Perspectives on DIS and the LHeC

DIS
Design Report
Relations to LHC and EIC
Next Steps

Max Klein (University of Liverpool)

XX Workshop on Deep Inelastic Scattering, Bonn, 30.3.2012

A summary of the LHeC Conceptual Design Report, not of the Workshop. Future session: E.Aschenauer and P.Newman

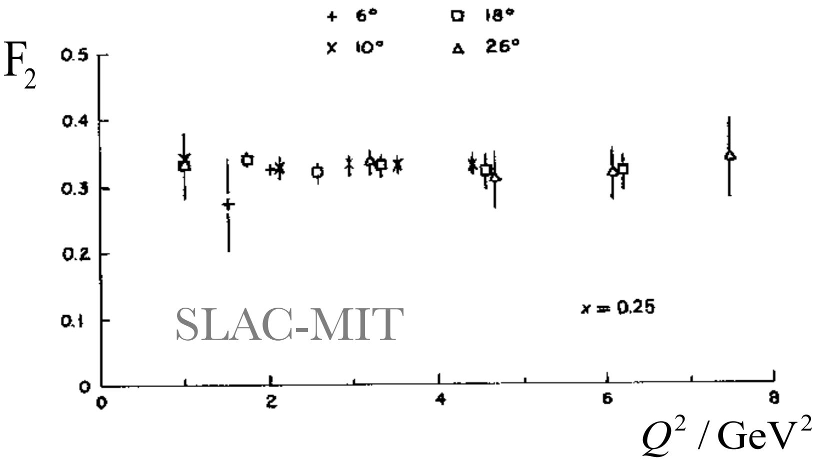
I. Deep Inelastic Scattering

2 mile LINAC at Stanford ("a bold extrapolation of existing technology" – R.Taylor)

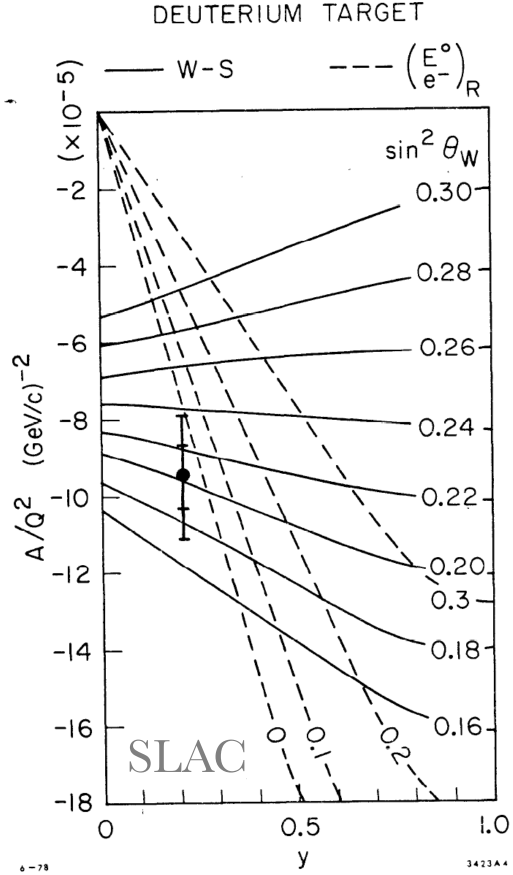
DIS → $SU_{2,L}$ x U_1 x $SU_{3,c}$

PV: Q_W
$I_3^R(e)=0$

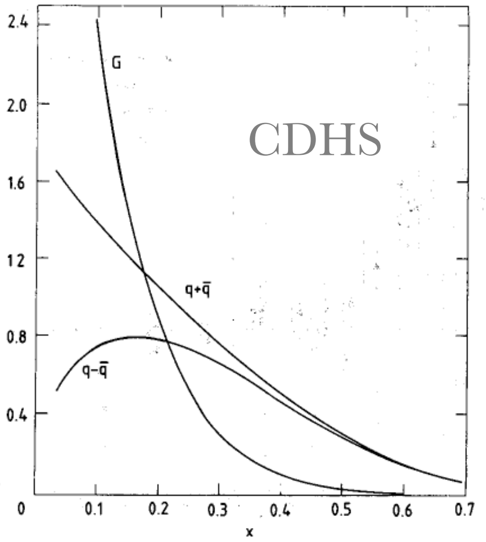
Scaling:
Partons



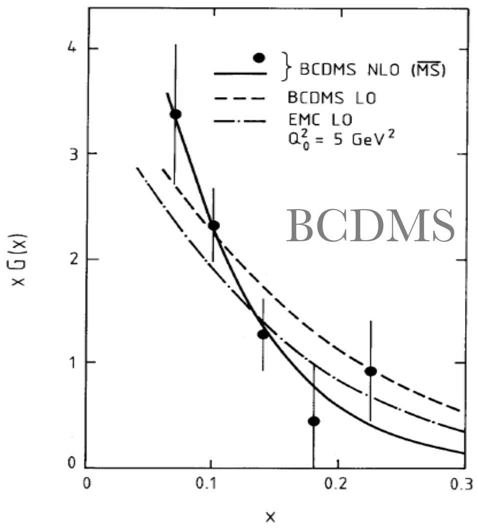
SLAC/GGM
0.29±0.05
$=(e_u^2+e_d^2)/2$



Valence and Sea



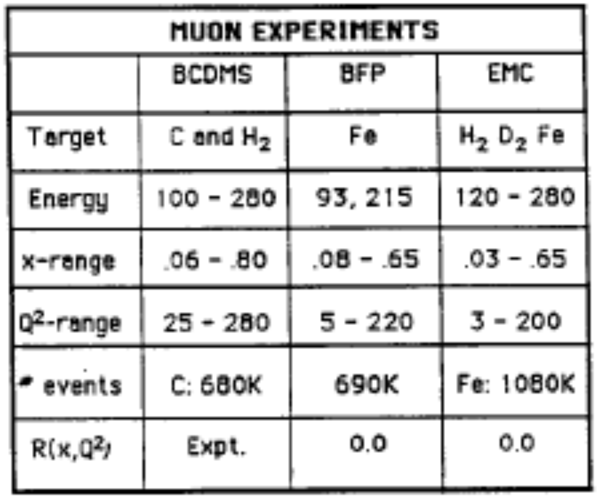
Scaling Violation - Gluon



α_s≅0.113 (AM+MV)

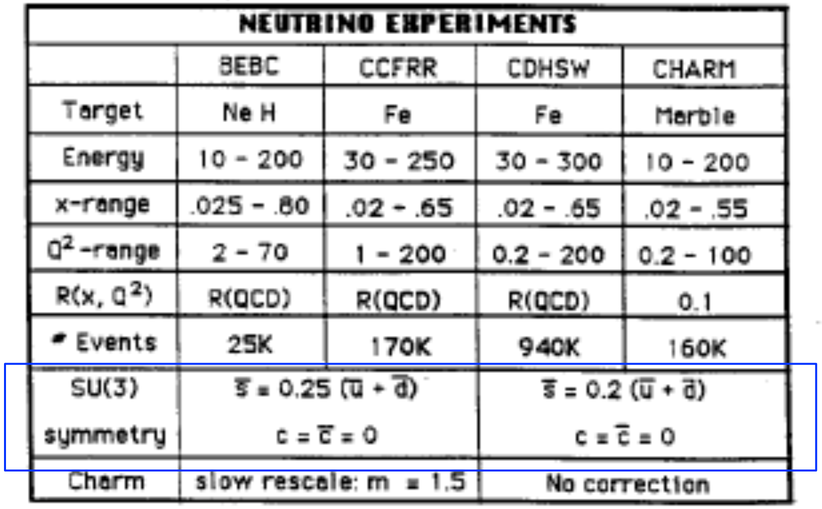
Many DIS experiments
in the US and Europe
were crucial to establish
the SM gauge theory.
No problem to justify
10 experiments …

Before HERA (1989)



MUON EXPERIMENTS			
	BCDMS	BFP	EMC
Target	C and H_2	Fe	H_2 D_2 Fe
Energy	100 - 280	93, 215	120 - 280
x-range	.06 - .80	.08 - .65	.03 - .65
Q^2-range	25 - 280	5 - 220	3 - 200
# events	C: 680K	690K	Fe: 1080K
$R(x,Q^2)$	Expt.	0.0	0.0

Table III-1: Major recent Muon Experiments.



NEUTRINO EXPERIMENTS				
	BEBC	CCFRR	CDHSW	CHARM
Target	Ne H	Fe	Fe	Marble
Energy	10 - 200	30 - 250	30 - 300	10 - 200
x-range	.025 - .80	.02 - .65	.02 - .65	.02 - .55
Q^2-range	2 - 70	1 - 200	0.2 - 200	0.2 - 100
$R(x, Q^2)$	R(QCD)	R(QCD)	R(QCD)	0.1
# Events	25K	170K	940K	160K
SU(3) symmetry	$\bar{s} = 0.25\,(\bar{u} + \bar{d})$ $c = \bar{c} = 0$		$\bar{s} = 0.2\,(\bar{u} + \bar{d})$ $c = \bar{c} = 0$	
Charm	slow rescale: m = 1.5		No correction	

Table III-2: Major recent charged-current Neutrino Experiments.

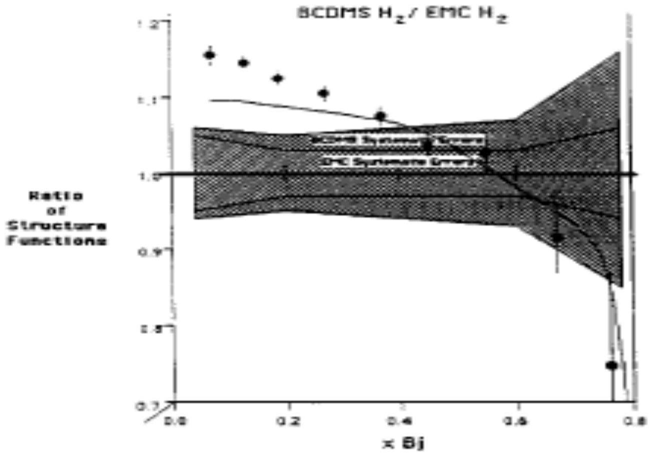
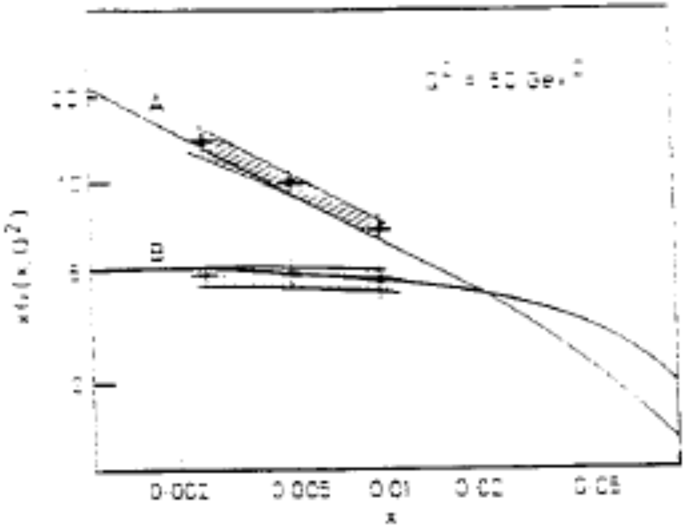


Fig.III-6: The Ratio of $F^2(x,Q)$ measured by BCDMS and EMC on hydrogen target (see text).

The anticipated resolving power



FERMILAB-Conf-89/26

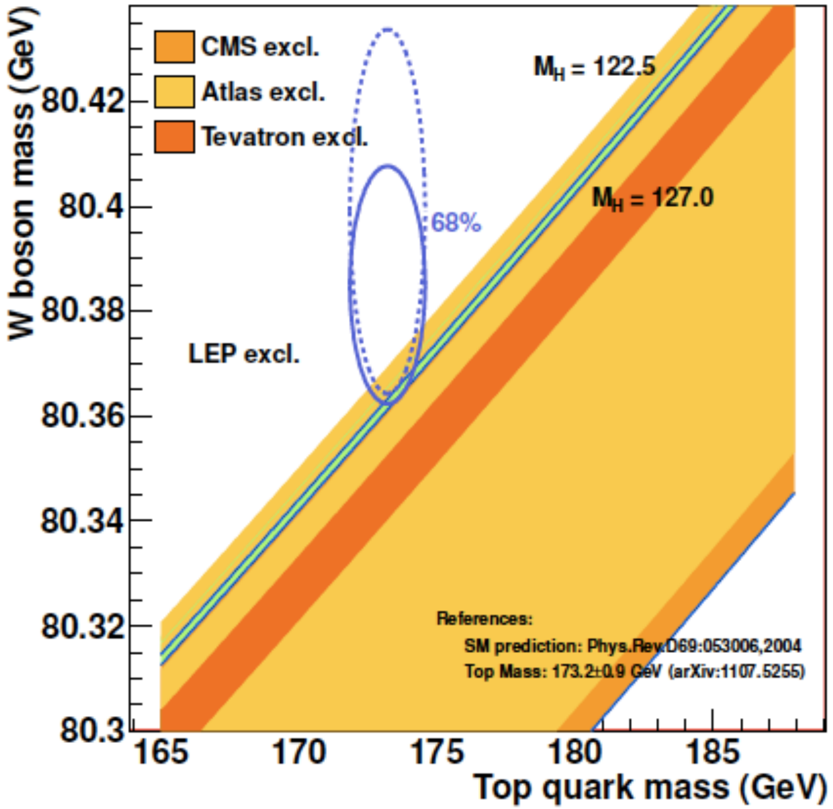
Wu-Ki Tung[a,b,c], J. G. Morfín[b], H. Schellman[b], S. Kunori[d], A. Caldwell[e], F. Olness[f]

Colliders explored the Fermi Energy Scale

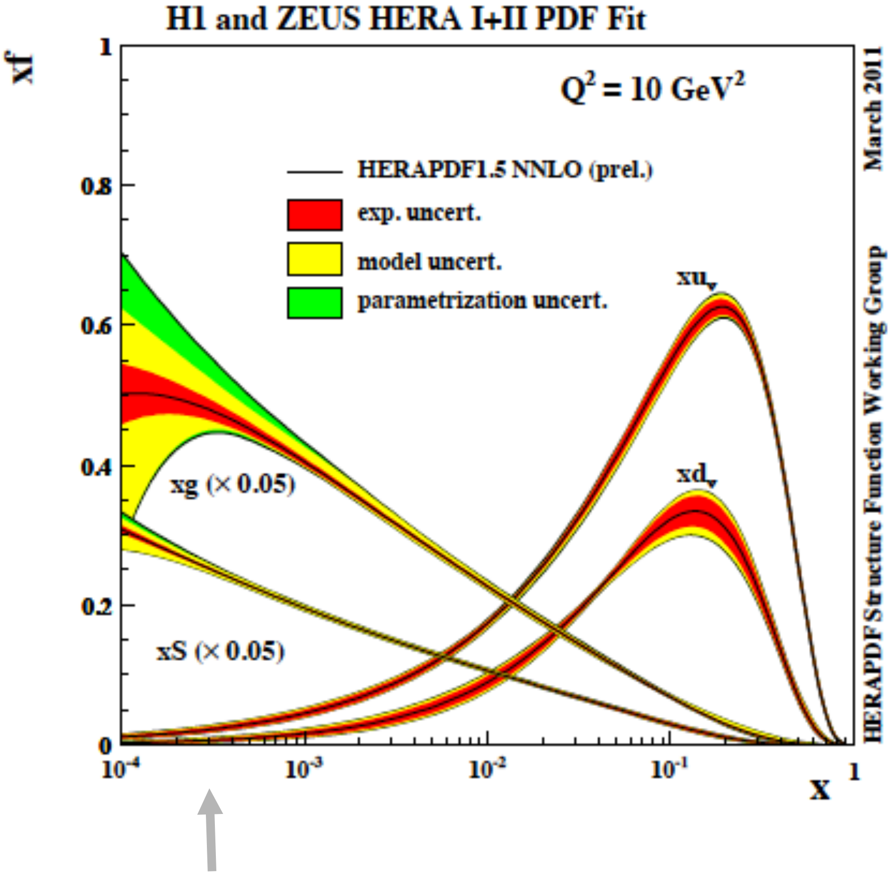
Tevatron to find SUSY and BSM; **LEP/SLC** to find SUSY and the Higgs; **HERA** to find Lepto-Quarks

probable legacy plots/numbers

NNLO!



R.Lopes de Sa (Moriond 11.3.12)



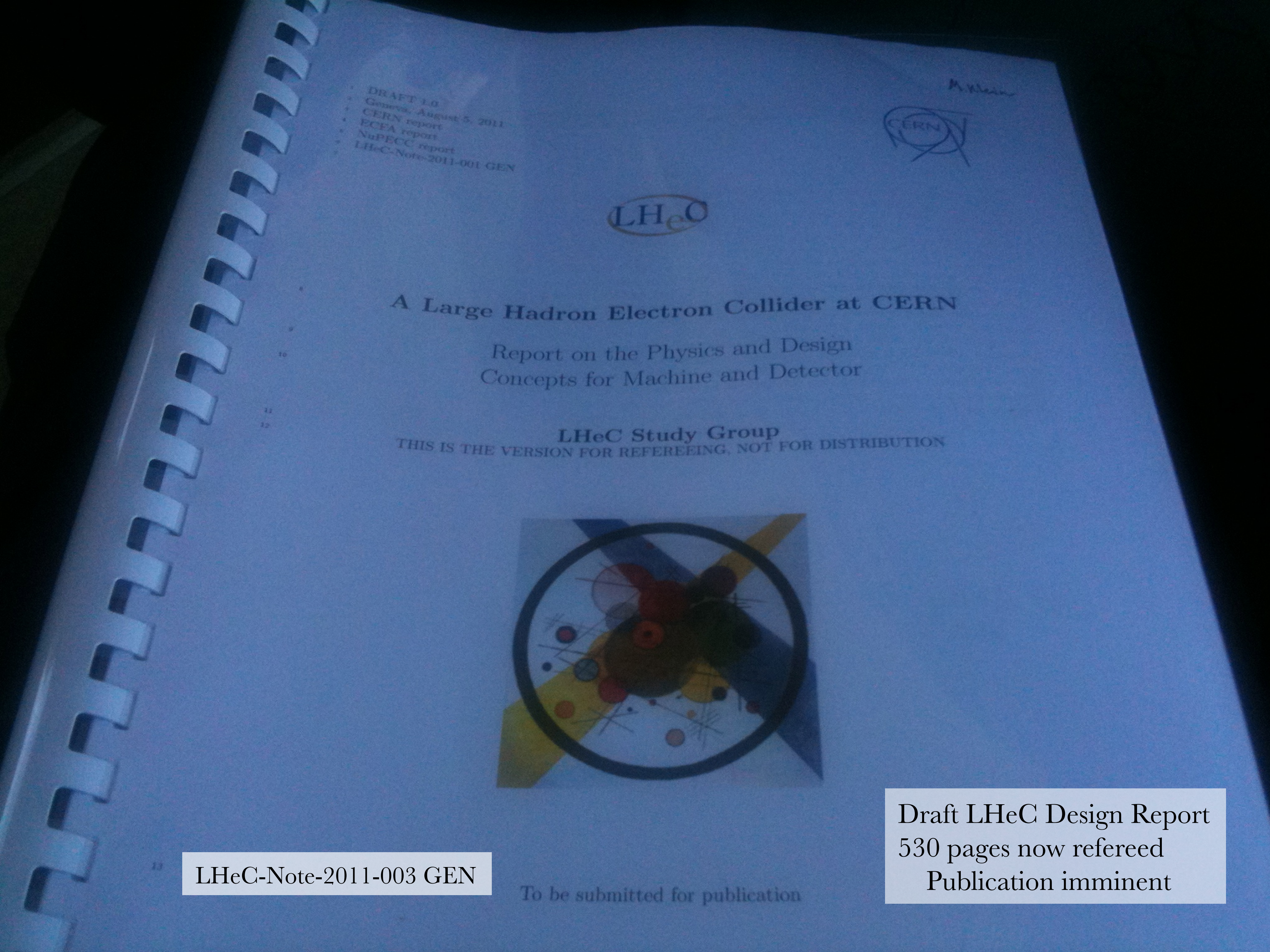
M_Z=91.1876±0.0021 GeV (PDG2010)

Practical end of HERA xg sensitivity

II. Conceptual Design of the LHeC

Project
Physics
Accelerator
Detector

LHeC Talks at this workshop
N.Armesto, A,Bunyatian, O.Behnke, R.Godbole, P.Newman, A.Polini, D.Schulte, A.Stasto, R.Tomas



M.Klein

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

LHeC

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

LHeC-Note-2011-003 GEN

Draft LHeC Design Report
530 pages now refereed
Publication imminent

“BFKL evolution and Saturation in DIS”

“Critical gravitational collapse”

Circles in a circle
V. Kandinsky, 1923
Philadelphia Museum of Art

5d tiny black holes and perturbative saturation
Talk by A.S.Vera at LHeC Workshop 2008

http://cern.ch/lhec

LHeC Study Group

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About 180 Experimentalists and Theorists from 60 Institutes
Tentative **list of those who contributed to the CDR**

Supported by
CERN, ECFA, NuPECC

Project Development

2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)
3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)
NuPECC puts LHeC to its Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
refereed and being updated

2012: Discussion of LHeC at LHC Machine Workshop (Chamonix)
Publication of CDR – European Strategy
New workshop (June14-15, 2012)

Organisation for CDR

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Linac Ring Design
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Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

Why an ep/A Experiment at TeV Energies?

1. For resolving the quark structure of the nucleon with p, d and ion beams

   QPM symmetries, quark distributions (complete set from data!), GPDs, nPDFs, γ..

2. For the development of perturbative QCD

   N^kLO ($k \geq 2$) and h.o. eweak, HQs, jets, resummation, factorisation, diffraction

3. For mapping the gluon field

   Gluon for $\sim 10^{-5} < x < 1$, J/ψ , $F_2^{c,b}$, … unintegrated gluon

4. For searches and the understanding of new physics

   GUT (α_s to 0.1%), LQs RPV, Higgs, PDFs4LHC, top in DIS, instanton, odderon,..?

5. For investigating the physics of parton saturation

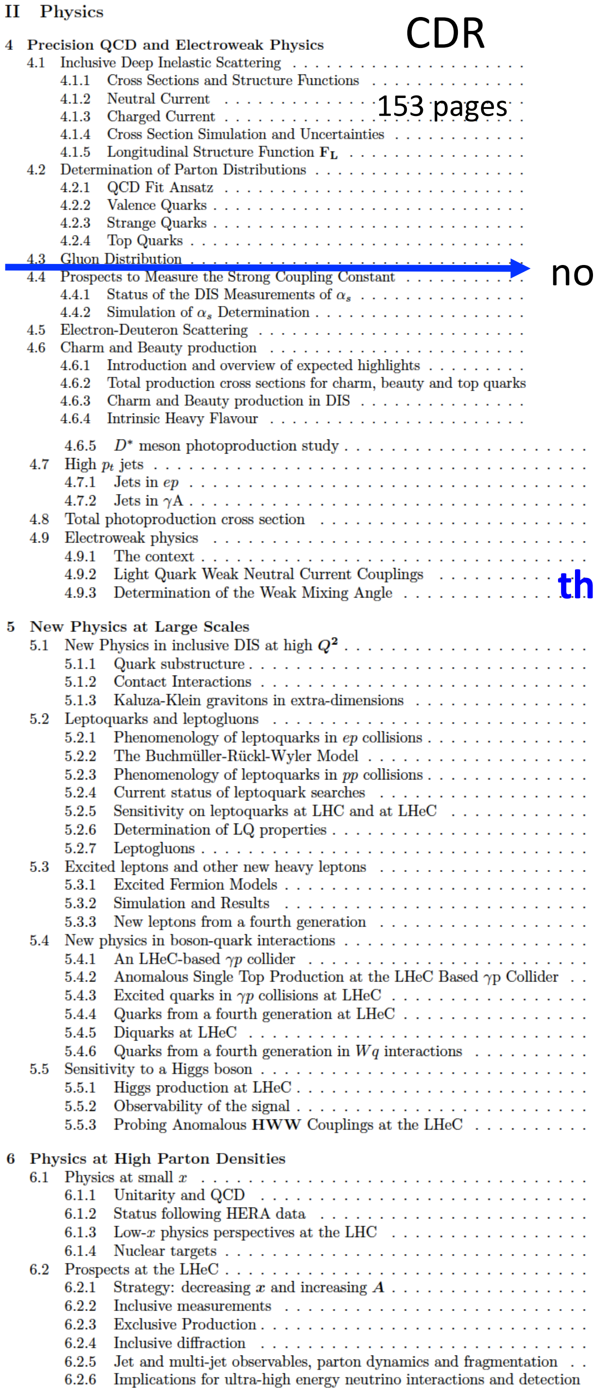
   Non-pQCD (chiral symm. breaking, confinement), black disc limit, saturation border..

