CURRENT STATUS ON THE 1ST PROTON CT SCANNER FOR PROTON THERAPY

Victor Rykalin   NIU

for pCT collaboration

CSUSB-NIU–SCIPP UCSC–LLUMC–UOW(A)-UH(I)

Overview

- Premises
- Current status of the pCT detector
- Upgrade issues
- Final

- After my talk you will get an impression of pCT system complexity and level of readiness !

2020 year. W. Chicago. Doctor's appointments.

When wish comes true

History of medical treatment with protons
&
History of pCT

- ►Midwest Proton Radiotherapy Institute at IUCF
- ►Loma Linda University Medical Center southern California
- ►M.D. Anderson Cancer Center's Proton Therapy Facility Houston
- ►Francis H. Burr Proton Therapy Center Boston
- ►The University of Florida Proton Therapy Institute Florida

&

► 2008 – present pCT project

History of treatment with protons

1946 R. Wilson suggested use of protons

1956 Treatment of pituitary tumors in Berkley, USA

1967 First large-field proton treatment in Sweden

1974 Large-field proton treatments program begins at HCL, Cambridge, MA

1990 First hospital-based proton treatment center opens at LLUMC, CA

► R. Wilson : Protons can be used clinically, Accelerators are available, Maximum radiation dose can be placed into the tumor, Proton therapy provides sparing of normal tissues, Modulator wheels can spread the narrow Bragg peak

History of pCT

► In his paper (J. Appl. Phys. 34, 1963 – Allan Cormack mentions pCT)

► 1968 – First proton radiography experiments at HCL, LBL (Koehler, Cormack, Lyman, Goitein

► 1979 – Cormack shares CT Nobel price with Hounsfield

► 1979 – 1981 First pCT experiments at Los Alamos NL (K. Hanson)

► 1990s – Talks on pCT at PTCOG meetings (R. Martin)

► 1994 – Proton radiography at PSI (Schneider, Pedroni)

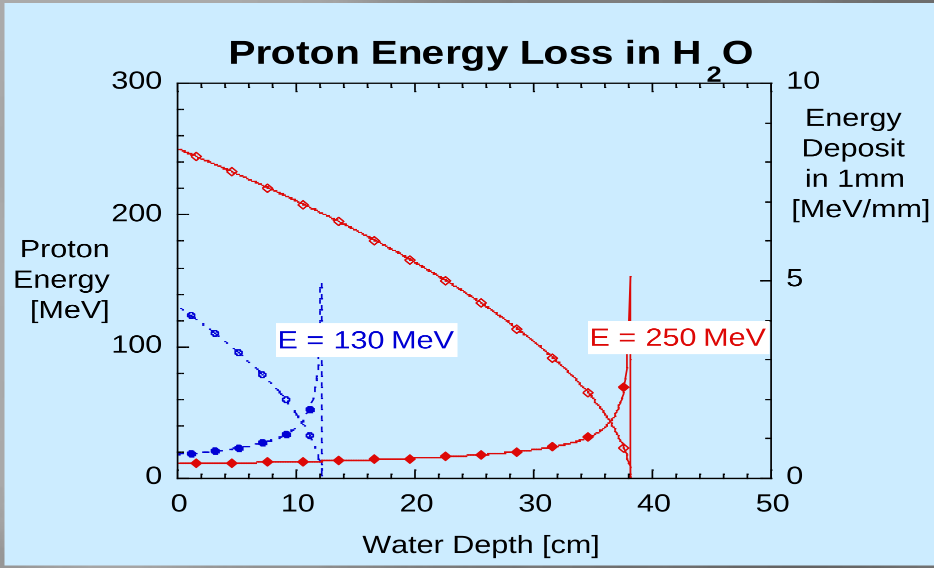
► 1999 – 2000 pCT with mod-wheel/CCD (Zygmanski, Gall)

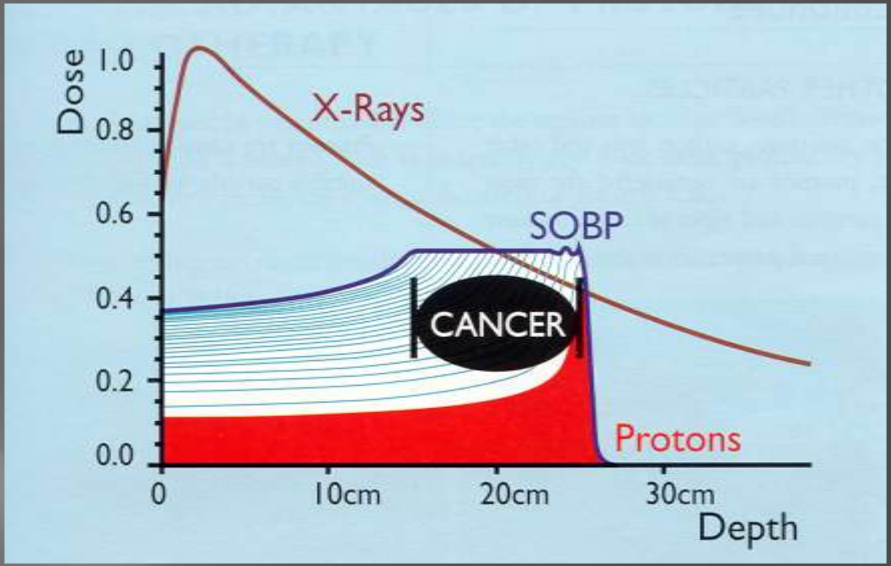
► 2003 – Formation of the pCT collaboration (SCIPP, BNL, SUNYSB, LLUMC)

► 2004 – MLP concept (D.C. Williams)

► 2008 – present, NIU-SCIPP-LLUMC pCT prototype scanner project

Still premises or why protons are so good





- **Relatively low entrance dose (plateau)**
- **Maximum at depth (Bragg peak)**
- **Rapid distal dose fall-off**
- **Energy modulation (Spread Bragg peak)**
- **RBE close to unity**

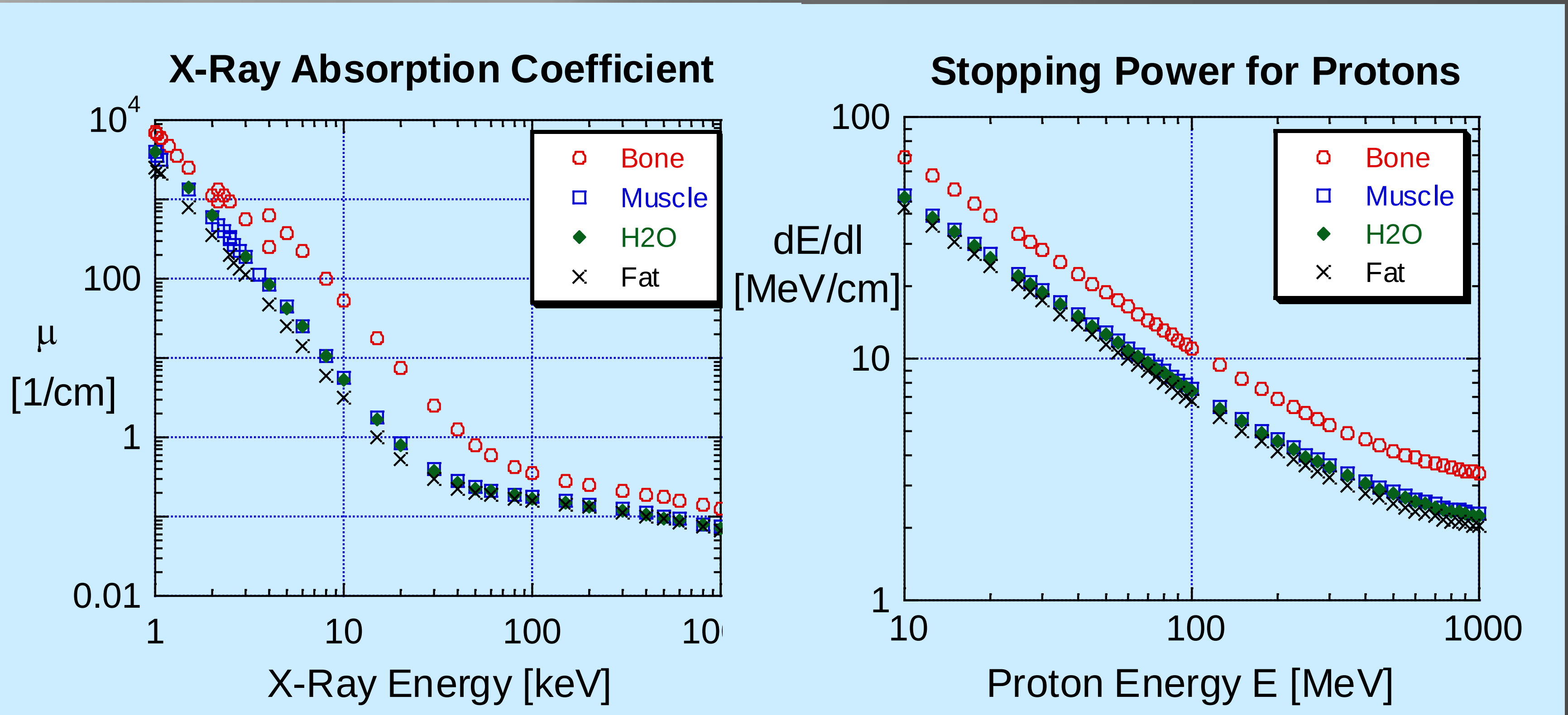
X-rays vs. Protons

Attenuation of Photons, Z

$N(x) = N_o e^{-\mu x}$

Energy Loss of Protons, ρ

$$\Delta E = \int \frac{dE}{dx} dx \approx \sum \rho \frac{dE}{dx} \Delta l$$



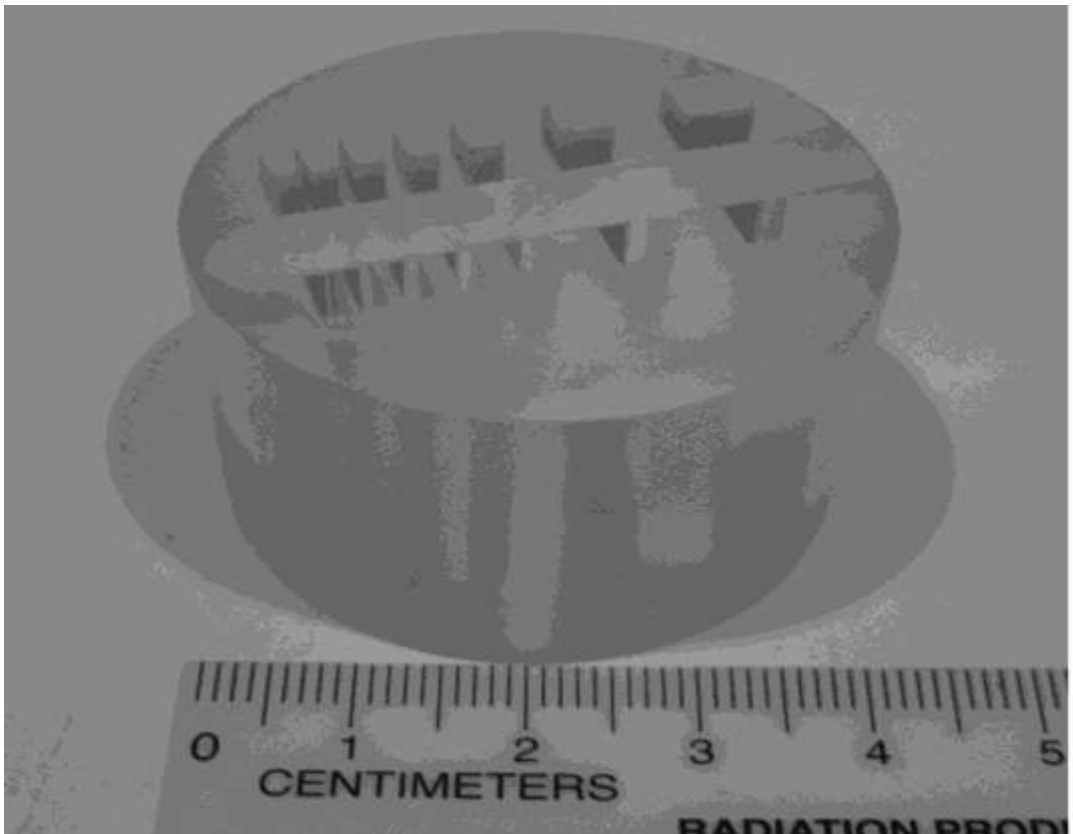
Measure Statistical Removal of X-rays

Measure Energy Loss on Individual Protons

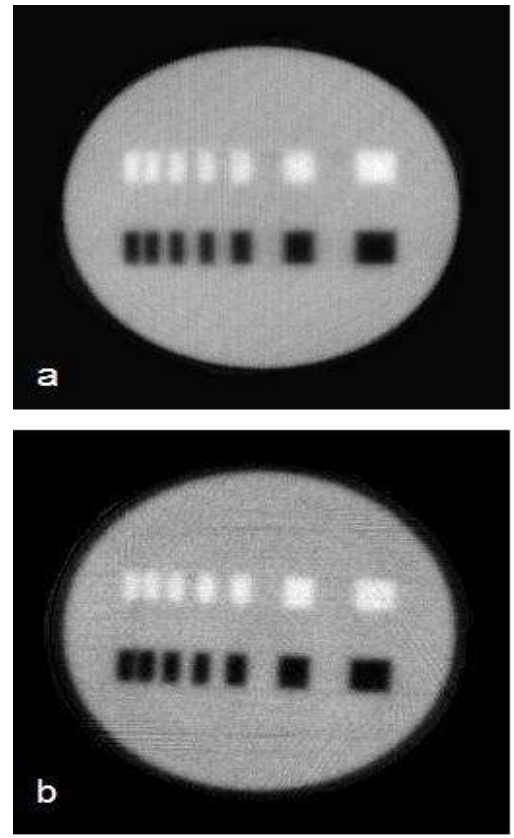
NIST Data

pCT collaboration 2003 - 2010

Development of Proton Computed Tomography for Applications in Proton Therapy
AIP Conf. Proc. -- March 10, 2009 -- Volume 1099, pp. 460-463
APPLICATION OF ACCELERATORS IN RESEARCH AND INDUSTRY: Twentieth International Conference; doi:10.1063/1.3120073

