DECAL beam test at CERN

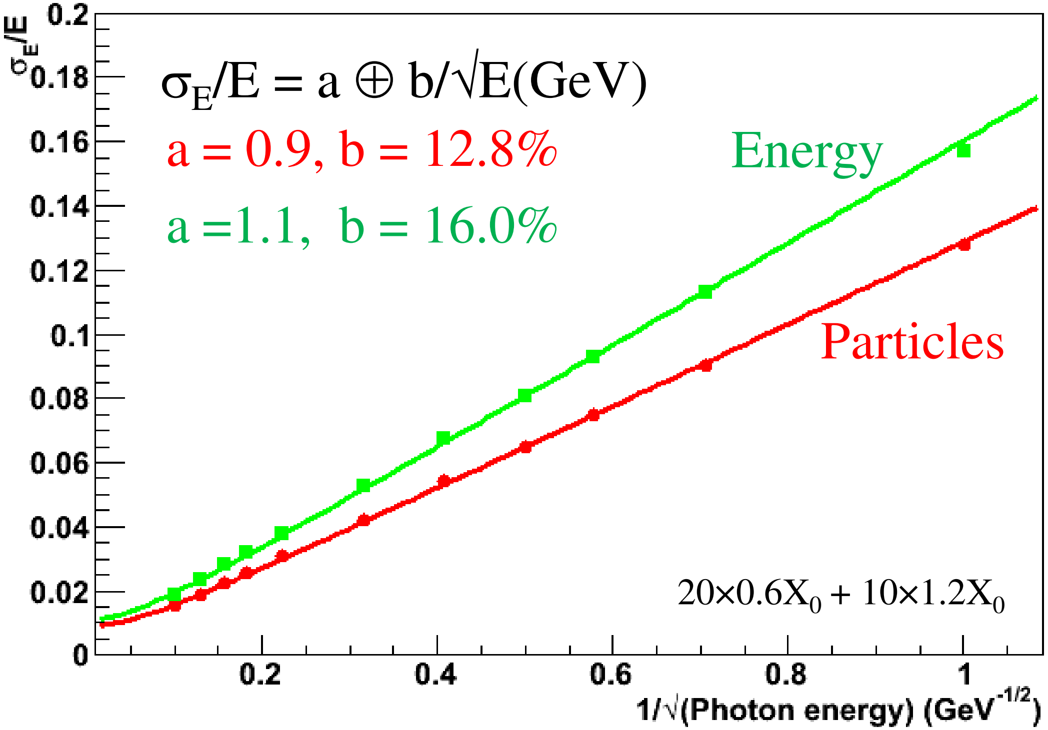
Paul Dauncey

for the CALICE-UK/SPiDeR groups:

Birmingham, Bristol, Imperial, Oxford, RAL

Digital ECAL

- Concept is to count particles, not deposited energy
  - Use very small pixels (~50μm) with binary readout
  - In principle removes Landau fluctuations so giving better ECAL resolution
  - Very small pixels should also help with PFA
  - Need very large number of pixels ~10^{12} for ILC ECAL



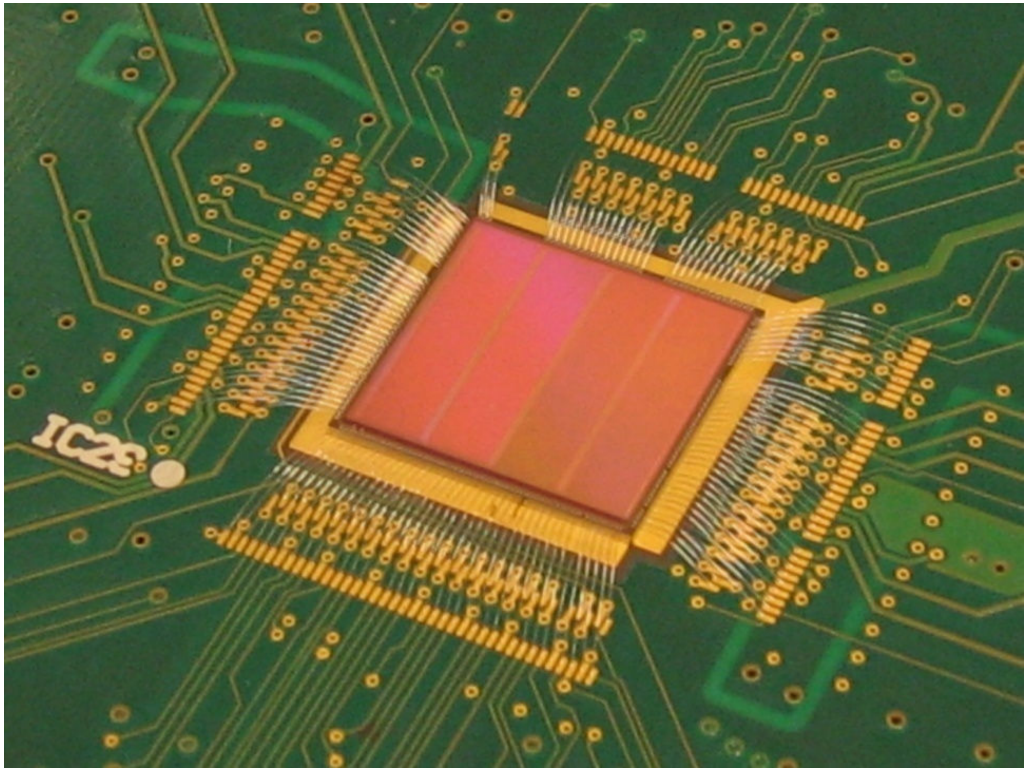
- Basic studies and proof-of-principle required
  - A DECAL has never been operated for real
  - Sensitive to core density of EM showers; not measured at high granularity

SPiDeR collaboration

- ILC work announced to be cut by UK funding agencies Dec 2007
  - CALICE-UK closed down by Mar 2009; UK still members of CALICE but no specific UK funding for CALICE activities
  - Same happened to UK vertex group, LCFI
- Regroup in the UK to form new collaboration, SPiDeR
  - Silicon Pixel Detector R&D
  - Remnants of CALICE-UK DECAL group and LCFI
  - “Generic” pixel detectors for future colliders...
  - ...which just so happen to be very ILC-like ☺
- SPiDeR in principle is approved and funded for three year programme
  - Part of which is to build a DECAL physics prototype calorimeter
  - But UK funding still in a mess; currently on temporary funds for one year
  - Will find out at end of 2009 if full funding will be given from Apr 2010
  - Delay to the DECAL project around two years, even if funded

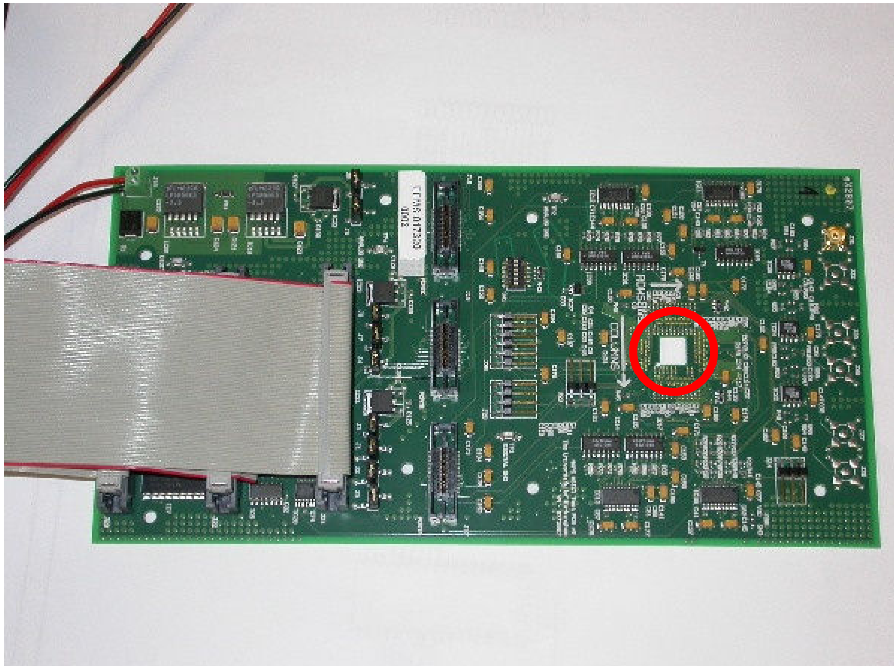
TPAC sensor

- Tera-Pixel Active Calorimeter
  - 0.18μm CMOS process
  - 168×168 pixels, each 50×50μm^2, total of 28k pixels
  - Active area 0.84×0.84cm^2
  - Per pixel trim and masking
  - Binary readout with common sensor threshold
  - No external readout chip needed
  - On-sensor memory storage