..For providing data which could be of use for future experiments [Proposal for SLAC ep 1968]

Gluon Distribution

CDR

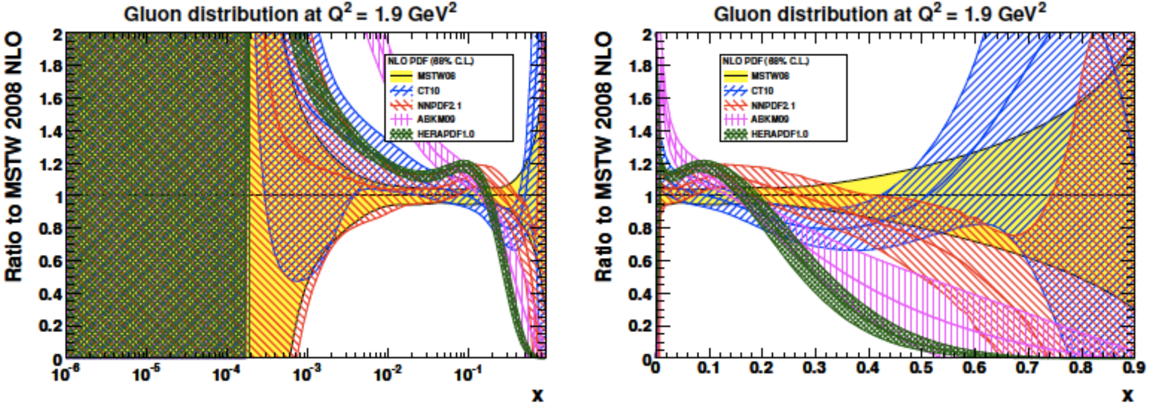
153 pages



II Physics

now

then



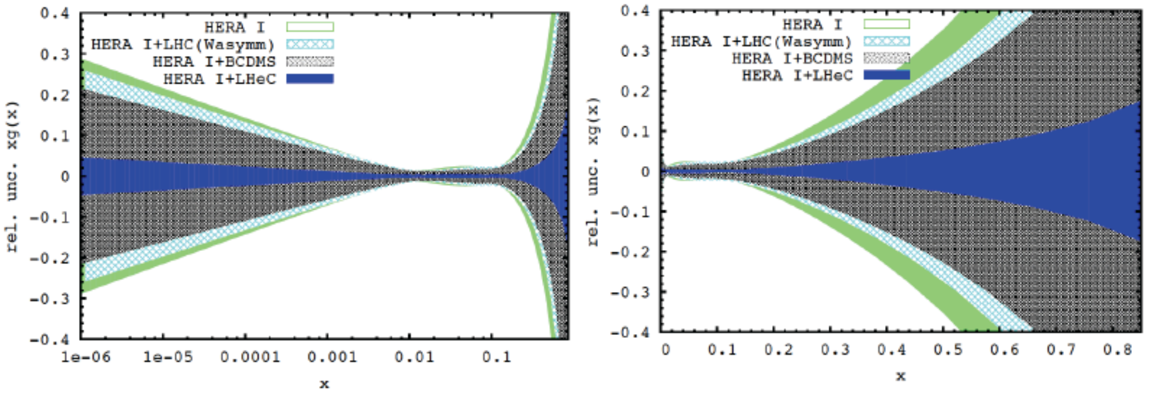


Figure 4.17: Relative uncertainty of the gluon distribution at $Q^2 = 1.9\,\text{GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Left: logarithmic x, right: linear x.

Precision measurement of gluon density to extreme x → α_s
Low x: saturation in ep? Crucial for QCD, LHC, UHE neutrinos!
High x: xg and valence quarks: resolving new high mass states!
Gluon in Pomeron, odderon, photon, nuclei.. Local spots in p?
Heavy quarks intrinsic or only gluonic?

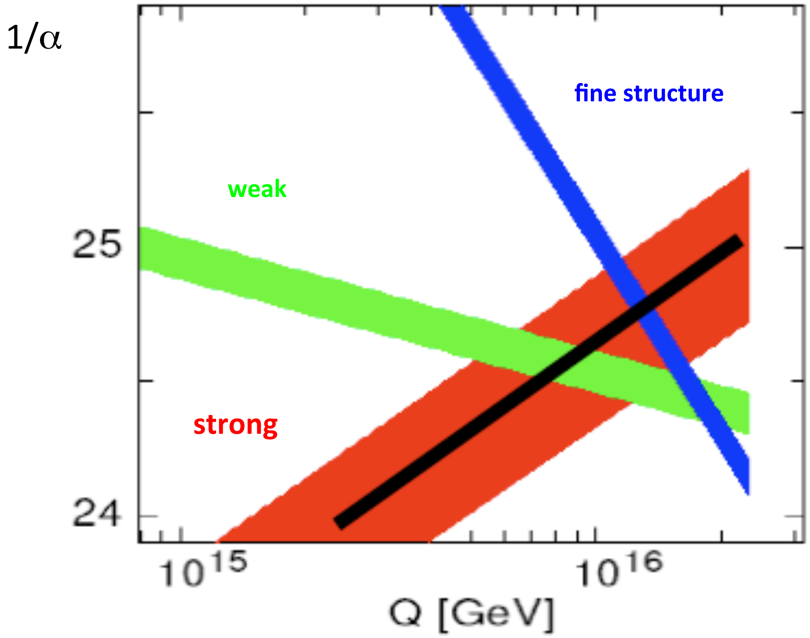
Strong Coupling Constant

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

DIS tends to be lower than world average
Recently challenged by MSTW and NNPDF – jets??

LHeC: per mille - independent of BCDMS.

Challenge to experiment and to h.o. QCD →
A genuine DIS research programme rather than
one outstanding measurement only.

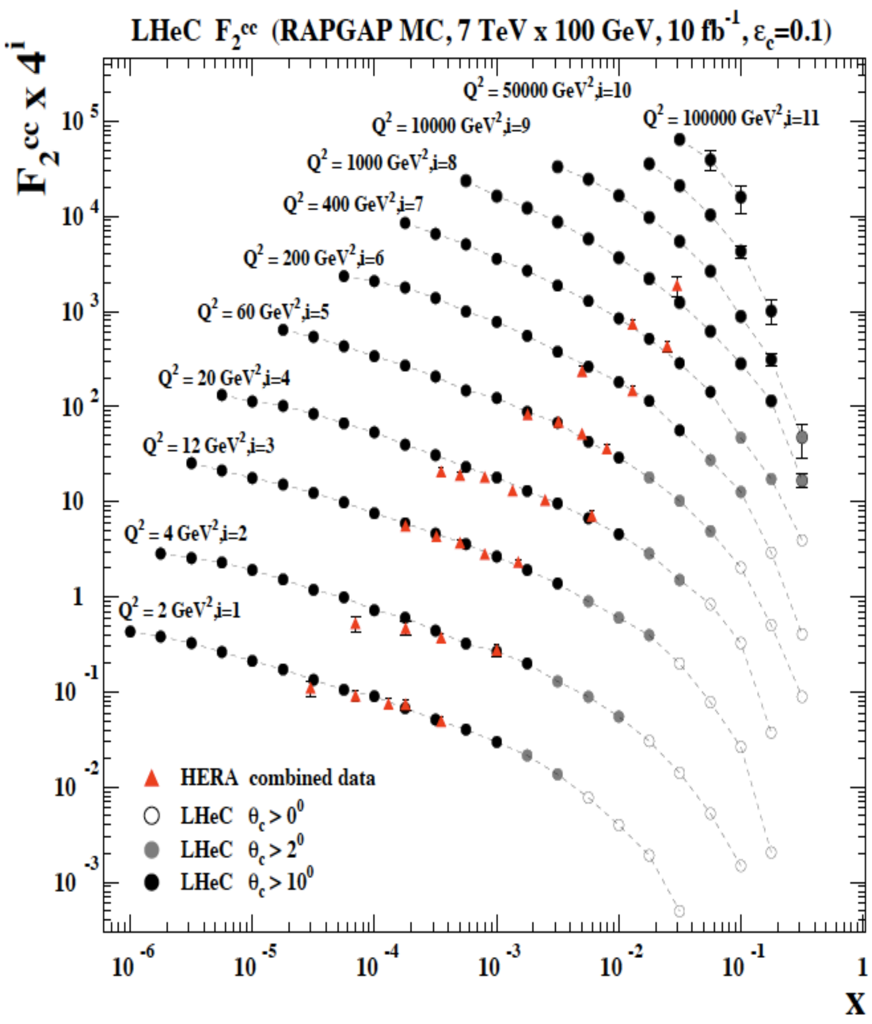


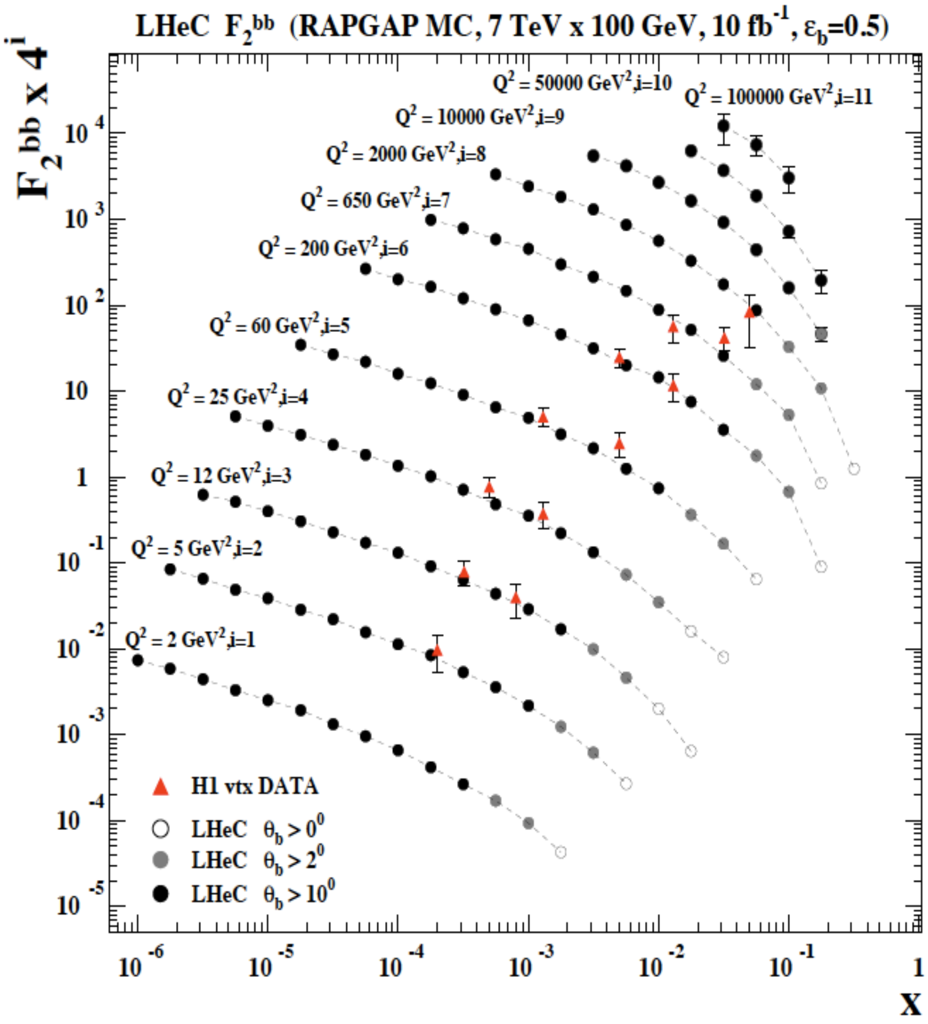
case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

Two independent QCD analyses using LHeC+HERA/BCDMS

DATA	exp. error on α_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%

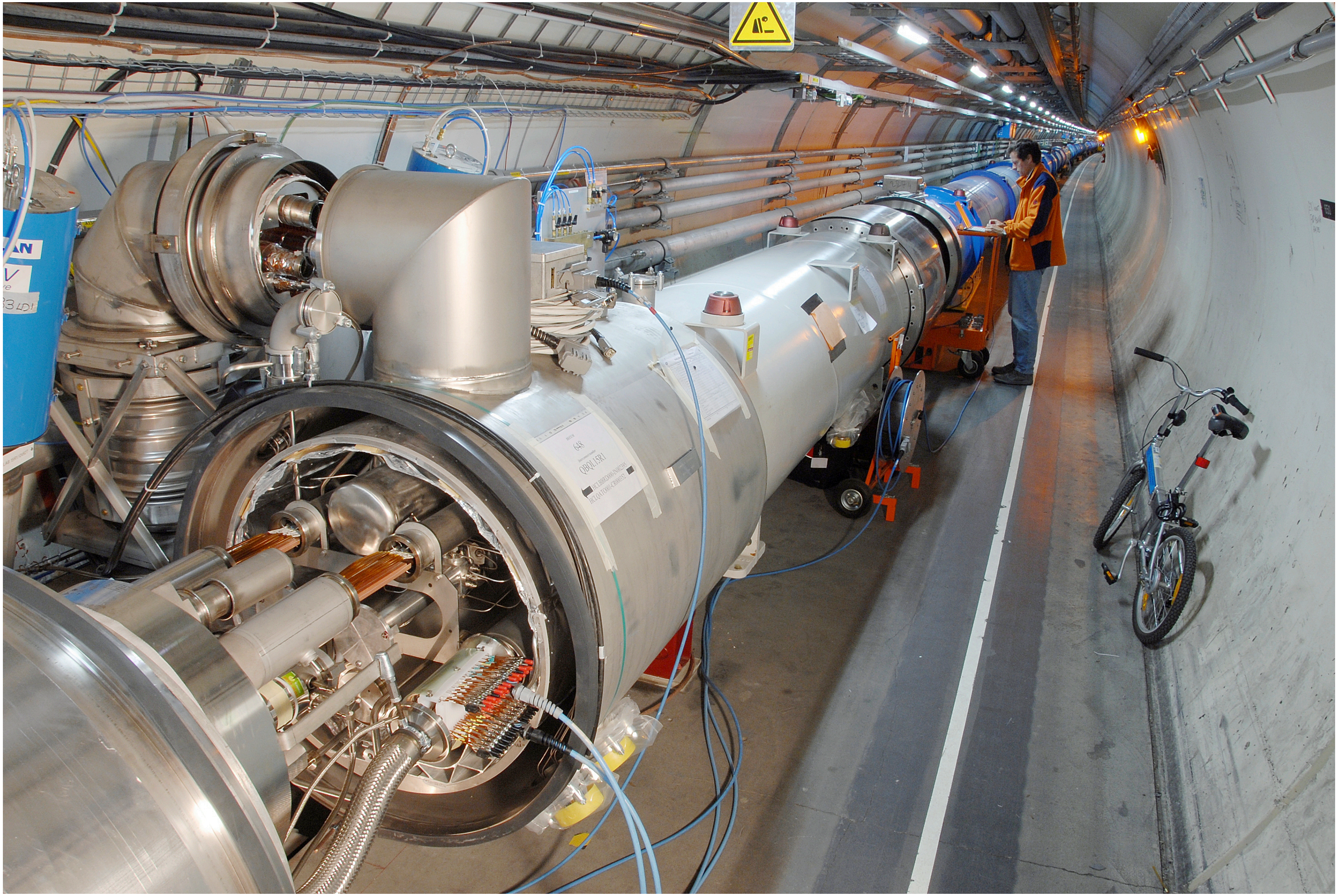
F_2^{charm} and F_2^{beauty} from LHeC





Hugely extended range and much improved precision
will pin down heavy quark behaviour at and away from thresholds

How can we use the LHC for ep/A?



S.Russenschuck

L vs E_e

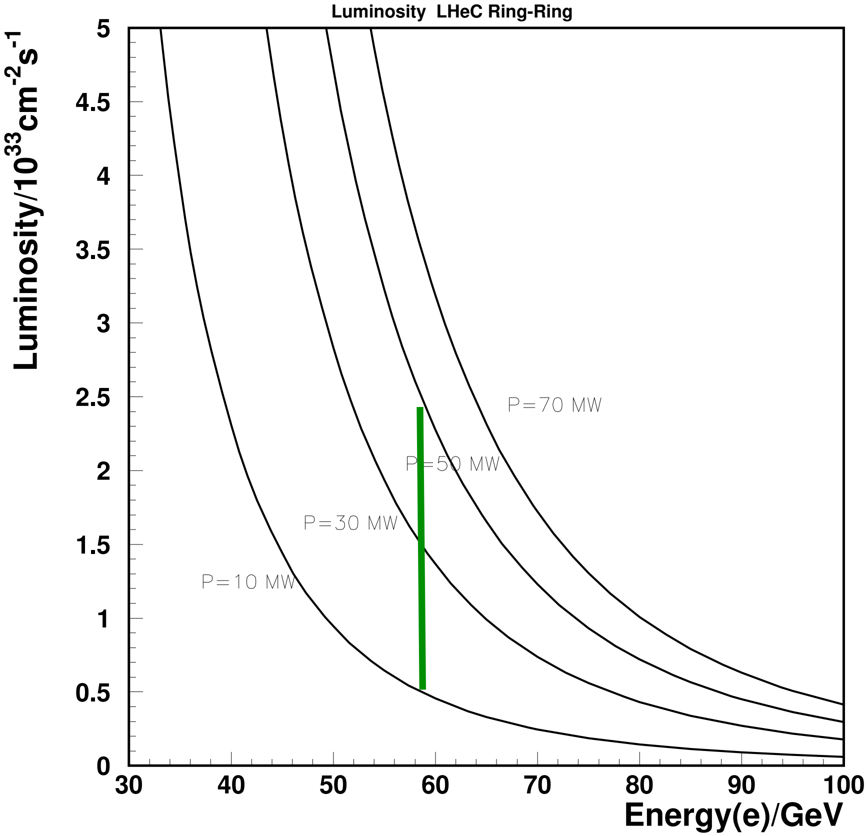
Storage Ring

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

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

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

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



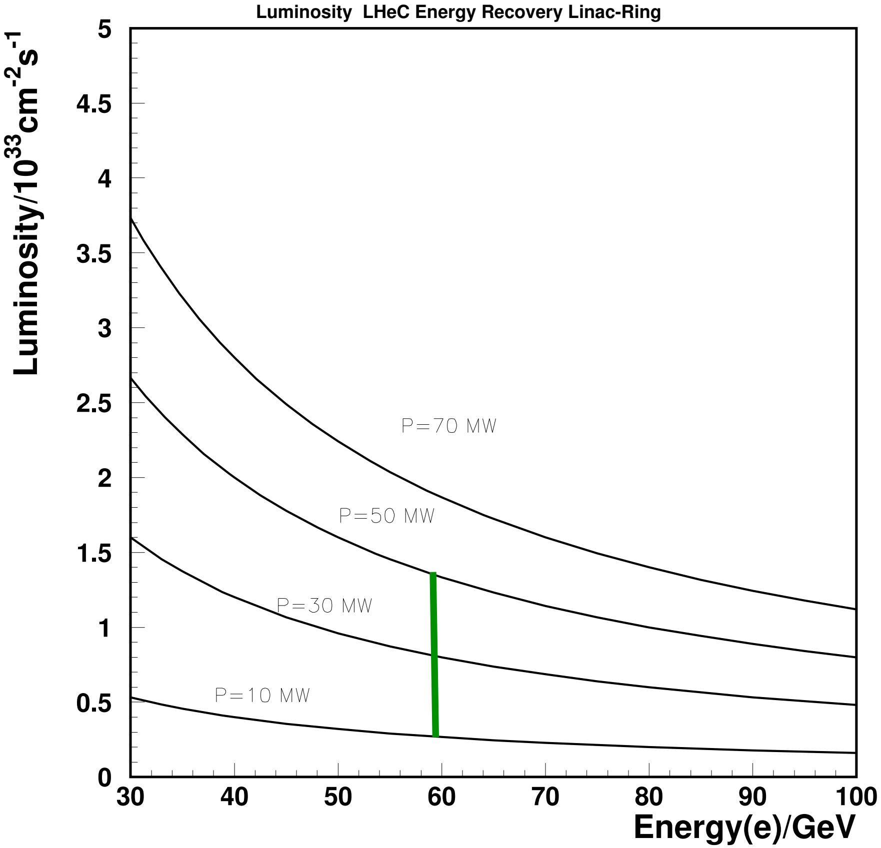
Energy Recovery Linac

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

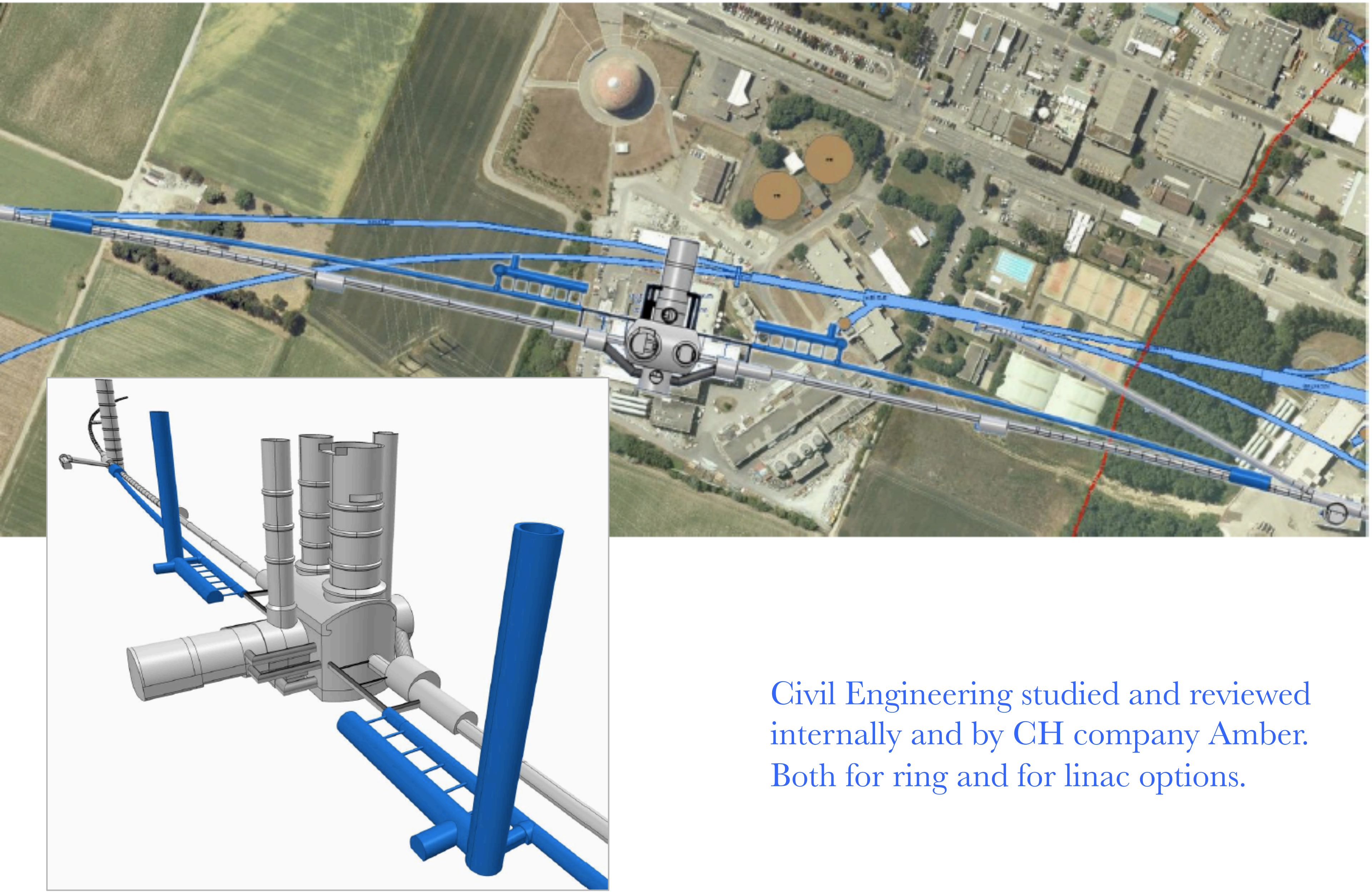
$$N_p = 1.7\cdot 10^{11}, \varepsilon_p = 3.8\mu m, \beta^* = 0.2m, \gamma = 7000/0.94$$