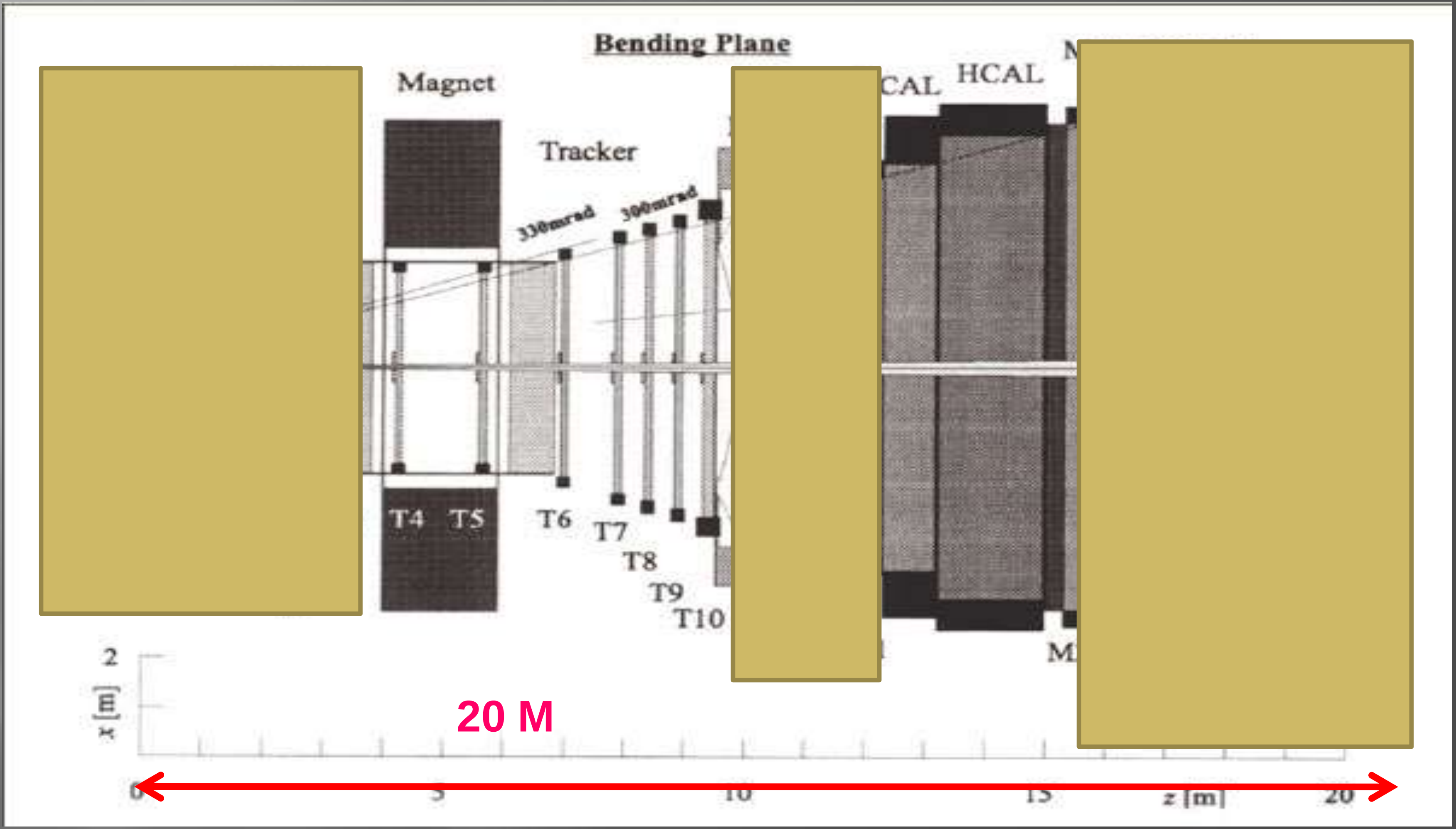


SIMULATED



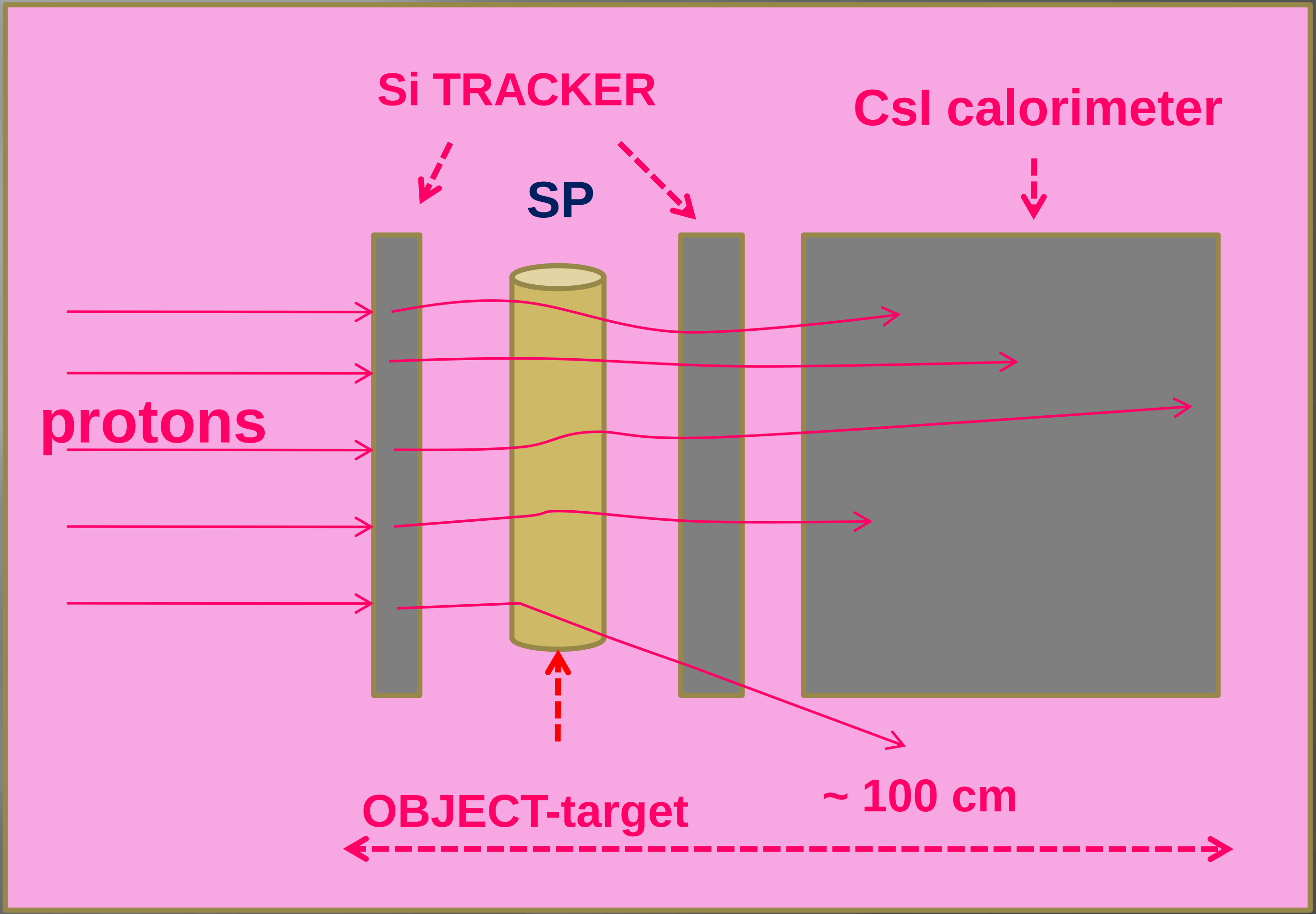
MEASURED

pCT is image reconstruction + fixed target experiment – particle identification !



