

Sensor anomalies Working Group. (The French side)

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LSST-France in Paris (March 2017)



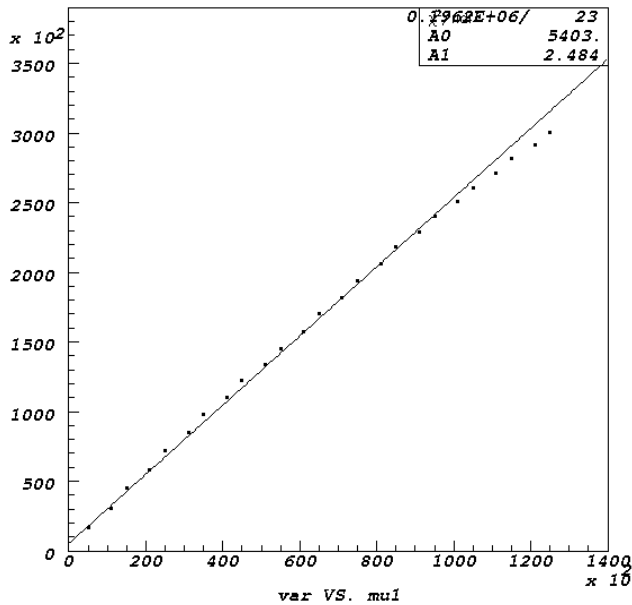
Pierre Astier

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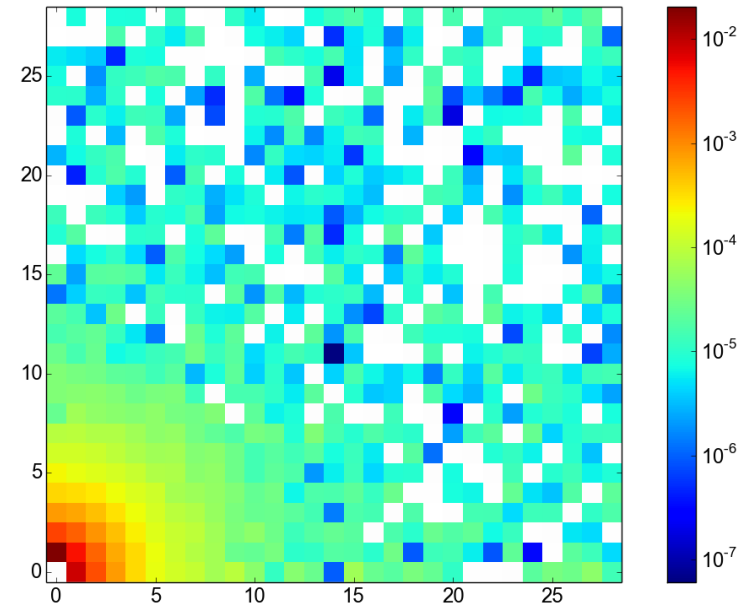
SAWG : Sensor Anomalies WG

- A DESC working group that complements “The Project” regarding sensors.
- Mostly working on the correction of sensor-induced image distortions:
 - Static distortions (side effects, tree rings)
 - Dynamic distortions (the “brighter-fatter” effect)
- These effects are not addressed in the sensor acceptance plan.
- The WG is now well integrated into the project given the pressure of construction.

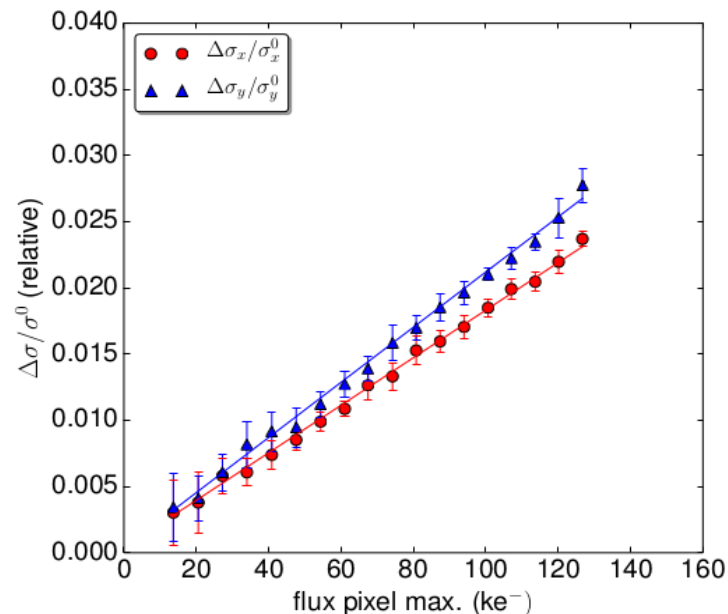
The brighter-fatter effect



Statistical
correlations
in flat fields

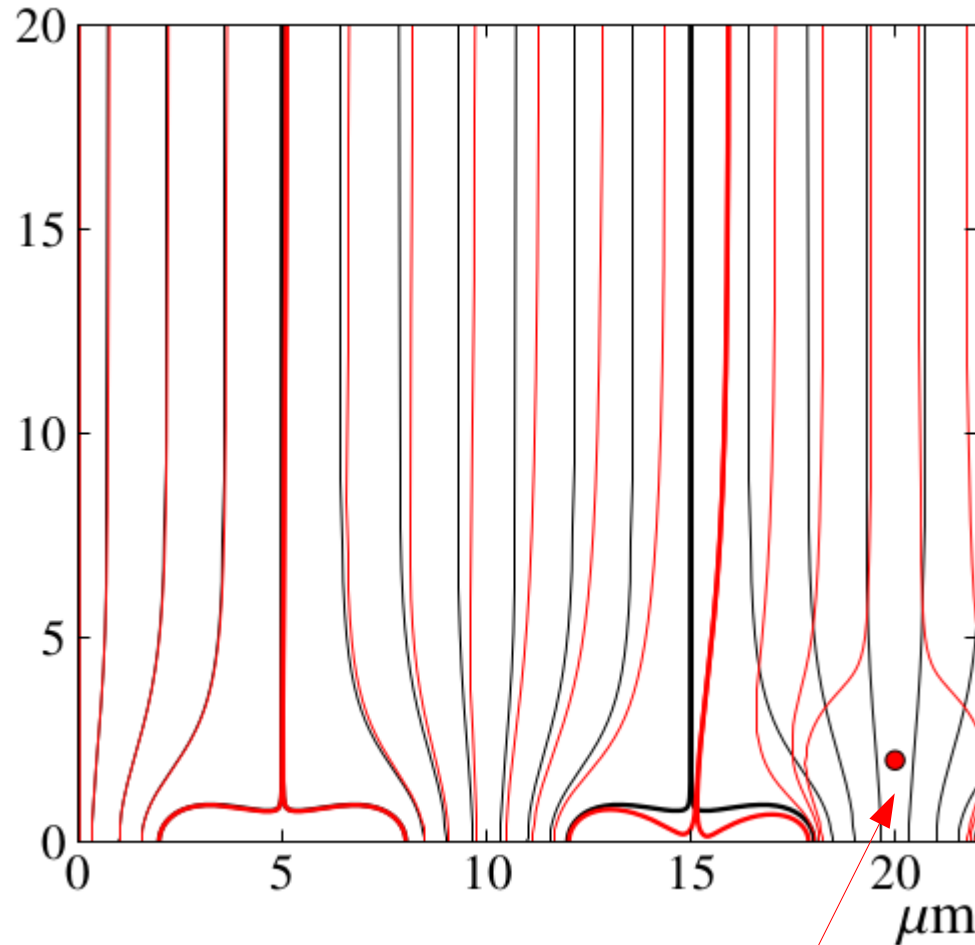


The variance of
flatfields does not
scale with their
average



The size of spots
increases with their
flux, too rapidly
to be ignored
when estimating PSF

The (now) adopted paradigm



Charge 50 ke

Charges representing the image, stored in the CCD, contribute a deflecting electric field.

