The LHeC Project at CERN – An Overview*

Max Klein

University of Liverpool

Choices and Status:
Perspective
Physics
Detector
Ring-Ring
Linac-Ring
Project

For the LHeC Study Group

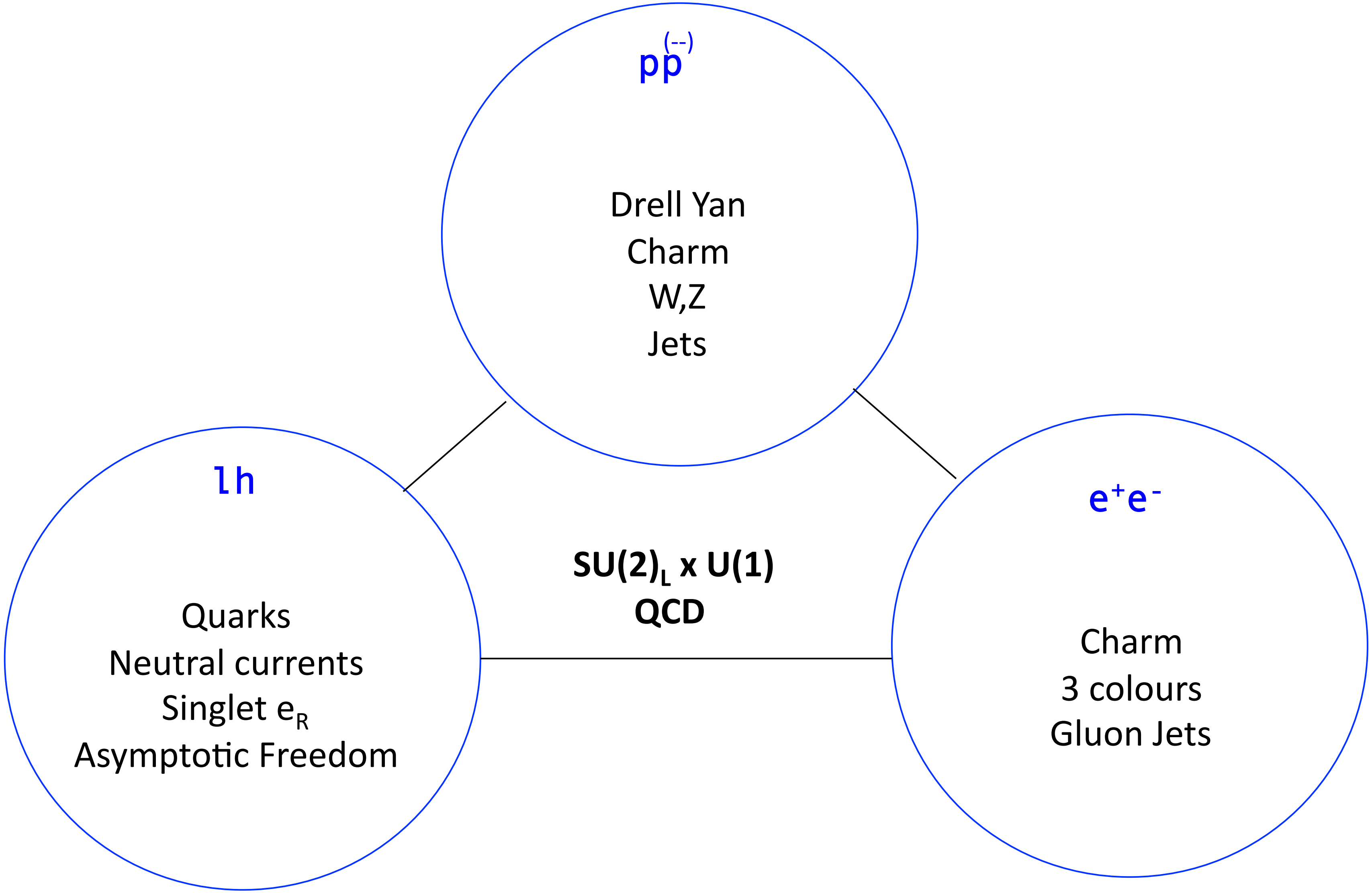
LHeC: $e^{\pm}p/A$
E_e=10…140 GeV
E_p=1..7 TeV
$E_A=E_p$ *Z/A
$L=10^{33} cm^{-2}s^{-1}$
while LHC runs

DIS11, Newport News, VA, 12.4.11

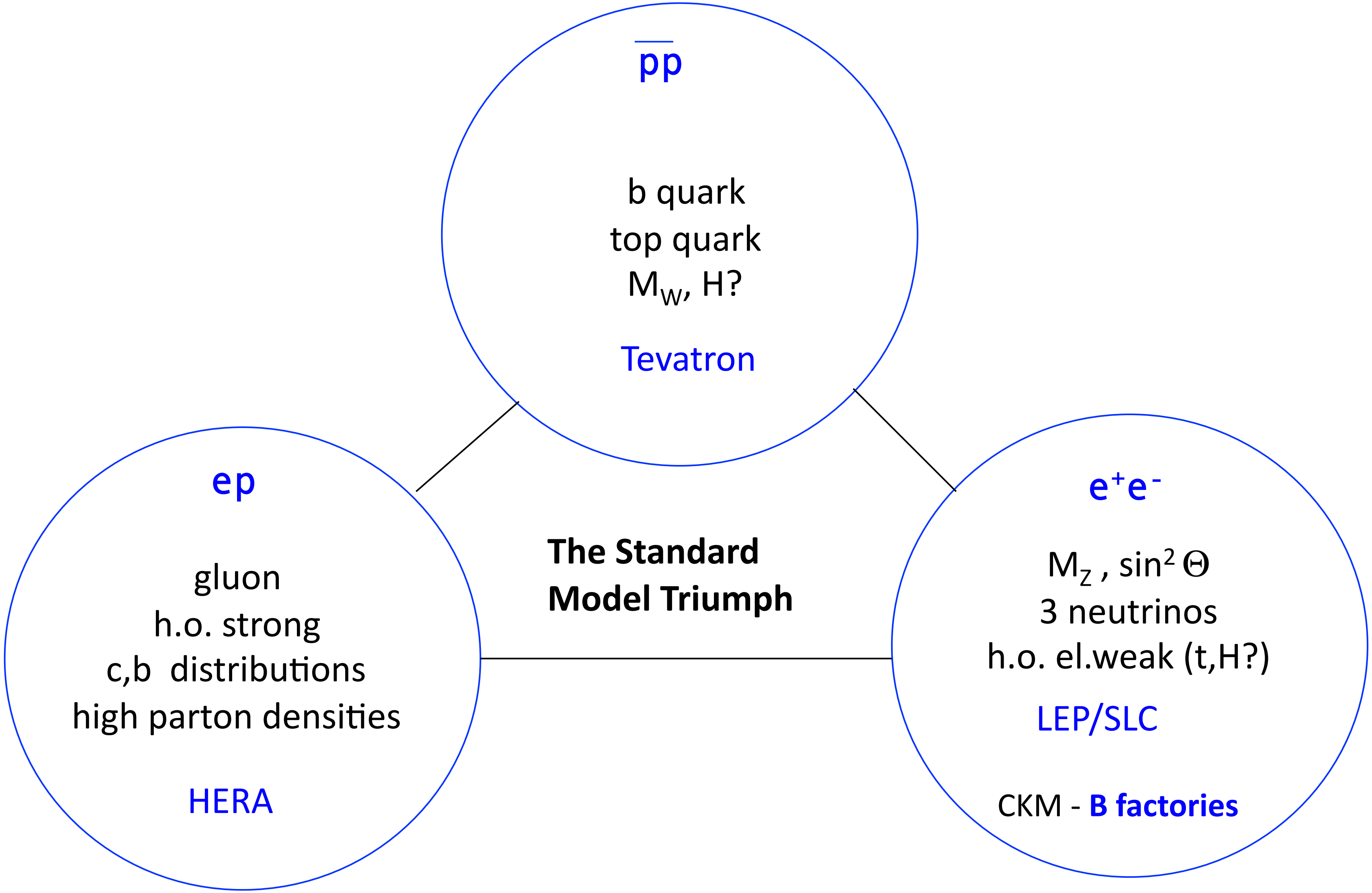
http://cern.ch/lhec

*All tentative - work in progress - prior to CDR publication..

The 10-100 GeV Energy Scale [1968-1986]



The Fermi Scale [1985-2010]



Colliders at the energy frontier

History

Electron-proton colliders open new horizons on all three of the fundamental questions: the spectroscopy of fundamental fermions, the spectroscopy of gauge bosons, and the problem of hadron structure. In addressing these issues, the ep collider is approaching the same physics as is studied in e^+e^- and $\bar{p}p$ colliders, but in a complementary way, with emphasis on the t-channel. Each technique has its own strengths and weaknesses, which I leave you to contemplate.

FERMILAB-Conf-81/52-THY Chris Quigg

Early studies

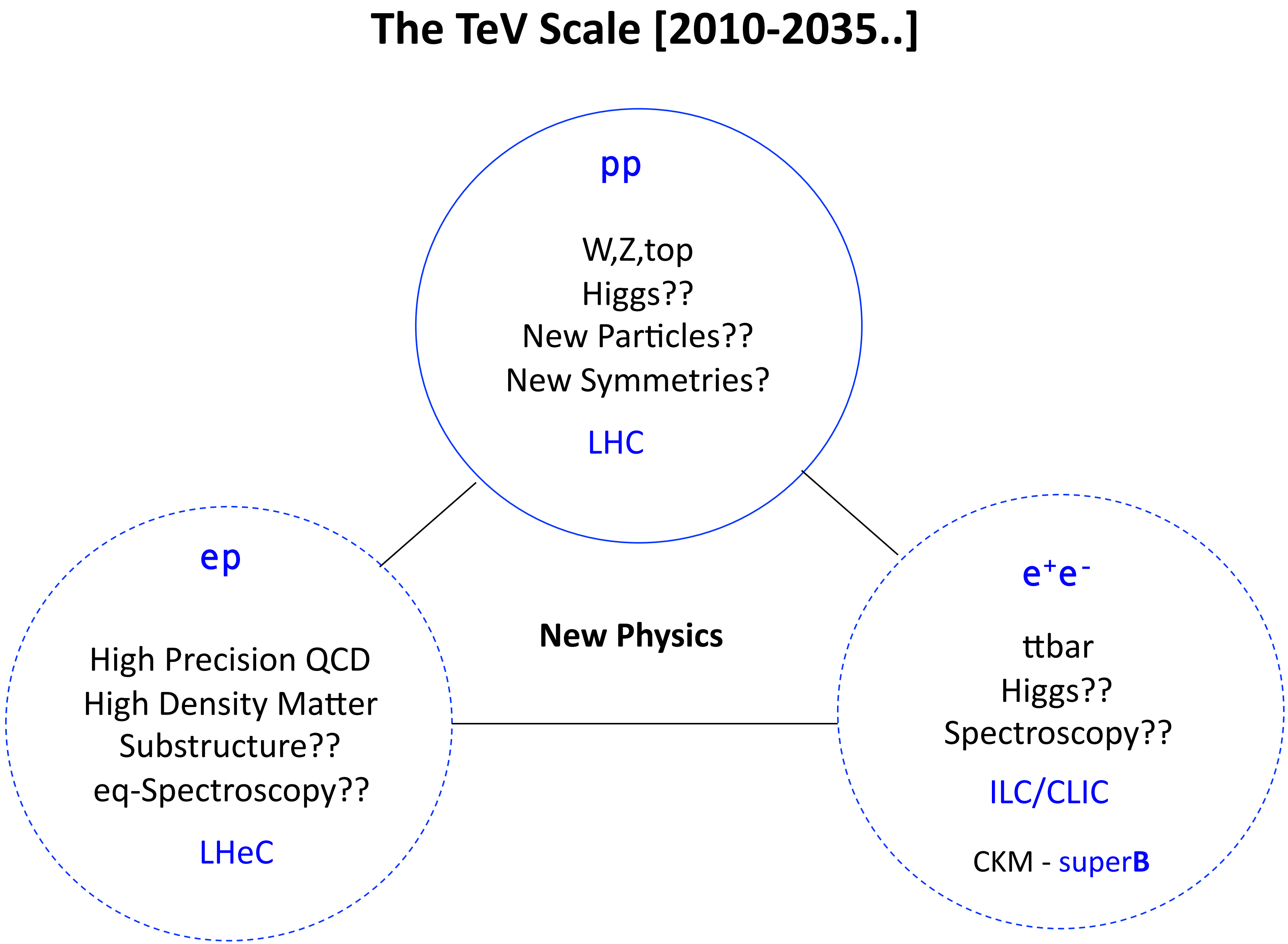
LEP*LHC (1984, 1990) - Lausanne, Aachen
E.Keil LHC project report 93 (1997)
Thera (2001)
QCD explorer (2003)
J.Dainton et al, 2006 JINST 1 10001

