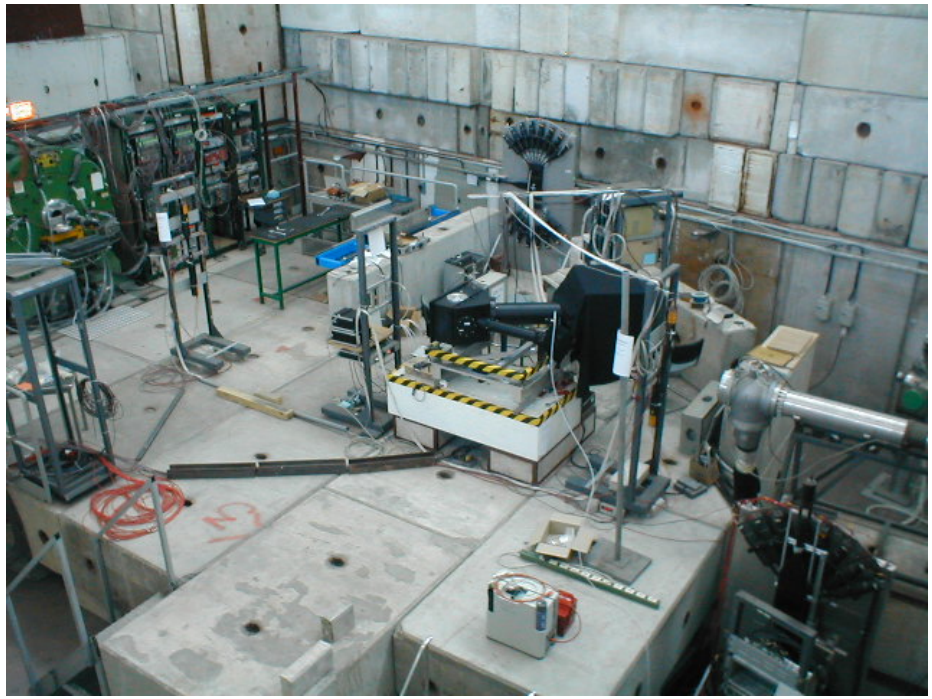
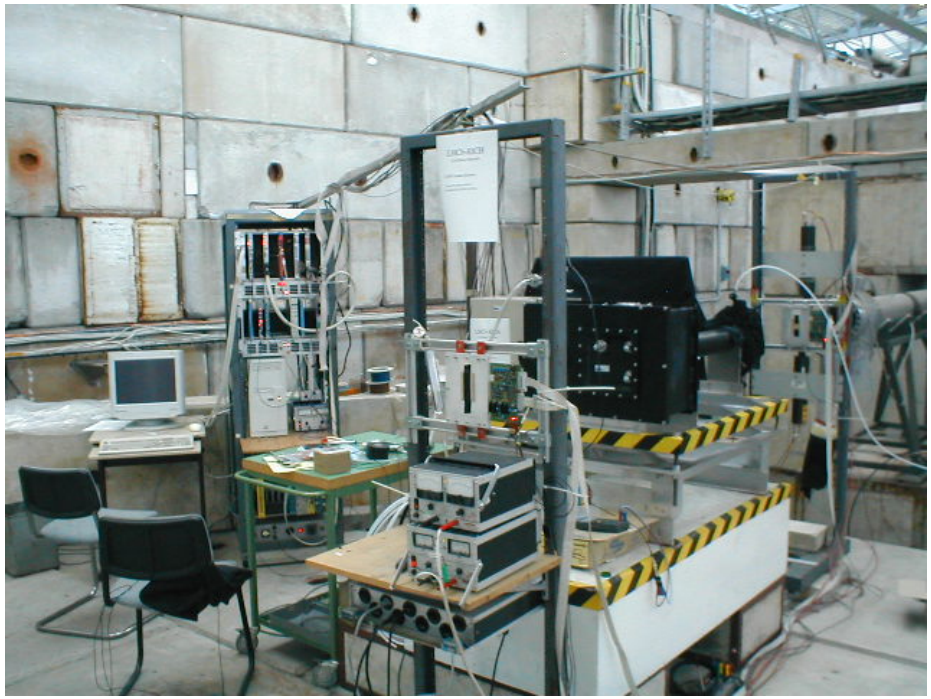
Review of Readout for the MaPMTs





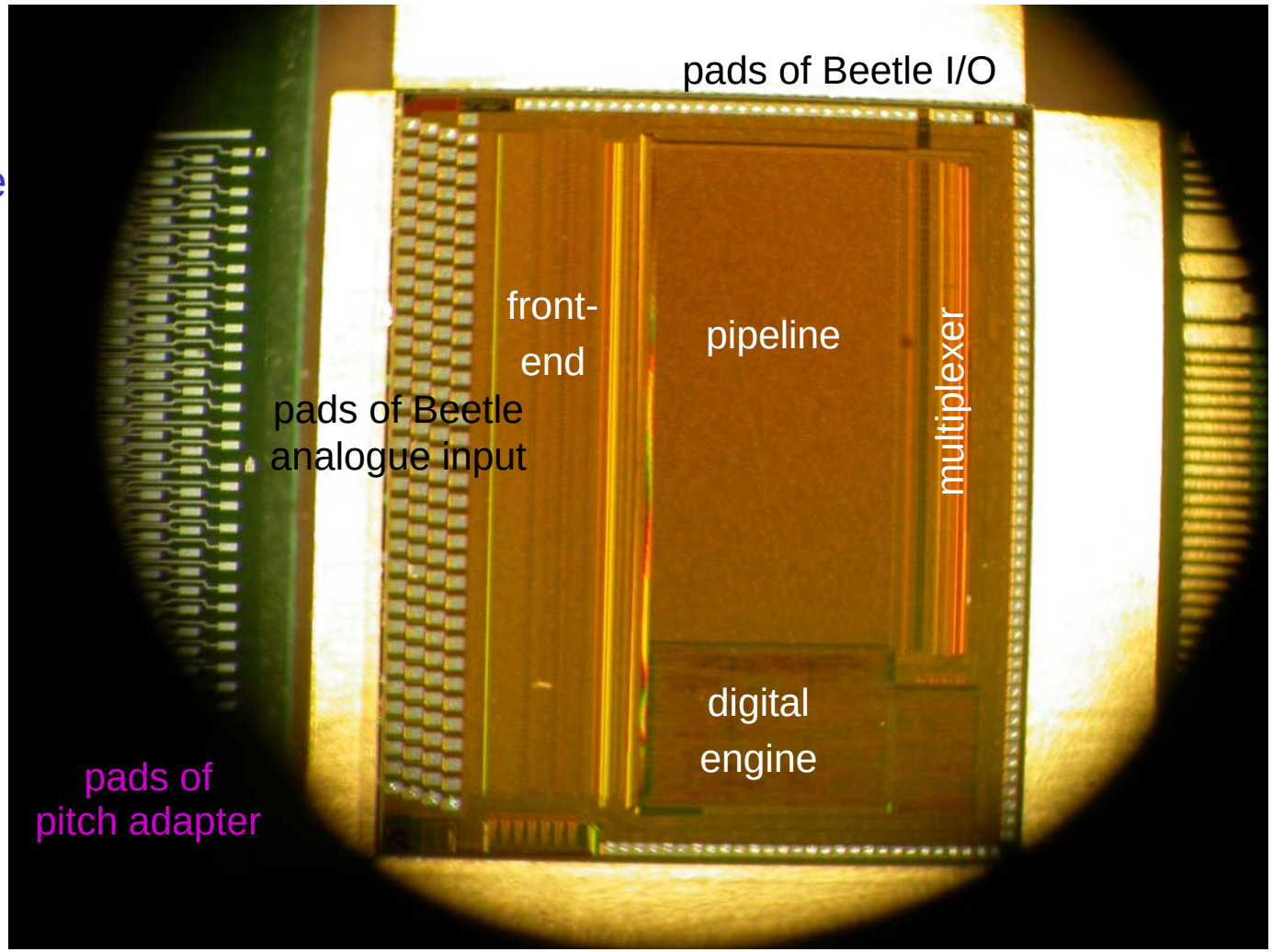
- Beetle chip (1.2 & 1.2MA0)
- results with Heidelberg board
- results with boardBeetle
- summary on magnetic field

RICH meeting, CERN, 02.10.2003

Stephan Eisenhardt
University of Edinburgh

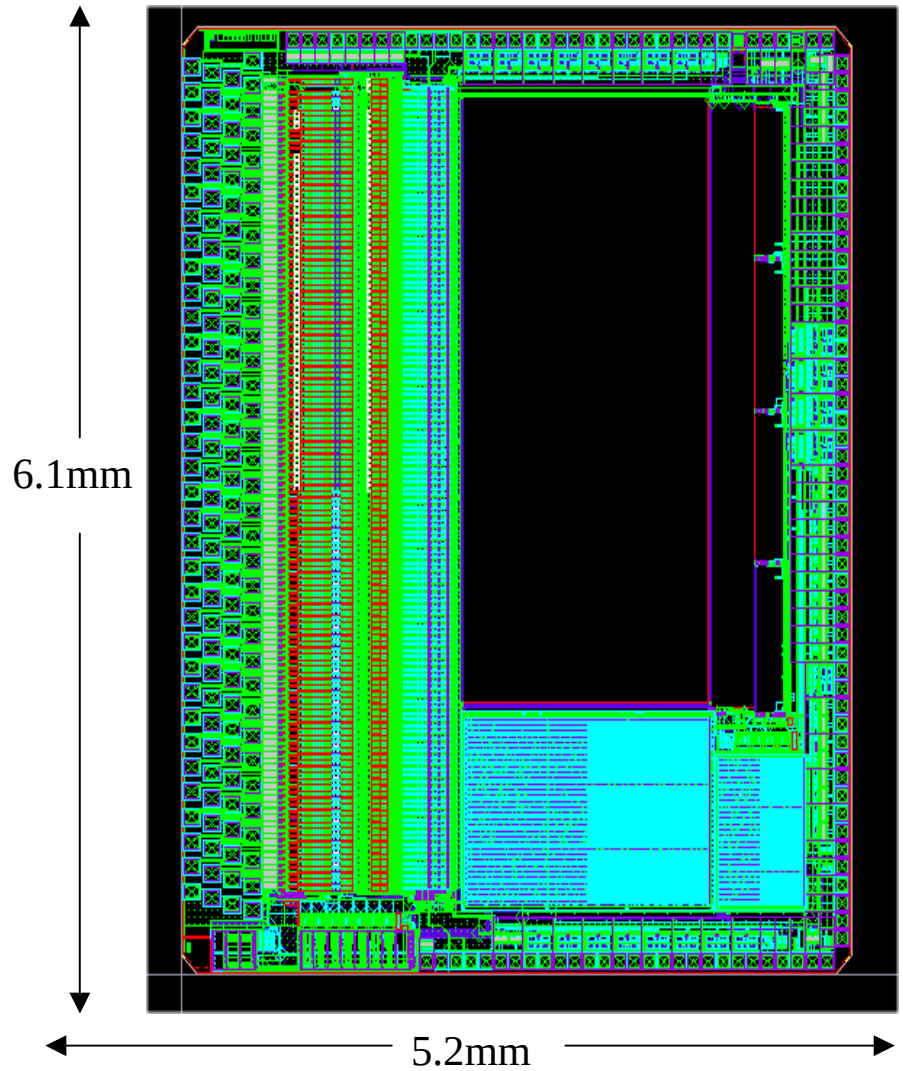
Beetle 1.2 chip

- standard front-end
  - 128 channels
- used with 8-dynode stage MaPMT
  - ~55000 e^- / photon
- tested:
  - on Heidelberg setup
  - on boardBeetle
  - in testbeam (with boardBeetle)

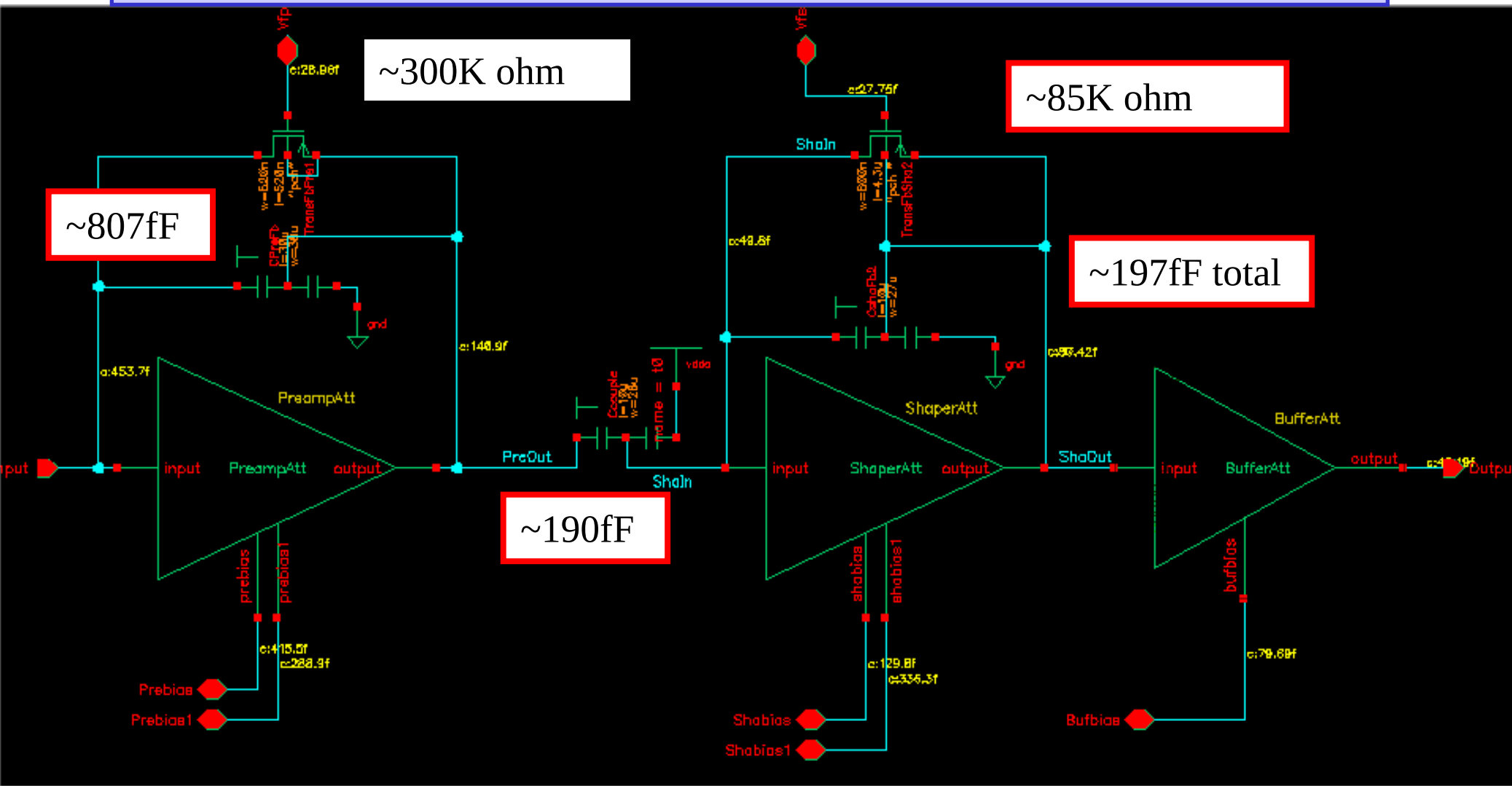


Beetle1.2MA0 chip

- standard front-end
  - 3 channels: input attenuator
  - 3 channels: standard Beetle1.2
  - 3 channels: charge divider
  - 2 channels: modified FBR
  - 53 channels: charge divider
  - 64 channels: input attenuator
- used with 12-dynode stage MaPMT
  - ~300000 e^- / photon
- tested:
  - on Heidelberg setup
  - on boardBeetle (briefly)
  - in testbeam (only quick check with boardBeetle)



