ATLAS BCM'
Sensor Sizes

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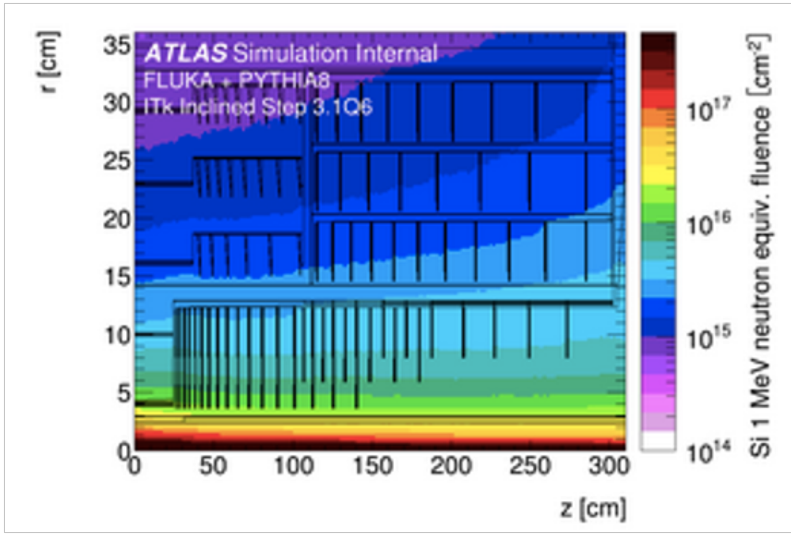
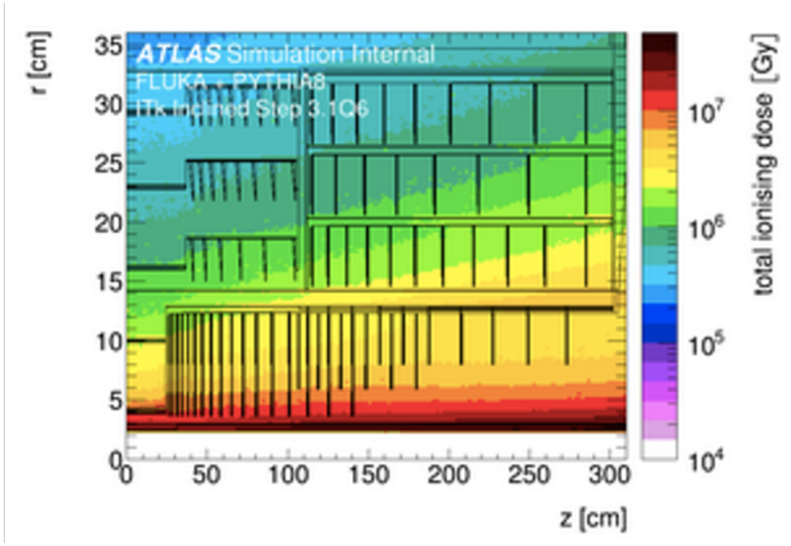
Environment

- ★ HL-LHC: particle density will increase by an order of magnitude
  - ★ Particle flux up to 160 MHz/cm² at pile up $\mu = 140$
  - ★ **NIEL 3 x 10^{15} n_{eq}/cm^2** , **TID 300 Mrad** after 2000 fb^{-1} (including x 1.5 safety factor)
  - ★ A new BCM' system will be installed in ATLAS ITk in 2024
  - ★ BCM' collaboration: OSU, JSI, Manchester, Wiener Neustadt, CERN





Conceptual design

★ Located at r = 100 mm, z ~ ± 1800 mm (~6 ns) from IP

★ Four stations per each side of the detector

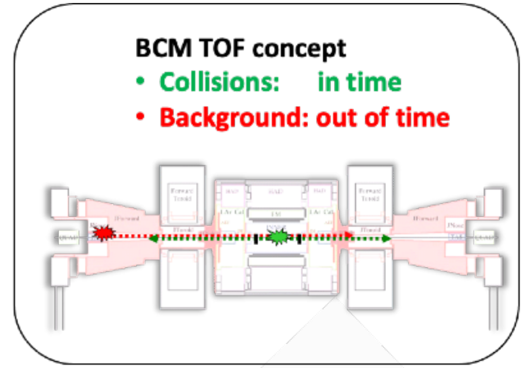
★ Collision/background separation based on Time of Flight

