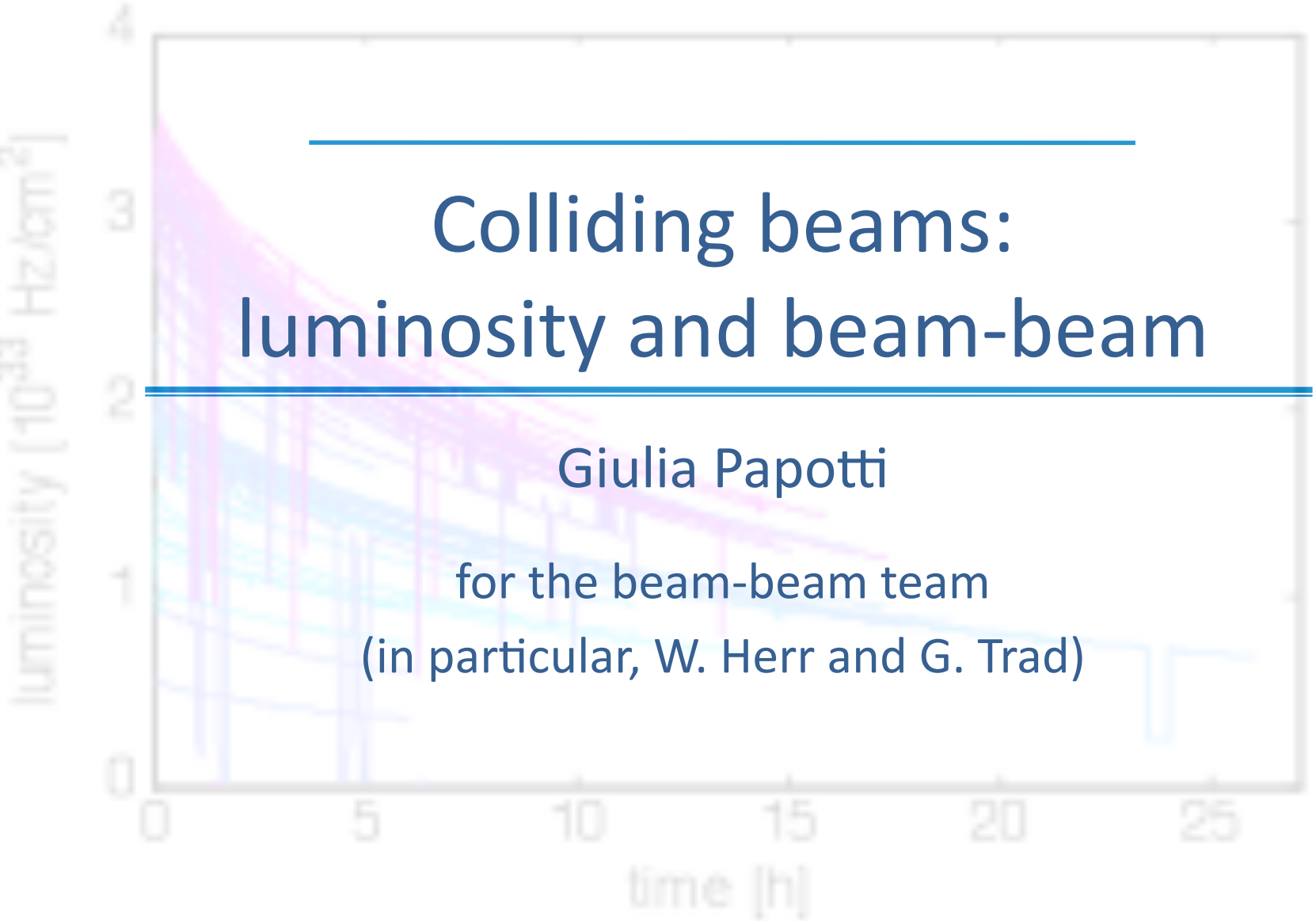
LHC Beam Operation workshop

Evian 2011



Colliding beams: luminosity and beam-beam

Giulia Papotti

for the beam-beam team

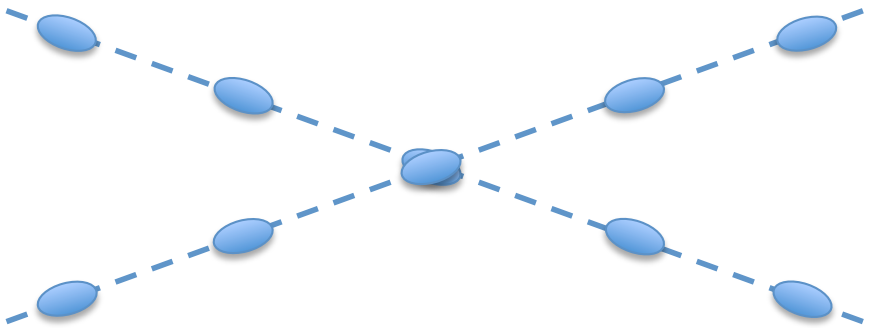
(in particular, W. Herr and G. Trad)

outline

- 2011 review
  - history, levelling, working point scans
  - observations towards a lumi model
    - high pile-up fill
    - non-colliding bunches
  - observed limitations from beam-beam force
    - head-on and long-range
- ideas for 2012
  - suggested parameters
    - 25 vs 50
  - suggested machine studies

