A Large Hadron electron Collider at the LHC

5-140 GeV $e^{\pm}$ on 1-7 TeV p,A

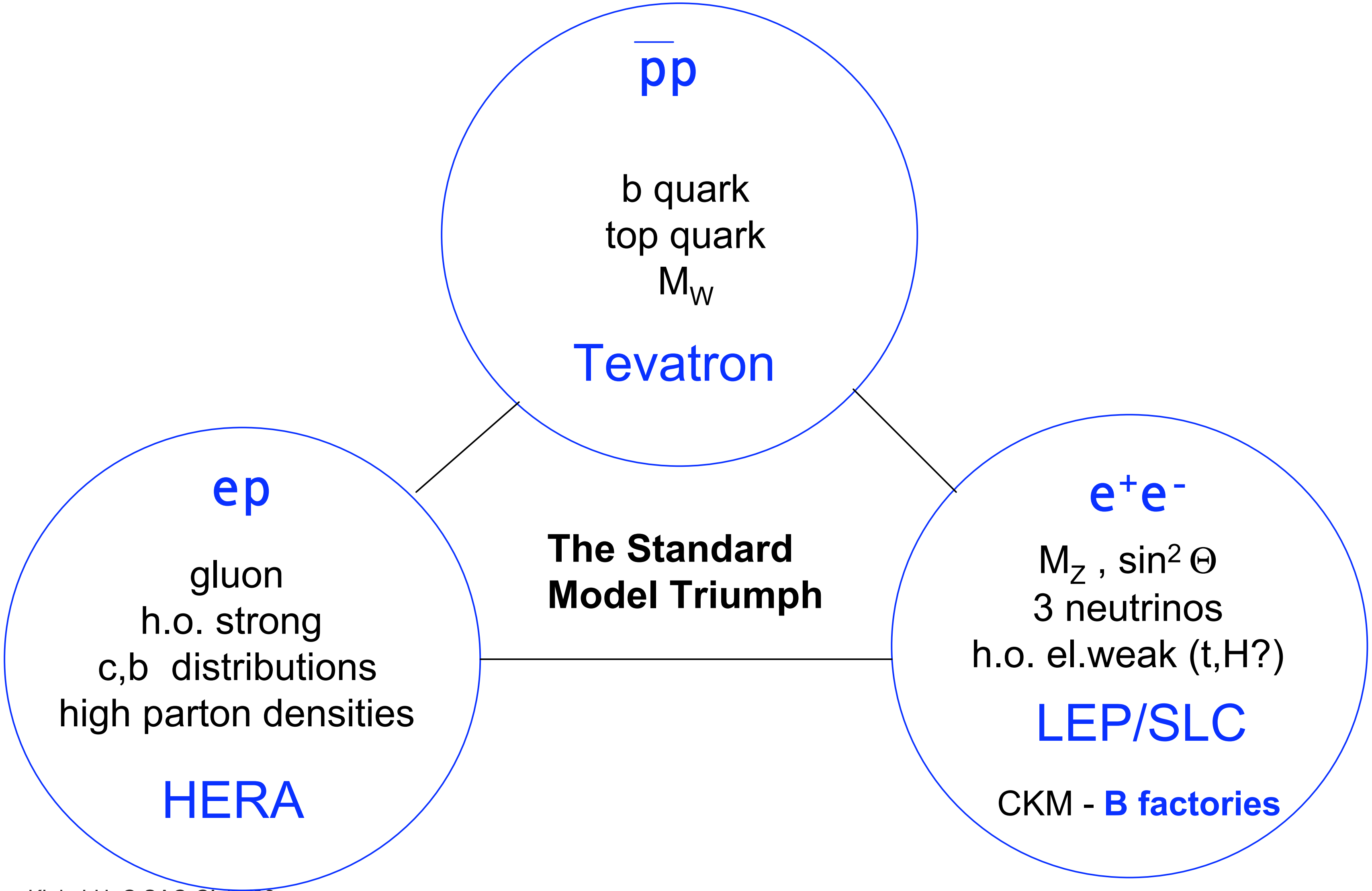
Max Klein
University of Liverpool and Cockcroft Institute
H1 and ATLAS

Report to the Cockcroft Institute's Advisory Board, 11.11.08

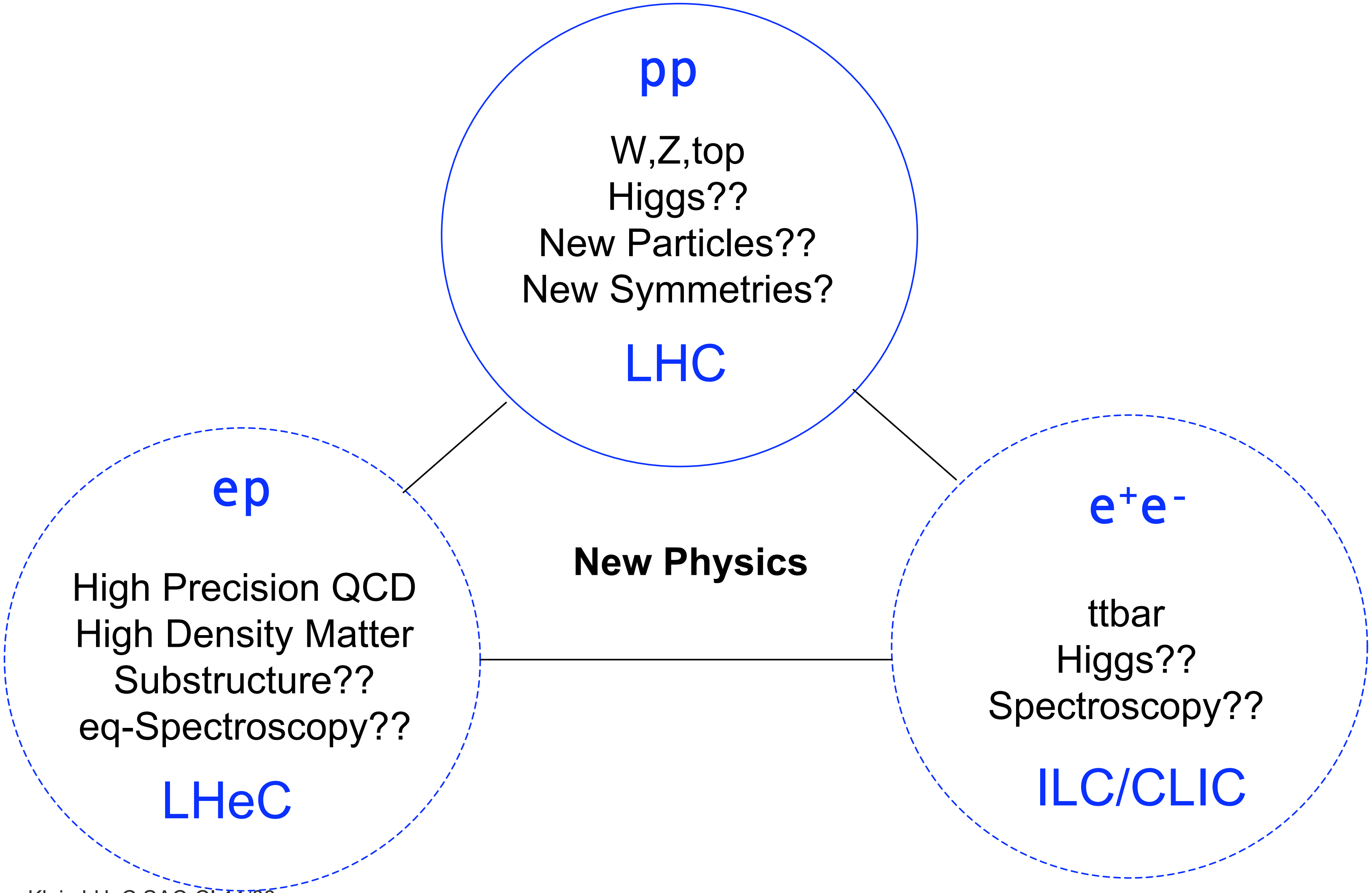
http://www.lhec.org.uk

klein@ifh.de

The Fermi Scale [1985-2010]



The TeV Scale [2008-2033..]



Predicting is difficult, in particular if it concerns the future

Scientific Advisory Committee

Guido Altarelli (Rome)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Rolf Heuer (DESY)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg, ECFA)
Richard Milner (Bates)
Steven Myers, (CERN)
Guenter Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Towards the CDR by 2009

ECFA + CERN in 11/07 set the task to work out a CDR within 2 years on the physics, machine and detector for a TeV energy ep collider based on the LHC

DIS workshops since 05,
EPAC08.
ECFA-CERN: Divonne - 9/08.

Steering Group

Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

First ECFA-CERN Workshop on the LHeC Divonne 1.-3.9.08

Opening: J.Ellis, Kh.Meier, G.Rosner, J.Engelen, G.Altarelli

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),

Uwe Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

New Physics at Large Scales

Emmanuelle Perez (CERN),

Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),

Paolo Gambino (Torino),

Thomas Gehrmann (Zuerich)