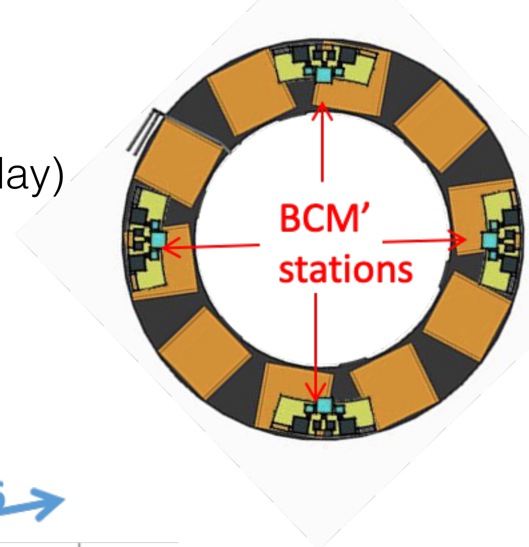
  ★ Luminosity: Collision products arrive simultaneously on both detector sides

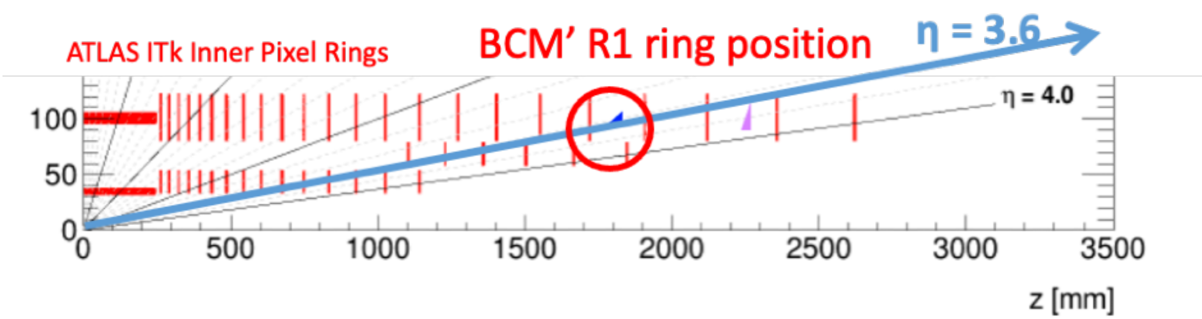
  ★ Beam protection: Background arrives out-of-time (~12 ns delay)

★ Multiple detectors by function

  ★ Abort, Beam Loss Monitor (BLM) – copy of LHC design, Luminosity

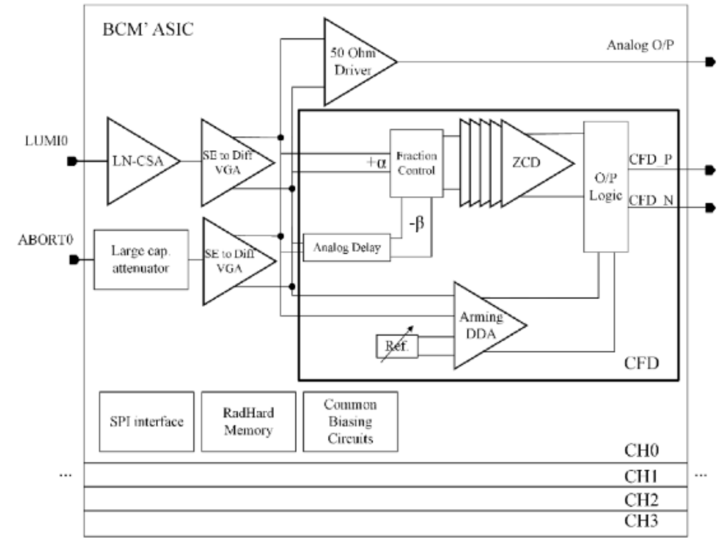






Calypso ASIC

- ★ Calypso: 4–channel FE ASIC
  - ★ TSMC 65 nm process, size 2x2 mm^2
  - ★ Two (mutually exclusive) input options per channel: lumi/abort



