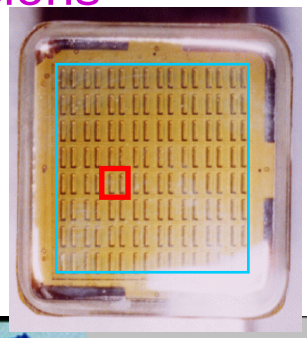
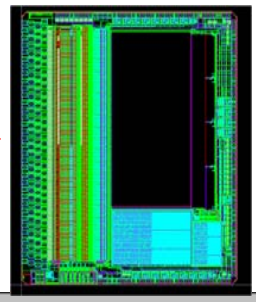
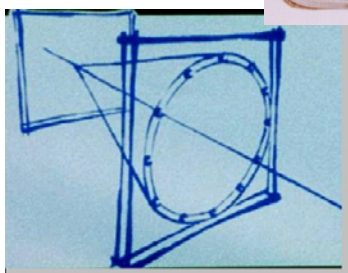
Performance of MaPMTs with Beetle-chip Read-out

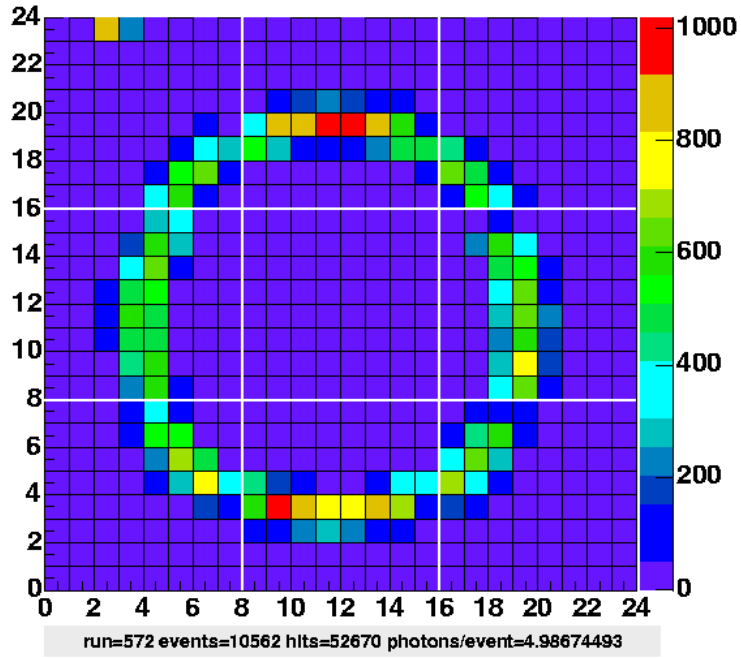
- Multianode Photo Multiplier Tubes, 8 & 12 Dynodes
- Beetle chip Read-out
- LED Light Studies
- Test Beam Results
- Conclusions







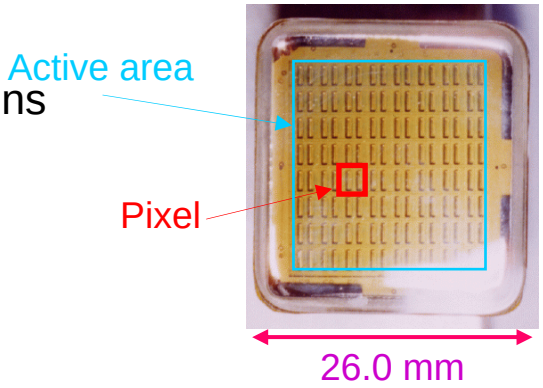
5th International Workshop on Ring Imaging Cherenkov Counters (RICH2004)
Playa del Carmen, Mexico
November 30 - December 5, 2004
Dedicated to the Centenary of Pavel Cherenkov's Birth



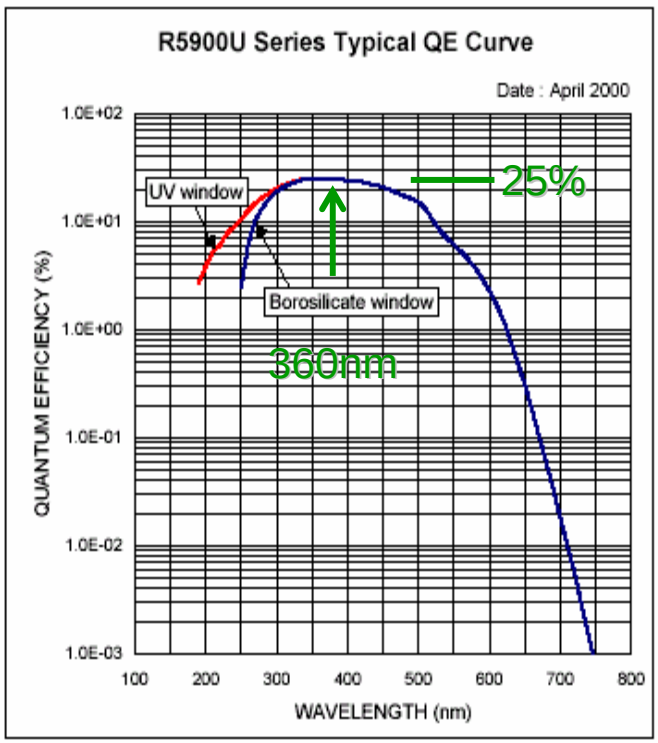
Franz Muheim
University of Edinburgh
for the LHCb MaPMT group

Multianode Photo Multiplier

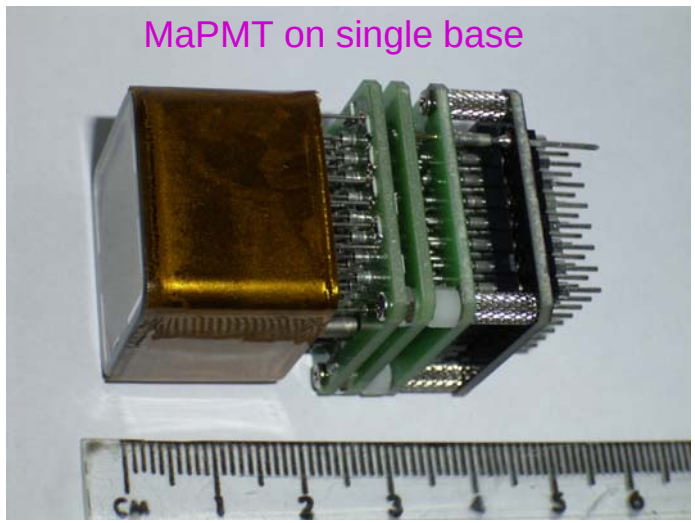
- Single photo tube with 8x8 array of 64 dynode chains
- Bialkali photo cathode
- UV glass window
- Quantum efficiency
  QE = 25 % at λ = 360 nm

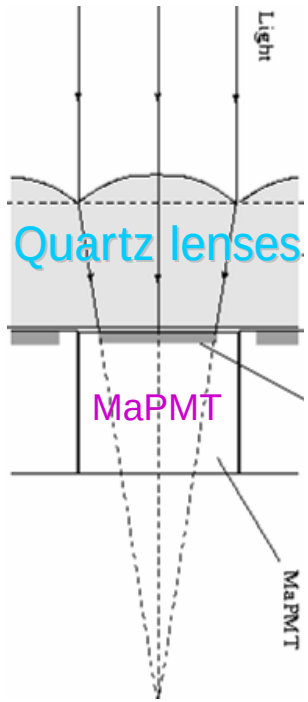


- Quartz lens to recover active area: 38% → 85%
- Effective pixel size: $(2.1mm)^2$ → $(3.2mm)^2$



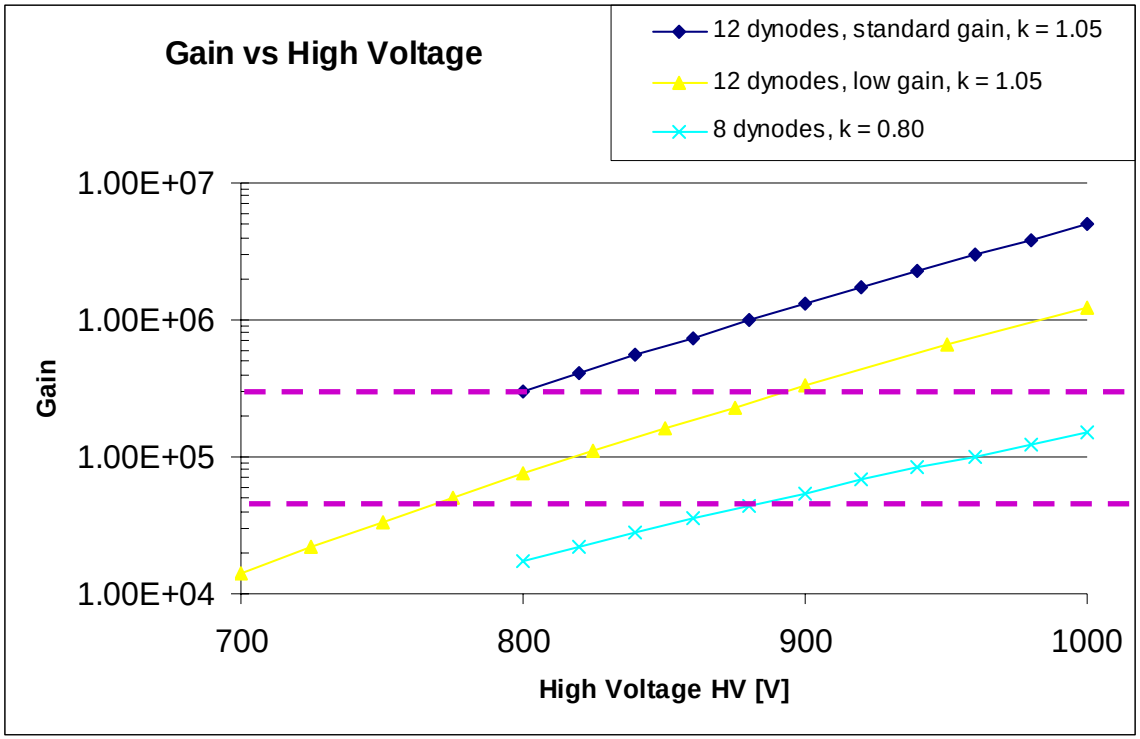
- MaPMTs were an option for the LHCb RICH photo detectors





12 versus 8 Dynode Stages

Single photo electron gain (average) versus high voltage



MaPMT gain: $G \sim V^k$ at each dynode
tuned to measured gain

12-dynode stage MaPMT

- Standard gain G ~ 300,000
  - requires customised read-out chip
- Low gain
  - altered bleeder chain
  - Running at lower HV
  - signal shape widened, increases signal loss

G ~ 300,000

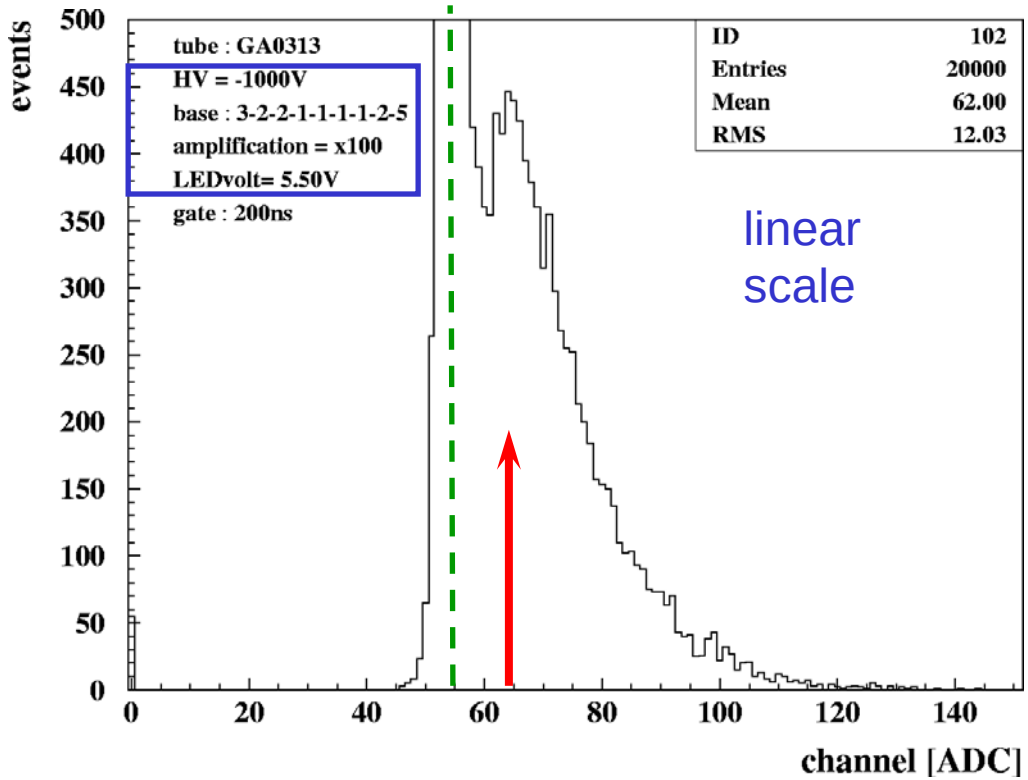
G ~ 50,000
2 mip equivalent

8-dynode stage MaPMT

- Gain
  - matched to silicon detector read-out

8 Dynode Stages MaPMT

- 8 dynode stages
  - gain G ~ 50000 at HV = 800 V
  - Proposed to Hamamatsu development costs
  - available in late 2002
- Bleeder resistor ratios
  - 3 - 2 - 2 - 1 - 1 - 1 - 1 - 2 - 5
- First Measurement
  - HV = 1000 V
  - adapt single base
  - Amp 2 x10, ADC
  - CAMAC Readout

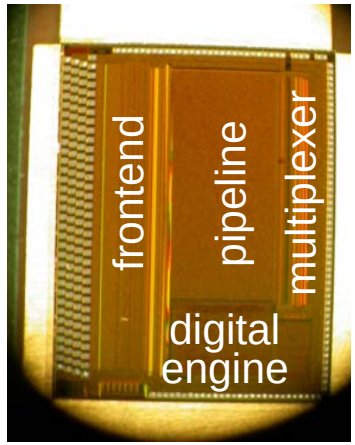


Single p.e. peak clearly separated from pedestal

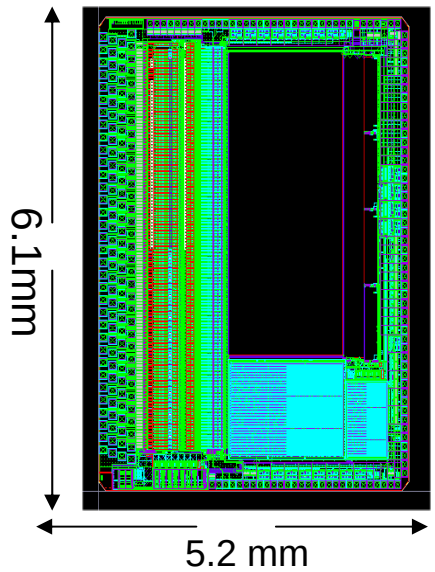
Gain ~ 150000
consistent with expectations