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

$$I_e = mA\frac{P_E/MW}{E_e/GeV}, P_E = P/(1-\eta), \eta \approx 0.95$$

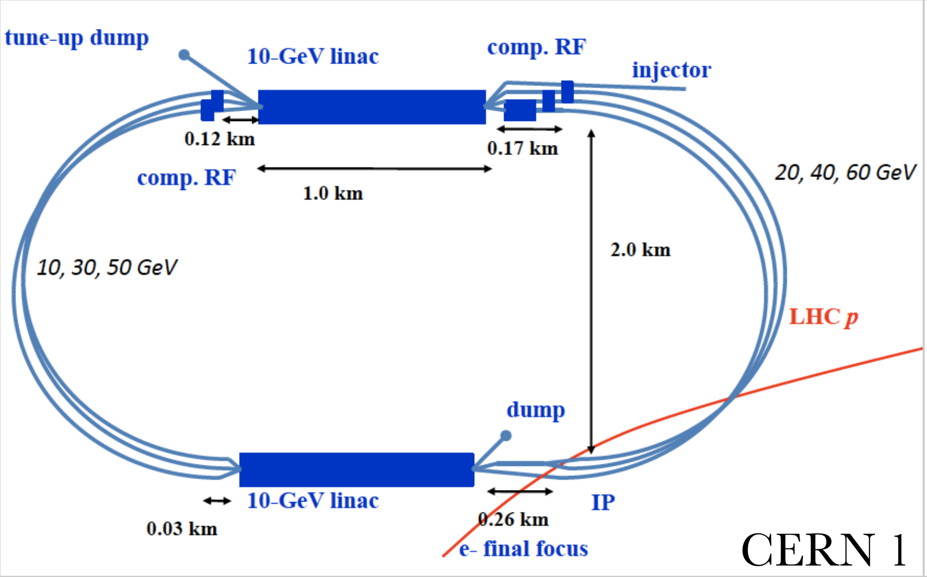


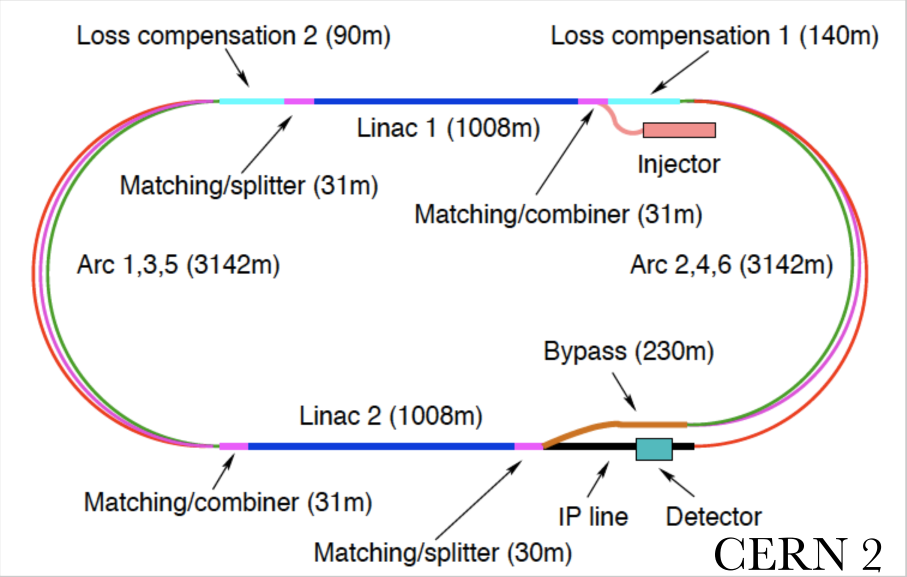
Bypassing ATLAS

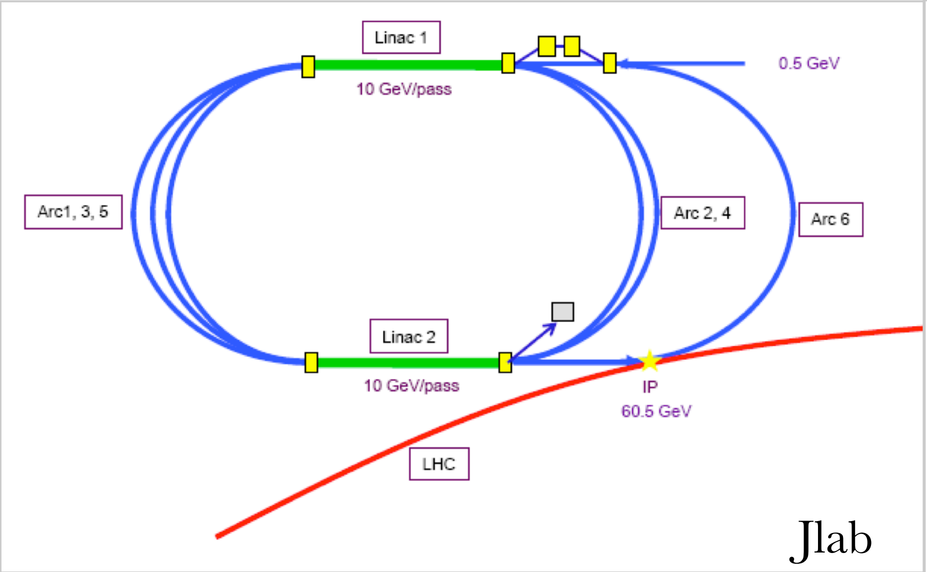


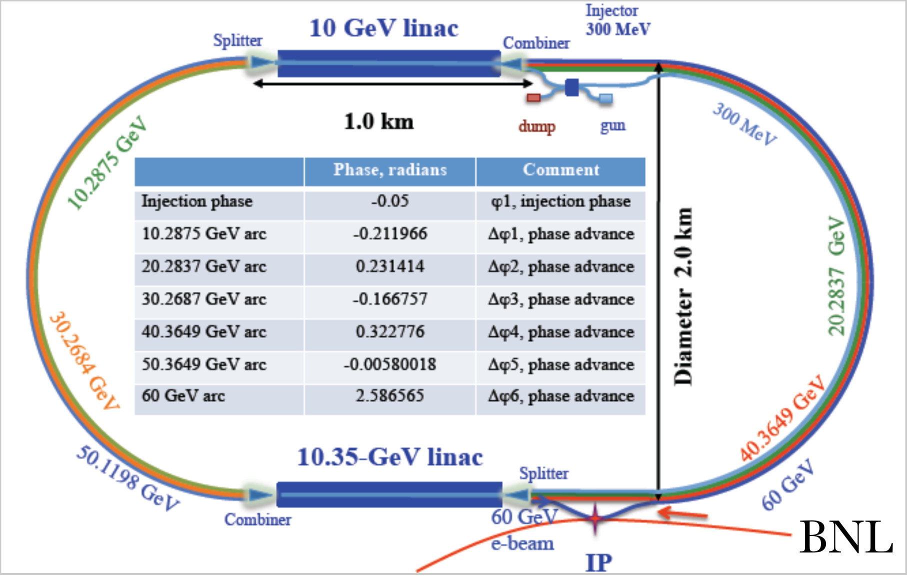
Civil Engineering studied and reviewed internally and by CH company Amber. Both for ring and for linac options.

60 GeV Energy Recovery Linac





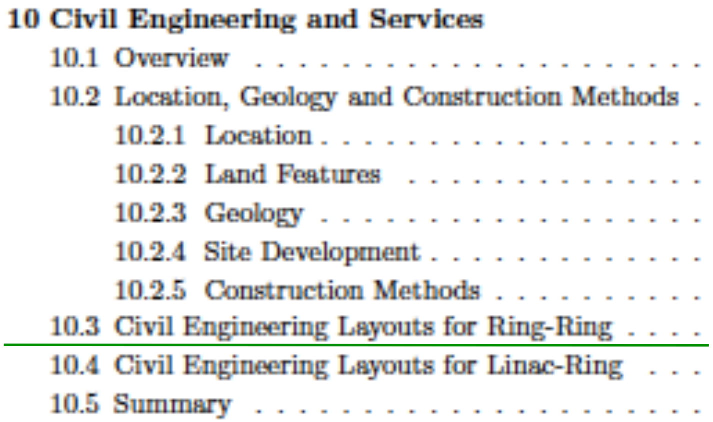




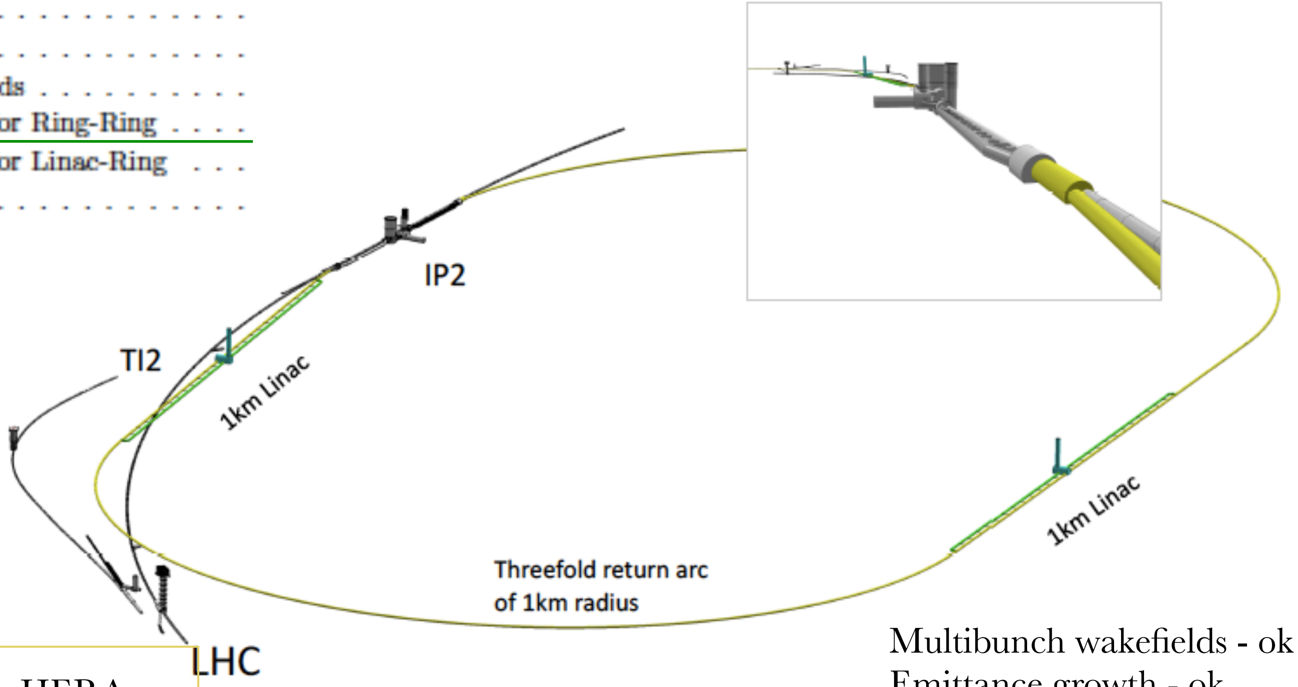
	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc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

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

Linac Characteristics



10 Civil Engineering and Services

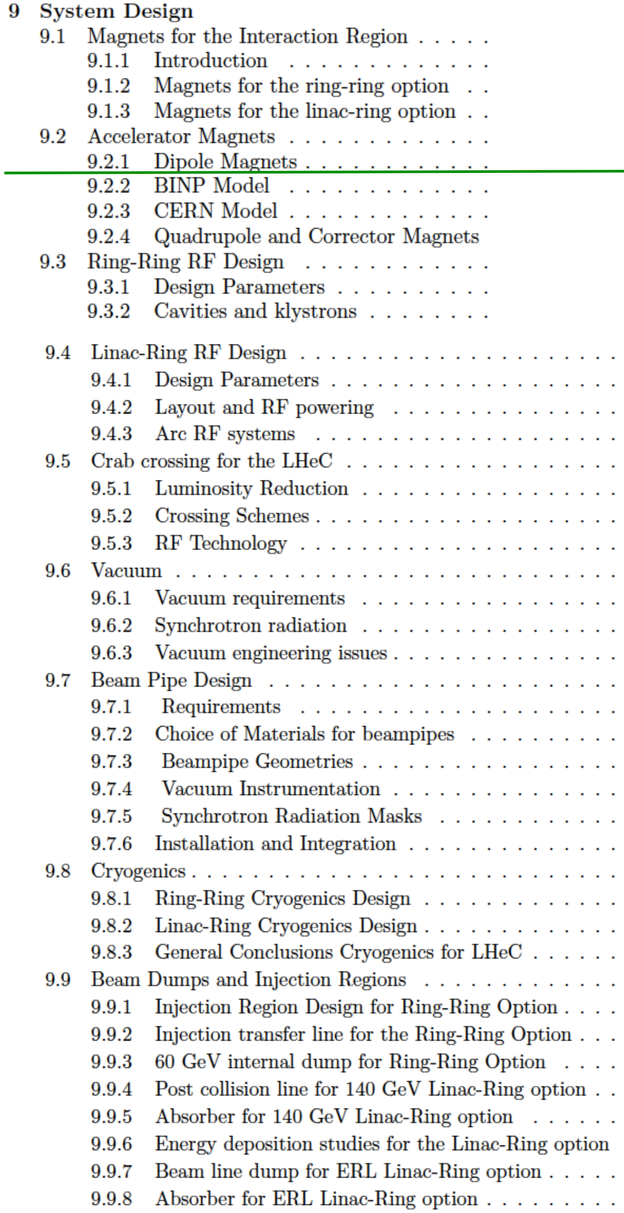


$U_{LHeC}=U_{LHC}/3$: 1.5 x HERA
Tunneling: 150m per week – 60 weeks
Two 1km linacs with 59 cryomodules
of 8 cavities each → 1000 cavities

Multibunch wakefields - ok
Emittance growth - ok
[ILC 10nm, LHeC 10 μ m]
36 σ separation at 3.5m - ok
Fast ion instability - probably ok
with clearing gap (1/3)

Figure 10.11: View on the ERL placed inside the LHC ring and tangential to IP2. TI2 is the injection line into the LHC. The insert shows the view towards IP2, which currently houses the ALICE experiment, from the direction of the protons colliding with the electron beam incoming from behind.

Accelerator Systems



Magnets

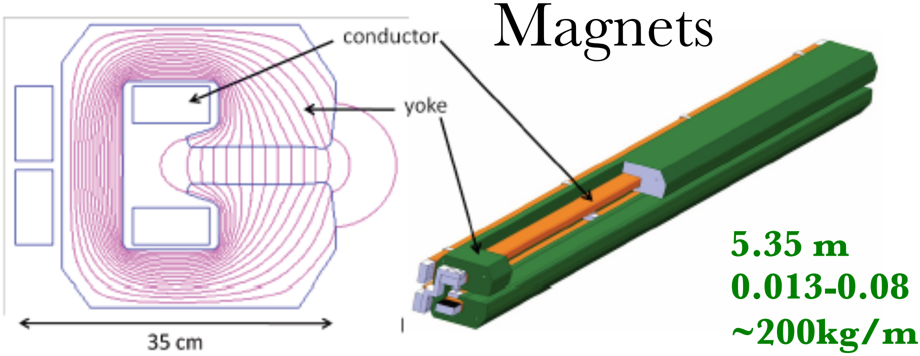
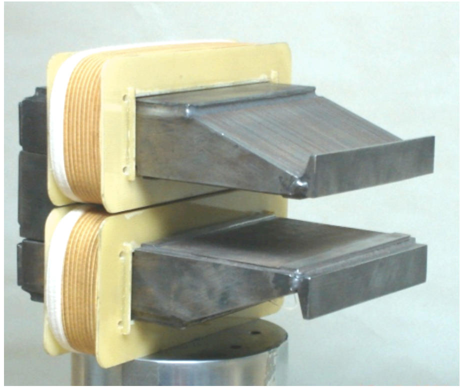
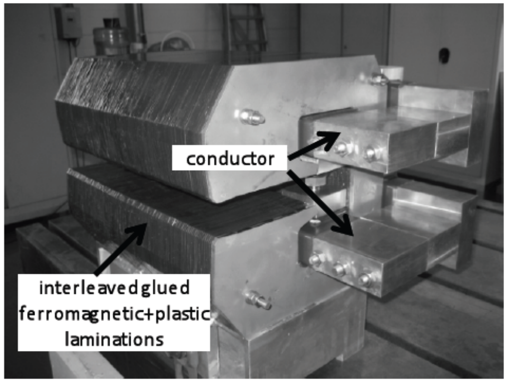


Fig. 2. Field lines and artistic view of a LHeC arc dipole.

5.35 m
0.013-0.08 T
~200kg/m





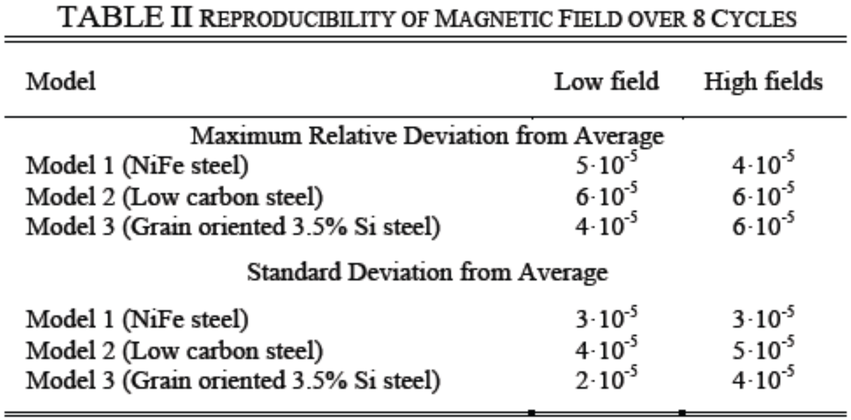
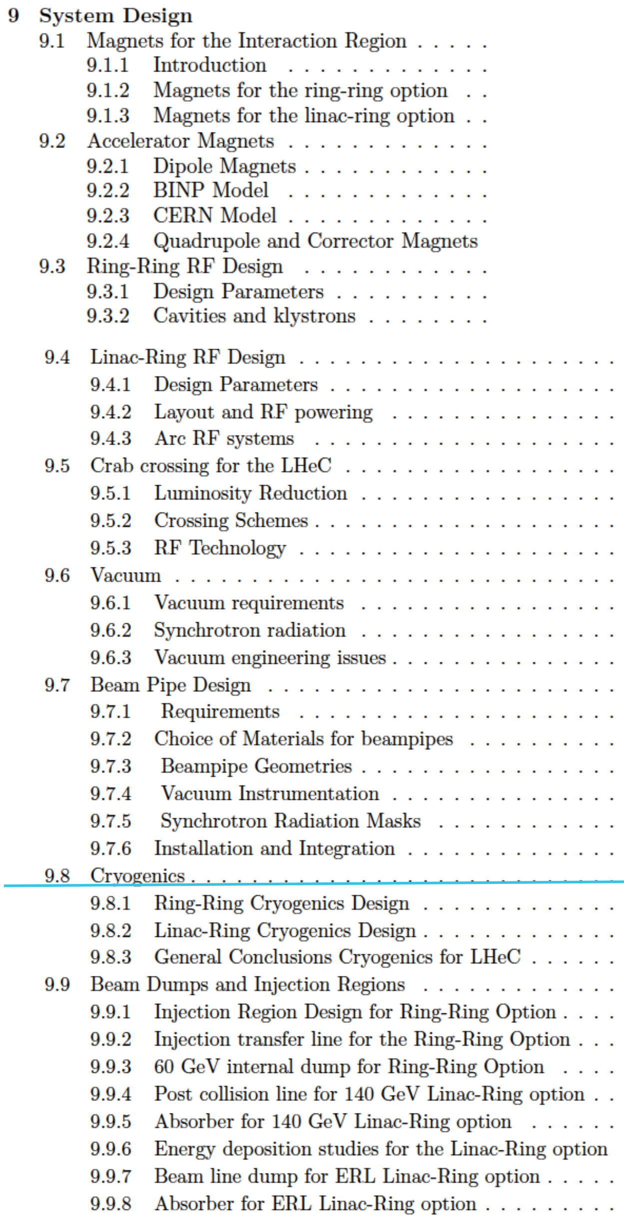


TABLE II REPRODUCIBILITY OF MAGNETIC FIELD OVER 8 CYCLES

Model	Low field	High fields
Maximum Relative Deviation from Average		
Model 1 (NiFe steel)	$5 \cdot 10^{-5}$	$4 \cdot 10^{-5}$
Model 2 (Low carbon steel)	$6 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
Model 3 (Grain oriented 3.5% Si steel)	$4 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
Standard Deviation from Average		
Model 1 (NiFe steel)	$3 \cdot 10^{-5}$	$3 \cdot 10^{-5}$
Model 2 (Low carbon steel)	$4 \cdot 10^{-5}$	$5 \cdot 10^{-5}$
Model 3 (Grain oriented 3.5% Si steel)	$2 \cdot 10^{-5}$	$4 \cdot 10^{-5}$

