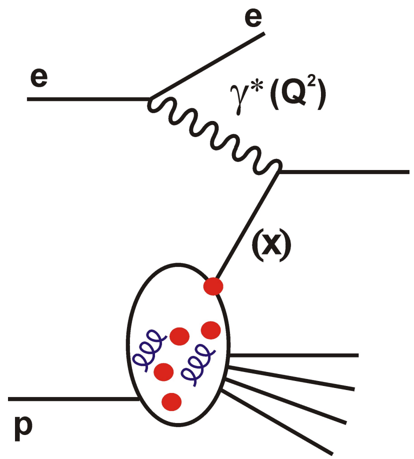
# Future of DIS
# Part II: “Europe”

Paul Newman
Birmingham University

Summary Talk from
DIS 2012 (Bonn)

Fri 30 March 2012



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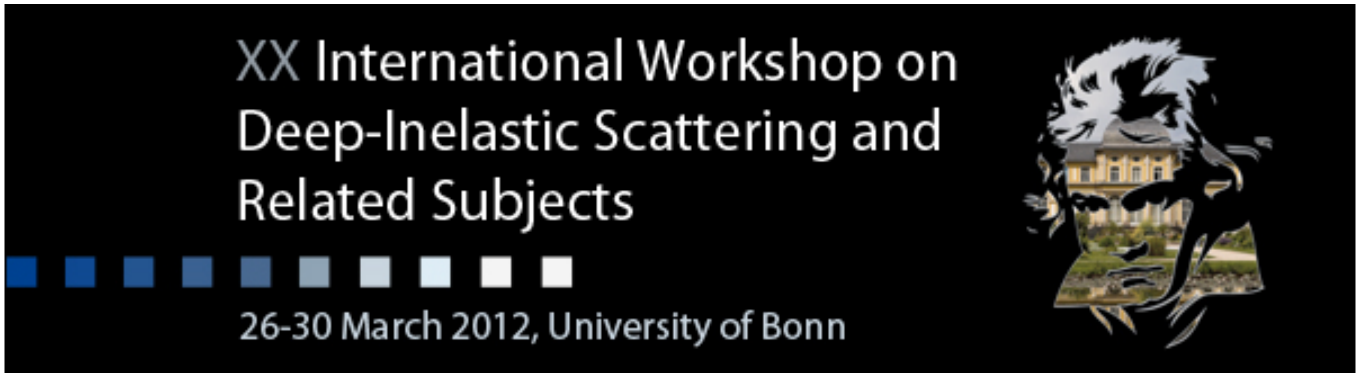
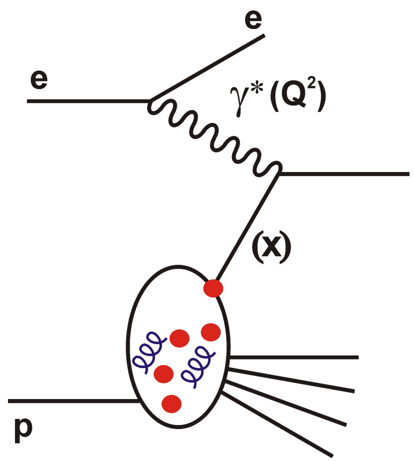


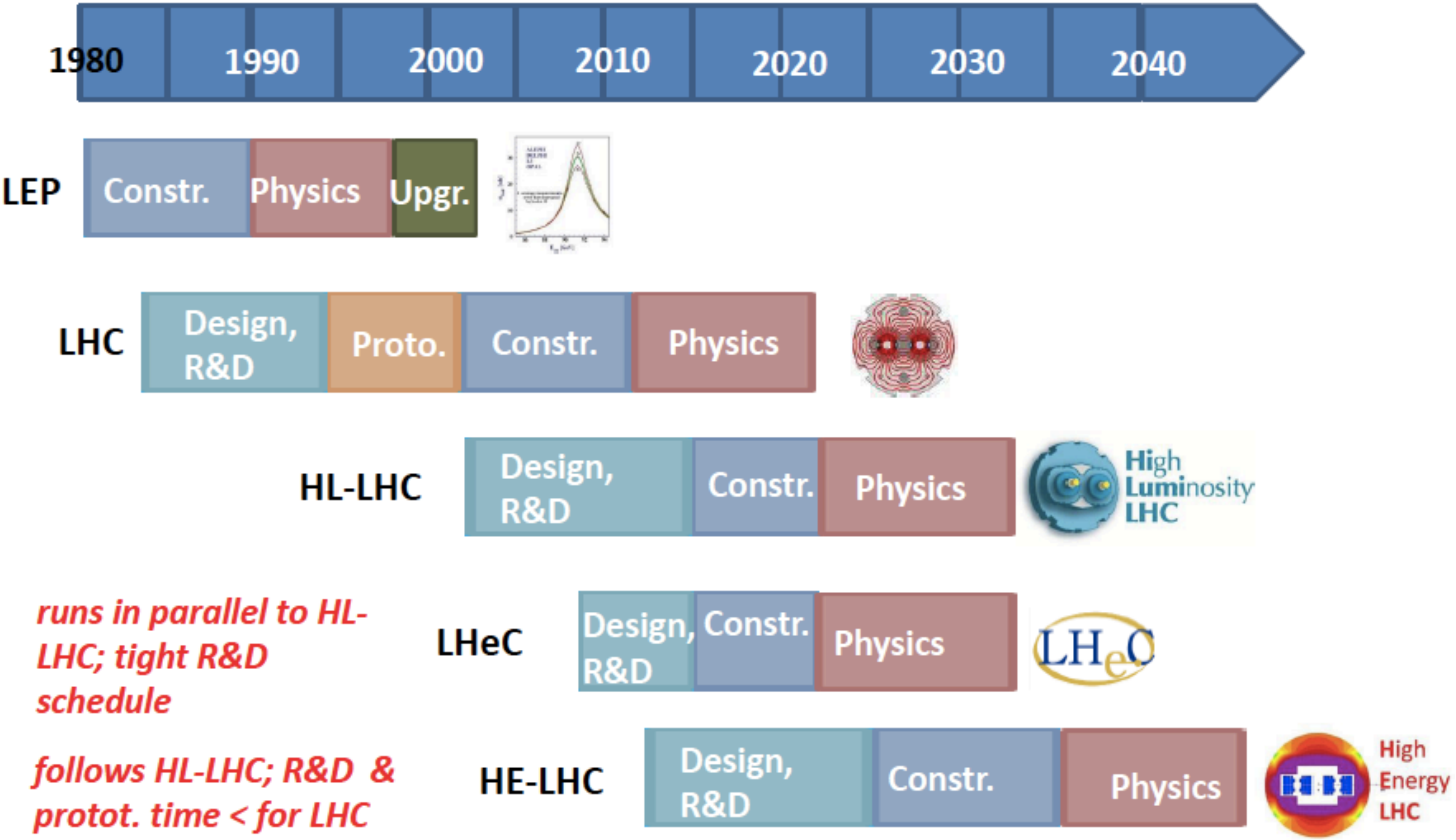



# … or to be more precise …


The Large Hadron Collider
VS
The Future

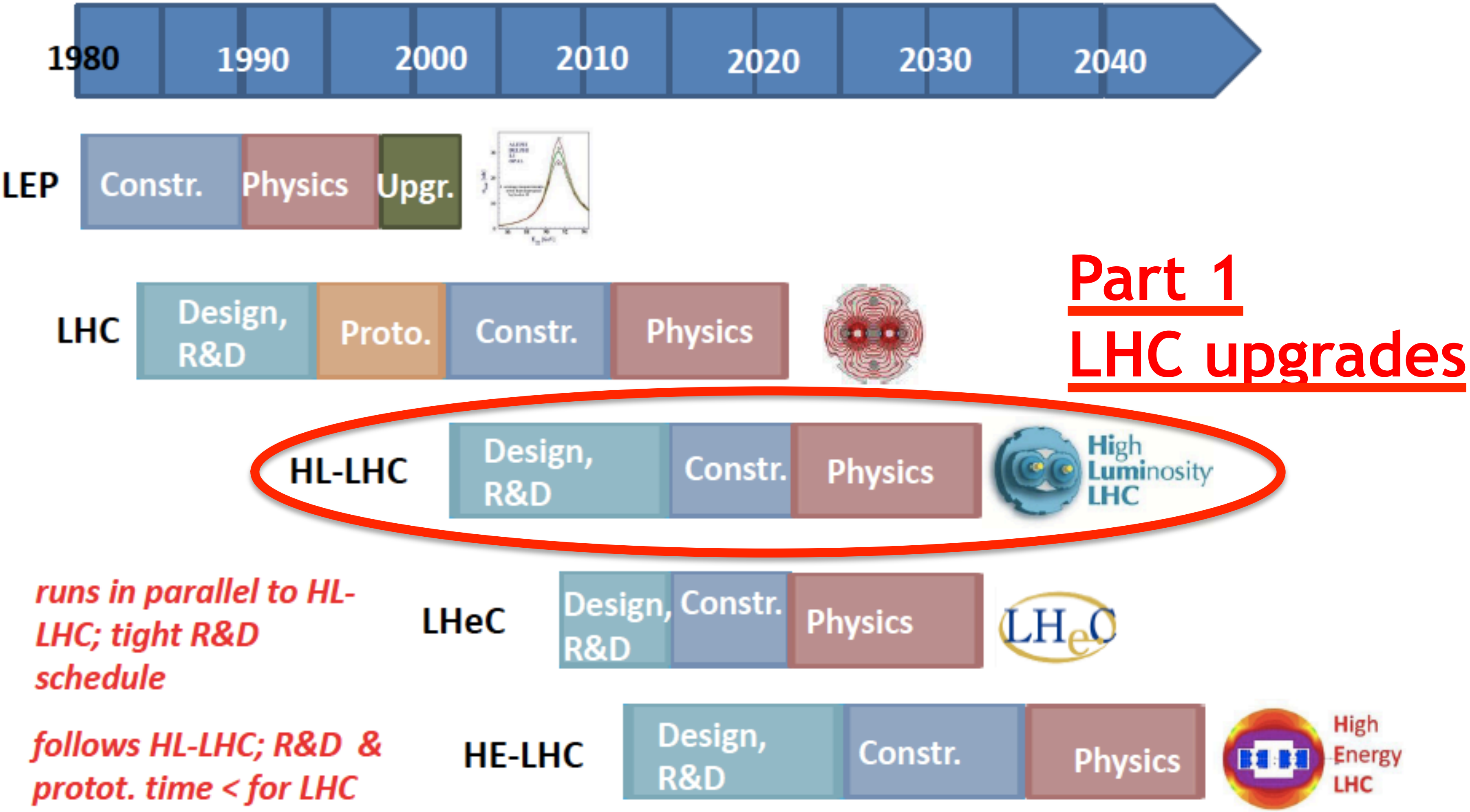
… not that being located in Europe means anything about participation …

# time line of CERN HEP projects



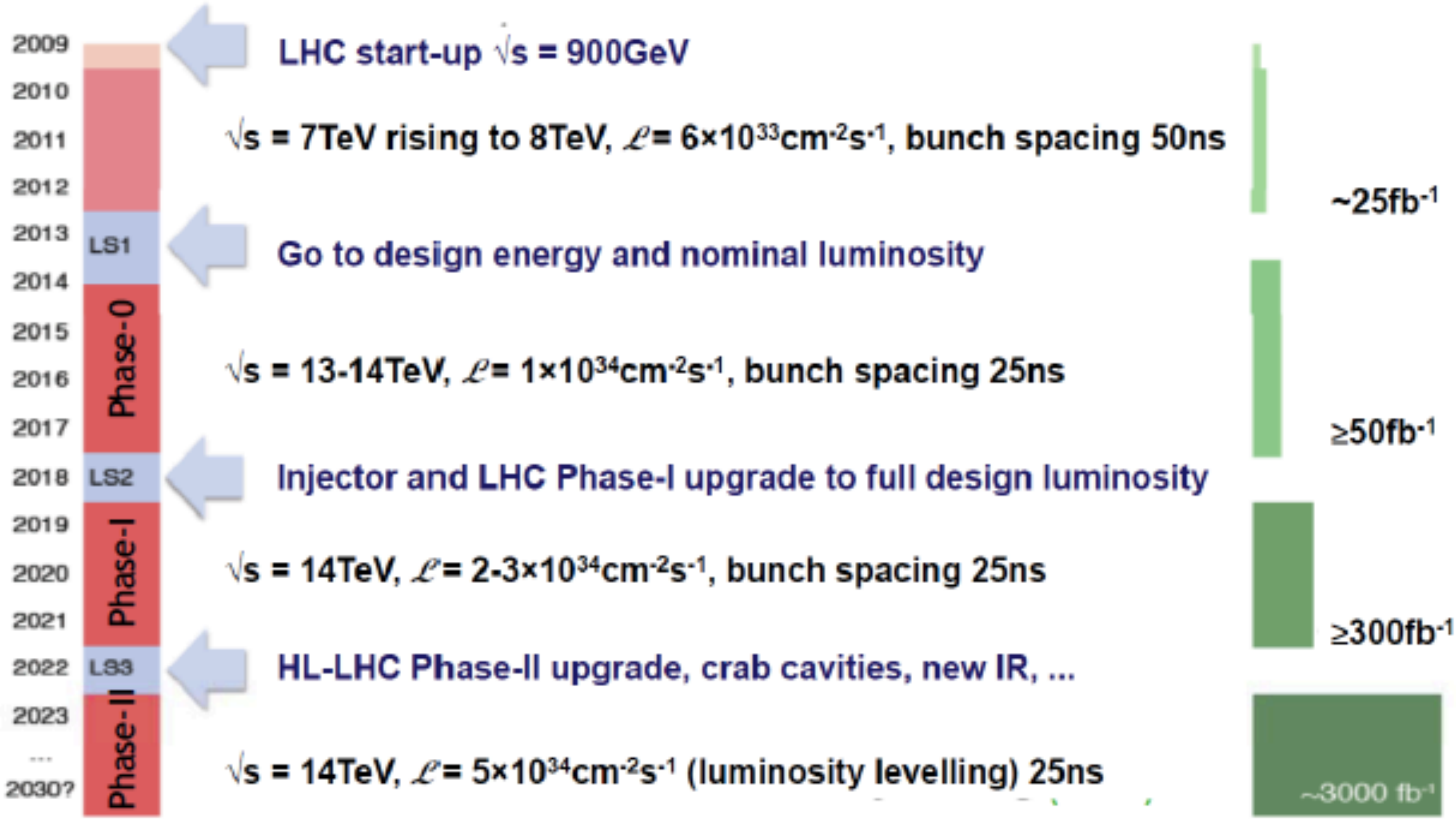

2012 Chamonix LHC Performance workshop summary (Rossi)

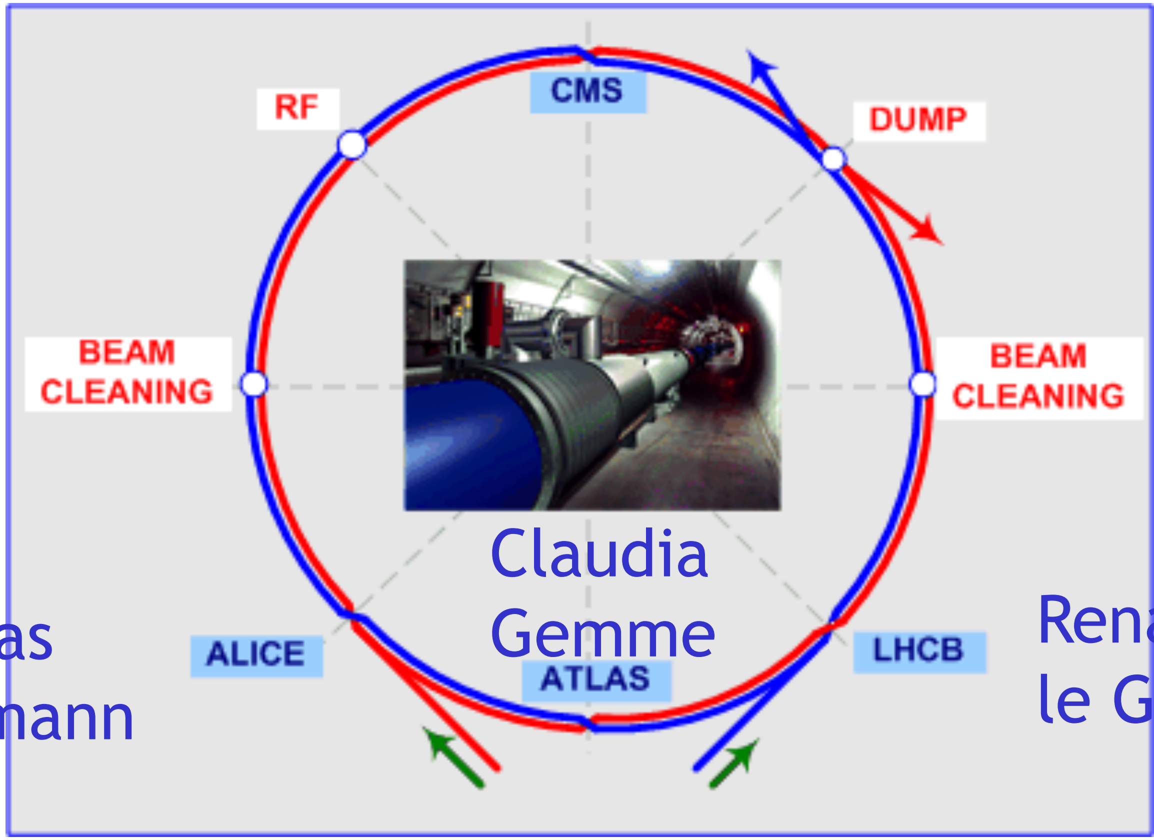
# time line of CERN HEP projects




2012 Chamonix LHC Performance workshop summary (Rossi)

# LHC Schedule






Thomas Peitzmann

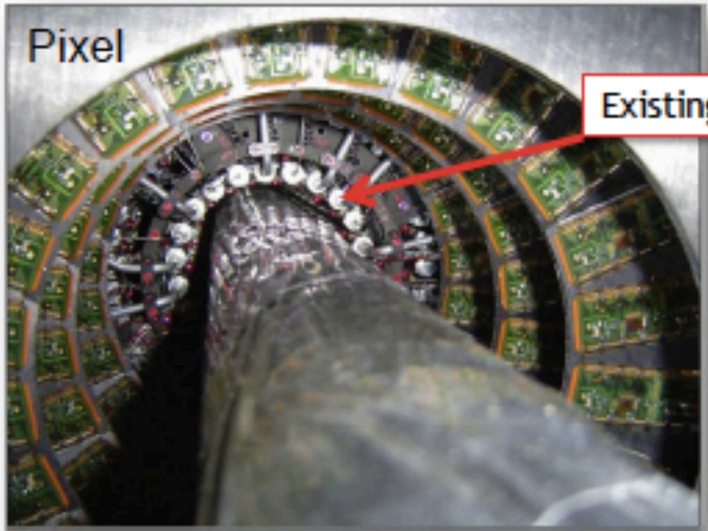
Claudia Gemme

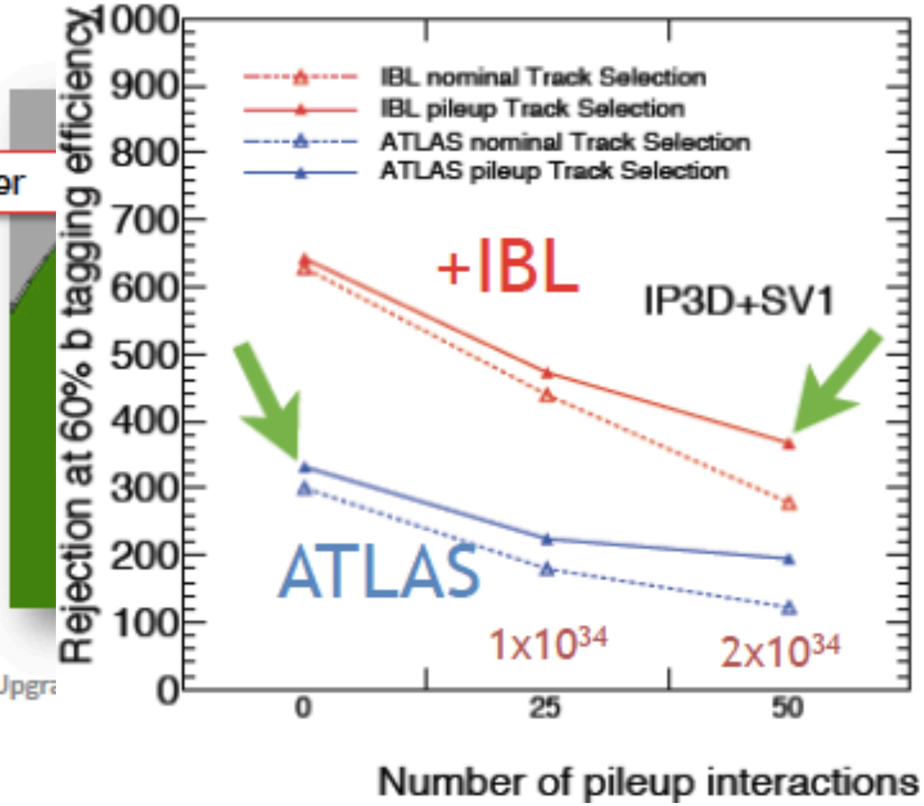
Renaud le Gac

- Mainly consolidation at phase 0
- Staged modifications to cope with high lumi at phases 1 and 2
  - ATLAS/CMS: coping with immense event rates / pile-ups
  - ALICE: enhance rate capabilities to 50 kHz (PbPb)
  - LHCb: Increase peak lumi to $2\times10^{33}$ $cm^{-2}s^{-1}$ → increase integrated lumi from 5 $fb^{-1}$ pre-2017 to 50 $fb^{-1}$

# Insertable B-Layer: Layout

- ✓ The Insertable B-Layer (IBL) will be built around a new beam pipe and slipped inside the present detector in situ or, if the pixel package is removed to replace the services, this operation can be carried out on the surface.
- ✓ IBL will have
  - $\langle r_{sens} \rangle$ = 33 mm vs present 50.5 mm→ smaller beam pipe radius (29→ 25 mm).




Running 2014-2018 | PHASE 0 Upgrades 2013-2014

# *Phase-I: LHC and ATLAS Plans*

Running 2019-21

PHASE 1 Upgrades 2018

**LHC**

$\sqrt{s}$ = 14 TeV, L = 2 x $10^{34}$ $cm^{-2}s^{-1}$, Bunch spacing 25 ns;
Integrated luminosity 300 $fb^{-1}$

Shutdown: 14 Months

Consolidation of injection chain; upgrade collimation system.

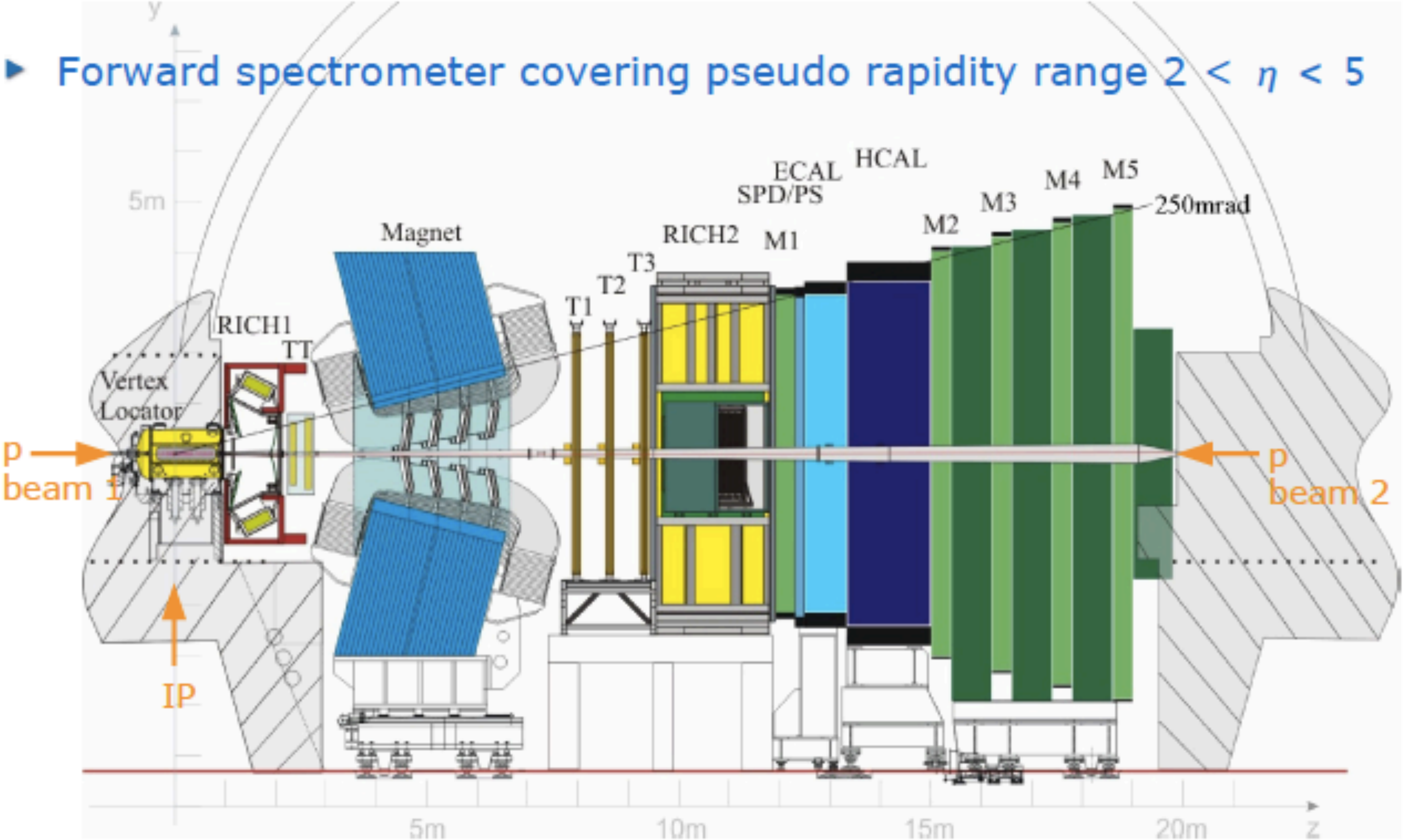
✓ ATLAS: Challenge of peak luminosity exceeding design luminosity

- New Muon Small Wheels
- Higher granularity in Level-1 trigger calorimeter
- Fast track trigger at Level-2
- Level-1 Trigger improvements
- New diffractive physics detector stations

