# Design and Performance of the CMS pixel detector barrel modules

## 11th Workshop on Electronics for LHC and future Experiments

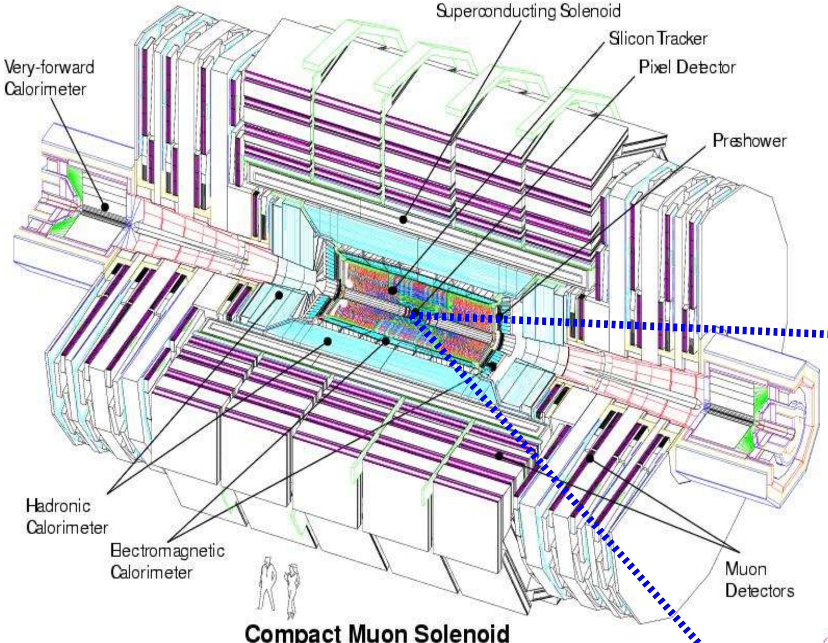
## 12.-16. September 2005, Heidelberg, Germany


**Christoph Hörmann**

**(Paul Scherrer Institut/University of Zürich)**


- CMS pixel barrel module
- laboratory measurements (crosstalk)
- beam test and preliminary results
- conclusions

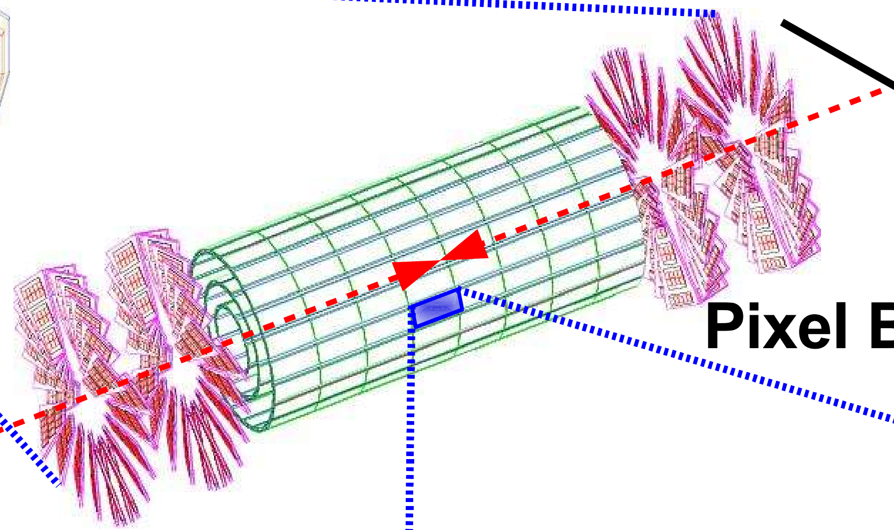
# CMS pixel detector




**CMS Detector**

innermost tracking detector

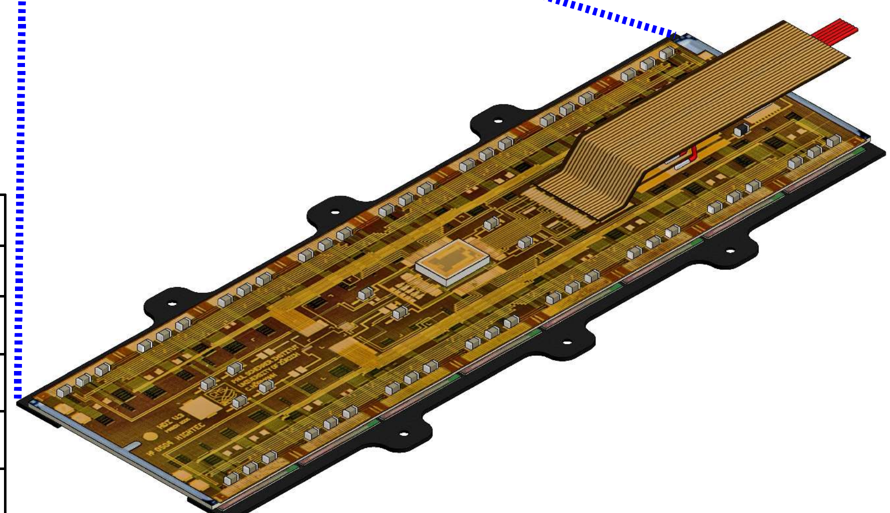
**CMS Pixel Detector**



basic building block of the pixel barrel

**Pixel Barrel Module**

proton beam



| Radius | # Modules | # Chips | # Pixels | Area |
|---|---|---|---|---|
| [cm] | | | [× $10^6$] | [$m^2$] |
| 4 | 128 + 32½ | 2`304 | 9.6 | 0.15 |
| 7 | 224 + 32½ | 3`840 | 16 | 0.26 |
| 11 | 352 + 32½ | 5`888 | 24.5 | 0.42 |
| total | 704 + 96½ | 12032 | 50.1 | 0.83 |

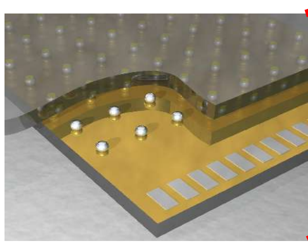
# components of the pixel barrel module

- **<u>Kapton cable:</u> transmits control signals from endring print to module; 21 signal traces; 300 $\mu$m pitch; length 10 cm to 36 cm**

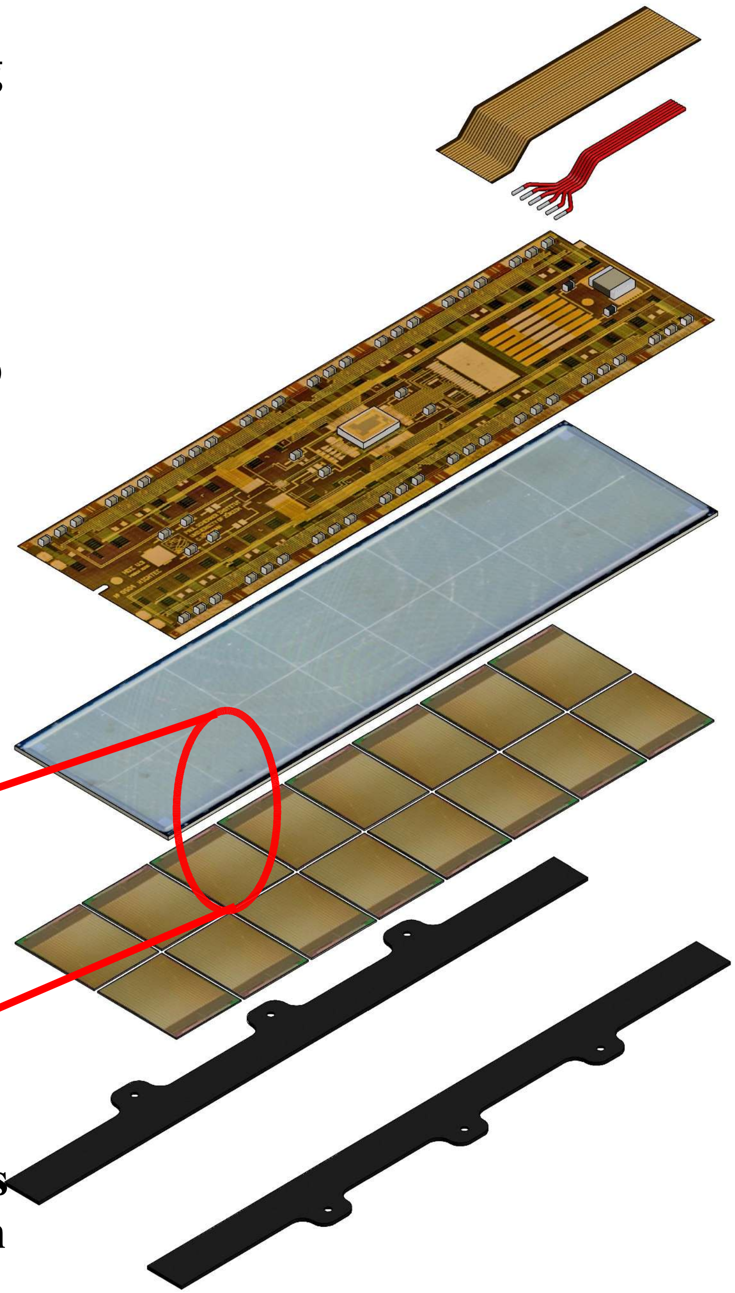
- **<u>Power cable:</u> six wires Al ribbon; $V_{ana}$, $V_{dig}$, $V_{Bias}$, GND**

- **<u>High Density Interconnect (HDI):</u> distributes control signals and power to ROCs and TBM; capacitors for decoupling; 3 layer design (Copper 7 $\mu$m and Kapton 10 $\mu$m)**

bump bonding technique



- **<u>Base Plate:</u> for mounting module on cooling and supply structure; two stripes of 250 $\mu$m $Si_3N_4$; CTE match to Si**



- **<u>Sensor:</u> 'n-in-n' type Si sensor on DOFZ material; processed in p-spray technique; segmented into pixels; thickness 285 $\mu$m; high voltage robustness up to 600 V; radiation hardness tested up to fluence of ~ $10^{15}$ $n_{eq}/cm^2$**

