Relative luminosity measurement with the ATLAS forward calorimeter

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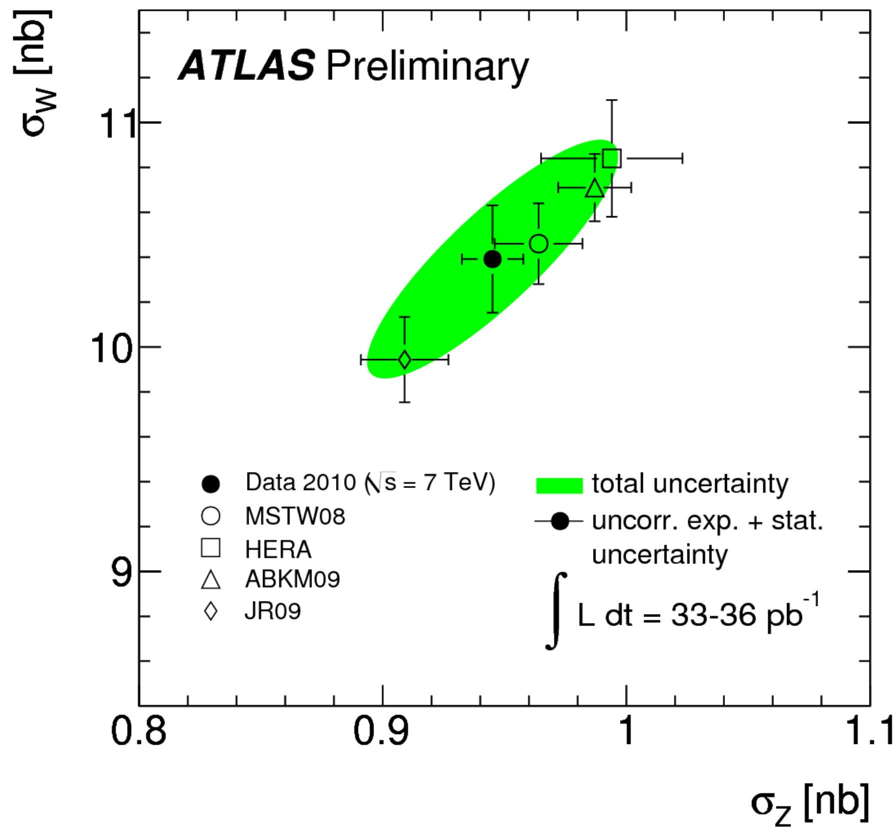
Introduction

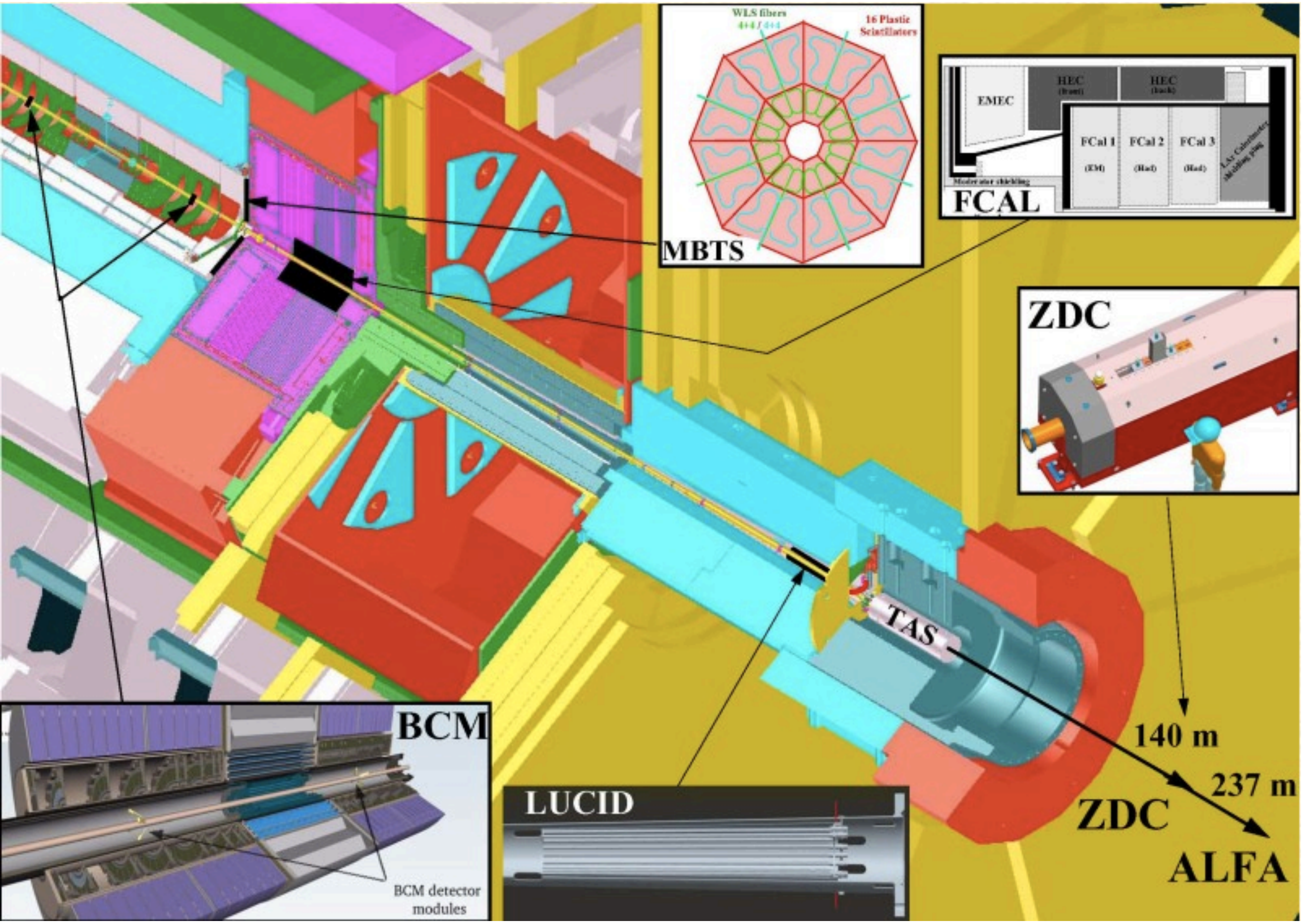
- At the LHC :
  - Standard Model cross section measurements, deviation of σ x BR w.r.t SM predictions (New physics)
  - Shorter term: jets, W and Z cross-section measurements
- Luminosity
  - "collision rate" of a collider
  - The highest the luminosity is, the fastest you will acquire collision data

$$N = \mathcal{L} \cdot \sigma$$



Uncertainty on cross-section measurement is dominated by luminosity measurement
➔ Need for a precise luminosity determination

ATLAS luminosity detectors



- LUCID : Cerenkov detectors
- BCM : diamond-based Beam Conditions Monitors
- ZDC : Zero-Degree Calorimeters
- MBTS : Minimum Bias Trigger Scintillators
- ALFA : Absolute Luminosity For ATLAS
- FCal : Liquid Argon Forward Calorimeters

Many handles on luminosity!