All upgrades to be compatible with Phase 2

# The LHCb detector

- Forward spectrometer covering pseudo rapidity range $2 < \eta < 5$

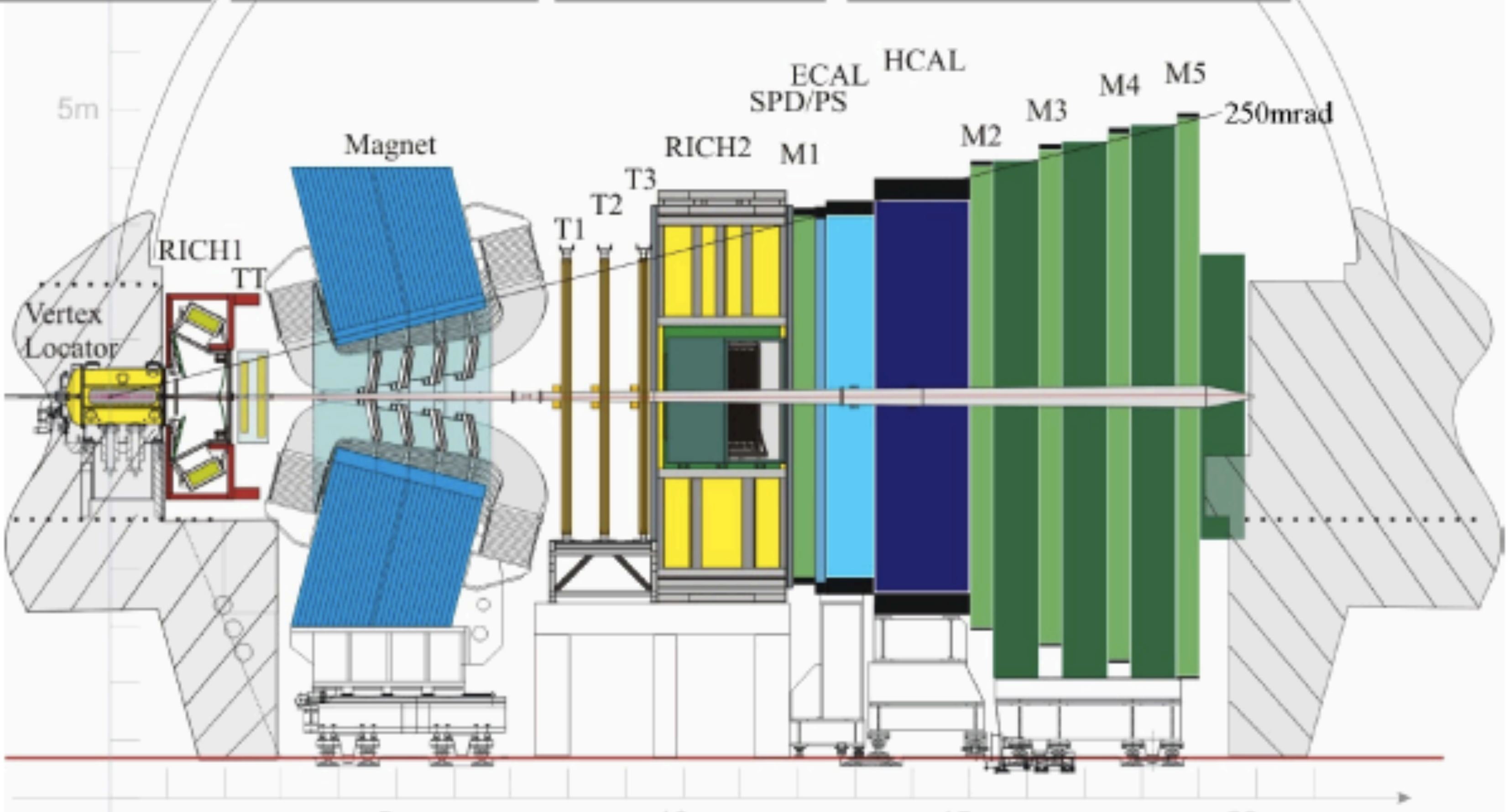



More details: The LHCb detector at LHC, JINST **3** (2008) S08005

# Detector modifications

[All for phase 1 upgrade]

| VELO | TRACKING | RICH | CALO + MUON |
|---|---|---|---|
| New pixel system | New TT and IT | New photon detector | Remove M1, SPD, PS |

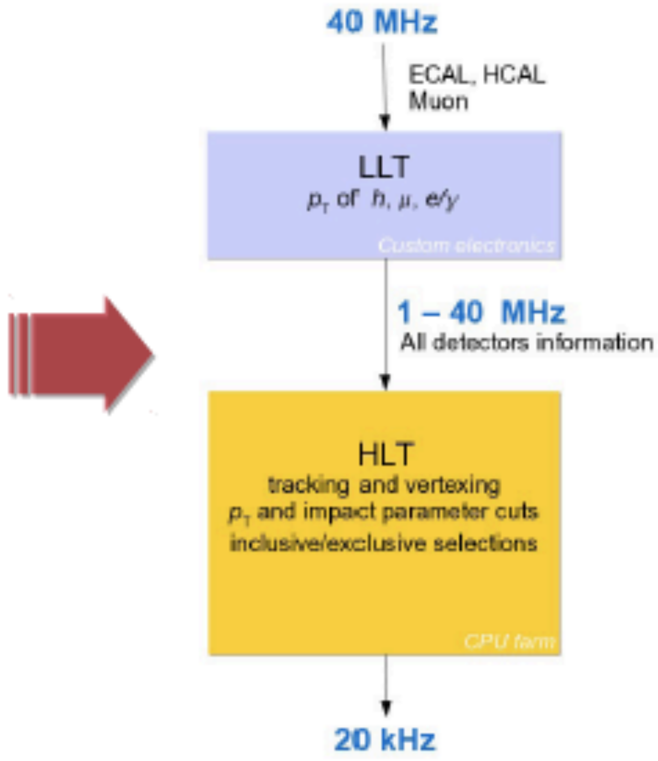



Replace all the front-end electronics + DAQ network

# Triggers upgraded

- Upgrade to a flexible **software** trigger processing all crossings:

[1MHz now]




[2kHz now]

| LLT-rate (MHz) | 1 | 5 | 10 |
|---|---|---|---|
| $B_s \to \phi\phi$ | 0.12 | 0.51 | 0.82 |
| $B^0 \to K^*\mu\mu$ | 0.36 | 0.89 | 0.97 |
| $B_s \to \phi\gamma$ | 0.39 | 0.92 | 1.00 |

LLT efficiencies

- A challenge to read out LHCb at **40 MHz**

# LHCb Time line

- Letter of Intend submitted in March 2011
  - Physics case fully endorsed by LHCC
  - 40 MHz readout reviewed, considered as challenging but feasible

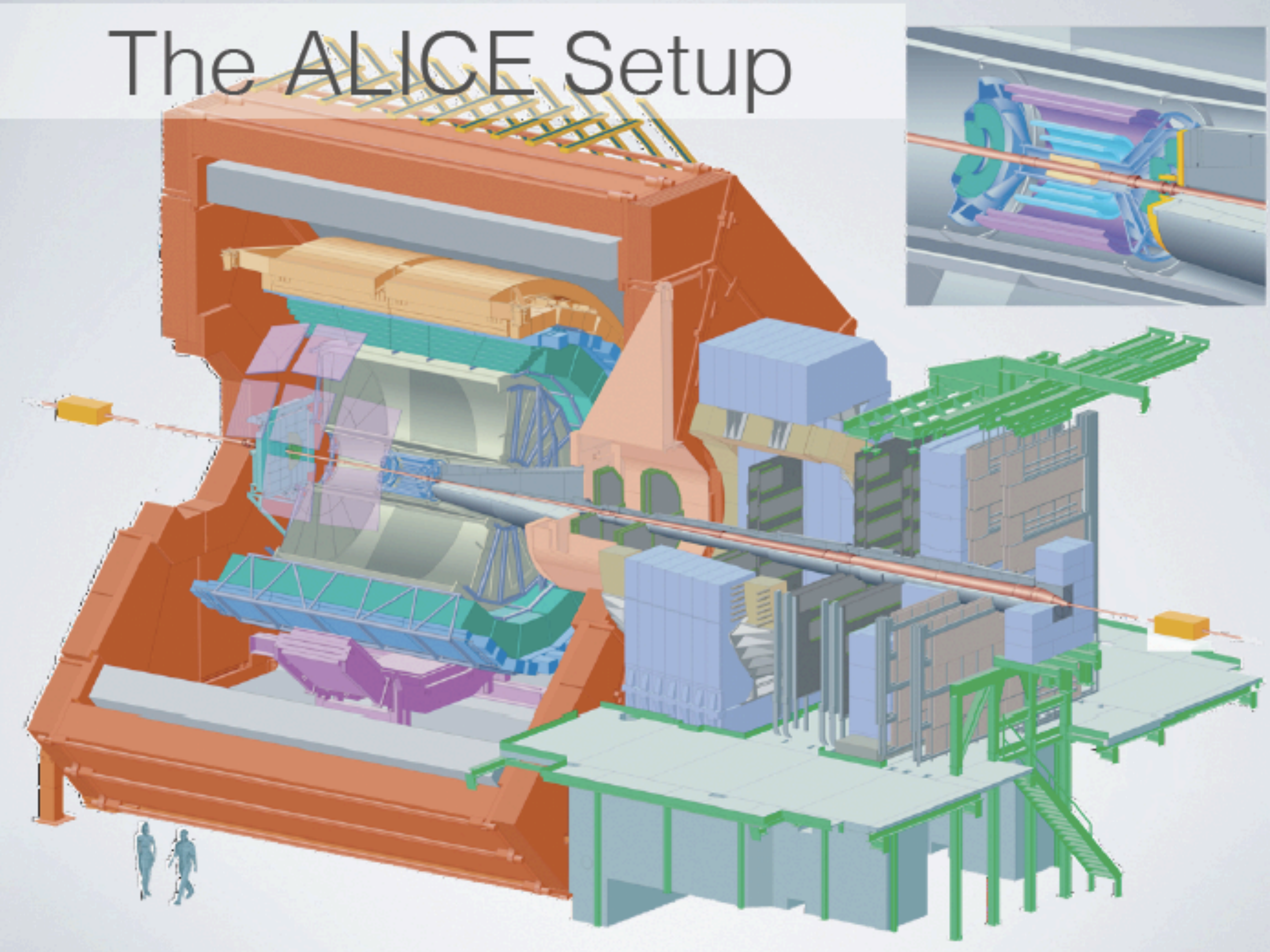
- Framework TDR to be submitted in June 2012
  It defines cost, milestones and institutes scientific interest

- TDR(s) in 2013

- Production and quality control in 2014 – 2017

- Installation and commissioning in 2018

# The ALICE Setup



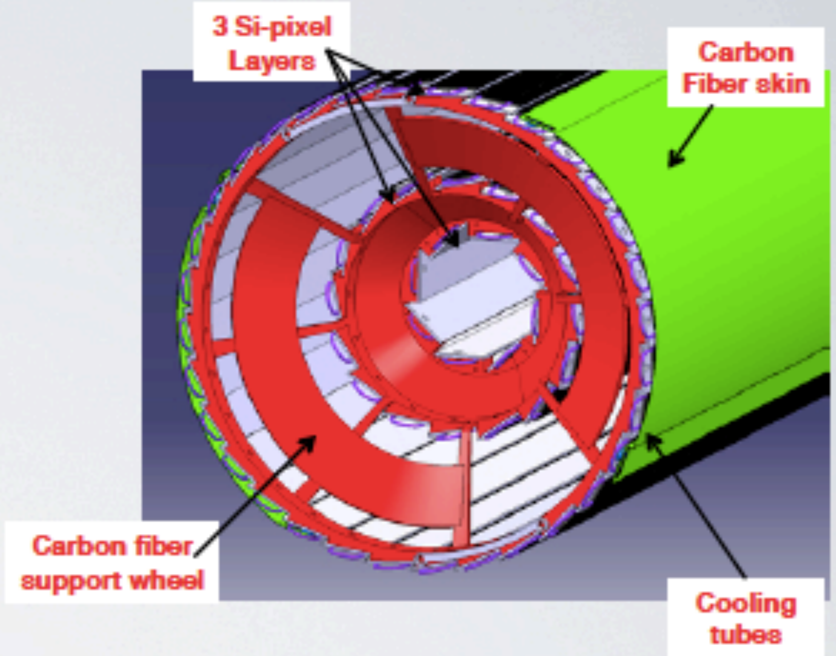
# Upgrade Strategy

- advanced probes are rare, but essentially "untriggerable"
  - rare low momentum signals
- current experimental setup is rate-limited
  - e.g. intrinsic limit of current TPC (gated operation)
- basic strategy:
  - enhance rate capabilities (50kHz Pb+Pb, ≈2MHz p+p)
    - upgrade TPC (GEMs), readout of all detector
  - enhance heavy flavor (ITS): low $p_T$, hf baryons, B-tagging
- further detector enhancements (under study)
  - enhanced high $p_T$ hadron ID (VHMPID) and large y muons (MFT)
  - add photons/pions @ large y (FoCal)

# ITS Technology

R&D ongoing:

- 2 pixel technologies being explored
  - hybrid pixel detectors
    - 100 μm thick sensor + 50 μm thick electronics
    - pixel size 30 μm x 100 μm
  - monolithic pixel detectors
    - 50 μm thick ASIC
    - pixel size 20 μm x 20 μm

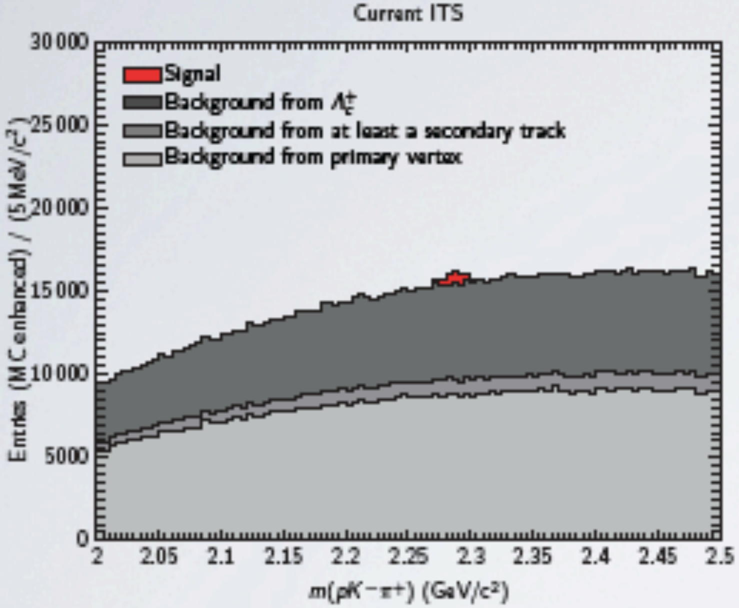


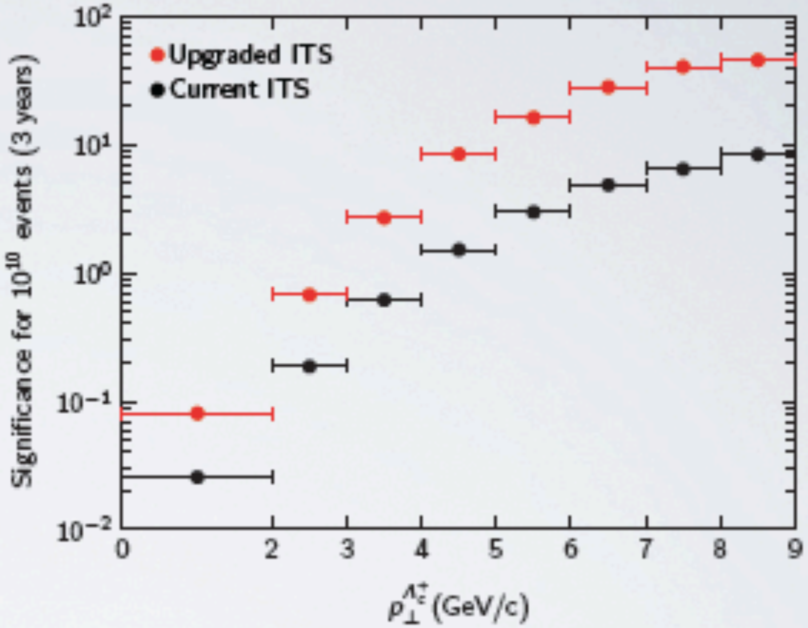

- new strip detector
  - smaller cell size (half length)
  - new front-end chip
    - CMOS 0.13 μm
    - on-chip ADC

final draft of CDR, endorsed internally in ALICE

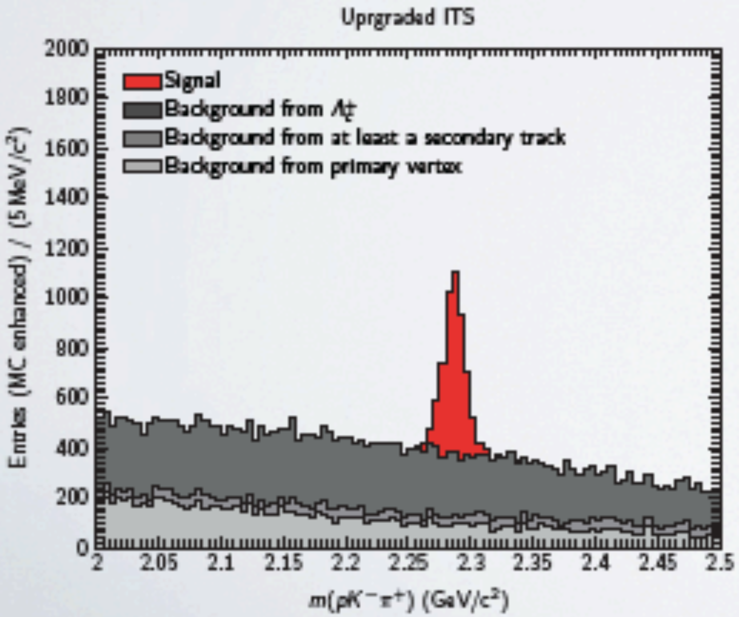
7 new layers, nearest at 2.2 cm from beam

# Example: Charmed Baryons



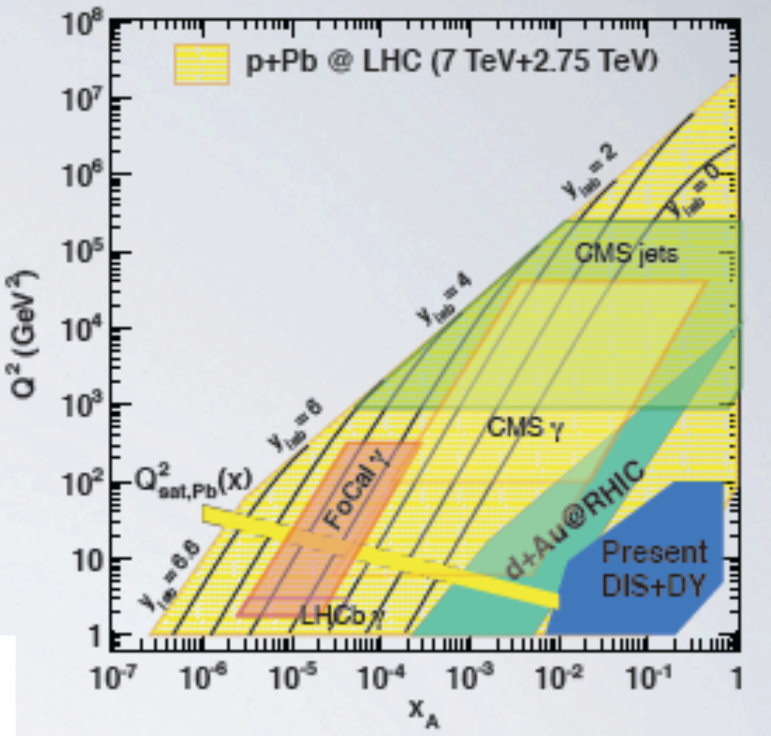

M. Mager



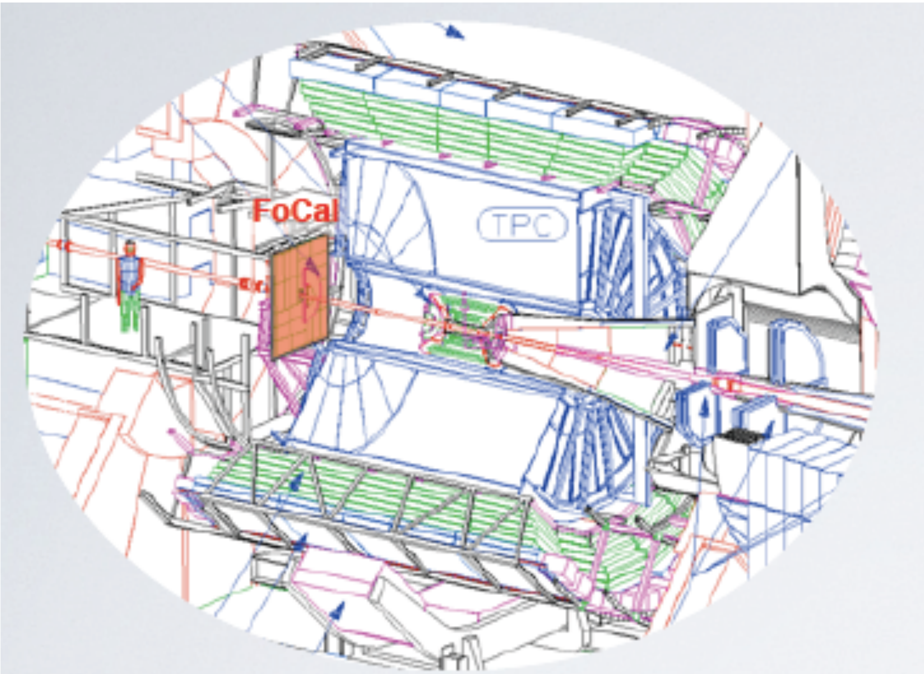

- strong advantage of new ITS for both S/B and significance
- optimization studies ongoing

# Small Bjorken-x

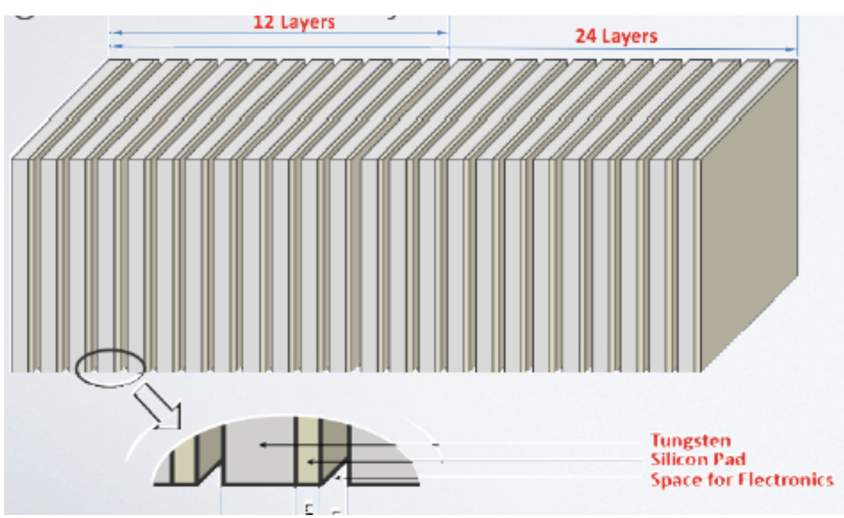
- physics at small x / large y enters new regime
- ALICE has the opportunity for a substantial upgrade at large rapidity




$2.5 < \eta < 4.5$




Various ideas under study e.g. Silicon Tungstate



# Phase-II: LHC and ATLAS Plans

Running 2023 onwards

PHASE2 Upgrades 2022

LHC use of crab cavities for luminosity leveling

$\sqrt{s}$ = 14 TeV, L = 5 x $10^{34}$ $cm^{-2}s^{-1}$

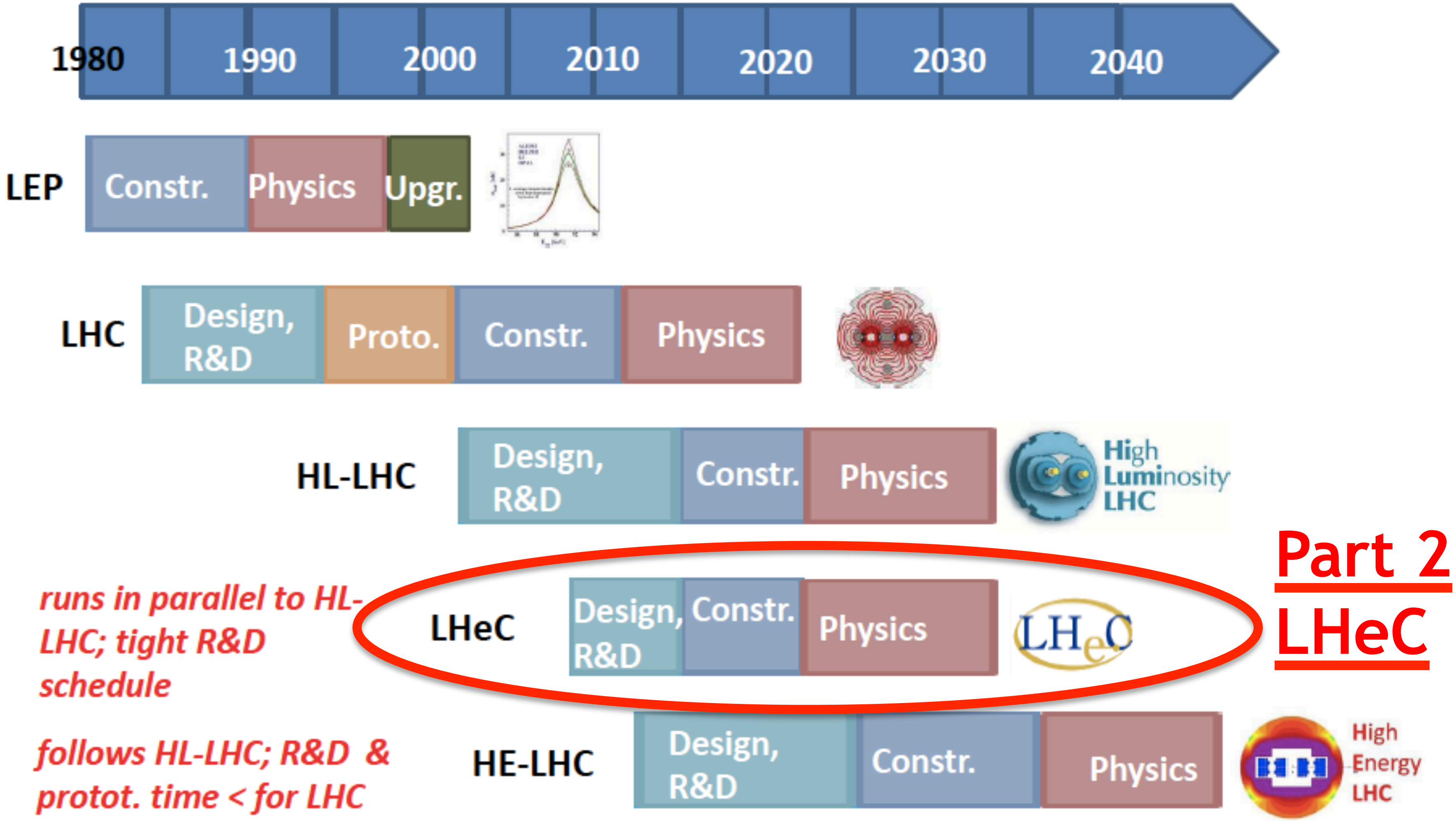
Shutdown: 18 Months

Total Integrated luminosity 3000 fb-1

ATLAS: Detector must cope with both peak and integrated luminosity. Still evaluating options..