- **<u>Read Out Chip (ROC):</u> 16 ROC PSI46V2; processed in 0.25 $\mu$m technology; 5 metal layers + MIMCAP; continuous data taking and simultaneous readout operation; zero suppression; radiation tolerant design (10 MRad/year for innermost layer @ high luminosity $10^{34}$ $cm^{-2}$ $sec^{-1}$)**

# Read Out Chip: overview PSI46

**sensitive pixel array:**

**52 columns * 80 rows = 4160 pixels**

**(organised in 26 double columns)**

**pixel size: 100 $\mu$m * 150 $\mu$m (r$\varphi$ * z)**

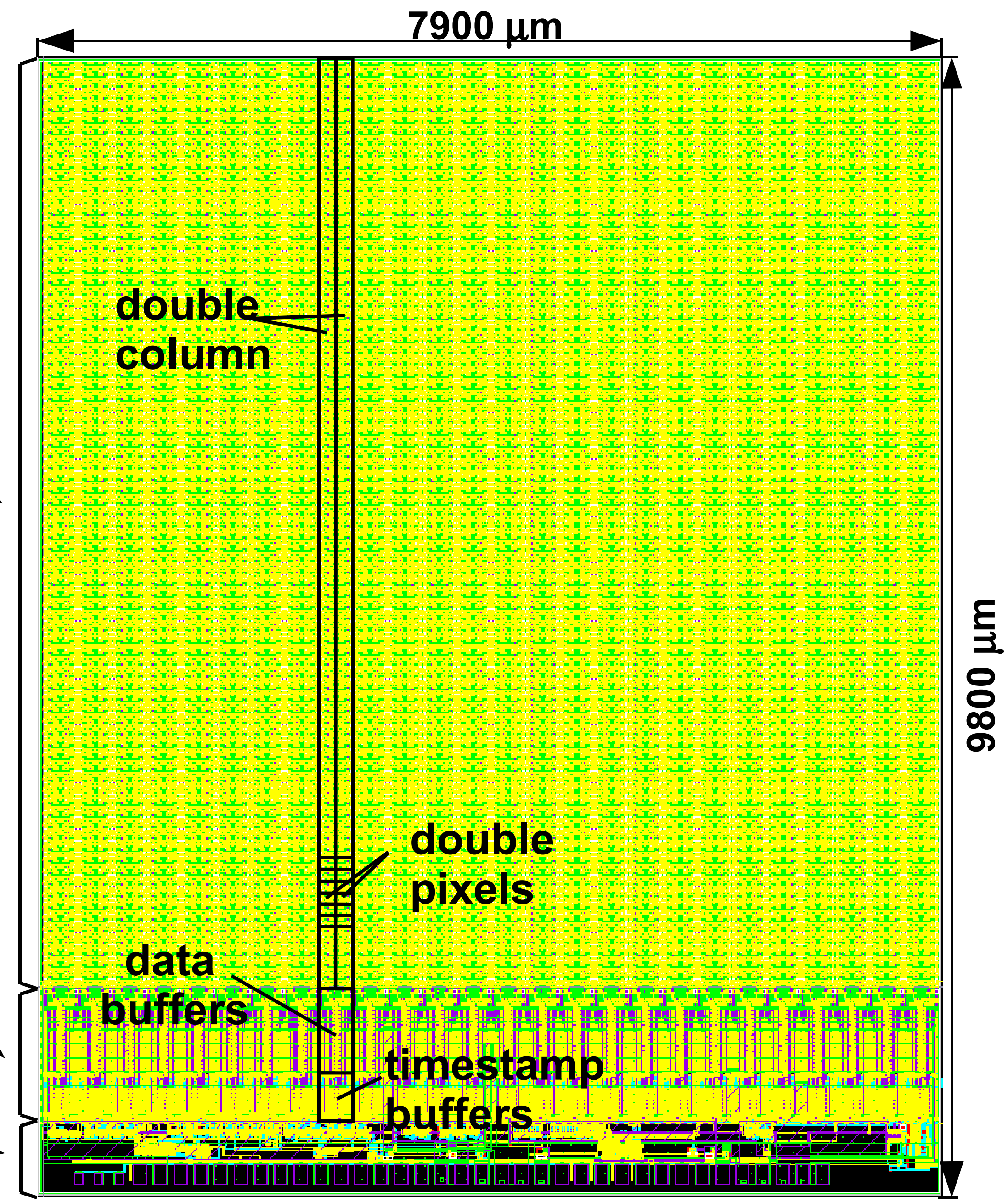
**double column periphery:**

**double column interface**

**32 data buffers, 12 time-stamp buffers**

**control interface block, I2C, DACs, regulators,**

**counters, supply pads**



# Read Out Chip: column drain mechanism

**column drain mechanism:**

- mechanism to copy the data (address and pulseheight) from the pixels with an hit down to double column periphery

**pixel:**

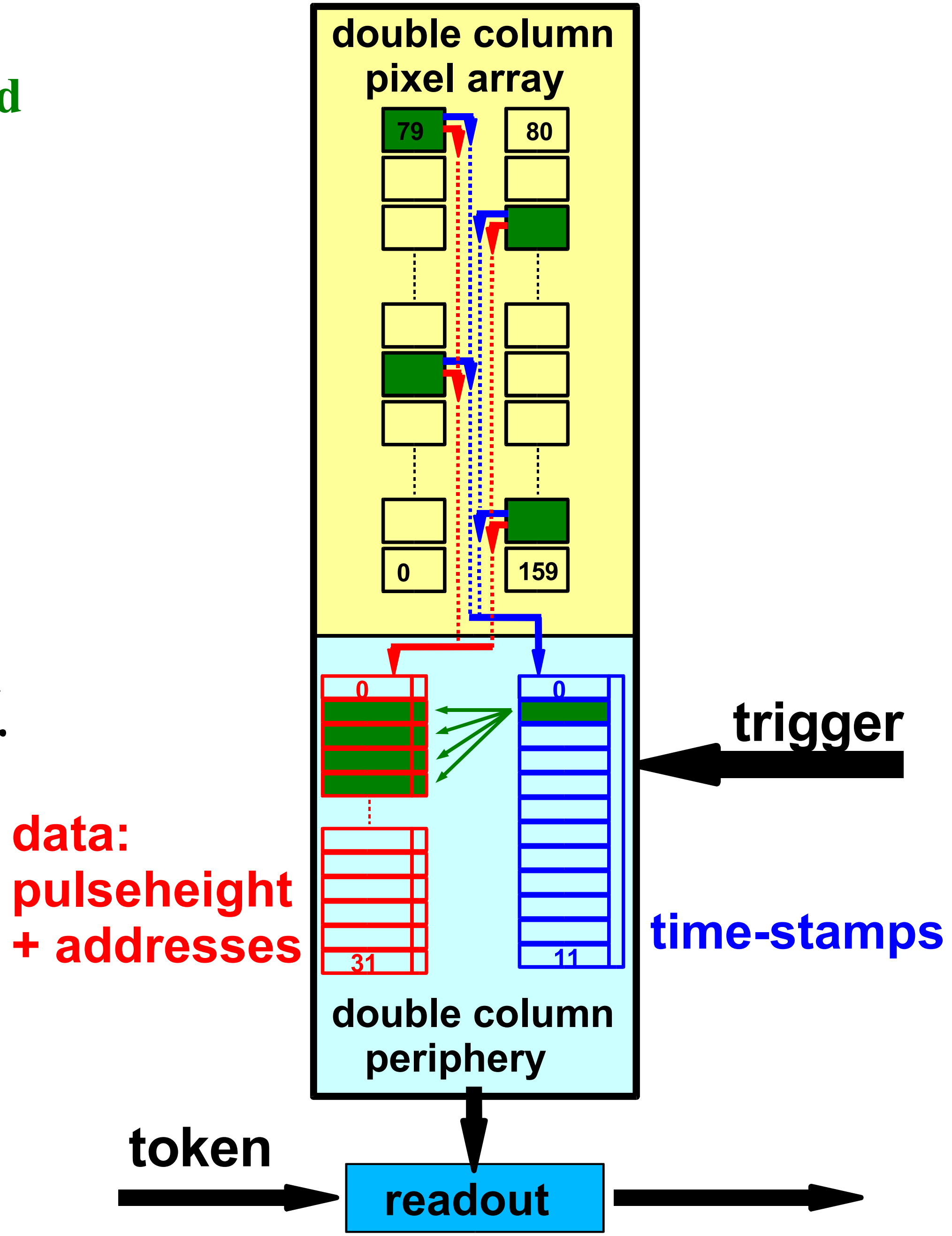
- waits for hits ($10^{-3}$ per bc), notifies periphery to set time-stamp and start column drain mechanism
- has no clock, no counter, no data buffer

**double column periphery:**

- sets time-stamps ($10^{-1}$ per bc)
- collects data from pixels, buffers data during the latency of the CMS trigger
- until the event is confirmed by the CMS trigger or latency passed

