HE CALORIMETER DETECTOR UPGRADE R&D

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for

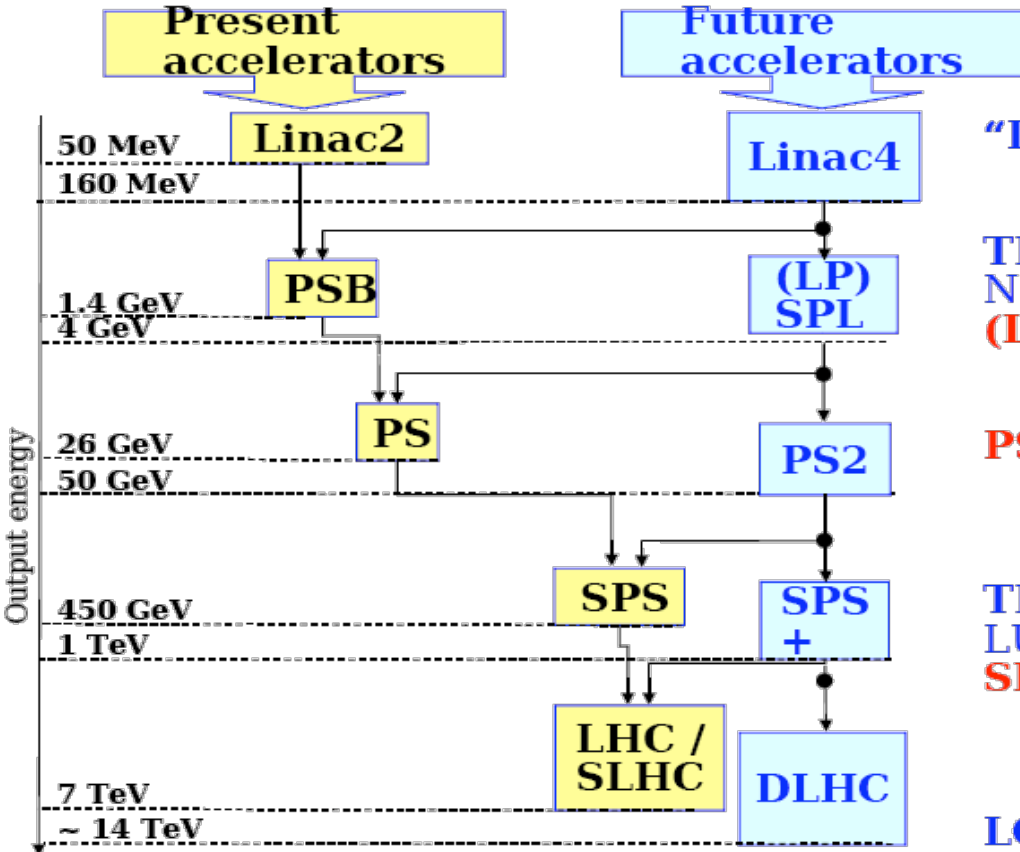
CMS Collaboration

Outline

- Introduction
  - SLHC Upgrade
  - Radiation problem for Hadronic Calorimeter Endcap
  - Summary of phase 1
- 2nd Phase of R&D
  - Light enhancement tools: ZnO, PTP
  - Radiation damage tests on Quartz and PTP
- **Results from July 2008 CERN Test Beam**
- 3rd Phase of R&D
  - Alternative readout options:
  - Radiation Hard WLS Fiber options

LHC Upgrade Options

Themes 1 (2012) & 3 (2016)



"DONE" DEAL **Linac4**

THEME 1
NEAR TERM FOCUS ~2012
(LP)SPL (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2 High Energy PS (~ 5 to 50 GeV – 0.3 Hz)

THEME 3
LUMI UPGRADE ~2016
SLHC "Superlumi" LHC (up to 10^{35} $cm^{-2}s^{-1}$)

LONG TERM FANTASY
SPS+ Superconducting SPS
DLHC "Double energy" LHC

SLHC: CMS Calorimeter

- Forward Calorimeter: Quartz Fiber
  - –Radiation tolerant
  - –Very fast
  - –Modify logic to provide finer-grain information
    - Improves forward jet-tagging

- Hadron Barrel & Endcap Calorimeters
  - –Plastic scintillator tiles and wavelength shifting fiber is radiation hard up to 2.5 MRad while at SLHC, expect 25MRad in HE.
    - R&D new scintillators and waveshifters in liquids, paints, and solids, and Cerenkov radiation emitting materials e.g. Quartz

- ECAL: PBWO4 Crystal: Stays
  - –Sufficiently radiation tolerant
  - –Exclude on-detector electronics modifications for now -- difficult:
    - Regroup crystals to reduce $\Delta\eta$ tower size -- minor improvement
    - Additional fine-grain analysis of individual crystal data -- minor improvement

The "Problem" and the "Solution"

- As a solution to the radiation damage problem in SuperLHC conditions, quartz plates are proposed as a substitute for the scintillators at the Hadronic Endcap (HE) calorimeter.
- Quartz plates will not be affected by high radiation. But the number of generated cerenkov photons are at the level of 1% of the scintillators.

Rad-hard quartz

– Quartz in the form of fiber are

irradiated in **Argonne IPNS** for 313 hours.

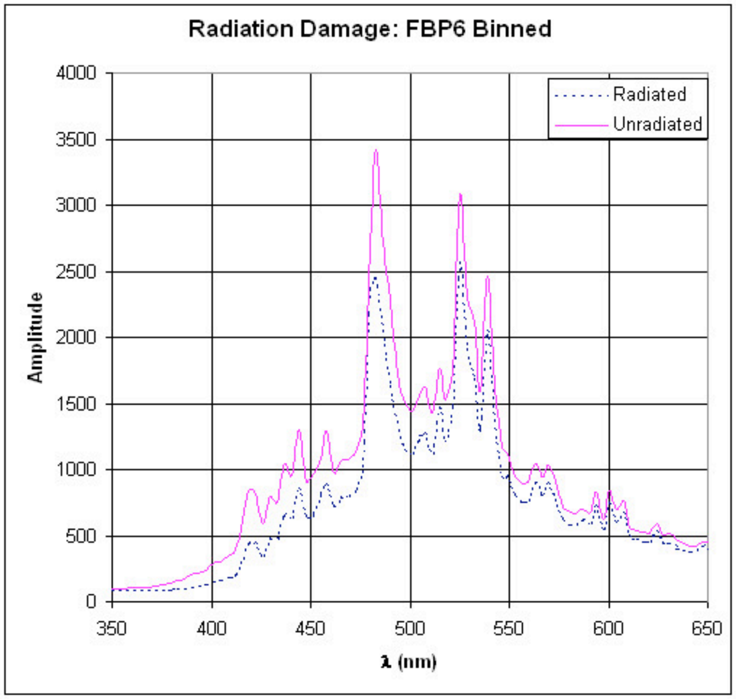
– The fibers were tested for optical degradation

before and after 17.6 Mrad of neutron and

73.5 Mrad of gamma radiation.

– Polymicro manufactured a special

radiation hard anti solarization quartz plate.



HCAL Upgrades

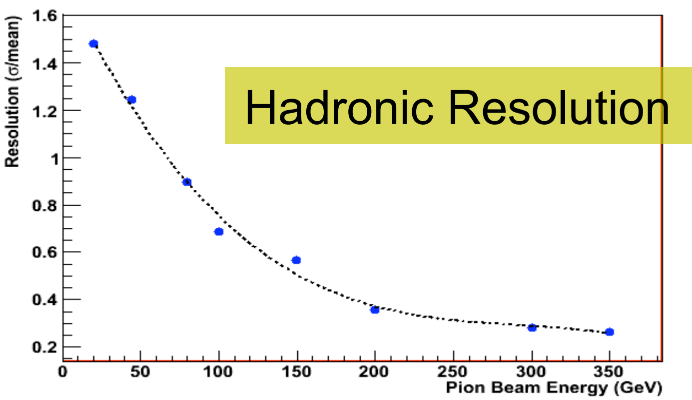
- 1st Phase of R&D
- 2nd Phase of R&D
  - Light enhancement tools: ZnO, PTP
  - Radiation damage tests on Quartz and PTP
- 3rd Phase of R&D
  - Alternative readout options:
    - PIN Diode, APD, SiPMT,
    - Microchannel PMT, MPPC
  - Radiation Hard WLS Fiber options
    - Quartz core sputtered with ZnO
    - Sapphire fibers

