

Possible Injection Scheme in the (80 km) TOE: Tunnel Of Everything

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Work of H. Piekarz (FNAL) widely used

HE-LHC cost:

rough evaluation based on LHC

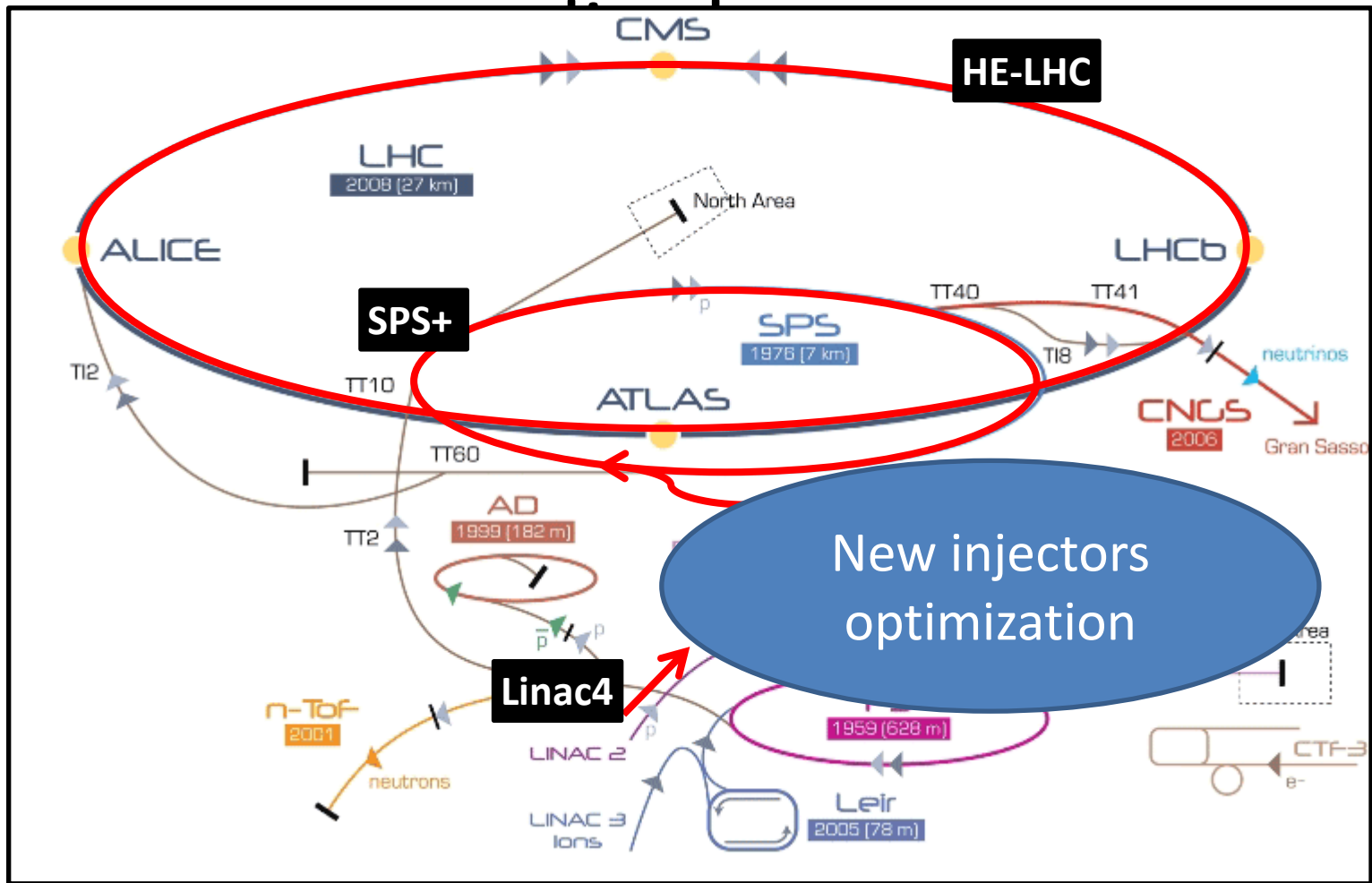
- LHC (machine): about 3 BCHF (material, 2008), **1.7 BCHF** for the magnet system,
- HE-LHC: The non-magnet is ~ same 1.5 BCHF
 - Magnet System Nb₃Sn (**26 TeV c.o.m.**) : ~ **3.5 BCHF**
(for a total of **5 BCHF for the whole machine**)
 - Magnet System HTS (**33 TeV c.o.m.**) : ~ **5 BCHF**
(for a total of **6.5 BCHF for the whole machine**)
 - The above cost are for a new machine, like LHC. Economy could be made because Cryo and other systems need only renovation;
 - **however one should consider cost of LHC removal**

