Chamonix 2011 LHC Performance Workshop, 27th Jan 2011

Luminosity Analysis

Giulia Papotti (BE-OP-LHC)

After fruitful discussions with:

M. Lamont, W. Herr,

M. Ferro-Luzzi, G. Sterbini, G. Rumolo,
W. Venturini Delsolaro, T. Mertens

outline

- look only at protons, and only ATLAS + CMS
    - eases the analysis and allows double-checks
- theory reminders
- historical overviews from 25 bunches to bunch trains
    - data from end of July (fill 1251)
- luminosity / intensity / emittance lifetimes comparison
    - for bunch trains
- bunch-by-bunch (*bbyb*) analysis on a “clean” fill (1440)
- others
    - fill 1459: 50 ns spaced beams
    - fill 1372: hump on and off
- Machine Development ideas

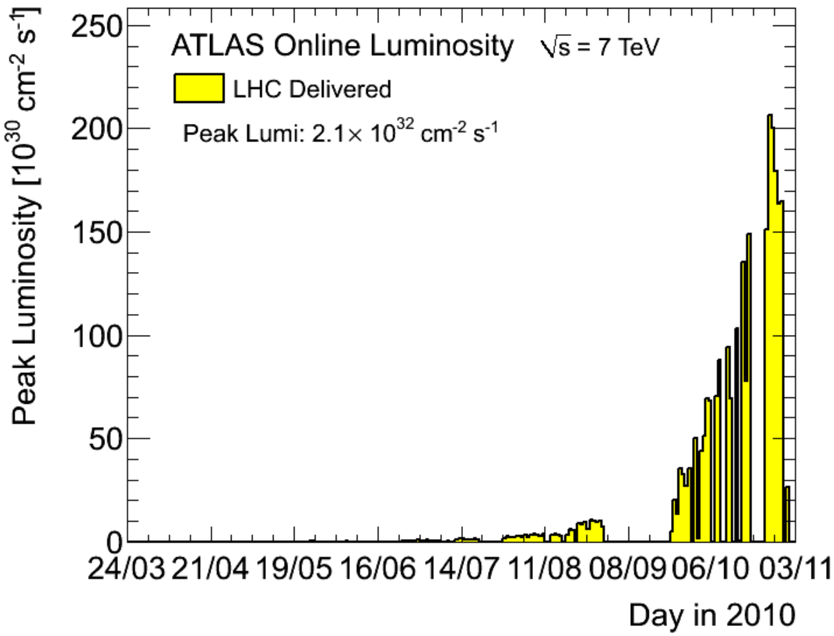
reminder

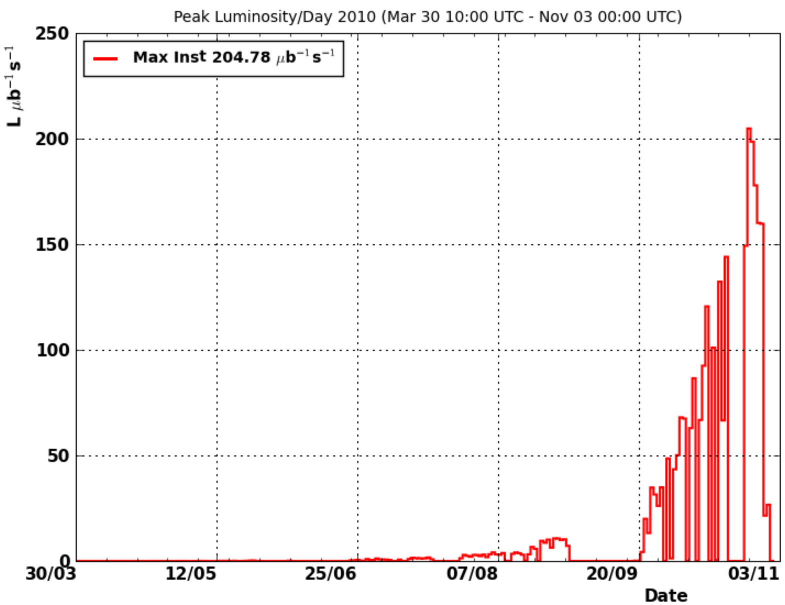
$$L_0 = \frac{N_1 N_2 n_b f}{2\pi \sqrt{\left(\sigma_{1h}^2 + \sigma_{2h}^2\right)\left(\sigma_{1v}^2 + \sigma_{2v}^2\right)}}$$

- luminosity decreases with time
  - beam size
    - elastic scattering at IPs and from residual gas, IBS
    - noise in PCs, RF (phase and amplitude)
    - LR beam-beam
    - non-linear resonances
    - hump, e-cloud
  - intensity
    - due to interaction of the two beams at the IPs
      - luminosity burn-off
      - from beam-beam
    - other causes
      - scattering on residual gas
      - IBS and Touschek effect (mostly through emittance growth)
  - overlap region from orbit drifts

2010 performance

- we have seen these many times



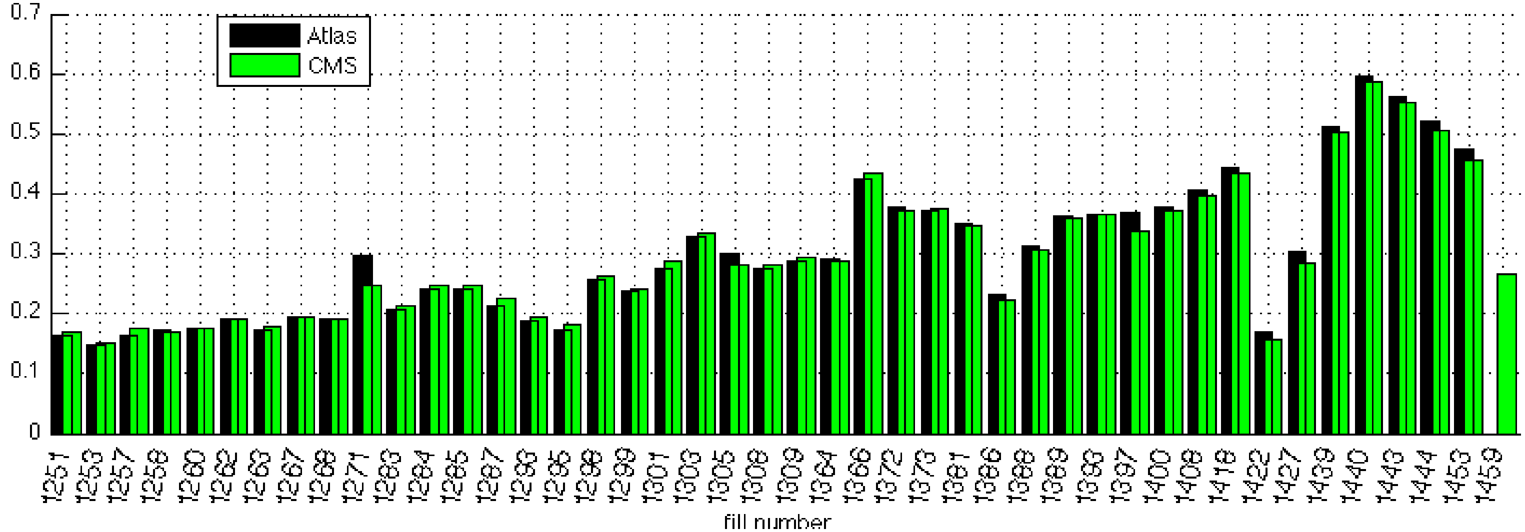


- but they only tell us that we were increasing n_b

peak luminosity per collision

- given that rMPP limits the n_b, how much L_{peak} per bunch?

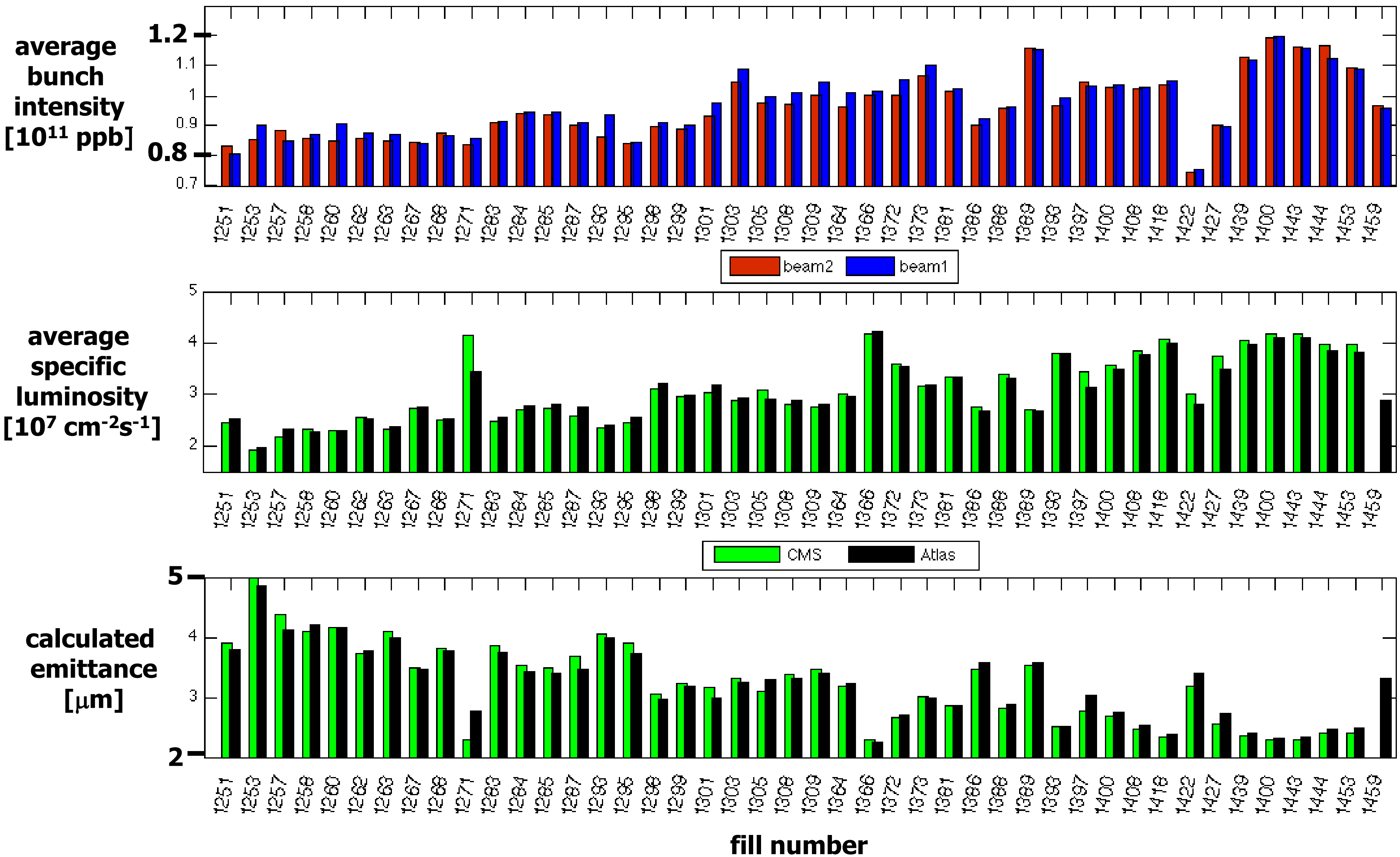
peak luminosity / n_b [10^{30} $cm^{-2}s^{-1}$]



