Precision Calibration of the Luminosity Measurement in ATLAS

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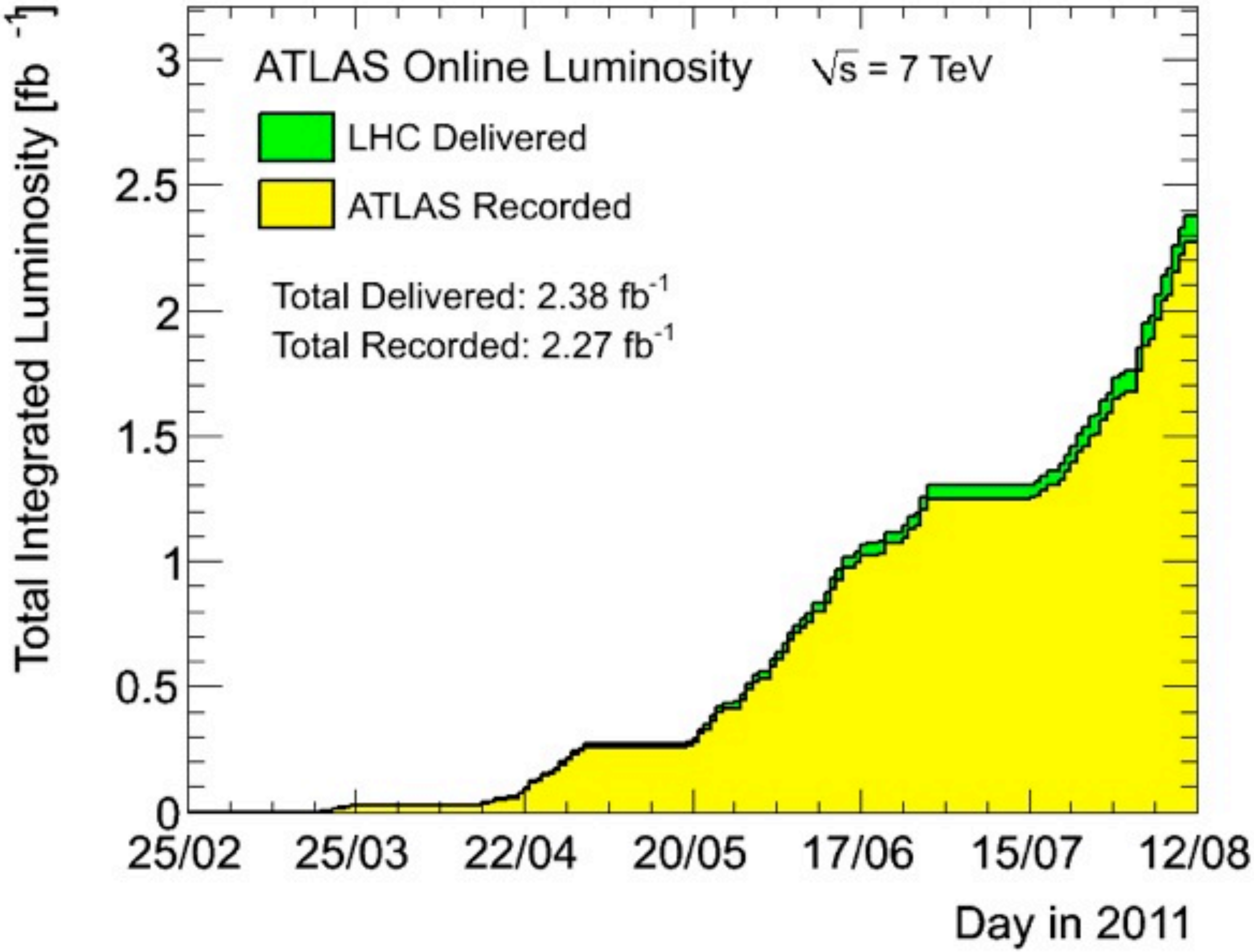
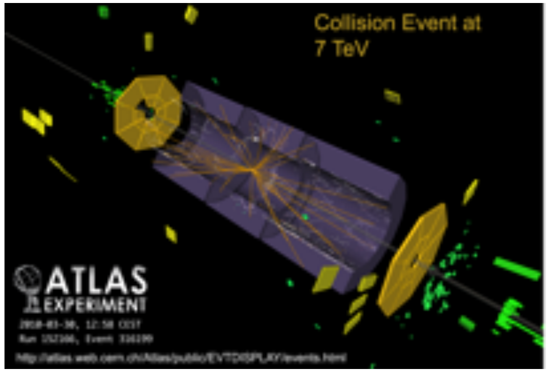
DPF 2011, Brown University

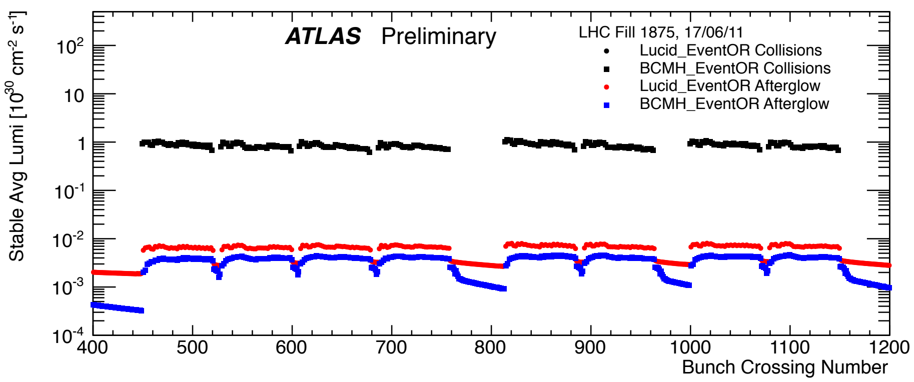


https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults

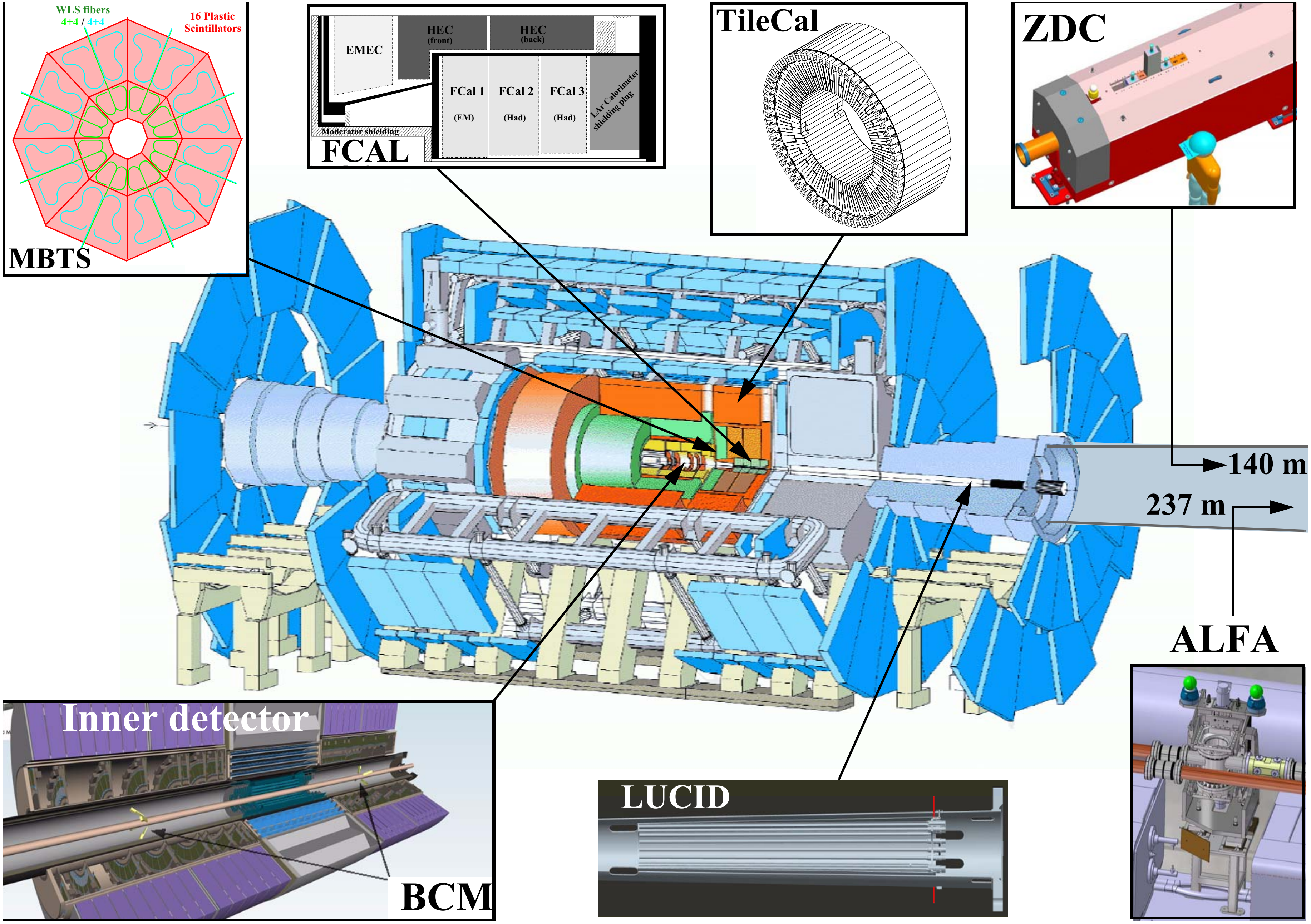
2011 Delivered Luminosity: $\int L dt = 2.38 \pm 0.09\ \mathrm{fb}^{-1}$

