



# Transfer and injection into LHC, is this a bottleneck?

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Acknowledgments: BLM, OP, CO, RF, MPE, Collimation team

# Outline

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- ▶ Operation achievement in 2011
- ▶ Issues and possible limitations
- ▶ Studies for future operation (nominal emittance, 25 ns bunch spacing)
- ▶ Summary and Conclusions

# Losses at Injection and Intensity Limitations

- ▶ Loss maxima per injected intensity (Verena's talk)

Loss type	Losses in % of dump threshold B1/B2						
	8b	16b	24b	32b	48b	96b	144b
TCDI shower	1/2	3/5	4/6	5/8	23/24	<50?	<75?
Uncaptured beam	4/2	12/3	12/5	16/8	20/8	<40?	<60?

2010 ↓ 2011

Unsafe beam ( $> 1 \times 10^{12} p^+$ )

Linear extrapolation for 2011 operation, still ok without mitigation

Operation related intensity limitations, **no machine protection issue!!**

- ▶ Possible solutions for higher intensity:

- ▶ Un-captured beam:

- Abort gap and injection cleaning
- Improved injectors diagnostics
- TDI Shielding ( $\times 10$  reduction at MQX BLMs)
- ! □ BLM sunglasses

- ▶ Cross-talks from TCDI:

- TCDI shielding
- ! □ TCDI larger aperture
- ! □ BLM sunglasses
- □ Increase BLM thresholds for short running sums

Presented in Chamonix 2011

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- ▶ Cross-talks from TCDI:

❑ **TCDI shielding**

! ❑ TCDI larger aperture

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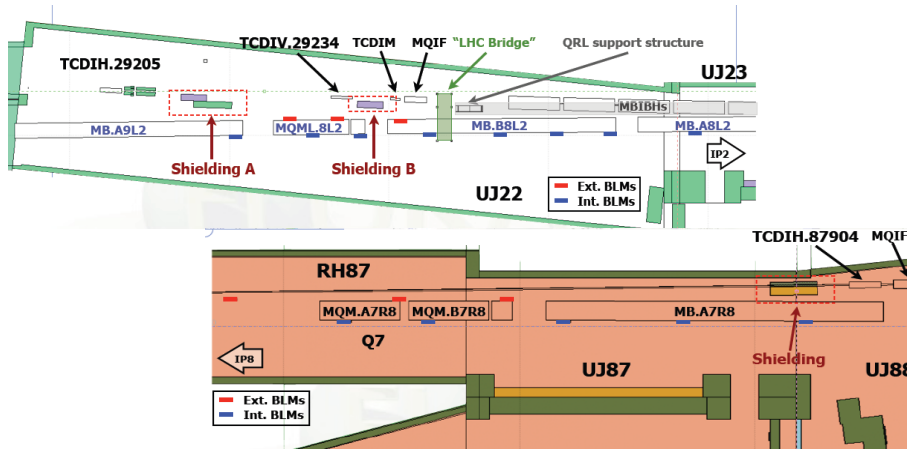
! ❑ Increase BLM thresholds for short running sums

Presented in Chamonix 2011

**Injection with 144 bunches is now operational !**

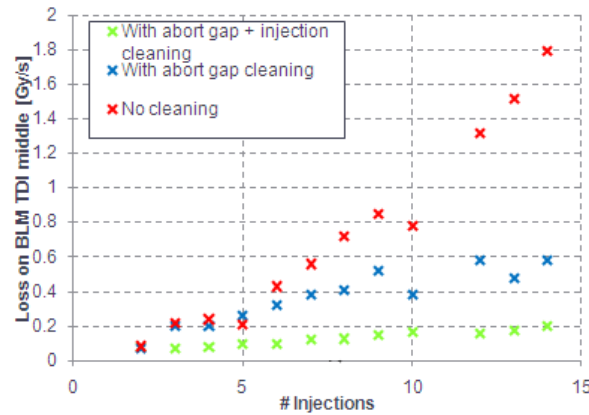
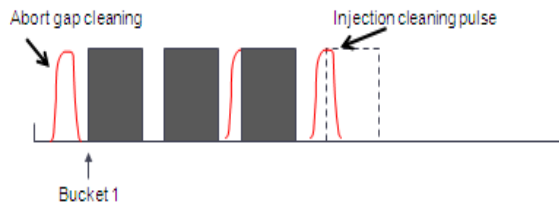
# Applied Mitigations

Shielding to reduce crosstalk losses from TCDI installed in TI 2 and TI 8



Loss reduction at downstream magnets by a factor of 2-3. Good agreement with FLUKA simulations: factor 4 predicted