Other important issues, among many

- **Synchrotron radiation**
 - 15 to 30 times!
 - The best is to use a window given by vacuum stability at around 50-60 K (gain a factor 15 in cryopower removal!)
 - First study on beam impedance seems positive but to be verified carefully
 - **Use of HTS coating at 50 K on beam screen to be explored**
- **Beam in & out**
 - Both injection and beam dump region are constraints.
 - Ideally one would need twice stronger kickers
 - Beam dumps seems feasible by increasing rise time from 3 to 5 μ s
 - Injection would strongly benefit from stronger kickers otherwise a new lay-out is needed (different with or without experiments)

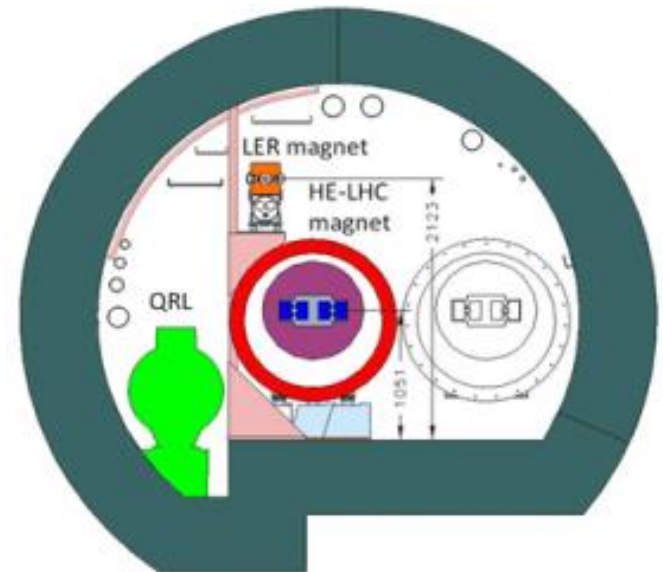
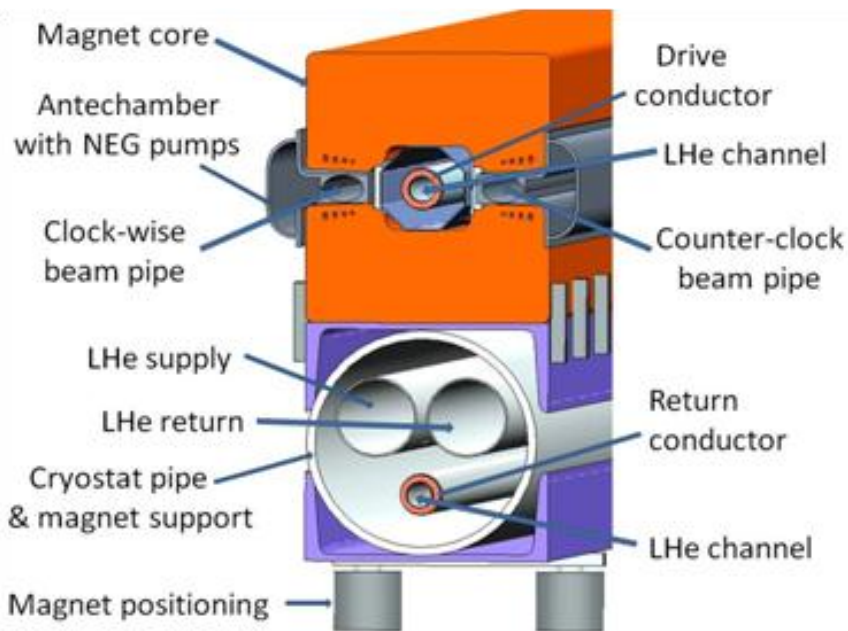
For HE-LHC :injection based on SPS+

Possible use of Tevatron and HERA



Alternate scenarios for Injectors

- Keeping SPS (and its transfer lines: 6 km!): Low Energy Ring in LHC tunnel with superferric Pipetron magnets (W. Foster).
- Work done by Fermilab (**H. Piekarz**), see Malta workshop proc.
 - **cost of LER is lower than SC-SPS option.**
 - Integration is difficult but no show-stoppers



