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Silicon Strip Beam Telescope at H8

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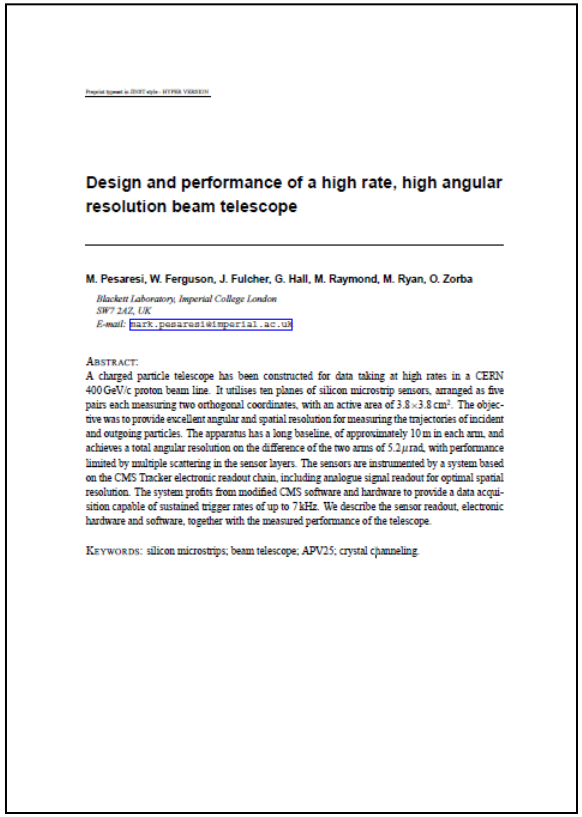
Silicon Strip Beam Telescope

New beam telescope built this year for CMS upgrade activities and UA9 experiment

- **Partly commissioned and tested in June at H8**
- **Fully tested and used for UA9 crystal qualification at H8 in September**

Test beam performance has been analysed over last few months

- **Paper to be submitted**



Prepared typeset in JINST style - HYPER VERSION

Design and performance of a high rate, high angular resolution beam telescope

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ABSTRACT:
A charged particle telescope has been constructed for data taking at high rates in a CERN 400 GeV/c proton beam line. It utilises ten planes of silicon microstrip sensors, arranged as five pairs each measuring two orthogonal coordinates, with an active area of 3.8×3.8 cm^2. The objective was to provide excellent angular and spatial resolution for measuring the trajectories of incident and outgoing particles. The apparatus has a long baseline, of approximately 10 m in each arm, and achieves a total angular resolution on the difference of the two arms of 5.2 μrad, with performance limited by multiple scattering in the sensor layers. The sensors are instrumented by a system based on the CMS Tracker electronic readout chain, including analogue signal readout for optimal spatial resolution. The system profits from modified CMS software and hardware to provide a data acquisition capable of sustained trigger rates of up to 7 kHz. We describe the sensor readout, electronic hardware and software, together with the measured performance of the telescope.

KEYWORDS: silicon microstrips; beam telescope; APV25; crystal channeling.

Beam Telescope for H8

Provides five 2D measurements

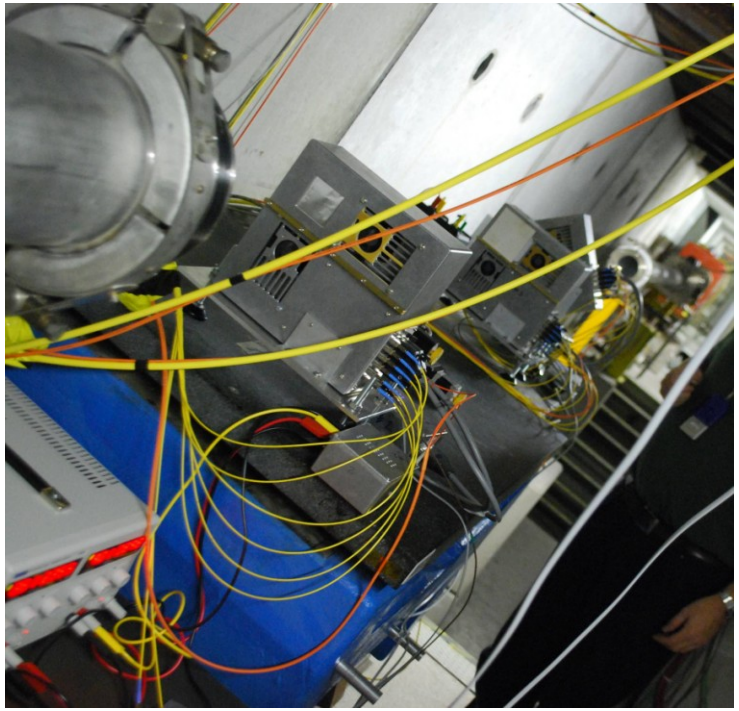
- 4 XY measurements and 1 UV (45° rotation) measurement to resolve track ambiguities

