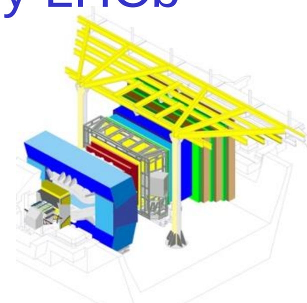
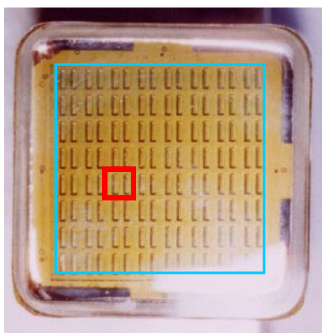
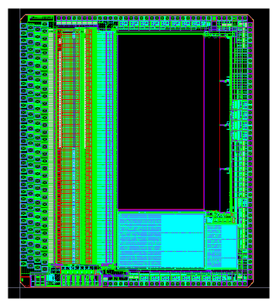
Performance of 8-stage Multianode Photomultipliers

- Introduction – requirements by LHCb
- MaPMT characteristics
- System integration
- Test beam and Lab results
- Conclusions

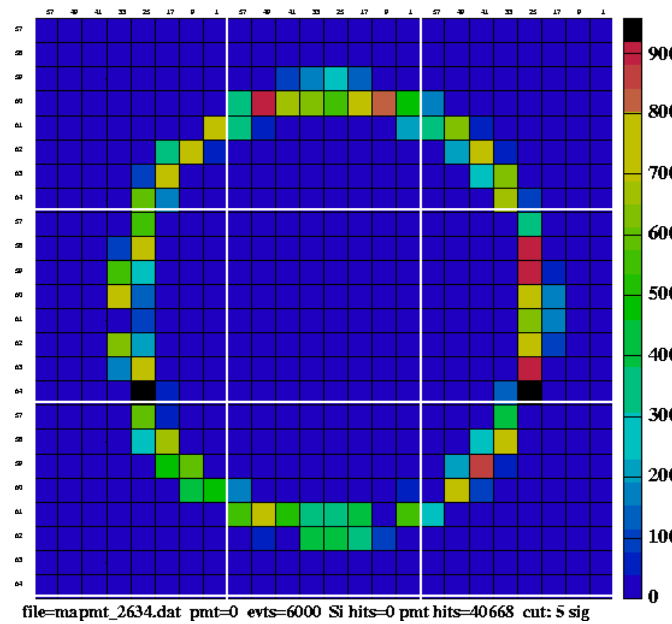




MaPMT



Beetle1.2

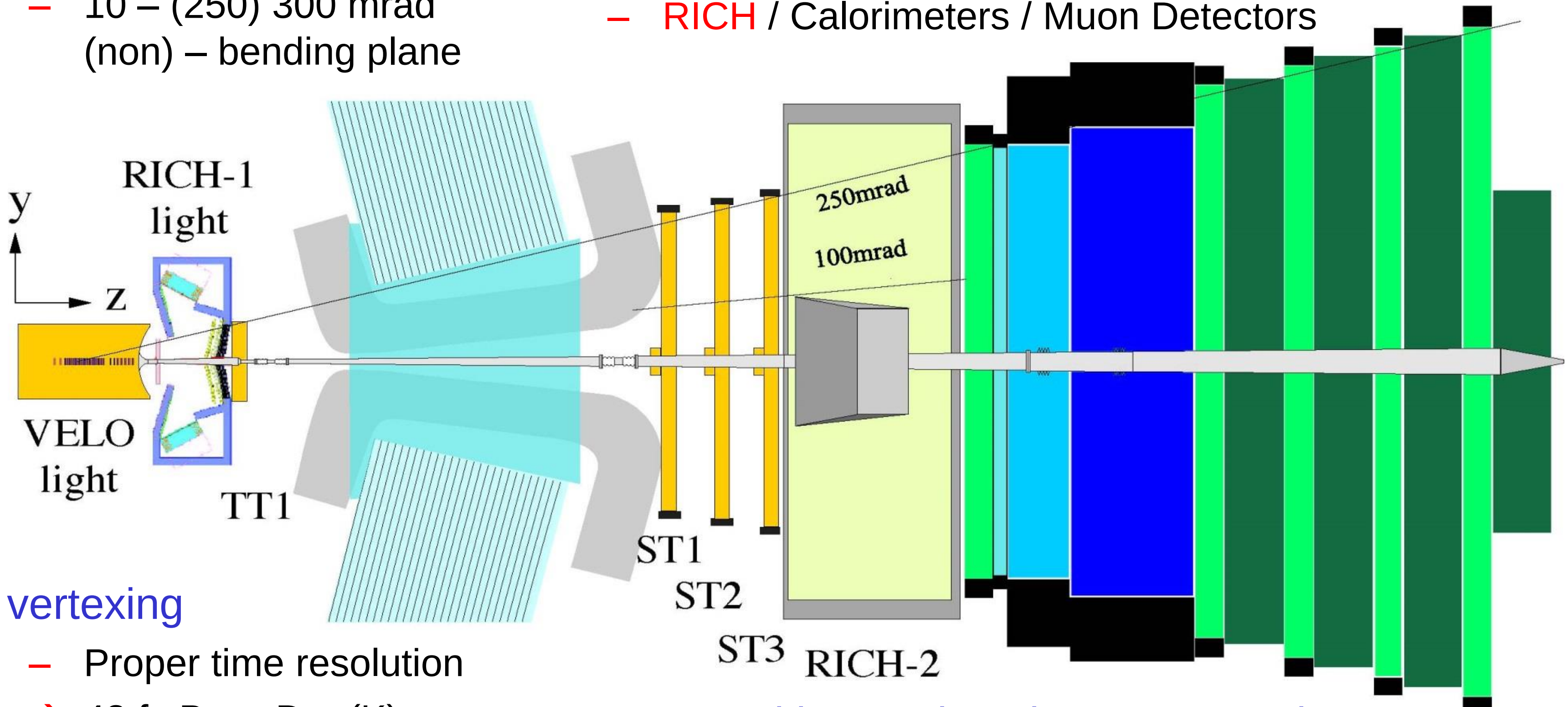


9th Topical Seminar on Innovative Particle and Radiation Detectors, Siena, 23-26.05.2004

Stephan Eisenhardt
University of Edinburgh

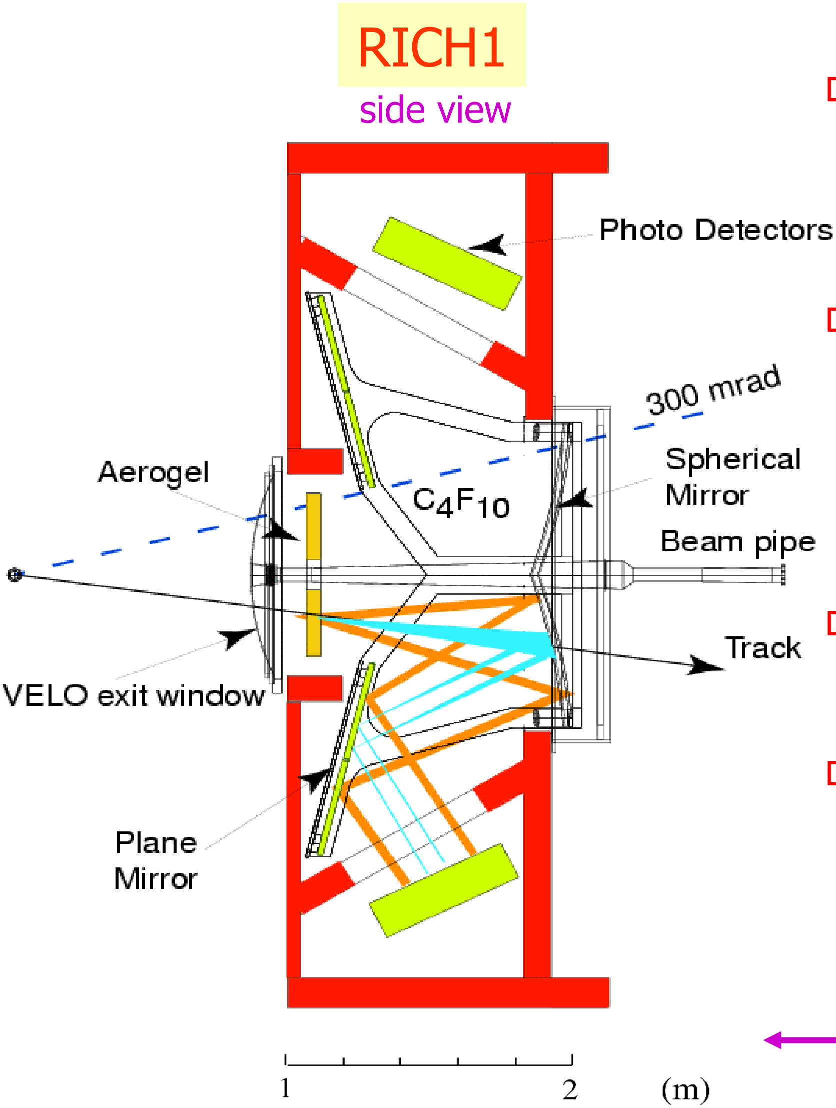
LHCb Experiment

- acceptance
  - 10 – (250) 300 mrad (non) – bending plane
- particle ID
  - π-K separation 1<p<150 GeV/c
  - RICH / Calorimeters / Muon Detectors



- vertexing
  - Proper time resolution
  - → 43 fs $B_s \rightarrow D_s\pi$ (K)
  - → 30 fs $B_s \rightarrow J/\psi\ \phi$
- no tracking stations in magnet region
- magnetic field at RICH 1
  - → "vertical" RICH 1

