Radiation Damage Effects in the LHCb Vertex Locator (VELO)

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On behalf of the LHCb collaboration
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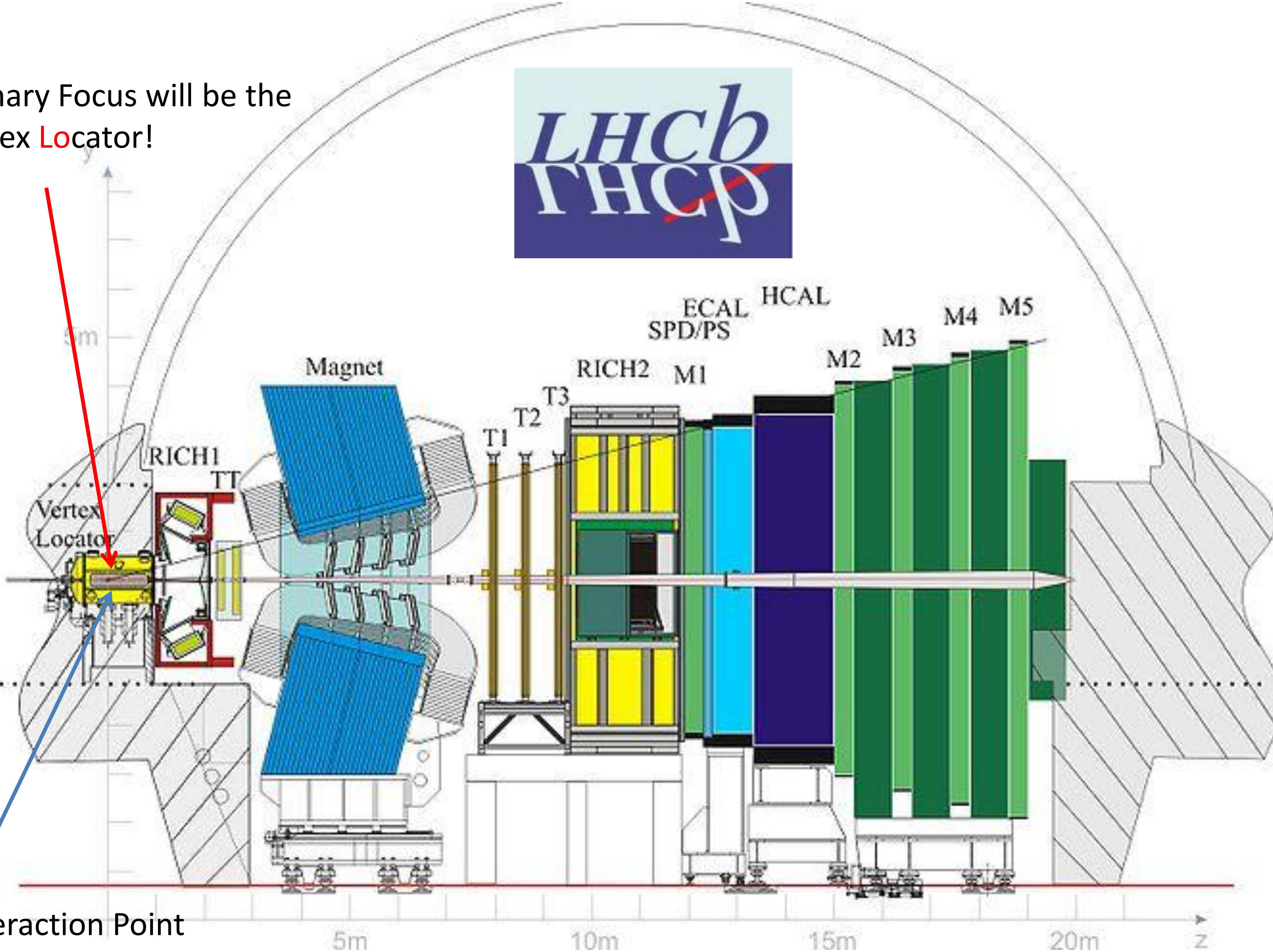
Primary Focus will be the Vertex Locator!



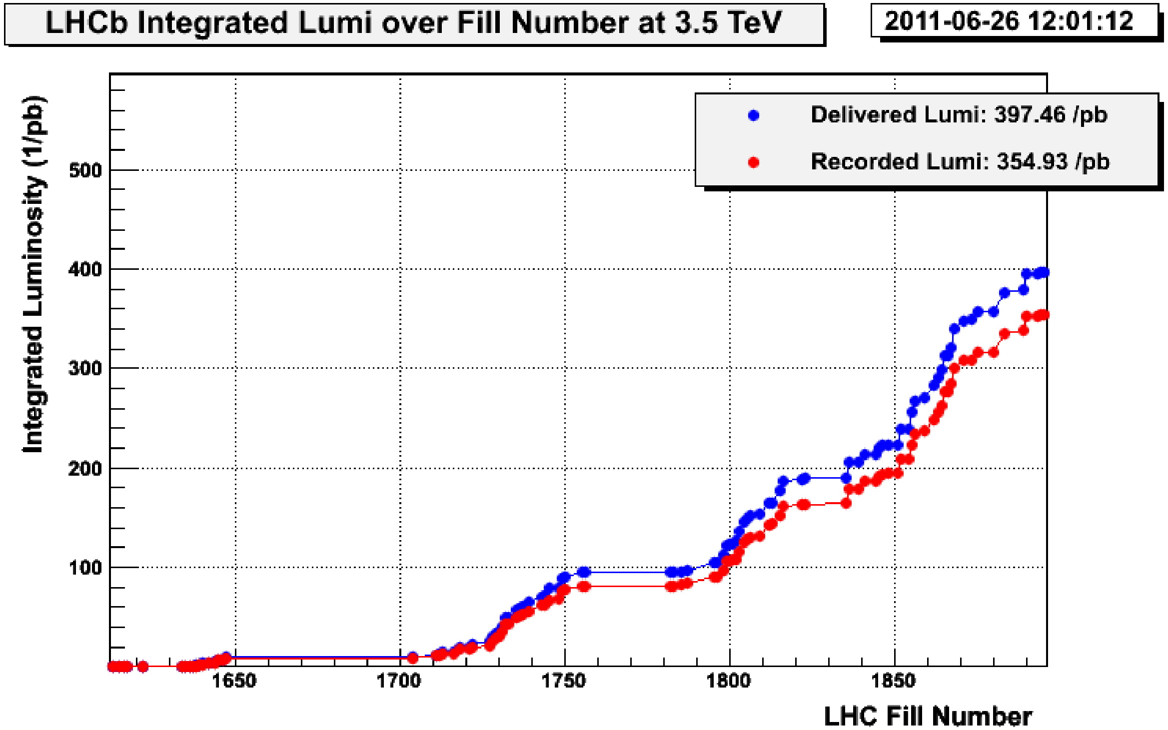
Interaction Point

LHCb Performance

Collecting data at a very good rate:
- Current performance is 1 pb^{-1} per hour (at LHCb)
- All of 2010 data can be collected in only a few days
- Progressing well towards year's target of 1 fb^{-1}

-In 2010 LHCb same luminosity as ATLAS & CMS

-Approx. $3x10^{12}$ n_{eq} p/cm^2 on sensors nearest the PV (at R = 0.7 cm)



Already producing an array of impressive results!

A couple of examples:

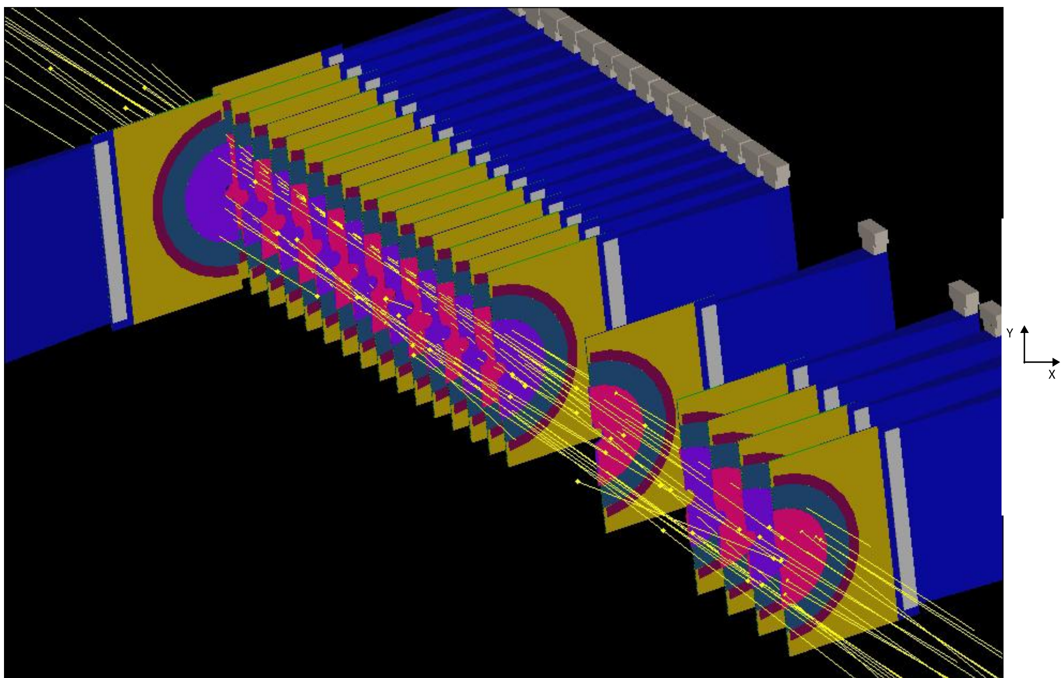
BR limit for $B_s \rightarrow \mu^+ \mu^-$ ($<5.6x10^{-8}$) competitive limit (using 37 pb^{-1} vs CDF 3.7 fb^{-1})

