Absolute $\mathcal{L}$ determination in 2011 – and towards 2012: first impressions & wishes from the experiments

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- **Absolute precision of $\mathcal{L}$ determination**
  - **σ_{vis} calibration: a survey of achieved & projected systematic uncertainties**
    - **the all-important bunch-current product**
    - **van der Meer method**
  - **long-term stability issues & extrapolation to (high-μ) physics conditions**
  - **the low-μ regime: calibration transfer btwn ALFA / TOTEM & ATLAS / CMS?**
  - **Heavy-Ion & low-energy pp collisions**
- **$\mathcal{L}$ - calibration plans for 2012 & wishes from the experiments**
  - **precision (and other) trade-offs**
  - **overview of luminosity-calibration requests**
- **Tools & procedures in 2012**
  - **critical instrumentation**
  - **LHC operations**
- **In lieu of conclusion…**

Disclaimer

- This is <u>not</u>
  - a workshop summary talk…
  - a summary talk for session 2…
  - an attempt at showing a few representative slides from each speaker…
  - a comprehensive compendium of all important issues…
  - a request for scheduling various scans (this belongs in the LPC)…
- …but it is a (feeble) <u>attempt</u> at extracting a <u>preliminary overview</u> of
  - the dominant systematic uncertainties, and where they may limit us
  - the main issues to keep in mind when preparing 2012
  - the (still evolving) wishes of the four large collaborations with respect to $\mathcal{L}$ calibration- & monitoring- scans, with their trade-offs & limitations
  - what our LHC colleagues could do (besides delivering clean, stable, bright beams 24/7 !) to help us improve our luminosity determinations
- … focussing on 7 TeV pp (most demanding in terms of precision)
- I beg your indulgence for the mistakes & misunderstandings you will no doubt spot… Corrections will be gratefully implemented!

Bunch-current product uncertainties: major progress in 2011

	Early 2010-11	2011 update
Total intensity scale: DCCT	**2.7 %**	**0.2 – 0.3 %**
Bunch-by-bunch fractions • **FBCT** • **x-checks: BPTX, LDM**	**1.3 - 1.7 %**	**0.1 - 0.2 %**

Satellites
• **vertexing (ATLAS, CMS)**
• **Timing**
  • **CMS ECAL**
  • **ALICE ZDC**
• **LDM**
	'Only' ATL/CMS vertexing
	+
	CMS ECAL
		LDM
		+
		ALICE ZDC (Pb-Pb only)
		+
		vertexing

Ghost charge + debunched beam • **LDM** • **LHCb beam-gas (BG)** • **ATLAS BCM halo**	LHCb B-G in learning curve	LDM LHCb B-G ATLAS BCM ?

Bunch-current product uncertainties: major progress in 2011 (2)

Summary of the DCCT uncertainties given as an envelope error
Multiply final number by 0.683 to interpret as 1-σ error

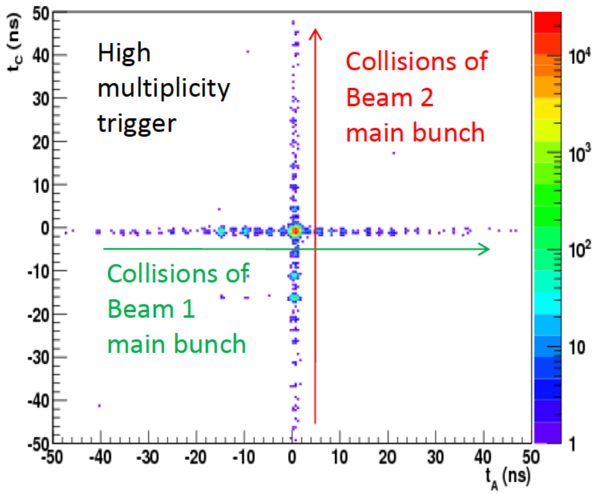
Final uncertainty depend on:
•Acquisition range
•Intensity relative to the full range
•Signal averaging time

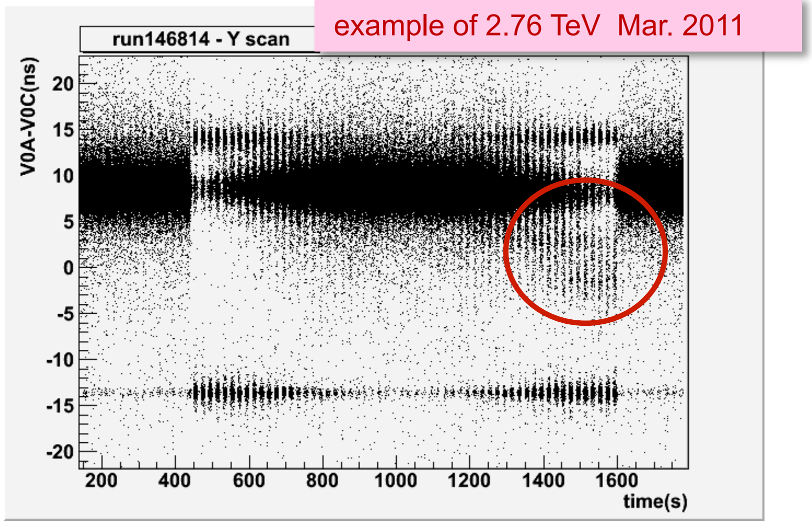
1 LSB = $I_{full}/(I_{DCCT} \times 2000)$
e.g. 0.06 % at 80% of the range

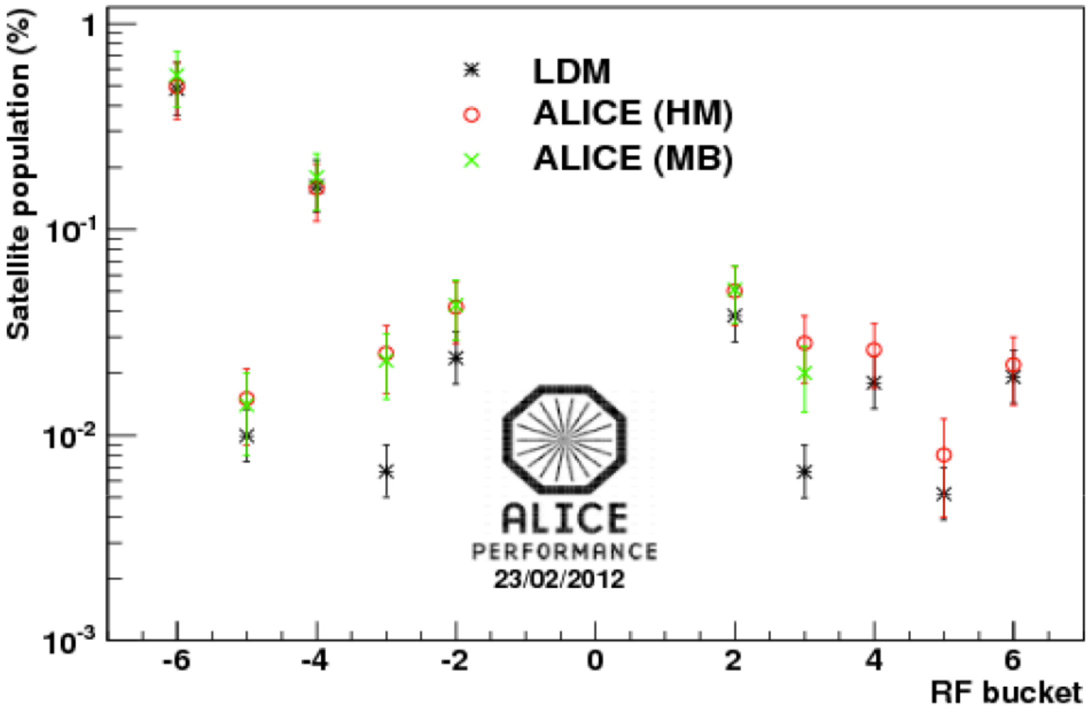
The highest accuracy is reached with ranges 1-3 close to the calibration point

Source of uncertainty	Range	Relative error (%)	Absolute error	Correlated btw. beams
Current source precision		$\pm$ 0.05%		yes
accuracy limited by instrumentation (Sec. 5.1)				
Baseline correction				
If data is manually baseline corrected (Sec. 3.1)			$\pm 1 \cdot 10^9\ e$	
If data is not baseline corrected (Sec. 3.2)	1		$(\pm 6 \cdot 10^{10}\ e)$	
	2		$(\pm 7 \cdot 10^9\ e)$	
	3		$(\pm 4 \cdot 10^9\ e)$	
	4		$(\pm 4 \cdot 10^9\ e)$	
Non-linearity of 12-bit ADC (Sec. 3.4.3)			$\pm$ 1 LSB	yes
non-linearity tue to acquisition chain				
beam 1, 2 and all ranges share same ADC				
Long term stability of baseline				
observed fluctuations within 2×12 hours	1		$\pm 1.1 \cdot 10^{11}\ e$	
if signal average $\geq$ 1 minute (Sec. 3.4.1)	2		$\pm 1.0 \cdot 10^{10}\ e$	
	3		$\pm 2.4 \cdot 10^9\ e$	
	4		$\pm 2.3 \cdot 10^9\ e$	
observed fluctuations within 2×12 hours	1		$(\pm 7.3 \cdot 10^9\ e)$	
if signal average $\geq$ 1 hour (Sec. 3.4.1)	2		$(\pm 1.1 \cdot 10^9\ e)$	
	3		$(\pm 1.1 \cdot 10^9\ e)$	
	4		$(\pm 1.0 \cdot 10^9\ e)$	
Long term stability of calibration	1,2,3		$\pm$ 1 LSB	
envelope observed within 8 month (Sec. 3.6)	4		$\pm$ 4 LSB	
Bunch pattern dependence (laboratory test)		$\pm$0.1%		yes
accuracy limited by instrumentation (Sec. 4.2.1)				
Difference between system A and B	1,2,3		$\pm$ 1 LSB	
observed during all physics injections 2011	4		$\pm$ 10 LSB	
range 4 limited by noise (Sec. 6)				

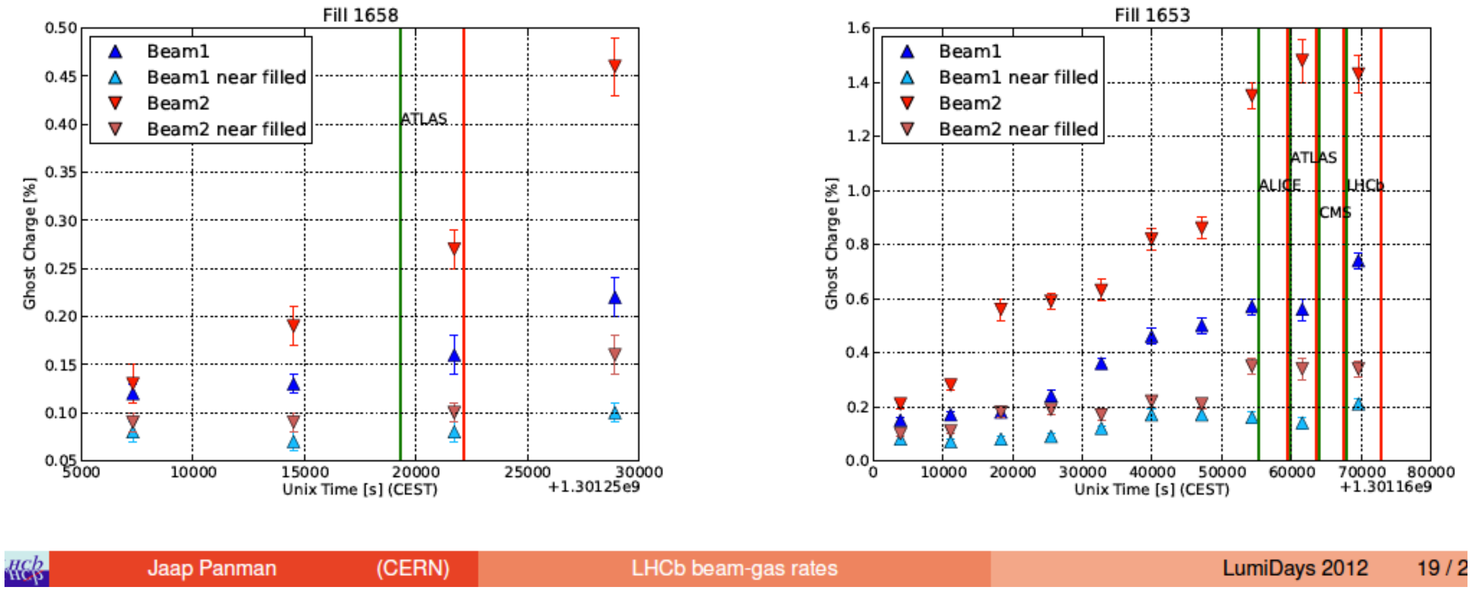
Satellites: ALICE + LDM → impressive progress in 2011