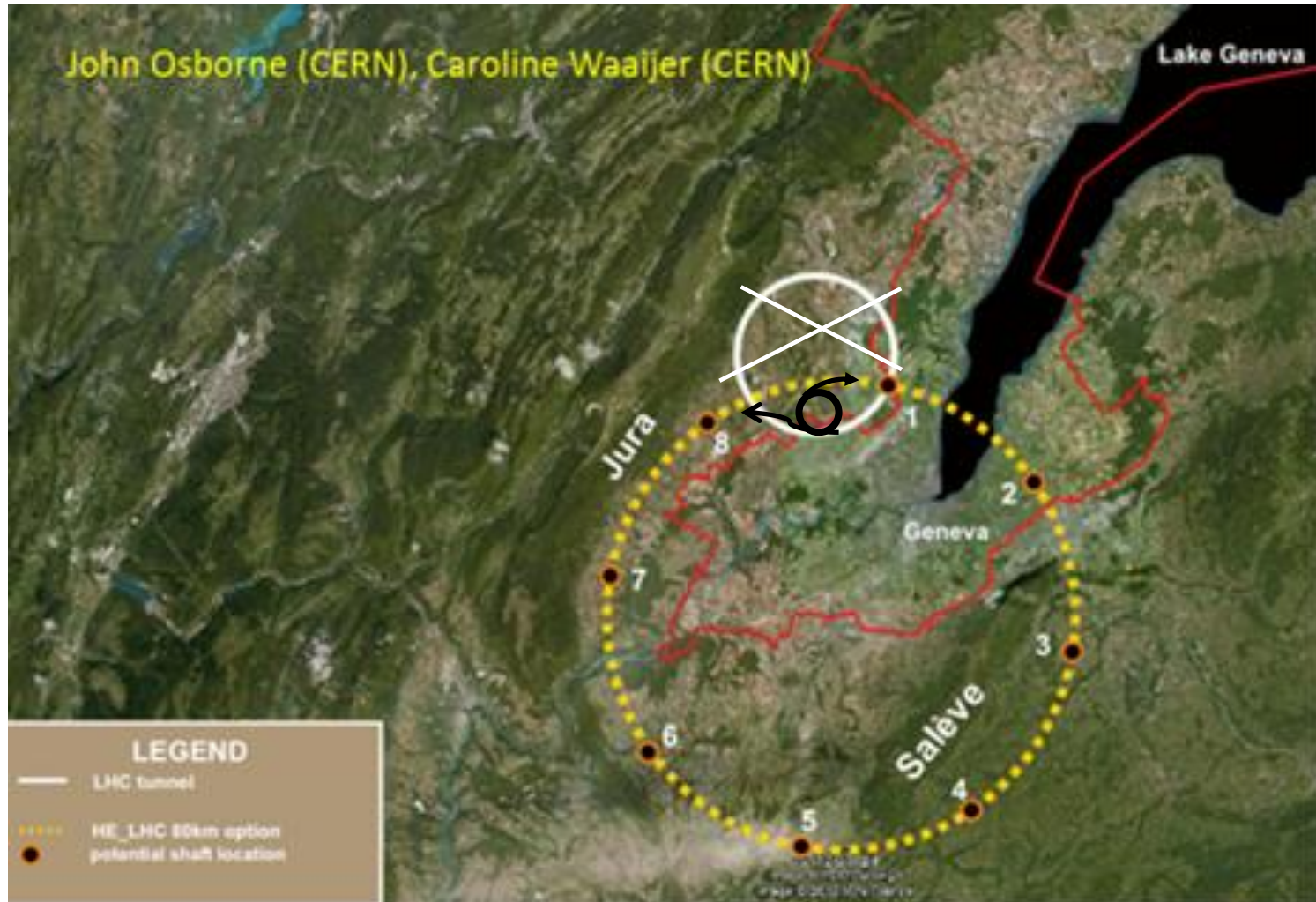
Specific issues of the VHE-LHC

- Beam Energy/Dipole Field optimization might be different
- Aperture can be larger
- Synchrotron radiation MUST be removed at the highest possible temperature: Photon stopper?
- A solution could be use of HTS coated on a beam screen at around 100 K. The wall resistance will be very low and the 2.5 MW/ring (about 30 W/m) can become 25(x2) MW of cryopower!
- Kicker problems will be strongly reduced.

