Design of a novel Cherenkov detector system for Machine Induced Background monitoring in the CMS cavern

S. Orfanelli (National Technical University of Athens, CERN),
A. Dabrowski, M. Giunta (CERN),
M. Ambrose, A. Finkel, R. Rusack (Univ Minnesota),
D. Stickland (Princeton University)

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Outline

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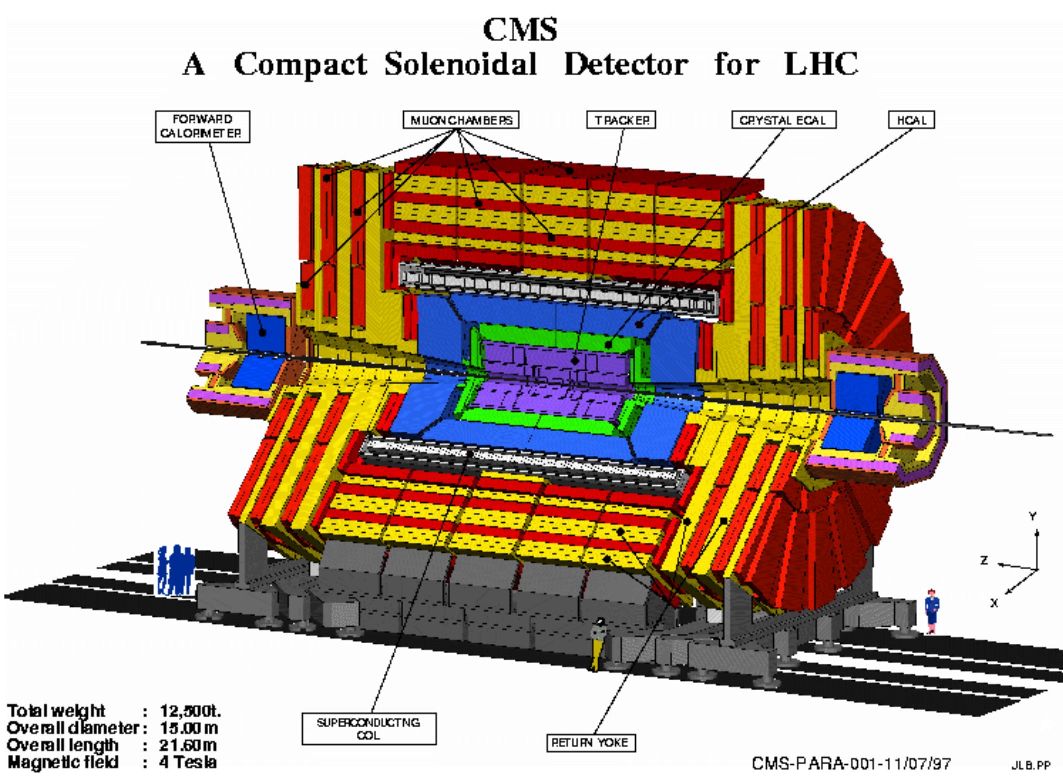
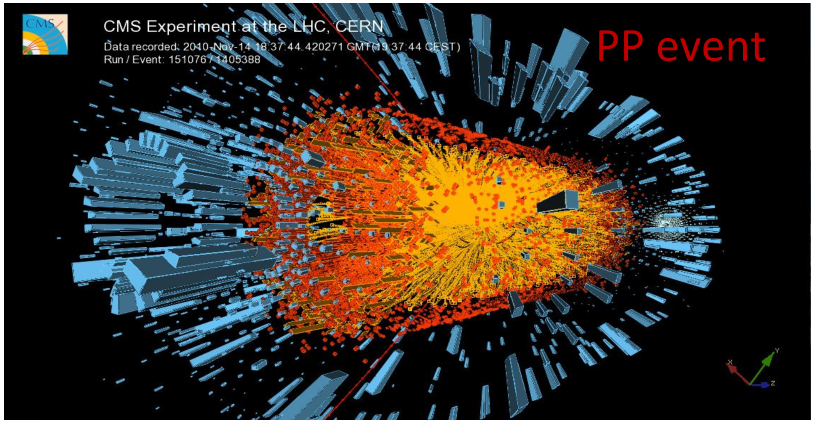
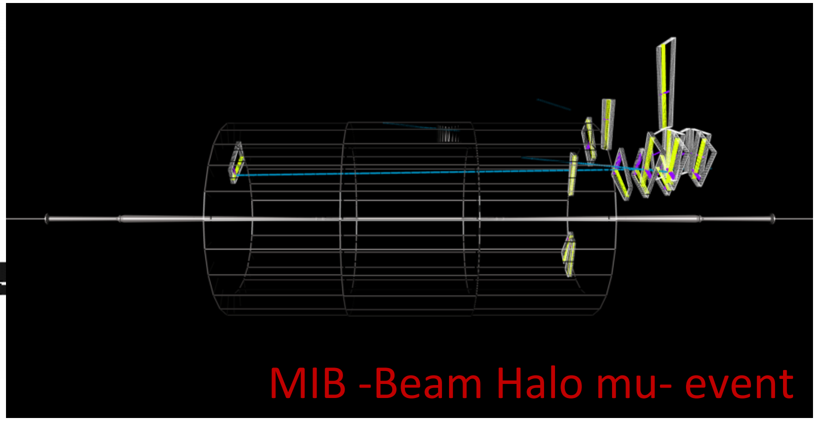
2. Design Requirements
   α) Timing & Choice of Location
   β) Directional Response
3. Mechanical optimizations
   α) Choice of material and components
   β) Shielding
4. Design Validation
5. System Overview &Outlook

Purpose

- **Purpose:** to provide an on-line measurement of the **Machine Induced Background (MIB)** at High Radius in CMS for each beam.







Motivation

- **After Long Shutdown 1:**

Exceeding nominal luminosity.
25ns bunch spacing.
Increased bunch charge.

→ Tighter LHC collimators settings.
Electron cloud effects.

→ **Higher MIB potential**

- **Why?**
  - Protection of the detector.
  - MIB contaminates Level 1 trigger rate and results in low data taking efficiency.
  - Flag poor beam conditions for CMS and LHC.
  - Verification of FLUKA model.
  - At High radius to complement MIB measurement at small radius from BCM1f and to have overlapping acceptance with muon chambers.