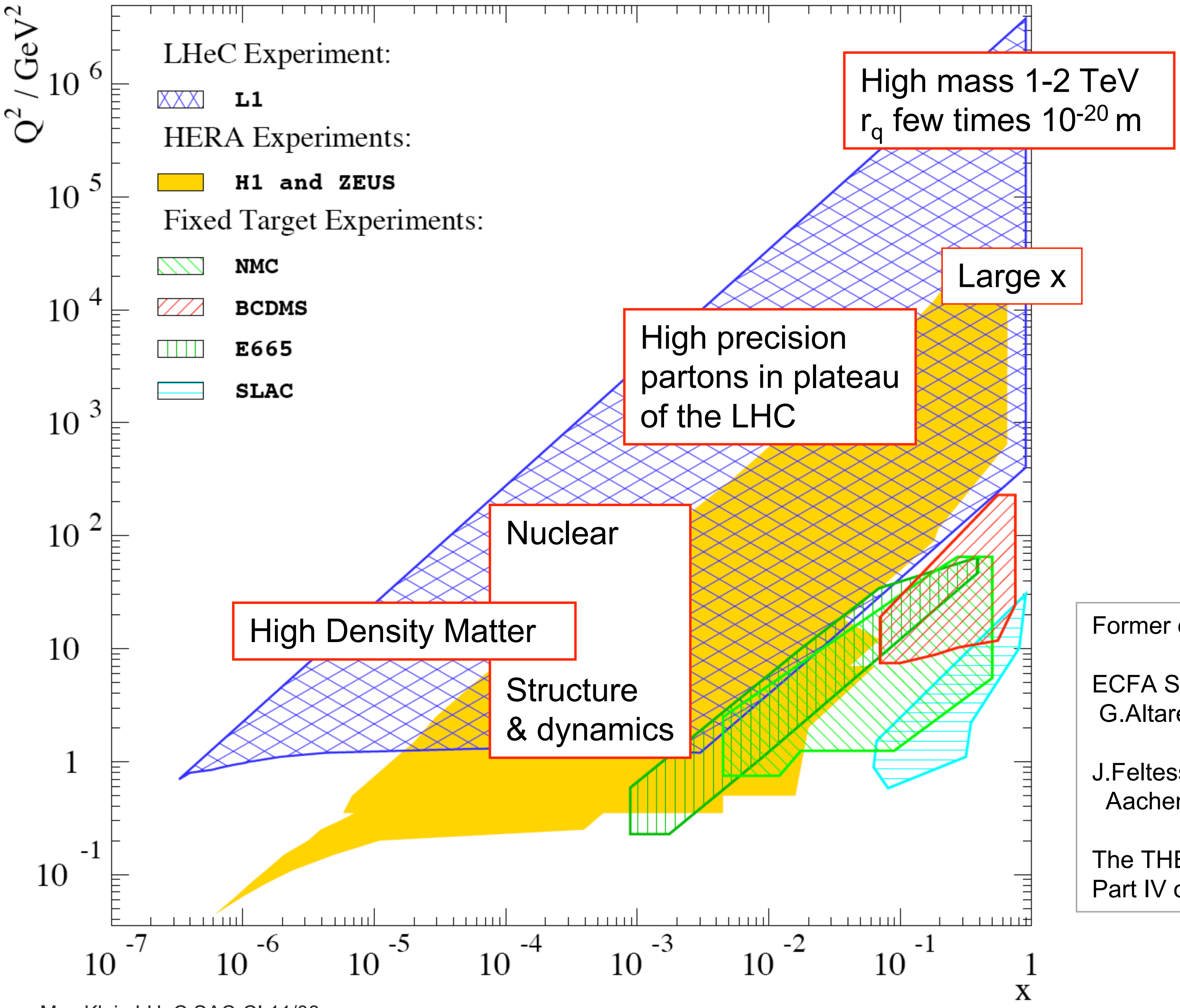
Physics at High Parton Densities

Nestor Armesto (CERN),

Brian Cole (Columbia),

Paul Newman (B'ham),

Anna Stasto (MSU)



Former considerations:

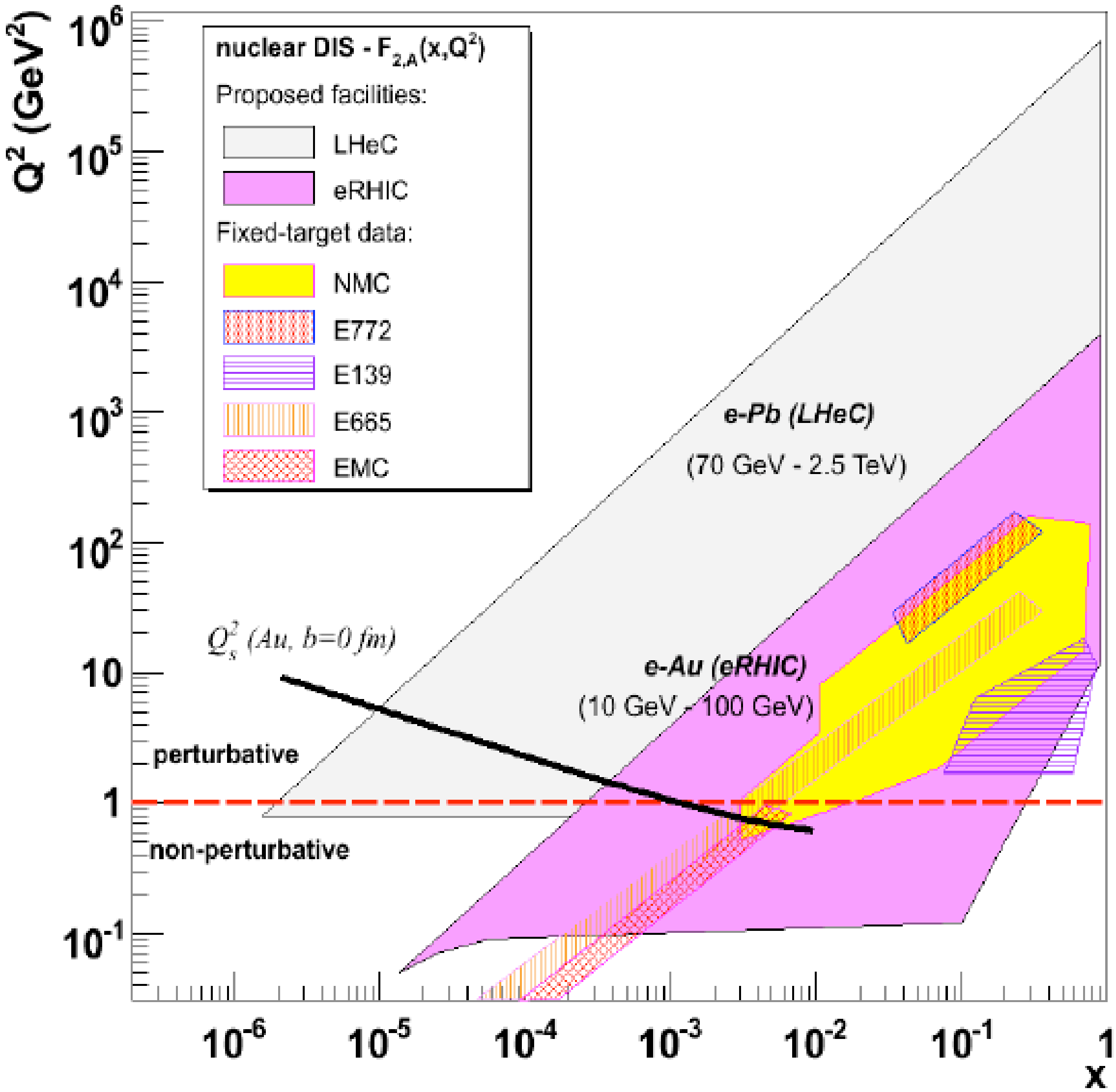
ECFA Study 84-10
G.Altarelli et al.

J.Feltesse, R.Rueckl et al.
Aachen Workshop (1990)

The THERA Book (2001)&
Part IV of TESLA TDR

Deep Inelastic Scattering off Nuclei (D,A)

DdE, arXiv:0706.4182



LHeC extends kinematic range of partonic structure of nuclei by 3-4 orders of magnitude.

It accesses saturation effects at low x in DIS region ("beyond unitarity")

$$\frac{g_A / \pi r_A^2}{g_p / \pi r_p^2} = A^{1/3} \frac{g_A}{A g_p}$$

eRHIC with nuclei could be complementary.

LHeC-A appears as natural complement and possible extension of ALICE physics programme.

Machine Requirements

-New physics expected at (multi??) TeV scale. Low $x=Q^2/sx$, $s=4E_eE_p$

highest possible E_e and E_p **1 TeV with 50GeV on 5000 GeV**

-New physics is rare [σ_{ep} (Higgs) = O(100)fb] , rate at high Q^2 , large x

L has to exceed 10^{32} and preferentially reaches 10^{33} and beyond

-New states, DVCS, electroweak physics

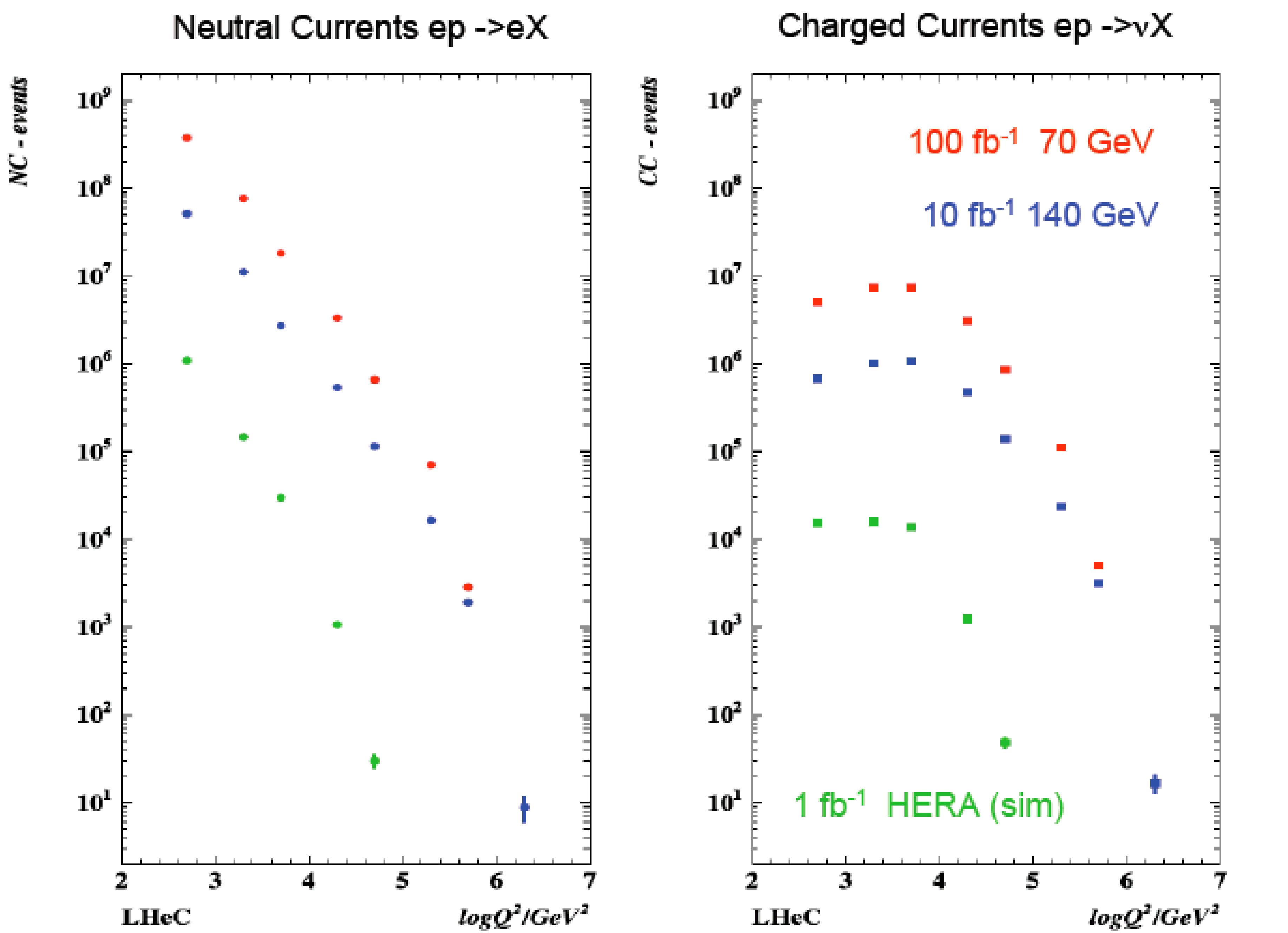
Need electrons and positrons and high lepton beam polarisation