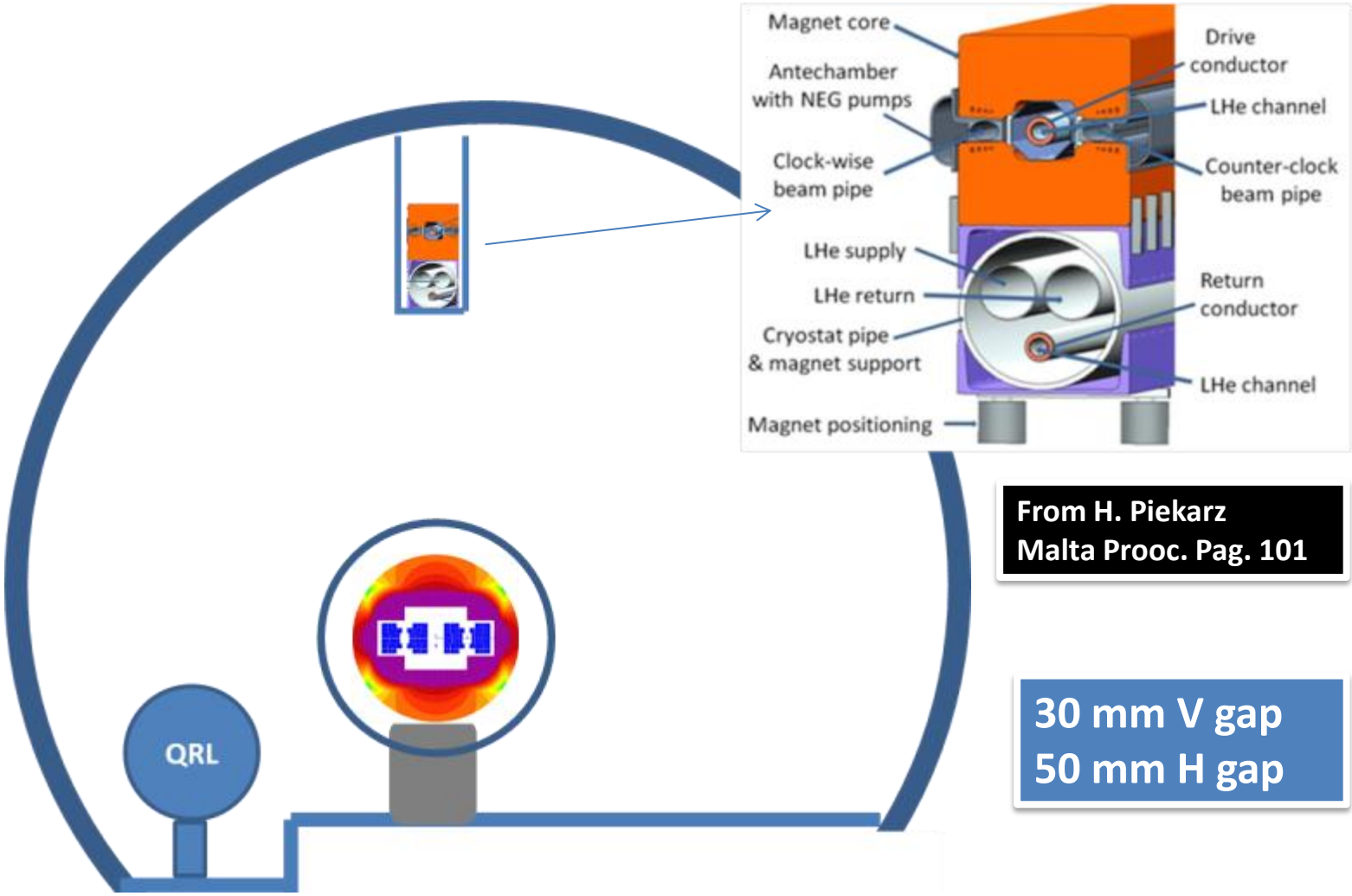
Injection Scheme

- The first baseline was to use LHC
- Either with a SPS+ or with a LER in LHC
- However if the LHC is used ONLY for injector it is not worth
 - About 40 MW continuous power at plug for Cryo only
 - Maintenance of a difficult 27 km tunnel and 7 km injection lines for 10% of use
- Proposal: remove LHC and inject from SPS into a 80km-LER

Injection scheme: SPS+ \rightarrow LHC \rightarrow VHE-LHC
is too expensive (50 MW power for cryo)