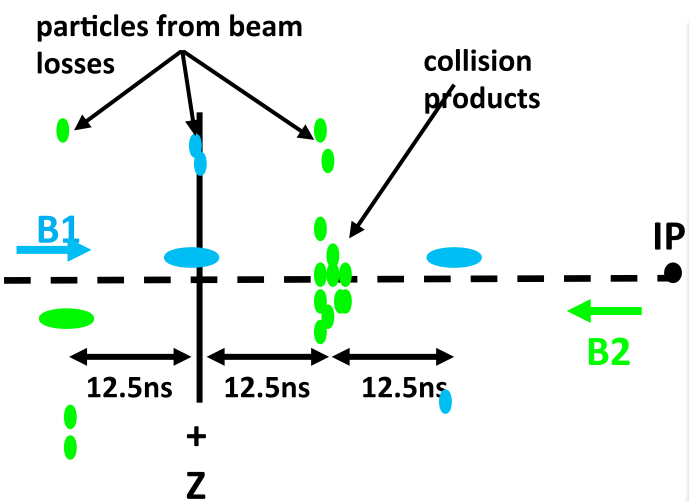
Detector Requirements

Cherenkov radiation

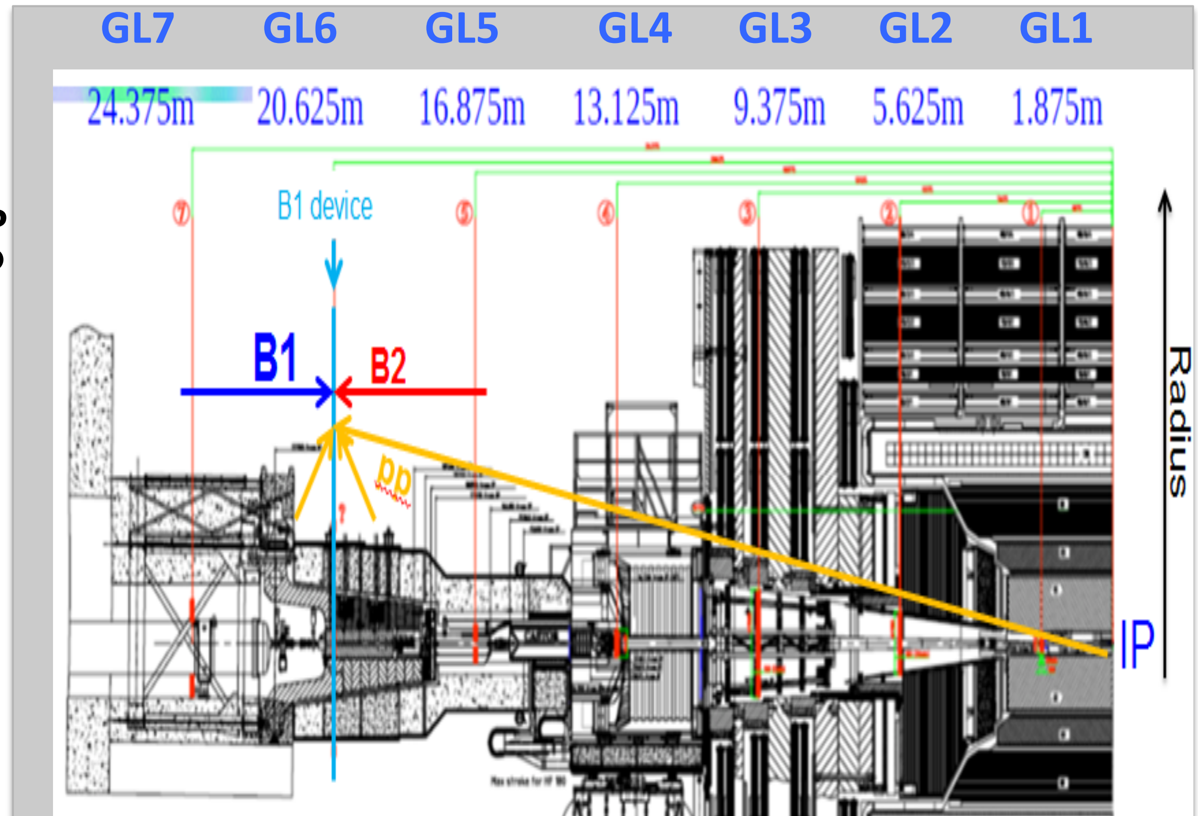
REQUIREMENT	CHALLENGE
DIRECTIONAL RESPONSE	Suppression of the pp-products arriving from the opposite direction.
RADIATION HARDNESS	50 krad for 10 years of operation (500fb^{-1}).
SENSITIVITY ONLY TO CHARGED PARTICLES	HE gammas and thermal neutrons in the CMS cavern.
FASTER THAN 12.5ns	Maximum time separation between MIB and pp-products 12.5ns.

Timing and Choice of Location

Golden locations: maximum timing separation MIB from pp products = 12.5ns



Be faster < 12.5ns



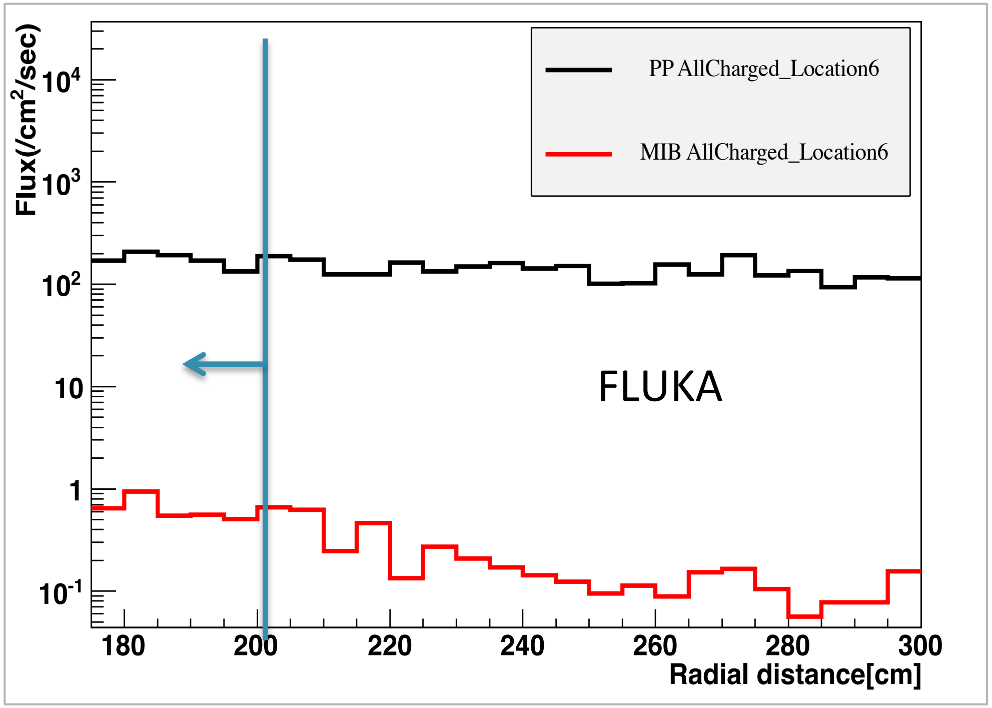
Golden Location 6

- Golden location:
  MIB – pp products **maximum time separation**

- Relatively good **environmental** conditions (**B** < 200gauss, dose < 50krad)

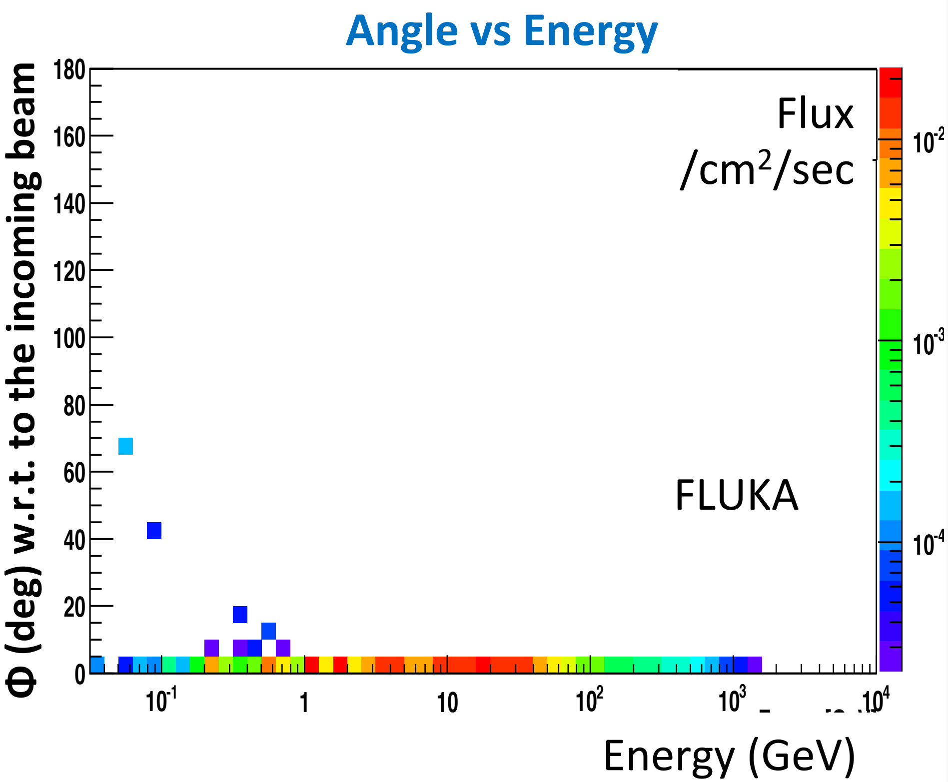
- **Available space** around the rotating shielding

- Absolute **MIB flux is higher** wrt other golden locations closer to the IP, based on FLUKA results

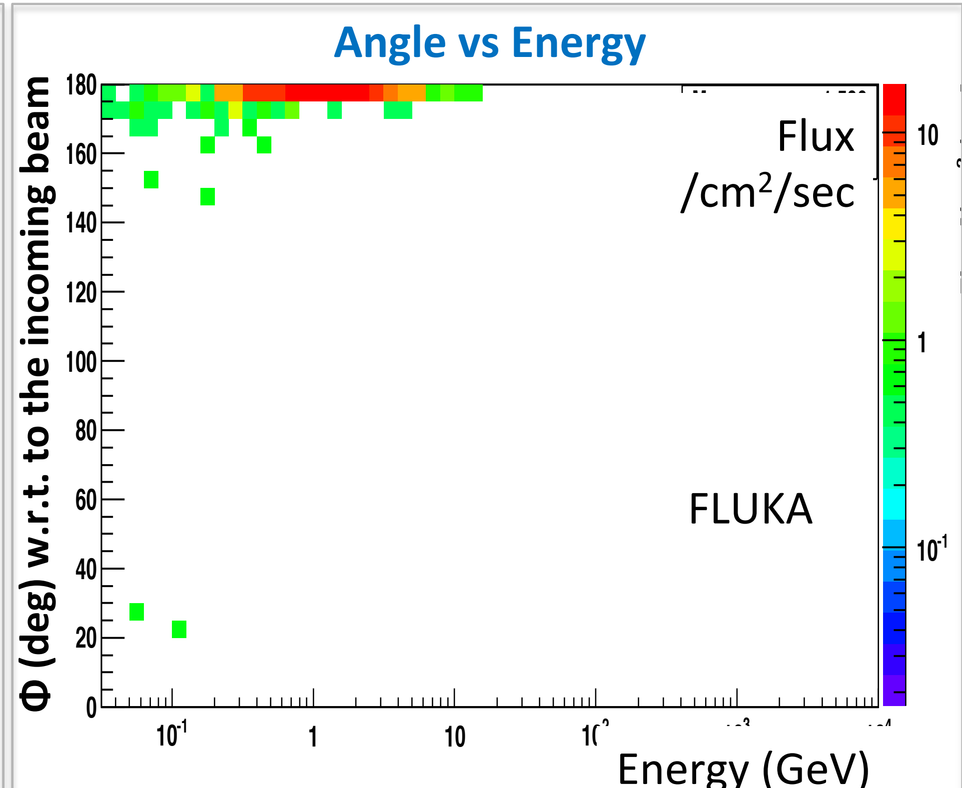


Suppression of PP to 0.1%

Muons from MIB and PP



- **Beam Halo Muons** produced at the collimators:
  - 10GeV region
  - concentrated in angle.

