ATLAS EXPERIMENT

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

ATLAS Luminosity Measurements

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On behalf of the ATLAS Collaboration

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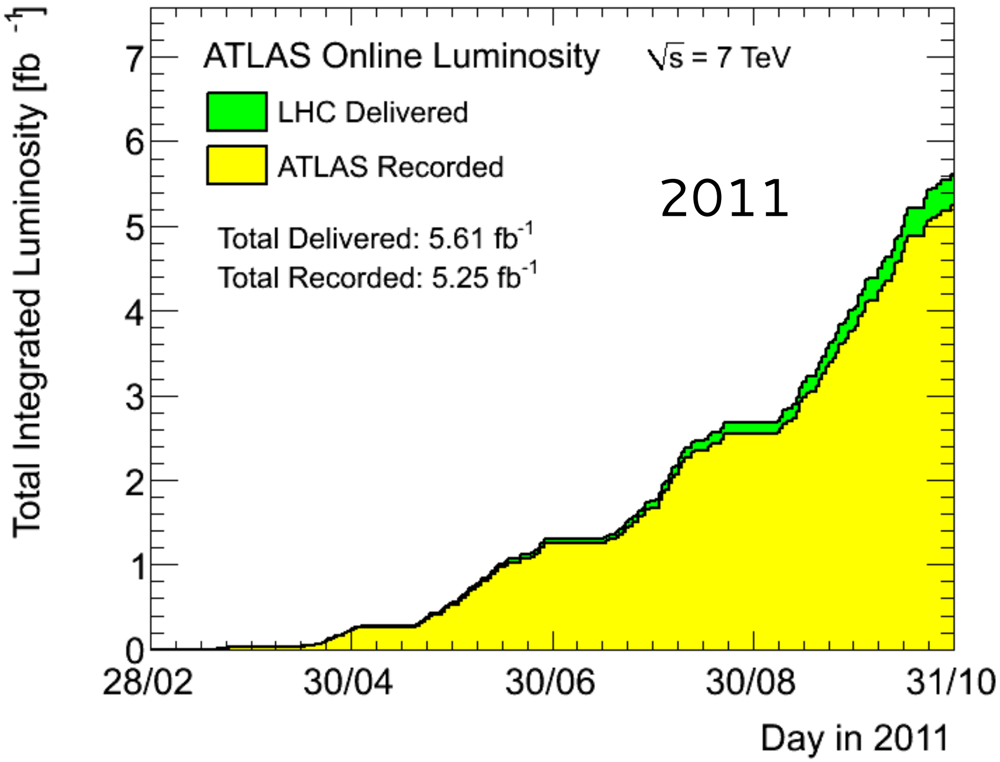
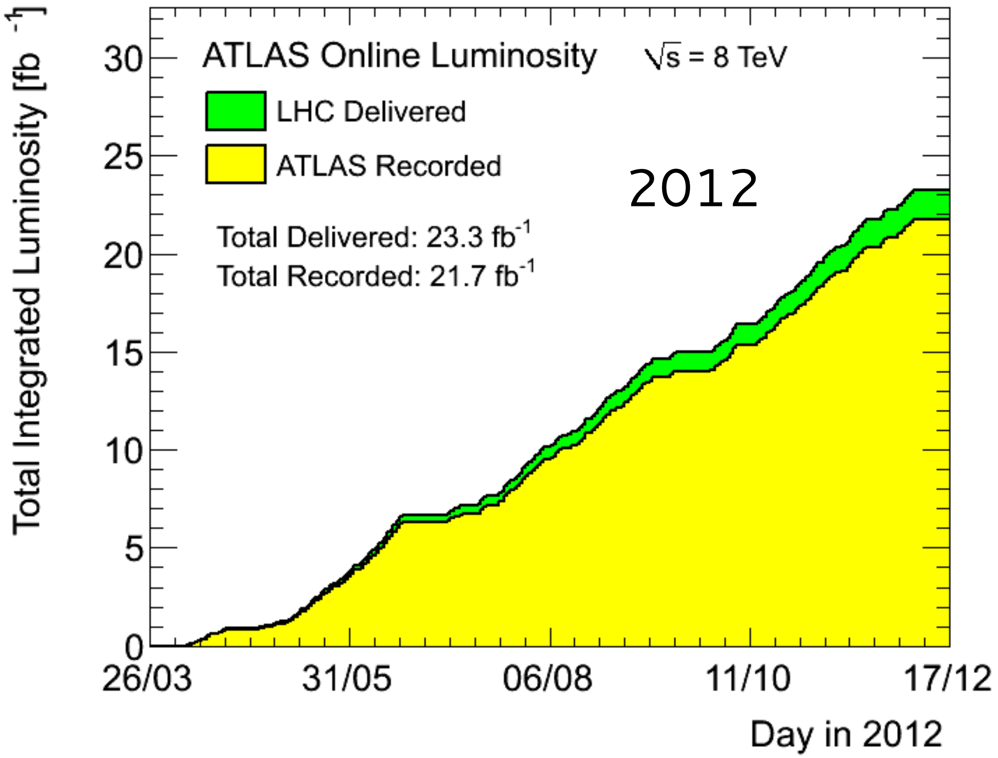
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Luminosity in 2011 and 2012





- First LHC running period concluded in 2013 with RECORDS in luminosity
  - Delivered Luminosity in 2011: $\int L\,dt = (5.61 \pm 0.10)\ \text{fb}^{-1}$
  - Delivered Luminosity in 2012: $\int L\,dt = (23.3 \pm 0.84)\ \text{fb}^{-1}$ (preliminary)
- Luminosity measurements played a major role in the Higgs boson discovery

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults

Luminosity Measurement

$$\mathscr{L} = \frac{R_{inel}}{\sigma_{inel}} = n_b f_r \frac{\mu_{vis}}{\sigma_{vis}}$$

Observed average number of inelastic interactions per bunch crossing

visible σ_{inel} → calibration of absolute luminosity scale

n_b: Number of colliding bunch pairs

f_r: Revolution frequency (f_{LHC} = 11245.5 Hz)

$$P_{EventOR}(\mu_{vis}^{OR}) = \frac{N_{OR}}{N_{BC}} = 1 - \exp(-\mu_{vis}^{OR})$$

Strategy:

- Several detectors and algorithms to measure μ_{vis} via inelastic rate
- Calibration of absolute luminosity scale by determining σ_{vis}