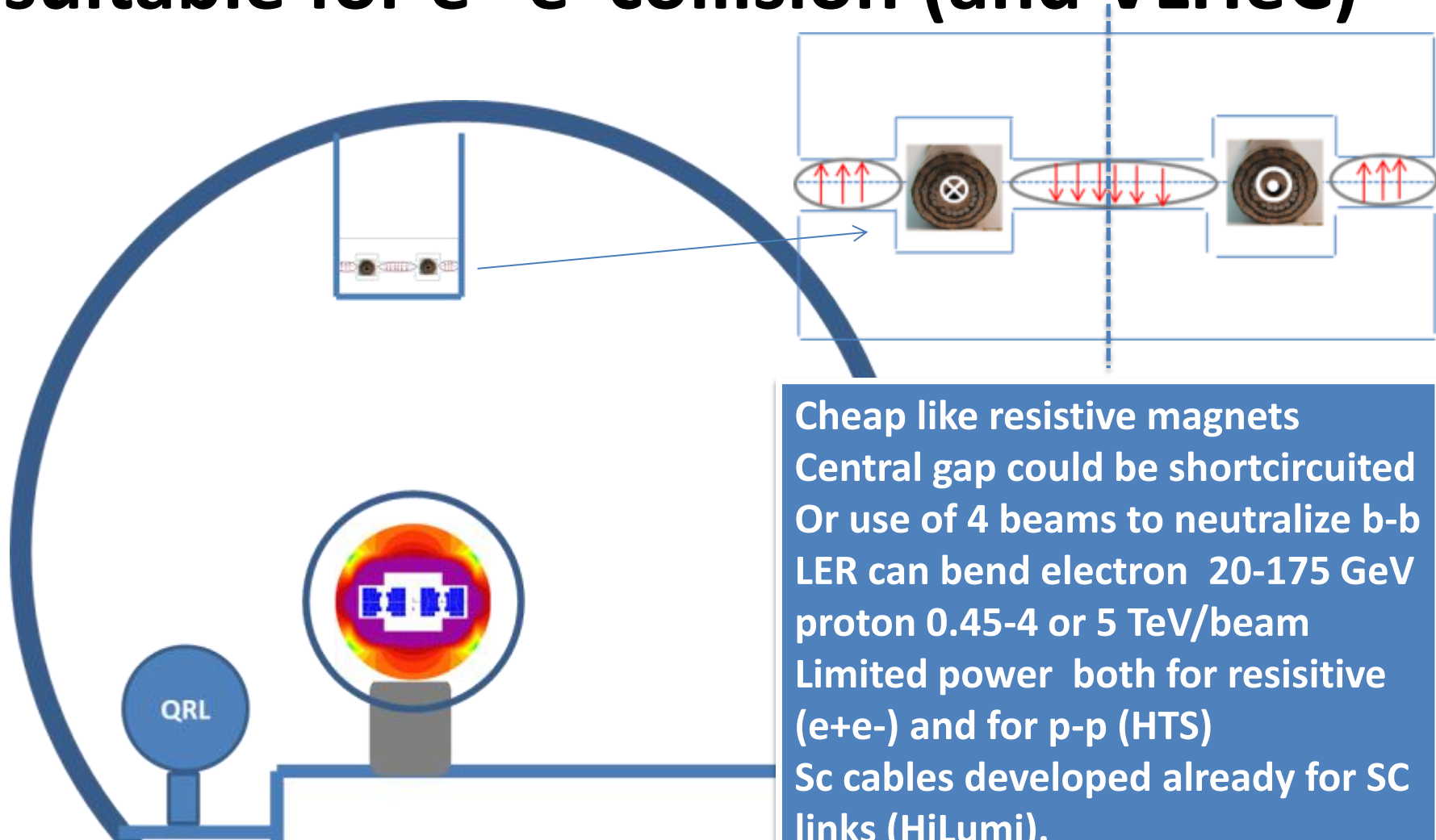
Possible arrangement in VHE-LHC tunnel



From H. Piekarz
Malta Proc. Pag. 101

30 mm V gap
50 mm H gap

Possible VHE-LHC with a LER suitable for e^+e^- collision (and VLHeC)



Cheap like resistive magnets
Central gap could be shortcircuited
Or use of 4 beams to neutralize b-b
LER can bend electron 20-175 GeV
proton 0.45-4 or 5 TeV/beam
Limited power both for resistive
(e^+e^-) and for p-p (HTS)
Sc cables developed already for SC
links (HiLumi).
SR by e^- taken at 300 K

