Muon R&D Status and Plans

H. R. Band, G. Fisk, P. Karchin

- *Muon Backgrounds – New Shielding Studies*
  - *Muon Backgrounds with Reduced Muon Spoilers – N. MOKHOV*
- *RPC Reports & Studies*
  - *R&D with the BES/Daya Bay RPCs – C. LU (Princeton)*
  - *Experience with the BELLE Glass RPCs - Leo PIILONEN (Va. Tech.)*

Muon System Talks

- **Scintillator/MAPMT Reports & Studies**
  - Calibration of MAPMT channels w/a QVT setup - P. KARCHIN (Wayne St)
  - MAPMT Chan. Response with a Radioactive Source – A. DYCHKANT (NIU)
  - Analysis of Scintillator/PMT Testbeam Data - C. MILSTENE (FNAL)
- **SiPMs MPPCs**
  - TCMT preliminary test beam results – K. FRANCIS (NIU) SiPM
  - Characterization Measurements – A. PARA (FNAL)
  - T2K experience with scintillator/MPPC detector – M. YOKOYAMA
- **Future Issues**
  - Plans for the Muon System – H. BAND (U. Wisc.)

Shielding Studies Report – N. Mokhov

GDE changed muon spoiler design last fall from a 9m + 18 m spoiler wall to a single 5 m wall

BDIR MARS calculation of muons produced upstream:

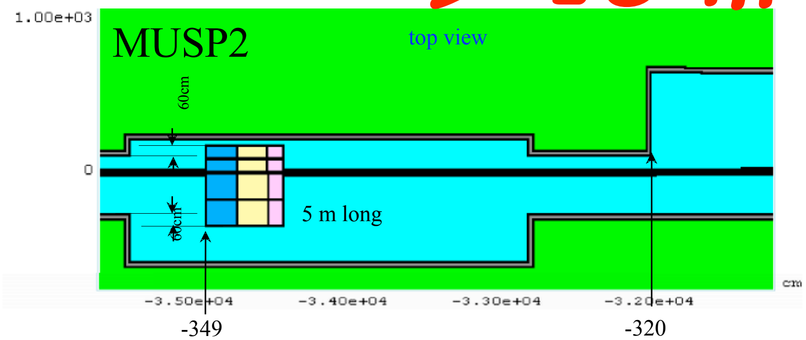
1700m, SiD (GEANT4) at IP, with 200m extraction line.

Install magnetized Fe spoilers or Fe doughnuts in the BDS.

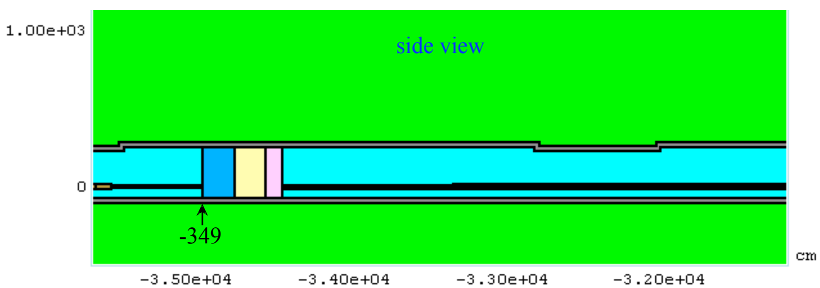
BEAM PARAMETERS

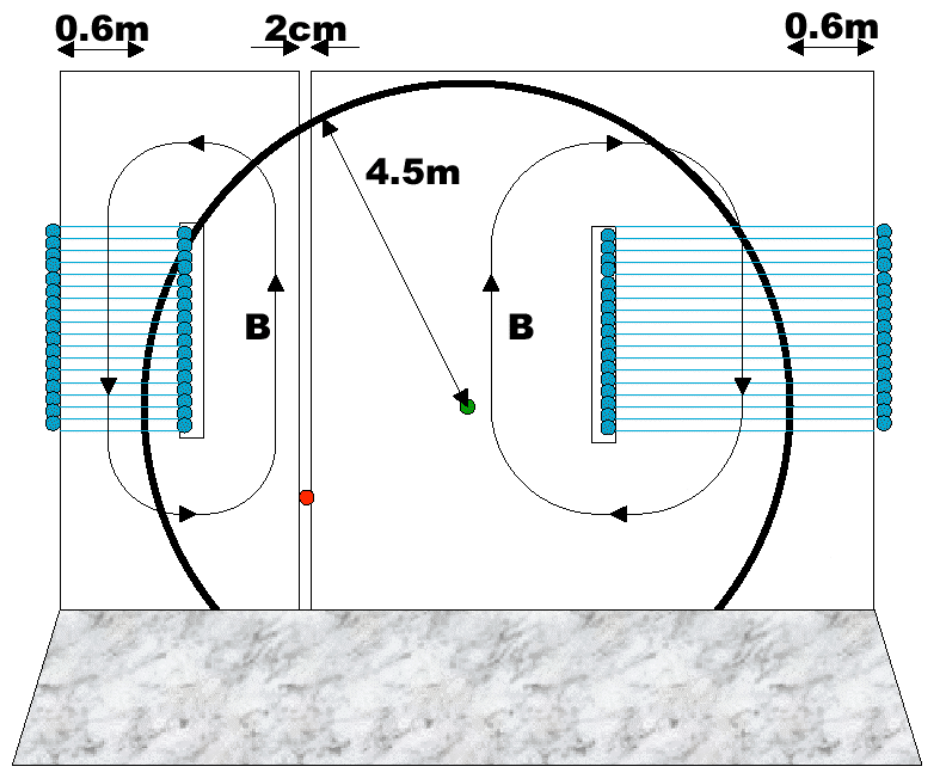
- *250-GeV*
- *5 trains per second*
- *2820 bunches in each train*
- *300 ns between bunches*
- *199 ms between trains*
- *Train length 868 μs*
- *2×10^{10} positrons/electrons per bunch*
- *Luminosity 2×10^{34} cm^{-2} s^{-1}*

TUNNEL MUON SPOILERS: 9+18 m or 5 m Walls

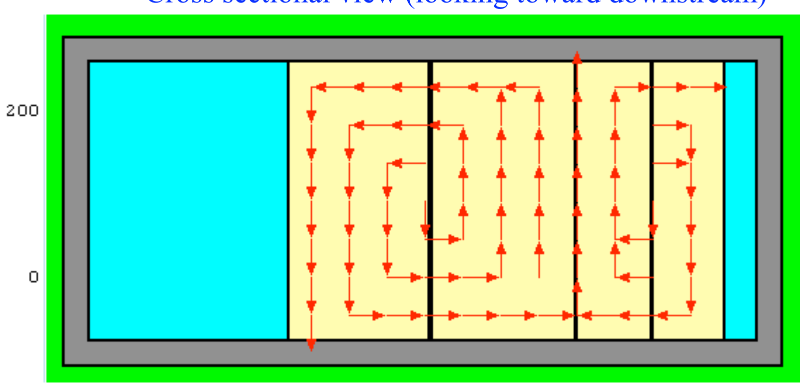


Thick steel 1.5-T magnetic wall sealing tunnel x-section, to spray the muons out of the tunnel

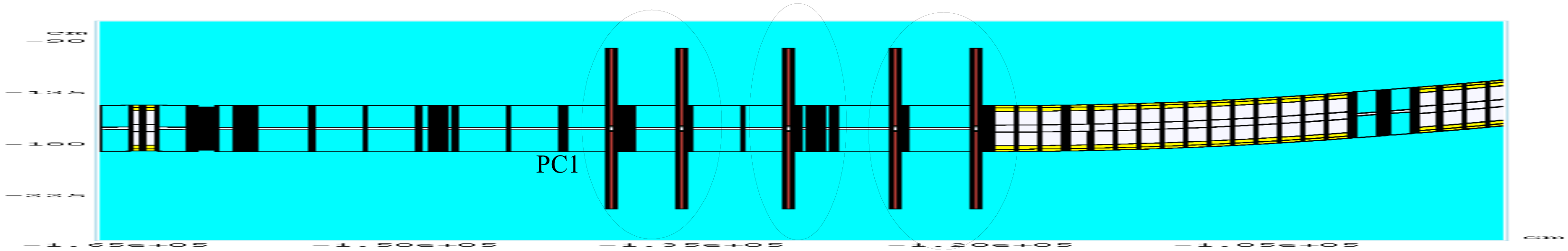


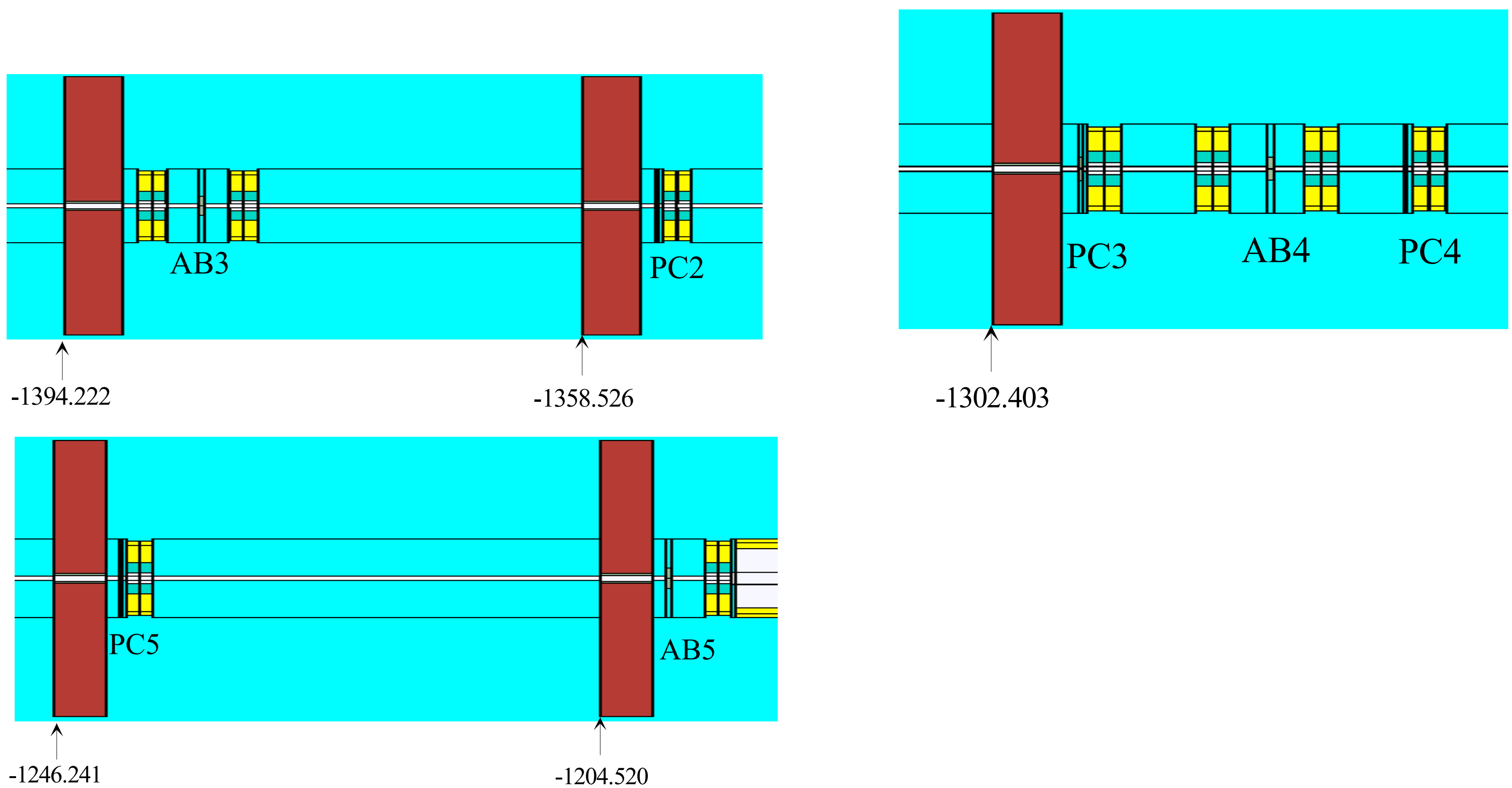


Cross sectional view (looking toward downstream)



Five 4-m Thick Doughnut Scheme





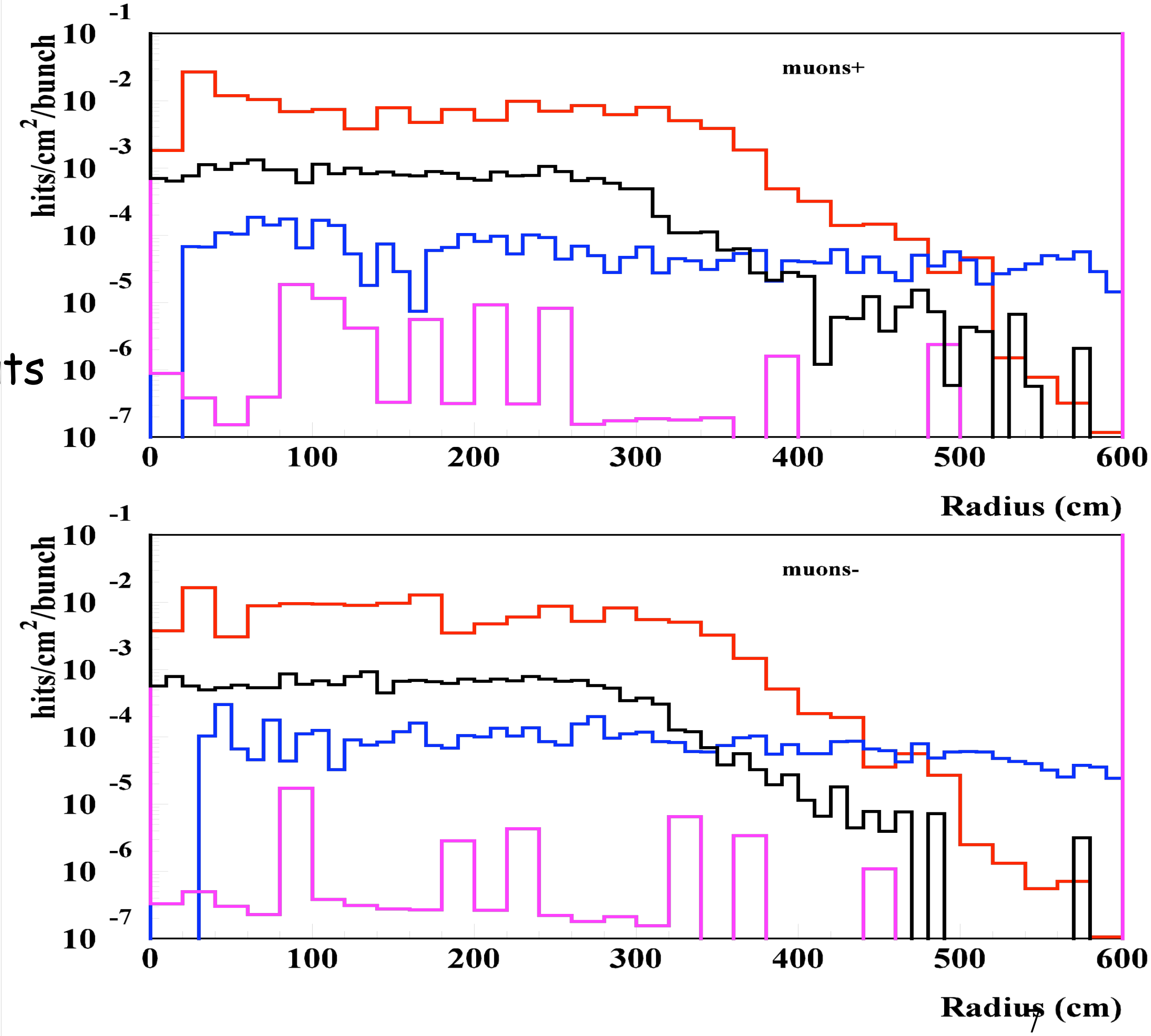
Hits in Muon Endcap (cm^{-2}/bunch) at SiD from e^+ BDS