-Neutron structure terra incognita

Deuterons

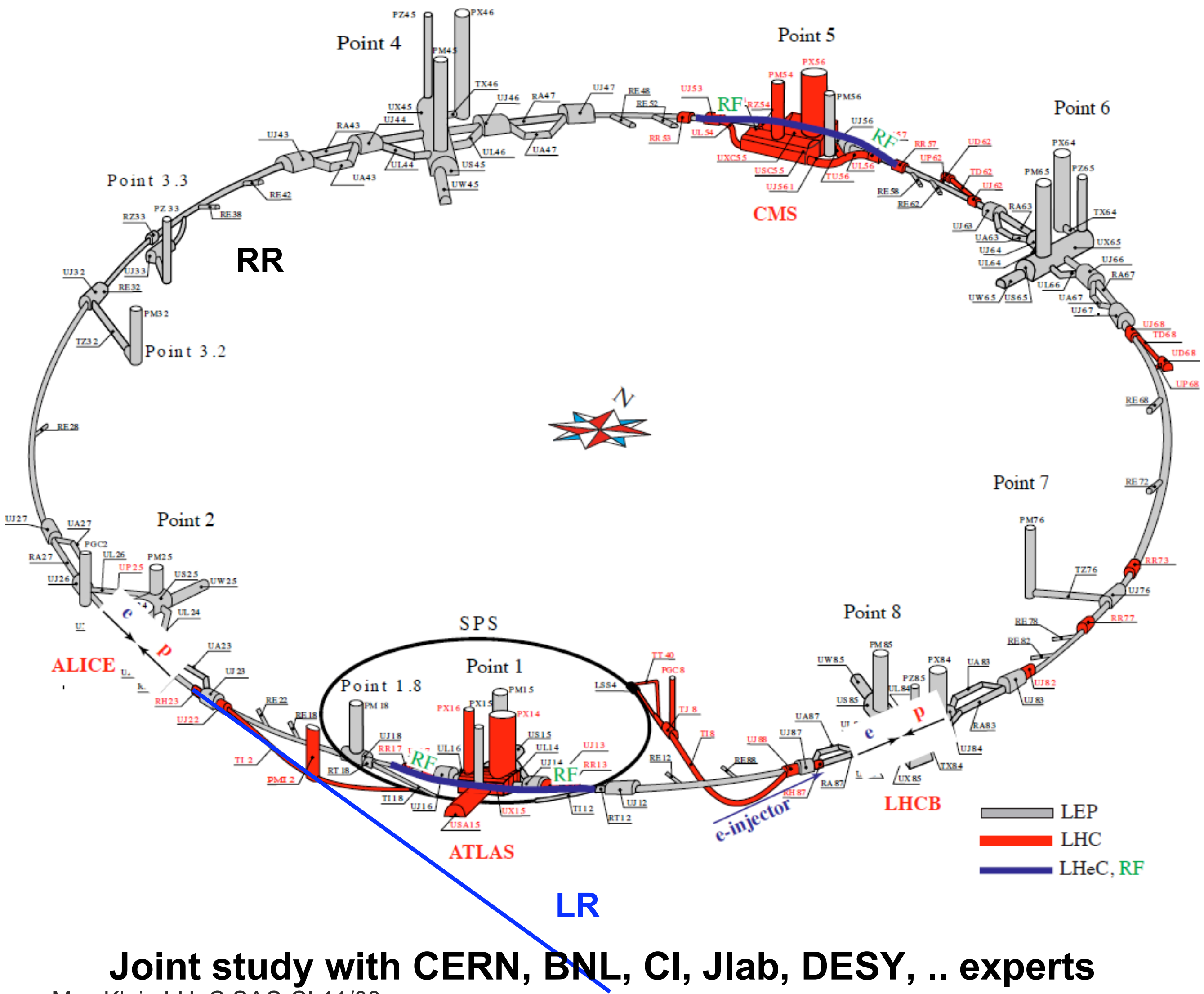
-Partonic Structure of Nuclei

a series of nuclei, Ca, Pb


Neutral Currents ep ->eX
Charged Currents ep ->νX
NC - events
CC - events
100 fb-1 70 GeV
10 fb-1 140 GeV
1 fb-1 HERA (sim)
LHeC
logQ²/GeV²

Machine Considerations and Studies

high $E_{e,p,A}$, $e^{\pm}$ polarised, high Luminosity



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

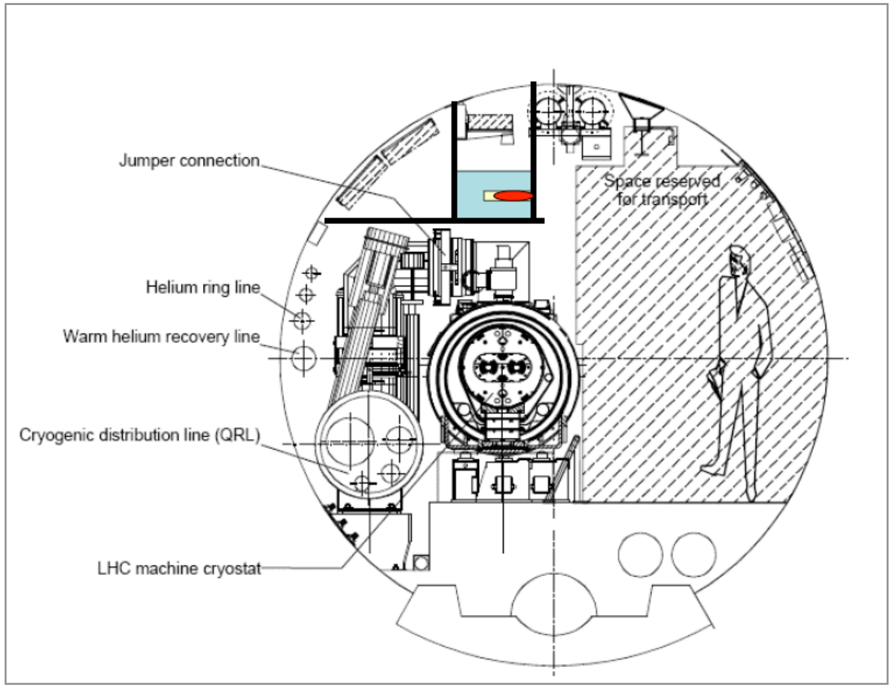
e Ring:

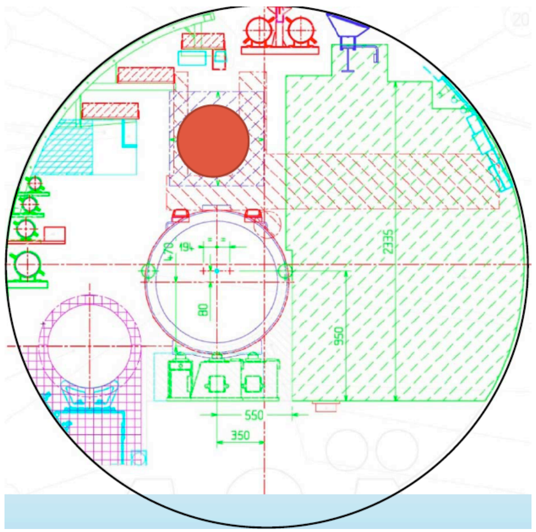
bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?





e Ring Further Considerations

Mount e on top of p - feasible at first sight
needs further, detailed study of pathway

Installation: 1-2 years during LHC shutdowns.
LEP installation was ~1 year into empty tunnel.
Radiation load of LHC pp will be studied.

Injection:
LEP2 was 4 10^{11} e in 4 bunches
LHeC is 1.4 10^{10} in 2800 bunches
may inject at less than 20 GeV.

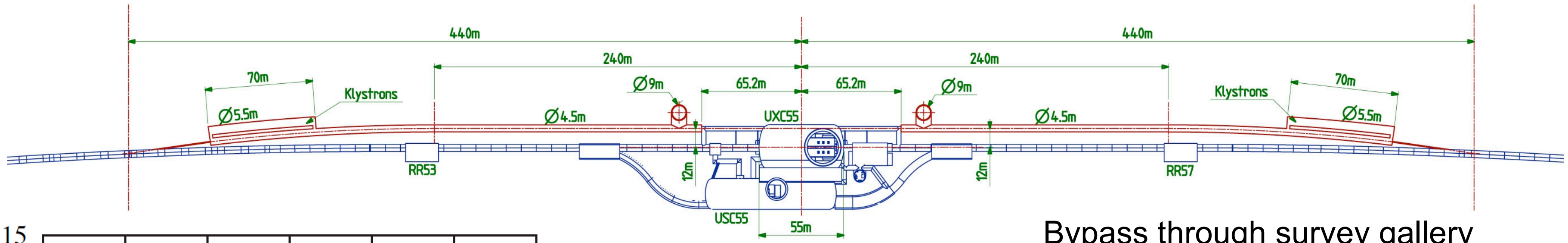
Power for 70 (50) GeV E_e fits into bypasses:

SC system at 1.9° K (1 GHz)
r.f. coupler to cavity: 500 kW CW - R+D
9 MV/cavity.
100(28) cavities for 900(250)MV
cavity: beam line of 150 (42) m
klystrons 100 (28) at 500kW
plus 90 m racks ..
gallery of 540 (150) m length required.