reminders

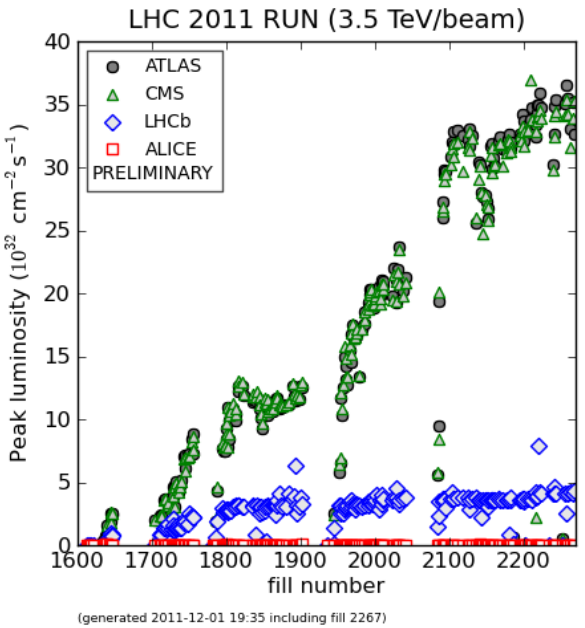
- luminosity $$L_0 = \frac{N_1 N_2 n_b f}{2\pi\sqrt{(\sigma_{1h}^2 + \sigma_{2h}^2)(\sigma_{1v}^2 + \sigma_{2v}^2)}} \frac{1}{\sqrt{1 + \left(\frac{\sigma_s}{\sigma_h}\frac{\phi}{2}\right)^2}}$$

