Performance of a single crystal diamond pixel telescope

Dmitry Hits
Rutgers University and CMS collaboration

Outline

- The Pixel Luminosity Telescope (PLT) Project
  - Overall design
  - Hybrid readout
- Detector Preparation
  - Diamond Sensors
  - Bump bonding
- Test Beam Setup
  - PLT telescope
  - DAQ
- Results
  - Illumination / Pixel yield
  - Tracking
  - Pulse height
  - Efficiencies
- Future Tests / Schedule

Authors

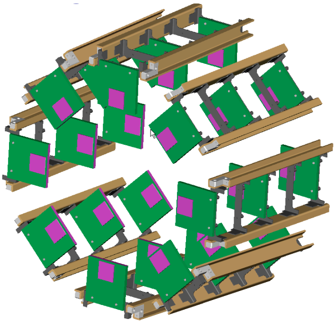
- CERN
  - Richard Hall-Wilton, Vladimir Ryjov
- HEPHY Vienna
  - Manfred Pernicka
- Rutgers University
  - Ed Bartz, John Doroshenko, Dmitry Hits, Steve Schnetzer, Bob Stone
- Princeton University
  - Valerie Halyo, Bert Harrop, Adam Hunt, Dan Marlow
- Vanderbilt University
  - Will Johns
- University of Tennessee
  - William Bugg, Matt Hollingsworth, Stefan Spanier

The Pixel Luminosity Telescope (PLT)

- Dedicated stand-alone luminosity monitor for CMS
  - ➡ independent of CMS trigger, other detector components
- Simple device stable over lifetime of CMS
- Precision measure of relative bunch-by-bunch luminosity
  - ➡ statistical precision of 1% in real time (a few seconds)
- Absolute luminosity calibration on:
  - ➡ electroweak process ($\approx$ 5%)
  - ➡ Optical Theorem and forward scattering ($\approx$ 2%)
  - ➡ QED process ($\approx$ 1%)
- Small systematic errors
  - ➡ designed to be below 1%
  - ➡ linear over full range of luminosity
- Self monitoring and calibrating
  - ➡ backgrounds
  - ➡ efficiency

PLT Basic Design

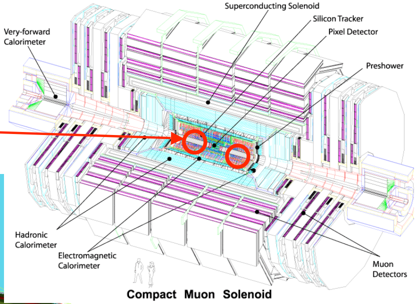
- Telescope Arrays
  - ➡ eight telescopes per CMS end
  - ➡ location: r ≈ 5 cm, z ≈1.75 m
- Telescopes
  - ➡ three planes
  - ➡ total length 7.5 cm
- Telescope Planes
  - ➡ diamond pixel sensors
  - ➡ active area 4.0 mm × 4.0 mm
  - ➡ bump-bonded to PSI46v2 pixel ROC

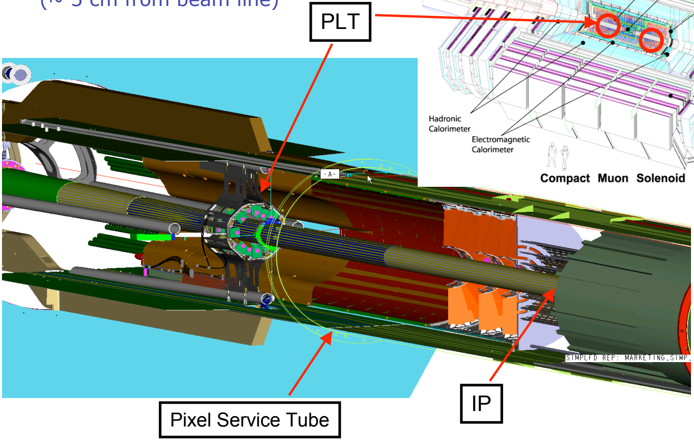


- Measure number of 3-fold coincidences in each bunch crossing (40MHz) using fast-or outputs of the PSI46 pixel chip
- Readout full pixel hit information of each plane at 1 to 10 kHz

