LHC Injectors Upgrade

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New ion injection system in the SPS

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Motivation: Higher $\mathcal{L}$ for ions after LS2 by increasing the total bunch number

- WHY?
  - The average bunch **brightness is already high** (twice nominal).
  - Increasing it (if possible) leads to more IBS in SPS and LHC, and also increases $\mathcal{L}$ burnoff.
- HOW?
  - Reducing average bunch spacing in the LHC.
  - Reducing bunch spacing by **batch compression in the PS**.
  - Decreasing batch spacing in SPS by a **shorter injection kicker rise time** to get batches closer.
- **Implies a new SPS injection system for ions.**

Review of early developments

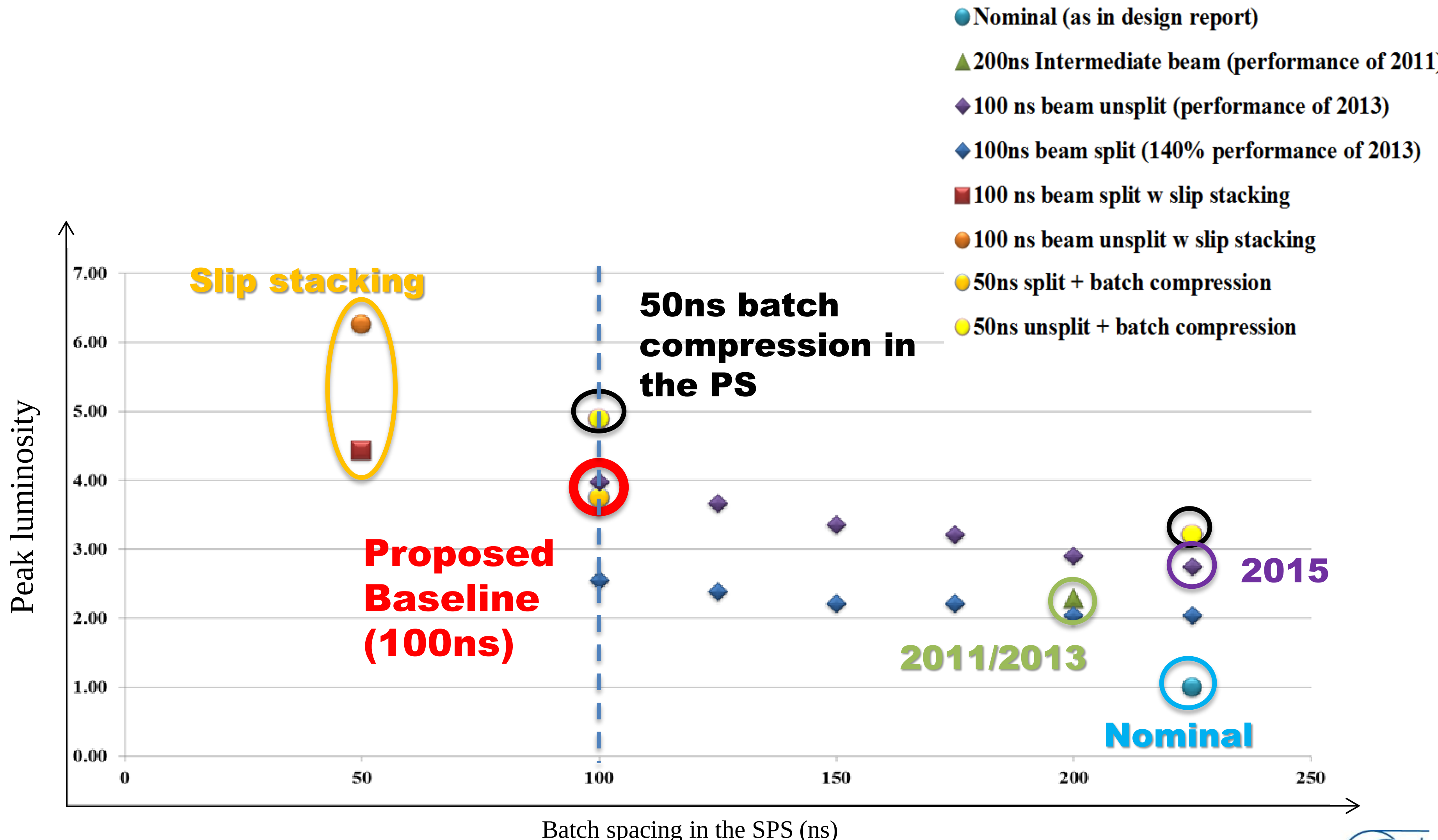
- In October 2013 a review took place to condense the various versions studied in the field of:
  - Injection concept/beam optics
  - Fast pulsed magnet systems
  - Septum System
  - Dump Block feasibility
  - Beam Instrumentation
  - Transverse Damper
  - Failure scenarios
  - Impedance considerations

https://indico.cern.ch/event/263338/overview

- A clear recommendation was made: "to follow the ***conservative 100ns approach*** rather than try to overcome all technical challenges for a faster 50 or 75ns solution."