- Luminosity Detectors
- Luminosity Scale Calibration
- Calibration Uncertainties
- 2011 Operations
- Conclusions

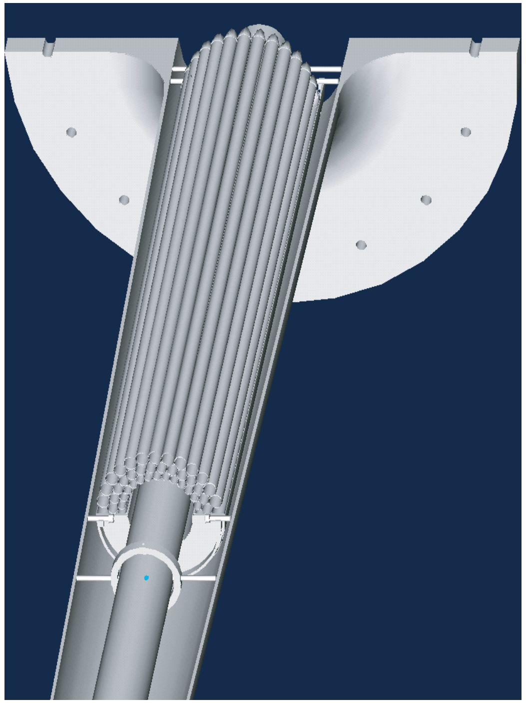




Luminosity Detectors



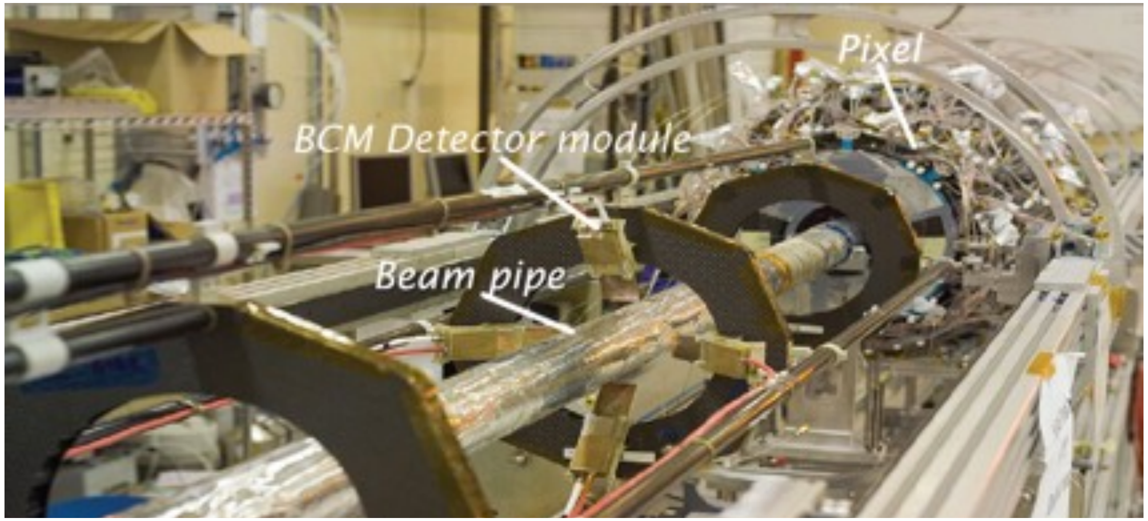
Luminosity Reference Reaction: inelastic pp scattering

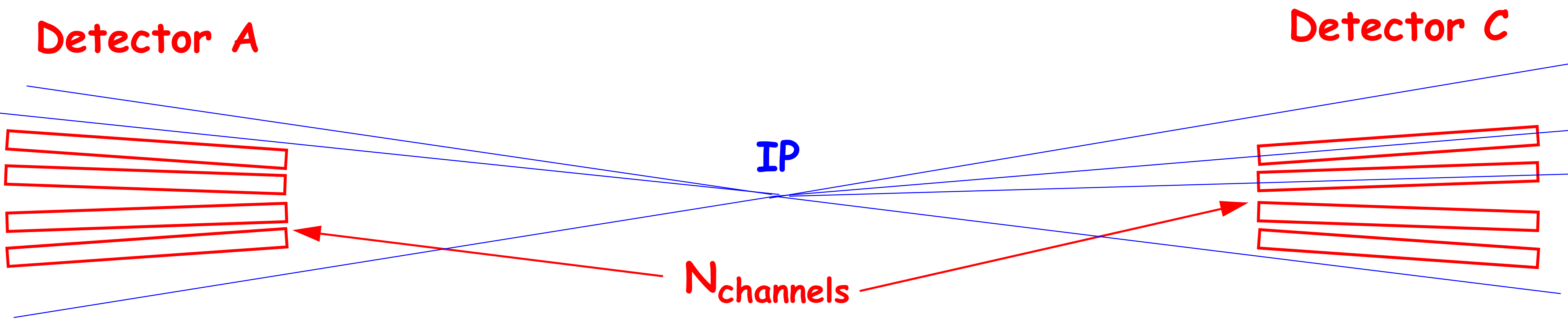


- LUCID
  - Dedicated Luminosity Monitor
  - Gas Cherenkov Tubes, $5.6 < |\eta| < 6.0$
- Beam Conditions Monitor (BCM)
  - Designed for beam abort system
  - Diamond Sensors, $|\eta| \sim 4.2$

Both measure luminosity every 25 ns

Redundancy with other methods to cross-check results





- Event Counting - criteria applied per beam crossing
  - Inclusive - EventOR - at least one hit either side
  - Coincidence - EventAND - at least one hit on both sides

Main method used to date in ATLAS

- Hit Counting
  - Better linearity, harder to calibrate
- Particle Counting
  - Most linear, need particle-sensitive detector

Interaction Rate

Algorithm Specific

$$L = \mu \, n_b \, f_r / \sigma_{inel} = \mu_{vis} \, n_b \, f_r / \sigma_{vis}$$

Inelastic Interactions / BC

Measured quantity

$\varepsilon \times \sigma_{inel}$
To be calibrated

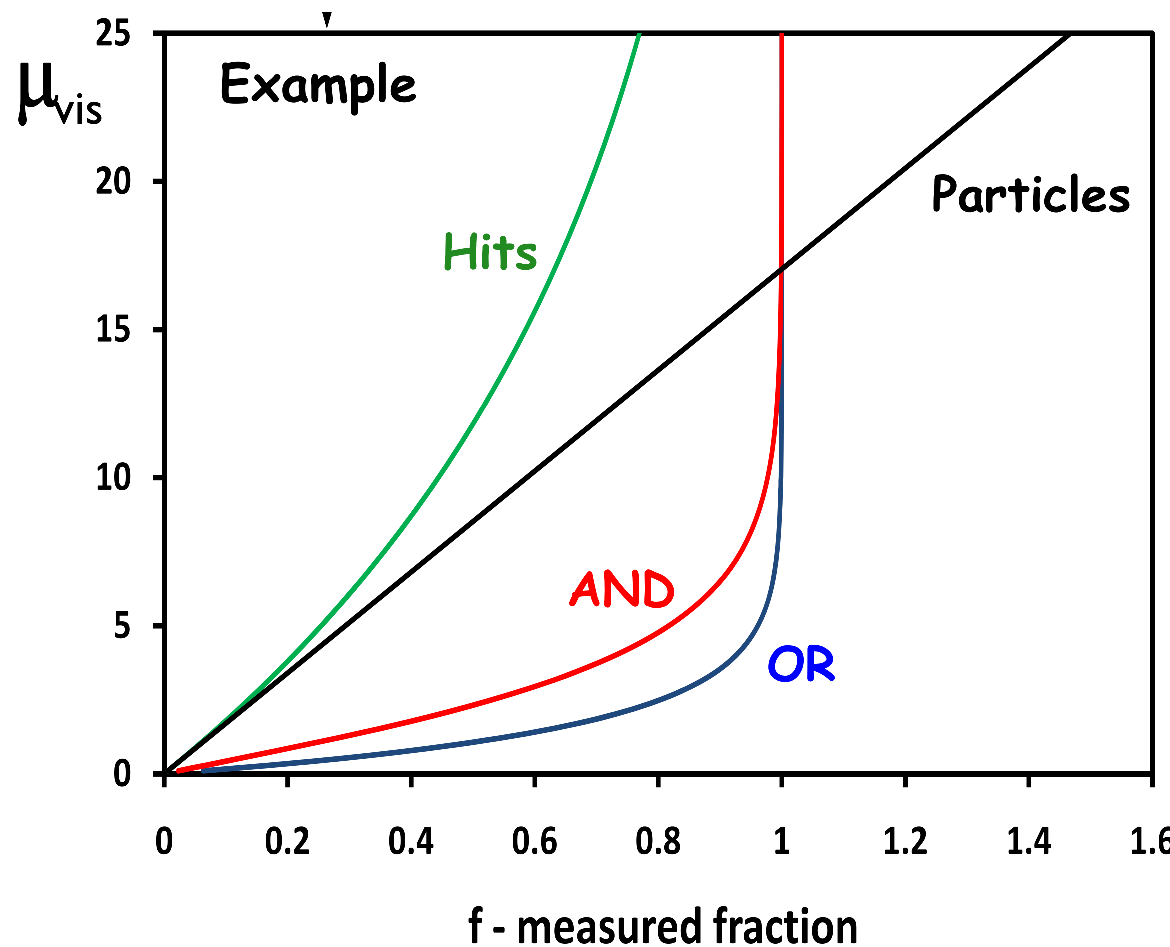
$$f_{OR} = \frac{N_{OR}}{N_{BC}} = 1 - e^{-\mu_{vis}}$$

$$f_{AND} = \frac{N_{AND}}{N_{BC}} = 1 - 2e^{-(1+R)\mu_{vis}/2} + e^{-R\mu_{vis}}$$