- ✓ New Inner detector
- ✓ Possible L1 track trigger
- ✓ Changes to the Forward Calorimeter
- ✓ New electronics for LAr calorimeter
- ✓ Possible upgrade of the muon system

# time line of CERN HEP projects




2012 Chamonix LHC Performance workshop summary (Rossi)

# Material Taken from Draft Conceptual Design Report

- 525 pages, summarising work of ~150 participants over 5 years

- Currently under review by CERN-appointed referees → final version expected April / May 2012

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

# … with thanks to many colleagues working on LHeC …

http://cern.ch/lhec

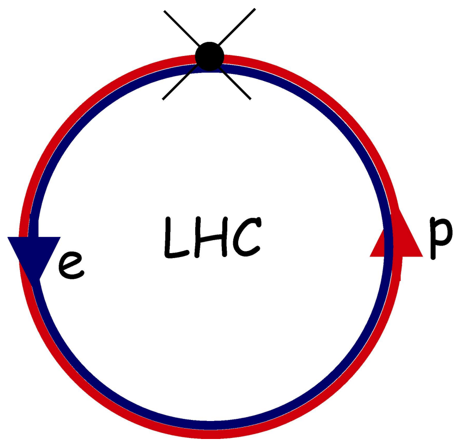
## LHeC Study Group

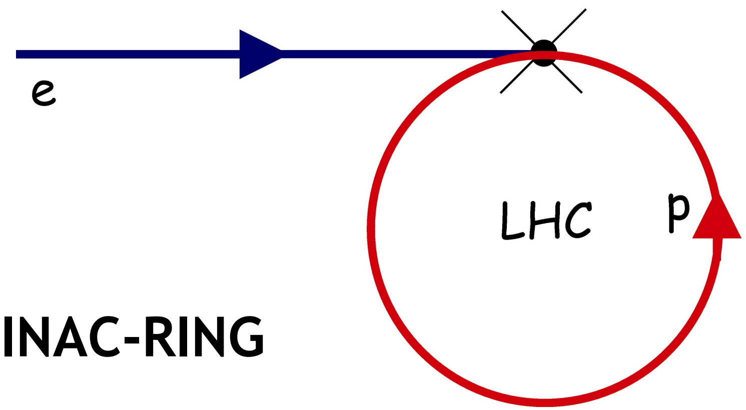

J. Abelleira Fernandez[10,15], C.Adolphsen[39], S.Alekhin[40,11], A.N.Akai[01], H.Aksakal[30], P.Allport[17], J.L.Albacete[37], V.Andreev[25], R.B.Appleby[23], N.Armesto[38], G.Azuelos[26], M.Bai[47], D.Barber[11], J.Bartels[12], J.Behr[11], O.Behnke[11], S.Belyaev[10], I.BenZvi[47], N.Bernard[16], S.Bertolucci[10], S.Bettoni[10], S.Biswal[32], J.Bluemlein[11], H.Boettcher[11], H.Braun[48], S.Brodsky[39], A.Bogacz[28], C.Bracco[10], O.Bruening[10], E.Bulyak[08], A.Bunyatian[11], H.Burkhardt[10], I.T.Cakir[54], O.Cakir[53], R.Calaga[47], E.Ciapala[10], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[29], J.C.Collins[46], J.Dainton[17], A.De.Roeck[10], D.d'Enterria[10], A.Dudarev[10], A.Eide[43], E.Eroglu[45], K.J.Eskola[14], L.Favart[06], M.Fitterer[10], S.Forte[24], P.Gambino[42], T.Gehrmann[50], C.Glasman[22], R.Godbole[27], B.Goddard[10], T.Greenshaw[17], A.Guffanti[09], V. Guzey[28], C.Gwenlan[34], T.Han[36], Y.Hao[47], F.Haug[10], W.Herr[10], B.Holzer[10], M.Ishitsuka[41], M.Jacquet[33], B.Jeanneret[10], J.M.Jimenez[10], H.Jung[11], J.M.Jowett[10], H.Karadeniz[54], D.Kayran[47], F.Kocac[45], A.Kilic[45], K.Kimura[41], M.Klein[17], U.Klein[17], T.Kluge[17], G.Kramer[12], M.Korostelev[23], A.Kosmicki[10], P.Kostka[11], H.Kowalski[11], D.Kuchler[10], M.Kuze[41], T.Lappi[14], P.Laycock[17], E.Levichev[31], S.Levonian[11], V.N.Litvinenko[47], A.Lombardi[10], C.Marquet[10], B.Mellado[07], K.H.Mess[10], S.Moch[11], I.I.Morozov[31], Y.Muttoni[10], S.Myers[10], S.Nandi[26], P.R.Newman[03], T.Omori[44], J.Osborne[10], Y.Papaphilippou[10], E.Paoloni[35], C.Pascaud[33], H.Paukkunen[38], E.Perez[10], T.Pieloni[15], E.Pilicer[45], A.Polini[04], V.Ptitsyn[47], Y.Pupkov[31], V.Radescu[13], S.Raychaudhuri[27], L.Rinolfi[10], R.Rohini[27], J.Rojo[24], S.Russenschuck[10], C.A.Salgado[38], K.Sampei[41], E.Sauvan[19], M.Sahin[01], U.Schneekloth[11], A.N.Skrinsky[31], T.Schoerner Sadenius[11], D.Schulte[10], H.Spiesberger[21], A.M.Stasto[46], M.Strikman[46], M.Sullivan[39], B.Surrow[05], S.Sultansoy[01], Y.P.Sun[39], W.Smith[20], I.Tapan[45], P.Taels[02], E.Tassi[52], H.Ten.Kate[10], J.Terron[22], H.Thiesen[10], L.Thompson[23], K.Tokushuku[44], R.Tomas.Garcia[10], D.Tommasini[10], D.Trbojevic[47], N.Tsoupas[47], J.Tuckmantel[10], S.Turkoz[53], K.Tywoniuk[18], G.Unel[10], J.Urakawa[44], P.VanMechelen[02], A.Variola[37], R.Veness[10], A.Vivoli[10], P.Vobly[31], R.Wallny[51], G.Watt[10], G.Weiglein[12], C.Weiss[28], U.A.Wiedemann[10], U.Wienands[39], F.Willeke[47], V.Yakimenko[47], A.F.Zarnecki[49], F.Zimmermann[10], F.Zomer[33]

# LHeC Accelerator Design (Daniel Schulte)

- Collide LHC beam with electrons or positrons
  - Required lepton energy is ≥60GeV
  - Luminosity of ≈$10^{33}cm^{-2}s^{-1}$
  - Polarisation
  - No interference with pp physics
  - Detector acceptance down to 1°
  - Power consumption for lepton complex ≤100MW

**RING-RING**




**LINAC-RING**

Baseline solutions exist in both versions

# e Ring- p/A Ring

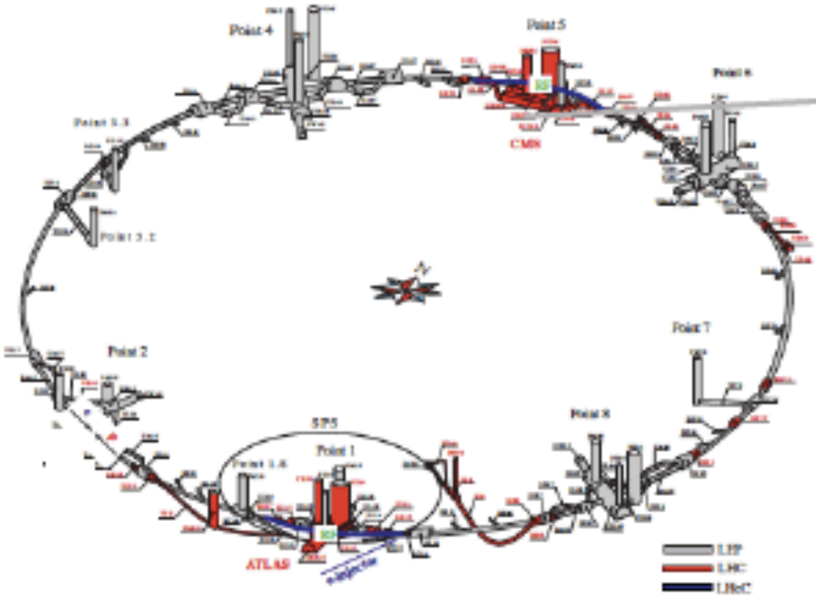
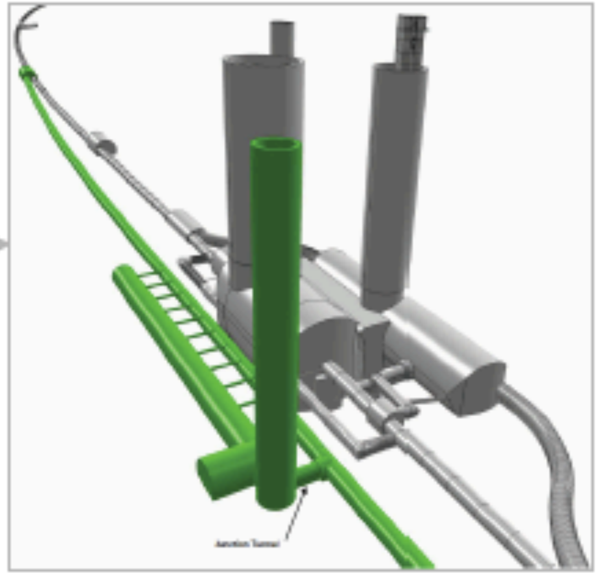
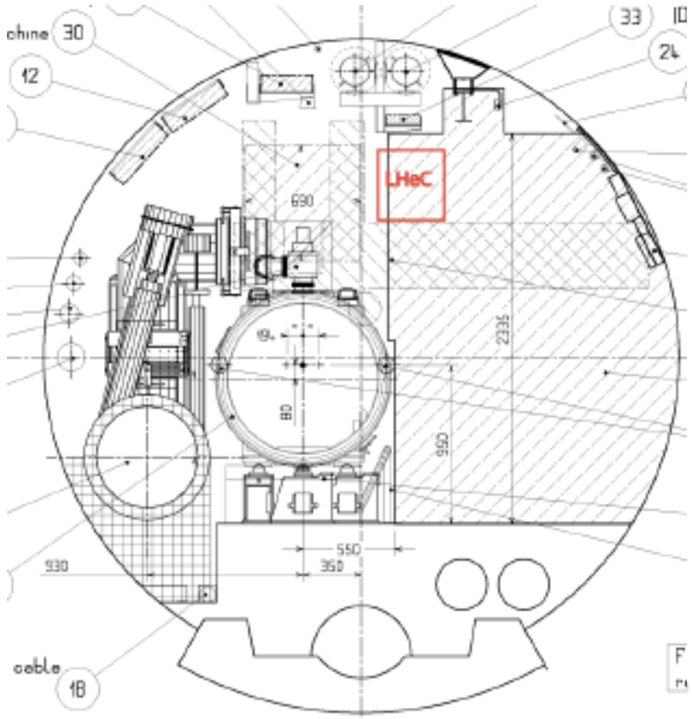
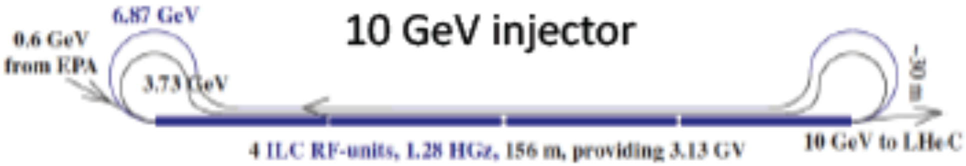



Figure 1: Schematic Layout of the LHC (grey/red) with the bypasses of CMS and ATLAS for the ring electron beam (blue) in the RR version. The $e$ injector is a 10 GeV superconducting linac in triple racetrack configuration which is considered to reach the ring via the bypass around ATLAS.






## 10 GeV injector



# Magnets for Electron Ring

5m long x $(35cm)^2$ transverse, 0.013 – 0.08 T, ~ 200 kg / m

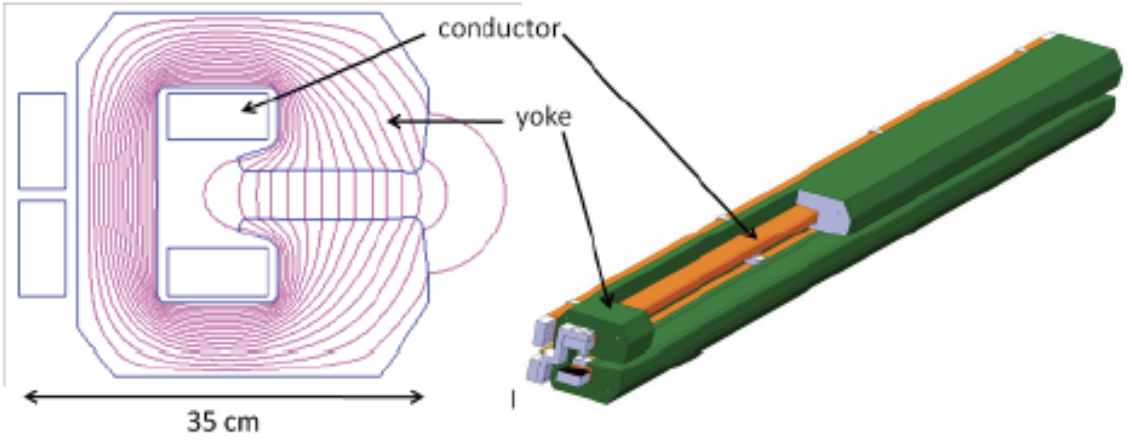



Fig. 2. Field lines and artistic view of a LHeC arc dipole.

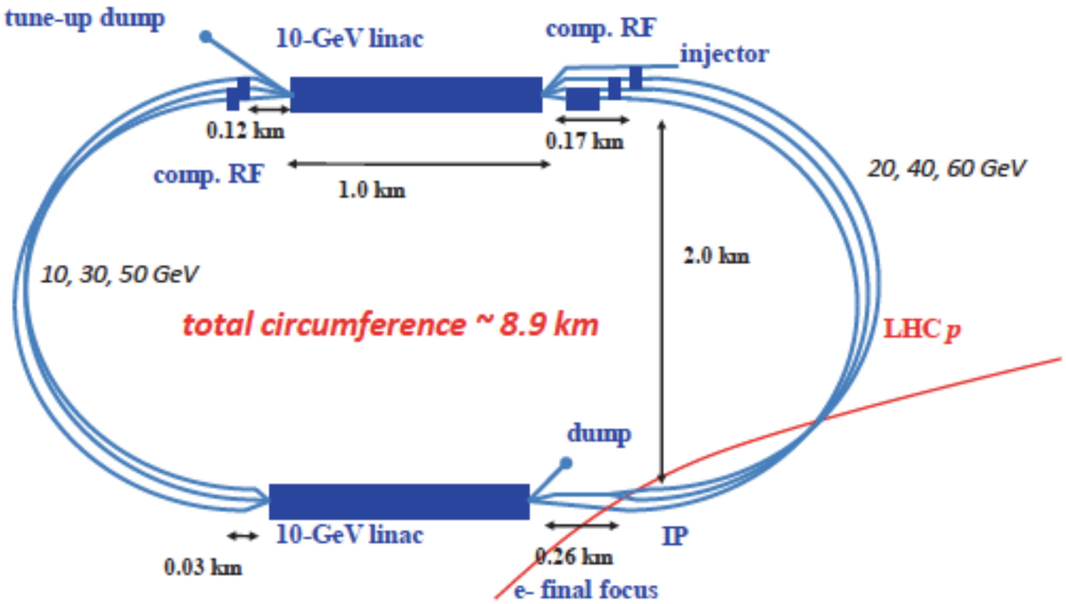
Prototypes (Novisibirsk)

Electron ring solution maximises luminosity ($\sim 2x10^{-33}$ $cm^{-2}$ $s^{-1}$)

(Serious?) disadvantage = interference with working LHC.
Long shutdown may be required

Linac solution avoids this (and offers valuable experience with linacs / energy recovery …)

# Accelerator Design in Linac-Ring Configuration

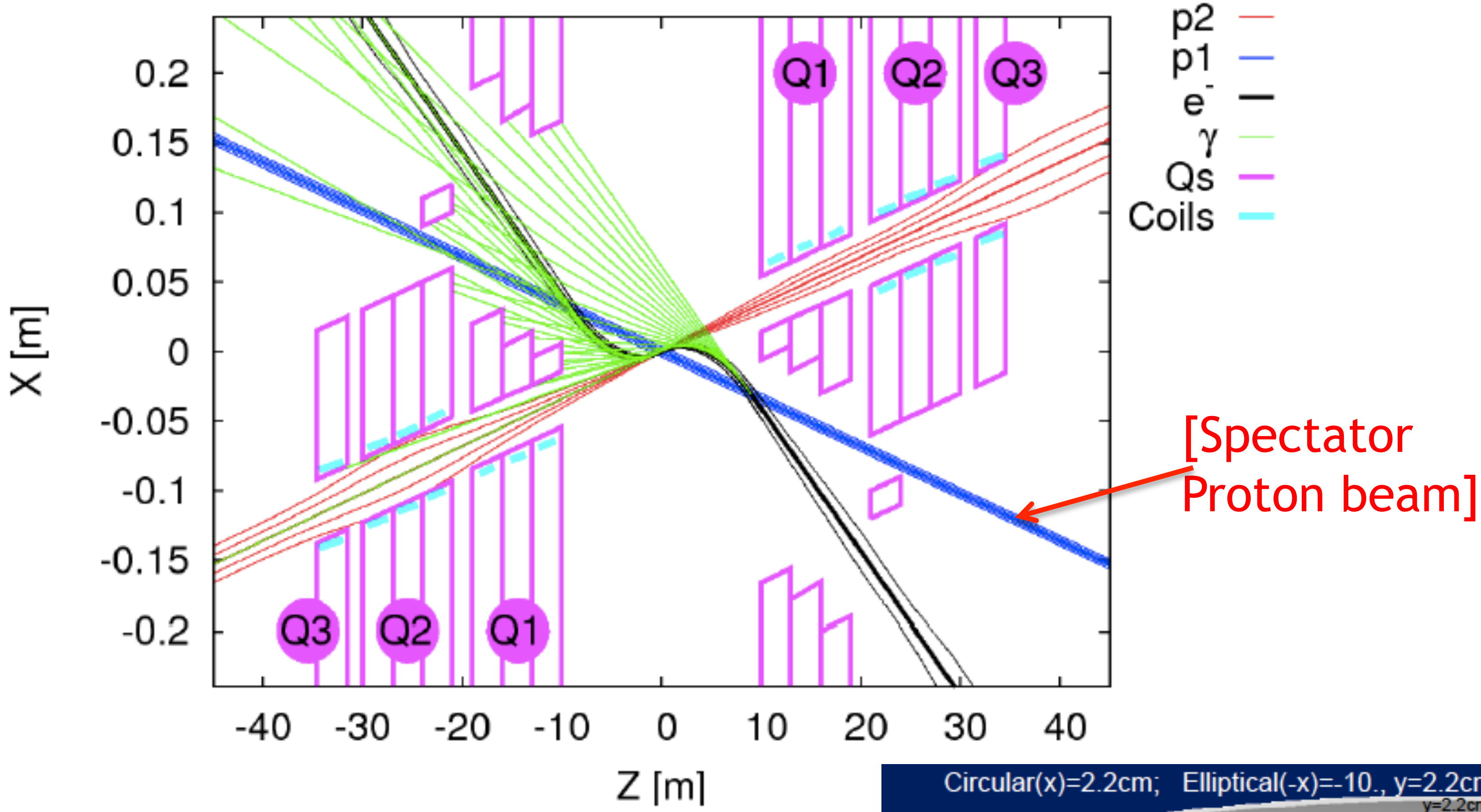


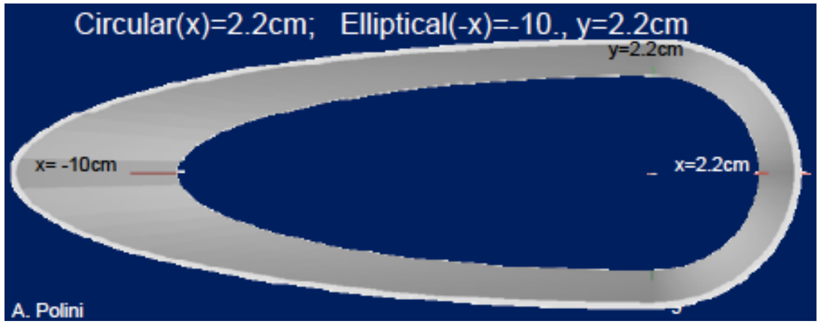

Baseline design:

- 500 MeV injection
- Two 10 GeV linacs,
- 3 returns, 20 MV/m CW
- Energy recovery in same structures


More ambitious:
Pulsed single
140 GeV Linac
31.5 MV/m (ILC)

# Interaction Region for LR (Rogelio Tomas)

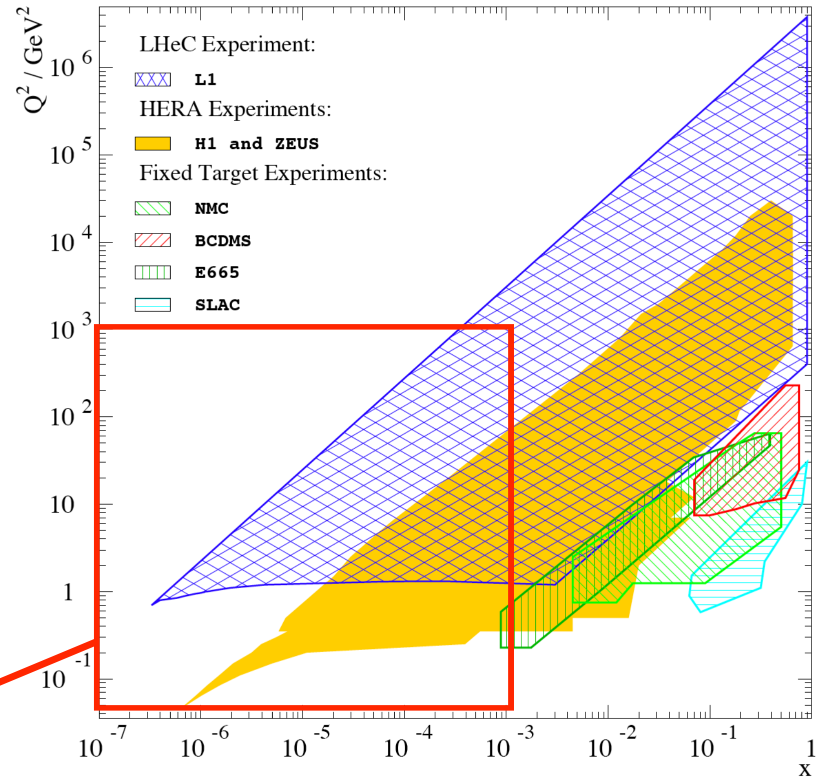


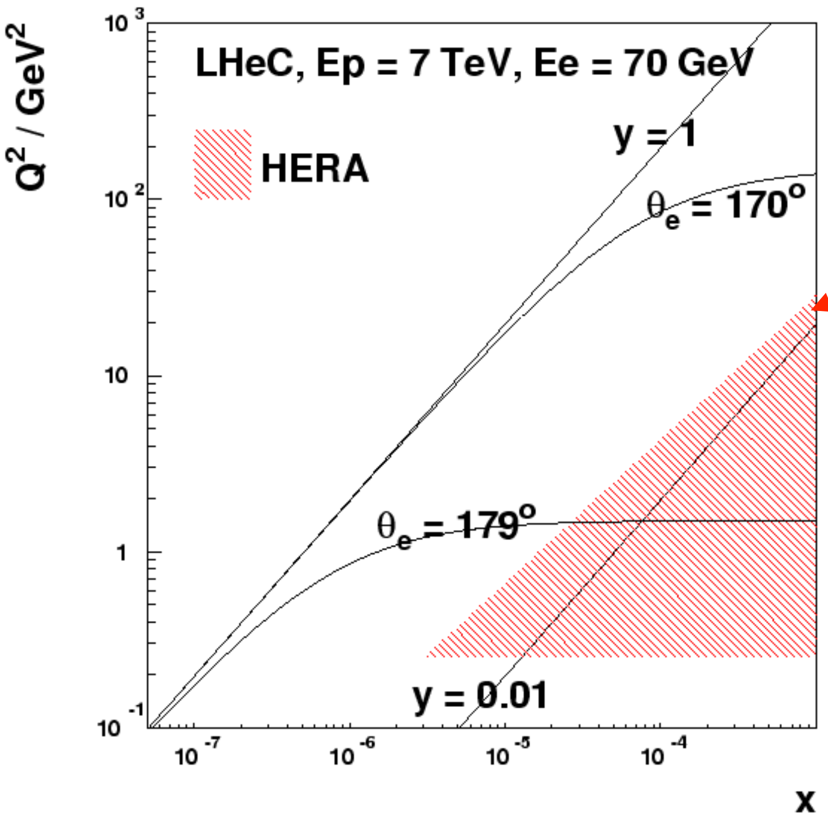




- 2 x 9m dipole magnets (0.3T) through detector region bend electrons into head-on collisions
- Synchrotron fan can be absorbed, but has implications for beampipe design