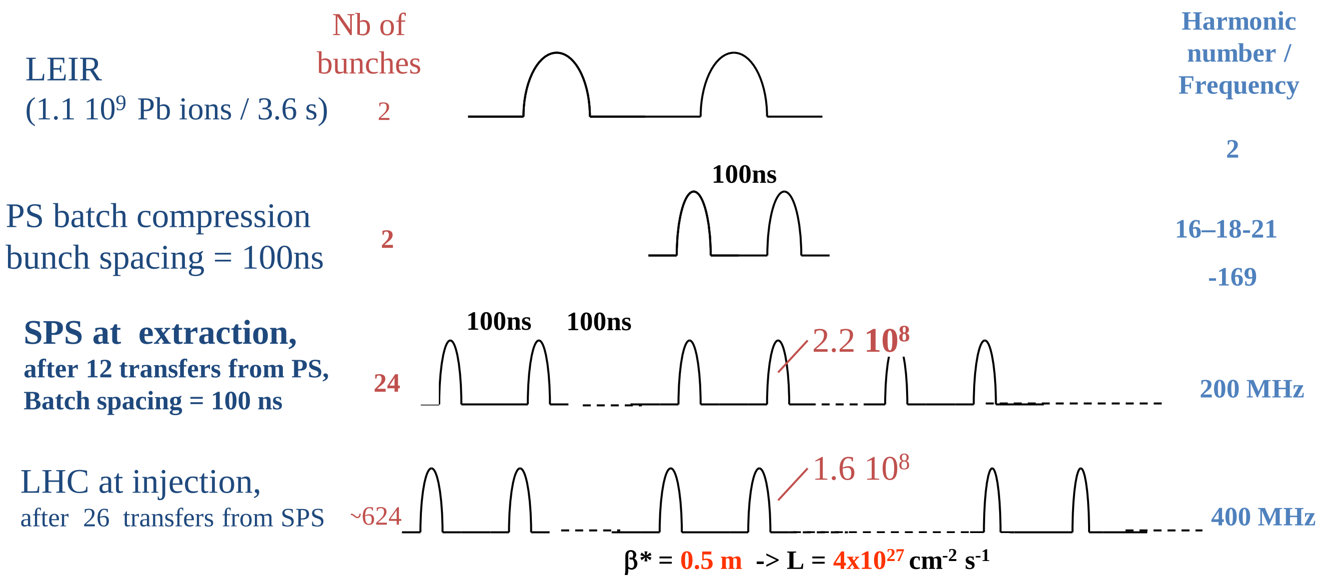
https://edms.cern.ch/document/1331860/1.0

Estimated Peak Luminosity (w.r.t. nominal)

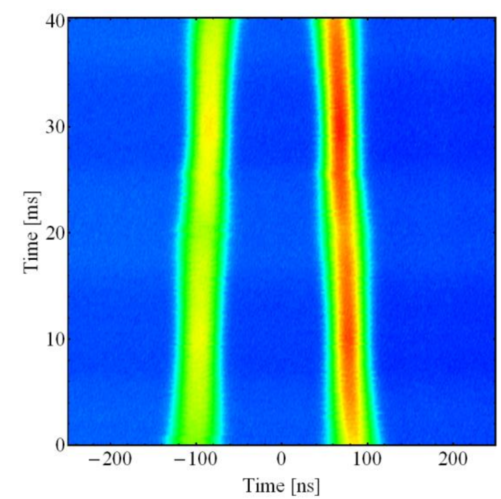


Courtesy D. Manglunki

100ns Baseline scheme and parameters



- Modified RF gymnastics in PS (demonstrated end 2012)
  - Batch compression (h = 16 – 18 – 21) -> 2 bunches spaced by 100 ns
- 12 (t.b.c./optimized) injections into SPS spaced by 100 ns
  - 2.3 µs trains of 24 bunches spaced by 100 ns
- 26 injections/ring into LHC
  - 624 bunches/ring (factor ~1.74)
  - >25' filling time per ring on paper