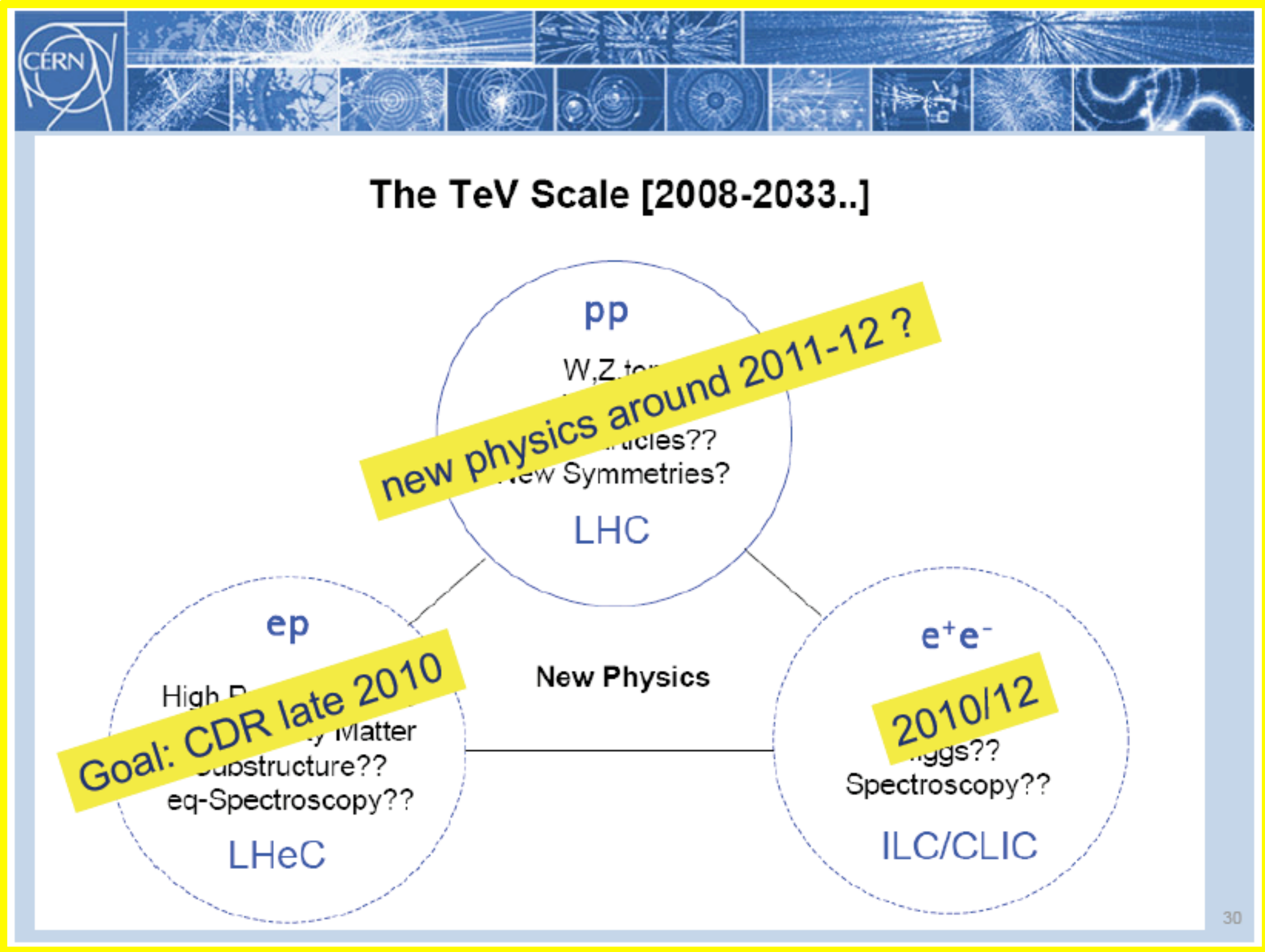
LHeC at DIS conferences since Madison 2005

Steps towards the CDR on the LHeC

2007 CERN SPC and [r]ECFA
2008 Divonne I, ICFA,ECFA
2009 Divonne II, NuPECC, ECFA
2010 Divonne III, NuPECC, ECFA

Series of 3 workshops, fall each year


The TeV Scale [2010-2035..]
pp
W,Z,top
Higgs??
New Particles??
New Symmetries?
LHC
ep
High Precision QCD
High Density Matter
Substructure??
eq-Spectroscopy??
LHeC
New Physics
e^+e^-
ttbar
Higgs??
Spectroscopy??
ILC/CLIC
CKM - superB



Rolf Heuer: 3/4. 12. 09 at CERN: From the Proton Synchroton to the Large Hadron Collider
50 Years of Nobel Memories in High-Energy Physics

LHeC Physics

1. Grand unification? α_s to per mille accuracy: jets vs inclusive
   ultraprecision DIS programme: N^kLO, charm, beauty, ep/eD,..

2. Complete unfolding of partonic content of the proton,
   direct and in QCD and mapping of the gluon field

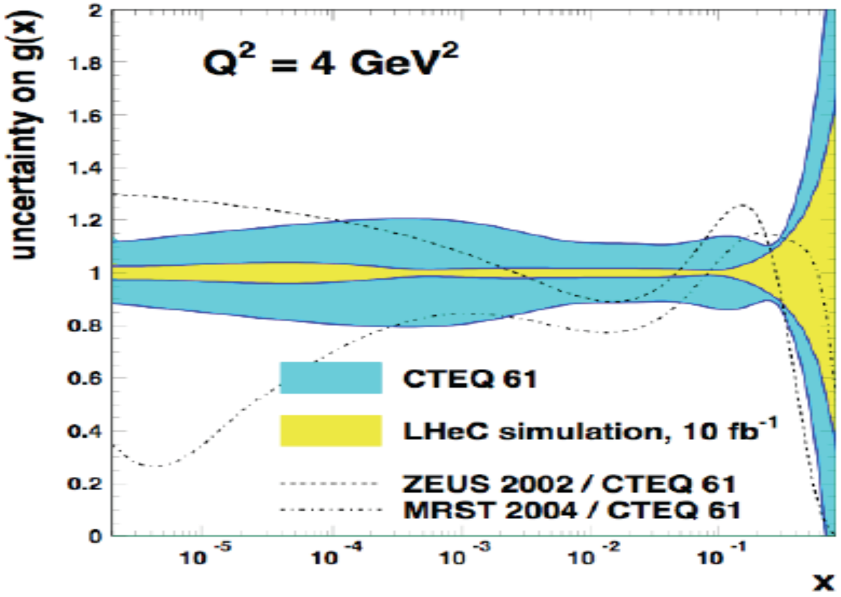
3. A new phase of hadronic matter: high densities, small α_s
   saturation of the gluon density? BFKL-Planck scale
   superhigh-energy neutrino physics (p-N)

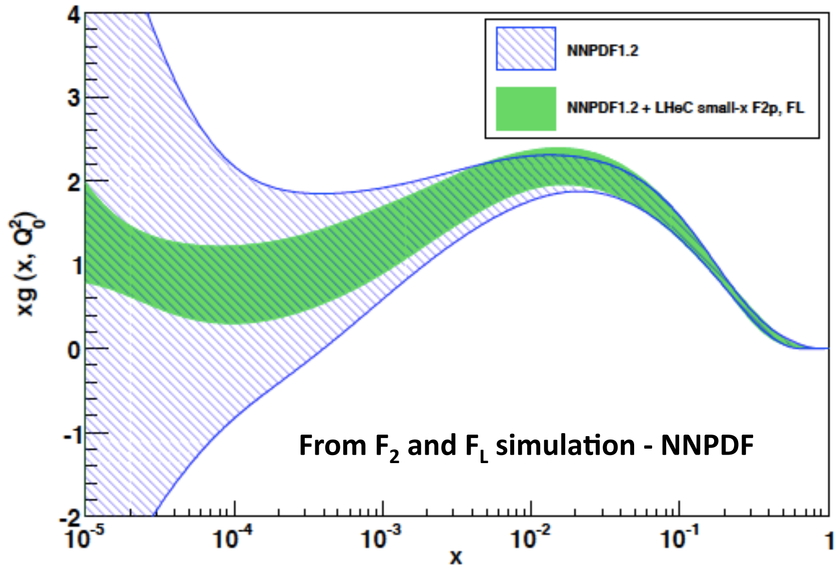
4. Partons in nuclei (4 orders of magnitude extension)
   saturation in eA ($A^{1/3}$?), nuclear parton distributions
   black body limit of F_2, colour transparency, …

5. Search for novel QCD phenomena
   instantons, odderons, hidden colour, sea=antiquarks (strange)

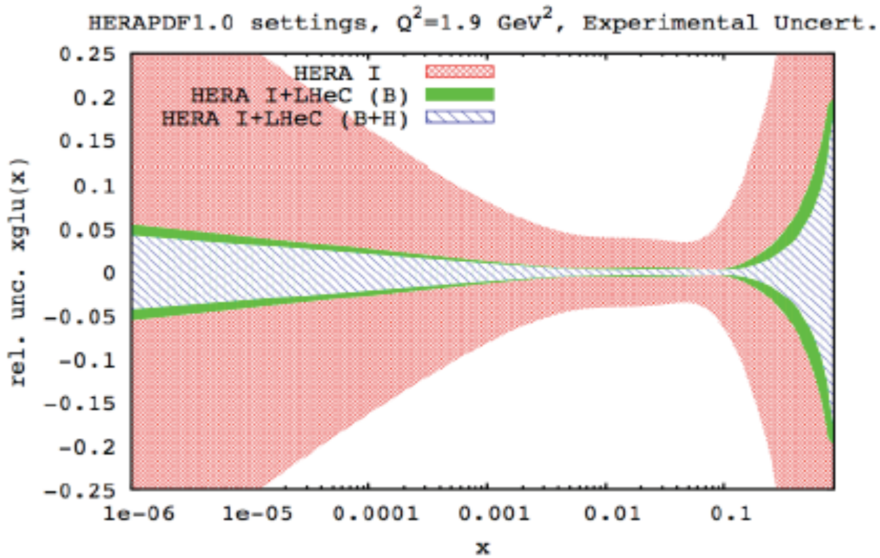
6. Complementarity to new physics at the LHC
   LQ spectroscopy, eeqq CI, Higgs, e^*