A few numbers for proton injector

	PROTONS		
	energy	field	
	[TeV]	[T]	
	0.026	0.117	
SPS	↓	↓	x 17.3
	0.450	2.03	
injector	0.450	0.167	
80 km tunnel	↓	↓	x 9.0
$\rho = 9.0$ km	4.1	1.5	75 kA

With $I = 115-120$ kA $B_{\max} = 2$ T

A few numbers to use the same magnet for e+ - e-

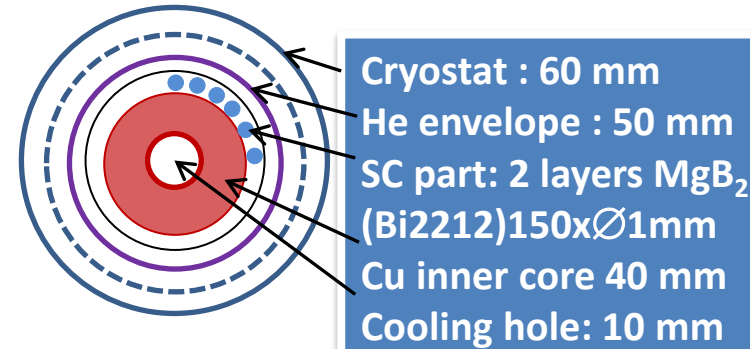
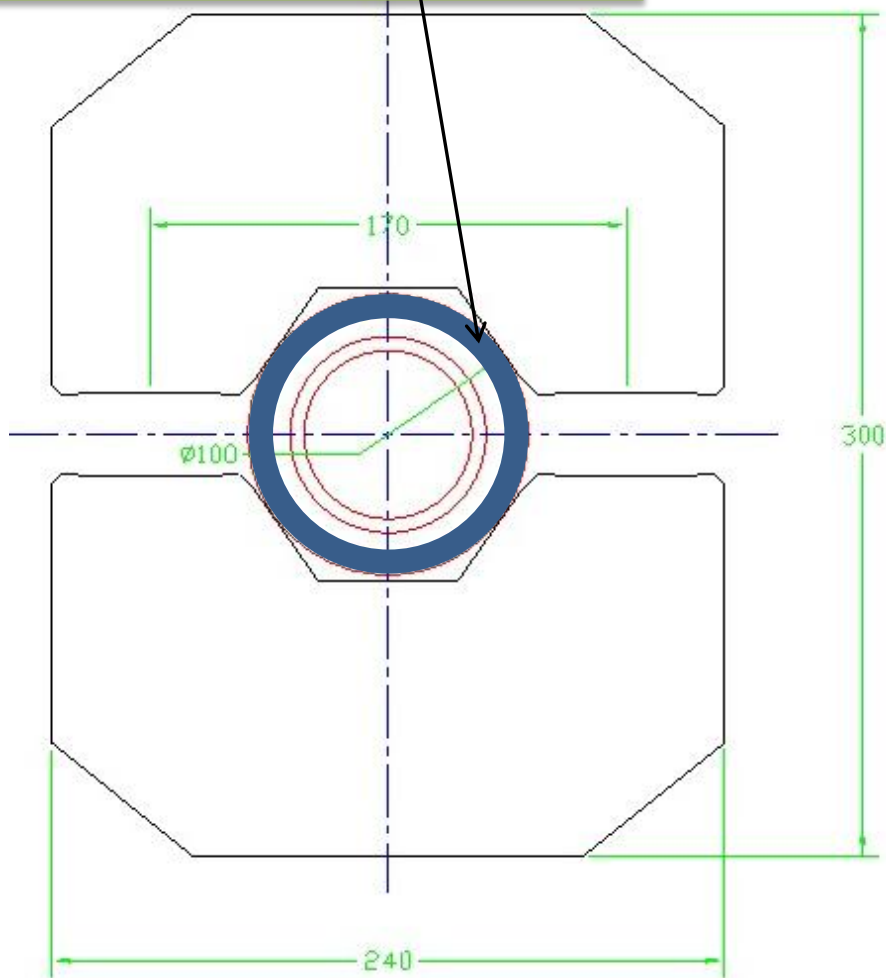
	ELECTRONS		
	energy	field	
	[GeV]	[T]	
	3.5	0.016	
SPS	↓	↓	x 5.7
	20	0.090	
e+ / e- machine	20	0.0074	
80 km tunnel	↓	↓	x 8.8
$\rho = 9.0$ km	175	0.0648	