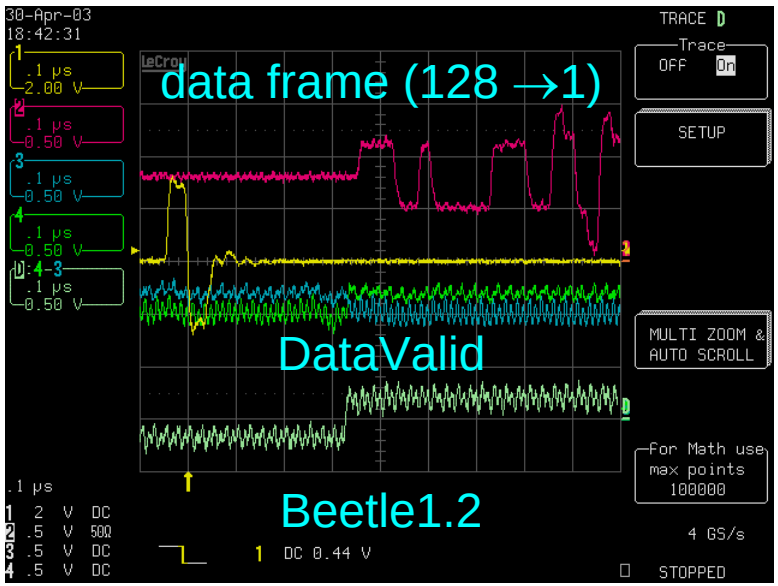
Beetle1.2MA0 Attenuation Front-end

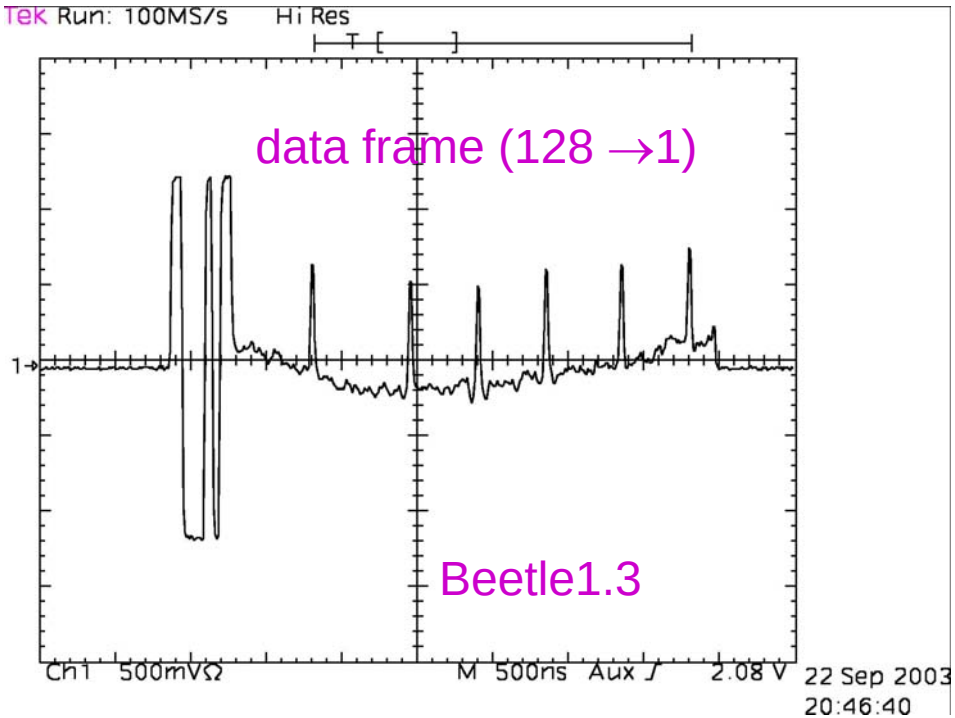


Red box means different to the standard Beetle1.2

Digital switching noise (80MHz)

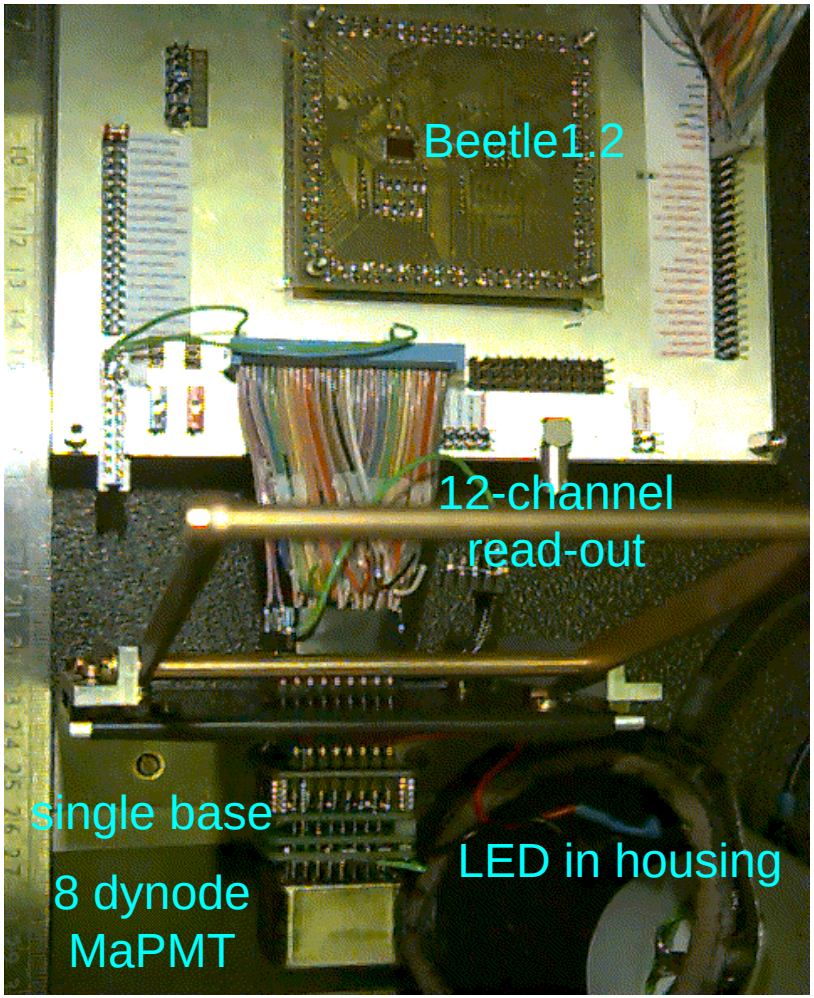
- As discussed at VELO Beetle meeting 30.04.2003:
  - 80 MHz noise on analogue outputs and DataValid
  - Stems from digital circuit and multiplexer
    (tested by cut in power line internal to the Beetle)
- fix implemented for Beetle1.3
- Beetle1.3 returned to HD last week → no 80MHz noise!!!



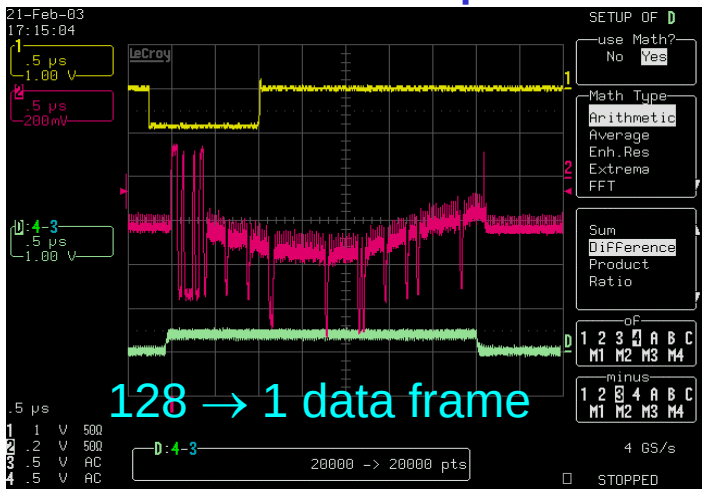


Setup with Heidelberg board

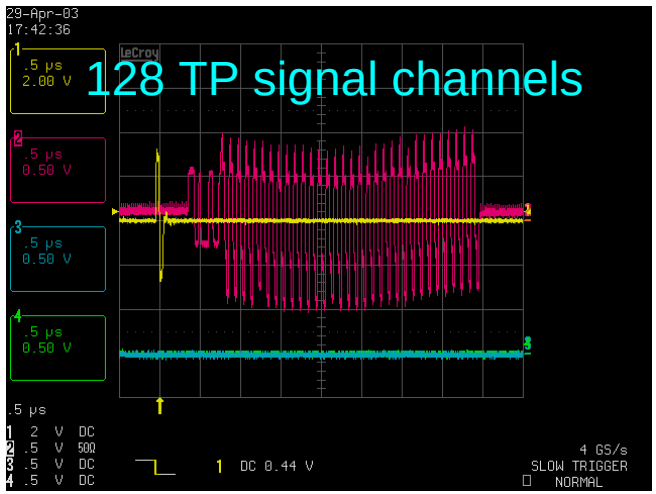
- Edinburgh setup



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



- **MaPMT test pulses**



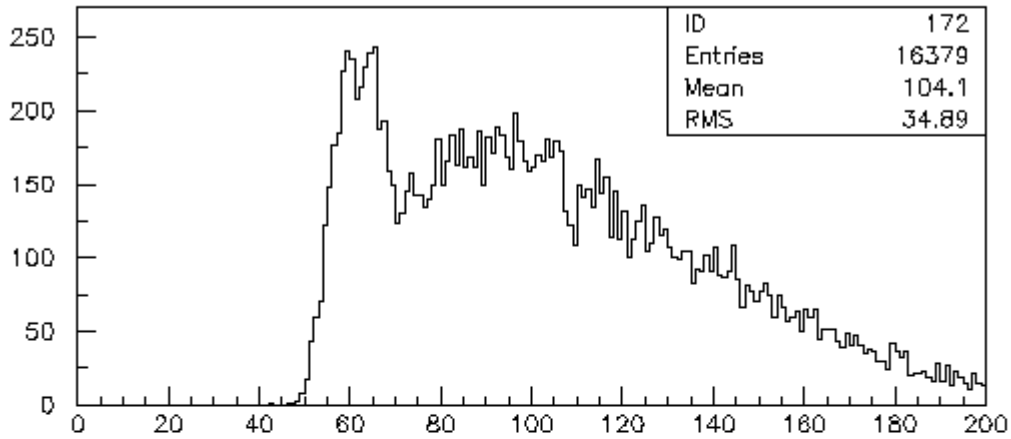
Heidelberg board: CM reduction

- New Beetle chip
  - ➔ visible noise factor 2-3 lower compared to the old chip which had died
- Tuning of existing setup:
  - ➔ noise reduction of factor ~2
- Noise reduction session:
  - rerouting of power supplies !!
  - shielding of LED pulser !
  - new coax cables between MaPMT and HD board !!!!
  - new GND routing layout for unused channels at PMT base !!!!
  - new star point for GND at front-end !!!!
  - massive (1/2 inch) Al GND plate below HD mother board !!!
  - ➔ all-in-all a noise reduction of factor ~5
- Common mode reduction:
  - problem: 12 connected channels move more than the others
  - solution: split into different groups and treat independently
  - ➔ noise reduction of factor ~3
  - problem: individual channels have ~10% weight
  - → artificial dip at cut position in corrected spectrum
  - solution: iterative CM reduction
  - → dip reduced and moved to pedestal, CM reduction stays efficient
- Total noise/CM reduction wrt. last photodetector review: factor ~80

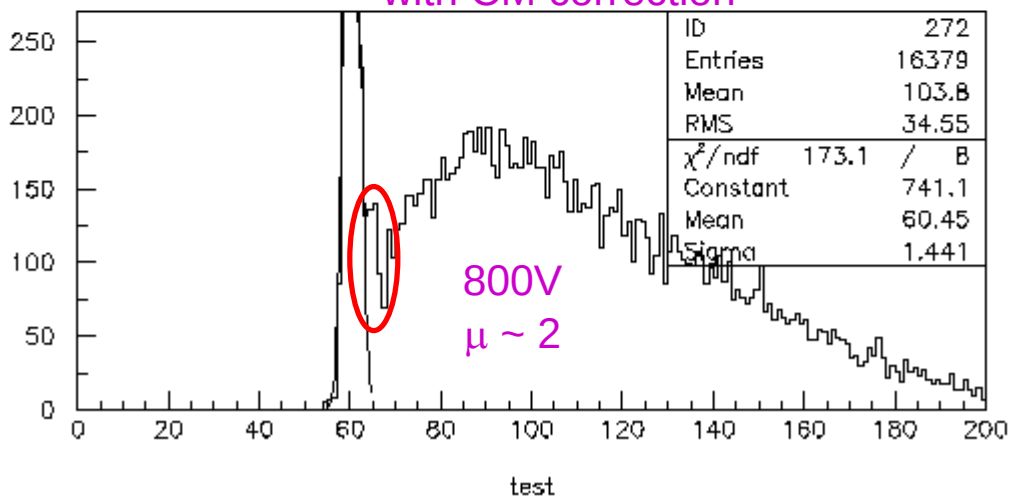
Signal with CM correction (HD board)

- Uncorrected pedestal width: $\sigma \sim 4.5$ ADC
- Corrected pedestal width: $\sigma \sim 1.4$ ADC
- artificial dip in spectrum from CM correction on only 10 channels

w/o CM correction



with CM correction



HV scan (HD board)

