On the LHeC Project

http://cern.ch/lhec

P. Kostka DESY - for the LHeC Study Group

NEW TRENDS IN HIGH-ENERGY PHYSICS
(experiment, phenomenology, theory)

Alushta, Crimea, Ukraine, September 3 - 10, 2011

The project is intended to becomes part of European deliberation of future directions of particle physics.

It must be seen in the context of the LHC and the results there; it will substantially enrich and extend its physics program and further exploits the investment made in the LHC

DRAFT 1.0
Geneva, August 5, 2011
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-001 GEN

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group
THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION

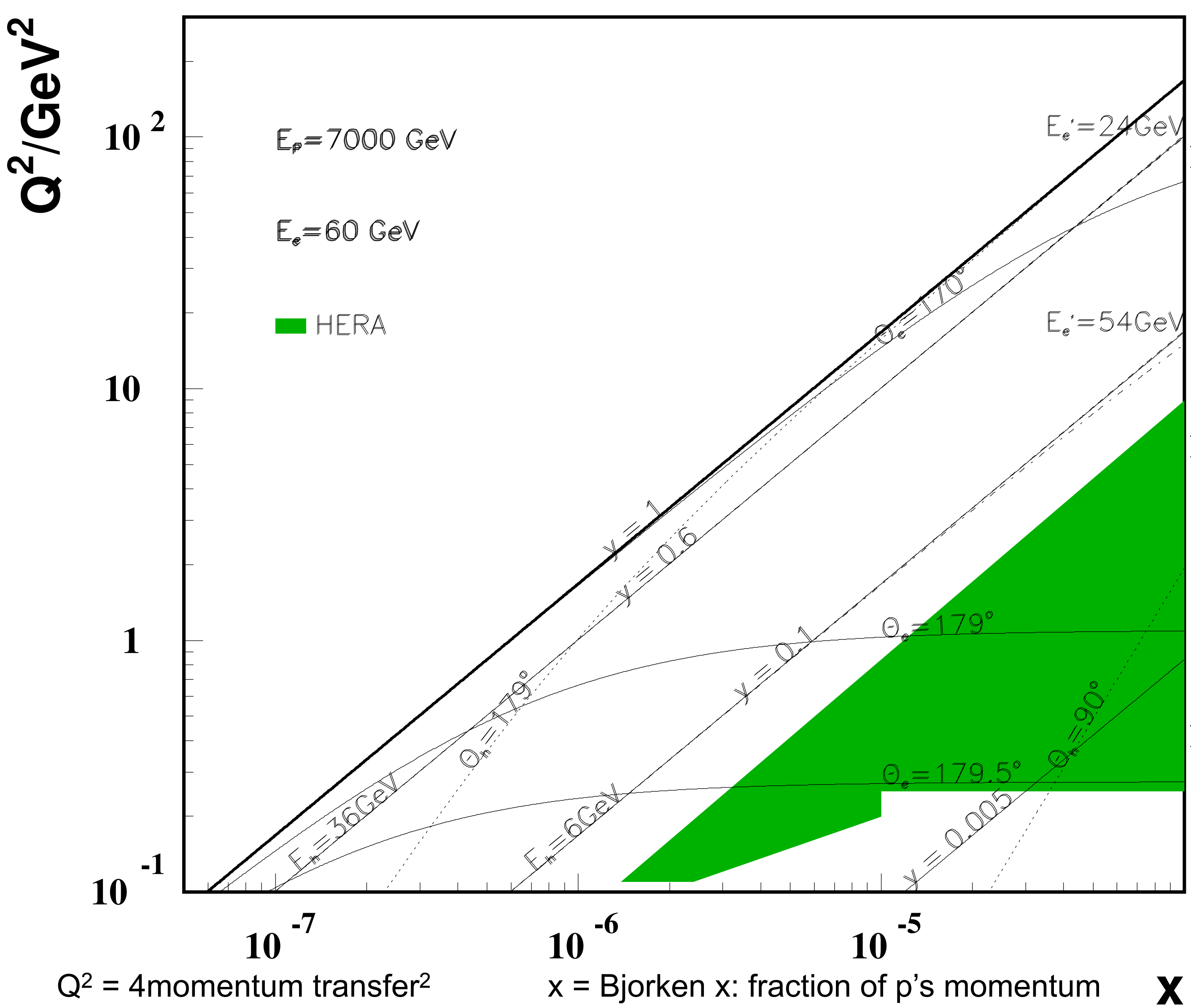
To be submitted for publication

1

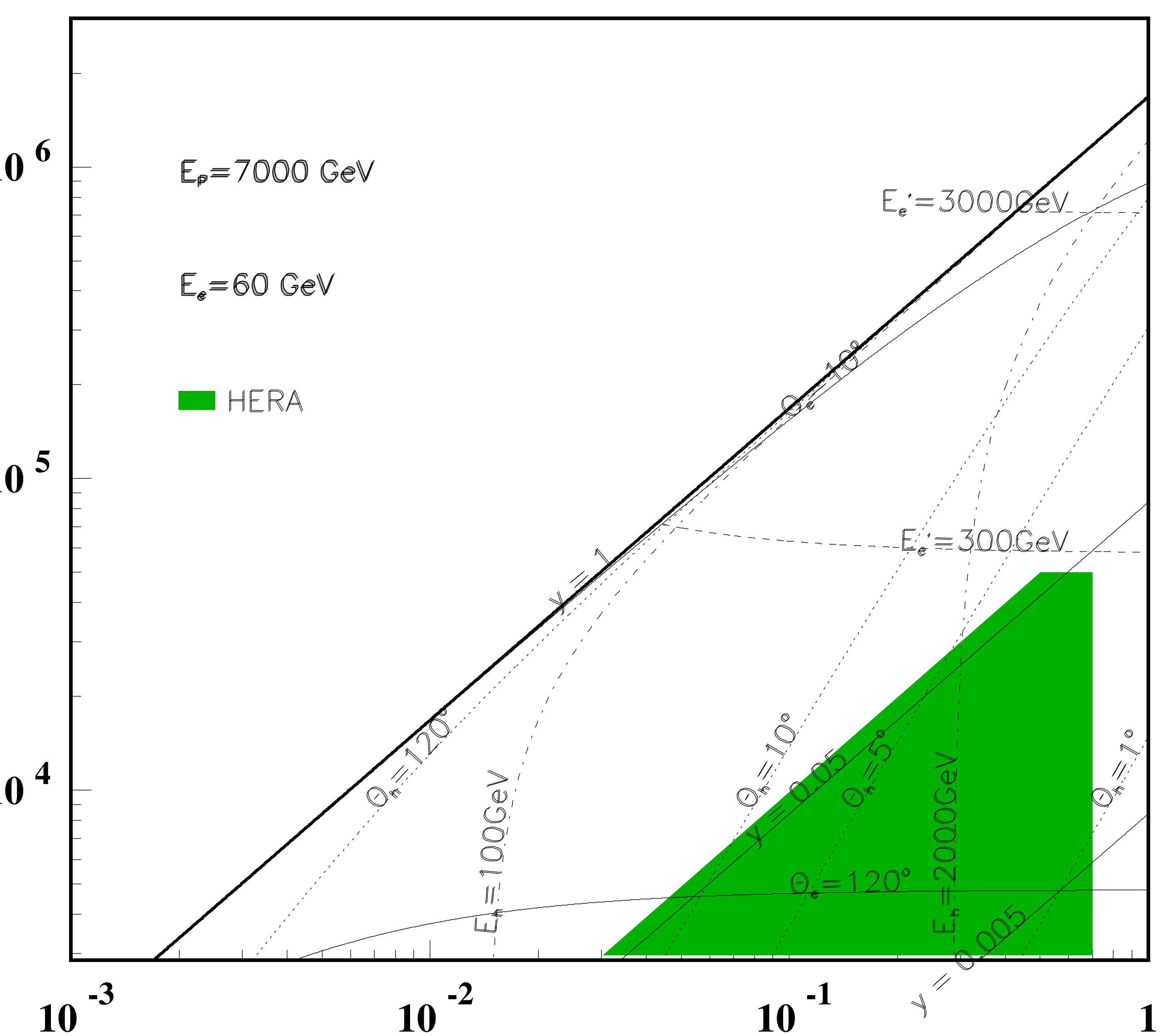
New Terascale Facility

- Electrons of 60-140 GeV collide with LHC protons of 7000 GeV
- ep design $L \approx 10^{33}$ cm^{-2}s^{-1} with E_{cms} in the range of 1-2 TeV
  - exceeding the integrated luminosity at HERA by 2 orders of magnitude and the kinematic range by a factor of 20 in (Q^2; x^{-1})

LHeC - Low x Kinematics



LHeC - High Q^2 Kinematics



Q^2 = 4momentum transfer^2 x = Bjorken x: fraction of p's momentum

Exciting Physics Program

- Electrons of 60-140 GeV collide with LHC protons of 7000 GeV

- ep design $L \approx 10^{33}$ cm^{-2}s^{-1} with E_{cms} in the range of 1-2 TeV
  - exceeding the integrated luminosity at HERA by 2 orders of magnitude and the kinematic range by a factor of 20 in (Q^2; x^{-1})

- Physics complementing the LHC

- High precision deep inelastic scattering (DIS)

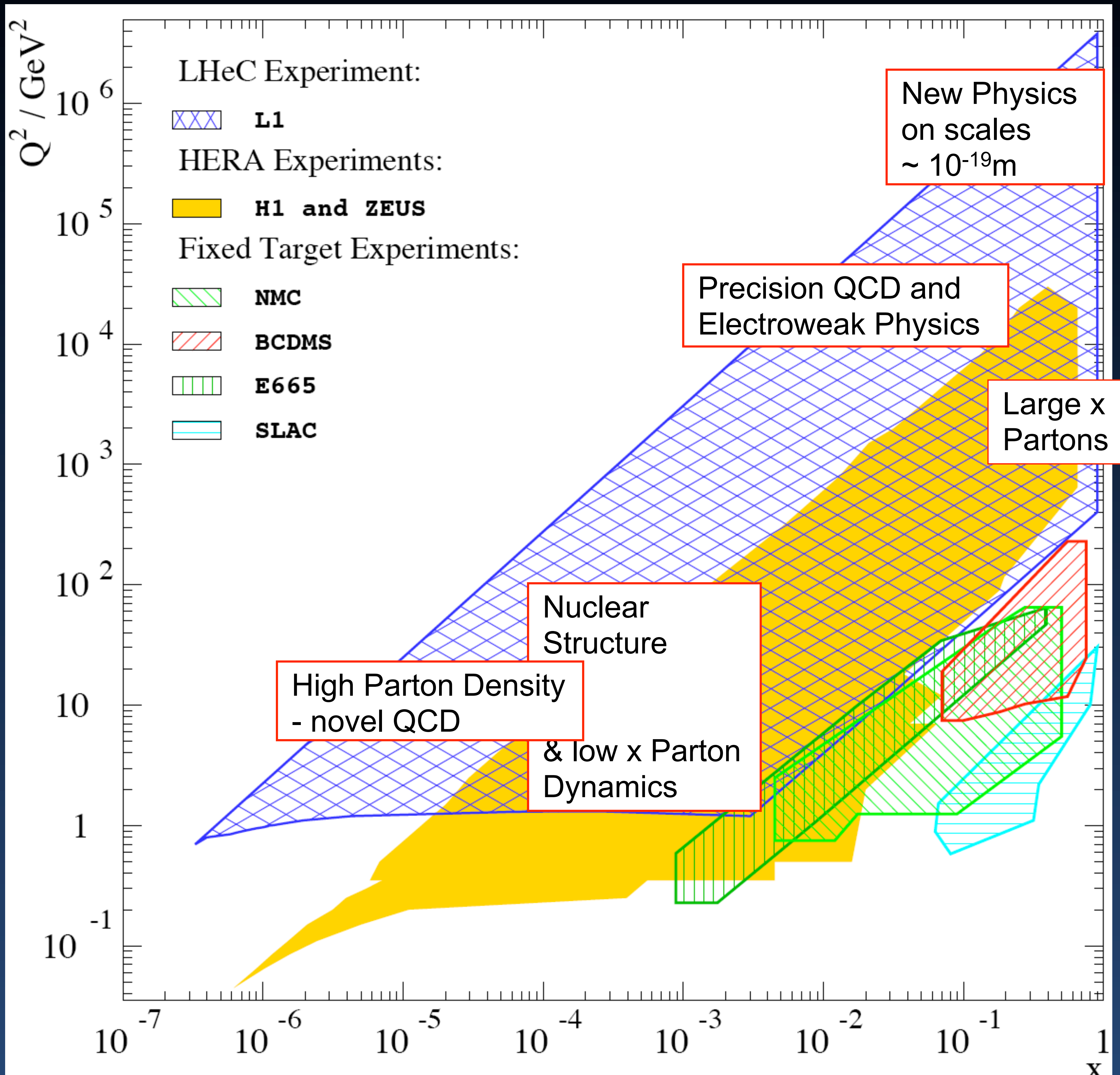
- Address important questions in strong and electroweak interactions

- Includes electron-ion (eA) scattering into a (Q^2; x^{-1}) 4 orders of magnitude extended compared to previous lepton-nucleus DIS experiments.

Selected Highlights

- α_s measured to per mille
  → Grand unification of the couplings
- Complete unfolding of proton structure
  → Maximise the potential of LHC
- Saturation at low x
  → Study in pQCD regime
- eA - nuclear structure functions
  → Complementary to e.g. EIC
- Heavy flavour factory, precision tests of the treatment of mass in pQCD
  → Understand the fits
- Leptoquarks, excited electrons, Higgs
  → Complementary to LHC searches

Deep Inelastic e/μ p Scattering



Q^2 = 4momentum transfer^2

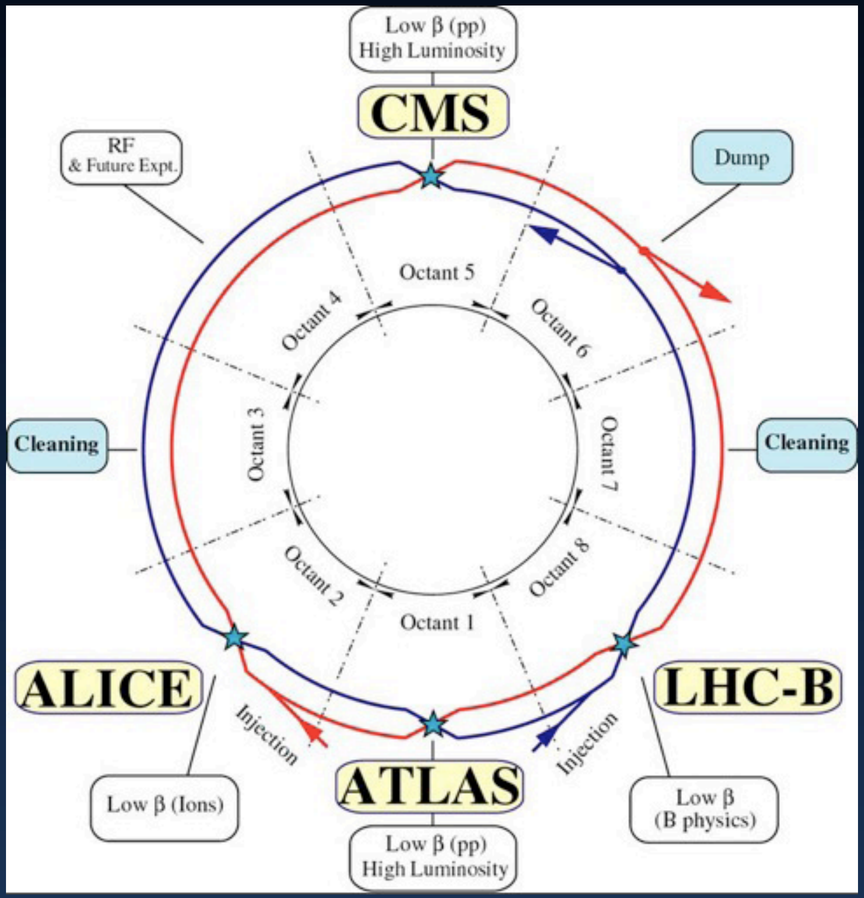
x = Bjorken x: fraction of p's momentum

Physics

- eQ states
- GUT ($\delta\alpha_s$=0.1%)
- Excited fermions
- Hot/cold spots
- Single top Higgs
- PDFs
- Multi-Jets
- DVCS
- Unintegrated partons
- Saturation
- Vector Mesons
- IP - graviton
- Odderons
- NC couplings
- $\sin^2\Theta$
- Beauty
- Charm
- Partons in nuclei
- Shadowing
- ….

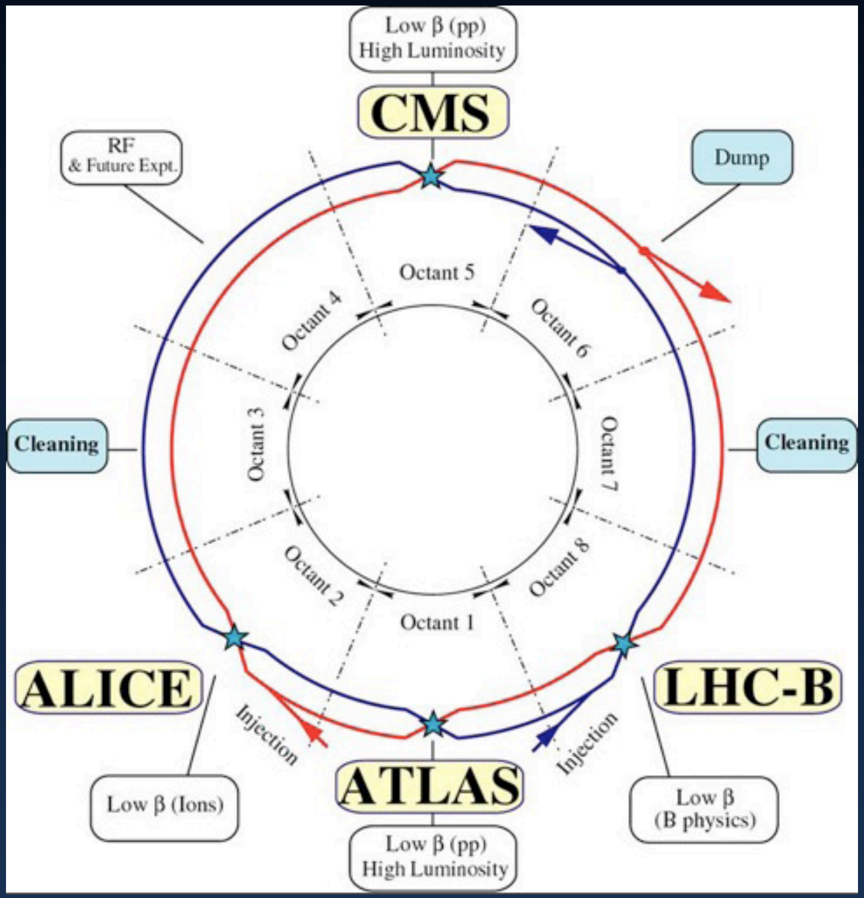
Accelerator Concept(s)

LH C



Accelerator Concept(s)

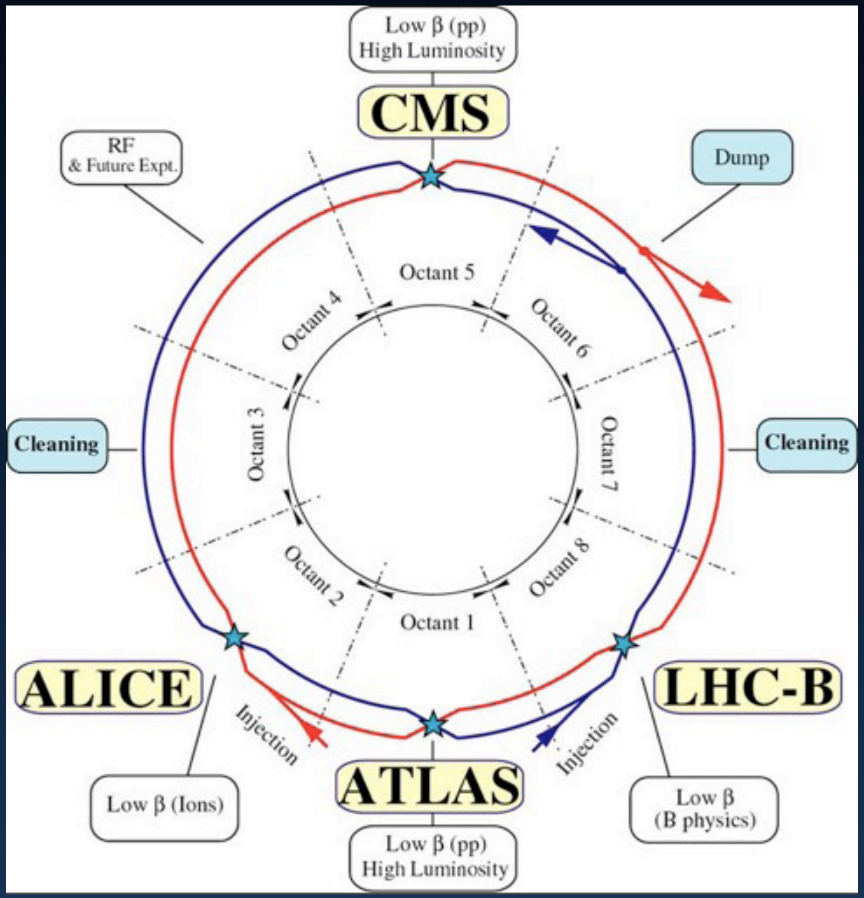
LHeC



Add e$^{\mp}$ (polarised) on genuine p/A beams and running **simultaneously** with LHC program

Accelerator Concept(s)

LHeC

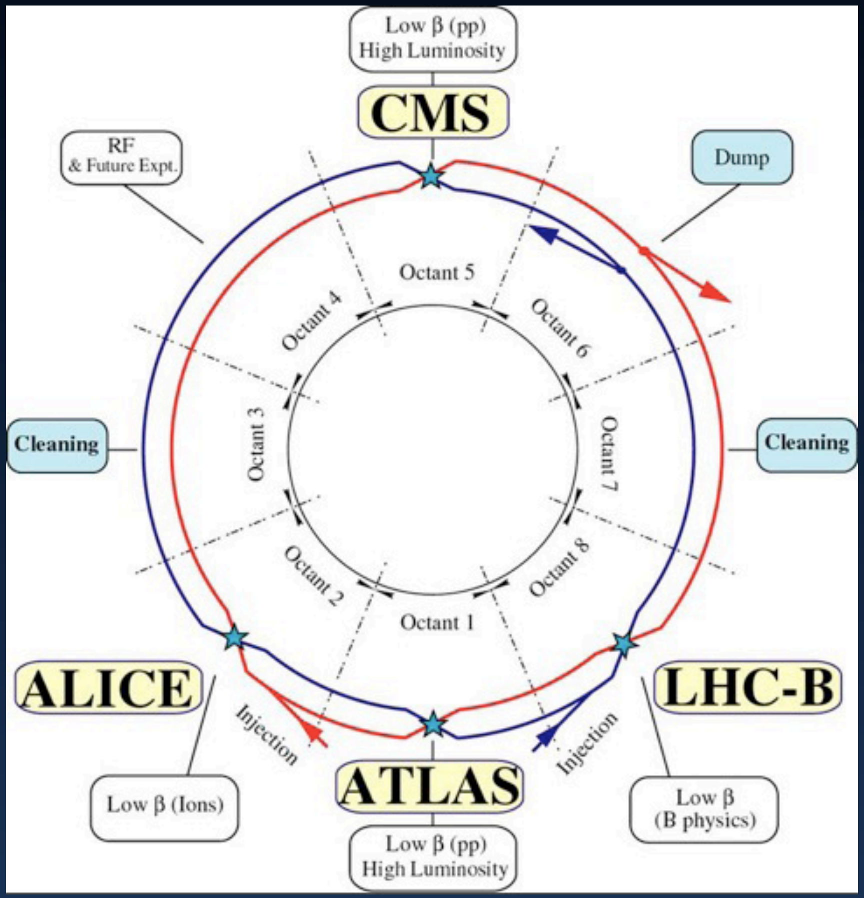


Add e$^{\mp}$ (polarised) on genuine p/A beams and running **simultaneously** with LHC program

Ring-Ring (RR)
First considered 1984: LEP x LHC
Difficulties:
building e ring into LHC tunnel,
synchrotron radiation and
limitations of energy

Accelerator Concept(s)

LHeC



Add e$^{\mp}$ (polarised) on genuine p/A beams and running **simultaneously** with LHC program

