CAN WE GET A RELIABLE ON-LINE MEASUREMENTS OF THE TRANSVERSE BEAM SIZE?

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Evian Workshop, Dec 2010

INTRODUCTION

Transverse Emittance diagnostics

- **Wire Scanners** (WS)
  - reference monitors, measurement on demand

- **Synchrotron light monitor** (BSRT)
  - imaging of the synchrotron radiation from superconducting undulator and D3 dipole

- **Ionization Gas Monitor** (BGI)
  - accelerate electrons produced by beam-gas ionizations towards electron multiplier+phosphor+ imaging system

WIRE SCANNERS

On demand measurements

Operation modes

- turn mode, 1 profile per scan, ~10us window around selected slot
- bunch-to-bunch mode, a maximum of 75 profiles per scan, limited by front-end memory and firmware

Intensity limitation

Energy Reason Design SW interlock put in place after gaining some experience)

450 GeV (wire damage)	5e13 p	2e13 p
3.5 TeV (quench)	1.5e13 p	2e13 p

but: WS studies quench test : can go factor 3 higher at 3.5TeV
Next year: updated interlock values to allow safe scans at higher intensities

During shutdown: remove wire used for quench test to investigate any damage

Gain / Attenuation

- PM tube voltage
- optical filters

Resolution

- depends on wire speed
  - @ 1 m/s : 1 profile point every 89um

Accuracy

- absolute accuracy on wire position given by potentiometer jitter (few microns)
- non linearity in PM gain (linear in a given voltage range)

BSRT

Continuos measurements

- 1 acquisition = signal over 20ms max, stored at 1Hz

Operation modes

- DC mode, 1 acquisition = average over all bunches during 20ms
- PULSED mode

  - gate synchronized to turn clock
  - 1 acquisition = average over number of gates in 20ms
  - minimum gate size: 25ns
  - maximum gate rate: 200Hz

    ➡ one 20ms acquisition can contain from 1 to 4 turns

    ➡ we can do single bunch, single turn every 55 turns

Limits on beam intensity. Can see:

- single turn proton pilot at injection
- ~30 nominal ion bunches at injection, integrated over 20ms

Gain / Attenuation

- Image intensifier voltage
- optical filters (neutral to attenuate all spectrum, color to select wavelengths)

Resolution

- geometric: depends on telescope magnification (not variable on line, now ~0.10 pix/mm)
- ultimate resolution (smallest measurable beam) depends on aberration, diffraction, depth-of-field

Accuracy

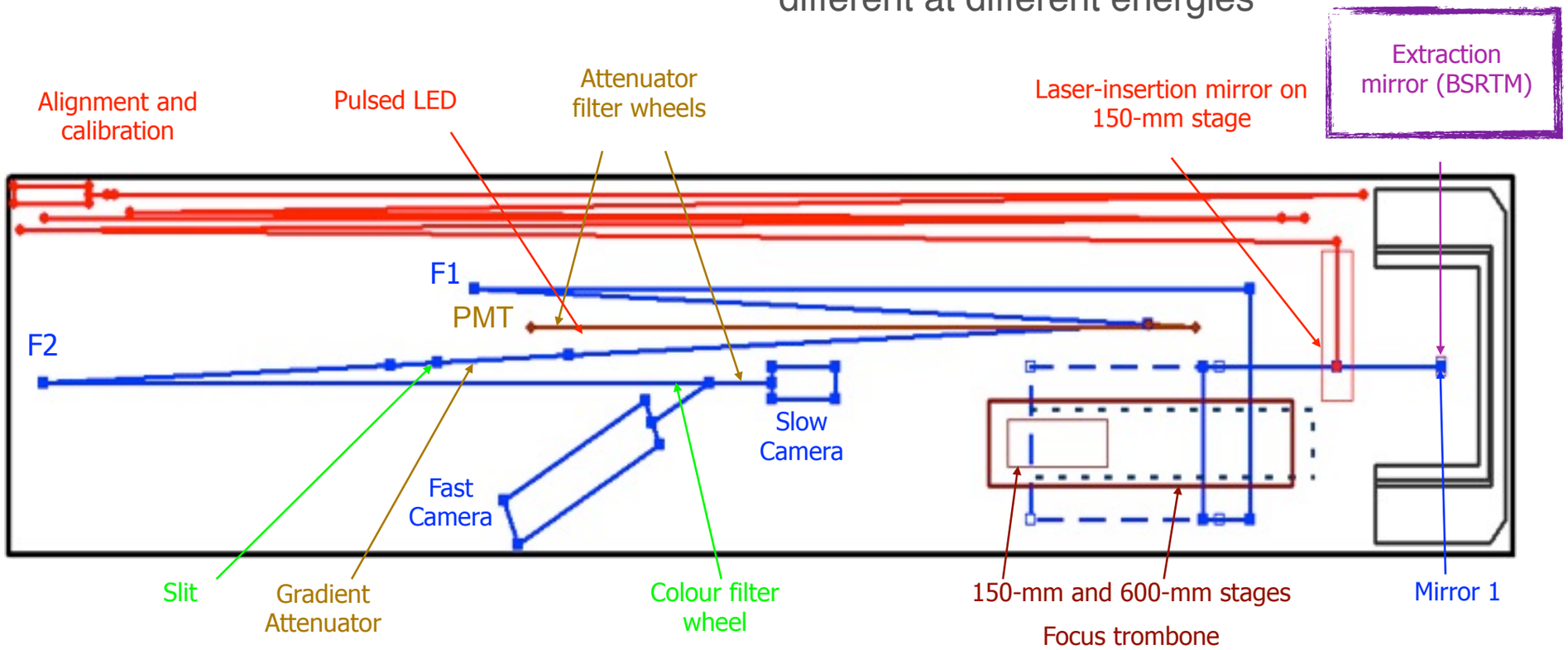
- absolute accuracy relies on reference target (gives magnification) and comparison to WS
- relative accuracy independent of absolute calibration as soon as beam size > ultimate BSRT resolution

BSR TELESCOPE

Light comes either from SC Undulator or D3

- Und. dominates up to 1 TeV protons, 1.5 TeV ions
- D3 at 3.5 TeV

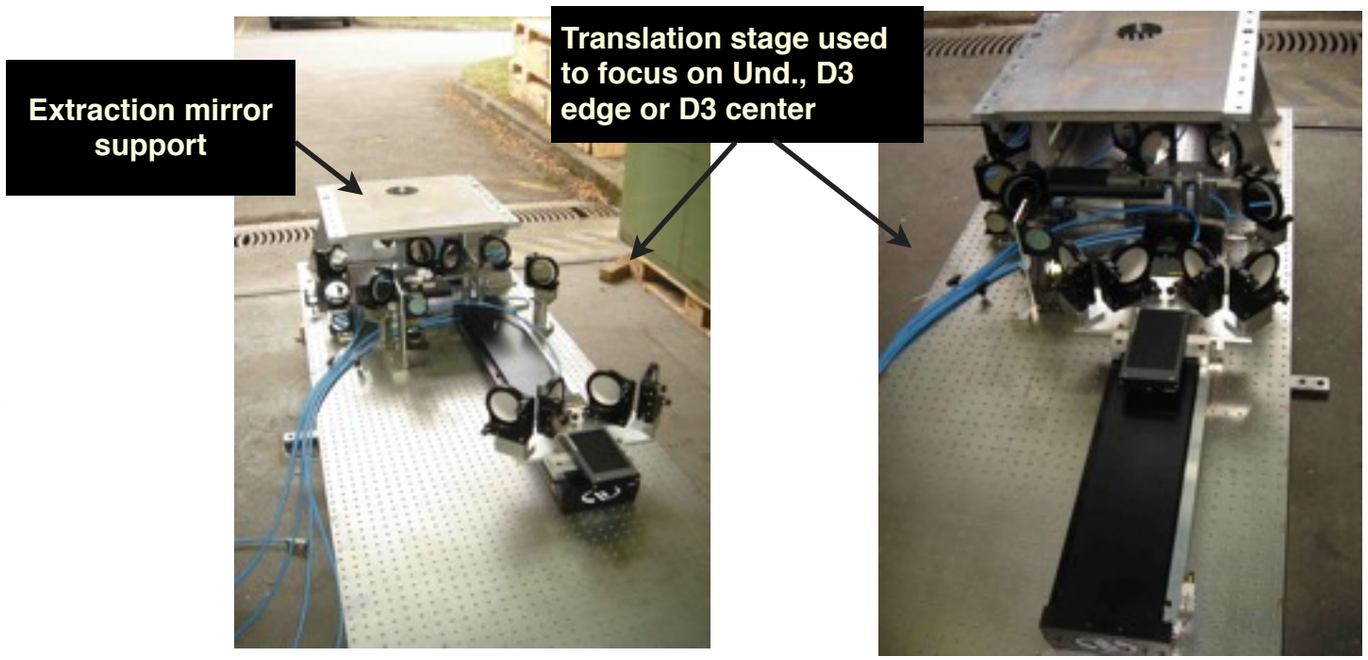
- need to adjust focusing on selected source as energy changes
- absolute accuracy (calibration w.r.t. WS) may be very different at different energies



Automatic settings

- ensure proper camera gain and optical filters as function of intensity and energy
- doesn't provide an automatic refocusing at different energies

During shutdown we are installing two permanent Longitudinal Density Monitors in the same telescopes (that are 'GOLD' quoting Massimiliano)



BSRT WITH IONS AT 450 GEV

10-Nov-2010: 17 Bunches

TV streamer

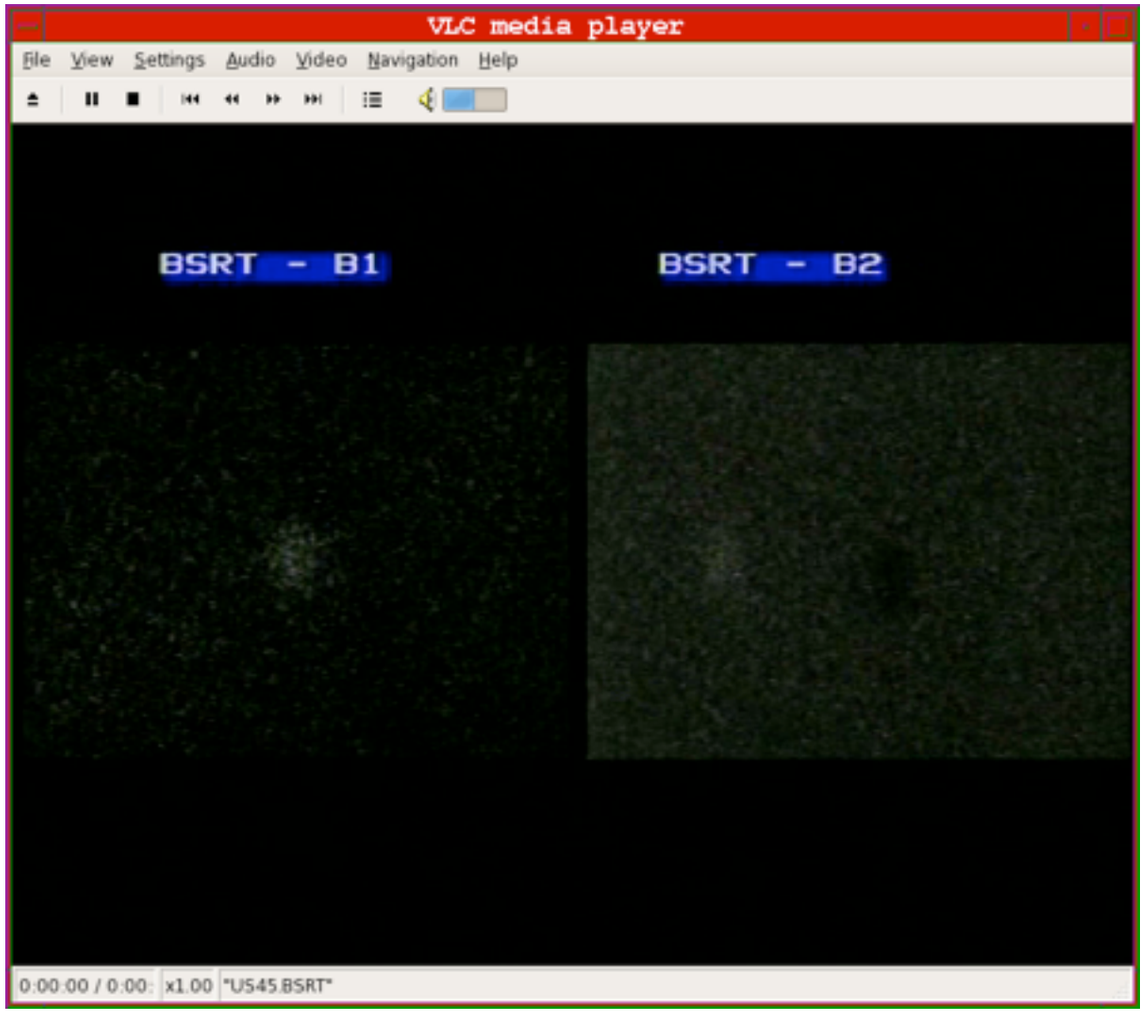
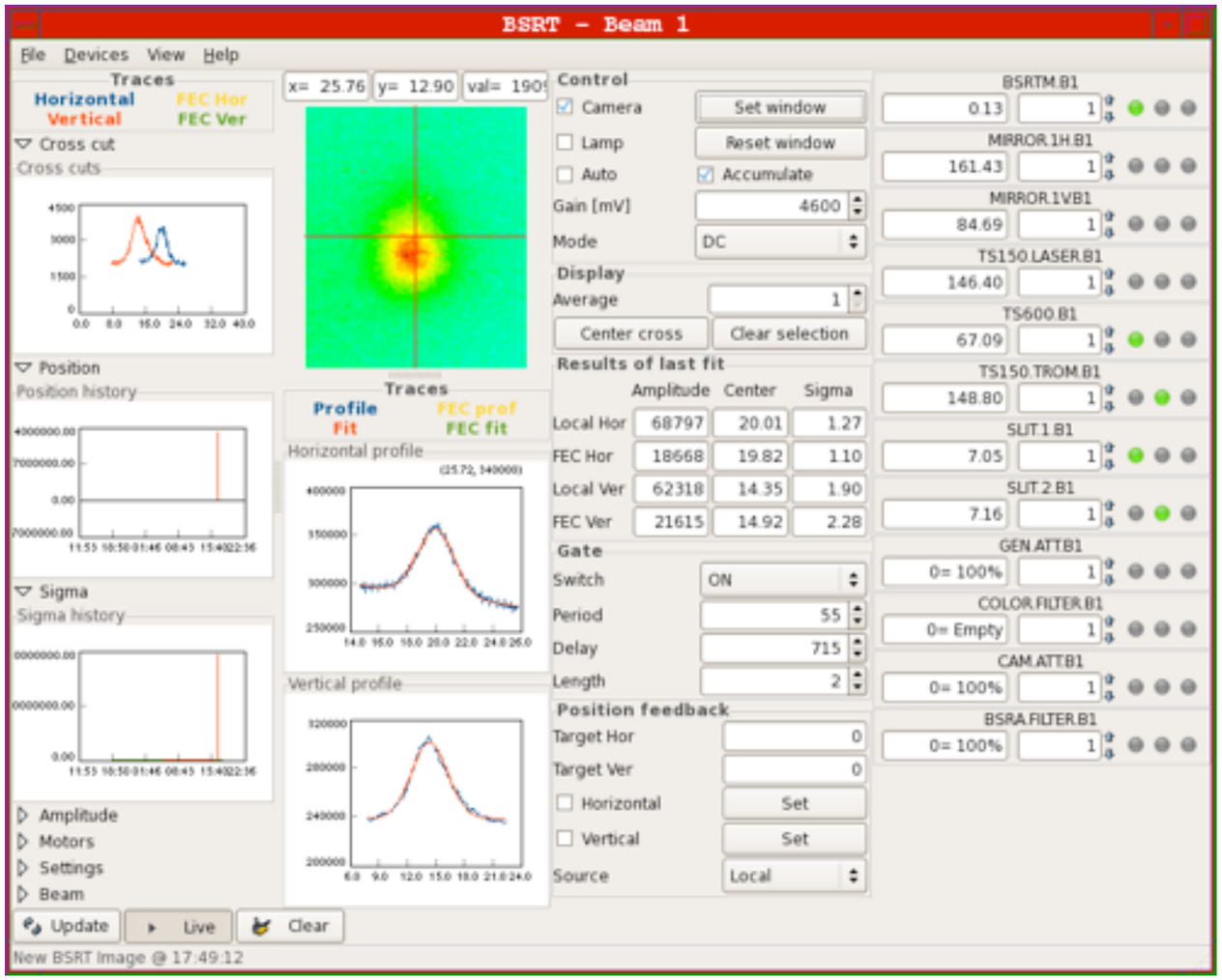