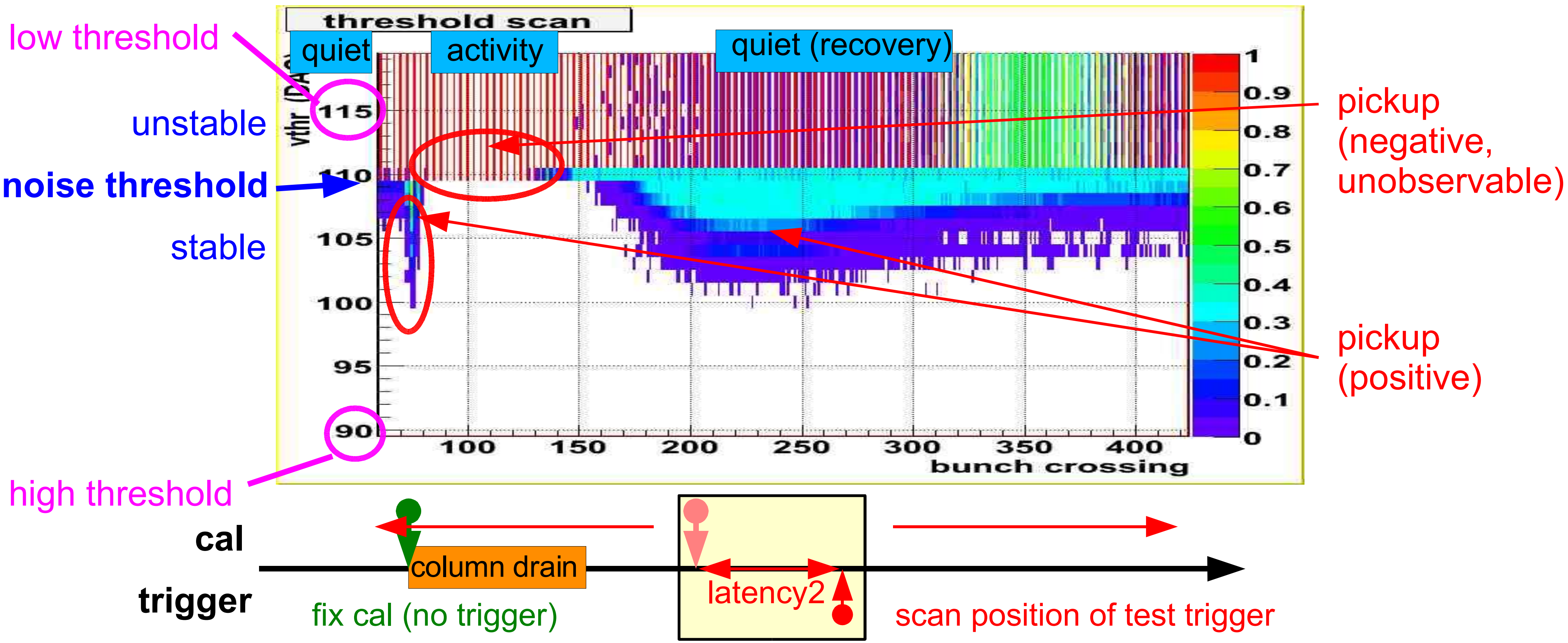
⇨ readout of triggered data (100kHz) after token enters the chip

⇨ Is data taking and simultaneously read out operation possible? crosstalk?



# column drain induced threshold shift 1

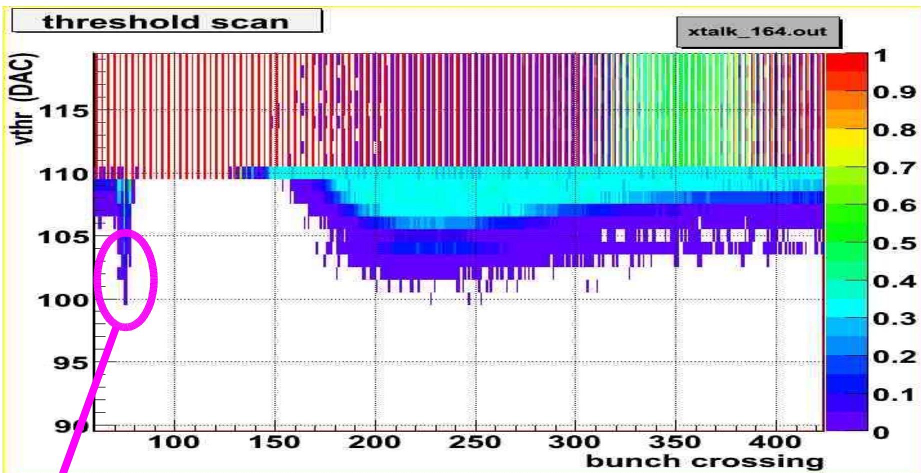
- **<u>explanation of the crosstalk measurement:</u>**
  - **all ROCs get calinject1 (# pixels are enabled)**
  - **all ROCs have latency1 apart from one ROC, which has latency2 (latency2>latency1)**
  - **no appropriate trigger is given for latency1, but an appropriate trigger is given for latency2**
    - ➪ **just ROC with latency2 is read out (one testpixel enabled ➪ noise threshold)**
    - ➪ **should see crosstalk caused by column drain in other ROCs**

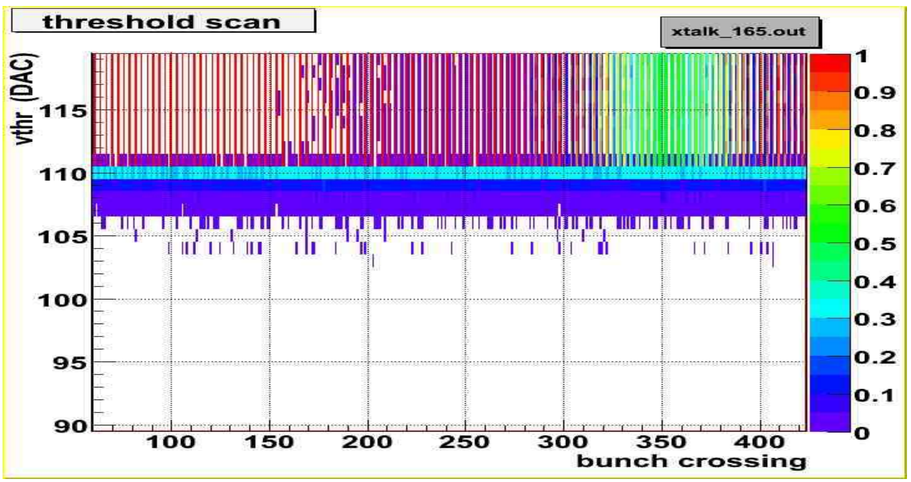


# column drain induced threshold shift 2

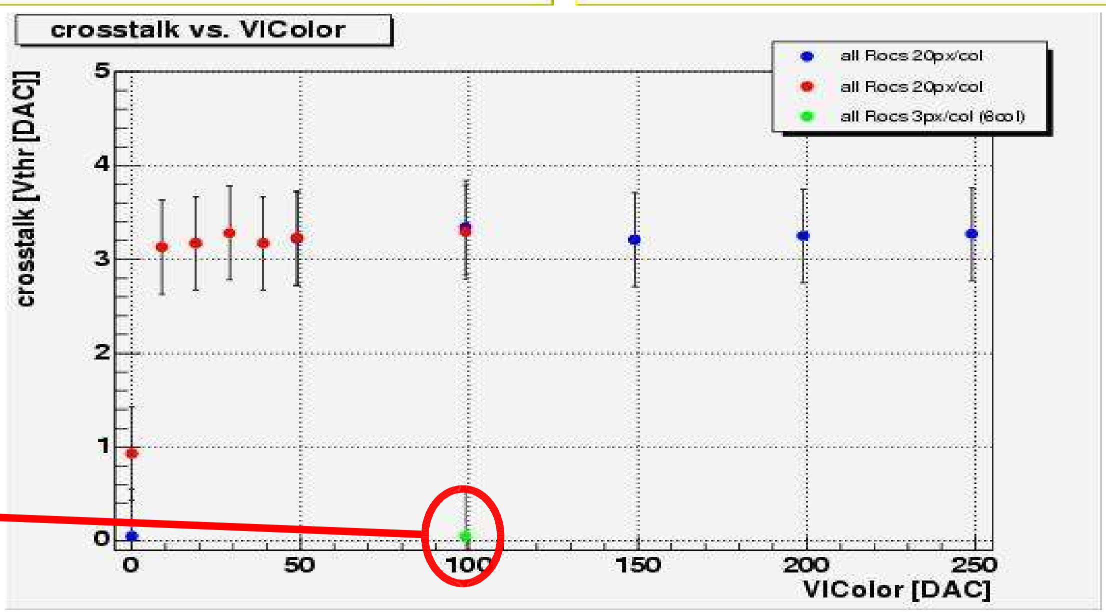


- **height of the initial spike just after charge injection (positive pickup):**
  - **grows with # pixels enabled on all ROCs**
  - **independent of VIColor (= double column notification)**