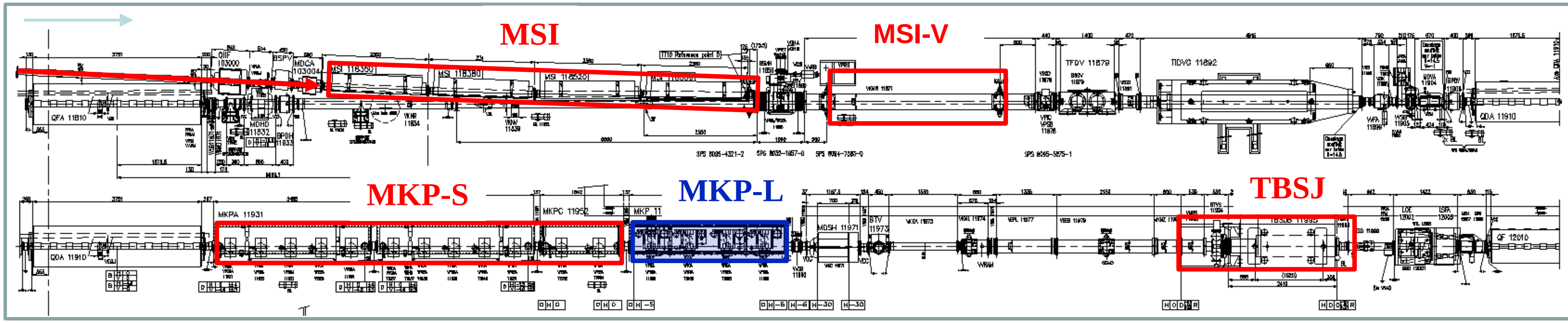
(H.Damerau)

- Expected Pb-Pb $\mathcal{L}_{peak}$ = 4.0×10^{27} cm^{-2}s^{-1} (β* = 0.5 m)

Courtesy D. Manglunki

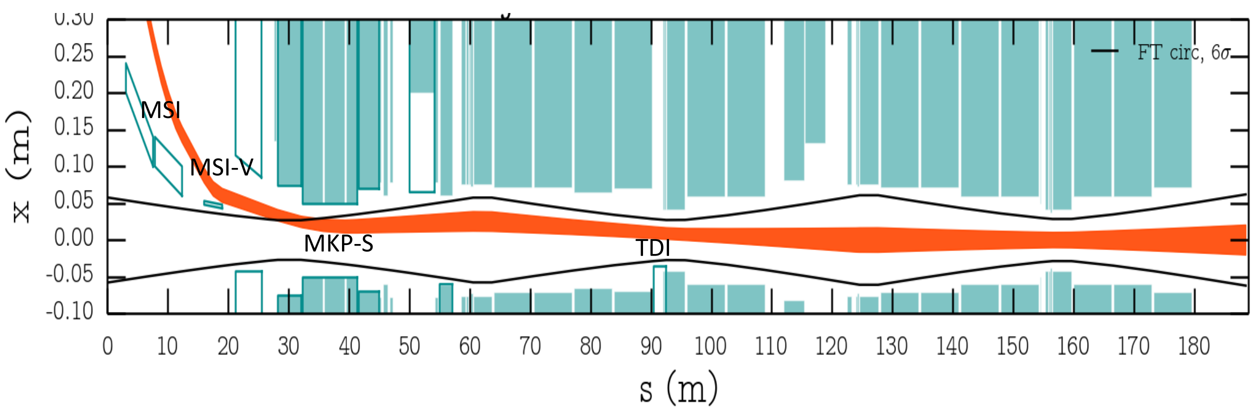
New SPS Injection Layout for Ions (100ns)

SPS LSS1



- Use existing (fast) MKP-S kicker with additional PFL.
- Additional septa (MSI-V) needed.
- Requires ion injection dump upstream QD12110.