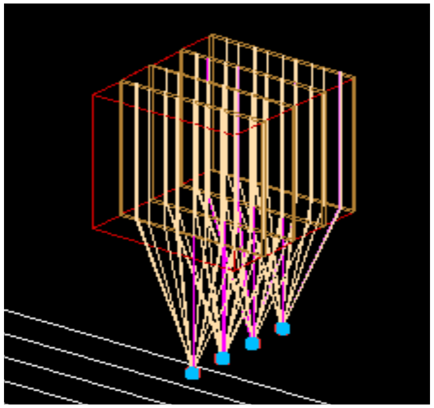
First Phase of the R&D

1. Show that the proposed solution is feasible
2. Tests and simulations of QPCAL-1

Summary of 1st Phase

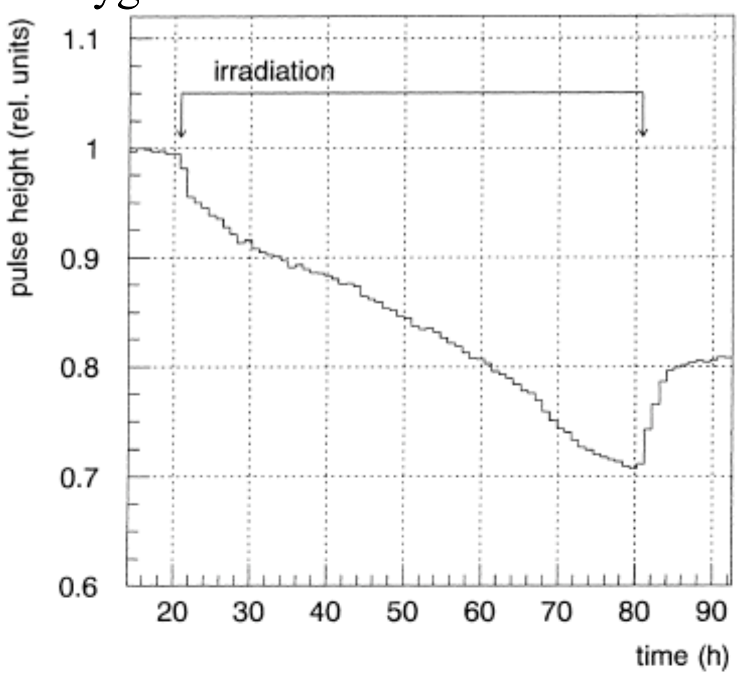
- As a solution to the radiation damage problem in SuperLHC conditions, quartz plates are proposed as a substitute for the scintillators at the Hadronic Endcap (HE) calorimeter.
  - *F. Duru et al*. "*CMS Hadronic EndCap Calorimeter Upgrade Studies for SLHC - Cerenkov Light Collection from Quartz Plates*" , *IEEE Transactions on Nuclear Science, Vol 55, Issue 2, 734-740, Apr 2008.*
- The first quartz plate calorimeter prototype (QPCAL - I) was built with WLS fibers, and was tested at CERN and Fermilab test beams.



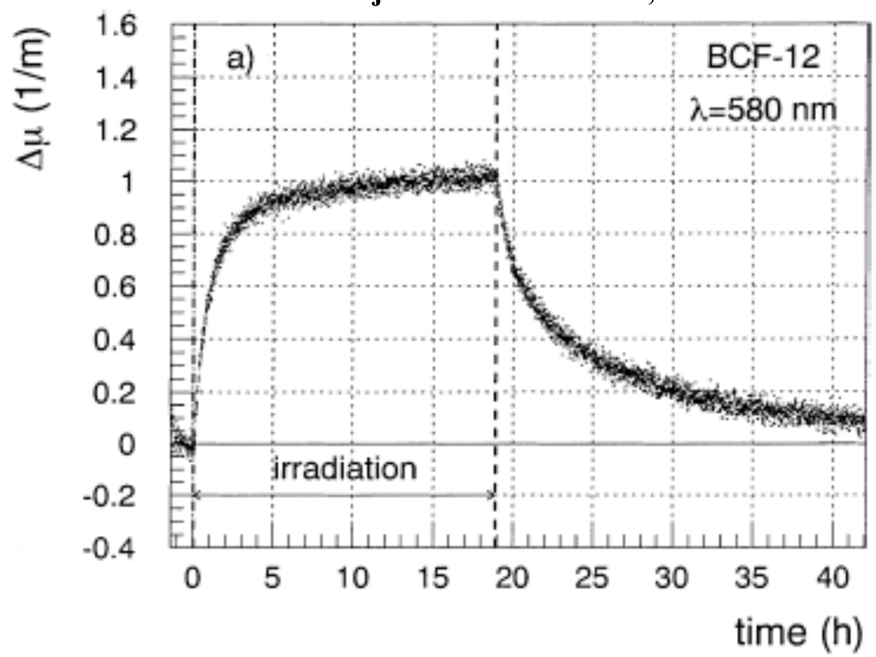


What is missing on the 1st Phase?

- The WLS fibers used in QPCAL are BCF-12 by Saint Gobain (old Bicron) are not radiation hard.
-The radiation hardness tests performed on BCF-12 shows that they are not very different than Kuraray 81 (current HE fibers).
-The studies shows that BCF-12 can be more radiation hard with the availability of oxygen.



W. Busjan et al. NIM B 152, 89-104



Second Phase of the R&D

1. How can we solve the fiber radiation problem?
   a) Use engineering designs
   b) Light enhancement tools (ZnO, PTP, etc.)

2. Radiation Damage Tests
   a) On Quartz
   b) On PTP

Light Enhancement Tools

Proposed Solution

*) Eliminate the WLS fibers: Increase the light yield with radiation hard scintillating/WLS materials and use a direct readout from the plate (APD, microPMT).

Possible Rad hard matrials include P-terphenyl (PTP) and ZnO

*) Current BCF-12 WLS fiber is not very radiation hard, but it can still be used

*) We can engineer a system with fibers continuously fed thru a spool system similar to the source drivers for all HCAL

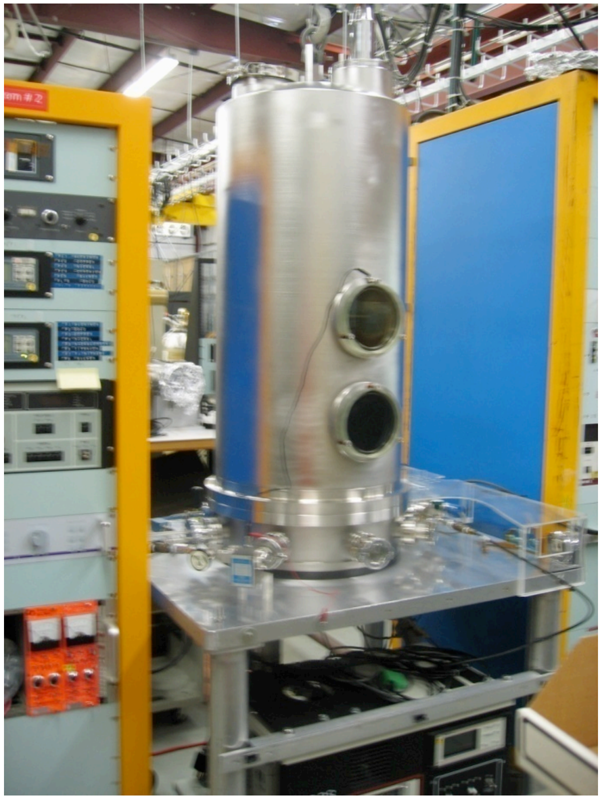
We have shown that a set of straight (or a gentle bend) quartz plate grooves
allow WLS fibers to be easily pulled out and replaced.

*) Different approach could be to use radiation hard quartz capillaries with pumped WLS liquid.

This has been studies at Fairfield. The liquid (benzyl alcohol + phenyl naphthalene) has an index of 1.6 but the attenuation length is still somewhat too short, possibly because of a too high WLS concentration.

