The Laser Alignment System (LAS) of the CMS Silicon Strip Tracker

- Working principle
- Layout & components
- Commissioning
- Operation & reconstruction
- Measurements & first results

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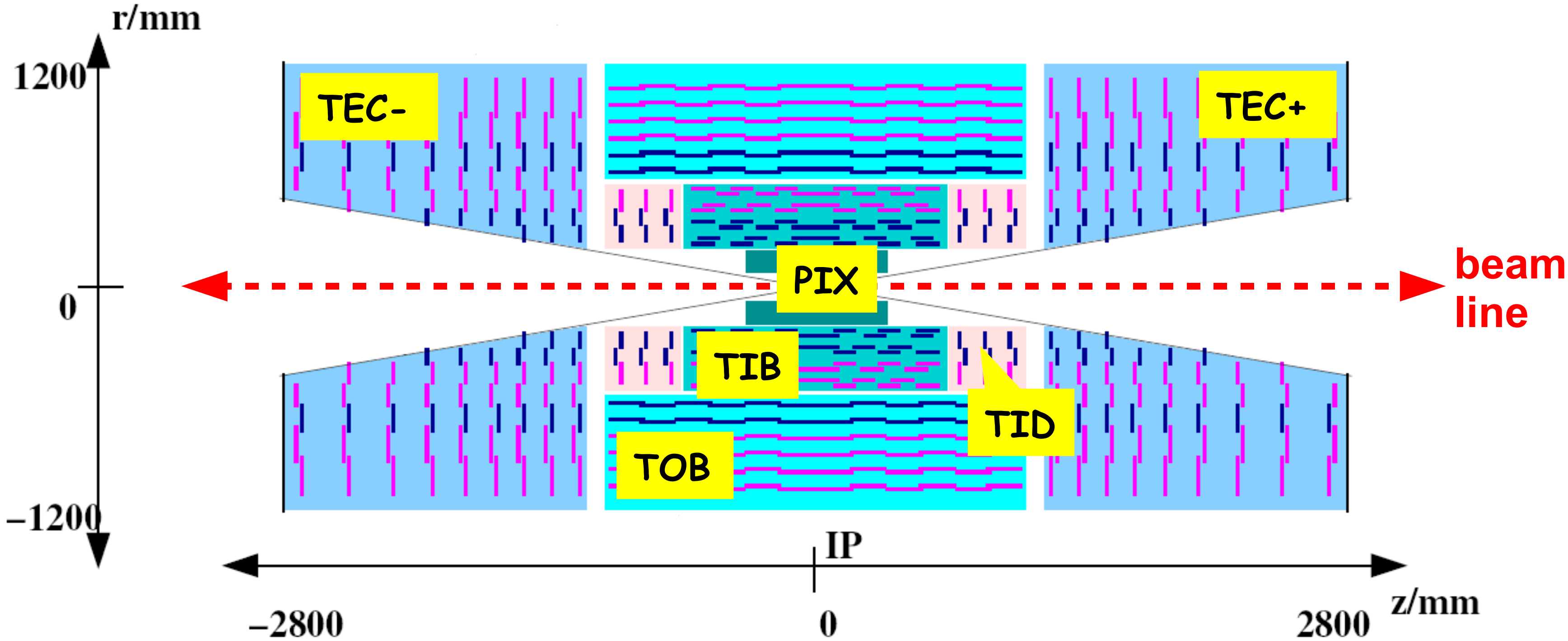
The CMS Silicon Strip Tracker

Inner / Outer barrel (TIB / TOB) – four / six cylindrical layers, carrying longitudinal structures (rods/strings)

Inner disks (TID) – three disks on either side of inner barrel

Tracker end caps (TEC) – nine disks each, staggered along z



LAS Purpose & Working Principle

Possible deformations of the tracker support structure due to ΔT, ΔB or humidity

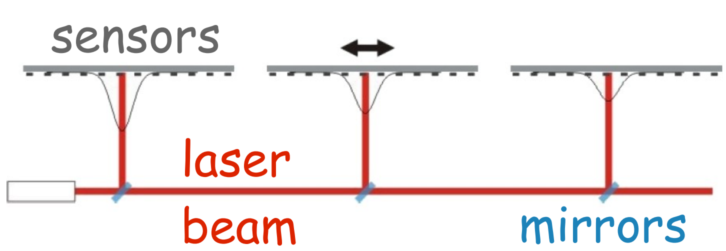
Purpose of the LAS -

- Monitor the geometry of large-scale support structures of the tracker:
  - Disks within an endcap aligned w.r.t. each other
  - TEC+, TEC-, TIB, TOB aligned w.r.t. each other
- Absolute precision: <100 μm
- Precision relative to a previous measurement: < 20 μm
- Very fast response: data acquisition & reconstruction: O(1 minute)

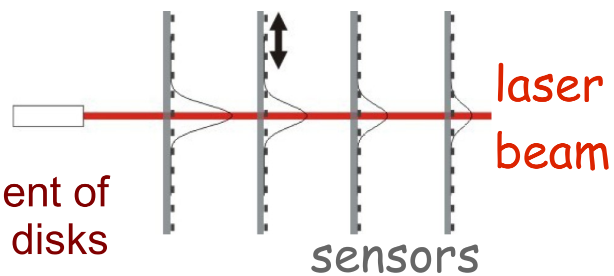
} high beam redundancy

Working principle -

- A system of infrared laser beams traverse the tracker volume (silicon is semitransparent at λ ≈ 1075 nm)
- Laser beams are detected on the microstrip sensors
- Sensor positions can be reconstructed from the measured laser spots