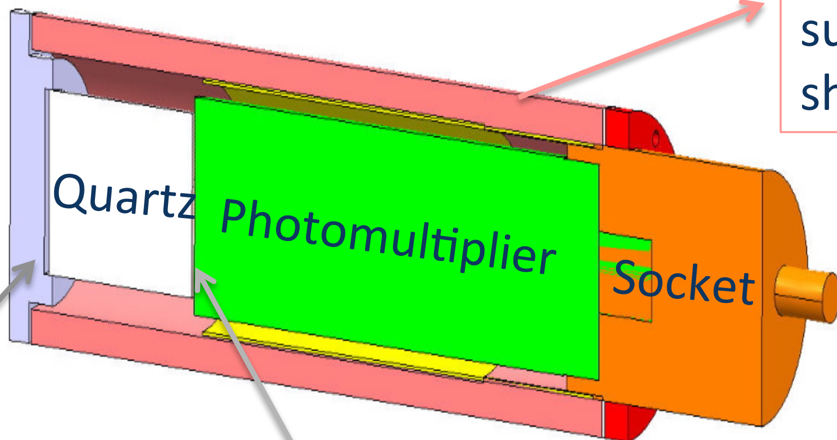


- **PP Muons** arriving straight from the IP
  - under very small angle
  - opposite direction of MIB
- Suppression to 0.1% based on direction.

Mechanical considerations

Aluminum Cap

Soft iron shielding for fake signal suppression & magnetic shielding of PMT.



Black UV absorbent paint

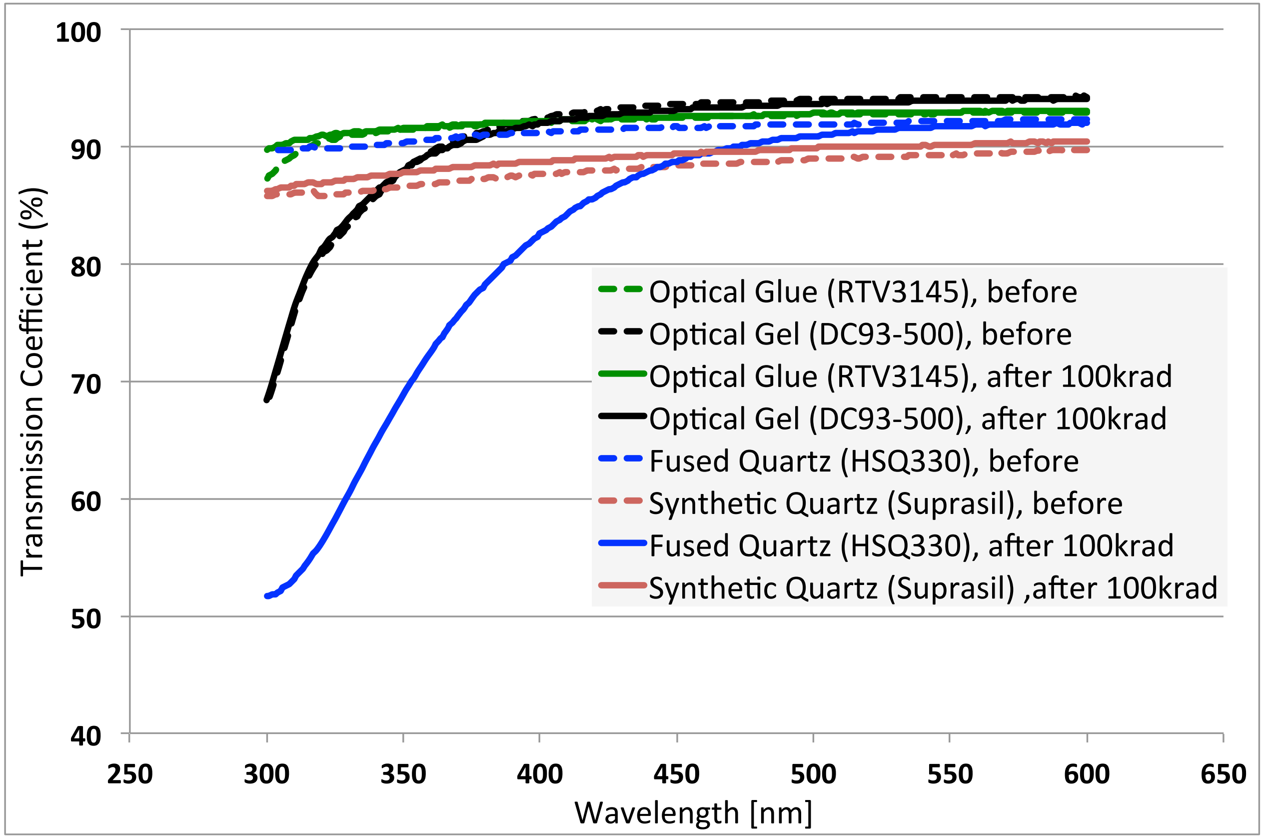
Optical coupling- glue or gel

Why Quartz?

- ✓ Large photon yield
- ✓ Cost Effective
- ✓ Radiation Hard
- ✓ Low scintillation
- ✓ Low attenuation of optical photons

Optical Materials

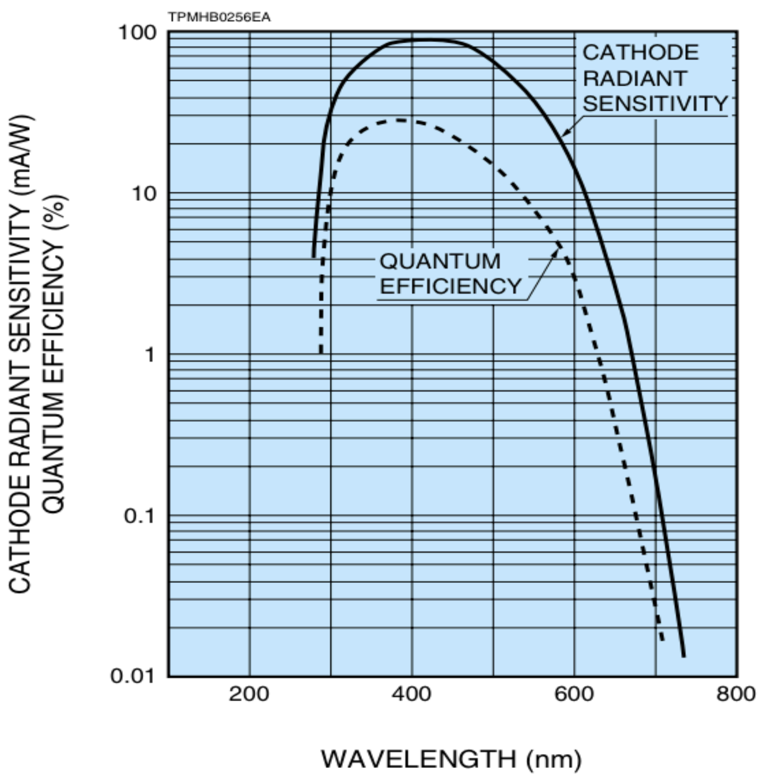
- Cherenkov Radiation more intense in shorter wavelengths.
- Materials chosen such that they transmit UV light even after irradiating samples with twice expected dose (100 krad) γ rays using Co^{60} source.