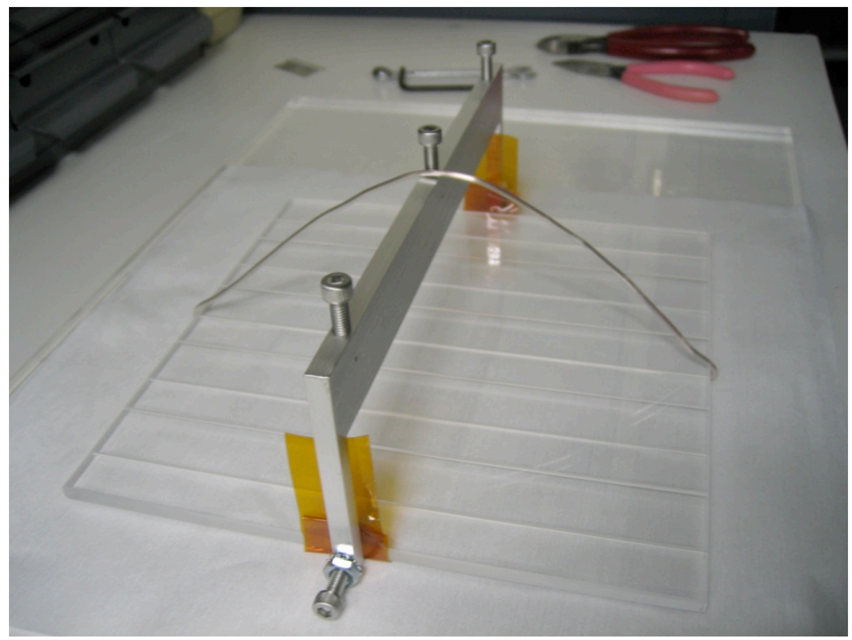
Quartz Plates with PTP

- At Fermilab Lab7, we have covered quartz plates with PTP by evaporation. We deposited 1.5, 2, 2.5, and 3 micron thickness of PTP.



Quartz Plates with PTP

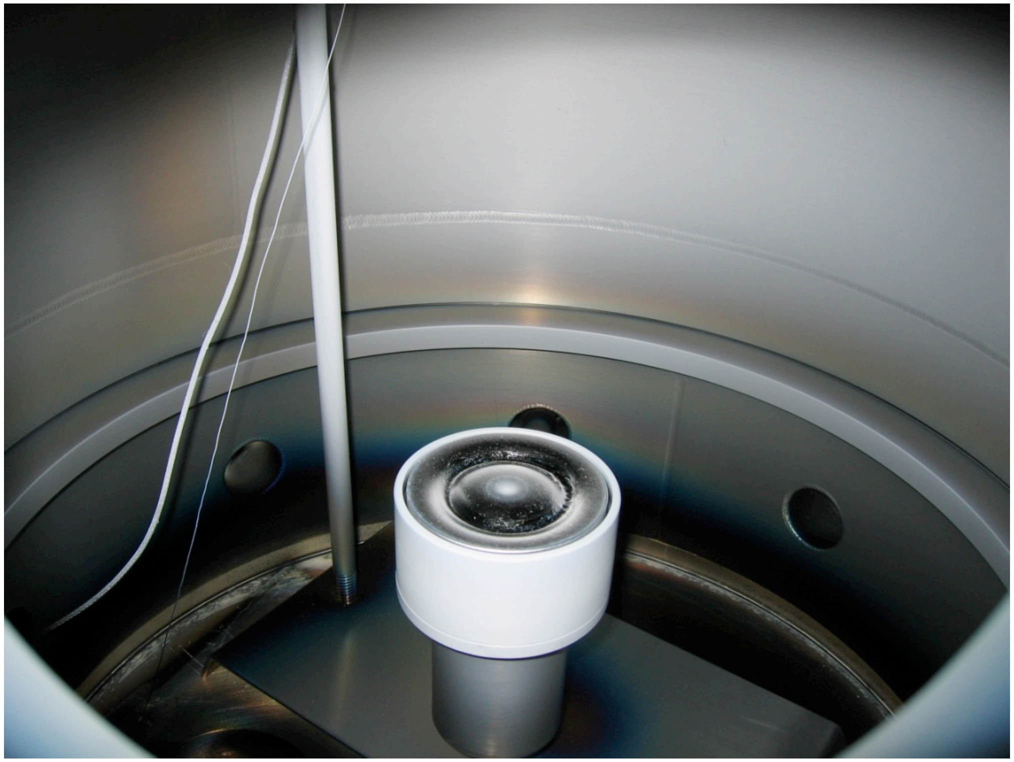
PTP evaporation setup, and quartz plate holder



Quartz Plates with ZnO

• We also cover quartz plates with ZnO (3% Ga doped), by RF sputtering.
0.3 micron and 1.5 micron.

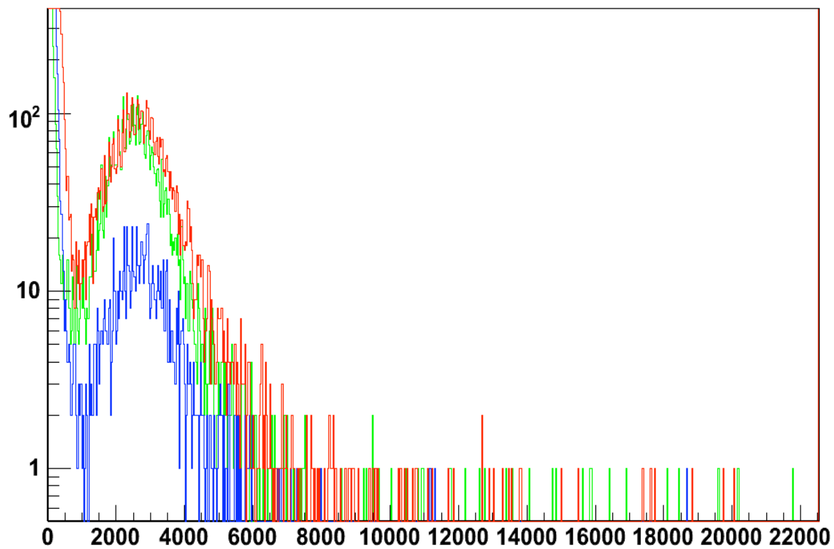
• We are currently working on 100 micron thick quartz plates, we've deposited ZnO on each layer and bundle the plates together, for a radiation hard scintillating plate

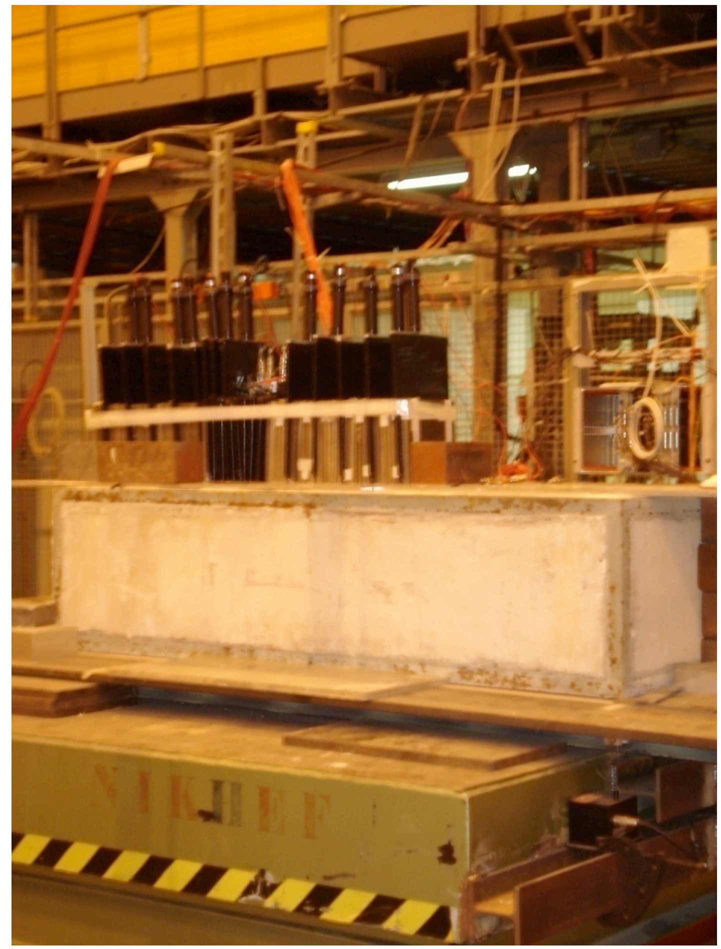


Fermilab Lab7, ZnO sputtering system and guns.