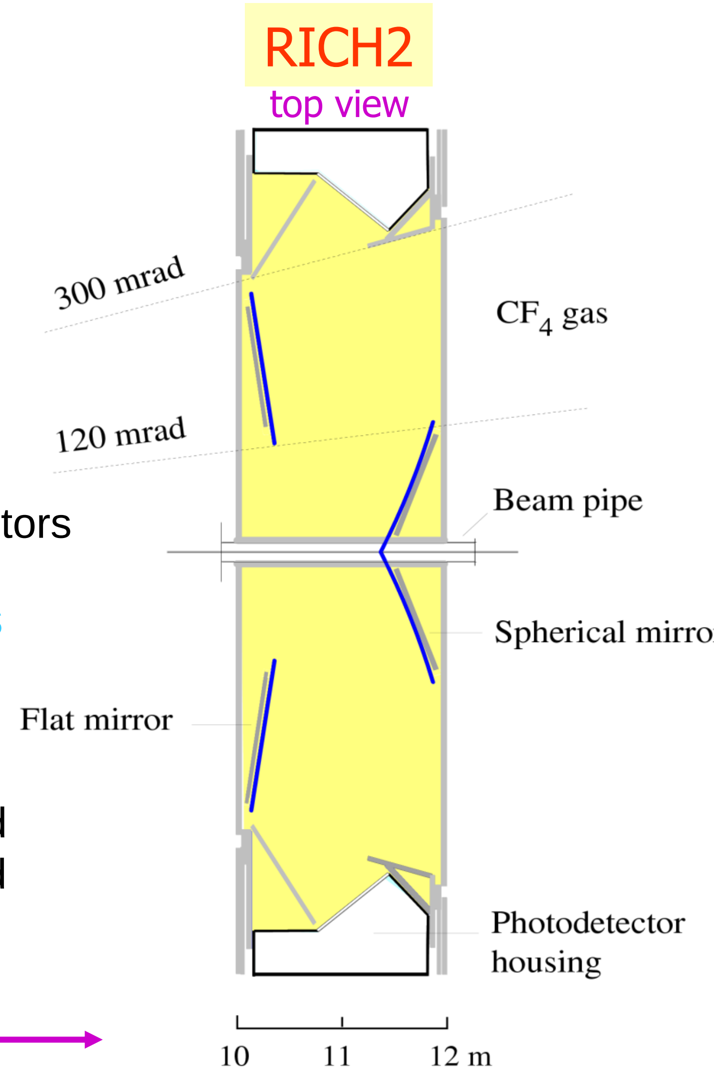
LHCb RICH System



- 3 radiator media

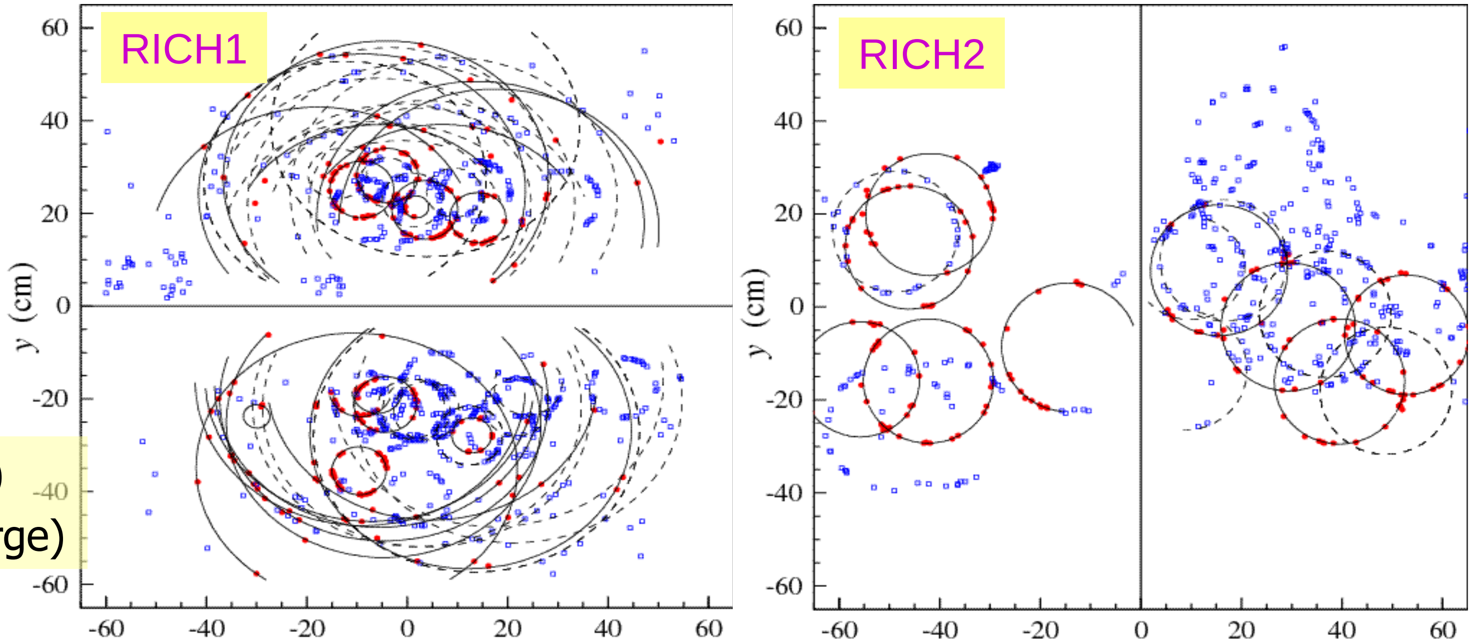
$$\cos(\theta_c) = \frac{1}{n \cdot v/c}$$

- spherical mirrors
  - focusing: onto ring image
  - tilted: to keep photo detectors outside acceptance
- secondary flat mirrors
  - enable magnetic shielding
- acceptance
  - RICH1: 25-300mrad
  - RICH2 :15-120mrad



note the scale difference

RICH Event Display



C_4F_{10} (small)
Aerogel (large)

CF_4

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

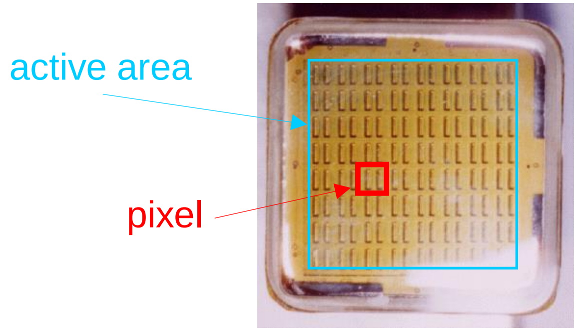
- photodetector area: 2.6 m^2
- single photon sensitivity: 200 - 600 nm
- quantum efficiency: >20%
- good granularity: ~ 2.5 x 2.5 mm^2
- large active area fraction: ≥ 73%
- ➔ # of electronic channels: 340k

candidates: MaPMT: this talk

HPD: G. Aglieri: Tue, P7, 17:30 chosen for LHCb in 11/2003

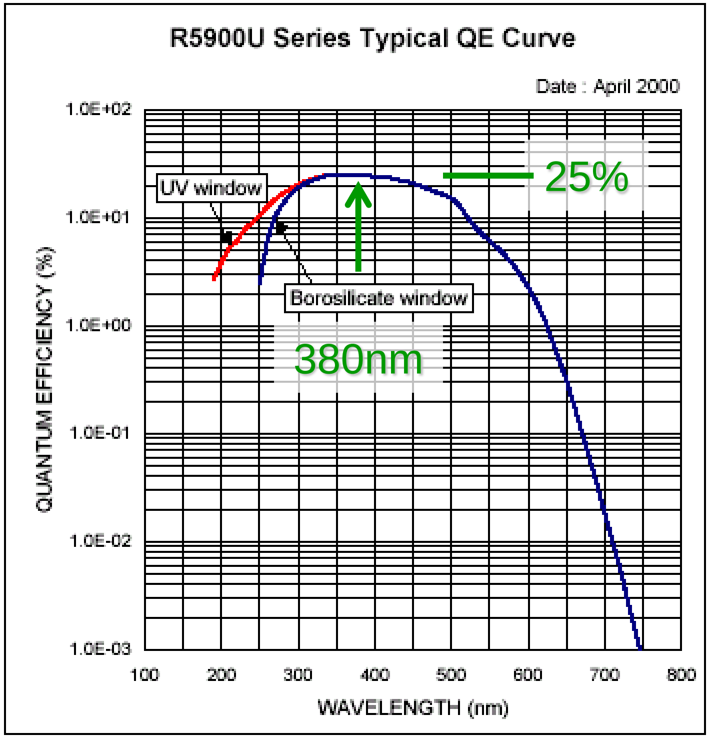
Multianode Photomultipliers

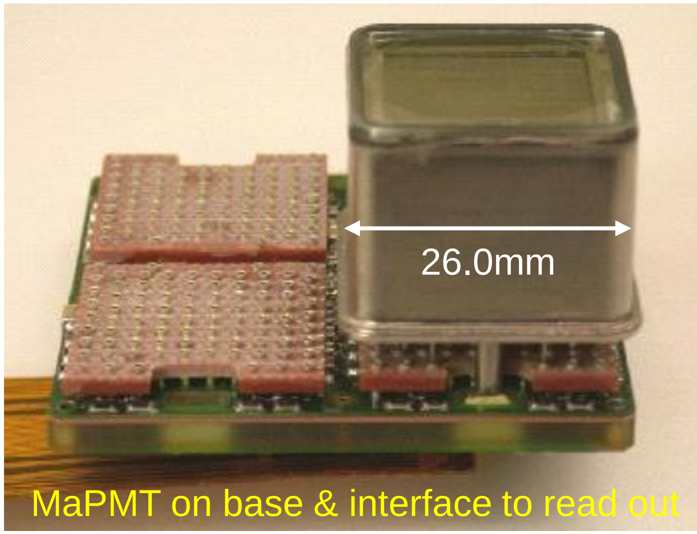
- commercial product
  - customised for LHCb
- highest possible segmentation:
  - 8x8 segmented anode
  - individual dynode chains

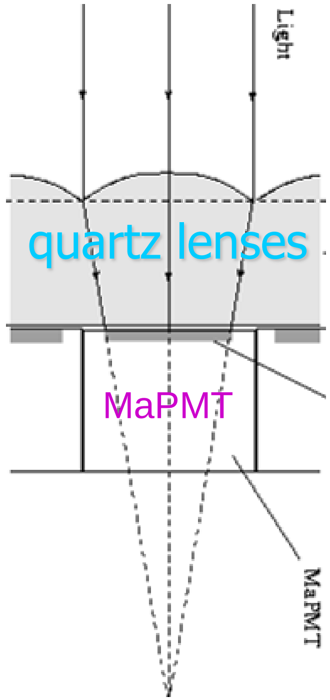


MaPMT window

- quartz lens to recover active area: 38% → 85%
- effective pixel size: $(2.1\text{mm})^2 \rightarrow (3.2\text{mm})^2$

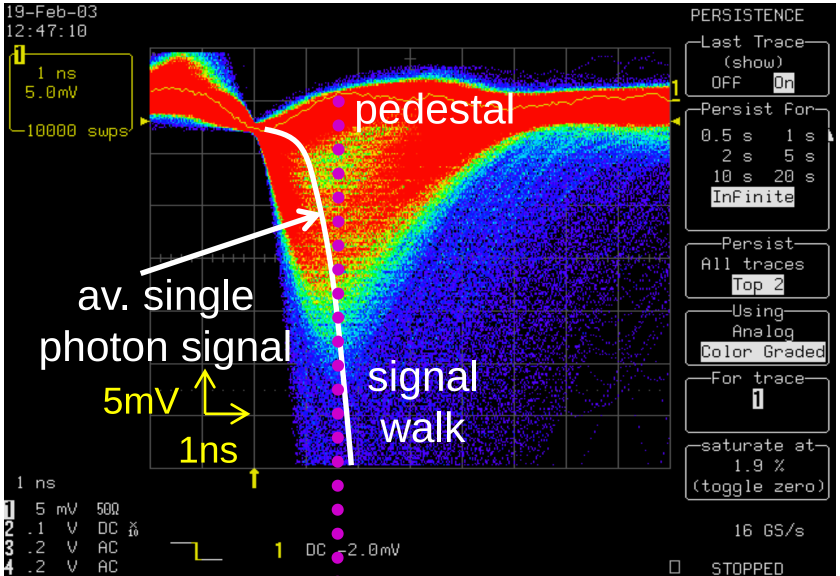


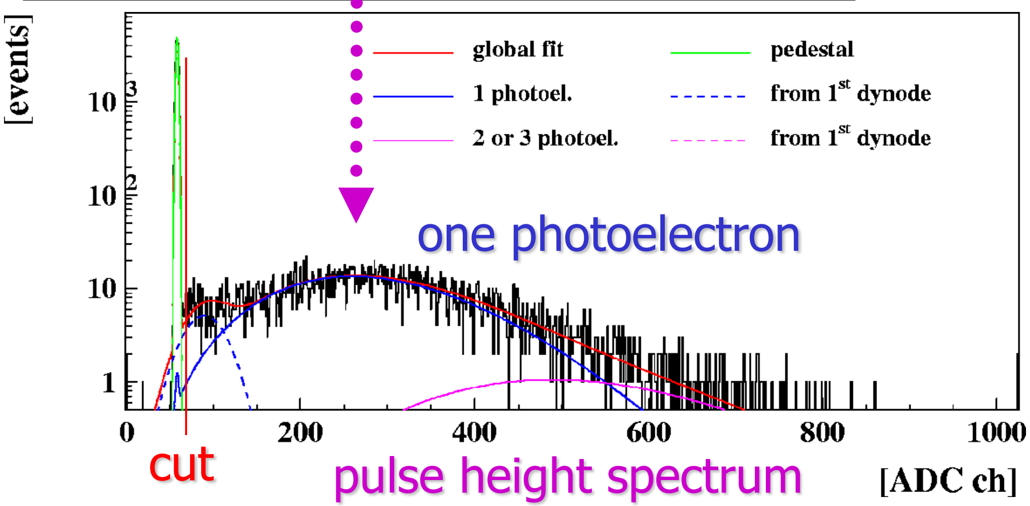




- 12-dynode or 8-dynode chain
- gain: $3{*}10^5$ or $5{*}10^4$ at 800 V
- QE = 25% at λ = 380 nm

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

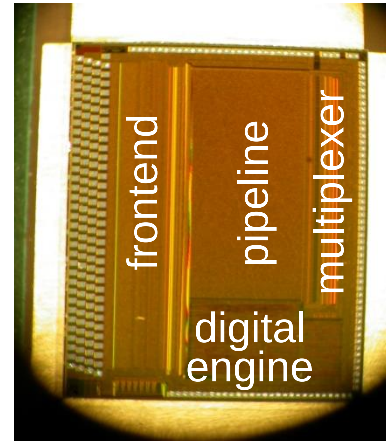
→ signal shape: τ_{fall} = 1.1ns, τ_{rise} = 2.7ns, τ_{FWHM} = 2.6ns

→ signal walk

- signal width: Poisson statistics
- charge integration or sampling at the peak
  → pulse height spectrum
- threshold cut → signal loss
- fit → signal components

MaPMT/Beetle Chip Scenarios

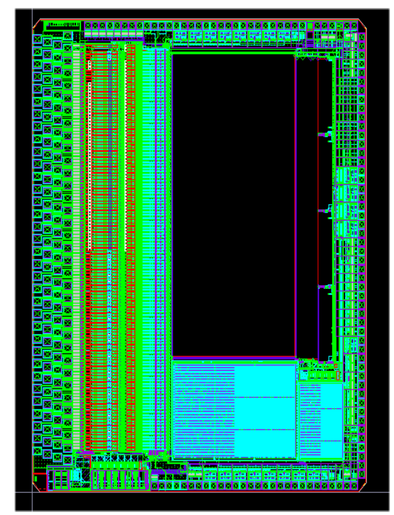
- R7600-03-M64 8-dynode stage MaPMT & Beetle1.2 chip
  - gain: 50000 e^- / photoelectron @ HV 800 V
  - standard Beetle1.2 chip 128 channels
  - single photon equivalent 60 mV (2 mip)
  - signal / noise ratio 40



