BCM1F: Luminosity Algorithms and Systematic Effects

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DESY

Workshop on CMS Beam Conditions,
Radiation Monitoring and Luminosity Systems

Zeuthen, 23.04.2013

Introduction

- Using as reference the beautiful work of the BRM group, in particular in 2012.
- Reference: Detector note DN-12-006 under construction.

CMS DN DN-12-006

The Compact Muon Solenoid Experiment

Detector Note

The content of this note is intended for CMS internal use and distribution only

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Luminosity Monitoring at CMS During the 2012 Run Using the BCM1F Detector

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Abstract

The BCM1F detector exploits single particle counting in the CMS inner detector region with nanosecond time resolution. It has the capacity to serve as an online monitor, and sample the average and the per bunch crossing instantaneous particle rates in the CMS inner detector. This allows for the extraction of information that can be used to optimize the beam characteristics and measure the delivered luminosity of the LHC to the CMS Experiment. In this paper we describe the method for determining luminosity from the measured particle rates using the BCM1F detector, and the method to derive an absolute luminosity calibration from a Van der Meer scan.

Luminosity basics

For a *pp* collider, the luminosity can be defined as,

$$L = \frac{\mu_{vis} \cdot n_b \cdot f_{orbit}}{\sigma_{vis}} \tag{1}$$

- $\mu \equiv$ average number of inelastic collisions
- $f_{orbit} \equiv$ orbit frequency ($= 11246$ Hz)
- $n_b \equiv$ number of colliding bunches ($\lesssim 1380$)
- $\sigma_{inel} \equiv$ inelastic *pp* cross-section

Where we account for the detection efficiency by considering $\sigma_{vis} = \varepsilon\sigma_{inel}$. σ_{vis} is measured using a Van der Meer scan

Zero Counting

Assuming that the number of observed interactions is Poisson distributed with and MPV of μ, we can determine μ by measuring the number of colliding bunch crossings with no observed interaction,

$$P_n = \frac{\mu^n e^{-\mu}}{n!} \rightarrow \mu = -\ln[P_0] \qquad \text{where} \qquad P_0 = 1 - P_{OR} = 1 - \frac{N_{OR}}{N_{BX}} \tag{2}$$

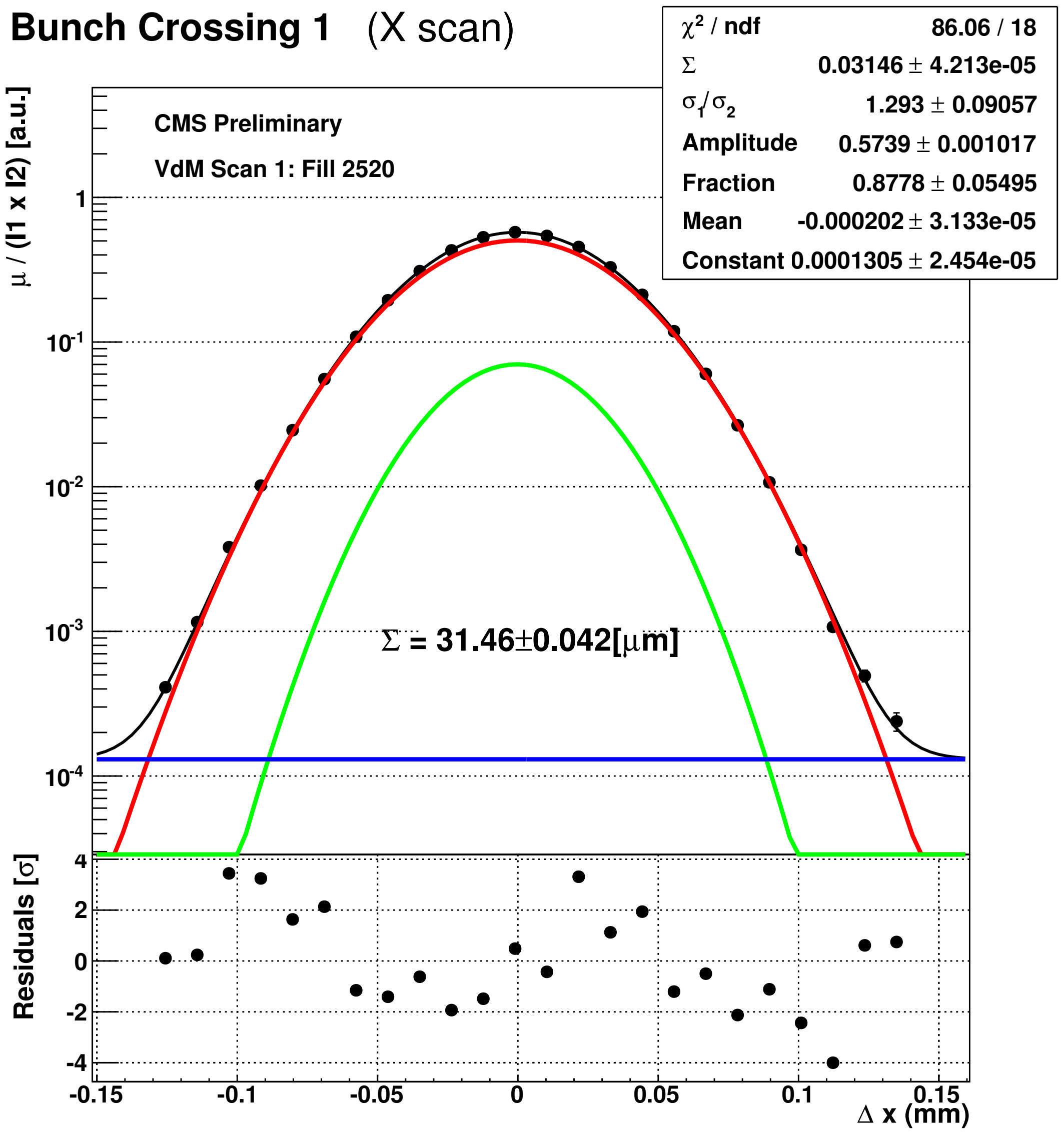
hits in the +z OR -z sides

Slide from N. Odell

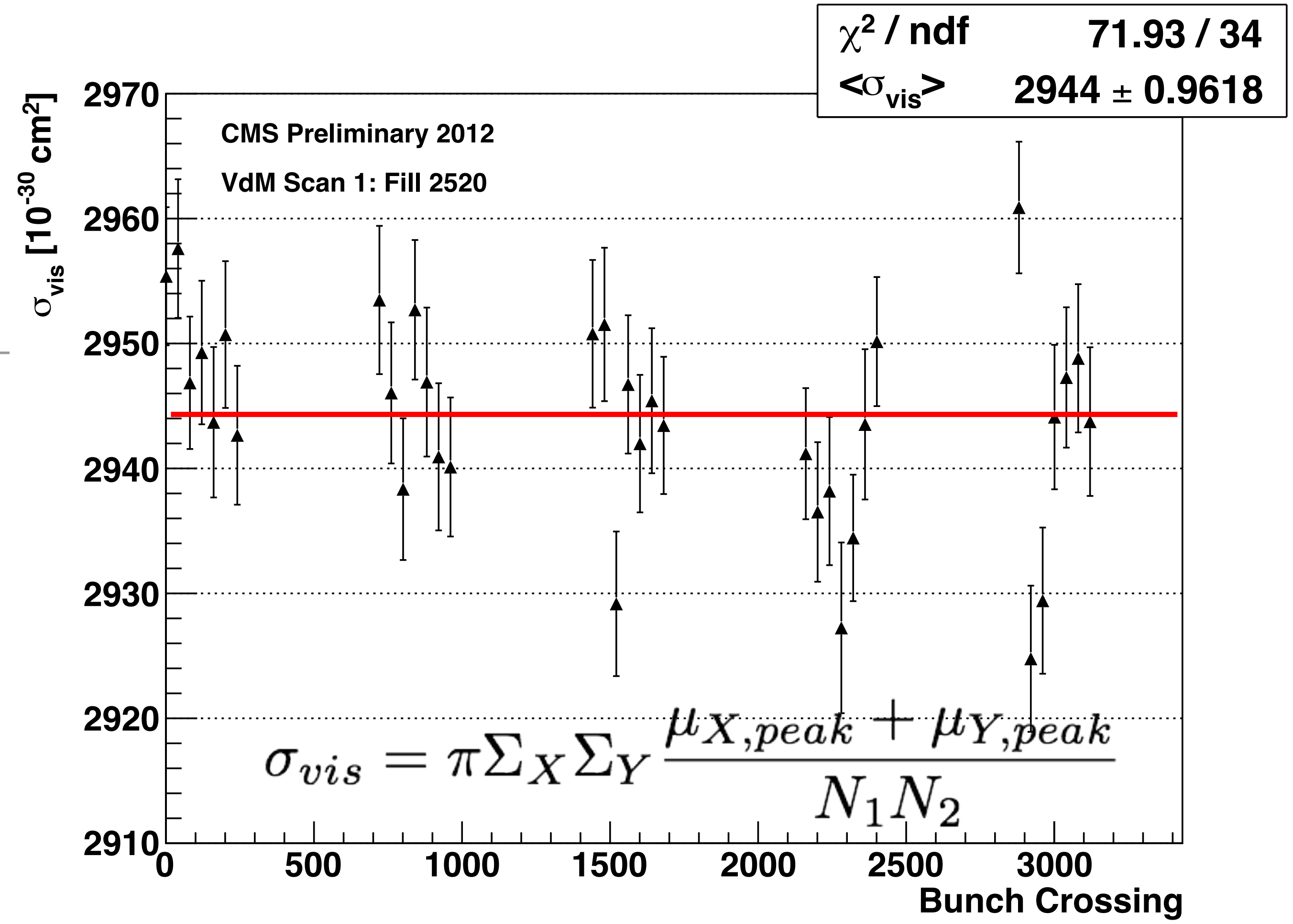
VdM scan results (OR)

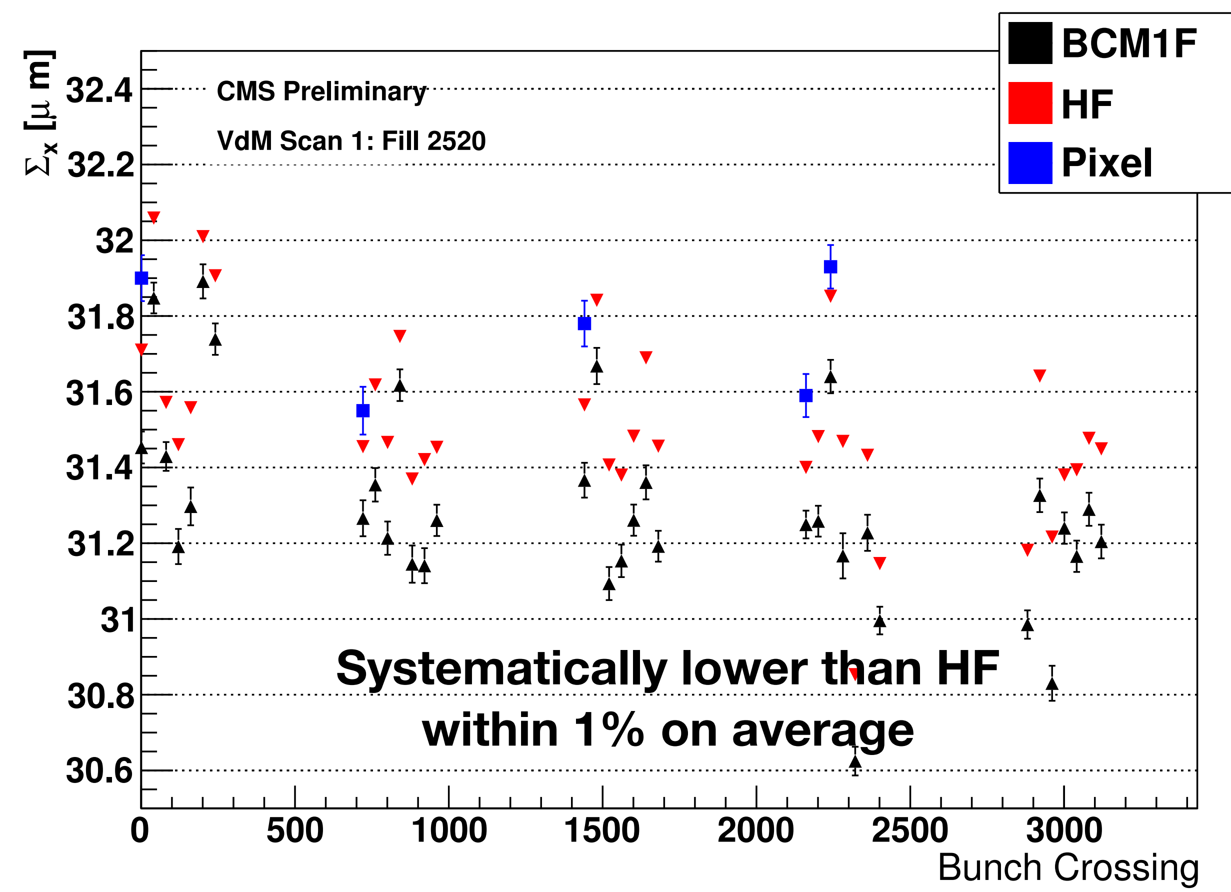
- Overlap region measured in the x and y directions

Bunch Crossing 1 (X scan)