prepared by G. Trad

- luminosity burnoff
  - L/coll = 0.4 10^{30} $cm^{-2}s^{-1}$; 3 collisions / bunch; 100 mb x-section
    - dN/dt = 1.2 10^5 p/s
  - Total Losses, after 10 hours: 4.3e9 protons lost…
- 5% (~1 pilot) after 10 hours, or $\tau_{burnoff}$ ~ 227.5 h

statistics across fills

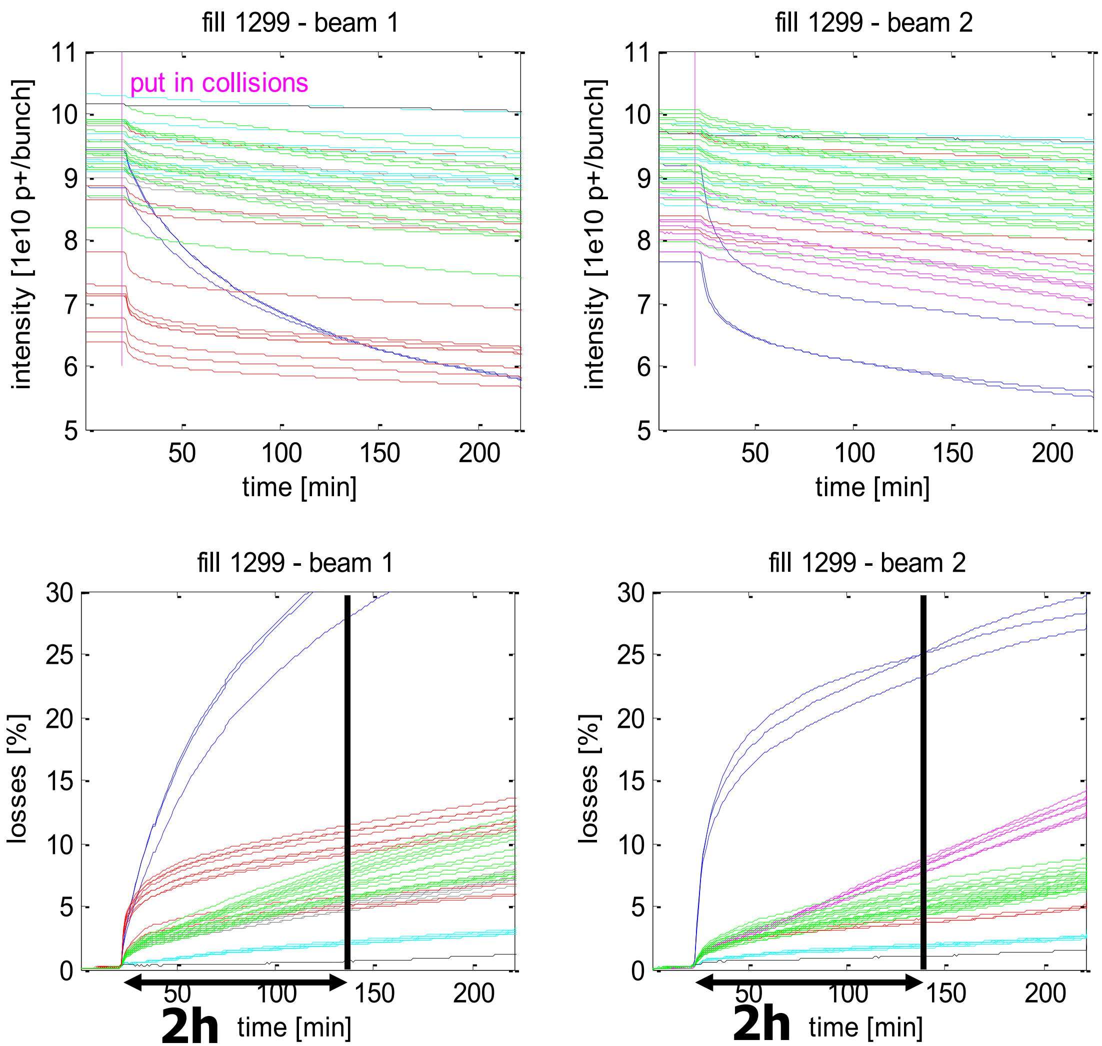


prepared by G. Trad

bunch-by-bunch losses

- take bbyb intensity starting before collisions
  - calculate % loss from there
    - @ time=0: 0% losses
  - colour code from head on collisions

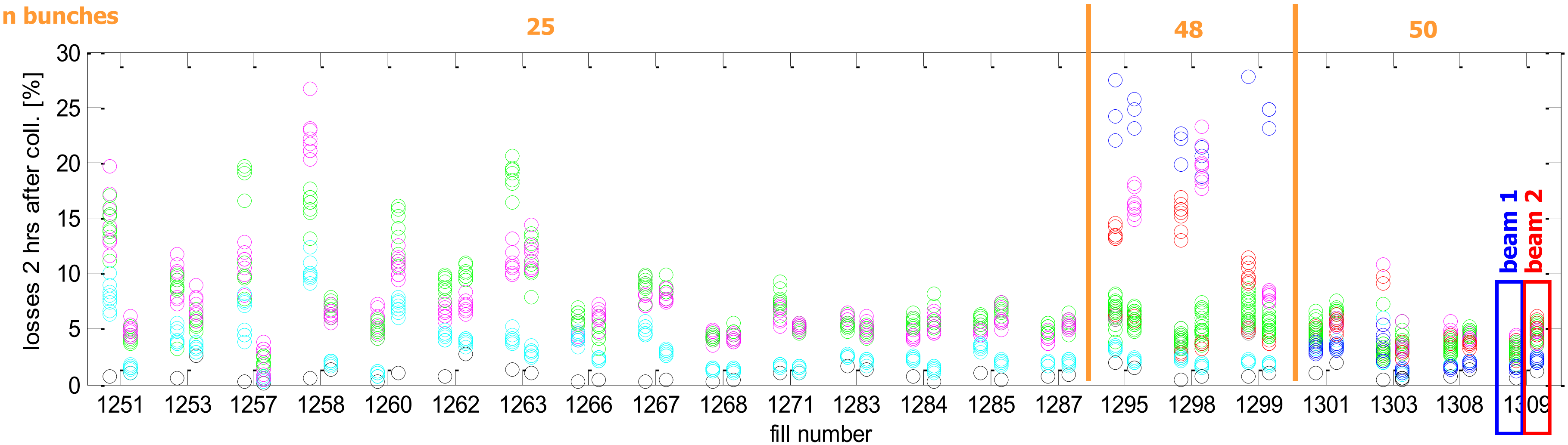
IPs: 1 5 2 8 - 1 5 8 - 1 5 2 - 1 5 - 2 8 - 8 - 2