Prototypes from BINP and CERN: function to spec's

Components and Cryogenics



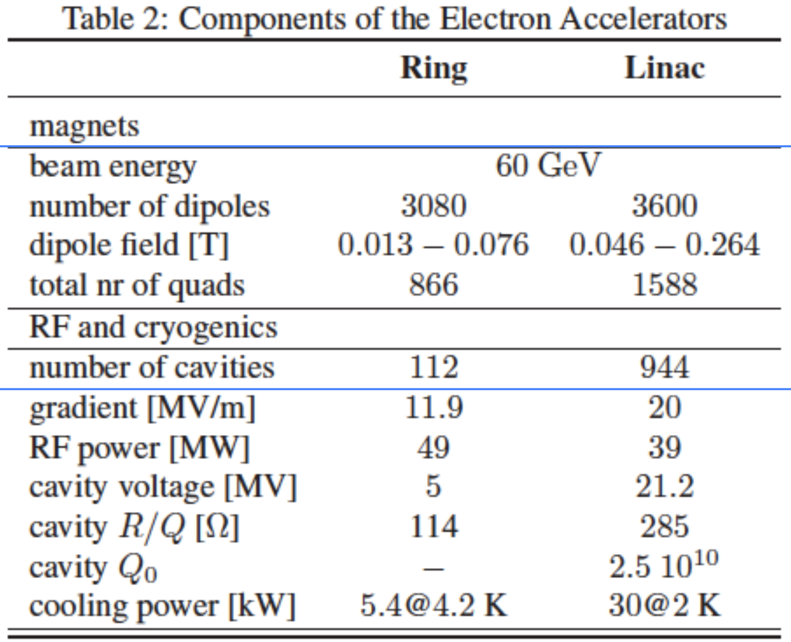
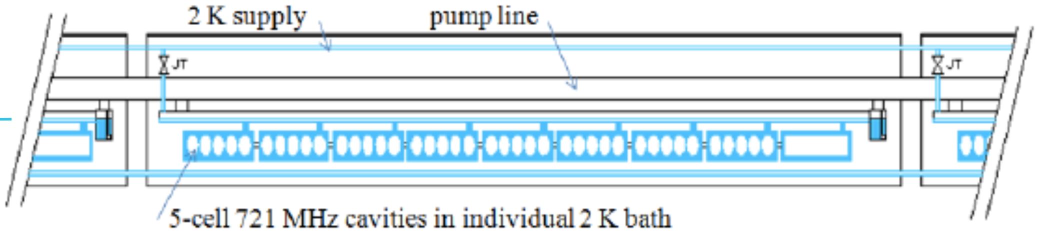
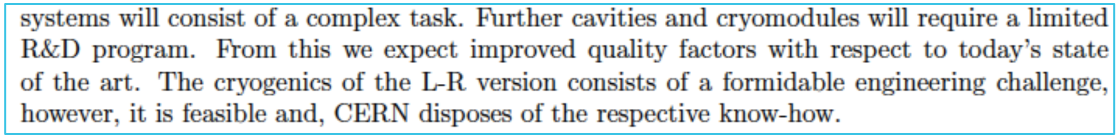


Table 2: Components of the Electron Accelerators

	Ring	**Linac**
magnets		
beam energy	60 GeV	
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	21.2
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K



5-cell 721 MHz cavities in individual 2 K bath



systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.

from CDR LHeC

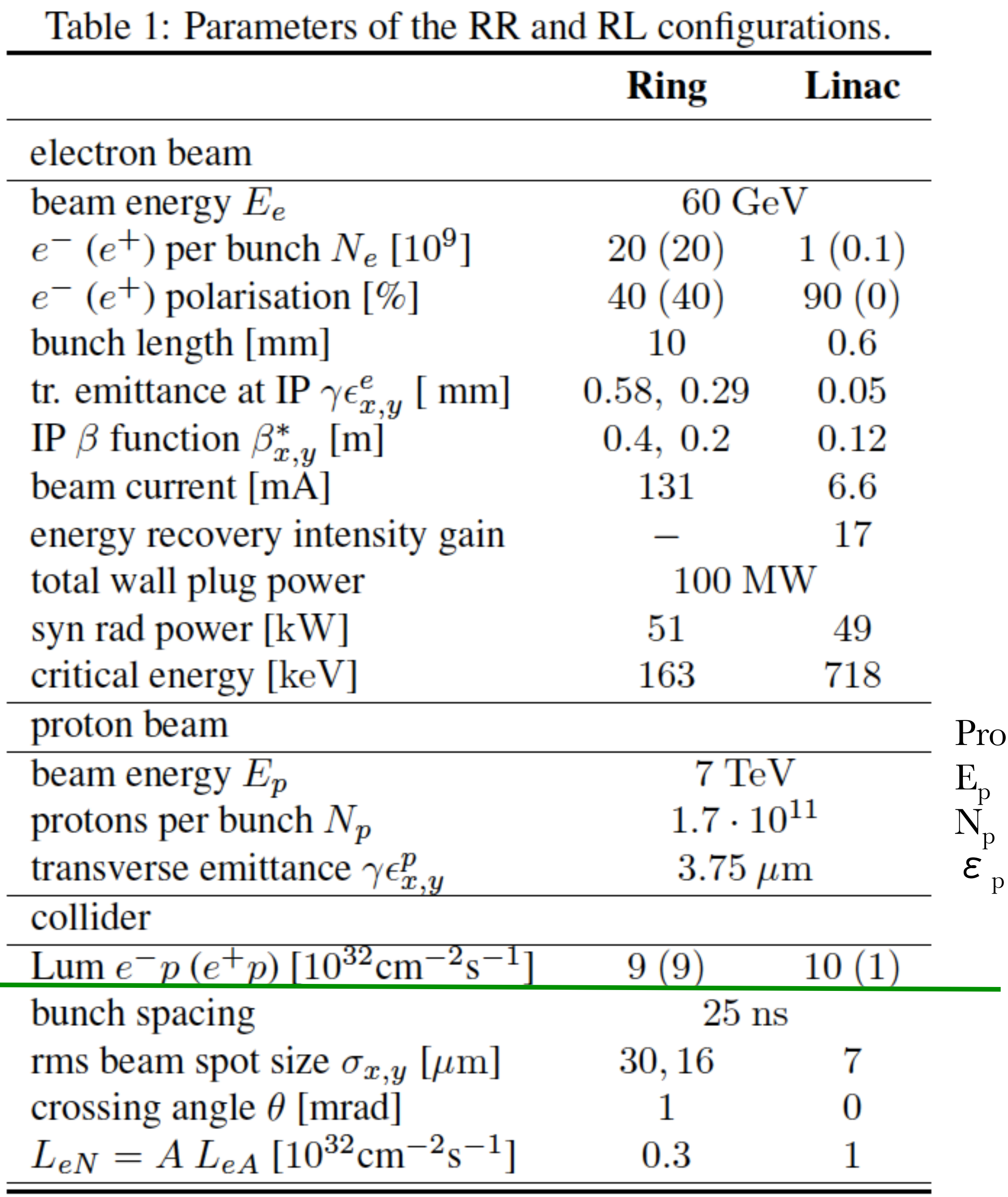


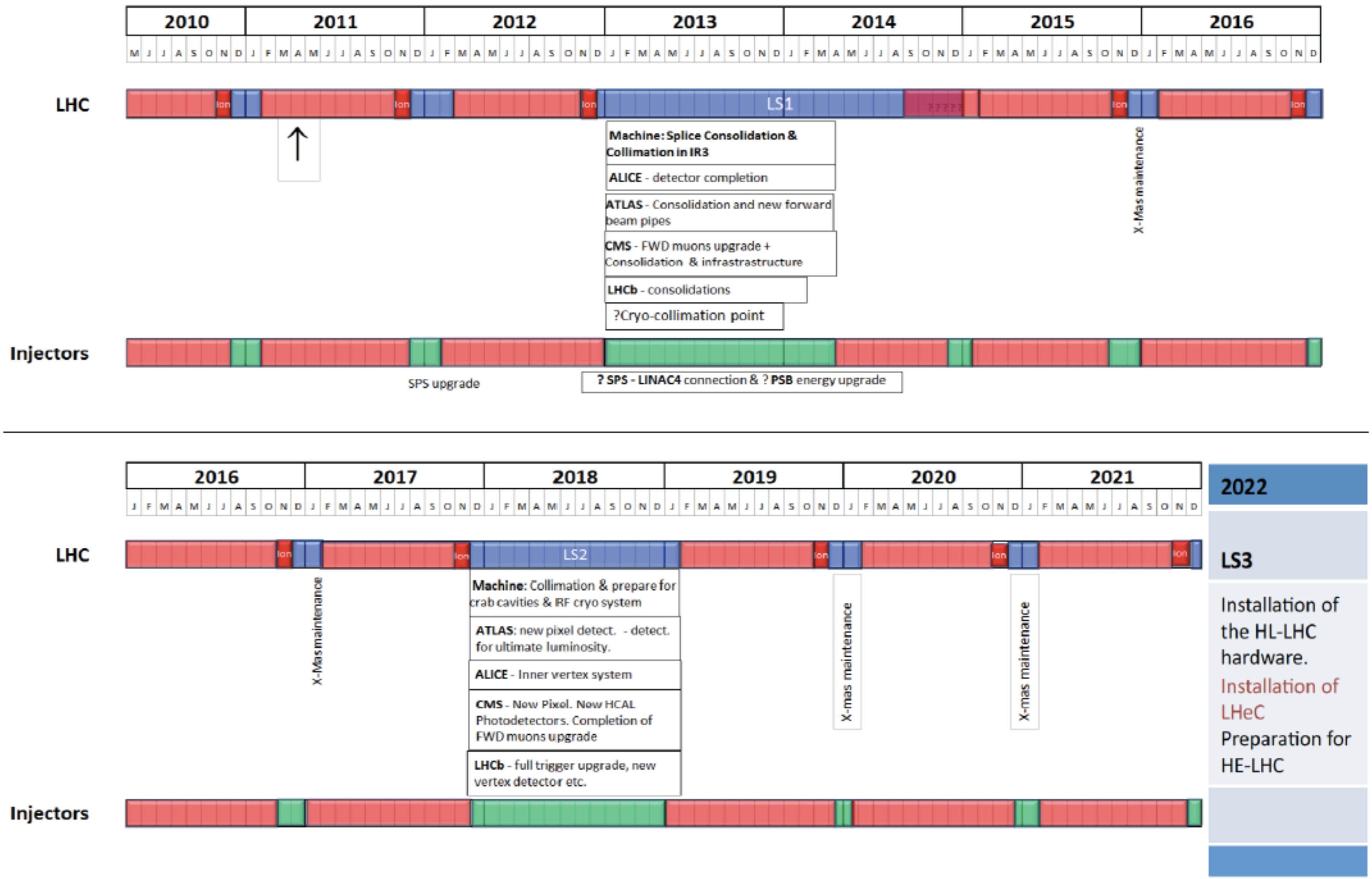
Table 1: Parameters of the RR and RL configurations.

	Ring	**Linac**
electron beam		
beam energy E_e	60 GeV	
e^- (e^+) per bunch N_e [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	100 MW	
syn rad power [kW]	51	49
critical energy [keV]	163	718
proton beam		
beam energy E_p	7 TeV	
protons per bunch N_p	$1.7 \cdot 10^{11}$	
transverse emittance $\gamma\epsilon^p_{x,y}$	3.75 μm	
collider		
Lum e^-p (e^+p) [10^{32}cm^{-2}s^{-1}]	9 (9)	10 (1)
bunch spacing	25 ns	
rms beam spot size $\sigma_{x,y}$ [μm]	30, 16	7
crossing angle θ [mrad]	1	0
$L_{eN} = A\, L_{eA}$ [10^{32}cm^{-2}s^{-1}]	0.3	1

Linac has real γ beam option

Proton beam parameters:
E_p perhaps 6.5 TeV
N_p almost achieved
ε_p already lower in 2011

Draft LHC Schedule for the coming decade



Machine: Splice Consolidation & Collimation in IR3

ALICE - detector completion

ATLAS - Consolidation and new forward beam pipes

CMS - FWD muons upgrade + Consolidation & infrastructure

LHCb - consolidations

?Cryo-collimation point

? SPS - LINAC4 connection & ? **PSB** energy upgrade

Machine: Collimation & prepare for crab cavities & RF cryo system

ATLAS: new pixel detect. - detect. for ultimate luminosity.

ALICE - Inner vertex system

CMS - New Pixel. New HCAL Photodetectors. Completion of FWD muons upgrade

LHCb - full trigger upgrade, new vertex detector etc.

Installation of the HL-LHC hardware.

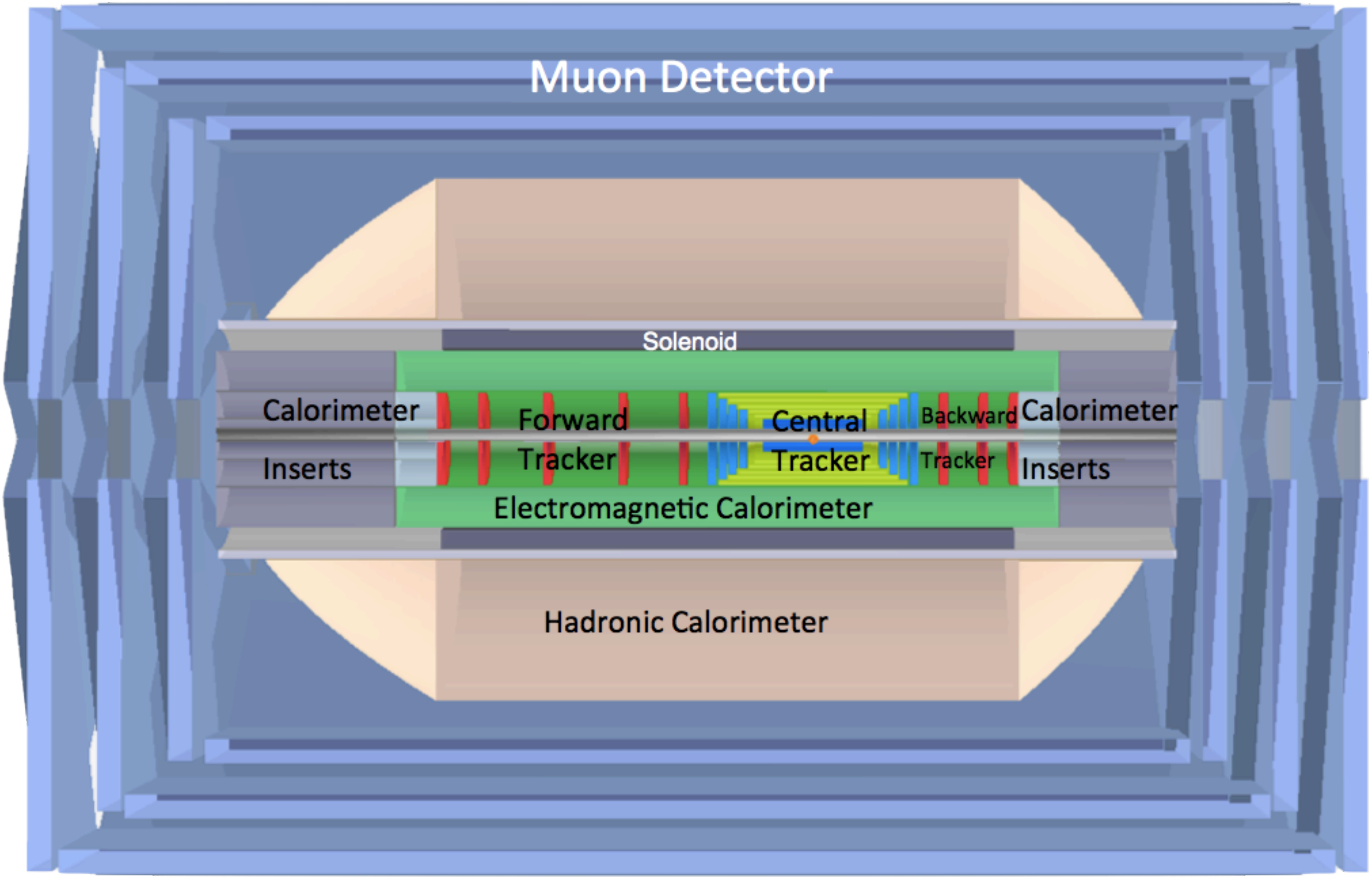
Installation of LHeC

Preparation for HE-LHC

Figure 11.1: CERN medium term plan (MTP), draft as of July 2011

as shown by S. Myers at EPS 2011 Grenoble

LHeC Detector Overview



Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Detector Magnets

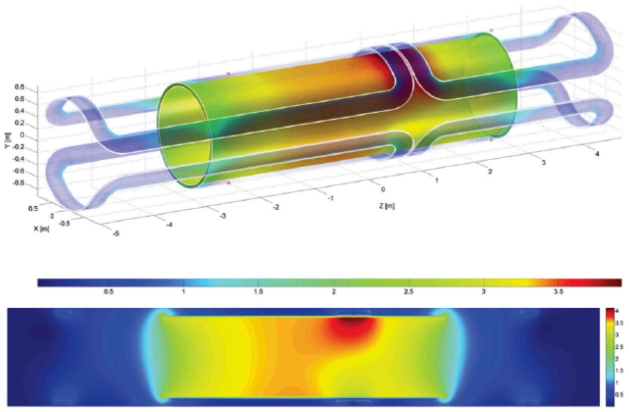


Figure 13.13: Magnetic field of the magnet system of solenoid and the two internal superconducting dipoles at nominal currents (effect of iron ignored). The position of the peak magnetic field of 3.9 T is local due to the adjacent current return heads on top of the solenoid where all magnetic fields add up.

Dipole (for head on LR) and solenoid in common cryostat, perhaps with electromagnetic LAr

3.5T field at ~1m radius to house a Silicon tracker

Based on ATLAS+CMS experience

Property	Parameter	value	unit
Dimensions	Cryostat inner radius	0.900	m
	Length	10.000	m
	Outer radius	1.140	m
	Coil windings inner radius	0.960	m
	Length	5.700	m
	Thickness	60.0	mm
	Support cylinder thickness	0.030	m
	Conductor section, Al-stabilized NbTi/Cu + insulation	30.0×6.8	mm^2
	Length	10.8	km
	Superconducting cable section, 20 strands	12.4×2.4	mm^2
	Superconducting strand diameter Cu/NbTi ratio = 1.25	1.24	mm
Masses	Conductor windings	5.7	t
	Support cylinder, solenoid section + dipole sections	5.6	t
	Total cold mass	12.8	t
	Cryostat including thermal shield	11.2	t
	Total mass of cryostat, solenoid and small parts	24	t
Electro-magnetics	Central magnetic field	3.50	T
	Peak magnetic field in windings (dipoles off)	3.53	T
	Peak magnetic field in solenoid windings (dipoles on)	3.9	T
	Nominal current	10.0	kA
	Number of turns, 2 layers	1683	
	Self-inductance	1.7	H
	Stored energy	82	MJ
	E/m, energy-to-mass ratio of windings	14.2	kJ/kg
	E/m, energy-to-mass ratio of cold mass	9.2	kJ/kg
	Charging time	1.0	hour
	Current rate	2.8	A/s
	Inductive charging voltage	2.3	V
Margins	Coil operating point, nominal / critical current	0.3	
	Temperature margin at 4.6 K operating temperature	2.0	K
	Cold mass temperature at quench (no extraction)	~ 80	K
Mechanics	Mean hoop stress	~ 55	MPa
	Peak stress	~ 85	MPa
Cryogenics	Thermal load at 4.6 K, coil with 50% margin	~ 110	W
	Radiation shield load width 50% margin	~ 650	W
	Cooling down time / quench recovery time	4 and 1	day
	Use of liquid helium	~ 1.5	g/s

Table 13.1: Main parameters of the baseline LHeC Solenoid providing 3.5 T in a free bore of 1.8 m.

Silicon Tracker and EM Calorimeter

Transverse momentum $\Delta p_t/p^2_t$ → 6 10^{-4} GeV^{-1}
transverse
impact parameter
→ 10 μ m

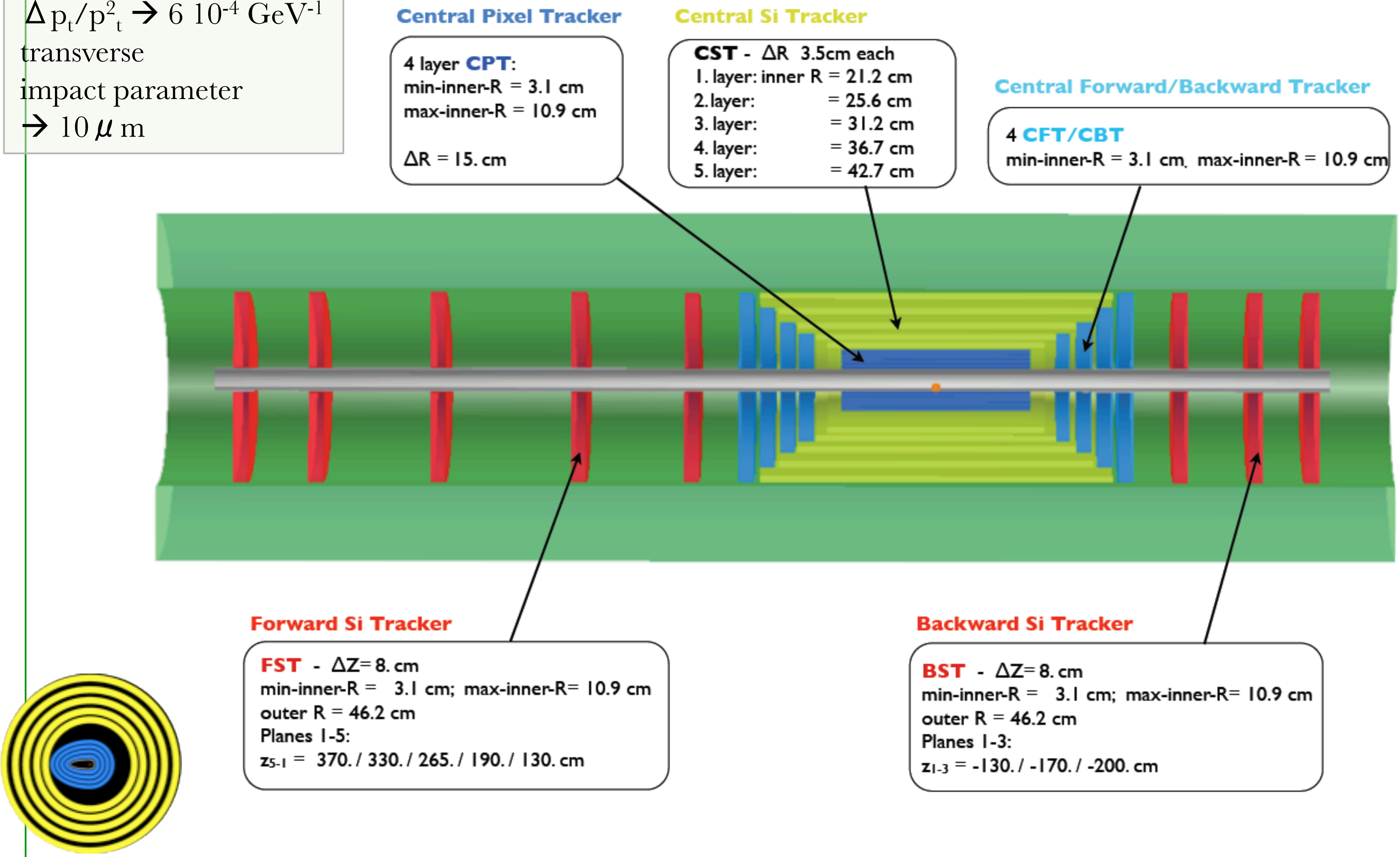
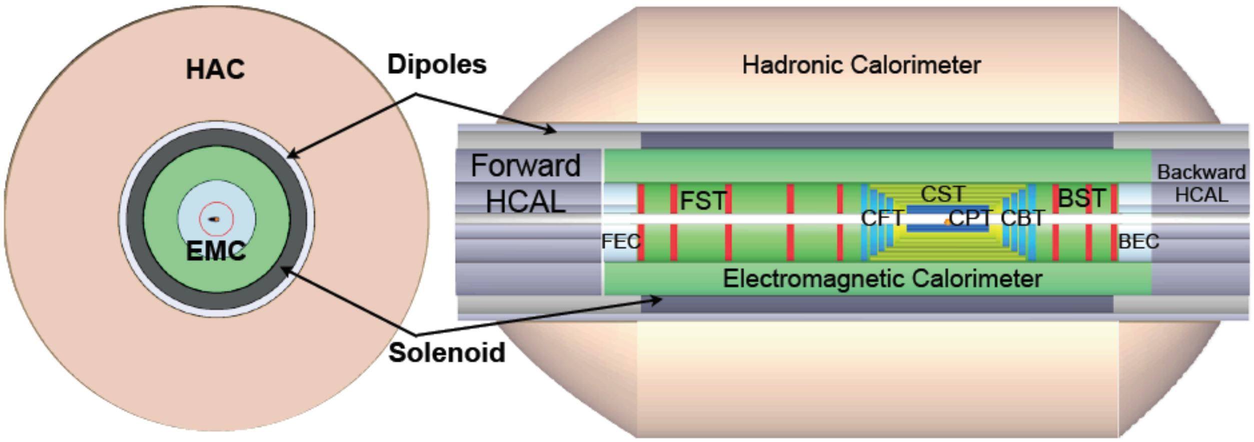


Figure 13.18: Tracker and barrel Electromagnetic-Calorimeter rz view of the baseline detector (Linac-Ring case).