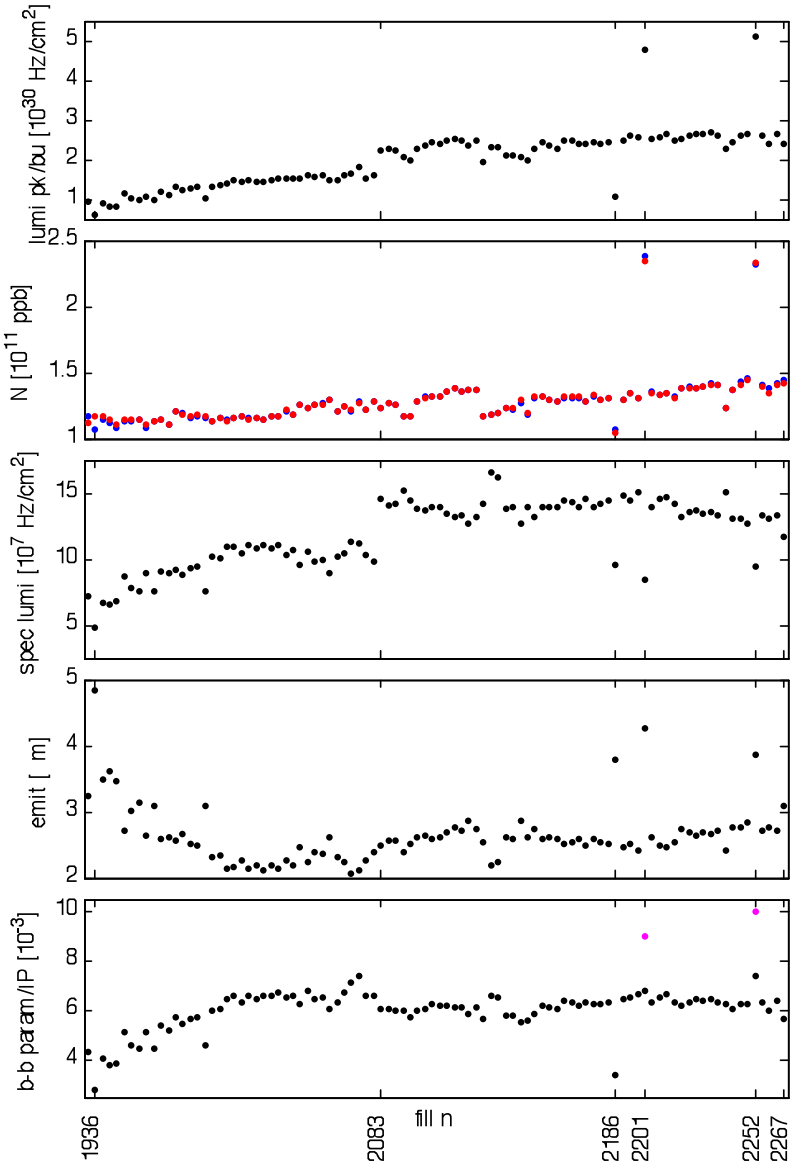


- head-on and long-range beam-beam

- beam-beam parameter $$\xi = \frac{N r_0}{4\pi\varepsilon_N}$$

2011 history

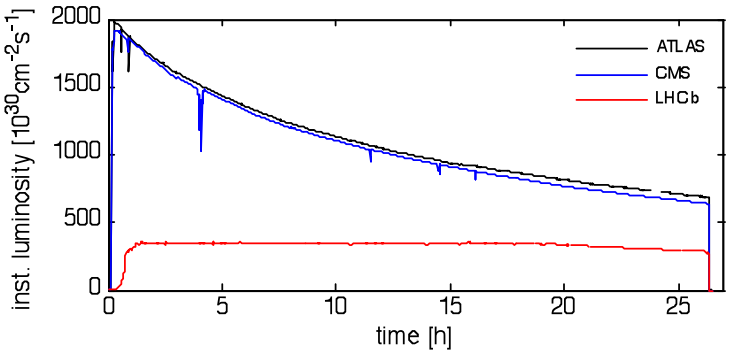


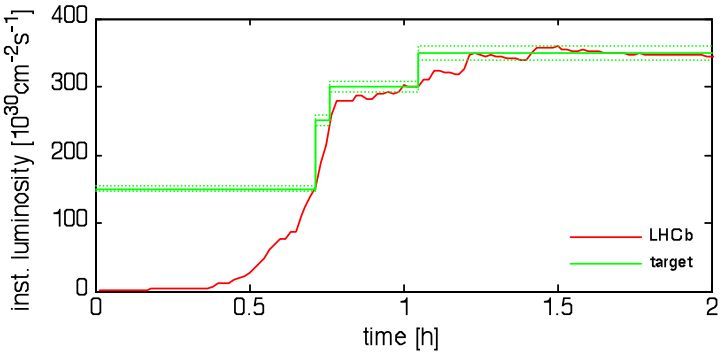


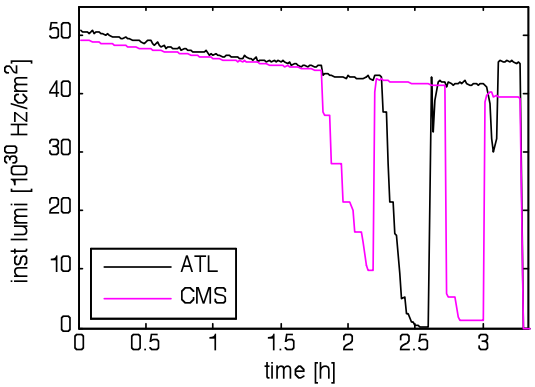
- most fills from 1380 bunches/ring
  - increasing intensity
  - emittance blown up first, then as available from injectors
  - note:
    - high pile-up fills (2201 and 2252)
      - b-b parameter from WS in magenta
    - 25 ns fill (2186)

luminosity levelling

- apply transverse offset to limit pile-up
  - for LHCb and Alice: $\mu_{LHCb} < 2.5$, $\mu_{Alice} < 0.05$
    - LHCb: $L < 350\ 10^{30}Hz/cm^2$
  - first tested in MD (adjust)
  - then used operationally throughout the year
- also done for high pile-up fill (2252)
  - ~2.4e11 ppb, 2.7-3.5 μm
  - luminosity peak could be recovered after separation



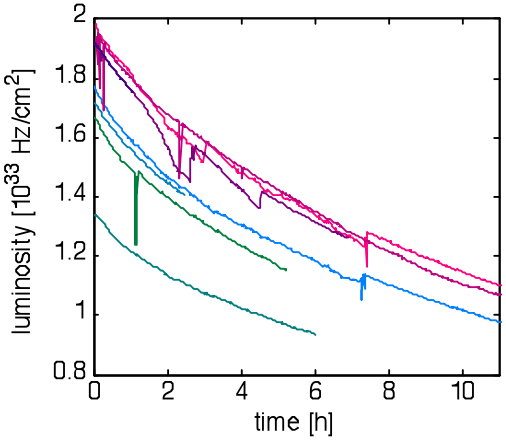


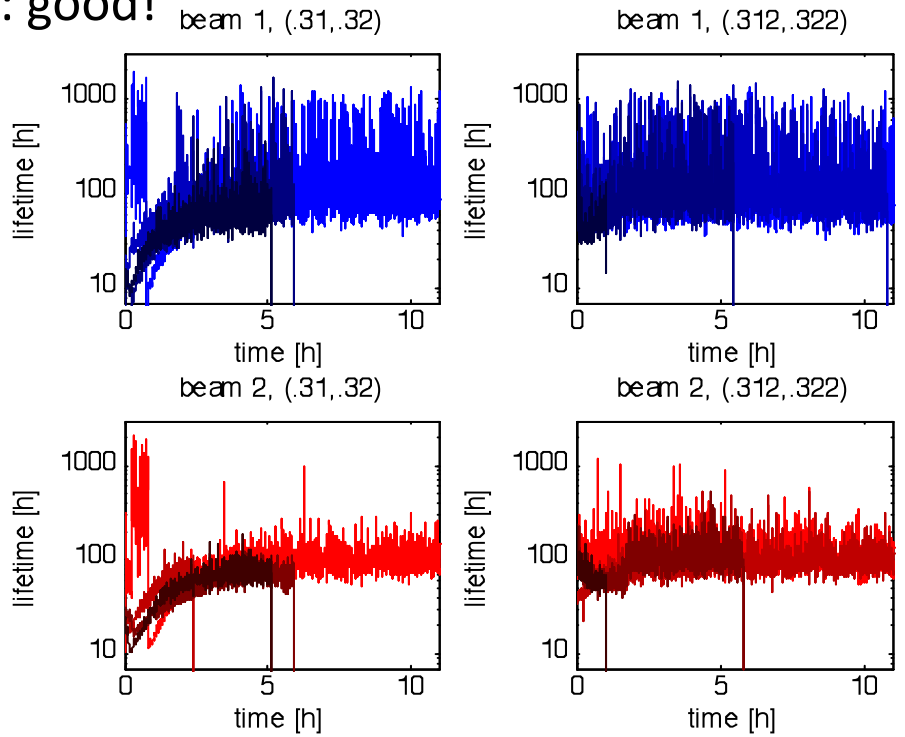


CERN-ATS-Note-2011-028 MD
IPAC'11 – TUPZ025

working point optimization

- summary of changes
  - until fill 1990, Q=(.31, .32),
  - fill 1991, Q=(.308, .318), worse initial lifetime and losses after 1 hour
  - from fill 1992 on: Q=(.312, .322), better initial lifetime
- improvement of initial intensity lifetime
  - reduced dip at start of collisions: good!
  - hard to compare afterwards
    - between 60 and 110 hours
- for lum. lifetime… hard to say