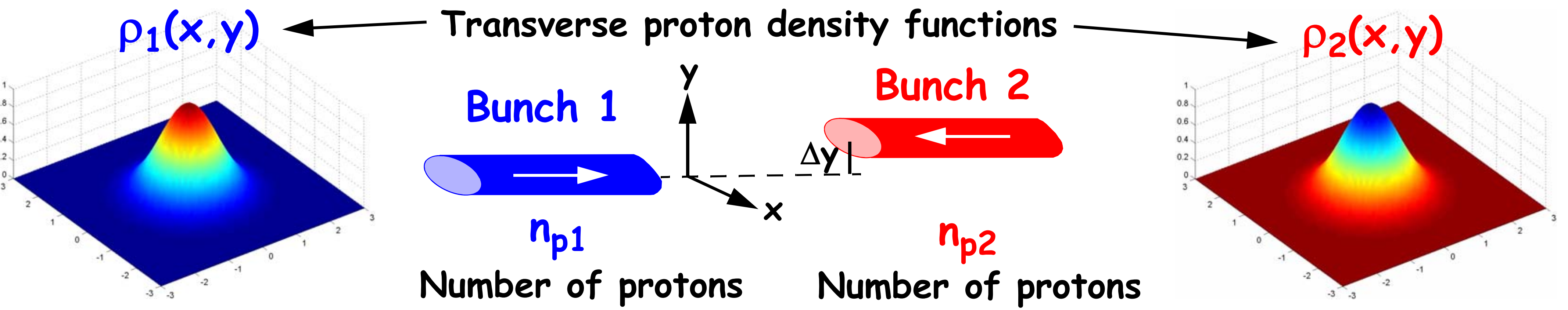
$$R = \sigma_{vis}^{OR} / \sigma_{vis}^{AND}$$

$$f_{hits} = \frac{N_{hits}}{N_{BC} N_{Ch}} = 1 - e^{-\mu_{vis}}$$

$$f_{part} = \frac{N_{part}}{N_{BC} N_{Ch}} = \mu_{vis}$$



van der Meer Scans



Beam separation scans provide absolute luminosity calibration

$$\mathcal{L}_{peak} = f_r n_1 n_2 \iint \rho_1(x,y)\rho_2(x,y)dxdy$$

$$= f_r n_1 n_2 \frac{1}{2\pi\Sigma_x\Sigma_y}$$

Σ_x, Σ_y - convolved beam widths

n_1 n_2 - bunch charge product

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

vdM Scans in Practice

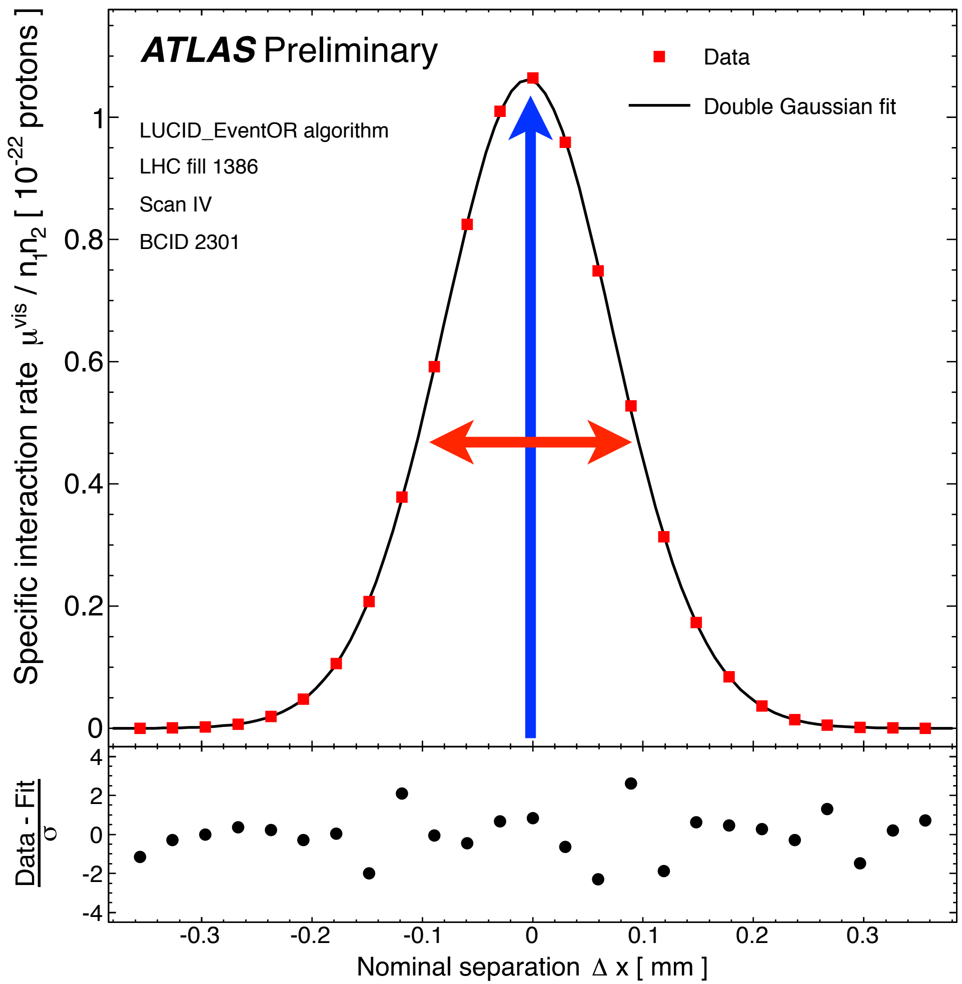
- Separate beams and measure specific interaction rate
- Directly calibrate σ_{vis} for each algorithm

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

Scan Widths

Bunch Charges

Peak Rate



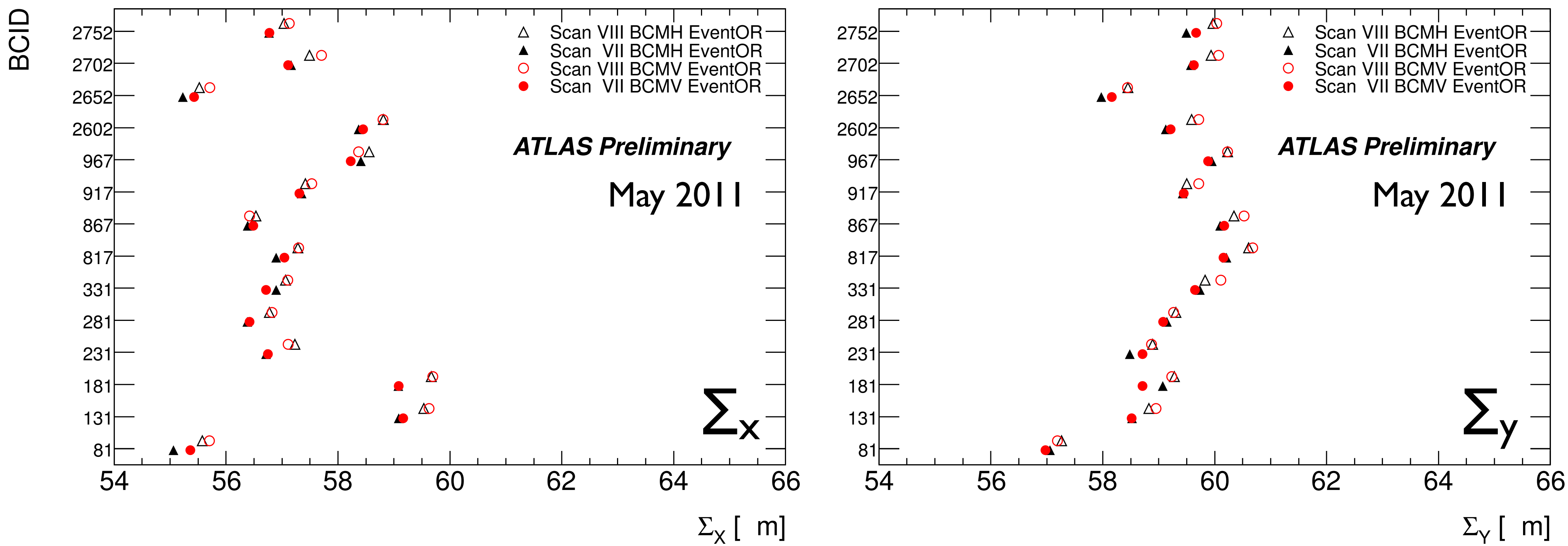
- Ideally would perform 2D scan, use 2 sets of x/y scans plus 'offset' scan to help control systematics
- Specific rate μ_{vis} / $(n_1\ n_2)$ removes current dependence

Scan Campaigns

	Apr `10	May `10	Oct `10	May `11
Scan Sets	1	2	2+1	2+1
Bunches Coll./Total	1/2	1/2	6/19	14/38
β* (m)	2	2	3.5	1.5
p/bunch (10^{11})	0.1	0.2	~0.9	~0.8
Beam Size (μm)	45	45	~60	~40
Crossing Angle (μrad)	0	0	200	240
Peak μ	0.03	0.11	1.3	2.3