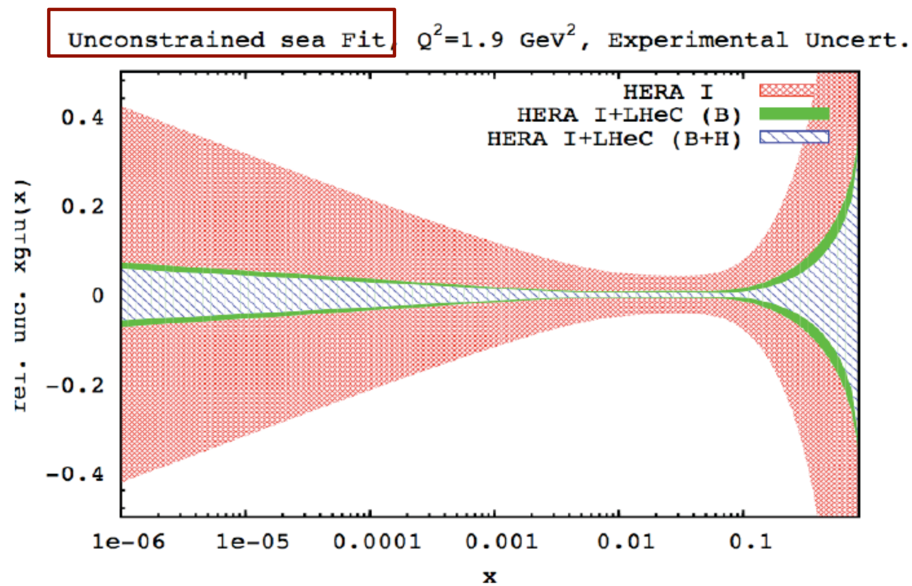
Gluon Distribution





NLO QCD "Fits" of LHeC simulated data





LHeC Physics

1. Neutron structure free of Fermi motion
2. Diffraction – Shadowing (Glauber). Antishadowing
3. Vector Mesons to probe strong interactions
4. Diffractive scattering “in extreme domains” (Brodsky)
5. Single top and anti-top ‘factory’ (CC)
6. GPDs via DVCS
7. Unintegrated parton distributions
8. Partonic structure of the photon
9. Electroweak Couplings to per cent accuracy

….

For numeric studies and plots see recent talks at DIS10/11, ICHEP10, EIC and LHeC Workshops [cern.ch/lhec] ..CDR

Every major step in energy can lead to new unexpected results

Requires: **High energy**, $e^{\pm}$, p, d, A, **high luminosity**, 4π acceptance, **high precision** (e/h)

↳ TeV scale physics, electroweak, top, Higgs, low x unitarity

LHeC Detector

Requirements

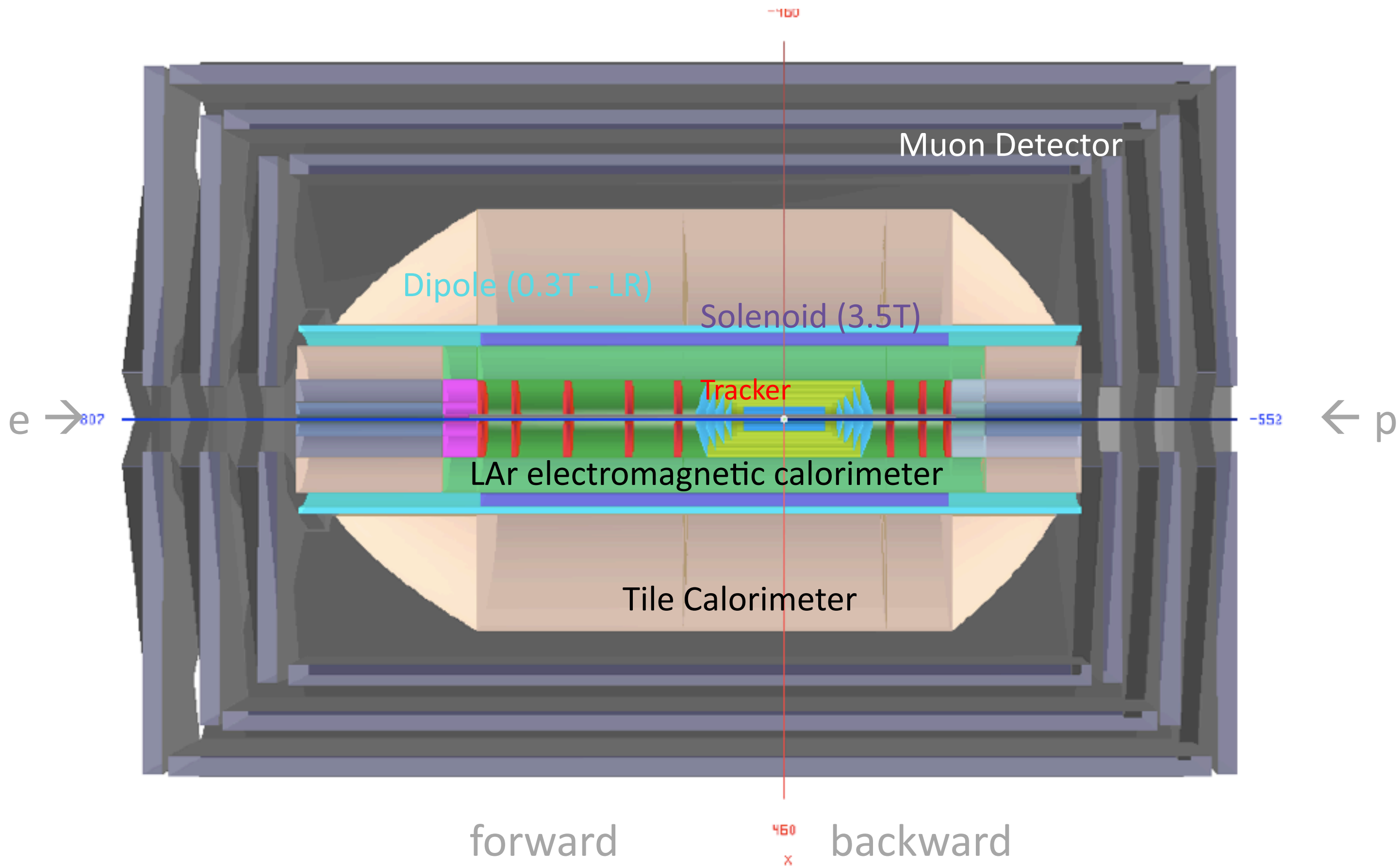
High Precision
(resolution,
calibration,
low noise at low y
tagging of b,c)

Modular for 'fast'
installation

State of the art
for 'no' R+D

1-179° acceptance
for low Q^2, high x

Affordable



Present dimensions: LxD =13x9m² [CMS 21 x 15m², ATLAS 45 x 25 m²]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Tentative 21.3.11

LHeC Accelerator: Participating Institutes

CERN

SLAC
NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

CLIC

The Cockcroft Institute
of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

ANKARA ÜNİVERSİTESİ
ANKARA ÜNİVERSİTESİ 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

DESY

LAL
Physique des accélérateurs

ECFA

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

BROOKHAVEN
NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера
630090 Новосибирск

KEK

Energy-Power-Luminosity: Ring-Ring

- Power Limit of **100 MW wall plug**
- "ultimate" LHC proton beam
- **60 GeV** $e^{\pm}$ beam

→ $L = 2\ 10^{33}\ cm^{-2}s^{-1}$ → O(100) fb^{-1}

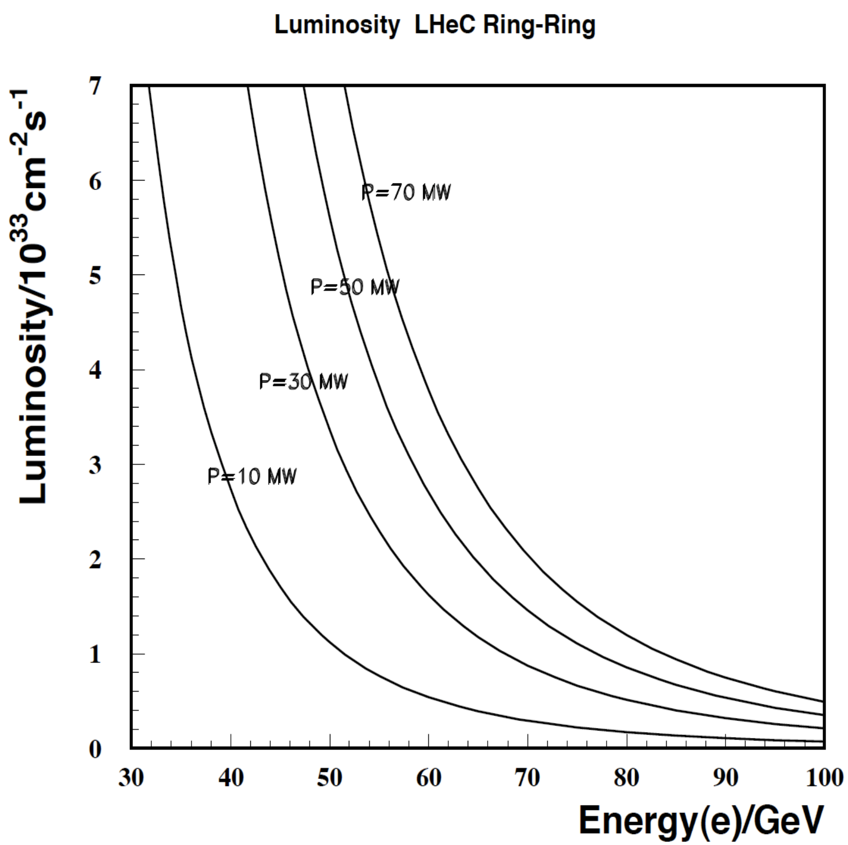
HERA 1..5 10^{31} → 1 fb^{-1} (H1+ZEUS)

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

$$N_p = 1.7\cdot 10^{11}, \varepsilon_p = 3.8\mu m, \beta_{px(y)} = 1.8(0.5)m, \gamma = \frac{E_p}{M_p}$$

$$L = 8.2\cdot 10^{32} cm^{-2}s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{m}{\sqrt{\beta_{px}\beta_{py}}} \cdot \frac{I_e}{50mA}$$

$$I_e = 0.35mA \cdot P[MW] \cdot (100/E_e[GeV])^4$$



Proton tune shift from ep interaction much smaller than from pp: Design for simultaneous pp and ep operation