# Detector Acceptance Requirements

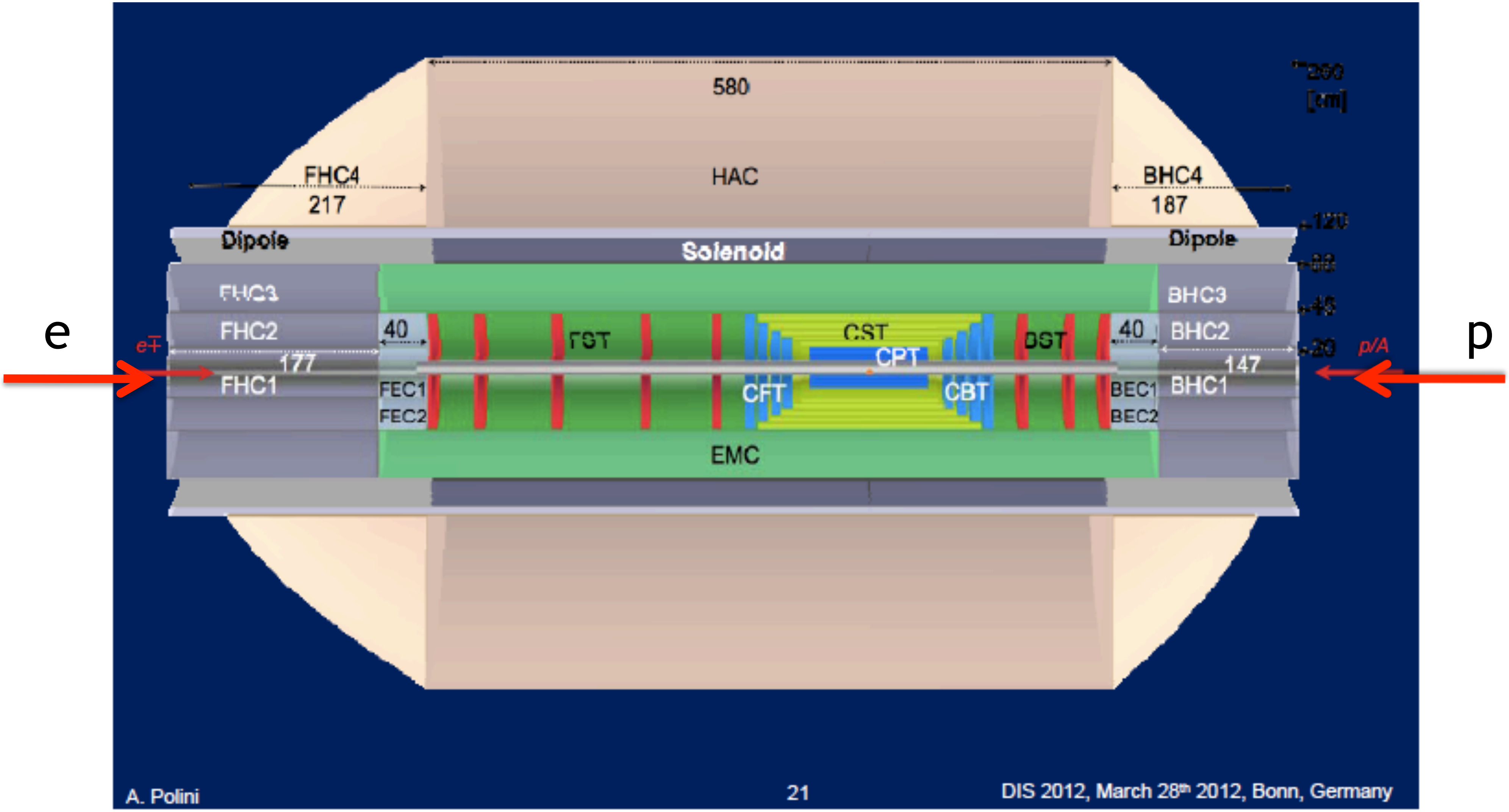
Access to $Q^2$=1 GeV$^2$ in ep mode for all x > 5 x $10^{-7}$ requires scattered electron acceptance to 179°




Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x (essential for good kinematic reconstruction)

# Central Detector (Alessandro Polini)

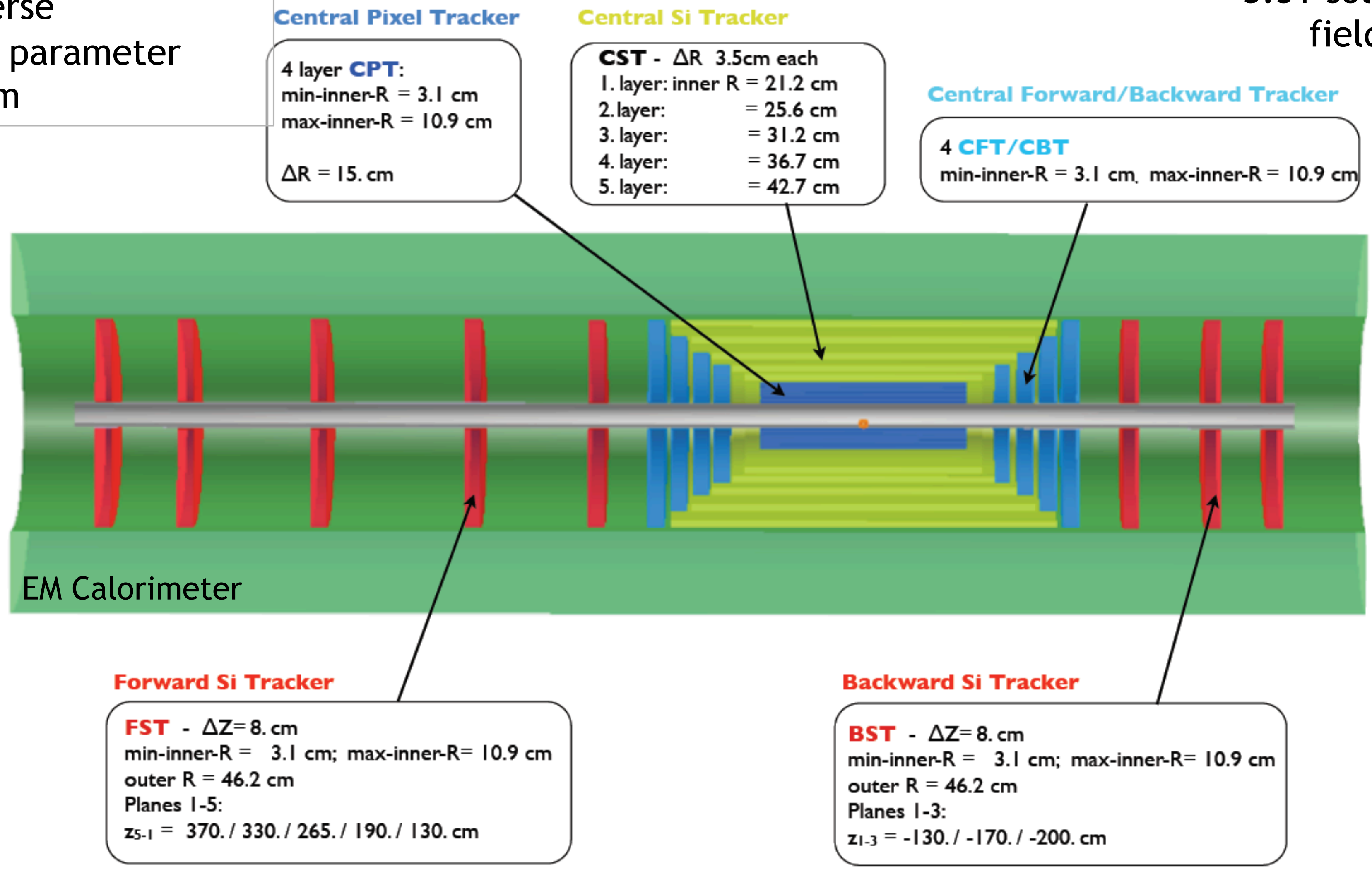



**Forward/backward asymmetry in energy deposited and thus in geometry and technology**
**Present dimensions: LxD =14x9m² [CMS 21 x 15m², ATLAS 45 x 25 m²]**
**Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)**

# Tracking Region

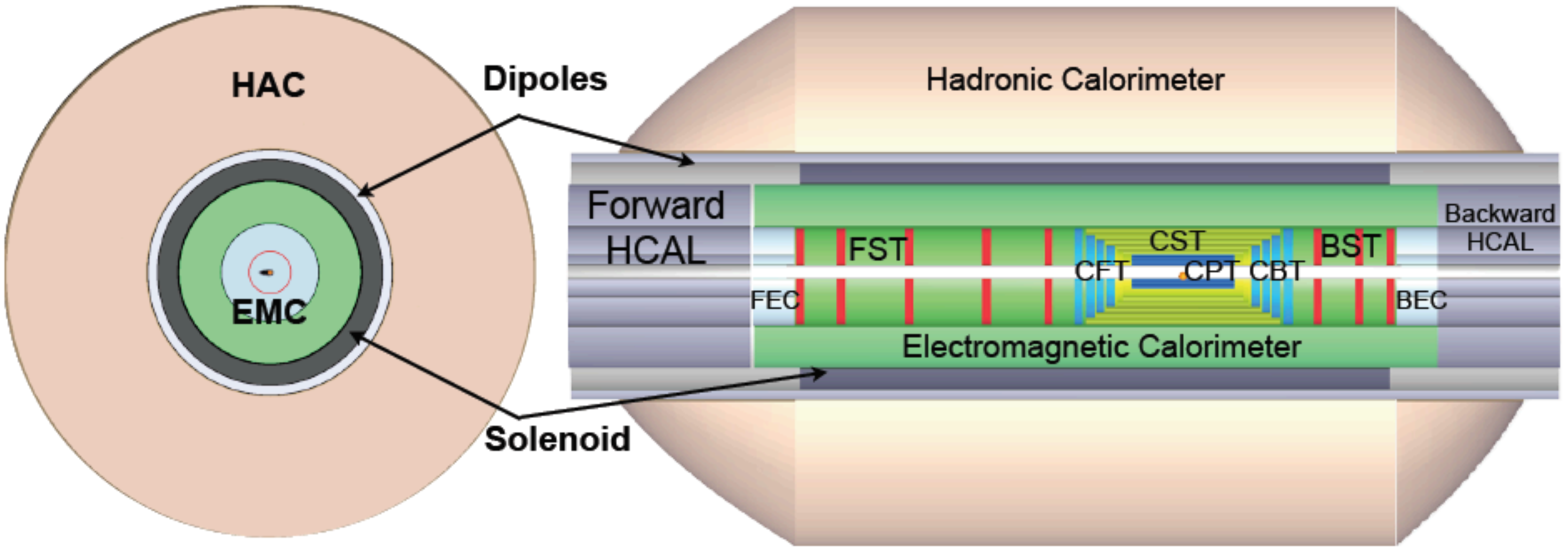
Transverse momentum
$\Delta p_t / p_t^2 \rightarrow 6\ 10^{-4}\ \mathrm{GeV}^{-1}$
transverse
impact parameter
→ 10μm

[encased in
3.5T solenoid
field]




- Full angular coverage, long tracking region → 1° acceptance
- Several technologies under discussion

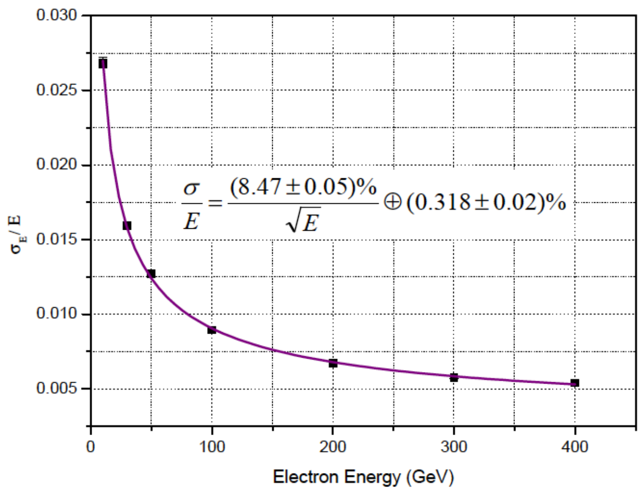
# Calorimeters

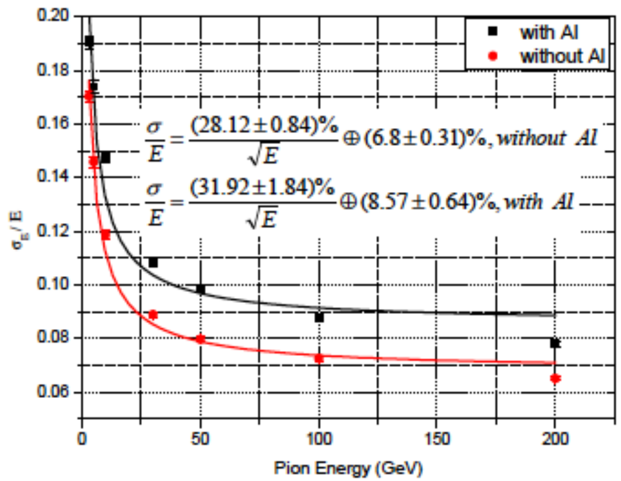



Liquid Argon EM Calorimeter [accordion geometry, inside coil]

Barrel: Pb, 20 $X_0$ , 11$m^3$ FEC: Si -W, 30 $X_0$ BEC: Si -Pb, 25 X

Hadronic Tile Calorimeter [modular, outside coil: flux return]

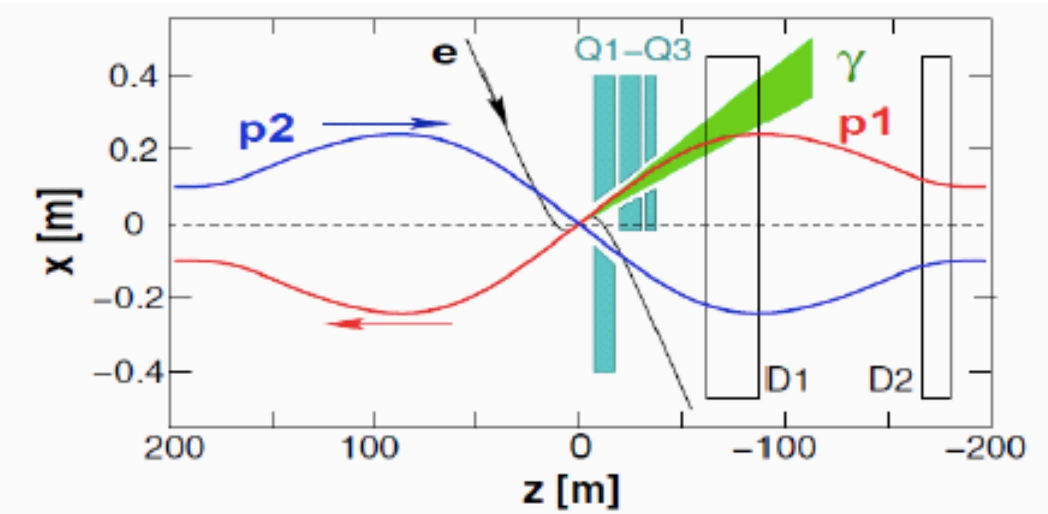


# Fwd / Bwd Detectors (Armen Bunyatyan)

## Luminosity measurement: Bethe-Heitler ($ep \rightarrow e\gamma p$)

For **LR** option the photons travel along the proton beam direction and can be detected at z≈-120m, after the proton bending dipole.
→ Place the photon detector in the median plane next to interacting proton beam




Main limitation – geometrical acceptance, defined by the aperture of Q1-Q3.
May be need to split dipole D1 to provide escape path for photons.
Geometrical acceptance of 95% is possible, total luminosity error δL=1%.



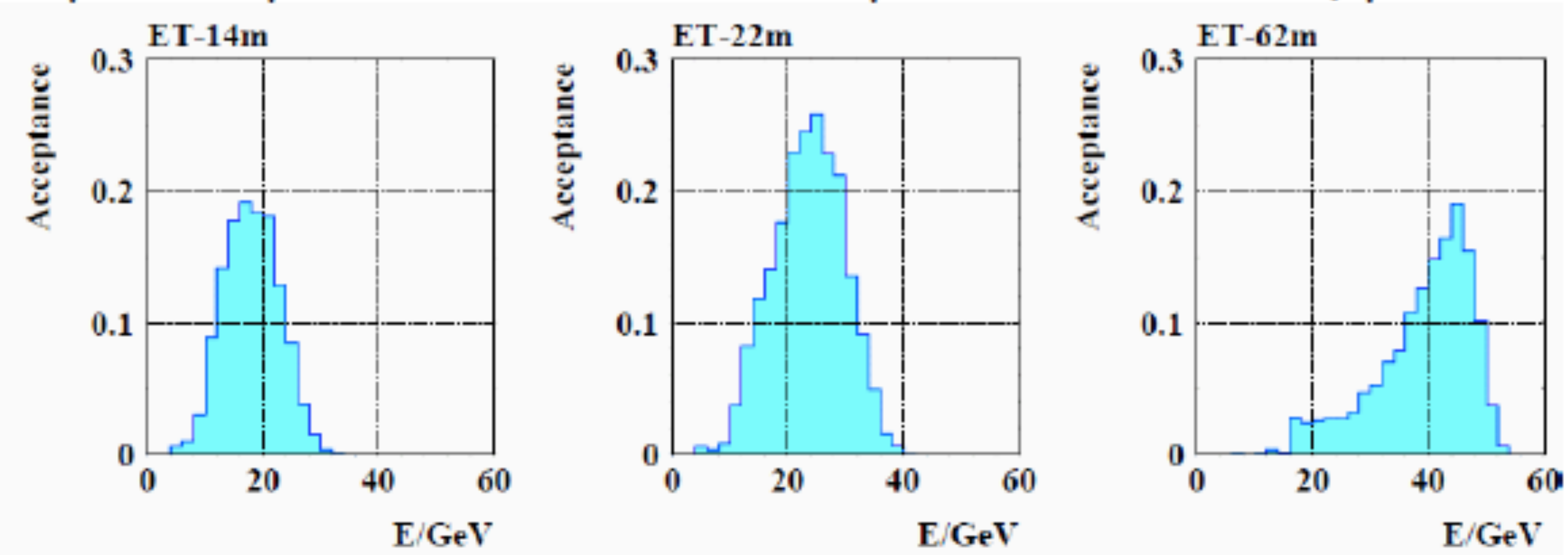
QED-Compton method and electron tagging also considered

# Electron tagger

detect scattered electron from Bethe-Heitler (also good for photoproduction physics and for control of $\gamma p$ background to DIS)

Clean sample – background from e-gas can be estimated using pilot bunches.

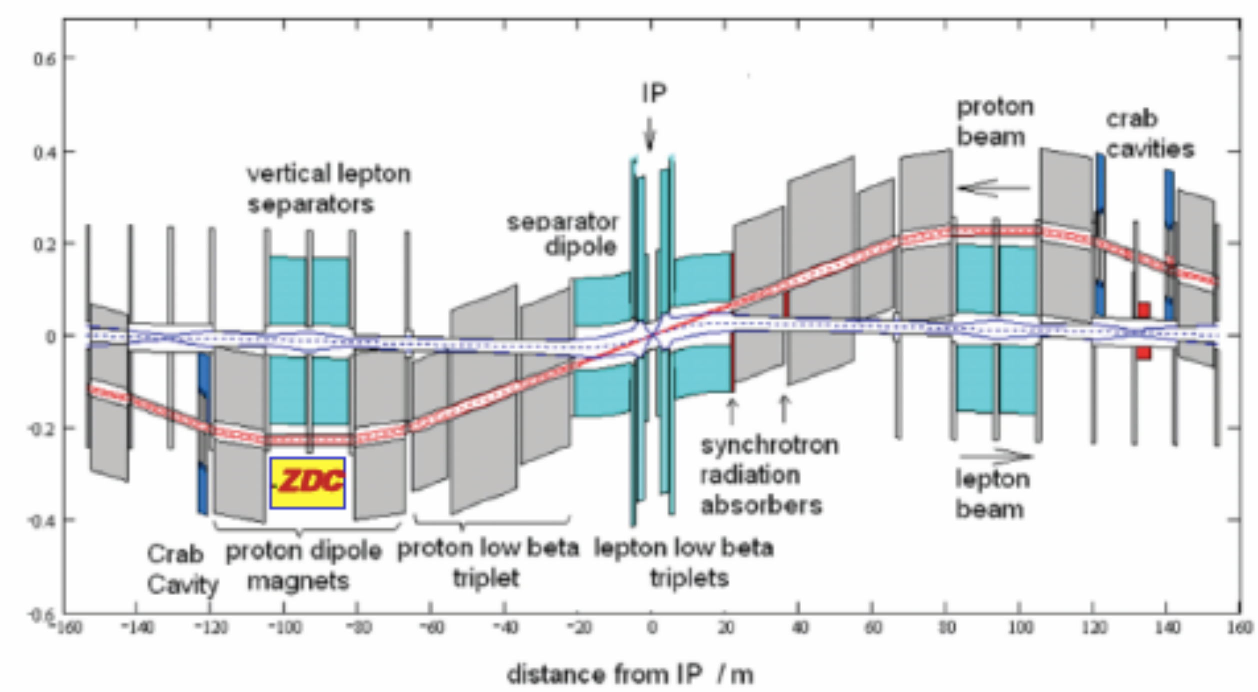
Three possible positions simulated→ acceptances reasonable (up to 20÷25%)



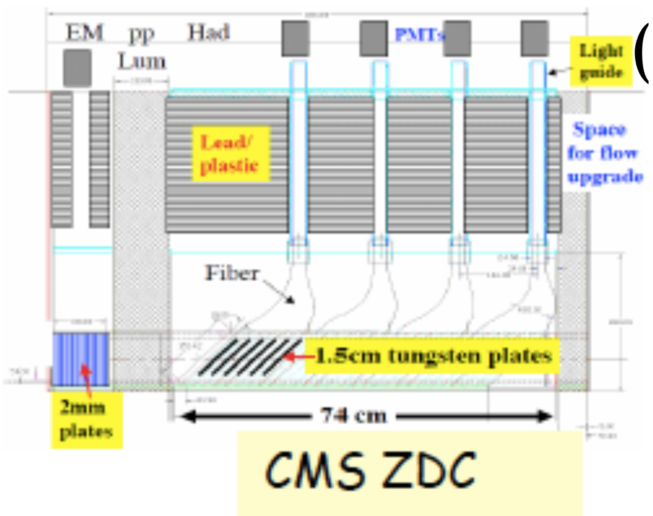

Acceptance depends on the distance of the detector from the e-beam axis and on the details of the e-beam optics (beam tilt, trajectory offset)

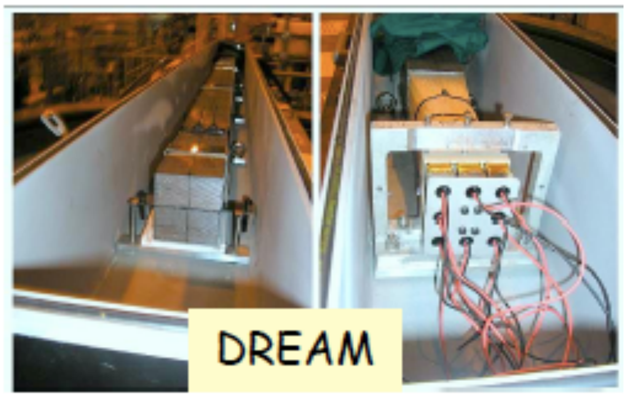
Need a precise monitoring of beam optics and accurate position measurement of the e-tagger to control geometrical acceptance to a sufficient precision (e.g. 20μm instability in the horizontal trajectory offset at IP leads to 5% systematic uncertainty in the visible cross section)

# Forward Neutron Calorimeter




ZDC can be similar to LHC experiments
(or can steal the DREAM prototype)



# Forward Proton Detection

Can also rely on work for existing LHC experiments (FP420, ATLAS AFP)

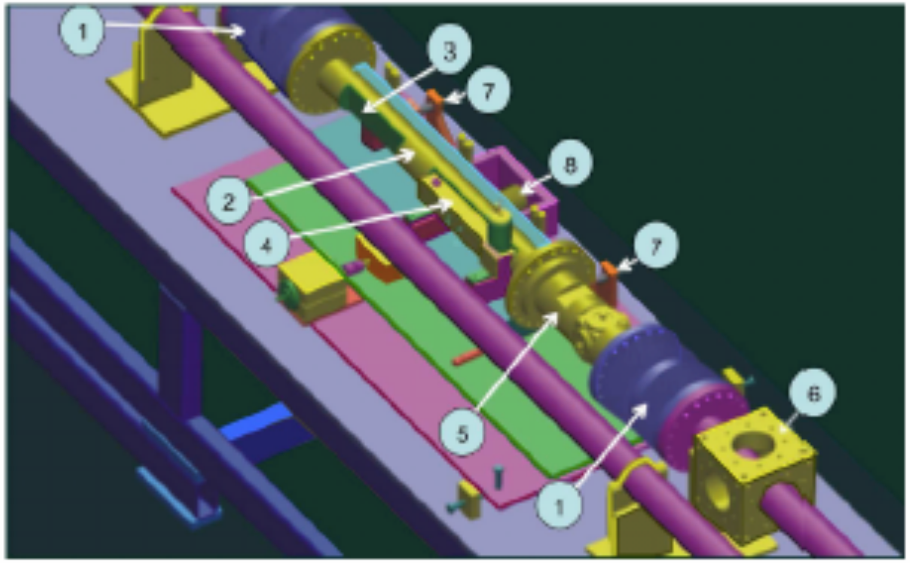
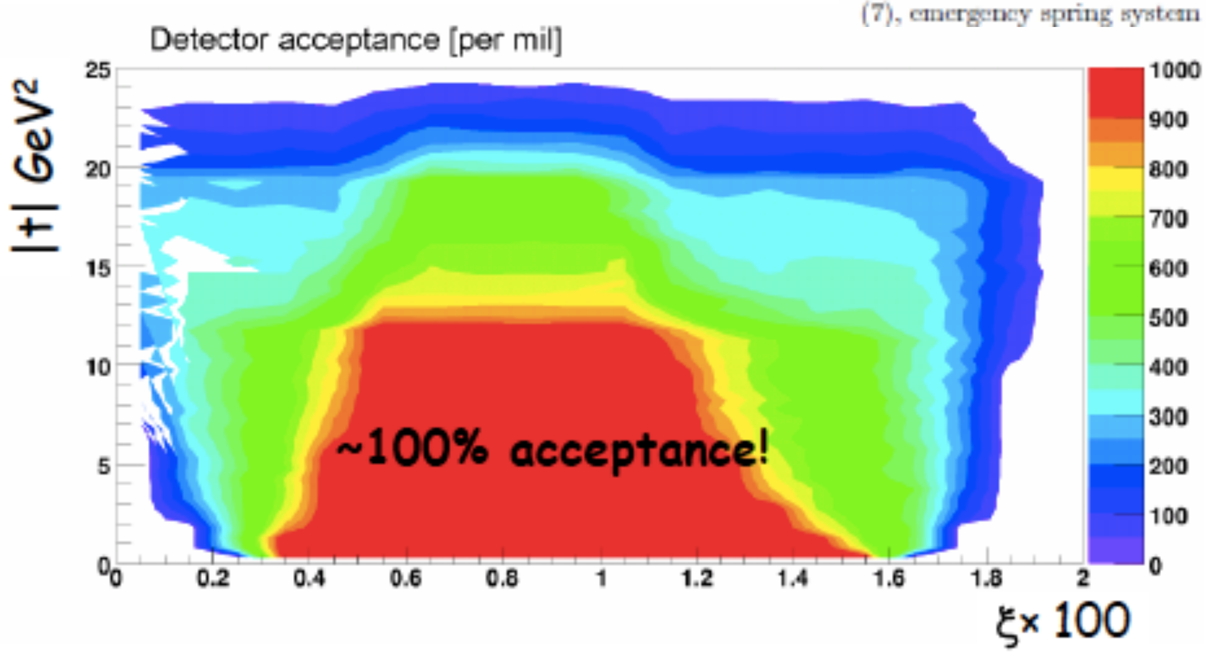



Figure 3.2: Top view of one detector section: bellows (1), moving pipe (2), Si-detector pocket (3), timing detector (4), moving BPM (5), fixed BPM (6), LVDT position measurement system (7), emergency spring system (8).