initial spike



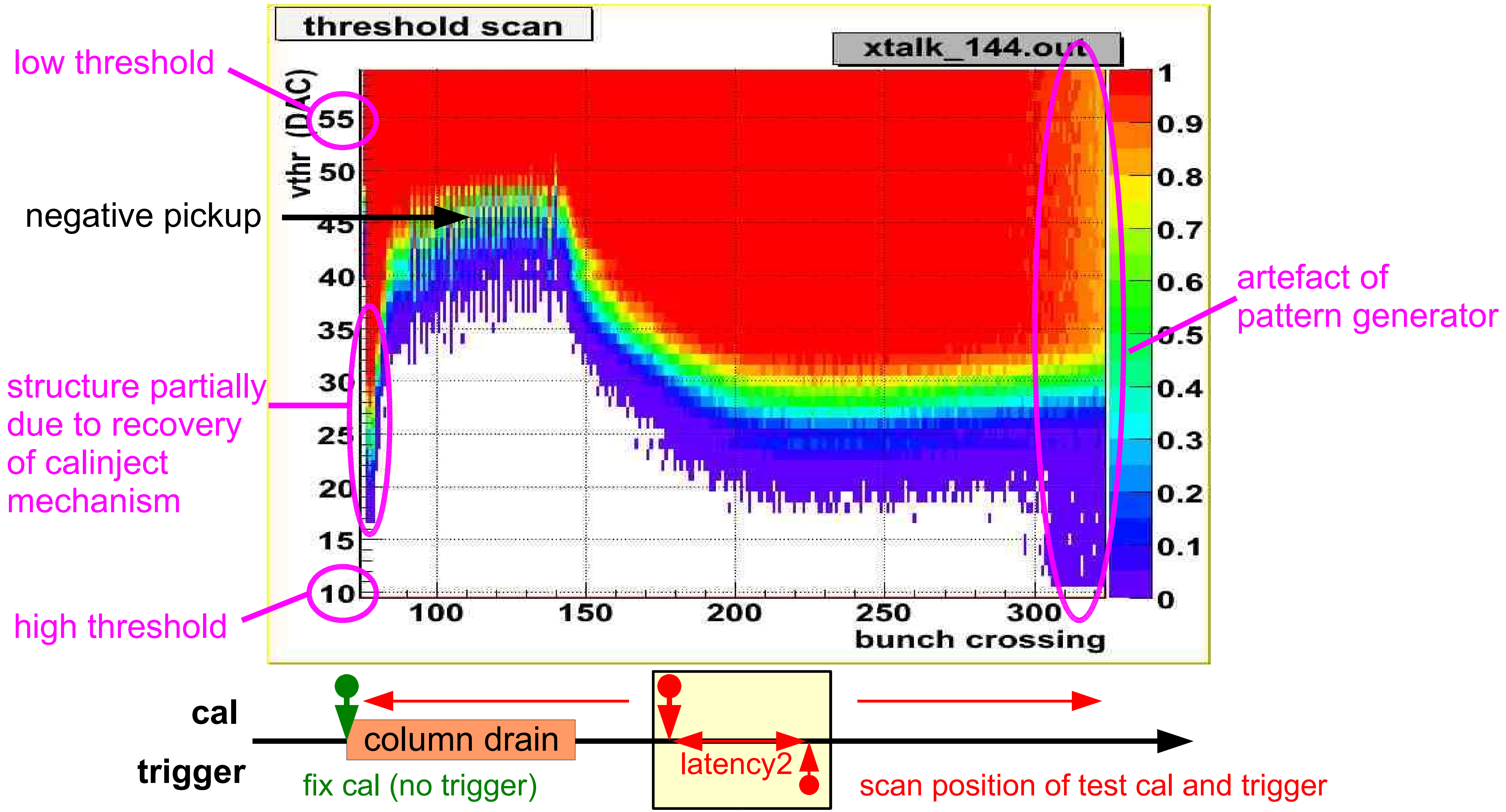

$200e^-/V_{thr}$ [DAC]

realistic scenario:
6 columns/ROC,
each 3 pixels

# column drain induced threshold shift 3



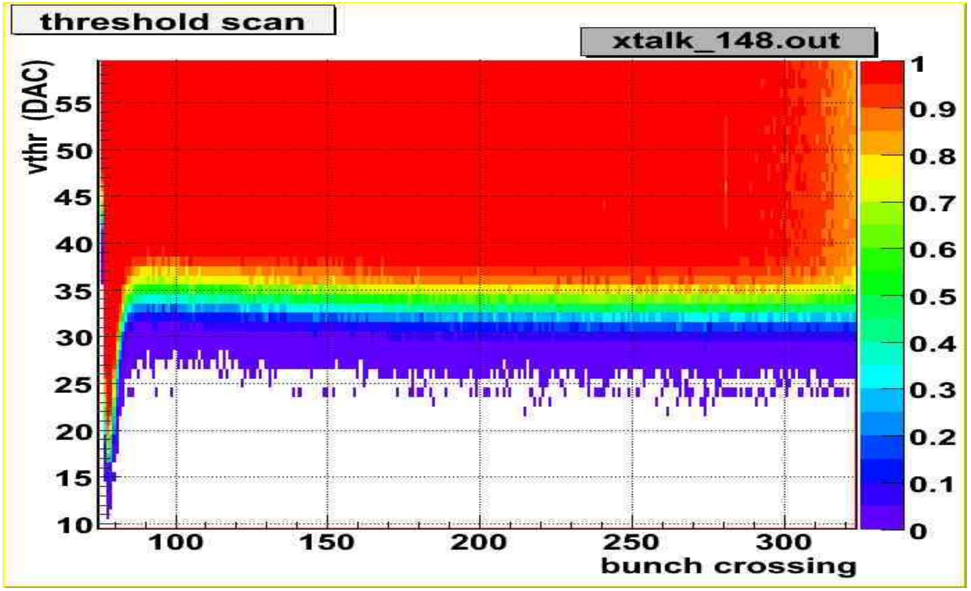
- **investigation of the negative pickup:**
  - **move testpixel of ROC with latency2 away from noise level by giving a second calinject2**



# column drain induced threshold shift 4

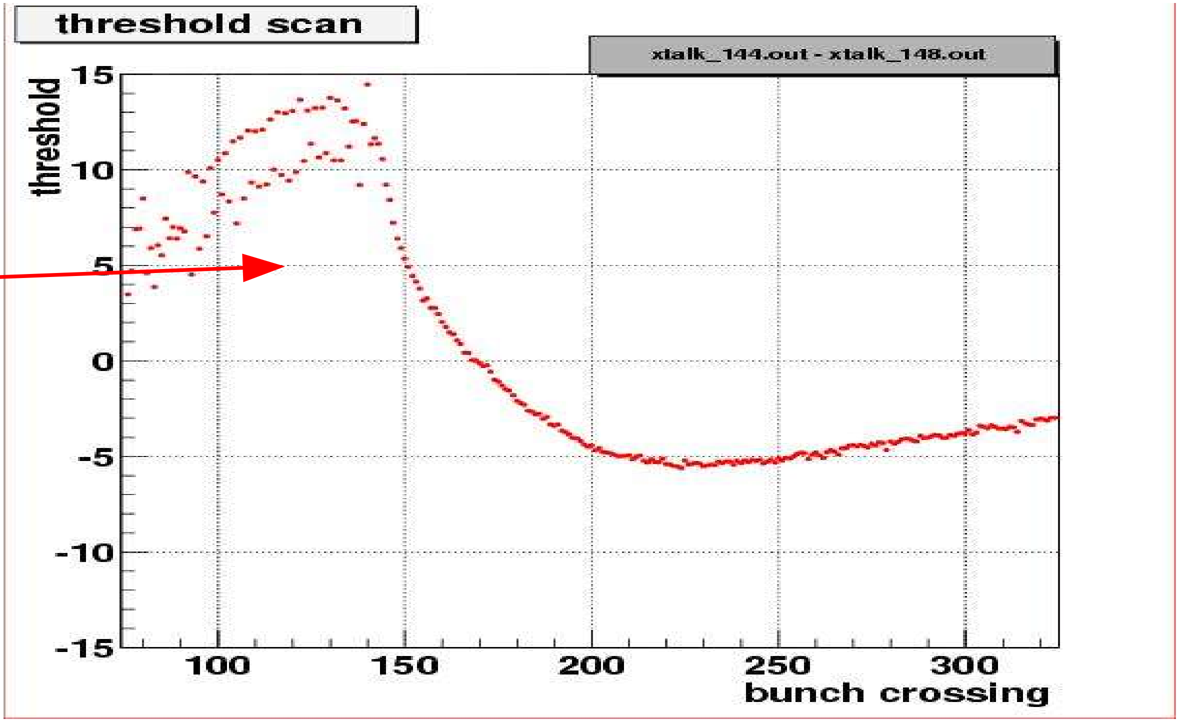


- **baseline for column drain induced threshold shifts:**
  - no pixels are enabled in all ROCs apart from one ROC with testpixel
    - first calinject generates no column drain



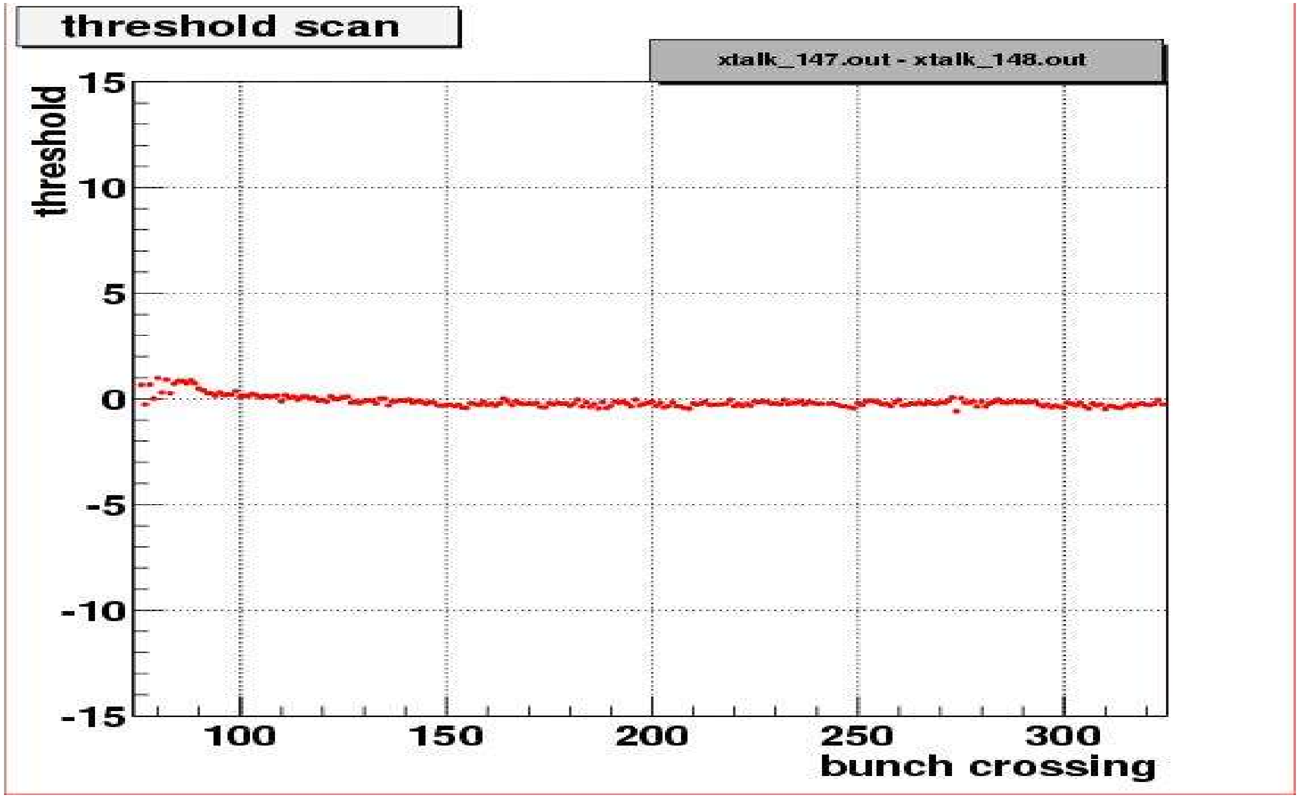

test scenario:

- 20 px/column * 52 columns
- all ROCs
  - different length of column drains visible
  - negative pickup observable during column drain: ~2000 e$^-$ (difference of ~ 50%)
  - measurement procedure is sensitive for cross talk



# column drain induced threshold shift 5

- **investigation of the negative pickup depending on different # pixels are enabled in all ROCs:**




**more realistic scenario:**

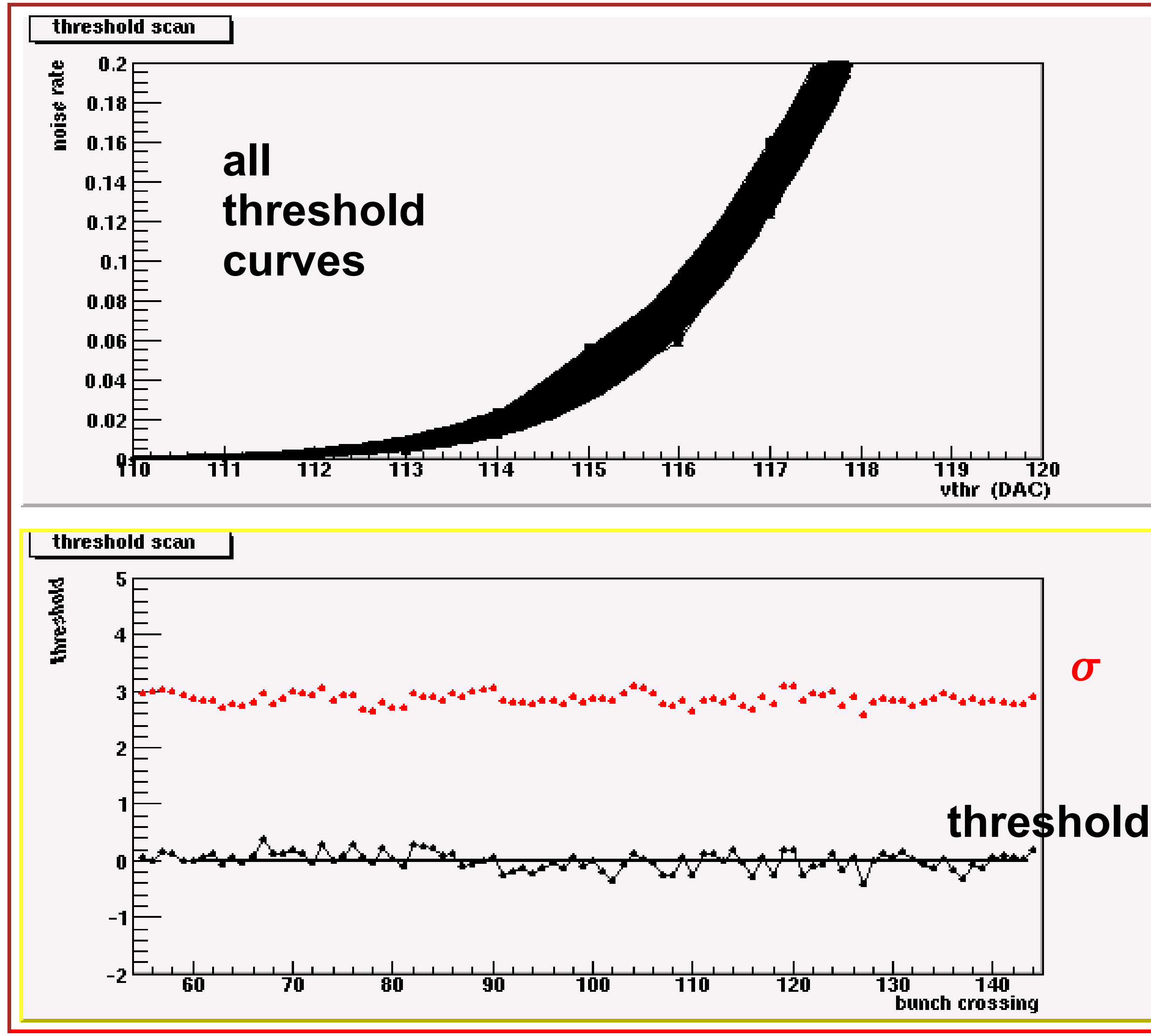
- **3 px/column * 6 columns (cluster)**
- **all ROCs**

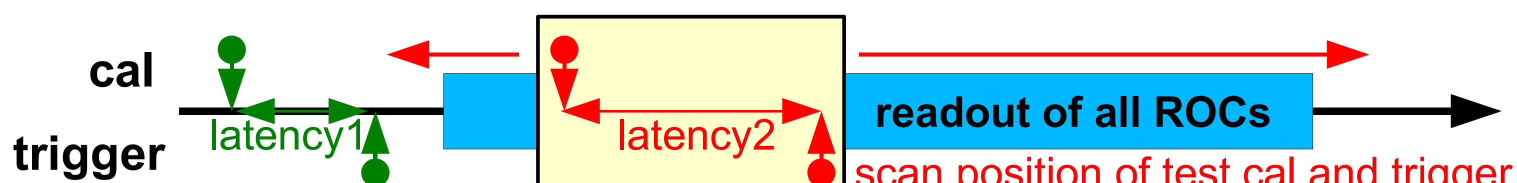
⇨ **for realistic scenario negligible cross-talk <200 $e^-$**

# read out induced threshold shift

look for crosstalk during read out of module:

- deterministic sequence
  - ⇨ pickup cause threshold shift
- scan position of test cal and trigger of test chip over period of activity of the others (read out)
  - ⇨ no significant pickup during
    - readout
    - data buffer-reset

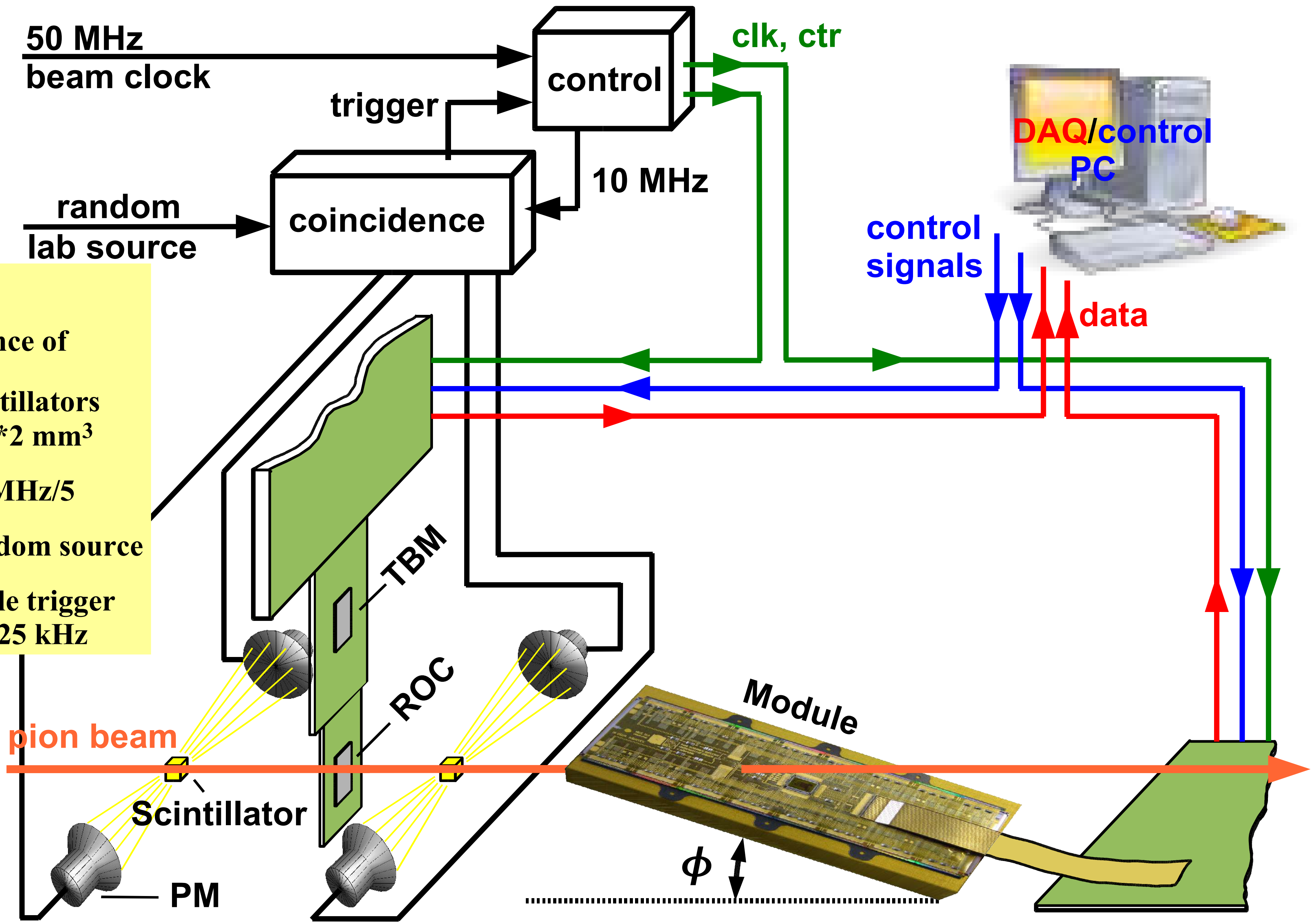


# PSI beamtest

- operate final modules under LHC (CMS) equivalent conditions before full production
  - track density up to 40 MHz/cm$^2$ (@ 4 cm layer and high luminosity $10^{34}$ cm$^{-2}$ sec$^{-1}$)
  - first level trigger rate up to $\simeq$ 100 kHz
  - bunch structure (25 ns $\triangleq$ 40 MHz)
  - continuous data taking and simultaneous readout operation
- PSI $\pi$E1 beam line:
  - 300 MeV/c $\pi^+$ ~ MIPs
  - variable intensity up to 100 MHz/cm$^2$
  - 50 MHz beam structure
    - operate module on synchronized 40 MHz clock
    - allow triggers only every 4$^{th}$ bunch (CMS: $\geq$ 3 separation)
  - but no B-Field

