# LHeC

a Large Hadron Electron Collider at CERN

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

Max Klein
University of Liverpool and Cockcroft Institute
H1 and ATLAS

**Physics**

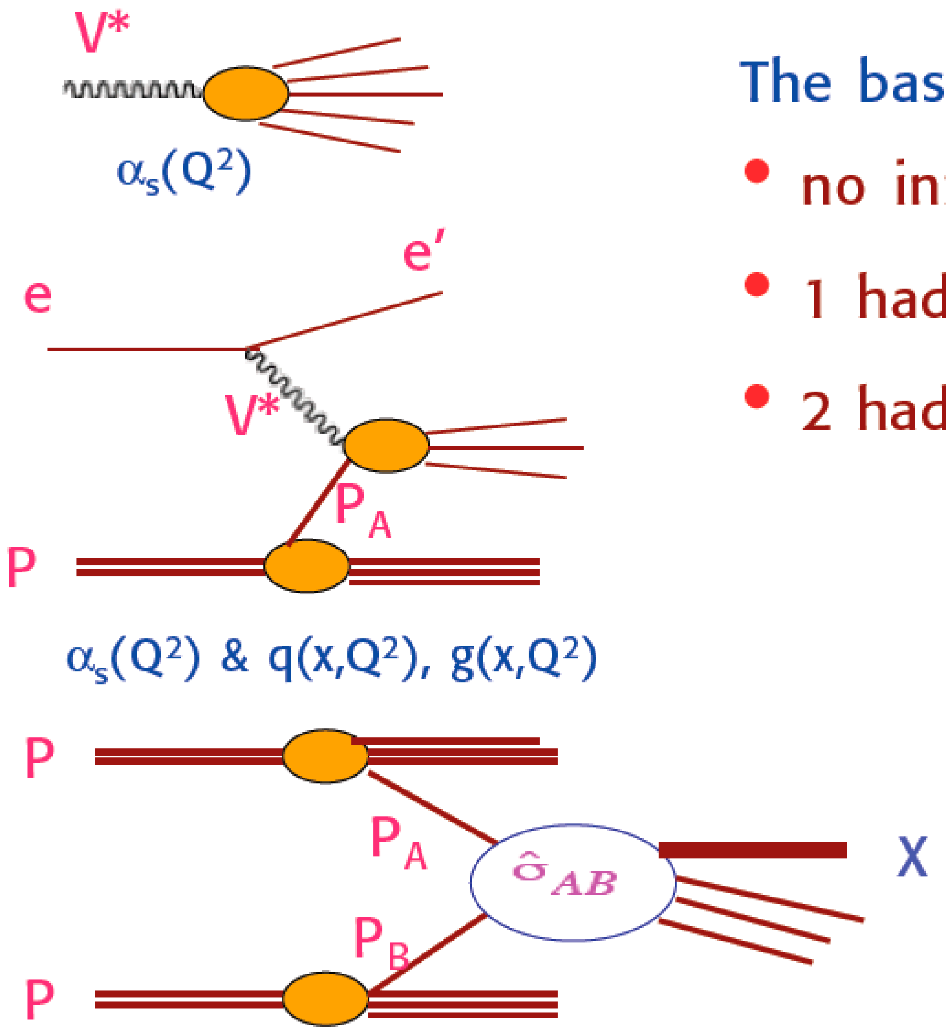
**Machine**

**Detector**

**DRAFT 28.10.**

Report on an **ongoing** ECFA-CERN study (2007-2009) towards a CDR
on behalf of the LHeC Steering Group.
ICFA Seminar, SLAC, Stanford, October 29, 2008
**http://www.lhec.org.uk**

klein@ifh.de

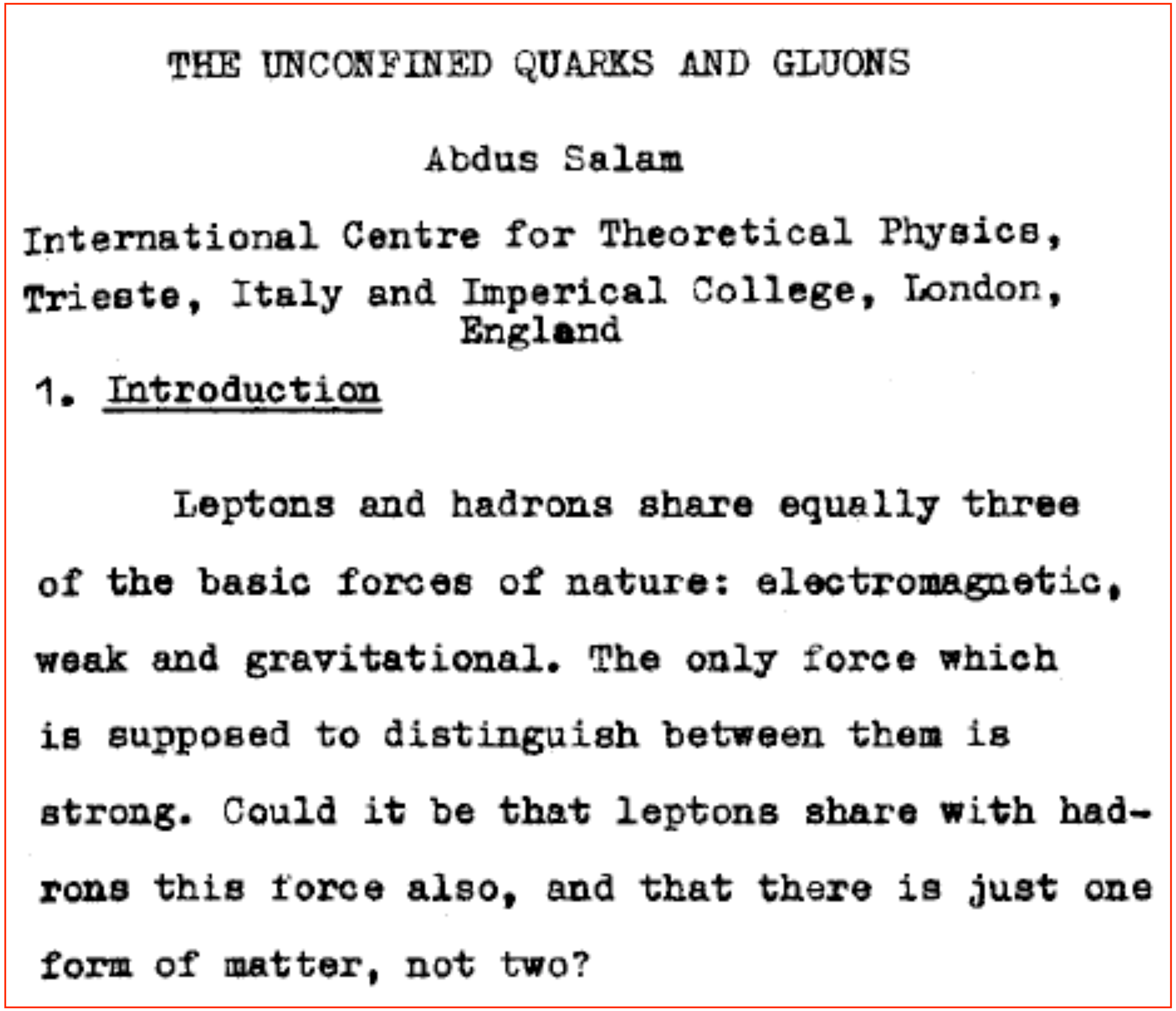


## The basic experimental set ups:

- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, LHeC)
- 2 hadrons (....SppS, Tevatron, LHC)

Progress in particle physics needs their continuous interplay to take full advantage of their complementarity

G.Altarelli, Divonne



## THE UNCONFINED QUARKS AND GLUONS

Abdus Salam

International Centre for Theoretical Physics,
Trieste, Italy and Imperical College, London,
England

### 1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

ICHEP1976 Tbilissi

# New Physics at the LHeC

- **Lepto-Quark Production and Decay (s and t-channel effects)**
- **Squarks and Gluinos**
- **ZZ, WZ, WW elastic and inelastic collisions**
- **Technicolor**
- **Novel Higgs Production Mechanisms**
- **Composite electrons**
- **Lepton-Flavor Violation**
- **QCD at High Density in ep and eA collisions**
- **Odderon**

Maximum $W < 1.4$ TeV
for $E_e = 140$ GeV, $E_p = 7$ TeV

Broad physics goals (to be discussed at the Workshop)

- Proton structure and QCD physics in the domain of x and $Q^2$ of LHC experiments
- Small-x physics in eP and eA collisions
- Probing the $e^{\pm}$-quark system at ~TeV energy
  eg leptoquarks, excited e*'s, mirror e, SUSY with no R-parity......
- Searching for new EW currents
  eg RH W's, effective eeqq contact interactions...

G. Altarelli

# Towards the CDR by 2009

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)
Roger 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)

**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 2005.**
**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),**

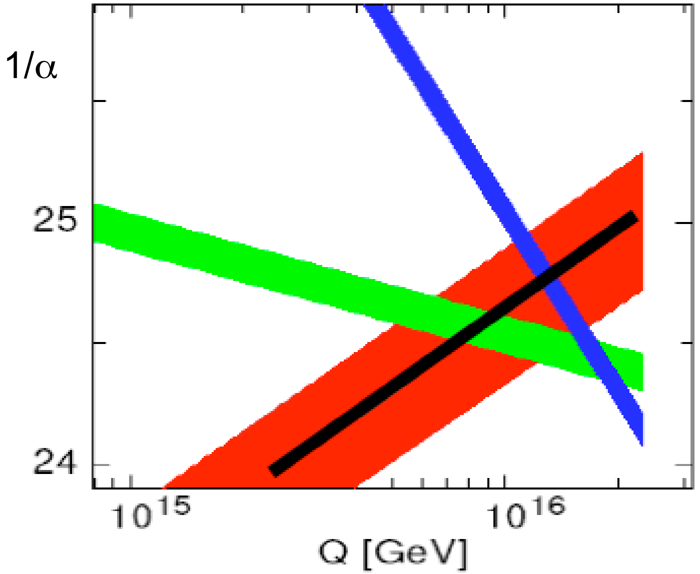
**Brian Cole (Columbia),**

**Paul Newman (B’ham),**

**Anna Stasto (MSU)**

# Strong Coupling Constant

Simulation of $\alpha_s$ measurement at LHeC



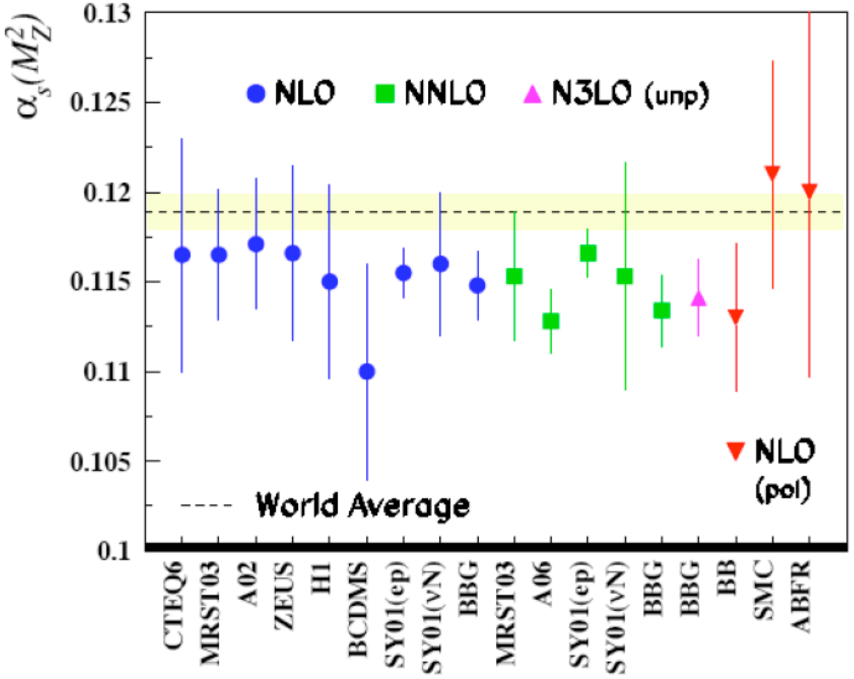
| DATA | exp. error on $\alpha_s$ |
|---|---|
| NC $e^+$ only | 0.48% |
| NC | 0.41% |
| **NC & CC** | **0.23% $:=^{(1)}$** |
| (1) $\gamma_h$>5° | 0.36% $:=^{(2)}$ |
| (1) +BCDMS | 0.22% |
| (2) +BCDMS | 0.22% |
| (1) stat. *= 2 | 0.35% |

**Worst of all measured coupling constants**

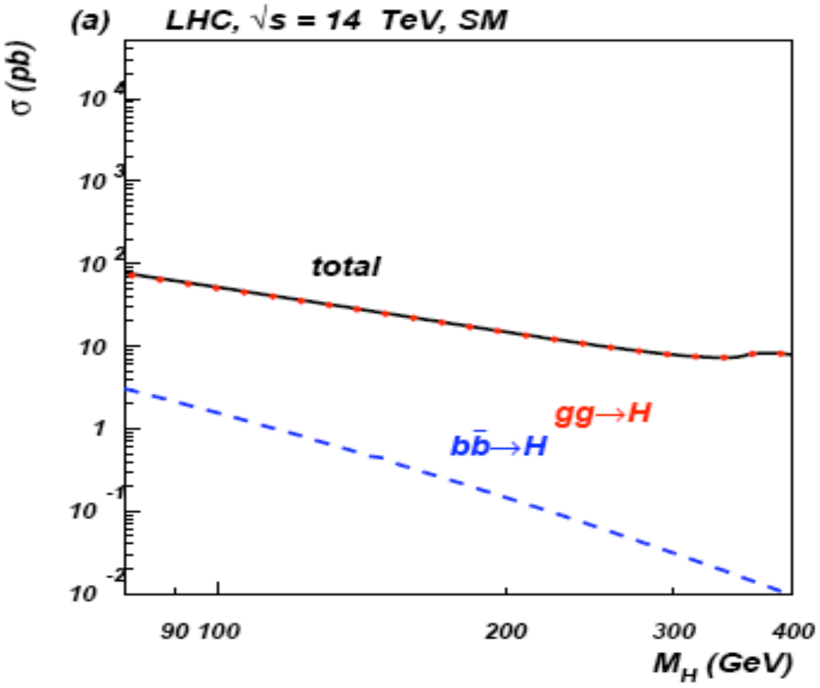
**DIS tends to be lower than world average**

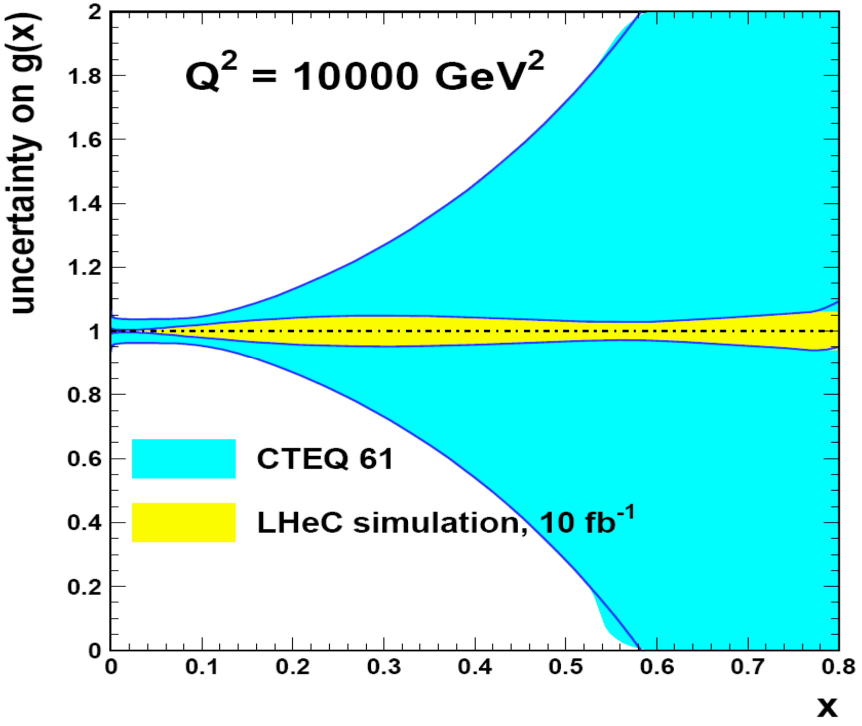
**LHeC: per mille accuracy indep. of BCDMS.**
**Challenge to experiment and to h.o. QCD**

Blumlein et al '06



# Gluon - SM Higgs

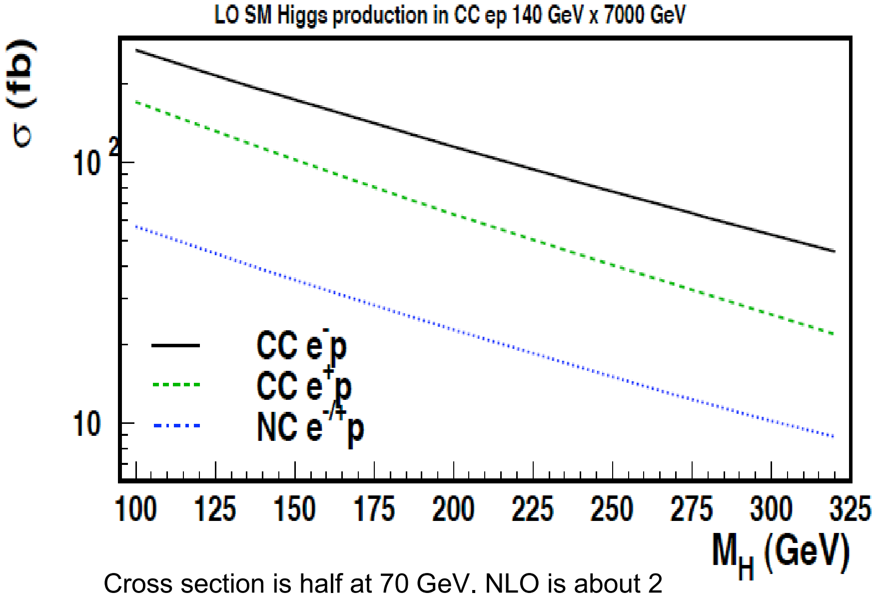




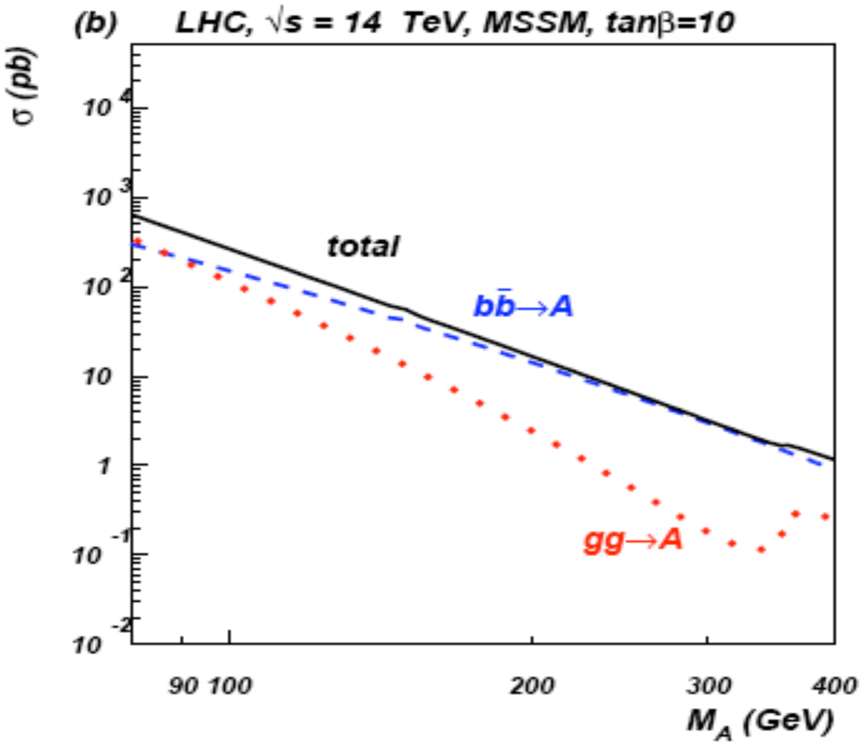
**In SM Higgs production is gluon dominated**

**LHeC: huge x,$Q^2$ range for xg determination**

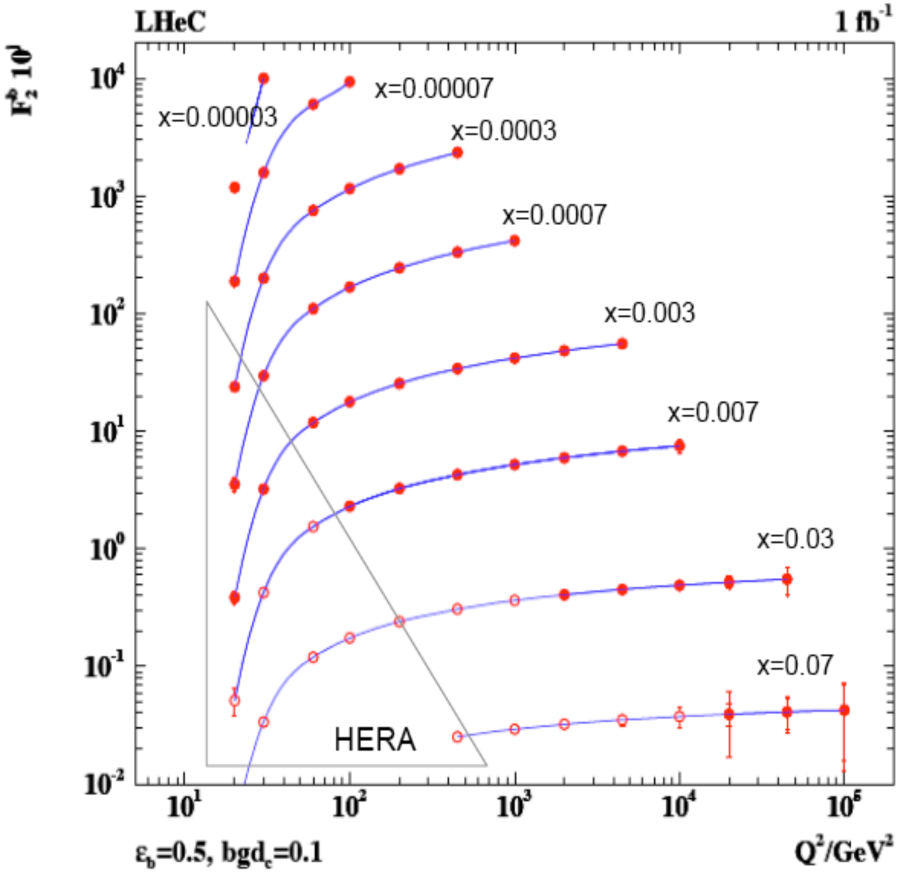
**WW to Higgs fusion has sizeable ep xsection**



Cross section is half at 70 GeV. NLO is about 2



# Beauty - MSSM Higgs

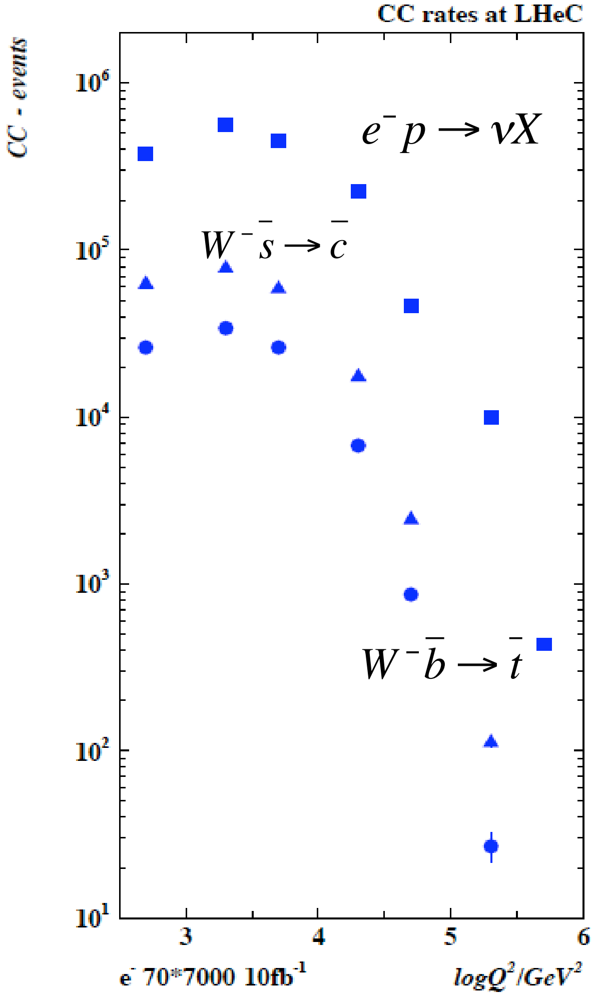


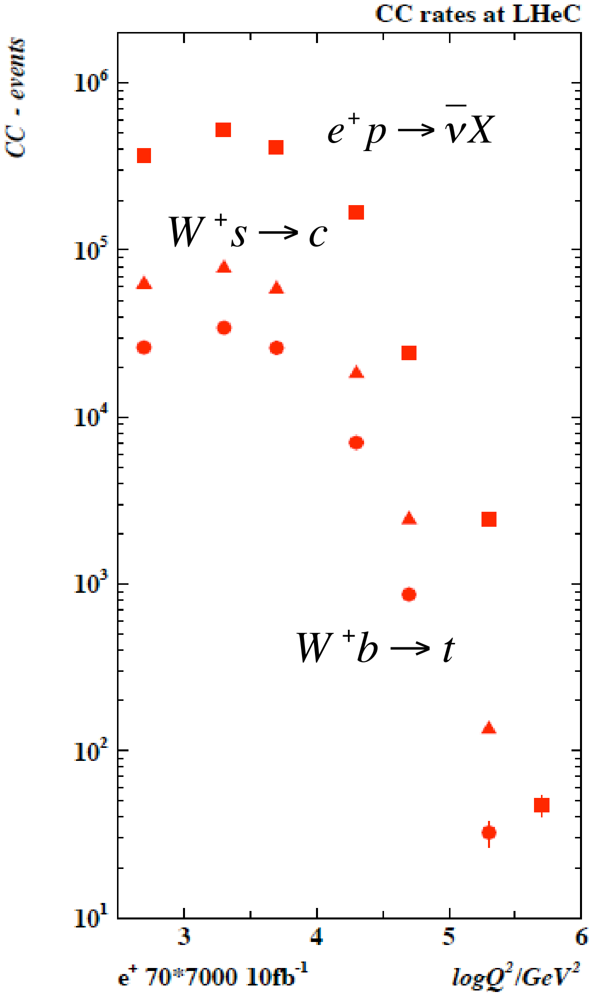
**In MSSM Higgs production is b dominated**