Injection and abort gap cleaning to reduce losses at TDI and downstream elements

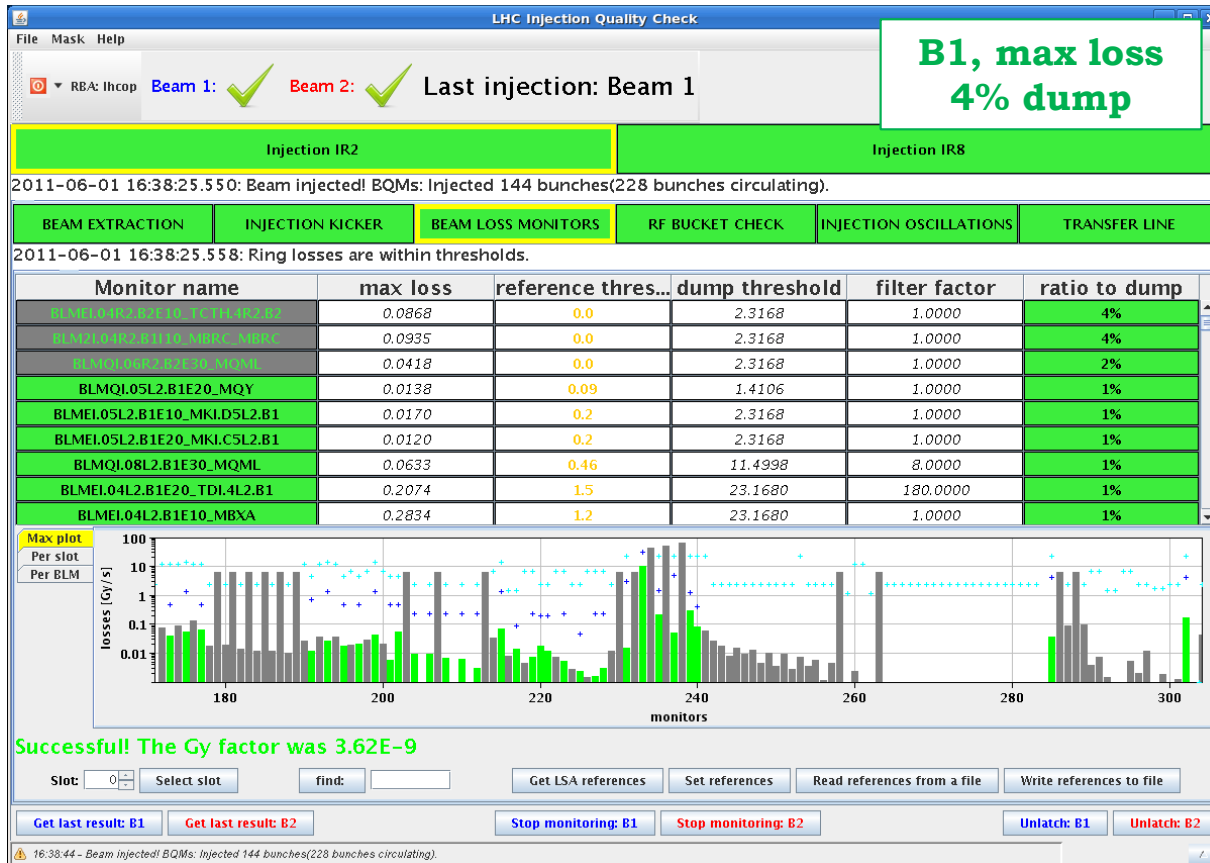


Now operational (sequencer)

V. Kain, Chamonix 2011

# 2011 Operation with 144 bunches

- ▶ First injection of 144 bunches for Physics (1<sup>st</sup> June)



# 2011 Operation with 144 bunches

- First injection of 144 bunches for Physics (1<sup>st</sup> June)

**B1, max loss 4% dump**

2011-06-01 16:38:25.550: Beam injected! BQMs: Injected 144 bunches (228 bunches circulating).

Monitor name	max loss	reference
BLMEI04L2.B1E10_TDI.4L2.B1	0.0868	
BLMEI04L2.B1E10_MBXA	0.0935	
BLMEI04L2.B1E10_TDI.4L2.B1	0.0418	
BLMQI05L2.B1E20_MQY	0.0138	
BLMEI05L2.B1E10_MKI.D5L2.B1	0.0170	
BLMEI05L2.B1E20_MKI.C5L2.B1	0.0120	
BLMQI08L2.B1E30_MQML	0.0633	
BLMEI04L2.B1E20_TDI.4L2.B1	0.2074	
BLMEI04L2.B1E10_MBXA	0.2834	

losses [Gy/s]

Successful! The Gy factor was 3.62E-9

Slot: 0 | Select slot | find: | Get last result: B1 | Get last result: B2 | Stop monitoring: B1

16:38:44 - Beam injected! BQMs: Injected 144 bunches(228 bunches circulating).

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**B2, max loss 2% dump**

2011-06-01 16:39:11.150: Beam injected! BQMs: Injected 144 bunches(228 bunches circulating).

Monitor name	max loss	reference thres...	dump threshold	filter factor	ratio to dump
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.0367	0.0	2.3168	1.0000	2%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.2502	4.0	23.1680	1.0000	1%
BLMEI05R8.B2E10_MKI.D5R8.B2	0.0139	0.2	2.3168	1.0000	1%
BLMQI07R8.B2E10_MQM	0.0321	0.8	4.5999	8.0000	1%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.1300	0.0	23.1680	1.0000	1%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.1185	0.0	23.1680	1.0000	1%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.1178	0.0	23.1680	1.0000	1%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.0249	0.0	2.3168	1.0000	1%
BLMEI06L8.B2I10_TCLIB.GL8.B2	0.0142	0.0	2.3168	1.0000	1%

losses [Gy/s]

No reference for BLM. The Gy factor was 3.62E-9

Slot: 0 | Select slot | find: | Get LSA references | Set references | Read references from a file | Write references to file

Get last result: B1 | Get last result: B2 | Stop monitoring: B1 | Stop monitoring: B2 | Unlatch: B1 | Unlatch: B2

16:39:29 - Beam injected! BQMs: Injected 144 bunches(228 bunches circulating).

# 2011 Operation with 144 bunches

## ► Injection degradation for B1 (16<sup>th</sup> June)

LHC Injection Quality Check

B1, max loss  
62% dump

File Mask Help
RBA: lhcop
Beam 1: ✓
Beam 2: ✓
Last injection: Beam 1

Injection IR2

Injection IR8

2011-06-16 2:38:54.350: Beam injected! BQMs: Injected 144 bunches(228 bunches circulating). BLM analysis was bad. Bad result for transfer li...

BEAM EXTRACTION

INJECTION KICKER

BEAM LOSS MONITORS

RF BUCKET CHECK

INJECTION OSCILLATIONS

TRANSFER LINE

2011-06-16 2:38:54.358: Losses on ring BLMs.