Alignment of barrel subdetectors

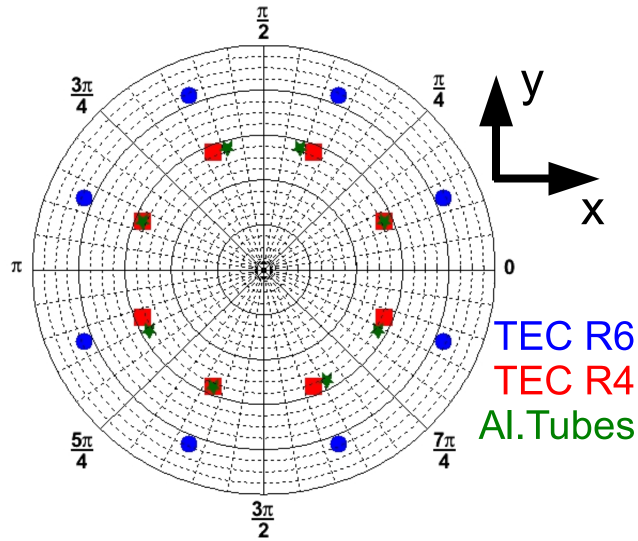


Alignment of endcap disks

LAS Layout

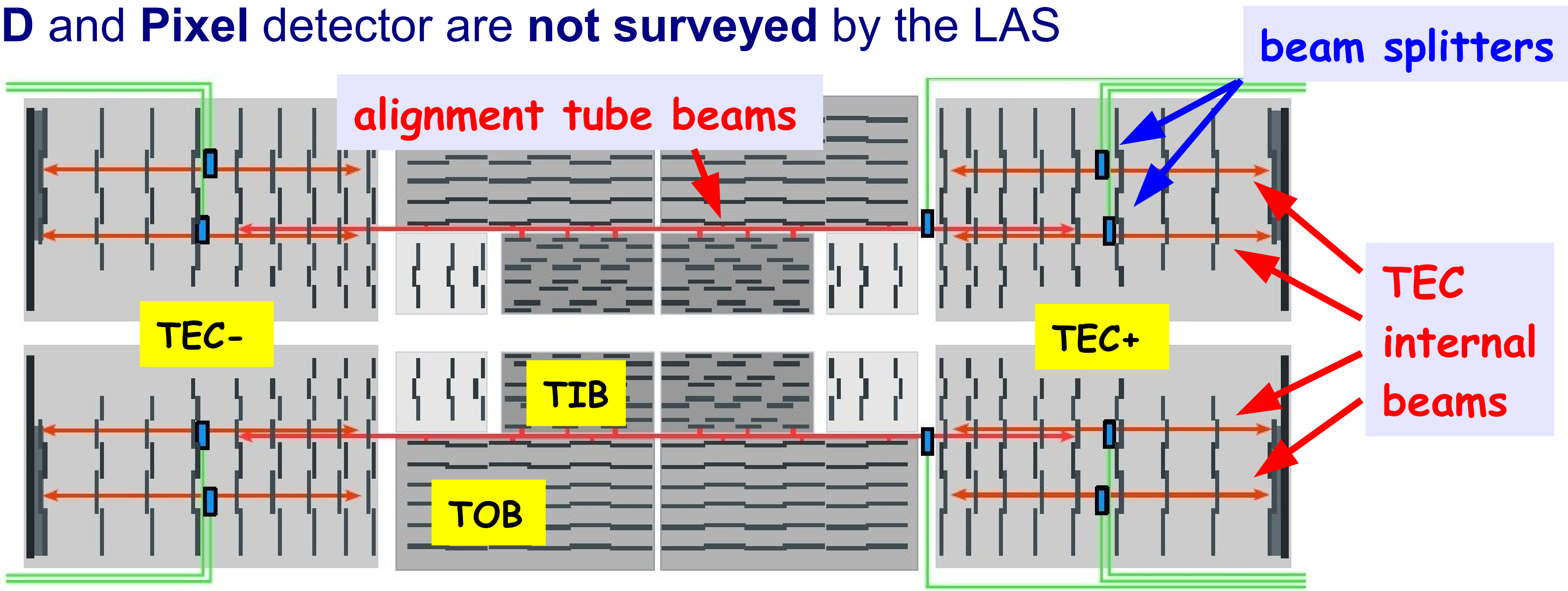
Total of 40 laser beams in **two beam systems**:

- Endcap internal alignment
  2 groups of 8 beams interconnect all disks in each TEC at two different radii (564 / 840 mm)
- Subdetector alignment beams ("alignment tubes")
  8 beams interconnect TIB, TOB, TEC+ and TEC- at 564 mm radius

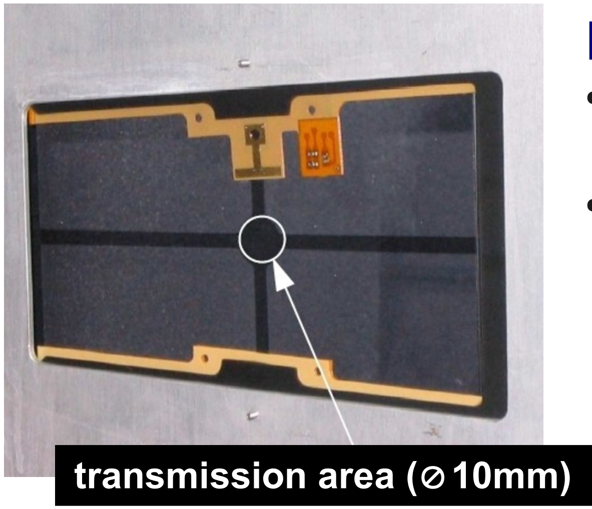


Total of **434** sensor modules hit by laser beams

TID and **Pixel** detector are **not surveyed** by the LAS

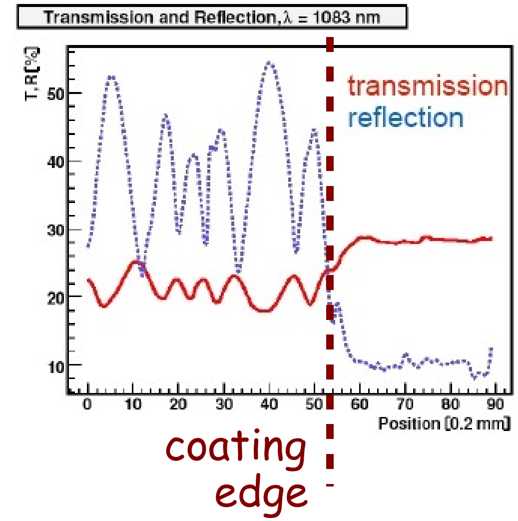


Alignment sensors & beam splitters



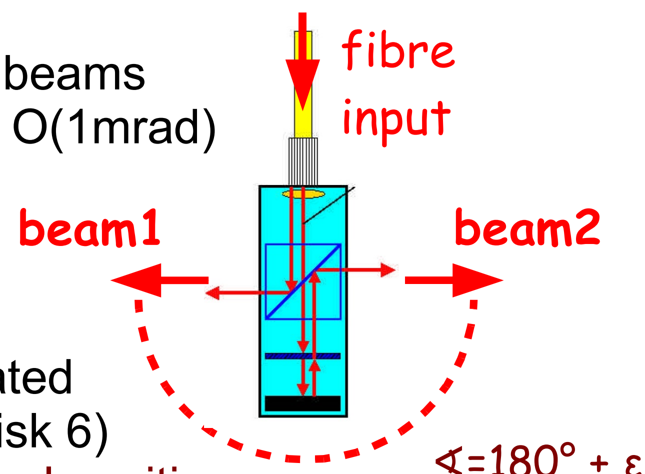
Endcaps: specially modified alignment sensors -