MaPMT/Beetle Read-Out

- 8-dynode stage MaPMT
  - gain 50000 p.e. @ HV 800 V
- Beetle1.2
  - silicon detector read out chip 128 channels
  - single photon equivalent 60 mV (2 mip)
  - signal / noise ratio ~40
- 12-dynode stage MaPMT
  - gain 300000 p.e. @ HV 800 V
- Beetle1.2-MA0
  - Customised Beetle1.2 front-end for MaPMT read-out
  - 1st test structures successfully tested in 2001
  - Input attenuator - 64 ch (rem. charge divider, test ch.
  - single photon equivalent 30 mV (2 mip)
  - signal / noise ratio ~40
  - available for testing in 2003
- Common Beetle back-end structure
  - sampling at 40MHz, 4μs pipeline
  - multiplexed analogue or binary readout mode



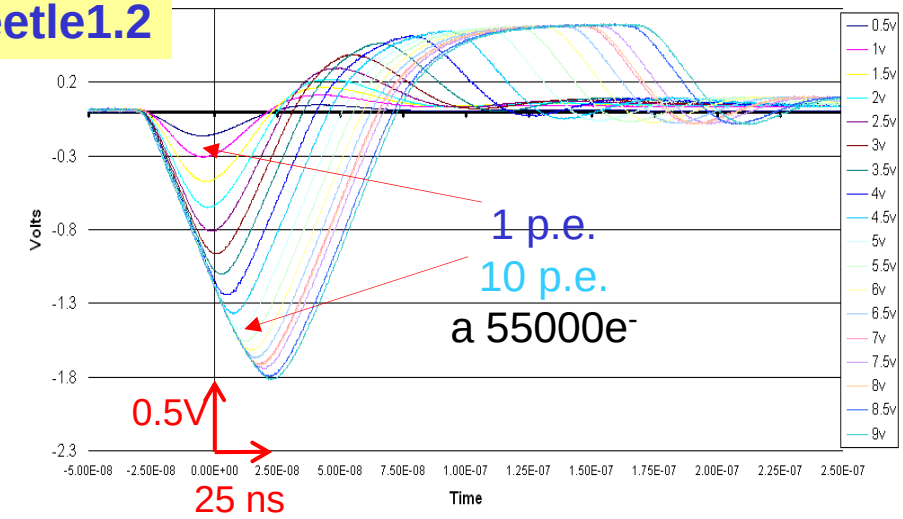
Beetle1.2



Beetle1.2-MA0 design

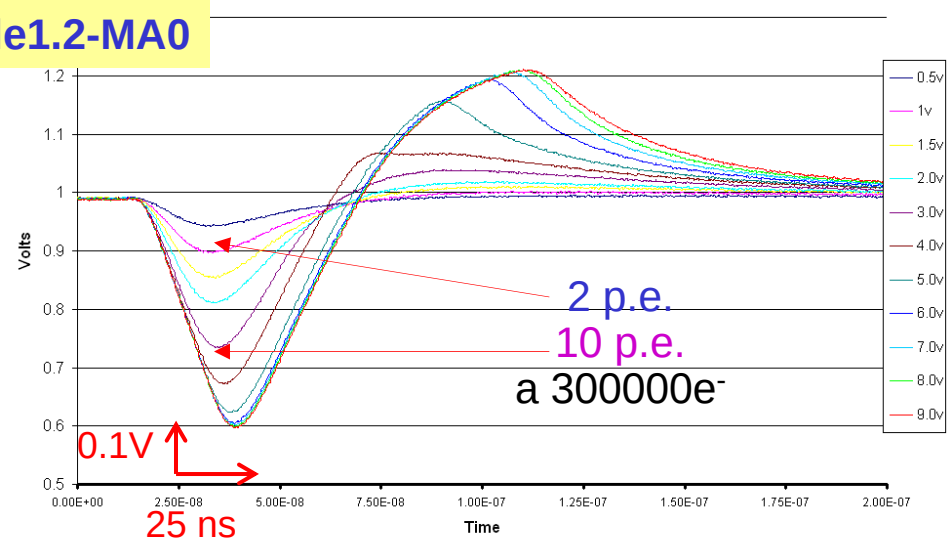
Pulse Shape Simulation

Beetle1.2



Signal shape after amplifier and shaper

Beetle1.2-MA0

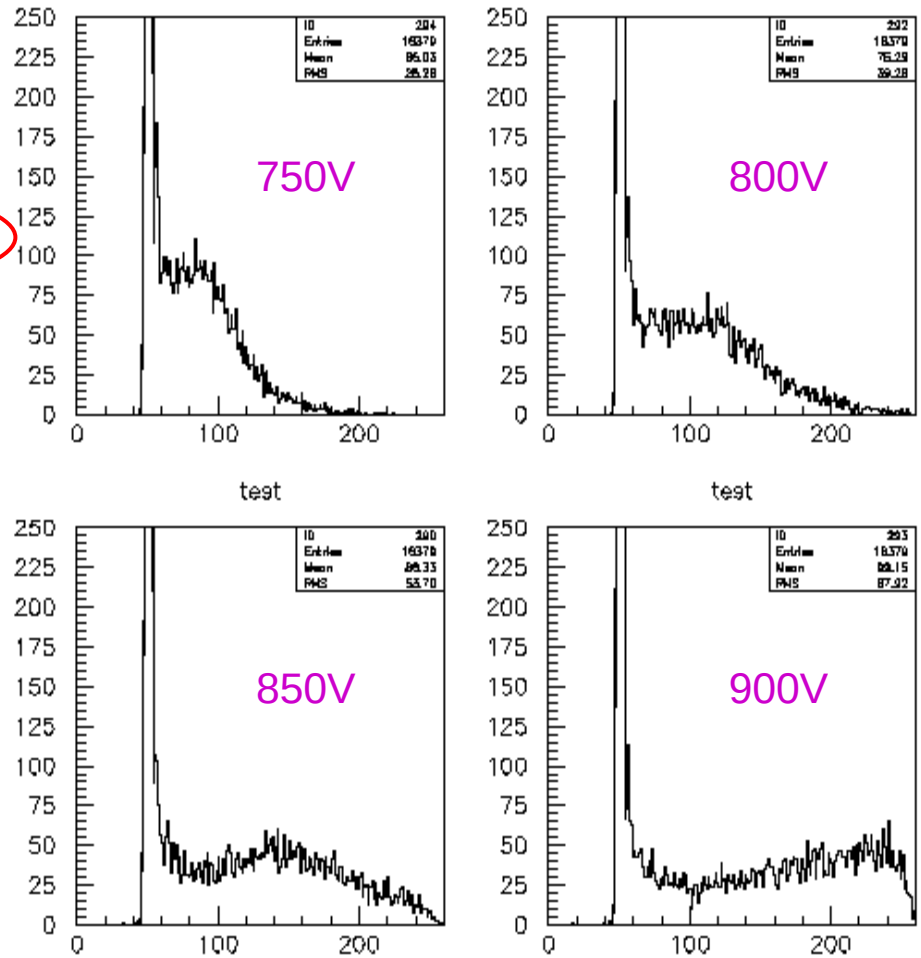


- Customised input attenuator
  - Changes to preamp & shaper
  - matches higher gain of 12-dynode MaPMT
  - shorter remainder/spill over
  - trade-off overshoot versus spill over
  - less relative noise than Beetle1.2

HV scan 8-dynode MaPMT

- 8-dynode stage MaPMT & Beetle1.2 chip
- Setup for single MaPMT 12 channels only
- HV -750…-900V
- LED light at 470nm
- single photoelectrons
- pedestal width
  $\sigma \sim 1.4$ ADC
- clear single photon signal
- gain doubles every ~50V

Pulse height spectrum from LED photons

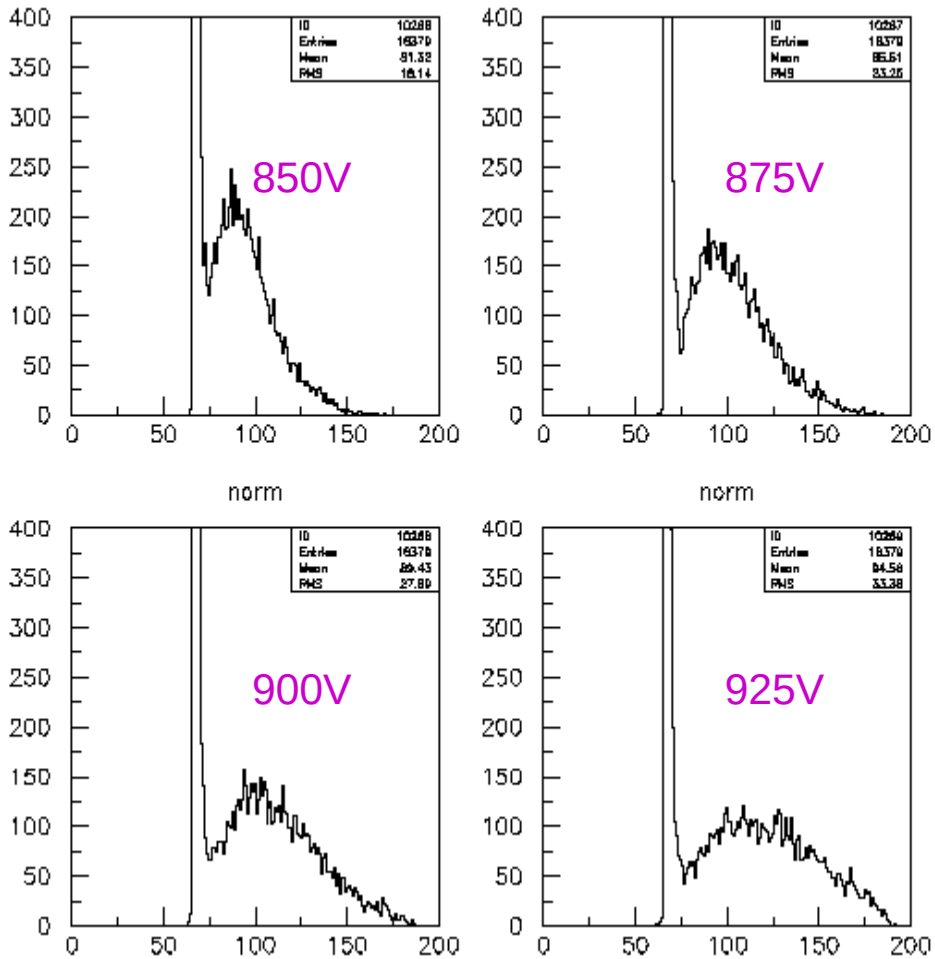


HV scan 12-dynode MaPMT

- 12-dynode stage MaPMT & Beetle1.2-MA0 chip
- HV: -850…-925V
- LED light at 470nm
- single photoelectrons
- pedestal width:
  σ ~ 0.9 ADC
- clear single photon signal
- gain doubles every ~50V

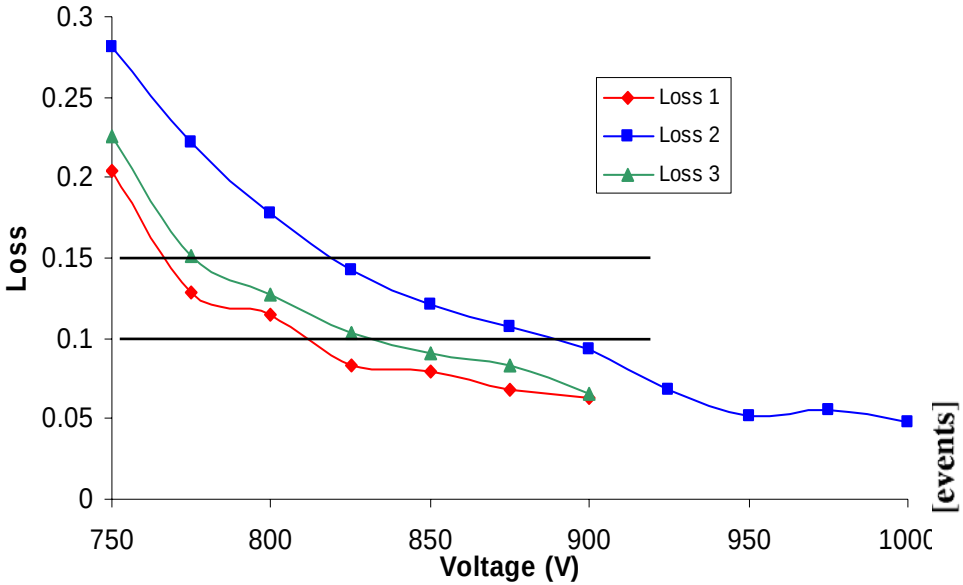
→ less noise
→ better separation
of signal from pedestal