Liquid Argon Electromagnetic Calorimeter



Inside Coil
H1, ATLAS
experience.

Barrel: Pb, 20 X_0 , 11m^3

fwd/bwd inserts:

FEC: Si -W, 30 X_0 ,0.3m^3

BEC: Si -Pb, 25 X_0,0.3m^3

Figure 13.30: *x*-*y* and *r*-*z* view of the LHeC Barrel EM calorimeter (green).

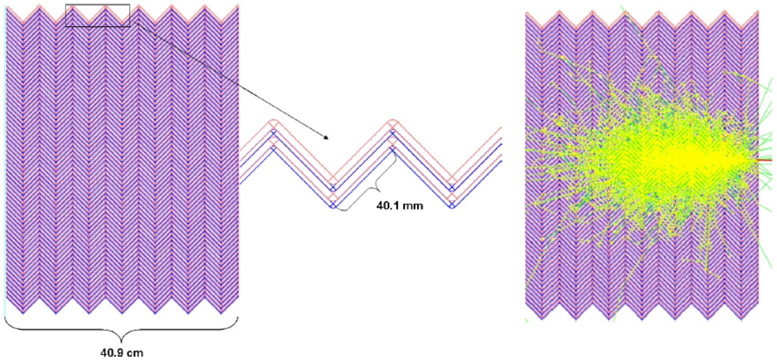


Figure 13.35: View of the parallel geometry accordion calorimeter (left) and simulation of a single electron shower with initial energy of 20 GeV (right).

GEANT4 Simulation

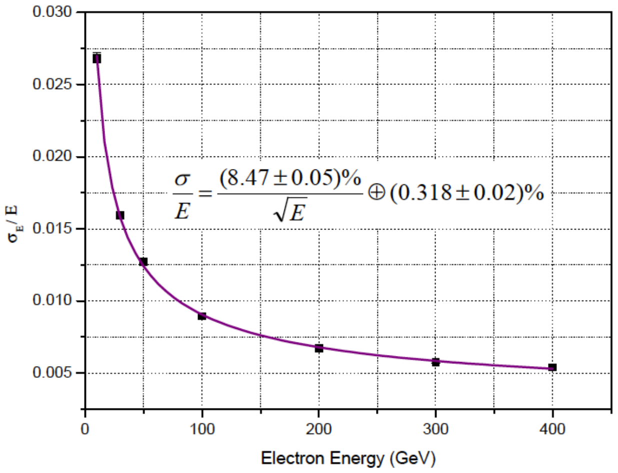
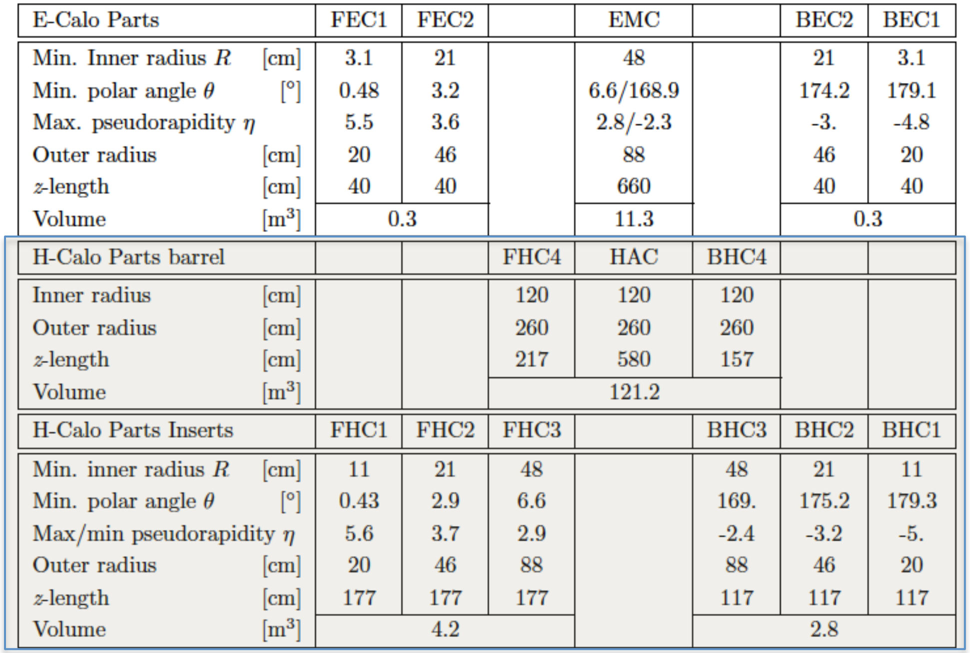


Figure 13.36: LAr accordion calorimeter energy resolution for electrons between 10 and 400 GeV.

Hadronic Tile Calorimeter

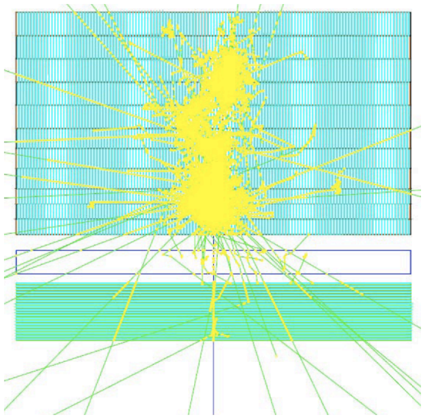
Outside Coil: flux return

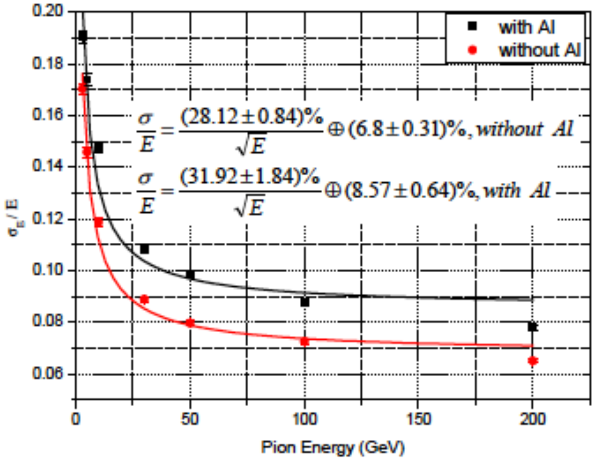
Modular. ATLAS experience.



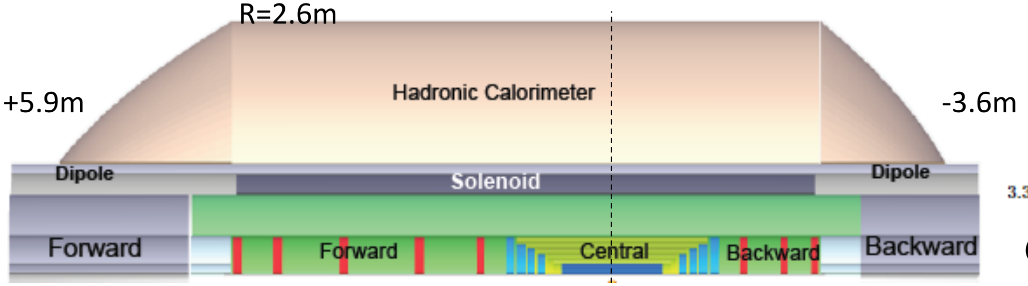
E-Calo Parts	FEC1	FEC2		EMC		BEC2	BEC1
Min. Inner radius R [cm]	3.1	21		48		21	3.1
Min. polar angle θ [°]	0.48	3.2		6.6/168.9		174.2	179.1
Max. pseudorapidity η	5.5	3.6		2.8/-2.3		-3.	-4.8
Outer radius [cm]	20	46		88		46	20
z-length [cm]	40	40		660		40	40
Volume [m^3]	0.3			11.3		0.3	
H-Calo Parts barrel			FHC4	HAC	BHC4		
Inner radius [cm]			120	120	120		
Outer radius [cm]			260	260	260		
z-length [cm]			217	580	157		
Volume [m^3]			121.2				
H-Calo Parts Inserts	FHC1	FHC2	FHC3		BHC3	BHC2	BHC1
Min. inner radius R [cm]	11	21	48		48	21	11
Min. polar angle θ [°]	0.43	2.9	6.6		169.	175.2	179.3
Max/min pseudorapidity η	5.6	3.7	2.9		-2.4	-3.2	-5.
Outer radius [cm]	20	46	88		88	46	20
z-length [cm]	177	177	177		117	117	117
Volume [m^3]	4.2				2.8		

Table 13.6: Summary of calorimeter dimensions.
The electromagnetic barrel calorimeter is currently represented by the barrel part EMC (LAr-Pb module); the setup reaches $X_0 \approx 25$ radiation length) and the movable inserts forward FEC1, FEC2 (Si-W modules ($X_0 \approx 30$) and the backward BEC1, BEC2 (Si-Pb modules; $X_0 \approx 25$).
The hadronic barrel parts are represented by FHC4, HAC, BHC4 (forward, central and backward - Scintillator-Fe Tile modules; $\lambda_I \approx 8$ interaction length) and the movable inserts FHC1, FHC2, FHC3 (Si-W modules; $\lambda_I \approx 10$), BHC1, BHC2, BHC3 (Si-Cu modules, $\lambda_I \approx 8$) see Fig. 13.9.





3.37: Accordion and Tile Calorimeter energy resolution for pions with and without 14cm Al block.

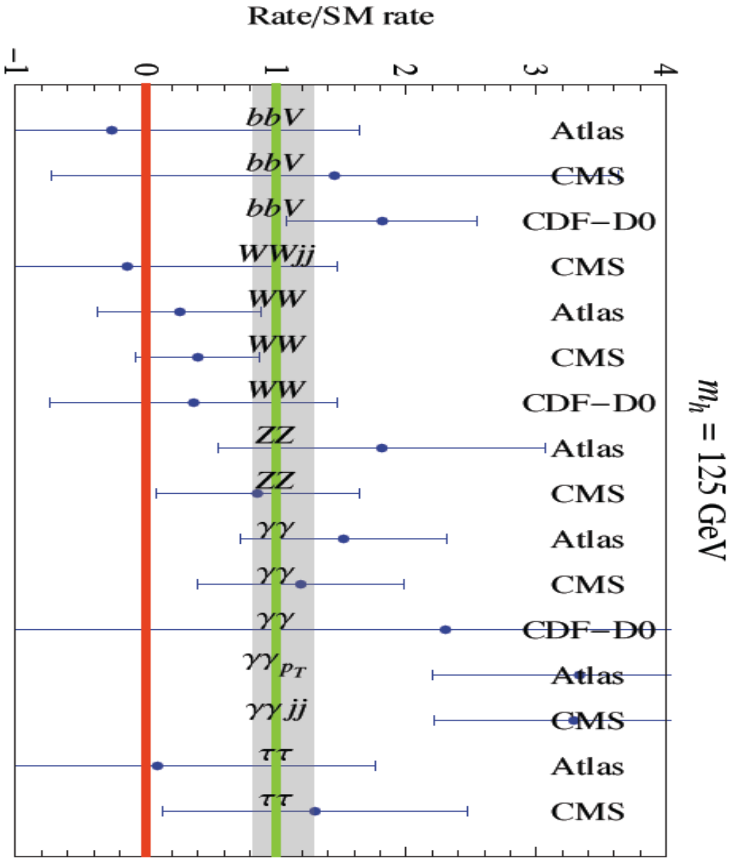


Combined GEANT4 Calorimeter Simulation

III. Relations to LHC and EIC

LHC

Selected SUSY Search Results → 3rd generation?

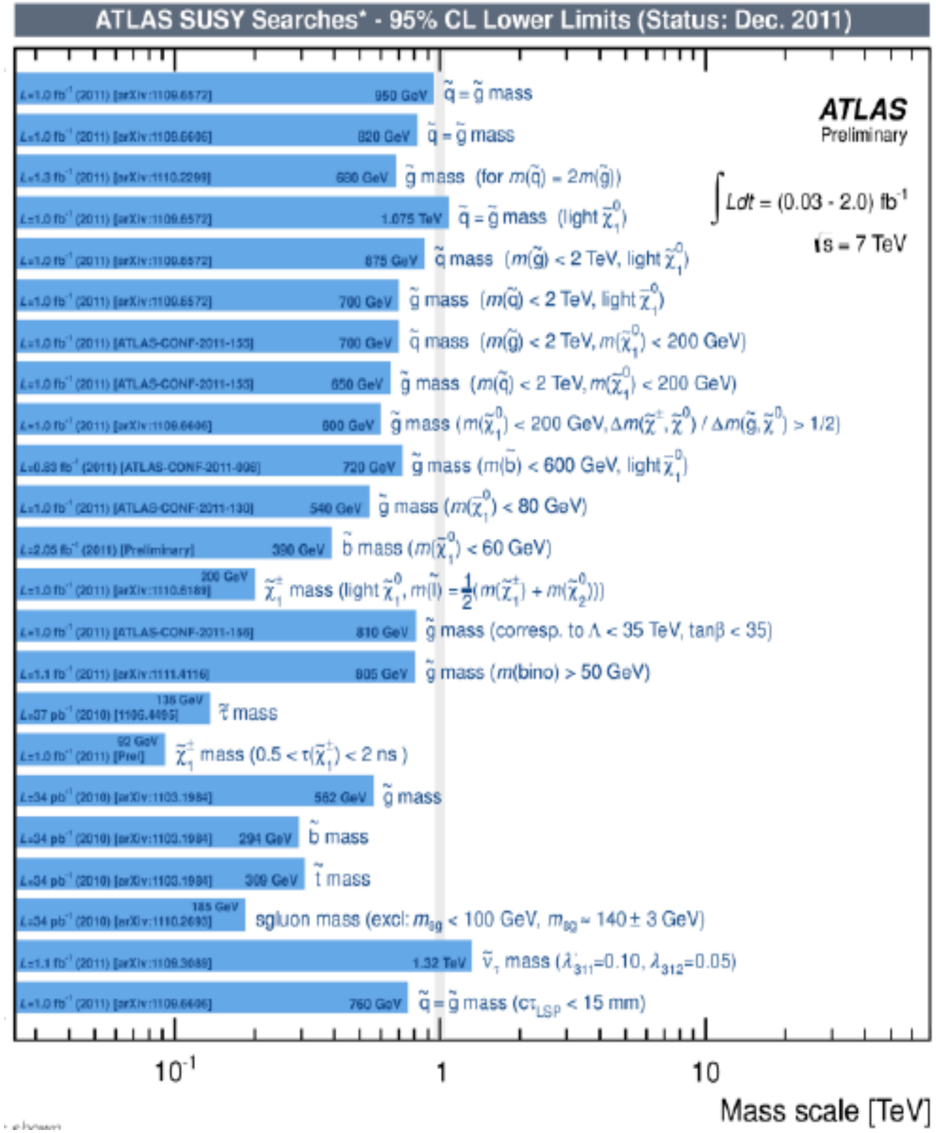


J.Gunion (CERN 27.3.2012)

Technicolor ??

"We argue that the existence of fundamental scalar fields constitutes a serious flaw of the Weinberg-Salam theory…

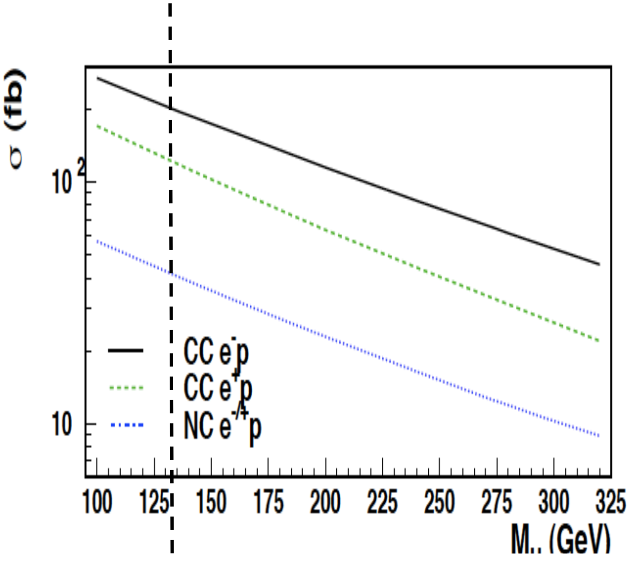
L.Susskind, Dynamics of Spontaneous Symmetry Breaking in the Weinberg Salam Theory.
Phys D20 (1979) 2619-2625
Dimopoulos,Susskind: Mass Without Scalars
NP. B155 (1979) 237



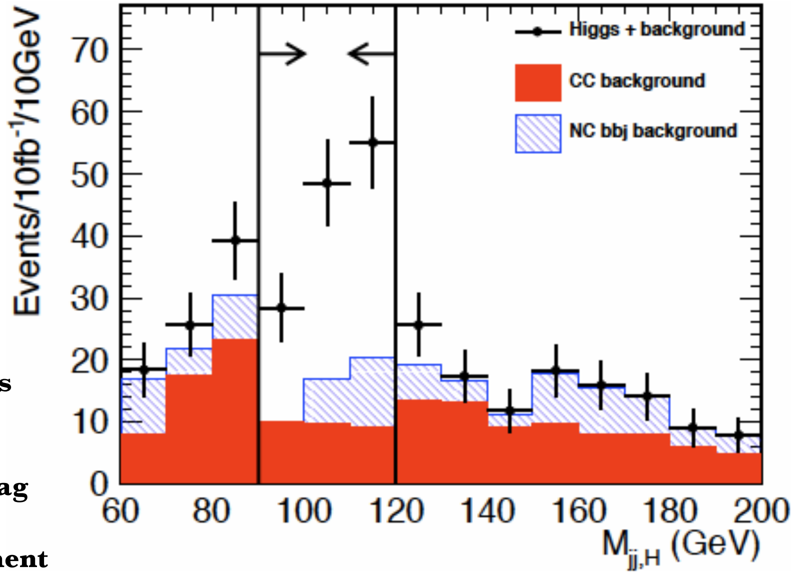
CMS similar results

LHCb: $B_s \rightarrow \mu\,\mu < 4.5\ 10^{-9}$ SM$(3.2 \pm 0.2)\ 10^{-9}$

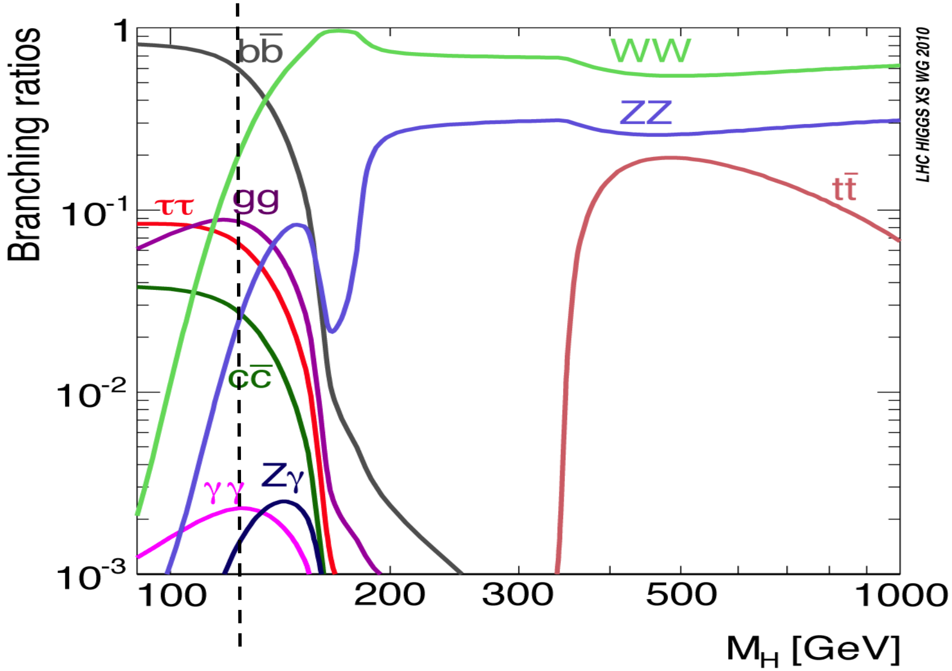
Higgs with LHeC

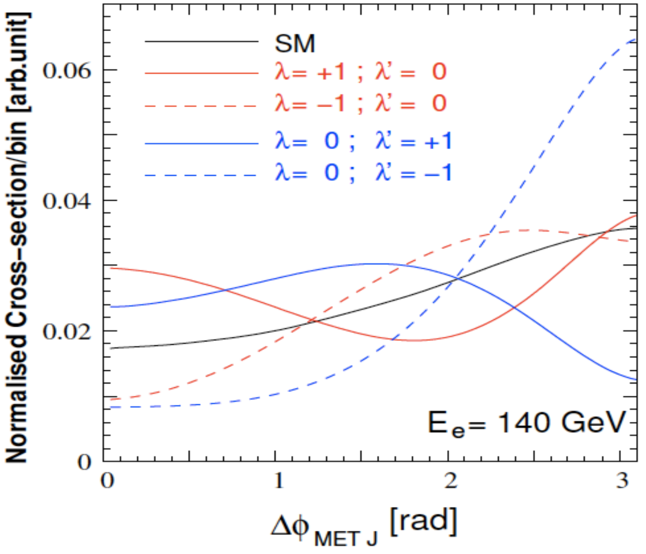


Process determines much of detector acceptance and calibration and b tag (also single top) and L/E$_e$ requirement

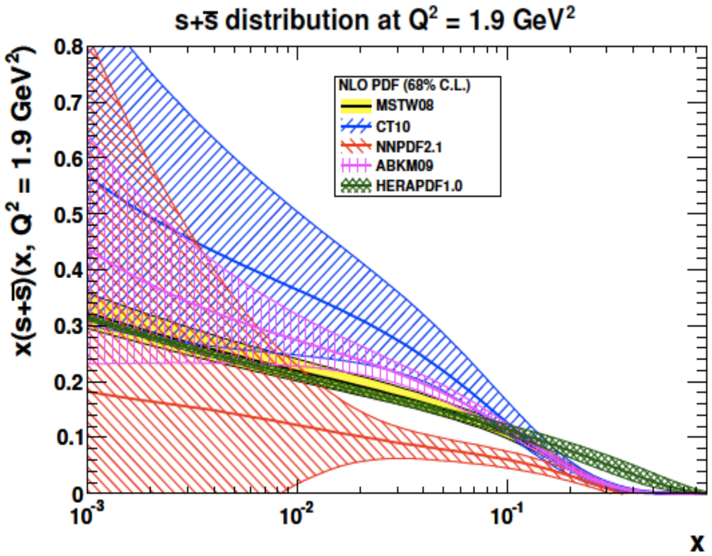


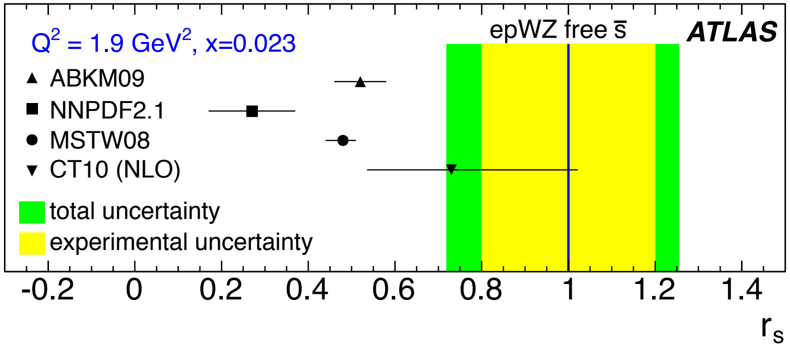
Higgs is light (or absent), CC: WW→H→bb
CP even: SM, CP odd: nonSM, mixture?