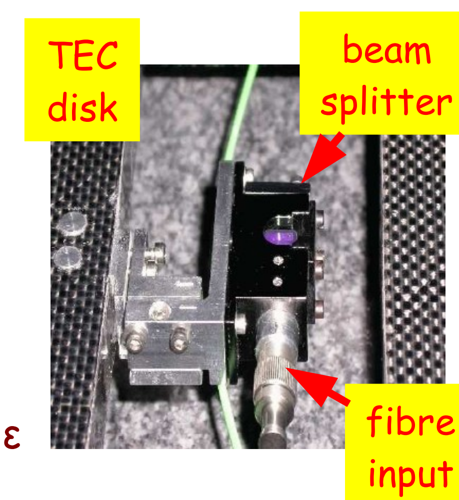
- Hole in backplane metallization (otherwise no transmission)
- Anti-reflective coating on back-side
  - improves transmission
  - reduces multi-reflections (better signal quality)



Light distribution with beam splitters -

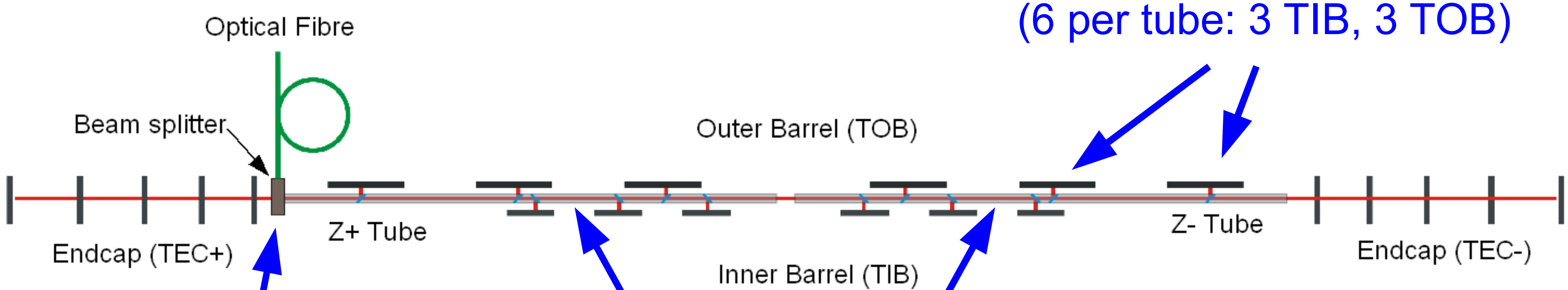
- Optics Laboratories, Islamabad
- Generates a pair of back-to-back beams
- Slight deviations from collinearity, O(1mrad)
  - have been measured in the lab
  - measurements must be corrected for this effect
- Endcap beam splitters are integrated in the tracker support structure (disk 6)
  → beams may deviate from nominal positions (devitations are free parameters)





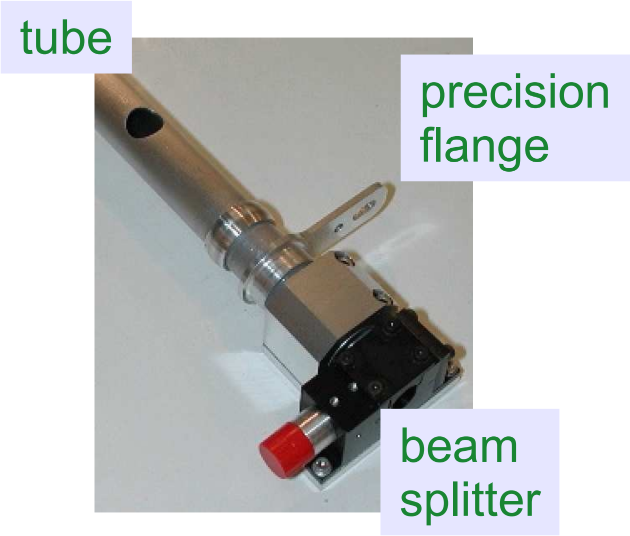
Alignment Tubes:
8 beams interconnecting TIB, TOB and TEC+/-

light deflected on modules by semitransparent mirrors (6 per tube: 3 TIB, 3 TOB)



1 beam splitter at plus-side end

2 aluminum tubes per beam



Mirrors -

- glass plates with single-sided anti-reflective coating
- 5% reflection per mirror

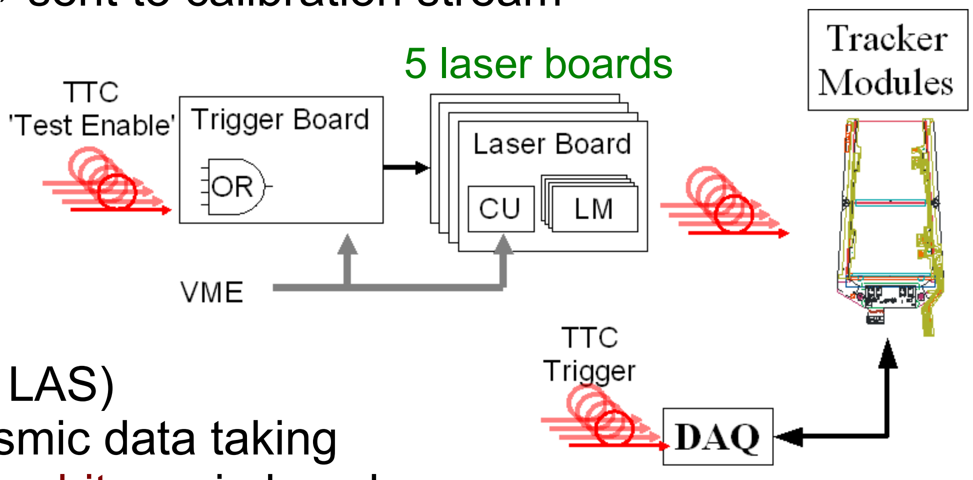
Coplanarity of mirrors / collinearity of beamsplitters -

