XXIst International Workshop on Deep-Inelastic Scattering and Related Subjects
Marseille, April 26th 2013

WG7 Highlights - Future DIS Experiments: Status of the LHeC

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At the conference:

➜ *Nuclear PDFs from the LHeC perspective*, H. Paukkunen, Tuesday (WG1/WG7).

➜ *Prospects for the LHeC*, M. Klein, Wednesday.

➜ *The LHeC accelerator system*, O. Bruening, Wednesday.

➜ *The LHeC detector*, D. South, Wednesday.

➜ *Looking at the photoproduction of massive gauge bosons at the LHeC*, M. Machado, Thursday.

➜ *Low-x Physics at the LHeC*, N.A., Thursday.

➜ *Physics of the Higgs boson at the LHeC*, B. Mellado, Thursday.

Also: LHeC CDR, arXiv:1206.2913, J. Phys. G 39 (2012) 075001; arXiv:1211.4831; arXiv:1211.5102

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1. Accelerator.
2. Detector.
3. QCD.
4. EW/BSM.
5. Status and plans.

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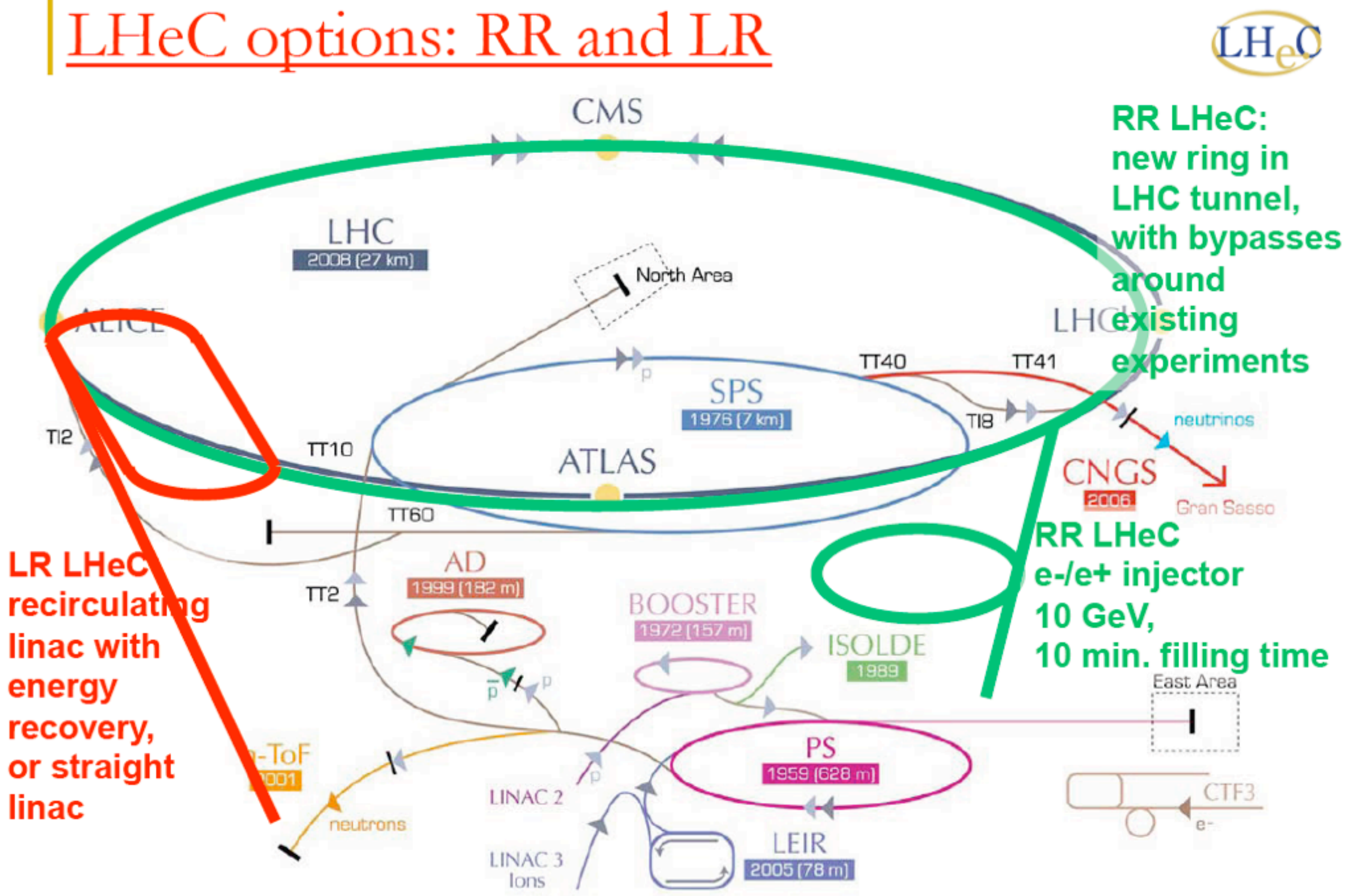
1. Accelerator:

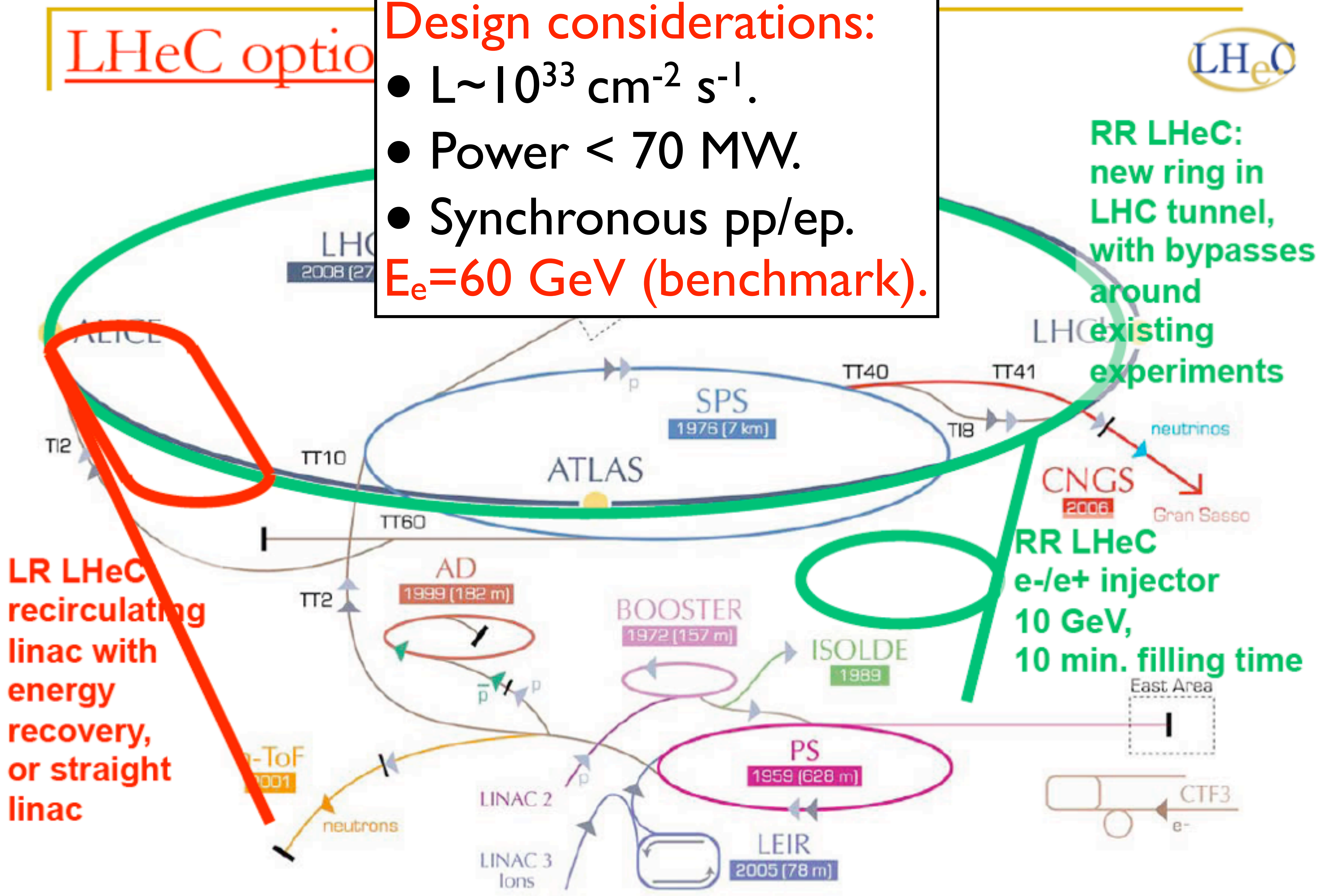
LHeC options: RR and LR



1. Accelerator:

Design considerations:
- $L \sim 10^{33}$ cm^{-2} s^{-1}.
- Power < 70 MW.
- Synchronous pp/ep.

E_e=60 GeV (benchmark).



1. Accelerator:

LHeC Options: Executive Summary

LHeC

Ring-Ring option:

-We know we can do it: ➔ LEP 1.5

-Challenge 1: integration in tunnel and co-existence with LHC HW

-Challenge 2: installation within LHC shutdown schedule

Linac-Ring option:

-Installation decoupled from LHC operation and shutdown planning

-Infrastructure investment with potential exploitation beyond LHeC

-Challenge 1: technology ➔ high current, high energy SC ERL

-Challenge 2: Positron source

1. Accelerator:

LI… •Details remain to be addressed …ary LHeC

Ring-R… •Decision to focus R&D work on LR technologies over coming 4 years

-We knc…

-Challer… …ith LHC HW

-Challer… …lule

➔Main Conclusion so far:
LHeC can be realized in parallel with HL-LHC if necessary studies are not delayed!

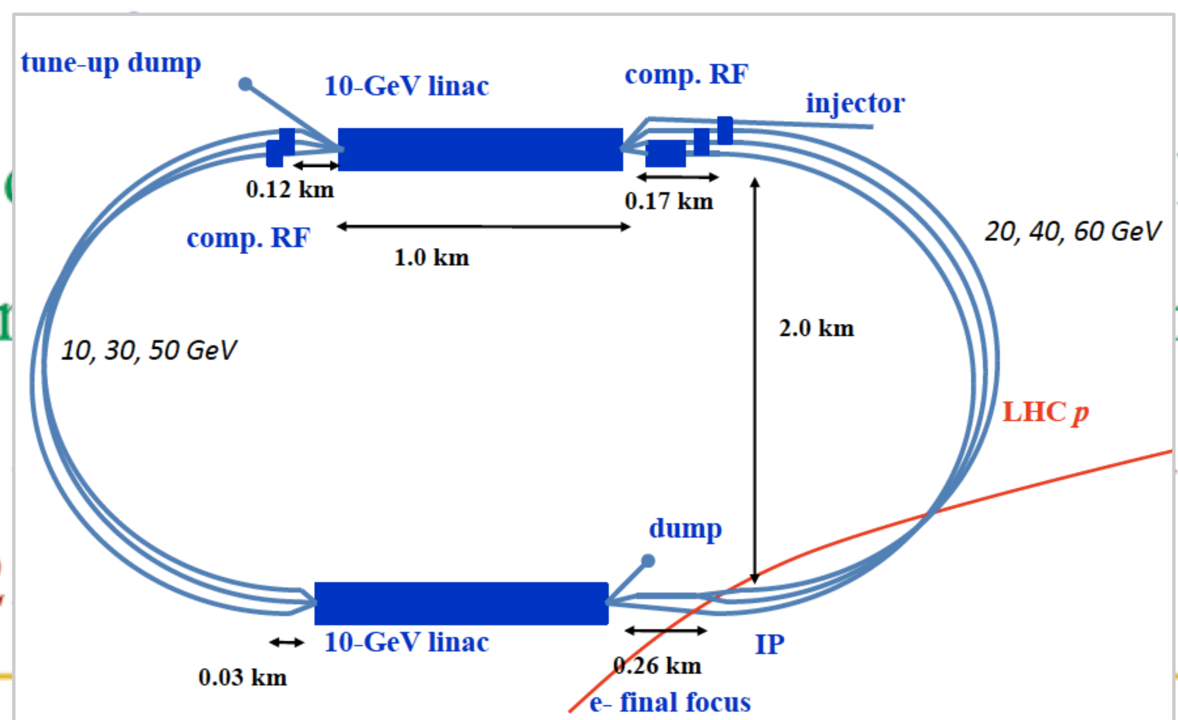
Linac-Ring

-Installation … …hutdown planning

-Infrastructur… …ion beyond LHeC

-Challenge 1 … …ergy SC ERL

-Challenge 2 …



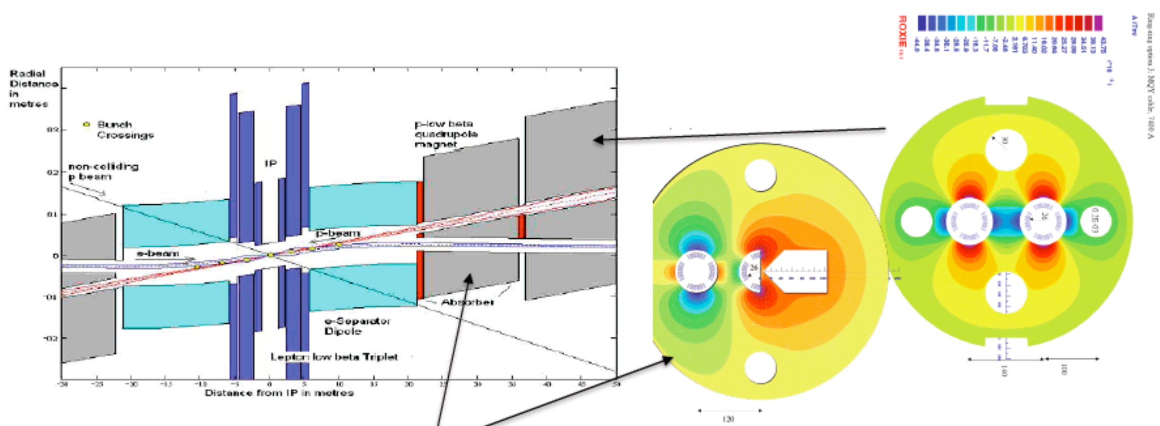
1. Accelerator:

Interaction Region: Accommodating 3 Beams

LHeC

Small crossing angle of about 1mrad to avoid first parasitic crossing (L x 0.77)
(Dipole in detector? Crab cavities? Design for 25ns bunch crossing [50ns?]
Synchrotron radiation –direct and back, absorption … recall HERA upgrade…)

Focus of current activity

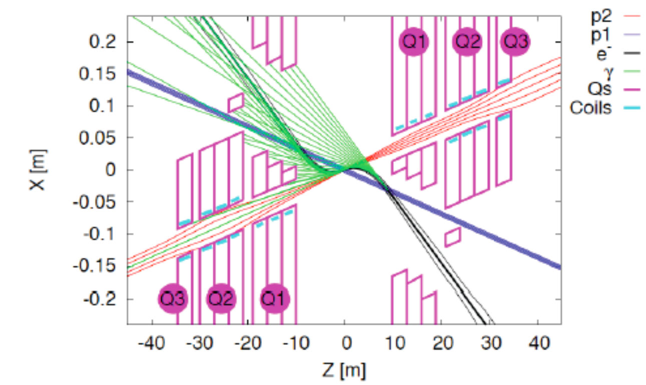


1st sc half quad (focus and deflect)
separation 5cm, g=127T/m, MQY cables, 4600 A

2nd quad: 3 beams in horizontal plane
separation 8.5cm, MQY cables, 7600 A

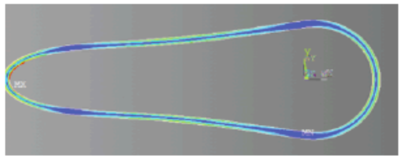
Next Steps: Interaction Region Design

LHeC



Beam pipe: in CDR 6m, Be, ANSYS calculations

Composite material R+D, prototype, support..
→ Essential for tracking, acceptance and Higgs



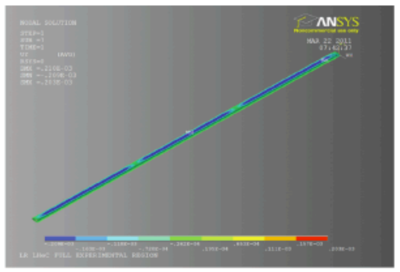


Figure 9.32: 3-D view of the IR geometry showing contours of bending displacement [m].