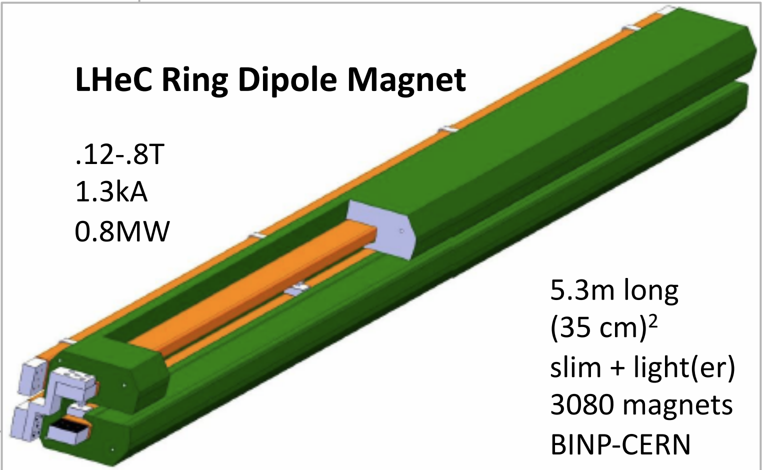
Accelerator: Ring - Ring

Workpackages for CDR [2008 – now available]

Baseline Parameters and Installation Scenarios
Lattice Design [Optics, Magnets, Bypasses]
IR for high Luminosity and large Acceptance
rf Design [Installation in bypasses, Crabs?]
Injector Complex [Sources, Injector]
Injection and Dump
Cryogenics – work in progress
Beam-beam effects
Impedance and Collective Effects
Vacuum and Beam Pipe
Integration into LHC
e Beam Polarization
Deuteron and Ion Beams

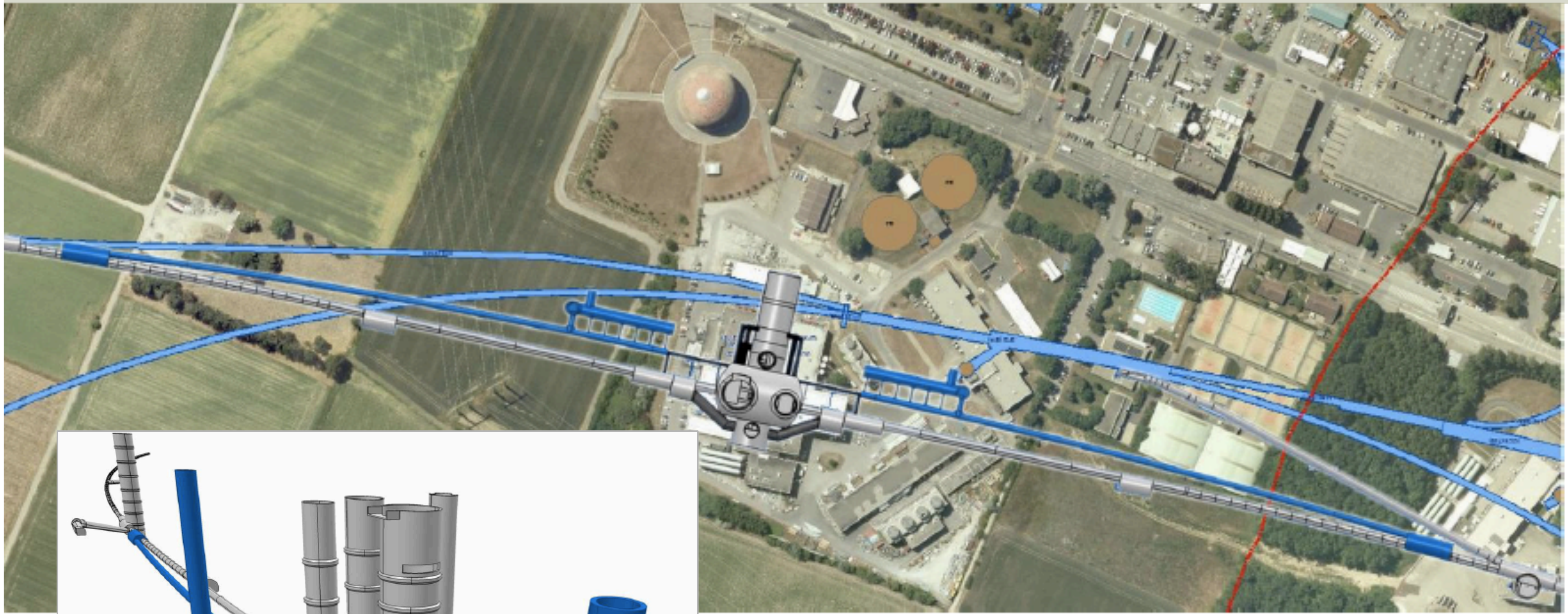
LHeC Ring Dipole Magnet

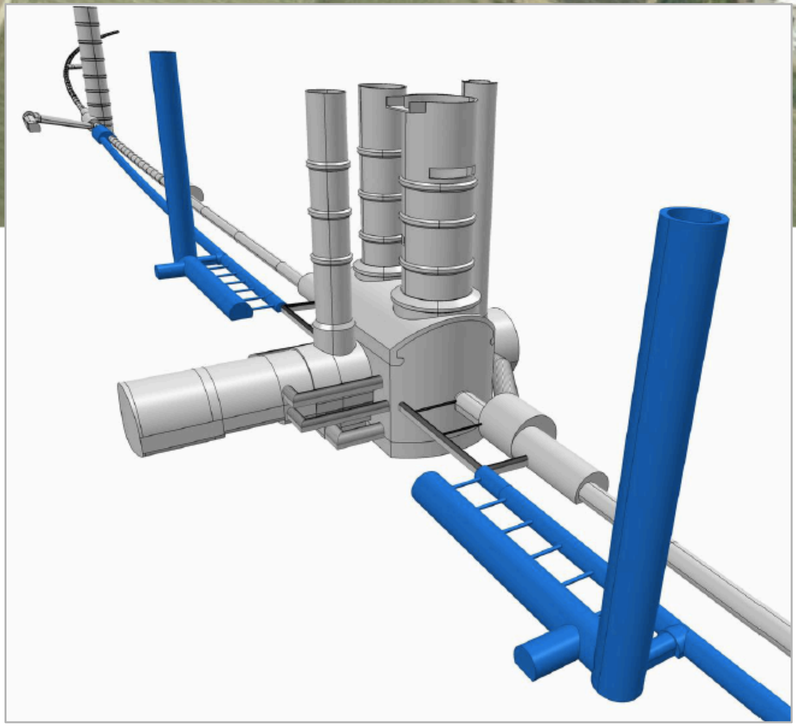
.12-.8T
1.3kA
0.8MW



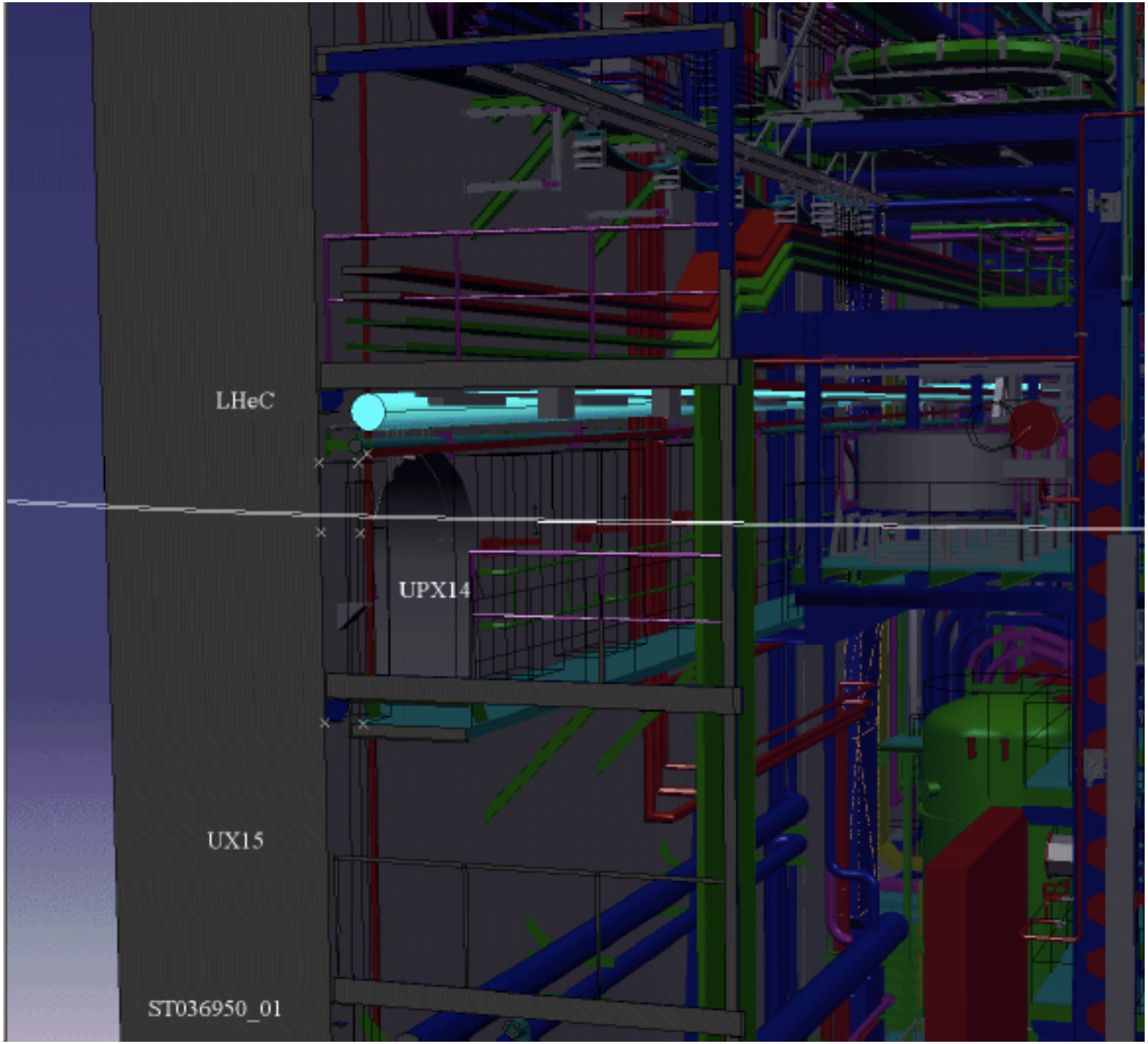
5.3m long
$(35\ \text{cm})^2$
slim + light(er)
3080 magnets
BINP-CERN

Bypassing ATLAS





For the CDR the bypass concepts were decided to be confined to ATLAS and CMS which is no statement about LHCB or ALICE



Study of how to pass through (or by) ATLAS

August 10
tentative

Energy-Power-Luminosity: Linac-Ring

$$L = \frac{1}{4\pi} \cdot \frac{N_p}{\varepsilon_p} \cdot \frac{1}{\beta^*} \cdot \gamma \cdot \frac{I_e}{e}$$

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000/0.94$$

$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^* / m} \cdot \frac{I_e / mA}{1}$$