- October 2010 and May 2011 scans dominate results
- Limited bunch conditions, but far fewer bunches colliding
- Multiple bunches and multiple complete scan sets allows test of consistency of results across algorithms and detectors

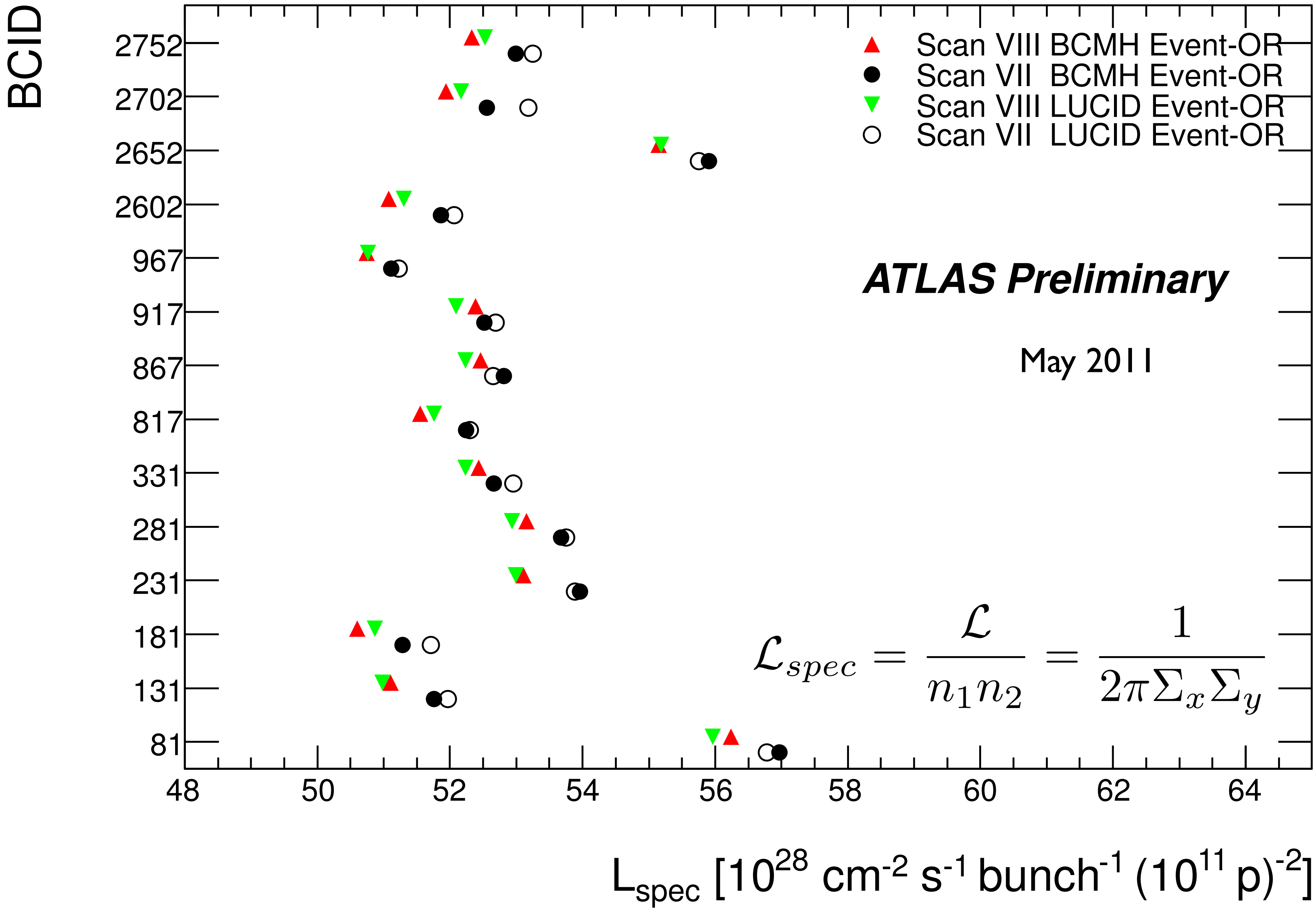
Convolved Beam Widths



- Widths of scan curves
- Variation between bunches ±5%
- Variation between successive scans ~ 1% (emittance growth)

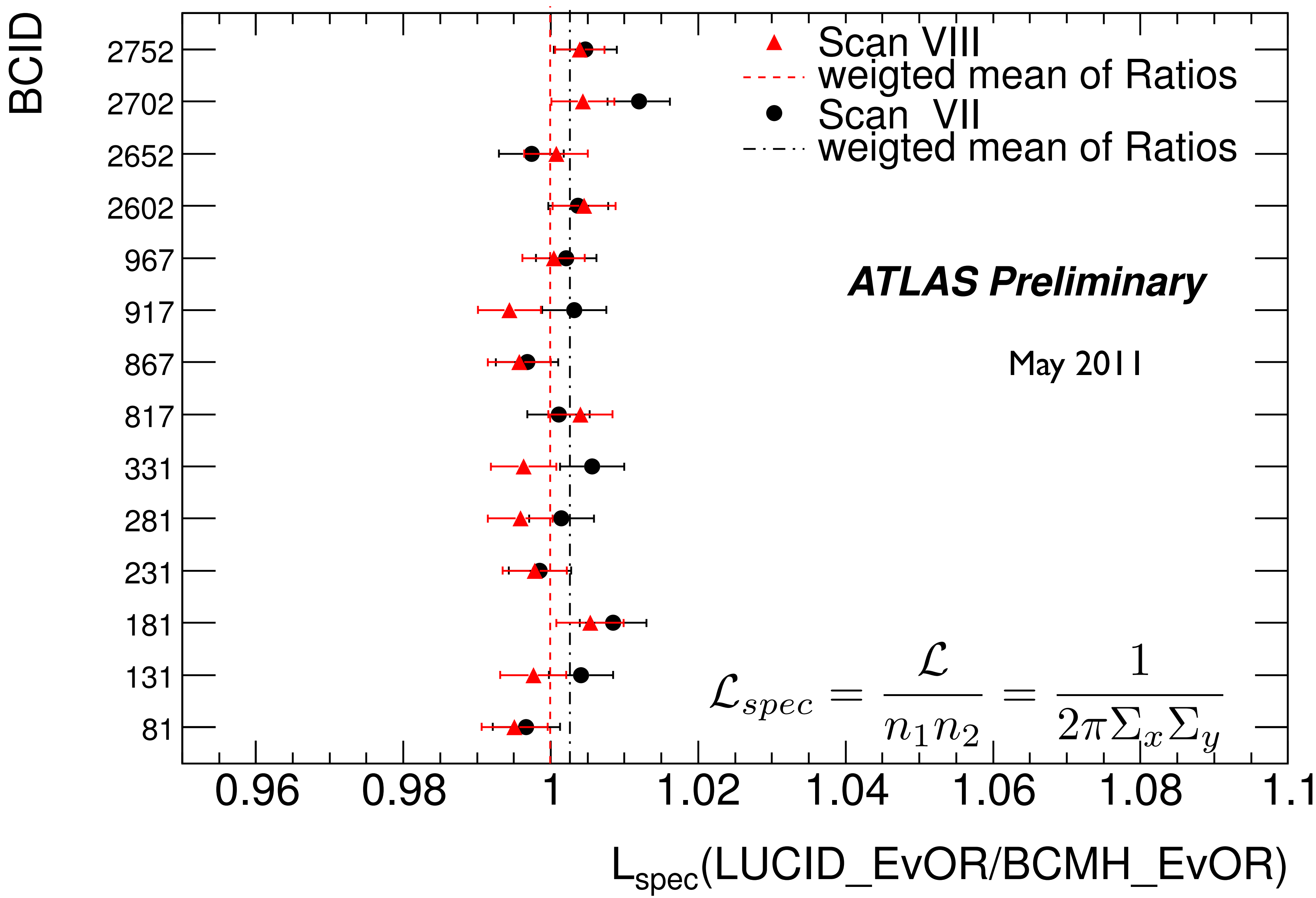
Critical to do analysis separately per colliding bunch
Provides multiple measurements to assess consistency

