# Tracking 3

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August 20, 2008

# Review and Outline

- Goals of tracking
  - Measure 4-vector and origin of particles.
  - Confirm and improve from other components
- Hardware
  - Measure position (“hits”) at points along path.
  - dE/dx ⇒ ionization ⇒ position
- Software
  - Collect measured hits and fit a helix.
  - Seed hypothesis then confirm and improve with hits
- Commissioning and Operation

# Commissioning and Operation

- Making it work

- Keeping it working

Challenging since detectors are necessarily complex.
I will try to convey that challenge, some of the details…
and I'll harp a bit on the importance of rigorous validation.

# Commissioning and Operation

- Making it work
  - Checkout of new detector
  - Calibration
  - Detector characterization
  - Validation
- Keeping it working
  - Monitoring
  - Aging

# Checkout of new detector

- They are not plug and play, or engineer's work.

  ```
  if (theTrack.isGood()) …
  ```

- Low level understanding of new detector is critical.

- Expect problems. You will find them iff you look.

# Some past problems

- Connections don’t stay (correctly) connected.

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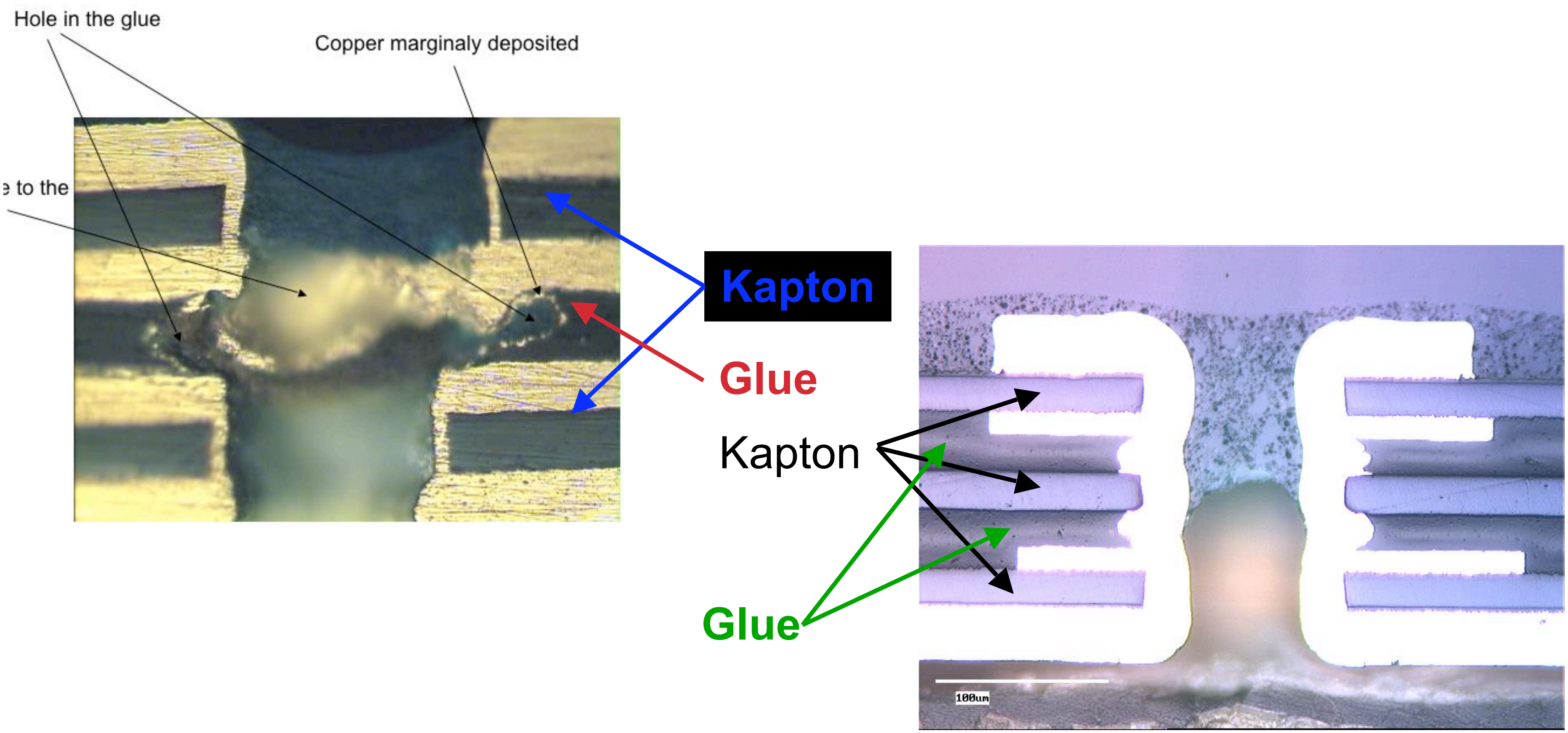
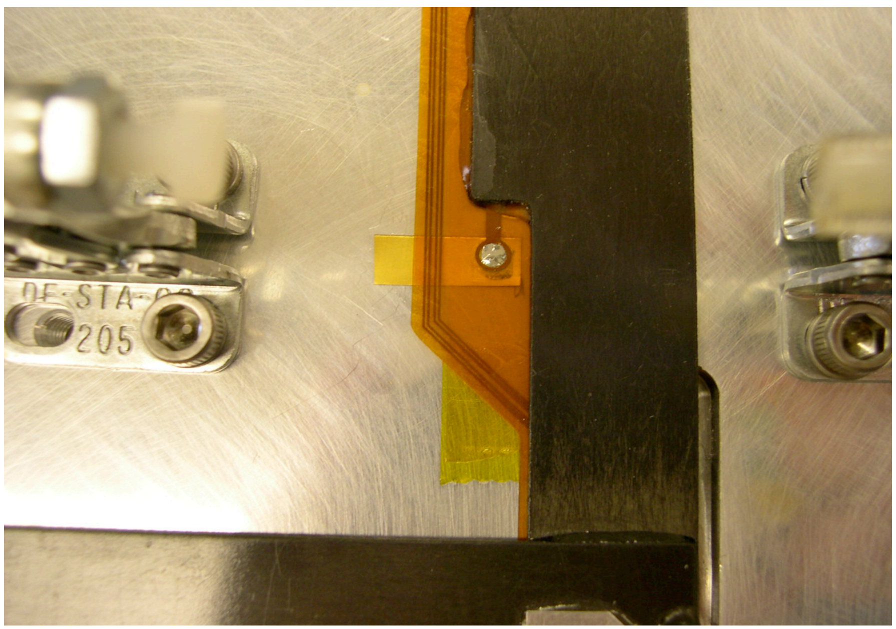
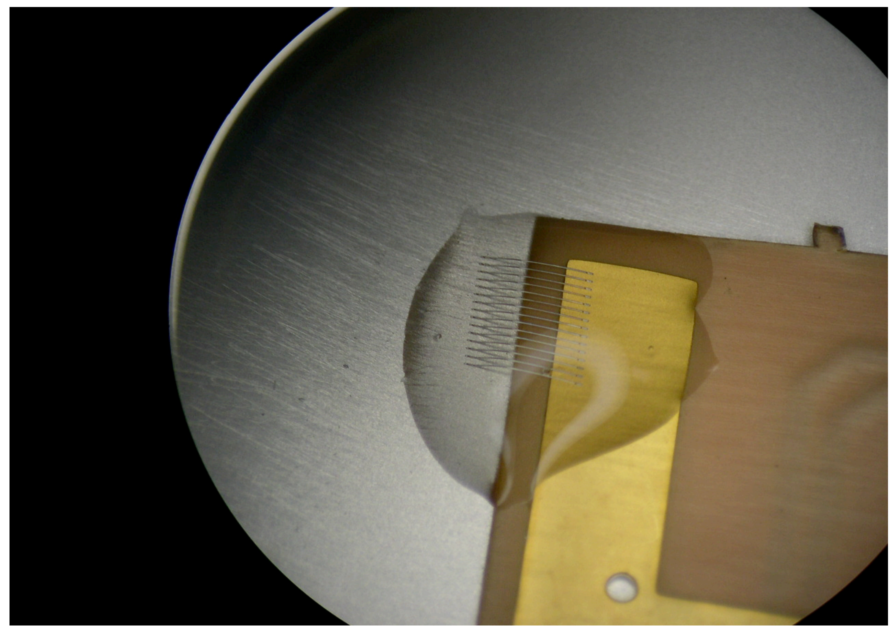


# Some past problems

- Connections don’t stay (correctly) connected.
  - Measuring HV connection resistance showed a long term change. Investigate and find silver epoxy problem.



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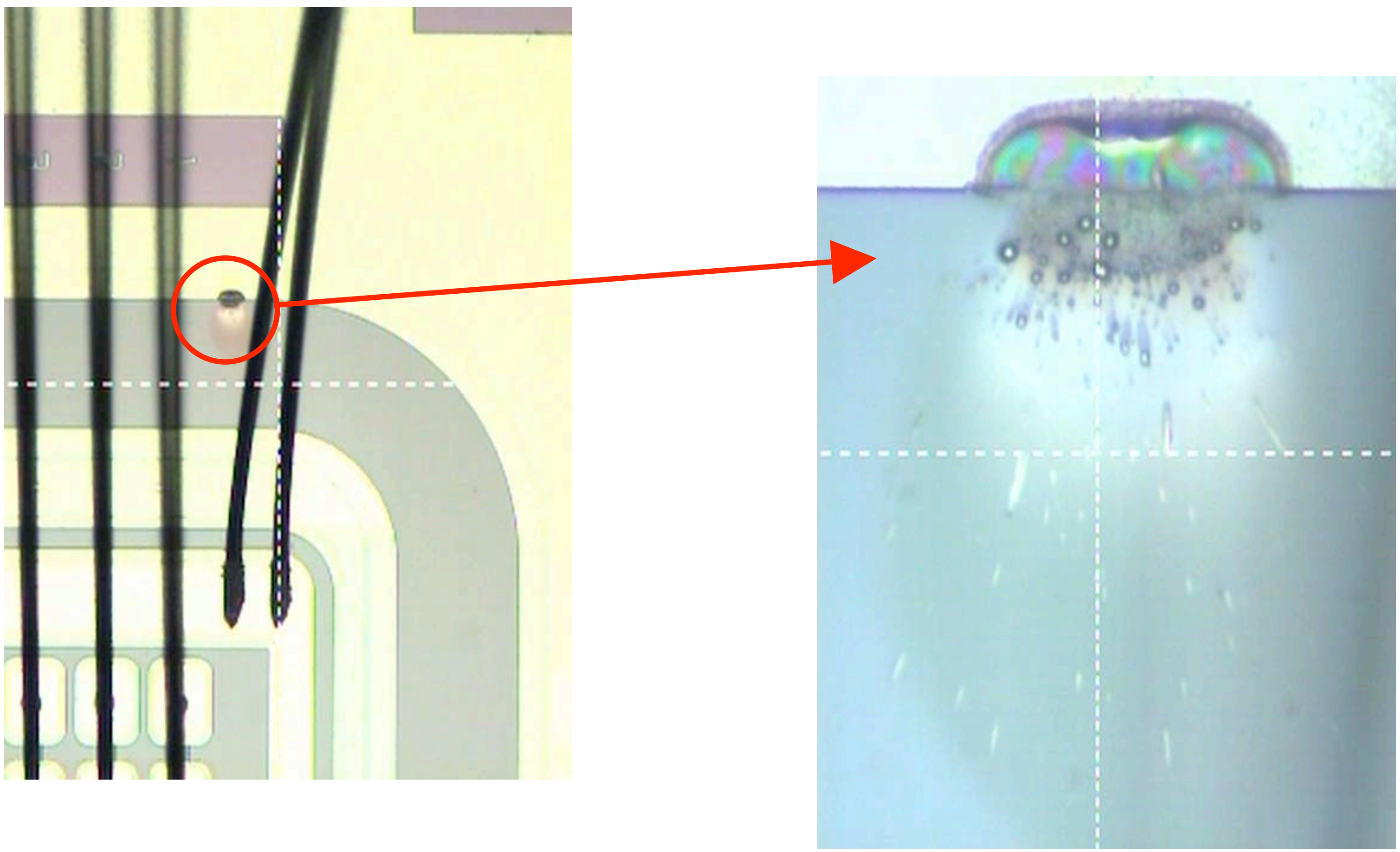

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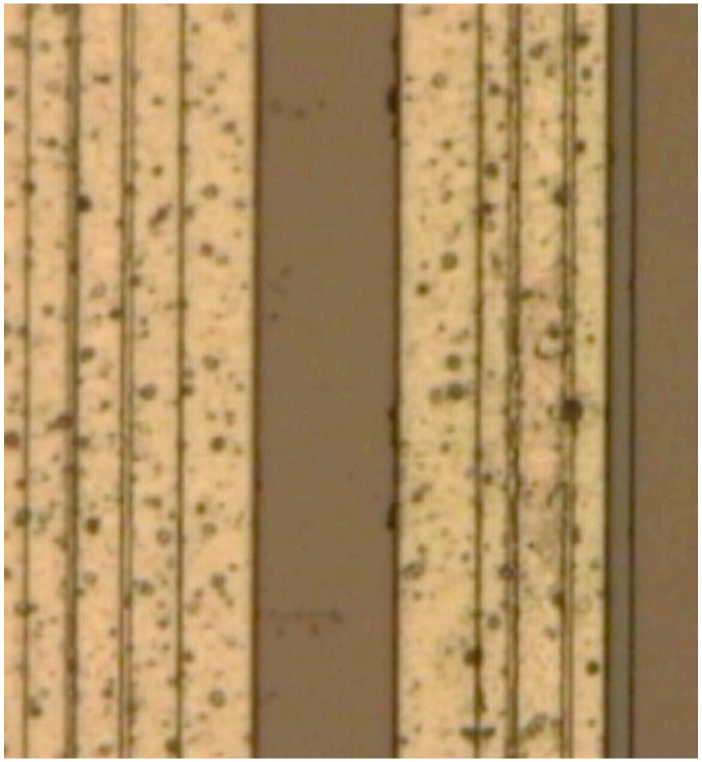
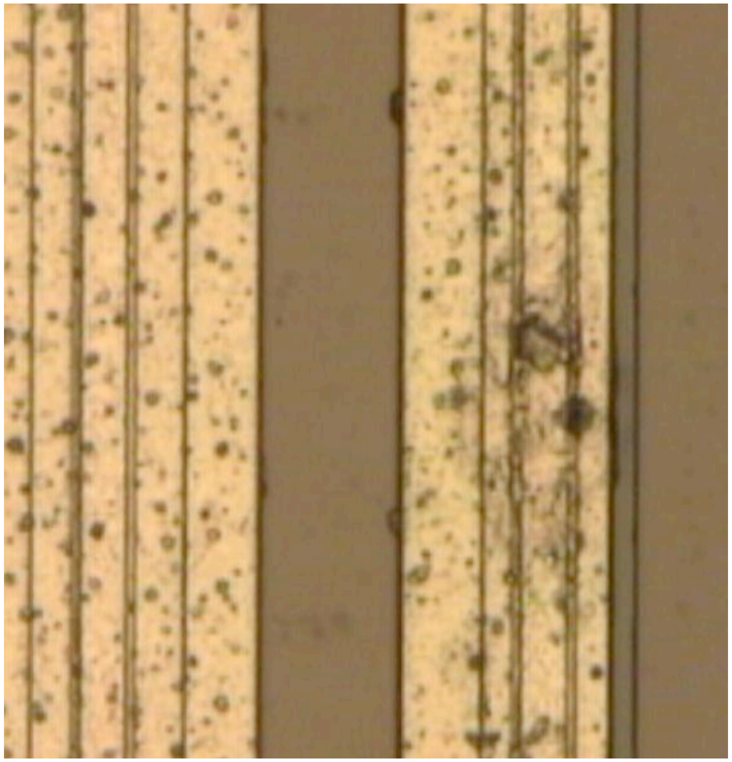


30 min, 40% RH



1h30, 40% RH

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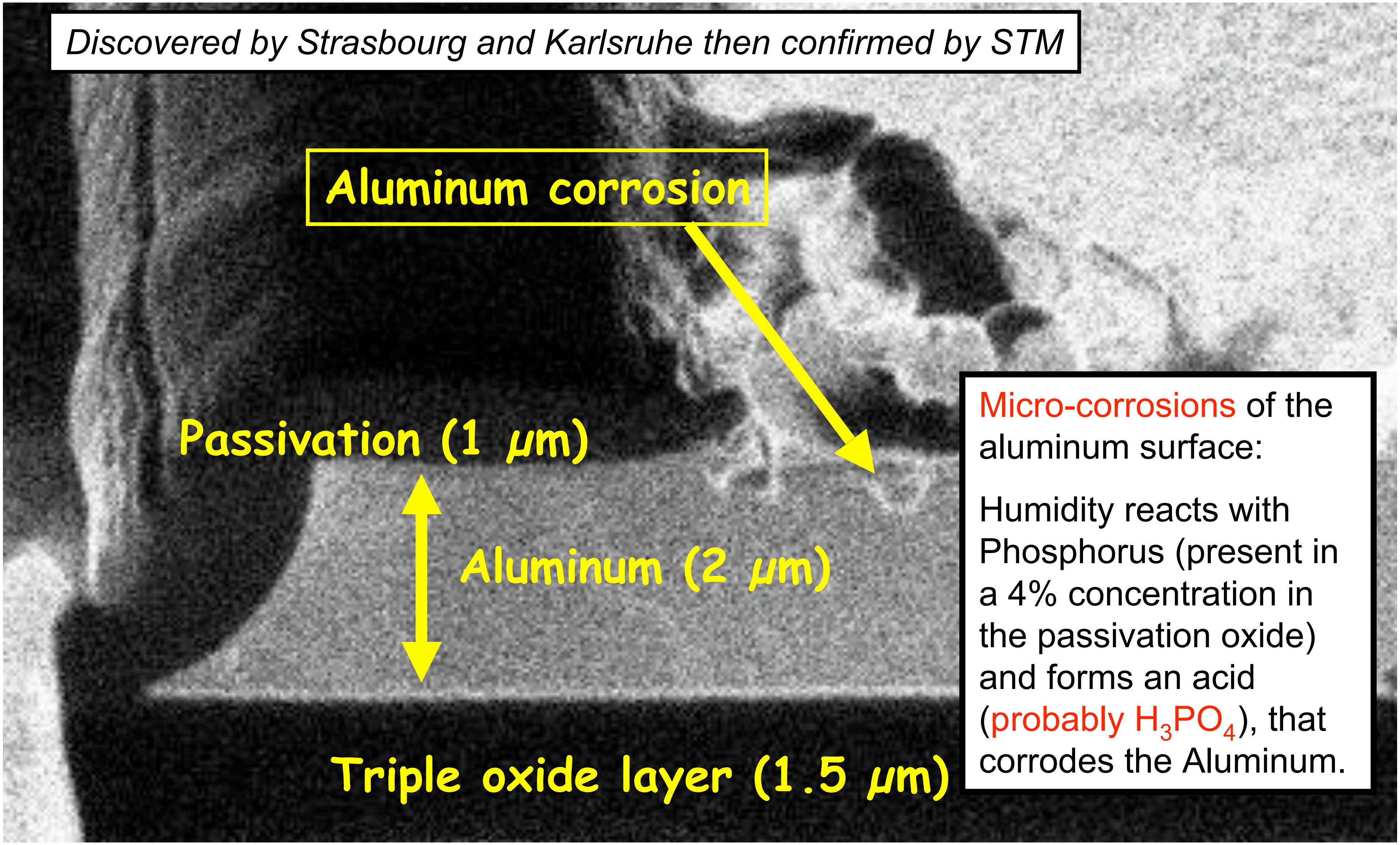

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- Unexpected tests occur
  - St. Catherine’s day massacre, where beam pipe work caused next store to spray the collision hall destroying power transistors.

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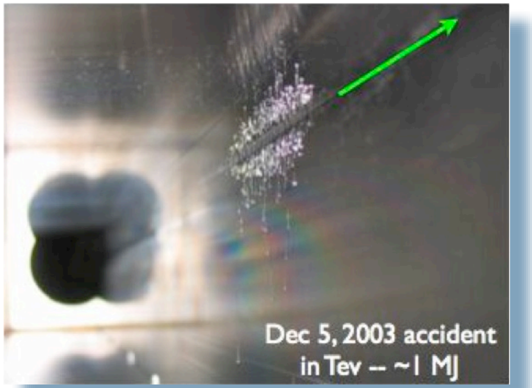
  - Kicker pre-fires.