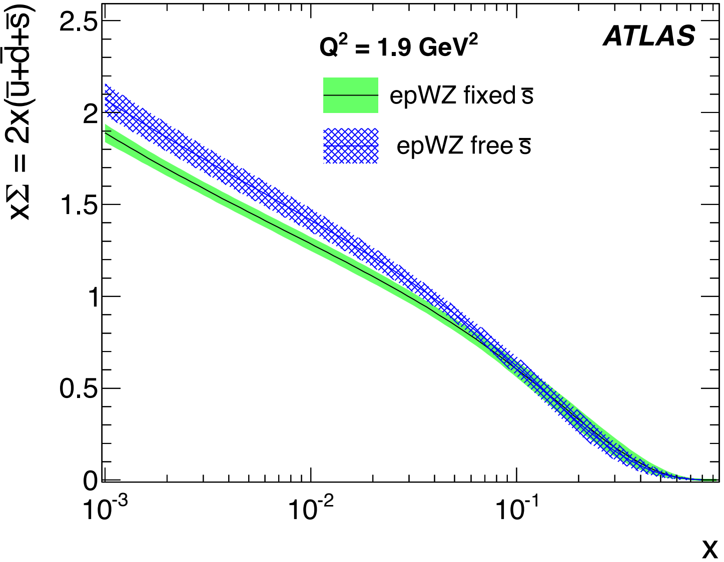


PDFs – Strange Quark Distribution

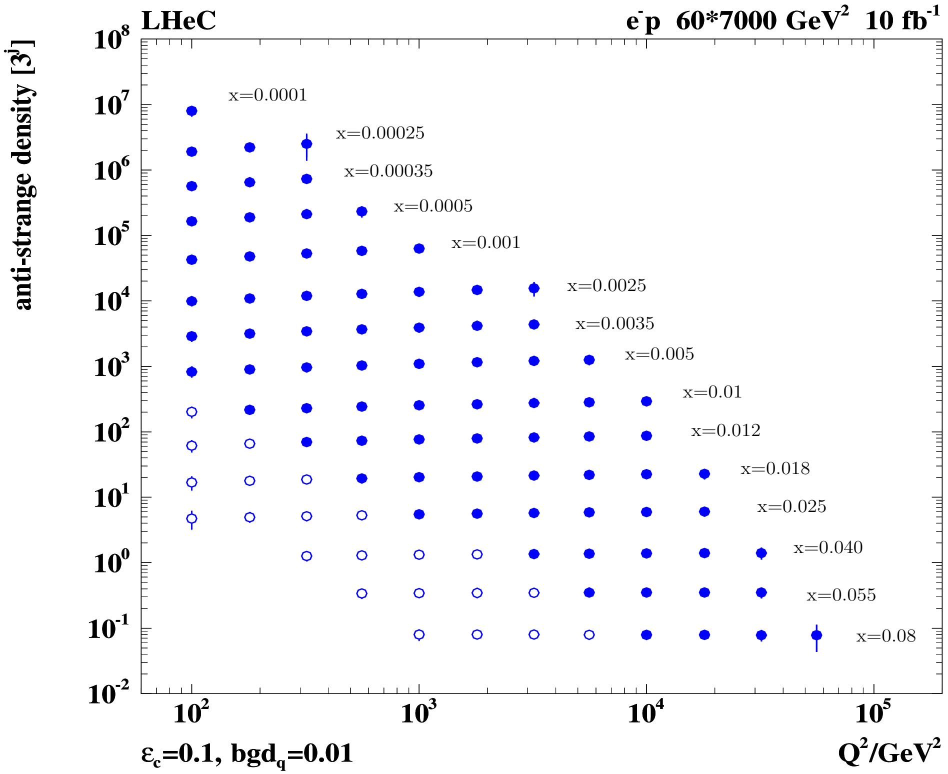


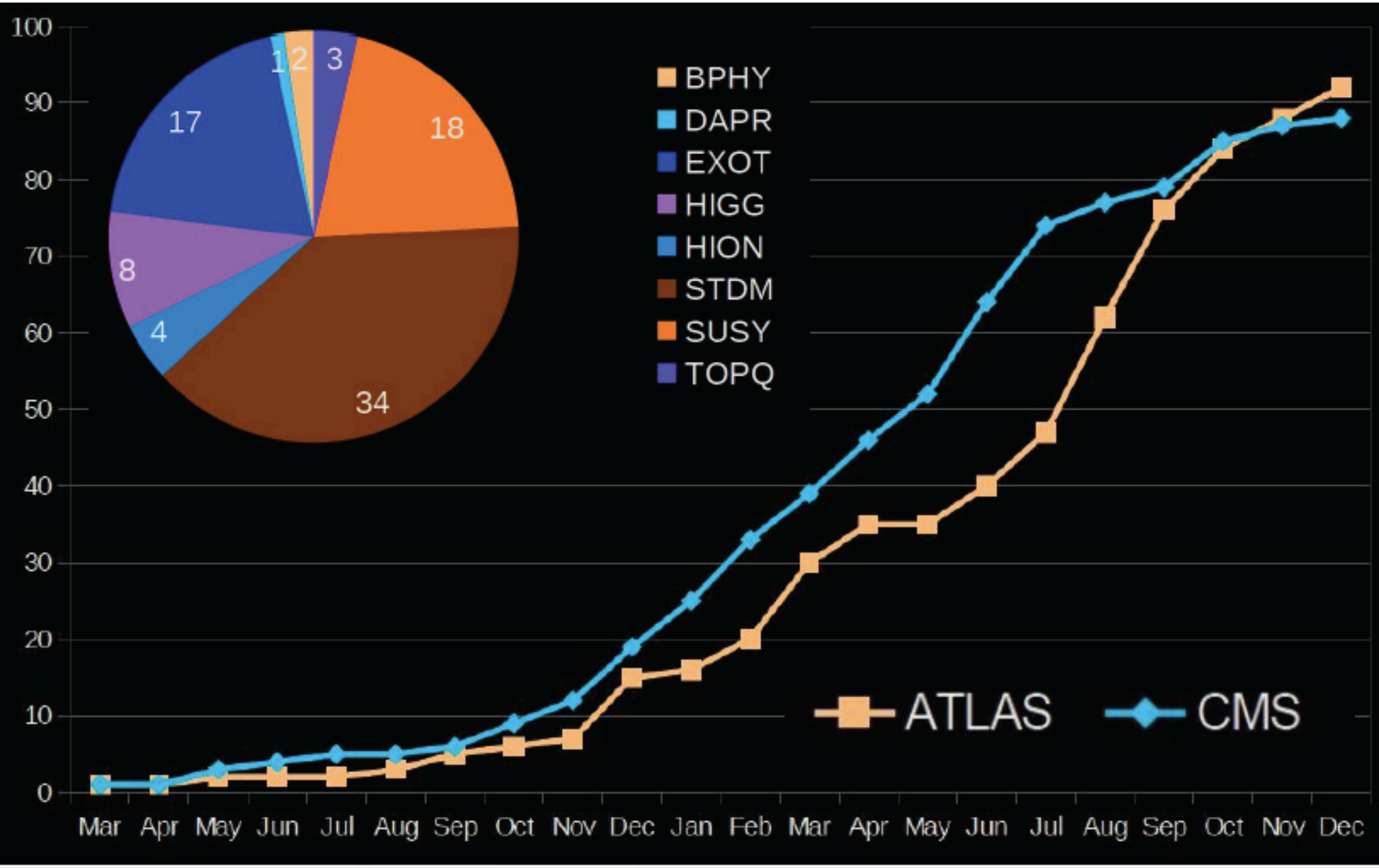


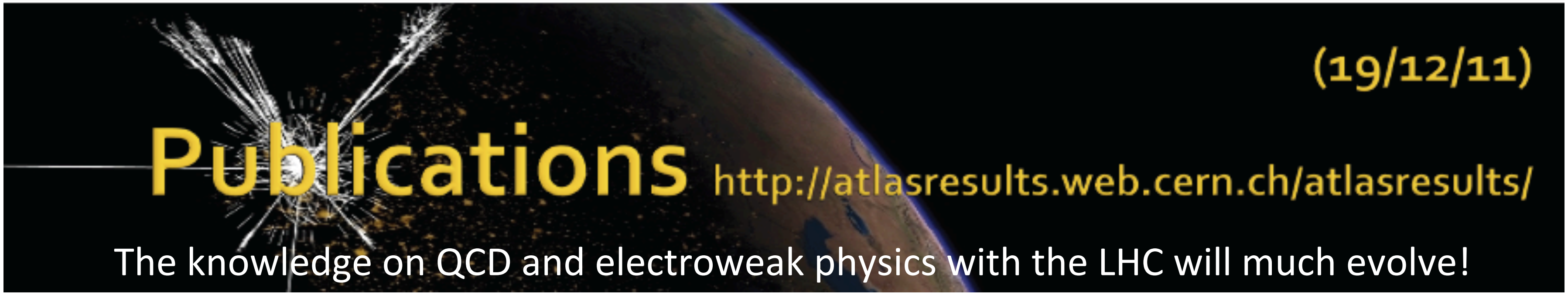
Trend confirmed in NNPDF collider only fit (Ubiali)



Change of strange affects sea - UHE ν





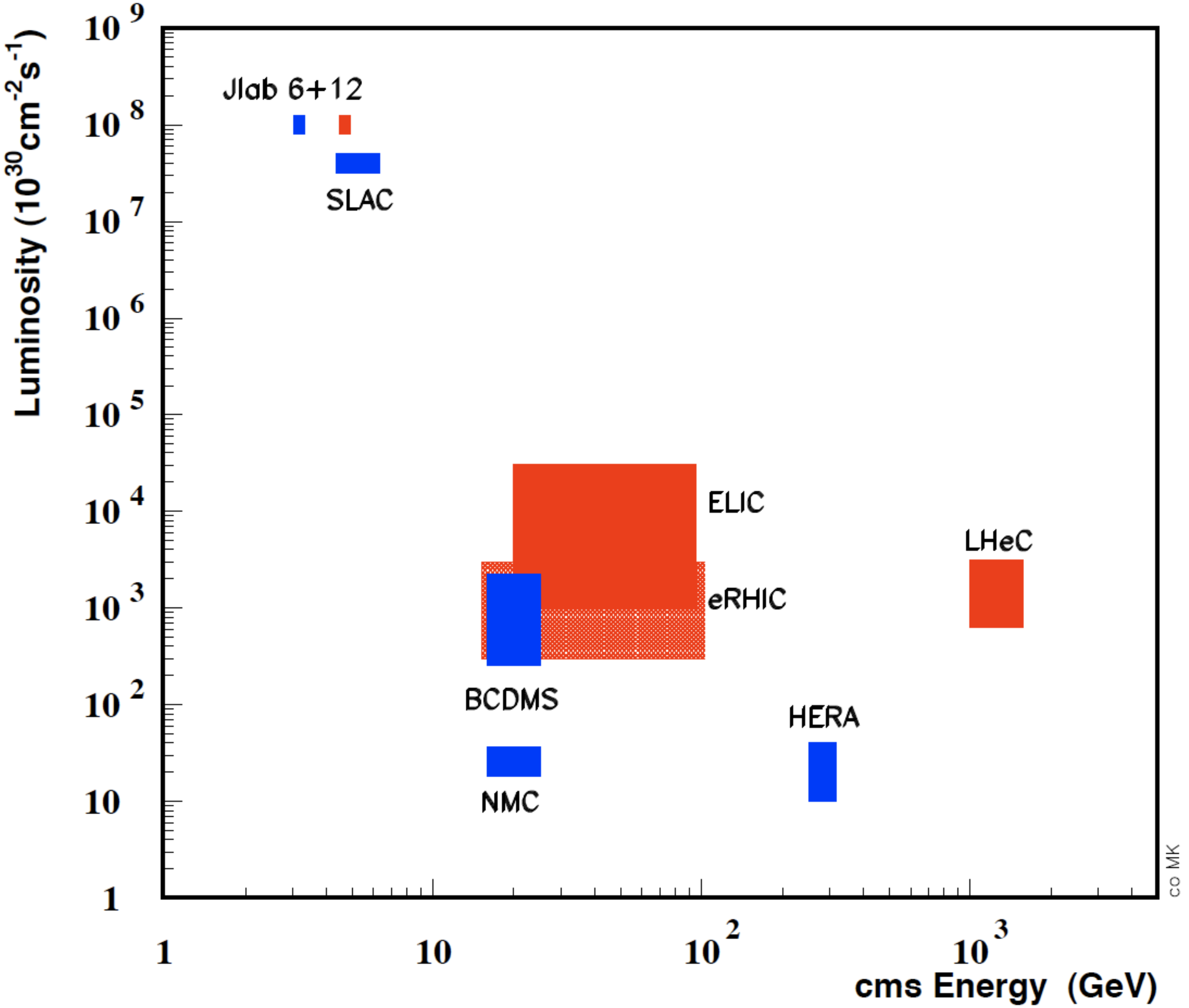


(19/12/11)

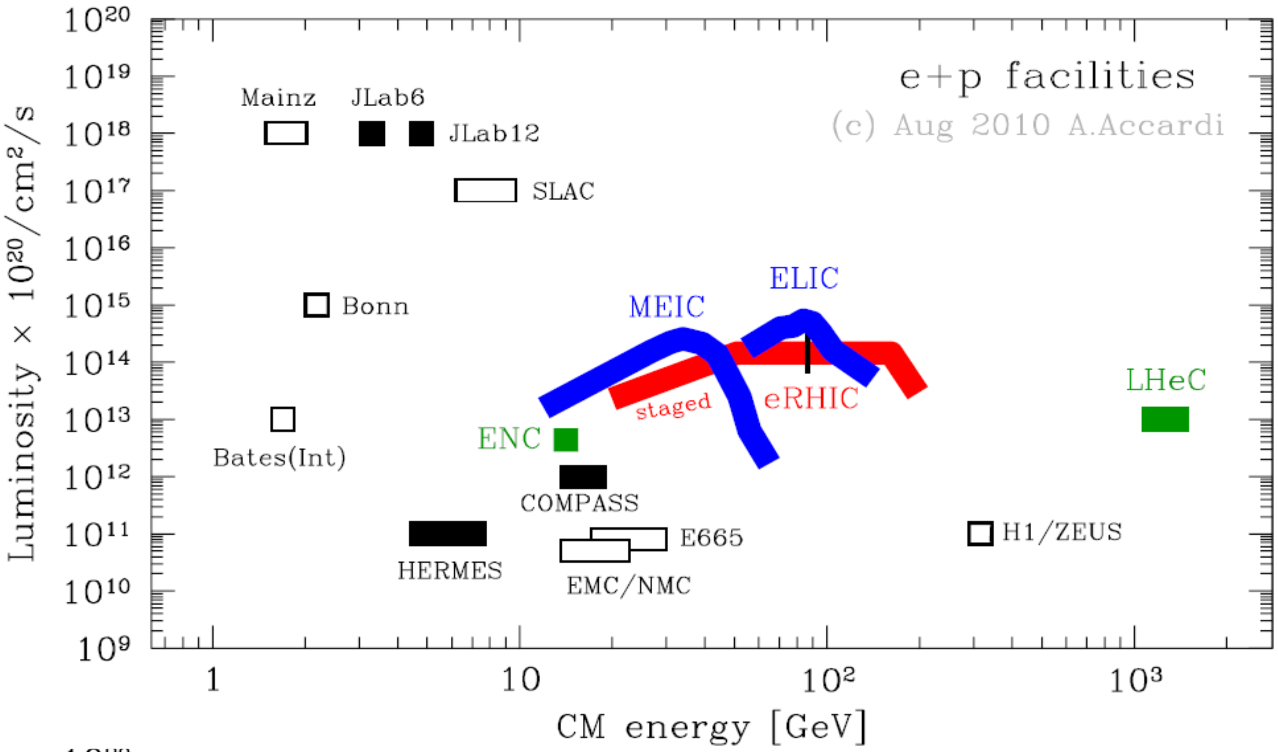
Publications http://atlasresults.web.cern.ch/atlasresults/

The knowledge on QCD and electroweak physics with the LHC will much evolve!

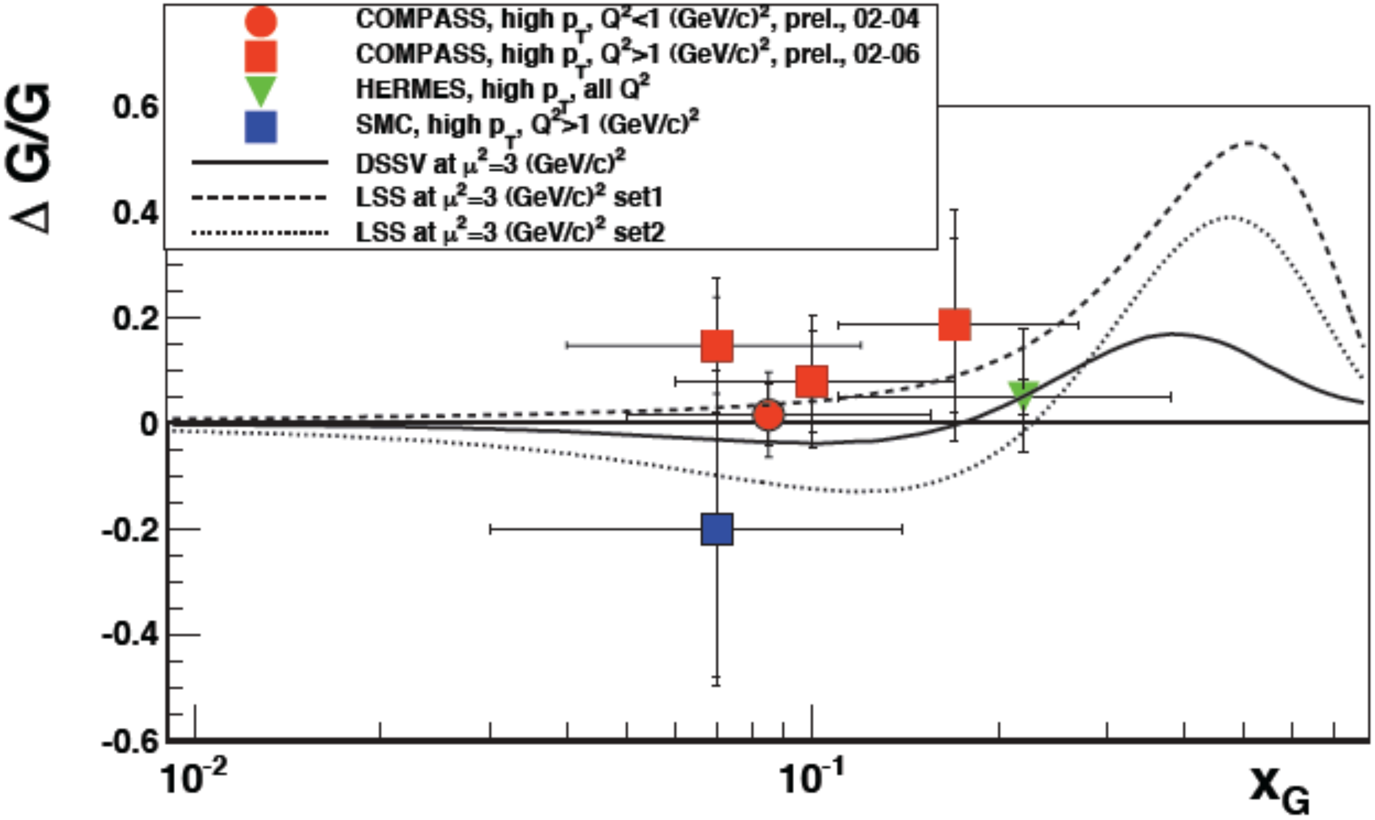
Lepton-Proton Scattering Facilities



EIC


e+p facilities
(c) Aug 2010 A.Accardi
Luminosity × 10^{20}/cm²/s
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
1
10
10^{2}
10^{3}
CM energy [GeV]
Mainz
JLab6
JLab12
SLAC
Bonn
Bates(Int)
HERMES
COMPASS
ENC
E665
EMC/NMC
MEIC
ELIC
staged
eRHIC
LHeC
H1/ZEUS

EIC



Marchand 26.3.12 DIS

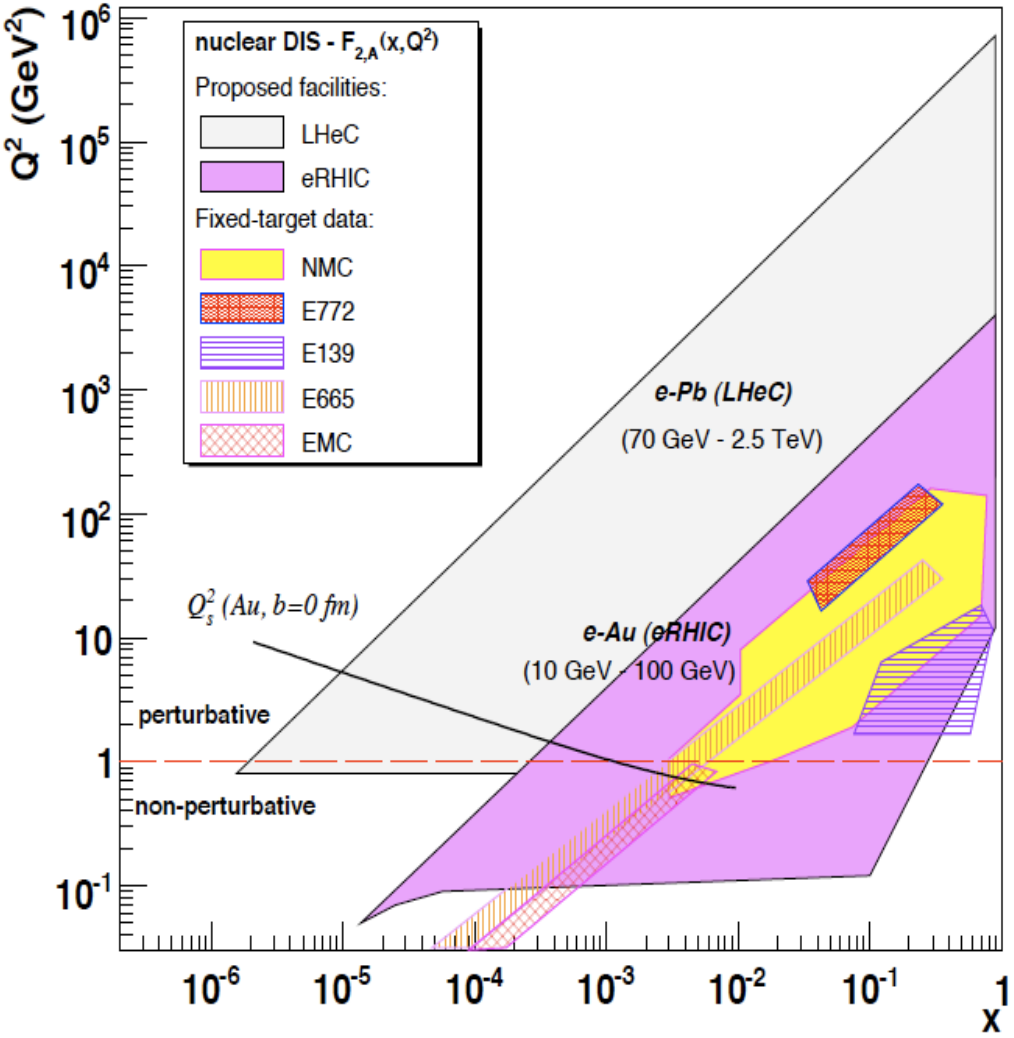
Determination of ΔG and polarised PDFs requires high luminosity ep collider of modest but variable energy with electron and proton polarisation.

