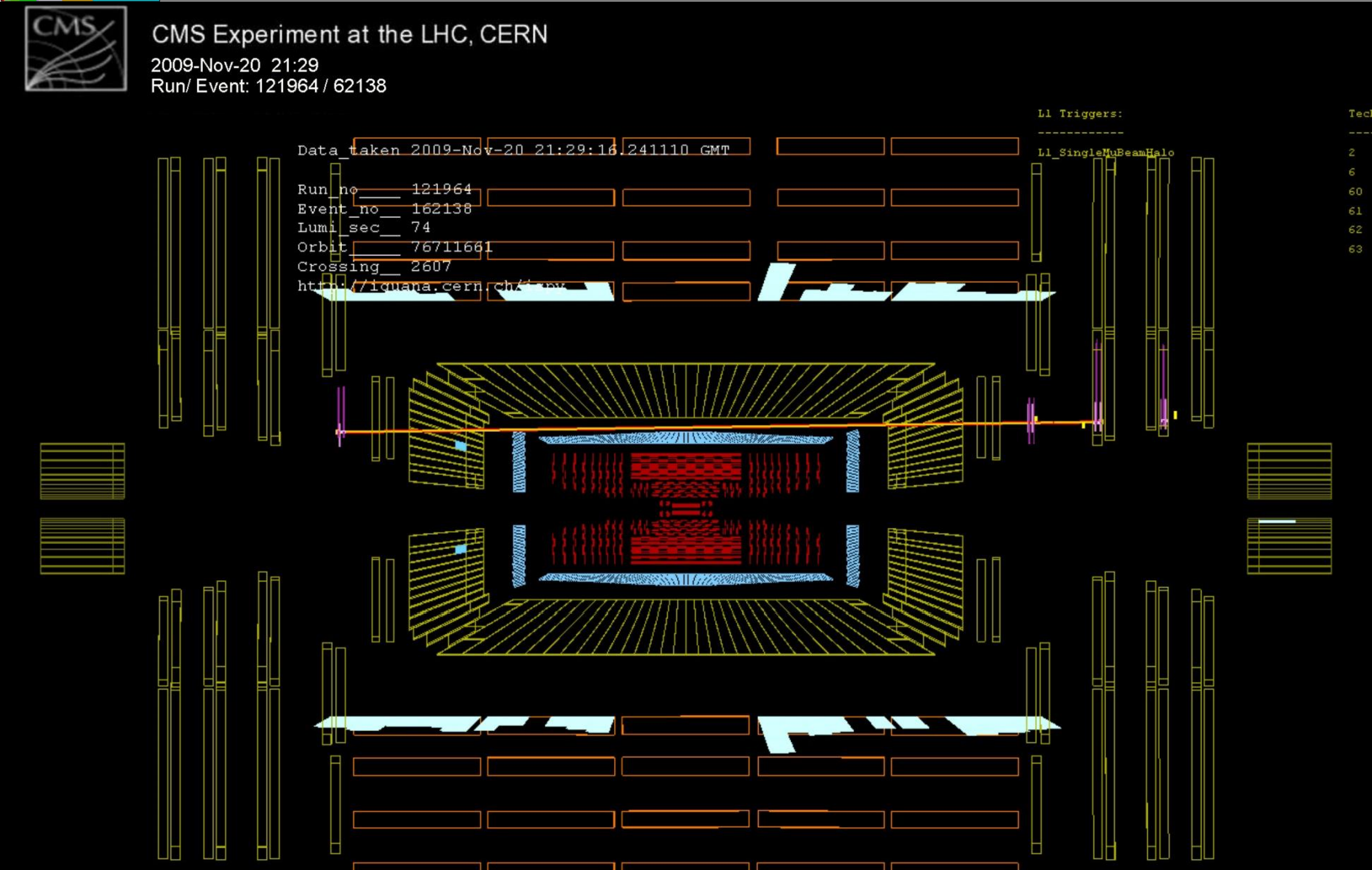
The CMS Beam Halo Monitor detector system

Kelly Stifter, University of Minnesota

08/04/15

2015 DPF Meeting, Ann Arbor

Machine-induced background



CMS BHM Group

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2. National Technical University of Athens, Greece

3. Princeton University, USA

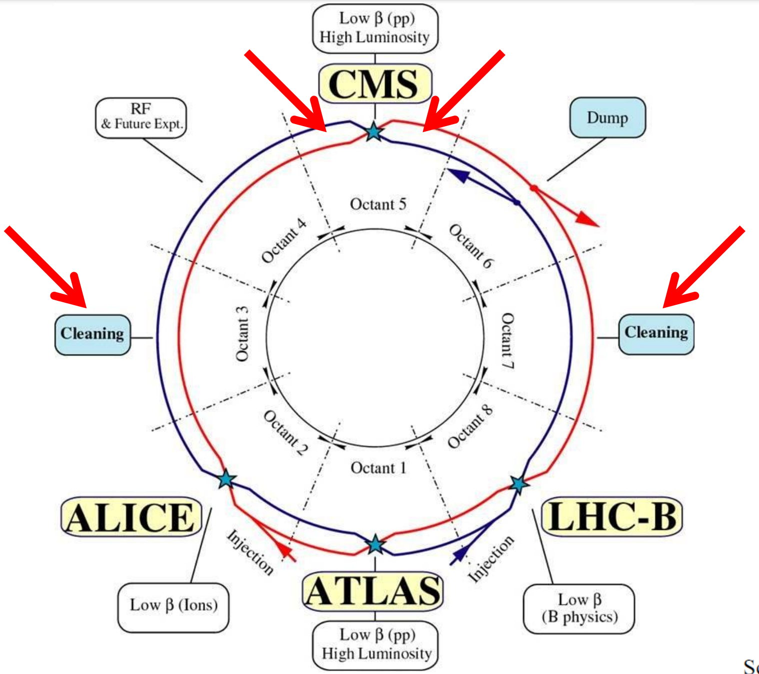
4. INFN Bologna, Italy

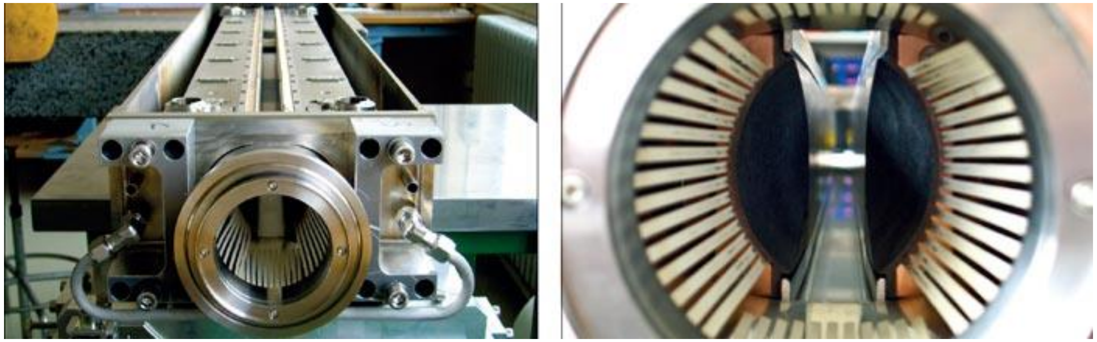
5. University of Minnesota, USA

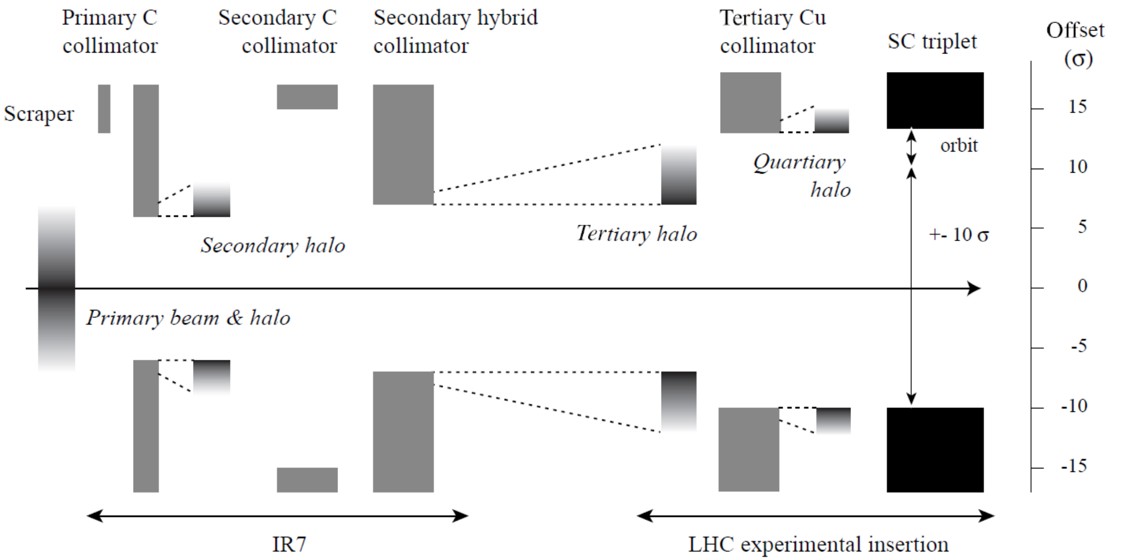
Outline

1. Machine-induced background
2. Beam Halo Monitor detector
3. Detector system
   – Detector units
   – Electronics
4. First results
   – Splashes
   – Correlation to collimator movement
   – Commissioning data

Machine-induced background (MIB)



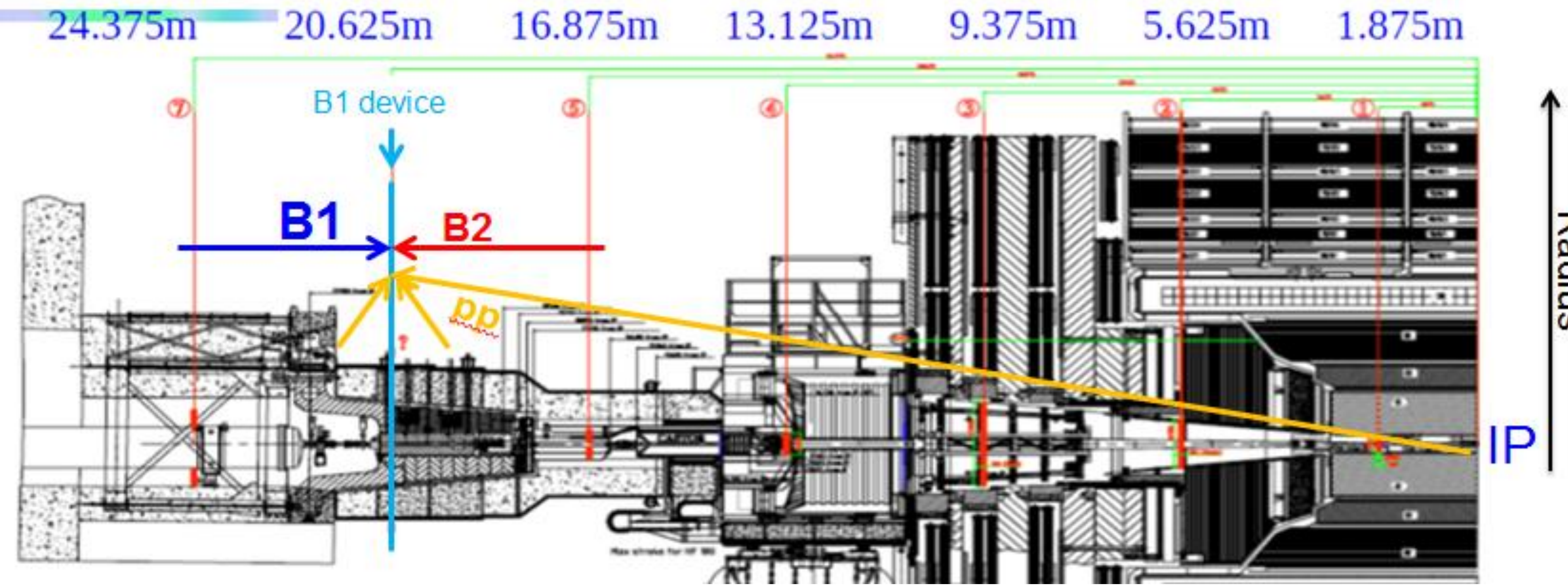




- Interactions with collimators
- Beam gas
- UFOs

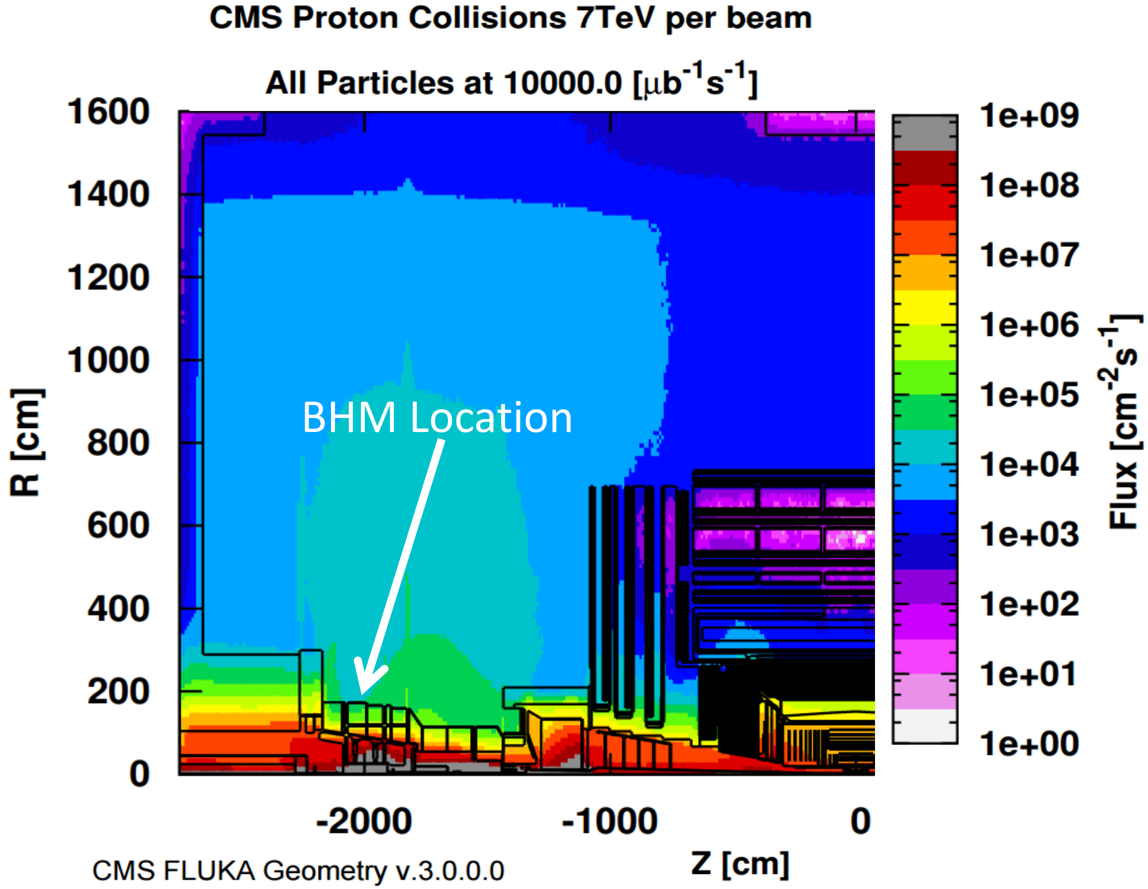
Beam Halo Monitor

- Purpose: Provide an online, bunch-by-bunch, per beam MIB rate arriving at CMS at high radius



Problem

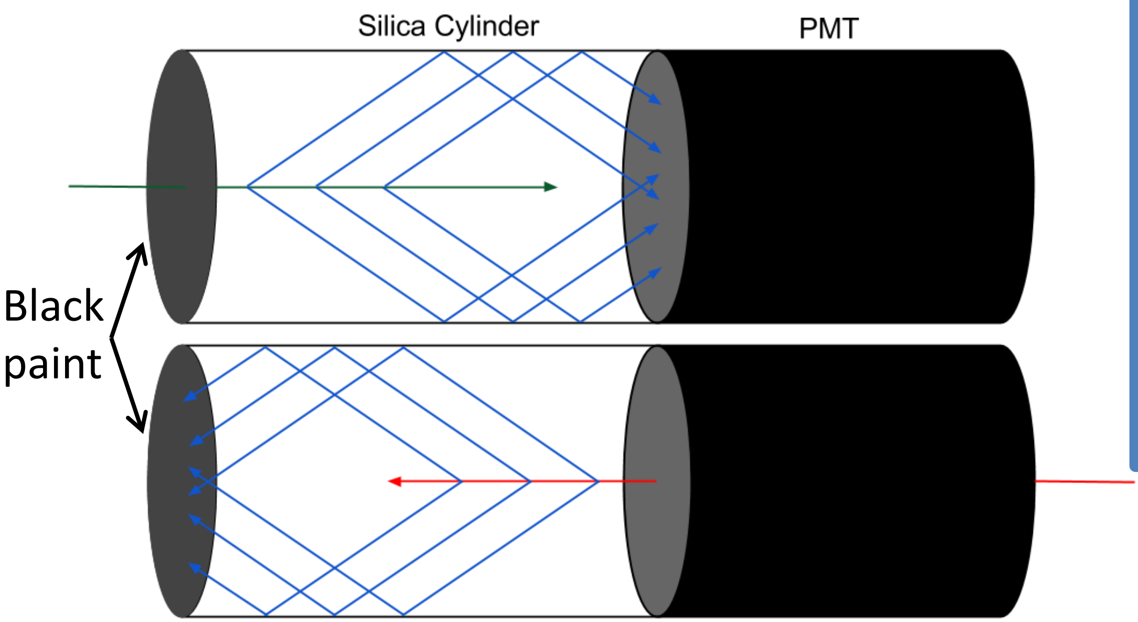
- Many more collision products (~10^4Hz/cm^2) than MIB particles (~1Hz/cm^2)



- Must find MIB signal amidst collision products ➔ factor of ≥10^4 suppression required
- Solutions: DIRECTION-SENSITIVITY and PRECISION TIMING

Direction sensitivity

MIB muon: Arrives with incoming beam. Cherenkov radiation is seen by PMT.



Collision product: Arrives in opposite direction. Cherenkov radiation is absorbed by black paint.

Cherenkov radiation:

- ✓ Insensitive to neutron and gamma backgrounds
- ✓ Prompt signal in time with incoming particle
- ✓ Use quartz, radiation hard & UV transmissive
- ✓ Large signals – ~60 p.e./cm for forward particle

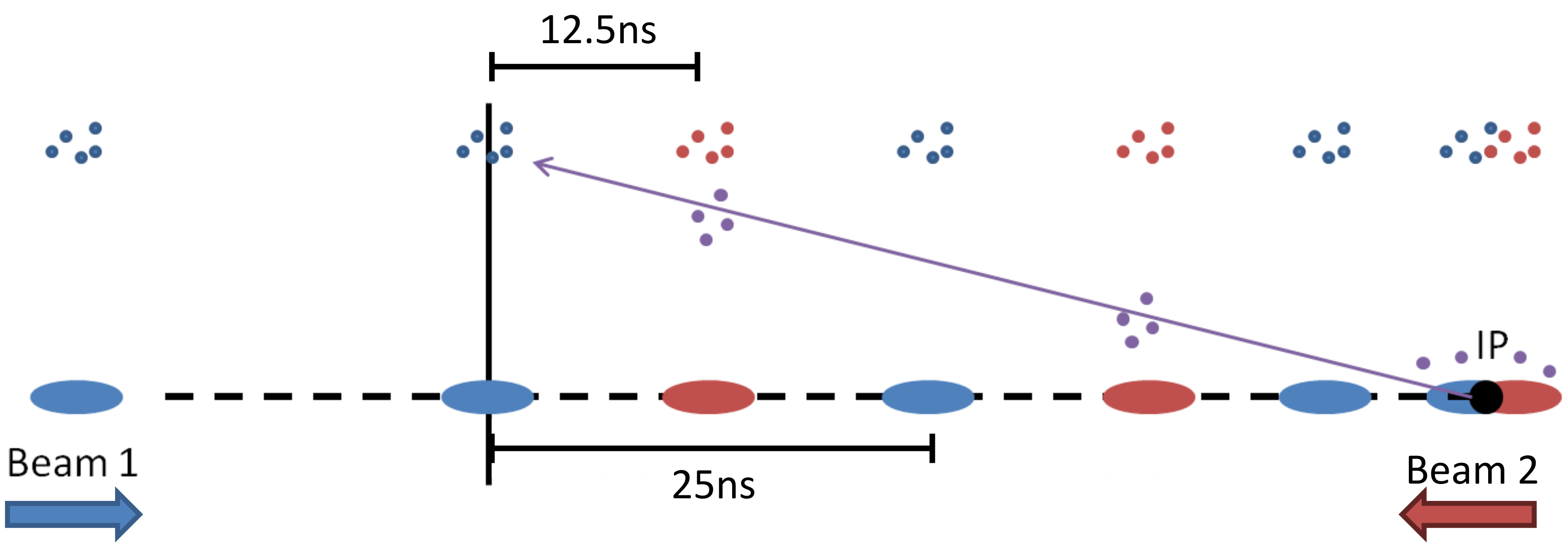
2014 DESY test beam:

Background rejection of >99.99%
With forward acceptance of >98%

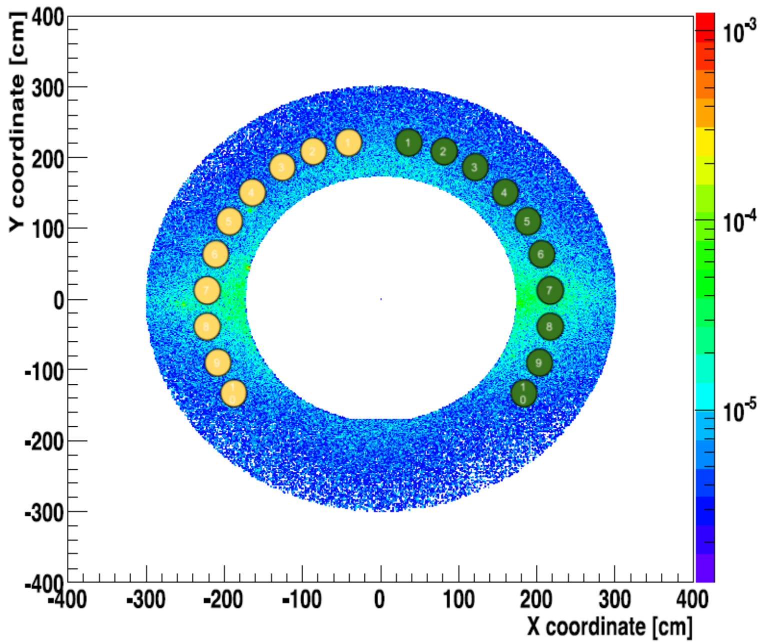
Timing

- Golden locations allow for maximum separation in timing

$$GL_{k+1} = \left(\frac{1}{4} + \frac{1}{2}k\right) \cdot (\text{BX spacing}) \approx 1.875m + 3.75m \cdot k$$



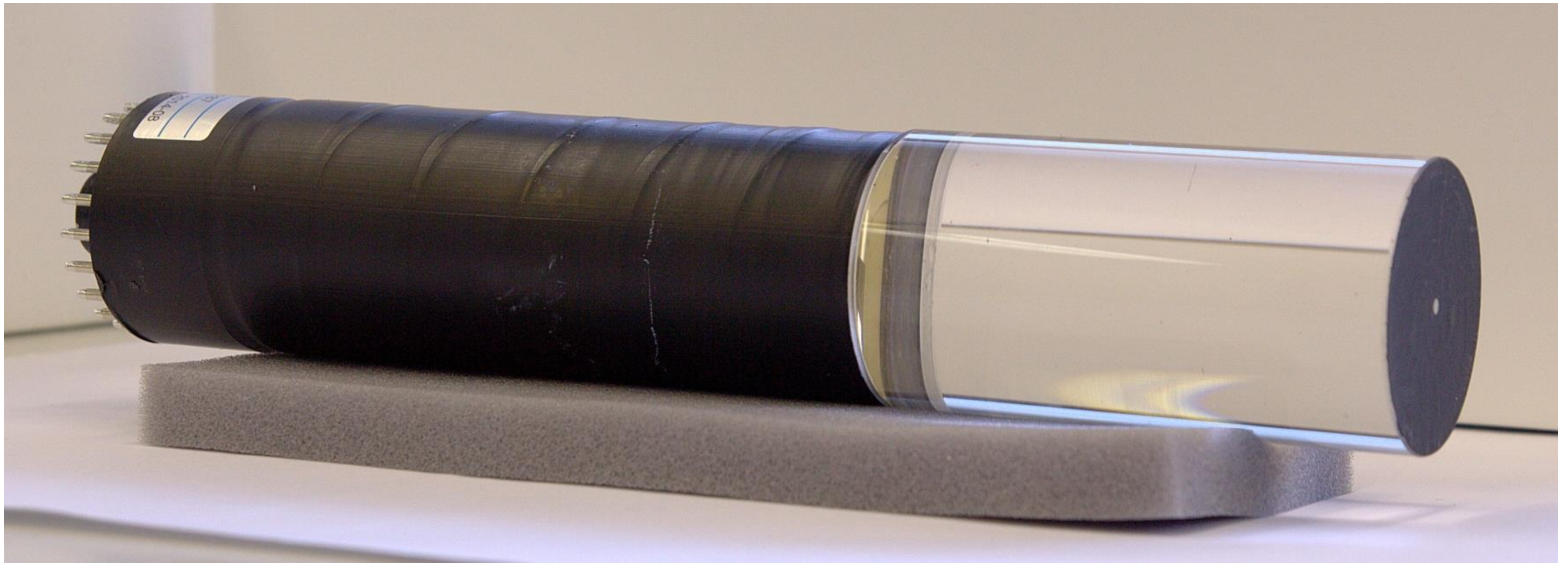
Detector placement



- Golden location 6 – 20.6m from IP
- 40 detectors, 20 at each end
- Acceptance of 21.2 cm^2/unit, 424 cm^2/beam
- Installed at radius of 1.8m from beam
- Placed in ϕ-region of highest flux