# Commissioning and Operation

- Making it work
  - Checkout of new detector
  - **Calibration**
  - Detector characterization
  - Validation
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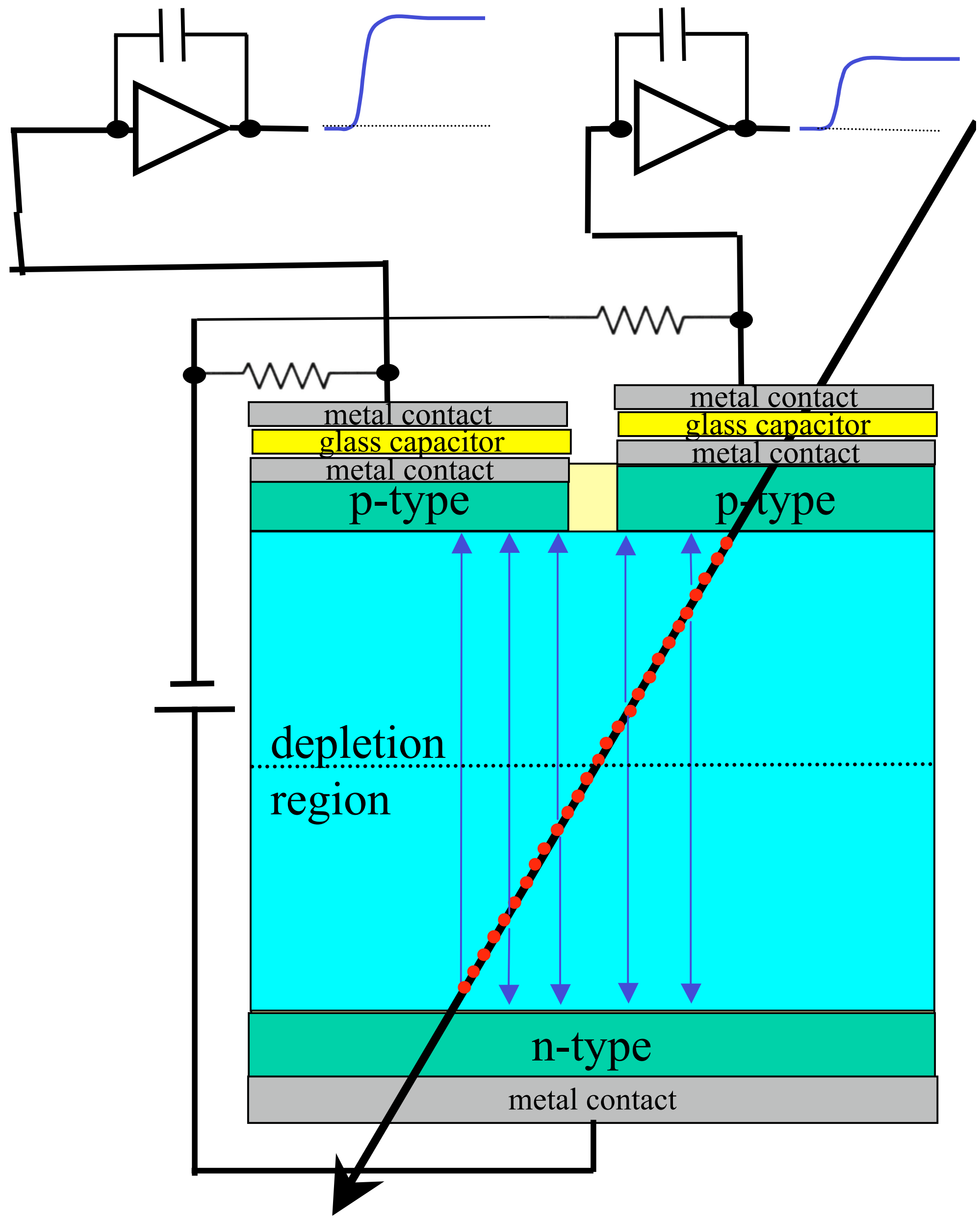
# Calibration

- Pedestal

  The mean value obtained when no signal is present.

- Noise

  The RMS of values obtained when no signal is present.

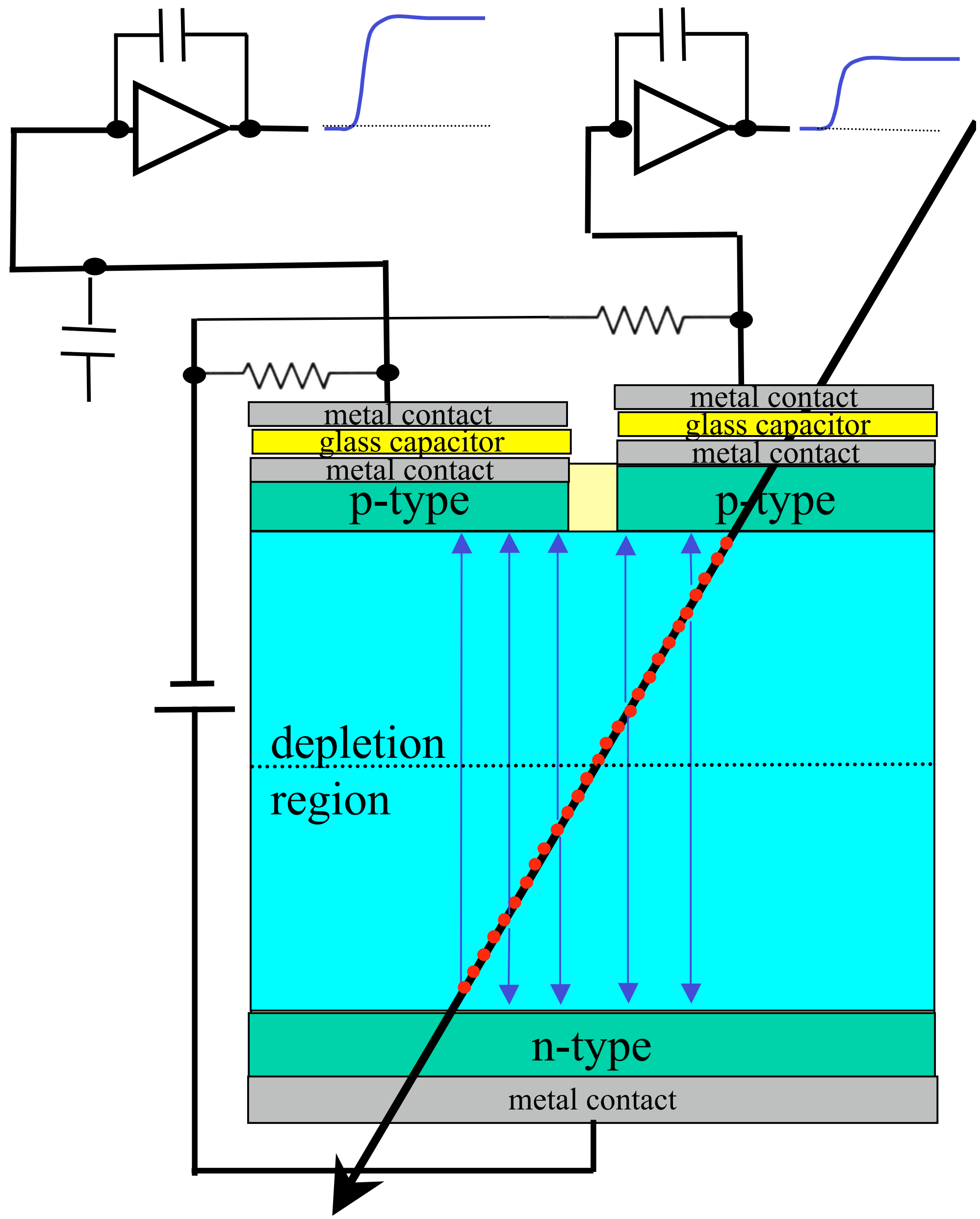


# Calibration

- Gain

  The slope of the response to a known input pulse. Checks:

  - Alive?
  - Electronic scale



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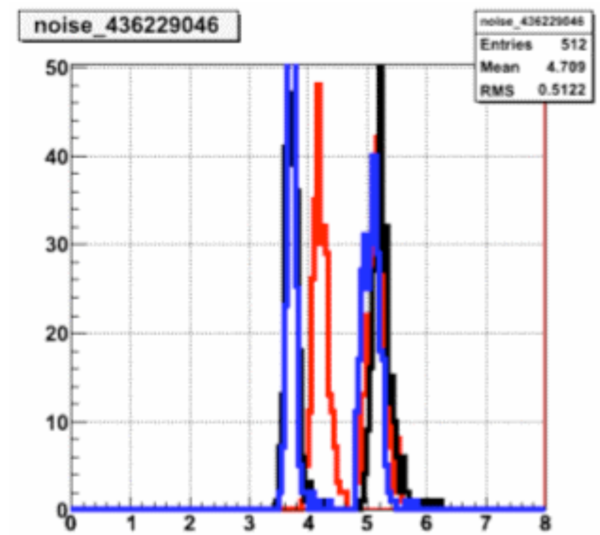
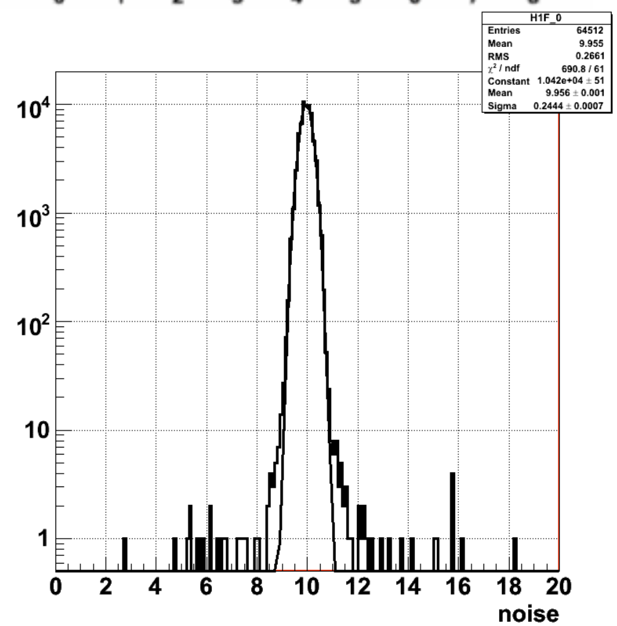
  Alive?

  Electronic scale

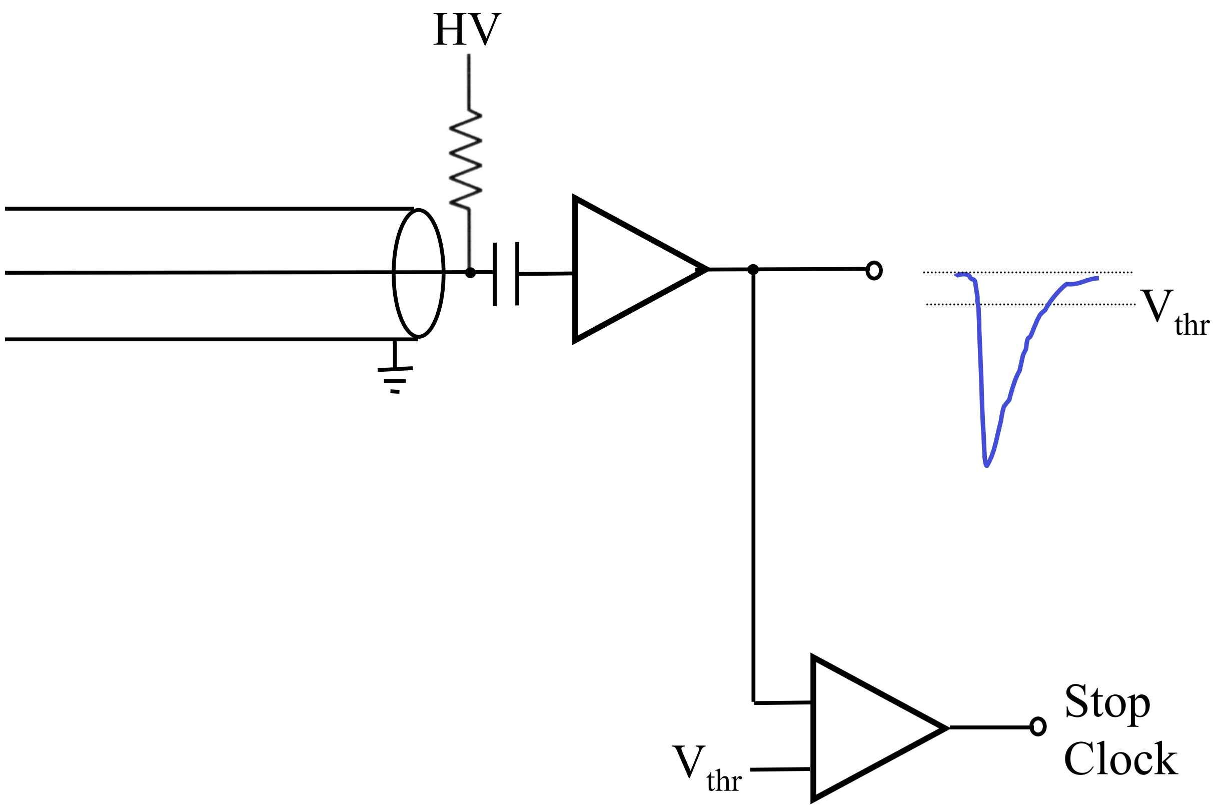
  Corrects for big effects to reveal small effects

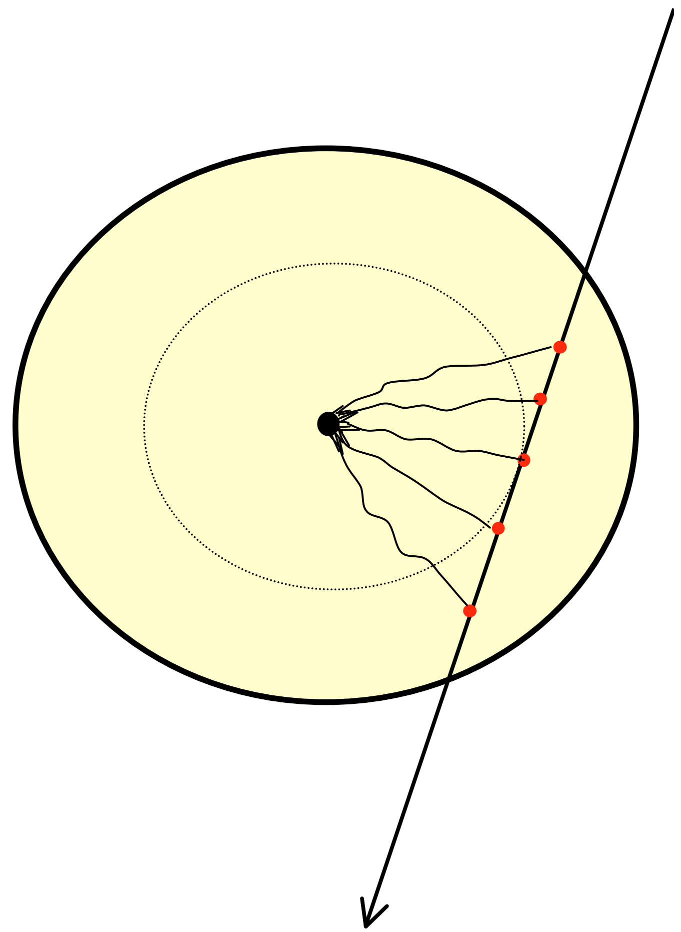


# Calibration

- t0, e.g. cable lengths.



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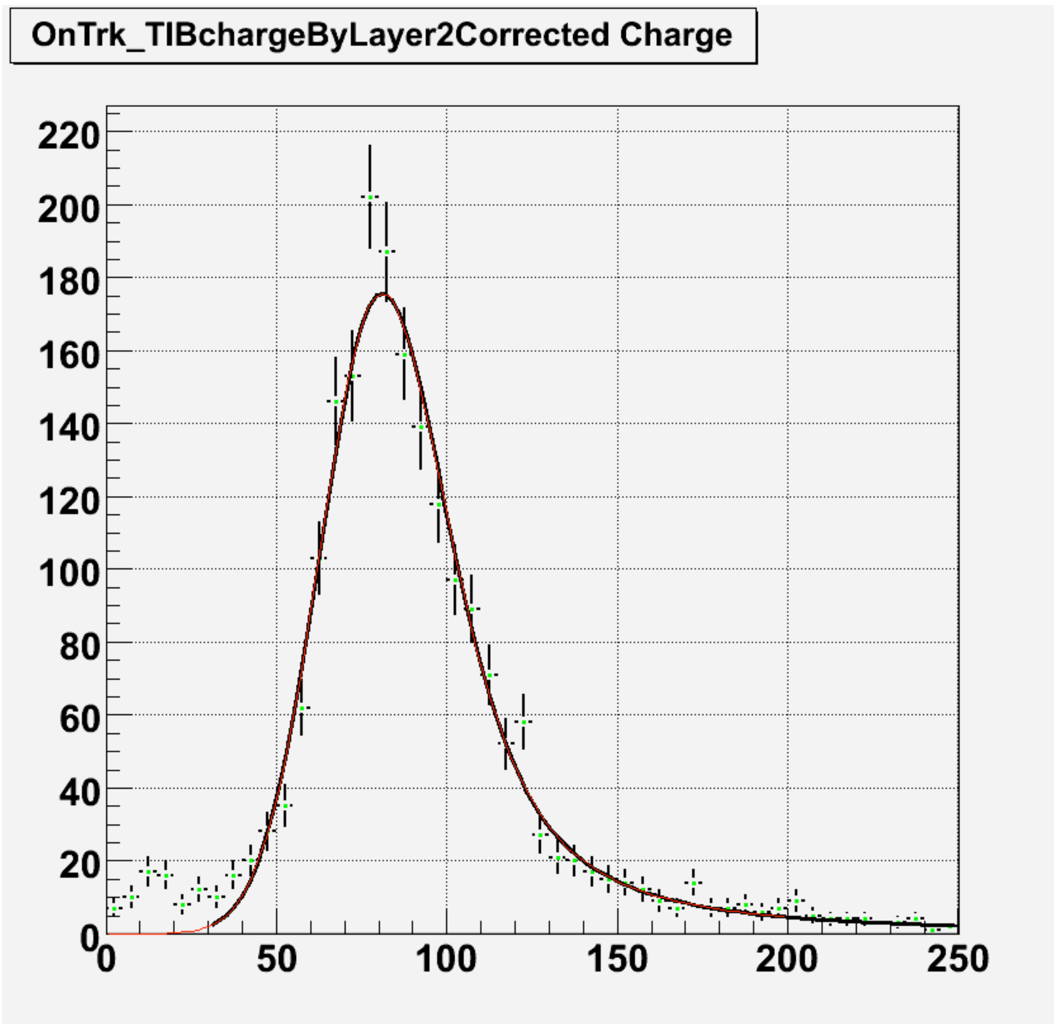
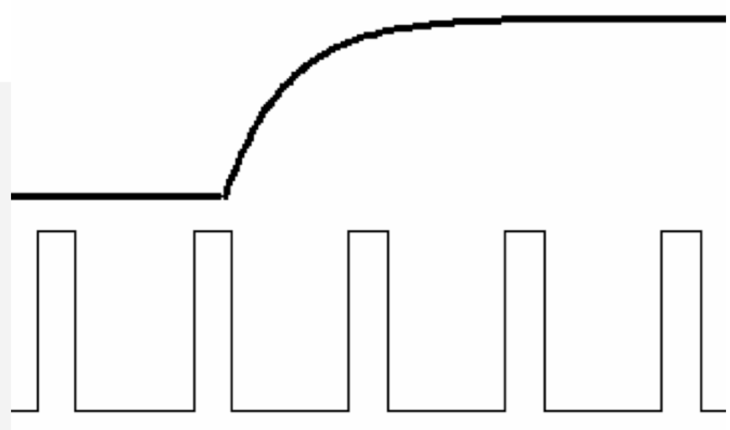


# Calibration

- Alignment
  - Both easy and hard.
    - Within 2*resolution easy.
    - Less than 1/2 resolution hard.
  - Needs to be done throughout
    - Construction (to limit degrees of freedom)
    - Assembly
    - With tracks
    - Monitoring

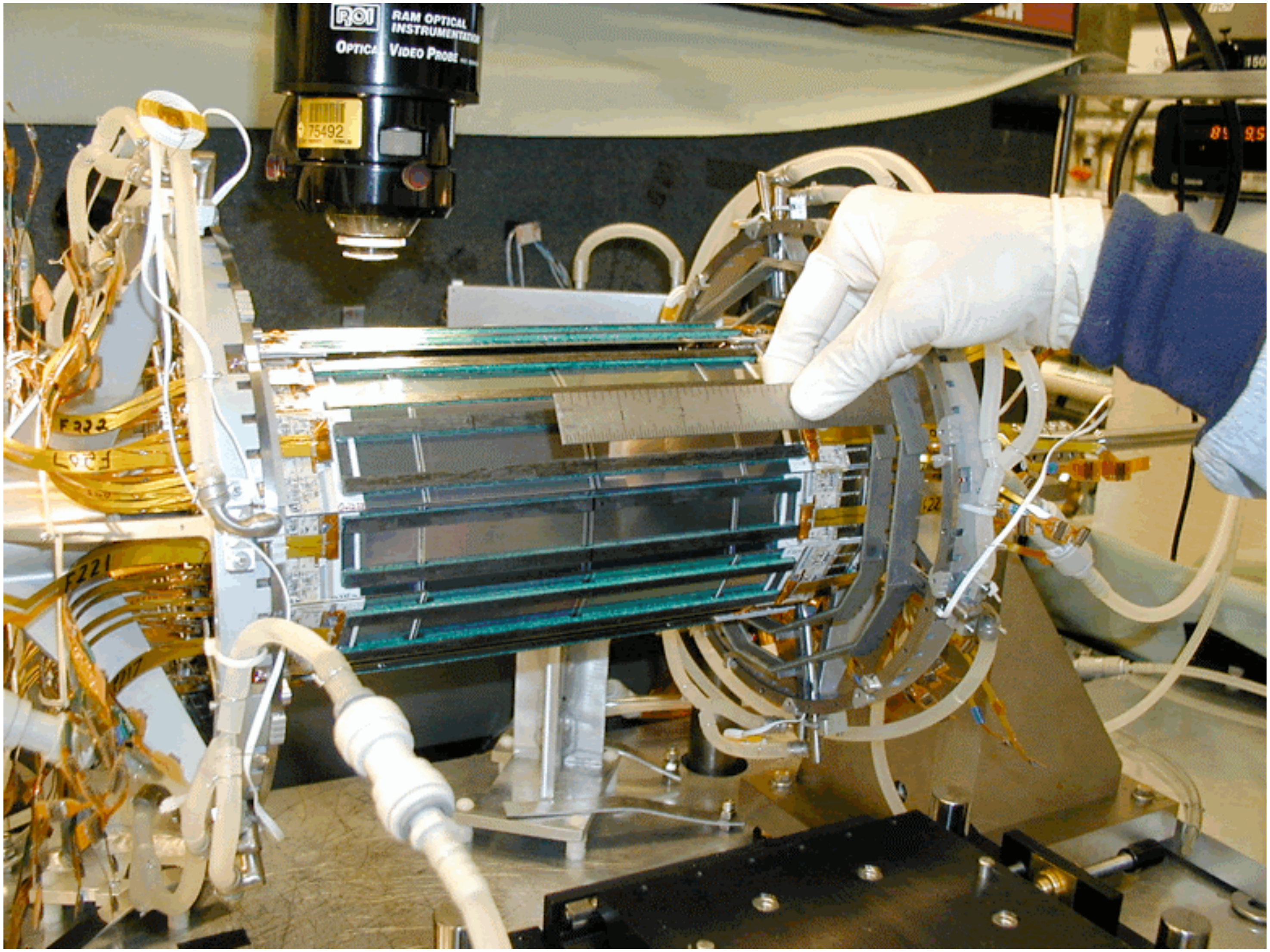
Understanding Check: Which analysis would be more sensitive to alignment?