Uses 10 silicon strip sensors intended for the D0 tracker upgrade

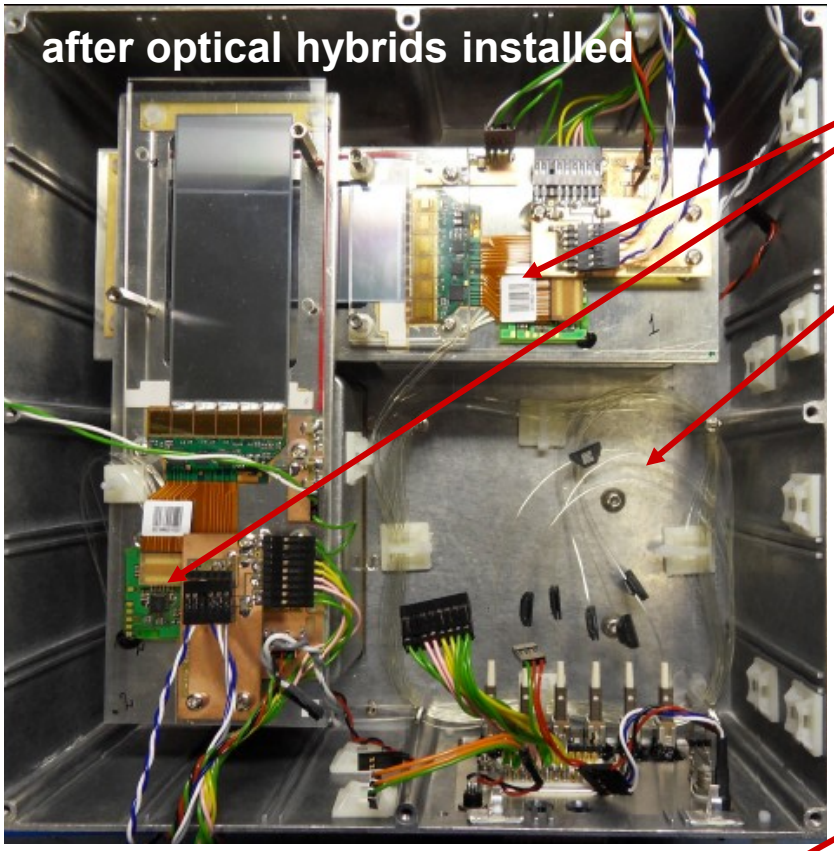
- 60μm strip pitch with intermediate floating strip to get an effective <8μm hit resolution

Readout system based on CMS tracker

- APV25 CMOS chip with 50ns CR-RC shaping time, up to 4μs trigger latency
- Analogue data transmitted over optical fibres to counting room
- Front End Driver digitises, pedestal/CM subtracts and sparsifies data