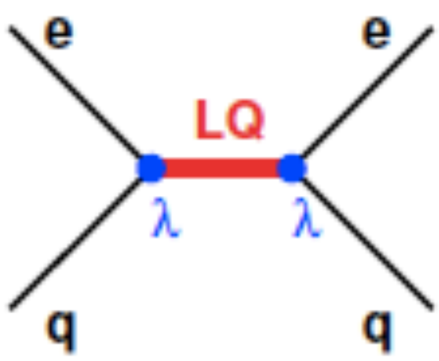
# Physics Programme

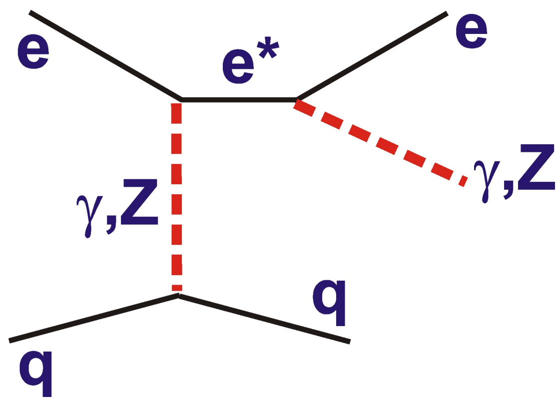
**Breaking News:** LHC is the discovery machine at the energy frontier for the foreseeable future.

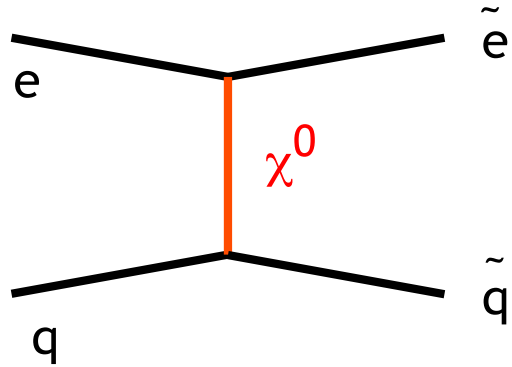
# Physics Programme

**Breaking News:** LHC is the discovery machine at the energy frontier for the foreseeable future.

• LHeC may compete with LHC in cases where initial state lepton is an advantage and offers cleaner final states



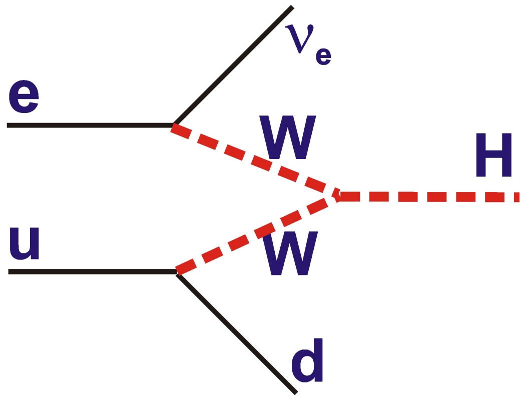

• LHeC enhances LHC discovery potential by clarifying signals

→ Quantum Number Determinations

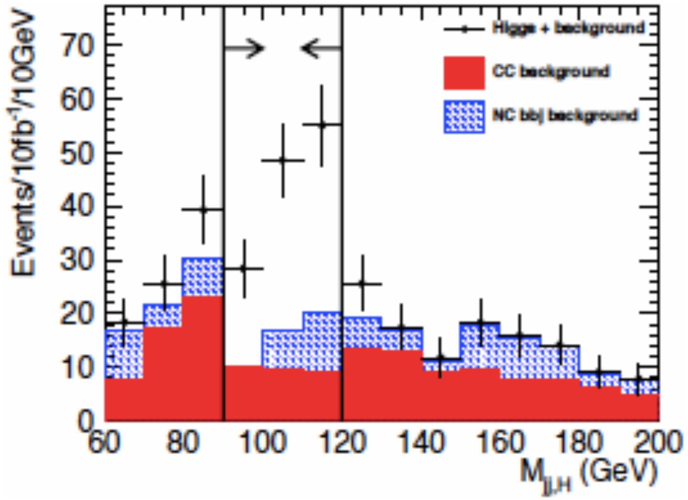
→ Reducing uncertainties due to PDFs / QCD modelling

• Unique sensitivity to novel low x effects, partonic structure of hadrons: **unprecedented breadth and precision in QCD studies**

# Anomalous Higgs Couplings (Rohini Godbole)



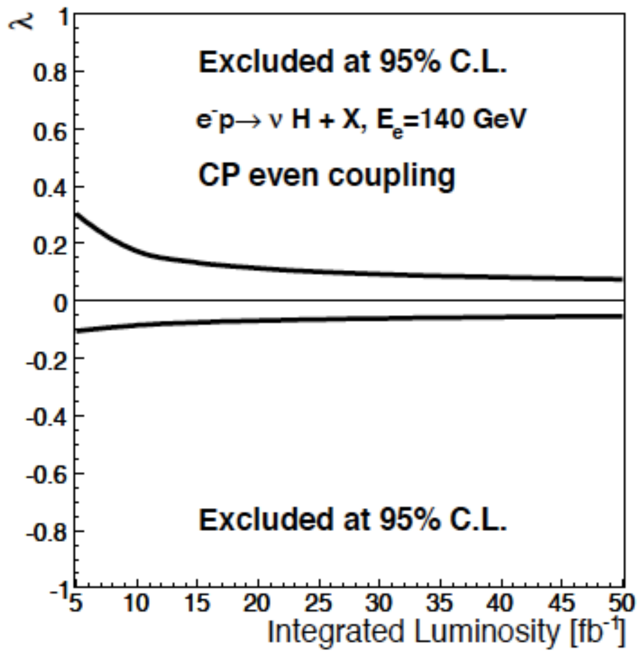

Clean signal to identify Higgs production via WW fusion (and decay to b-bbar) $H + j + E_t^{miss}$

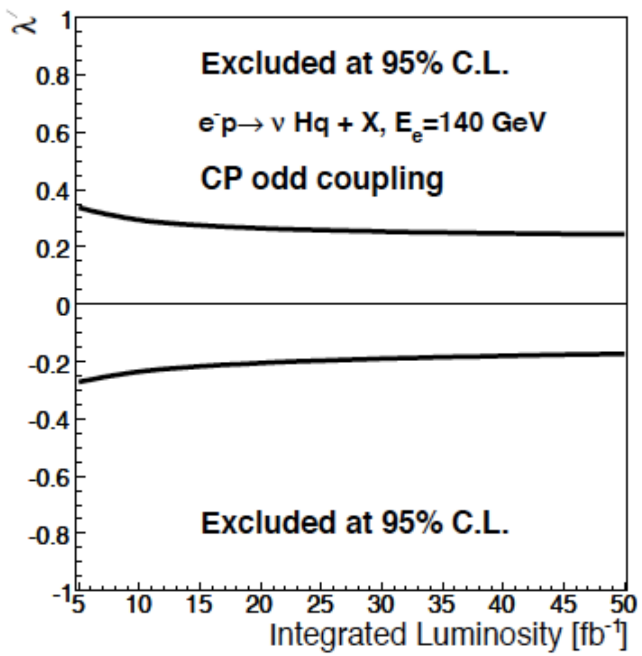



~ 100 events / year after cuts (S/B = 1.8)

e.g. Search for anomalous CP structure of HWW vertex using $\Delta\phi$ between jet / Etmiss

(c.f. Zeppenfeld et al for VBF Higgs at LHC)



# QCD and Electroweak Physics (Olaf Behnke)

## General Remark: LHeC can uniquely reach/exploit electroweak sector:

- Z and W exchanges assist $\gamma$ exchange for complete quark flavour decomposition of proton structure (next slides)
- precision electroweak tests, e.g. $\sin^2\theta_W(\mu)$ (end of talk)

# LHeC Impact on Parton Densities

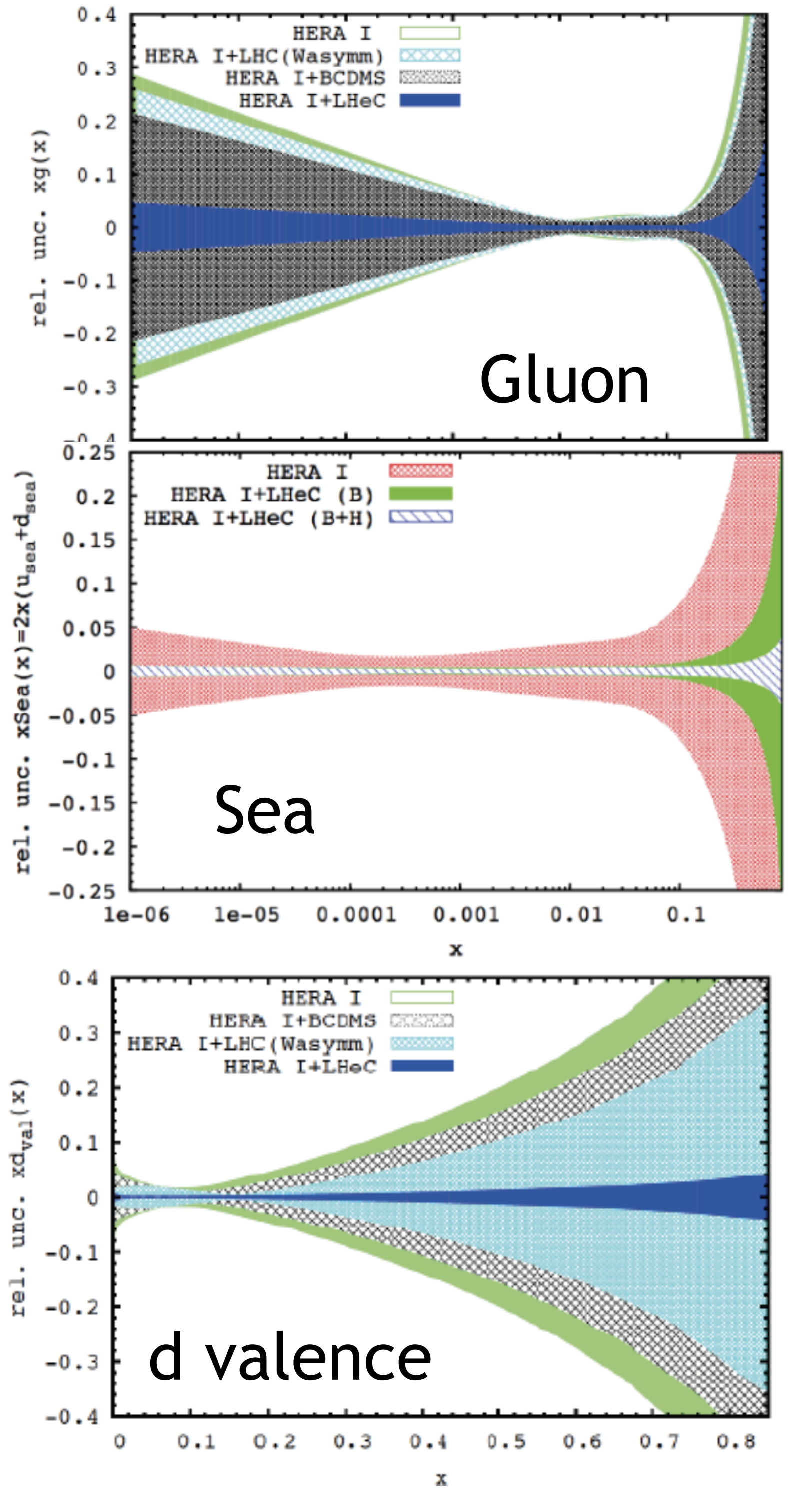
Full simulation of inclusive NC and CC DIS data, including systematics → NLO DGLAP fit using HERA technology…

… typically expect 100 times HERA Event yields in DIS region, with extended kinematic range

… big impact at low x (kinematic range) and high x (luminosity)

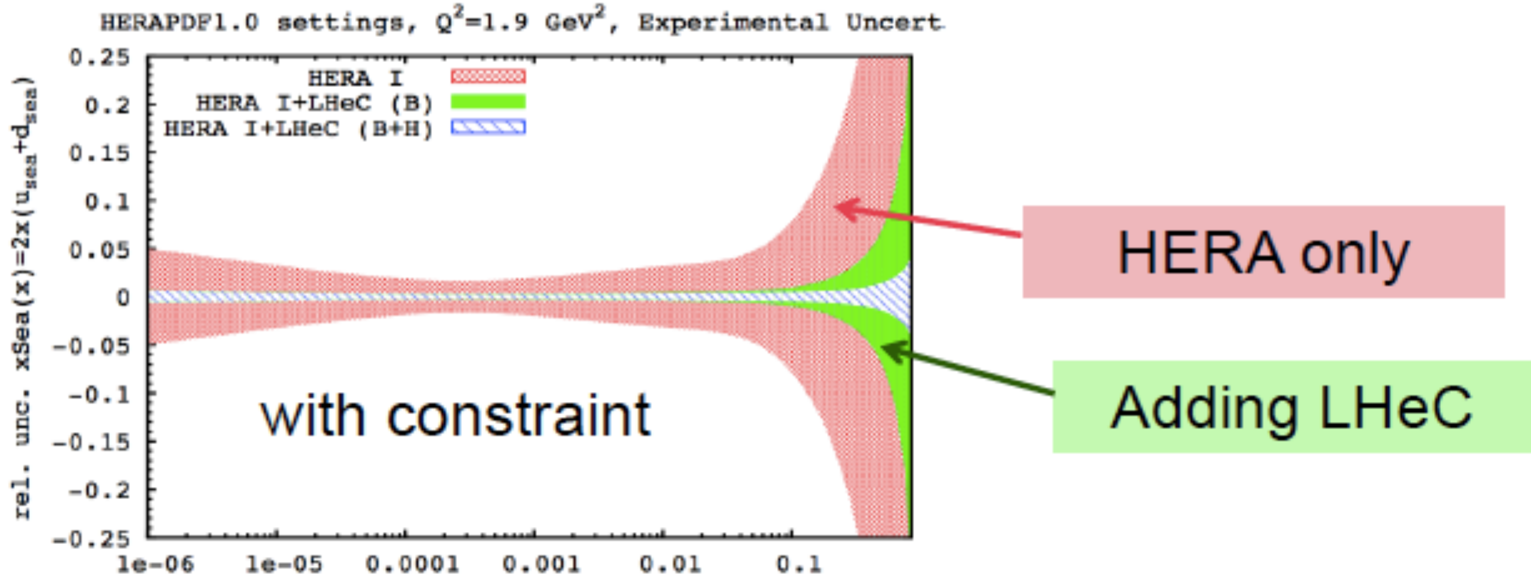
… precise light quark vector, axial couplings, weak mixing angle

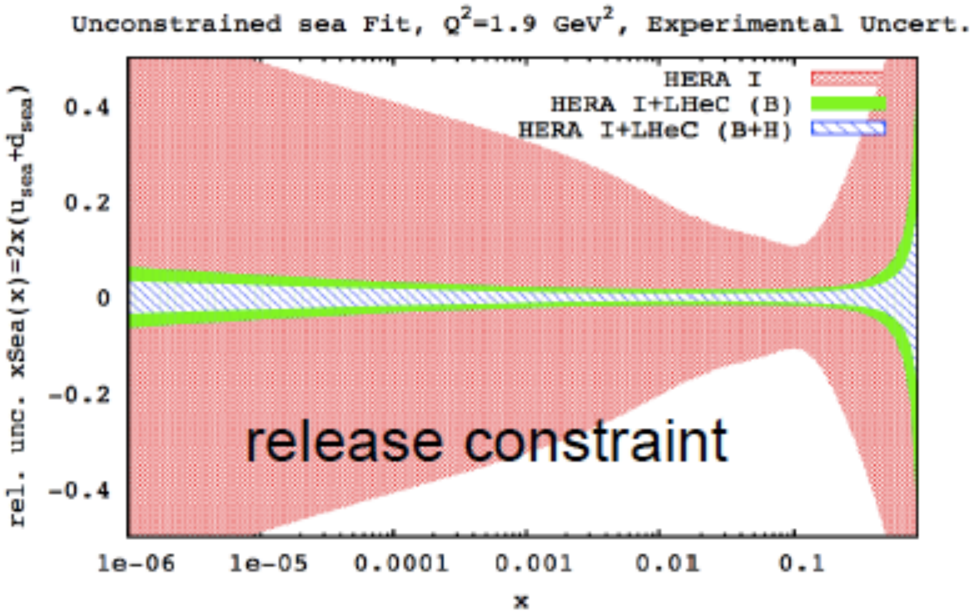
… full flavour decomposition



# Sea quark uncertainties and usual constraint ubar=dbar for x→0

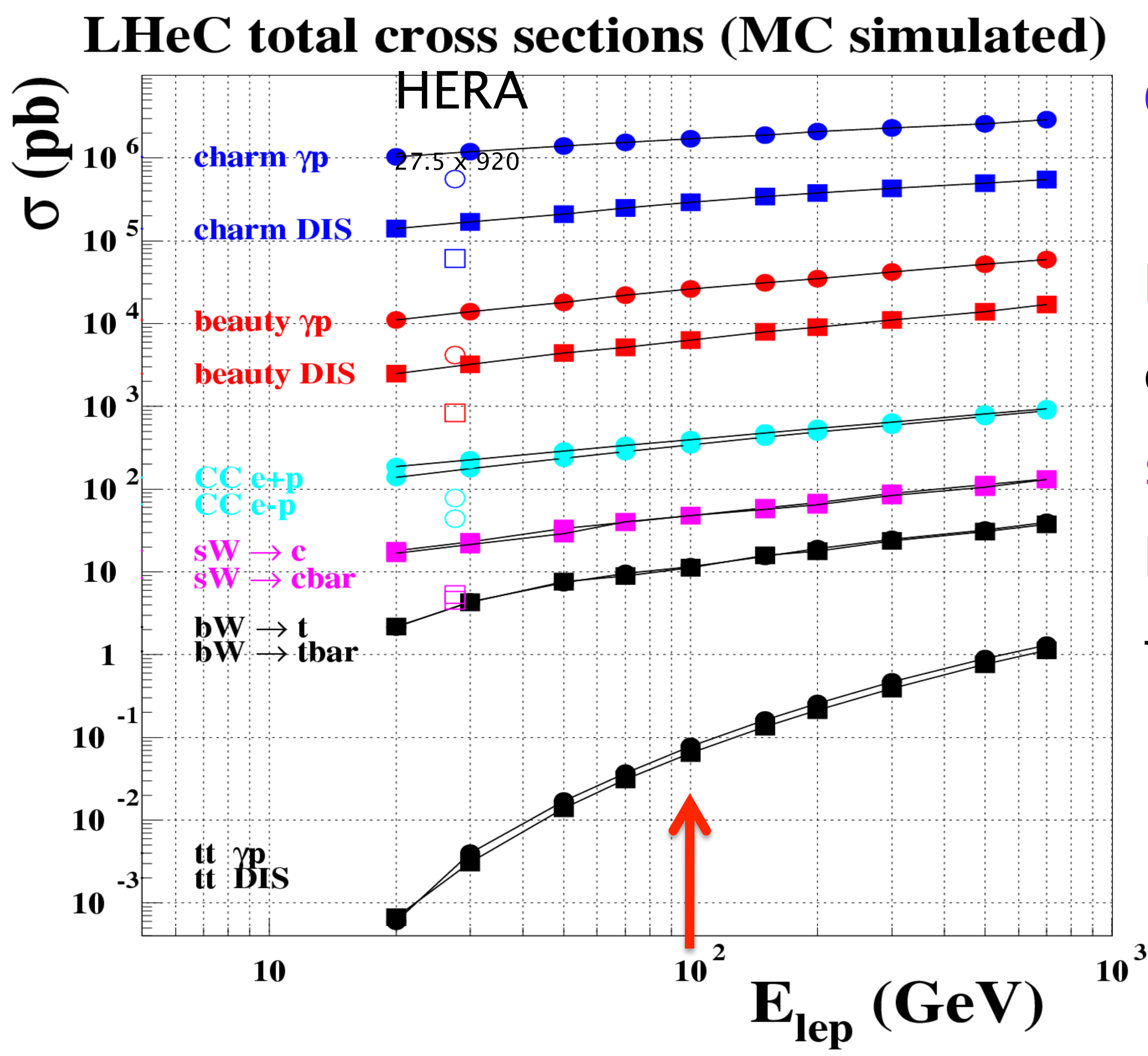
Voica Radescu




With LHeC can get rid of such assumptions

# Cross Sections and Rates for Heavy Flavours




Charm [$10^{10}$ / 10 $fb^{-1}$]

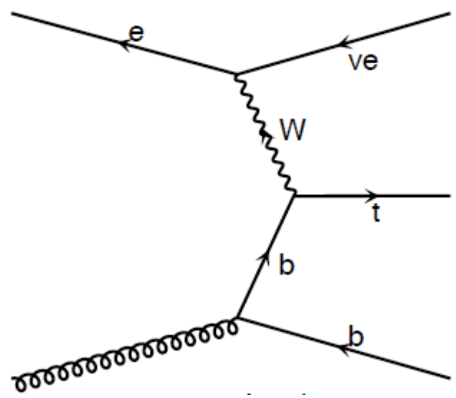
Beauty [$10^{8}$ / 10 $fb^{-1}$]

cc

sW → c [4.$10^{5}$ / 10 $fb^{-1}$]

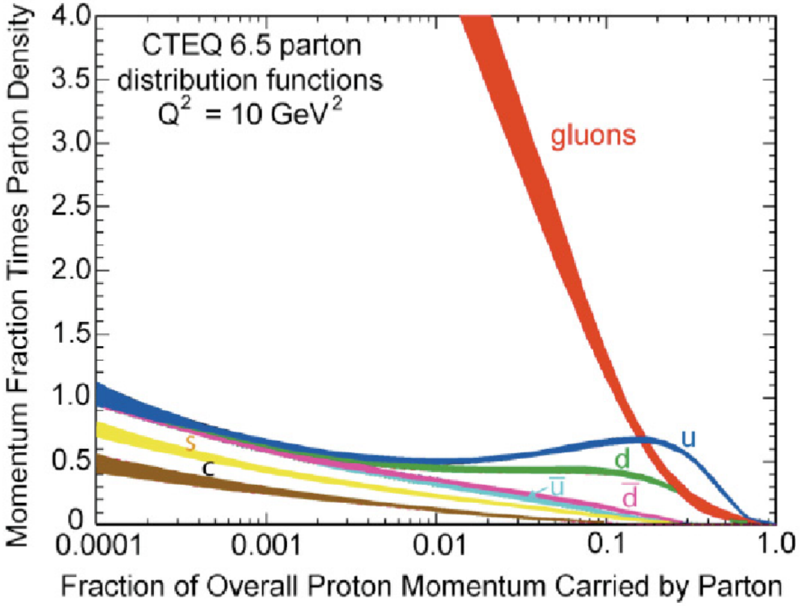
bW → t [$10^{5}$ / 10 $fb^{-1}$]

ttbar [$10^{3}$ / 10 $fb^{-1}$]

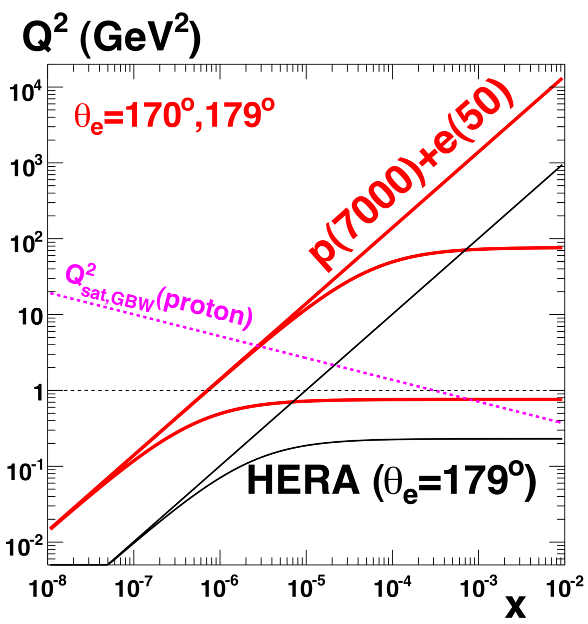


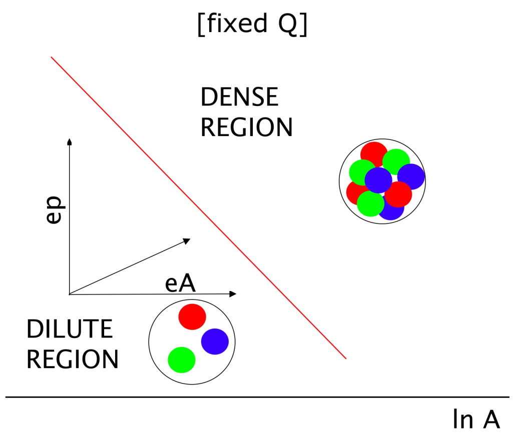

c.f. luminosity of ~10 $fb^{-1}$ per year …

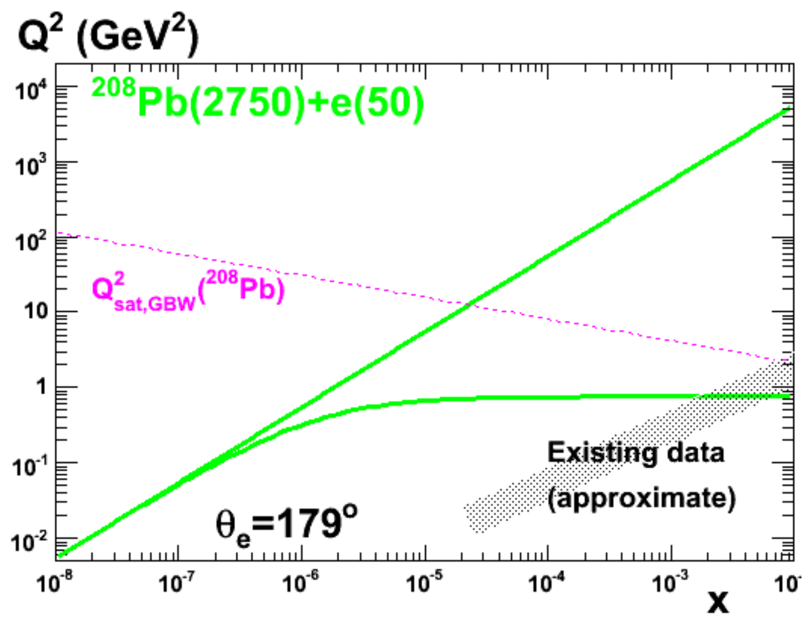
# Low-x Physics / Parton Saturation (Nestor Armesto and Anna Stasto)




