CERN

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Hadron Injectors, Injection and Transferlines

Outline

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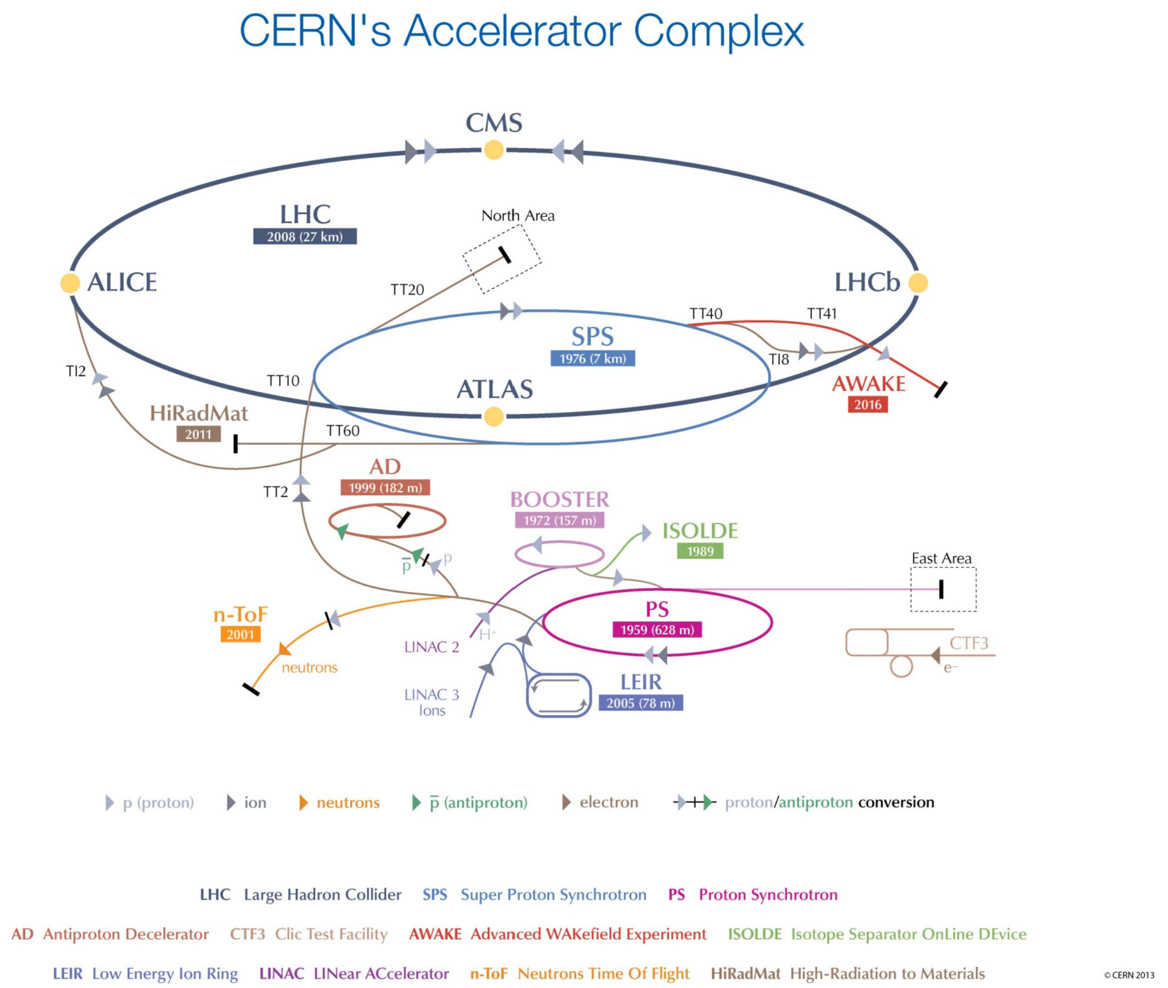
LHC x5
HEB@SPS
HEB@FCC
Other options
Summary

Requirements

The High Energy Booster should:

- Reuse the existing CERN p+ and ion chains.
- Deliver the desired beam parameters.
- Fill ~ 80% of FCC with 1-6 TeV (baseline 3.3 TeV) protons in about 30 minutes.
- Be reliable and (considerably) easier to operate than the FCC.