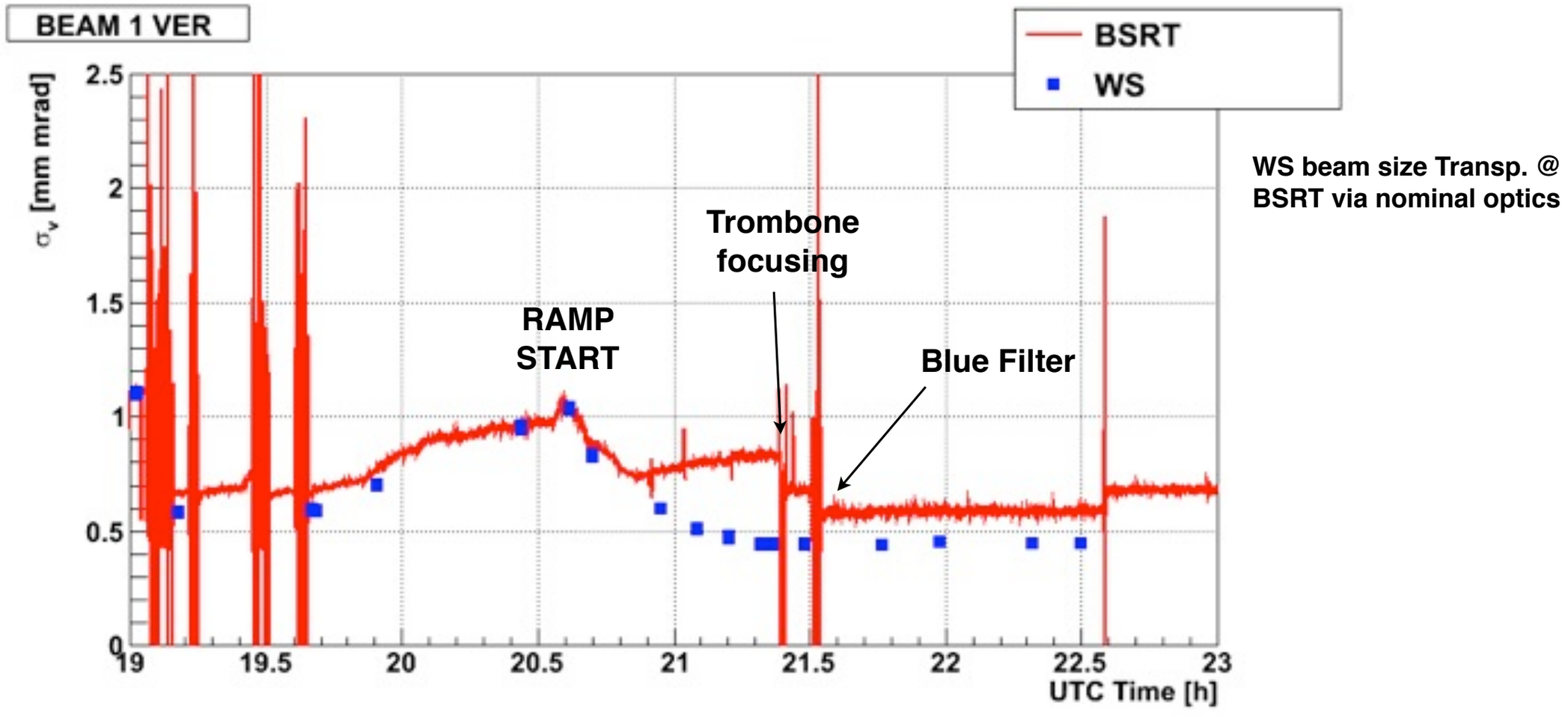
Image obtained accumulating 20ms acquisitions for few seconds



BSRT SETTINGS

Effect of focusing with translation stage at 3.5 TeV and color filter

29-03-10, protons, ramp to 3.5TeV



Here: sigma measured by BSRT corrected (in quadrature) with a constant factor at 450 GeV and 3.5 TeV

BSRT STATUS

What is available to OP today

- fixed display
- the logged data

Basic Setting and Operation

- by BI experts

Resolution/Accuracy

- apart from proton physics fills with small emittances (for which studies are on-going) system is above ultimate resolution limit --> relative variation always reliable
- at the moment correction on beam size not applied on logged data
- correction factors changed during the year as BSRT system optimized (alignment, focusing, S/N)

What is available on demand to BI experts

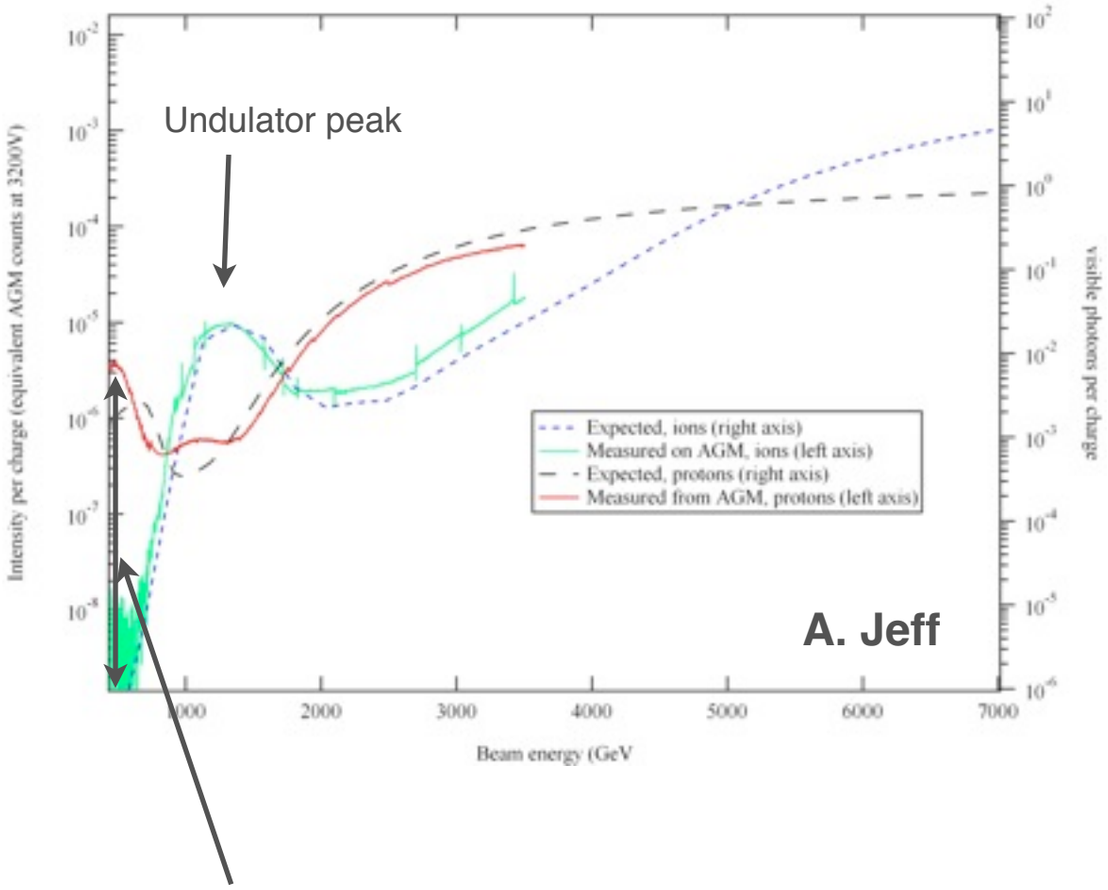
- slot scans --> bunch per bunch data (3 sec per bunch enough --> xx min for yy bunches)
- off-line analysis (limited resources from BI, concentrate on analysis to validate/understand the system)
- best estimation of correction factors

What will be available in 2011

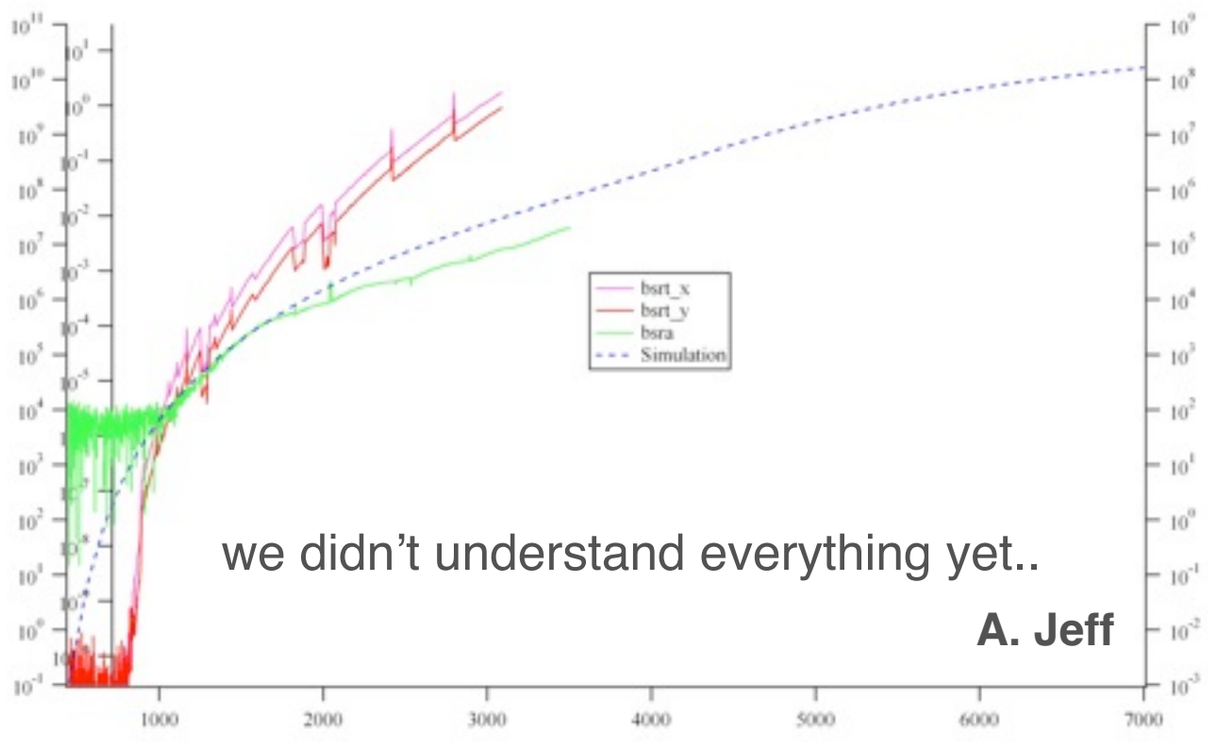
- immediately
  - logged corrected beam size values (even though correction may change during the year)
  - Intensified Fast Cameras tests --> turn-by-turn, bunch-per-bunch : in principle few minutes to scan many bunches
- during the year
  - improved automatic settings (feedback on position, automatic focusing vs energy)
  - OP application with options for slot scans?
  - Fast Cameras operational?

BSRT VS SIMULATIONS

Photons per charge as simulated and measured by **Abort Gap monitor** (that shares light with BSRT)



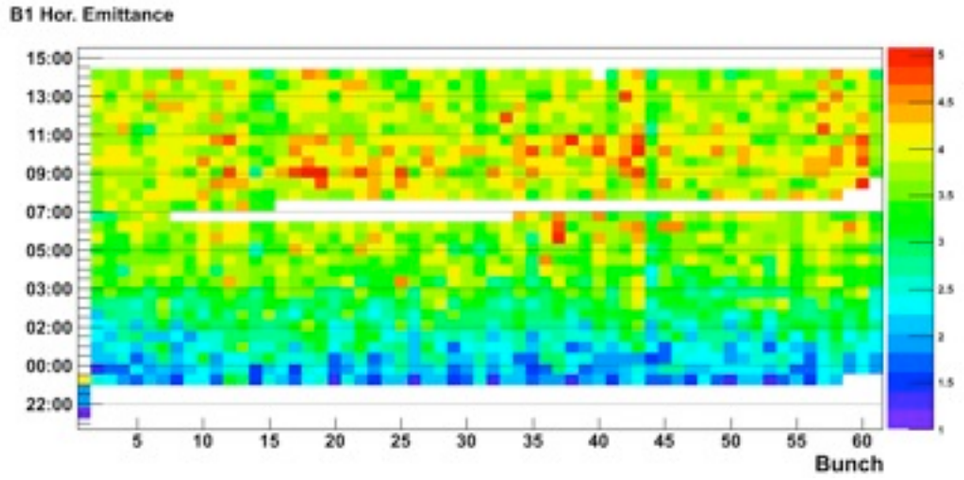
Photons per charge as simulated and measured by **BSRT** during a ramp with IONS without Undulators

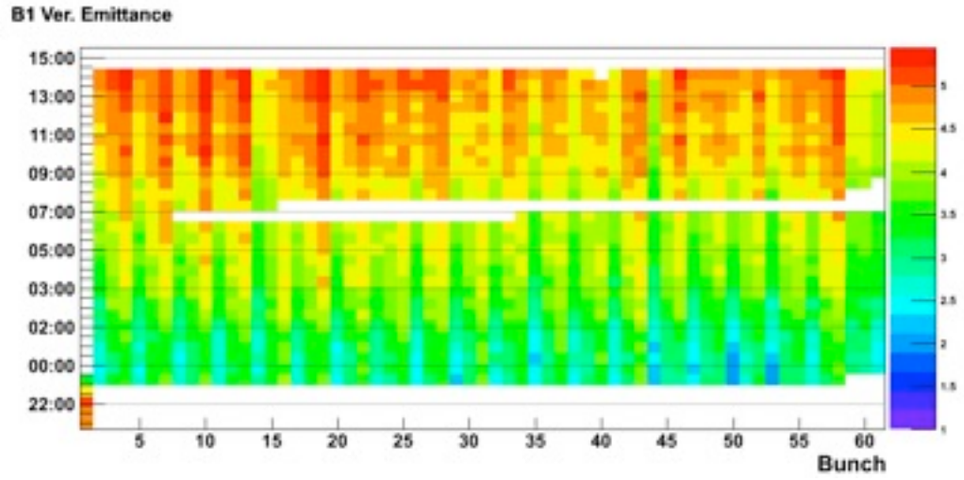


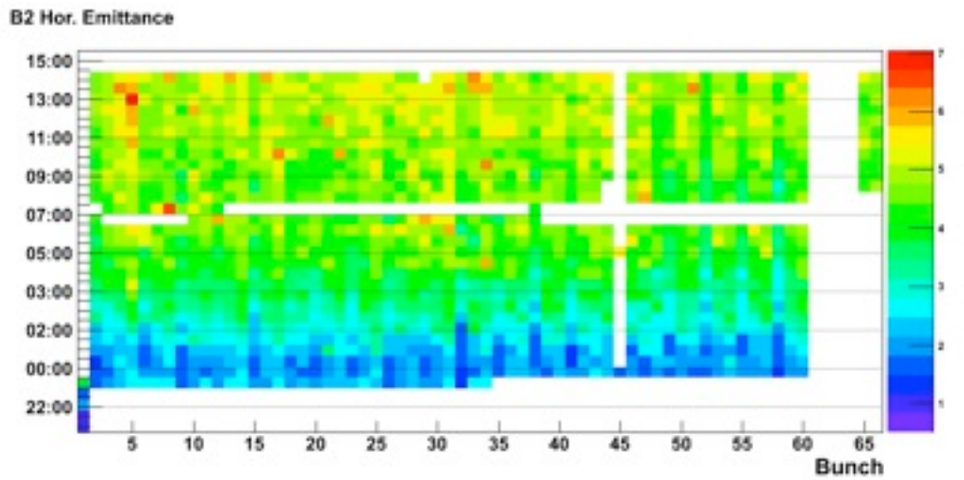
At least a factor 10e4 difference between protons and ions at injection
But: we managed to see light at injection with Ions.