Beam Consistency



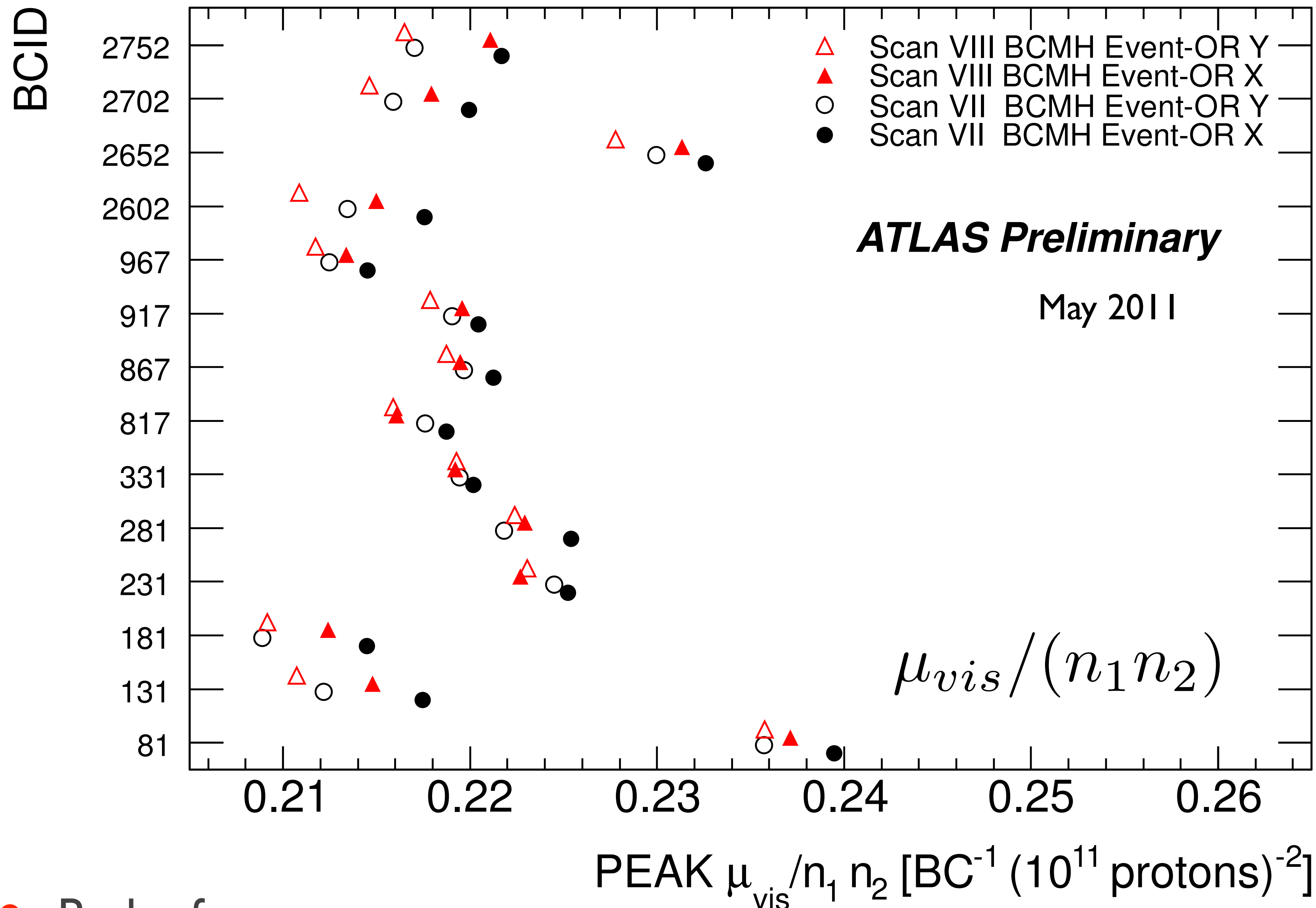
- Property of beams, should be independent of detector/algorithm

Beam Consistency



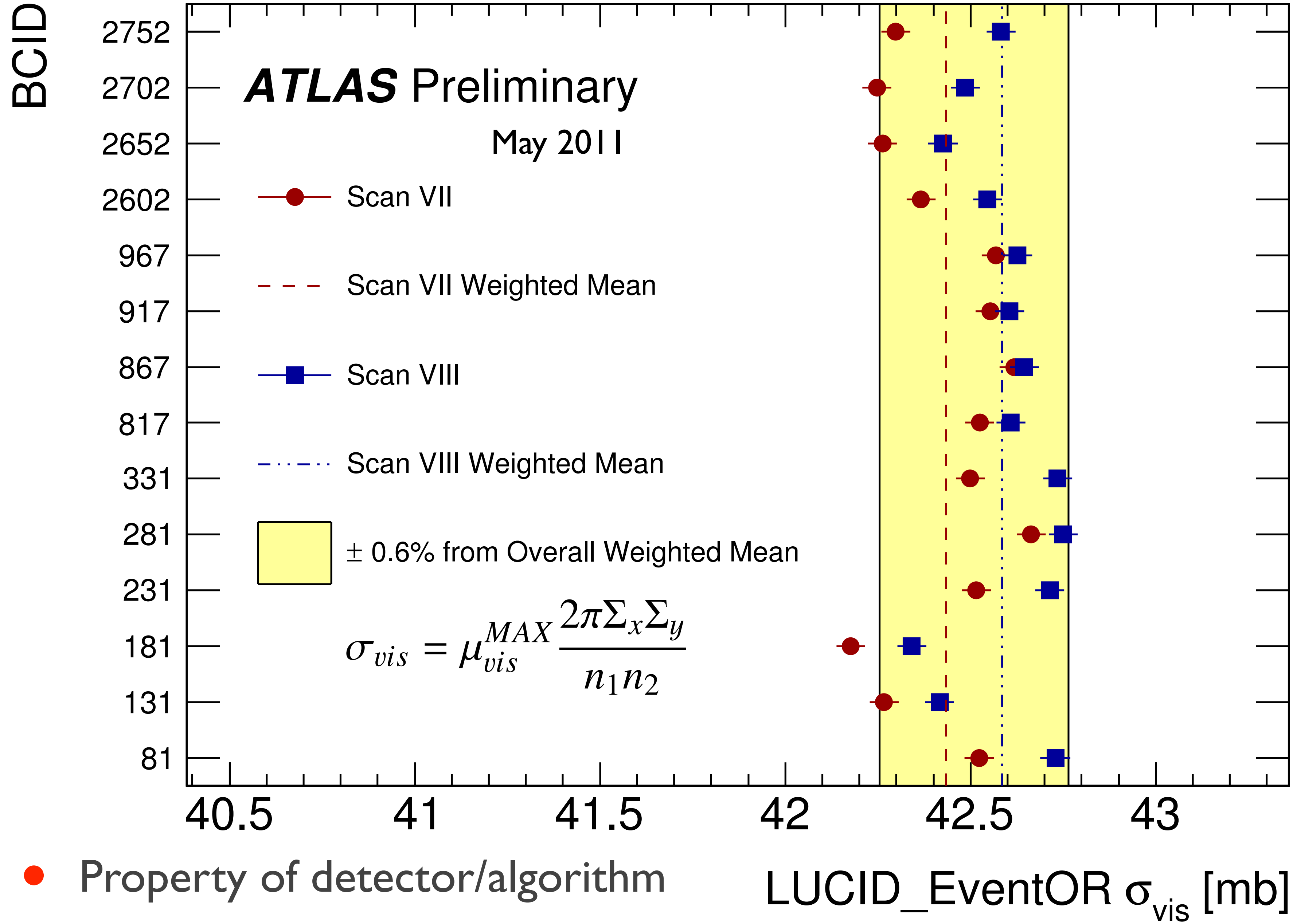
- Good agreement between detectors

Specific Interaction Rate



- Peak of scan curves
- Measured separately in X and Y scans, small emittance growth seen

Calibration Consistency

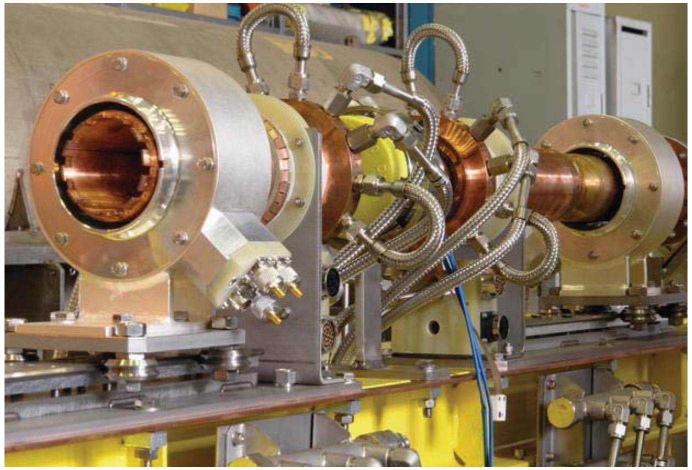


- Property of detector/algorithm
- Consistent results to ±0.6%

Bunch Charge

DCCT - DC Current Transformer

accurate, but measures everything



FBCT - Fast Beam Current Transformer

bunch-by-bunch measurements

$$n_i = (\alpha\ S^{DCCT} - S_{Baseline} - S_{ghost})\ S_i^{FBCT} / \sum S_i^{FBCT}$$

- Uncertainty on bunch charge product $n_1\ n_2$
  - DCCT Scale α - 2.7%
  - DCCT baseline (early scans only)
  - Bunch-to-bunch fraction - 1.3%
  - Ghost Charge - 0.2%

Scan	Uncertainty
Apr. `10	5.6%
May `10	4.4%
Oct. `10	3.1%
May `11	3.0%

e.g. 2010 Scan Systematics

Scan Number	I	II–III	IV–V	
Fill Number	1059	1089	1386	
Bunch charge product	5.6%	4.4%	3.1%	Partially correlated
Beam centering	2%	2%	0.04%	Uncorrelated
Emittance growth and other non-reproducibility	3%	3%	0.5%	Uncorrelated
Beam-position jitter	–	–	0.3%	Uncorrelated
Length scale calibration	2%	2%	0.3%	Partially Correlated
Absolute ID length scale	0.3%	0.3%	0.3%	Correlated
Fit model	1%	1%	0.2%	Partially Correlated
Transverse correlations	3%	2%	0.9%	Partially Correlated
μ dependence	2%	2%	0.5%	Correlated
Total	7.8%	6.8%	3.4%	

σ_{vis} consistency

$\rho(x,y) \neq \rho(x)\,\rho(y)$

Algorithm linearity

- 2010 results dominated by final October Scan: $\delta\sigma_{vis}/\sigma_{vis}$ = 3.4%
- 2011 scan different in detail, but results similar: $\delta\sigma_{vis}/\sigma_{vis}$ = 3.4%