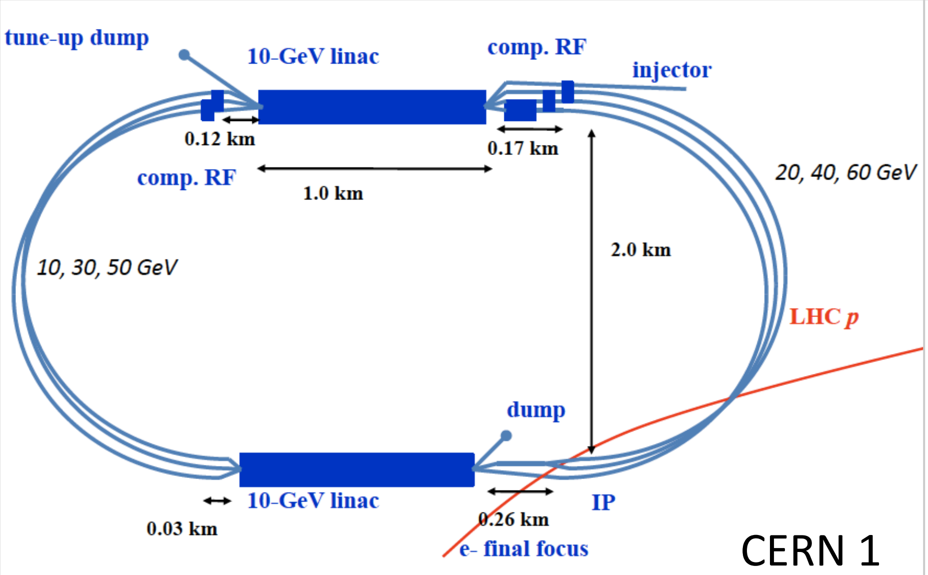
$$I_e = mA \frac{P / MW}{E_e / GeV}$$

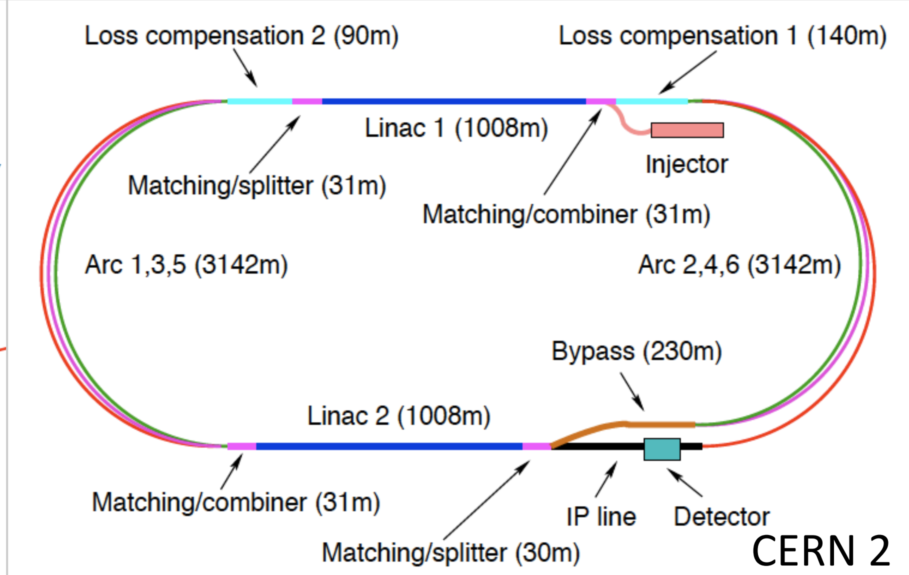
Pulsed**, 60 GeV**: ~10^{32}cm^{-2}s^{-1}
High luminosity:
Energy recovery: $P=P_0/(1-\eta)$
β*=0.1m
[5 times smaller than LHC by reduced l*, only one p squeezed and IR quads as for HL-LHC]
L = 10^{33} cm^{-2}s^{-1} → O(100) fb^{-1}

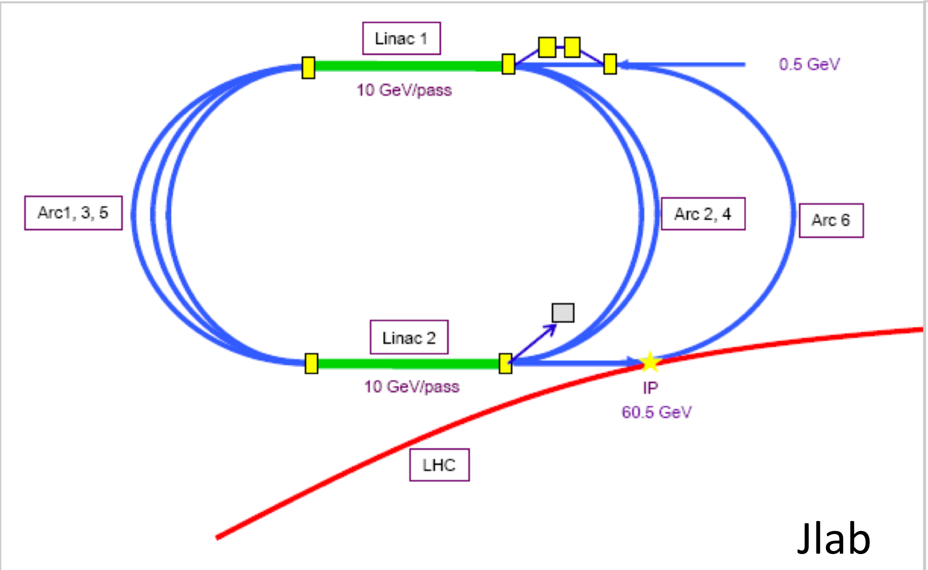
The cryopower for two 10-GeV accelerating SC linacs is 28.9 MW, assuming pessimistically 37 W/m heat load at 1.8 K and 18 MV/m cavity gradient (this is a pessimistic estimate since the heat load could be up to 3 times smaller; see Table 9.1), and 700 "W per W" cryo efficiency as for the ILC. The RF power needed to control microphonics for the accelerating RF is estimated at 22.2 MW, considering that 10 kW/m RF power may be required, as for eRHIC, with 50% RF generation efficiency. The electrical power for the additional RF compensating the synchrotron-radiation energy loss is 24.1 MW, with an RF generation efficiency of 50%. The cryo power for the compensating RF is 2.1 MW, provided in additional 1,44 GeV linacs, and the microphonics control for the compensating RF requires another 1.6 MW. In addition, with an injection energy of 50 MeV, 6.4 mA beam current, and as usual 50% efficiency, the electron injector consumes about 6.4 MW. A further 3 MW is budgeted for the recirculation-arc magnets [?]. Together this gives a grand total of 88.3 MW electrical power, some 10%.below the 100 MW limit.

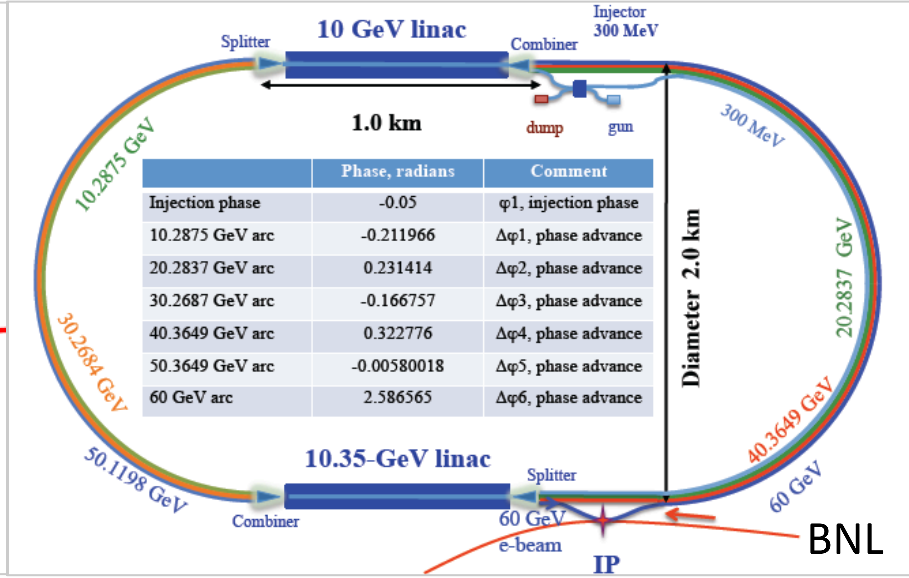
Description of LINAC power consumption from draft of CDR

60 GeV e "LINAC"



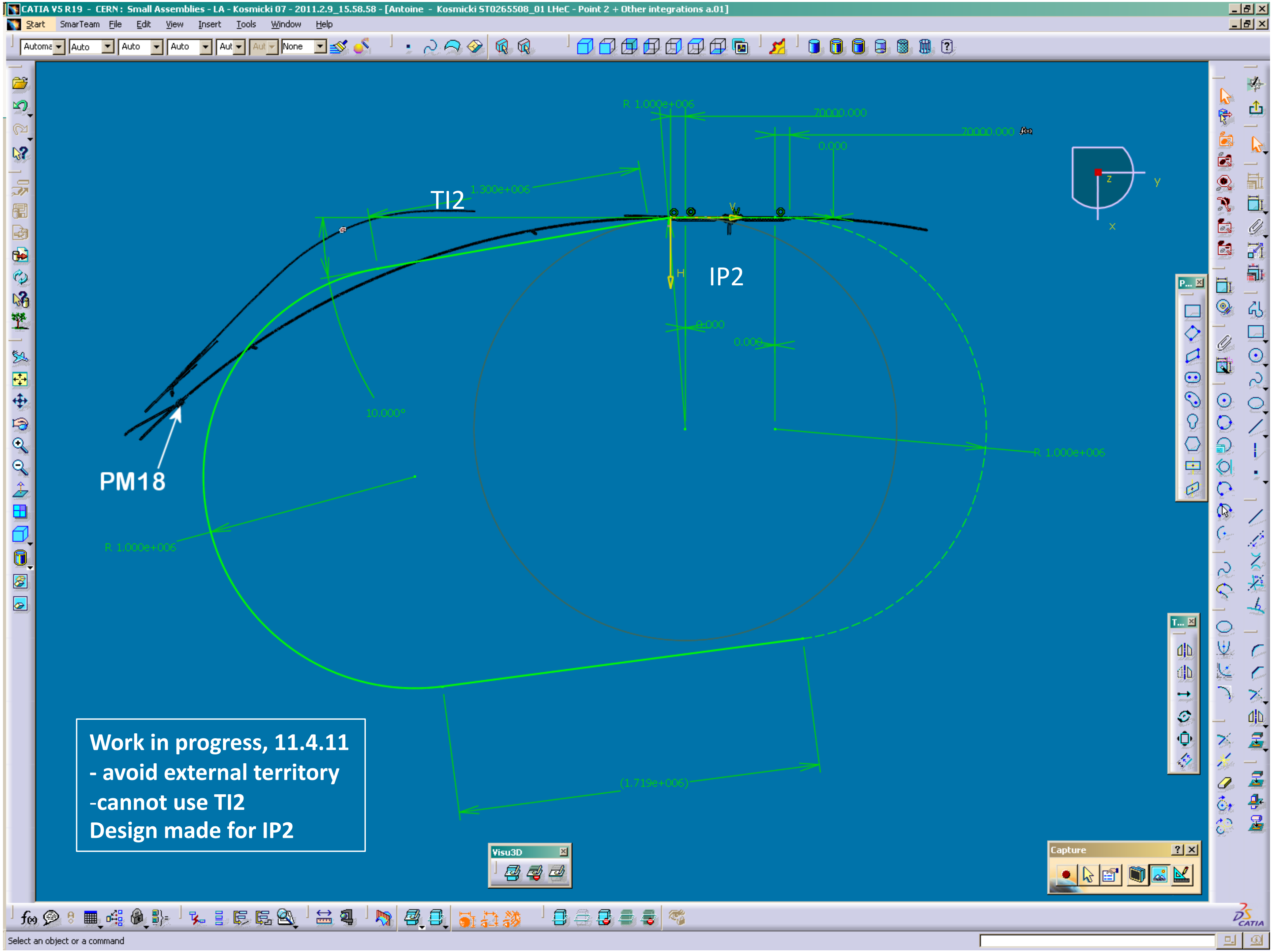






	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities


CATIA V5 R19 - CERN : Small Assemblies - LA - Kosmicki 07 - 2011.2.9_15.58.58 - [Antoine - Kosmicki ST0265508_01 LHeC - Point 2 + Other integrations a.01]
Start
SmarTeam
File
Edit
View
Insert
Tools
Window
Help
TI2
IP2
PM18
R 1.000e+006
70000.000
0.000
1.300e+006
10.000°
(1.719e+006)
Visu3D
Capture
Select an object or a command
Work in progress, 11.4.11
- avoid external territory
-cannot use TI2
Design made for IP2