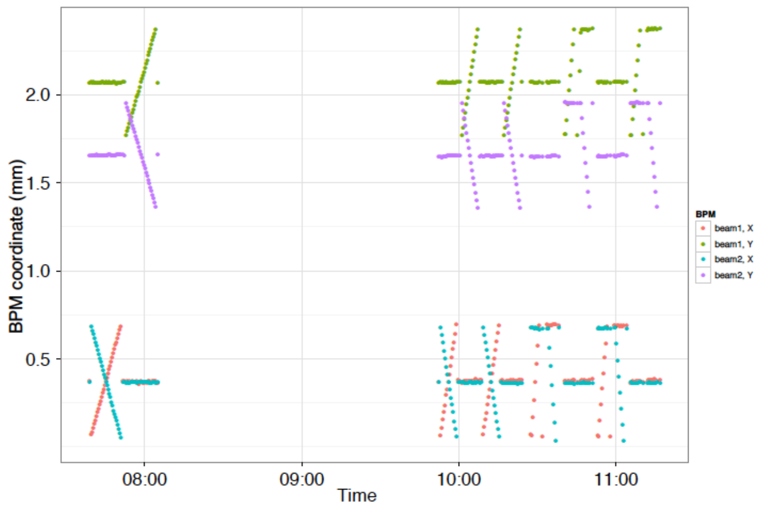
Ghosts: LHCb + LDM → impressive progress in 2011

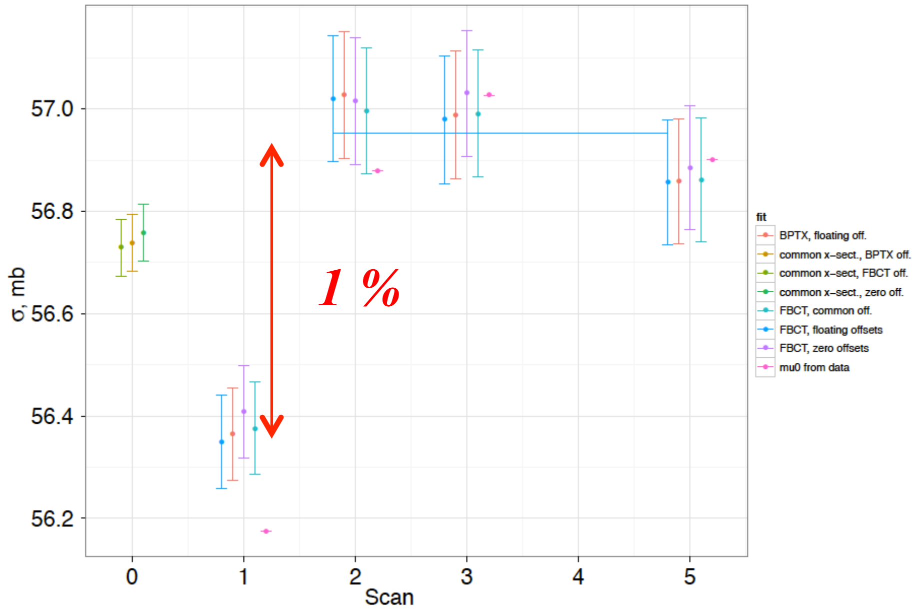


LDM error inventory

	Error for ghost charge	Error for Satellites
Statistical	10 %	5 %
Baseline uncertainty	12 %	3 %
Emittance dependence	20 %	20 %
Debunched beam	100 % ?!	25 % ?!
Total	**-25% / +100%**	**-20% / + 30%**

The importance of being earnest…: the LHCb example

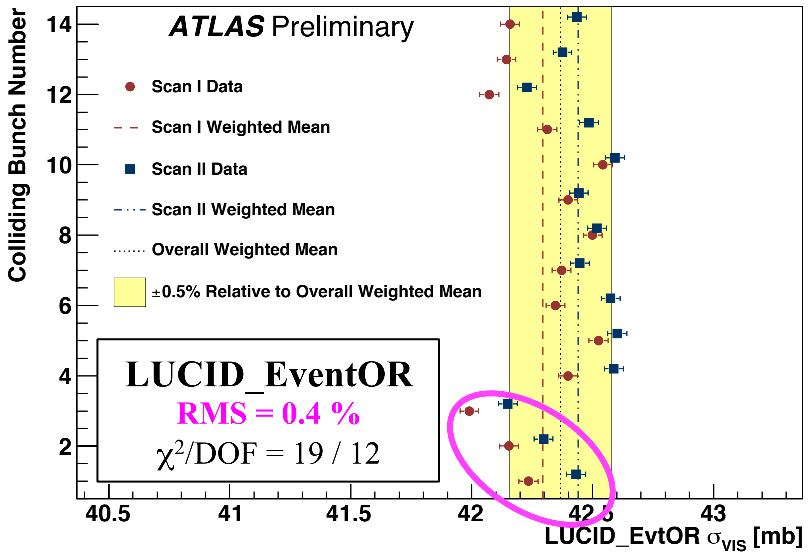




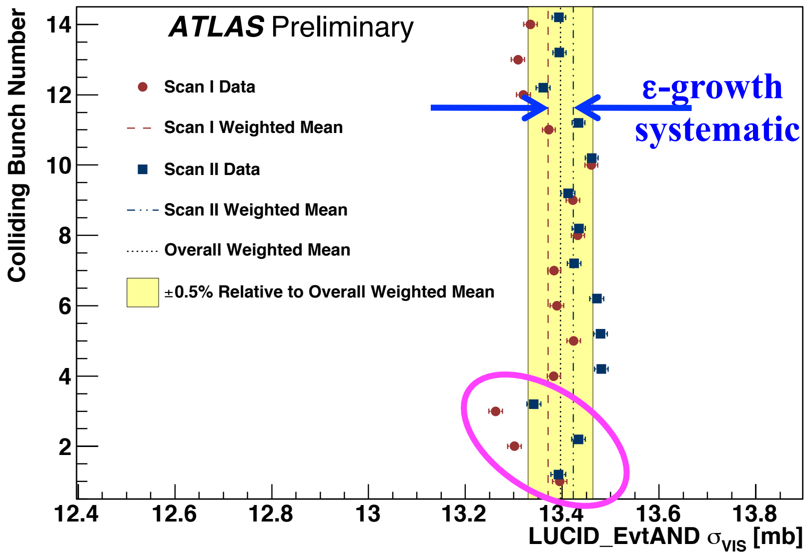
	Error, %	Correction, %
DCCT normalization	0.23	
FBCT w-wo offset	0.05	
FBCT vs BPTX	0.02	
ghost charge	0.20	+1.50
satellites	0.34	+0.68
statistical	0.15	
scan difference	1.06	
integral/sum difference	0.04	
zero point stability	0.00	
zero point pulls	0.29	
background subtraction	0.00	
length scale calibration	0.14	+0.37
X-Y tilt of luminous region	0.01	
beam scale difference	0.00	
beam-beam effects	0.80	
Total VDM calibration error	1.45	

Consistency checks on ATLAS May'11 vdM scan analysis

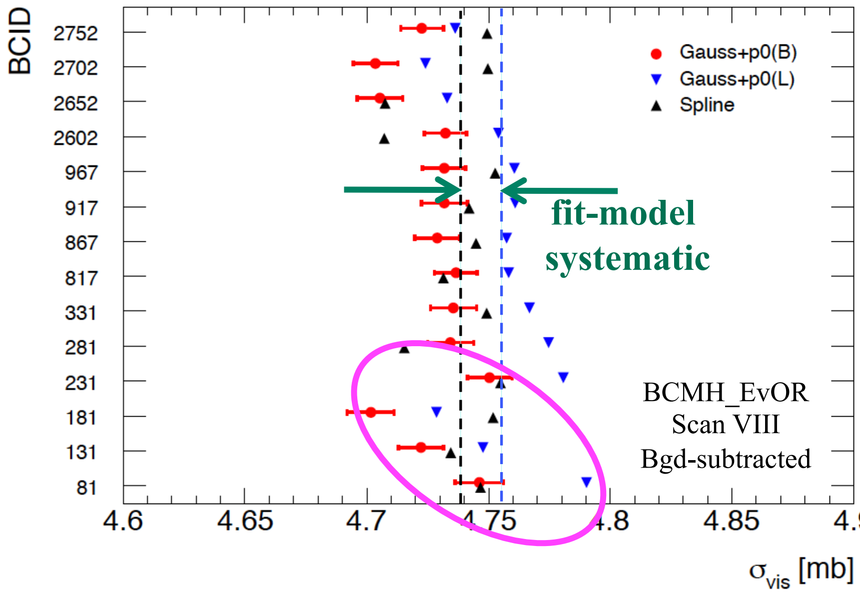
σ_{vis}: btwn bunches within one scan



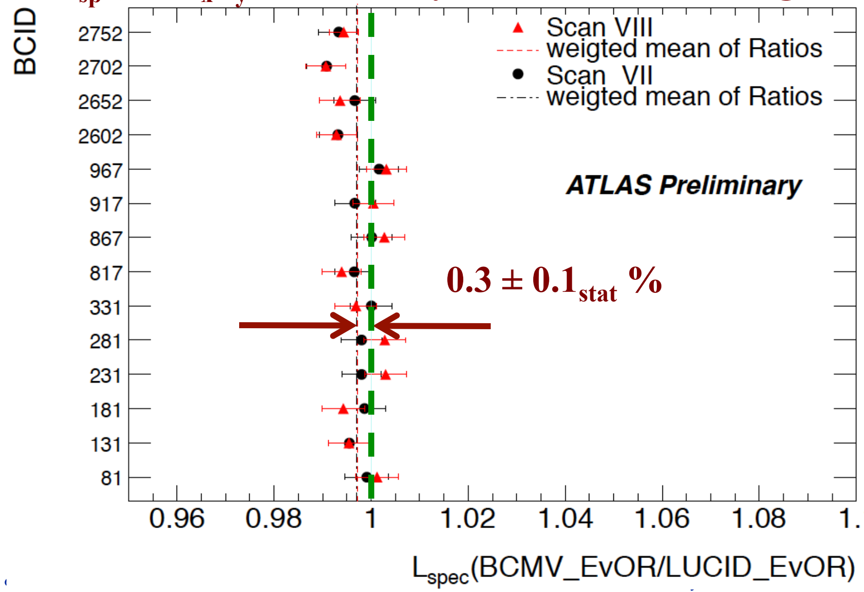
σ_{vis}: bunch-averaged btwn consecutive scans



