Session 4 Summary: HE-LHC Injector and Infrastructure

Conveners: Eric Prebys; Luca Bottura (s. secr.)

Speakers

Session 4: HE-LHC injector & infrastructure - (15:15-19:10)

- Conveners: Eric PREBYS; Luca BOTTURA, (s.secr.)

time	[id] title	presenter
15:15	[28] Optimal injector cascade for HE-LHC and possible implementations 15'	GAROBY, Roland
15:35	[29] Using Tevatron magnets for HE-LHC or new ring in LHC tunnel? 15'	Dr. PIEKARZ, Henryk
15:55	[30] FAIR magnets and design concepts of interest to HE-LHC 15'	Dr. SPILLER, Peter
16:15	[31] Magnet design issues & concepts for the new injector 15'	FABBRICATORE, Pasquale
16:35	COFFEE BREAK 15'	
16:50	[32] Using LHC as injector, and possible uses of HERA magnets/coils? 15'	Dr. MESS, Karl Hubert
17:10	[33] Intensity limits and machine protection 25'	Dr. ASSMANN, Ralph
17:40	[34] Beam transfer and beam dump issues 20'	Dr. GODDARD, Brennan
18:05	[35] Radioprotection issues after 20 years of LHC operation 15'	FORKEL-WIRTH, Doris
18:25	[36] Questions and discussion 45'	

Roland Garoby: Injector Cascade Issues

- Note:
  - Matching the needs of the „High Luminosity LHC“ (HL-LHC) is the objective of the „LHC Injectors Upgrade“ (LIU) project
    [time period: ~2017 – 2030],
  - The „High Energy LHC“ (HE-LHC) sets different requirements on the injectors, and with a different time-scale
    [time period: ~2030 – 2050],
  - Past workshops (especially LER06 and LUMI06) are highly valuable sources of information.

Beam specifications

Derived from CERN-ATS-2010-177 [„First thoughts on a higher energy LHC"]

Specific to HE-LHC

	Nominal LHC	HL-LHC	HE-LHC
Beam energy [GeV]	450	450	> 1000
Distance between bunches [ns]	25	25 (resp. 50)	50
Bunch population* [10^{11} p/b]	1.2	~1.8 (resp. 3.6)	~1.4
Transverse normalized emittance [μm]	3.75	$\geq$ 2	3.75 (H) 1.84 (V); 2.59 (H & V)
Longitudinal emittance [eVs]	1	1	? (<4)

* At LHC entrance, assuming 5% loss wrt to start of physics data taking at high energy

Only injection energy beyond existing injector complex

Highest energy injector

Only requirement outside the capability of the existing injectors: need for > 1 TeV.

Two options:

1. In the SPS tunnel
   - ⇒ New SPS (HE-SPS) with fast cycling sc dipoles
   - ⇒ Replacement of equipment in TI2 and TI8 transfer lines (sc magnets)

2. In the LHC tunnel
   - ⇒ No change to SPS and transfer lines
   - ⇒ Additional double aperture 27 km ring compatible with detectors
     - ⇒ Bypasses
     - ⇒ Passage through detectors‘ centres using fast deflecting magnets

However…

- Existing complex aging
  - PS will be 70 years old before HE-LHC could be built
- Consider an integrated plan for HL-LHC, HE-LHC, and other CERN physics programs.
- Perhaps arrive at something like Fermilab is considering

Bmax~5 T
Bdotmax~2T/s

Bmax~4 T
Bdotmax~3T/s

Energy range	Machine	Other application
100 GeV – 1.2 TeV	HE-SPS	RIB acceleration?
~8 - 100 GeV	HE-PS	RIB acceleration ?
Up to ~8 GeV	SC linac	(+ 2 fixed energy rings) μ production for ν factory

S-SPS and LER injector options for 33 TeV HE-LHC

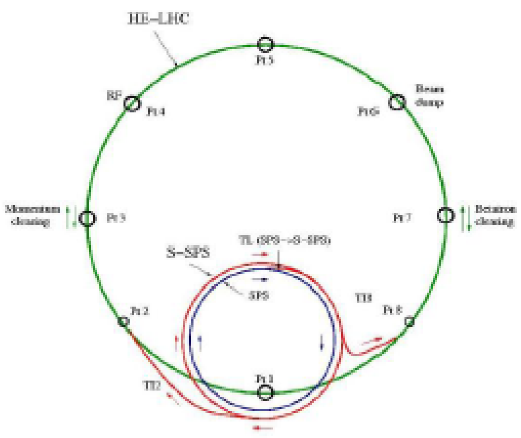
Option 1: Super-SPS (S-SPS) accelerator in SPS tunnel –> single, 1 (1.3) TeV beam

Option 2: LER (Low-Energy-Ring) in LHC tunnel –> dual, 1.65 TeV beam

S-SPS OPTION

SPS (150 GeV) -> S-SPS (1, 1.3 TeV) -> HE-LHC (16.5 TeV)

24 S-SPS injections to fill HE-LHC



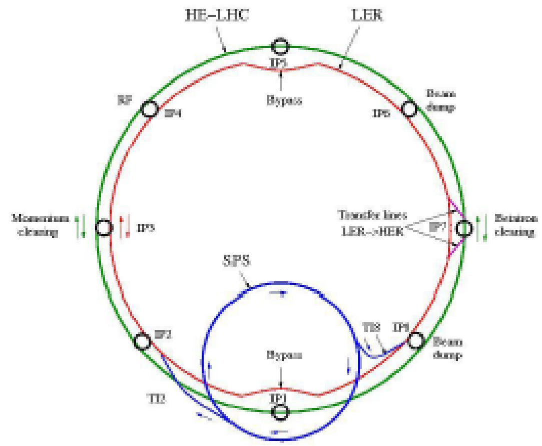
New beam lines: 12560 m

S-SPS: 6900 m (main ring) + 2 x 2800 m (S-SPS->HE-LHC transfer lines)

LER OPTIONS

SPS (450 GeV) -> LER (1.65 TeV) -> HE-LHC (16.5 TeV)

Single LER transfer to HE-LHC



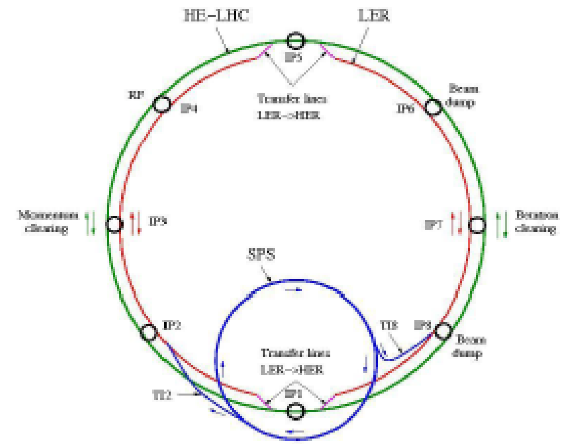
Option 1

Bypassing detectors & transferring beams at IP7

New beam lines: 26700 m

LER: 24240 m (main ring) + 2 x 1000 m (bypass) + 2 x 104 m (LER-> HE-LHC transfer lines)