Mapping of spin and spatial structure of partons in nucleons.

Novel programme in eA: between fixed target experiments and LHeC

cf Summary by E.Aschenauer

Heavy Ion Physics



EIC programme:
see recent workshop arXiv:1108.1713 [nucl-th]

Initial state of QGP

Hadronization in Media

Nuclear Parton Distributions

Black body limit

Saturation in *ep* AND in *eA*?

Diffraction in *eA* scattering

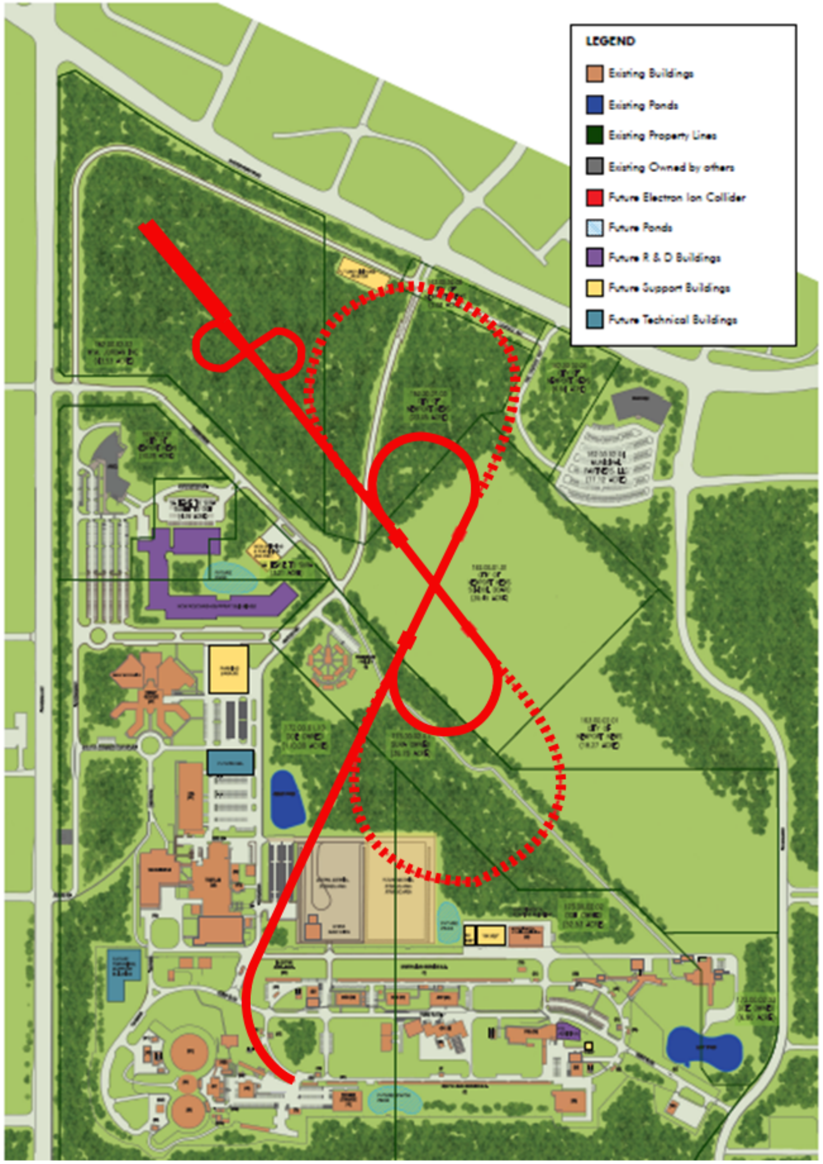
Deuterons: tag *p* in *en* to beat
Fermi motion and exploit
Diffraction-shadowing relation

…

LHeC eA is natural continuation of (part of) the heavy ion physics of the LHC (*AA* and *pA*, forward)

MEIC at Jlab

E.Nissen



		Proton	Electron
Beam energy	GeV	60	5
Collision frequency	MHz	750	750
Particles per bunch	10^{10}	0.416	2.5
Beam Current	A	0.5	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1
RMS bunch length	mm	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54
Vertical emittance, normalized	µm rad	0.07	11
Horizontal β*	cm	10	10
Vertical β*	cm	2	2
Vertical beam-beam tune shift		0.014	0.03
Laslett tune shift		0.06	Very small
Distance from IP to 1st FF quad	m	7	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6	

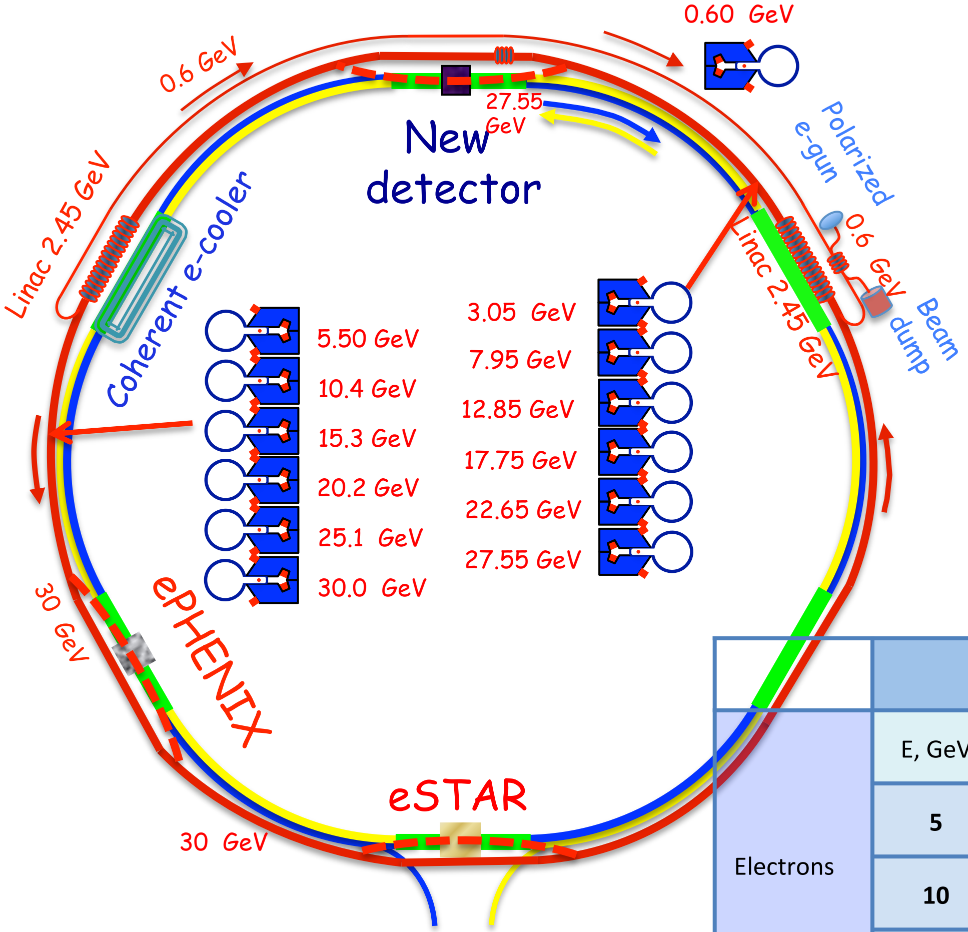
Crabs, e Cooling, ERL: 14 10^{33} with reduced Acc

Dashed: staged higher energy option 250x20 GeV^2

MEIC: 1340m circumference

Detector and Physics Studies (C.Keppel et al.)

eRHIC at BNL



Crabs, e Cooling, ERL

Detector and Physics Studies
(K.Dehmelf et al.)

Staging considered

V.Ptitsyn

		Protons					
Electrons	E, GeV	**50**	**75**	**100**	**130**	**250**	**325**
	5	0.077	0.26	0.62	1.4	9.7	15
	10	0.077	0.26	0.62	1.4	9.7	15
	20	0.077	0.26	0.62	1.4	9.7	15
	30	0.019	0.06	0.15	0.35	2.4	3.8

IV. Next Steps on LHeC

Physics: Top, SUSY, Higgs, Relations to LHC – QCD+Eweak

Detector: Simulations, Forward Region, Beam Pipe, IR, Installation

Accelerator: f, ERL, Q1, Civil Engineering, LR-RR

Adjust the organisational structure to new phase of LHeC

Workshop June 14/15.6. at Chavannes near Coppet+CERN

https://indico.cern.ch/conferenceDisplay.py/183282

4th CERN-ECFA-NuPECC Workshop on the LHeC

14-15 June 2012 *Chavannes-de-Bogis, Switzerland*
Europe/Zurich timezone

The 4th Workshop on the Large Hadron electron Collider will provide an overview on the completed concerptual design report, and is directed to steps for the further development of the LHeC, its physics programme & detector design.

More information on LHeC **webpages**.

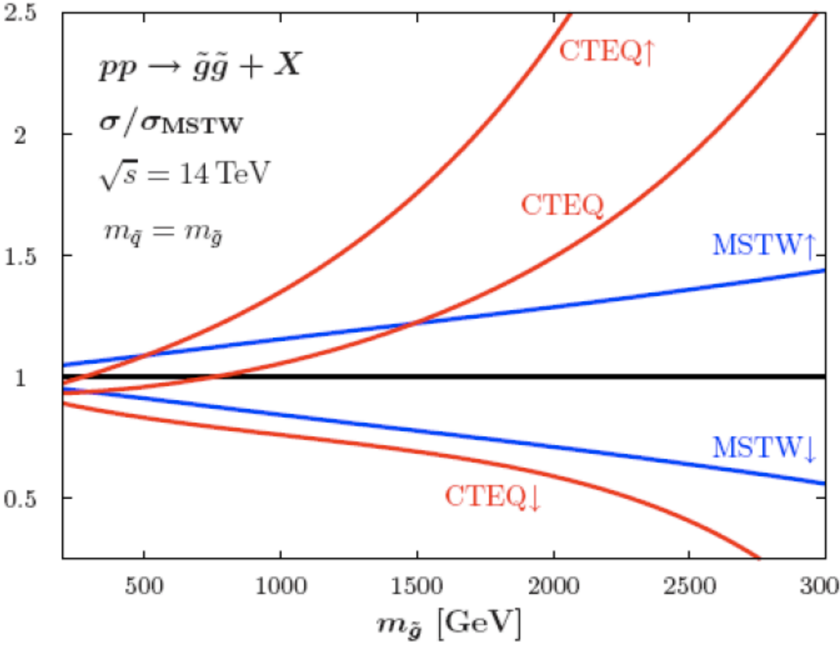
Contact address:
ECFA-CERN LHeC Workshop Secretariat
Mailbox L01800
CERN
1211-Geneva 23
or e-mail

Join the workshop (there is no fee) and join the LHeC (there is much work) if you are interested.

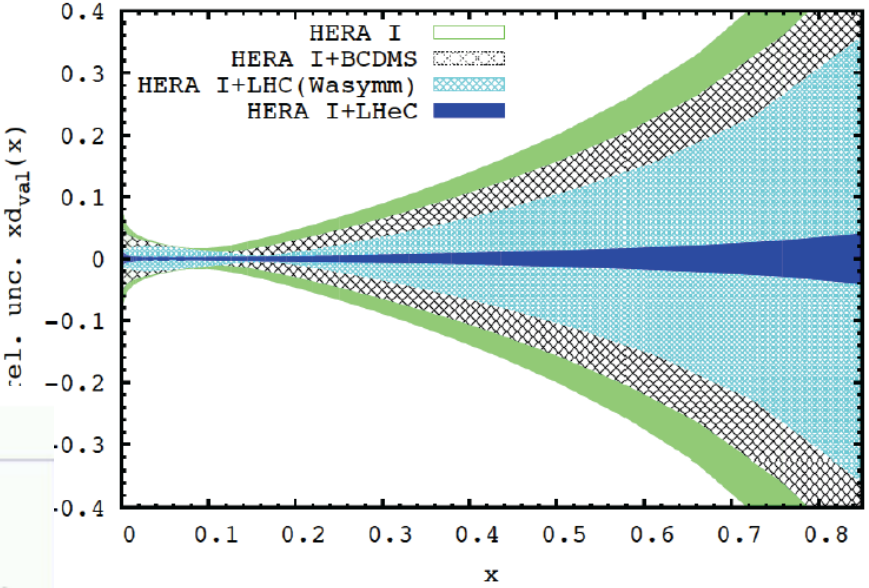
Dates:	from 14 June 2012 09:00 to 15 June 2012 18:00
Timezone:	Europe/Zurich
Location:	*Chavannes-de-Bogis, Switzerland*

https://indico.cern.ch/conferenceDisplay.py/183282

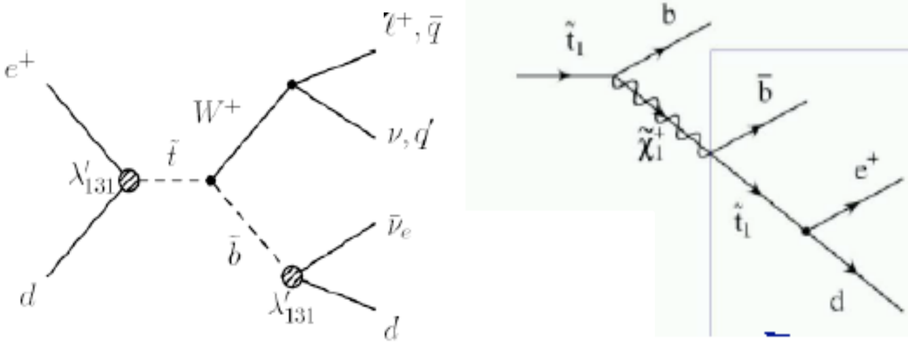
SUSY



HL-LHC will explore highest mass range which requires to control very high BJ x, where LHeC pins down partons such that resummation and factorisation effects can be tested.



RPV SUSY in 3^{rd} generation?



$$W_R = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

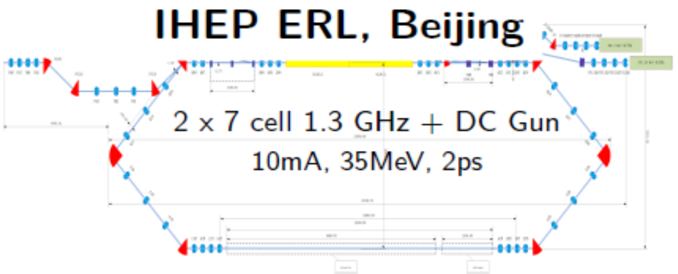
L: LH (s)leptons, **Q**: LH (s)quarks, **D**: RH down-type (s)quarks

i,j,k generation indices (27 couplings)

ERL Choice of frequency (Erk Jensen - Chamonix12)

- The frequency has to be a harmonic of 20.04 MHz!
- LHeC baseline: 721.42 MHz, alternative 1322.6 MHz.
- **Advantages of lower frequency:**
  - Less cryo-power
  - High-power couplers easier
  - Less cells per cavity – less trapped modes
  - Less beam loading and transverse wake – better beam stability
  - Less HOM power
  - Synergy with SPL, e-RHIC and ESS.
- **Advantages of higher frequency:**
  - Larger R/Q → with same Q_{ext} less RF power (but Q_{ext} must be reduced!)
  - Synergy with ILC/X-FEL

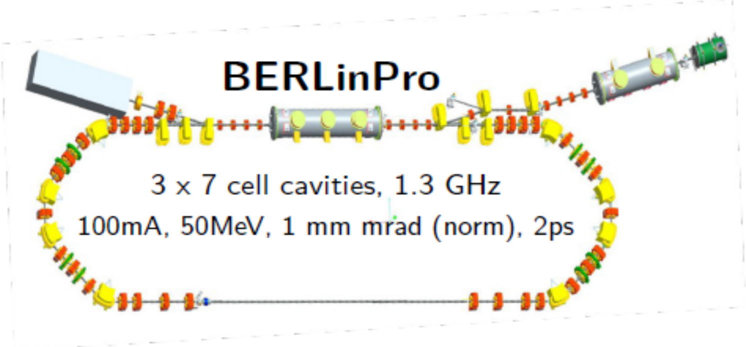
Collaboration on ERL



IHEP ERL, Beijing

2 x 7 cell 1.3 GHz + DC Gun

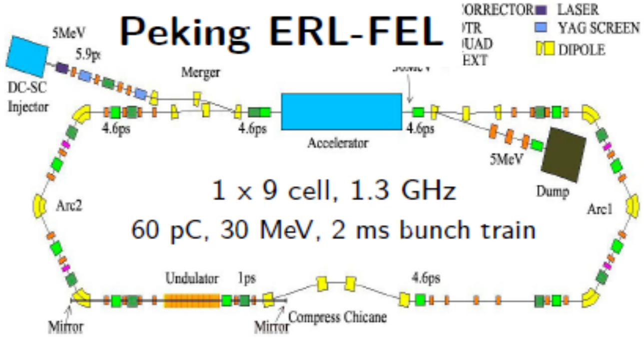
10mA, 35MeV, 2ps



BERLinPro

3 x 7 cell cavities, 1.3 GHz

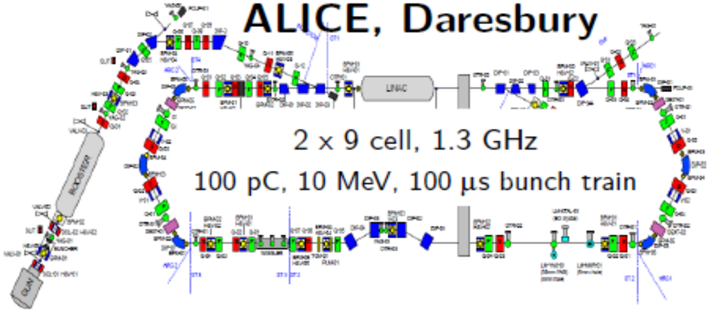
100mA, 50MeV, 1 mm mrad (norm), 2ps



Peking ERL-FEL

1 x 9 cell, 1.3 GHz

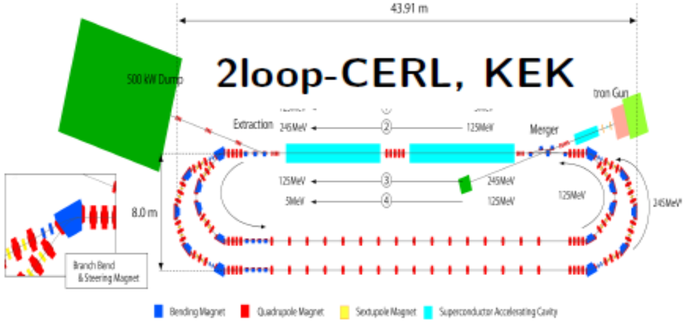
60 pC, 30 MeV, 2 ms bunch train



ALICE, Daresbury

2 x 9 cell, 1.3 GHz

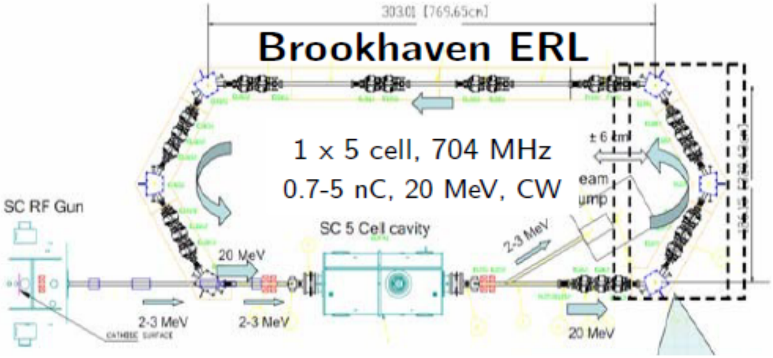
100 pC, 10 MeV, 100 μs bunch train



2loop-CERL, KEK

9 cell, 1.3 GHz cavities, 4 modules

77 pC, 245 MeV, 1-3 ps



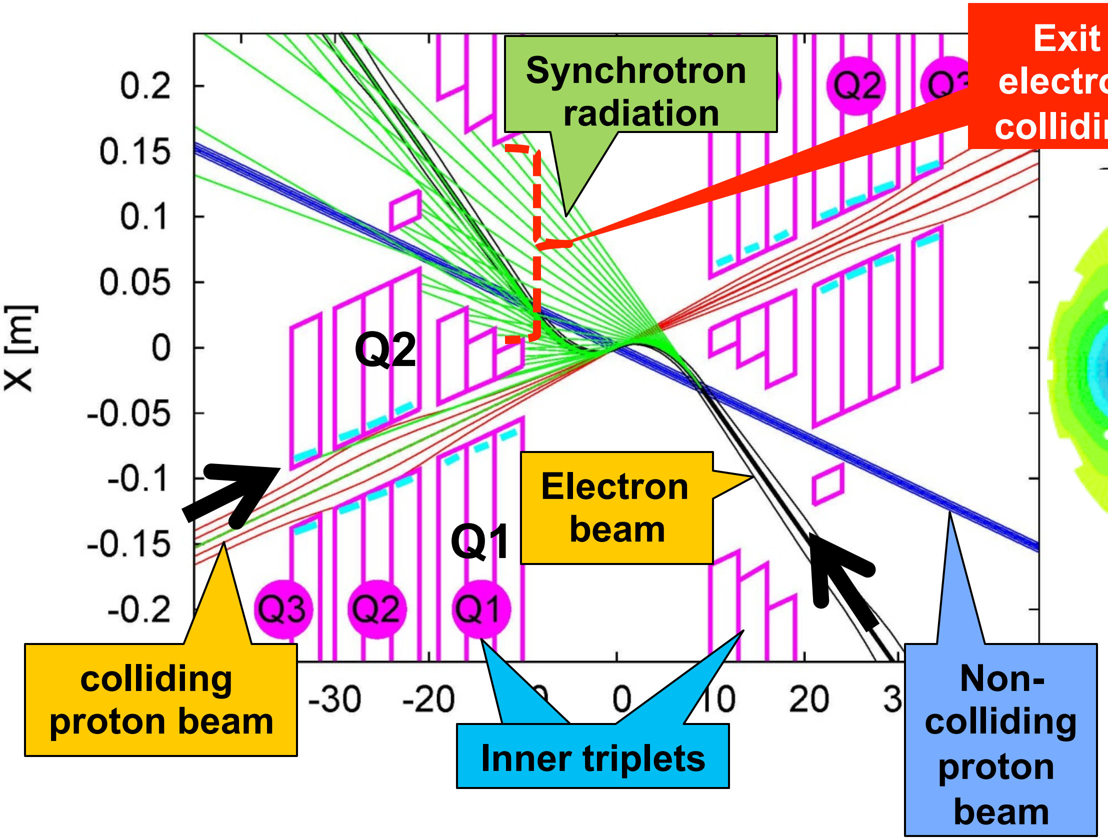
Brookhaven ERL

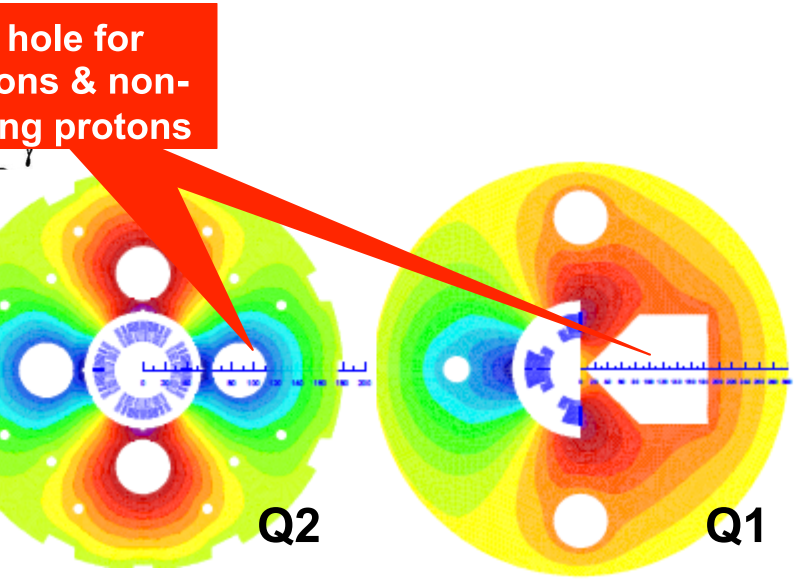
1 x 5 cell, 704 MHz

0.7-5 nC, 20 MeV, CW

Budker Institute

LR LHeC IR layout & SC IR quadrupoles





Nb_3Sn (HFM46): 5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K	Nb_3Sn (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K
46 mm (half) ap., 63 mm beam sep.	23 mm ap.. 87 mm beam sep.
0.5 T, 25 T/m	0.09 T, 9 T/m