Luminosity with the LAr FCal

- Goal: Provide an additional handle on luminosity
- Why?
  - Additional redundancy for luminosity measurement
  - Linear with luminosity :
    - Very strong advantage compared to the other luminosity measurements
    - Could give handle on understanding mu-dependancy (see backup slides)
- How?
  - Calibration w.r.t. other luminosity measurements
    - LUCID, BCM, … which are independently calibrated from vdM scans
- Steps :
  - Compare FCal/LUCID
  - Extract calibration (linear fit)
  - Apply calibration to all data
  - Understand/correct possible miscalibration
  - Give calibration to luminosity group for online luminosity monitoring using FCal

Measurement principle

Total HV current → Number of pairs created in the detector → Total energy deposited in the detector → Luminosity

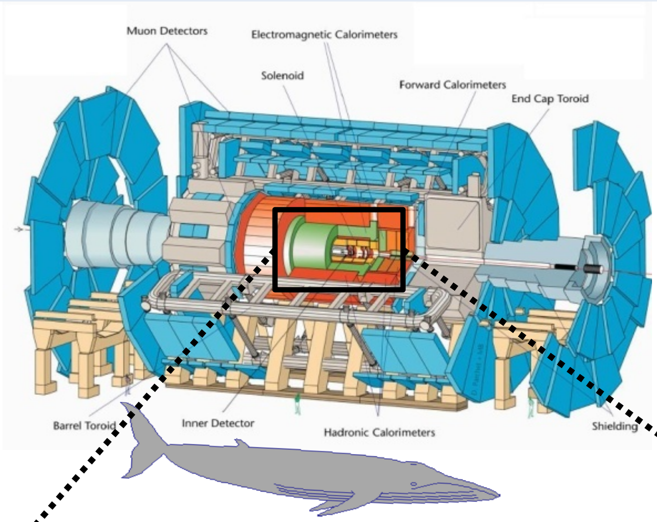
$$I = N_{pairs} \cdot e = \left(P_R \cdot f \cdot \frac{K}{W} \right) \cdot e = \left[\left(L \cdot \sigma \cdot E_{event} \right) \cdot f \cdot \frac{K}{W} \right] \cdot e$$

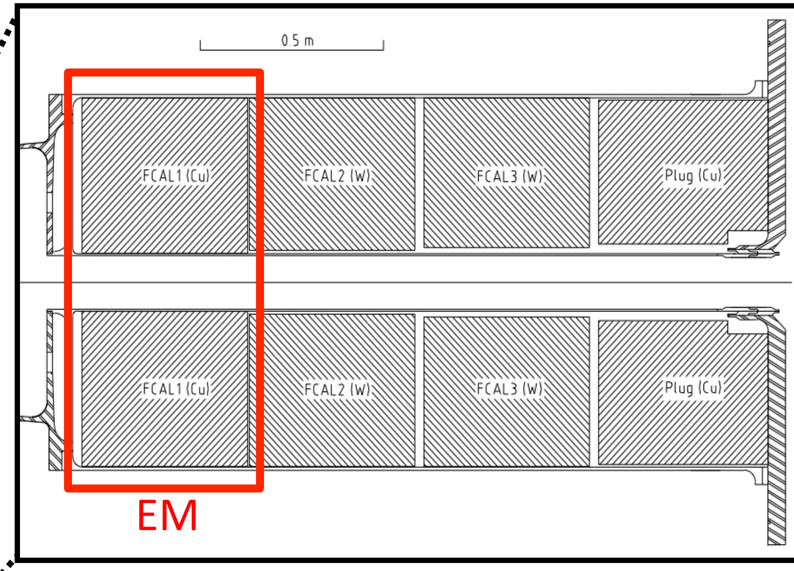
f: calorimeter sampling fraction
K: suppression factor for electron response wrt mip
W: liquid Argon ionization potential

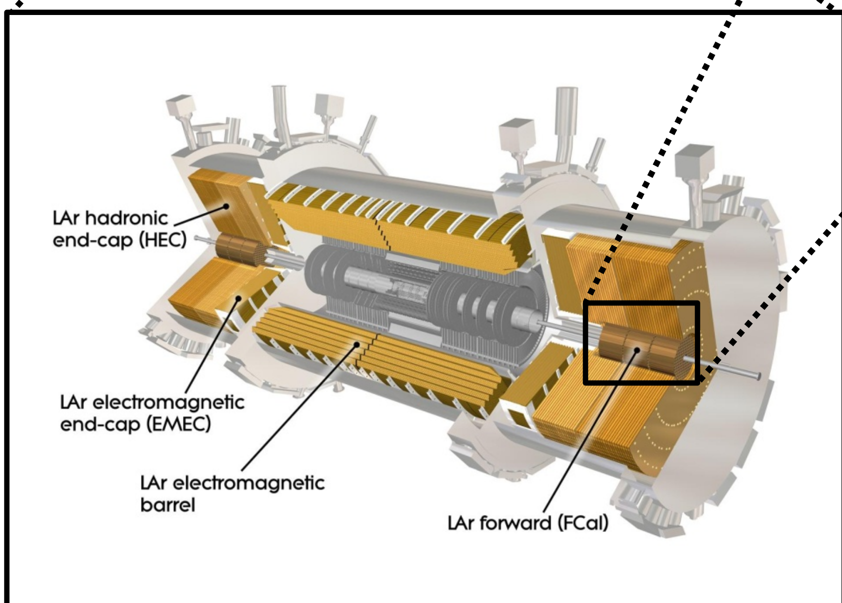
Pros:
- Trigger independent
- DAQ independent
- Linear with luminosity

Cons:
- Low sampling rate (0.2Hz)
- No bunch-by-bunch capabilities

LAr Forward Calorimeter (FCal)