σ_{vis}: bunch-avrgd btwn different fit models

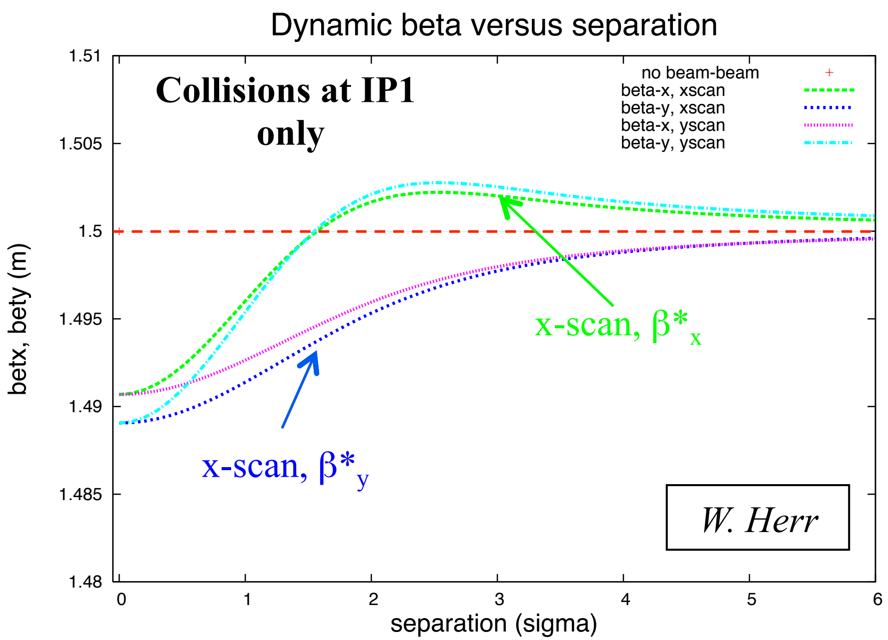


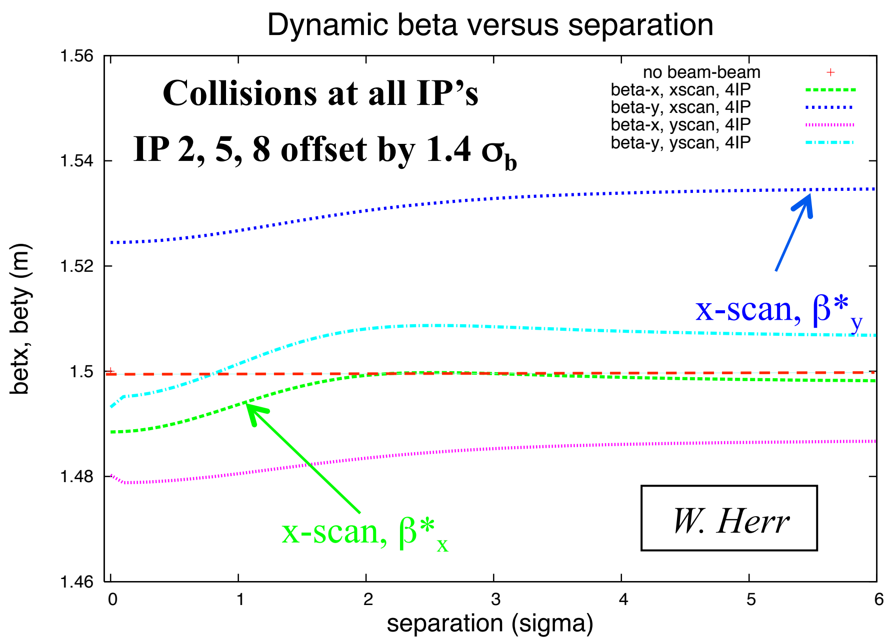
$\mathcal{L}_{sp}$ ($\sim 1/\Sigma_x\Sigma_y$) consistency bwtn detectors or algorithms



Dynamic-β effect: MADX simulations for IP1

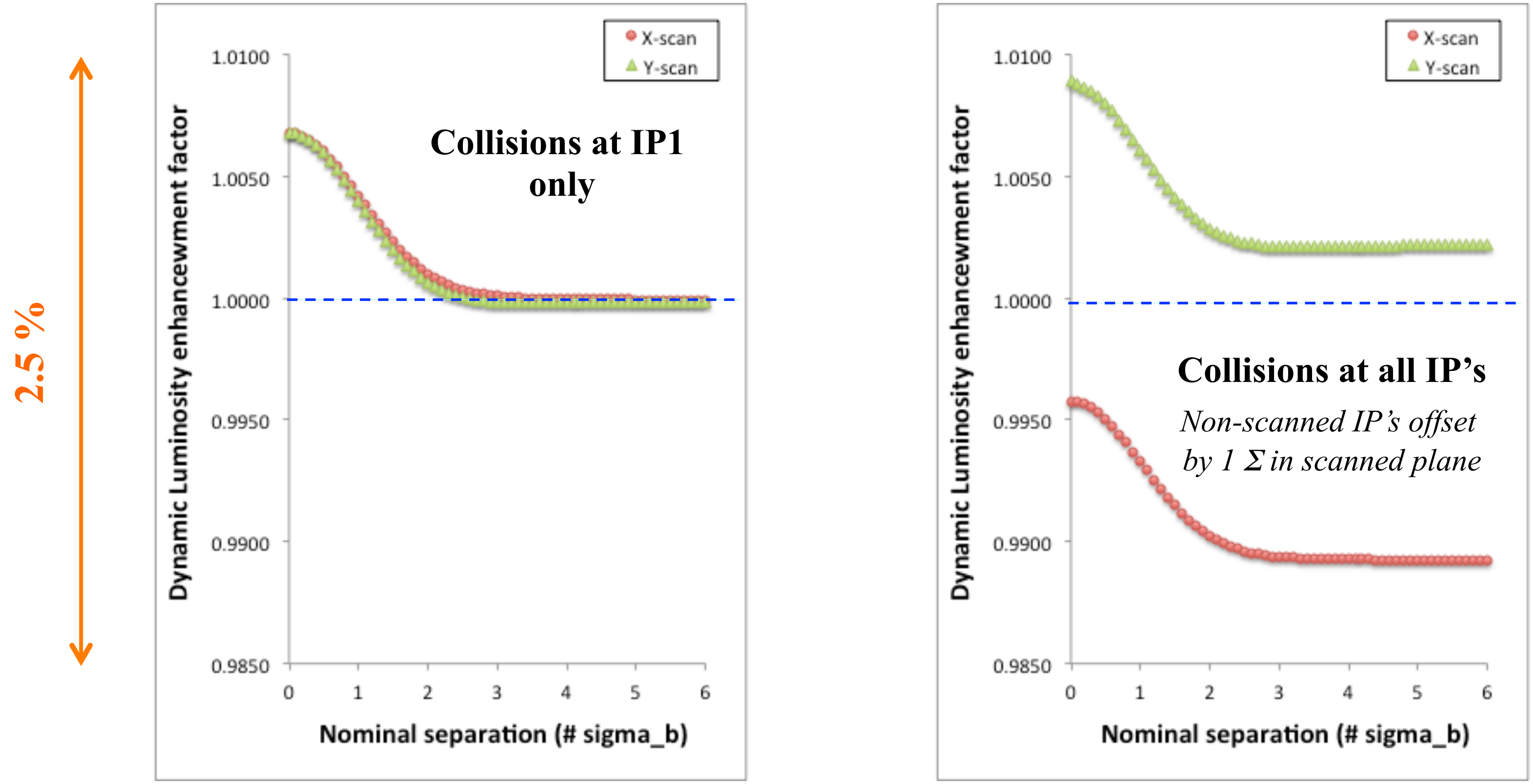
- Compute dynamic β as a function of beam separation, using MADX for typical conditions during May'11 scan:
  - 0.85 10^{11} p/bunch, ε_{inv} = 4 μm, Q_x/Q_y = .31/.32, scan +- 6 σ_b (β^* = 1.5 m)





Dynamic-β effect: impact on luminosity-scan curves

- Compute effect of dynamic β on x & y scans: $\mathcal{L} \sim 1 / \sqrt{\beta^*_{dyn,x}} \sqrt{\beta^*_{dyn,y}}$



- Refit gaussians and compute impact on $\sigma_{vis} \sim \Sigma_x \ \Sigma_y \ \mu_{vis,pk}$
  - collisions at IP1 only: $\Delta\sigma_{vis} / \sigma_{vis}$ = + 0.80 %
  - collisions at all IP's (non-scanned IP's offset): $\Delta\sigma_{vis} / \sigma_{vis}$ = + 0.36 %
  - ATLAS took ± 0.8 % as systematic (safe? over conservative?)

Dynamic-β effect: effect of collsions at other IP's

May'11 vdM scan, 8.5E10/bunch, ε = 4 μ, w/o & w/ head-on collisions at IP5/IP1 only

	Horizontal scan			Vertical scan			σ_{vis} bias (%)	σ_{vis} bias (%)
	β^*_x / β^*_{x0}	β^*_y / β^*_{y0}	$L_{peak,x} / L_{peak,x0}$	β^*_x / β^*_{x0}	β^*_y / β^*_{y0}	$L_{peak,y} / L_{peak,y0}$	(pk var only)	(pk + Σ)
IP1 only	0.994	0.993	1.0065	0.994	0.993	1.0065	0.65	**0.80**
s IP1, c IP5	0.983	1.011	1.0031	0.983	1.011	1.0031	0.31	tbd
IP5 only	0.989	1.018	0.9966	0.989	1.018	0.9966	-0.34	tbd
s IP5, c IP1	0.983	1.011	1.0031	0.983	1.011	1.0031	0.31	tbd

Luminosity distortions scale like N_p / ε_{inv}

May'11 vdM scan, 8.5E10/bunch, ε = 4 μ, 1 Σ (= 1.4 σ_b) offset in scanning plane @ non-scanned IP's

	Horizontal scan			Vertical scan			σ_{vis} bias (%)	σ_{vis} bias (%)
	β^*_x / β^*_{x0}	β^*_y / β^*_{y0}	$L_{peak,x} / L_{peak,x0}$	β^*_x / β^*_{x0}	β^*_y / β^*_{y0}	$L_{peak,y} / L_{peak,y0}$	(pk var only)	(pk + Σ)
IP1	0.9923	1.0163	0.9958	0.9869	0.9955	1.0089	0.23	**0.36**
IP2	0.9943	1.0143	0.9958	0.9971	0.9964	1.0033	-0.05	tbd
IP5	0.9948	1.0147	0.9953	1.0002	0.9965	1.0017	-0.15	tbd
IP8	0.9991	1.017	0.9921	1.0241	0.9968	0.9897	-0.91	tbd