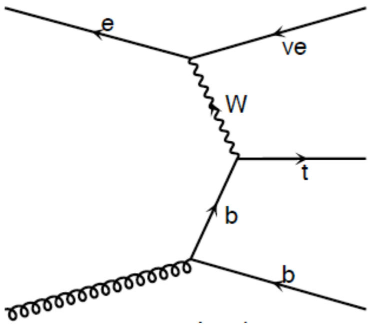
**First measurements of b at HERA can be turned to precision measurement of bdf.**

**LHeC: higher fraction of b, larger range, smaller beam spot, better Si detectors**

# (Anti) top and strange production in CC



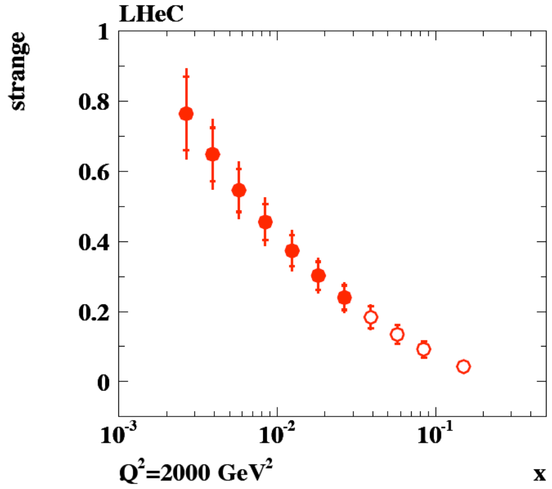




**LHeC is a single top and single tbar quark `factory'**

**CC t cross section O(5)pb**

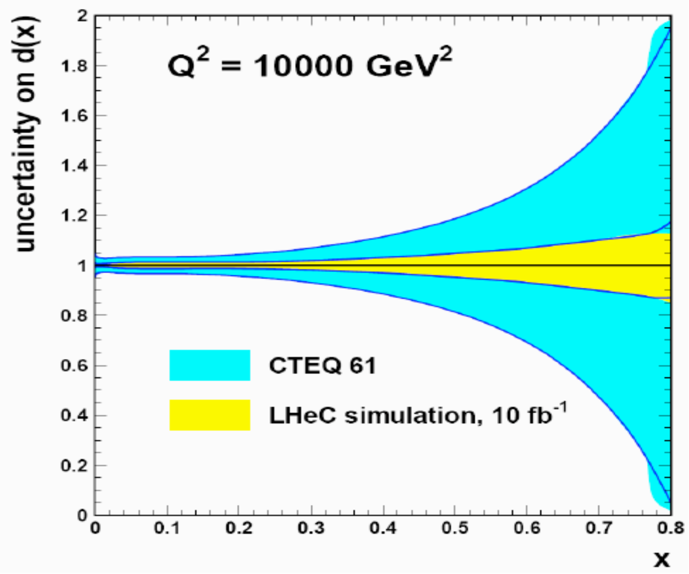
**S, sbar-df for the 1st time.**



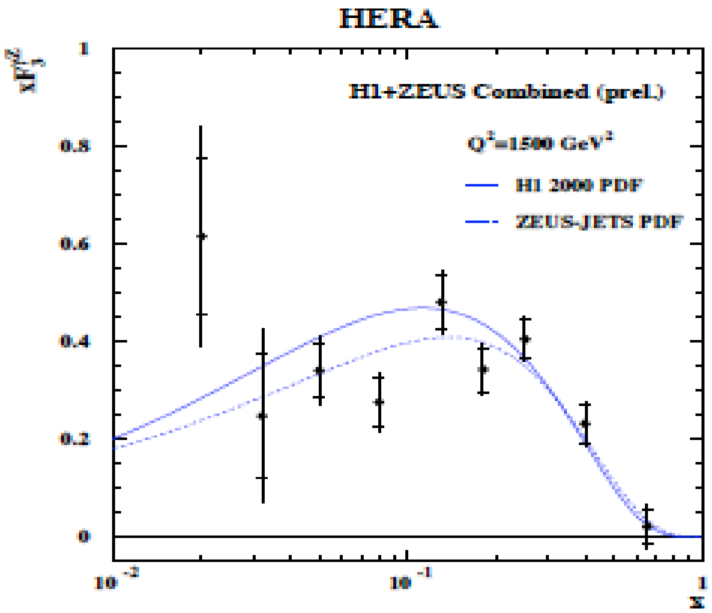
# Light Quark Distributions

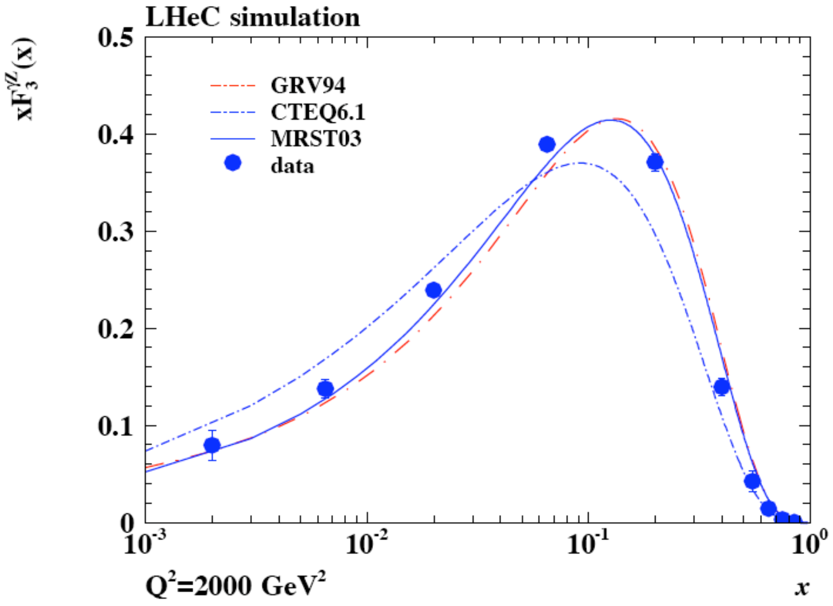
d and u at high x: a longstanding puzzle
NC/CC: free of HT, nuclear corrections.
Essential for predictions at high x

LHeC is an electroweak machine.
e.g.: Charge asymmetry in NC measures
valence quarks down to x ~$10^{-3}$ at high $Q^2$

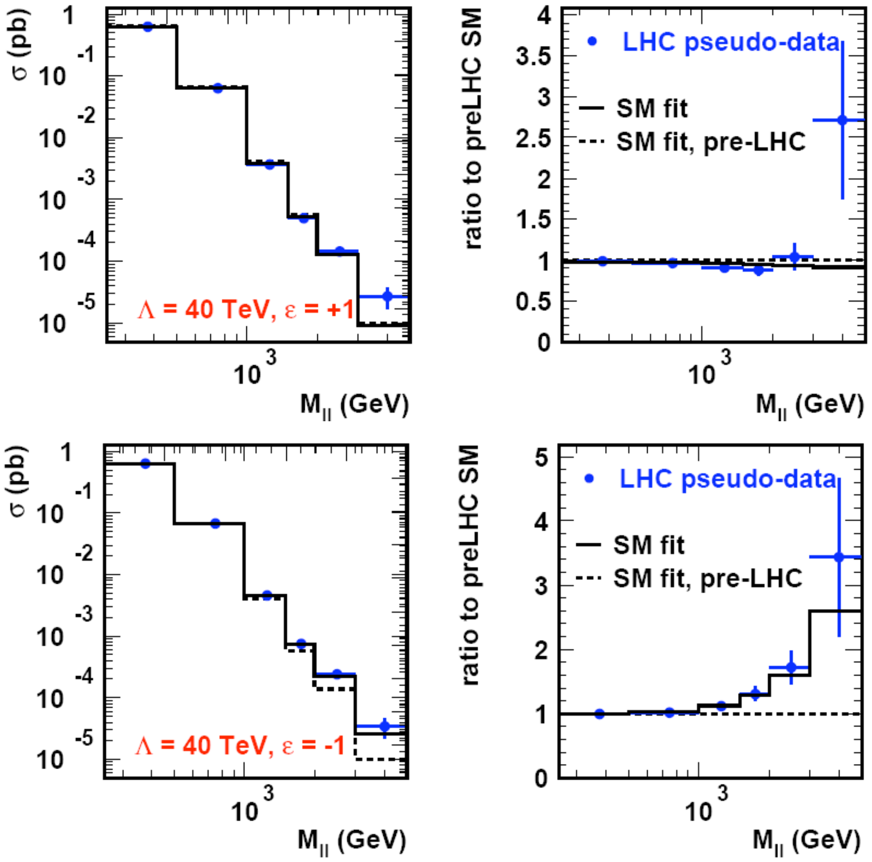


$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v)$$

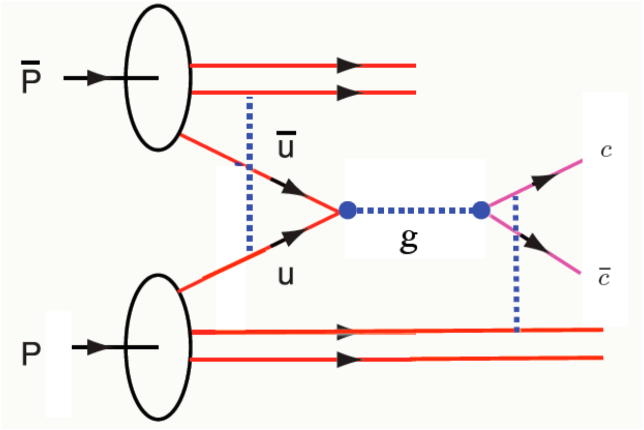




# pdf’s and new physics at the LHC

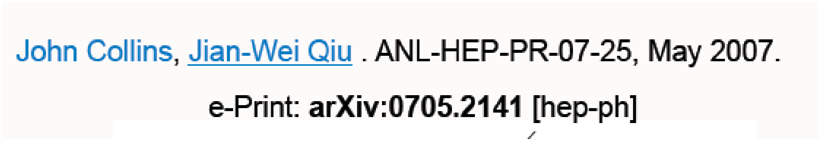


Blue & red data points = NP scenario (Λ= 40 TeV)
Black curve = SM cross-sections
**NP may be accommodated by HERA/BCDMS DGLAP fit. It can not by the fit to also LHeC.**
(recall high Et excess at the Tevatron which disappeared when xg became modified)



**Factorisation is violated in production of high $p_T$ particles (IS and FS i.a.s).**

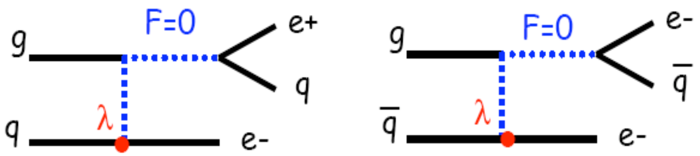
Important, perhaps crucial, to measure pdf’s in the kinematic range of the LHC. cf also ED limits vs pdf’s.

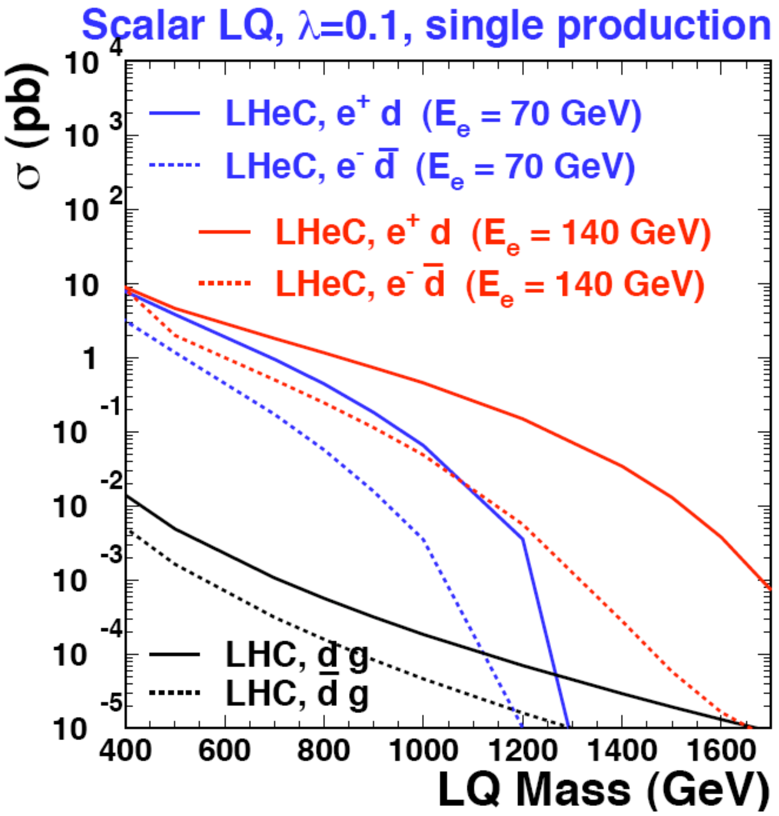


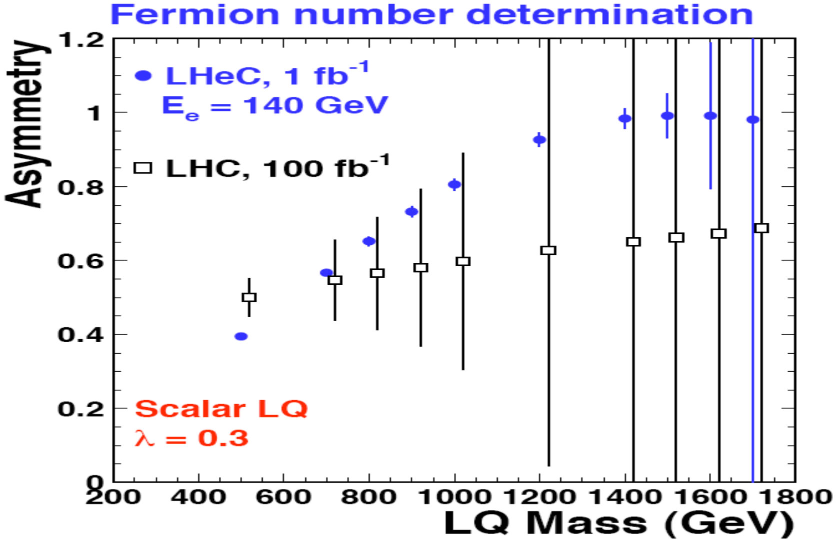
John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.

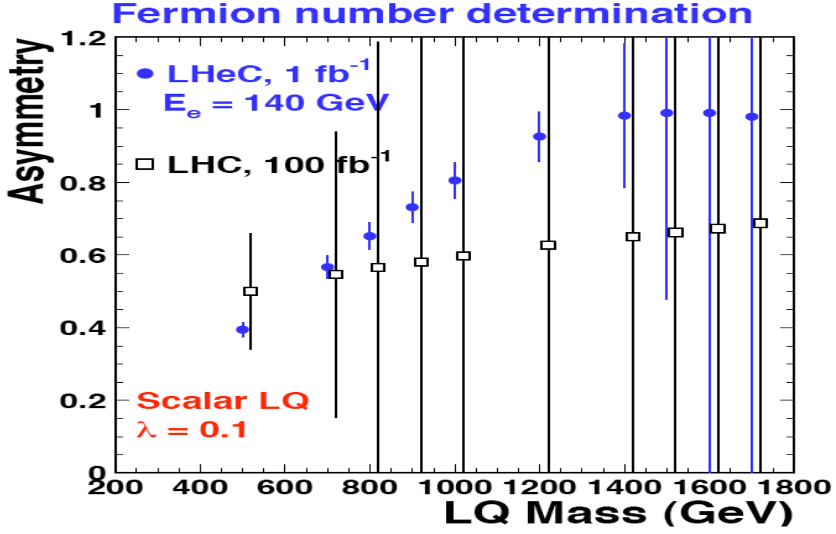
e-Print: **arXiv:0705.2141** [hep-ph]

# LQ Quantum Numbers



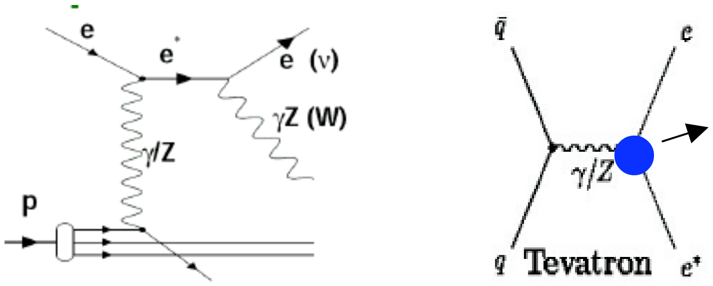






**Charge asymmetry much cleaner in ep than in pp. Similar for simultaneous determination of coupling and quark flavour. Polarisation would be essential for spectroscopy**

# Electron-Boson Resonances : excited electrons

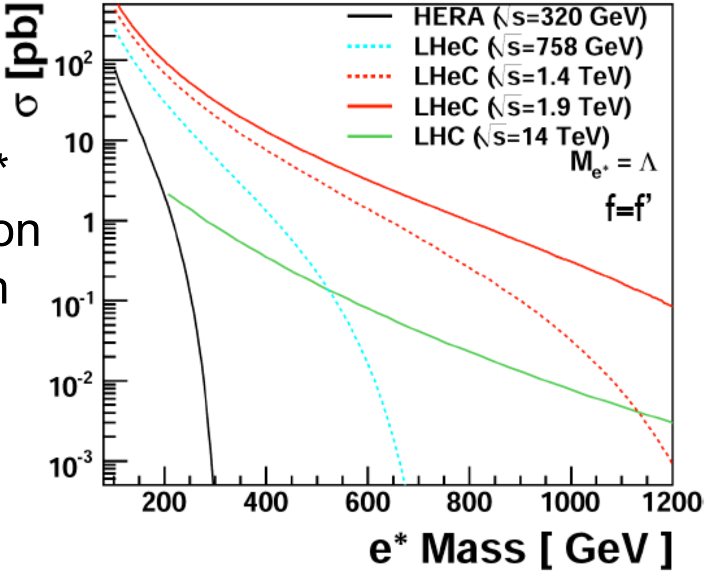


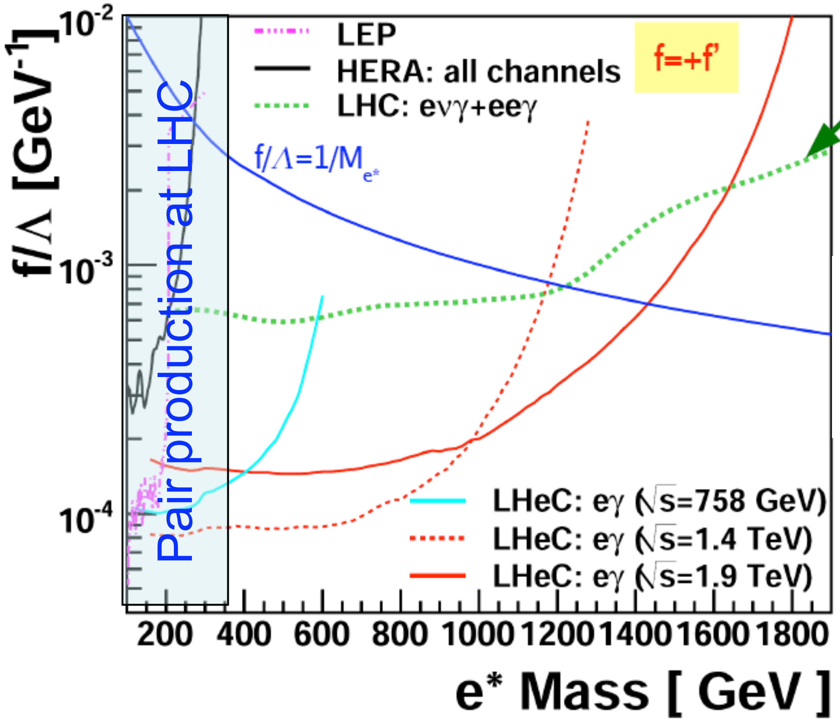
coupling
~ f / Λ

[Hagiwara et al. ZPC 29(1985)115]

[Boudjema et al. ZPC 57(1990)425]

Single e*
production
x-section





[ Phys. Rev D 65 (2002) 075003 ]

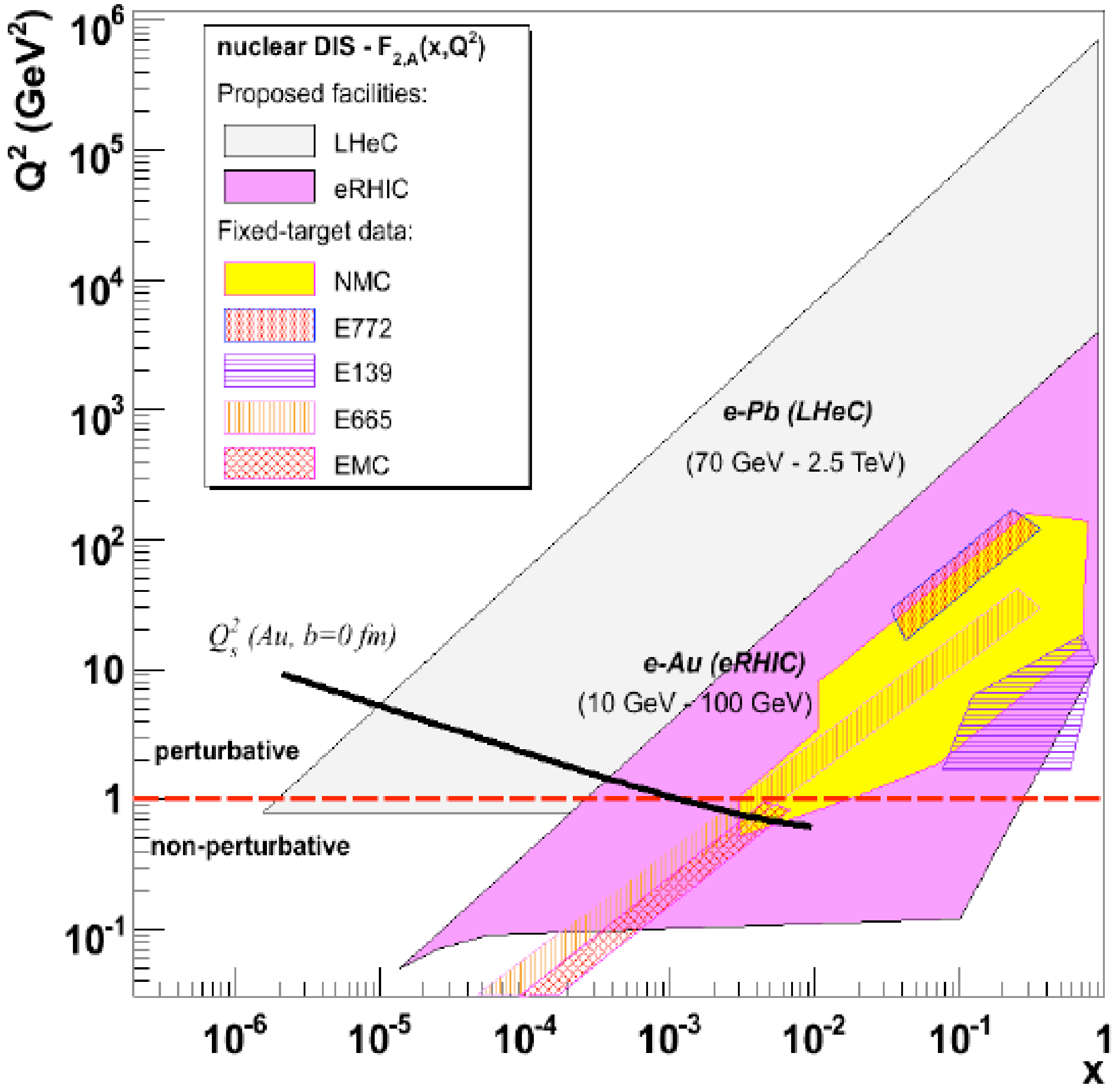
LHeC prelim. analysis, looking at e* → eγ