Z’ $\rightarrow \mu\mu$

Z’ $\rightarrow$ ee

Higgs to b bbar

# Alignment during construction



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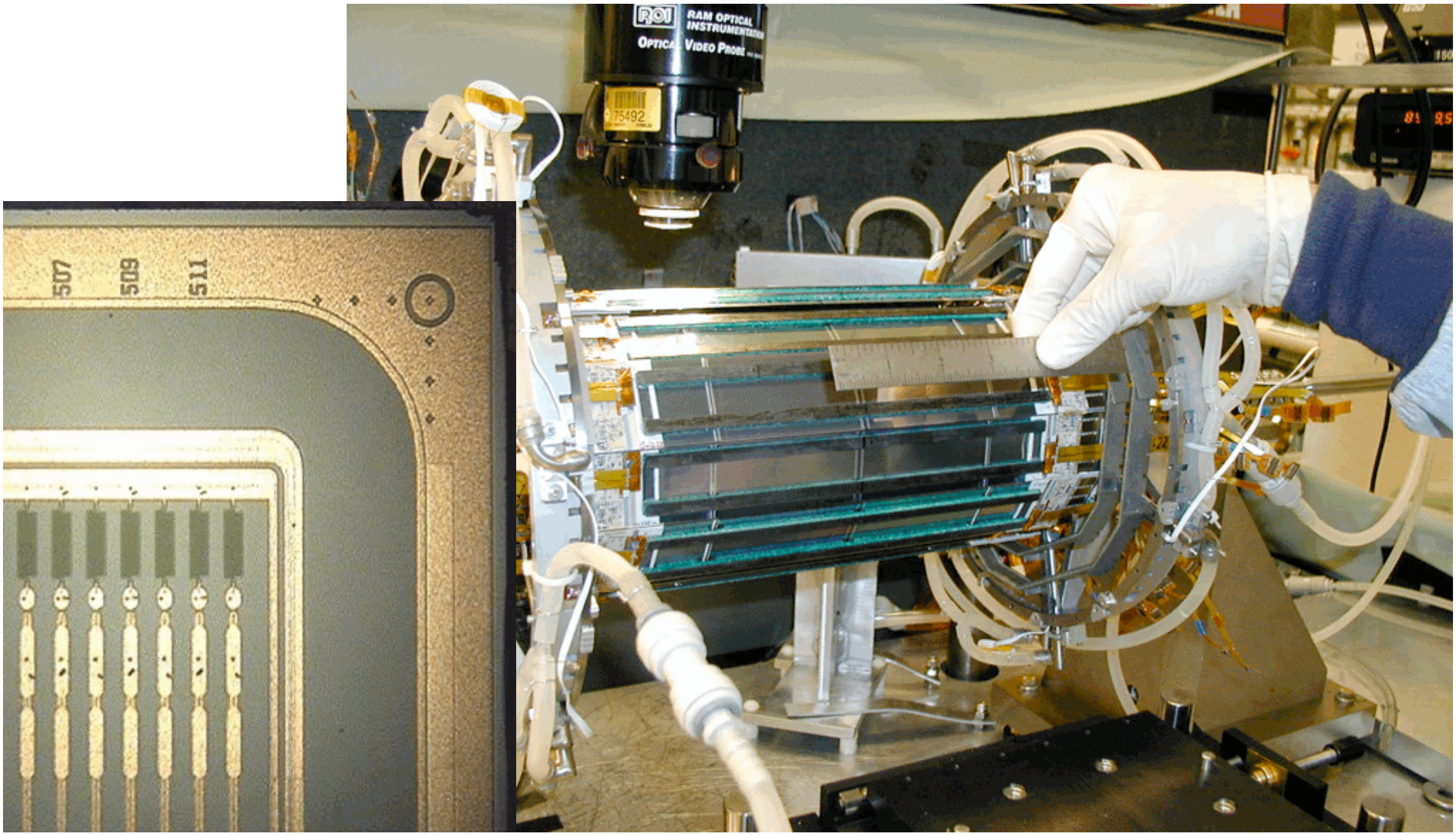

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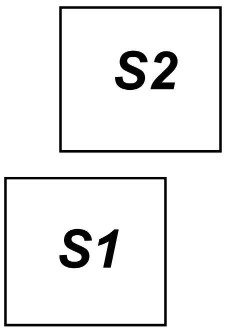
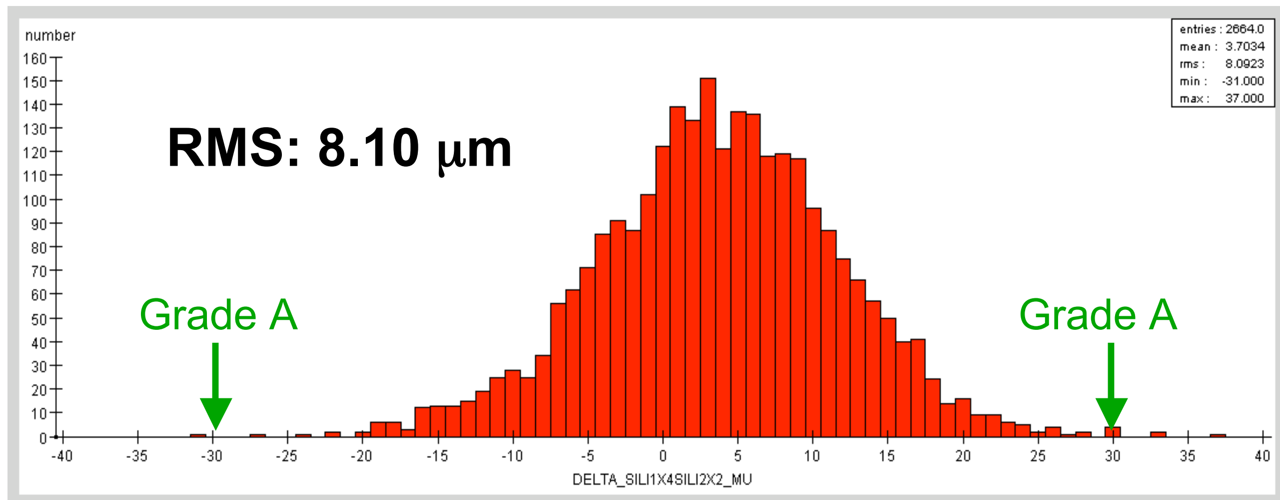
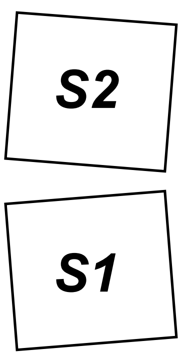
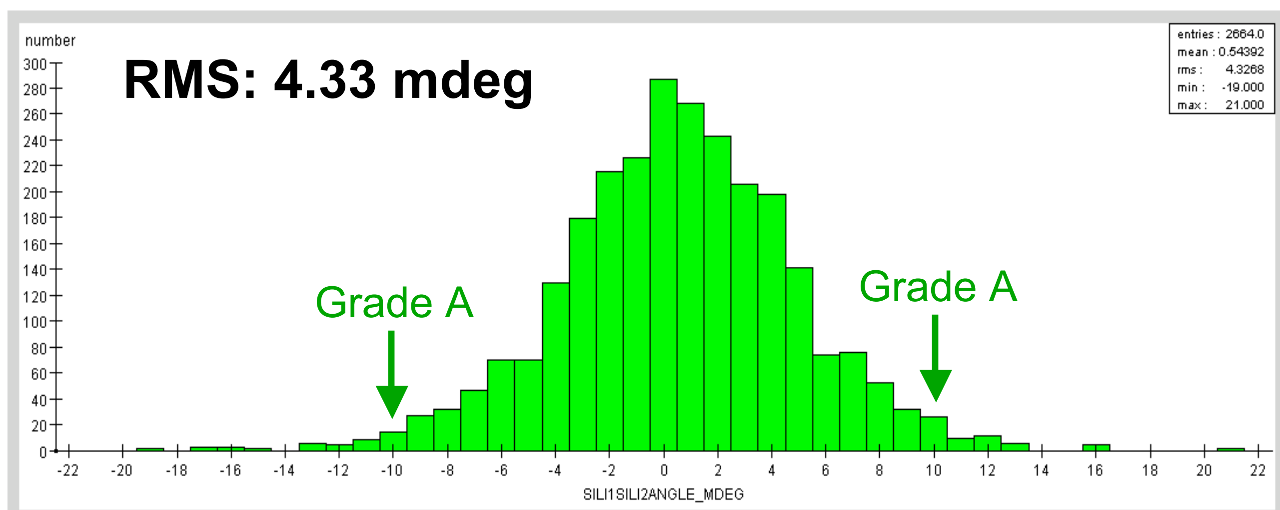



$\Delta(x_{sensor\ 1}, x_{sensor\ 2})$



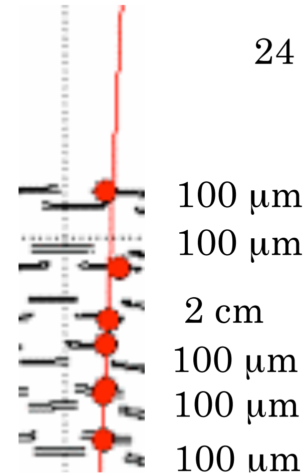




$\Delta(\theta_{sensor\ 1}, \theta_{sensor\ 2})$

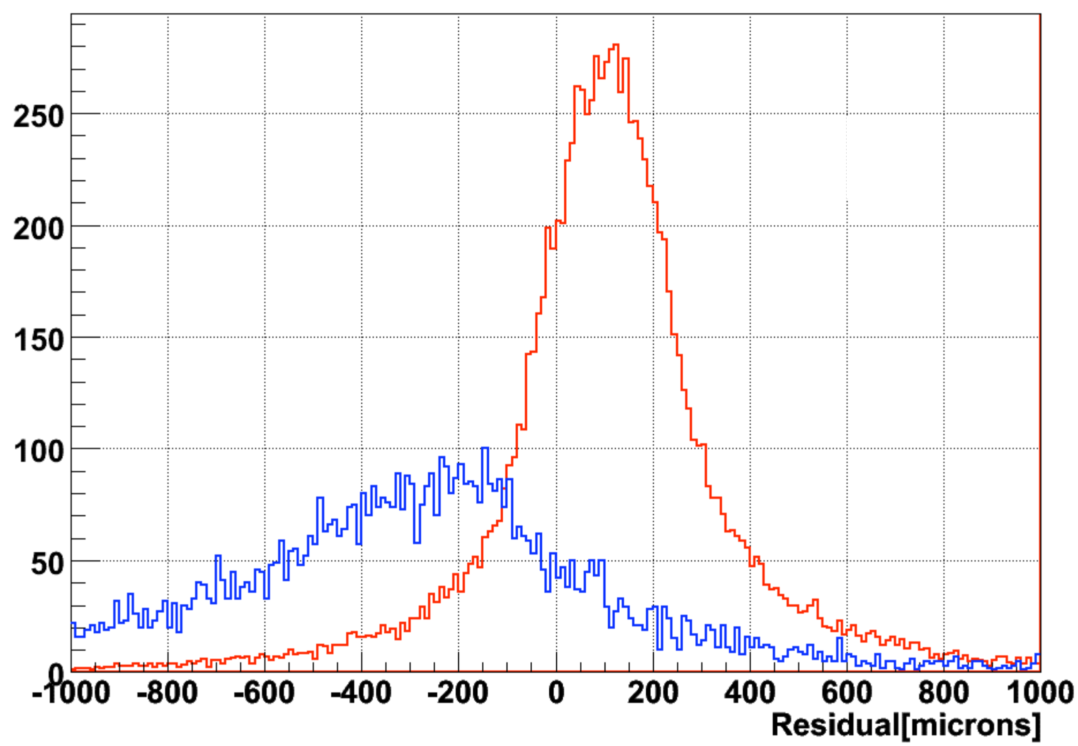


# Crude Track Alignment

```
while ( ! goodEnough)
 foreach (movable object)
   Refit track with that object deweighted
   Measure mean residual of its hits to all good tracks
   Move it (slightly) to reduce that mean
 end
end
```




$P(\chi^2)>0.1$



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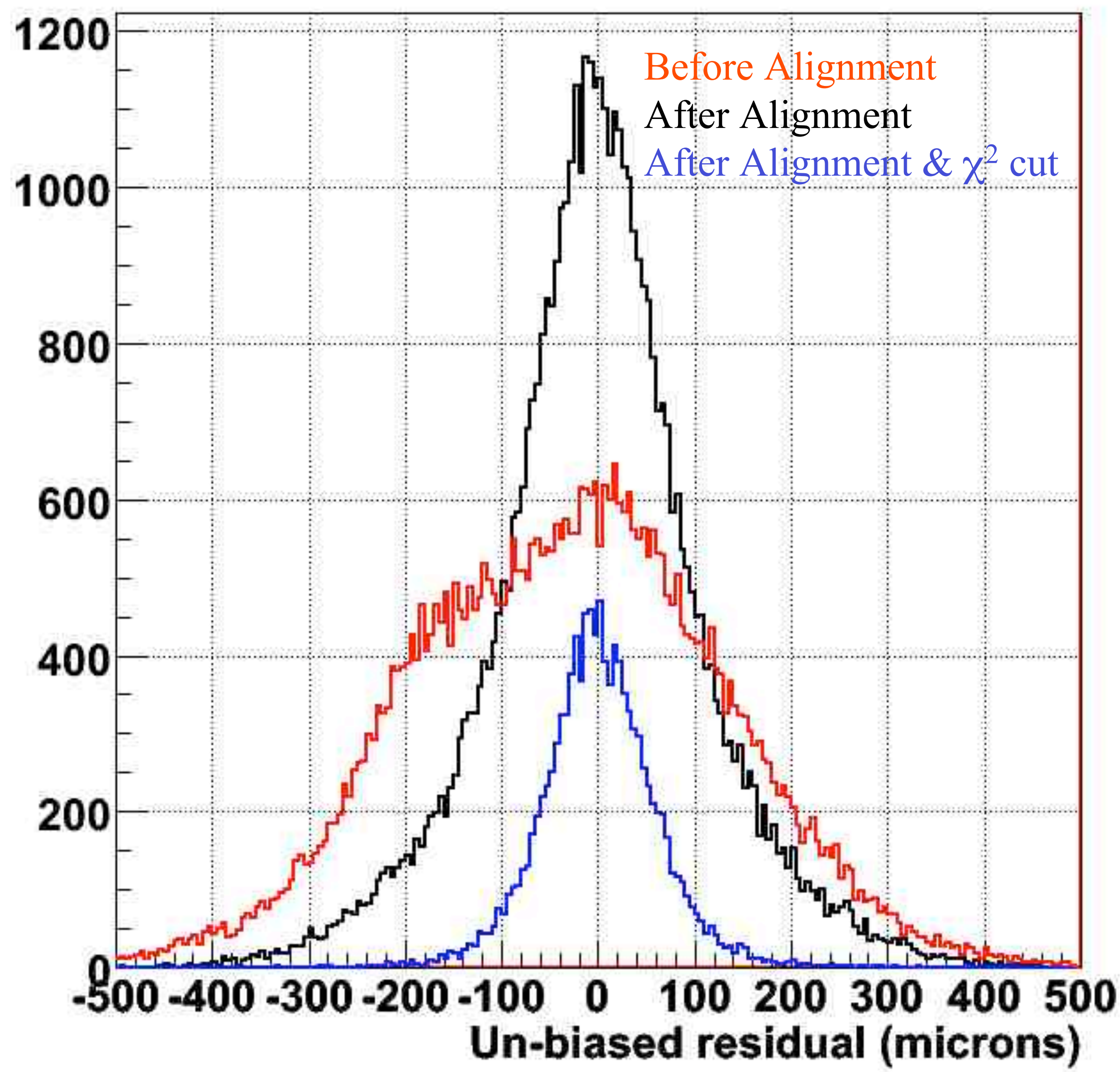


# Track Alignment: HIP

Hit and Impact Point

$$\epsilon = \begin{pmatrix} \epsilon_u \\ \epsilon_v \end{pmatrix} = \begin{pmatrix} u_x - u_m \\ v_x - v_m \end{pmatrix}$$

Similarly use residuals, but formally minimize the $\chi^2$, then iterate.

$$\chi^2 = \sum_{i=1}^{\mathrm{N_{hits}}} \epsilon_i^T V_i^{-1} \epsilon_i$$

Provides also uncertainty on the alignment parameters.

Can include constraints from survey.

$$\chi^2 = \sum_{i=1}^{\mathrm{N_{hits}}} \epsilon_i^T V_i^{-1} \epsilon_i + \sum_{j=1}^{\mathrm{N_{struct}}} \epsilon_{j,\mathrm{survey}}^T V_{j,\mathrm{survey}}^{-1} \epsilon_{j,\mathrm{survey}}$$

# Track Alignment

- Millepede
  - Simultaneous solution to system of equations floating hit positions & track parameters.
  - Avoids iteration.

- Kalman Filter
  - Each track is a new measurement of the detector position
  - Average that measurement with the previous prediction to obtain new alignment parameters.

# Track Alignment

Different methods.

Which is best?

# Track Alignment

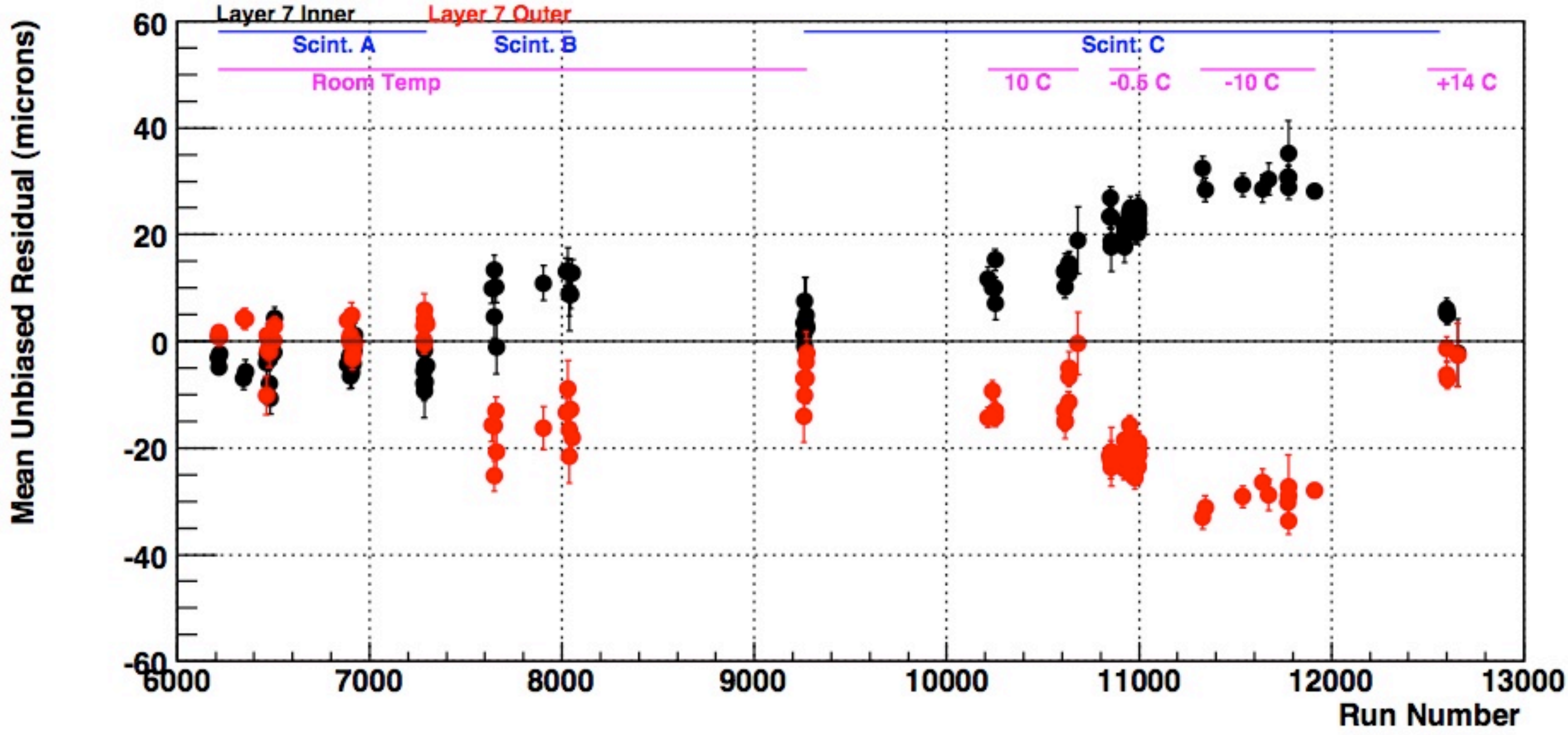
Different methods.