Accelerator: LINAC - Ring

Workpackages for CDR [2008 – now available]

Baseline Parameters [Designs, Real photon option, ERL]
Sources [Positrons, Polarisation] – work in progress
Rf Design
Injection and Dump
Beam-beam effects
Lattice/Optics and Impedance
Vacuum and Beam Pipe
Integration and Layout
Interaction Region
Magnets
Cryogenics – work in progress

1056 cavities
66 cryo modules per linac
721 MHz, 19 MV/m CW
Similar to SPL, ESS, XFEL, ILC, eRHIC, Jlab
21 MW rf
Cryo 29 MW for 37W/m heat load
Magnets in the 2 * 3 arcs:
600 - 4m long dipoles per arc
240 - 1.2m long quadrupoles per arc

Design Parameters

electron beam	RR	LR	LR
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17	10	0.44
polarization [%]	40	90	90
bunch population [10^9]	26	2.0	1.6
e- bunch length [mm]	10	0.3	0.3
bunch interval [ns]	25	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.58, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	30, 16	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.18, 0.10	0.12	0.14
full crossing angle [mrad]	0.93	0	0
geometric reduction H_{hg}	0.77	0.91	0.94
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	131	6.6	5.4
tot. wall plug power[MW]	100	100	100

High E_e Linac option (ERL?) if physics demands, HE-LHC?

proton beam	RR	LR
bunch pop. [10^{11}]	1.7	1.7
tr.emit.$\gamma\varepsilon_{x,y}$ [μm]	3.75	3.75
spot size $\sigma_{x,y}$ [μm]	30, 16	7
$\beta^*_{x,y}$ [m]	1.8,0.5	0.1
bunch spacing [ns]	25	25

"ultimate p beam"
1.7 probably conservative

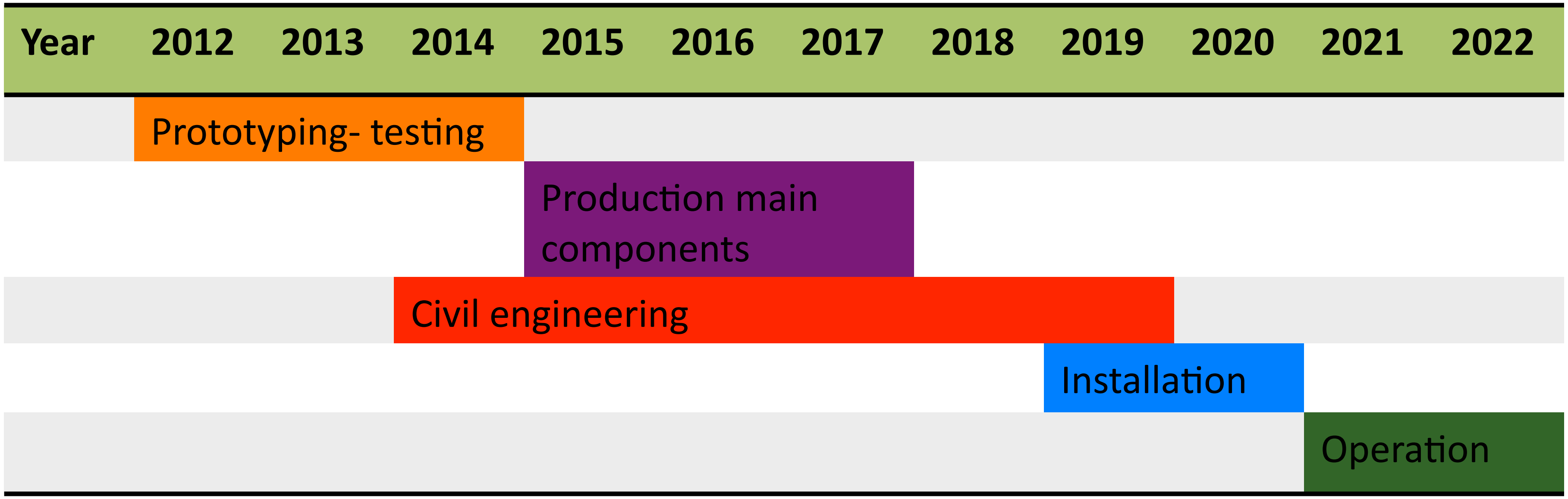
Design also for
D and A (L_{eN} = 10^{31} $cm^{-2}s^{-1}$)

RR= Ring – Ring
LR =Linac –Ring

Parameters from 8.7.2010
New: Ring: use 1° as baseline : L/2
Linac: clearing gap: L*2/3

LHeC_DRAFT_Timeline

Based on LHC constraints, ep/A programme, series production, civil engineering etc

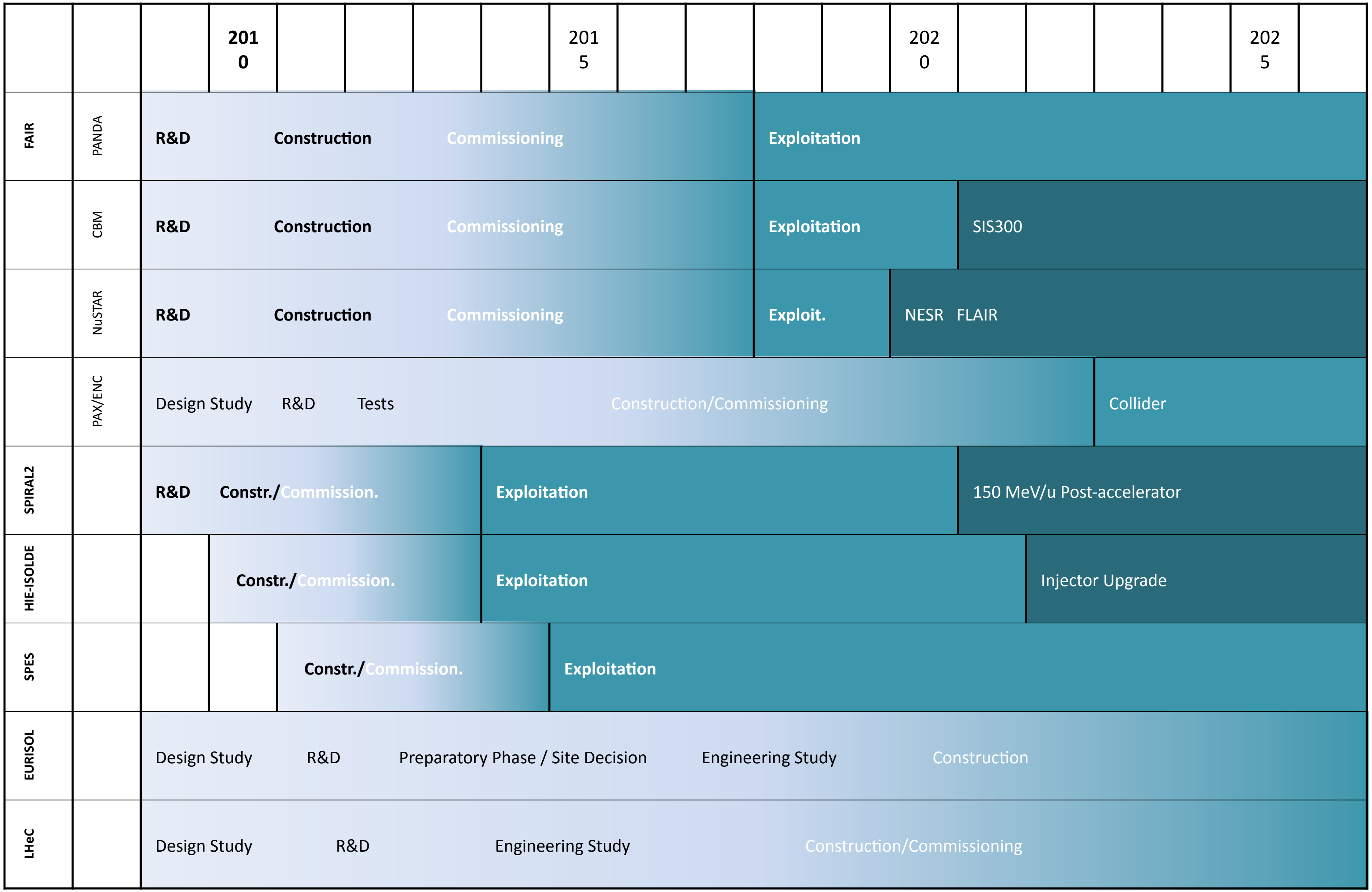


Variations on timeline:

- ➔ production of main components can overlap with civil engineering
- ➔ Installation can overlap with civil engineering
- ➔ Additional constraints from LHC operation not considered here
- ➔ in any variation, a start by 2020 requires launch of prototyping of key components by 2012

[shown to ECFA 11/2010: mandate to 2012]

NuPECC – Roadmap 2010: New Large-Scale Facilities



G. Rosner, NuPECC Chair, Madrid 5/10

Organization for the CDR

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
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)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg)
Richard Milner (Bates)
Joachim Mnich (DESY)
Steven Myers, (CERN)
Tatsuya Nakada (Lausanne, ECFA)
Guenther Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Committee

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

Working Group Convenors

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 (U Zurich),

Alessandro Polini (Bologna)

New Physics at Large Scales

George Azuelos (Montreal)

Emmanuelle Perez (CERN),

Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),

Paolo Gambino (Torino),

Thomas Gehrmann (Zuerich)

Claire Gwenlan (Oxford)

Physics at High Parton Densities

Nestor Armesto (Santiago),

Brian Cole (Columbia),

Paul Newman (Birmingham),

Anna Stasto (MSU)

Referees invited by CERN

QCD/electroweak:
Guido Altarelli, Alan Martin, Vladimir Chekelyan

BSM:
Michelangelo Mangano, Gian Giudice, Cristinel Diaconu

eA/low x
Al Mueller, Raju Venugopalan, Michele Arneodo

Detector
Philipp Bloch, Roland Horisberger

Interaction Region Design
Daniel Pitzl, Mike Sullivan

Ring-Ring Design
Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

Linac-Ring Design
Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

Energy Recovery
Georg Hoffstatter, Ilan Ben Zvi

Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz

Next Steps of the LHeC Project

2011

1. Complete CDR Draft
2. Workshop on positron intensity (20.5.11 at CERN)
3. Referee Process (5-9/11)
4. Update and Print and Hand in to ECFA/NuPECC/CERN
5. Workshop on Linac vs Ring (Fall 2011) [main features, R+D design]

2011/12

1. Participation in European Strategy Process (EPS Grenoble … 2012 conclusion)
2. Update physics programme when LHC Higgs/SUSY results consolidate (DIS12)