Photodetector Choice

Hamamatsu R2059

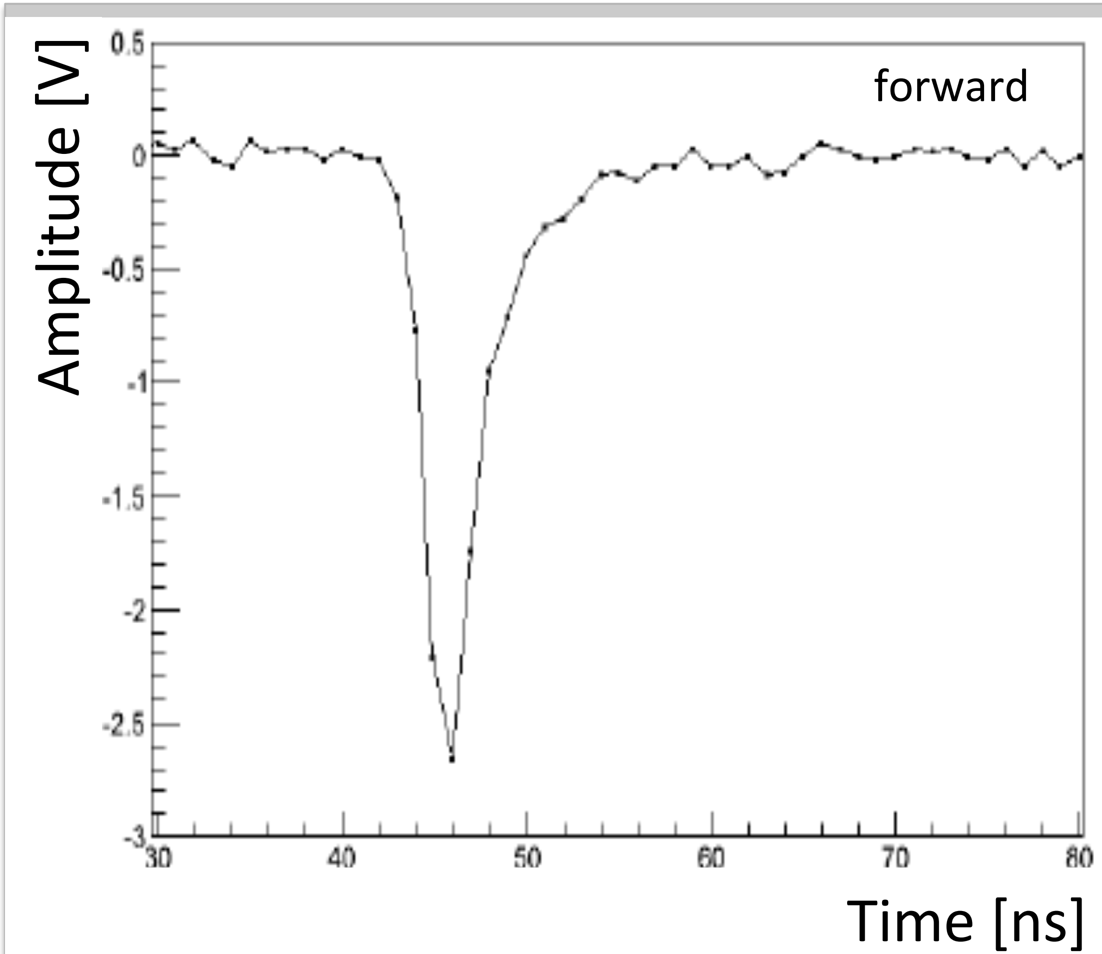
Spectral response	160 to 650nm
Window size	Dia. 51mm
Window material	Quartz
Effective area	d = 46mm Area = 16.6cm^2
Rise time	1.3ns



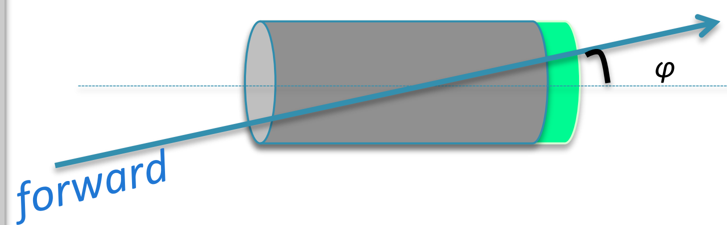
Typical Spectral response of R2059

DECIDED ON 51mm diameter quartz bar to match PMT window.

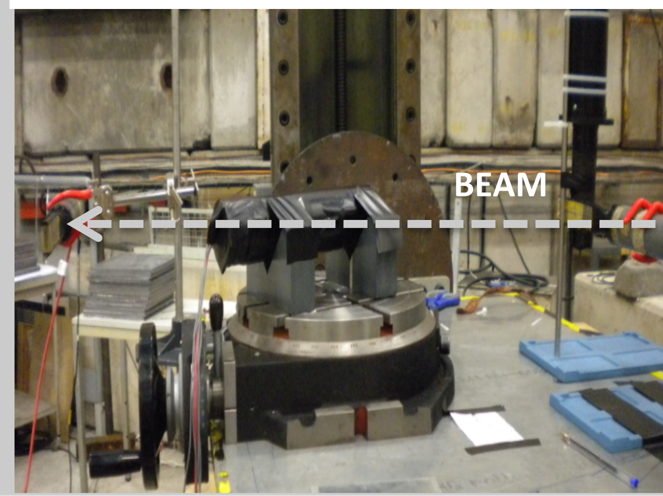
Response to forward particles



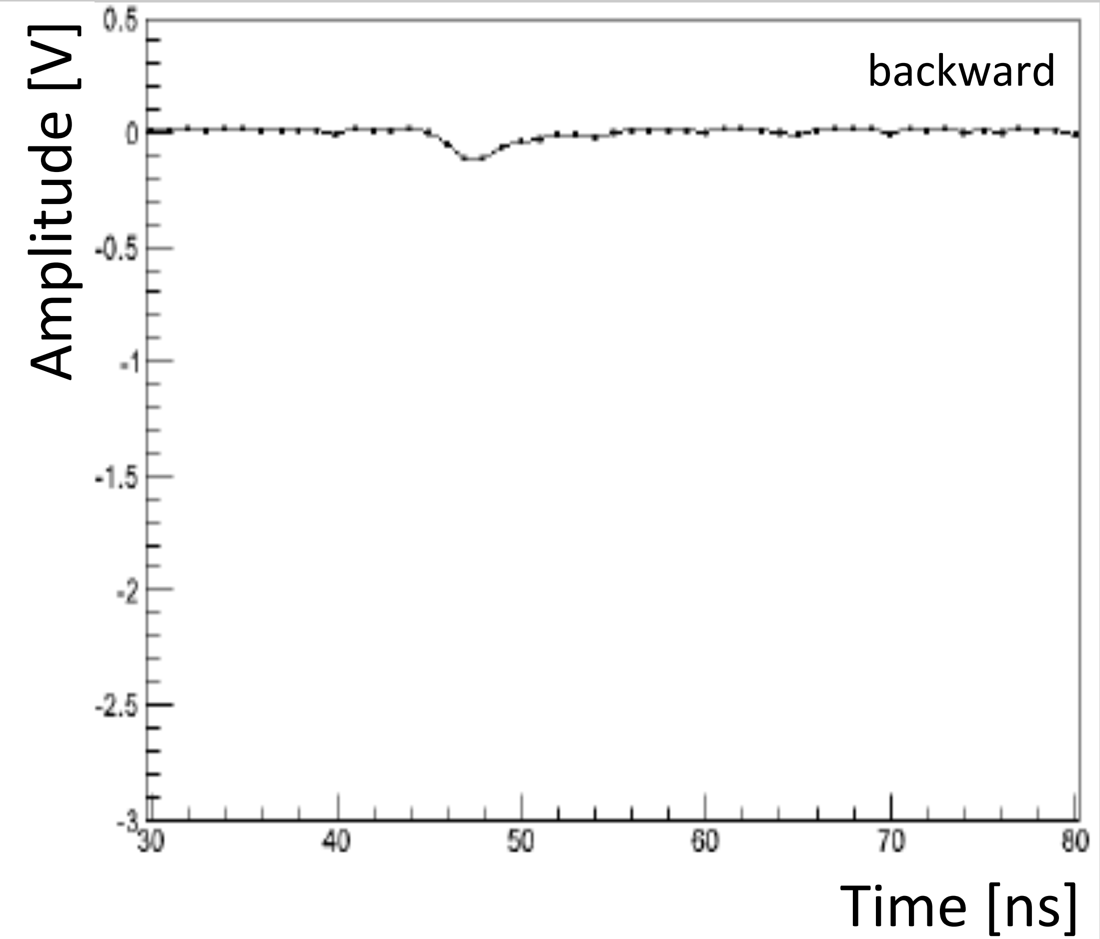
Example waveform from muon arriving under 30deg.



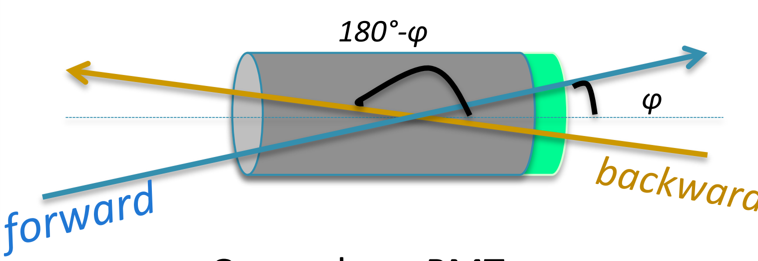
T9 test beam, July 2012



Response to backward particles

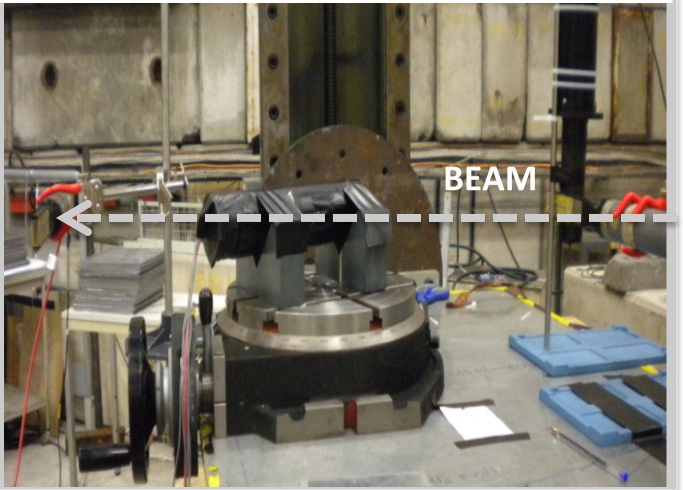


Example waveform from muon arriving under 150deg.



