FCC-hh proton transfer line

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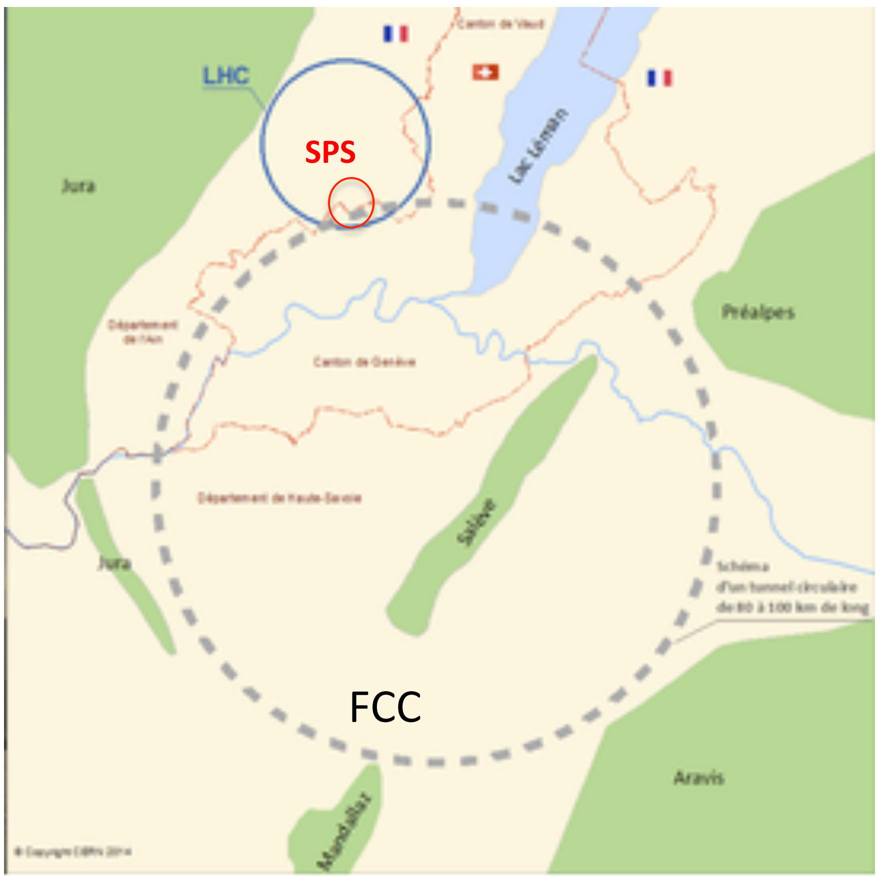
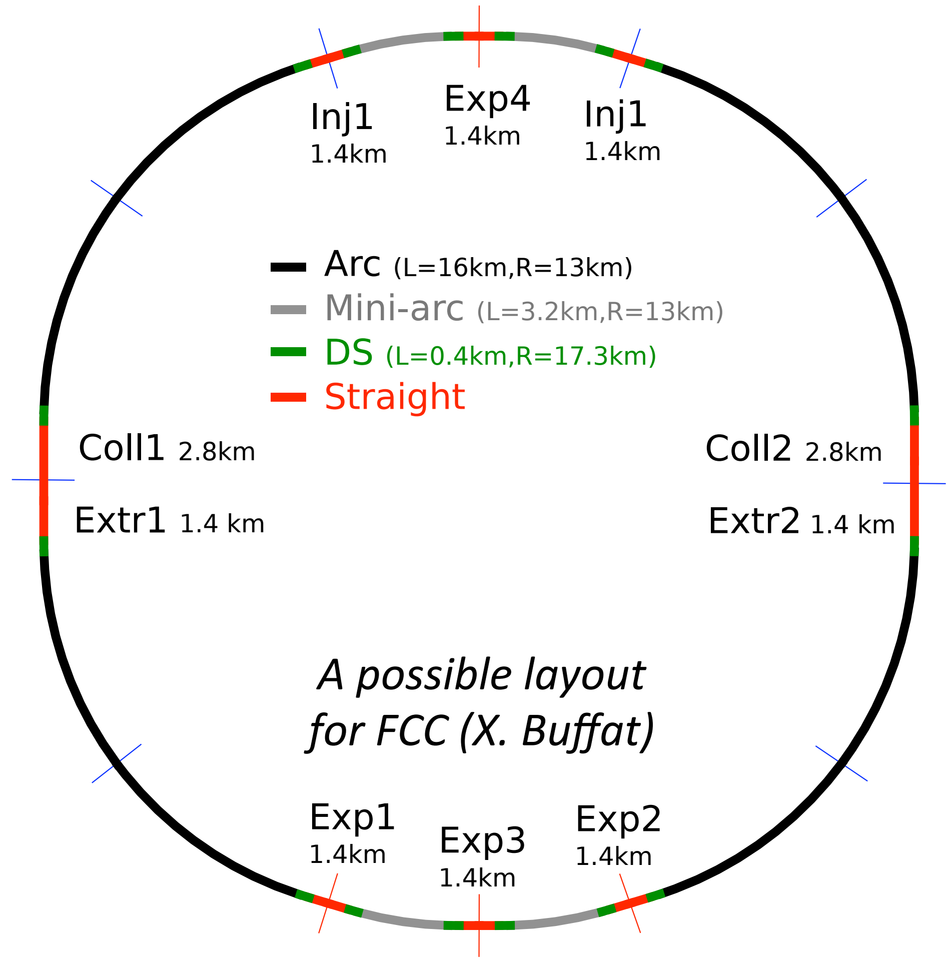
Introduction