Detector units

- SQ0 synthetic fused silica: 10 cm long, 5.2 cm diameter, UV transmissive, radiation hard
- Optically coupled to UV sensitive Hamamatsu R2059 PMT
- 3 layers of magnetic shielding: Permalloy, mumetal, iron



Detector units

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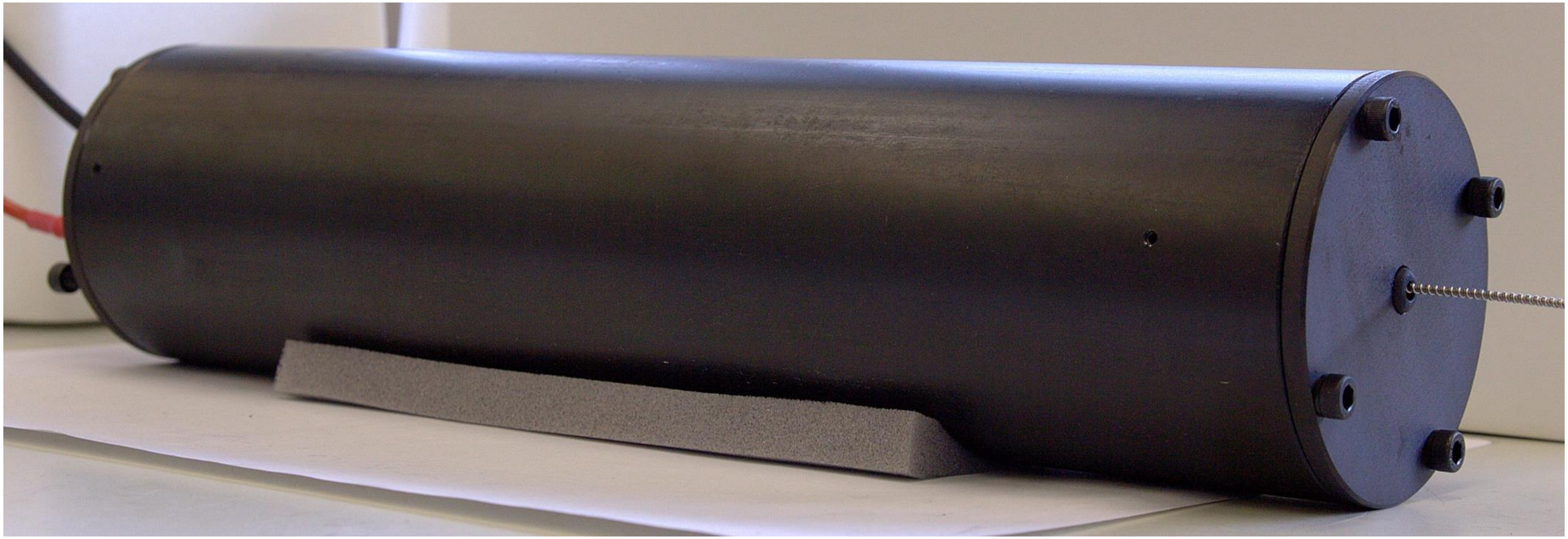
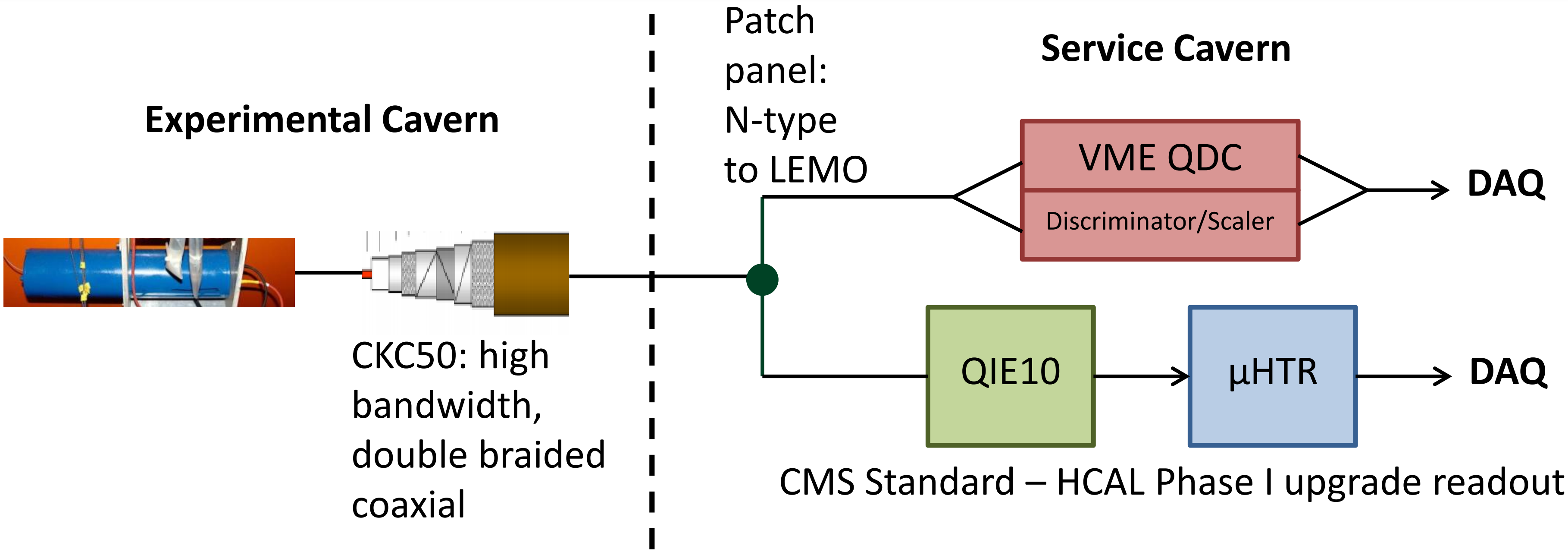
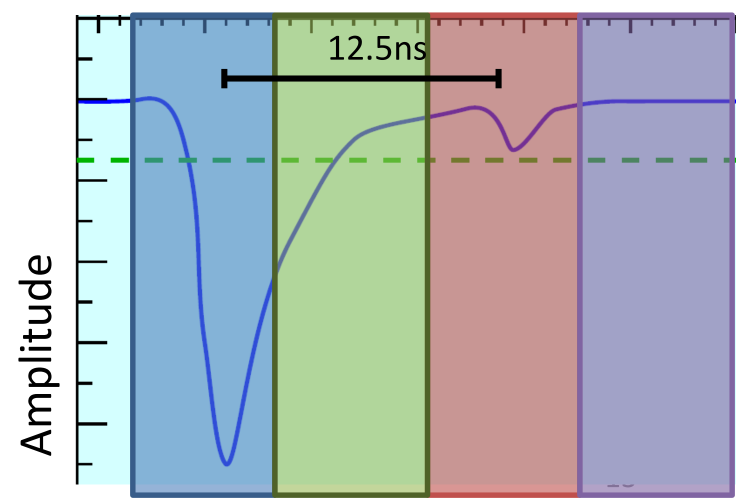


Read-out chain

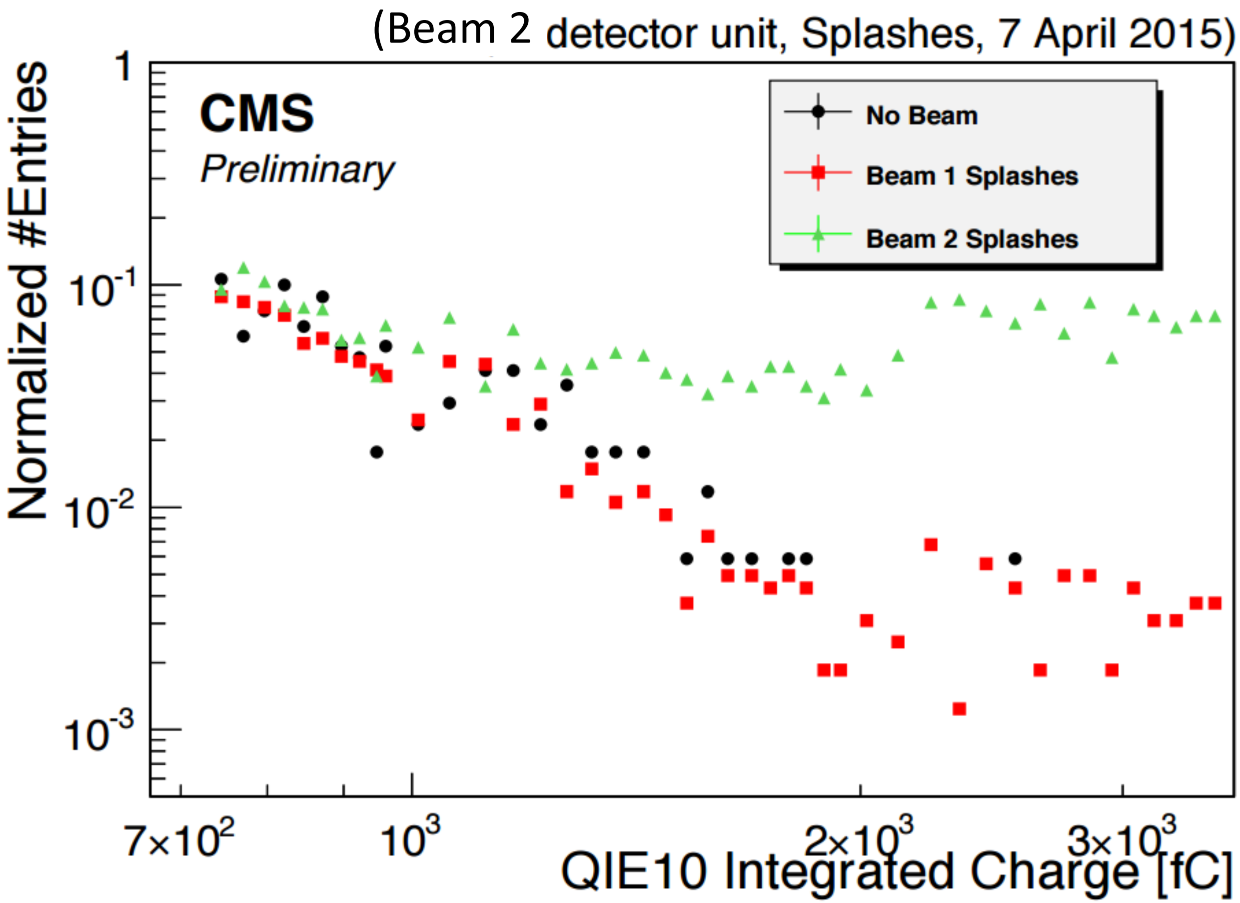


- Every BX, every detector ➔ get 8-bit charge and 6-bit timing information
  - Histogram (µHTR)
- Calculate flux
  - Published to CMS and LHC operations every ~23s

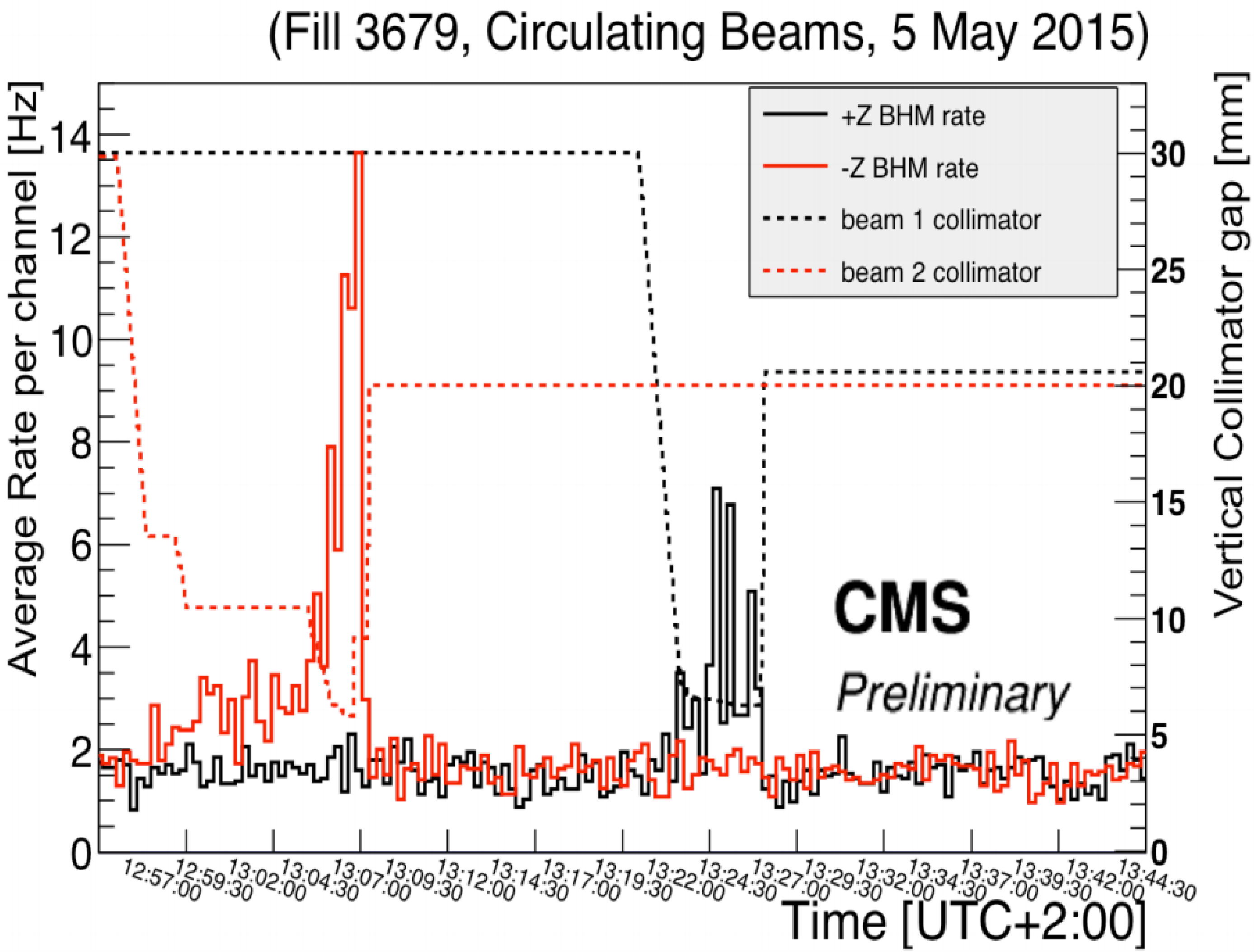


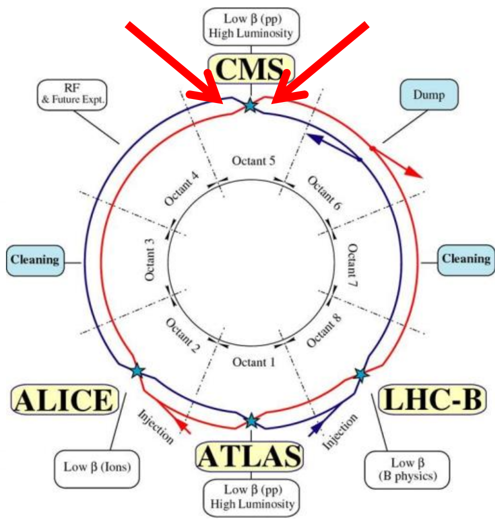
Splashes

- Indication of directionality: a unit measuring beam 2 sees only beam 2 splashes, no beam 1 splashes



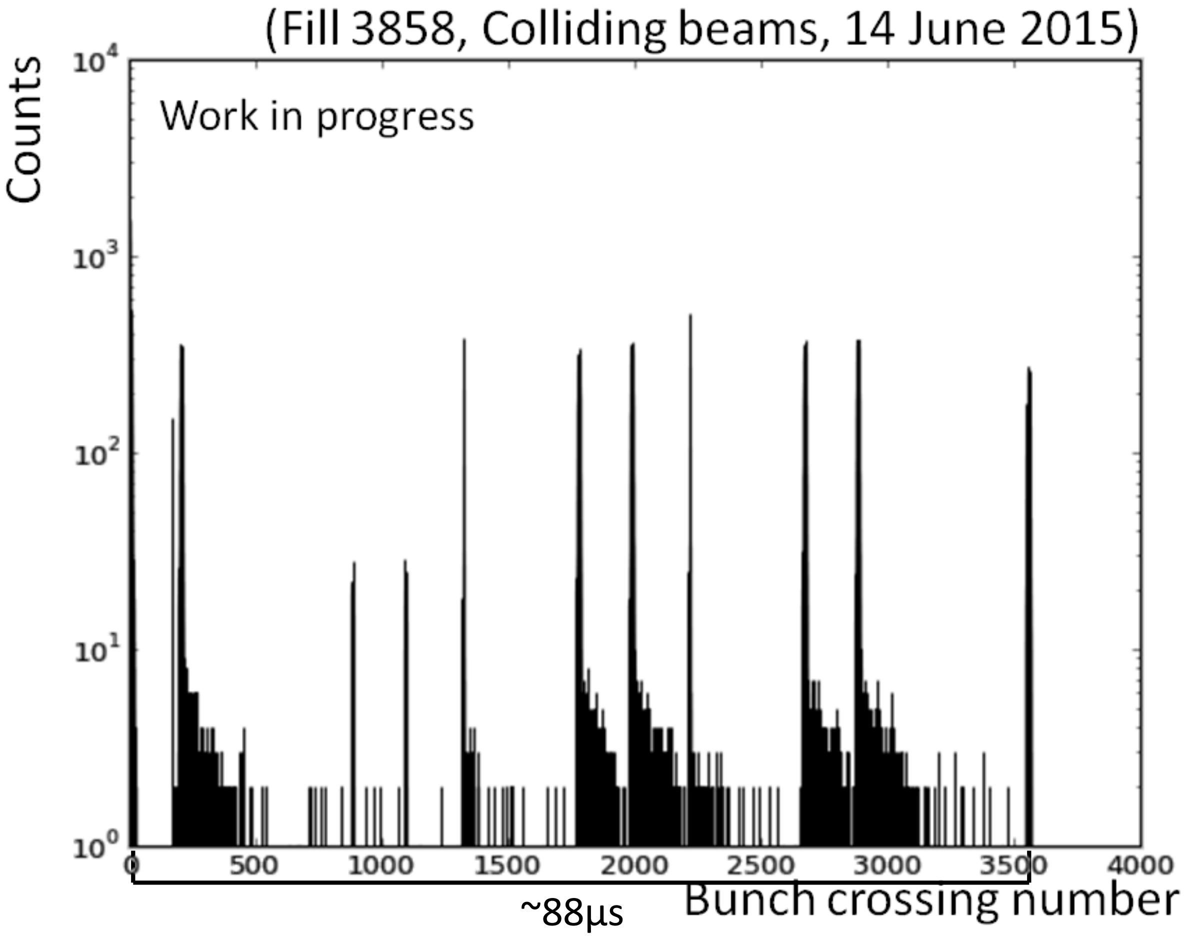
Correlation to collimator movement





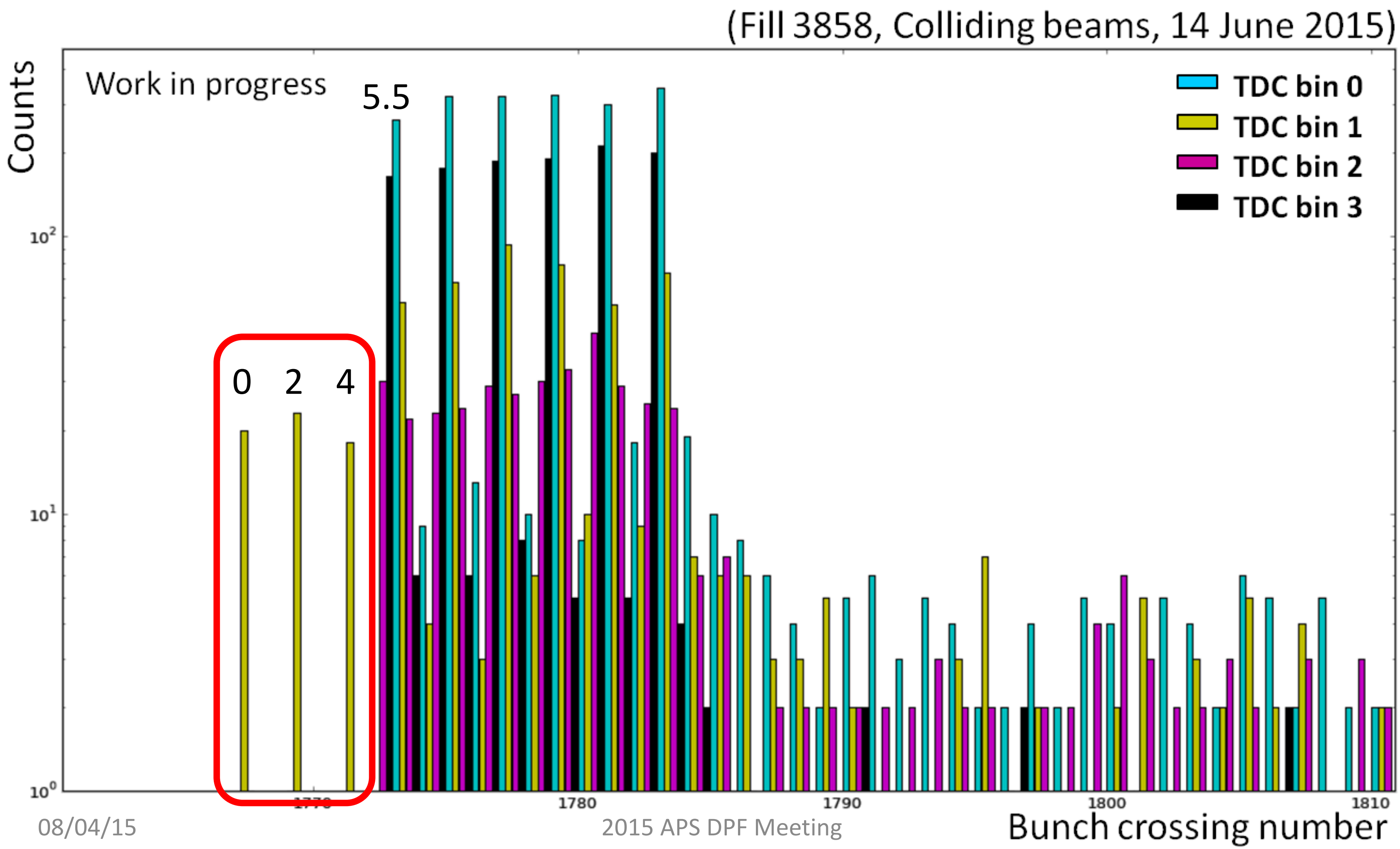
Detector commissioning

- Commissioned with low detector thresholds
- Detailed bunch structure seen
- Tail consistent with albedo from cavern