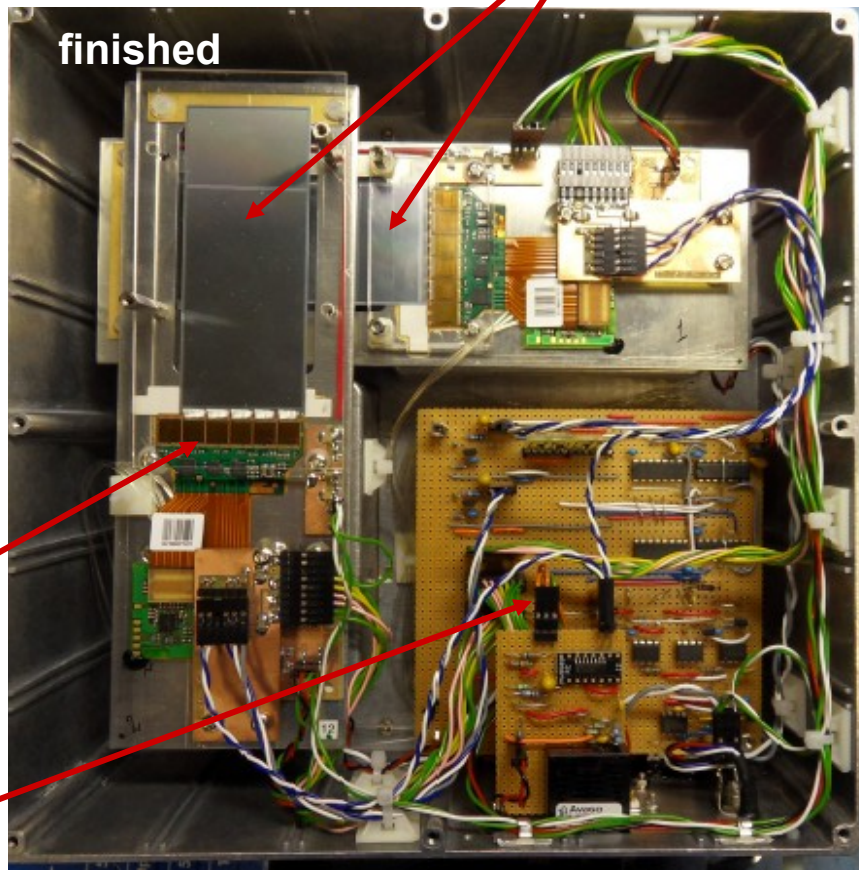
XY Plane Construction



analogue opto-hybrids

fibres

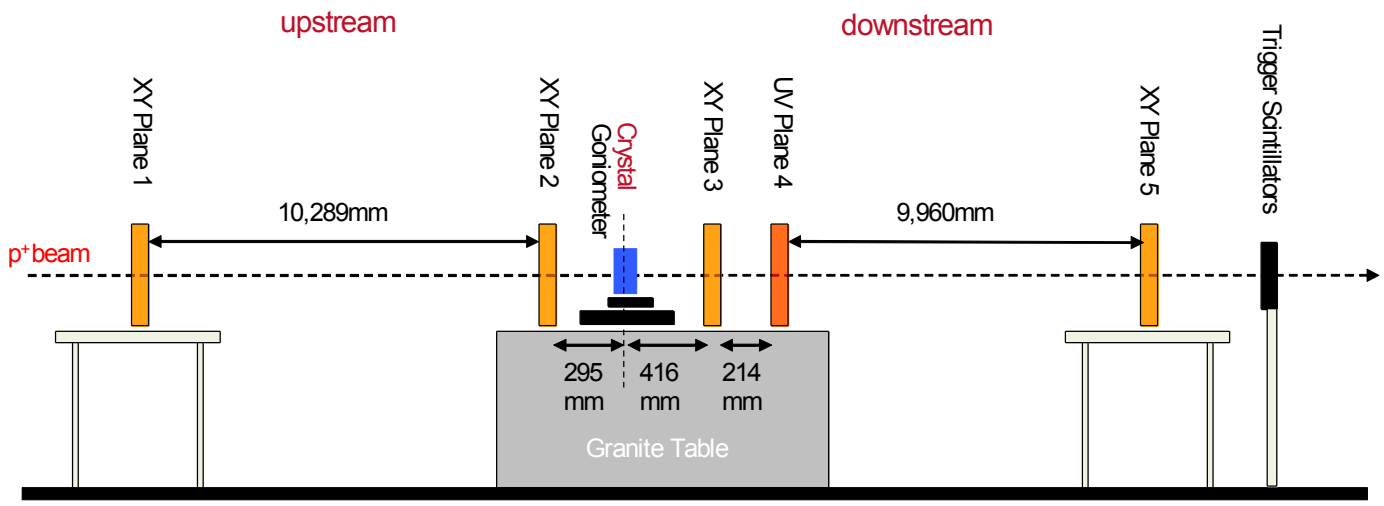
sensors



APV25 readout chips

I2C interface circuitry,
power supply conditioning,
peltier cooling control

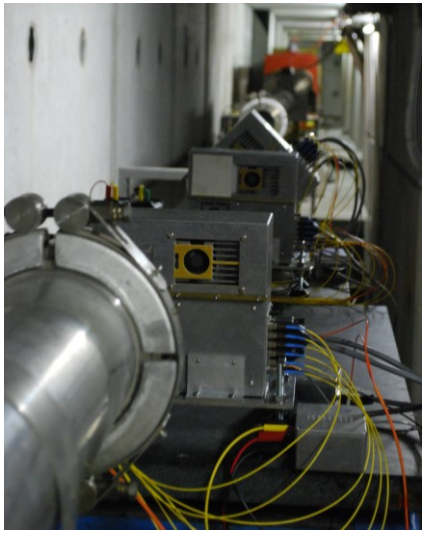
Telescope Layout



Two measurement arms – approximately 10m length in each

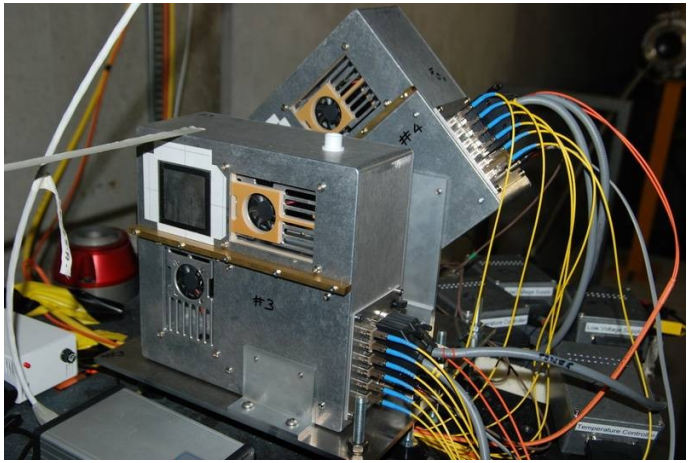
- **Dominant contribution to angular error from multiple scattering (~2.4μrad from ~640μm silicon per plane)**
- **Outgoing arm uses additional UV plane to disambiguate multiple hits downstream of crystal**