- measured in the lab before assembly
- values used for correction of LAS data

LAS electronics & operation

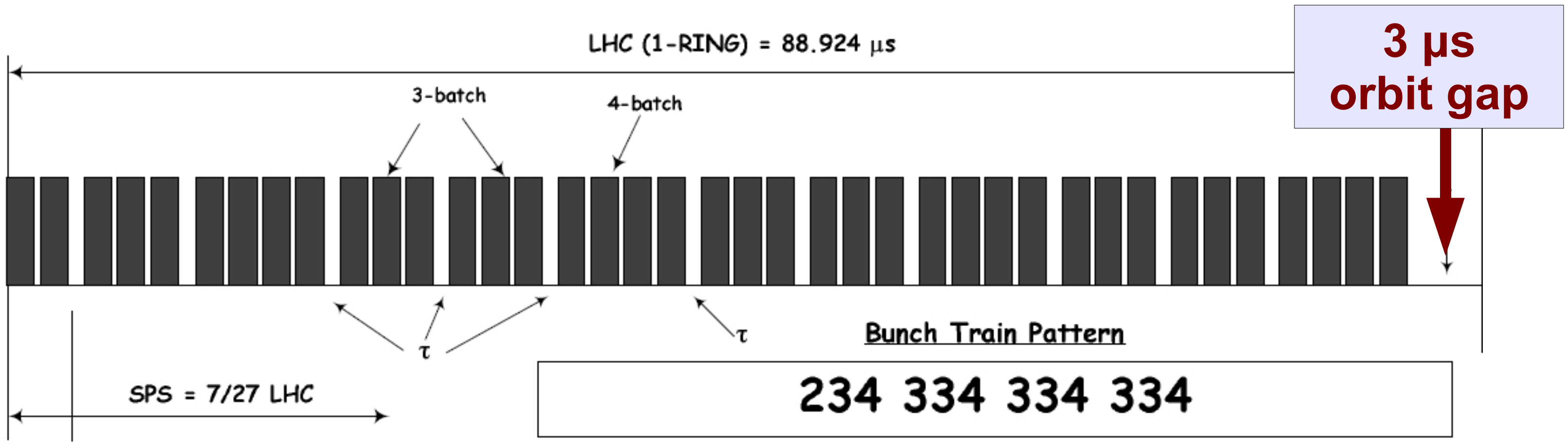
Laser event generation:

- lasers in service cavern are fired upon TTC-B (calibration) triggers (100 Hz)
- front end drivers tags laser events → sent to calibration stream



Modes of operation:

- dedicated alignment runs
  (all tracker parameters optimized for LAS)
- 2008 / 2009 running in parallel to cosmic data taking
- for regular monitoring, later use 3 µs orbit gap in bunch train pattern (avoid interference with physics events)



Endcap Beam Profiles

In the endcaps, beams traverse up to 4 silicon sensors

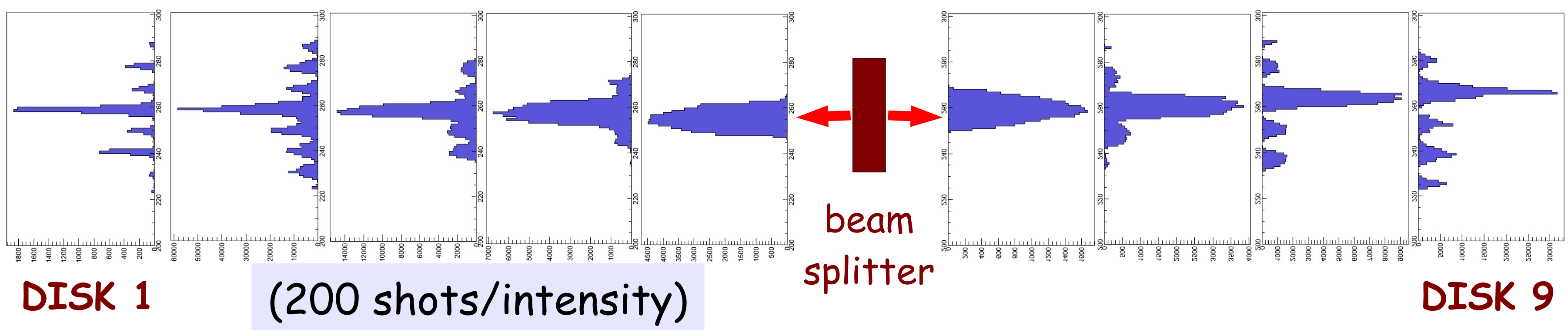
- 20-30 % transmission: impossible to induce good signal on all layers simultaneously
  → lasers must operate with up to 5 alternating intensities (shot-by-shot)
  → some modules will be saturated with too high intensities (distorted beam spots) in a subset of the events

Distortion of beam profiles:

- Non-ideal beam optics
- Interference inside silicon bulk from multiple reflections