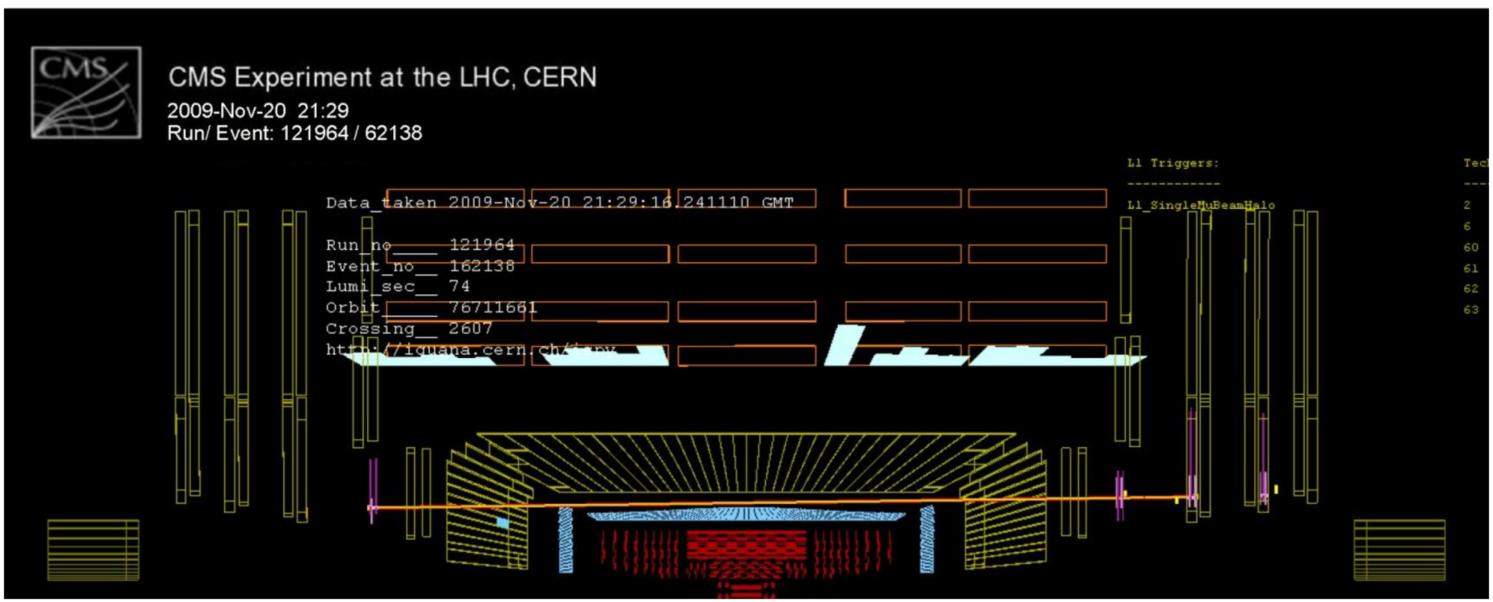
Detector commissioning

- Three bunches of pure background



Summary

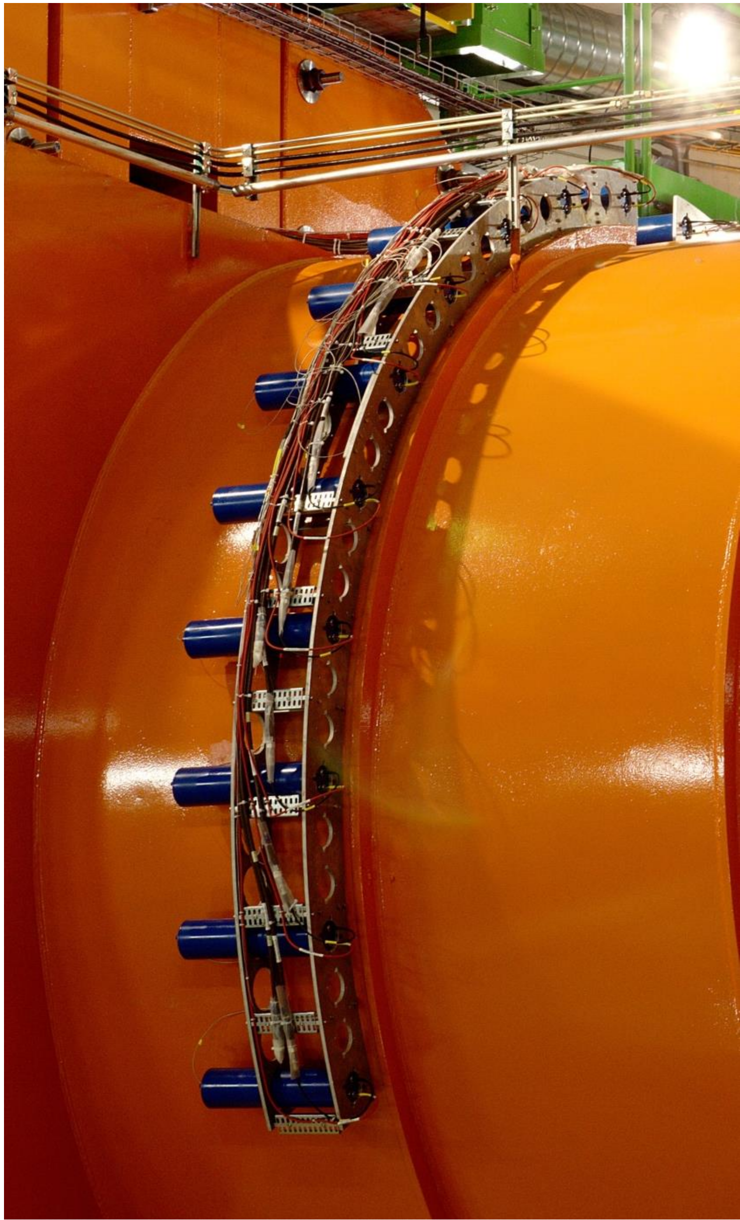
- New Beam Halo Monitor (BHM) will provide an online, bunch-by-bunch, per beam MIB rate arriving at CMS at high radius
- Takes advantage of directional nature of Cherenkov radiation and golden location timing to separate MIB from collisions product signals



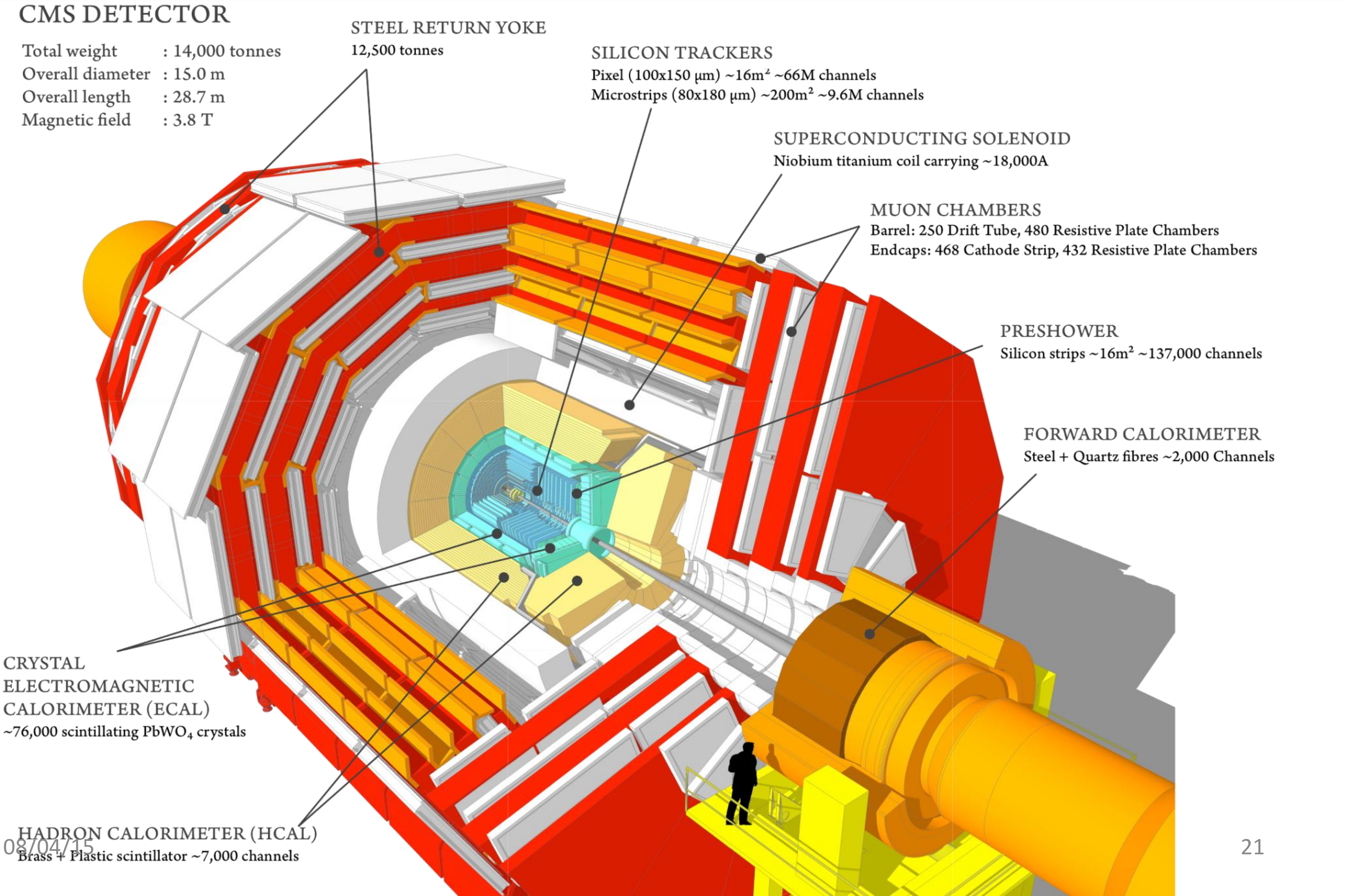
Acknowledgements

- University of Minnesota: R. Rusack, J. Mans
- BRIL: A. Dabrowski
- BHM: N. Tosi, S. Orfanelli
- Other UMN, CERN, and Bologna students and technicians

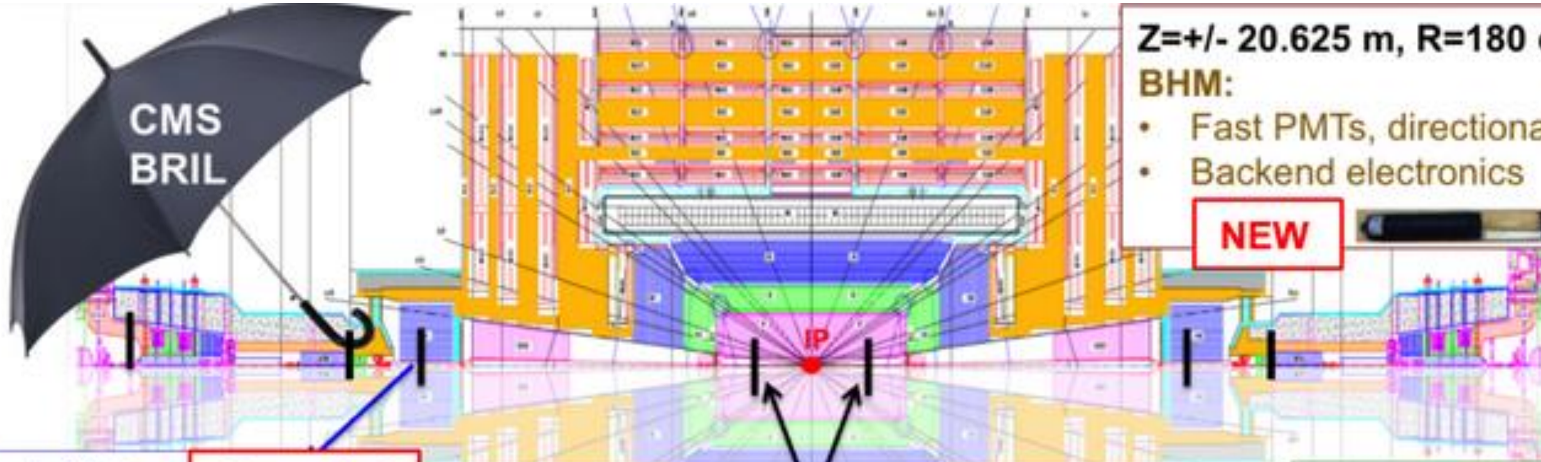
ADDITIONAL SLIDES



The CMS detector



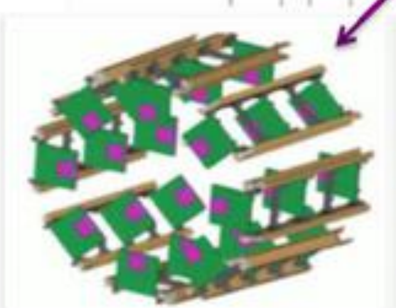
Beam, Radiation, Instrumentation, and Luminosity



Z=+/- 20.625 m, R=180 cm
BHM:
- Fast PMTs, directionality
- Backend electronics

NEW

Z = +/-11.2 m **Upgraded**
HF Luminosity:
- Quartz fiber calorimeter
- Photodetectors
- uTCA backend



Z=+/- 1.8 m, R=5 cm

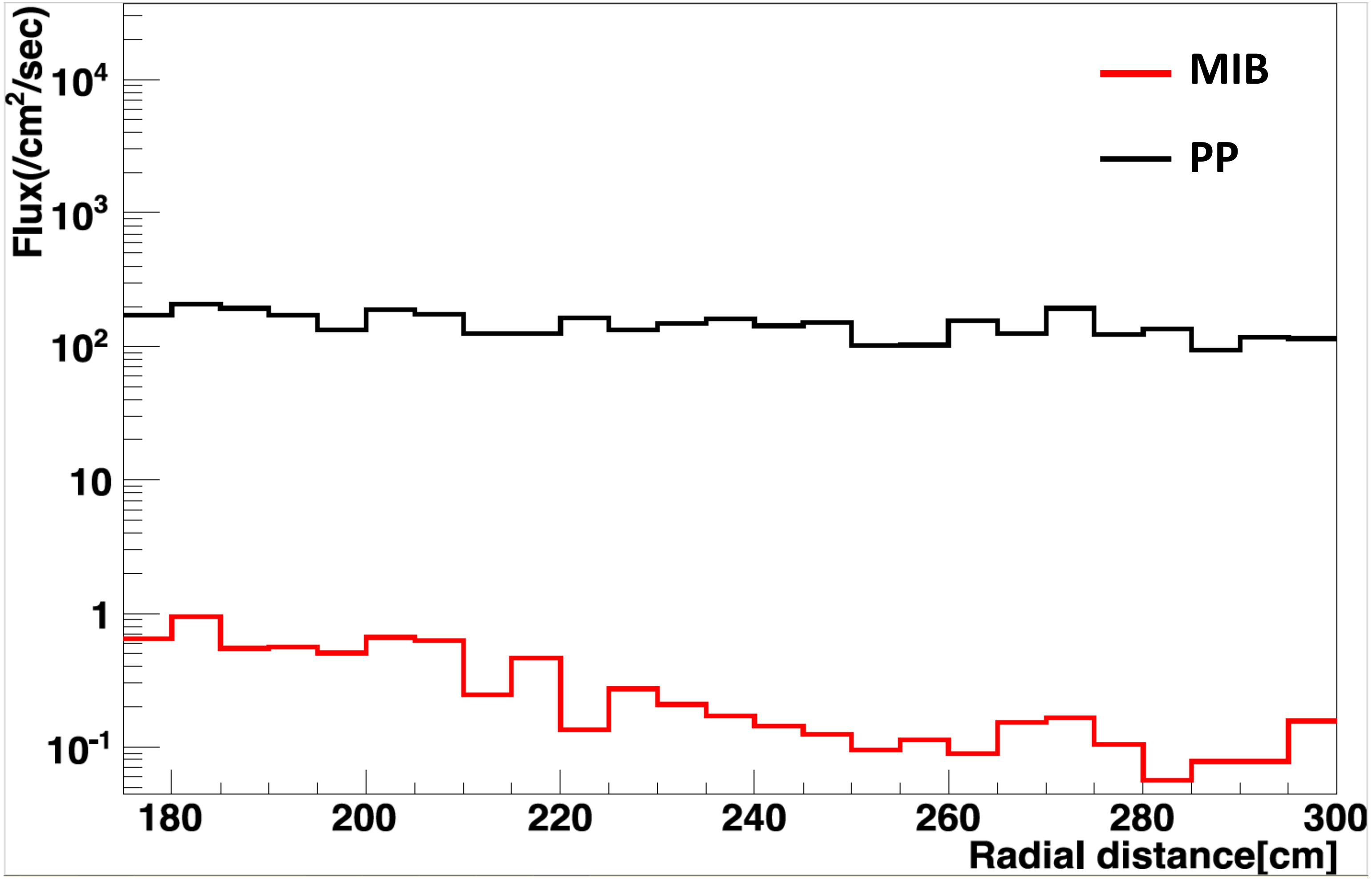
PLT: **NEW**
- 48 si-pixel sensors
- Special 40 MHz readout

BCM1F: **Upgraded**
- 24 sCVD diamond sensors, 48 channels
- Fast MIP counter, triggerless readout

BCM1L: **Upgraded**
- 8 pCVD diamond sensors
- Beam background monitoring
- Protection of CMS pixel detector

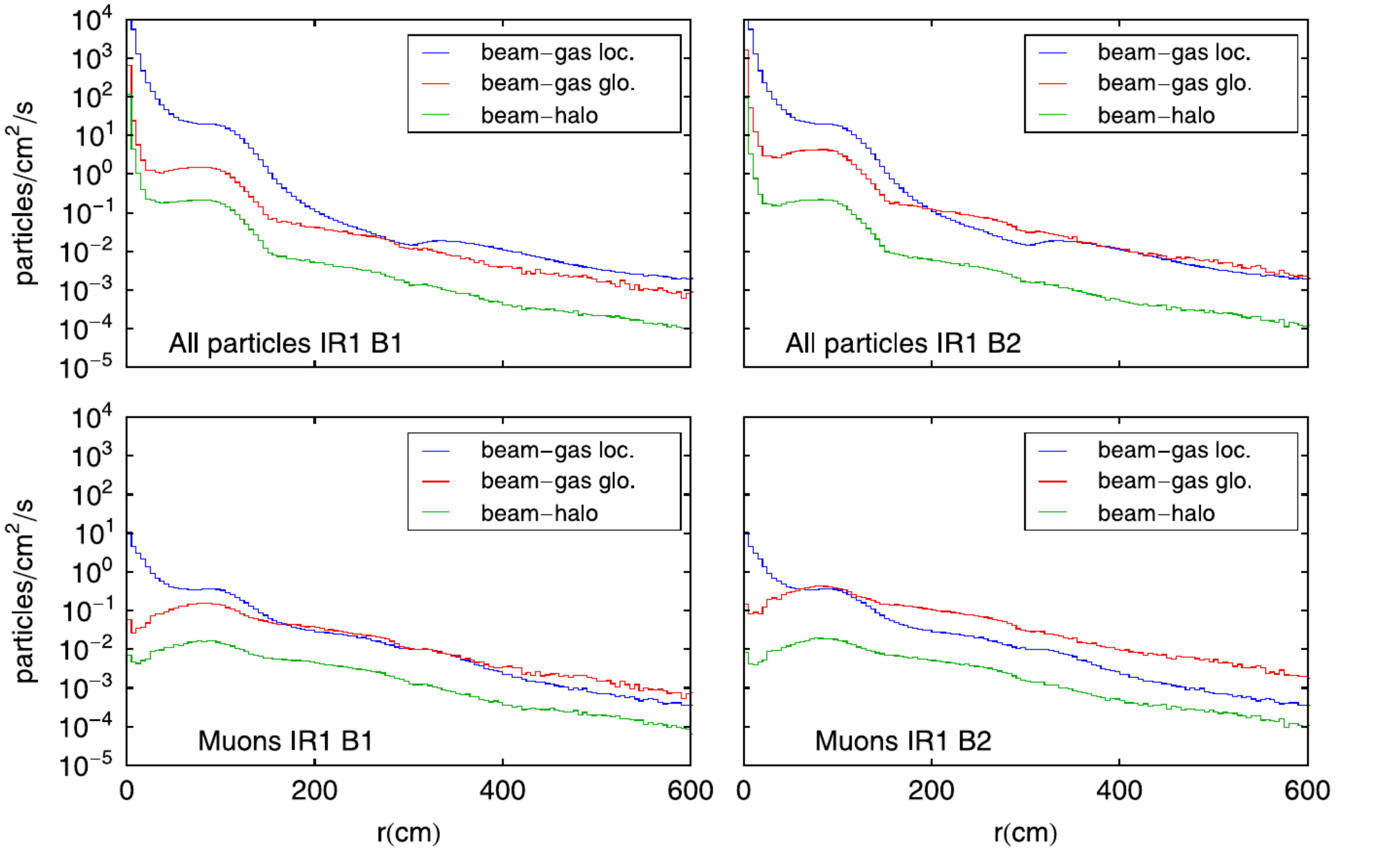
Z = +/-14.4 m **Upgraded**
BCM2L:
- Inner ring: 4 sensors, R = 5 cm
- Outer ring: 8 sensors, R = 28 cm

MIB vs. PP

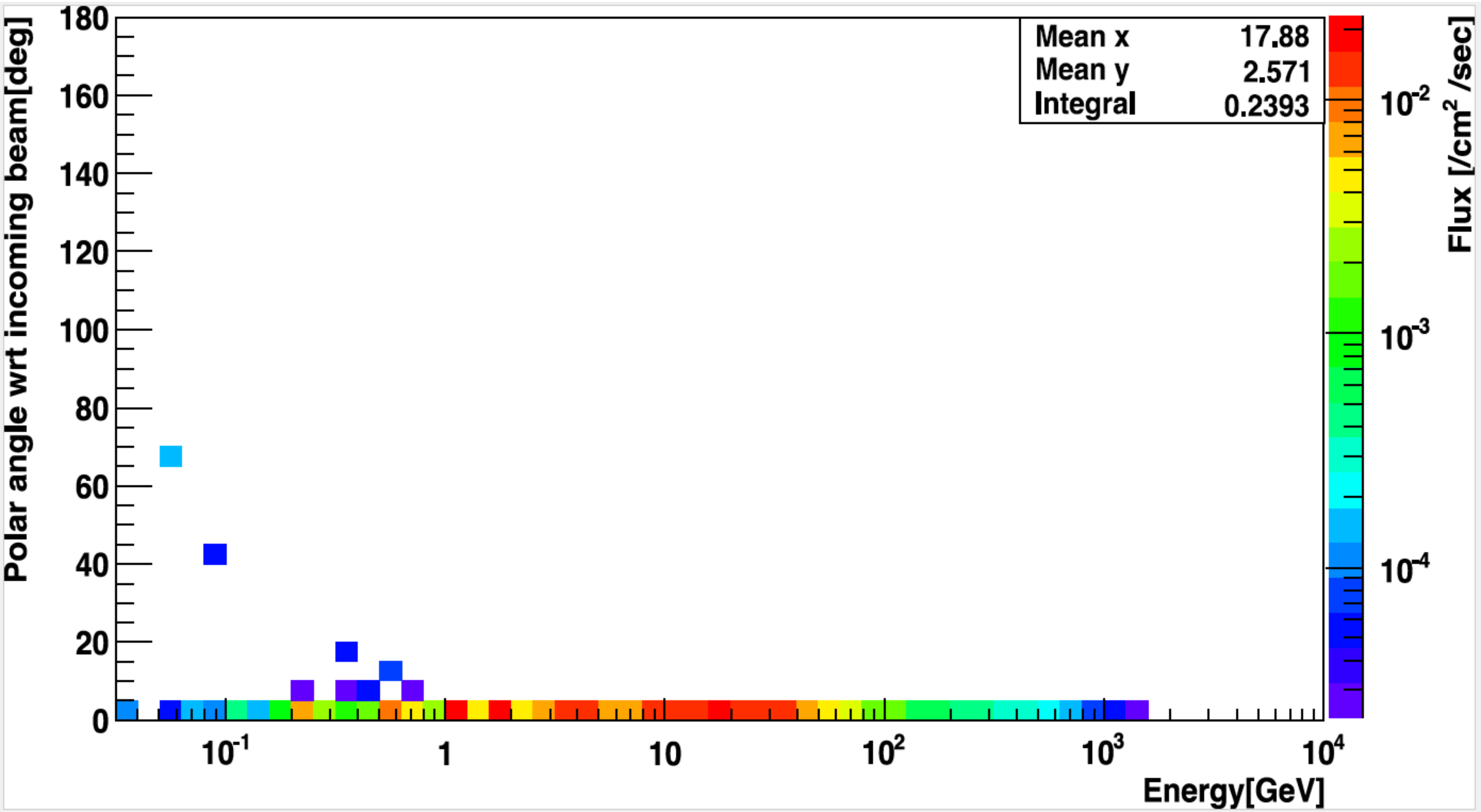


Flux(/cm^2/sec)
10^4
10^3
10^2
10
1
10^{-1}
MIB
PP
180
200
220
240
260
280
300
Radial distance[cm]