Pulse height spectrum from LED photons



Signal Loss Study

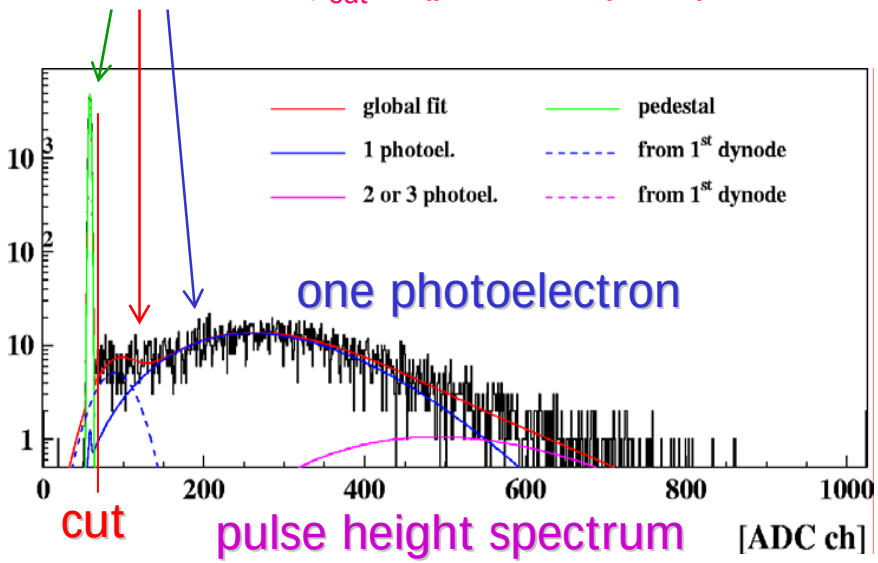
- 8-dynode stage MaPMT & Beetle1.2 chip



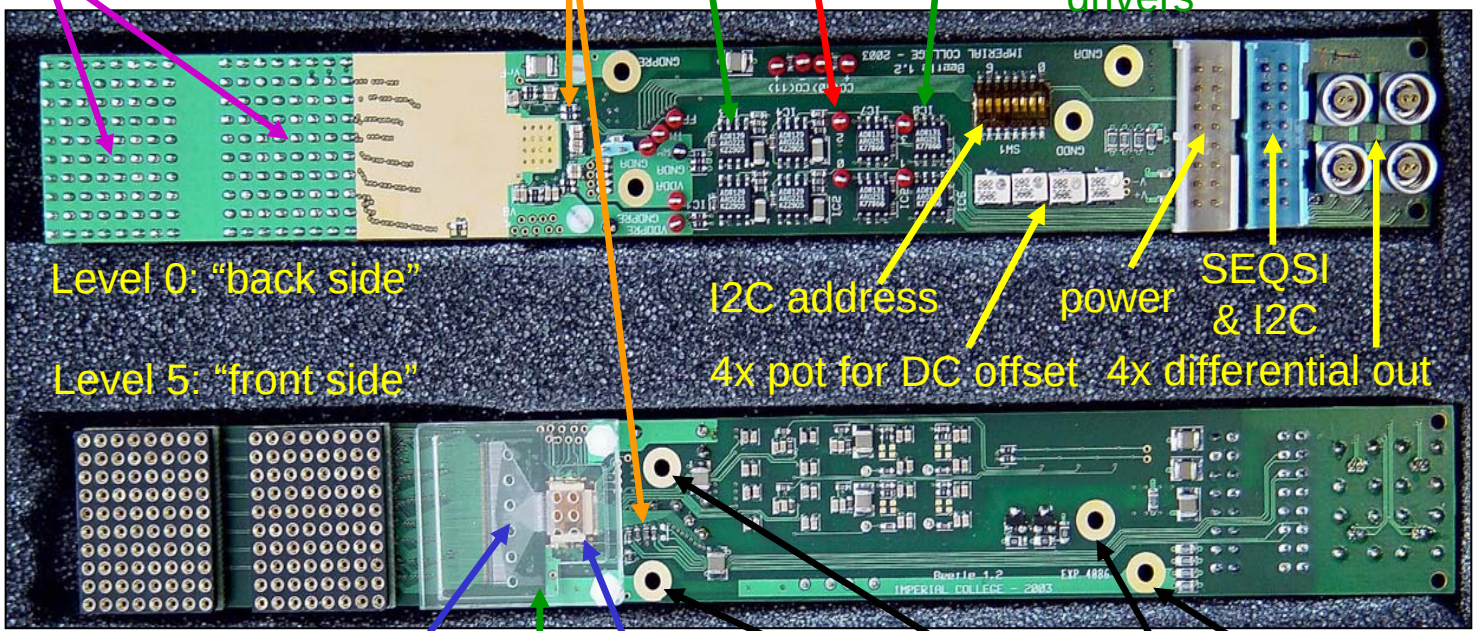
signal loss vs. high voltage

- Signal loss estimates
  - 7 - 10% for HV = 900V
  - 10 -15% for HV = 820V

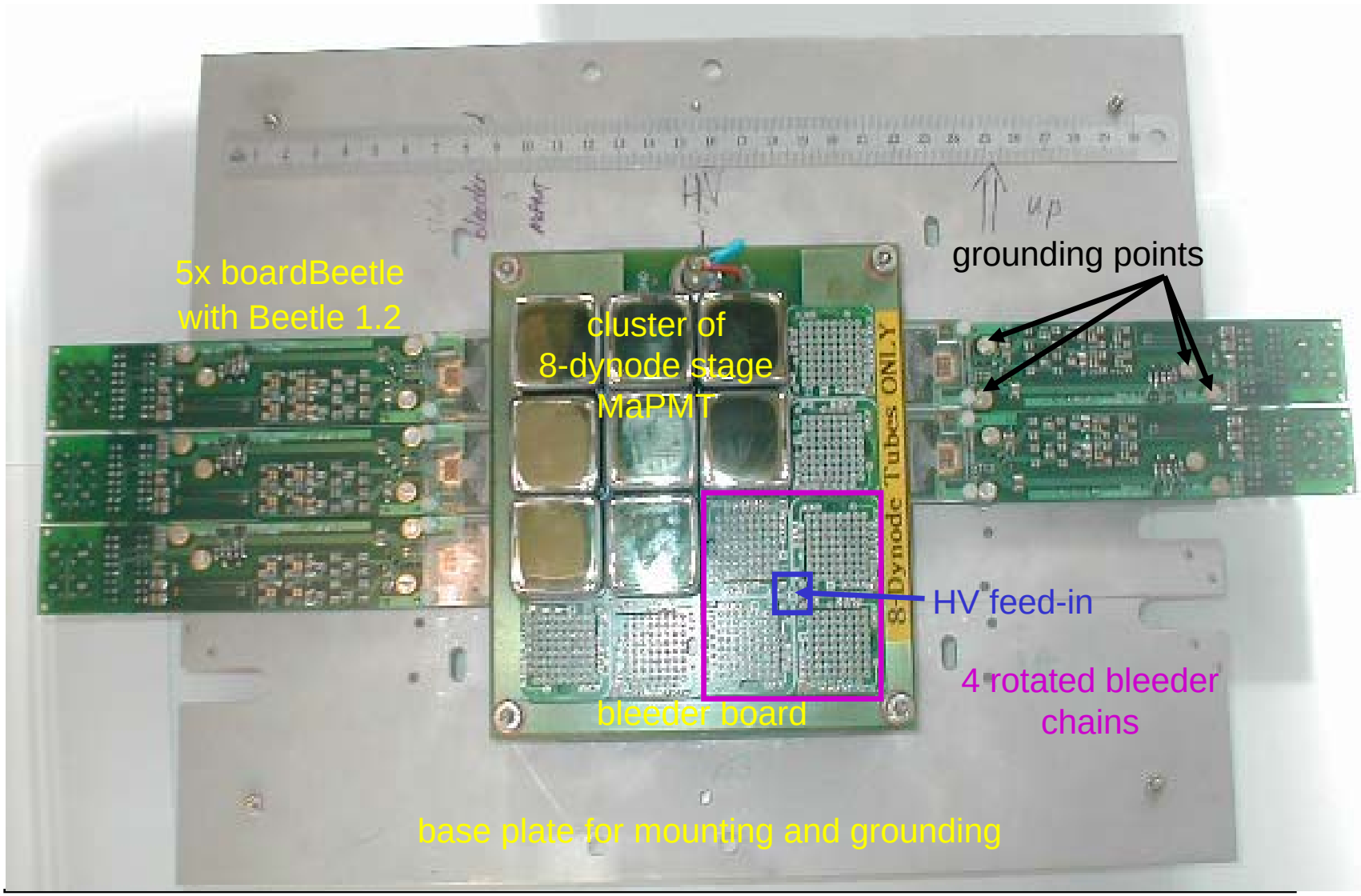
- Signal loss: defined in 3 different ways
  - N # of events
  - $N_{>cut}$ # of events above 5σ cut
  - loss 1 ~ $N_{ev}\,(1-e^{(-\mu)}) - N_{>cut}$
  - loss 2 ~ ∫(single p.e. fit) – $N_{>cut}$
  - loss 3 ~ $N_{>cut}$ - ∫(pedestal peak)



Board Beetle



Board Beetle Cluster



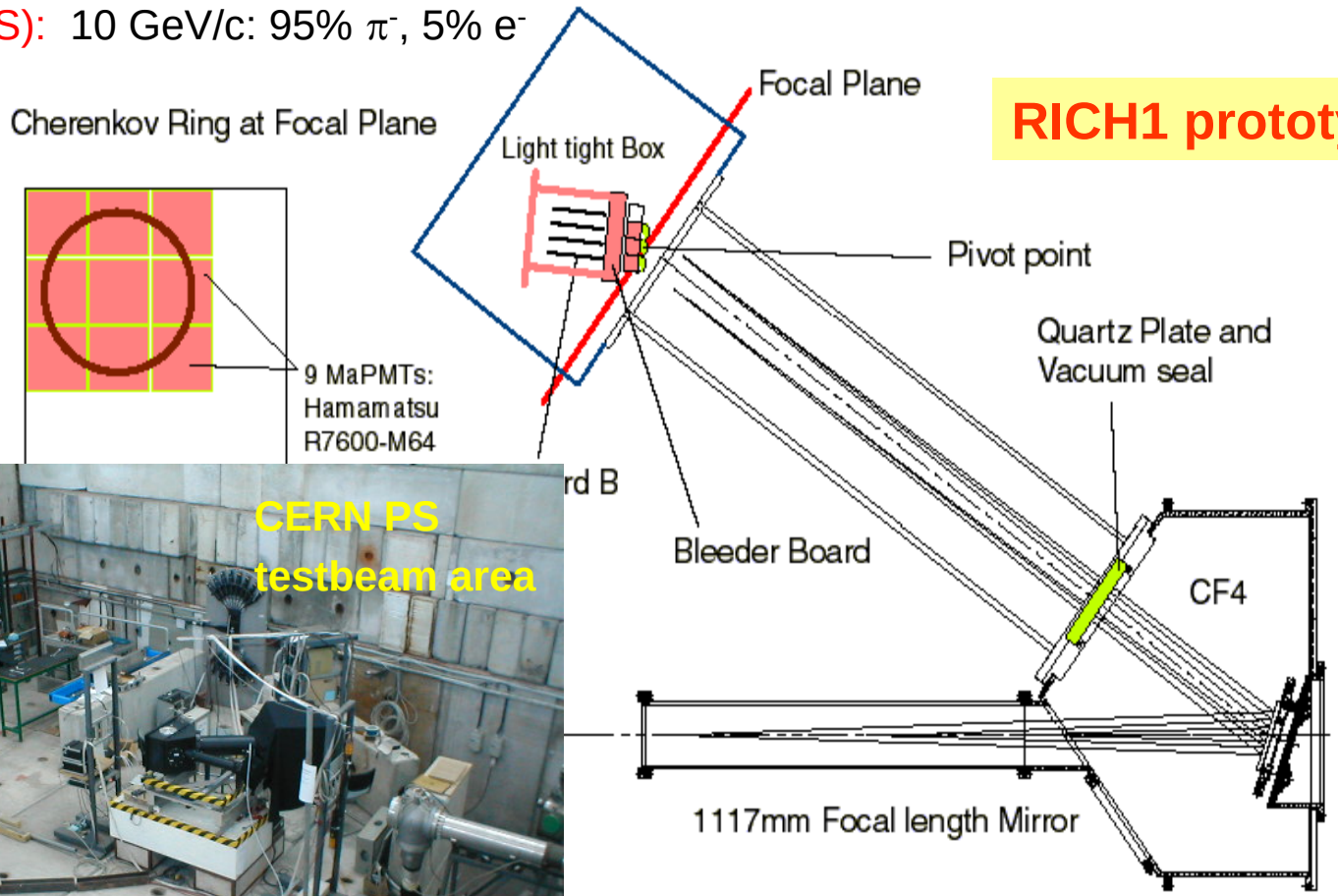
Test Beam Set-up

Radiator: 800 mbar CF_4 (also N_2, air)

Beam (PS): 10 GeV/c: 95% π^-, 5% e^-

Test beam results are preliminary!

RICH1 prototype

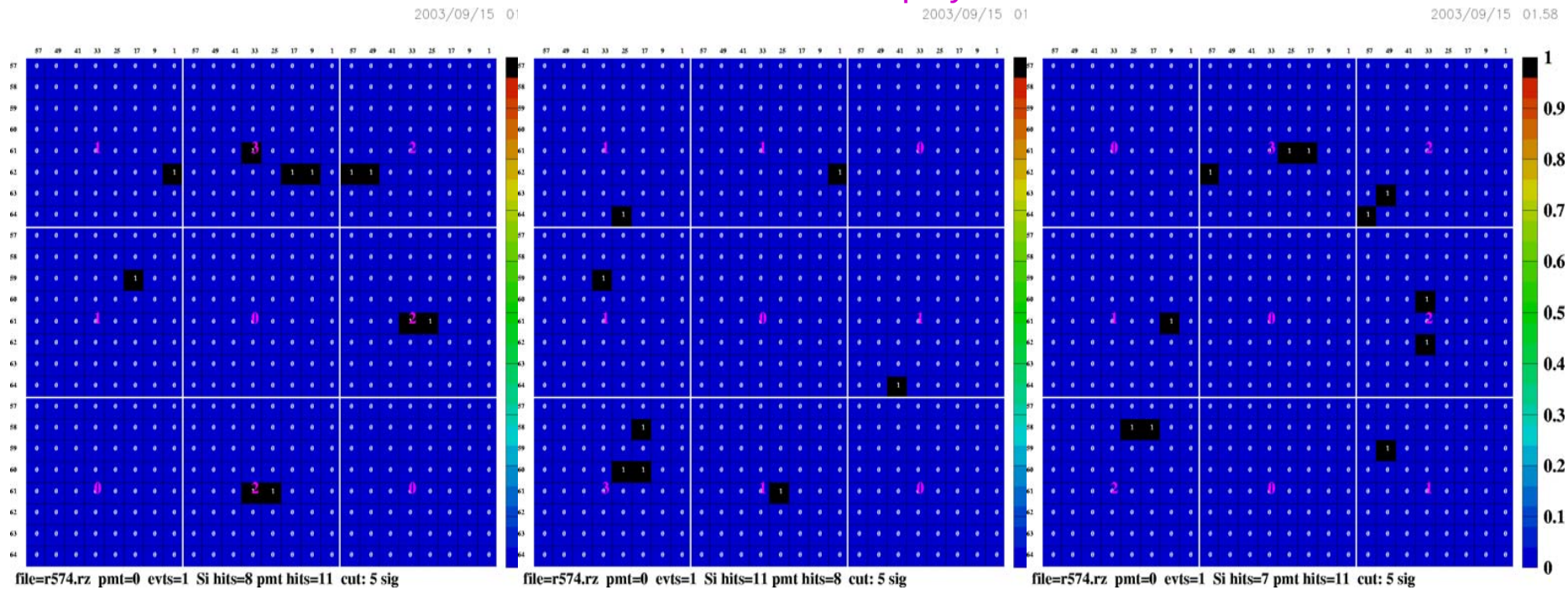


Single Events

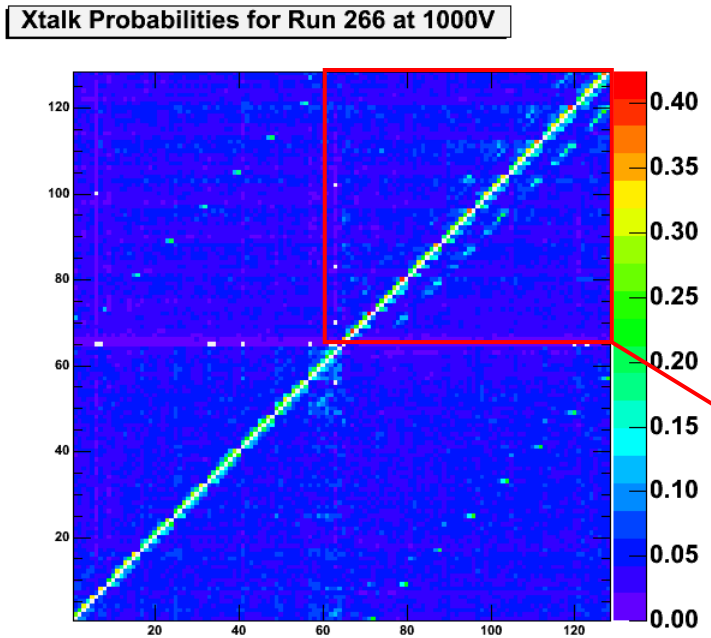
- Cherenkov photons
- CF_4: 800mbar
- 8-stage MaPMT & Beetle1.2
- HV = -900V
- with lenses