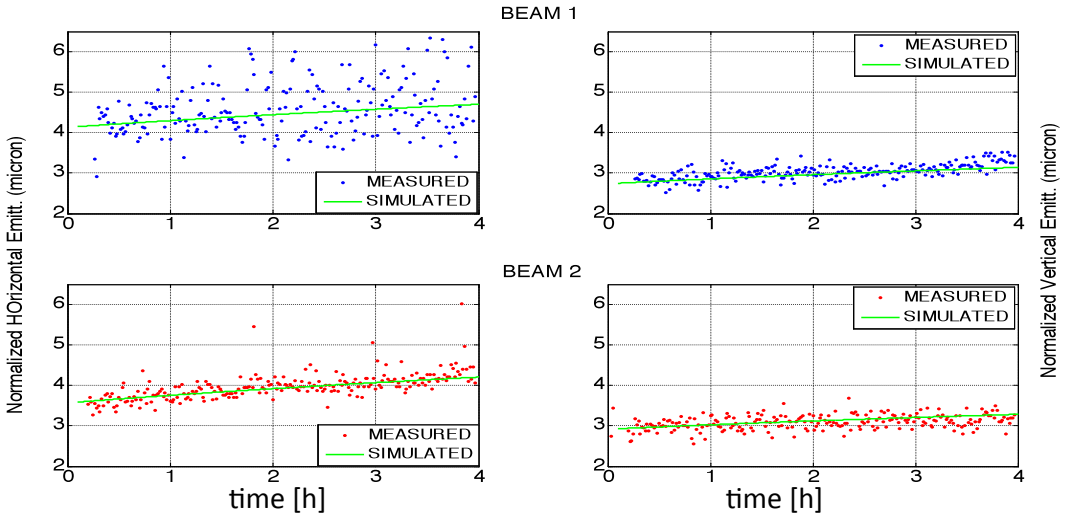
luminosity model

- luminosity evolution model for Tevatron by V. Lebedev
  - ODE: from initial parameters (σ_P, ε_H, ε_V,N), predicts evolution
    - emittance: scattering on gas and in IP, IBS
    - intensity: burn off, losses out of the bucket from IBS and RF noise
    - momentum spread increase from IBS and RF noise
  - does not include beam-beam, synchrotron radiation damping, ADT (predicted as constant growth term)
    - plus bucket full since start of collisions

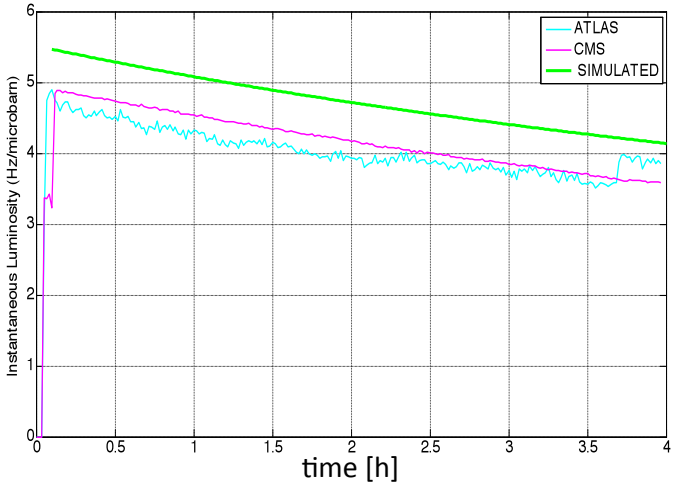
- work ongoing on adapting it to LHC (G. Trad)
  - example for high pile-up fill (plots in next slide)
    - consistent emittance measurements from WS and BSRT
      - good prediction for growth (H: ADT+IBS, V: ADT)
    - good bunch length agreement
    - losses non fully explained
  - multi-bunch agreement less good
    - would require bunch-by-bunch tunes