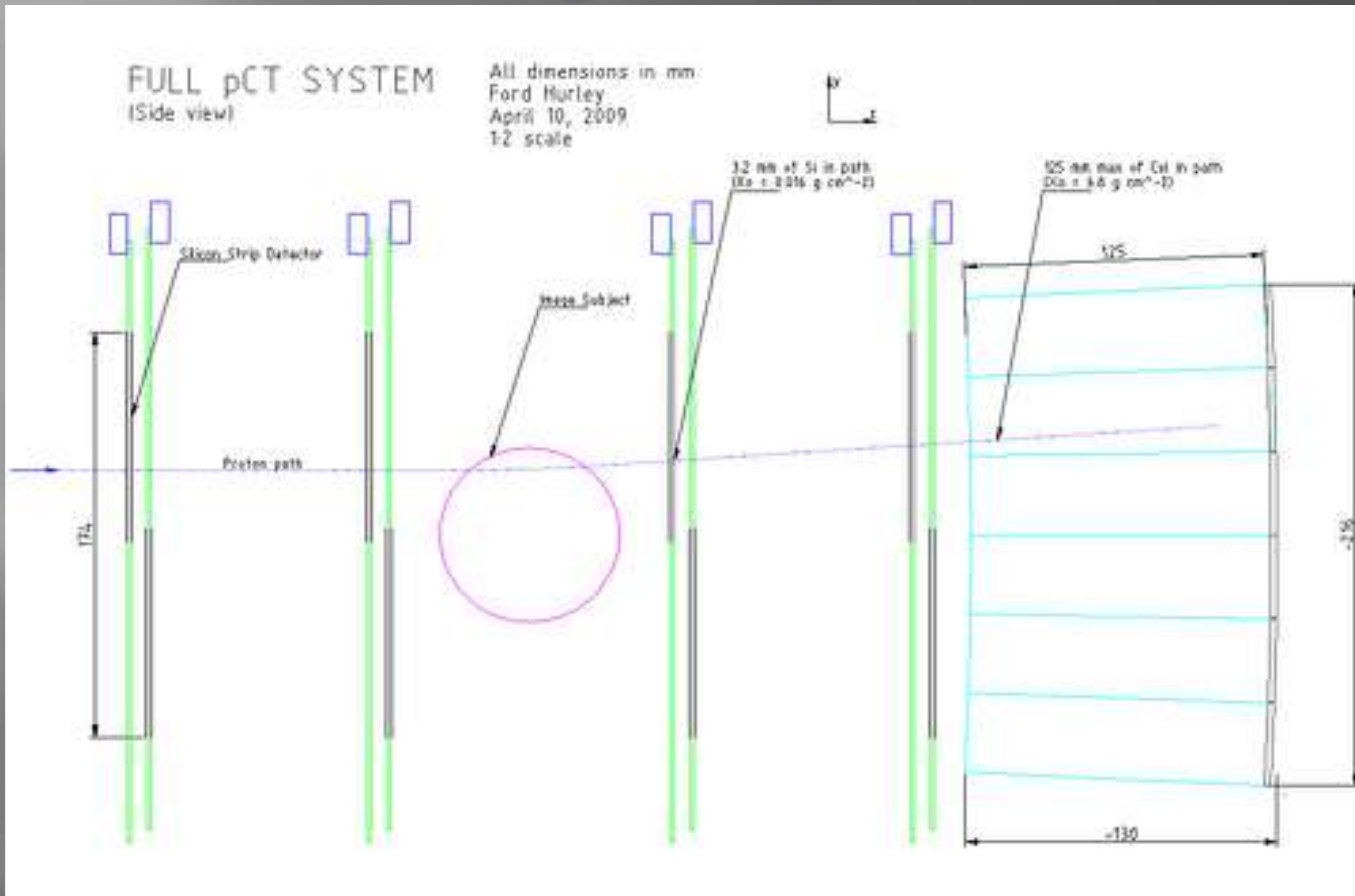
pCT detector core

Sensitive detector area is 9×18 cm^2

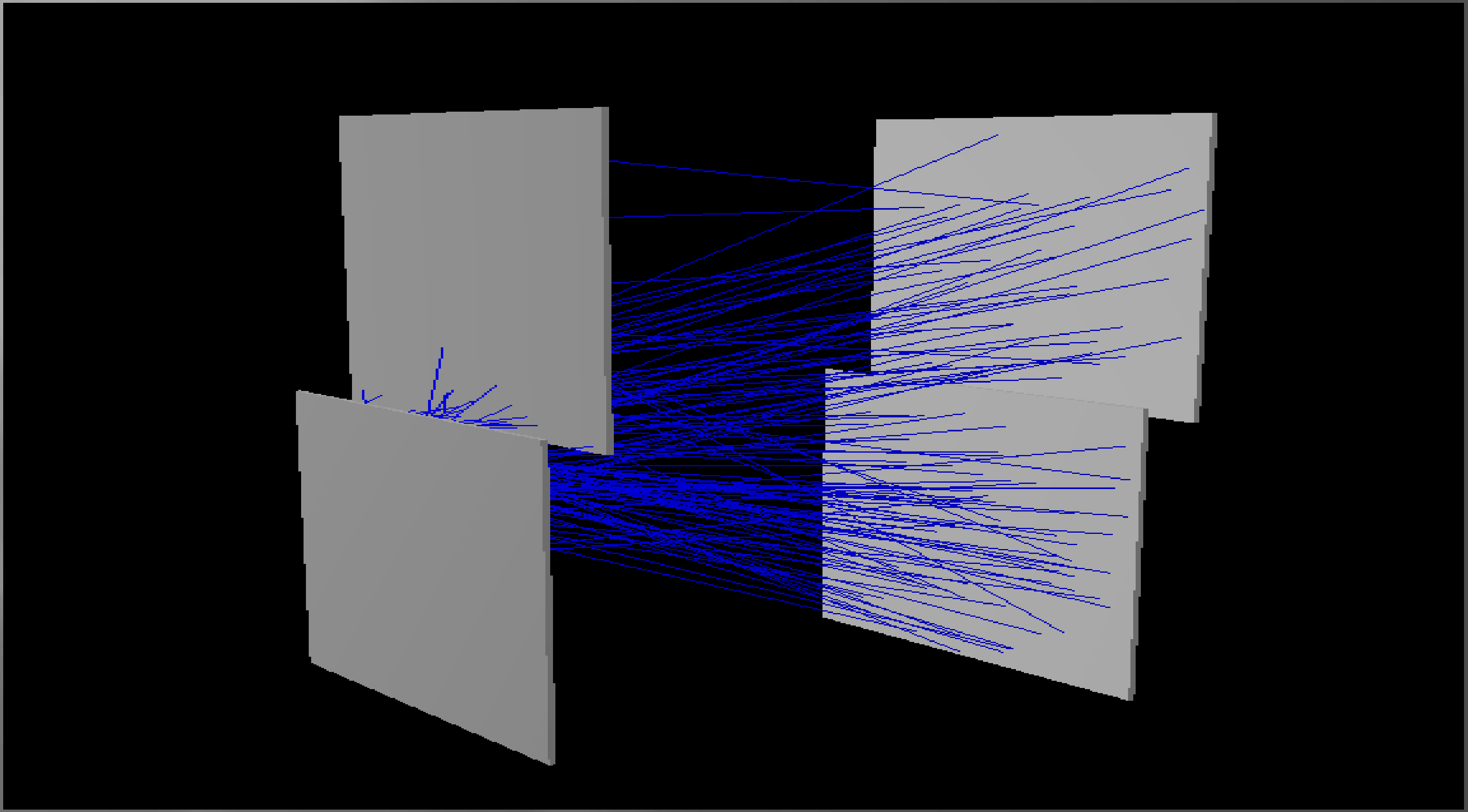


pCT includes : Si tracker, Calorimeter, DAQ

In drawings (April 2009)



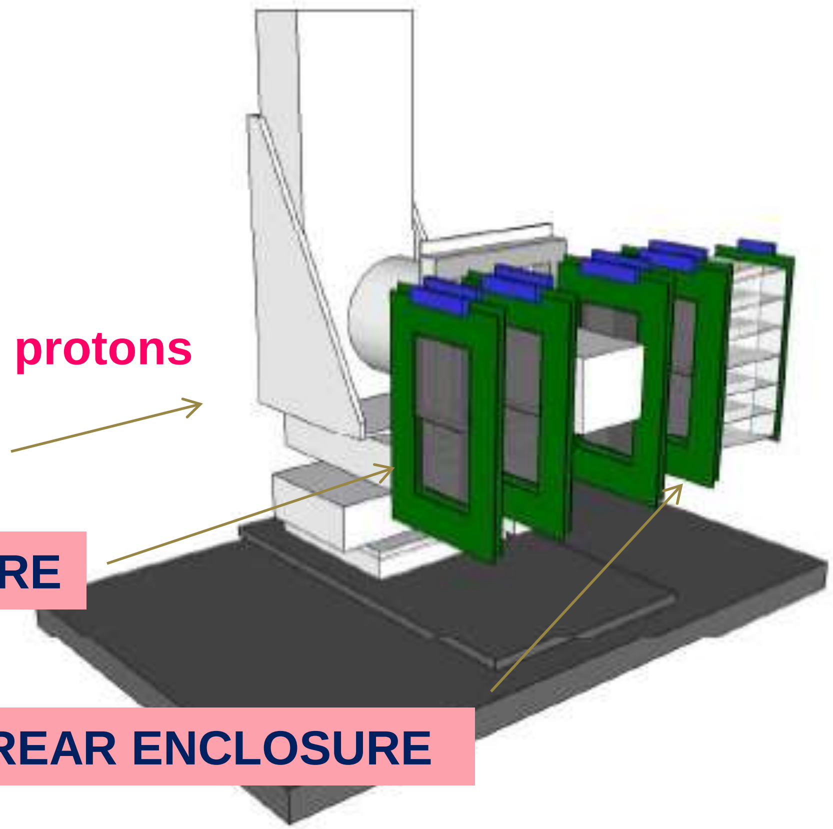
3D each proton is tracked down



Courtesy of Ford Hurley LLUMC

3D pCT vew

- Horizontal beamline setup
- Rotational stage for object rotation
- Upstream and downstream tracker modules
- Downstream energy detector (calorimeter)




04/01/2010

pCT TREE

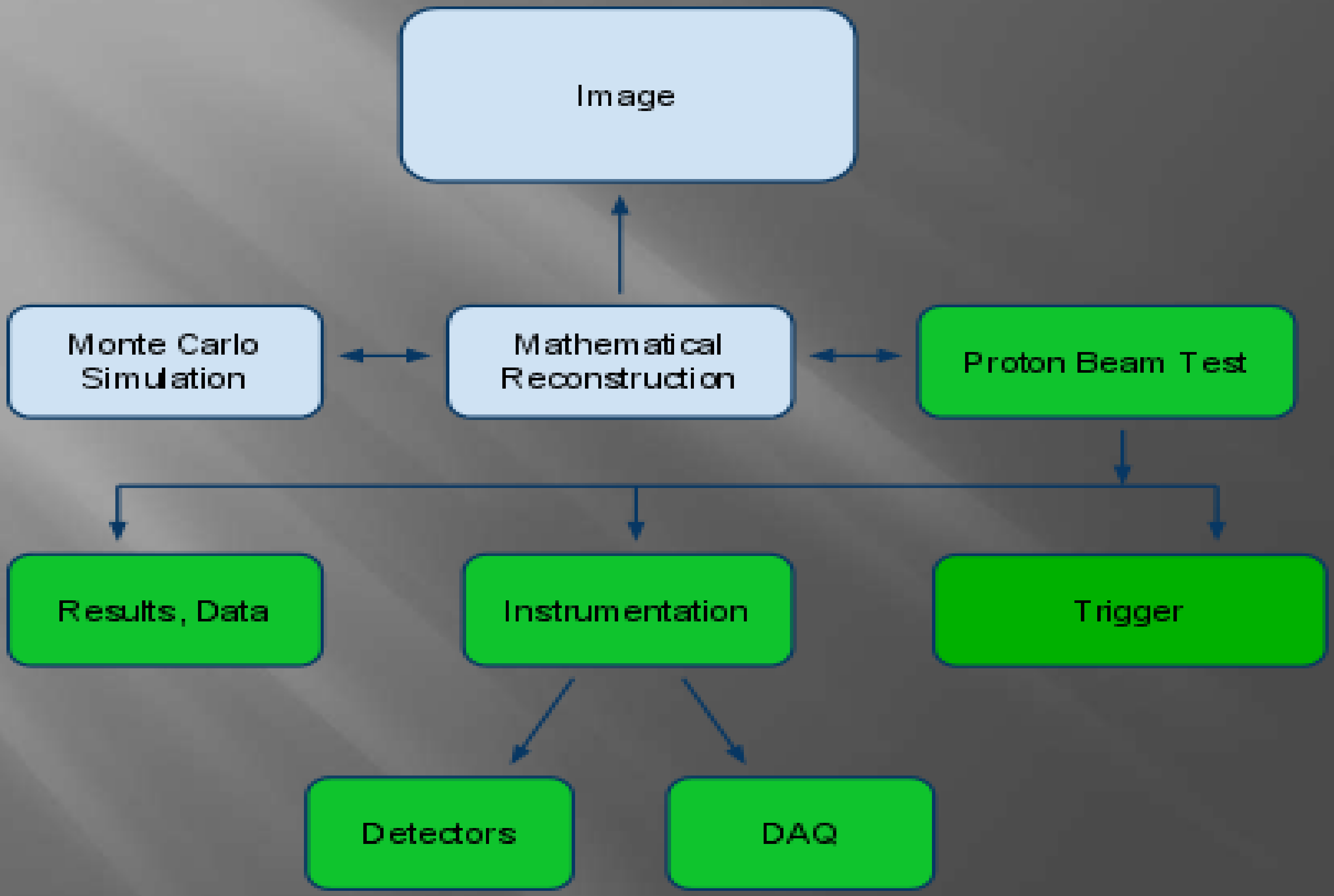
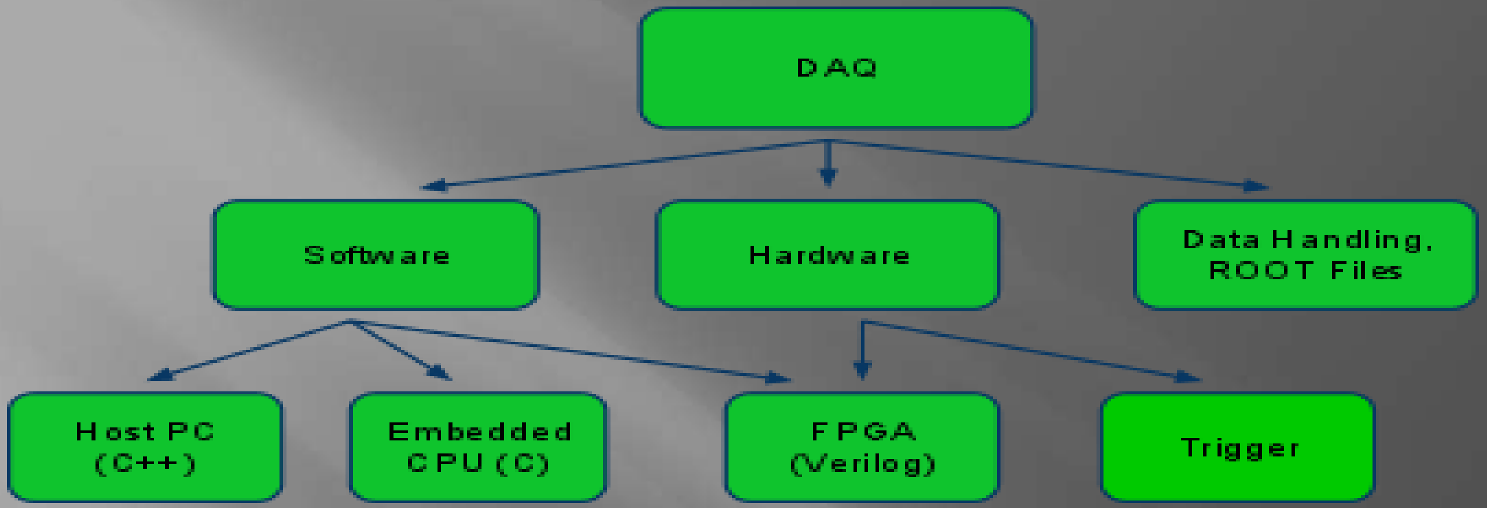
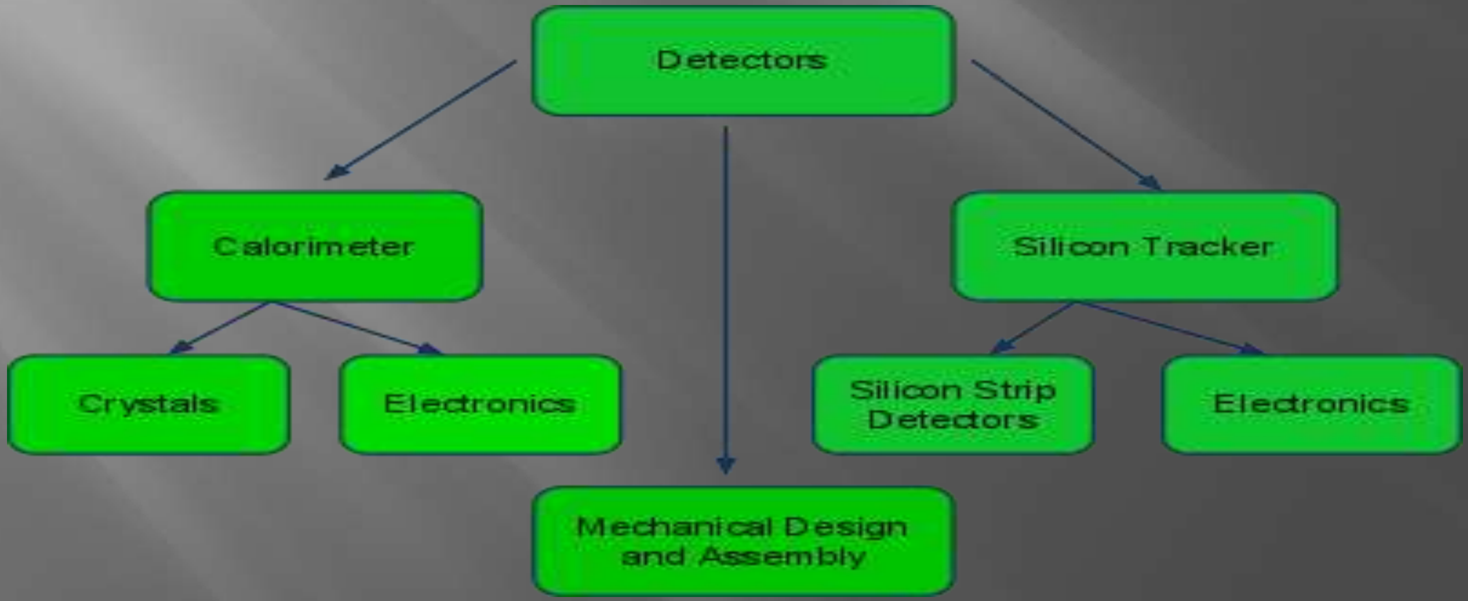
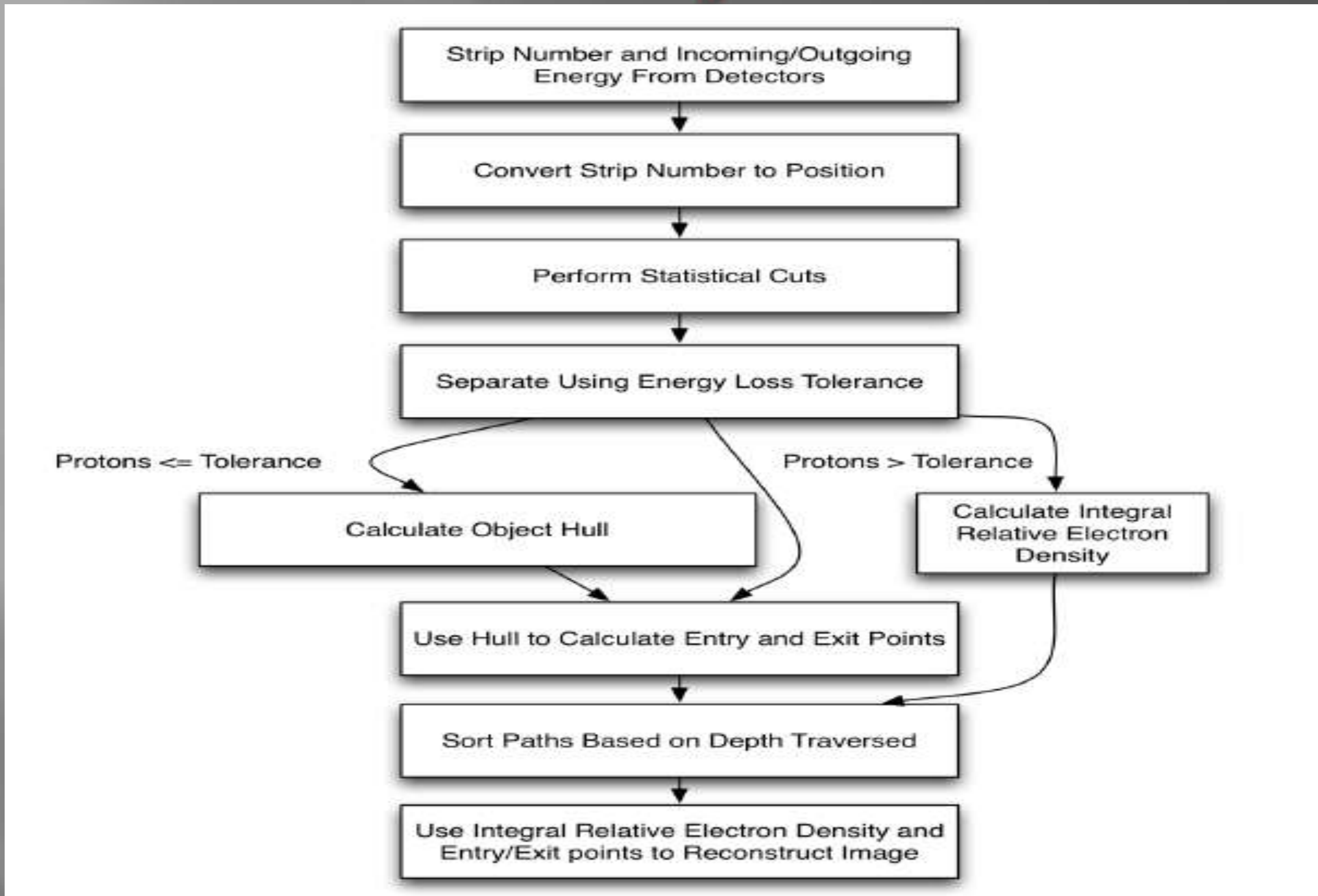