Red lines: no shielding
Magenta: 9m + 18m walls
Blue: 5m wall
Black: Five 4-m doughnuts

~4.1 Hz/cm^2

~0.04 Hz/cm^2

~1.2 10^{-3} Hz/cm^2



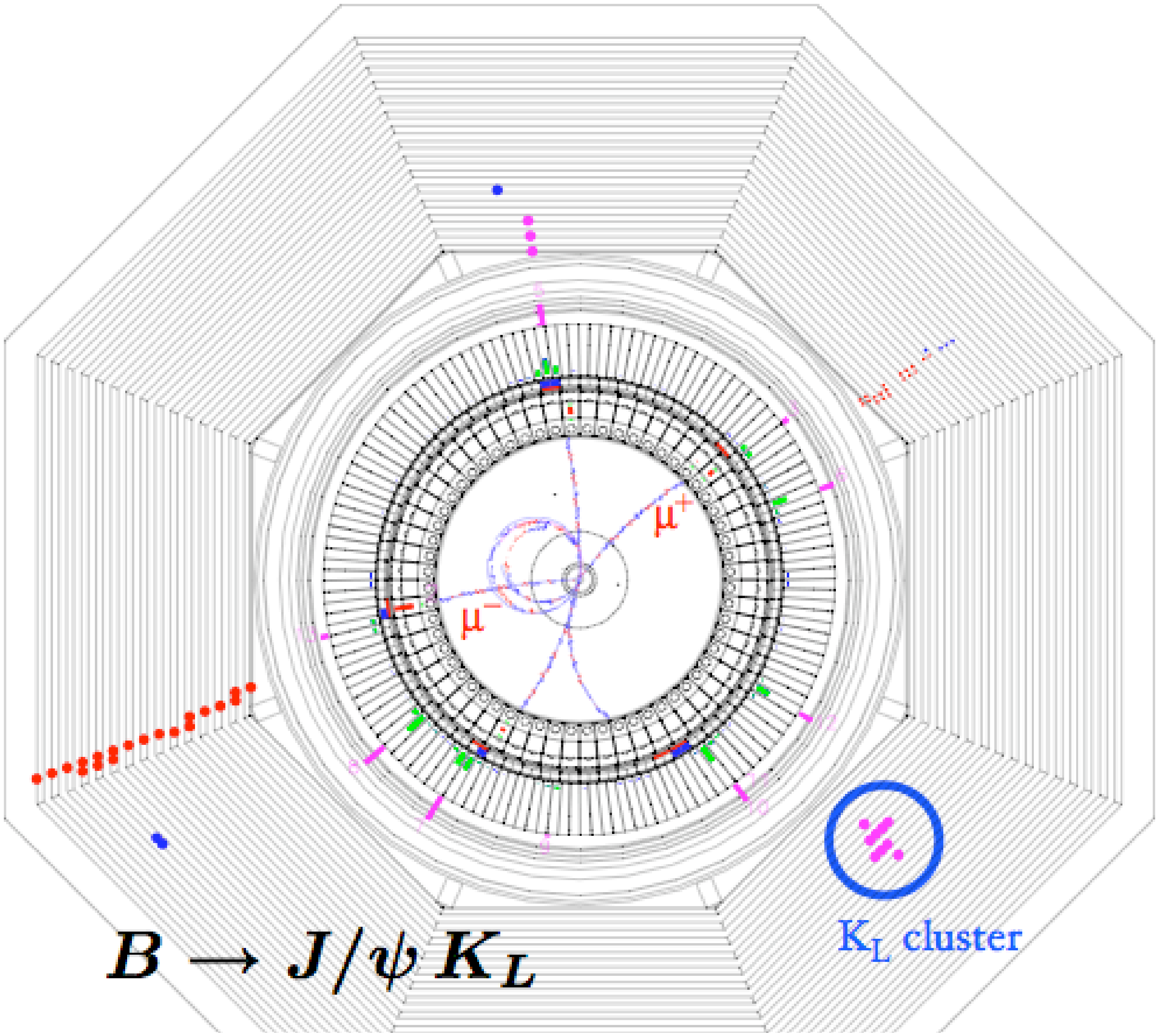
SUMMARY

• 5-m thick tunnel-filling iron magnetic walls at ~350 m from IP (both sides) provide adequate reduction of BDS-originated muon backgrounds at SiD, improving its longevity and performance. They also provide radiation protection needed for work underground when beam is on with two IRs or in a push-pull scenario.

• Five 4-m long 0.7-m radius magnetic doughnuts provide needed suppression of muon fluxes at SiD. An increased scheme (with 7-10 doughnuts) can provide sufficient safety margin. Alternatively, additional shielding wall close to IP would work. Such a wall may be needed anyway to bring the radiation levels in the IR below the regulatory limits with two IRs or in a detector push-pull case.

Bell Glass RPCs

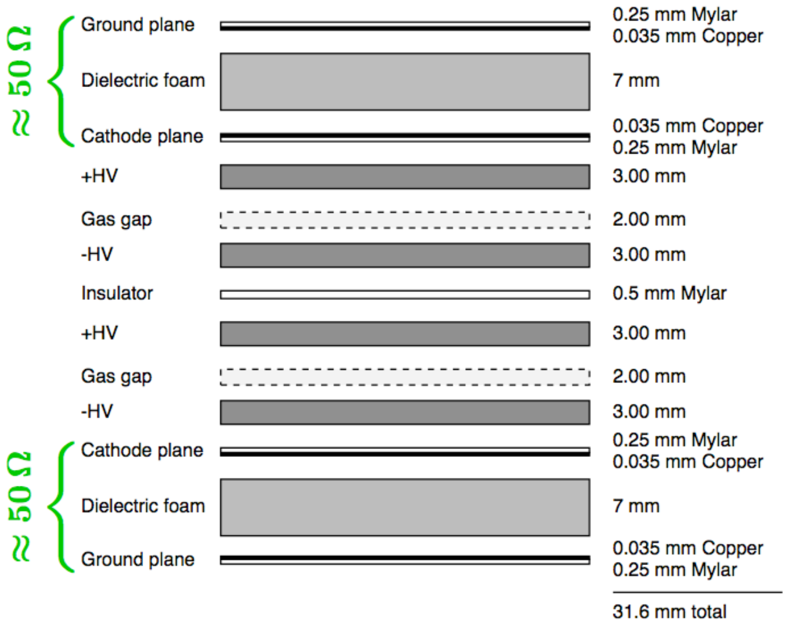
Leo PIILONEN (Va. Tech.)



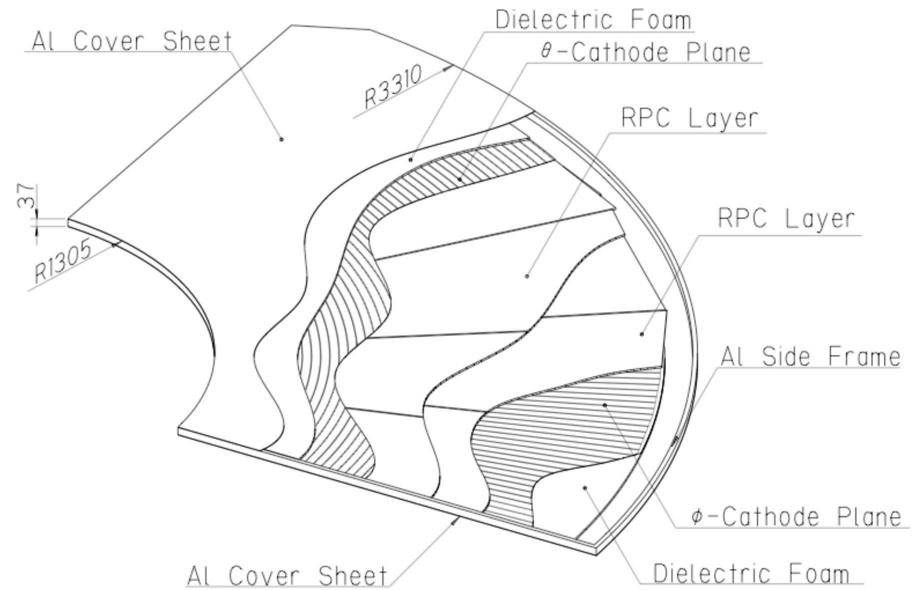
$B \to J/\psi\, K_L$

Belle Glass RPCs

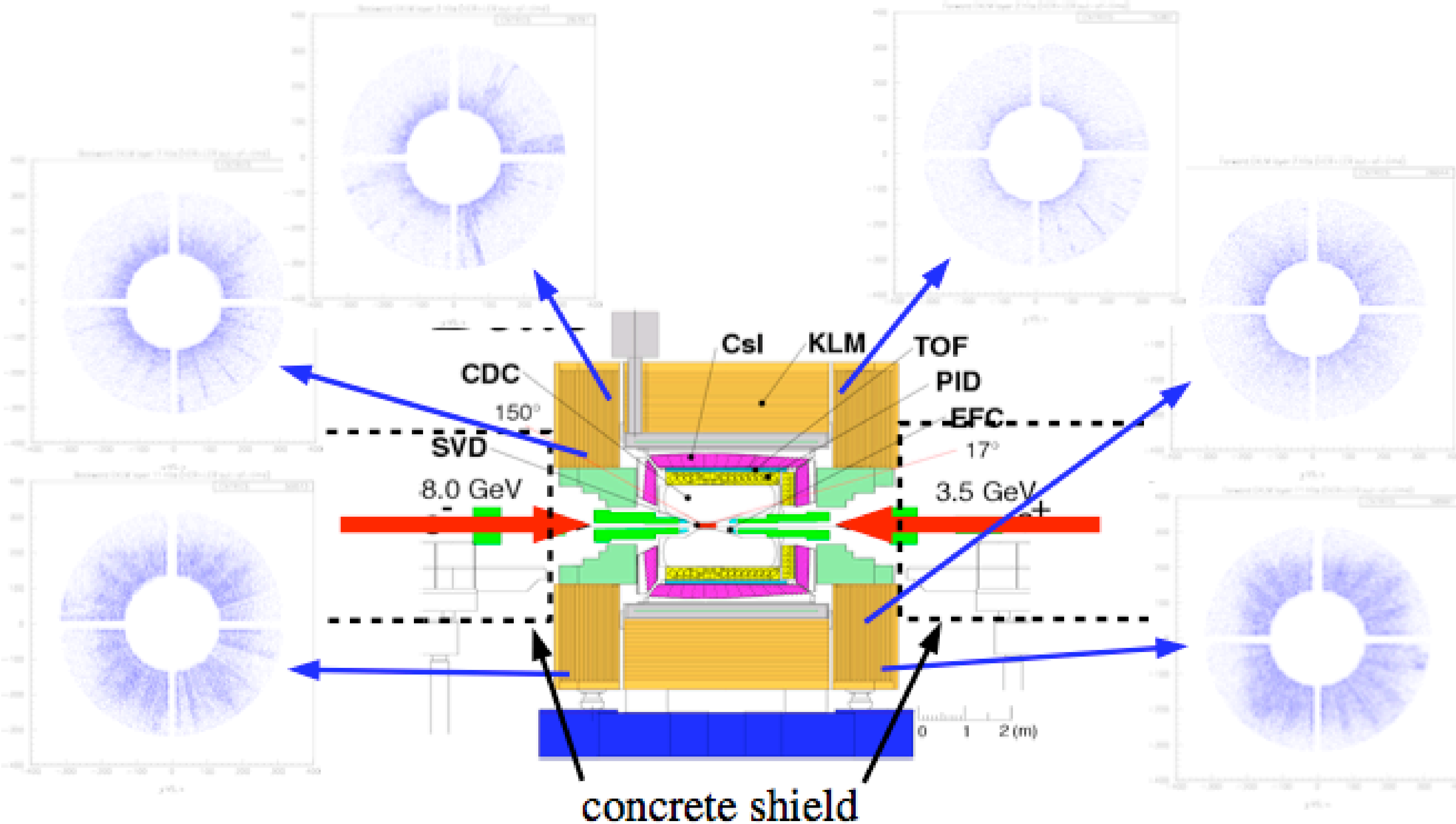
An RPC superlayer contains two RPCs and *x-y* electrodes