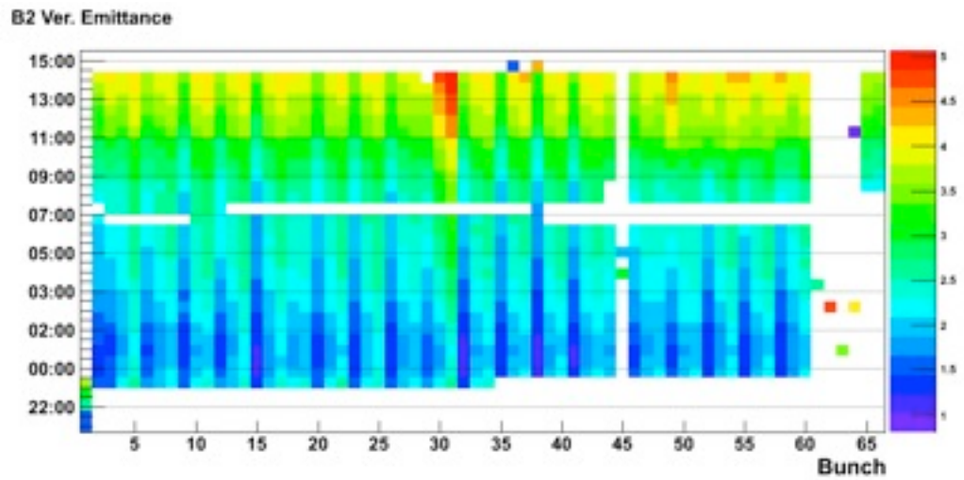
BSRT BUNCH PER BUNCH MEASUREMENTS

28-10-10, protons, 368b /beam / 150ns / 19 injections, gating on 3 b per injection

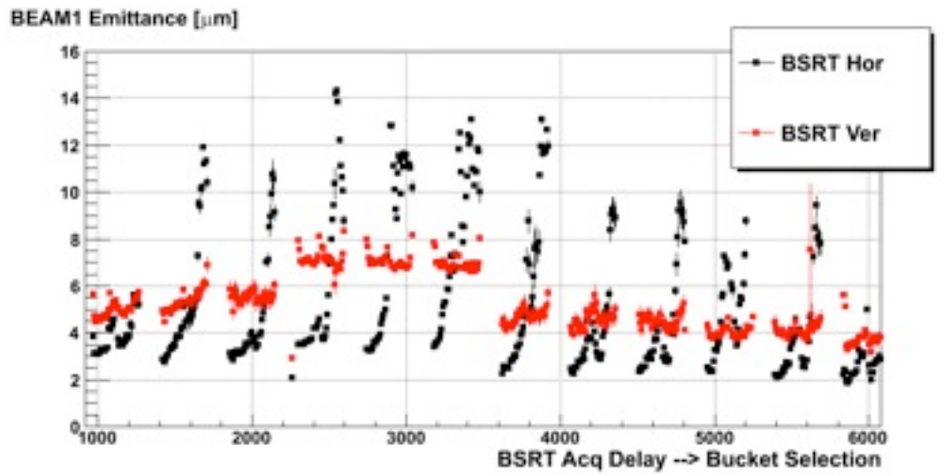








08-11-2010, 680b , 75 ns
Average bunch emittance



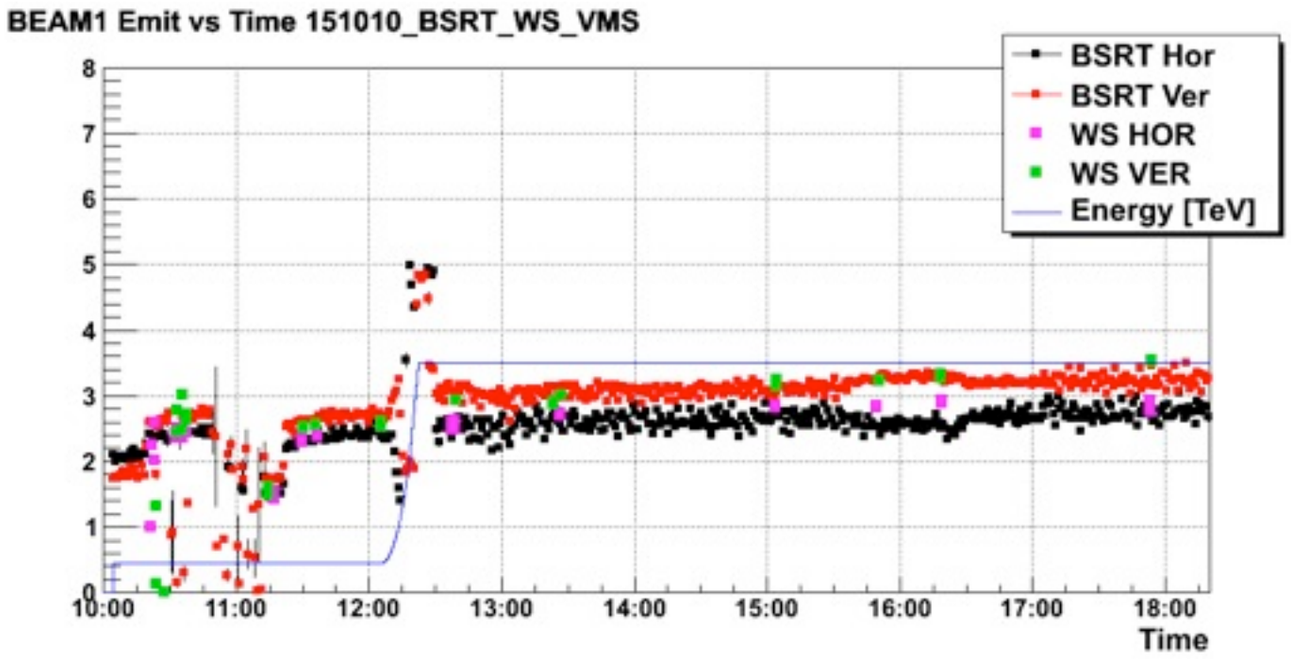
BSRT VS WS

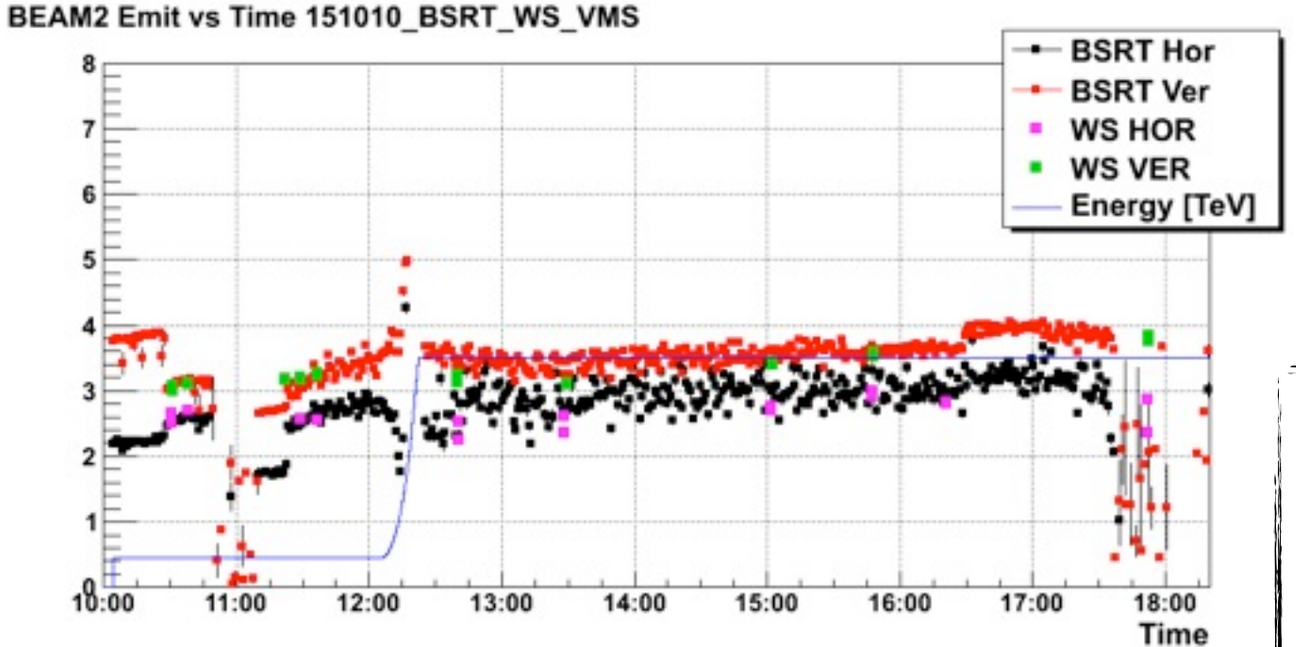
Cross-cal vs WS --> Correction

- subtraction in quadrature on the measured beam size
- changes with energy
- changes with protons/ions

$$\sigma = \sqrt{\sigma_{mes}^2 - \sigma_{corr}^2}$$

- Changes after optimization of the systems during accesses
  - realignment, change optical filters, mirrors etc...





CORRECTION FACTORS

Protons Oct		450 GeV	3500 GeV
B1	H	0.70	0.57
	V	0.63	0.50
B2	H	0.60	0.59
	V	0.50	0.77

Protons Nov		450 GeV	3500 GeV
B1	H	0.60	0.50
	V	0.95	0.55
B2	H	0.60	0.52
	V	0.65	0.42

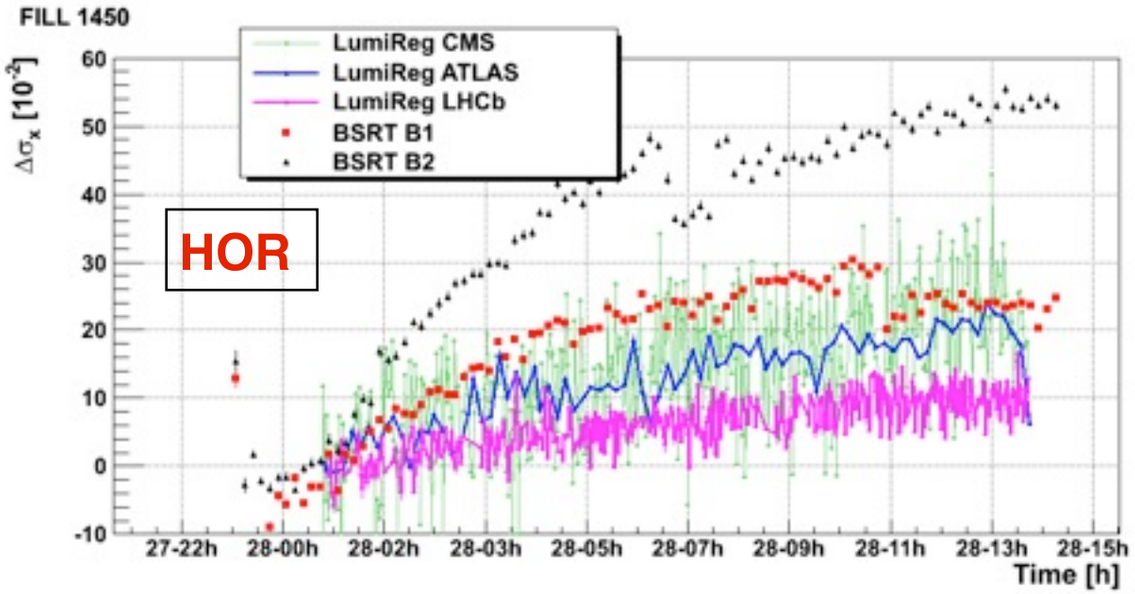
Ions		450 GeV	3500 GeV
B1	H	0.60	0.40
	V	0.99	0.65
B2	H	0.60	0.55
	V	0.50	0.40

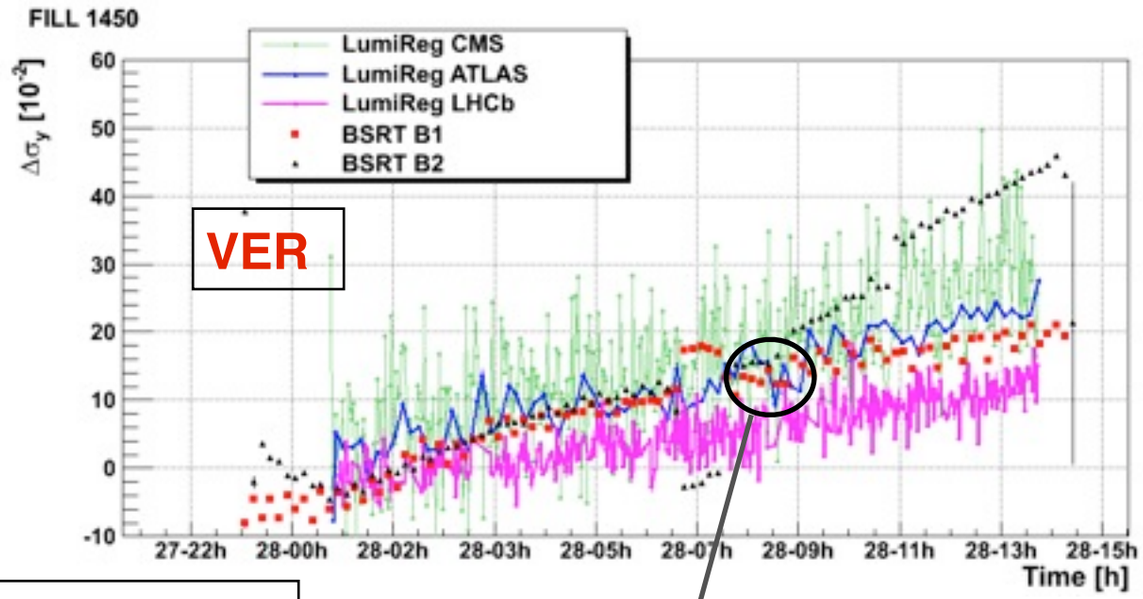
We still have to learn a lot about absolute and relative calibration
-simulations
-laboratory (copy of telescope being setting up)
-beam based meas. during MD