Requirements



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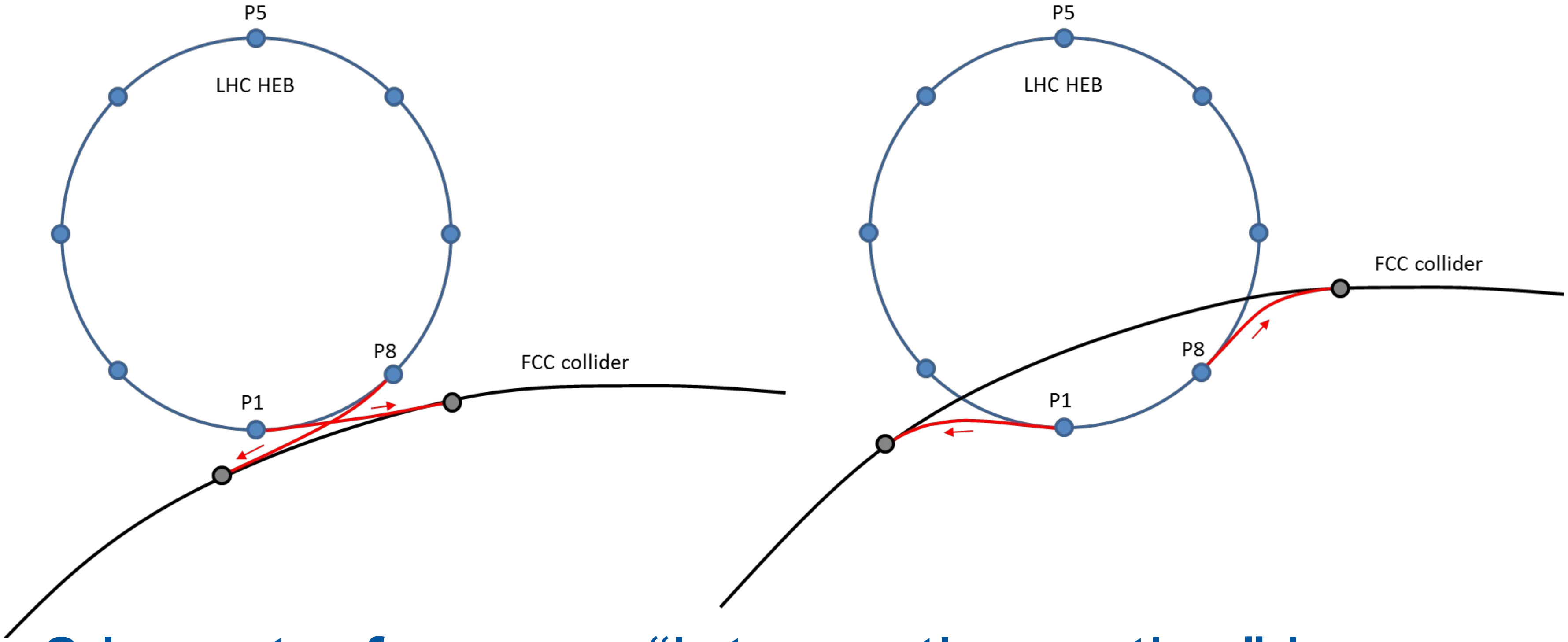
Requirements

- The HEB energy also determines the damage limits for FCC injection protection
  - 82 bunches for 3.3 TeV (baseline)
  - 325 bunches for 1.5 TeV
  - 27 bunches for 6.5 TeV
- This means we should do a “staggered transfer”, which leads to strict requirements for the HEB extraction and FCC injection kickers. (Talk by T. Kramer 13:30, 2015 talk by W.Bartmann.)