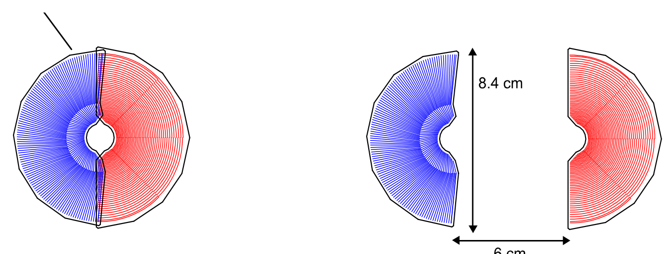
$B_s \rightarrow K^+K^-$ lifetime 1.440 ps $\pm$ 0.096 (stat) $\pm$ 0.010 (syst) (vs CDF $\pm$ 0.18)

- 2 Halves (A&C side)
- 21 modules/half
- R & Phi sensors/module

- Closed as soon as we reach stable beams.

- Require at least 6 hits (3 each R&Phi) to reconstruct tracks





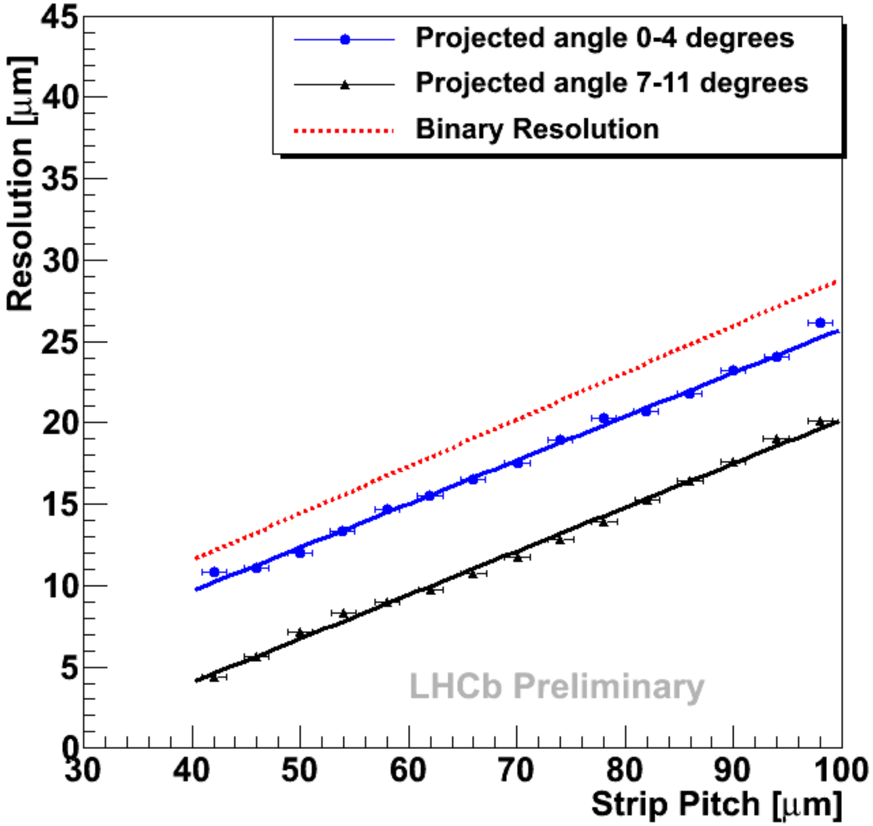
VELO fully closed (stable beam)

VELO fully open

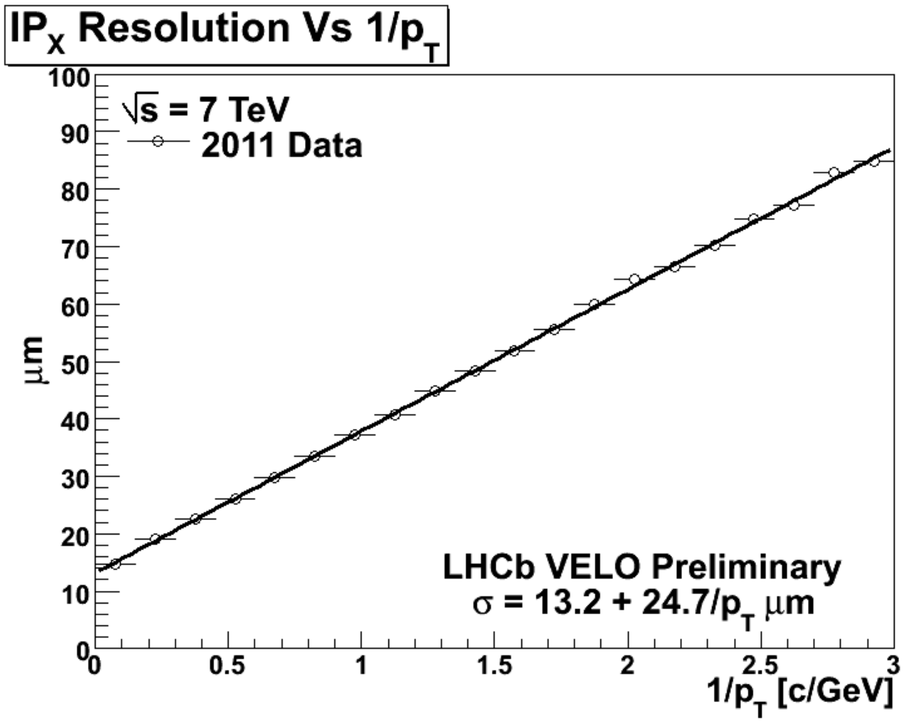
VELO Facts

- It is the closest detector of the main experiments at LHC to the beam, closes to 8mm
- Most modules are n-on-n
  - Two n-on-p prototypes
- Nominal peak radiation damage is about $1.3x10^{14}$ n_{eq} $p/cm^2/2$ fb^{-1} at R=0.7 cm (from 2001 prediction)

VELO Performance



Can deliver 5 micron resolution!
Gives better separation of primary vertex with secondary verticies



The impact parameter of the VELO is also exceptionally good

Monitoring Radiation Damage

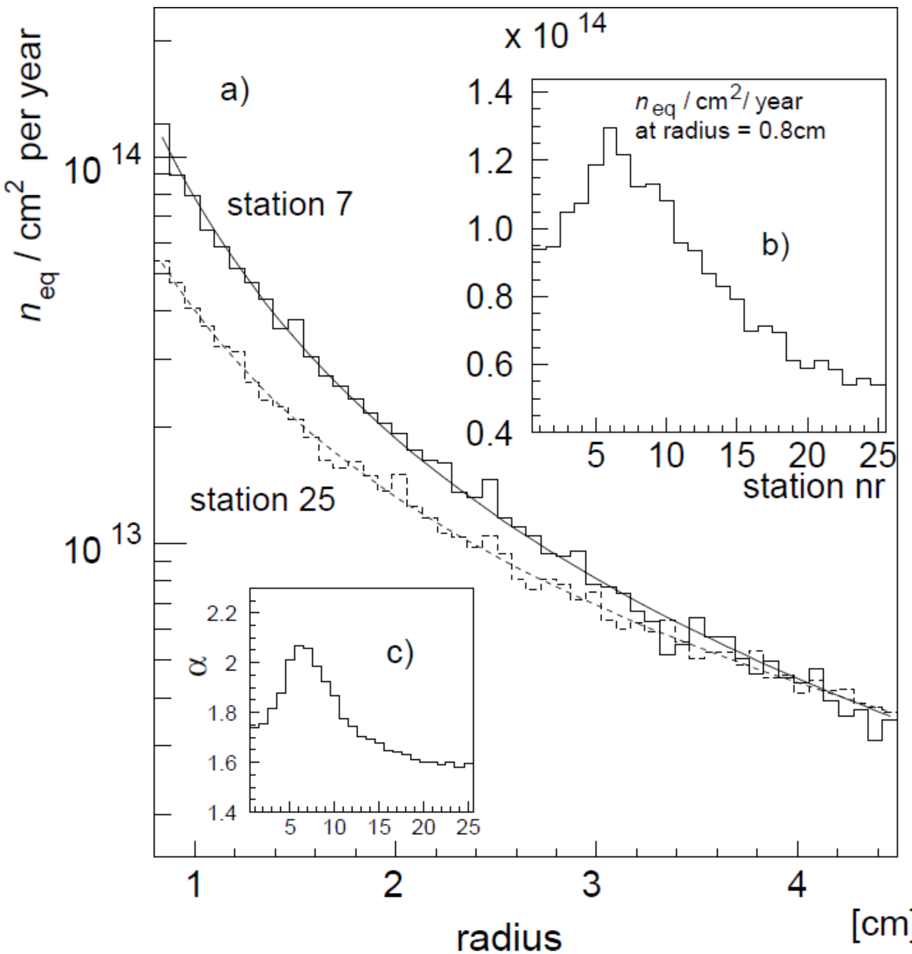
- We have four methods of monitoring the radiation damage:
- IV Scans
  - done weekly
  - no measure of depletion voltage (but can trend the current)
- Temperature dependent current measurement
  - done before and after long shutdown
  - do an IV scan at room temperature (significantly larger bulk current, see later)
- Charge collection efficiency (CCE)
  - every ~6 months
  - effective depletion voltage
- Noise vs voltage scan
  - done monthly, gives us another effective depletion voltage
- Due to geometry, we have different bands of radiation damage
  - innermost highest damage, outermost least