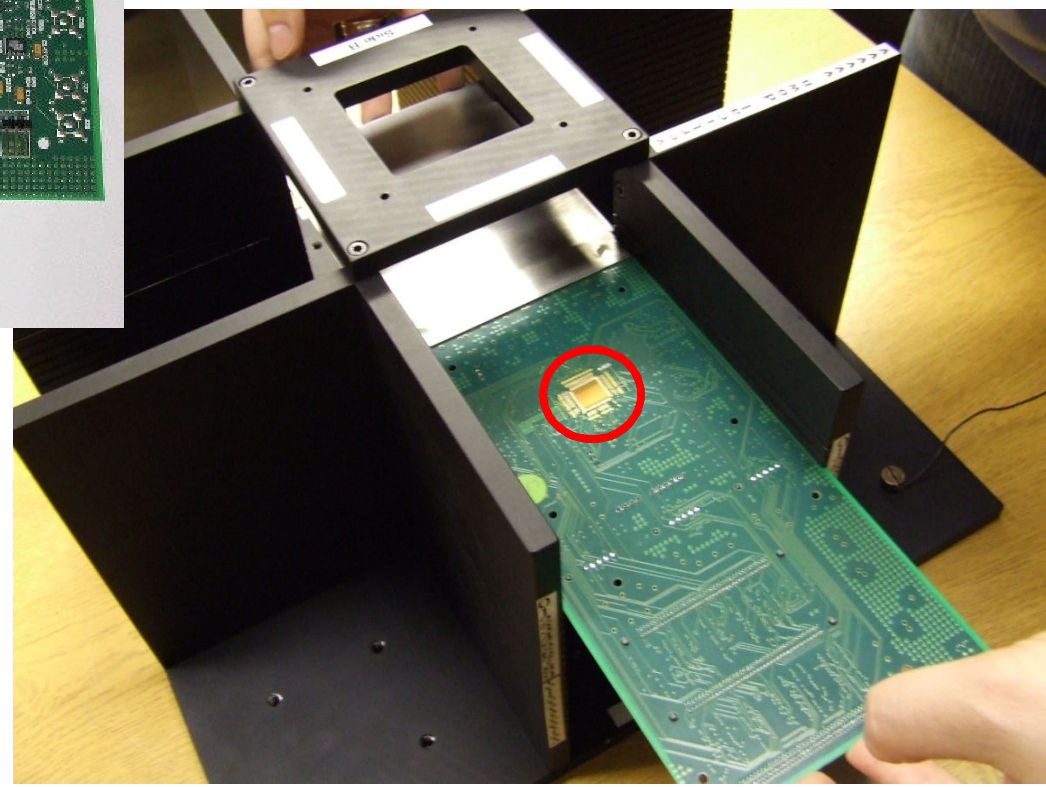


- Sensor operates in ILC-like mode
  - Sensitive for "bunch train" period, consisting of many "bunch crossings" (BX)
  - Readout must be completed before next bunch train

TPAC sensor on PCB



1×1cm^2 TPAC sensor



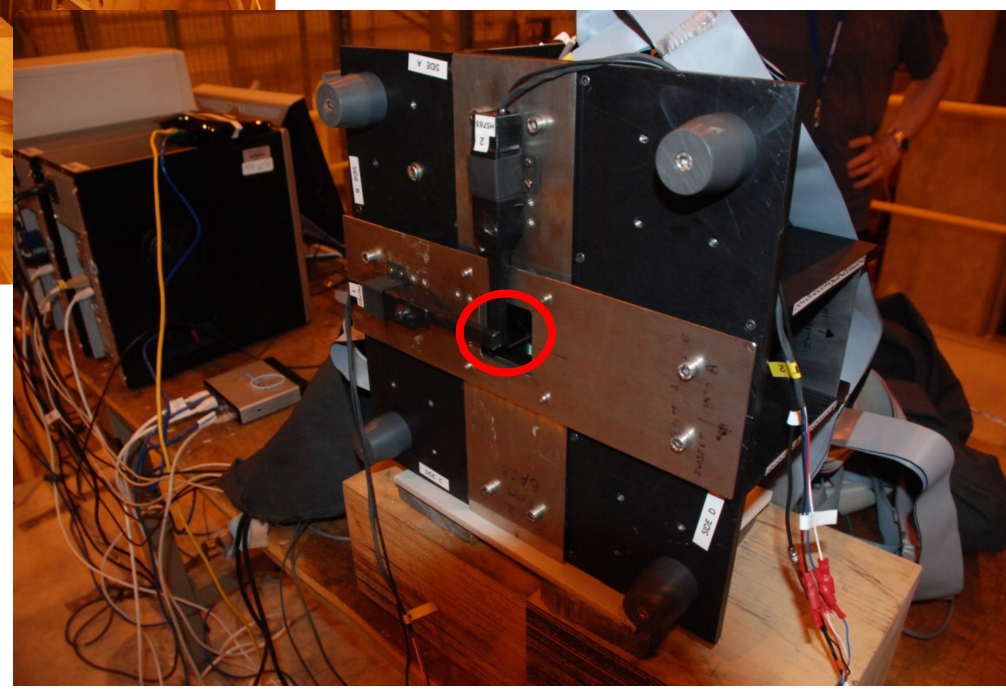
Sensor being inserted into slot of mechanical stack

CERN beam test

- Beam test at CERN 13-27 August
  - Main aim was to measure pixel efficiency for MIPs using 120GeV pions
  - Not possible to measure EM resolution; sensors too small to contain showers as size < Molière radius
- Ran parasitically for two weeks
  - Behind two other primary users both using the EUDET tracking telescope
  - First week; Fortis pixel sensors (connected with SPiDeR so effectively collaborators but the two systems ran independently)
  - Second week; SiLC strip sensors
  - Back in the same old H6B beam line as used by CALICE in 2006/07
- Six sensors in a stack
  - 170k pixels total
  - No tungsten within stack; run as six-layer tracker
  - Track interpolation should allow efficiency measurement

DECAL stack in H6B

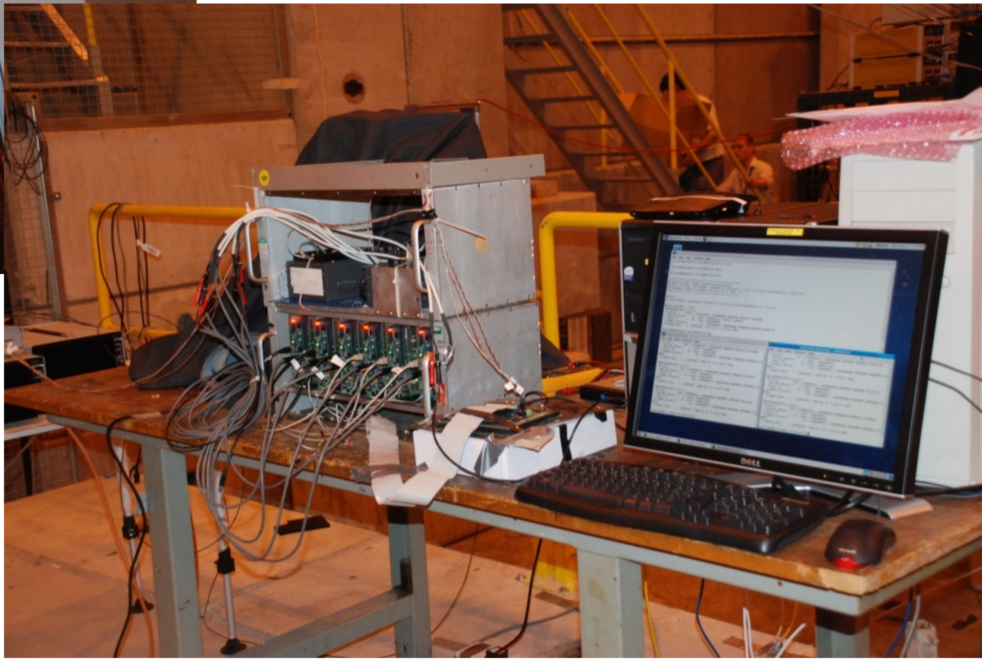
Placed exactly where CALICE SiECAL/AHCAL used to be



Two 1×1cm^2 scintillators mounted at front (another one at back)