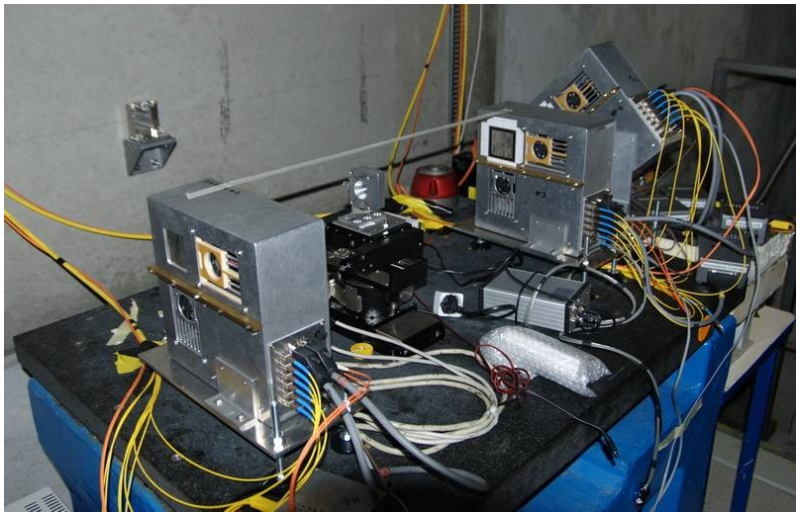
Telescope Performance



As a whole, system performed well

- All XY planes operationally stable, no connectivity problems
- Temperatures remained constant at 20°
- Took ~3-4 days to commission and debug system after cabling





DAQ/Run Performance

DAQ relatively easy to use and control

Stable operation by the end of the run but some improvements, bug fixes to be implemented

Run statistics summary:

Runs 292-391 (~6 days)

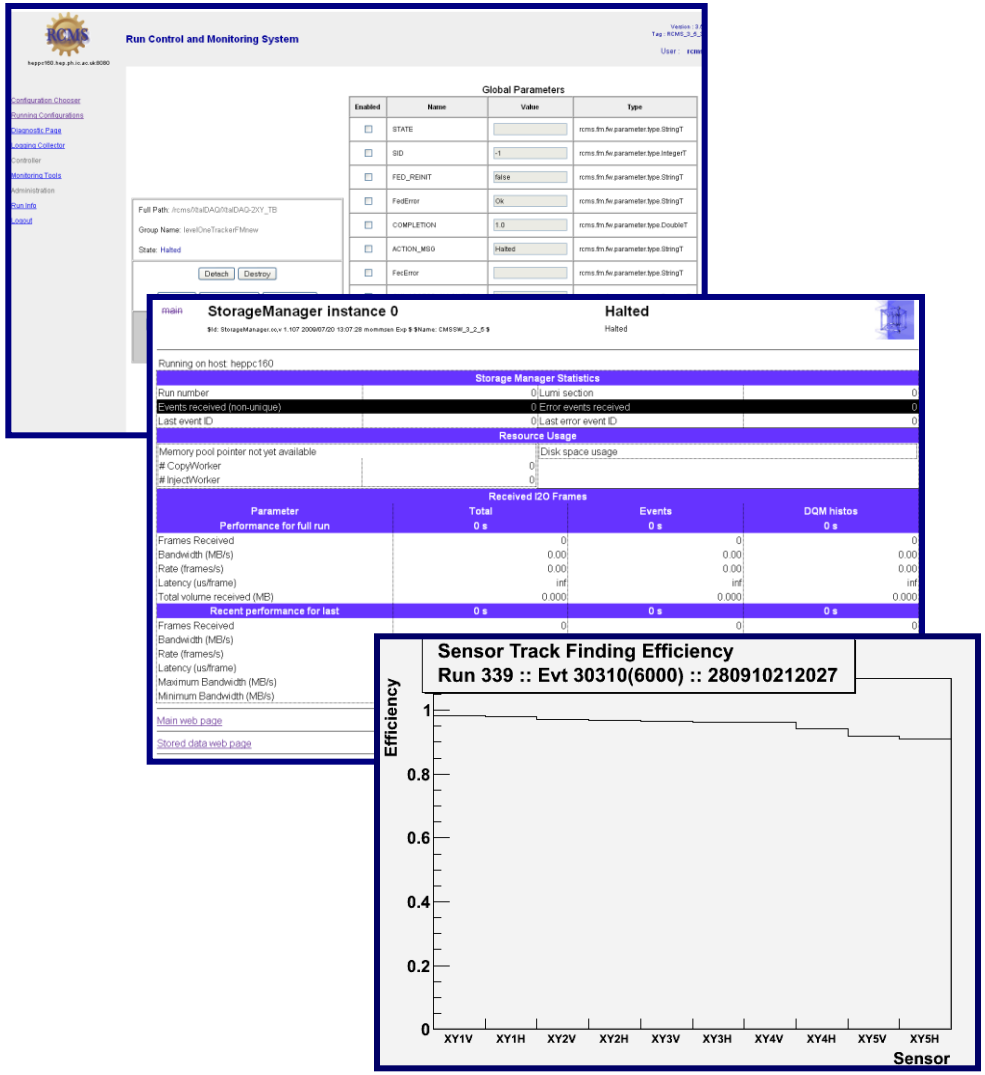
- 50K events per file
- ~6000 events/spill
- ~55 million events collected