Bypass lines require ~ 2000 m of new tunnel



Option 2

Transferring beams at IP1 & IP5

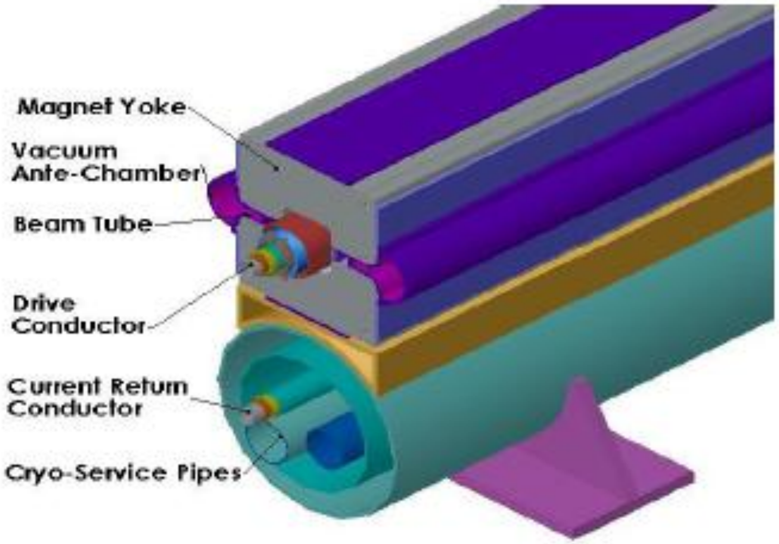
New beam lines: 26320 m

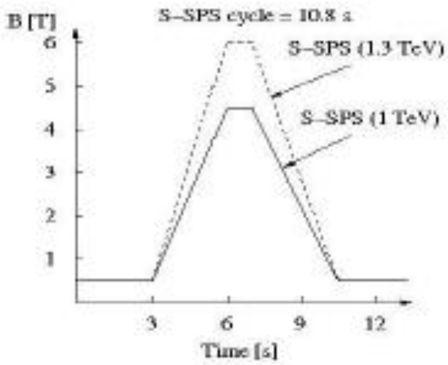
LER => 25904 m (main ring) + 4 x 104 m (LER-> HE-LHC transfer lines)

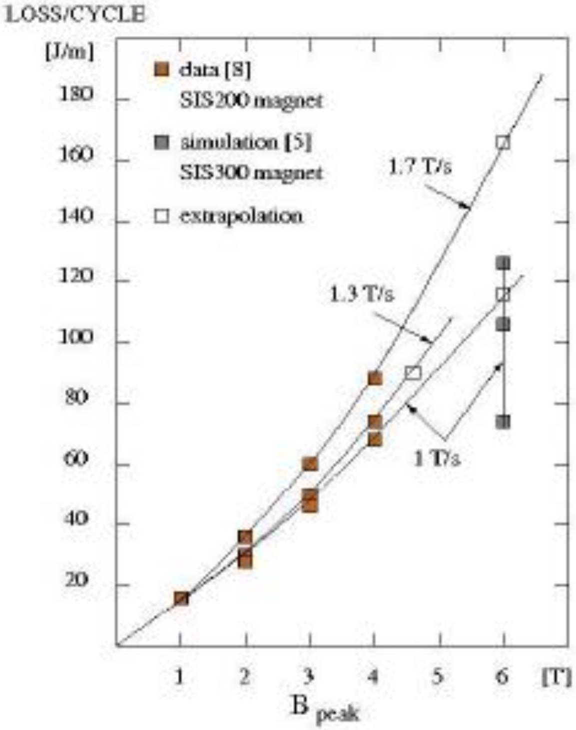
10/15/2010 HE-LHC'10 Henryk Piekarz 4

S-SPS vs. LER cont.

- S-SPS complicated because of high ramp rate
  - Power for 4.5 T @ 1.3 T/s 15 W/m (might be high)
  - Cost: $2B based on FAIR
- Consider LER based on VLHC design







Summary

Injector properties	S-SPS	LER
Injection energy [TeV]	1 (1.3)	1.65
Doubling bunch intensity	NO	YES
Injection to HE-LHC	24	1
HE-LHC filling cycle [min]	4.5 (6.8)	10.5
Temperature margin [K]	0.5 (<0.5)	2.7
Quench probability	HIGH	LOW
Operation complexity	HIGH	LOW
Construction complexity	HIGH	MEDIUM
Construction cost (est.) [M€]	2,000	370 (260)
Electric power use (est.)[MW]	129 (187)	26 (12)

S-SPS injector qualities are likely to be incompatible with HE-LHC

LER is well qualified as injector to HE-LHC

Peter Spiller: FAIR magnet R&D

FAIR

- FAIR experiments require high average intensity > Fast ramped magnets

(short cycle times)

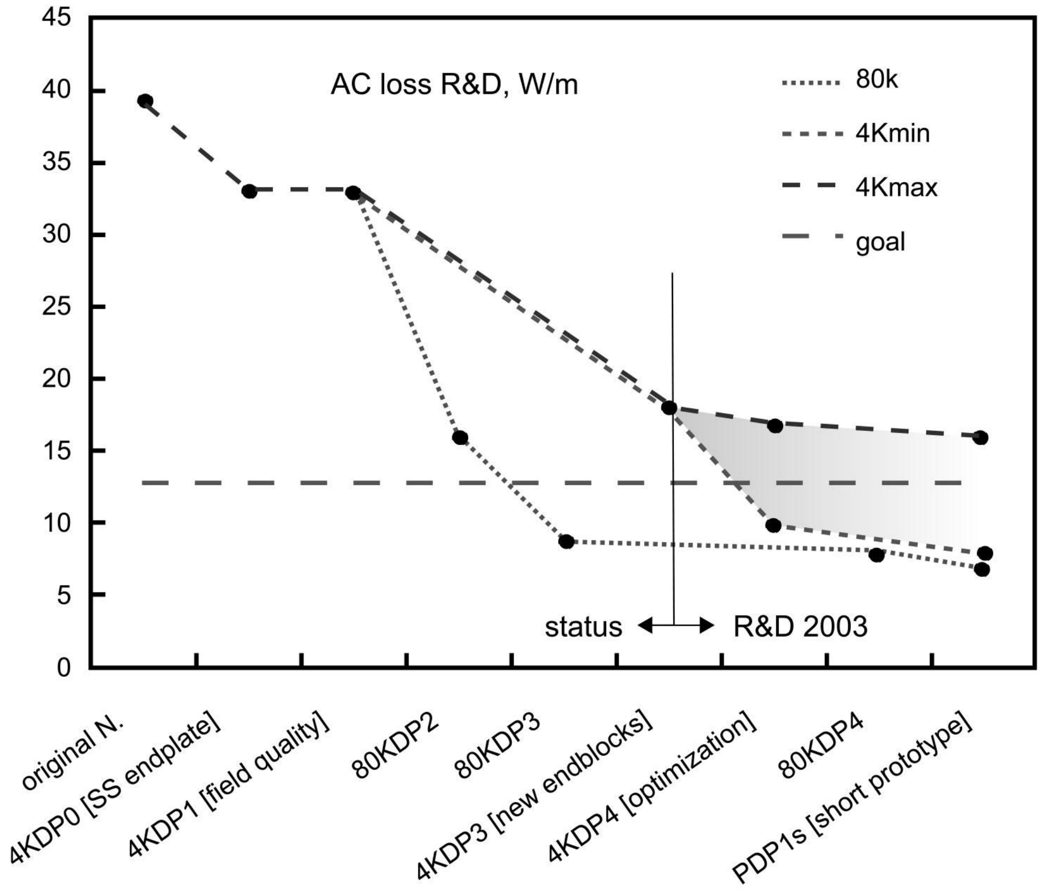
- FAIR is supposed to be highly parallel and flexible
- At a circumference of about 1km, curved dipole magnets are needed. > Restriction in total pulse power (magnet aperture) and acceptance drop by large sagitta.