DECAL readout

Side view showing six layers

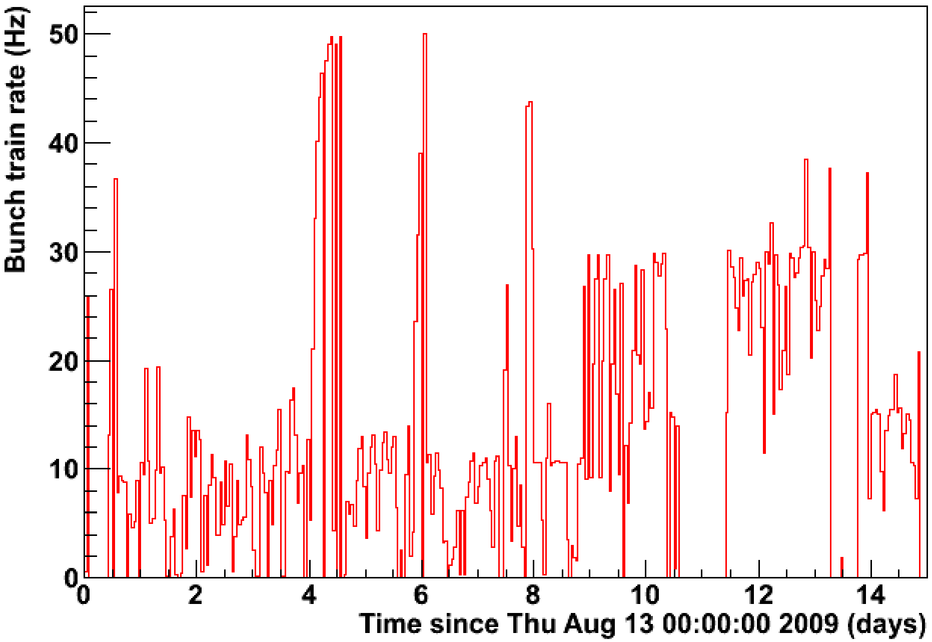


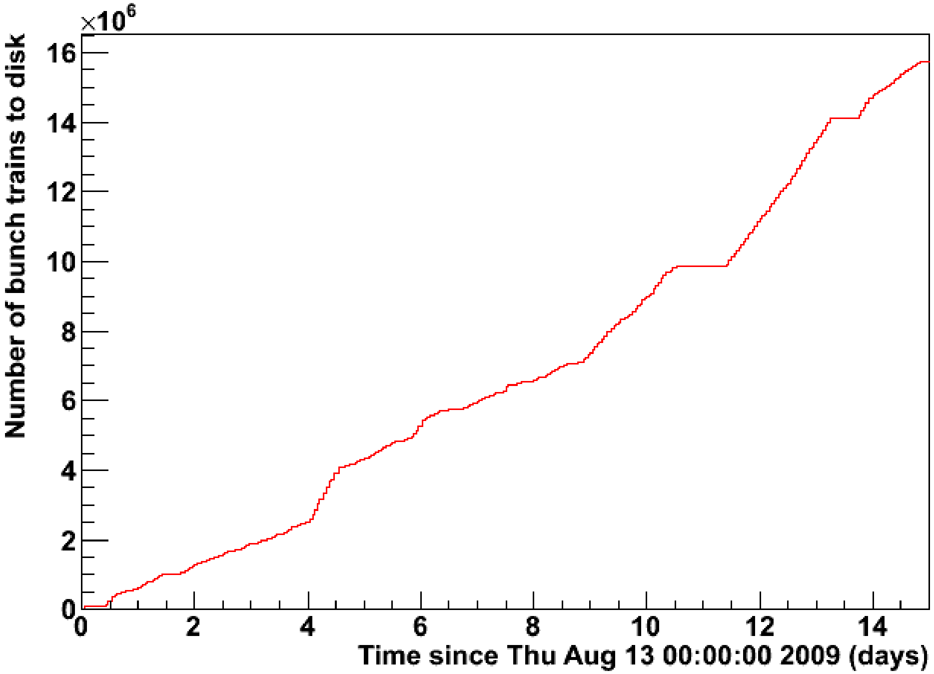
Readout via USB;
no VME crates

Fake bunch train operation

- ILC-like; no trigger...
  - Sensor needs to operate with bunch trains
  - Pre-bunch train reset period ~0.5ms needed; cannot start train with trigger
  - Operated by generating fake bunch trains and hope some beam particles arrive during the train
- ...but not very ILC-like!
  - To get rate up, needed to push all parameters beyond ILC
  - Bunch train = 8000BX (not ~3000BX)
  - 1 BX = 400ns (not ~300ns) so bunch train = 3.2ms (not ~1ms)
  - Bunch train repetition rate up to 30Hz (not ~5Hz)
- Longer bunch trains/crossings give more particles per train but
  - More noise hits per BX and per train
  - On-sensor memory more likely to saturate; inefficiency
  - Masked noisiest pixels to reduce rate; trade-off for efficiency
  - Need to take out these effects in analysis to see "real" pixel efficiency

Bunch train rates and total





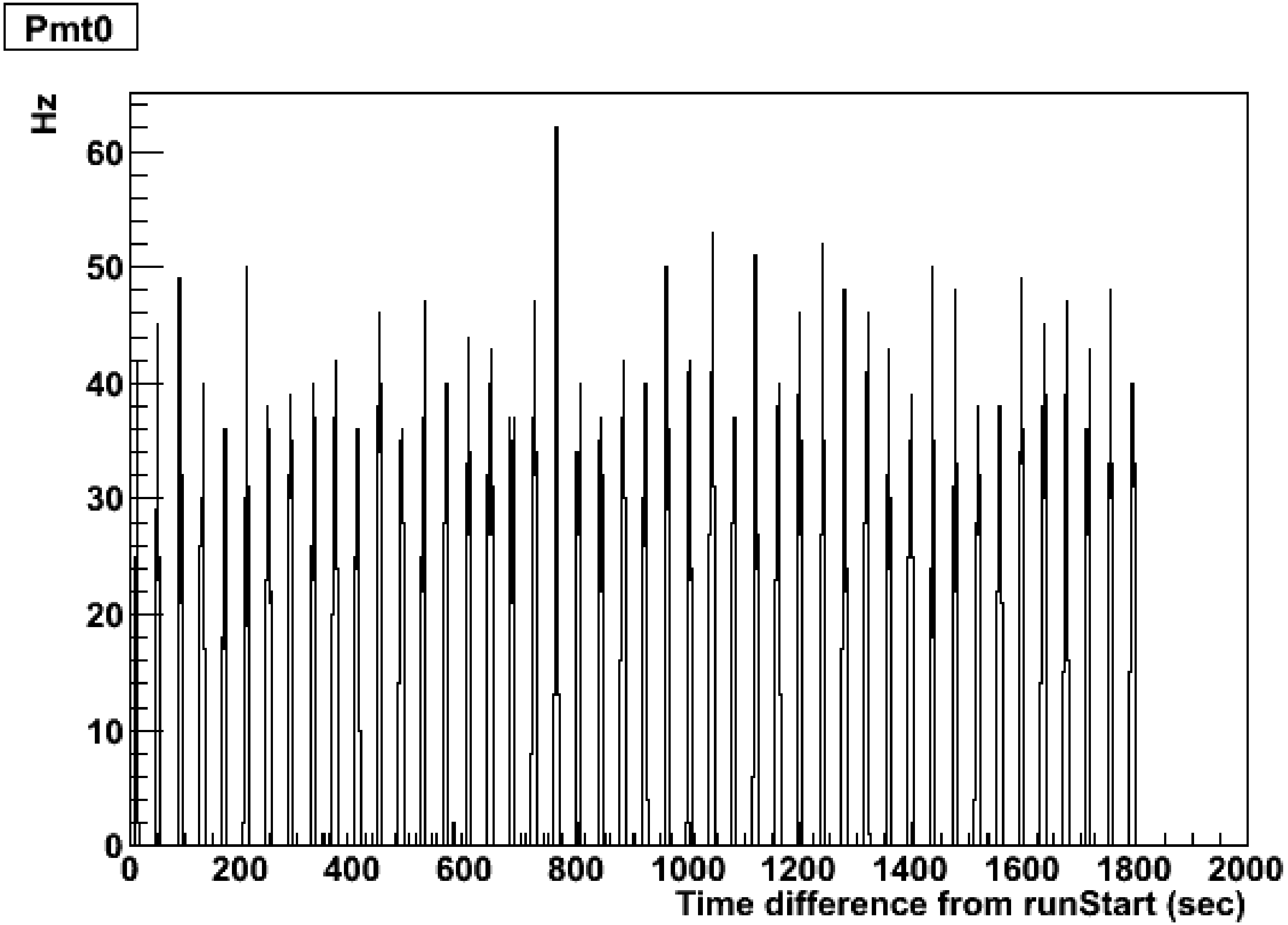
- Reasonably smooth running throughout the two weeks
- But bunch train rate does not say anything about particle rate

Scintillator/PMT timing

- Three scintillators installed
  - Two in front, one behind the TPAC stack
- Used to tag time of particles within bunch train
  - PMT outputs discriminated, latched and read out per BX
- Use PMT coincidence to define BX of particle
  - Coincidence count gives number of particles
  - Look for sensor hits with fixed BX offset from particle
  - Offset allows for timing differences in two systems (including epitaxial charge drift time)