Runs 406-552 (~3.5 days)

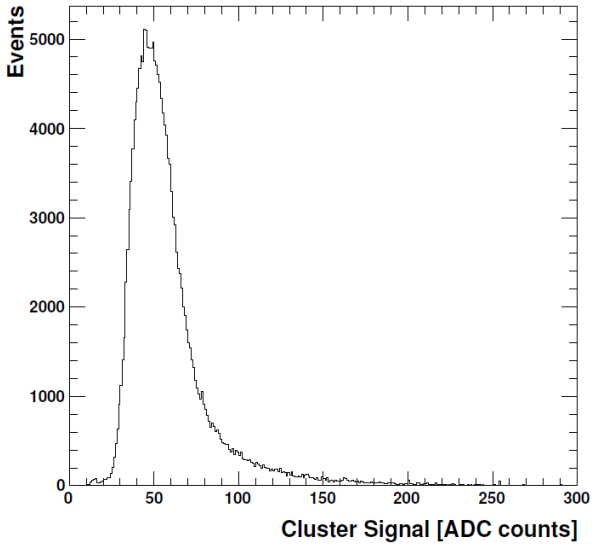
- 40K events per file
- >60,000 events/spill
- ~133 million events collected

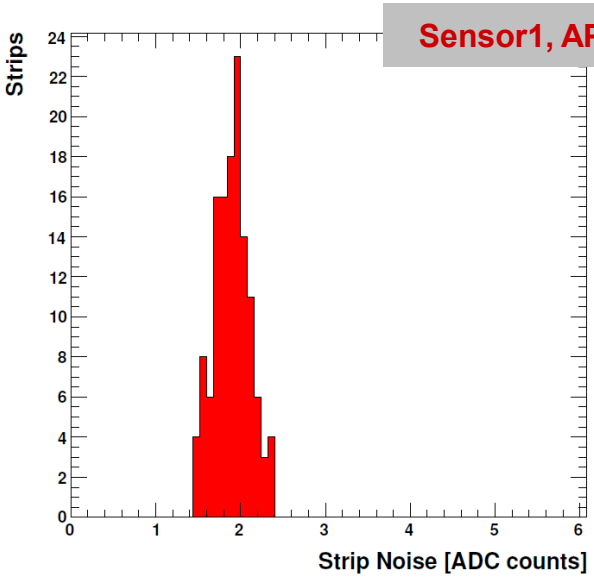
~90-95% events with at least 1 hit per plane

Reached ~7kHz peak readout rate



Sensor Performance

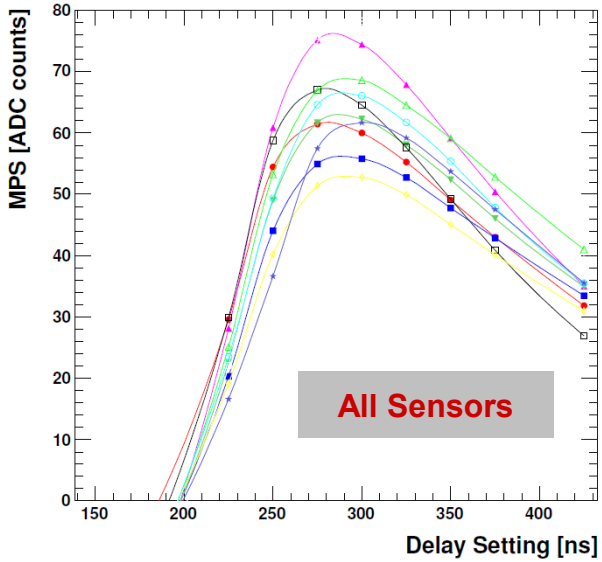




Measured sensor performance during and after test beam

Commissioning steps

- FED fine delay adjustments, frame finding thresholds
- Pedestal analysis for zero suppression
- Trigger latency scan



- Cluster signal maximised by reconstructing APV pulse shape and sampling at peak of pulse