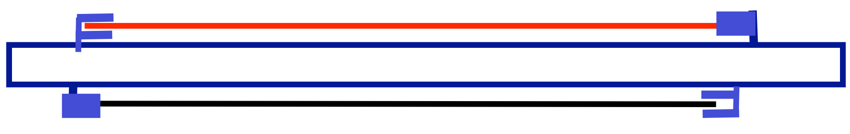
Which is best?

All is best.

Redundancy: confirm & improve

# Alignment monitoring



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- Making it work
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# Detector characterization

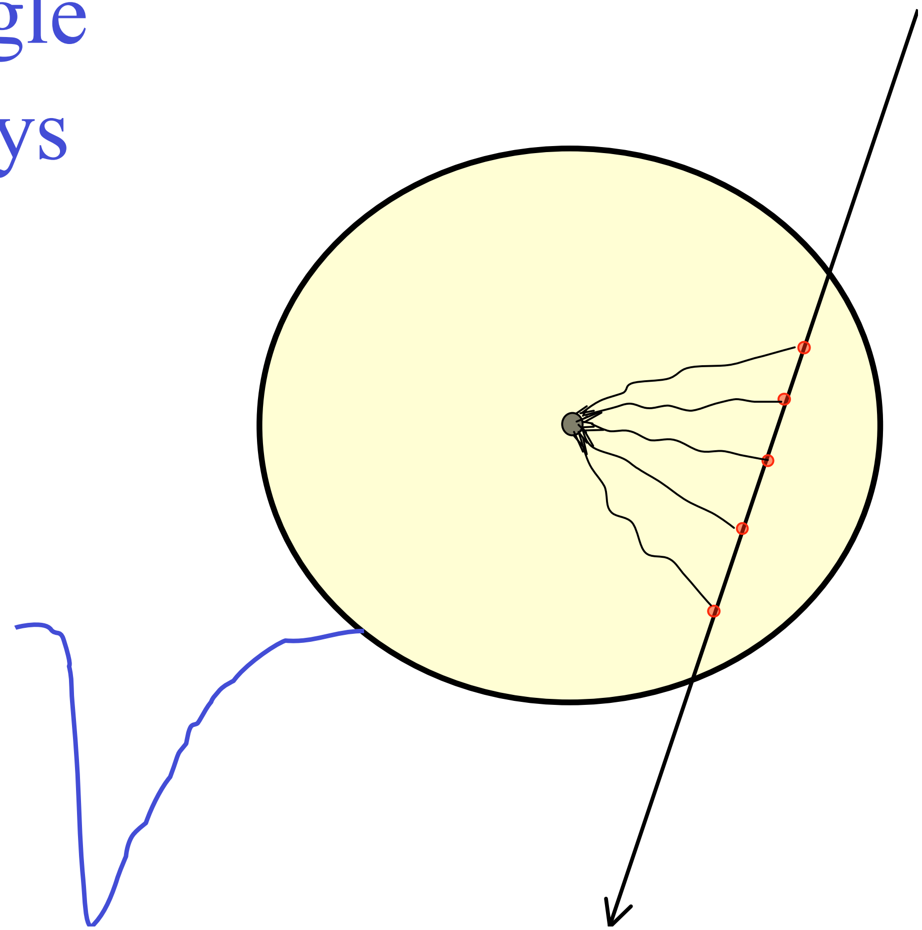
## Can learn from low-level quantities:

- Signal collection
- Response vs track angle
- Frequency of delta rays
- Silicon cluster size

You should be able to see charge vary with:

cot(θ)

pathlength in gas



# Detector characterization

## Can learn from low-level quantities:

- Signal collection
- Response vs track angle
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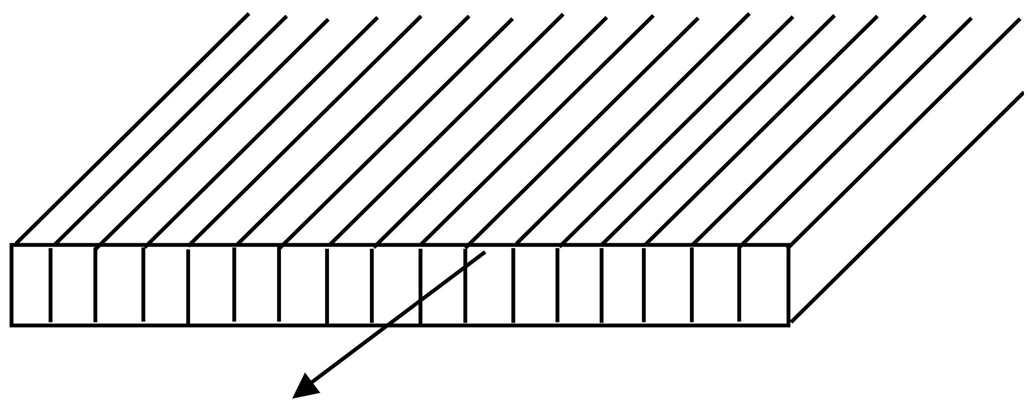
You should be able to see charge and size vary with:

cot(θ)

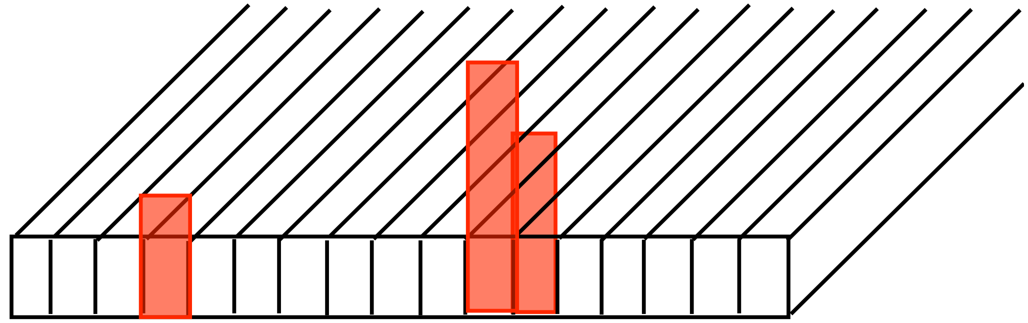
pathlength in silicon

Straightforward, but will reveal bugs.



# Algorithm Optimization

Clustering thresholds



$$\bar{x} = \frac{\Sigma x_i q_i}{\Sigma q_i}$$

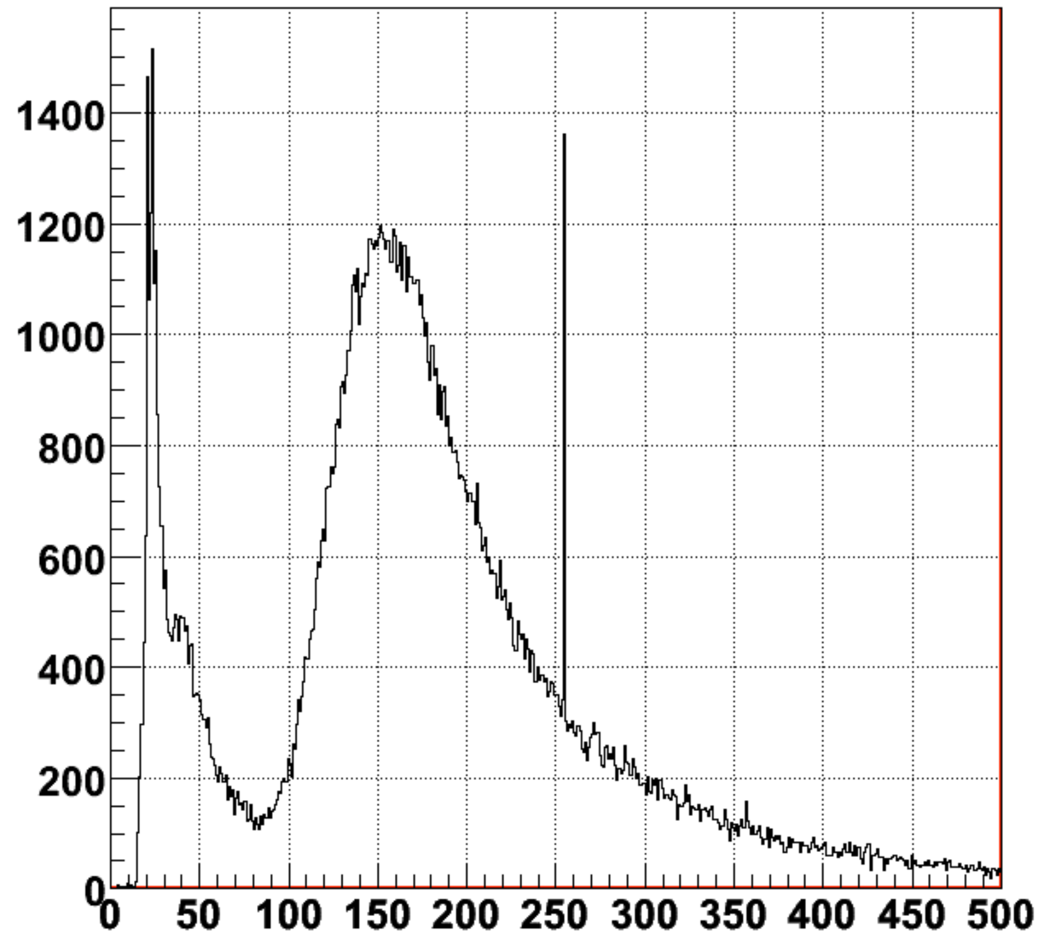
Which is worse:

a bit of inefficiency

or a bit of fakes?

# Algorithm Optimization

## Clustering thresholds

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Check: Can you spot, and explain, four effects present in this plot?
How would you test your explanation?

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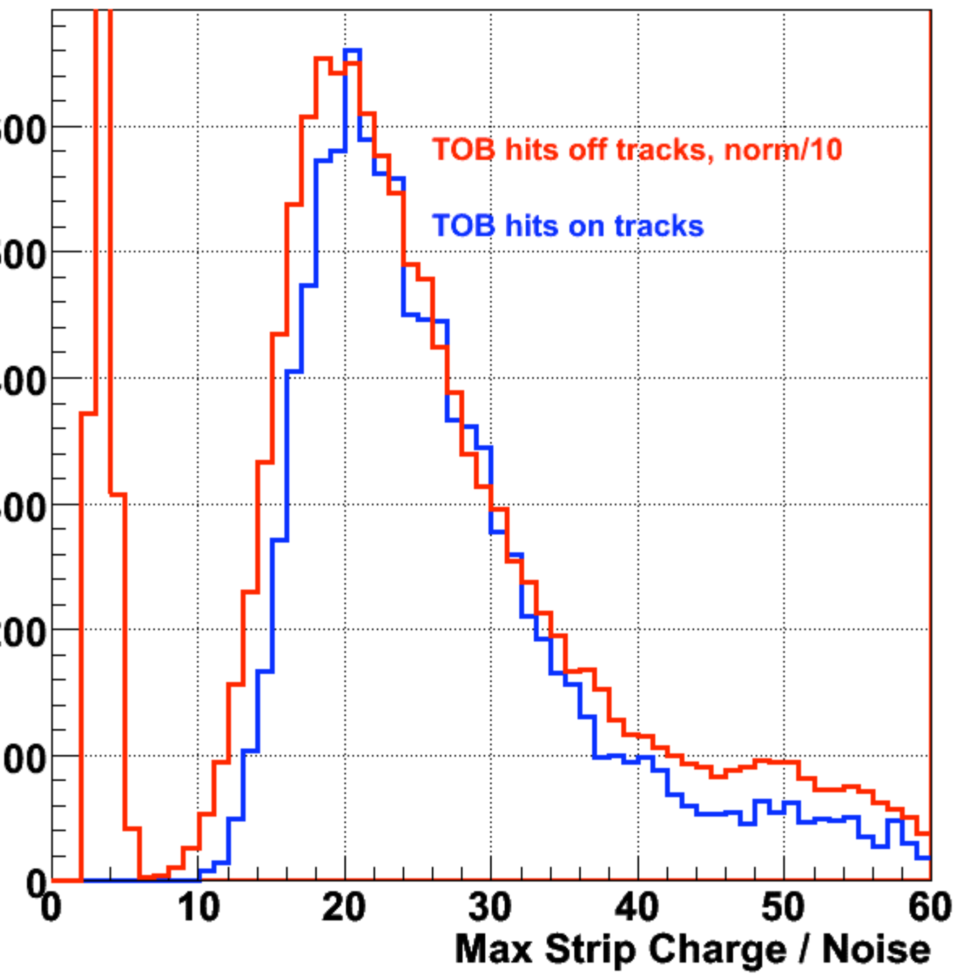


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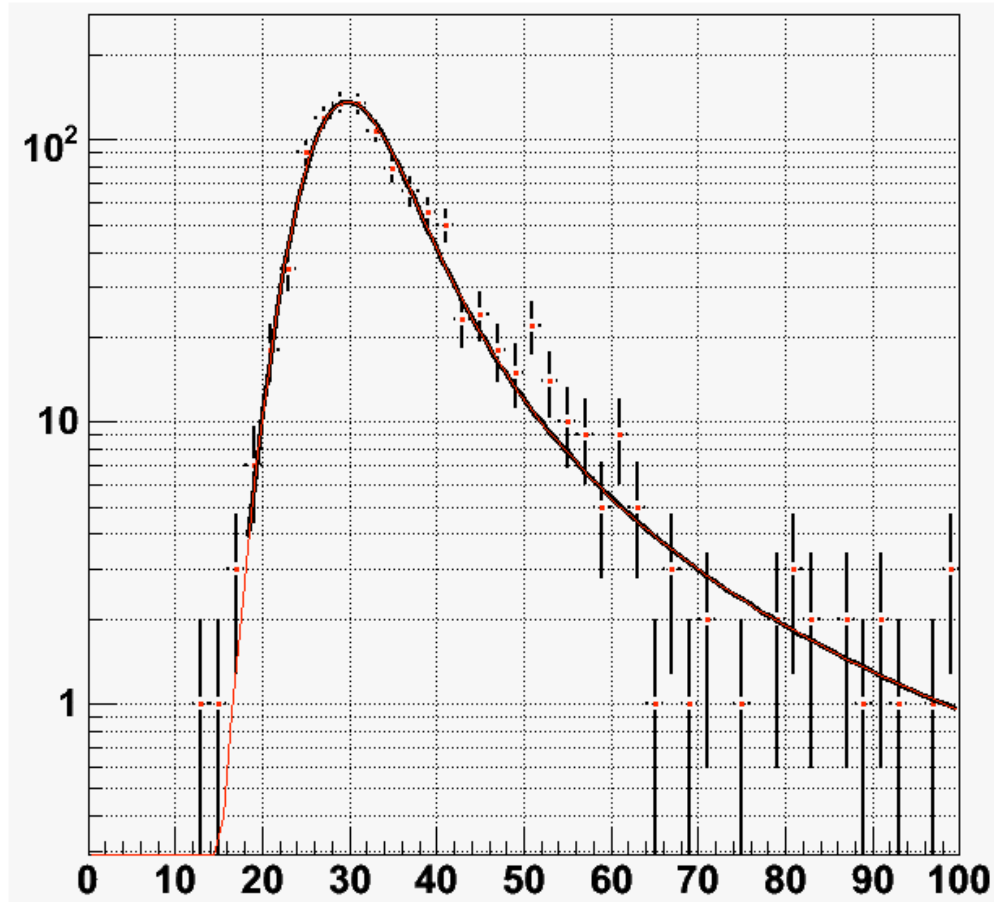


Max strip, Q/noise, pathlength normalized

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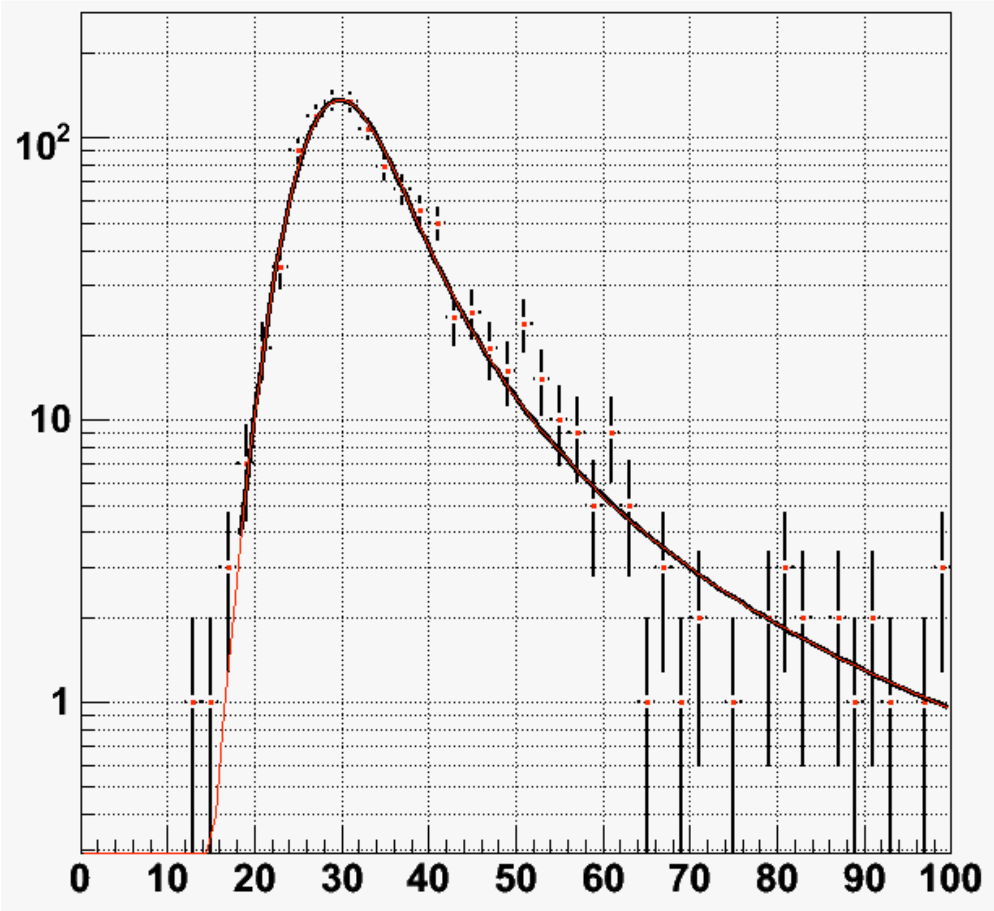


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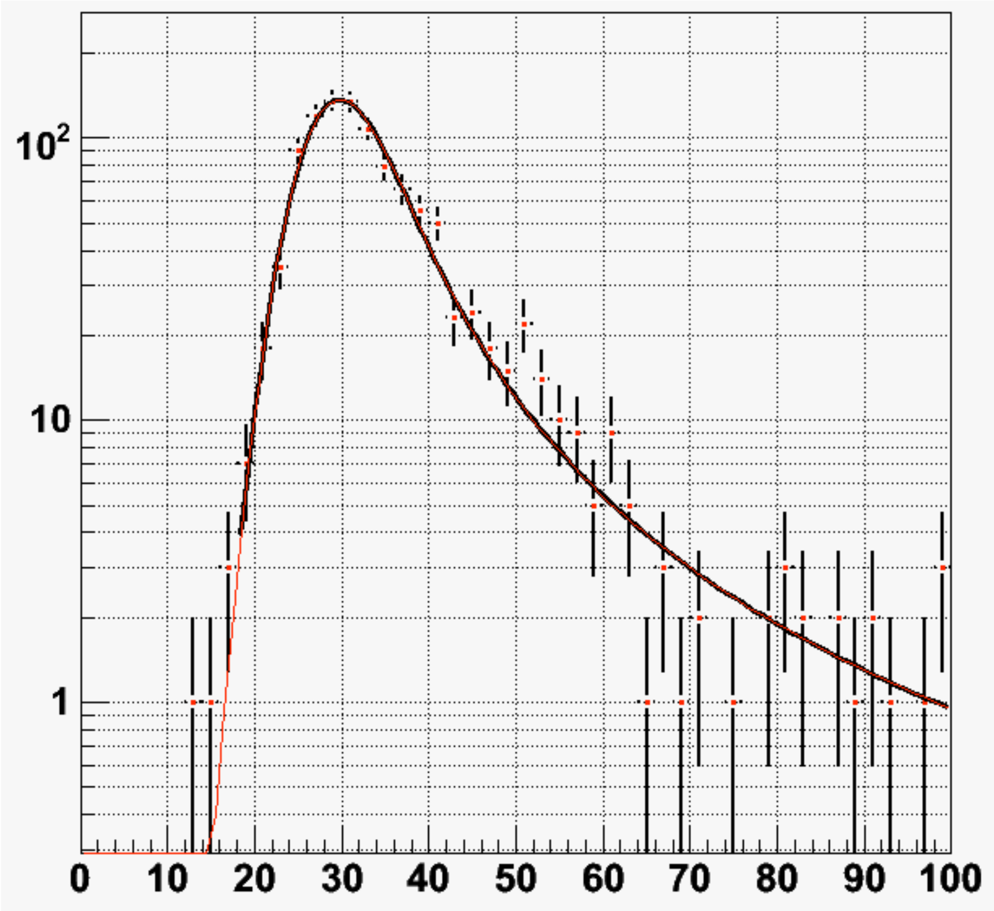


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Depends…actually the worst is not understanding either.