BSRT VS EXPERIMENTAL LUMINOUS REGION

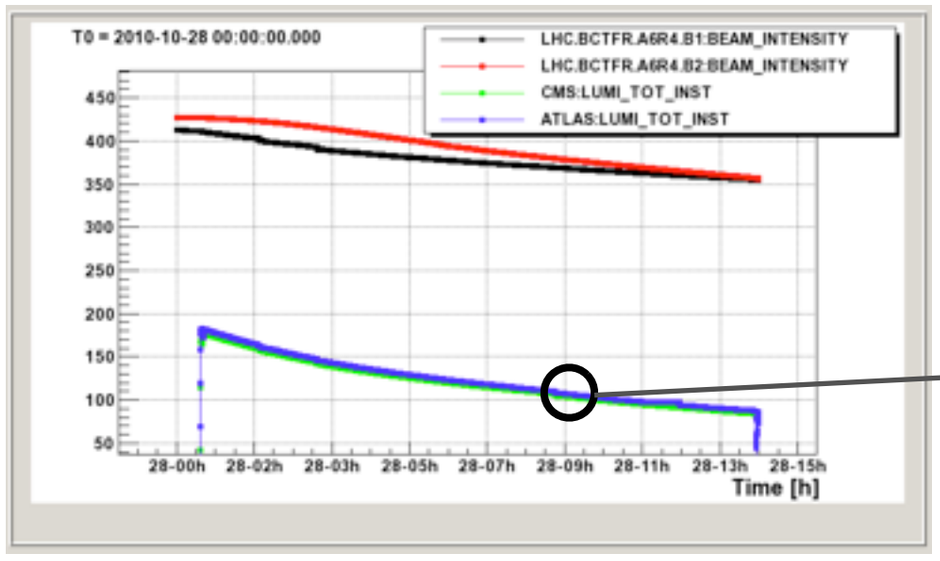
28-10-10, protons, 368b /beam / 150ns / 19 injections, gating on 3 b per injection

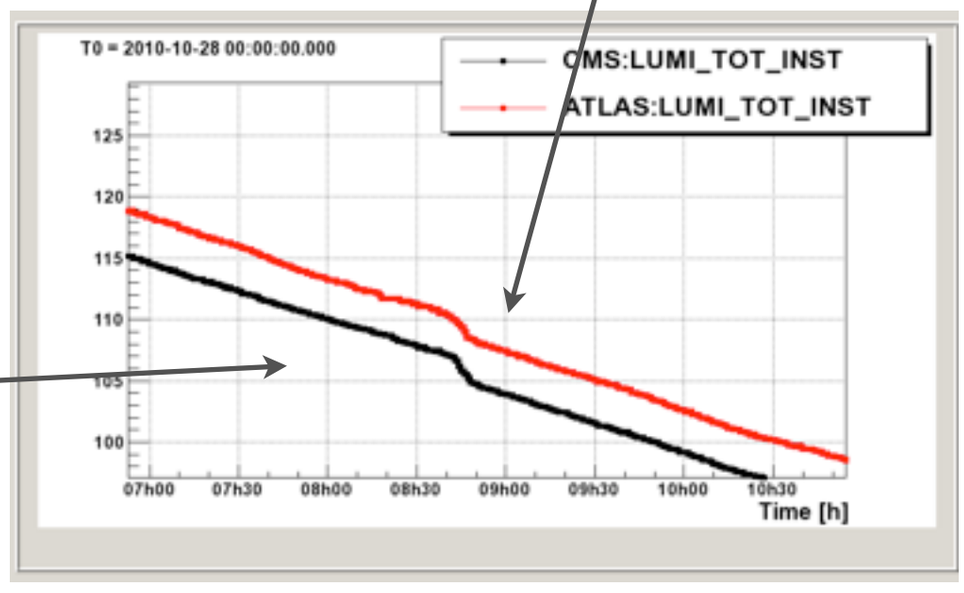
Comparison between Expts luminous region evolution (average over all bunches) and BSRT beam sizes evolution





Absolute luminous regions





Assuming that lumi-region is dominated by smallest beam: all is consistent

BGI

Continuous measurements (logged at 1Hz, more than 250h logged from Oct 1st)

- gated cameras are at the moment in ‘automatic mode’
  - camera gain is fixed, gate is changed automatically
- in principle: average over all bunches

Limits on beam intensity

- protons: needs gas injection for I<400b (before scrubbing, next year will see). With 2e-8 mbar (10 times below interlock) can see single bunch
- ions (without gas injection): 2 nominal bunches

Limits on beam energy (no limit)

Gain / Attenuation (as in 2010)

- camera gain is fixed (at max), can play with vacuum pressure
- MCP gain in front of camera (electrons from ionization multiplication)
- HV between MCP and phosphor

Accuracy

- reference wire-grid calibration
- calibration w.r.t. bpms (bumps)
- cross cal w.r.t. WS

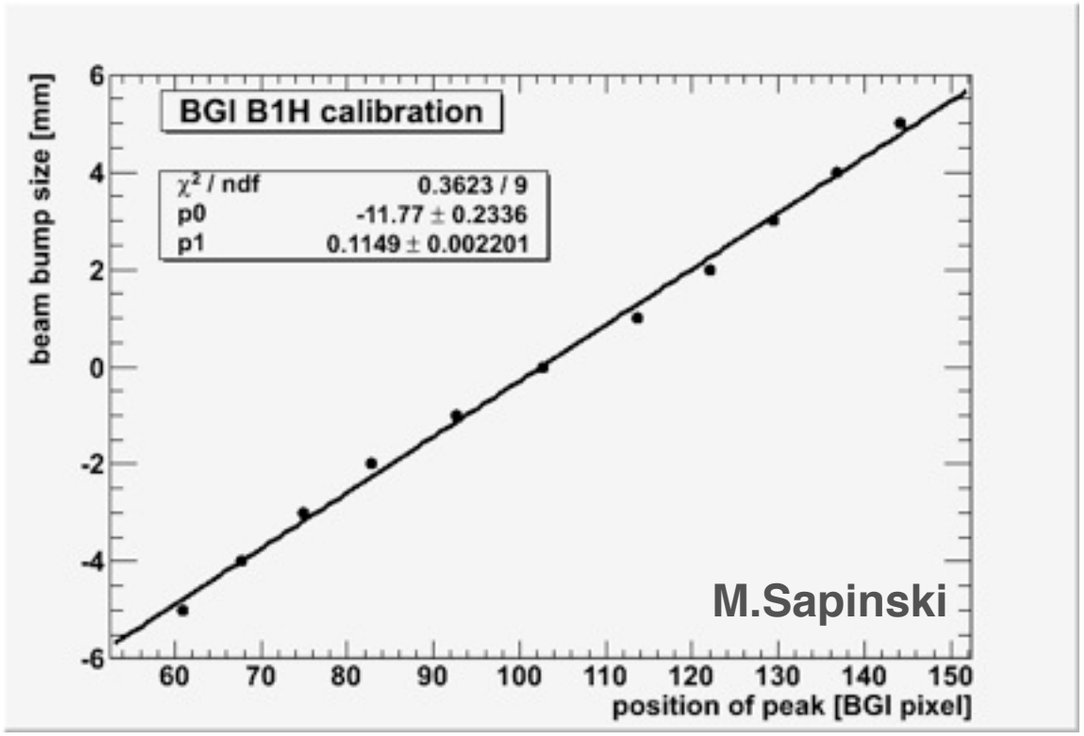
Next (2011)

- remote camera gain and gate control
- gas injection remote control

BGI STATUS

Cross calibration w.r.t. nominal bump amplitude

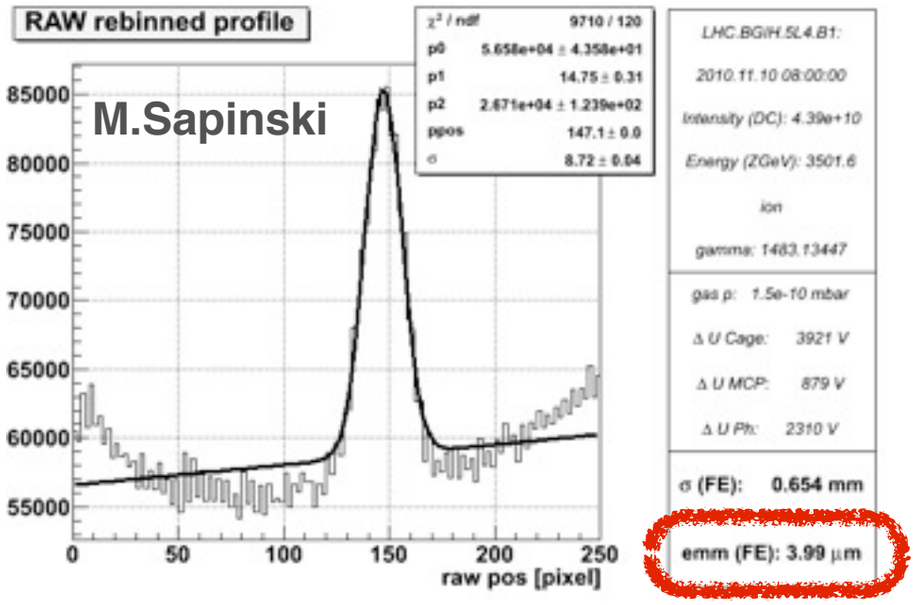
- 1.4-1.5 correction on beam size w.r.t. present raw data
- analysis to compare w.r.t. actual BPM reading during bumps on going (no big changes expected)

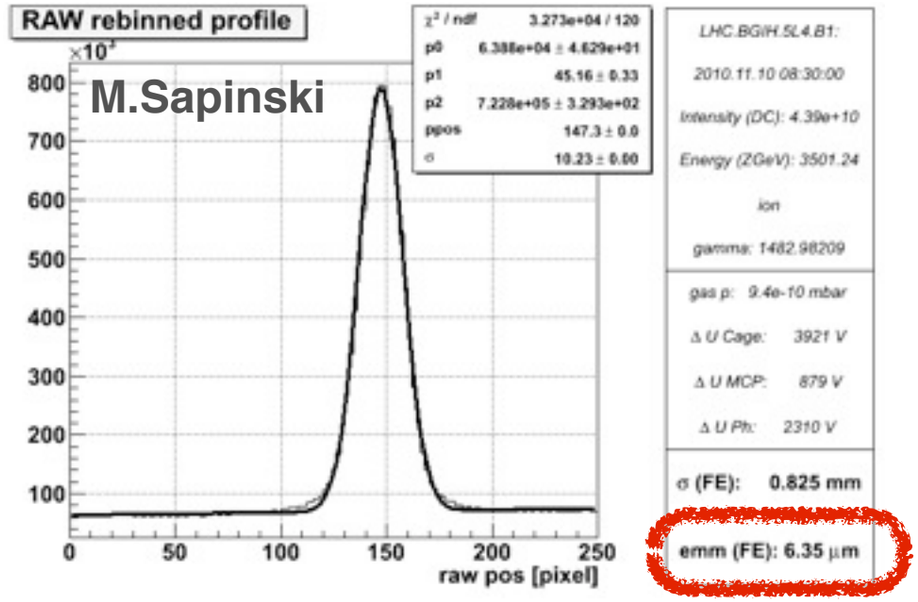


- **In general**
  - BGI in commissioning phase
  - logged beam sizes sometimes affected by profile fitting failures --> one should look carefully into logged profiles and perform off-line fit