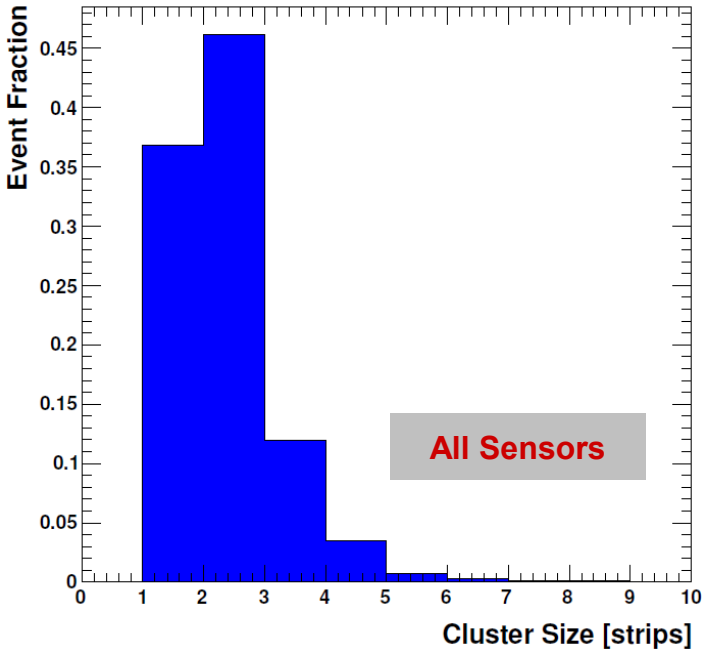
Average channel noise of 2.5 adc counts

S/N measured between 26-36

Clustering and Hit Finding

Hit finding using thresholds to suppress noise/pileup

- Seed strip S/N>3, neighbouring strips S/N>2, cluster S/N>5
- Hits of cluster size >4 strips rejected
- Average 1.05 clusters per sensor per event
- Intermediate floating strip increases charge sharing across strips – 65% clusters >1 strip wide



Hit position interpolated using analogue data

- Using simple linear interpolation between two highest charged consecutive strips in a cluster gives hit position
- Intermediate floating strip should therefore give better than half readout strip resolution

Track based alignment procedure

- Uses samples of ~100,000 single track events to measure translational and rotational misalignments between planes

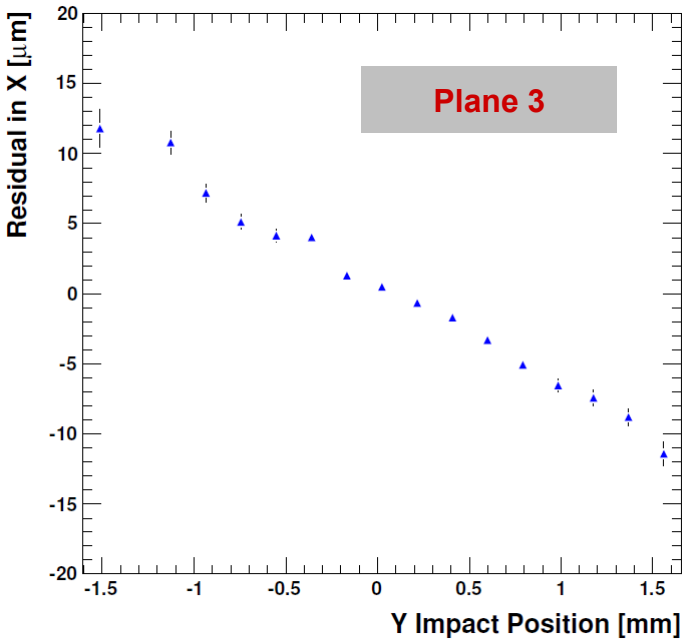
- Translational misalignments estimated using straight line fits between the two most separated planes

- Rotational misalignments estimated by measuring hit residual in one projection vs the impact position in the other projection

- Iterative calculation of misalignment parameters until residual distributions are centred

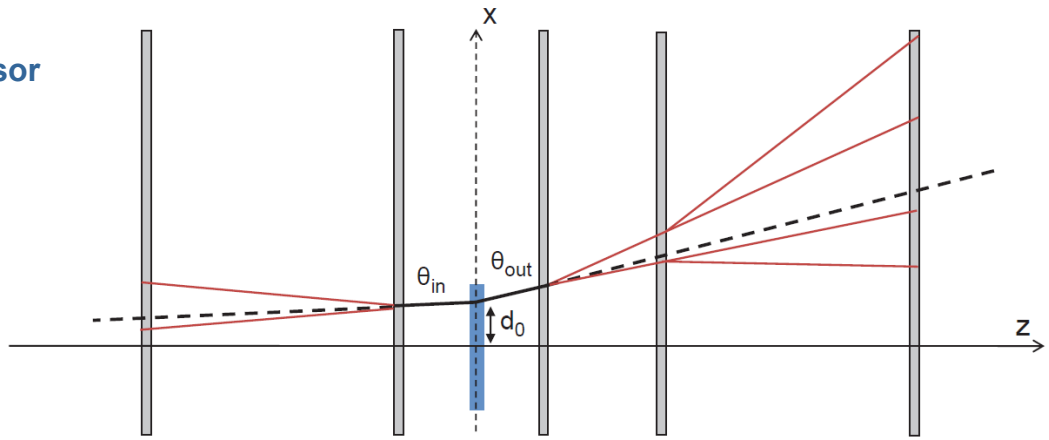
Rotational misalignments vary between 0.1 and 8 mrad

Alignment accuracy <1μm for translations and <0.1mrad for rotations



Track reconstruction

- At least one 2D hit is required in each sensor
- Fitting procedure is a minimisation of two straight line fits (1&2, 3&4&5)
- Three parameter fit (θ_{in}, θ_{out}, d_0) per projection
- Tracks with χ^2>10 are rejected