Monitor name	max loss	reference thres...	dump threshold	filter factor	ratio to dump
BLMEI.06L2.B1E10_MSIB	2.8857	0.4634	4.6336	8.0000	62%
BLMEL.06L2.B1E11_MQA	6.1345	0.0	11.5840	1.0000	53%
BLMEL.06L2.B1E11_MQB	1.1337	0.0	2.3168	1.0000	49%
BLMQI.05L2.B1E20_MQY	0.6532	0.09	1.4106	1.0000	46%
BLMEL.06L2.B1E11_MQA	1.0297	0.0	2.3168	1.0000	44%
BLMEL.06L2.B1E11_MQB	4.2578	0.0	11.5840	1.0000	37%
BLMEL.06L2.B1E11_MQA	0.8387	0.0	2.3168	1.0000	36%
BLMEL.06L2.B1E11_MQB	0.7376	0.0	2.3168	1.0000	32%
BLMEL.06L2.B1E11_MQA	0.7454	0.0	2.3168	1.0000	32%

Max plot  
 Per slot  
 Per BLM

**Max larger than reference. The Gy factor was 3.62E-9**

Slot: 
Select slot
find: 
Get LSA references
Set references
Read references from a file
Write references to file

Get last result: B1
Get last result: B2

Stop monitoring: B1
Stop monitoring: B2

Unlatch: B1
Unlatch: B2

02:39:13 - Beam injected! BQMs: Injected 144 bunches(228 bunches circulating). BLM analysis was bad. Bad result for transfer line.



# 2011 Operation with 144 bunches

## ► Injection degradation for B1 (16<sup>th</sup> June)

**LHC Injection Quality Check**

File Mask Help

RBA: lhcop Beam 1: ✓ Beam 2: ✓ Last injection: Beam 1

Injection IR2 Injection IR8

2011-06-16 2:38:54.350: Beam injected! BQMs: Injected 144 bunches

BEAM EXTRACTION INJECTION KICKER BEAM LOSS MONITORS

2011-06-16 2:38:54.358: Losses on ring BLMs.

Monitor name	max loss	reference
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BLMQI.05L2.B1E20_MQY	0.6532	
BLMFI.06L2.B1E11_MSIB	1.0297	
BLMFI.06L2.B1E12_MSIB	4.2578	
BLMFI.06L2.B1E11_MSIB	0.8387	
BLMFI.06L2.B1E13_MSIB	0.7376	
BLMFI.06L2.B1E14_MSIB	0.7454	

Max plot  
Per slot  
Per BLM

Max larger than reference. The Gy factor was 3.62E-

Slot: 0 Select slot find: Get L

Get last result: B1 Get last result: B2 Stop monitoring: B1 Stop monitoring: B2

02:39:13 - Beam injected! BQMs: Injected 144 bunches(228 bunches circulating). BLM analysis was bad.

**B1, max loss  
62% dump**

**LHC Injection Quality Check**

File Mask Help

RBA: lhcop Beam 1: ✓ Beam 2: ✓ Last injection: Beam 2

Injection IR2 Injection IR8

2011-06-16 2:34:06.350: Beam injected! BQMs: Injected 144 bunches(228 bunches circulating).

BEAM EXTRACTION INJECTION KICKER BEAM LOSS MONITORS RF BUCKET CHECK INJECTION OSCILLATIONS TRANSFER LINE

2011-06-16 2:32:30.358: Ring losses are within thresholds.

Monitor name	max loss	reference thres...	dump threshold	filter factor	ratio to dump
BLMQI.07R8.B2E10_MQM	0.3094	0.8	4.5393	8.0000	7%
BLMFI.06L2.B1E10_MSIB	0.0736	0.0	2.3168	1.0000	3%
BLMFI.06L2.B1E11_MSIB	0.8035	0.0	23.1679	1.0000	3%
BLMFI.06L2.B1E12_MSIB	0.6136	0.0	23.1680	1.0000	3%
BLMFI.06L2.B1E11_MSIB	0.0644	0.0	2.3168	1.0000	3%
BLMFI.06L2.B1E12_MSIB	0.0643	0.0	2.3168	1.0000	3%
BLMFI.06L2.B1E13_MSIB	0.1784	0.0	6.9504	1.0000	3%
BLMFI.07R8.B2E10_MQM	0.3803	0.0	11.5840	1.0000	3%
BLMQI.05R8.B2E20_MQY	0.0333	0.044	1.4106	1.0000	2%

Max plot  
Per slot  
Per BLM

Slot: 0 Select slot find: Get LSA references Set references Read references from a file Write references to file

Get last result: B1 Get last result: B2 Stop monitoring: B1 Stop monitoring: B2 Unlatch: B1 Unlatch: B2

02:34:25 - Beam injected! BQMs: Injected 144 bunches(228 bunches circulating).

**B2, max loss  
7% dump**

# Observations on B1

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- ▶ TL trajectories were not reproducible from shot to shot  
→ different corrections proposed by YASP
- ▶ Local variations of trajectory at the location of the TCDI (end of the line: 29012-29509)
- ▶ High loss level at the MSIB already when injecting 12 bunches (5%)
- ▶ 500-600  $\mu\text{m}$  oscillations coming from the line
- ▶ Difficult to correct and to find a good **tradeoff** between **injection oscillations** and **losses**

# Observations on B1

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- ▶ TL trajectories were not reproducible from shot to shot  
→ different corrections proposed by YASP
- ▶ Local variations of trajectory at the location of the TCDI (end of the line: 29012-29509)

- ▶ High loss level at bunches (5%)