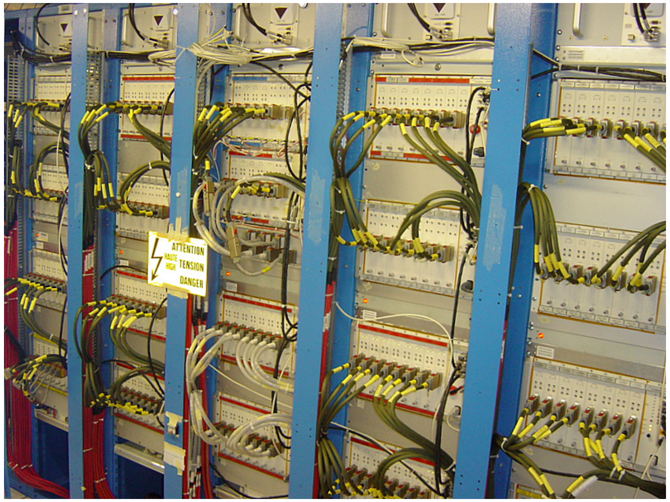




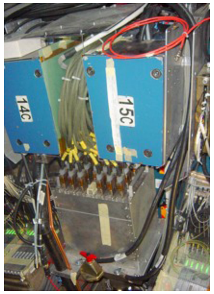
- Coverage : $3.2 < |\eta| < 4.9$
- FCal 1 : EM part of the Fcal
- Copper matrix
- 12000 electrodes (tubes)
- 1008 calorimeter cells (tube groups)
- High Voltage ~ 1kV/mm

High-Voltage System

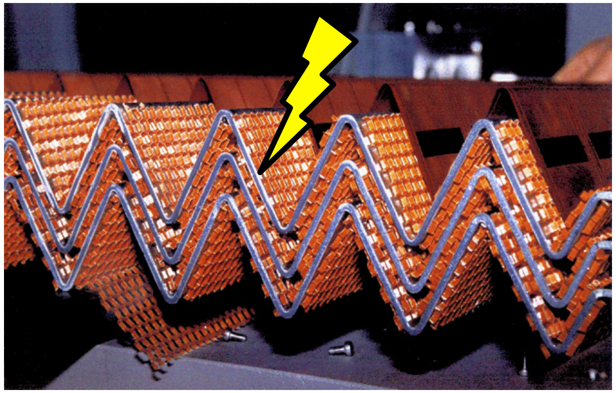
- E ≈ 1 kV/mm in each liquidargon gap
- Adjustable voltage up to 3kV / HV line
- Slow control infrastructure (DCS) for operation and monitoring → V, I, …
- ~4500 HV lines ↔ ~182000 calorimeter cells
- Power supply ↔ Detector: ~110m cables



High-voltage system



Feedthrough

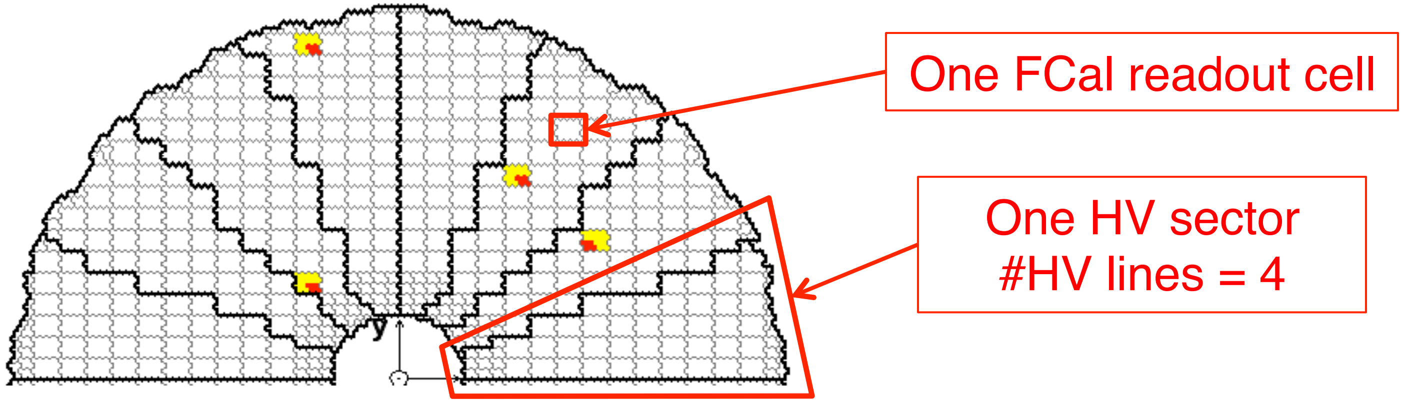


Calorimeter electrodes

Room Temperature

Cryostat: 88K (Liquid argon)

FCal HV distribution



FCal 1 (EM)

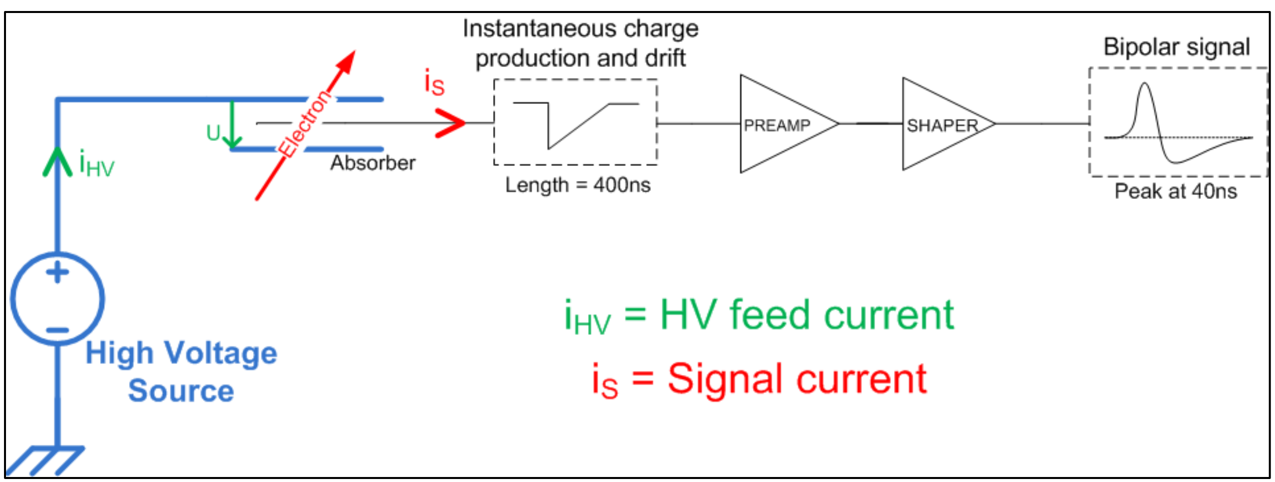
<u>FCal 1 module</u>

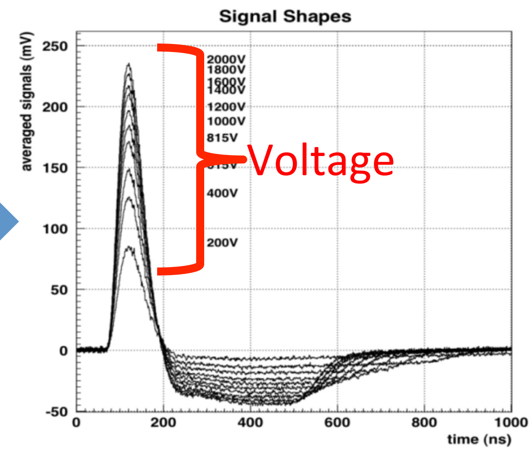
- 1008 readout cells
- 16 HV sectors
- 64 HV lines
  - Each sector is fed by 4 separate HV lines
  - Each HV line feeds ¼ of a readout cell (for redundancy)
    - Innermost (and edge) cells are fed by only one HV line