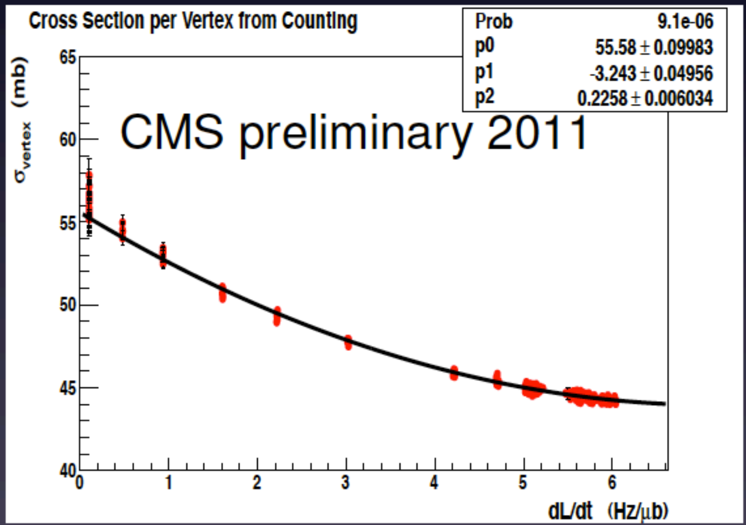
Systematic uncertainties on σ_{vis} (*pp* @ 7 TeV, vdM scans)

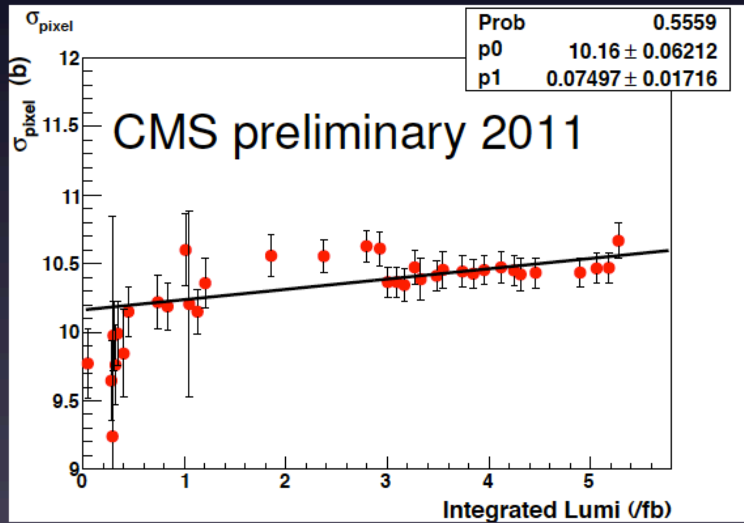
	ATLAS-CONF-2011-116 (2 fb^{-1}) May 2011 vdM %	ATL Upd 2011 5 fb^{-1}, projected May 2011 vdM %	ATL est. 2012 for precision vdM scan	CMS 2011 pp 7 TeV May 2011 vdM %	ALICE 2011 pp 2.76 TeV Mar 2011 vdM %	LHCb 2011 pp 7 TeV Oct 2011 vdM %
DCCT calibration	2.73	0.23			0.4	0.23
FBCT bunch-by-bunch fractions	1.30	0.20			?	0.05
Ghost charge & satellites	0.18	0.18			0.4	0.39
Subtotal, bunch-charge product	*3.0*	*0.35*		*3.10*	*0.64*	*0.46*
Statistical	0.04	0.04		0?	0?	0.15
Beam centering	0.10	0.10		?	0	0
Beam position jitter	0.30	0.30	*depend*	?	?	?
ε growth & other non-reproducibility	0.40	0.77		1.34	0.64	1.06
Bunch-to-bunch σ_{vis} consistency	0.40	0.55	*on*	2 bunches	?	-> inflate stat err
Fit model	0.80	0.29		0	?	0.29
Background subtraction	N/A	0.31	*beam*	N/A	0.30	0
Reference $\mathcal{L}_{sp}$	NC	0.30		only 1 det/alg	only 1 det/alg	only 1 det/alg
Dynamic beta	NC	0.80	*conditions*	?	1.00	0.80
Linear x-y coupling	negligible	negligible?		?	0.60	0.01
Non-linear transverse correlations	0.50	0.50		?	?	?
μ-dependence during vdM scan	0.50	0.50		?	negligible	no effect seen
Length scale calibration	0.30	0.30		0.50	1.41	0.14
ID lengh scale	0.30	0.30		?	?	?
Instrumental issues (e.g. BCM H/V)	0.70	0.70		-	-	-
Subtotal, calibration-scan syst.	*1.5*	*1.75*		*1.43*	*1.96*	*1.38*
Total syst. uncertainty on σ_{vis}	***3.4***	***1.8***		***3.4 (1.5?)***	***2.1***	***1.5***

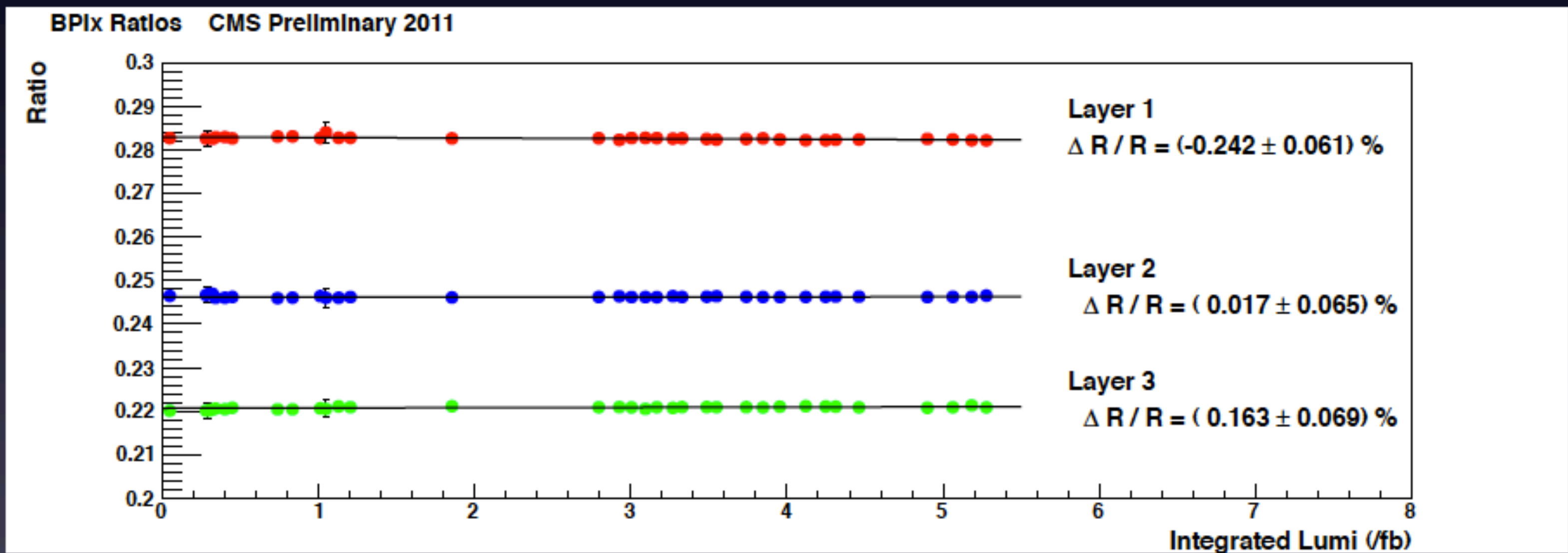
The numbers are the systematic uncertainties (%) as reported by each experiment (and regrouped to fit roughly in the same descriptive scheme)

"?" reflect this speaker's ignorance as to how this uncertainty was treated; it does not necessarily imply that it was ignored in the analysis – only that it was unclear where to find it.

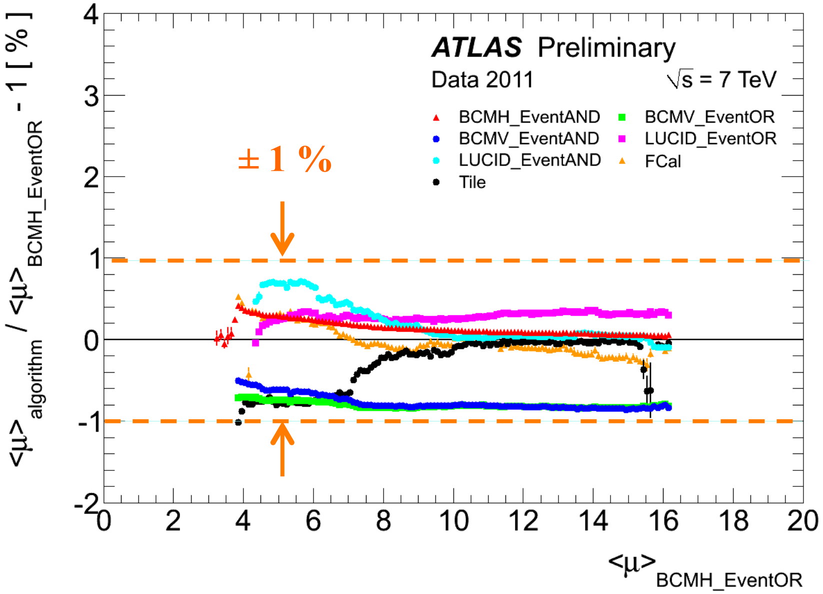
μ-dependence & long-term reproducibility: CMS examples

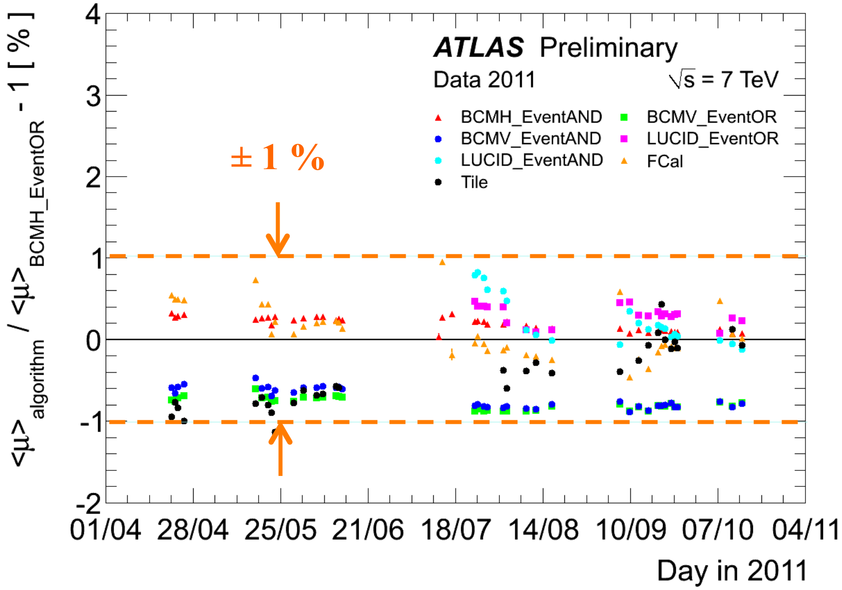






Projected total luminosity uncertainties for 2011 & 2012 (pp, 7 TeV)





TILE / FCal crucial!