- ▶ 500-600  $\mu\text{m}$  oscillations

- ▶ Difficult to correct **injection oscillations**

## Why is Beam 1 more critical?

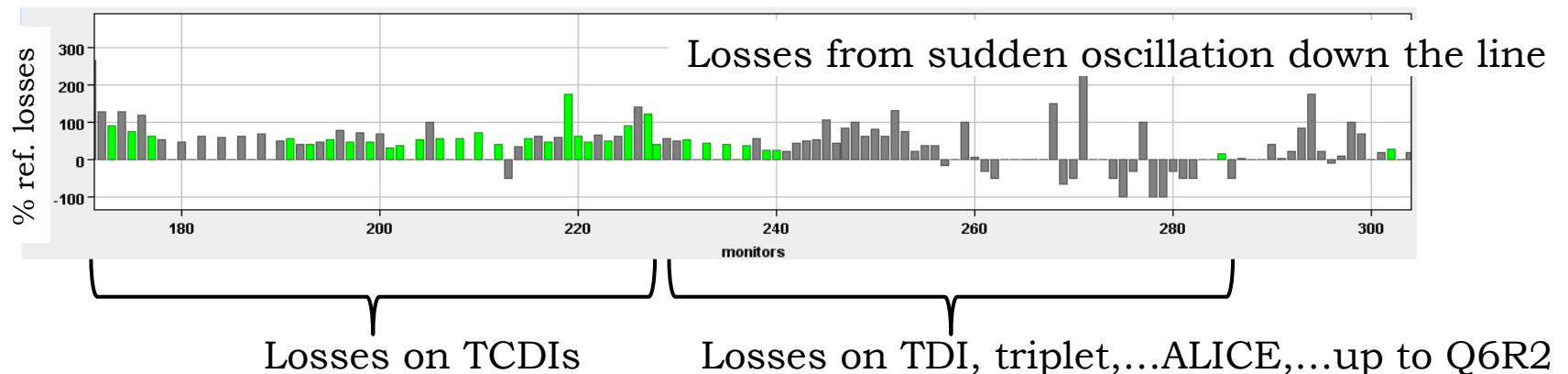
1. Flattop of the SPS extraction kicker (MKE) longer for B1 than for B2 → more **satellites** from the SPS?
2. MST septum in extraction channel
3. High dispersion collimator close to the end of the line (29205) → more sensitive to any  $\Delta p$  or wrong SPS harmonic?
4. Higher sensitivity to steering ?

**Dedicated MD** to investigate these options and to check operation with **nominal emittance**.

# MD: Effect of longitudinal parameters

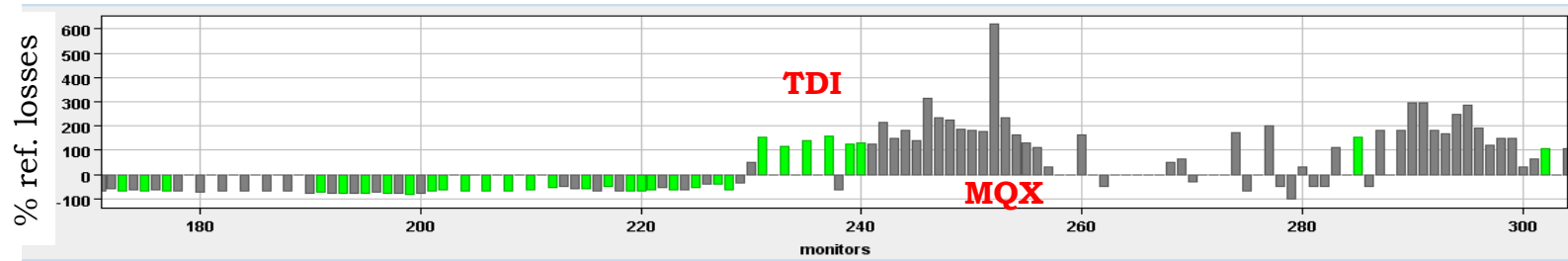
Most cases gave low/same losses as reference:

- ▶ Bad radial steering
- ▶ Satellites from PS
- ▶ RF on for all booster rings
- ▶ SPS 800 MHz on wrong harmonic
- ▶ Radial steering affected the scraping efficiency – but: radial steering can move the beam at the scraper → increase losses
- ▶ Longitudinal parameter changes determine similar increase in losses as sudden oscillations down the line from MSE ripple.