  → beam separation scans
- Consistency of algorithms → systematic uncertainties

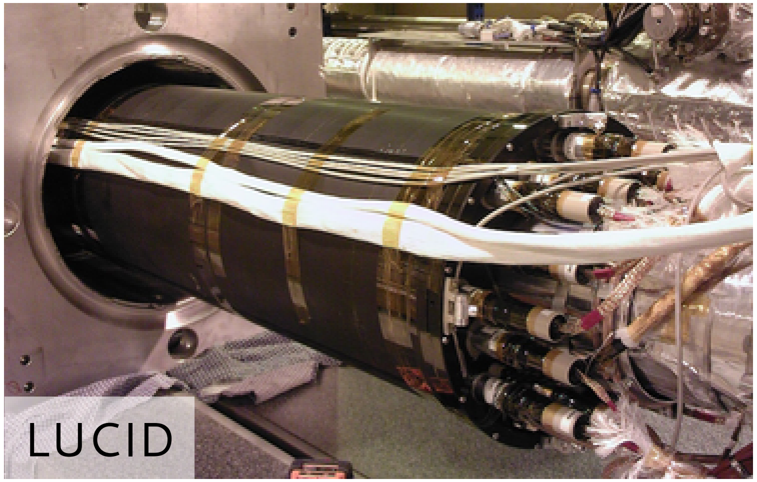
Luminosity Detectors

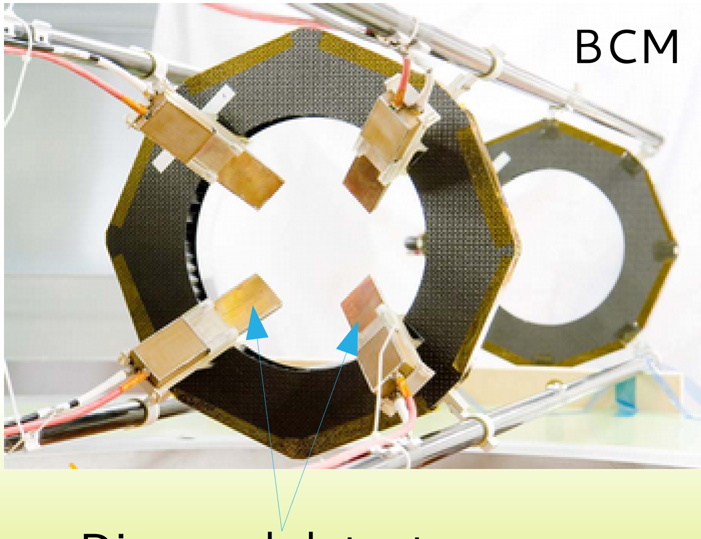
Bunch-by-bunch luminosity:

- LUCID
  - Dedicated Luminosity Monitor ($5.6 < |\eta| < 6$)
- Beam Condition Monitor (BCM)
  - Diamond sensors ($|\eta| = 4.2$)
  - Horizontal and vertical pairs
- Inner detector system
  - Primary vertex counting ($|\eta| < 2.5$)
  - Special conditions needed

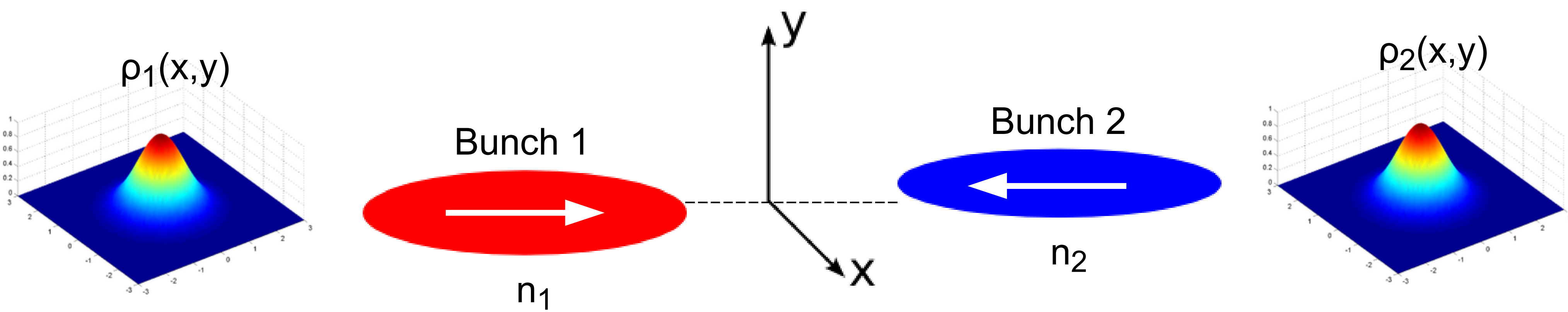
Bunch-blind luminosity:

- Calorimeter currents
  - TileCal PMT ($|\eta| < 1.7$)
  - FCal HV ($3.2 < |\eta| < 4.9$)





Beam separation scans



$$\mathscr{L} = n_b f_r n_1 n_2 \iint \rho_1(x,y)\rho_2(x,y)\,dx\,dy = \frac{n_b f_r n_1 n_2}{2\pi \Sigma_x \Sigma_y}$$

- Proposed by van der Meer
- Measure specific interaction rate for several beam separations