- ★ Calypso specs:
  - ★ Optimized for **C_{det} 2–5 pF**
  - ★ **t_{peak} < 1.5 ns**, **$t_{settling}$ < 15 ns** (at C_{det} = 2 pF)
  - ★ **σ_{jitter} < 100 ps** (at C_{det} = 2 pF for > 3.6 ke$^-$ signals in simulation)
  - ★ **lumi:** ***(110 + 55/pF) e$^-$ noise*** , ± 50 ke$^-$ dynamic range, gain 55mV/fC
  - ★ **abort:** 830 ke$^-$ noise, ± 750 Me$^-$ dynamic range, gain 8.2μV/fC
  - ★ **digital LVDS output**, analog preamp output for testing

- ★ Shown to be radiation tolerant, exact performance after irradiation needs to be thoroughly evaluated

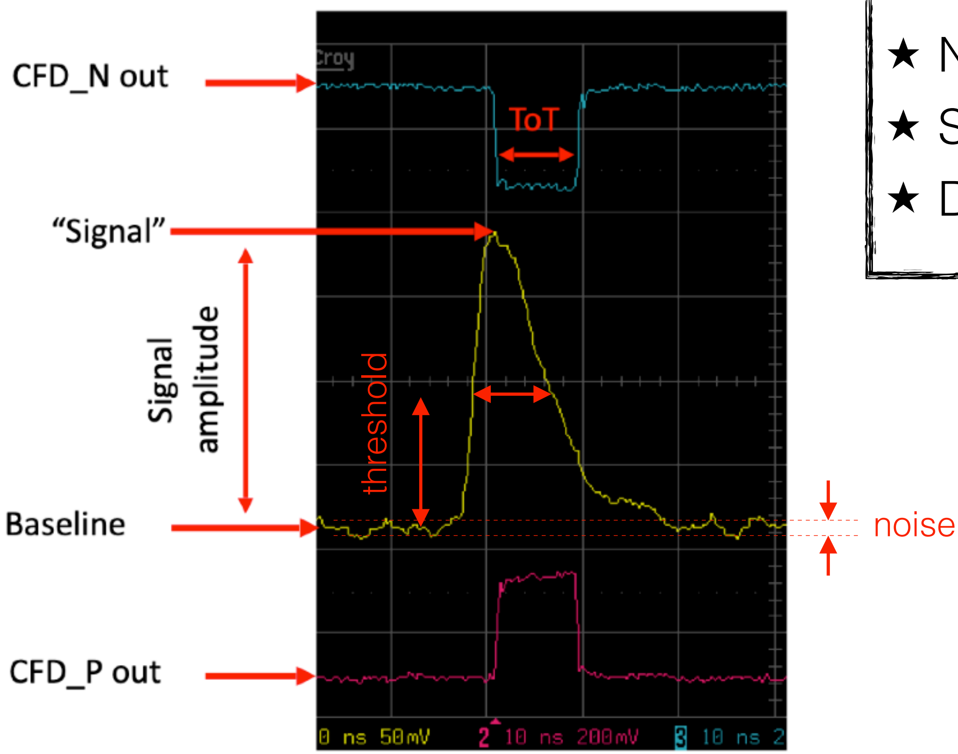
Sensor choices

material	capacitance
Si 300µm	0.36 pF/mm²
C 500µm	0.10 pF/mm²

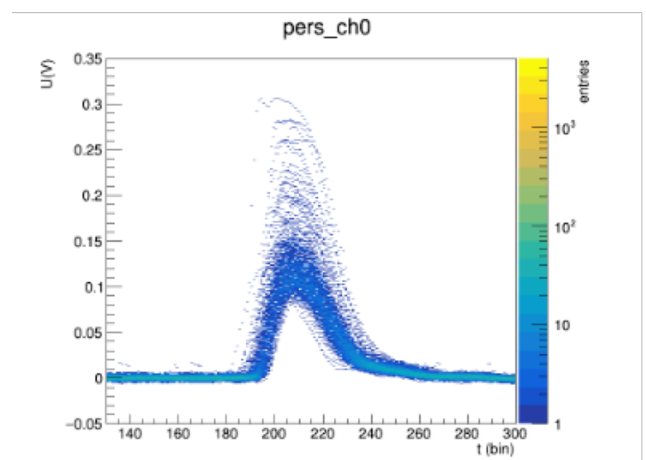
- ★ Very broad range of particle fluxes, dynamic range flexibility required