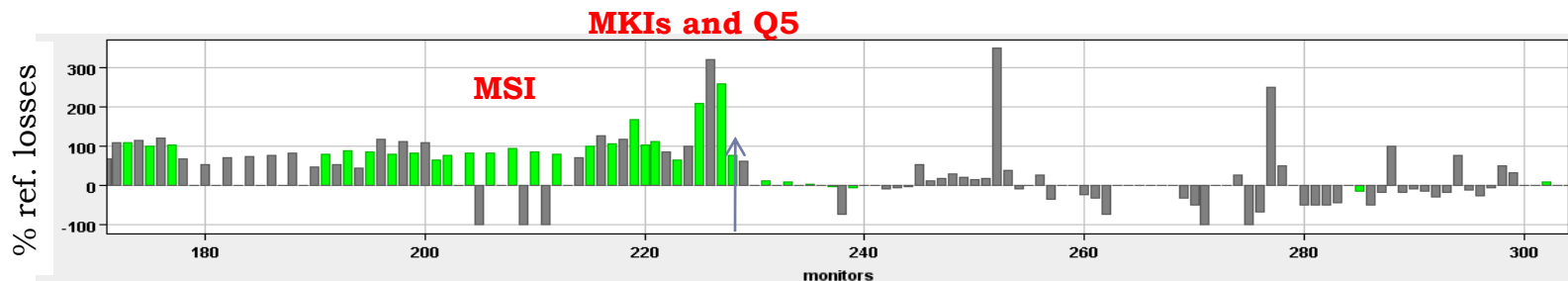


# MD: Effect of longitudinal parameters

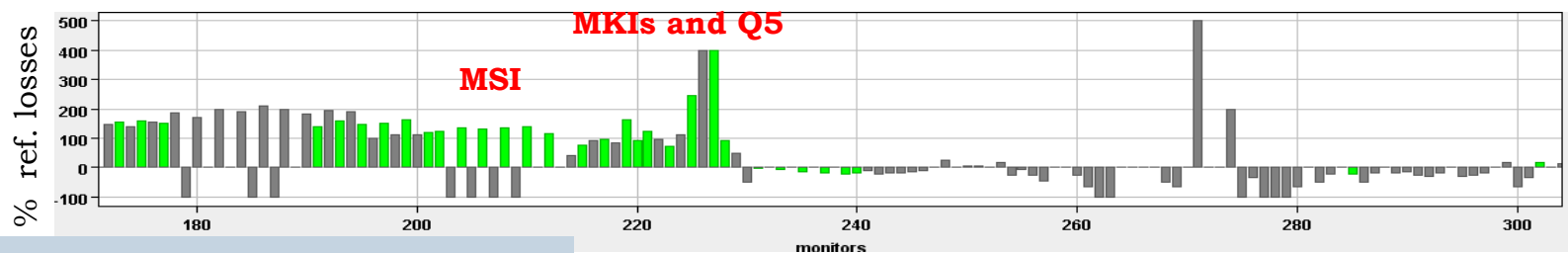
- ▶ **Increased injected bunch length into the SPS:** 4.1 → 4.9ns (SPS BQM warning, but no interlock)  
→ Observed losses on the TDI/MQX



- ▶ **Increased  $\Delta p/p$  at extraction:** bunch length at extraction: 1.5 → 2.2 ns → Losses on the TCDIs