Image
Monte Carlo Simulation
Mathematical Reconstruction
Proton Beam Test
Results, Data
Instrumentation
Trigger
Detectors
DAQ


DAQ
Software
Hardware
Data Handling, ROOT Files
Host PC (C++)
Embedded CPU (C)
FPGA (Verilog)
Trigger


Detectors
Calorimeter
Silicon Tracker
Crystals
Electronics
Silicon Strip Detectors
Electronics
Mechanical Design and Assembly

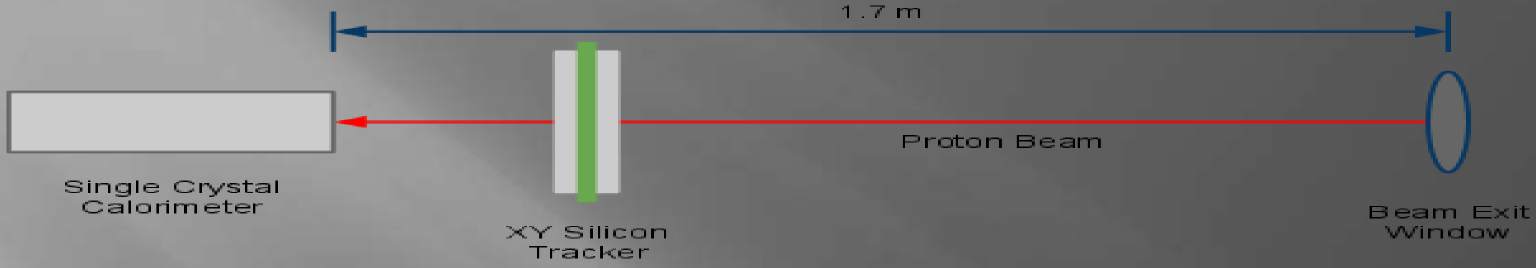
Reconstruction algorithm.



Keith Schubert, pCT meeting, October 2009

DAQ

Beam test geometry and setup arrangement



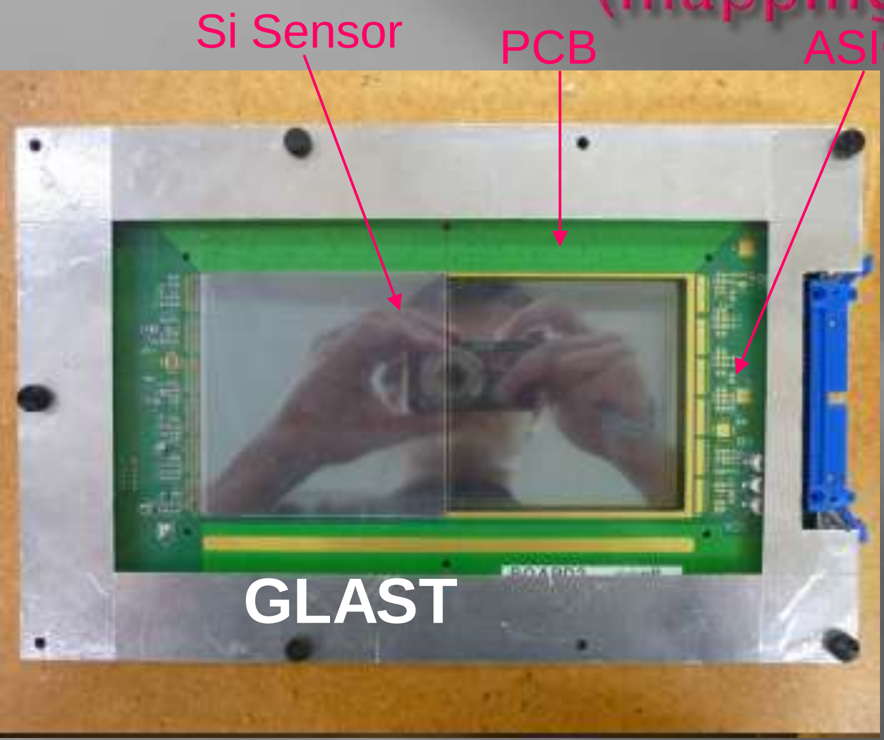
Cycle 2 s

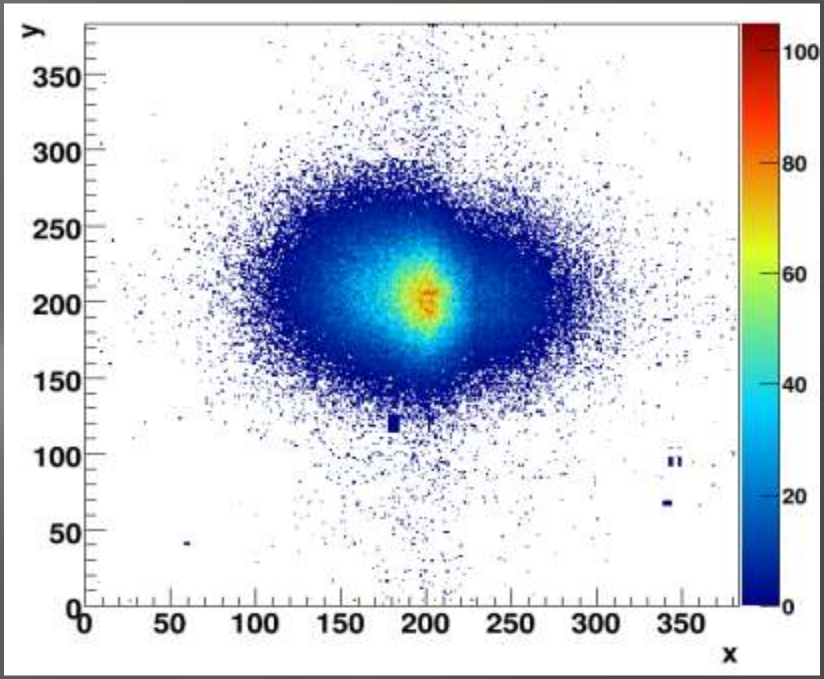
Spill 0.5 s

FPGA

Custom made ADC board

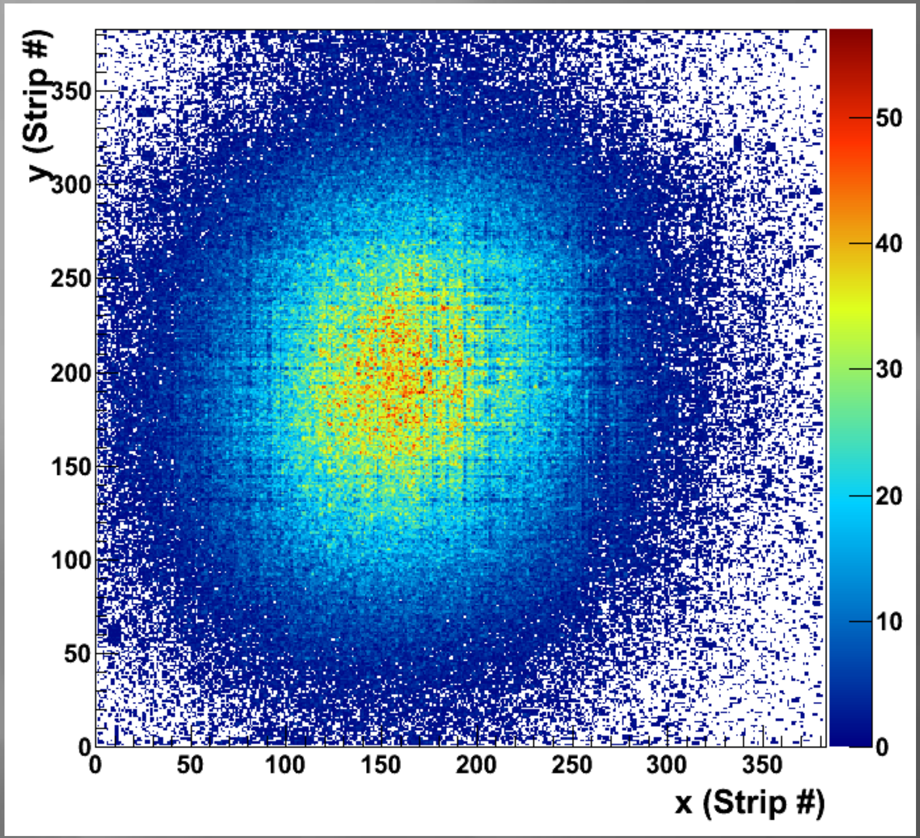
Detectors : Si Strip detector as part of Si tracker (mapping the proton)

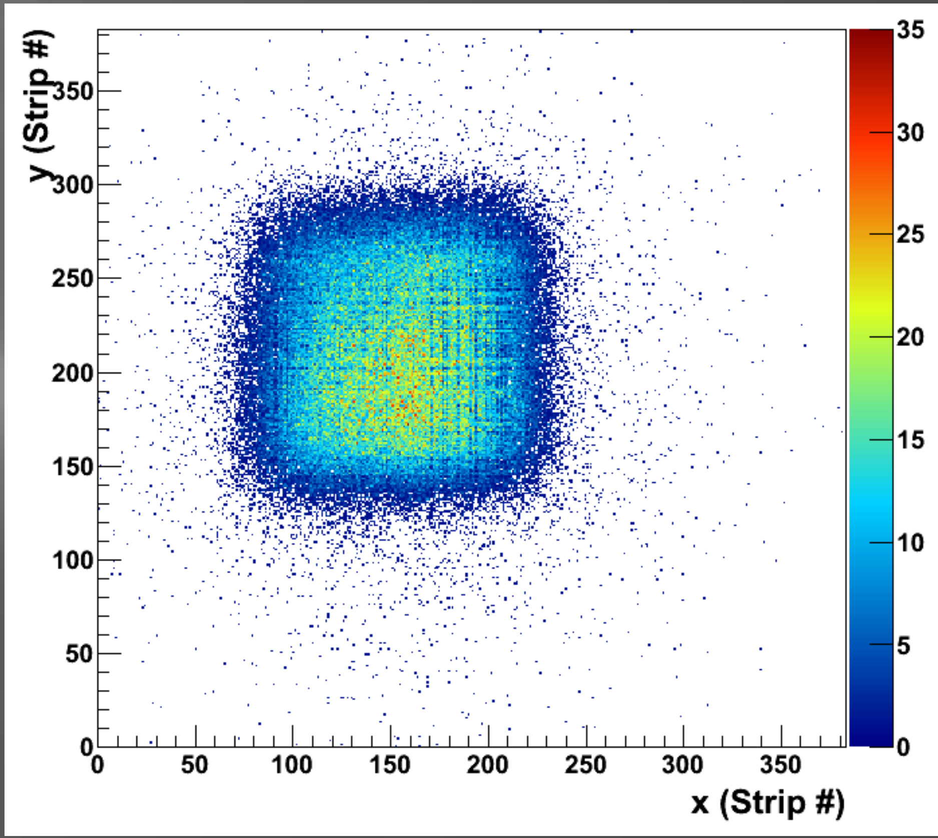




- The silicon detector - two layers of silicon strip detectors.
- The sensors are 89.5 x 89.5 mm^2 with strip pitch of 238 um and 400 um thickness.
- The strips of each layer are individually connected to 6 ASICs*64 strips.