Radiation Damage Expectation

The radiation damage in the VELO is modeled by:
Nr^{-power}
N = n_{eq}/cm^2 /2fb^{-1} at 0.8cm (diagram b)
power = radial dependence

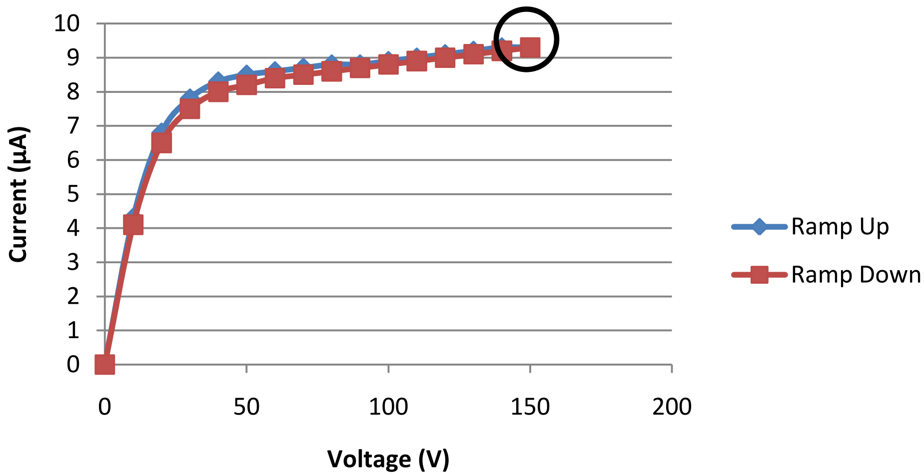
We get non-uniform radiation damage, N can vary by a factor 2 and power ranges from 1.6 to 2.1

Please note this is from 2001 predictions



IV Scan

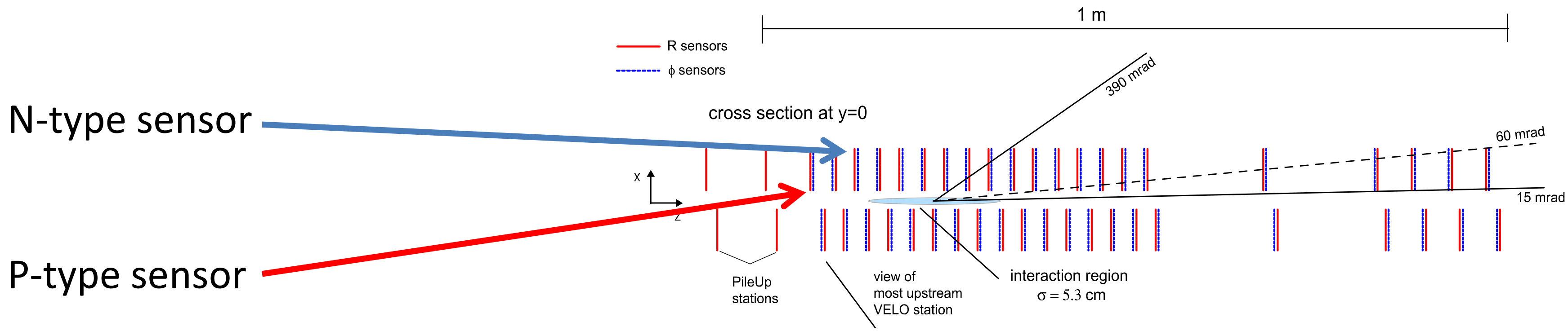
IV Scan



An example of a ramp up/ramp down cycle on a particular sensor.

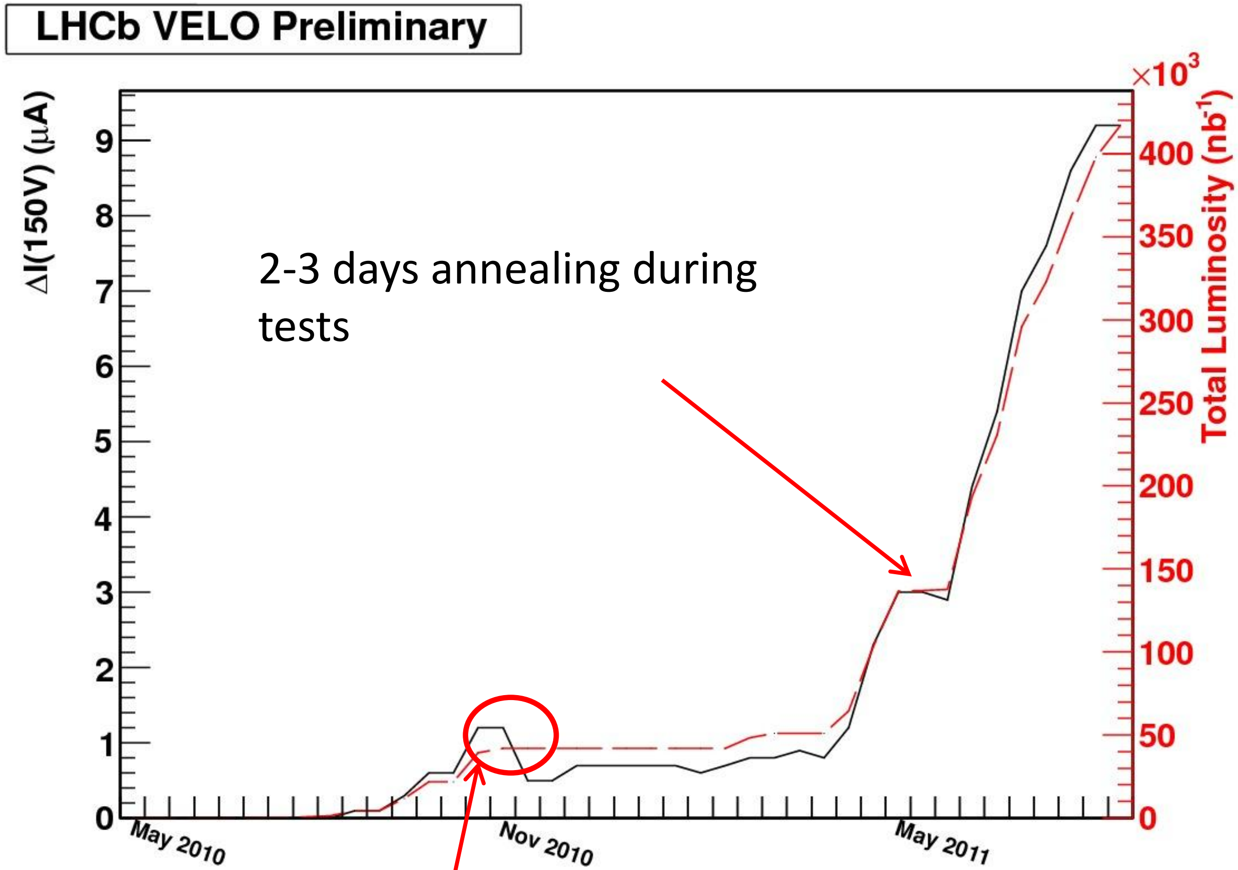
We trend the 150V point as a function of time to see how the current changes with luminosity, annealing, and other affects.