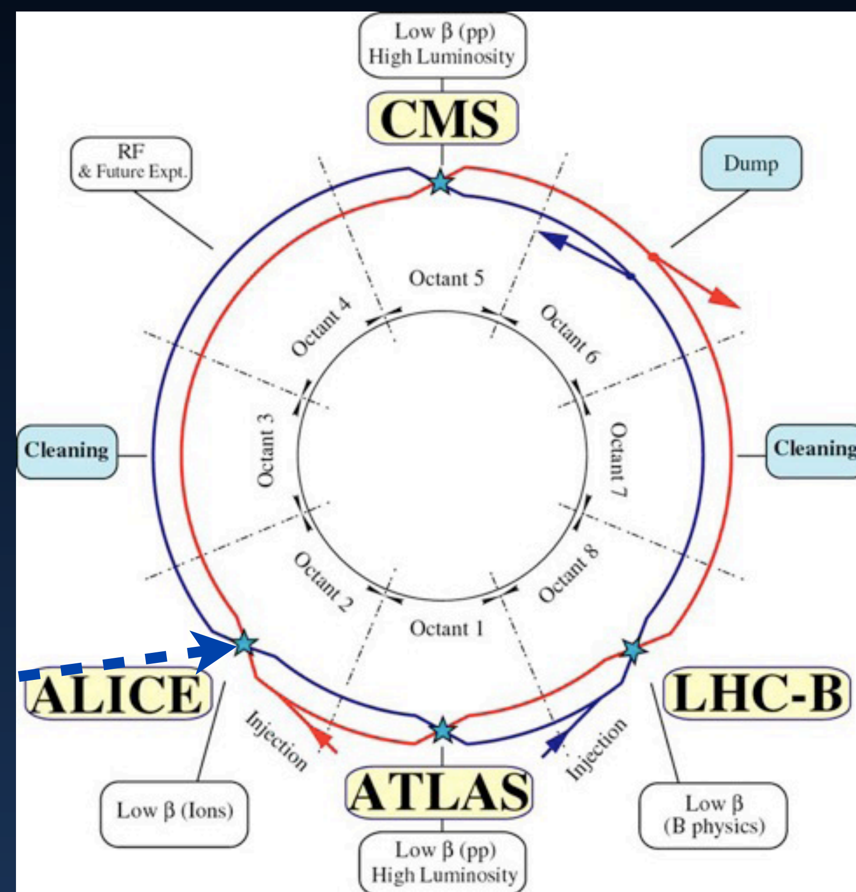
Ring-Ring (RR)
First considered 1984: LEP x LHC
Difficulties:
building e ring into LHC tunnel,
synchrotron radiation and
limitations of energy

Linac-Ring (LR)
THera (DESY)
low interference with LHC,
higher electron energy,
lower lumi at reasonable power

Accelerator Concept(s)

LHeC

Assuming that ep collisions take place at point IP2 which currently houses the ALICE experiment



IP2

Add $e^{\mp}$ (polarised) on genuine p/A beams and running **simultaneously** with LHC program

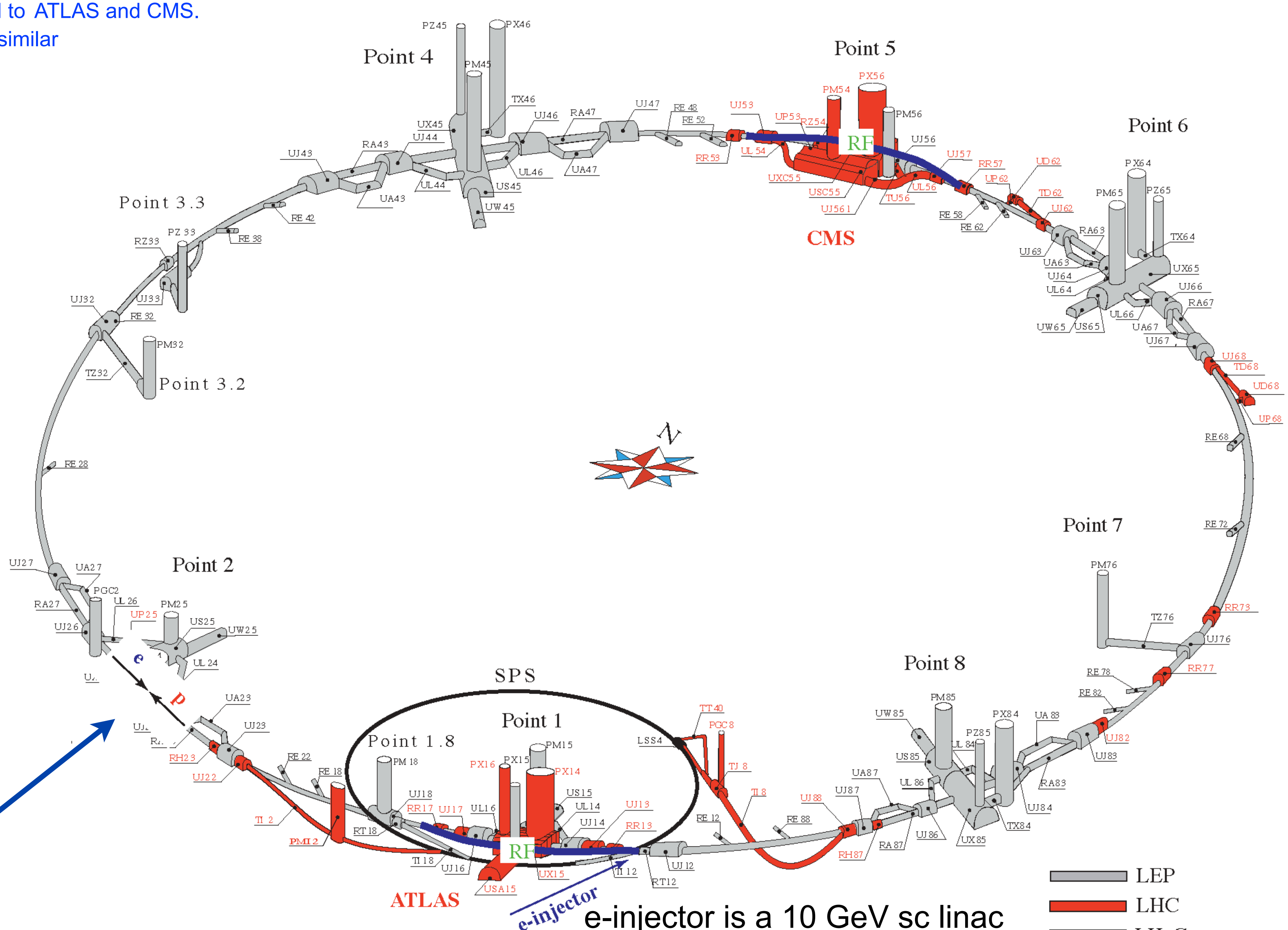
Ring-Ring (RR)
First considered 1984: LEP x LHC
Difficulties:
building e ring into LHC tunnel,
synchrotron radiation and
limitations of energy

Linac-Ring (LR)
THera (DESY)
low interference with LHC,
higher electron energy,
lower lumi at reasonable power

The LHeC Ring-Ring

For the CDR the bypass concepts were decided to be confined to ATLAS and CMS. LHCb bypass may be similar

Challenging: bypassing the main LHC Detectors



IP2

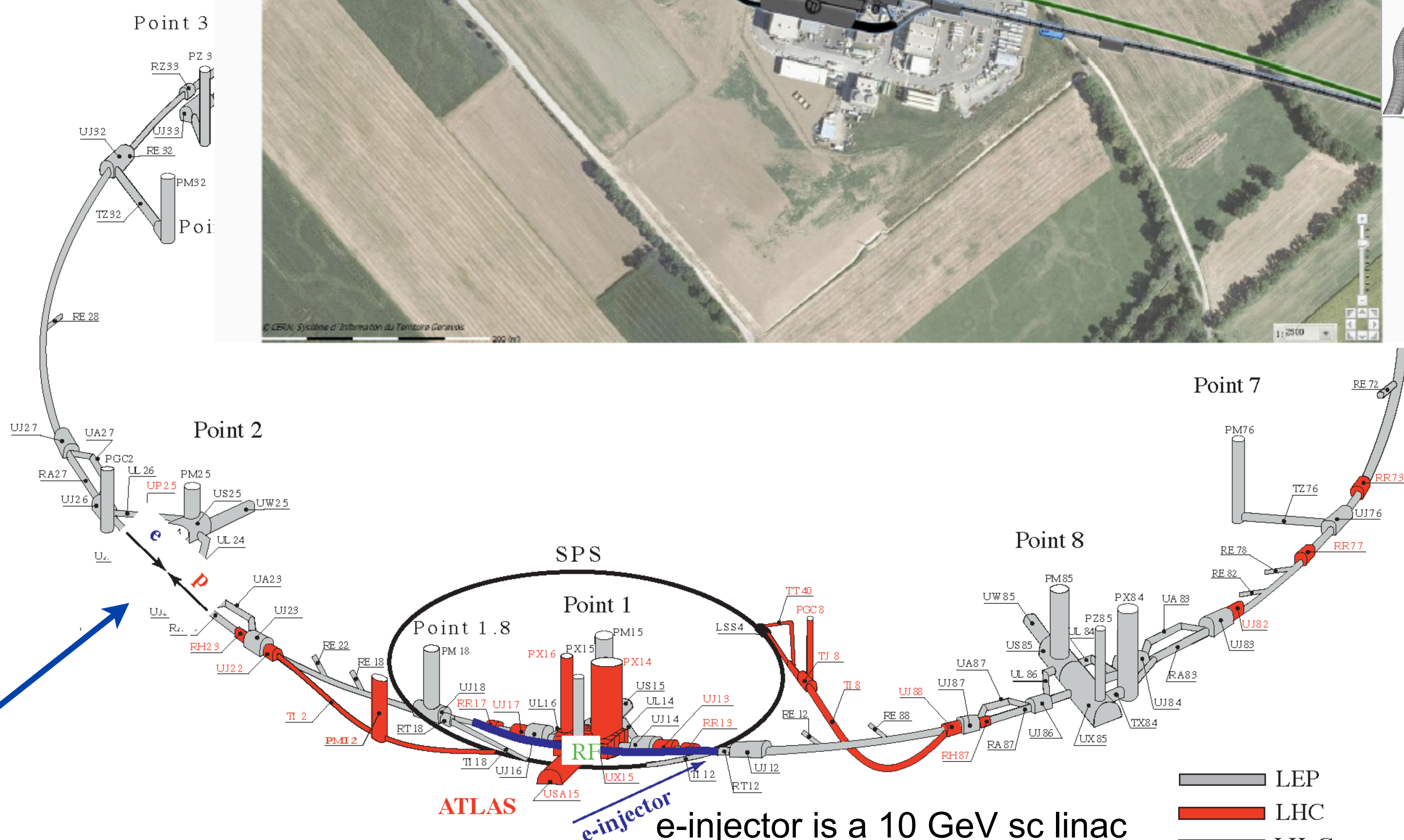
e-injector is a 10 GeV sc linac in triple racetrack configuration

Figure 7.1: Schematic Layout of the LHeC: In grey the LEP tunnel now used for the LHC, in red the LHC extensions. The two LHeC bypasses are shown in blue. The RF is installed in the central straight section of the two bypasses. The bypass around Point 1 hosts in addition the injection.

The LHeC Ring-Ring

Bypassing CMS: 20m distance to Cavern

For the CDR the bypass concepts were decided to be confined to ATLAS and CMS
LHCb bypass may be similar



IP2

e-injector is a 10 GeV sc linac
in triple racetrack configuration

Figure 7.1: Schematic Layout of the LHeC: In grey the LEP tunnel now used for the LHC, in red the LHC extensions. The two LHeC bypasses are shown in blue. The RF is installed in the central straight section of the two bypasses. The bypass around Point 1 hosts in addition the injection.

The LHeC Ring-Ring

Bypassing CMS: 20m distance to Cavern

For the CDR the bypass concepts were decided to be confined to ATLAS and CMS
LHCb bypass may be similar

IP2

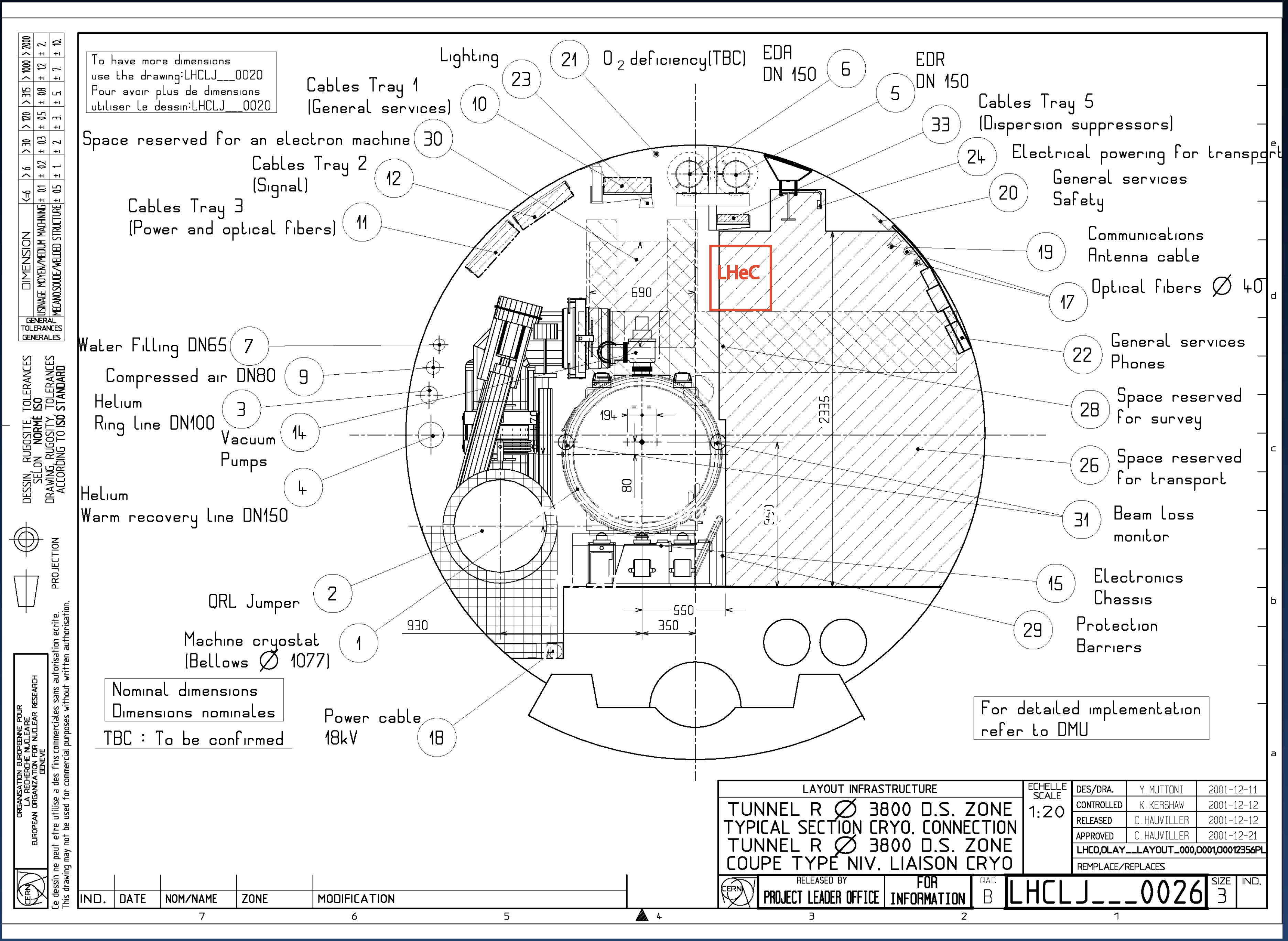
Bypassing ATLAS: 100m wo survey gallery

Figure 7.1: Schematic Layout of the LHeC: In grey the LEP tunnel now used for the LHC, in red the LHC extensions. The two LHeC bypasses are shown in blue. The RF is installed in the central straight section of the two bypasses. The bypass around Point 1 hosts in addition the injection.

The LHeC Ring-Ring

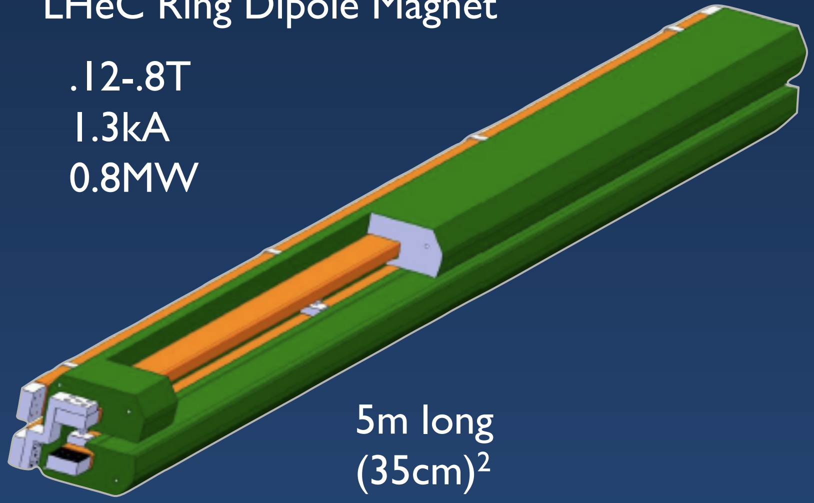
Challenging: Installation with LHC circumference

requires:
support structure with
efficient installation and
compact magnets (Novosibirsk, CERN dipole-prototypes)