Si tracker imaging





. XY scatter plot of all hits recorded by the tracker during a beam test run at 35 MeV (left) and the plot of hits after cutting protons that did not register in the calorimeter (right).

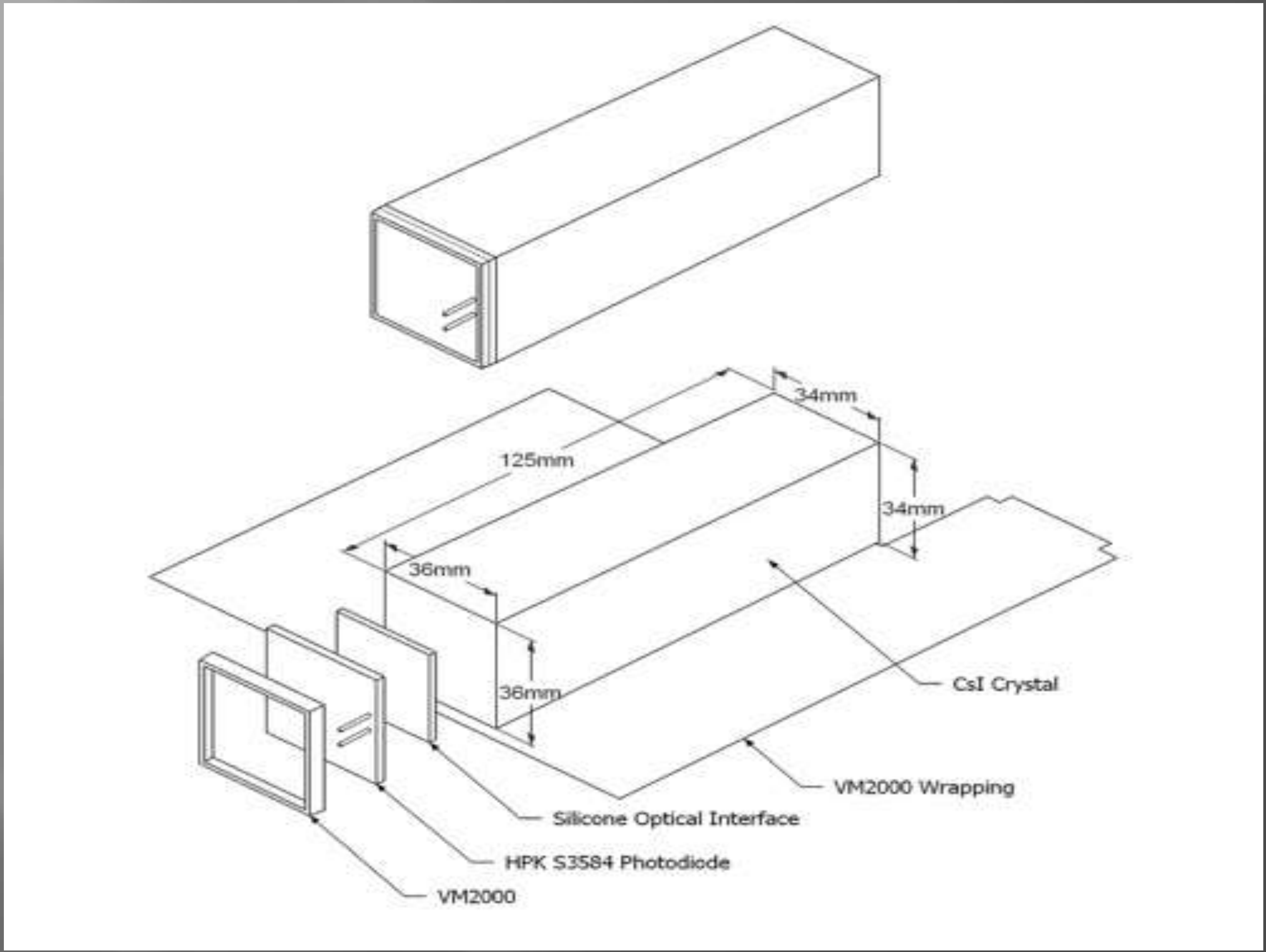
Detectors: CsI calorimeter

Table 1: Useful Characteristics of Some Crystals as Calorimeter Material.

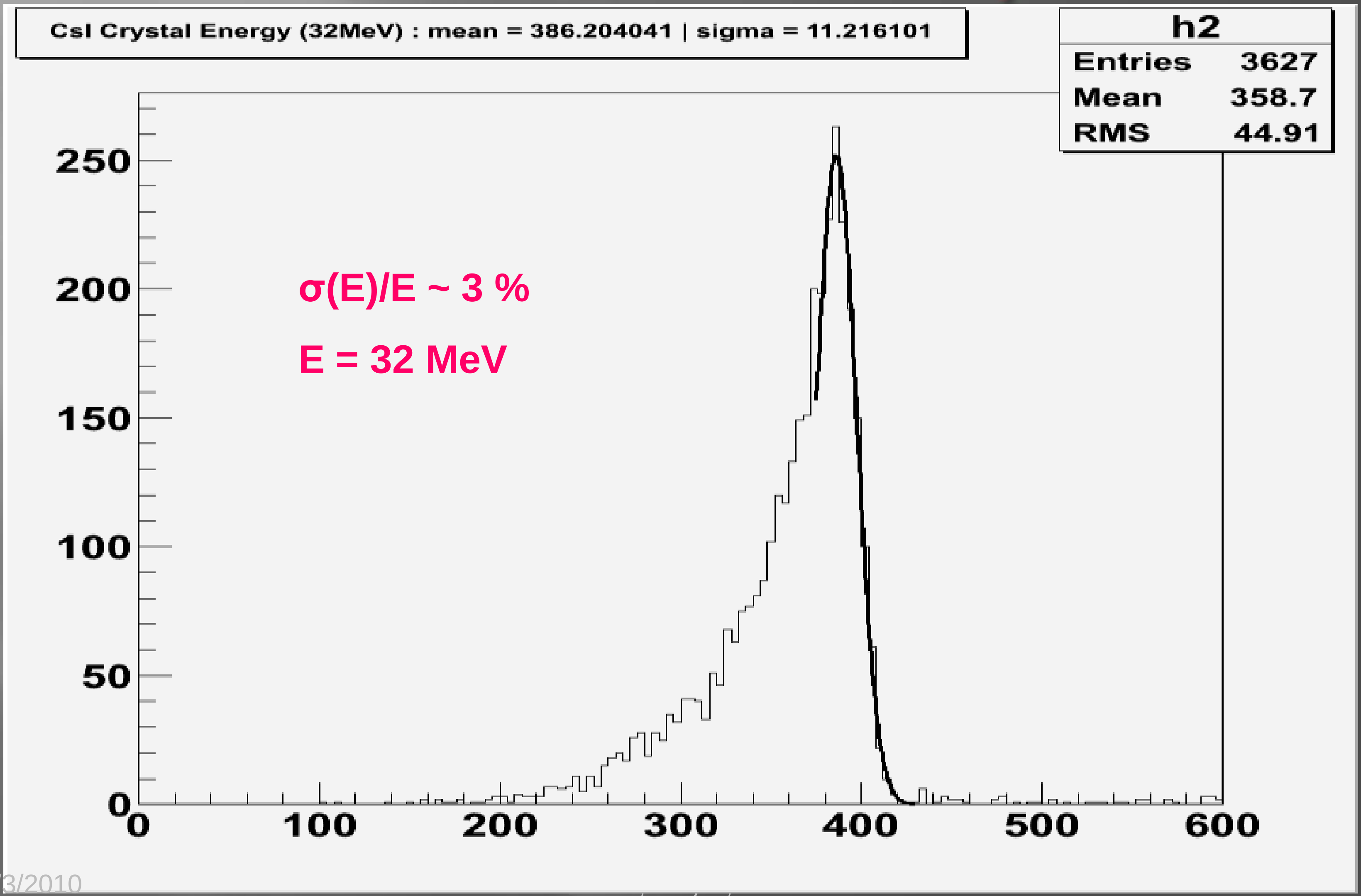
Properties	CsI(TI)	CsI	BGO	$PbWO_4$:Y	GSO:Ce	LSO:Ce
X_0(cm)	1.86	1.86	1.12	0.89	1.39	1.14
$R_{Moliere}$(cm)	3.8	3.8	2.3	2.2	2.4	2.3
Rad hard(Mrad)	0.01	0.01-0.1	0.1 - 1	100	100	100
Density(g/cm^3)	4.51	4.51	7.13	8.28	6.70	7.40
Cost($/cc)	3.2	4	4	2.5	see text	50
Refractive index	1.79	1.95	2.15	2.20	1.85	1.82
Decay time(ns) (slow component)	680 3340	16	300	5 15	56 600	47

Limits the rate capability, we need ~ 2 MHz

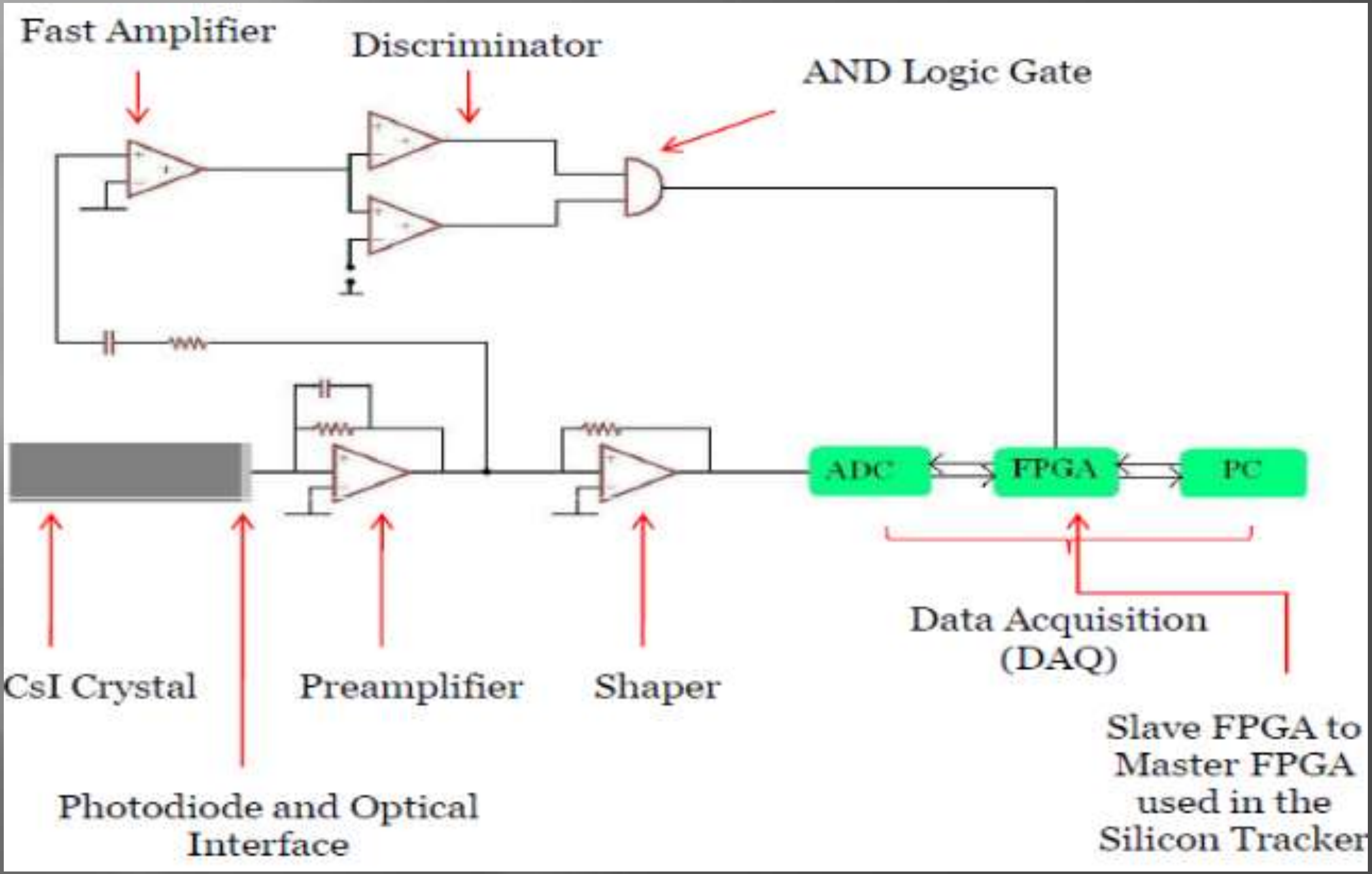
1 KGy


34mm
125mm
34mm
36mm
36mm
CsI Crystal
VM2000 Wrapping
Silicone Optical Interface
HPK S3584 Photodiode
VM2000