  - ★ Four orders of magnitude:
    $\mu_{vdM} = 0.01$ — $\mu_{ultimate} = 140$
  - ★ Dynamic range flexibility by segmenting the sensors into pads of varying size
- ★ Three types of pCVD diamond sensors and one silicon sensor per station:
  - ★ lumi: 10 x 10 mm^2, three pads (size 1 mm^2 – 50 mm^2) **~ 0.1 – 5 pF / pad**
  - ★ abort: 5 x 5 mm^2, four pads
  - ★ lumi: 1 x 1 mm^2 3D, single pad, C = **~5 pF** – **highest radiation tolerance**
  - ★ lumi: Si pad/strip (~10 mm2, **~4 pF**)
- ★ Diamond sensors produced by US vendor II-VI (worked with RD42)

Signal processing

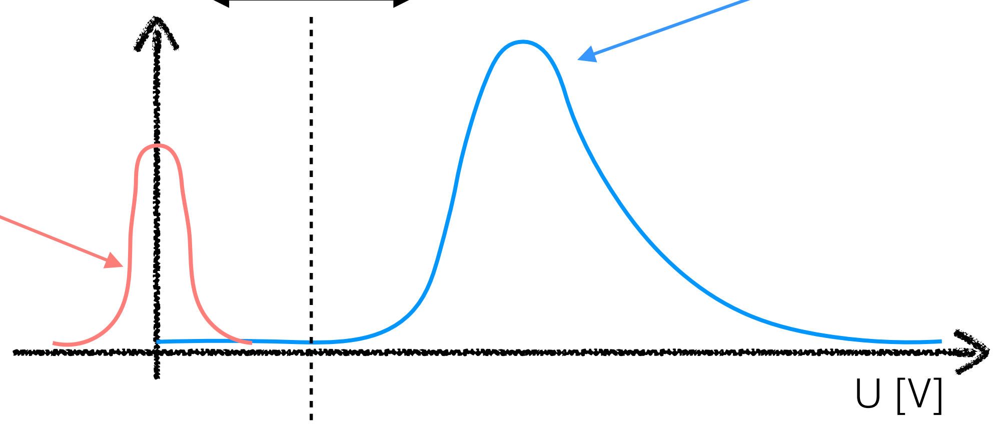
- ★ Amplifier output and two digital outputs of Calypso ASIC shown



- ★ Typical signal (C CCD 200μm): ~7ke⁻
- ★ Noise at 5pF: ~400e⁻
- ★ SNR < 20
- ★ Deteriorated with rad. damage