Beetle1.2

- R7600-03-M64 12-dynode stage MaPMT & Beetle1.2-MA0 chip
  - gain: 300000 e^- / photoelectron @ HV 800 V
  - Beetle1.2-MA0 chip 64 'charge attenuator' ch.
    front-end customised for MaPMT (+ other test ch.)
  - single photon equivalent 30 mV (2 mip)
  - signal / noise ratio 40

6.1mm



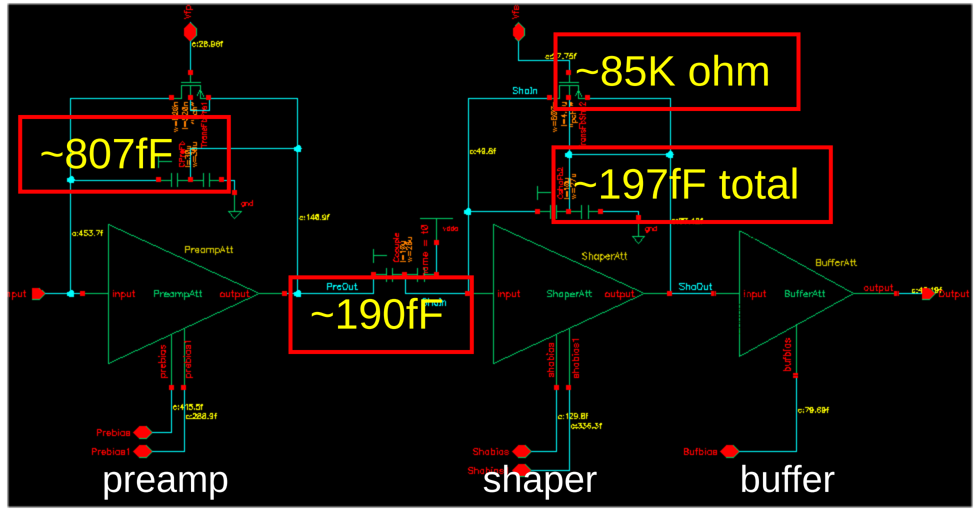
5.2mm

Beetle1.2-MA0 design

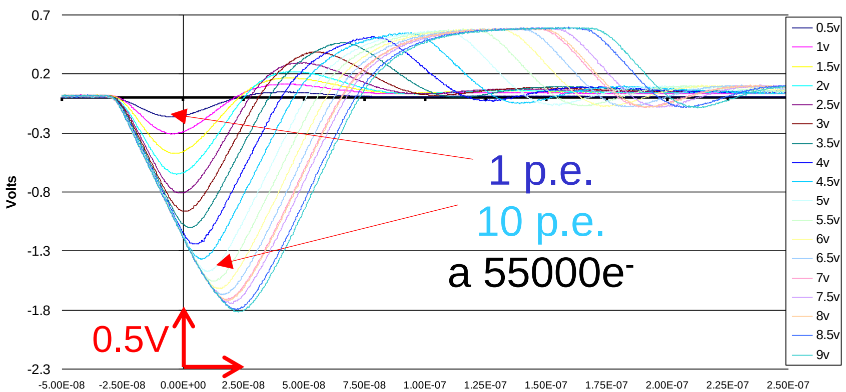
- common structure:
  - shaper, sampling at 40MHz, 4µs pipeline
  - multiplexed analogue or binary readout mode

Beetle Design

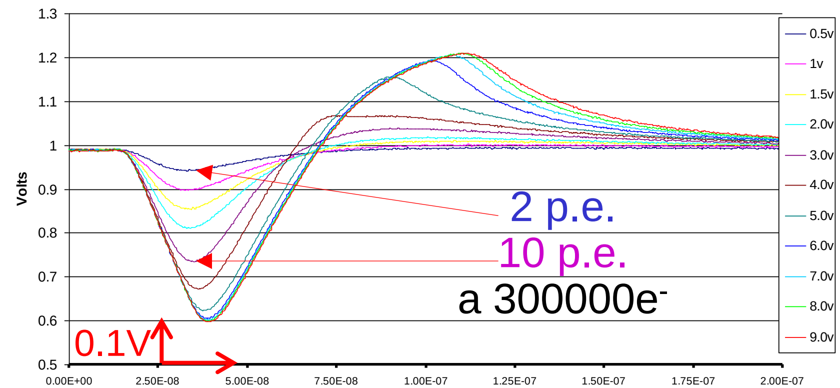
- Beetle1.2-MA0:
  - changed preamp & shaper
  - matches higher gain of 12-dynode MaPMT
  - less relative noise than Beetle1.2
  - less overshoot
  - trade-off: overshoot vs. spill over
  - ➔ more margin than Beetle1.2



changes Beetle1.2 → Beetle1.2-MA0 design



25ns Beetle1.2

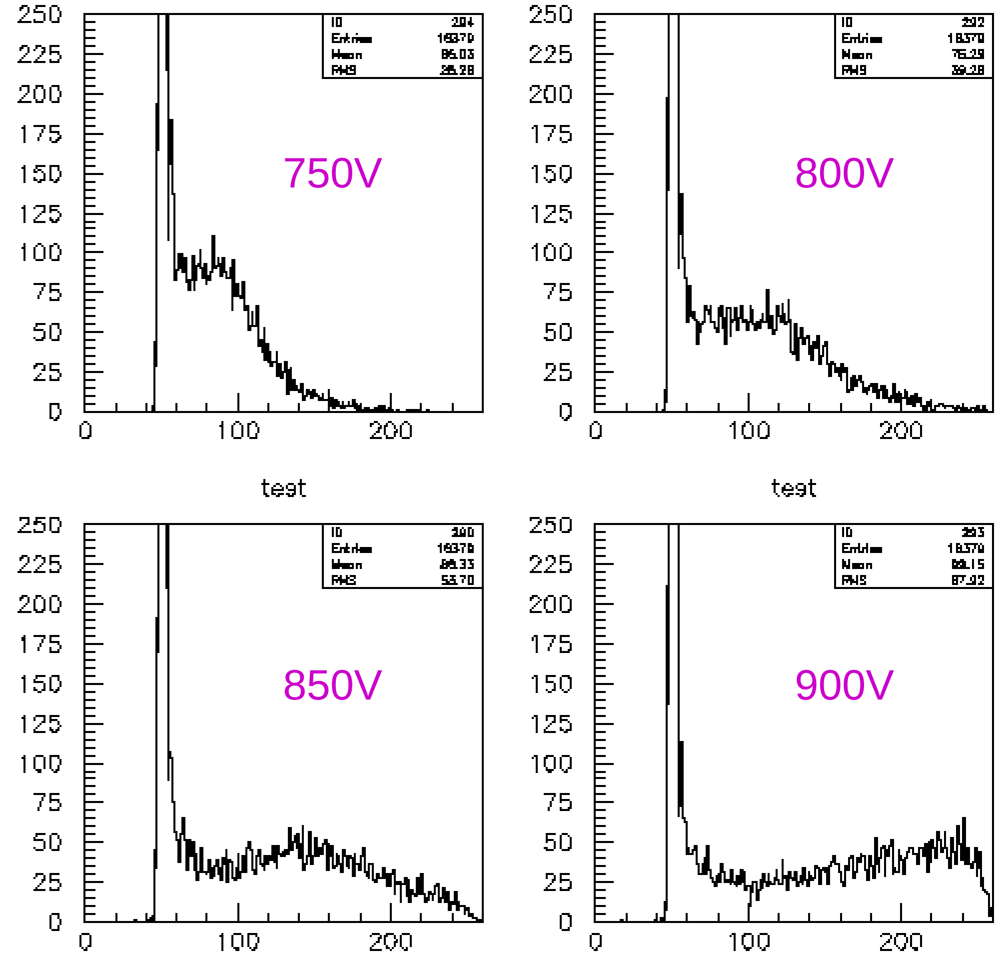


25ns Beetle1.2-MA0

signal shape after shaper

HV scan 8-dynode MaPMT

single channel pulse height spectrum of LED photons



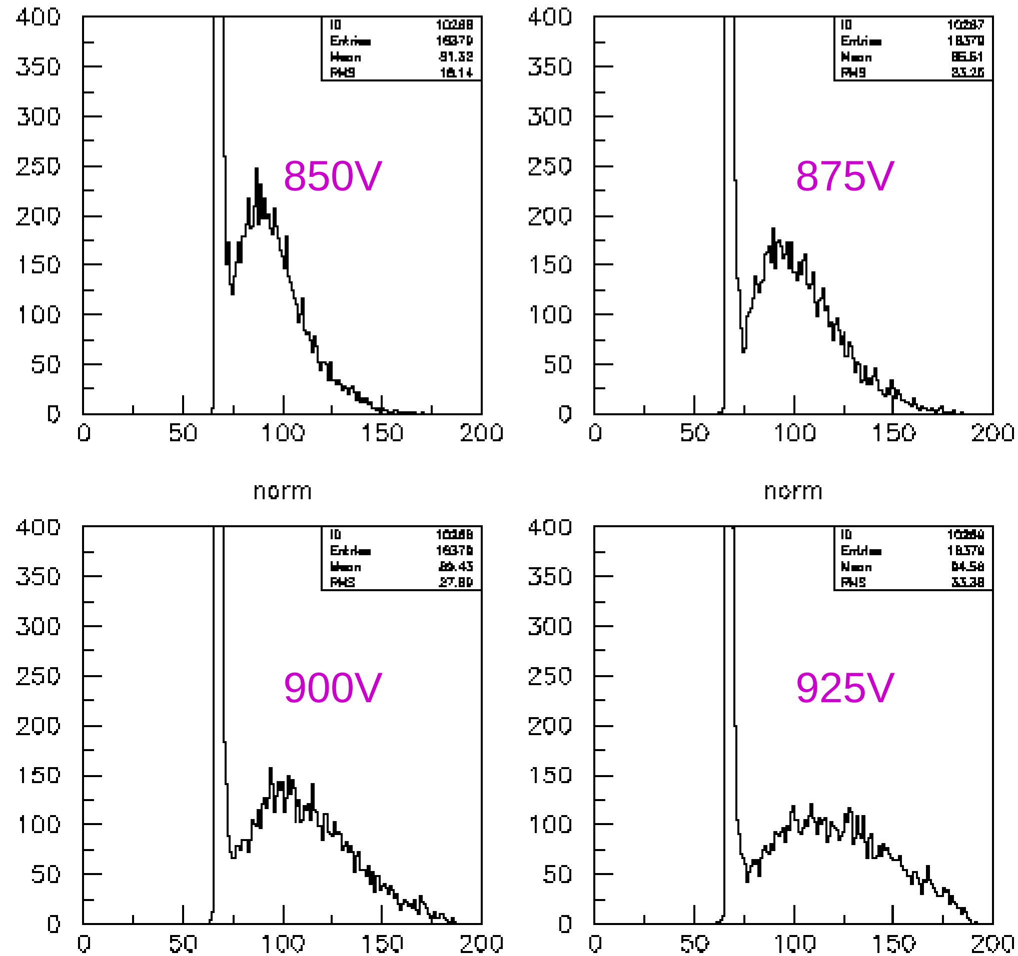
- 8-dynode stage MaPMT & Beetle1.2 chip
- HV: -750…-900V
- LED light at 470nm
- single photoelectrons
- pedestal width:
  $\sigma \sim 1.4$ ADC
- clear single photon signal
- gain doubles every ~50V