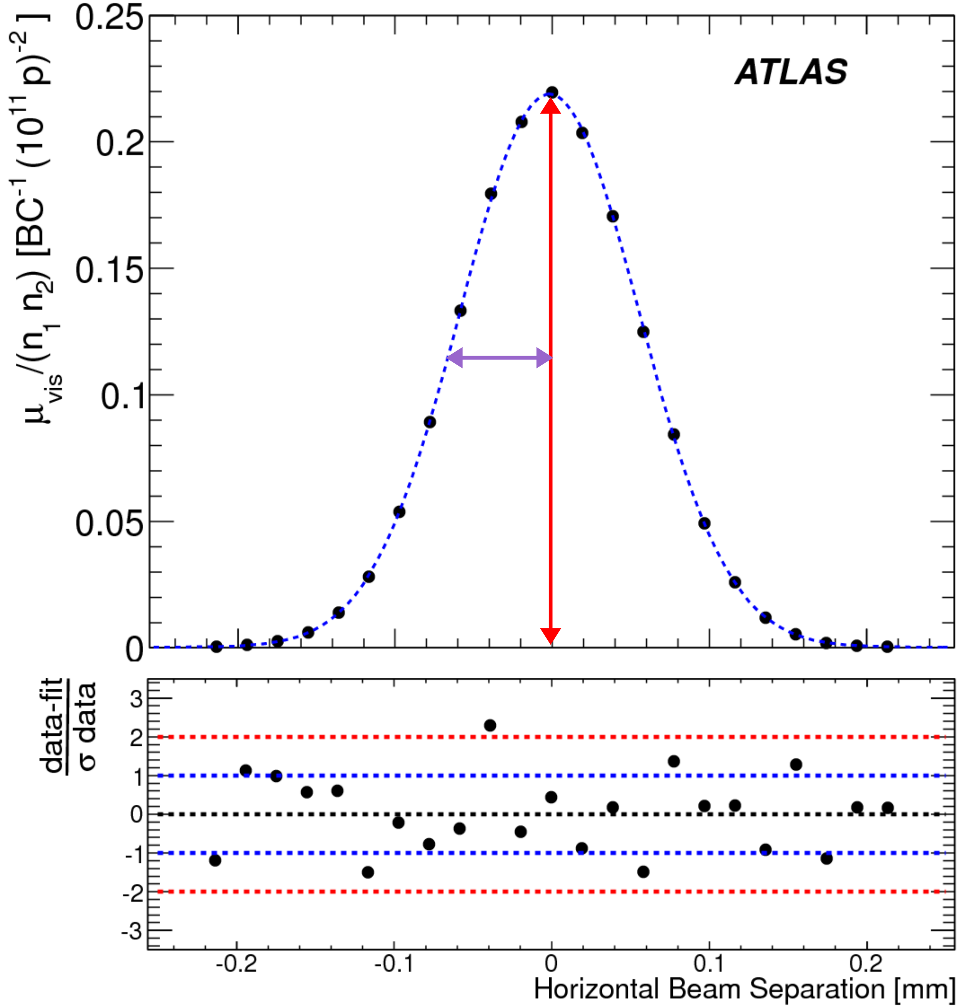
Σ_x, Σ_y: convolved beam widths

n_1 n_2: bunch population product

ρ_1, ρ_2: normalized particle density in transverse plane

S. van der Meer, CERN-ISR-PO-68-31 (1968)

Separation scans in practice

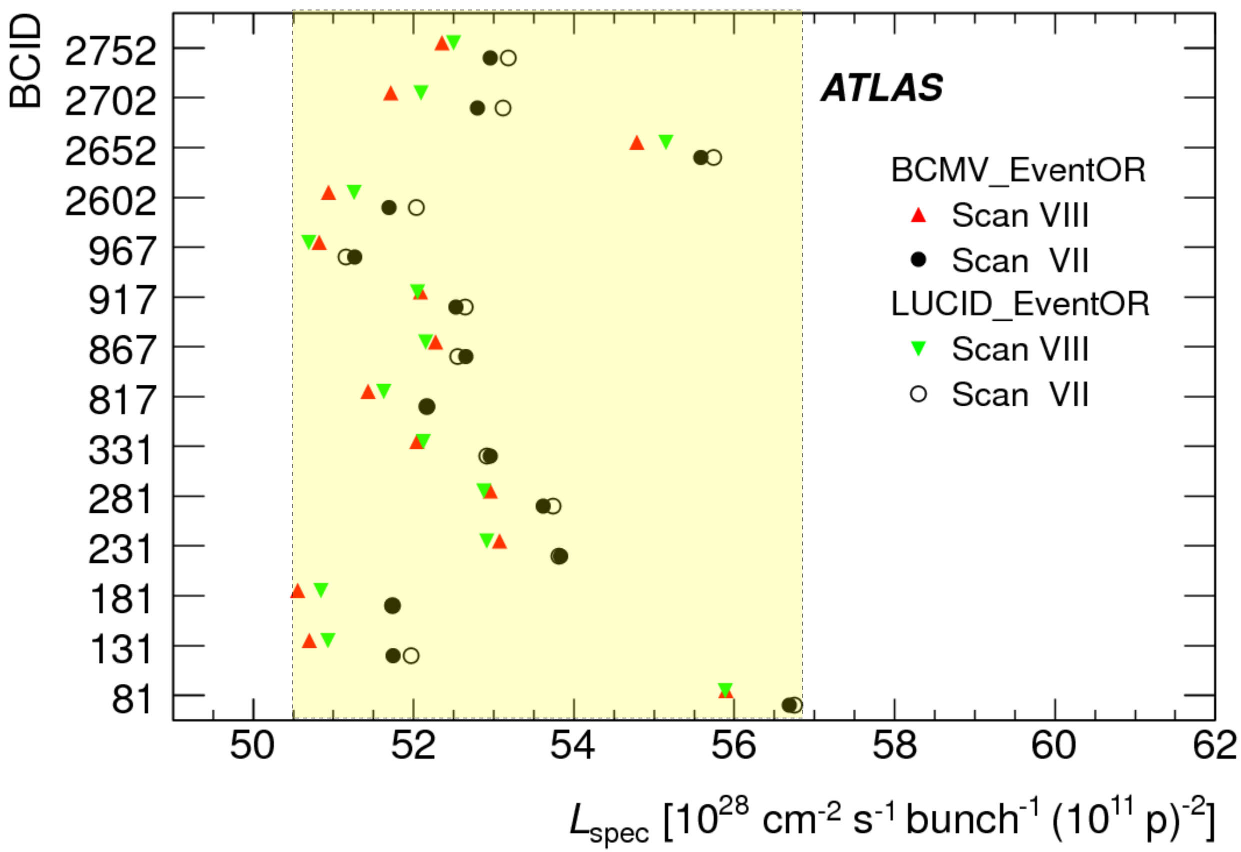


Luminosity from scan and rate:

$$\Rightarrow \sigma_{vis} = \mu_{vis}^{MAX} \frac{2\pi \Sigma_x \Sigma_y}{n_1 n_2}$$

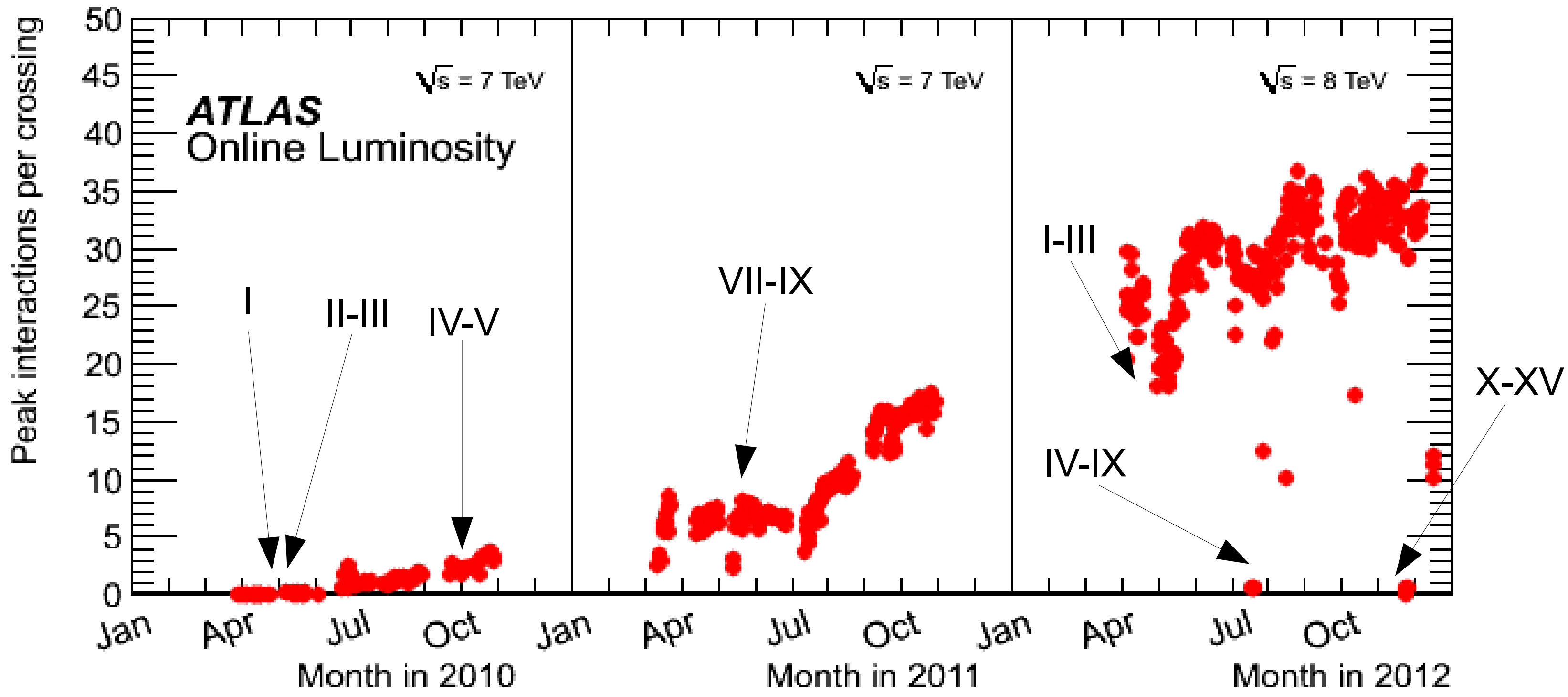
- From scan data:
  - Convolved beam widths (if gaussian → RMS)
  - Peak interaction rate
- Bunch population product from *external* beam current measurement (LHC group)
- Conditions with relative low number of bunches and peak rate
- Stability of measured σ_{vis} with BCID and different scans → assess uncertainties