Beam halo contributions

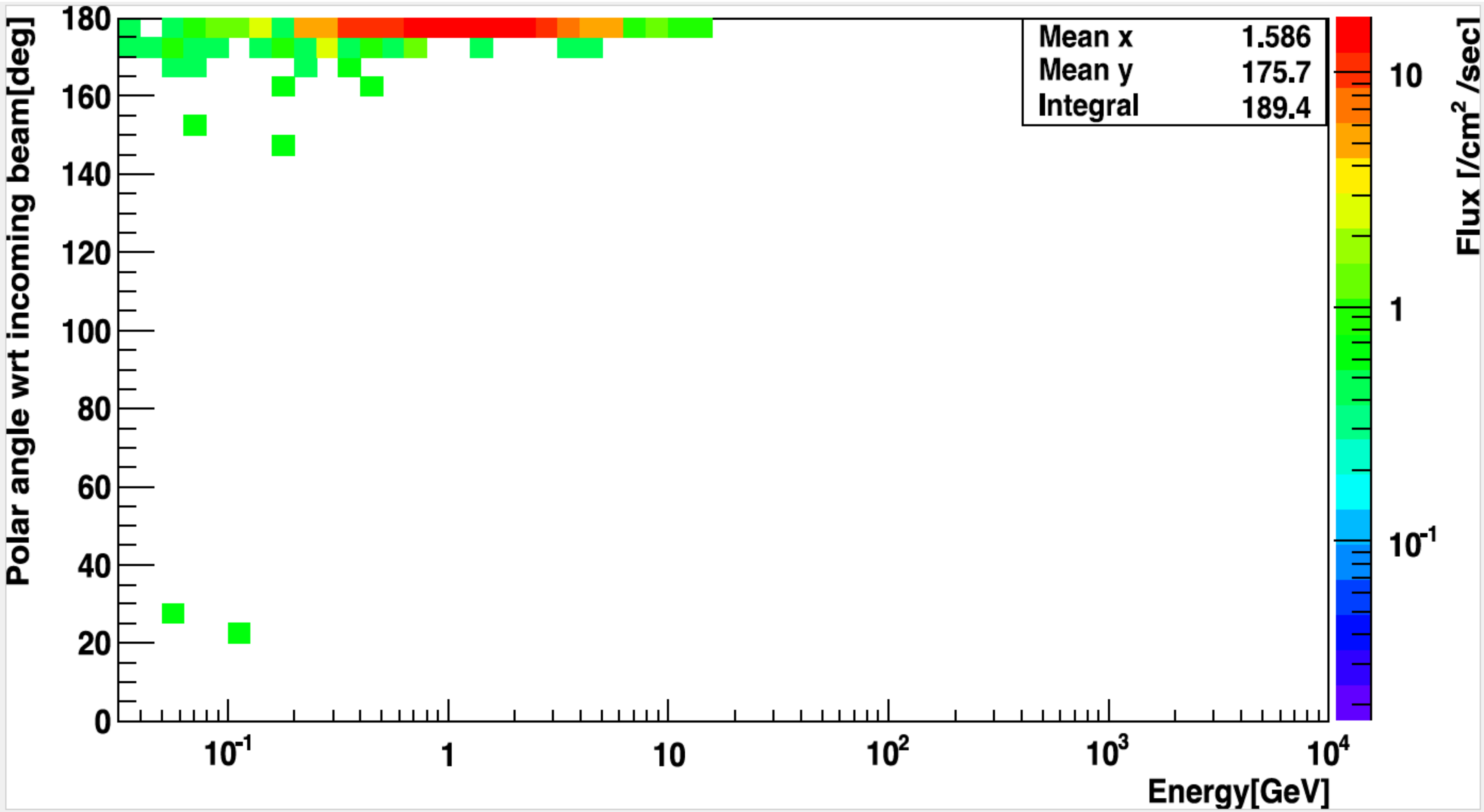


MIB muons



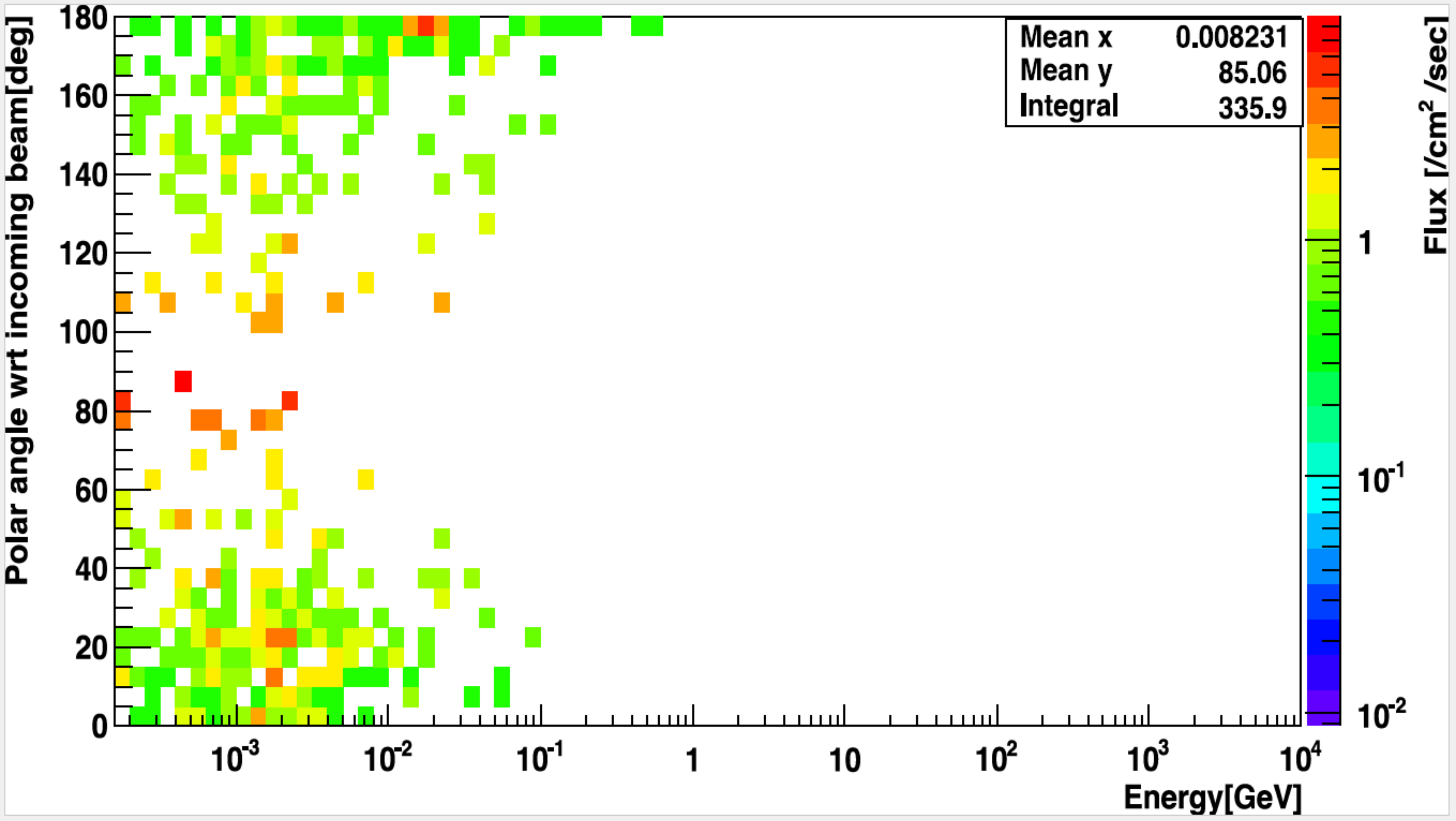
Polar angle wrt incoming beam[deg]
180
160
140
120
100
80
60
40
20
0
Mean x 17.88
Mean y 2.571
Integral 0.2393
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
Energy[GeV]
10^{-2}
10^{-3}
10^{-4}
Flux [/cm^2 /sec]

PP muons

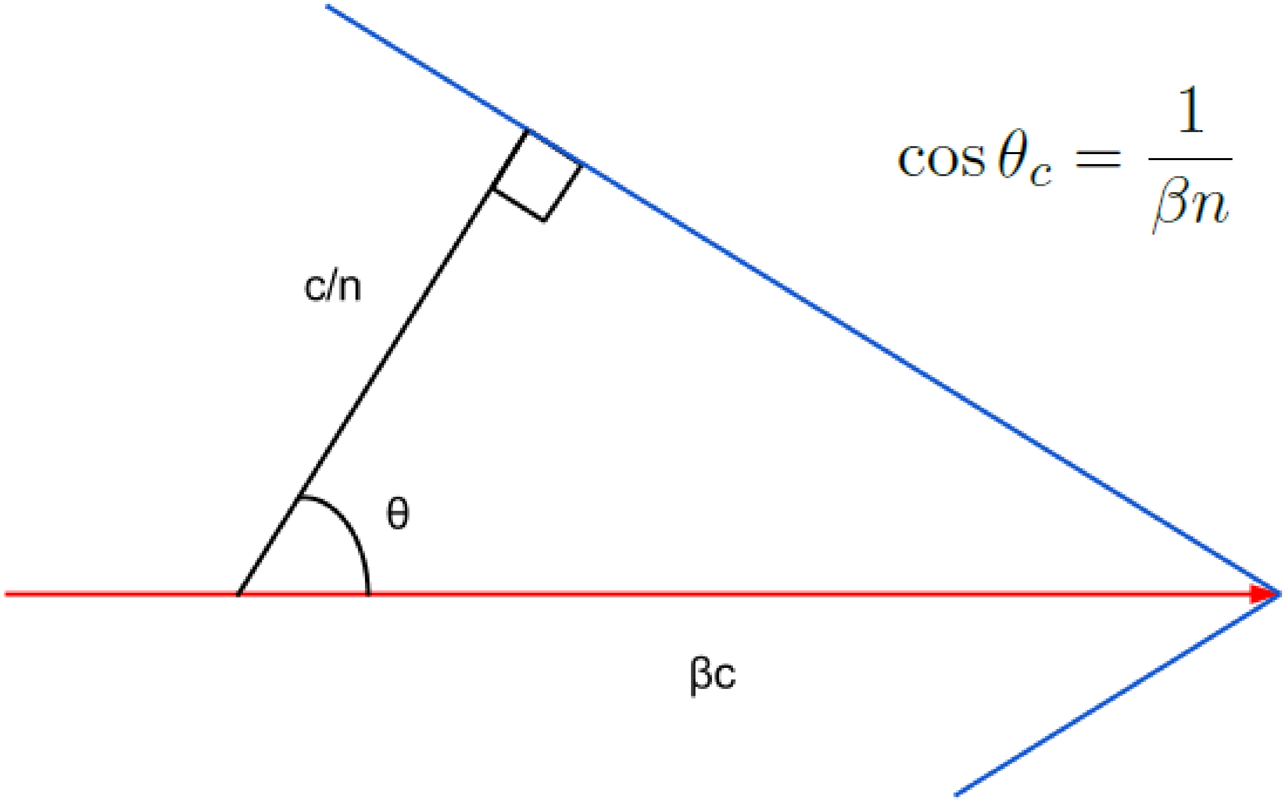


Polar angle wrt incoming beam[deg]
180
160
140
120
100
80
60
40
20
0
10^{-1}
1
10
10^2
10^3
10^4
Energy[GeV]
Mean x 1.586
Mean y 175.7
Integral 189.4
10
1
10^{-1}
Flux [/cm^2 /sec]

PP electrons



Cherenkov angle



$$\cos\theta_c = \frac{1}{\beta n}$$

$$E_{th} = \frac{nmc^2}{\sqrt{n^2 - 1}}$$ ≈ 142 MeV for muons

Cherenkov radiation

$$\frac{\partial^2 N}{\partial x \partial \lambda} = \frac{2\pi\alpha}{\lambda^2}\left(1 - \frac{1}{\beta^2 n(\lambda)^2}\right)$$

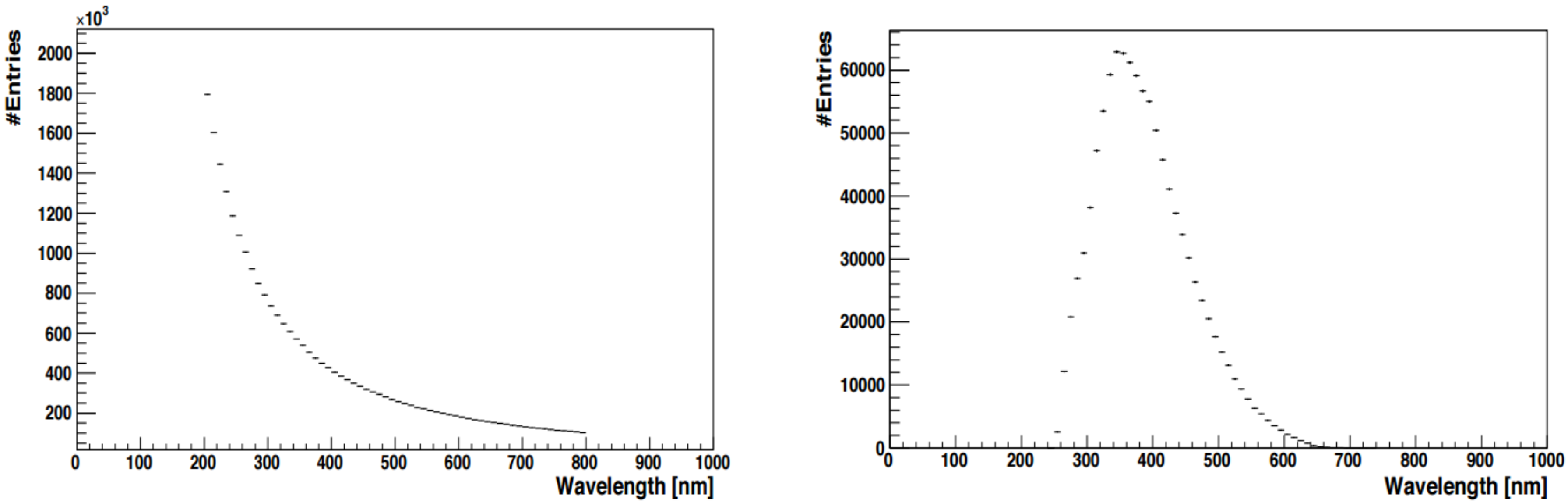
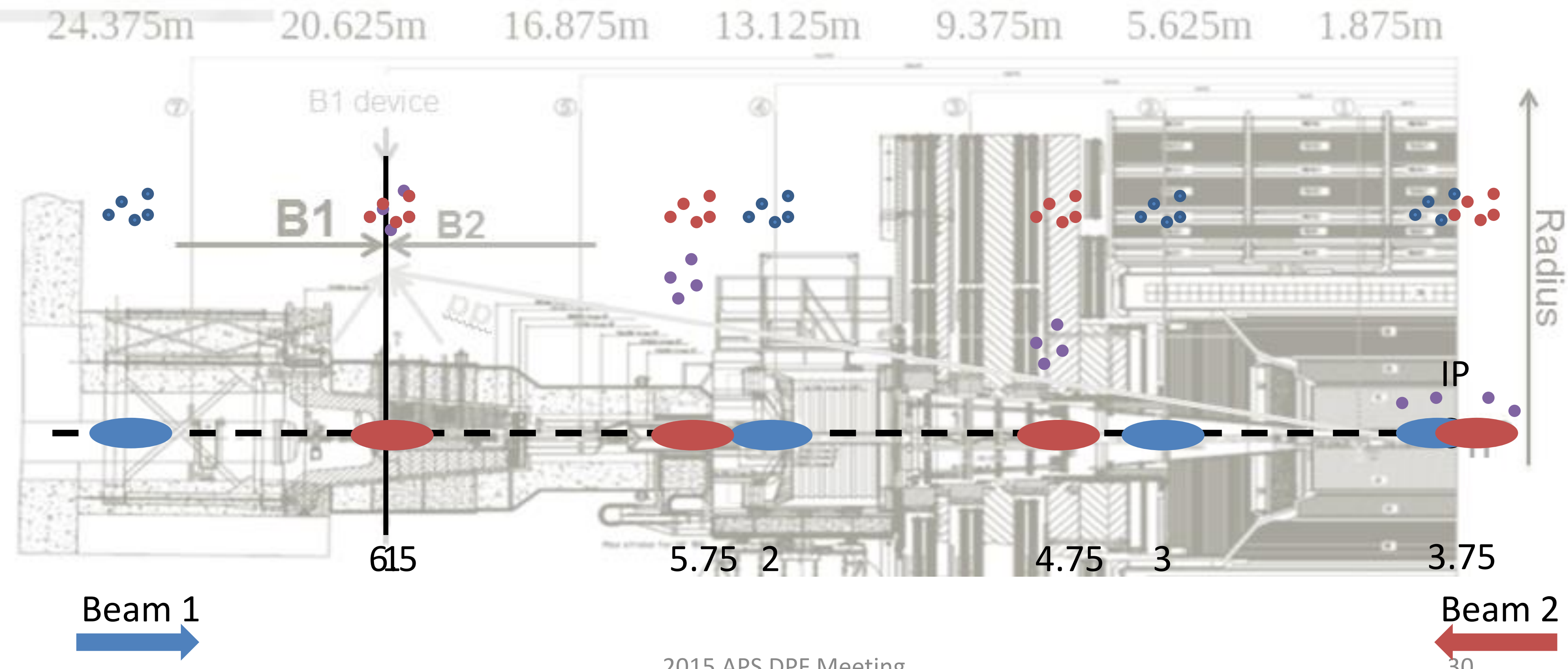


Figure 9 The wavelength of the Cherenkov light produced (left) and detected by the photocathode (right) as simulated when a muon of 4 GeV crosses 10 cm long quartz radiator, entering from the centre of the front face of the bar.

Timing

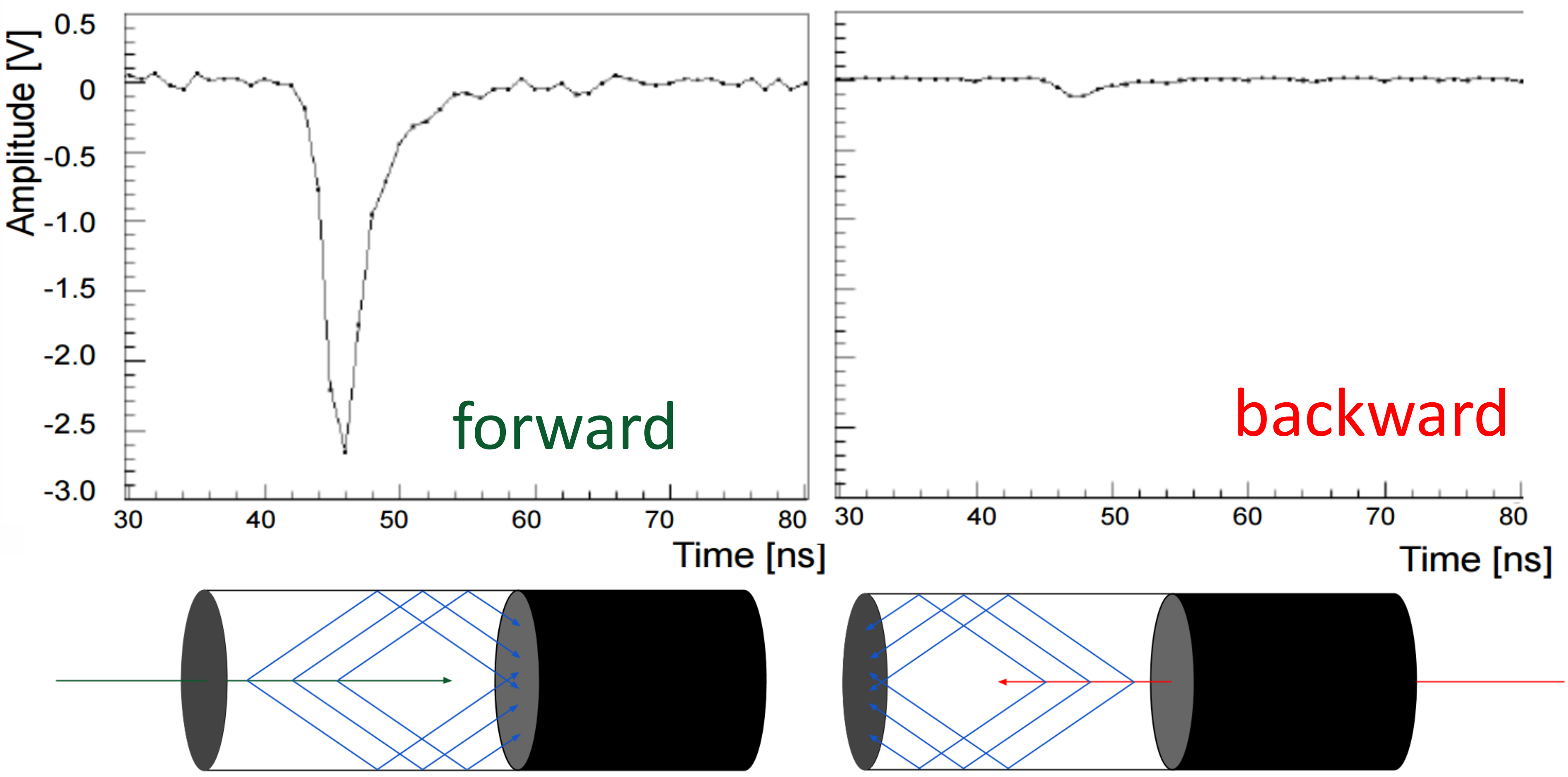
- Golden locations allow for maximum separation in timing

$$GL_{k+1} = \left(\frac{1}{4} + \frac{1}{2}k\right) \cdot (\text{BX spacing}) \approx 1.875m + 3.75m \cdot k$$