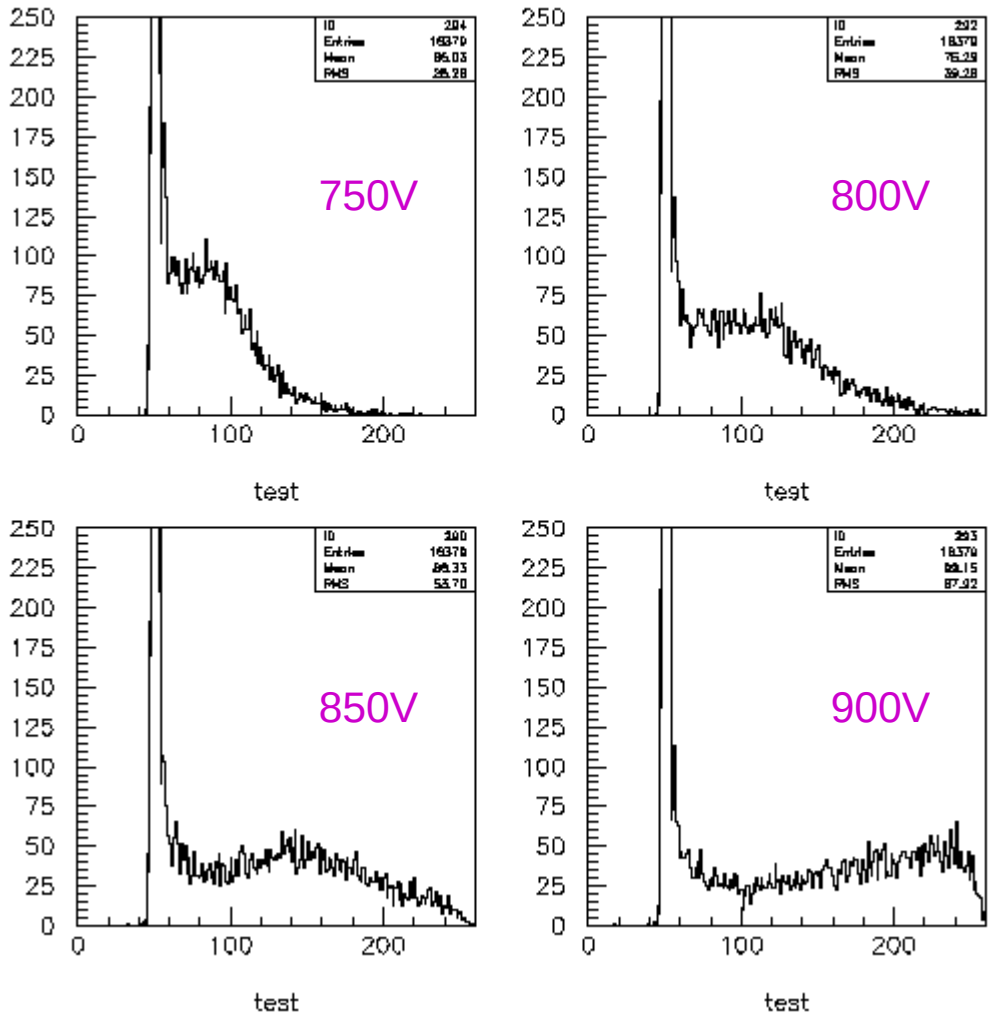
- Beetle1.2
- HV: -750…-900V

- uncorrected pedestal width: σ ~ 4.5 ADC

- CM corrected pedestal width: σ ~ 1.4 ADC

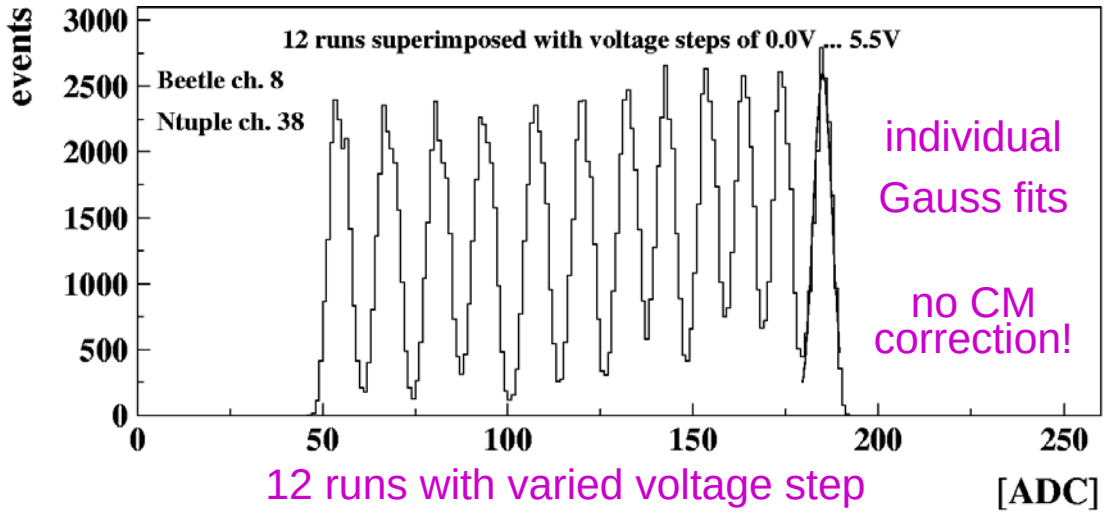
- clear single photon signal
- gain doubles every ~50V