} asymmetric or non-gaussian beam spots

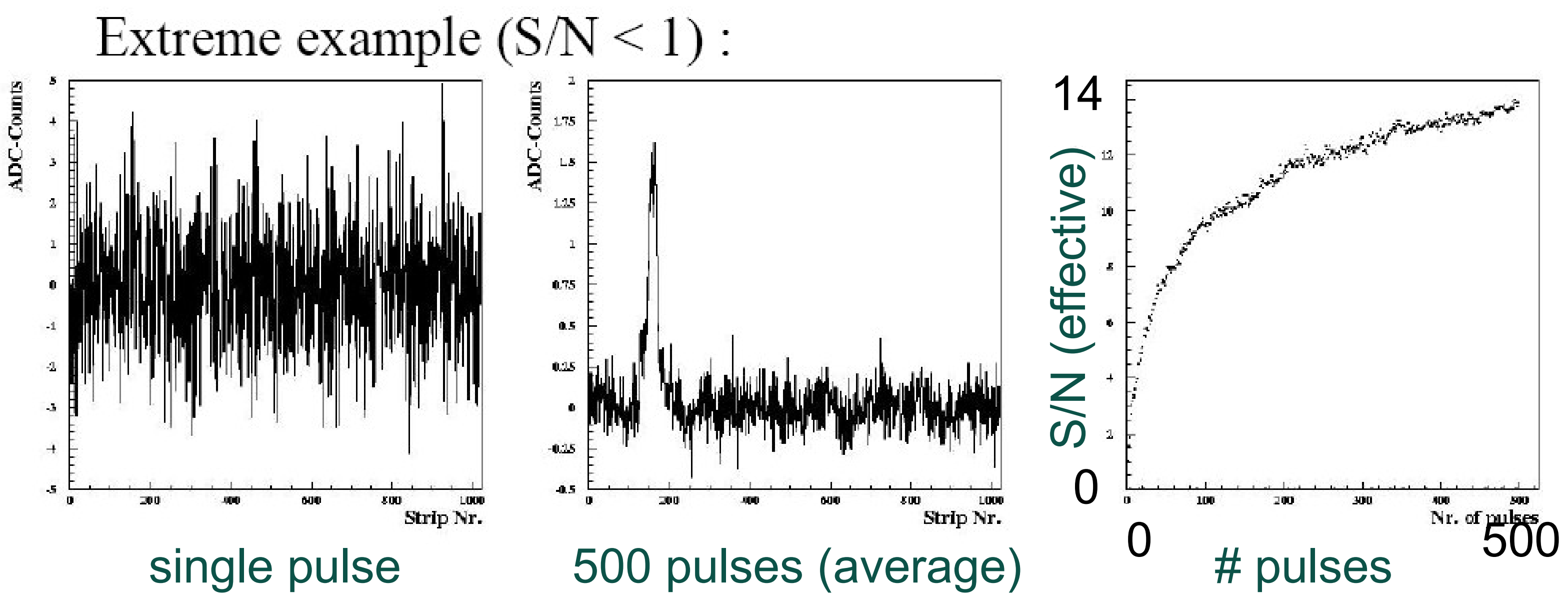
- (Multiple) diffraction at strip metallization → side maxima



→ Need sophisticated filtering & fitting algorithms to handle these effects

Signal-over-noise

Noise reduction by summing up events:



Limited by zero suppression -

- only strip signals with S/N above threshold recorded (nominal data taking mode)

Required number of events for one alignment “snapshot” -

- 5 different intensities
- ~200 pulses summed per module
- alternating operation of endcap / alignment tubes

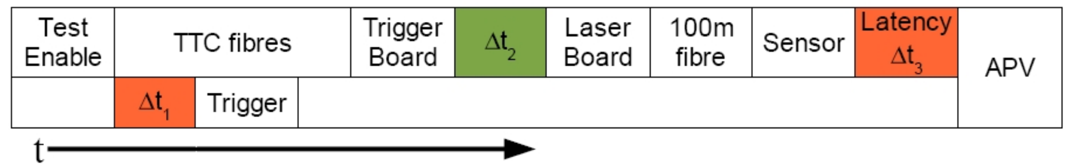
} total of 2000 pulses

Calibration trigger rate: 100 Hz → 20 sec.

LAS Commissioning

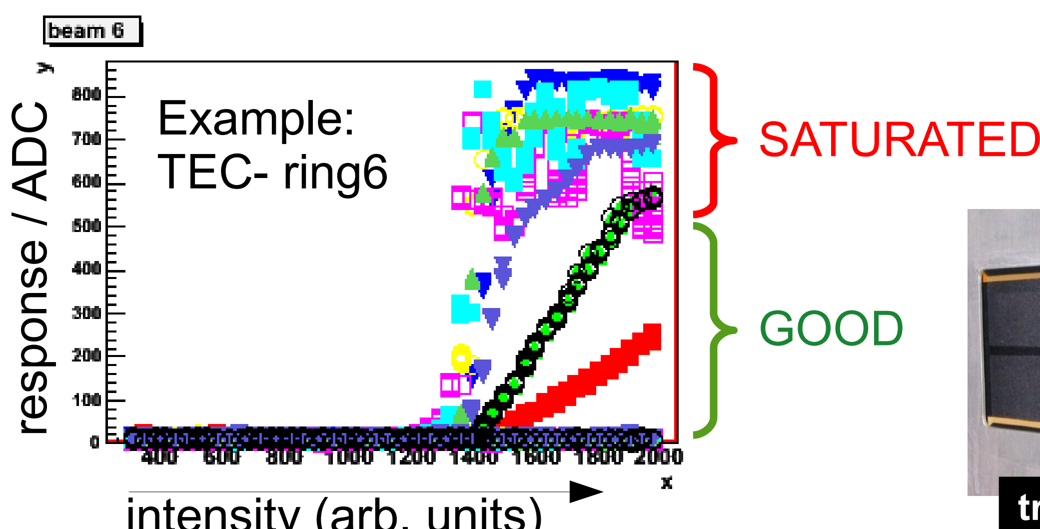
Timing adjustment -

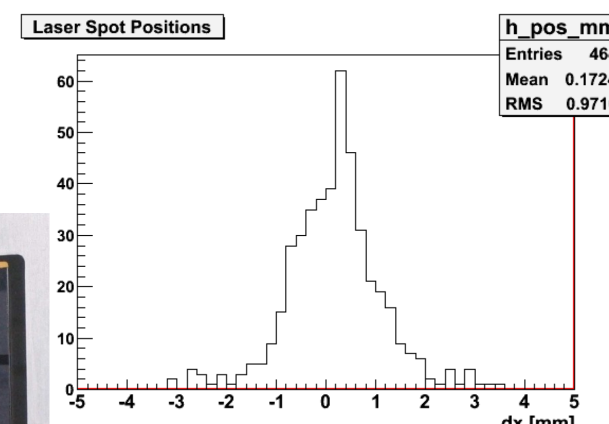
- global coarse timing (in bc. = 25 ns):
  trigger latency Δt_1 (FIXED), readout latency Δt_3 (FIXED),
  → LAS trigger delay Δt_2 (adjustable)
- fine timing (individual beams) to correct for fiber lengths & photon TOF