➔ Cherenkov rings from single events

Raw data event display

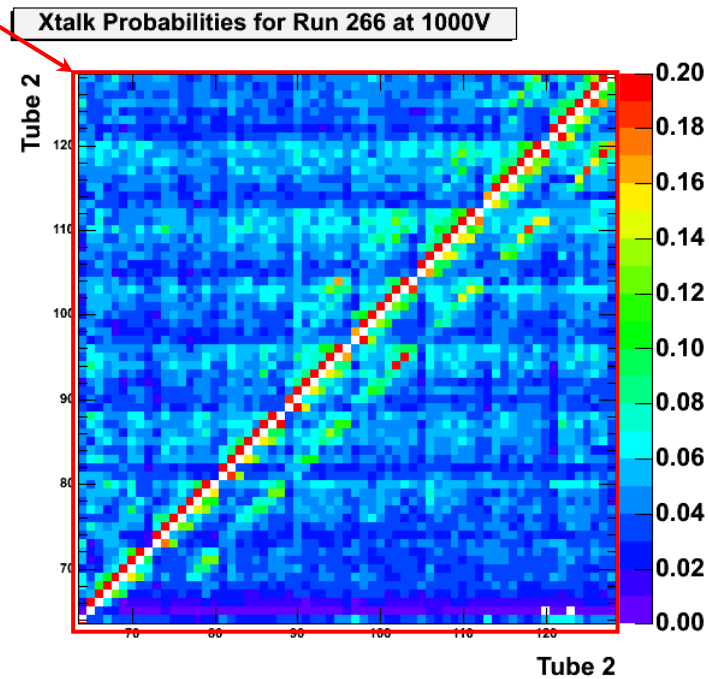


Cross talk



Probability that y talks to x

- Cross-talk
  - Mainly asymmetric & horizontal (± 1)
    - ~13% right → left
    - ~4% left → right
  - some vertical (± 8)
  - Mainly due to Beetle pipeline, supply voltage variations, amplifier bandwith



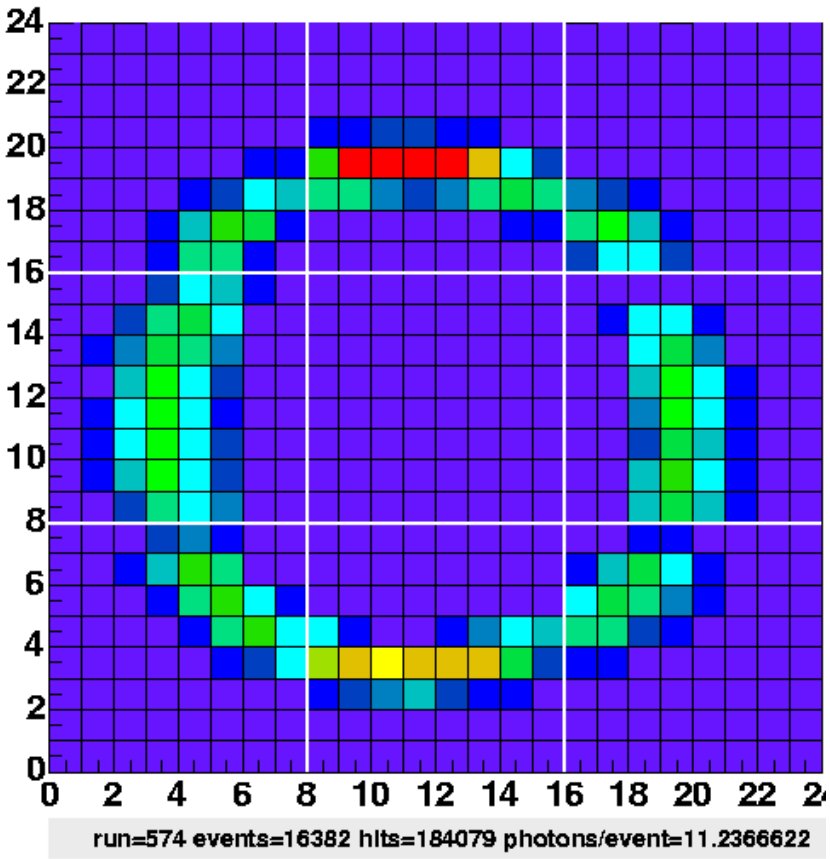
- Produce map of cross-talk partners
- Reject or Correct hit in pixel if a cross-talk partner has hit with larger pulse height
- Need to correct for genuine photon hits

Cherenkov Rings

- CF_4 800 mbar
  beam 10 GeV/c mostly pions

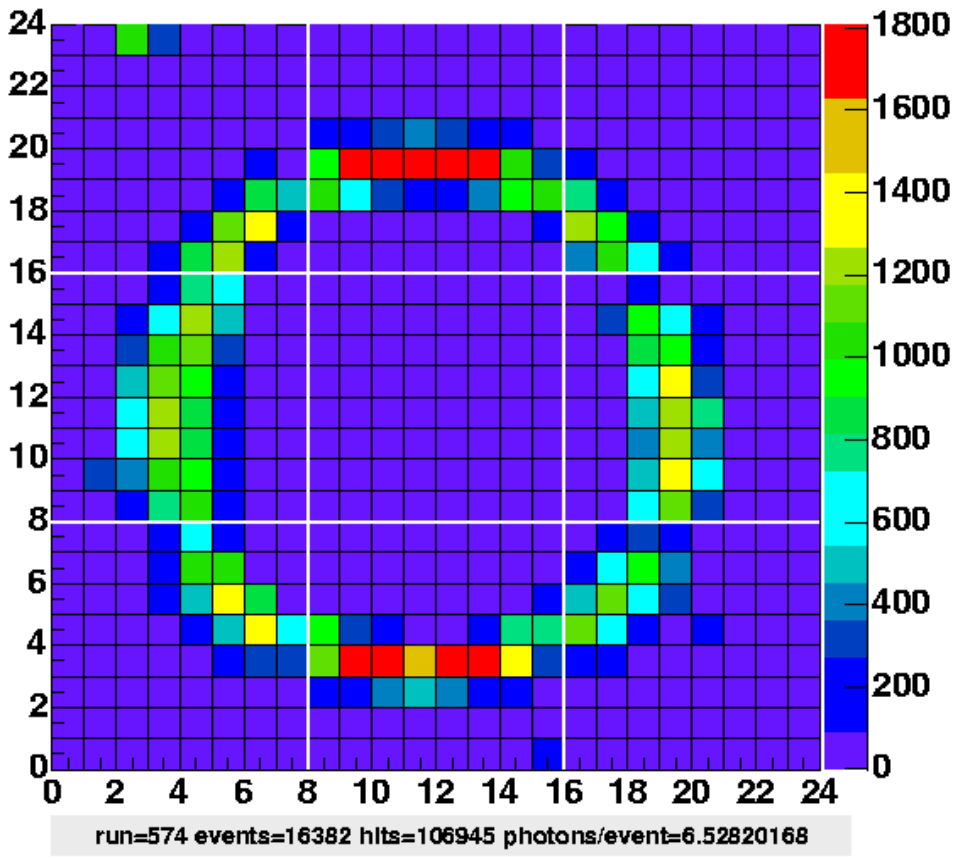
- 8-stage MaPMT HV - 900V
  Beetle1.2; with lenses