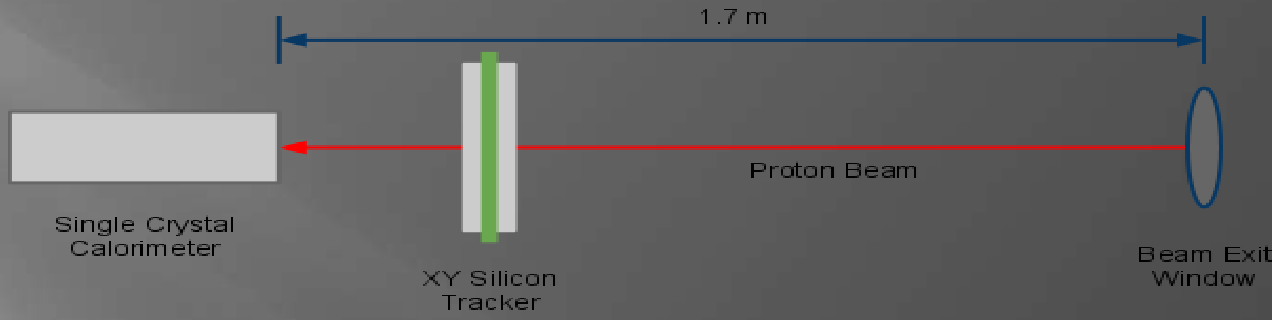
Detectors: CsI calorimeter, measuring residual energy in order to reconstruct SP for each proton