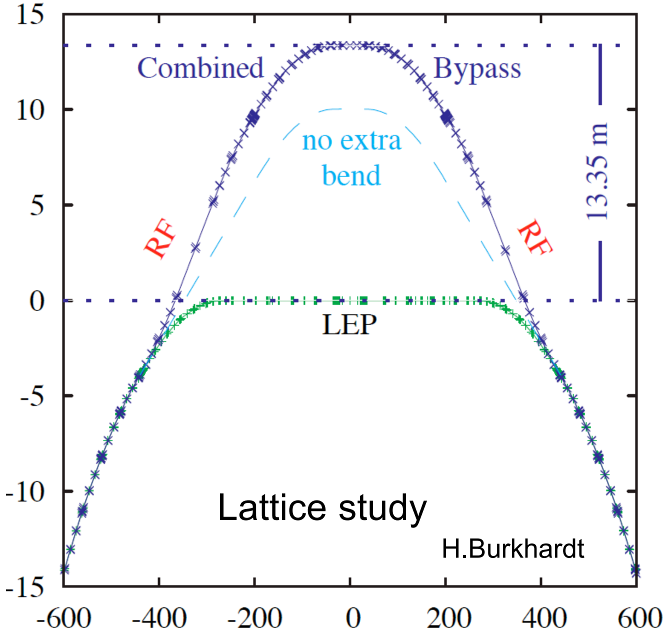
T.Linnecar

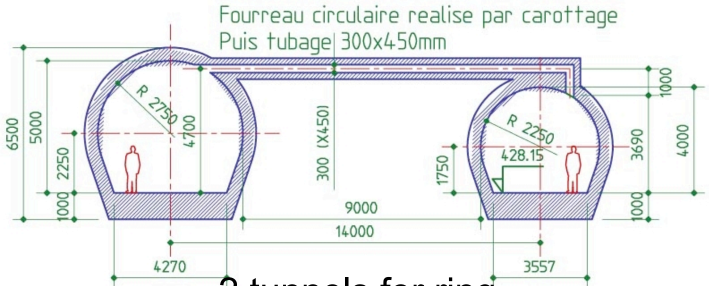
Bypass

point 5

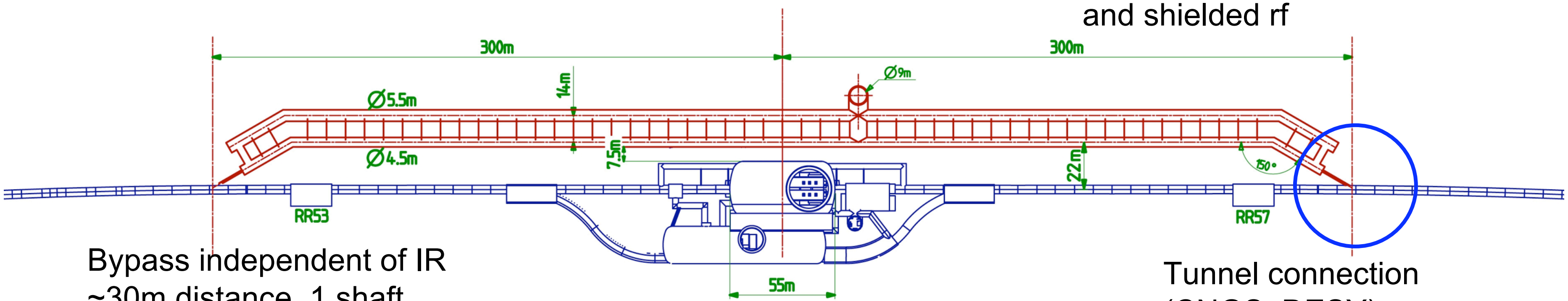


Bypass through survey gallery
13m distance, 2 shafts





2 tunnels for ring
and shielded rf



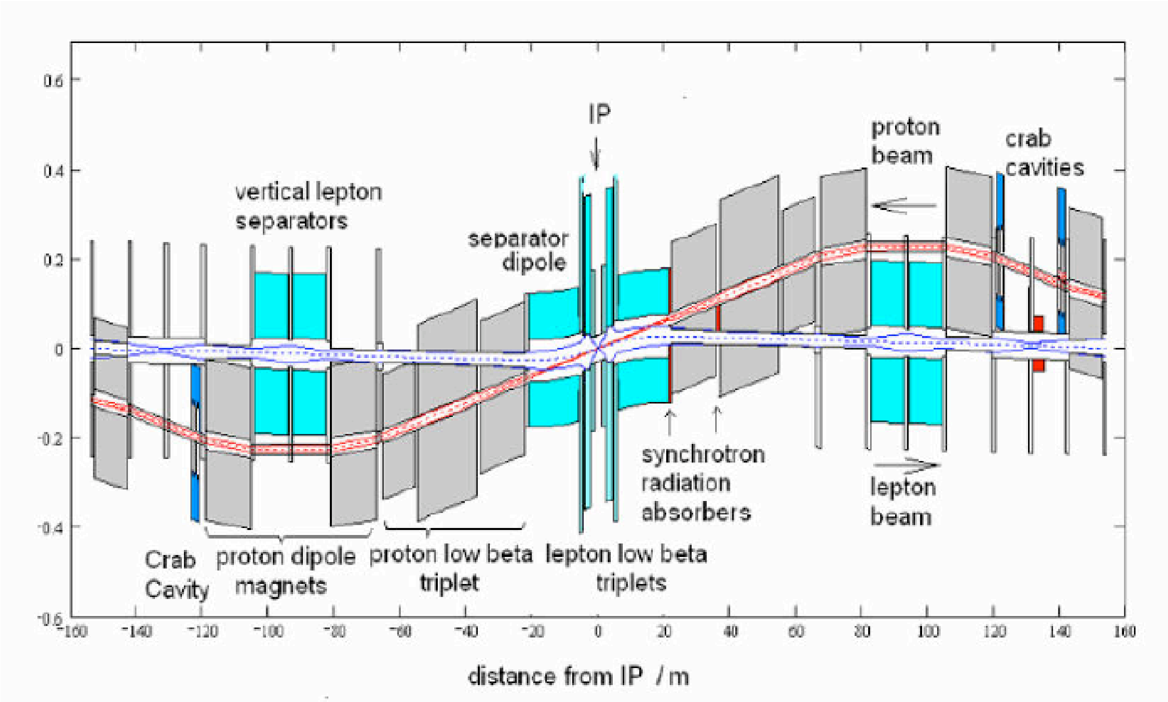
Bypass independent of IR
~30m distance, 1 shaft

Tunnel connection
(CNGS, DESY)

S.Myers, J.Osborne

LHeC
View from UPS54 Survey Gallery into CMS Cavern on Walkways

IR Design



builds on F.Willeke et al, 2006 JINST 1 P10001
design for 70 GeV on 7000 GeV, 10^{33}
and simultaneous ep and pp operation

Need low x (1°) and hi L (10° ?)

Separation (backscattering)

Synchrotron radiation (100 keV E_{crit})

Crab cavities
(profit from LHC developments)

e optics and beam line

p optics

Magnet designs for IR

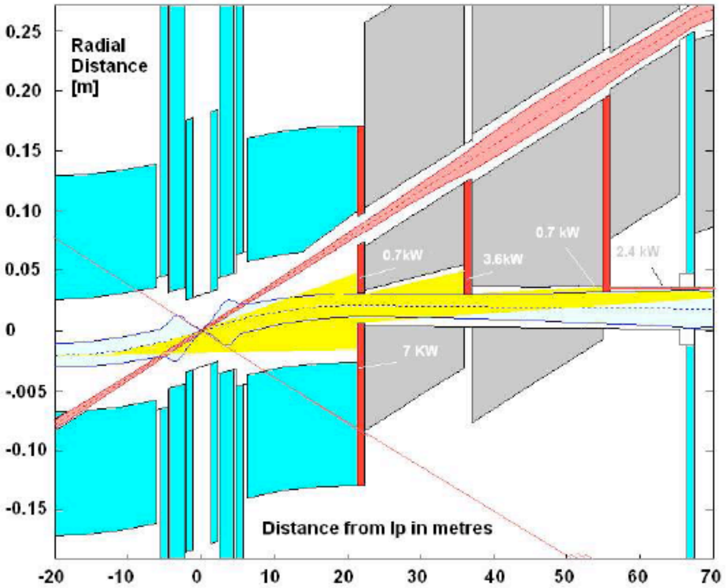
S shaped IR for Linac-Ring option.

…

Input/experience from
HERA, LHC, ILC, eRHIC, SUPER-B

B.Holzer, A.Kling, et al

Design Details

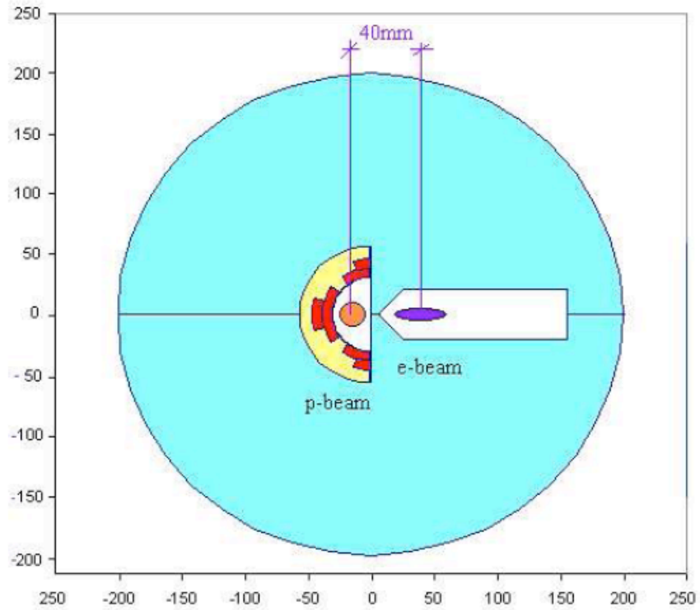


Synchrotron radiation fan

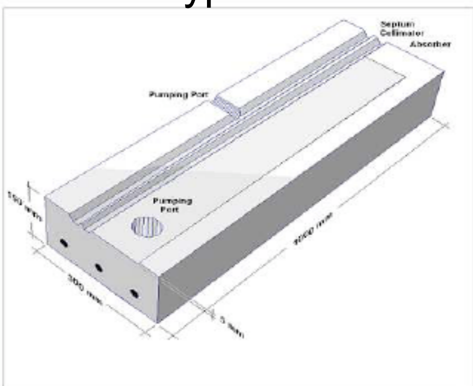
and HERA type absorber

$9.1kW$

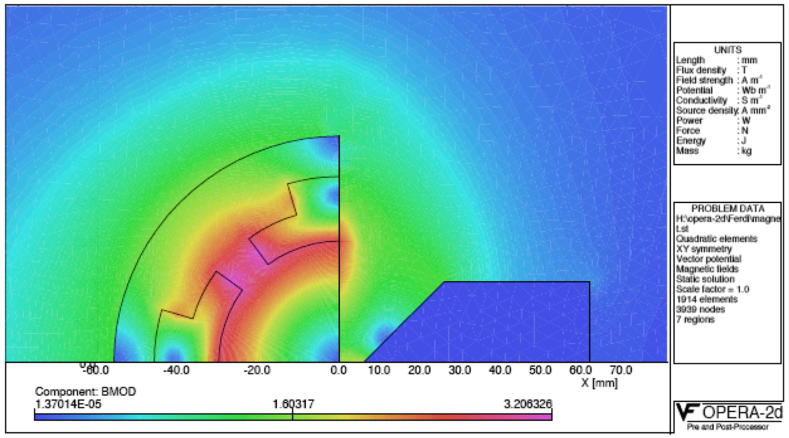
$E_{crit} = 76keV$



First p beam lens: septum quadrupole.
Cross section and Field calculation



100W/mm^2



cf also W.Bartel
Aachen 1990

Ring-Ring Parameters

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}}$$

$$L = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

Luminosity safely $10^{33}cm^{-2}s^{-1}$
HERA was 1-5 10^{31}

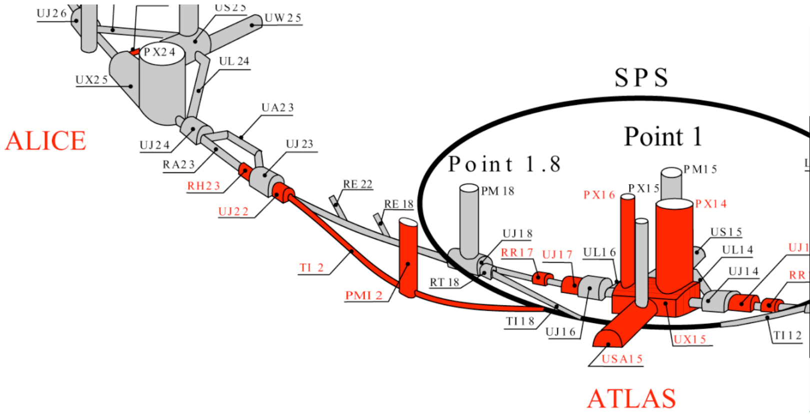
Table values are for 14MW synrad loss (beam power) and 50 GeV on 7000 GeV. May have 50 MW and energies up to about 70 GeV.