raw data



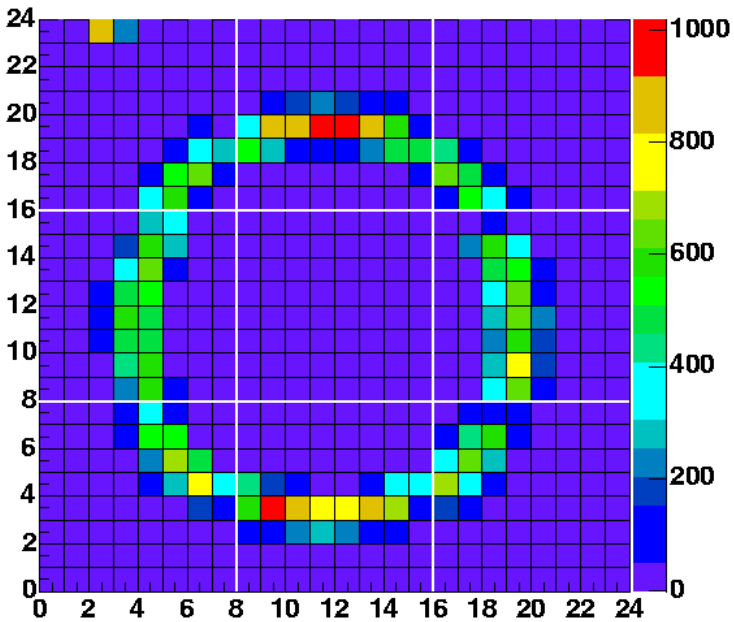
11.2 photons/evt

cross-talk corrected

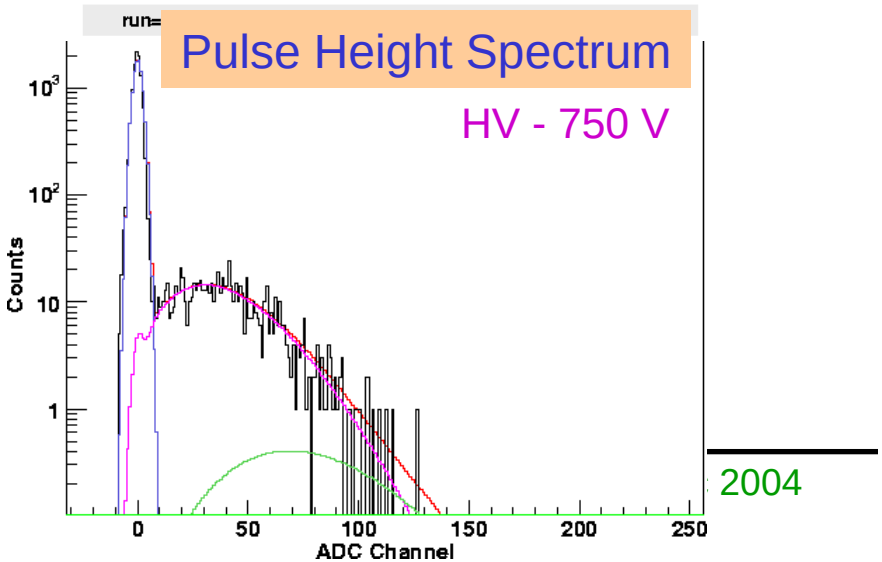


6.5 photons/evt

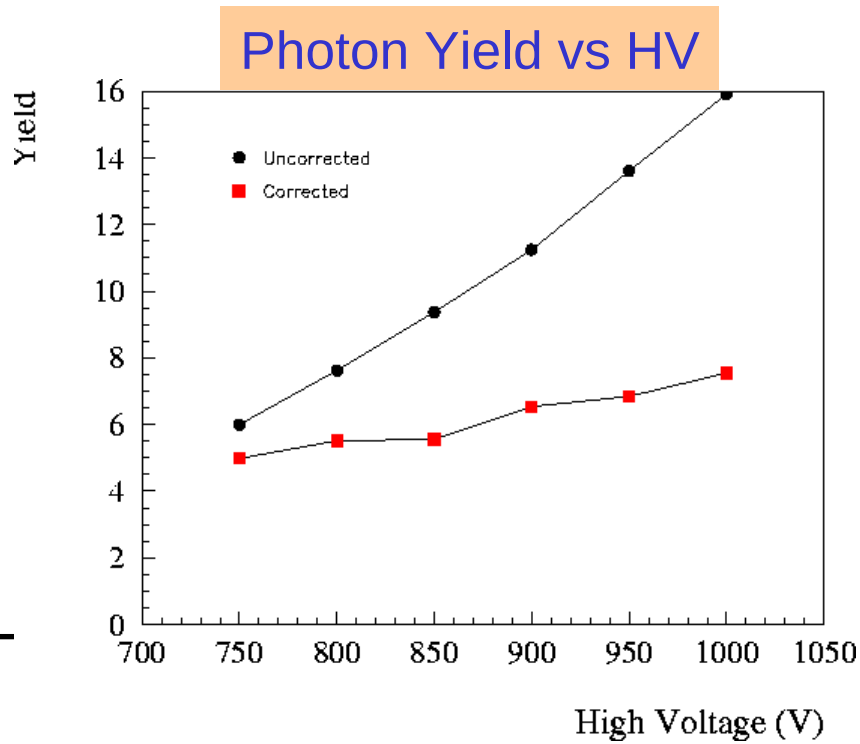
Photon Yield



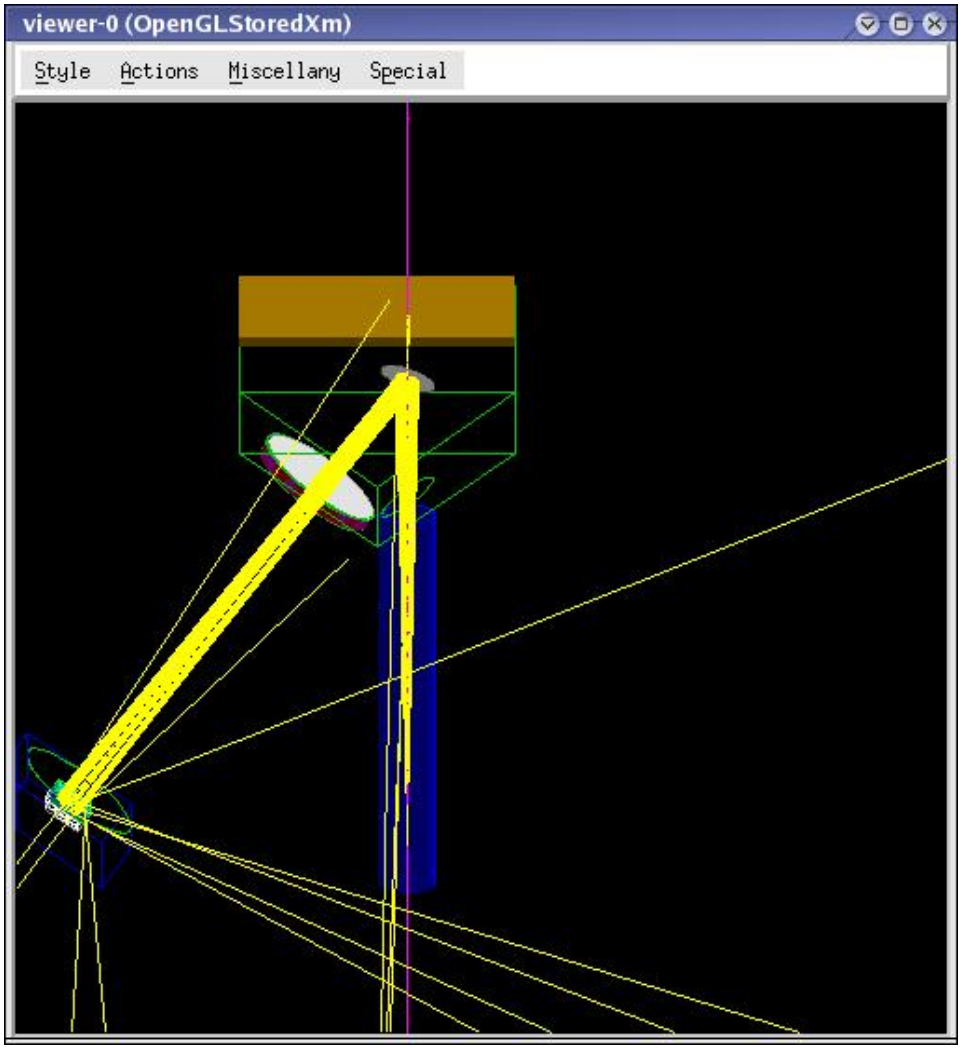
- 8-dynode stage MaPMT & Beetle1.2 chip
  - crosstalk corrected
  - removes 5 -10% genuine hits
  - Photon yield
    n_pe = 6.5 at 900 V preliminary
  - not corrected for signal loss



2004



Monte Carlo Simulation

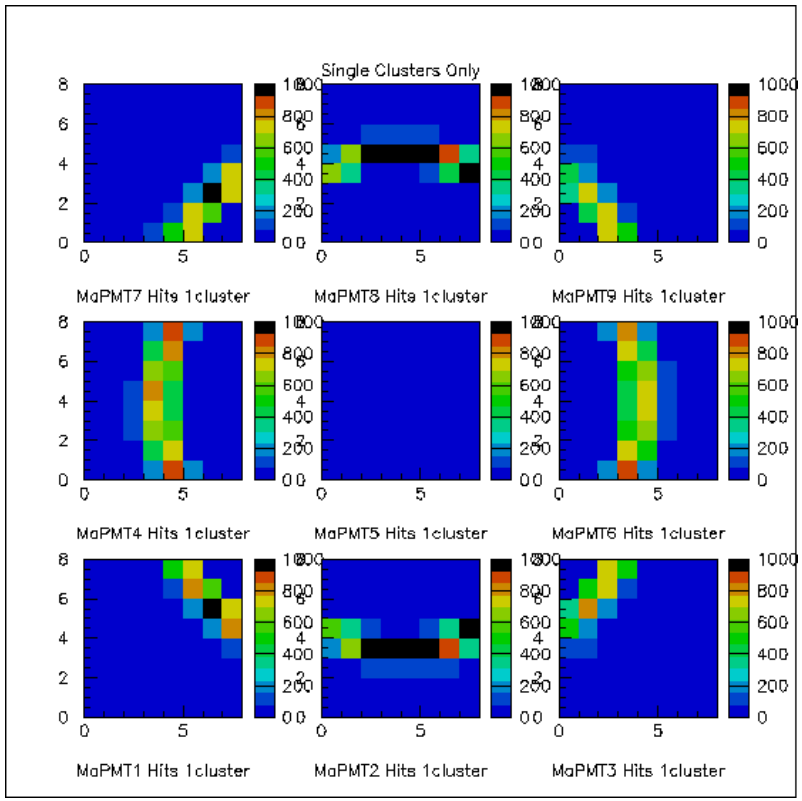


- Geant4
- Cherenkov photons produced in radiator and traced to MaPMT photo cathode
- Optics includes mirrors, quartz windows and lenses
- Radiator: 800 mbar CF_4,
- Beam: 10 GeV/c: 95% π^-, 5% e^-
- Beam divergence from measurement with silicon telescope

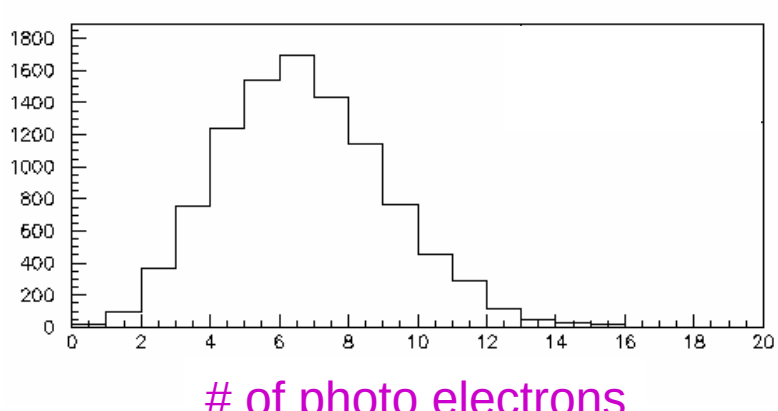
Simulation Results

8-dynode stage MaPMT

& Beetle1.2 Read-out



Photon yield distribution



# of photo electrons

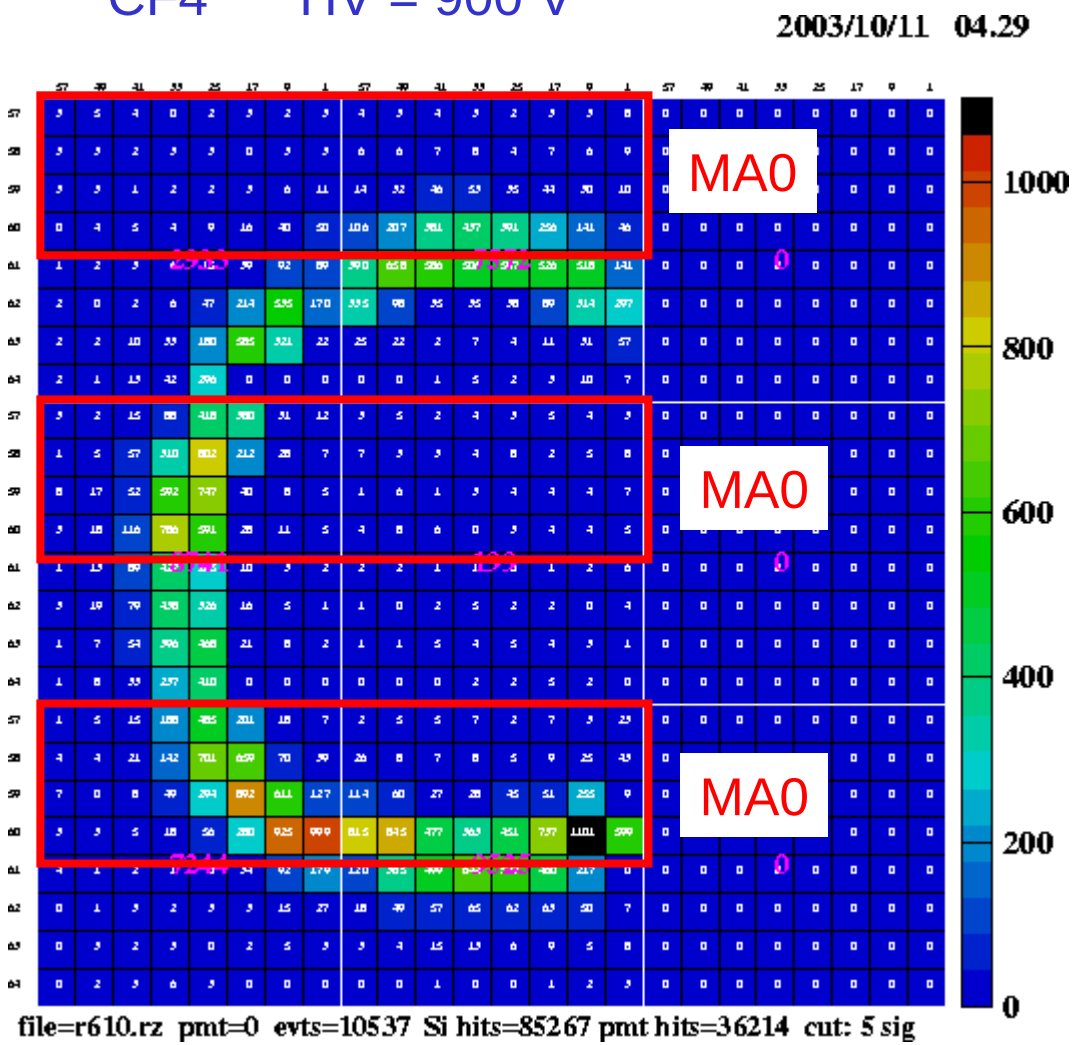
- Photon yield, per tube, per event

  0.59 0.98 0.50
  1.05 0.00 1.01
  0.62 0.97 0.51
  total 6.24

- No signal loss correction ~10%
- Good agreement with data
- Consistent with earlier measurements with 12-dynode stage MaPMTs
- 8-dynode MaPMT fulfils LHCb RICH requirements

Beetle 1.2-MA0 Read-out

CF4 HV = 900 V

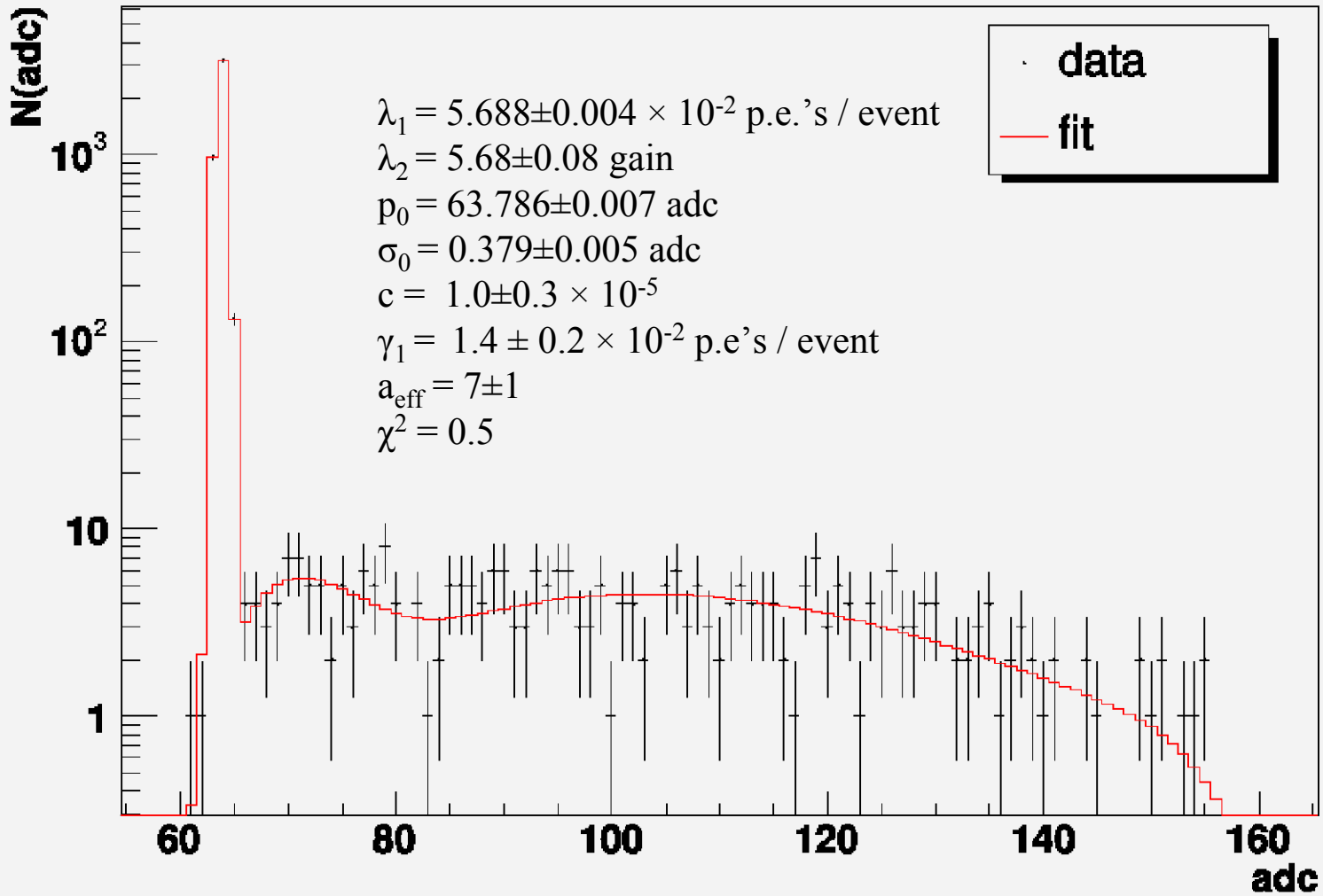


12 dynode stage MaPMT

- 3 boardBeetles / 6 MaPMTs
  - only 64 MA0 channels 32 ch per MaPMT
  - remaining channels charge attenuator / test
- Cherenkov photons visible
  - Photon yield roughly ok
  - cross-talk also present removed in analysis
- Pulse shape Analysis
  - Uses timing information