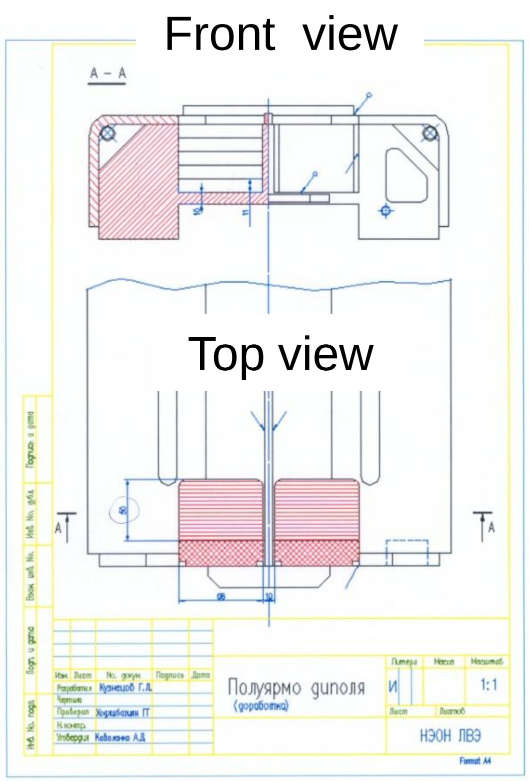
CERN/SLHC

- SIS100 magnet technolgy, its design and R&D may be of interest for a s.c. PS.
- SIS300 magnets technology, its design and R&D may be of interest for a s.c. SPS (e.g. increase of final energy, energy consumption/pulse power)

SIS 100 Fast Ramped S.C. Magnets

R&D goal: AC loss reduction to 13 W/m @ 2T, 4 T/s, 1 Hz





New endblock design

Pasquale Fabbricatore: SIS300 R&D

SIS300 dipoles: fast cycled and curved magnet

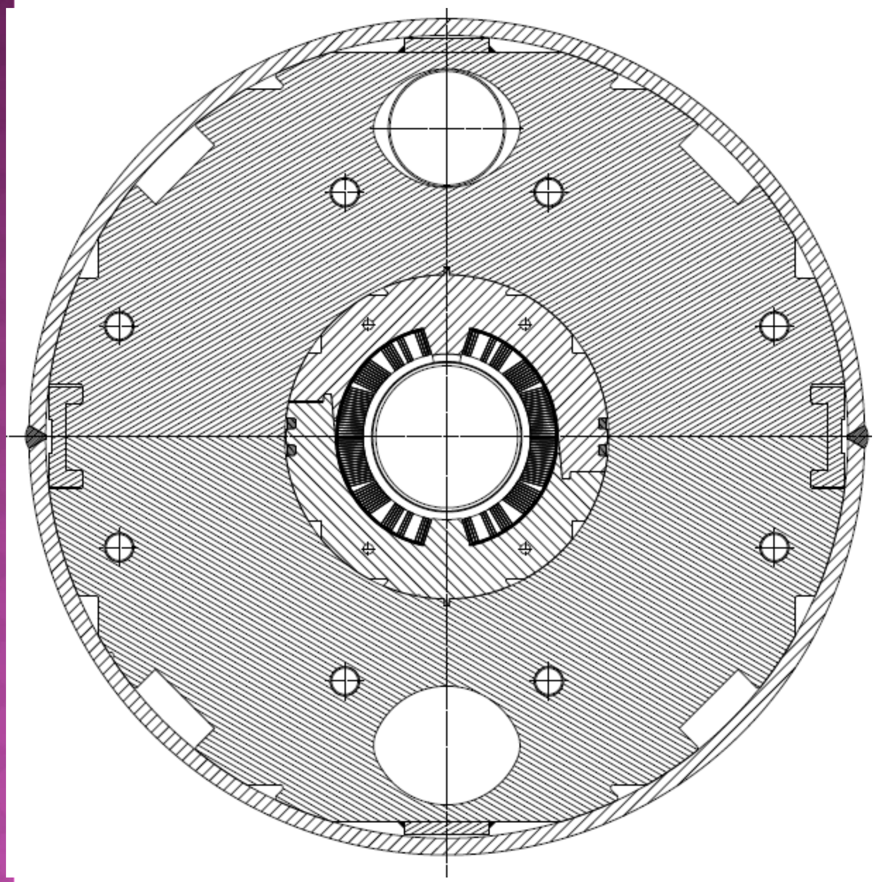


TABLE I MAIN REQUIREMENTS OF SIS300 SHORT DIPOLES

Nominal Field (T) :	4.5
Ramp rate (T/s)	1
Radius of magnet geometrical curvature (m)	66 2/3
Magnetic Length (m)	3.879
Bending angle (deg)	3 1/3
Coil aperture (mm)	100
Max operating temperature (K)	4.7

TABLE II MAIN CARACTERISTICS OF THE MODEL MAGNET

Block number	5
Turn number/quadrant	34 (17+9+4+2+2)
Operating current (A)	8920
Yoke inner radius (mm)	96.85
Yoke outer radius (mm)	240.00
Peak field on conductor (with self field) (T)	4.90
B_{peak} / B_o	1.09
Working point on load line	69%
Current sharing temperature (K)	5.69

Criticities of SIS300 dipoles

	Aperture (mm)	B (T)	dB/dt (T/s)	Π (T^2/s)	Q (W/m)
LHC	53	8.34	0.008	0.067	0.18
RHIC	80	3.5	0.06	0.21	0.35
SIS300	**100**	4.5	**1**	**4.5**	**<10**