===> Current measured in one HV line corresponds roughly to ¼ of the current induced in the HV sector by minimum bias events

Signal generation

- Charged particle traverses liquid argon gap
  - Liquid argon ionisation
  - Electrons produced drift due to electric field
  - Singal current i_s is generated proportional to energy deposited
  - To maintain electric field constant, HV system injects i_{HV} to compensate

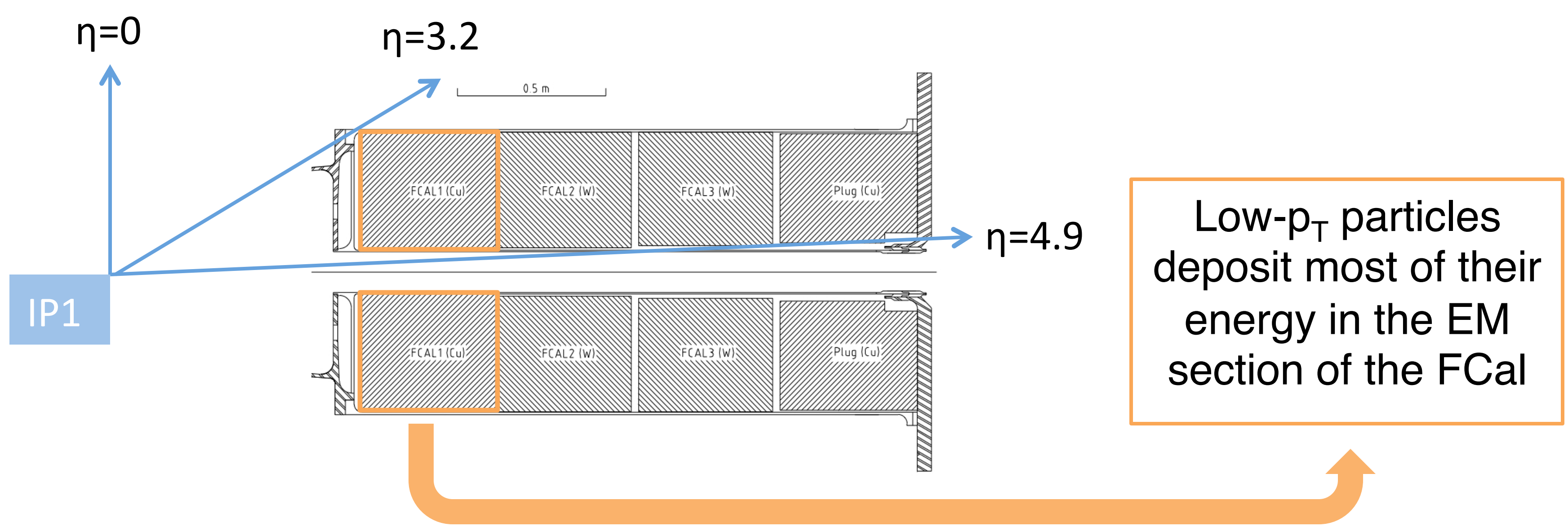




$$i_S \propto U^{0.38} \Rightarrow \frac{\Delta i_S}{i_S} = 0.38\,\frac{\Delta U}{U}$$