LHeC Ring Dipole Magnet

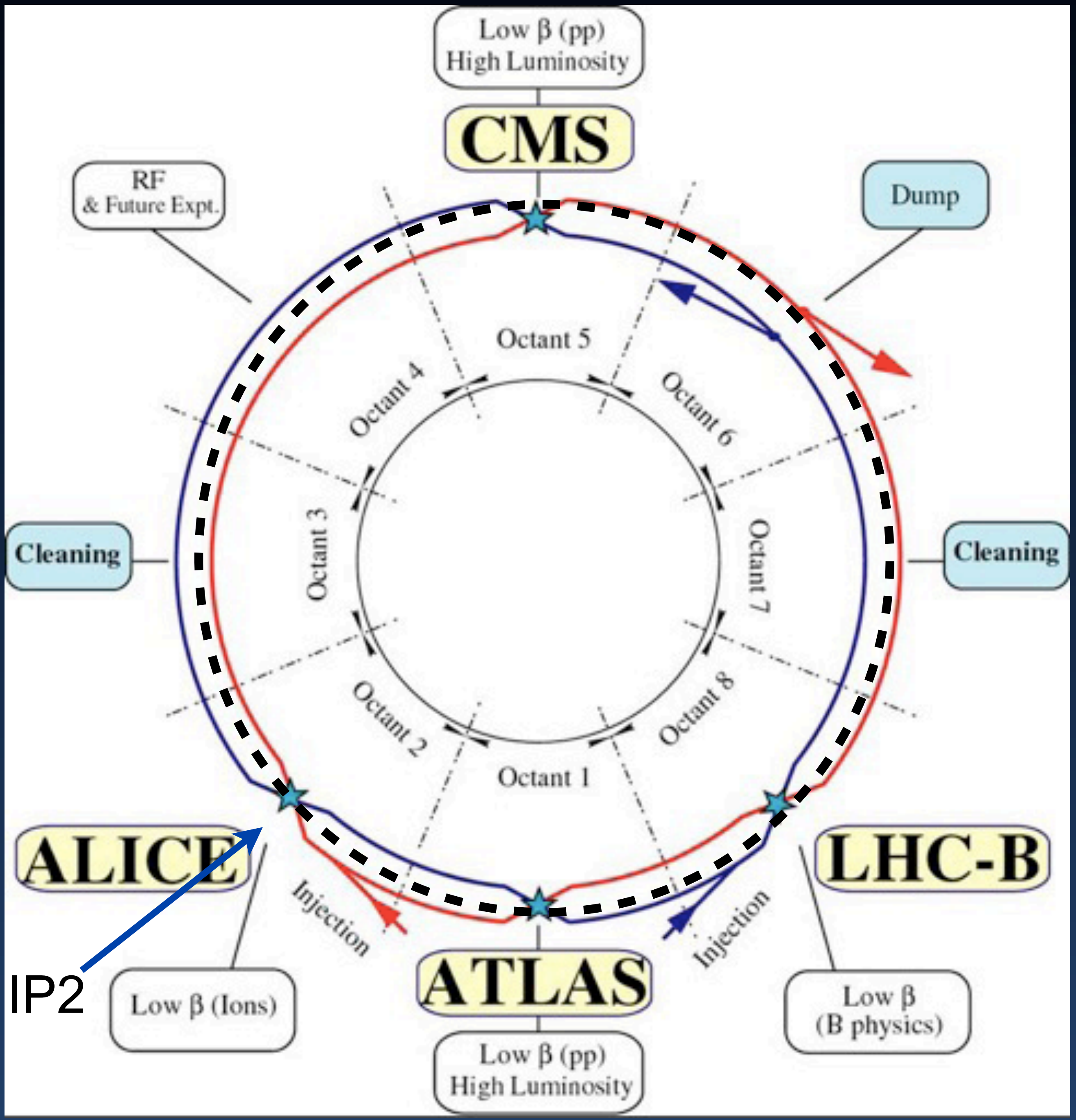
.12-.8T
1.3kA
0.8MW



5m long
$(35cm)^2$
slim + light
for installation

The LHeC Ring-Ring

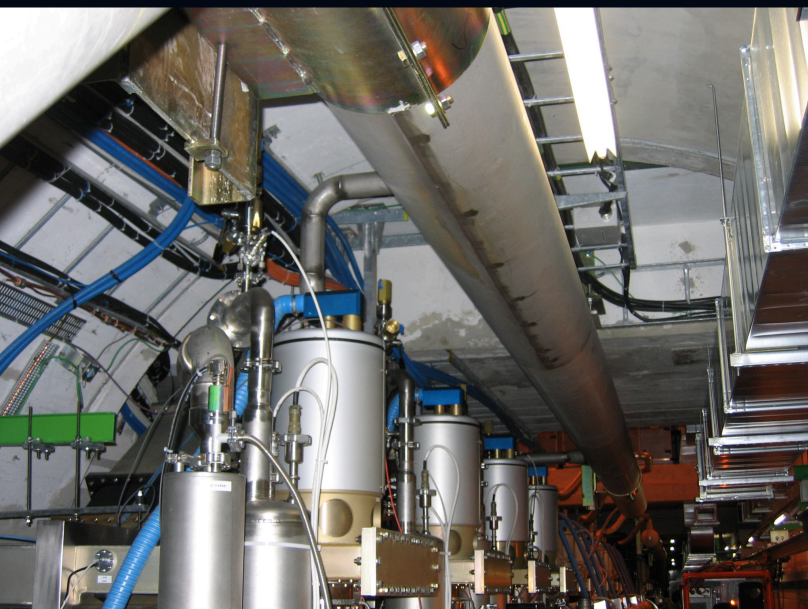
Integration in the LHC tunnel

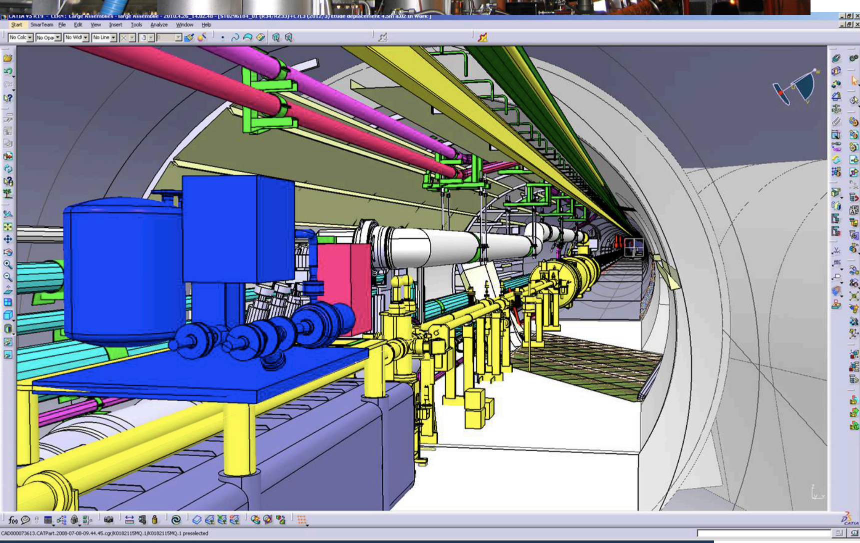


The LHeC Ring-Ring

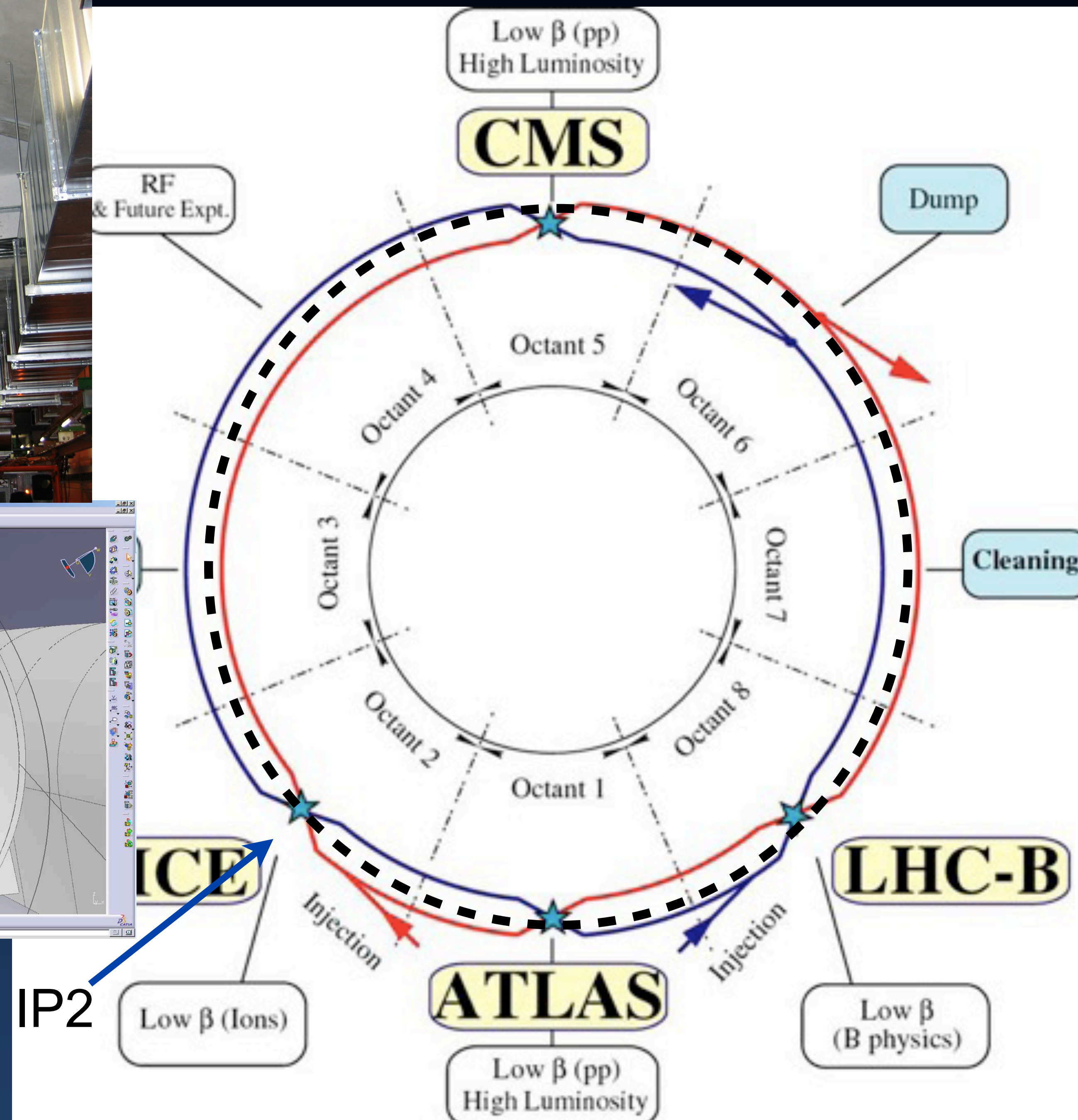
RF Installation in IR4

Integration in the LHC tunnel





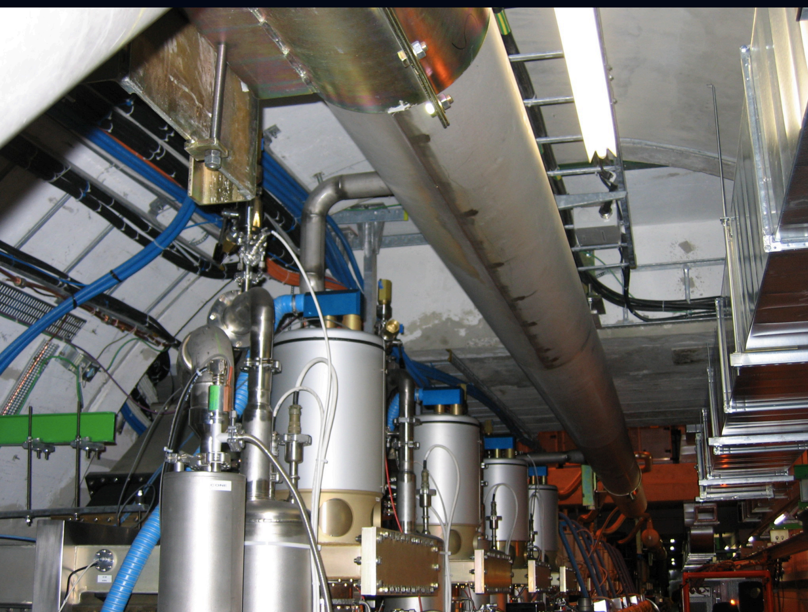
Cryo link in IR3

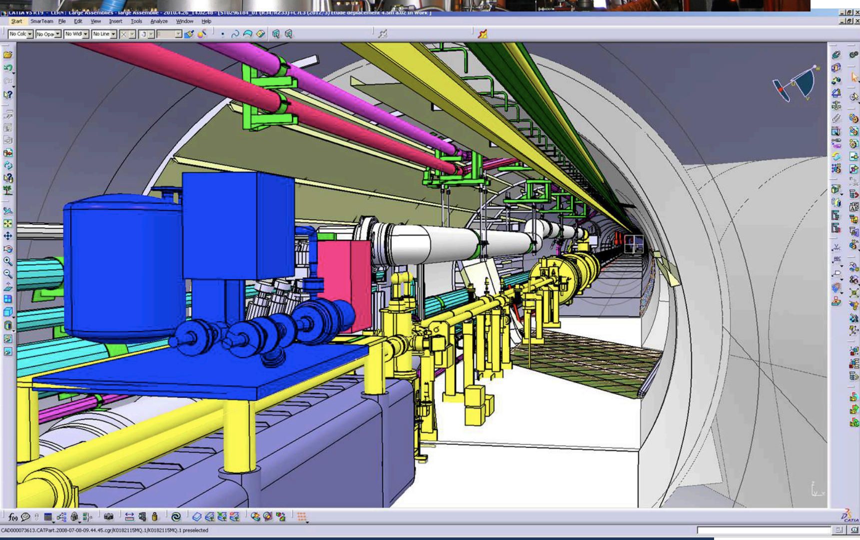


The LHeC Ring-Ring

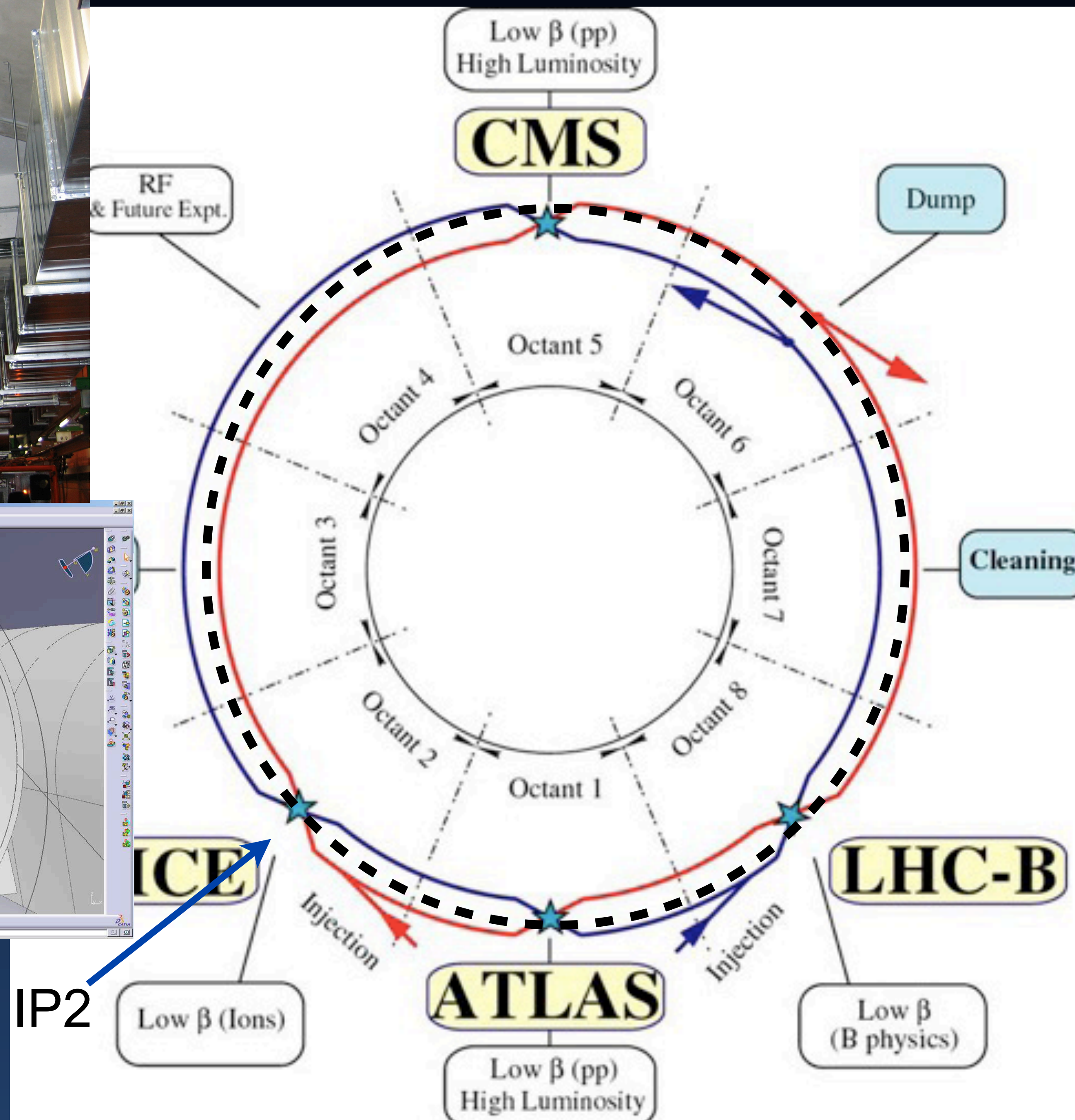
Integration in the LHC tunnel

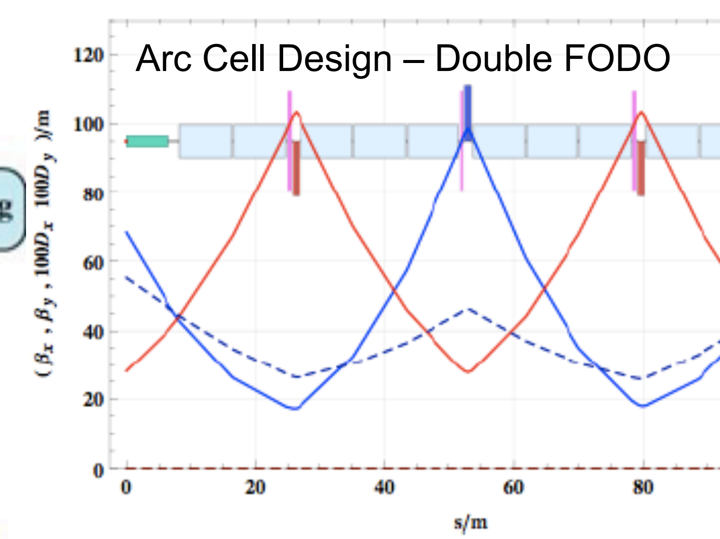
RF Installation in IR4





Cryo link in IR3





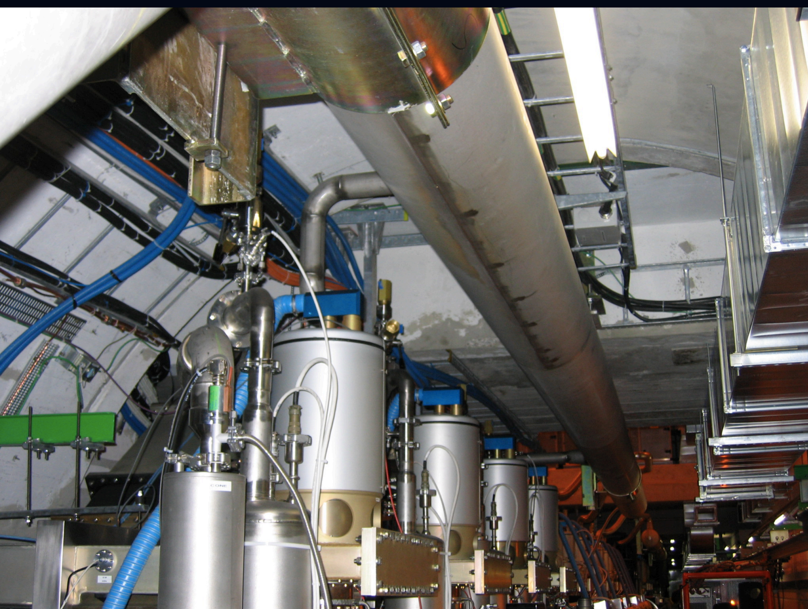
- No interference with LHC
- meets design parameters
- synchrotron radiation energy loss < 50 MW (maximum dipole filling)
- 2 quadrupoles families
- reasonable sextupole strength and length

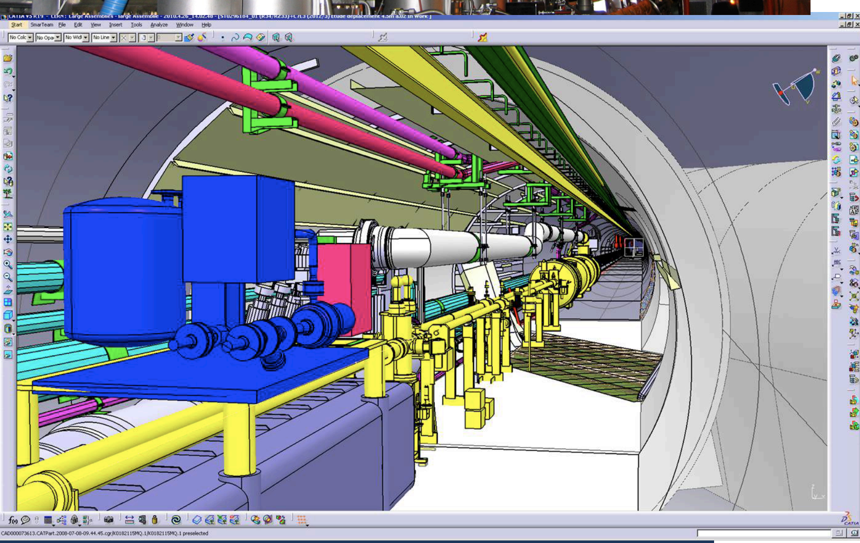
J.M. Jowett, LHeC Design Status, DIS2010, Florence, 22/4/2010

The LHeC Ring-Ring

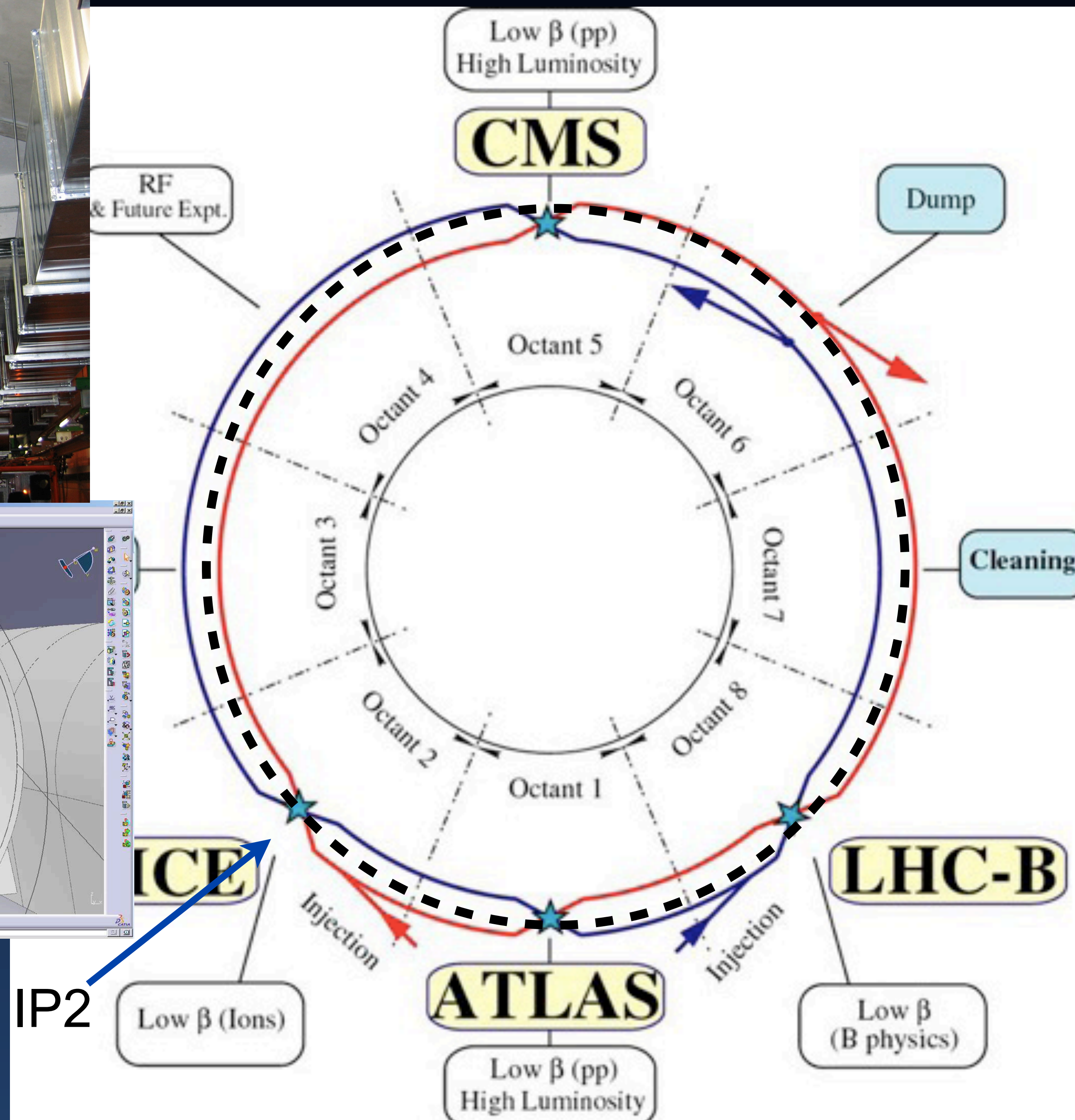
RF Installation in IR4

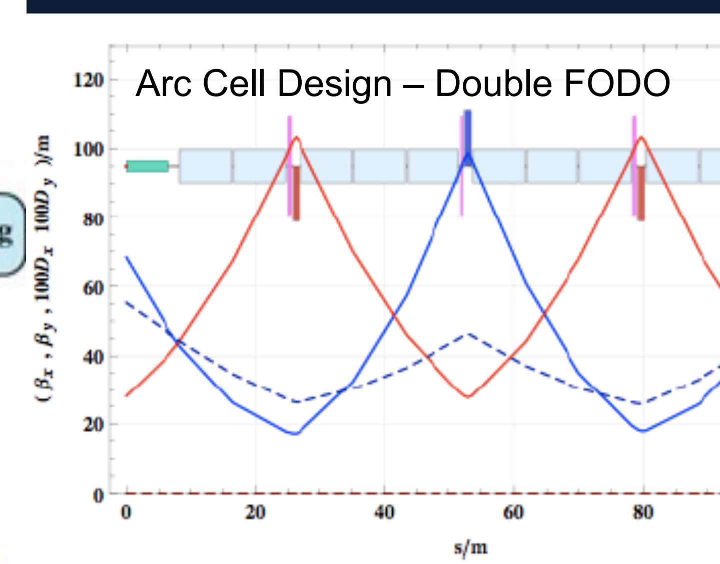
Integration in the LHC tunnel





Cryo link in IR3



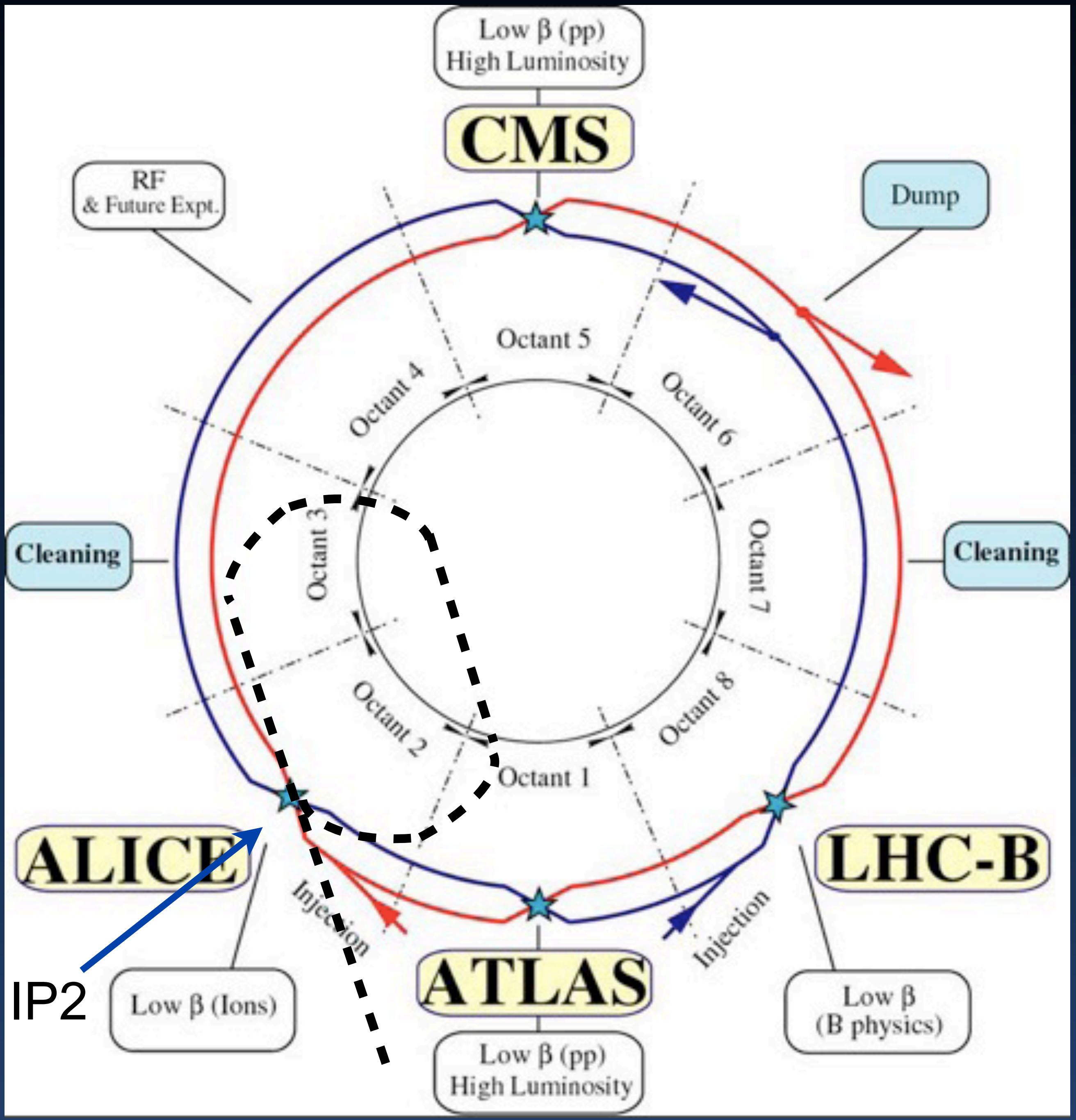


- No interference with LHC
- meets design parameters
- synchrotron radiation energy loss < 50 MW (maximum dipole filling)
- 2 quadrupoles families
- reasonable sextupole strength and length