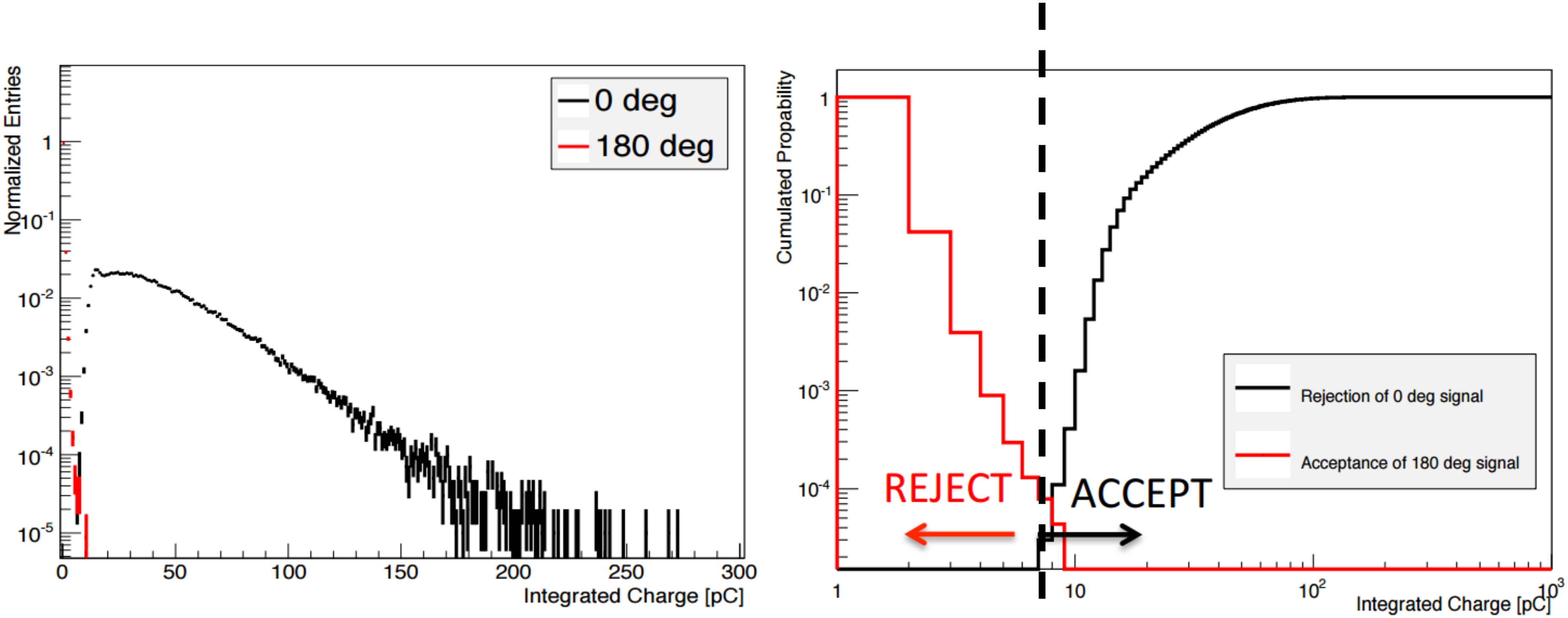
Test beam results

- Test beam studies performed at CERN in 2012



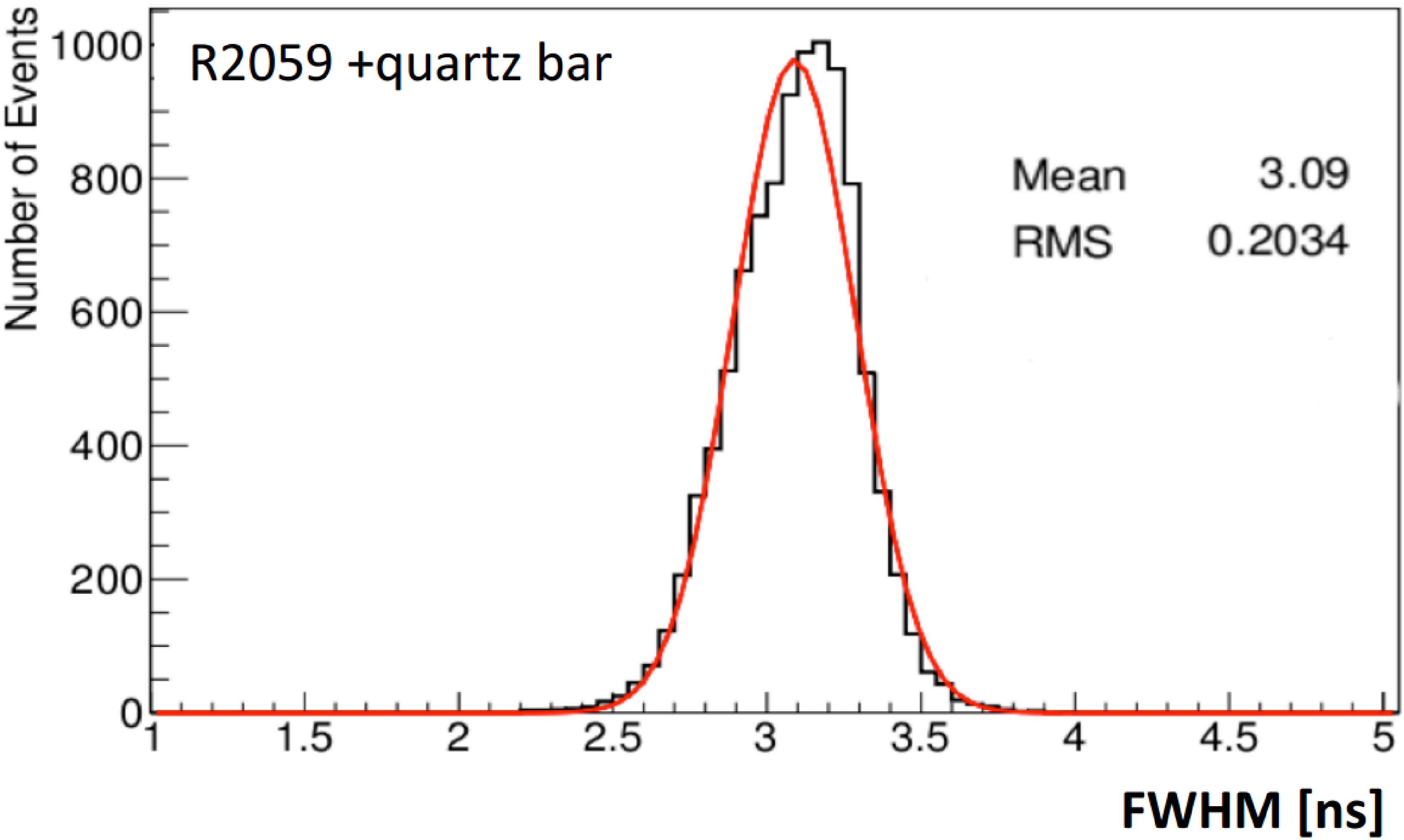
Test beam results

- Test beam studies performed at DESY in 2014

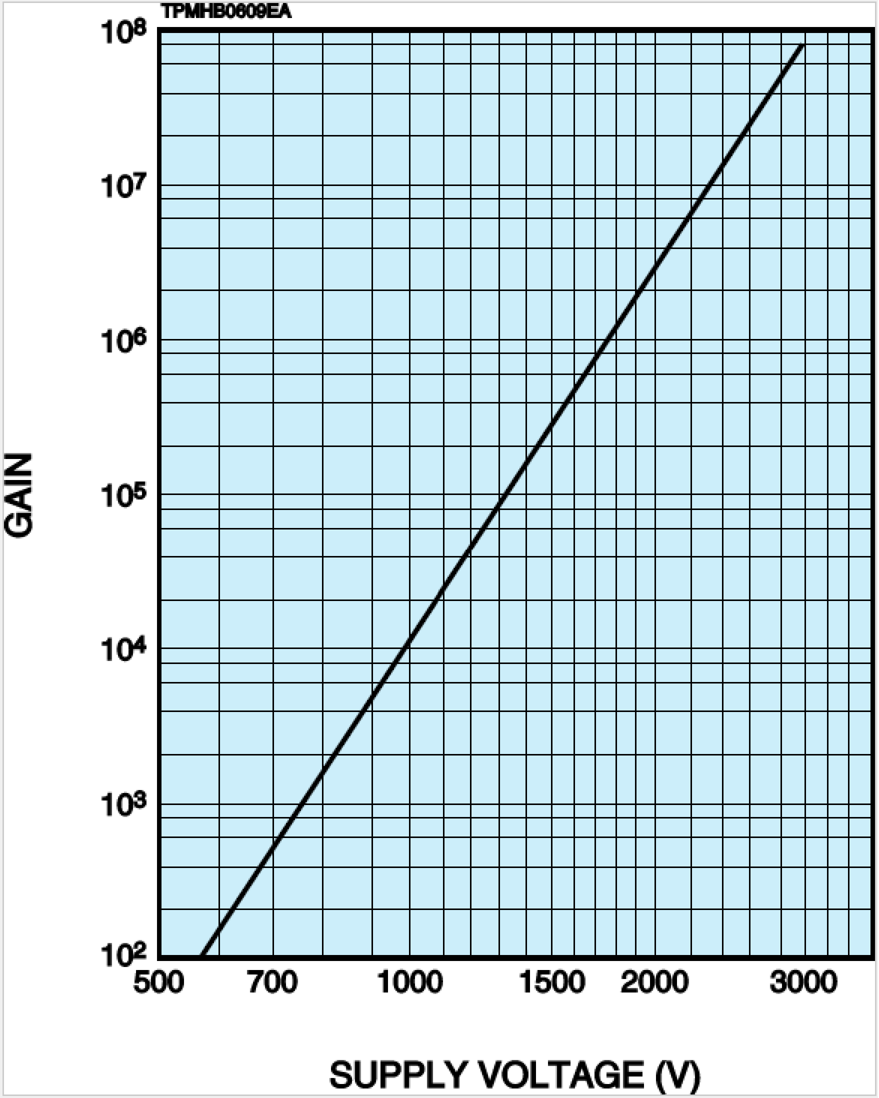


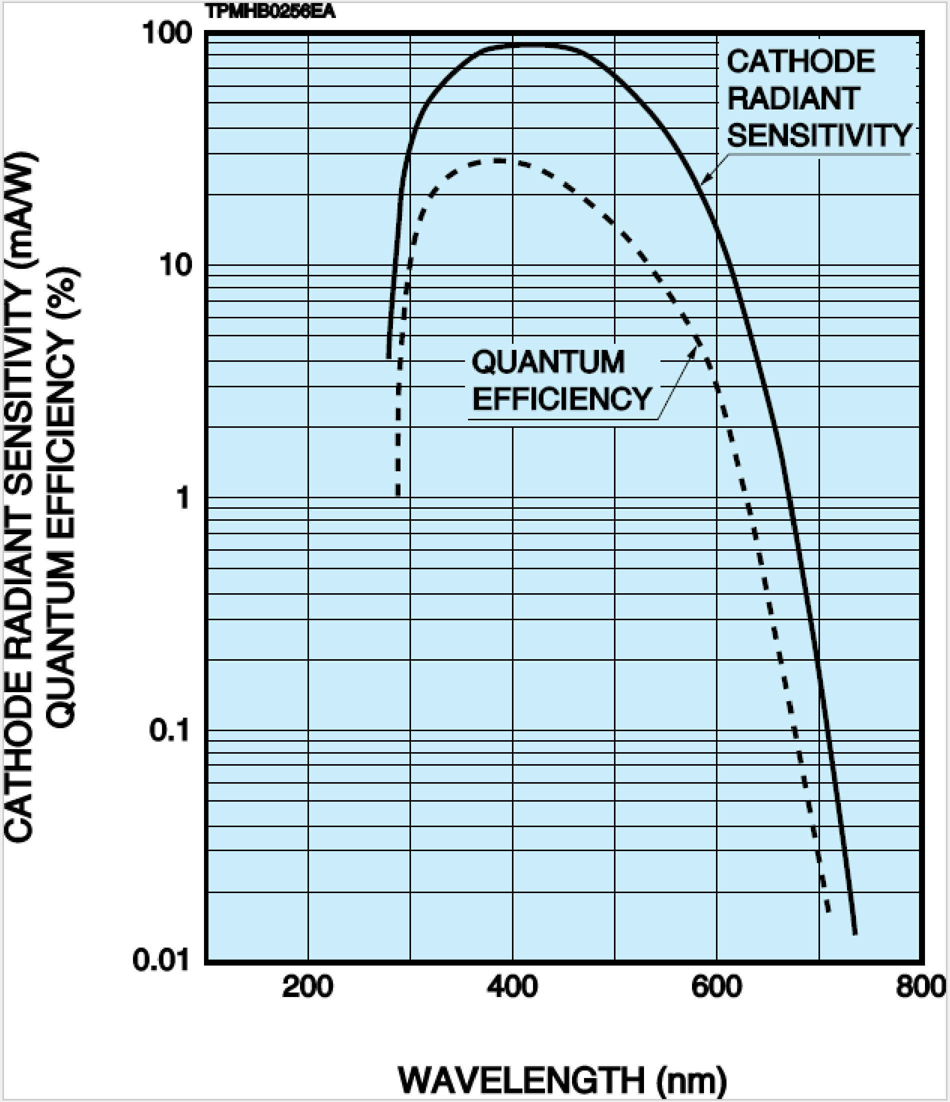
Amplitude cut: Backward suppression to 0.01%, forward acceptance 100%