Test Beams for PTP and ZnO

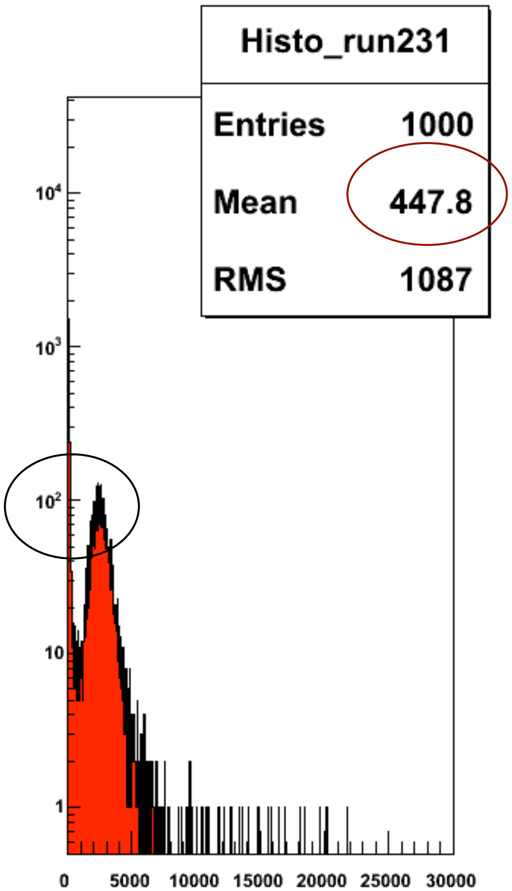
We have opportunity to test our ZnO and PTP covered plates, at CERN (Aug07), and Fermilab MTest (Nov 07, and Feb 08).



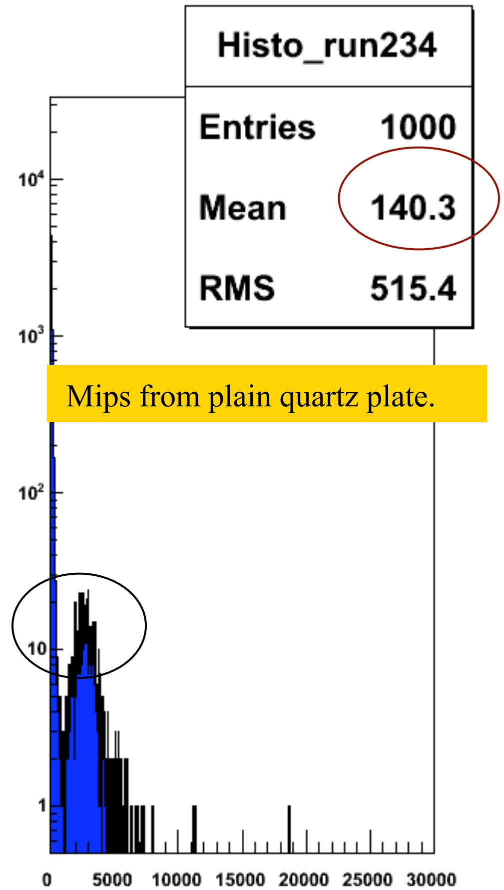


Blue : Clean Quartz
Green : ZnO (0.3 micron)
Red : PTP (2 micron)

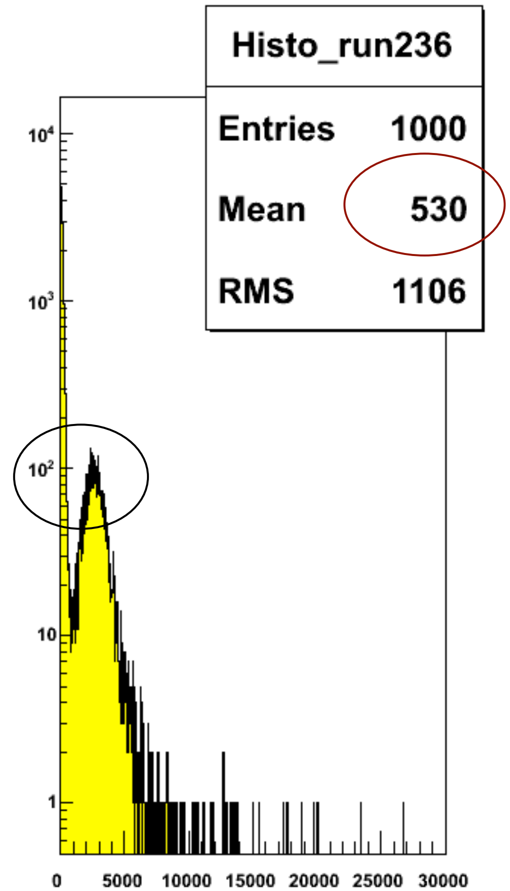
Test Beams for PTP and ZnO



Mips from 0.3 micron thick ZnO (3% Ga) sputtered quartz plate.

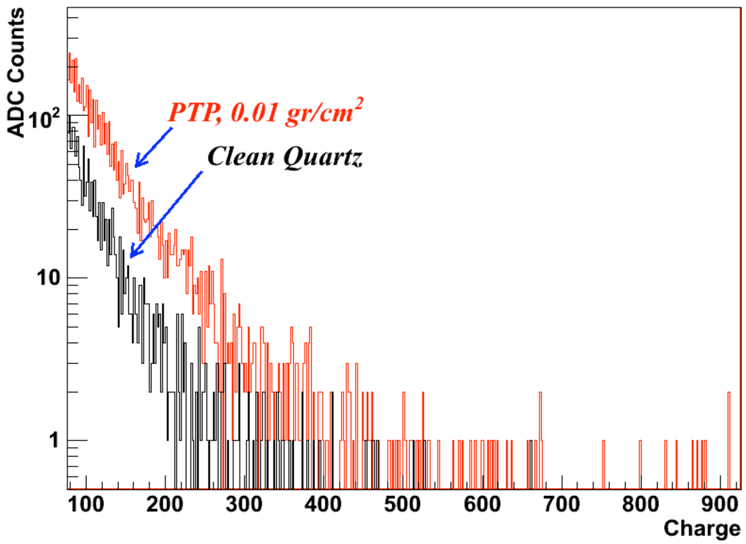


Mips from plain quartz plate.

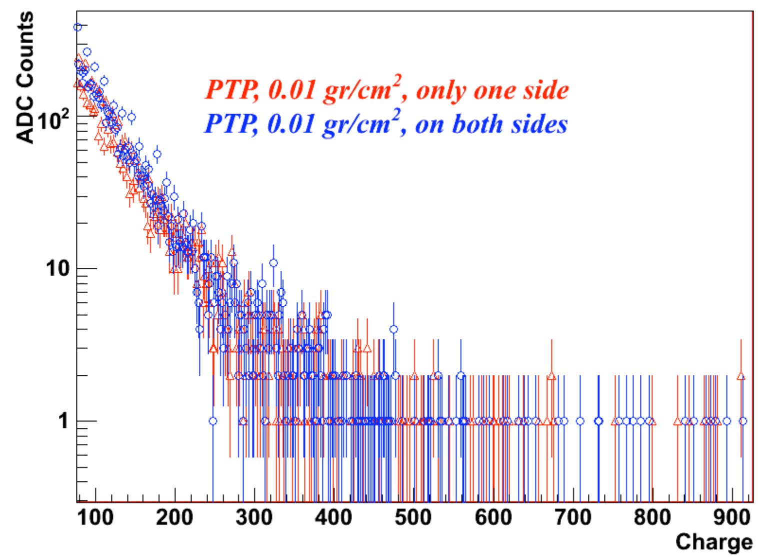


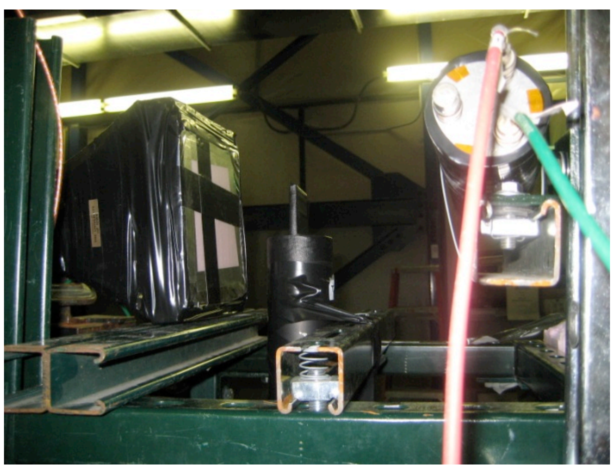
Mips from PTP evaporated quartz plate.