Have optics compatible with LHC ATS optics and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector

Adapt LHeC to LHC ATS optics
Specification of Q1 – NbTi prototype

Revisit SR (direct and backscattered),
Masks+collimators
Beam-beam dynamics and 3 beam operation studies

Optimum RF Frequency: around 800 MHz

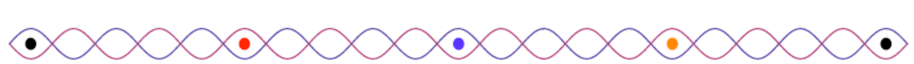
Erk Jensen @ March 2013 LHeC Seminar

- F_{RF} = 20* 40.079 MHz → 801.58 MHz

→Buckets with slightly unevenly spaced bunches

1st pass 2nd pass 3rd pass 1st pass

→One could vary the number of passes through the ERL:



1st pass 2nd pass 3rd pass 4th pass 1st pass

→Synergy with HL-LHC: Higher Harmonic RF System and TLEP!

Final parameter set will be developed as we gain experience with LHC operational (beam-beam, spacing etc.)

Performance reach of L = 10^{34} $cm^{-2}s^{-1}$ seems to be well within reach of the LHeC!

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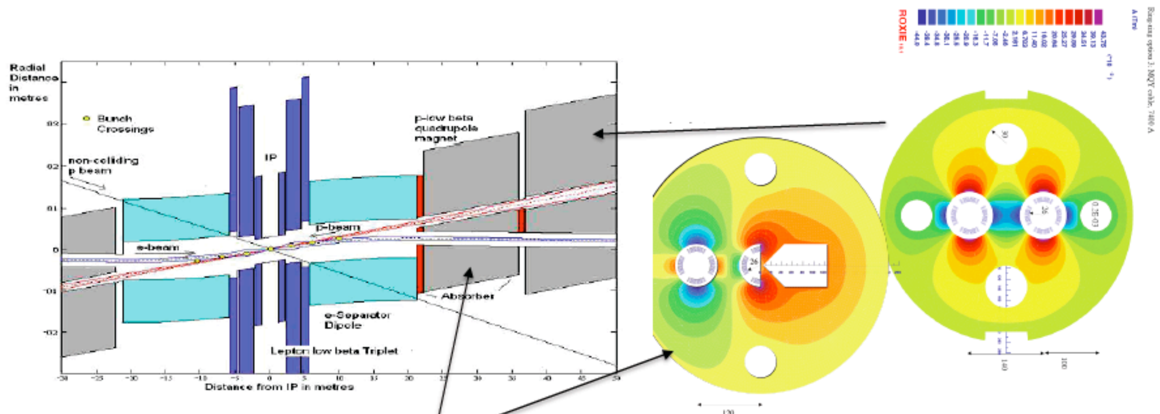

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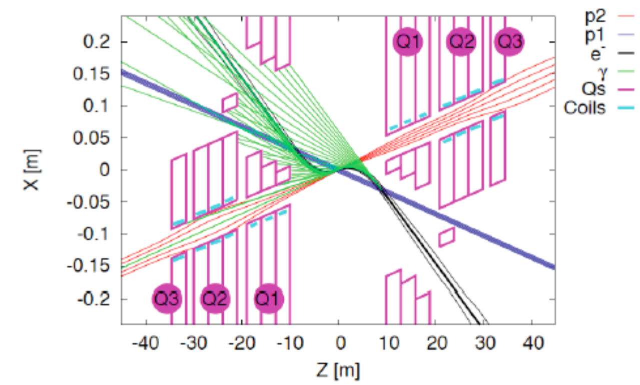
Next Steps: Interaction Region Design



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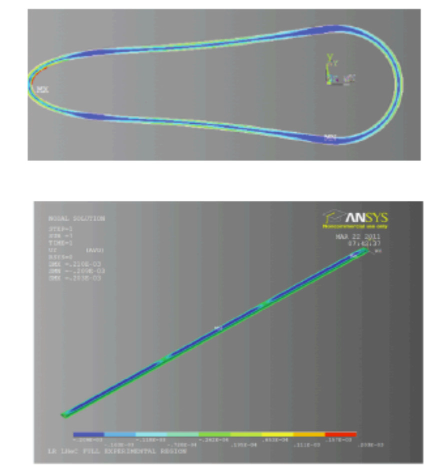

Figure 9.32: 3-D view of the LR geometry showing contours of bending displacement [m].

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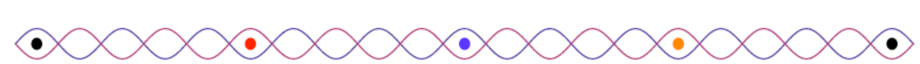

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Performance reach of L = 10^{34} $cm^{-2}s^{-1}$ seems to be well within reach of the LHeC!

Some gain on the e, HL-LHC values for p.

1. Accelerator:

5. Workshop on LHeC ERL Test Facility at CERN

Klein

STRAWMAN OPTICS DESIGN FOR THE LHeC ERL TEST FACILITY

A. Valloni*, O. Bruning, R. Calaga, E. Jensen, M. Klein, R.Tomas, F. Zimmermann,
CERN, Geneva, Switzerland
A. Bogacz, D. Douglas, Jefferson Lab, Newport News Virginia

Contribution to IPAC13

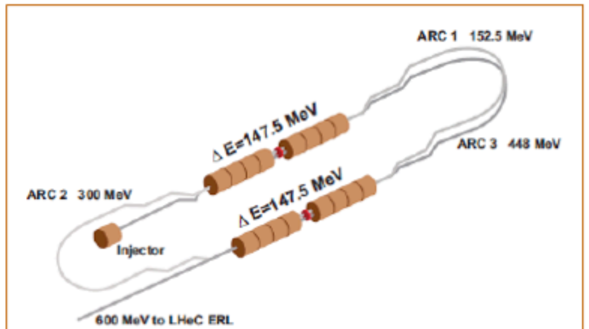


Figure 2: Consequent upgrade to LHeC pre-accelerator. By modifying the machine backleg to include a second full cryomodule, the recirculator can deliver higher beam energy of 600 MeV.

Proposal for an LHeC ERL Test Facility at CERN

R. Calaga, E. Ciapala, E. Jensen
CERN, Geneva, Switzerland

CERN-LHeC-Note-2012-001 ACC
October 17, 2012
Rama.Calaga@cern.ch

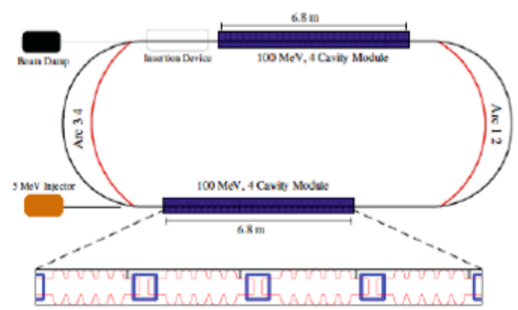


Table 3: Future ERLs for electron-hadron colliders

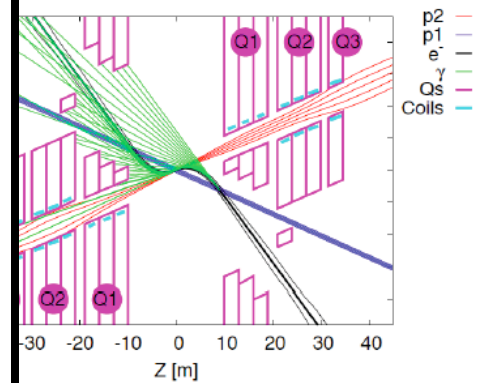
Parameter	JLab MEIC	BNL eRHIC	CERN LHeC
Energy [GeV]	5-10	20	60
Frequency [MHz]	750	704	n×40
# of passes	-	6	3
Current/pass [mA]	3	50	6.6
Charge [nC]	4	3.5	0.3
Bunch Length [mm]	7.5	2.0	0.3

Workshop:
- Collaboration: CERN, AsTEC, CI, JeffersonLab, U Mainz, +
- LHeC Parameters (C,Q,source,I) rather conservative
- Test Facility to develop full technology, key: cavity
- RF frequency chosen

22/23.1.2013 Daresbury (UK) http://cern.ch/lhec

Next Steps: Interaction Region Design

LHeC



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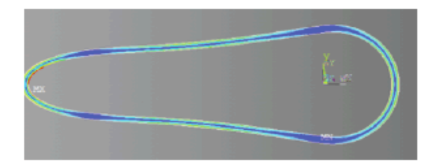

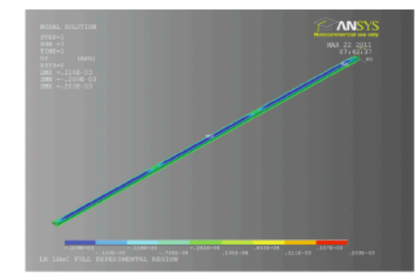

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2. Detector:

Key elements to the detector design

- To provide a baseline detector design, which satisfies not only the **physics requirements** but fits the **machine and interaction region constraints** for running during phase 2 of the LHC
- The detector needs to be designed, constructed and **ready for use 12 years from now**, to be able to **run concurrently** with the other LHC *pp* and *pA* experiments, in order to record the respective *ep* and *eA* data
- Such a timescale **prohibits a dedicated, large scale R&D programme**, but the **LHeC detector can profit** from current and upgrade LHC technologies, as well as ILC development, and the HERA experience
- The LHeC detector therefore should be **modular and flexible in design**, with **assembly above ground**, be able to accommodate upgrade programmes and **be affordable**, with a comparatively reasonable cost

David South | The LHeC Detector | DIS 2013, 22-26 April 2013 | Page 5

2. Detector:

High resolution tracking | Full coverage calorimetry | Baseline muon system

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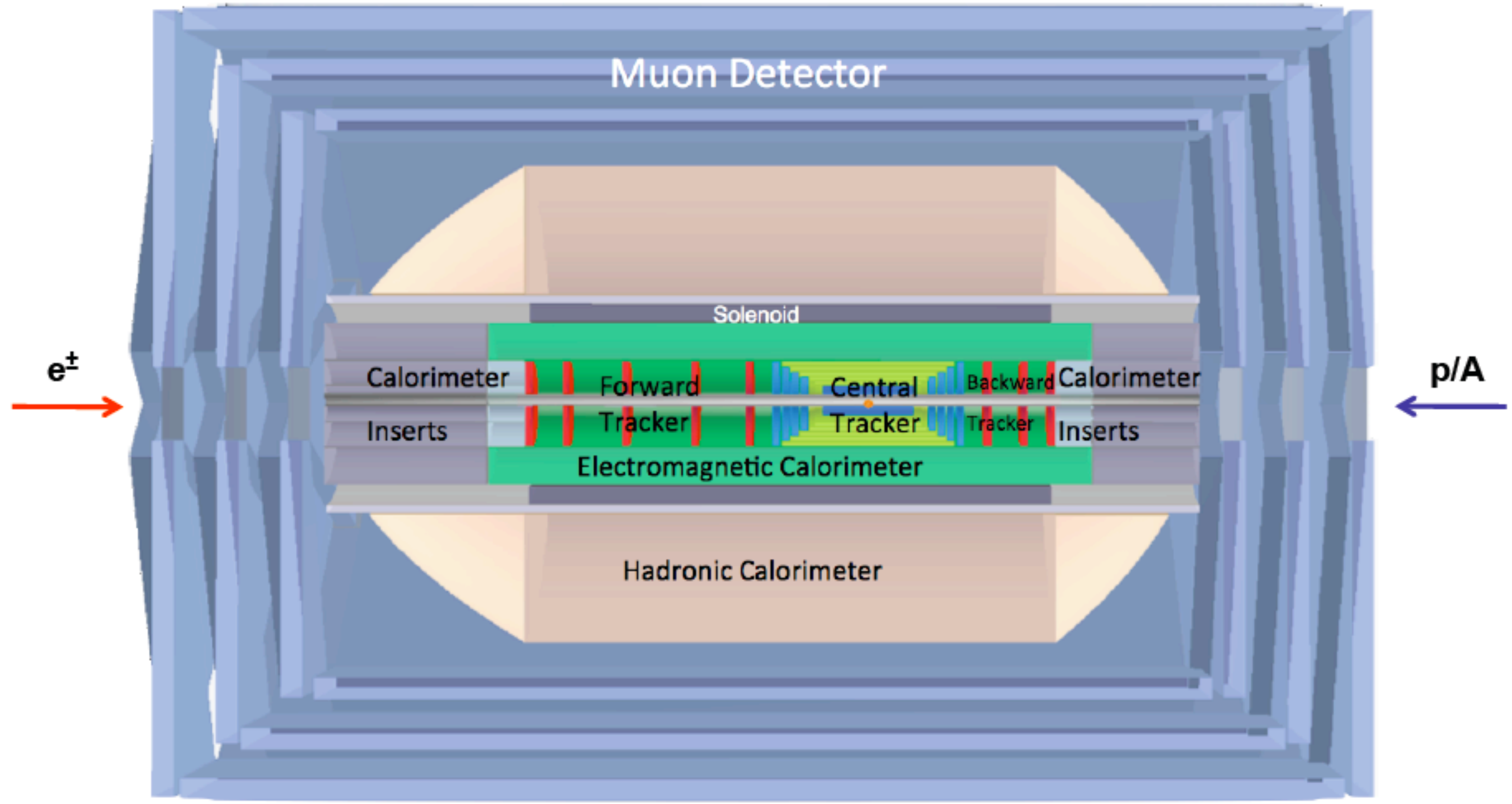
2. Detector:

LHeC detector overview



- Forward/backward asymmetry in energy deposited and thus in geometry and technology
- Present dimensions: L x D = 14m x 9m (compared to CMS 21m x 15m, ATLAS 45m x 25 m)
- Not shown: Taggers at -62m (e), -100m (B-H photons), +100m (n) and +420m (p)

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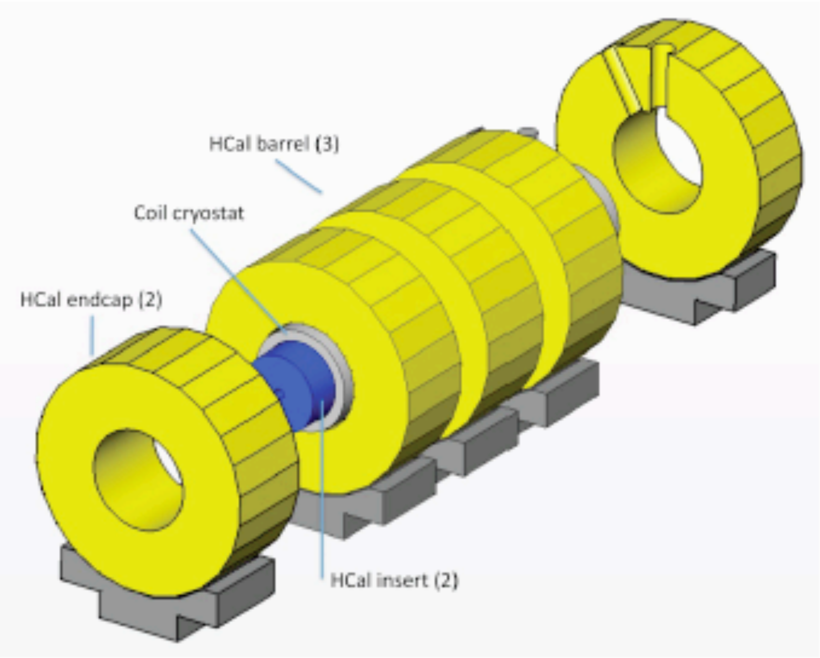
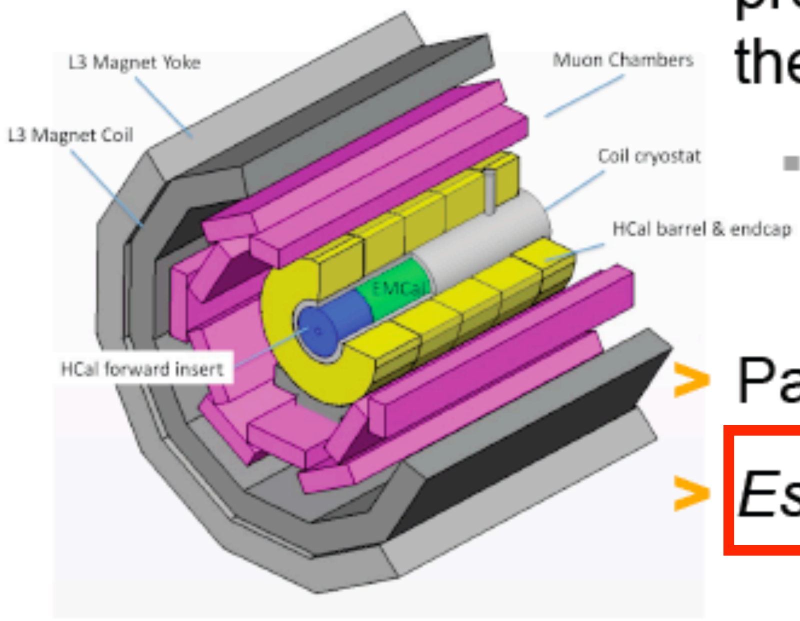
2. Detector:

Main detector assembly and integration

- Detector assembled on the surface as much as possible: approximately 16 months
  - Split the detector into three main parts:
    1. Coil cryostat, including the superconducting coil, the two dipoles and eventually the EMC (LAr)
    2. Three barrel wheels and two end-caps of the HAC, fully instrumented and cabled
    3. Two HAC inserts, forward and backward





- Three months commissioning of coil system on site; preparation for lowering one month; lowering each of the 8 pieces: one week
  - Underground completion of the integration of the main detector elements inside the L3 magnet would require a further 2 months for cabling and connection to services
- Parallel installation of muons, tracker, EMC: 6 months
- *Estimated total time:* 30 months (+ 1 month for B-map)

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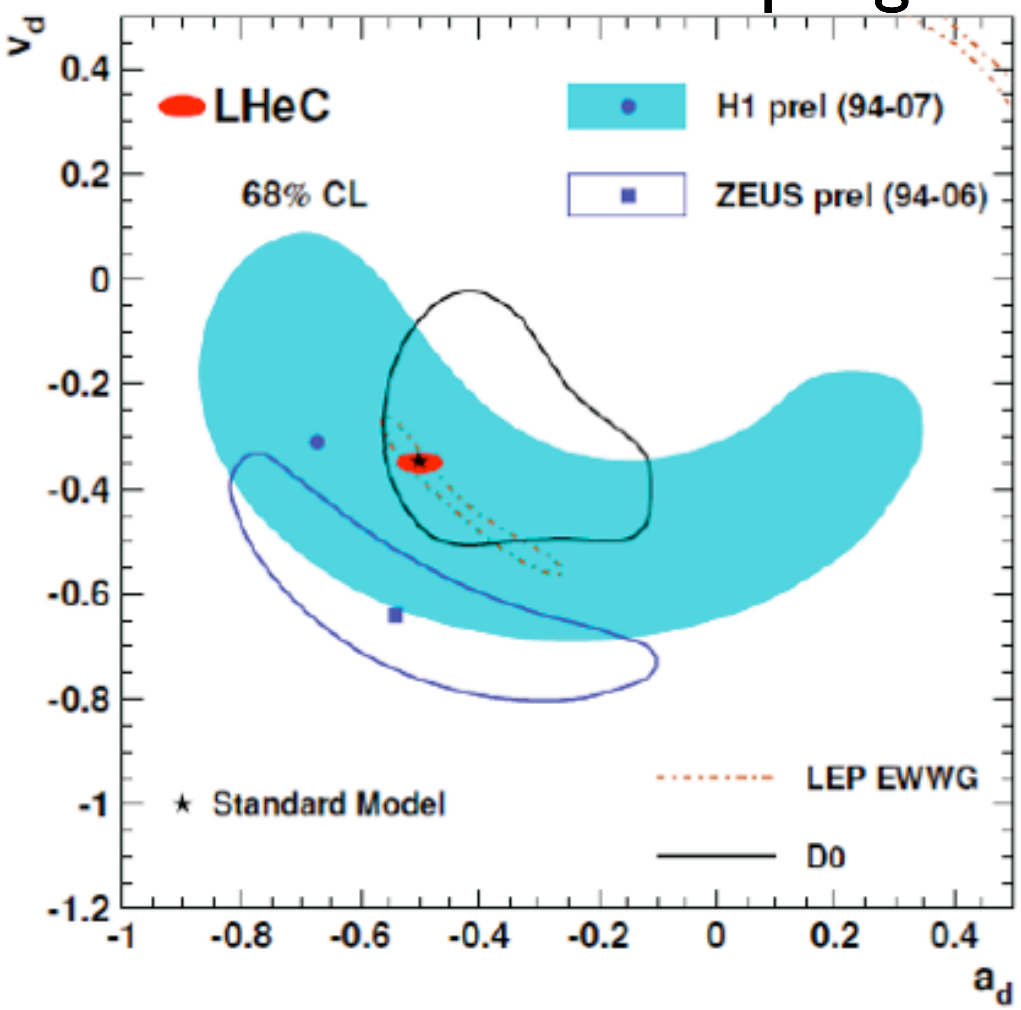
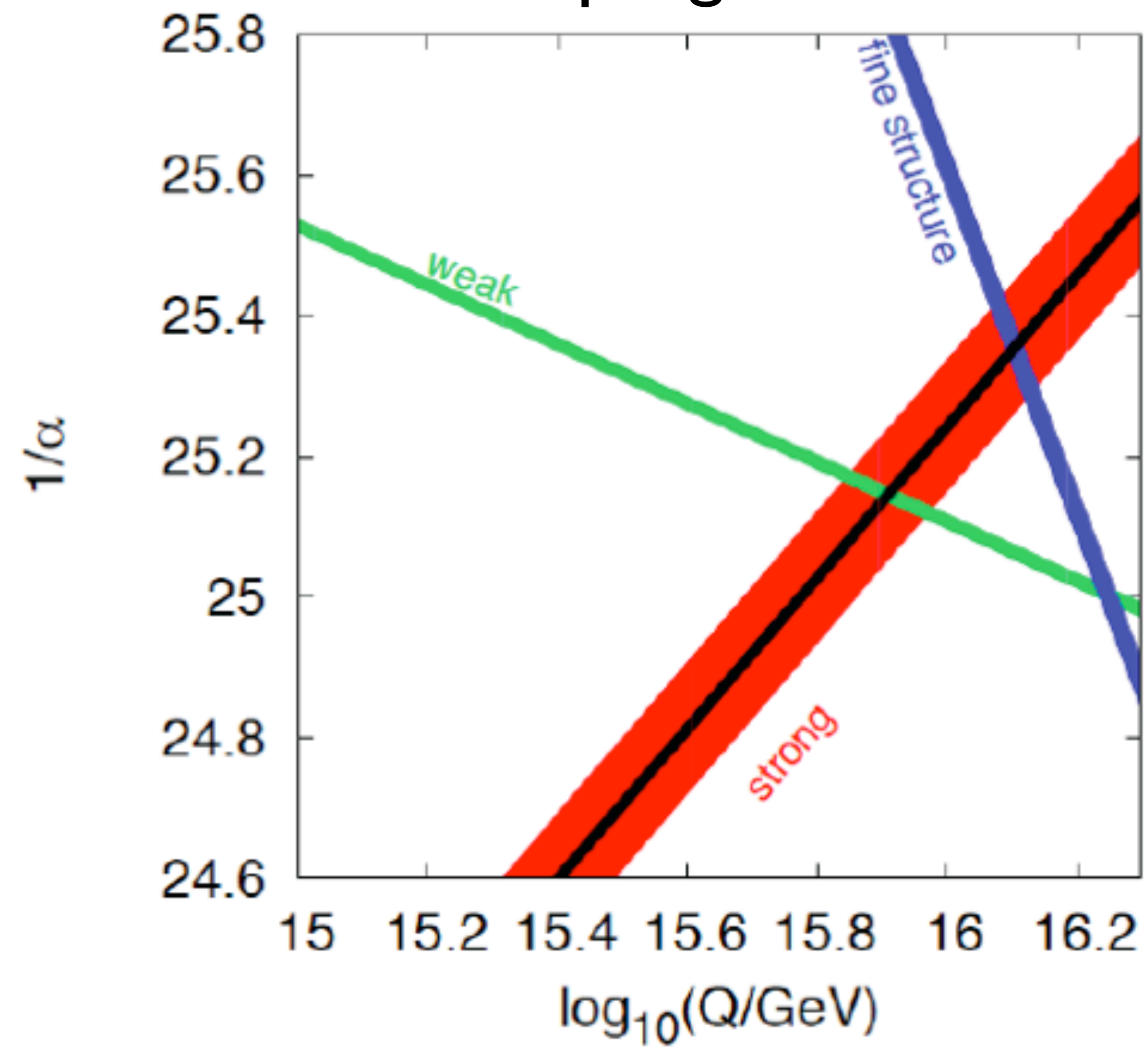
3. QCD:

High Precision DIS

neutral current couplings of d



1/coupling constant



$Q^2 >> M_{Z,W}^2$, high luminosity, large acceptance
Unprecedented precision in NC and CC
Contact interactions probed to 50 TeV
Scale dependence of $\sin^2\theta$ left and right to LEP