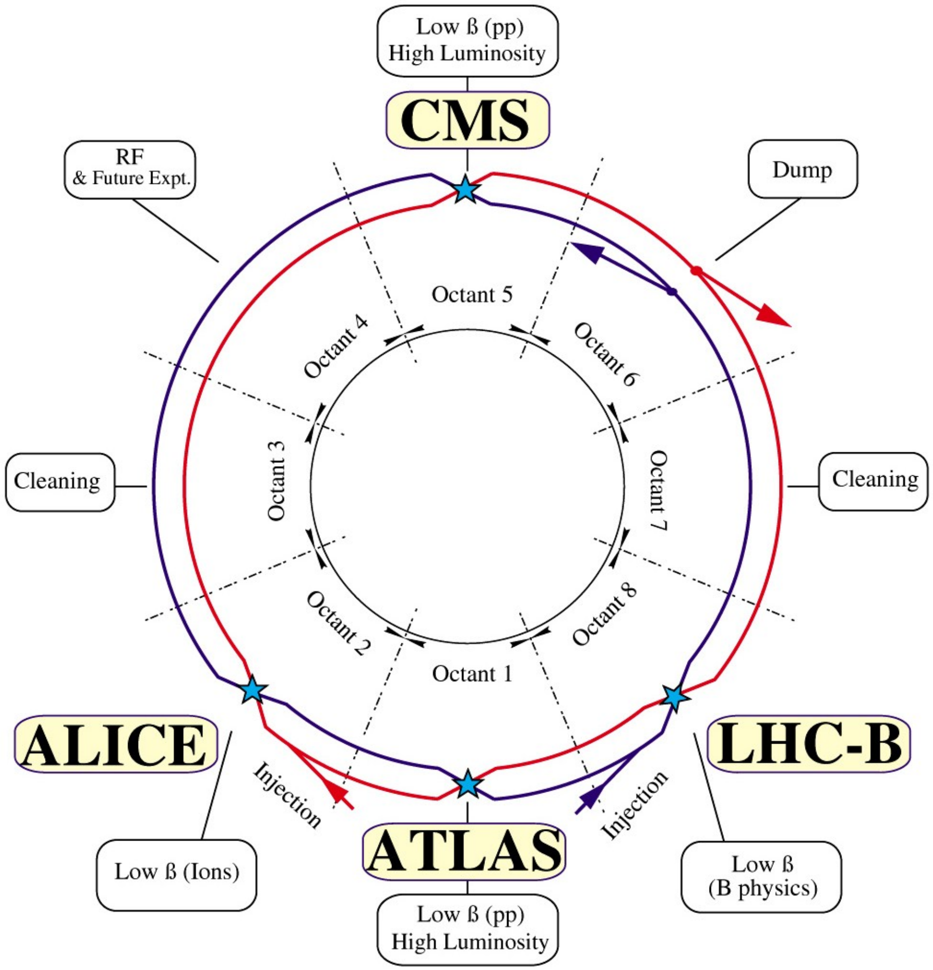
FCC position



2 layouts, focus on "intersecting option" here, but non-intersecting is also investigated.

(Talk by C. Cook, Thu 13:30.)

LHC x5 – Original LHC



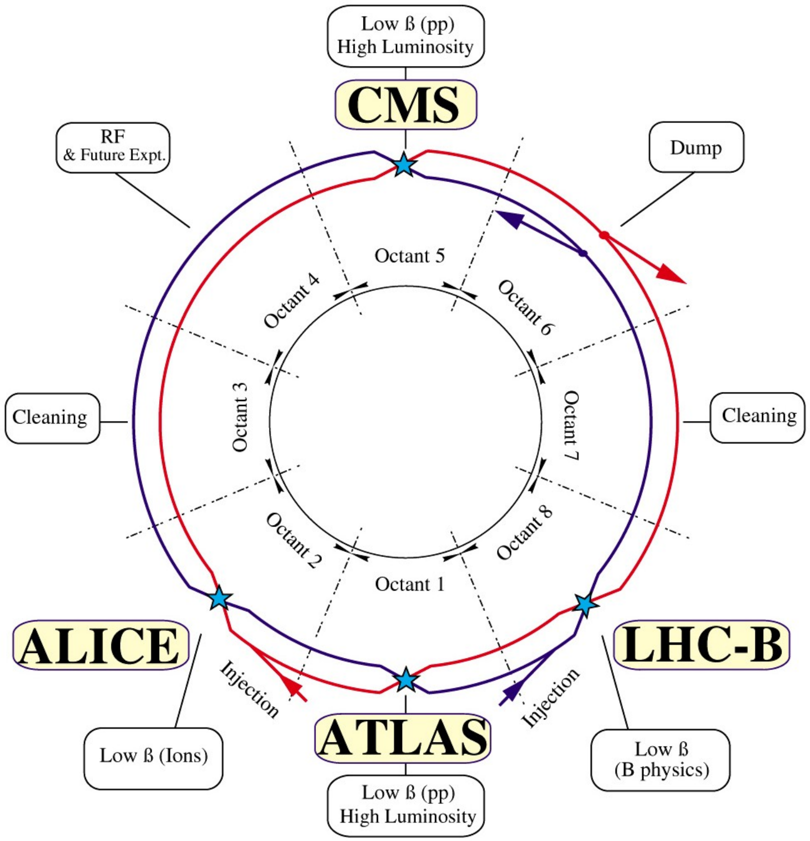
- 27 km, 107 m cell length
- Superconducting
- Double aperture
- 450 GeV – 6.5 TeV
- Four beam crossings
- Eight straight sections of about 528 m