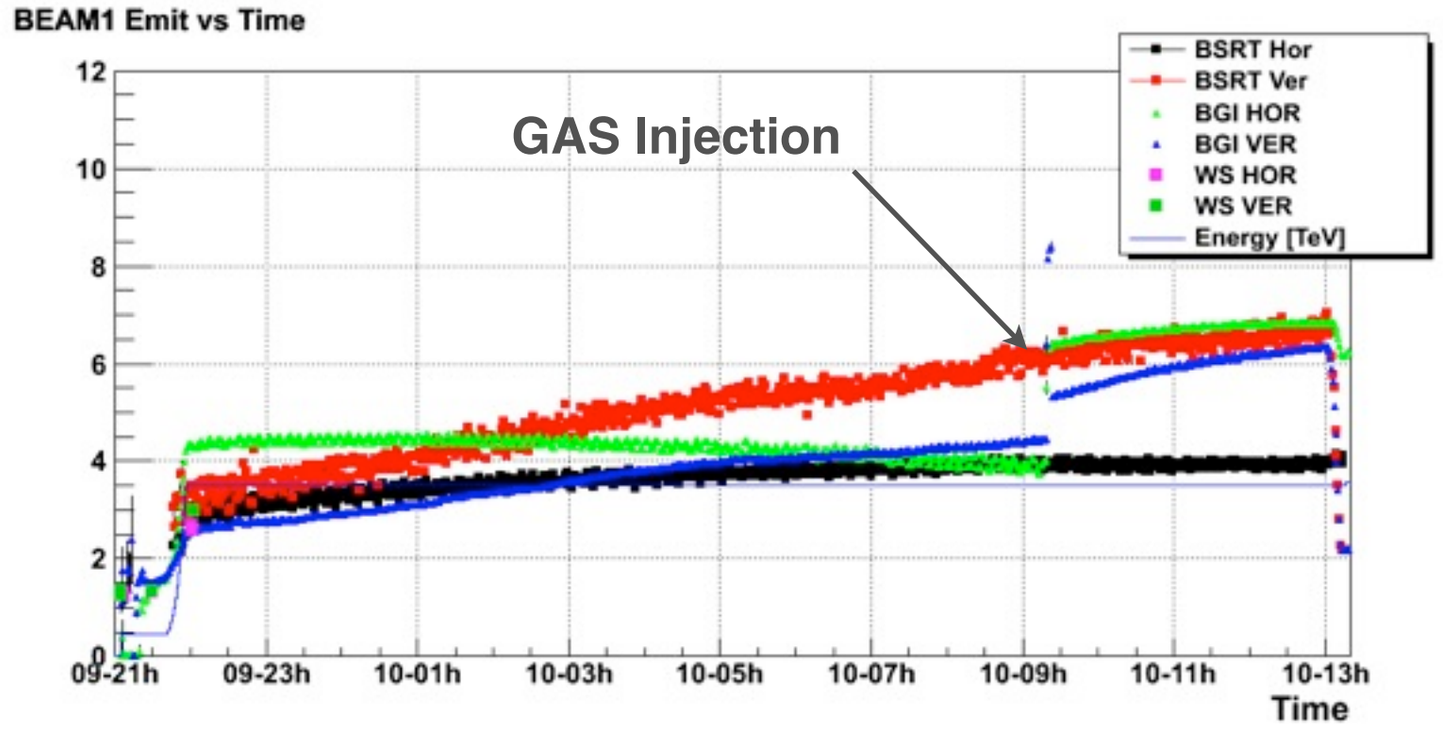
BGI - EFFECT OF GAS INJECTION

Horizontal Profiles before and after gas injection





9-10 Nov,
17 bunches



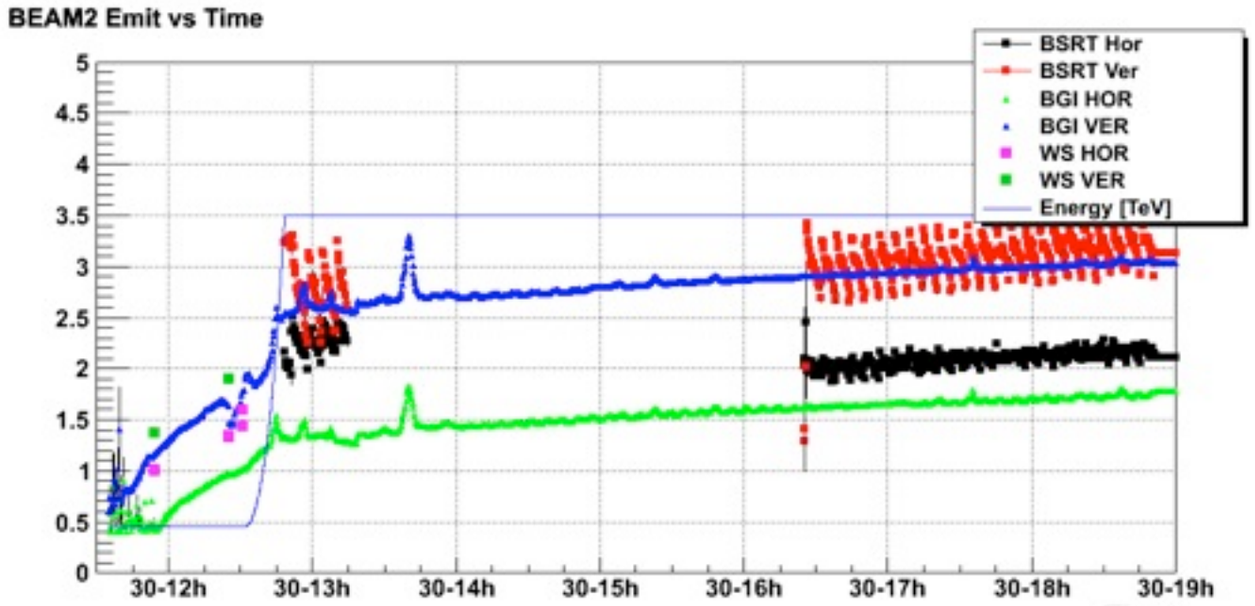
BGI VS BSRT VS WS

Examples BEAM 2

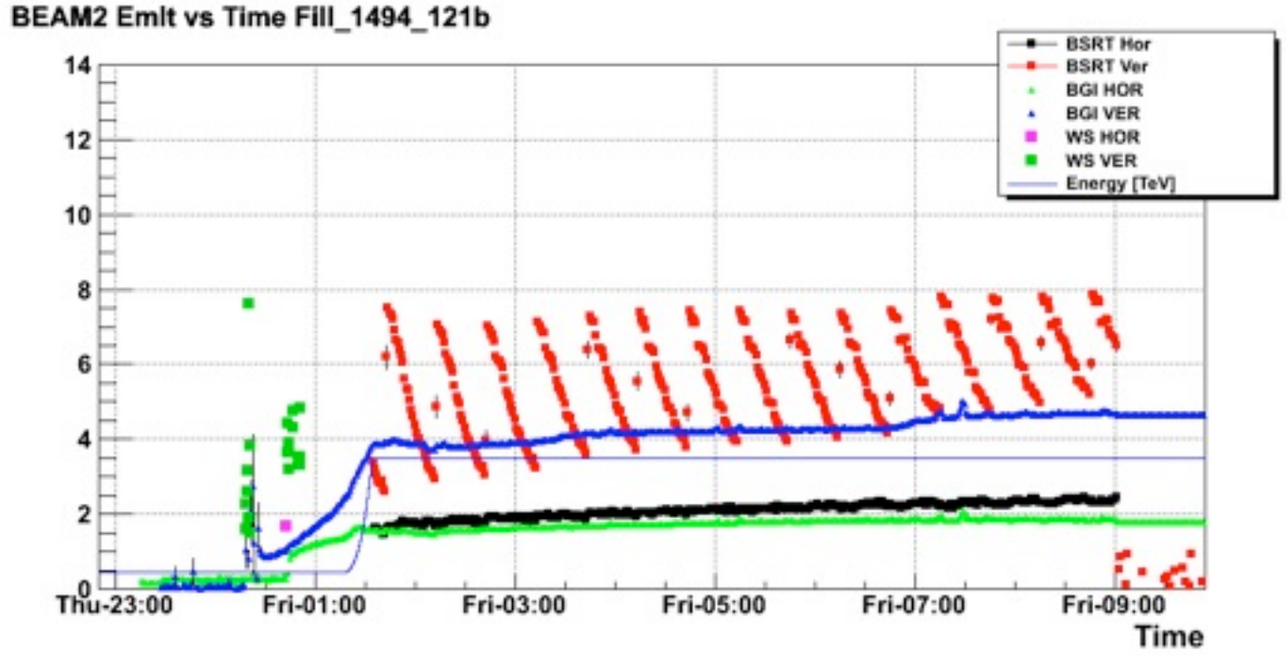
- BGIs tracks well WS blow-up at injection
- BGI Vert. in good agreement with BSRT V
- BGI Hor. gives smaller emittance w.r.t. WS (450GeV) and BSRT (3.5TeV)
- Unless off-line analysis on BGI profiles will show saturation effects (due to beam size shrinking) during and after the ramp:

  BGI estimate of relative blow-up during ramp can be considered correct

During VMS 30-11-2010, 121b



During Physics Fill 121b



CONCLUSIONS AND OUTLOOK

WS act as a reference and are routinely used by OP

- bunch per bunch mode will become operational in 2011
- possible improvements:
  - automatic PM gain/filter settings by reading FBCT ?
  - systematic studies on saturation levels (as done in PSB) ?

Guarantee proper reference measurement without BI experts presence in CCC

BSRT provides relative emittance variation (at const. energy) with ~10% accuracy

- absolute calibration and ultimate resolution: still to be studied
- automatic settings:
  - gain/attenuation vs intensity and energy reliable during last months
  - to be implemented: ‘auto focusing’ vs energy, position feedback
- bunch-to-bunch (3 seconds per bunch)
  - basically automatic after BI experts start it from BI expert application
  - to be implemented (?): OP application providing basic functionalities including bunch scans
- bunch-to-bunch (FAST camera, turn-by-turn)
  - tests as beams are back

BGI is in a commissioning phase

- relative accuracy reliable once beam profile quality has been checked
- absolute calibration to be studied in detail to complement cross-calibration with bumps
- 2011: gas inj. remote control, better camera control

Emittance Logging

- Logging DB is already equipped with virtual variable
  - in 2011 should become operational after applying best estimated calibration factors to BSRT and BGI

MESSAGES

Many studies can be done parasitically, **but MD time is fundamental to improve the systems understanding and performance**

Systematic publication of bunch-per-bunch luminous region is really useful for BSRT and BGI comparisons





EMITTANCE PRESERVATION THROUGH THE LHC CYCLE

V. Kain, R. Assmann, C. Bracco, F. Follin, B. Goddard, B. Holzer, J. Jowett, M. Meddahi, T. Mertens, F. Zimmermann

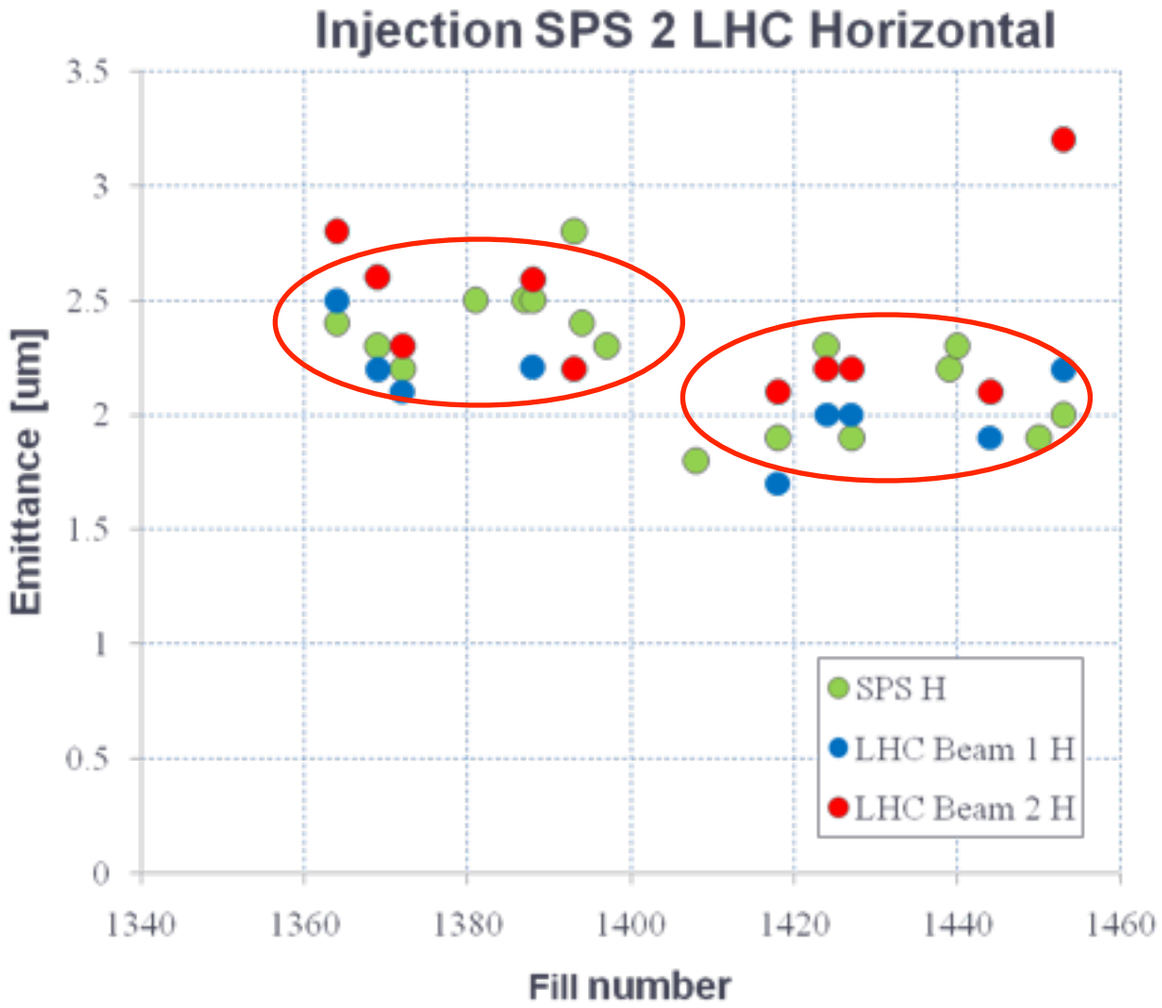
Data of 150 ns run – **end of September '09 to end of October '09**

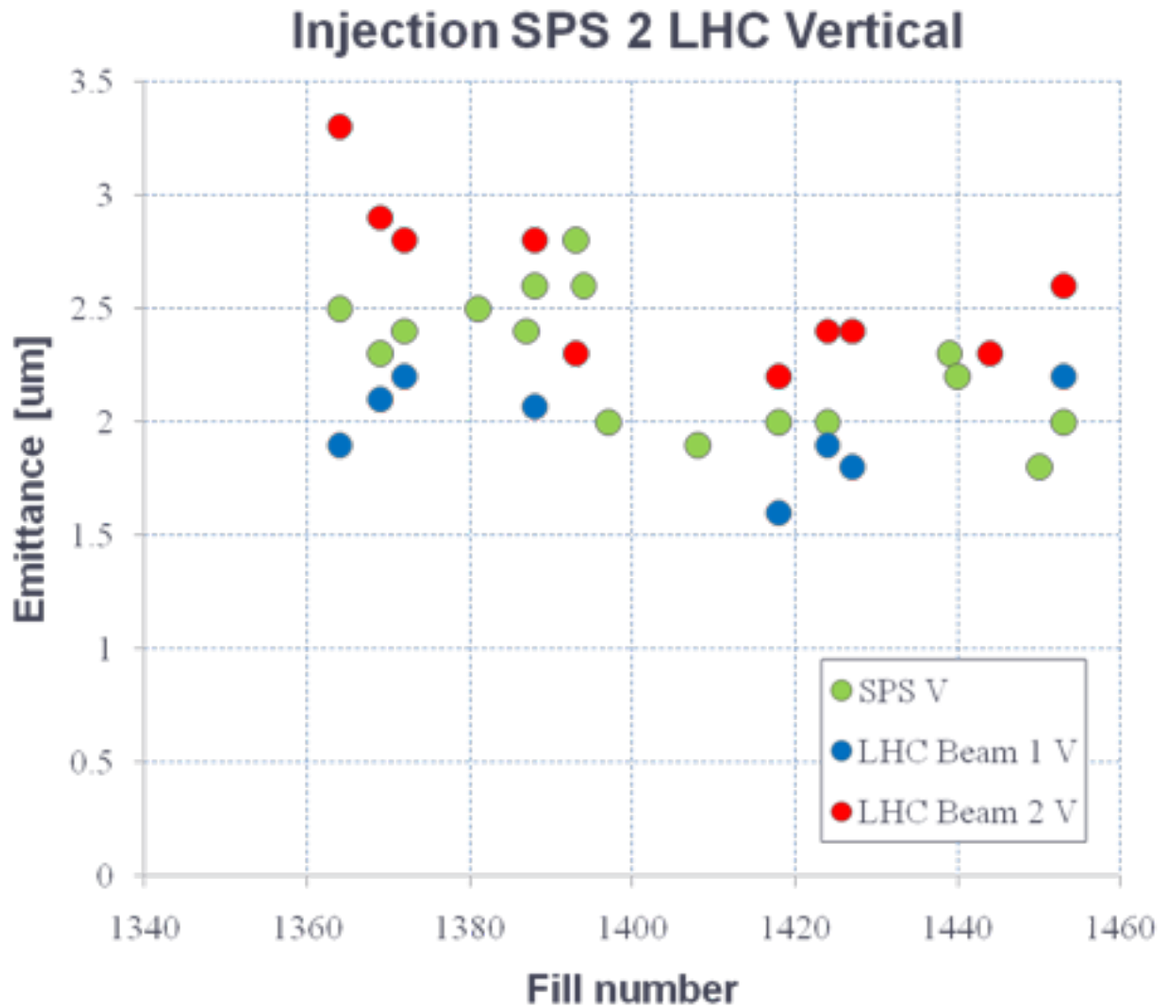
Design criteria for transverse emittance preservation - protons:

- Keep it small to increase luminosity
- Through the whole LHC cycle: $\varepsilon/\varepsilon_0 < 1.07$
- @ injection: emittance increase < 1.05
- Nominal emittance: 3.5 μm