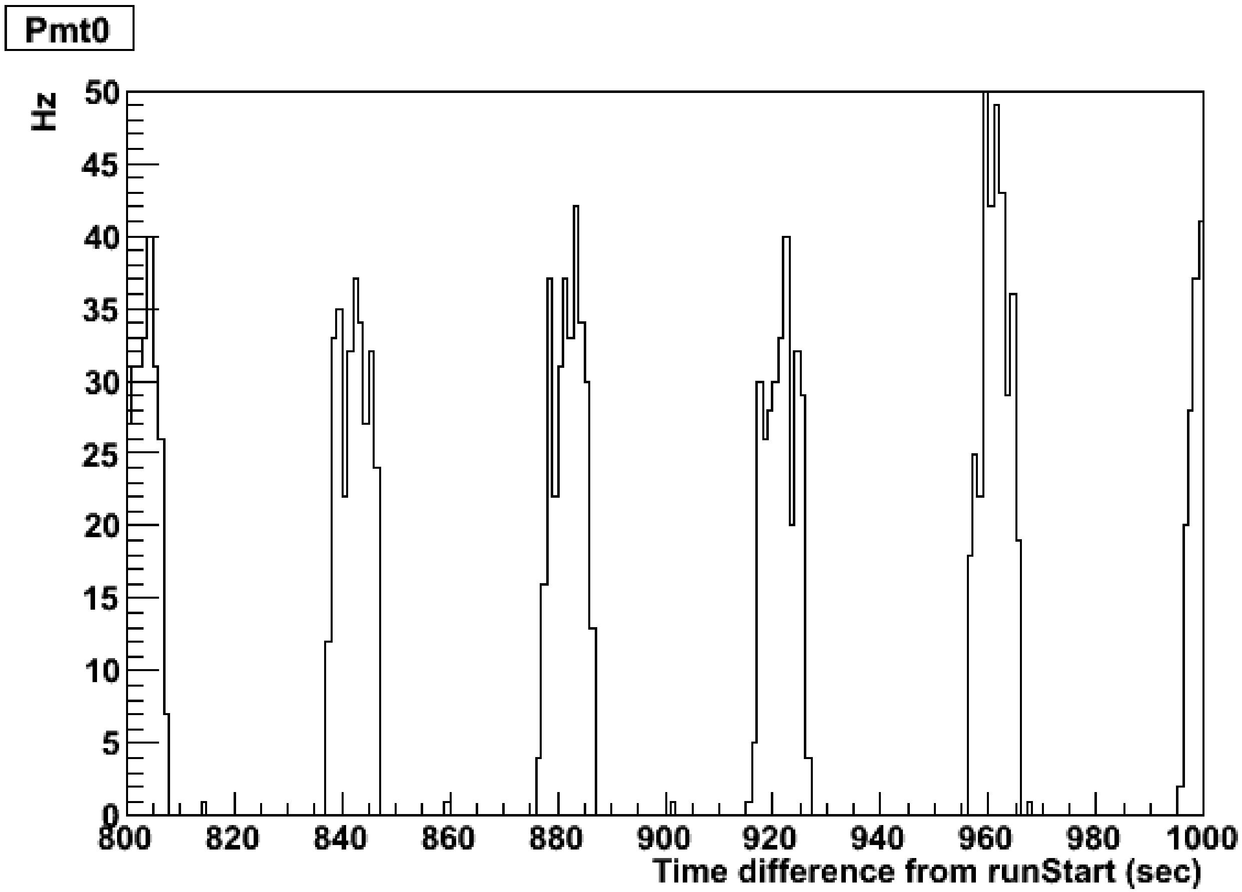
Spill structure

- Typical run: even single hit rate shows beam spill structure



Spill structure

- Zoom in to see detail



Spill structure

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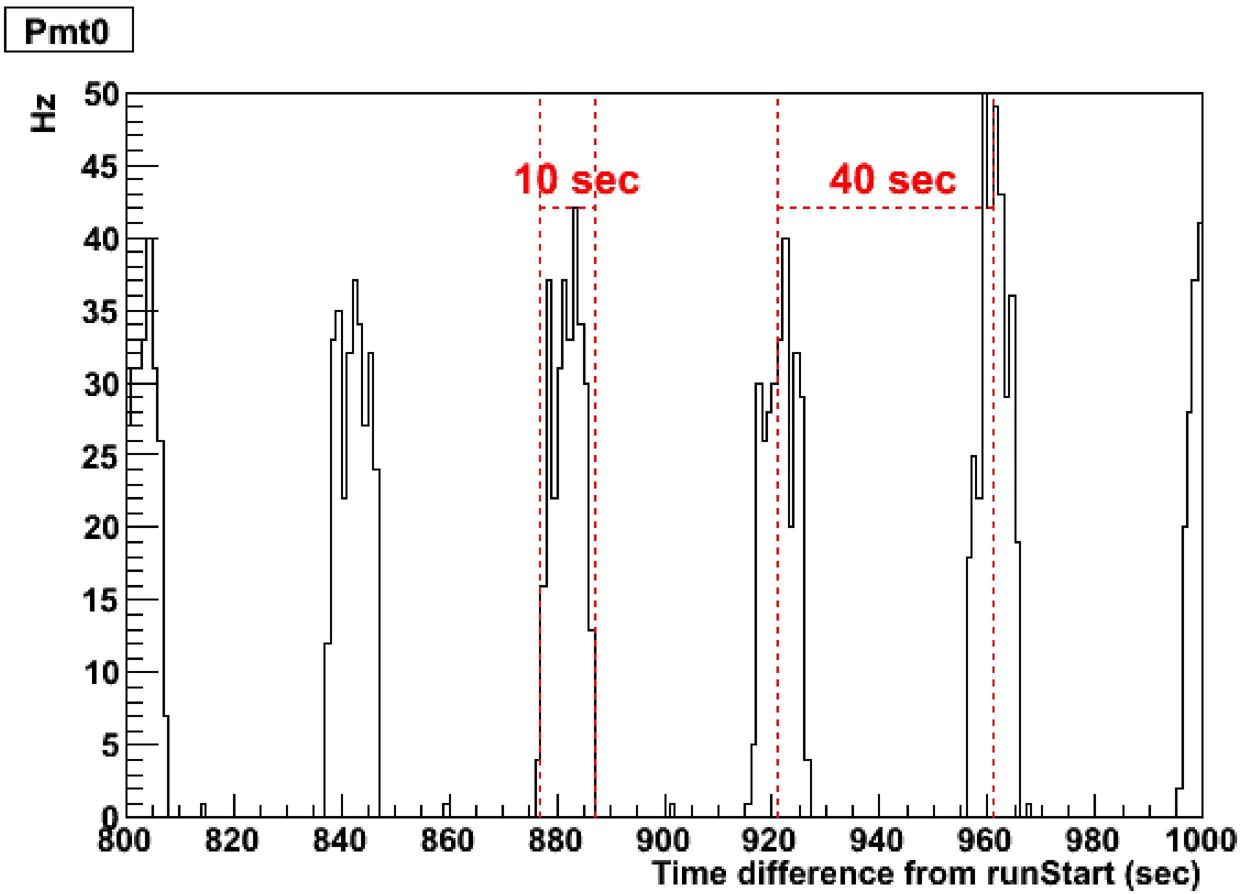
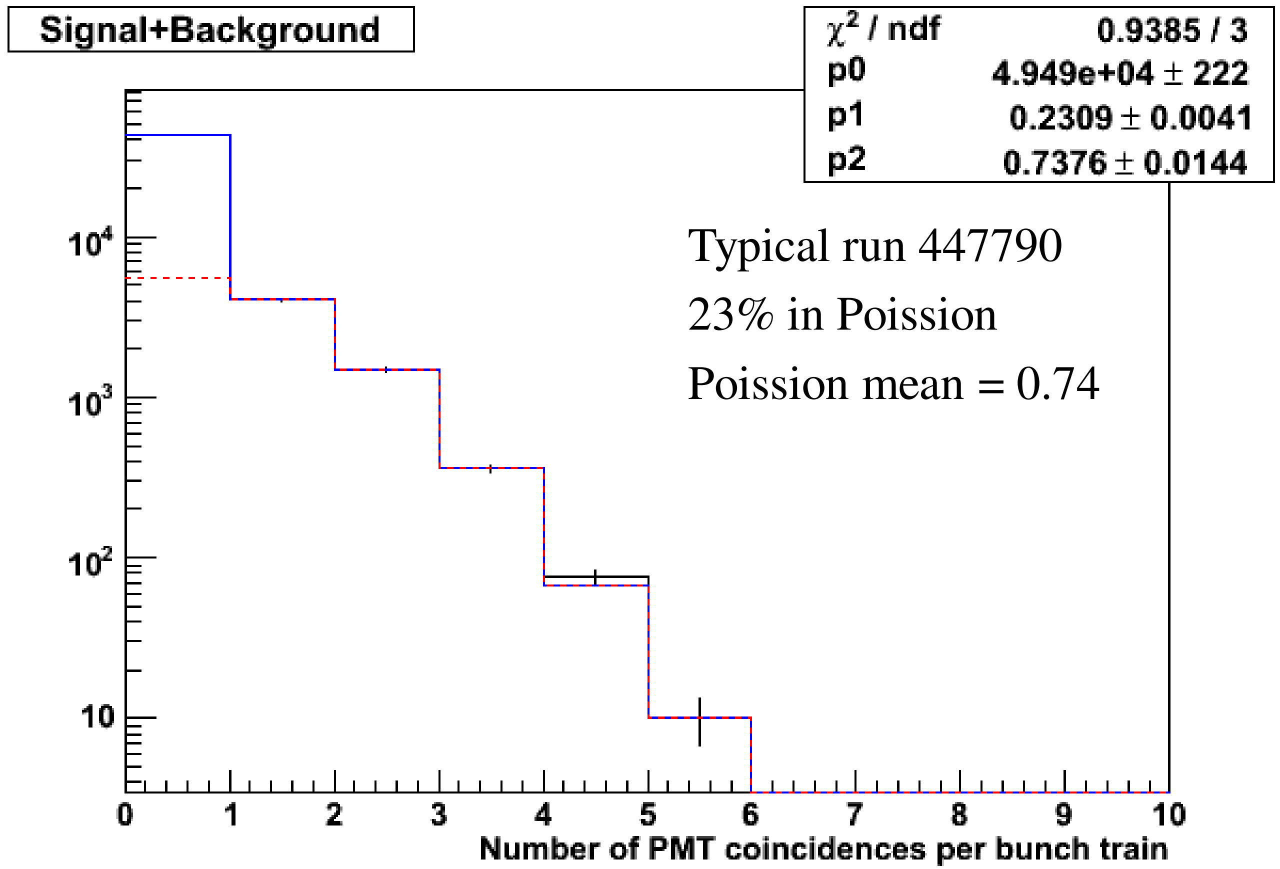


- Duty cycle ~25% (maximum, assuming no beam loss)
- Some runs had 49sec spill period rather than 40sec; ~20%