I = 3 kA

The injection field is low, 74 Gauss (no dilution). Concern for field quaity. We think is possible with «noble» Fe grain oriented but probably also with normal Fe-Si. Already tested at 100 Gauss. Next magnet (for RCS) will be tested to 50 Gauss. Dilution can also be a possibilty (not good for p-p injector)

A Super-Resistive cable

20 mm thick shield around cable
Gaps: 2 x V30xH60 mm



Cable:

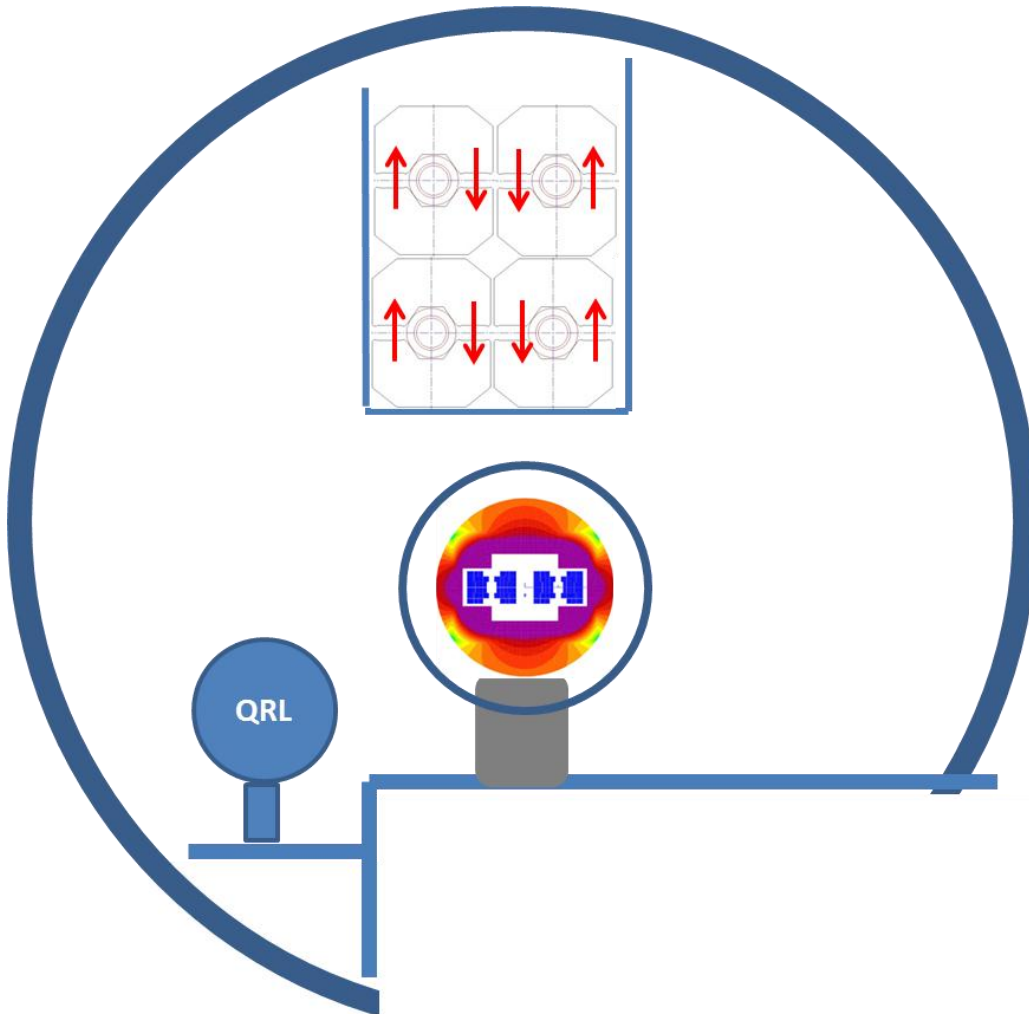
inner core of 40 mm Cu (700 mm²)
+ outer core : 2 layers, 150 strands of
MgB₂, 1 kA each; Outer size 45 mm.
120 kA =>120 k€/km !