Test beam timing



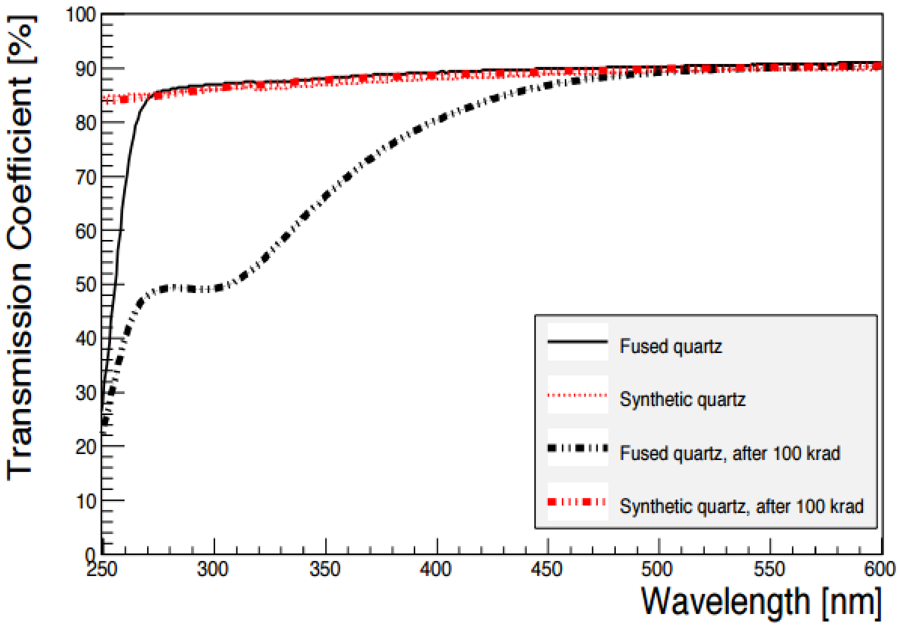
Hamamatsu R2059

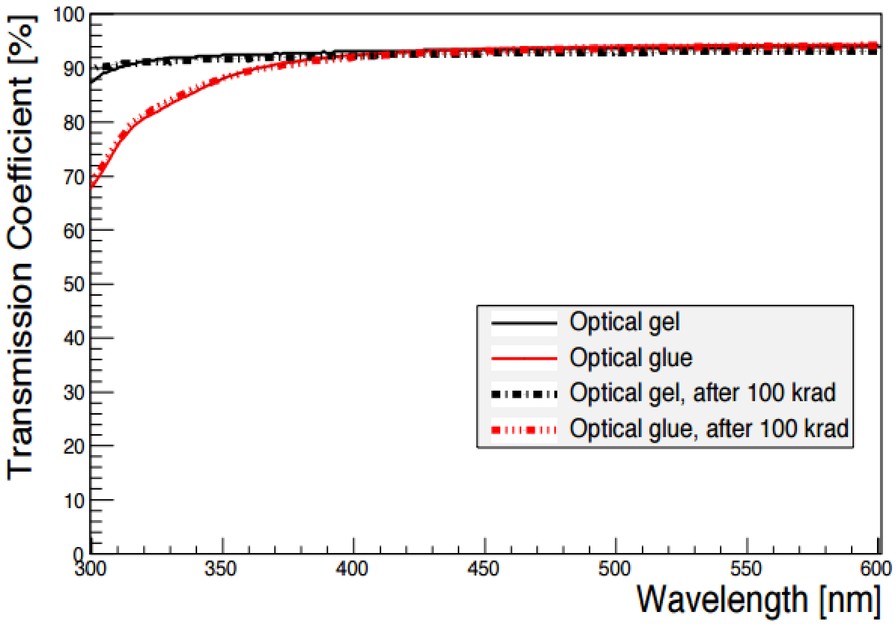




Radiation studies

- Unit irradiated with 3000 fb^{-1} of γ rays



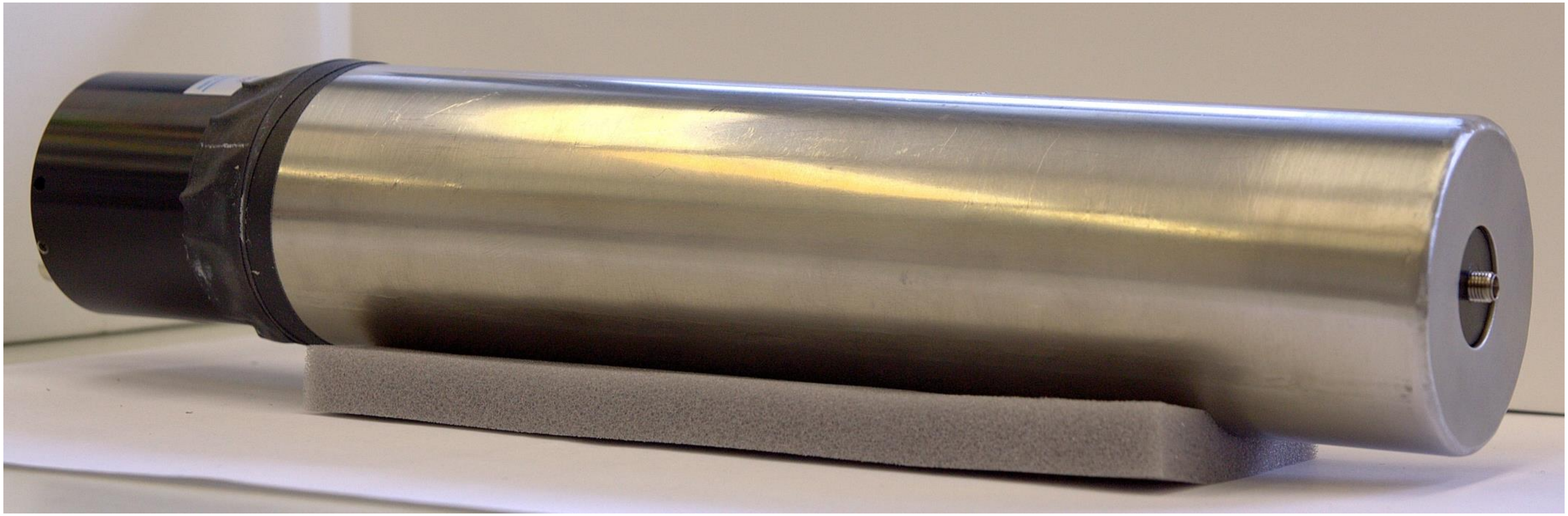


Detector units

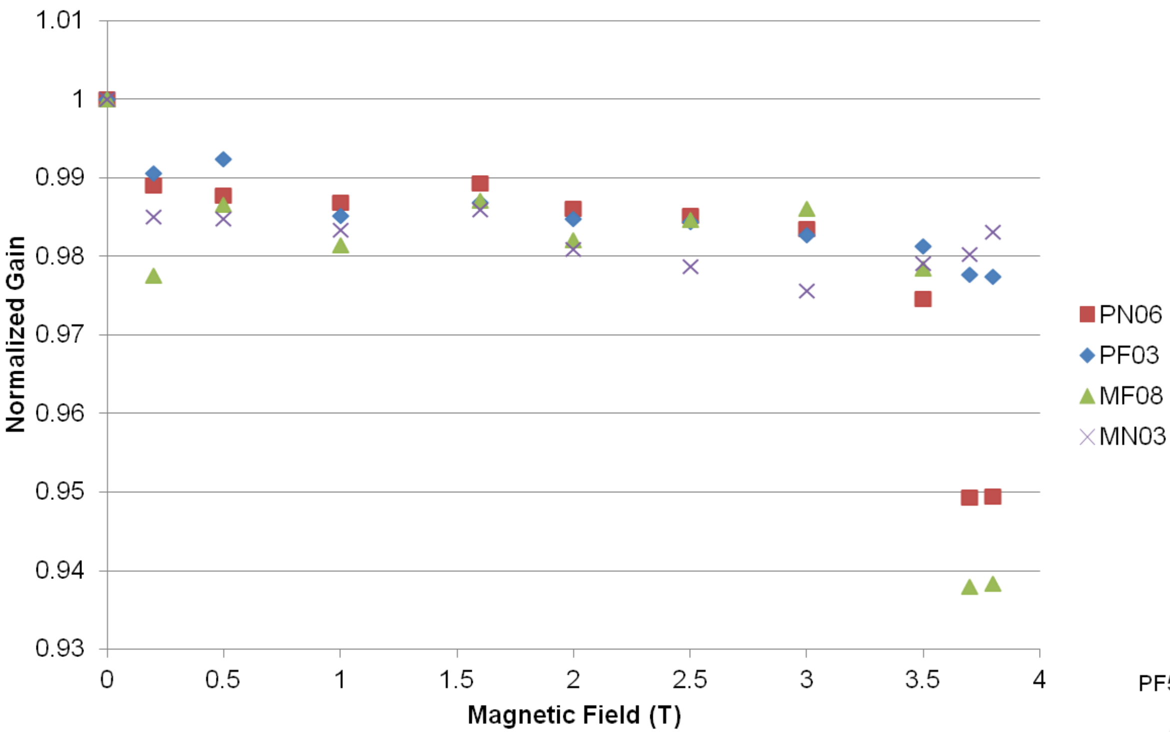
- Permally layer

Detector units

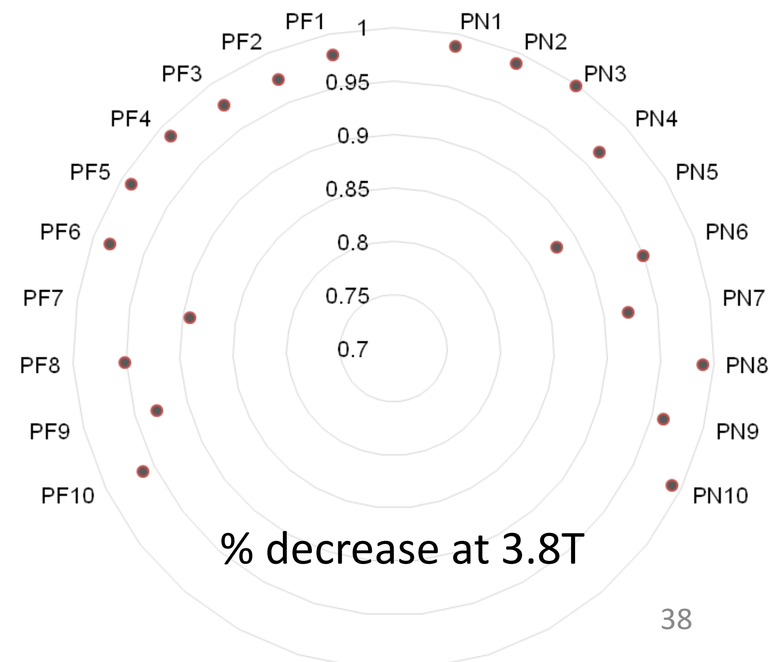
- Mumetal layer



Magnetic shielding efficiency



- Gain decreases as field increases

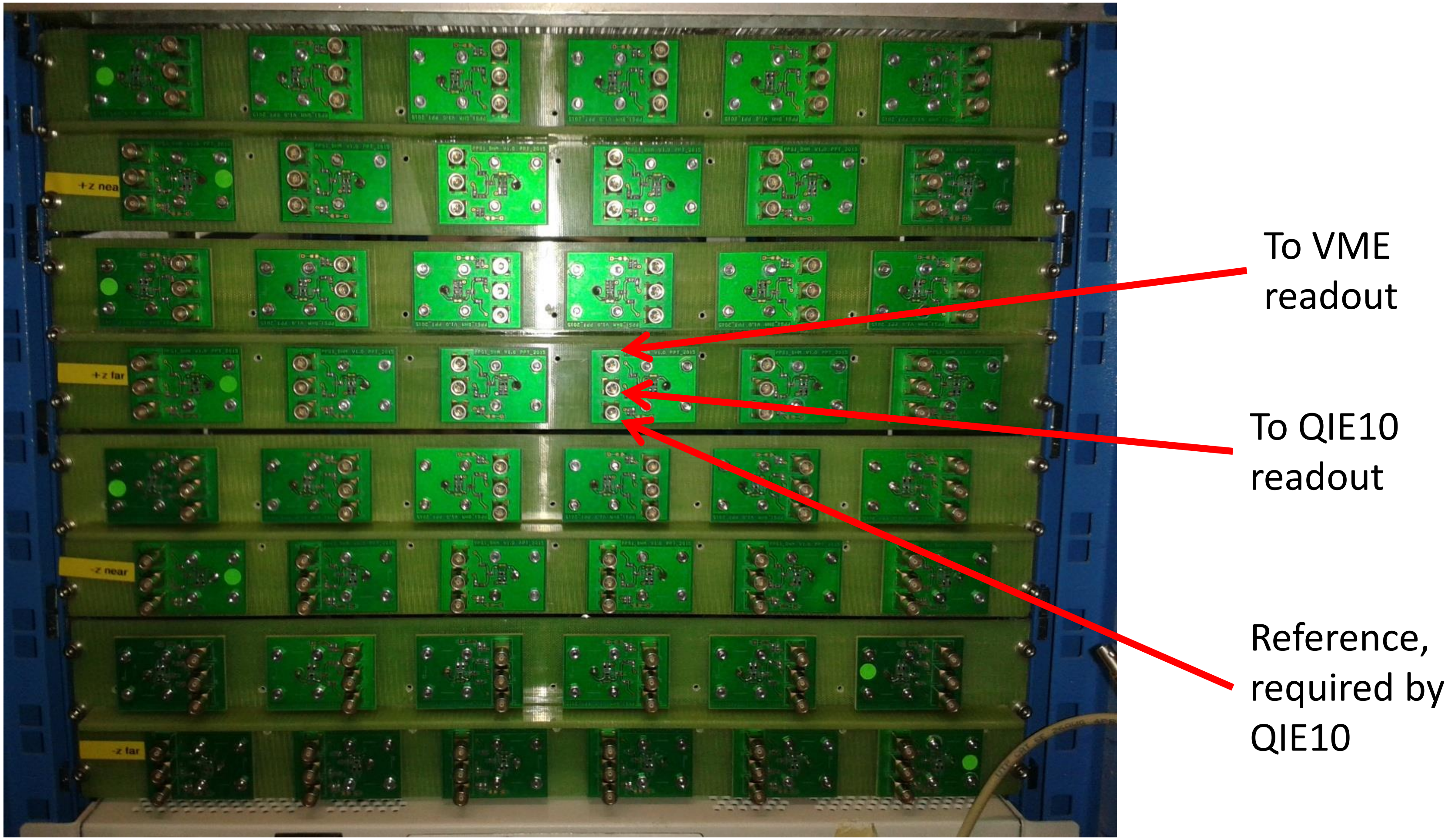


% decrease at 3.8T

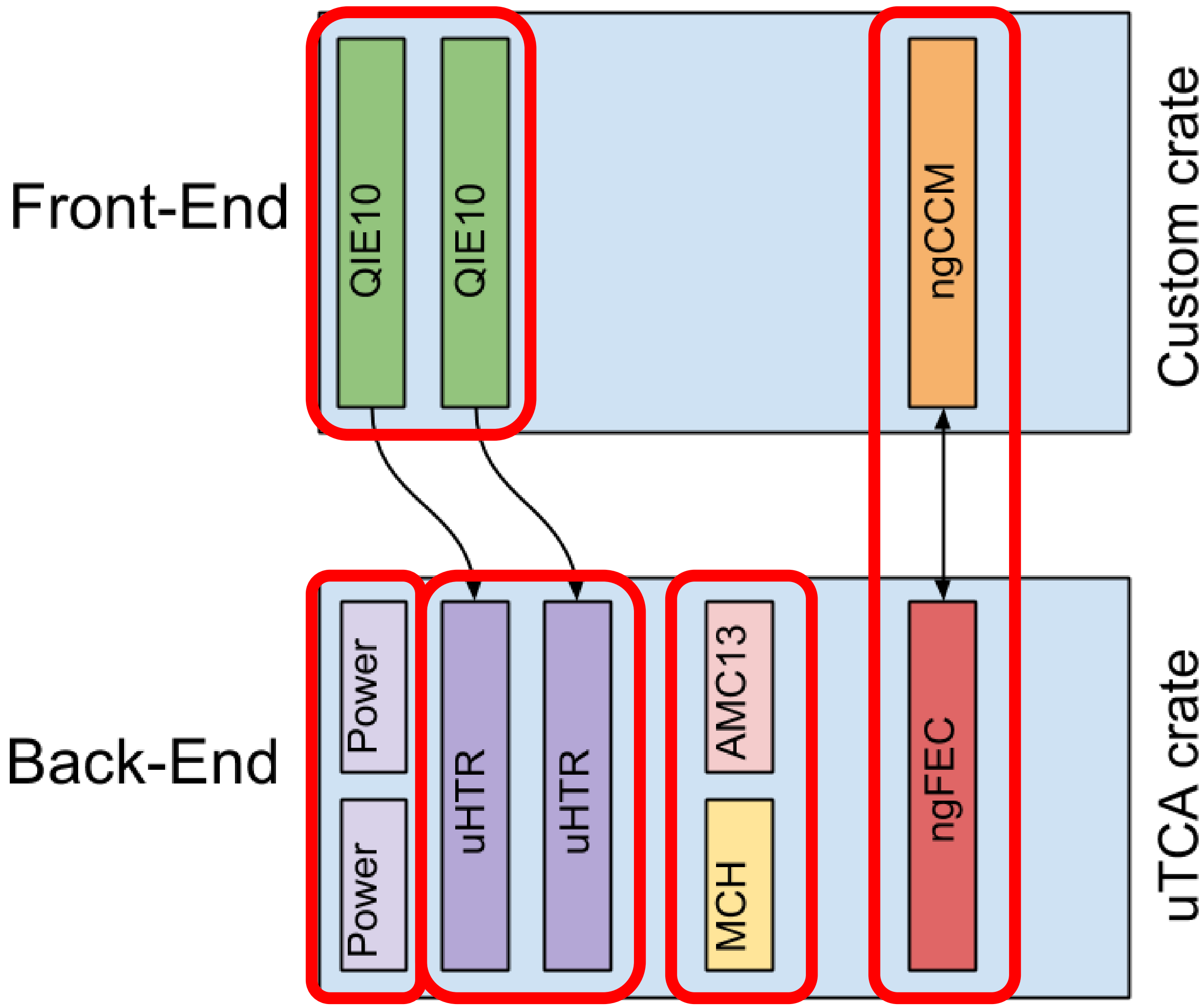
- Largest decrease ~10%

Patch panel

- Acts as passive splitter and attenuator

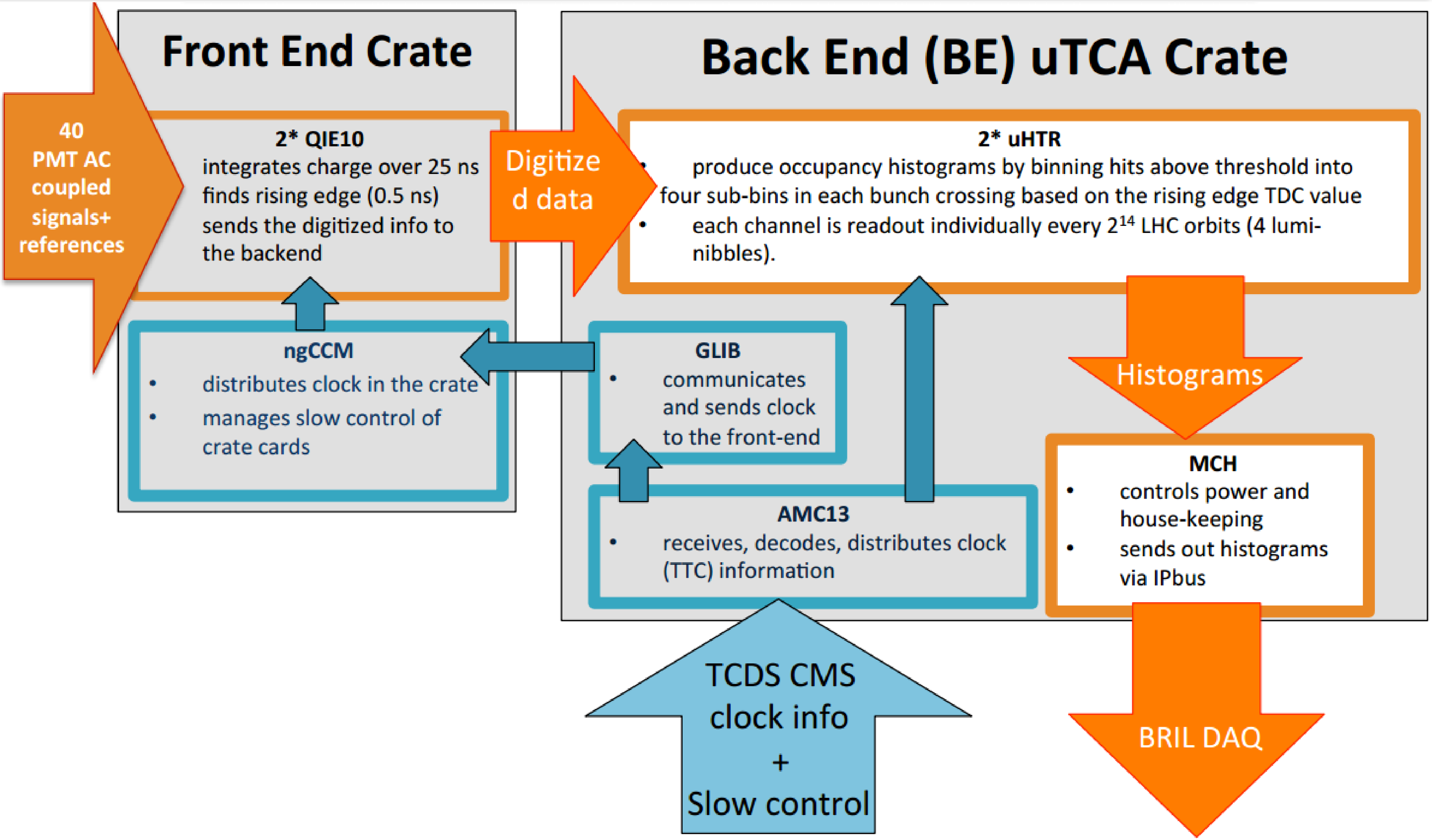


Read-out electronics



- QIE10: digitizer
- uHTR: histogramming unit
- Other units: power, clocks, slow control, data read-out

Electronics Overview



QIE10

- Reads analog PMT signal

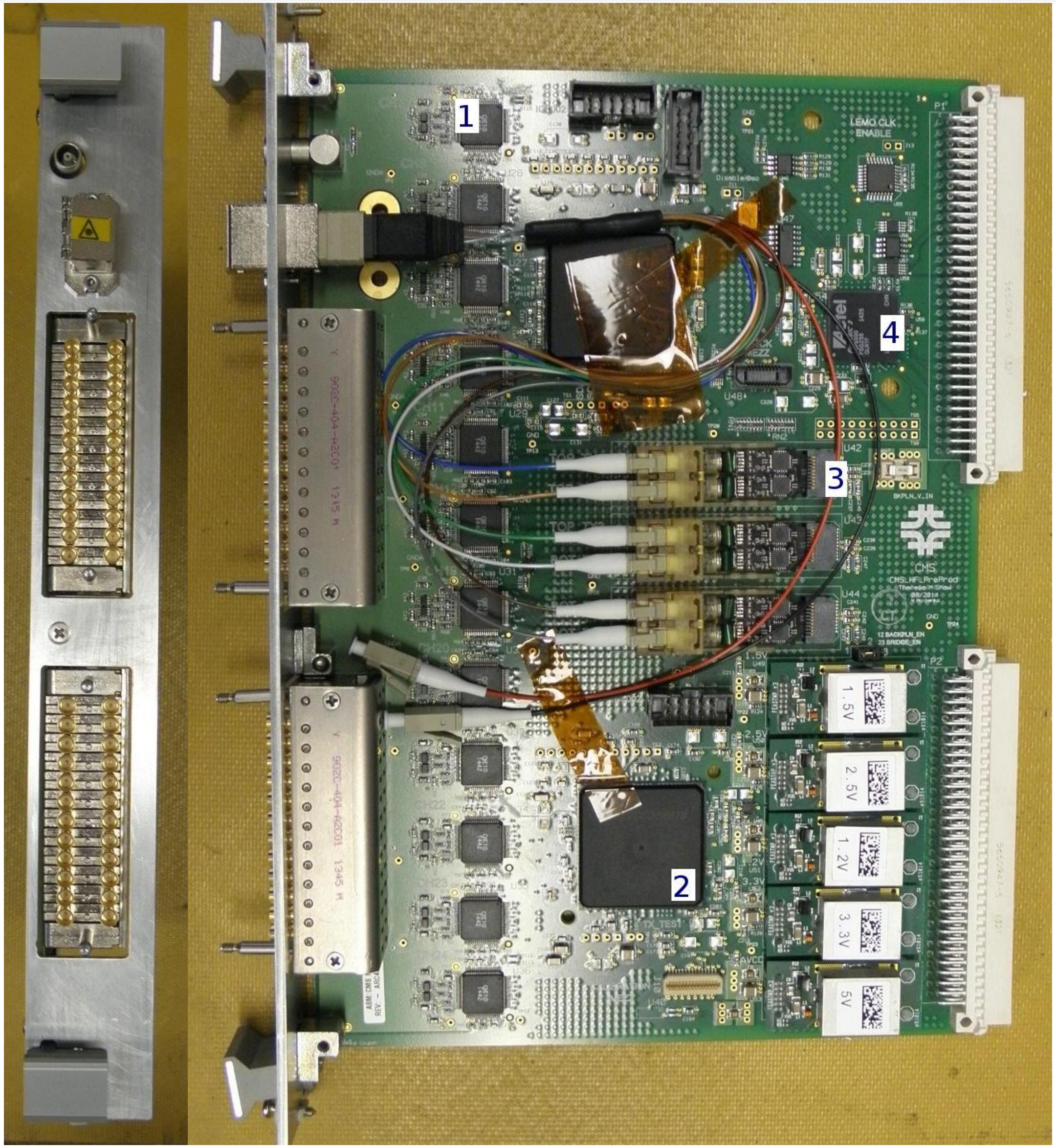
24 QIE10 ASICs:

- Integrates charge over 25ns, produces 8-bit ADC value (0-340pC)
- Produces 6-bit TDC value based on fixed-threshold leading edge measurement (.5ns resolution)

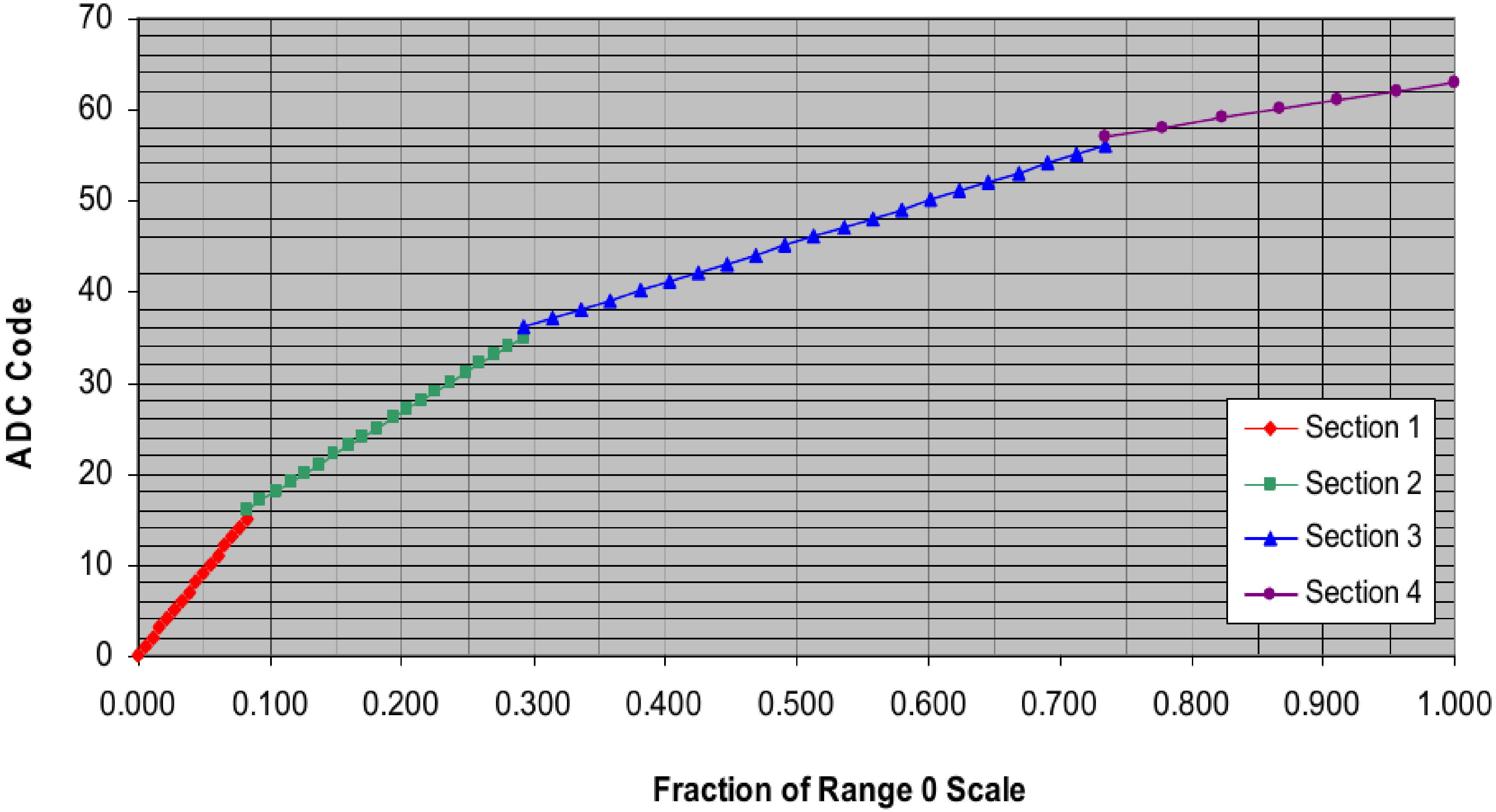
Igloo2 FPGAs:

- Collect and format data

- Data sent to back-end via 5Gbps asynchronous optical link

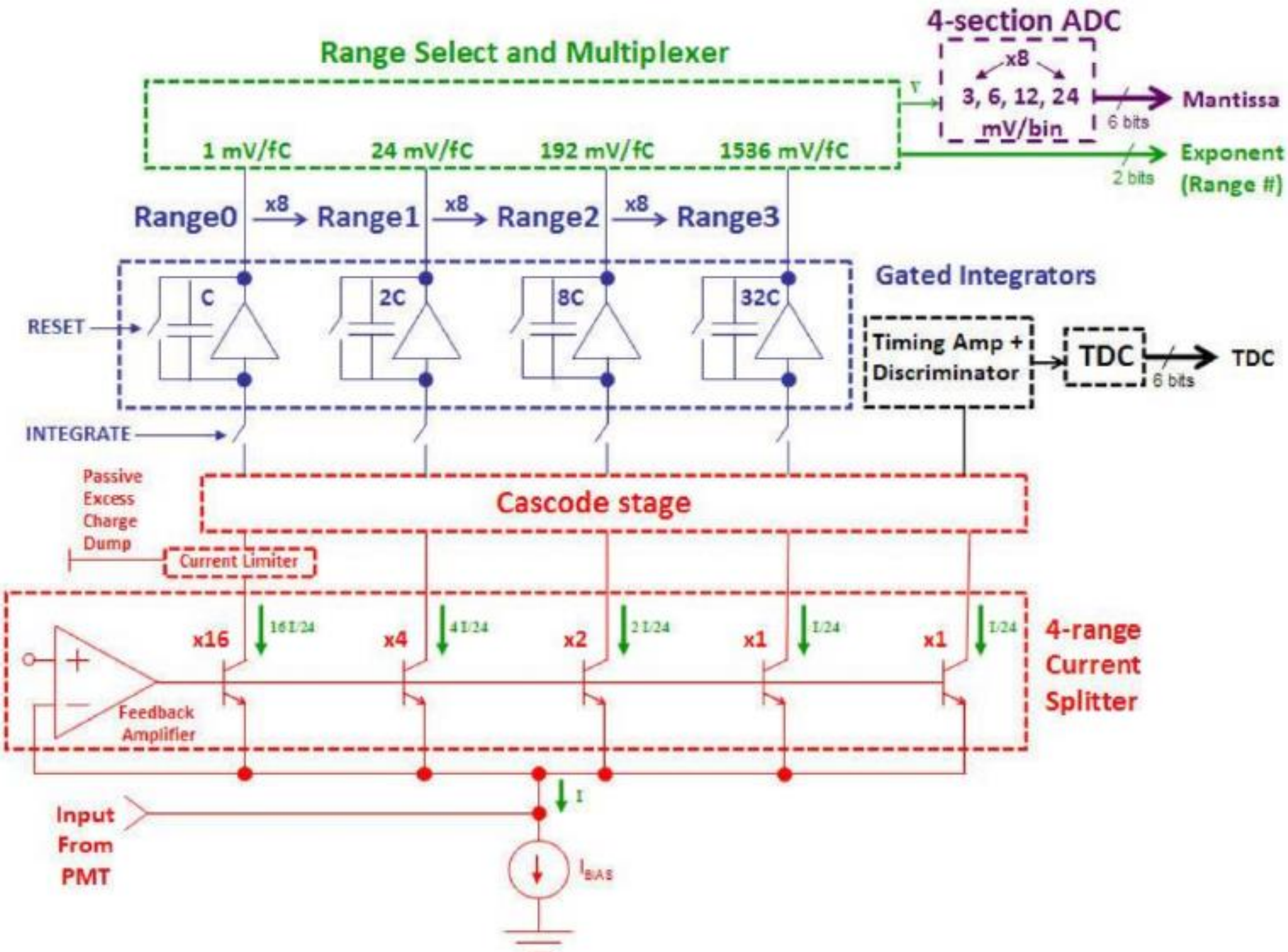


QIE10 Range



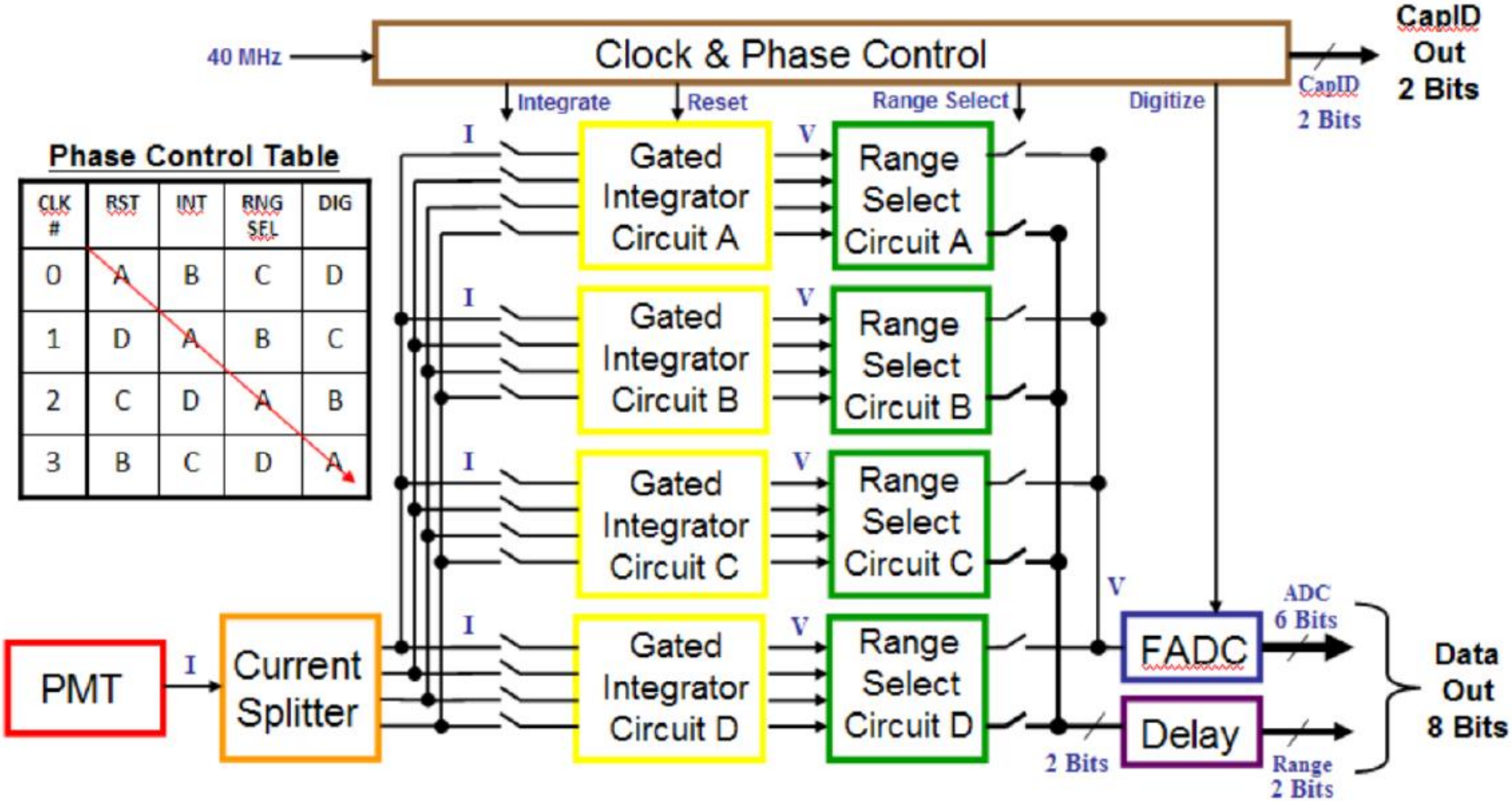
70
60
50
40
30
20
10
0
ADC Code
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Fraction of Range 0 Scale
Section 1
Section 2
Section 3
Section 4

QIE10 input



4-section ADC
Range Select and Multiplexer
x8
3, 6, 12, 24
mV/bin
Mantissa
6 bits
Exponent
(Range #)
2 bits
1 mV/fC
24 mV/fC
192 mV/fC
1536 mV/fC
Range0
x8
Range1
x8
Range2
x8
Range3
Gated Integrators
C
2C
8C
32C
RESET
Timing Amp +
Discriminator
TDC
TDC
6 bits
INTEGRATE
Passive
Excess
Charge
Dump
Cascode stage
Current Limiter
x16
x4
x2
x1
x1
4-range
Current
Splitter
Feedback
Amplifier
Input
From
PMT