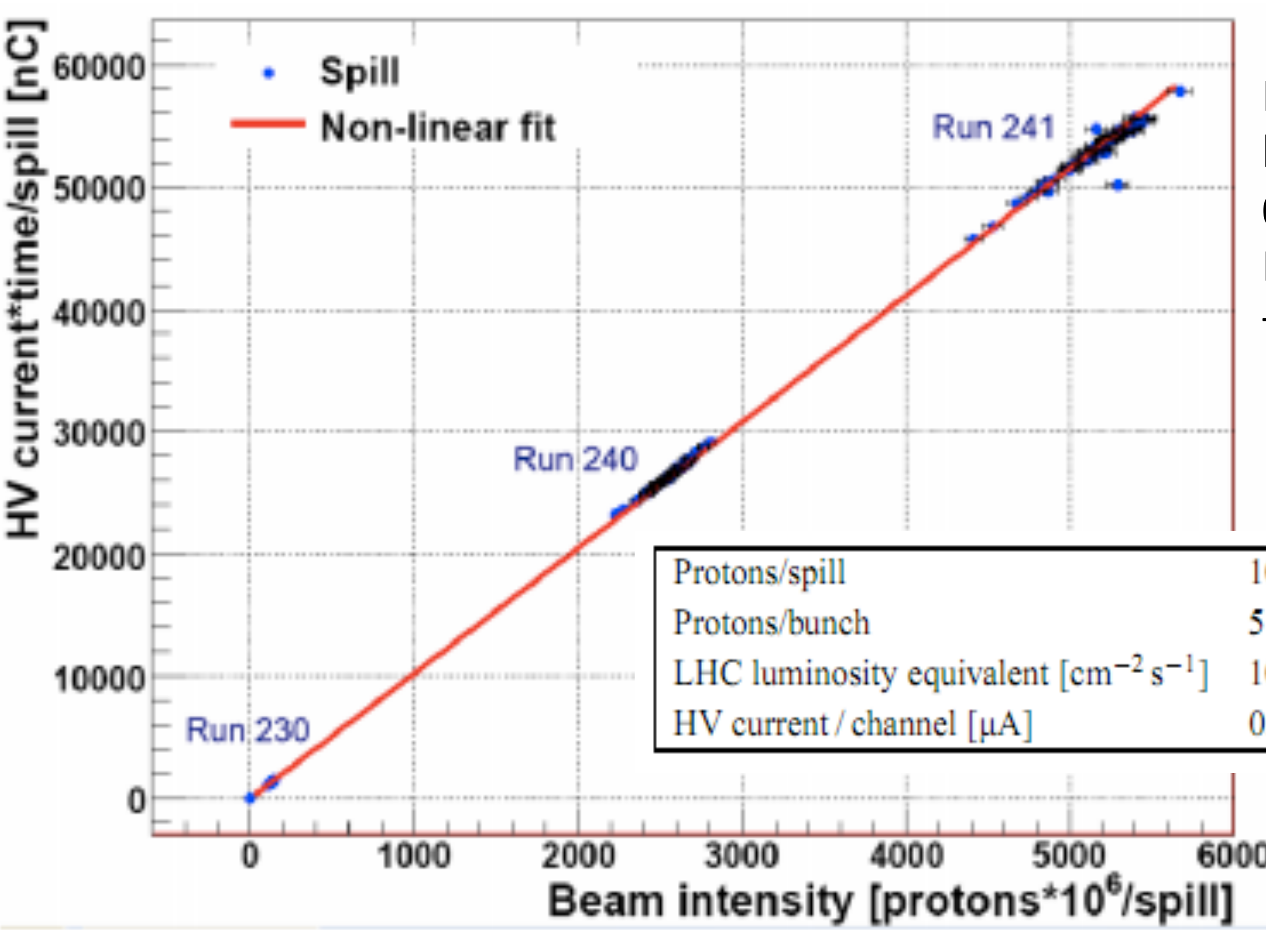
Minimum bias events

- « Soft » interactions
- $\sigma_{TOT} \approx 70$mb
- ~ 10^{13} interactions/bunch crossing @ LHC lumi. (10^{34} cm^{-2} s^{-1})
- Products: mostly low p_T neutral pions (=> photon pairs)
- Flux increases with η => Most of the energy is deposited in the forward region



Why assume linearity?

http://cdsweb.cern.ch/record/1265045



Protons/spill	10^7	10^8	10^9	10^{10}	10^{11}	10^{12}
Protons/bunch	5	50	500	5000	$5 \cdot 10^4$	$5 \cdot 10^5$
LHC luminosity equivalent [$cm^{-2} s^{-1}$]	10^{32}	10^{33}	10^{34}	10^{35}	10^{36}	10^{37}
HV current / channel [µA]	0.12	1.2	12	120	1200	12000

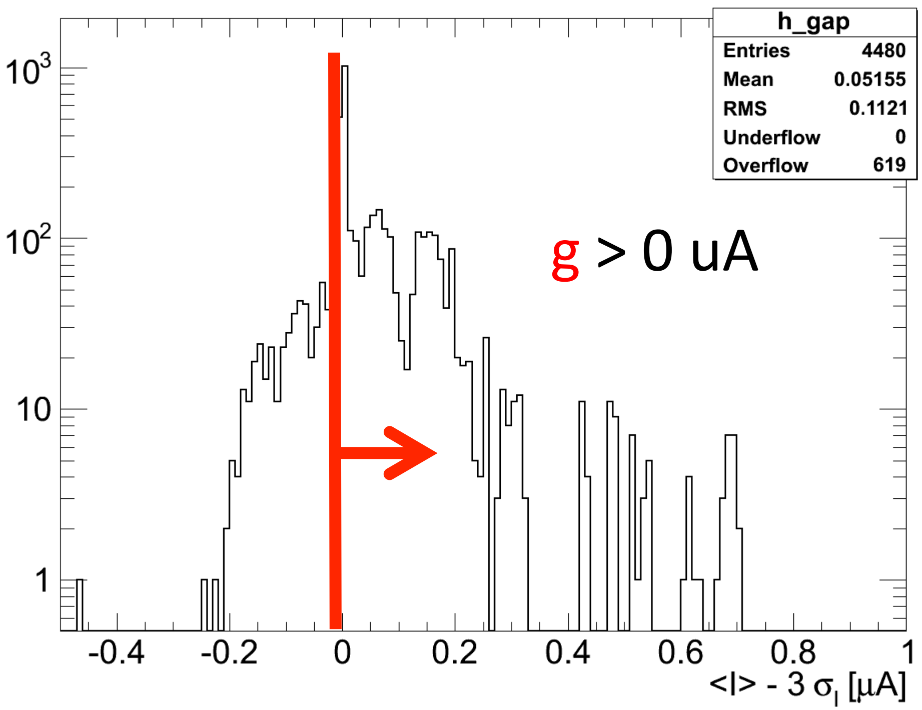
HiLum group quotes a non-linear fraction smaller than 0.36% for the entire equivalent LHC luminosity range. Based on test beam studies at Protvino.

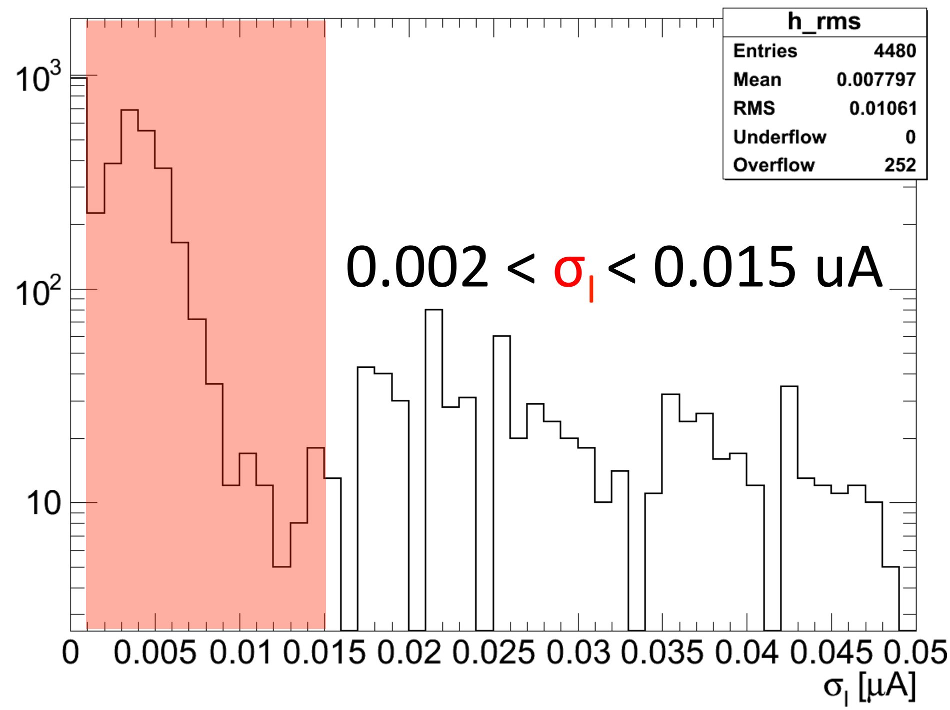
➔ Safe to assume linearity

Channel selection – 2010 (1/2)