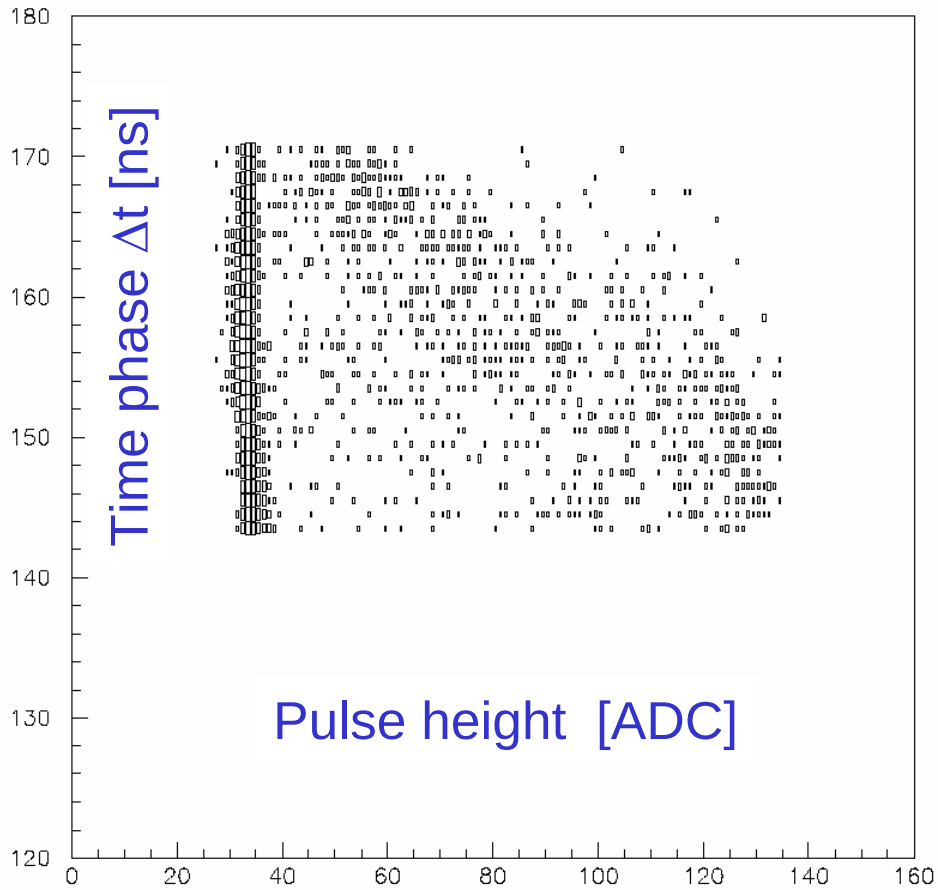
Pulse Height Spectrum Fit

12 dynode stage MaPMT Beetle 1.2-MA0



Beetle 1.2-MA0 Timing

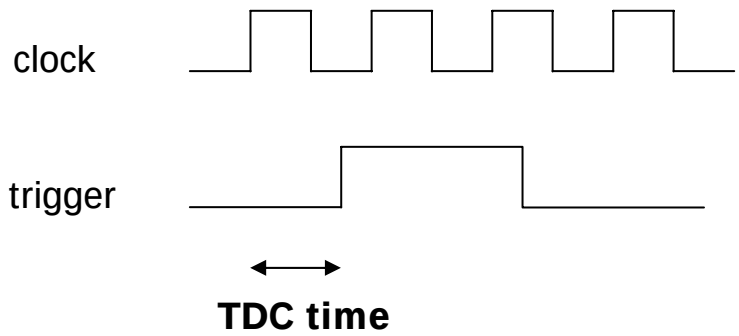
CF4 HV = 900 V BeetleMA0



Latency setting

# of 25 ns clock periods between signal entering beetle pipeline & the trigger decision

TDC value

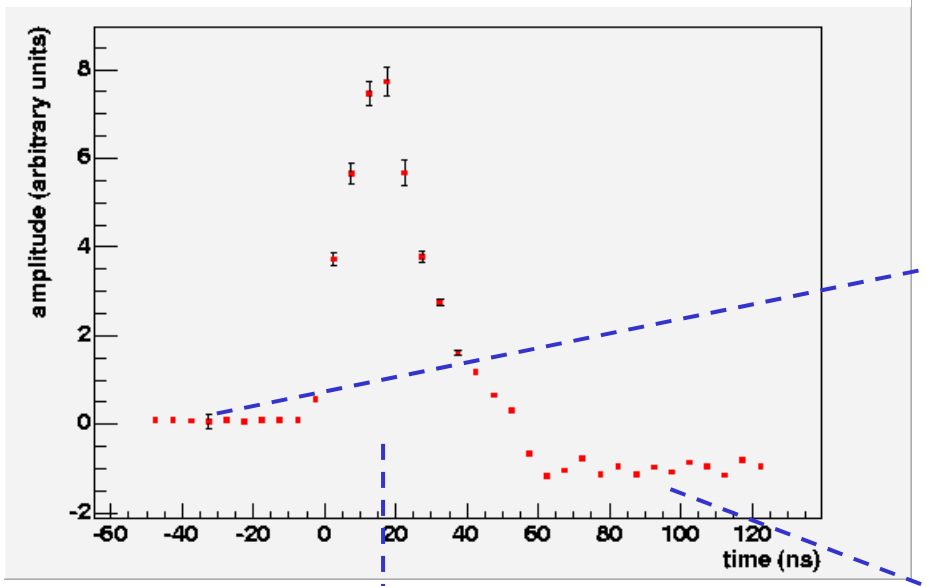


TDC – time between 40 MHz clock & testbeam trigger

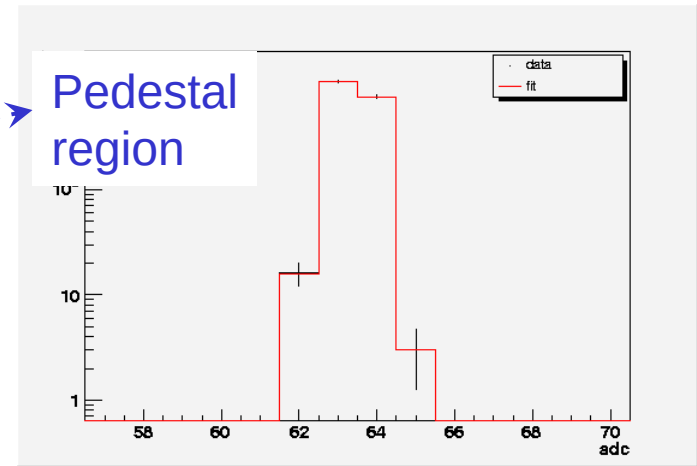
- Fit single p.e pulse height as a function of time (latency &TDC)

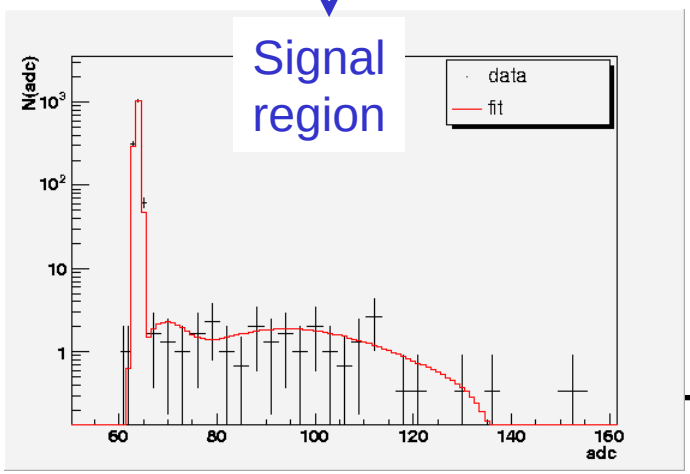
Beetle 1.2-MA0 Pulse Shape

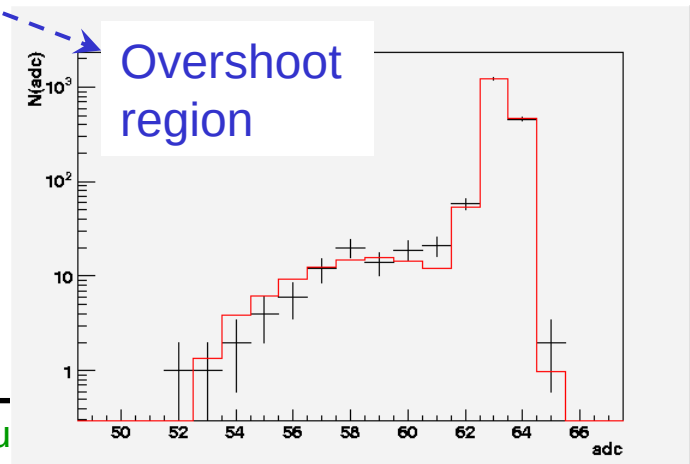
Single p.e. pulse height vs time



- Beetle 1.2-MA0 pulse shape agrees well with simulation



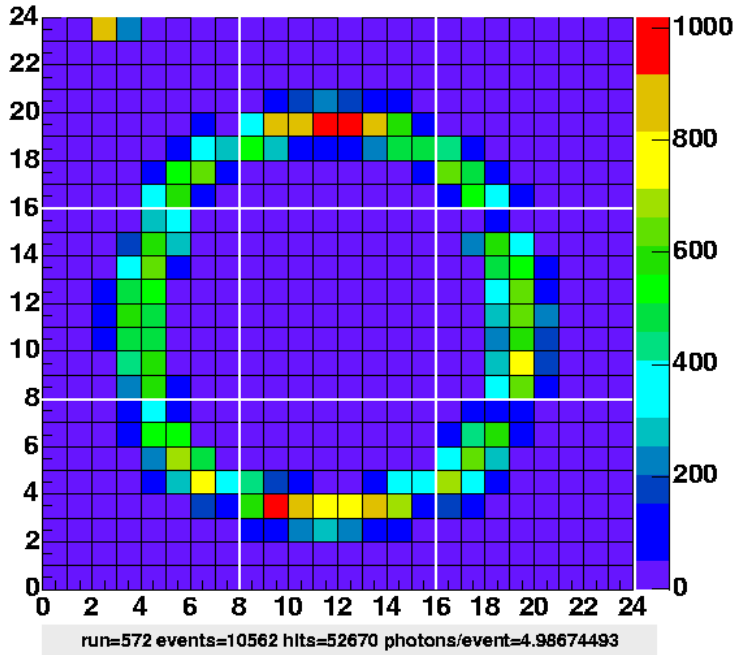




Conclusions

- 8-dynode stage MaPMT read-out with Beetle1.2 chip developed
  - 1 Board beetle for 2 MaPMTs
- Evaluation by measurements with test beam and LED light sources
  - Successful test of close packed 3x3 array of 8-dyn stage MaPMTs
  - Photon yield for 8-dynode stage MaPMT is in agreement with expectations
  - Fulfils LHCb RICH requirements
  - Crosstalk in read-out is a concern
- Customised Beetle1.2-MA0 chip developed for 12-dyn stage MaPMTs
  - Pulse shape measured
- 12-dynode MaPMT & Beetle1.2-MA0
  - Slighty better separation between single p.e peak and pedestal

