SCT Lorentz angle & Cluster Width Simulations

From first principles

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In consultation with

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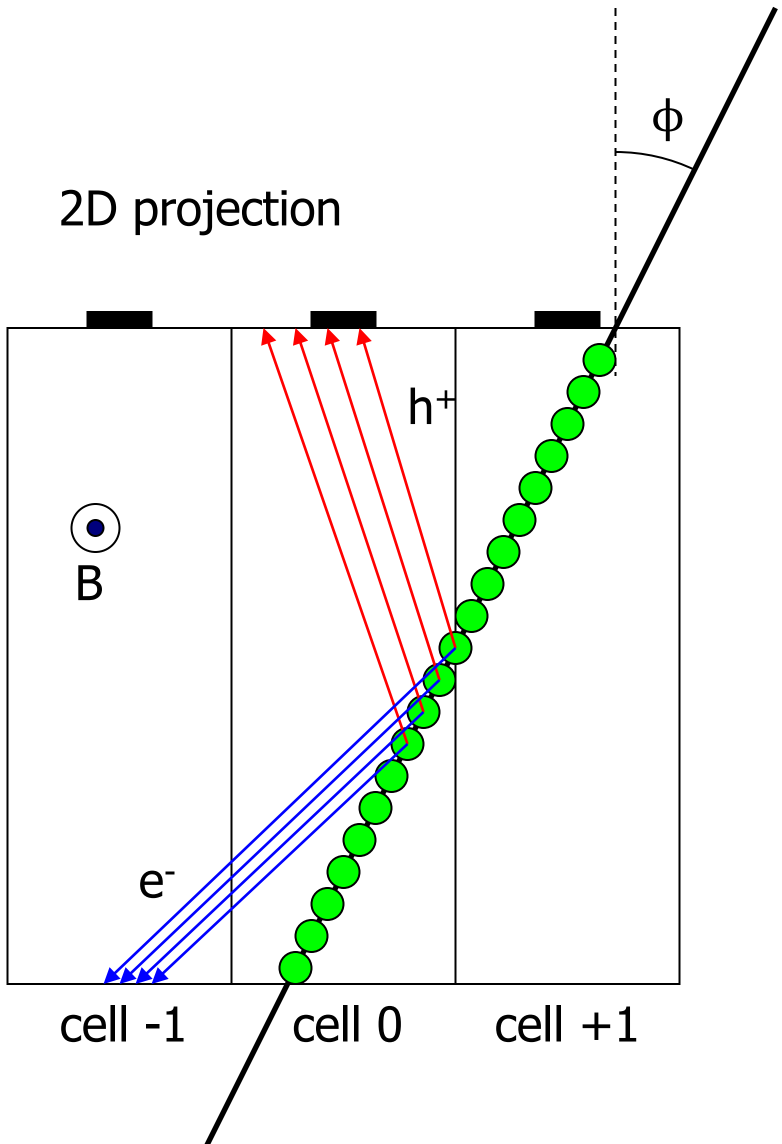
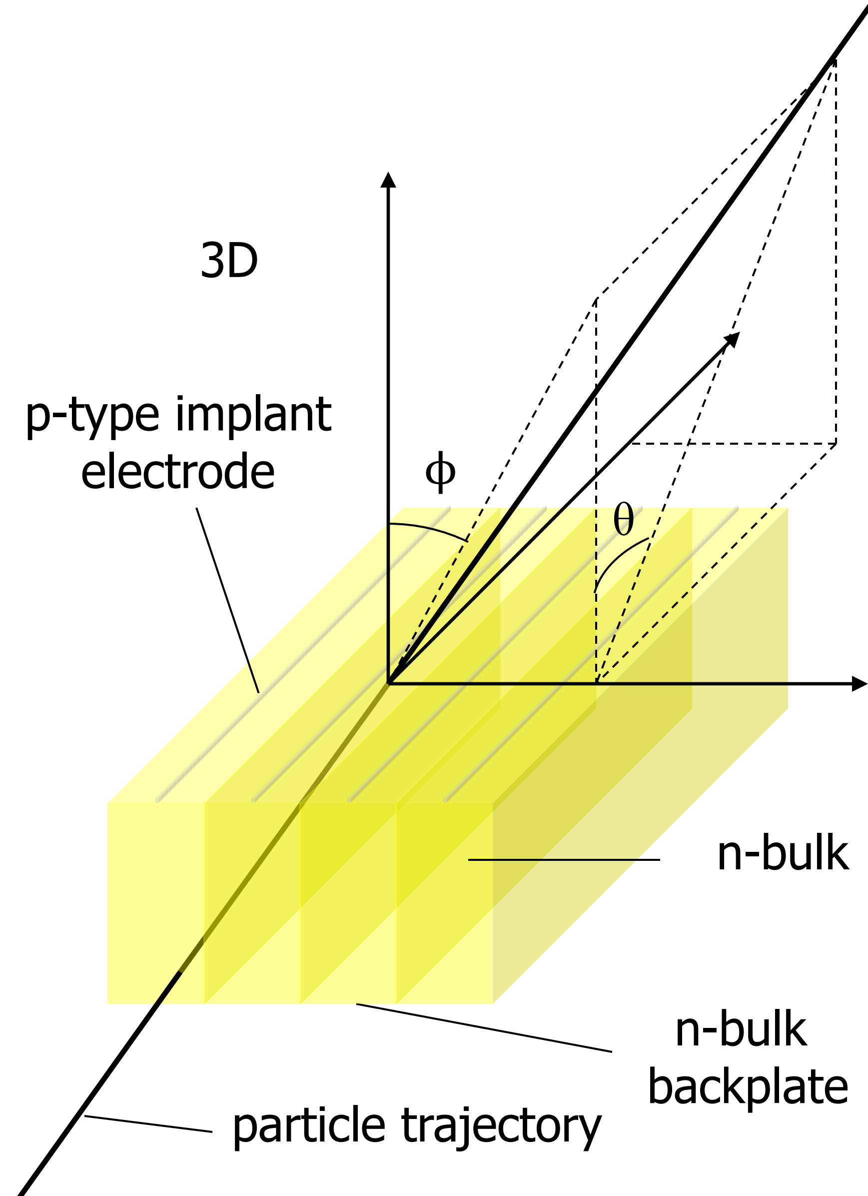
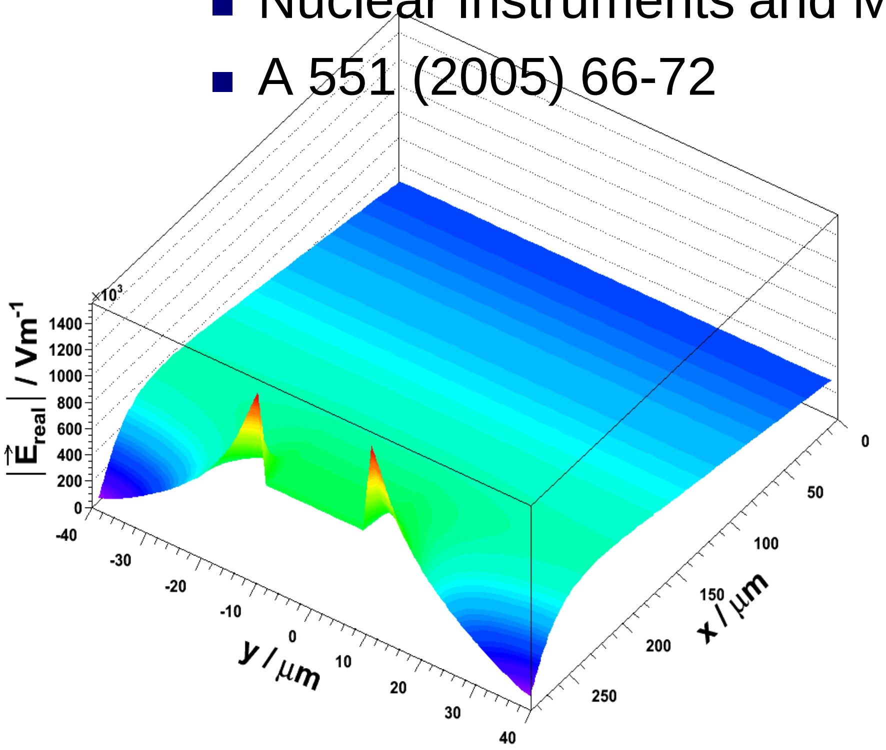
Geometry