	ATLAS-CONF-2011-116 (2 fb^{-1}) %	ATL Upd 2011 5 fb^{-1}, projected %		CMS 2011 May 2011 vdM %	ALICE 2011 Mar 2011 vdM %	LHCb 2011 Oct 2011 vdM %
Subtotal, syst. uncertainty on σ_{vis}	*3.4*	*1.8*		*3.4 (1.5 ?)*	*2.1*	***1.5***
Long-term stability	1.0	1.0		0.7	?	0.5 ?
μ-dependence during physics running	1.0	1.0		?	negligible	0.5 ?
Afterglow subtraction	0.2	0.2		1.0	0.2	0
Subtotal, rel. luminosity monitoring	*1.4*	*1.4*		*1.2*	*0.2*	*0.7 ?*
Total luminosity uncertainty	***3.7***	***2.3***		***3.6 (1.9 ?)***	***2.1***	***1. 6 ?***

A few (preliminary!) words about correlations

- ATLAS, across vdM sessions (hence 2011 ←→ 2012)
  - most systematics associated with beam conditions, hence uncorelated
  - exceptions
    - ID scale: 0.3 %
    - perhaps BCM H/V ratio: 0.7 % (depending on actual cause) ?
- CMS, across vdM sessions (hence 2011 ←→ 2012)
  - see J. Hegeman's talk
    - some of the 'correlations' may need to be rediscussed (IMHO)
- ATLAS vs. CMS
  - uncorrelated when calibrated in 2 separate vdM sessions
  - if calibrated within same vdM session
    - bunch-intensity measurements are correlated
    - other beam-related sytematics are uncorrelated in practice – even if common source
      - e.g. bunch-to bunch σ_{vis} inconsistencies in May'11 vdM scans

Calibration transfer btwn ALFA / TOTEM ← → ATLAS / CMS

- $\mathcal{L}$ from ATLAS/CMS luminometers to ALFA/TOTEM for σ_{tot} msmts
  - LHC Fill 2232, β^* = 90 m, $n_{1,2}$ ~ 0.6 10^{11}/ bunch + pilots
    - μ_{pp} ~ 0.03 - 0.05 for "nominal" bunch
    - ALFA/ATLAS example using BCM (LUCID) for $\mathcal{L}$ measurement
      - beam-gas/pp ~ 1% (0.2 %) – should be manageable…
      - activation/afterglow ~ 1% (<< 1%) – should be manageable…
      - …but: sizeable inconsistencies across LUCID & BCM algorithms: instrumental? Vertex methods crucial to resolve this (~ 10 kHz data stream w/ pixel+SCT only)
      - similar problems observed in μ –scan: check of μ–dependence at low μ complicated by much stronger afterglow (> 800 bunches) & beam-gas background
    - TOTEM/CMS: assumed $\Delta_{\mathcal{L}} / \mathcal{L}$ = 4% → $\Delta\sigma_{tot} / \sigma_{tot}$ ~ 2%
      - how did/can one check consistency between $\mathcal{L}$ response at high μ & very low μ ?
  - extrapolation to β^* = 500-600 m
    - μ_{pp} ~ 0.005 - 0.009 → beam-gas/pp ~ 6 % (1.5%) – or more: systematics?
    - cannot push intensity too high ←→ dynamic β !
    - hard to predict achievable accuracy until inconsistencies understood

Calibration transfer btwn ALFA / TOTEM ← → ATLAS / CMS (2)

- **Absolute $\mathcal{L}$ calibration transfer**

  from ALFA/TOTEM: $d\sigma_{el}/dt$ + [Coulomb interference or total rate]

  to ATLAS/CMS for normal physics running

  - **what is achievable precision in ALFA/TOTEM ?**
    - **technical proposals: 2 - 3 % ?**
    - **2012: what is realistic estimate?**
  - **what is precision of calibration transfer?**
    - **today: unknown? (early ALFA experience + issues at higher β^*)**
    - **achievable 2012: 0.5 – 2 % ??**
  - **total luminosity accuracy for normal physics running: must add…**
    - **μ-dependence uncertainty: 0.5 % ultimate?**
    - **long-tem stabiity: 0.5 – 1.0 %**
  - **hence $\sigma_{\mathcal{L}} / \mathcal{L}$ ~ 2.1 – 3.7 % ? (but… I hope I am wrong here!)**

Heavy-Ion & low-energy pp collisions

- The absolute $\mathcal{L}$ accuracy (1.5 - 2.5 %) achieved for high-$\mathcal{L}$ *pp* running at $\sqrt{s}$ = 7 TeV doesn't necessarily apply to other running modes!
- low-$\mathcal{L}$ *pp* running at $\sqrt{s}$ = 2.76 TeV, β^* = 10-11 m
  - larger bunch-current uncertainties (FBCT non-linearities/offsets?)
  - systematic checks complicated by
    - sizeable bunch-by-bunch intensity and ε variations + lower statistics/bunch
    - beam aborted between 2 pairs of scans → very different beam profiles (ATLAS)
  - larger (relative) beam-gas background, esp. in ATLAS very-low-μ run
- HI running (2010 + 2011): e.g. ALICE, Nov 2010, $\sigma_{\mathcal{L}} / \mathcal{L}$ = -5.2 / +6.4 %
  - larger bunch-current uncertainties (DCCT in 2010; sat's + ghost charge)
  - large systematic spread in bunch intensities & emittance across trains
  - faster emittance growth
  - larger single-beam background that grows with time in fill (2011 HI !)
  - instrumental issues (ATLAS ZDC aging)

vdM calibration: a random list of observations, nagging questions or potential traps

- **Lack of reproducibility: why?**
  - **orbit jitter? LHCb study suggests not…**
  - **emittance growth?**
    - **but peak rate & convolved width should compensate !**
    - **could it be related to the 'chronological ordering' problem – and to the adequacy of the fit model to the data ?**
  - **what (anything?) can be done to control the injected-beam tails?**
    - **non- or 2nd-gaussian signature varies fill to fill, or even x ≠ y in same fill**

- **Satellites & ghost during vdM scans**
  - **becoming a significant limitation to abs. precision**
  - **LDM is crucial; the precision of its baseline subtraction is v. important**
  - **we need ΣΜΟΓ running during vdM scans!**
  - **would be helpful to have ALICE monitor satellites also in pp – but: Xing angle? ZDC rate?**

vdM calibration: a random list of nagging questions & potential traps (2)

- **Scan with or without Xing angle?**
  - satellites may come back & bite us (ALICE example in Mar'11 scans)

- **Distance-scale calibration**
  - what is the magic to get it right– every time and cheaply?

- **Transverse correlations**
  - linear x-y coupling: seems OK – or is it just that we were expecting it to be small? Did we look hard enough ?
    - learn more from study of luminous-centroid & -width evolution during scan?
  - non-linear correlations: does the x-shape of the scan depend on y & vv?
    - is it a red herring? or …
    - … a real issue we are blind to?
      - For ATLAS in 2010+2011, syst. uncertainty ranges from 0.5 to 3 % depending on fill considered (somewhat correlated with non-gaussian character of beam)
      - Could the other experiments try to fit the naïve ATLAS model (correlated g+g) ?
      - Need β^* = 11 vdM scans to settle this one way or the other

Absolute $\mathcal{L}$ determination:
a random list of nagging questions & potential problems

- **Monitoring long-term stability**
  - **BCID-blind relative-$\mathcal{L}$ monitoring**
    - **ATLAS Fcal + TILE proved invaluable**
      - **saved early 2011 $\mathcal{L}$ calibrations!**
      - **were crucial in quantifying the μ-dependence and the long-term stability**
    - **other ideas? e.g. RPC's, Medipix…**
  - **automated monitoring using Z's should be put in place in both ATLAS & CMS**

- **Is there really a ~ 8% discrepancy between the ATLAS & CMS integrated luminosities in 2011 pp running?**
  - **hopefully an accounting problem…**
  - **otherwise hard to reconcile with ~ 2% absolute precision**
  - **should reactivate the comparison of luminosity candles (track-based event counting, Z's?)**

$\mathcal{L}$ – calibration plans & wishes for 2012: overview

- $\mathcal{L}$-calibration transfer from 2011 to 2012 very delicate at best
  - σ_{vis} changes (σ_{tot} + eff'cy) with $\sqrt{s}$ significant (ATLAS: $\Delta\mathcal{L}/\mathcal{L} \sim 5$ - 17 %)
  - detector reproducibility/consistency problems at startup?
  - … especially in view of expected achievable precision ($\sigma_{\mathcal{L}}/\mathcal{L} \sim$ 2 % ?)

- Calibration scans essential for both absolute $\mathcal{L}$ & μ-dependence
  - vdM scans (+ distance-scale calibration for every new value of E_b, β^*)
    - trade-offs = f(β^*, ε_{inv}, θ_c, $n_{1,2}$, n_{coll}, bunch pattern, schedule, …)
    - early, 'low-cost' beam-separation scans (= before April TS)
    - 'ultimate' vdM scans in pp (= after closing ICHEP dataset) + p-Pb (all expts)
  - μ scan [ATLAS + CMS]
    - essential to control systematics (pile-up + aging >> 2011!)
    - ATLAS: needs $\mathcal{L} > 2\ 10^{33}$ (Fcal, TILE) + μ as high as stable running permits
    - CMS: 'regular' beam-sep scans in physics for stability checks, on request
  - afterglow scan: calibrate afterglow subtraction [ATLAS + CMS]
    - ≤ 4 colliding bunches > 700 BCID apart, no pilots, no interleaved unpaired
    - highest possible μ to minimize data-taking time

van der Meer strategy in 2012: precision trade-offs

β^* (m)	0.6	11	Comments
ε_{inv} (μm-rad)	3	3	Often as large as 4
Σ_y (μm)	29	124	
$\sigma_{\mathcal{L}}$ (mm)	15	62	σ(vtx) ~ 30-50 μm
$N_{1,2}$ (10^{10}/bunch)	(< ?) 6 - 12	6 - 12	Low $N_{1,2}$ → • fewer/weaker ghosts/satellites Sparse pattern (no trains) → • fewer ghosts/satellites • cleaner transverse phase space (tails) ? • less impact of afterpulsing, instrumental tails, reflections, etc • less collsion/induced afterglow
μ (inel pp / BX)	4.1 – 16.6	0.27 – 1.09	
Peak counts / step [30 s] (worst case)	2700 – 10800	175 - 710	μ_{vis} (ATLAS BCM_AND) ~ 0.002
$\Delta\mathcal{L}/\mathcal{L}$ [dyn. β] (%)	0.75 – 1.50	0.75 – 1.50	assumes worst case: collisions @ IP1 only

van der Meer strategy in 2012: precision trade-offs (2)

β* (m)	0.6	11	Comments
$N_{1,2}$ (10^{10}/bunch)	6 (?) - 12	6 (?) - 12	see previous slide
μ (inel pp / BX)	4.1 – 16.6	0.27 – 1.09	
$\Delta\mathcal{L}/\mathcal{L}$ [dyn. β] (%)	0.75 – 1.50	0.75 – 1.50	Can do better wih compensation?
Advantages	• high-stat consistency checks, bunch-by-bunch & btwn detectors/algorithms • allows x-calibrtn to TILE in same fill (ATLAS)	• access to imaging & non-linear correlations: is x (y)shape y- (x-) dependent ?	
Disadvantages	• mixes detector calib'tn & μ-correction: scan-curve distortions for some detectors (tbc) ? • no lum. reg. imaging → non-linear correlation syst. (0.5 – 3 %?) from arbitrary model • ↑ afterglow (if trains)	• Lowest efficiency detector/algorithm: σ_{vis} = statistics- limited • dynamic-β limited: cannot buy rate with more protons • some syst. checks statistics-limited • low-μ inconsistencies ?	Dynamic β caps usable brightness ($N_{1,2}$ / ε) and makes statistics limitations @ 11 m more acute

van der Meer strategy in 2012: trade-offs (3)