Test Beams for PTP and ZnO

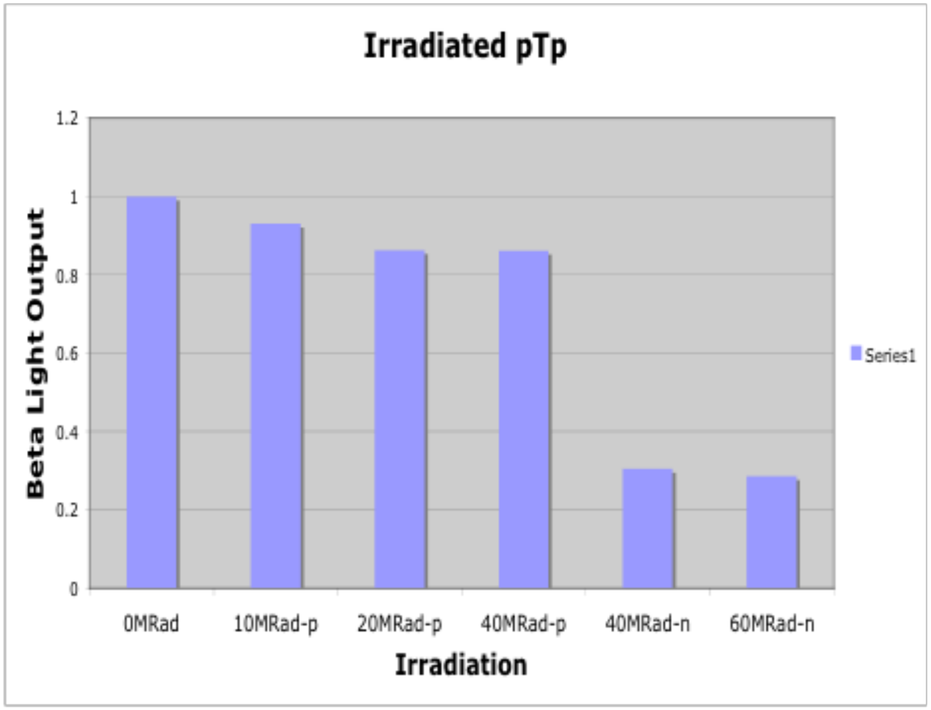


We evaporated PTP on quartz plates in IOWA and tested them in MTest.
Different deposition amounts and variations Were tested.





PTP Radiation Damage Tests



- Sr-90 activated scintillation light output of the different pTP samples which are saturated in toluene.
- The toluene makes no measurable scintillation contribution.
- Protons were done at CERN and Indiana Cyclotron.
- The neutron data from Argonne.

What is learned from Phase II ?

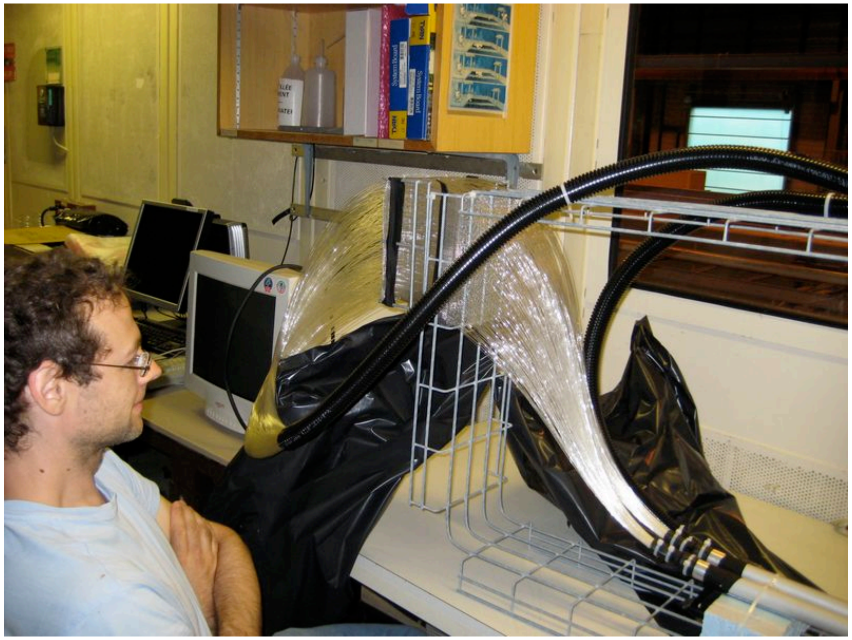
- The PTP and Ga:ZnO (4% Gallium doped) enhance the light production almost 4 times.
- OTP, MTP, and PQP did not perform as well as these.
- PTP is easier to apply on quartz, we have a functioning evaporation system in Iowa, works very well. We also had successful application with RTV. Uniform distribution is critical!!
- ZnO can be applied by RF sputtering, we did this at Fermilab-LAB7. We got 0.3 micron, and 1.5 micron deposition samples. 0.3 micron yields better light output.
- In light of these results we focused our efforts to Summer08 Cern Test Beam.

Cern Test Beam – Summer 2008

- We have constructed and tested the QPCAL-II, with PTP deposited quartz layers.
- The 20cmx20cmx5mm, GE-124 quartz plates are used.
- 2 µm PTP is evaporated on every quartz plate at Fermilab Lab 7.
- The readout has been performed with Hamamatsu R7525 PMTs.
- For hadronic configuration 7cm iron absorbers used between layers.
- No WLS fiber! This is the second prototype **"QPCAL-II"**

Cern Test Beam – Summer 2008

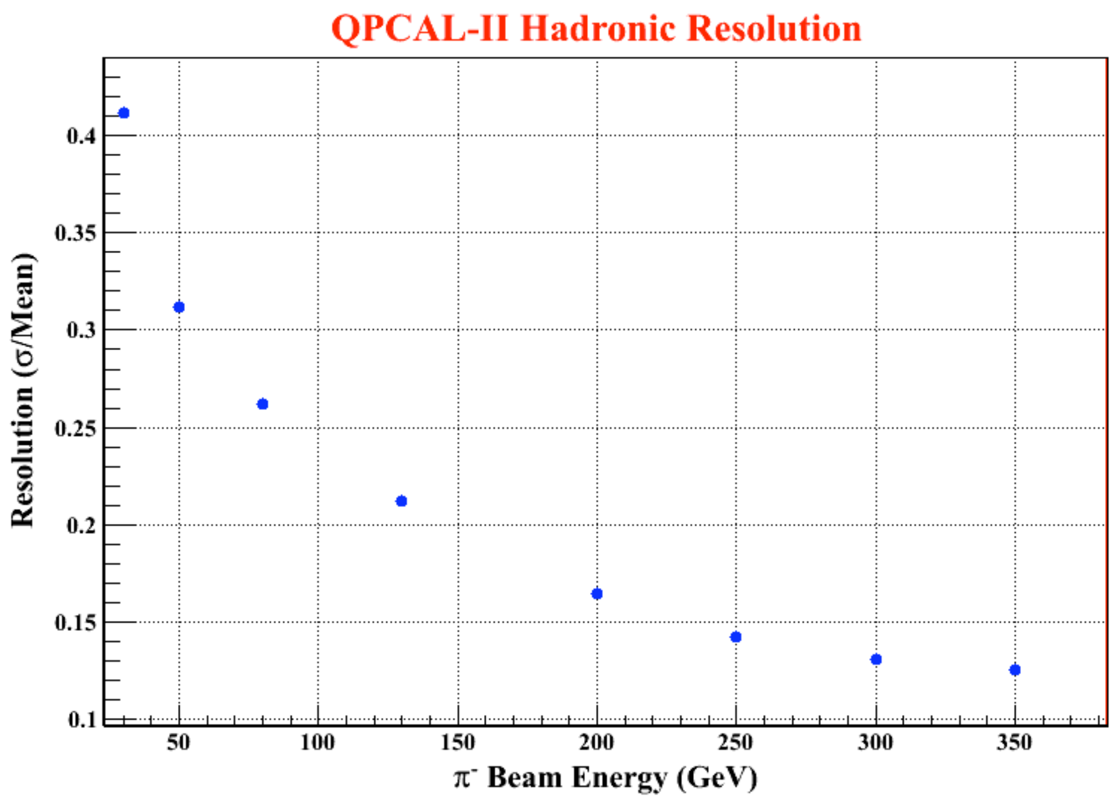
- We also have tested different thickness of ZnO and PTP deposited plates for mips.
- Micro channel PMT prototype
- Also HF PMT tests are performed by the same team.



Cern Test Beam – Summer 2008

- The "new plate" with stack of seven 100 μm thick quartz plates, each sputtered ZnO on. This can give us a very radiation hard scintillating quartz plate. As a by product of our work.