Fit (black) to double gaussian (red and green) + constant (blue)



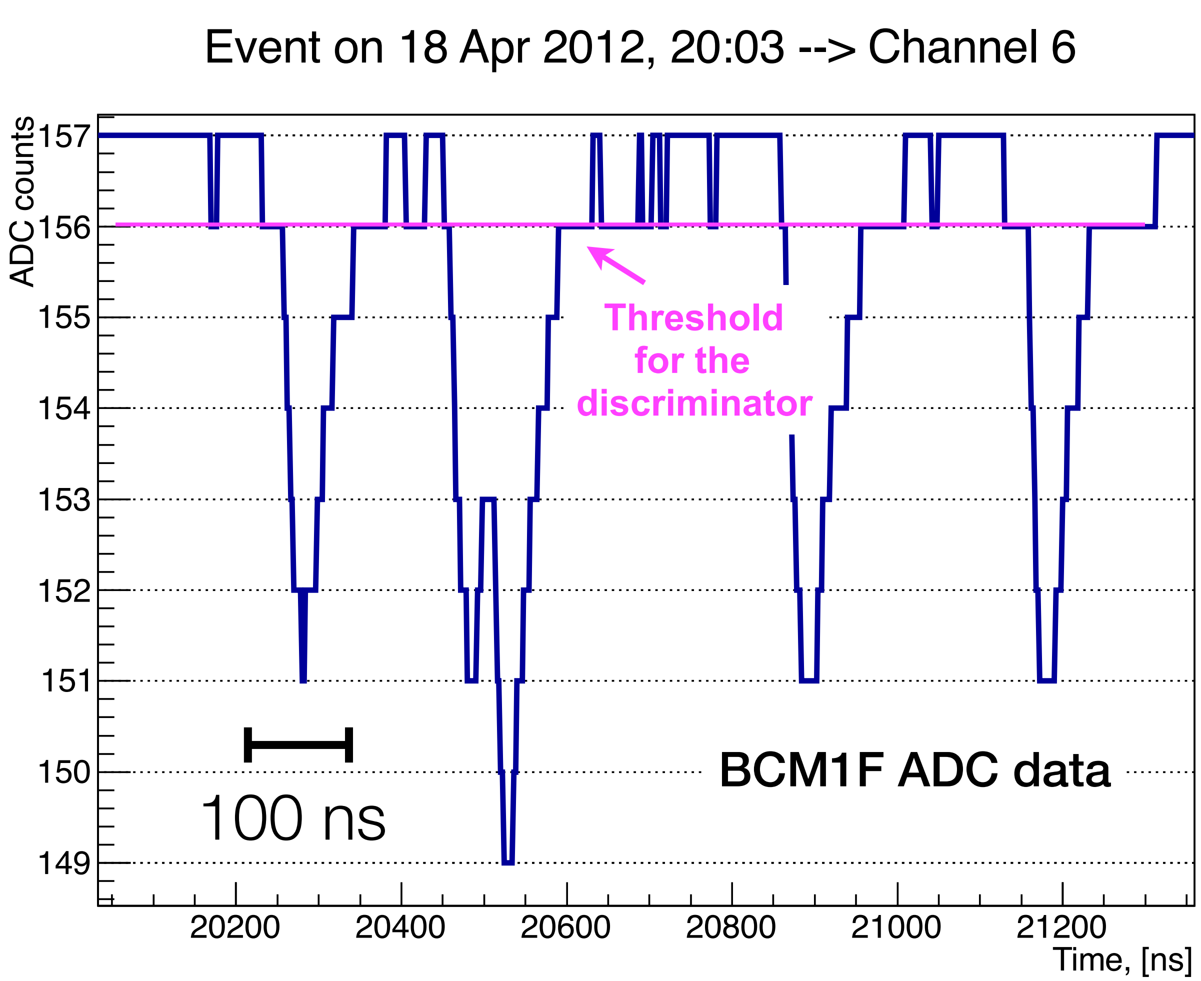


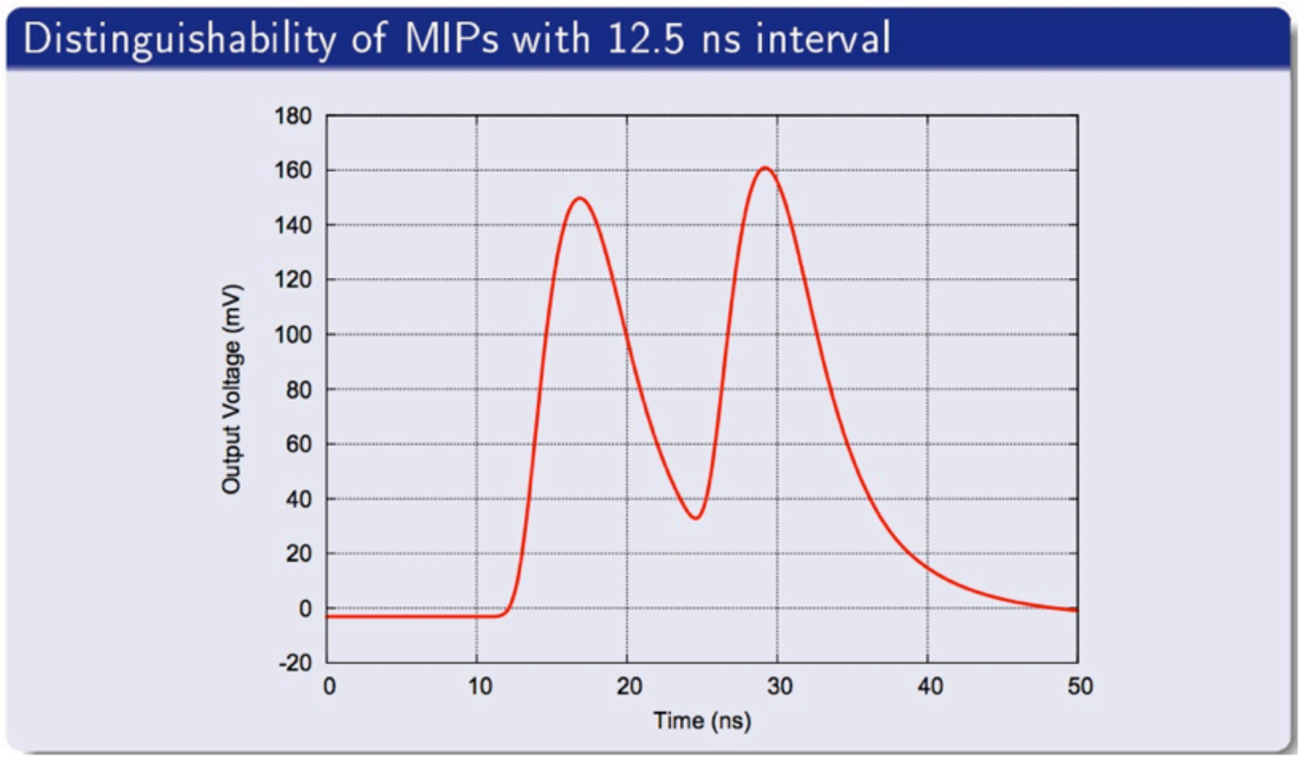
Algorithms for luminosity

- The main logic for μ used in BCM1F is the OR logic:
  - Require hits in the +z OR -z sides.
  - May suffer from zero starvation at high luminosity.
- The OR counts can be divided into:
  - AND: Require hits in the +z AND -z sides.
  - XOR+: Require hits on the +z side and no hit on the -z side.
  - XOR-: Require hits on the -z side and no hit on the +z side.
- In principle these algorithms can be used individually to determine the luminosity, with all or small groups of channels.
- Certain algorithms may present very low rates in the VdM scan → particularly the tails of the beam profile are not well described.
- Use the μ_{peak} of an algorithm (e.g. AND) with the measured beam profile from another logic (e.g. OR) to extract the calibration constant (σ_{vis}^{AND}).
- Need Monte Carlo simulation studies to make an optimal choice.

Systematic effects (I)

- Signals are detected using a constant threshold discriminator.
- LHC Run I: Inefficiency due to the response of preamplifier – time under threshold
- LS1 upgrade: New front-end design should be able to distinguish two MIP signals 12 ns apart → suppress inefficiency!