# Algorithm Optimization

Clustering thresholds

Bad channels (noisy or dead)

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# Tracking validation

Simple checks:

- Missed hits?
- $\chi^2$ probability flat?
- Hit isolation
- Phi dependence
- +/- charge ratio
- dE/dx

- Measure anything that you think you can predict
  - Discrepancies will reveal
    - Bugs
    - Interesting effects

(Note that this applies beyond tracking e.g., model independent searching).

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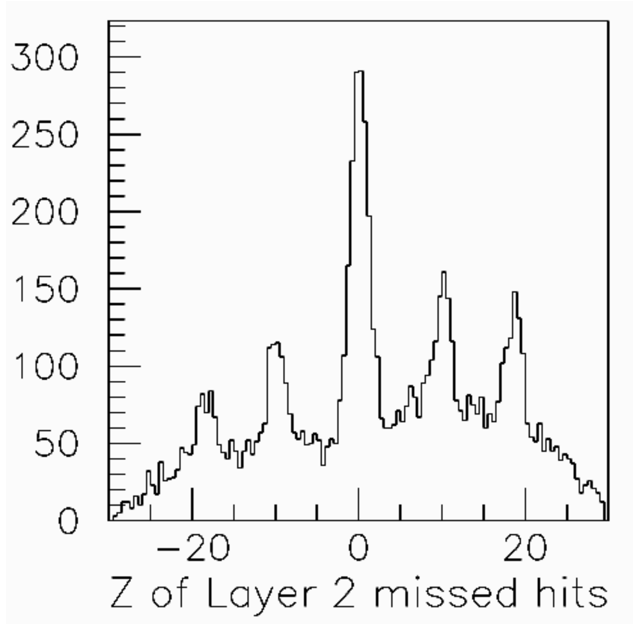


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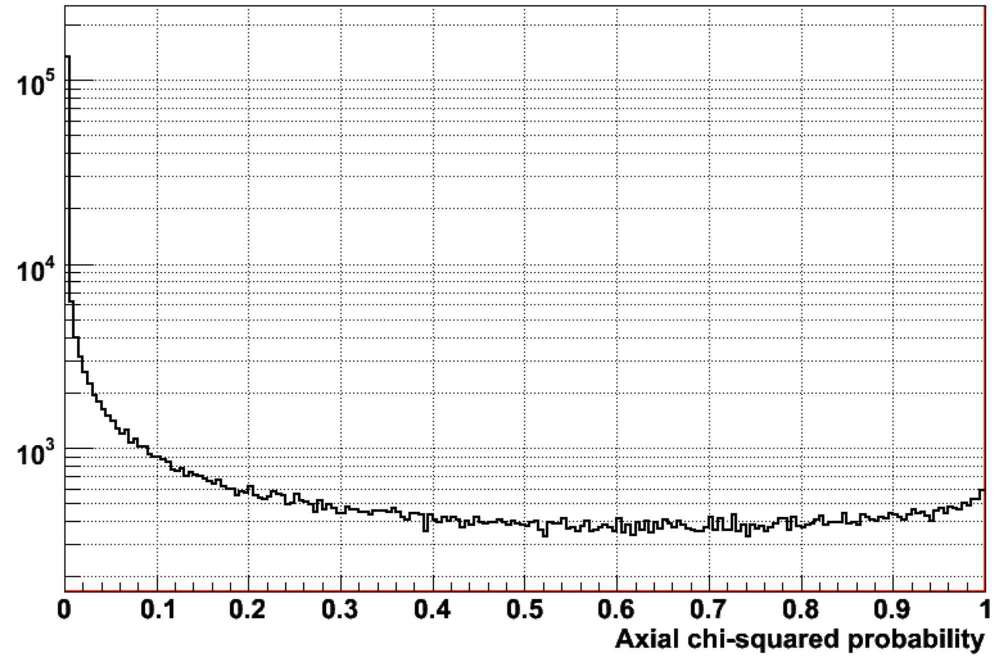


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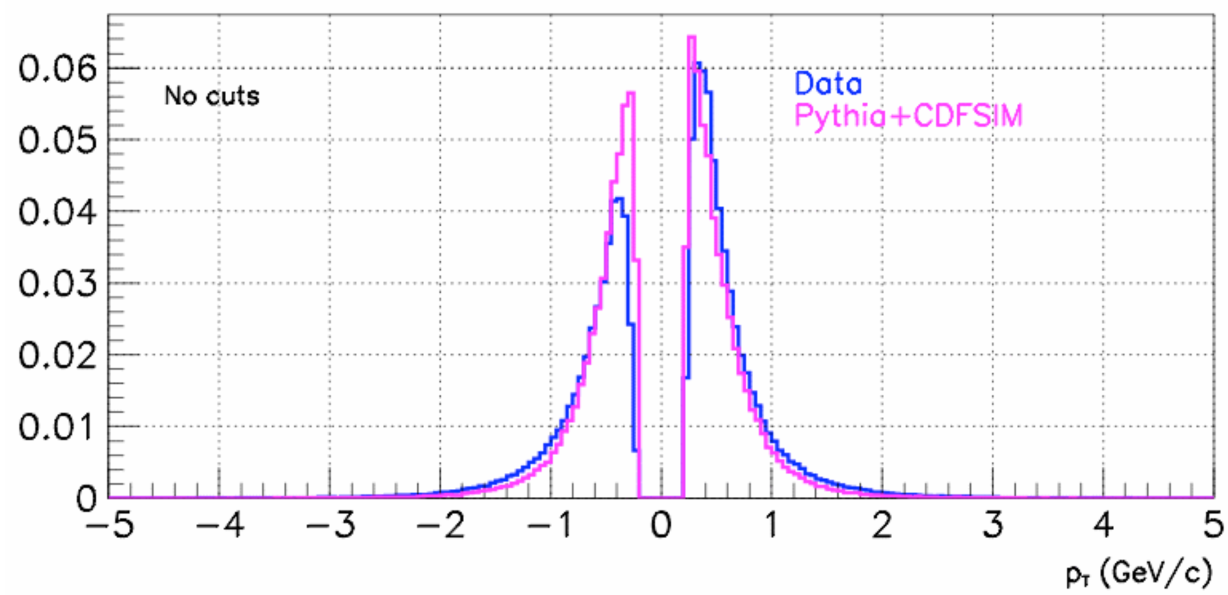


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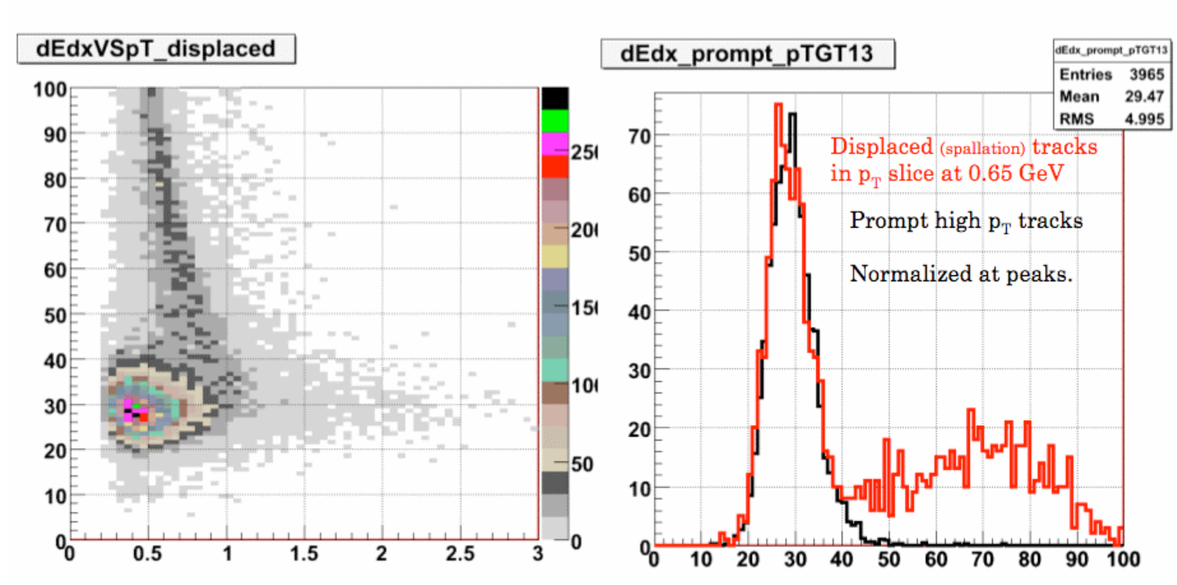


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# Tracking validation

## Simple checks:

- Dump events and cross-check
- Look at event displays and cross-check
- Move hits or seeds and see effect on tracking.
  - It is easy to get a pure background sample.

# Tracking validation

Role of Monte Carlo?

- Calculates integrals for you.
- Convolves messy functions (e.g. response functions)
- Allows bug checks (see previous) in absence of data

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But the Monte Carlo is wrong!

# Tracking validation

Don’t trust Monte Carlo efficiency or fake rate.

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Overlay hits from a track found in one data event into a jet in another event. Re-track. Gives $\varepsilon_{jet}$.

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But, there is background in the data…

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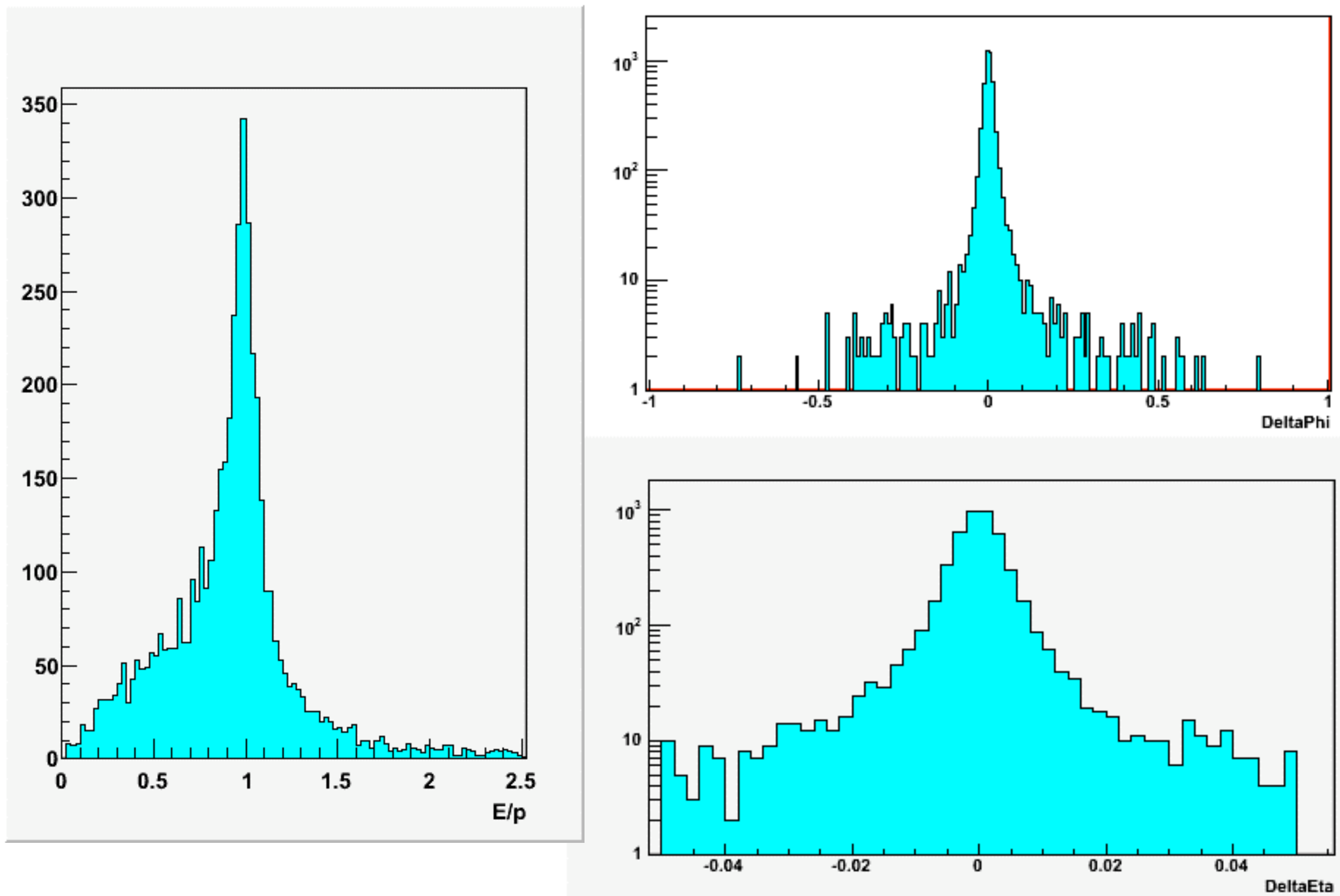
Predict presence of track with calorimeter (e.g. in $Z \rightarrow ee$). Do you find it?

But, there is background in the data… Fine, measure it.

# Tracking validation

Recall from Lecture 1: Comparison between tracker and calorimeter:
p, η and ϕ of track and calorimeter measurements should match.




Low pT electrons, in a CMS simulation. Wing To, UC Santa Barbara

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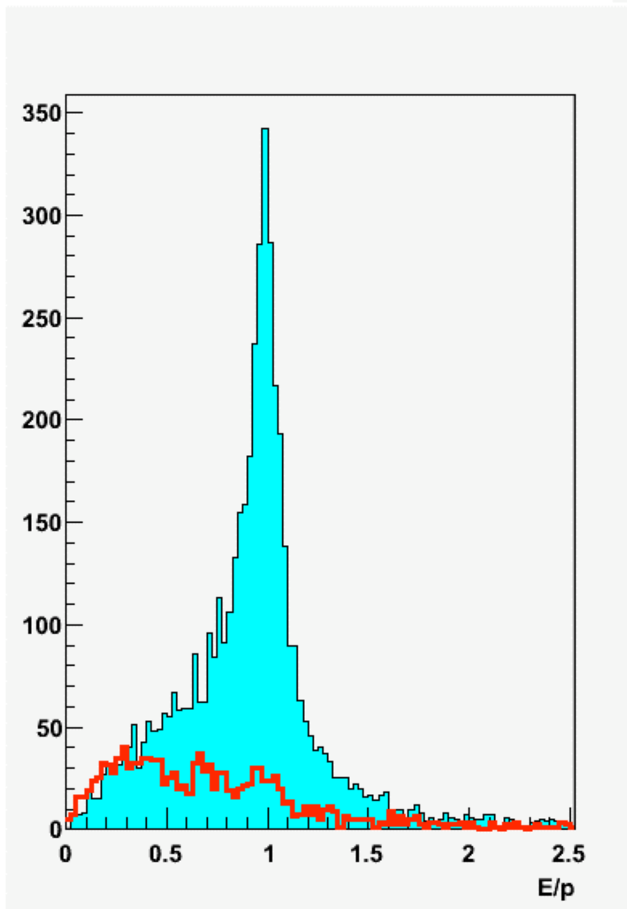


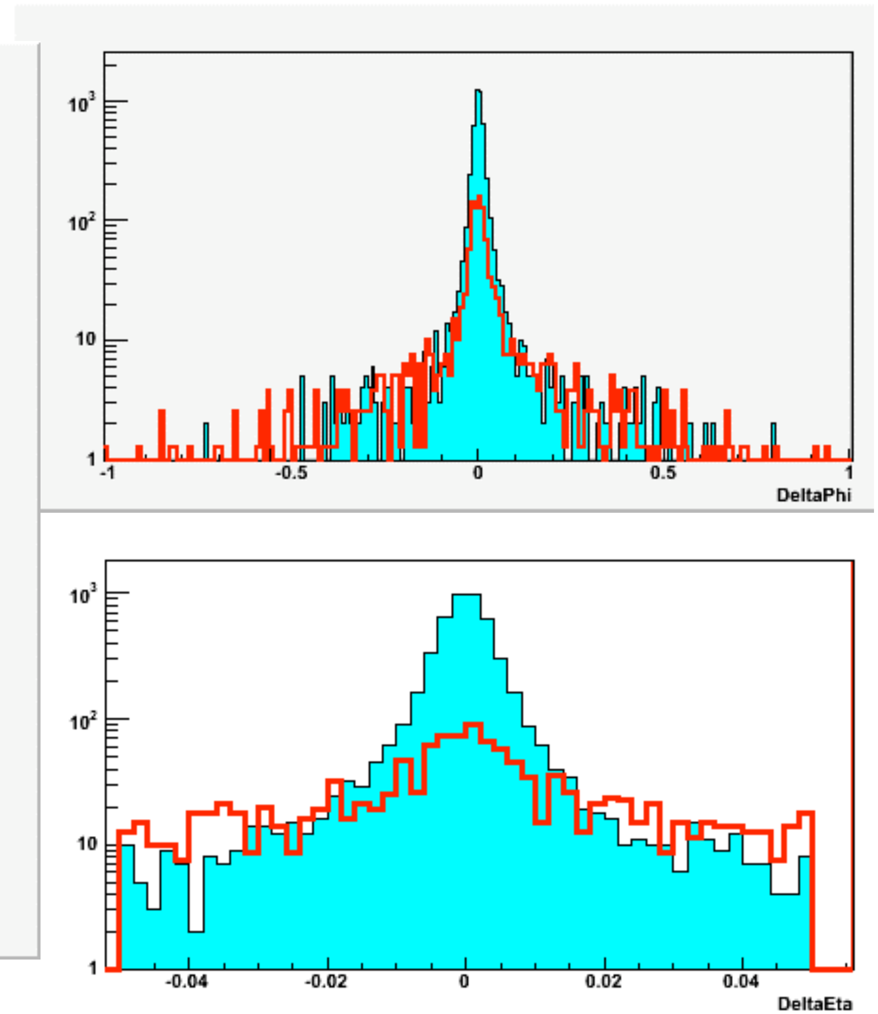


Subtract background shape to get
pure signal shape…then compare to MC.

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# Commissioning and Operation

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- **Keeping it working**
  - Monitoring
  - Aging

# Tracking Monitoring

Repeat all of the above regularly.

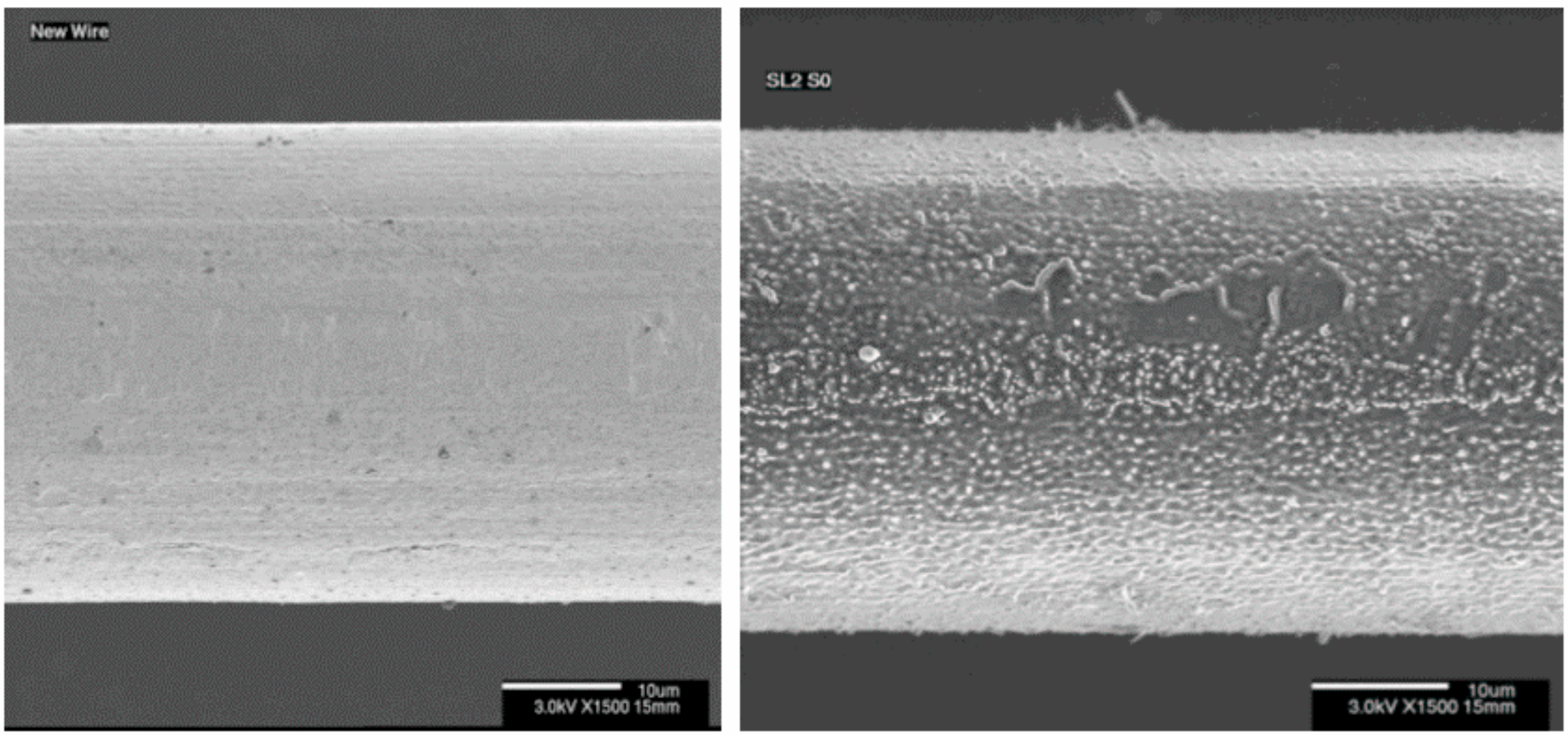
- Check for time and dependence
- Check for problems introduced by software improvements

This is not a coding challenge, it just requires studying the results.