Location of PLT

- End of Be section of beam pipe
  (~ 1.7 m from IP)
- Just outside of beam pipe
  (~ 5 cm from beam line)

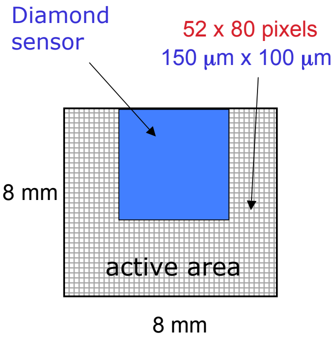




CMS Pixel Readout Chip

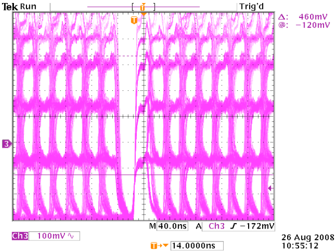
CMS PSI46 pixel chip has “fast” multiplicity counting built in

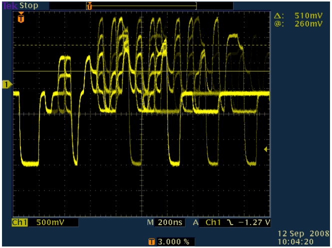
- Double column architecture
- Fast-Or output level
  - ➡ 0, 1, 2, 3, ≥4 double column hits
  - ➡ each bunch crossing
- Individual pixel thresholds adjustable
- Individual pixels can be masked
- Full pixel readout
  - ➡ address and pulse height of hit pixels
  - ➡ every L1 trigger



Two Complimentary Readout Modes

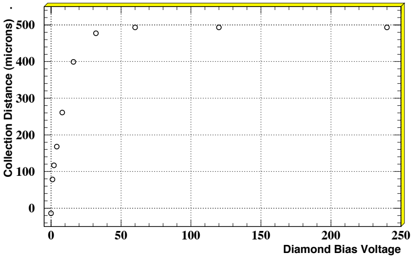
- Fast Or Output
  - every bunch crossing (40 MHz)
  - level → number of double columns hit
  - bunch-by-bunch luminosity
  - abort gap particles
- Full Pixel Readout
  - 1 kHz to 10 kHz rate
  - hit pixel addresses and pulse heights
  - powerful diagnostic for fast hit output mode
  - corrections for accidentals and overlaps
  - pixel efficiencies
  - IP centroid measurement
  - beam halo

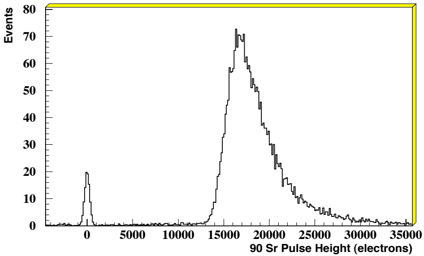


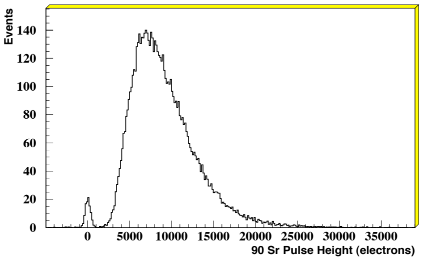


Diamond Sensors

- Radiation hard (few × 10^{15} p/cm^2)
- No need for cooling
- Full charge collection < 0.2 V/μm
  - ➡ 18,000 e^- signal for 500 μm diamond
  - ➡ Landau 60% narrower than for Si
- Pulse height well separated from pedestal
  - ➡ compare poly crystalline diamond



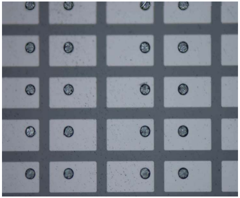




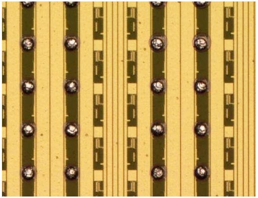
Bump bonding

Challenge: Bump bonding individual 4.7 mm × 4.7 mm diamond sensors to single ROC die.