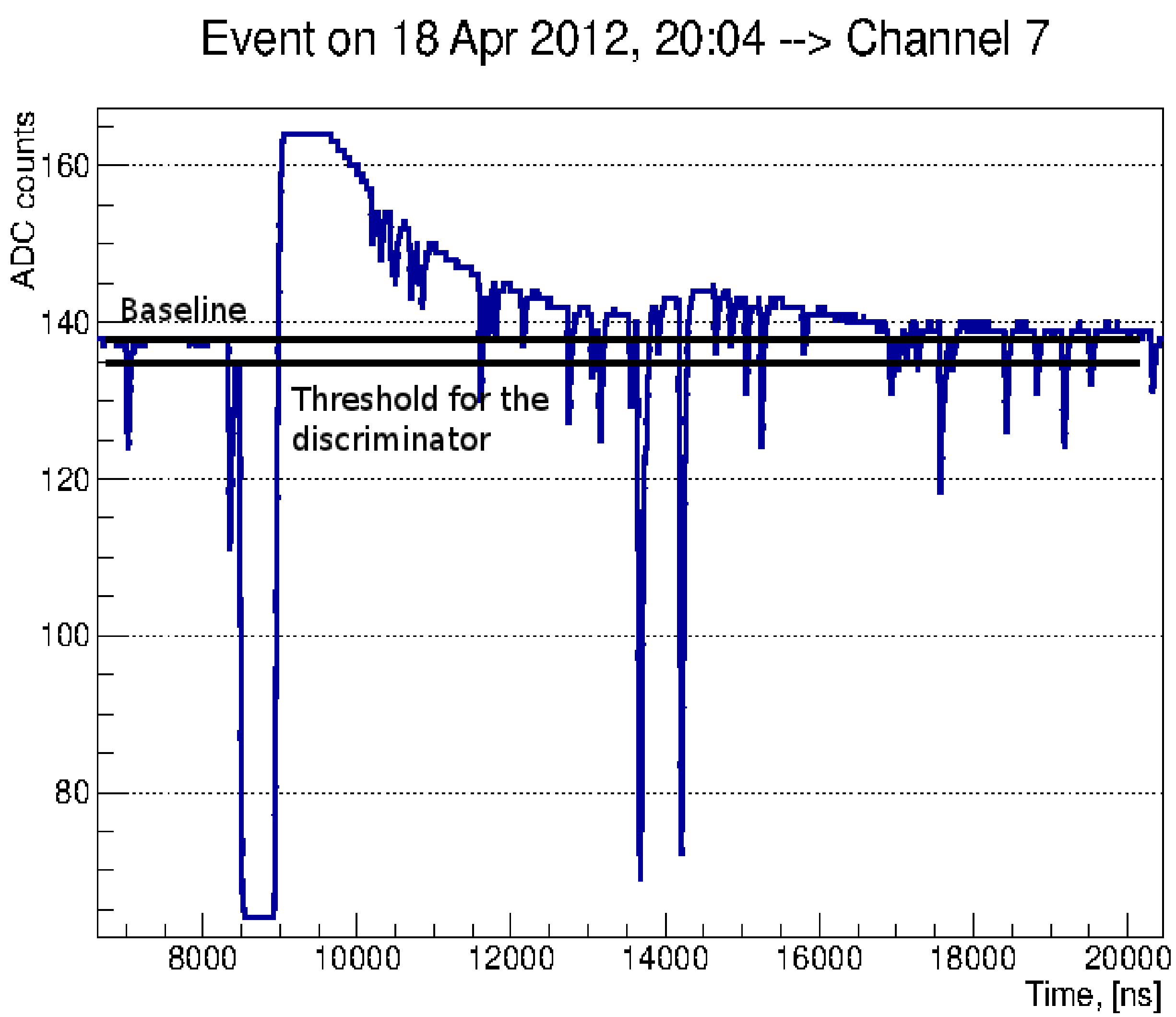


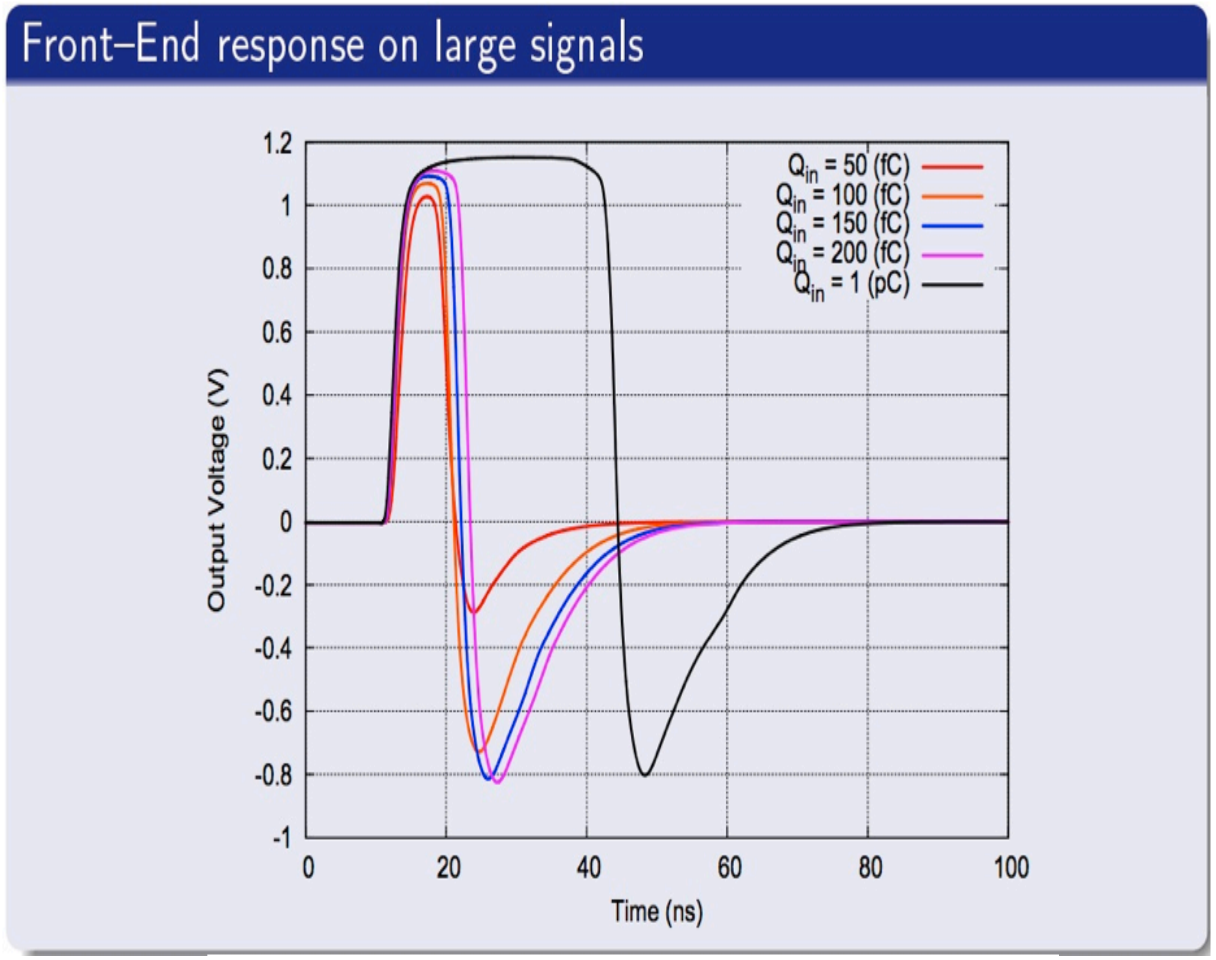


Simulation by Dominik Przyborowski
UST Kraków

Systematic effects (II)

- Time above threshold: saturation of the front-end due large amplitude signals → deadtime of hundreds of ns in LHC Run I
- LS1 upgrade: New front-end design – fast baseline recovery after overdrive detector signal.





Simulation by Dominik Przyborowski
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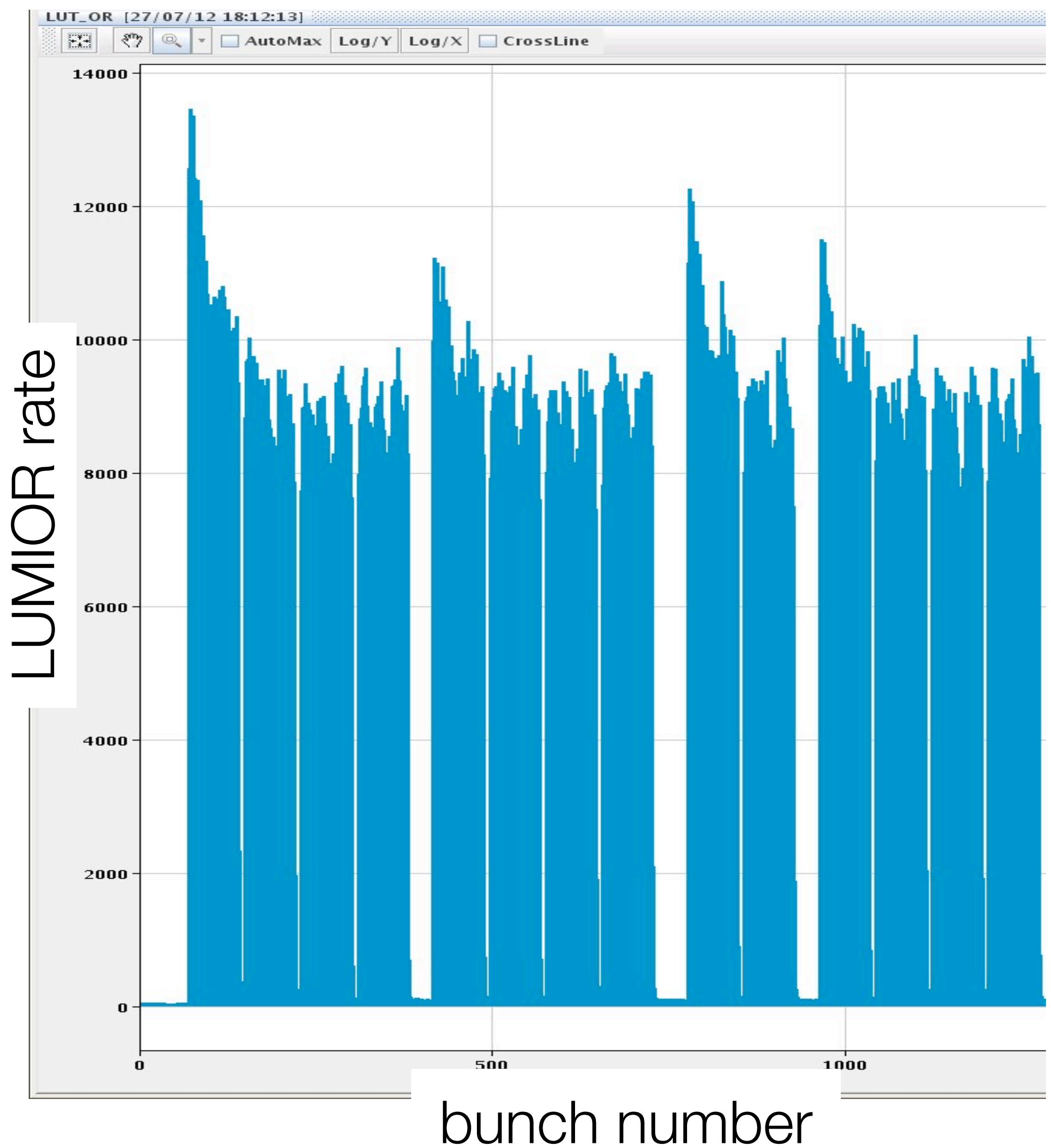
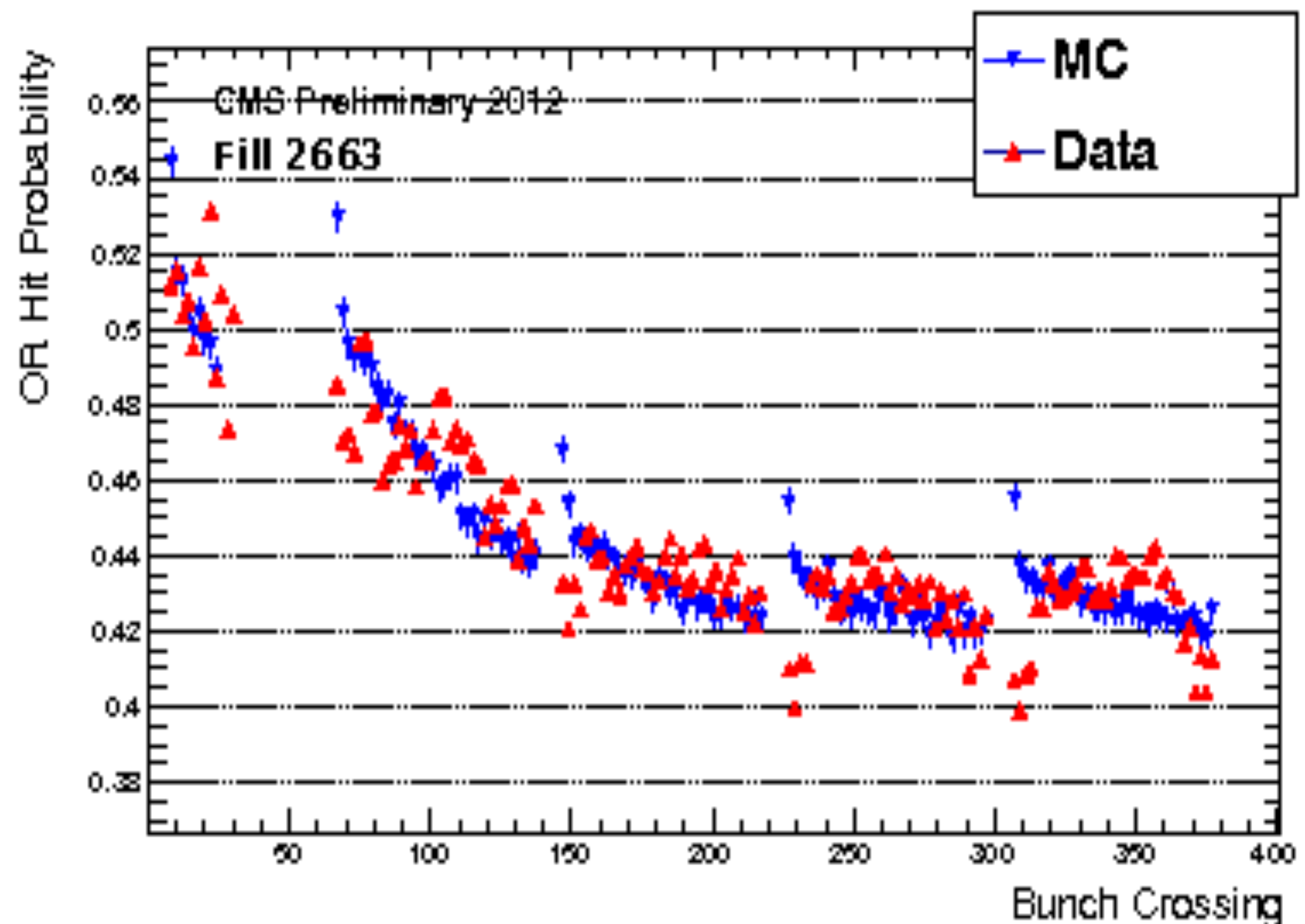
Systematic effects (III)

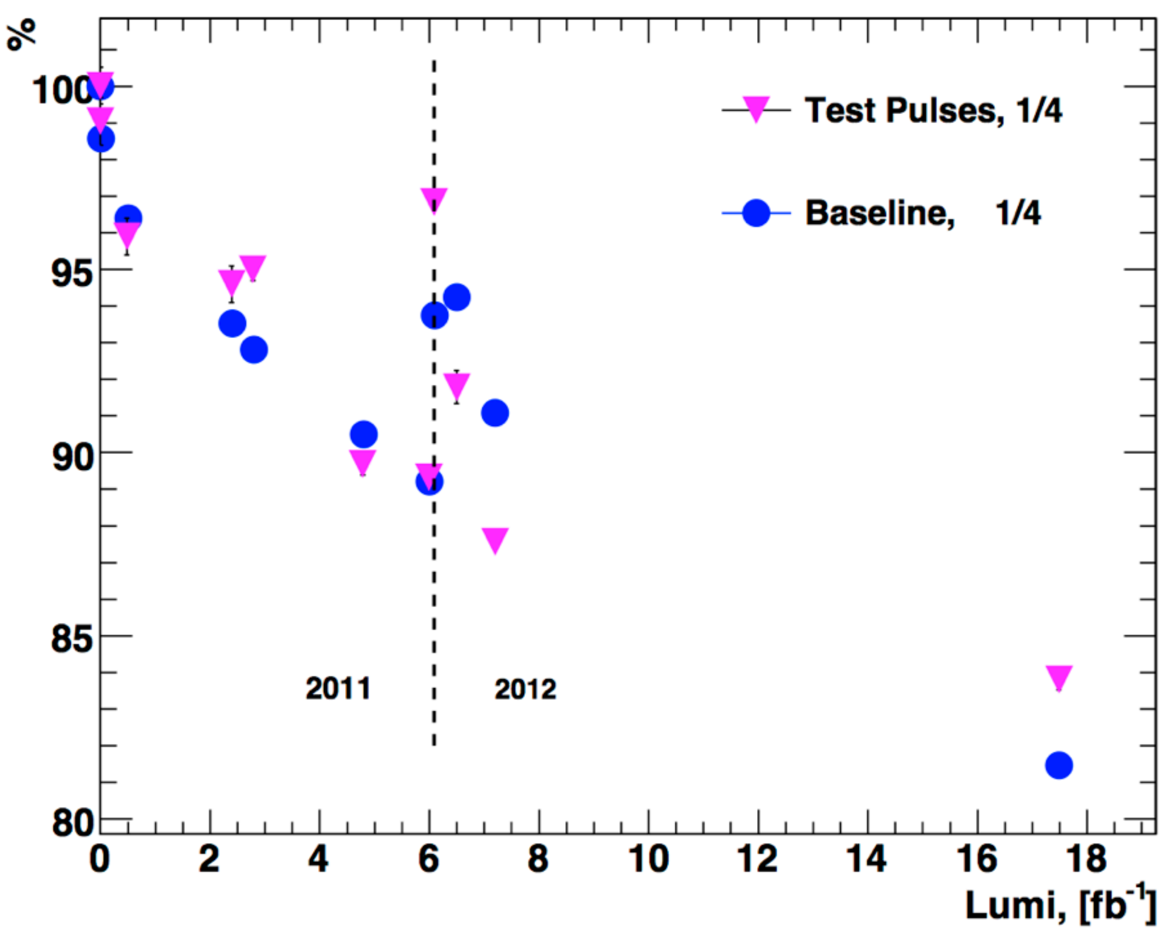
- Effect of time above threshold: efficiency drop during bunch train.
- Corroborated by simulation studies.