HV scan 12-dynode MaPMT

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

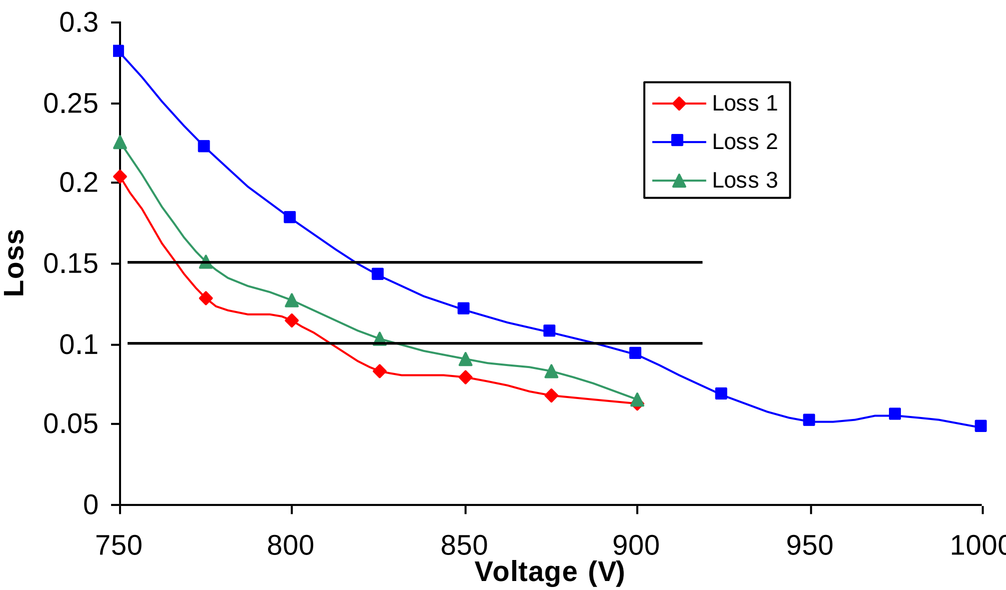
→ less noise (common mode)
→ better separation signal vs. pedestal

single channel pulse height spectrum of LED photons



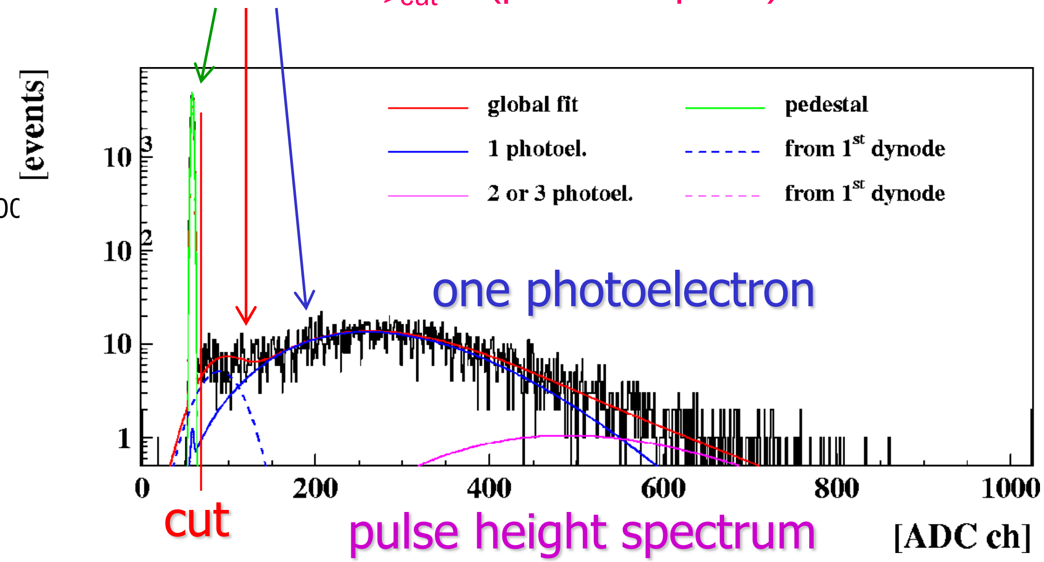
Signal Loss Study

- for 8-dynode stage MaPMT & Beetle1.2 chip



signal loss vs. high voltage

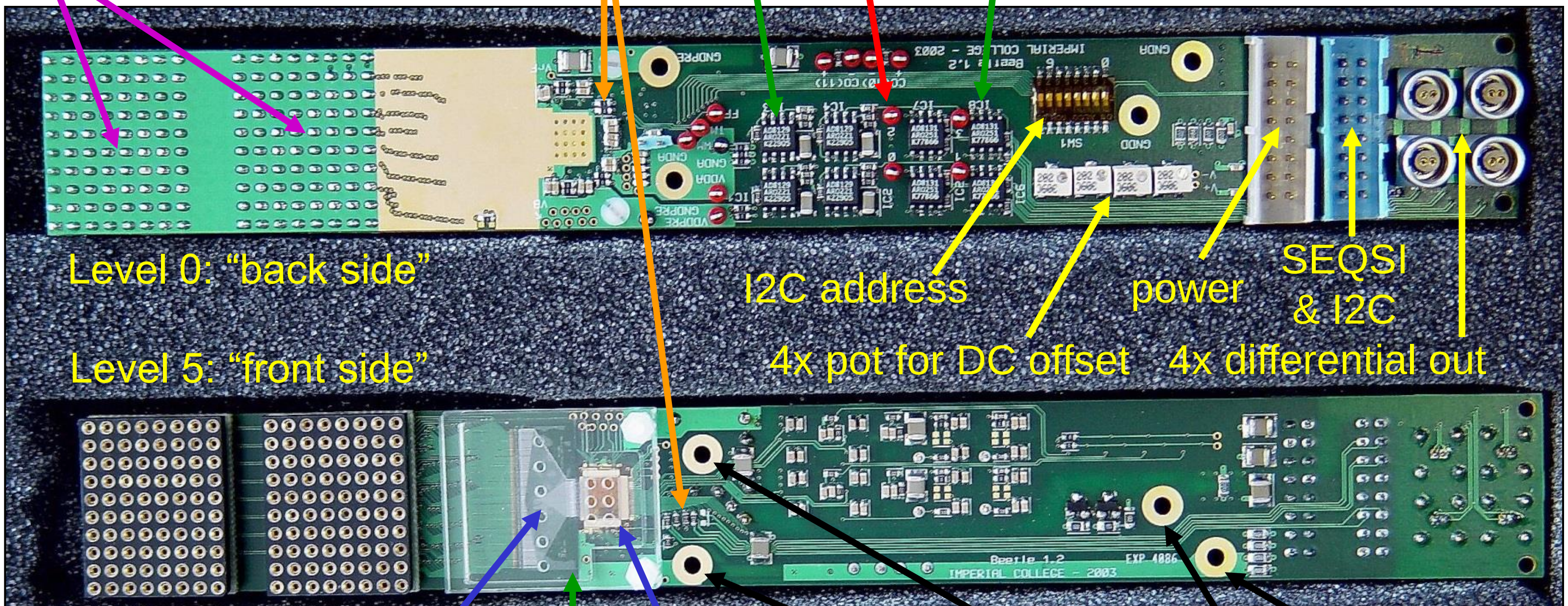
- signal loss: defined in 3 different ways
  - N # of events
  - $N_{>cut}$ # of events above 5σ cut
  - loss 1 ~ $N_{ev}\,(1-e^{(-\mu)}) - N_{>cut}$
  - loss 2 ~ ∫(single p.e. fit) – $N_{>cut}$ (upper limit)
  - loss 3 ~ $N_{>cut}$ - ∫(pedestal peak)



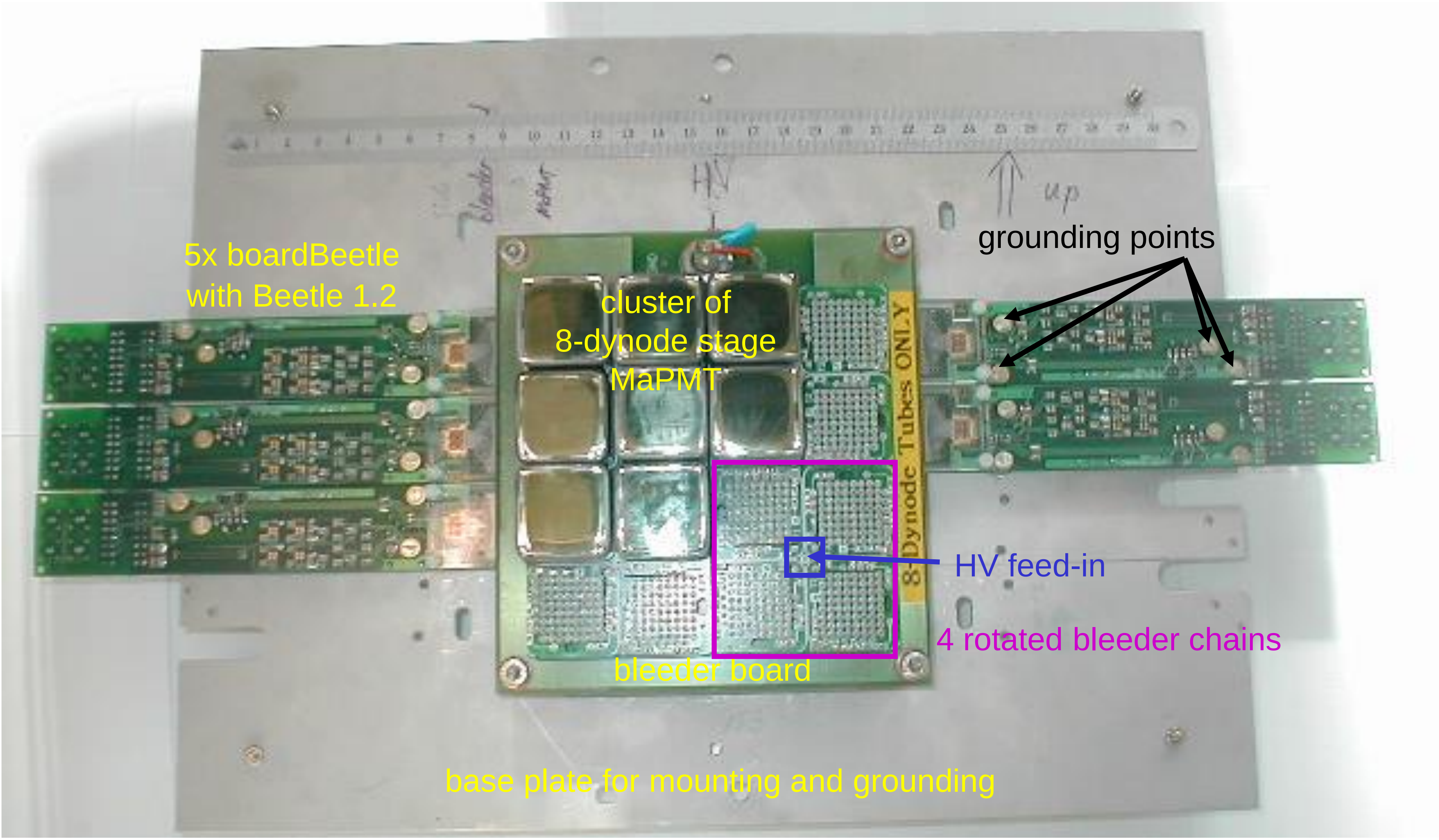
pulse height spectrum

- signal loss (conservative estimate):
  - <10% for HV = 900V
  - <15% for HV = 820V

Board Beetle



Cluster Setup



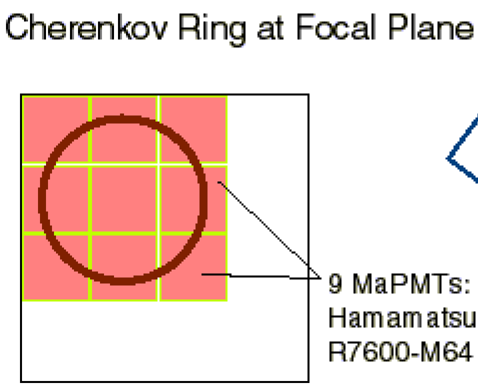
Test Beam Set-up

radiator: 800mbar CF_4 (also N_2, air)

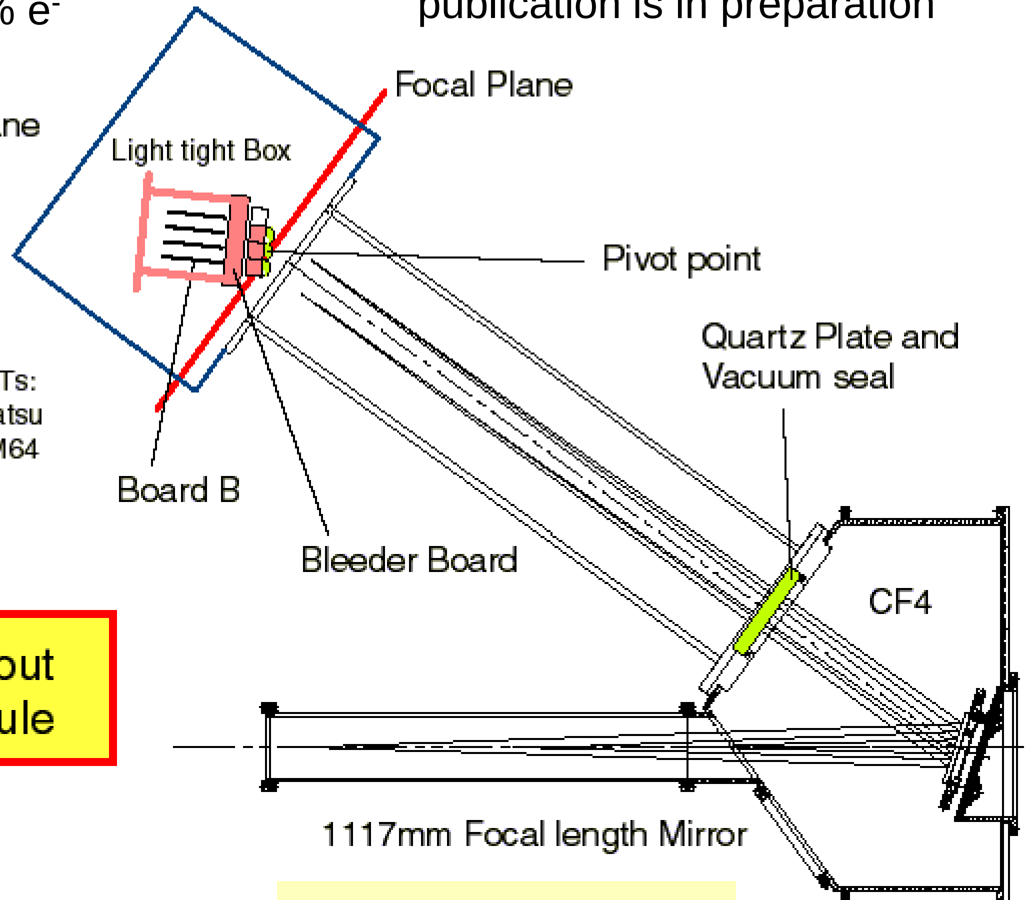
beam: 10 GeV/c: 95% π^-, 5% e^-

all test beam results are preliminary!!