- **Preferred bunch pattern: <u>no trains</u>!**
  - transverse & longitudinal phase space cleaner with individual bunches (non-gaussian tails, satellites, ghost charge, …)
    - associated systematics vary from one scan period to the next, and can only be quantified with the actual scan data themselves
    - all experiments insist on a sparse (no trains) pattern for "ultimate" vdM scan
  - dynamic β is different for each bunch in a train (parasitic crossings)
- **Sparse pattern (widely separated paired bunches + a few unpaired)**
  - mitigates afterpulsing + reduces collision-induced afterglow
  - allows to decouple collisions at IP1+5, 2, 8 (dyn. β!)
  - # bunches: trade-off between
    - more bunch-to-bunch consistency checks (favored by LHCb ?)
    - more bunches → better statistics (average bunch-by-bunch σ_{vis} values) ?
    - fewer bunches: less afterglow (favored by ATLAS - so far)
    - FBCT systematics ('all' bunches should be colliding)
- **Hybrid pattern: sparse (for vdM) followed by a 'growing' train (for MPP validation)?**

van der Meer scans (+ DSC) in 2012: "wish" matrix (pp only)

	β^* (m)	ε_{inv} (μm)	$\theta_c/2$	N (10^{10})	Pattern # b	E / U	Comments or special requests
ATLAS	0.6	~ 3	standard	5 - 6 (ALAP)	sparse < 20 coll ?	E ?	• IP5 head-on; mostly private b (or separ. IP2, 8) • LDM • ALICE satellite + LHCb ghost trigs • ATLAS BPTX • timing of U being discussed
	11	~ 3	standard (tbc)	tbd (statistics vs.dyn. β)	sparse < 20 coll ?	U E ?	
CMS	0.6		standard		sparse or hybrid	E	asar
	11		no pref		sparse	U	

van der Meer scans (+ DSC) in 2012: "wish" matrix (pp only) (2)

	β^* (m)	ε_{inv} (μm)	$\theta_c/2$	N (10^{10})	Pattern # b	E U	Comments or special requests
ALICE	standard			low	sparse or hybrid > 200-500 ns	E	if opportunity
	3				sparse > 200-500 ns > 16 b	U	May request 2-d raster to study x-y correlations
LHCb	standard		standard		sparse or hybrid	E	if opportunity
	10	possibly enlarged	large in 1 plane only		sparse ~ 36 b w/ 16 private (~ Oct '11)	U	• LDM • ATLAS BPTX • several scans: reproducibility? • SMOG • extra running w/ head-on/separt'd beams for B-G

Tools & procedures for absolute $\mathcal{L}$ determination in 2012

- **Critical instrumentation**
  - DCCT: monitor/maintain calibration stability over long term
  - FBCT + BPTX: availability of <u>both</u> during vdM scans
  - LDM: automatic logging to TIMBER, both during vdM sessions & physics periods (satellite corrections?)
  - LHCb beam-gas (SMOG active): during all vDM sessions, for all expts
  - ALICE ZDC: monitor satellites in vdM sessions, p-Pb; possible in pp?
- **LHC operations**
  - Choose bunch pattern & "colliding IP's" to minimize dyn-β distortions
    - e.g. when scanning IP1, collide in IP5 but not in IP2 + 8 ?
  - No lumi levelling/optimization at IP1/2/8 during vdM scan @ IP5 (and all permutations thereof, even if only private bunches are used)
  - New scan software (esp. automated leapfrog)
    - will make scans
      - less expensive
      - more robust against cockpit errors, DAQ failures, etc
    - will need time to be tested (and may require adjustements to DIP folders)

A conclusion in 7.5 words – in order of growing importance

- Dynamic β !
- ghosts & satellites
- Redundancy → internal consistency?
- Reproducibility !

Additional material

van der Meer scan: Basic Observables

- Absolute luminosity measurement using beam separation scans

$$\mathcal{L} = \frac{n_b f_r n_1 n_2}{2\pi \Sigma_x \Sigma_y}$$

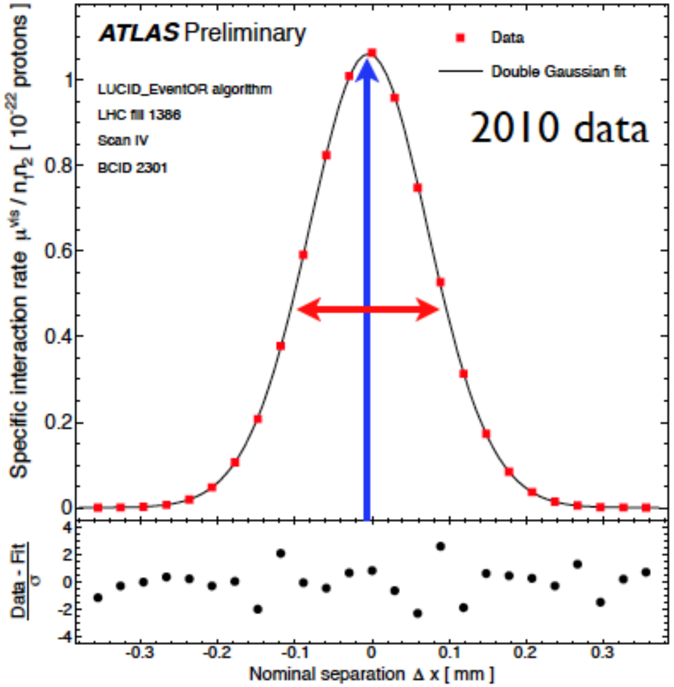
- Can directly calibrate σ_{vis} per lumi alg.

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

Peak Rate

Scan Widths

Bunch Charges



n_b	= number of colliding bunch pairs
f_r	= LHC revolution frequency
μ_{vis}	= number of detected "events" per bunch crossing = $\mu\ \varepsilon$
σ_{vis}	= visible cross-section = luminosity calibration constant

Luminosity: basic observables

$$\mathcal{L} = \frac{\mu n_b f_r}{\sigma_{inel}} = \frac{\mu_{vis} \; n_b f_r}{\varepsilon \sigma_{inel}} = \frac{\mu_{vis} \; n_b f_r}{\sigma_{vis}}$$

μ = number of inelastic collisions per bunch crossing

n_b = number of colliding bunch pairs

f_r = LHC revolution frequency (11245.5 Hz)

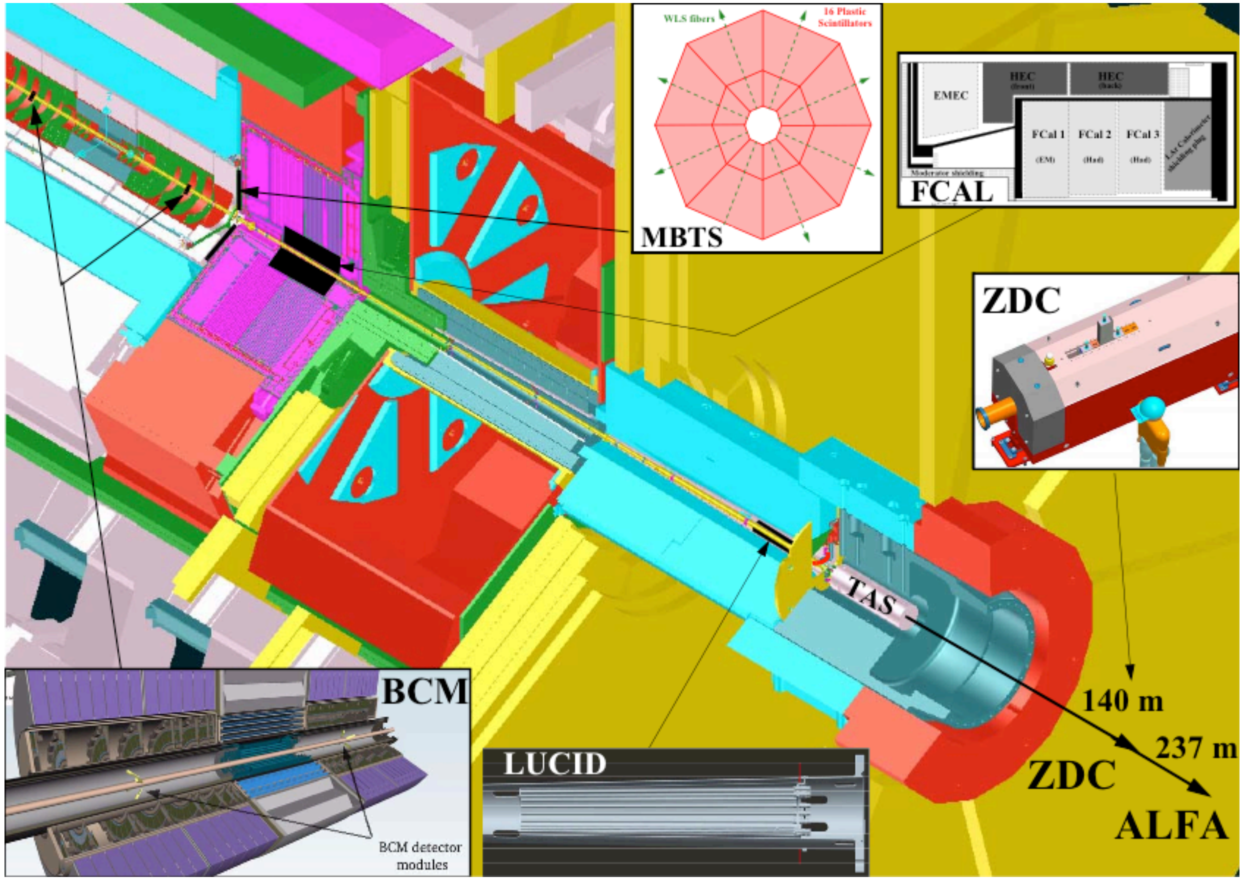
σ_{inel} = total inelastic [pp] cross-section

μ_{vis} = number of detected "events" per bunch crossing = $\mu \, \varepsilon$

ε = acceptance x efficiency of luminosity detector

σ_{vis} = visible cross-section = luminosity calibration constant

Luminosity measurements used in the ATLAS 2011 $\mathcal{L}$ analysis



- BCM: bbb
  - Event OR, AND for BCM H/V separately
- LUCID: bbb
  - Event OR, AND, A, C
  - Hit OR/AND
- vtx methods: bbb
  - vtx-based event counting
  - vertex counting
- FCAL (fwd LAr)
  - gap currents
- TILE calorimeter
  - PMT currents
- RPC, Medipix, ZDC

- bbb = bunch-by-bunch (+ bunch-integrated over colliding bunches ATLAS triggers on)
- BCID-blind = sums over all BCID's

van de Meer scan analysis: formalism

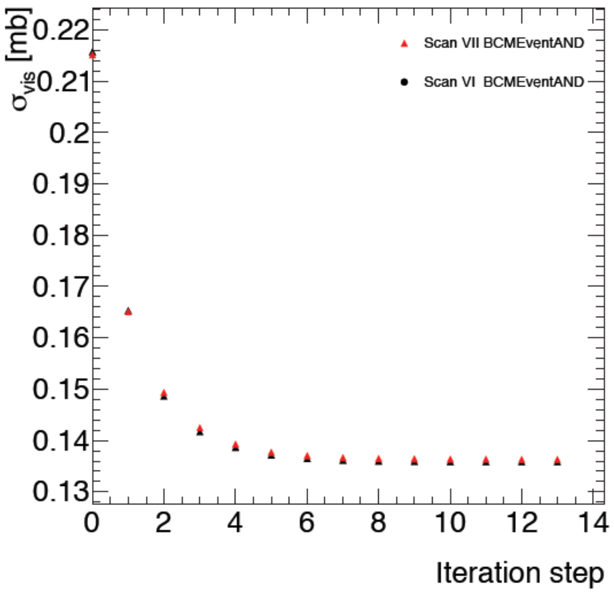
- **From "event" counting (actually 0-counting) to μ_{vis}**

  And/Or algorithms count 'events' - N_{BC} passing some criteria

  - Assuming Poisson statistics:

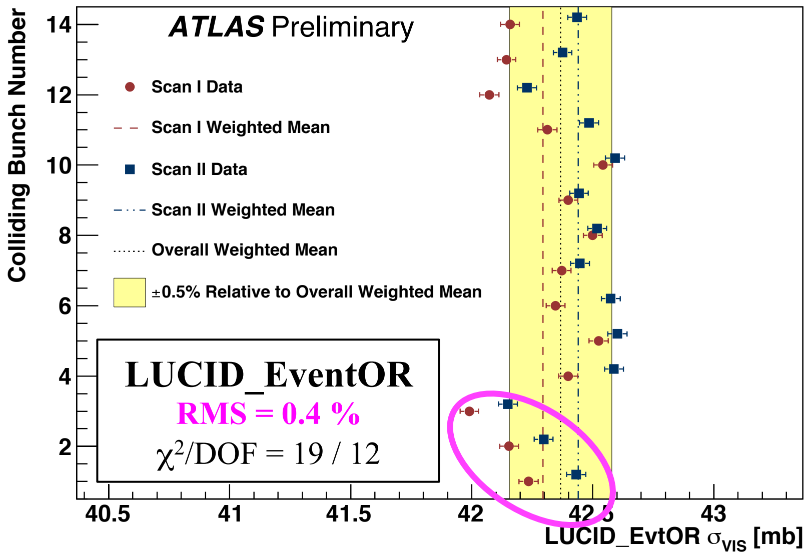
$$P_{\text{Event\_OR}}(\mu_{vis}^{OR}) = 1 - e^{-\mu_{vis}^{OR}} = \frac{N_{OR}}{N_{BC}}$$

$$P_{\text{Event\_AND}}(\mu_{vis}^{AND}) = 1 - 2e^{-(1+\sigma_{vis}^{OR}/\sigma_{vis}^{AND})\mu_{vis}^{AND}/2} + e^{-(\sigma_{vis}^{OR}/\sigma_{vis}^{AND})\mu_{vis}^{AND}} = \frac{N_{AND}}{N_{BC}}$$

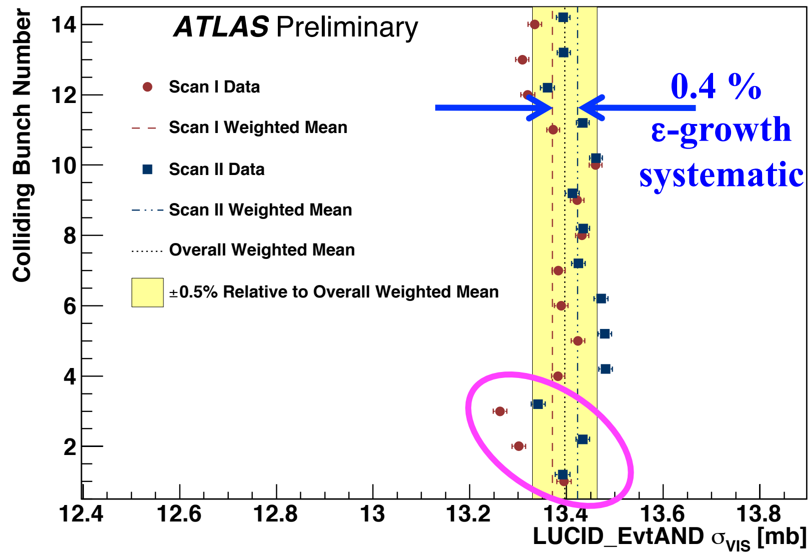


Consistency checks on May'11 vdM scan analysis

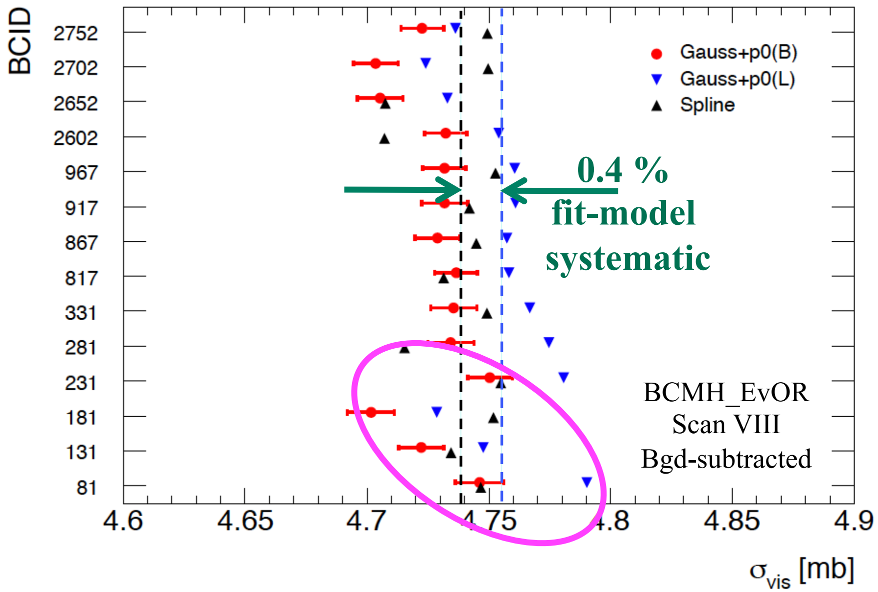
σ_{vis}: btwn bunches within one scan



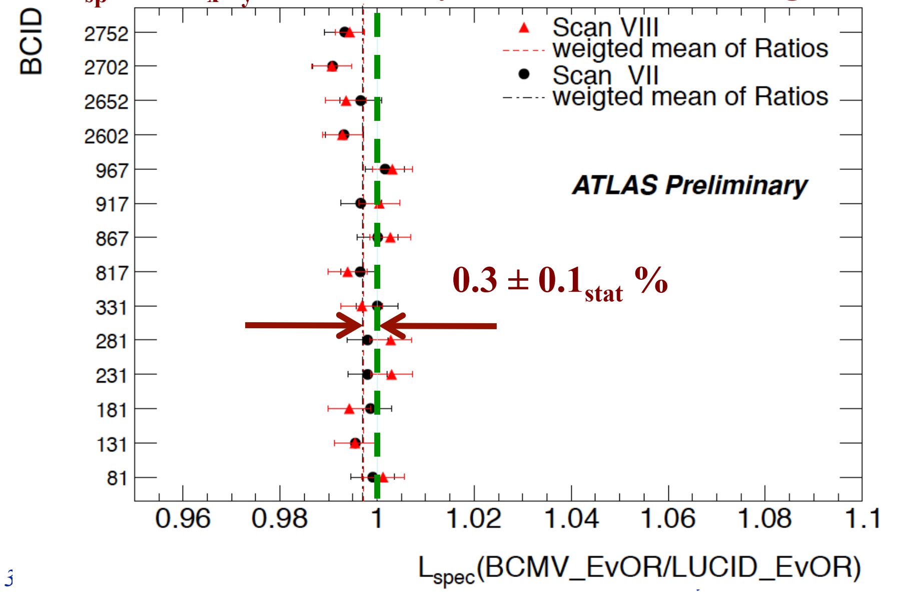
σ_{vis}: bunch-averaged btwn consecutive scans



σ_{vis}: bunch-avrgd btwn different fit models

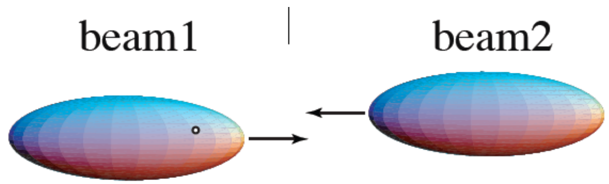


$\mathcal{L}_{sp}$ (~ $1/\Sigma_x\Sigma_y$) consistency bwtn detectors or algorithms



Dynamic-β effect

- The electromagnetic field produced by a B1 bunch (de)focusses the particles in the B2 bunch (& vice-versa)



  - → beam-beam deflection (observed in May'11 vdM, consistent w/ exp.)
  - → each beam acts as a (de)focussing quadrupole on the other. This modifies the machine optics, and in particular the β* values (hence the name 'dynamic β'), in a manner that depends on
    - the magnetic lattice – and in particular the tunes
    - the bunch intensities and emittances ($\sim N_{1,2} / \varepsilon_{inv}$)
    - whether the beams collide at other IP's (more beam-beam, but with different phase advances between IP's)

- During a beam-separation scan, the ***dynamic-β*** effect may enhance (or reduce) the instantaneous luminosity, thereby ***distoring the scan shape slightly*** *(first pointed out by H. Burkhardt - afaik)*

Systematic uncertainties in pp

item	Scan-II Oct. 2010 7 TeV	Scan-V Mar. 2011 2.76 TeV	comment
Beam intensity $\delta(N_1 N_2)$	3.2%	2.7% → 0.4%$^{(ghost)}$ ⊕ 0.4%$^{(DCCT)}$	2.76 TeV to be updated
Length scale calibration	1%⊕1%	1%⊕1%	
Luminosity decay	neglig.	0.5%	50% of corr. effect
Hysteresis & reproducibility	NA	0.4%	50% of observed pk-pk
Beam centering	neglig.	0.0%	no effect with corr. seen
After-pulse / after-glow	neglig.	0.2%	(*)
Background & satellite rate	neglig.	0.3%	50% of corr. effect
Pile-up correction	neglig.	neglig.	well under controlled
X-Y coupling	NC	0.6%	worst case observed
Beam-beam interaction	NC	? (1%)	under investigation
Total in experiment	**1.41%**	**1.70% (1.97%)**	
Total with beam intensity	**3.50%**	**1.79% (2.05%)**	

NA: not available at that time, NC: not considered at that time

(*) estimated as observed after-pulse and after-grow, together with observed cross section of exclusive events

Total systematic uncertainties for PbPb

Bunch intensity	
DCCT scale	2.7%
Relative bunch populations	<0.1%
Ghost charge	–1.4% +3.9%
Satellites	0.5%
Other	
Length scale calibration	2.8%
Inclusive v.s. b-by-b difference	2%
Background	1%
Scan-to-scan discrepancy	1%
luminosity decay	2%
Total	–5.2% +6.4%

Values are preliminary, and still being studied

CMS systematics summary

Preliminary and under scrutiny

Source	Uncertainty (%)
Stability across pixel detector regions	0.3
Pixel gains and pedestals	0.5
Dynamic inefficiencies	0.4
Length-scale correction	0.5
Beam width evolution	0.6
Beam shape	-
Beam intensity	3.1
Scan-to-scan variations	1.2
Afterglow	1.0
Total	**3.6**

Preliminary 2011 integrated luminosity

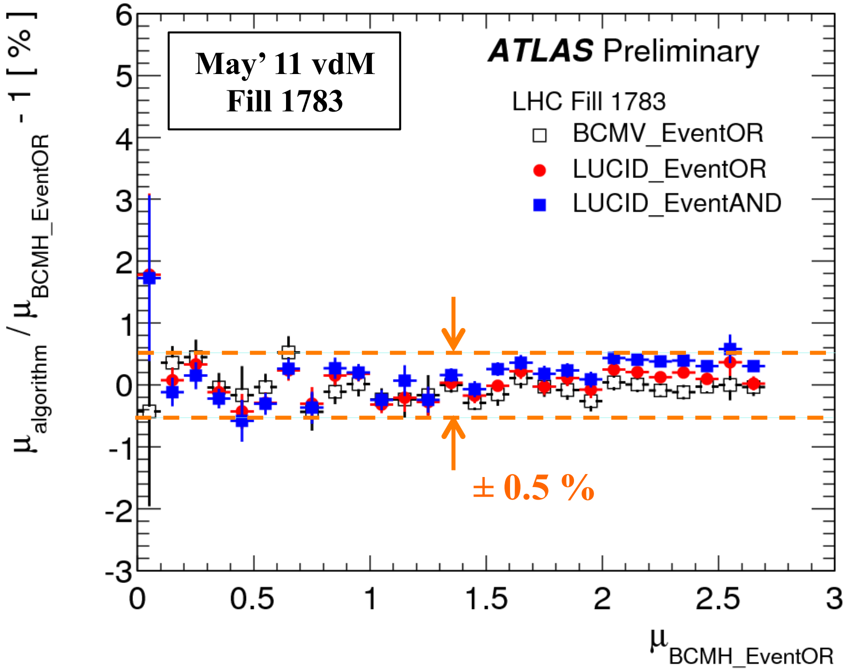
Extrapolating from the pixel live-time to the total delivered luminosity in 2011 this comes to 6.1 fb$^{-1} \pm \approx 5\%$.