Scan stability



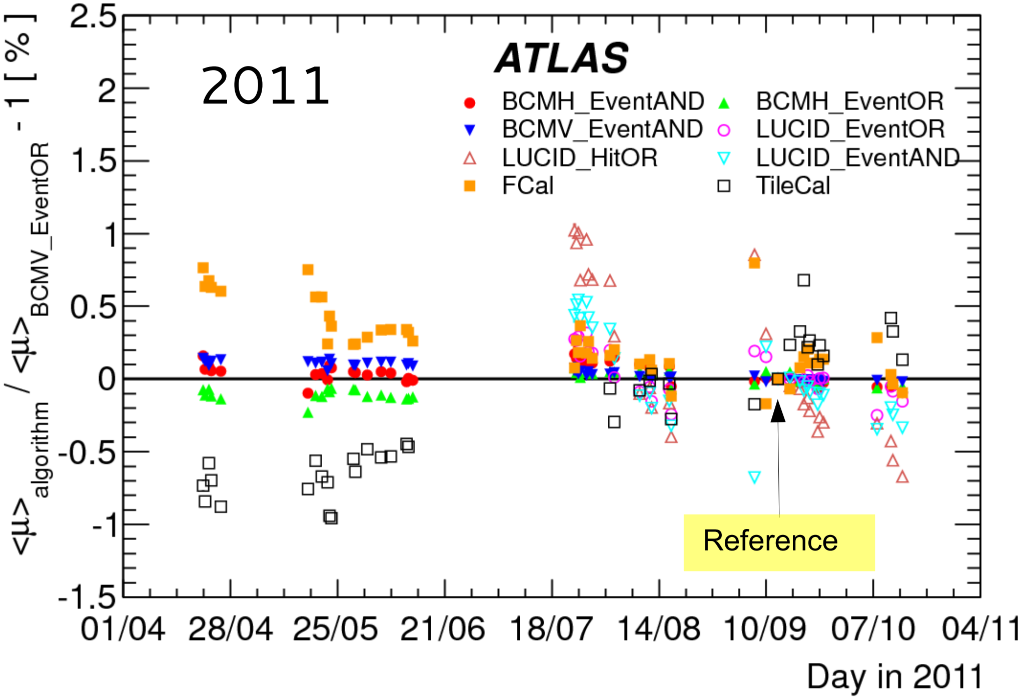
- $L_{spec} = L/(n_b n_1 n_2)$
- Up to ≈10% variation by colliding bunch pairs (BCID) due to transverse emittance (yellow band)
- Emittance growth between scans
- Uncertainty: variation between BCIDs and scans
- Good algorithm consistency

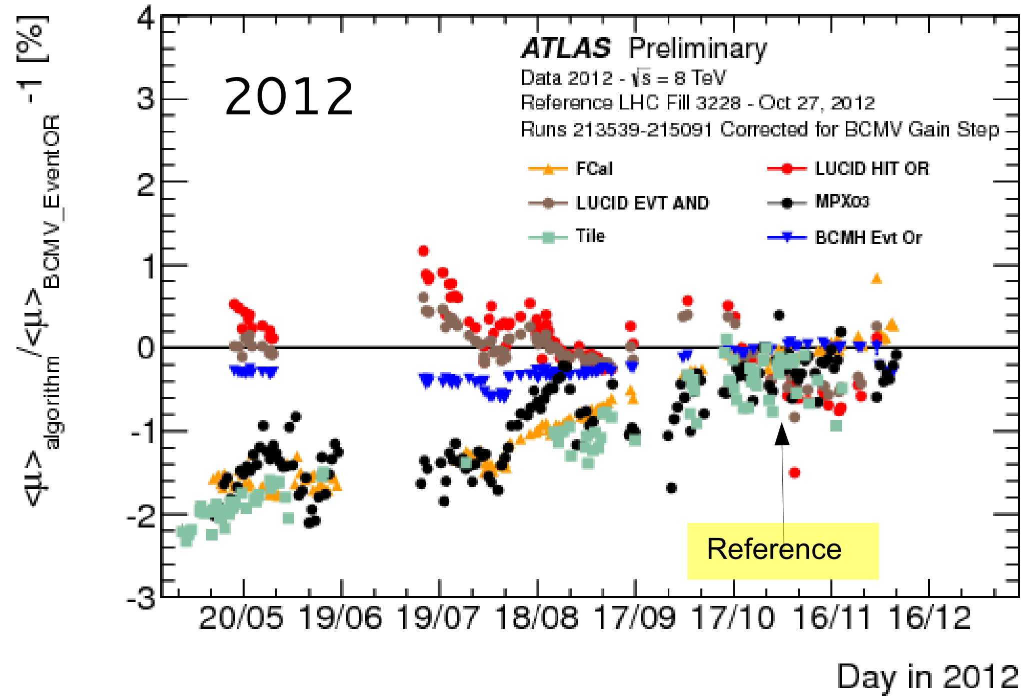
Extrapolation



- Calibration for whole data taking periods
  → long term stability, highest rates, different bunch structure
- (Online) Luminosity from BCMV_EventOR algorithm
- Consistency of algorithms provides data driven uncertainties