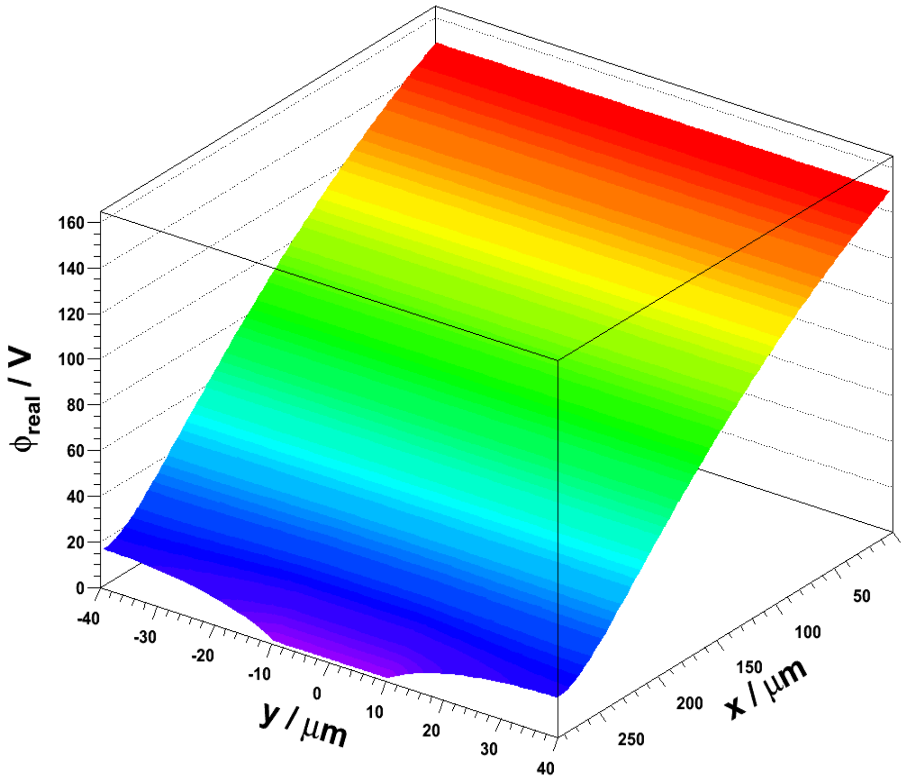

2D projection
ϕ
h+
B
e-
cell -1
cell 0
cell +1


3D
p-type implant
electrode
ϕ
θ
n-bulk
n-bulk
backplate
particle trajectory

Detector electric field

- Real field
  - Analytical expression (Fourier expansion)
    - P. Wiacek & W. Dabrowski
    - Nuclear Instruments and Methods in Physics Research
    - A 551 (2005) 66-72





Charge drift

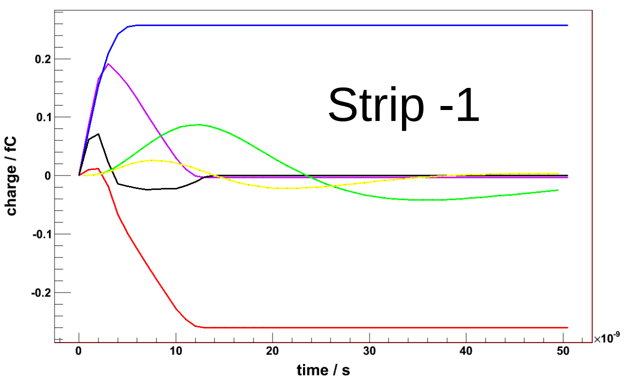
- Modify deposited charge w/ Landau distribution w/ arbitrary cutoff at 500 for mean of 108 (Taka).
- Charge deflection by magnetic field proportional to
  - Magnetic field
  - Hall mobility
    - Function of electric field strength
      - Electric field function of position
  - Non-linear motion
- Add diffusion: Random walk
  - Model with Gaussian distribution to each charge
    - y^2= 2 X Average diffusion constant X drift time
- Charge drift induces currents on electrodes
  - Ramo's theorem

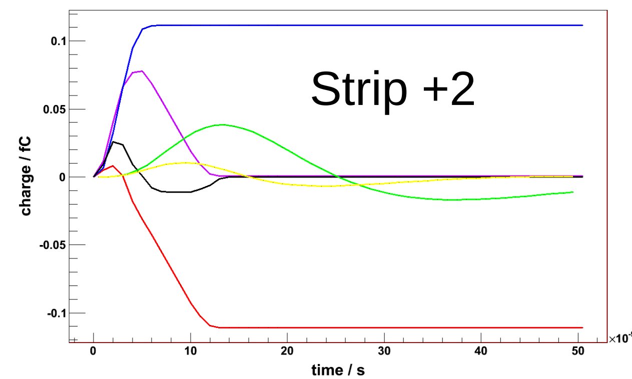
Frontend output

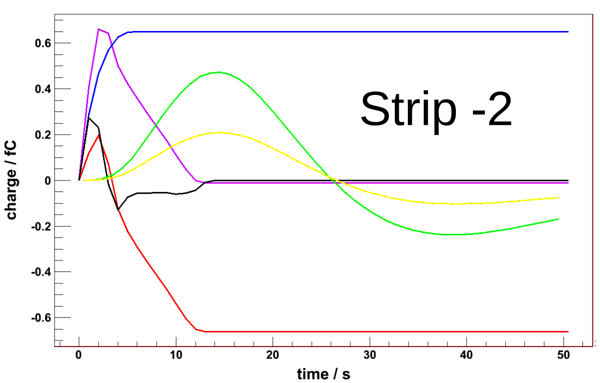
- Simulate hole and electron trajectories
  - Currents amplified and shaped by ABCD chip (Integrator ^ 3)
    - Peaking time = 21ns
- Capacitive coupling between strips
  - Differential Cross-Talk (DCT)
    - Peaking time = 9ns
- If response > 1.0fC (equivalent) in 25ns bins
  - Hit registered on electrode 1/0
    - Digitization
- No. hits recorded = Cluster width
  - No reconstruction to combine groups of hits from one particle
- Let us call this the Induced Current Model (ICM)
  - ~10ms for one particle