- 17 GeV/c/u PB^{82+}
- 100 ns rise time
- Q20 compatible
- Low impedance impact

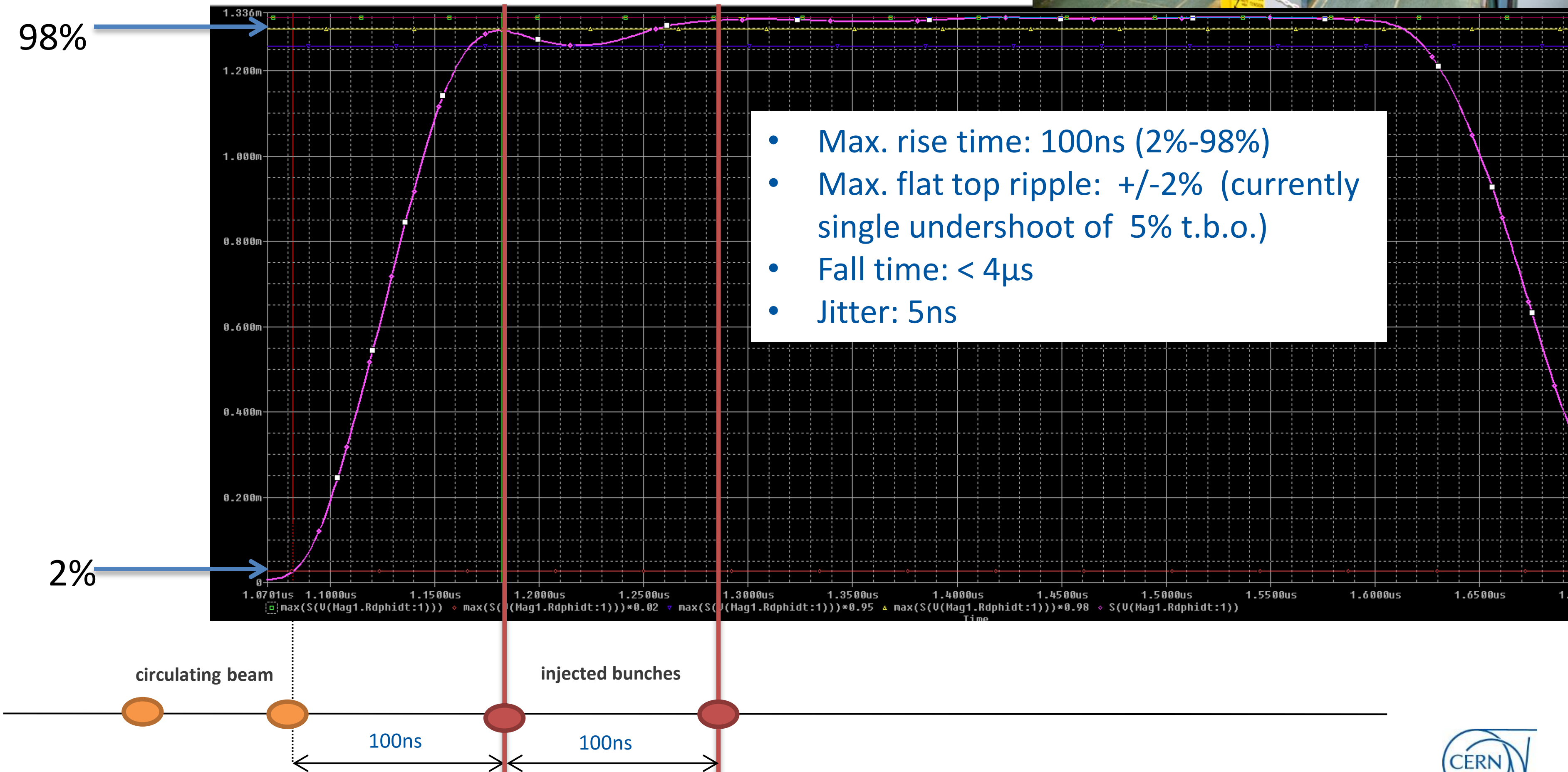


Element	Magnetic Length [m]	Deflection [mrad]
MSI-V (2)	2	12.3
MSI (4)	8.4	42.8
MKP-S (12)	8.63	2.07

Courtesy B. Goddard et al.

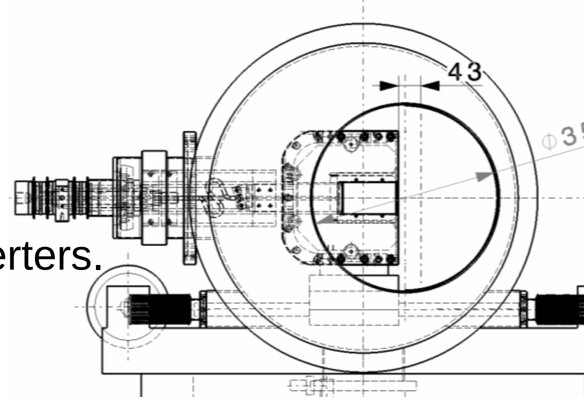
Fast injection kicker system

- Use MKP-S magnets with new PFL (MKP-L too slow).
- No layout or equipment change in the tunnel!
- No change to p^+ inj. System (except switch).
- Needs transverse damper to limit blow up.