publication is in preparation

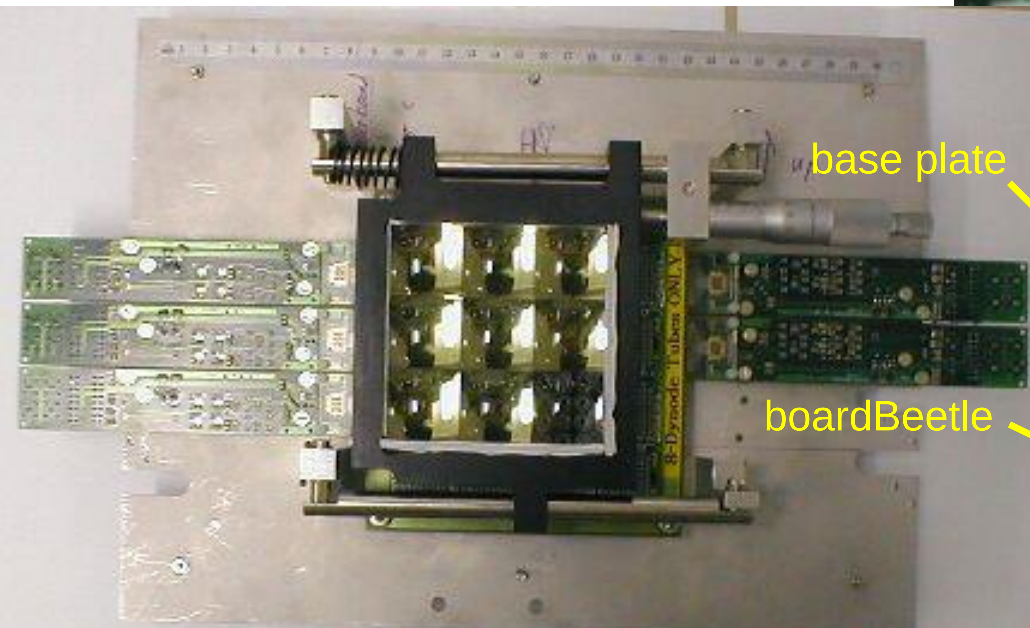


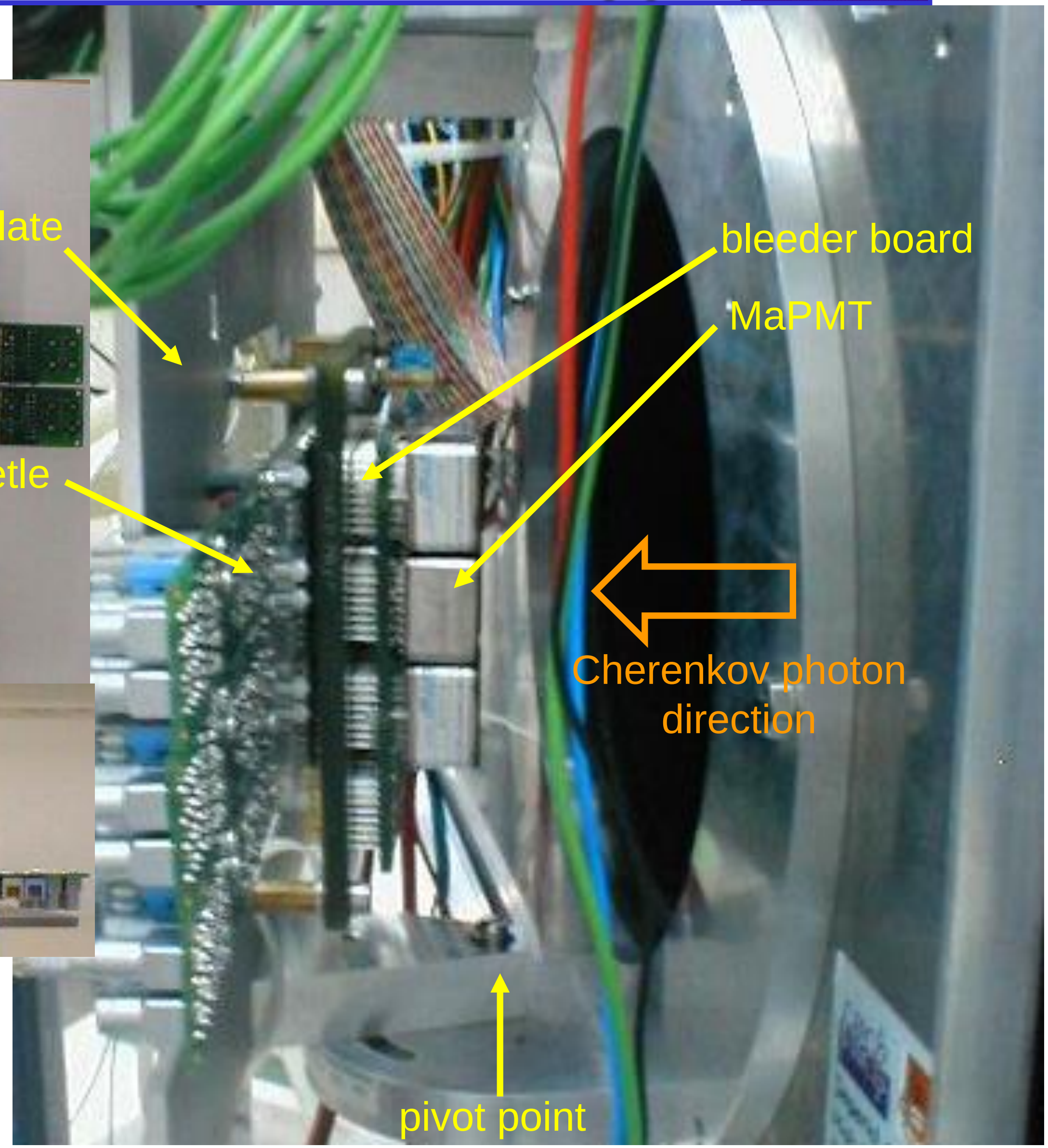
Sketch of prototype layout
for test of MaPMT module



RICH1 prototype

Cluster Setup in RICH1 Prototype



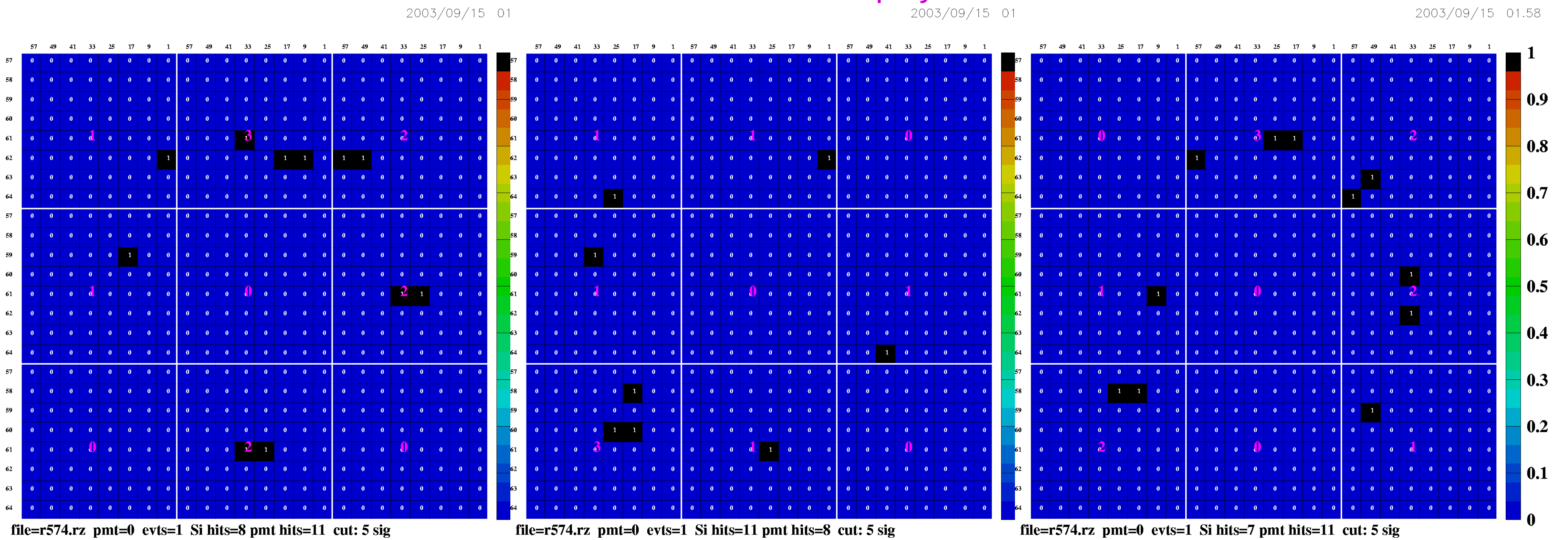


Single Events

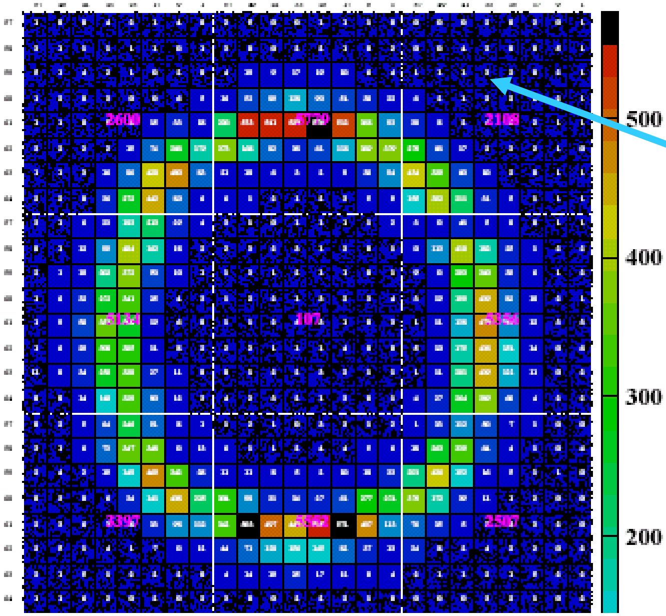
- Cherenkov photons
- CF_4: 800mbar
- 8-stage MaPMT & Beetle1.2
- HV = -900V
- with lenses

➔ Cherenkov rings from single events

raw data event display



Photon Yield

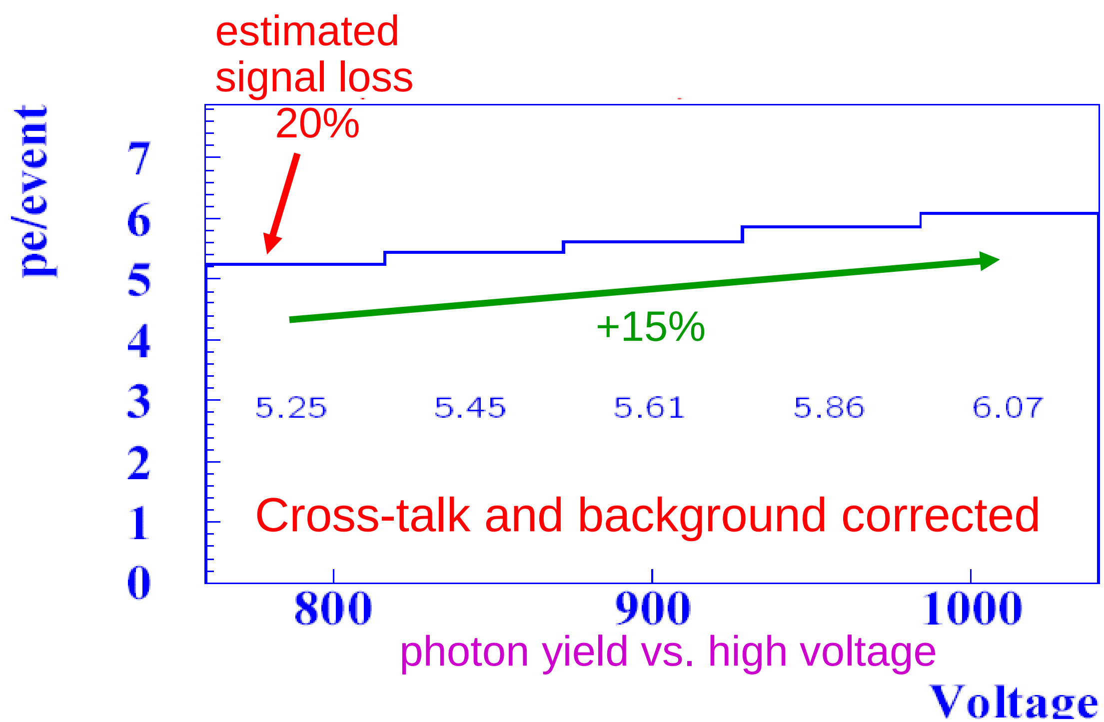


- for 8-dynode stage MaPMT & Beetle1.2 chip
- photon counts, per tube, per event
- background subtracted, by tube
- crosstalk correction preliminary