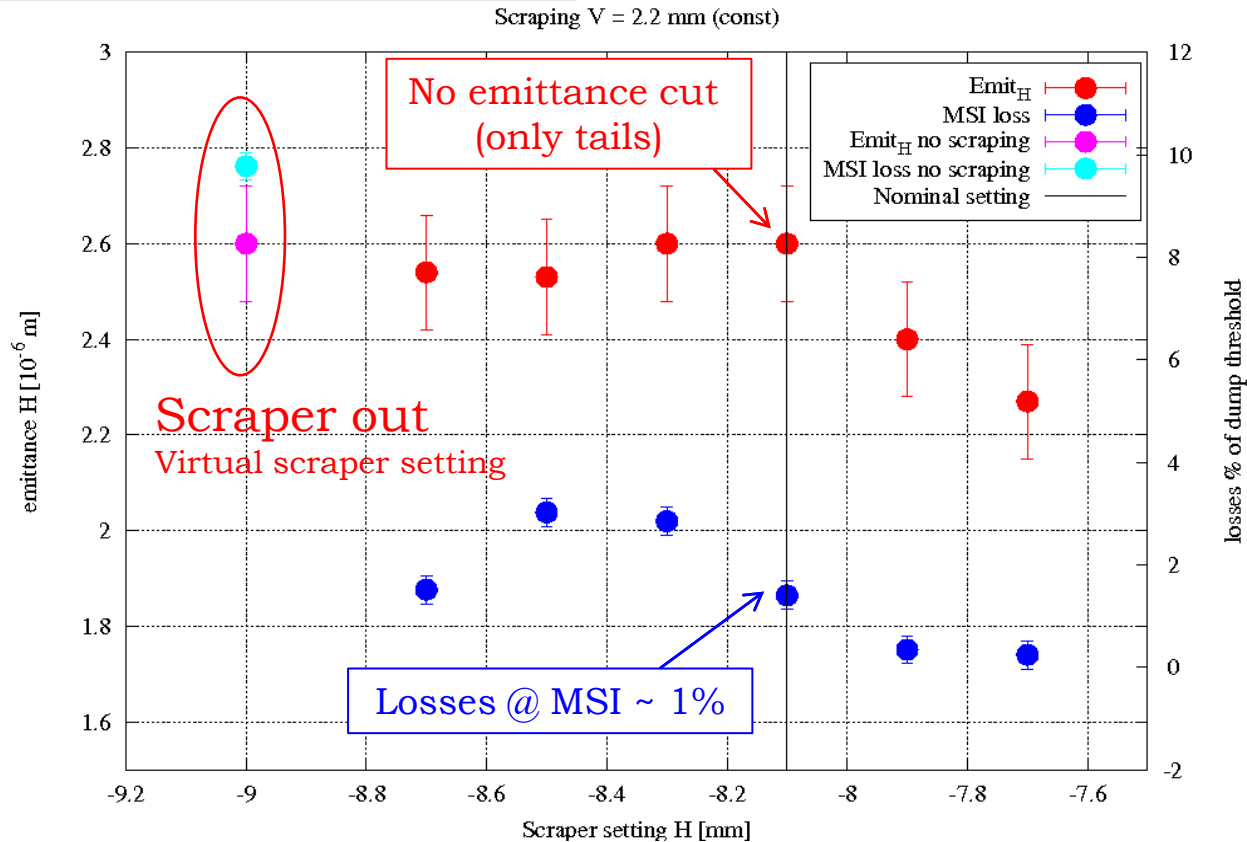


- ▶ **Turned off the 800 MHz in SPS** → Losses on the TCDIs



# MD: SPS Scraping and Nominal Emittance

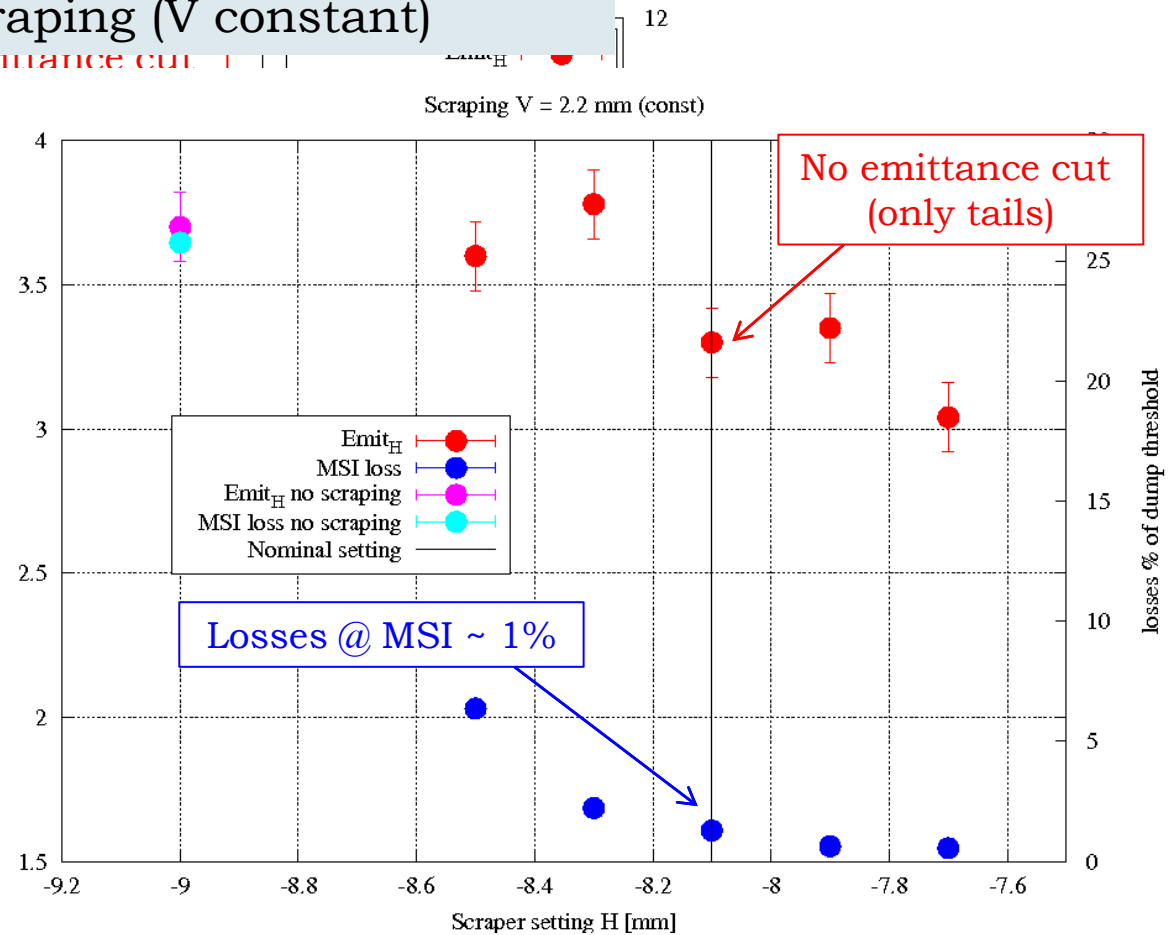
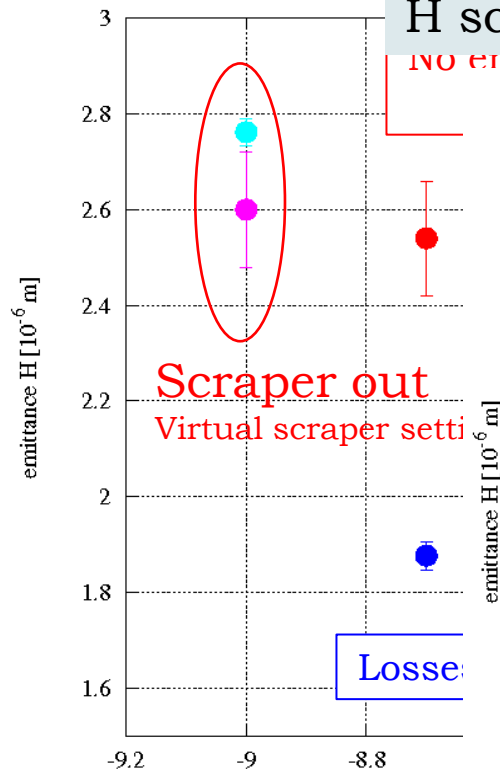
No blow up  
H scraping (V constant)



# MD: SPS Scraping and Nominal Emittance

No blow up  
H scraping ( $V$  constant)

Blow up: **Nominal Emittance**  
H scraping ( $V$  constant)