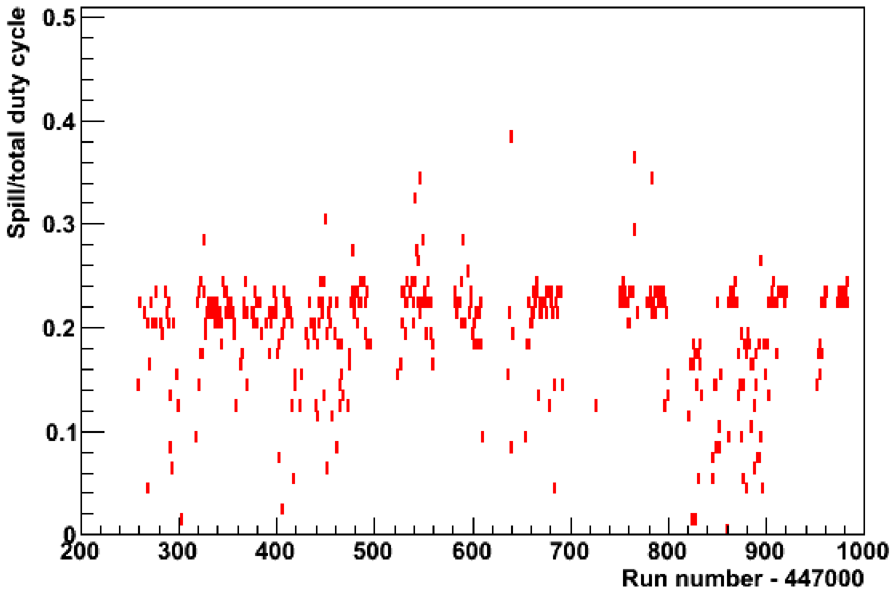
Scintillator/PMT rates

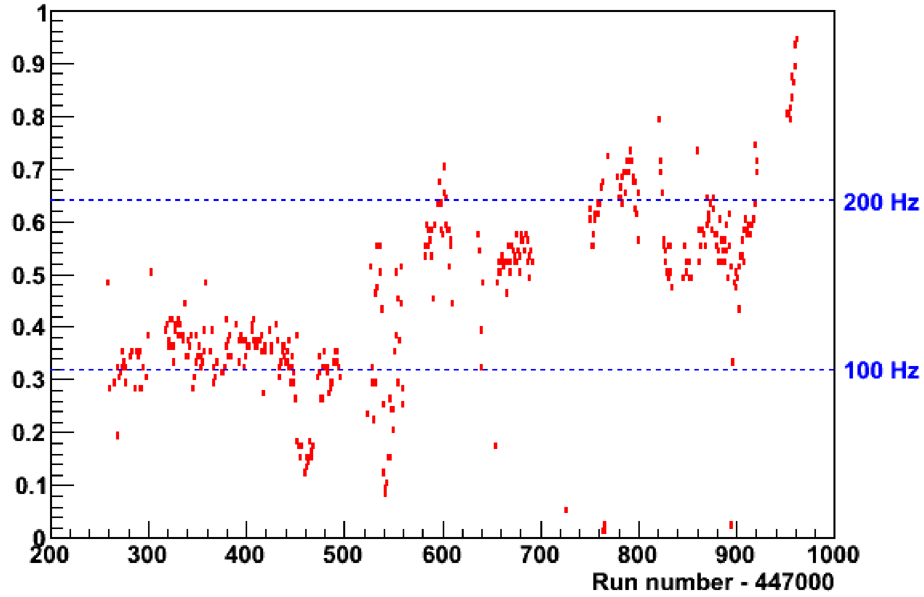
- Fit number of coincidences per bunch train
  - Poisson distribution for number of particles
  - Zero for bunch trains outside of spill



Scintillator/PMT rates vs run number

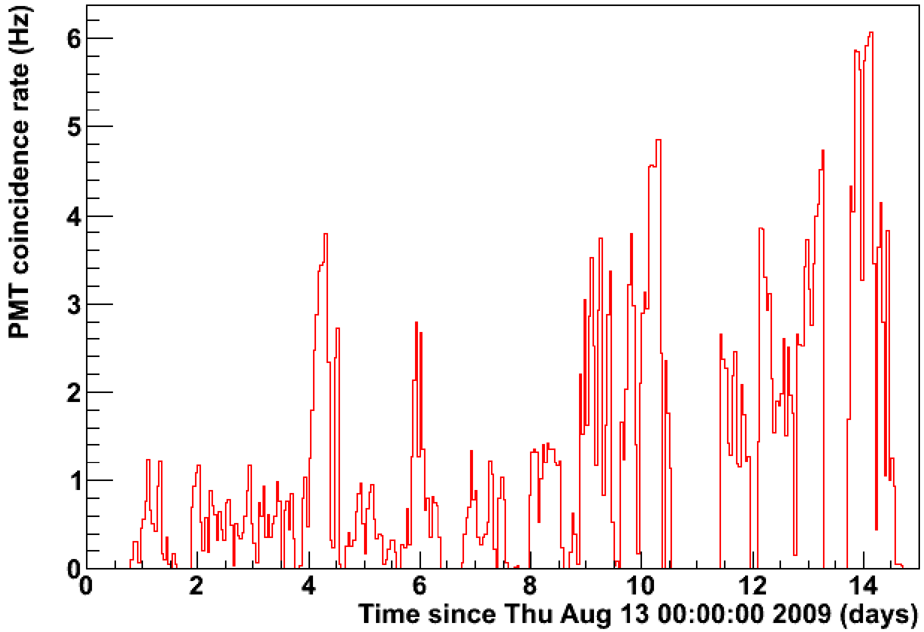
- Check duty cycle and Poisson mean per bunch train
  - Poisson mean of 0.32 during the 3.2ms bunch train is equivalent to 100Hz beam rate on scintillators