- problems start at collisions
  - before, single beam lifetimes are excellent

- next: cut 2 hours after collisions to compare fills

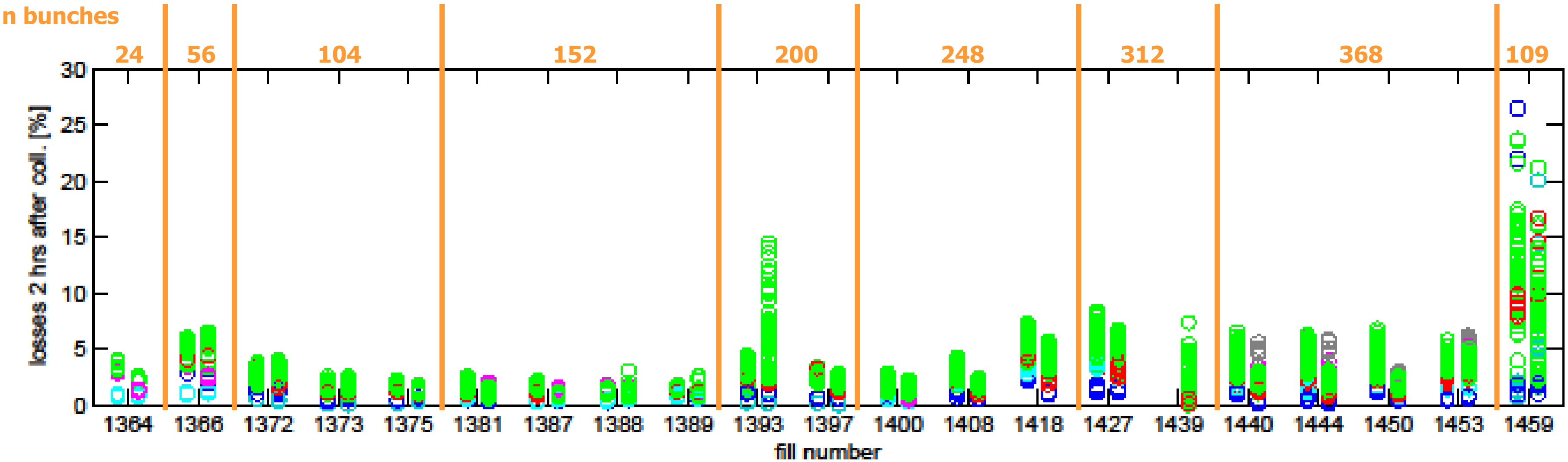
bbyb losses summaries – 1



- history of fills until 50 bunches/ring (fills longer than 2h)
  - tune split until 1258
    - $\Delta Q_{1x,y}$= -0.0025; beam 1 always on a bad tune!
  - 1260: tune split inverted
  - 1263: tunes +0.002
  - afterwards: no tune split and chroma corrected to ~1/2 units
  - 48 bunches/ring: some bunches have very high losses
    - bunches with LR (33m) in IP 2 and 8
  - then changed to 50 bunch scheme

IPs:
1 5 2 8
1 5 8
1 5 2
1 5
2 8
8
2

bbyb losses summaries – 2



- history of 150 ns spacing fills + 50 ns fill (fills longer than 2h)
  - 1364, 1366: Alice had wrong polarity
  - 1393: b2 a mystery, high losses at collisions
  - 50 ns fill (1459) losses out of scale (up to 50% for some bunches)

IPs:
1 5 2 8
1 5 8
1 5 2
1 5
2 8
8
2

- nb: little statistics for "luminosity analysis"
  - start with 11 fills longer than 8 hours, can use only 6
    - remove 1366 (wrong Alice pol), 1372 (with hump), 1373 (with hump), 1393 (strange losses), 1450 (RF module trips)

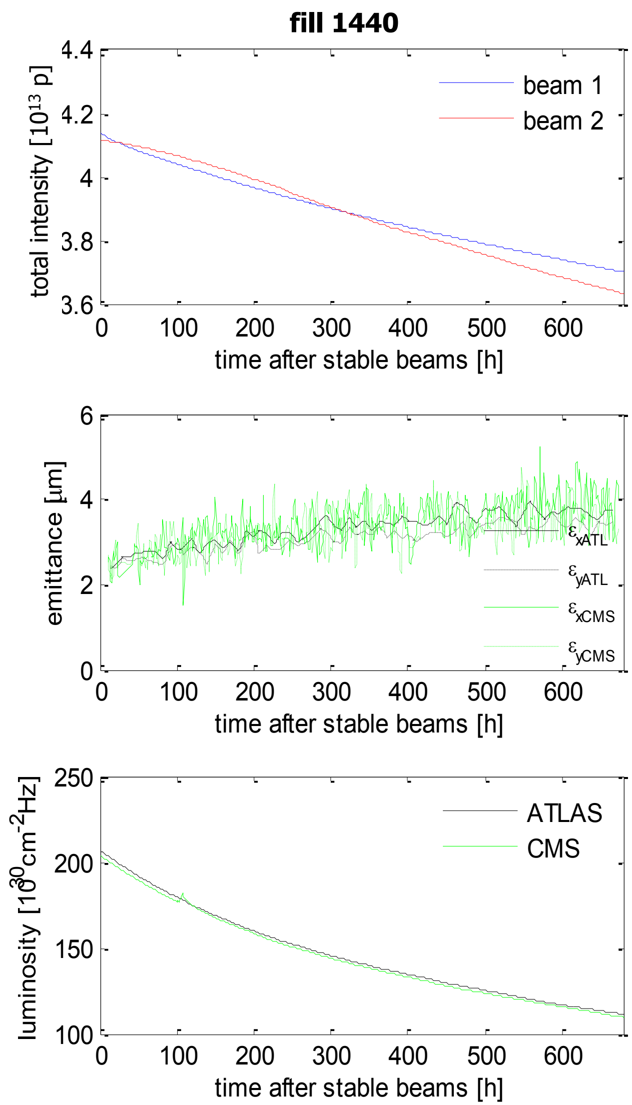
lifetimes

- using: $$\frac{1}{\tau_L} = \frac{1}{\tau_{b1}} + \frac{1}{\tau_{b2}} + \frac{1}{\tau_{\sigma_h}} + \frac{1}{\tau_{\sigma_v}}$$

	τ_{b1}	τ_{b2}	$\tau_{\sigma h}$	$\tau_{\sigma v}$	$\tau_{L,calc}$	$\tau_{L,publ}$
first 1000 s (M. Lamont)	81.3	103.3	44.9*	53.5*	15.9	11.9° 11.0ˣ
whole fill	106.1	86.1	2x30.6° 2x29.5ˣ	2x36.6° 2x35.9ˣ	19.6° 19.3ˣ	18.3° 18.3ˣ

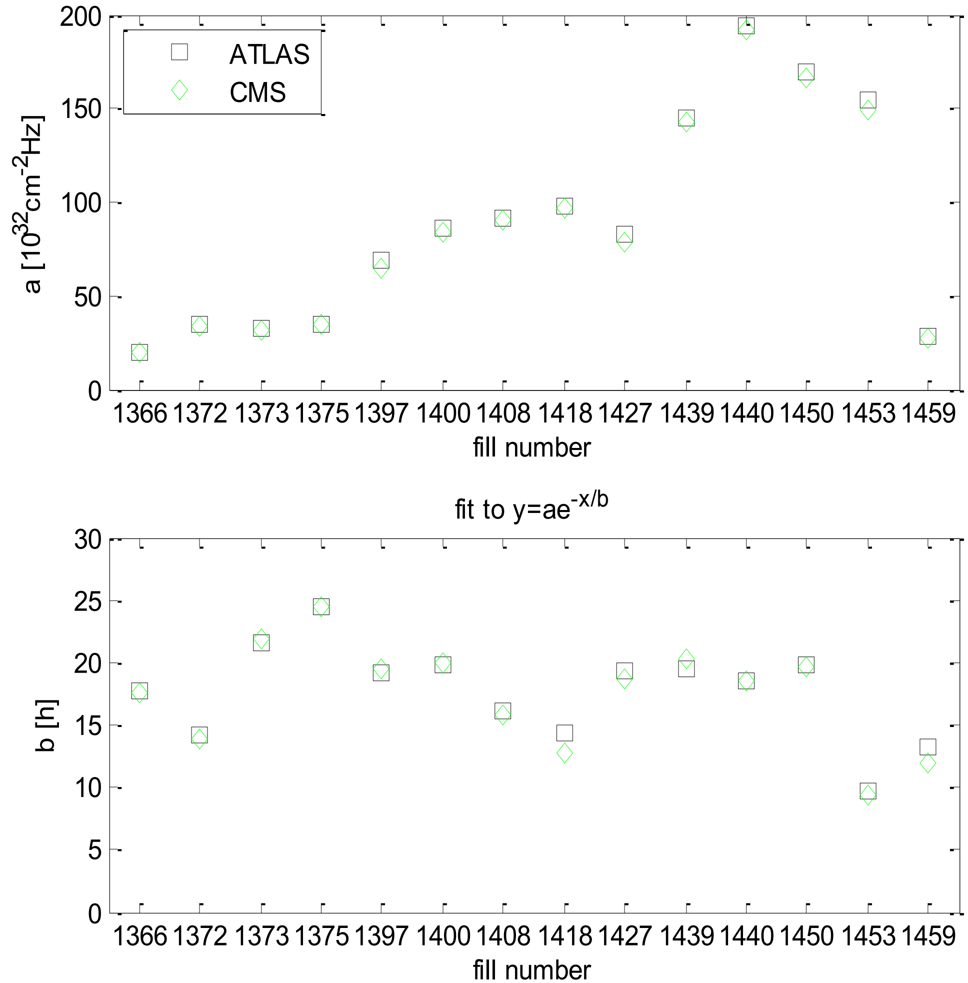
* BSRT, ° ATLAS, ˣ CMS, all τ's in hours

- good agreement on whole fill
  - luminosity decay is explained by emittance growth and intensity decay
  - orbit stability is good
    - no overlap issues