# Wire chamber aging

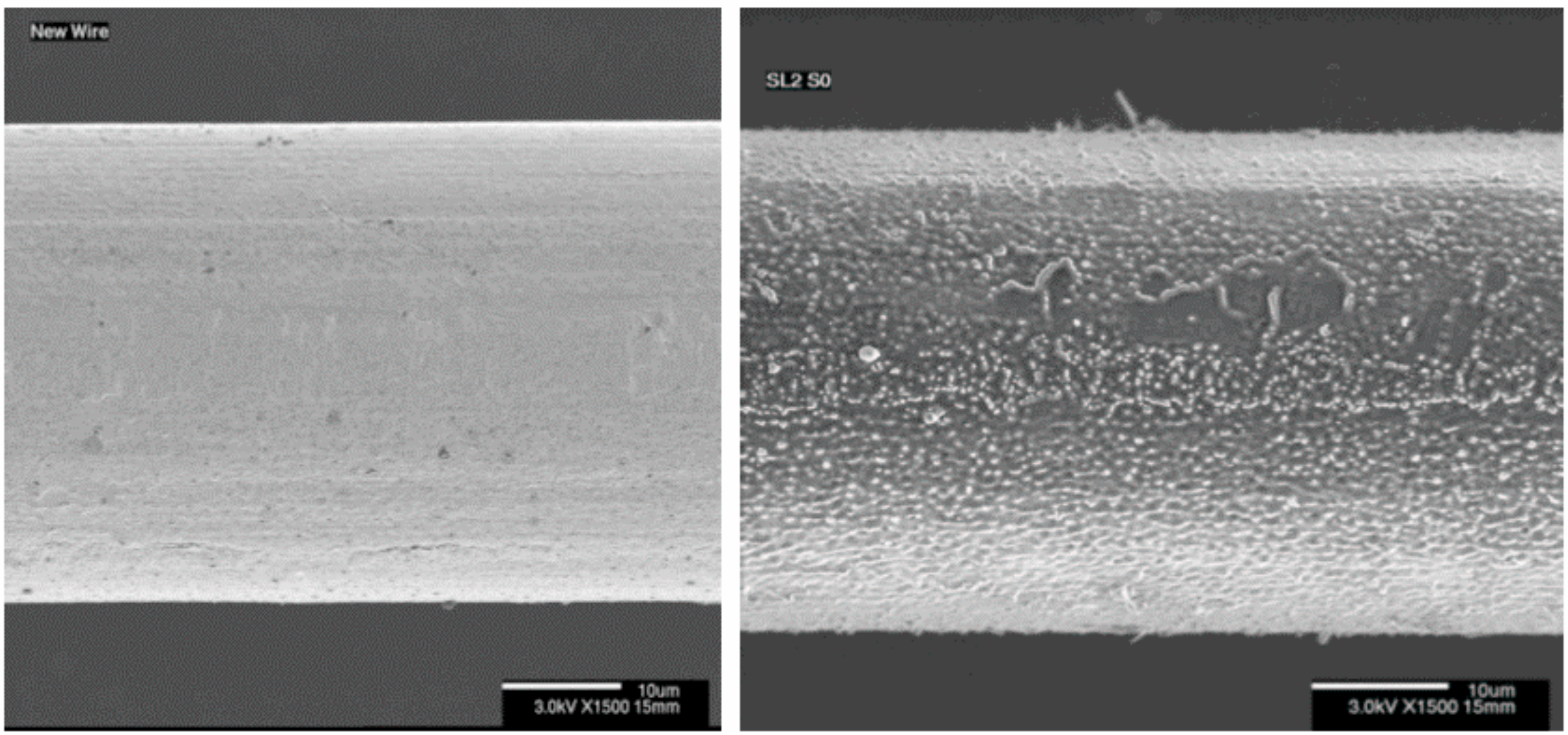
Ionization generates muck out of the gas that coats the wire.

- Sparking
- Lower gain



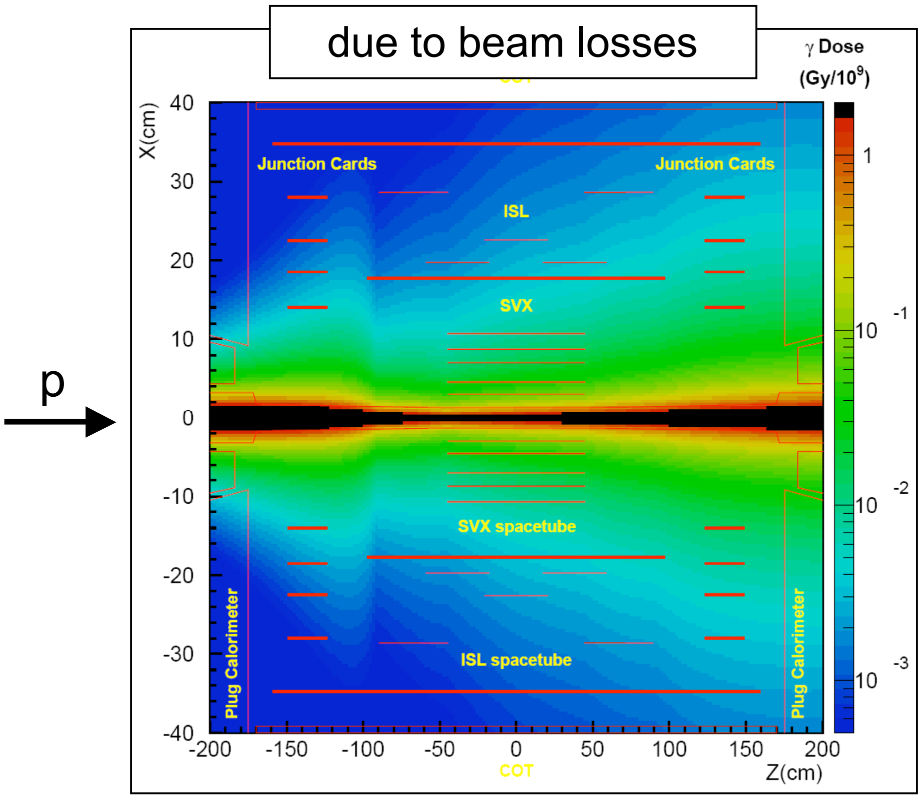
# Wire chamber aging

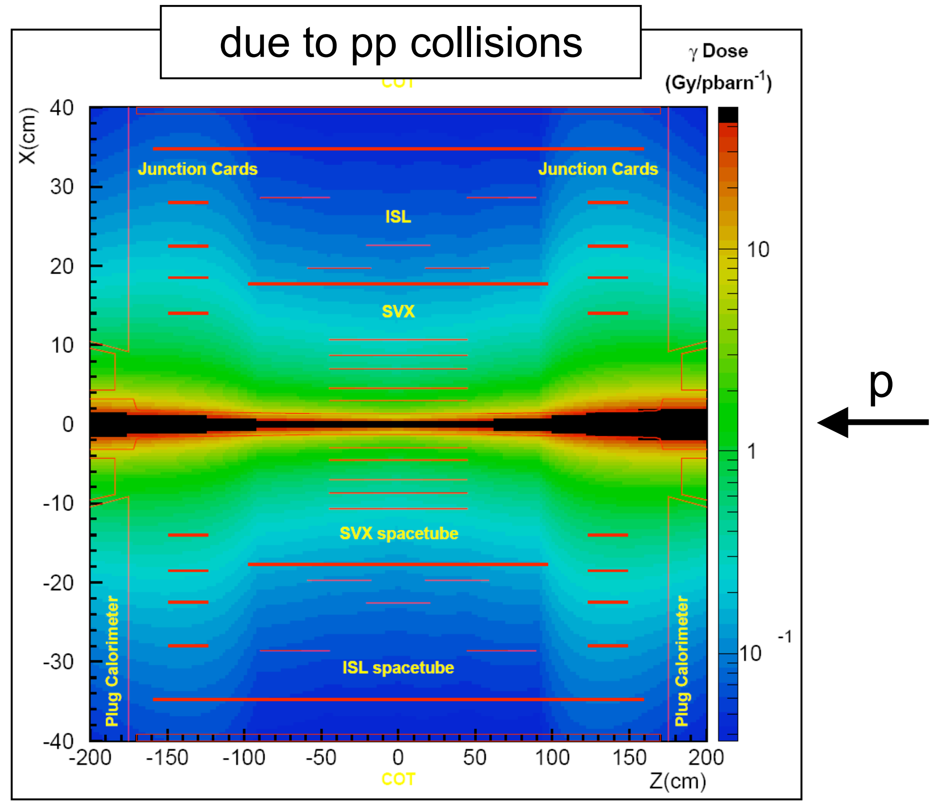
- Monitor currents and gain
- Scrub gas, e.g., with $O^2$ or alcohol



# Silicon aging

- More of a challenge because usually at low radius



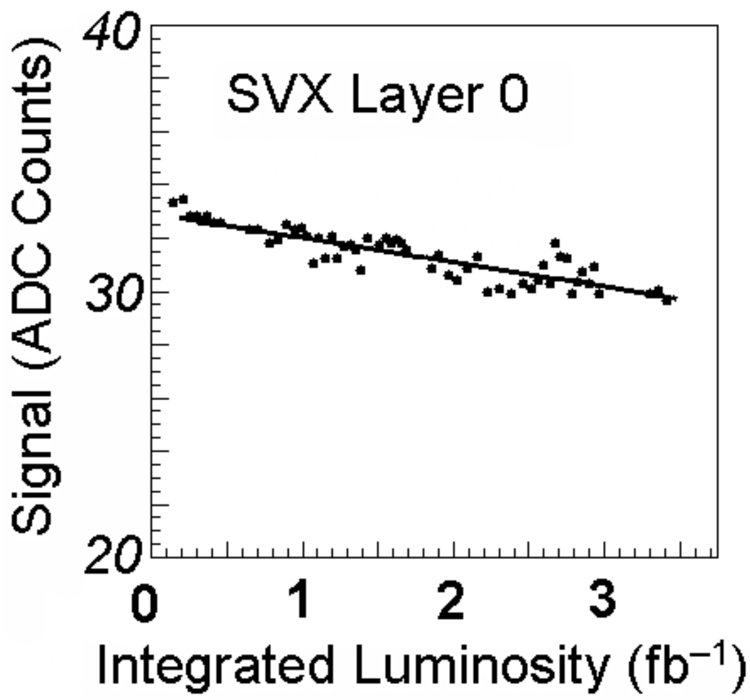



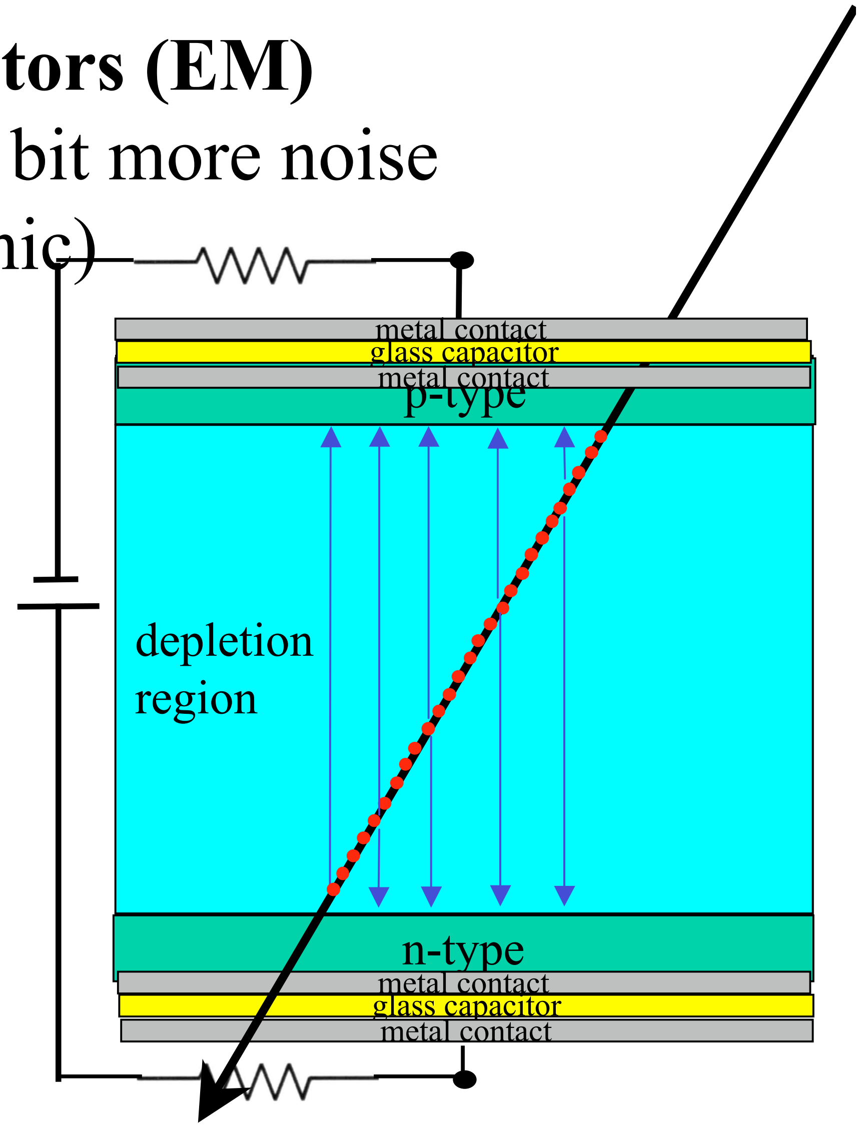

**(See R. J. Tesarek *et al.*, IEEE NSS 2003)**

$$r^{-\alpha(z)}\text{, with } 1.5 < \alpha(z) < 2.1$$

# Silicon aging

- Main effects are:
  - **Charge build-up in insulators (EM)**
    Collect less charge and a bit more noise
  - Damaging the bulk (Hadronic)



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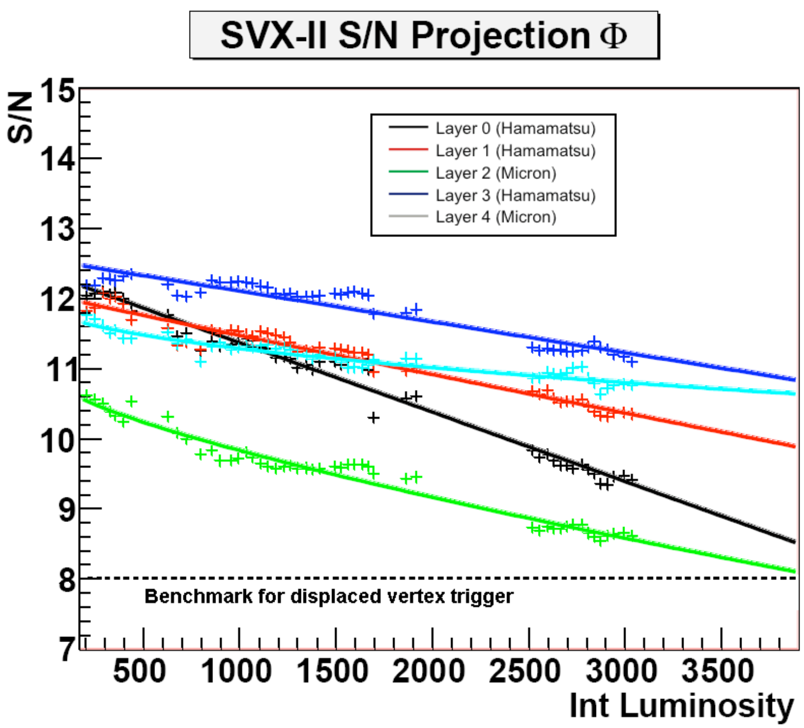


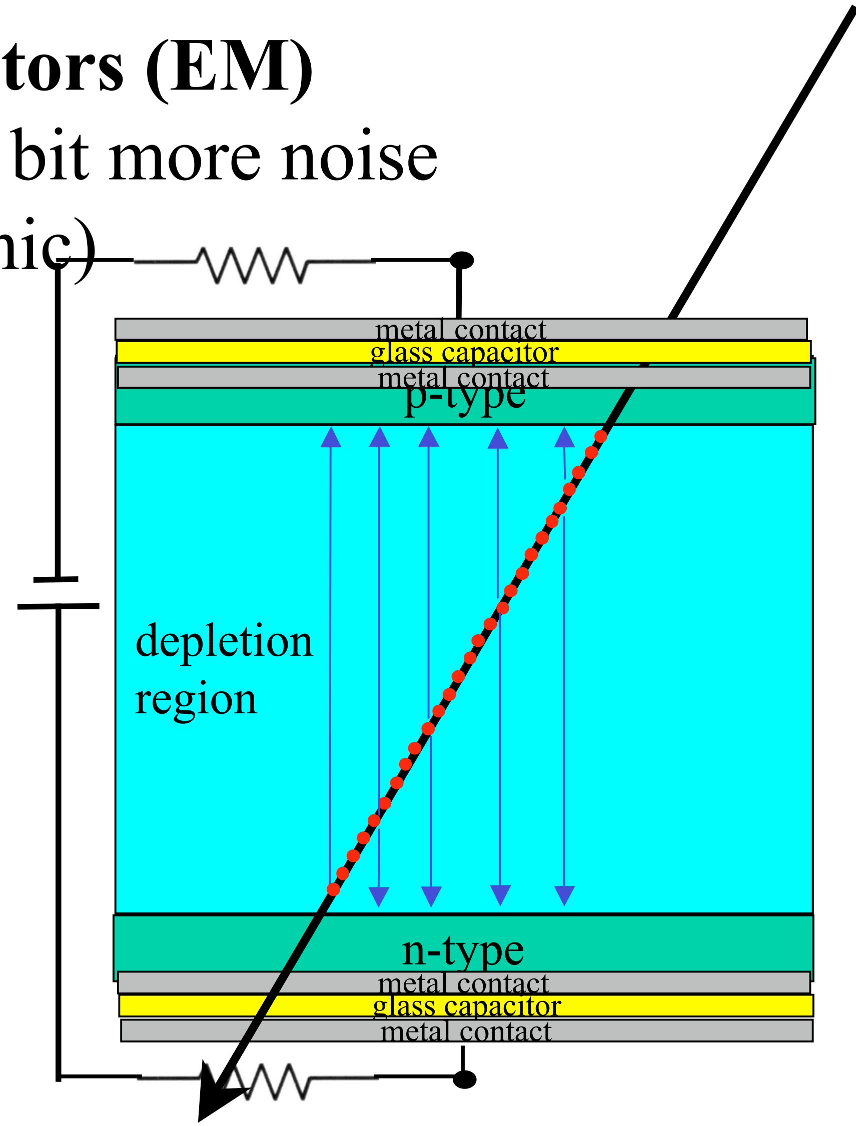

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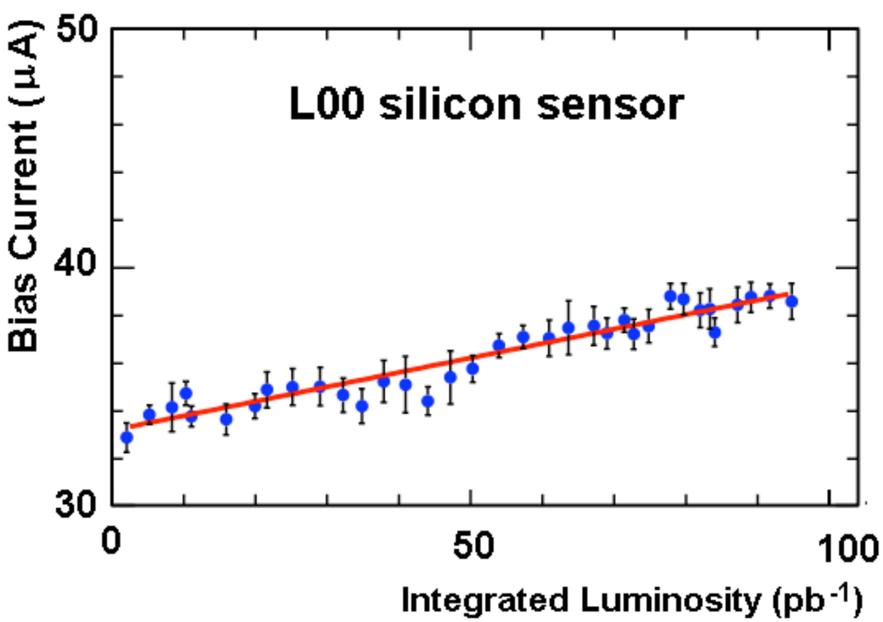