It causes:

- A non-linearity of response
- A smoothing of the collected image

Guyonnet+ (2015)

SAWG's program

- The static effects (mostly tree-rings and deflections on the edge) are easy to characterize and correct.
 - OK, but not fully done yet.
 - Tree rings may be behind us.
- Brighter-fatter is more difficult:
 - Figuring out electrostatics is difficult because we do not know all boundary conditions.
 - A general model (ignoring Coulomb's law) has more parameters than observables.
 - Constraints are derived from correlations in flats.

The Paris CCD test stand

- Flats :
 - Lamp, monochromator, fiber, integrating sphere, monitoring photodiode (aka CLAP), LSST electronics read out.
 - Saturation reached in ~ 10 s.
- Patterns :
 - Transparent patterns (e.g. Ronchi stripes) can be imaged through a (motorized) lens
- Can acquire ~ 3 images per minute.
- We have been studying an E2V sensor, with excellent cosmetics, since ~ 8 months.

French contributions

- All contributions to SAWG come from labs which run a test stand.
- Same for France: contributions to SAWG come from Paris.
- However, anybody willing to challenge the current paradigm is welcome. We'll do our best to coordinate !
- Currently, we concentrate on improving the method to handle the brighter-fatter effect.

Cracking the BF effect: three strategies (so far)

All methods derive a model for pixel boundary displacements from correlations in flats

- Minimal: assume a mild continuity of electrostatic effects as a function of distance and transform correlations into boundary shifts.
 - Guyonnet+, adopted by DES & HSC
- Cook up a full electrostatic model from correlations and read the boundary shifts from the model.
 - Craig Lage & Co, UC Davis
- Identify the electric field parameters that determine for boundary shifts and fit them.

Analysis of a set of flats

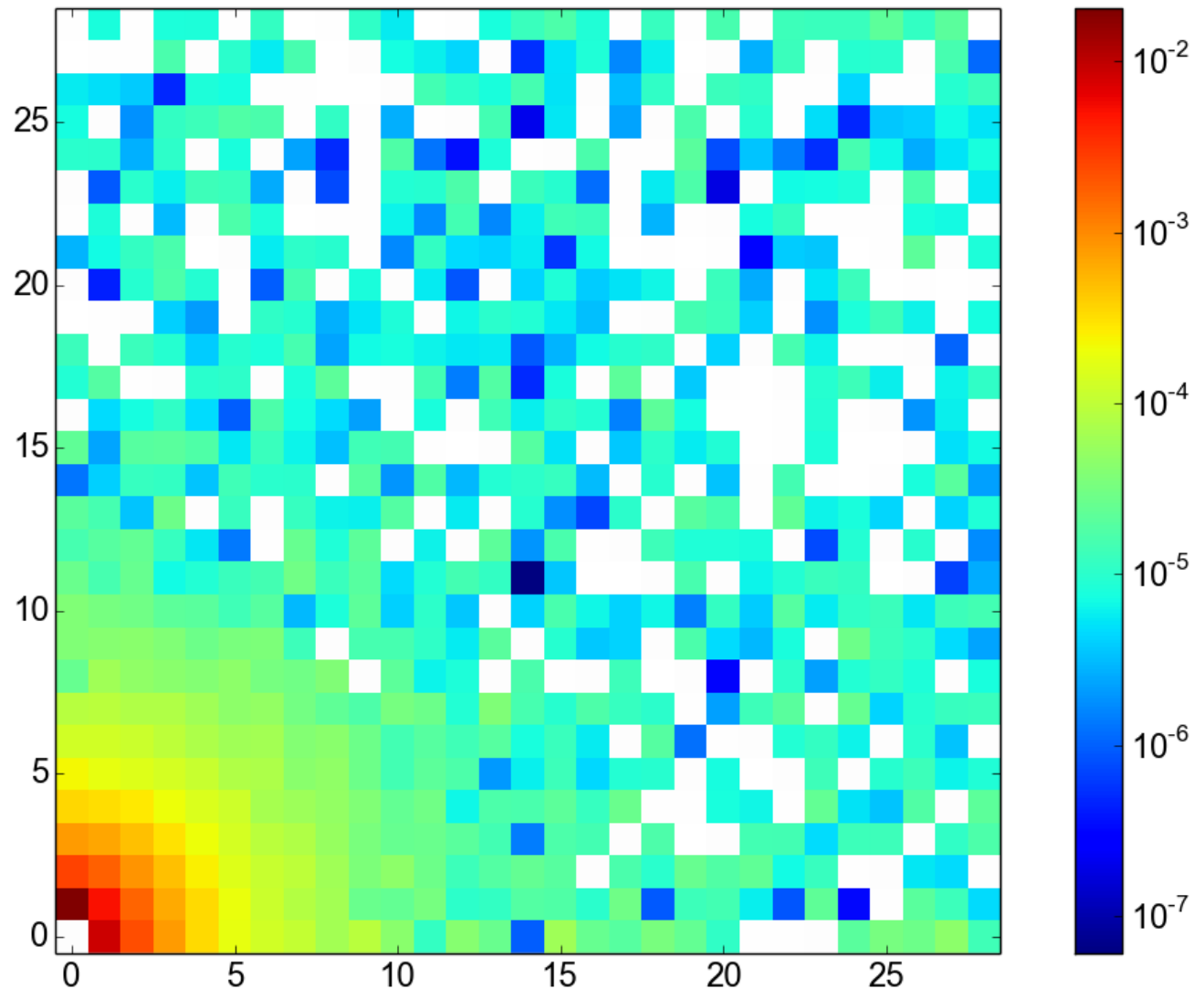
- This is meant to measure correlations. We routinely acquire sequences of 500 flat pairs
- Such a sequence allows one to measure correlations down to 10^{-5} .
- Provided the setup is stable enough.
- It is!