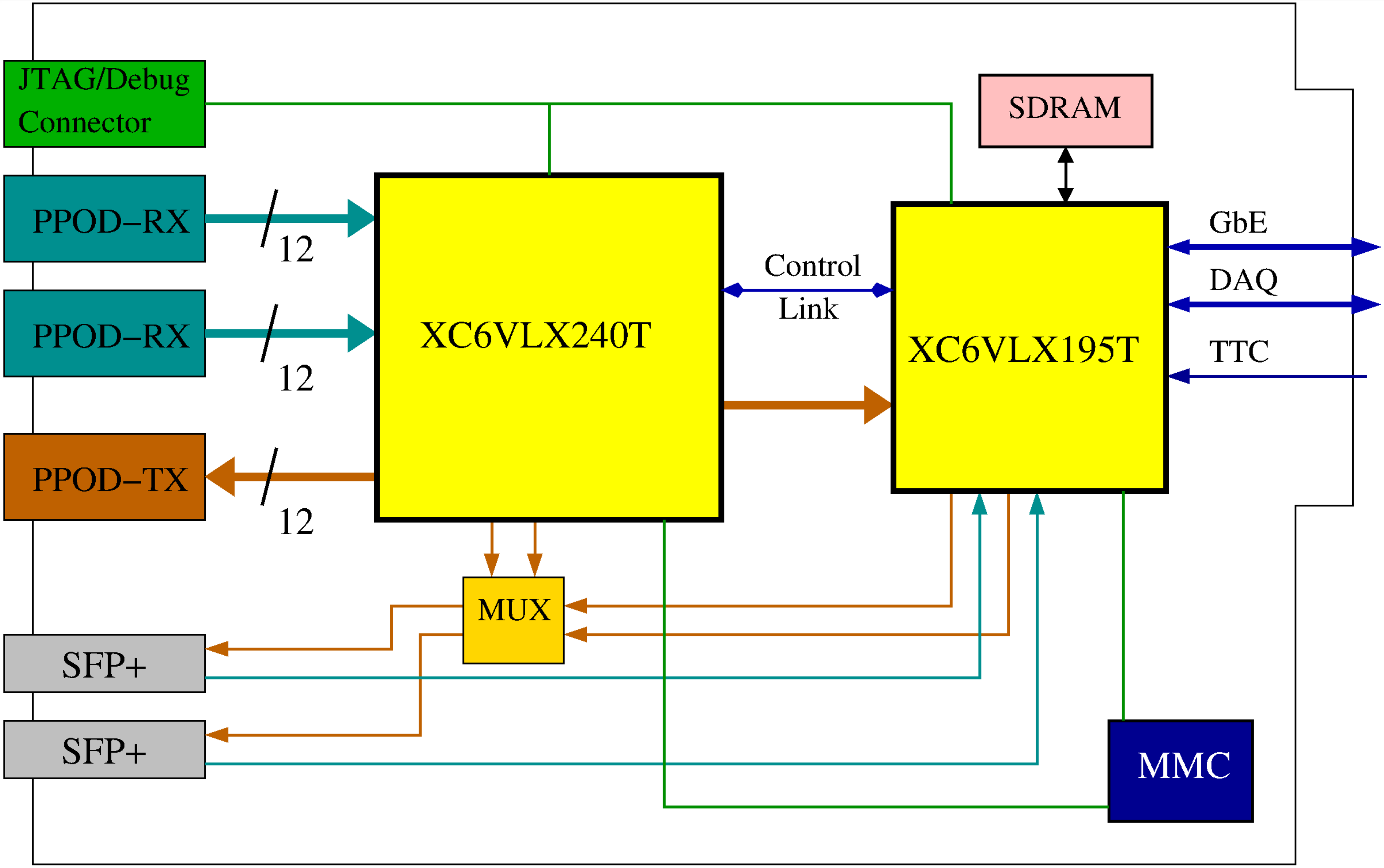
QIE10 block diagram



Phase Control Table

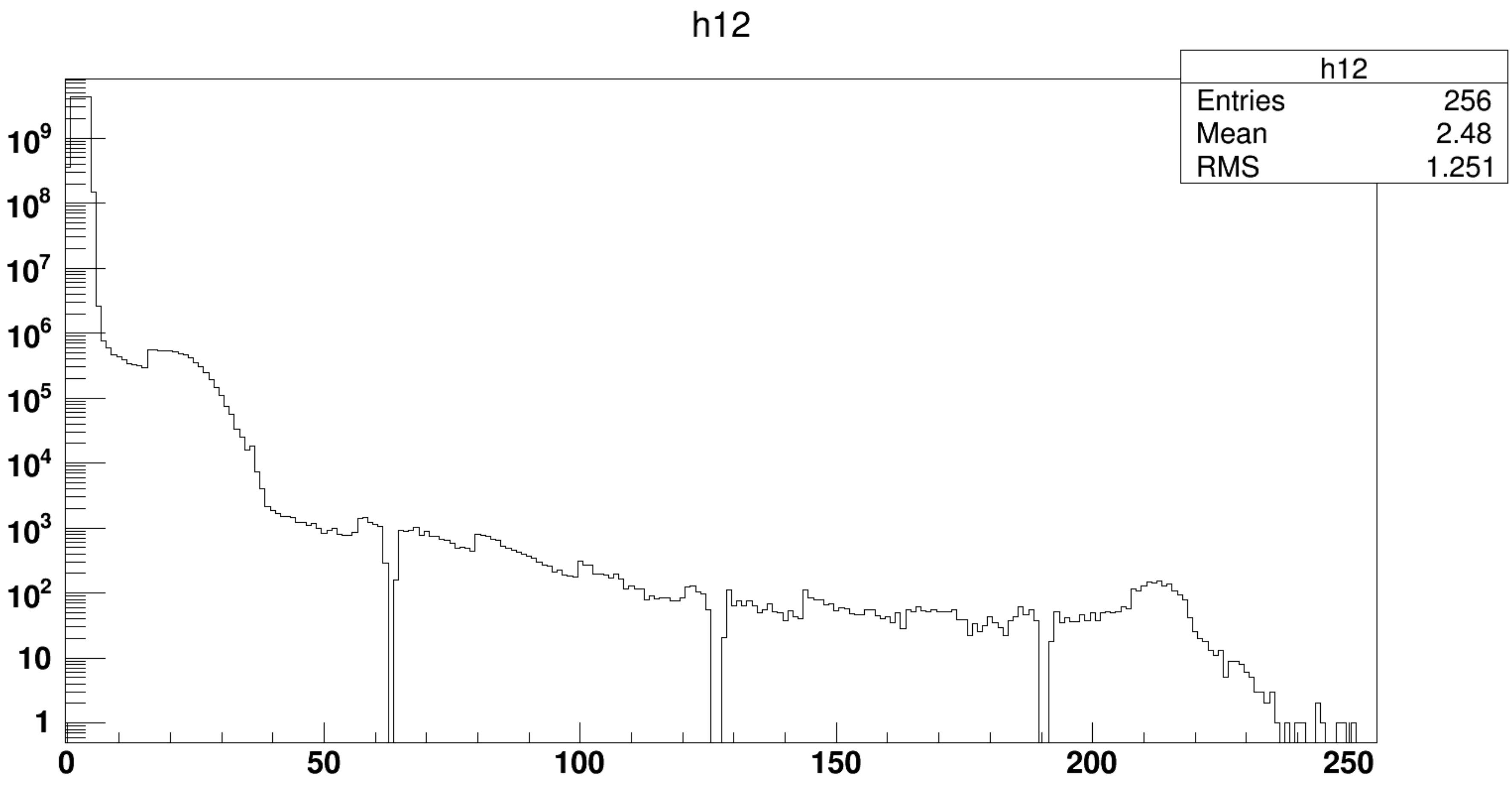
CLK #	RST	INT	RNG SEL	DIG
0	A	B	C	D
1	D	A	B	C
2	C	D	A	B
3	B	C	D	A

uHTR block diagram

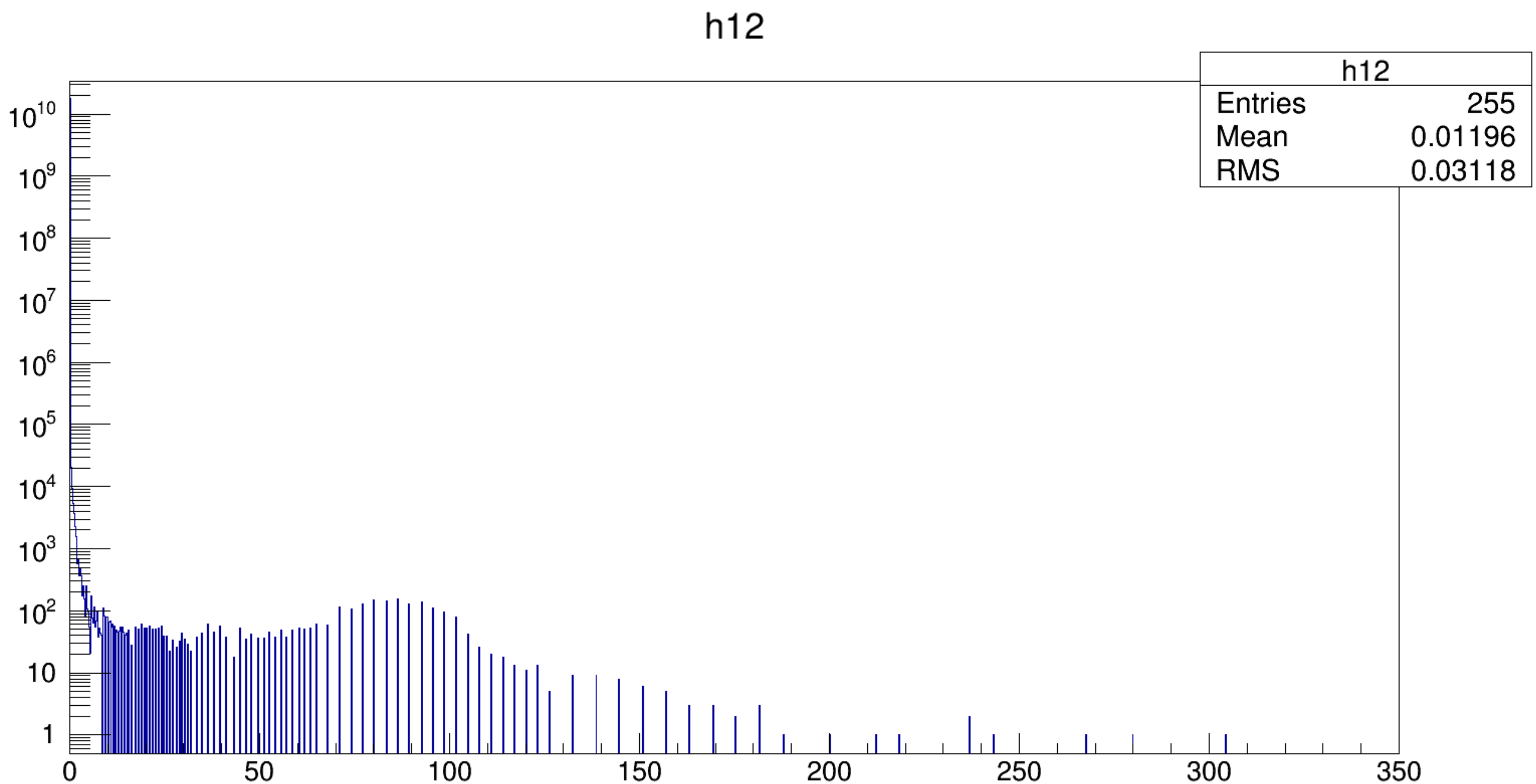


Setting thresholds

- Cut out majority of PP events, in addition to cosmics



Setting thresholds



Read-out electronics: VME

- Background rate:

  Fan out

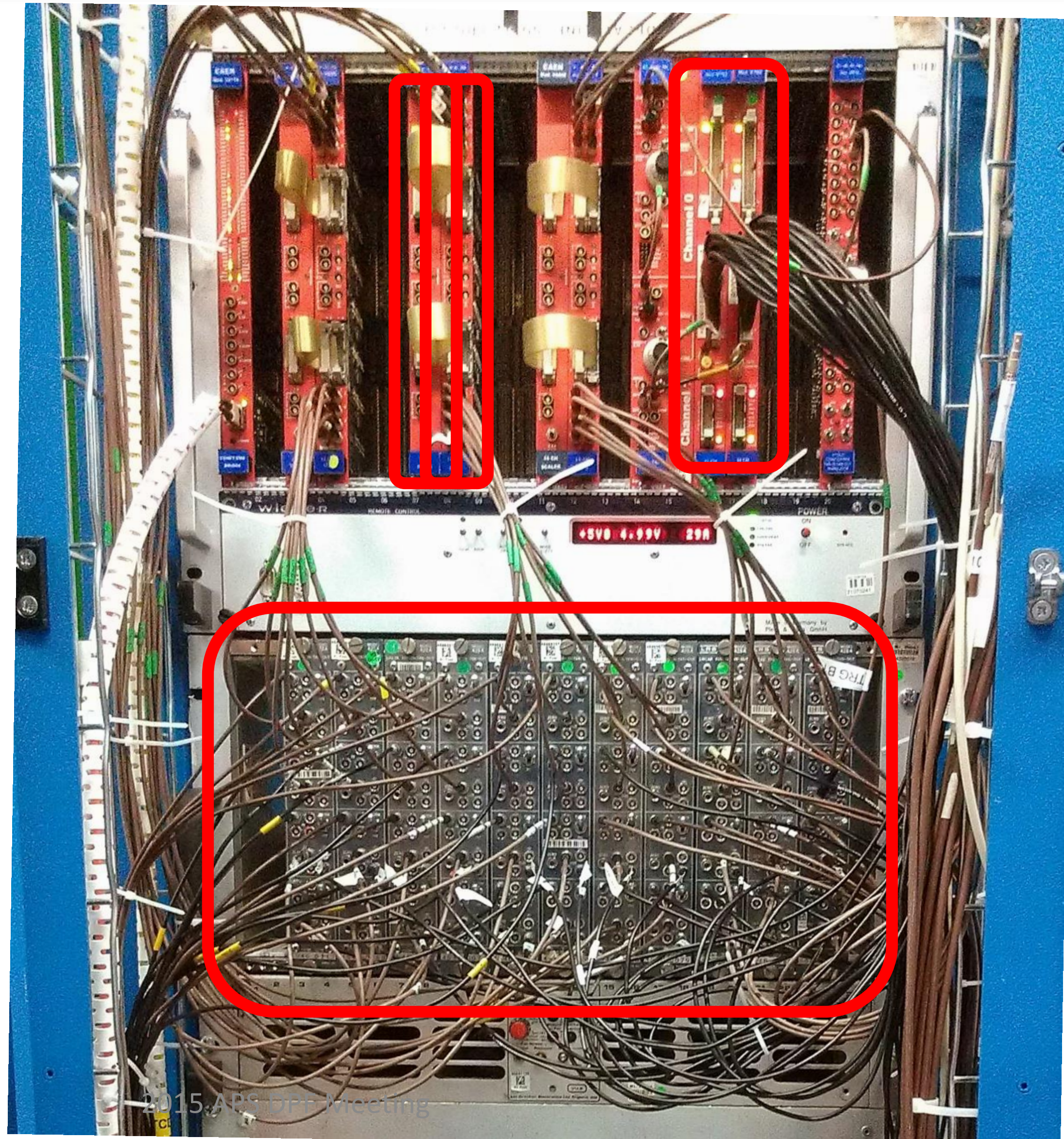
  ↳ Discriminator

    ↳ Scaler

- Amplitude measurement:

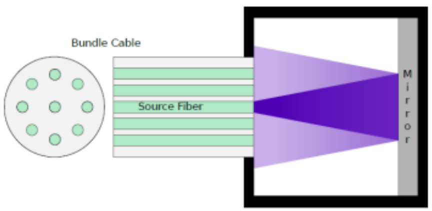
  Fan out

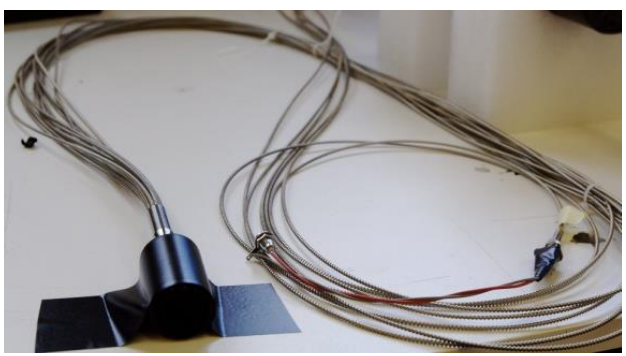
  ↳ QDC

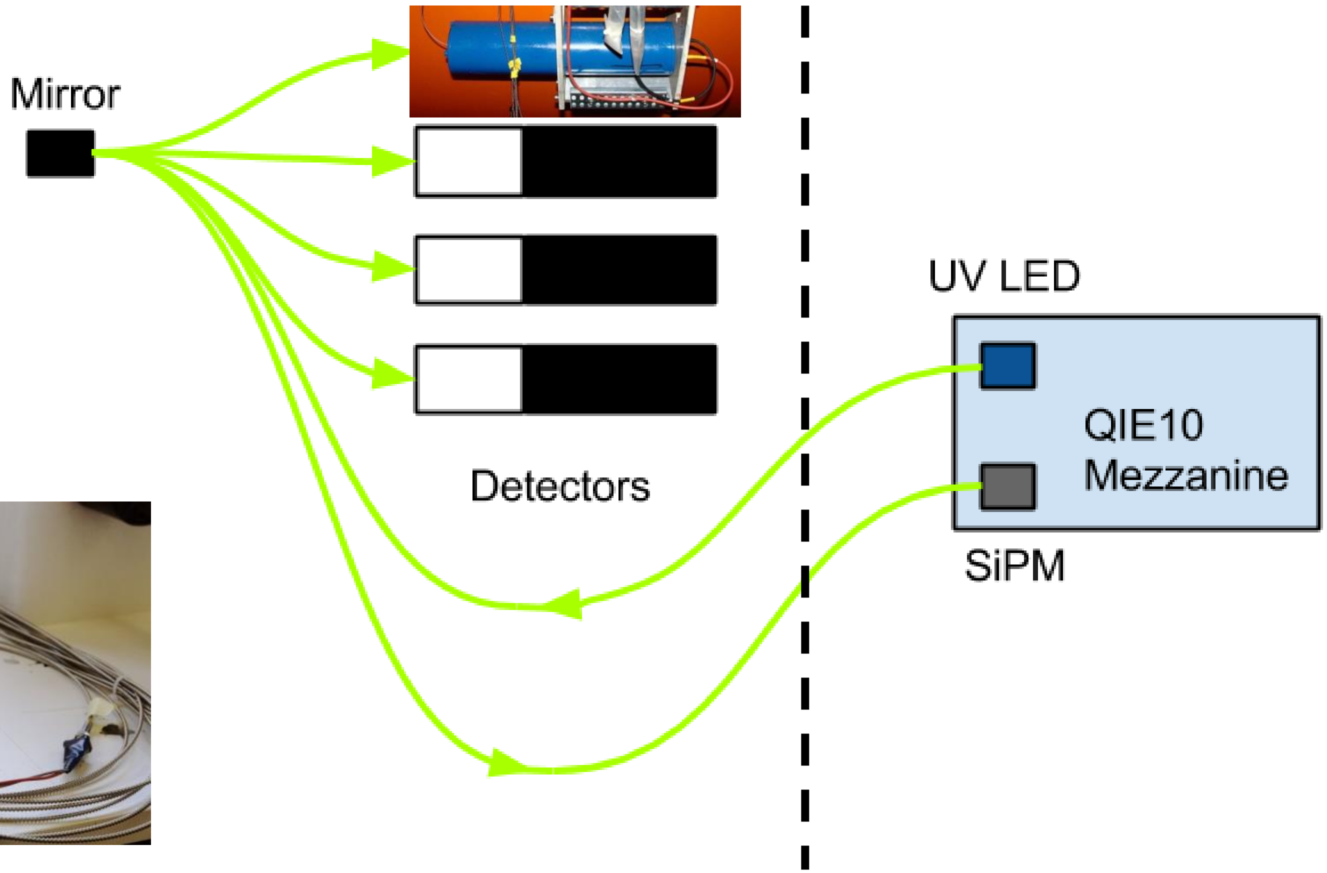


Calibration system

- Measures health of system over time
- UV LED pulses of known timing and amplitude distributed to all PMTs, plus reference

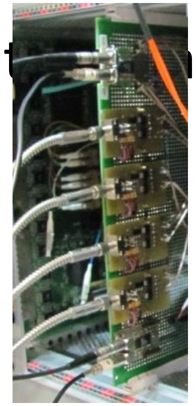


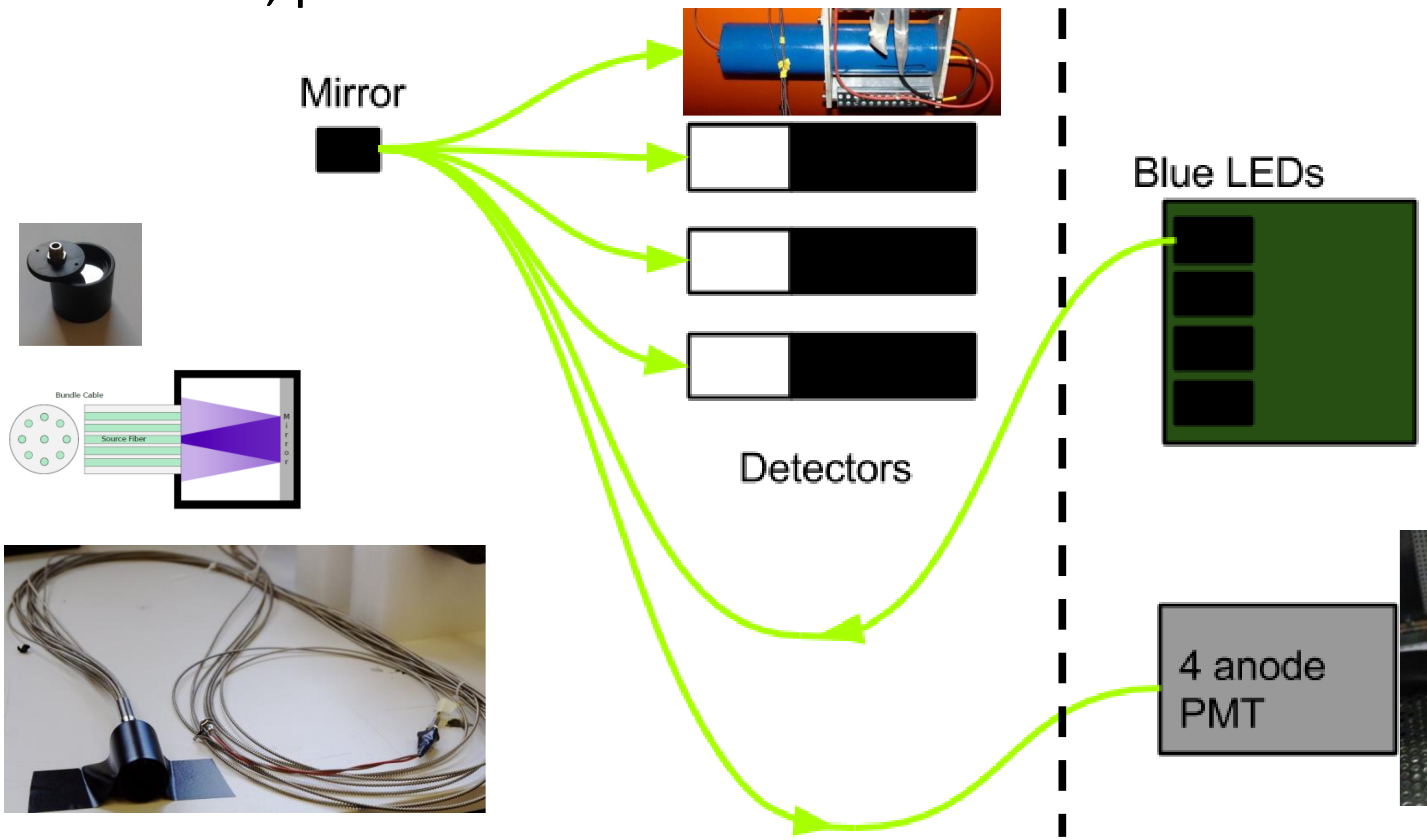




Temporary calibration system

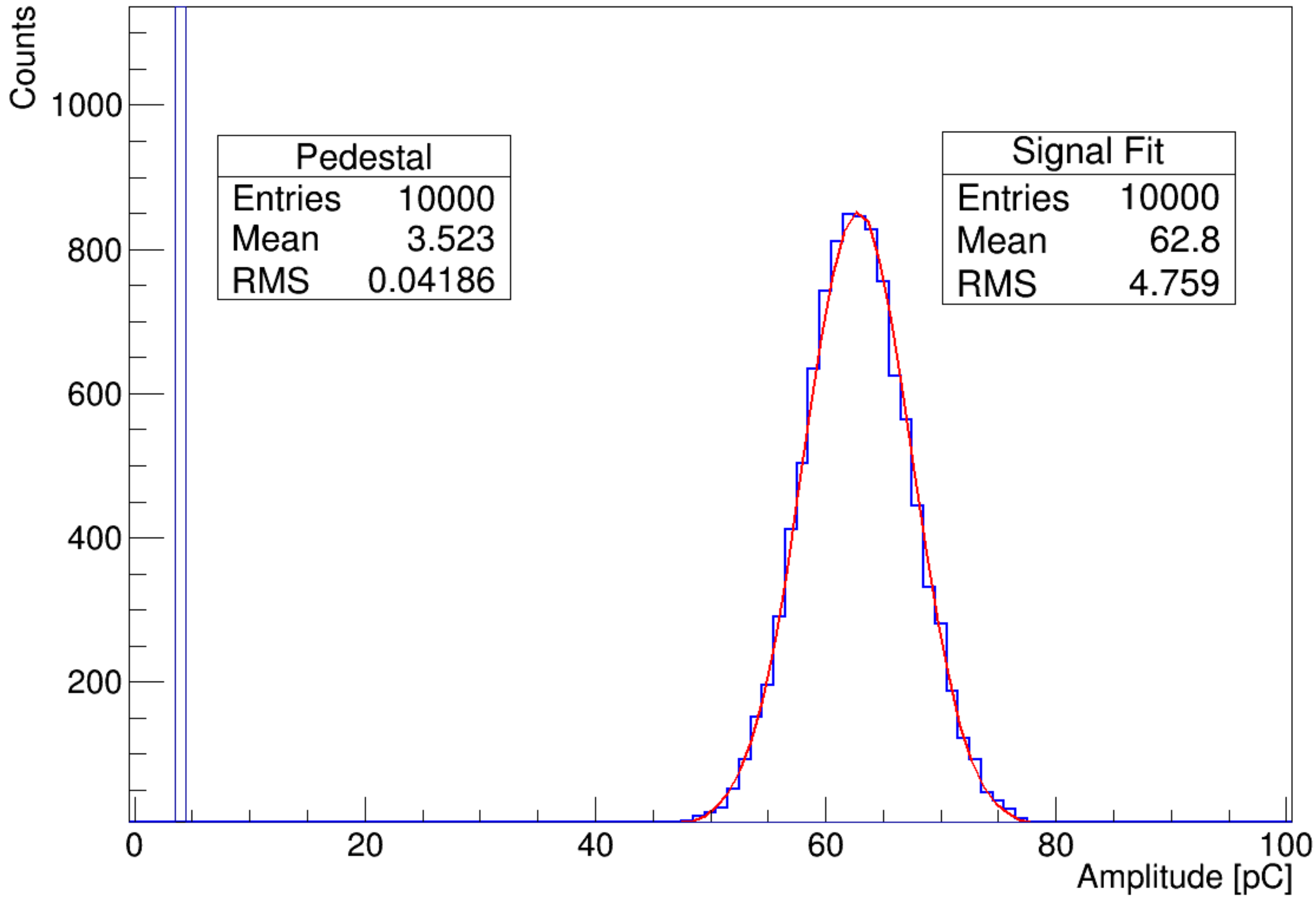
- Measures health of system over time
- UV LED pulses of known timing and amplitude distribut ll PMTs, plus reference