QPCAL-II Hadronic Resolution

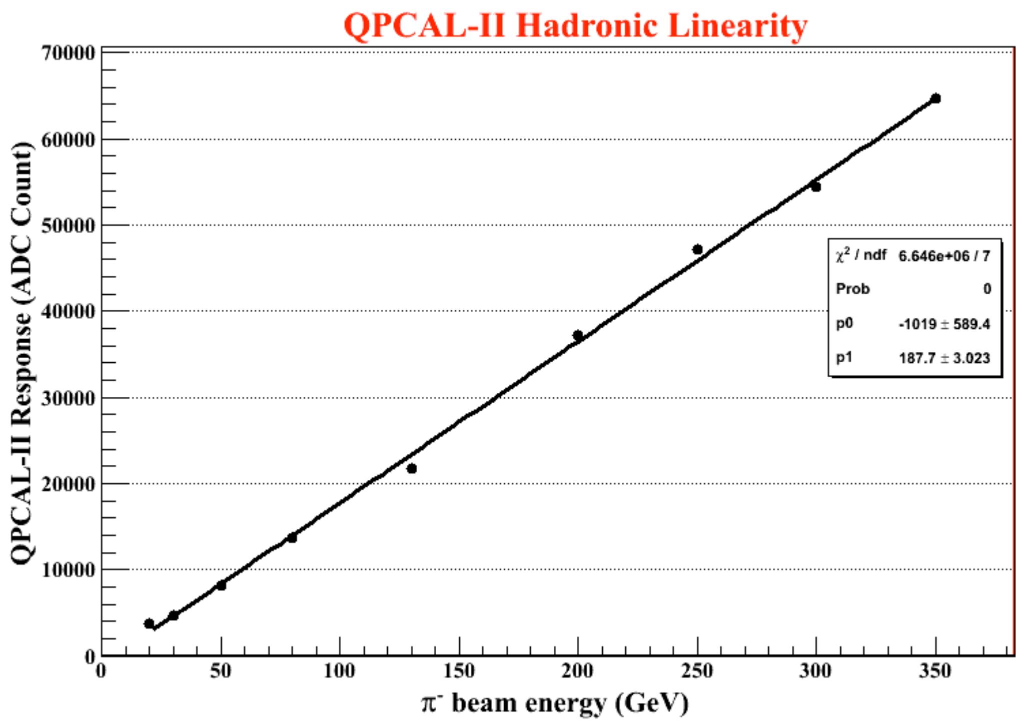


- We have taken data with 30, 50, 80, 130, 200, 250, 300, and 350 GeV Pion beam.

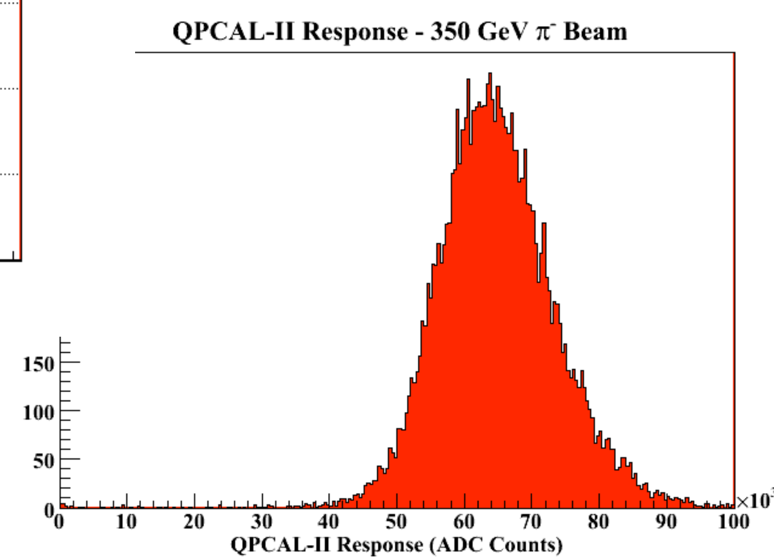
- Hadronic resolution is better than 12% at E > 350 GeV.

*) At QPCAL-I the hadronic resoution was 18% at 300 GeV.

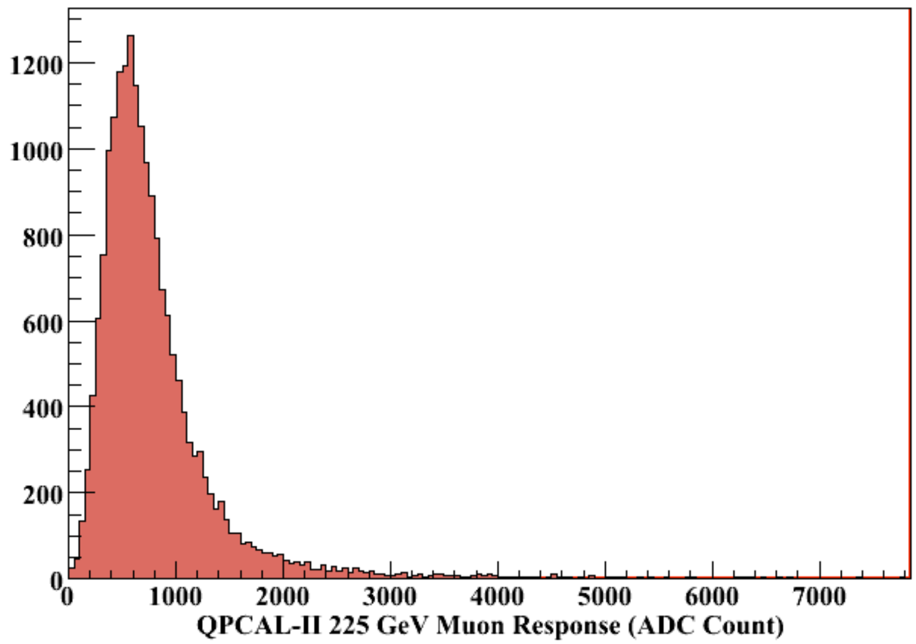
QPCAL-II Hadronic Response Linearity



Very linear response and
A nice signal distribution



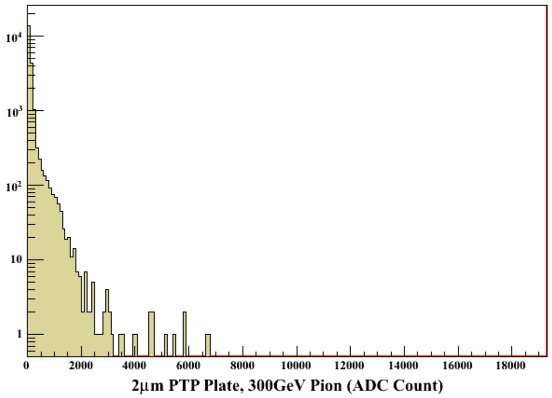
QPCAL-II Muon Response

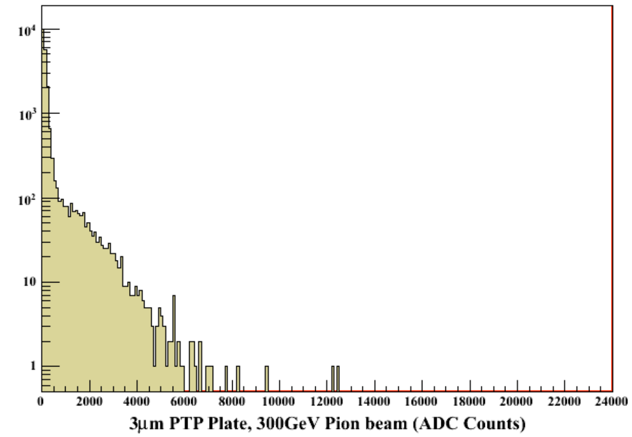


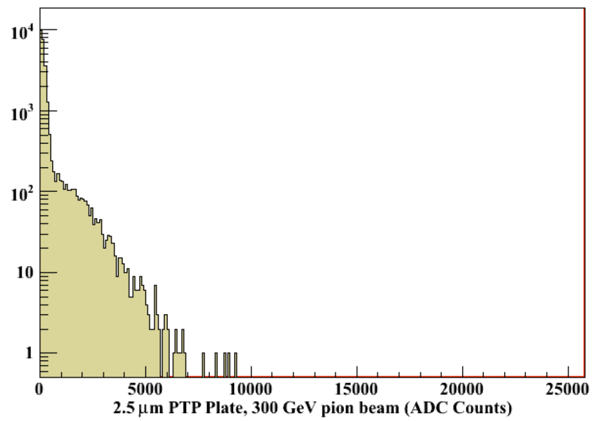
225 GeV Muon signal on QPCAL-II

Different PTP Thickness on Quartz

We did not see drastic variations between 2, 2.5, and 3 micron PTP deposited plates