with CM correction

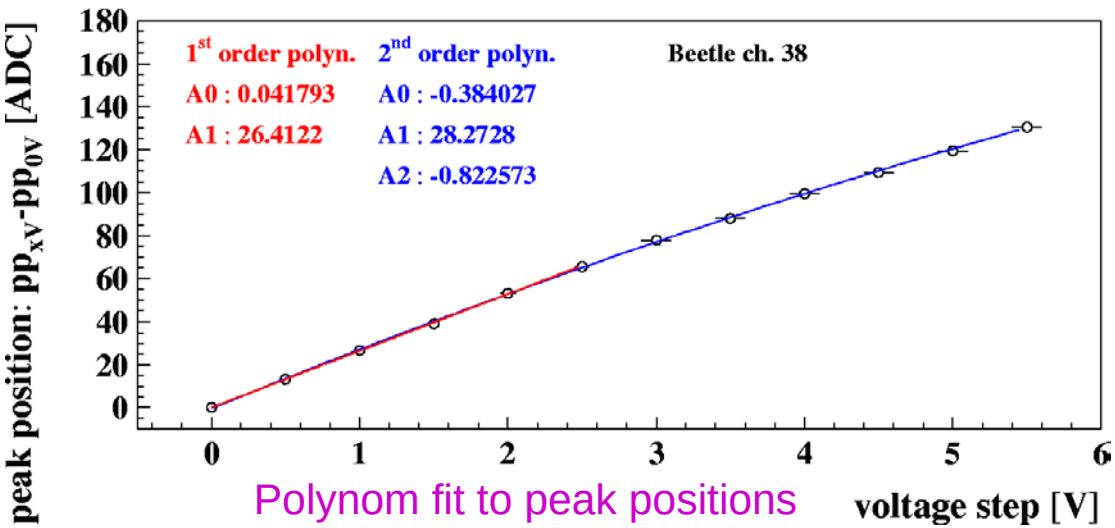


Beetle Readout Calibration

- 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

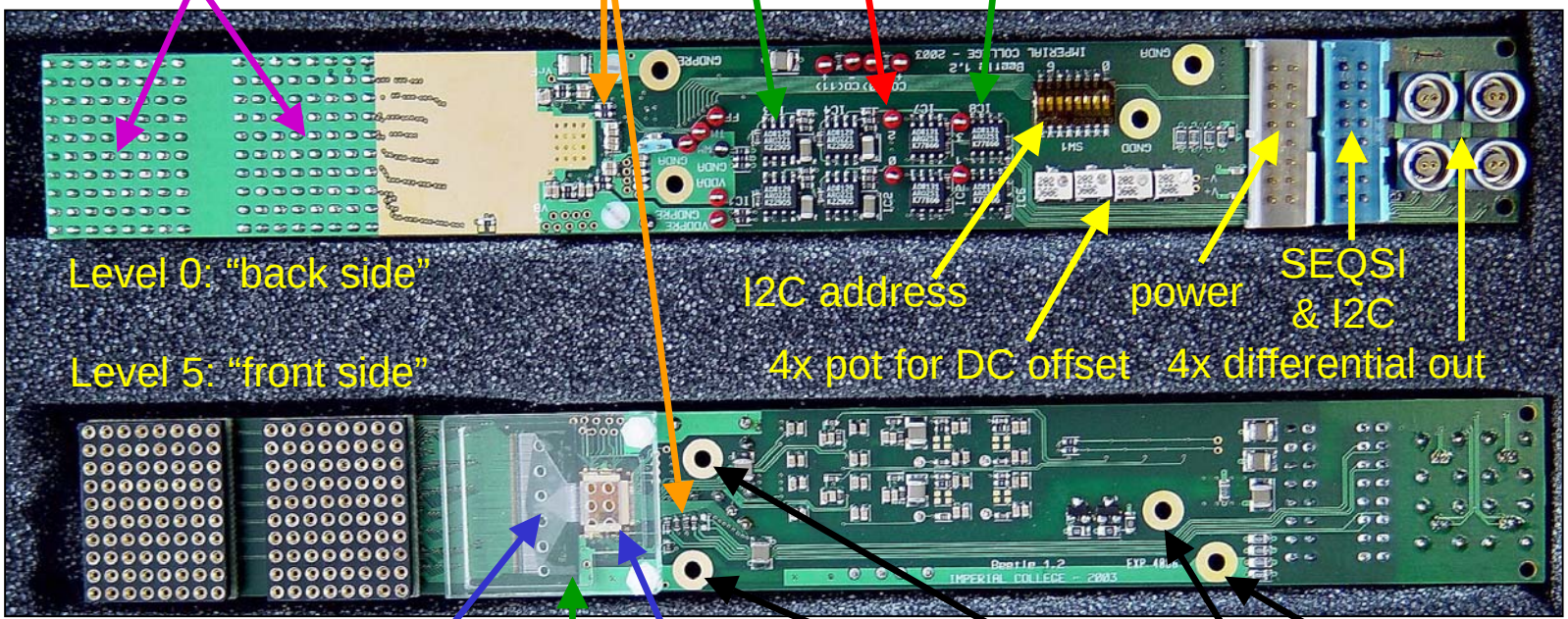


12 runs with varied voltage step

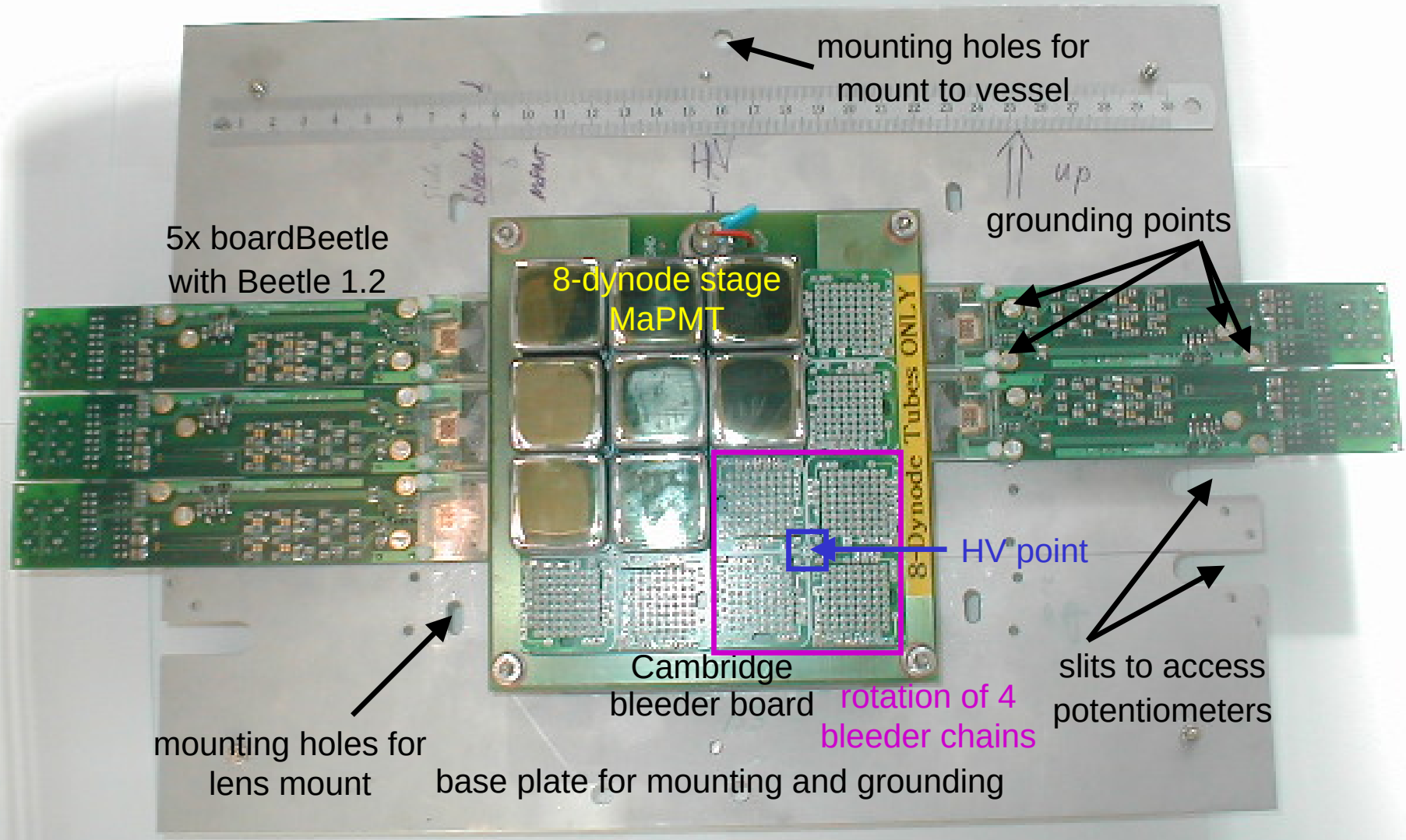


Polynom fit to peak positions

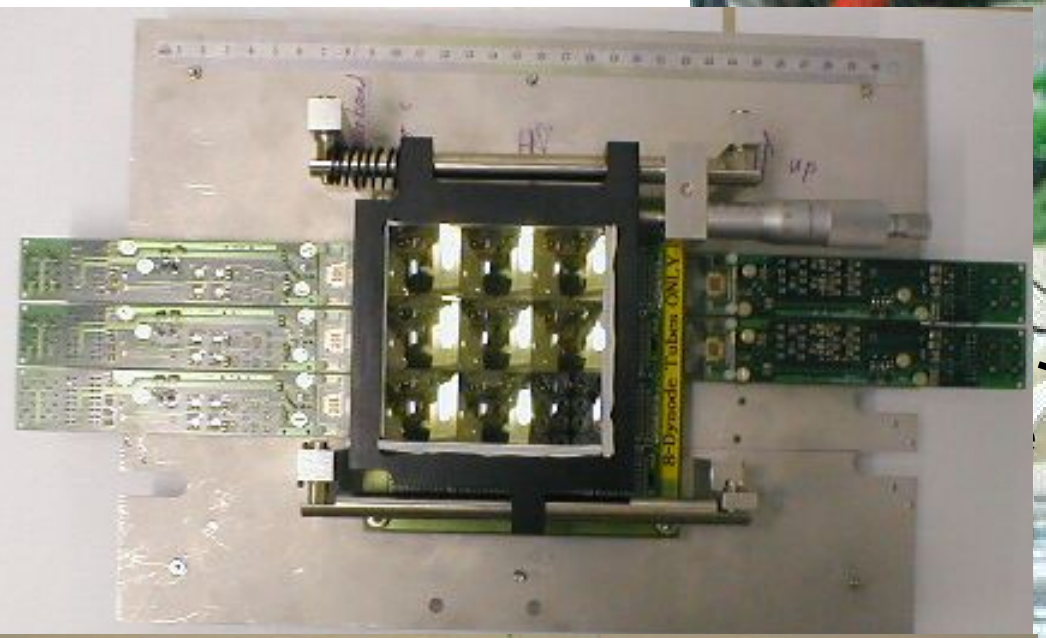
Equipped boardBeetle



Cluster Setup



Cluster Setup



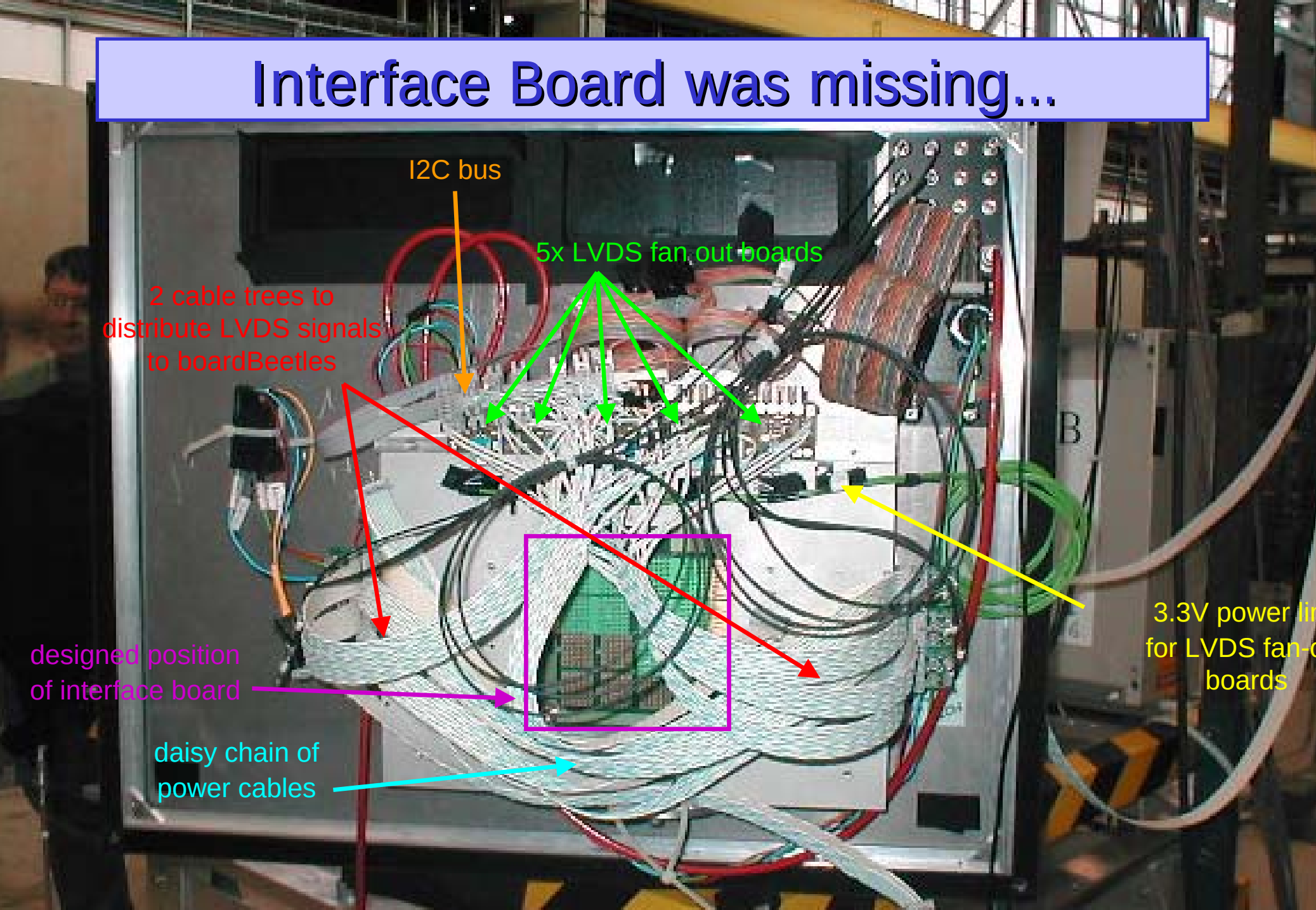
bleeder board

MaPMT

photon direction

pivot point

Interface Board was missing...

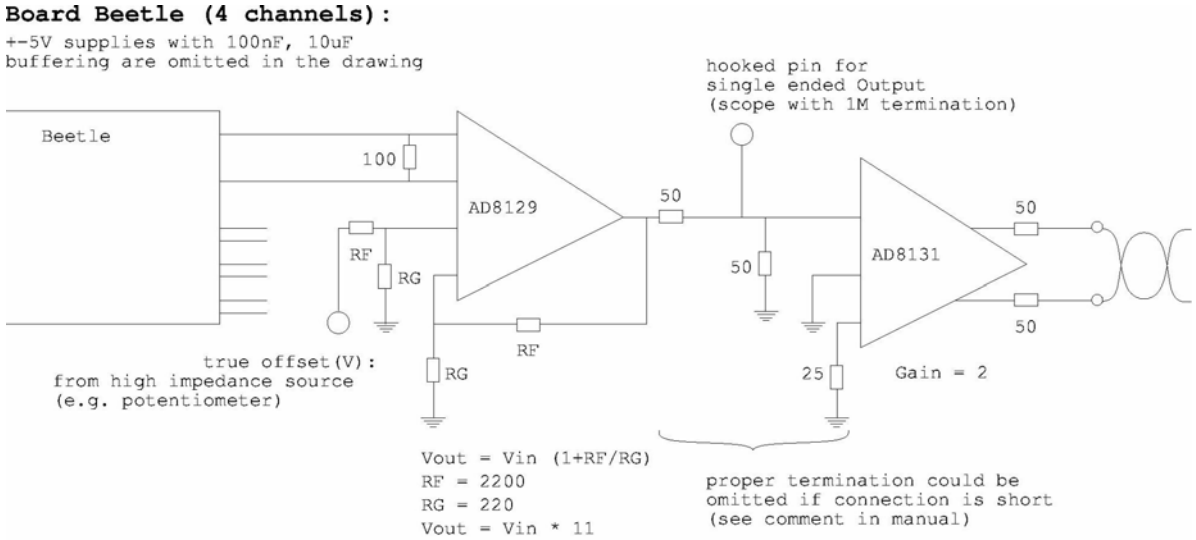


Saturation in Testbeam data

- A) differential amplifier
  - gain 10 seems too much for our signals
  - easy fix:
    - gain 5
    - remove serial 50Ω

    ➔total gain maintained

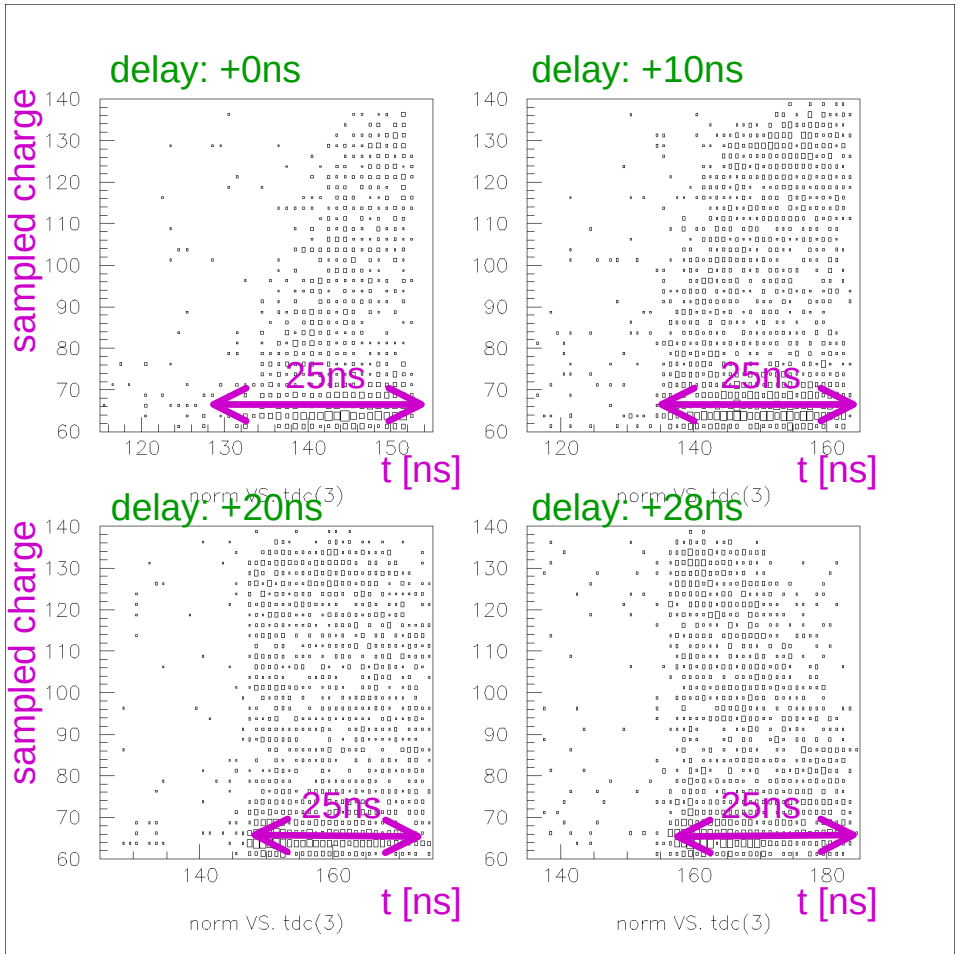
    ➔dynamic range doubled



- B) FED
  - Edinburgh FED was configured single-ended, unipolar
  - conversion to differential OK, but still unipolar (no level shifters),
    i.e. 0…0.75V instead of –0.75…0.75V ➔ 8-bit → 7-bit reduction

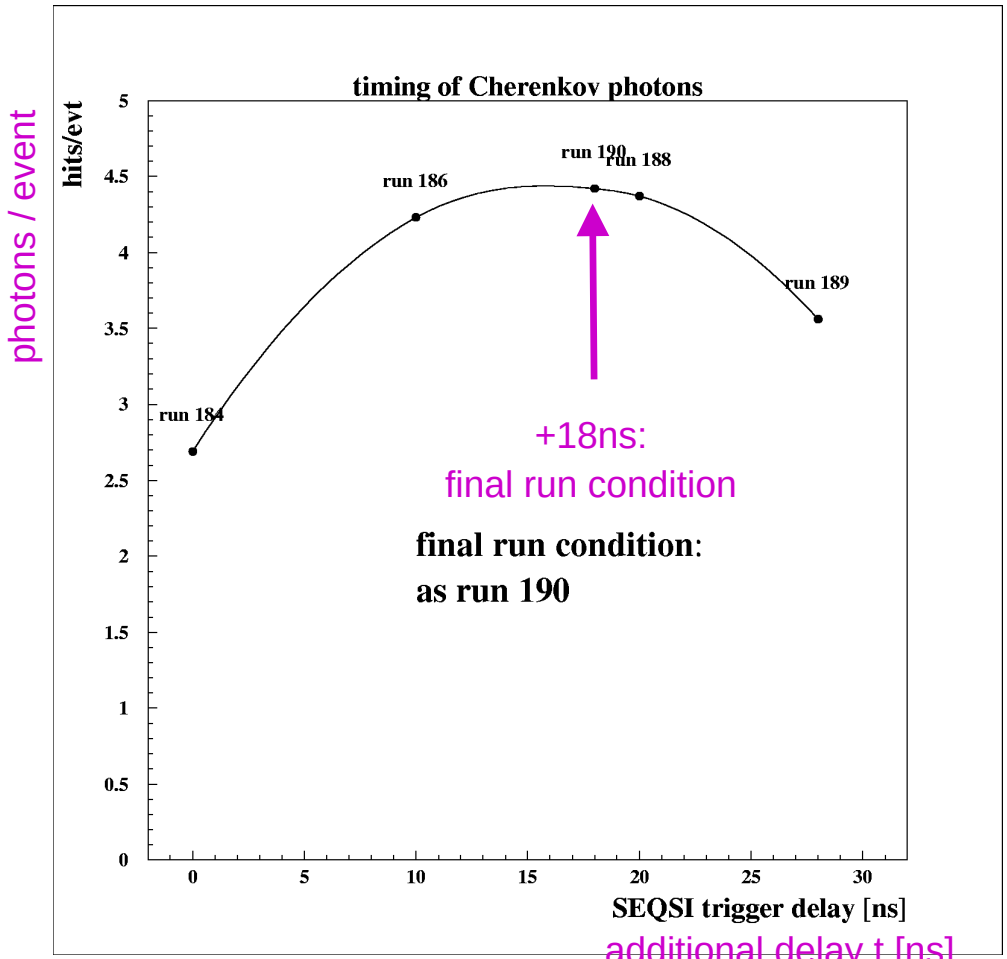
- … at least the two devices match…

Timing of Beam Photons



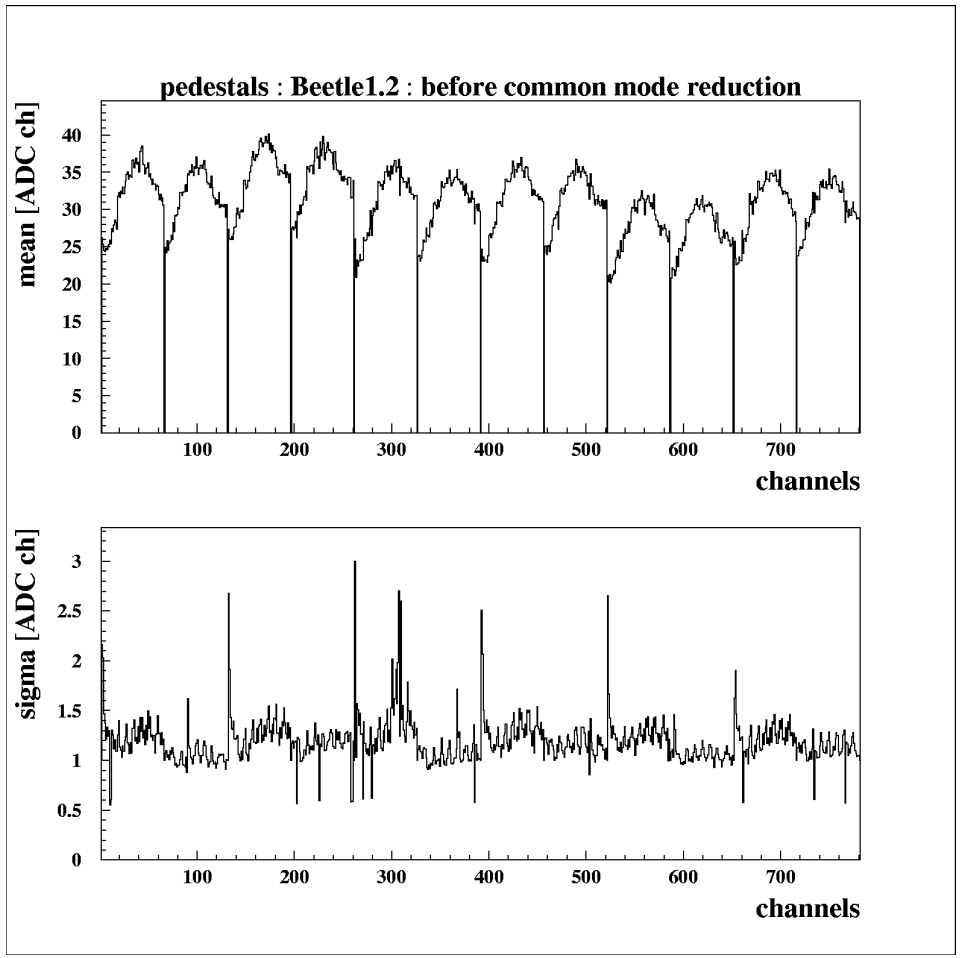
- adjusted average timing between beam photons and Beetle clock
  - 25ns jitter
  - measured by TDC
- aim to sample at peak of signal
  - adjustment for average by cable delay