Signal distribution I

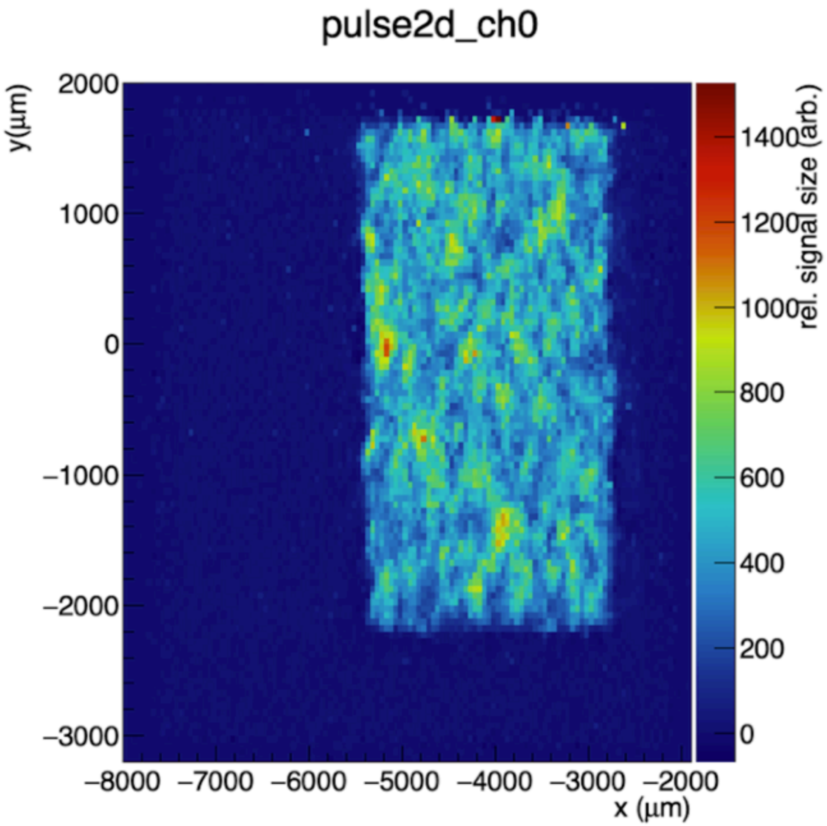


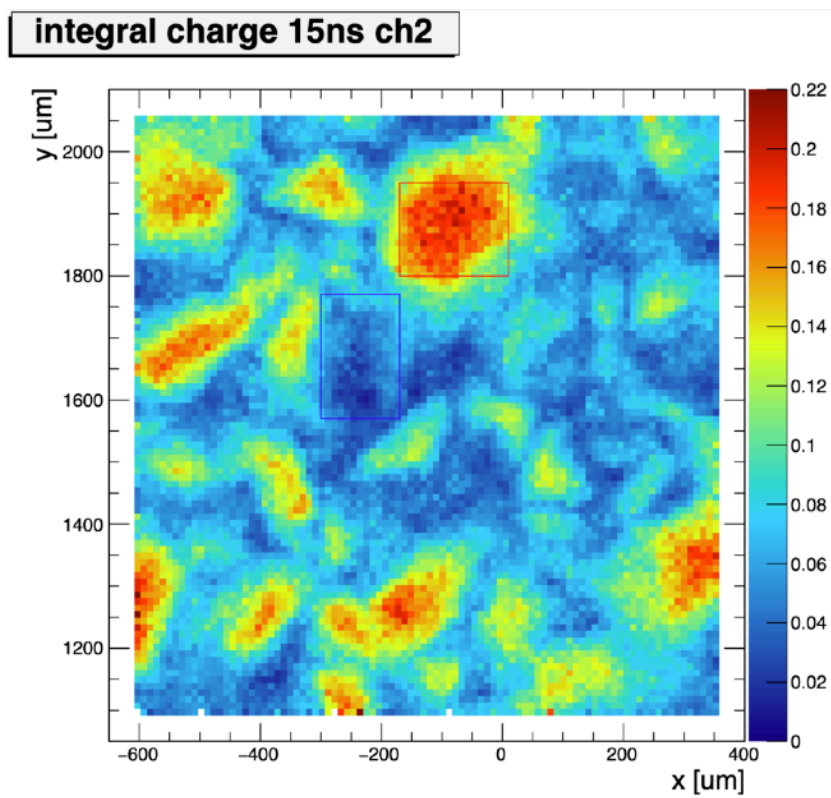
- ★ For efficient and stable luminosity measurement
  - ★ High efficiency for identifying MIP signals
  - ★ Low probability for false triggers from noise fluctuations