- If LHC discovers (pair prod) an e*: LHeC would be sensitive to much smaller f/Λ couplings
- Discovery potential for higher masses

**LHeC sensitivity,**
**with L=10 fb$^{-1}$ for Ee=70/20 GeV**
**with L=1 fb$^{-1}$ for Ee=140 GeV**

N. Trinh, E. Sauvan

# DIS eA Kinematics



DdE, arXiv:0706.4182

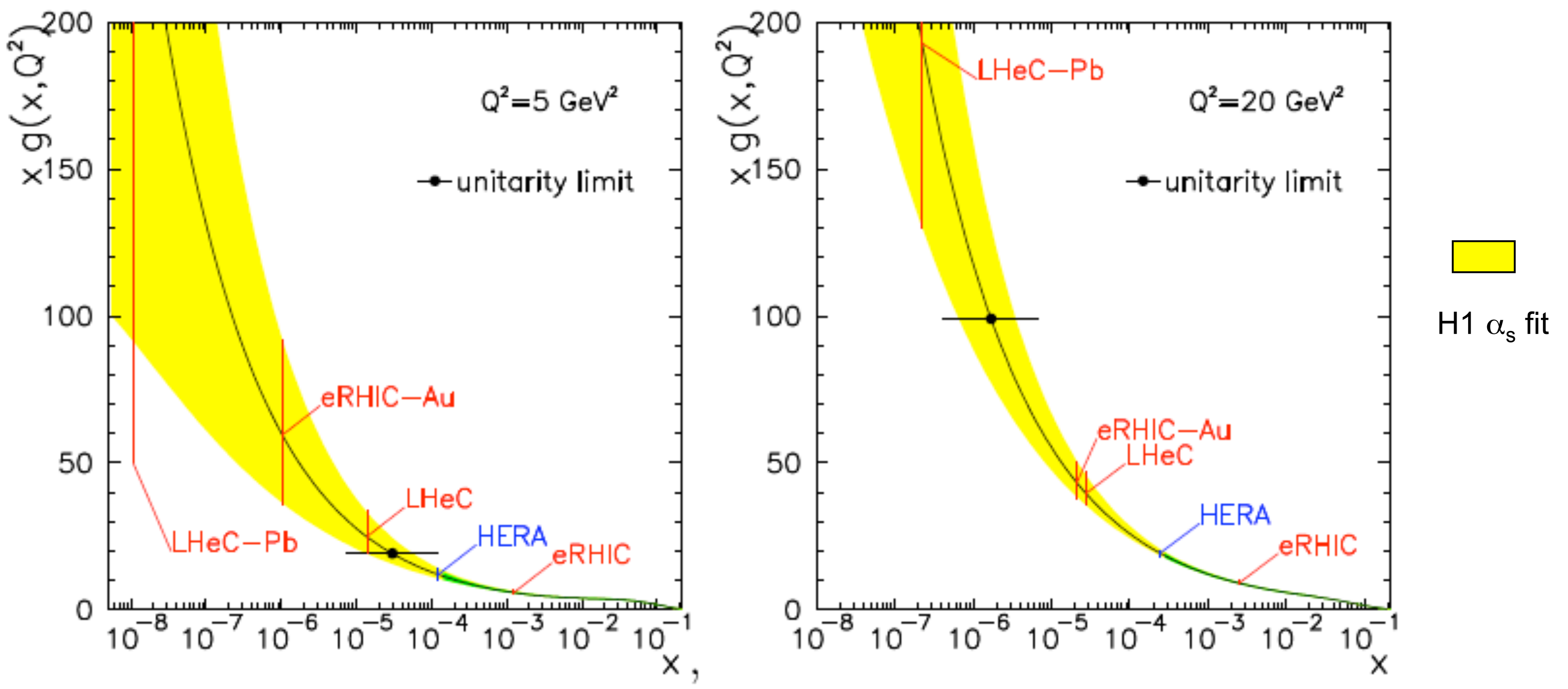
**LHeC extends kinematic range of partonic structure of nuclei by 3-4 orders of magnitude.**

**It accesses saturation effects at low x in DS region.**

**eRHIC with nuclei could be complementary.**

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

# Nuclei - gluon density amplification



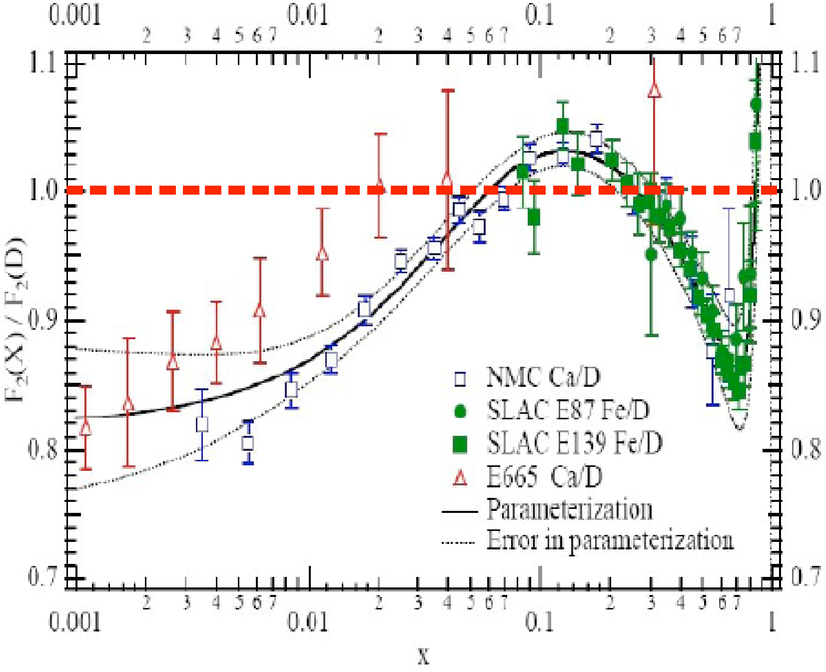
High density $$\frac{g_A/\pi r_A^{2}}{g_p/\pi r_p^{2}} = A^{1/3}\,\frac{g_A}{A g_p}$$

Unitarity $$\boxed{xg(x,Q^2) \leq \frac{1}{\pi N_c \alpha_s(Q^2)} Q^2 R^2 \simeq \frac{Q^2}{\alpha_s}}$$

**Striking effects predicted**:

Bj → black disc limit $F_2 \sim Q^2 \ln(1/x)$
~50% diffraction
colour opacity, change of J/Ψ(A) ...

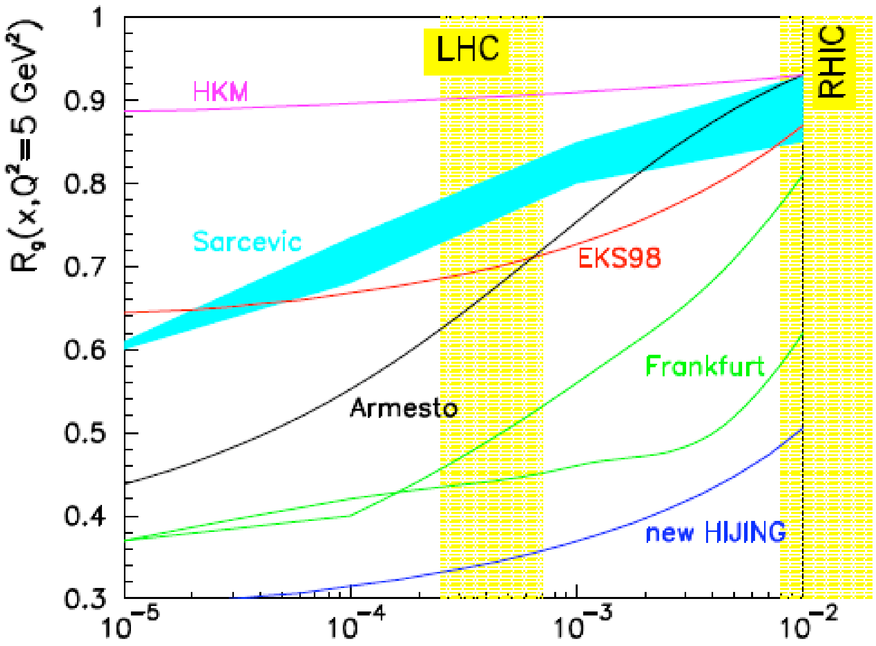
# Need eA collider data to determine nuclear parton distributions in the kinematic range of pA/AA collisions at the LHC



See e.g. M.Arneodo
Phys. Rept. 240 (94) 301

**NuPECC EIC-LHeC Study group**

Tullio Bressani, INFN, Torino Univ.
Jens Jørgen Gaardhøje, Niels Bohr Inst.
Günther Rosner, Glasgow Univ.
Hans Ströher, FZ Juelich



K.Eskola et al. JHEP 0807 (08)102

# Saturation - Black Hole Duality.?

## 4d Perturbative QCD

1. Dilute/dense transition
2. Geometric scaling
3. Critical exponent 2.44
4. IR/UV competition

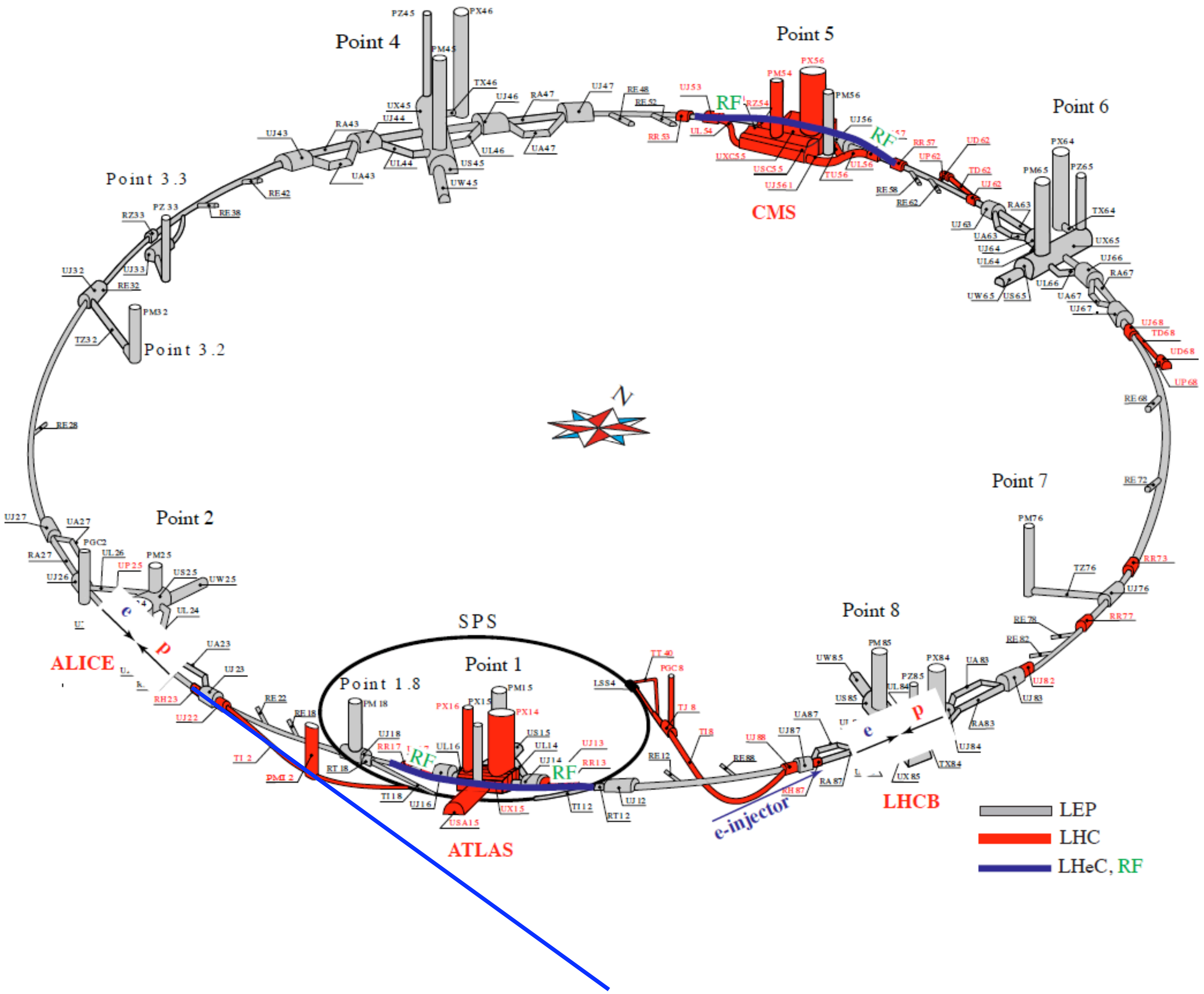
## 5d Tiny Black hole

1. Flat/black hole transition
2. CSS
3. Critical exponent 2.58
4. Gravity/kinetic competition

Agustin Sabio Vera (Divonne)

# Machine Considerations and Studies

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



**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:**

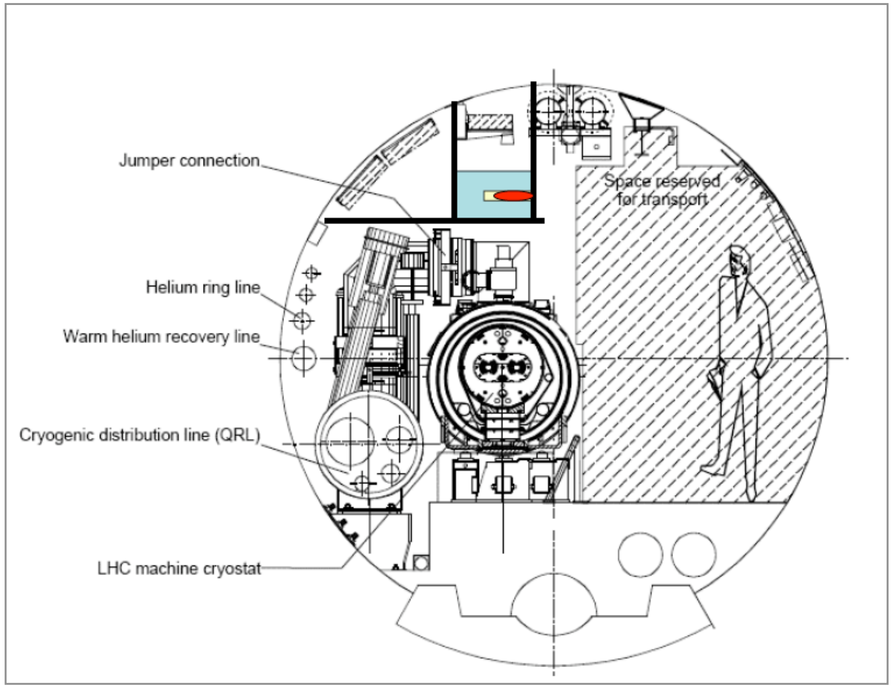
bypasses: 1 and 5
[use also for rf]

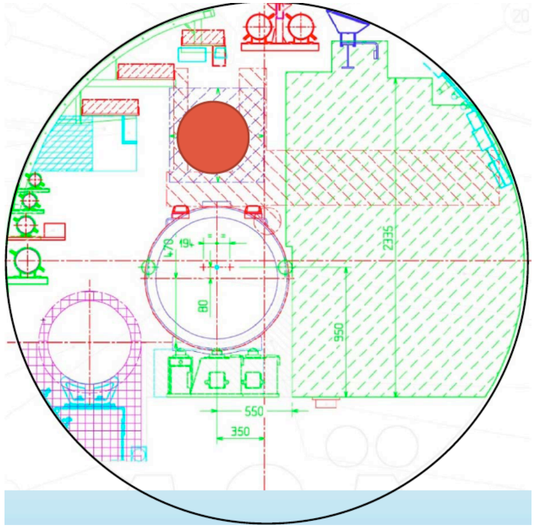
injector: SPL, or dedicated

**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.

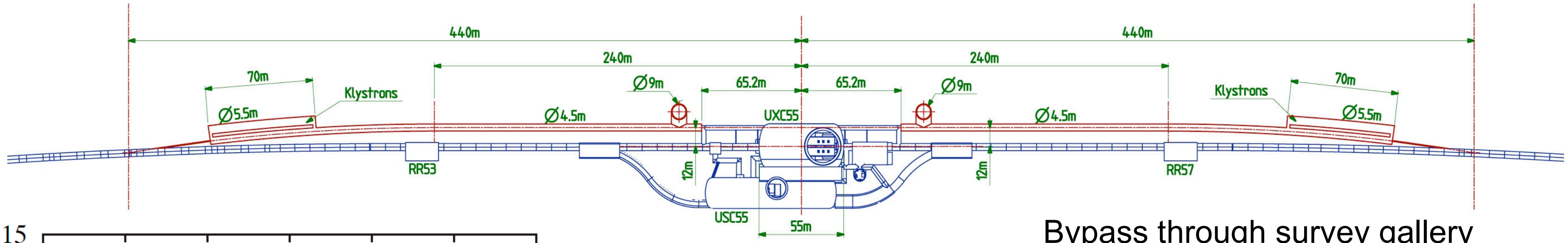
**Injection:**
LEP2 was 4 $10^{11}$ e in 4 bunches
LHeC is 1.4 $10^{10}$ in 2800 bunches
may inject at less than 20 GeV.

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

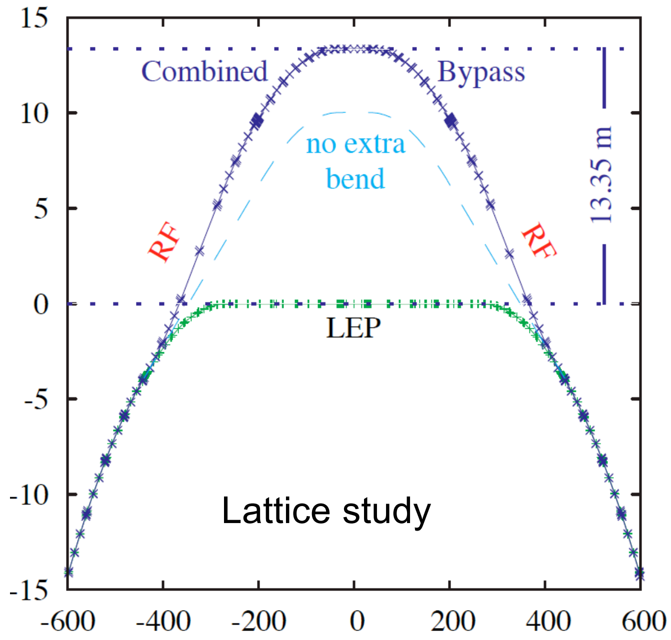
SC system at 1.9° K (1 GHz)
r.f. coupler to cavity: 500 kW CW - R+D
9 MV/cavity.
100(28) cavities for 900(250)MV
cavity: beam line of 150 (42) m
klystrons 100 (28) at 500kW
plus 90 m racks ..
**gallery of 540 (150) m length required.**

# Bypass

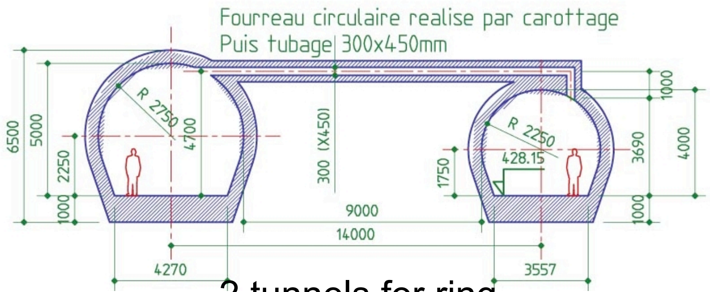
point 5



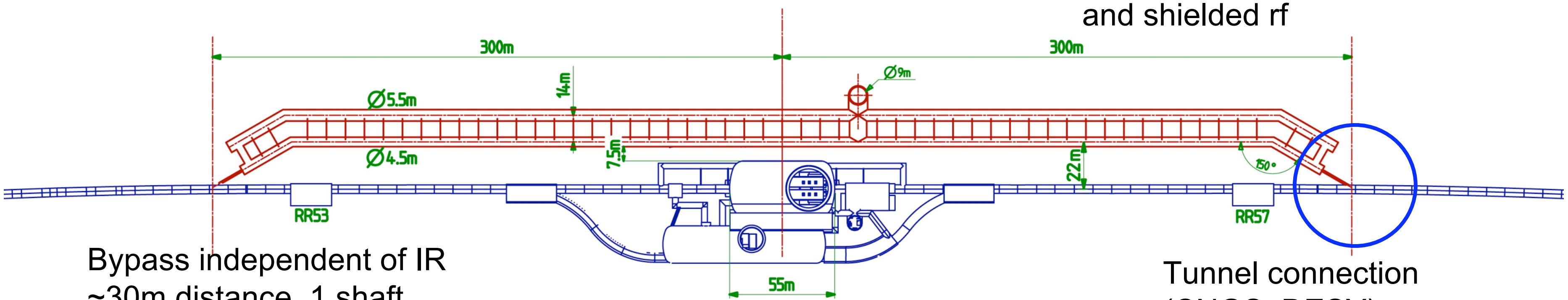
Bypass through survey gallery
13m distance, 2 shafts



Lattice study



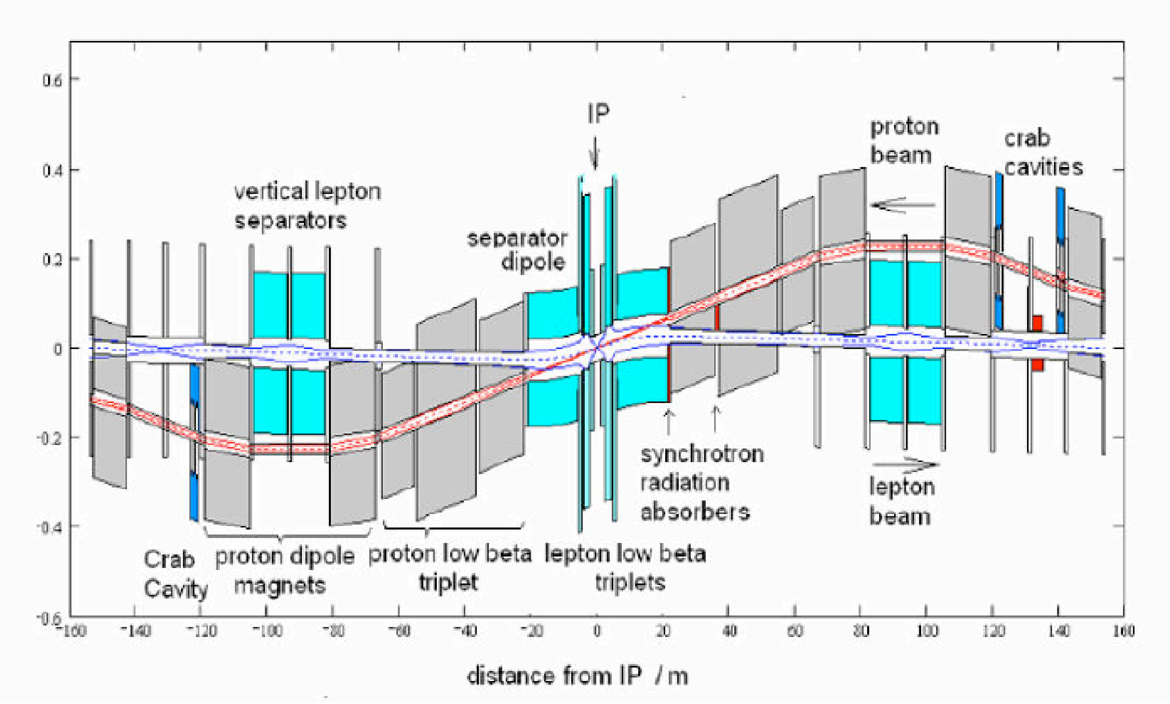
2 tunnels for ring
and shielded rf



Bypass independent of IR
~30m distance, 1 shaft

Tunnel connection
(CNGS, DESY)