J.M. Jowett, LHeC Design Status, DIS2010, Florence, 22/4/2010

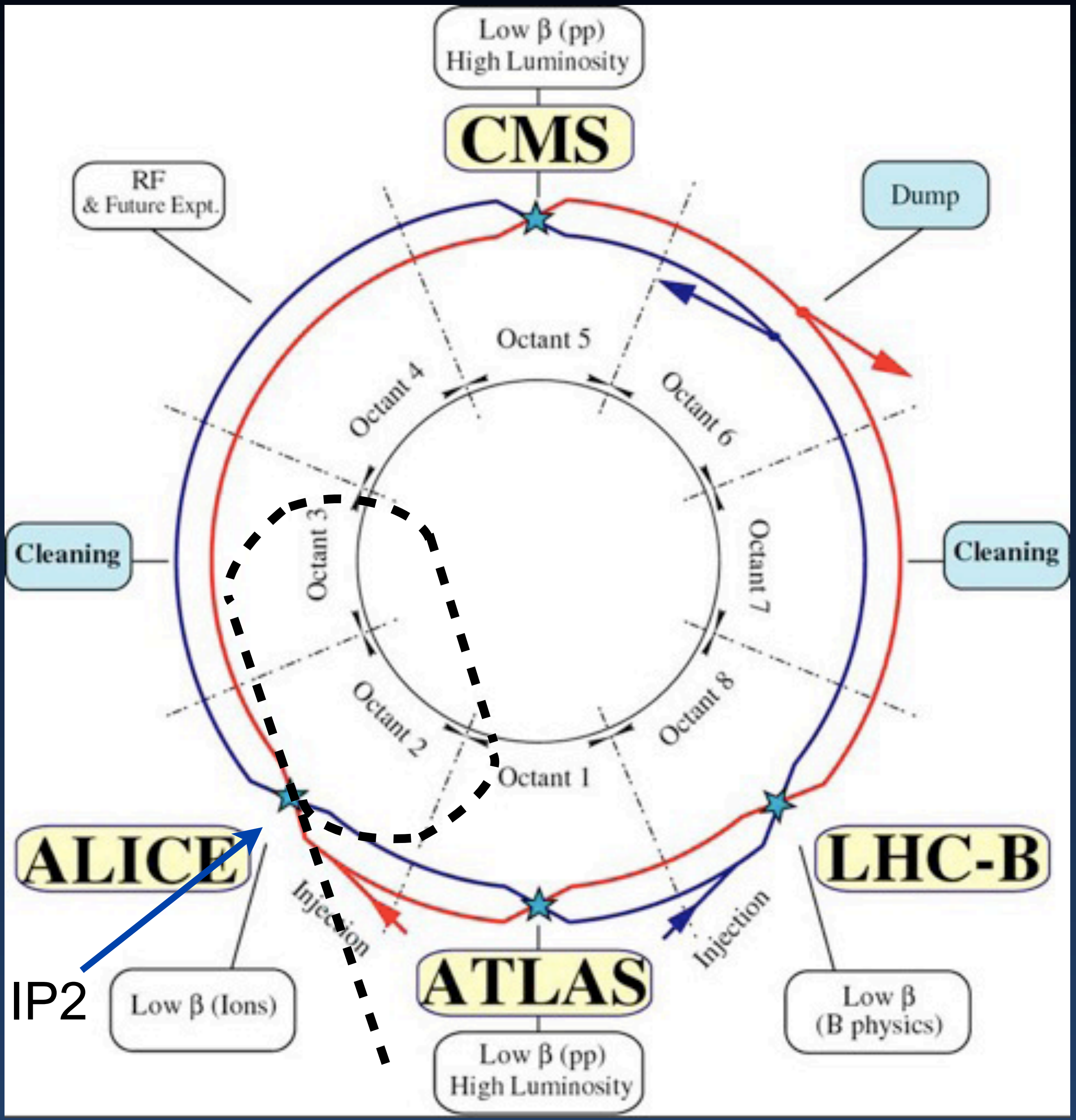
Maximum energy with the Ring-Ring arrangement could reach about 120 GeV
- however, many parameters to be extreme
  - rf power and synchrotron radiation effects increase $\propto E_e^4$

The LHeC Linac-Ring



The LHeC Linac-Ring

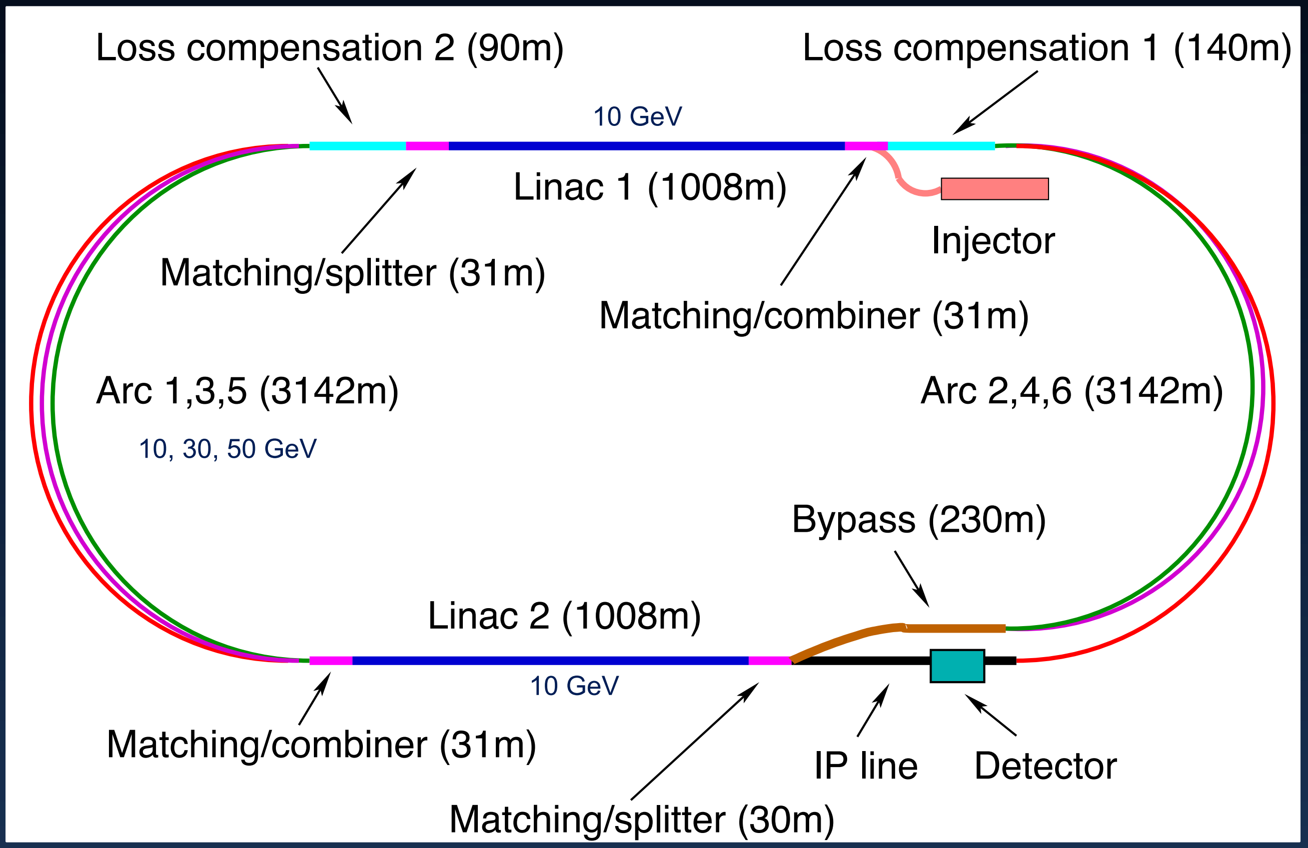
LR LHeC: recirculating linac with $e^{\mp}$ energy recovery, or straight linac*



**) bypassing own IP*

Baseline Linac-Ring Option

Super Conducting Linac with Energy Recovery & high current (> 6mA)

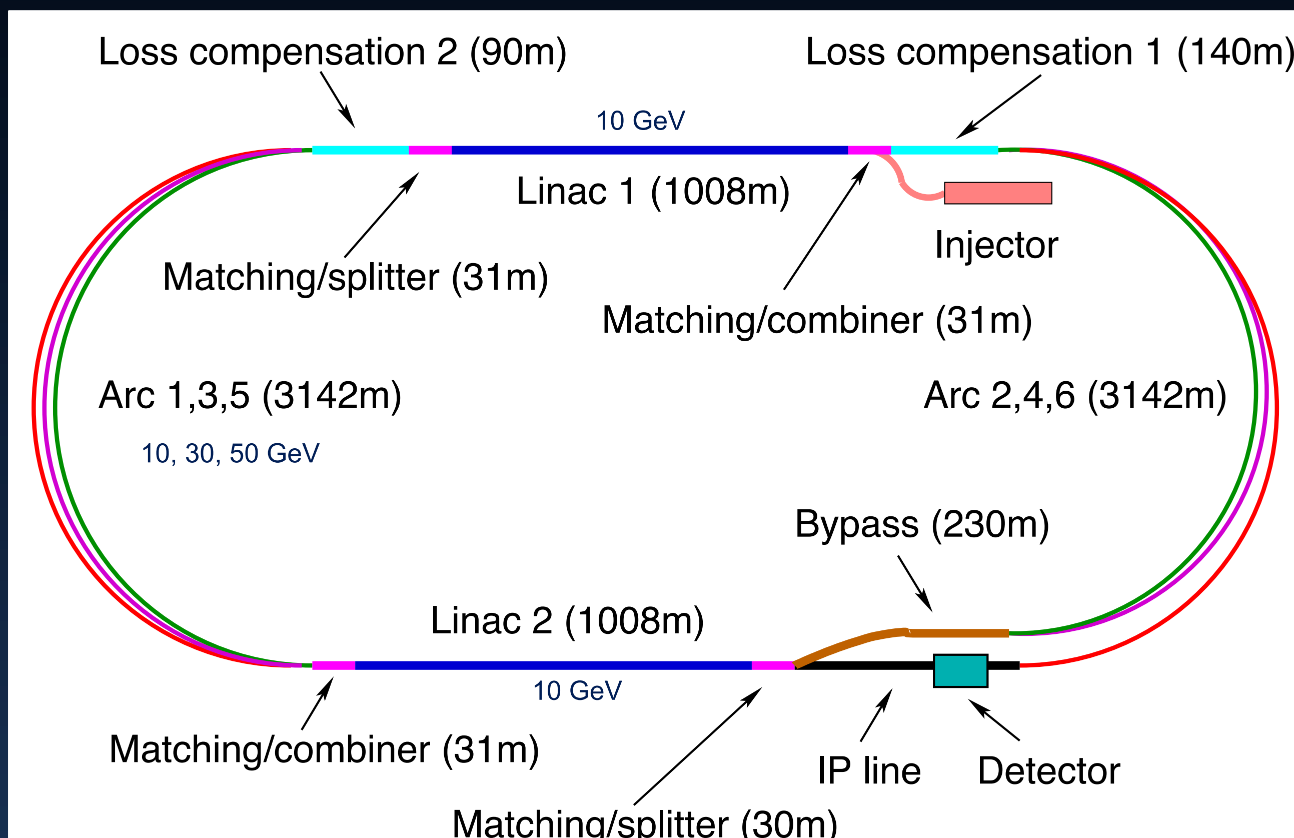


Two 1 km long sc Linacs (10GeV) in cw operation (Q ≈ 1010)

Relatively large return arcs
- ca. 9 km underground tunnel installation
- total of 19 km bending arcs
- same magnet design as for RR option: > 4500 magnets

Baseline Linac-Ring Option

Super Conducting Linac with Energy Recovery & high current (> 6mA)



Two 1 km long sc Linacs (10GeV)
in cw operation (Q ≈ 1010)

Relatively large return arcs
- ca. 9 km underground tunnel installation
- total of 19 km bending arcs
- same magnet design as for RR option: > 4500 magnets

required for high luminosity, the linac must be based on superconducting (SC) radiofrequency (RF) technology. The development and industrial production of its components can exploit synergies with numerous other advancing SC-RF projects around the world, such as the DESY XFEL, eRHIC, ESS, ILC, CEBAF upgrade, CESR-ERL, JLAMP, and the CERN HP-SPL.

g CERN

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)

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)

RR: electrons beam circulates in the existing LHC tunnel

LR: less invasive with respect to the existing LHC, needs the construction of a new linear accelerator complex

LR Interaction Region

Special attention is devoted to the interaction region design, which comprises beam bending, direct and secondary synchrotron radiation, vacuum and beam pipe demands.

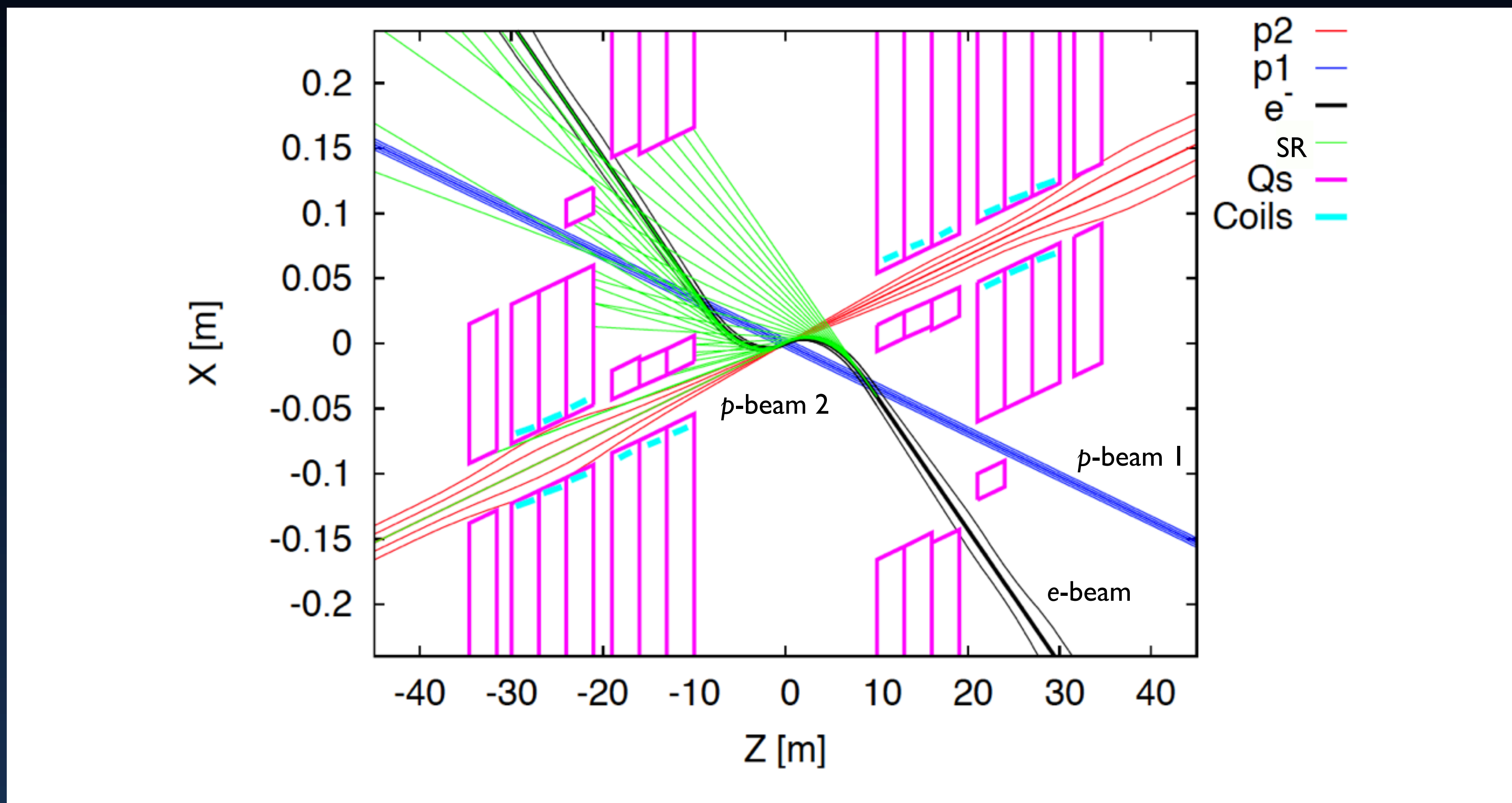
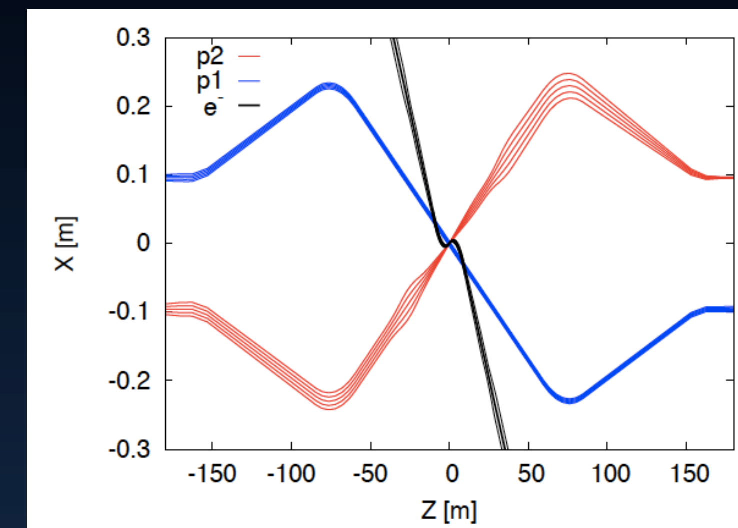
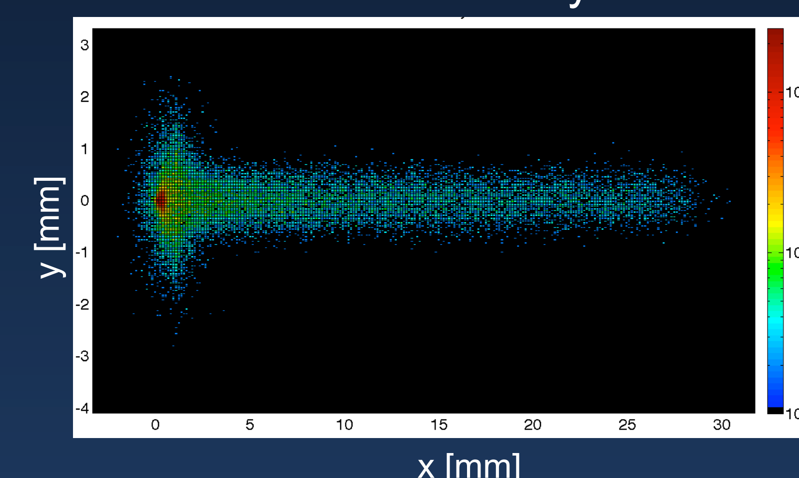


Figure 9.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam trajectories with 5σ and 10σ envelopes are shown.

3 beams, head-on collisions



Photon Number Density at the IP



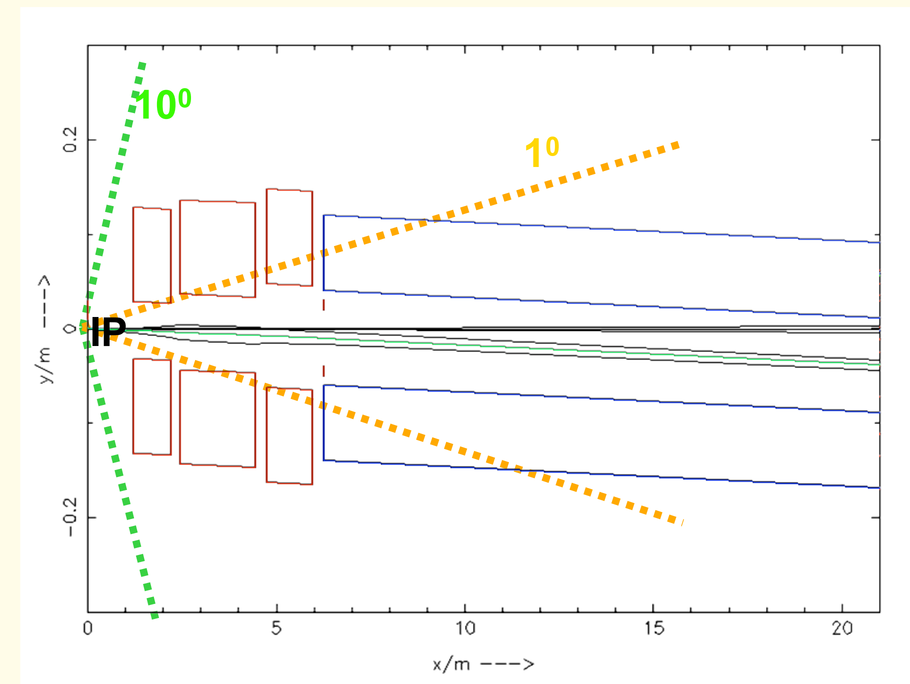
- Dipoles around the IP (2 x 9m, 0.3T)
  make electrons collide head-on with *p-beam 2* & safely extract the disrupted electron beam.

- Simulation of SR load in the IR and design of absorbers / masks
  shielding SR from backscattering into the detector & from propagating with $e^{\pm}$ beam.