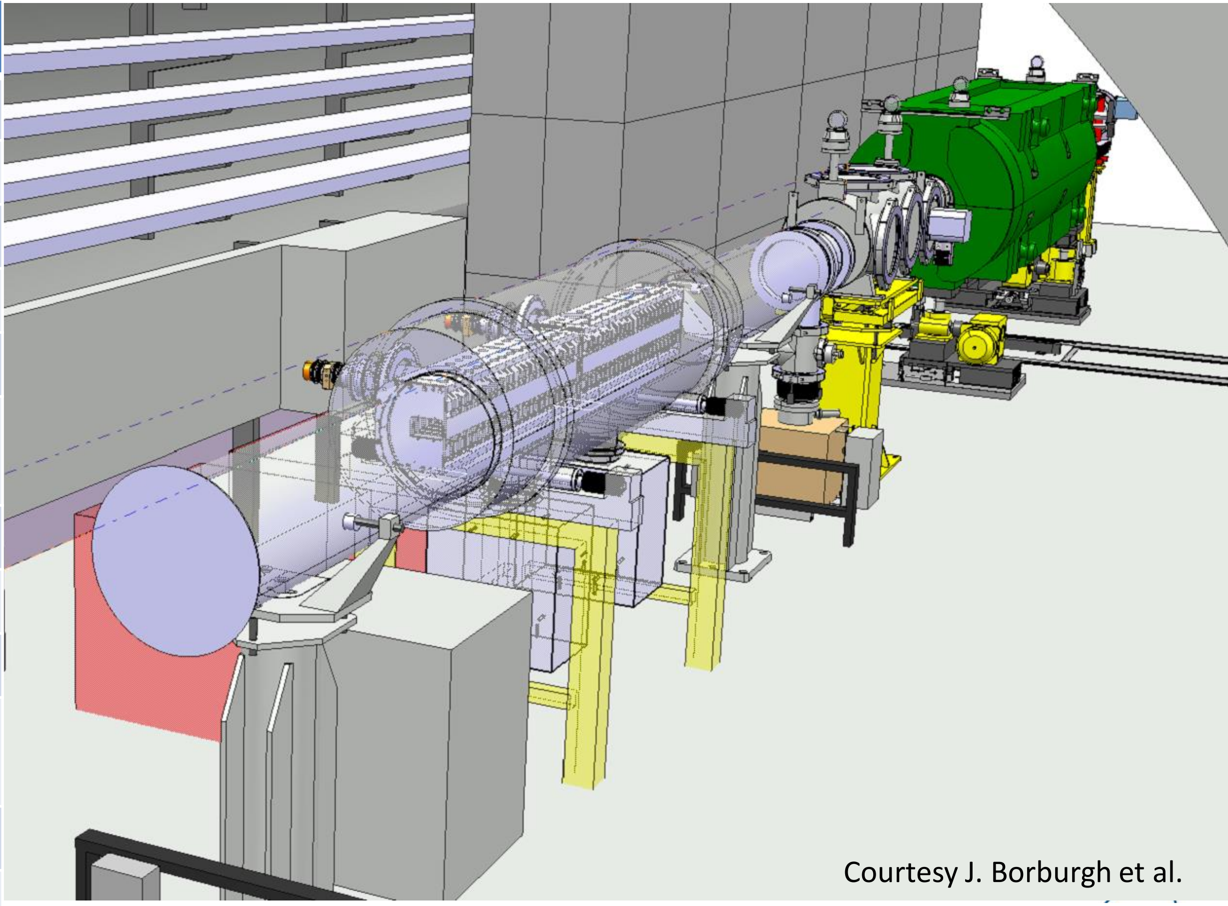
- Max. rise time: 100ns (2%-98%)
- Max. flat top ripple: +/-2% (currently single undershoot of 5% t.b.o.)
- Fall time: < 4µs
- Jitter: 5ns

Ion injection septum (MSI-V)



- Under vacuum pulsed magnet, powered by 2 MegaDiscap converters.
- Newly to build vacuum vessel.
- 2 magnets re-used from PSB to PS TL.
- Outstanding challenges:
  radiation hardness, reliability and integration in the existing (crowded) area.

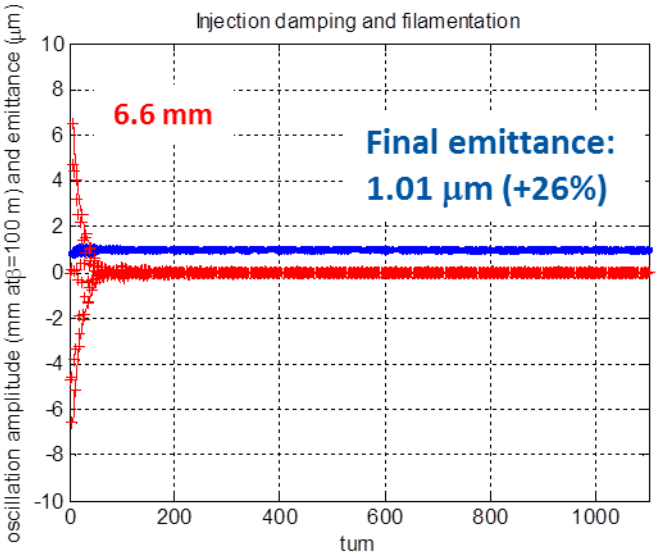
Magnetic length	996 + 996	mm
Physical length	1060 + 1060	mm
Gap height	60.4	mm
Horiz. aperture	102	mm
Magnetic field	0.541	T
∫B.dl	0.583 + 0.583	T.m
Deflection angle	6.5 + 6.5	mrad
I_{peak}	28.2	kA
Pulse width	~3	ms
Septum thickness	4.5 + 0.5	mm
Tank length	~ 2500	mm
Lifetime	60.10^6	pulses