- Most people agree that somewhere & somehow, the low x growth of parton densities must be tamed by non-linear effects (`Saturation').
- Can it be understood microscopically?
- 2 pronged approach at LHeC …



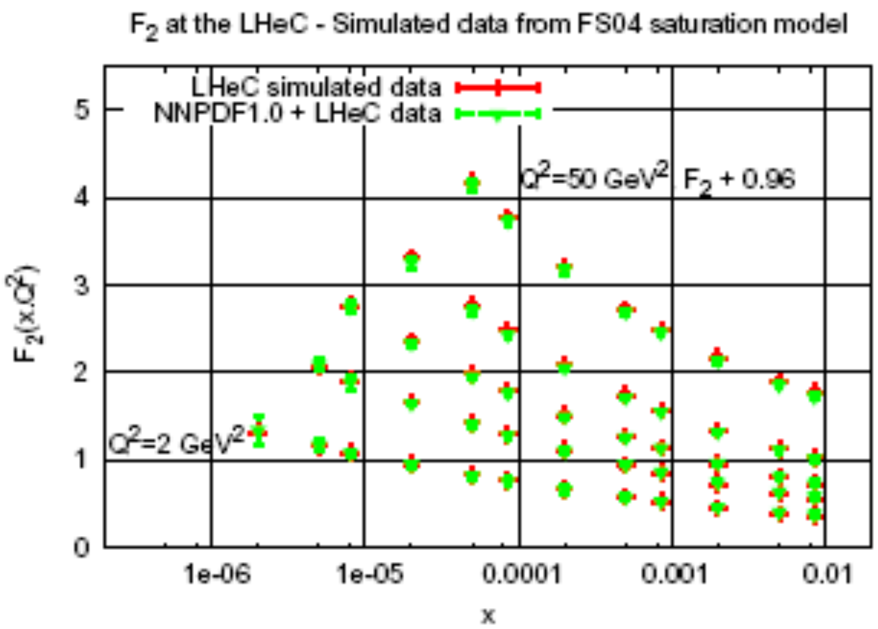



# Can Parton Saturation be Established in ep @ LHeC?

Simulated LHeC data based on a dipole model containing low x saturation (FS04-sat)… Fit with standard (NNPDF) NLO DGLAP

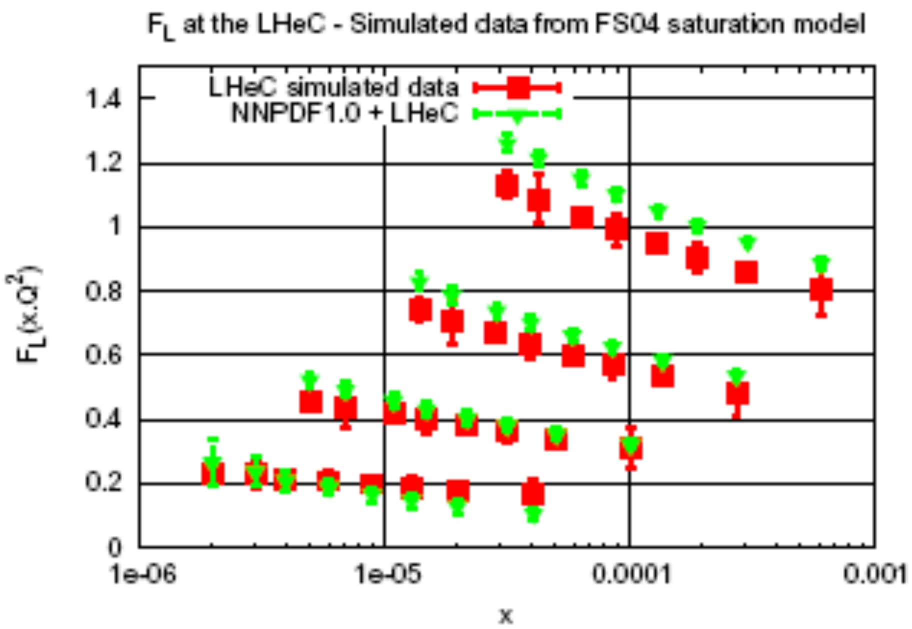
Fitting $F_2$ only



# Can Parton Saturation be Established in ep @ LHeC?

Simulated LHeC data based on a dipole model containing low x saturation (FS04-sat)… Fit with standard (NNPDF) NLO DGLAP

Fitting $F_2$ and $F_L$

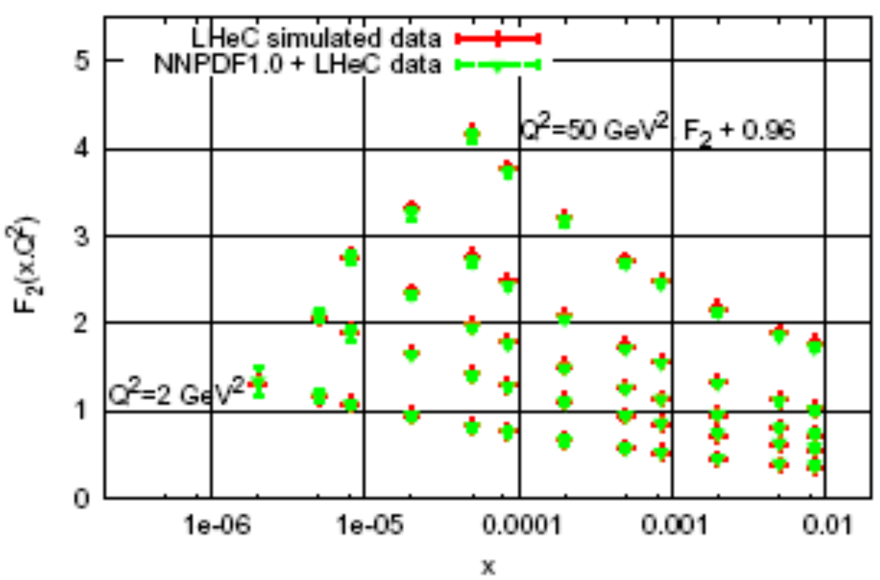


# Can Parton Saturation be Established in ep @ LHeC?

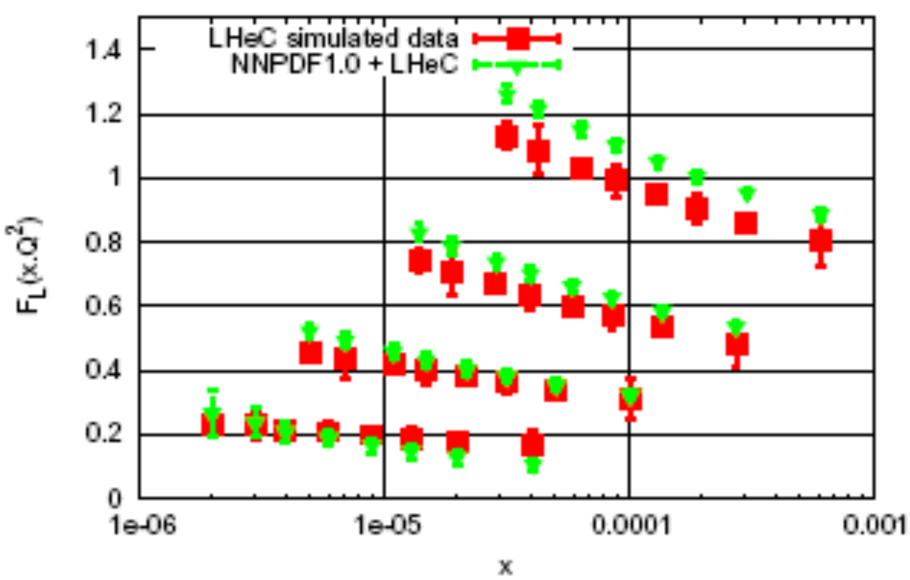
Simulated LHeC data based on a dipole model containing low x saturation (FS04-sat)… Fit with standard (NNPDF) NLO DGLAP

… NNPDF (also HERA framework) DGLAP QCD fits cannot accommodate saturation effects if $F_2$ and $F_L$ both fitted

$F_2$ at the LHeC - Simulated data from FS04 saturation model



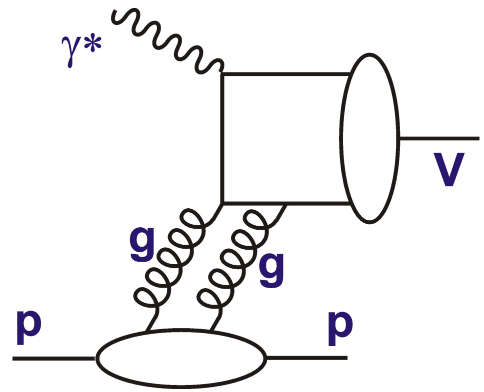

$F_L$ at the LHeC - Simulated data from FS04 saturation model



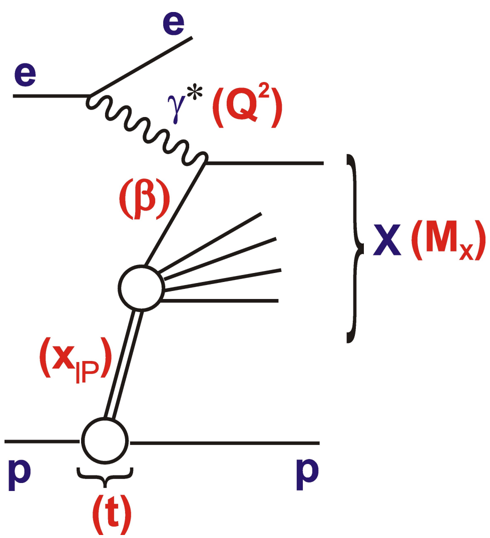

Conclusion: clearly establishing non-linear effects needs a minimum of 2 observables … <u>($F_2^c$ may work in place of $F_L$)</u>…

# Exclusive / Diffractive Channels and Saturation

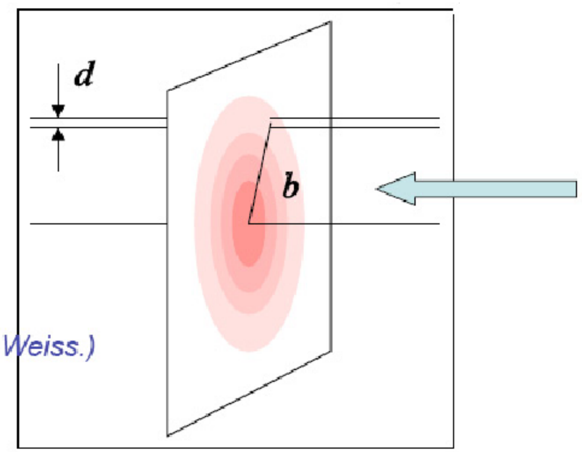
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon




2) Additional variable t gives access to impact parameter (b) dependent amplitudes




→ Large t (small b) probes densest packed part of proton?



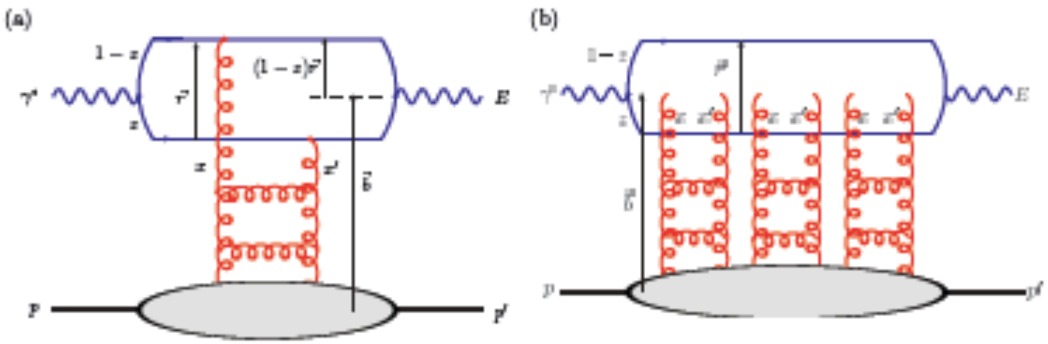

(figure from C. Weiss.)

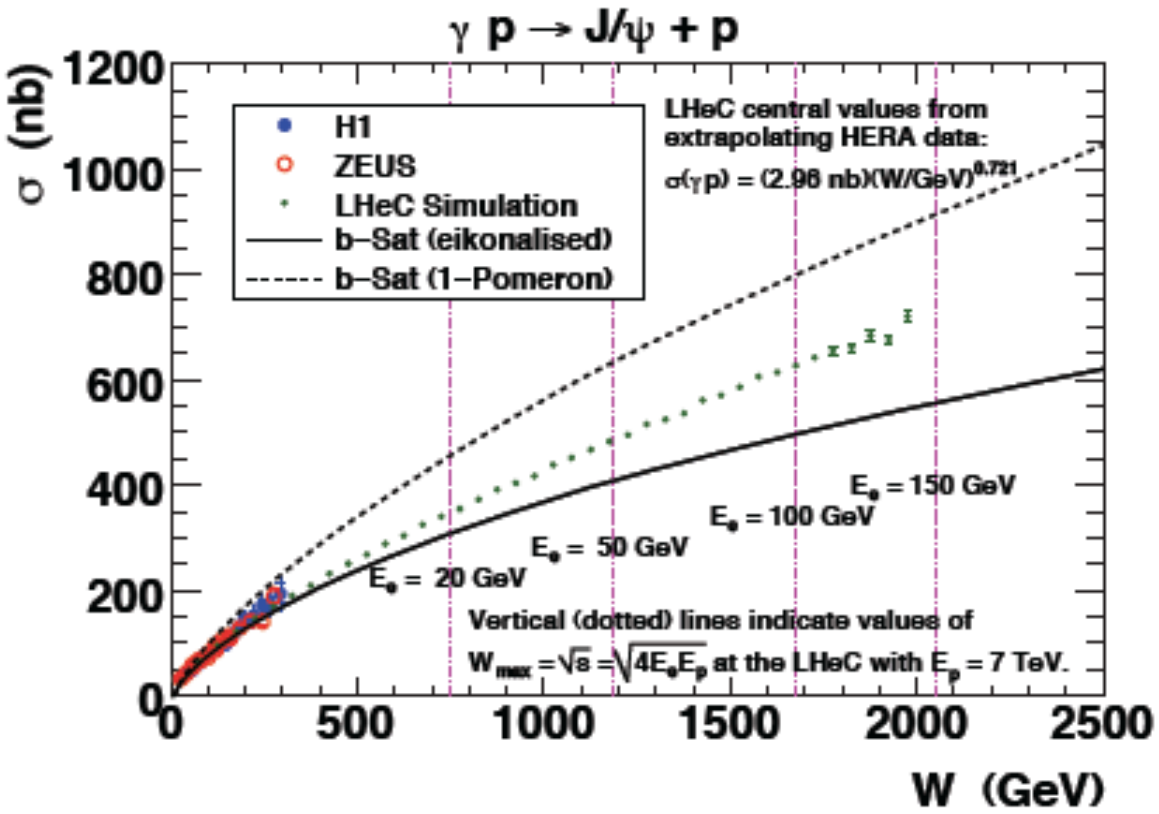
Central black region growing with decrease of x.

# Exclusive diffraction: vector mesons

$$\sigma^{\gamma p \to J/\Psi + p}(W)$$

- b-Sat dipole model (Golec-Biernat, Wuesthoff, Bartels, Motyka, Kowalski, Watt)
- eikonalised: with saturation
- 1-Pomeron: no saturation





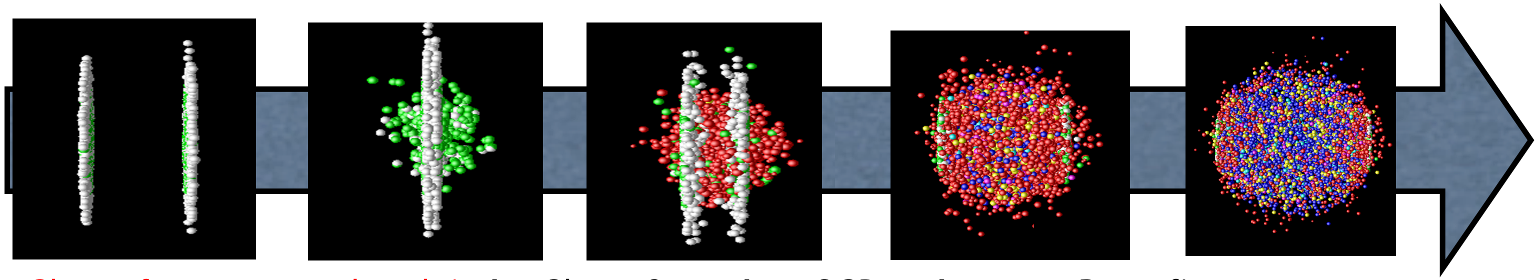

Large effects even for the t-integrated observable.

Different W behavior depending whether saturation is included or not.

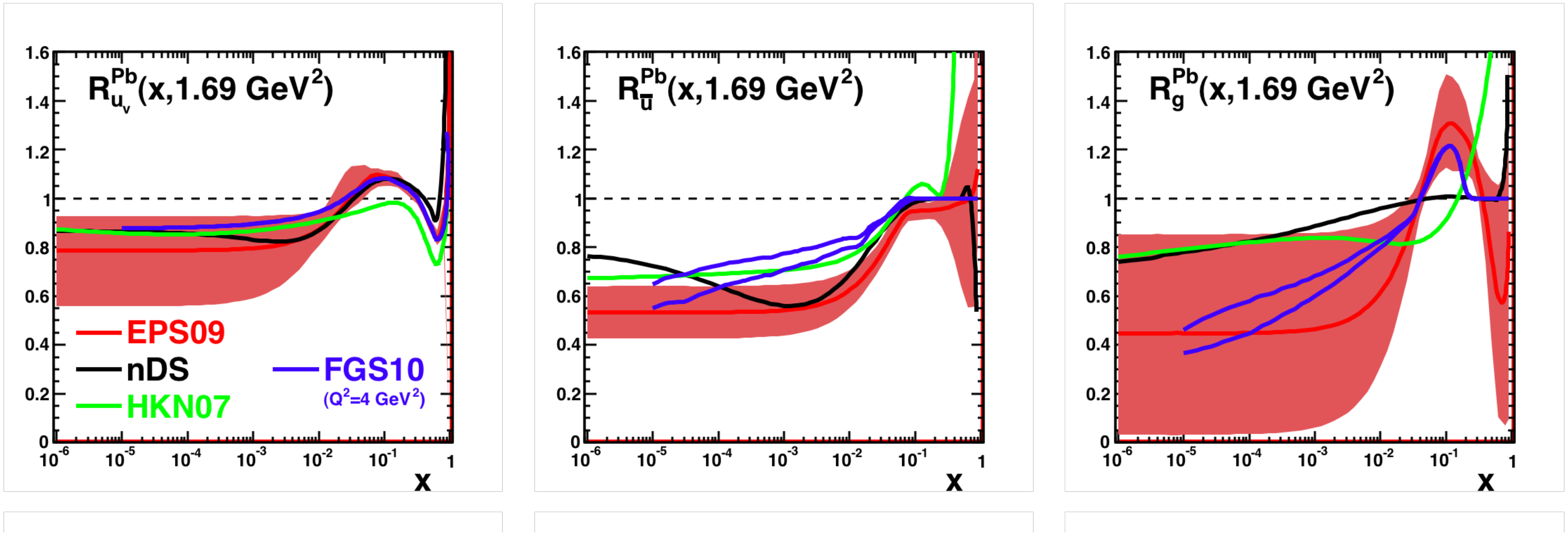
Simulated data are from extrapolated fit to HERA data

LHeC can distinguish between the different scenarios.

# What is Initial State of LHC AA Collisions?



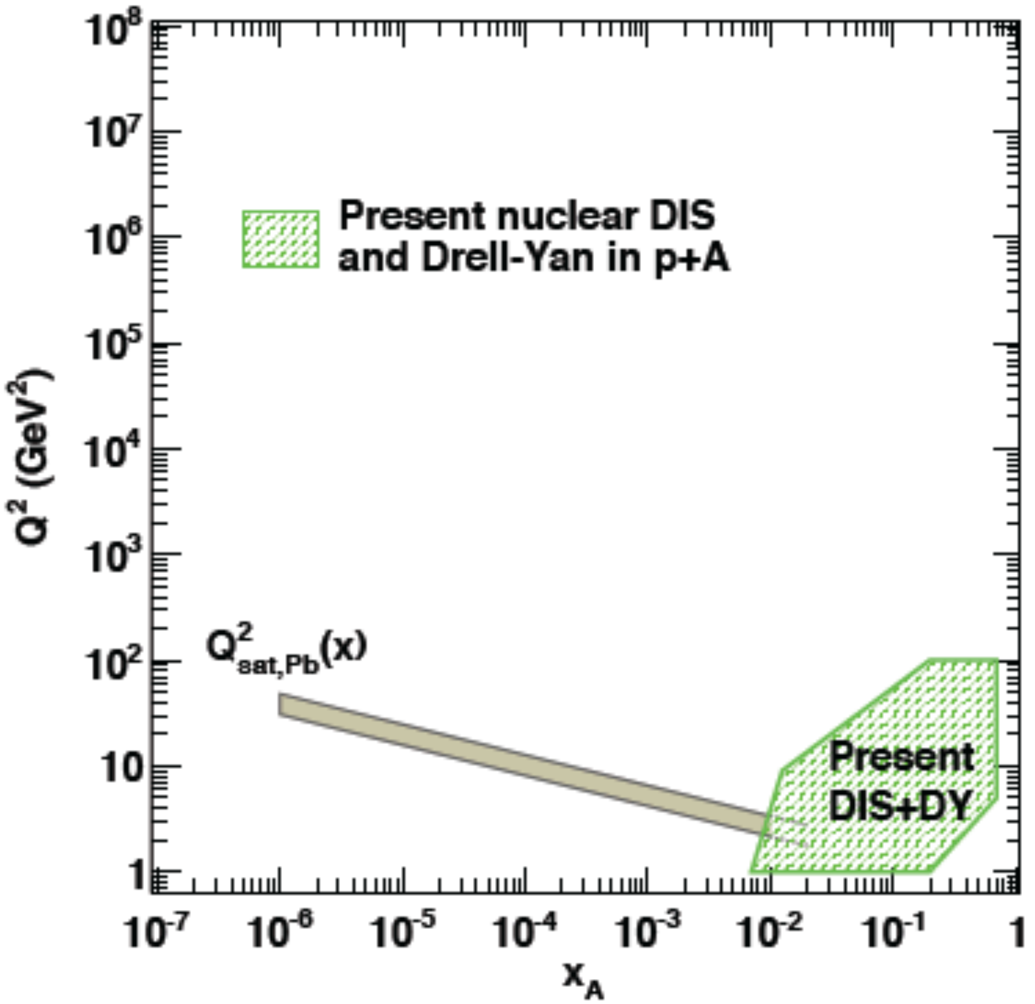
Gluons from saturated nuclei → Glasma? → QGP → Reconfinement




$R_i$ = Nuclear PDF i / (A * proton PDF i)

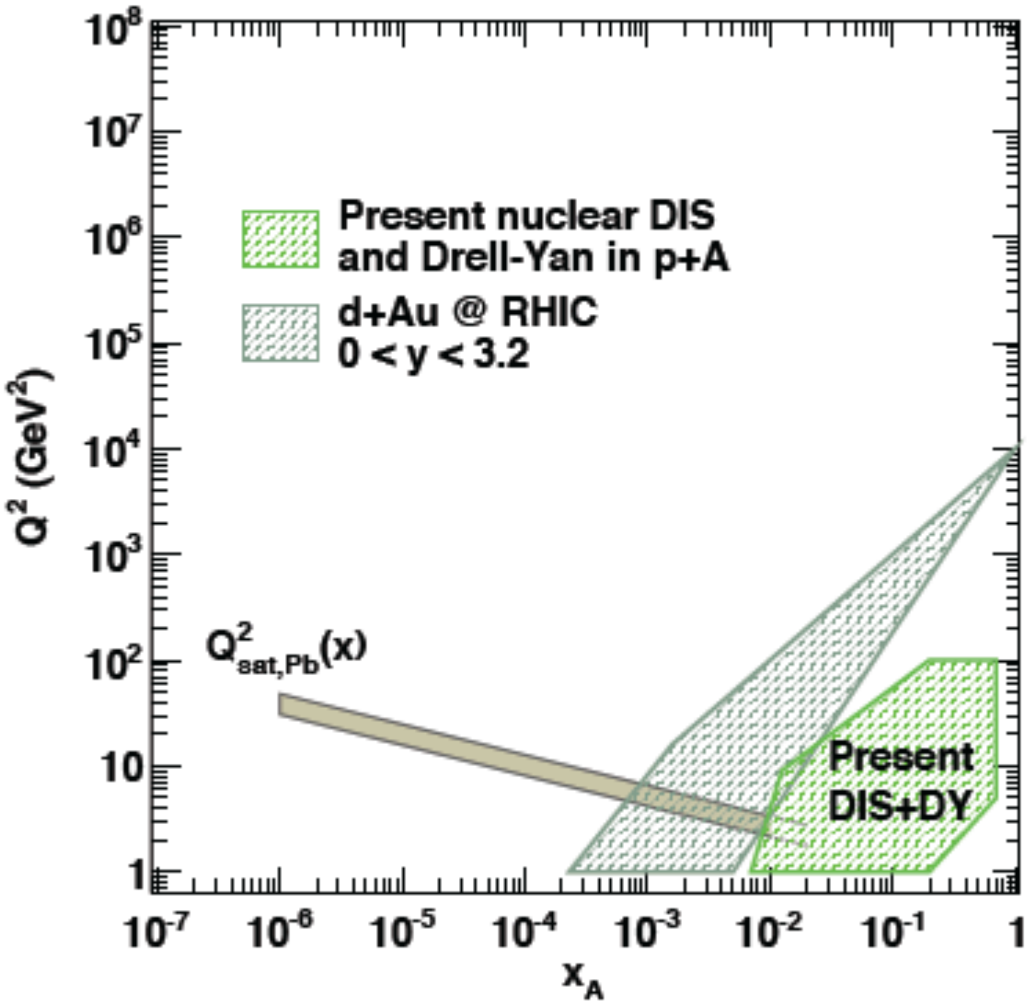
# Nuclear PDFs (Carlos Salgado)