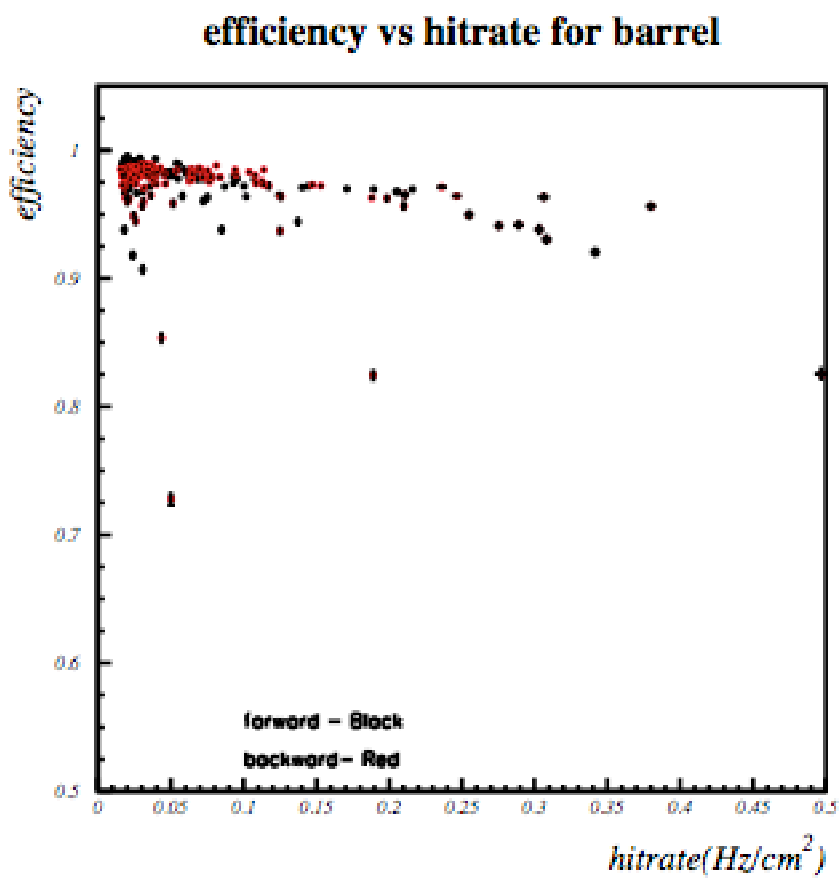
An endcap RPC superlayer quadrant contains ten RPCs

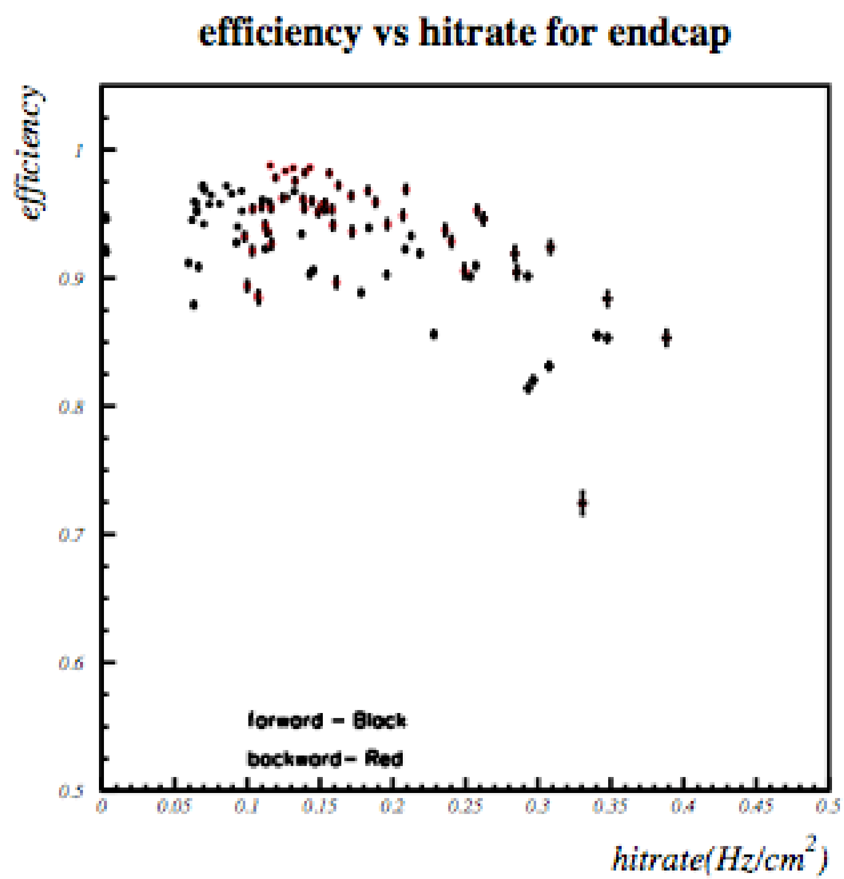


Beam background (neutrons) illuminates the endcaps



High glass-electrode resistivity causes efficiency to drop with increased hit rate





Summary

- Glass-electrode RPCs have performed well in the Belle KLM subsystem

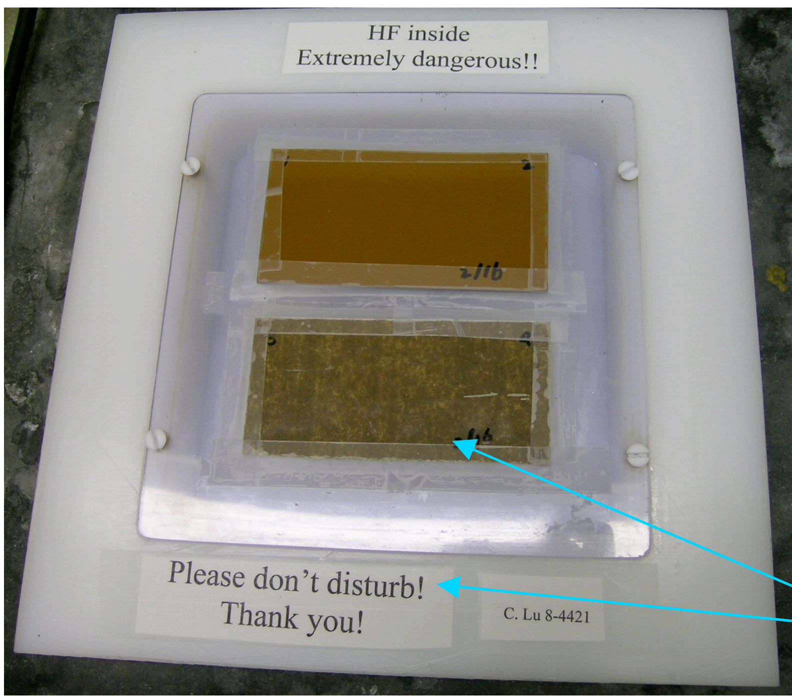
- No irreversible deterioration seen since commissioning in 1999 *[sensitivity to water vapour in gas corrected by replacing polyolefin gas lines with copper]*

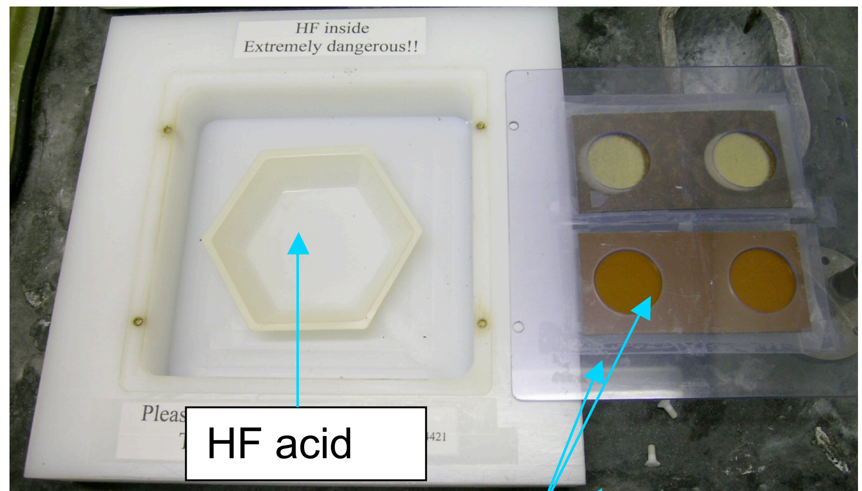
- Extrapolated efficiencies at Super-KEKB luminosity imply that endcap RPCs will have to be replaced *[with scintillators?]*

RPC - Tests

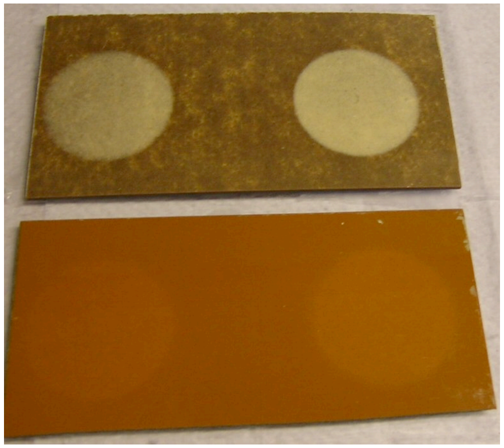
C. - Lu Princeton

Test resistance to HF gas exposure



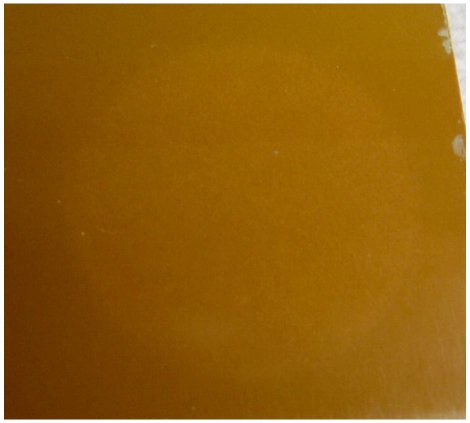


Effect on BaBar Bakelite surface

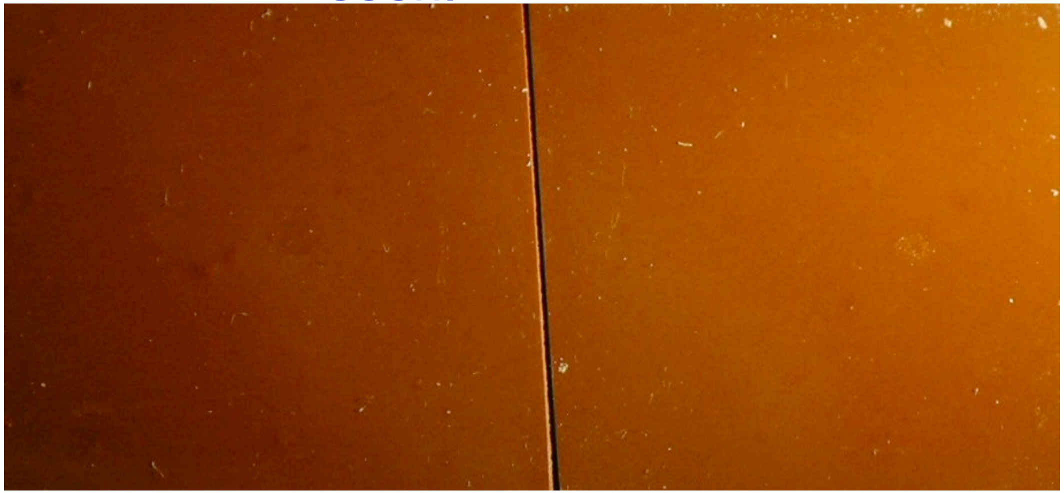


Marble side of BaBar Bakelite plate, the marble-pattern is completely disappeared, also discolored.

The Linseed oil coated Bakelite surface is much better protected from HF vapor attack. After 24 hours of exposure there is no discolored area can be seen.

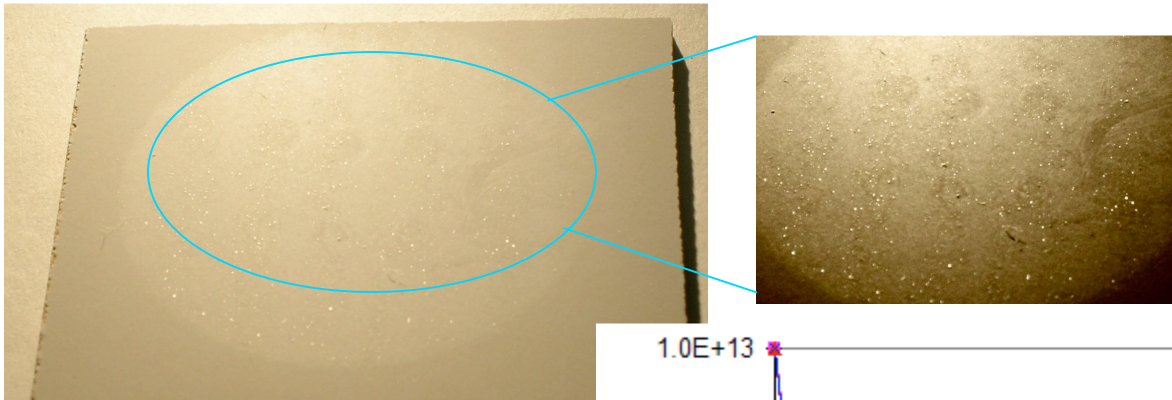


Brown side of Bakelite plate shows slightly discolored mark.