→ **A renaissance of deep inelastic scattering** ←

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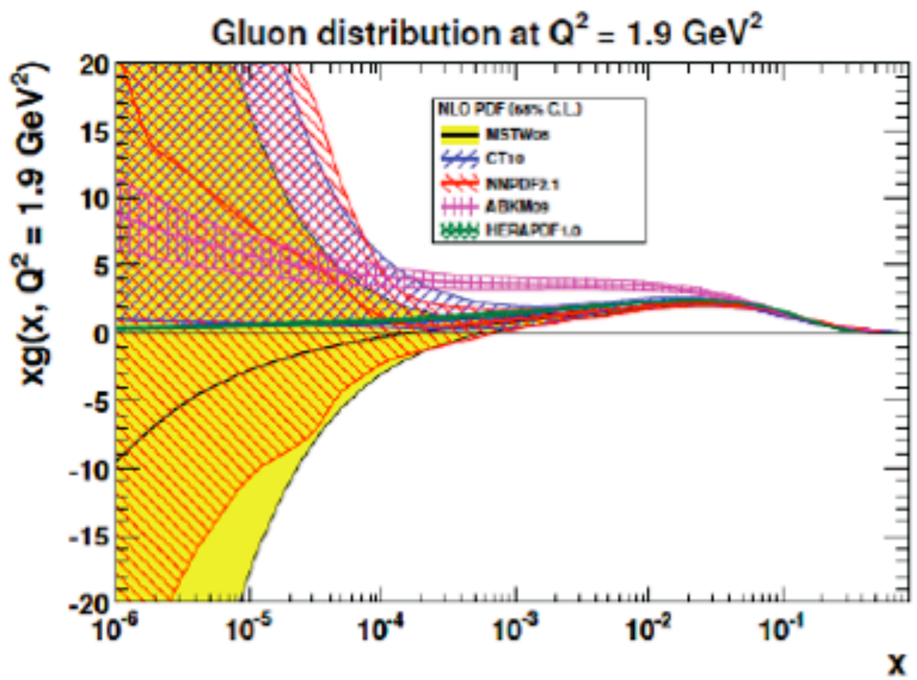
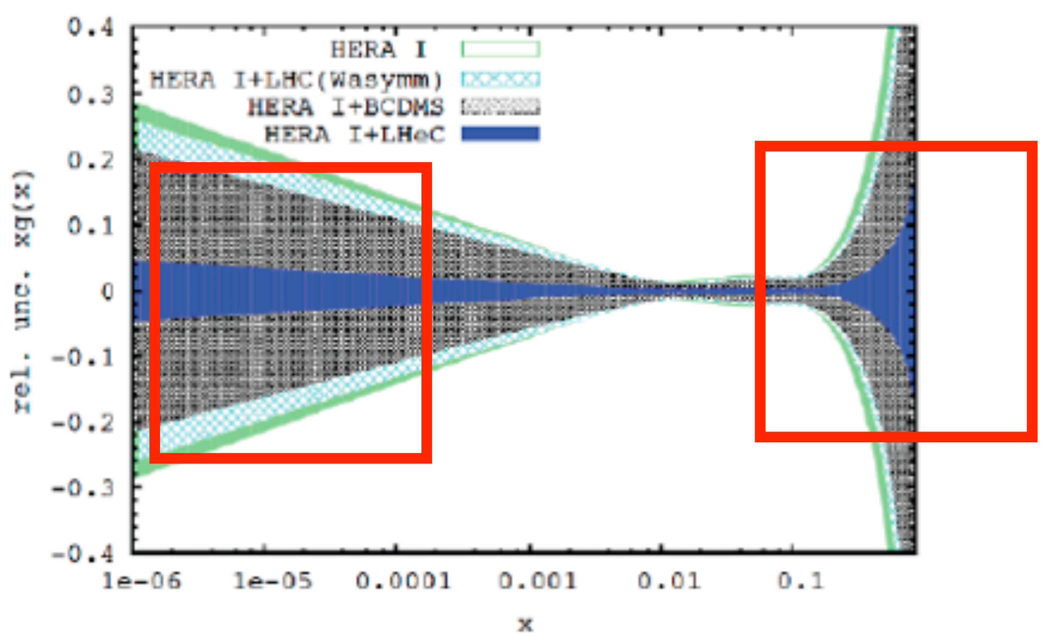
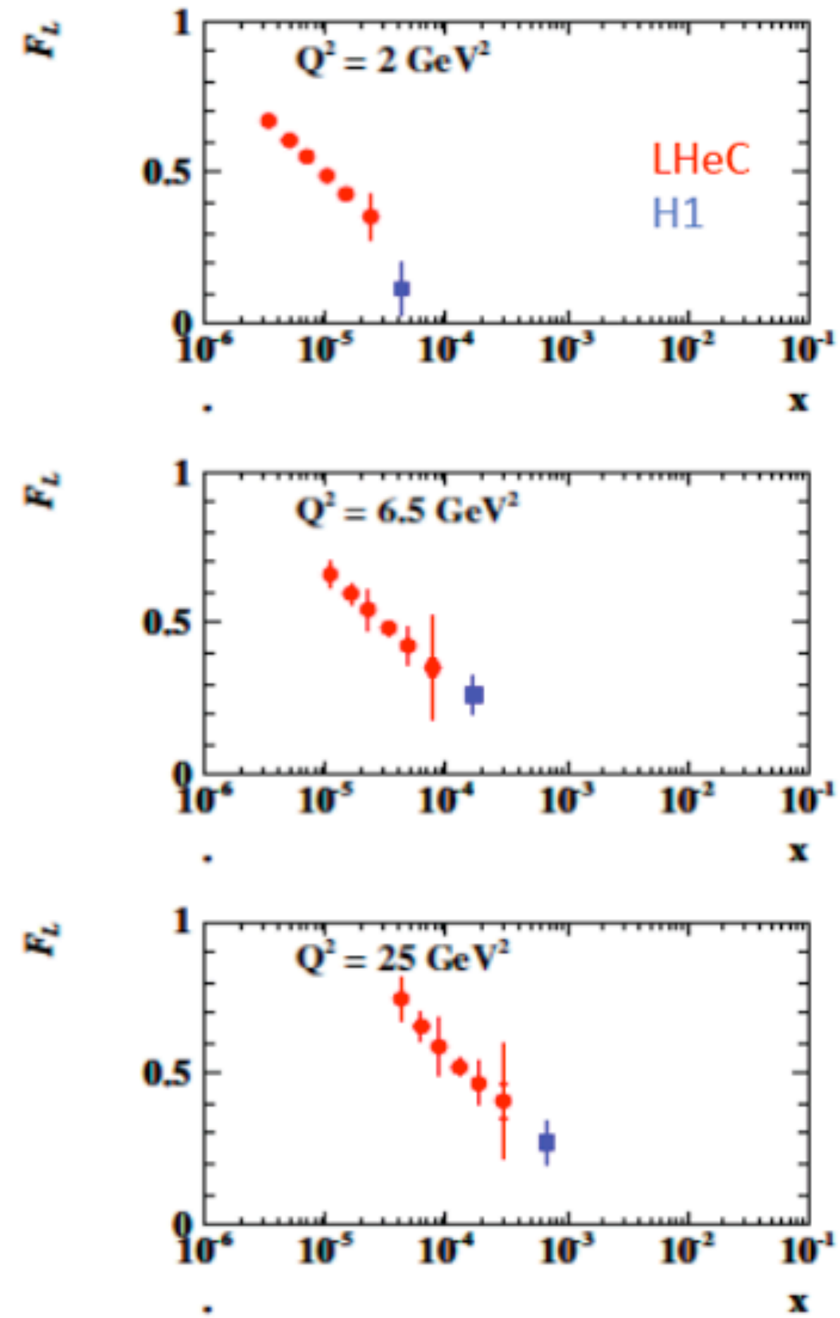
Solving a 30 year old puzzle:
α_s small in DIS or high with jets?
Per mille measurement accuracy
Testing QCD lattice calculations
Constraining GUT (CMSSM40.2.5)
Charm mass to 3MeV, N^3LO

3. QCD:

Gluon Saturation at Low x?







Gluon measurement down to x=10^{-5}, **Saturation or no saturation** (F_2 and precise F_L)
Non-linear evolution equations? Relations to string theory, and **SUSY at ~10 TeV**?

cf H.Kowalski, L.Lipatov, D.Ross, arXiv:1205.6713

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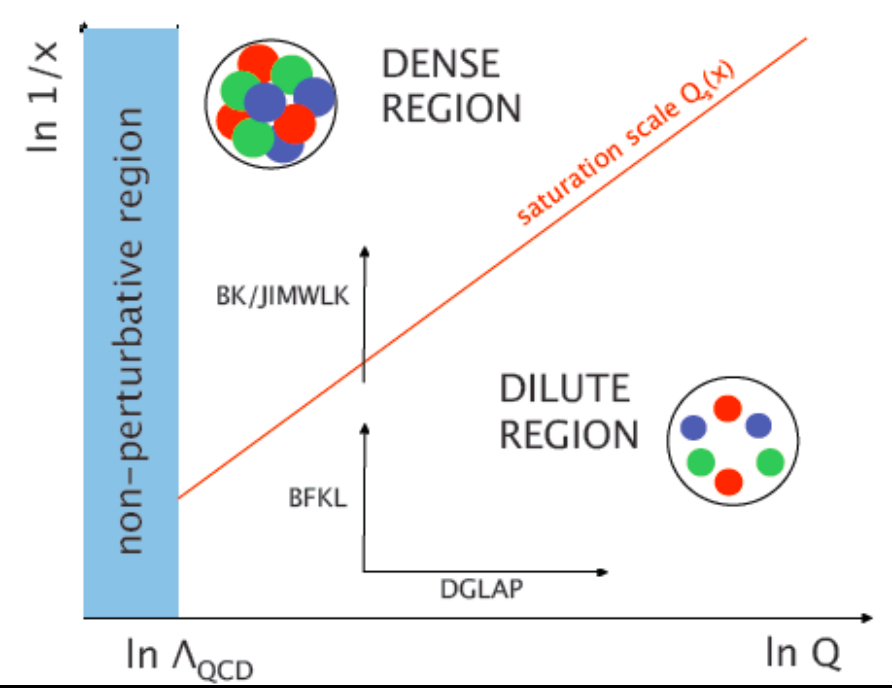
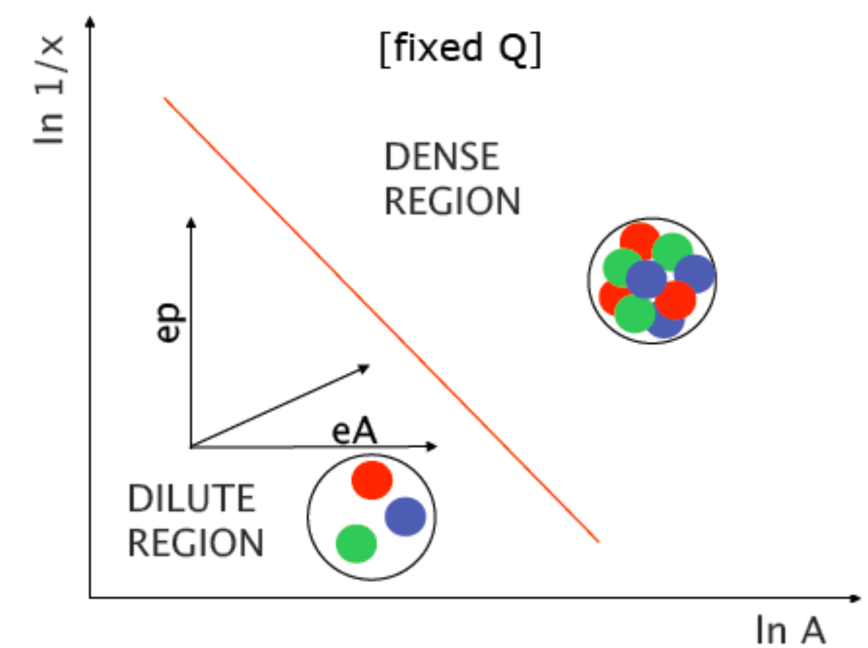
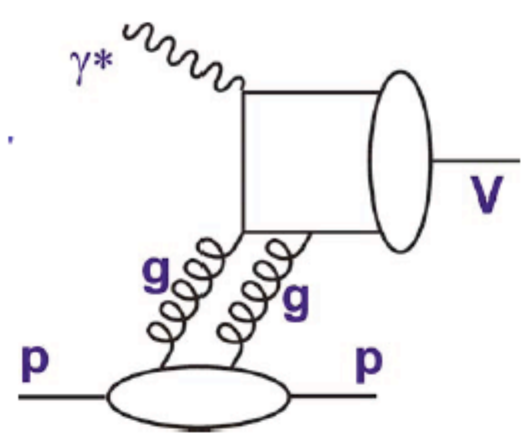
3. QCD:

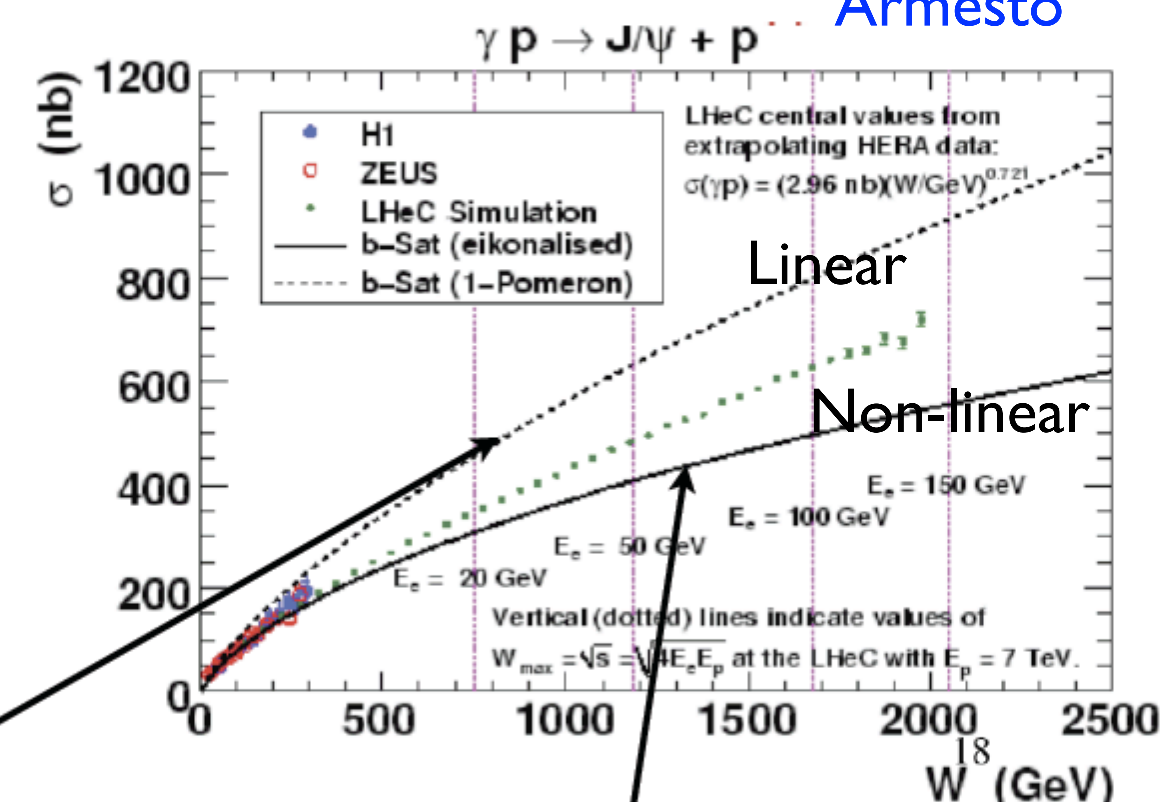
• **Non-linear effects** (unitarity constraints) are density effects: where? ⇒ **two-pronged approach at the LHeC**: ↓ x / ↑ A.







• Elastic J/ψ production appears as a candidate to signal saturation effects at work!!!