Long term stability

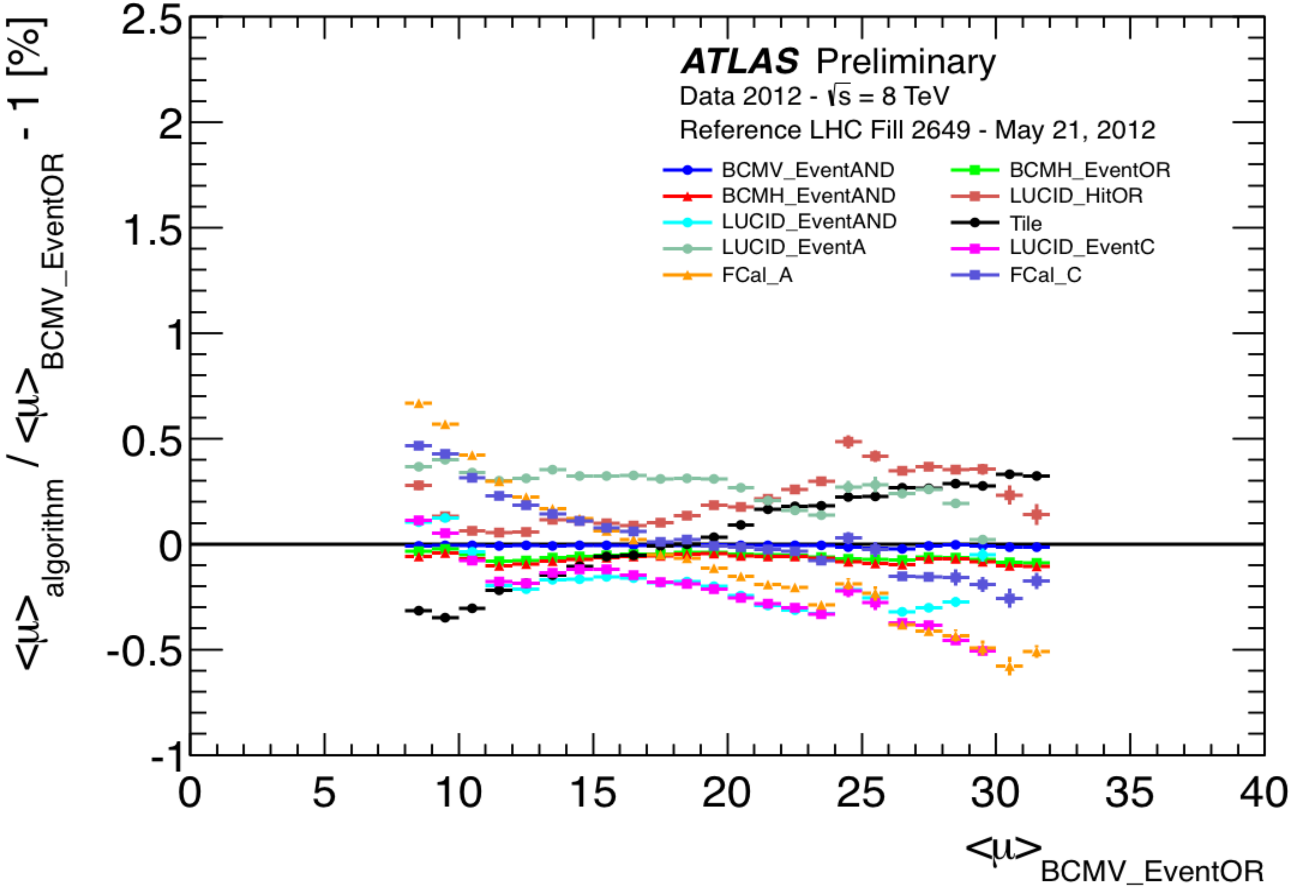




- Calibration of σ_{vis} by only few vdM scans → assume stable σ_{vis} over data taking period
- <μ>: average number of interactions of one ATLAS run

- Very small variations in BCM algorithms
- Slow drifts in TileCal and FCal
- Larger variations in 2012 than 2011

μ dependence



- Pile-up effects increase at larger rates
  → linear measurements up to highest μ?
- apparent <μ> dependence actually time dependence from "ramp up"
- Variation in FCal: systematic non-linear dependence on total luminosity

Systematic uncertainties

Uncertainty source	δL / L		
	2010	2011	2012
Bunch population product	3.1%	0.5%	
Other vdM calibration uncertainties	1.3%	1.4%	
Afterglow correction		0.2%	
BCM stability		0.2%	
Long−Term stability	0.5%	0.7%	
μ dependence	0.5%	0.5%	
Total	**3.4%**	**1.8%**	**2.8%**