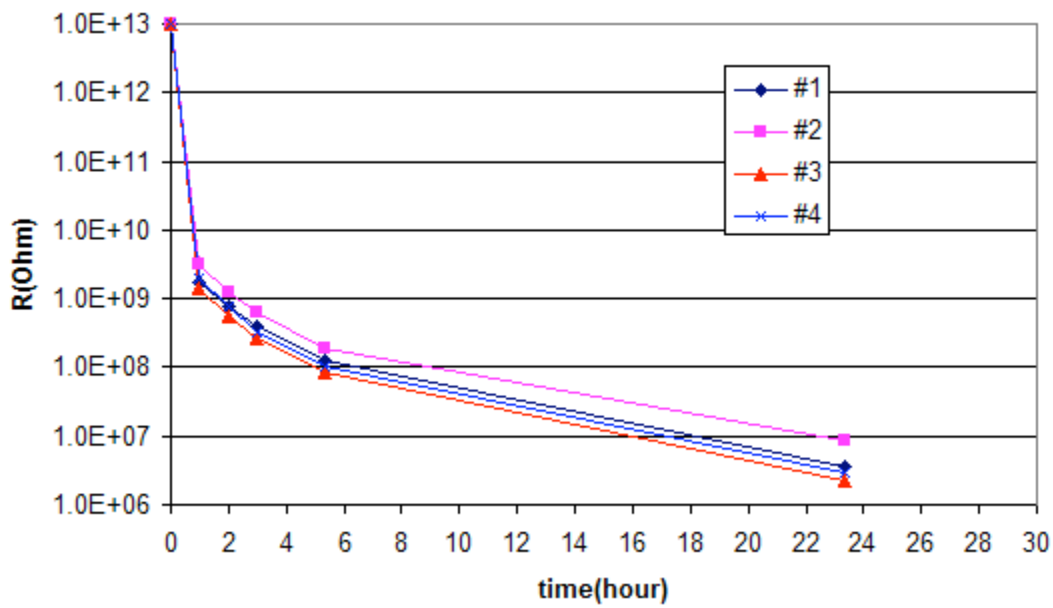


Effect on IHEP Bakelite surface

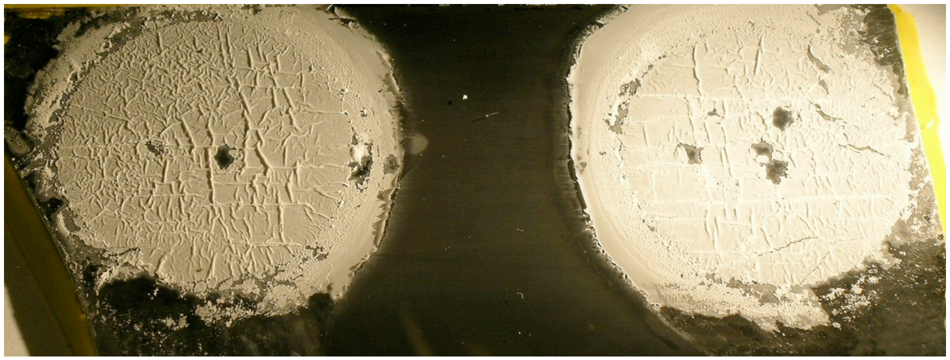
Surface has been badly attacked by HF vapor.



Surface resistivity drops very fast in first hour of exposure.

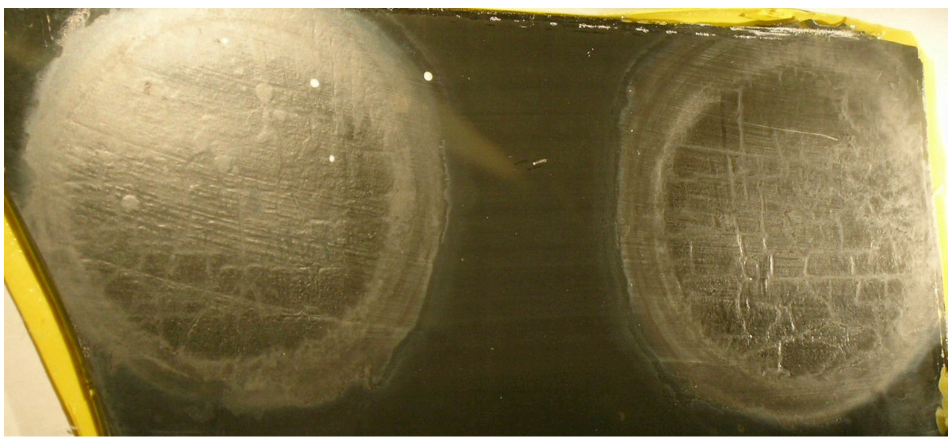


Effect on various other materials



Belle's RPC glass surface

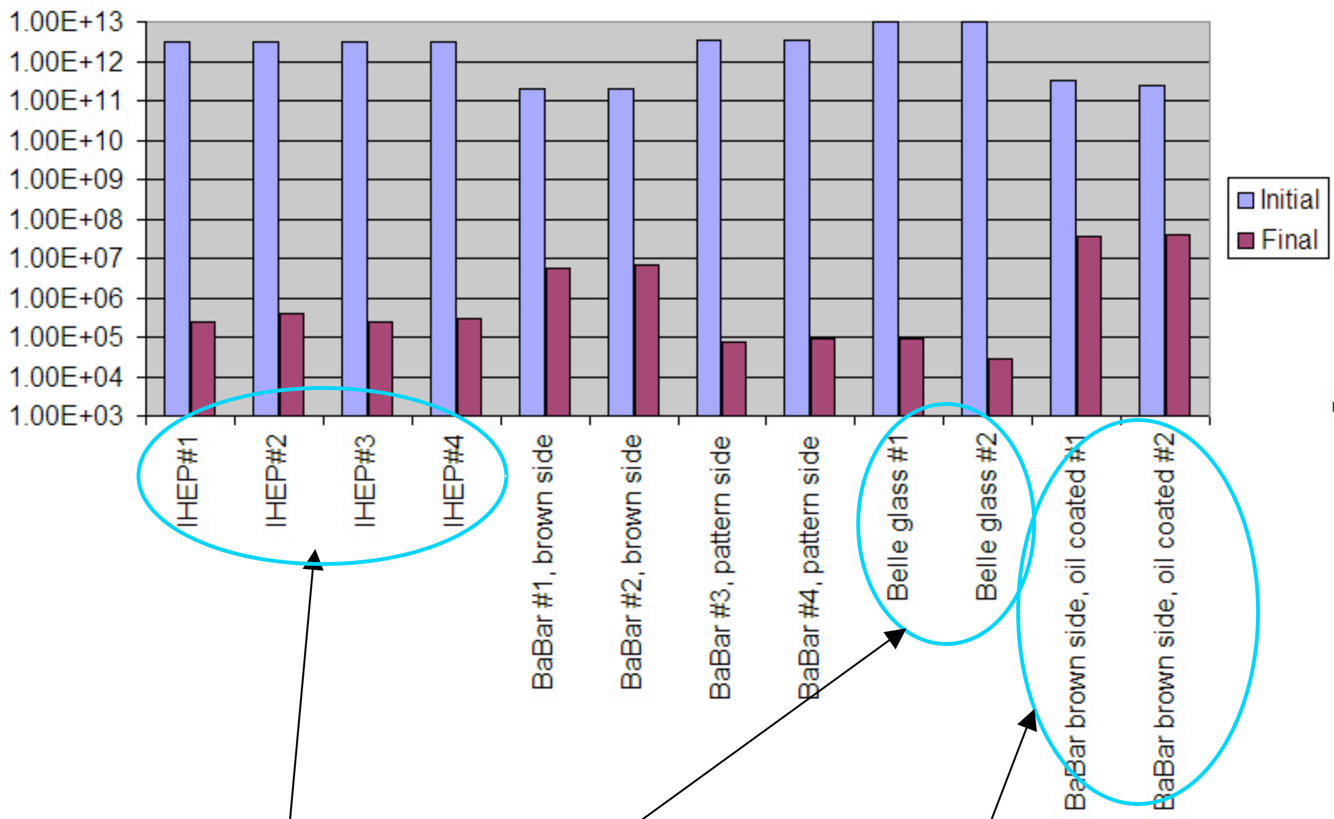
After exposed to HF vapor for ~24 hours, the surface looks powdery fluffy.



After water rinses the surface, the fluffy "skin" is removed, the glass surface looks cracky.

Summary of the HF tests

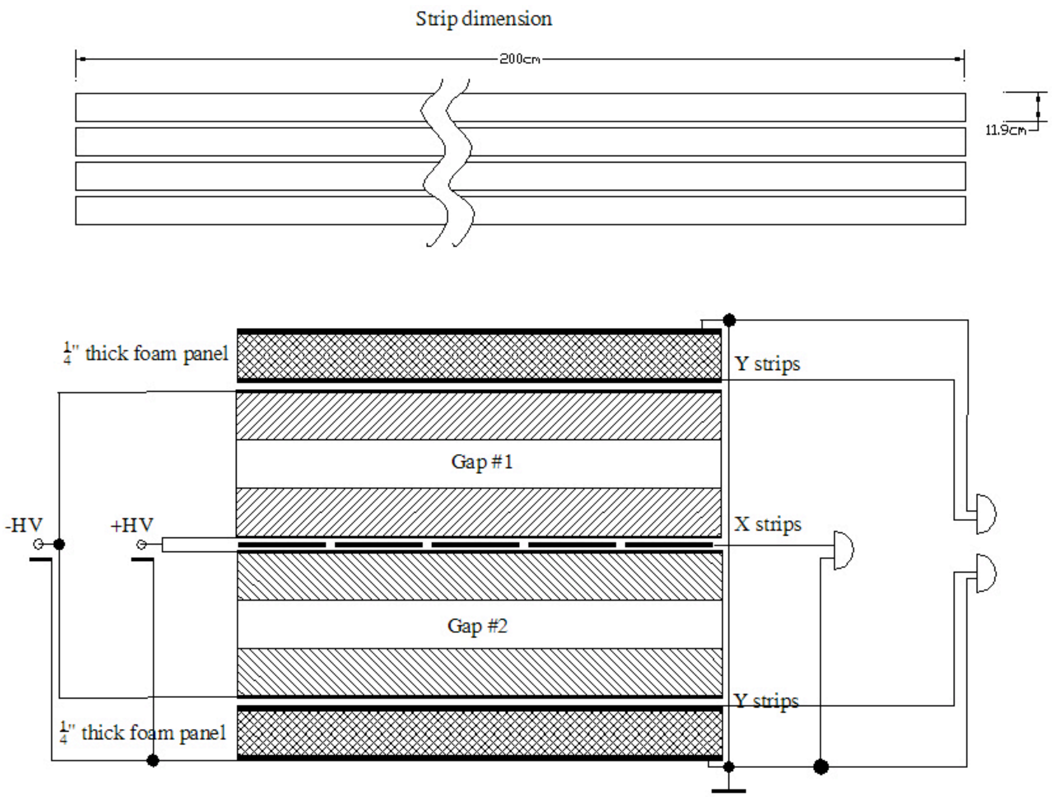
Surface resistivity change after exposed to HF vapor



We can see that the surface resistivity reduction for IHEP Bakelite samples is ~10^{-7}, for Linseed oil coated BaBar Bakelite samples is ~ 10^{-4}, the glass surface is worse than IHEP Bakelite.

IHEP Double-gap RPC

Strip dimension and double gap RPC structure:



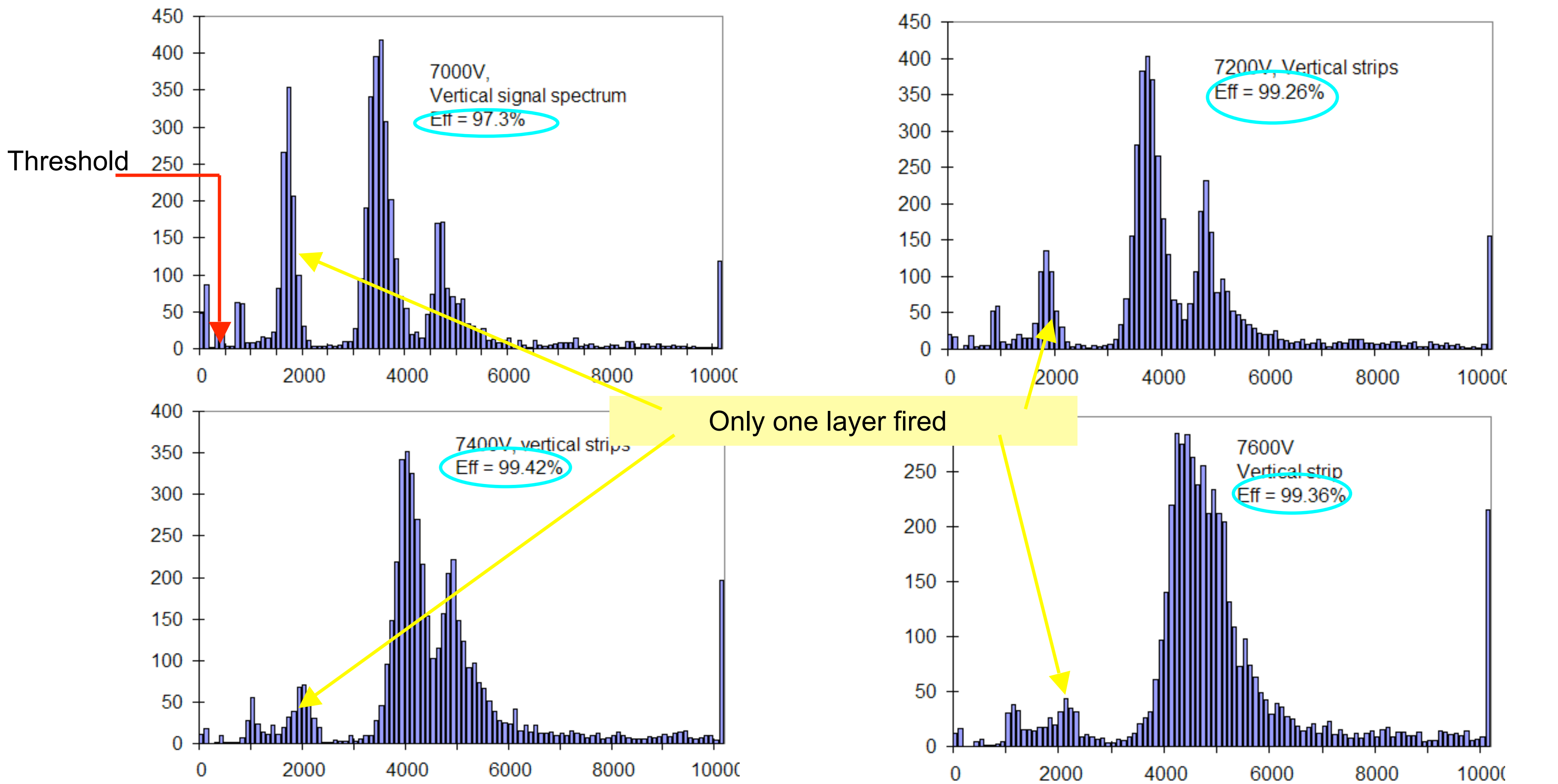
The X-strips have induced charge from both top and bottom gaps, so the signal size would be doubled!