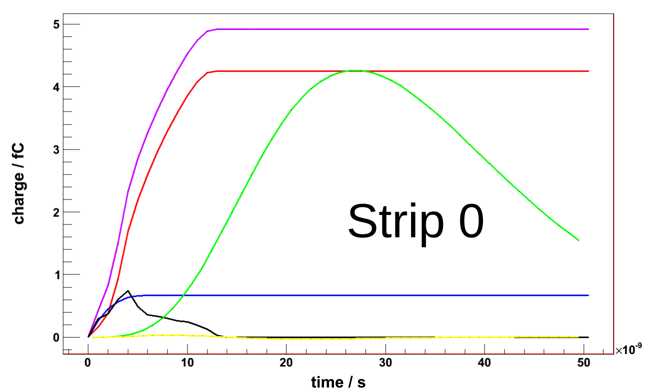
Example of responses

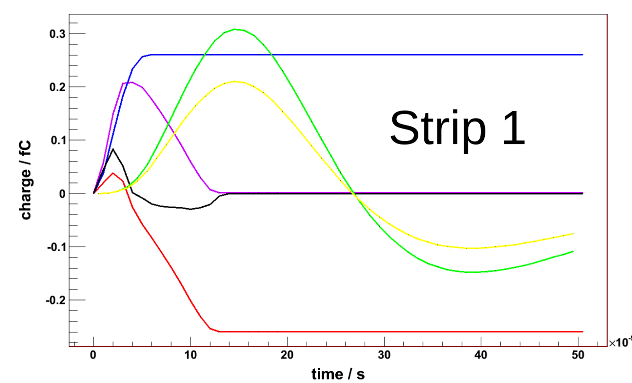
- Particle incident at ϕ = 0, x = -40μm
  - Hole charge; Electron charge; Net charge; Differential cross-talk; Net response; Induced current – normalised to Current * 1n
  - Diffusion / Landau fluctuations not modeled in these











Some observations about response

- Electron charge induced always monotonically increasing
  - Hole charge may have peaks / valleys
- Electron charge reaches extremal value within 5ns
  - 5ns ~ time taken for electron to drift across n-bulk from one end to the other
  - Implication: model with some analytical function that reaches maximum in 5ns.
- Simulations done with full electron trajectory / model with uniform current
  - Negligible shift in Lorentz angle / cluster width for small ϕ about the Lorentz angle
    - <0.1% (well within statistical fluctuations).

Possible approximations

- Not concerned with time variation of I
  - Only concerned with final charge state

- Integrate Ramo's theorem
  - Charge induced = count number of holes that reach an electrode

- Let us call this the Charge Counting Model (CCM)
  - Why do it
    - Up to 100 times faster than ICM; can be used for tuning simple models

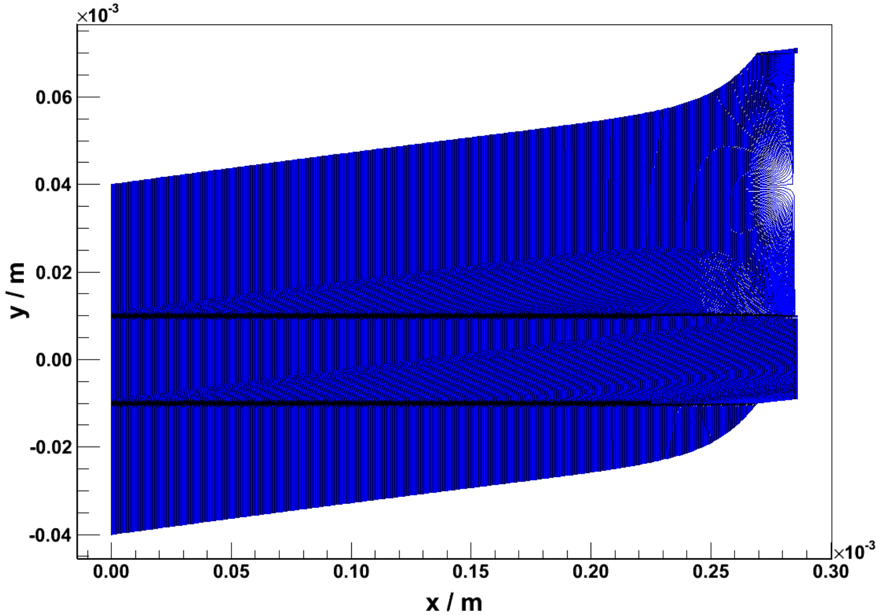
- Coss-talk
  - Share 5% of charge induced with neighbouring strips.
  - Normal Cross-Talk (NCT)

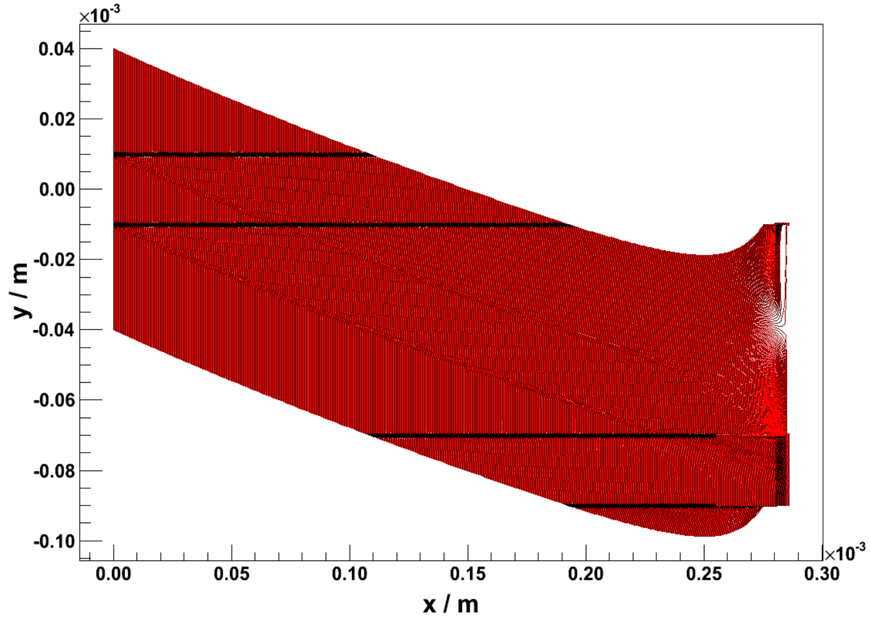
Cluster widths

- Repeat
  - 1000 steps ($-40\ \mu m \leq y < 40 \mu m$)
    - Only for Real field
  - 41 steps ($-6.0 \leq \phi \leq 14.0$)
  - 25 steps ($|\theta| \leq 60$)
    - Only for Real field
    - Uniform in η
- Slow
  - Use precomputed database and other tricks