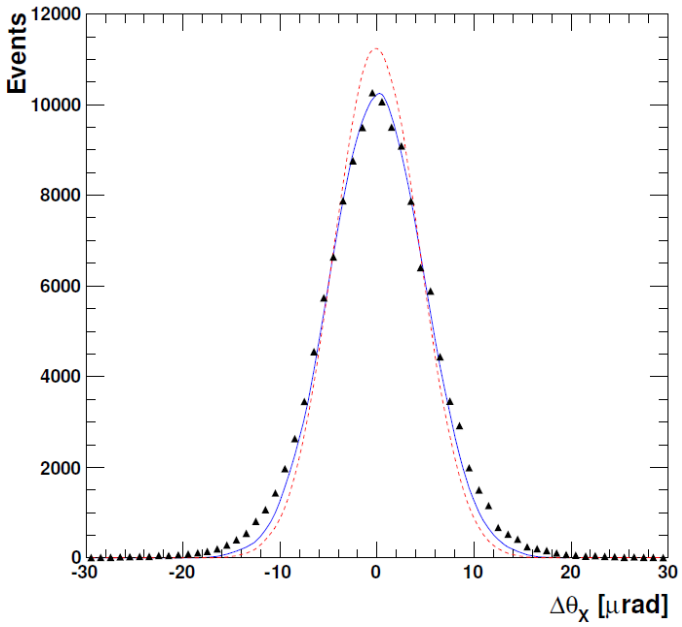
Covariance matrix used in fit takes into account measurement errors for each plane – including contributions from scattering and error correlations between planes

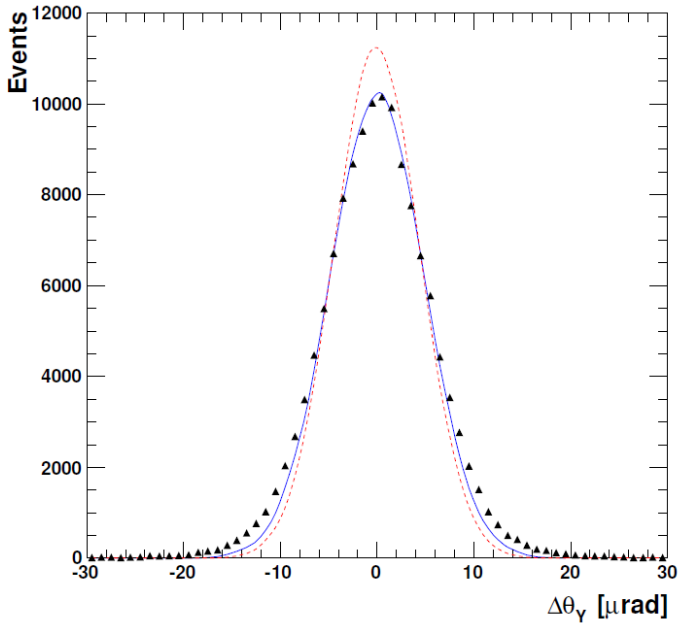
- Simulations give the scattering contribution of each plane as 2.4μrad – affects plane 1, 4 and 5
- Error correlations are taken into account between planes 4 and 5
- Sensor resolutions dominate errors in planes 2, 3 and 4 – measured using data to be between 6.8-7.0μm

Angular Resolution

Angular resolution of $\Delta\theta = \theta_{in} - \theta_{out}$ measured

- **Using alignment run events (no crystal), resolution of deflection angle is estimated as 5.2μrad in both x and y**
- **Simulations predict an angular resolution of 4.4μrad (red curve)**
- **Including estimates of air in the September test beam within the simulation predicts 5.0μrad (blue curve) – with just a small deviation in the tails**