3. Form an international accelerator development group based at CERN
4. Build an LHeC Collaboration for preparation of LoI on the Detector

Predicting is difficult, in particular when it concerns the future (V. Weisskopf)

but there is a project and a plan and so there shall be a future for DIS at the energy frontier

Summary

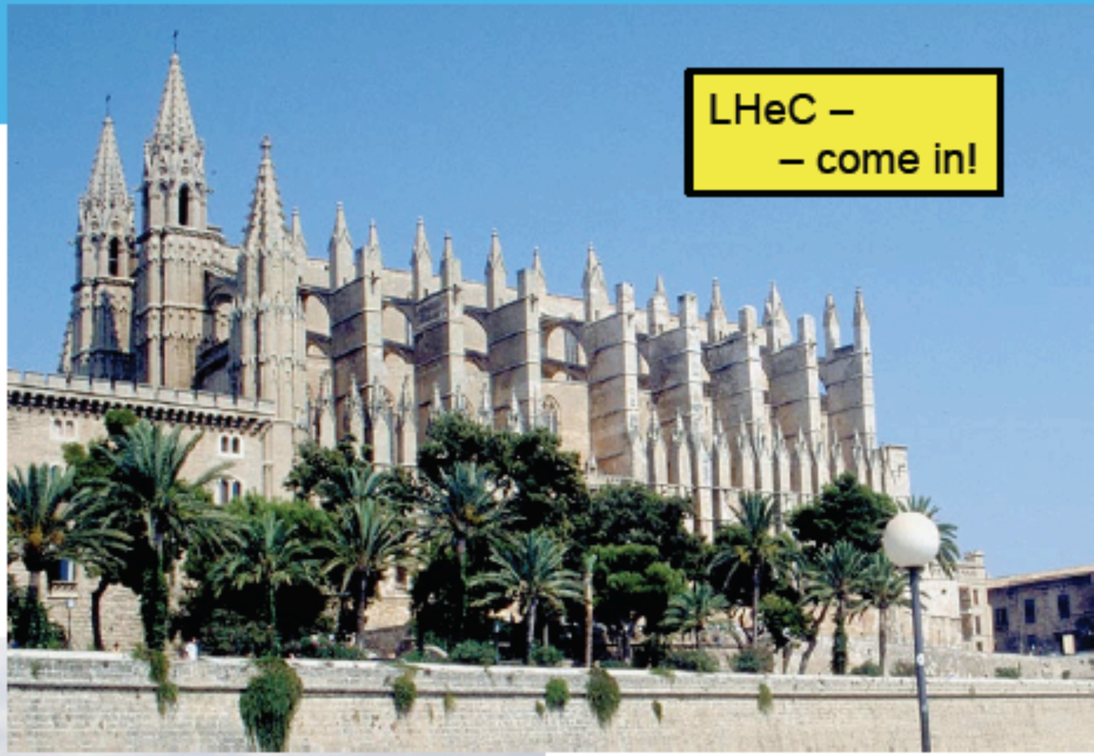
The LHeC is the only way for the foreseeable future to realize DIS at the TeV energy scale, leading to new insight and continuing the path from 1911 to now. It will substantially enrich and extend the physics provided by the LHC, and it represents a new opportunity for challenging accelerator and detector developments

Talks on Tuesday and Thursday

Miriam Fitterer (CERN)	Ring-Ring
Alex Bogacz (Jlab)	Linac-Ring
Peter Kostka (DESY)	Detector
Anna Stasto (PennState)	Inclusive Low x Physics
Paul Newman (Birmingham)	Exclusive Low x Physics
Brian Cole (Columbia)	Heavy Ion Physics
Voica Radescu (Heidelberg)	Partons and α_s
Olaf Behnke (DESY)	Jets and Heavy Quarks
Uta Klein (Liverpool)	BSM with the LHeC

MY WAY TO LHeC

TSS'



Draft **CDR Authorlist** 11.4.11

C. Adolphsen (SLAC)
H. Aksakal (CERN)
P. Allport (Liverpool)
J.L. Albacete (IPhT Saclay)
R. Appleby (Cockcroft)
N. Armesto (St. de Compostela)
G. Azuelos (Montreal)
M. Bai (BNL)
D. Barber (DESY)
J. Bartels (Hamburg)
J. Behr (DESY)
O. Behnke (DESY)
S. Belyaev (CERN)
I. Ben Zvi (BNL)
N. Bernard (UCLA)
S. Bertolucci (CERN)
S. Bettoni (CERN)
J. Bluemlein (DESY)
S. Brodsky (SLAC)
A. Bogacz (Jlab)
C. Bracco (CERN)
O. Bruening (CERN)
A. Bunyatian (DESY)
H. Burkhardt (CERN)
R. Calaga (BNL)
E. Ciapala (CERN)
R. Ciftci (Ankara)
A.K.Ciftci (Ankara)
B.A. Cole (Columbia)
J.C. Collins (Penn State)
J. Dainton (Liverpool)
A. De Roeck (CERN)
D. d'Enterria (CERN)
A. Dudarev (CERN)
A. Eide (NTNU)

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K.J. Eskola (Jyvaskyla)
L. Favart (IIHE Brussels)
M. Fitterer (CERN)
S. Forte (Milano)
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R. Godbole (Tata)
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J.M. Jimenez (CERN)
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A. Kilic (Uludag}
K. Kimura (Tokyo I.Tech.)
M. Klein (Liverpool)
U. Klein (Liverpool)
T. Kluge (Hamburg)
G. Kramer (Hamburg)
M. Korostelev (Cockcroft)
A. Kosmicki (CERN)
P. Kostka (DESY)

No one full time – THANK YOU

H. Kowalski (DESY)
M. Kuze (Tokyo I.Tech.)
T. Lappi (Jyvaskyla)
P. Laycock (Liverpool)
E. Levichev (BINP)
S. Levonian (DESY)
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V. Ptitsyn (BNL)
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V. Radescu (Heidelberg U)
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J. Rojo (Milano)
S. Russenschuck (CERN)
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U. Schneekloth (DESY)
T. Schoerner Sadenius (DESY)
D. Schulte (CERN)

N. Soumitra (Torino)
H. Spiesberger (Mainz)
A.M. Stasto (Penn State)
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S. Sultansoy (Ankara)
Y.P. Sun (SLAC)
W. Smith (Madison)
I. Tapan (Uludag)
H. Ten Kate (CERN)
J. Terron (Madrid)
H. Thiesen (CERN)
L. Thompson (Cockcroft)
K. Tokushuku (KEK)
R. Tomas Garcia (CERN)
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K. Tywoniuk (Lund)
G. Unel (CERN)
J. Urukawa (KEK)
P. Van Mechelen (Antwerpen)
R. Veness (CERN)
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G. Watt (CERN)
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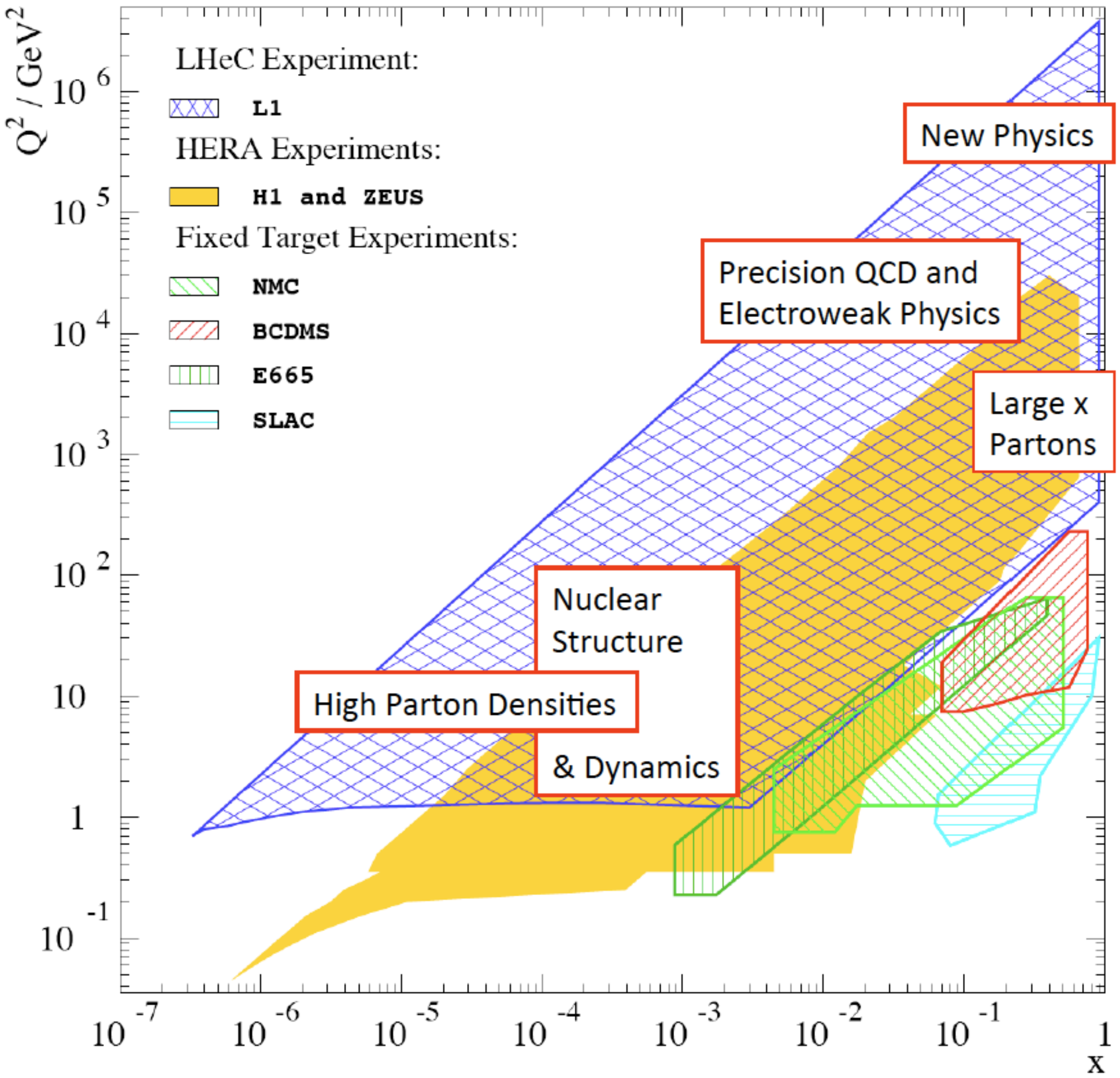
U. Wienands (SLAC)
F. Willeke (BNL)
V. Yakimenko (BNL)
A.F. Zarnecki (Warsaw)
F. Zimmermann (CERN)