Case Study: FCC-hh transfer line

- FCC (Future Circular Collider) proposal for hh physics: a 100 km ring.





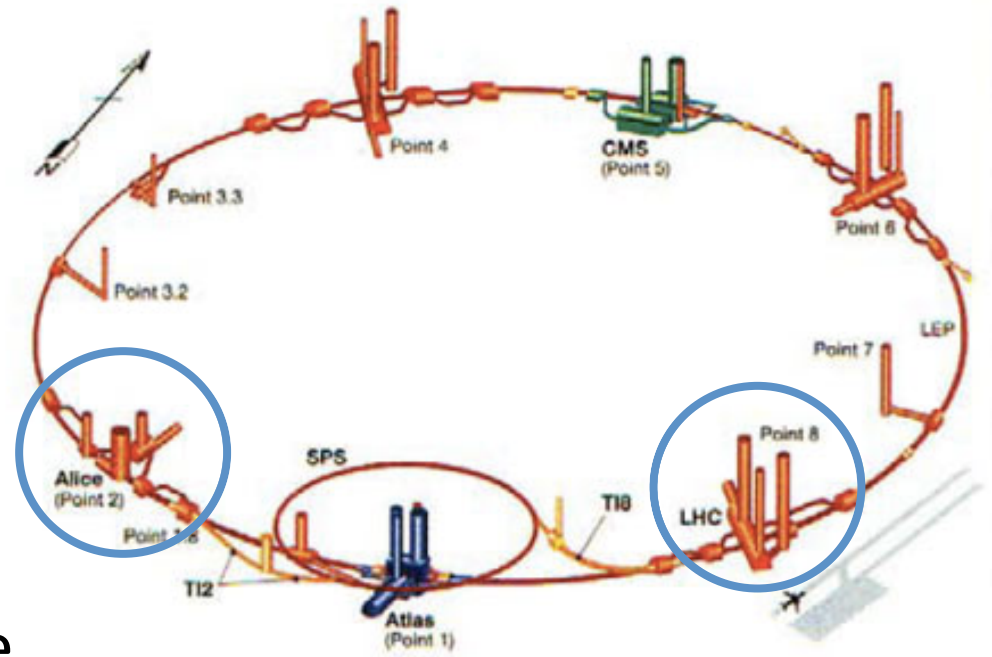
FCC Beam Parameters

Energy	**100 TeV c.m.**
Dipole field	**~ 16 T (Nb_3Sn), [20 T option HTS]**
Circumference	**~ 100 km**
#IPs	**2 main (tune shift) + 2**
Luminosity/IP$_{main}$	**5×10^{34} cm^{-2}s^{-1}**
Stored beam energy	**8.2 GJ/beam**
Synchrotron radiation	**26 W/m/aperture** (filling fact. ~78% in arc)
Long. emit damping time	**0.5 h**
Bunch spacing	**25 ns [5 ns option]**
Bunch population (25 ns)	1×10^{11} p
Transverse emittance	2.2 micron normalized
#bunches	10500
Beam-beam tune shift	0.01 (total)
β*	1.1 m (HL-LHC: 0.15 m)

already available from SPS for 25 ns

LHC-FCC Transfer Lines

- Need to descend by ~200 m from LHC to FCC
  - Vertical bending achieved with SC dipole magnet
- Location:
  - Assuming no experiments in IP2 and IP8
  - Assuming location of FCC to be south of LHC
  - Put transfer lines on the other side of IP2 and IP8