# 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 ($1^o$ ) and hi L ($10^o$ ?)**

**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**

# Ring-Ring  Parameters

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

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

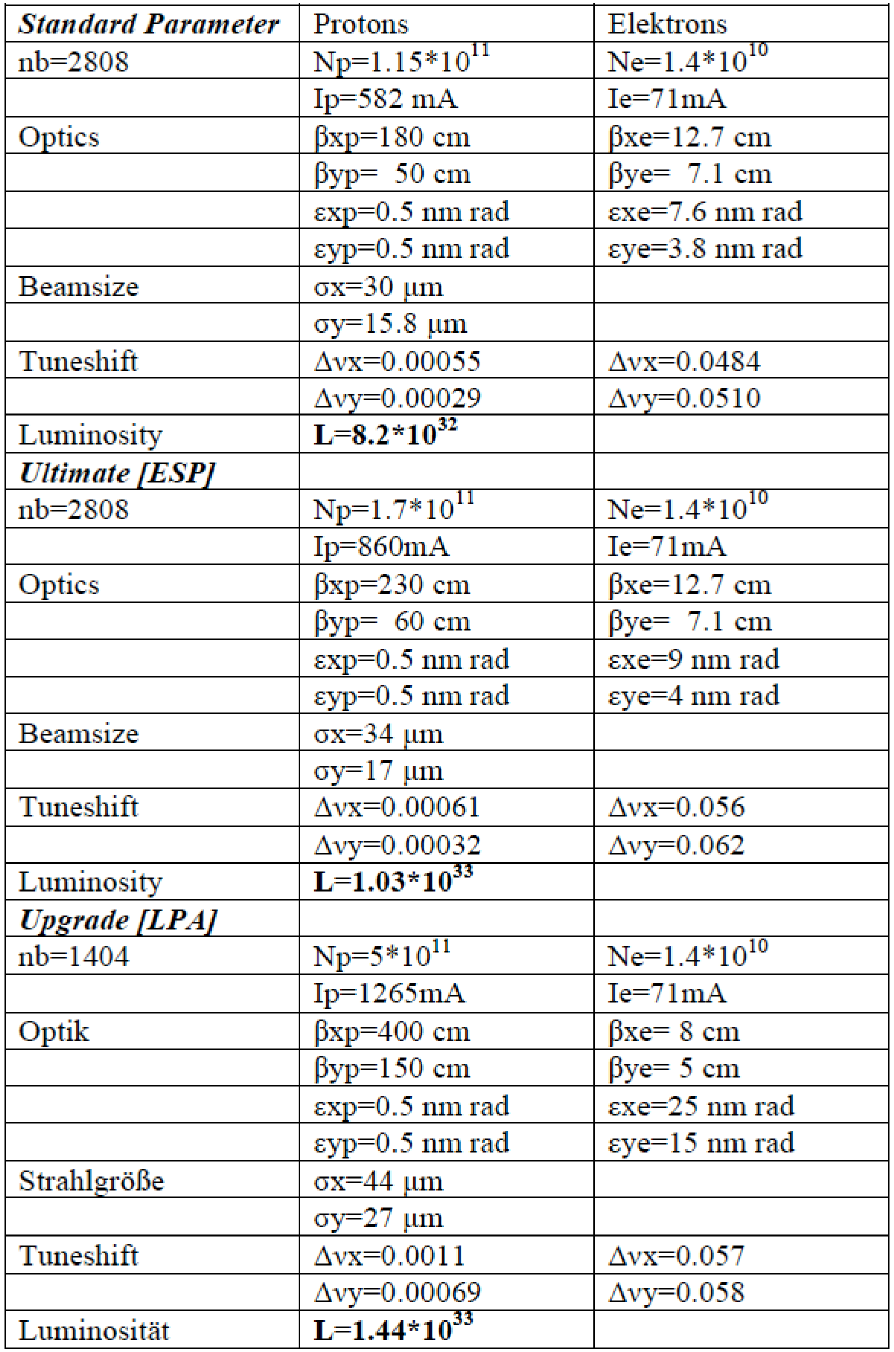
**Luminosity safely $10^{33}$**
**HERA was 1-5 $10^{31}$ (I to II)**

**Table values are for 14mA synrad loss (beam power) and 50 GeV on 7000 GeV. May have 50 MW and option to 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 $\beta_p$, decreasing $\beta_e$**
**but enlarging e emittance,**
**to keep e and p matched.**

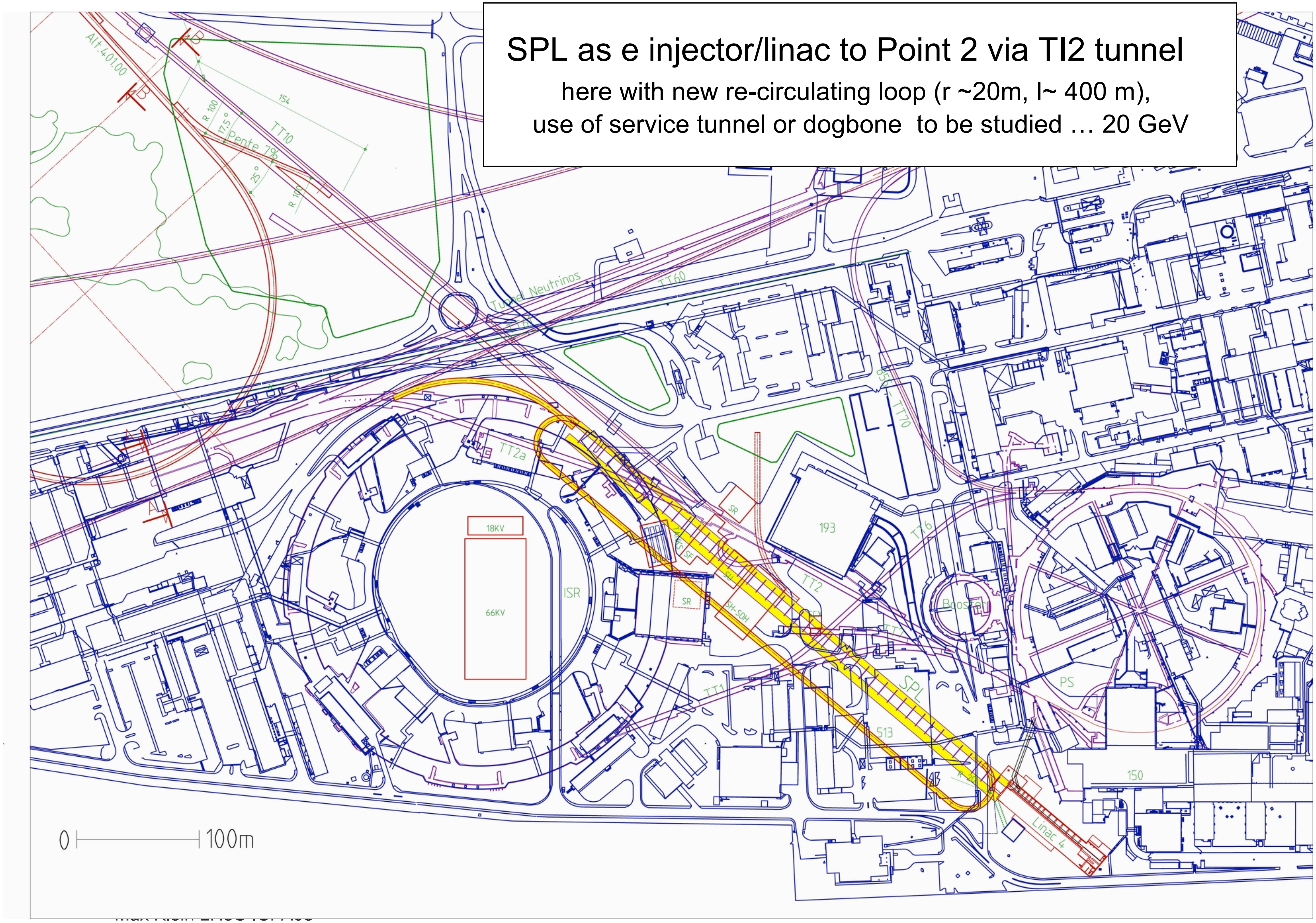
**LHeC profits from LHC upgrade but not proportional to $N_p$**



| ***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*$10^{33}$** | |

# 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



# Luminosity: Linac-Ring

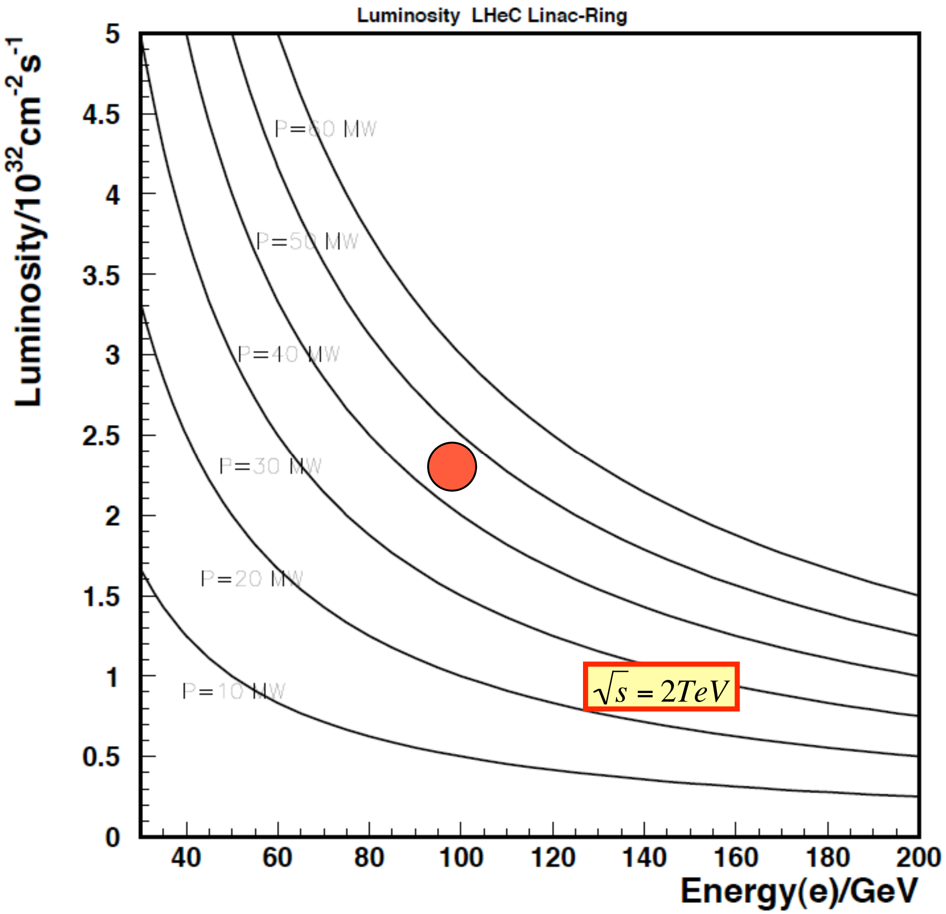
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$

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 $E_e$.**

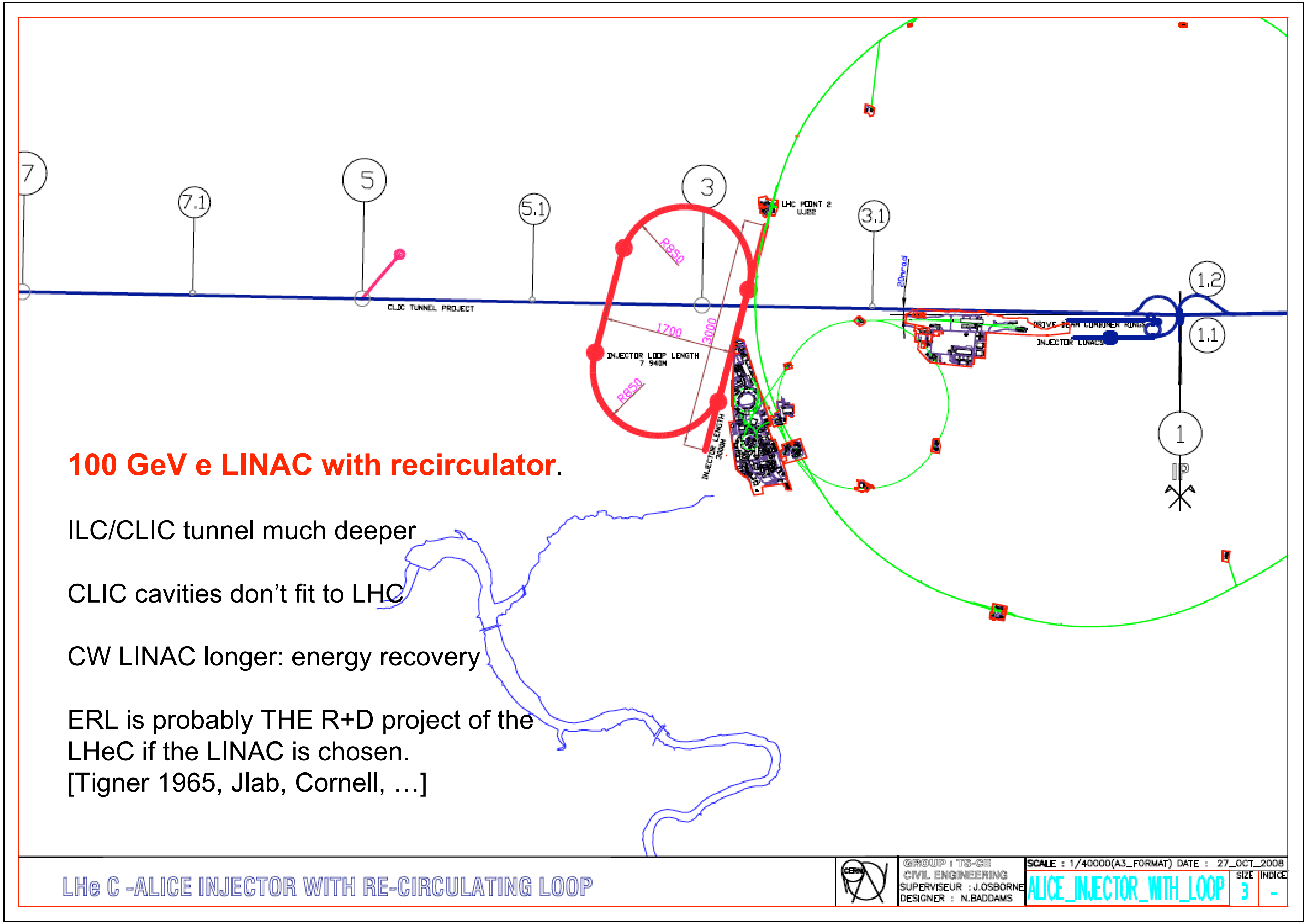
**LINAC - no periodic loss+refill,
~twice as efficient as ring…
8,4,3fb$^{-1}$ /year at (50)100[150] GeV**

**Note: positron source challenge:**

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

| 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 $\gamma\varepsilon$ [$\mu$m] | 50 | 50 | 50 |
| RF gradient [MV/m] | 25 | 25 | 13.9 |
| total linac length $\beta$=1 [m] | 350+333 | 3300 | 6000 |
| minimum return arc radius [m] | 240 (final bends) | 1100 | 1100 |
| beam power at IP [MW] | 48 | 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$^{-1}$]** | **5** | **2.2** | **1.3** |

**proton parameters: LPA upgrade SLHC: $N_b$=5x$10^{11}$, 50 ns spacing, $\gamma\varepsilon$=3.75 $\mu$m, $\beta^*$=0.1 m, $\sigma_z$=11.8 cm**



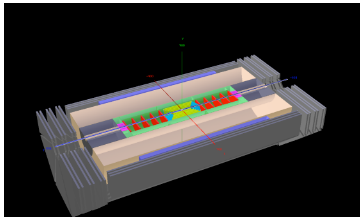
## 100 GeV e LINAC with recirculator.

ILC/CLIC tunnel much deeper

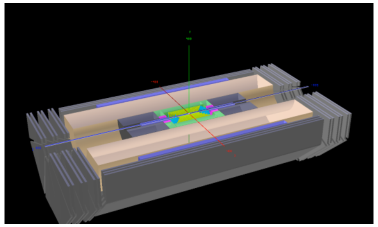
CLIC cavities don't fit to LHC

CW LINAC longer: energy recovery

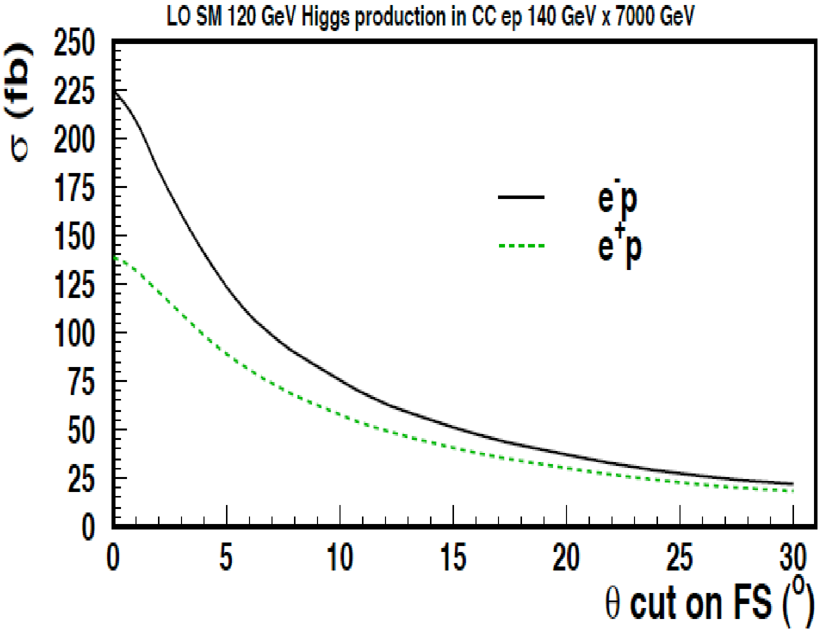
ERL is probably THE R+D project of the LHeC if the LINAC is chosen.
[Tigner 1965, Jlab, Cornell, …]



# Detector Design Considerations



**Large fwd acceptance at 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**

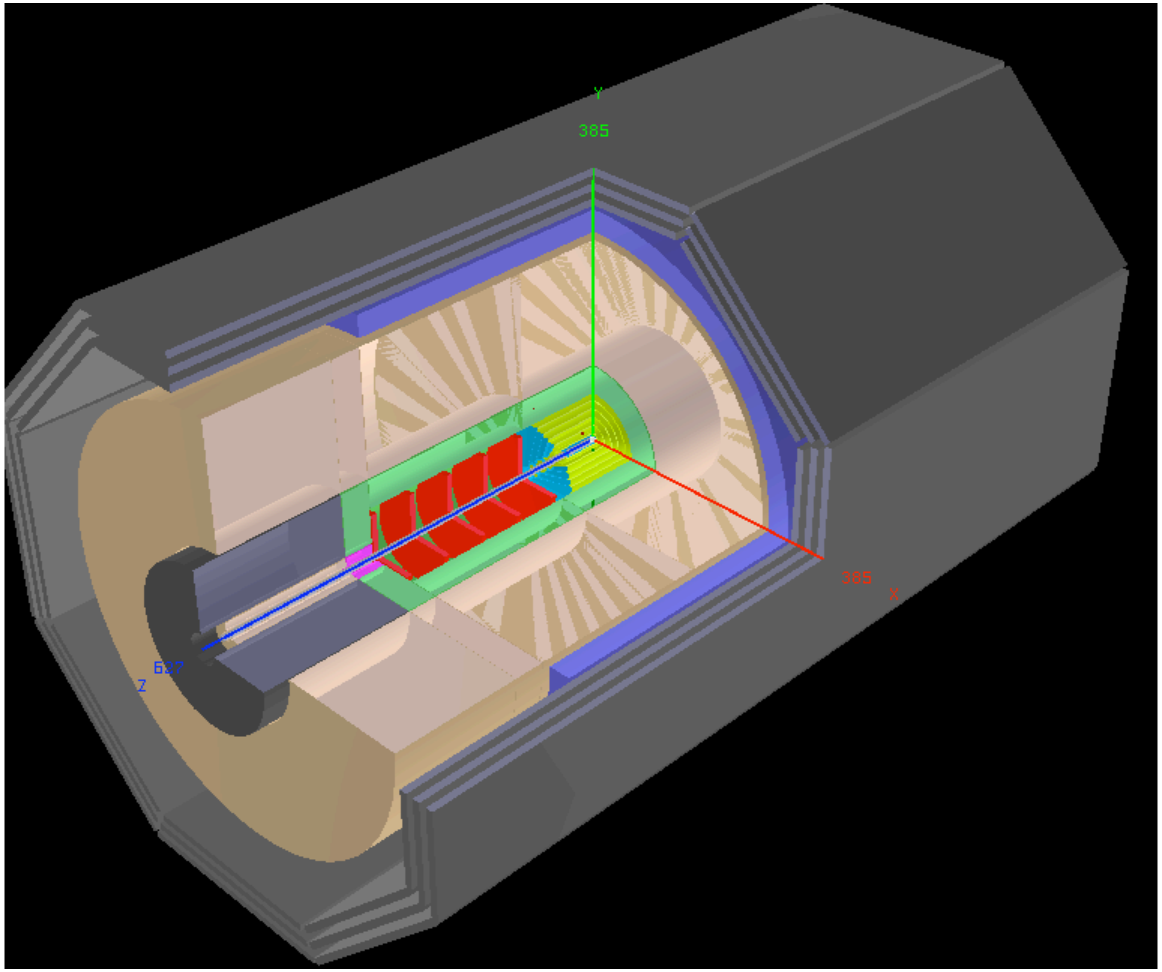
**Hadronic Calo (Fe/LAr)**
**El.magn. Calo (Pb,Sc)**
**GOSSIP**
**[Gas on Slimmed Si Pixels]**
**[0.6m radius for 0.05% * pt in 2T field]**
**Pixels**
Elliptic beam pipe (~3cm)

**Fwd Spectrometer**
**(down to $1^o$)**

**Tracker**
**Calice (W/Si)**
**FwdHadrCalo**

**Bwd Spectrometer**
**(down to $179^o$)**

**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**

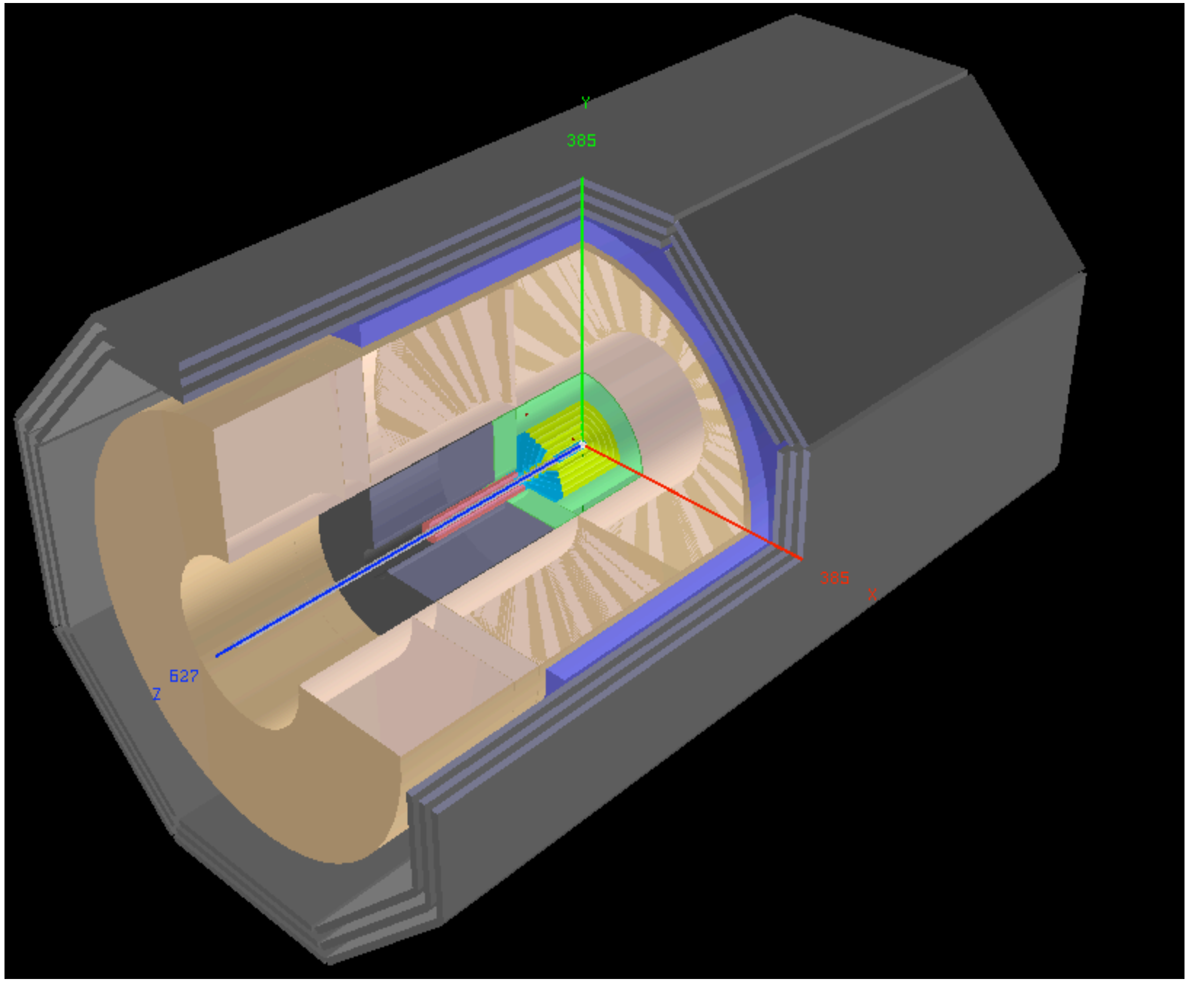
**Hadronic Calo (Fe/LAr)**
**El.magn. Calo (Pb,Sc)**
GOSSIP
**Pixels**
Elliptic pipe (~3cm)