Measured correlations at ~ 60 ke/pix

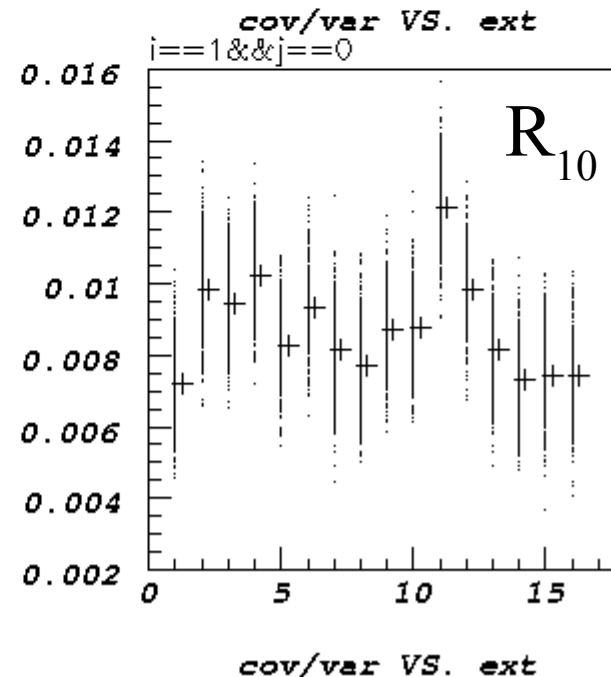
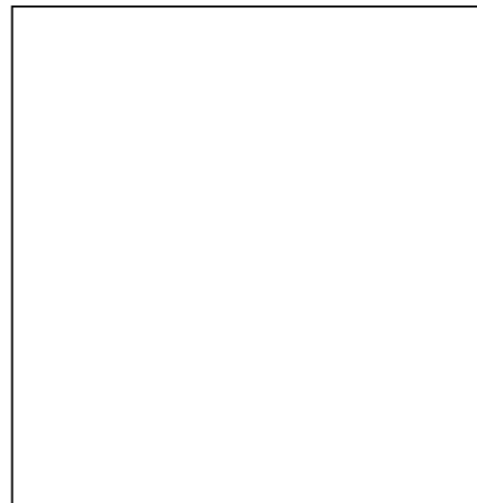
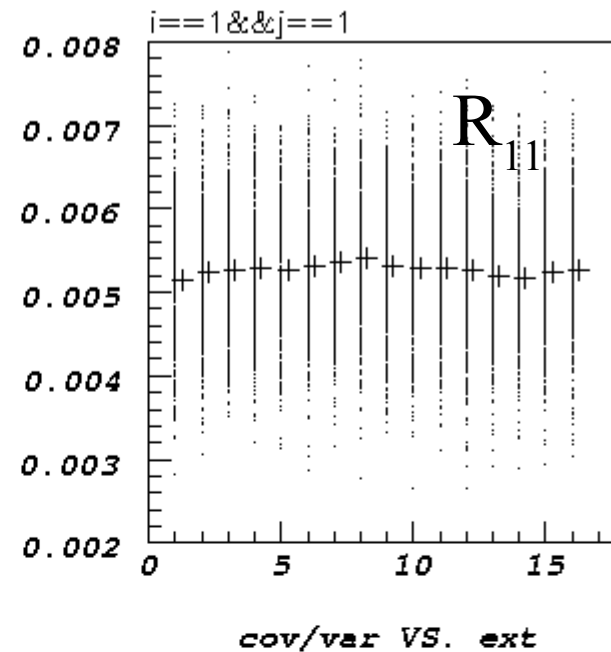
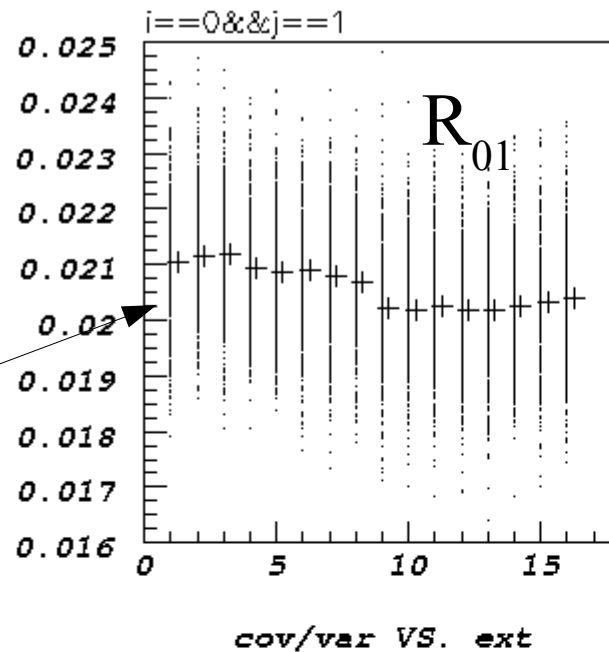
Correlations become rapidly isotropic