- To define if and HV line current measurement can be used to determine the luminosity
  - It must not be connected to a shorted FCal tube
    - Very high current (> 120 uA)
    - Unstable current flow (inherent to short, unpredictable)
  - It must have a measurable pedestal
    - Since the measurement is relative, need for an accurate pedestal determination
  - It must have low noise
- To make the selection
  - Look at 1h measurement before each LHC fill
    - 720 measurements at 0.2 Hz sampling rate
  - Three variables
    - $<I>$: average current over 1h
    - σ_I : RMS of distribution over 1h
    - $g = <I> - 3*\sigma_I$: gap
      - This ensures the noise fluctuations are positive around a positive value

Channel selection – 2010 (2/2)





➔With theses criteria, channel selection yields to

➔16/64 HV lines on side A

➔15/64 HV lines on side C

Analysis

- Subtract pedestal from current measured

$$I_{FCal} \rightarrow I_{FCal} - pedestal$$

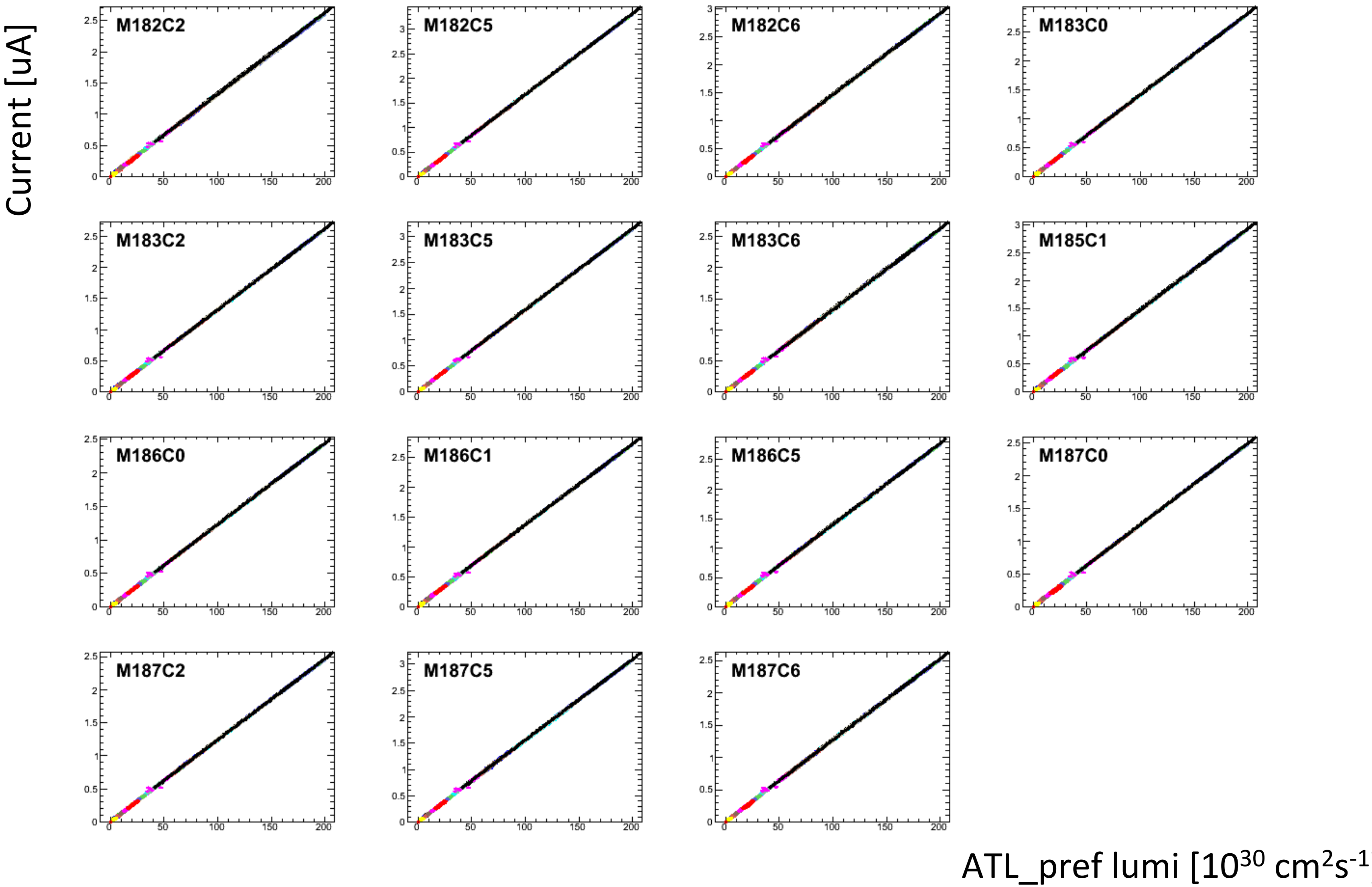
- Fit 1st degree polynomial

$$I_{FCal} = a \cdot L_{ATLAS} + b$$

- Apply calibration to I_{FCal} to obtain L_{FCal}

$$L_{FCal} = \frac{1}{a} \cdot I_{FCal} - \frac{b}{a}$$

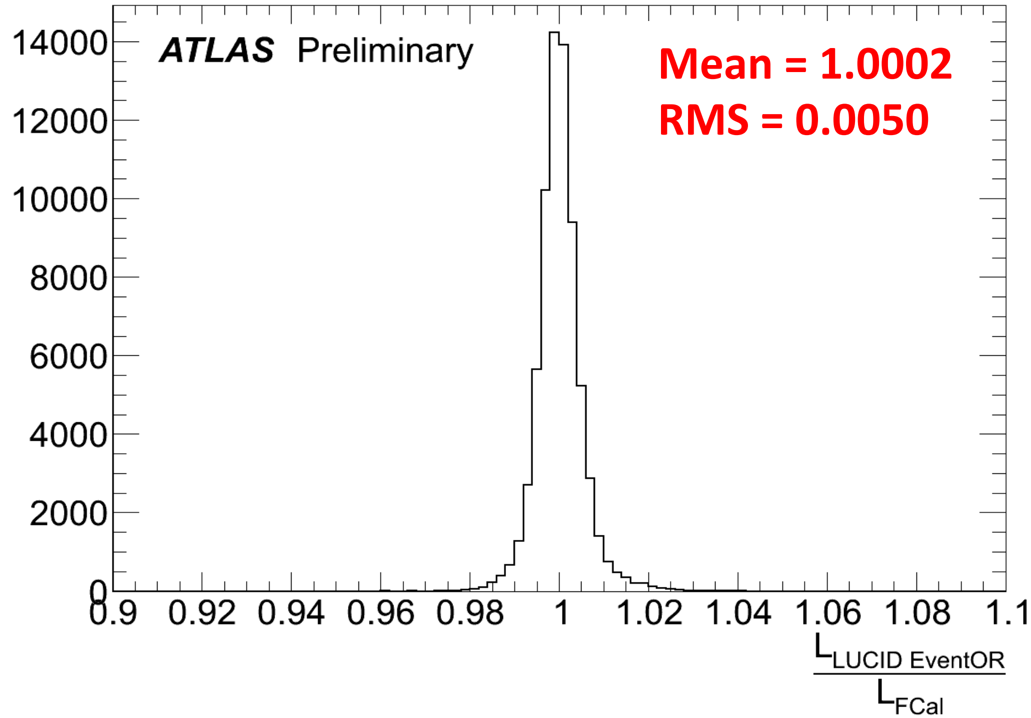
Calibration with 2010 data (1/2)