- Beam pipe design - space for SR fan - tracking/calorimetry close to the IP / beam line (goal: 1°-179°)

RR Beam Optics and Detector Acceptance

- High Acceptance
  first e beam magnet placed at z= ±6.2m
  L ~ 7.3 x 10^{32} cm^{-2} s^{-1} (1° < θ < 179°)



- L ~ 1.3 x 10^{33} cm^{-2} s^{-1} (10° < θ < 170°)
  High Luminosity
  Low β* magnets near the IP (HERA2) (at z= ±1.2m)

- Detector flexible accommodating both HA / HL
  (forward / backward tracker & calorimeter end-caps)

RR: 1mrad crossing angle (25ns bunch spacing; avoiding parasitic interactions);
LR: head on (but dipoles for beam separation over full detector length + beyond)

Consequences on detector design:

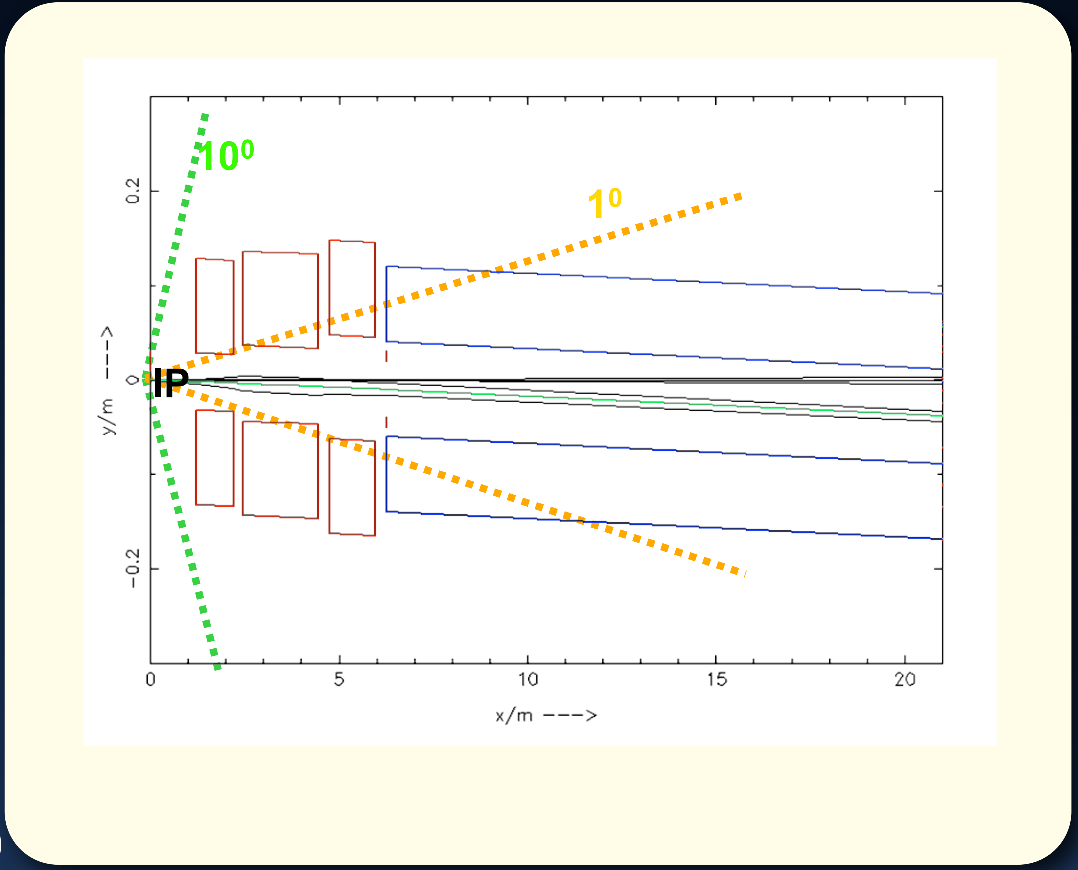
- RR Lower Lumi, Low Q^2 access → High Acceptance detector 1° - 179°
- RR Higher Lumi, High Q^2 access → High Luminosity detector 10° - 170° aperture

RR Beam Optics and Detector Acceptance

- High Acceptance
  first e beam magnet placed at z= ±6.2m
  L ~ 7.3 x 10^{32} cm^{-2} s^{-1} (1° < θ < 179°)

  ↕ factor ~ 2 only

- L ~ 1.3 x 10^{33} cm^{-2} s^{-1} (10° < θ < 170°)
  High Luminosity
  Low β^* magnets near the IP (HERA2) (at z= ±1.2m)



- Detector flexible accommodating both HA / HL
  (forward / backward tracker & calorimeter end-caps)

RR: 1mrad crossing angle (25ns bunch spacing; avoiding parasitic interactions);
LR: head on (but dipoles for beam separation over full detector length + beyond)

Consequences on detector design:

- RR Lower Lumi, Low Q^2 access → High Acceptance detector 1° - 179°
- RR Higher Lumi, High Q^2 access → High Luminosity detector 10° - 170° aperture

The LHeC Detector Concept(s)

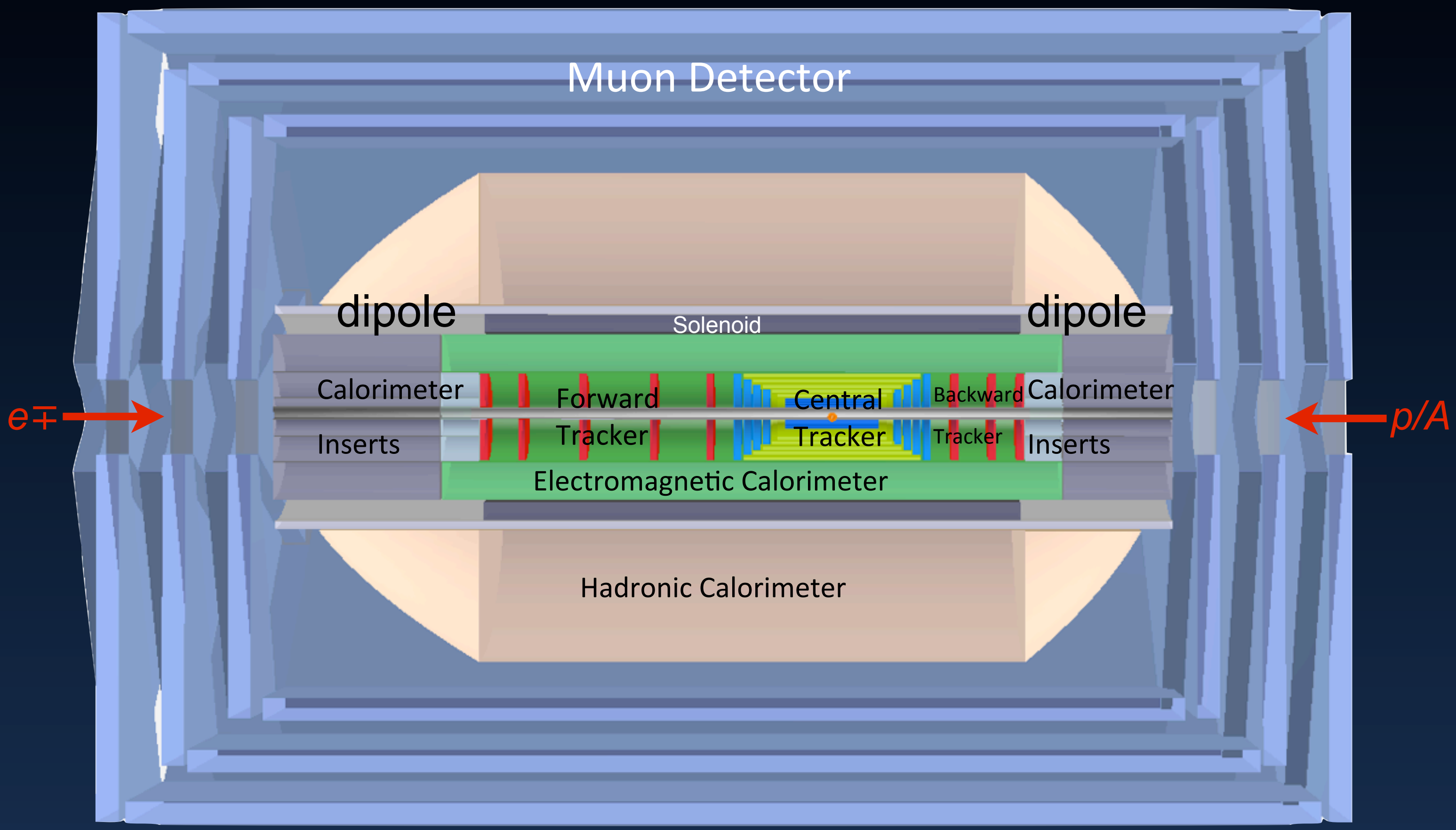
- High Precision
  resolution, calibration, low noise at low y, tagging of b,c;
  based on the recent detector developments, using settled technology,
  avoiding R&D programs.

- Modular and flexible - accommodating the HA/HL physics programs (RR);
  High modularity - “fast” detector construction above ground; access.

- Small radius and thin beam pipe optimized in view of aperture
  (1-179^{o} acceptance for low Q^2, high x access),
  synchrotron radiation and background production.

- Affordable - comparatively reasonable cost.

Detector Options - 1

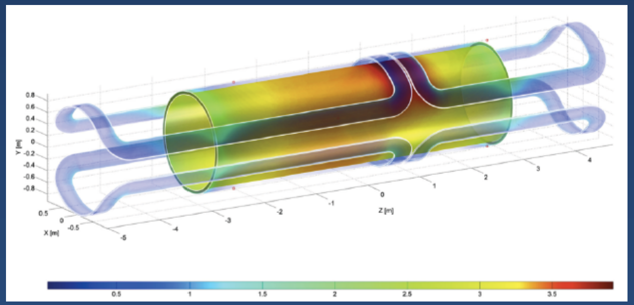


LR detector in the r-z plane
dipole (radius ~0.6m, 0.3T) and solenoid (3.5T) placement
between the electromagnetic and the hadronic calorimeters.

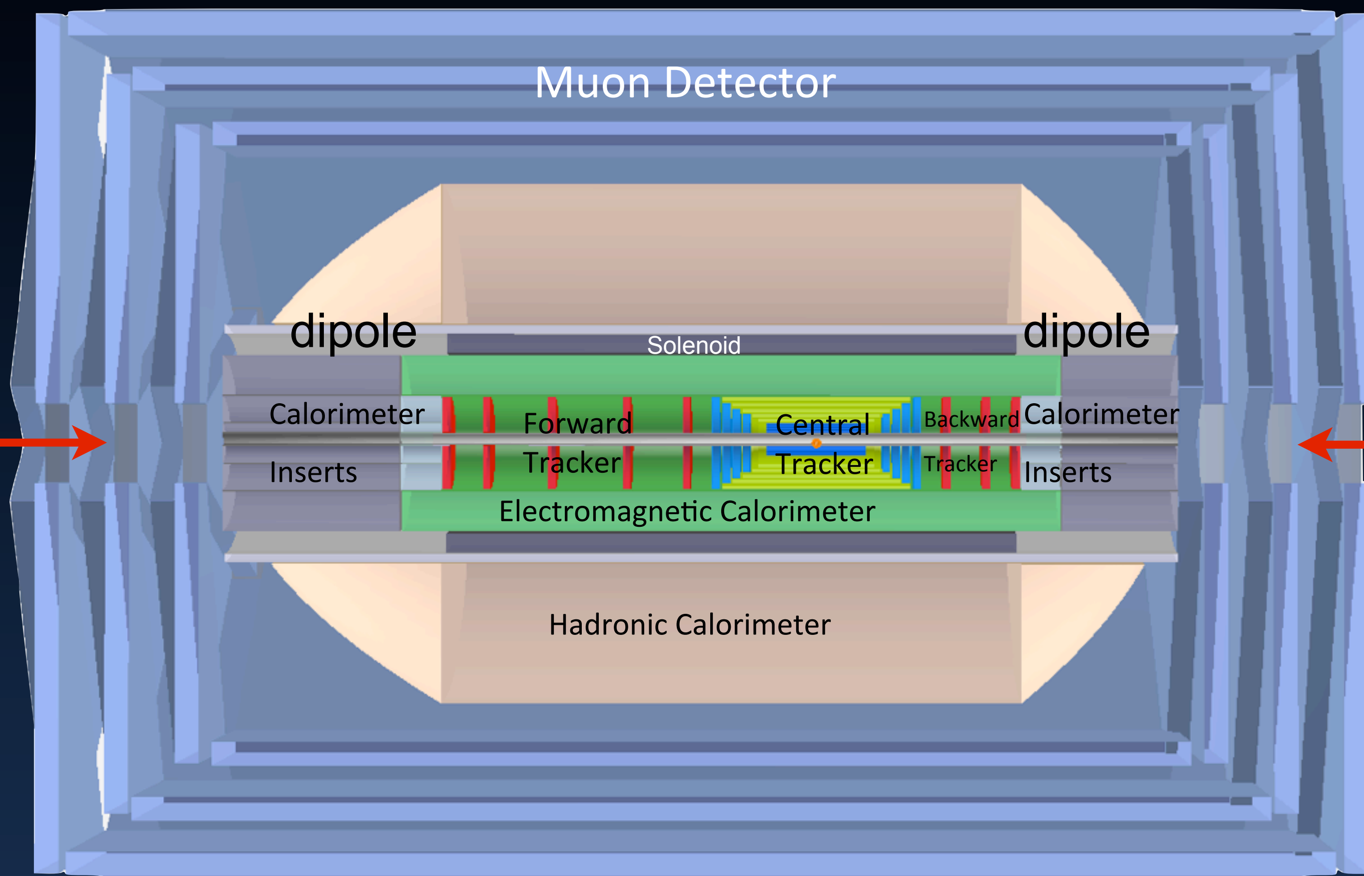
The IP is surrounded by a central tracker system,
large forward and backward tracker telescopes
and sets of calorimeters.

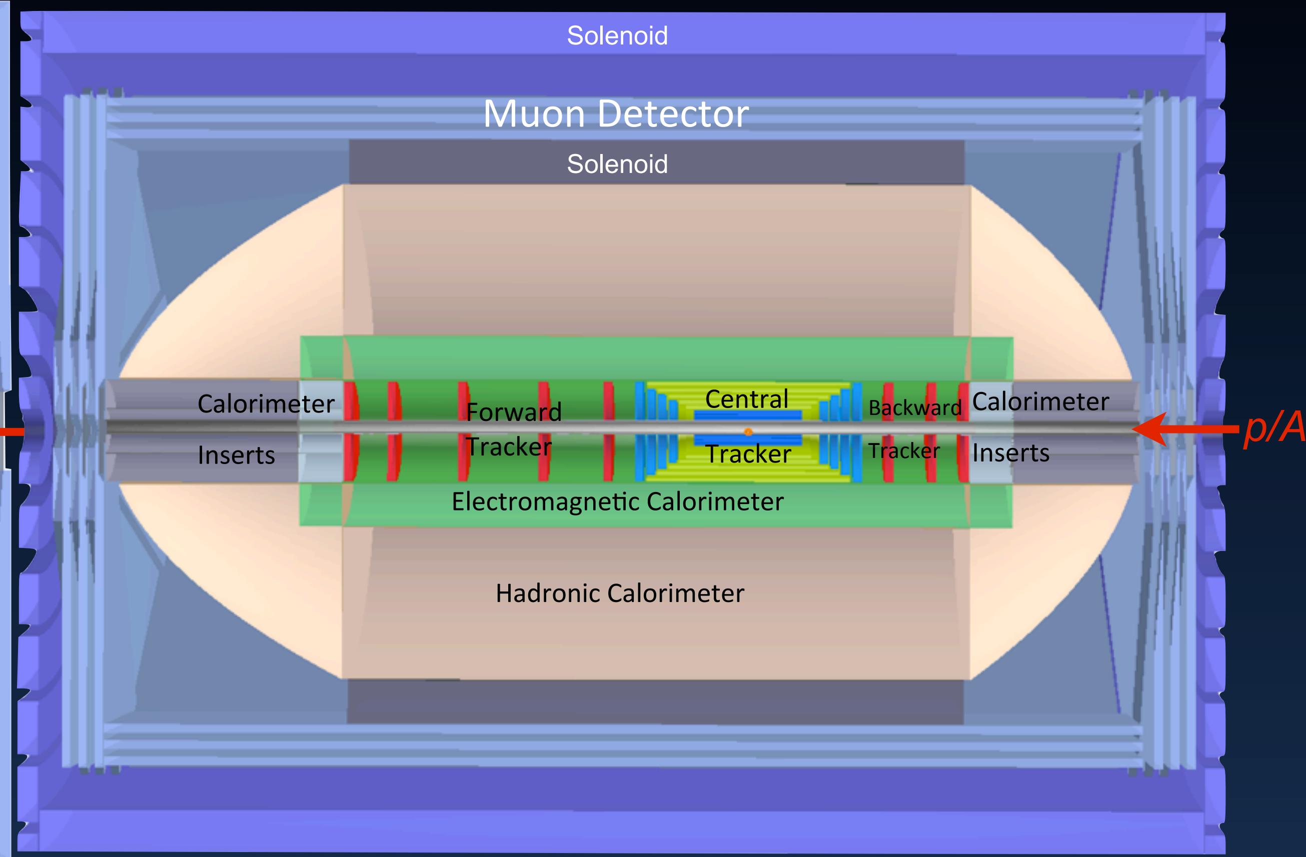
Detector dimensions z≈14m, diameter ∅≈9m.

dipole layout



Detector Options - 1





LR detector in the r-z plane
dipole (radius ~0.6m, 0.3T) and solenoid (3.5T) placement between the electromagnetic and the hadronic calorimeters.

The IP is surrounded by a central tracker system, large forward and backward tracker telescopes and sets of calorimeters.

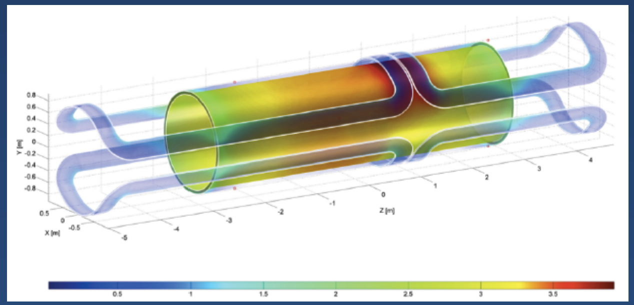
Detector dimensions z≈14m, diameter ∅≈9m.

RR option only (no dipole) - High Acceptance
Option studied also where the larger solenoid surrounds the hadronic calorimetry.

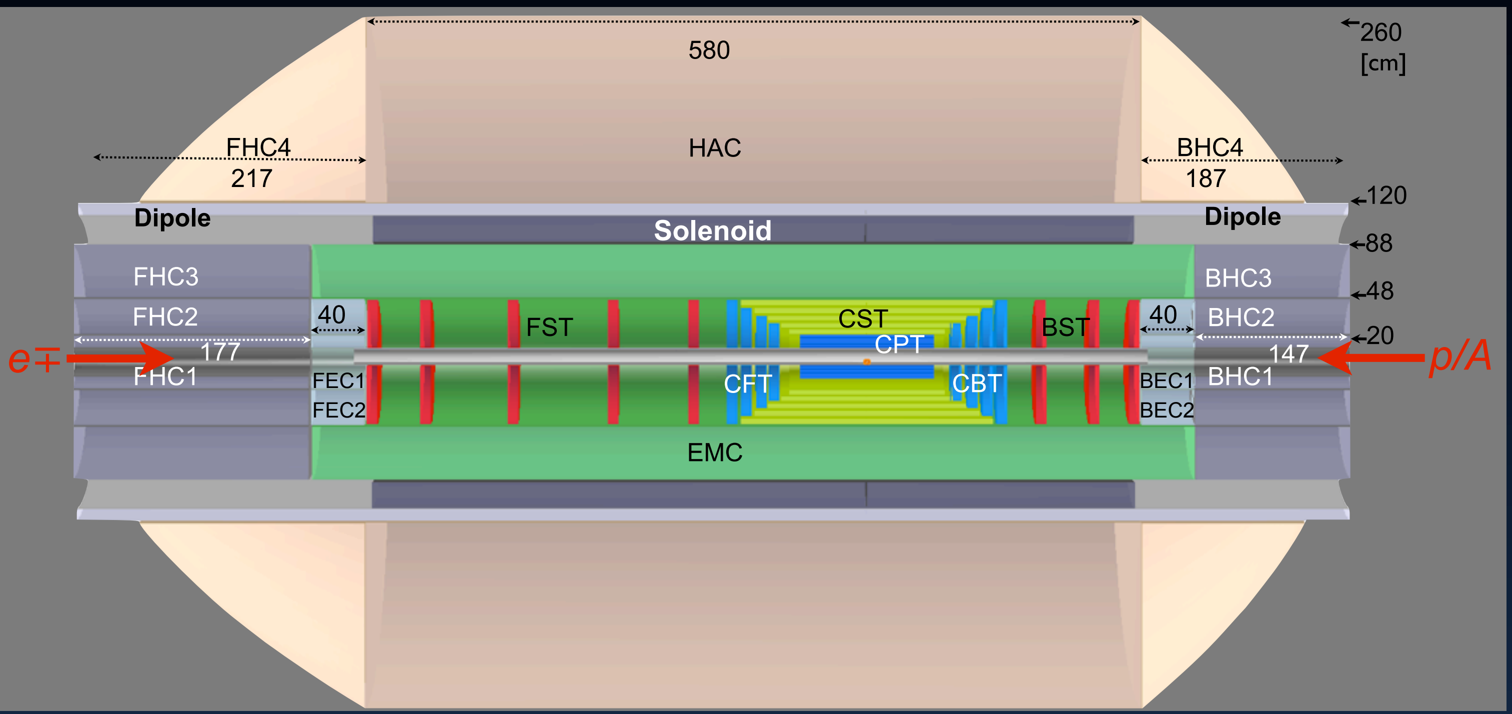
Magnetic field outside the solenoid (3.5T) is ≈1.5T;
Volume instrumented with 3 multilayers of muon chambers.

The overall dimensions of this detector configuration are about 11m length and 8m diameter.

dipole layout



Detector Options - 2

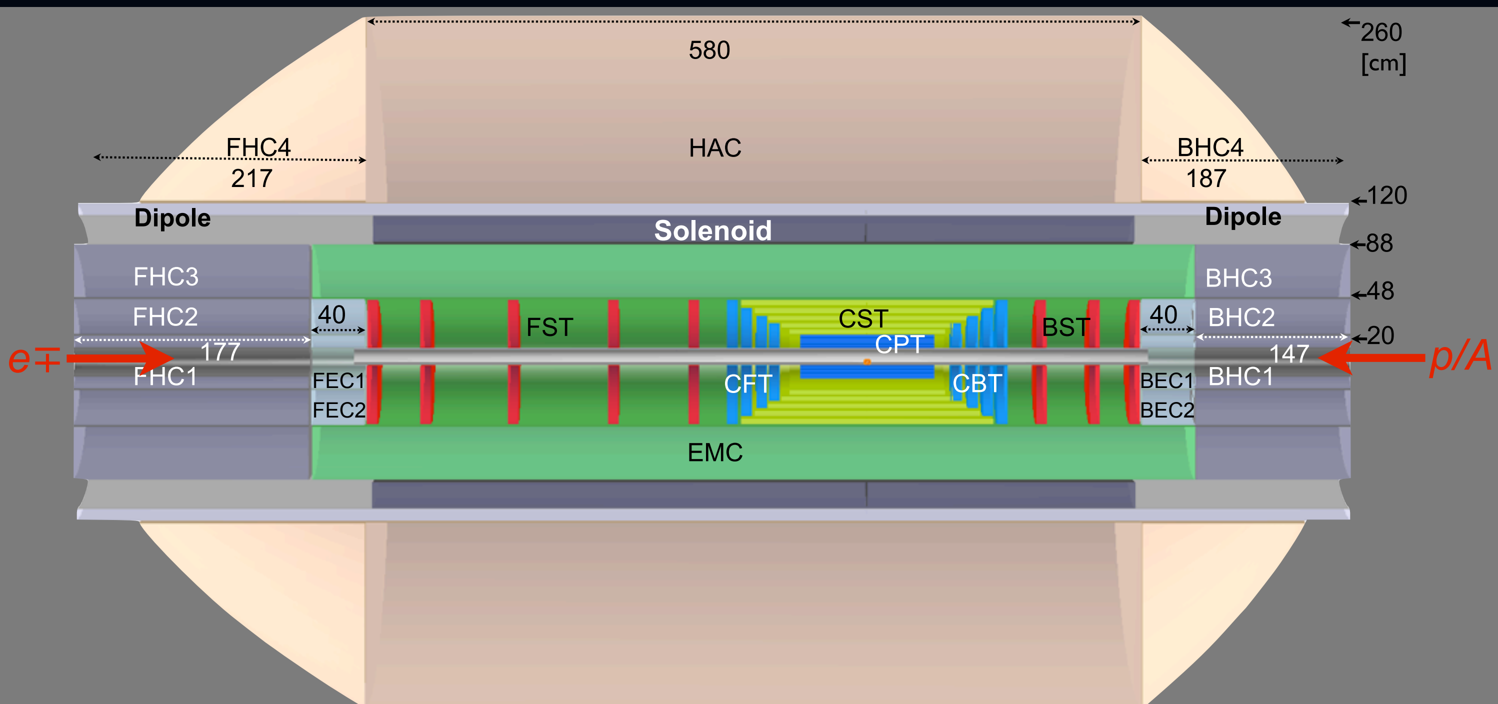


The baseline configuration (LR case).
Central barrel:
- silicon pixel detector (CPT)
- silicon tracking detectors (CST,CFT/CBT)
- electromagnetic calorimeter (EMC)
- surrounded by the magnets (Solenoid, Dipoles)
- hadronic calorimeter (HAC)

Backward silicon tracker (BST)
- energy measured in the BEC and BHC calorimeters

Forward silicon tracking (FST)
- and calorimetry (FEC, FHC) measuring TeV energy final states

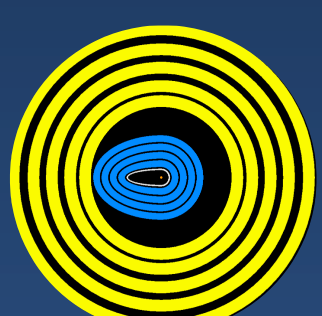
Detector Options - 2



The baseline configuration (LR case).
Central barrel:
- silicon pixel detector (CPT)
- silicon tracking detectors (CST,CFT/CBT)
- electromagnetic calorimeter (EMC)
- surrounded by the magnets (Solenoid, Dipoles)
- hadronic calorimeter (HAC)

Backward silicon tracker (BST)
- energy measured in the BEC and BHC calorimeters

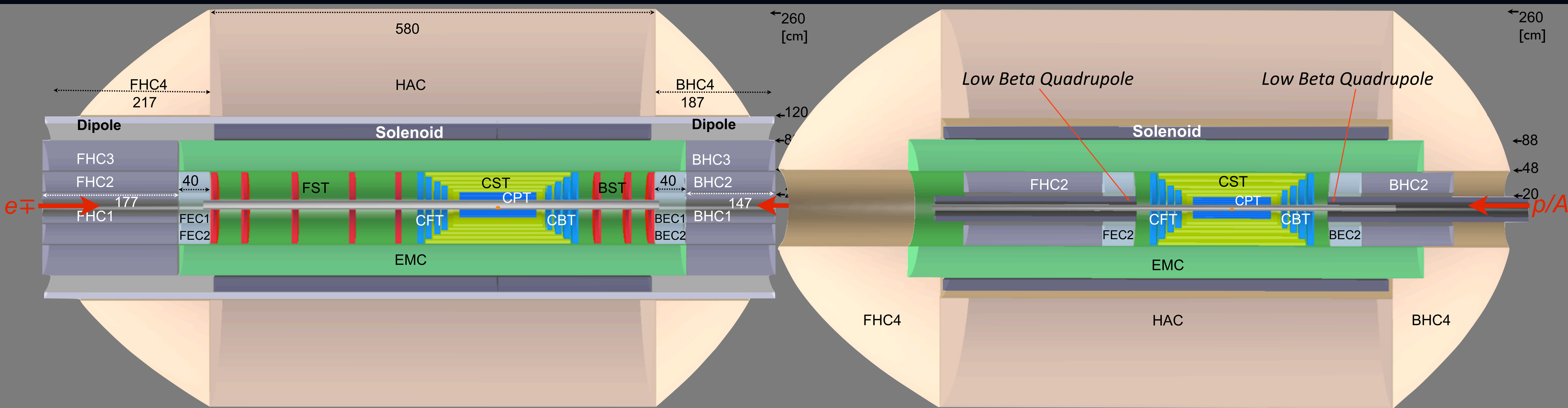
Forward silicon tracking (FST)
- and calorimetry (FEC, FHC) measuring TeV energy final states