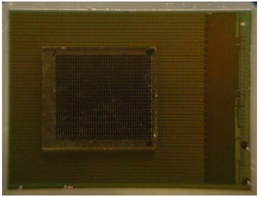
Process developed at Princeton micro-fabrication lab.



Bumped diamond



bumped ROC

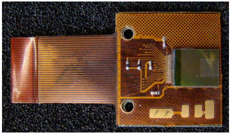


bump bonded detector

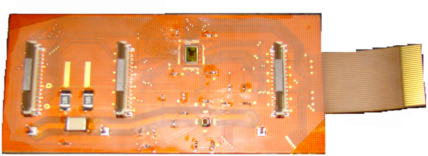
Telescope

- Components are full PLT prototypes

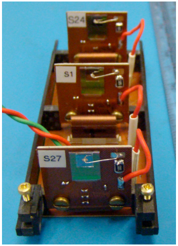
Hybrid board



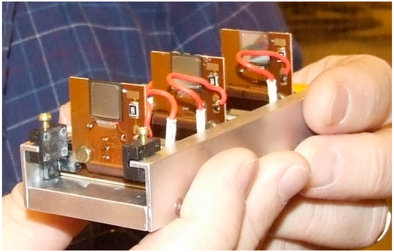
HDI



assembled telescope

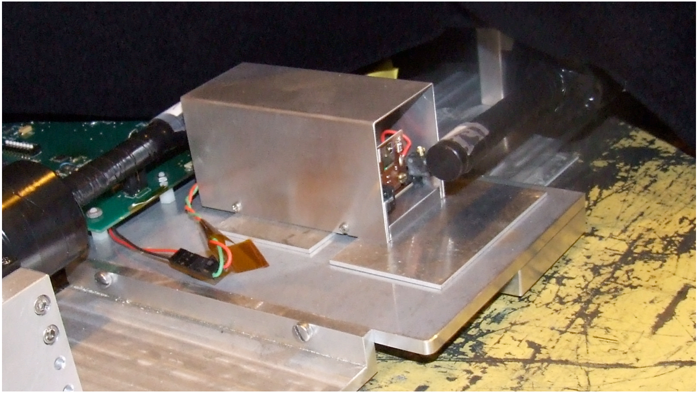


assembled telescope in the cartridge



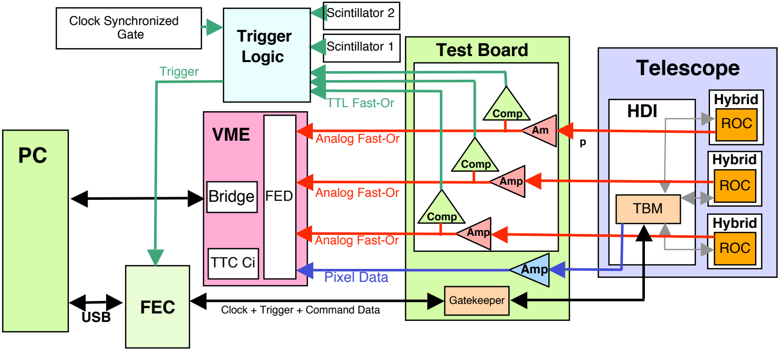
Test beam setup

150 GeV/c π^+ beam line at CERN SPS



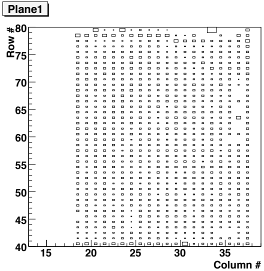
- Two small 6 mm × 6 mm trigger scintillators upstream and downstream of telescope
- Allocated 7 days of beam time.
- Received only 48 hours of beam time (weekend before allotted time)