vdM calibration

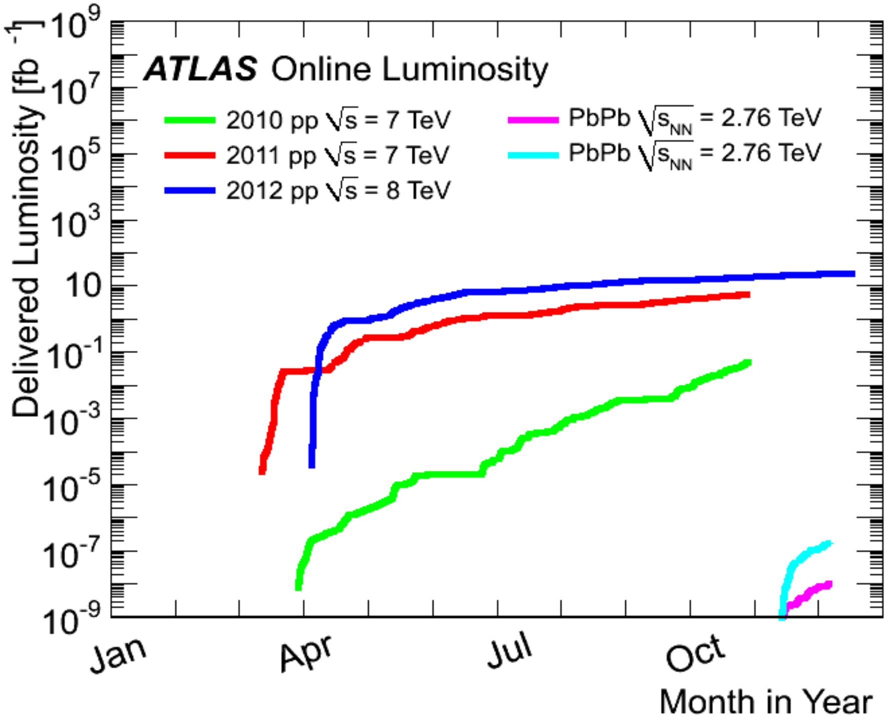
extrapolation

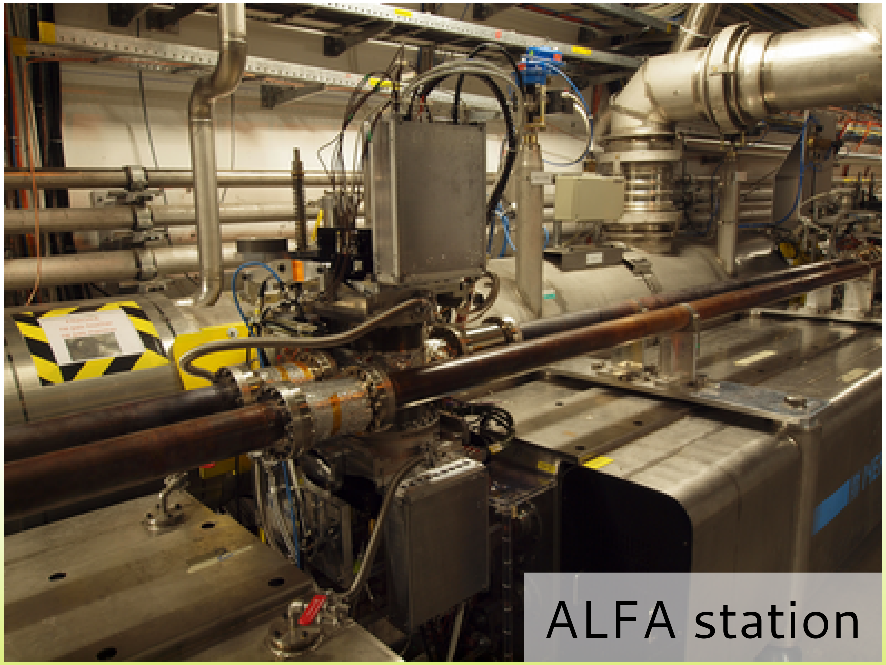
Preliminary

- Uncertainty of bunch population product reduced significantly
- 2012 analysis ongoing → preliminary result as input for winter conferences

Outlook

- Accuracy of luminosity calibration exceeded predictions
- Several luminosity calibrations from first LHC run still ongoing:
  - 2012 p-p; 2011 Pb-Pb; 2013 p-Pb
- New challenges after LS1 with higher energies and interaction rates



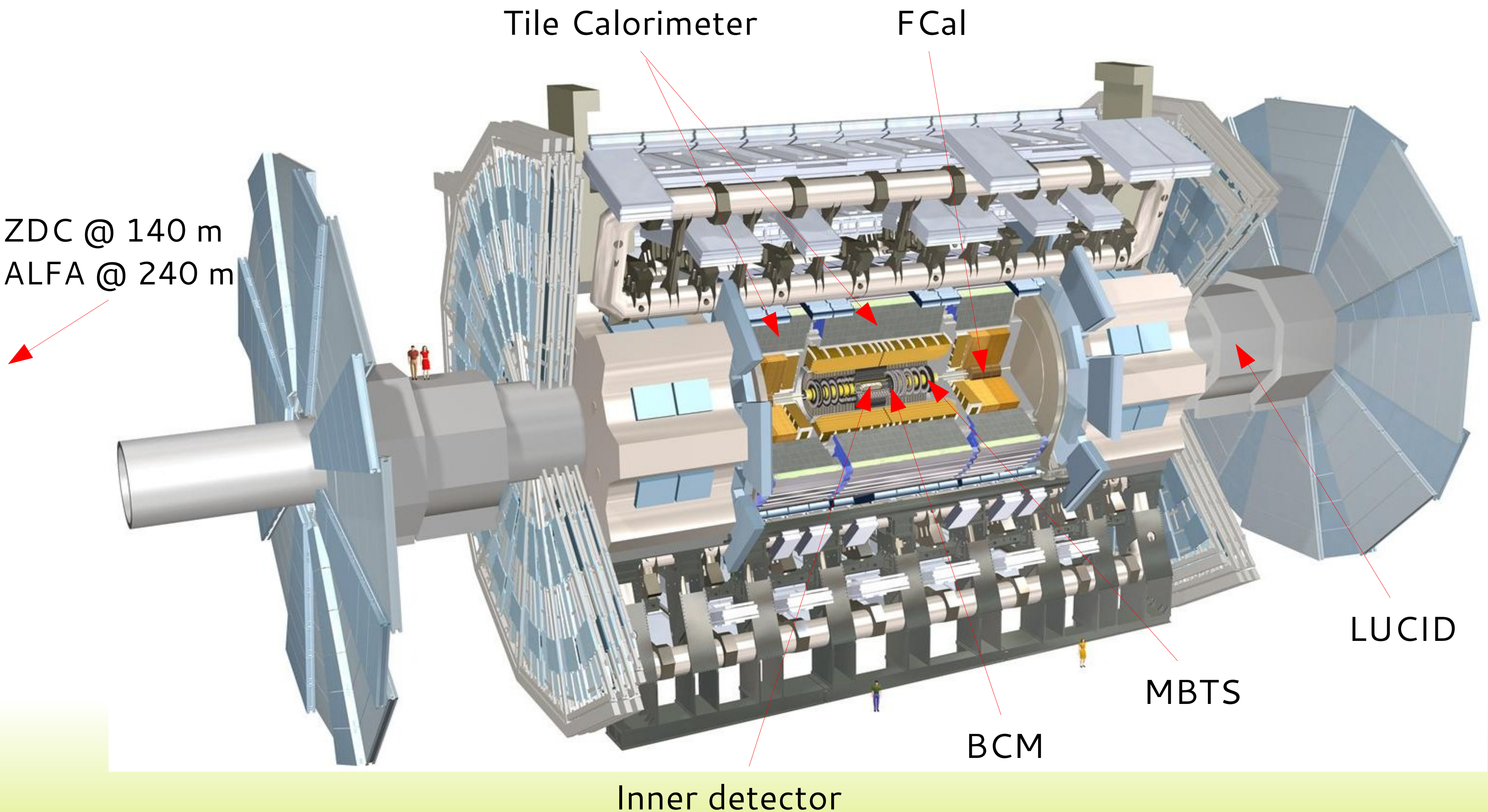


Additional calibration method beside vdM scans for the future:

- Measure small angle elastic p-p scattering in the Coulomb-Nuclear interference region with the ALFA detector (special beam optics needed)