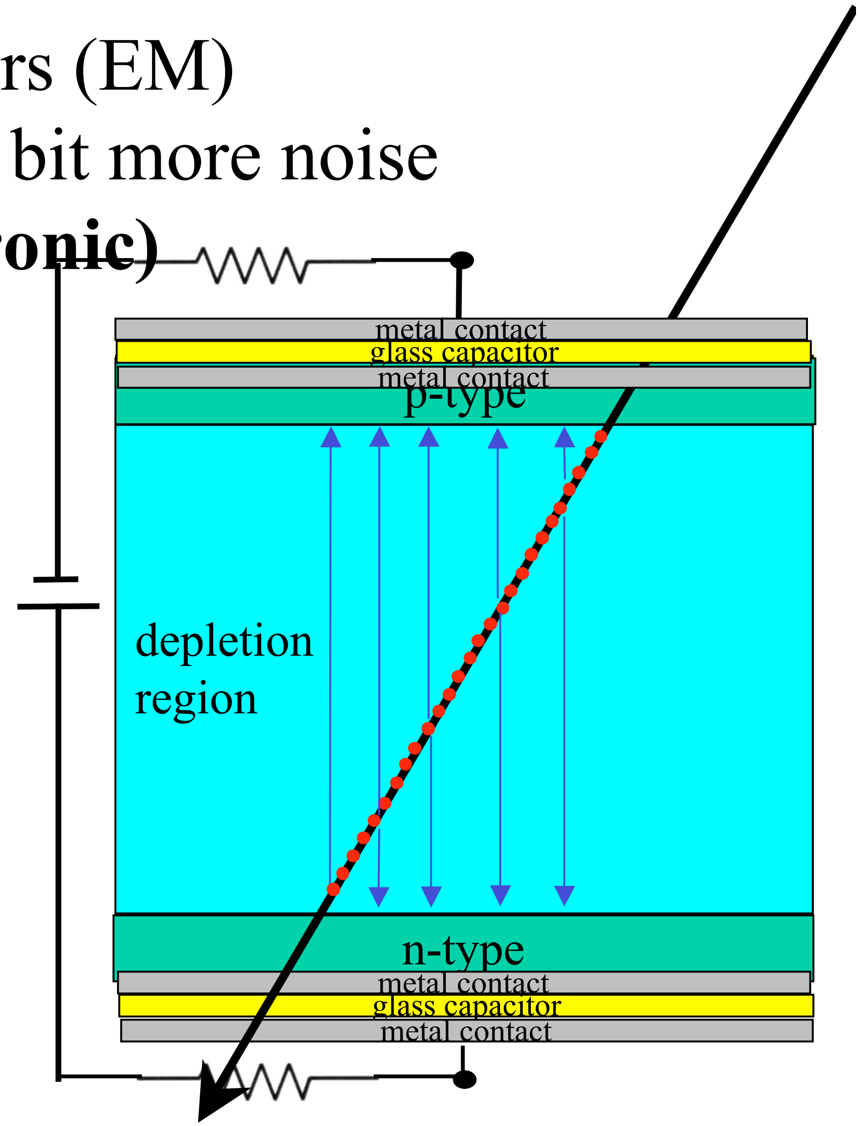

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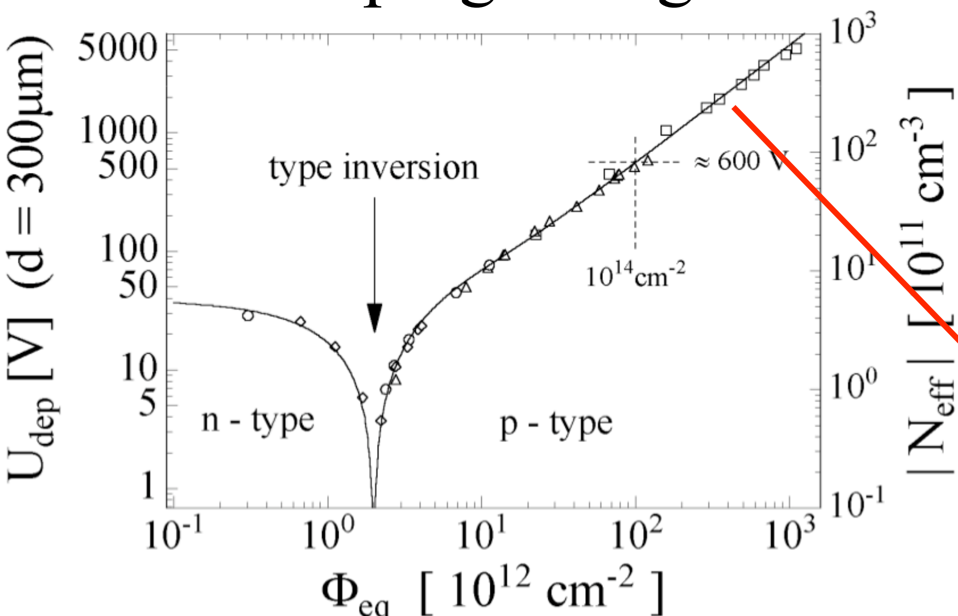


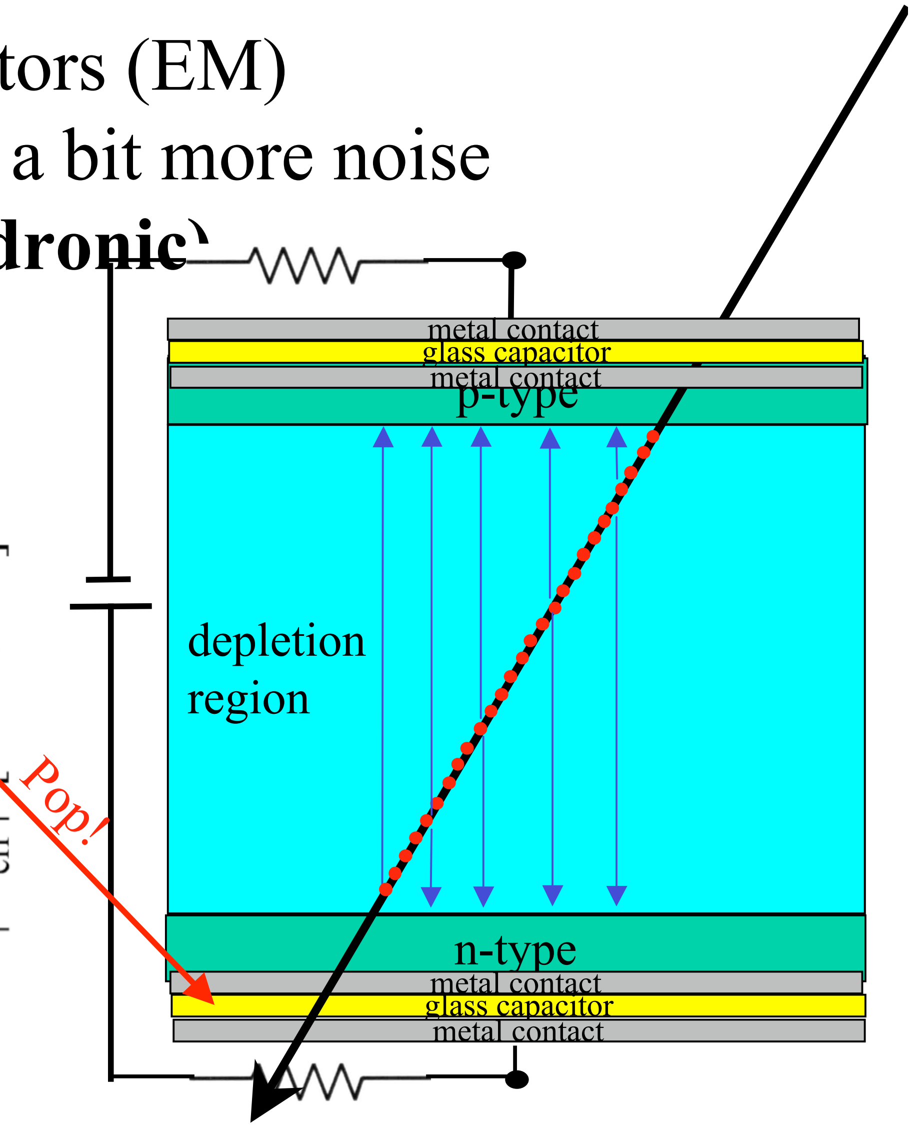


Ron Lipton

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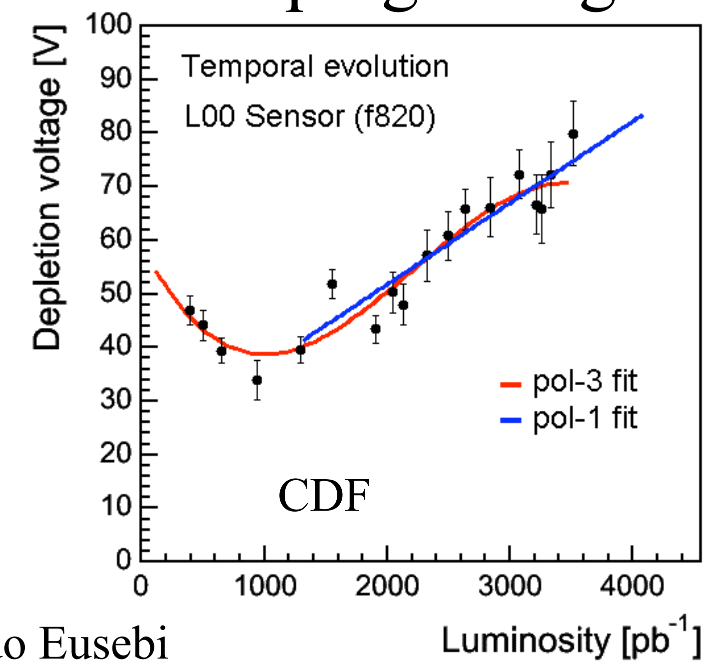


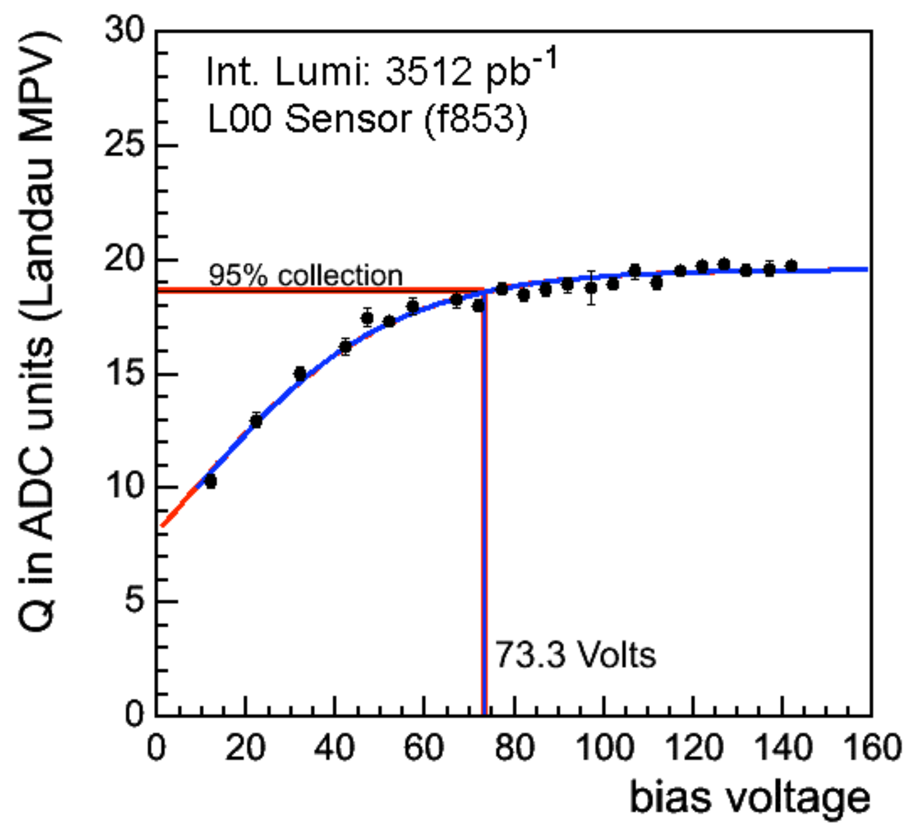

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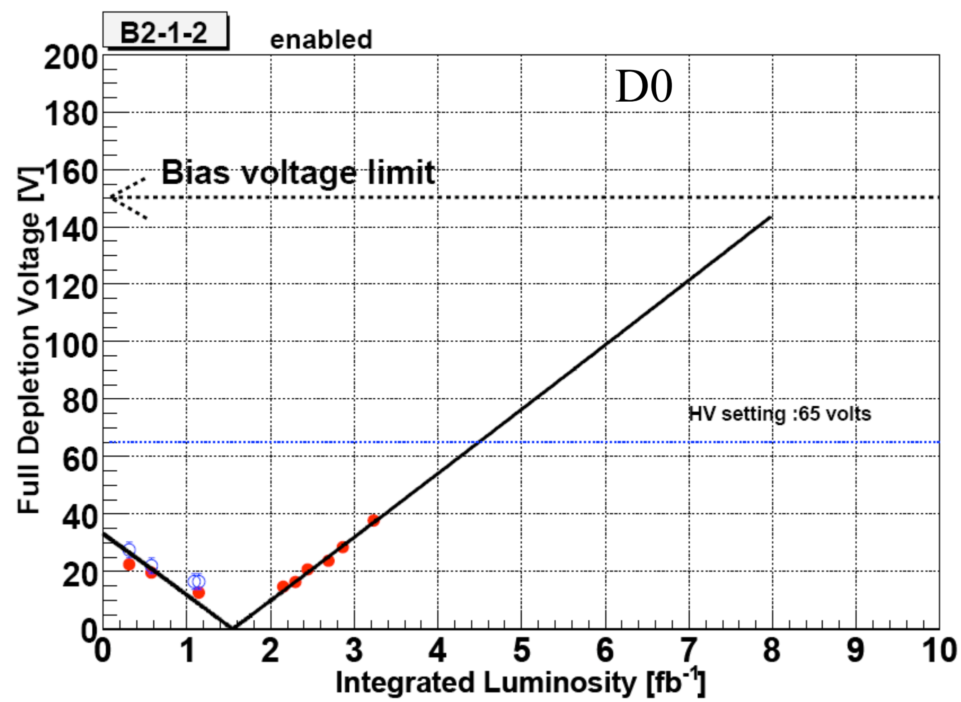


Ron Lipton

# Silicon anti-aging

- Keep it cold
  - Bulk damage anti-anneals after inversion
  - $$I \propto T^2 \exp\left(-E_g / 2k_B T\right)$$
  - Thermal runaway.
- Run at -20° C

# Silicon anti-aging

- Make it thin
  - Need less voltage to deplete
  - But less signal

- Make it small
  - Less capacitance = less noise
  - Less current = less noise

    $\Rightarrow$ Can detect a small signal

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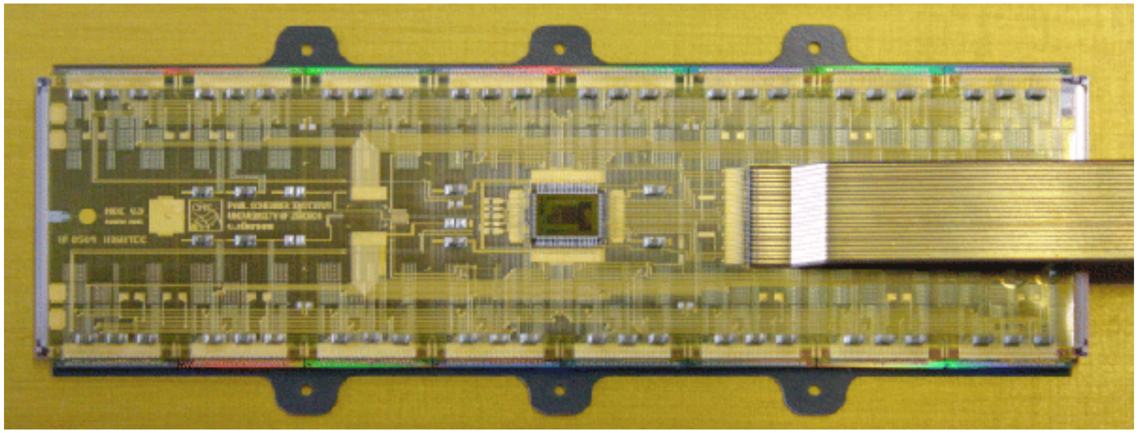
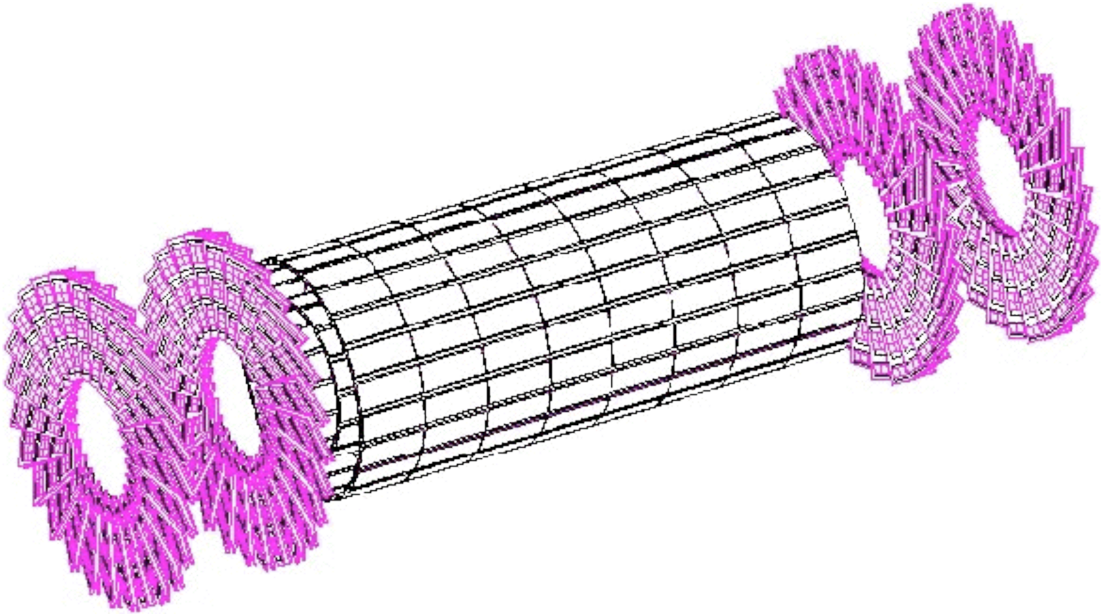
Pixels are naturally more radiation resistant.