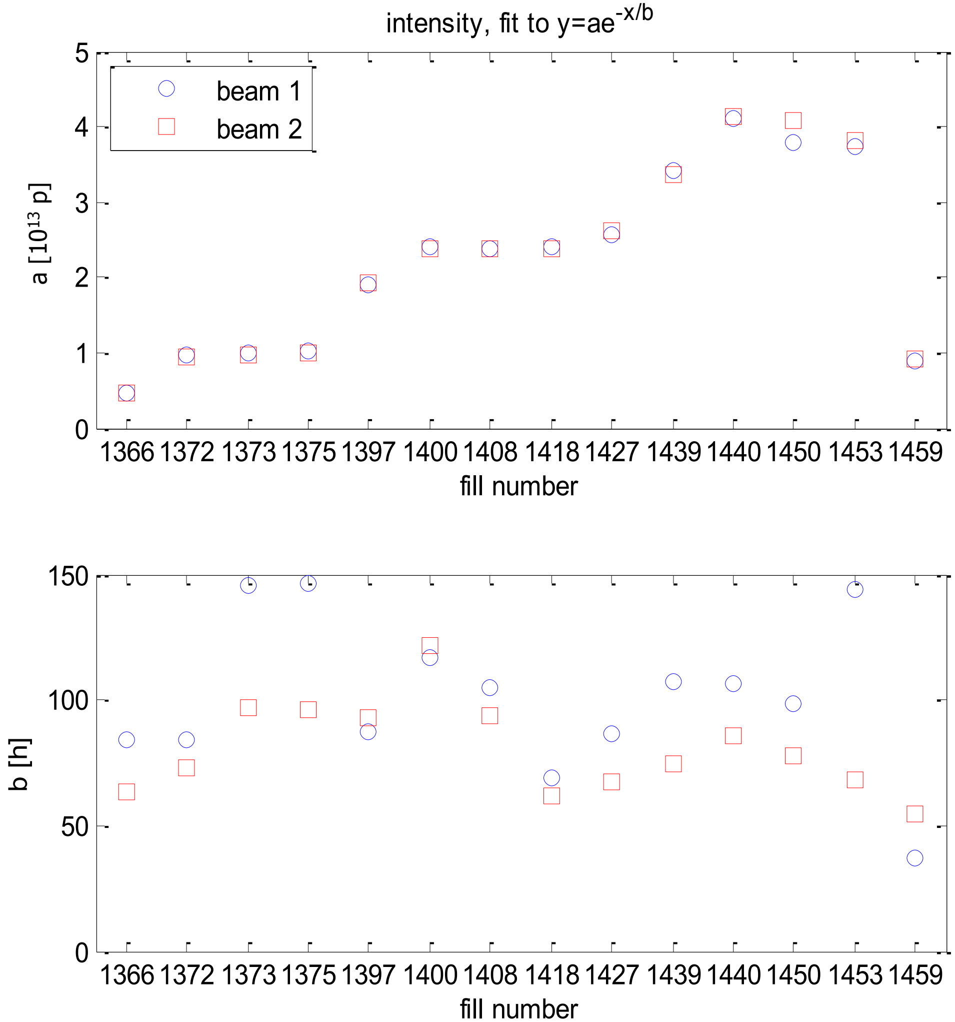
luminosity lifetime summary

- compare different fills
  - initial value (a) follows n_b increase
  - lifetimes (b) slowly descending
    - very similar even removing first 1 h or 2 h
    - 50 ns fill: not particularly good



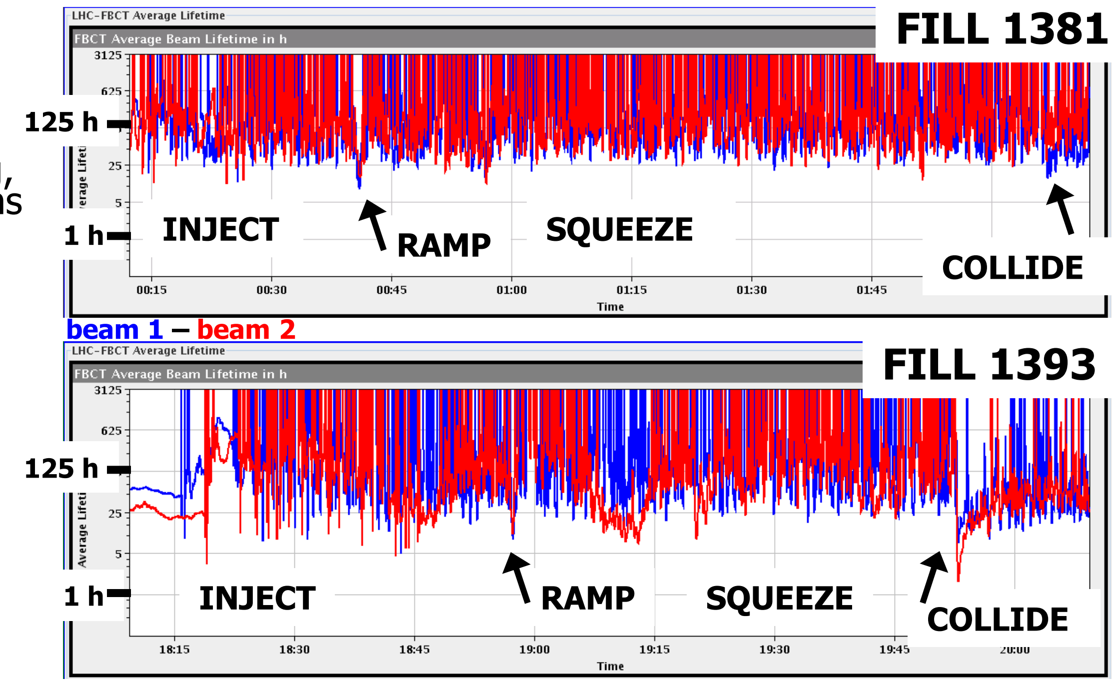
intensity lifetime summary

- compare different fills
  - initial value (a) follows n_b increase
  - lifetimes (b) beam 2 often worse than beam 1
    - very similar even removing first 1 h or 2 h
  - lifetime lowest for 50 ns
    - later: 1 slide on losses



intensity lifetimes

- single beam lifetimes
  - not so easy to recalculate
    - squeezed + not colliding, lasts <10 minutes vs tens of hours lifetimes
  - most of the time: >100 h
    - can't give a number!



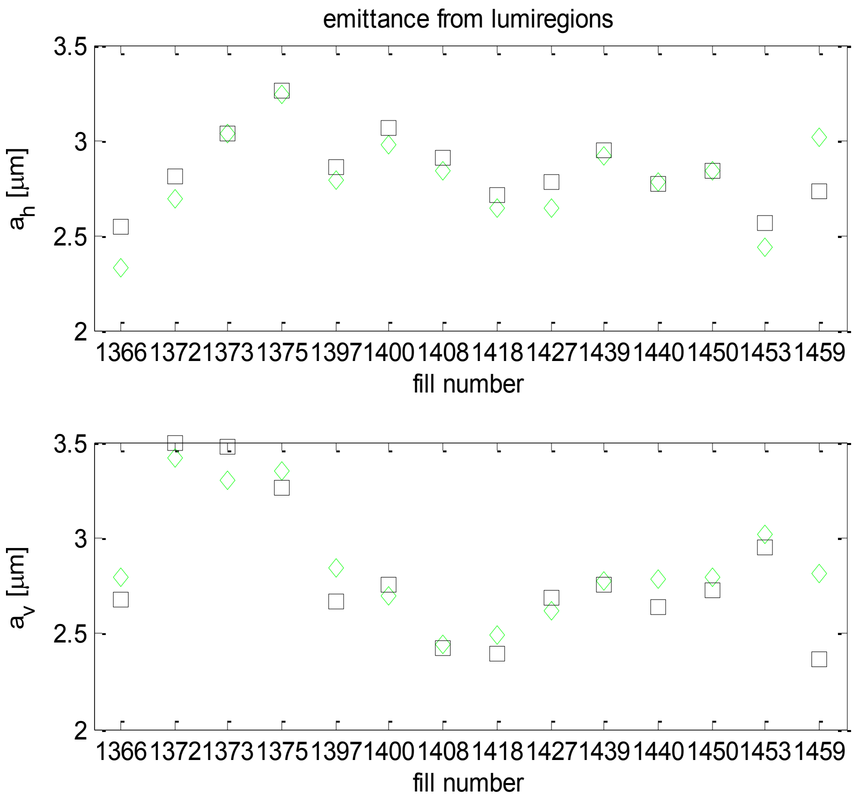
- in collisions, add all causes:

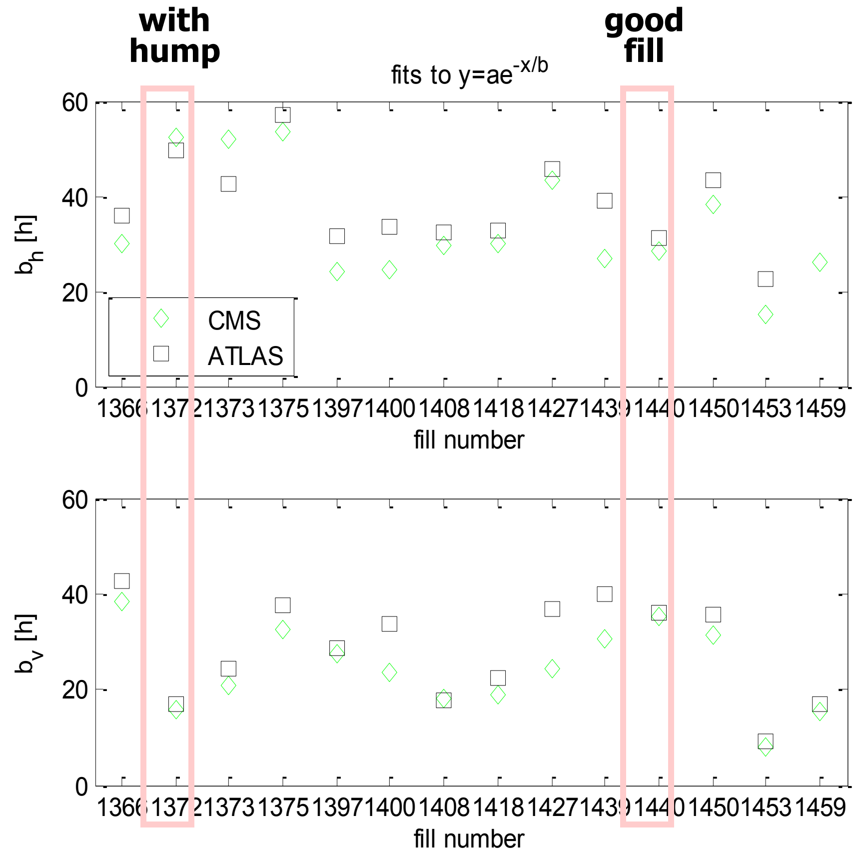
$$\frac{1}{\tau_{b1}} = \frac{1}{\tau_{burnoff}} + \frac{1}{\tau_{gas}} + \frac{1}{\tau_{coll}} + \ldots$$

  - calculated τ_{burnoff} ~230 h
  - for t_{gas} need a measurment
    - 100 h in Design Report
  - losses on collimators, Mike predicts τ_{coll} ~ 120 h
    - from D. Wollmann's presentation in Evian, proton loss rate ~ 1.e8 p/s
  - still missing: longitudinal losses, …
  - but only τ_{burnoff} and τ_{coll} give already τ_{b1} ~ 80 h
- need controlled experiment: measure single beam lifetime

ε growth summary

- compare different fills, ε from lumi regions
  - τ_v (b_v) generally worse than τ_h (b_h)
    - v would be better than h if IBS dominated
    - hump probably
    - something else maybe?