Maybe some positive offset visible at large distance

~ 100 correlations measured at > 3 sigma



Nearest neighbors vs CCD channel



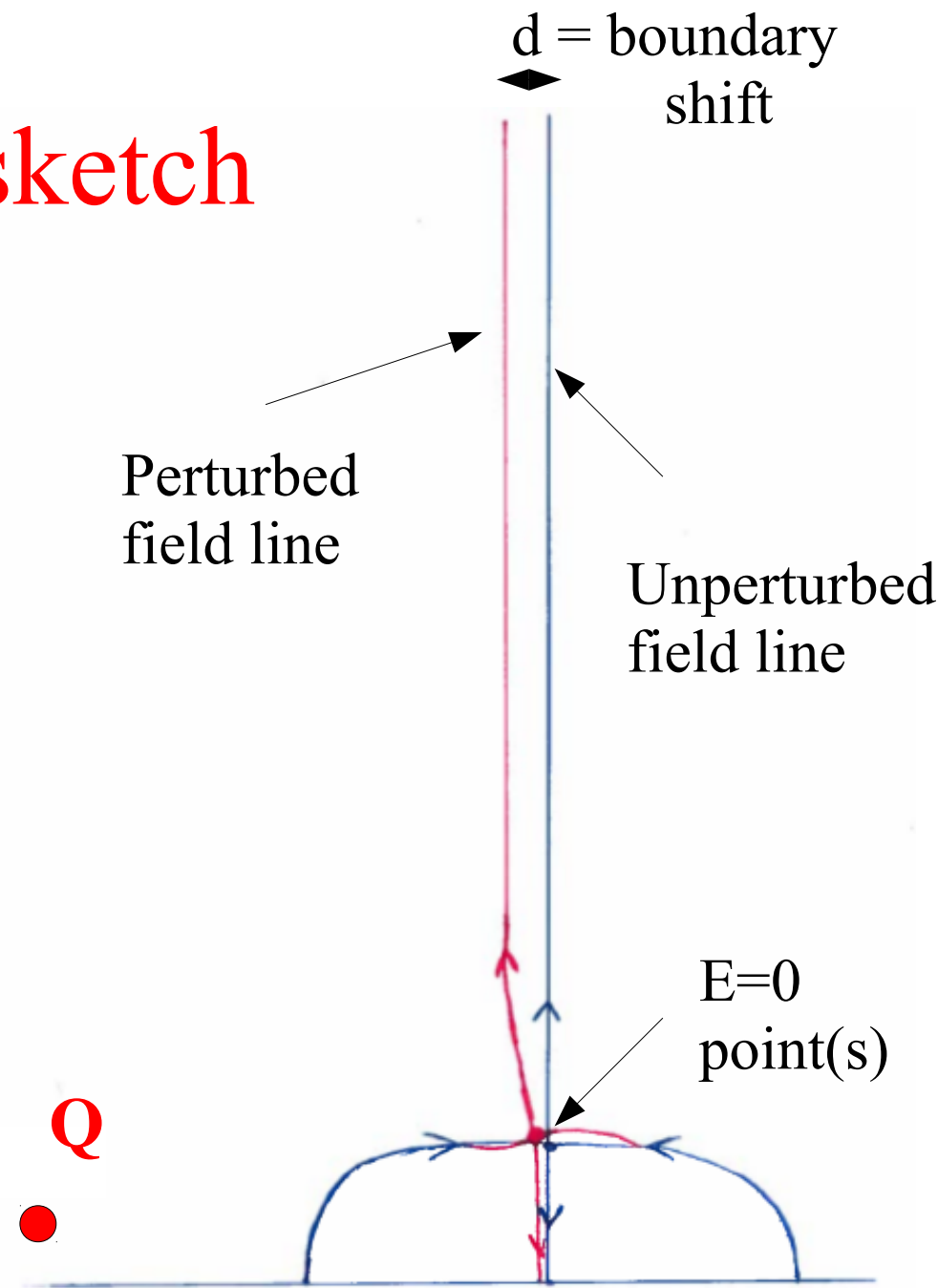
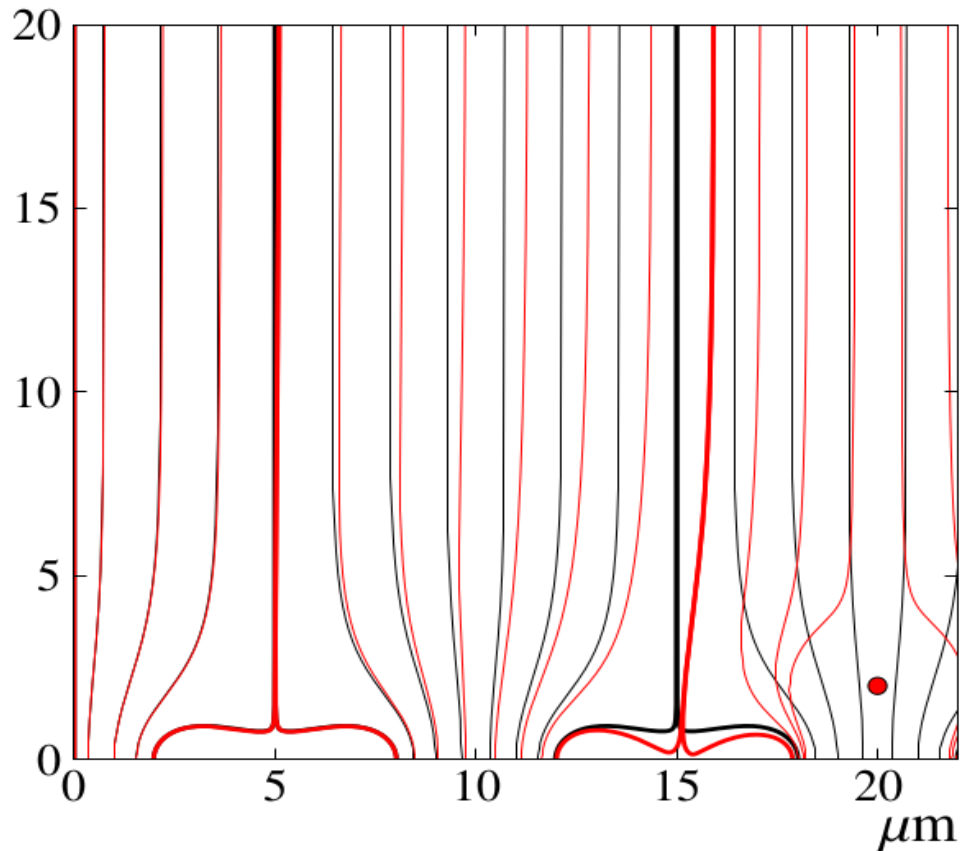
Top vs bottom
difference.
Induced by
parallel shifts ?
E2V specific ?
~5% though

Huge spread,
not due to
a channel
dependent
offset.

From correlations to pixel boundary shifts

- Modeling the boundary shifts is required in order to put the charges back where they belong.
- For N measured correlations, there are $\sim 2*N$ boundary shifts. Too bad.
- We have to add extra information, e.g:
 - Smoothing (Guyonnet+, Gruen +, ...)
 - Full electrostatic modeling (Laige+, Rasmussen+, ...)
 - Simplified electrostatic modeling

Electrostatic sketch



4

$$\mathbf{E} = \mathbf{E}_0 + \mathbf{E}_Q$$

$$\int \mathbf{E} \cdot \hat{\mathbf{n}} dl \quad ?$$

1

3

- 1) is a field line: 0
- 2) is almost a field line and very short (\rightarrow order 2 of perturbations)
- 3) only \mathbf{E}_Q because it is a field line
For \mathbf{E}_0
- 4) $d^* \mathbf{E}_{\text{drift}}$

Q

2

$$d \times E_{\text{drift}} + \int_{\textcircled{3}} \mathbf{E}_Q \cdot \hat{\mathbf{n}} dl = \Sigma \rho_S / \epsilon$$