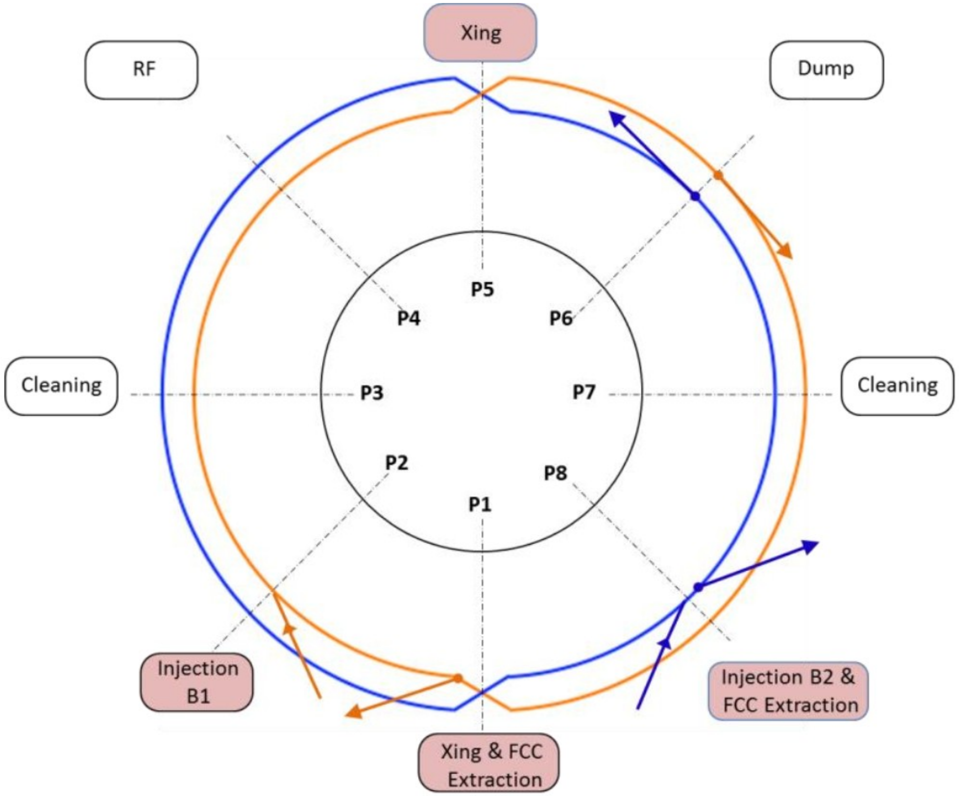
LHC x5 – Changes

Attempt to minimize changes, but some changes are necessary:

- More space needed for added extractions → Remove two crossings (IR2 and IR8).
- Keep RF, collimation and beam dumps as they are → Move injection to the inner rings.
- Decommission experiments and low beta insertions.
- Increase the speed of the ramp by a factor 5. (Talk by A. Milanese.)

LHC x5 – Changes





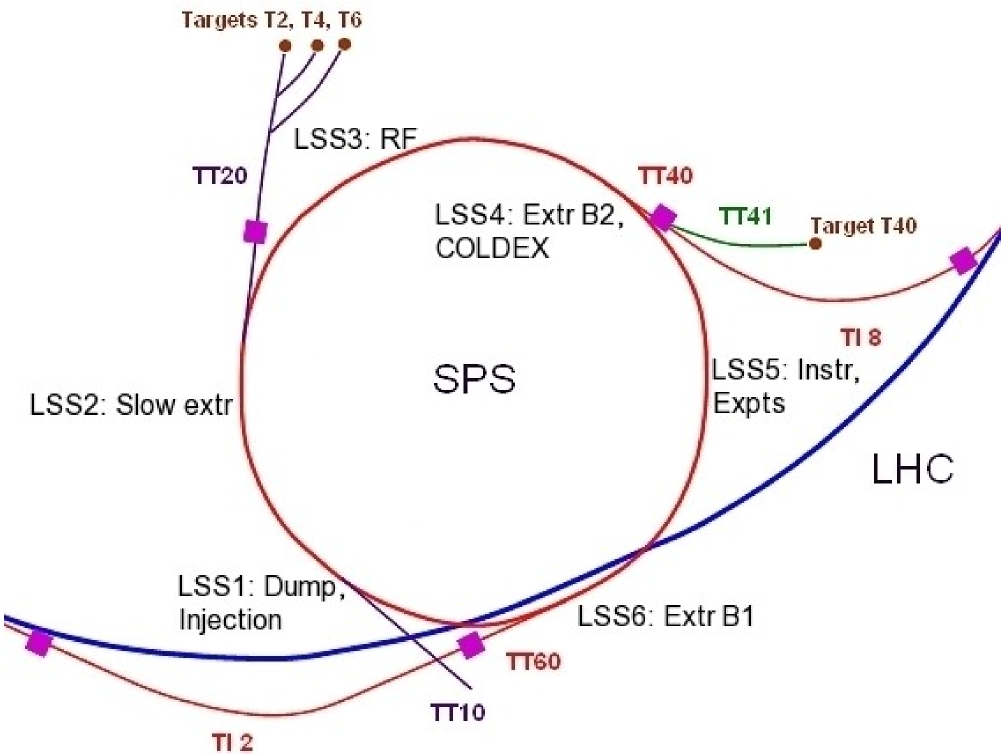
LHC x5 – Overview

- Use present LHC, with upgraded ramping and decommissioned experimental IRs.
- Min. FCC filling time of 40 mins (4 ramps).
- Inject/extract mostly with the old hardware (designs), but more advanced extraction kickers. (Posters by M.J. Barnes, D. Woog.)
- TLs complicated, at 3.3 TeV, 8 Tesla:
  - Up to ~ 8% slope. (From experience >6% is an issue for transport and supports.)
  - 6.5 km of lines, 4 km superconducting! (Quenches?)

LHC x5 – Overview

- Cryo plants will be available in points 1 and 8, which probably have sufficient capacity.
- Extraction and transfer are more challenging at higher energy.
- Some optimization in FCC location/layout possible, but there are contradicting constraints.
- The LHC is complex and demanding, and likely expensive to operate and maintain in comparisson to other options.