Ramp 1T/s → ac losses → Limited performances
→ Costs of Cryogenics

Hence: Development of a low loss conductor
Design with loss minimization (taking care of eddy currents in structures)

Low ac losses→ Cored conductor→ Constructive problems

Curvature R=66.667 m (sagitta 117 mm) → Design and constructive problems

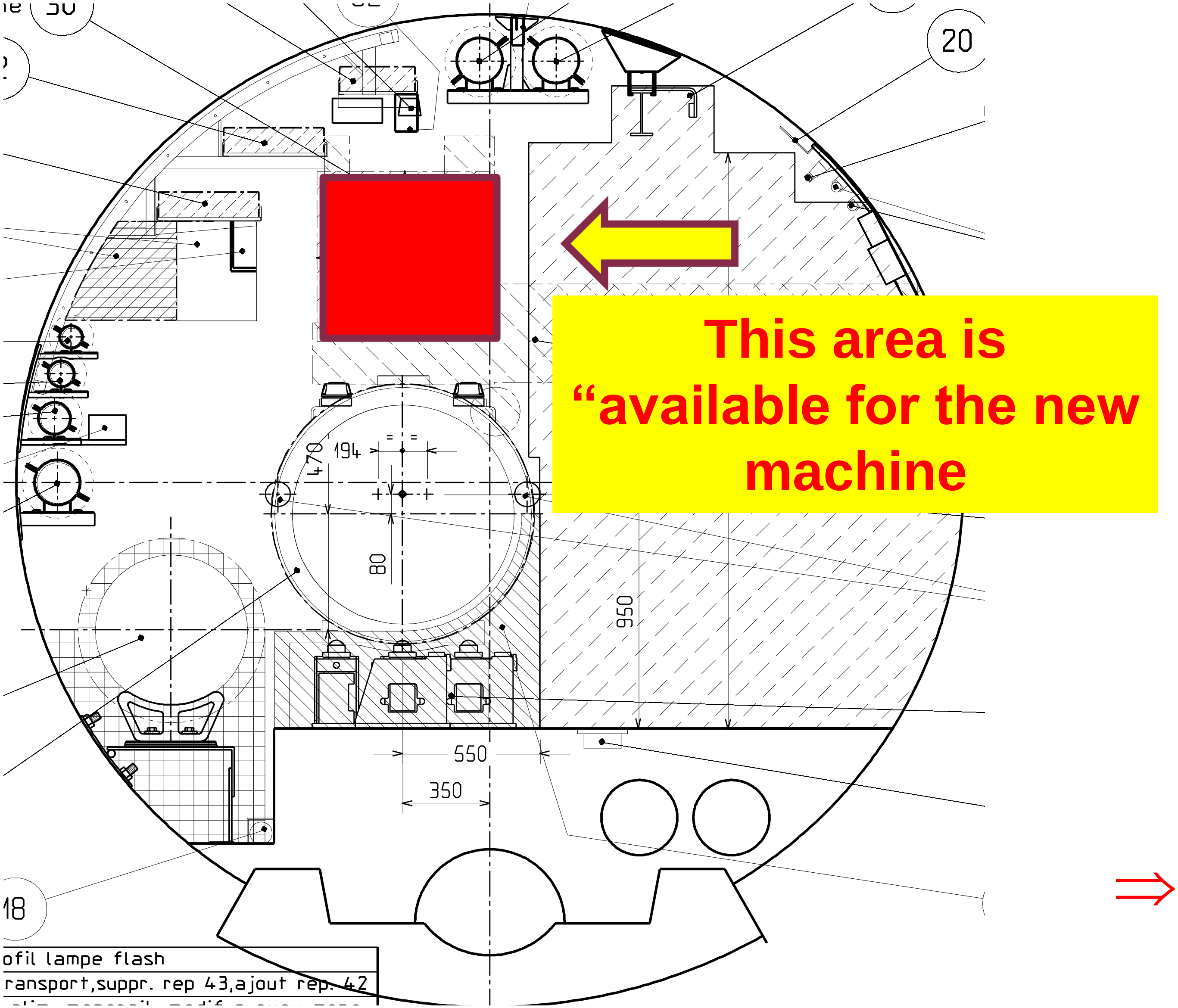
10^7 cycles → Fatigue → Mechanical design and materials optimization

Parameters	SIS300 dipole	Injector 4T 100mm 1.5T/s	Injector 6T 100mm 1.0T/s
Injection magnetic field [T] and b_3	1.5/ -0.75	0.4/ -4.5	0.4/-5.9
Maximum/ Peak magnetic field [T]	4.5/4.9	4.0/4.4	6/6.42
Temperature Margin (K)	0.97	1.66	0.65
AC losses in the superconducting cable during ramp [W/m]	3.5	5.6	6.3
AC losses in the structures during ramp (eddy currents and magnetization) [W/m]	3.5	5.9	4.3
Weight [T/m]	1.28	1.28	1.68
Const. Cost [K€/m] evaluated on 60 magnets	60-70	60-70	80-90

Karl Hubert Mess: LHC as injector + possible use of HERA magnets

Machine	LHC [1]	HERA [2]
Circumference	26.7 km	6.4 km
# of main bends	1232	422
Magnet length	14.3 m	8.9 m
Field	0.535...8.33 T	0.227...4.649 (5.216) T
Current	763...11850 A	245...5027 (5640) A
Beam energy	450...7000 GeV	40...820 (920) GeV
Bending radius	2804 m	588 m
Sagitta	9.14 mm	14.4 mm
Inner coil diameter	56 mm	75 mm
Cold tube diameter	50 mm	55.3 mm
Nom. dI/dt	10 A/s	10 A/s
Tunnel diameter	3.76 m	5.20 m