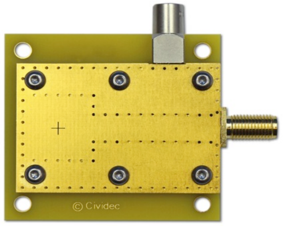
Transfer Line Elements

- Quadrupole magnets (focusing)
- Superconducting dipole magnets (bending)
- Fast septum + kicker magnets (LHC extraction + FCC injection)
- Beam instrumentation
- Machine protection systems

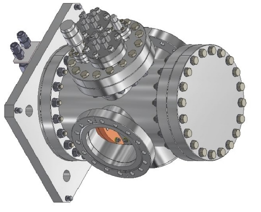
Beam instrumentation, Failure Scenarios and MPS

Transfer Line Beam instrumentation

- Diamond Beam Loss Monitors (BLM)
  - Capture bunch-by-bunch losses



- Beam Position Monitors (BPM)



- Beam Current Transformers (BCT)

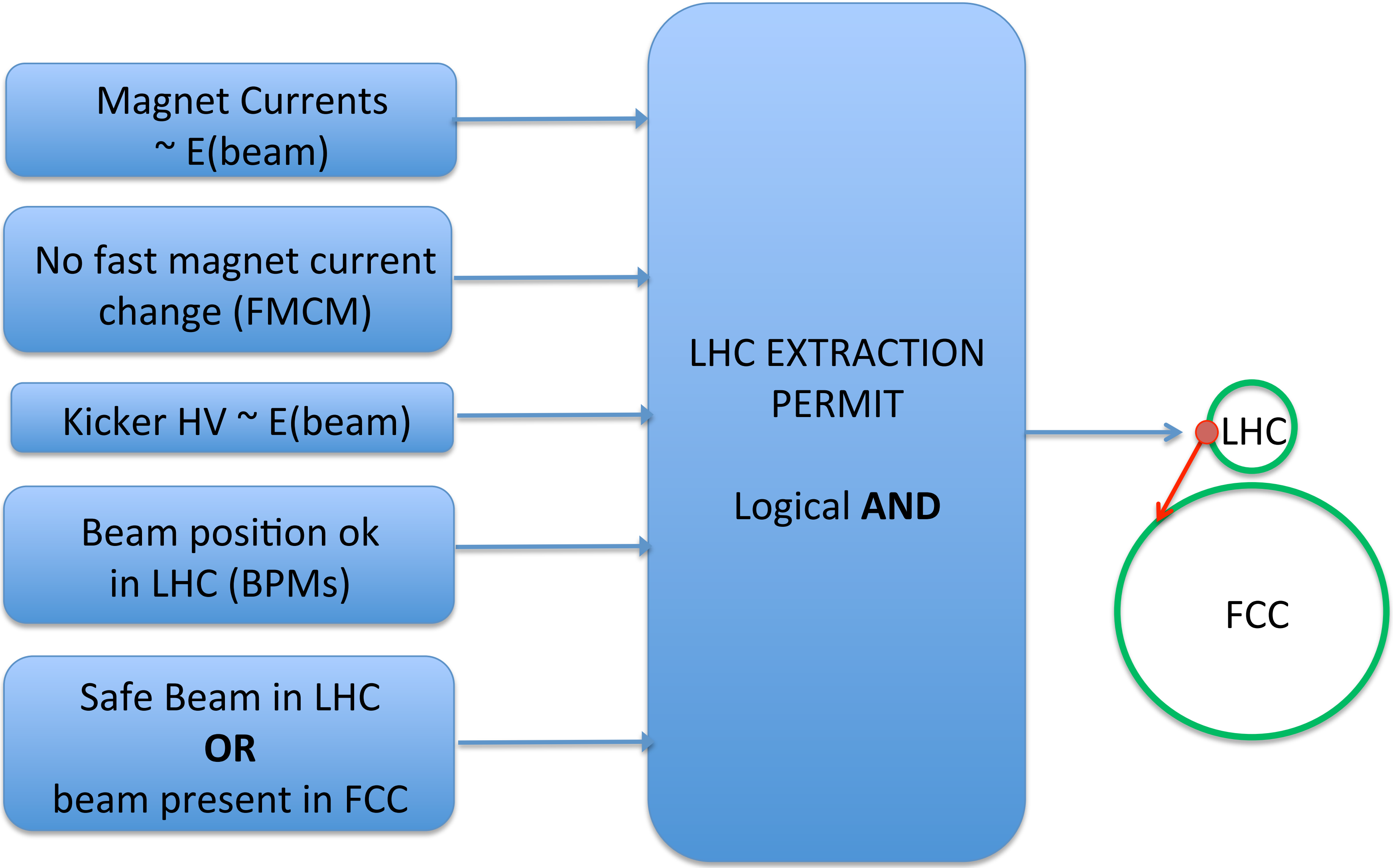
Transfer Line Failure Scenarios

- Extraction / Injection septum or transfer line magnet power failure
  - magnet current inconsistent with beam energy (Safe beam parameters)
  - undesired fast magnet current change
- Extraction / Injection kicker failure