Area of the contour

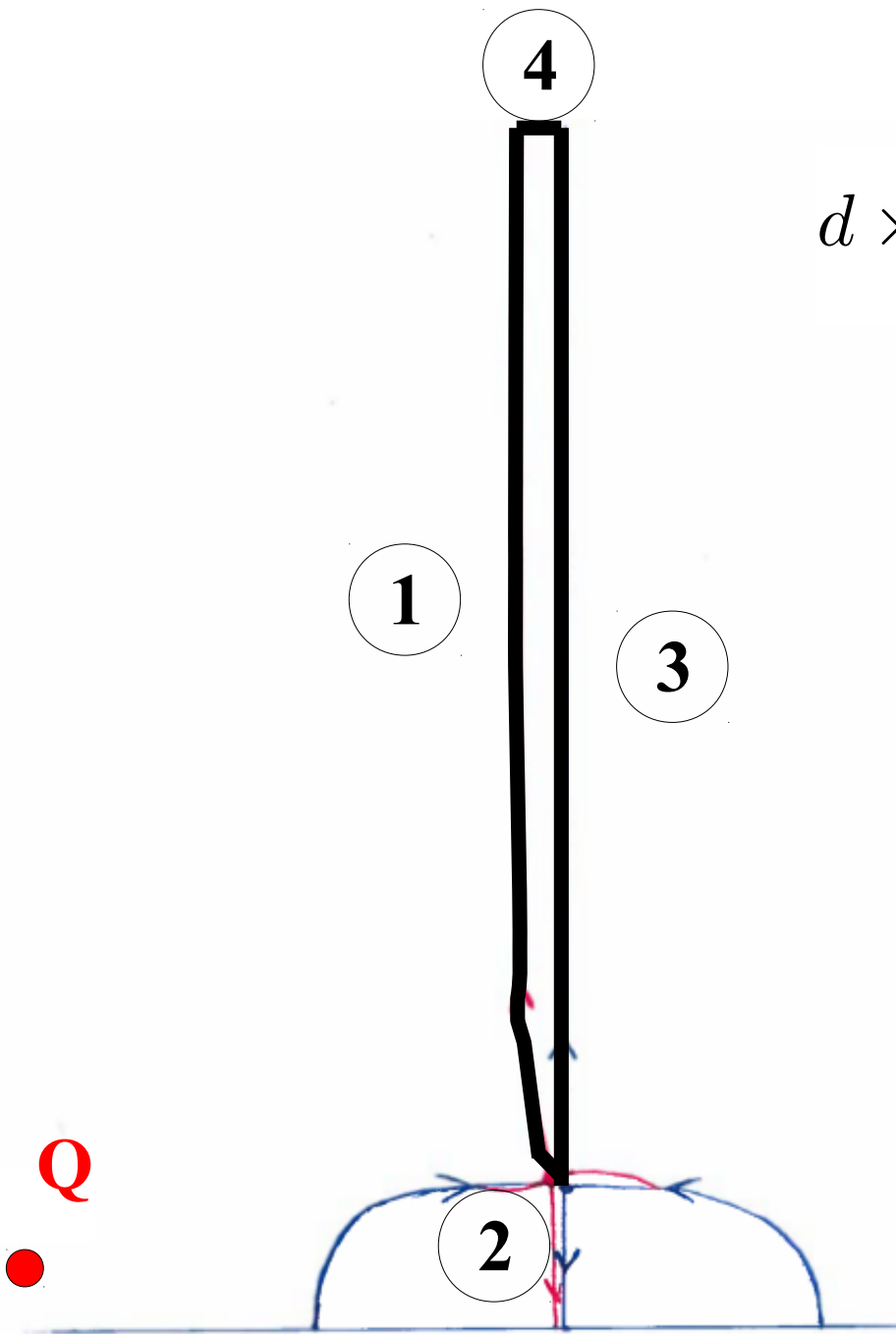
Charge density

$$d \times E_{drift} + \int_{\textcircled{3}} \mathbf{E}_Q \cdot \hat{\mathbf{n}} dl = \Sigma \rho_S / \epsilon$$

$$\Sigma \propto d$$

$$d \propto \int_{\textcircled{3}} \mathbf{E}_Q \cdot \hat{\mathbf{n}} dl$$

The boundary shift scales as the integral of the perturbing field over the unperturbed trajectory.
To first order !



What are the parameters ?

$$d \propto \int_{z_{vertex}}^{z_{conversion}} E_Q(z)^T dz$$

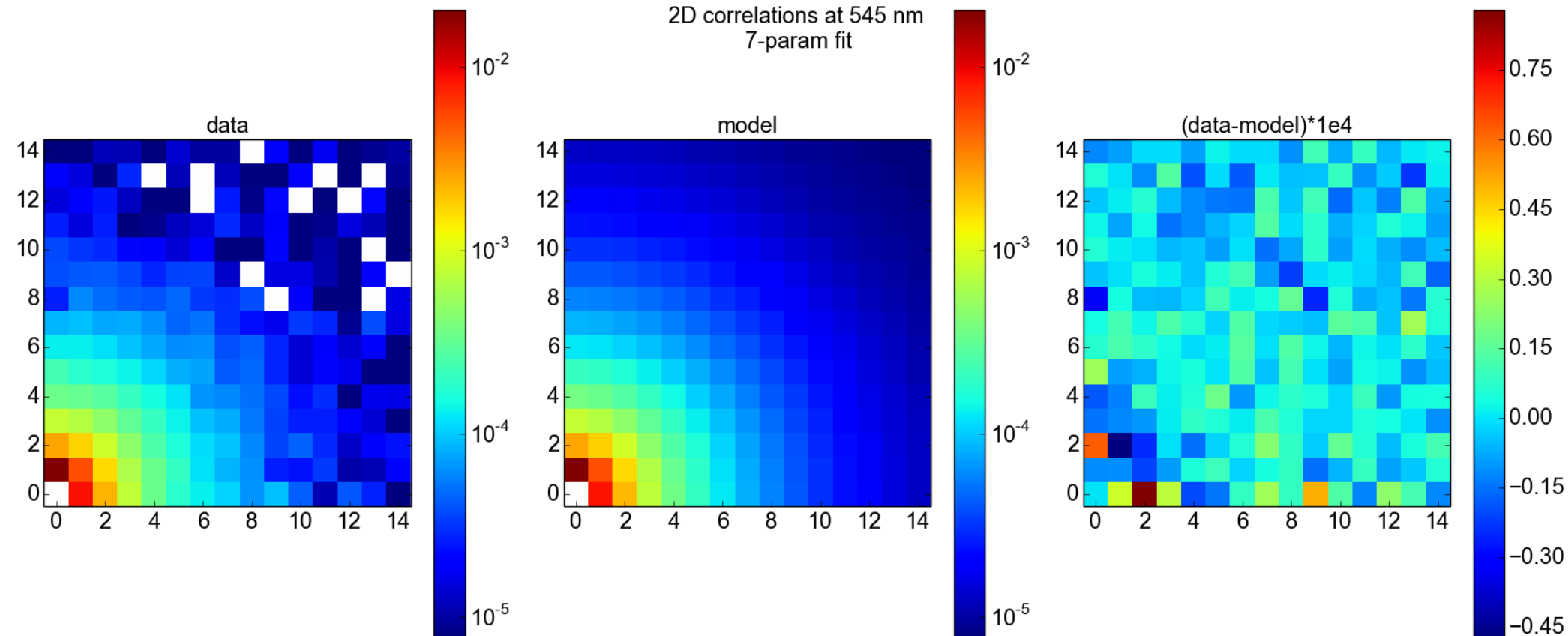
Z_{vertex} depends on the chip design, voltages,
and is different for serial and parallel boundaries

E_Q depends on the location (and distribution) of the
“aggressor” charge, e.g. the charge altitude z_q

The normalization depends on voltages, z_{conv} and ρ

$Z_{conversion}$ depends on wavelength. From there on, we set
it at the top of the sensor because we are studying 545 nm data

7-parameter fit



The fit is almost acceptable: $\chi^2 = \sim 2 N_{\text{dof}}$
All residuals below 10^{-4} .