Signal height 2D distribution

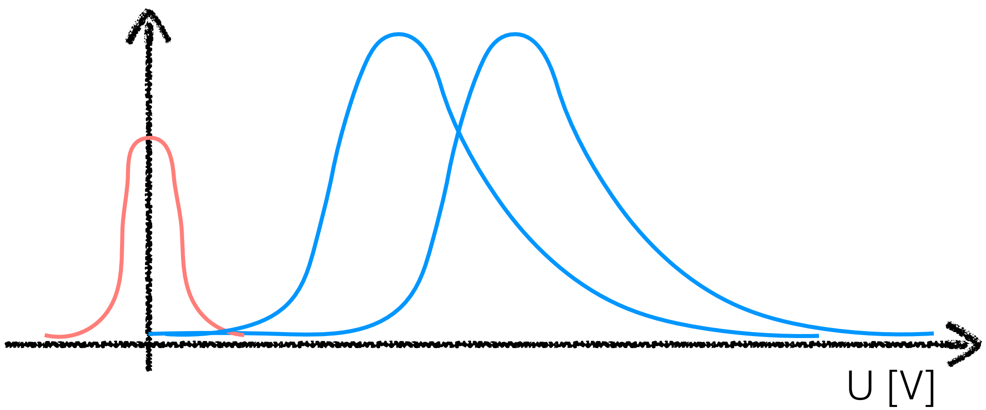
★ Large variation of real signal amplitudes due to non-homogeneity of pCVD material (al least factor of ~2)