Calibration system

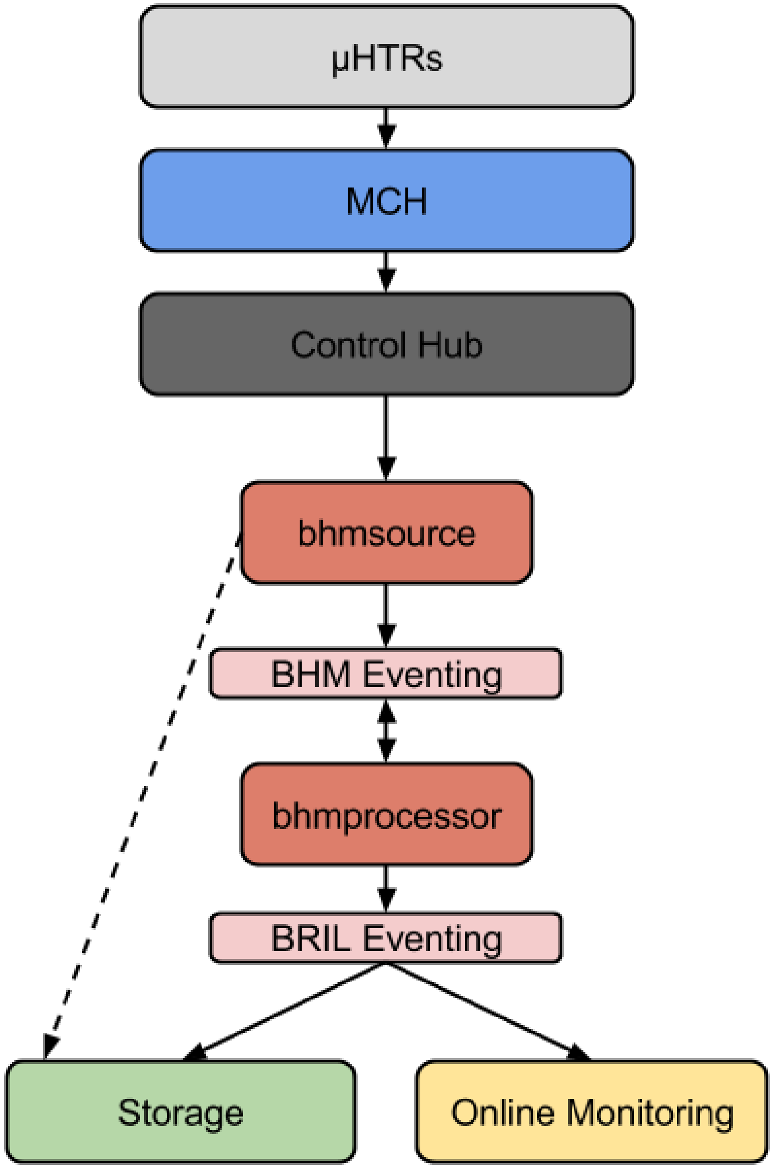
- Delivers pulses of expected signal size, ~600 photoelectrons



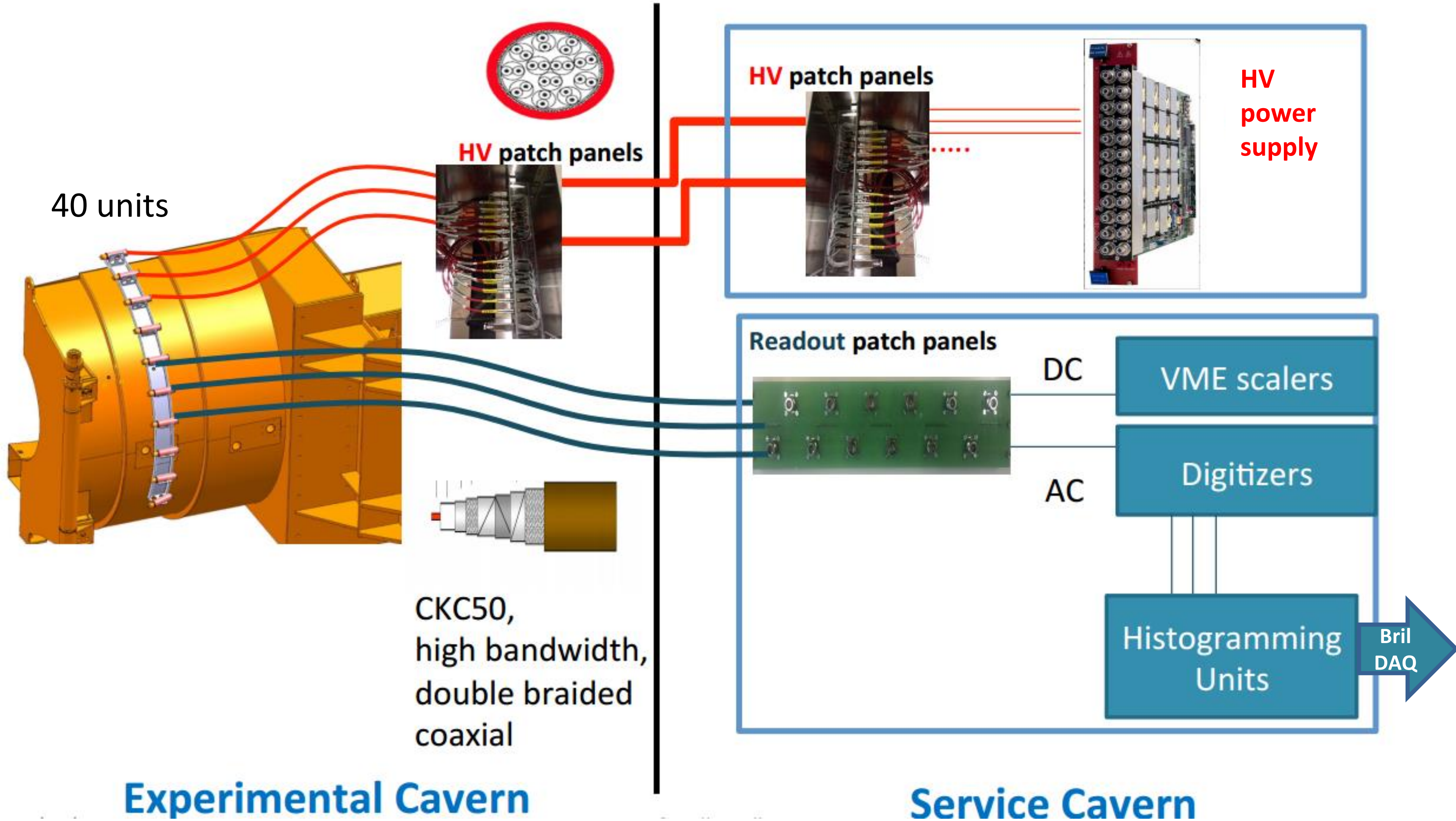
BHM in BrilDAQ

- BrilDAQ: based on xDAQ publisher/subscriber framework

- bhmsource – reads out histograms from uHTRs
- bhmprocessor – calculates background rate for each beam, publishes every lumi section (2^{18} orbits = ~23s)

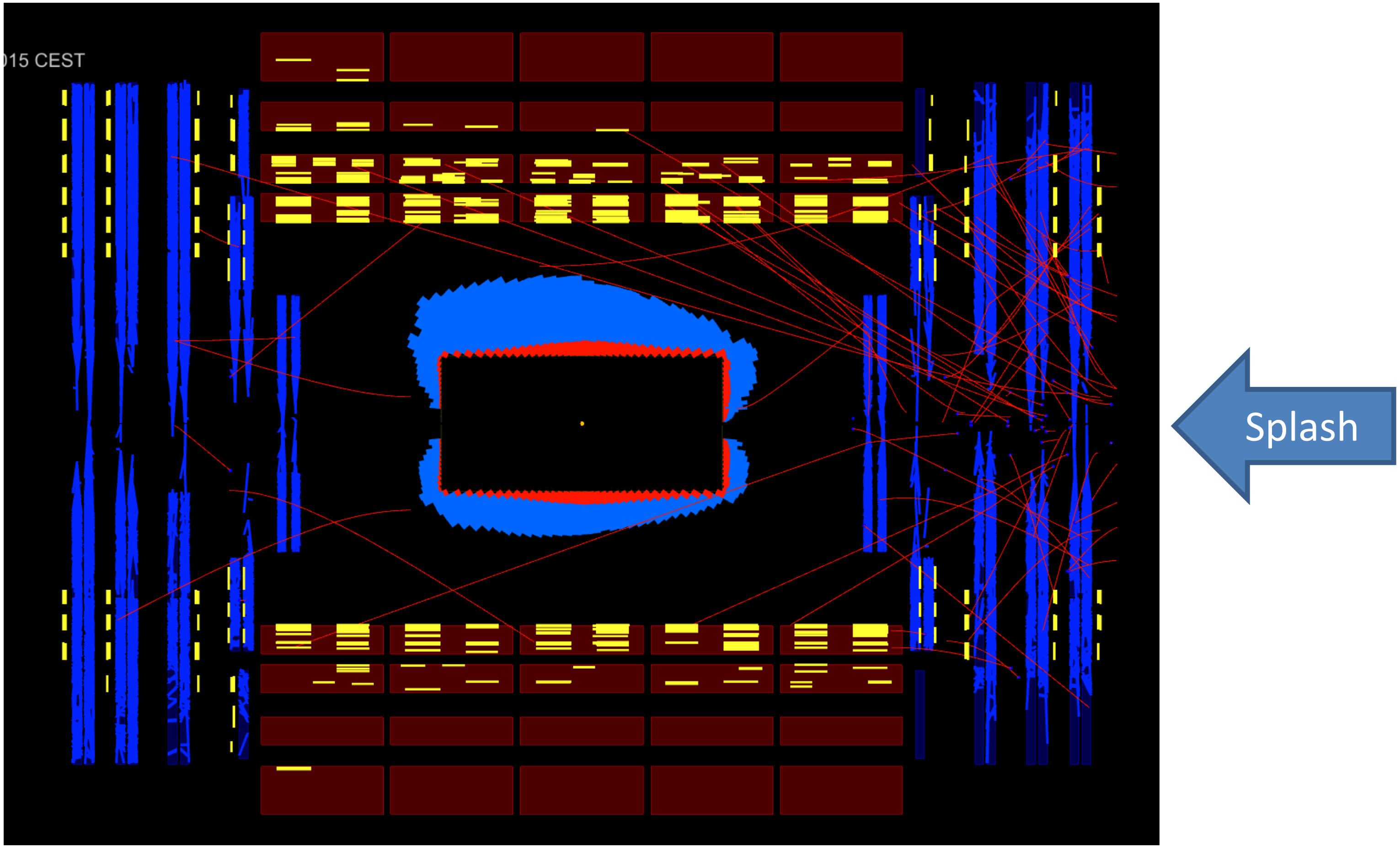


System overview

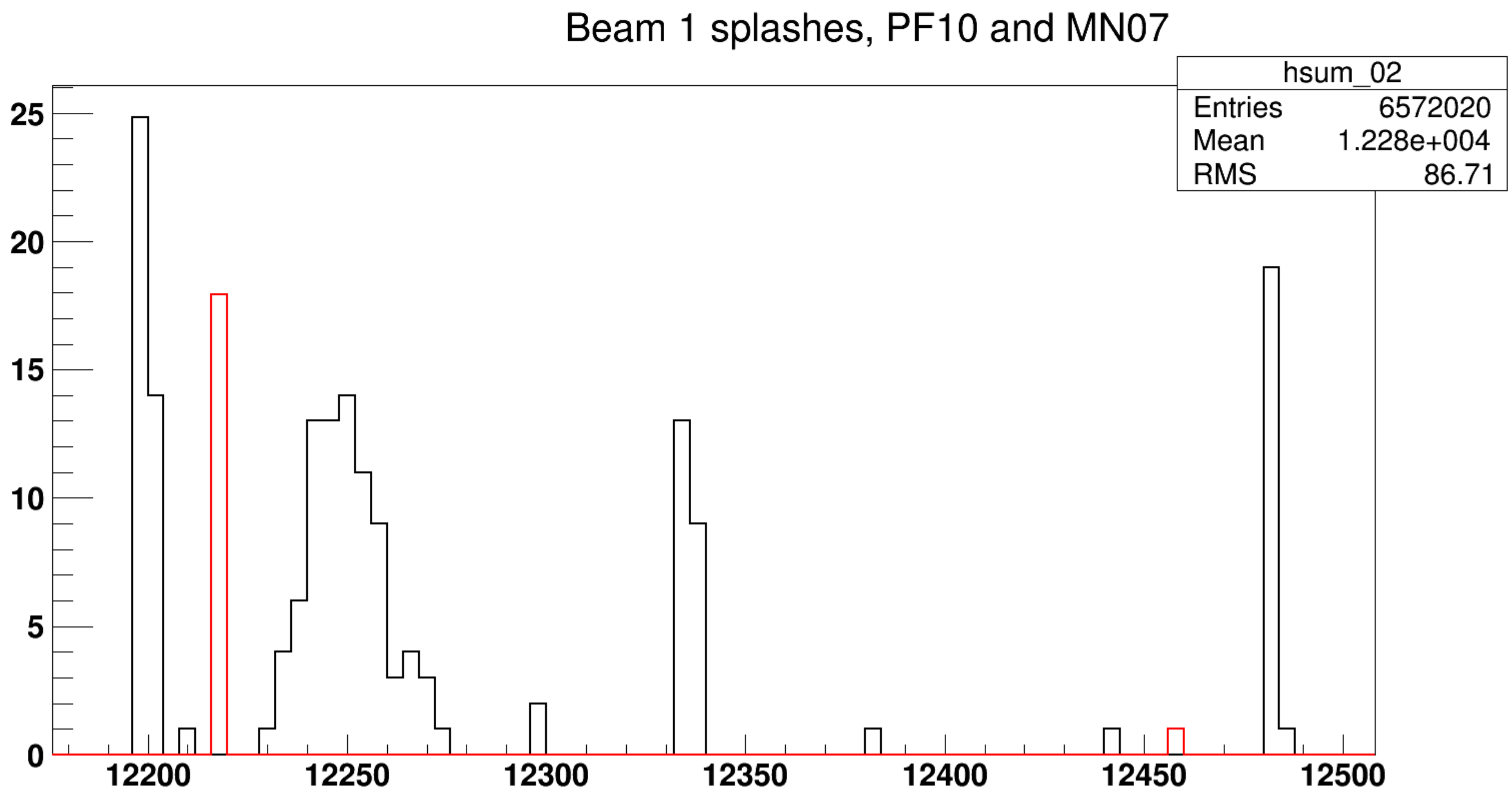


Splash events

- Send a bunch directly into the TCTs – creates a 'splash' of particles in one direction

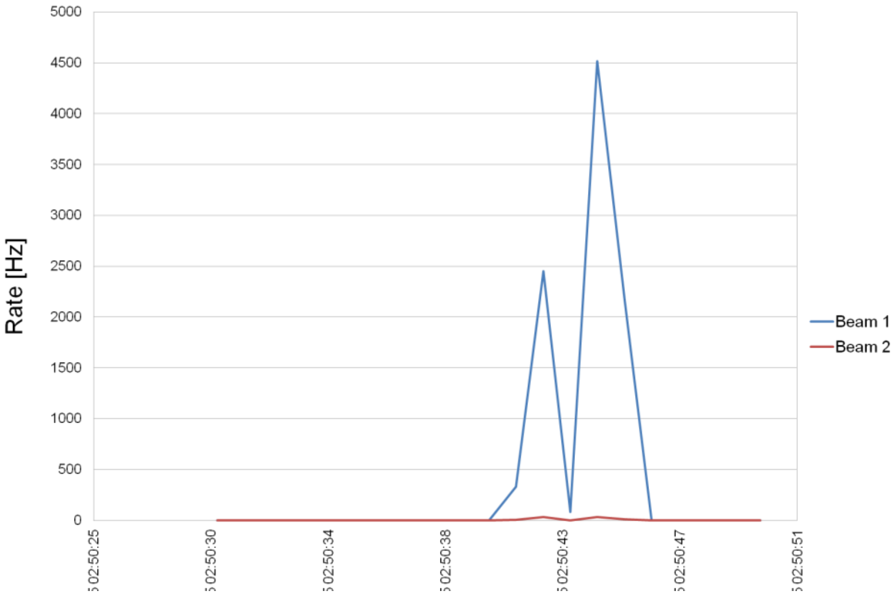


Splashes

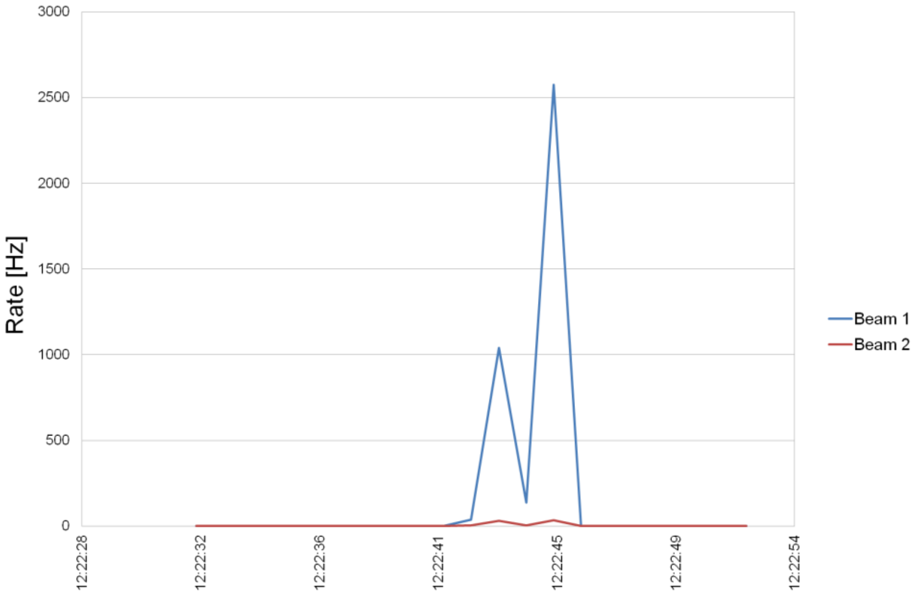


Beam 1 splashes, PF10 and MN07
hsum_02
Entries 6572020
Mean 1.228e+004
RMS 86.71
0
5
10
15
20
25
12200
12250
12300
12350
12400
12450
12500

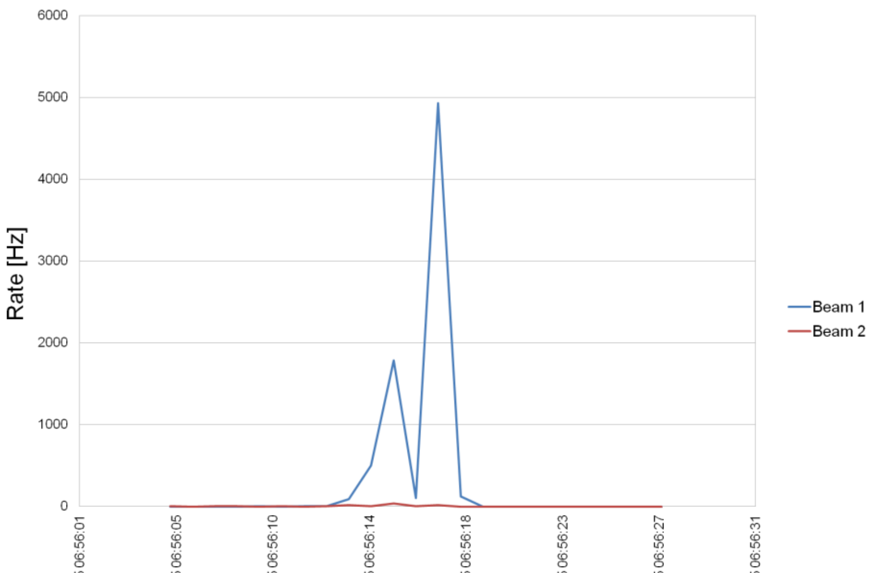
Beam losses



Rate [Hz]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Beam 1
Beam 2

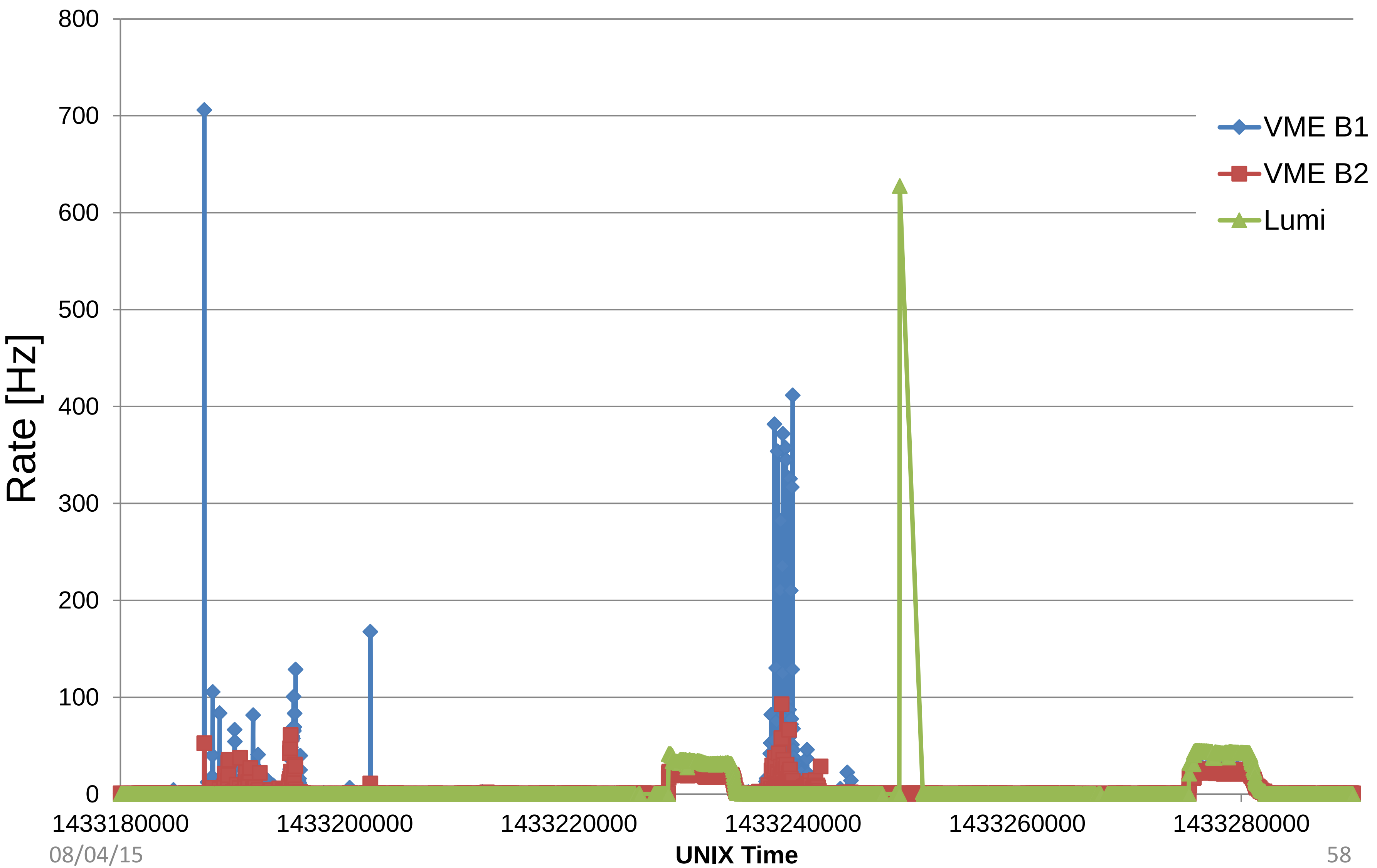


Rate [Hz]
3000
2500
2000
1500
1000
500
0
12:22:28
12:22:32
12:22:36
12:22:41
12:22:45
12:22:49
12:22:54
Beam 1
Beam 2



Rate [Hz]
6000
5000
4000
3000
2000
1000
0
Beam 1
Beam 2

VME results



800
700
600
500
400
300
200
100
0
Rate [Hz]
1433180000
1433200000
1433220000
1433240000
1433260000
1433280000
UNIX Time
VME B1
VME B2
Lumi