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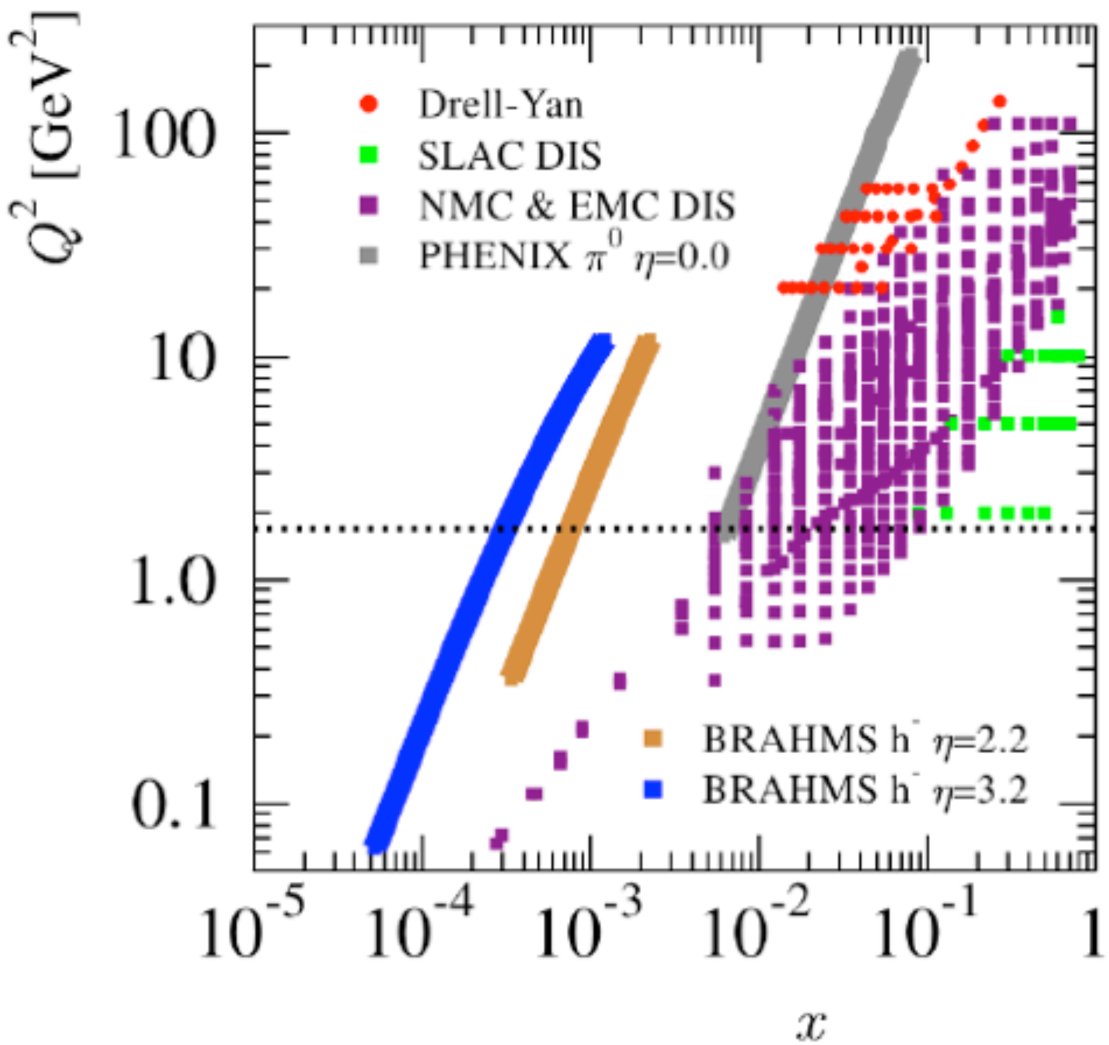
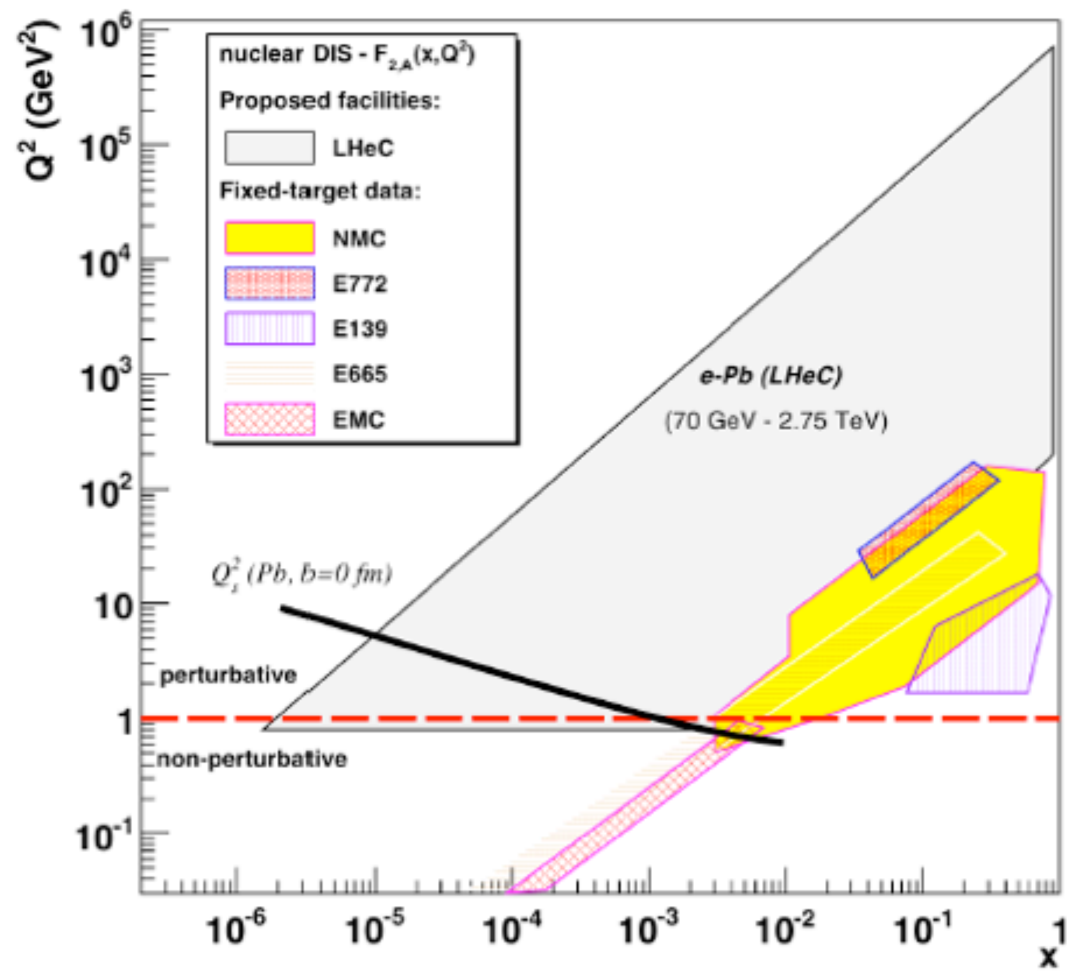
3. QCD:

LHeC kinematics

- **The proposed LHeC collider would hugely enlarge the kinematic coverage in nuclear DIS.**



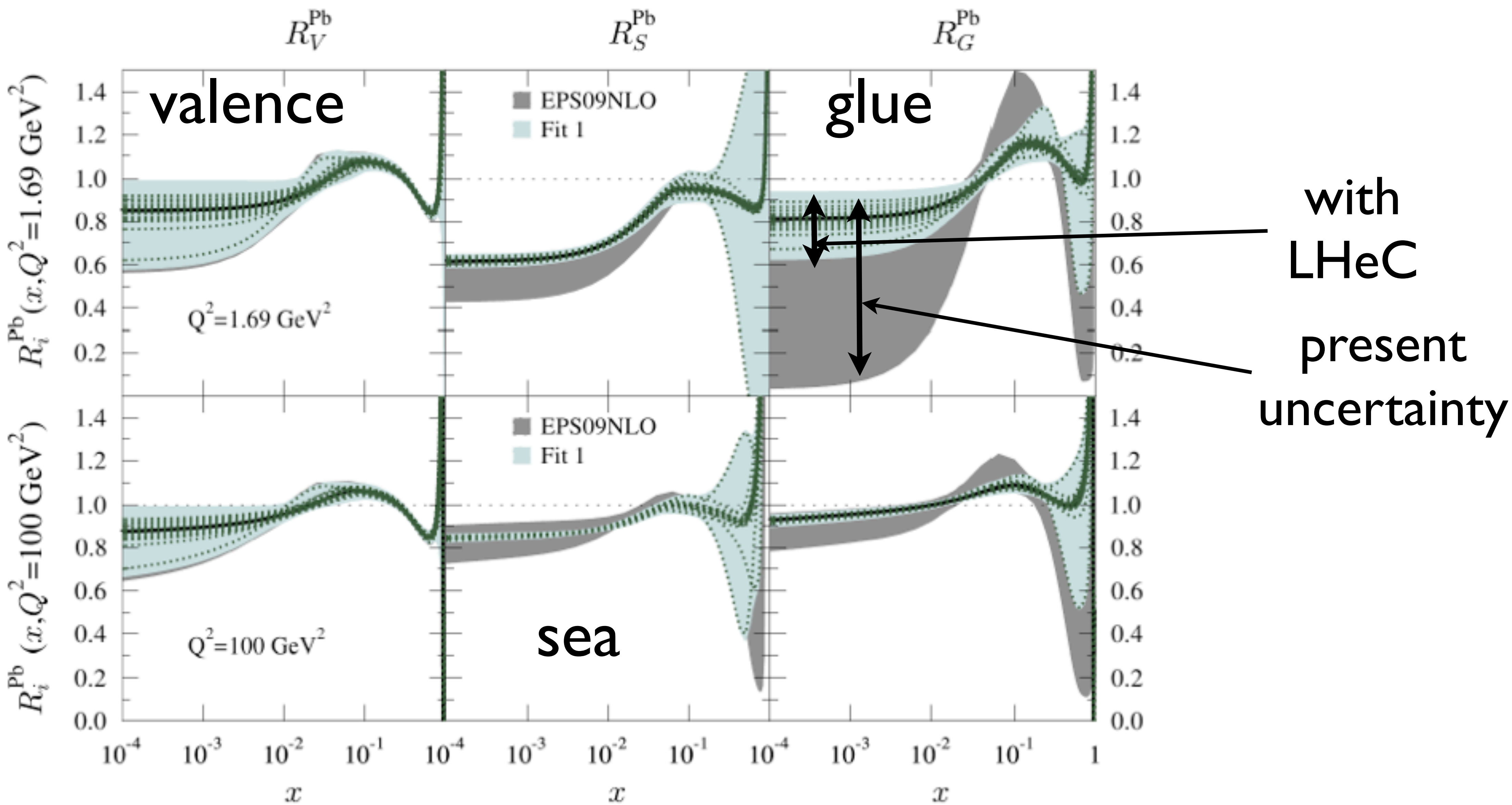


Paukkunen

- **We estimate the impact of the LHeC data on the nPDFs by a fit to a sample of pseudodata**

3. QCD:

Effect in the nuclear modificaton factors $= \frac{\text{PDF in A}}{\text{PDF in p}}$

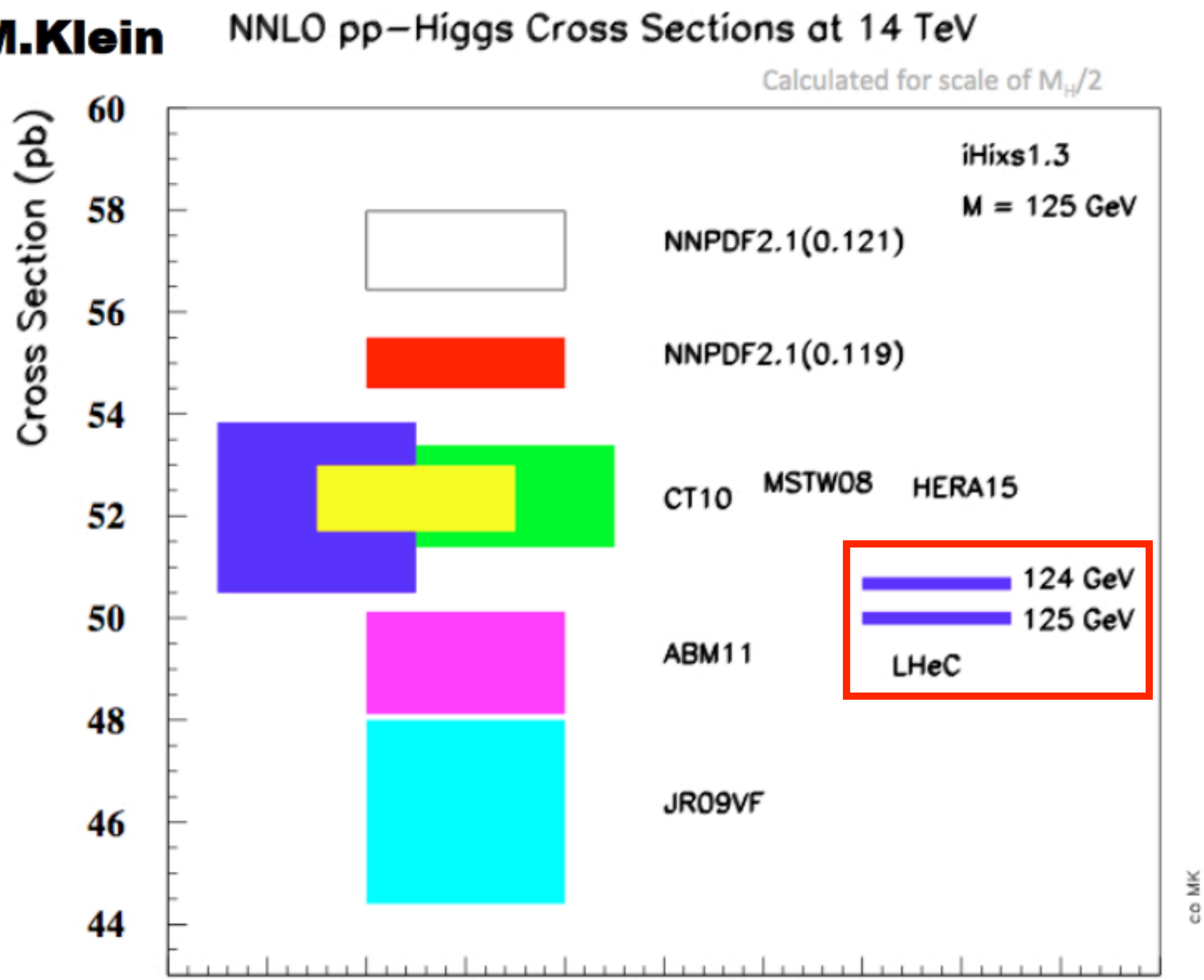


- A drastic reduction in the small-x gluon and sea quark uncertainties

Paukkunen

4. EW/BSM:

M.Klein



Exp uncertainty of LHeC Higgs cross section is 0.25% (sys+sta), using LHeC only.

Leads to mass sensitivity..