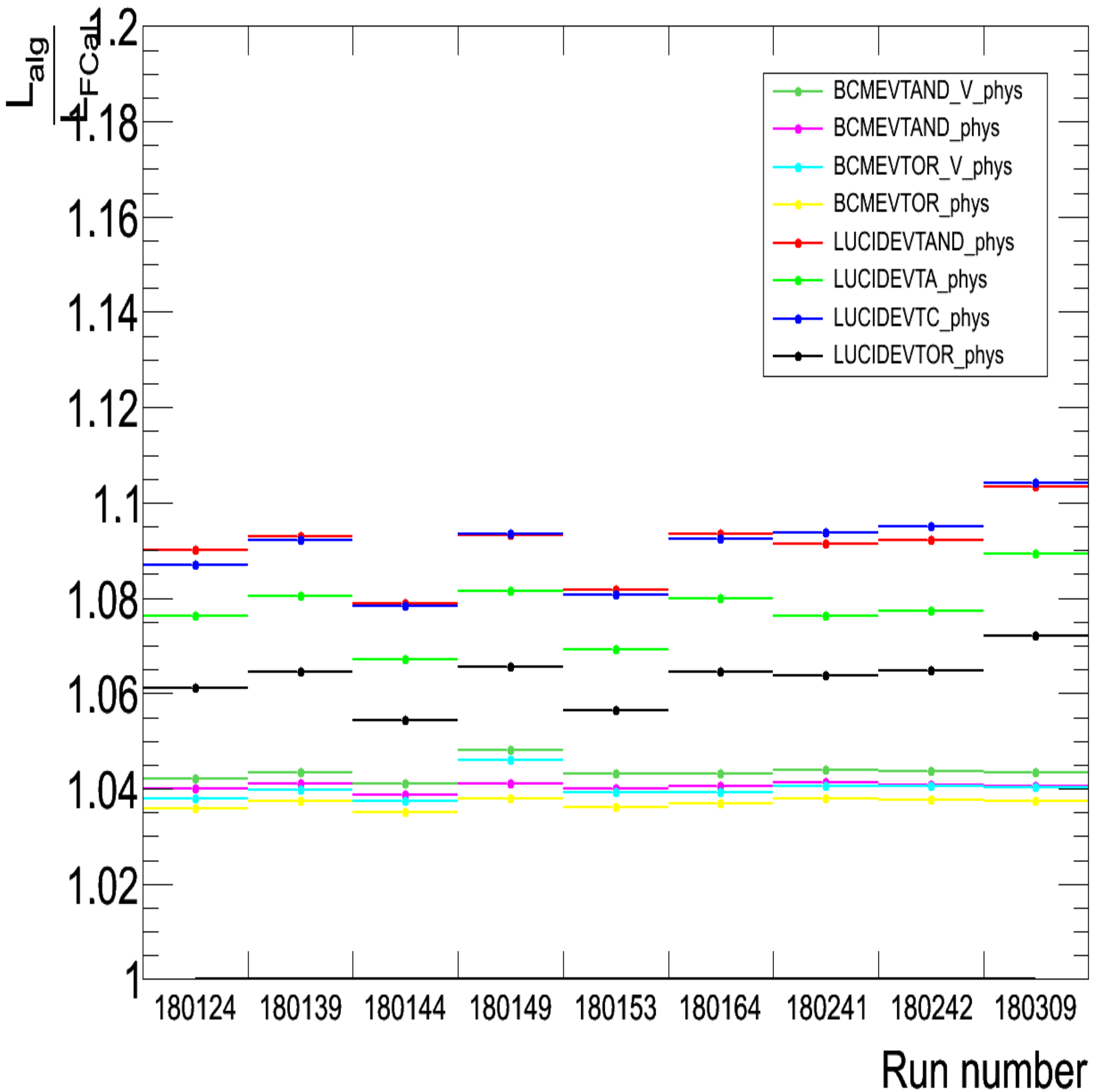
Calibration with 2010 data (2/2)

- Procedure

1. Select good HV lines
2. Fit each current LUCID luminosity → One ATLAS run only: 166786
3. Apply single HV line calibration to all runs but 166786 (17 total)
4. Calculate **L_LUCID / L_FCal** for run each HVline/A/C/run/LB