Without bunch charge uncertainty ~1.3%

2010 - 2011 comparison

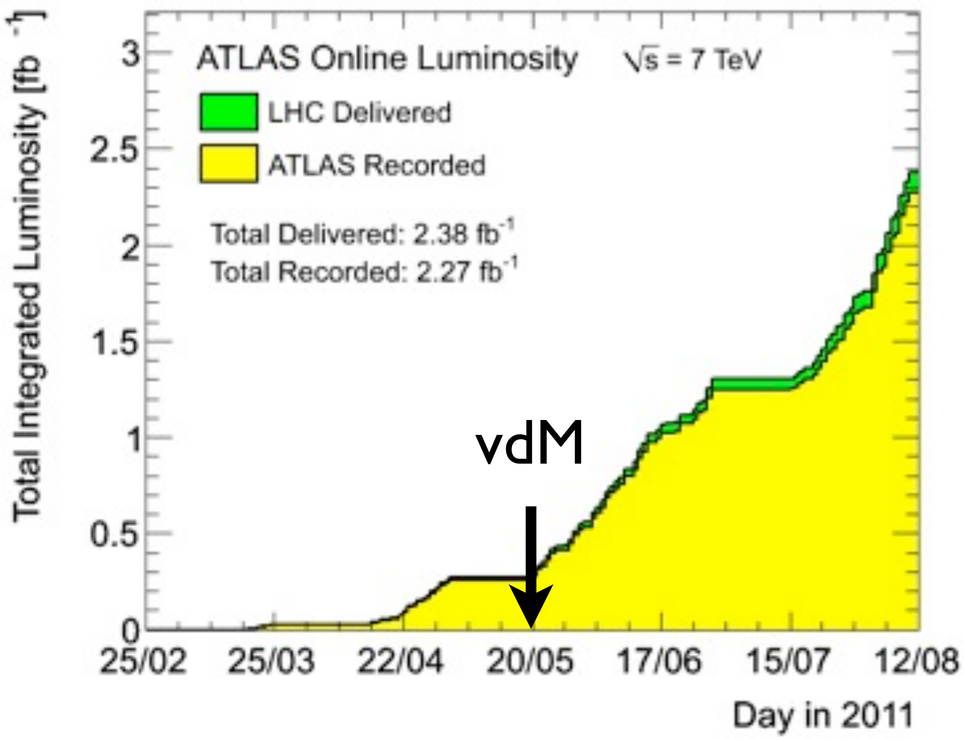
Preliminary vdM σ_{vis} (in mb) calibration

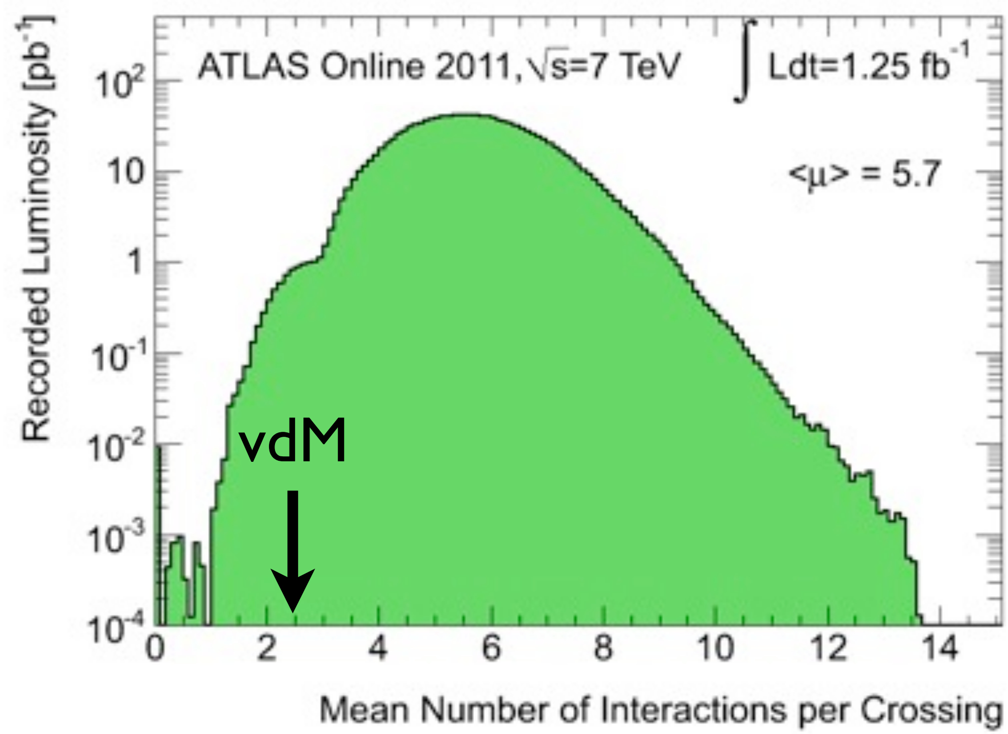
	Oct `10	May `11	Change
BcmH_Or	4.594	4.689	+2.1%
BcmH_And	0.1316	0.1359	+3.3%
Lucid_Or	41.67	42.51	+2.0%
Lucid_And	13.04	13.44	+3.1%

- Hardware changes in both BCM and LUCID over Winter shutdown mean numbers aren't directly comparable
- Observed change consistent at ~percent level with expectation
- May 2011 scan very important for 2011 luminosity uncertainty

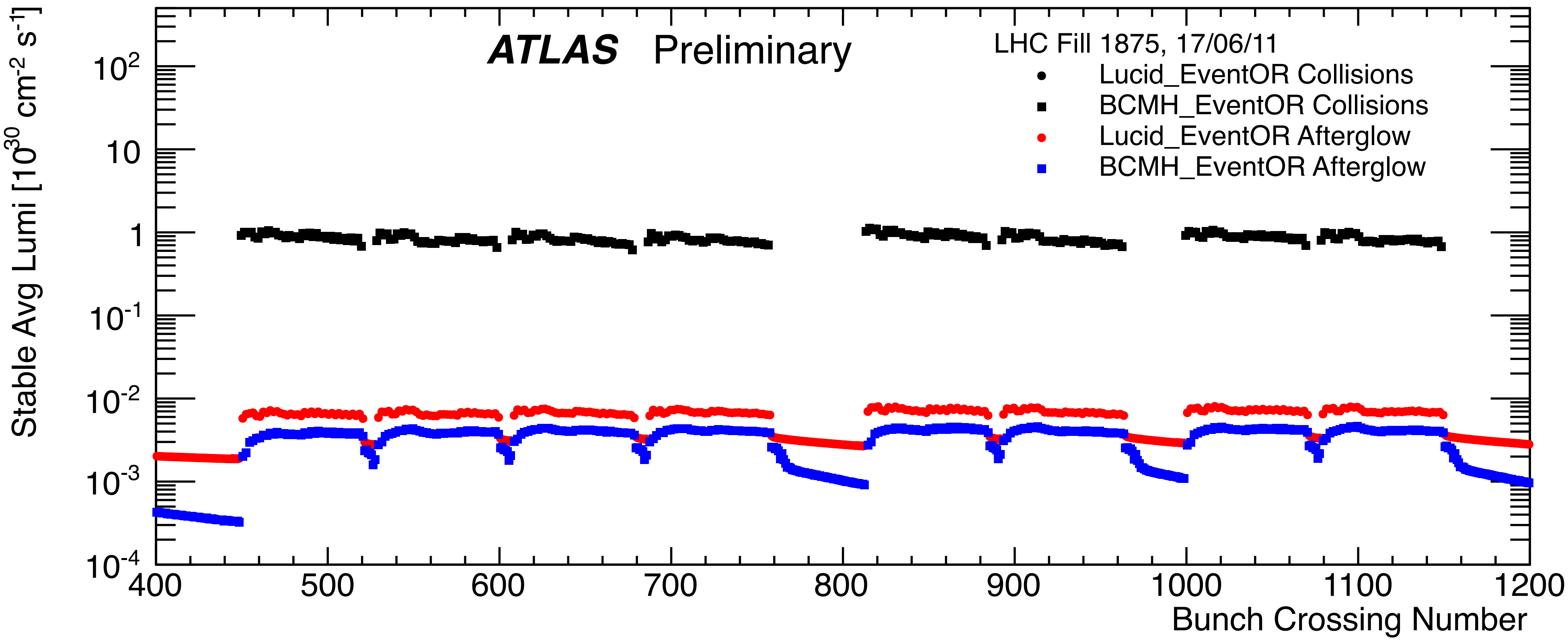
- vdM scans provide calibrated σ_{vis} at one point in time, at lowish μ
- Must be extrapolated to much higher μ to each individual BCID
- Must be applied over months of operations
- Must be applied to rather different operational conditions