Strong coupling underlying parameter (0.005 – 10%). LHeC: 0.0002

Needs N^{3}LO

HQ treatment important

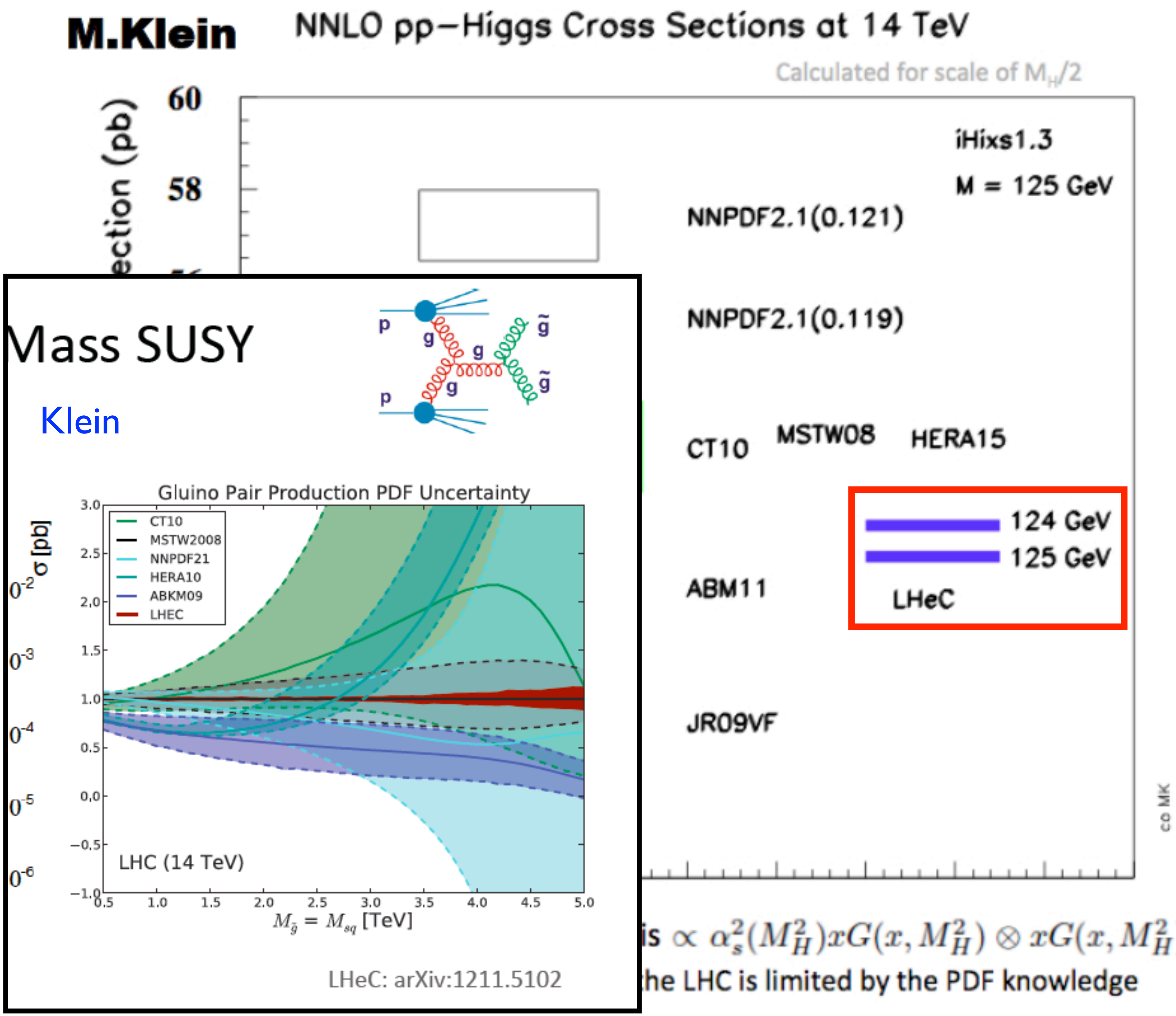
PRECISION σ(H)

Mellado

Higgs production (gg) at the LHC is $\propto \alpha_s^2(M_H^2)xG(x, M_H^2) \otimes xG(x, M_H^2)$

Bandurin (ICHEP12) Higgs physics at the LHC is limited by the PDF knowledge

4. EW/BSM:



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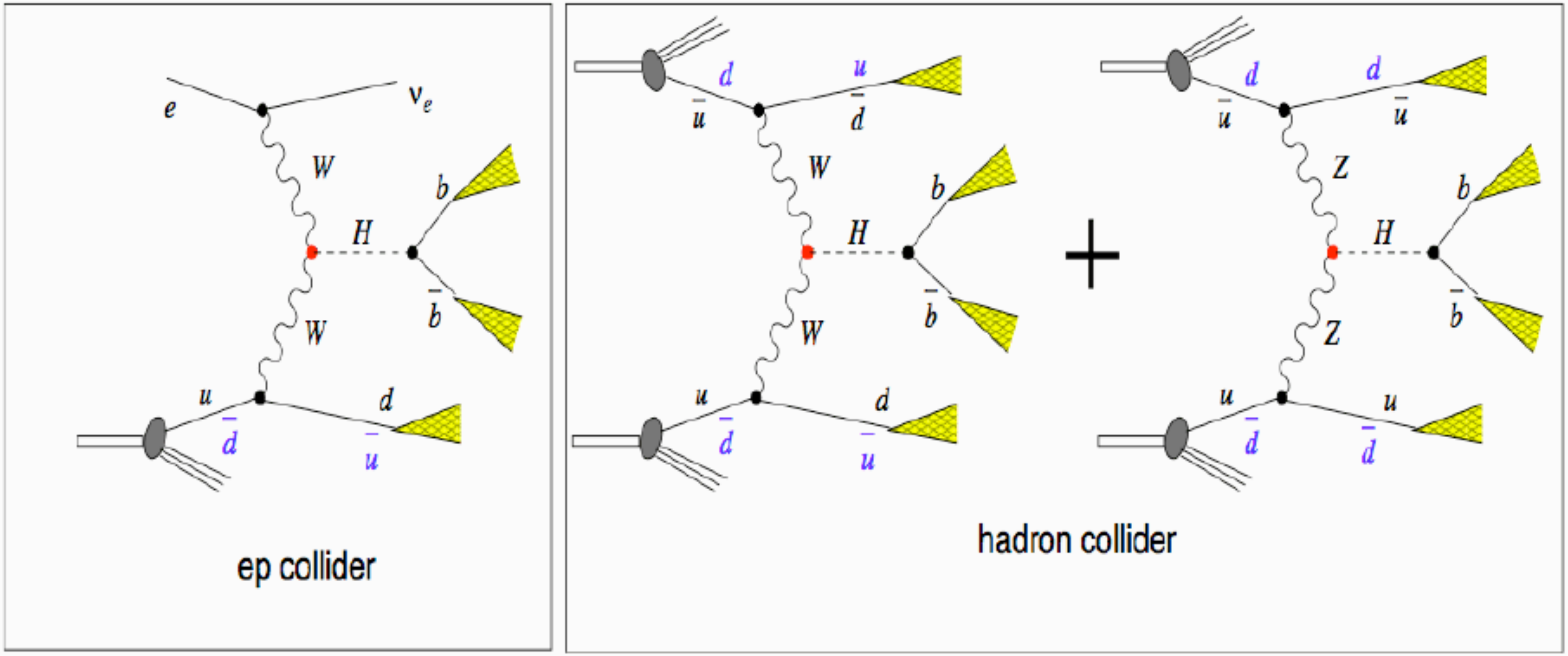
higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)

Mellado



ep **process uniquely addresses the** *HWW* **vertex.**

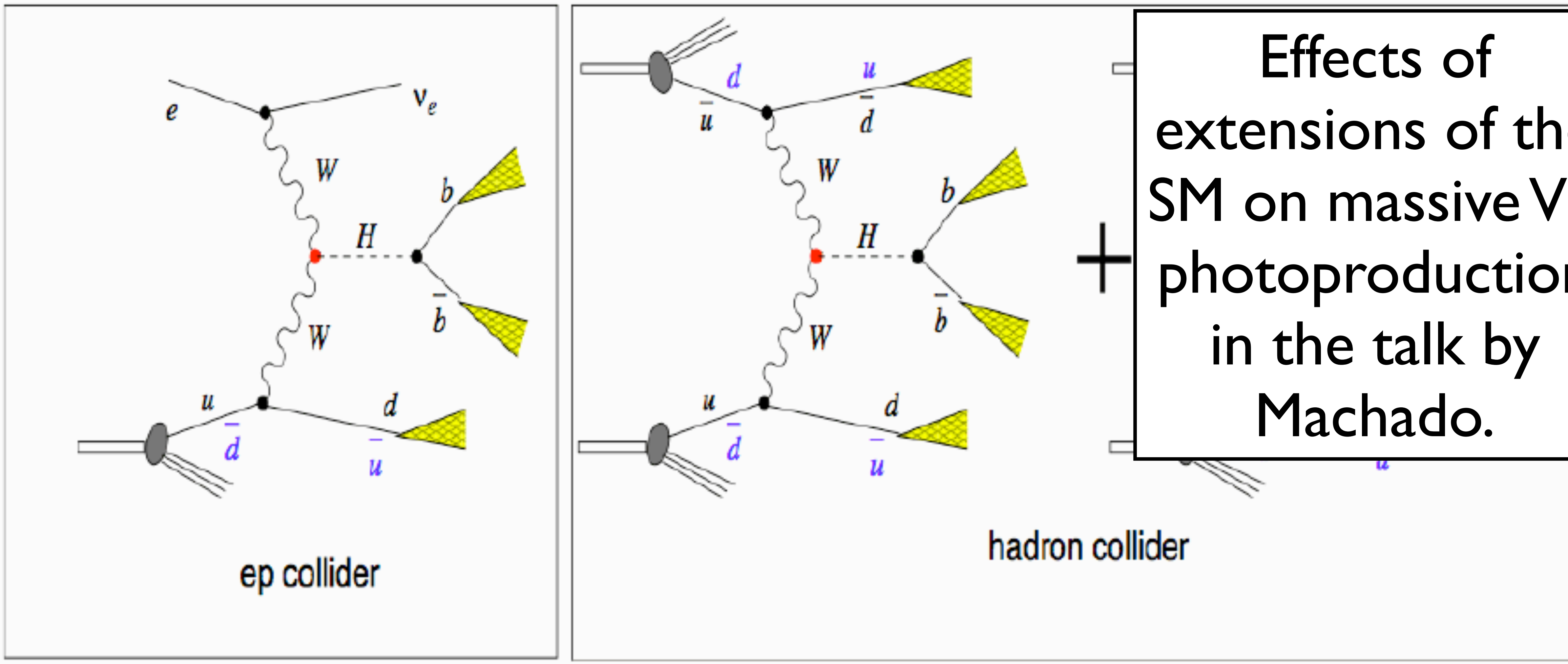
Need to investigate physics beyond the SM within the 0^+ hypothesis with high precision

16

4. EW/BSM:

higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)

Mellado



Effects of extensions of the SM on massive VB photoproduction in the talk by Machado.

ep process uniquely addresses the HWW vertex.

Need to investigate physics beyond the SM within the 0^+ hypothesis with high precision

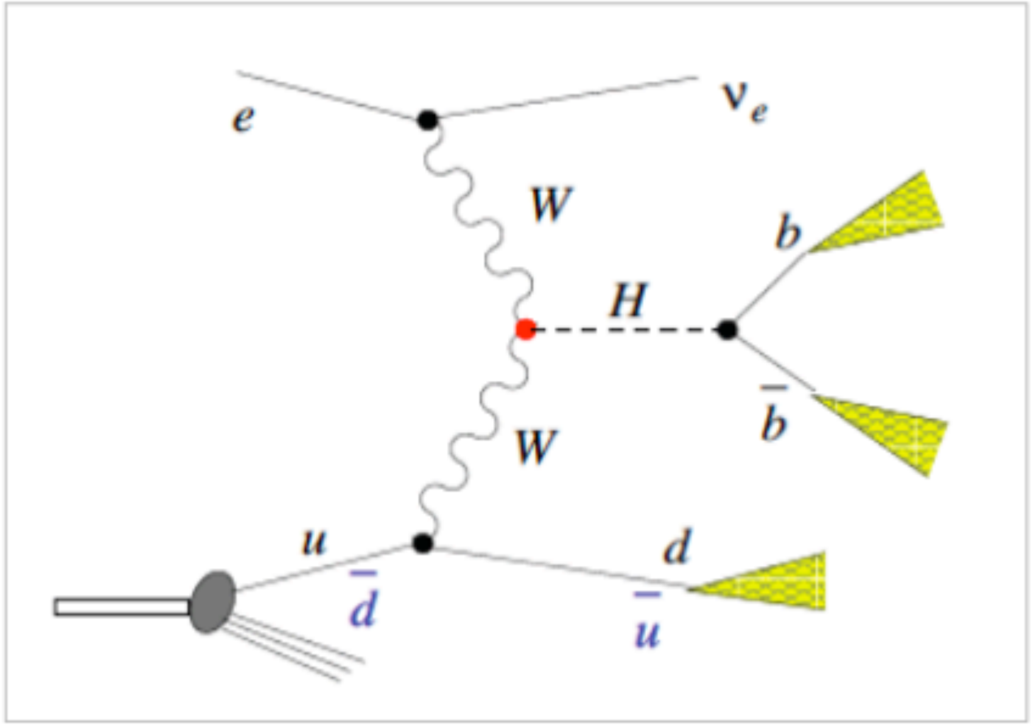
16

4. EW/BSM:

Higgs at the LHeC

Klein

LHeC is a Higgs "Factory": 200 fb cross section in CC e⁻p: L= 1 ab^{-1}: 2 10^5 Higgs events
Clean final state, no pile-up, low QCD bgd, uniquely WW and ZZ, small theory unc.ties



LHeC Higgs	CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation	-0.8	0	0
Luminosity [ab^{-1}]	1	1	0.1
Cross Section [fb]	196	20	58
Acceptance	0.92	0.93	0.94
Decay Channel	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	97 500	12 000	3500
$H \to c\bar{c}$	5 900	600	180
$H \to gg$	16 200	1 600	480
$H \to WW$	25 200	2 600	760
$H \to ZZ$	2 880	1900	560
$H \to \tau^+\tau^-$	10 260	1 000	310
$H \to \gamma\gamma$	360	40	12

Ultimate e and p beams, 10 years of operation

Table 1: Cross sections and rates of Higgs production in ep scattering with the LHeC. The cross sections are obtained with MADGRAPH5 (v1.5.4) using the p_T of the scattered quark as scale, CTEQ6L1 partons and $M_H = 125\,\mathrm{GeV}$. The acceptance is obtained with kinematic cuts on final state particles ($|\eta_{jet}| < 5$, $|\eta_{e,\gamma}| < 4.7$, $p_{T,jet} > 1\,\mathrm{GeV}$, $E_{jet} > 15\,\mathrm{GeV}$, $E'_e > 10\,\mathrm{GeV}$, $E_\gamma > 5\,\mathrm{GeV}$) but excludes the tagging probabilities for b, c, τ and further g, W, Z reconstruction efficiencies. In an initial study (CDR) the bb final state is reconstructed with an efficiency of about 5%. This leads to $\simeq$ 5000 events in this channel, at an S/N of 1.