high pile-up fill simulations

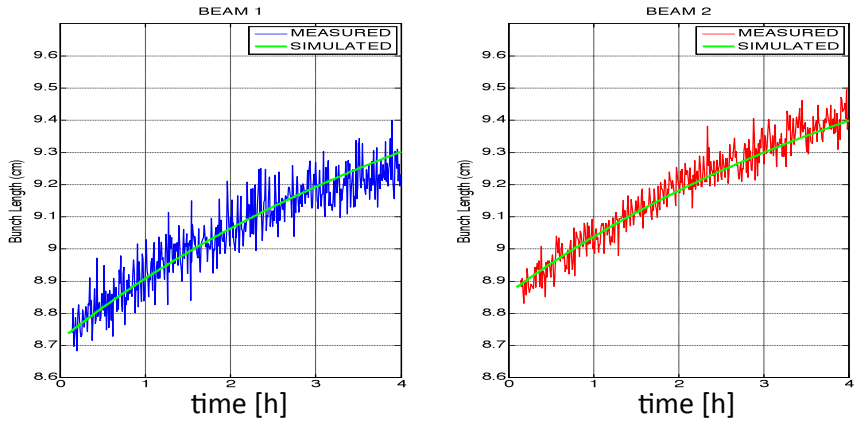
emittance



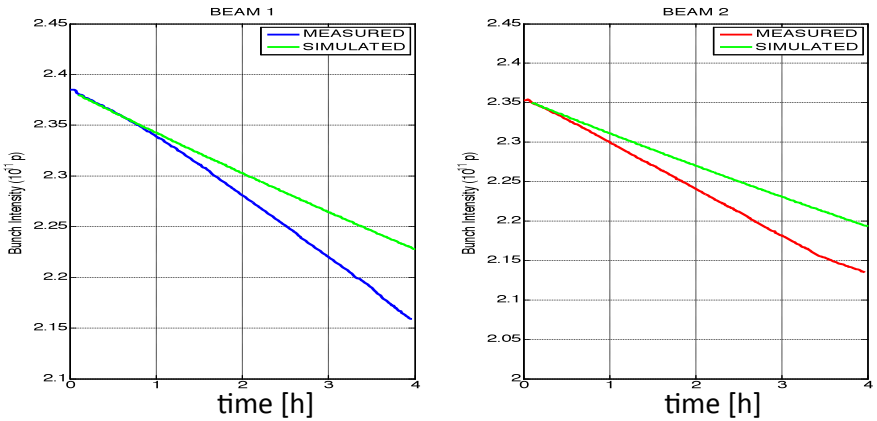
luminosity



bunch length

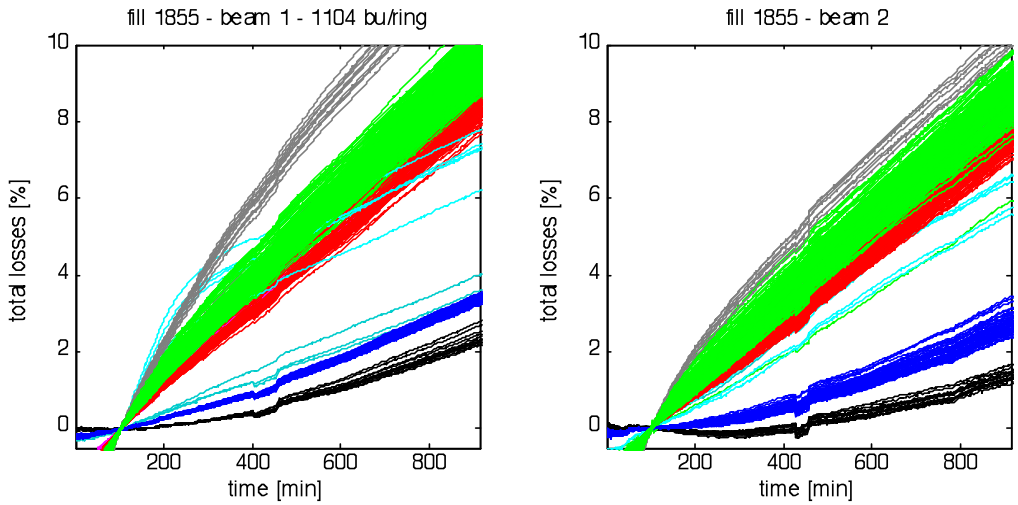


intensity



non colliding bunches – 1

- intensity
  - fBCT not yet corrected for bunch length dependence
  - adjust between 400 and 500 minutes
- negligible losses on residual gas: τ_{gas}>600h
  - losses below 1% in 6 hours
- losses out of the bucket after few hours



collide in IPs:

1 5 2 8

1 5 8

1 5 2

1 5

2 8

8

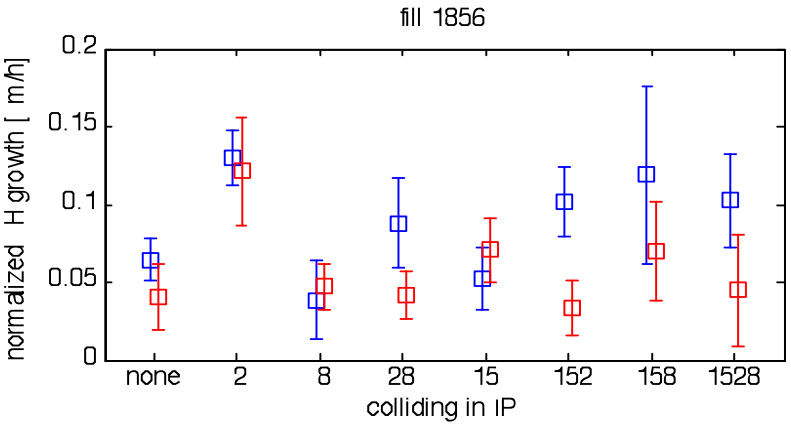
2

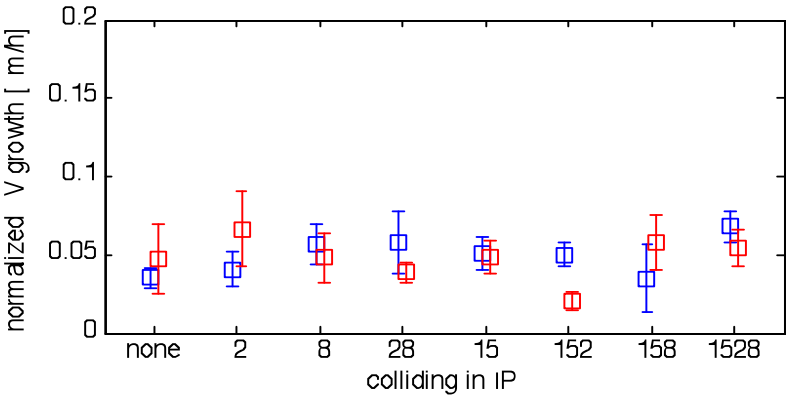
none

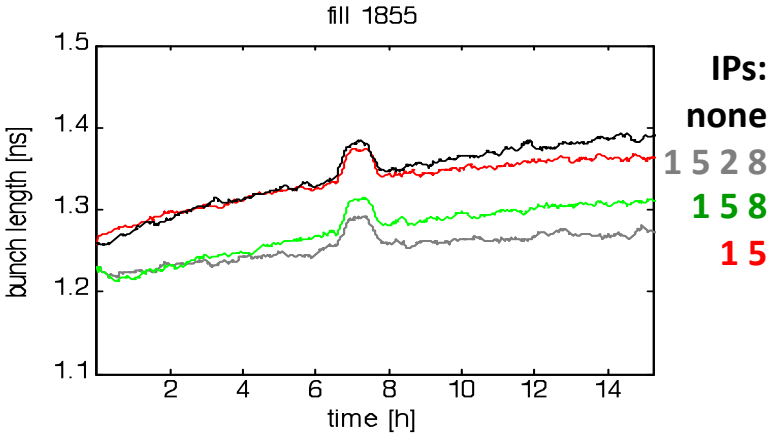
MD Note being published

non colliding bunches – 2

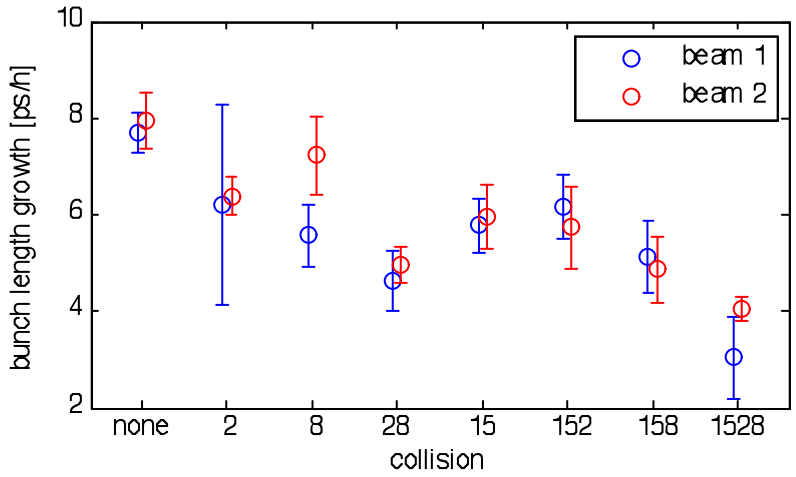
- bunch length growth clipped for colliding bunches
- transverse emittance growth
  - H more than V







IPs:
none
1 5 2 8
1 5 8
1 5



n. of bunches: 12 3 43 5 71 10 945 15

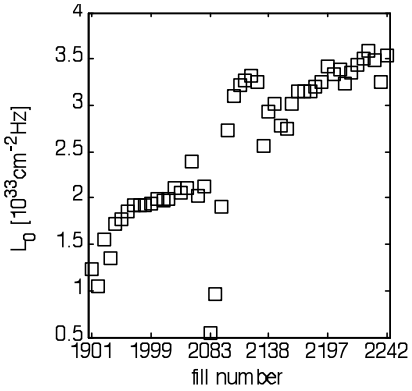
MD Note being published

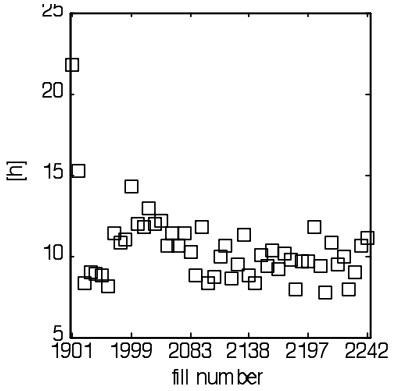
luminosity analysis

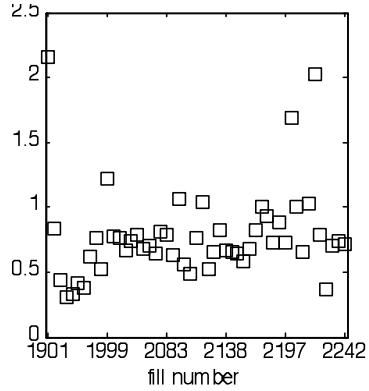
- fits

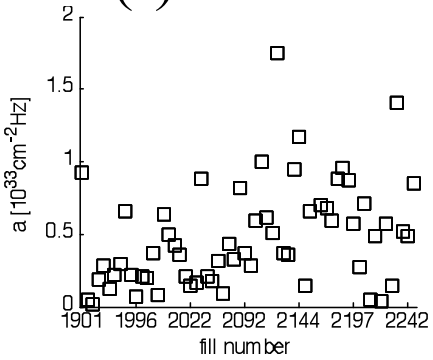
$$L = \frac{L_0}{\left(1 + \frac{t}{\tau b}\right)^b}$$

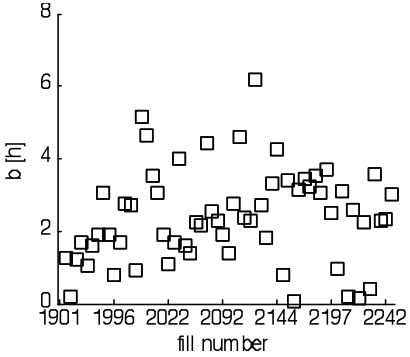
$$L(t) = a \cdot e^{-t/b} + c \cdot e^{-t/d}$$