Quartz bar +PMT

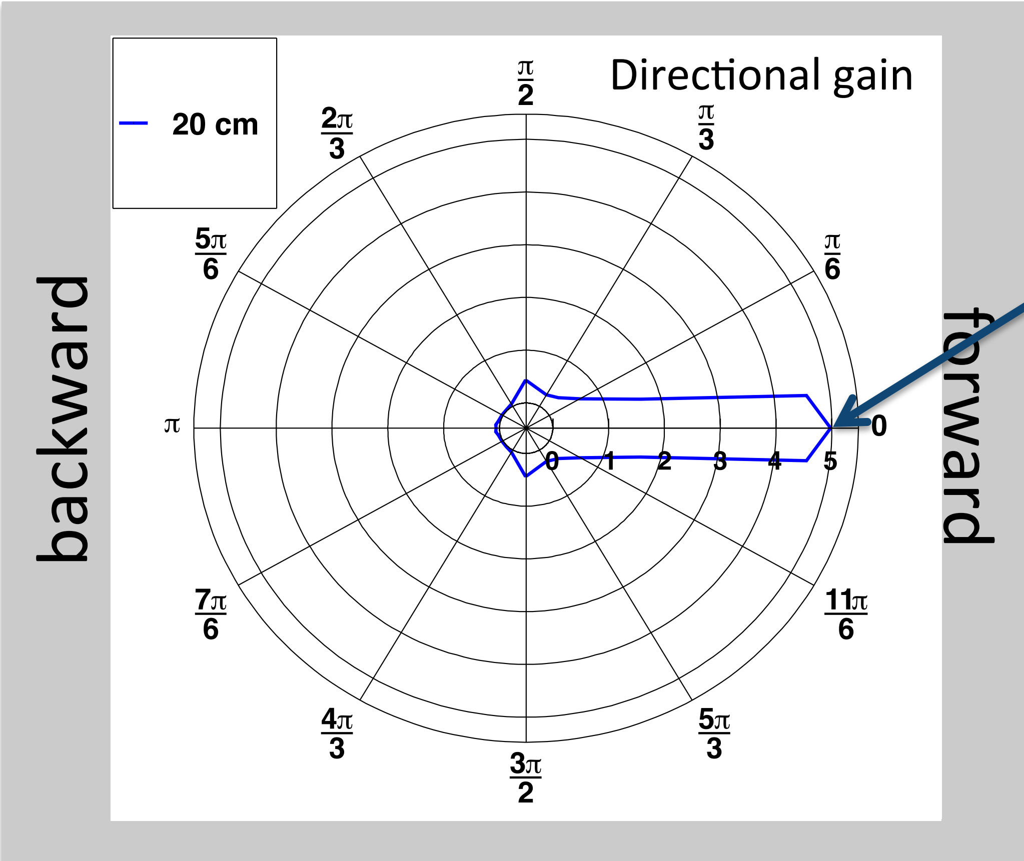
T9 test beam, July 2012



Length of radiator

$$Directional\ Gain\ (l, \varphi) = \frac{Number\ of\ photoelectrons\ (l, \varphi)}{Average\ number\ of\ photoelectrons\ (l)}$$

Geant4 study for lengths of 20cm, 14cm, 10cm, 6cm, 2cm.



Directivity (l) = Max Dir.Gain (l, φ)= Dir.Gain (l ,0°)

Length of radiator

$$Directional\ Gain\ (l, \varphi) = \frac{Number\ of\ photoelectrons\ (l, \varphi)}{Average\ number\ of\ photoelectrons\ (l)}$$

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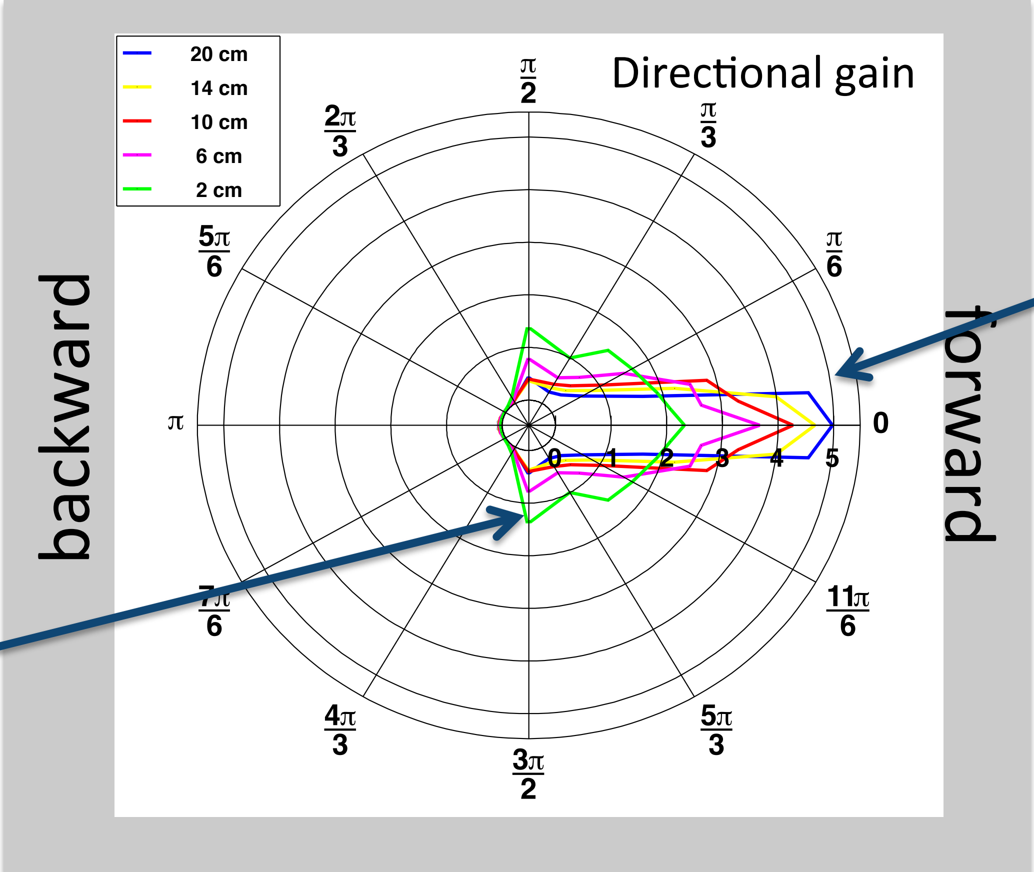
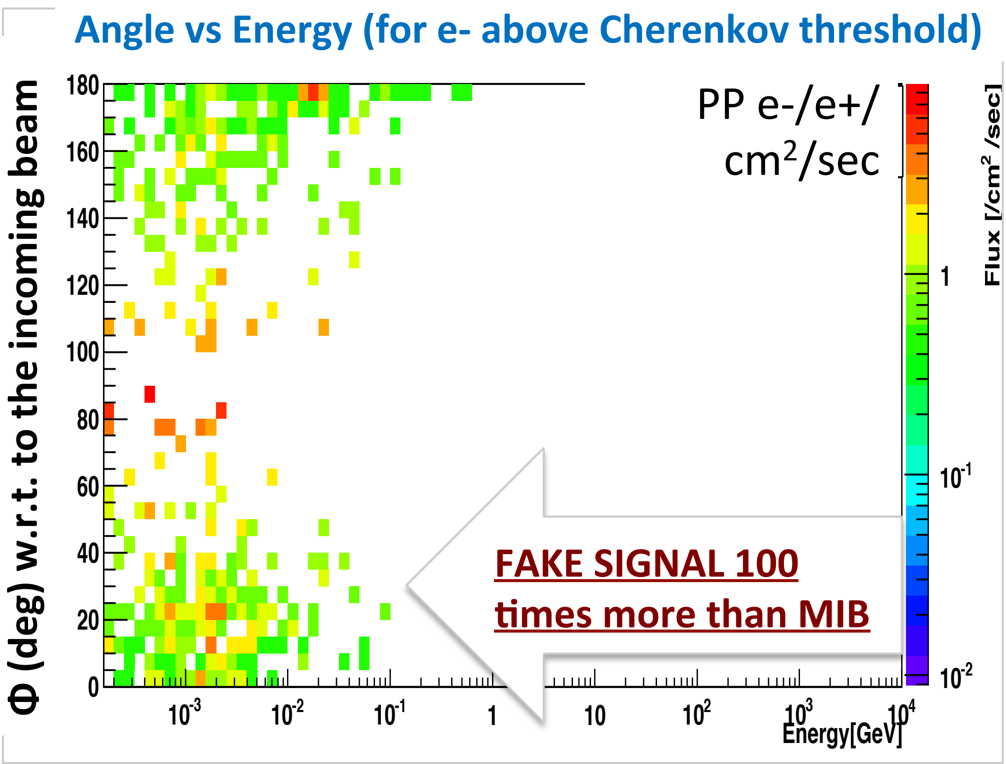