Precomputed database

- Hole / Electron trajectories

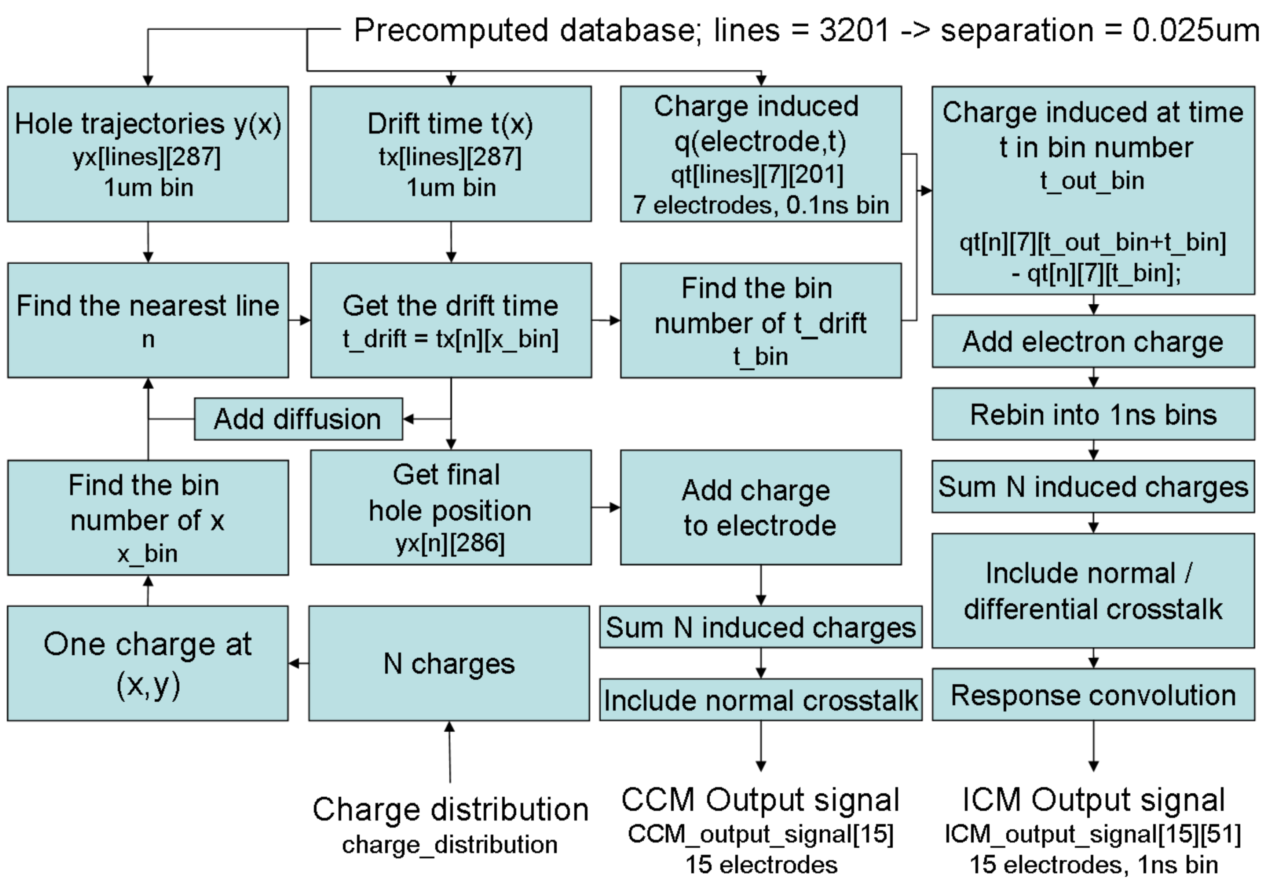




- Drift time vs. distance
- Electrode charge induced vs. time

Computational flowchart

- Good: Can easily apply hyper-realistic FEM field; 'fast'
- Bad: Problems with modeling diffusion
- Bad: Large memory, mainly due to 3200 lines.



Tricks

- Formula to parameterise many parameters
  - Charge deposited per micron (N)
  - Incident angle (θ)
  - Charge lost to backplate (C_bulk)
  - Changing SCT comparator threshold (Q = 1fC)

$$N_{effective} = \frac{N_0(1 - C_{bulk})}{\cos\theta},$$

$$N_{effective} = \propto \frac{1}{Q},$$

$$N_{effective} = \propto Q_{out}.$$

- Reinterprete same electrode output dataset
  - Fast
  - Can have systematic effects, but generally works well with enough samples

Lorentz angle (ϕ_L)

- Definition
  - Incident angle ϕ at which the average cluster width is a minimum
- Obtained by fitting a function to cluster width plots
  - (a $|\tan \phi - \tan \phi_L|$ + b)
    - Free parameters: a, b, ϕ_L.
    - Exact for mean field (Ignoring frontend).
  - Convolve with a gaussian for diffusion

Results

Temperature = -2 C

Magnetic Field = 2.0T

$V_{depletion}$ = 65V

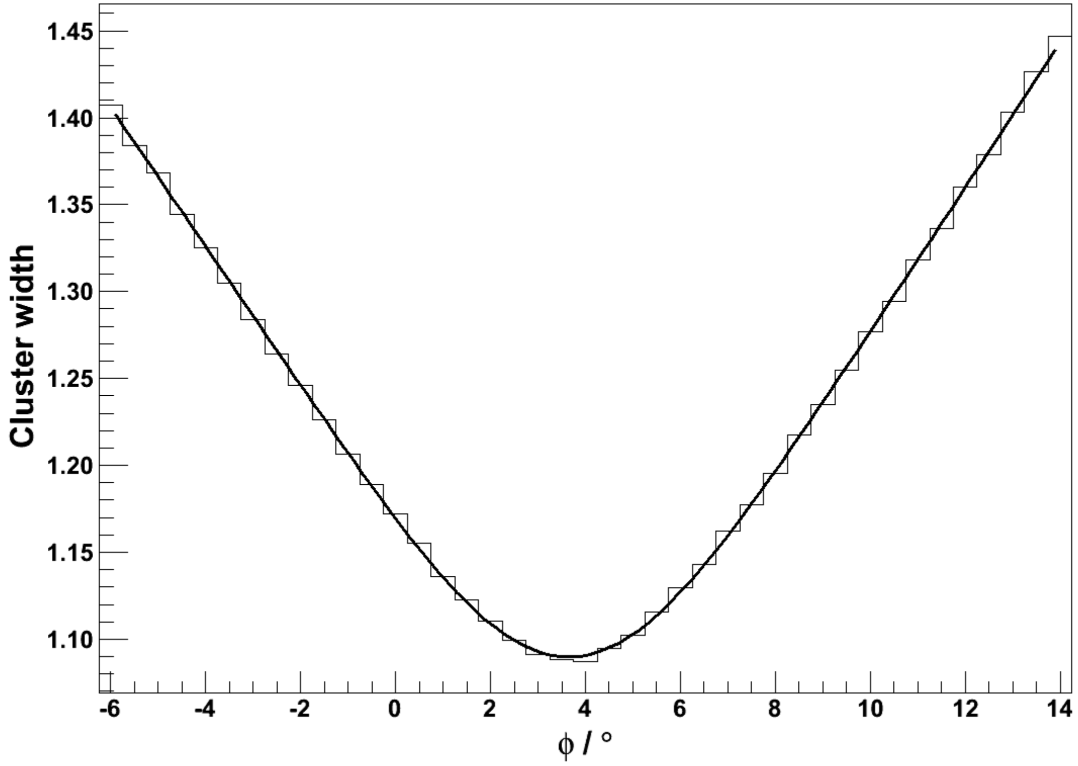
V_{bias} = 150V

Mean and Flat diode fields (CCM)