Looking for next-to-leading-order effects in BF

- We assume that pixel boundary shifts are proportional to the stored charge. Can we challenge the assumption?
- Under this assumption, we have:

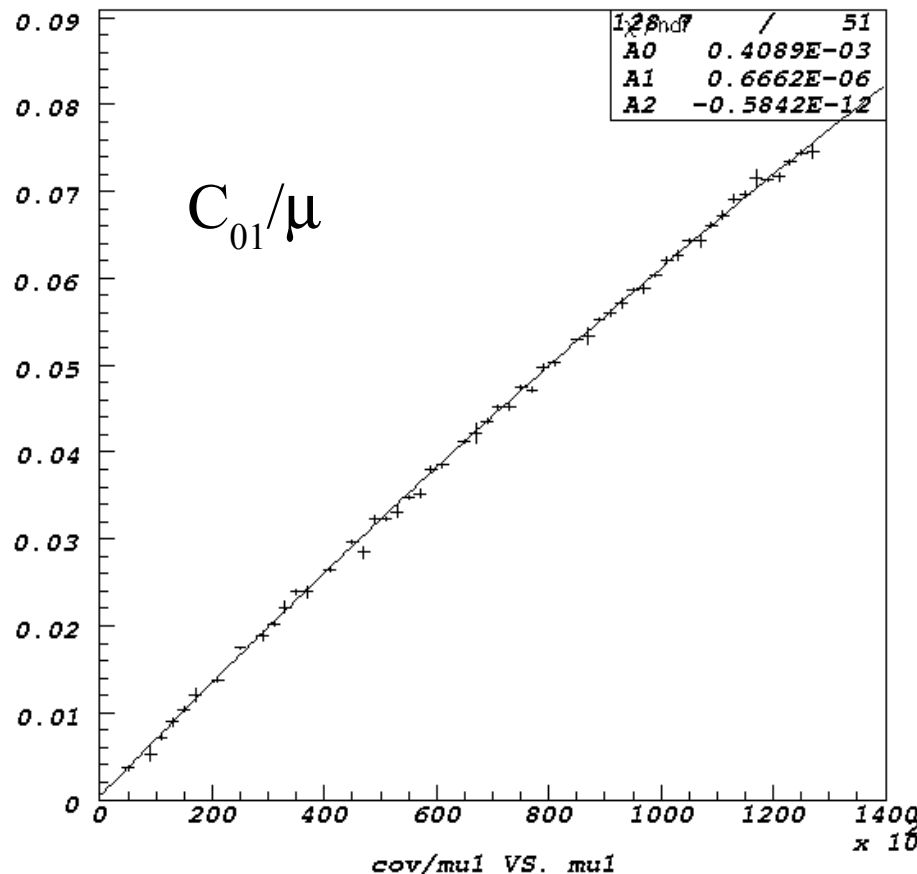
Covariance $C_{ij}(\mu) = k_{ij}\mu^2 \left[1 - \frac{2}{3}k\mu + \dots \right]$

Variance $C_{00}(\mu) = \mu \left[1 - k\mu + \frac{2}{3}(k\mu)^2 + \dots \right]$

gain=1

One test for NLO effects

From $C_{00}(\mu)$, we find $k \simeq 2.2 \cdot 10^{-6}$ (per electron)



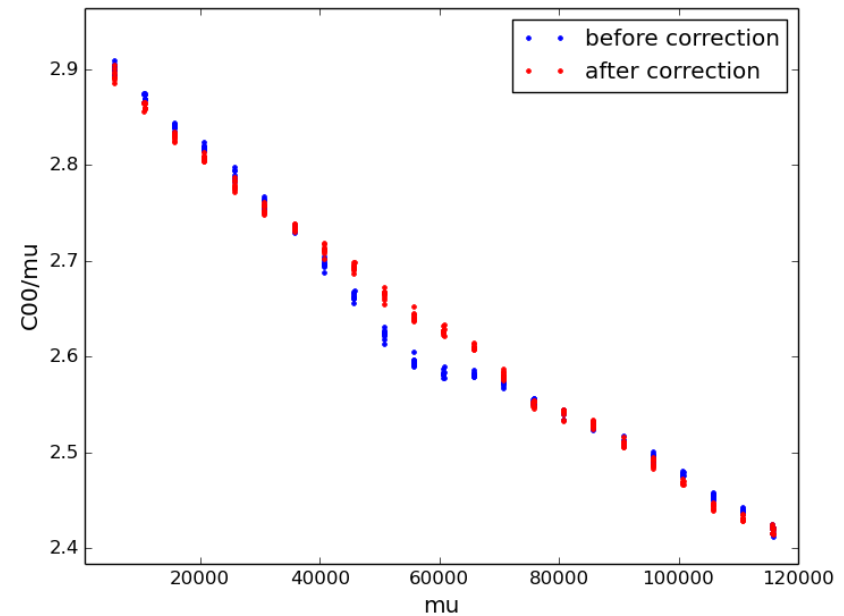
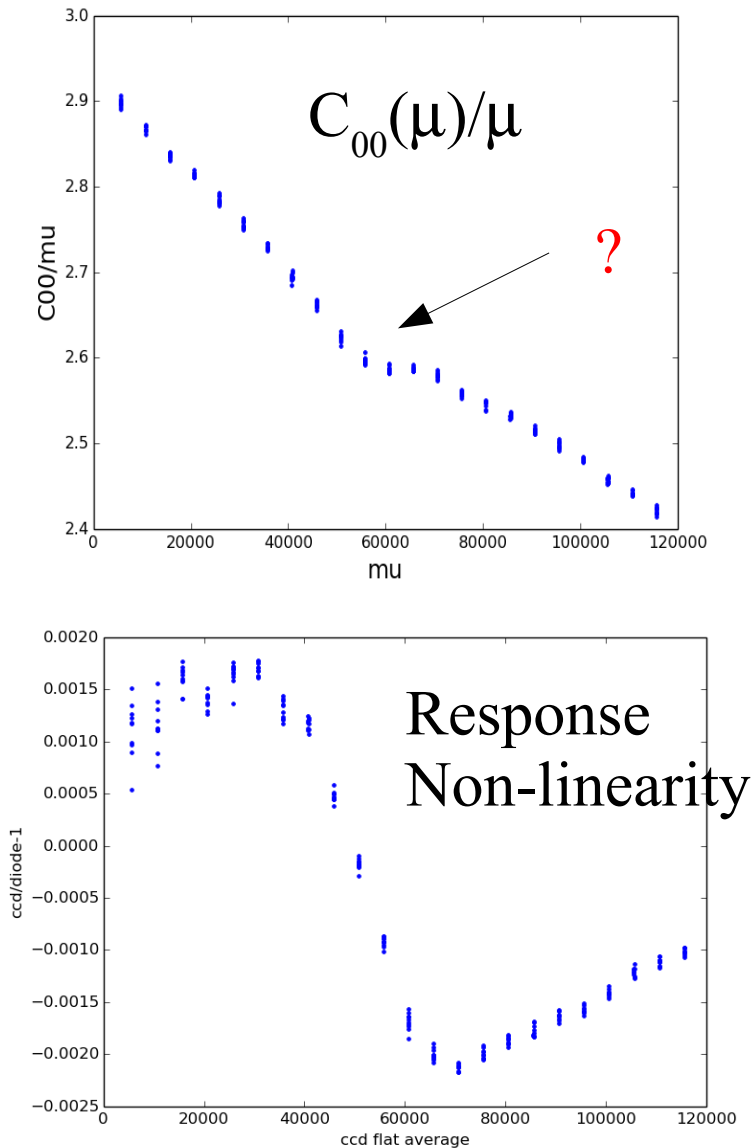
Curvature is clearly visible
and yields $k = 1.9 \cdot 10^{-6}$

However, uncertainties
are sizable...