ILC: 10^{34} cm^{-2}s^{-1}, 280fb, 15000 cavities, width - LHeC: 10^{34} 200fb 960 cavities, no width

cf CDR, **Talk of Bruce Mellado**, also Uta Klein ICHEP12

4. EW/BSM:

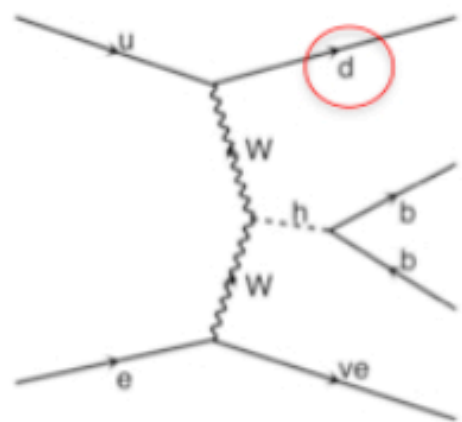
LHeC $H \to b\bar{b}$ results [M_H=120 GeV, E_p=7 TeV]

- Forward jet tagging
  - $\eta_{jet} > 2$ (lowest η jet excluding b-tagged jets)

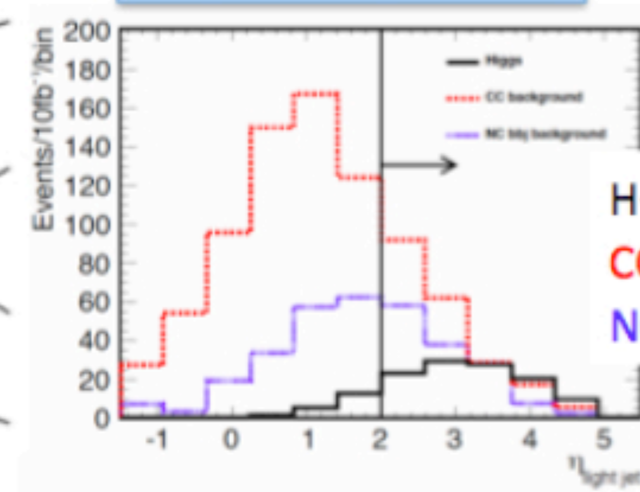
Coordinate:
Fwd: +z-axis along proton beam

Mellado

$H \to b\bar{b}$ signal



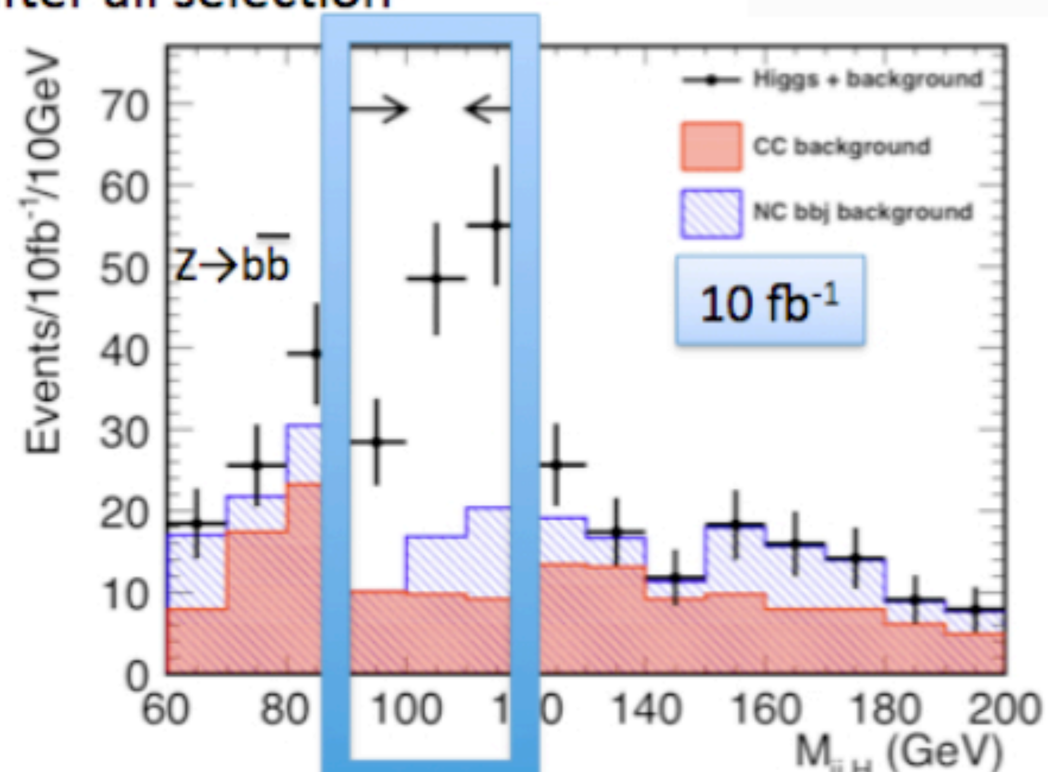
Forward jet η tag



$H \to b\bar{b}$
CC BG
NC BG

- Higgs invariant mass after all selection

E_e=150 GeV



Expect 500 H->bb events at 60 GeV for 100 fb^{-1} -> 3% cross section measurement

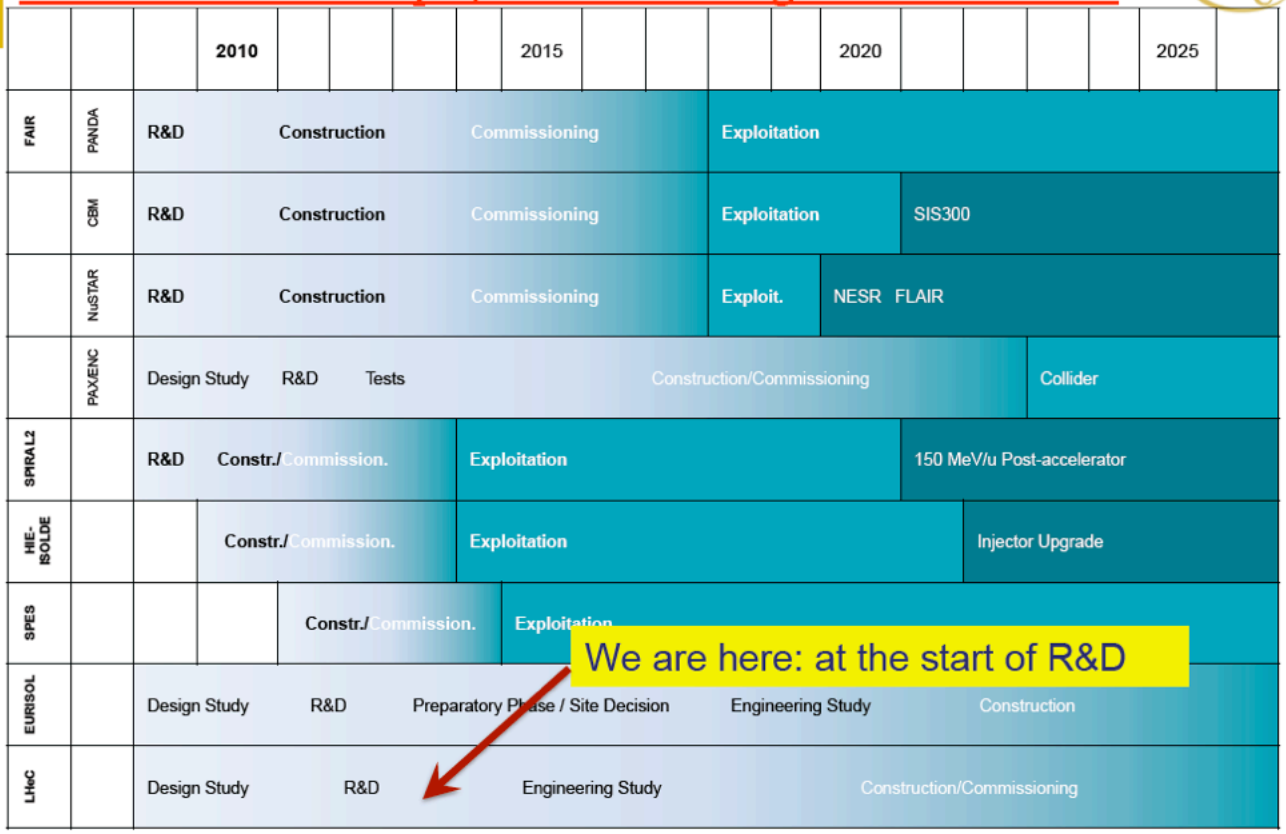
Clear signal obtained with just cut based analysis already!

ICHEP2012, Uta Klein, Higgs@LHeC 12

5. Status and plans:

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

LHeC



CERN Mandate: 5 main points

The mandate for the technology development **includes studies and prototyping of the following key technical components**:

- Superconducting RF system for CW operation in an Energy Recovery Linac (high Q_0 for efficient energy recovery) S
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models
- Studies related to the experimental beam pipes with large beam acceptance in a high synchrotron radiation environment
- The design and specification of an ERL test facility for the LHeC.
- The finalization of the ERL design for the LHeC including a finalization of the optics design, beam dynamics studies and identificationof potential performance limitations

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators. Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies with existing CERN studies.**

S.Bertolucci at Chavannes workshop 6/12 based on
CERN directorate's decision to include LHeC in the MTP

5. Status and plans:

Next Steps: RF Prototype and Test Facility

LHeC

- Develop 2 RF Cryomodule Prototypes over the nest 3 years
  - -LHeC RF frequency choice driven by power considerations
    - ➔ Choice of ERL RF frequency: 801.58 MHz
    - ➔ Synergy with HL-LHC and Higher Harmonic RF system!
- Design an ERL test facility @ CERN:
  - -Optimize magnet design for ERL return arcs
- Optimize and Iterate on LHeC ERL layout:
  - -Optimization of linac configuration & of number of passages
  - -Optimization of Civil Engineering layout
  - -Optimization of Interaction Region (L^*) and Synchroton Light

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5. Status and plans:

LHeC Summary Spring 2013

1. The LHeC is the natural (and the only possible) successor of the energy frontier exploration of deep inelastic scattering with fixed target experiments and HERA at 10, 100 and then 1000 GeV of cms energy.

2. Its physics programme has key topics (WW→ H, RPV SUSY, α_s , gluon mapping, PDFs, saturation, eA…) which ALL are closely linked to the LHC (Higgs, searches for LQ and at high masses, QGP ..). With the upgrade of the LHC by adding an electron beam, the LHC can be transformed to a high precision energy frontier facility which is crucial for understanding new+"old" physics and its sustainability.

3. The LHeC will deliver vital information to future QCD developments (N3LO, resummation, factorisation, non-standard partons, neutron and nuclear structure, AdS/CFT, non-pQCD, SUSY..) and as a gigantic next step into DIS physics it promises to find new phenomena (no saturation, instantons, substructure of heavy elementary particles ??).

4. The default LHeC configuration is a novel ERL (with < 100MW power demand) in racetrack shape which is built inside the LHC ring and tangential to IP2. This delivers multi-100fb^{-1} (> 100 * HERA) and a factor of larger than 10^3 increased kinematic range in lN DIS, accessing the range of saturation at small α_s in ep+eA.

5. The LHeC is designed for synchronous operation with the LHC (3 beams) and has to be operational for the final decade of its lifetime. This gives 10-12 years for its realisation, as for HERA or CMS.

6. A detector concept is described in the CDR suitable for the Linac-Ring IR and to obtain full coverage and ultimate precision. This can be realised with a collaboration of ~500 physicists.

7. Half of the LHeC is operational. The other half requires next: an ERL test facility at CERN, IR related proto-typing (Q1, pipe), to develop the LHC-LHeC physics links, to simulate and preparing for building the detector.

5. Status and plans:

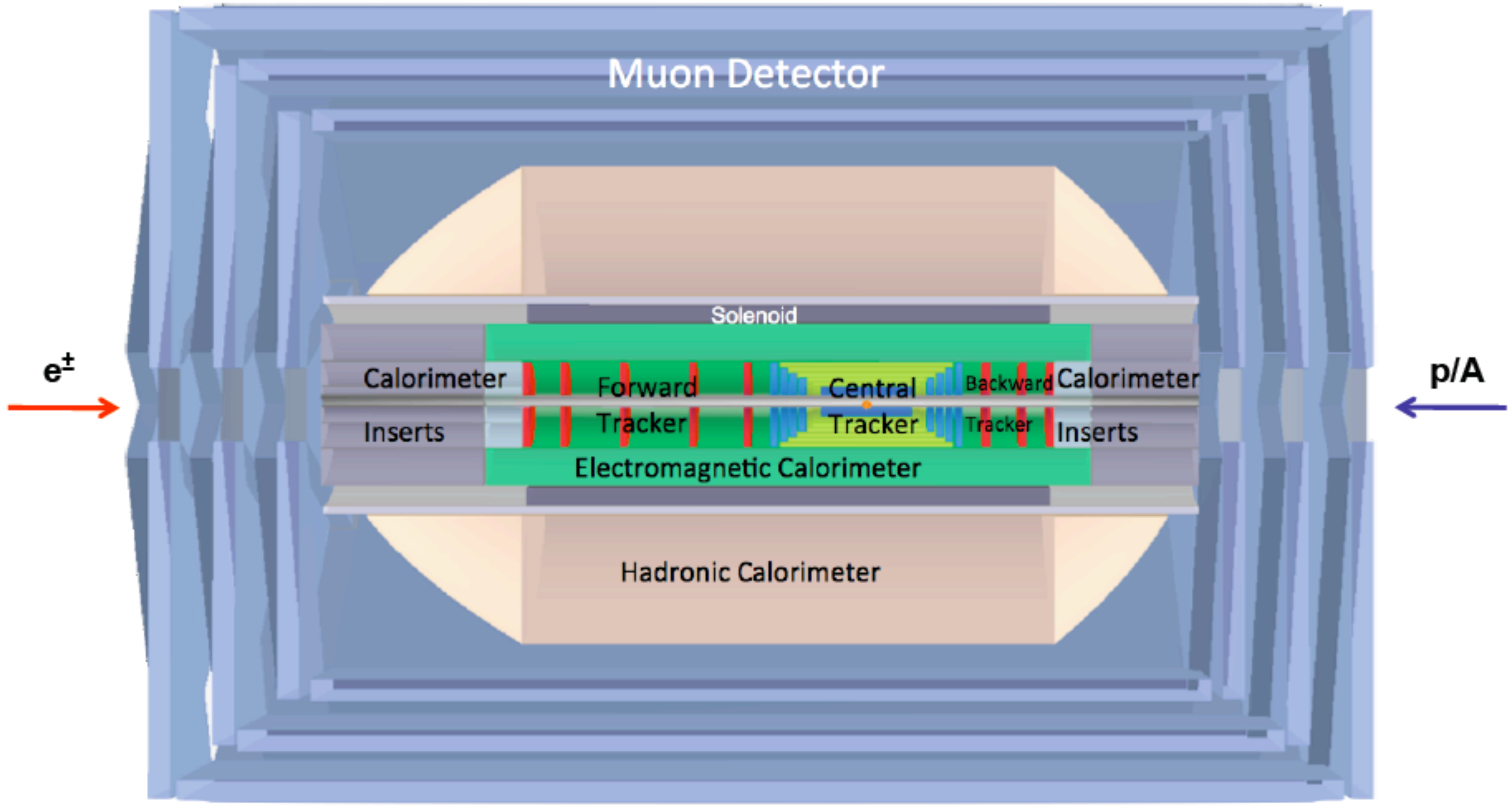
- The LHeC is an upgrade to the LHC, complementary to the (HL-)LHC program: implications on SM/BSM, QGP,...
- It has a very interesting program on its own: QCD in ep/A, EW.
- Luminosities around 10^{34} $cm^{-2}s^{-1}$ would transform the LHeC into a precision Higgs machine.
- Installation during LS3 is challenging but not impossible if resources (support) for R&D and design are allocated soon.
- Steps towards a TDR in ~ 4 years: refine physics case with its relation to the LHC, develop ERL test facility/magnets, design detector.
- ***Manpower is needed: everybody is welcome!!!***