We were doubt about the signal return path for the X-strips and didn't find report on this readout scheme, so just test with the real chambers.

X-strips: vertical; Y-strips: horizontal.

Charge spectrum on middle strip plane

Use QDC system to test the charge spectrum at various HV.



Conclusions

• Because of the simplicity of the RPC technology and the knowledge accumulated in the past 25 years, the Bakelite RPC becomes a commercially available “standard” product.

• G. T. (Italy) and Gaonenkedi (Beijing) have manufactured Bakelite RPCs for several large muon systems.

• After L3, BaBar and Belle, the next big step to validate this technology will be the experiments at LHC. IHEP shall be eagerly waiting for BESIII muon system’s running experience.

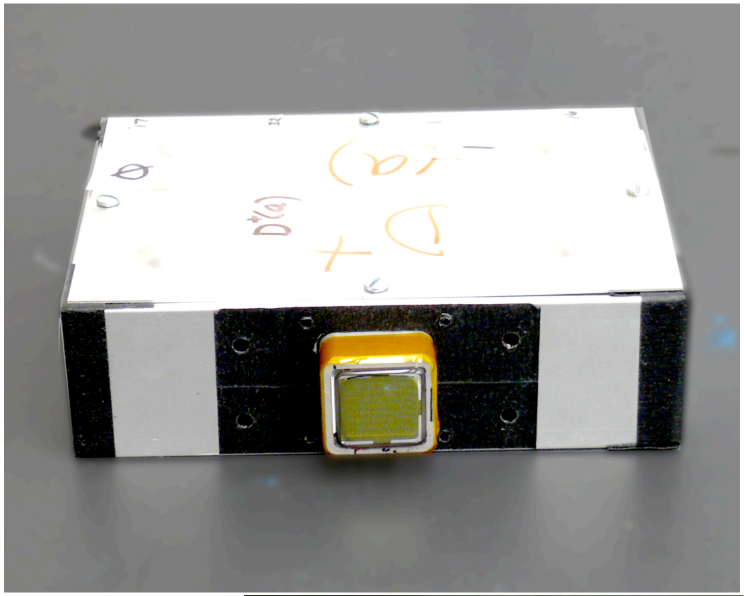
• Belle’s RPC is a successful story of glass RPC.

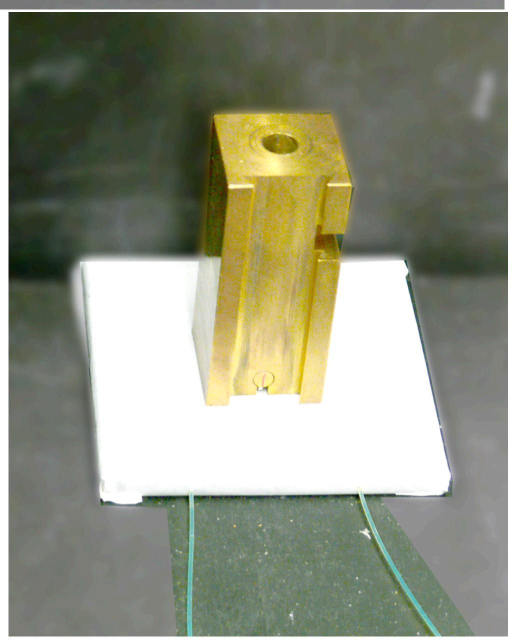
• For Daya Bay application both Bakelite and glass RPC will do the job. BESIII Bakelite RPC is a “glass-like” Bakelite RPC (BESIII - 2.5×10^{12} $\Omega\cdot$cm vs. Belle - 6.6×10^{12} $\Omega\cdot$cm).

Scintillator MA-PMT Planes in Fermilab Test beams

- *P. Karchin -Characterize the PMT response with LED calibration pulses*
- *A. Dyshkant - Measure Relative gains of the 64 channels of each PMT using a radioactive source*
- *C. Milstene - Analysis of test beam data*

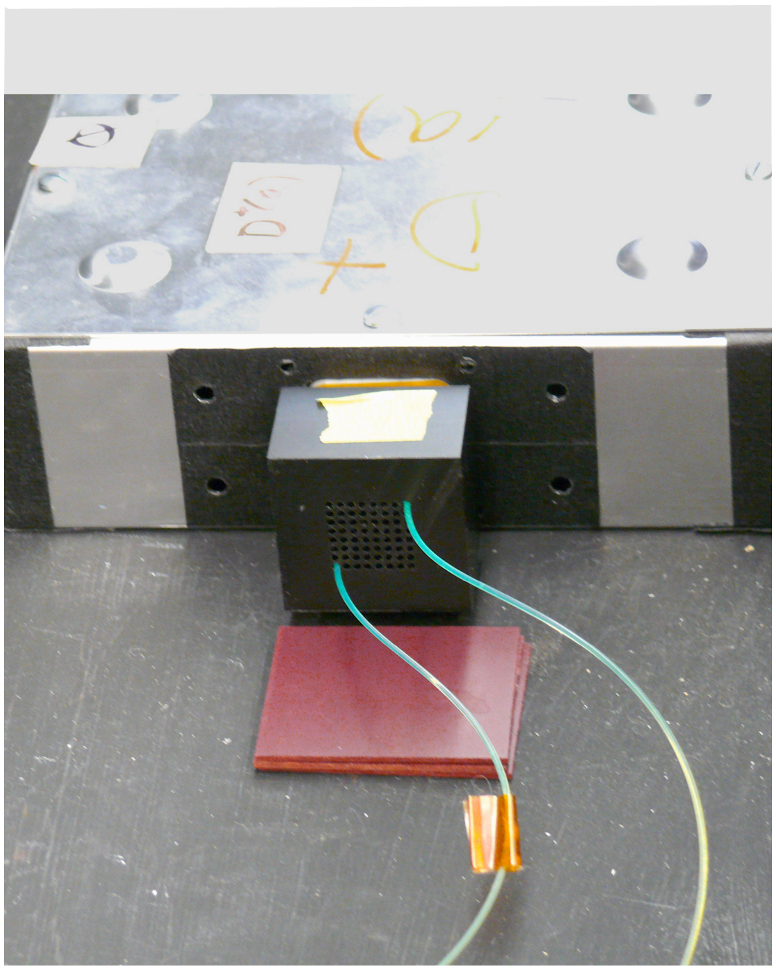
Custom Made Permanent Source of Light



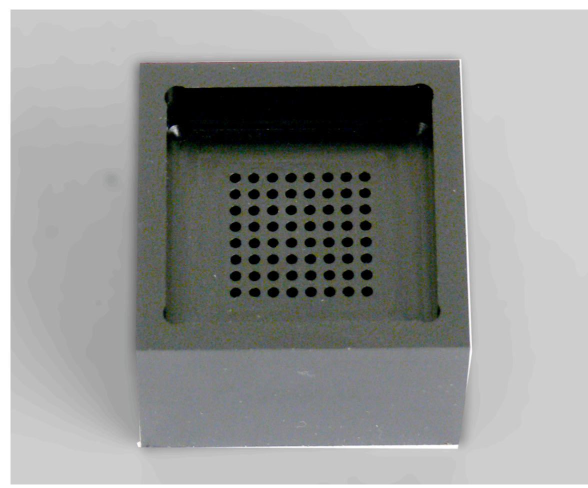


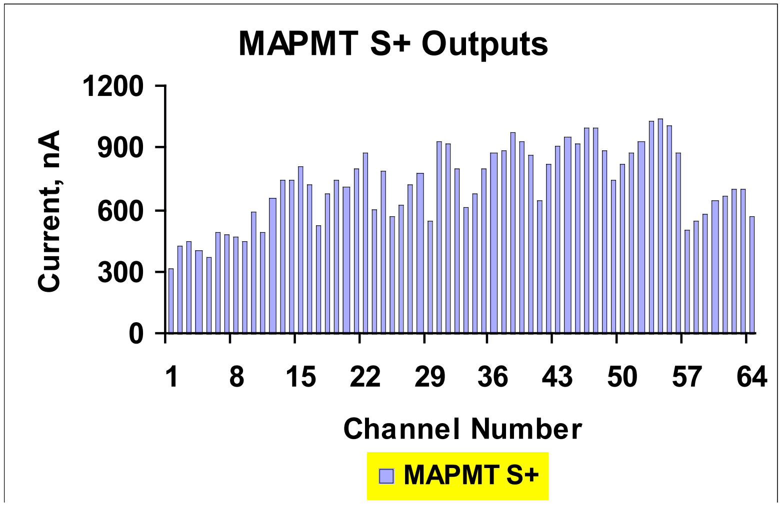
- *Radioactive source Sr-90.*
- *Cast scintillator EJ-200, 10 mm thick with two grooves.*
- *WLS fibers Y-11, 1.2 mm in diameter, 1.01 m long, polished mirrored, UV protected.*
- *Two layers of Tyvek.*
- *Two WLS fibers were used because of the double reference method measurements.*

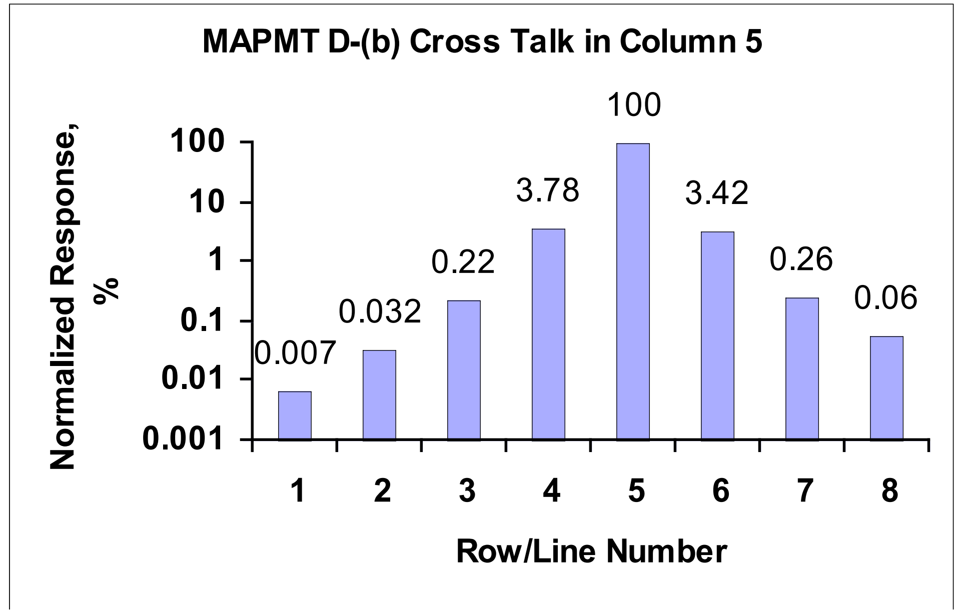
Boxed MAPMT with Interface and WLS Fibers Connected