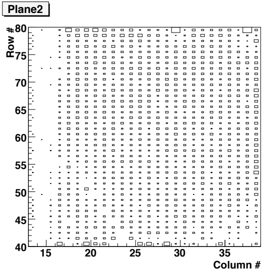
DAQ

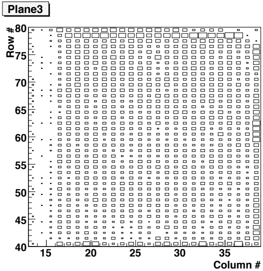


- Readout in test beam electrical
- Developing optical readout system
- Used CMS pixel FED (flash ADC) with electrical input
- Triggering inputs: scintillators, fast-or TTL
- For present results used only scintillator triggers

Plane Occupancies



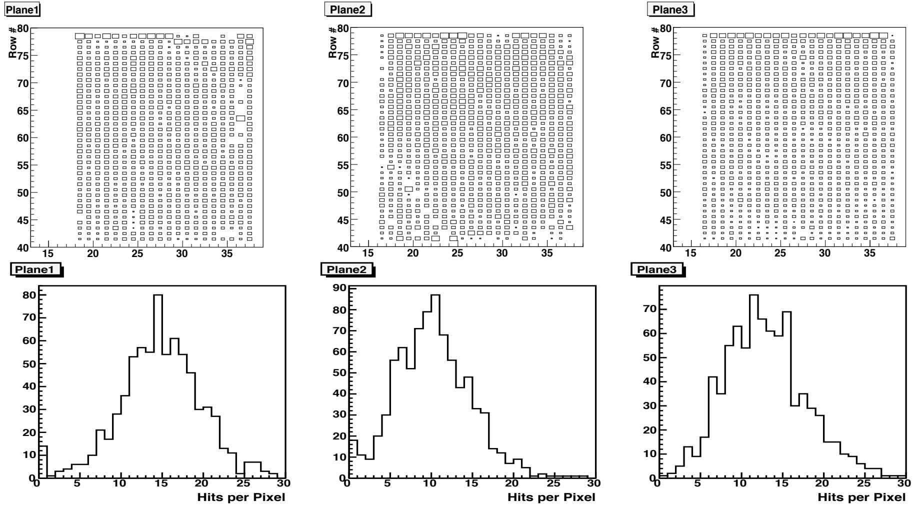




For further analysis, remove:

- Left most 5 columns of Plane 1
  - ➡ disabled during data taking
- Right most column of Plane 1
  - ➡ disabled during data taking
- Left most 3 columns of all planes
  - ➡ not covered by scintillator
- Outer most rows and outer most columns of all planes
  - ➡ defines fiducial region

Pixel Yields

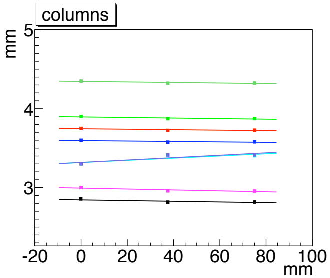


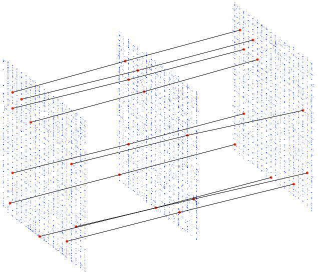
Percentage of pixels with no hits:

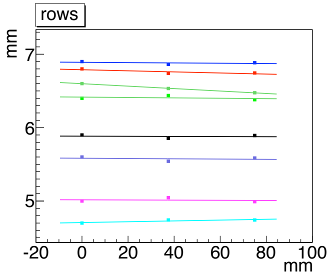
Plane 1: 1.8%   Plane 2: 2.2%   Plane 3: 0.1%