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

LHC upgrade: N_p increased.
Need to keep e tune shift low:
by increasing β_p, decreasing β_e
but enlarging e emittance,
to keep e and p matched.

LHeC profits from LHC upgrade but not proportional to N_p

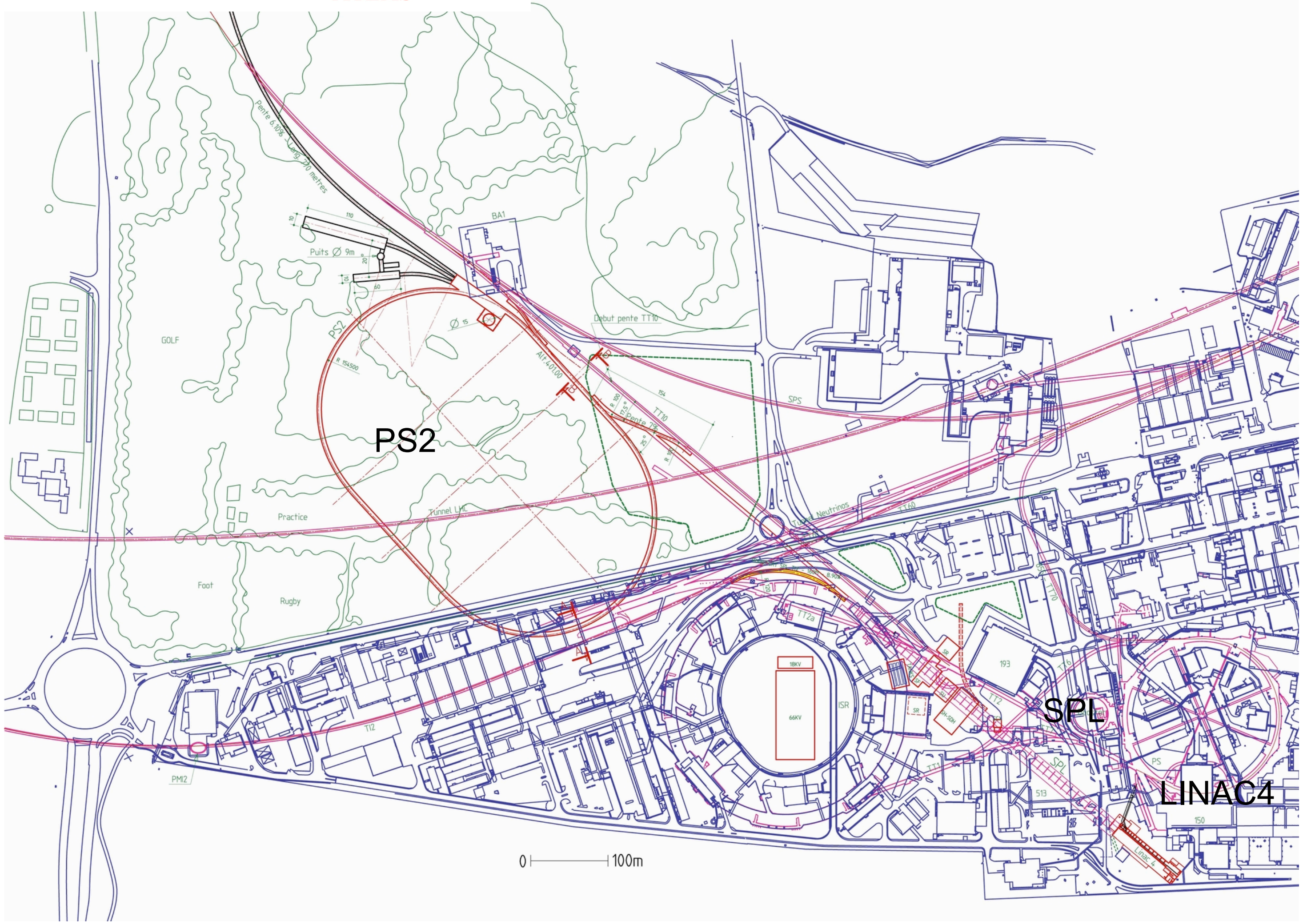
Standard Parameter	Protons	Elektrons
nb=2808	Np=1.15*10^{11}	Ne=1.4*10^{10}
	Ip=582 mA	Ie=71mA
Optics	βxp=180 cm	βxe=12.7 cm
	βyp= 50 cm	βye= 7.1 cm
	εxp=0.5 nm rad	εxe=7.6 nm rad
	εyp=0.5 nm rad	εye=3.8 nm rad
Beamsize	σx=30 µm	
	σy=15.8 µm	
Tuneshift	Δνx=0.00055	Δνx=0.0484
	Δνy=0.00029	Δνy=0.0510
Luminosity	**L=8.2*10^{32}**	
Ultimate [ESP]		
nb=2808	Np=1.7*10^{11}	Ne=1.4*10^{10}
	Ip=860mA	Ie=71mA
Optics	βxp=230 cm	βxe=12.7 cm
	βyp= 60 cm	βye= 7.1 cm
	εxp=0.5 nm rad	εxe=9 nm rad
	εyp=0.5 nm rad	εye=4 nm rad
Beamsize	σx=34 µm	
	σy=17 µm	
Tuneshift	Δνx=0.00061	Δνx=0.056
	Δνy=0.00032	Δνy=0.062
Luminosity	**L=1.03*10^{33}**	
Upgrade [LPA]		
nb=1404	Np=5*10^{11}	Ne=1.4*10^{10}
	Ip=1265mA	Ie=71mA
Optik	βxp=400 cm	βxe= 8 cm
	βyp=150 cm	βye= 5 cm
	εxp=0.5 nm rad	εxe=25 nm rad
	εyp=0.5 nm rad	εye=15 nm rad
Strahlgröße	σx=44 µm	
	σy=27 µm	
Tuneshift	Δνx=0.0011	Δνx=0.057
	Δνy=0.00069	Δνy=0.058
Luminosität	**L=1.44*10^{33}**	



e injector from SPL to Point 2 via TI2

Alternative injectors considered too

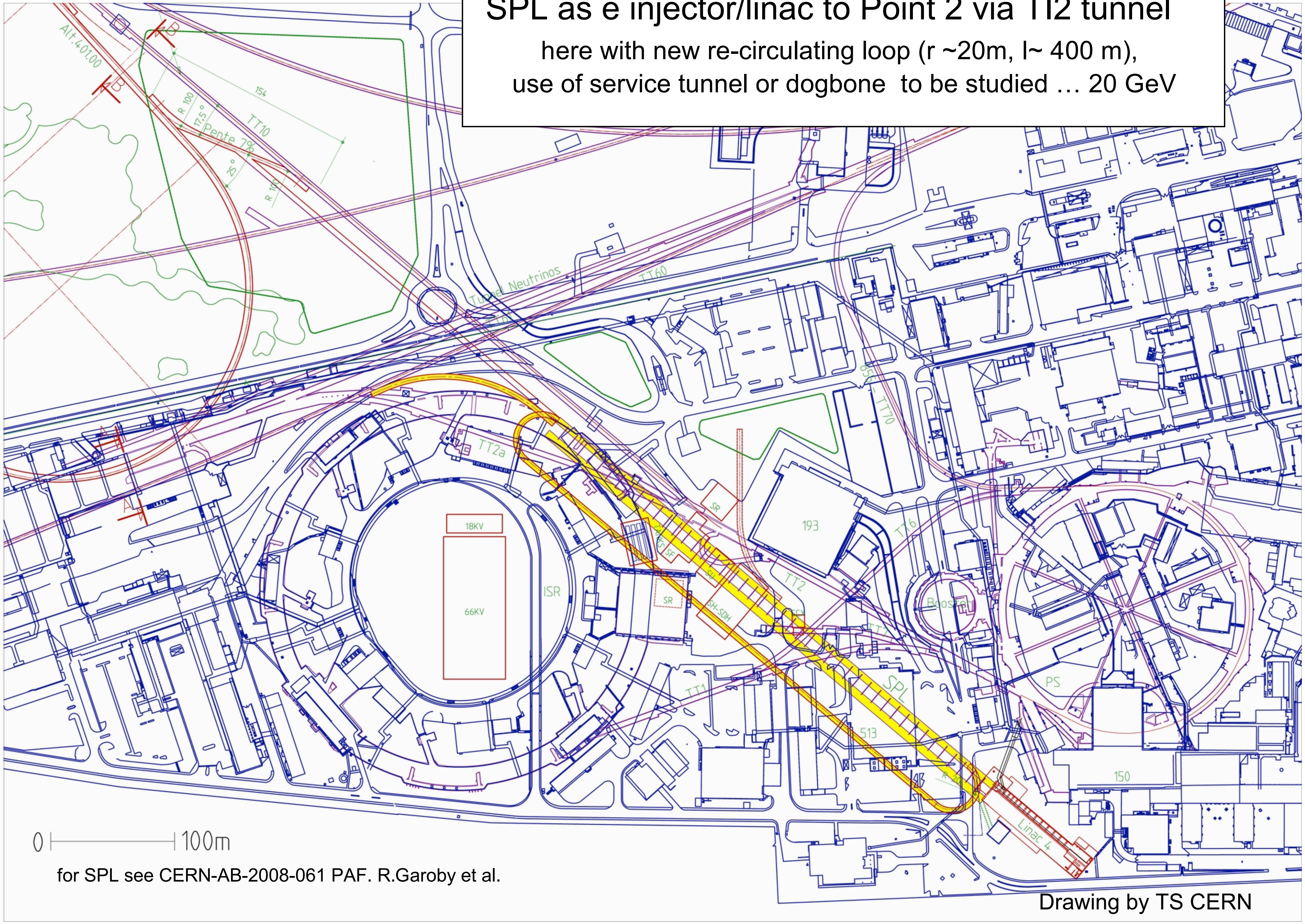
(cf H. Burkhard, DIS08, Proceedings)



Max Klein

SPL as e injector/linac to Point 2 via TI2 tunnel

here with new re-circulating loop (r ~20m, l~ 400 m),
use of service tunnel or dogbone to be studied … 20 GeV



for SPL see CERN-AB-2008-061 PAF. R.Garoby et al.