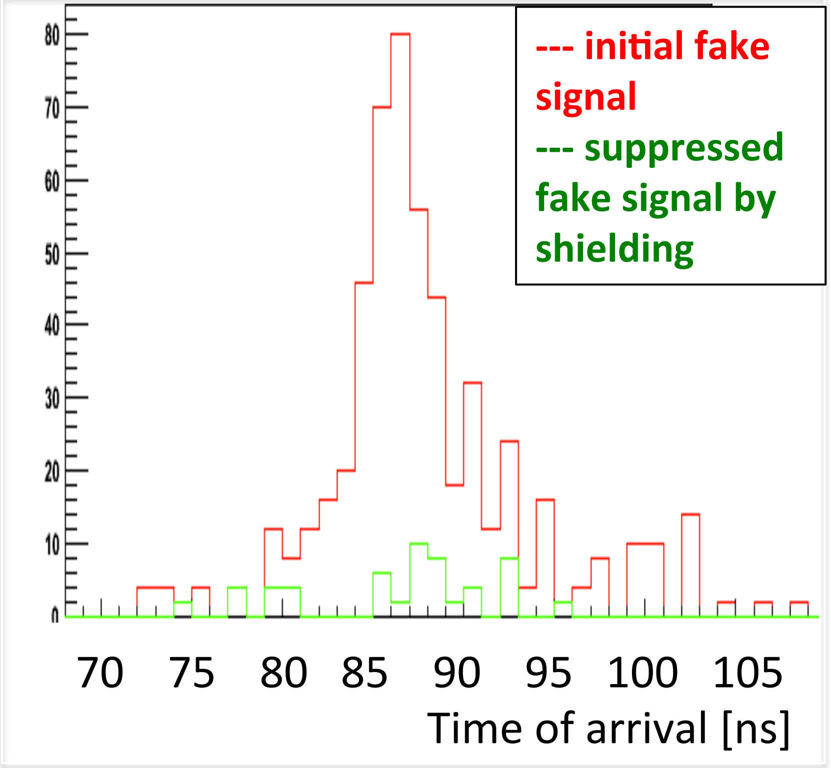
Side lobes and back lobes start becoming significant for $l \leq$ 6cm.

Directivity decreases as the length decreases.

DECIDED ON 10cm length (Directivity > 4).

Shielding



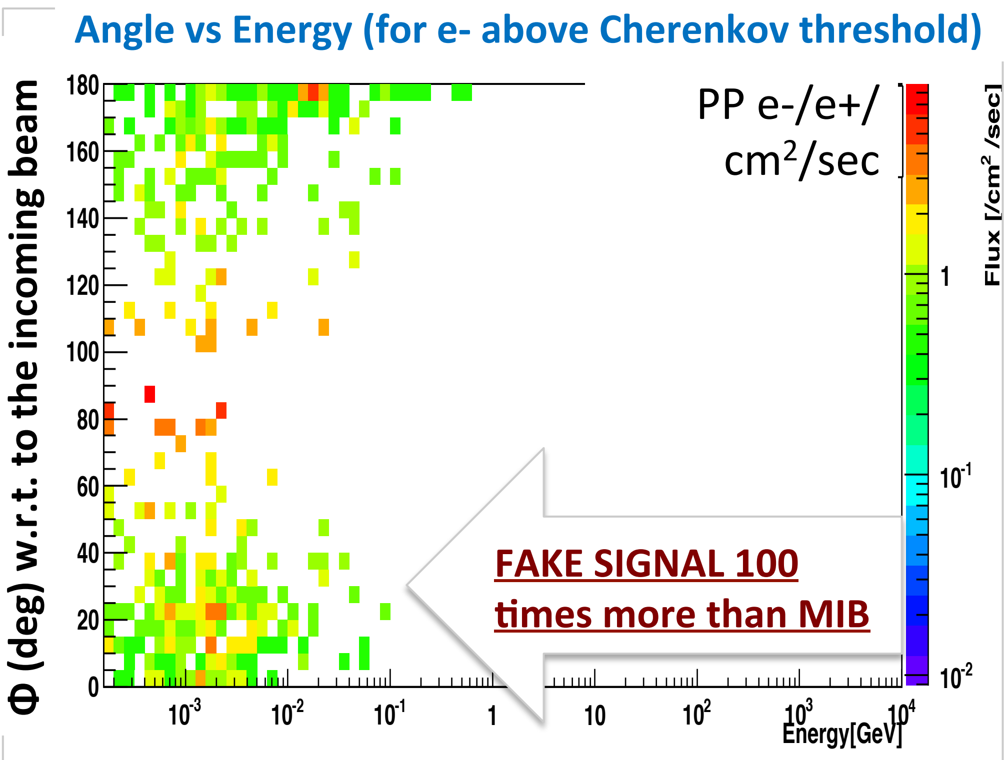


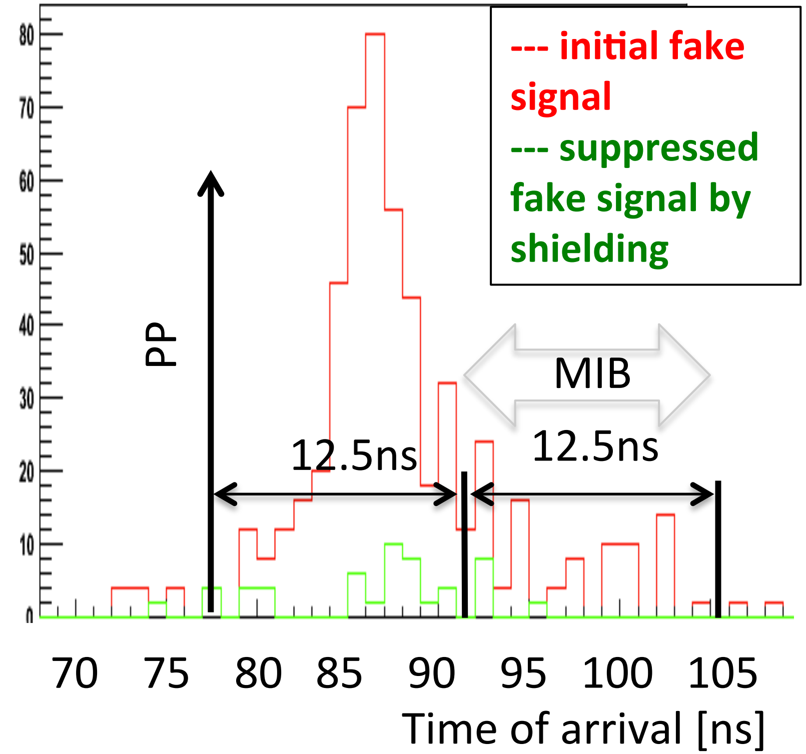
Shielding 5mm soft iron:

- ✓ Stops e-/e+ E<10MeV (>90% of fake signal)
- ✓ Suppresses signal form HE γ's
- ✓ Shields PMT from 200gauss magnetic field

Cherenkov threshold	100%
Passing the shielding	8%

Shielding





Shielding 5mm soft iron:

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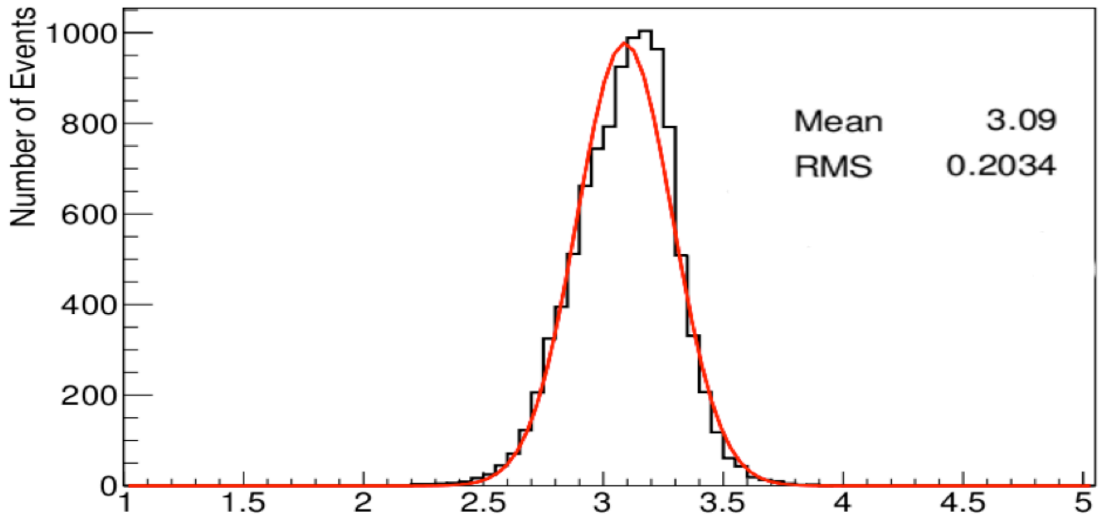
- ✓ Shields PMT from 200gauss magnetic field

Cherenkov threshold	100%
Passing the shielding	8%
Passing shielding and arriving later than 12.5ns	1%