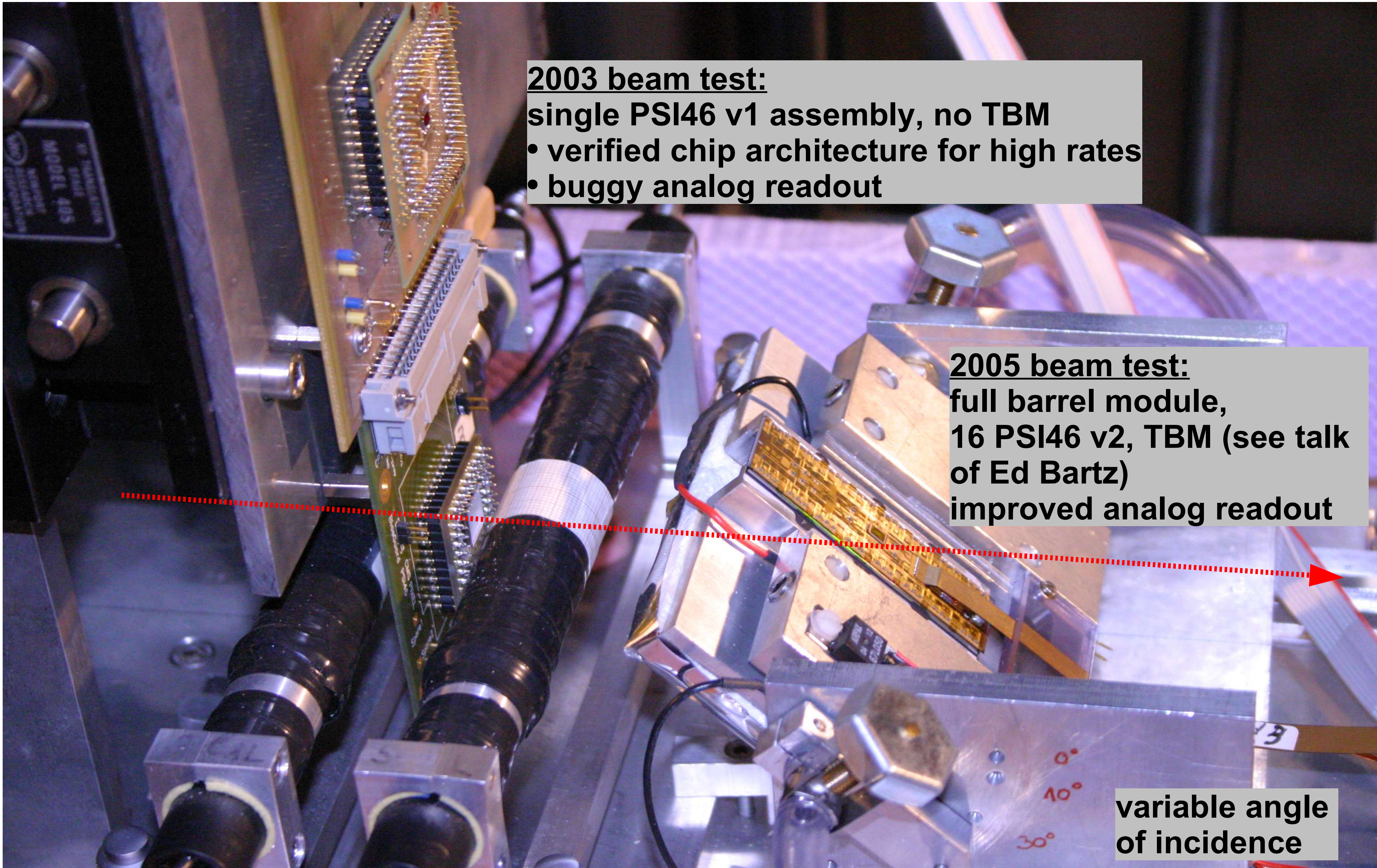
# beamtest setup




trigger:

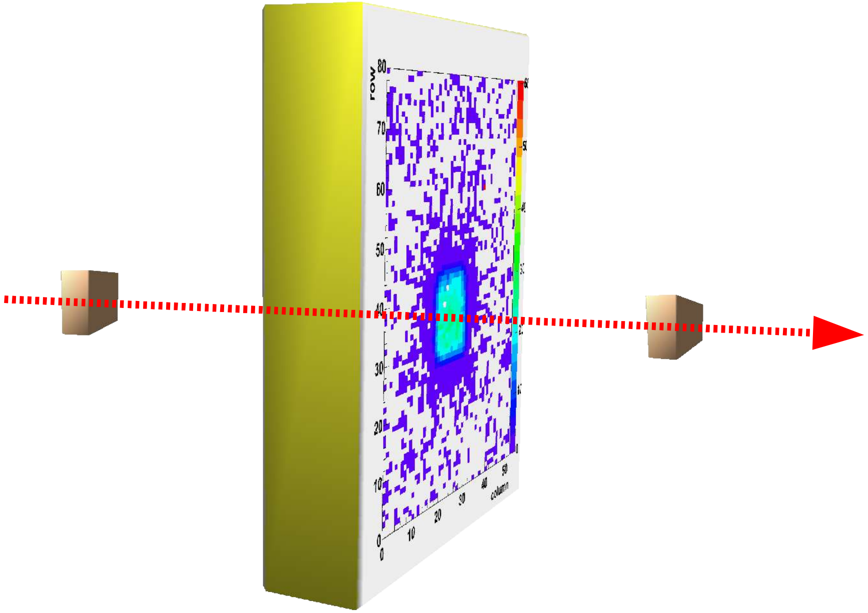
- coincidence of
  - scintillators $2*2*2\ mm^3$
  - 50 MHz/5
  - random source
- adjustable trigger rate 1 ... 25 kHz

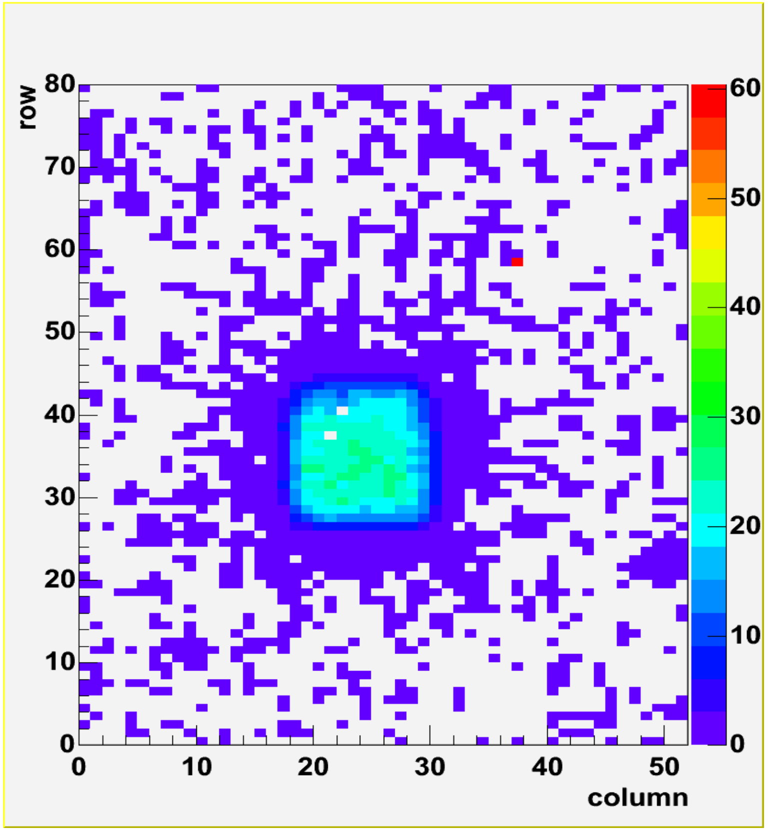
# beamtest setup



# ROC hitmap

- scintillator trigger used as telescope (2*2*2 mm³)
- flat illumination covers entire ROC/module
- triggered events should have hits in an area ~ scintillator size
- high intensity: many random coincidences