Intensity adjustment -

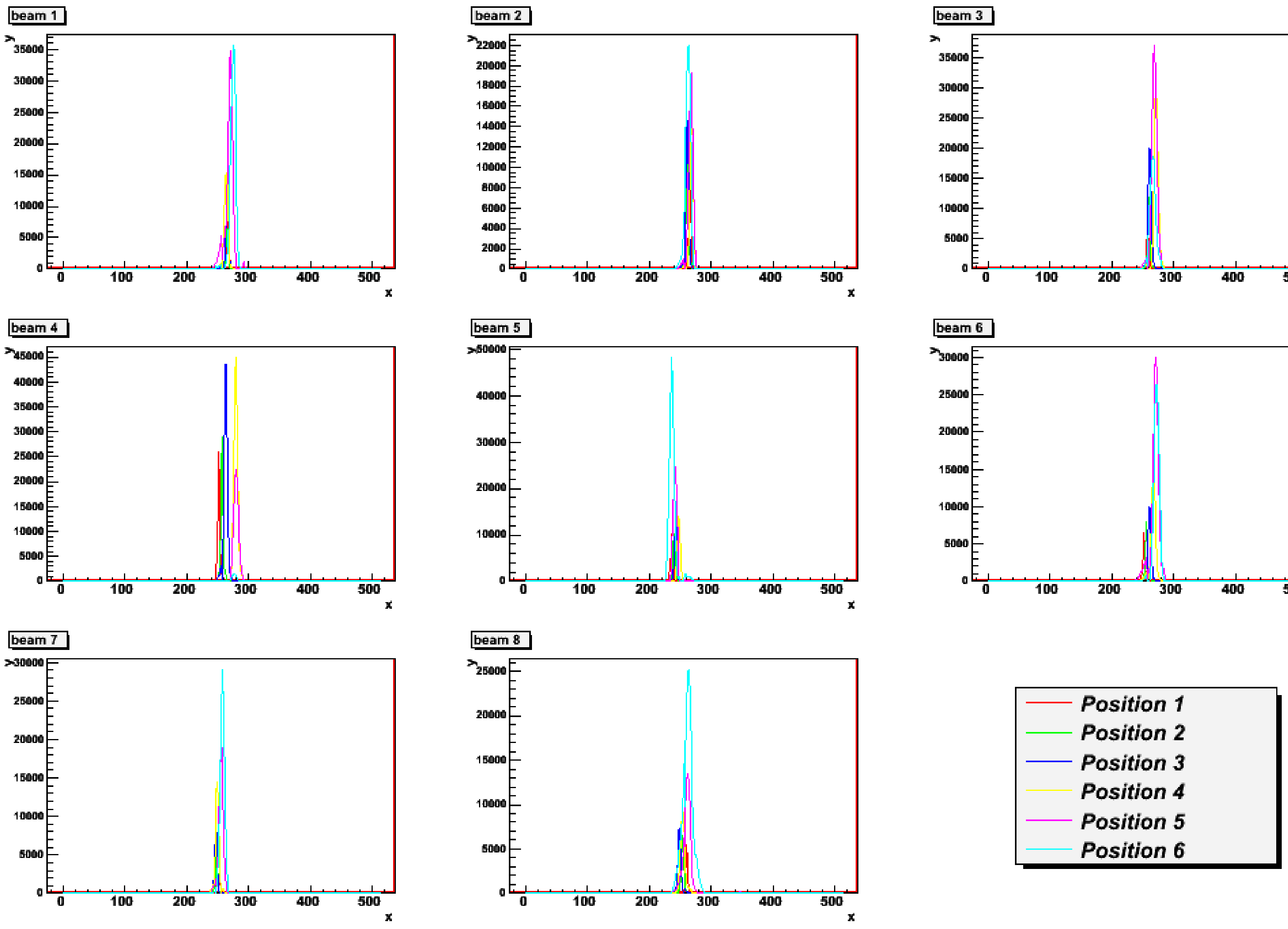
- Scanning laser intensity to determine proper settings for all individual layers