Drawing by TS CERN

		Pulsed	CW
e- energy [GeV]	30	100	100
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo [MW]	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [MV/m]	25	25	13.9
total linac length β=1 [m]	350+333	3300	6000
minimum return arc radius [m]	240 (final bends)	1100	1100
beam power at IP [MW]	24	48	30
e- IP beta function [m]	0.06	0.2	0.2
ep hourglass reduction factor	0.62	0.86	0.86
disruption parameter D	56	17	17
luminosity [10^{32} cm^{-2} s^{-1}]	**2.5**	**2.2**	**1.3**

proton parameters: LPA upgrade SLHC: N_b=5x10^{11}, 50 ns spacing, $\gamma\varepsilon$=3.75 μm, β^*=0.1 m, σ_z=11.8 cm

F.Zimmermann, S. Chattopadhyay

Luminosity: Linac-Ring

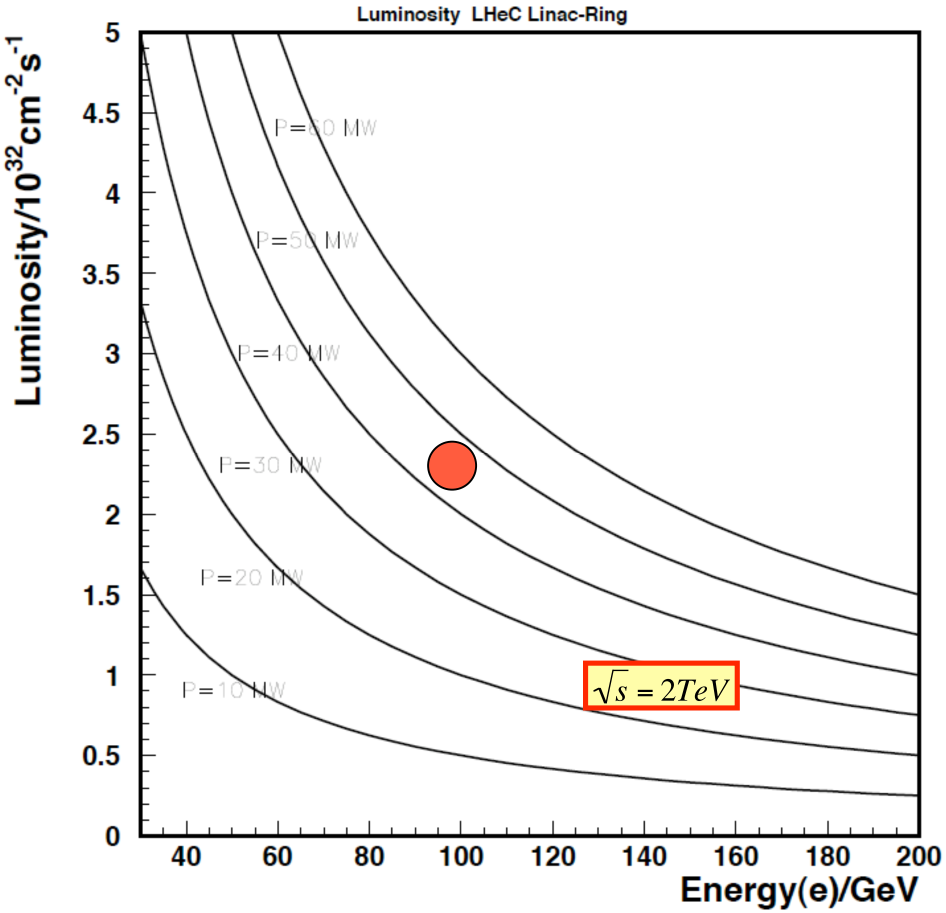
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$

M.Tigner, B.Wiik, F.Willeke, Acc.Conf, SanFr.(1991) 2910

SLHC - LPA

cf. R.Garoby EPS07,
J.Koutchouk et al PAC07

$$\varepsilon_{pn} = 3.8 \mu m$$
$$N_p = 5 \cdot 10^{11}$$
$$\beta^* = 0.10 m$$



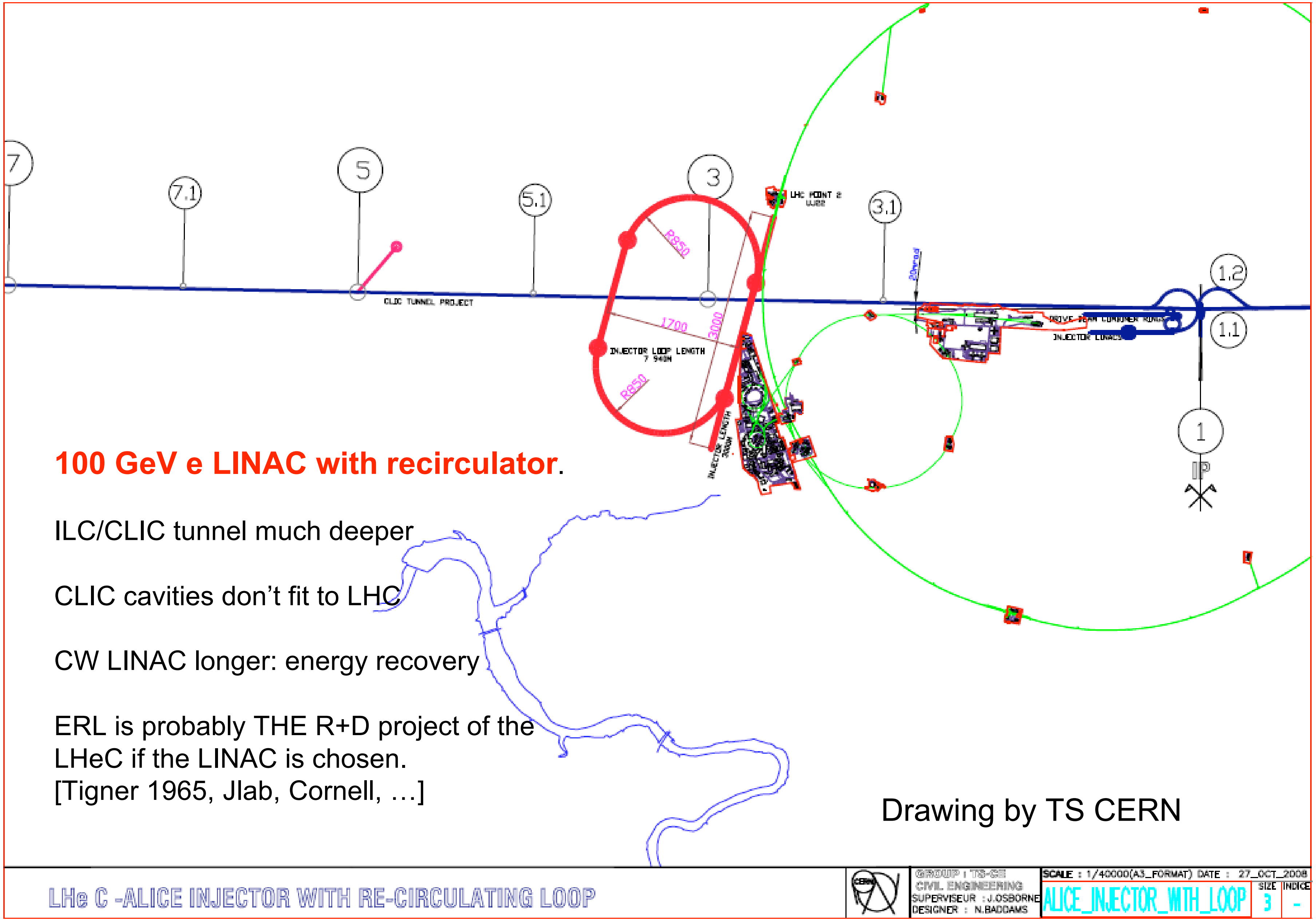
LINAC is not physics limited in energy, but with its cost/length + power

➢ **10^{32} are in reach at large E_e.**

LINAC - no periodic loss+refill, ~twice as efficient as ring…
8,4,3fb^{-1} /year at (50)100[150] GeV

Note: positron source challenge:

LHeC 10^{32} needs few times 10^{14} /sec



100 GeV e LINAC with recirculator.

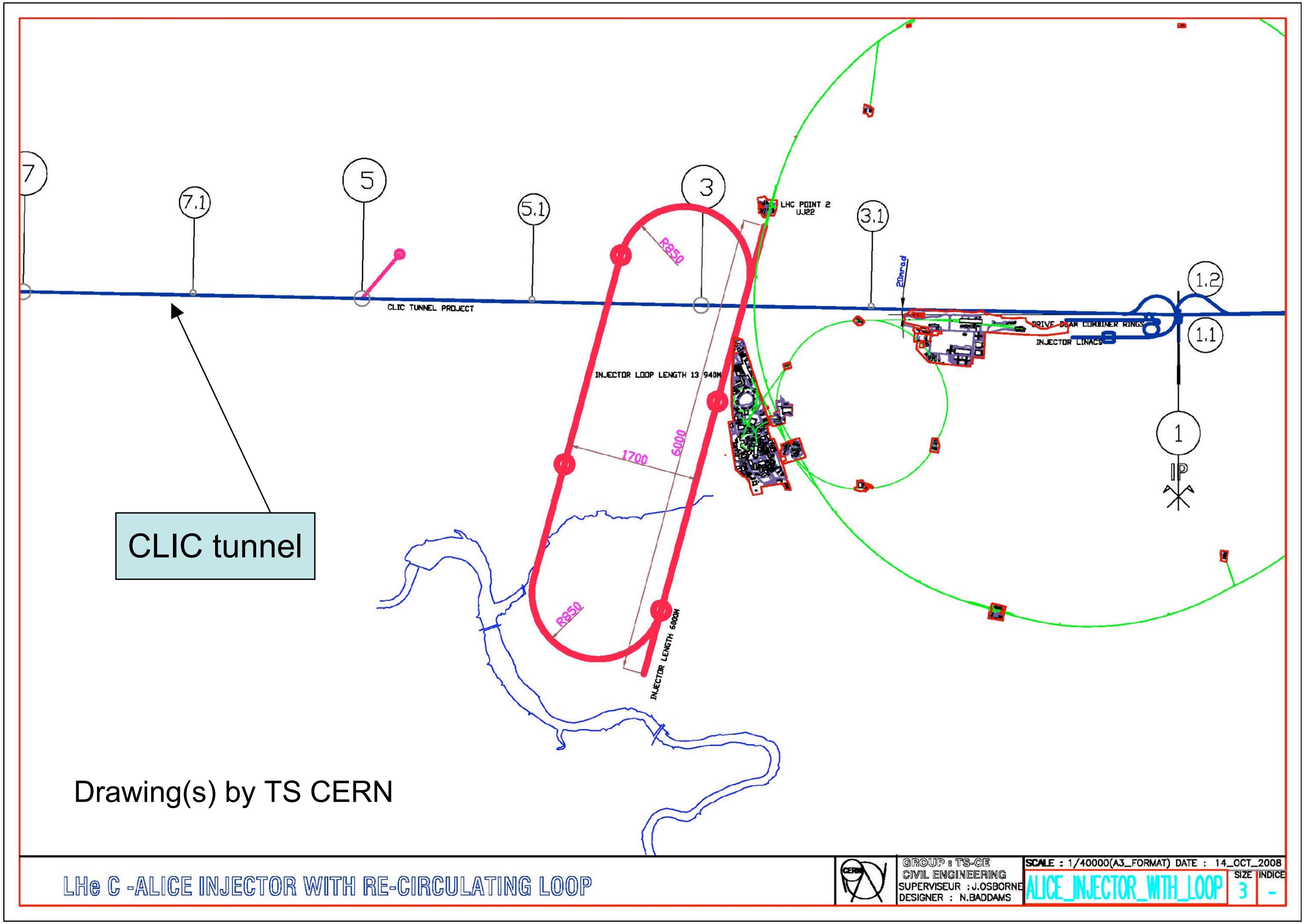
ILC/CLIC tunnel much deeper

CLIC cavities don’t fit to LHC

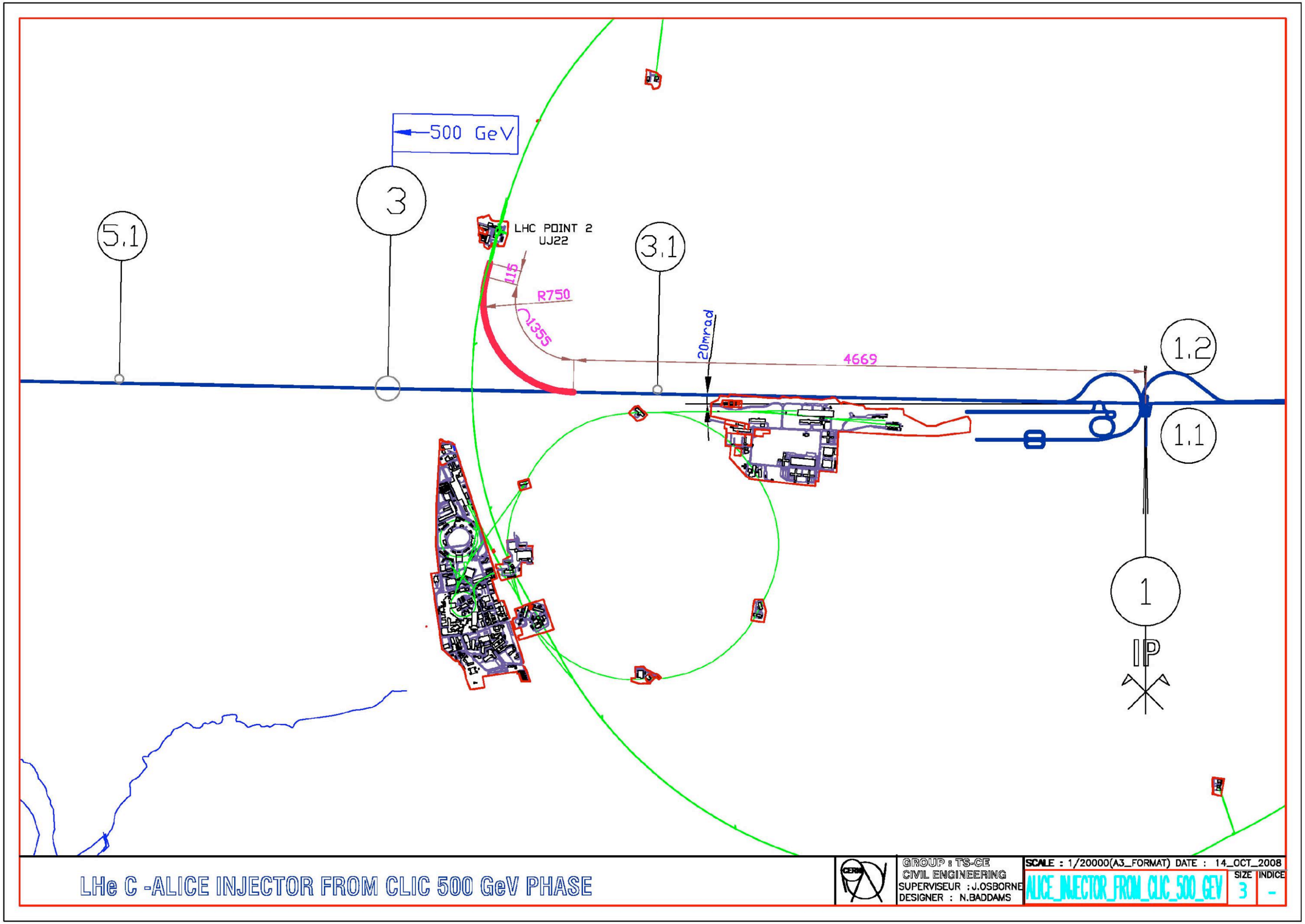
CW LINAC longer: energy recovery

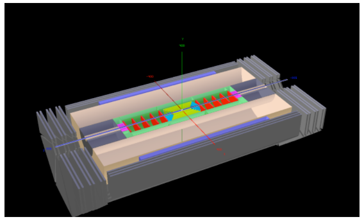
ERL is probably THE R+D project of the LHeC if the LINAC is chosen.
[Tigner 1965, Jlab, Cornell, …]

Drawing by TS CERN

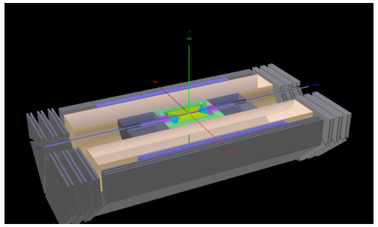


Drawing(s) by TS CERN

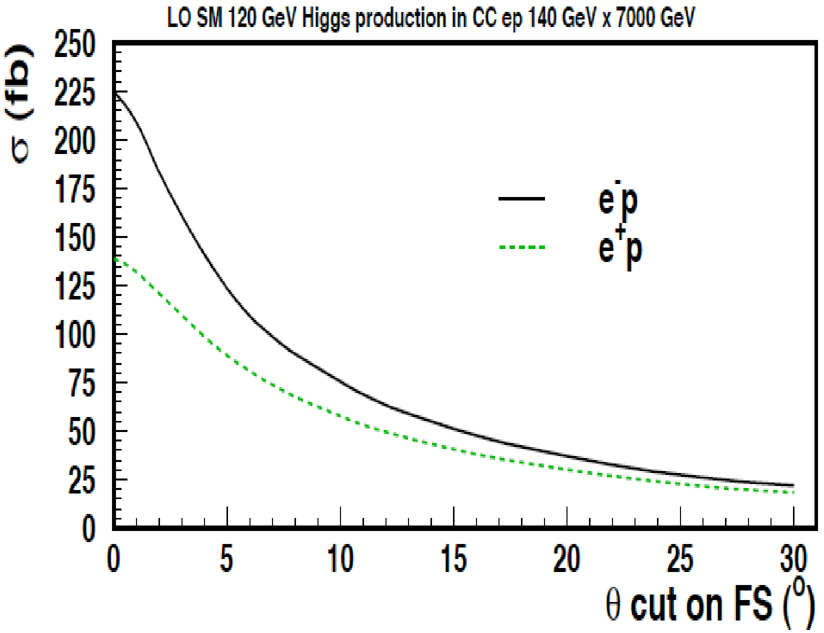

500 GeV
3
5.1
LHC POINT 2
UJ22
3.1
115
R750
1355
20mrad
4669
1.2
1.1
1
IP
LHe C -ALICE INJECTOR FROM CLIC 500 GeV PHASE
GROUP : TS-CE
CIVIL ENGINEERING
SUPERVISEUR : J.OSBORNE
DESIGNER : N.BADDAMS
SCALE : 1/20000(A3_FORMAT) DATE : 14_OCT_2008
ALICE_INJECTOR_FROM_CLIC_500_GEV
SIZE
3
INDICE
-



Detector Design Considerations



Large fwd acceptance and high luminosity



Forward tagging of p,n,d
Backward tagging of e,γ
Tagging of c and b in max. angular range
High resolution final state (Higgs to bbar)

High precision tracking and calorimetry

Largest possible acceptance	
1-179°	7-177°
High resolution tracking	
0.1 mrad	0.2-1 mrad
Precision electromagnetic calorimetry	
0.1%	0.2-0.5%
Precision hadronic calorimetry	
0.5%	1%
High precision luminosity measurement	
0.5%	1%
LHeC	HERA

L1 Detector: version for low x Physics

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn]

Central Detector

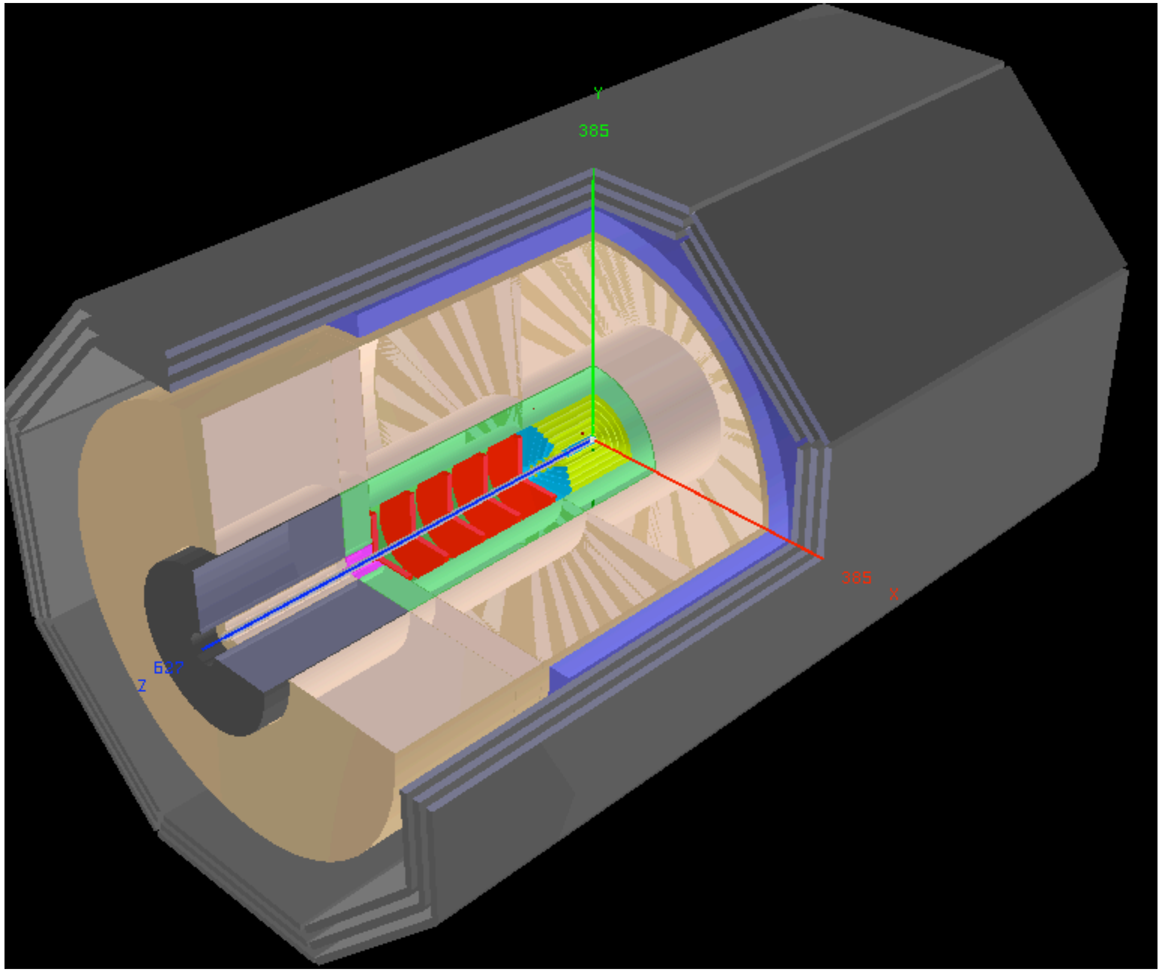
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)