Tracking

- Define cluster: group of neighboring “hit” pixels
- Define cluster position: center of gravity
- Correct for relative plane rotation
- Correct for relative plane offset
- Select events with one and only one cluster in each plane (89% of events with hits in all three planes)

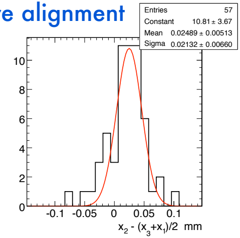




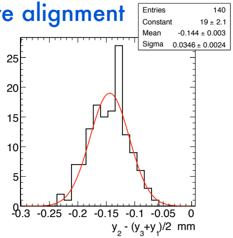


Alignment

before alignment



before alignment

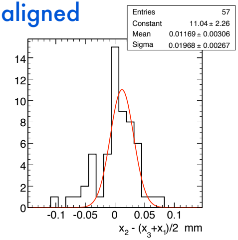


Alignment offsets

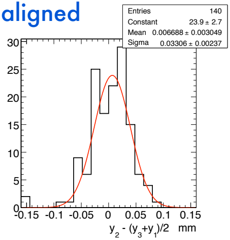
- x offset: 25μm
- y offset: 144μm
- θ offset: 0.6°

(40 μm over 4 mm)

aligned



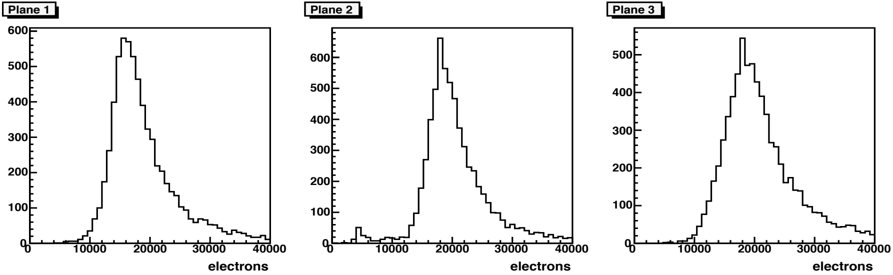
aligned



Readily found and corrected

Pulse heights

- Require single cluster in all three planes
- For Plane c, require hit in regions of Planes a and b such that track is certain to pass through fiducial region of Plane c
- Plot pulse height summed over cluster

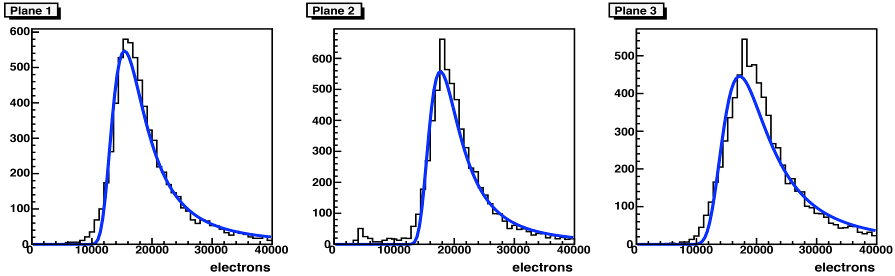


Most probable pulse heights:

Plane 1: $16{,}000e^-$ Plane 2: $18{,}500e^-$ Plane 3: $18{,}500e^-$

Pulse heights

- Require single cluster in all three planes
- For Plane c, require hit in regions of Planes a and b such that track is certain to pass through fiducial region of Plane c
- Plot pulse height summed over cluster

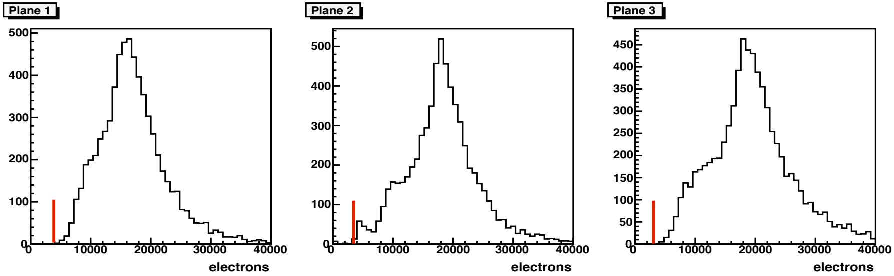


Most probable pulse heights:

Plane 1: 16,000e⁻ Plane 2: 18,500e⁻ Plane 3: 18,500e⁻

Efficiency

- Require single cluster in all three planes
- For Plane c, require hit in regions of Planes a and b such that track is certain to pass through fiducial region of Plane c
- Plot pulse height of pixel with a maximum pulse height



Pixel threshold range:

Plane 1: 3500 - 4500 e^-

Plane 2: 3000-4000 e^-

Plane 3: 2500-3500 e^-

Fast-Or efficiencies

- In CMS, particles arrive at a definite phase of the 40 MHz clock.
- Test beam particles arrive at random phases of the clock.
- For triggers occurring near a clock edge some fast-Or's, due to time walk, may occur one clock cycle early (late) for large (small) pulse heights.
- With sufficient statistics, test beam events could be selected for which triggers occurred at a definite phase of the clock.
- For now, early (or late) Fast-Or's must be counted as part of the efficiency

	Plane 1	Plane 2	Plane 3
Early Fast-Or only	0.5%	21%	2.5%
Late Fast-Or only	0.0%	0.4%	0.1%
Total events	7,146	9,049	7,814
Events with no Fast-Or	53	37	7
Efficiency	99.3%	99.6%	99.9%

Future Plans /Schedule

- Irradiate telescope planes ~ full LHC lifetime (2×10^{15} p/cm^2)
- Beam test winter Fermilab or CERN
  - ➡ Compare irradiated / unirradiated telescopes

    pulse heights, fast-or efficiencies
  - ➡ Study fast-or timing

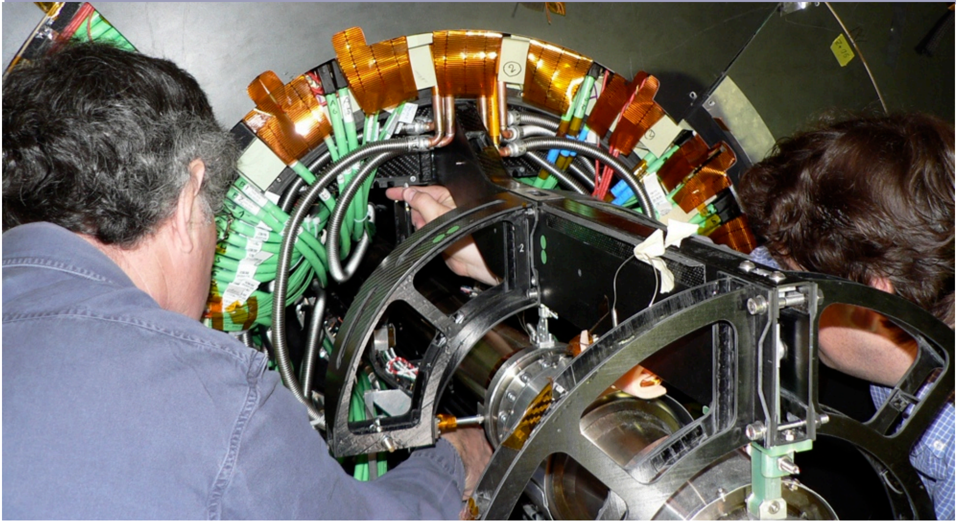
    TDC of trigger and clock
  - ➡ Determine spatial resolution

    planes rotated 20° with respect to beam external tracking telescope
- CMS Engineering Design Review of PLT project this fall
- Begin production of 16 (+4) telescopes early next year
- PLT ready for installation in CMS fall 2010