CF_4, HV=800V

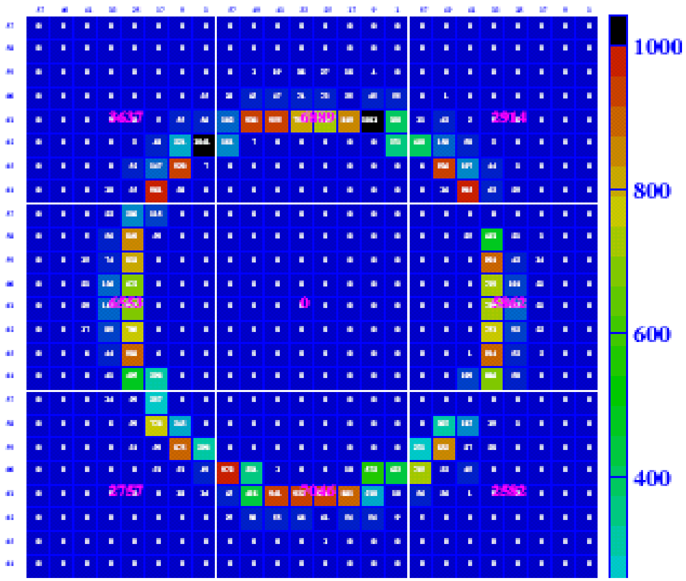
0.42+0.02	0.94+0.02	0.34+0.01
0.83+0.03	0.00+0.02	0.87+0.02
0.54+0.03	0.91+0.02	0.40+0.02

total signal+background: 5.25+0.13



photon yield vs. high voltage

Monte Carlo Simulation



- for 8-dynode stage MaPMT & Beetle1.2 chip
- photon counts, per tube, per event
- 800mbar CF_4, 10 GeV/c: 95% π^-, 5% e^-
- no signal loss correction yet (-20%)
- beam divergence too small

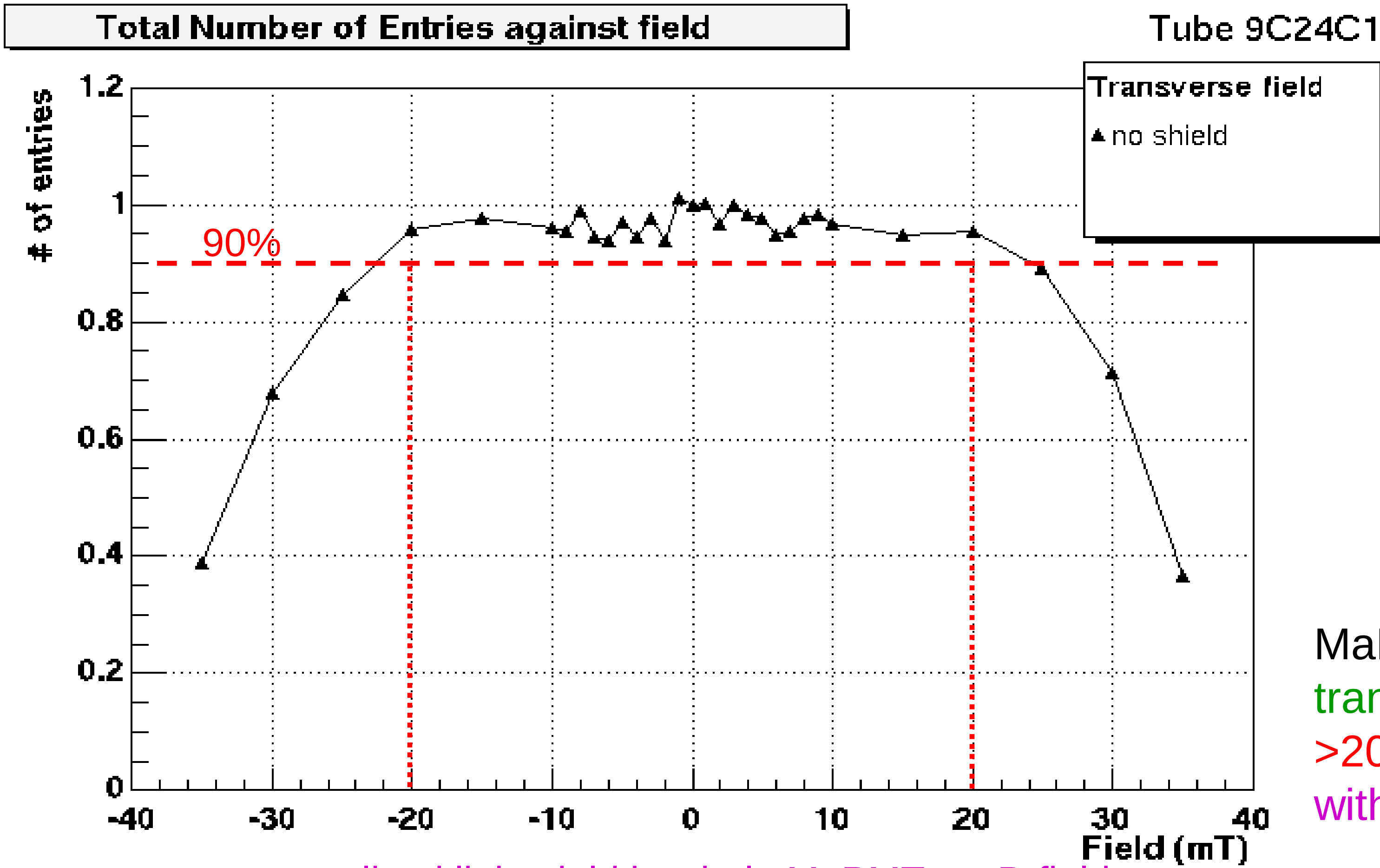
MC: CF_4, HV=800V

0.61	1.15	0.48	0.42	0.94	0.34
1.09	0.00	0.98	0.83	0.00	0.87
0.46	1.17	0.43	0.54	0.91	0.40
total MC: 6.37 (-20%)			total DATA: 5.25		

- good agreement between MC and data at HV=800…1000V
- consistent with earlier study:

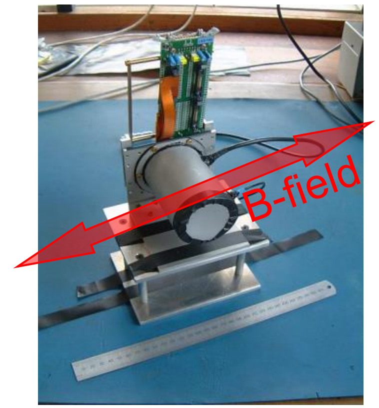
  12-dynode MaPMT with APVm chip & external 30:1 attenuation

Transverse B-Field



normalised light yield in whole MaPMT vs. B-field

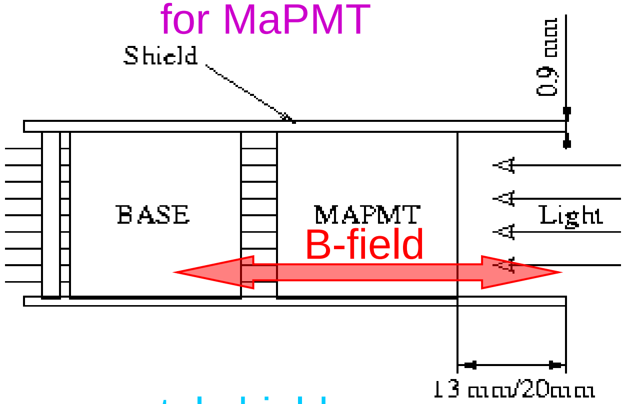
transverse field setup for MaPMT



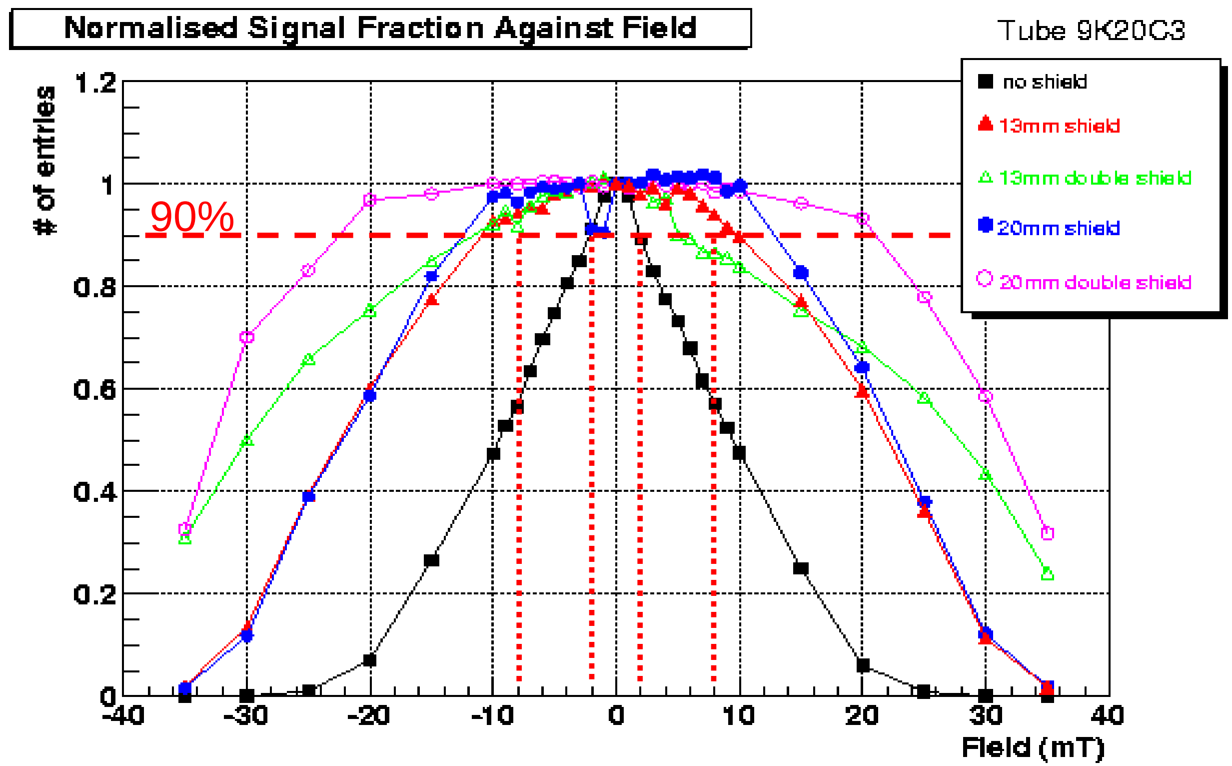
MaPMT insensitive to transverse fields up to >20mT (>200 Gauss) without shielding