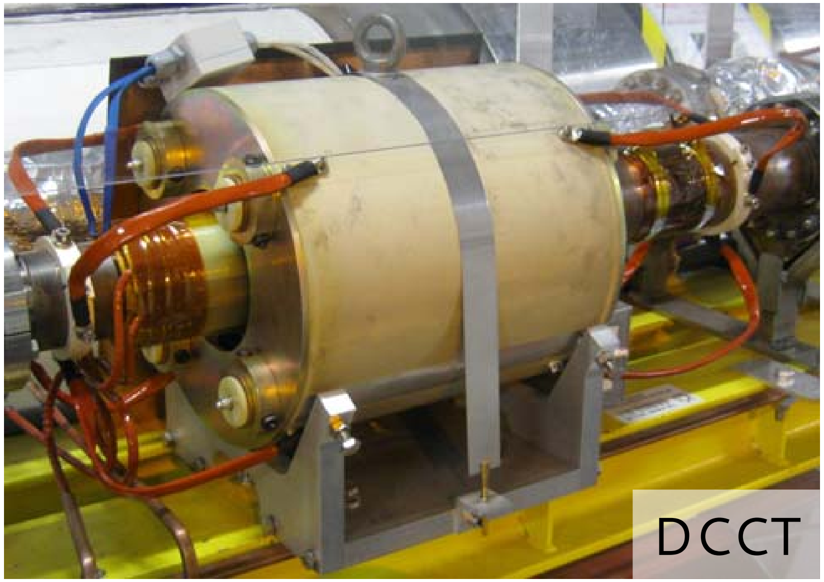
Backup

ATLAS detector



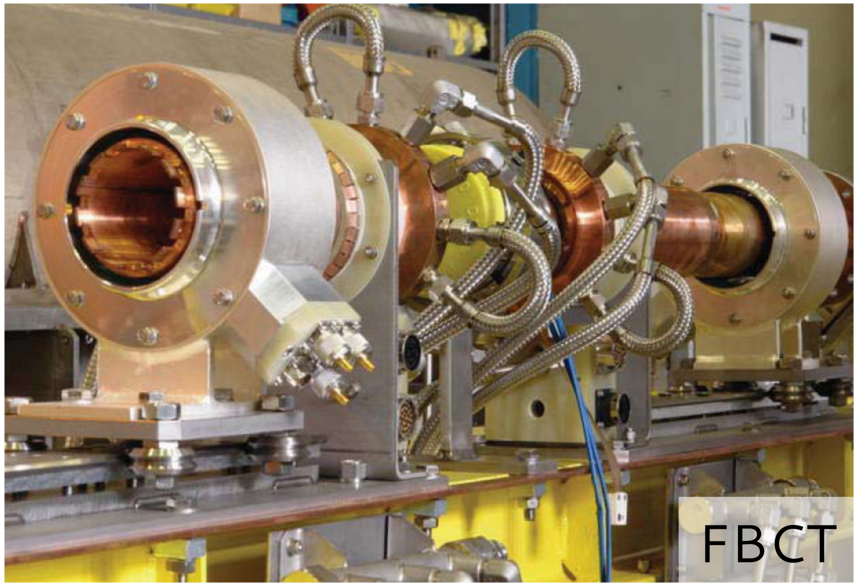
Bunch population product

DC Current Transformer



- total current measurement with high accuracy
- two in each beam

Fast Beam Current Transformer

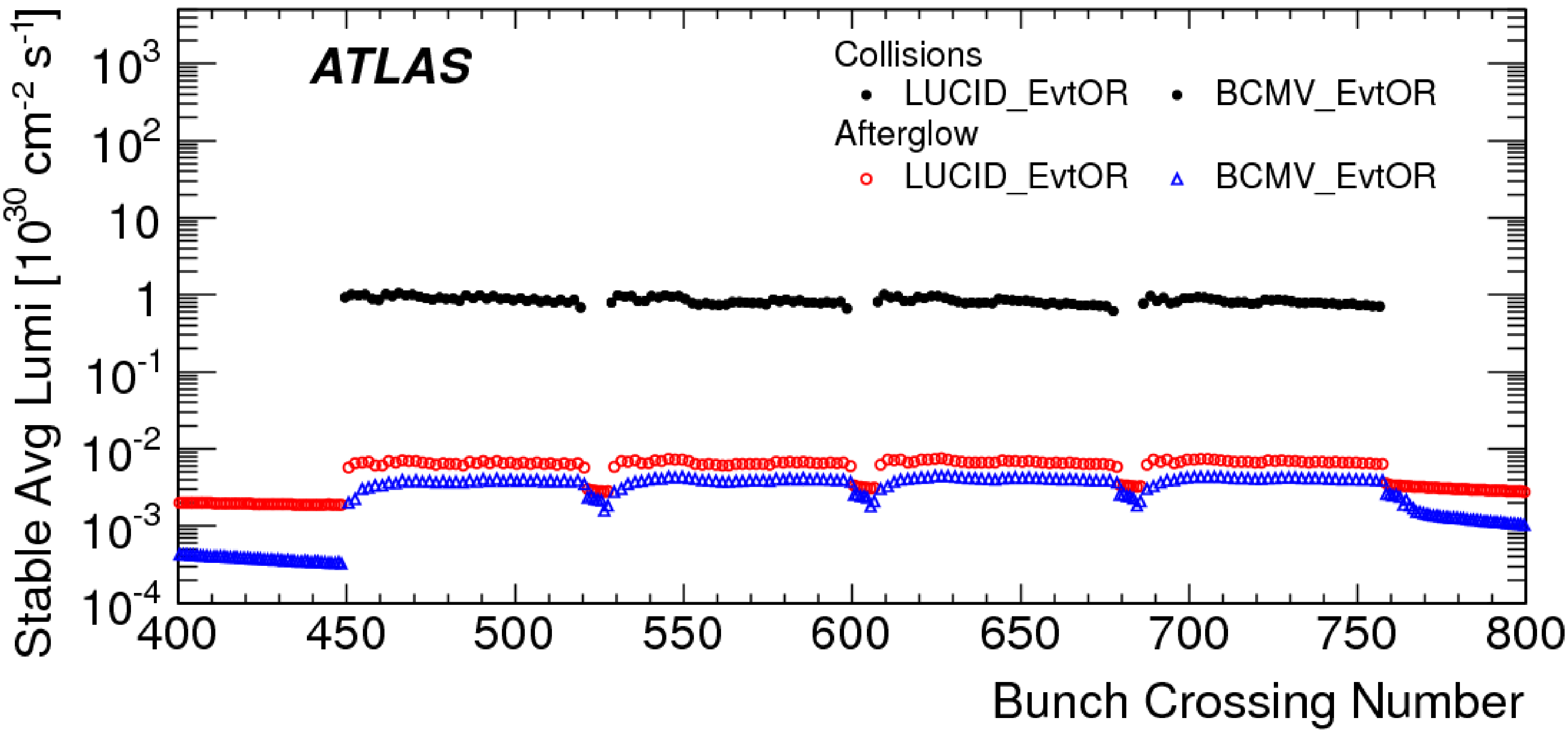


- bunch-by-bunch current measurement
- two in each beam

- Relative fraction of total current in each BCID from FBCT
- Normalization to overall current scale provided by DCCT