Result of Timing Optimisation



- made from Cherenkov Ring
  - Air 960 mbar
  - no lenses
  - HV = 800 V
  - 8 8-stage MaPMTs
  - 5 Beetle 1.2
- narrow distribution
  - as one expects
  - indicates shape of analog pulse signals at sampler in the Beetle

Noise in Beetle1.2



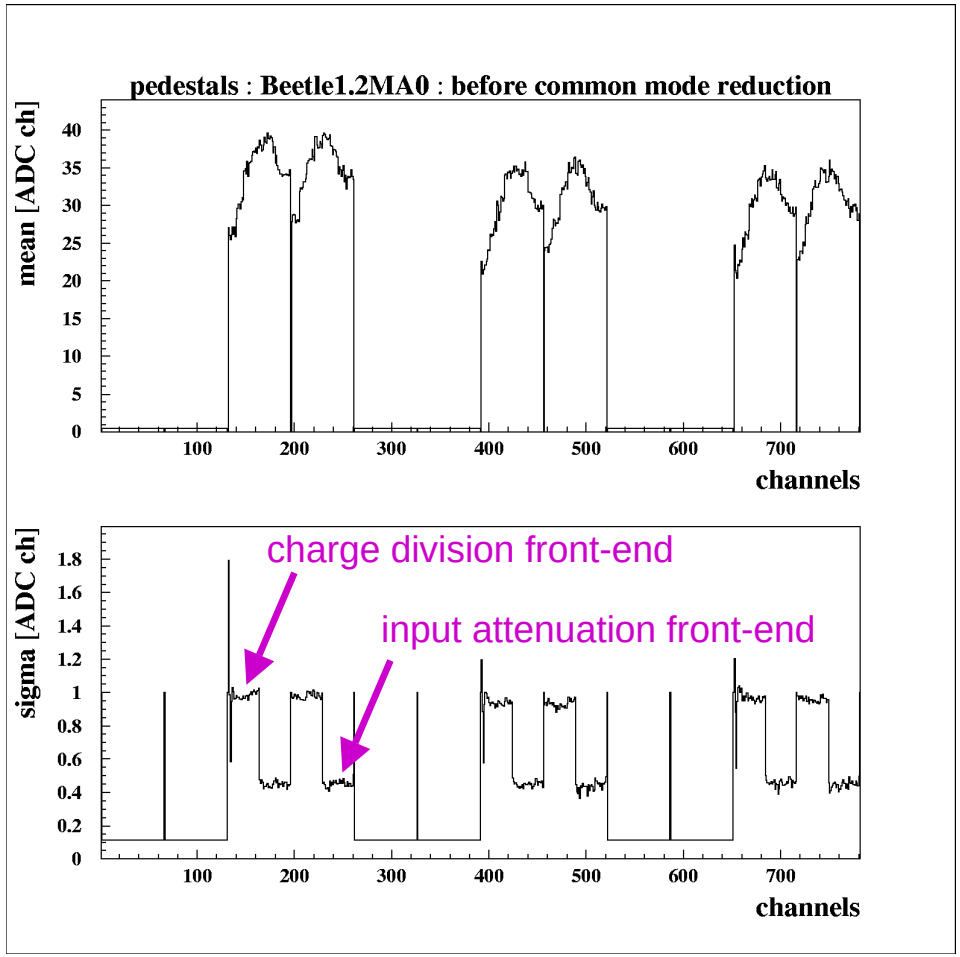
- final noise level
  - after DC-offset tuning
  - after tuning of timing
- full cluster
  - 6 boardBeetle1.2
  - 9 8-stage MaPMT
- from pedestal run
  - before CM correction
  - shape due to baseline of Beetle1.2

➔ low σ (1.0…1.5 ADC)

➔ no CM problem

➔ uniform offsets

Noise in Beetle1.2MA0



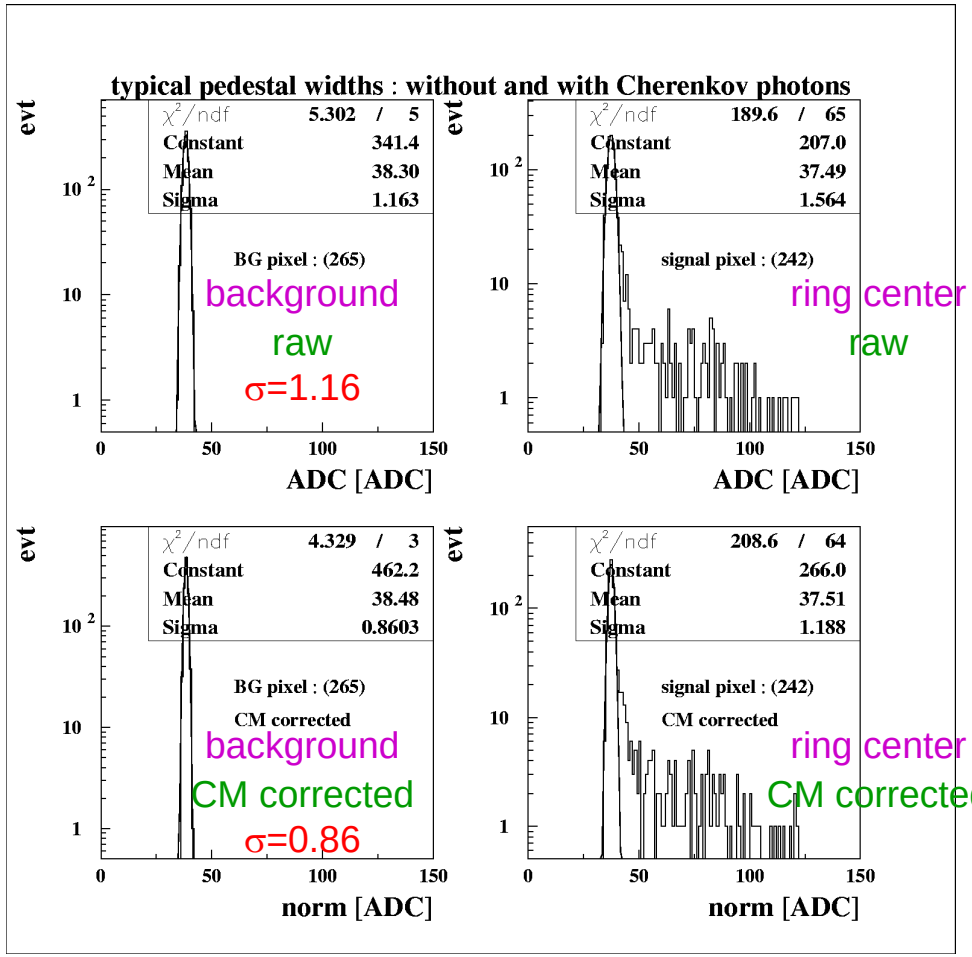
- final noise level
  - after DC-offset tuning
  - after tuning of timing
- half cluster
  - 3 boardBeetle1.2MA0
  - 6 12-stage MaPMT
- from pedestal run
  - before CM correction

➔ lower σ for charge divider (1.0 ADC)

➔ even lower σ for attenuator (0.5 ADC)

➔ uniform offsets

CM Suppression in Beam Run

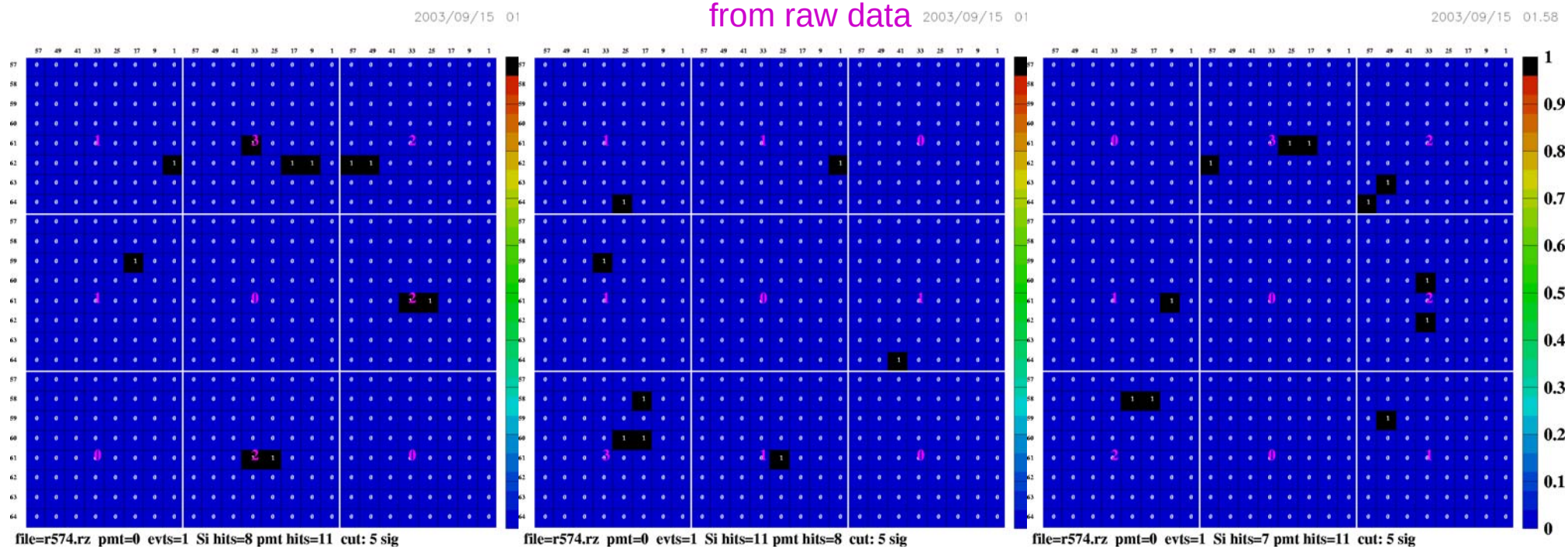


- from CF_4 beam run
  - HV= 800V
  - cluster of 8-stage MaPMT with Beetle1.2
- common mode correction:
  - on boardBeetle ~20%
  - as the noise already is as good or better than with CM correction for the Heidelberg board

Single Events

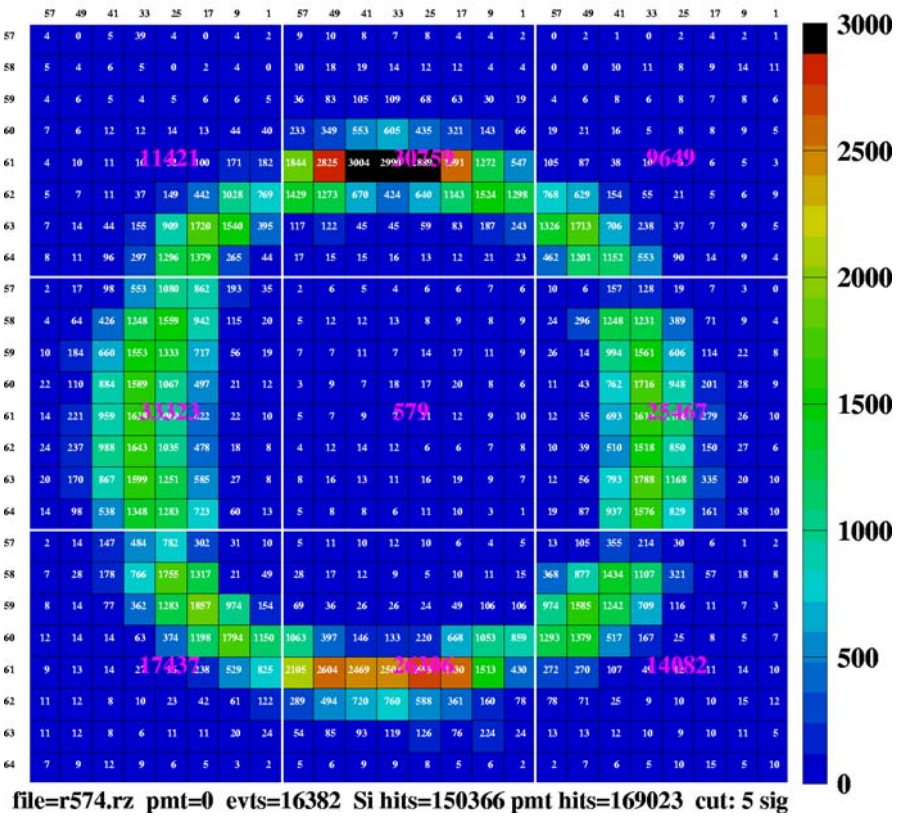
- Cherenkov photons
- CF_4: 800mbar
- 8-stage MaPMT & Beetle1.2
- HV = -900V
- with lenses

from raw data

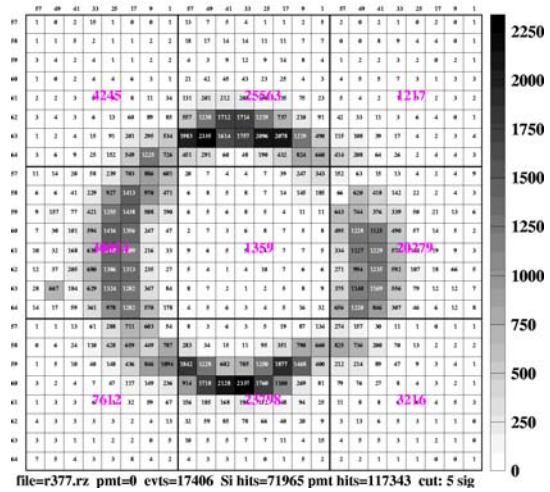


Cherenkov Rings

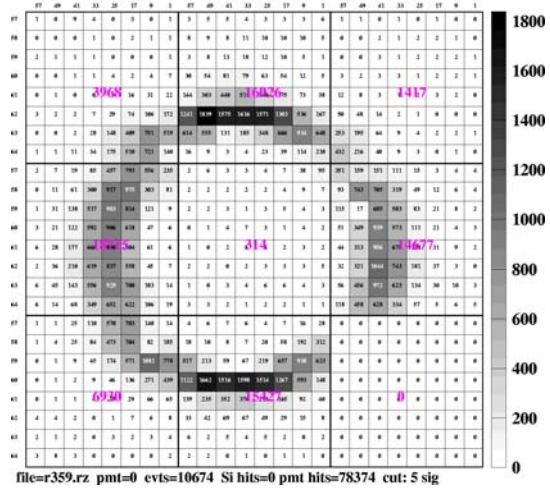
- Cherenkov photons (from raw data)
  - beam: -10 GeV → mostly π^-
- 8-stage MaPMT & Beetle1.2
  - with lenses; HV = -900V (from HV scan)