My summary

Backup:

2. Detector:

LHeC detector overview



- Forward/backward asymmetry in energy deposited and thus in geometry and technology
- Present dimensions: L x D = 14m x 9m (compared to CMS 21m x 15m , ATLAS 45m x 25 m)
- Not shown: Taggers at -62m (e), -100m (B-H photons), +100m (n) and +420m (p)

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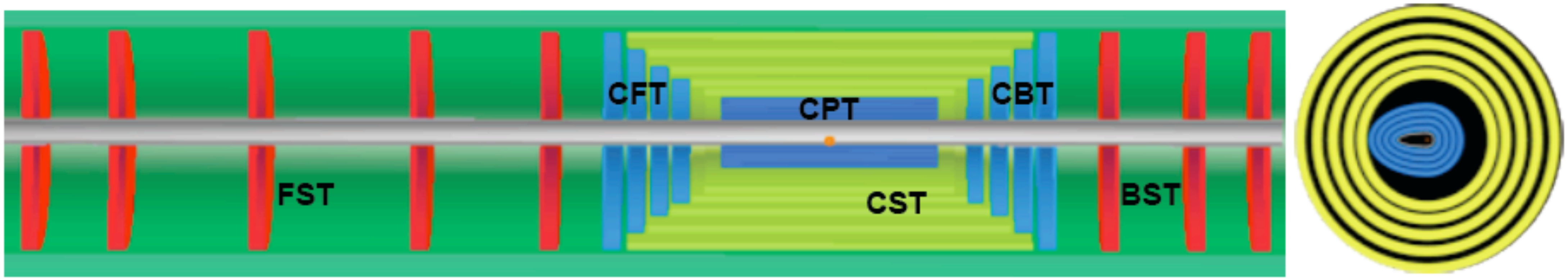
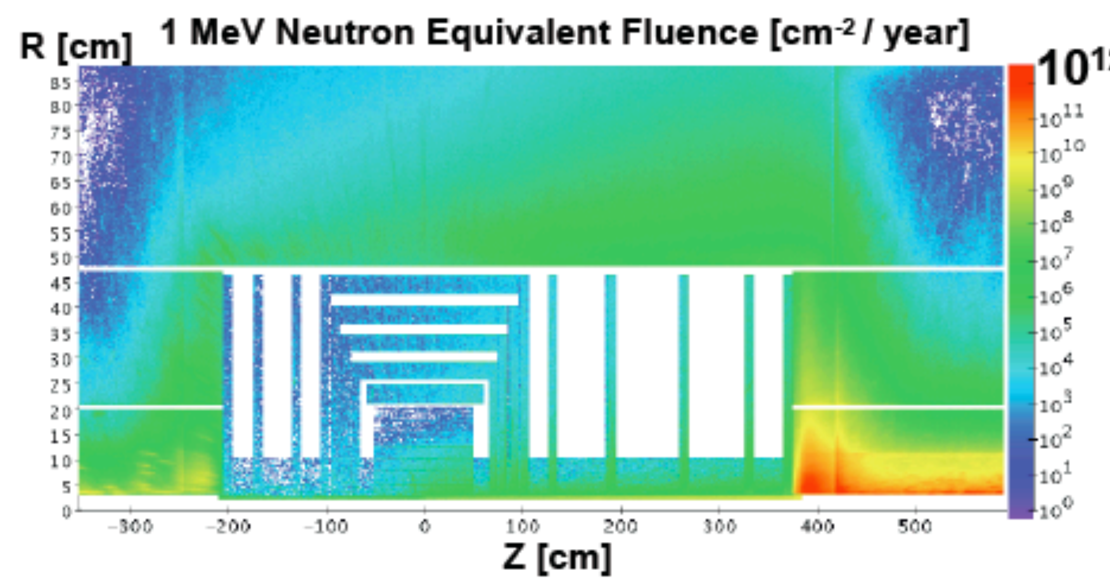
2. Detector:

Tracker technology



- All Silicon design, employing (e.g) Pixel and strip detectors, using available technologies from the LHC experiments
  - Advantages of Silicon: compact design, low budget material, radiation hard
  - Elliptical shape of CPT due to beam-pipe; then the CST is circular

- Radiation hardness in LHeC not as challenging as for the LHC
- Study of neutron fluences using GEANT4 and FLUKA show rates far lower than LHC (~ 5 x 10^{14})



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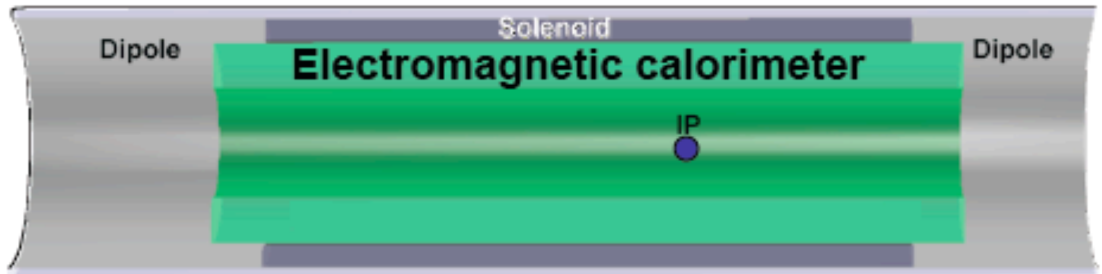
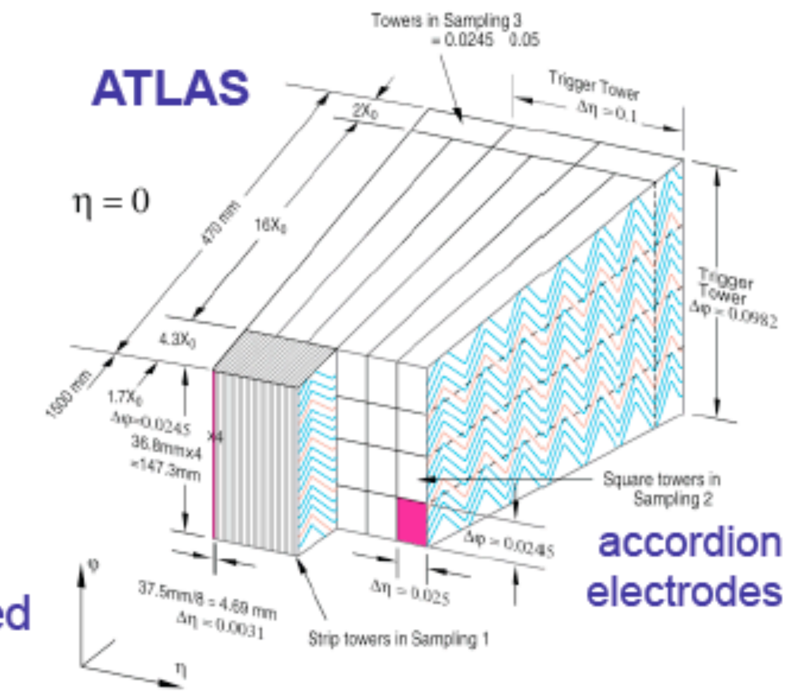
Simplified studies:

- $\Delta p_t/p_t^2 \sim 10^{-3}$ at 90°.
- b-resolution 10 μm.

2. Detector:

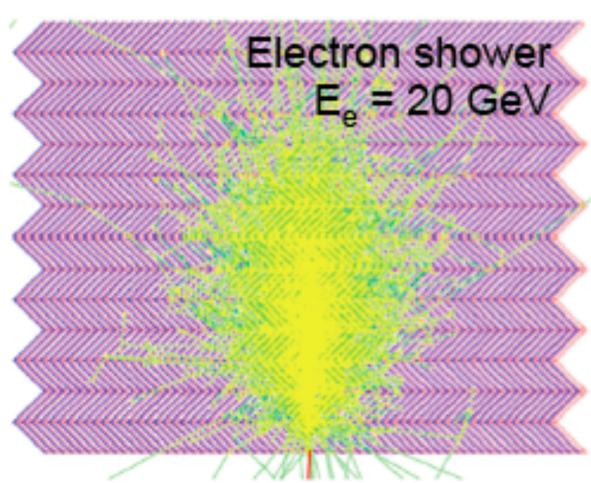
Electromagnetic calorimeter

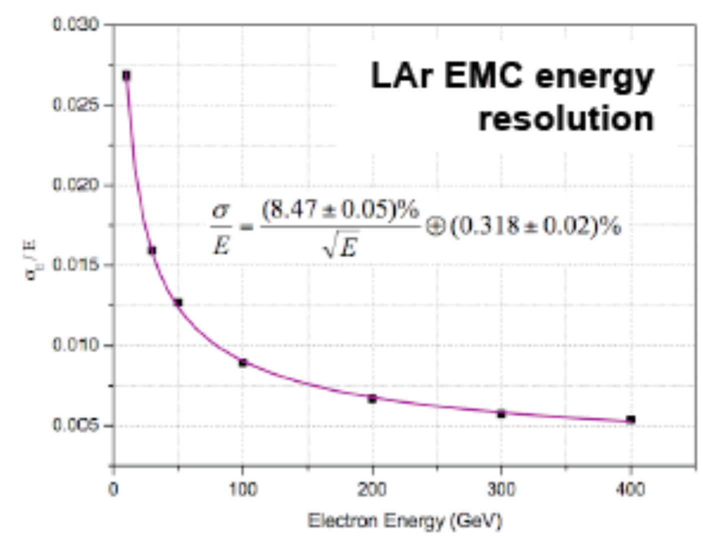




- Main EMC, in the barrel region: 2.8 < η < -2.3
  - Based on LAr/Pb design used in ATLAS, ~25-30 X_0
  - Employs 3 different granularity sections longitudinally
  - Alternative design using Pb/Scintillator also investigated
- Simulation studies of simplified design with respect to ATLAS

LHeC





Calorimeter resolution:

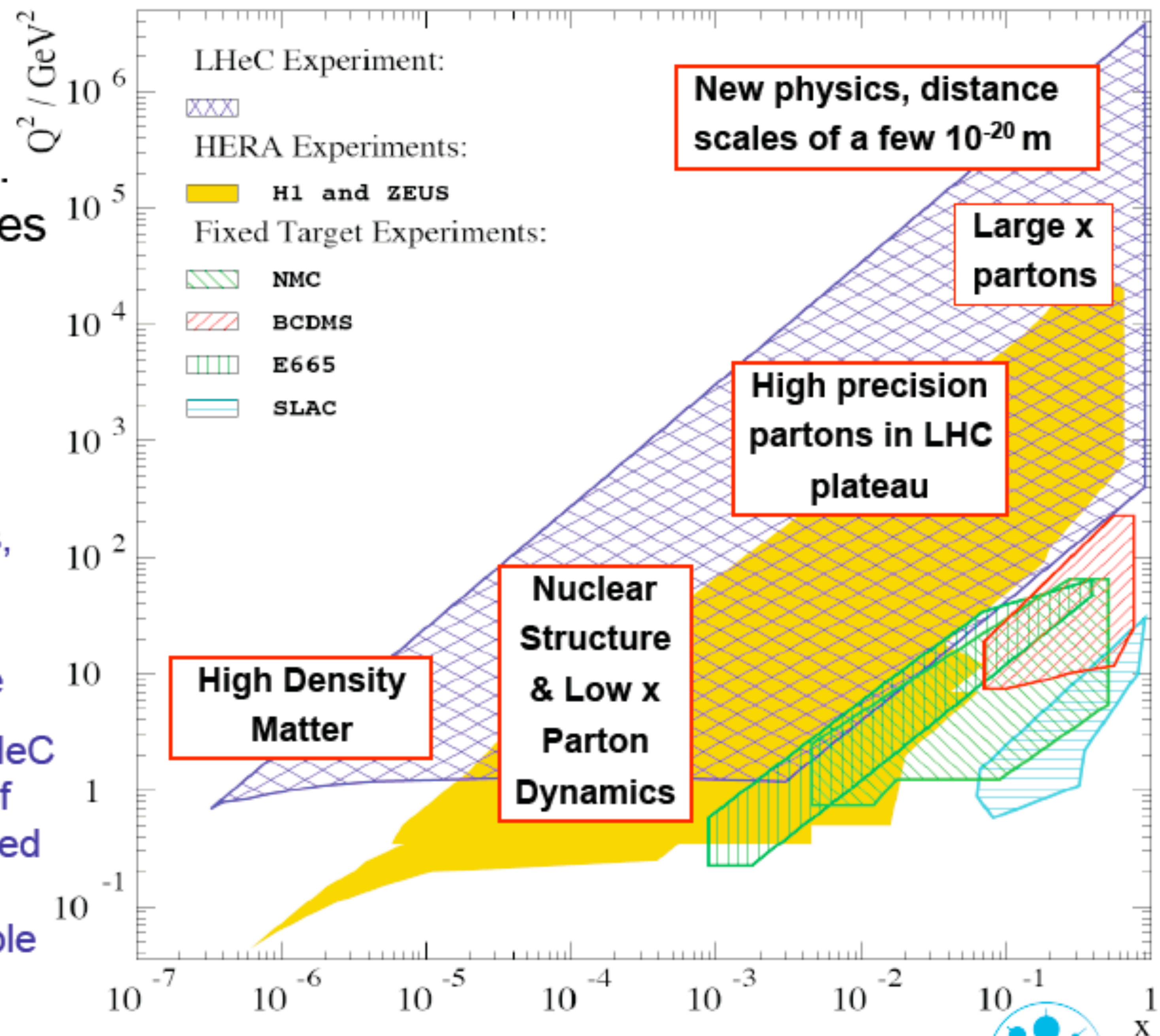
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

stochastic term, a
constant term, b

Physics goals:

The LHeC physics programme

- LHeC: High energy, high precision and high luminosity DIS... and a lot more besides
  - QCD measurements and discoveries, PDF determination, Higgs physics, top quark measurements, BSM physics including LQs, RPV SUSY, CI..., as well as a dedicated heavy-ion programme
  - More details in the LHeC CDR and in Table 3 of the document submitted to the Cracow ESG Review 09/12, available at *arXiV:1211.4831*



- More details talk by M. Klein

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