Timing Performance in Test Beams

July 2012 test beam, R2059 +quartz bar, FWHM distribution



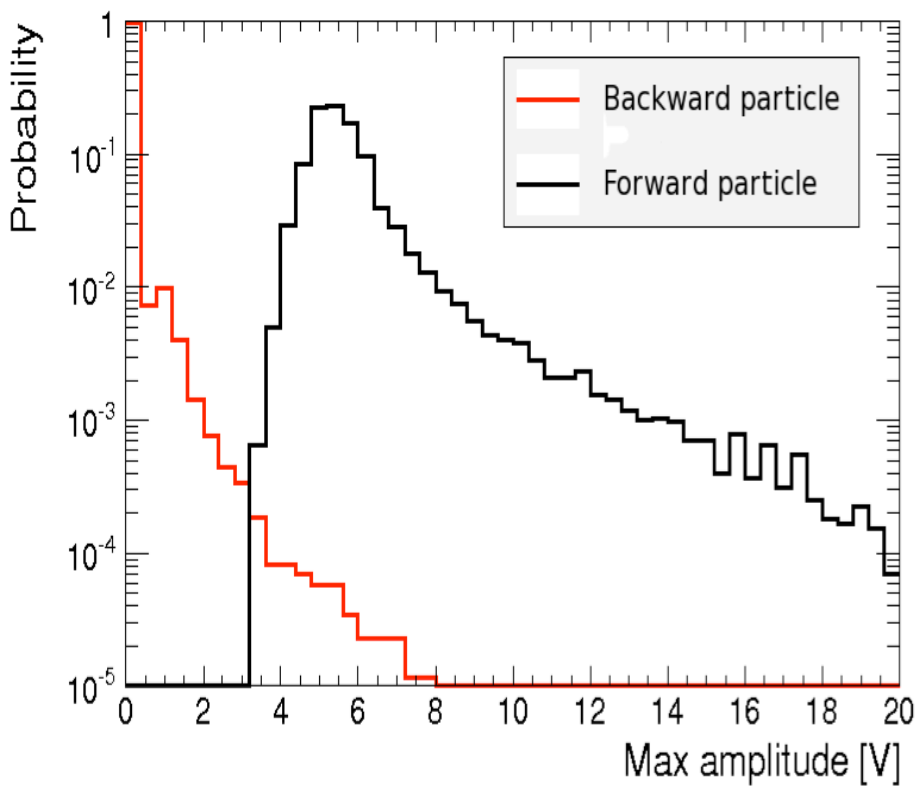
FWHM [ns]

Hamamatsu
R2059 PMT

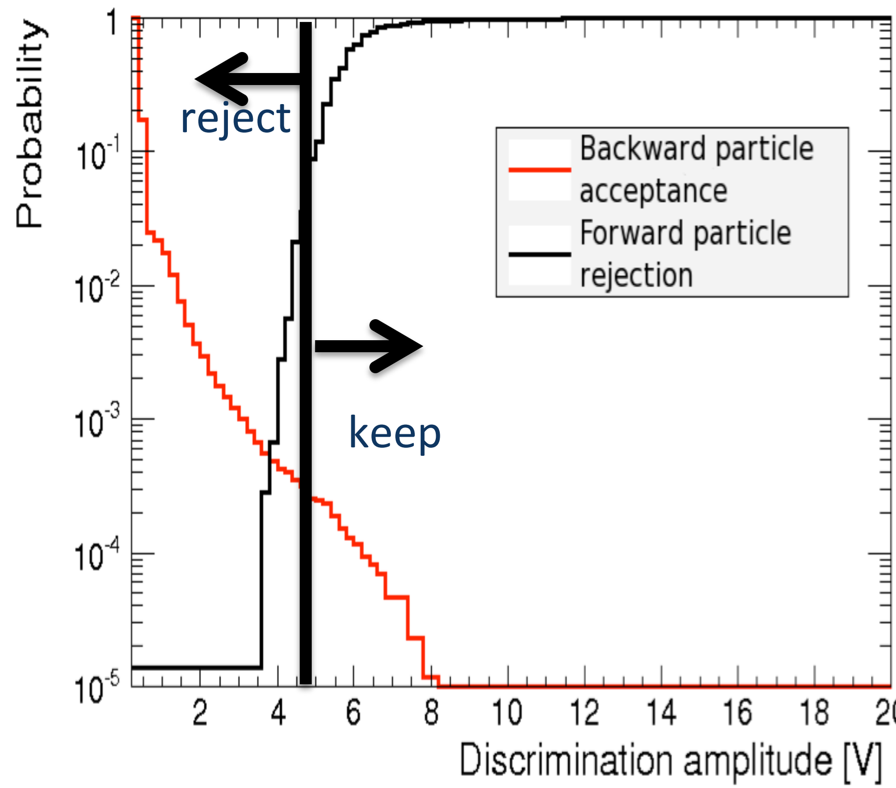
✓ **Fast timing distribution of the signal = 3.1ns FWHM << 12.5ns**

Rejection Efficiency in Test Beams

December 2012 test beam, 0deg (forward) vs 180deg (backward) proton



Normalized amplitude distributions

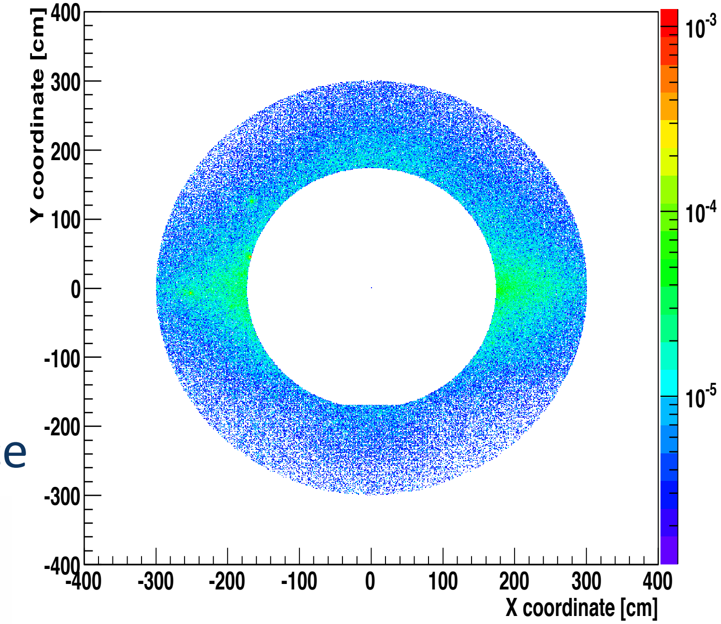


Accumulative (0deg) and Inverse accumulative (180deg) amplitude distributions

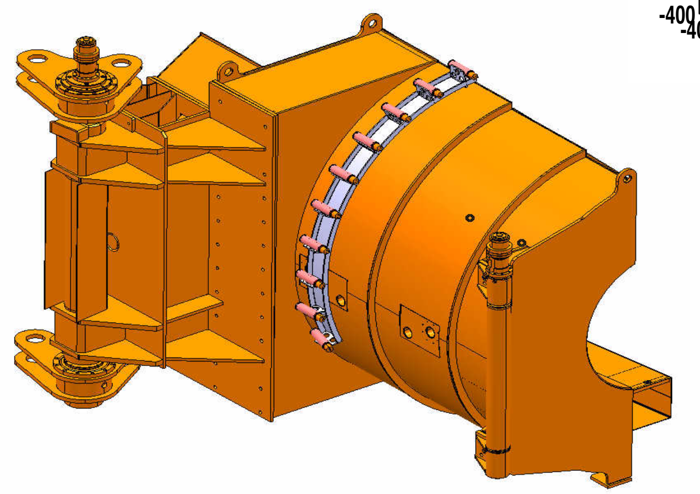
✓ **Cut @4.8V: Backward suppression to 0.03%, forward acceptance 91%**

System overview

- 51mm diameter->20.4cm^2 /channel
- MIB rate *O*(Hz/cm^2)
- Need a ~1MIB hit/bunch crossing
  - acceptance of ~400cm^2
  - 20 channels / Z end
- Orientation of 0deg for max. directional gain
- Azimuthal distribution with overlapping acceptance with the CSC muon chambers



MIB XY distribution at Golden Location 6.