Longitudinal B-Field

longitudinal field setup
for MaPMT

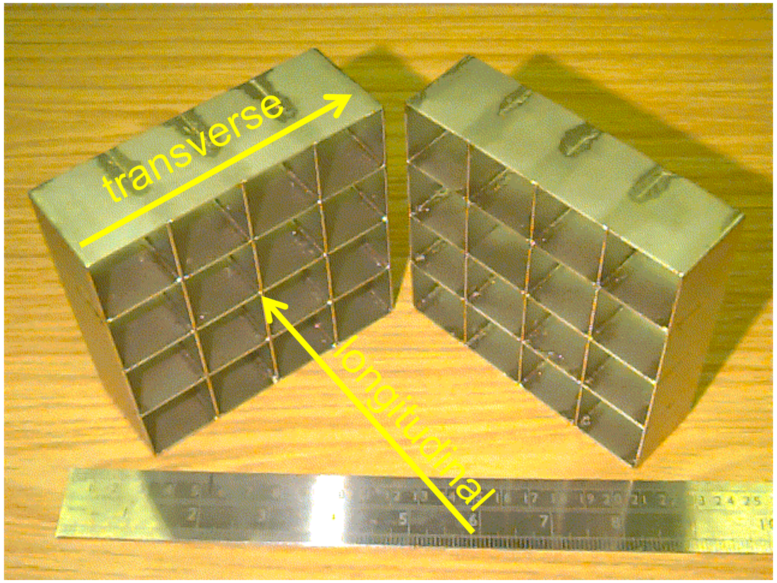


μ-metal shield:
0.9 mm thick
13 or 20 mm extension



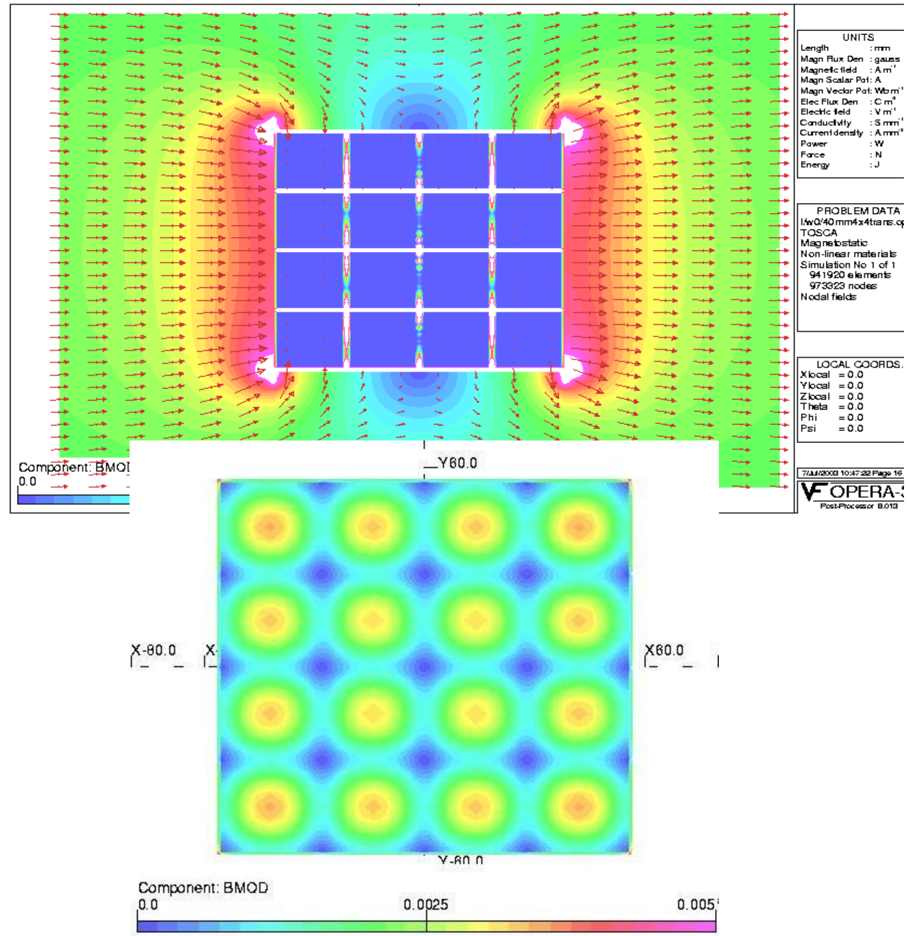
- unshielded MaPMT
  - >20 G B longitudinal
  - >200 G B transverse
- single μ-metal shield
  - 0.9 mm thick, 13 mm extension
  - >80 G B longitudinal

Magnetic Shield Array



- simulation for 20 to 150 Gauss ambient field

transverse field, 20 Gauss



longitudinal field, 150 Gauss

- protrusion of shield: 13mm or 20mm
- shielding power in the worst case:
  - for B<150Gauss ambient field
  - transverse field: >18
  - longitudinal field: >5
- detector layout: 25 Gauss ambient field

Conclusions

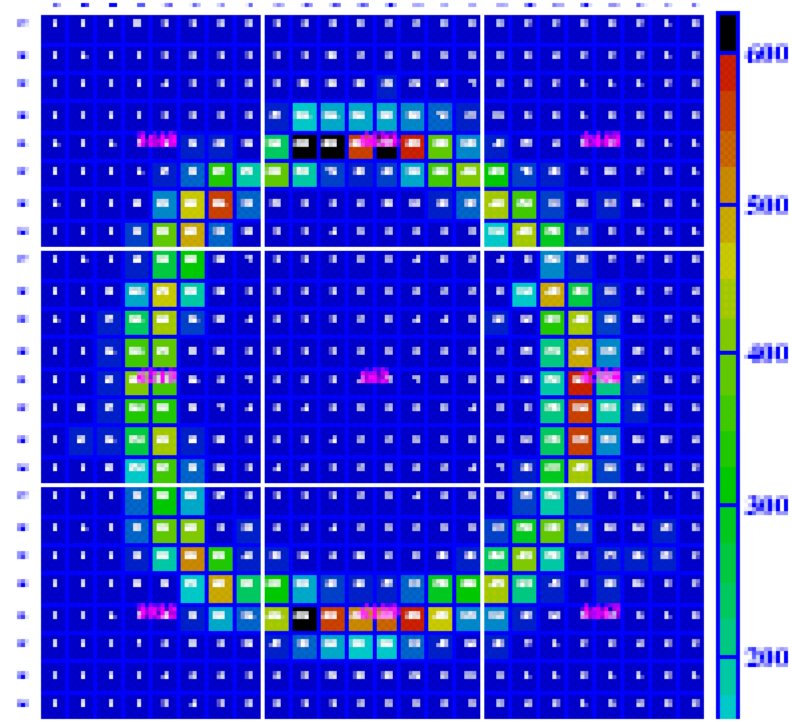
- readout for 8- and 12-dynode MaPMT developed on the Beetle1.2 chip
- customised front-end of Beetle1.2-MA0
- evaluation in test beam & lab
- operation in magnetic fields & shielding

- 8-dynode MaPMT & Beetle1.2
  - proven to work for LHCb RICH

- 12-dynode maPMT & Beetle1.2-MA0
  - some superior characteristics
  - analysis less advanced
  - but works as well…

- publication in preparation

8-dynode stage MaPMT & Beetle1.2 chip

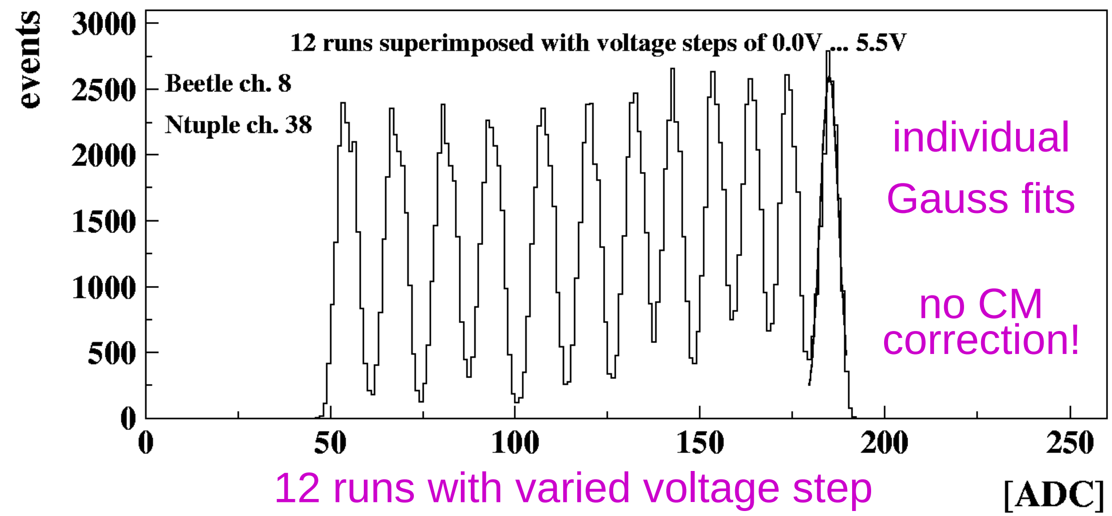


CF_4, HV=1000V 6.07 p.e./evt

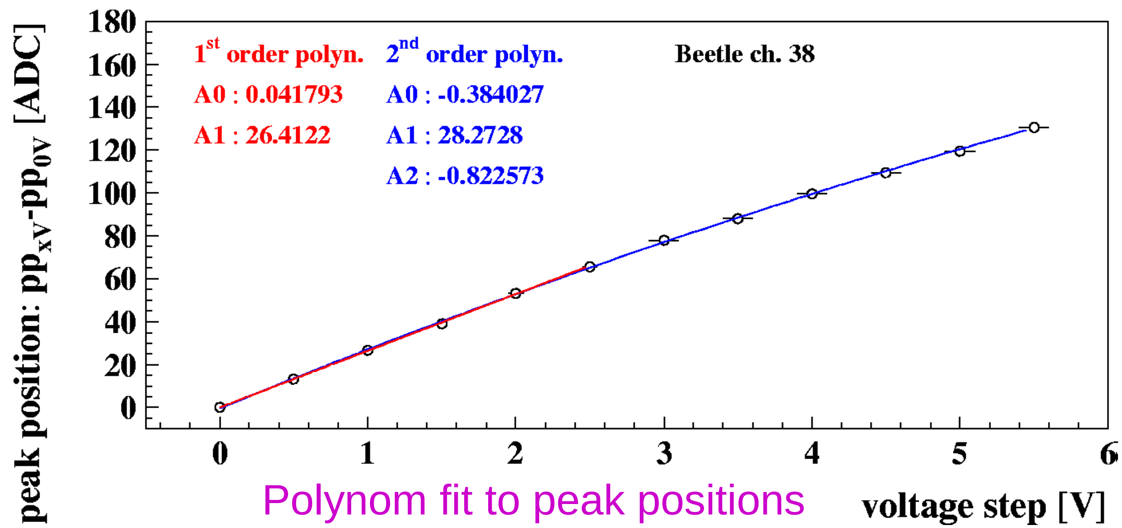
Spare Slides

Beetle Readout Calibration

- Voltage step: 0.0V,0.5V,…5.0V,5.5
- Error: ±0.025V… ±0.2V
- Rise time: <10ns
- Ringing: within 25ns
- Attenuation: 400 ±10
- C_{eff}: 3.0 ±0.1pC
- 1V: Q = CV = 47±2.3 ke$^-$
  = ~150mV
- ➔ 1 photoelectron
- Linear description up to 2.5V (2.5 photons)
- Quadratic description beyond