IV scans taken weekly. Currently approx 50-70 pb^{-1} between them
Approx lumi granularity = 7.5×10^{12} n_{eq}/cm^2 (for peak r=0.7 cm).
Only requires 20-30 minutes, so done between fills



IV Trending

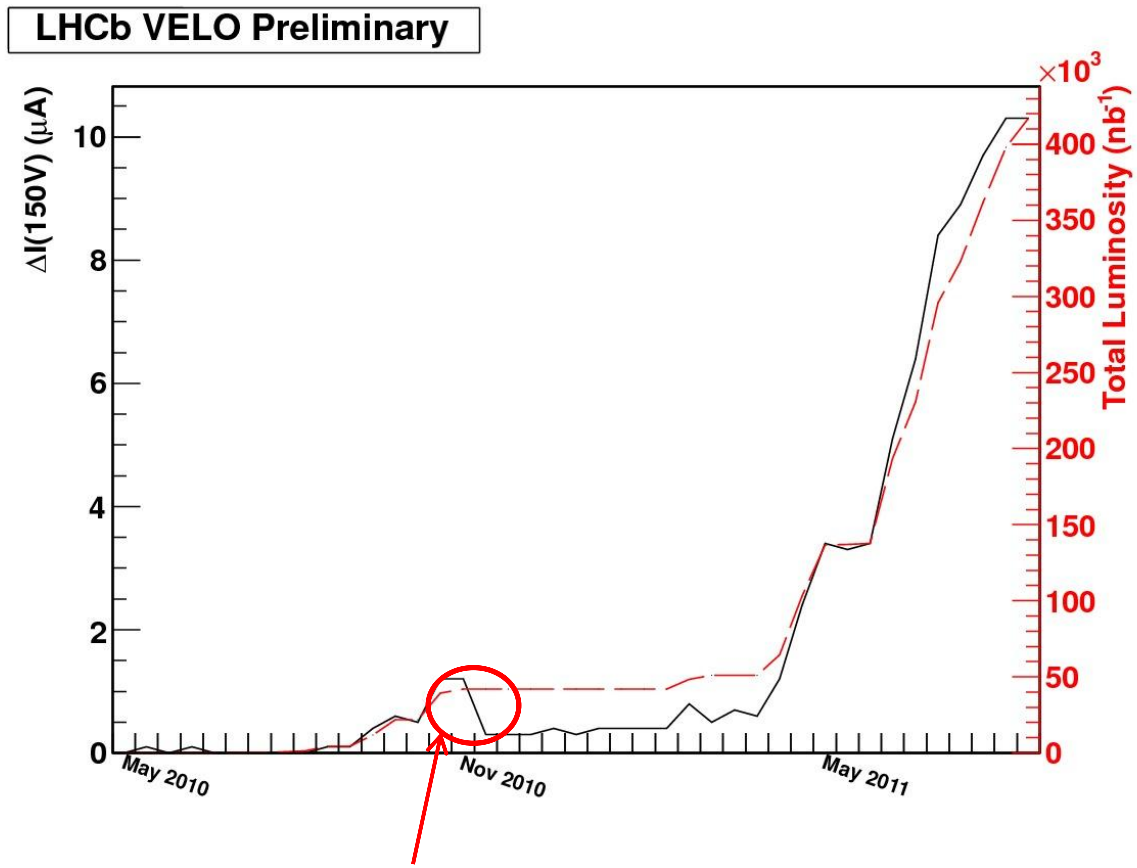
- For example, VL03AT (n-on-n sensor, near primary vertex)
- Superimpose luminosity, clear trend in current (measure ΔI = 2.2 μA per 100 pb^{-1}).
- Can do a comparative calculation for the n-on-p sensor (see following slide)



Winter shutdown (annealed at 20 C for 40 days)

P-type sensor

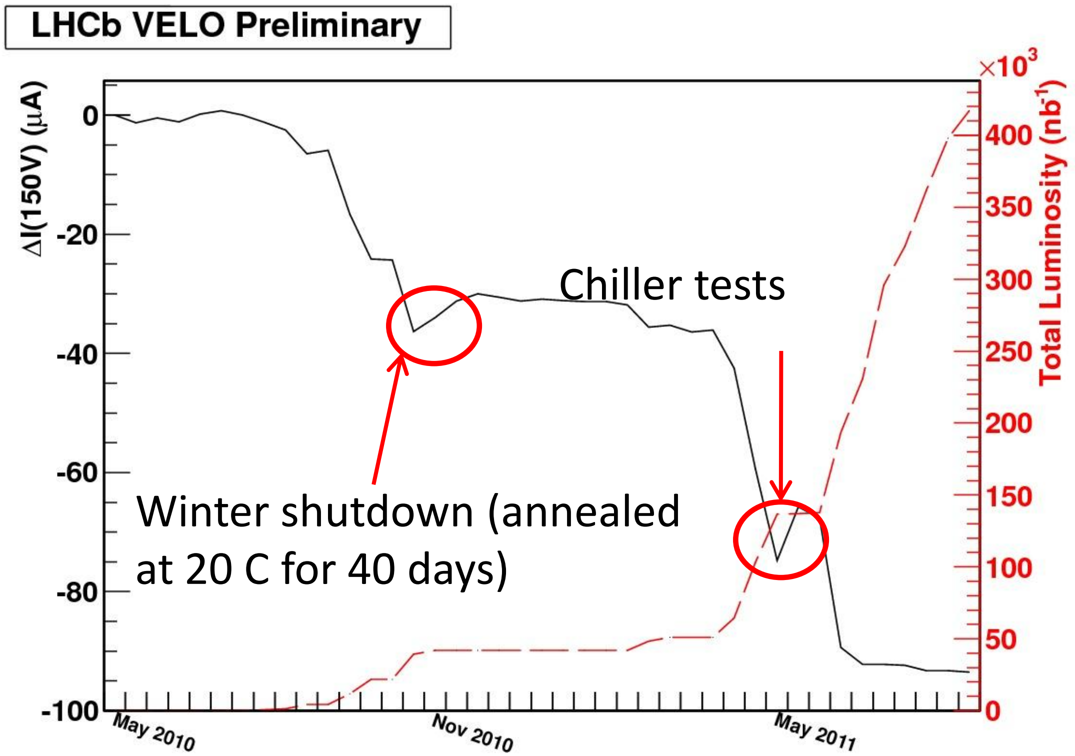
- The same plot for the p-type sensor
- Same features (eg winter annealing)
- Measured ΔI = 2.5 μA per 100 pb^{-1}
  - Very close agreement to previous value!
- Close to PV



Winter shutdown (annealed at 20 C for 40 days)

High Current Sensors

- Some sensors have very high initial currents
- These have been normalizing over time (as a function of radiation damage)
- All plateaued now and we expect them to increase in next few hundred pb^{-1}.