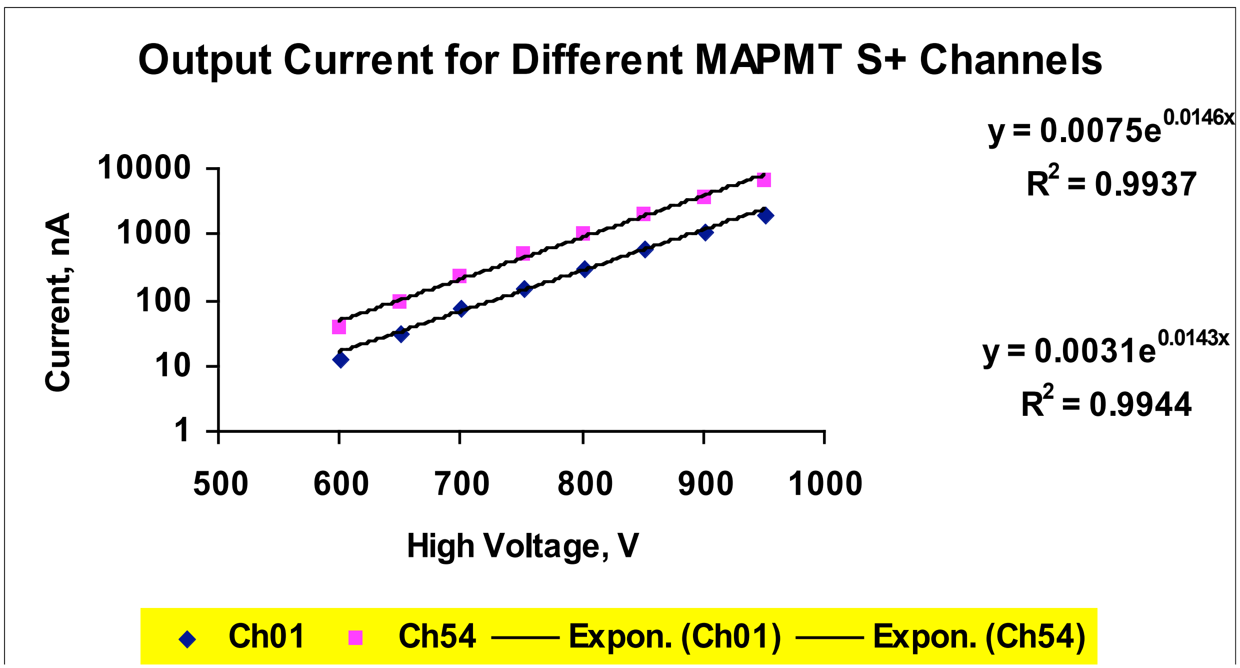


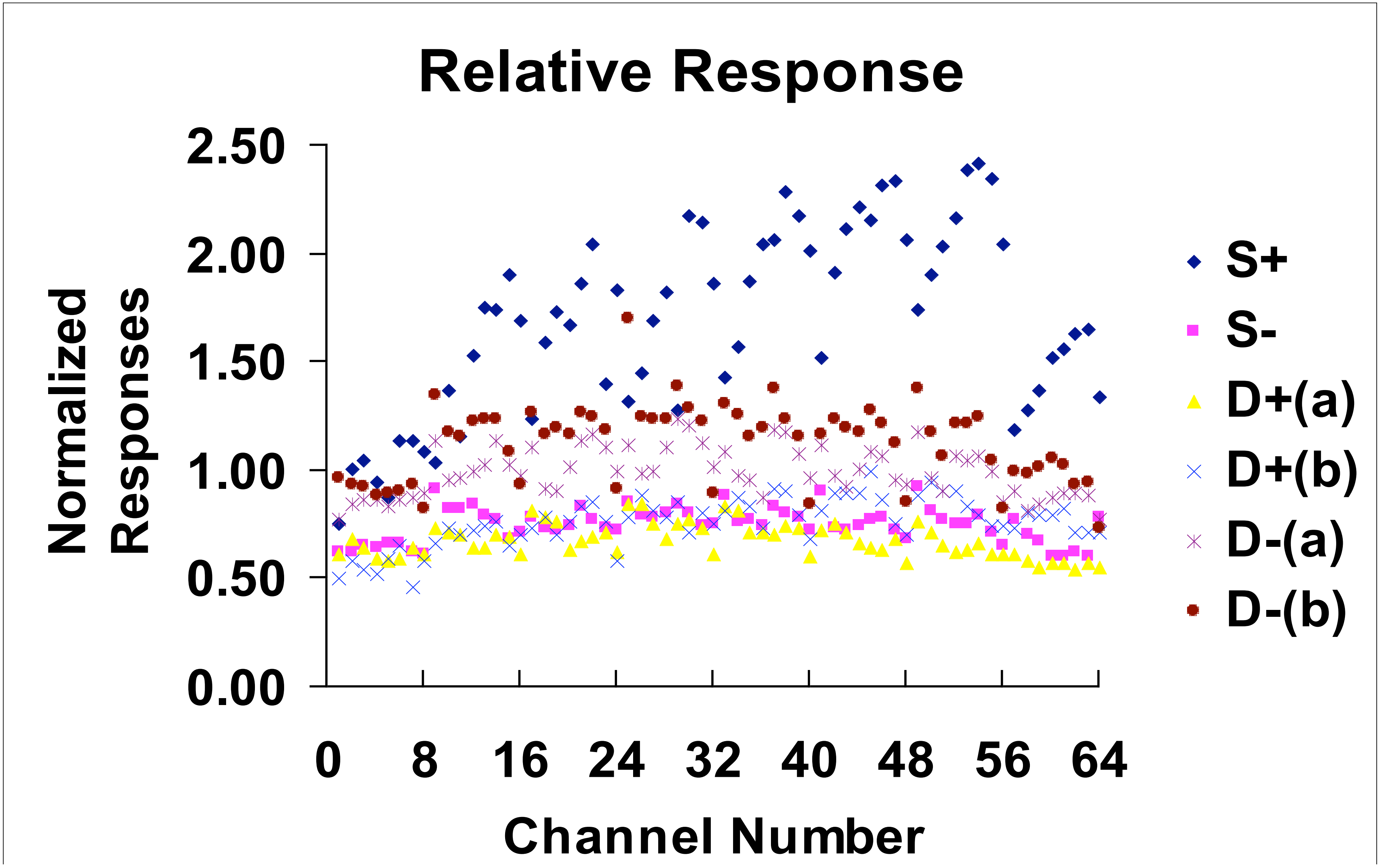
Labeled WLS fiber is a reference one that positioned at channel number 57 permanently in each MAPMT.
Control measurements were performed using the second fiber by repeating the measurement in channel number 64




MAPMT S+ Outputs
1200
900
600
300
0
Current, nA
1
8
15
22
29
36
43
50
57
64
Channel Number
MAPMT S+


MAPMT D-(b) Cross Talk in Column 5
Normalized Response, %
100
10
1
0.1
0.01
0.001
0.007
0.032
0.22
3.78
100
3.42
0.26
0.06
1
2
3
4
5
6
7
8
Row/Line Number


Output Current for Different MAPMT S+ Channels
y = 0.0075e^0.0146x
R^2 = 0.9937
y = 0.0031e^0.0143x
R^2 = 0.9944
10000
1000
100
10
1
Current, nA
500
600
700
800
900
1000
High Voltage, V
Ch01
Ch54
Expon. (Ch01)
Expon. (Ch54)



Relative Response
Normalized Responses
2.50
2.00
1.50
1.00
0.50
0.00
0
8
16
24
32
40
48
56
64
Channel Number
S+
S-
D+(a)
D+(b)
D-(a)
D-(b)

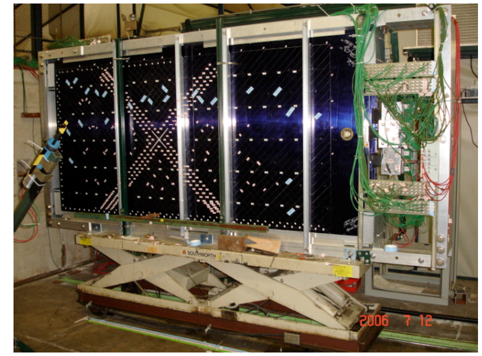
Table of MAPMTs Anode Output Current Parameters (units in nA)

MAPMT	Mean	St.Dev.	Min	Max	Ratio
S+	726.1	184.9	323.4	1040.	3.22
S-	322.2	34.2	258.8	400	1.55
D+(a)	291.0	33.0	235	362.7	1.54
D+(b)	328.5	48.0	198.9	427.5	2.15
D-(a)	427.7	49.3	332.3	532.1	1.60
D-(b)	484.6	76.3	315.4	731.3	2.32
			198.9	1040.	5.23

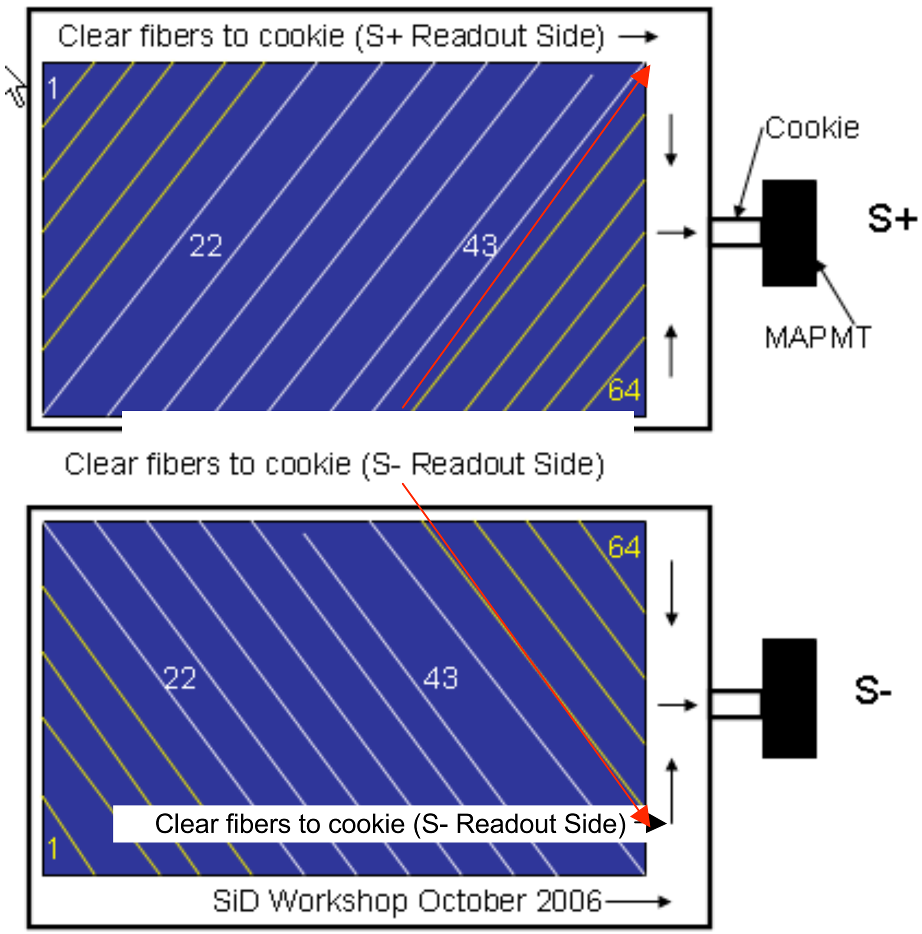
Prototype Scintillator Planes R&D Goals

- ***Performance Related***
  - -Muon detection efficiency per layer.
    - Meas. charge => no. of photo-electrons.
    - Dependence on WLS fiber.
  - – Uniformity of the response across the detector?
  - - Utilization as a tail catcher
- ***Design and Cost Related***
  - – Readout both ends versus one end of each strip? (cost effectiveness)
  - – Refinements or modifications needed? .
  - – Basis for comparison with other techniques. e.g. RPC's
  - – New photo-detector technology? e.g. Si PM

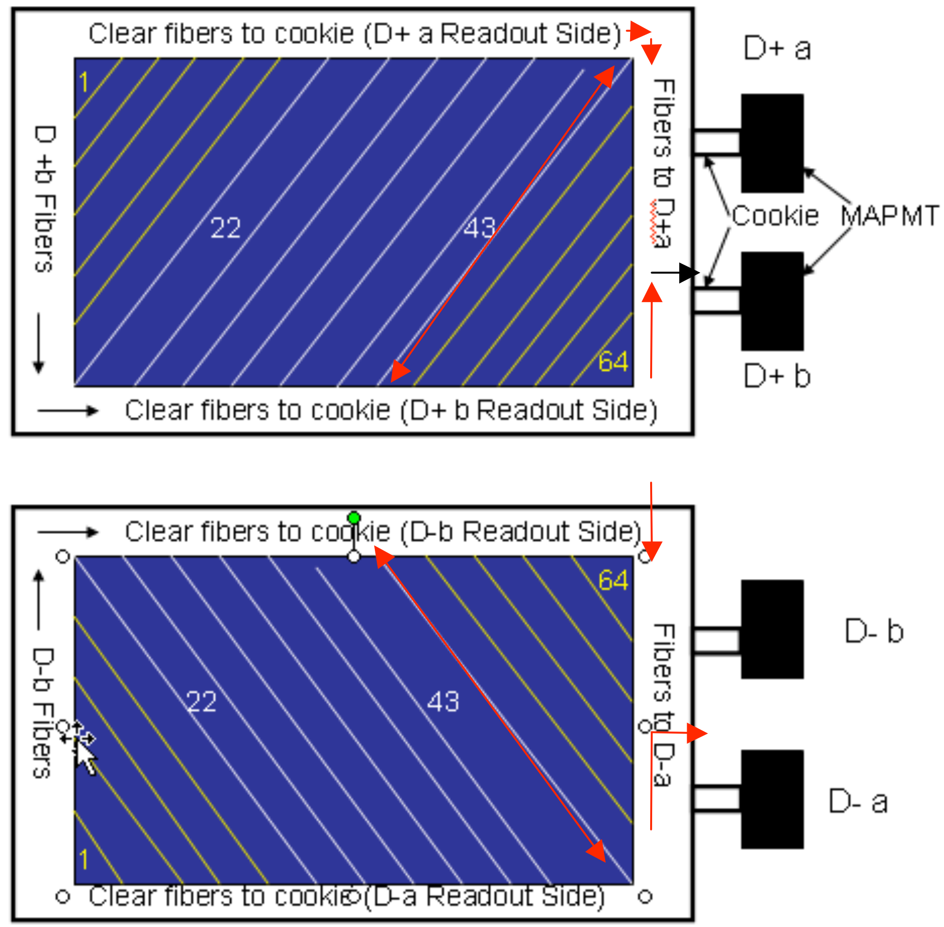
Four Detector planes



Single ended readout



Dual readout



Data

Distributions from Composite Run 6446 at (+38, -38)

11450 Total Events

S+ mean 439.2

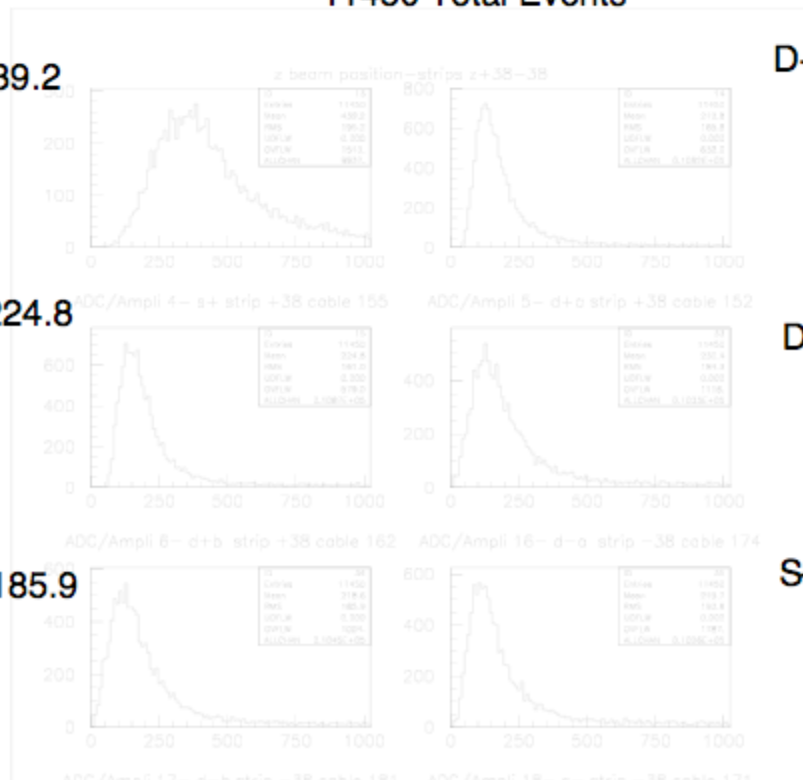
D+a mean 212.8

D+b mean 224.8

D-a mean 230.4

D-b mean 185.9

S- mean 219.7



R & D Plans

- Near Term Objectives
  - MAPMT Absolute gain a channel/MAPMT by Wayne State University, work in Progress presented here.
  - Replace LeCroy ADCs with 64 channel version of Minerva front-end digitizers and test at MTBF. (IU, FNAL, UCD)
- Future Plans
  - Procure SiPMs/Multi-Channel Photon Counters;
  - Bench Test at SiDet.
  - R&D and beam tests of ILC muon scintillation counters with Si PMs at MTest
    - A supplementary LCRD proposal (IU, WSU, UND, UCD and NIU) has been submitted for this work.
  - Test of Geiger-mode Avalanche Photo-diodes developed by A-Peak and Colorado State Univ (SBIR) with scintillator strips at MTest in a few months. (D. Warner - CSU)
  - Because SiPM/MPPCs look very promising we expect to build additional prototypes with NIU style scintillator and SiPM readout. Will be tested at MTest.