HEB@SPS – Original SPS



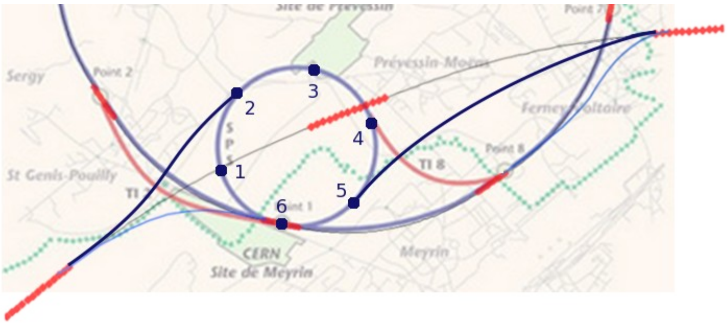
- 7 km, 64 m cell length
- Normal-conducting, 2T
- Single aperture
- 26 GeV – 450 GeV
- Six straight sections of about 128 m

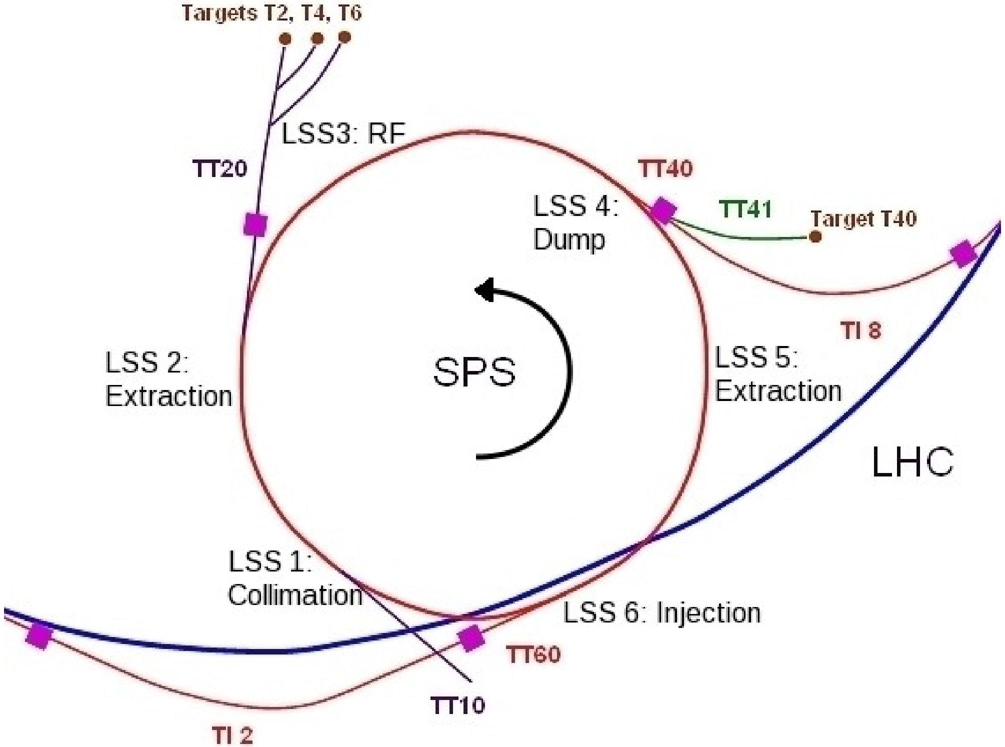
HEB@SPS – Changes

- Reasonable magnetic field aiming at 0.1 – 1.0 T/s (7 – 7.5 T) → Extract at 1.4 - 1.5 TeV.
- Keep SPS geometry (6 LSS), but change to superconducting magnets.
- SPS energy swing increases from ~20 to ~60. Feasibility to be investigated with new magnet design.
- FCC energy swing increases from ~15 to ~30. (LHC MD on energy swing planned.)

HEB@SPS – Changes

- In the straights we need:
  - Two high energy extractions
  - Injection
  - Dump
  - RF
  - Collimation





HEB@SPS – Overview

- SPS replaced by a new supercondunctingsingle aperture machine.
- Lower energy (1.5 TeV), high dynamic range.
- Magnets, beam transfer and RF seem feasible.
- Collimation may be a challenge.
- Normal conducting TLs possible, slope of up to ~ 8.5%.
- Min. FCC filling time of 34 minutes (34 ramps), roughly half due to filling SPS.

HEB@FCC – Introduction

- A second accelerator sharing the FCC tunnel.
- Single aperture, polarity reversal.
- Dipole fields ≤ 2T (iron dominated magnets).
- Needs bypasses around the experiments → Roughly 15.5 km added tunnel length!