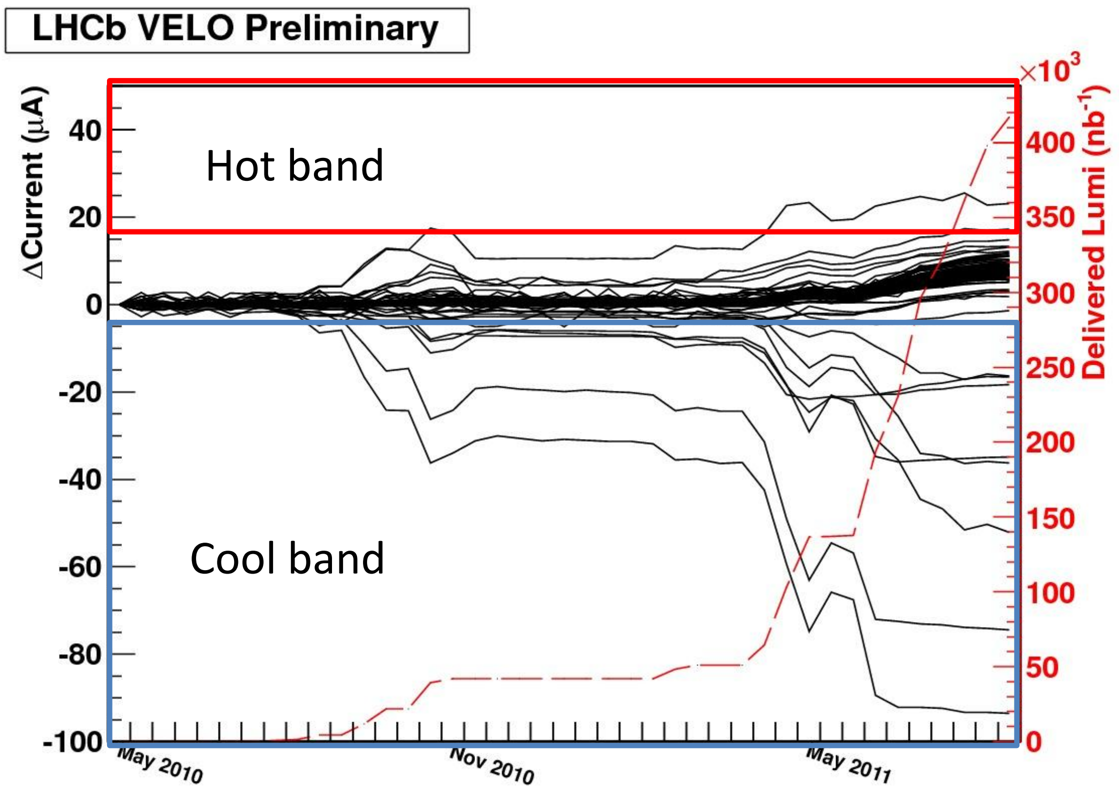


IV Summary

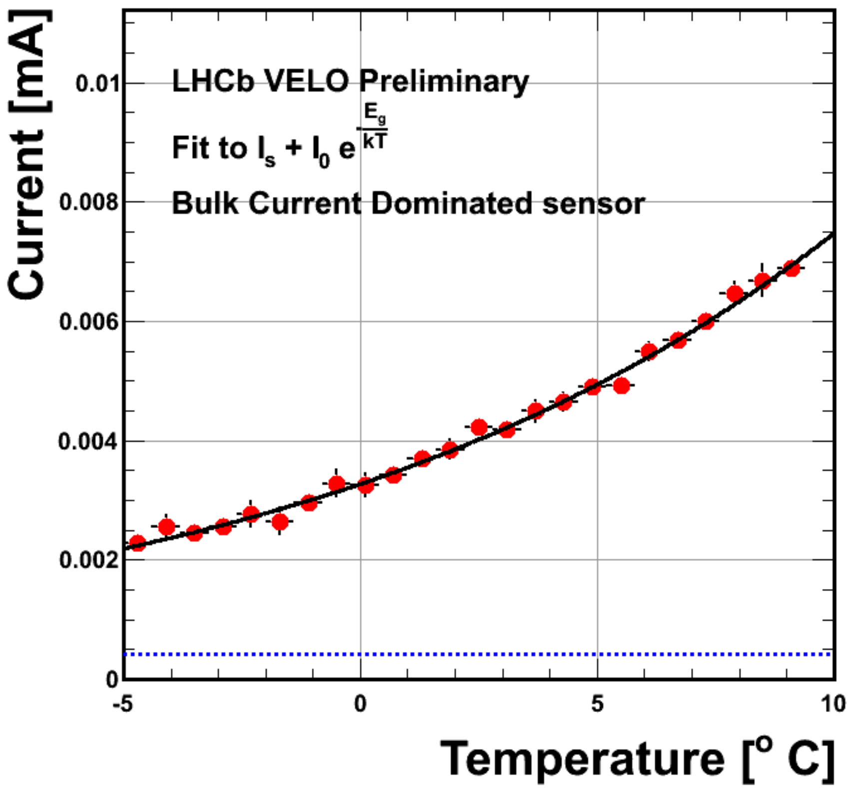
Summarize all the currents with luminosity

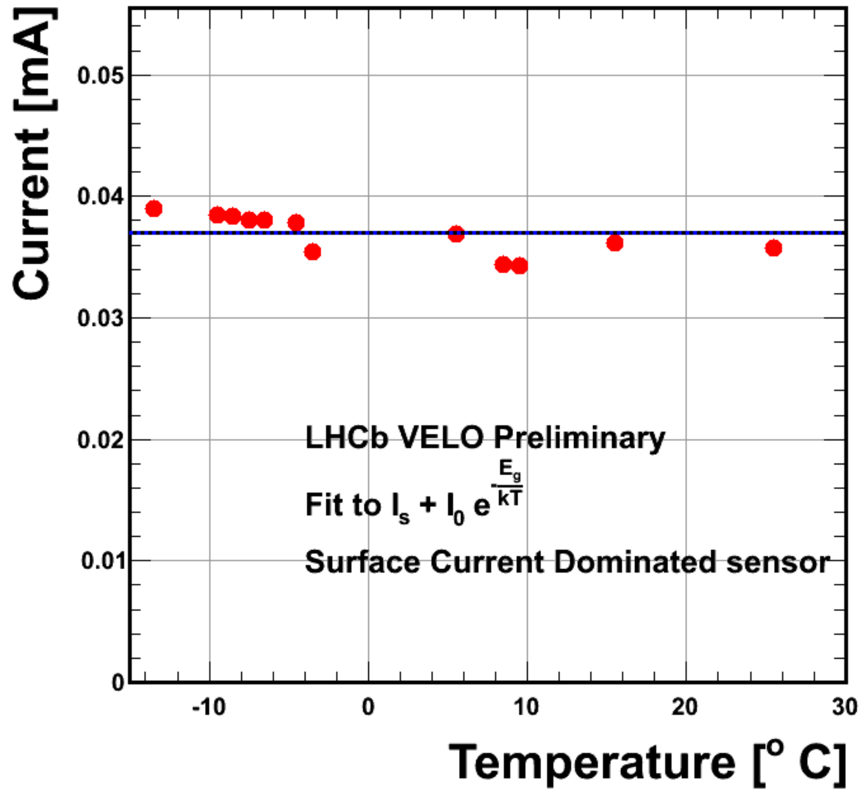
The clear recent trend of current with the large increase in luminosity delivered is apparent, especially in the most recent data points.

Negative ΔI sensors are the high current sensors, they have all plateaued we expect to see increases over next few weeks



Surface vs Bulk currents





We can separate sensors by how their currents evolve with temperature

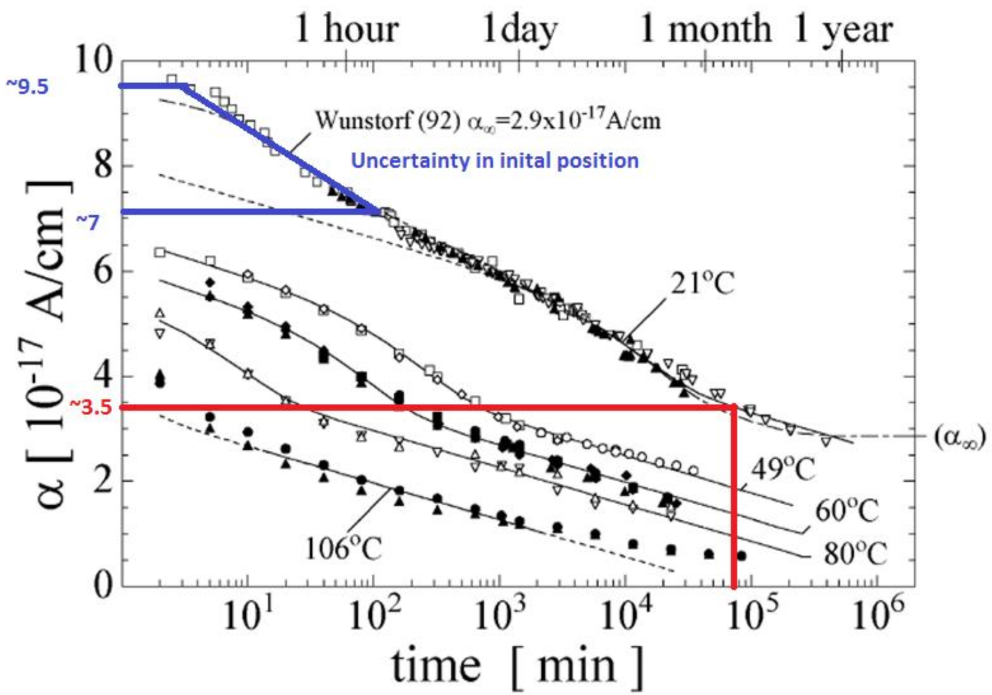
Temperature dependent Current measurement

IT scan Introduction

- Take IV scan at room temperature
  - We have a warm IV scan previously taken in June 09 (no radiation damage) so any relative changes should arise entirely from irradiation
  - See previous plots from IV scan section

IT Scan pt II

- We expect the bulk current to anneal significantly over the winter shutdown (approx 40 days of room temperature).
- α = ~7 dropping to α = ~3.5
- Expect currents to roughly halve (a lot of uncertainty in initial position)