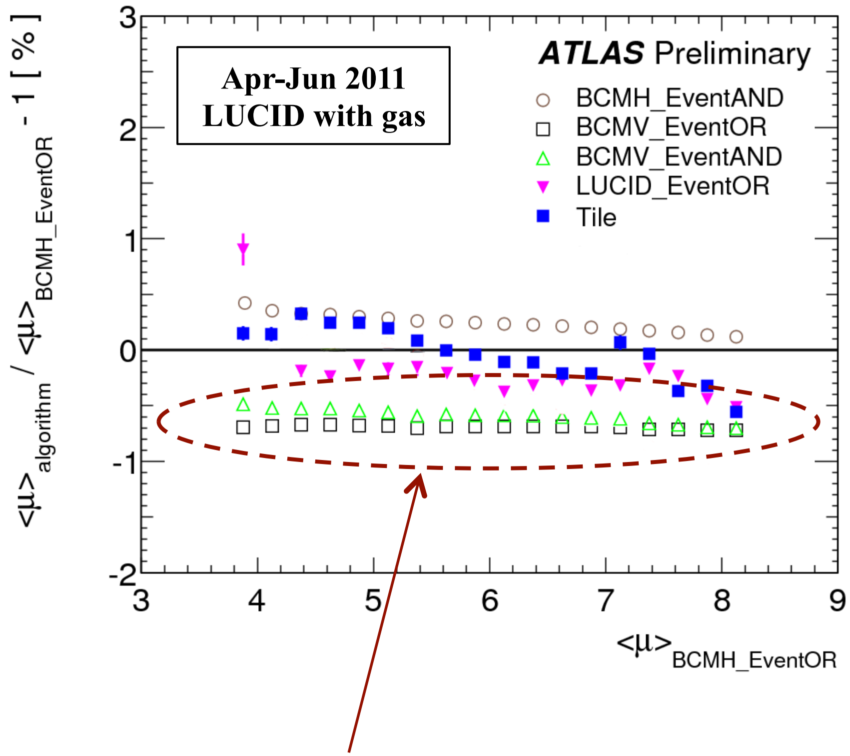
LHCb systematics summary

	Oct	May	Oct'10	Apr'10	Mar(1.38)
σ, mb	58.20	59.03	58.37	58.7	50.8
Calibration error, %	1.45	2.3	3.6	7.5	3.8
BCT	0.23	0.22	2.7	5.5	2.7
FBCT w-wo offset	0.05	0	0	-	0.71
FBCT vs BPTX	0.02	0.18	0.2	-	0.59
ghost charge	0.20	0.23	0.15	0.09	0.37
satellites	0.34				
statistical	0.15	0.10	0.09	0.9	0.2
scan difference	1.06	(2.1)	2.1	4.4	(2.1)
integral/sum difference	0.04				
zero point stability	0.00	0	0.4	0	0
zero point pulls	0.29				
length scale calibration	0.14	0.27	1	2	0.99
X/Y tilt of luminous region	0.01	0.01	0.3	-	0
beam scale difference	0.00	0	0.1	0	0
beam-beam effects	0.80	0.80			0.80

Error of relative luminosity monitoring during physics running is not included and not yet finalized. In 2010 it was 0.7%.
Further information may be found at http://cern.ch/balagura. Oct'10 scan results are published in JINST 7 P01010 (2012).
Beam-gas and beam-beam imaging studies are ongoing.

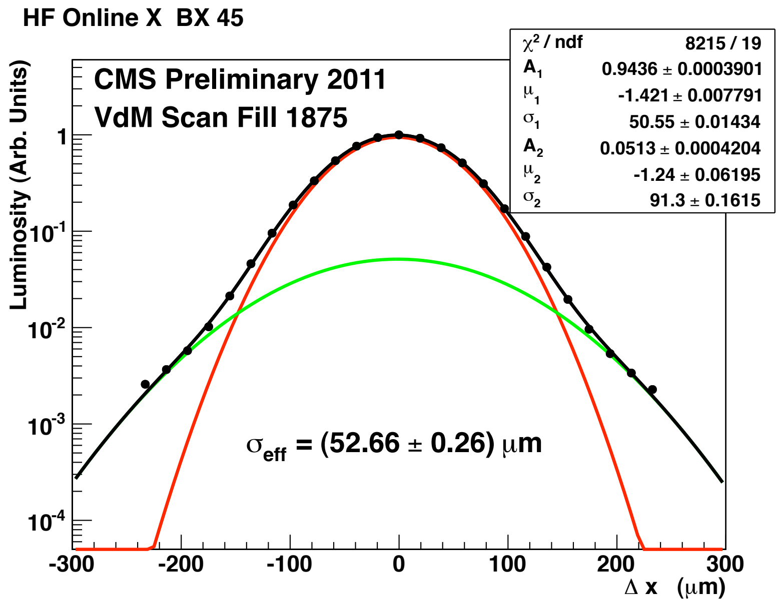
May'11 vdM analysis : self-consistency of absolute $\mathcal{L}$ calibration





Relative BCM H/V calibrations appear to have shifted by 0.7% shortly after vdM scan

Beam-separation scan under physics conditions: CMS



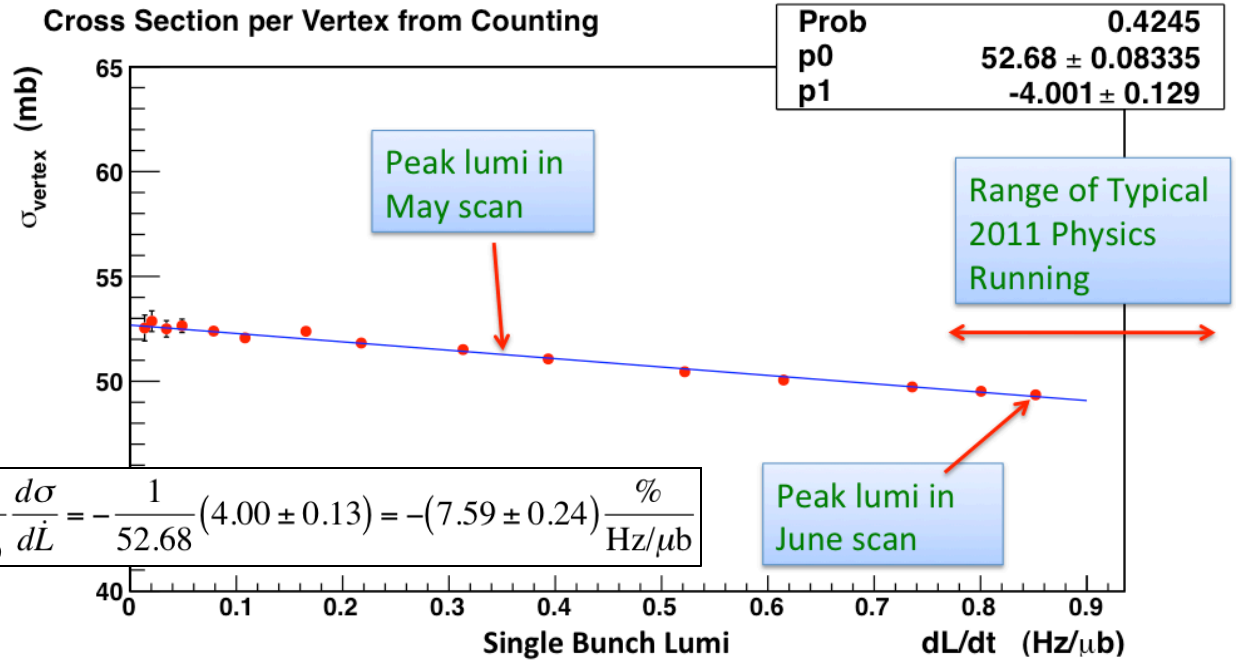
A scan done in June 2011, under more or less standard data taking conditions, was used to cross-check the May'11 scan.

Month	Fill/Cond.	L_{peak} (Hz/μb)	k_{av}
May	1753	0.34	$k_{\text{May}} = 1.115$
June	1875	0.86	$k_{\text{June}} = 1.064$
May	Extrapolated	0.86	$k'_{\text{May}} = 1.071$
June	Corrected	0.86	$k'_{\text{June}} = 1.087$

1.5%

The June scan also provided useful data on the HF non-linearity

$(1/\mathcal{L})\, d\mathcal{L}/d\mu \sim 1\%$

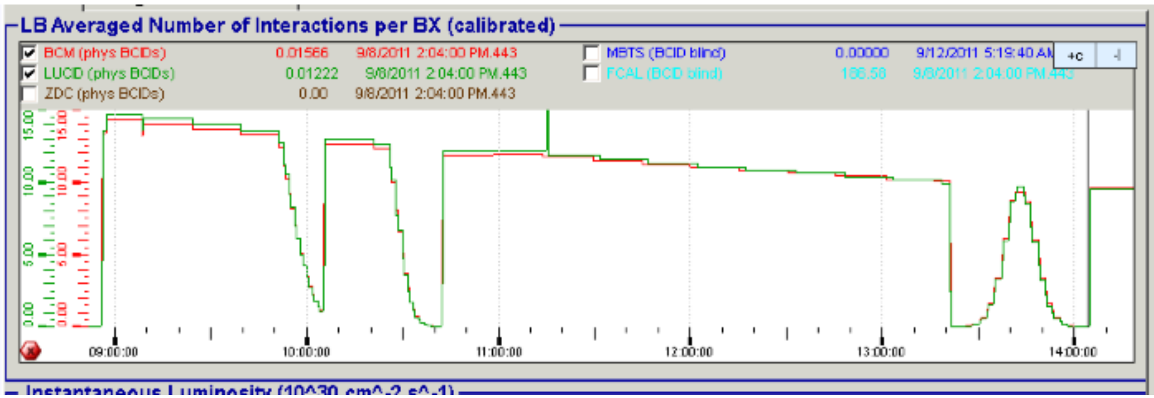


$$\frac{1}{\sigma_0}\frac{d\sigma}{dL} = -\frac{1}{52.68}(4.00 \pm 0.13) = -(7.59 \pm 0.24)\frac{\%}{\text{Hz}/\mu\text{b}}$$

Direct measurement of μ-dependence: ATLAS pile-up ('μ') scan

'μ sweep' performed by beam-separation in F 2086 (873 b, $\mathcal{L} \sim 1.9\ 10^{33}$)

→ characterize the relative μ-dep. of BCM H/V, FCal, LUCID, TILE, vtx algos



3 scans, covering
10 - 15 > μ > 0.02
i.e. all the way from
normal physics conditions
to (slightly below) the μ regime
for the β = 90 m ALFA run*