To be extended further in fwd direction. Tag p,n,d. Also e,γ (bwd)

L1 Detector: version for hiQ^2 Physics

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)

Central Detector

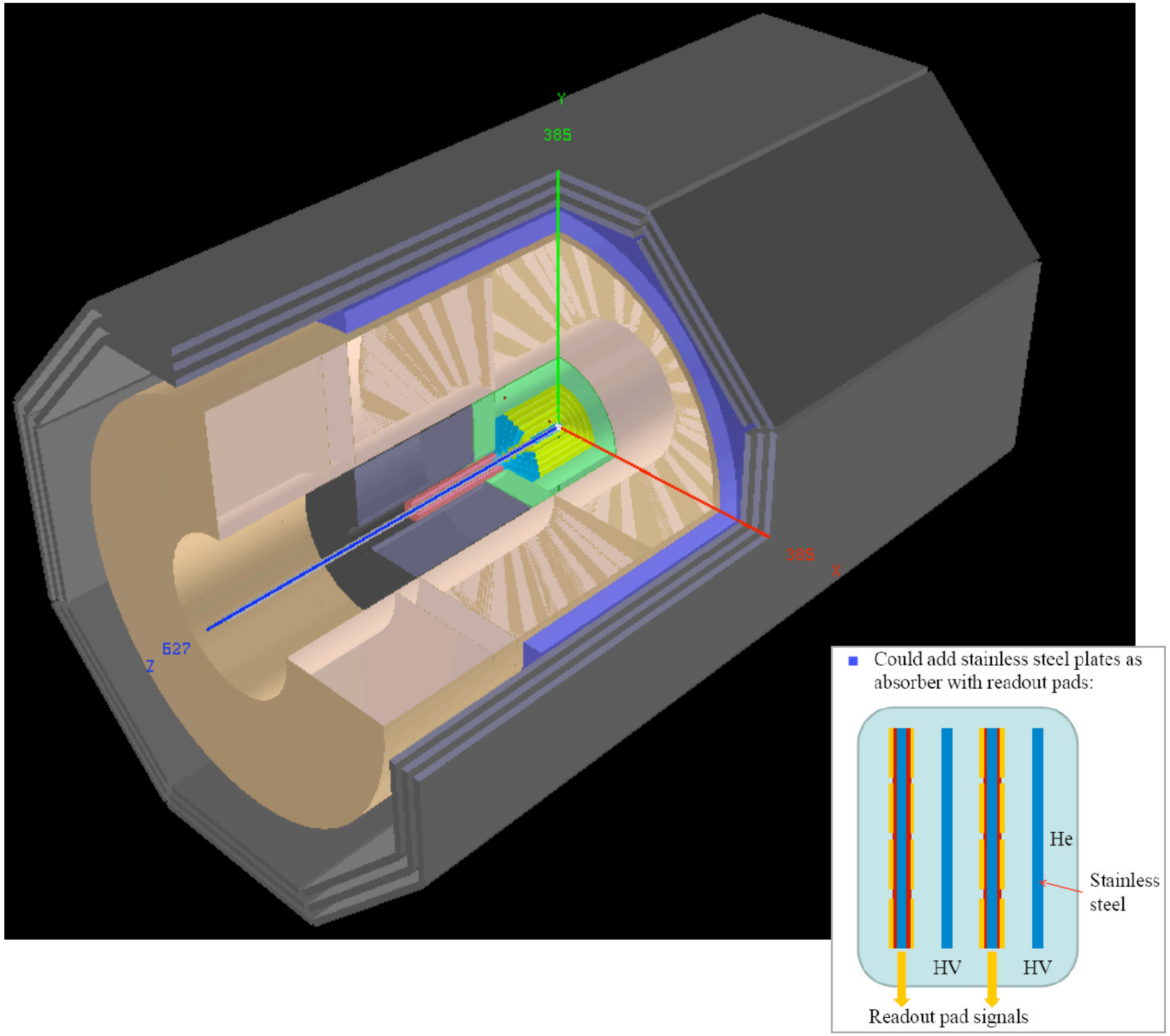
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

Fwd Calorimeter
(down to 10^o)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170^o)

Lepton low β magnets
Spacal (elm, hadr)



Active magnets? (TG.)

Tasks on the Machine

for the CDR - incomplete

-Infrastructure (Interaction Region, SPL/TI2, LINAC site)

-IR for ring and for LINAC and its interface with LHC, e beam and the detector

-Optics and lattice designs (high luminosity and small angle acceptance)

-Identification of R+D projects for LHeC (active magnets?, rf Coupler, …)

-LINAC: is ER feasible for a 100 GeV beam or is the LR limited to 10^{32} ?
what is the luminosity in e^+ ?

-Ring: installation: pathway and radiation
injector (SPL and its possible use for an initial eA phase)

The LHeC is a PeV equivalent fixed target ep scattering experiment.

At ~50 000 times higher Q^2 than the SLAC MIT experiment it needs an only few times longer LINAC (or a ring).

Its physics potential is extremely rich.

ECFA 11/07

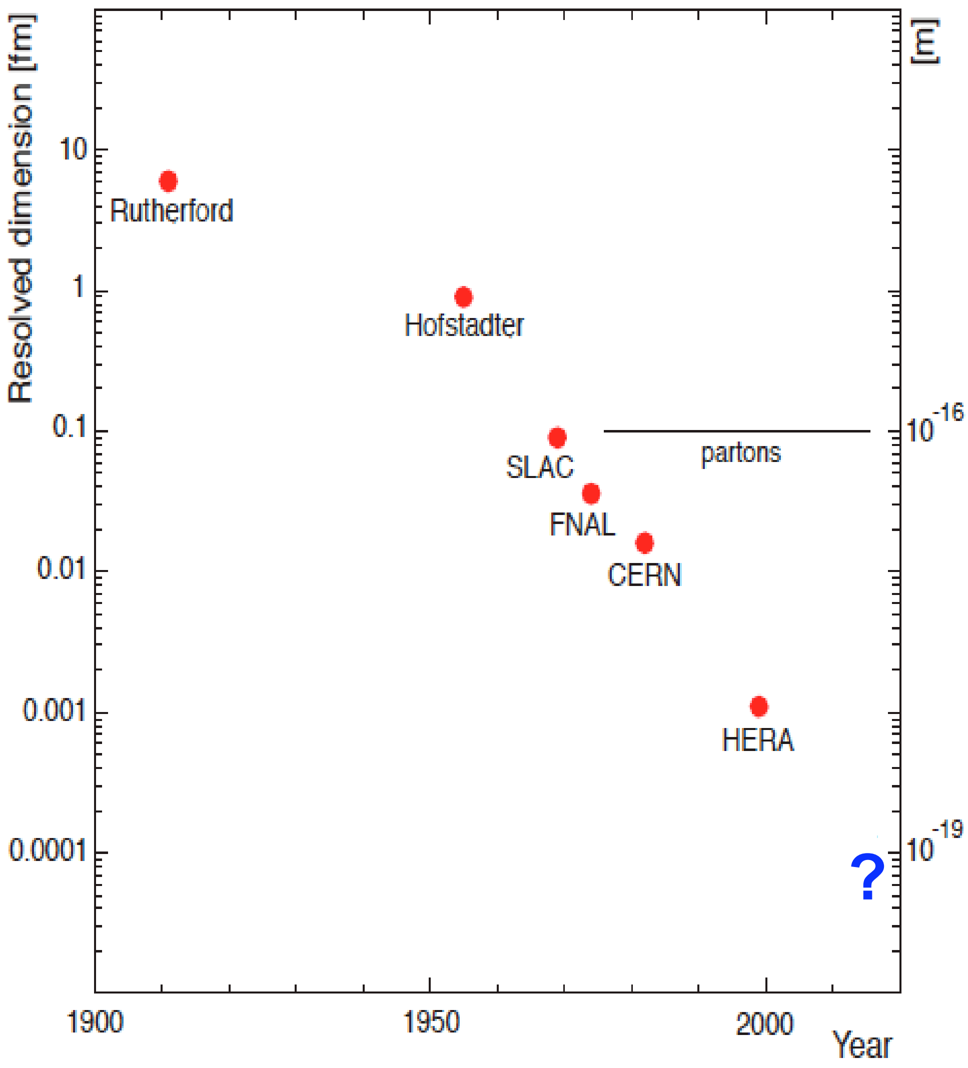
NuPECC 9/08

ICFA 10/08

ECFA 11/08

Final report to ECFA: 11/09.

Written CDR 3/10



“It would be a vaste not to exploit the LHC for ep/A” (G.A.) and the continuation of an historic path

http://www.lhec.org.uk

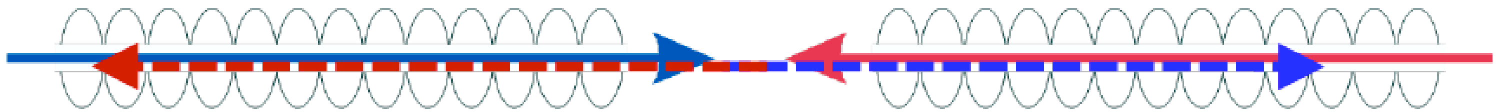
Backup slides

Energy Recovery

Jlab: **recirculating linac**, 99.5% of energy recovered at 150 MeV and 10 mA, ~98% recovery at 1 GeV and 100 μA with beam swung between 20 MeV to 1 GeV, plans for multi-GeV linacs withcurrents of ~100 mA

S. Chattopadhyay

M. Tigner, "A possible apparatus for electron clashing-beam experiments," Nuovo Cim.37:1228-1231 (1965).



J. Sekutowicz et al, "Proposed continuous wave energy recovery operation of an XFEL," Phys.Rev.ST Accel.Beams 8:010701,2005, up to 98% efficient