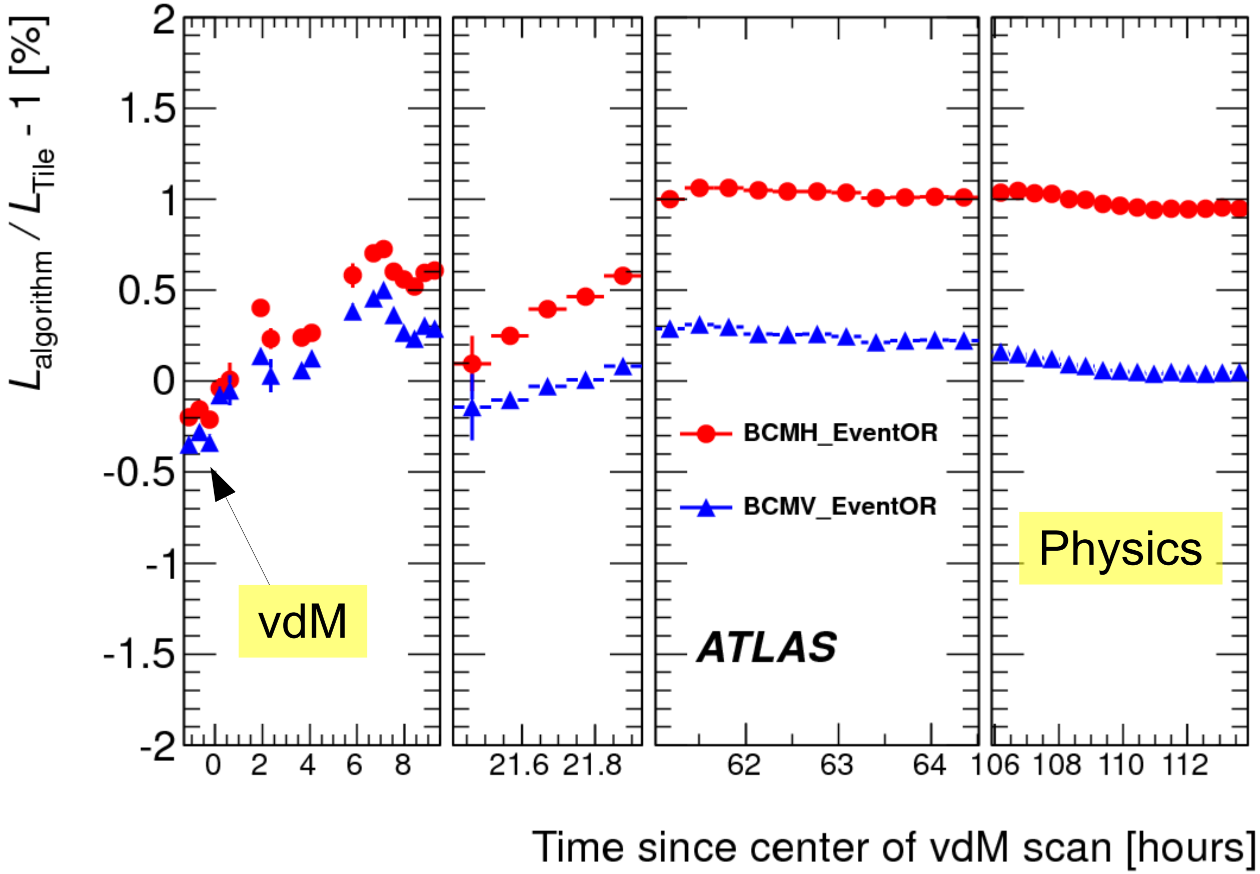
CERN-ATS-Note-2012-026
CERN-ATS-Note-2012-028
CERN-ATS-Note-2012-029

Afterglow



- Likely caused by photons from nuclear de-excitation
- Luminosity background in bunch trains
- Corrected by subtracting luminosity in previous BCID

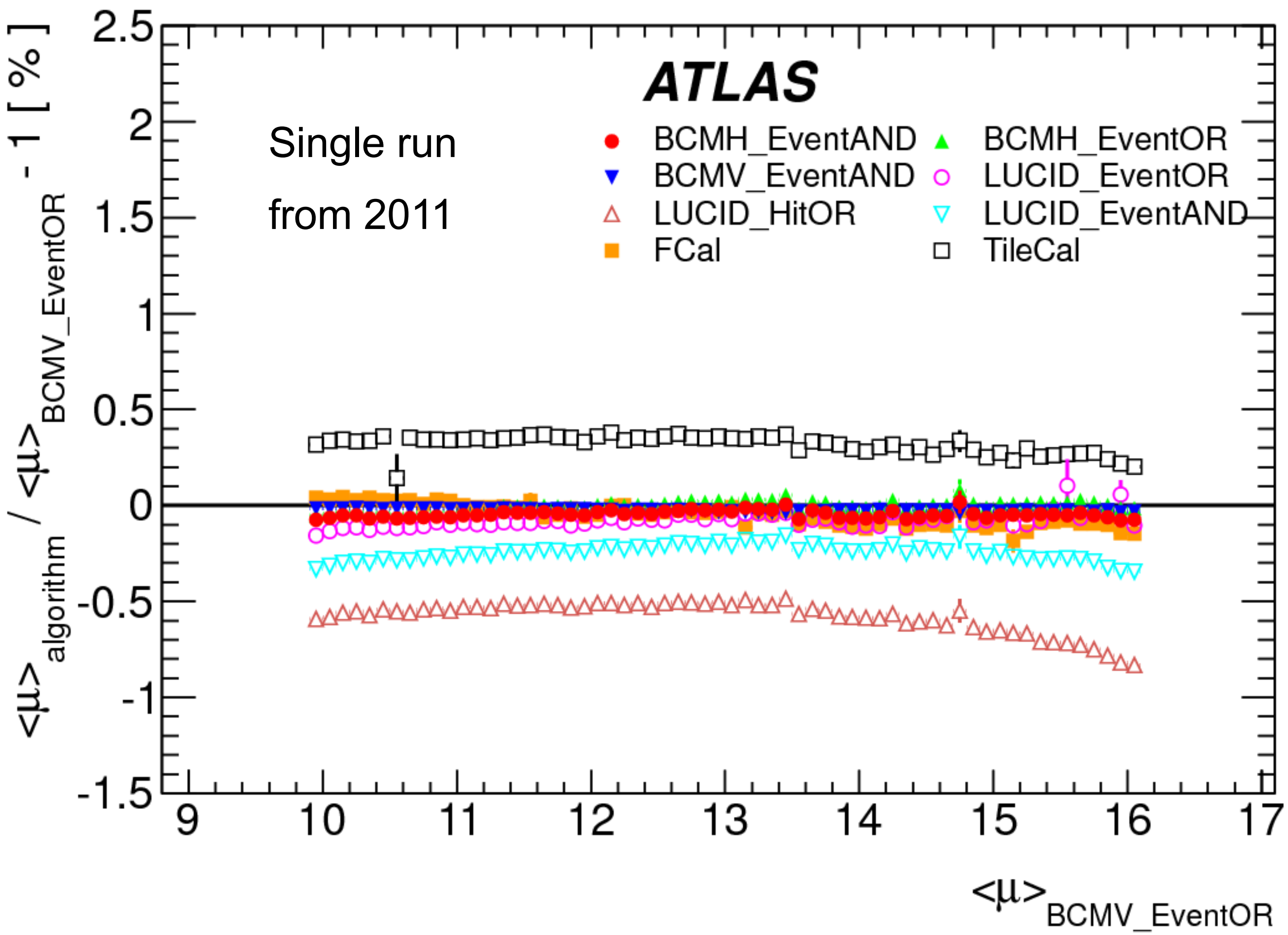
BCM calibration shifts



- Diamond sensors
- Luminosity scale varies up to 1% right after extended period without beam
- Stable value after several hours of exposure ($\int L\, dt \approx 5 \times 10^{36}$ cm^{-2})

- BCMH calibration corrected for this drift
- No net drift for BCMV after several hours
- Additional systematic uncertainty applied

Single run μ dependence



- Shifts of algorithms result from long term stability variations
- Linear response with variations up to 0.5% level