However…

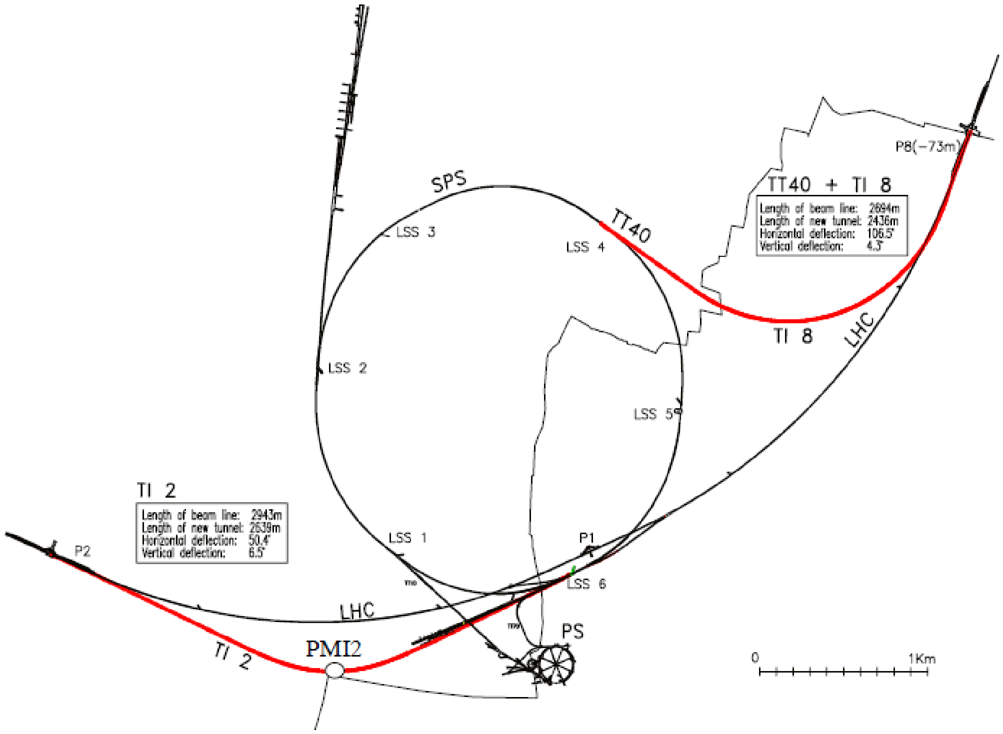

20
18
194
470
80
950
550
350
ofil lampe flash
ransport,suppr. rep 43,ajout rep. 42
This area is "available for the new machine

⇒NO!

Recycling in a most drastic fashion ?

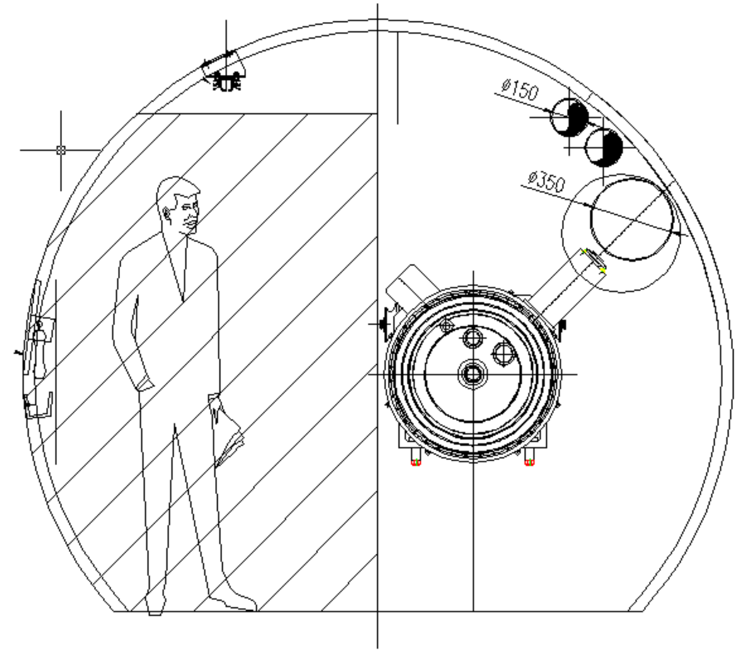
HERA Magnets [6]

- The injection lines TI2 and TI8 have almost the bending radius as HERA.
- The SPS has a larger radius and a wide tunnel, the HERA magnets would fit.
  - However HERA is slow and useless as a SPS upgrade.

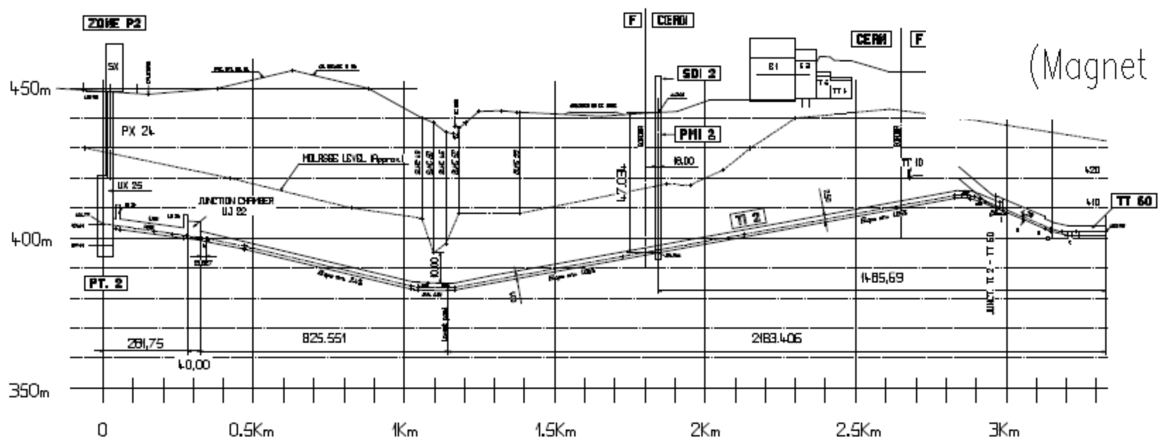


However…

- Transfer lines very small
- Polarity wrong
- Cryogenics wrong
- T12 slope a problem