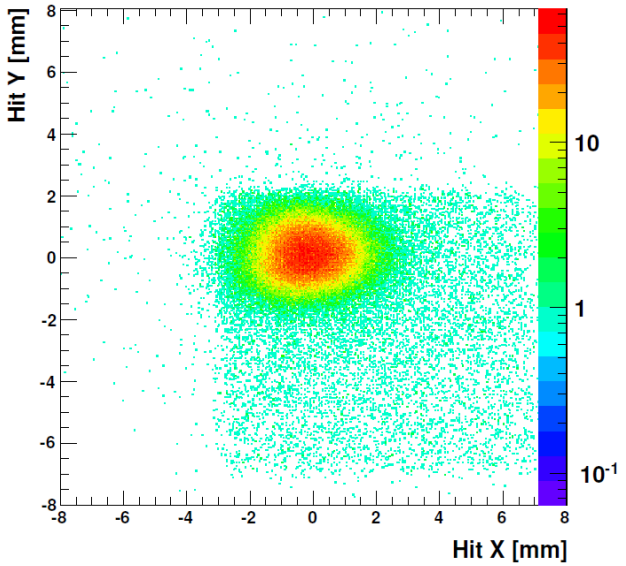


Simulations predict ultimate angular resolution of incoming arm as 2.6μrad

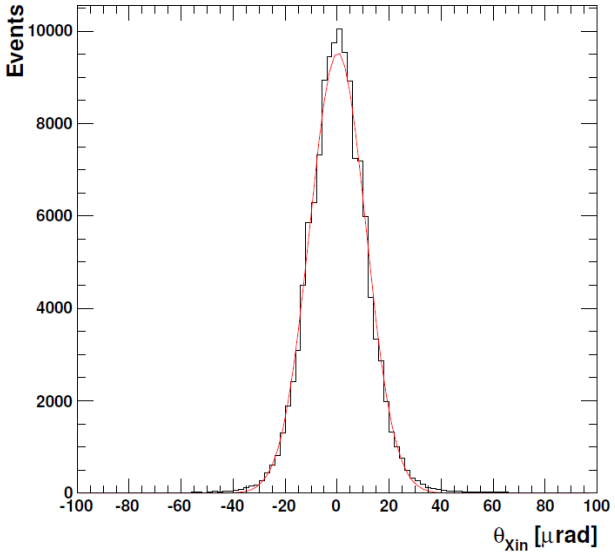
Beam Measurements

September beam properties measured

- Roughly gaussian beam with a spread of 1.0mm in x and 0.8mm in y
- Non gaussian background probably due to collimators upstream

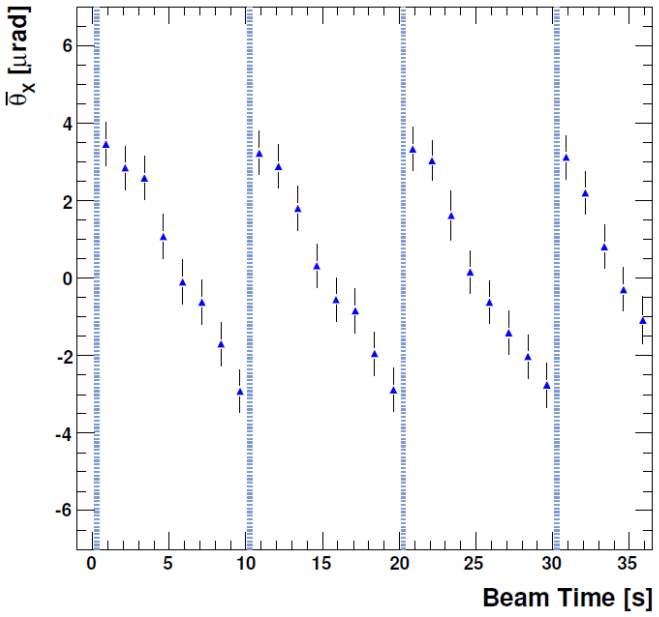


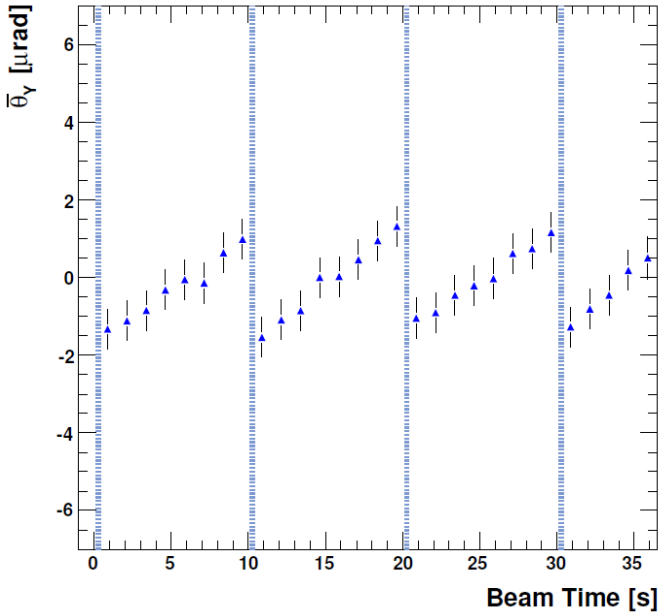
- Spread in θ_{in} is effectively the divergence of the beam (small contribution from measurement error of θ_{in})
- Divergence measured as 10.7μrad in x and 7.6μrad in y
- But probably smaller… (next slide)



Periodic beam deflection discovered

- During data analysis, a shift in the beam direction was discovered over the course of a run
- Beam deflection is periodic with period equal to that of spill (~10s)





- Total deflection measured at 6.5μrad in x and 2.5μrad in y over a spill
- Will clearly increase divergence – and possibly other channeling measurements to date, or in future

Summary/Outlook

Silicon strip telescope commissioned and tested last year at H8

Performance studied in detail

- Average S/N ~31; good noise rejection
- Sensors give good spatial resolution; ~7.0μm
- Each XY plane contributes ~2.4μrad to angular error due to multiple scattering
- Track based alignment now takes into account translational and rotational misalignments to within 1μm and 0.1mrad respectively
- Track reconstruction now estimates angular resolution on deflection measurement as 5.2μrad
- Angular error on incoming arm ultimately estimated at 2.6μrad

Possibility to reduce total angular resolution by eliminating air from system

Cause of beam deflection effect should be investigated – can it be eliminated? Is it important for channeling measurements?