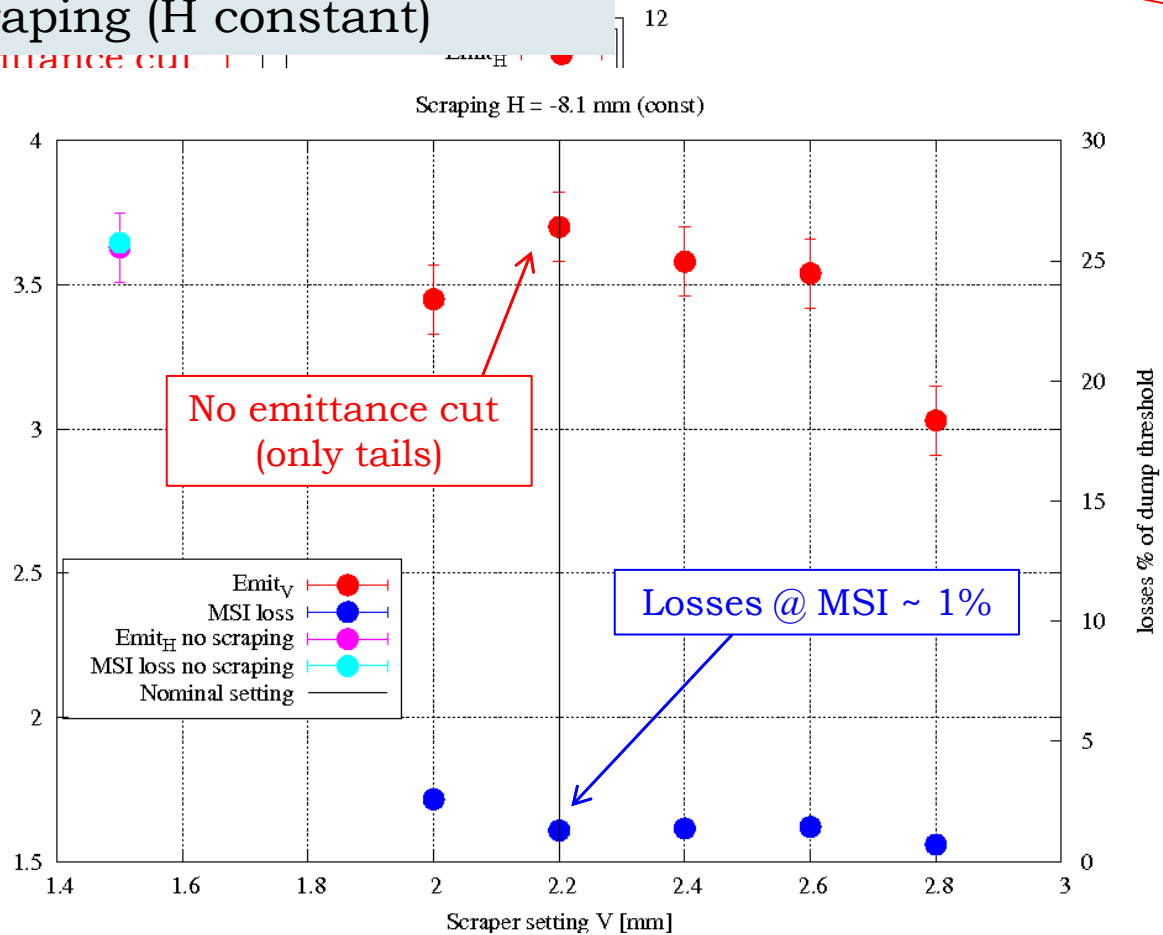
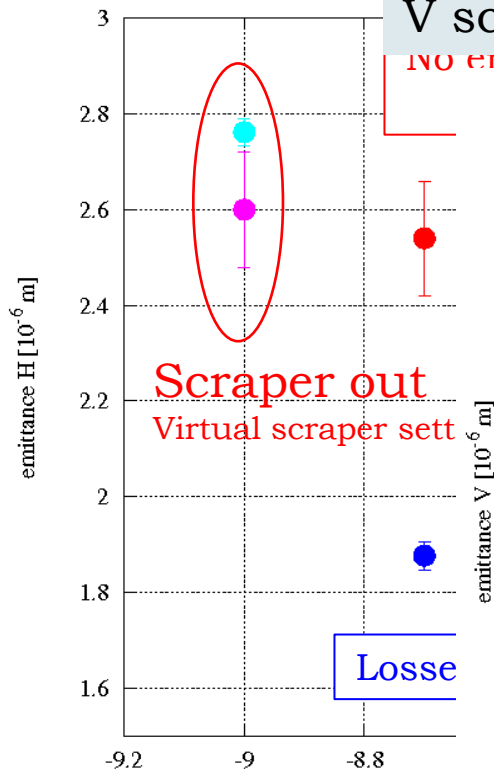


# MD: SPS Scraping and Nominal Emittance

No blow up  
H scraping (V const)

Blow up: **Nominal Emittance**  
V scraping (H constant)

**No limitations expected!**



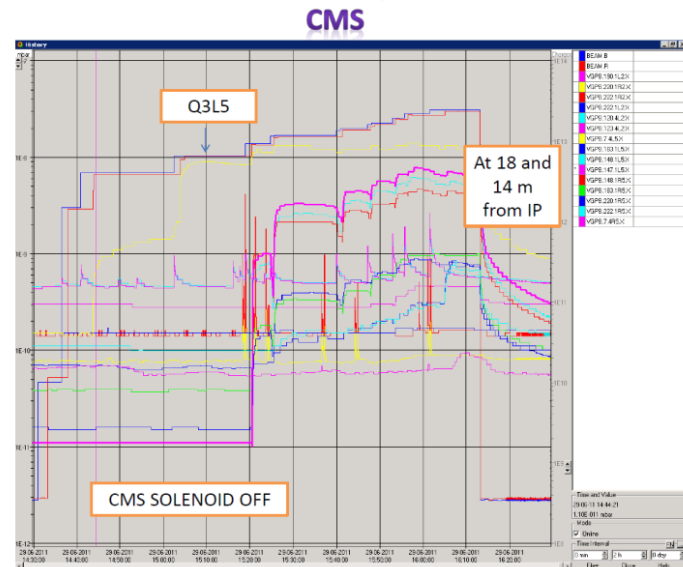
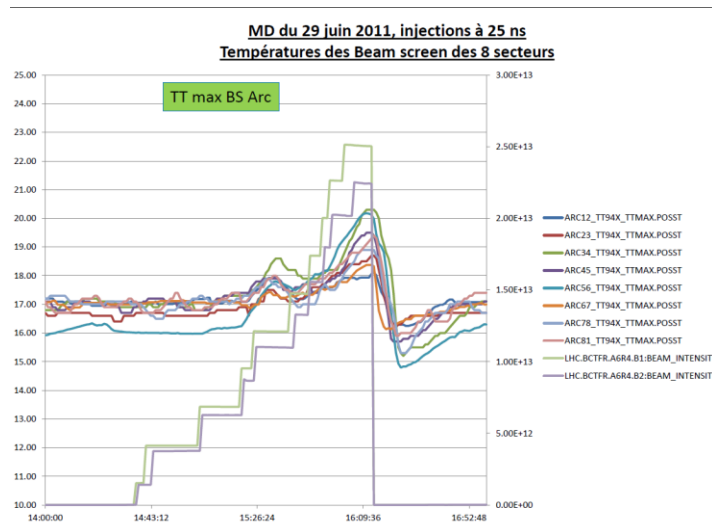