CF_4 800mbar 10.3 photons/evt



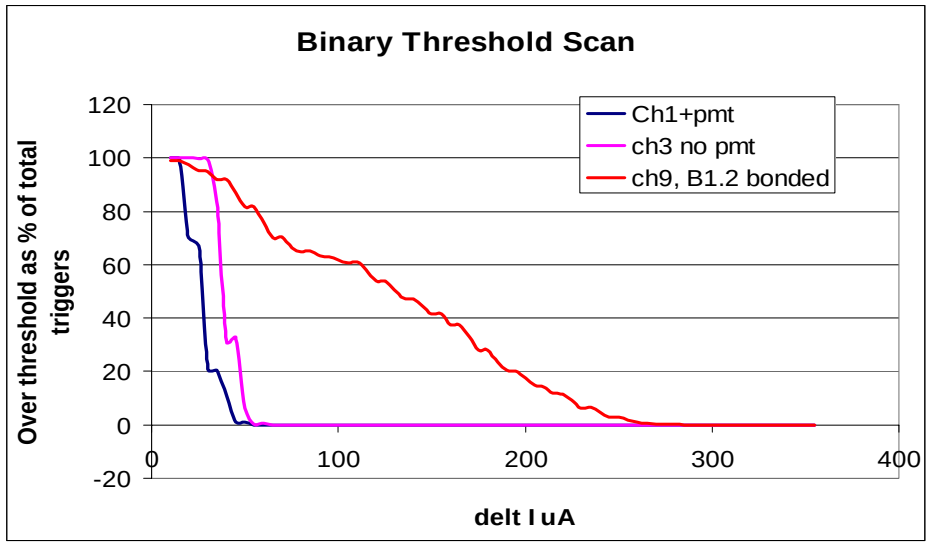
Air 960mbar 6.7 photons/evt



N_2 960mbar 7.3 photons/evt

Binary Readout

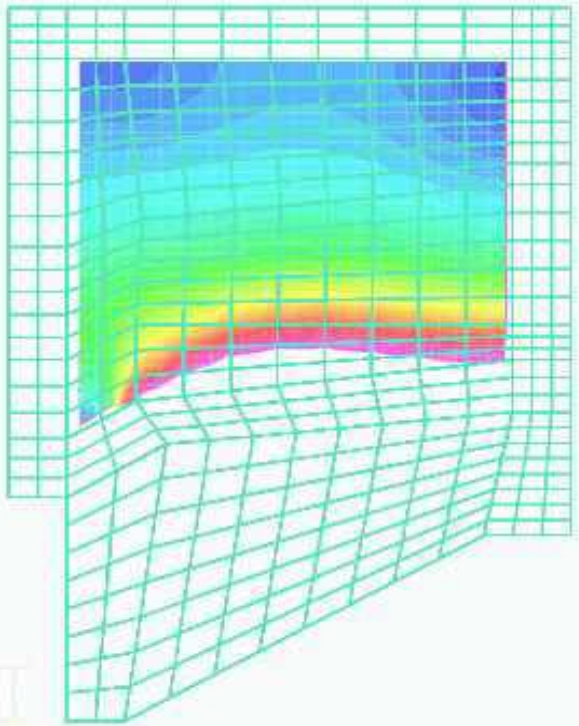
- Study of single channels in Oxford lab: Beetle1.2MA0
  - part of S-curve, as negative DC-offsets are not accessible in Beetle1.2:



- at testbeam: threshold scan of cluster of Beetle1.2
  - work unfinished: results not yet understood
  - more lab-studies needed

Magnetic Field Map of RICH1

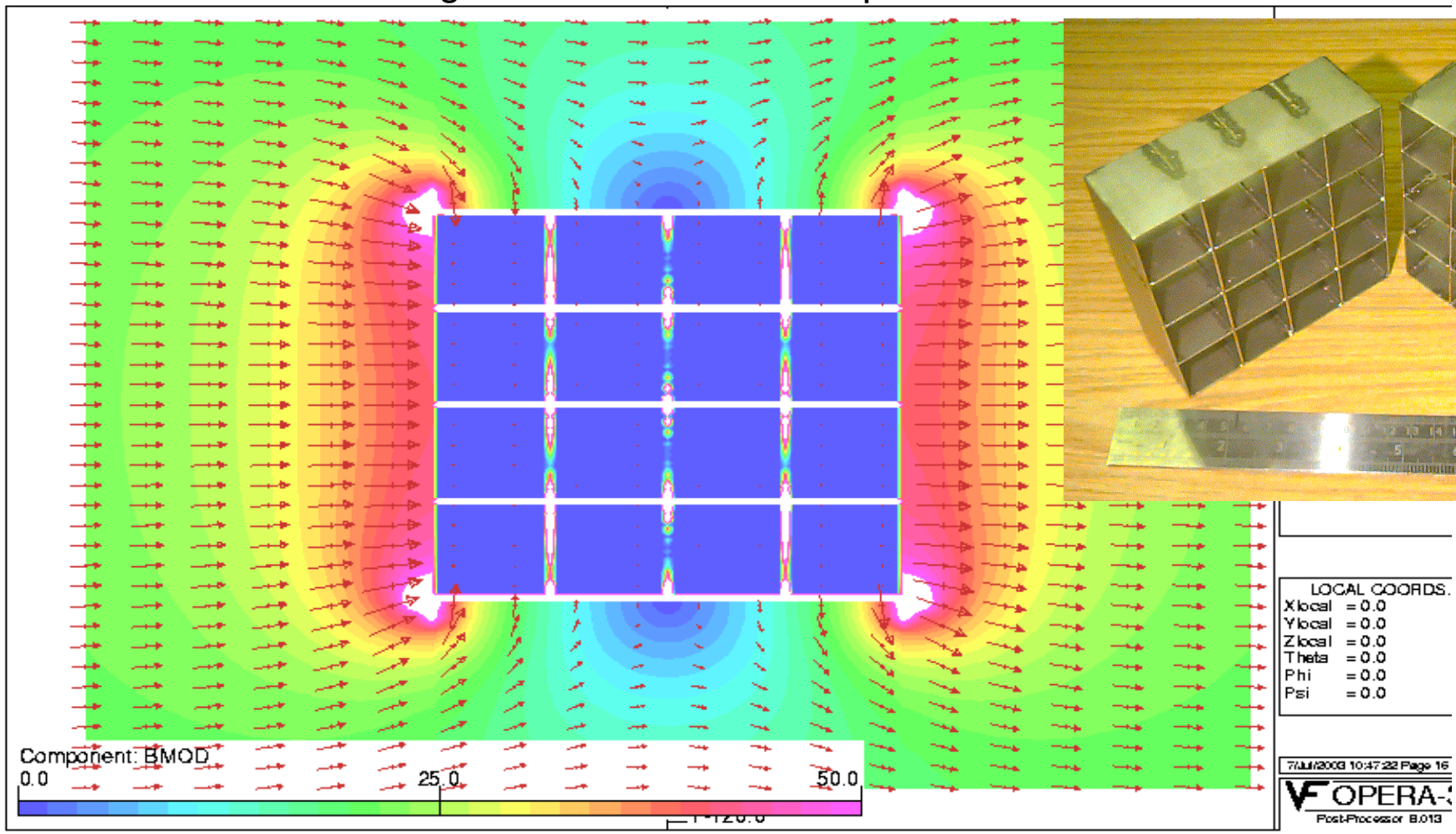
- magnetic field at photodetectors up to 25Gauss



- dated map: for illustrative purpose

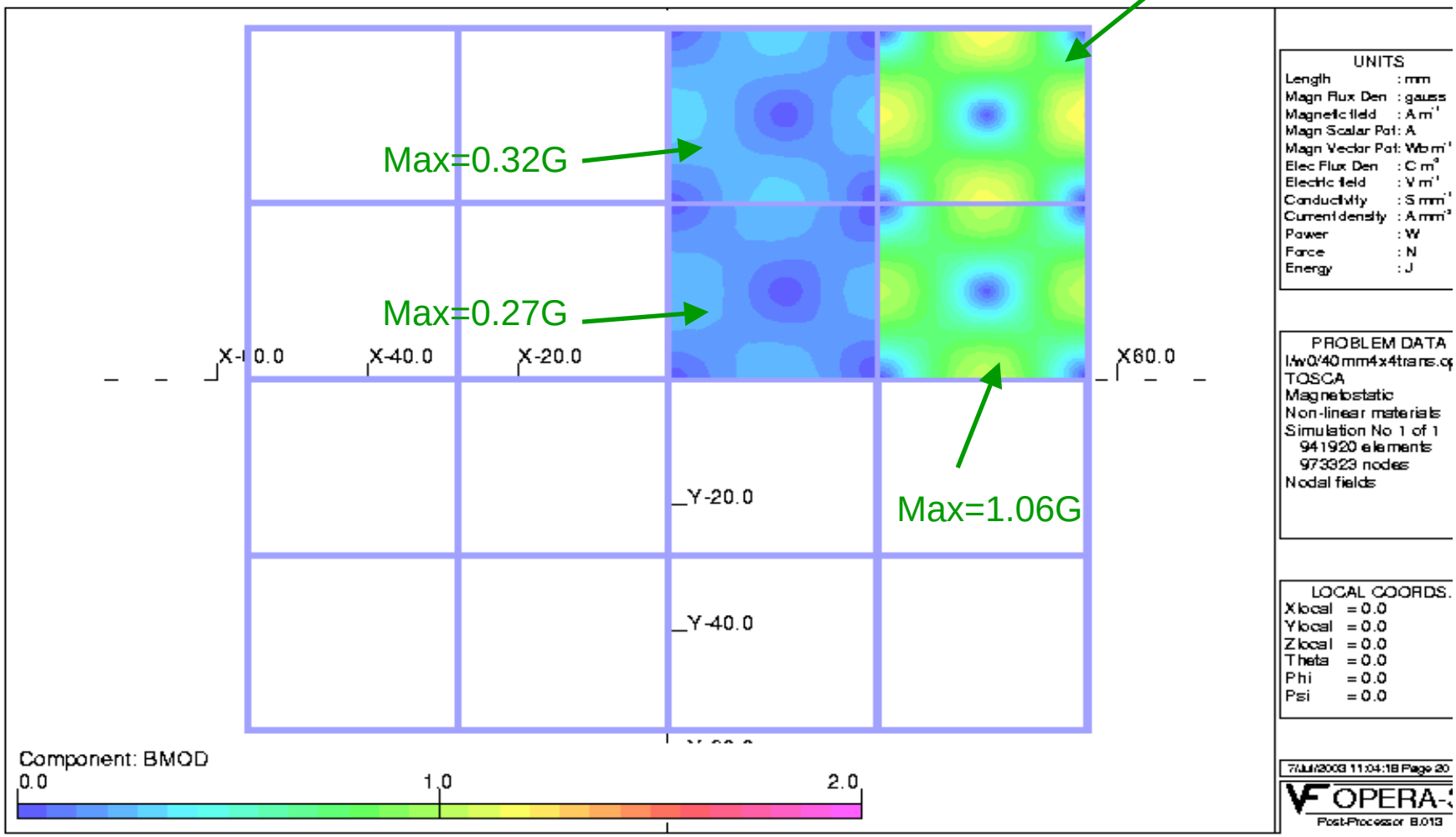
4x4 Shield

- 20 Gauss ambient transverse field
  - Cut through the centre of the XY-plane at Z=230mm



4x4 Shield: transverse field

- 20 Gauss ambient transverse field
  - Cut through the centre of the XY-plane at Z=230mm