Statistics: 500 flats at
20 different intensities.

Let us have a closer look

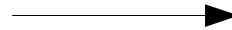
Without surprise, the differential non-linearity alters the measured variance:



We have to accurately measure non-linearity before concluding anything from $C_{00}(\mu)$ and $C_{ij}(\mu)$

The practical test

Measurement
of correlations



Model



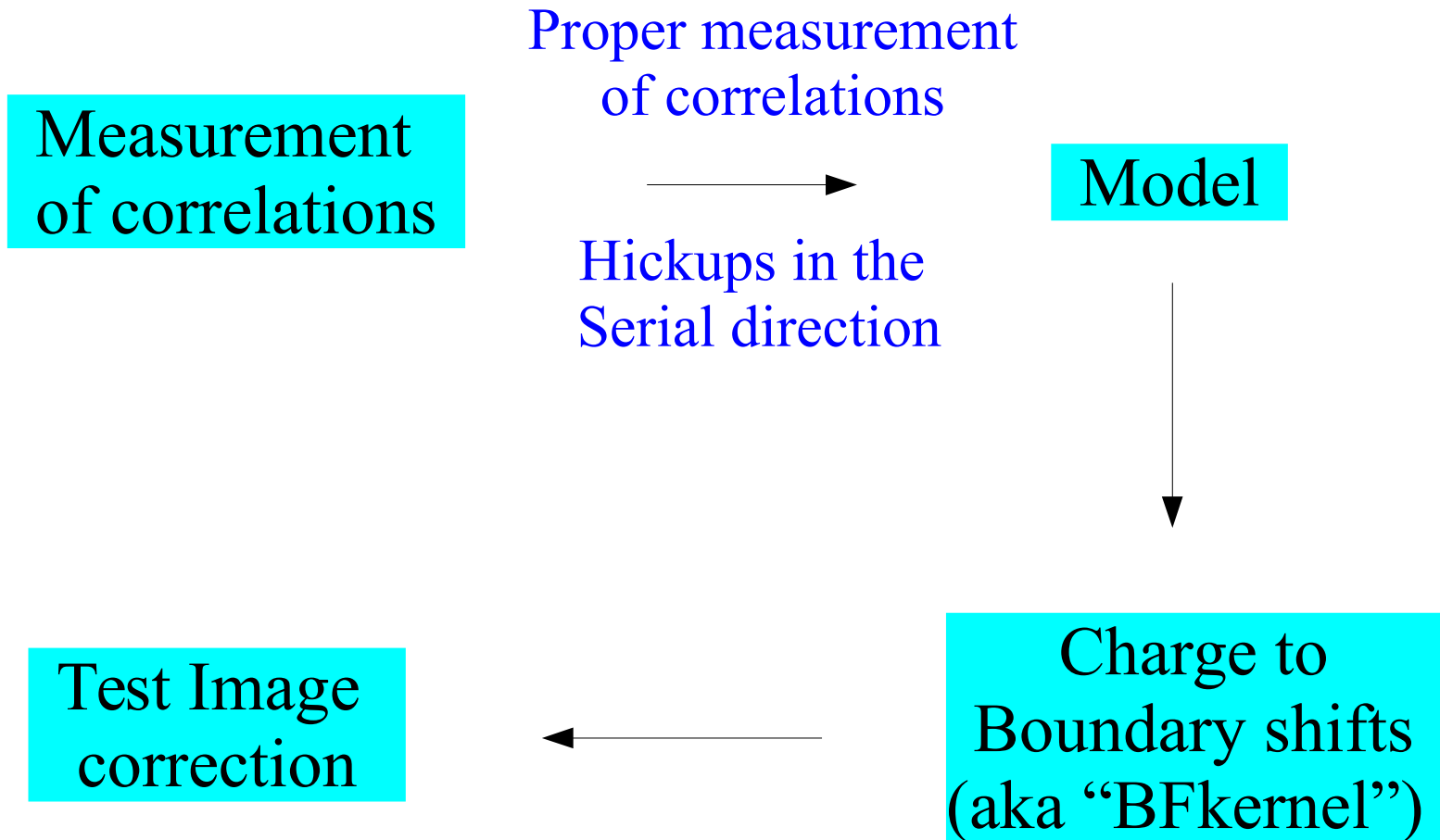
Test Image
correction



Charge to
Boundary shifts
(aka “BFkernel”)