For electrons: us Cu water cooled,
 J_{ov} 2.5 A/mm² (easy): P_{plug} =11 MW/80km

For protons: 800 A/strands
120 kA (for >2.1 T); the central copper is
the stablizer

Power: 0.1-W/m at T_{op} = 10 K
consumption/cable should be possible:
10 kW of cold power: P_{plug} = few MW
This is for each channel...

Possible arrangement



LER for e^+e^- 350 GeV
4 magnets, 8 channels
4 channel
 $P = 44$ MW (say 50)

LER p-p injector
1 Magnet, 2 channels
 T_{op} 10 K; $P_{cryostat} < 10$ MW
If useful the second magnet is
powered as return line
 T_{BS} : 100 K ? ; $P = 2 \times 25$ MW
Photon stoppers are a must

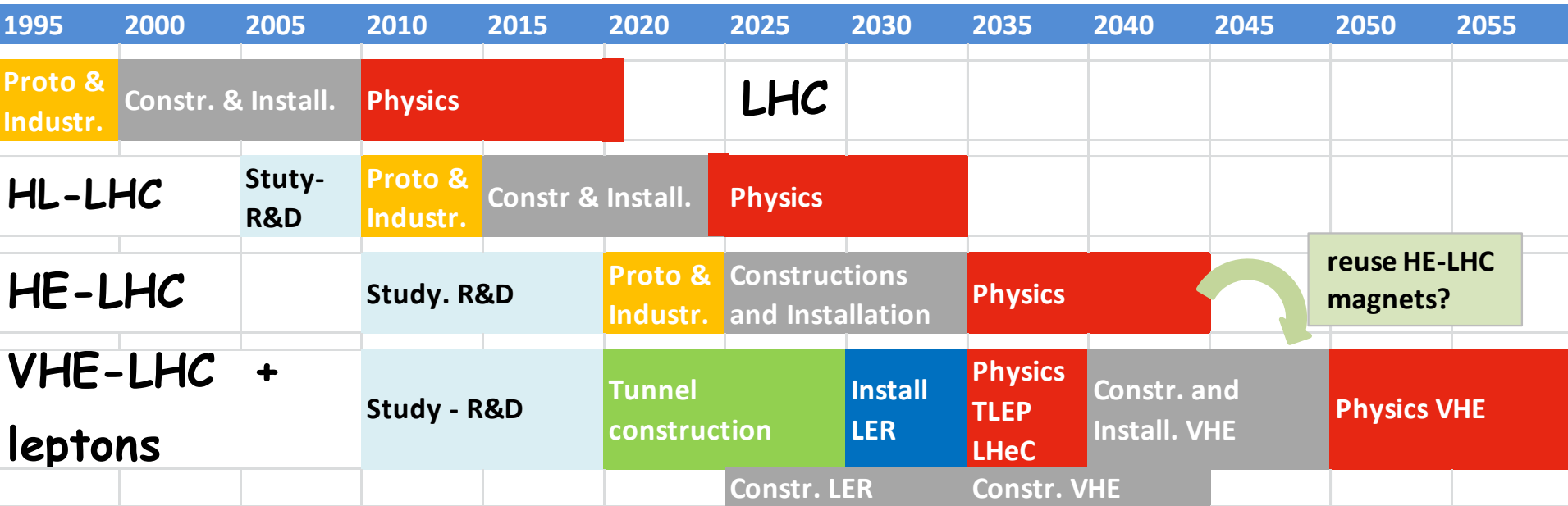
Use of 1 or 2 channels for e ring
for a 150 GeV e^- vs. 7-50 TeV p

e^- vs. ions is also possible

Few preliminary considerations

- Probably different optimization is possible for the channels used as collider at flat top and the ones used as synchrotrons for continuous injections
- Relatively fast cycle (Hz) seems possible
- Very rough cost of the LER magnets (no cryo): <500 MCHF for 2 magnets (4 channels)
- If the TLEP is to be pursued before VHE-LHC and if there is an interest for HE-LHC anyway in // one can install HE-LHC (27 TeV) meanwhile installing TLEP, and then re-use the HE-LHC magnets and cryo-system for VHE-LHC (saving 1/3).

In principle a plan for all is possible (for LHC exploitation): **2018-2020 is critical time**



- According to Physics needs, the 80 km tunnel can:
 - Be alternative to HE-LHC
 - Or complementary to HE-LHC
 - Accomodating at moderate extra-cost TLEP and VLHeC
 - Skipping HE-LHC, TLEP/VLHeC may shorten 5-10years VHE-LHC