Courtesy J. Borburgh et al.

Possible Impact On/From the SPS Transverse Damper

- Large kick angle of injection kicker: 2.07mrad @ avg.β=45.4m
  - for given specs (100ns, 2%-98%, 5ns jitter, steering error 0.5mm) worst case: 6.6mm @β_{ref}=100m
- **Estimation of emittance blow-up**
  - based on numerical simulations (MATLAB)
  - assuming amplitude detuning of 5e-5 m^{-2}
  - Damper gain 0.1 or damping time 20 turns
  - **Expected final emittance: 1.01 μm (26 % blow-up)**



- Damper kick strength for ions (horizontal plane)
  - $$\delta_{ions} = \delta_{protons} \frac{\beta\gamma_{protons}}{\beta\gamma_{ions}} \frac{82}{208} = 1.5\,\delta_{protons}$$
  - γ_{ions} = 7.3: kick per turn 5.7 μrad (→ 0.49 mm at β =100 m)

→ for damping time 20 turns gain of 0.1 needed, requires at max. 10% reduction/turn

→ 0.49 mm/turn is sufficient to damp 4.9 mm with 20 turns.

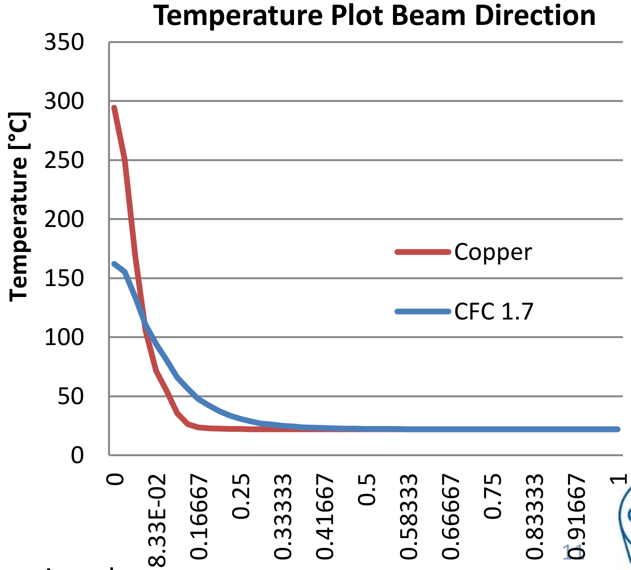
- **Transverse damper vital to limit emittance blow up. (Estimated 200% emittance blow up without damper!)**
- **Ion specific Low-Level needed** due to the frequency modulation of the RF: 4 different clocks from RF (BA3) to damper (BA2) with frequency modulation shifted to correct azimuthal position for pick-ups and kickers.

Courtesy G. Kotzian et al.

Ion Injection Dump

- **FLUKA simulations** were run to estimate levels of energy deposition and escaping neutrons for a 1m-long absorber protecting QD.12110;
- **Full impact case** of the SPS $^{208}Pb^{82+}$ ion beam (50ns, 4 bunches) at inj. energy was **studied**;
- **Two materials** considered: Cu and CfC:
  - Energy deposition: CfC is generally featured by values lower than those of Cu;
  - Cu absorbs more beam energy (60% vs 20%) and generates more populated but softer spectra of escaping neutrons;
  - With respect to CfC, Cu generates more populated but softer neutron spectra; with CfC, a more intense high energy neutron component can start particle showers in the downstream device(s);
  - for both material, **activation** of the surroundings is **expected** (actual estimation only possible at a more advanced stage of design);

- The dump block **is feasible**, however further **optimisations must be done** in terms of length, activation, escaping neutrons etc…
- **Material** characteristics **to be adjusted** to match the requirements.



Courtesy A. Mereghetti et al.