  - HV inconsistent with beam energy (Safe beam parameters)
- Superconducting magnet quench

Pilot bunch

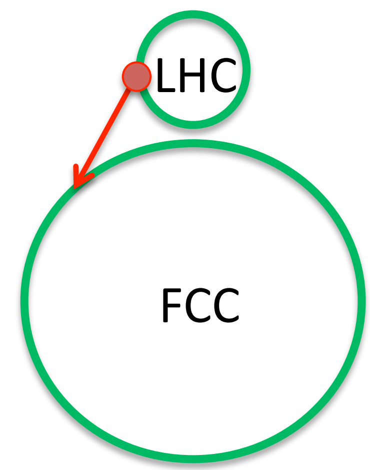
- First a **pilot bunch** is injected into LHC, ramped up and injected into FCC.
- **The circulating bunch indicates that transfer line and FCC settings are ok.**
- Then this procedure is repeated with more bunches.

Transfer Line BIS



Passive protection

- Extraction collimators (in LHC)
- Transfer line collimators
  - Full phase space coverage
- Injection collimators (in FCC)
  - After injection kicker
  - Collimator for grazing events



- Collimator design:
  - Fixed: more robust material e.g. graphite
  - Rotatable: less robust (Glidcop), can be rotated to achieve fresh surface after impact

Operational parameters

Injection parameters

- Which beam energy?
- Which filling scheme?