Detector design
- follow BP shape (CPT/CST shown)

Linac-Ring - beam pipe
inner-R_{circ}=2.2cm
inner-$R_{elliptical}$=10.cm

Detector Options - 2



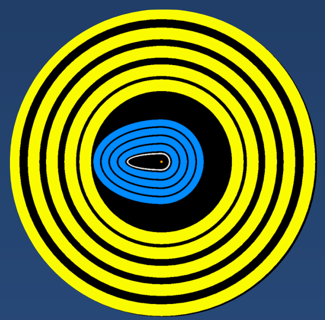
The baseline configuration (LR case).
Central barrel:
- silicon pixel detector (CPT)
- silicon tracking detectors (CST,CFT/CBT)
- electromagnetic calorimeter (EMC)
- surrounded by the magnets (Solenoid, Dipoles)
- hadronic calorimeter (HAC)

Backward silicon tracker (BST)
- energy measured in the BEC and BHC calorimeters

Forward silicon tracking (FST)
- and calorimetry (FEC, FHC) measuring TeV energy final states

Main detector for the RR
- luminosity maximised by low β quadrupole magnets

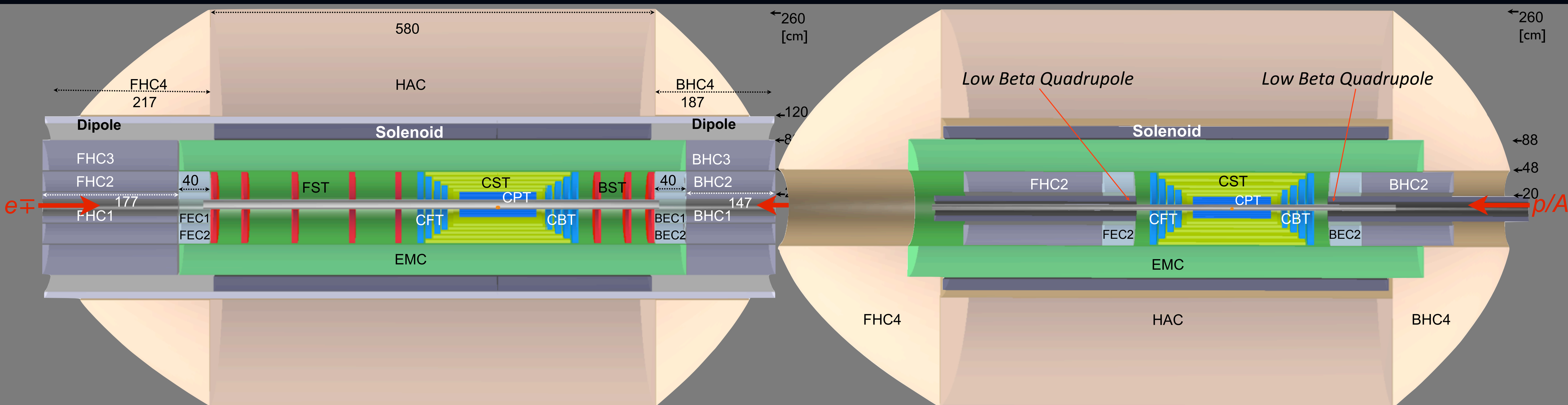
The forward/backward tracking has been removed and the outer calorimeter inserts have been moved nearer to the interaction point.



Detector design
- follow BP shape (CPT/CST shown)

Linac-Ring - beam pipe
inner-R_{circ}=2.2cm
inner-$R_{elliptical}$=10.cm

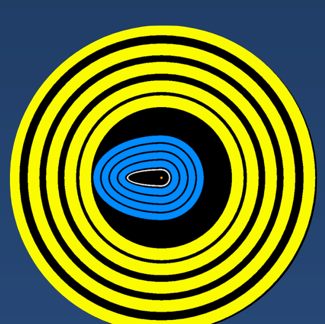
Detector Options - 2



The baseline configuration (LR case).
Central barrel:
  silicon pixel detector (CPT)
  silicon tracking detectors (CST,CFT/CBT)
  electromagnetic calorimeter (EMC)
  surrounded by the magnets (Solenoid, Dipoles)
  hadronic calorimeter (HAC)
Backward silicon tracker (BST)
  energy measured in the BEC and BHC calorimeters
Forward silicon tracking (FST)
  and calorimetry (FEC, FHC) measuring TeV energy final states

Main detector for the RR
- luminosity maximised by low β quadrupole magnets

The forward/backward tracking has been removed and the outer calorimeter inserts have been moved nearer to the interaction point.



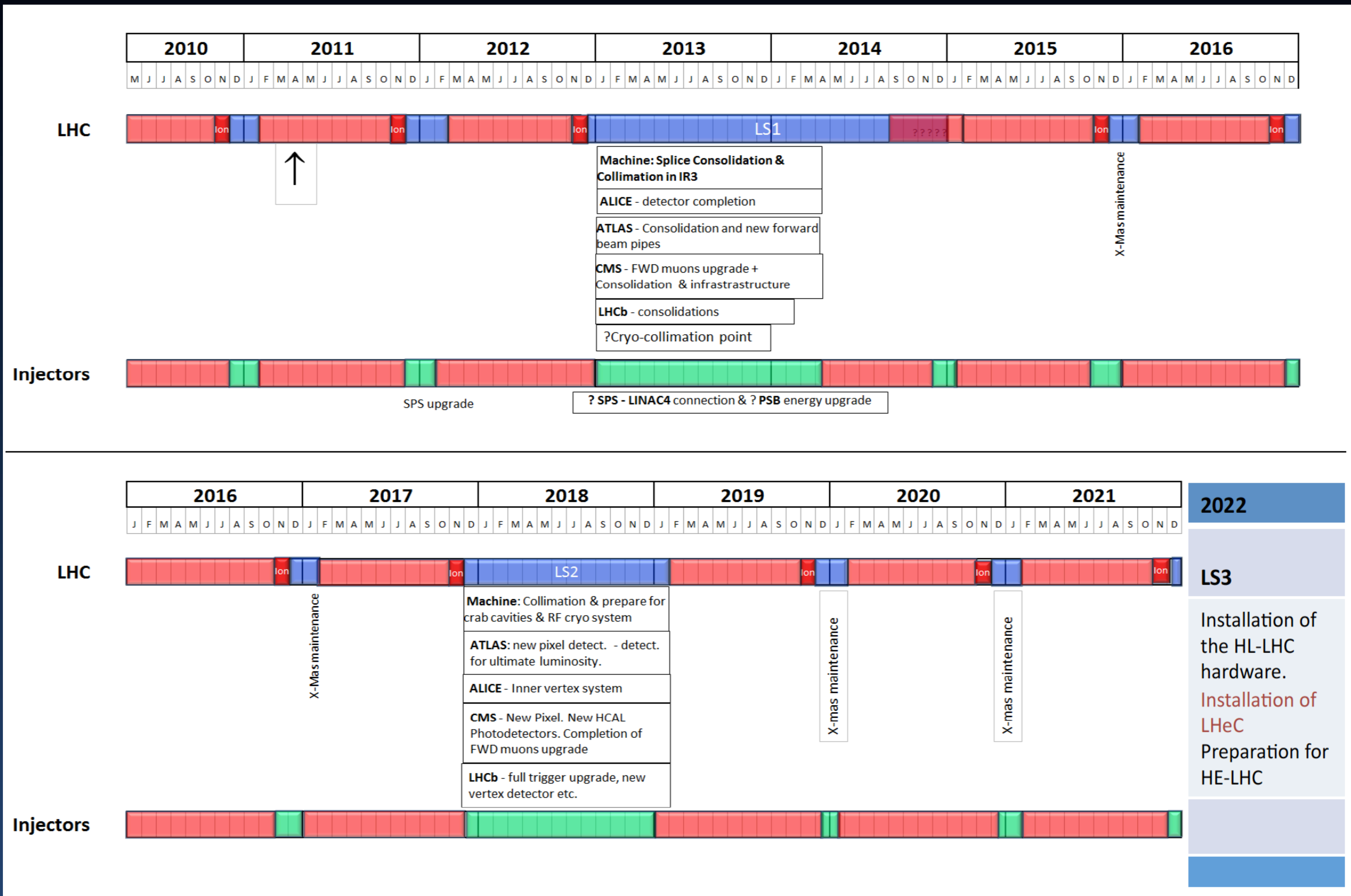
Detector design
- follow BP shape (CPT/CST shown)

Linac-Ring - beam pipe
inner-R_{circ}=2.2cm
inner-$R_{elliptical}$=10.cm

For numeric studies and plots see recent talks at
DIS10, DIS11, ICHEP10, EPS11, IPAC11, …
EIC and LHeC Workshops
at http://cern.ch/lhec
of course: CDR to be published (more then 500 pages yet)

CERN Medium Term Plan

draft as of July 2011, from [724]

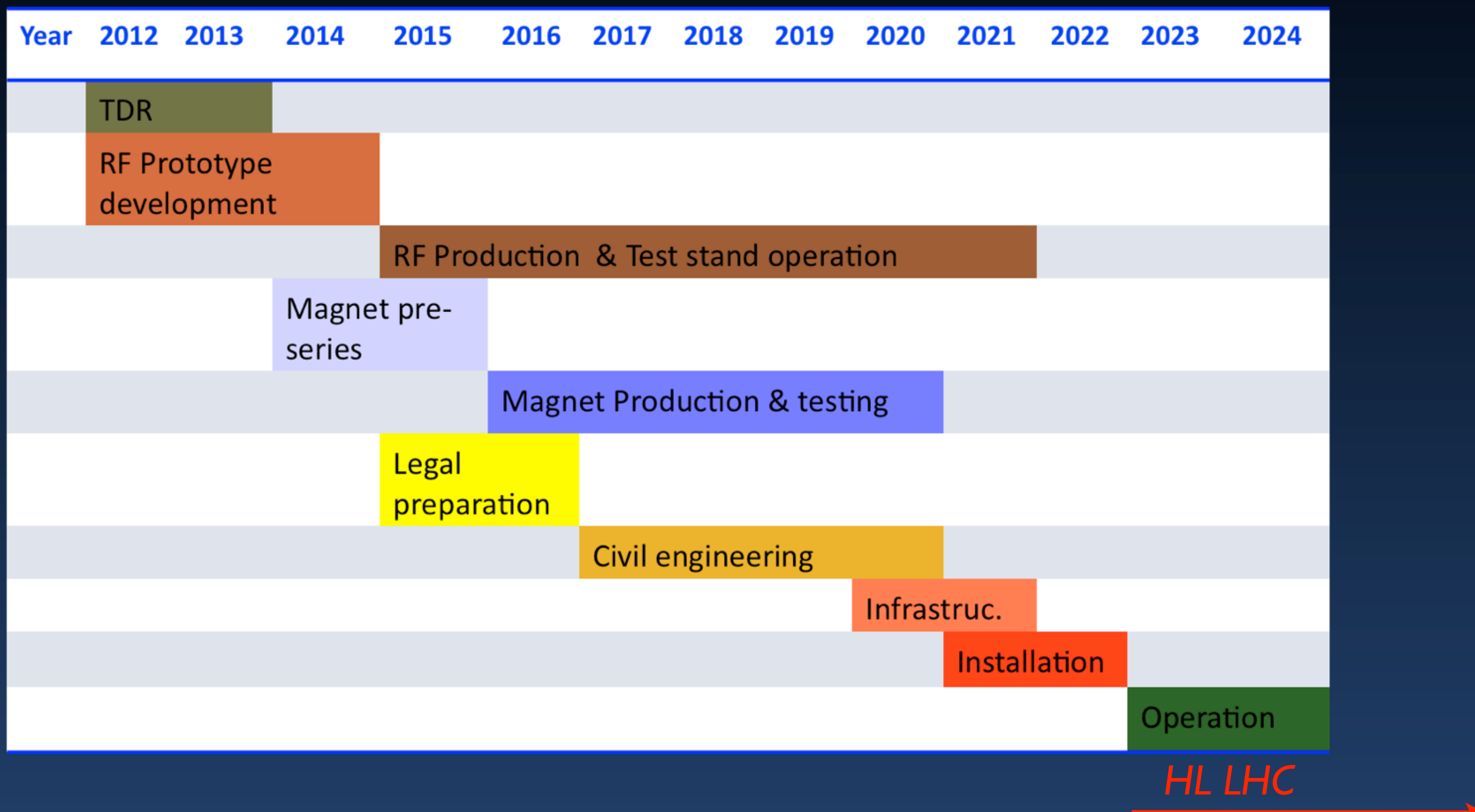


Not yet approved!

[724] S. Myers, *LHC: Machine Status and Prospects for the Short, Medium and Long Term,*, Invited Plenary Talk at EPS, Grenoble, July 2011.

LHeC Tentative Time Schedule

Machine only



We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL). In

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) **(8-11/11)**
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

- Both machine variants RR/LR could be realised in time for the HL LHC running (~2023)
  - some R&D / prototyping necessary (LR mostly);
  - synergies with other projects

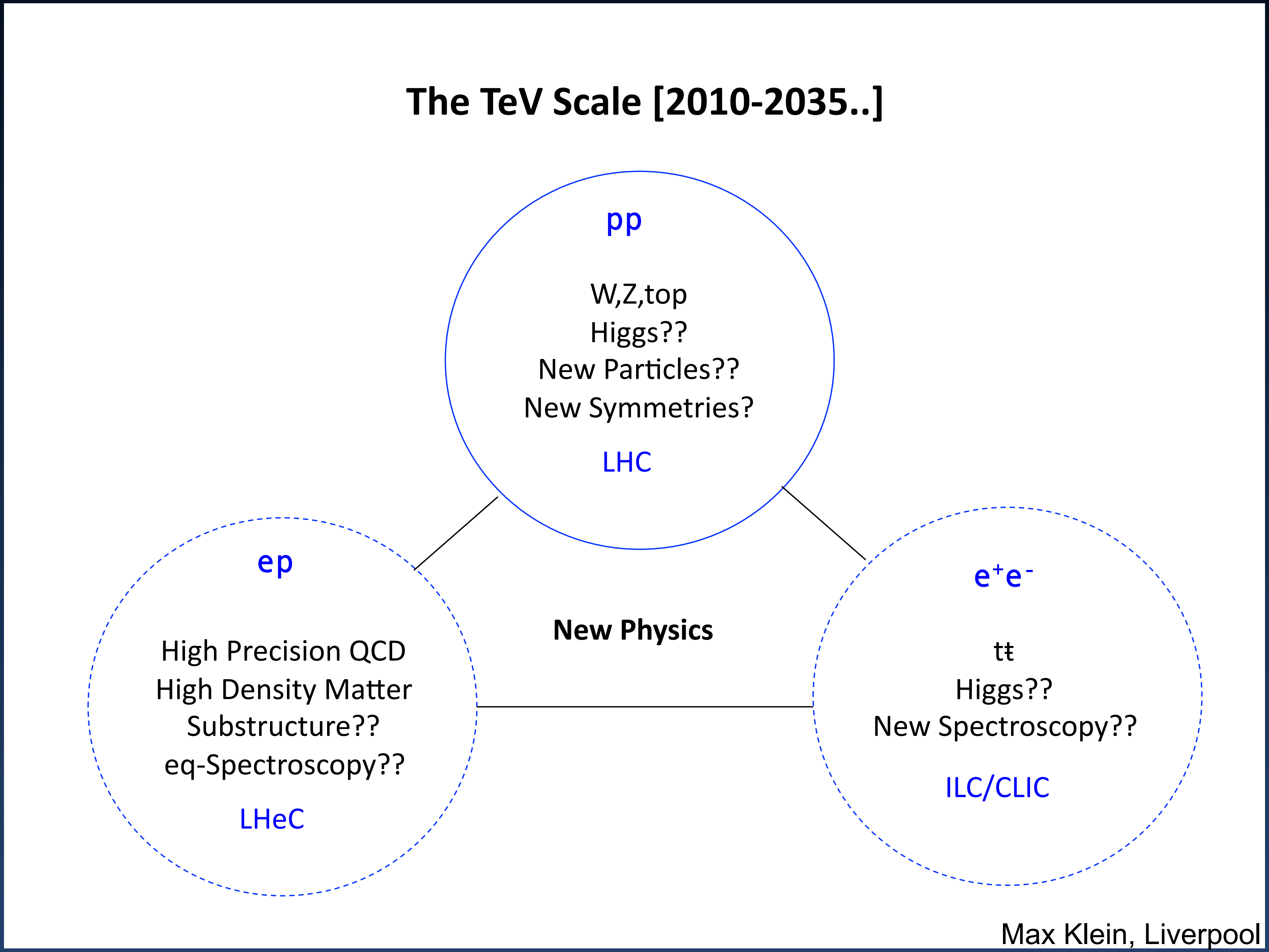
- The detector ensuring the physics program
  - high precision; first simulations promising
  - flexible/modular
  - using available technology

- New and exciting physics of DIS in $\mathbf{e}^{\mp}_{\mathbf{polarized}} \cdot \mathbf{p}/\mathbf{A}$ at CERN

- Thanks to my colleagues from whom I have taken slides/details and with whom I'm enjoying the LHeC adventure

- … the LHeC is already half built (J.Engelen)

Fruitfully Collider Triumvirate at Terascale



It should be used

Backup Slides

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

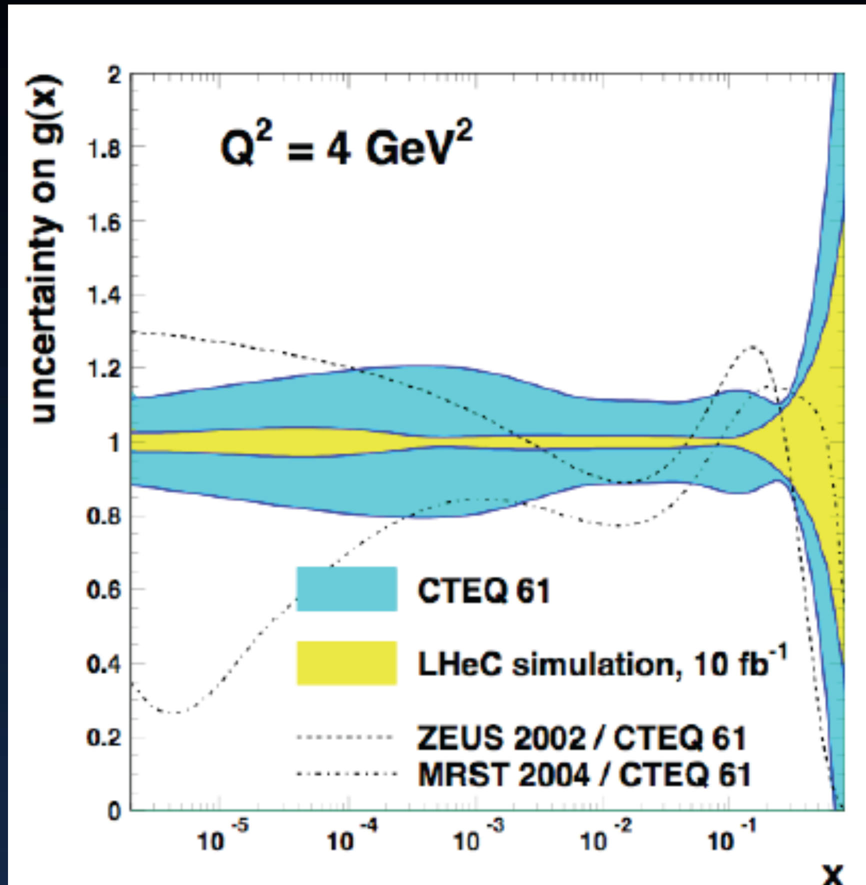
Partonic structure of the photon

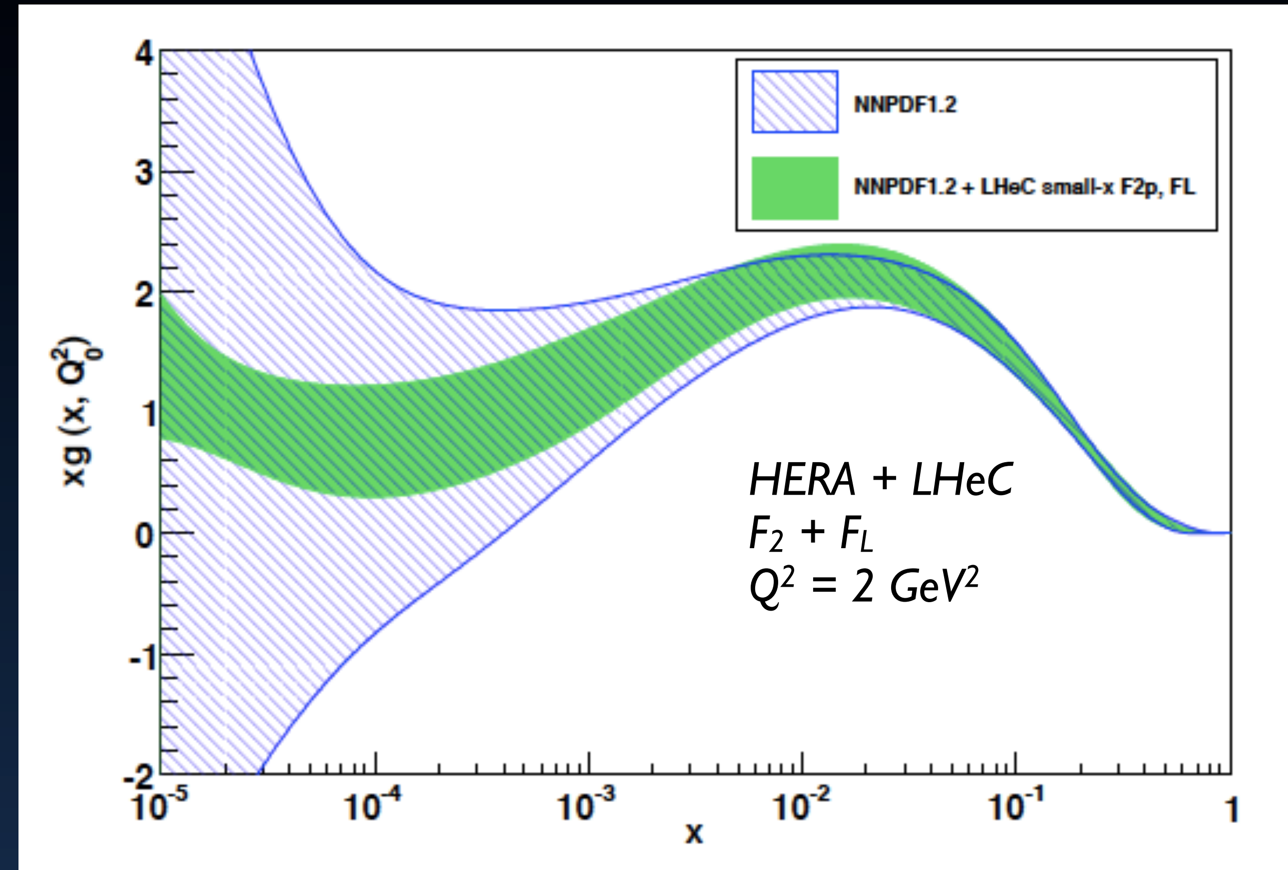
Instantons not observed

Odderons not found
…

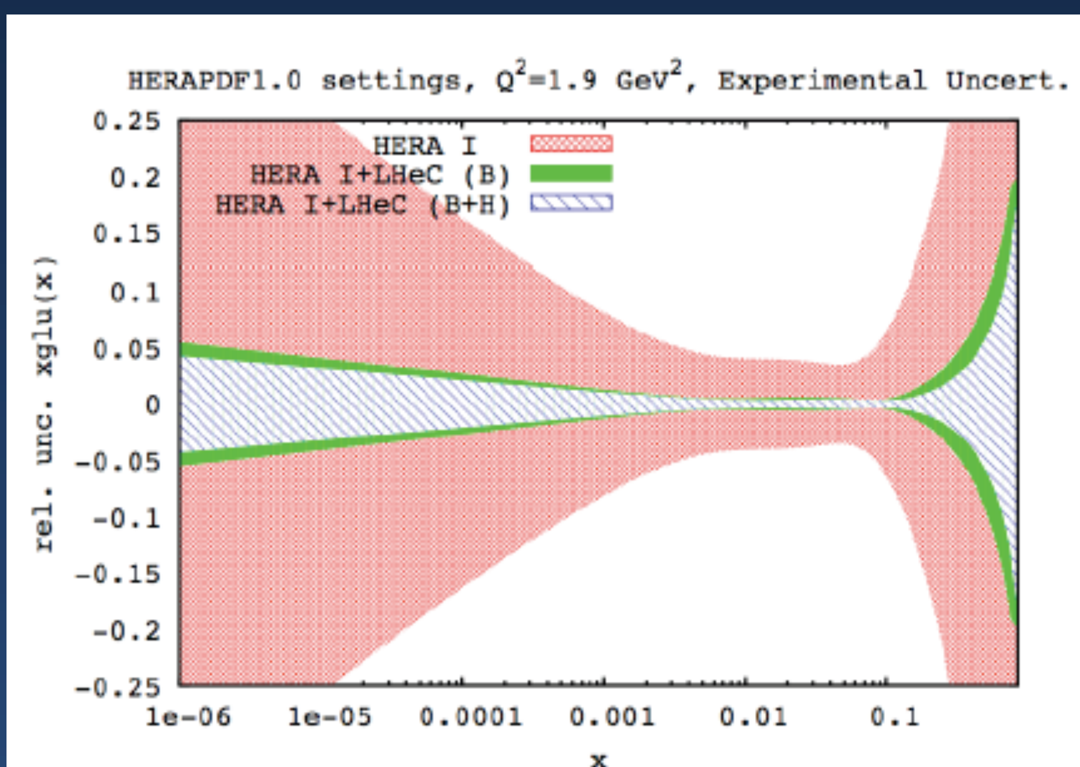
Fermions still pointlike
Lepton-quark states (as in RPV SUSY) not observed