Beam Instrumentation

- Existing beam instrumentation (TT10 and RING) can be used.
- Additional BTV to be integrated on new dump. (radiation-hard “Vidicon”-camera)
- BLMs to be specified and placed for new injection septum and dump
- New BPM electronics expected to bring new functionalities for injection oscillation and covering long cycles
- Fast kicker synchronization to be done as for protons (BCT)

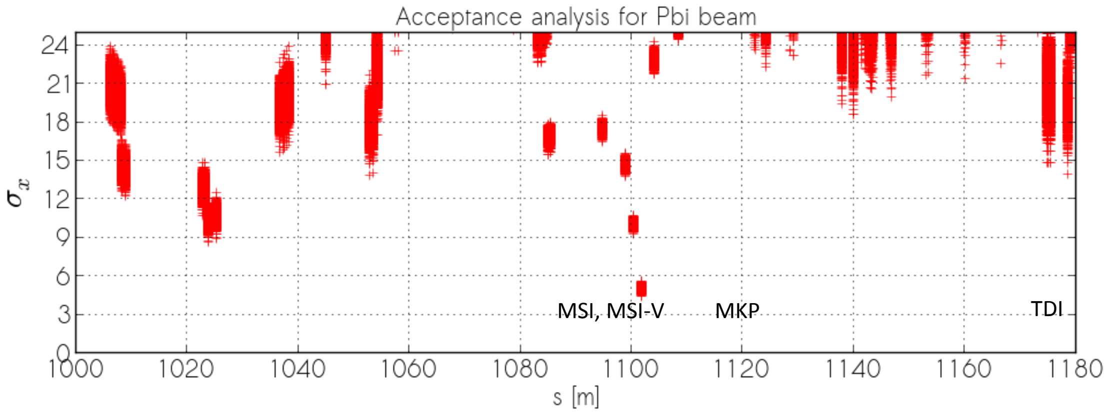
Next steps:

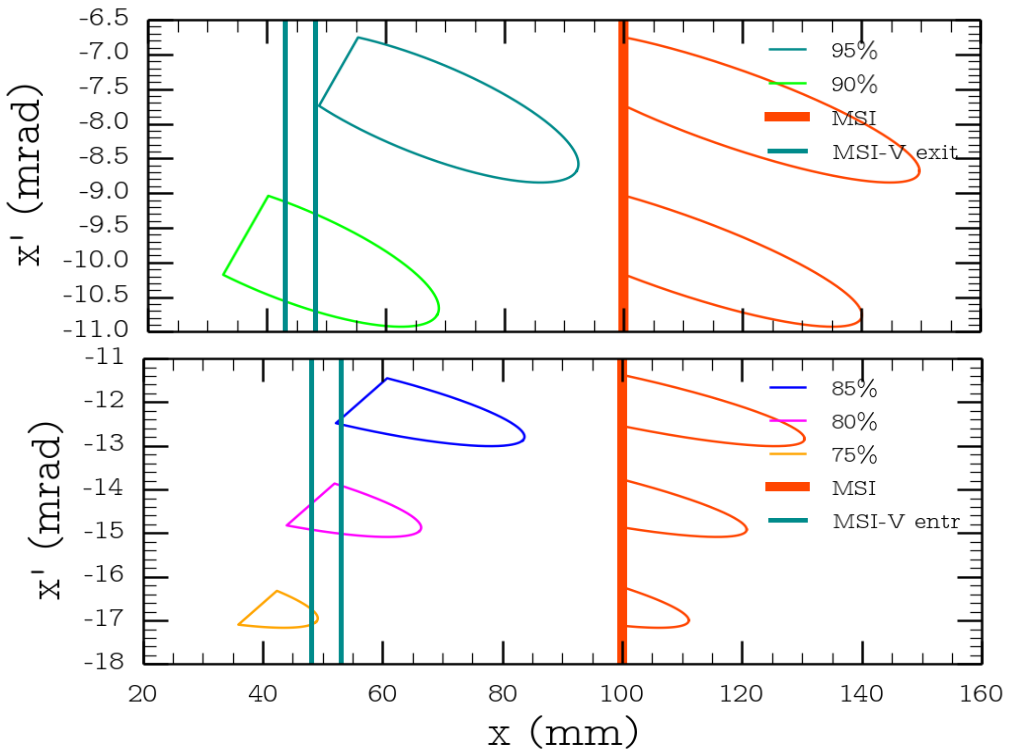
- Choice of screen materials to be reviewed
- Review of BTV tank impedance

Courtesy L. Jensen et al.

Failure Analysis

- Failure cases considered:
  - Injection kicker, MKP, not firing;
  - Main magnet failures in the transfer line PS to SPS;
  - MSI-V failures;
  - Proton injection septum, MSI, failures.
- Ion operation with 2 bunches **not critical**
- Proton operation needs MSI **current to be monitored and interlocked** to protect MSI-V.