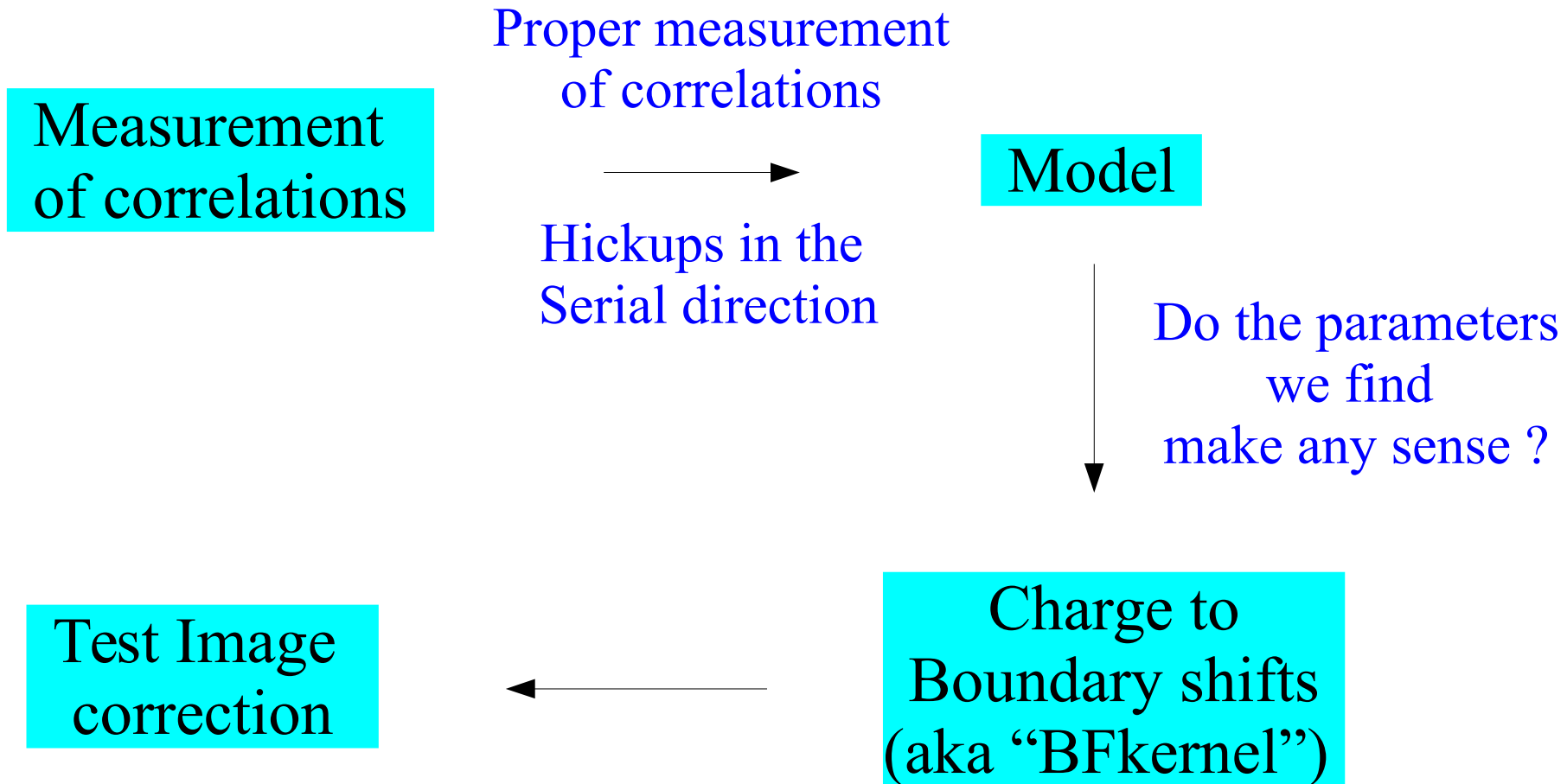
Is linearity
restored ?

The practical test



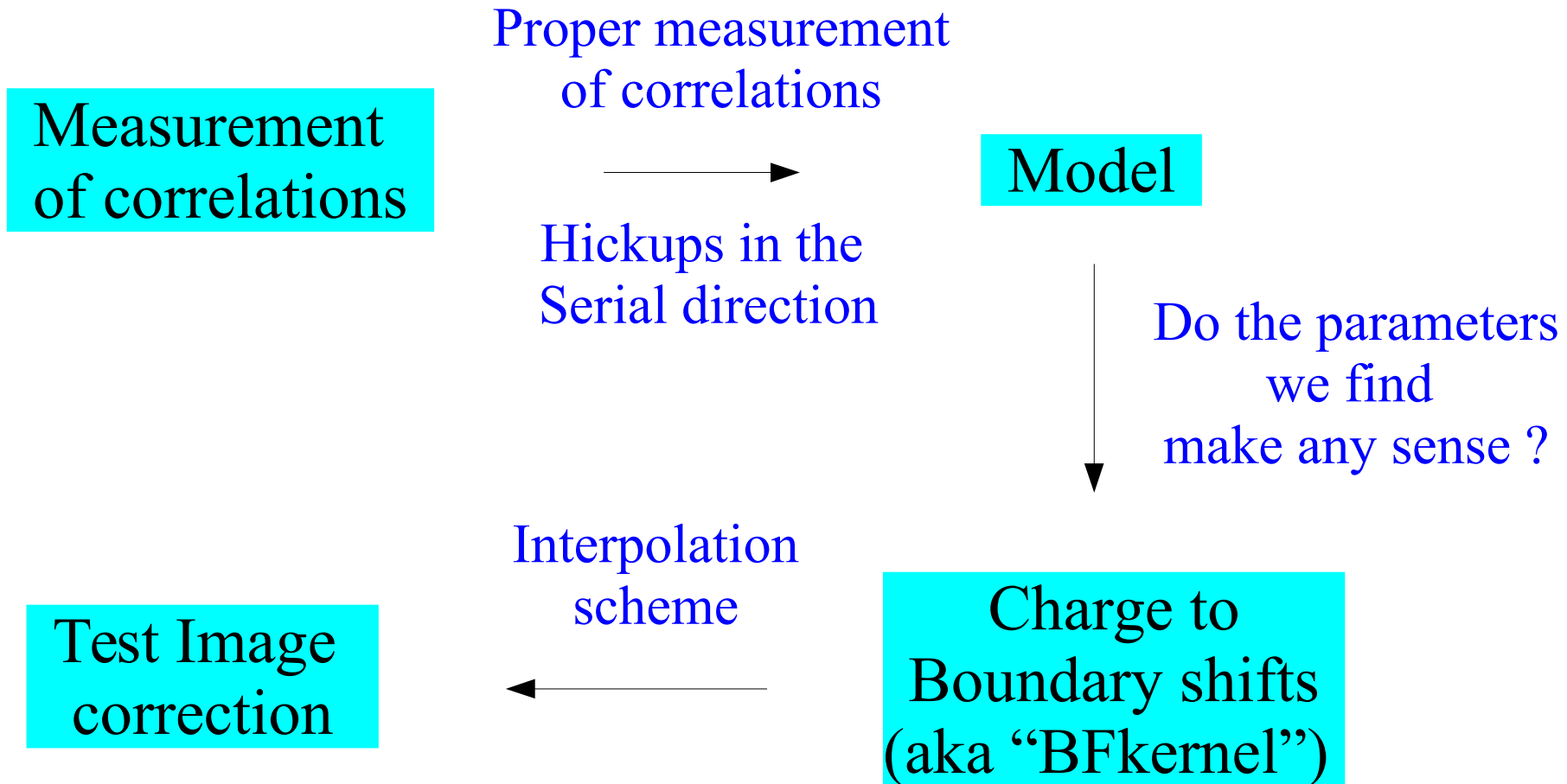
Is linearity
restored ?

The practical test



Is linearity
restored ?

The practical test



Is linearity
restored ?

Current goals

- Rémy to finish his PhD : implementation of the test.
- Reproduce our measurements on a ITL sensor.
- Assess the (small but measurable) chromaticity of the brighter-fatter effect.
- Understand hickups along the serial direction.

Conclusions/summary

- The brighter-fatter effect is not behind us yet.
- There is room for short-term visible contributions (aka “papers”).
- Regarding HSC, the stack implements an arguable variant of Guyonnet+ (2015). Implementing and testing a modern alternative would certainly be useful, in the short term.
- At least, an assessment of the quality of the currently implemented correction in the DM stack is welcome. HSC is the obvious candidate.