4x4 Shield: longitudinal field

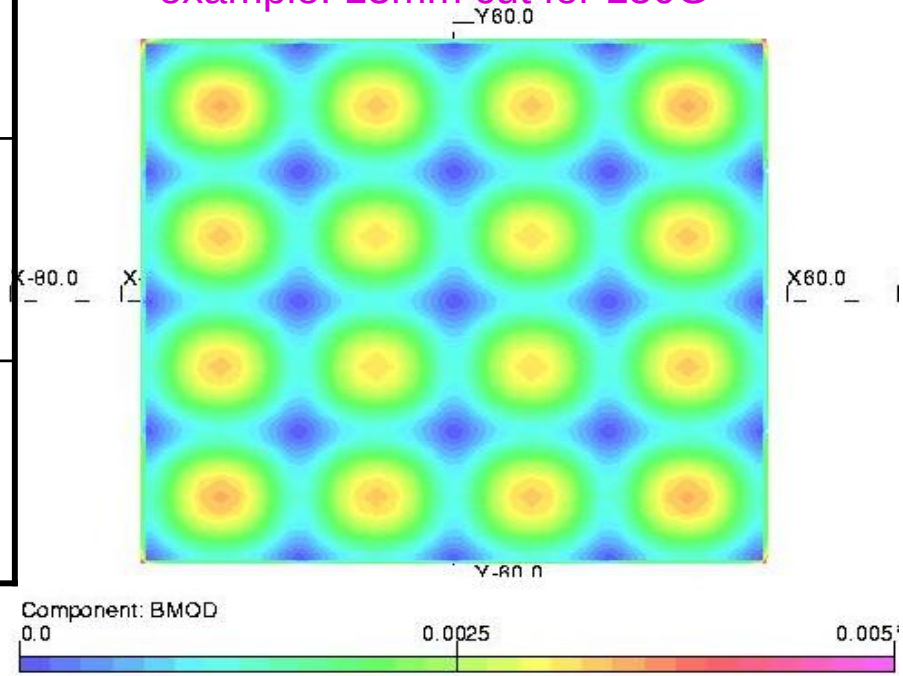
- max field values at the center points

2.25 G 3.75 G 16.90 G 28.14 G	2.11 G 3.55 G 15.85 G 26.63 G		
	1.97 G 3.34 G 14.80 G 25.08 G		

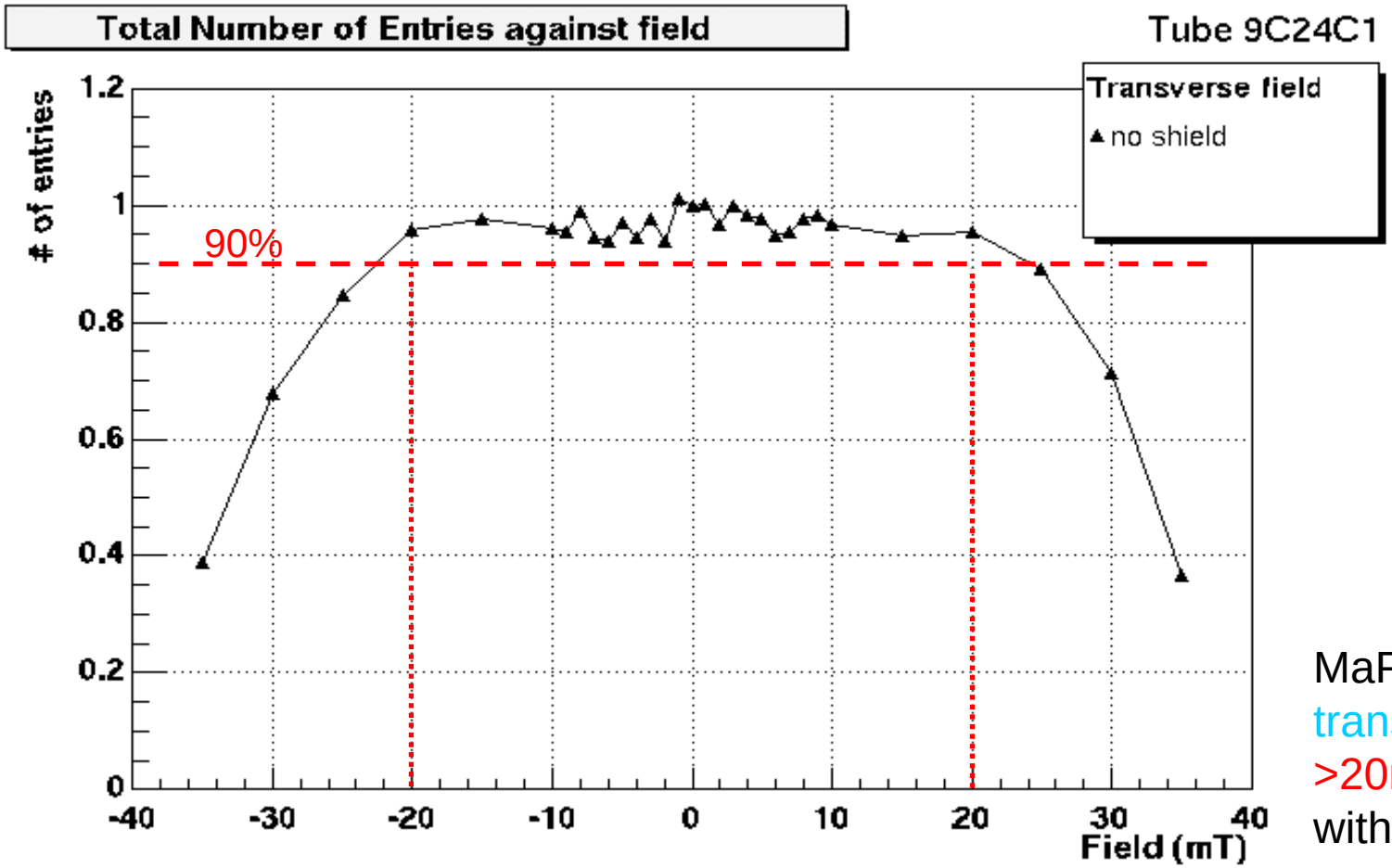
Field values:

- 40mm for 20Gauss
- 33mm for 20Gauss
- 40mm for 150Gauss
- 33mm for 150Gauss

example: 13mm cut for 150G

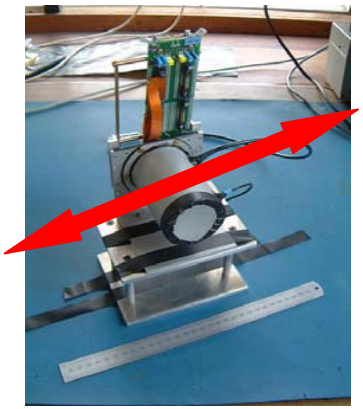


Transverse B-Field



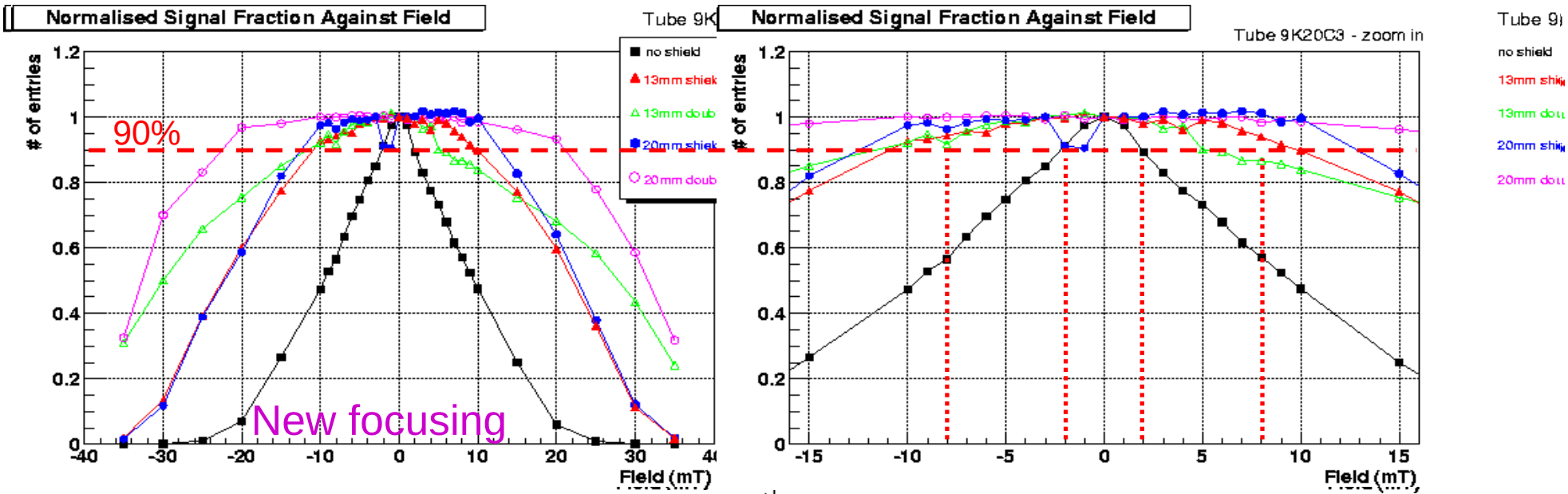
normalised light yield in whole MaPMT

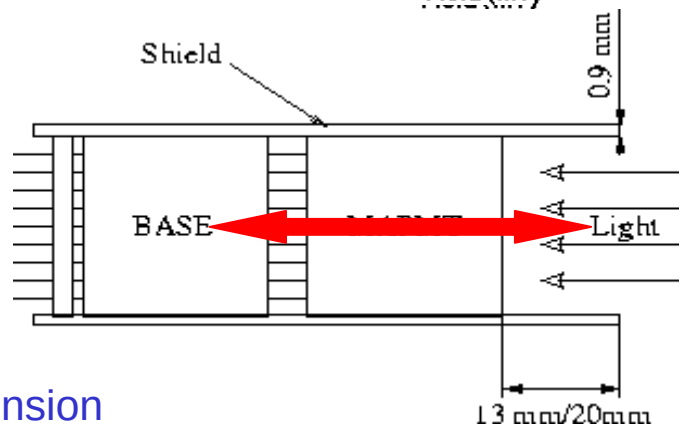
Transverse field in x-direction



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

Longitudinal B-Field



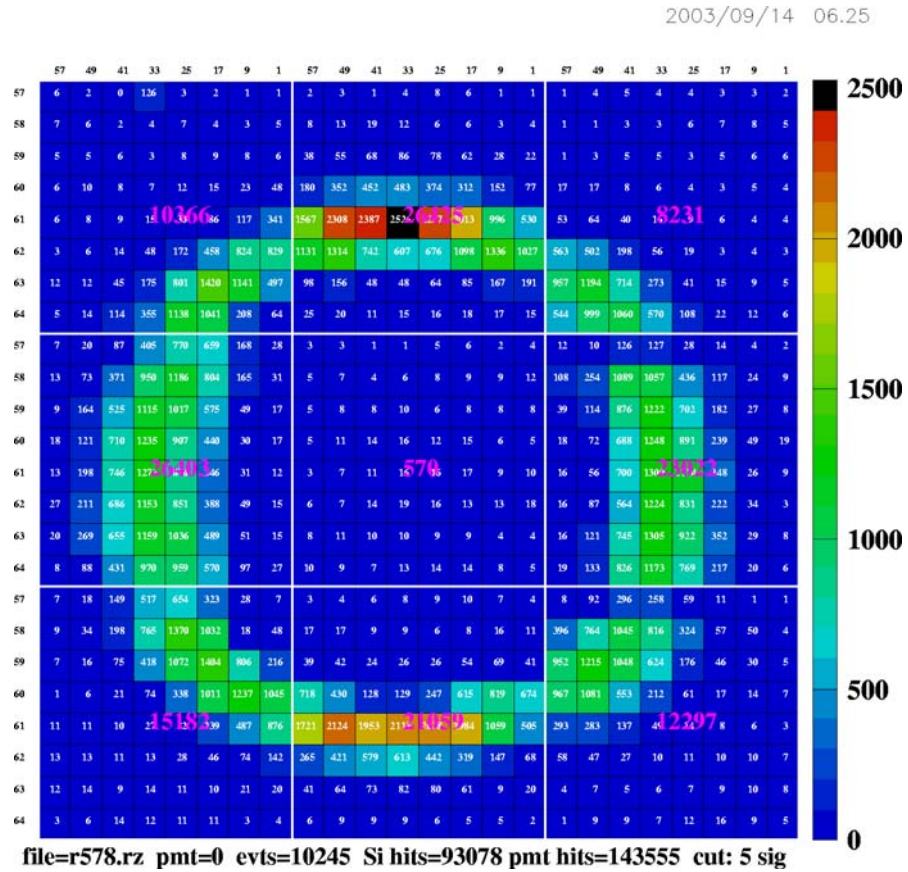


μ-metal shield:
0.9 mm thick
13 or 20 mm extension

- 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

Conclusions

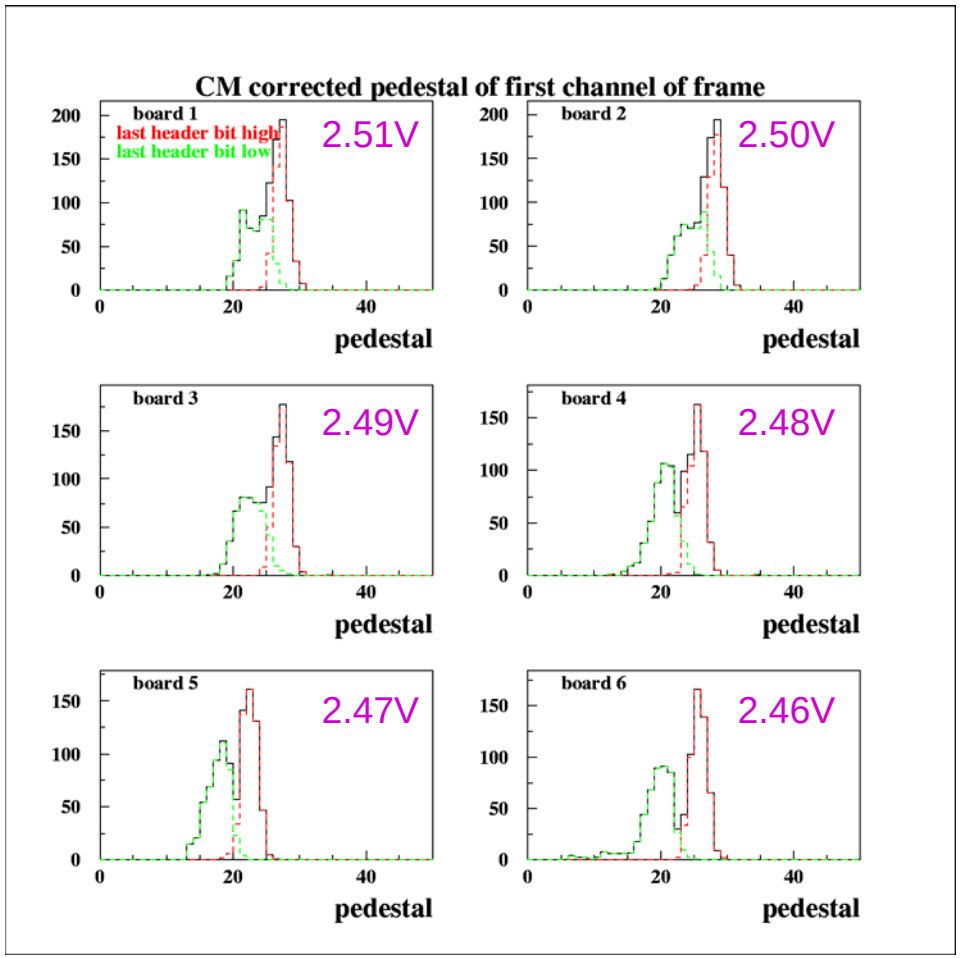
- Beetle1.2 & Beetle1.2MA0:
  - functionality proven in lab tests
  - no noise/CM problem anymore
- boardBeetle:
  - noise excellent, almost no CM
- the testbeam was a success:
  - Beetle1.2 & 8-stage MaPMT comprehensively tested
- expected magnetic field will be no problem to MaPMTs
- issues:
  - binary studies only started
  - Beetle1.2MA0 not fully tested



Thanks to all the people who made this result possible!!!