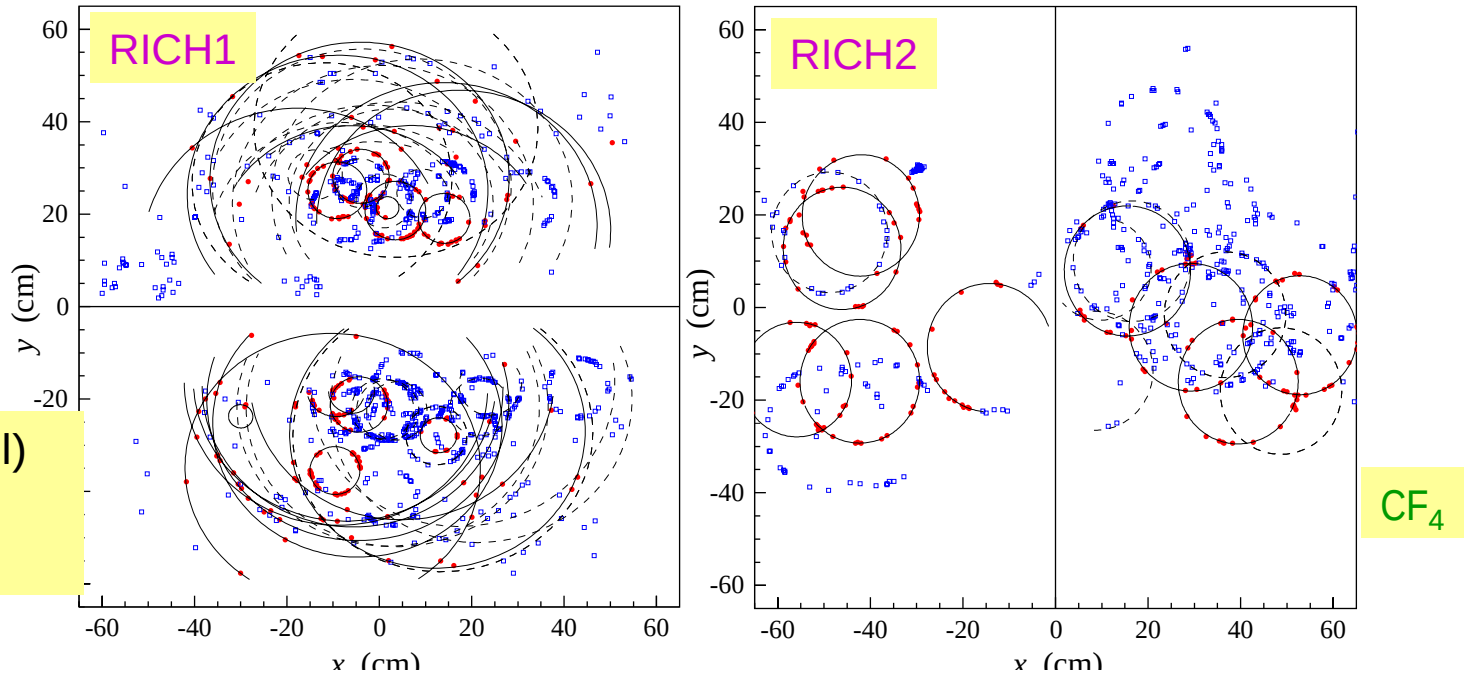
8-dynode stage MaPMT
& Beetle1.2 chip



CF_4, HV = 800V

Backup Slides

LHCb RICH Detectors



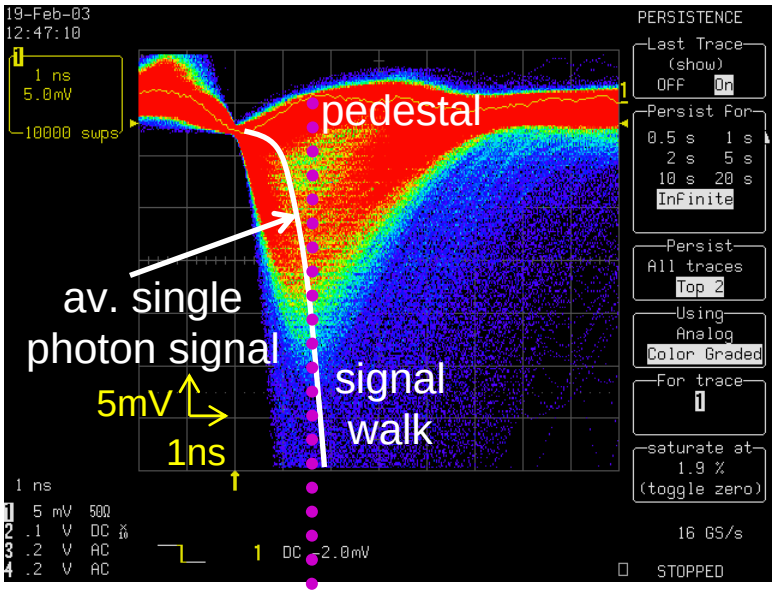
C_4F_{10} (small)
Aerogel
(large)

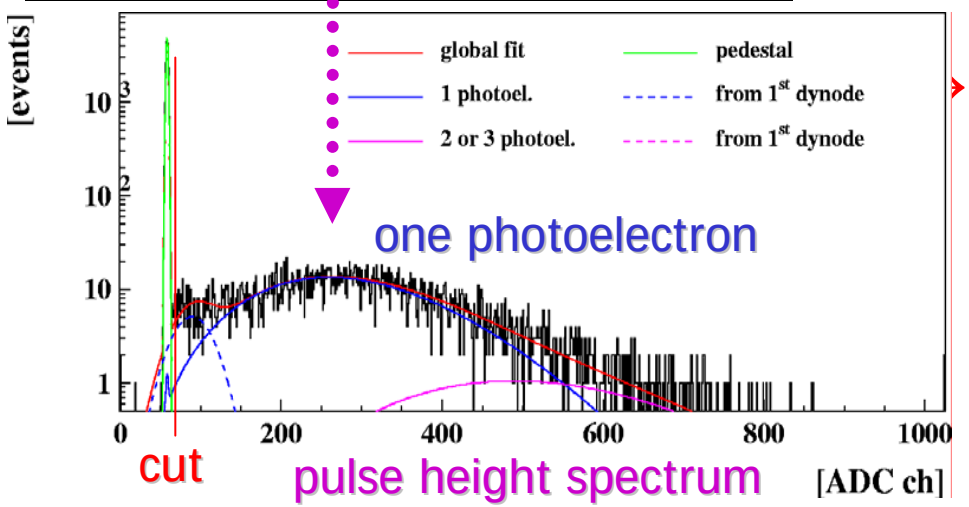
CF_4

single event in the full GEANT3 based simulation used in performance studies

- photodetector area: ~ 3.0 m^2
- single photon sensitivity: 200 - 600 nm
- quantum efficiency: >20%
- MaPMTs were option for RICH photo detectors
- good granularity: ~ 2.5 x 2.5 mm^2
- large active area fraction: ≥ 73%
- # of electronic channels: 340k

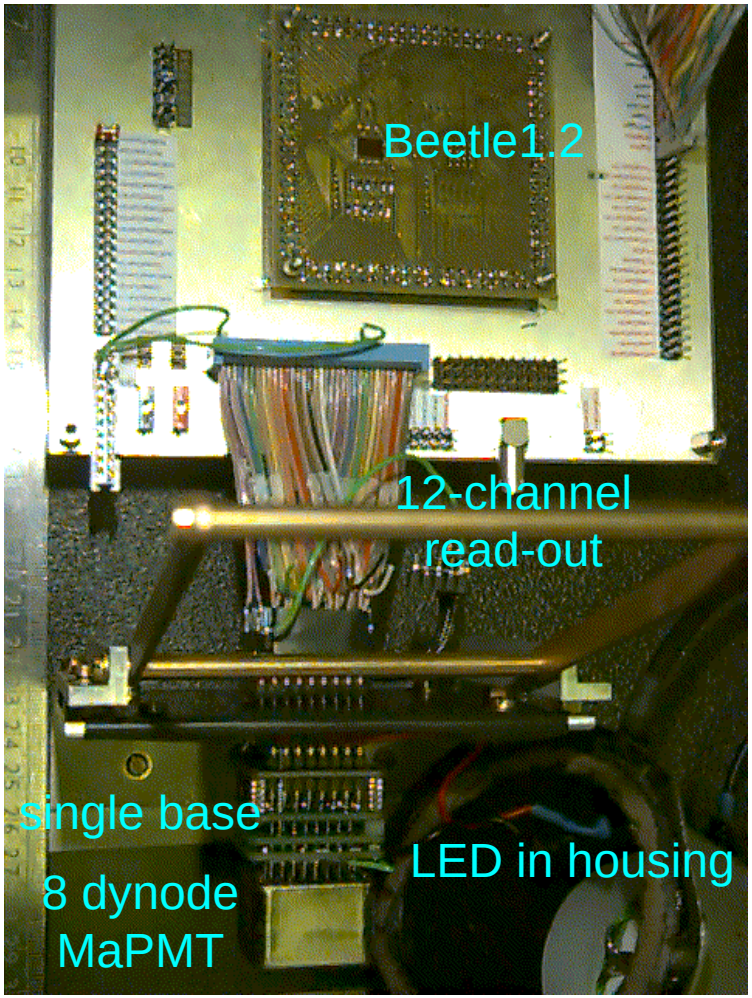
MaPMT Signal Shape



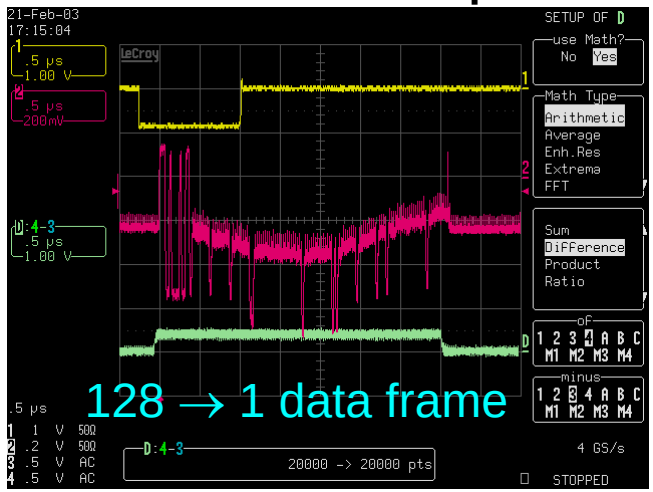


- individual pixel of 12-dynode MaPMT
  - @ HV = -1000V → nominal gain: 3.3M e^-
- direct to scope (50Ω) → density plot
  - ~5000 single photon events (stray light)
  - ~5000 pedestal events
- → signal shape: τ_{fall} = 1.1ns, τ_{rise} = 2.7ns, τ_{FWHM} = 2.6ns
  - signal width: Poisson statistics
- → signal walk
  - charge integration or sampling at the peak → pulse height spectrum
  - threshold cut → signal loss
  - fit → signal components