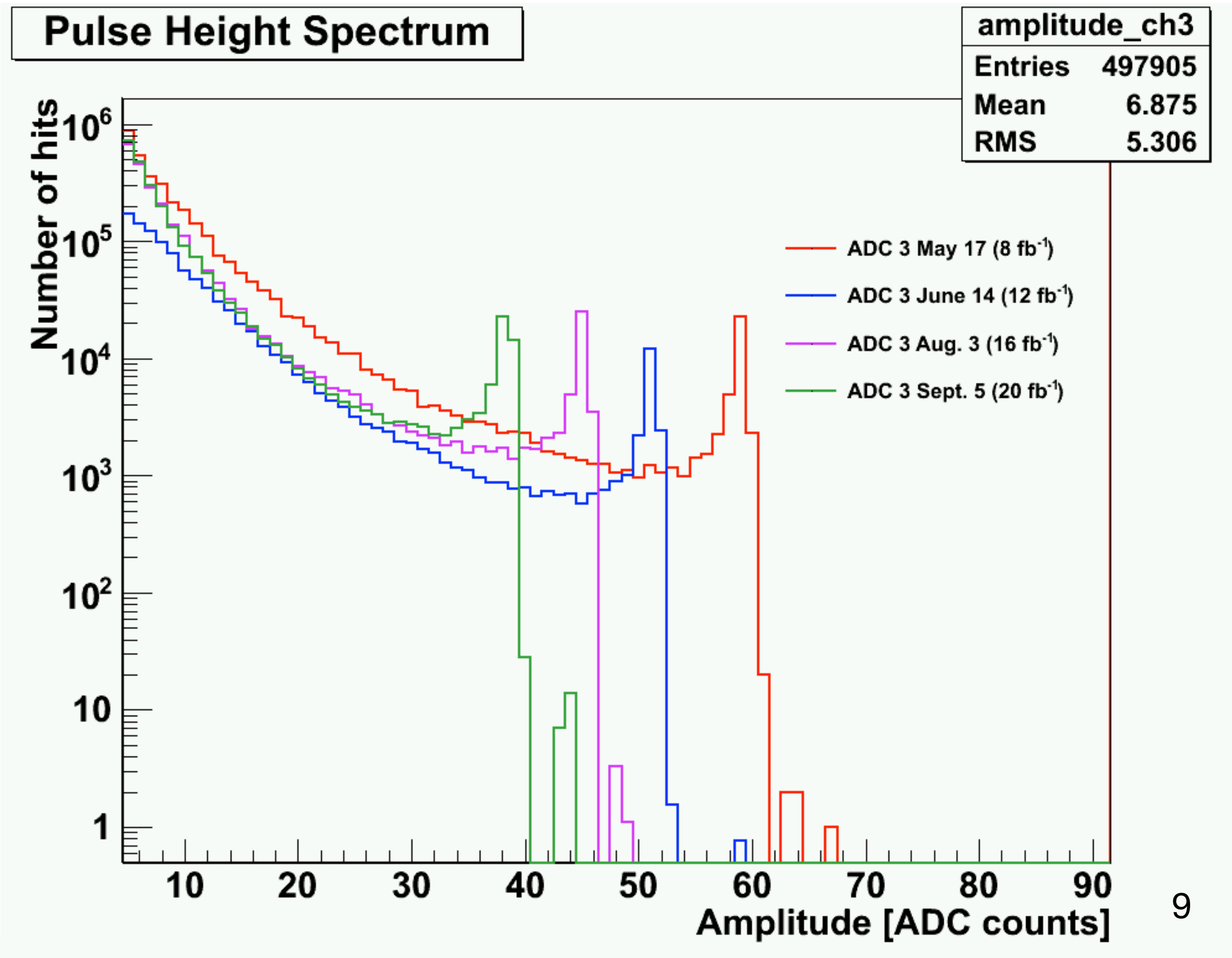




Systematic effects (IV)

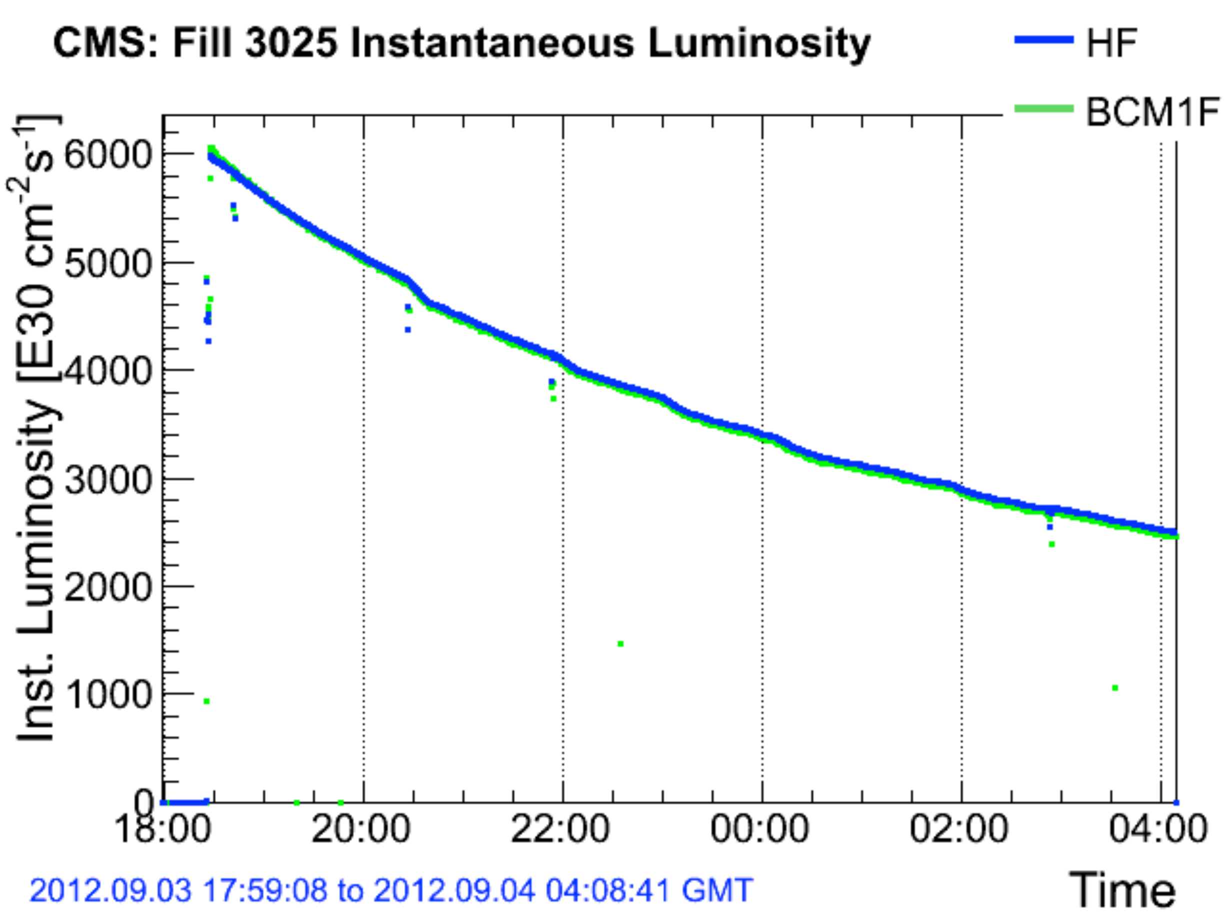
- Linear laser driver very sensitive to radiation.
- Optical signal degrades with integrated luminosity.
- Degradation of baseline and test pulse amplitude observed. Reduced bandwidth of signal amplitude.
- After LS1 upgrade BCM1F should feature an online baseline monitoring.

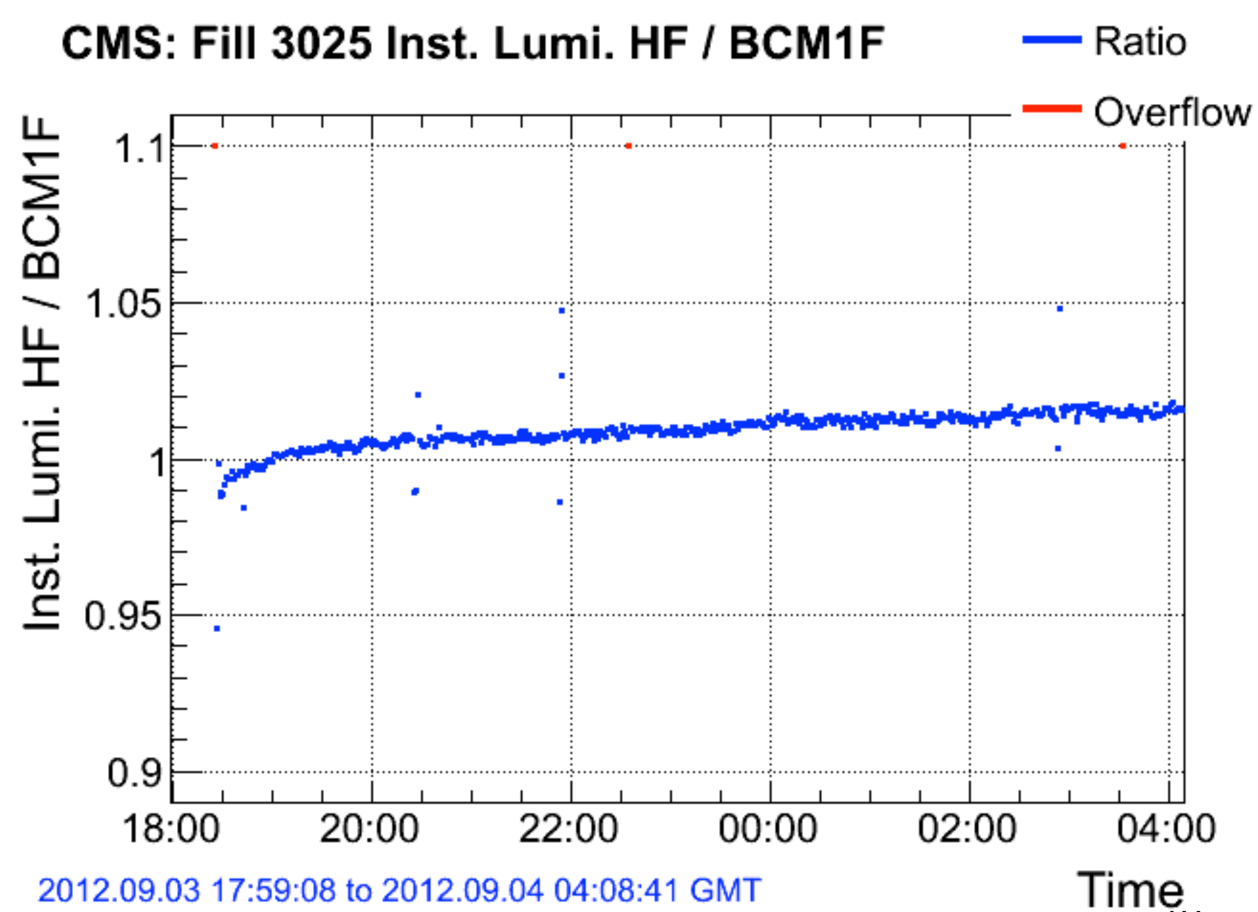




Systematic effects (V)