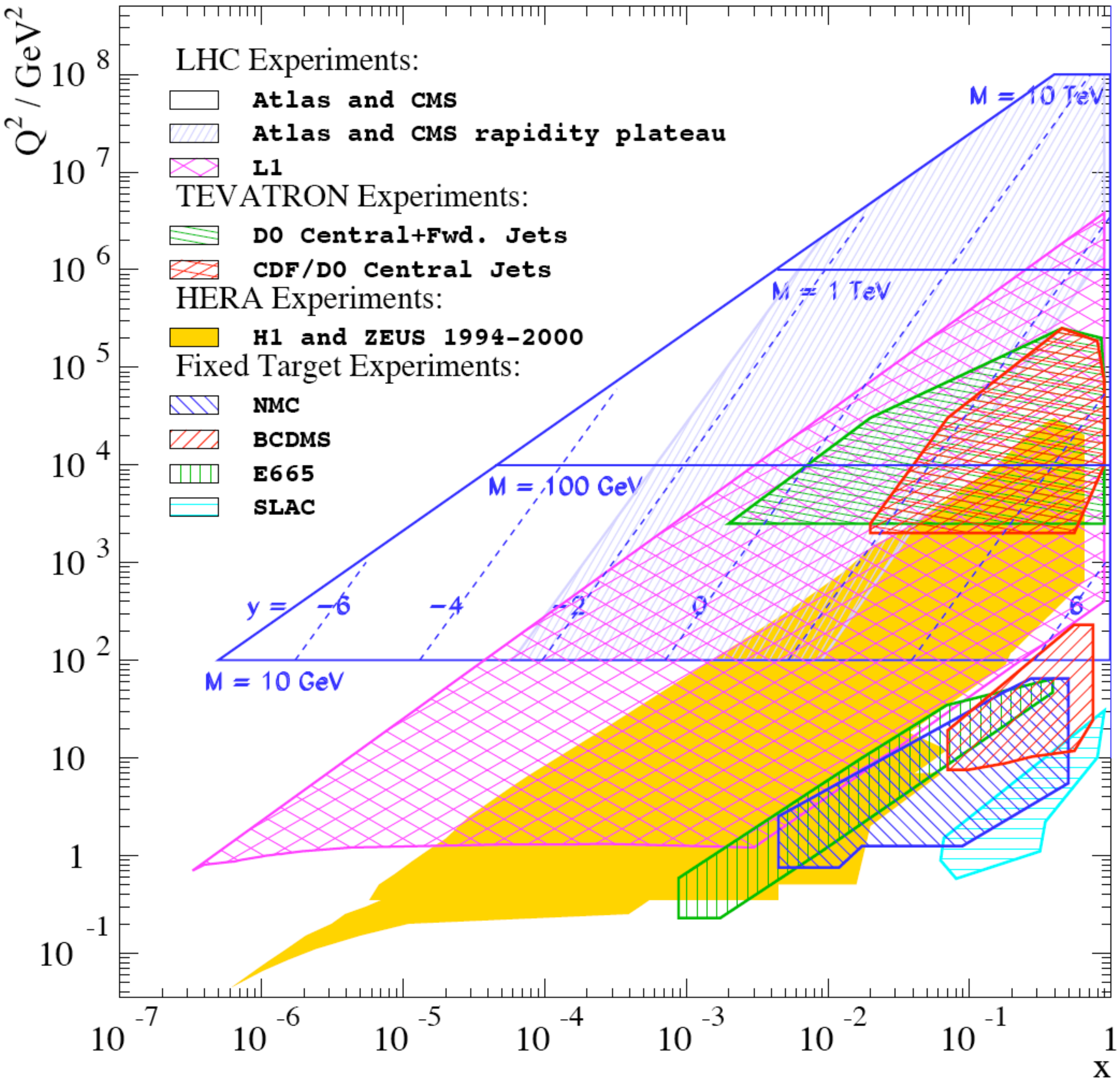
**Fwd Calorimeter**
**(down to 10°)**

**Lepton low β magnets**
**FwdHadrCalo**

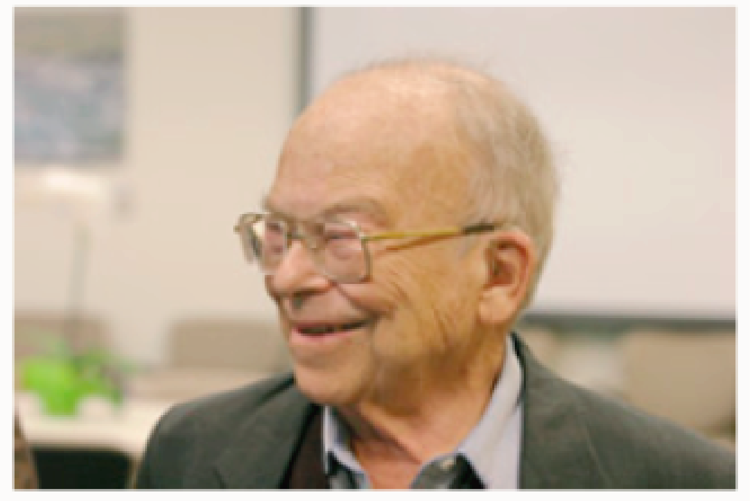
**Bwd Spectrometer**
**(down to 170°)**

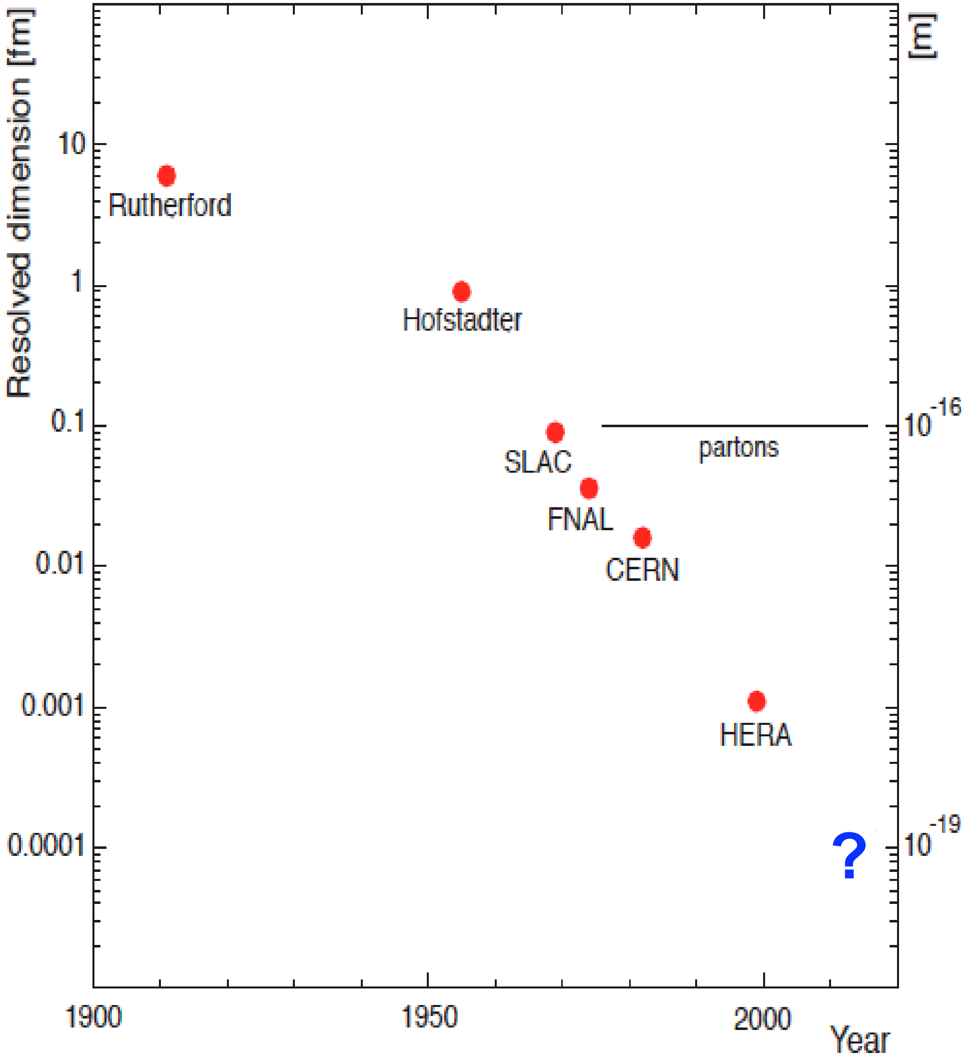
**Lepton low β magnets**
**Spacal (elm, hadr)**




$Q^2$ / GeV$^2$
$10^8$
$10^7$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-7}$
$10^{-6}$
$10^{-5}$
$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
1
x
LHC Experiments:
Atlas and CMS
Atlas and CMS rapidity plateau
L1
TEVATRON Experiments:
D0 Central+Fwd. Jets
CDF/D0 Central Jets
HERA Experiments:
H1 and ZEUS 1994-2000
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = −6
−4
−2
0
2
4
6

The LHeC is a PeV equivalent fixed target ep scattering experiment, at ~50 000 times higher $Q^2$ than the SLAC MIT experiment with an only ~5 times longer LINAC (or a ring). Its physics potential is extremely rich. Its technology is at hand, but it poses R&D challenges too.

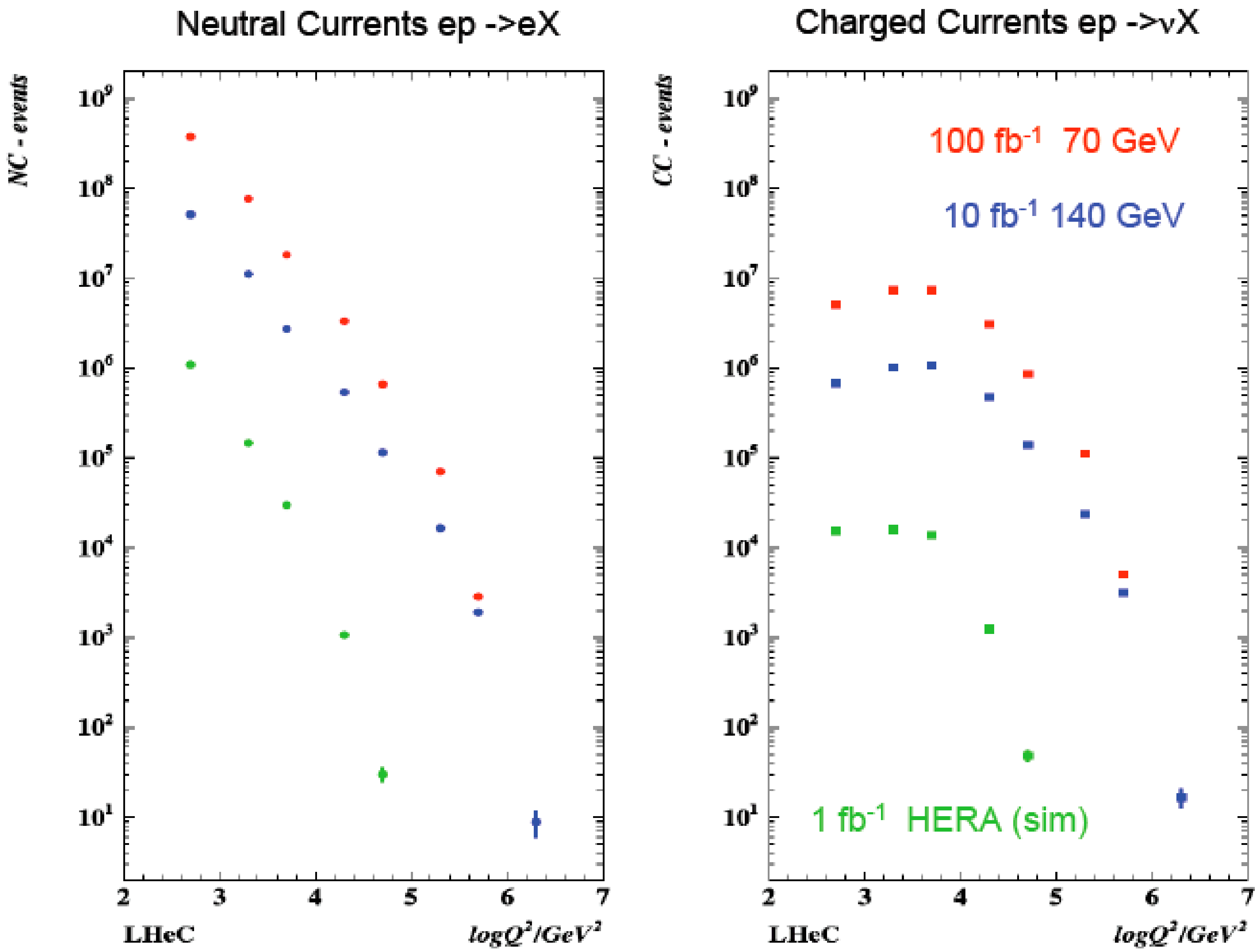




**The LHeC would be a tribute to Wolfgang P. and Bjoern W. and the continuation of an historic path**

# Backup slides

# Backup slides


Neutral Currents ep ->eX

Charged Currents ep ->$\nu$X

# The Past - Fermi Scale [1985-2010]

$\bar{p}p$

b quark
top quark
$M_W$

Tevatron

ep

gluon
h.o. QCD
c,b distributions
high parton densities

HERA

**The Standard Model Triumph**

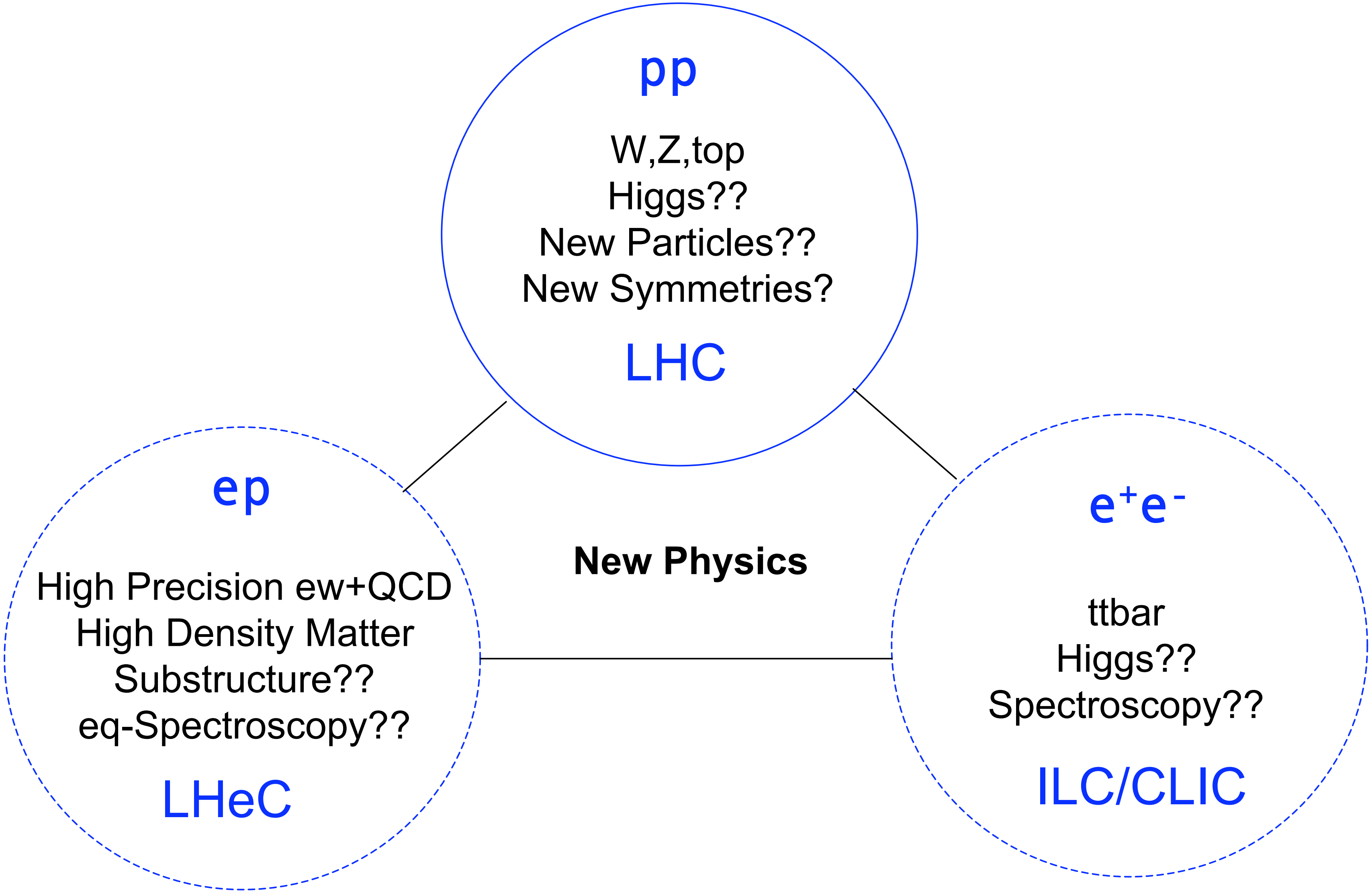
$e^+e^-$

$M_Z$ , $\sin^2 \Theta$
3 neutrinos
h.o. el.weak (t,H?)

LEP/SLC

CKM - **B factories**

# The Future - TeV Scale [2008-2033..]



**pp**

W,Z,top
Higgs??
New Particles??
New Symmetries?

LHC

**ep**

High Precision ew+QCD
High Density Matter
Substructure??
eq-Spectroscopy??

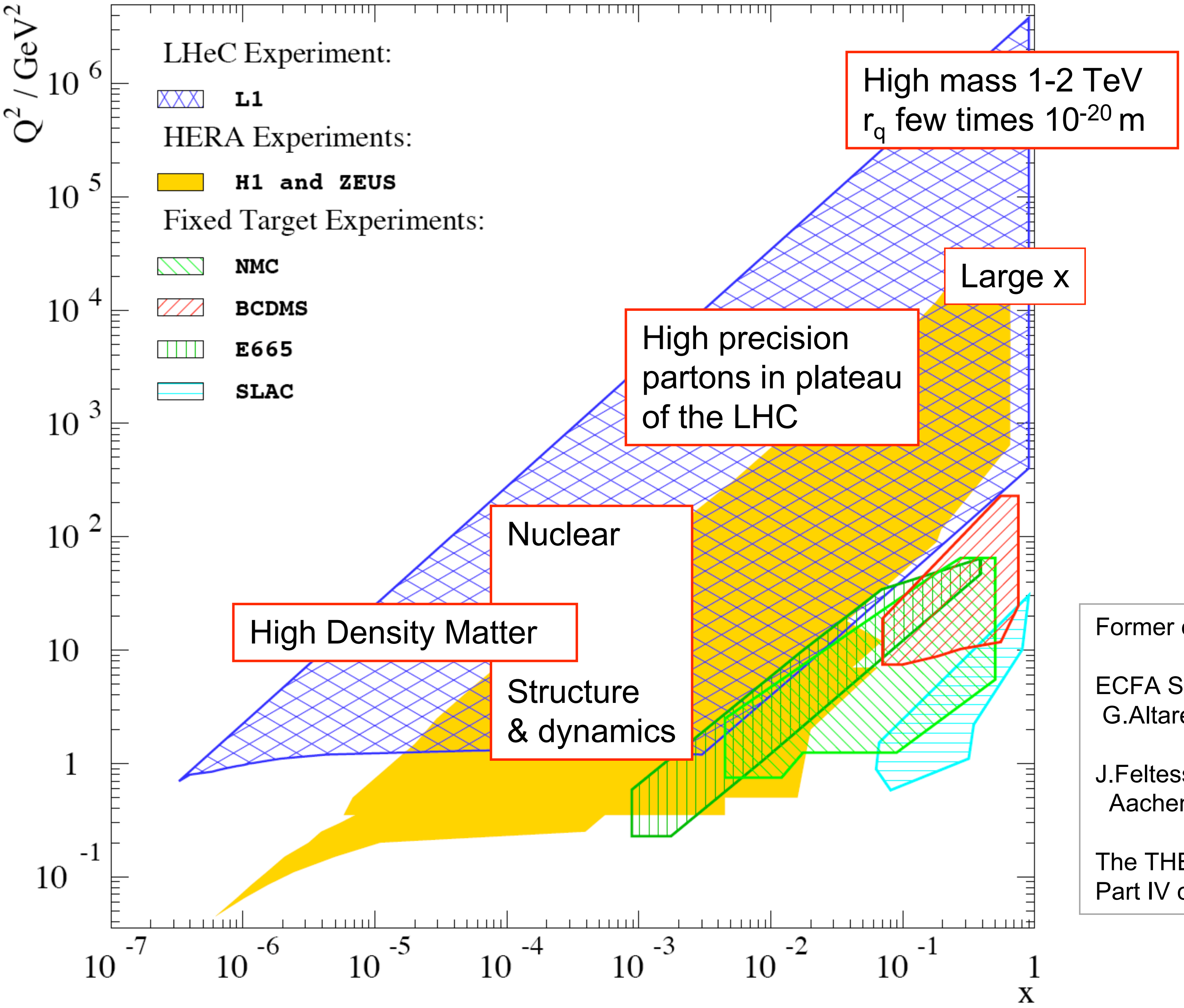
LHeC

**New Physics**

**$e^+e^-$**

ttbar
Higgs??
Spectroscopy??

ILC/CLIC



High mass 1-2 TeV
$r_q$ few times $10^{-20}$ m

Large x

High precision
partons in plateau
of the LHC

Nuclear

High Density Matter

Structure
& dynamics

Former considerations:

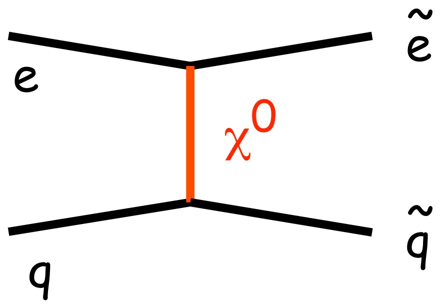
ECFA Study 84-10
G.Altarelli et al.

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

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

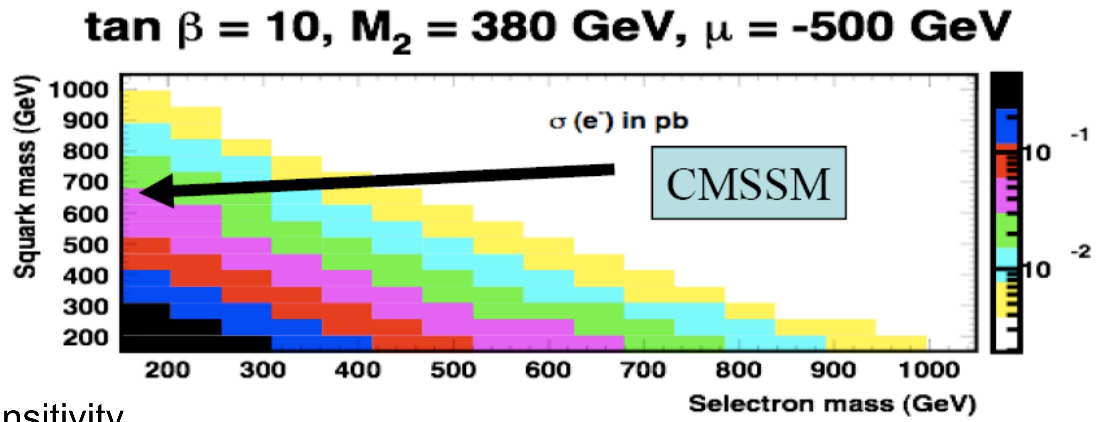
# Supersymmetry (R-parity conserved)

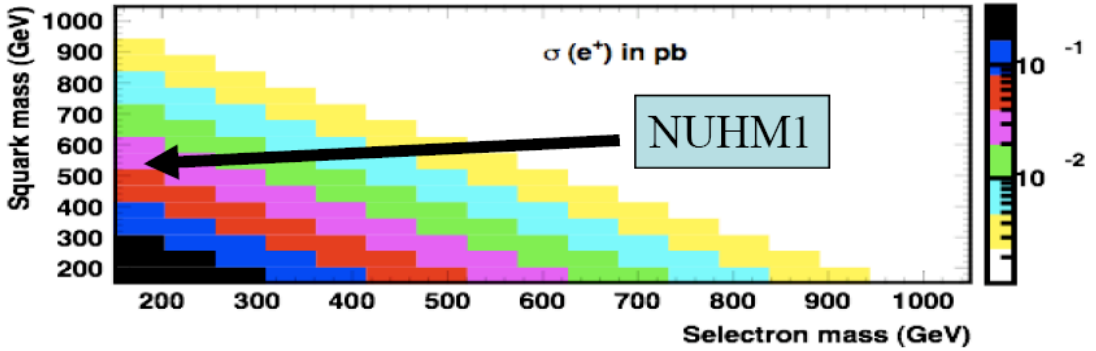
Pair production via t-channel exchange of a neutralino.
Cross-section sizeable when $\Sigma M$ below ~ 1 TeV.
Such scenarios are "reasonable".