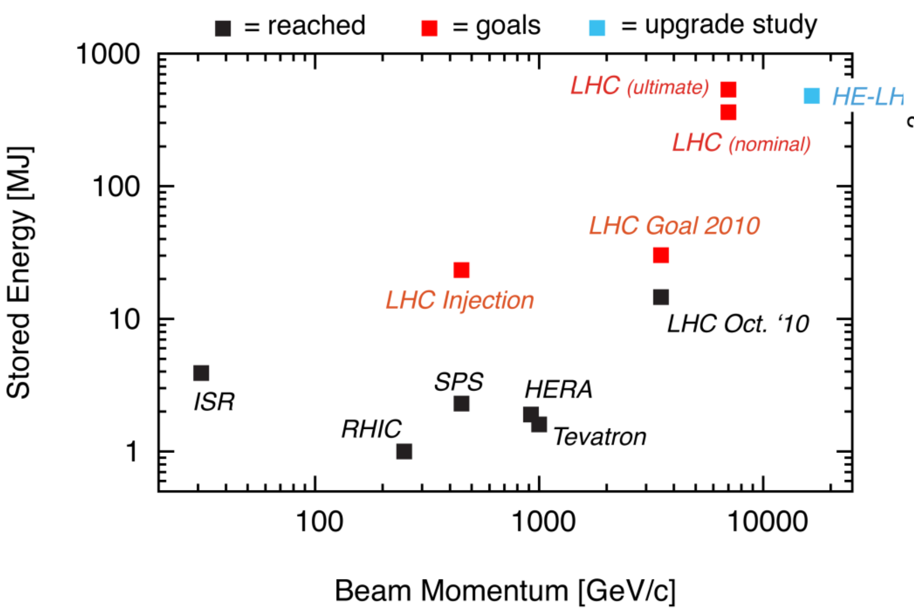


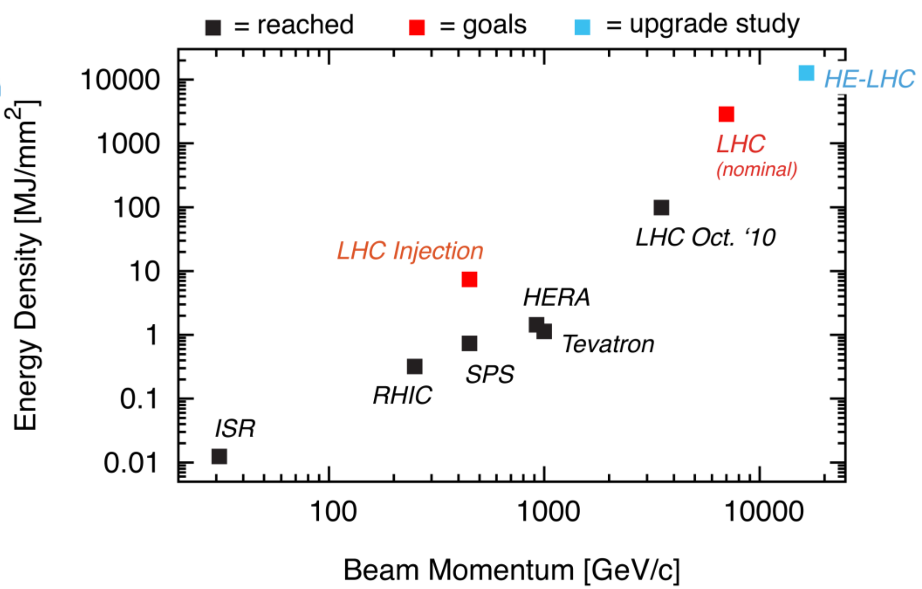
TI8 Cross–Section
(Magnet on the tunnel outer curvature)