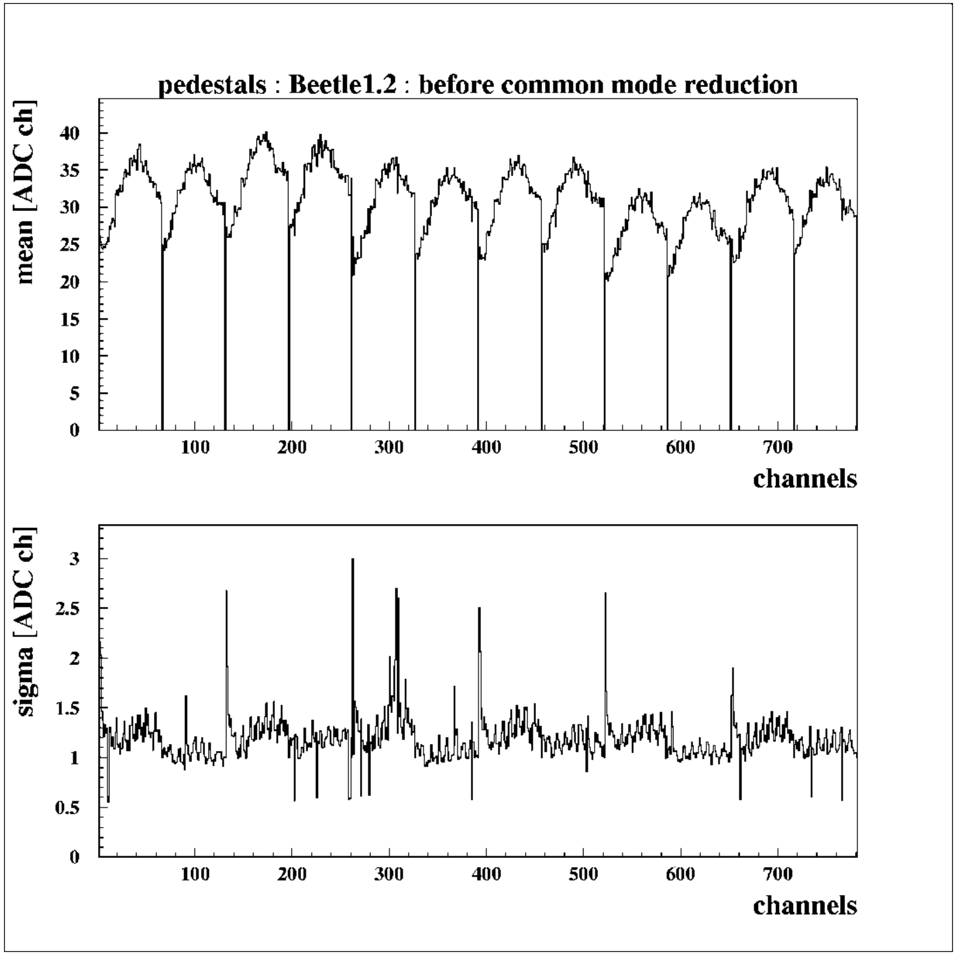


12 runs with varied voltage step



Polynom fit to peak positions

Noise in Beetle1.2



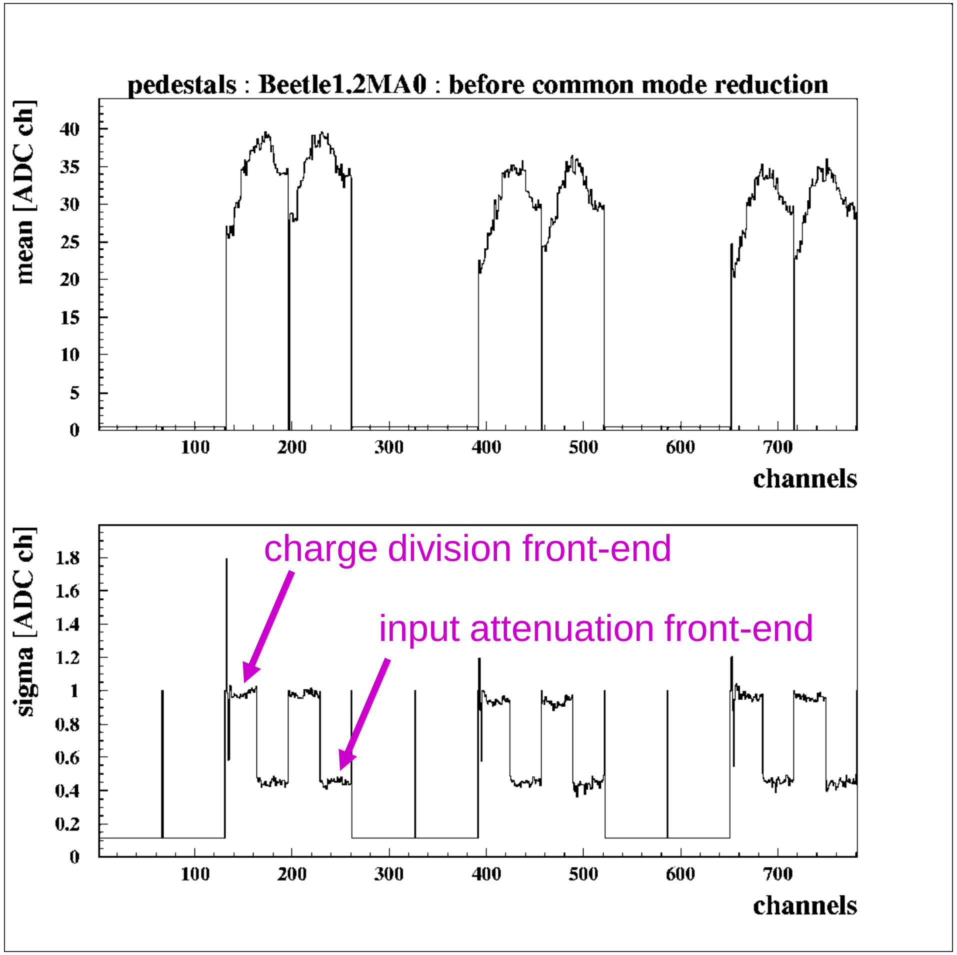
- final noise level
  - after DC-offset tuning
  - after tuning of timing
- full cluster
  - 6 boardBeetle1.2
  - 9 8-stage MaPMT
- from pedestal run
  - before CM correction
  - shape due to baseline of Beetle1.2

➔ low σ (1.0…1.5 ADC)

➔ no CM problem

➔ uniform offsets

Noise in Beetle1.2MA0

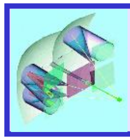


- final noise level
  - after DC-offset tuning
  - after tuning of timing
- half cluster
  - 3 boardBeetle1.2MA0
  - 6 12-stage MaPMT
- from pedestal run
  - before CM correction

➔ lower σ for charge divider (1.0 ADC)

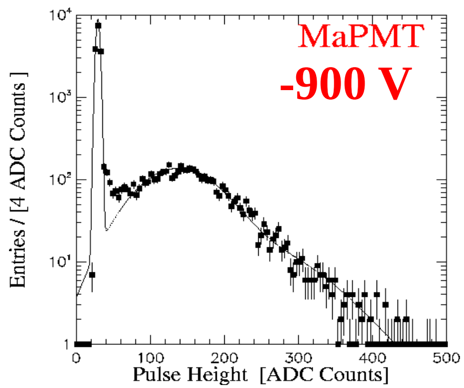
➔ even lower σ for attenuator (0.5 ADC)

➔ uniform offsets



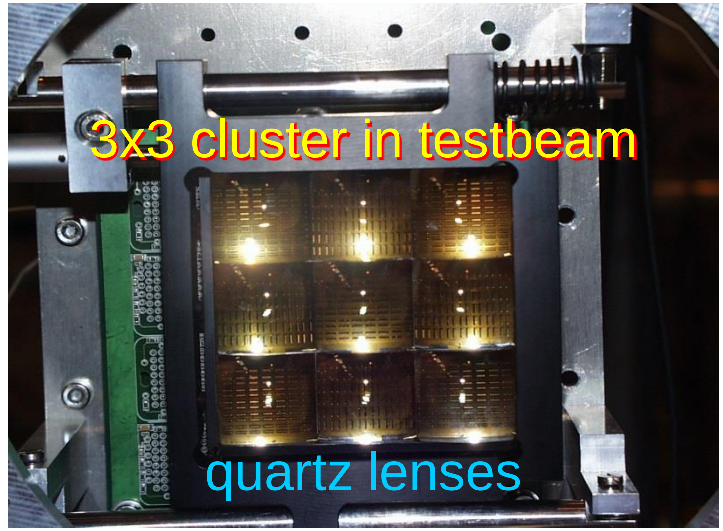
RICH Photodetectors

Multianode Photomultipliers (MaPMT):
dropped for LHCb RICH in 11/2003

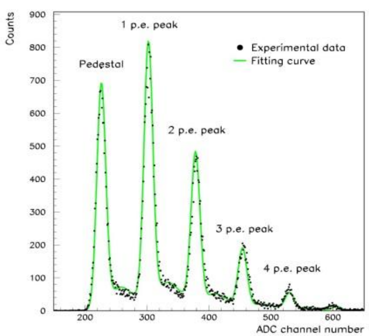


single pixel:
spectrum of LED light

analogue readout



Hybrid Photo Diodes (HPD):
see talk of G. Aglieri: Tue, P7, 17:30



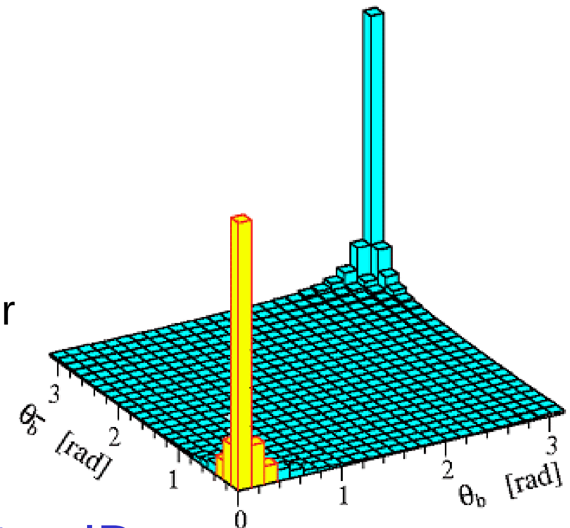
single pixel:
spectrum of
Cherenkov light

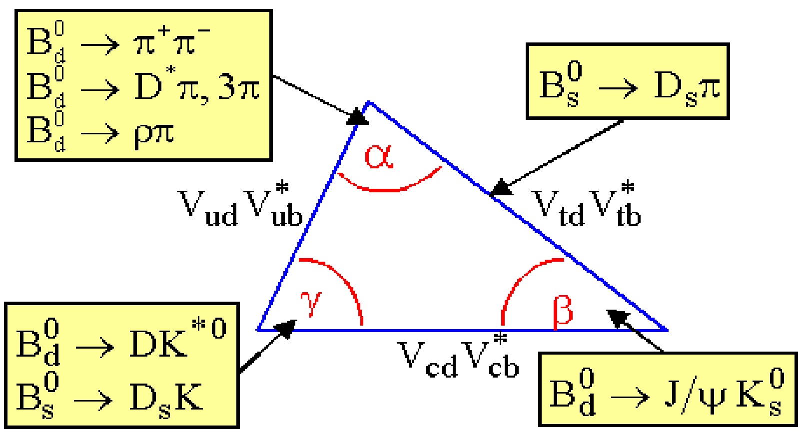
binary readout

Experimental Goals for LHCb

Precision Measurements of CP Violation in b decays

- Large Samples of b decays
  - from 14 TeV pp collisions: $N_{bb} = 10^{12}$ / year from the start of LHC
  - b production predominately at small polar angles
    - LHCb optimized as single forward arm spectrometer

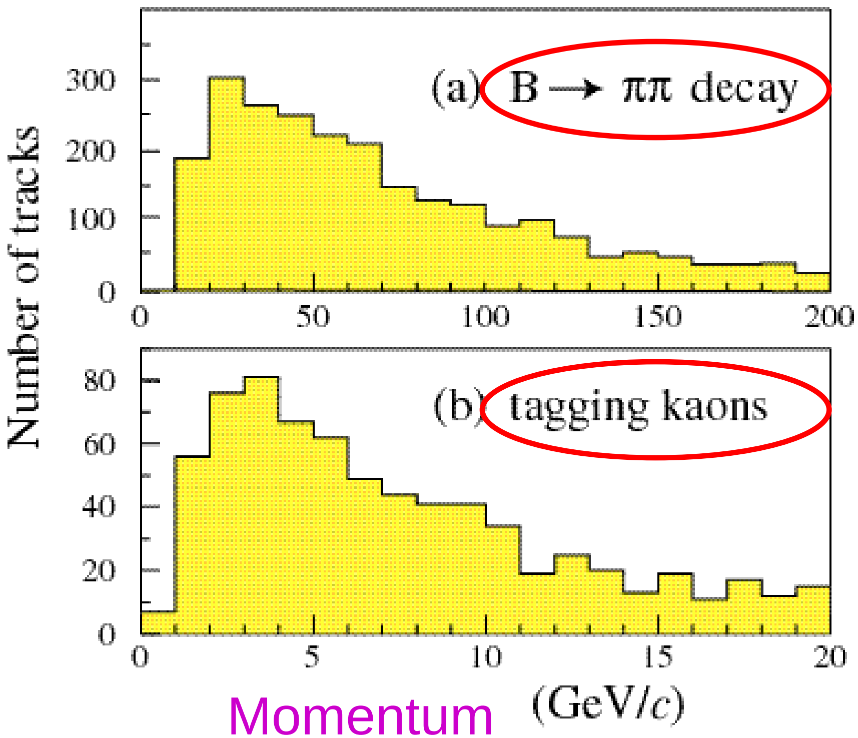


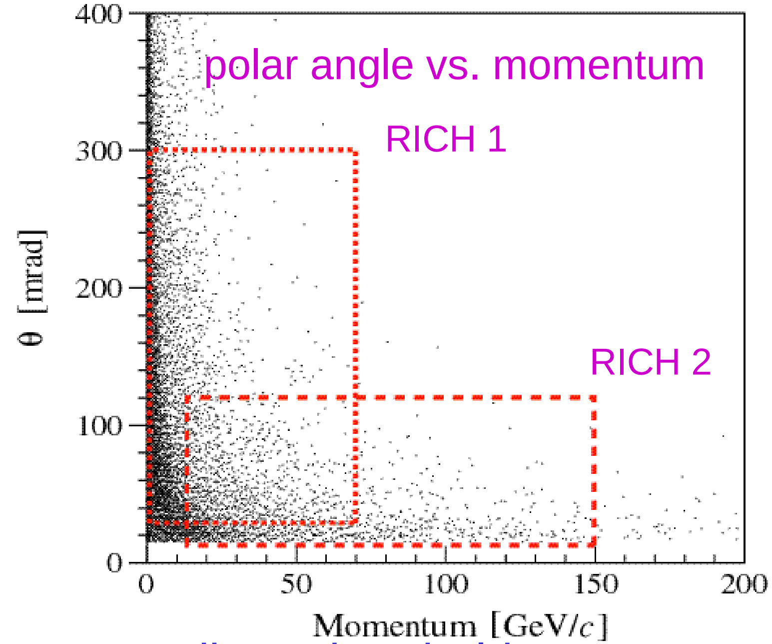


Example decays

- Hadron and Lepton ID
  - many pure hadronic final states
    - particle identification (π/K) essential
  - leptonic final states
    - efficient electron/muon ID
  - flavour tagging

Cherenkov Detectors





- radiator thresholds:

	Aerogel	C_4F_{10}	CF_4	
n:	1.03	1.0014	1.0005	
L:	50	850	1670	mm
π:	0.6	2.6	4.4	GeV
K:	2.0	9.3	15.6	GeV

- require π/K separation for 1<p<150 GeV/c
  - ➔ two independent detectors