E.g. global SUSY fit to EW & B-physics observables
plus cosmological constraints (O. Buchmueller et al, 2008),
within two SUSY models (CMSSM & NUHM) leads to masses
of ~ (700, 150) GeV.

SUSY cross-section at LHeC:
about 15 fb for these scenarios.

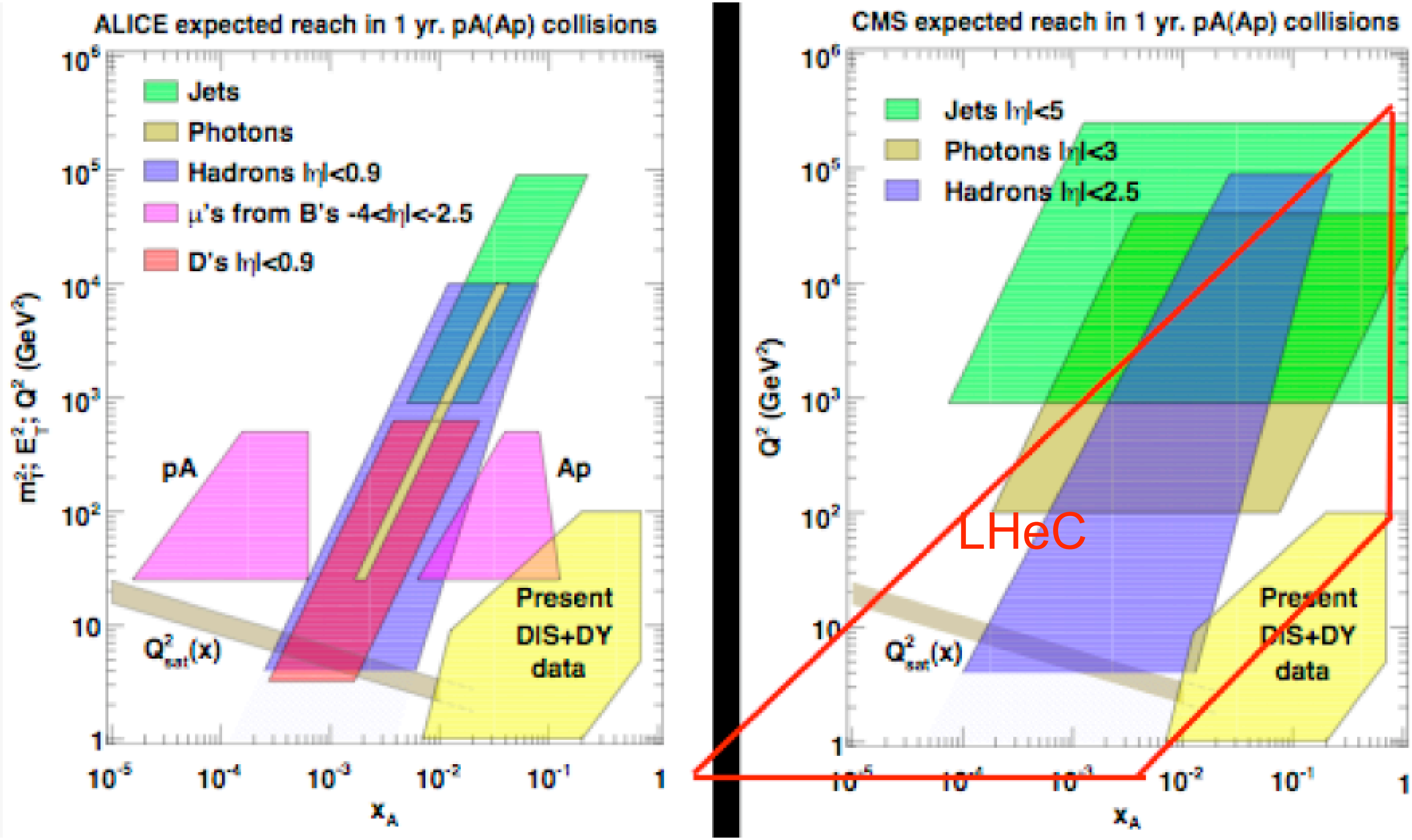




Added value w.r.t. LHC to be studied :

- could extend a bit over the LHC slepton sensitivity
- precise mass measurements
- relevant information on $\chi^0$ sector

# Complementarity of Ap and ep

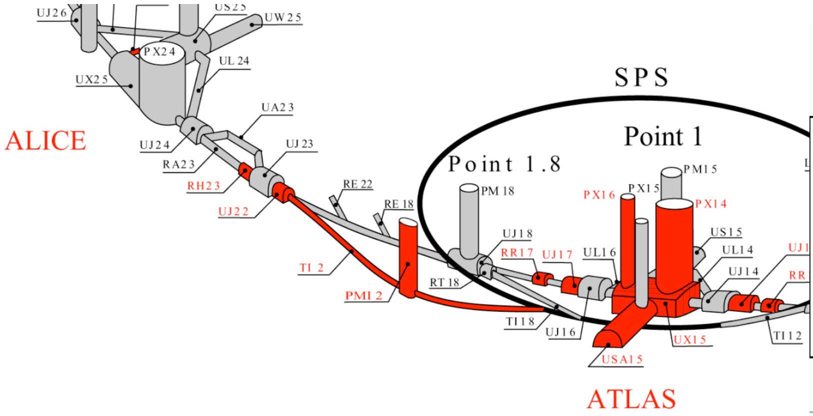


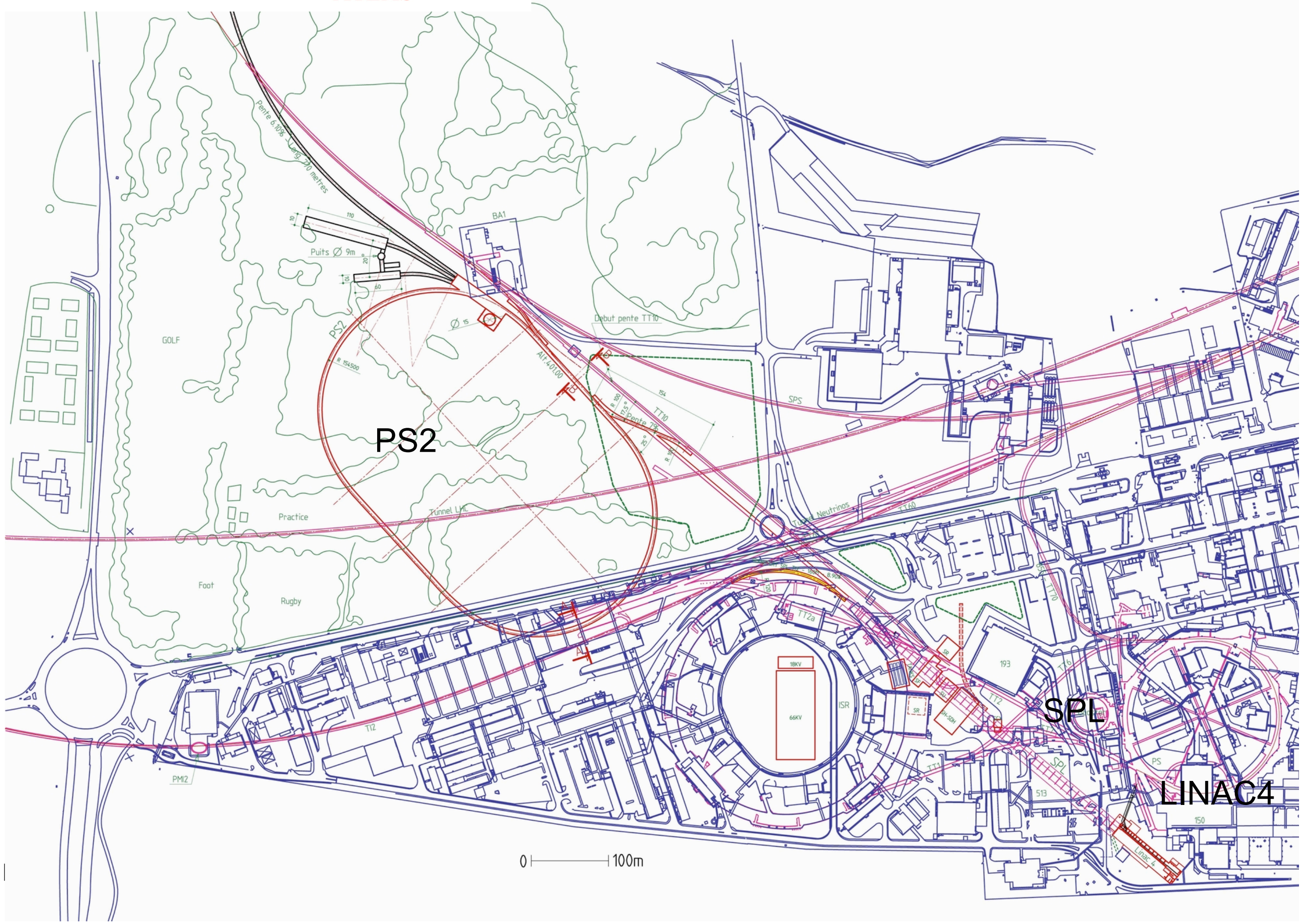
D'Enterria Divonne

**Note that DY is not DIS**

# e injector from SPL to Point 2 via TI2

Alternative injectors considered too
(cf H. Burkhard, DIS08, Proceedings)

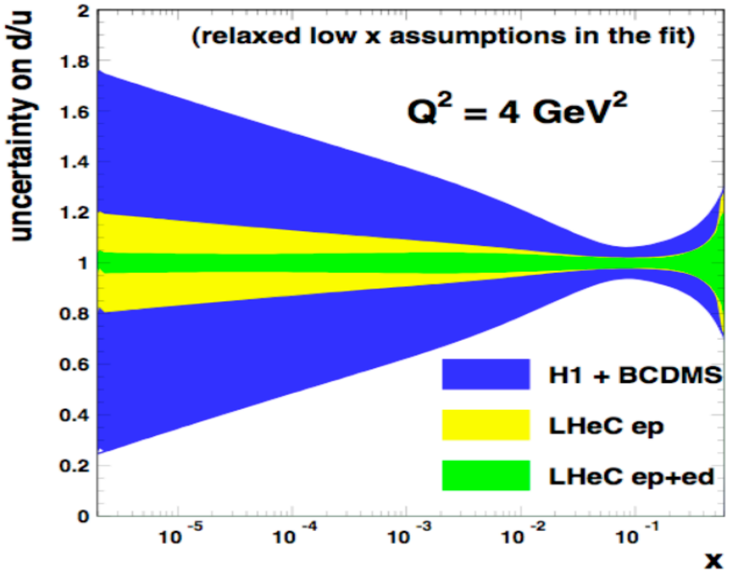




Max

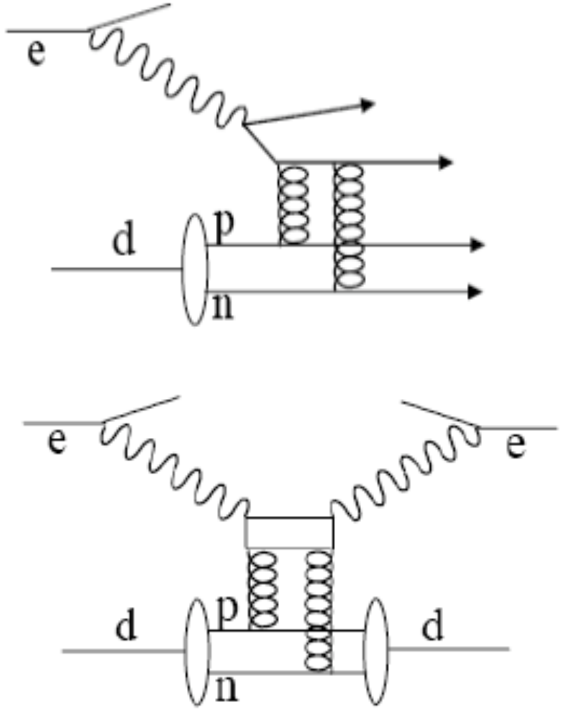
# Neutron Structure (ed → eX)

d/u at low x from deuterons



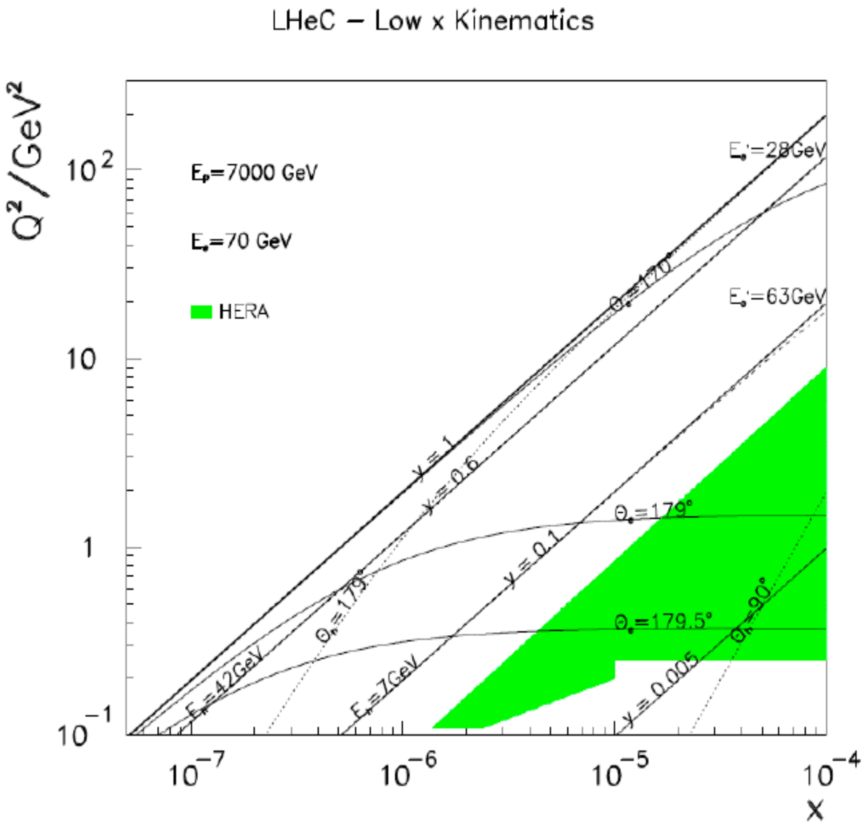
(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

crucial constraint on evolution (S-NS), improved $\alpha_s$

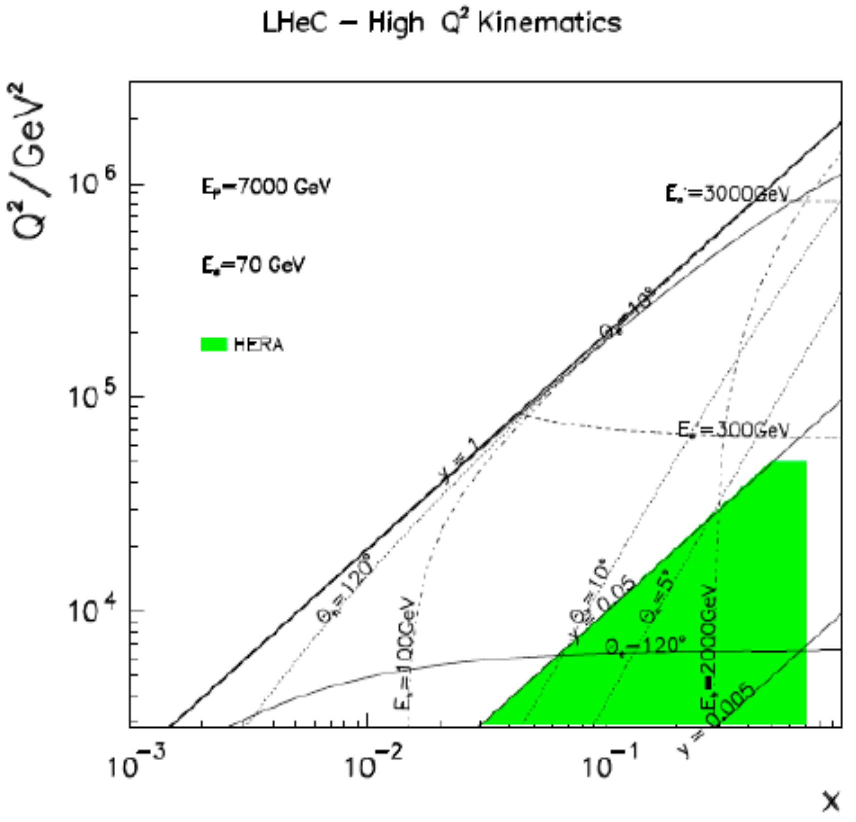


In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

# Interaction Region - Kinematics



LHeC – Low x Kinematics

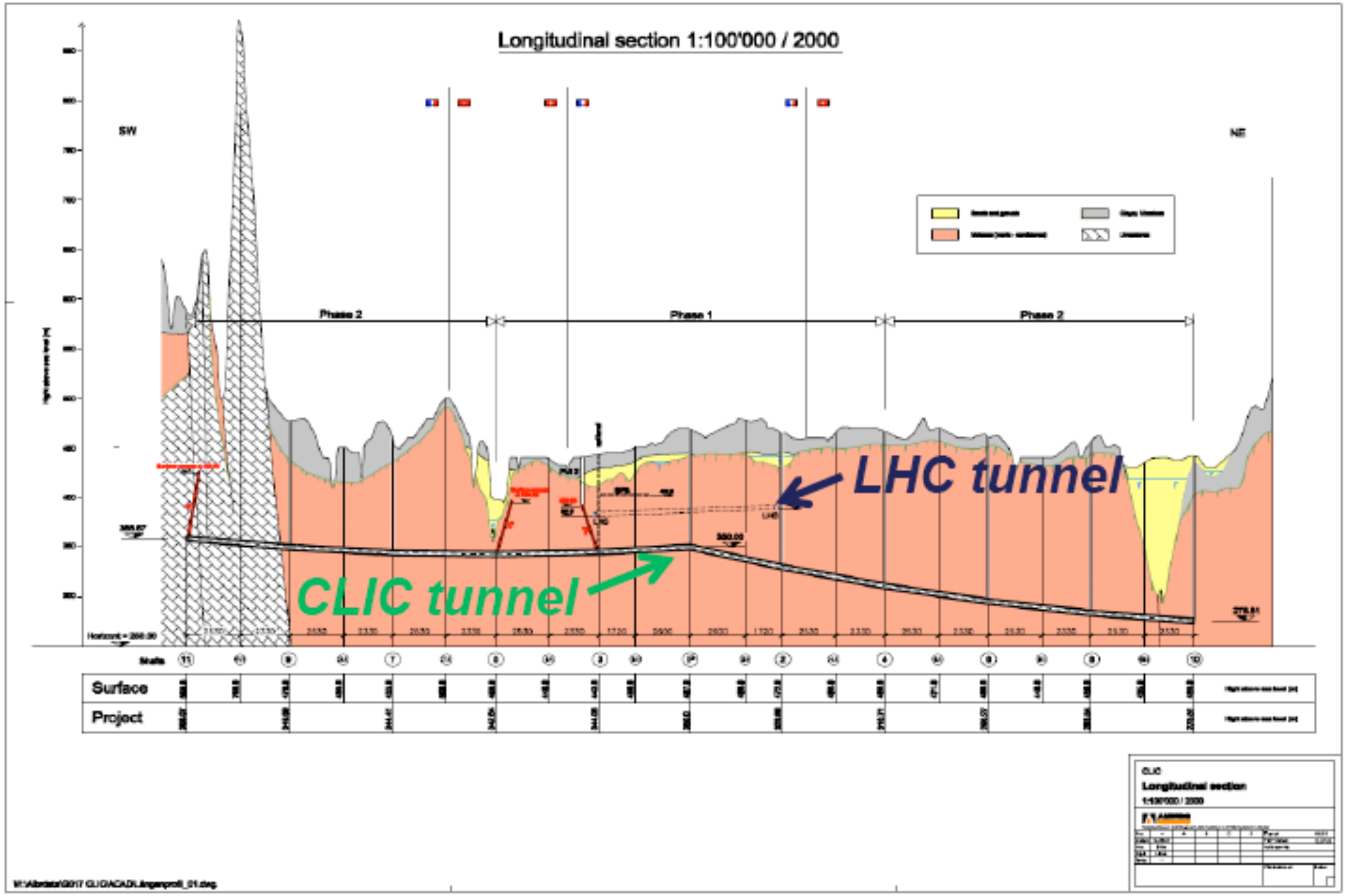


LHeC – High $Q^2$ Kinematics

Max Klein LHeC ICFA08

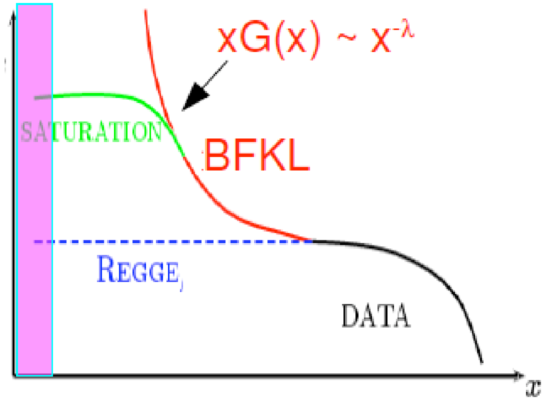
## *Can tunnel for LHeC Linac be build as first part of a LC tunnel at CERN ?*

Tunnel studies for CLIC and ILC at CERN both have tunnels which are deeper underground than LHC and seen from top they both pass close to LHC ring center. Therefore they are not suited to send e$^-$ beam tangential to LHC ring.