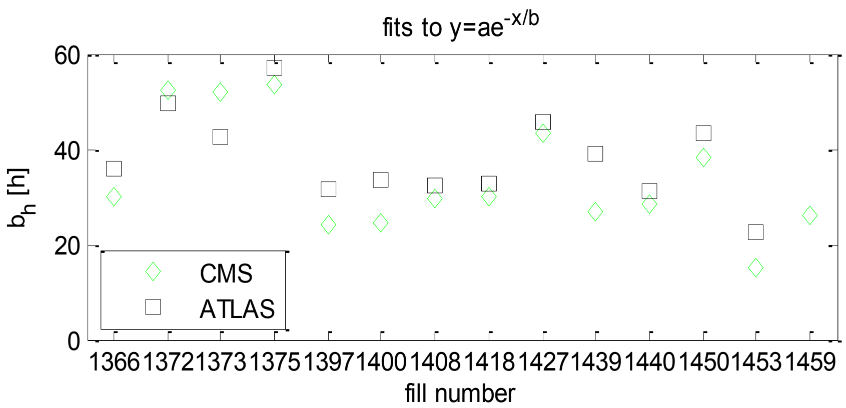
IBS

- emittance growth times from Design Report (7 TeV)
  - longitudinal: τ_{IBS}~ 63 h
  - horizontal: $\tau_{\varepsilon h,IBS}$~ 105 h
  - from theory:
    - factor 2 from γ
    - smaller than nominal ε
  - scaling from DR: $\tau_{\varepsilon h,IBS}$~ 37.5 h

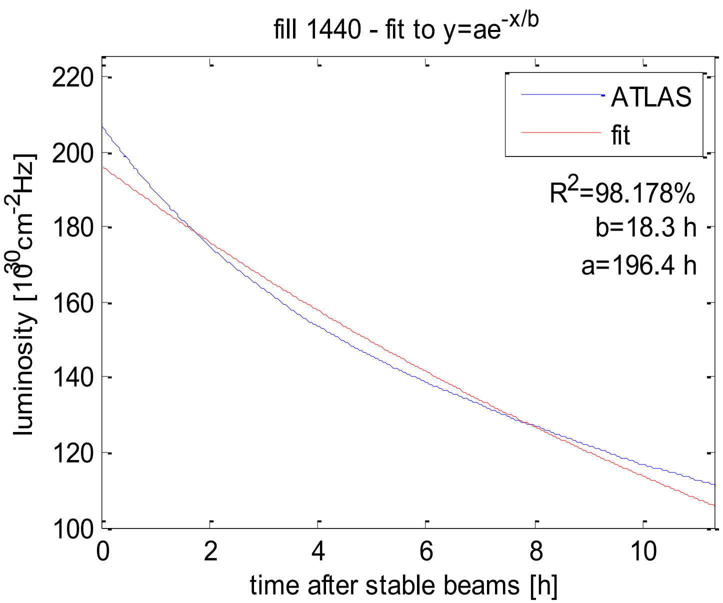
$$\frac{1}{\tau_0} \propto \frac{N_{ppb}}{\gamma \varepsilon_h^* \varepsilon_v^* \varepsilon_l^*}$$

- from V. Lebedev $\tau_{\varepsilon h,IBS}$(2.5μm, 3.5 TeV) ~ 38.6 h

- IBS does not explain the whole blow up
  - noise? beam-beam? hump?
  - need controlled experiment: estimate IBS at least

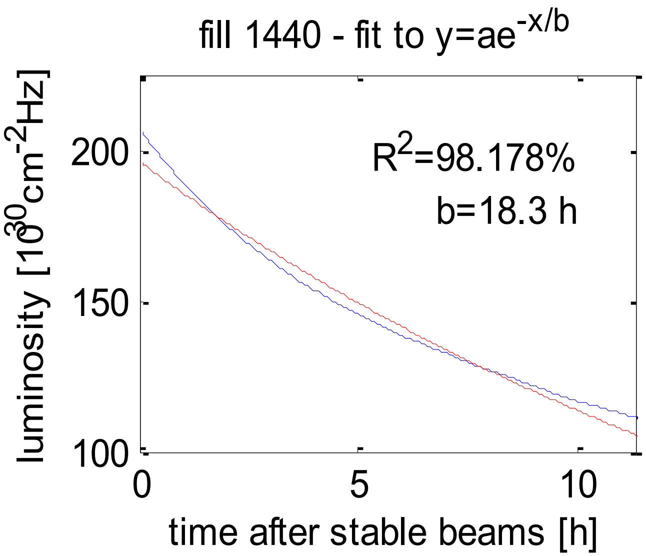


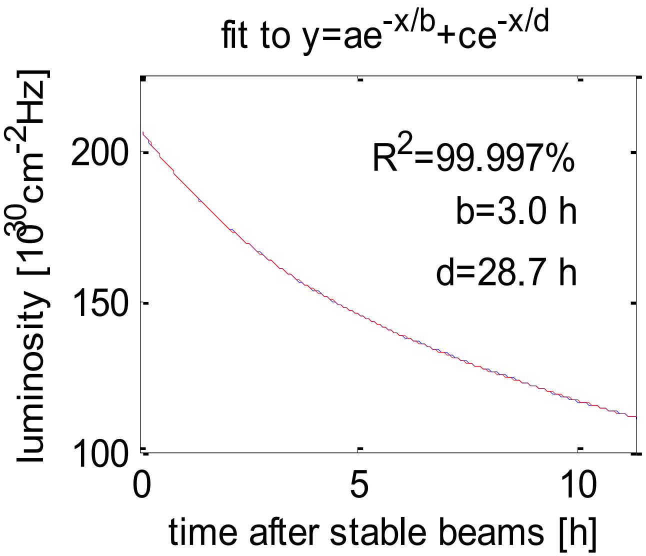
luminosity lifetime



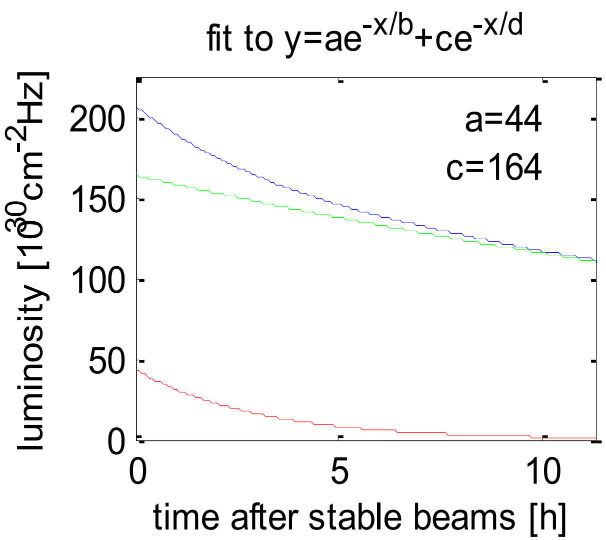
- fill 1440, from ATLAS total instantaneous luminosity
  - long fill and very clean data sets
  - – exponential fit: not very good fit
  - – overall: lifetime ~18.3 hours
    - first 30’: lifetime ~10.9 h
    - at around 2h: lifetime ~13.8 h
    - at around 6h: lifetime ~24.0 h
    - at around 10h: lifetime ~31.4 h