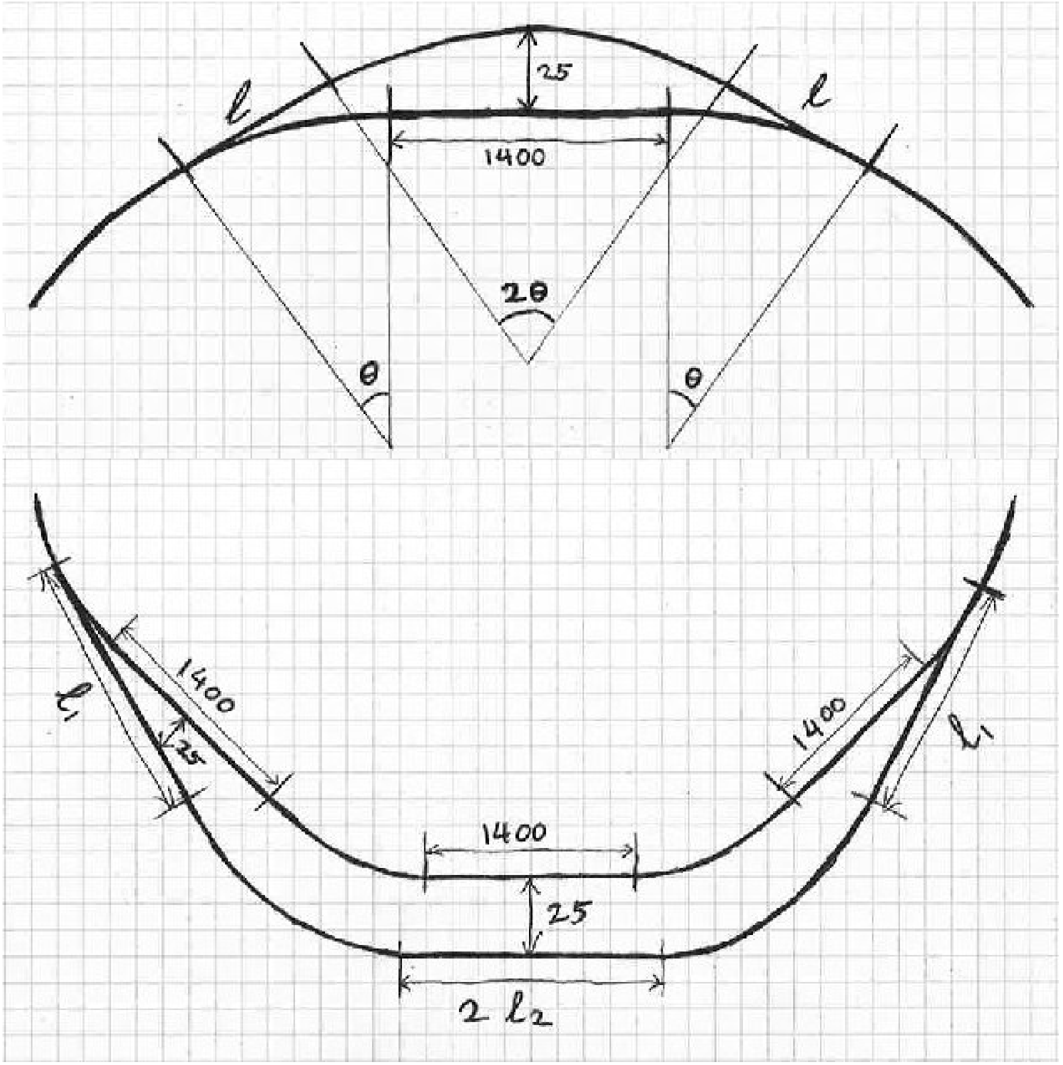
HEB@FCC – Tevatron lessons

- The Tevatron was built in the same tunnel as the “Main Ring”, its injector.
- The Main ring went through the D0 detector and over the CDF detector. Many constraints due to pre-existing tunnel.
- There were issues with:
  - Background to the experiments
  - Radiation damage to detectors
  - Crosstalk of power supplies, magnetic fields, losses

HEB@FCC – Tevatron lessons

- For HEB@FCC use bypass tunnels, to avoid any radiation to experiments.
- Cross-talk
  - Power supplies: easily prevented.
  - Magnetic fields: to be checked.
  - Beam losses: Could be critical, especially near collimation/protection, to be investigated.

HEB@FCC – Bypasses



- Initial design with the same bending radius and total bending angle, +15.5 km tunnel.
- Optimize distance between experiments?
- Compatibility FCC-ee?

HEB@FCC – Main dipoles

- Due to impedance and collective effects a halfgap of 39 mm is needed.
- At this gap height, 1T normal-conducting dipoles with an integrated length of 65 km have a peak dissipated power of about 1.12 GW – 5% of the nameplate capacity of world's largest power station. (Three Gorges Dam, China.)
- Superferric magnets are seen as the only reasonable option. (SC drive cable, iron yoke.)