# Saturation?

$xG(x) = dN_g/dy$

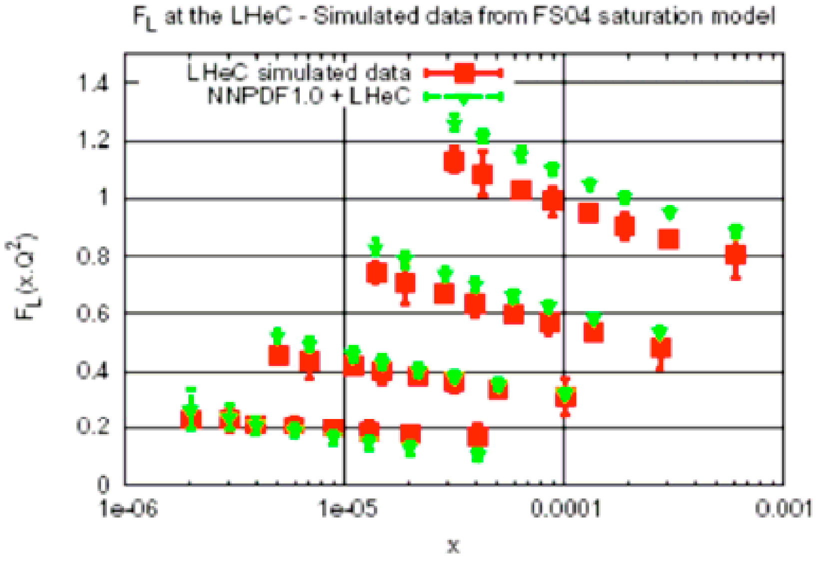


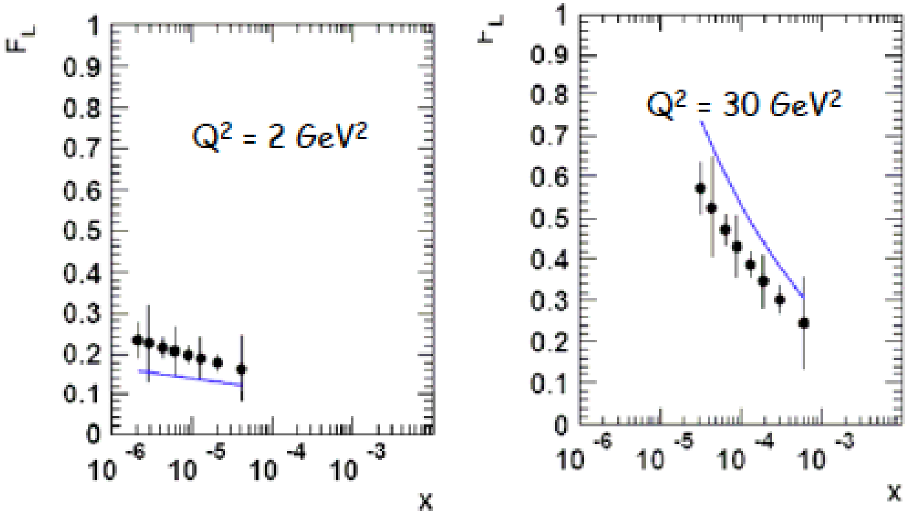
**Cross sections shall saturate because of unitarity.**
(notice link to superhigh energy neutrino physics)

**A new phase of matter:**
**density high but coupling is small (CGC).**

**HFS, fwd jets, unintegrated pdf's, diffraction, $F_L$**
The dynamics at low x is not settled with HERA
(energy too small, no nuclei)

LHeCsat data in NNPDF1.0





**Measurements of $F_2$ and $F_L$ at LHeC should allow to establish saturation in DIS range**

# Lepton Polarisation

## Self polarization / depolarization.

- Electrons in storage rings can become spin POLARIZED due to emission of synchrotron radiation: Sokolov–Ternov effect (1964).
- The polarization is perpendicular to the machine plane.
- The maximum value is $P_{st} = 92.4\%$.
- Sync. radn. also excites orbit motion. This leads to DEPOLARIZATION!
- The attainable polarization results from a balance between polarization and depolarization.

$$P_{\infty} \approx P_{st} \frac{1}{1 \; + \; (\frac{\tau_{dep}}{\tau_{st}})^{-1}}$$

- Depolarization is worst at RESONANCES:

$$\nu_s = k_0 + k_1 Q_1 + k_2 Q_2 + k_3 Q_3$$

At high energy the synchrotron sideband resonances take control:

$$\text{Strength scale :} \qquad \xi = (\frac{\alpha\gamma \, \sigma_\delta}{Q_s})^2$$

- Overall, roughly at each energy:

$$\tau_{dep}^{-1} \propto \text{ (a polynomial in } \gamma^{2N}) \times \tau_{st}^{-1}$$

- For longitudinal polarization the polarization vector must be rotated into the longitudinal direction before an IP and back to the vertical afterwards ===> spin rotators.
- Depolarization can be strongly enhanced by misalignments, regions where the polarization vector is horizontal between spin rotators etc, etc.....

LEP: 46 GeV 1993. R. Assmann et al. reached 57 percent by tuning the orbit for many hours: $\tau_{pol} \leq 300$ min and $\xi = O(1)$

The good news: at 70 GeV $\tau_{pol} \approx\leq 36$ min (scales like $\gamma^{-5}$ ).

The bad news: depolarization is relatively much stronger than at 46 GeV.

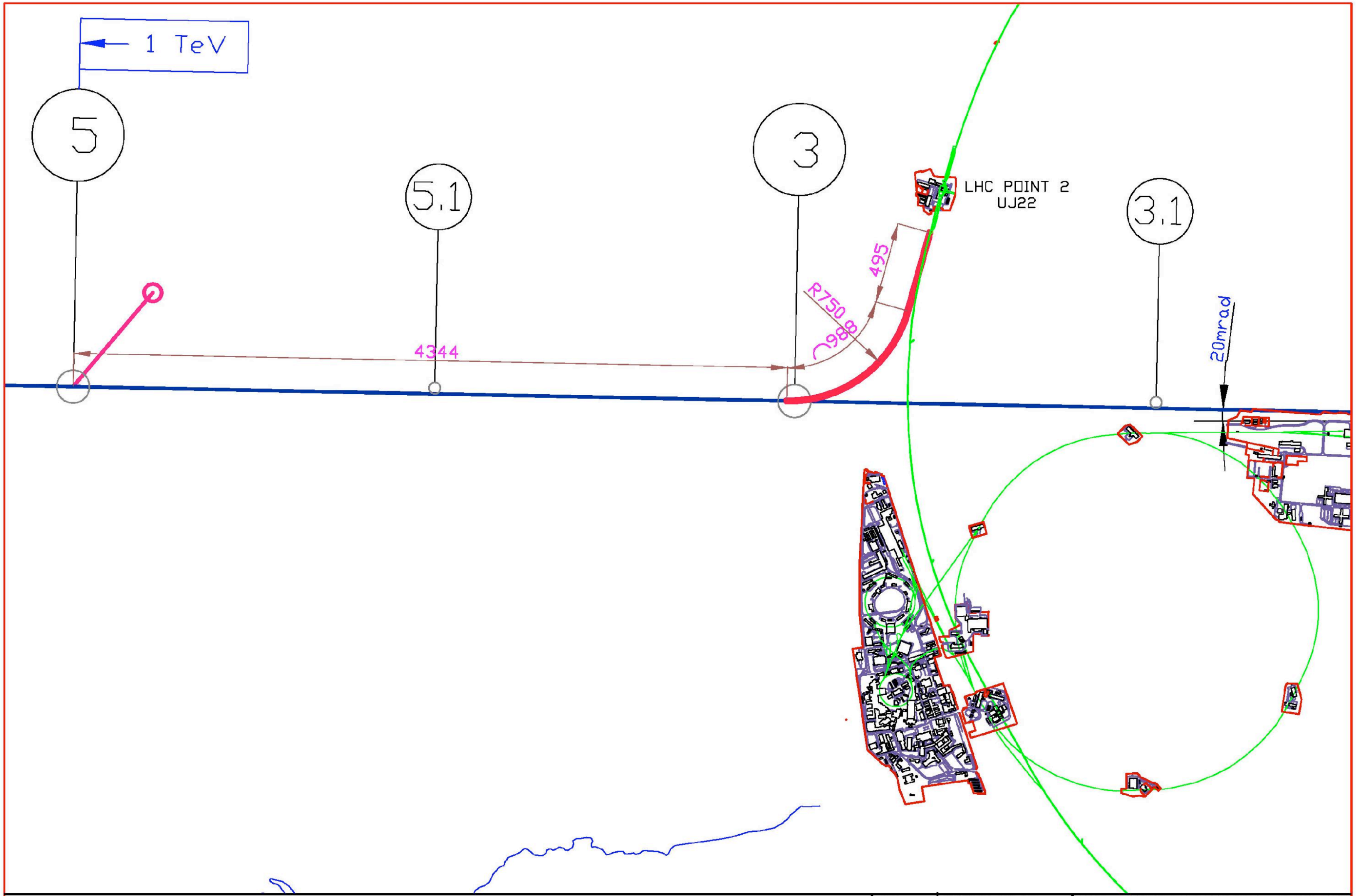
### The way forward

Plan for polarization from the start! Polarization can never be an after thought!

Begin NOW with intense careful study based on experience to investigate tricks.

- Need very good alignment – better than at LEP.
- Siberian Snakes to suppress the effect of energy spread and synchrotron motion on spin motion?
  These are essential in proton rings to suppress depolarising resonances during acceleration (e.g., RHIC).
  But in electron rings they kill the S-T effect if the synchrotron radiation is evenly distributed around the ring!!!
- Can an arrangement be found based on a correct snake layout combined with uneven synchrotron radiation from super bends?

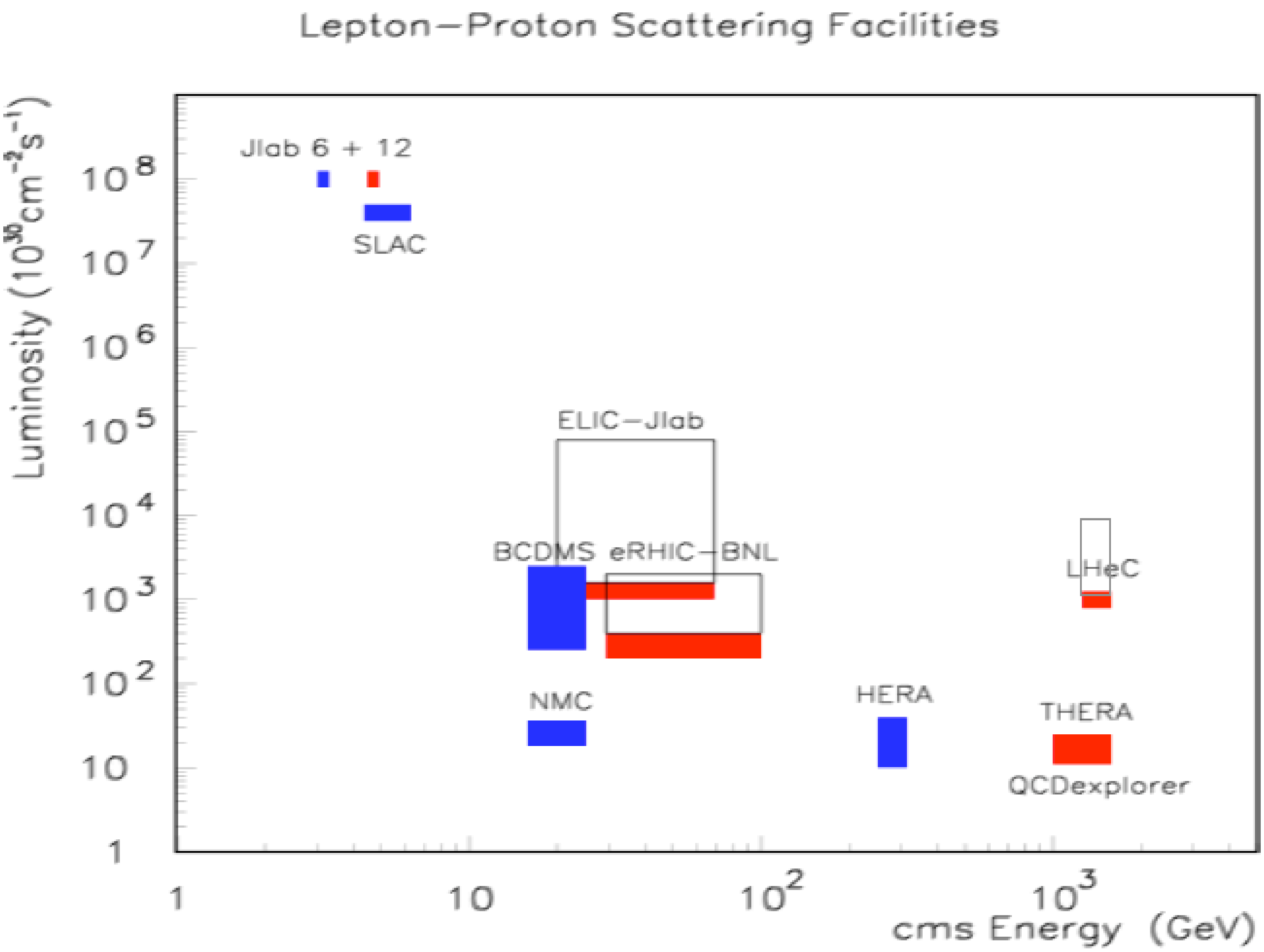
D.Barber



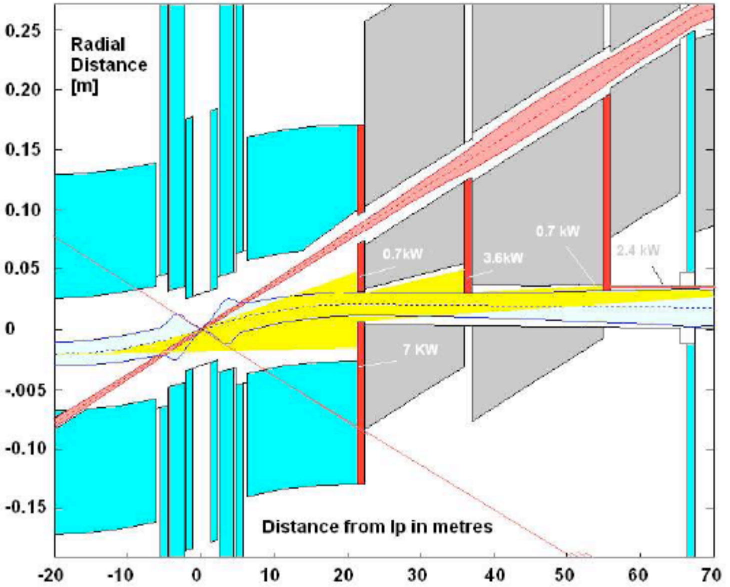
# LHe C -ALICE INJECTOR FROM CLIC 1 TeV PHASE

GROUP : TS-CE
CIVIL ENGINEERING
SUPERVISEUR : J.OSBORNE
DESIGNER : N.BADDAMS

SCALE : 1/20000(A3_FORMAT) DATE : 14_OCT_2008
ALICE_INJECTOR_FROM_CLIC_1_TEV
SIZE 3
INDICE -


Lepton–Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
1
10
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
$10^7$
$10^8$
1
10
$10^2$
$10^3$
cms Energy (GeV)
Jlab 6 + 12
SLAC
ELIC–Jlab
BCDMS
eRHIC–BNL
LHeC
NMC
HERA
THERA
QCDexplorer

# Design Details

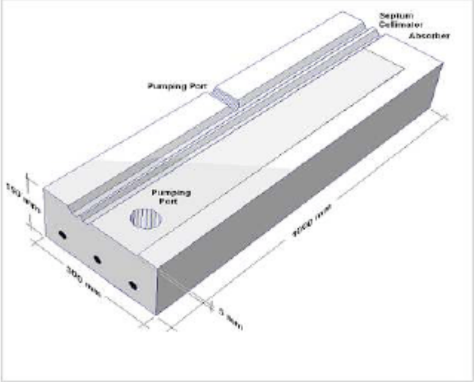


Synchrotron radiation fan

and HERA type absorber

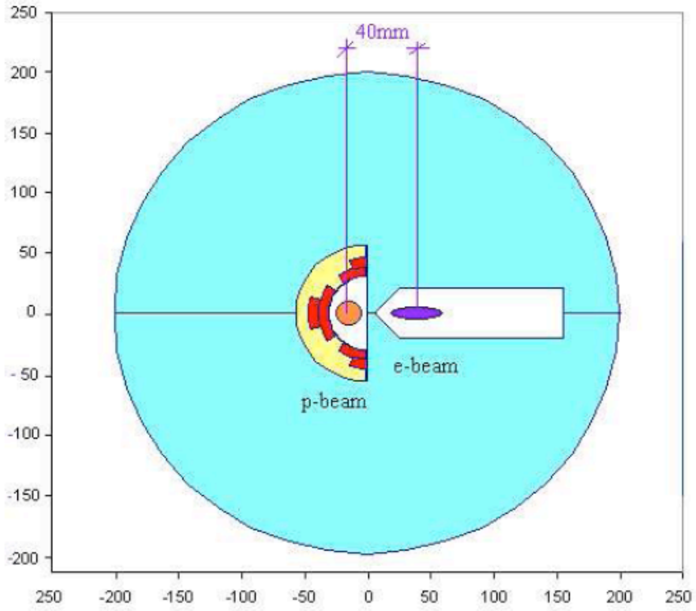
$9.1kW$

$E_{crit} = 76keV$

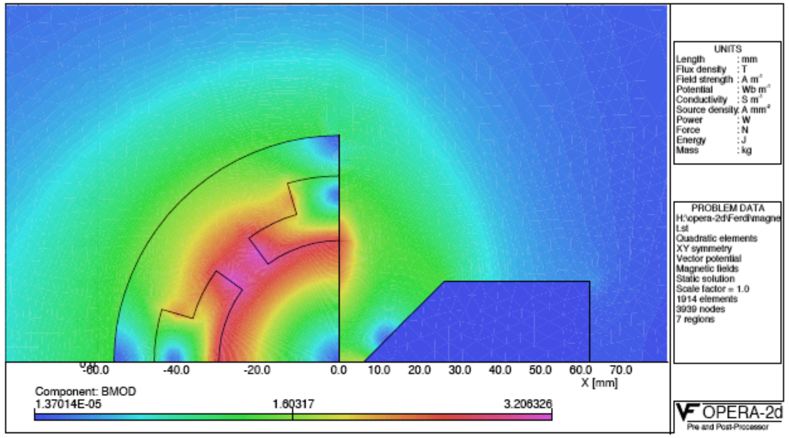


100W/mm$^2$

cf also W.Bartel
Aachen 1990



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



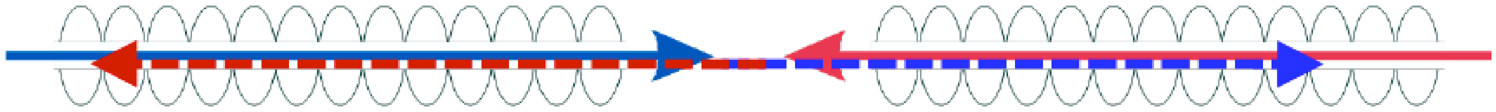
# LHeC
## View from UPS54 Survey Gallery into CMS Cavern on Walkways

# Energy Recovery

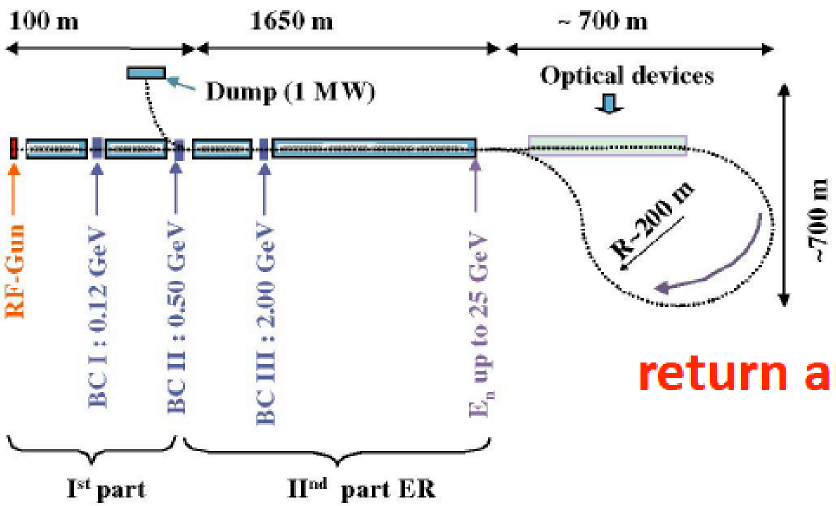
**Jlab:** **recirculating linac**, 99.5% of energy recovered at 150 MeV and 10 mA, ~98% recovery at 1 GeV and 100 μA with beam swung between 20 MeV to 1 GeV, plans for multi-GeV linacs withcurrents of ~100 mA

**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**



**return arc**

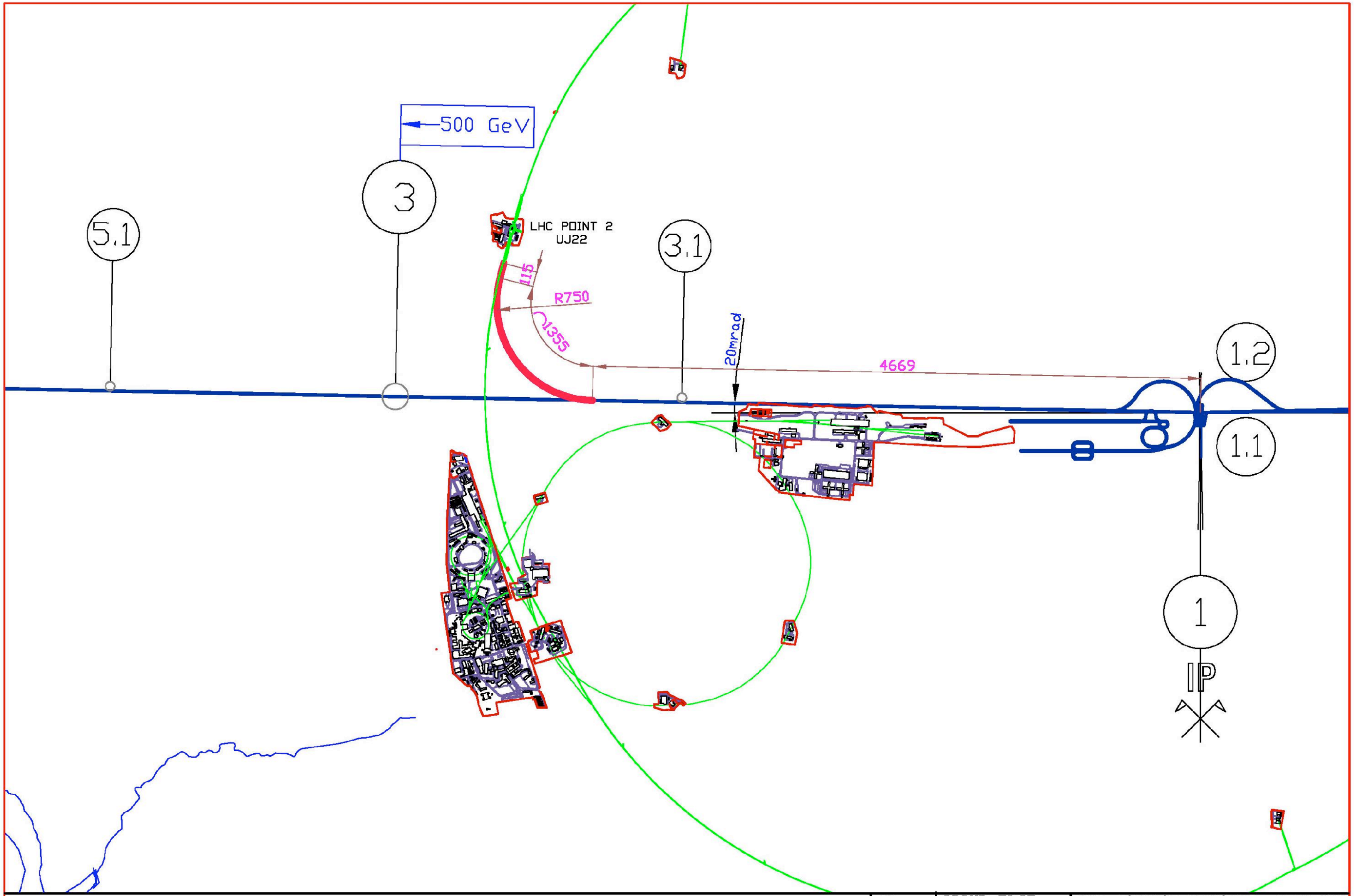
# Parameters for pulsed Linacs for 140 GeV, $10^{32}cm^{-2}s^{-1}$

SC technology

NC technology

| | X FEL<br>20 GeV | LHeC<br>140 GeV,<br>$10^{32}cm^{-2}s^{-1}$ | LHeC<br>140 GeV,<br>$10^{32}cm^{-2}s^{-1}$ |
|---|---|---|---|
| $I_{Beam}$ during pulse | 5 mA | 11.4 mA | 0.4 A |
| $N_E$ | $0.624\cdot10^{10}$ | $5.79\cdot10^{10}$ | $6.2\cdot10^{10}$ |
| Bunch spacing | 0.2 μs | 0.8 μs | 25 ns |
| Pulse duration | 0.65 ms | 1.0 ms | 4.2 μs |
| Repetition rate | 10 Hz | 10 Hz | 100 Hz |
| G | 23.6MV/m | 23.6MV/m | 20.0 MV/m |
| Total Length | 1.27 km | 8.72 km | 8.76 km |
| $P_{Beam}$ | 0.65 MW | 16.8 MW | 16.8 MW |
| Grid power for RF plant | 4 MW | 59 MW | 96 MW |
| Grid power for Cryoplant | 3 MW | 20 MW | - |
| $P_{Beam}/P_{AC}$ | 10% | 21% | 18% |

H.Braun, DIS08 workshop, cf also EPAC paper and F.Zimmermann here.