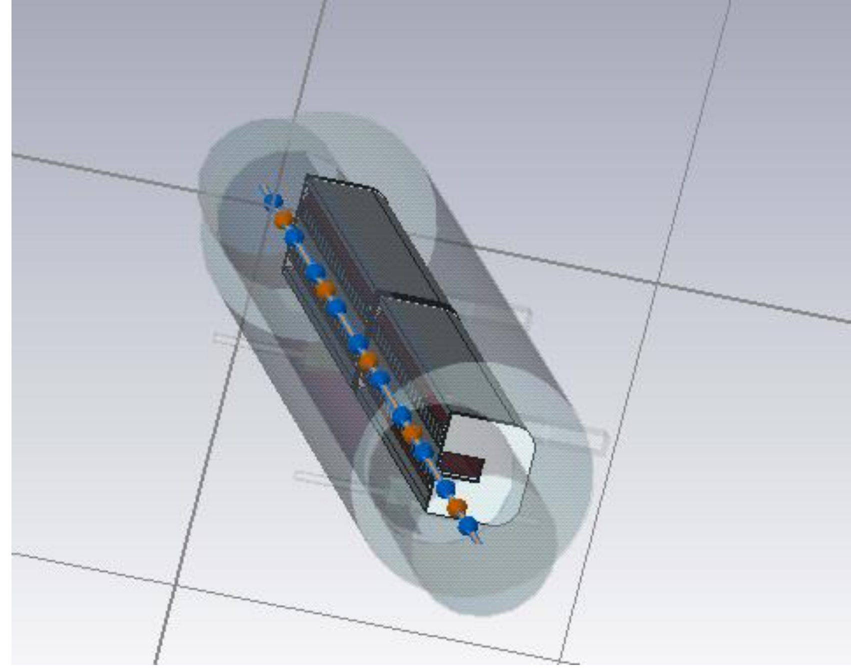


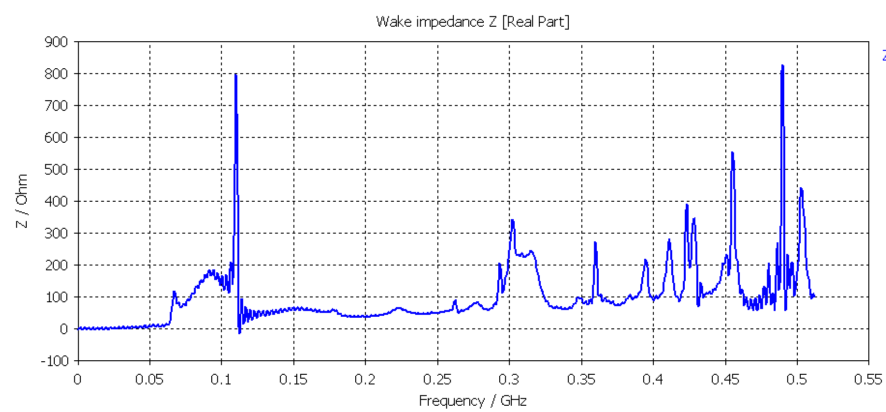


Courtesy F.M. Velotti et al.

Impedance

- Studies for the impedance impact of a dedicated **50 ns** ion kicker have been made and yield a **significant contribution** to long. and transv. impedance.
- Significant reason for the review committee recommendation (100ns upgrade) was to **not add additional impedance** for kicker systems.
- Preliminary studies for MSI-V done. Further optimization envisaged.
- Check for BTV and dump to be done.





Courtesy B. Salvant, C Zannini

Conclusions

- **Various designs** have been elaborated in 2013.
- **Review** concluded on a clear **recommendation** for a **100ns upgrade**.
- **Feasible and cost effective** solution:
  - New PFL system on MKP-S allows to not change the kicker infrastructure in the tunnel. No dose taken by FPS-personal (next to TIDVG). Further development ongoing.
  - No new ion kicker magnets thus **no additional impedance for kickers** added.
  - Additional MSI-V **Septa** will make use of recovered PSB2PS septa magnets. Impedance to be checked.
  - Most **existing beam instrumentation** can be used.
  - **Transvers damper** vital to keep emittance blow up small.
  - New **ion dump feasible**. Requirements to be defined-> Further detailed studies needed.
  - SPS **amplitude detuning** needs to be evaluated.
  - **Emittance blow up budget** for ion injection activities needs to be defined.

Outlook / Timeline

- 2013
  Review of variants – Decision for 100ns upgrade.

- 2014
  Specifications, start of technical design.

- 2015-2017
  Prototypes, production.

- 2018-2019 (LS2)
  Installation.

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THANK YOU FOR YOUR ATTENTION!

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