- ⇒ with "free" stuff, sometimes you get what you pay for

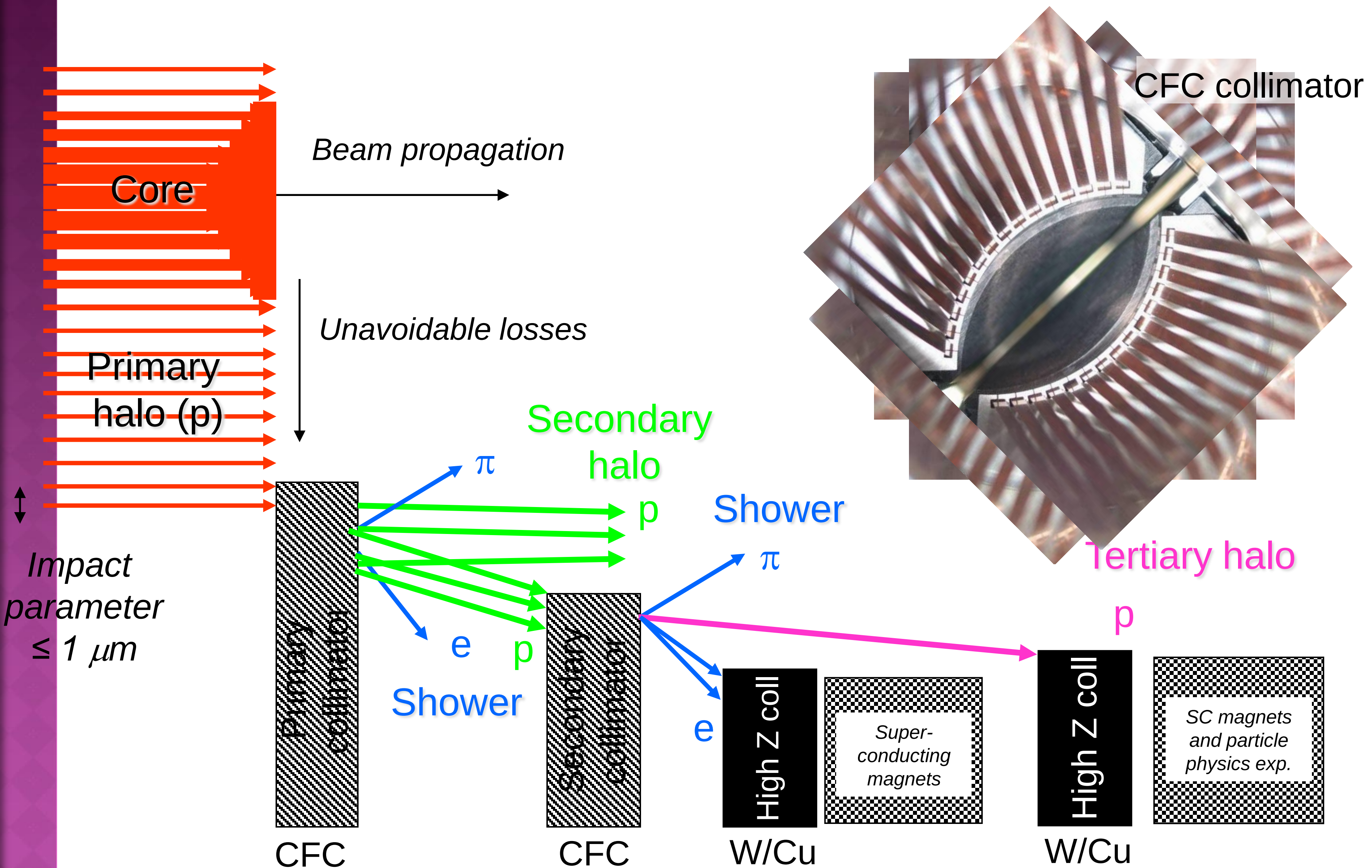
Ralph Assmann: Intensity Issues



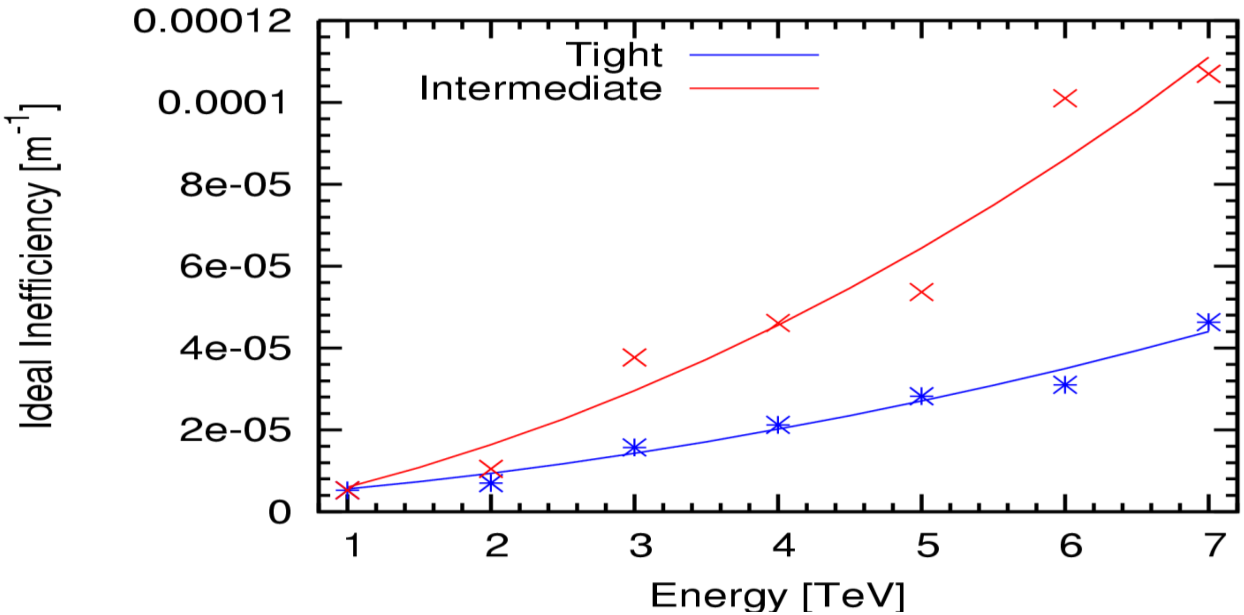


Multi-Stage Cleaning & Protection

3-4 Stages



Cleaning inefficiency



- The cleaning inefficiency is approximately proportional to the relative probability of a single diffractive scatter

$$P_1 = P_0 \cdot \frac{E_1 \cdot \ln(0.3 \cdot E_1)}{E_0 \cdot \ln(0.3 \cdot E_0)} \qquad \text{with } E_1 > E_0$$

  - Factor of 2.6 worse at 16.5 TeV than 7 TeV, but probably not a show stopper

HE-LHC Situation for Robustness

- Respect absolutely the following condition:

$$\frac{\mathbf{N_p}}{\epsilon} \leq 3.4 \times 10^{20}\,\mathrm{m}^{-1}$$

- Present design parameters HE-LHC at 16.5 TeV:

$$\mathrm{HE\text{-}LHC} \longrightarrow \quad \frac{\mathbf{N_p}}{\epsilon} = 8.7 \times 10^{20}\,\mathrm{m}^{-1}$$

→ **Not a priori OK!**

Comparison assumes similar kicker rise times, leakage, failure scenarios,…

HE-LHC with Present Technologies

- **Bunch density factor 2.6 above limit.**
- Possibility 1 (this works for sure):
  - Increase emittance: **0.15 nm → 0.38 nm**
  - Feasible with present technologies.
  - Luminosity reach: 9.4×10^{33} cm^{-2} s^{-1} (~ half)
- Possibility 2 (can be good or bad news):
  - Review damage limits.
  - Further simulations.
  - Experimental studies: HiRadMat
- Possibility 3 (looks quite promising):
  - **New collimator and absorber technology**
  - Studies are underway → EuCARD/ColMat

No showstopper

Issues with Smaller Gaps

- Must try to keep collimator gaps reasonably large.
- Ideally for available SC aperture a [σ] in collision:

$$a\,[\sigma]\,(16.5\ \text{TeV}) = 1.5 \times a\,[\sigma]\,(7\ \text{TeV})$$

- This costs reach in β^* or requires the same IR/DS apertures (in mm).
- Alternative (if we keep collimation at ~6 σ):
  - New LHC collimator technology for factor 2 smaller gaps and even higher precision and reproducibility.
  - Live with much higher impedance.
  - Live with operational tolerances (orbit) at the 20-30 μm level.

Doris Forkel-Wirth: HE-LHC from RP's Point of View

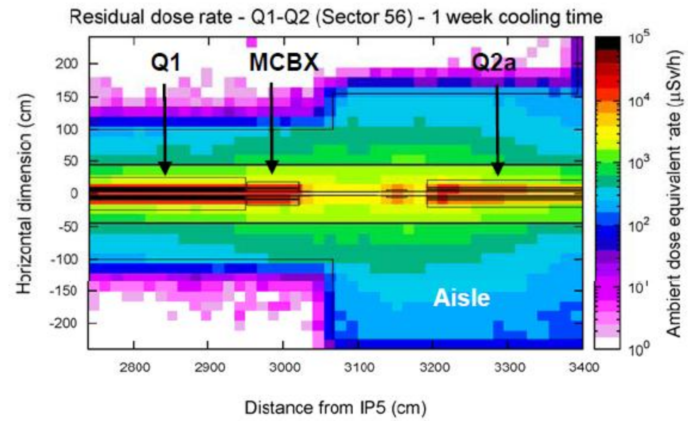
To convert LHC/HL-LHC into HE-LHC after 20 years of operation implies:

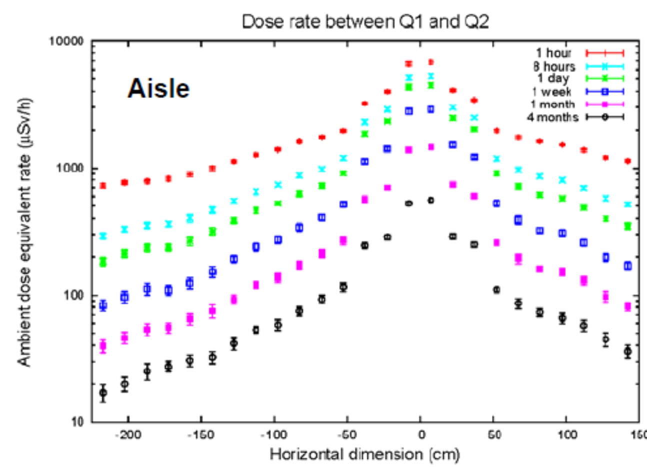
- exposure of workers to ionizing radiation
  - removal of dipoles
  - removal of inner triplets (?)
  - removal of collimators (?)
  - modification of beam dumps (?)
  - LHC experiment modifications/upgrades
  - installation of new components
- radioactive waste
  - production
  - conditioning
  - interim storage
  - final disposal

Inner Triplet

LHC mode	Duration	Ambient dose equivalent rate
nominal	5 y	up to 600 uSv/h
HL-LHC	10 y	up to 1 mSv/h