★ hot spots vs. cold spots



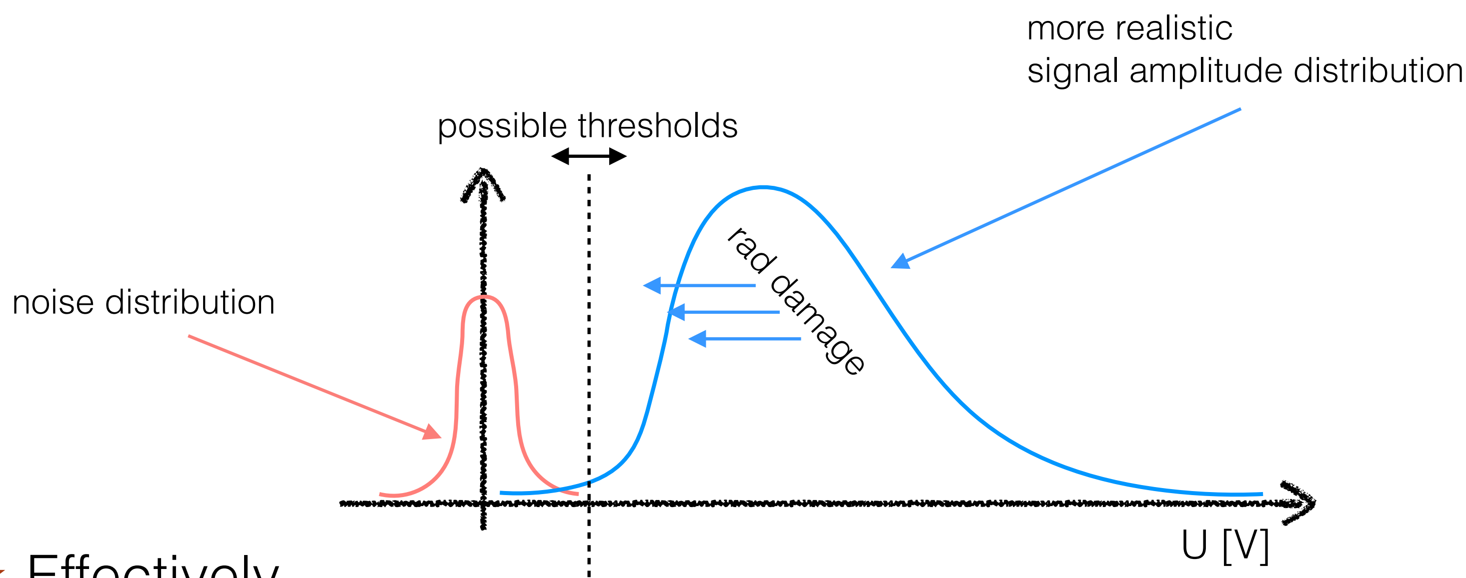


Signal distribution II



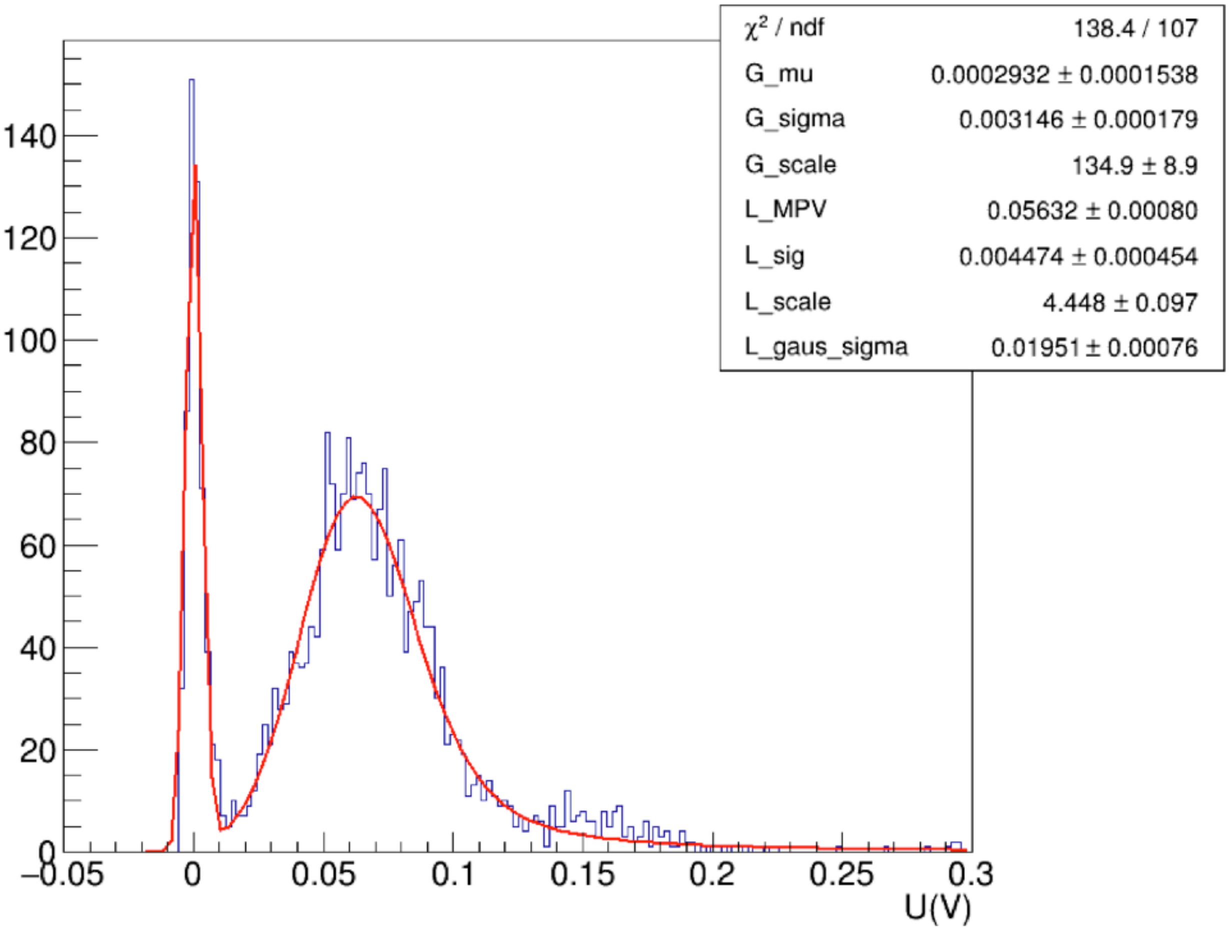
★ Signal variations across sensor surface