- Trade-off between operational efficiency and machine protection

- LHC filling time:
  - **#SPS bunch trains** x 20 s + **E (Tev)** * 200 s ramp

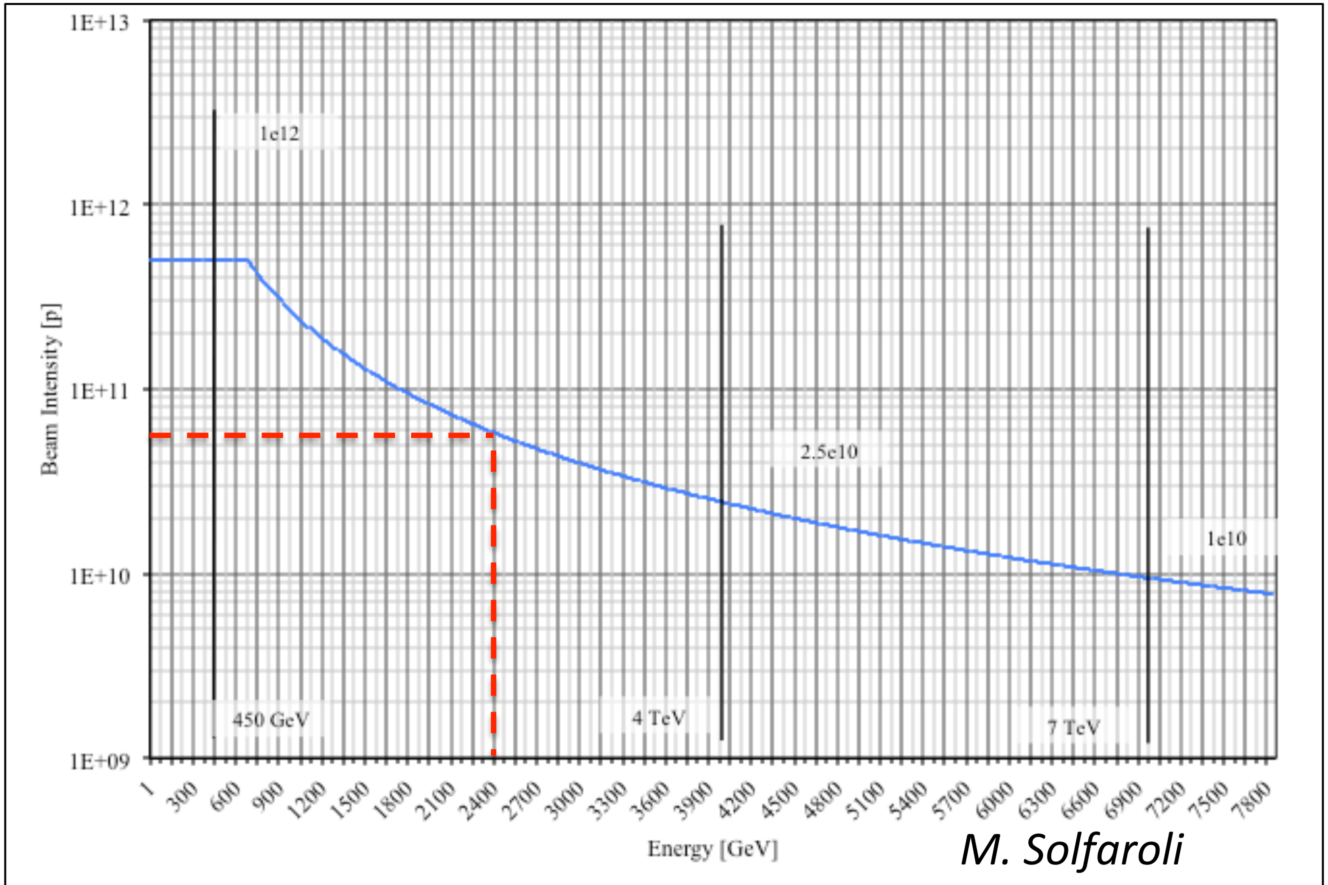
- Injection energy: 2.5 TeV (minimum of factor 20 constraint)
  - Least time for LHC ramp, ramp-down, pre-cycle
  - Lowest energy for transfer line MP
  - Safer for LHC circulating beam (quenches)
  - Lowest field strength and rise time for kicker magnet

FCC Filling Procedure

- Inject from SPS to LHC @ 450 GeV
- Ramp LHC to 2.5 TeV
- Extract from LHC to FCC @ 2.5 TeV
- **Variable:** #bunches/FCC injection

Pilot bunch

- Inject pilot bunch from SPS, ramp from 450 GeV to 2.5 TeV in LHC, inject to FCC and circulate.
- Pilot bunch intensity: 5E10 p



M. Solfaroli

Filling Scheme

- "Safe" beam intensity / injection = 72 bunches @ 2.5 TeV = 2.88 MJ

- Inject 18 trains of 72b from SPS to LHC (1296 total), with 3 μs spacing for FCC injection / LHC dump.

LHC INJ

$$18\text{x}\ \{(72\text{b} + 8\text{e}) + 31\text{e} + 80\text{e}\}$$

SPS INJ

FCC INJ / LHC DUMP

b = full bunch
e = empty bunch

- 9 LHC fills needed to fill FCC

- Allow circulation for several turns in FCC, then fire LHC-FCC kickers to close the empty space (boxcar stacking).

- Leave > 5 μs empty for FCC beam abort.

Risk Calculation for Transfer Line

- Risk = Probability * Consequence
- The more times the LHC-FCC kickers are fired, the more likely a failure will occur in X years
- Going to higher bunch multiples (144, 288, ..) does not mean lower #LHC fills by same factor
  - 288b trains still need 5 LHC fills (vs 9 for 72b)
- The exact #bunches will depend on the robustness of passive protection + accepted downtime