# Operation with 25 ns Bunches

MD: injection of 24 nominal bunches separated by 25 ns

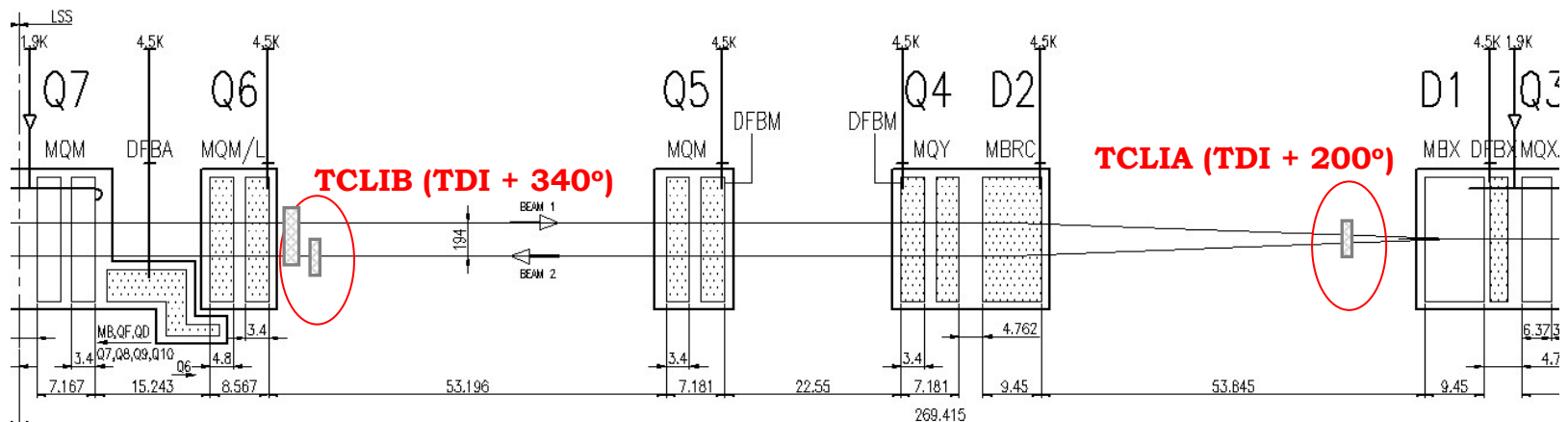
- ▶ 2.8  $\mu\text{m}$  normalized emittance
- ▶ SPS Scraping ON
- ▶ Good trajectories without steering (50 ns reference)
- ▶ Clean injection with low transversal and longitudinal losses
- ▶ Accumulation of 216 bunches in the LHC, preliminary RF and damper setup → some emittance blowup to be studied
- ▶ Slight increase in beam screen temperature ( $T_{\text{max}} \sim 20$  K)
- ▶ Moderate vacuum activity (e-cloud higher intensity?)

**No limitations expected !**



# MKI Flashover

- ▶ 18/04/2011 MKI D flashover
  - ▶ 36 bunches hitting the TDI with 75-90% of the nominal MKI deflection
  - ▶ Nearly all p+ of these 36 bunches impacted TDI/TCLIB → 12 magnets quenched
- ▶ Follow-up:
  - ▶ TDI setup, in particular angular alignment (4 m long jaw: 1 mrad tilt → 4 mm offset), re-checked → improved MP!
  - ▶ TCLIB aperture relaxed by  $1.5\sigma$  to reduce the load of primary protons on Q6 (right downstream) → OK for half nominal injected intensity (validations required for higher intensity)
  - ▶ **Check loss rate at Q6 w.r.t. TCLIB setting → scale for 288 bunches (MD)**



# Quench Margin at Injection (MD)

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With view to better understand BLM thresholds in injection regions.....

- ▶ First Method (gentle):
  - ▶ Checked **BLM** (@ **TCLIB**, **Q6** and **Q7**) and **QPS** for different TCLIB settings from nominal ( $8.3 \sigma$ ) to  $1.3 \sigma$  + offset (full beam on TCLIB).
  - ▶ Repeated measurements for 3 different intensities:  $1e10p+$ ,  $2e10p+$  and  $3e10p+$

No quench/quenchino observed

- ▶ Second Method (aggressive):
  - ▶ Injection of  $2e9 p+$  with a horizontal bump at Q6 ( 21-23-25 mm)

Losses at 1000% above dump thresholds but

No signal from QPS → Can we increase BLM thresholds?

# Summary and Conclusions

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- ▶ Nominal operation with 144 bunches reliably achieved (TCDI shielding + injection and abort gap cleaning)
- ▶ B1 seen to be more critical in operation
  - ▶ **Periodical re-steering** of the TL (with 12 bunches) is needed
  - ▶ **Good tradeoff** between **injection oscillations** and **losses** to define
  - ▶ MD studies to define origin of Beam 1 problems:
    - ▶ **No evidence of strong dependence** on **SPS longitudinal parameters** (**BQM** already “selecting good beams”)
    - ▶ **Nominal settings of SPS scraper** provide the best solution to reduce losses without reducing emittance (**orbit control** at the scraper, not too high losses at SPS)
    - ▶ Still pending: sensitivity of TI 2 to steering
- ▶ MD results:
  - ▶ Injection with **nominal emittance** does **not** look like a **limit** (provided correct scraping)
  - ▶ Injection with **25 ns** does **not** look like it will be a **limit** – to check 144 bunches and more (next MD)
- ▶ Possible improvements in case of continued issues:
  - ▶ Maybe needs more frequent setup of TCDIs....each 4-6 weeks?
  - ▶ Relaxed setting of TCDI to  $5\sigma$  (factor of 4 improvement)
  - ▶ Better understanding/increase of BLM thresholds, sunglasses,.....