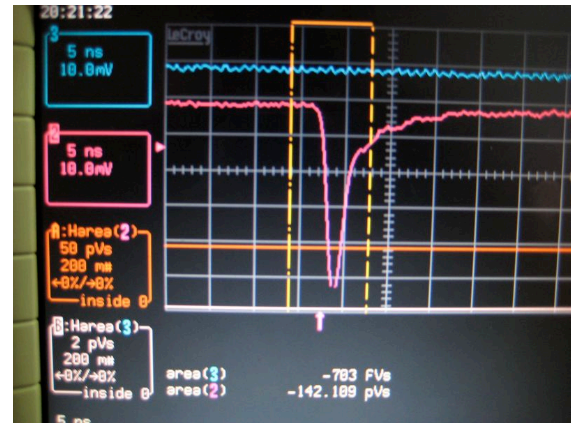


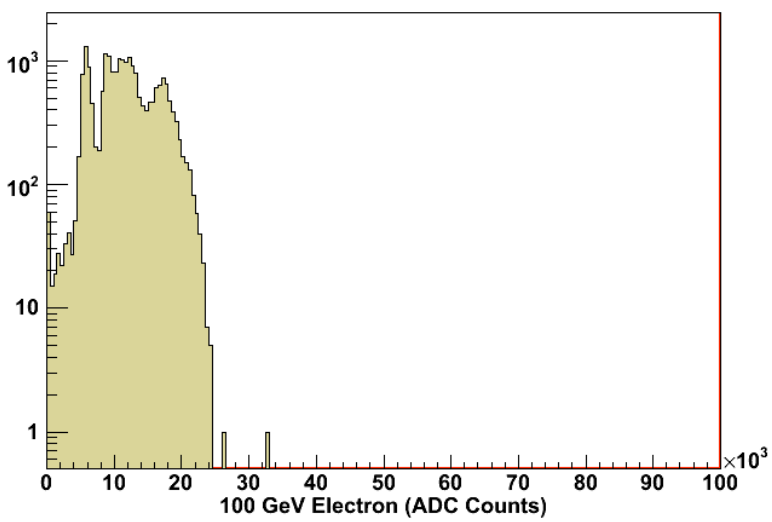


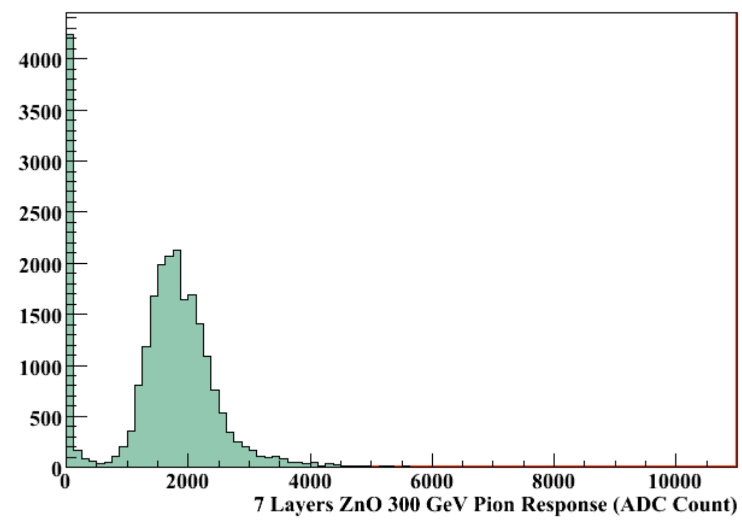


7 layer 700 micron ZnO plate

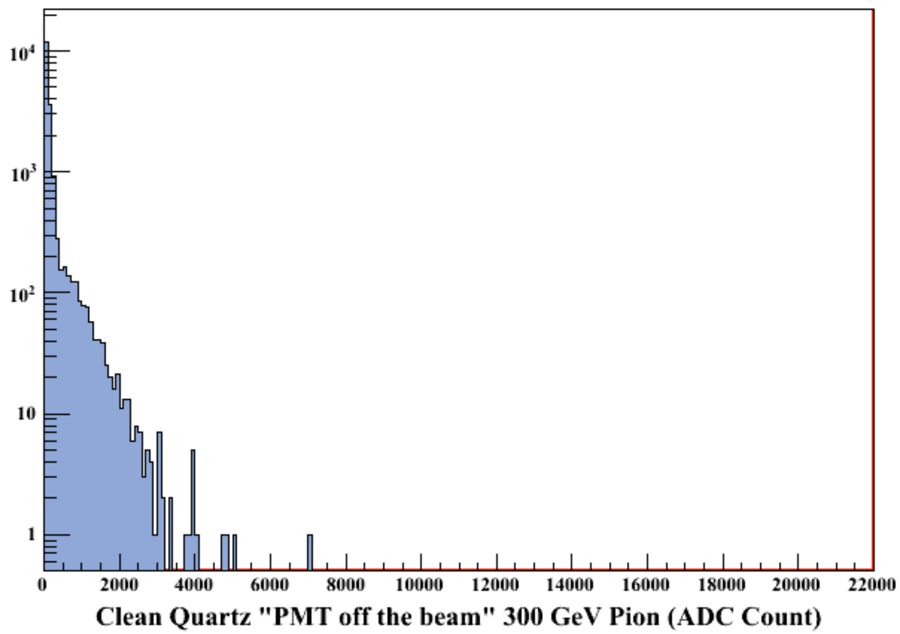
- We have deposited 0.2 micron ZnO (%4 Ga) to 100 micron thick quartz plates.
- This sandwich structure with 0.7 mm total thickness is placed in an aluminum frame and tested for mips on this test beam for the first time.
- We got very promising results, for both pion and electron beams. We need to work on this technique to develop future "radiation hard scintillators".



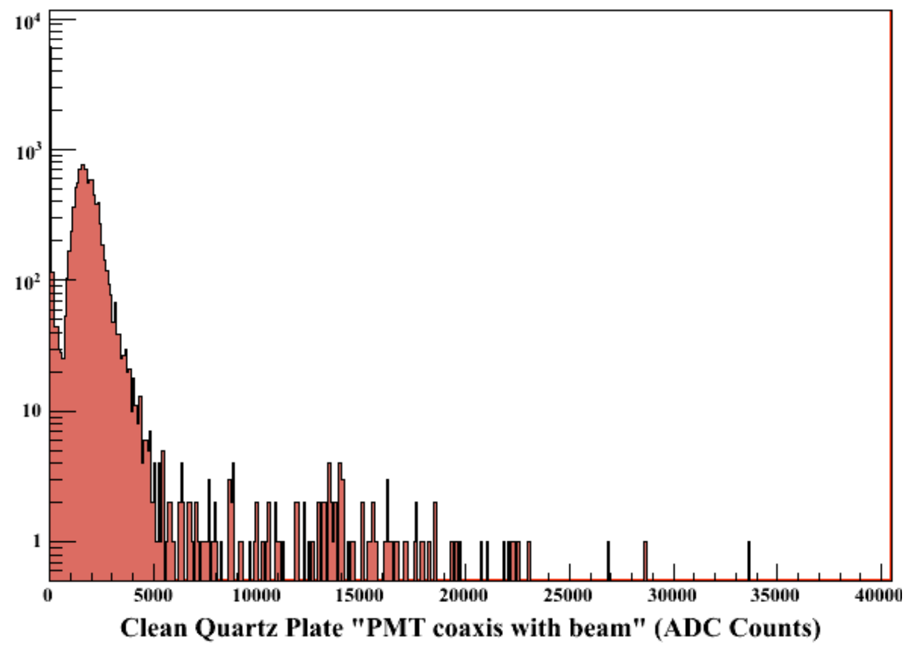




off-axis beam vs co-axis beam



The pyramids are positioned so the PMTs
Are not aligned with the beam.
When they are aligned with beam, we observe
Cerenkov from pmt window.



Results from Cern TB 08

- We had very successful test beam, performed various tests at a very short time.
- QPCAL-II with PTP deposited plates and performed better than QPCAL-I (withWLS fibers). With the obtained hadronic resolution of better than %13, we successfully finished the 2nd phase of our R&D.

- As one of the many spinoffs of this R&D , we showed than stacking very Thin ZnO treated quartz plates, we can Get “new rad-hard scintillators”.

Third Phase of the R&D

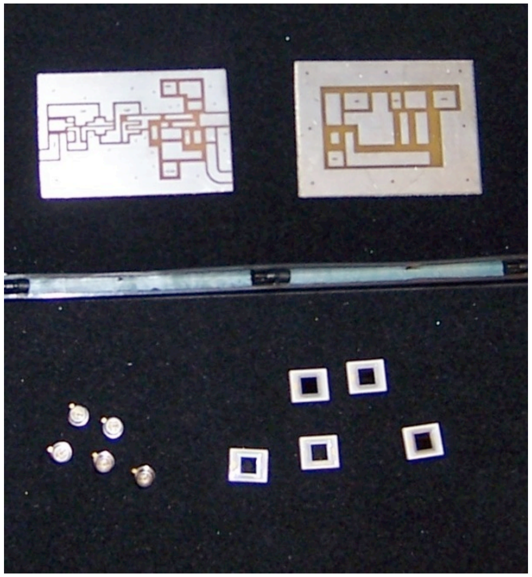
Alternative Readout Options : APD, SiPMT, PIN diode.