- Mean field: $\phi_L = 3.88 \quad 0.20$
- Flat diode field: $\phi_L = 3.89 \quad 0.22$
- Systematic errors only.
  - Uncertainty Mobility, Temperature, Magnetic Field, V
- Measured ϕ_L 6% greater ($\approx 1\sigma$ or $> \sigma$) than values obtained from these fields
  - Cosmics (Elias Coniavitis)
  - 7 TeV (Elisa Piccaro)

Real field (ICM)

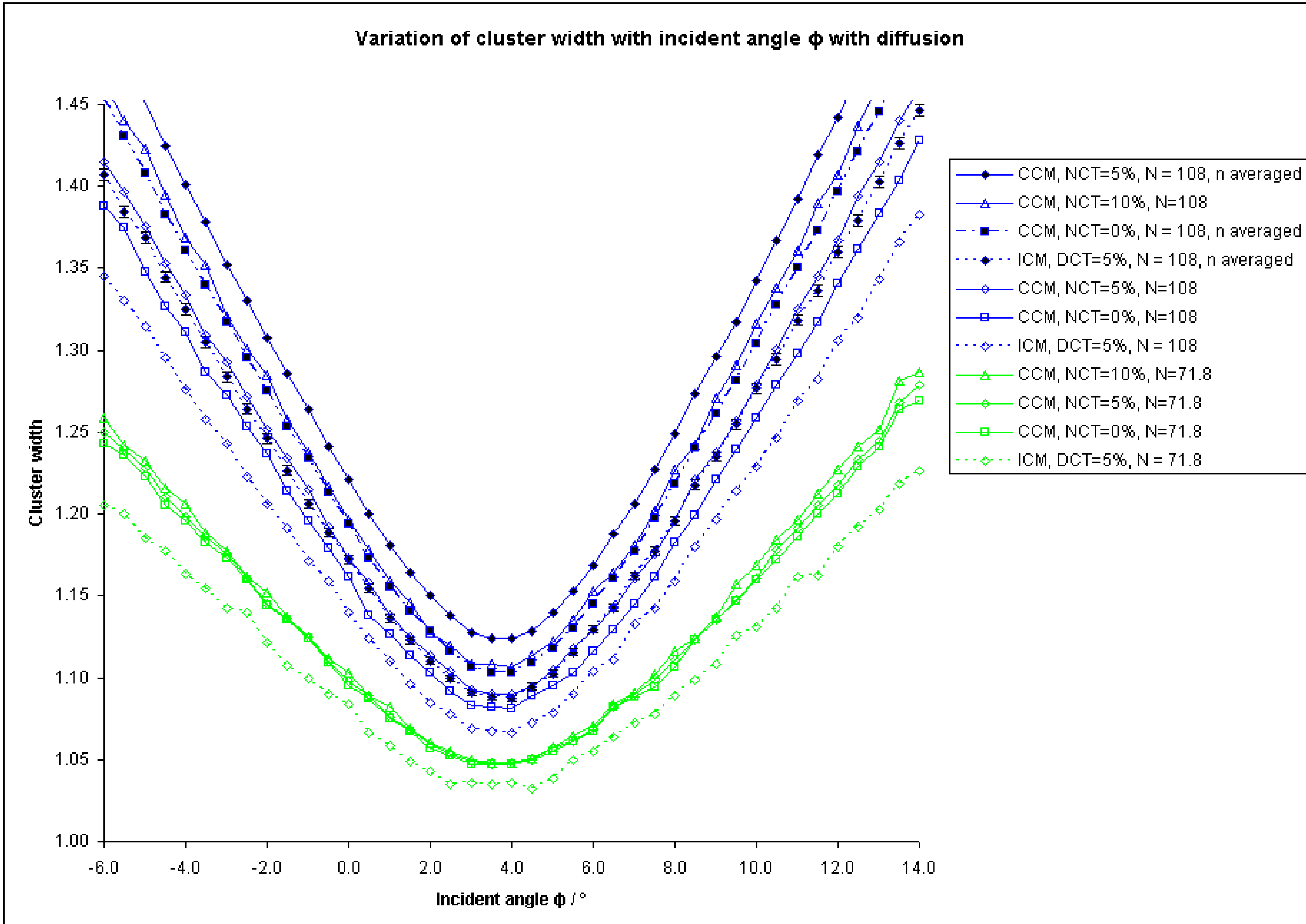
- ϕ_L = 3.66   0.02   (statistical error only)
  - Systematic error ~   0.20 .
  - Diffusion, crosstalk, Landau fluctuations, Electron-hole trajectories