2011 FCal luminosity



<u>Ratios 2011:</u> All larger than 1

<u>2010 ➔ 2011</u>

LUCID

Changes not expected

FCal overestimates it by approx. 6%

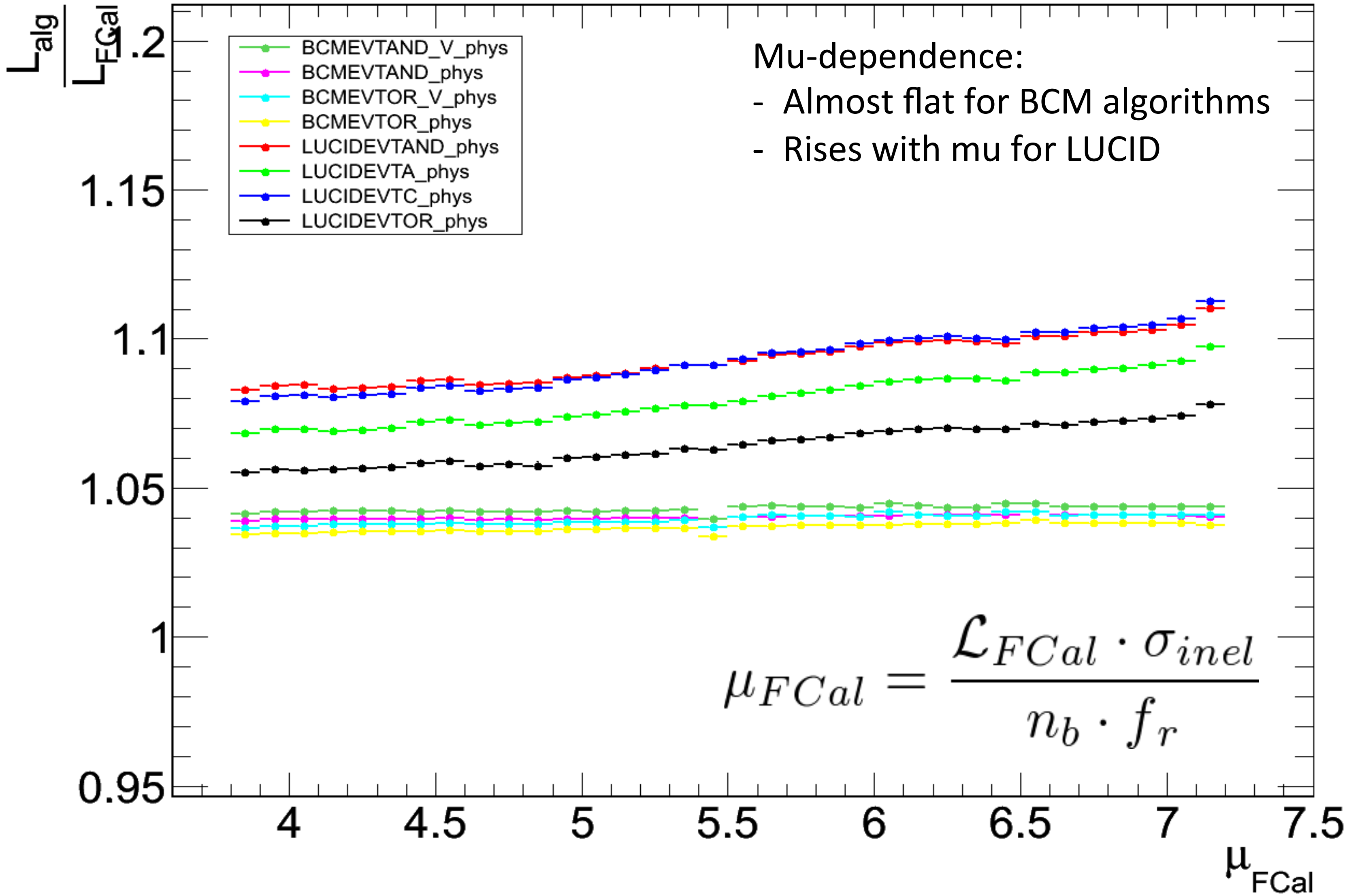
BCM

Some changes expected (work on the hardware done during winter shutdown)

FCal overestimates it by approx. 4%

➔ Rescaling of LUCID & BCM using FCal measurement

2011 FCal luminosity



Rescaling the 2011 luminosity

Period	Run Range	Lumi (pb^{-1})	Lucid σ_{vis} scale (OR/AND)	BCM σ_{vis} scale (OR/AND)	Notes
A	177531 - 177965	8	1.035/1.08*	1 / 1	Magnets partly off
B	177986 - 178109	17	1.035/1.08*	1 / 1	before RX card swap
D1-D3	179581 - 180122	36	1.06/1.15	1 / 1	after RX card swap
D3-E	180124 - 180710	200	1.06/1.15	1.037 / 1.075	after BCM threshold
F1	180776	1	1 / 1	1 / 1	OLC updated

* Educated guess, not in FCal study
no attempt to correct for magnet-off data

Scaling factors for 2011 dataset

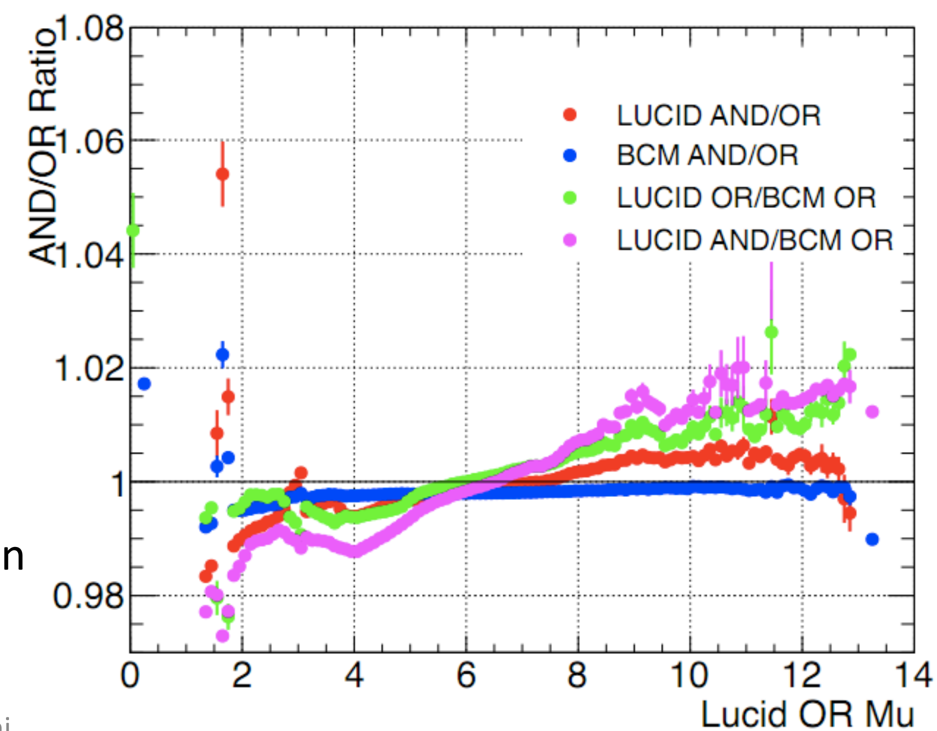
➔ Numbers from FCal analysis

➔ Officially in place since May

Ratios after rescaling

BCM
➔ Compatible with 1, ~flat mu-dependence

LUCID
➔ Strong mu-dependence, under investigation



Summary

- Importance of precise luminosity measurement
  - For cross-section measurements
  - For discoveries and exclusions
  - Need as many handles as possible
- Using the ATLAS Forward Calorimeter
  - Linear response up to LHC design parameters
  - Independent from trigger and data acquisition
- Calibration of FCal with 2010 data
  - Stable within 0.5%
- Cross-calibration of LUCID and BCM in 2011
  - Calibrated FCal luminosity use to extract scaling factors
  - Additional cross-check with Tile calorimeter
  - New total systematic uncertainty: 4.5%