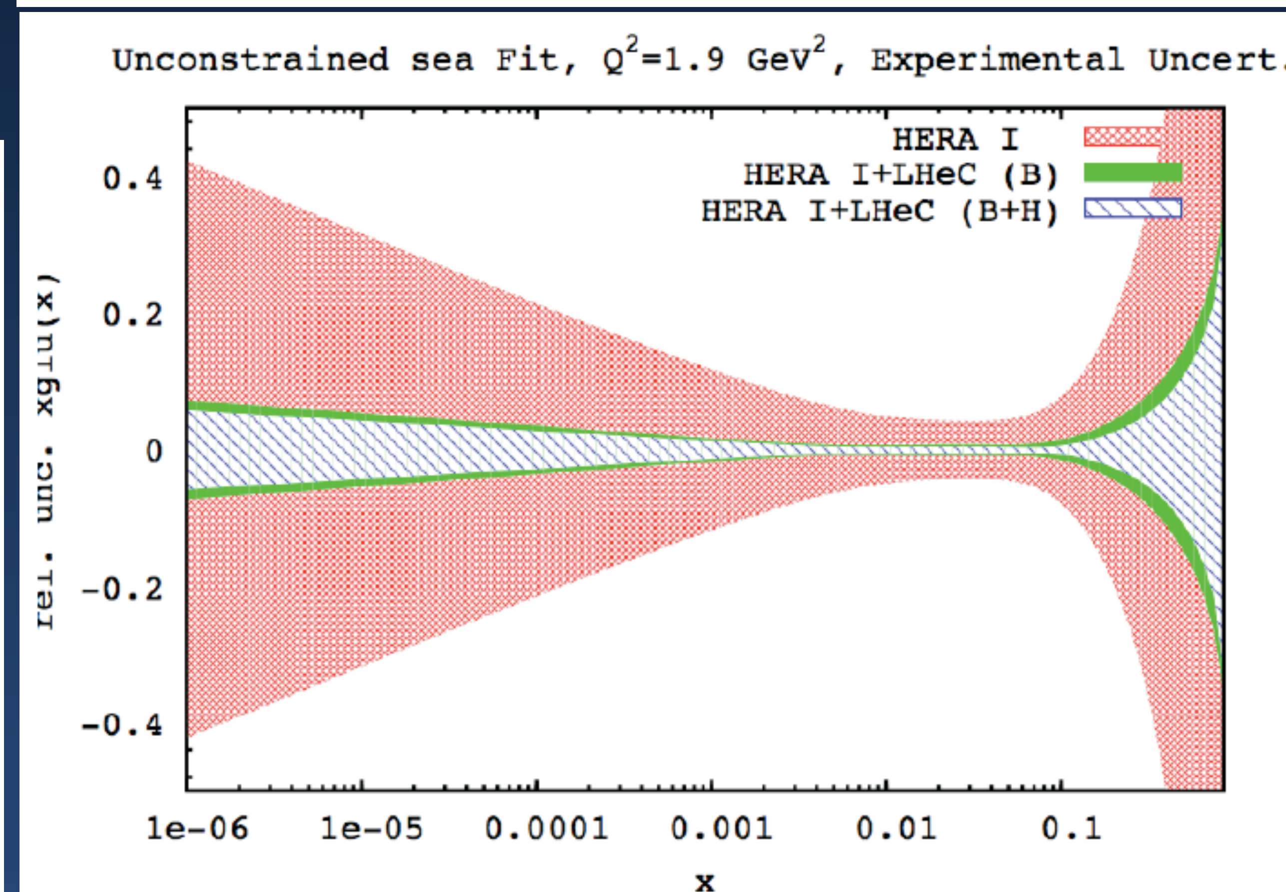
High Precision Gluon Measurements



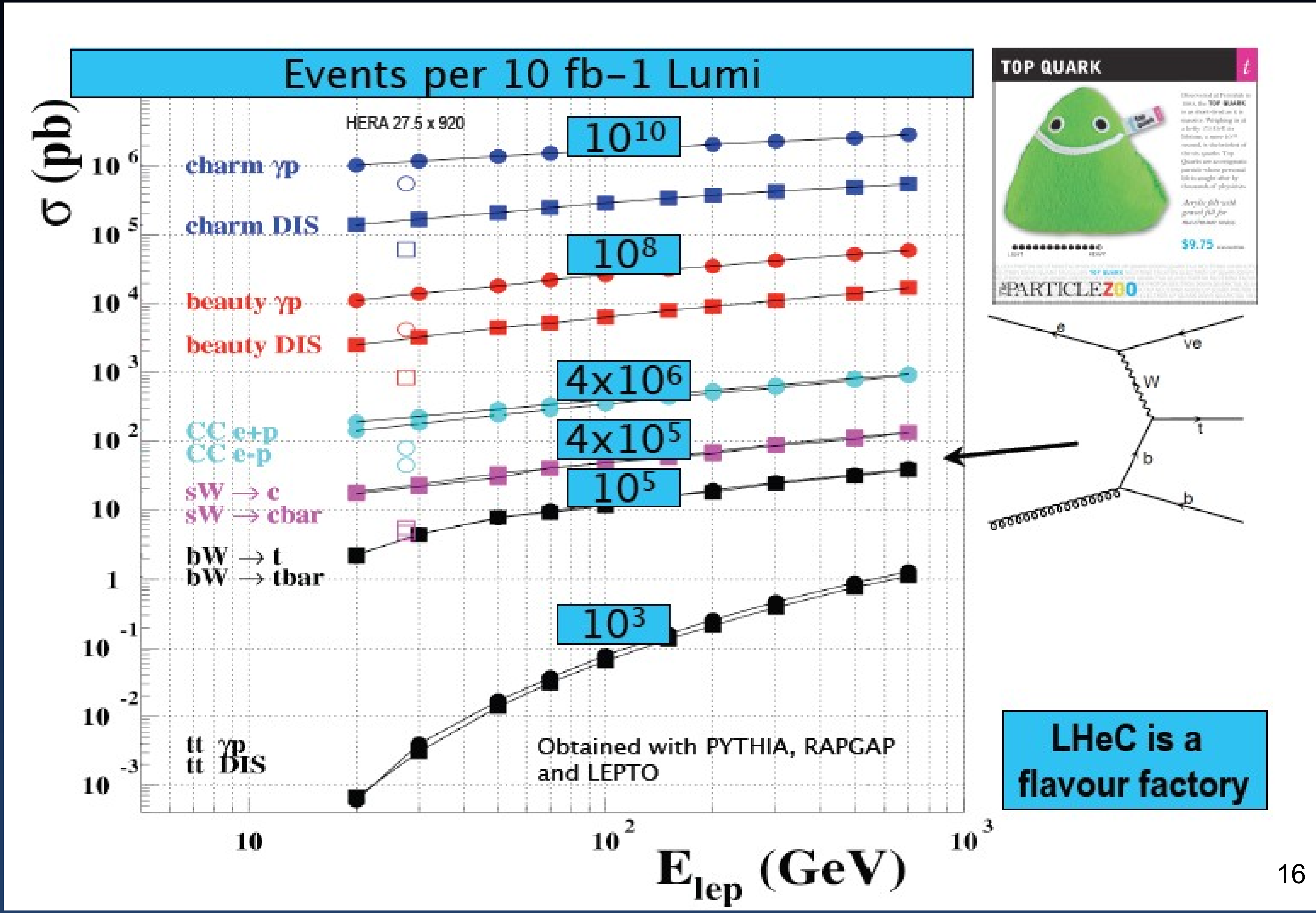


NLO QCD “Fits” of LHeC simulated data

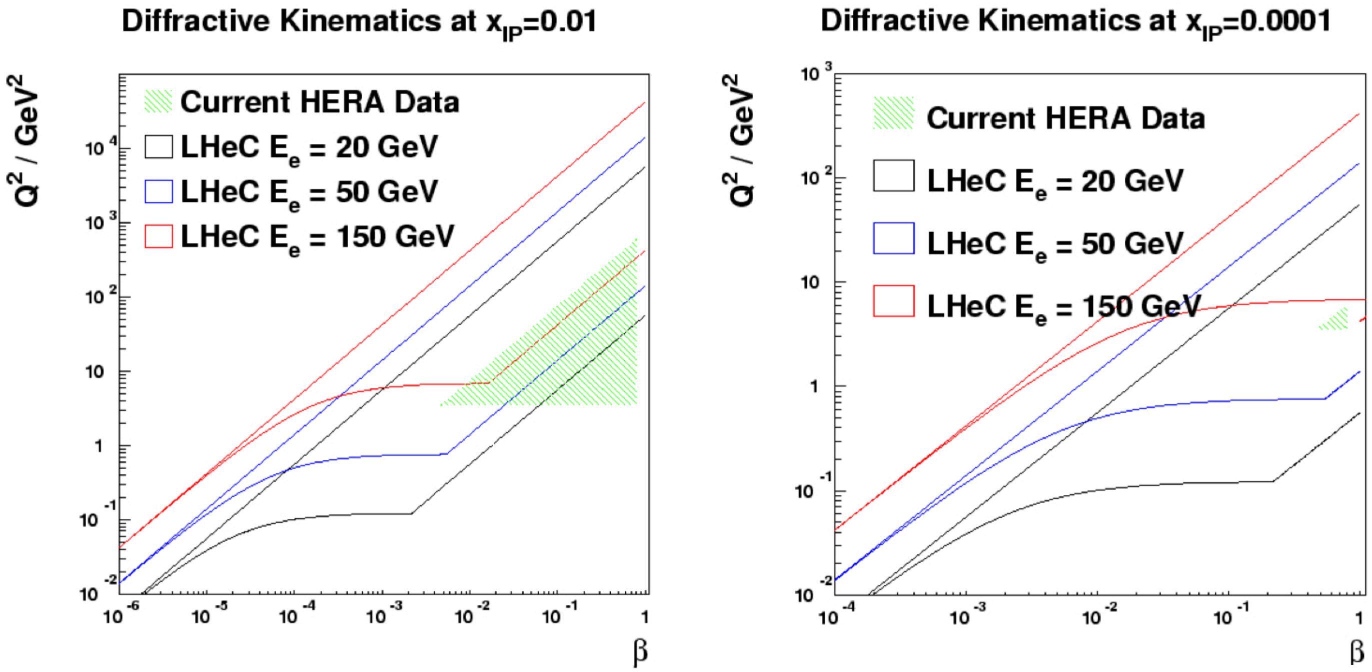


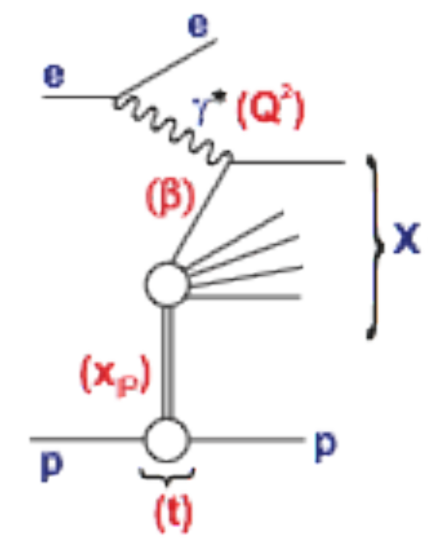


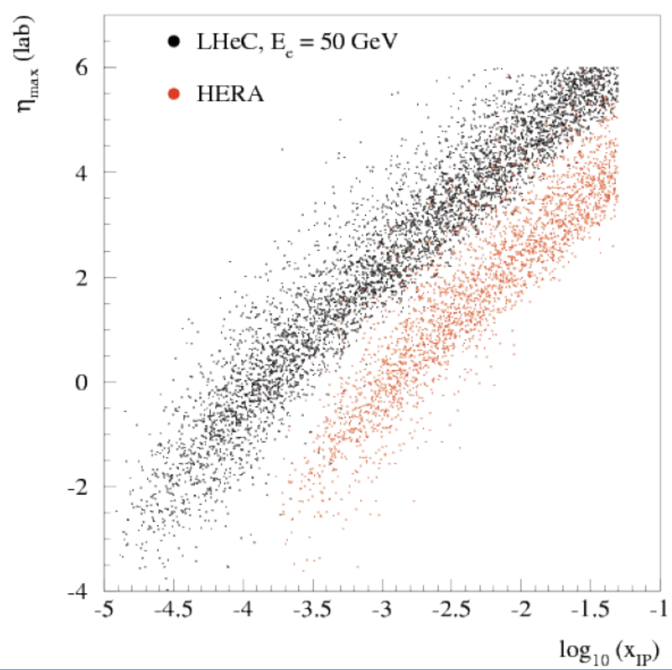
Heavy Flavour @ LHeC



Inclusive diffraction: new possibilities



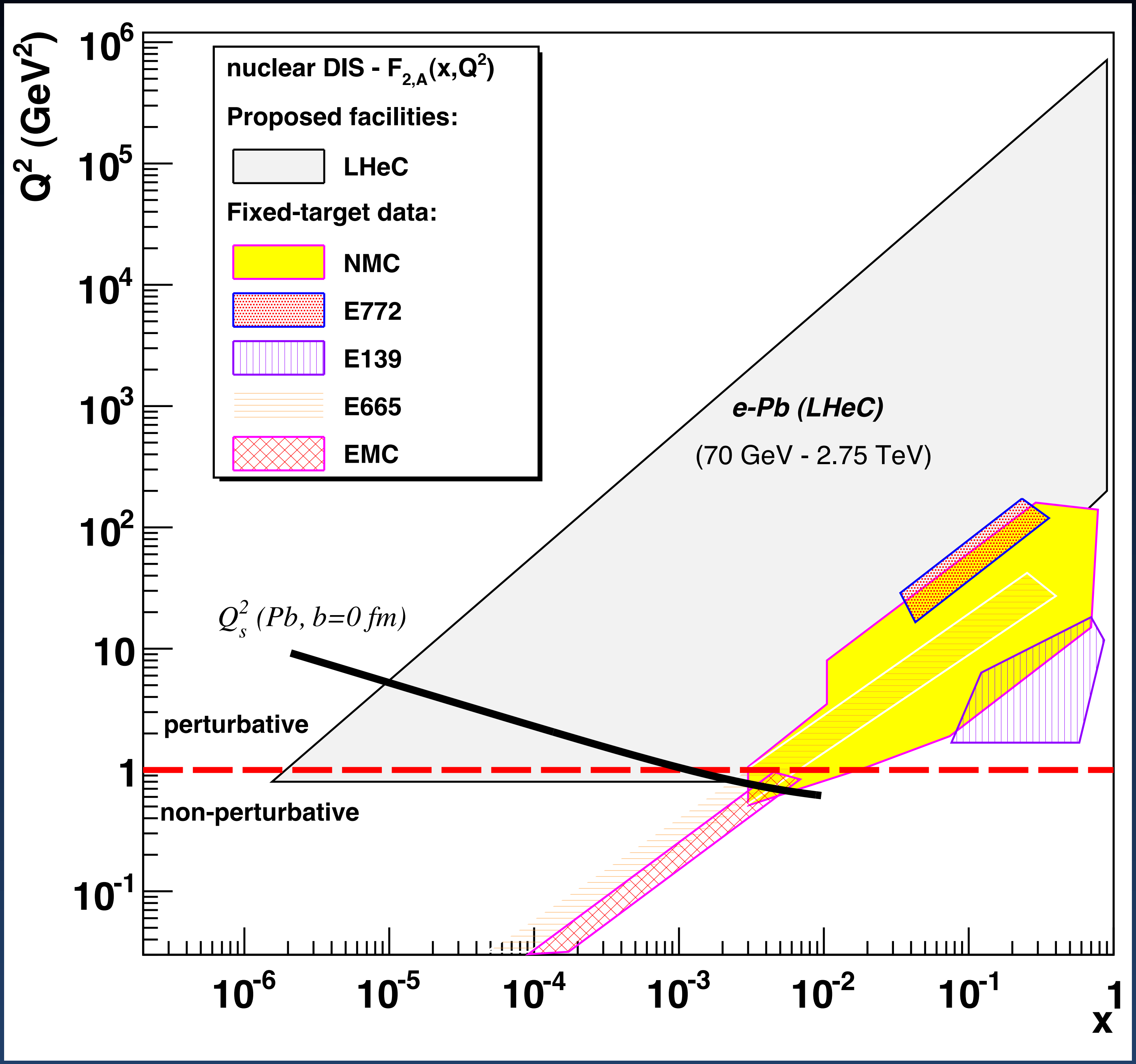




- Studies with 1 degree acceptance,
- Constraints on diffractive-PDFs
- Factorization (tests) in much bigger kinematics range.
- Diffraction is much more sensitive to the semi-hard regime.
- Enhanced sensitivity to nonlinear/saturation effects.

Figure 6.34: Diffractive DIS kinematic ranges in Q^2 and β of HERA and of the LHeC for different electron energies $E_e = 20, 50, 150$ GeV at $x_{I\!P} = 0.01$ (left plot), and $x_{I\!P} = 0.0001$ (right plot). In both cases, 1^o acceptance is assumed for the scattered electron and the typical experimental restriction $y > 0.01$ is imposed. No rapidity gap restrictions are applied.

LHeC e+A Kinematic Coverage



The LHeC will dramatically expand $x - Q^2$ coverage of nuclear DIS measurements.
- Nuclear PDF's

Access to saturation scales $Q_s^2 \sim 5\,\mathrm{GeV}^2$ – at b = 0.

Improvements in Nuclear PDFs

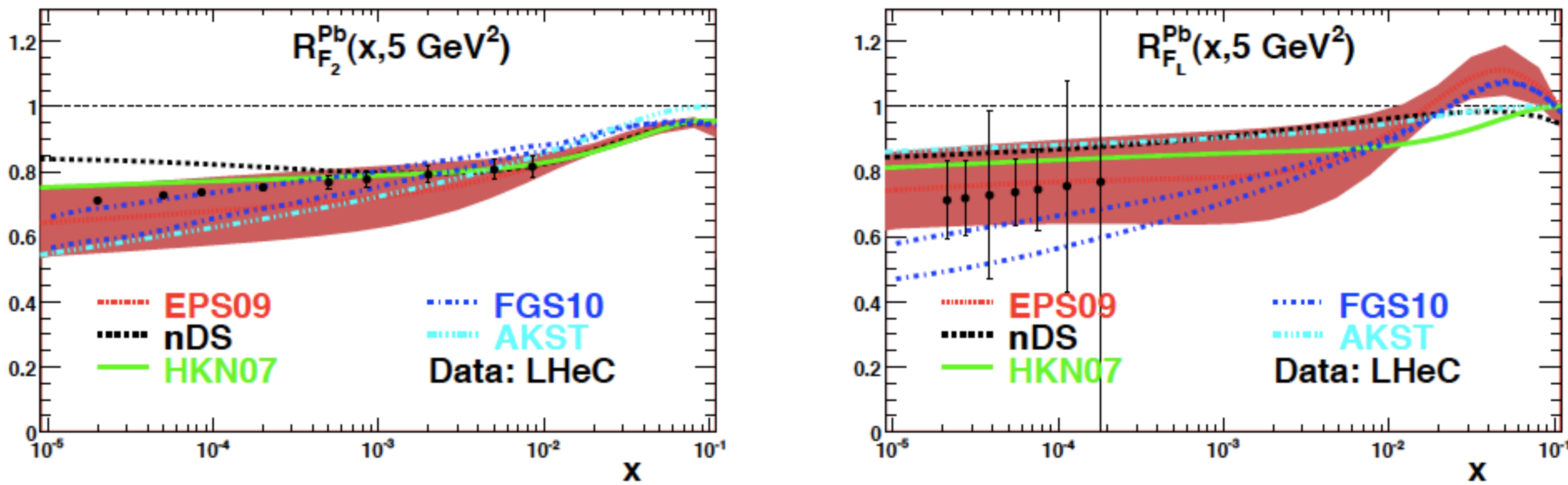


Figure 6.18: Predictions from different models for the nuclear modification factor, Eq. (6.5) for Pb with respect to the proton, for $F_2(x, Q^2 = 5\ \mathrm{GeV}^2)$ (plot on the left) and $F_L(x, Q^2 = 5\ \mathrm{GeV}^2)$ (plot on the right) versus x, together with the corrresponding LHeC pseudodata. Dotted lines correspond to the nuclear PDF set EPS09 [153], dashed ones to nDS [405], solid ones to HKN07 [406], dashed-dotted ones to FGS10 [407] and dashed-dotted-dotted ones to AKST [302]. The band corresponds to the uncertainty in the Hessian analysis in EPS09 [153].