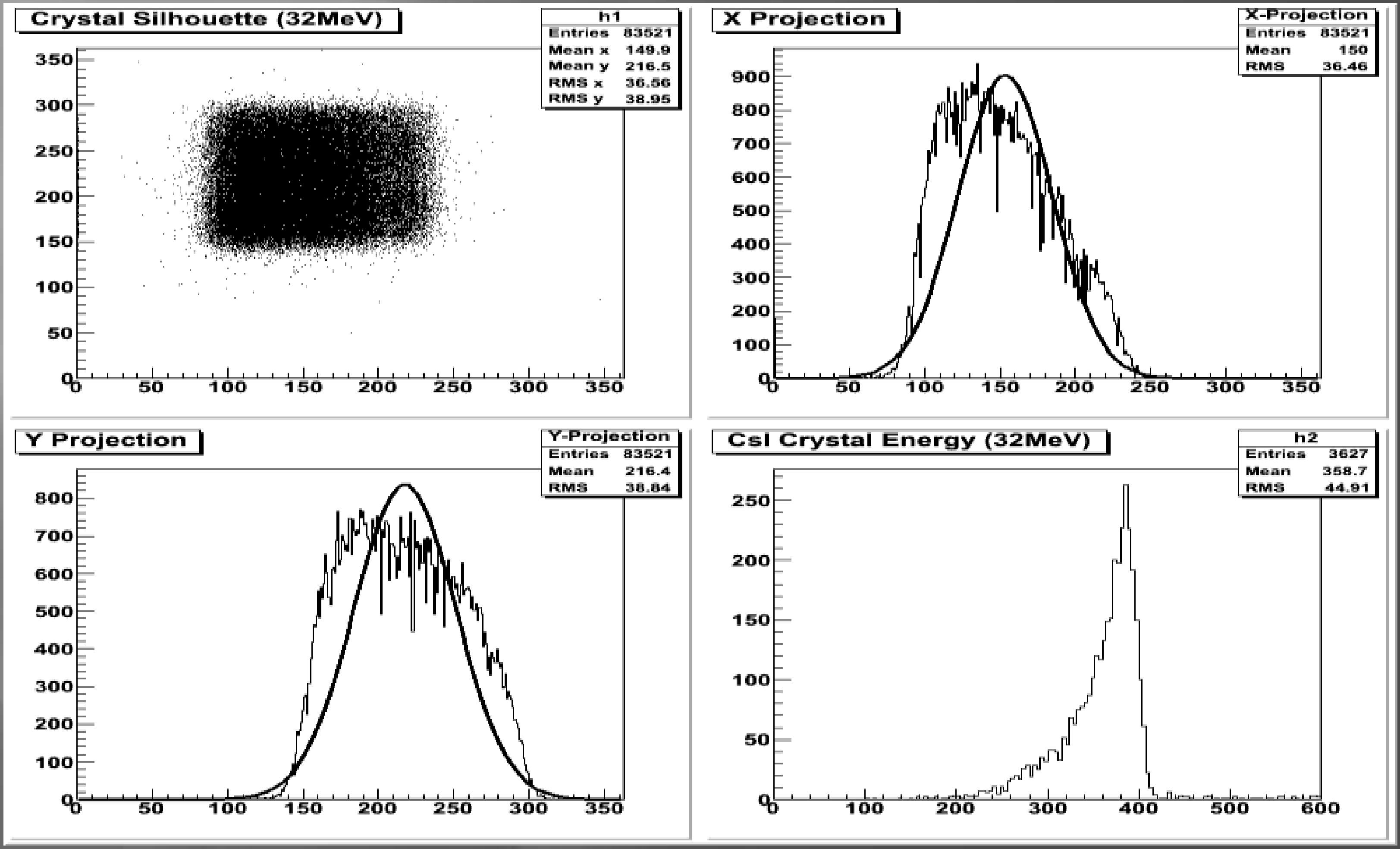


Read out diagram of the CsI calorimeter element

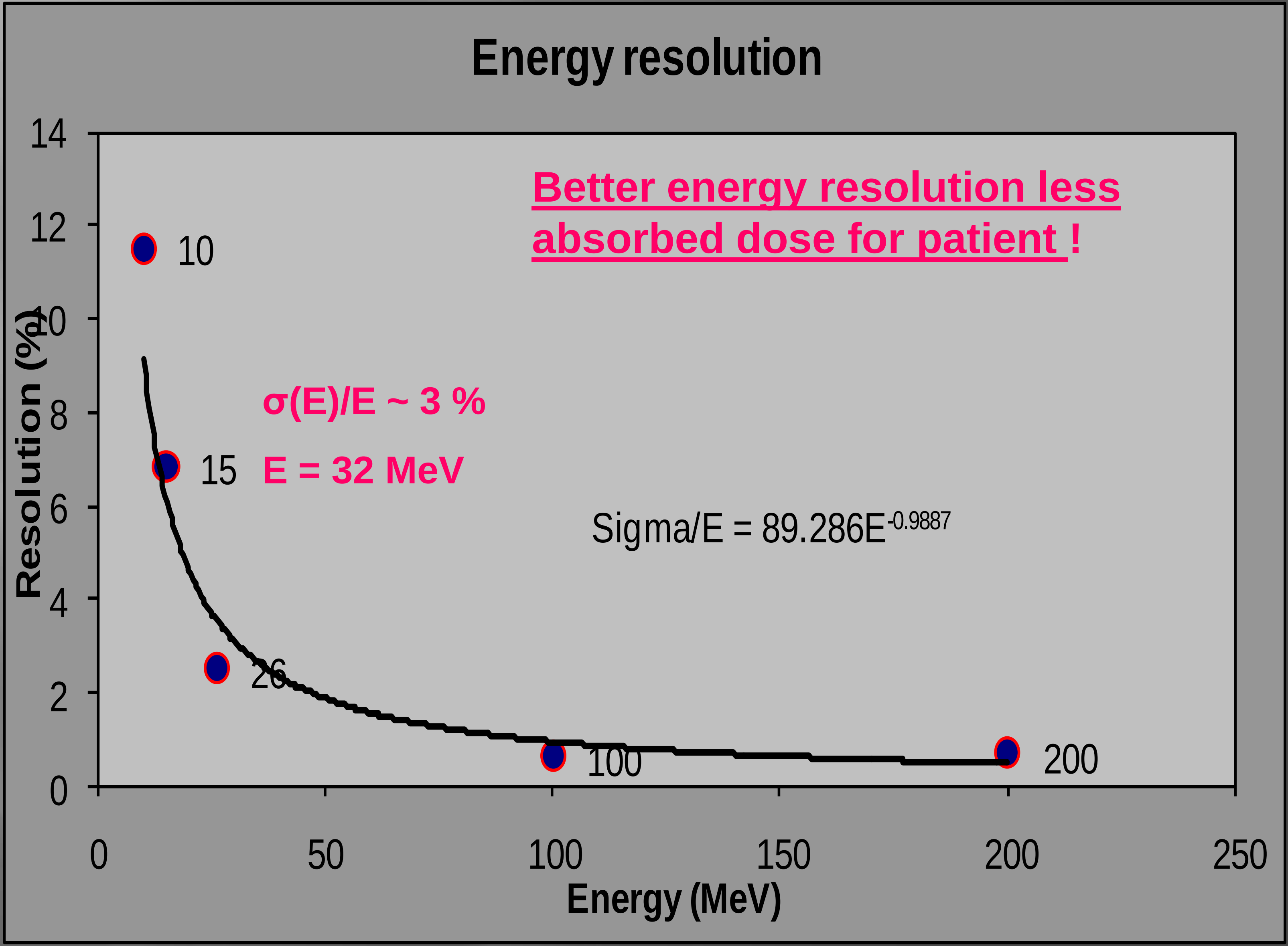


Beam test results





Energy resolution of CsI crystal

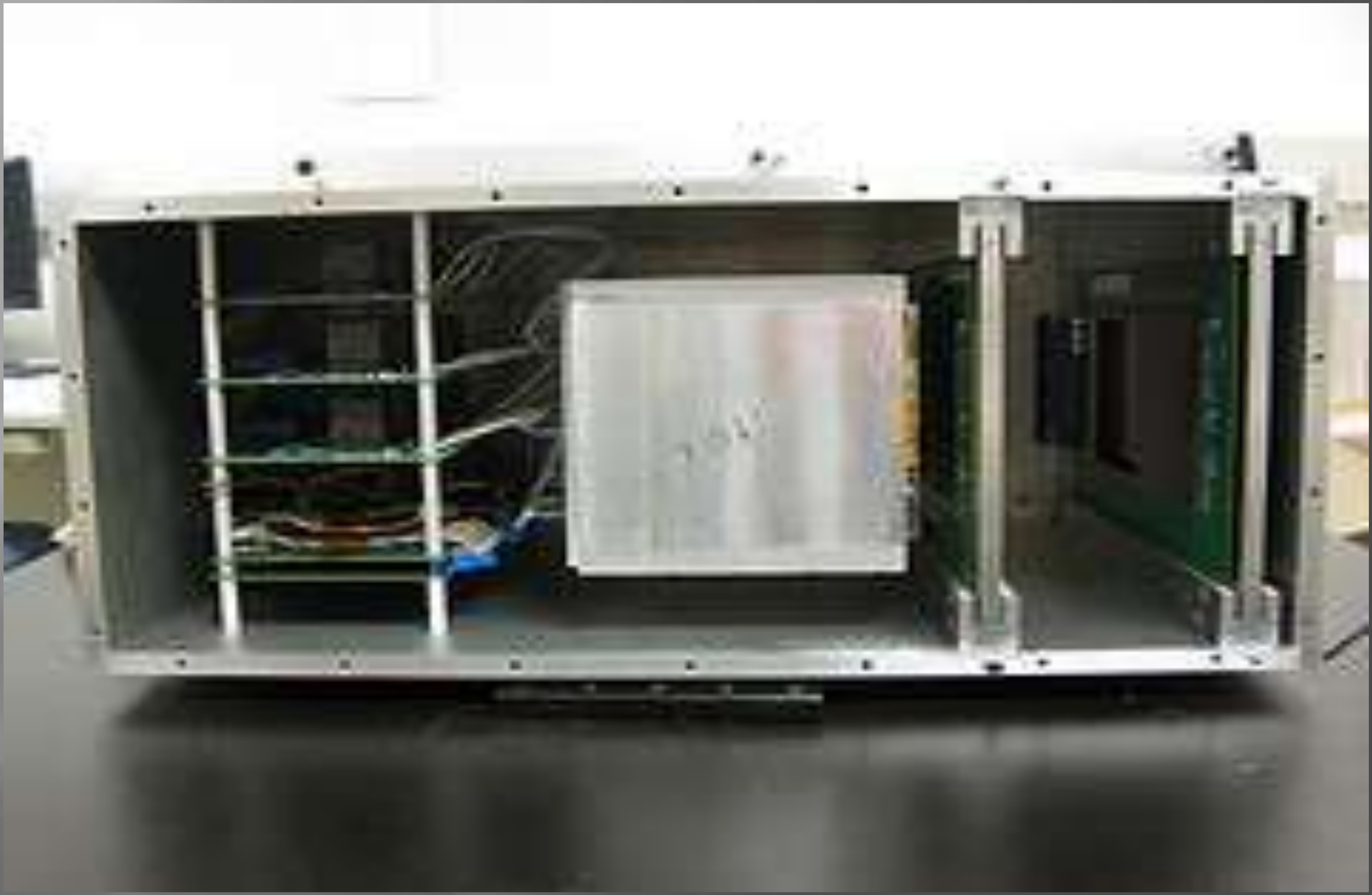


Bringing all parts together

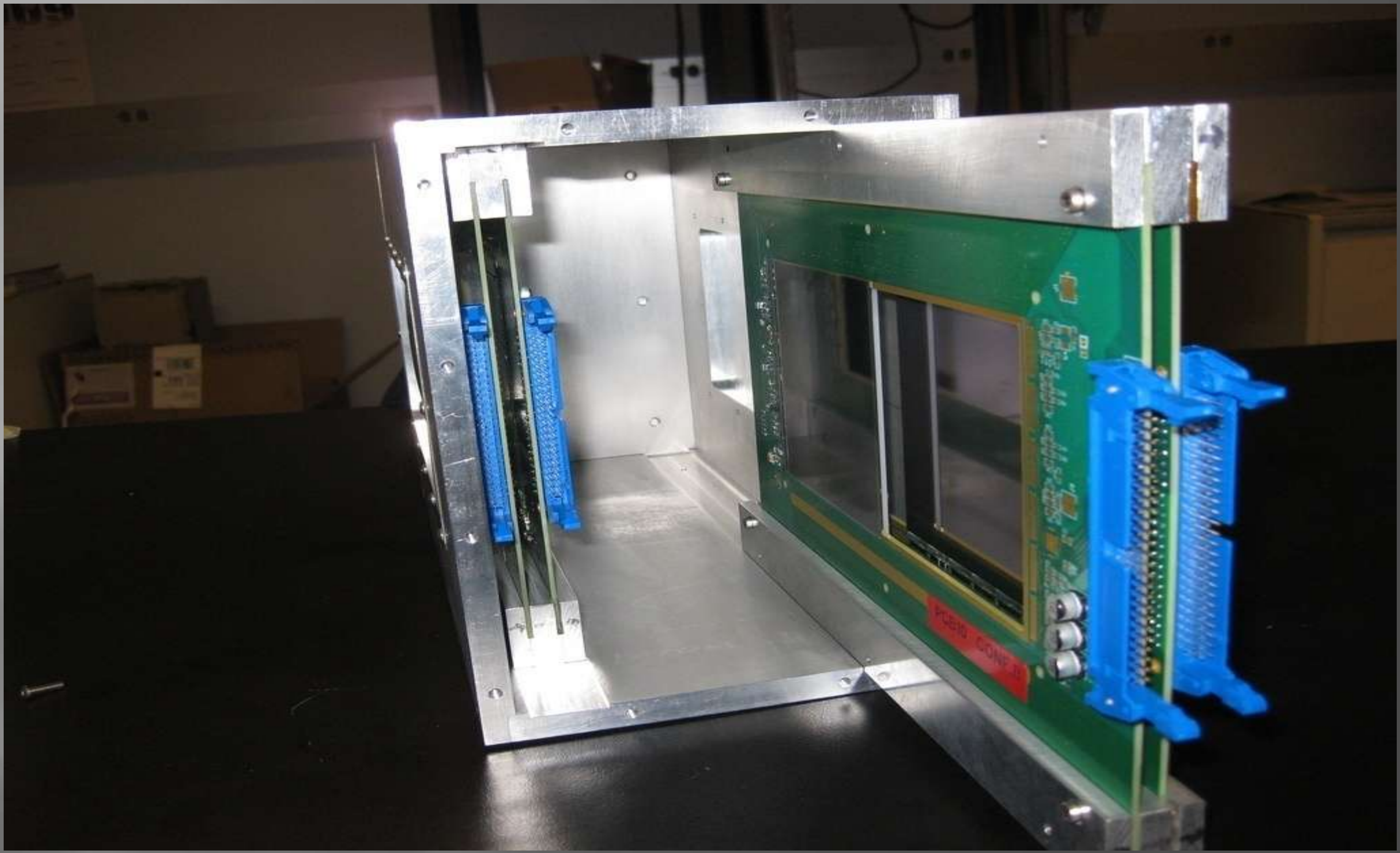
- **Upstream detector includes 2 Si X-Y planes + electronics(front enclosure)**
- **Downstream detector includes 2 Si X-Y planes + 18 CsI crystals + electronics (rear enclosure)**
- **Rotational stage with a phantom**
- **DAQ**
- **Mech. Support**

Si detector assembly made at SCIPP, enclosures at LLUMC and NIU

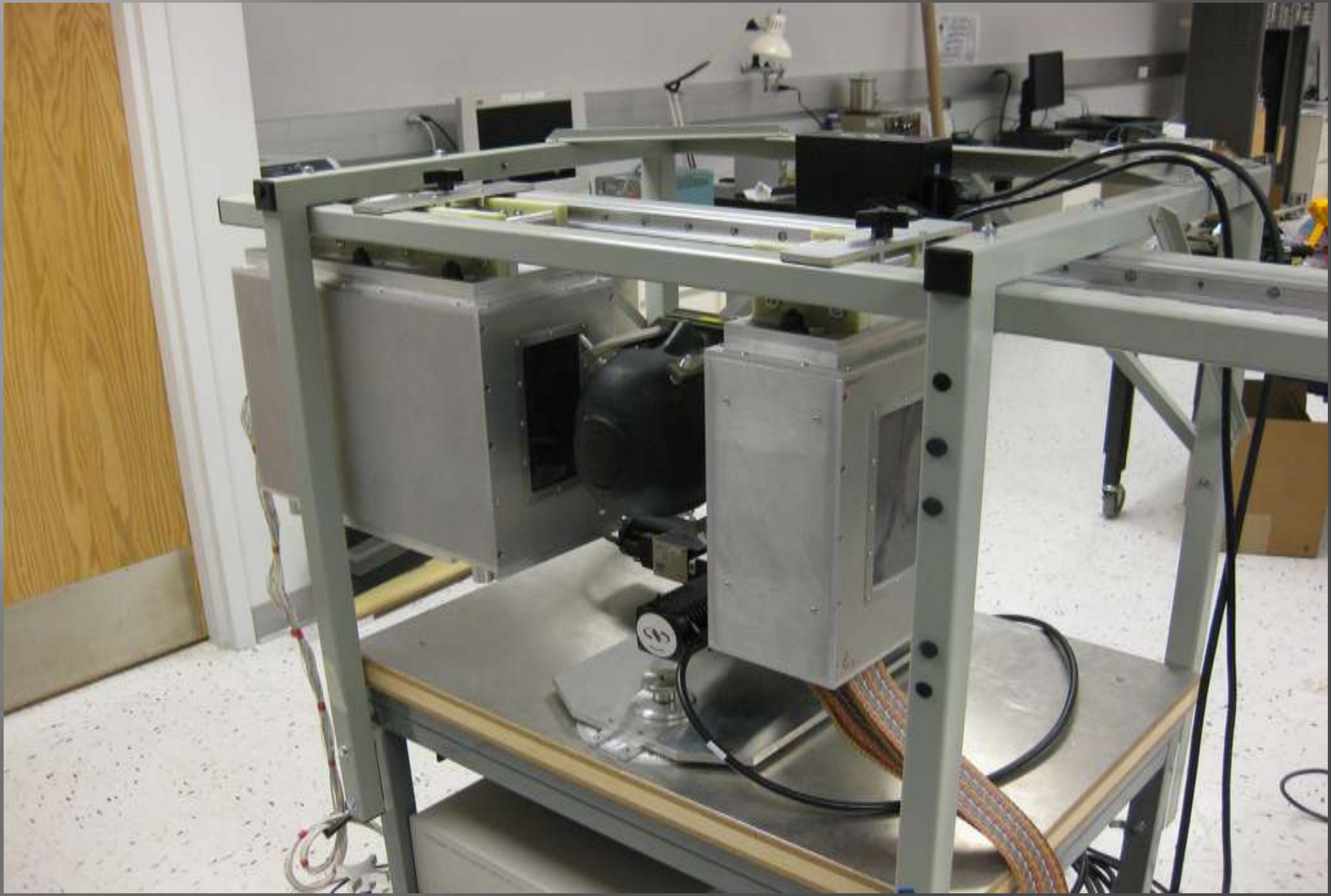
Rear enclosure, CsI calorimeter matrix, Si tracker



Front enclosure, Si tracker

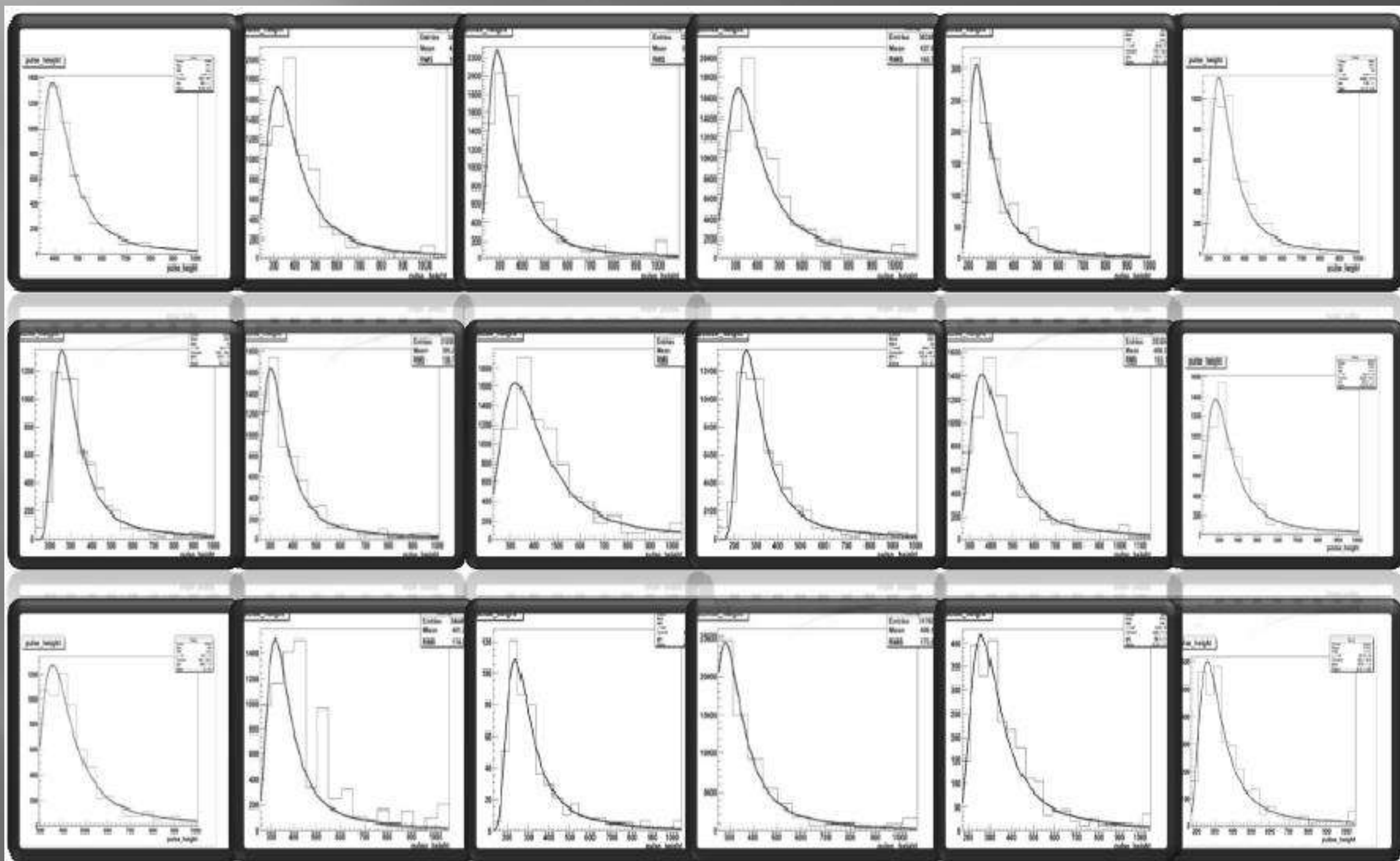


pCT detector is under testing, our plans to start measurements shortly.



http://www.flickr.com/photos/fordhurley/

All 18 CsI crystals amplitude distribution from cosmic



Upgrade issues: tracker, DAQ

GLAST/Fermi: ~10 kHz
Serial readout of GTFE into GTRC and of GTRC into DAQ to save power and reduce cables

pCT Phase I: ~100 kHz
Increase number of GTRC by factor 4, read them in parallel into FPGA

pCT Phase II: ~ 1 MHz
Direct readout of combined function GTFE/GTRC into FPGA

Upgrade issues, calorimeter:

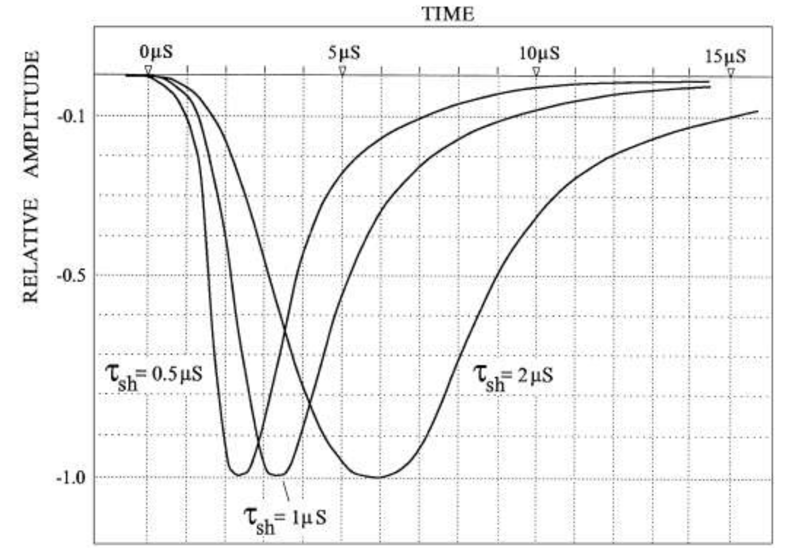
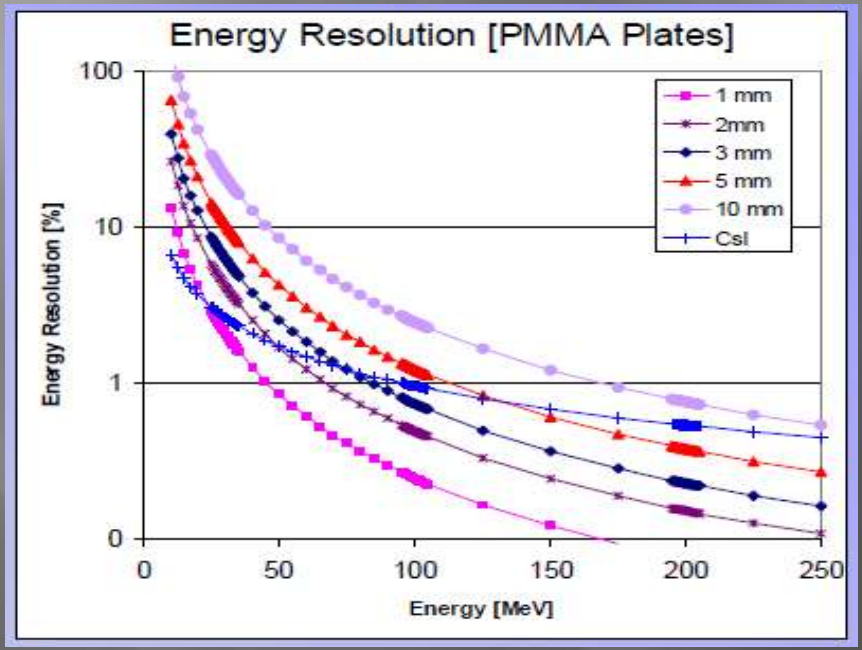


Fig. 12. Amplifier output waveforms of CsI(Tl) signals at different shaping times of 0.5, 1.0 and 2.0 μs.



Why ?

→ ~ 300 kHz current limit

10^8 protons / head volume (360°)

2 min

→ ~ 2 MHz

(2 sec duty cycle, 500 msec spill)

To use fine segmentation CsI (expensive)

LSO crystal gives 50 nS decay time (expensive)

Hartmut F.-W. Sadrozinski: pCT Tracker, LLU Dec 30, 2009

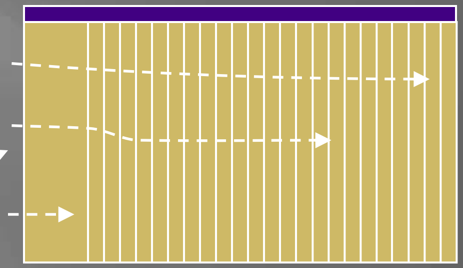
Things to do

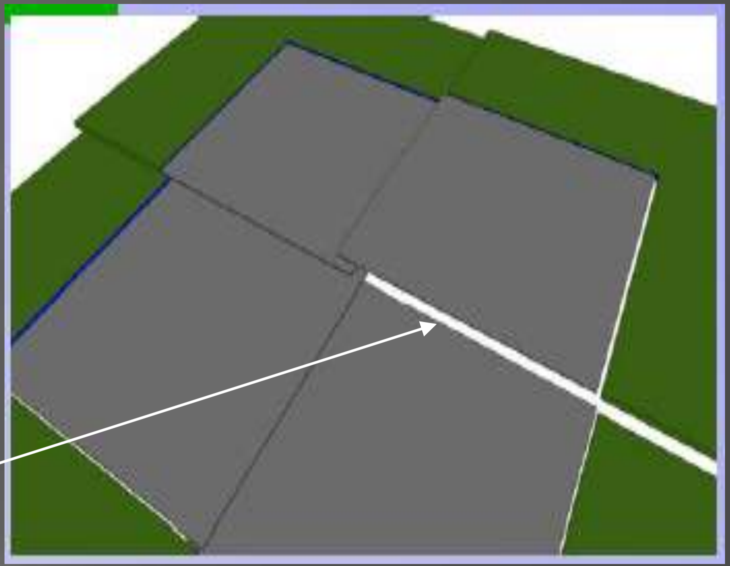
Geant 4 simulation of range detector

Prototype test beam

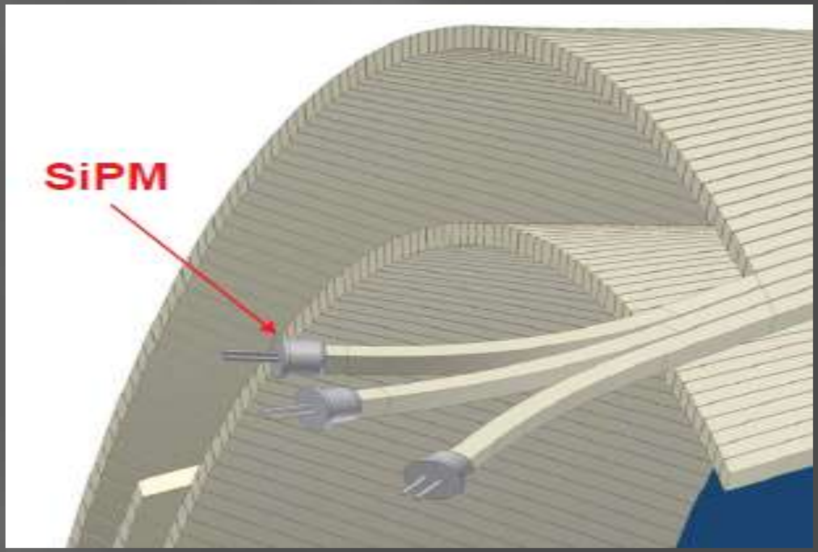
To built a new detector what also includes PCB design, front- end readout (Si PM) design, prototyping.

Upgrade issues:



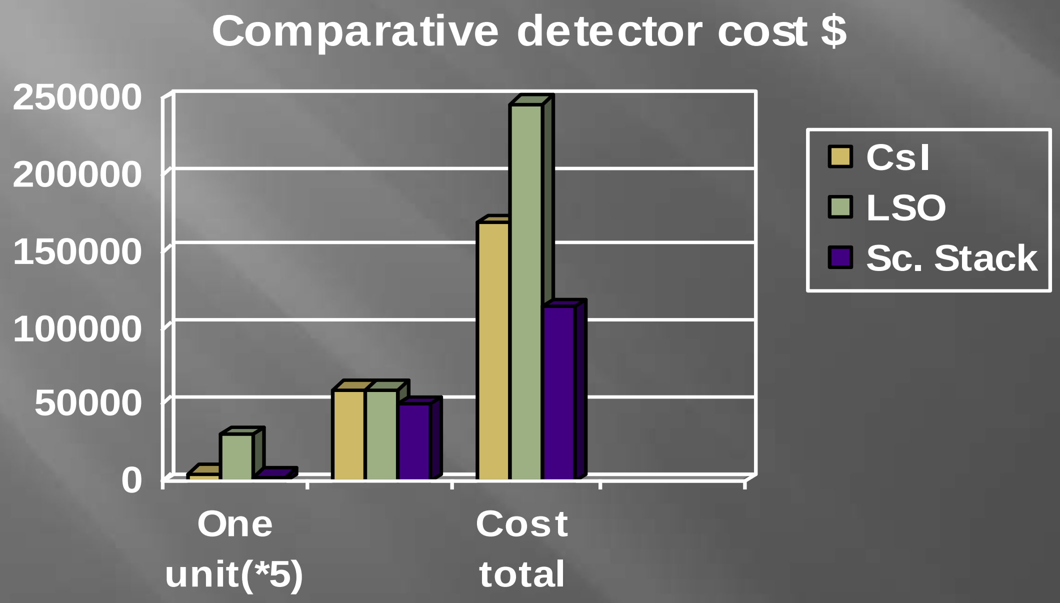


- Current system with CsI readout allows 300 kHz rate.
- Range detector (SiPM readout) vs. fast crystal detector?.
- Si strip tracker : Maximum size is 10*10 cm^2
- To cut Si detector and to built Si tracker based on edgeless sensors . Shingling possibility still works. This is a mainstream option.
- To consider Scintill. Fiber Tracker with SiPM multi-channel readout (FUTURE)?



Comparative cost analysis for Calorimeter!

Detector type	price/unit ($)	Units number	Time frame to built (months)	Total (components)estimated cost ($)
CsI	1086	100	6	108600
LSO	6034	31	6	187054
Scintillator stack	600	107	12	64200



Calorimeter unit means:

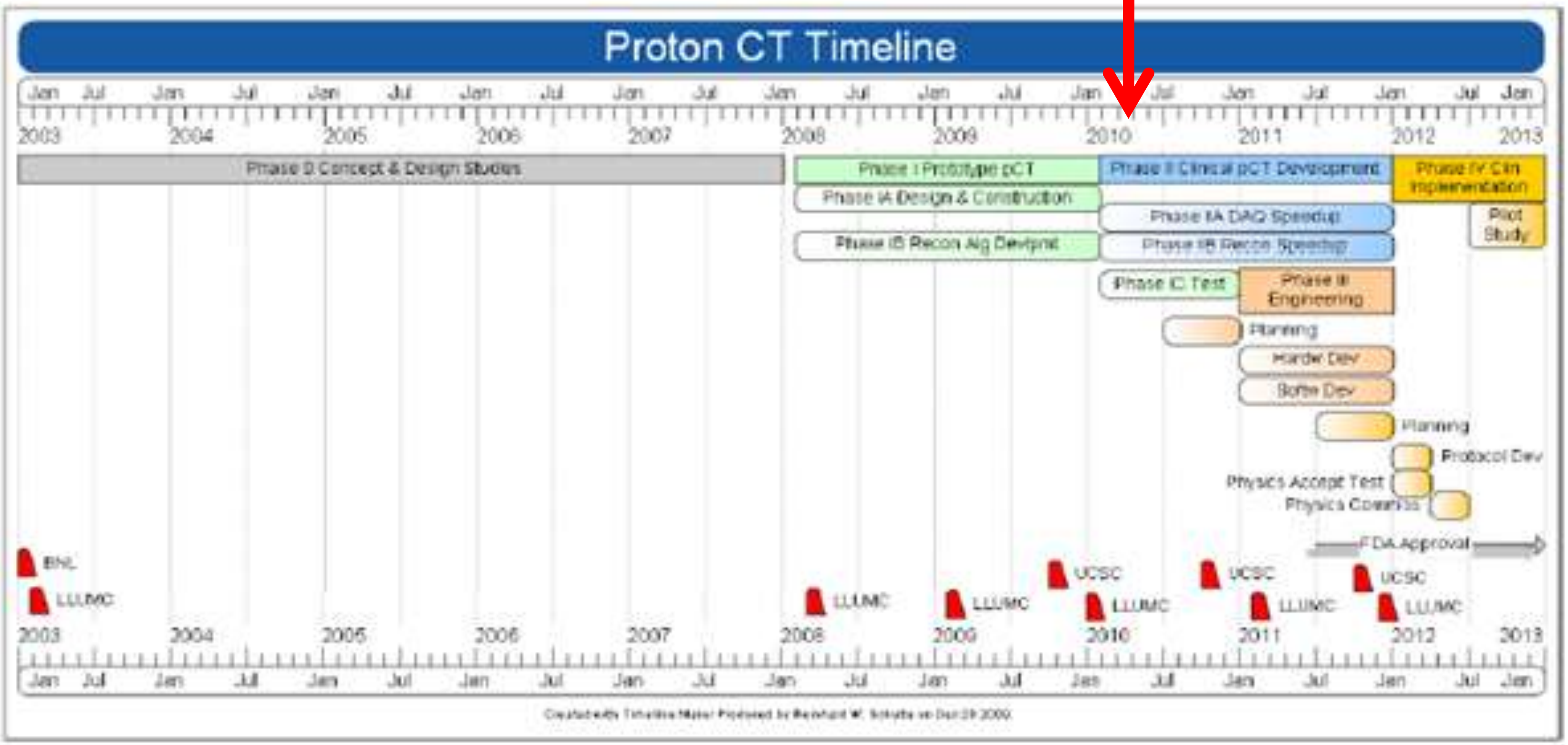
Crystal+PHD+one channel of front end electronics

Scintillator stack unit means:

Scintillator plate with grooved WLS fiber+SiPM

Time scale

pCT Project Timeline



Conclusion

- **All detector parts: electronics, detectors, enclosures, computer controlled rotational mech. system are on place.**
- **Currently we are testing whole system.**
- **Planning to have pCT scanner up and running in a month.**
- **Expect first images in a two months.**
- **Upgrade for the final clinical pCT is a way to go !**

- *THIS IS REALLY CHALLENGING, INTERDISCIPLINARY CUTTING – EDGE TECHNOLOGY PROJECT*

- **{Medical physics, Accelerator Physics, Tracking Simulation Expertise, Particle Detector Physics, Material Science, Mech. Engineering, Electrical Engineering, Computer Science}**

Thank You

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