luminosity lifetime

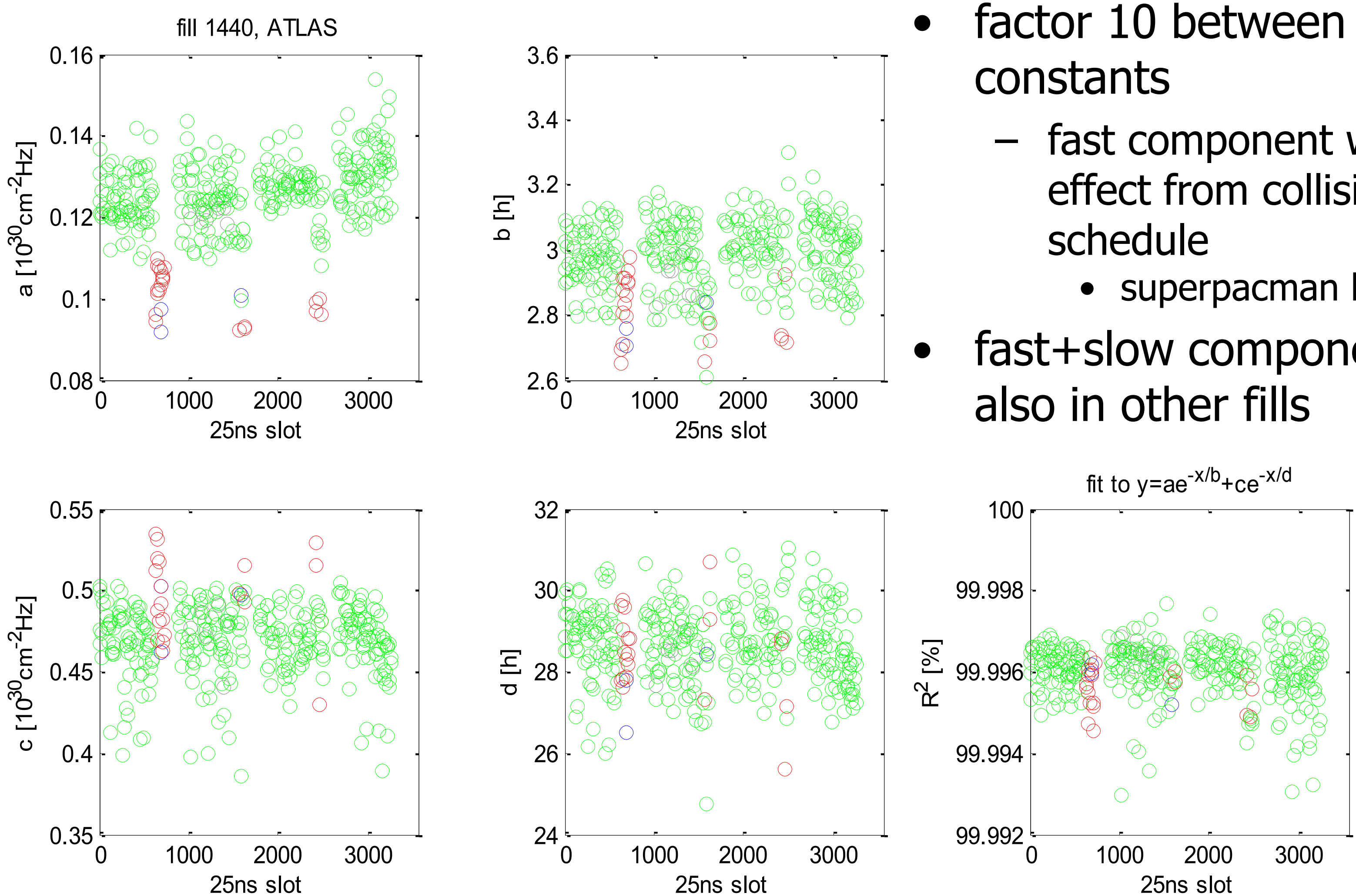




- e.g.: from ATLAS total lumi
- much better with 2 exponentials instead of 1
  - $y = a\ e^{-x/b} + c\ e^{-x/d}$
    - $a+c = L_{peak}$
    - b, d time constants
- …can do the same on bbyb lumi data
  - works also for single beam lifetimes



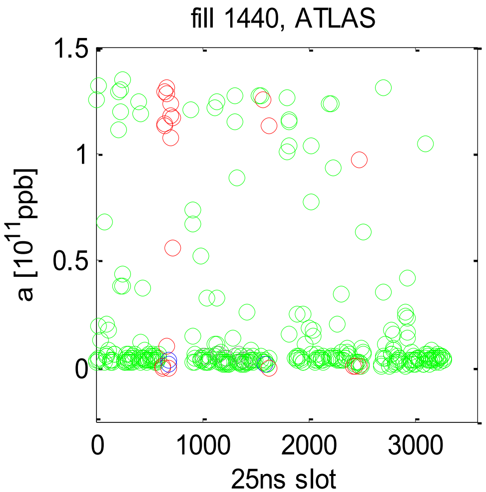
bbyb lumi lifetimes

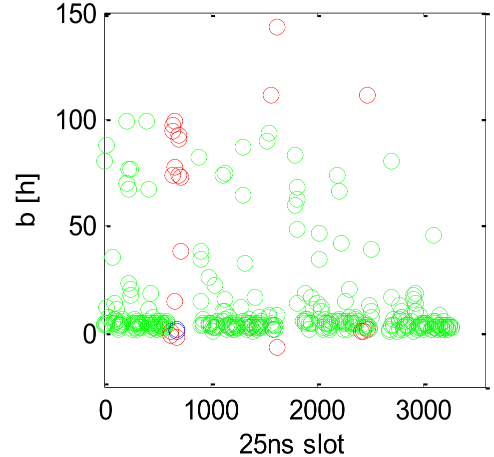


- factor 10 between time constants
  - fast component with effect from collisions schedule
    - superpacman bunches
- fast+slow component also in other fills

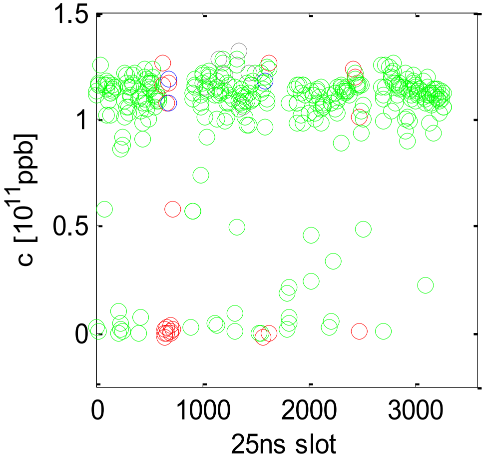
IPs: 1 5 2 8 - 1 5 8 - 1 5 2 - 1 5

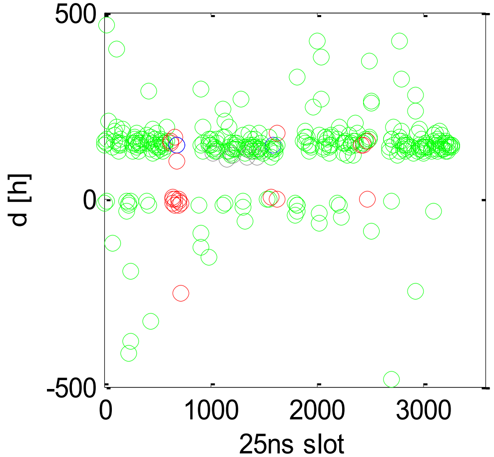
intensity lifetimes in collisions

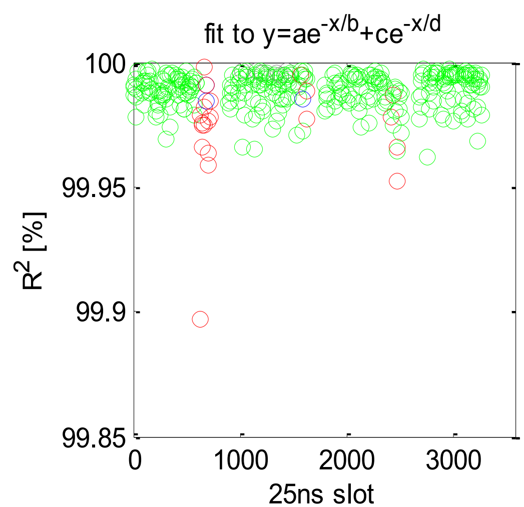




- need the 2-exp model
  - single exp not good
- much more variation
  - no simple correlation with collision schedule
  - some correlation with injection pattern
- a lot of variation across different fills