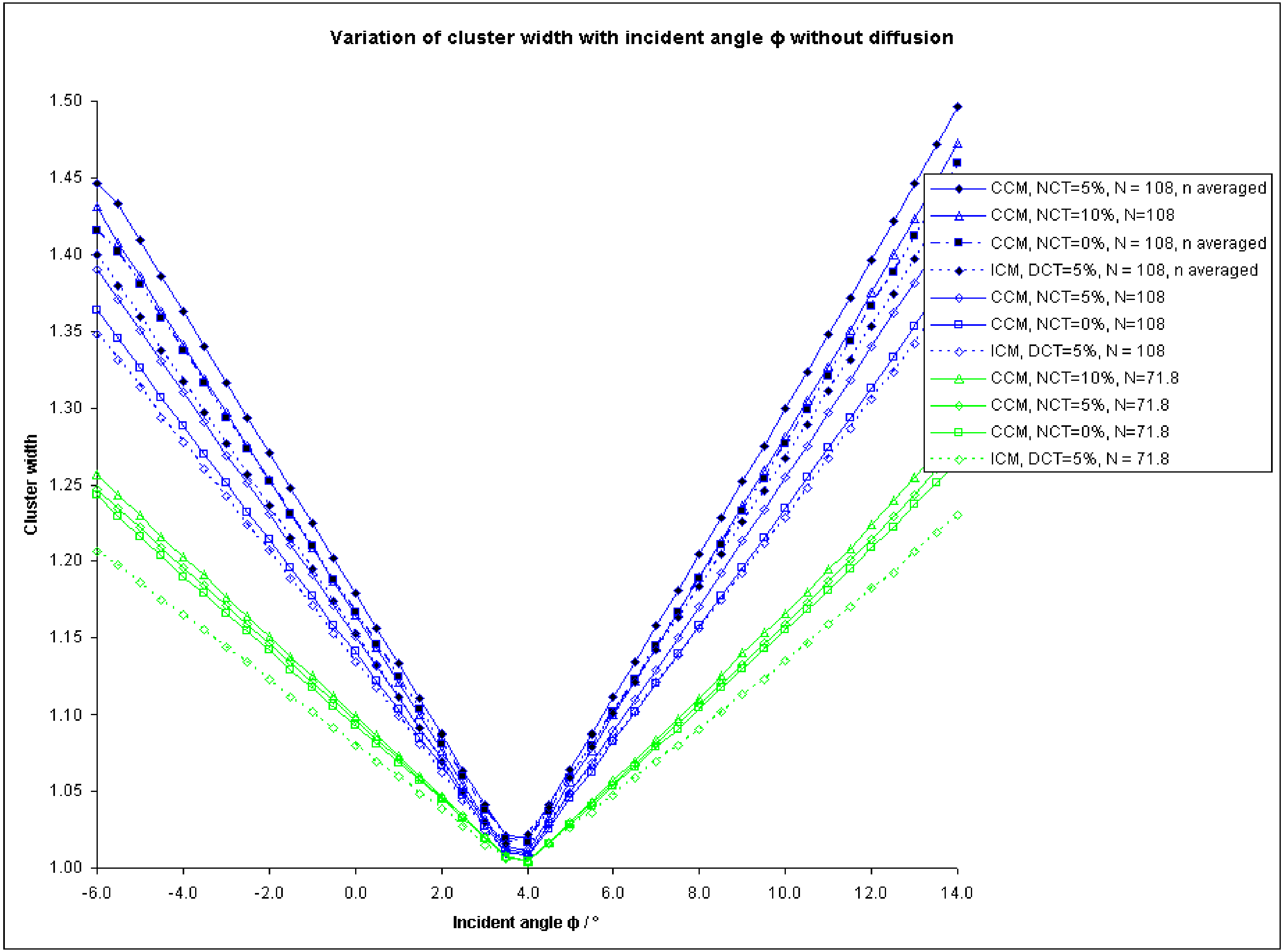
Sensivitity

- Is ϕ_L sensitive to model parameters?
  - Amount of crosstalk
  - Amount of charge deposited / lost
  - η
  - CCM vs. ICM
  - Diffusion vs. no diffusion

Some parameters



No diffusion

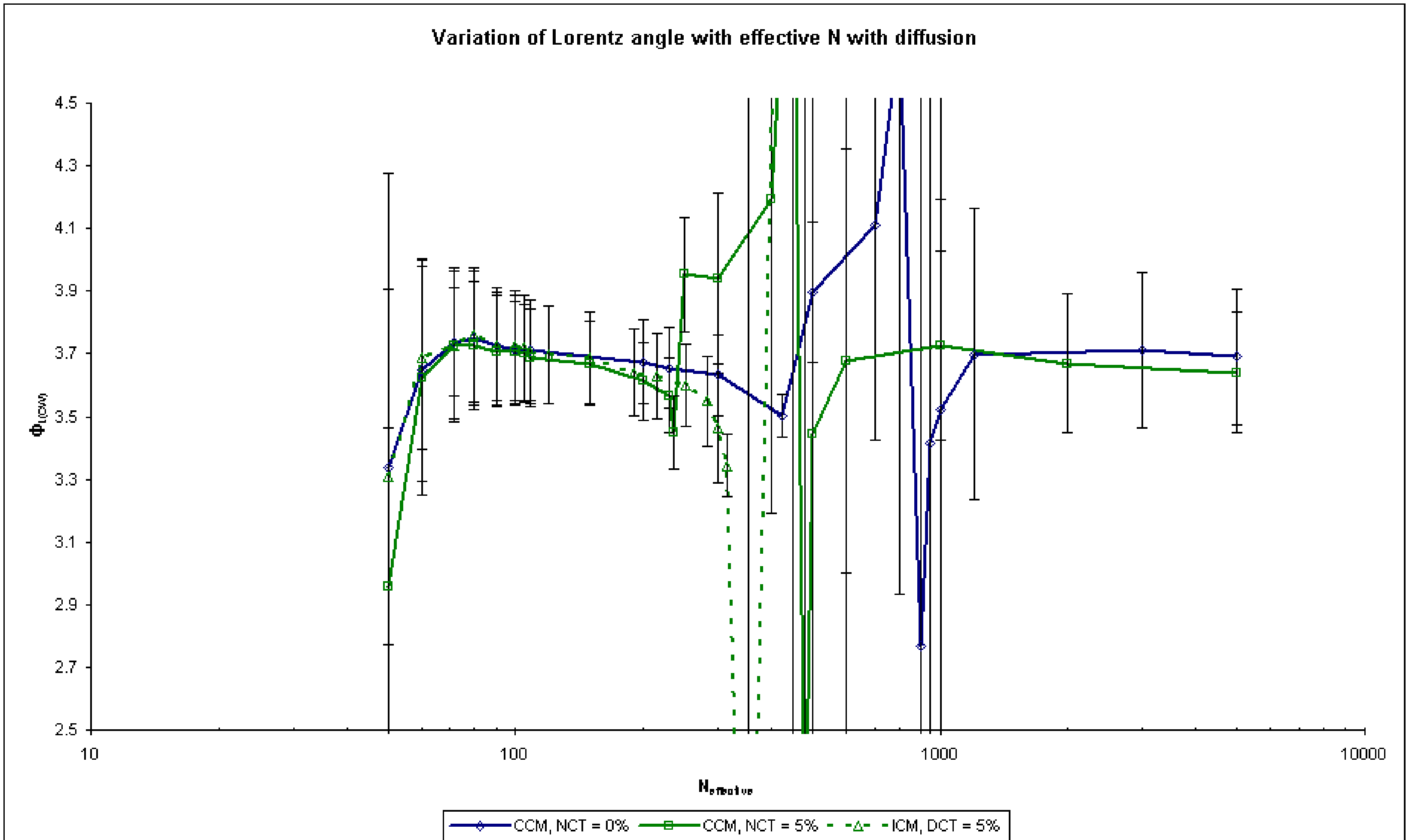


Is ϕ_L sensitive?