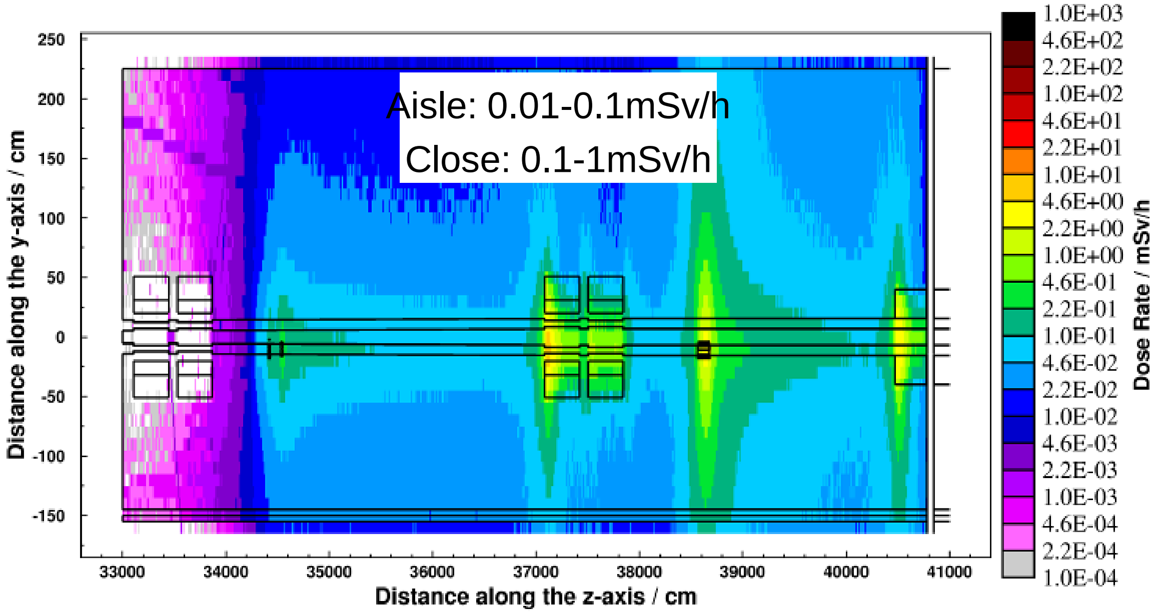
Monte Carlo results for 180 days at nominal luminosity





Collimators

2030 – after HL-LHC:
Aisle: 0.03 – 0.3 mSv/h
Close 0.3 – 3 mSv/h



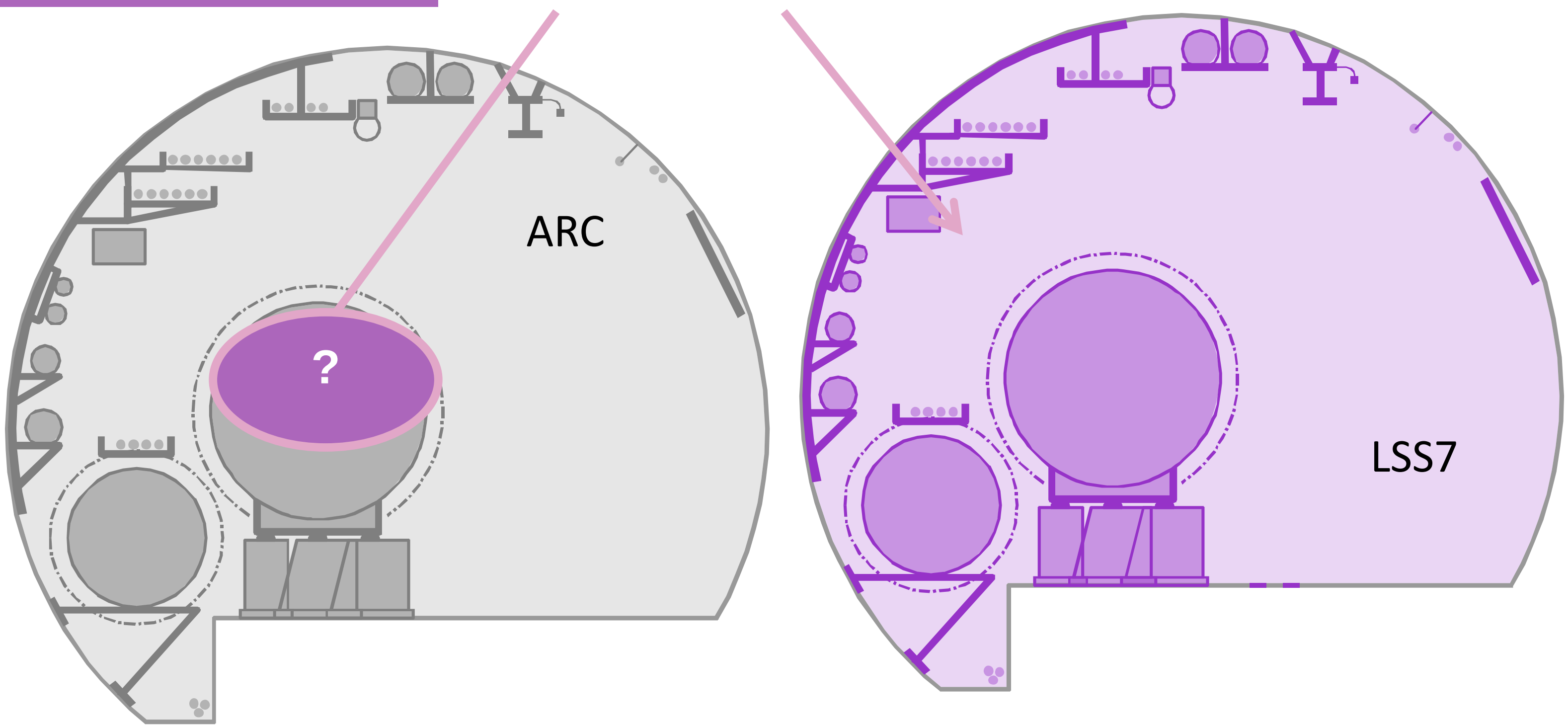
Monte Carlo results for 180 days of nominal operation, 4 months cooling

Bottom line: need ALARA and possibly remote handling facilities

Waste Production

2030: LH-LHC, lower release limits

Radioactive after 10 years of LHC nominal operation and 4 months of cooling



- Low level waste at CSTFA: 3000 Euros/m^3
- High level at CERN

(brief) Discussion of transfer kickers

- Unfortunately, Brennan Goddard was not able to come, but some feeling that he "had a proposed solution"
- Obviously an important issue
- Discussion
  - Kicker effectiveness $\propto 1/E$
  - Required septum aperture $\propto 1/E^{1/2}$
  - Prob lem $\propto E^{1/2}$

Summary of summaries

- HE injector
  - S-SPS: Difficult and expensive because of high dB/dt
    - But lots of good work is being done
  - LER: Easier from an accelerator standpoint, but can it fit?
- Intensity
  - Cleaning inefficiency a factor of 2-3 worse
    - Probably manageable
  - Energy density too high for carbon
    - Investigate new materials
- Radioprotection
  - Levels on the order of ~1 mSv/hr after four month cooldown
    - Need to take care, but doable
- Transfer kickers
  - Very important topic, not really covered
  - Encourage Brennan to to contribute to proceedings