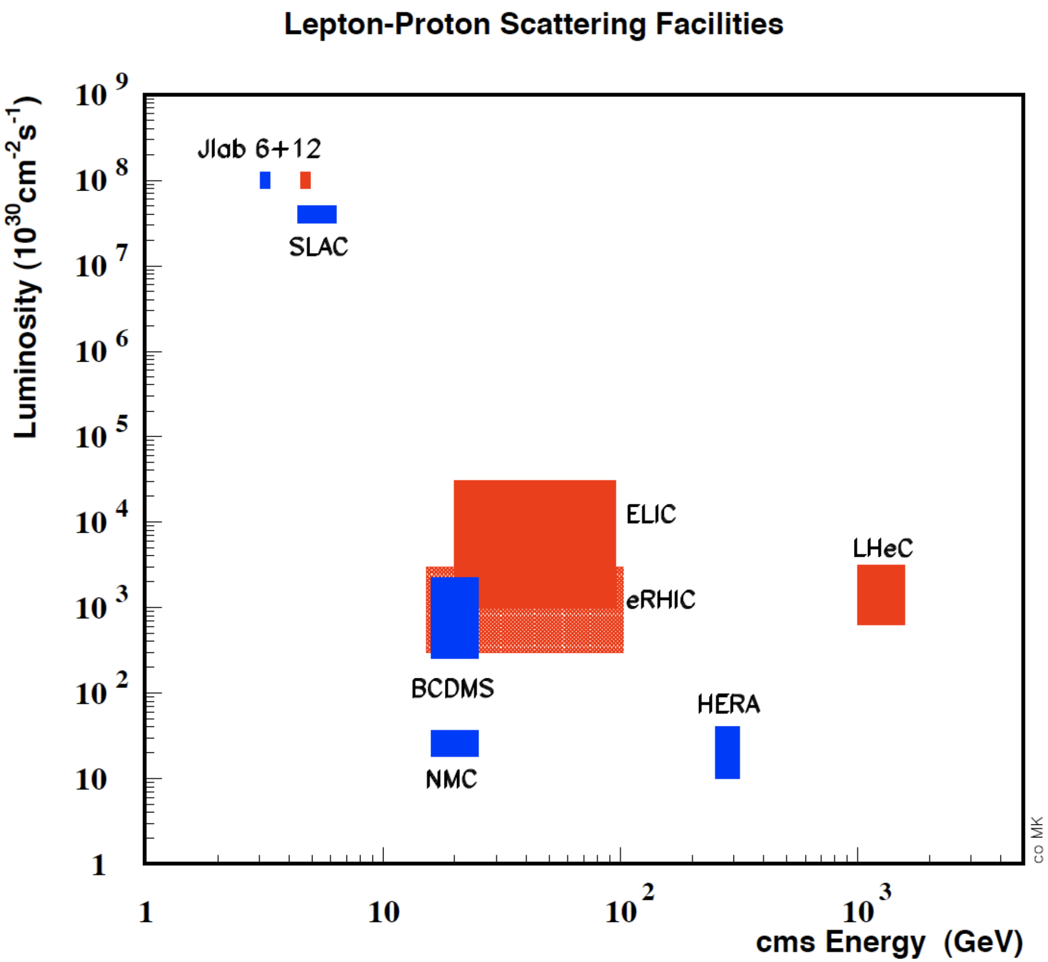
Subject to personal ok

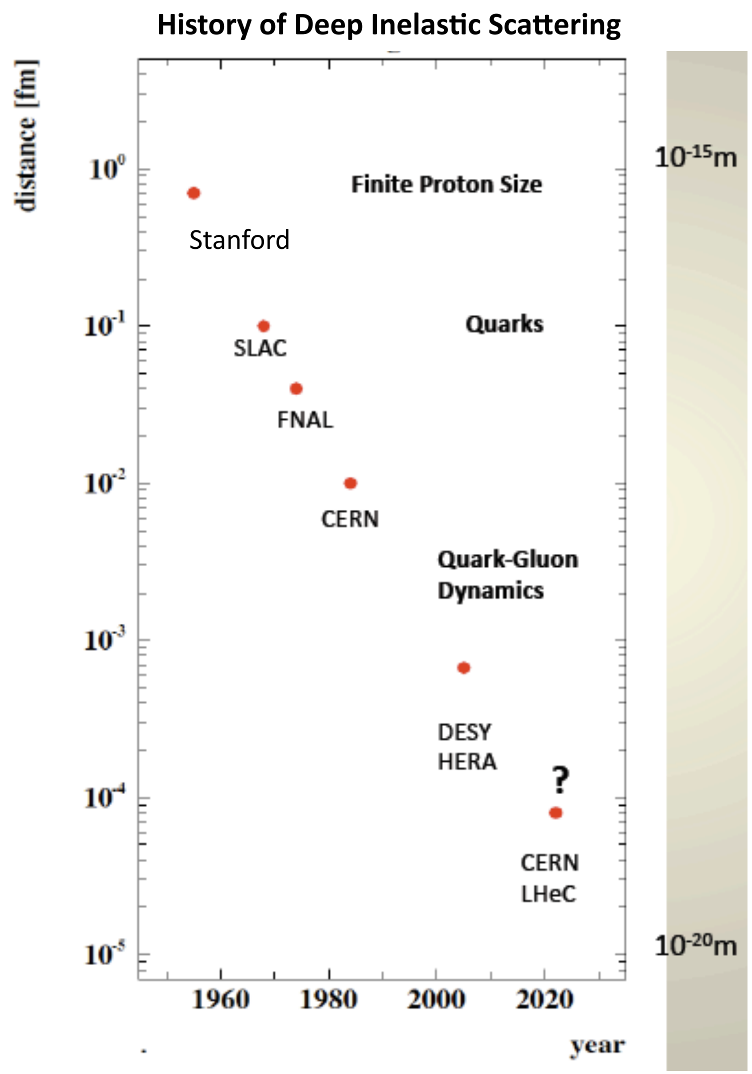
backup

Deep Inelastic e/μ p Scattering



Deep Inelastic Scattering - History and Prospects





HERA – an unfinished programme

Low x: DGLAP seems to hold though ln1/x is large
Gluon Saturation not proven

High x: would have required much higher luminosity
[u/d ?, xg ?]

Strange quark density ?

Neutron structure not explored

Nuclear structure not explored

New concepts introduced, investigation just started:
-parton amplitudes (GPD's, proton hologram)
-diffractive partons
-unintegrated partons

Partonic structure of the photon

Instantons not observed

Odderons not found
…

Fermions still pointlike
Lepton-quark states (as in RPV SUSY) not observed

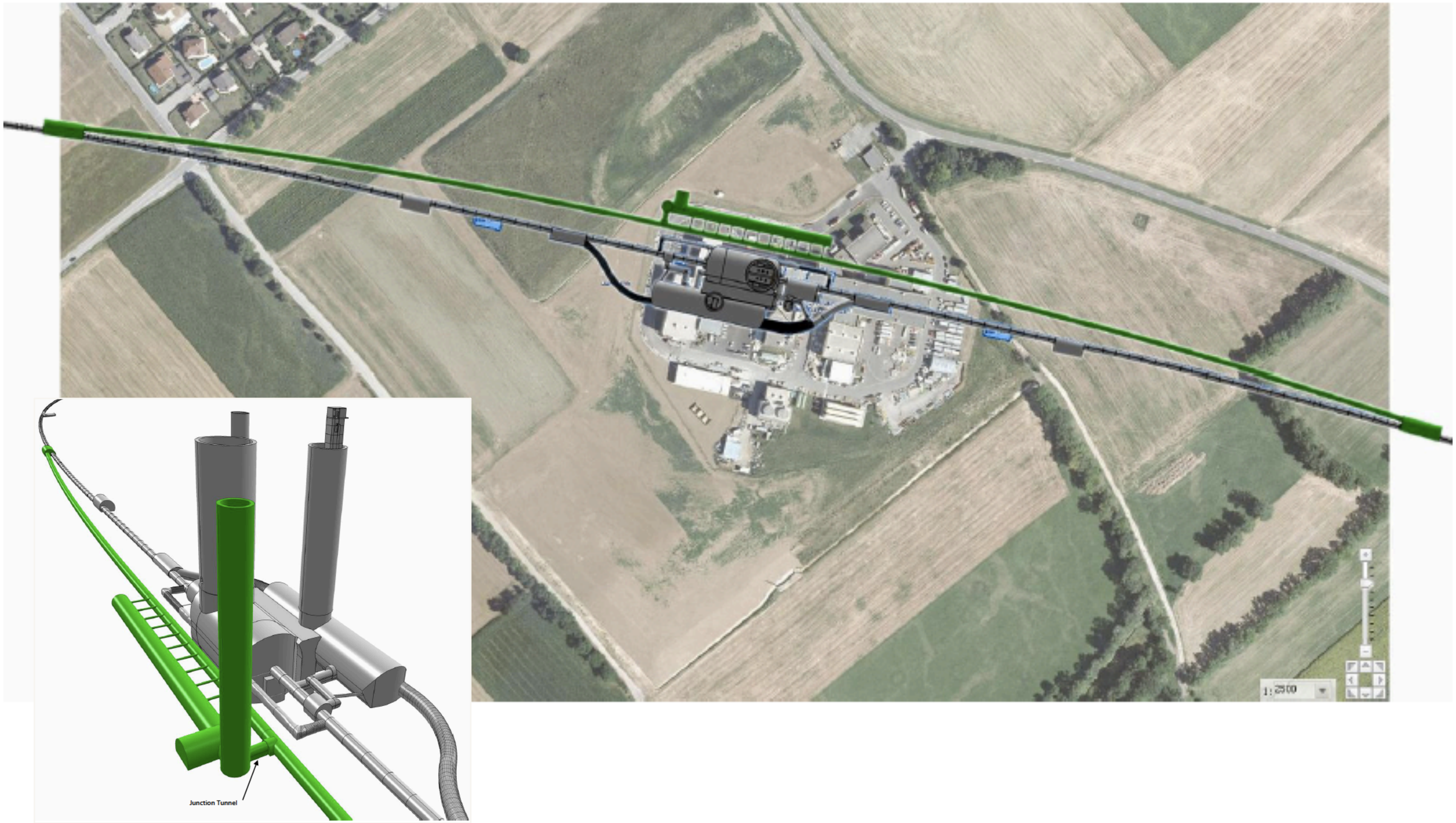
Ring-Ring Option

Luminosity $10^{33}cm^{-2}s^{-1}$ rather ‘easy’ to achieve
Electrons and Positrons
Energy limited by synchrotron radiation
Polarisation ~30%
Magnets, Cryosystem: no major R+D, just D
10 GeV Injector possibly using ILC type cavities
Interference with the proton machine
Bypasses for LHC experiments (~3km tunnel)

LINAC-Ring Option

Luminosity $10^{33}cm^{-2}s^{-1}$ possible to achieve for e^- with ERL
Positrons require E recovery AND recycling, L+ < L-
Energy limited by synchrotron radiation in racetrack mode
Polarisation ‘easy’ for e^- ~90%, rather difficult for e^+
721 MHz Cavities: Synergy with SPL, ESS, XFEL, ILC, eRHIC
Cryo: fraction of LHC cryo system
Smaller interference with the proton machine
Bypass of own IP
Extended dipole at ~1m radius in detector
Shafts on CERN territory (~9km tunnel below St Genis for IP2)

Bypassing CMS



e-Pb Collisions (RR)

- Assume present nominal Pb beam in LHC
  - Same beam size as protons, fewer bunches

  $k_b = 592$ bunches of $N_b = 7 \times 10^7$ ${}^{208}Pb^{82+}$ nuclei

- Assume lepton injectors can create matching train of e^-

  $k_b = 592$ bunches of $N_b = 1.4 \times 10^{10}$ e^-

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

  $$L = 1.09 \times 10^{29}\ \text{cm}^{-2}\text{s}^{-1} \quad \Leftrightarrow \quad L_{en} = 2.2 \times 10^{31}\ \text{cm}^{-2}\text{s}^{-1}$$

  gives 11 MW radiated power

  - May be possible to exploit additional power by increasing electron single-bunch intensity by factor 592/2808=4.7.