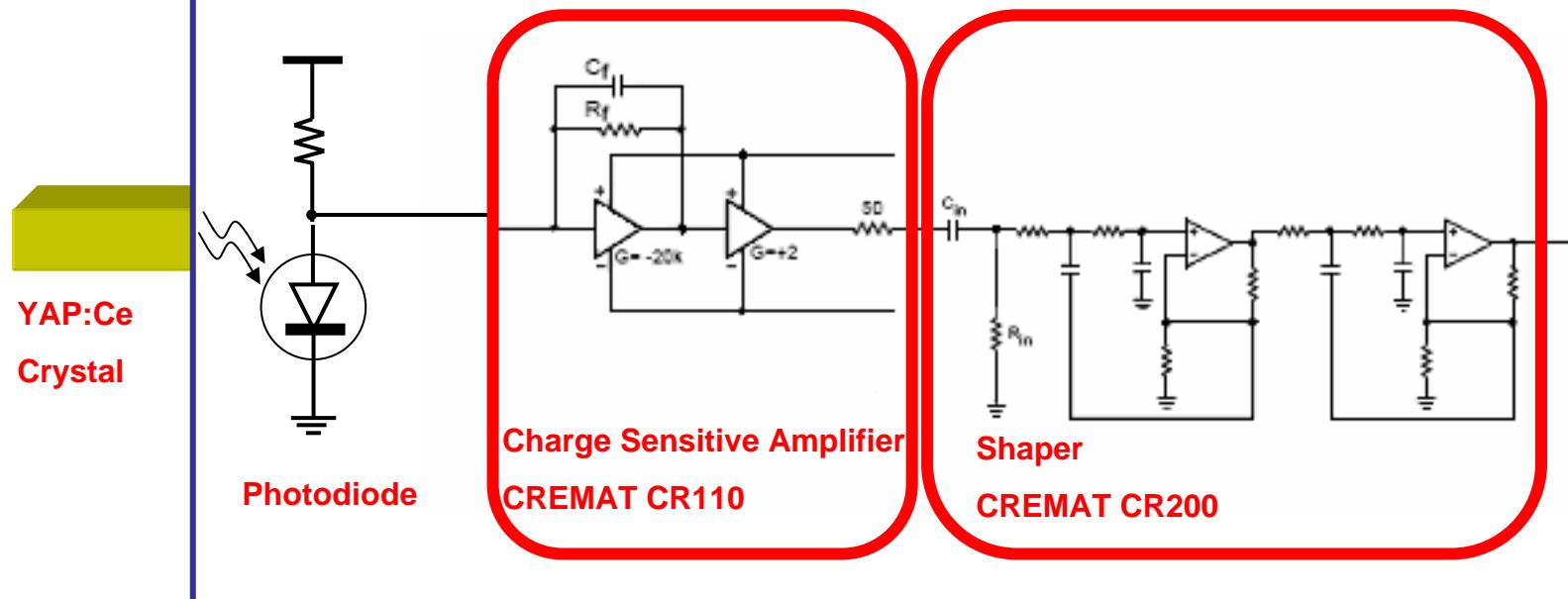


YAG:Ce properties	
Physical properties	
Density [g/cm ³]	4.57
Hygroscopic	No
Chemical formula	$\text{Y}_3\text{Al}_5\text{O}_{12}$
Luminescence properties	
Wavelength of max. emission [nm]	550
Decay constant [ns]	70
Photon yield at 300k [10 ³ Ph/MeV]	40-50

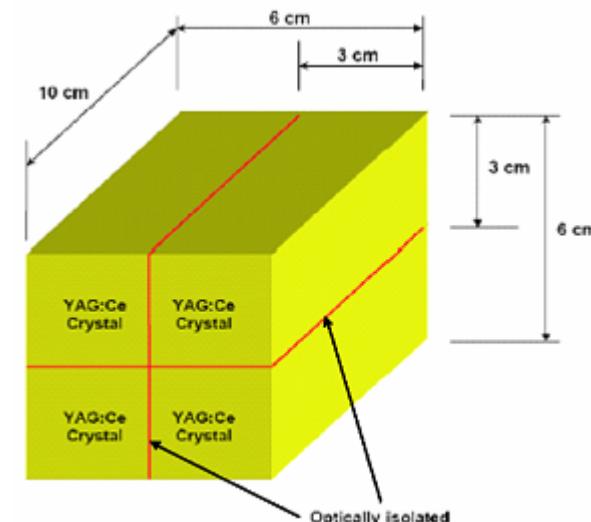
The relationship between the input energy beam and the resolution