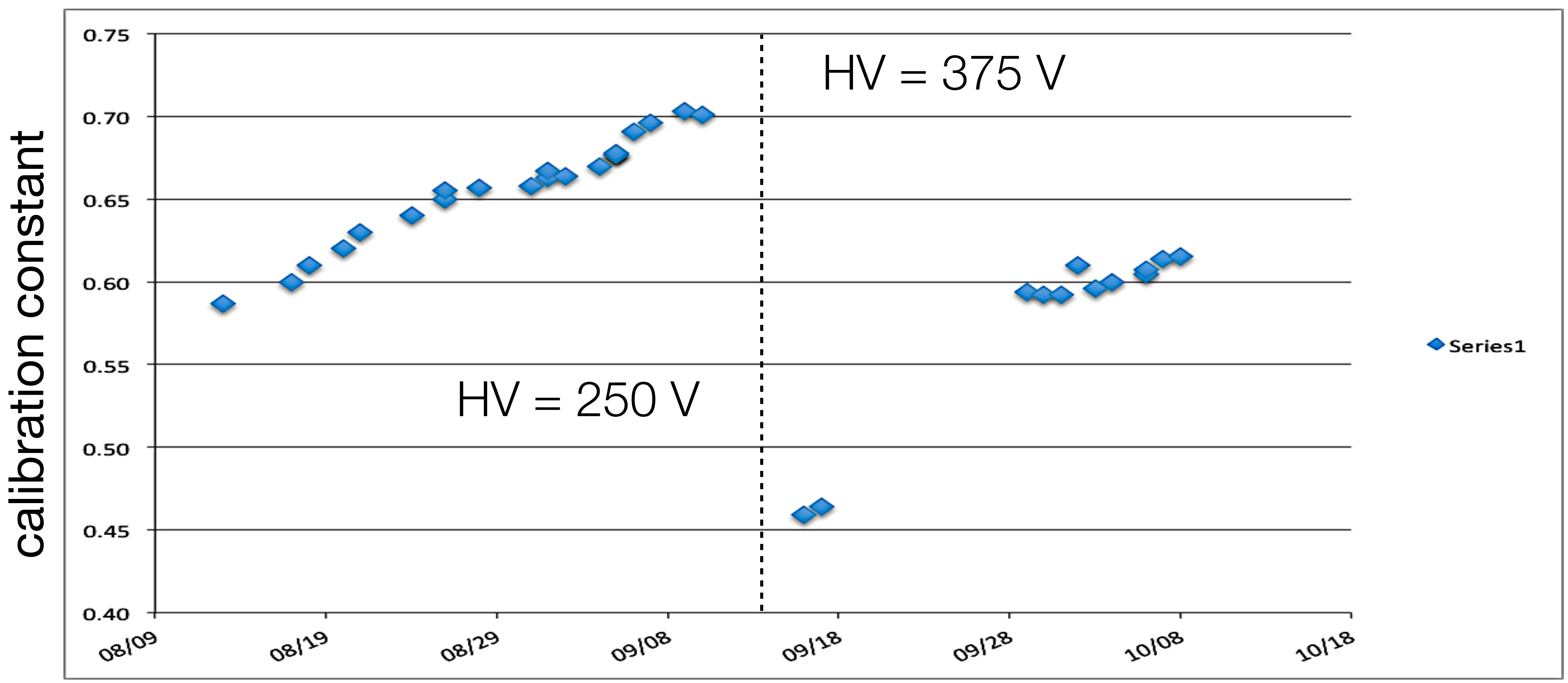
- Laser also sensitive to thermal effects.
- Discrepancy w.r.t HF observed in the beginning of the fill correlated with temperature variations measured in the vicinity of BCM1F.
- LHC Run 1: Corrected with HF data from previous fill.
- After LS1 upgrade, temperature monitoring (possibly cooling?) will be provided.





Systematic effects (VI)

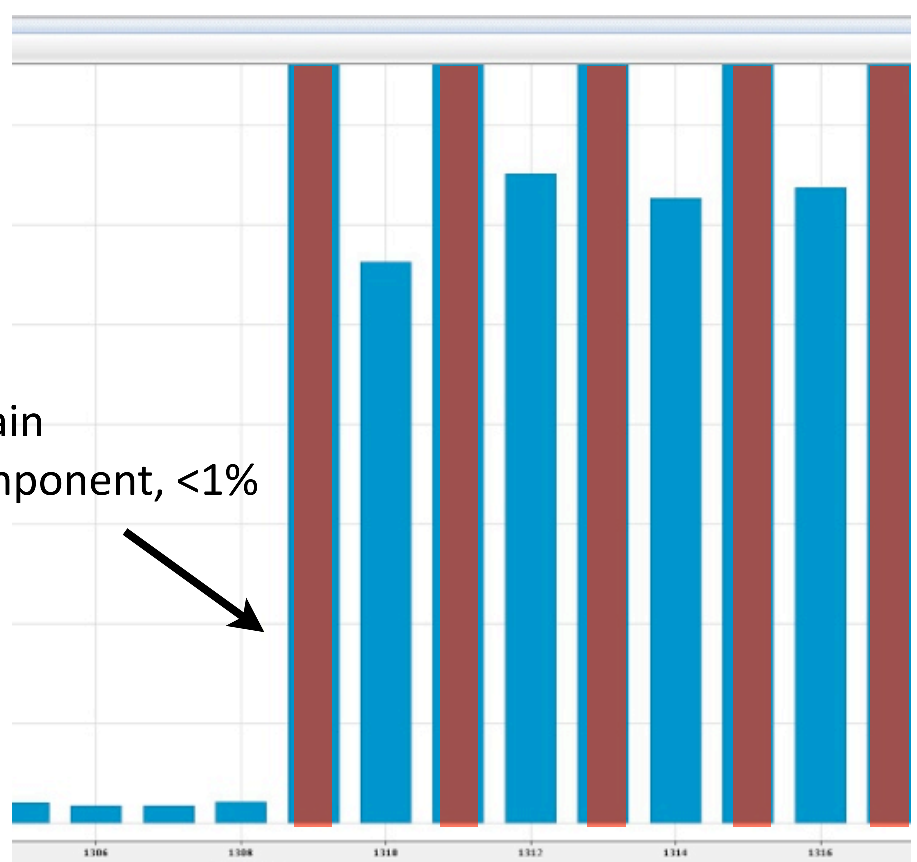
- Degradation also caused by the diamonds – polarisation effects? (see Jessica's talk)
- Time running luminosity calibration constant.
- Increase of HV improved performance temporarily.

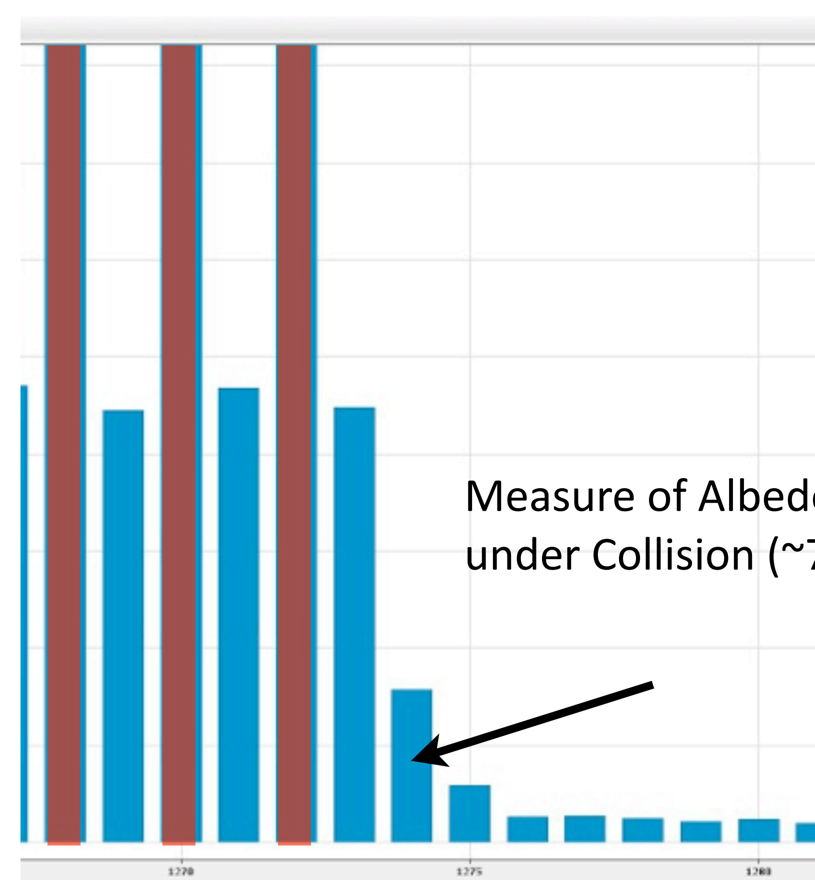


Systematic effects (VII)

- Albedo and beam-gas contributions can be estimated with gating system.
- Reduced bunch space after LS1 will increase Albedo contribution.
- Need to test luminosity algorithms with largest suppression of Albedo effects.
- See Jessica's talk for more details.

8 TeV data



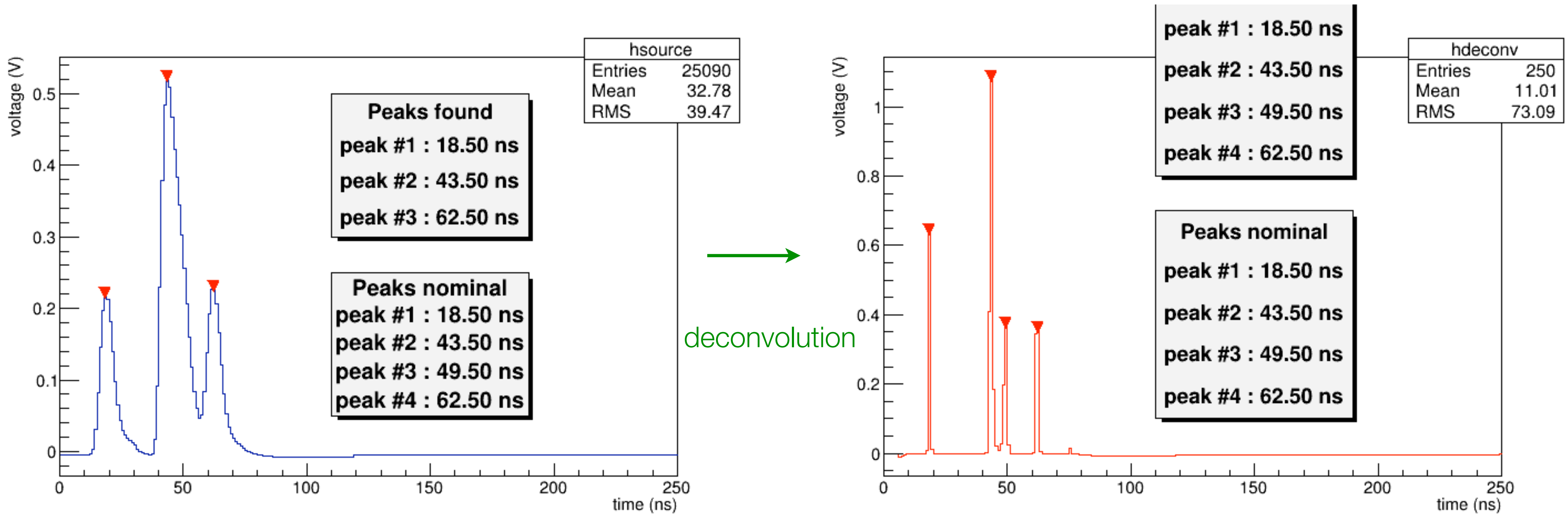


Back-end upgrade

- See David's talk for more details.
- Should feature:
  - Gain monitoring: single channel, pulse height and baseline monitoring, with known deadtime.
  - Signal processing for pulse identification, with zero deadtime, particle counting as a function of time since the start of orbit.
  - Real-time logic between channels, with zero deadtime.
  - Apply calibration factors, corrections.
- Possibly use digitisers with built-in FPGA(?)
- Feasibility studies of possible back-end design: **simulation, simulation, simulation!**

Back-end: data storage and suppression of systematics

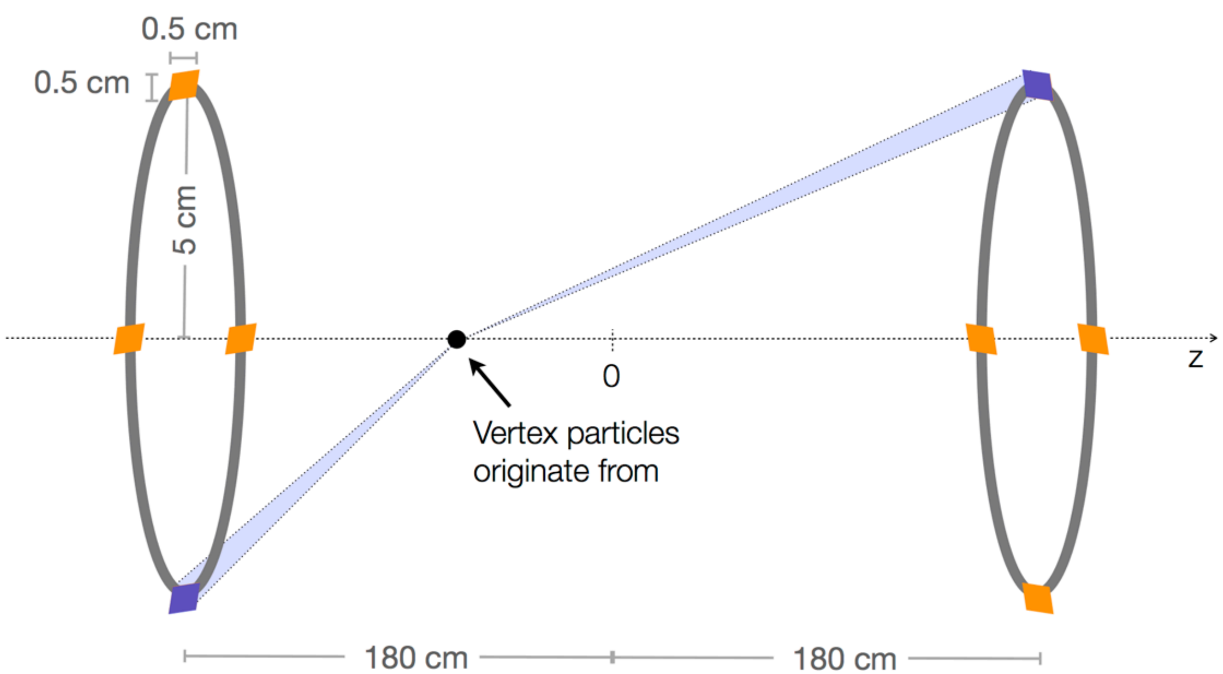
- Methods such as deconvolution or alike should reduce the amount of storage needed without significant loss of information.
- Moreover, signals with arrival time very close (non-resolved peaks) can still be distinguished; overshoot identified and saved for offline analysis.
- More details in Piotr's talk.