HEB@FCC – Overview

- Additional ring in the FCC tunnel.
- Single aperture with polarity reversal.
- Superferric dipoles.
- 15.5 km bypasses around the experiments.
- Integration to be studied.
- TLs to be studied, probably relatively easy. (450 GeV transfer).
- Min. 29 mins FCC filling time, 2 minute ramp.
- High reliability.
- ...If we can deal with cross talk of losses.

Other options

- Exist but are not well studied
- Inject from SPS at 450, maybe energy swing too large for FCC, also influences FCC aperture. But it's cheap. If it seems like a serious option, it's fairly simple to implement.
- Superferric or fast-ramping superconducting machine in LHC tunnel.

Summary

- Three main injector options, with initial designs for optics and transfer.
- Each has their own advantages and challenges.
- Each design will be further explored until a good comparison can be made and the best option can be selected.
- Possibilities for fixed target beams and other non-FCC physics need to be addressed for all options.

Summary

- Baseline of 3.3 TeV requires transfer from a booster in the LHC or FCC tunnel.
- 1.5 TeV FCC injection is an important option to study, since it is compatible with all injector options and offers advantages for transfer and injection protection.

	LHC x5	HEB@SPS	HEB@FCC
Energy	3.3 TeV (1-6.5)	1.5 TeV	3.3 TeV (1-5.5)
FCC filling time	40 min	34 min	29 min

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Backup slides

LHC x5 – Changes to IR2

LHC x5 – Changes to IR1

[redacted]

[redacted]

[redacted]

LHC x5 – Changes to IR8

[redacted]

HEB@FCC – Tevatron BLMs

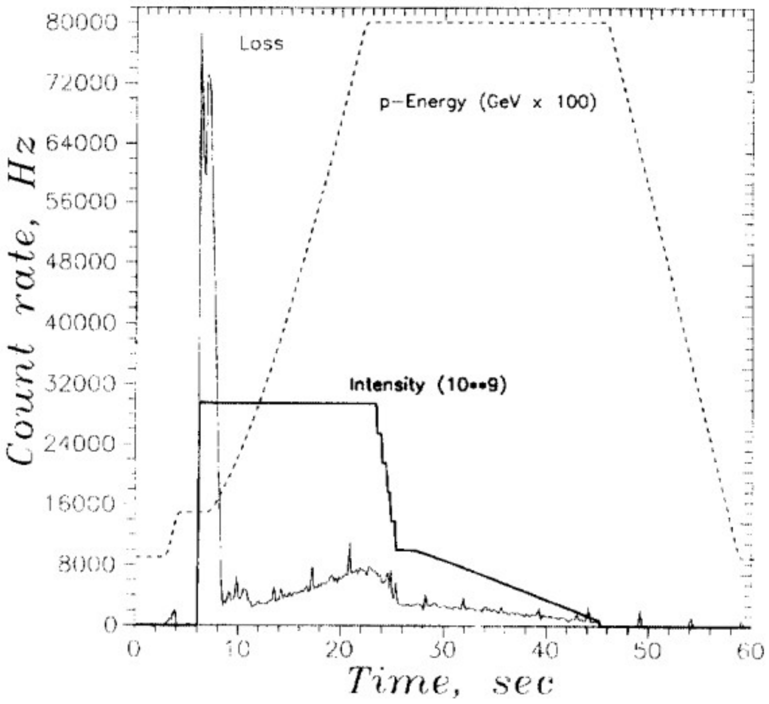
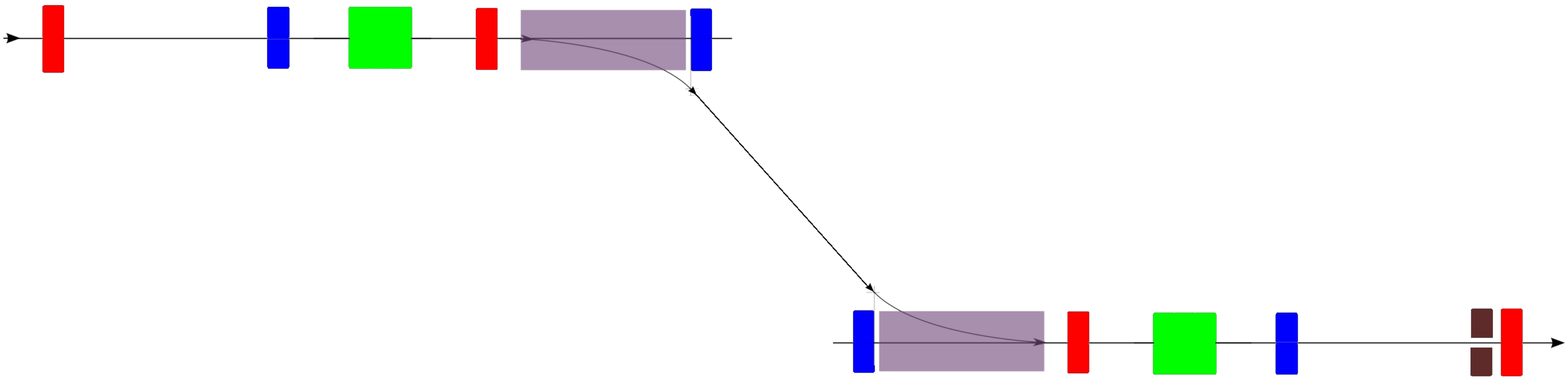


Fig. 6. The BLM count rate (thin line), proton beam intensity (thick solid line) and proton energy (dashed line) over one cycle of acceleration in Tevatron.