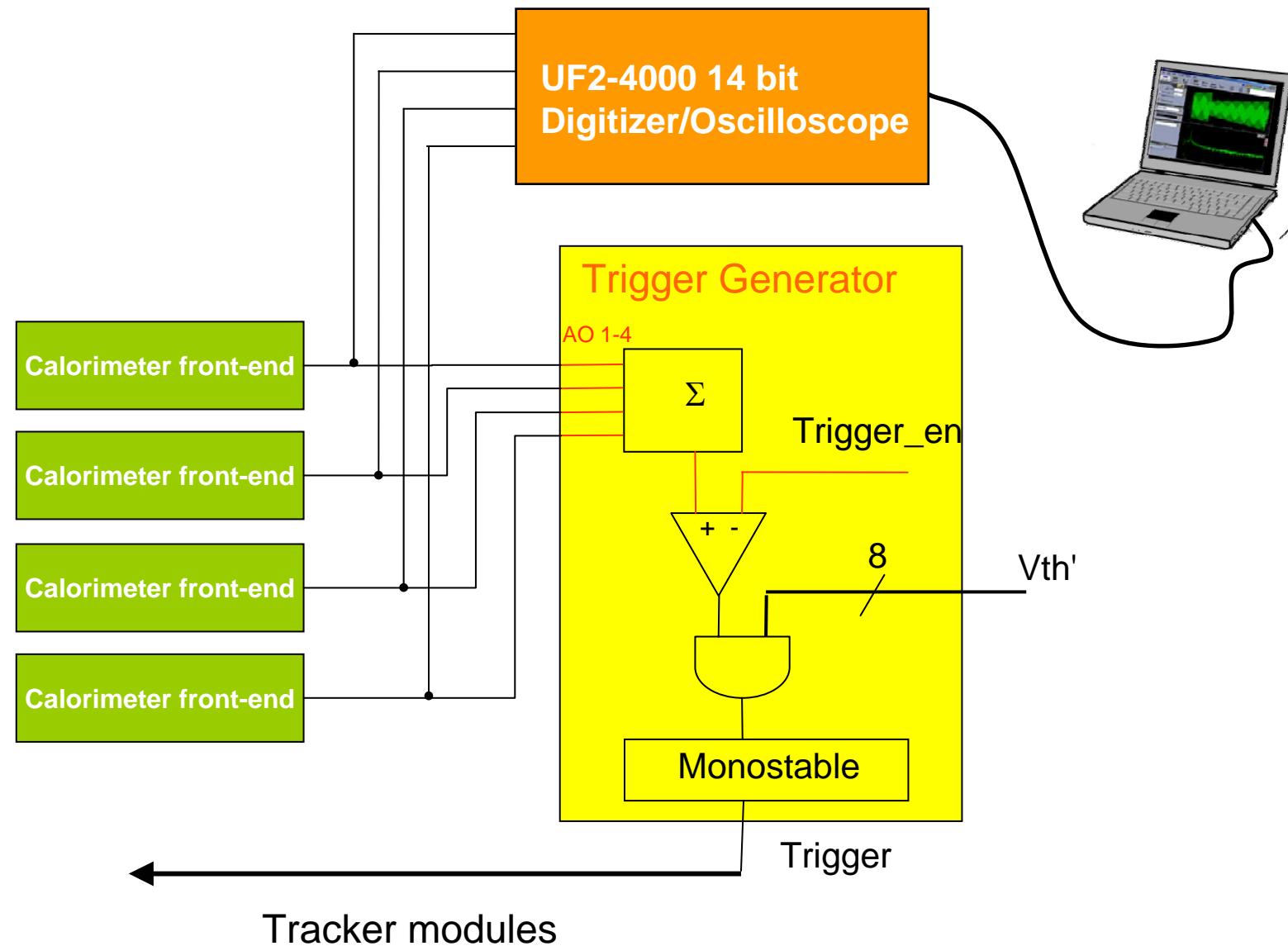
Calorimeter front-end



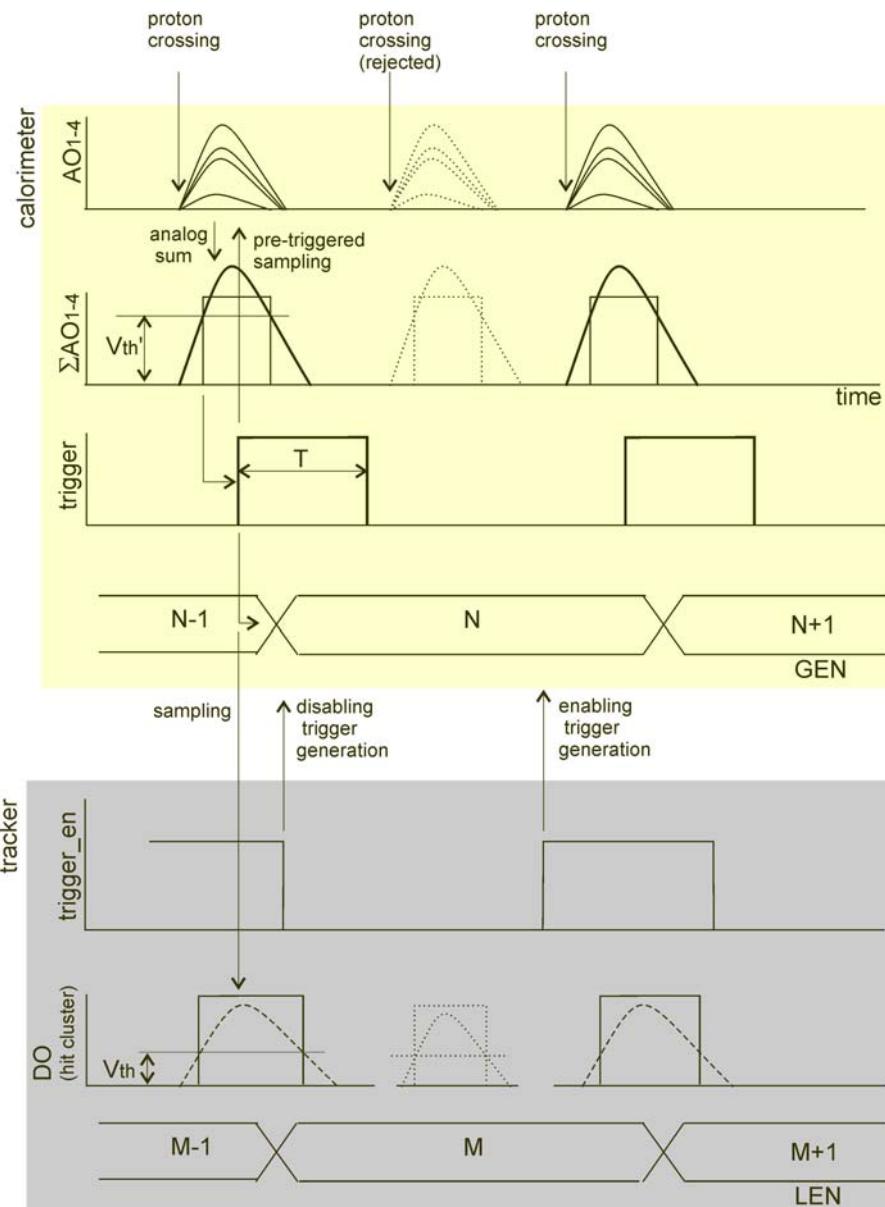
Final calorimeter layout
to be realized in 2007



CALORIMETER READOUT DESIGN

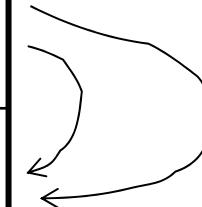


TIMING



TELESCOPE DEVELOPMENT PROGRESS

Tracker (1st module)	Detector	Design Production Test (IV, CV)	
	ASIC	Design Production Test	Delivery: Sept. 2007. Test & debug: Sept. 2007.
	Front end board	Design Production Bonding Test & debug	Delivery: Sept. 2007 Bonding: Oct. 2007 Test & debug: Nov. 2007
	Digital board	Design Production Test & debug	Delivery: Oct. 2007 Test & debug: Nov. 2007
Calorimeter	Crystals	Purchased	
	Readout electronics	Purchased	
	Digital board	Design Production Test & debug	Commissioning: Sept. 2007 Production: Oct. 2007 Test & debug: Nov. 2007
	DAC board	Purchased	
Software	FPGA	Development	Preliminary versions available during Nov. 2007.
	DAC board	Development	
	Communication	Development	



Assembling of 1st
tracker module:
dec. 2007

Test with
calorimeter:
during 2008.

Assembling of the
full telescope:
dec. 2008

CONCLUSIONS

The construction of a pCT system has been approached

A telescope has been designed:

- a. SSD Si tracker;
- b. YAG:Ce segmented calorimeter.

Electronics characteristics:

- a. 1 MHz event rate.
- b. 32 ch readout ASICs designed within the collaboration;
- c. control and data acquisition by FPGA circuits;
- d. trigger generation from calorimeter data;
- e. pre-triggered calorimeter waveforms acquisition (precise energy loss meas.)
- f. possible energy loss in silicon measured by TOT.

Milestones

- a. Dec. 2007: assembling of first tracker module.
- b. Dec. 2008: assembling and test of the full telescope.
- c. Dec. 2008: design of the pCT system.