Emittance preservation at injection

- Preservation at injection



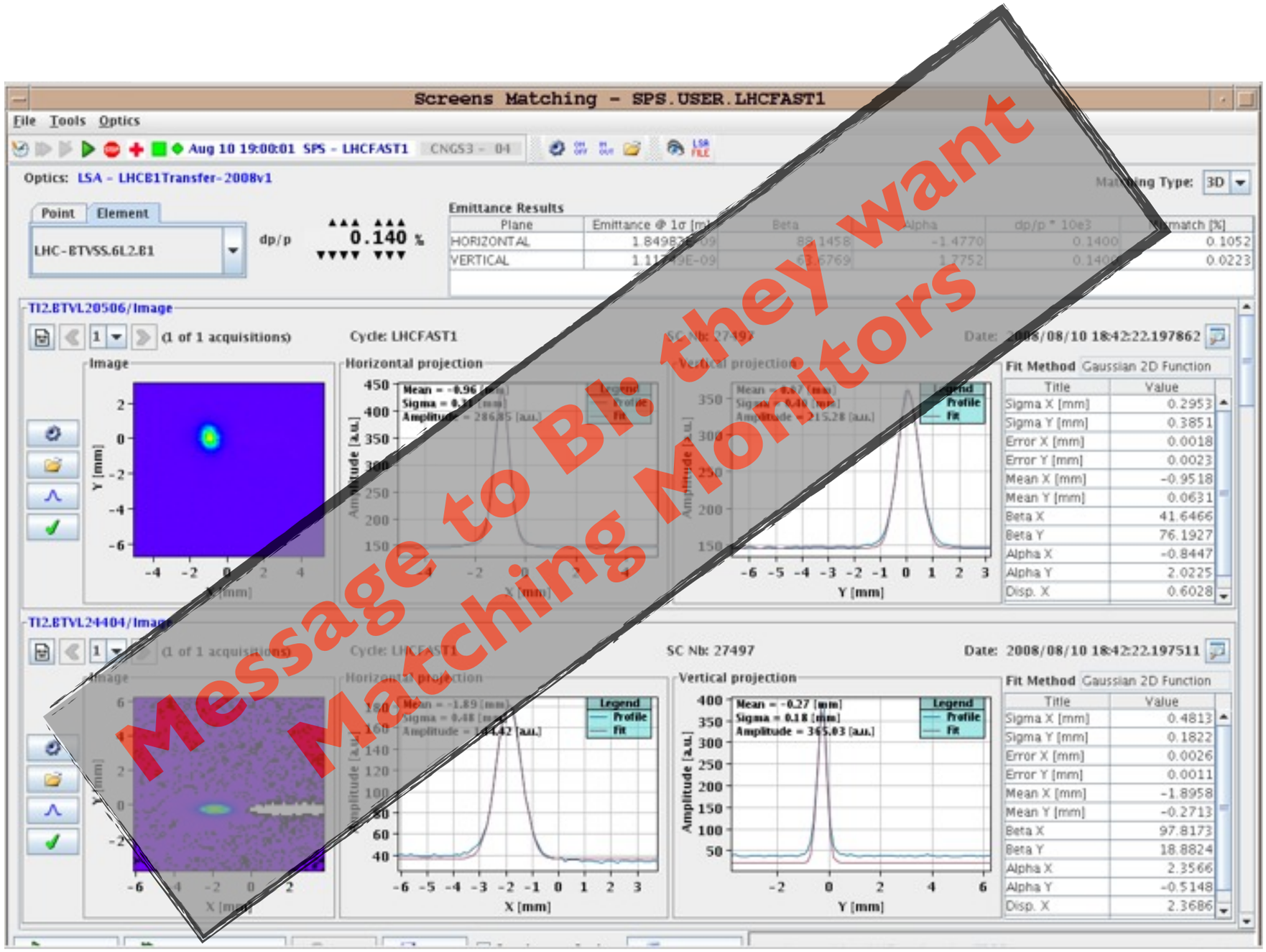


- Difficult to say whether emittance blowup from SPS
- LHC: beam 2 seems to be systematically bigger than beam 1.
- SPS emittance 2.5 um, 2 um after fill 1400

Theory: Betatron mismatch (nominal inj. Optics): $\lambda \sim 1.05 - 1.1 \rightarrow \varepsilon/\varepsilon_0 : \sim 3\ \%$ → **Well in agreement with measurements (plots)**

Injection Matching

- Should look at injection matching with turn-by-turn screen.
- Need to adapt application



Emittance Preservation until Collision

Calculate emittance @ start of physics

1 - from luminosity and intensity

2 - from expts luminous region

→ compare to emittance at Inj (WS)

Emittance growth :

1

1 -From beam 1 ~ 30 – 40 %

- But we are still below nominal

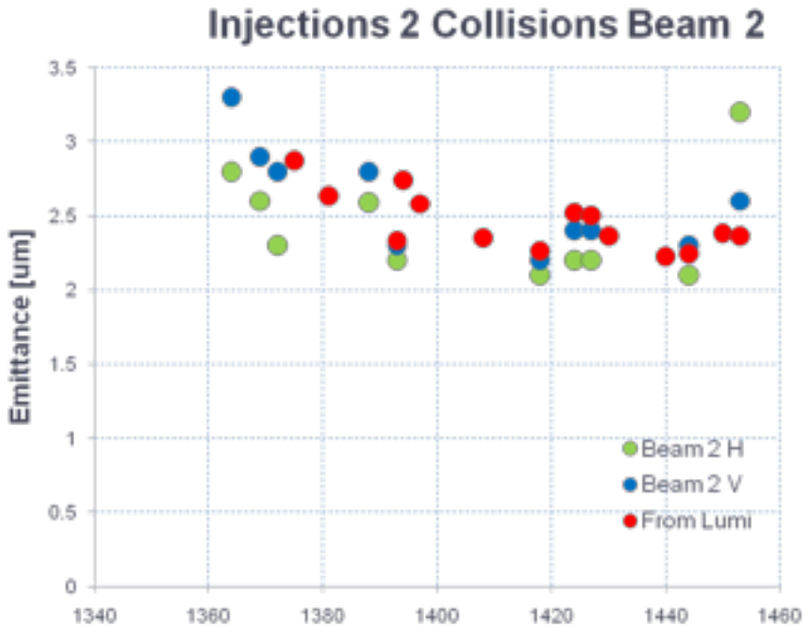
2

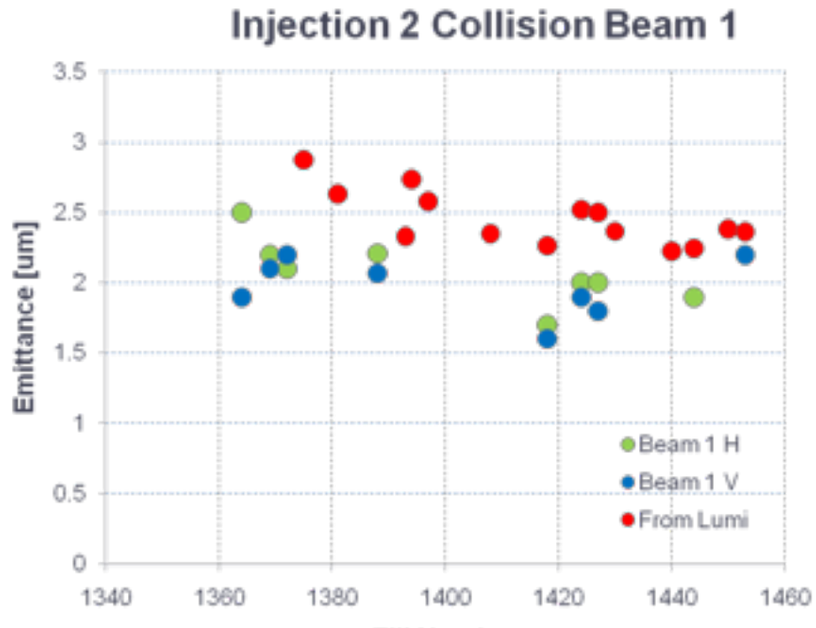
beam 1 H/V max ~ 50 %

beam 2 H/V max ~ 15 %

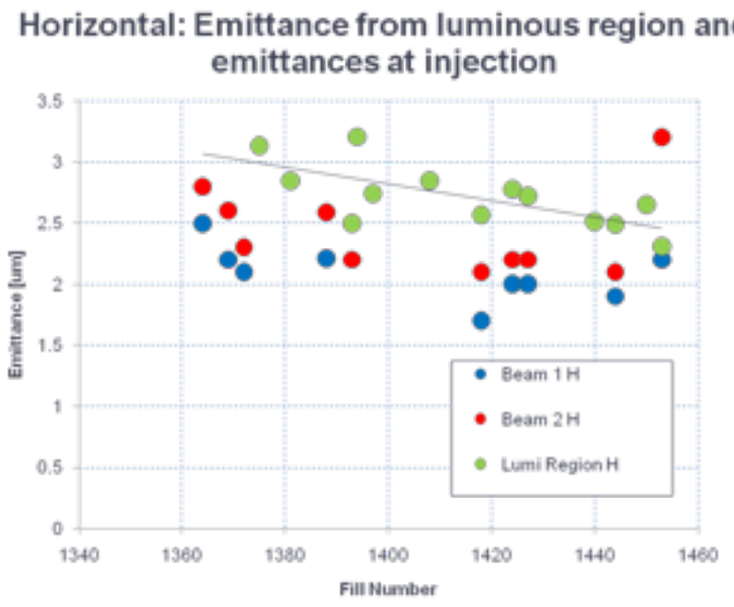
Luminous Region

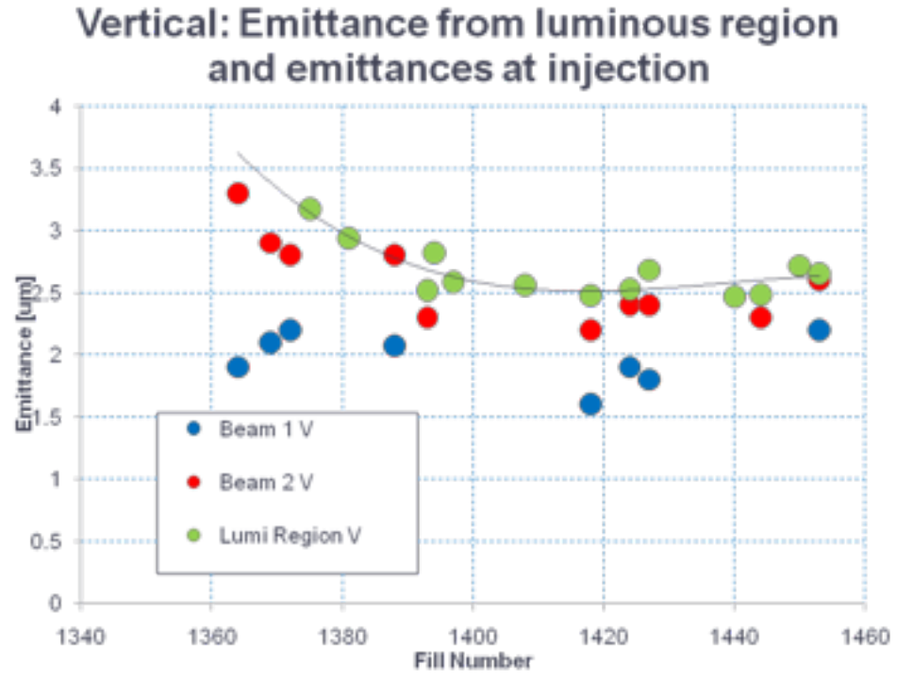
1 From Luminosity





2 From Luminous region





Things to understand

- Emittance blow up at injection, B2 V - hump
  - Is damper damping these properly for ions?

69	13:42		Wire scan with all bunches in B1 : H=3.5, V=5.4; B2 : H=3.8, V=14.3;

- Bunch-by-bunch diagnostic: useful and should become operational

Q'H,V=14 Q'H,V=24

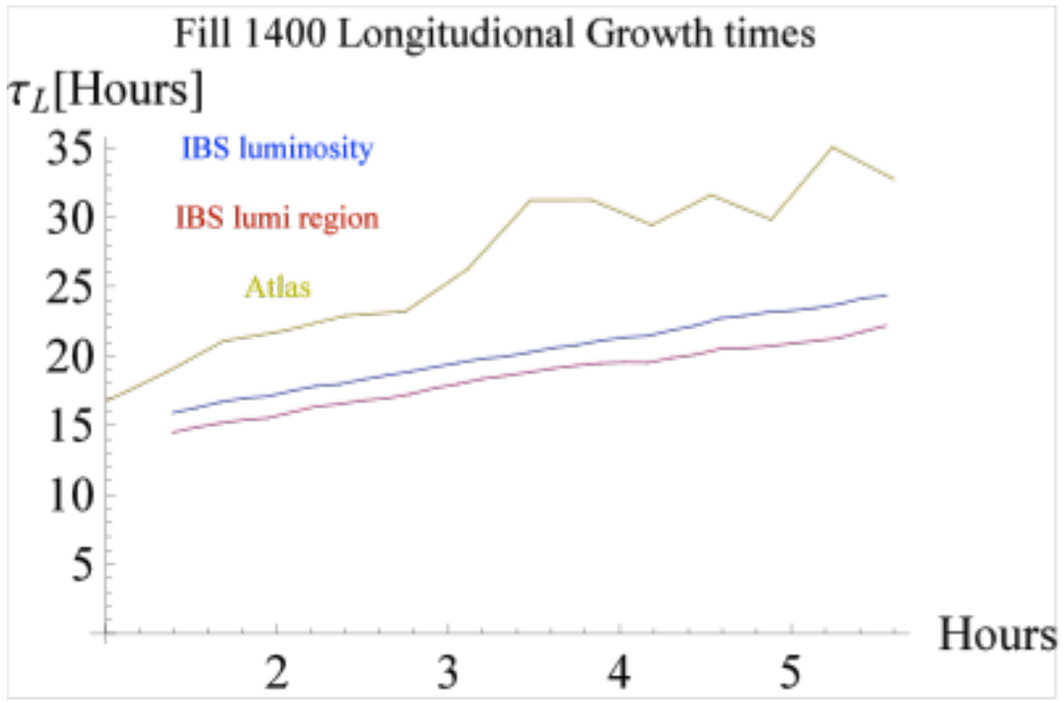
Message to BI: they want better WS and BSRT

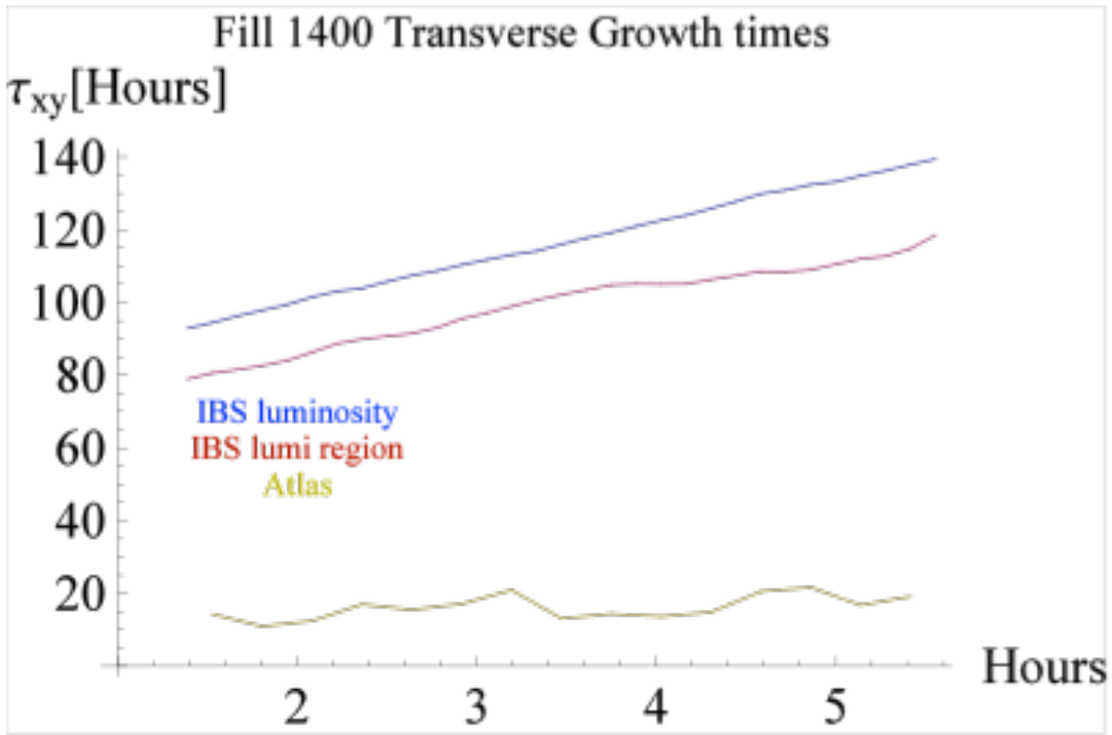
Electron cloud - 75 ns checks

- IBS – also at injection especially for ions
- What is happening during collisions: is this mainly IBS and beam-beam, hump?
  - Need to check this with next year's diagnostics

IBS - How does this compare?