High-gradient SC IR quadrupoles based on Nb_3Sn for colliding proton beam with common low-field

As shown by F. Zimmermann at Chamonix12

L.Bottura
Chamonix 2/12
on Magnet R+D
for LHeC + HE-LHC

Magnet Development at CERN

			LHeC RR dipole prototype	CRISP and fast cycled SC magnets	MQXC R&D	EuCARD FReSCa-II	DS 11 T MB program	US-LARP IR quadrupole program	EuCARD HTS insert	EuCARD2 HTS model	activated SC magnets handling for	Comments
LHeC	Low field resistive magnets	field quality and reproducibility	X									demonstrated
		operating cost		x								tests planned in 2012
		integration in the LHC tunnel									x	study launched in 2012 (LS1)
	IR magnets	large aperture			X			X				results in 2012…2014
		large gradient						X				
		heat removal		x	X							results in 2012
	co-activities and tunnel works										x	integration study and models (BINP); schedule revision
HE-LHC	Very high field magnets	15 T dipole outsert				X						deliverable Q1 2014
		5 T dipole insert							X	X		EuCARD2 proposal
		high gradient quadrupoles						X				US-LARP technology demonstration by 2014
		magnet protection				X	X	X				
		heat loads and removal			x	X						dedicated model tests
		field quality					X	X		X		
	Pulsed SC magnets	quench performance and margin		X								
		low-loss cables		X								
	Transfer lines											options reviewed at HE-LHC workshop in Malta, 2010
	Material availability and cost					X	X	X	x	x		
	Installation in 2030										X	study launched in 2012 (LS1)

Concluding Remarks

The physics of deep inelastic scattering has been an essential part of HEP.

Major breakthroughs in (particle) physics are difficult to plan, despite the “overconfidence of theorists” [Ledermann ICHEP 1980] in the past.

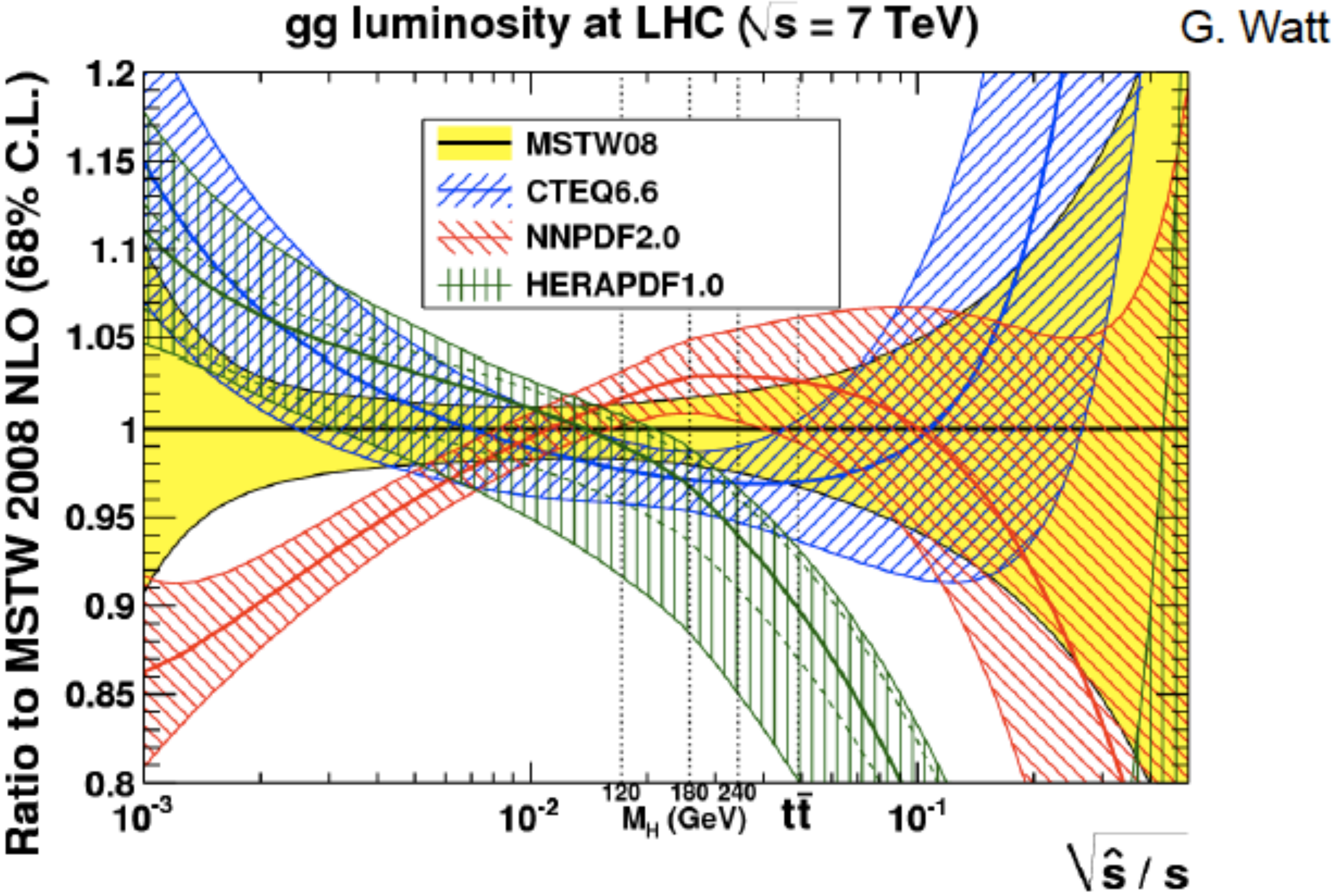
The LHeC has passed a major milestone with a refereed CDR, supported and monitored by CERN, ECFA and NuPECC, soon to be published.

The time schedule of the LHC is such that there is not more time than a decade+ for realising the LHeC. This requires to continue to be realistic.

Collaborations are soon to be built for further design, of the machine and the detector. The experimental prospect challenges theory and requires to continue our intimate interaction with our thy colleagues.

While the LHeC is crucial for the DIS exploration of the energy frontier, the medium energy, polarised eN collider(s) and a vigorous fixed target programme as at FNAL, CERN and Jlab are essentials of DIS to be maintained as a rich part of our culture, which we jointly develop.

Backup


gg luminosity at LHC (√s = 7 TeV)
G. Watt
Ratio to MSTW 2008 NLO (68% C.L.)
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
MSTW08
CTEQ6.6
NNPDF2.0
HERAPDF1.0
10^{-3}
10^{-2}
120
180
240
M_H (GeV)
$t\bar{t}$
10^{-1}
$\sqrt{\hat{s}/s}$

linac e^+ source options

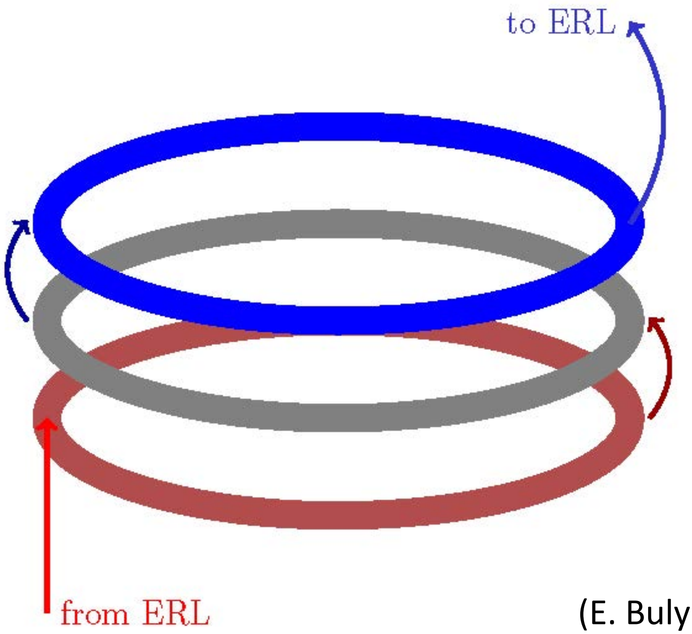
- recycle e+ together with energy, multiple use,
  damping ring in SPS tunnel w $\tau_\perp$~2 ms

(D. Schulte)

(Y. Papaphilippou)

- Compton ring, Compton ERL, coherent pair production, or undulator for high-energy beam
- 3-ring transformer & cooling scheme

(H. Braun,
E. Bulyak,
T. Omori,
V. Yakimenko)



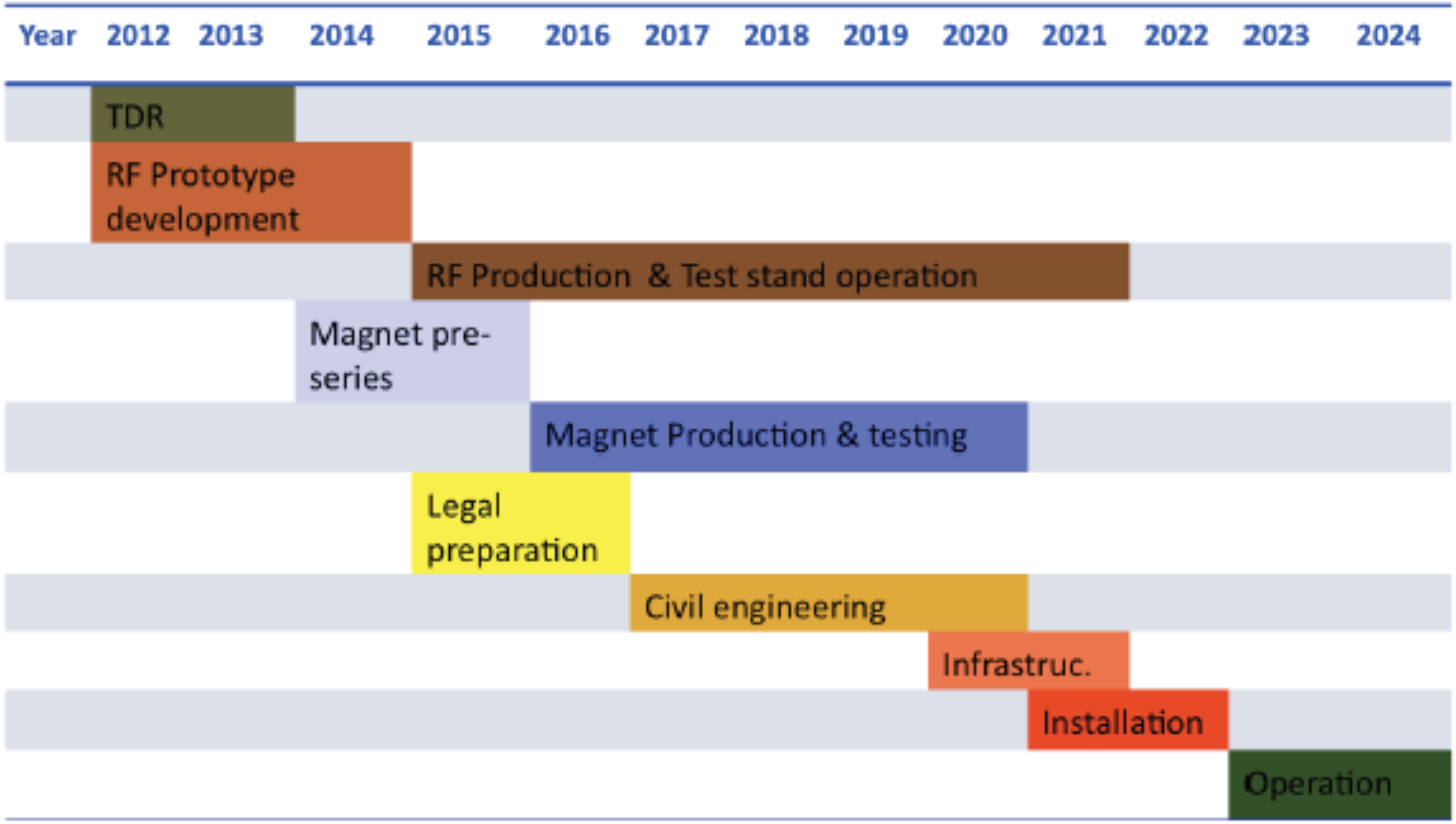
extraction ring (*N* turns)

fast cooling ring (*N* turns)

accumulator ring (*N* turns)

(E. Bulyak)

Tentative Time Schedule

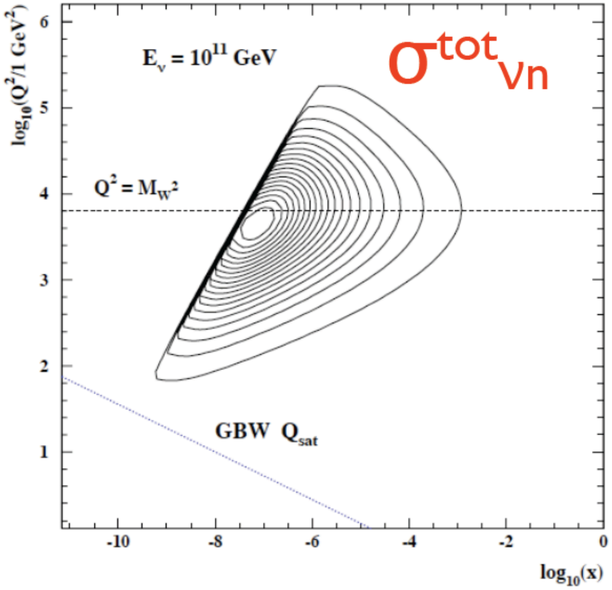


LS3 --- HL LHC →

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)

from draft CDR

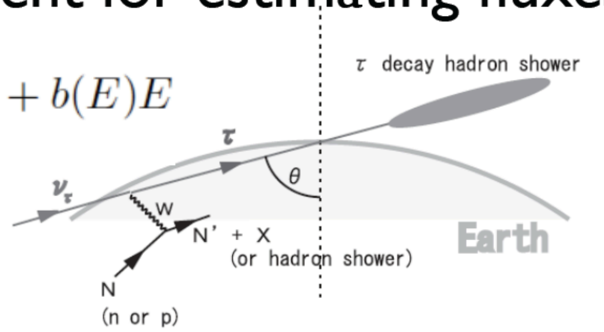
Neutrino Scattering

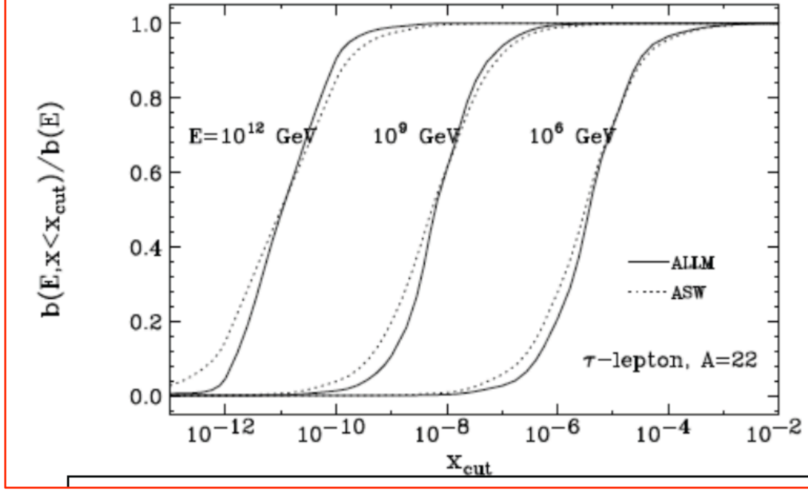


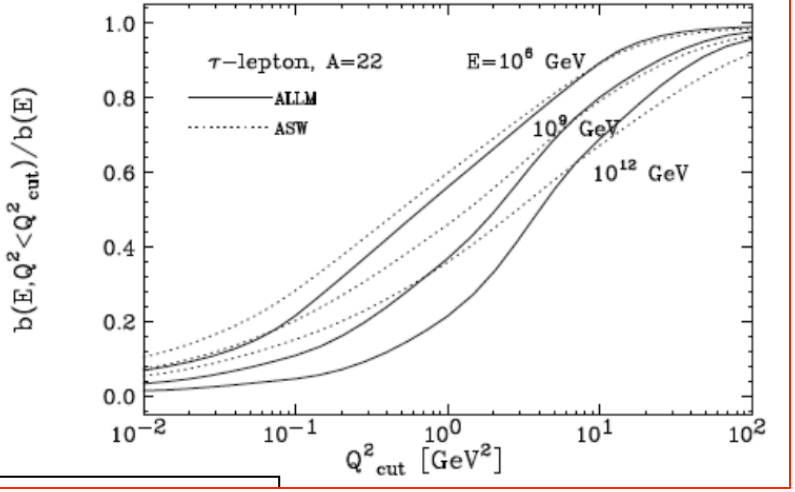
$\sigma^{tot}_{\nu n}$

- ν-n/A cross section (τ energy loss) dominated by DIS structure functions (n)pdfs at small-x and large (small) Q^2.
- Key ingredient for estimating fluxes.

$$-\left\langle \frac{dE}{dX} \right\rangle = a(E) + b(E)E$$







N.Armesto at DIS12

What HERA could not do or has not done

HERA in one box
the first ep collider

$E_p*E_e=$
$920*27.6\,\mathrm{GeV}^2$
$\sqrt{s}=2\sqrt{E_e E_p}=320$ GeV

$L=1..4\ 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
→ $\Sigma L=0.5\mathrm{fb}^{-1}$
1992-2000 & 2003-2007

$Q^2= [0.1 \text{ -- } 3 * 10^4]\ \mathrm{GeV}^2$
-4-momentum transfer^2

$x=Q^2/(sy) \cong 10^{-4}$ .. 0.7
Bjorken x

$y \cong 0.005$ .. 0.9
inelasticity

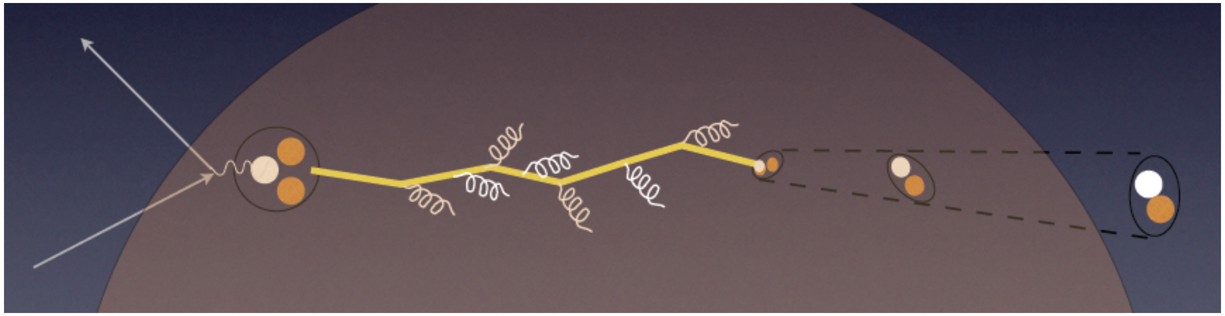
Test of **the isospin symmetry** (u-d) with eD - no deuterons
Investigation of the q-g dynamics in **nuclei** - no time for eA
Verification of **saturation** prediction at low x – too low s
Measurement of the **strange** quark distribution – too low L
Discovery of **Higgs** in WW fusion in CC – too low cross section
Study of **top** quark distribution in the proton – too low s
Precise measurement of $\mathbf{F_L}$ – too short running time left
Resolving d/u question at **large Bjorken x** – too low L
Determination of **gluon distribution at hi/lo x** – too small range
High precision measurement of α_s – overall not precise enough
Discovering **instantons, odderons** – don't know why not
Finding **RPV SUSY** and/or leptoquarks – may reside higher up
…

The H1 and ZEUS apparatus were basically well suited
The machine had too low luminosity and running time

HEP needs a TeV energy scale machine with 100 times higher luminosity than HERA to develop DIS physics further and to complement the physics at the LHC. The **Large Hadron Collider p and A beams offer a unique opportunity to build a second ep and first eA collider** at the energy frontier [discussed at DIS since Madison 2005]

In-medium Hadronisation

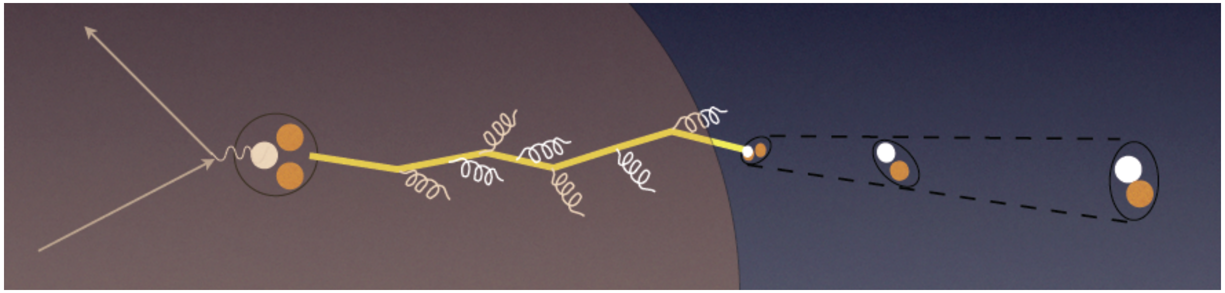
The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).



Low energy (ν): need of hadronization inside.

Parton propagation: pt broadening

Hadron formation: attenuation



High energy (ν): partonic evolution altered in the nuclear medium.

W.Brooks, Divonne09

LHeC :

+ study the transition from small to high energies in much extended range wrt. fixed target data

+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC

+ detailed study of heavy quark hadronisation …