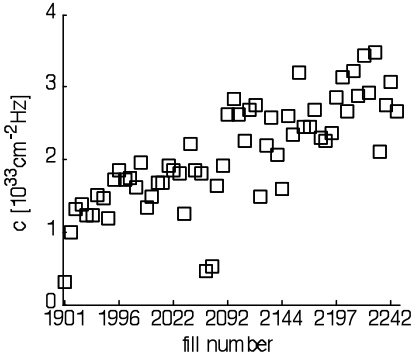


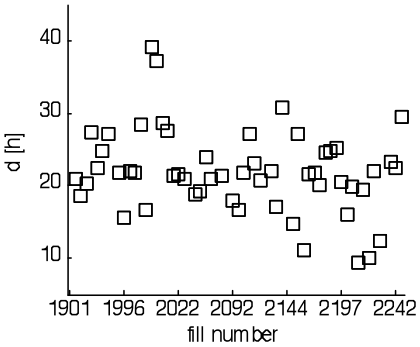












- less scatter than in 2010 in τ and b
- time constants ~3 h and ~23 h

- burn off: τ = 50-60 h
  - ~750000 p/s or 2.5e9 p/h
- τ_{gas} > 600 h
- τ_{IBS} ~40 hours

b-b limitations: head-on

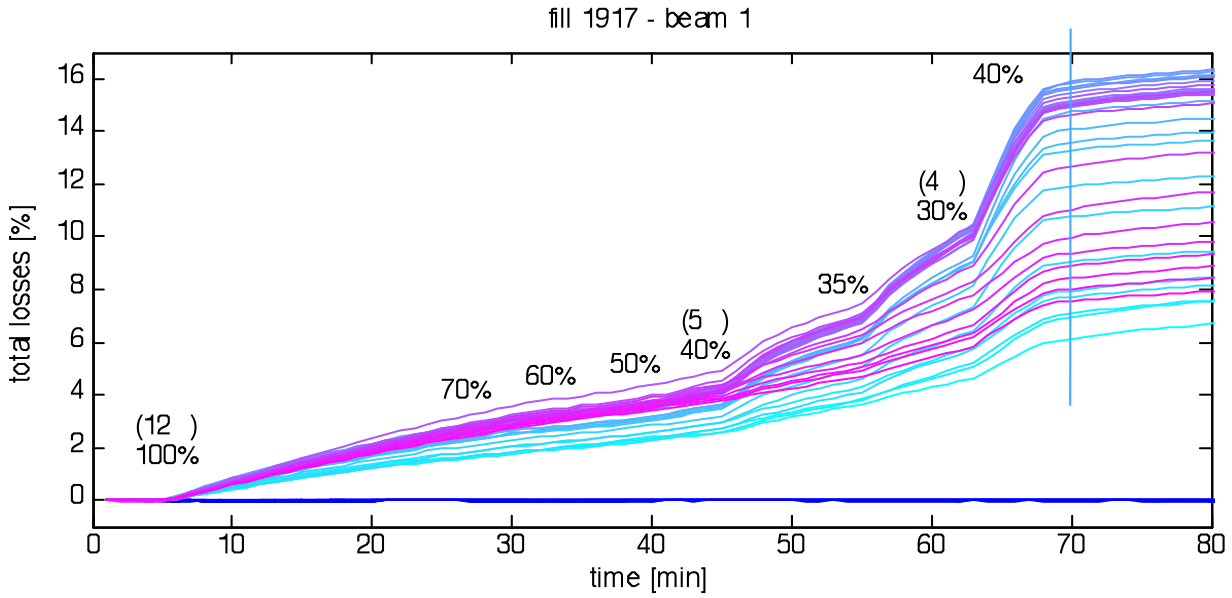
- dedicated MDs from beam-beam team
  - high brightness bunches at injection and flat top
  - ~2.4e11 ppb, 2-2.5μm at injection (but blow up before physics)
- at injection: up to 0.017 beam-beam parameter per IP
  - 0.034 total
    - reminder: 0.0035/IP in Design Report
  - some reduction in lifetime, possibly due to emittance
- at the flat top: 'high pile-up' fills for experiments
  - pile-up of 35 achieved, it just worked!

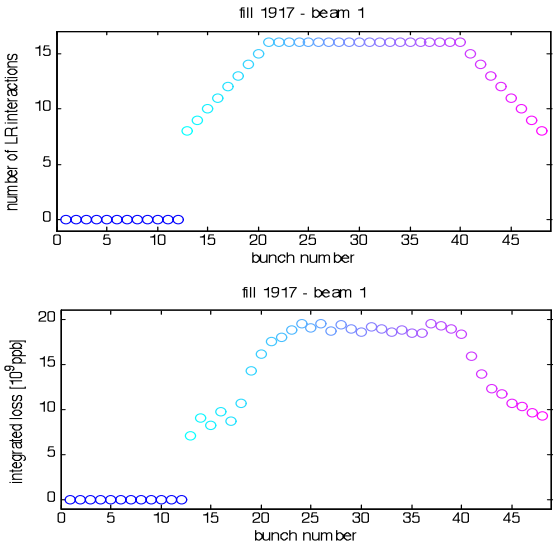
- no sensible limit from head-on found yet
  - can collide 2.4e11 ppb!

CERN-ATS-Note-2011-029 MD
CERN-ATS-Note-2011-105 MD

b-b limitations: long-range

- dedicated MDs by reducing crossing angle to observe separation at which losses/lifetime problems start
  - dynamic aperture effect
    - no effect on emittance and losses recover if wider crossing restored
  - clear dependence on bunch position in batch (anti-PACMAN)
  - evidence for alternate crossing effectiveness
  - dependence on number of head-on collisions also