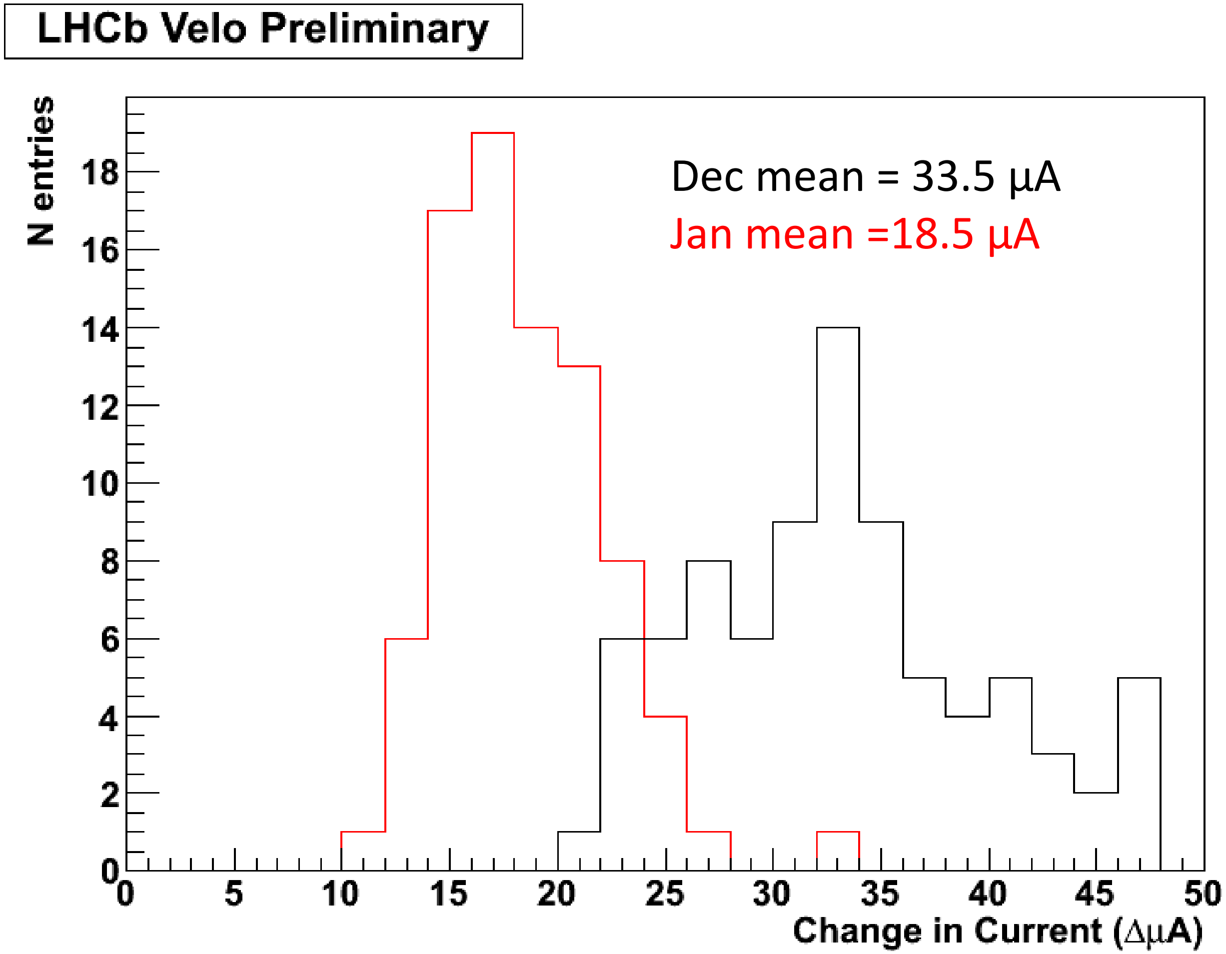
From M. Moll's thesis

IT Scan Results

Current increases between June 09 and Dec 10 are plotted to give us a measure of the amount arising from radiation damage.

We expect these to roughly halve in the Jan '11 data

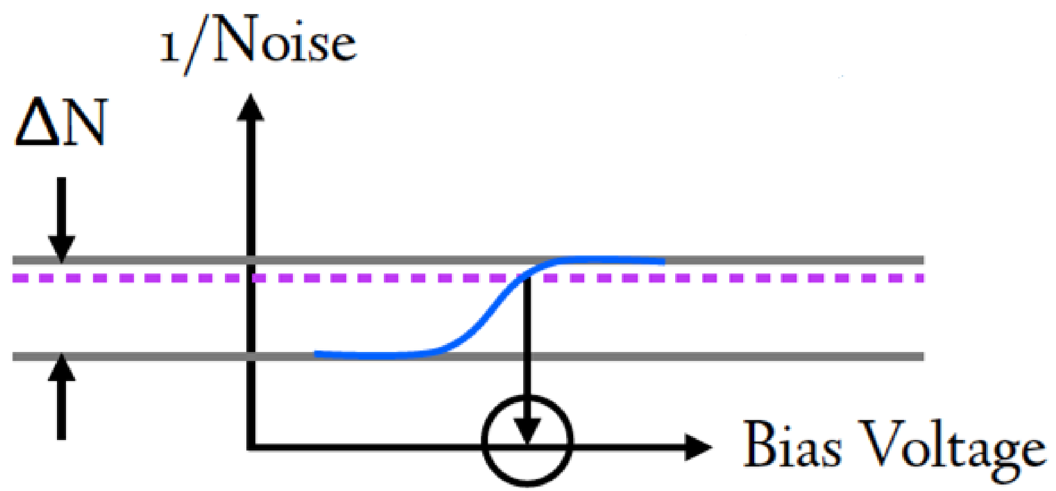
- Calculate Δ α , ~=200 minutes of pre-annealing before warm IV scan
- Consistent with warming up detector



Noise vs Voltage Scan

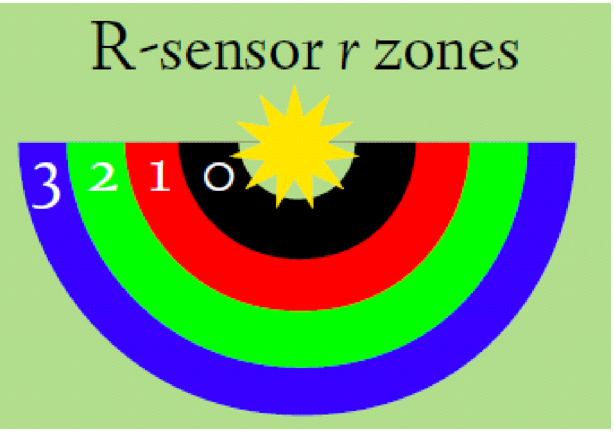
Noise vs Voltage scan

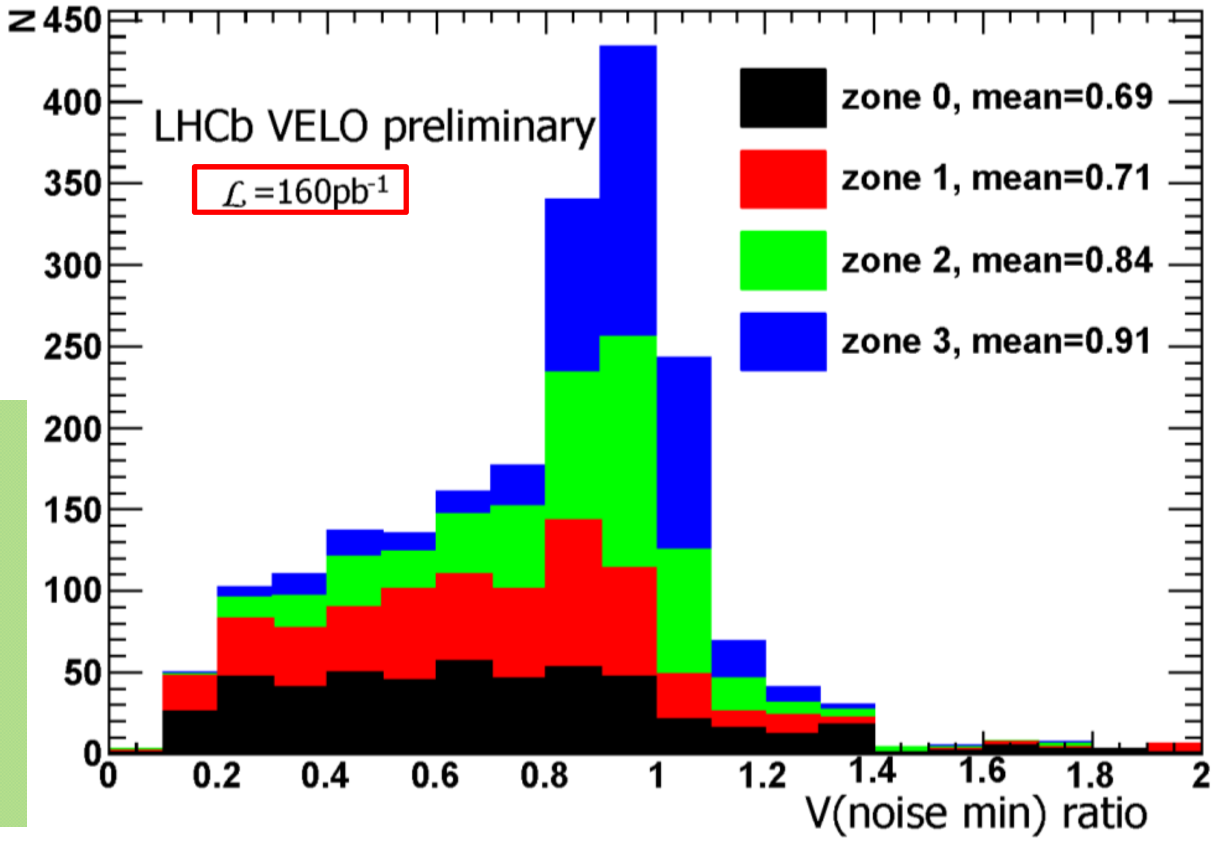
- Ramp voltage up and take raw data at set points
  - Looking for when noise is 80% of minimum, we call this point 'Effective Minimal Noise Voltage' or EMNV.
  - Taken once a month



Noise vs Voltage results I

Ratio r=1 indicates no change in depletion voltage, ratio r=0.6 means 60% of the original depletion voltage