## Kinematical reach in nuclear collisions



# Nuclear PDFs (Carlos Salgado)

## Kinematical reach in nuclear collisions



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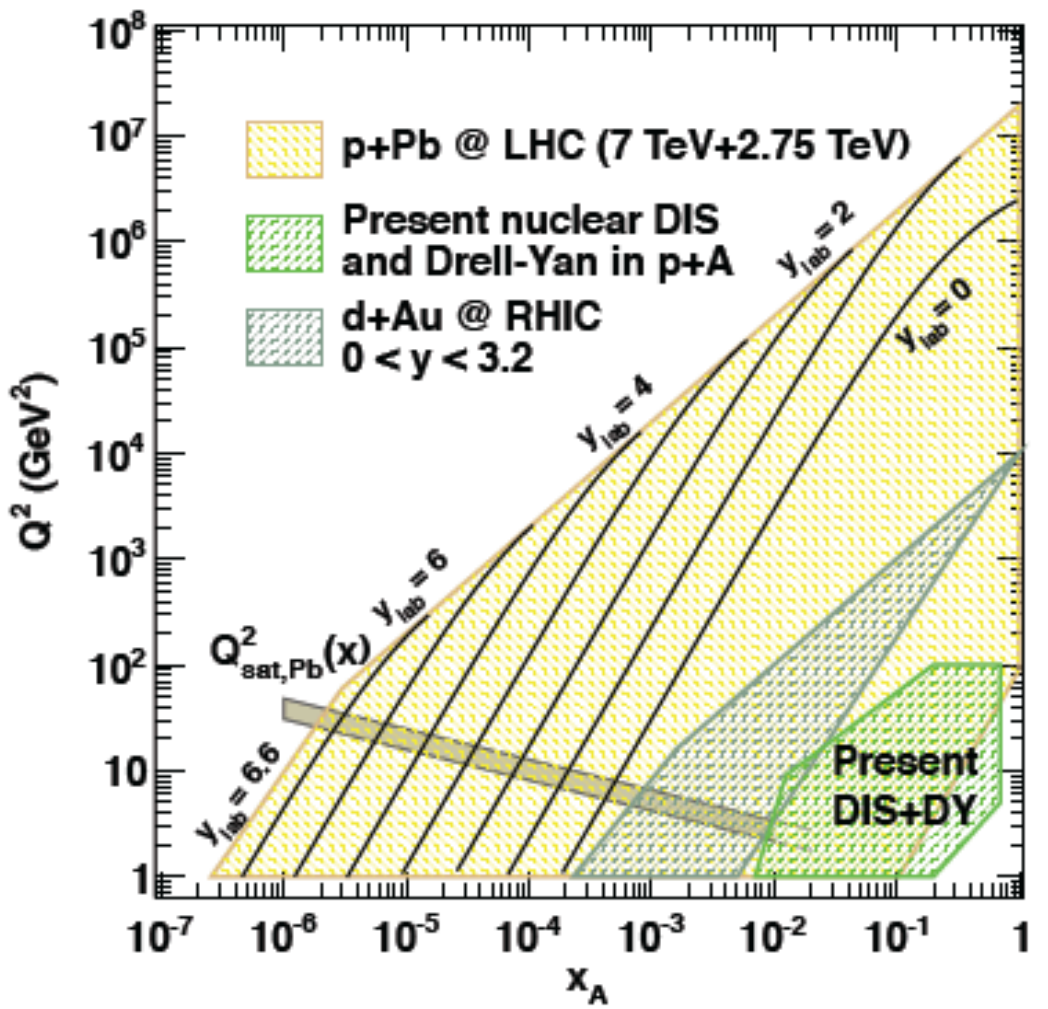

# Nuclear PDFs (Carlos Salgado)

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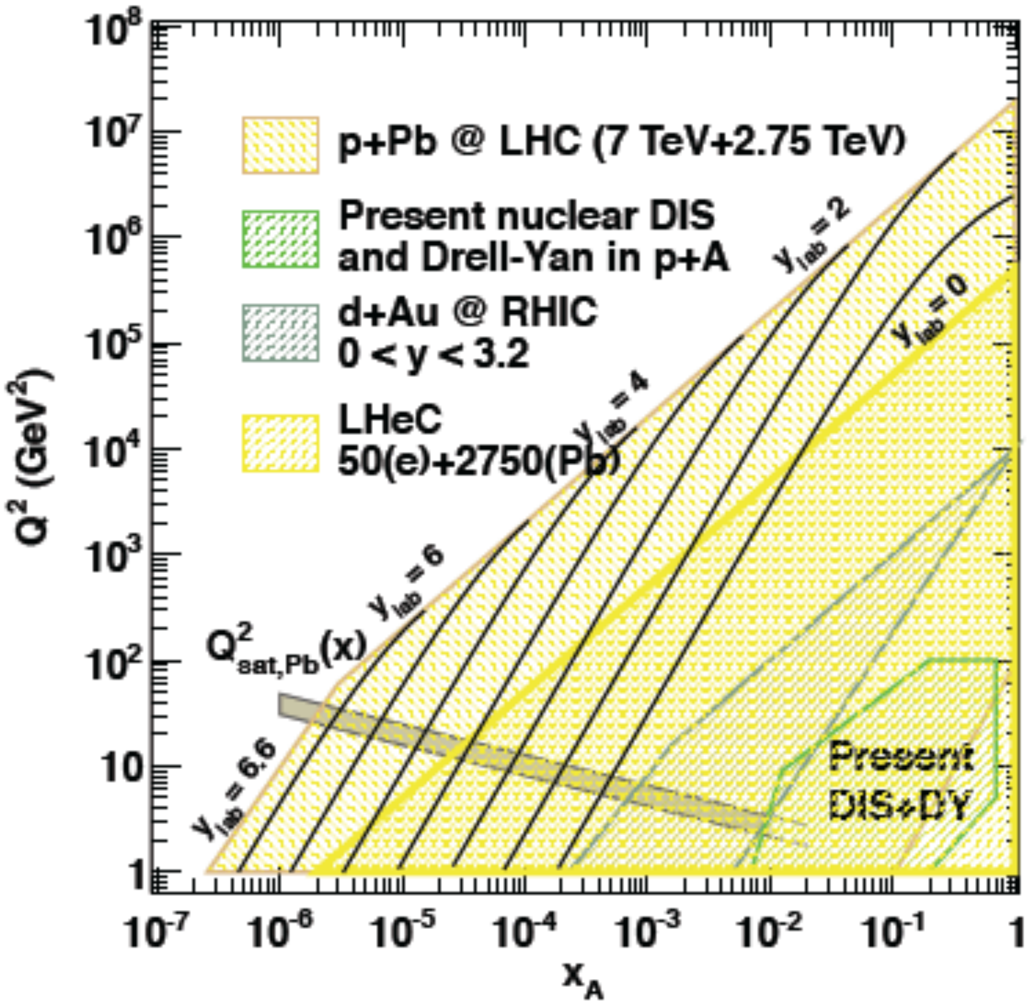
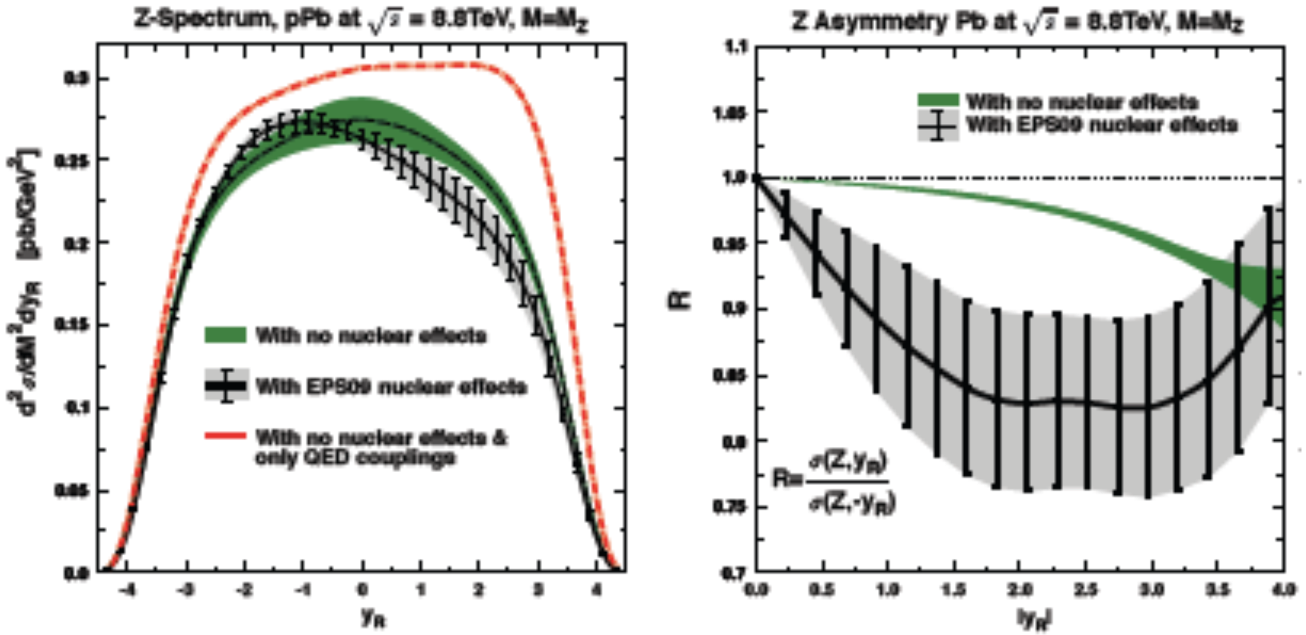


# Nuclear PDFs

Fixed target pA and RHIC dAu data already play a role in nuclear PDF determinations.

pA at LHC will give new constraints at low x




[Paukkunen, Salgado 2011]

… implementation of observables in fitting code non-trivial and uncertainties often large

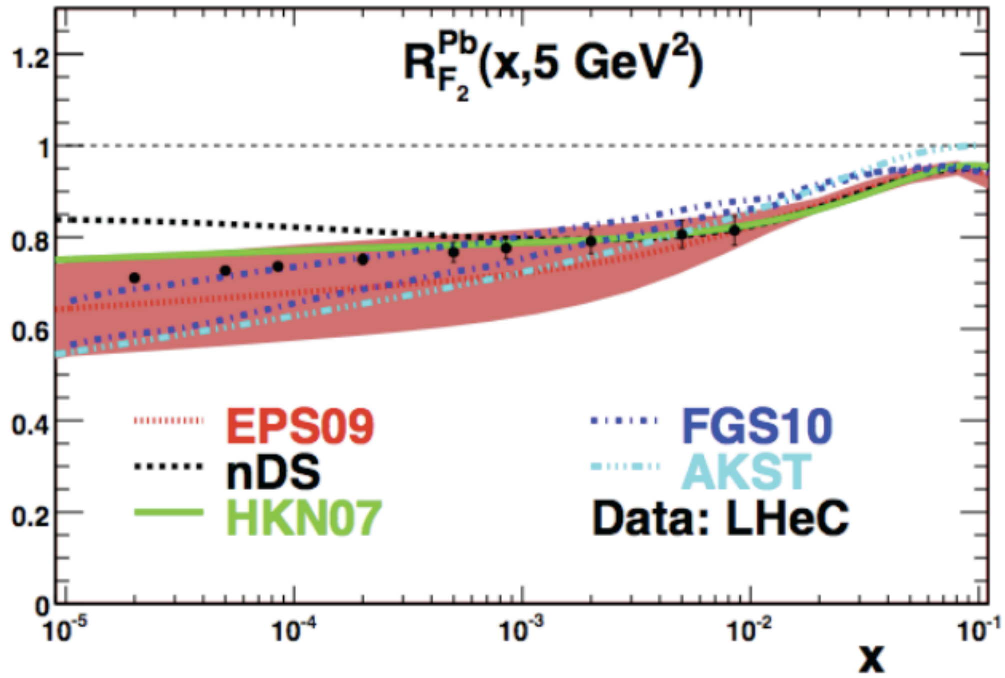
**No substitute for low x DIS data**

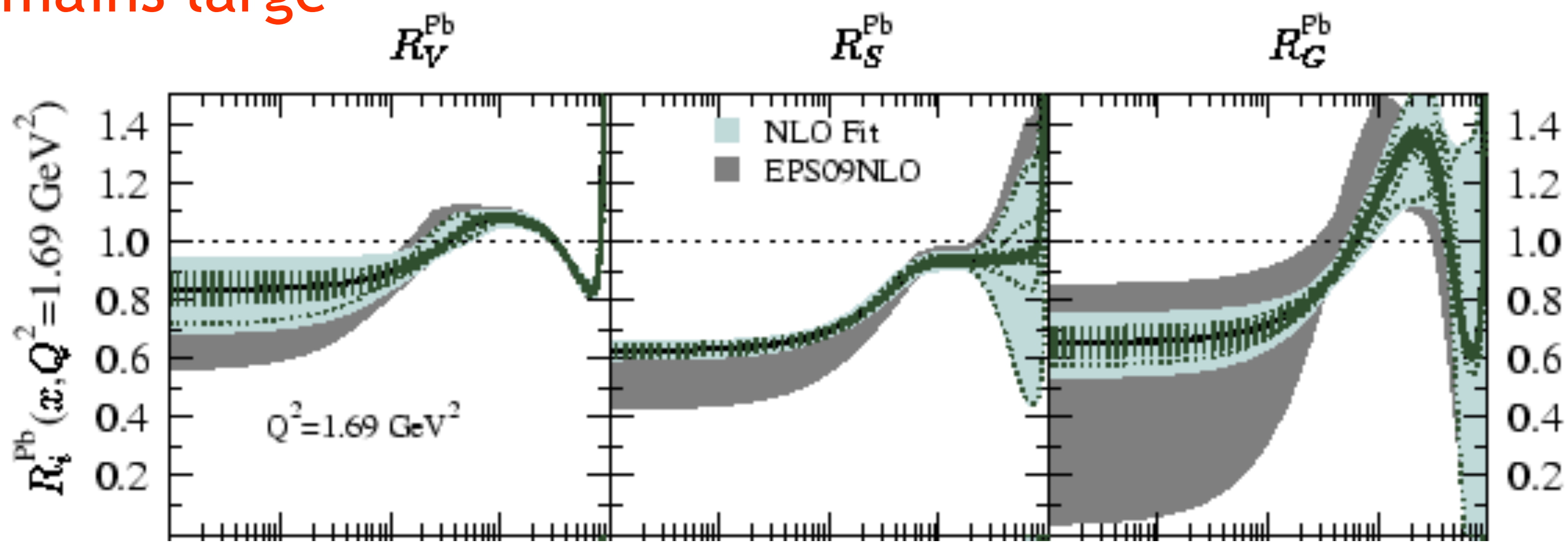
# Study of Impact of e-Pb LHC data

- LHeC ePb $F_2$ measurement has huge impact relative to current uncertainties

- Striking effect on quark sea and gluons in particular

- High x gluon uncertainty remains large



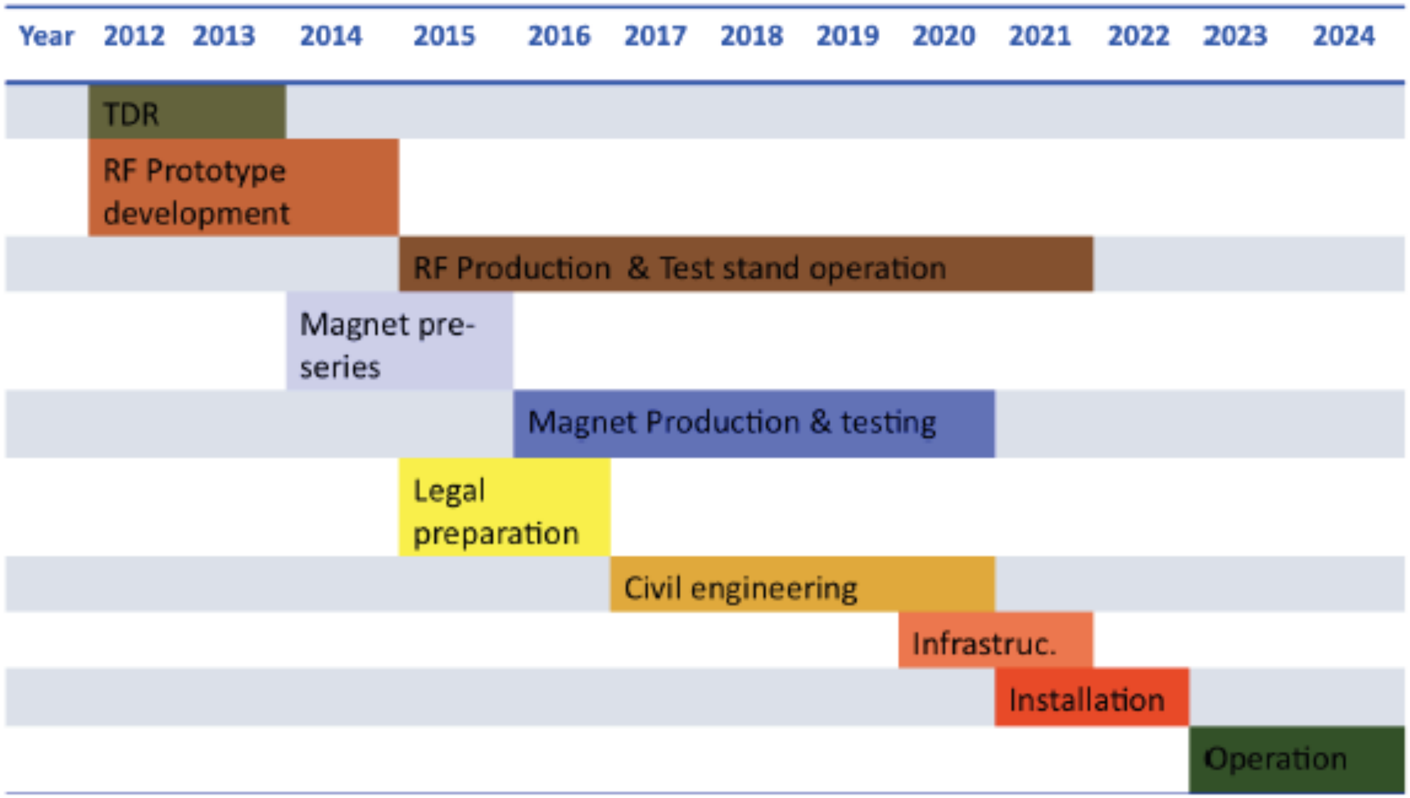



# LHeC Physics Studies I didn't cover

eD scattering
$\alpha_s$ determination and $\sin^2 \theta_W$ determinations
Beauty and charm (high $Q^2$, low x, intrinsic …)
s-sbar from charm in charged current
Jet production in DIS (with $E_T$ up to 500 GeV)
Jet photoproduction in ep and eA
Forward jets, azimuthal decorrelation between jets
$F_L$ in eA
Inclusive diffraction in ep and eA
Diffractive jet production
DVCS
Vector mesons in eA
Odderon searches
Total photoproduction cross section
Connections to ultra-high energy neutrinos
Forward $\pi^0$ production
Medium-induced soft gluon radiation

# Schedule and Remarks

- Aim to start operation by 2023 [high lumi phase of LHC]
- The major accelerator and detector technologies exist
- Cost is modest in major HEP project terms
- Steps: Conceptual Design Report, 2012
  Evaluation within CERN / European PP/NP strategy
  Move towards a TDR 2013/14



# Closing (Personal) Remarks

1) LHeC and EIC are not in competition (largely different physics, funding streams, communities). Mutual learning curves.

2) Strong interactions, QCD, low x physics, proton and nuclear structure and spin are fundamentally important topics, contain much to be discovered and new projects should be worthy of funding on breadth and precision alone

3) The LHC is a milestone in our field. It is entirely reasonable to ask what else it can do beyond pp and AA

4) We have an opportunity in around 10 years … not very long! – Serious detector R&D etc needs to start now!

Big Thanks to all speakers in our sessions...

Claudia Gemme
Thomas Peltzmann
Renaud le Gac
Joel Mousseau
Jorge Morfin
Markus Diefenthaler
Gerhard Mallot
Feng Yuan
Tom Burton
Salvatore Fazio
Dieter Mueller
Marco Stratmann

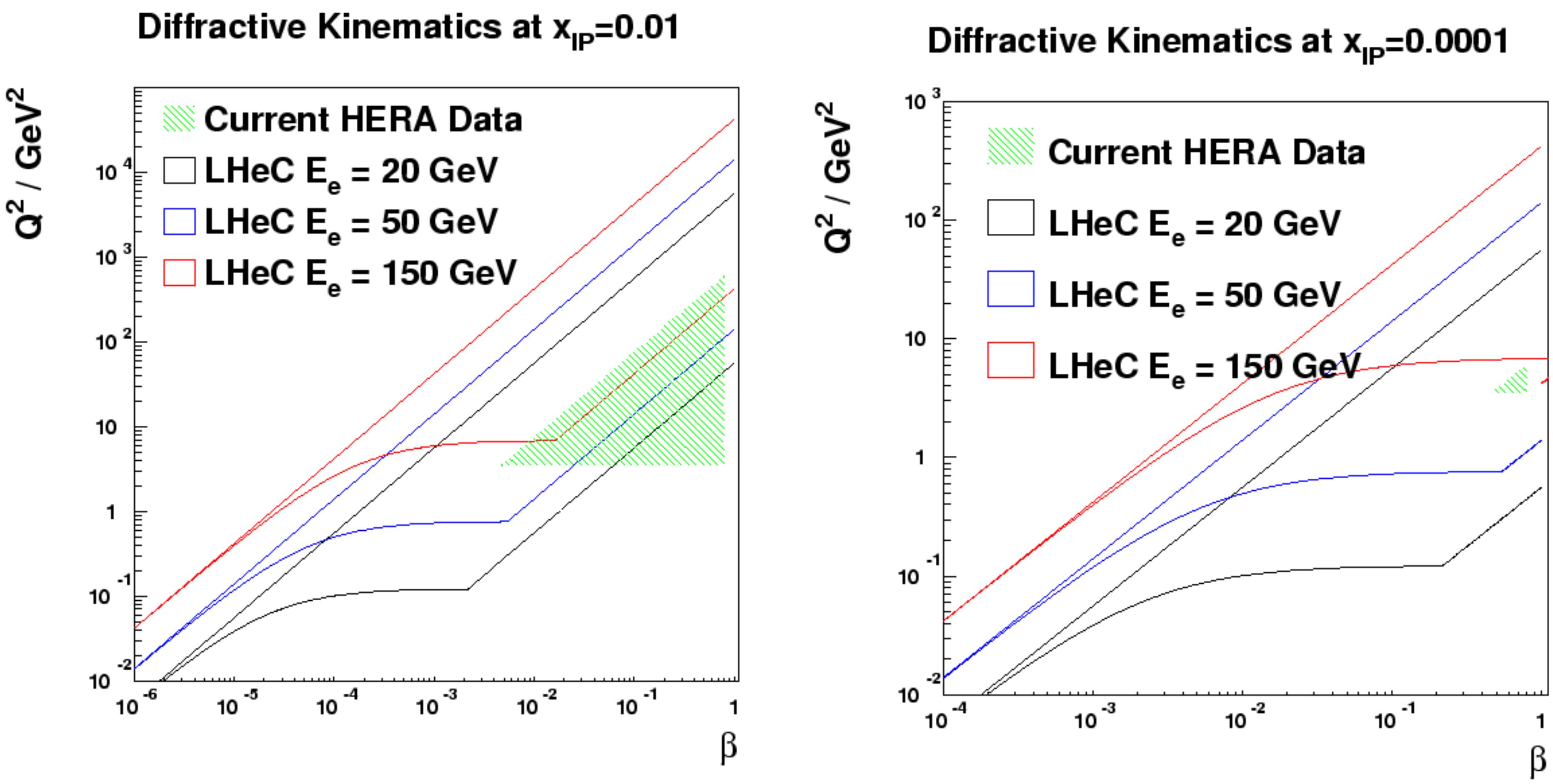
Benedikt Zihlmann
Keith Griffioen
Kalyan Allada
Kieran Boyle
Ed Nissen
Vadim Ptitsyn
Cynthia Keppel
Matthew Lamont
Armen Bunyatyan
Alessandro Polini
Rogelio Tomas
Klaus Dehmelt

Alexander Bazilevsky
Rohini Godbole
Hubert Spiesberger
Hao Ma
Carlos Salgado
Nestor Armesto
JH Lee
Daniel Schulte
Olaf Behnke
Anna Stasto

Apologies if time (or incompetence) prevented us from doing justice to your work in the summary

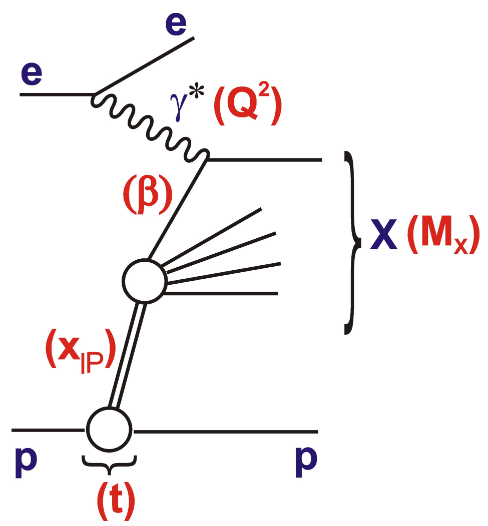
# Back-Ups Follow

# Diffractive Kinematic Plane at LHeC



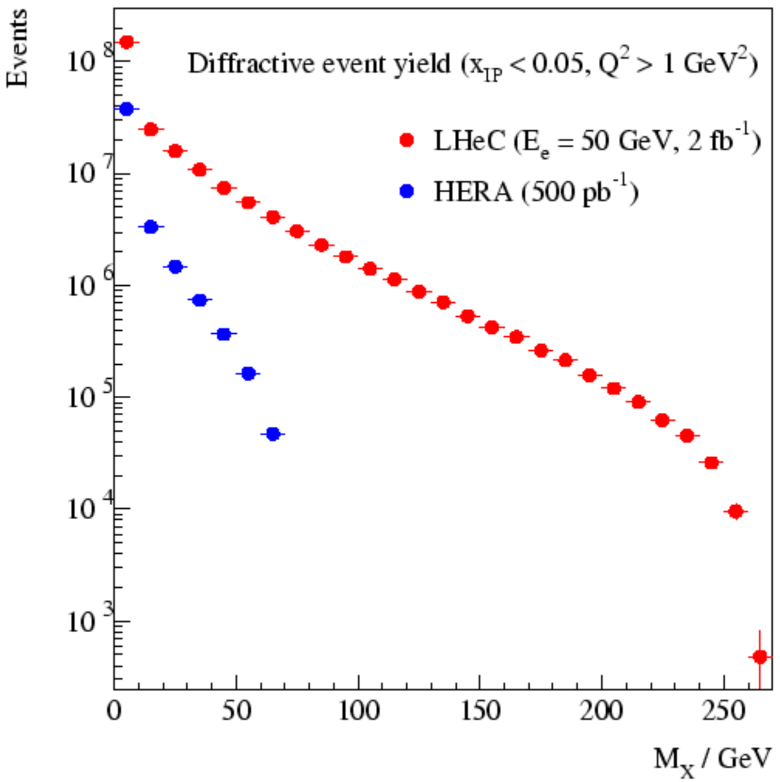

- Higher $E_e$ yields acceptance at higher $Q^2$ (pQCD), lower $x_{IP}$ (clean diffraction) and $\beta$ (low x effects)
- Similar to inclusive case, 170° acceptance kills most of plane