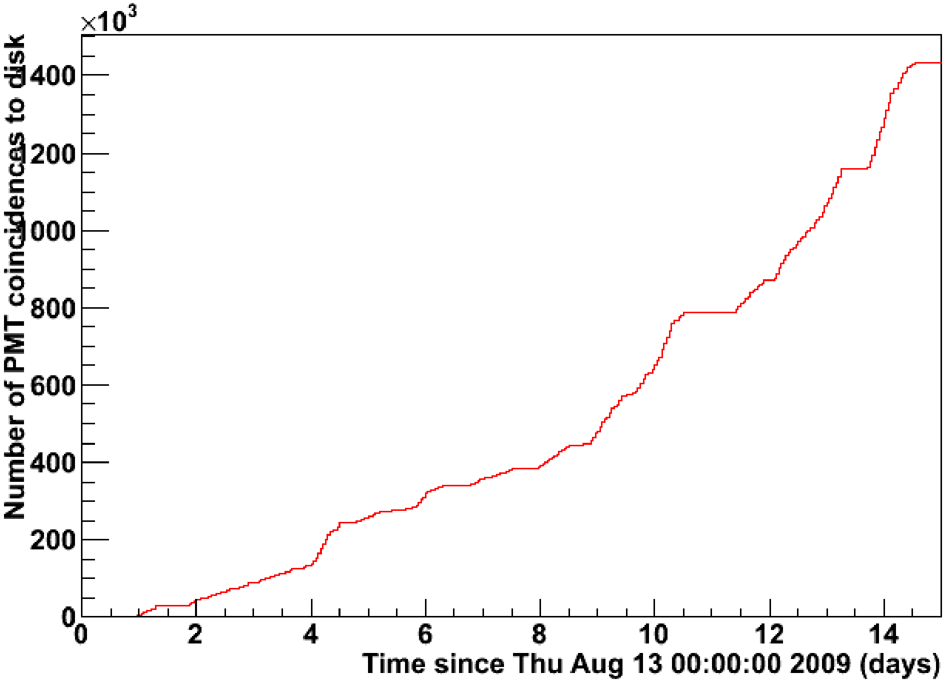




- Max rate seen was ~250Hz; was hoping for >1kHz

Scintillator coincidence rates to disk

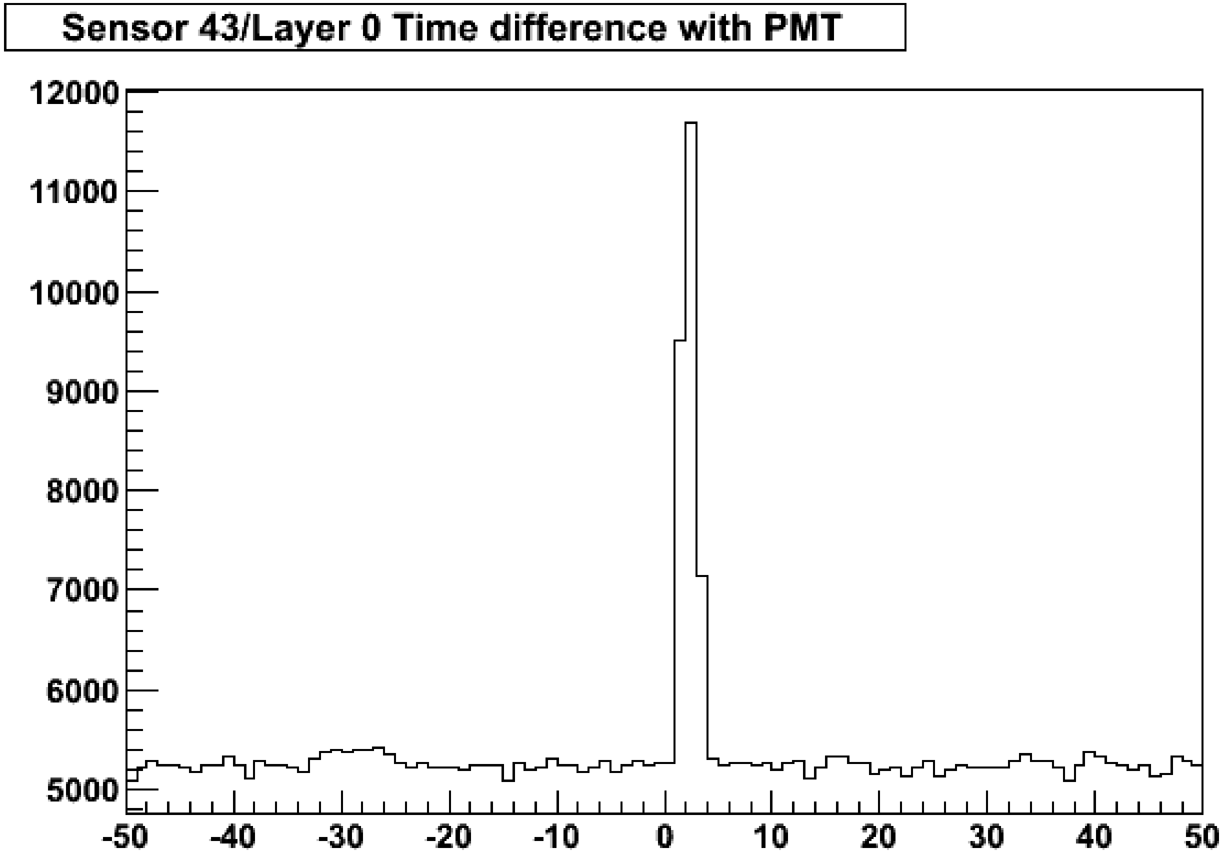




- Total sample ~1.4M time-tagged particles

Sensor hits relative to PMT coincidence

- Typical run 447790, layer 0



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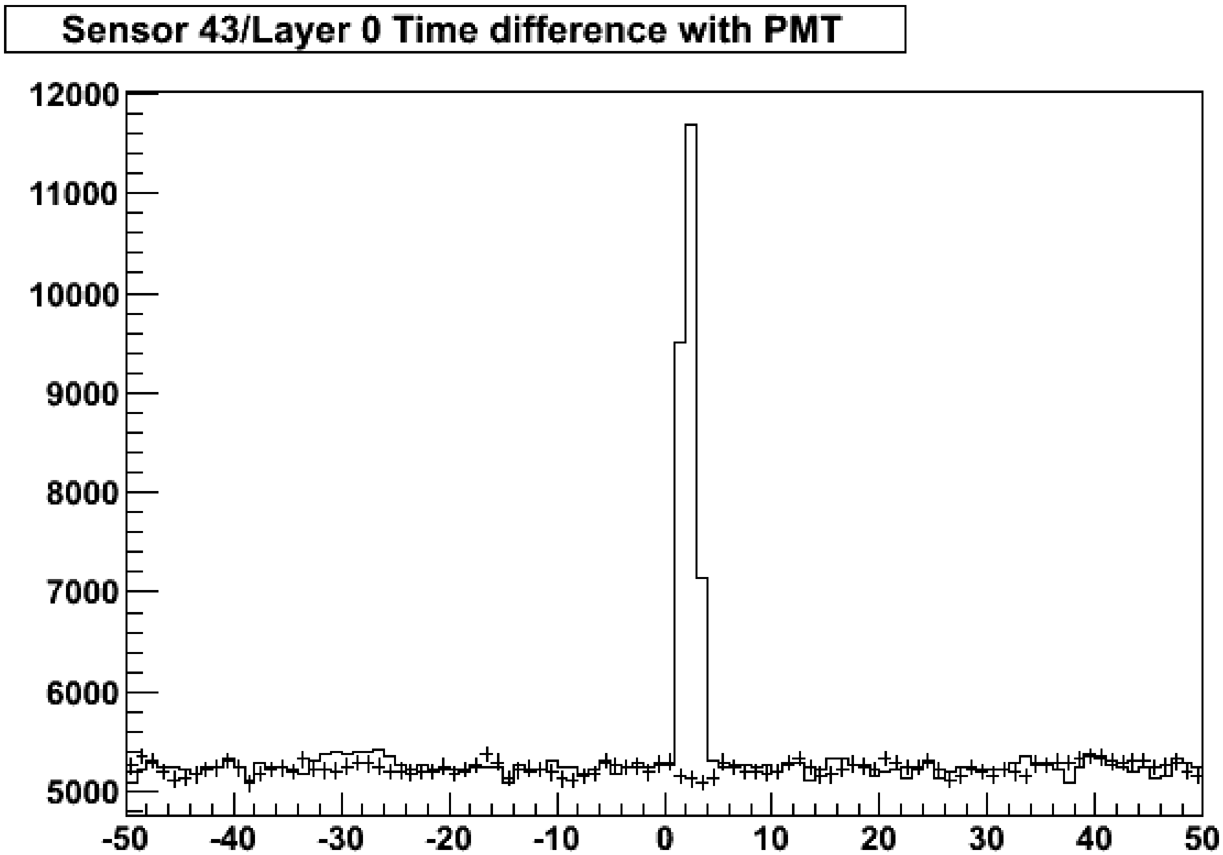
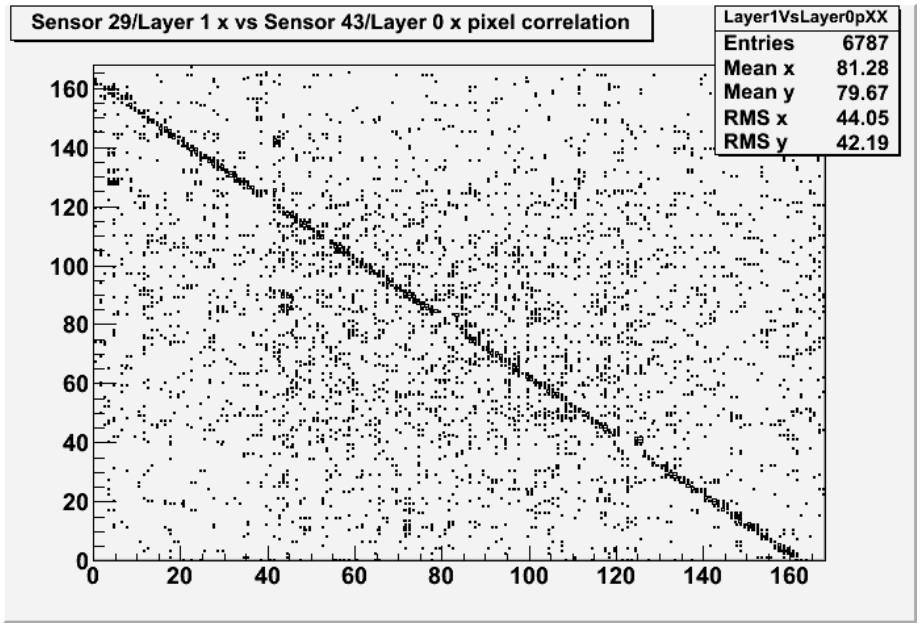
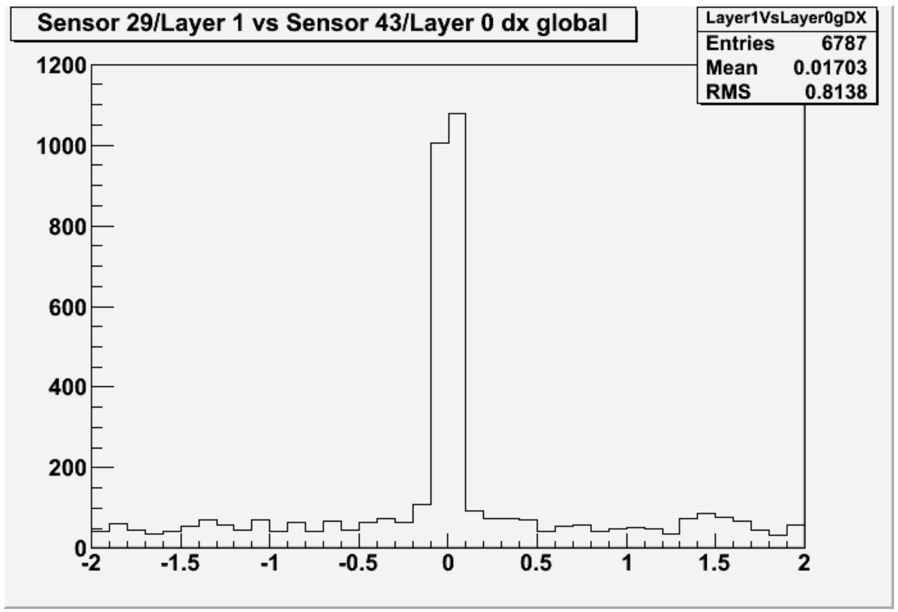


- Use PMT coincidence BX offset in time by 4000BX for background level, i.e. $t_b = (t_s+4000)\%8000$

Particle correlations in sensors

- Use time-tagged sensor hits for all studies
- Beam particles ~parallel to z axis
  - Strong correlation layer to layer in sensor hit positions