CALICE Tail-Catcher Muon-Tracker(TCMT) Preliminary Test Beam Results

Kurt Francis
NICADD/Northern Illinois University
For
CALICE Collaboration

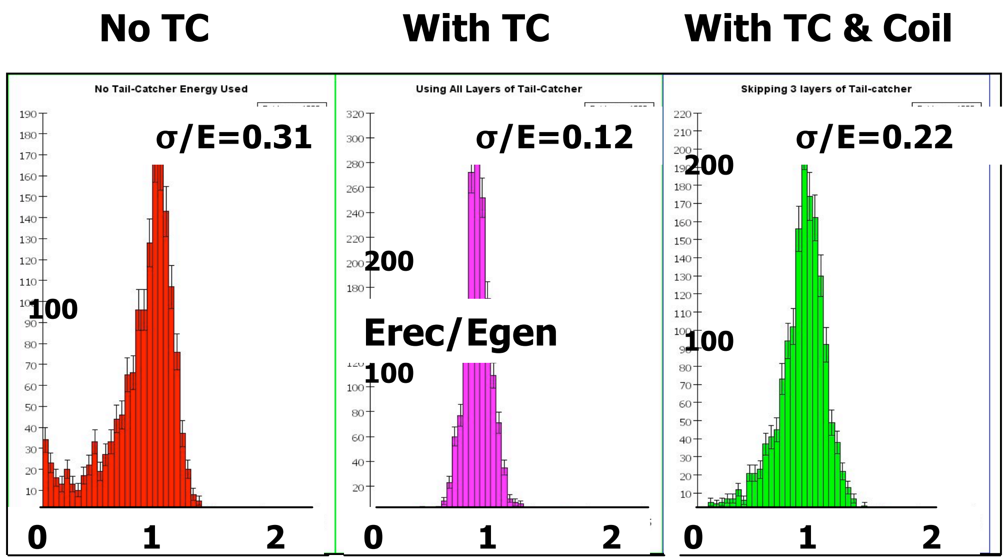
CALICE Tail-Catcher Muon-Tracker Prototype

- The CALICE Tail-Catcher Muon-Tracker
  - Goals:
    - Prototype ILC muon detector using SiPMs
    - Correct for leakage due to thin calorimeters
  - Test Beam needed to:
    - Study end of hadronic shower & validate simulations available
    - Understand
- Mechanical Structure/Absorber
  - "Fine" section (8 layers)
    - 2 cm thick steel
  - "Coarse" section (8 layers)
    - 10 cm thick steel
- 16 Cassettes:
  - Extruded Scintillator Strips
    - 5mm thick
    - 5cm wide strips
    - Tyvek/VM2000 wrapping
    - Alternating x-y orientation

- Readout
  - WLS Fiber
  - SiPM photo detection
  - Uses common electronics (DESY) readout with CALICE HCAL
  - Uses common CALICE DAQ (Imperial college)

Design Motivations

- TCMT required for sufficient depth to contain hadronic showers and validate Monte Carlos for PFA studies.
- For many ILC concepts calorimetry is thin and inside the coils. The outer solenoid flux return is composed of layers of Fe plates with gaps: consideration of a tail catcher is natural.
- Used SiD ECAL/HCAL simulation to understand effects:

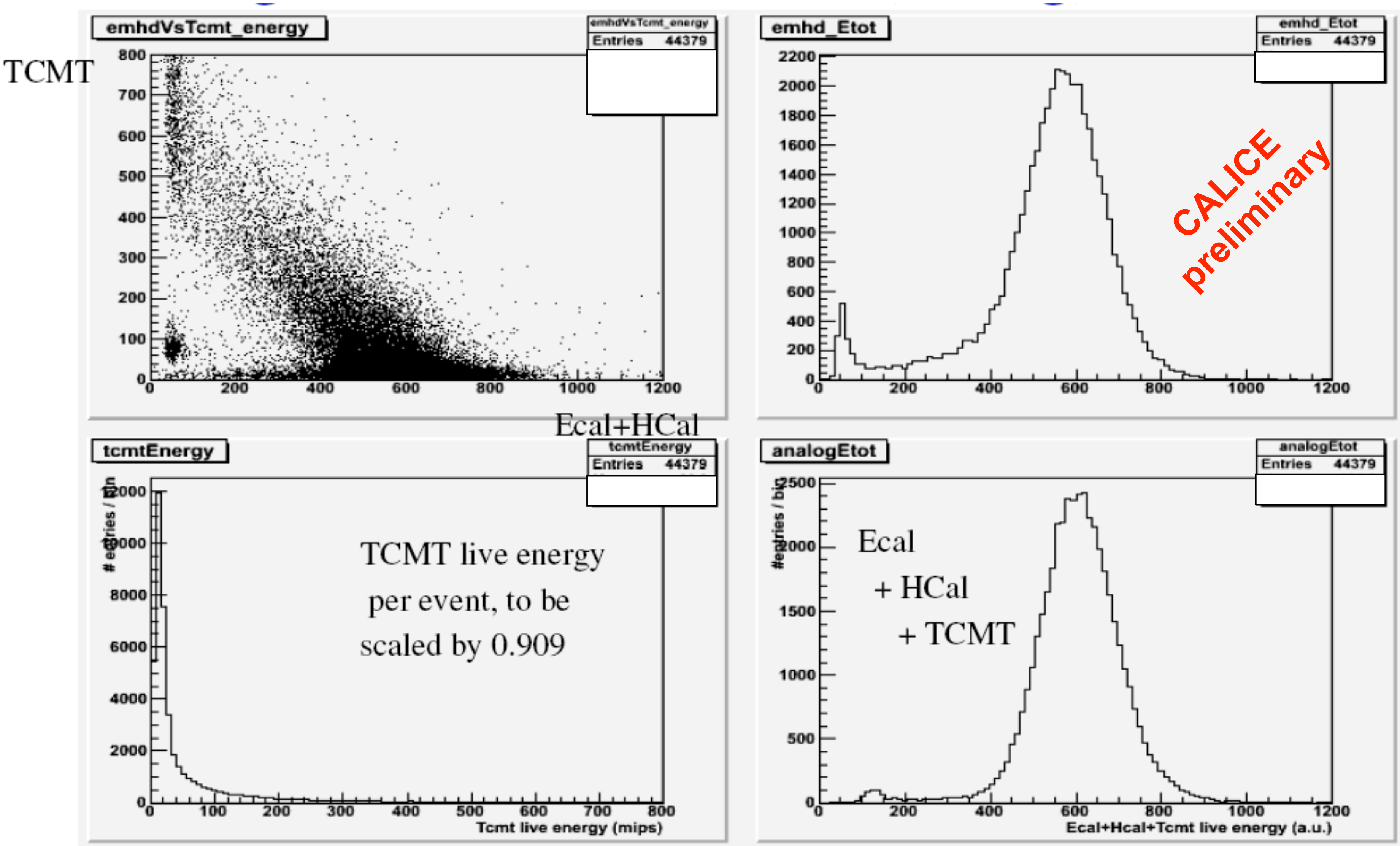


CALICE Calorimeters at Test Beam

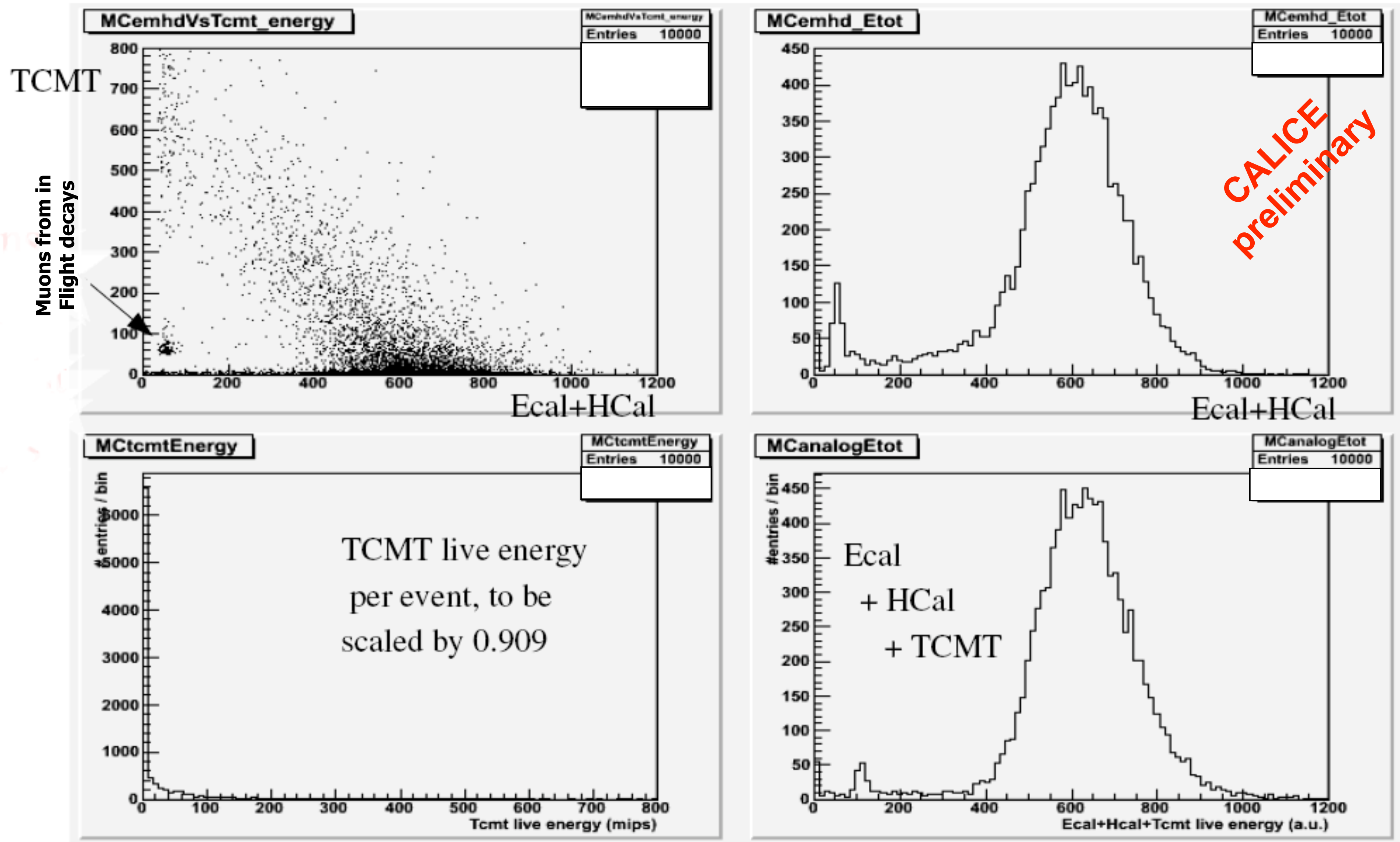
- ECAL
  - 30 active layers of silicon diode pad detectors with ~10,000 channels
  - tungsten absorbers with thickness of 1.4mm to 4.2mm
  - total thickness $24X_0$

- HCAL
  - 30 out of 38 absorbers in place – 1.6cm thick steels
  - Gaps instrumented with 0.4mm thick modules with high granularity core (3x3cm^2)
    - Layers 1-17 - all instrumented
    - Layers 19-29 - every other layer instrumented
    - Total of 23 layers x 216 chan/layer = 4968 channels
  - 4.5 interaction lengths

Analog Energy Response - 20Gev pi-



Analog Energy Response - MC



CALICE TCMT Plans

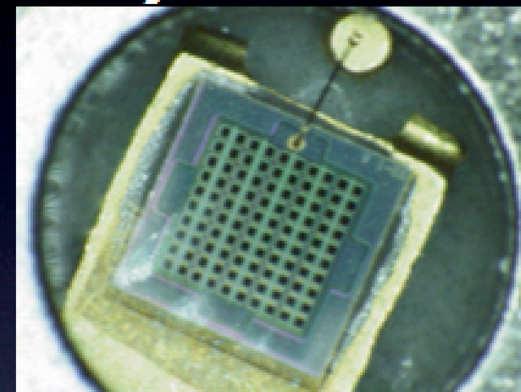
- Continue Data Analysis
  - Currently focusing on stability of peds/gains
  - Ultimately: study shower shape in terms of hits & energy
- Additional CALICE running
  - Summer 2007 run at CERN
    - Calibrate with improved LED calibration system
    - Combine data with fully instrumented HCAL and ECAL
    - Collect more statistics
  - Move to MTBF at FNAL thereafter
  - HCAL & TCMT infrastructure available to test other technologies
- Cassettes at SiDet facility at Fermilab for Calibration LED Upgrade
- SiPMs show good potential for calorimetry and muon detection


T2K experience with scintillator/MPPC detectors
Masashi Yokoyama
Kyoto University