Spare Slides

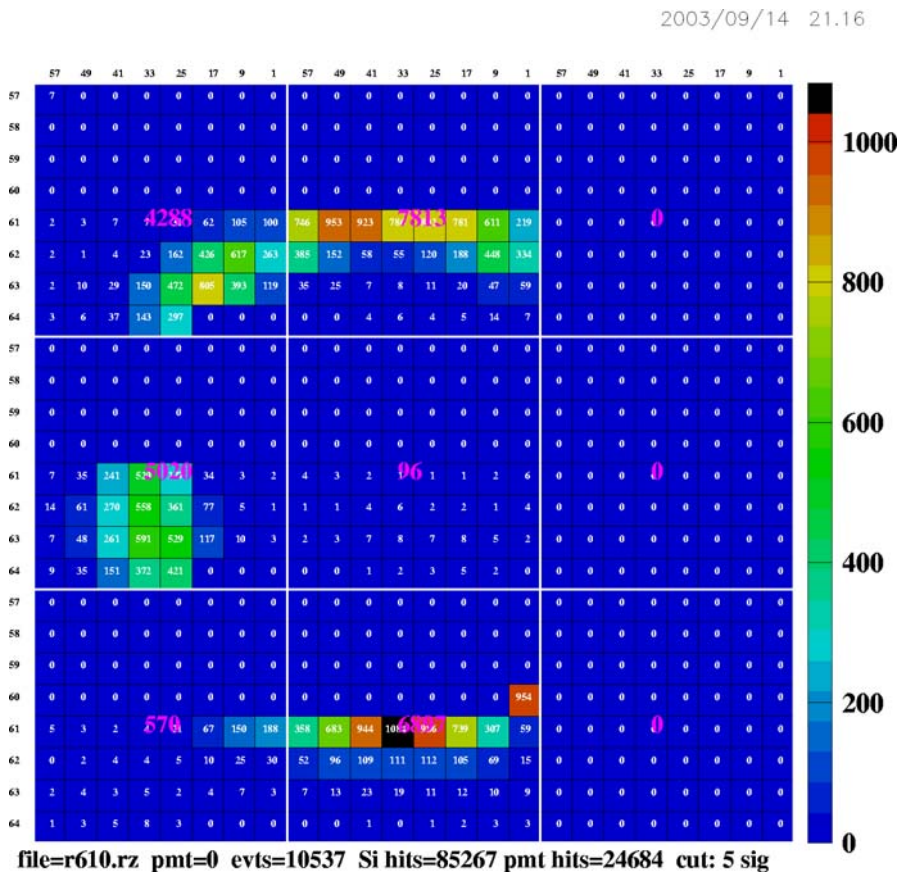
Cross-talk from Header to First Channel



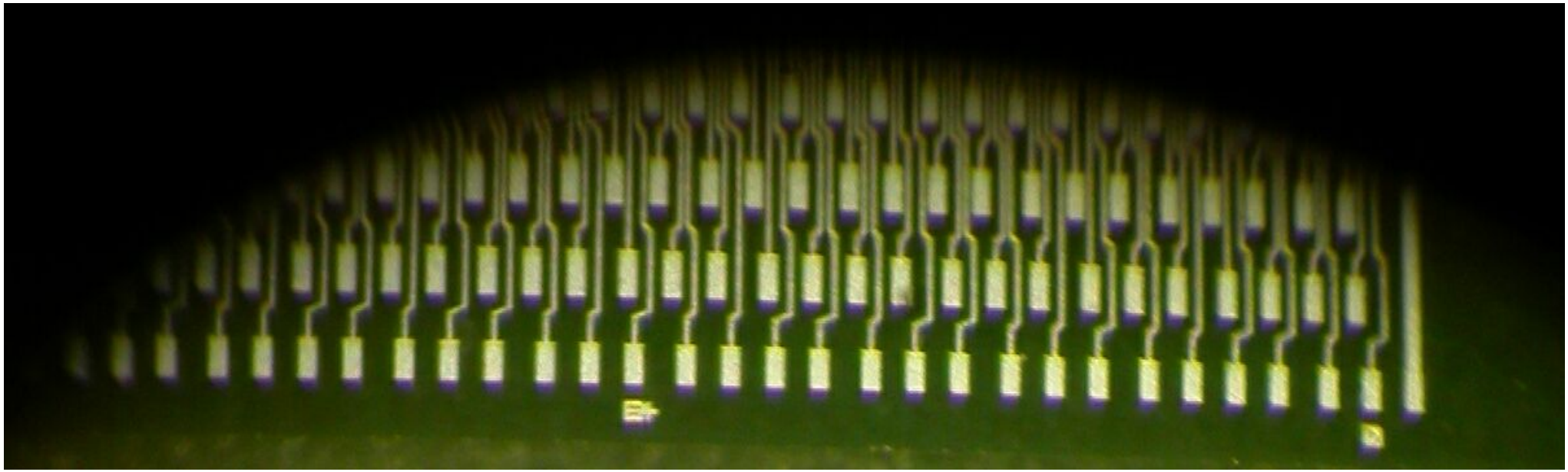
- clear correlation of pedestal of first channel with state of last header bit:
  - header high
  - header low
- due to daisy chain of power cables:
  - voltage drop along chain
  - ➔ the lower the voltage, the more pronounced the sensitivity to the header

Beetle1.2MA0 cluster test (quick shot)

- cluster of 6 12-stage MaPMT & 3 boardBeetle1.2MA0:
  - time too short to get it to run properly
  - only ring fragments



Pitch adapter I

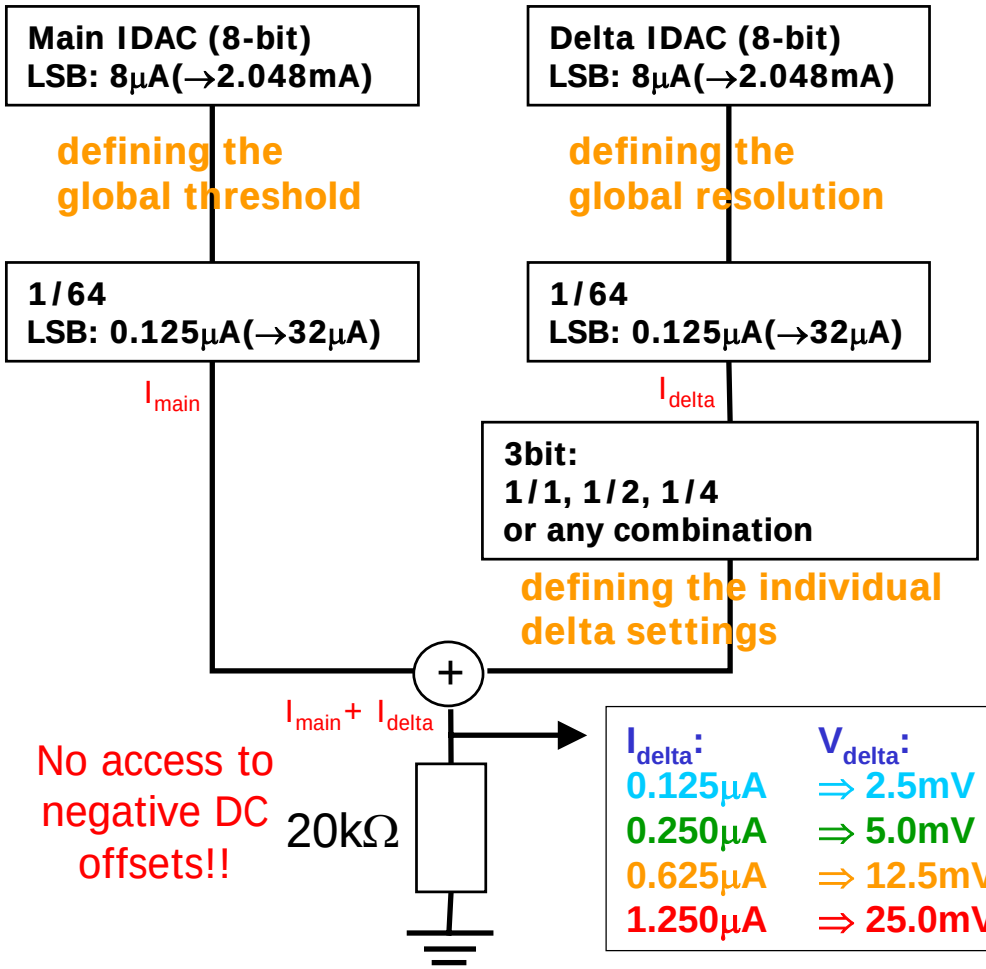


- Pitch adapter is irregular: due to accident in submission
  - design was sent in low accuracy ➔ rounding errors & shorts
  - layout altered at CERN to fix shorts (but not the rounding errors…)
  - not communication back to IC
  - so this structure only was found at bonding…
- Cause of cross-talk??

Pitch Adapter II

3-bit comparator in Beetle1.2

- from discussions with Hans Verkooijen:

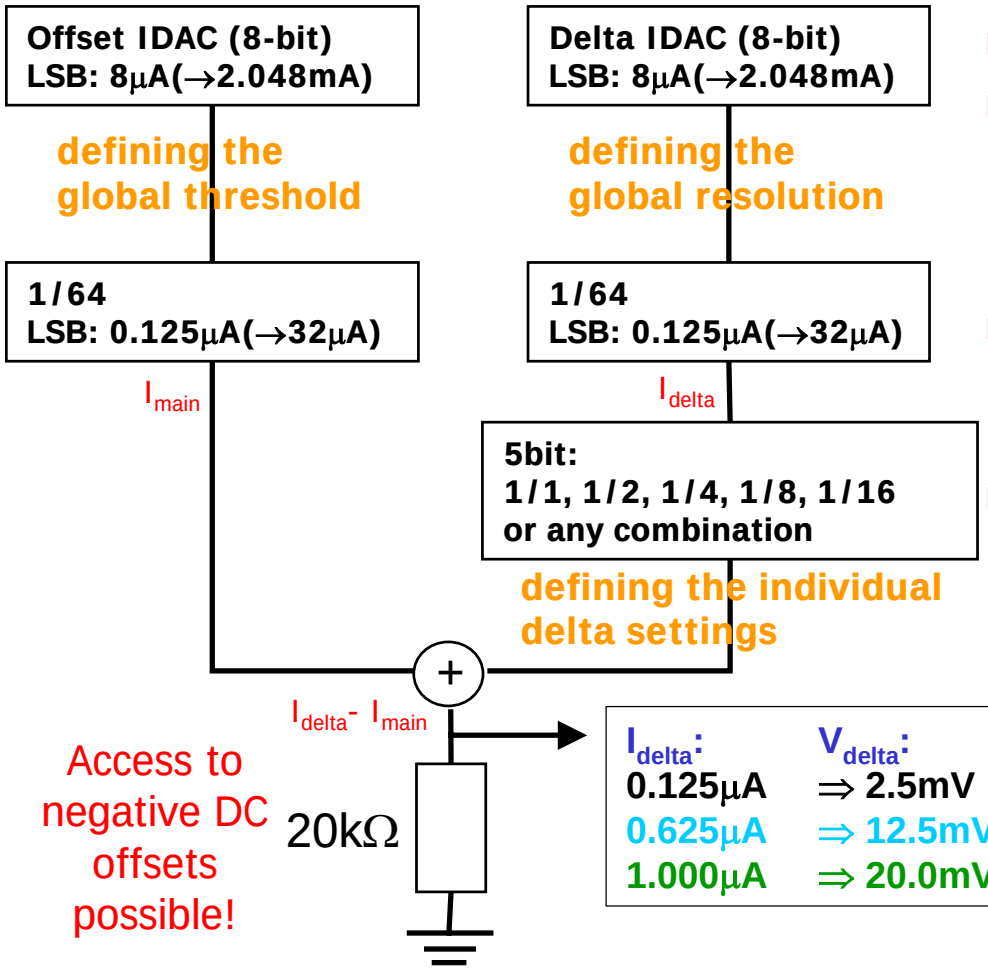


- **1 MIP = 22000e⁻ = 15…38mV**
- **comparator DC offsets: ± 26mV (3σ)**
  - **trade off:**
    range covered at a time vs. resolution,
    e.g. 1*40mV, 2*20.0mV, 4*10.0mV or 8*5.0mV
- **Comparator buffer: gain *0.7**
- **Beetle1.2MA0 : 12-dyn : 300000e⁻ → 30mV**
  - **Signal: 300000e⁻ → 0.7*30mV = 21mV**
  - **Noise: 7500e⁻ → 0.7*0.75mV = 0.525mV**
- **Beetle1.2 : 8-dyn : 50000e⁻ → ~85mV**
  - **Signal: 50000e⁻ → 0.7*85mV = 60mV**
  - **Noise: 1000e⁻ → 0.7*1.7mV = 1.2mV**

I_{delta}:	V_{delta}:	V_{delta} range:	V_{delta} step size:
0.125μA	⇒ 2.5mV	0…4.375mV ☹	0.625mV ☺
0.250μA	⇒ 5.0mV	0…8.75mV ☹	1.25mV ☺
0.625μA	⇒ 12.5mV	0…21.875mV 😐	3.125mV ☹
1.250μA	⇒ 25.0mV	0…43.75mV ☺	6.25mV ☹

5-bit comparator in Beetle1.3 (08/2003)

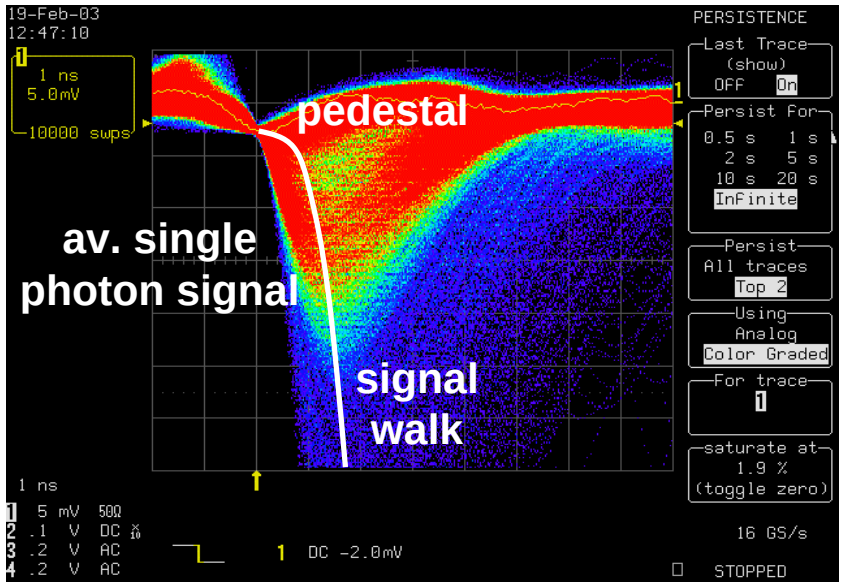
- from discussions with Hans Verkooijen:



- 1 MIP = 22000e⁻ = 15…38mV
- comparator DC offsets: ± 15mV (3σ)
  - wrt. Beetle1.2:
    - comparator input buffer gain *0.7 → *1.0
    - DC offsets reduced due to removal of one buffer
- Beetle1.3MA0 : 12-dyn : 300000e⁻ → 30mV
  - Signal: 300000e⁻ → 1.0*30mV = 30mV
  - Noise: 7500e⁻ → 1.0*0.75mV = 0.75mV
- Beetle1.3 : 8-dyn : 50000e⁻ → ~85mV
  - Signal: 50000e⁻ → 1.0*85mV = 85mV
  - Noise: 1000e⁻ → 1.0*1.7mV = 1.7mV

I_{delta}:	V_{delta}:	V_{delta} range:	V_{delta} step size:
0.125μA	⇒ 2.5mV	0…4.84375mV	0.15625mV
0.625μA	⇒ 12.5mV	0…24.21875mV ☺	0.78125mV ☺
1.000μA	⇒ 20.0mV	0…38.75mV ☺	1.25mV ☺

MaPMT signal shape measurement



- 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

→ signal walk

→ input to simulations by Nigel Smale

- 12-dynode MaPMT @ HV = -1000V
  (nominal gain: 3.3M e$^-$)
- direct to scope (50Ω)
- average of time measurements
- ~5000 single photon events (stray light)

→ av. fall time: 1.1ns

→ av. rise time: 2.7ns

→ av. pulse width: 2.6ns