Must carefully examine long-term stability and μ dependence





2011 Afterglow

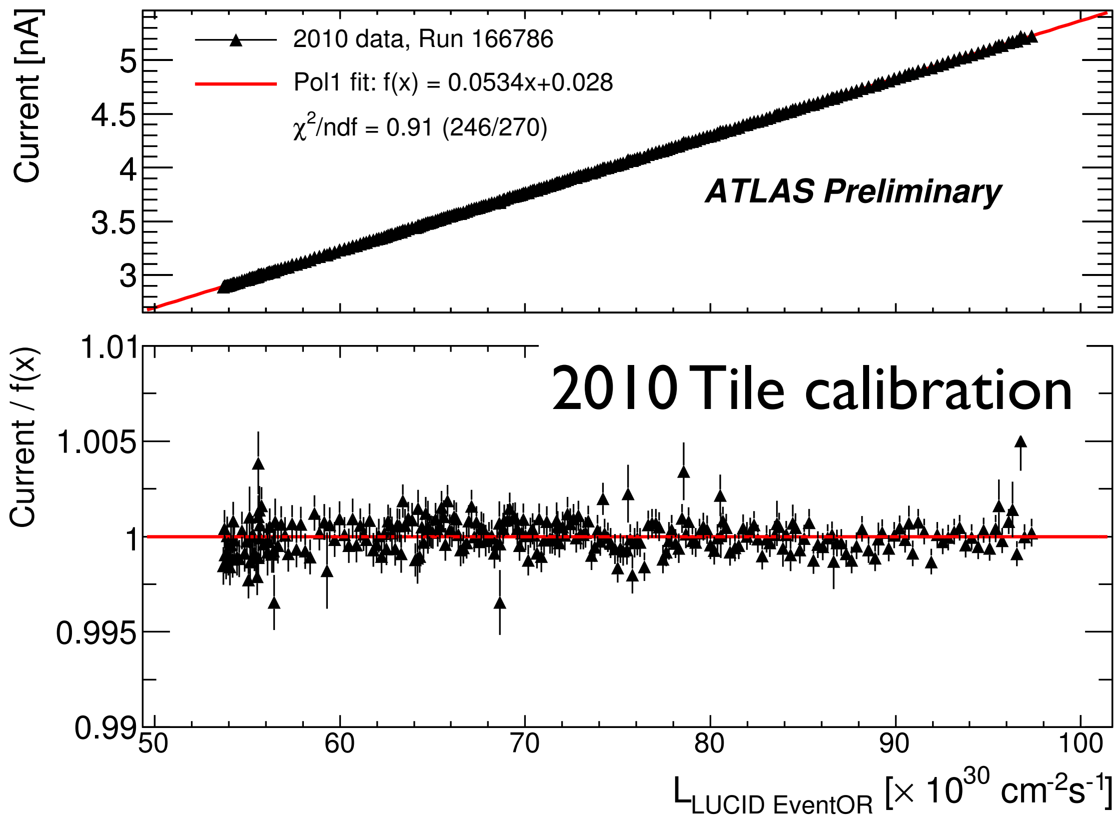


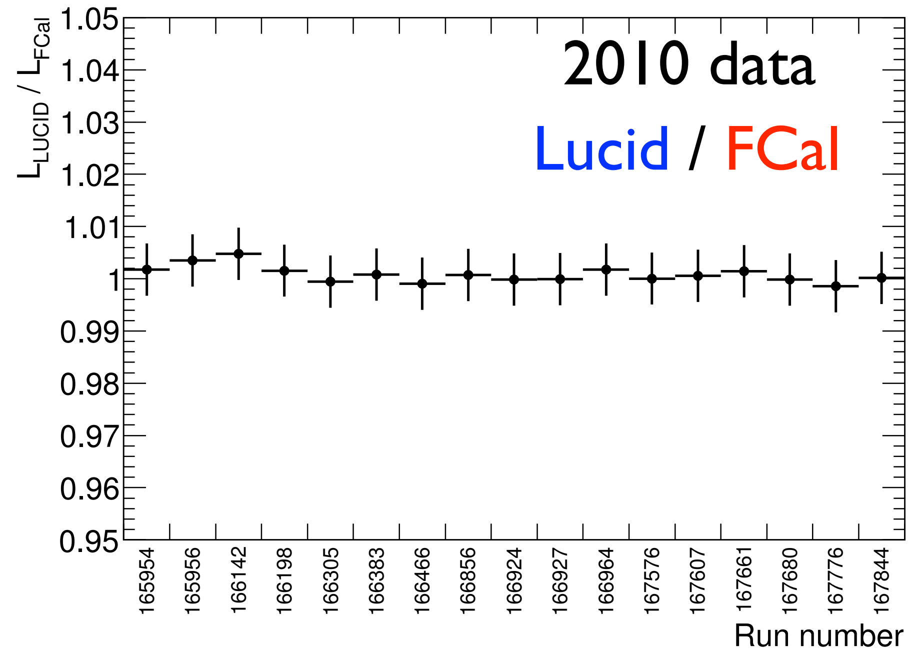
- 2011 has seen 50 ns bunch spacing in 'trains'
- Up to 1331 bunch pairs colliding in ATLAS
- 'Afterglow' at ~1% level (depending upon detector/algorithm)

TileCal/FCal Luminosity Measurements

- TileCal - PMT currents from ~250 PMTs
- FCal - LAr currents from ~30 selected HV lines