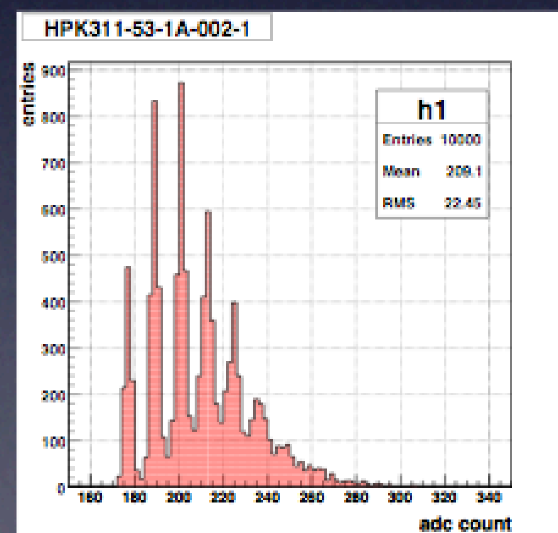
Pre-T2K detector: K2K-SciBar

- Constructed for K2K
- Fully active detector with scintillator/ WLS fiber/MA-PMT
  - ~15,000 1.3x2.5x300cm^3 scintillators
  - Hamamatsu 64-ch MAPMT (x224)
  - ~3m WLS fiber (Kuraray Y11)
  - 10~20p.e./MIP/cm
- Now moved to FNAL for new experiment (E-954/SciBooNE)

Multi-Pixel Photon Counter (MPPC)

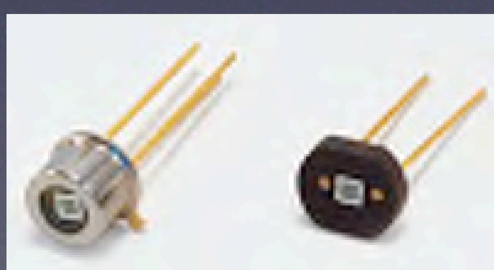


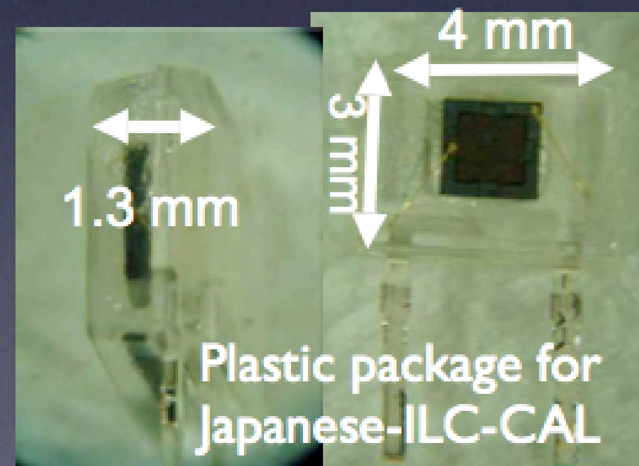
- Product of Hamamatsu Photonics
  - “silicon PM” family
- Characteristics:
  - Gain ~10^6 w/ 70~80V
  - Noise ~O(100kHz) @room temp
  - Photon eff. >~ PMTx2
  - Insensitive to B-field
  - Compact

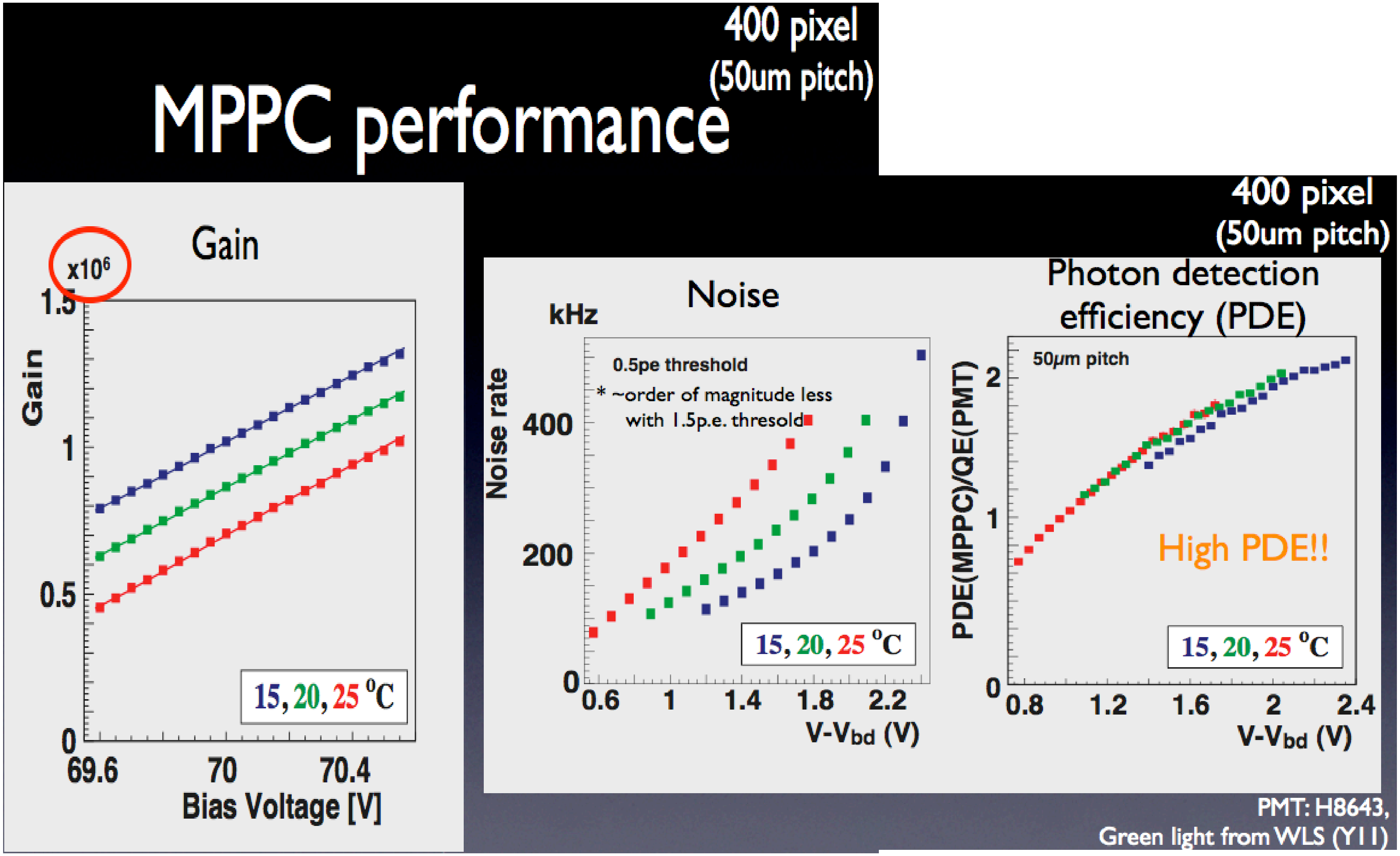


Current MPPC lineup

- Active area size: 1x1mm^2
  (larger size device under development)
- Pixel pitch: 100, 50, 25um
  Number of pixels/device: 100, 400, 1600
- Package: can or ceramic
  other package needs negotiation
  (and possibly additional cost)







MPPC performance
400 pixel
(50um pitch)
Gain
x10^6
Gain
1.5
1
0.5
0
69.6
70
70.4
Bias Voltage [V]
15, 20, 25 °C
400 pixel
(50um pitch)
Noise
kHz
Noise rate
0.5pe threshold
* ~order of magnitude less
with 1.5p.e. thresold
400
200
0
0.6
1
1.4
1.8
2.2
V-Vbd (V)
15, 20, 25 °C
Photon detection
efficiency (PDE)
PDE(MPPC)/QE(PMT)
50μm pitch
High PDE!!
2
1
0
0.8
1.2
1.6
2
2.4
V-Vbd (V)
15, 20, 25 °C
PMT: H8643,
Green light from WLS (Y11)

Needs for T2K

- Total number of devices: ~60,000
  - MRS-APD by CPTA will be also used for some of sub-det. (contribution from Russian collaborators)
- PDE > MA-PMT (used in K2K/SciBooNE)
- Number of pixel: ~500 (~100 for on-axis)
- <u>Basic performance OK ☺ with current MPPC</u> (although continuing improvement)
  - Active area: 1.2x1.2mm^2 to match 1.0mm dia. fiber (under development)
  - Cross-talk/after-pulse reduction

Characterization of Silicon Photodetectors (Avalanche Photodiodes in Geiger Mode)

S. Cihangir, G. Mavromanolakis, A. Para. N.Saoulidou

Existing

Hamamatsu (100, 50 and 25 μ micropixels)

IRST (several designs)

CPTA

Mehti

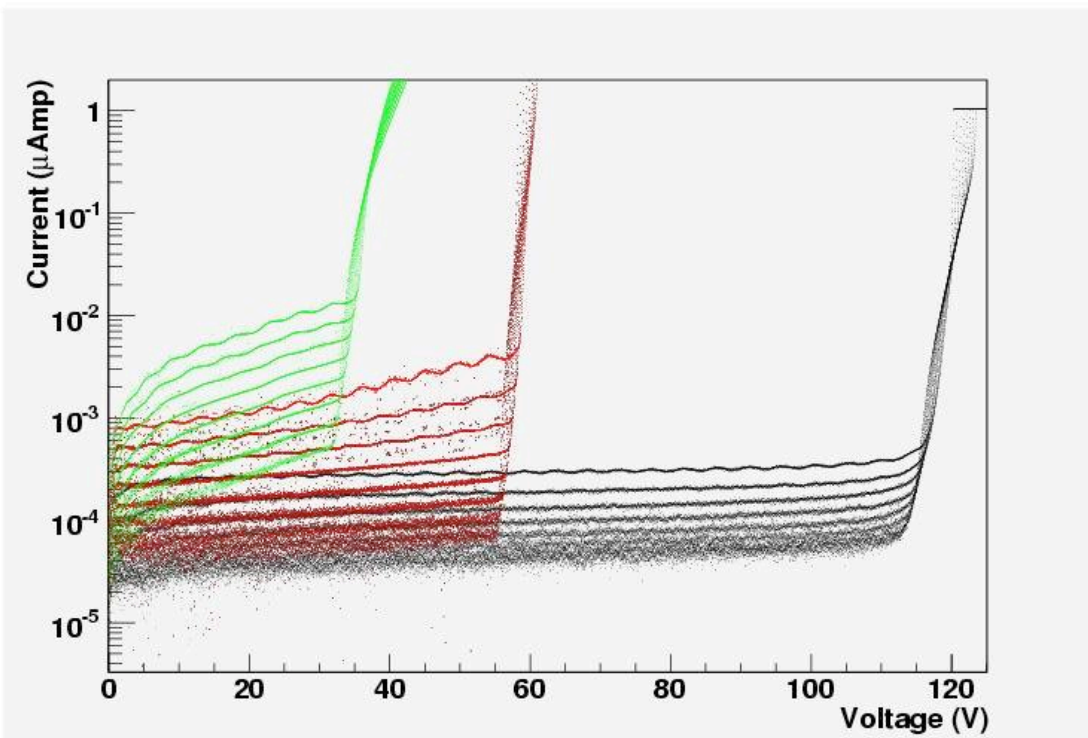
Dubna (two designs)

Forthcoming

SensL

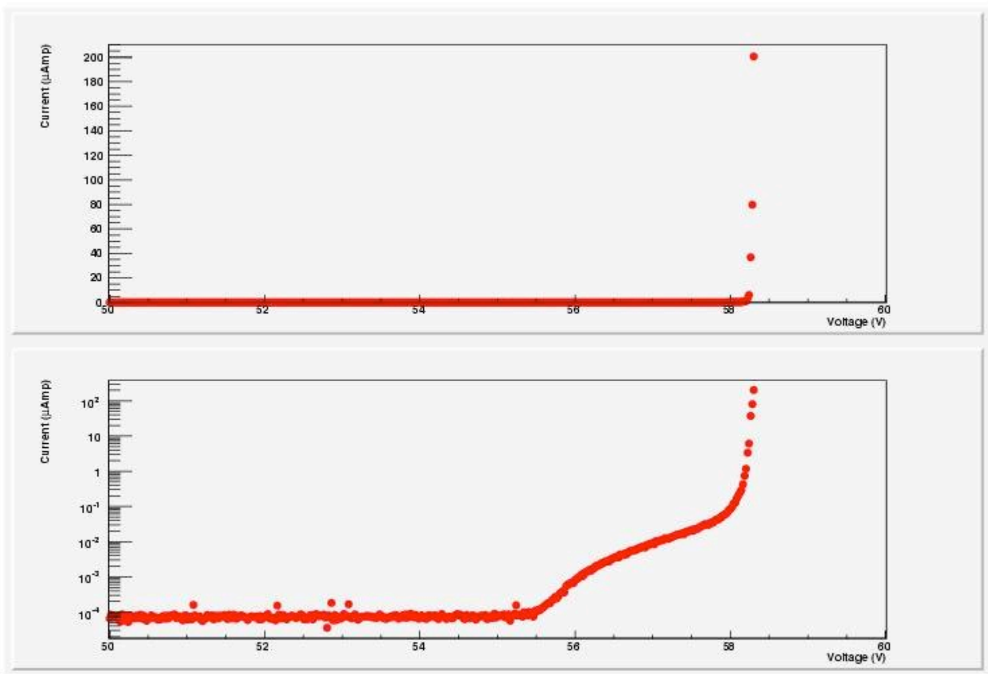
Others?

I-V Characteristics at Different Temperatures



- *Different detectors have quite different operating point*
- *Dark current and the operating point depend on temperature*

Breakdown Voltage: a Knee on the I-V plot?



- *Linear or logarithmic plot (derivative)?*
- *What is the shoulder on the IV log plot?*
- *Different pixels break-down at different voltages??*
- *Is it related to the resolution/width of the single electron peak??*

Step 4: Microscopic Studies of the Photodetector (Planned)

- Focused (calibrated) light source, 2-3 μ spot size (Selcuk C.)
- Microstage (<1 μ stepping accuracy)
- Dark box containing the detector, focusing lenses and the stage
- Readout as before
- Spatial characteristics of the photodetector, intra and inter-micro pixel variation of:
  - Gain
  - PDE
  - Afterpulses
  - Cross-talk

Muon Detector R&D

- Several parallel efforts with scintillators - MAPMT and SiPMs
- Gaining extensive experience with RPCs
- Connection with IHEP RPCs
- Need to set up cost estimate framework so technology decision can be made