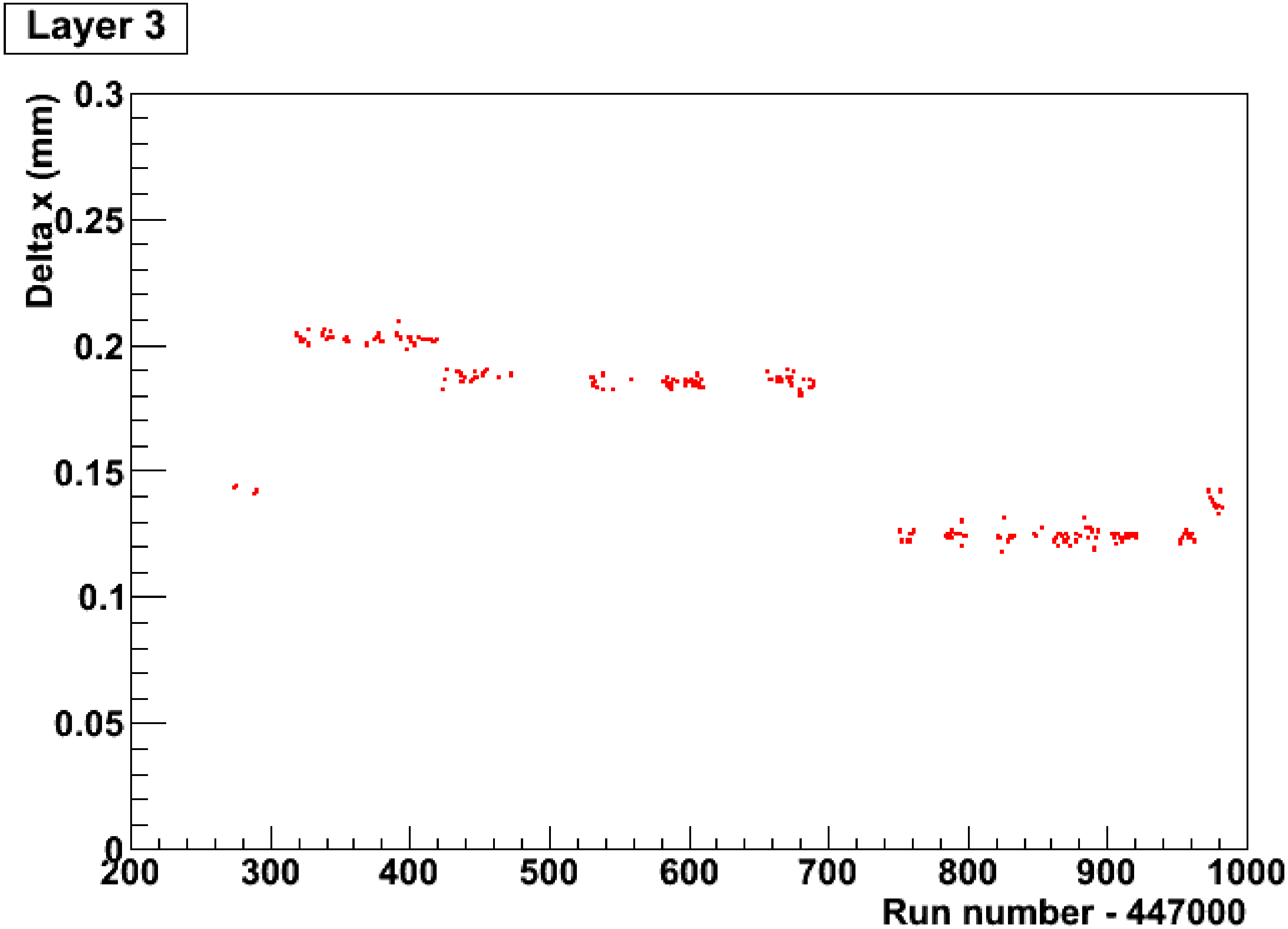




- Layers 0 backward-facing, layer 1 front-facing so local x is anti-correlated
- Correct for orientations and offsets to align the six sensors

Alignment Δx vs time

- Typical layer 3



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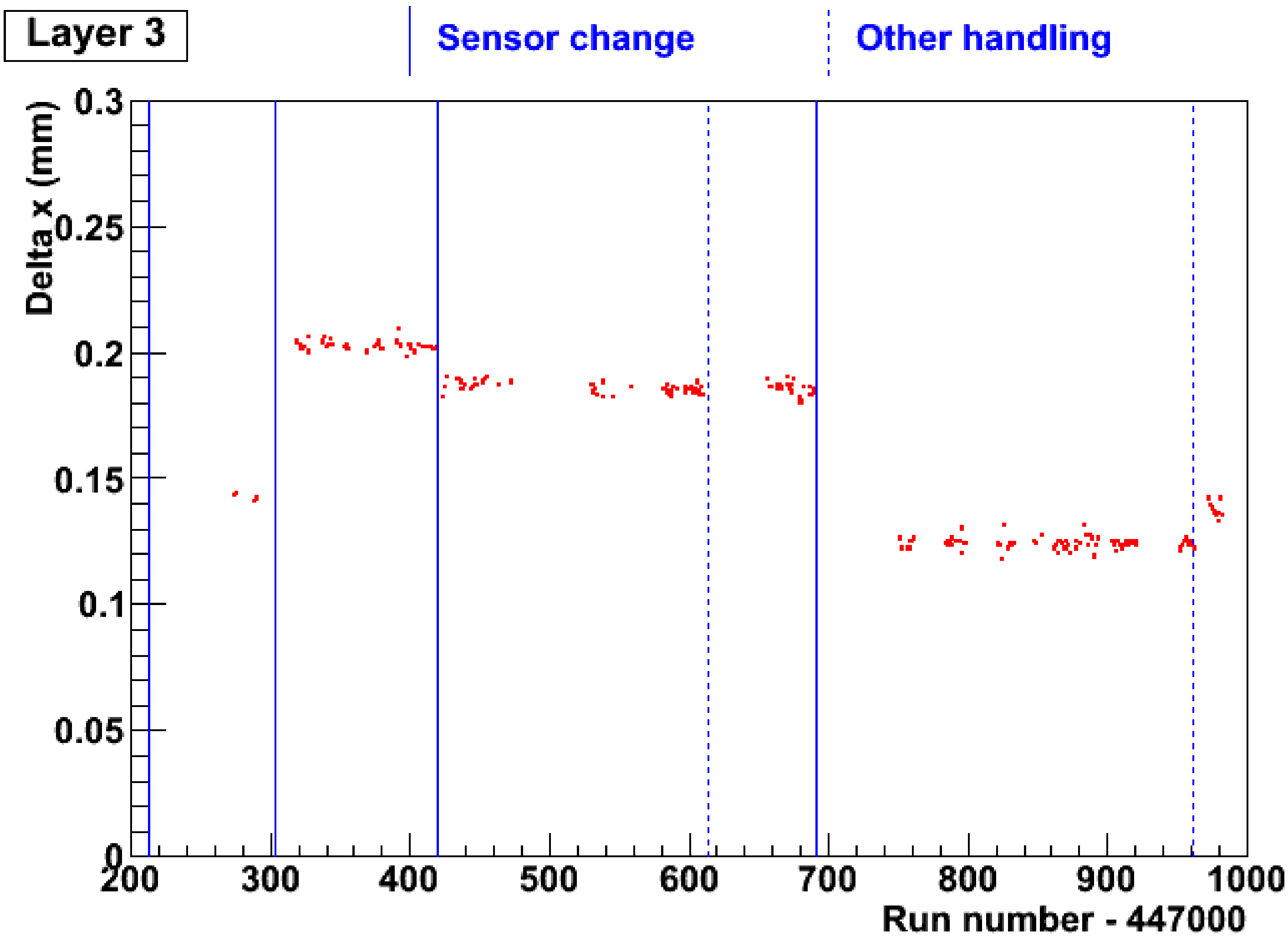
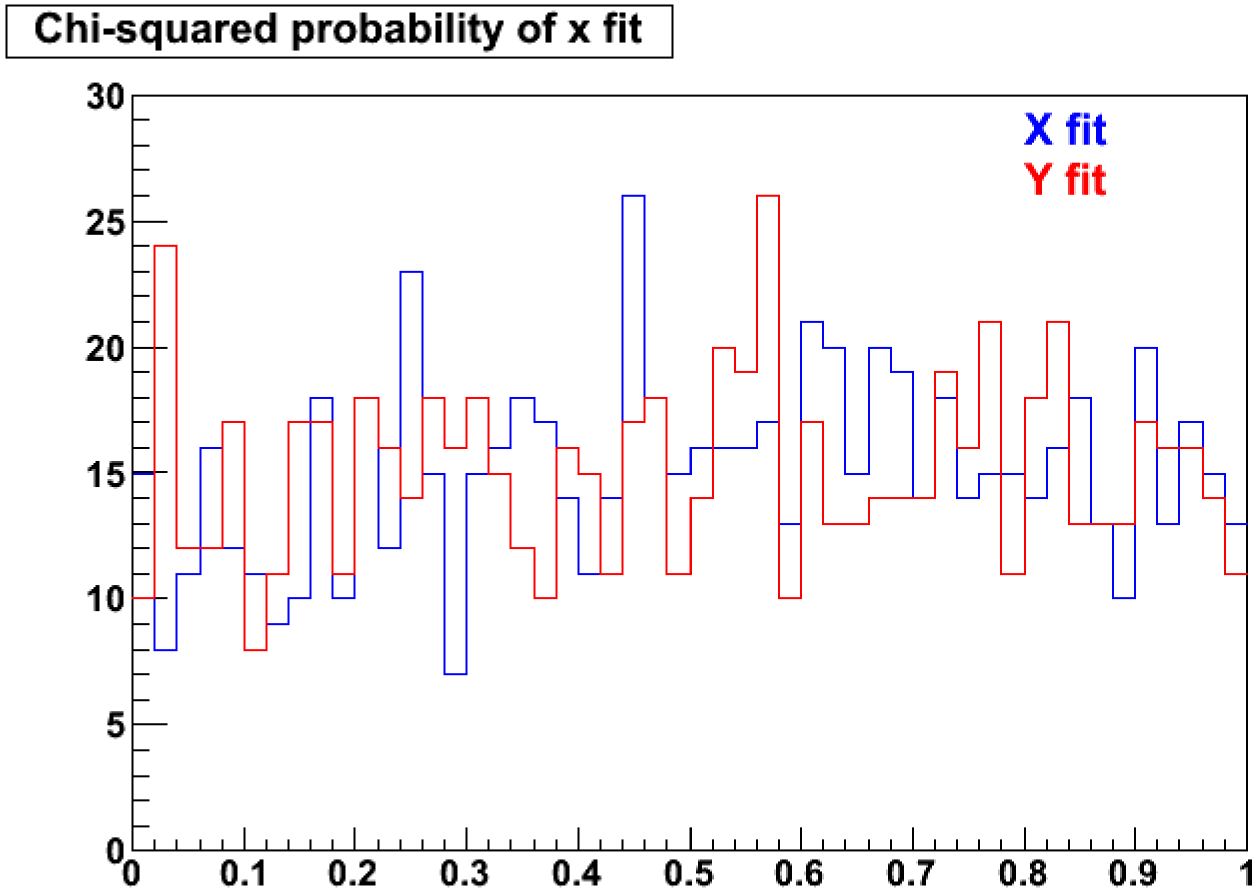