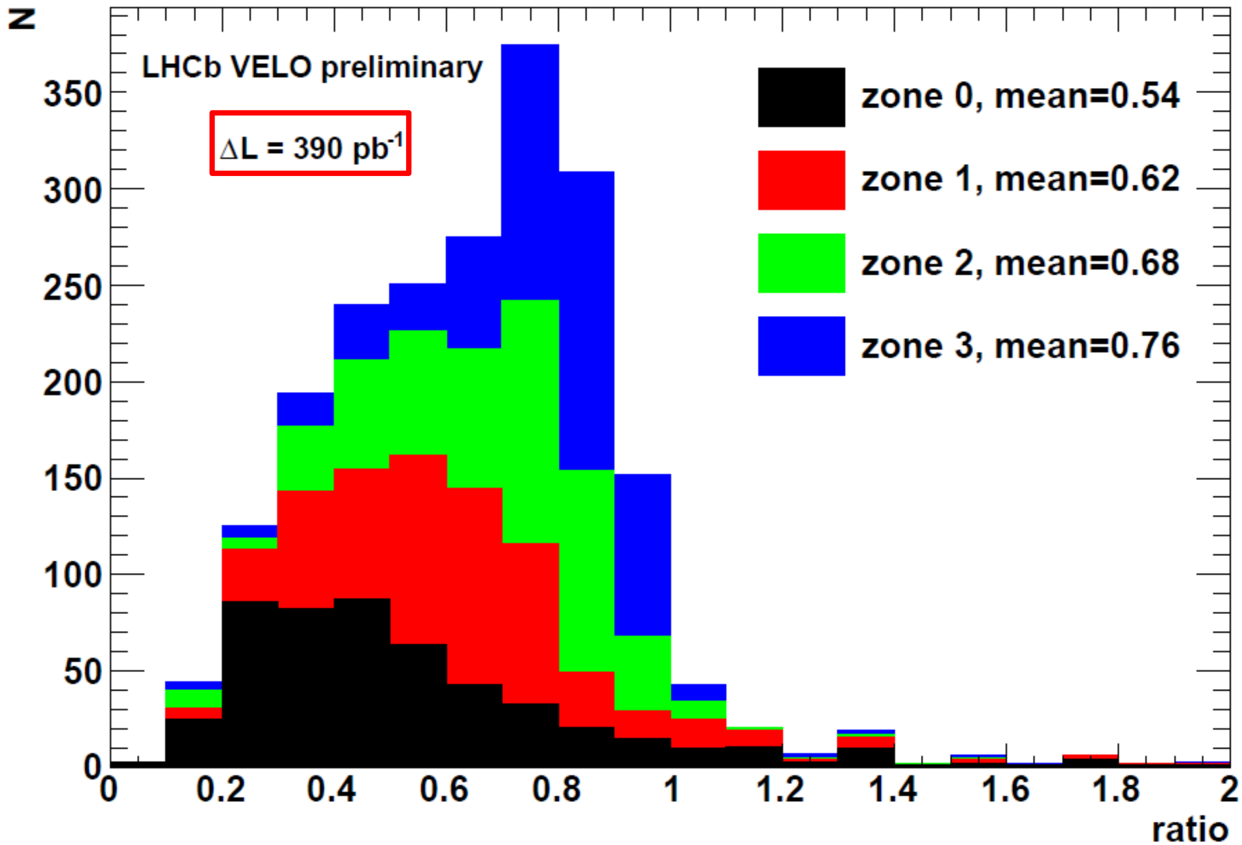




As expected, there is a clear trend in the results showing less change in depletion voltage the further out they are. Expect to see these continue to drop as we get closer to type inversion.

Latest Results

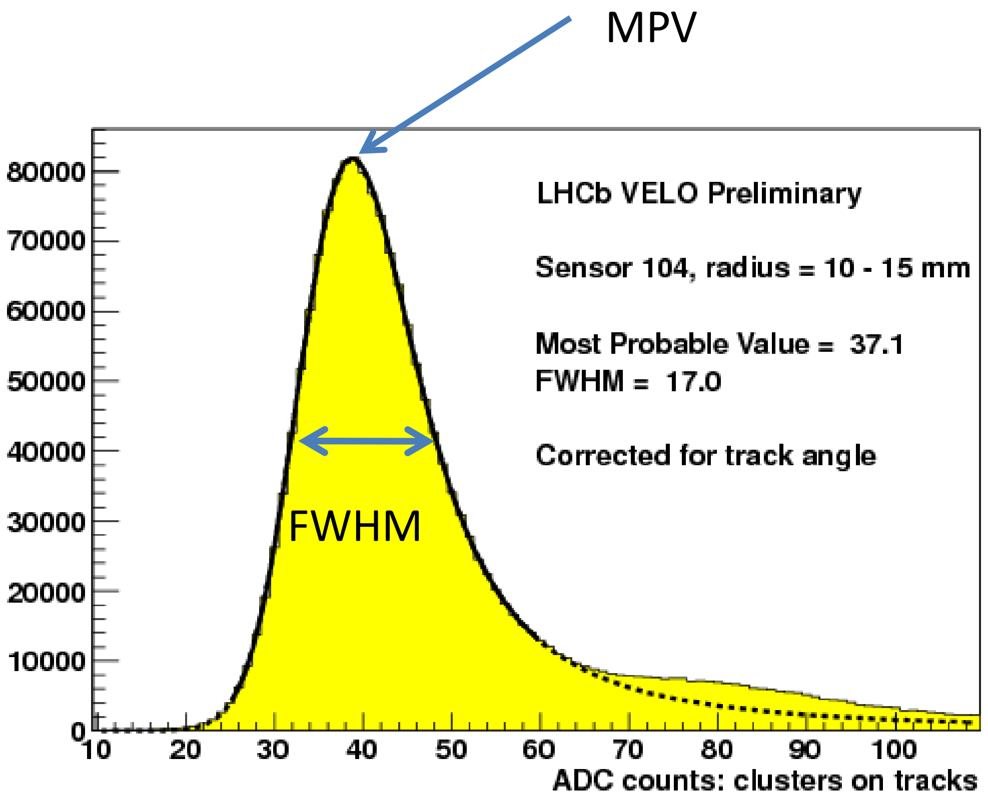
-Latest results as of 04/07/11
-Zonal bands still match expectation
-Significant decrease since previous results



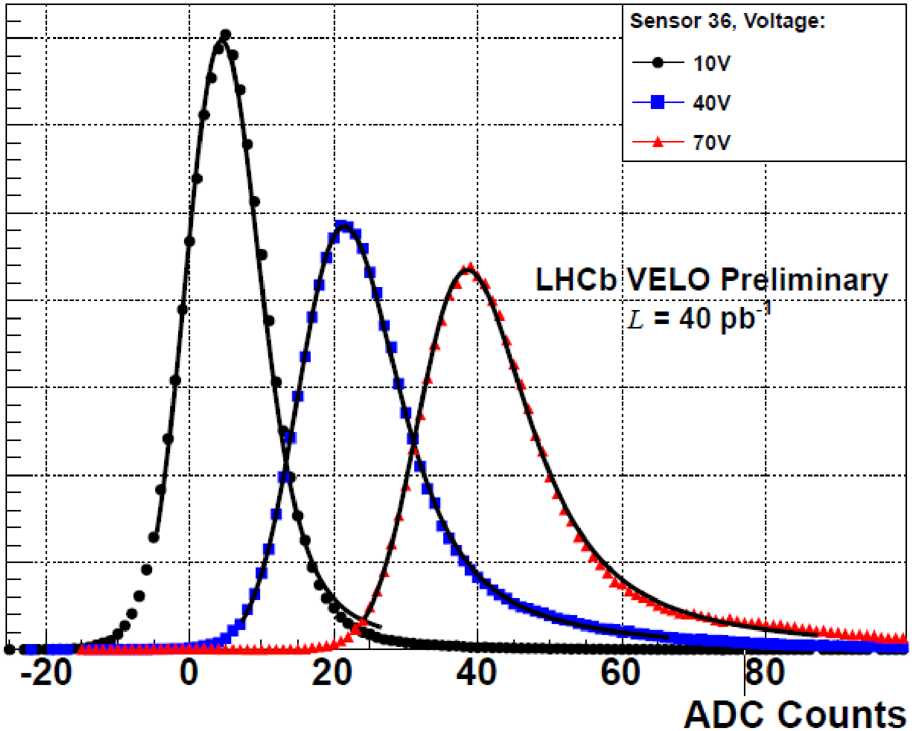
Charge Collection Efficiency

CCE Introduction

- Take data for a range of voltages
- Plot these and fit a Landau/Gauss
- Take the MPV and trend it as a f(V)
- Defined 80% of depleted electrons = effective depletion voltage (done to match production)
- Will also be able to see the change in signal number of electrons as the radiation damage gets significantly higher
- Infrequently taken as requires several hours of beam (data can't be used for physics)