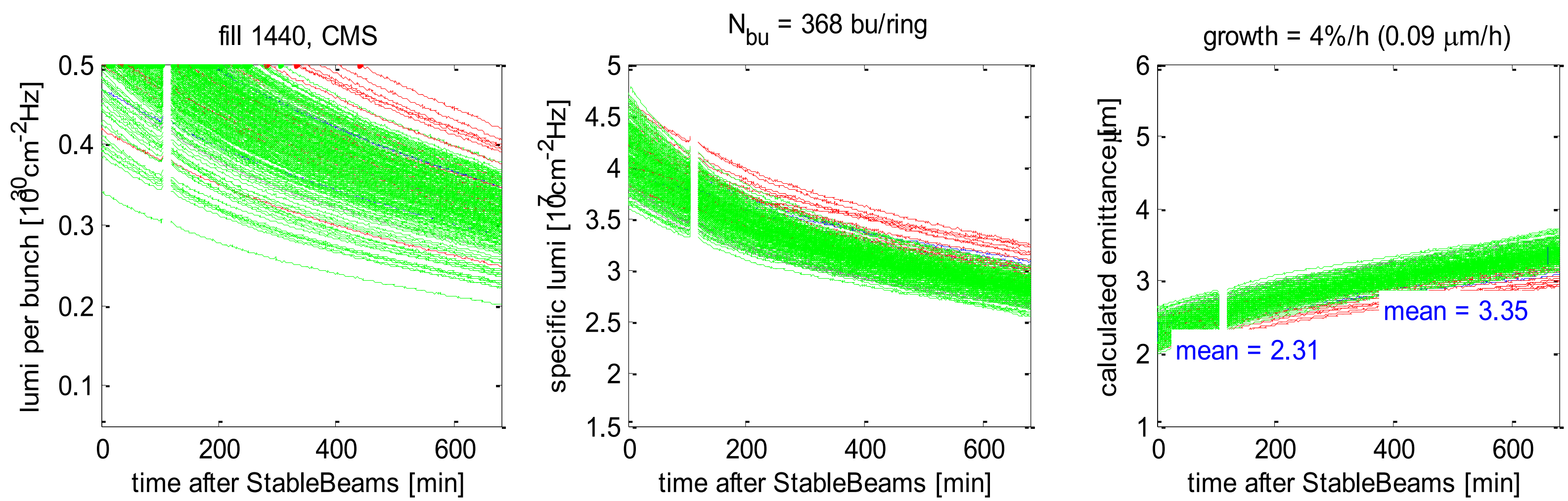






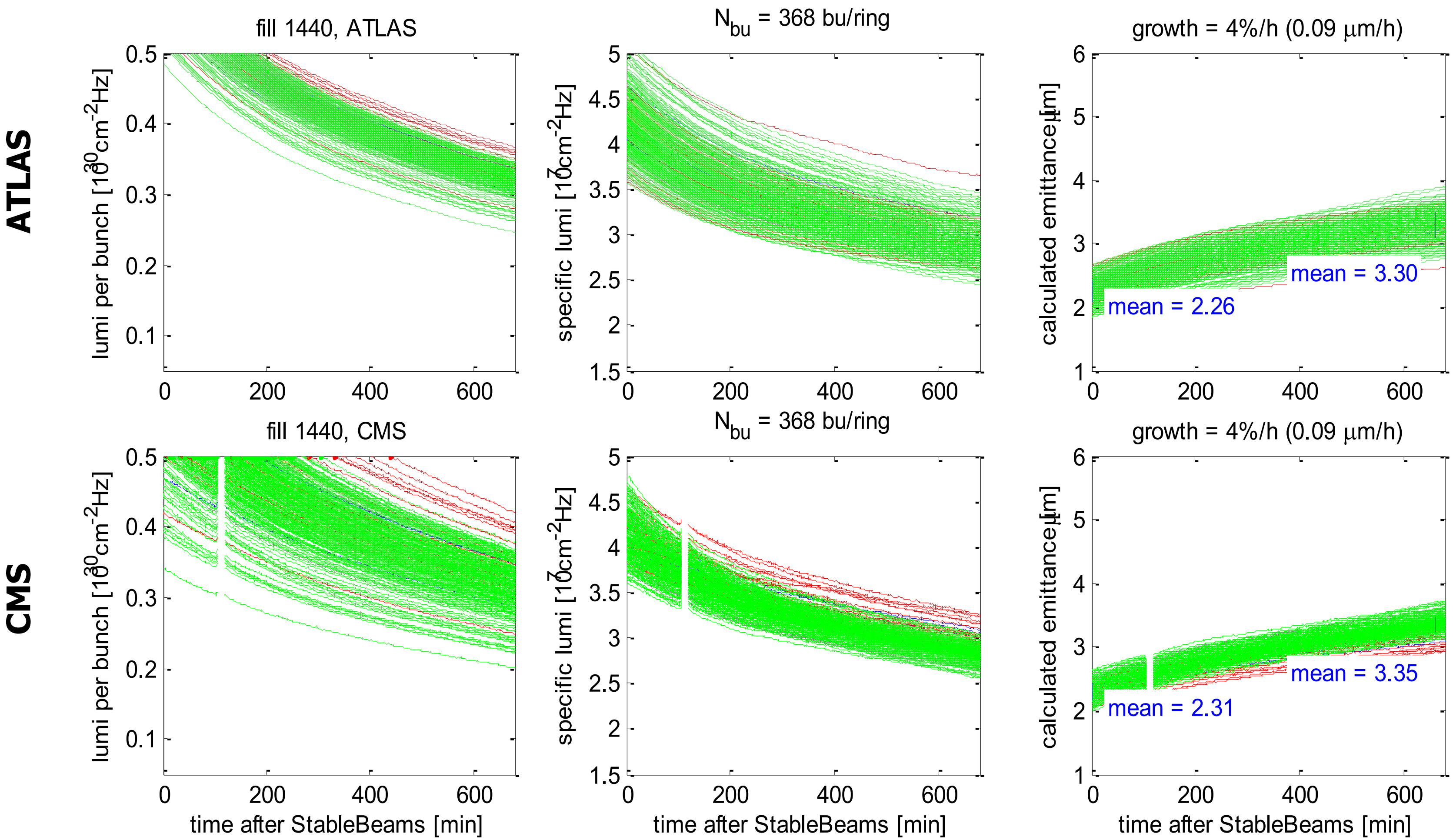
bbyb ε growth – 1

- bbyb luminosities from experiments
- combine with fBCT to get specific luminosities
- unfold emittance
  - assumes very small orbit drifts
    - verified in few occasions with end-of-fill lumi scans



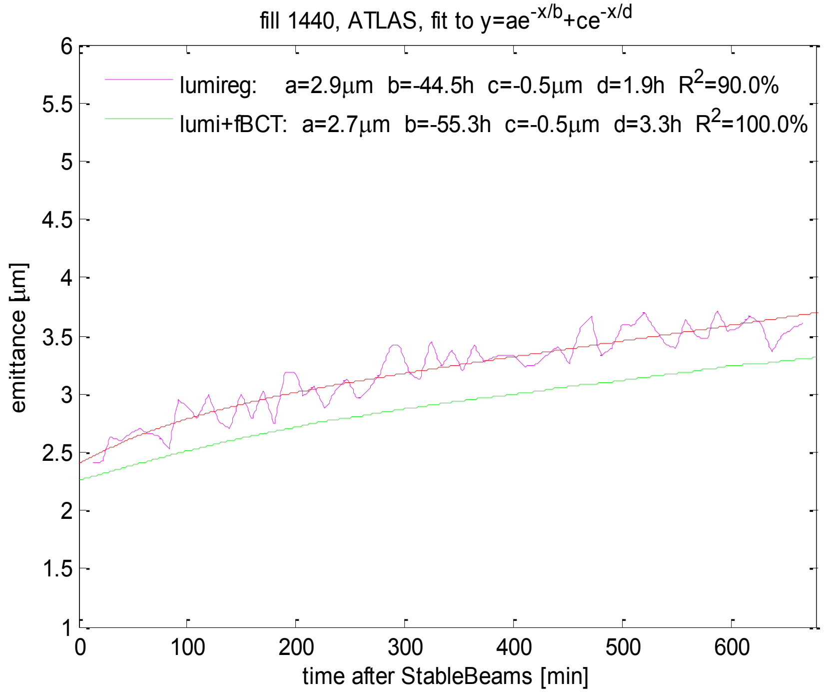
bbyb ε growth – 2

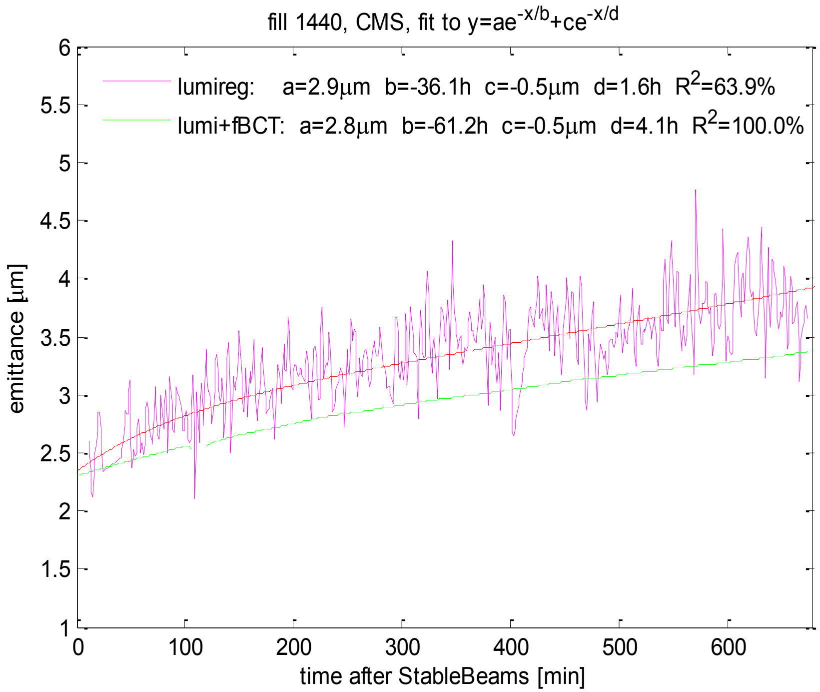
- ATLAS vs CMS: good agreement on average emittance
  - use end-of-fill lumi scans for emittance cross-check
  - quite some spread on bbyb luminosity, from experiments



ε estimation vs lumireg

- compare
  - emittance calculated from luminosity + fBCT
  - luminous region (average)
- good agreement!