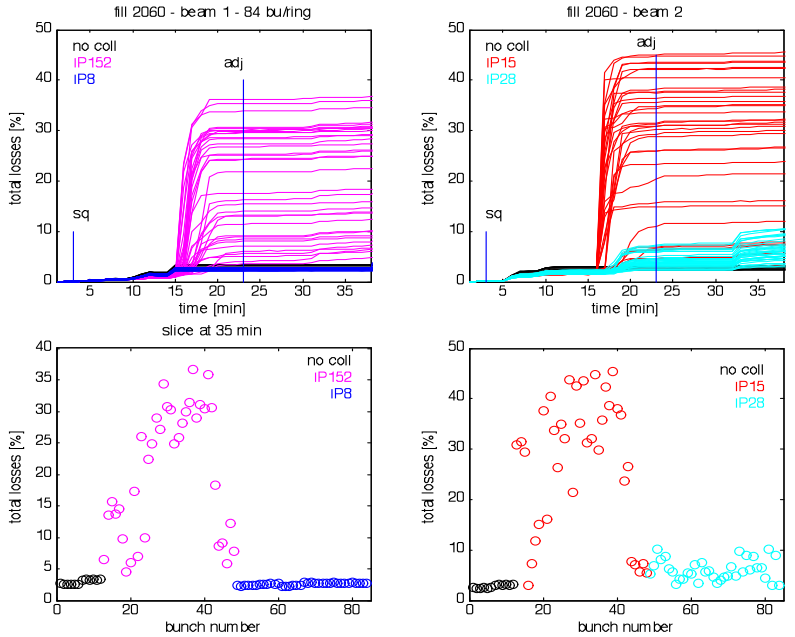


CERN-ATS-Note-2011-058 MD, IPAC'11 TUPZ023

crossing angle

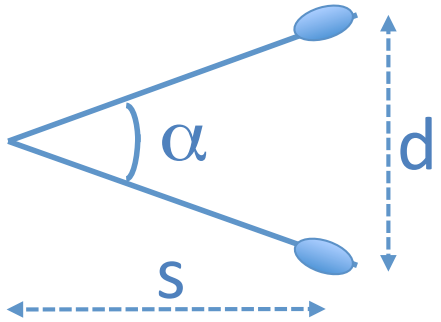
IPAC'11 TUPZ023

- ex: β*=1m commissioning
  - separation bumps not collapsed
  - losses in IP1 and 5 only



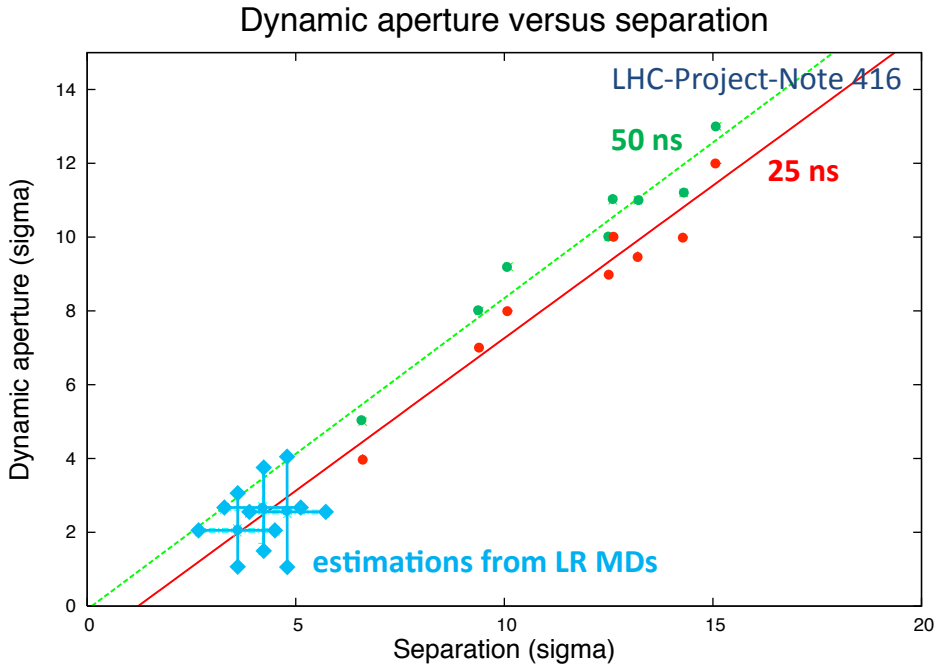
- separation and crossing angle depend on β*

$$d = \frac{\alpha \cdot s}{\sigma(s)} = \frac{\alpha \cdot s}{\sqrt{\varepsilon \cdot \beta(s)}} = \frac{\alpha \cdot s}{\sqrt{\varepsilon \cdot \left(\beta^* + \frac{s^2}{\beta^*}\right)}} \approx \frac{\alpha\sqrt{\beta^*}}{\sqrt{\varepsilon}}$$



25 ns vs 50 ns

- 25 ns spaced beams have twice the number of LR
- dynamic aperture versus separation
  - simulations: LHC Project Note 416
  - estimations: LR MDs



- aim for 10 σ dyn aperture
  - suggestion:
    - 10 σ sep for 50 ns
    - 12 σ sep for 25 ns

studies for next year

- more tune scans in operation
- by beam-beam team
  - head on limit with unequal emittances
  - long-range limit
    - with 25 ns spaced beams
    - with 50 ns beams and b*=1m and 2m
    - also ultimate intensity for after LS1
  - half integer tune working point
  - emittance growth by transverse noise (for HL-LHC)
  - ADT off in physics for studies of coherent beam-beam modes, emittance growth and luminosity model
    - for this year only lowered gain by 30% for too short time
- lumi model: need absolute emittance, RF noise, ADT emittance growth, …
- repeat the non-colliding bunches (improved fBCT)
- look at luminous region data and compare with BSRT

conclusions

- 3h + 23h time constants for lumi lifetime, τ_{gas}>600h, different growth rate for emittances
  - work ongoing on luminosity model and more data analysis needed
- head-on much less of a problem than long-range
  - can collide up to 2.4e11 ppb without problems
- number of LR and separation matter
  - 50 ns easier than 25 ns
  - recommended separation: 10 σ for 50 ns, 12 σ for 25 ns
- many studies proposed
  - head-on and long-range limits (25 ns, different β*, high intensity), emittance growth
  - tweaking of parameters for lumi model
    - non-colliding bunches