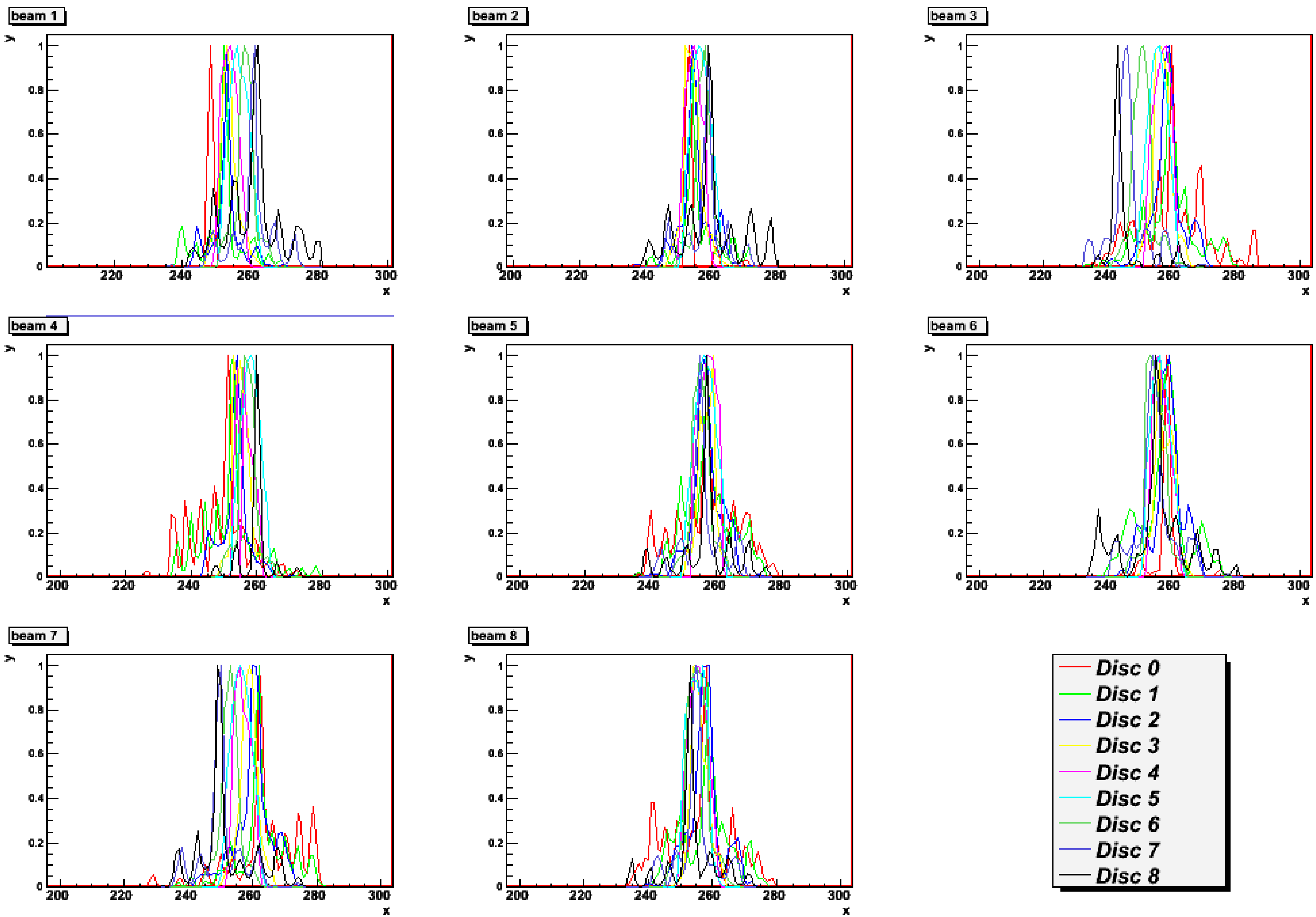


All beam spots within dynamic range

Laser profiles for Inner Barrel



Laser profiles for Forward Endcap

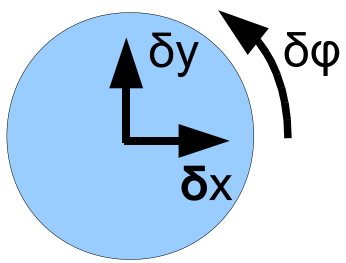


LAS Alignment Parameter Reconstruction

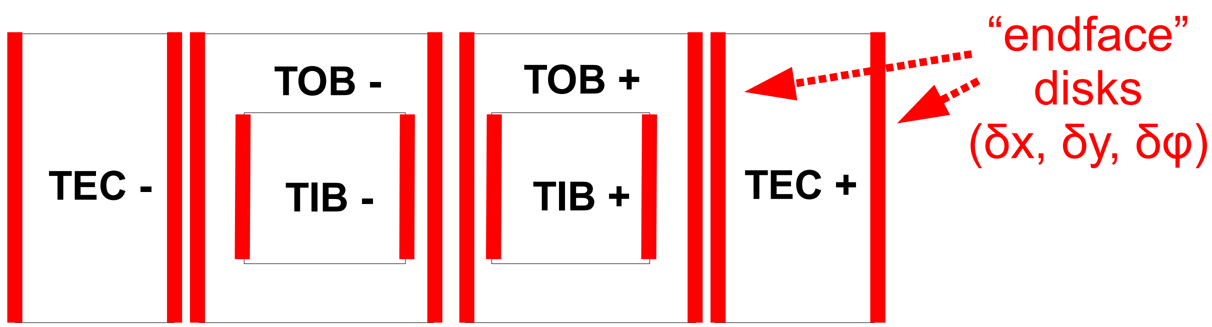
LAS output is two-fold:

- Fast standalone geometry reconstruction for CMS data quality monitoring
- Delivers refined laser hit positions as additional input for track-based alignment

Alignment parameters accessible to the LAS:



- endcap internal alignment: three parameters per disk (δx, δy, δφ)
- subdetector alignment (alignment tubes):
  endcaps / barrel detector halves modeled with disk-like “endfaces”

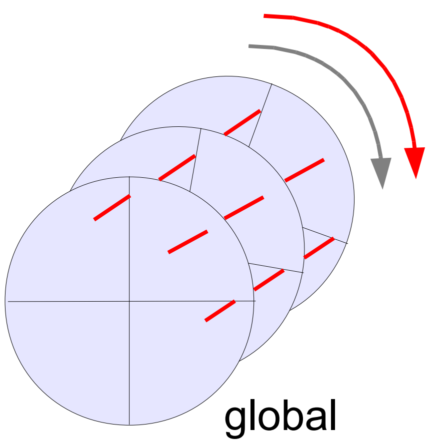


Standalone reconstruction:

434 laser hit residuals as functions of alignment parameters:

$$\Delta ym_{i,k} = -R_0 \cdot \Delta\phi_0 + \sin(\theta_i) \cdot \Delta x_0 - \cos(\theta_i) \cdot \Delta y_0 - \frac{z_k \cdot R_0}{L} \cdot \Delta\phi_t + \frac{z_k \cdot \sin(\theta_i)}{L} \cdot \Delta x_t \quad \text{(TEC)}$$

$$- \frac{z_k \cdot \cos(\theta_i)}{L} \cdot \Delta y_t - R_0 \cdot \Delta\phi_k + \sin(\theta_i) \cdot \Delta x_k - \cos(\theta_i) \cdot \Delta y_k - (z_k/L - 1) \cdot R_0 \cdot \Delta\theta A_i - z_k/L \cdot R_0 \cdot \Delta\theta B_i$$



global
disk/beam torsions
indistinguishable

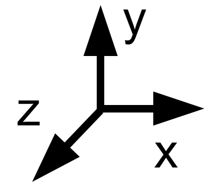
Equation system can be solved analytically:

→ Alignment parameters = $f(\sum_{\text{Residuals}})$ → Inverse transformation

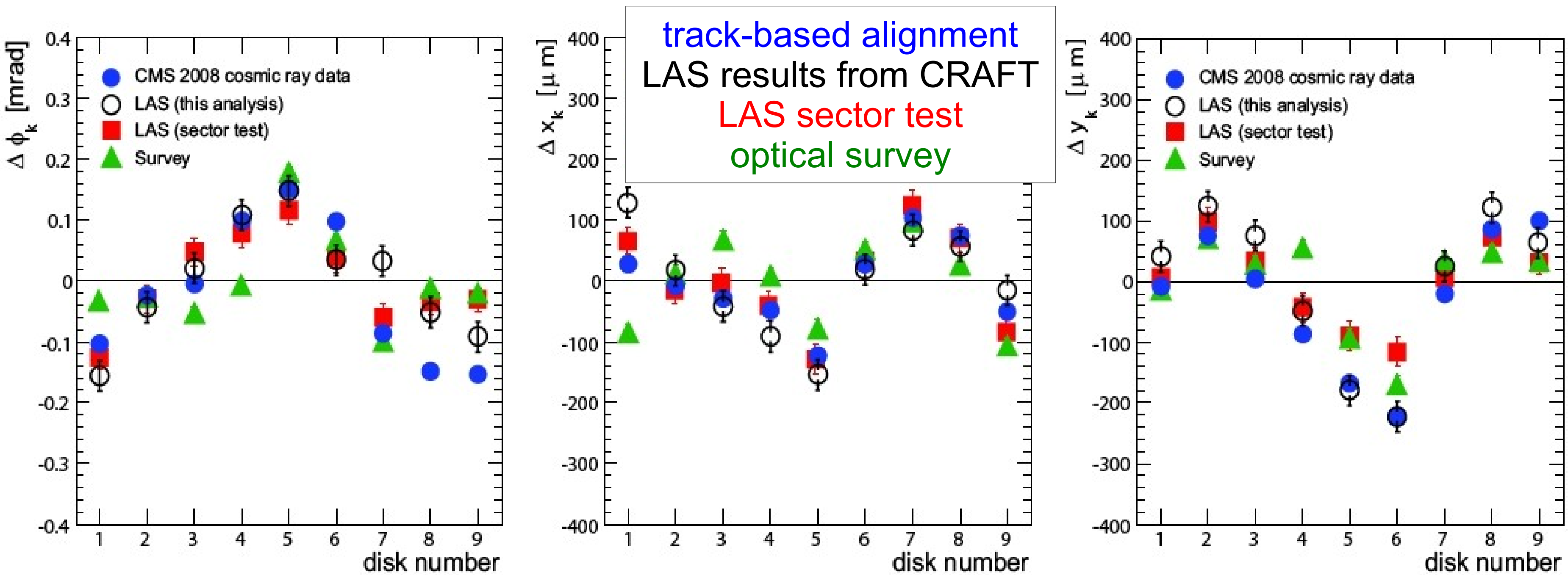
Results from 2008 cosmic data taking

LAS was operated during **CRAFT '08** (2008 cosmic data taking campaign) -

- Main purpose was hardware commissioning
- Data also used for alignment parameter reconstruction
- 31 out of 40 laser beams operational



Alignment parameters for the TEC+ endcap disks:



Δφ (rotational displacement) Δx (horizontal displacement) Δy (vertical displacement)

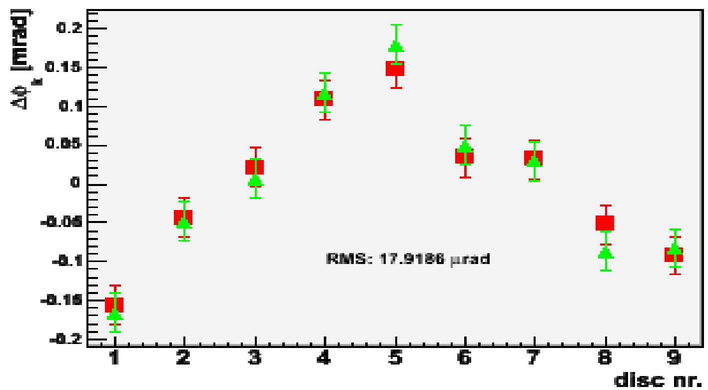
Good agreement with track-based alignment -

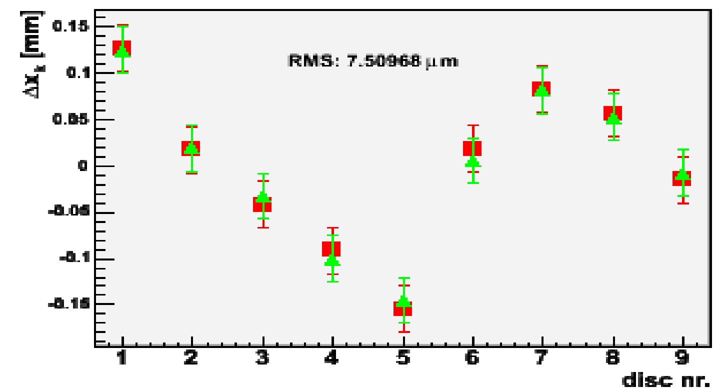
- LAS monitors only a subset of modules
- Discrepancies with sector test & survey: TEC rotated and shipped in between

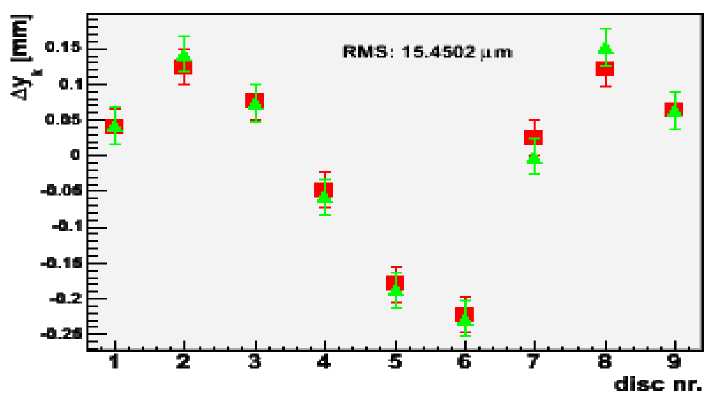
Comparison: cosmic data taking 2008 / 2009
- preliminary results -

Conditions during LAS operation:

	CRAFT '08	CRAFT '09
B-Field	0 T	3.8 T
Readout mode	Peak	Deconvolution







LAS CRAFT '08
LAS CRAFT '09

Alignment parameters reproduced within 18 μrad / 15 μm

Summary

The CMS Tracker Laser Alignment System provides fast monitoring of the tracker support structure's stability -

- Endcap disk inter-alignment
- Alignment of TIB, TOB, TEC+ and TEC- with respect to each other
- Absolute precision < 100 μm, < 20 μm relative to a previous measurement

The system is fully integrated and commissioned -

- All beams operational
- Timing and intensity scans completed

LAS measurements in forward endcap (TEC+) currently best-studied and understood -

- Good agreement with results from track-based alignment
- Accuracy expectations were confirmed

Extend alignment to TEC- and barrel subdetectors -

→ study corrections for mirror coplanarity & beam splitter collinearity