Signal distribution III



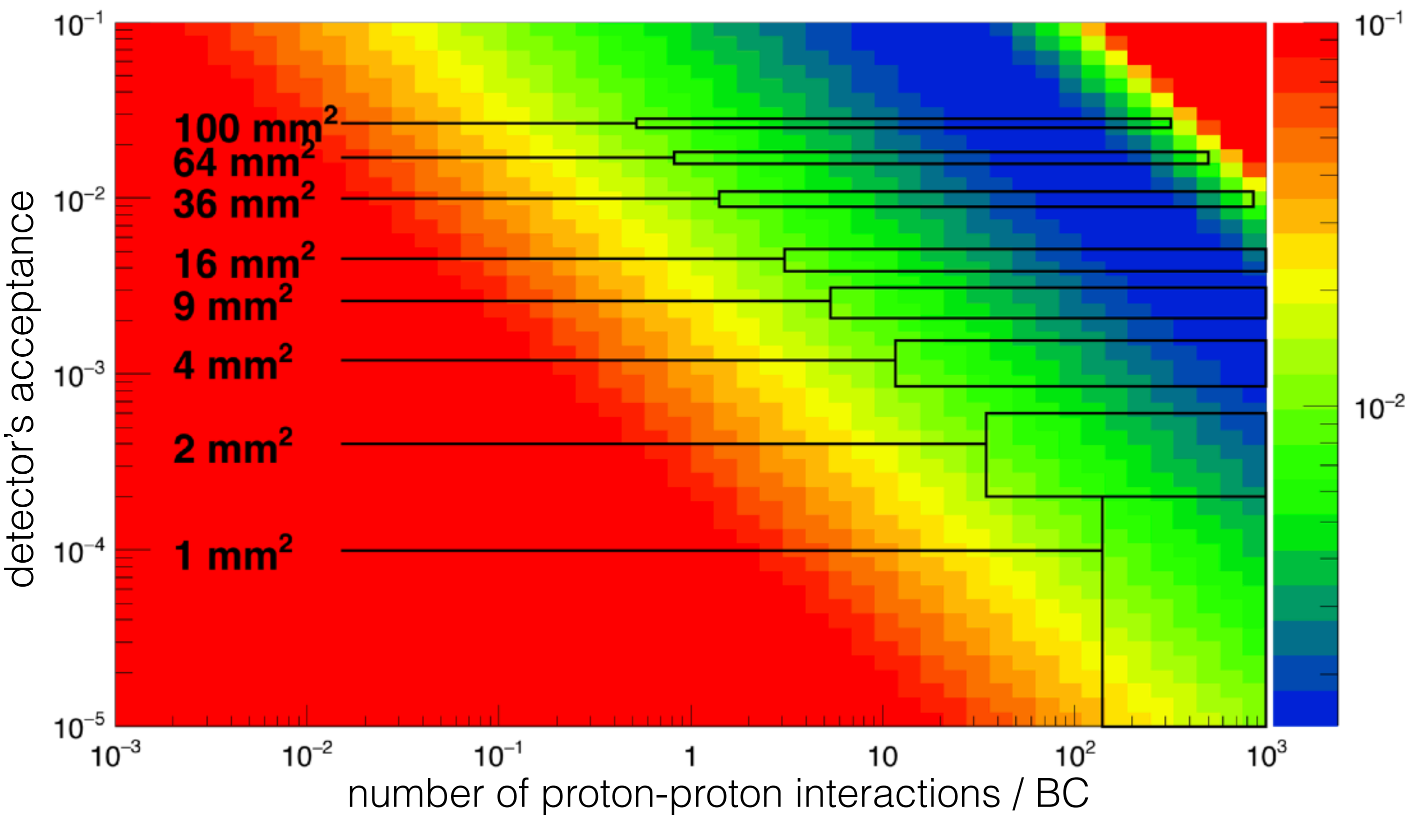
- Effectively
  - broadens the signal amplitude distribution and
  - lower signal to noise separation power —> systematic effects in measurements (try precise monitoring – pulser)
  - After rad. damage signals will additionally deteriorate

Real signal distribution



Statistical error

- ★ Relative statistical error of per-bunch luminosity monitoring for OR algorithm
  - ★ 60s worth of LHC data; based on ATHENA simulation
  - ★ box: H indicates error in acceptance due to simulation and W the interval with stat. error less than 1%



Summary

- ★ Available sensors <100 mm^2 (C) <25 mm^2 (Si) <5 mm^2 (C-3D)
  - ★ Signal to noise separation power decreases with capacitance
- ★ Additional deterioration of signal to noise due to radiation damage
  - ★ Will try to monitor and calibrate (standardised pulse input)
- ★ Possible ∑ of multiple channels (effectively OR algo?)