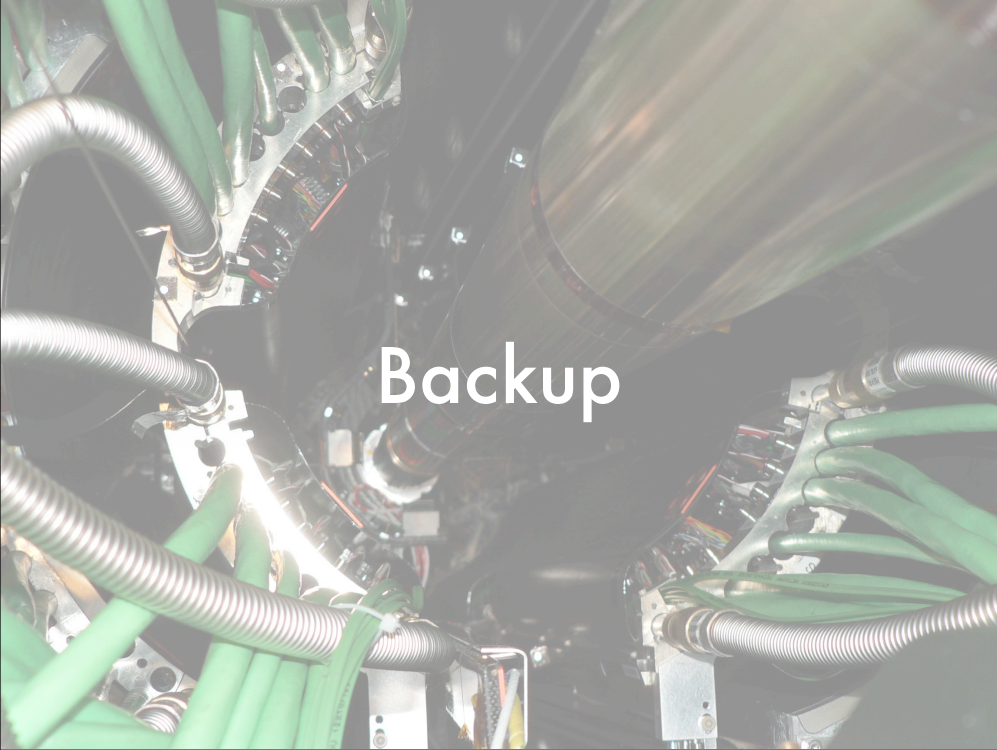
Conclusions

- Analysis of beam test data of a three-plane prototype PLT telescope has been completed
- The prototype meets all design requirements
- Percentage of good bump-bonds: > 98% in each plane
- Pulse height for high energy pions: ~ 18,000 e^- most probable
- Pulse heights well above pixel threshold range
- Tracks readily and clearly reconstructed
- Rapid alignment (translation and rotation) of planes with beam
- Fast-Or Efficiency: > 99% in each plane

On course for PLT installation during 2010-2011 shutdown



Backup



Passage of particles through matter (PDG)

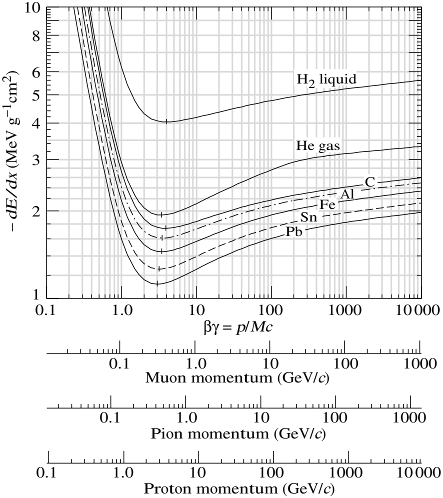


Figure 27.3: Mean energy loss rate in liquid (bubble chamber) hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. Radiative effects, relevant for muons and pions, are not included. These become significant for muons in iron for $\beta\gamma \gtrsim 1000$, and at lower momenta for muons in higher-Z absorbers. See Fig. 27.21.