- Fits longitudinally, but not transversely



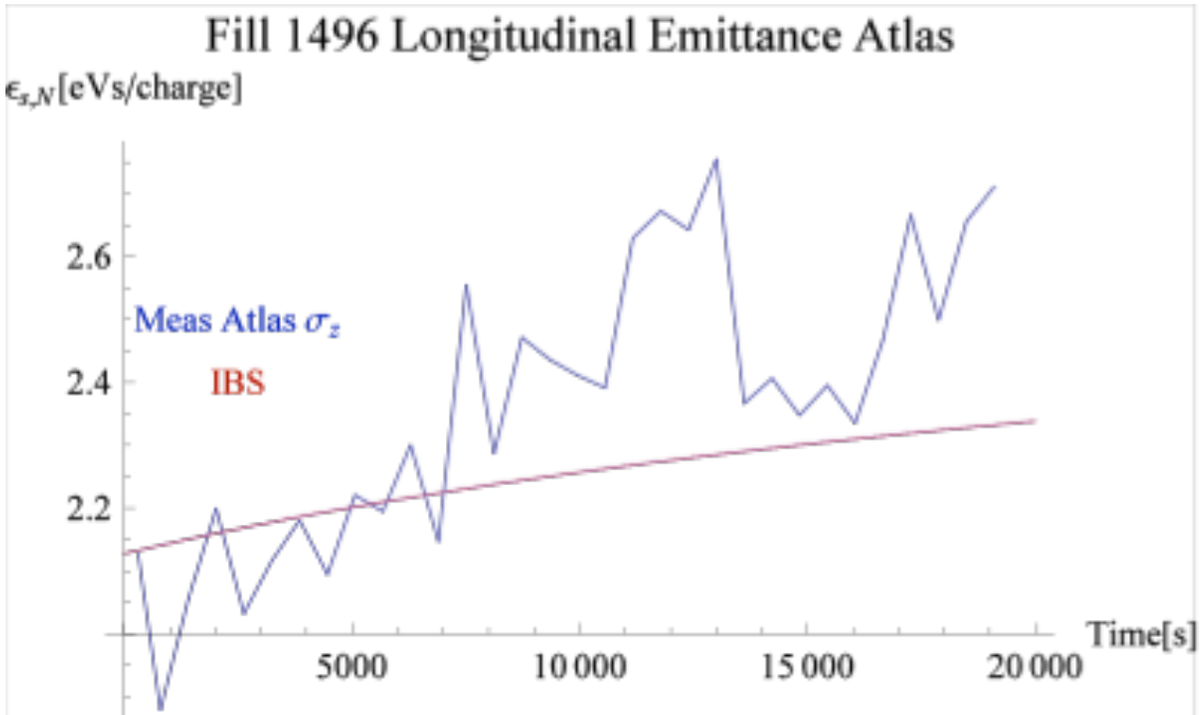


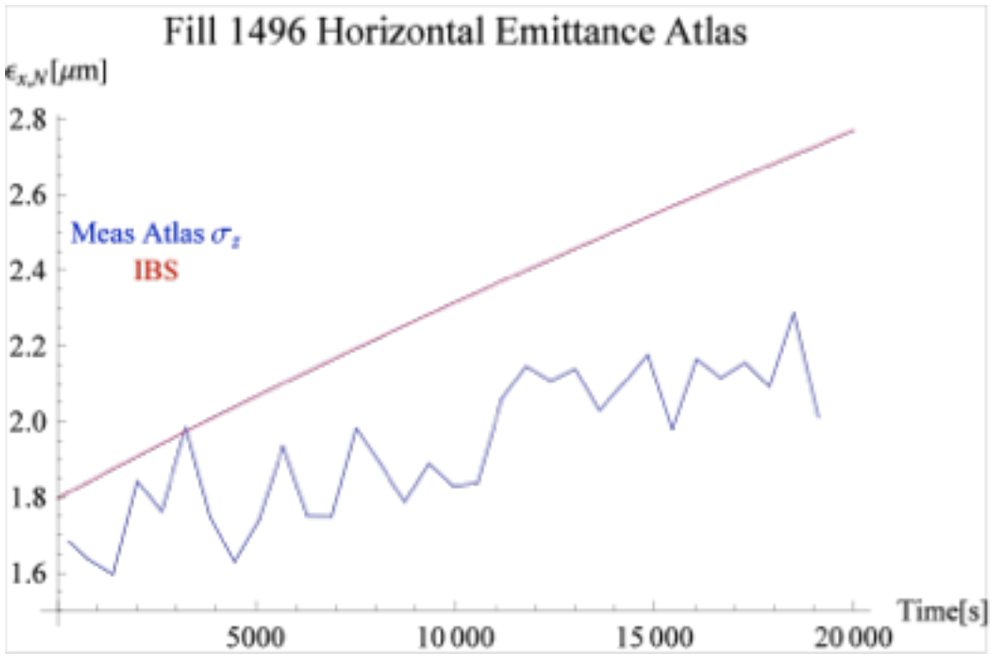
Plots by T. Mertens:
At each data point taking measured emittances (ATLAS lumi, lumi region), RF voltage and bunch length to calculate IBS growth time.

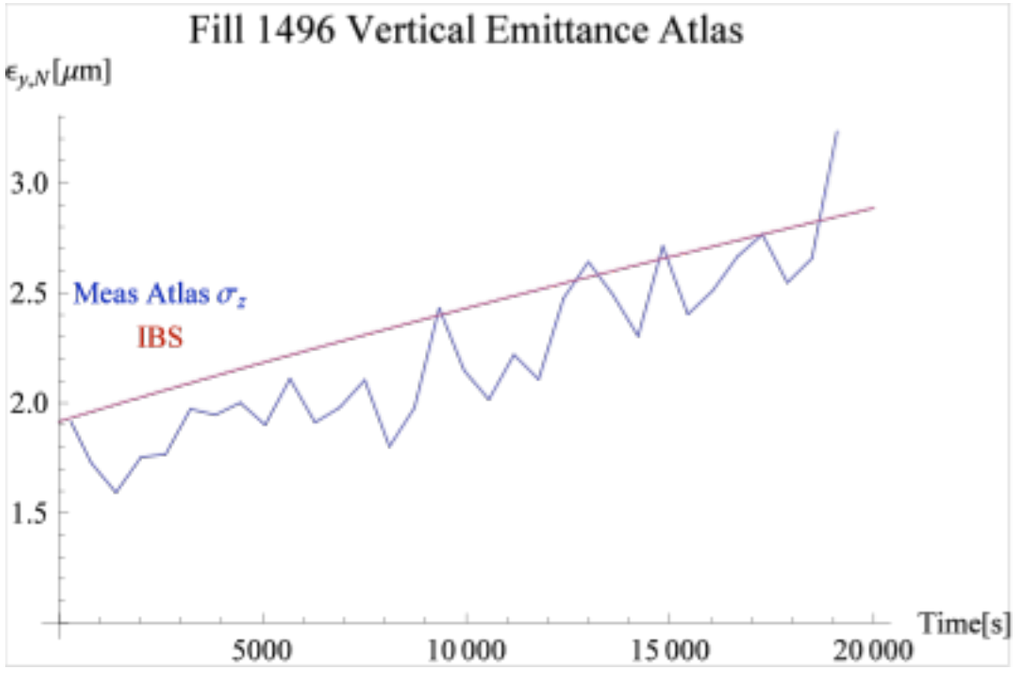
Looks similar for other fills

Ions

- Comparison with IBS for two fills: plots from T. Mertens

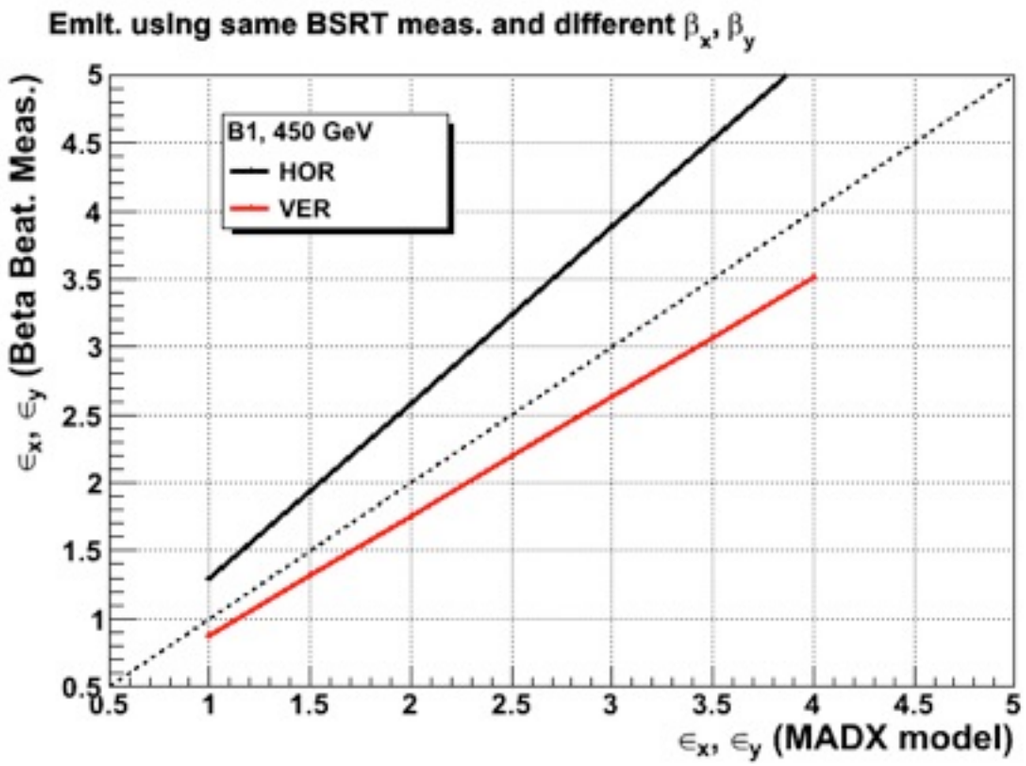


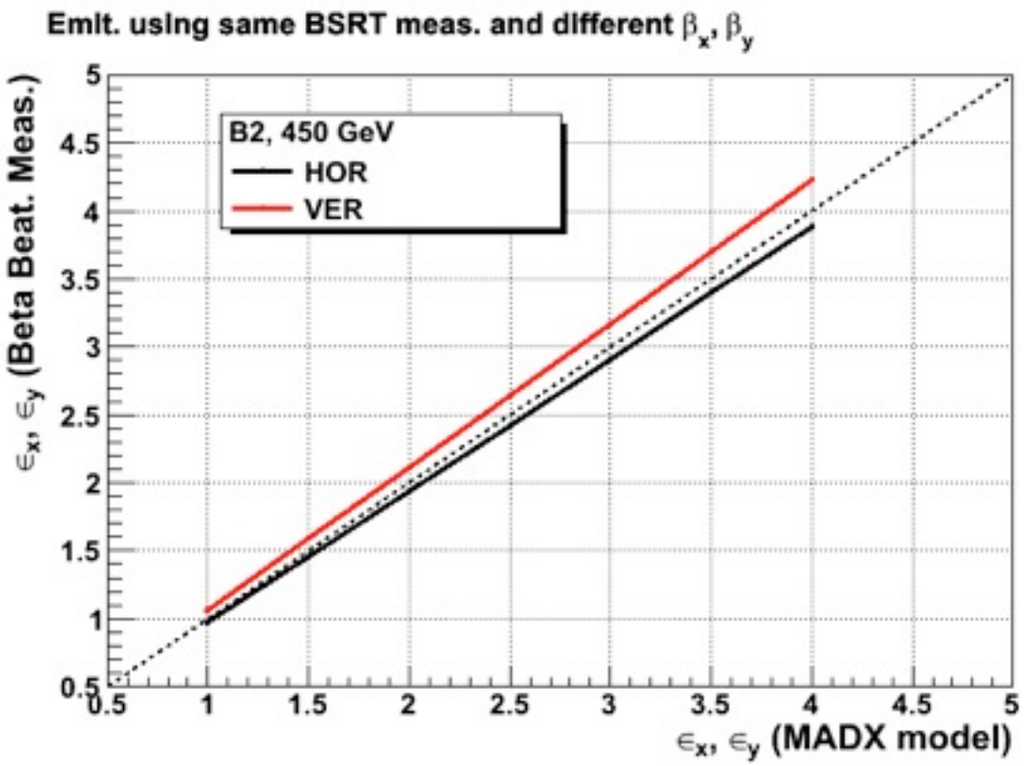




SPARE

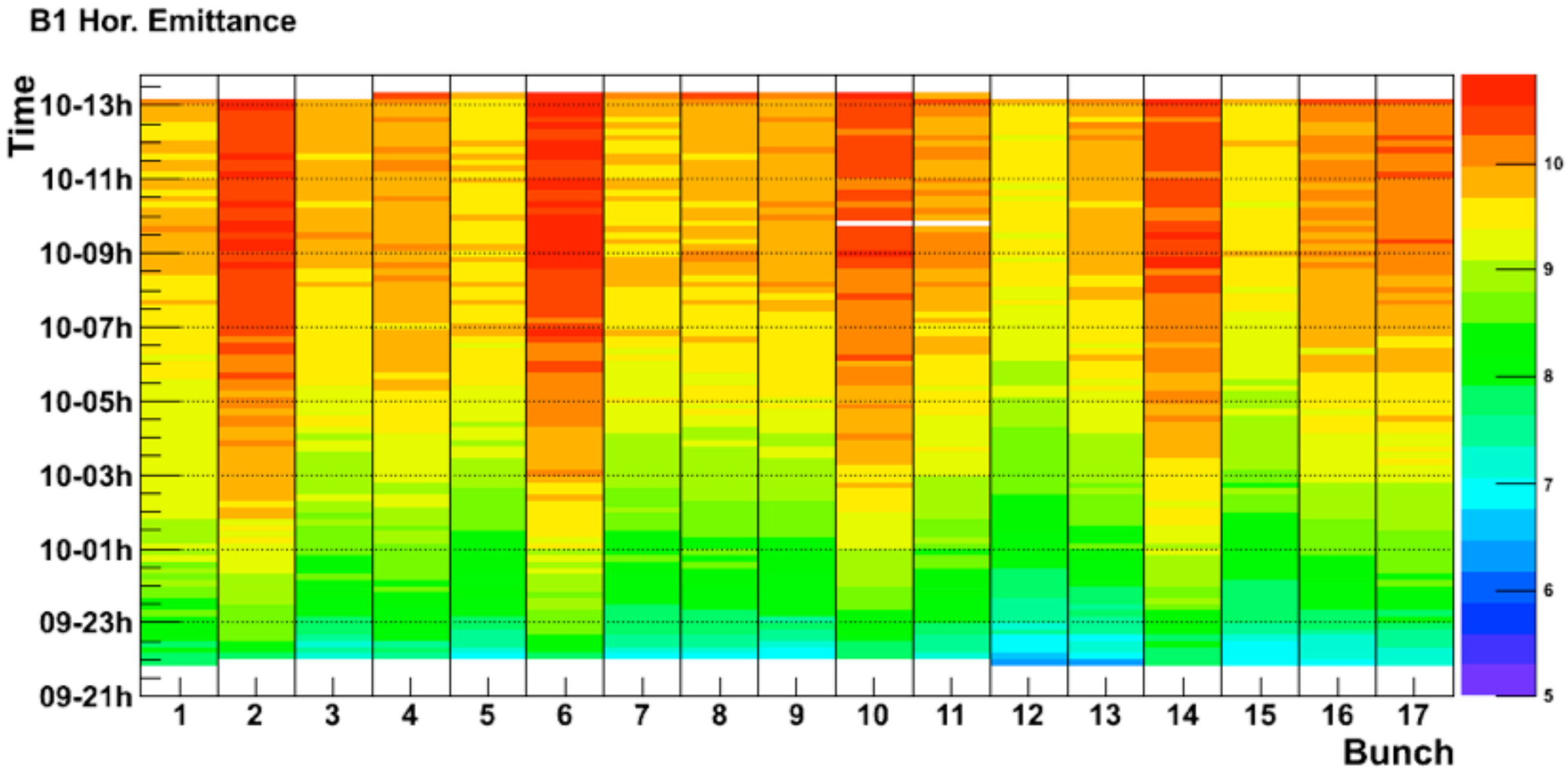
UNCERTAINTIES ON OPTICS





same applies to WS and BGI
impact on relative diff among monitors smaller (monitors not far apart, beating is similar)