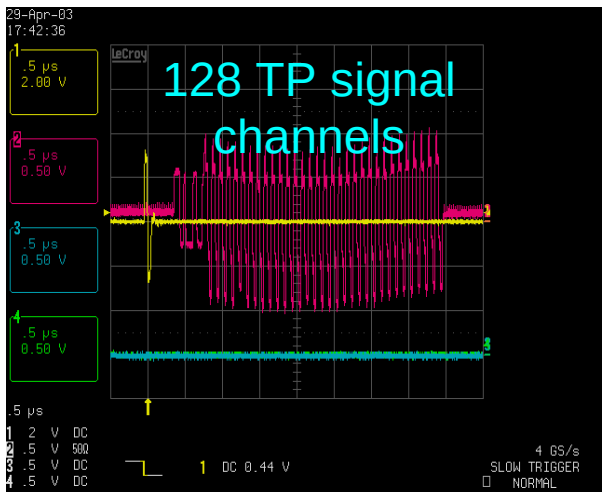
Beetle Setup for LED



- **Beetle1.2 data frames: pedestal**

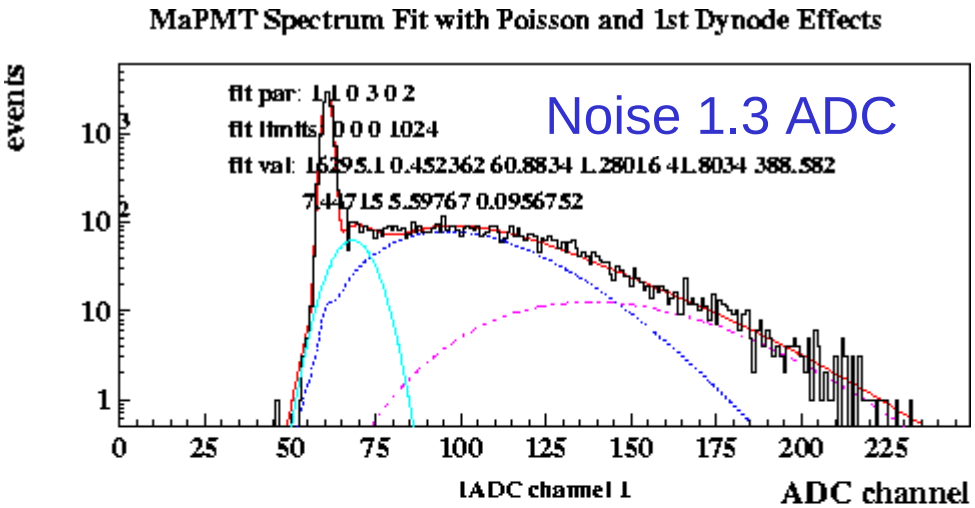


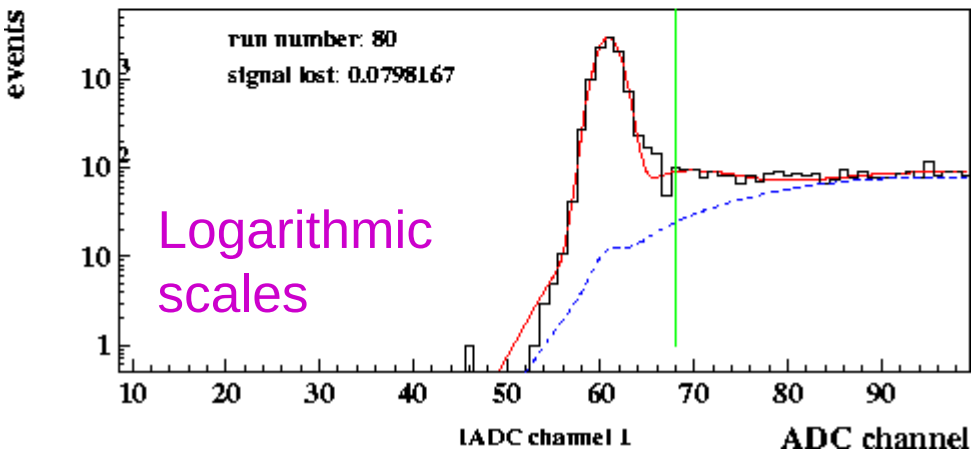
- **MaPMT test pulses**



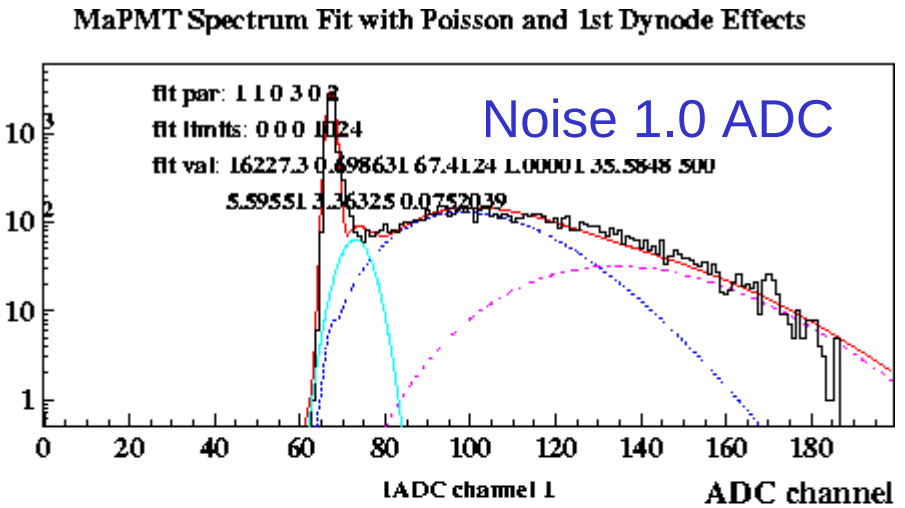
Comparison

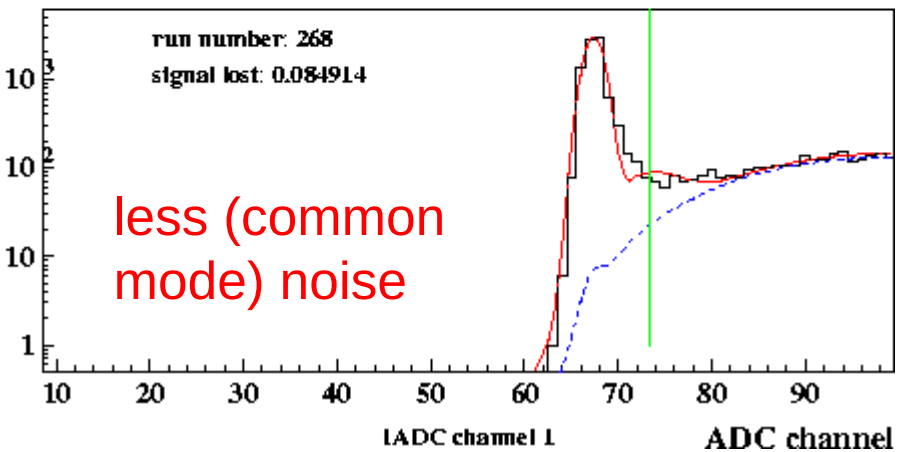
8-dynode/Beetle1.2



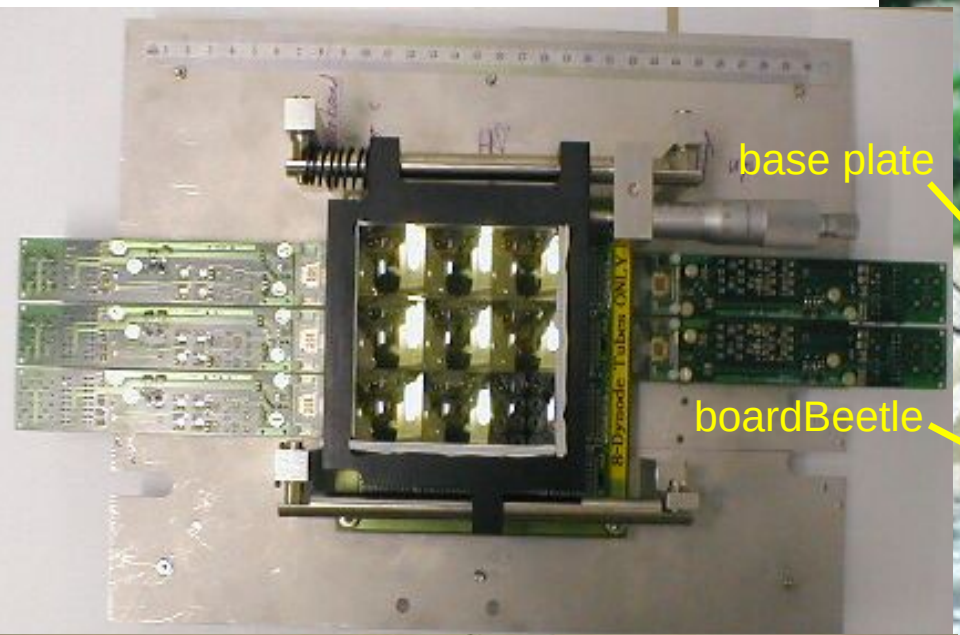


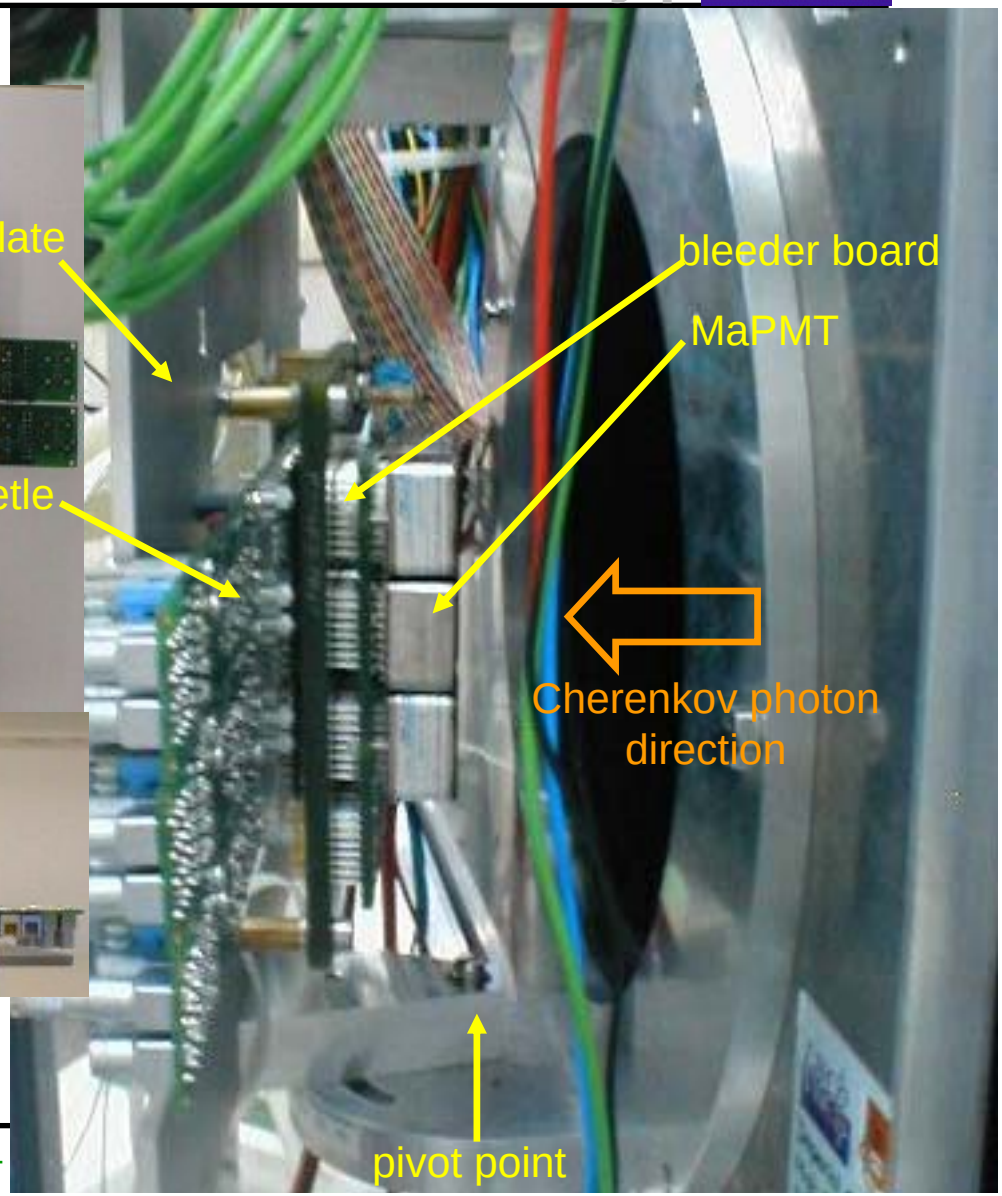
12-dynode/BeetleMA0





Cluster Setup in RICH1 Prototype

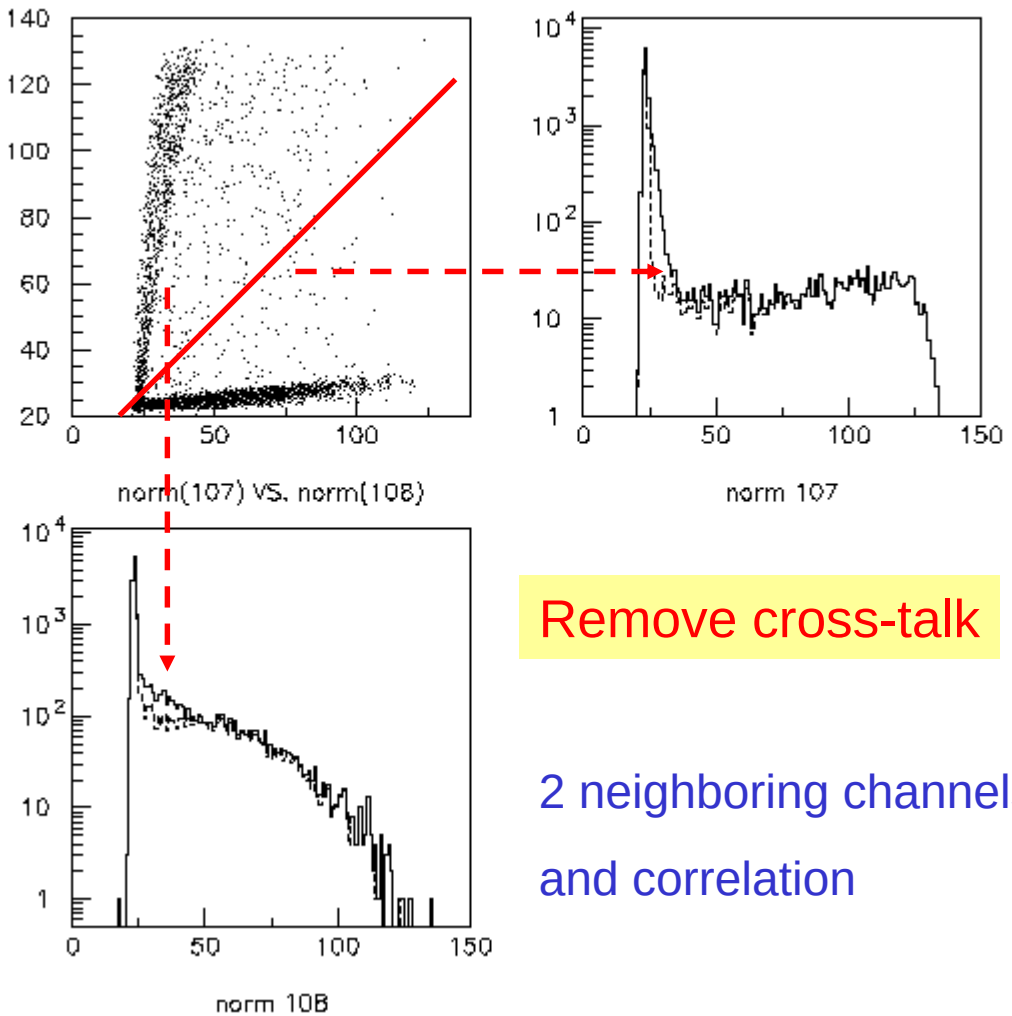




Cross-talk Study II

Pulse Height Spectra

LED Data



Remove cross-talk

2 neighboring channels

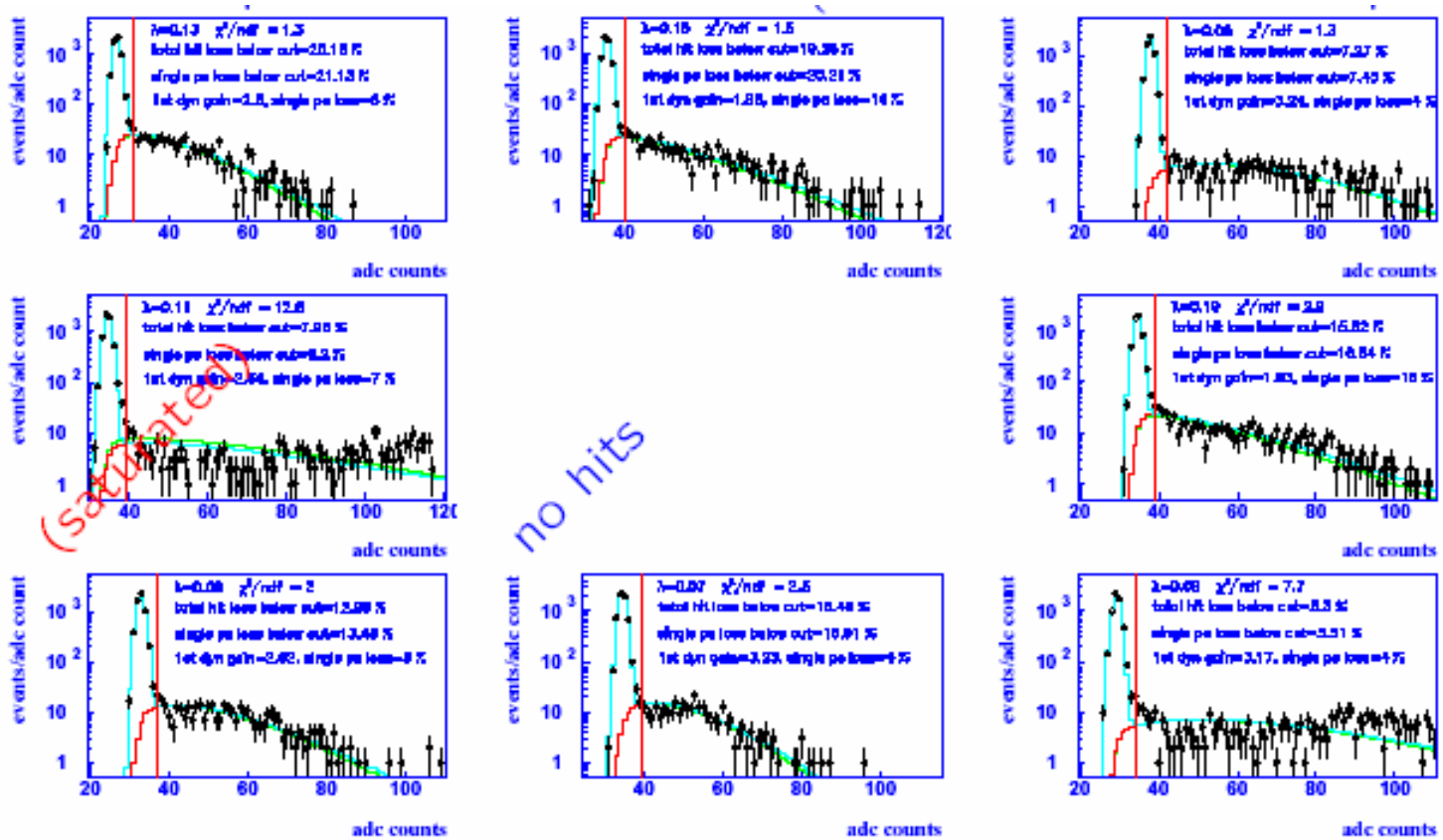
and correlation

- Cross-talk
  - horizontal
  - asymmetric
    - ~13% right → left
    - ~4% left → right
- Possible Causes
  - Beetle
    bandwith limitation
    supply voltage
    termination
  - Amplifier AD8129
    bandwith
  - tracks on boardBeetle
    or pitch adaptor
  - MaPMT?

Signal Spectra

CF4 HV = 800 V

Beetle1.2



- Signal Loss
  - 7% - 20 % fit gives gain at 1st dynode => 4% - 14% loss
  - total single p.e loss ~ 20% at 800 V