Track χ^2 probability

- Use correlations to pick hits for tracks and fit straight lines

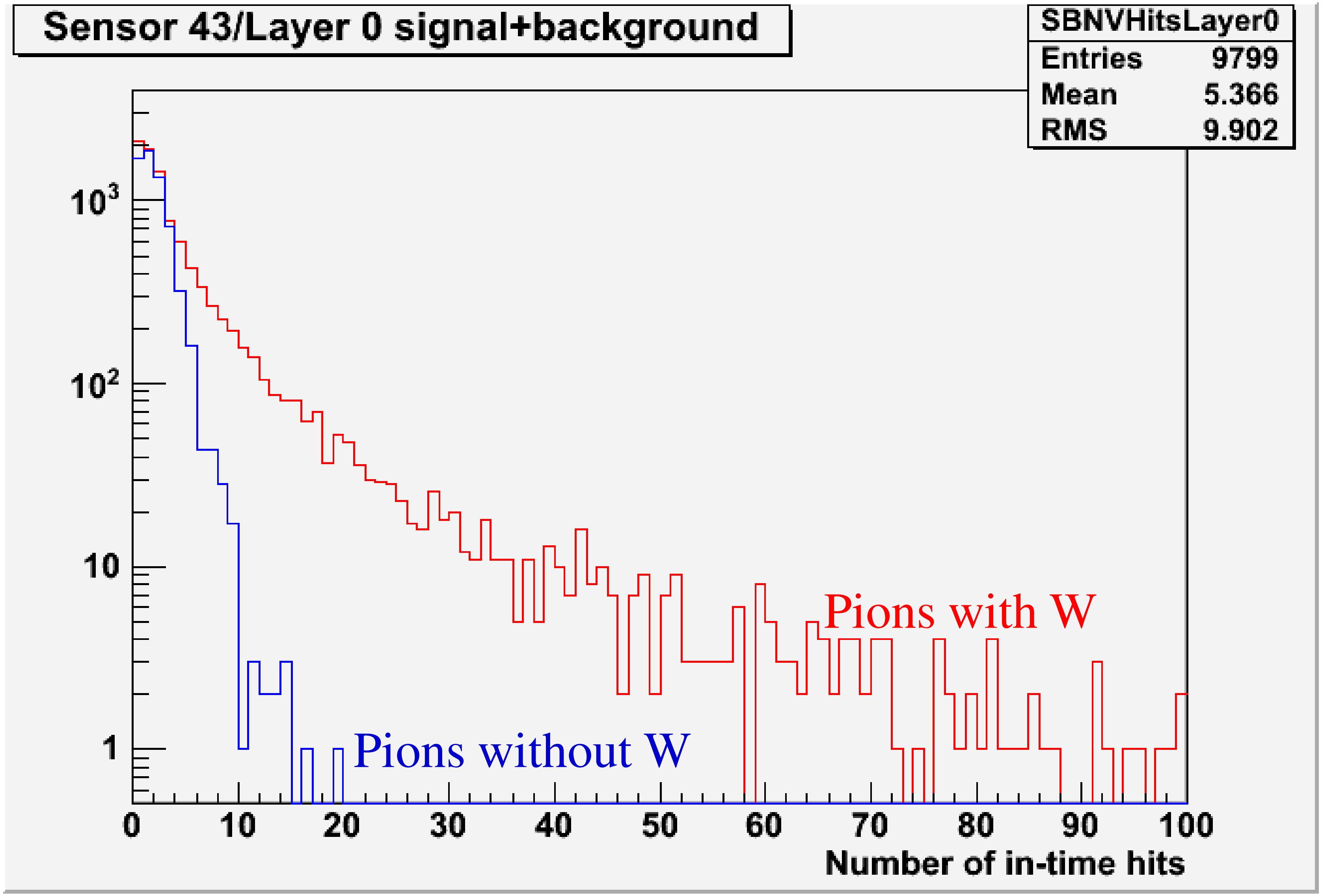


- χ^2 probability reasonably flat; indicates alignment and track fit is sensible

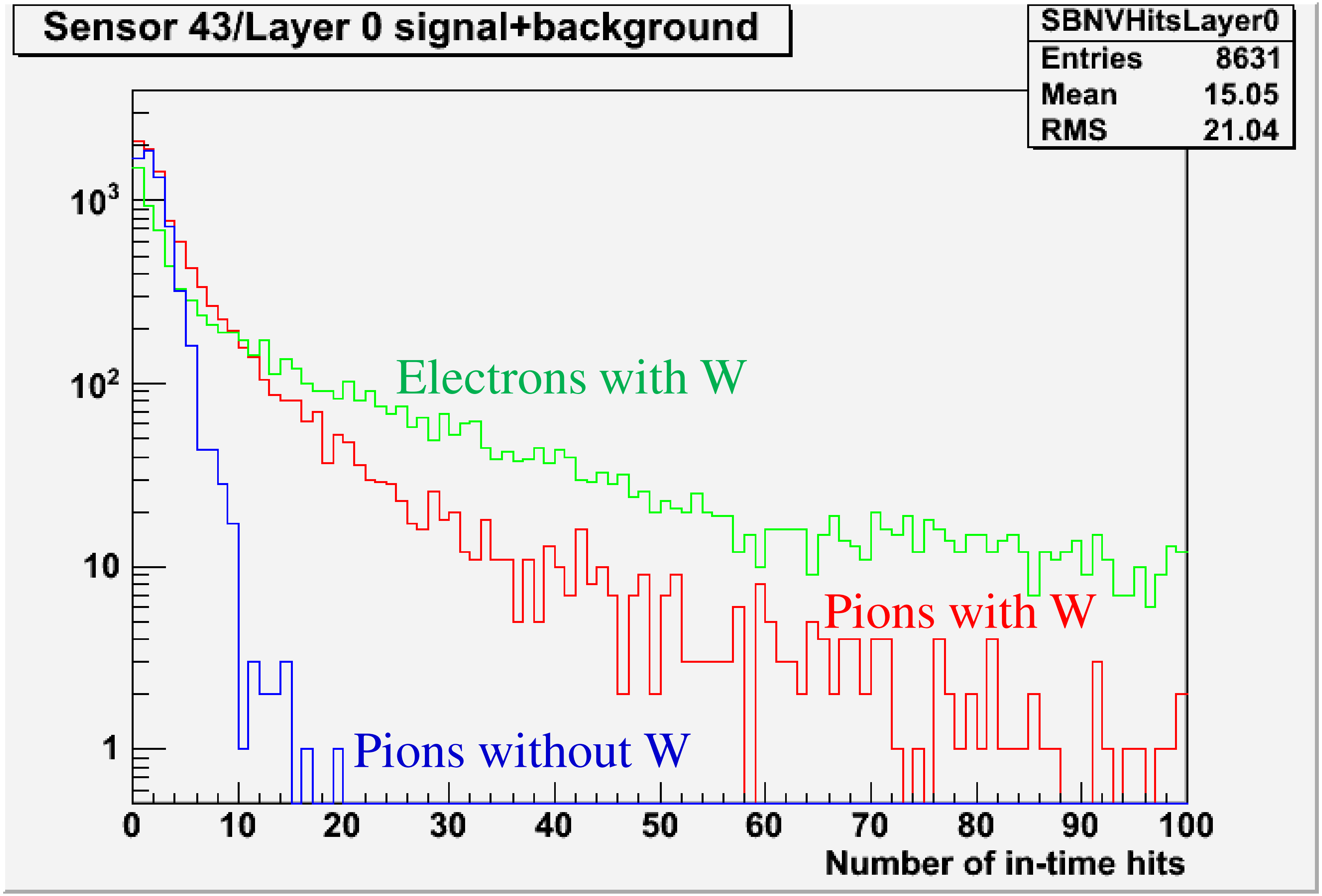
Got lucky on the last day

- SiLC group finished data-taking one day before schedule
  - After they packed up, we could control beam
- Before end of pion runs, put 30mm of tungsten in front of stack
  - Corresponds to $8.6X_0$ or 0.31 interaction lengths
  - Around ¼ of pions should interact
- Then on last day changed to electron runs
  - Five energies; 20, 40, 60, 80, 100GeV
  - Should give first data on EM shower core density
- Must understand sensor hit efficiency first
  - Must do comparison with MC showers
  - Efficiency needed for meaningful comparison with data
  - Electron analysis will take some time

Tungsten converter with pions



Tungsten converter with electrons



Next steps

- Do analysis of efficiency measurement from these data
  - Basic property of the sensor
- Must do detailed comparison with MC to understand EM shower core densities
  - Core density sets main requirement for pixel size (and hence pixel count, power, etc)
  - Probably need more electron data so bid for beam time at DESY, most likely early 2010
- Assuming three years funding really appears in April 2010
  - Build DECAL physics prototype by ~2012
  - 20-30 layers (depending on funding)
  - Should allow full EM shower containment
  - Proof-of-principle of DECAL concept

Conclusions

- Data from the DECAL CERN beam test look good
- Scintillators/PMTs give a good time tag for sensor hits
- Sensors were mechanically stable when not touched but moved significantly during handling of the stack
- Efficiency for sensors is critical measurement
  - Affected by non-ILC operation
  - Will have many effects contributing
  - Need full tracking analysis to untangle; watch this space
- Have some EM shower data to start shower density studies
- Will probably need DESY beam test in 2010
- If funded, aim to build DECAL physics prototype by 2012