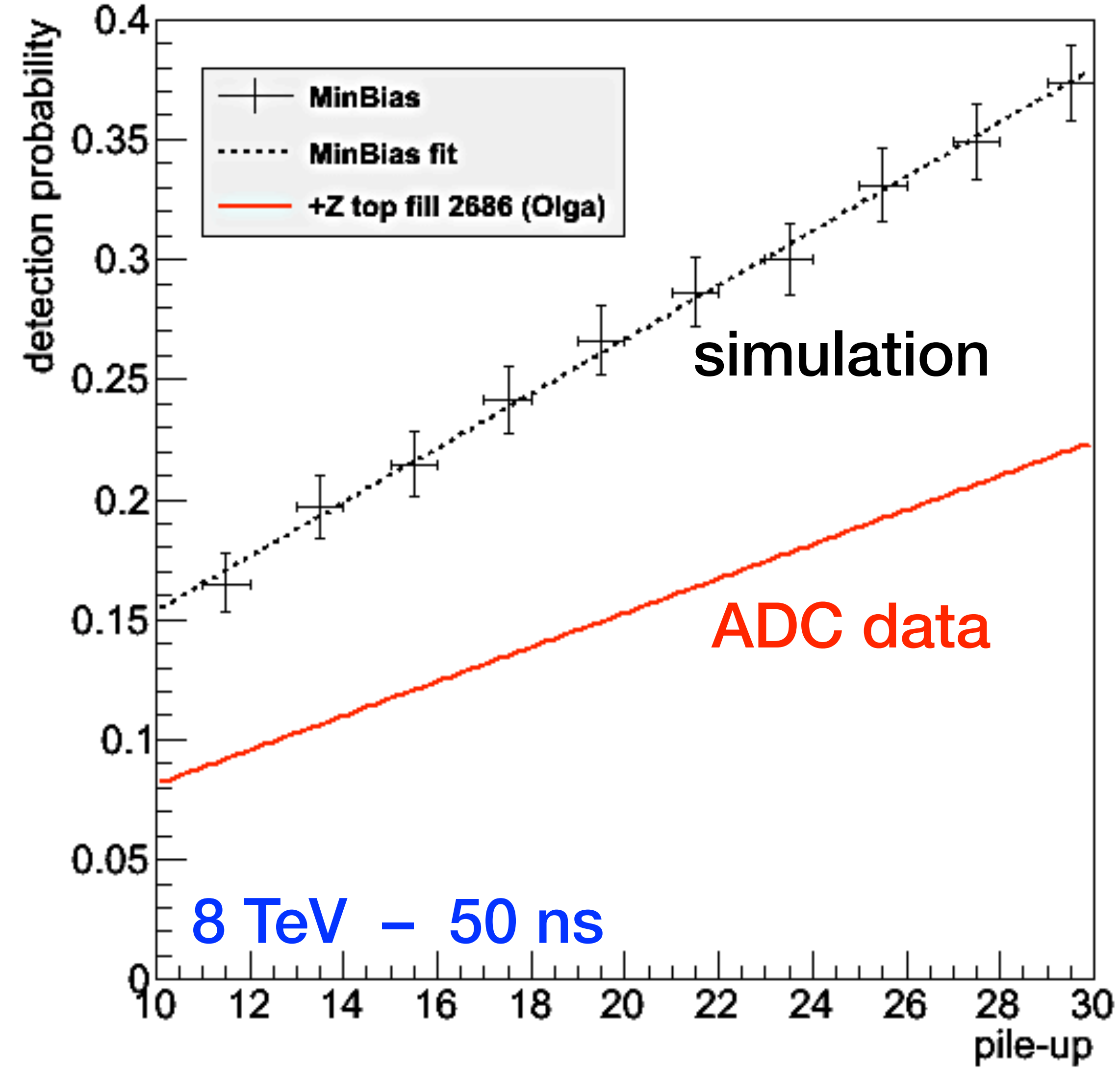


MC simulation (I)

Very preliminary

- Simulations will help optimisations and understanding of systematic effects.
- First BCM1F rate studies using simulated Pythia events within the CMSSW framework, with Minimum Bias in- and out-of-time pile-up.
- Emulation: particles in the sensitive area of BCM1F are counted as one hit.
- MC hit prob. ~ twice than from data (inefficiencies, discr. threshold, polarisation…)
    - Rate at 8 TeV with PU = 30: 3.1 (5.9) MHz for observed (expected)

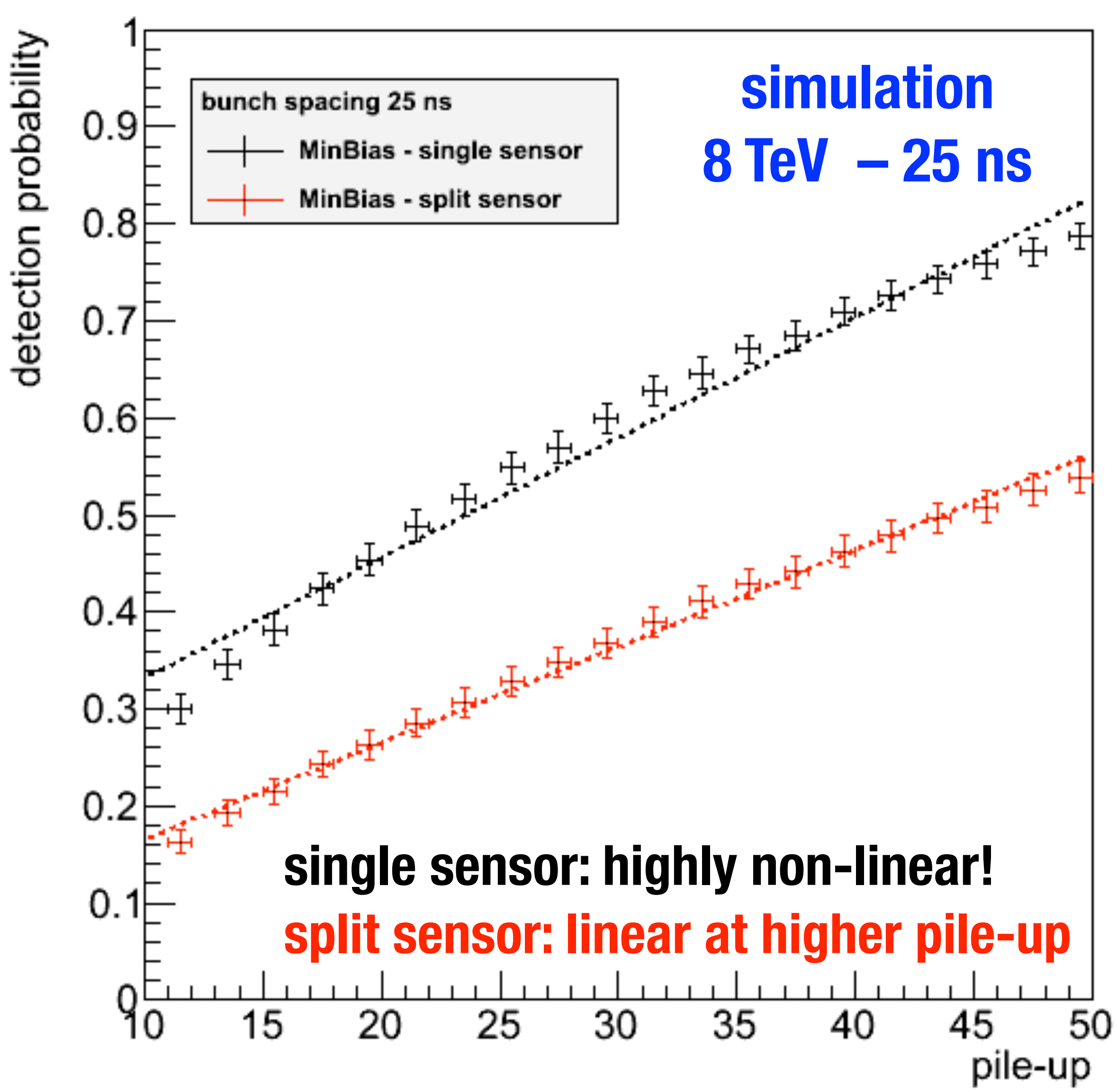


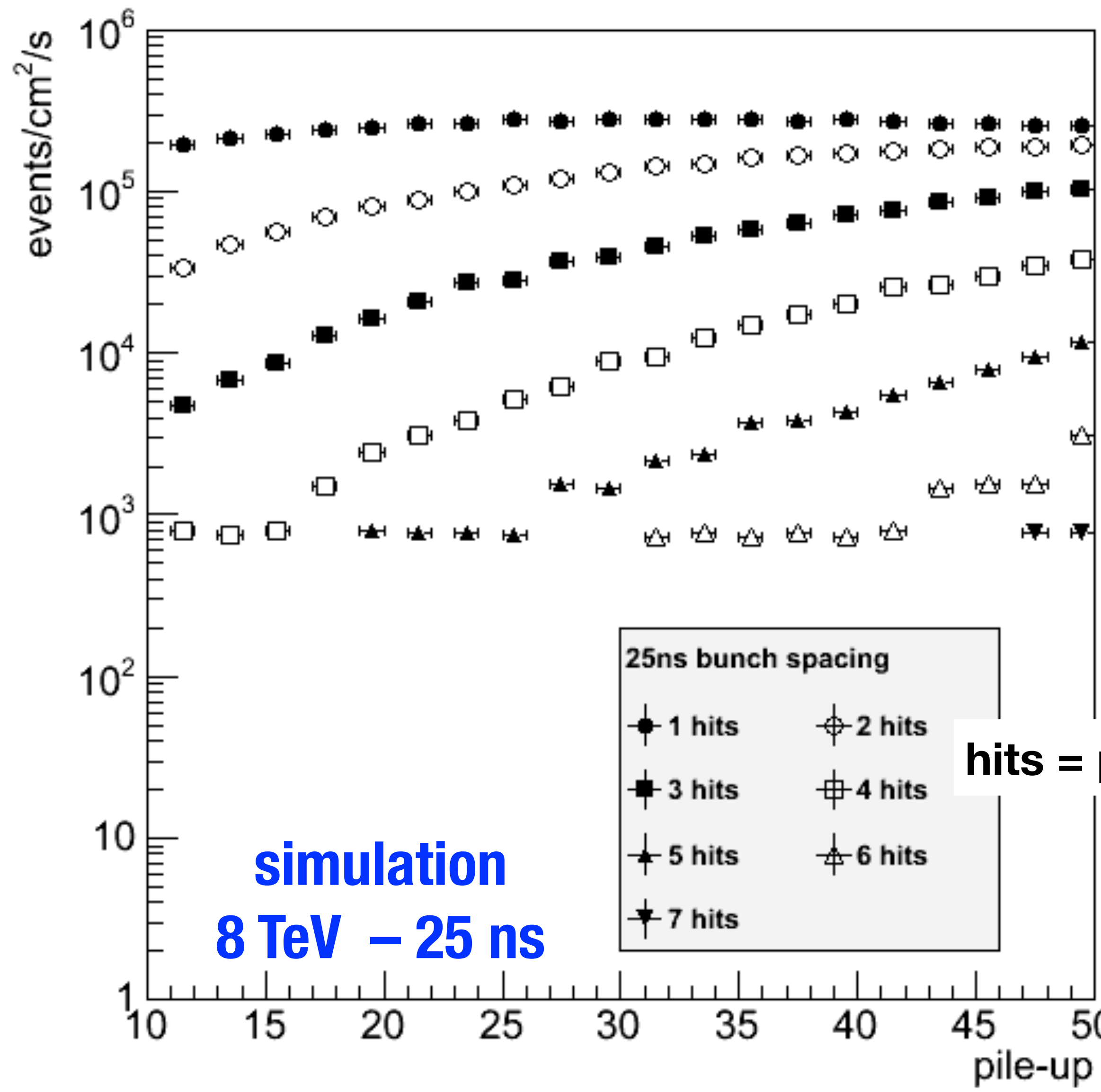


MC simulation (II)

Very preliminary

- 25 ns bunch space: Splitting the sensors should reduce non-linear effects.
- Split sensors: rate with 25 ns similar to full sensor in 50 ns.
- Increase with pile-up of simultaneous particles in the sensitive area.