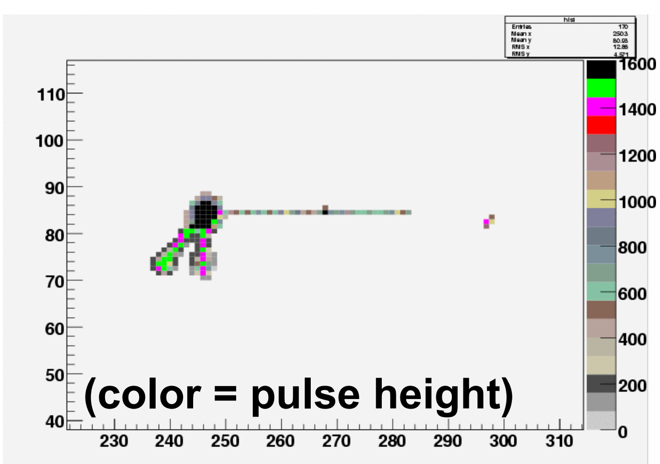


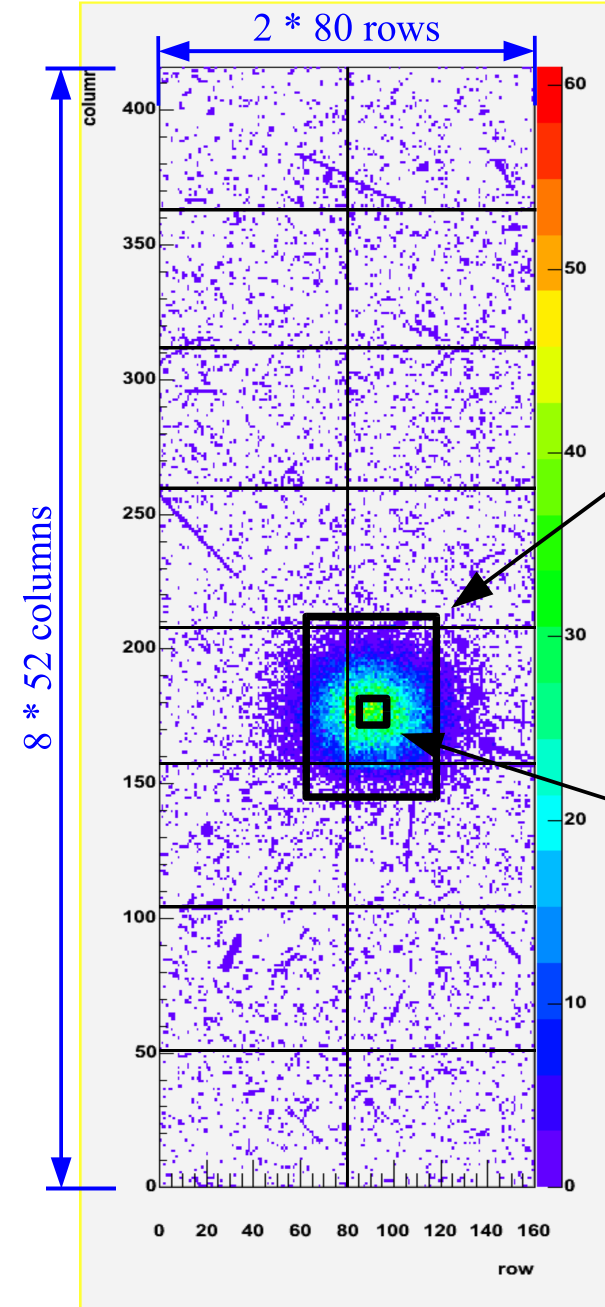



- superposition of 30k events
- intensity: 1 MHz/$cm^2$
- two empty pixels in the trigger region
- one noisy pixel

# module hitmap for 90°

- same run: 30k events
- intensity: 1 MHz/cm$^2$
- beam covers entire module
- 16 ROCs: 160 * 416 pixels
- trigger image blurred by beam divergence
- observed tracks of secondary particles



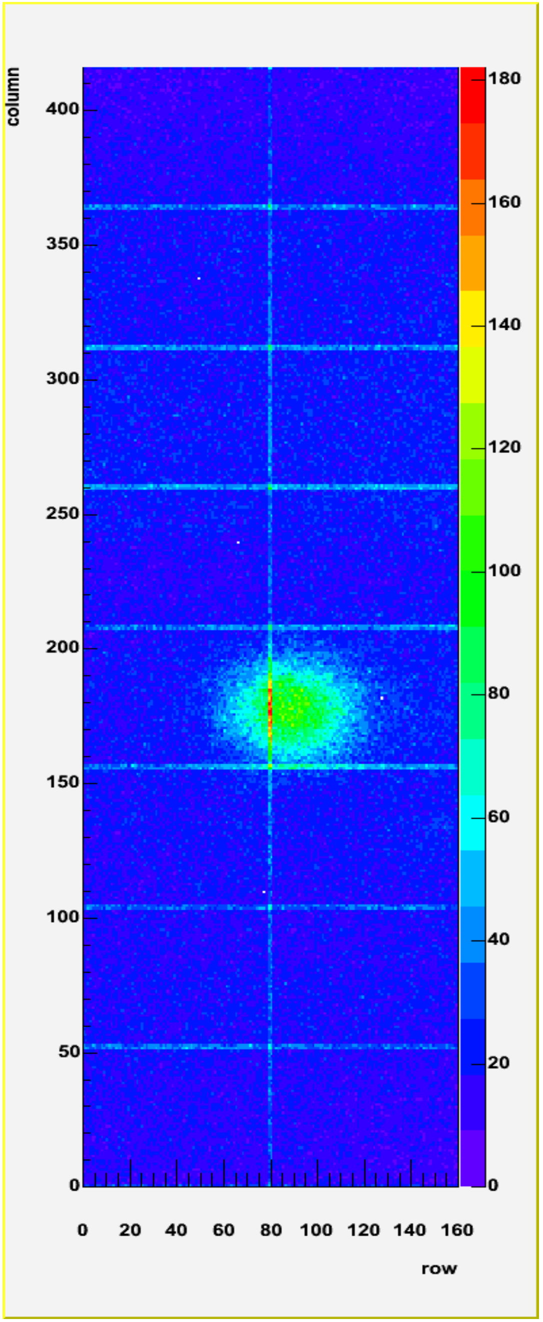




single ROC assembly outline

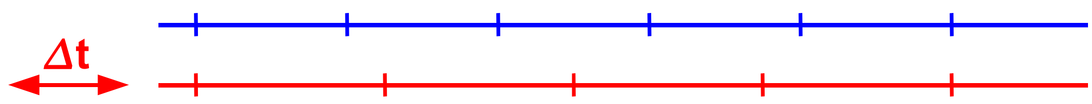
trigger scintillator shadow

# module hitmap for 90°

- **high intensity run:**
  - **90k events**
  - **intensity: 47 MHz/cm$^2$**
  - **trigger rate 18 kHz**
- **random rates (random coincidence)**
- **higher rates in edge pixels:**
  - **2 * area of regular pixel**



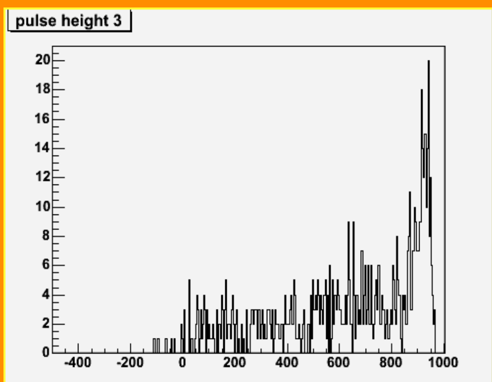
# delay scan: vary system clock wrt beam

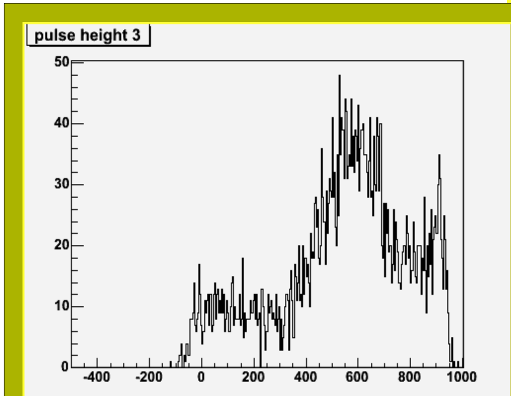


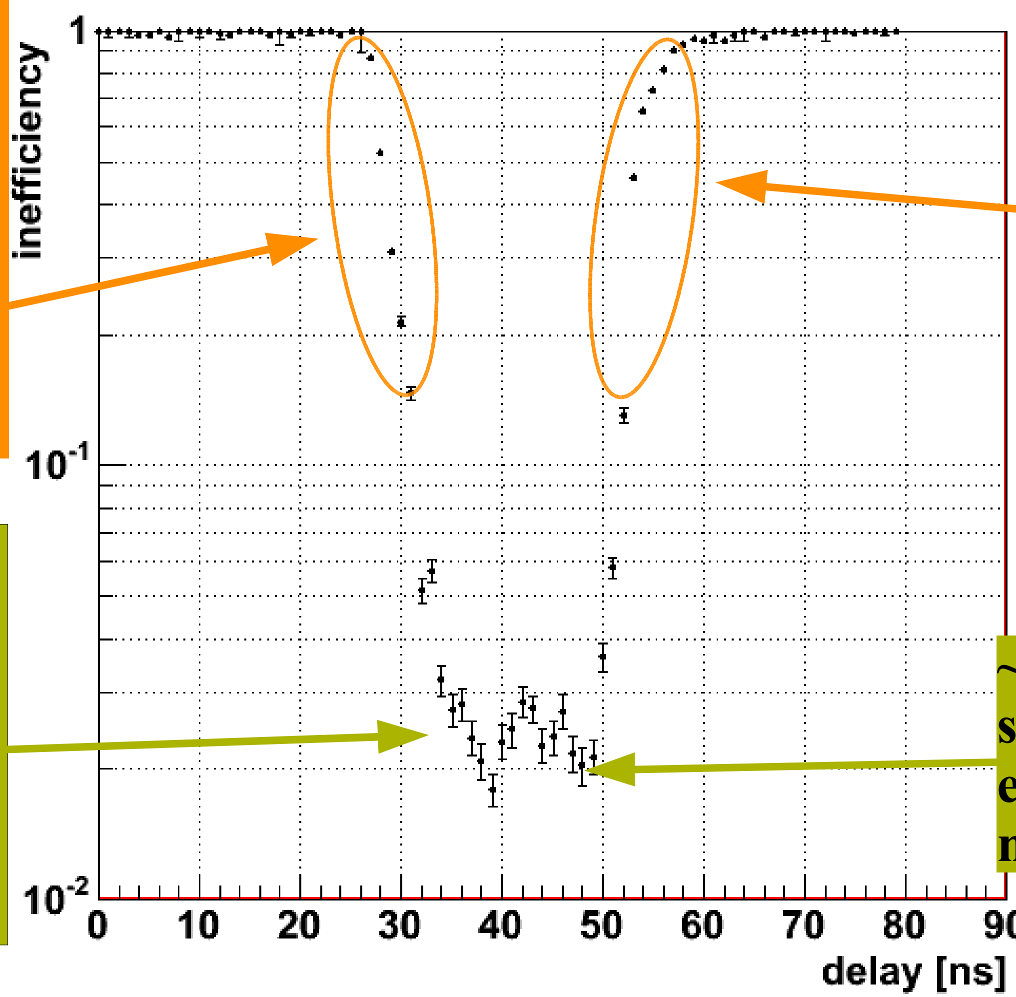

50 MHz beam structure

40 MHz system clock

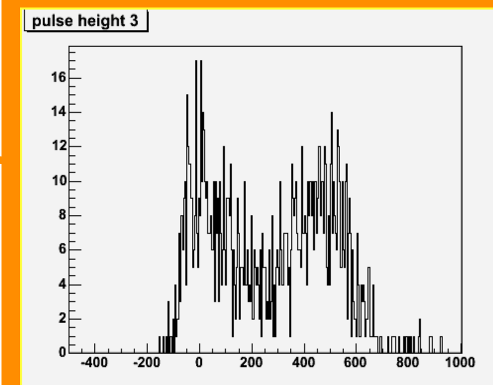
too early, see only large pulses:




too late, loose already large pulses:




~ 15 ns plateau
select timing:
efficient for large pulses,
minimize loss at low Q

# module: calibrated analog pulse-heights

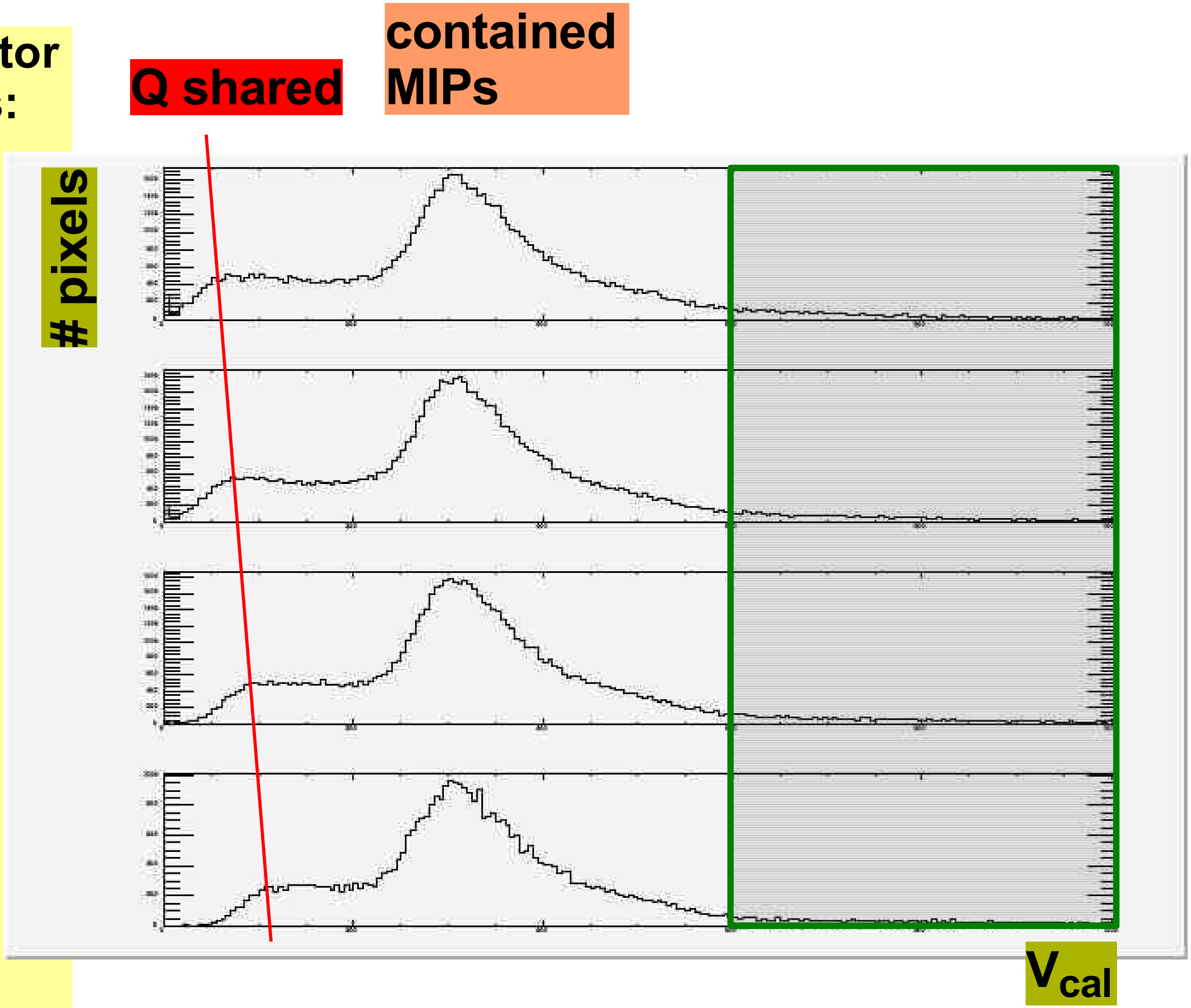
discriminator thresholds:

3000 e$^-$

3500 e$^-$

4900 e$^-$

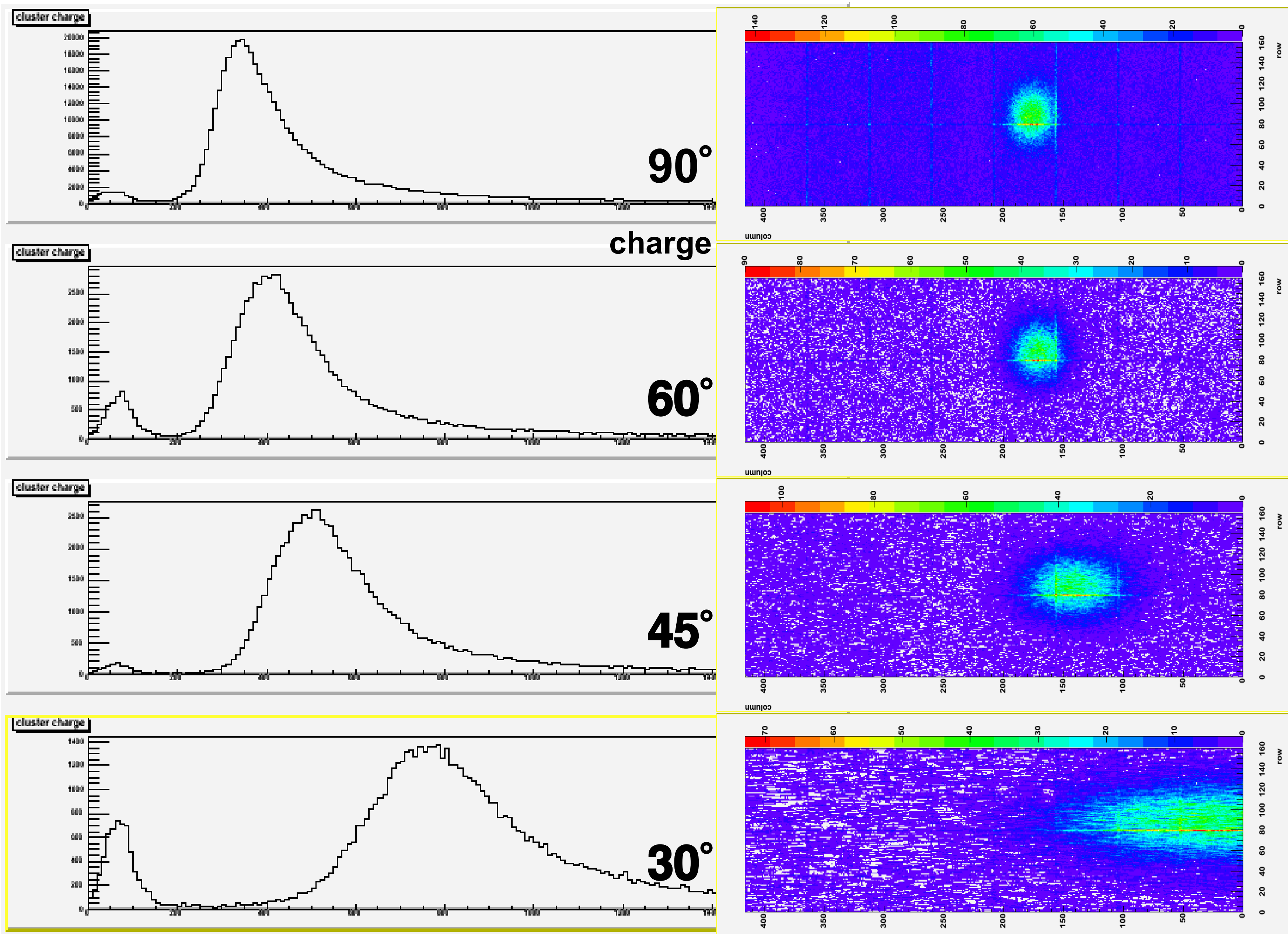
6300 e$^-$




- single pixel pulse-heights plotted
- corrected using internal calibration signals
- saturation @ ~ 2 MIPs (correction with large error)

# module: cluster charge for various angles

- **cluster charge ~ t/sin $\Phi$**
- **pixel charge decreases with $\Phi$**
- **test for cluster reconstruction and analog readout**



# summary

- intra-module crosstalk investigations:
  - evidence for crosstalk for simultaneous column drains in large fractions of a module
  - negligible crosstalk in realistic scenario
  - no crosstalk seen during readout
- beam test with final barrel module:
  - CMS pixel barrel module with final components operated in high rate beam ⇨ TBM05 & PSI46 v2 co-operate without evident problems
  - good time walk behavior, effective thresholds ~ 3-4ke$^-$
  - improved analog readout works very well
  - analysis of high rate data not finalized
  - problems:
    - preliminary inefficiency results are inconsistent with previous beam test results (even for single ROC) ⇨ analysis in progress
    - PSI46 needs resets
    - brand-new DAQ/software, some bugs, impacts on results unclear

⇨ follow-up beam test later this month with improved setup (telescope, ...)