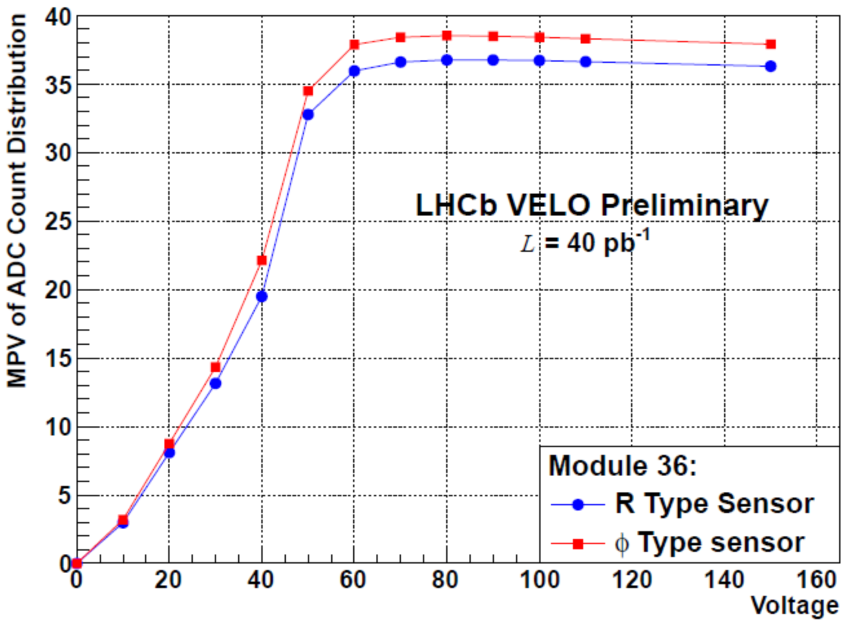


CCE Introduction 2



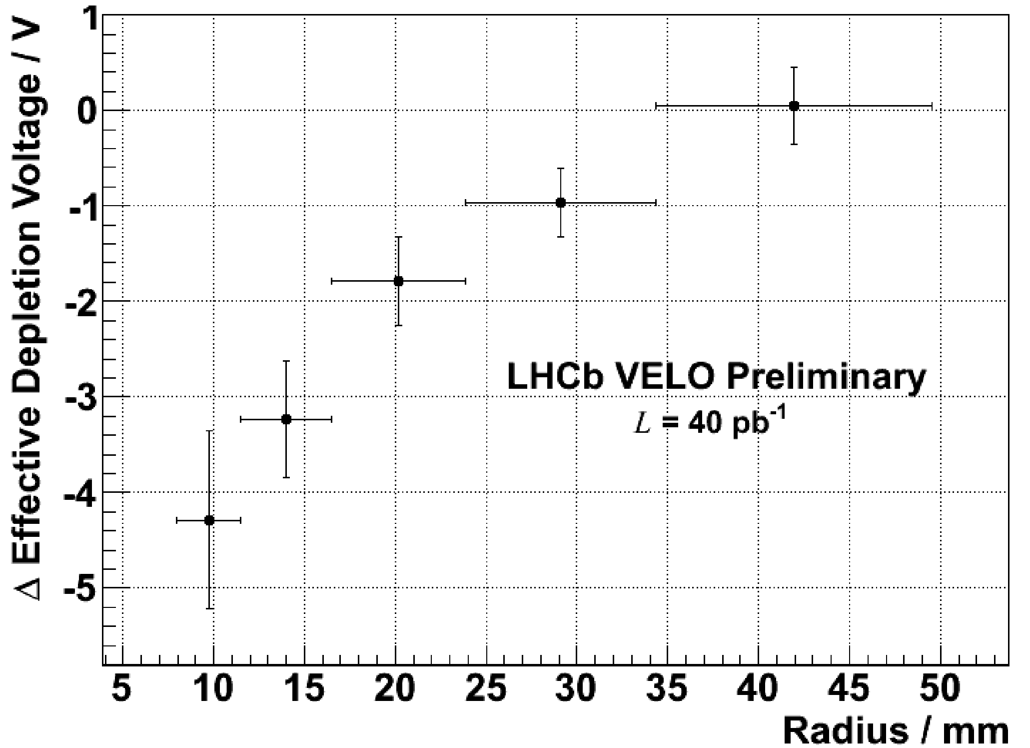
On the left, an example of the Landaus at a range of voltages, we take these MPVs and plot them as a function of voltage.

We take 80% of the maximum charge collection to be the 'effective depletion voltage' for a sensor.



CCE Results

- We can divide the R sensors into bands
- Compare to 2010 data (no radiation damage) and see how EDV has changed
- Only done for 40 pb^{-1} next CCE scan due in next couple of weeks after ~400 pb^{-1}



Summary

- VELO has clear radiation damage effects
  - A number of measures of keeping track of these, including a novel way of looking at depletion voltage without affecting data taking ability
  - Sensors with bulk defects are normalizing as expected
  - Interesting annealing affects are being observed too
  - Next few months will have confirmation on data of the radiation model, damage observed vs predicted, etc

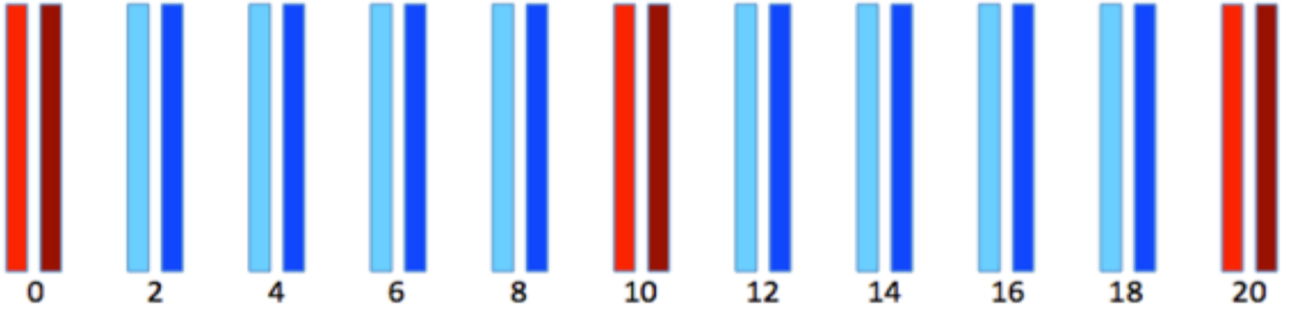
Future Expectations

- We expect to see the depletion voltage to minimize soon, and type inversion
  - Taking a CCE scan very shortly to analyze for this
    - Fortunately with different bands of R we don’t need to be exactly at the right luminosity to see the type inversion
- Another warm IV scan over winter shutdown 2011 to anneal currents further

BACKUP SLIDES

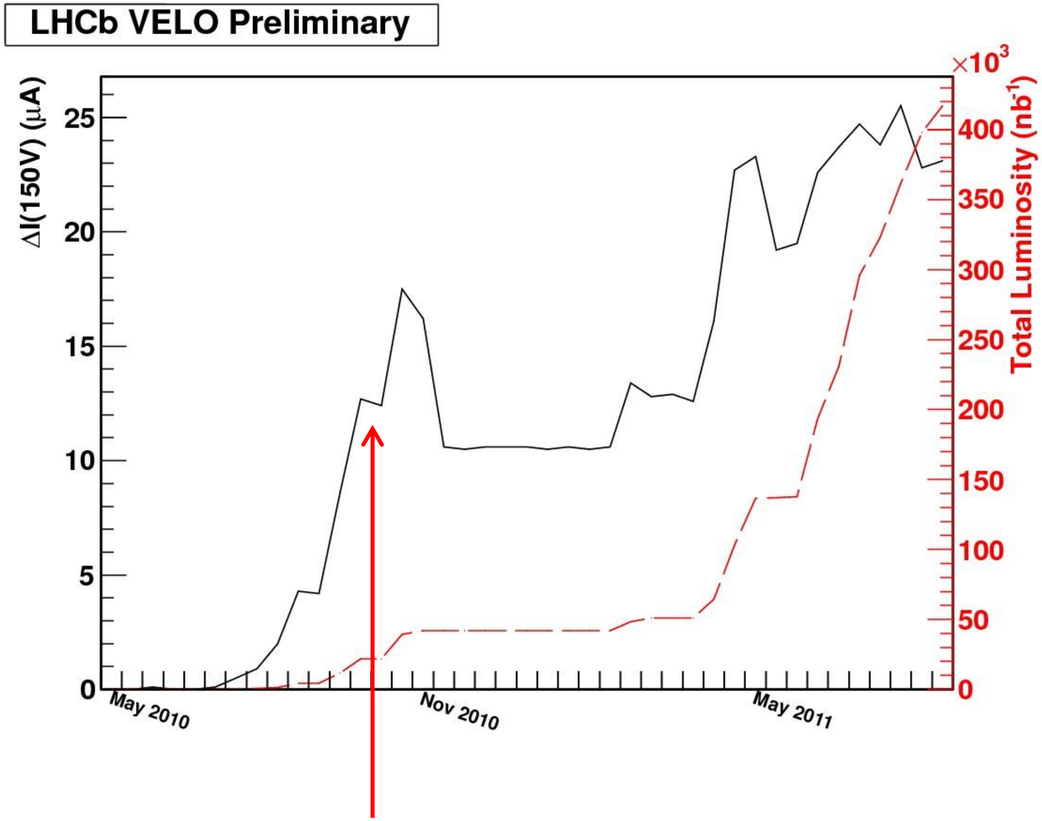
Backup – CCE Track Selection

- Look for ‘golden tracks’ – we voltage step one in every five sensors whilst holding the neighbouring sensors at operational voltage
- Allows us to use tracking information to look for sensors



IV Backup – Surface Damaged Sensor

- One anomalous sensor that has massive current increase with luminosity
- Approximately 6 μA per 100 pb^{-1}!
- Surface oxide charge saturation theory



Four days with no beam, surface oxide discharged

Backup – Two bands of DV

- There are two groups of sensors w.r.t DV in the VELO
  - One band around 30-40 V
  - Another band at 50-60 V

Backup - Noise vs Voltage for p-type

- EDV very different vs n-type (deplete from different side of sensor – n-type will minimize noise before DV)

Sensor	Initial EDV (V)	40 pb^{-1} EDV (V)	ΔEDV (f/i)
P-type	10	8.4	0.84
Close n-type	50	52.8	1.06

Backup - CCE Results for p-type

- P-type
  - Nominal production DV = 100V
  - CCE results = 70 V

R band(mm)	P-type sensor (ΔEDV) (V)	Mean (ΔEDV) (V)	Nominal n-type (ΔEDV)
11-16	-9	-3.2	-2
16-23	-1	-1.8	N/A
23-34	-2	-1	-1
34-45	-1	0	0

- Higher production EDV than other sensors
  - Rate at which it is falling is higher too