CDR Authorlist

5th August 2011

C. Adolphsen (SLAC)
S. Alekhin (Serpukhov, DESY)
A.N.Akai (Ankara)
H. Aksakal (CERN)
P. Allport (Liverpool)
J.L. Albacete (IPhT Saclay)
V. Andreev (LPI Moscow)
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. Biswal (Orissa)
S. Bettoni (CERN)
J. Bluemlein (DESY)
H. Boettcher (DESY)
H. Braun (PSI)
S. Brodsky (SLAC)
A. Bogacz (Jlab)
C. Bracco (CERN)
O. Bruening (CERN)
E. Bulyak (Charkov)
A. Bunyatian (DESY)
H. Burkhardt (CERN)
I.T. Cakir (Ankara)
O. Cakir (Ankara)
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)
E. Eroglu (Uludag)
K.J. Eskola (Jyvaskyla)
L. Favart (IIHE Brussels)
M. Fitterer (CERN)
S. Forte (Milano)
P. Gambino (Torino)
T. Gehrmann (Zurich)
C. Glasman (Madrid)
R. Godbole (Tata)
B. Goddard (CERN)
T. Greenshaw (Liverpool)
A. Guffanti (Freiburg)
V. Guzey (Jefferson)
C. Gwenlan (Oxford)
T. Han (Harvard)
Y. Hao (BNL)
F. Haug (CERN)
W. Herr (CERN)
B. Holzer (CERN)
M. Ishitsuka (Tokyo I.Tech.)
M. Jacquet (Orsay, LAL)
B. Jeanneret (CERN)
J.M. Jimenez (CERN)
H. Jung (DESY)
J. Jowett (CERN)
H. Karadeniz (Ankara)
D. Kayran (BNL)
F. Kosac (Uludag)
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)
H. Kowalski (DESY)
D. Kuchler (CERN)
M. Kuze (Tokyo I.Tech.)
T. Lappi (Jyvaskyla)
P. Laycock (Liverpool)
E. Levichev (BINP)
S. Levonian (DESY)
V.N. Litvinenko (BNL)
A.Lombardi (CERN)
C. Marquet (CERN)
B. Mellado (Harvard)
K-H. Mess (CERN)
S. Moch (DESY)
I.I. Morozov (BINP)
Y. Muttoni (CERN)
S. Myers (CERN)
S. Nandi (Montreal)
P.R. Newman (Birmingham)
T. Omori (KEK)
J. Osborne (CERN)
Y. Papaphilippou (CERN)
E. Paoloni (Pisa)
C. Pascaud (LAL Orsay)
H. Paukkunen (St. de Compostela)
E. Perez (CERN)
T. Pieloni (CERN)
E. Pilicer (Uludag)
A. Polini (Bologna)
V. Ptitsyn (BNL)
Y. Pupkov (BINP)
V. Radescu (Heidelberg U)
S. Raychaudhuri (Tata)
L. Rinolfi (CERN)
R. Rohini (Tata India)
J. Rojo (Milano)
S. Russenschuck (CERN)
C. A. Salgado (St. de Compostela)
K. Sampai (Tokyo I. Tech)
E. Sauvan (Lyon)
M. Sahin (Ankara)
U. Schneekloth (DESY)
A.N. Skrinsky (Novosibirsk)
T. Schoerner Sadenius (DESY)
D. Schulte (CERN)
N. Soumitra (Torino)
H. Spiesberger (Mainz)
A.M. Stasto (Penn State)
M. Strikman (Penn State)
M. Sullivan (SLAC)
B. Surrow (MIT)
S. Sultansoy (Ankara)
Y.P. Sun (SLAC)
W. Smith (Madison)
I. Tapan (Uludag)
P. Taels (Antwerpen)
E. Tassi (Calabria)
H. Ten Kate (CERN)
J. Terron (Madrid)
H. Thiesen (CERN)
L. Thompson (Cockcroft)
K. Tokushuku (KEK)
R. Tomas Garcia (CERN)
D. Tommasini (CERN)
D. Trbojevic (BNL)
N. Tsoupas (BNL)
J. Tuckmantel (CERN)
S. Turkoz (Ankara)
K. Tywoniuk (Lund)
G. Unel (CERN)
J. Urakawa (KEK)
P. Van Mechelen (Antwerpen)
A. Variola (SACLAY)
R. Veness (CERN)
A. Vivoli (CERN)
P. Vobly (BINP)
R. Wallny (ETHZ)
G. Watt (CERN)
G. Weiglein (Hamburg)
C. Weiss (JLab)
U.A. Wiedemann (CERN)
U. Wienands (SLAC)
F. Willeke (BNL)
V. Yakimenko (BNL)
A.F. Zarnecki (Warsaw)
F. Zimmermann (CERN)
F. Zomer (Orsay LAL)

No one could work full time on LHeC

LHeC Organisation

Scientific Advisory Committee

Guido Altarelli (Roma)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell (MPI Muenchen) - Chair
Swapan Chattopadhyay (Cockcroft Institute)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (NWO)
Joel Feltesse (Saclay)
Roland Garoby (CERN)
Rolf Heuer (CERN)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Lev Lipatov (St. Petersburg)
Karlheinz Meier (Heidelberg)
Richard Milner (MIT)
Joachim Mnich (DESY)
Steve Myers (CERN)
Guenther Rosner (Glasgow)
Alexander N. Skrinsky (INP Novosibirsk)
Anthony Thomas (JLab)
Steve Vigdor (Brookhaven)
Ferdinand Willeke (Brookhaven)
Frank Wilczek (MIT)

Steering Committee

Oliver Bruening(CERN)
John Dainton (Liverpool)
Albert De Roeck (CERN)
Stefano Forte (Milano)
Max Klein (Liverpool) - Chair
Paul Laycock (Liverpool)
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

Oliver Bruening (CERN)
John Dainton (Liverpool)

Interaction Region

Bernhard Holzer(CERN)
Uwe Schneekloth (DESY)
Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY)
Alessandro Polini (Bologna)
Rainer Wallny (Zurich)

New Physics at Large Scales

Georges Azuelos (Montreal)
Emmanuelle Perez (CERN)
Georg Weiglein (Hamburg)

Precision QCD and Electroweak

Olaf Behnke (DESY)
Paolo Gambino (Torino)
Thomas Gehrmann (Zurich)
Claire Gwenlan (Oxford)

Physics at High Parton Densities

Néstor Armesto (Santiago de Compostela)
Brian A. Cole (Columbia)
Paul R. Newman (Birmingham)
Anna M. Stasto (PennState)

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

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

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

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

Design Parameters

Draft CDR - 5th August 2011

electron beam		RR	LR	LR^*_{pulsed}
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
transv. emit. $\gamma\epsilon_{x,y}$	[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
bunch interval	[ns]	25	50	50
e^- bunch length	[mm]	10	0.3	0.3
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

*) but high energy ERL not impossible; **RR**=Ring-Ring, **LR**=Linac-Ring

proton beam		RR	LR
bunch population*	$[10^{11}]$	1.7	1.7
transv. emit. $\gamma\epsilon_{x,y}$	[mm]	3.75	3.75
spot size $\sigma_{x,y}$	[μm]	30, 16	7
$\beta^*_{x,y}$	[m]	0.18, 0.5	0.1
bunch spacing	[ns]	25	25

*) "ultimate p beam" - 1.7 probably conservative

Design also for deuterons (new) and lead (exists)

Summary of Machine Parameters

Parameters of the RR and RL configurations.

		Ring	Linac
electron beam			
beam energy E_e	[GeV]	60	
e^- (e^+) per bunch	$N_e \cdot [10^9]$	20 (20)	1 (0.1)
e^- (e^+) polarisation	[%]	40 (40)	90 (0)
bunch length	[mm]	10	0.6
tr. emittance at IP $\gamma\epsilon^e_{x,y}$	[mm]	0.58, 0.29	0.05
IP β function $\beta^*_{x,y}$	[m]	0.4, 0.2	0.12
beam current	[mA]	131	6.6
energy recovery intensity gain		–	17
total wall plug power	[MW]	100	
syn rad power	[kW]	51	49
critical energy	[keV]	163	718
proton beam			
beam energy E_p	[GeV]	7000	
protons per bunch	$N_p \cdot [10^{11}]$	1.7	
transverse emittance $\gamma\epsilon^p_{x,y}$	[μm]	3.75	
collider			
Lum e^-p (e^+p)	$[10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	9 (9)	10 (1)
bunch spacing	[ns]	25	
rms beam spot size $\sigma_{x,y}$	[μm]	30,16	7
crossing angle θ	[mrad]	1	0
$L_{eN} = A\, L_{eA}$	$[10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	0.3	1

The LHeC may be realised either as a ring-ring (RR) or as a linac-ring (LR) collider.

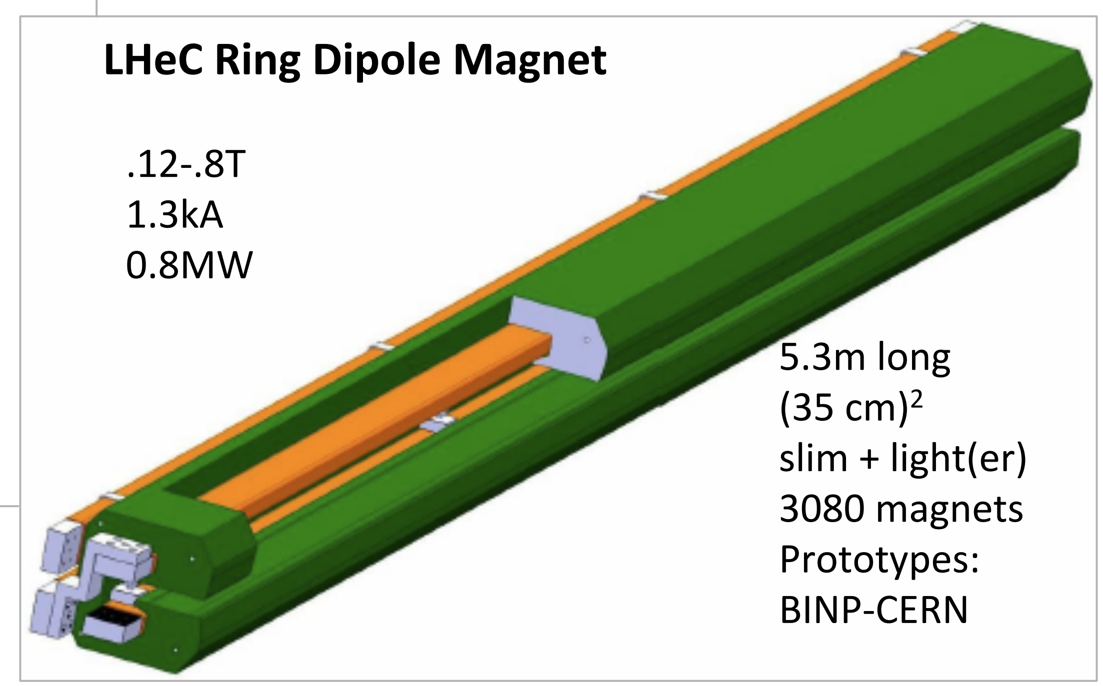
Components of the electron accelerators.

		Ring	Linac
magnets			
beam energy	[GeV]	60	
number of dipoles		3080	3600
dipole field	[T]	0.013 - 0.076	0.046 - 0.264
total nr. of quads		866	1588
RF and cryogenics			
number of cavities		112	944
gradient	[MV/m]	11.9	20
RF power	[MW]	49	39
cavity voltage	[MV]	5	21.4
cavity R/Q	[Ω]	114	285
cavity Q_0		-	$2.5\cdot 10^{10}$
cooling power	[kW]	5.4@4.2 K	30@2 K

Accelerator: Ring - Ring

Workpackages as formulated in 2008, now in the draft CDR

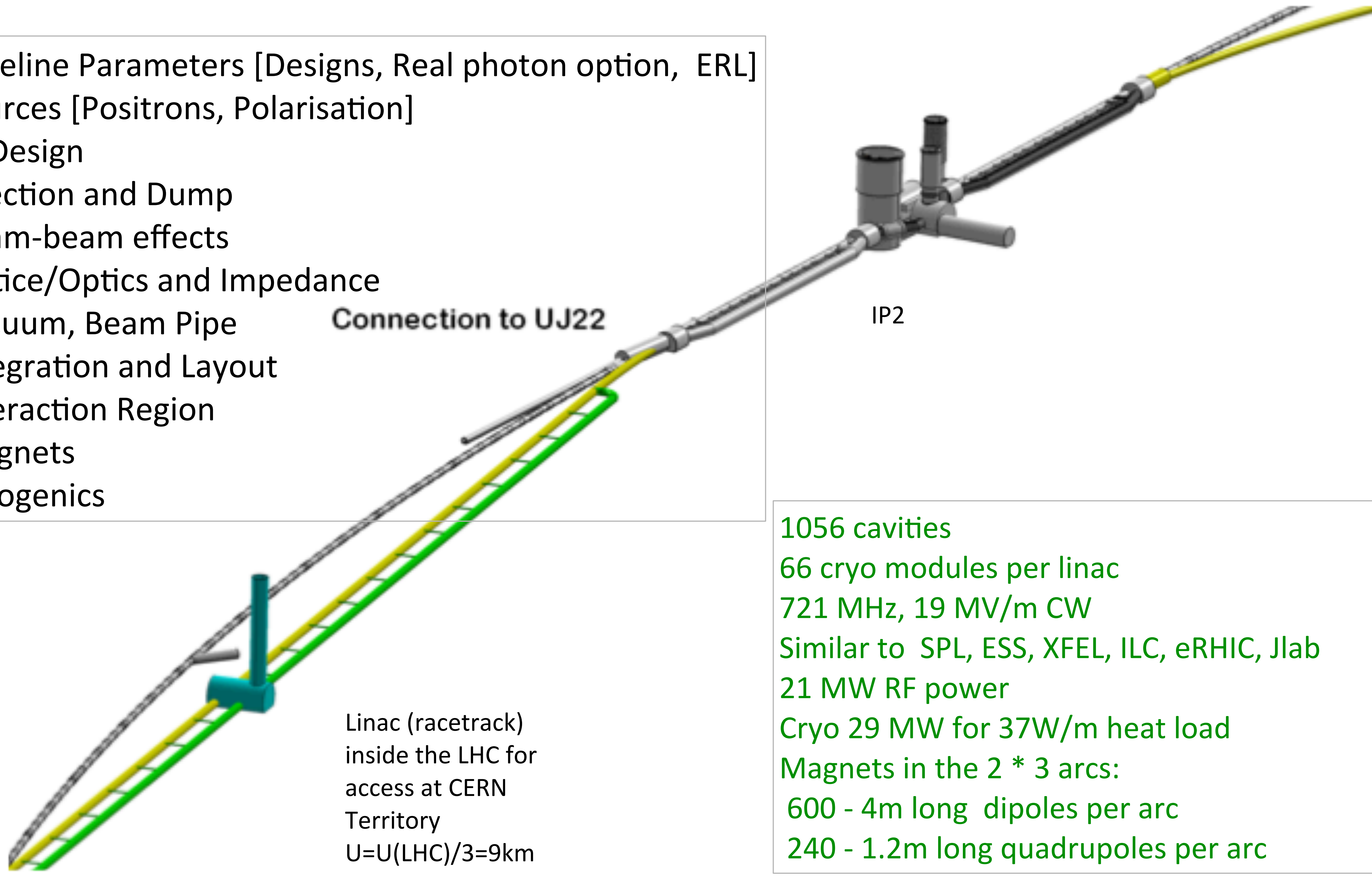
Baseline Parameters and Installation Scenarios
Lattice Design [Optics, Magnets, Bypasses]
IR for high Luminosity and large Acceptance
rf Design [Installation in bypasses, Crabs?]
Injector Complex [Sources, Injector]
Injection and Dump
Cryogenics – work in progress
Beam-beam effects
Impedance and Collective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



LINAC - Ring

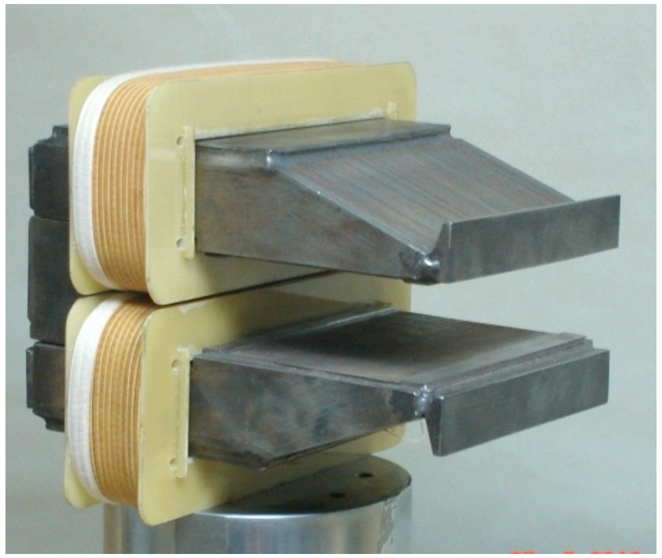
Workpackages as formulated in 2008, now in the draft CDR

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



1056 cavities
66 cryo modules per linac
721 MHz, 19 MV/m CW
Similar to SPL, ESS, XFEL, ILC, eRHIC, Jlab
21 MW RF power
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

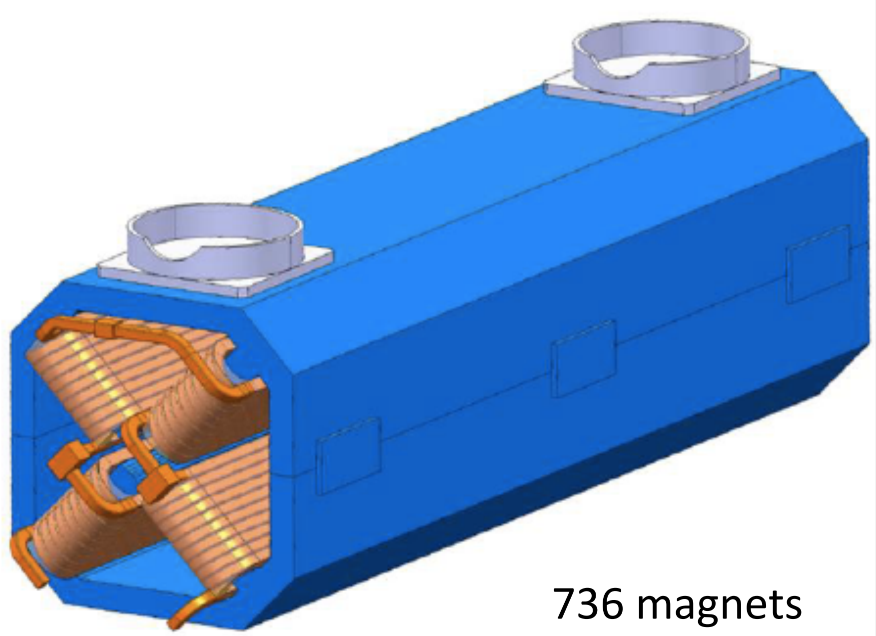
Ring: Dipole + Quadrupole Magnets



BINP &
CERN
prototypes

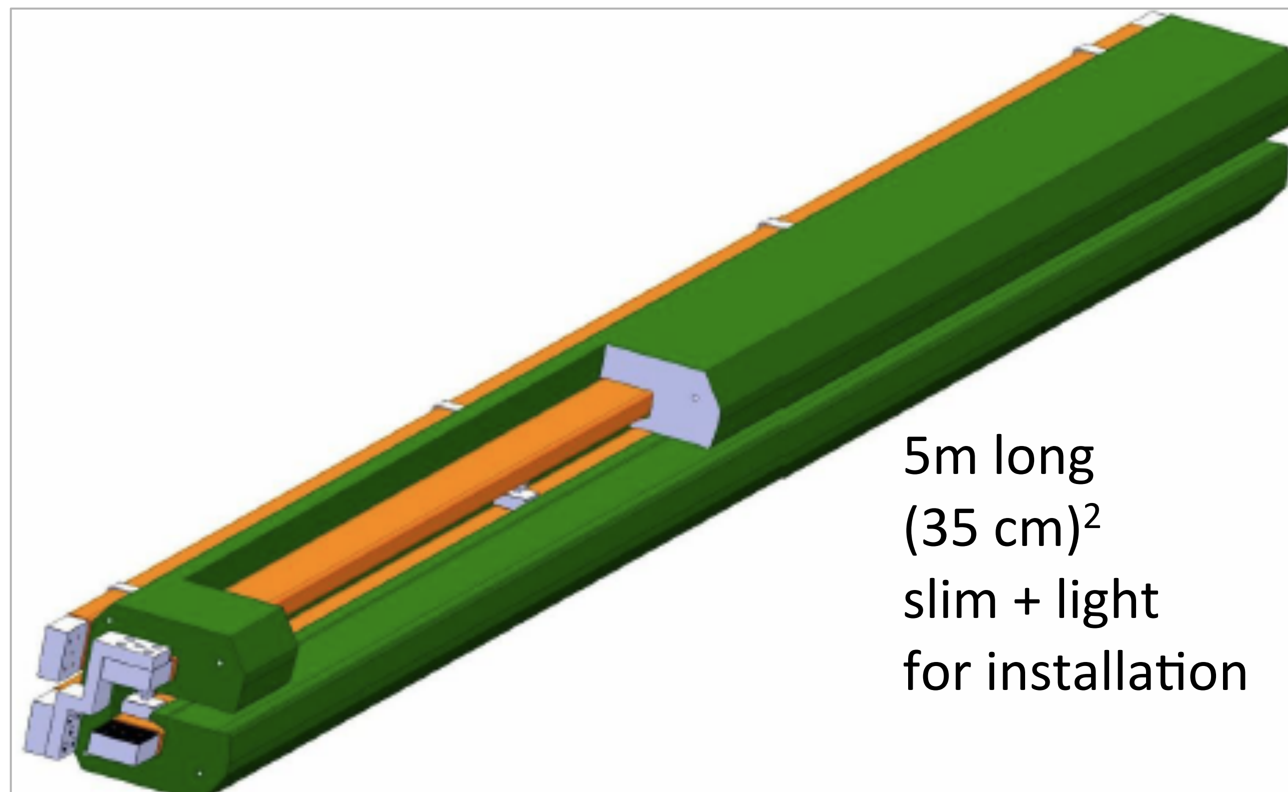
Parameter	Value	Units
Beam Energy	10-60	GeV
Magnetic Length	5.35	Meters
Magnetic Field	0.127-0.763	Tesla
Number of magnets	3080	
Vertical aperture	40	mm
Pole width	150	mm
Number of turns	2	
Current @ 0.763 T	1300	Ampere
Conductor material	copper	
Magnet inductance	0.15	milli-Henry
Magnet resistance	0.16	milli-Ohm
Power @ 60 GeV	270	Watt
Total power consumption @ 60 GeV	0.8	MW
Cooling	air or water	depends on tunnel ventilation

Table 3.2: Main parameters of bending magnets for the RR Option.



736 magnets
1.2 m long

Arc quadrupole magnets for the RR Option



5m long
$(35\ \text{cm})^2$
slim + light
for installation

High Energy Frontier (Colliders)

- Recent Progress
  - Tevatron
  - RHIC
  - LHC

Operating

- Future Directions
  - Future Ion Colliders
  - HL-LHC
  - ILC/CLIC
  - electron-hadron colliders
  - HE-LHC
  - Neutrinos (Intensity Frontier)
  - Muon collider

Approved, funded?

Not yet approved

Ad personam Issues (1)

- The physics output from the LHC will be decisive
- If 500GeV cm is sufficient:
  - ILC500; almost ready to go with construction (>200MW of electrical power, capital cost)
  - CLIC500; staged version, several years technical development needed (>200MW of electrical power, capital cost)
- If 1000GeV is needed and sufficient
  - ILC1000; at the upper energy limit of this technology (~400MW Electrical power, serious issue, capital cost, 50km)
  - CLIC1000; staged version, several years technical development needed (~400MW Electrical power is a serious issue)
- If 3000GeV is needed and sufficient
  - CLIC3000; maximum energy imaginable, still some major feasibility issues (560MW of electrical power would make this highly undesirable for the ecologists + operational costs)
- If even higher energies are needed
  - HE-LHC; aggressive R&D for high field sc magnets needed, SPS upgrade, injection/extraction systems, synchrotron radiation…
  - Muon collider; many as yet unsolved technical issues (list too long to record), but very interesting accelerator physics… very long term

Ad personam Issues (1)

- The physics output from the LHC will be decisive
- If 500GeV cm is sufficient:
  - ILC500; almost ready to go with construction (>200MW of electrical power, capital cost)
  - CLIC500; staged version, several years technical development needed (>200MW of electrical power, capital cost)
- If 1000GeV is needed and sufficient
  - ILC1000; at the upper energy limit of this technolo capital cost, 50km)
  - CLIC1000; staged version, several years technical c power is a serious issue)
- If 3000GeV is needed and sufficient
  - CLIC3000; maximum energy imaginable, still some major feasibility issues (560MW of electrical power would make this highly undesirable for the ecologists + operational costs)
- If even higher energies are needed
  - HE-LHC; aggressive R&D for high field sc magnets needed, SPS upgrade, injection/extraction systems, synchrotron radiation…
  - Muon collider; many as yet unsolved technical issues (list too long to record), but very interesting accelerator physics… very long term

Aggressive R&D needed to increase the efficiency wall-plug to beam

Summary (2)

- If e-p is interesting as a complimentary project:
  - LHeC (RR): certainly technically do-able. Integration presents major challenges, impact on the LHC operation is a major concern. By-passes are not trivial
  - LHeC (LR): luminosity (10^{33})may be difficult to achieve, ERL a major challenge but is very interesting due to synergy with many other projects.

All these projects need continuing accelerator R&D so that the right decision can be made when the time comes to identify the next energy frontier accelerator (collider). We need to keep our choices open.

NuPECC – Roadmap 5/2010: New Large-Scale Facilities

2010 2015 2020 2025

FAIR	PANDA	**R&D**	**Construction**	**Commissioning**	**Exploitation**	
	CBM	**R&D**	**Construction**	**Commissioning**	**Exploitation**	SIS300
	NuSTAR	**R&D**	**Construction**	**Commissioning**	**Exploit.**	NESR FLAIR
	PAX/ ENC	Design Study	R&D	Tests	Construction/Commissioning	Collider
SPIRAL 2		**R&D**	**Constr./Commission.**	**Exploitation**	150 MeV/u Post-accelerator	
HIE-ISOLDE		**Constr./Commission.**	**Exploitation**	Injector Upgrade		
SPES		**Constr./Commissio**[n.]				
EURISOL		Design Study	R&D	Preparatory Phase / Site Decision	Engineering Study	Construction
LHeC		Design Study	R&D	Engineering Study	Construction/Commissioning	

We are here: at the transition from Design Study to R&D

G. Rosner, NuPECC Chair, Madrid 5/10 – published in December 2010