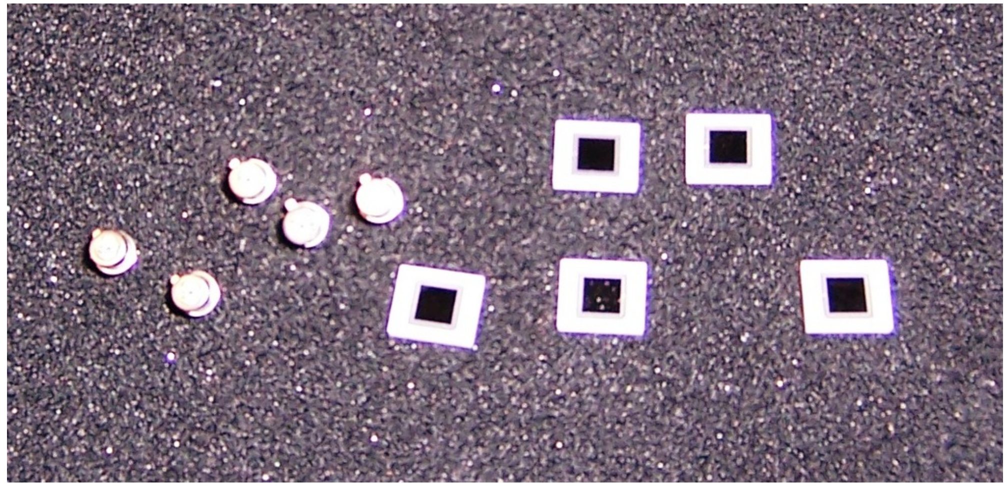
- Which one is better? Wavelength response? Surface area?
- Are they radiation hard?

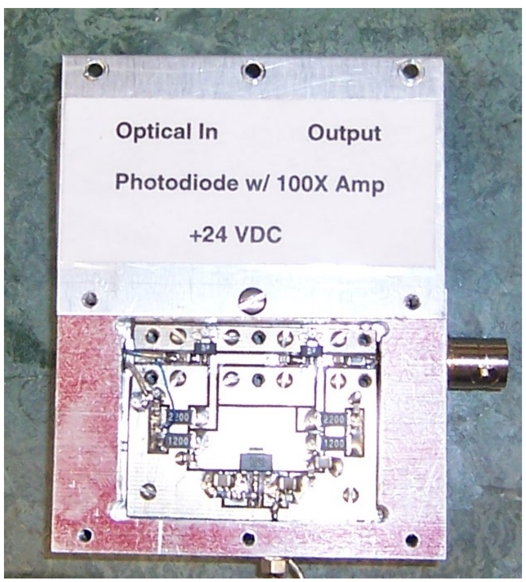
Developing Radiation Hard Wavelength Shifing Fibers

- Quartz fibers with ZnO covered core.
- Sapphire fibers

New Readout Options





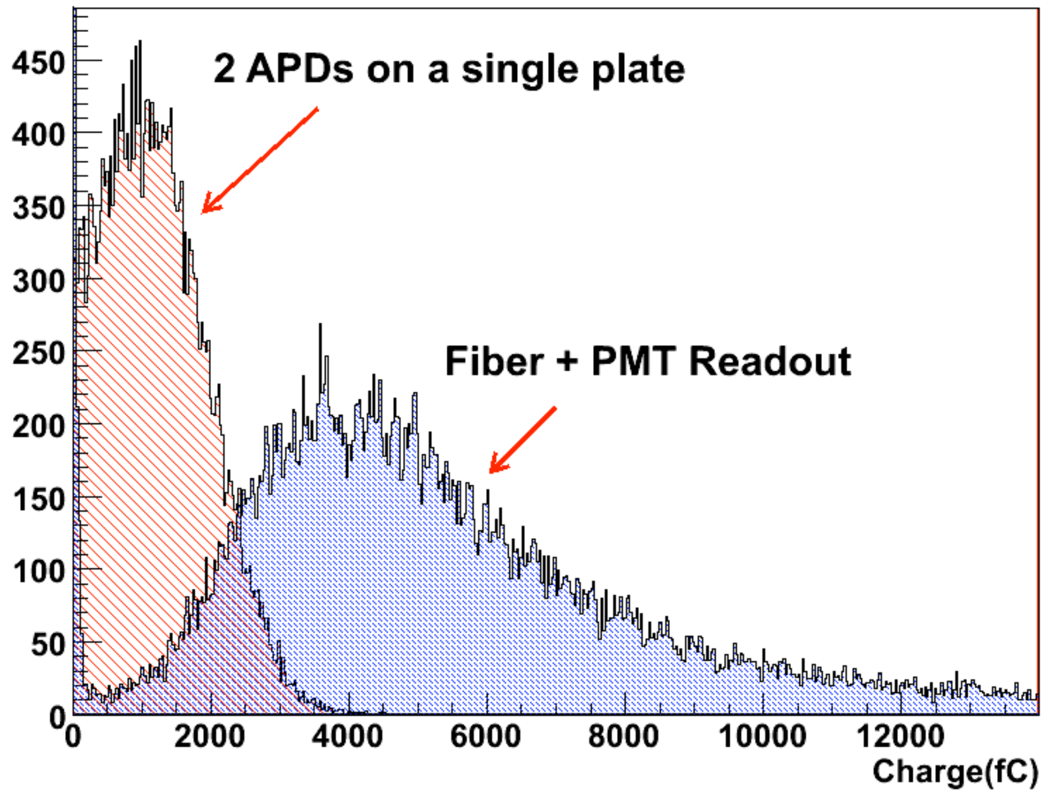


We tested;

*) Hamamatsu S8141 APDs (CMS ECAL APDs).
The circuits have been build at Iowa. These APDs are known to be radiation hard; *NIM A504, 44-47 (2003)*

*) Hamamatsu APDs: S5343, and S8664-10K
*) PIN diodes; Hamamatsu S5973 and S5973-02
*) Si PMTs

New Readout Options



We have tested ECAL APDs as a readout option. 2 APD connected to plain quartz Plate yields almost 4 times less light than fiber+PMT combination.

So far what is learned from Phase III ?

- Single APD or SiPMT is not enough to readout a plate. But 3-4 APD or SiPMT can do the job.
- SiPMTs have less noise, higher gains, better match to PTP and ZnO emission λ.
- As the surface area get bigger APDs get slower, we cannot go above 5mm x 5mm.
- The PIN diodes are simply not good enough.
- The APD and SiPMTs are not radiation hard. The ECAL APDs are claimed to be radiation hard, but the study does not look very reliable to us. There is no rad-hard readout technology option;
  - Feed the linear arrays of SiPMT or APD to the system, arranged as a strip of 5mm x 20-50 cm long… engineering…
  - A cylindrical HPD, 5-6 mm in diameter, with a sequence of coaxial target diodes anodes on the axis, 20-50 cm long, and a cylindrical photocathode.

Developing new technologies

- We propose to develop a radiation hard readout option.
  - Microchannel PMT.
  - MPPC (Multi Pixel Photon Counter)

- We also propose to develop a radiation hard WLS fiber option.
  - Doped sapphire fibers.
  - Quartz fibers with ZnO sputtered on core.

What about treating quartz fibers?

- **Heterogenous nanomaterials**
  Scintillating glass doped with nanocrystalline scintillators has also been shown to be a good shifter.

  We propose

  (i) testing radiation hardness and

  (ii) to investigate doping quartz cores with nanocrystalline scintillators (ZnO:Ga and CdS:Cu). The temperatures involved are very reasonable.

- **Thin film fluorescent coatings on quartz cores**
  250-300 nm UV has been shown to cause 5-10 ns fluorescence in MgF2, BaF2, ZnO:Ga. We propose coating rad-hard quartz fibers with a thin film, and then caldding with plastic or fluoride doped quartz. CVD deposition of Doped ZnO is now a commercial process, as it is used to make visible transparent conducting optical films as an alternative to indium tin oxide, as used in flat panel displays and solar cells.

Ongoing / Future Work

- Presently finishing test beam 2009 at CERN
- We have tested 4 APD and 4 SiPMT attached to plate
- Also test first rad hard WLS fibers
  - Quartz fibers with cores coated in ZnO are currently being tested at CERN