There are some smaller, sharp peaks in loss rate, with a period of about 4s, due to injection losses in the Main Ring.

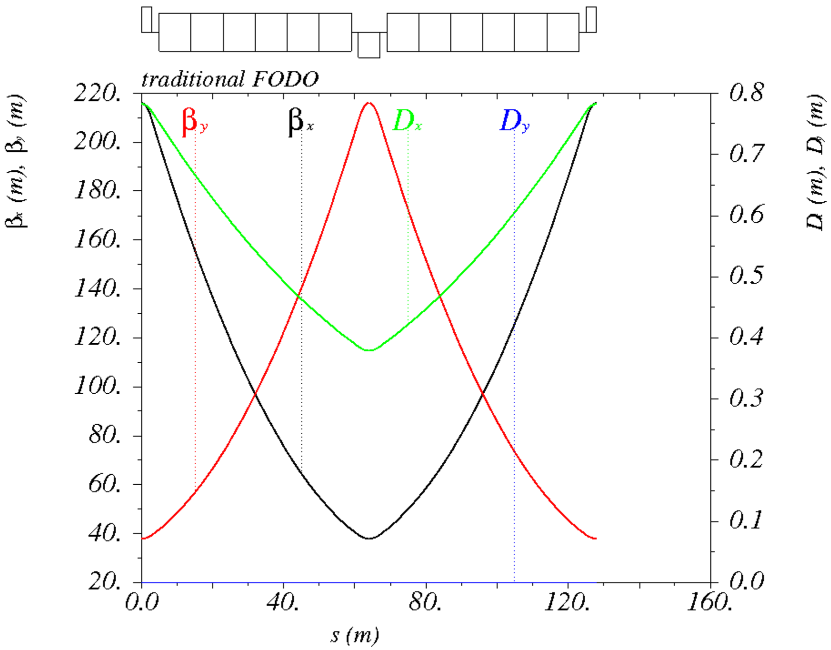
Source: Vladimir D. Shiltsev, "Fast PIN-diode beam loss monitors at Tevatron" (1998)

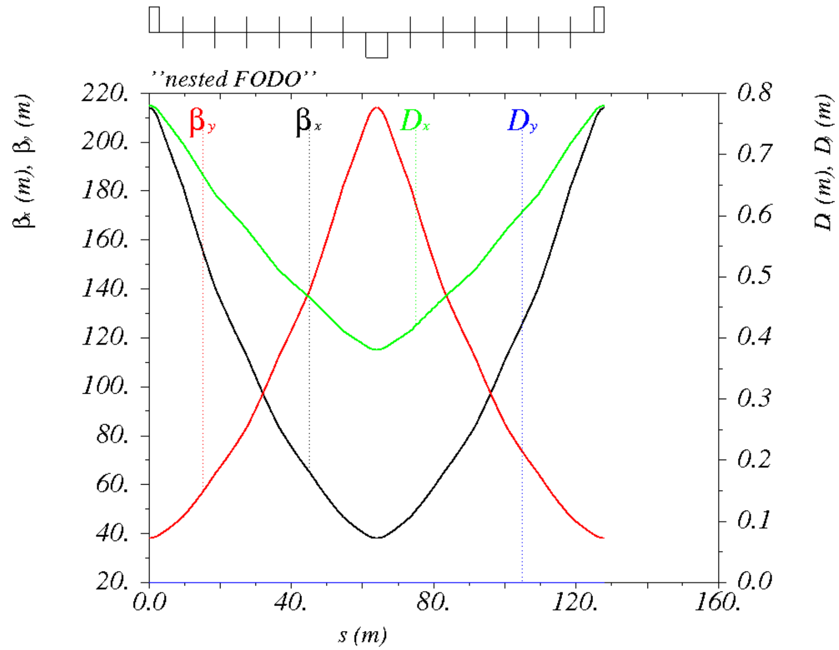
HEB@FCC – Transfer concept



- FCC injection similar to baseline, same layout in HEB.
- Careful integration needed.

HEB@FCC – Optics





Using combined function dipoles (|B1|=4*|B0|) with alternating gradients together with reduced strength quadrupoles (about -12%), we obtain results very similar to the traditional FODO optics.

HEB@FCC – FCC filling time

- SF magnets can ramp fast (0.5-1.0 T/s).
- A reasonable RF system would dictate a significantly longer ramp up of 2 min.
- Most of the filling time is dictated by the existing injection chain. (Potential for upgrades.)
- Total "on paper" FCC filling time: 29 min.