- Not really
- Variation of up to 3% from 3.66 .
- However, cluster sizes are sensitive
  - Especially at large ϕ.
  - Especially at large N_effective or θ

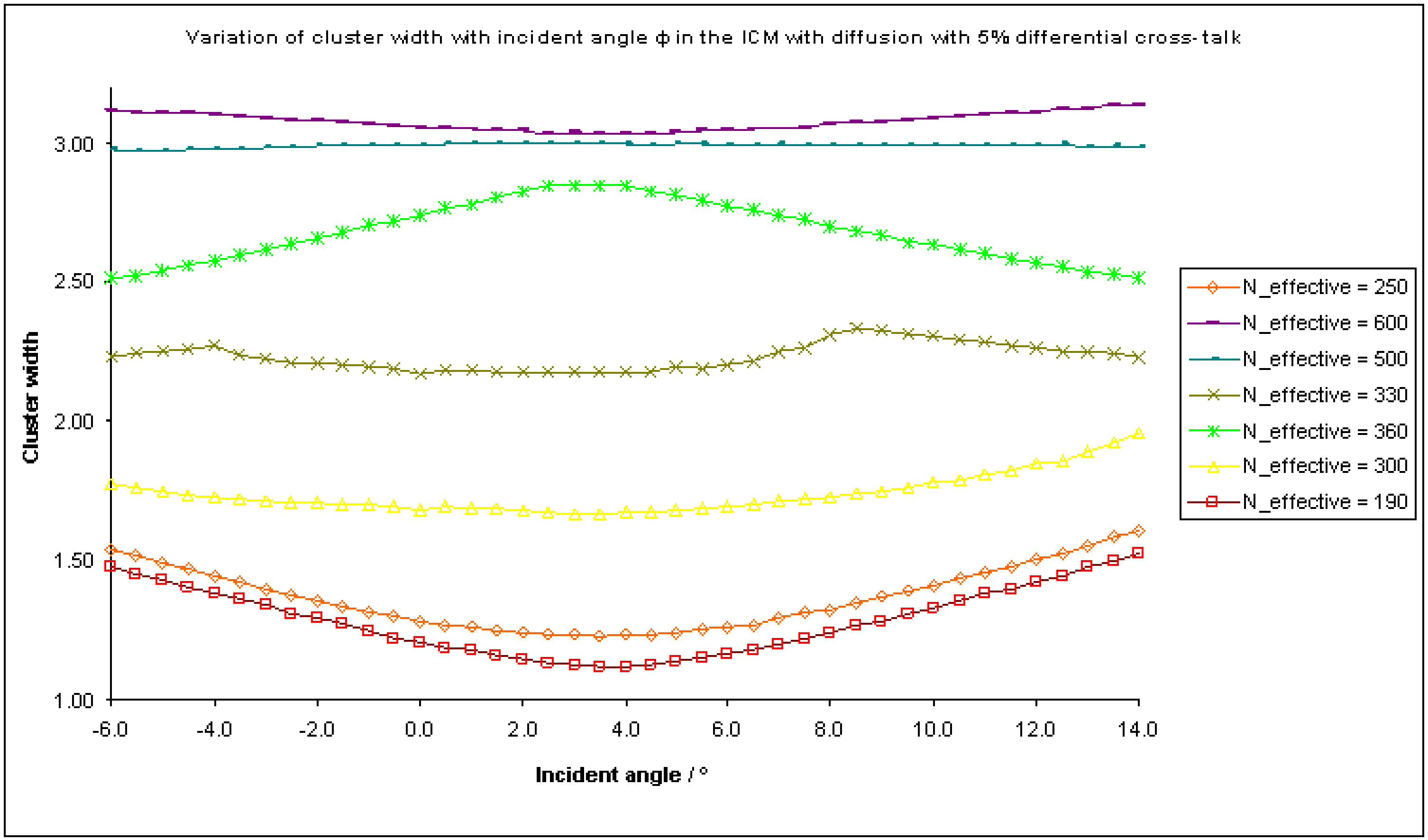
Plot of Lorentz angle vs N_effective

- Lorentz angle goes crazy for large N
  - Begins at ~θ=60



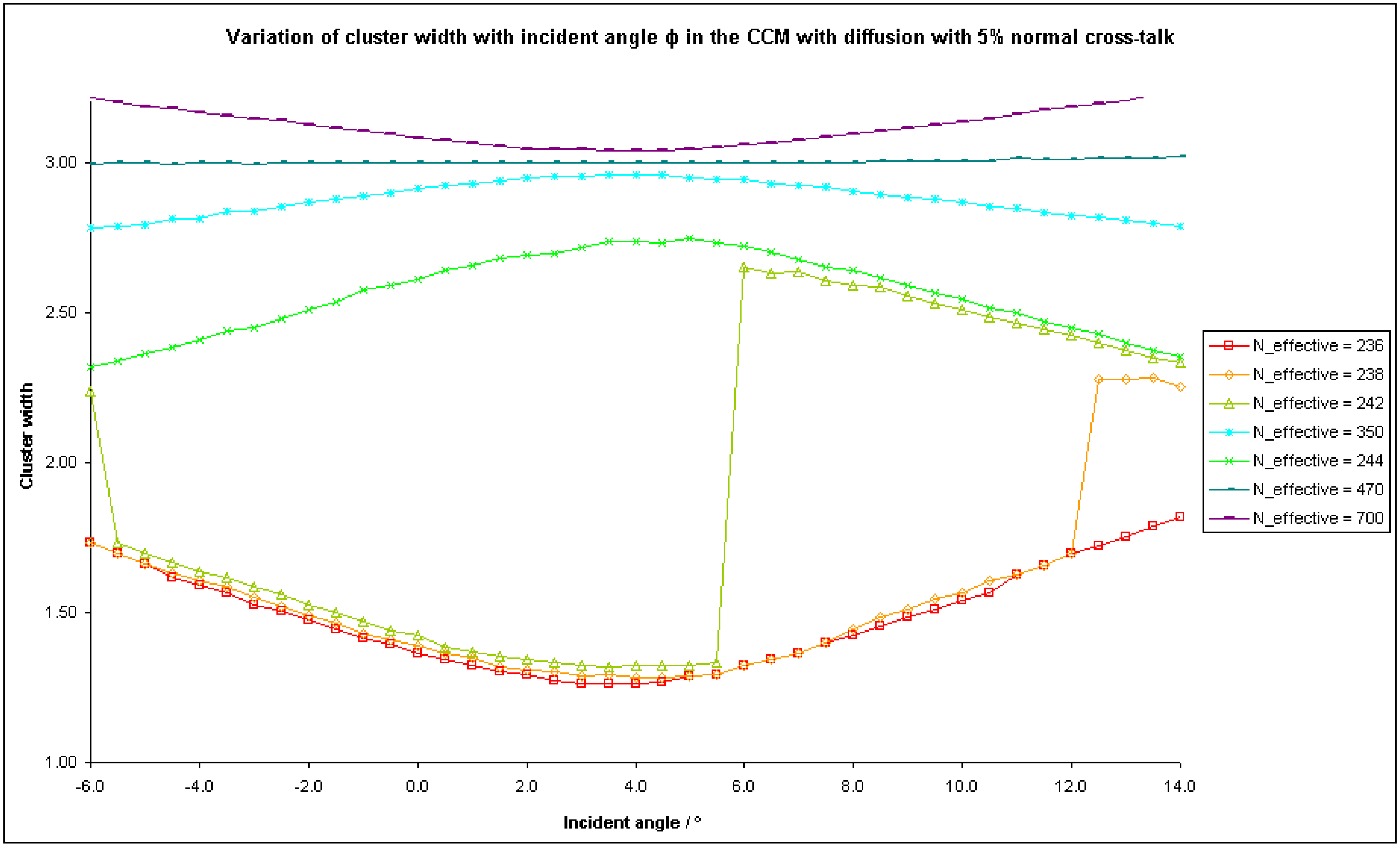
Cluster width inversion (ICM)