Conclusions

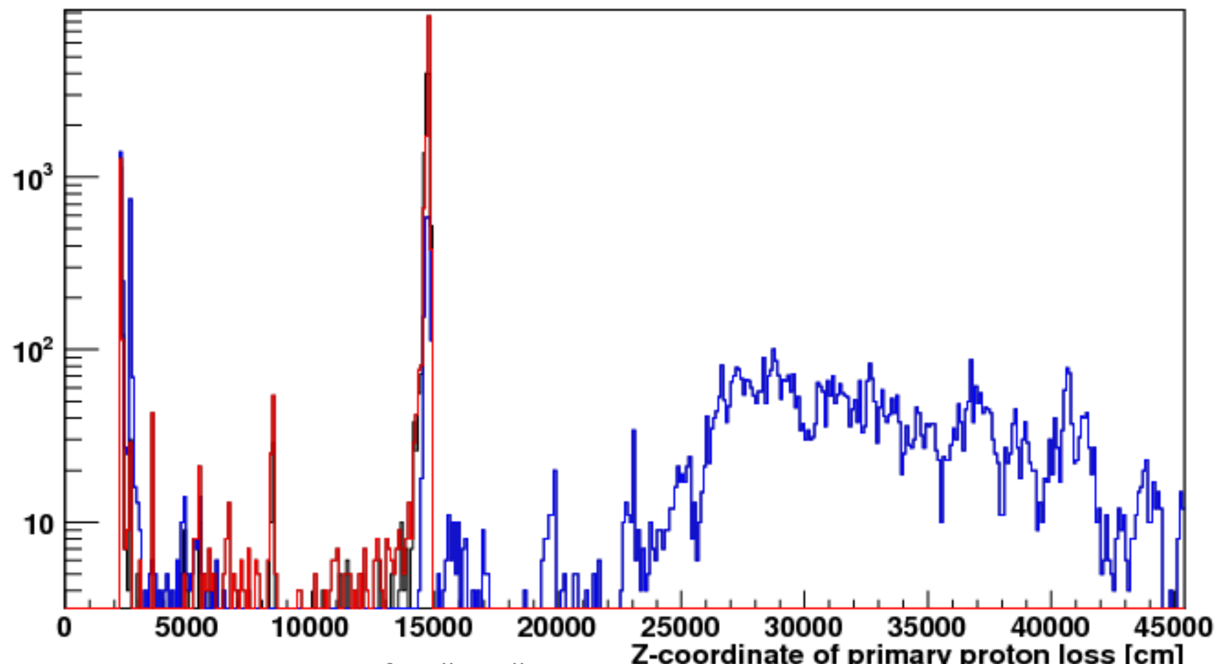
- A new Cherenkov-based MIB monitoring system has been designed and will be installed during LS1.
- The system has a response
  - 3.1ns and is able to distinguish MIB from pp based on time of arrival by standing in a Golden Location.
  - directional to suppress the signal produced from backward particles to 0.1%.
- Basic components of the detector unit:
  - Synthetically fused silica
  - R2059 Hamamatsu photomultiplier.
  - Soft iron shielding to suppress fake signal, HE γ, magnetic field.
- System performance has been verified during test beams.
- 20 channels / end will be azimuthally distributed.

THANK YOU!

MIB Components

- Beam Halo & Beam Gas Elastic: originate mostly from interactions with TCT
- Beam Gas Inelastic: originate all along LSS

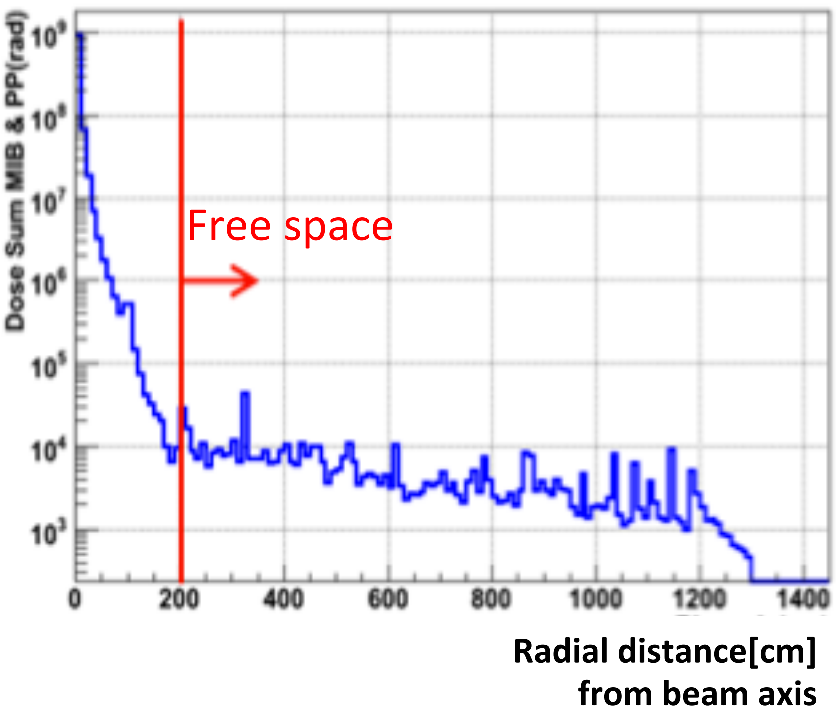
→ mainly sensitive to MIB created at $z>20m$ (~parallel to beam pipe)



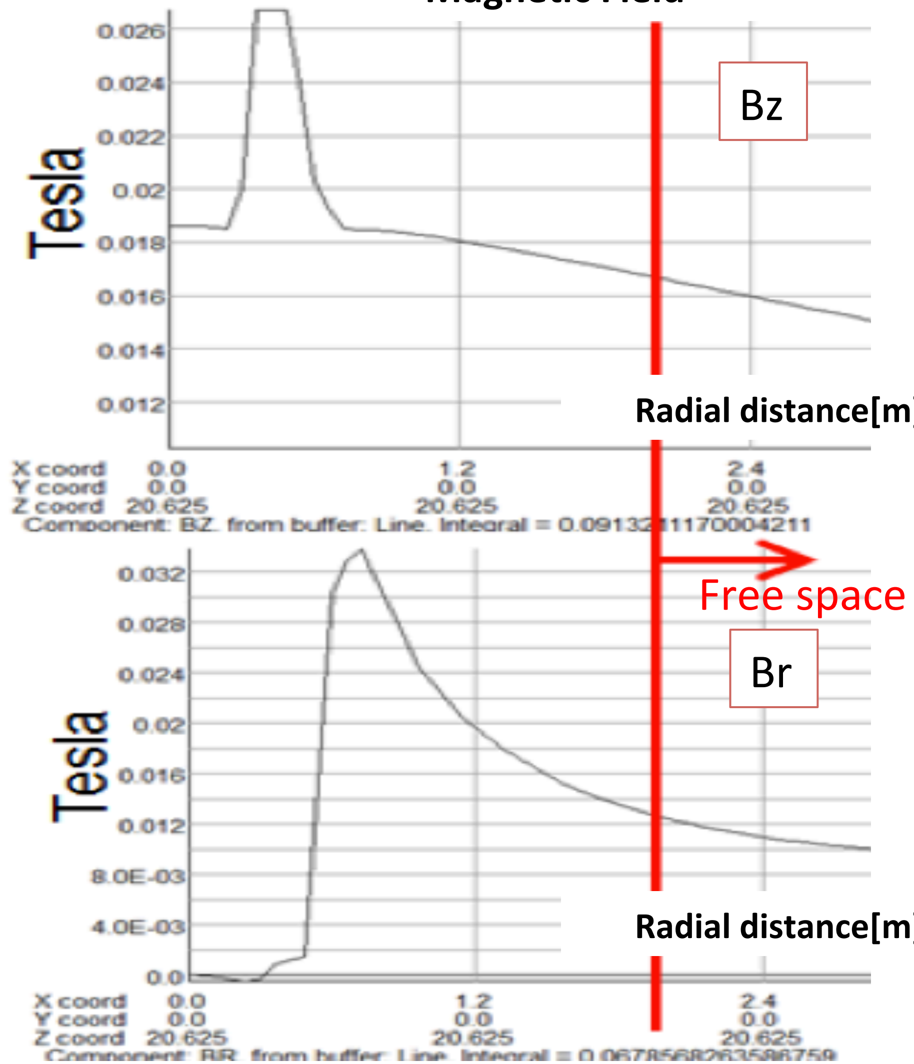
Golden Location 6 Environmental Parameters

1)Expected dose for 10 years of operation <1kGy
2)Magnetic Field <200gauss

Radiation dose in rad for 10years of operation



Magnetic Field



Golden Location choice

Two metrics used to conclude to the most preferable:
1) MIB/PP flux ratio 2) Absolute value of MIB flux.

Golden Locations 1 to 3:

Are very close to the IP ->very high PP contribution ✗

Golden Locations 4 to 6:

Closer to the tunnel than to the IP -> higher MIB flux (see table*) ✓

4: Difficult in integration (not much free space) ✗

5: Lower MIB flux values than GL4 and GL6 ✗

6: High MIB flux and much free space ✓✓✓✓

Golden Location	Z (m)	Min Ratio	Max Ratio	MIB Flux (cm^2/s)
4	13.125	$(1.94 \pm 16.3) \times 10^{-3}$	$(2.43 \pm 0.32) \times 10^{-2}$	$0.099 - 0.512 \pm 0.237$
5	16.875	$(4.42 \pm 7.64) \times 10^{-4}$	$(1.64 \pm 0.15) \times 10^{-3}$	$0.154 - 1.160 \pm 0.446$
6	20.625	$(5.07 \pm 2.00) \times 10^{-4}$	$(2.63 \pm 0.52) \times 10^{-3}$	$0.142 - 0.975 \pm 0.289$

MIB/PP Ratio:
~O(10^-3-10^-4)
MIB flux:
~O(0.1-1) part/cm^2/sec

Spectral Response of Radiator

Expected wavelength from quartz bar