## 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 -

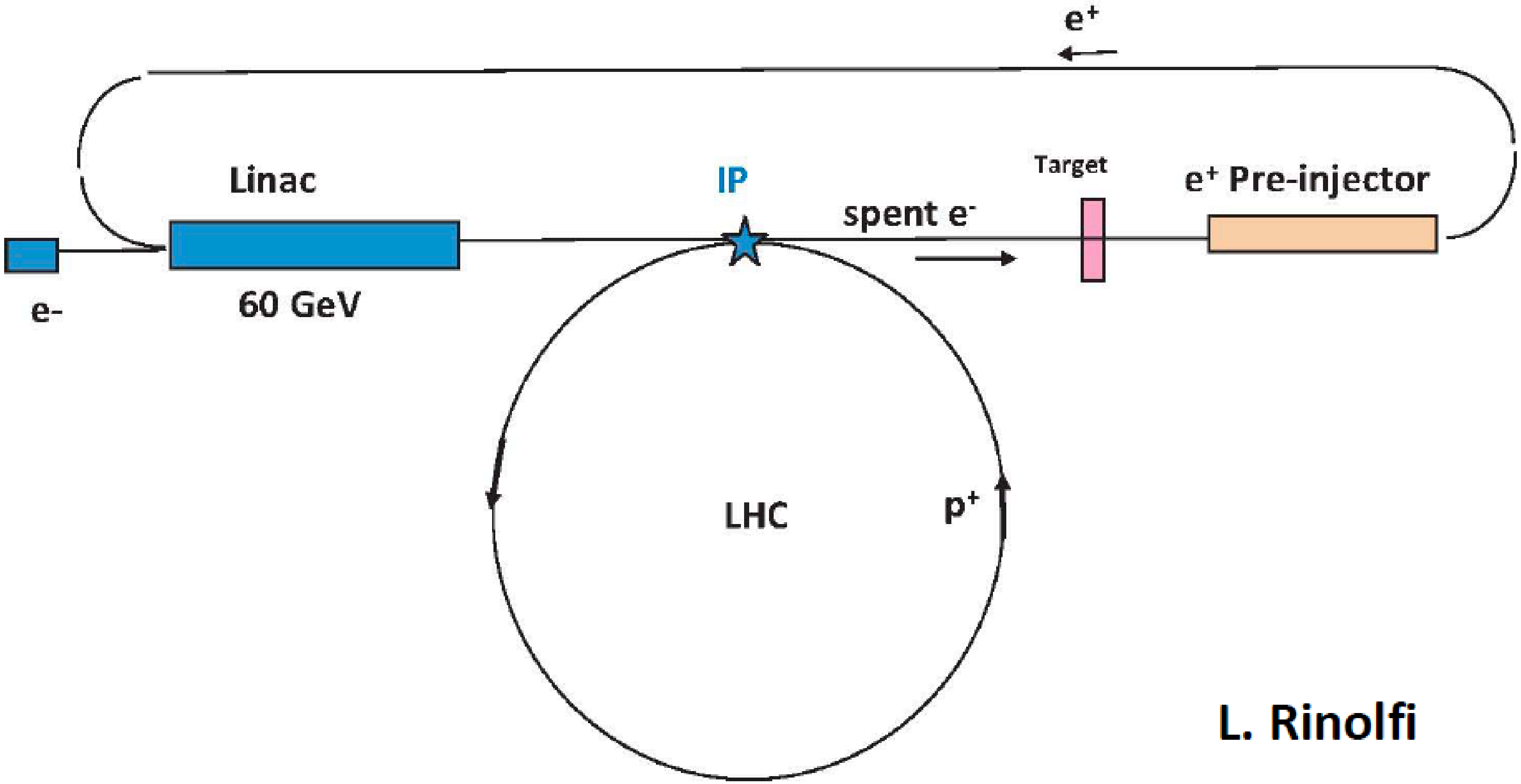
# e- source

the e- beam can be produced from a polarized dc gun (e.g. SLC, E-158, or NLC type), with 90% polarization

depending on the bunch charge a normalized emittance between 10 and 100 μm is expected after bunching and acceleration

this is much (~3 orders of magnitude) smaller than might be hoped for in a ring at 70 GeV beam energy

# e+ production



schematic linac-ring collider with integrated e+ production

# A first ‘complete’ design for $10^{33}$

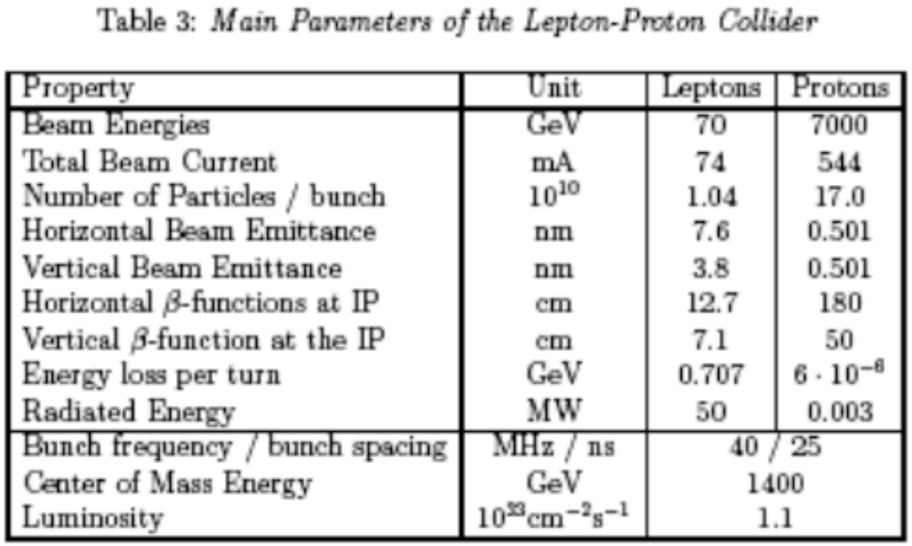
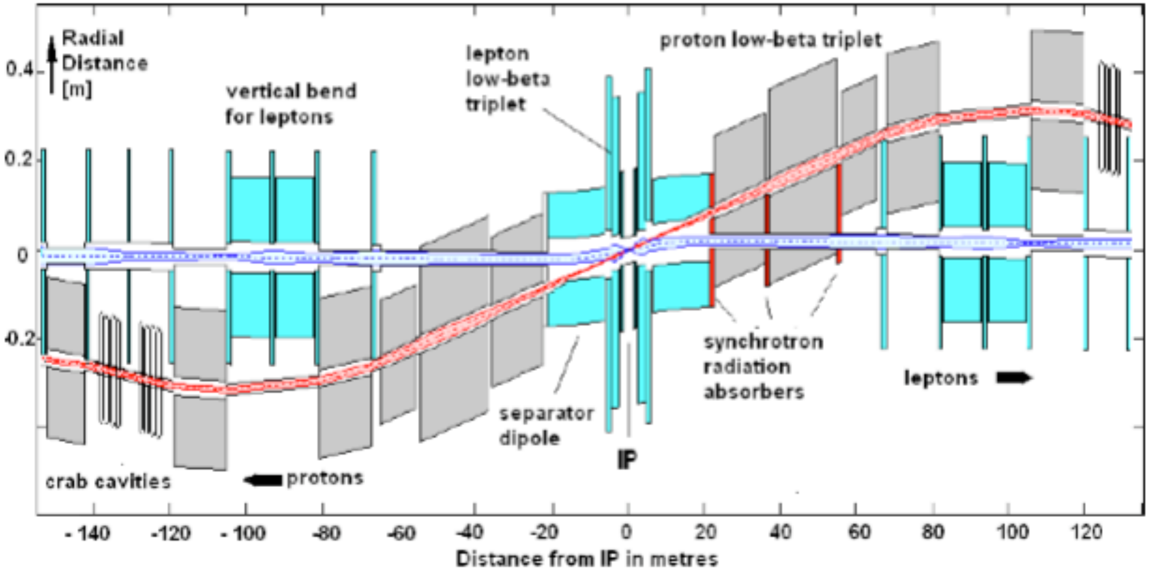
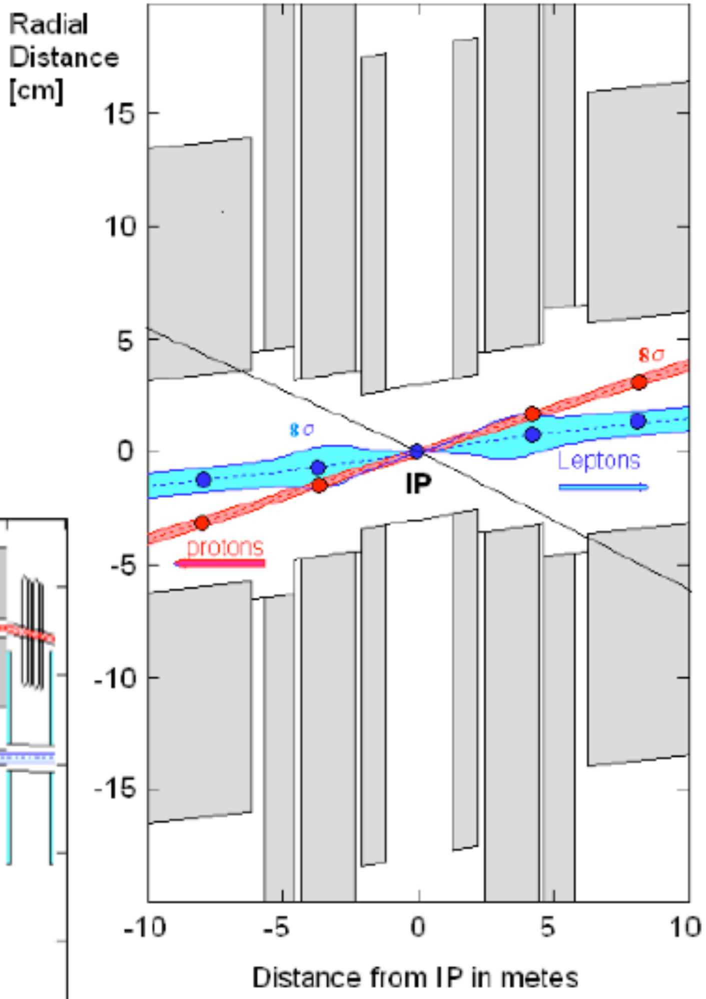


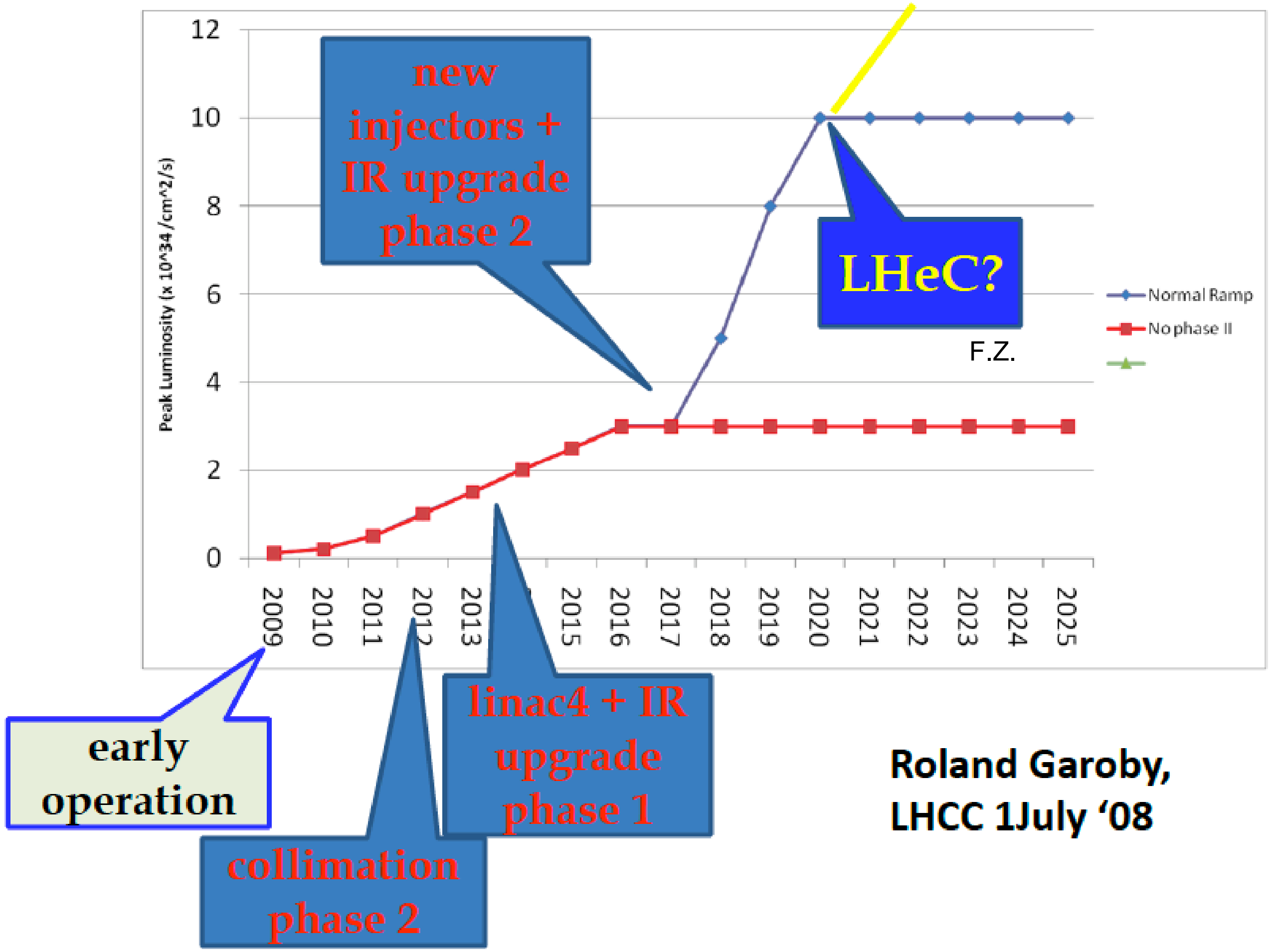
Table 3: *Main Parameters of the Lepton-Proton Collider*

| Property | Unit | Leptons | Protons |
|---|---|---|---|
| Beam Energies | GeV | 70 | 7000 |
| Total Beam Current | mA | 74 | 544 |
| Number of Particles / bunch | $10^{10}$ | 1.04 | 17.0 |
| Horizontal Beam Emittance | nm | 7.6 | 0.501 |
| Vertical Beam Emittance | nm | 3.8 | 0.501 |
| Horizontal $\beta$-functions at IP | cm | 12.7 | 180 |
| Vertical $\beta$-function at the IP | cm | 7.1 | 50 |
| Energy loss per turn | GeV | 0.707 | $6 \cdot 10^{-6}$ |
| Radiated Energy | MW | 50 | 0.003 |
| Bunch frequency / bunch spacing | MHz / ns | 40 / 25 | |
| Center of Mass Energy | GeV | 1400 | |
| Luminosity | $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ | 1.1 | |





# LHC Time Schedule



new injectors + IR upgrade phase 2

LHeC?

early operation

collimation phase 2

linac4 + IR upgrade phase 1

**Roland Garoby,**
**LHCC 1July '08**

# Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2} s^{-1}$$

$\varepsilon_{pn} = 3.8\mu m$

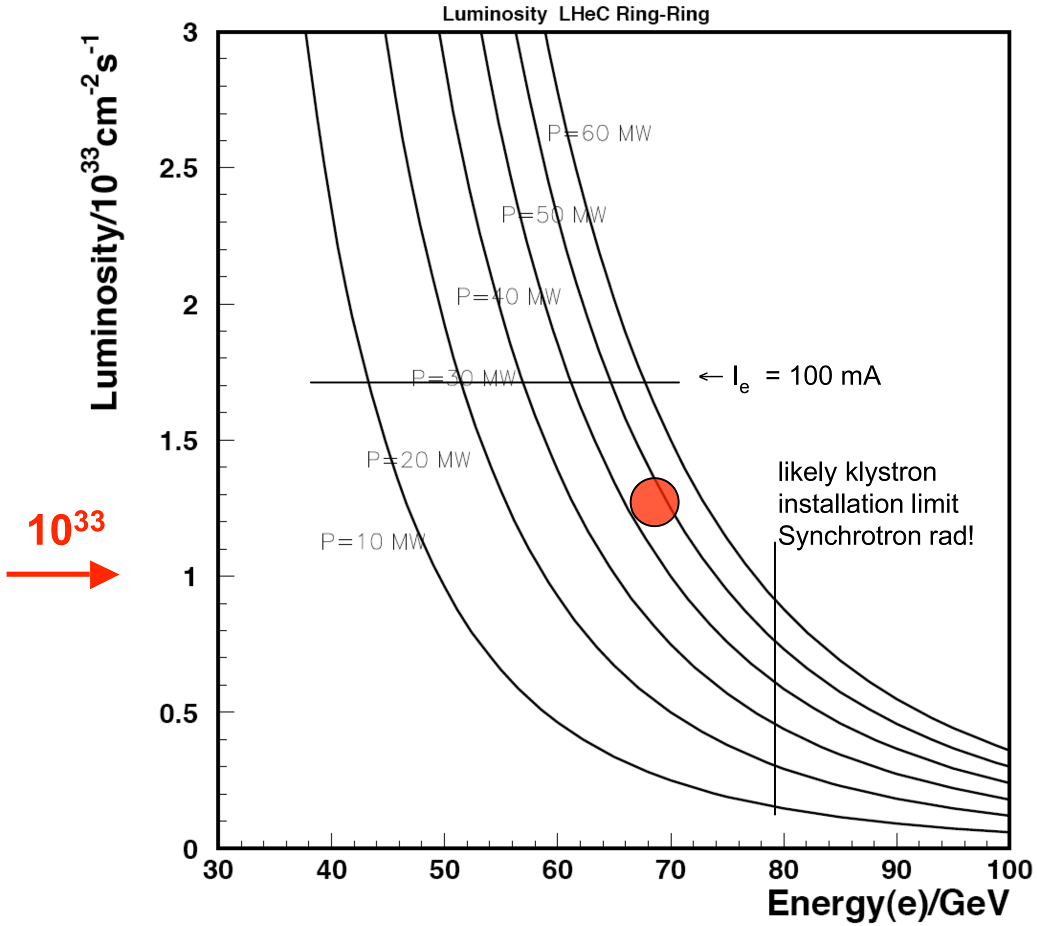
$N_p = 1.1 \cdot 10^{11}$

$\sigma_{p(x,y)} = \sigma_{e(x,y)}$

$\beta_{px} = 1.8m$

$\beta_{py} = 0.5m$

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



Power to beam ~ 50 MW:
50 (70) GeV: 4 (1) $10^{33}$cm$^{-2}$ s$^{-1}$
2x larger for ESP (‘ultimate’) beam

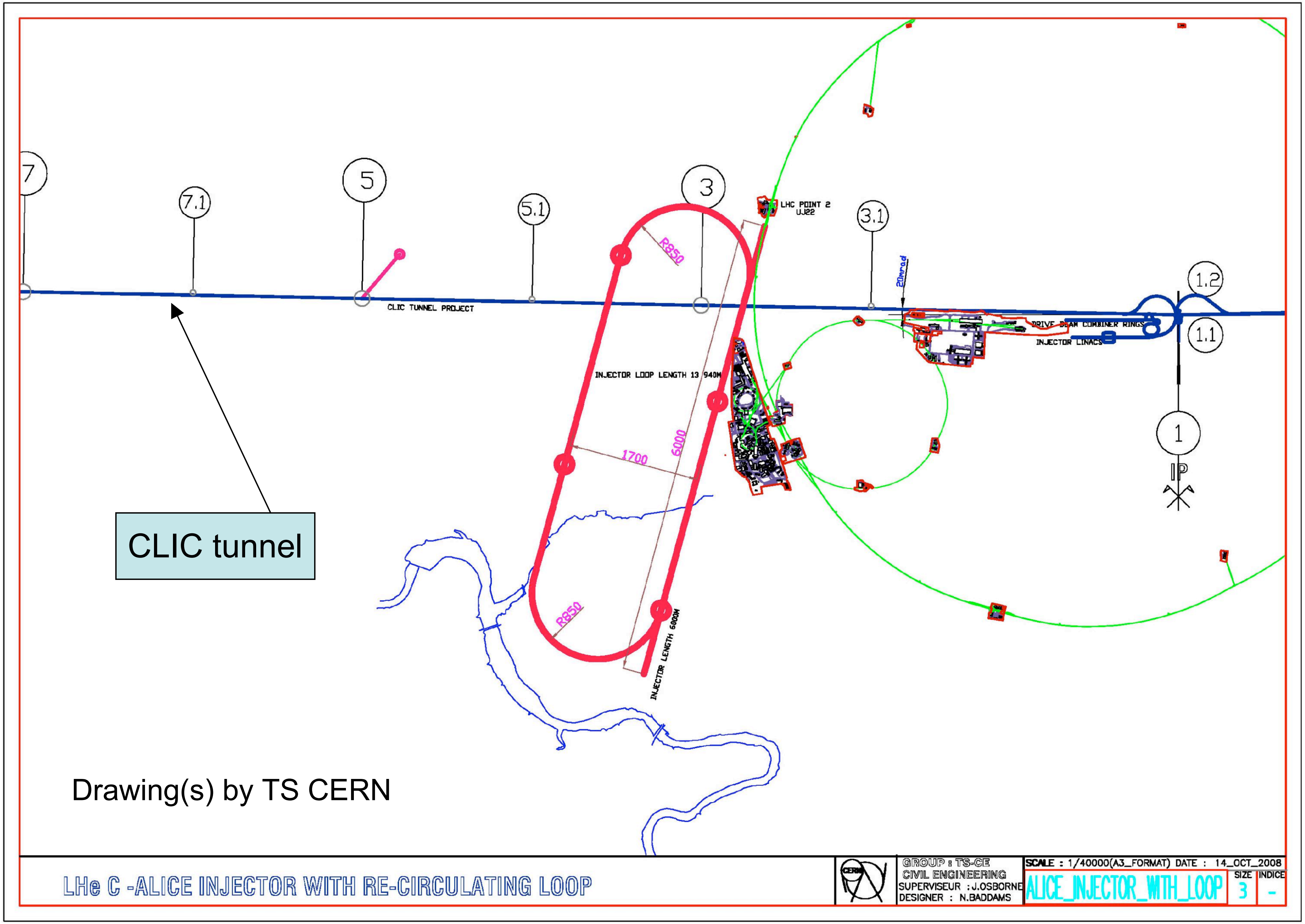
HERA was 1-5 $10^{31}$ cm$^{-2}$ s$^{-1}$

**At $E_e$=50 GeV: $\int$ L~100 fb$^{-1}$ /a**
**with SLHC: L near to $10^{34}$cm$^{-2}$ s$^{-1}$**

Ten times lower than SLHC, but
300 times higher than HERA II
and no pile up ….

● F.Willeke et al (JINST 2006 )

cf also A.Verdier 1990, E.Keil 1986



CLIC tunnel

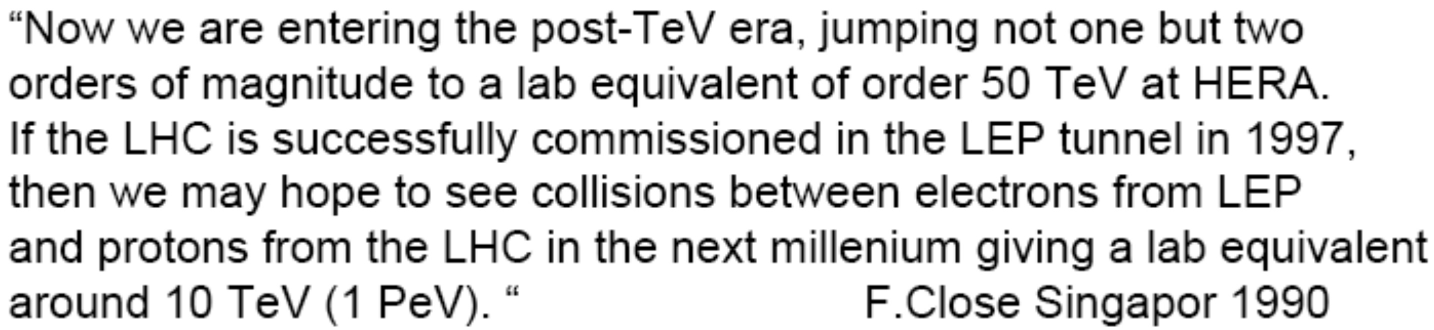
Drawing(s) by TS CERN

# ep with the LHC

three ECFA CERN Studies

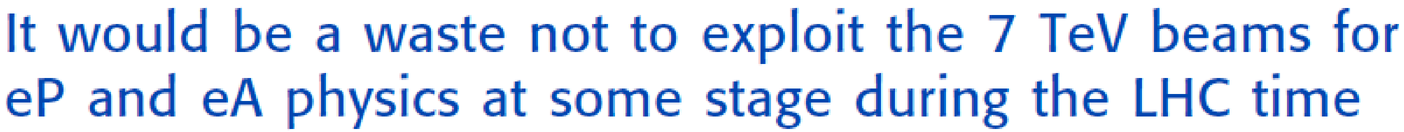
If a hadron collider will be built in the LEP tunnel then ep collisions are really a must

G.Altarelli et al, **Lausanne LHC Workshop 1984**, Proc. p549



“Now we are entering the post-TeV era, jumping not one but two orders of magnitude to a lab equivalent of order 50 TeV at HERA. If the LHC is successfully commissioned in the LEP tunnel in 1997, then we may hope to see collisions between electrons from LEP and protons from the LHC in the next millenium giving a lab equivalent around 10 TeV (1 PeV). “ F.Close Singapor 1990

**Aachen Workshop 1990**



It would be a waste not to exploit the 7 TeV beams for eP and eA physics at some stage during the LHC time

G.Altarelli et al, **Divonne LHeC Workshop 2008**