- Due to enough charge activating 3 electrodes simultaneously
- Flipping occurs between 190 ≤ N_effective ≤ 360



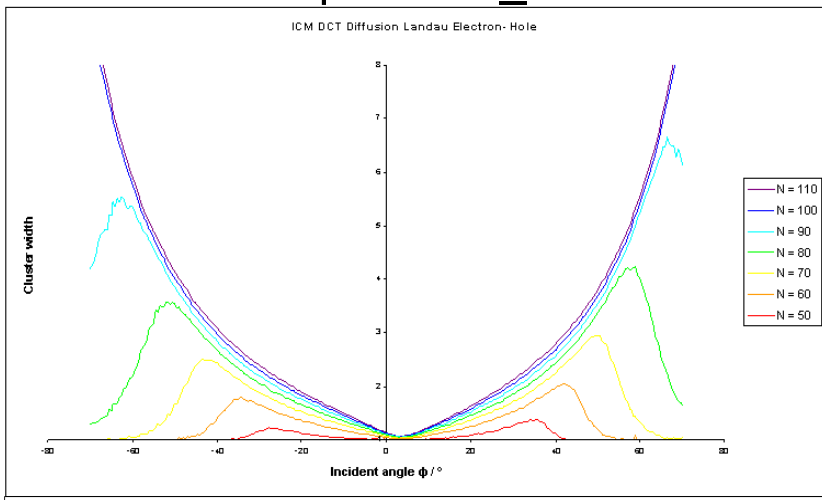
Cluster width inversion (CCM)

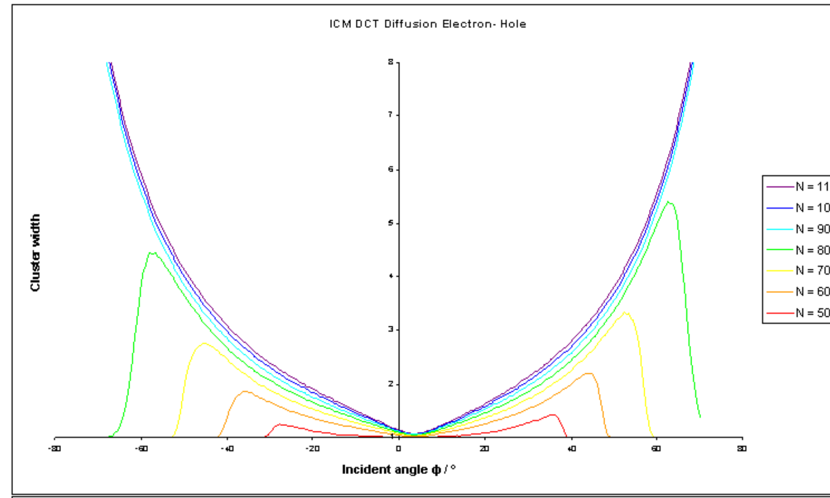
- Flipping occurs between 236 ≤ N_effective ≤ 244

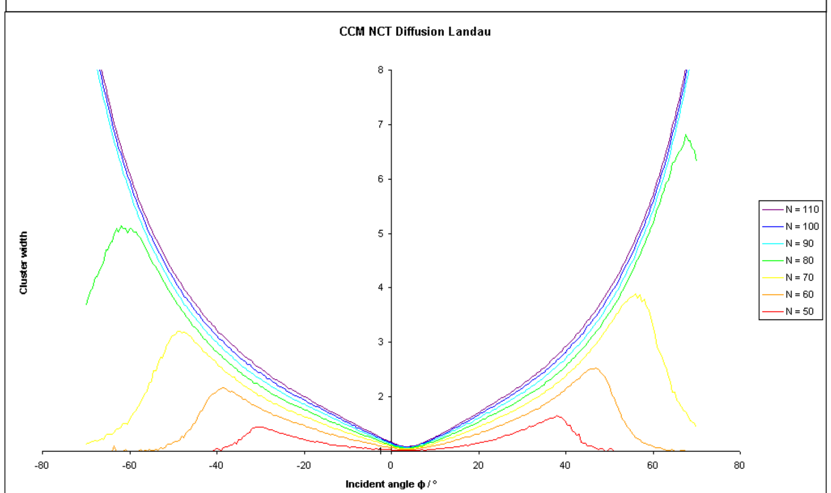


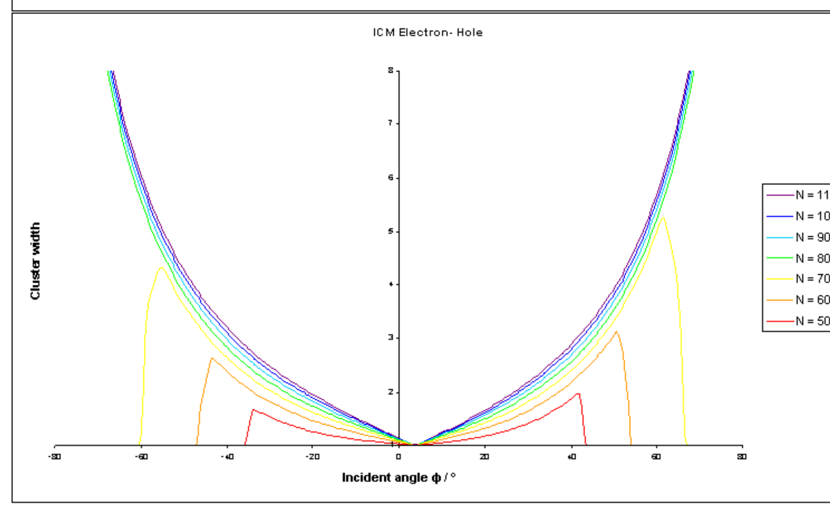
Plot of cluster widths at large ϕ

- Drop-off extremely sensitive to everything
  - Tuning this to experimental results will be challenging
  - No drop-off if N_effective is large









General trends

- Crosstalk increases cluster widths
- Diffusion increases cluster widths
- CCM increases cluster widths more than ICM
- N_effective increases cluster widths
- Landau fluctuations affect cluster widths negligibly for small ϕ
  - Large effect for large ϕ
- Considering electron-hole motion does not affect cluster widths
  - Not surprising – electrons well modeled with ~uniform current

General trends

- Lorentz angle most sensitive to
  - Electric field geometry
  - Mobility
- Lorentz angle reasonably sensitive to
  - N_effective, but upper bound ~ 3.73 @ N_effective = 80
- Lorentz angle not particularly sensitive to
  - Cross-talk
  - Diffusion
  - Landau fluctuation

End

Questions

Additional slides