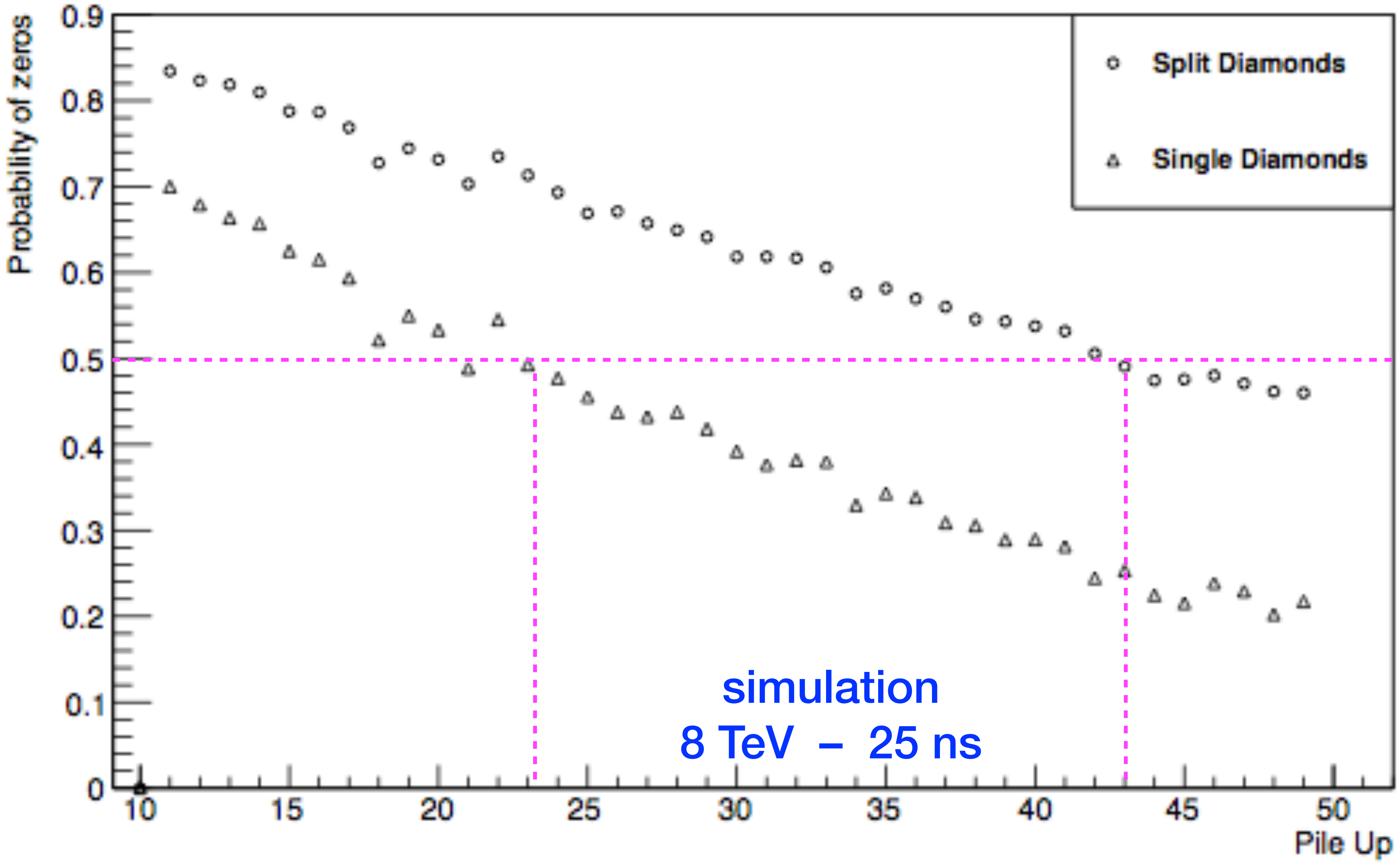


hits = particles

MC simulation (III)

Very preliminary

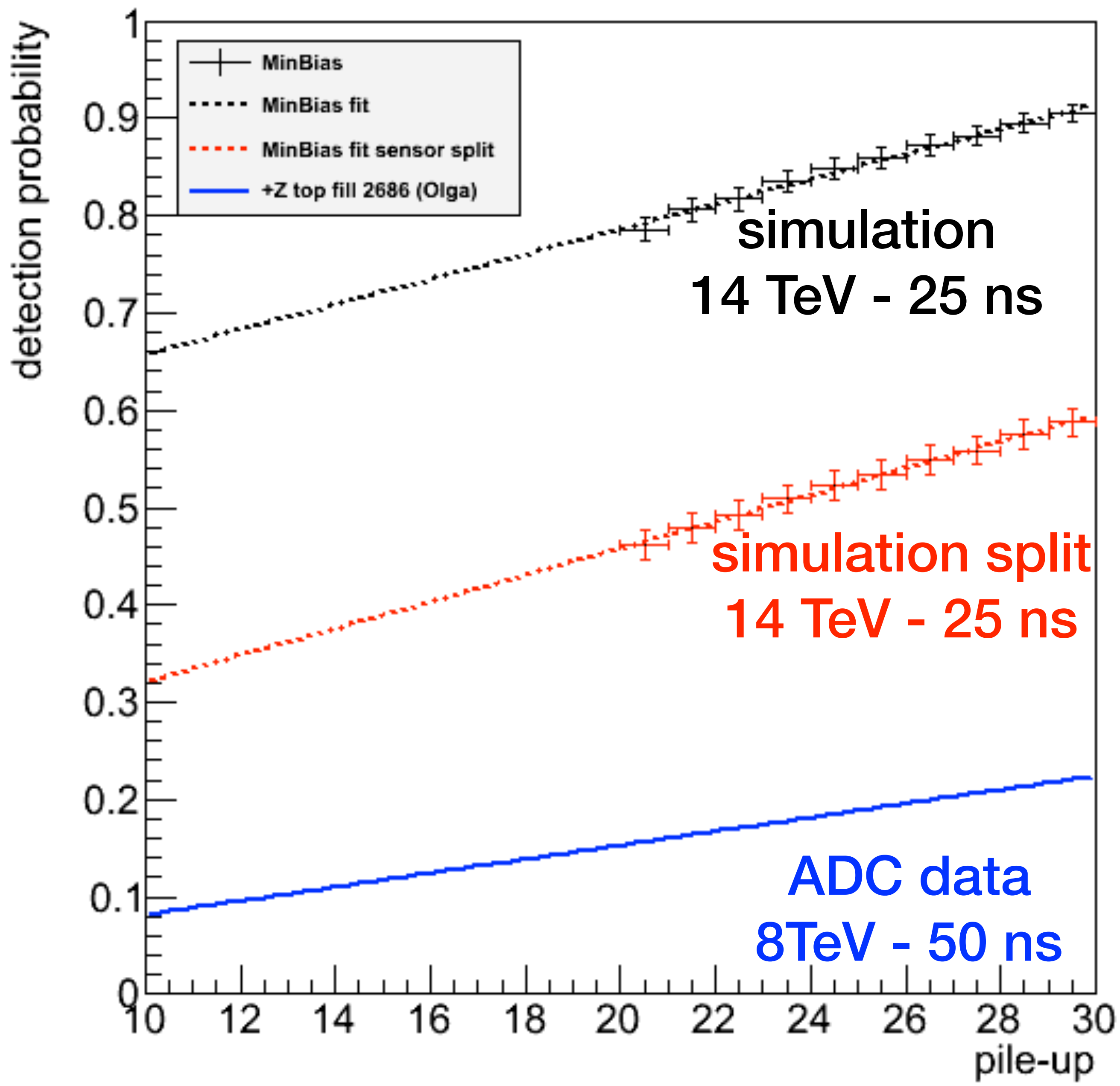
- Probability of zeros with OR logic, 24 (single) and 48 (split) channels.
- Studies will help optimise the luminosity algorithms.



MC simulation (IV)

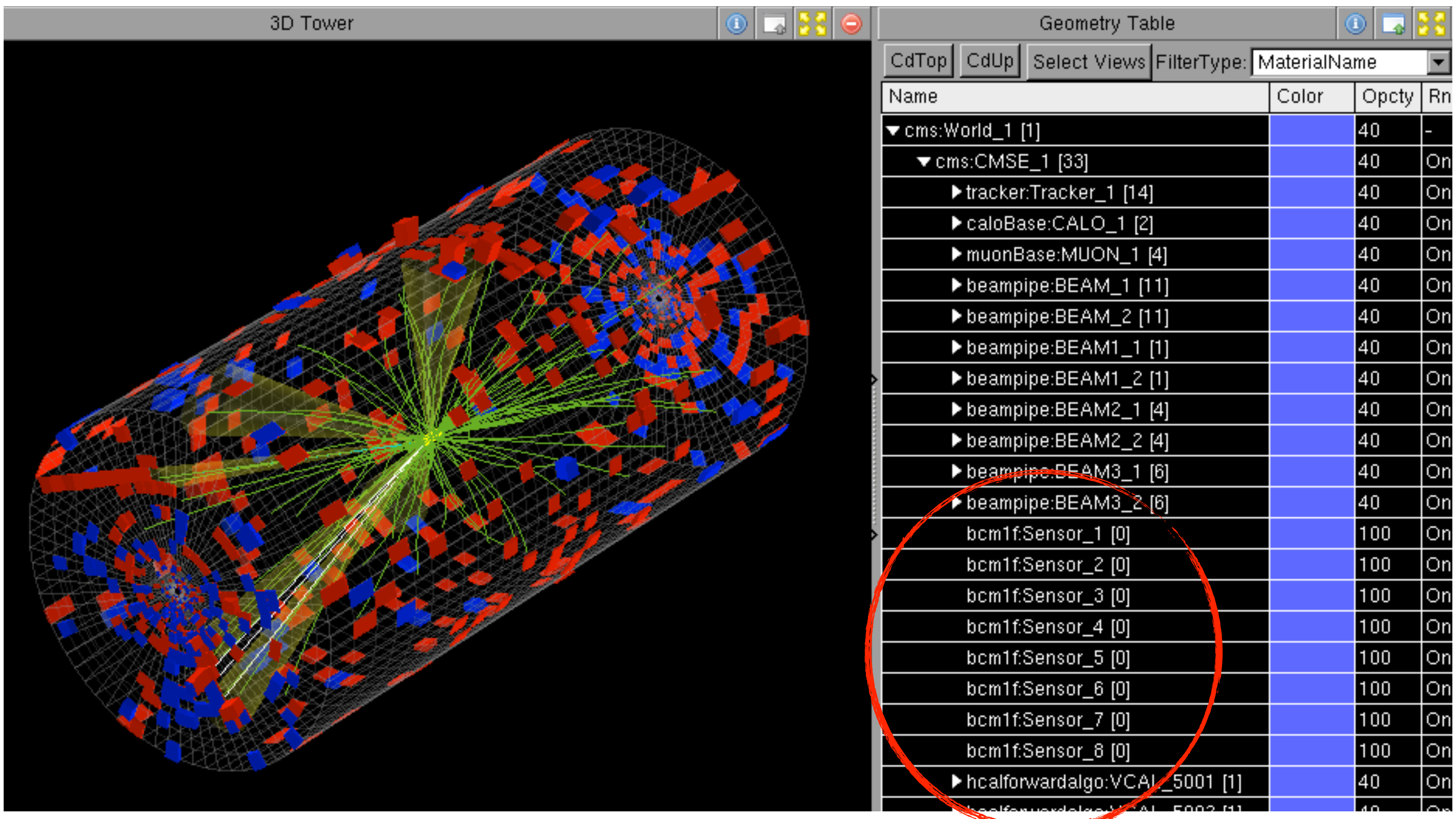
Very Very preliminary

- First samples at 14 TeV c.m. energy.
- Track multiplicity higher than at 8 TeV (as expected).
- Some technical limitations running high pile-up at 14 TeV, 25 ns.
- Rate at PU=30 with split sensor, for LHC Run II expected to be **17 MHz per channel!**
- For LHC Run I observed (but uncorrected) 3 MHz per channel at PU = 30.
- Need more investigation, cross checks.



MC simulation (V)

- Implementation of BCM1F in the CMS geometry (XML) ongoing
- Request MC samples for LS1 upgrade studies.



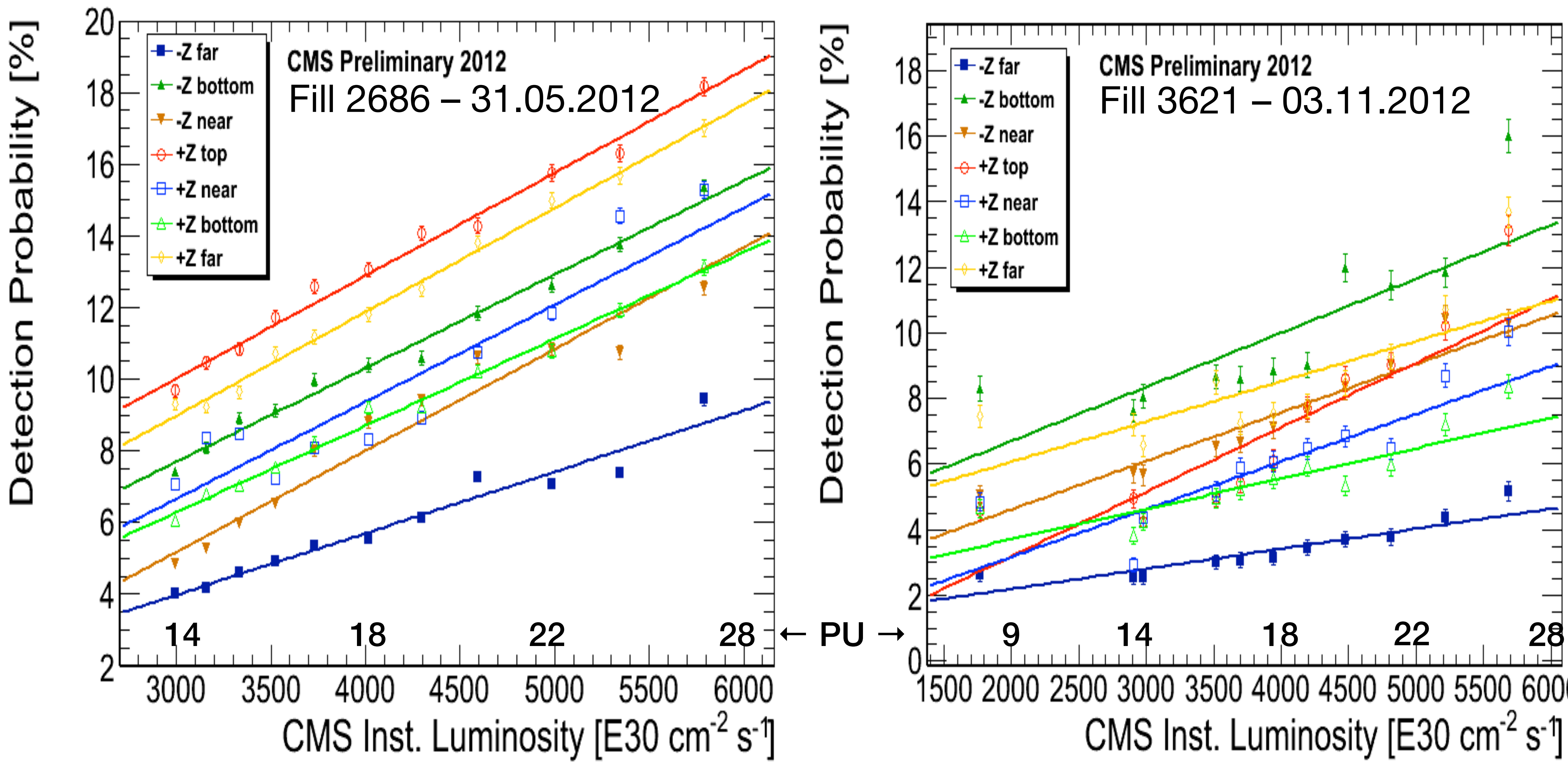
Summary – Plans

- Perform various studies with Monte Carlo:
- Determine performance of luminosity algorithms.
- Determine corrections to be applied to data.
- Understand better systematic effects.
- Guidance for the back-end design.