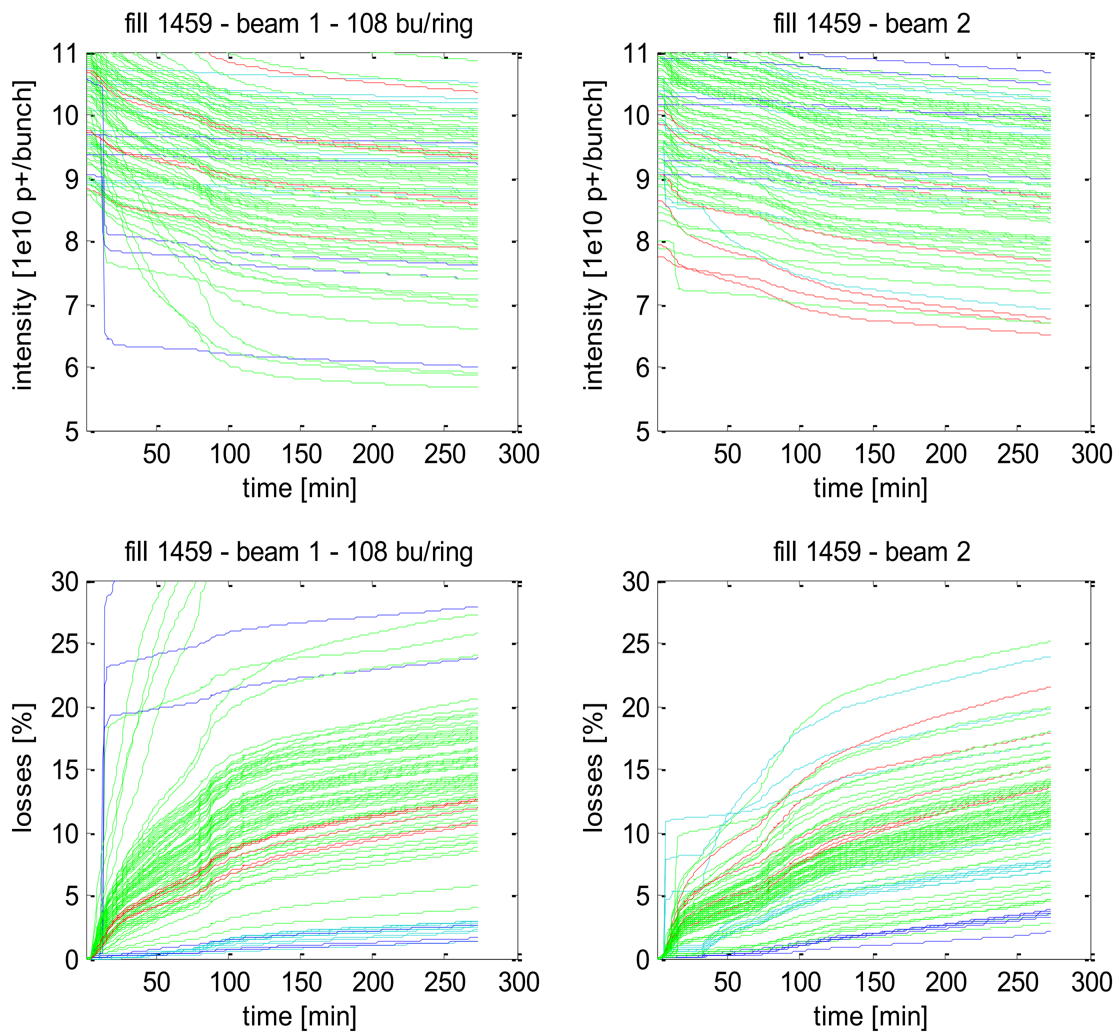


50 ns spaced beam

- fill 1459
- 9 trains of 12
  - summer to winter time change in the middle of the fill, some problems with data extraction
- very sudden losses for some bunches
  - mid-train bunches
    - seem due to initial parameters
  - had no extra LR
  - e-cloud?

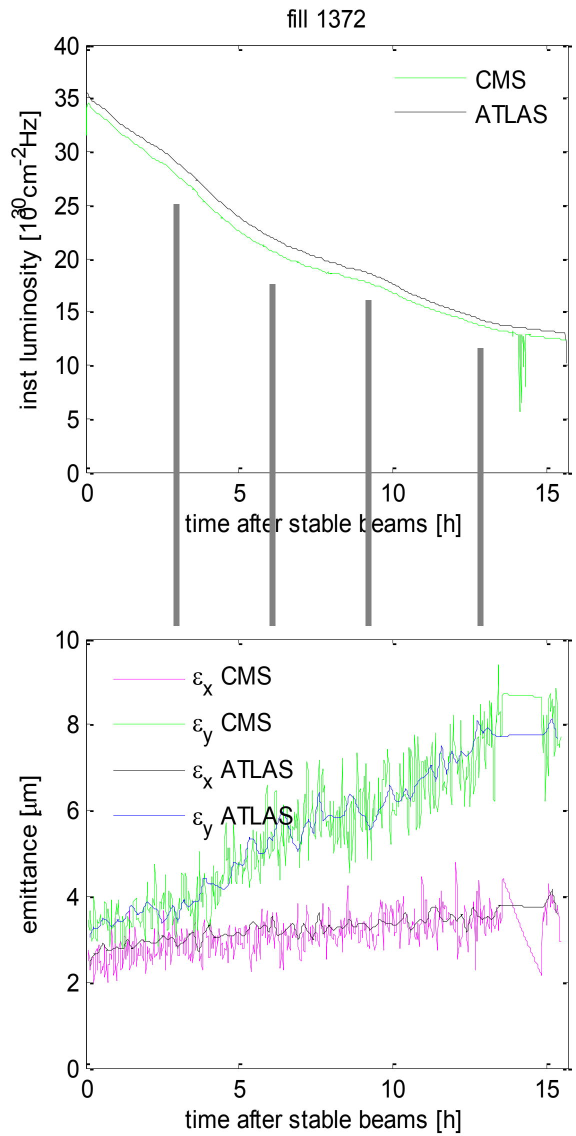
	τ_{Lumi} [h]	$\tau_{\varepsilon h}$ [h]	$\tau_{\varepsilon v}$ [h]
ATLAS	**13.2**	**153.9**	**19.7**
CMS	**12.1**	**25.9**	**15.5**

- no statistics: only 1 fill!



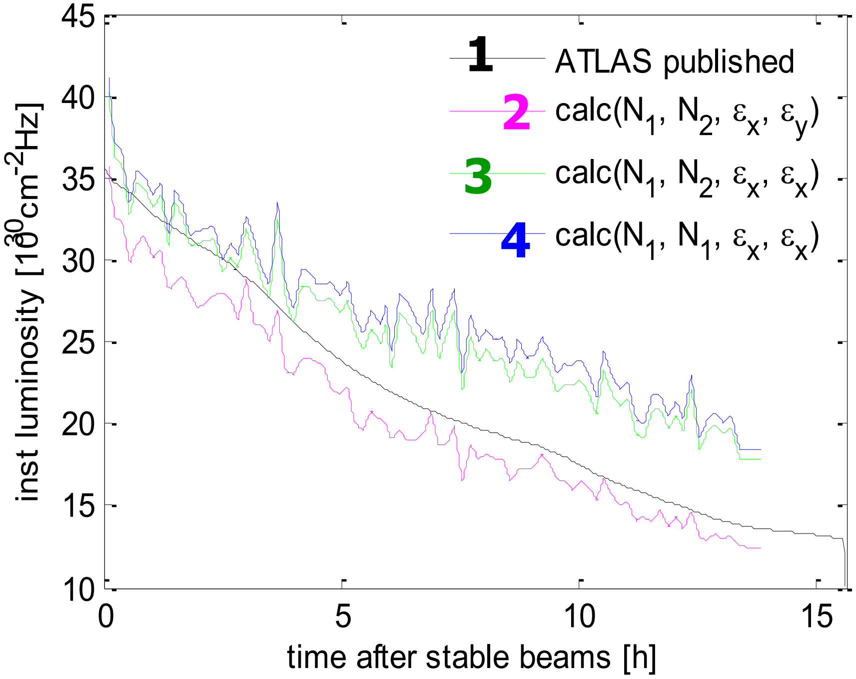
a fill with the hump – 1

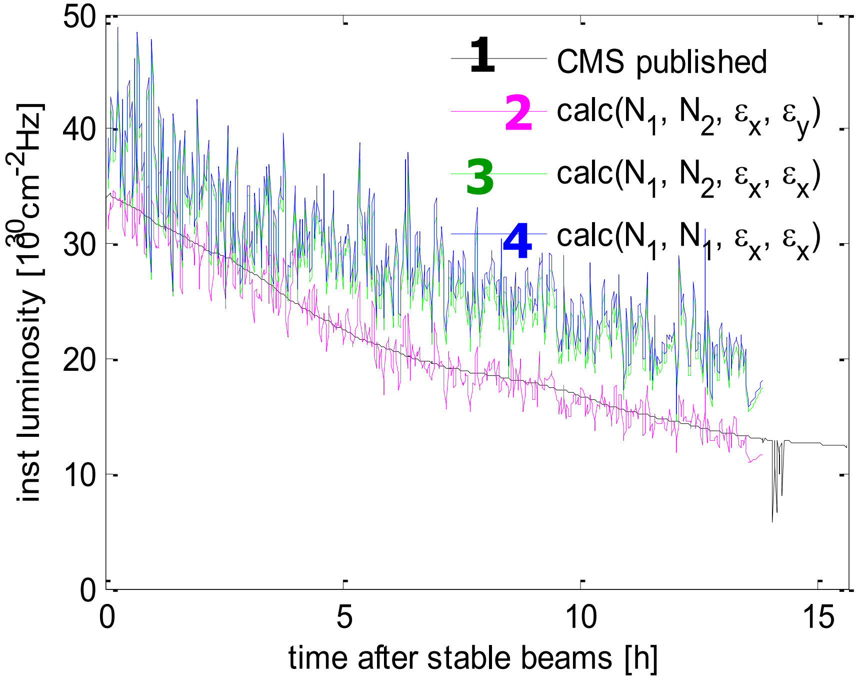
- fill 1372
- particularly bad vertical blow up
  - emittances from lumi region
- clear correlation with instantaneous luminosity slope changes



a fill with the hump – 2

- difference in integrated luminosity with / without extra ε_V blow up
  - 3 calculated curves
    - with $\varepsilon_{h,v}$ from luminous regions (ATLAS or CMS)
    - N_1, N_2 average intensity beam 1 and beam 2





  - integral(3) - integral(2) = 25% (ATLAS) / 27% (CMS)
  - integral(3) - integral(1) = 15% (ATLAS) / 18% (CMS)
- 20% integrated luminosity lost due to the hump!

used and requests

- data used for this analysis
  - machine measurements (always available)
    - fBCT: bbyb intensities
    - single beam lifetime
  - from experiments (only for stable beams, in LPC folders)
    - single bunch luminosities
    - average luminous region size
  - looking forward to BSRT bbyb emittance
- requests for Machine Developments
  - “hands off” squeezed beams for machine time constants
    - few hours for tens of hours time constants?
    - and IBS studies?
      - if after a test ramp… only net time for the measurement
      - possibly on a day with no hump
  - tune scans!
    - working point almost never optimized so far
  - end-of-fill VdM scans for emittance measurement, bbyb emittance and orbit differences

conclusions

- 150 ns spaced beam lifetimes
  - luminosity lifetime (~20 h)
    - decay explained by emittance growth and intensity decay
    - fast and slow component
      - fast component dependence on collision pattern
  - intensity lifetime (~90 h)
    - single beam lifetime is excellent, need a hard number
    - drops after collisions
      - dependence on collision pattern
  - emittance grows (ε_x: ~ 30 h; ε_y: ~ 20-40 h)
    - minimum overlap/orbit drifts
      - also verified with end-of-fill lumi scans
    - need to look at causes
      - probably not only IBS

- many fills have different characteristics
    - fill 1459: with 50 ns spacing, very fast losses
    - fill 1372: hump caused loss of 20% of integrated lumi

- nb: results are preliminary due to the lack of statistics