# Pixels

The many connection challenge is squared.
Internal electronics
Cooling
Material
Mechanically hard
Complex

Radiation hard
Fine granularity





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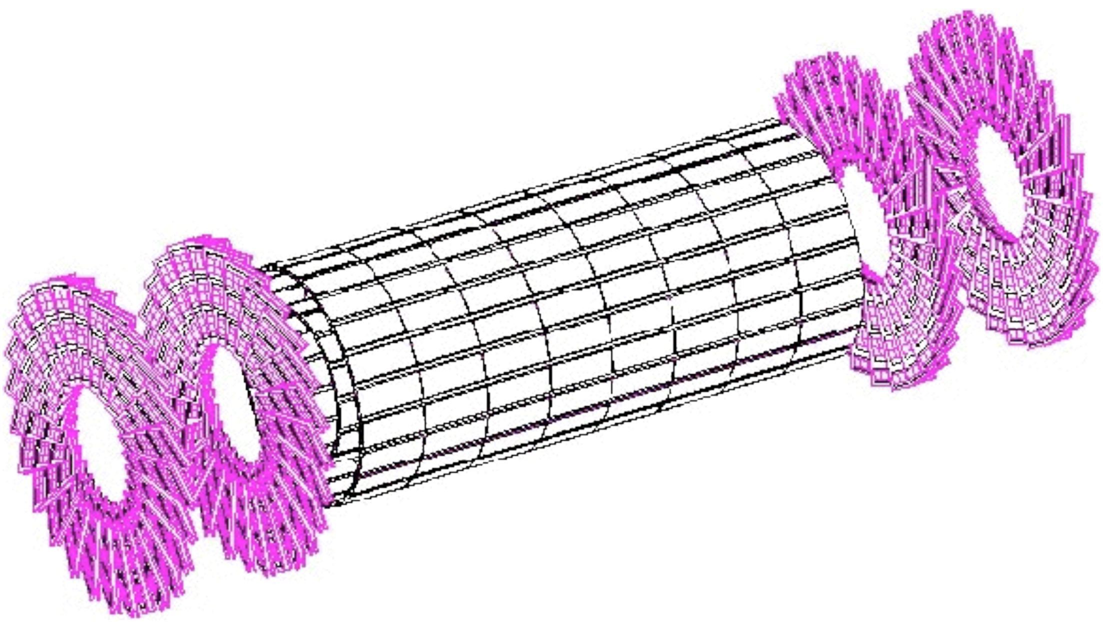
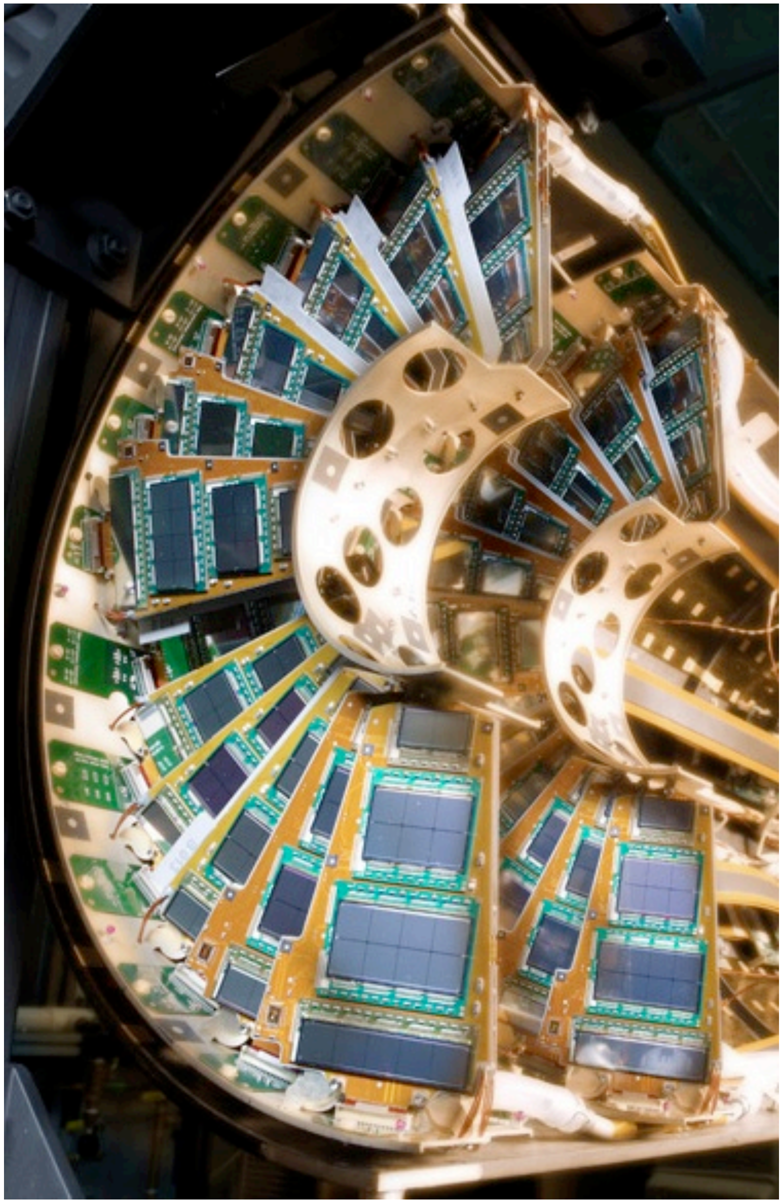




# Summary

What to say without being boring?!…

# Summary

Redundancy is good.

- Confirm.
- Improve.

Rigorously validate everything.

- Test every hypothesis.

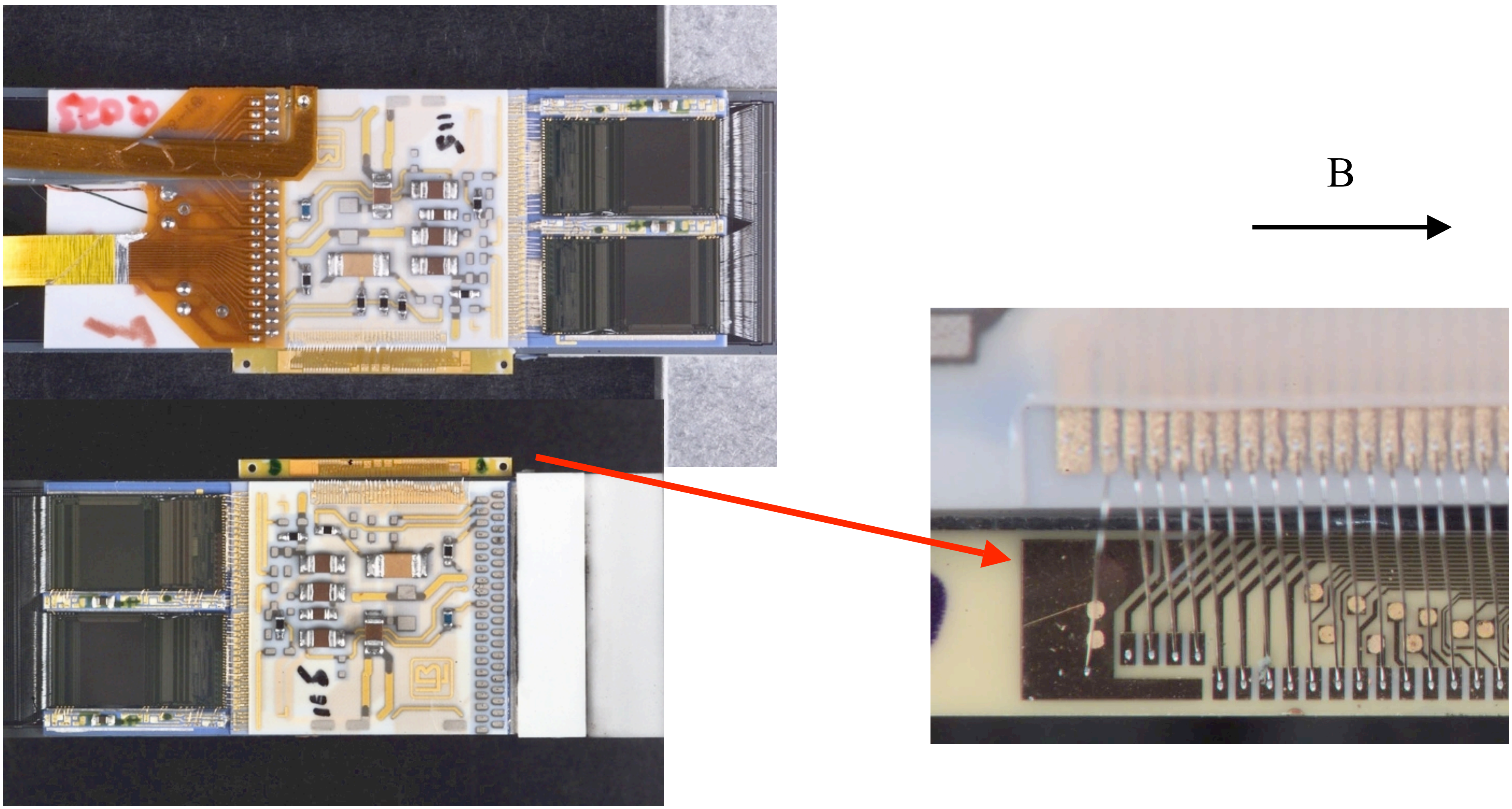
Have fun.

- There are always interesting games to play.

# Extraneous slides

# Some past problems

- Physics happens in the detectors.



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- Connections don’t stay (correctly) connected.
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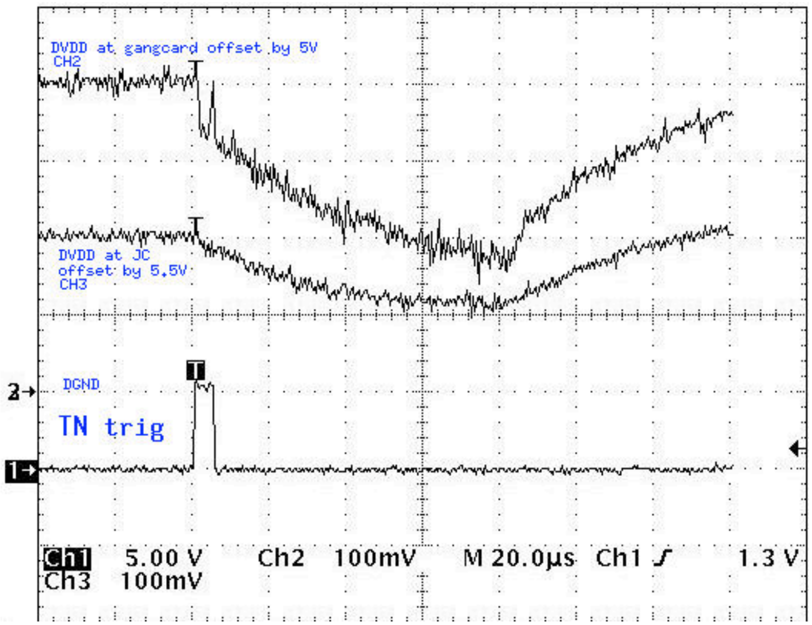
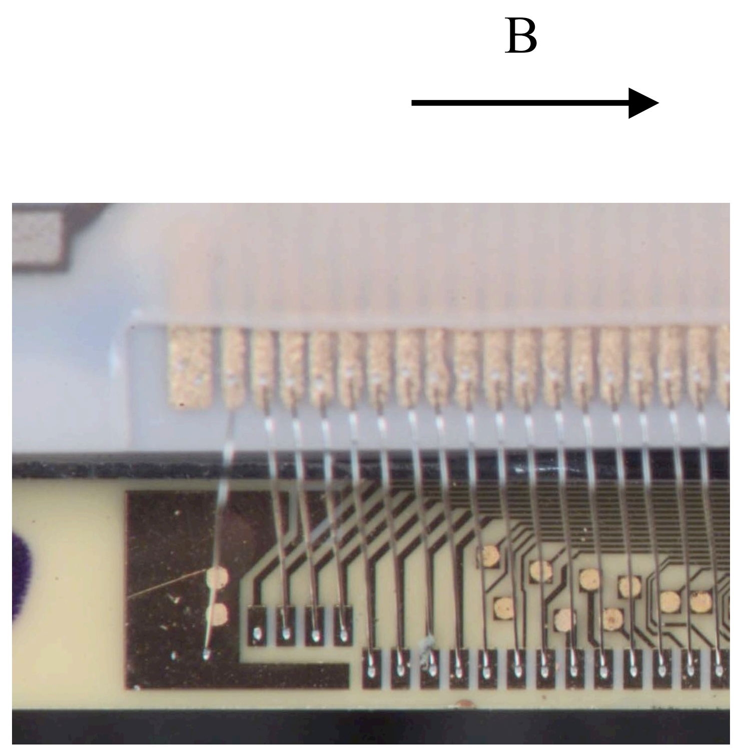



Large current draw during readout.
Readout is rare and random.



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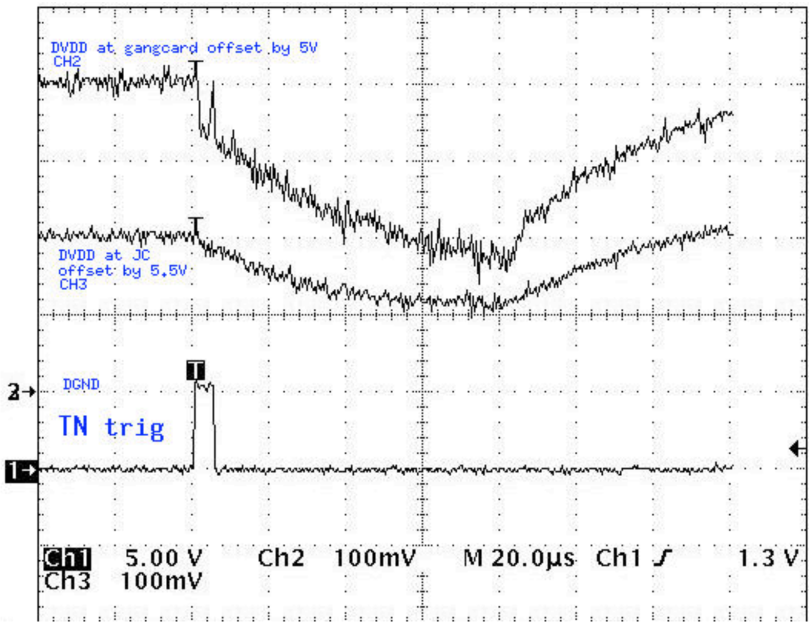
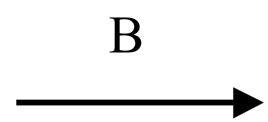
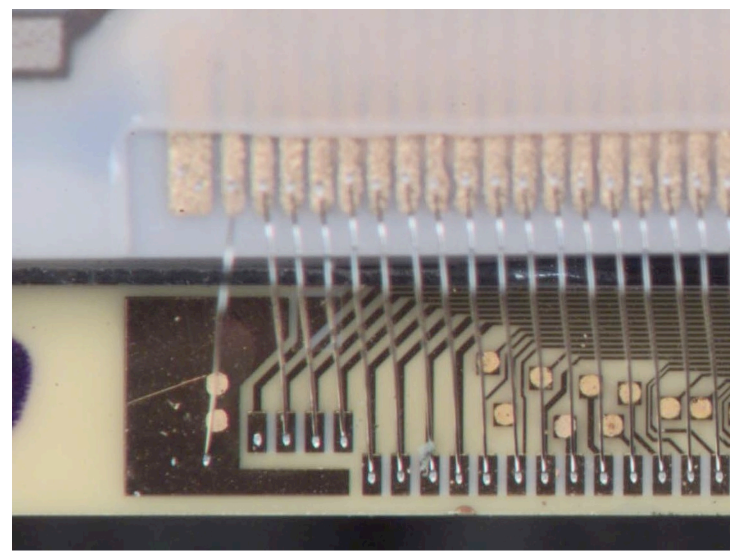
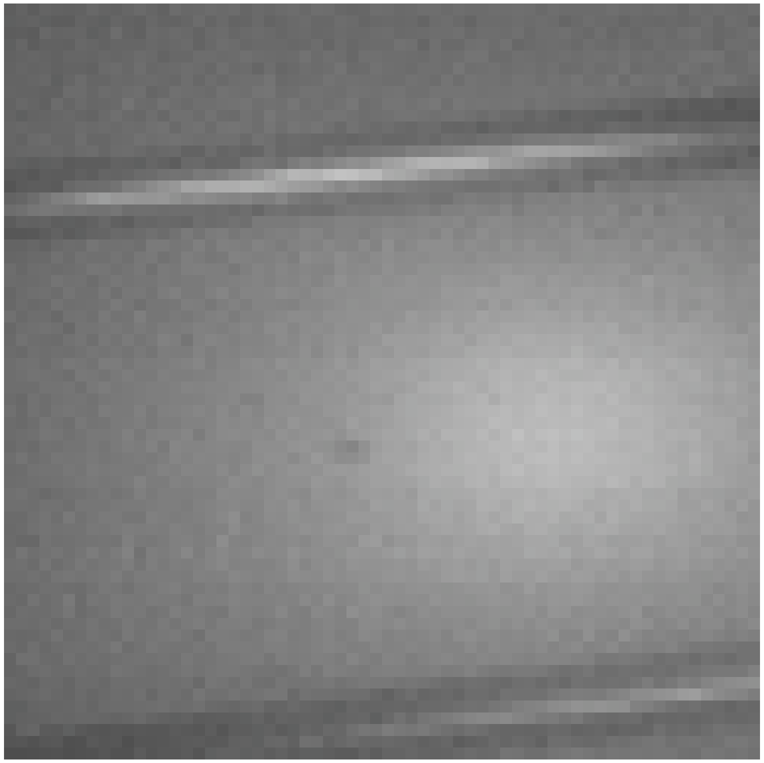


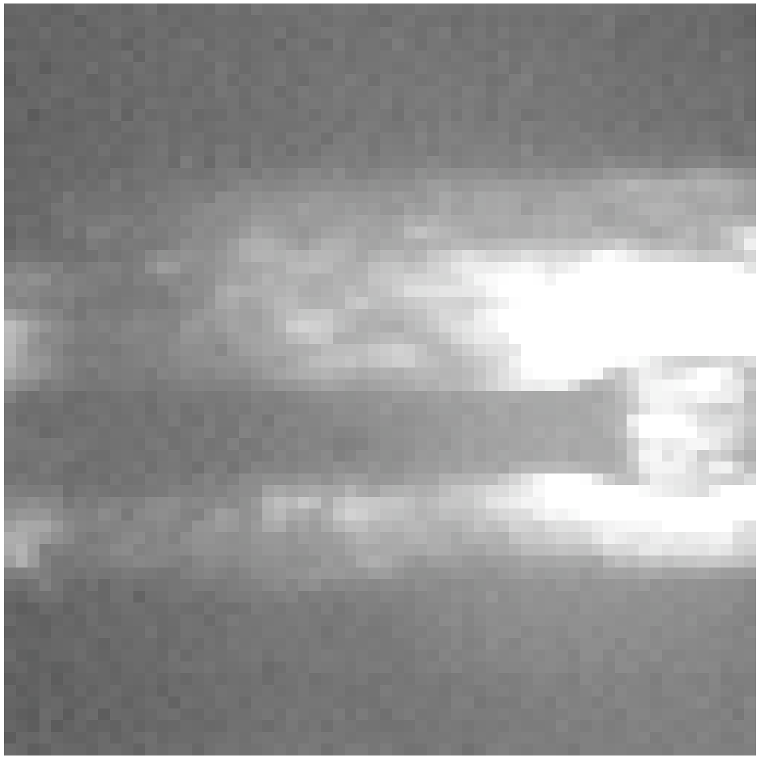

Large current draw during readout.
Readout is rare and random.
Unless it is not random. Resonance!



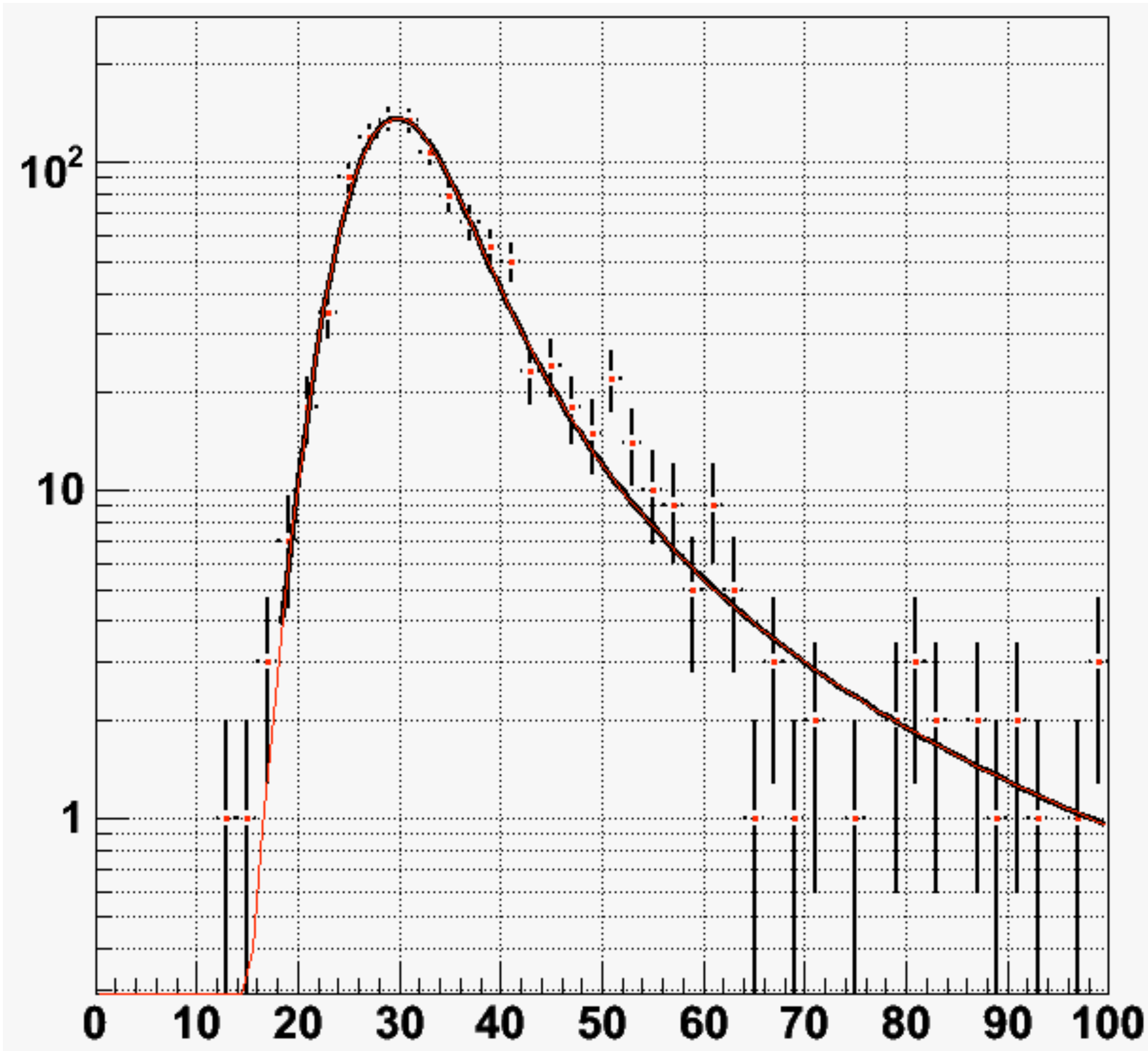



# Resonating wirebonds





# What caused the low charge clusters?




Max strip, Q/noise, pathlength normalized

# What caused the low charge clusters?