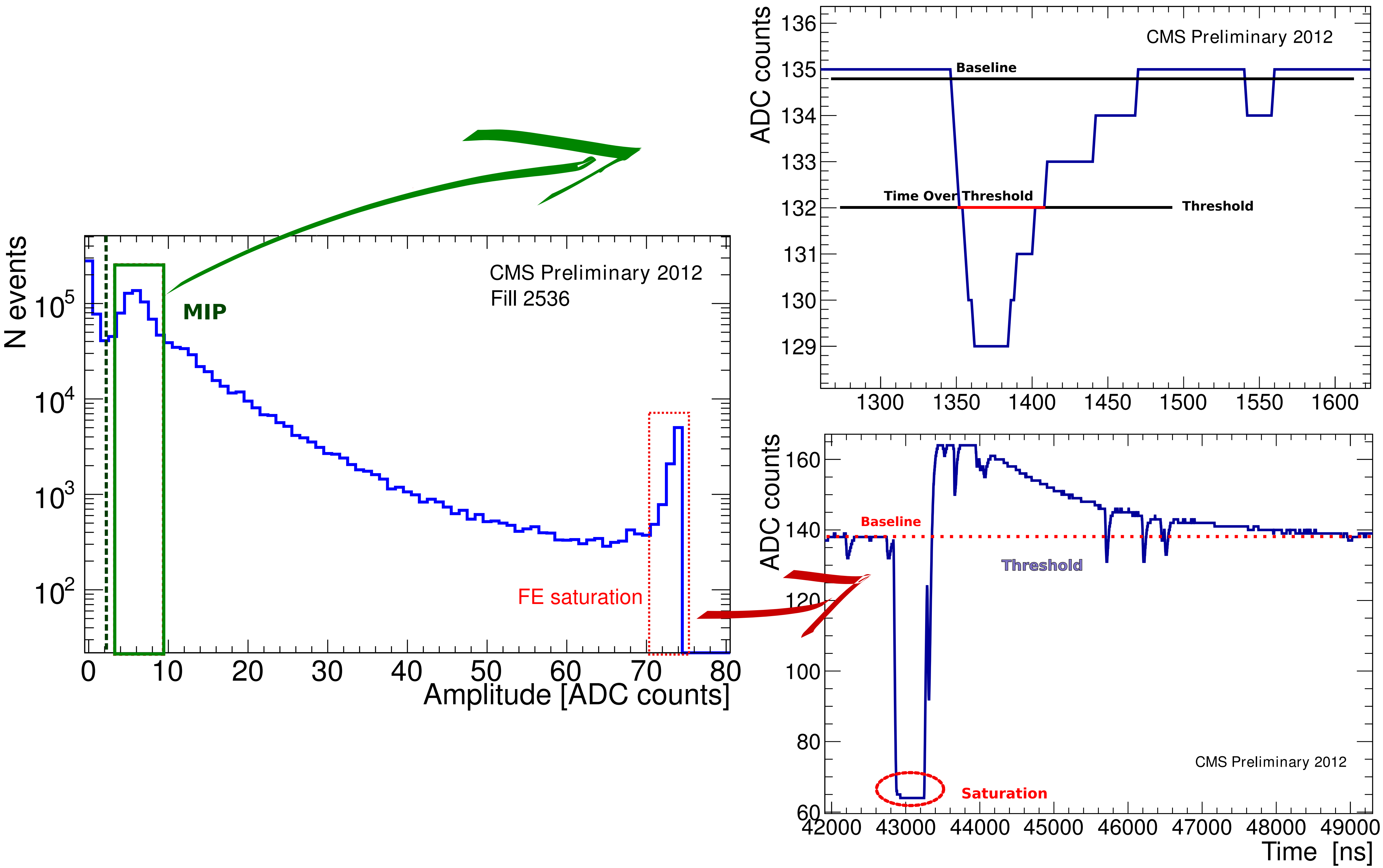
Backup

Hit detection probability from data

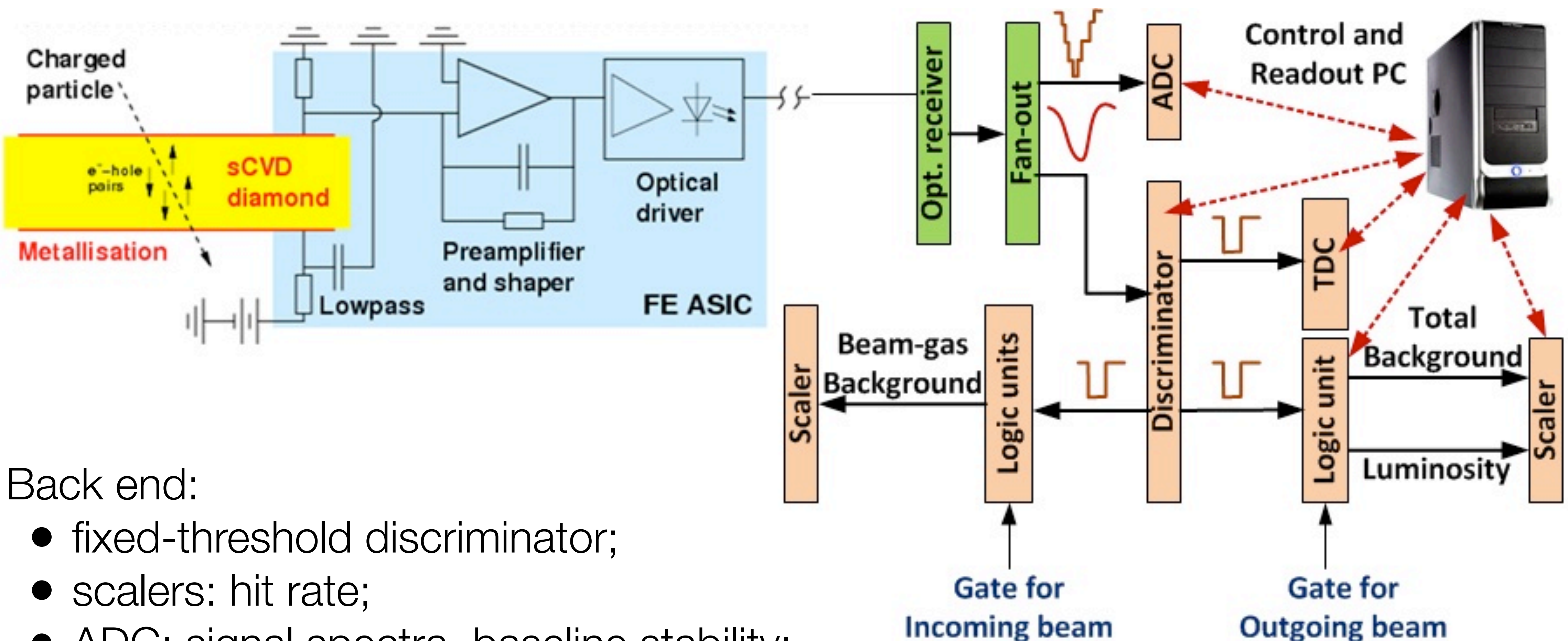
- From O. Novgorodova
- Rate ≃ 11245*1380*prob
  - Example: Fill 2686; +z top (-z far); @ 5E33 → rate ≃ 2.3 (0.85) MHz



Signal characteristics



BCM1F DAQ system



Back end:

- fixed-threshold discriminator;
- scalers: hit rate;
- ADC: signal spectra, baseline stability;
- TDC: time info, bunch structure;
- Logic units for beam-gas background rates and luminosity monitoring;
- Delay units, synchronisation with BPTX

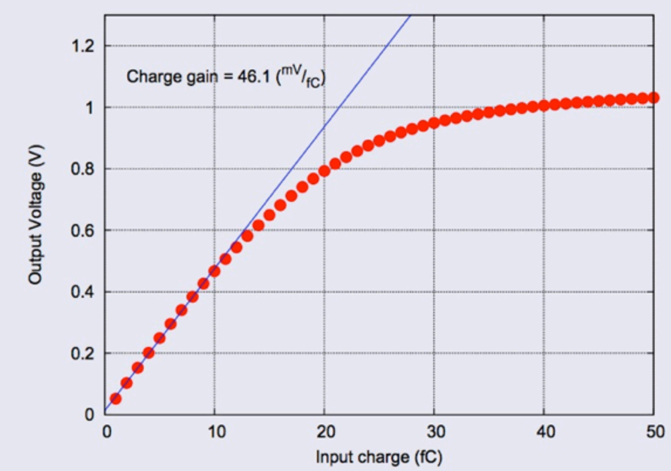
BCM1F front end upgrade (simulations)

Dominik Przyborowski, UST Kraków

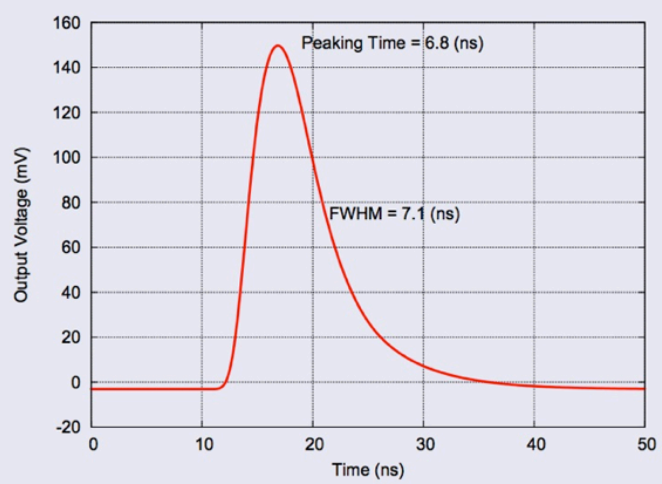
The Design Goals

- 2 – 5 pF detector capacitance range
- Linearity range ∼ up to 20 fC
- 50 mV/fC of charge gain
- Equivalent Noise Charge $< 1\text{ke}^-$
- Quasi–Gaussian shaping with T_P and FWHM < 10 ns
- Fast baseline recovery after overdrive detector signal

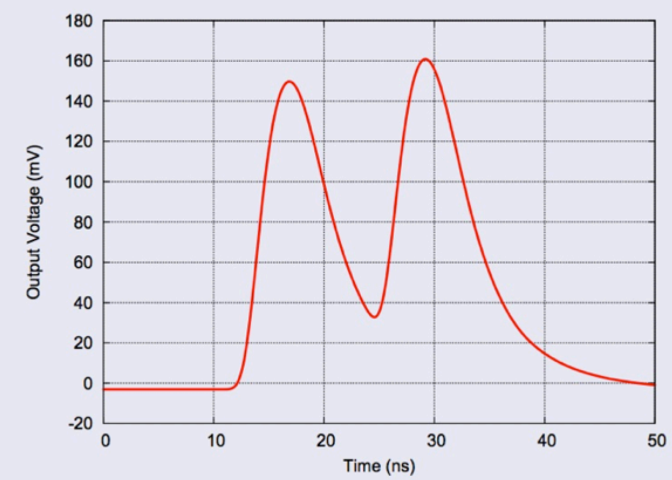
Linearity and Gain



Front–End response on MIP signal



Distinguishability of MIPs with 12.5 ns interval



- Main goals: higher gain, faster peaking time and smaller FWHM, timing resolution able to separate incoming machine induced background hits from outgoing collision hits.

Albedo effect

- Collisions produce long tails, of exponential and constant shapes.
- The long exponential component has a ‘lifetime’ of (2.12 ± 0.02) μs.
- Simulation (FLUKA) was performed and show good agreement with the data. Tails are mostly populated by electrons and positrons (up to 400 bunch crossing) and by neutrons and photons.