Particle counting

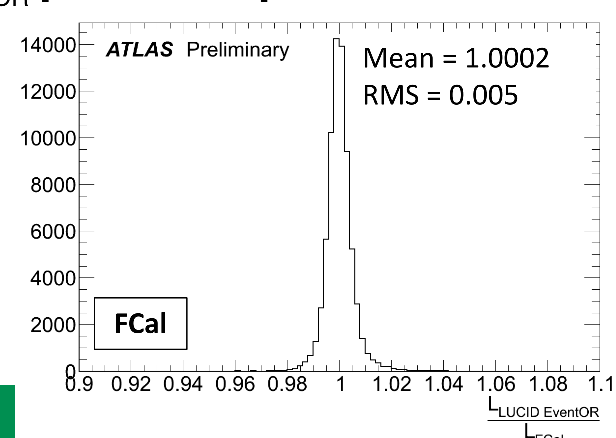


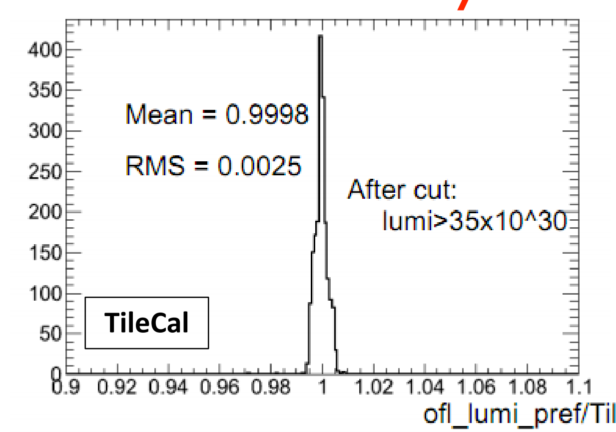


Too slow for vdM scans

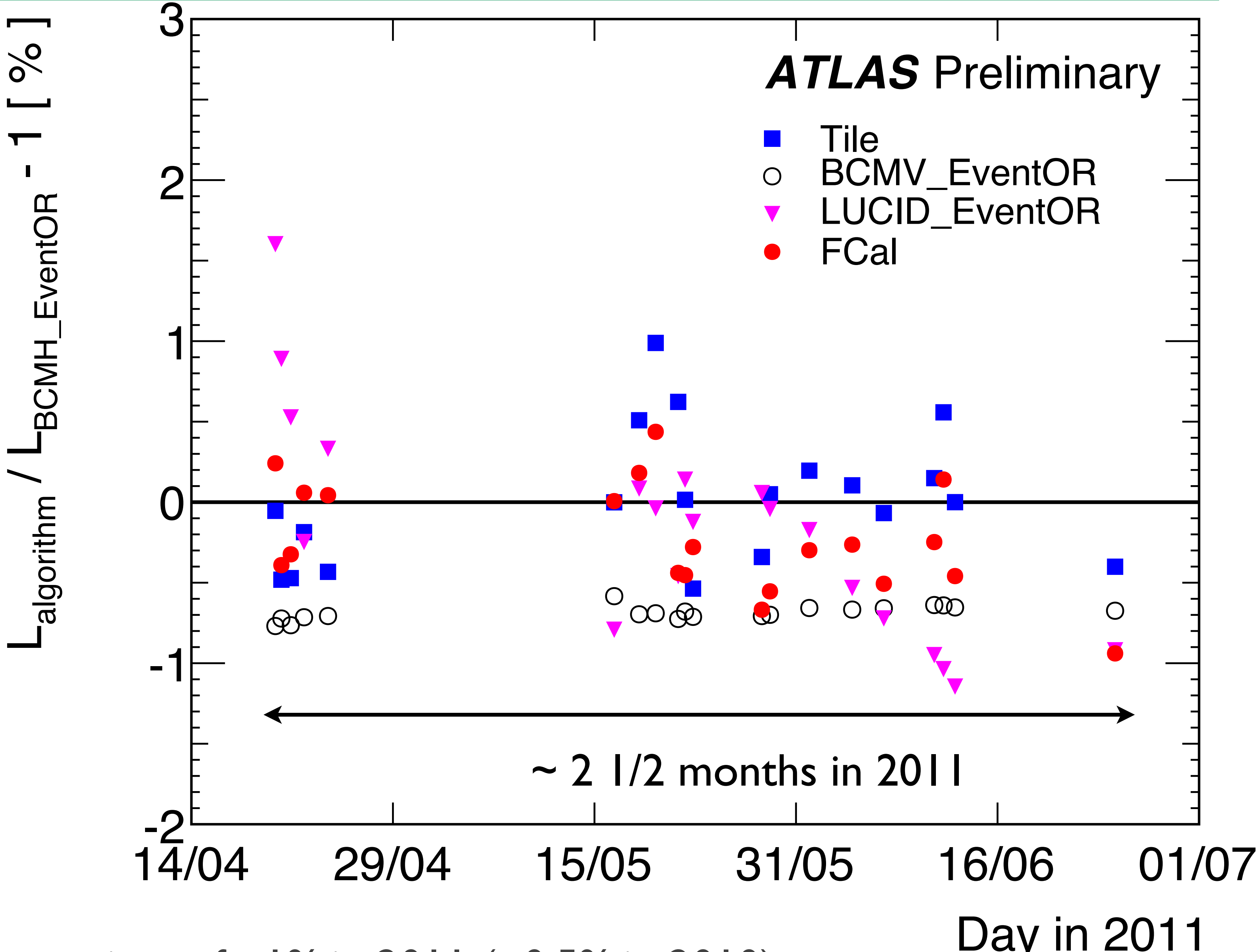
relative measurements only

Good agreement to 2010 lumi data



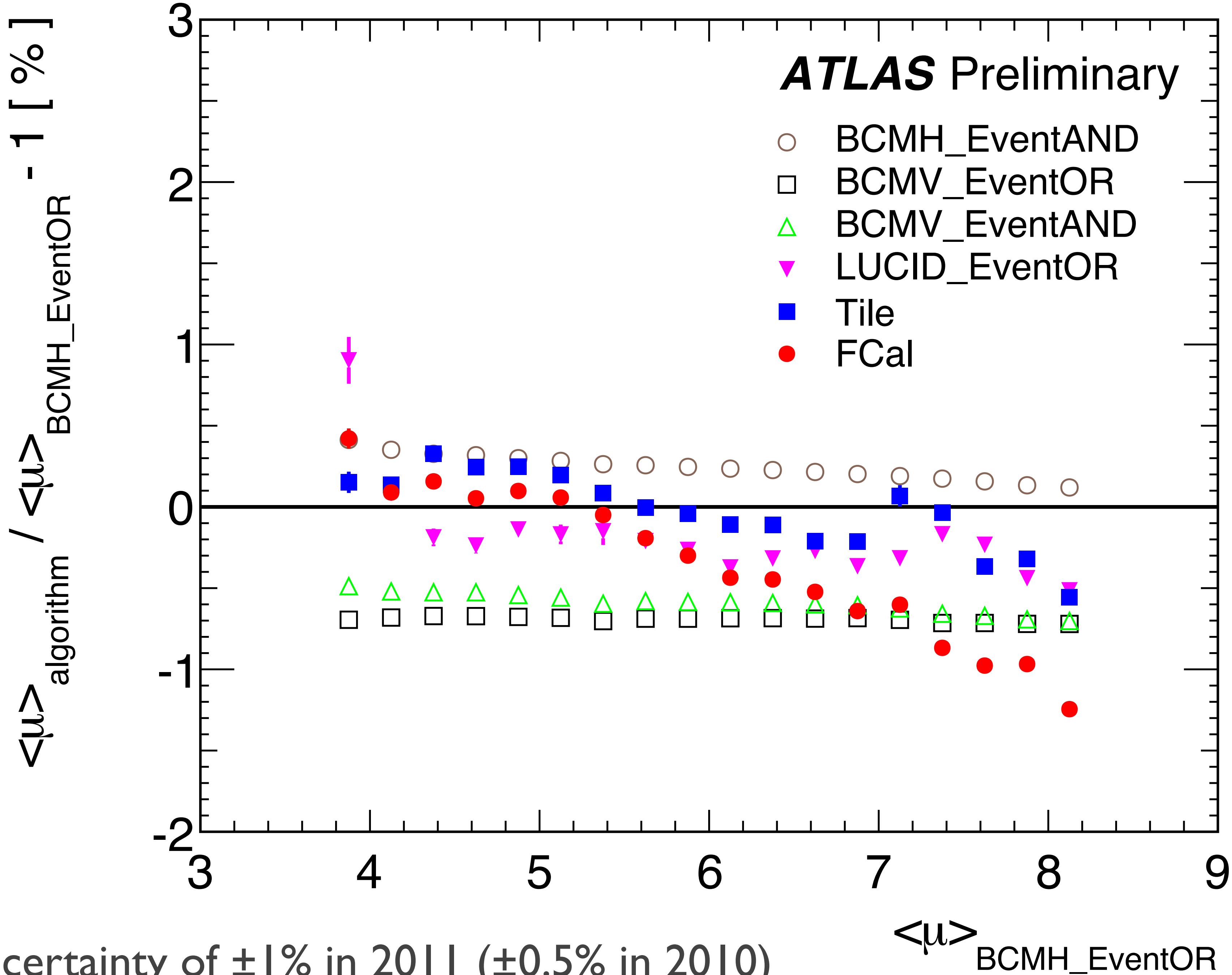


2011 Long-term consistency



- Uncertainty of ±1% in 2011 (±0.5% in 2010)

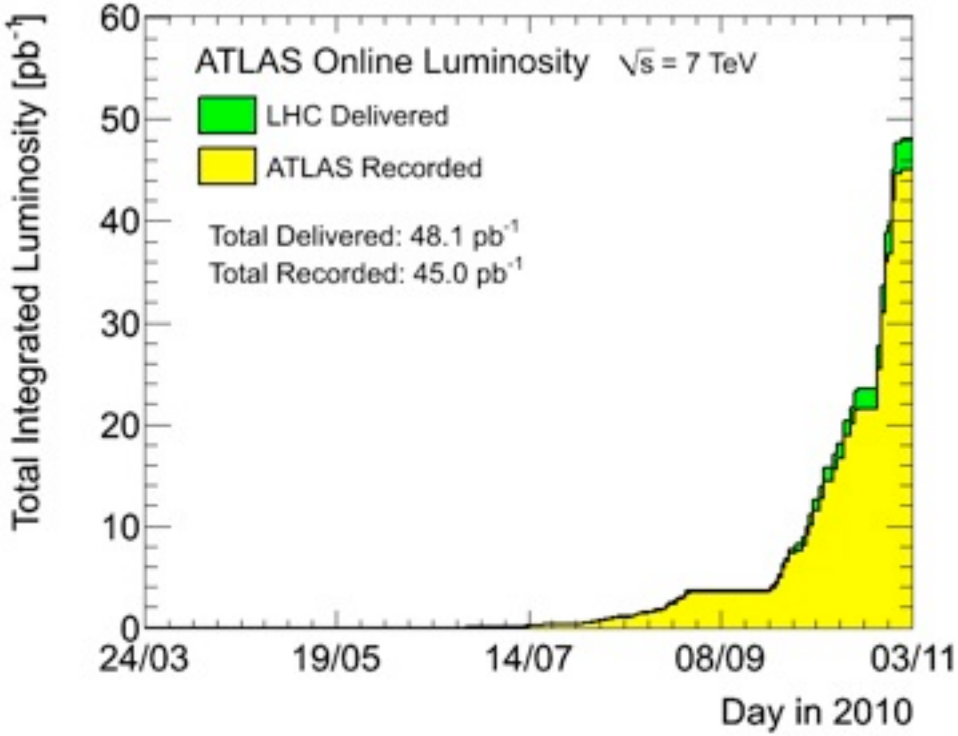
2011 Mu Dependence



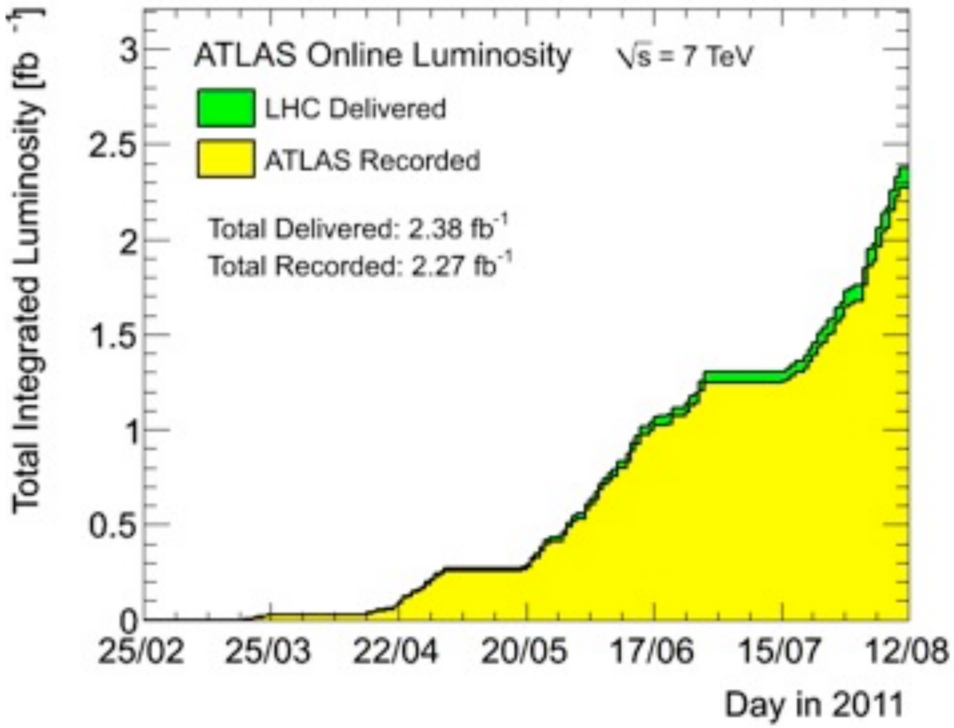
- Uncertainty of ±1% in 2011 (±0.5% in 2010)

Preliminary Luminosity Results

2010



2011



	2010	2011
vdM Calibration	3.4%	3.4%
μ Linearity	0.5%	1.0%
Long-term Stability	0.5%	1.0%
Afterglow	-	0.2%
Total Uncertainty	3.4%	3.7%

Conclusions

- Calibrations based on vdM beam separation scans
- Calibration Uncertainty currently dominated by bunch charge
- 2011 operations have brought additional challenges, higher luminosities (μ~20) will bring more

~ 0.5 fb^{-1} delivered last week

The ATLAS luminosity group looks forward to the future challenges the LHC will deliver...