ions 17b

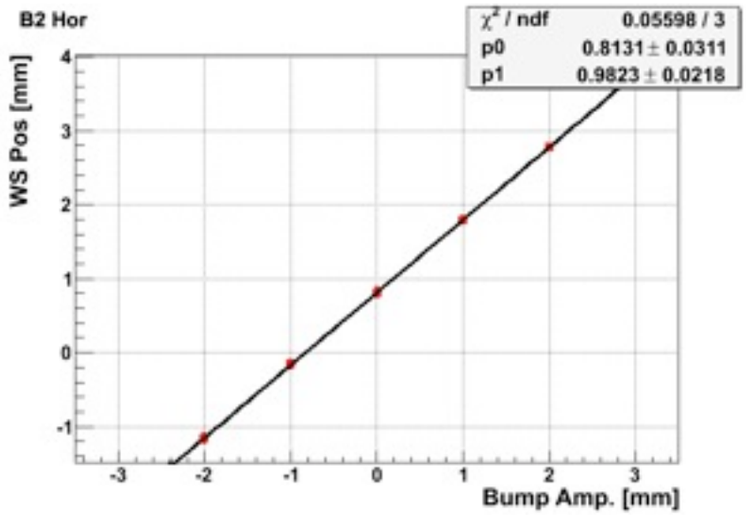

B1 Hor. Emittance
Time
10-13h
10-11h
10-09h
10-07h
10-05h
10-03h
10-01h
09-23h
09-21h
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Bunch
10
9
8
7
6
5

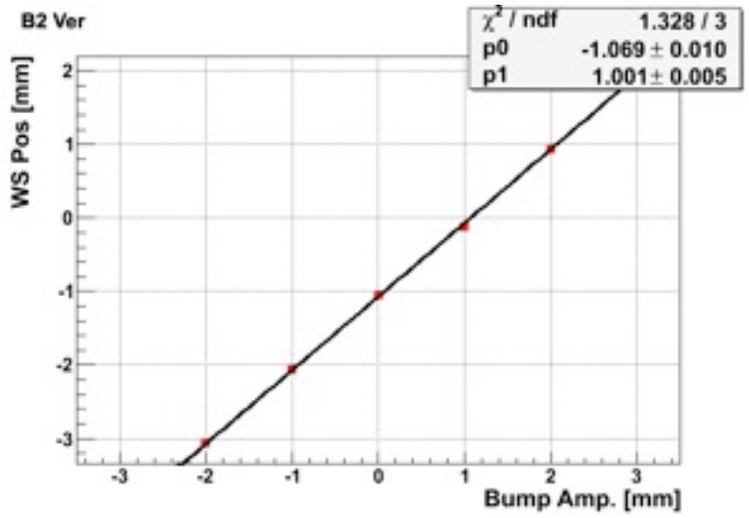
WS

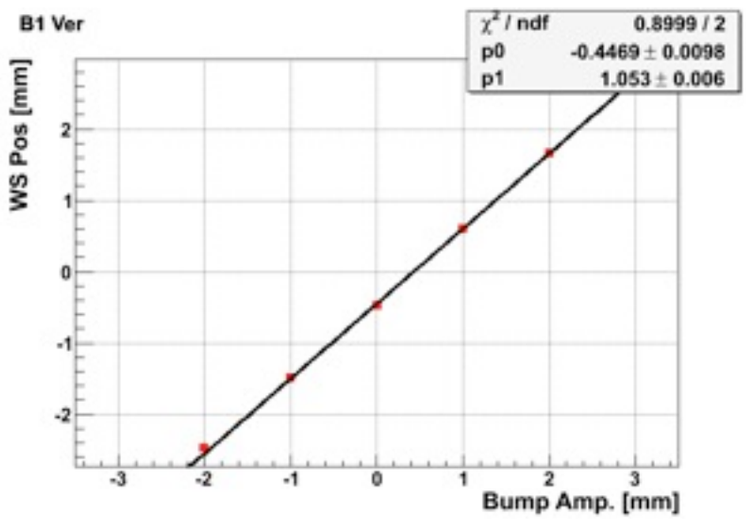
Absolute calibration benchmarked to BPMs (bumps, see plots) : all systems within +-5% accuracy
PM linearity: studied in 2010, more systematic studies in 2011
Bunch to bunch electronics:

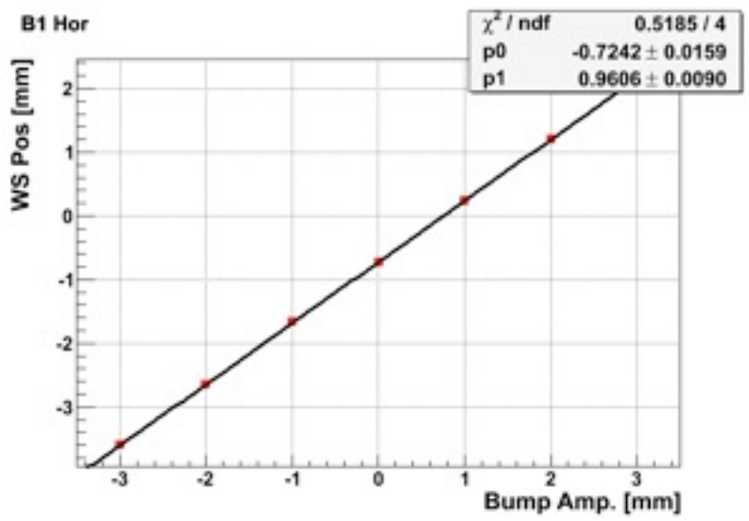
- too high amplifier gain, cross-talk between bunches spaced of 50ns
- plan to change amplifier gain during xstmas shut-down

See also T.Lefevre's presentation







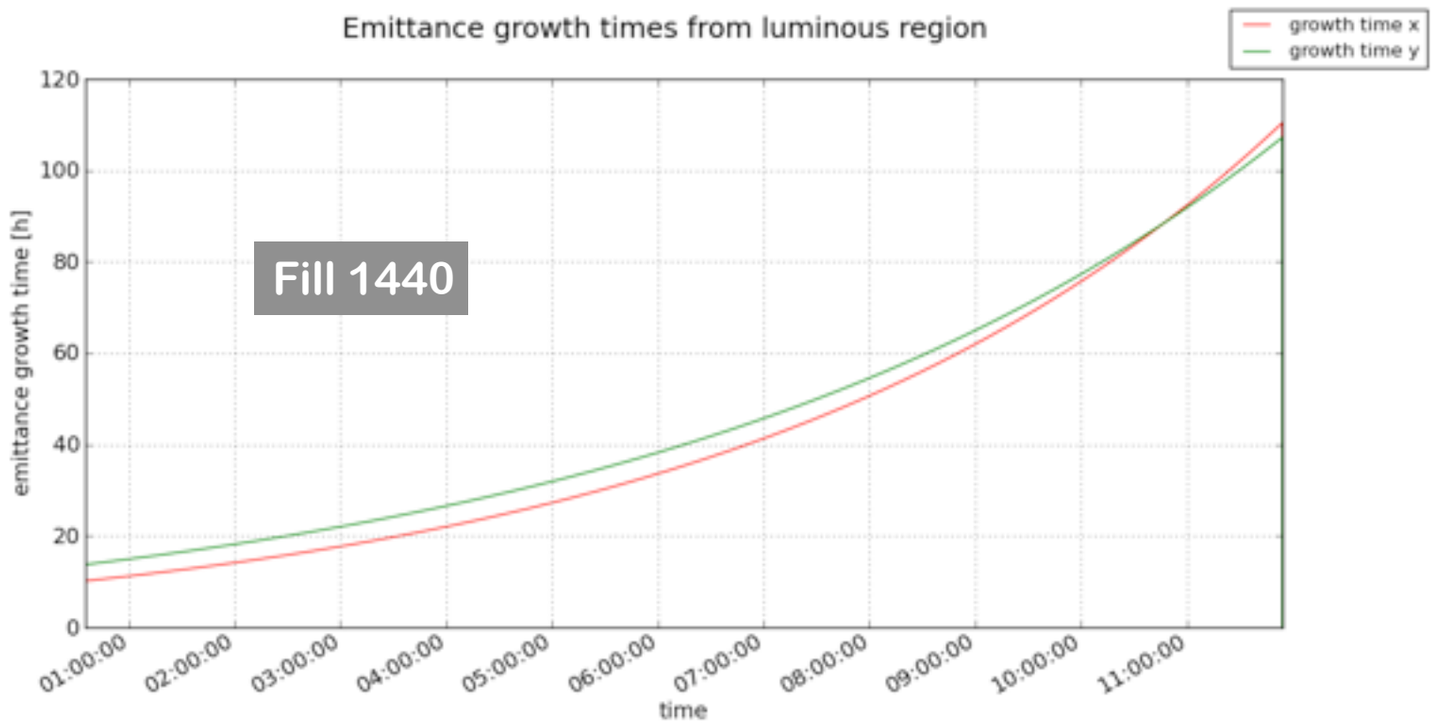


Summary

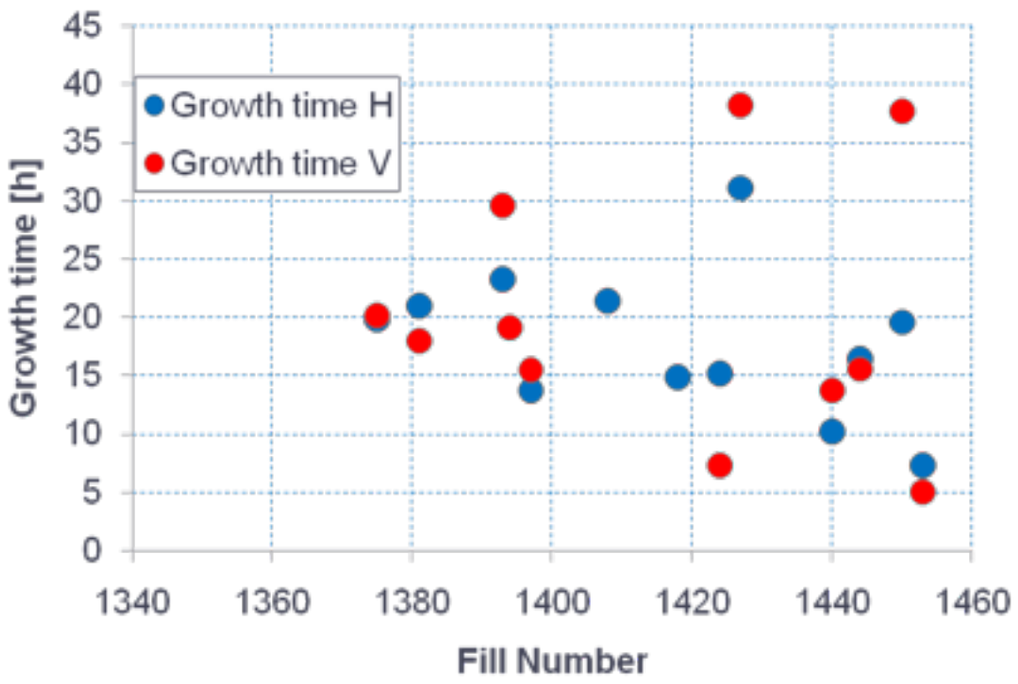
- Emittances from the injectors to collisions in LHC well below nominal
  - We can get it in small, we can keep it small
  - 2010 specific luminosities very good → did not investigate or optimise too much
- Preliminary analysis results
  - Injection: Emittances kept small. Matching good, transverse damper working well
    - Dedicated studies needed to really quantify actual blowup…instruments
    - B2V systematically largest blowup: Hump + damping?
  - Emittances are growing until collision:
    - By how much exactly and when (ramp, squeeze) needs proper continuous measurement
  - Emittances are growing during collisions:
    - P+ growth times (using luminous region data) typically 15-20 hours (min 5, max 35)
    - P+ behaviour (I, ε) compatible with IBS and beam beam expectations but absolute times are too short: needs bunch-by-bunch and reproducible BSRT data for 2011 for full understanding
    - Ions look in better agreement with IBS model
- Plan for next year
  - Calibrated continuous emittance measurement + bunch-by-bunch
  - Injection matching: turn-by-turn screens
  - Try to analyse and understand from the start – make sure data coherent and reliable

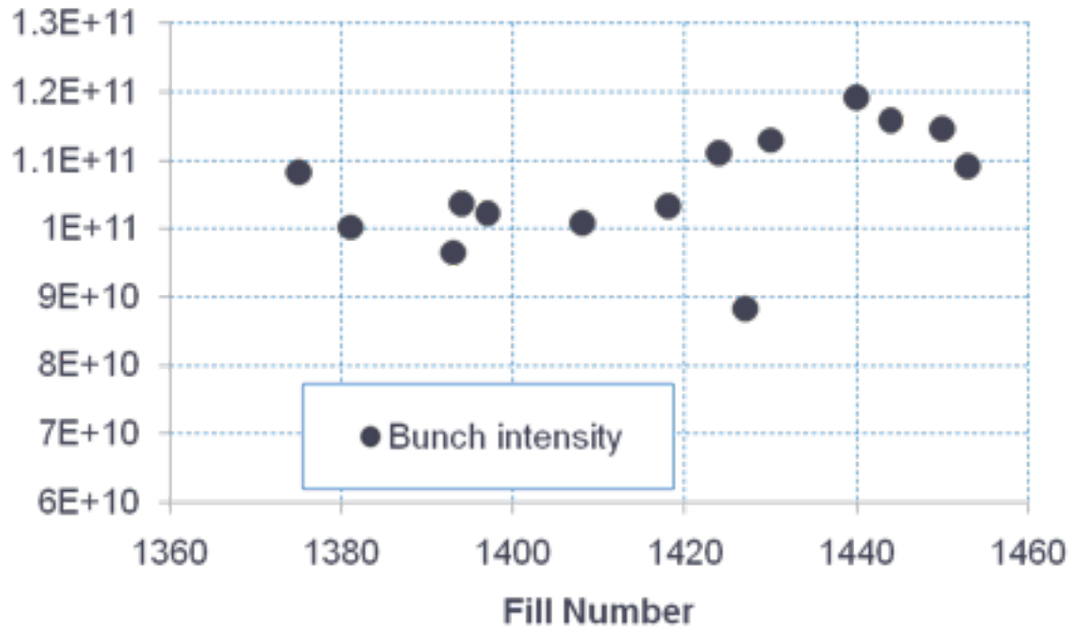
Emittance growth time

- Differentiate and calculate τ



Emittance growth time at beginning of collisions





Growth times smaller with higher intensity and smaller emittances

Ions again

- Another ion fill