# Simulated Diffractive DIS Data



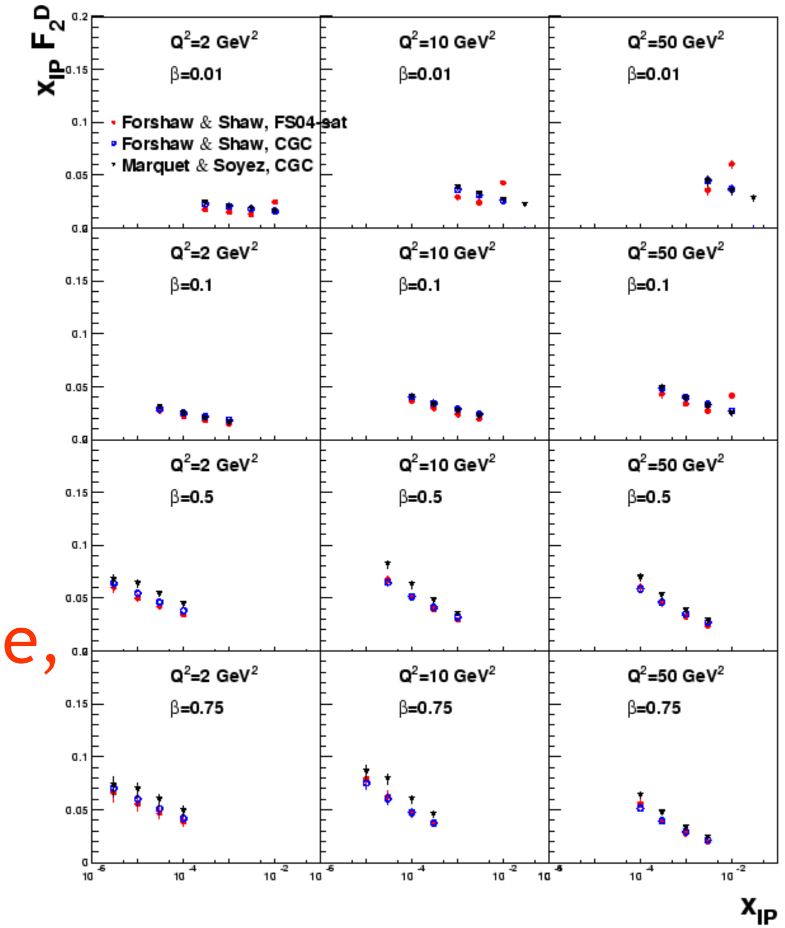

- 5-10% data, depending on detector
- DPDFs / fac'n in much bigger range
- Enhanced parton satn sensitivity?
- Exclusive production of any 1⁻ state with Mx up to ~ 250 GeV

  → X including W, Z, b, exotics?




1° acceptance, 2 fb$^{-1}$

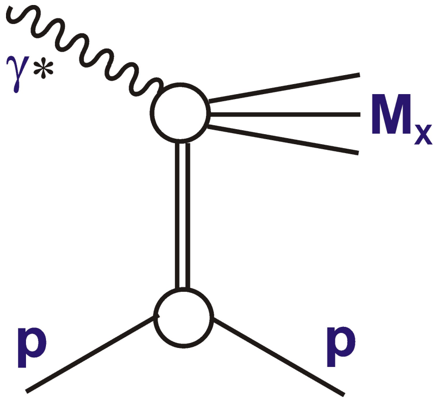
[Forshaw, Marquet, PN]

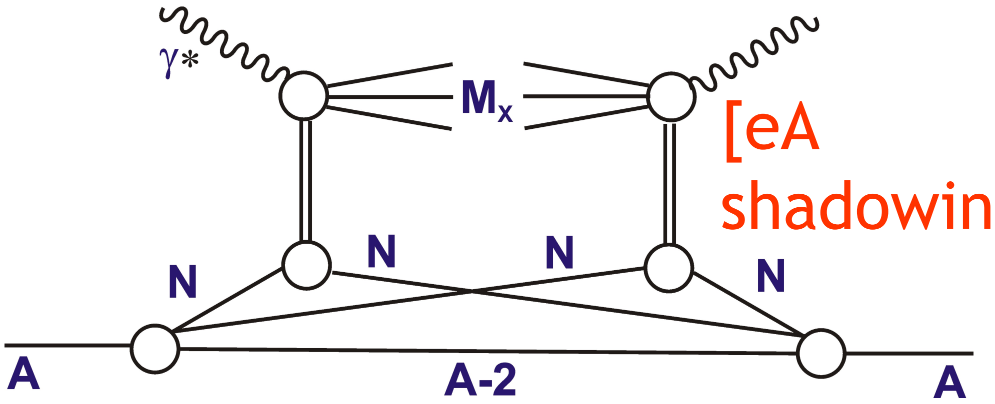


# $F_2^D$ and Nuclear Shadowing

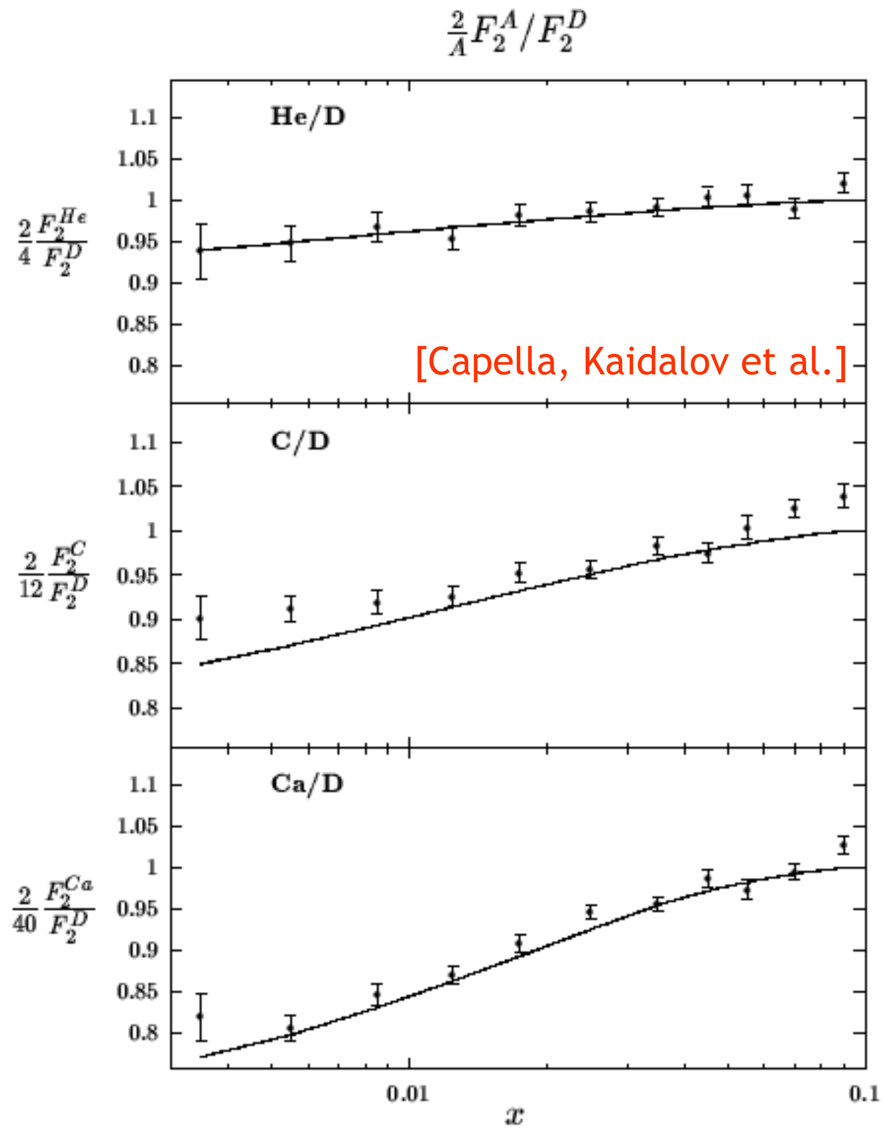
Nuclear shadowing can be described (Gribov-Glauber) as multiple interactions, starting from ep DPDFs

[Diff DIS]



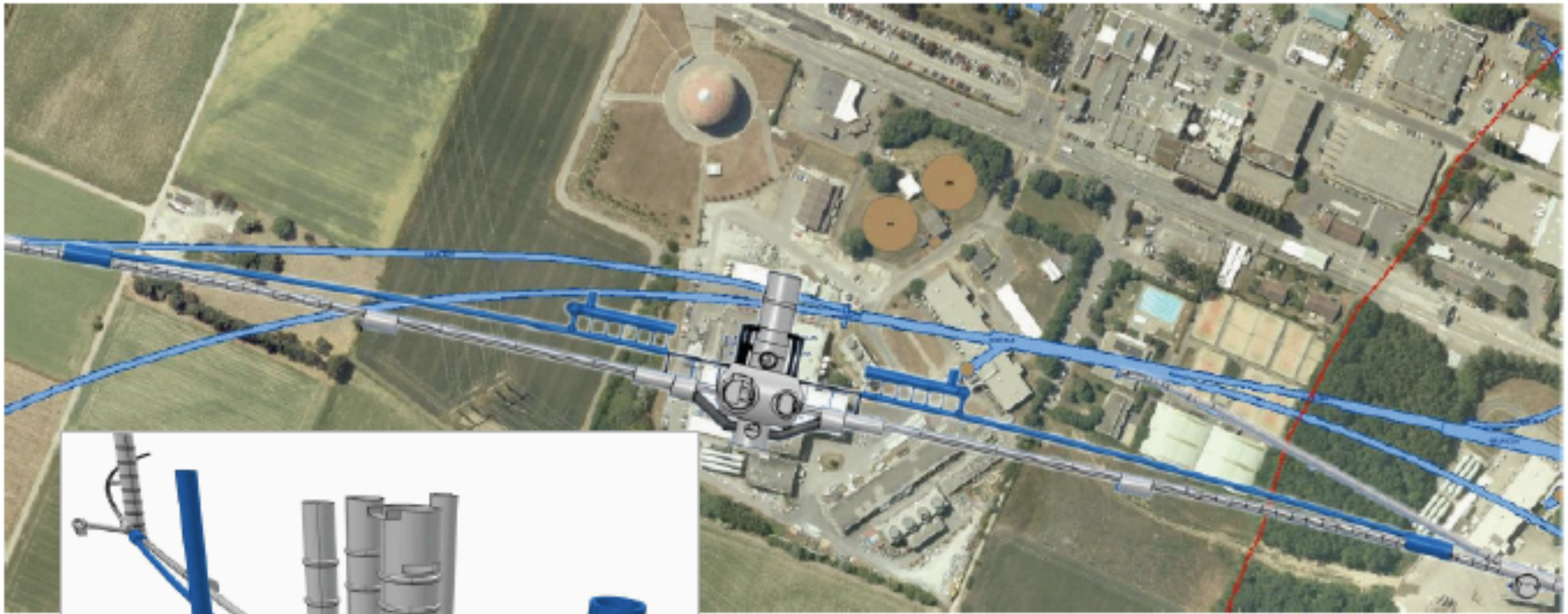




[eA shadowing]



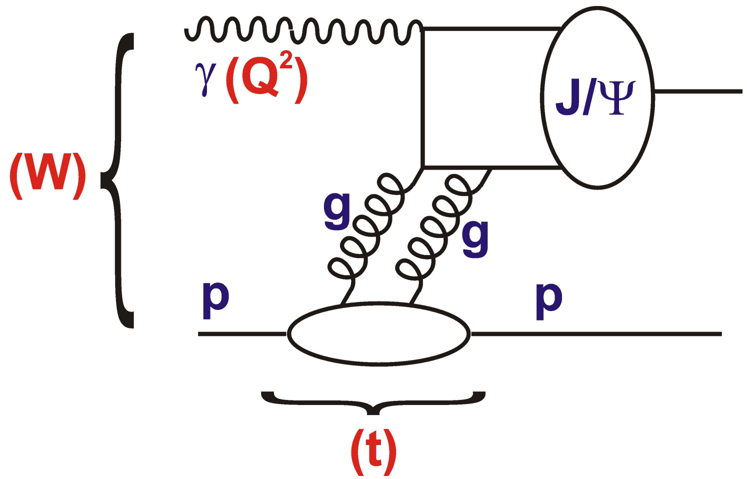

… starting point for extending precision LHeC studies into eA collisions

# Bypassing ATLAS



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

# Elastic J/Ψ Photoproduction: Golden Channel?




- \`Cleanly' interpreted as hard 2g exchange coupling to qqbar dipole … enhanced sensitivity to low x gluon

- c and c-bar share energy equally, simplifying VM wavefunction

- Clean experimental signature (just 2 leptons)

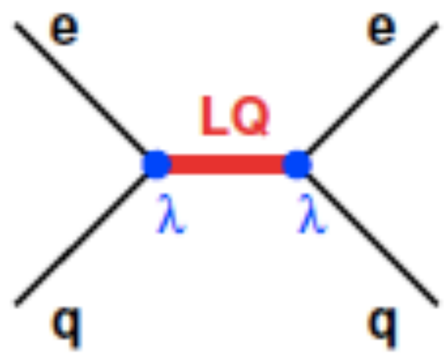
… LHeC reach extends to $x_g \sim 6.10^{-6}$ at $\overline{Q^2} \sim 3$ GeV$^2$

(MNRT etc) $X_g \sim (Q^2 + M_V{}^2) \;/\; (Q^2 + W^2)$ $\overline{Q^2} = (Q^2 + M_V{}^2) \;/\; 4$

- Simulations of elastic J/Ψ → μμ photoproduction

→ scattered electron untagged, 1° acceptance for muons (similar method to H1 and ZEUS)

# Lepton-quark Resonances



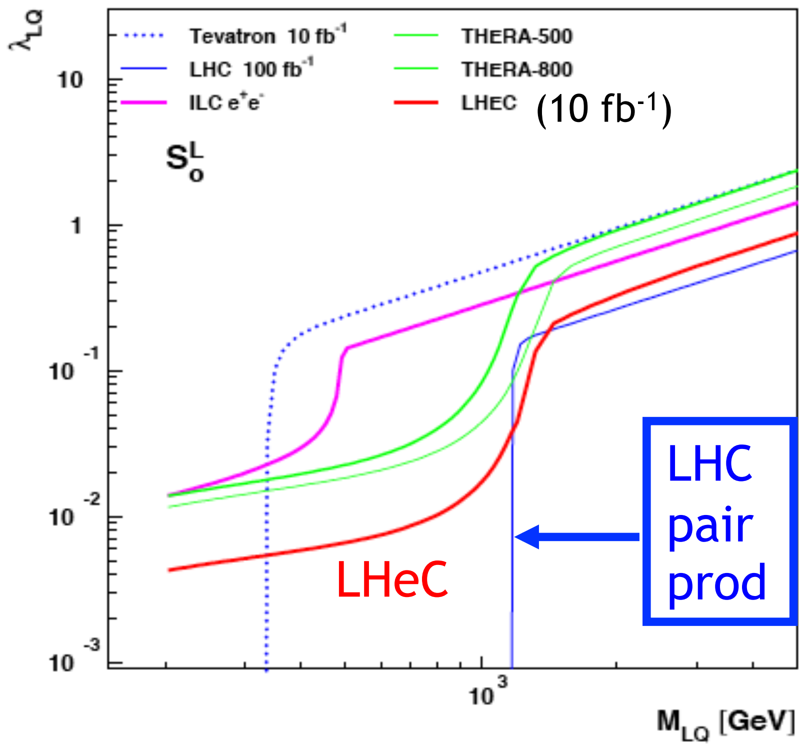

Yukawa coupling, λ

- Leptoquarks appear in many extensions to SM… (eg R-parity violating SUSY) … explain apparent symmetry between lepton and quark sectors.

- Scalar or Vector color triplet bosons Carrying L, B and fractional Q, complex spectroscopy?

- (Mostly) pair produced in pp, single production in ep.

- LHeC discovery potential for masses <1.0 - 1.5 TeV for 10 $fb^{-1}$ – Comparable to LHC, but cleaner!

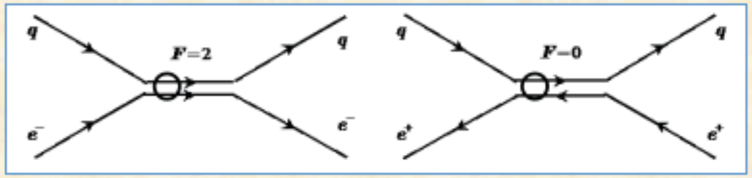


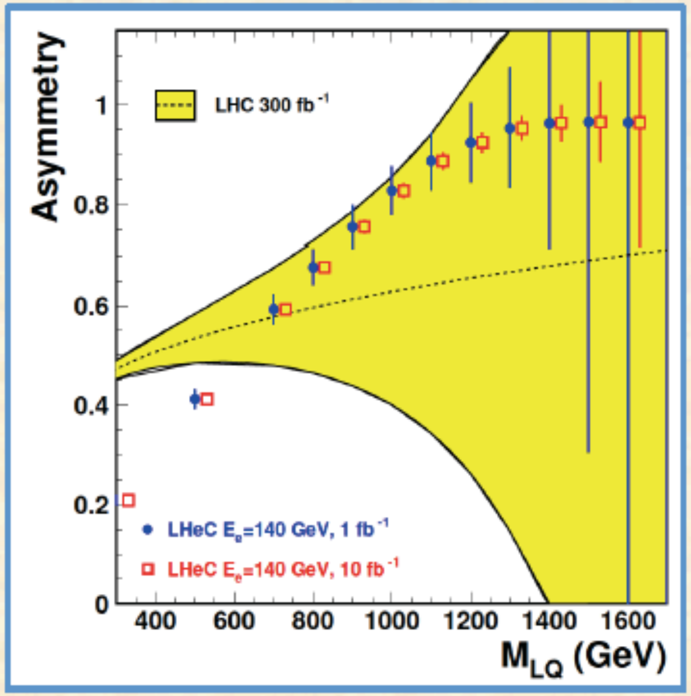
# Determining Leptoquark Quantum Numbers

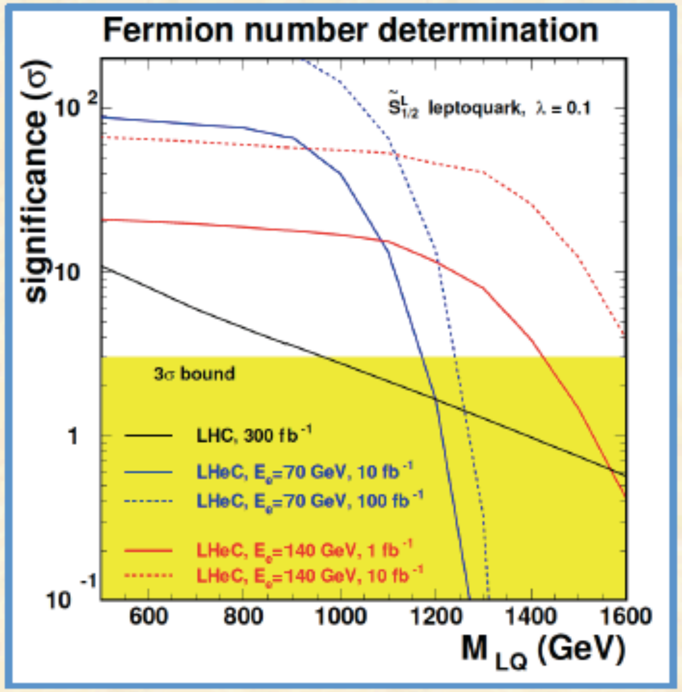
Single production gives access to quantum numbers:
- fermion number (below)
- spin (decay angular distributions)
- chiral couplings (beam lepton polarisation asymmetry)

- Fermion number *F* from asymmetry in e+/e-p cross sections
- Much cleaner accessible in DIS

$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$

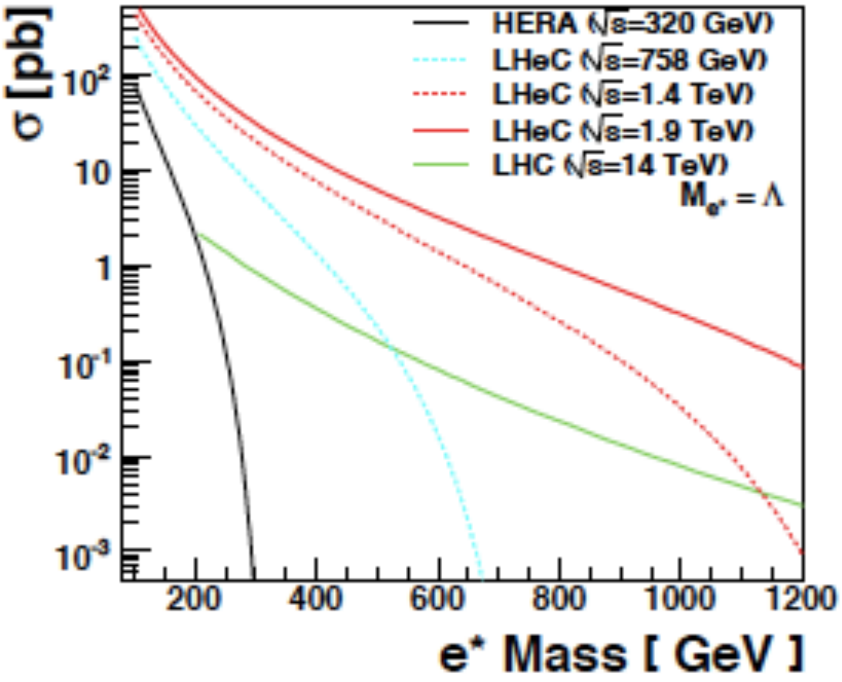


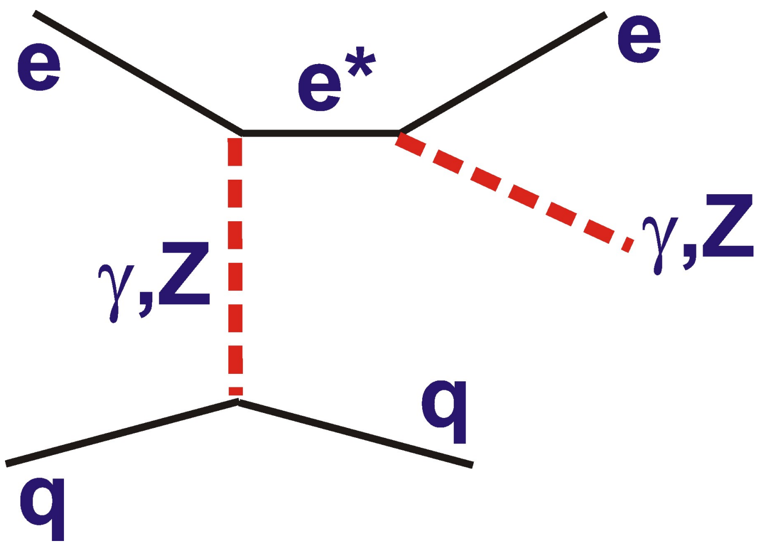

Studies for "low`` lumi assumptions for pp and ep

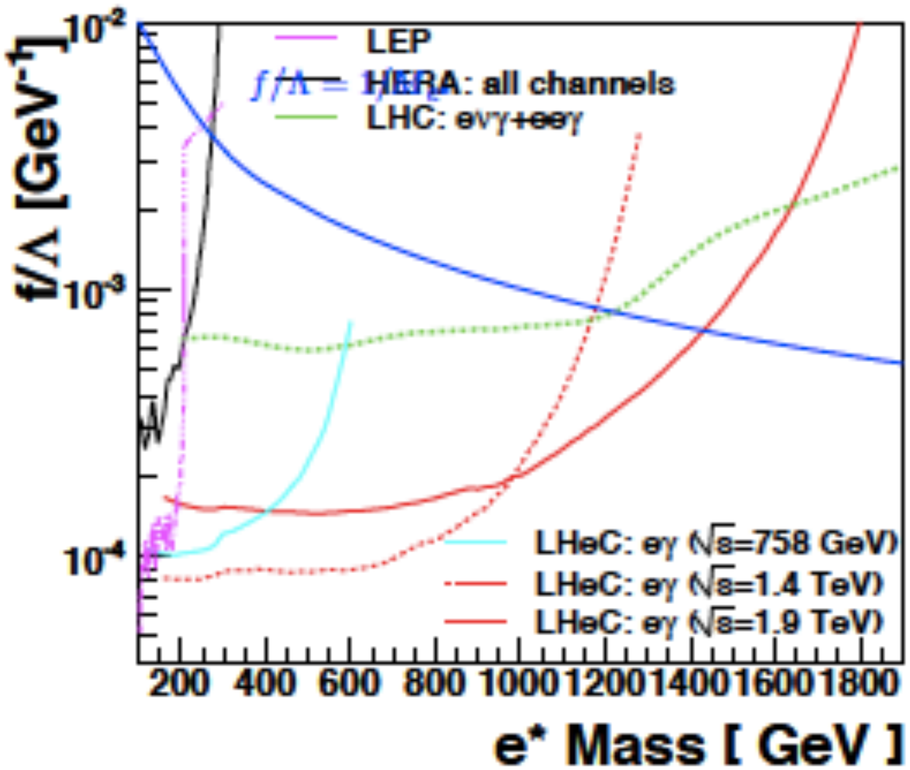
# Excited Leptons




LHeC sensitivity with 1-10 fb-1 competitive with LHC

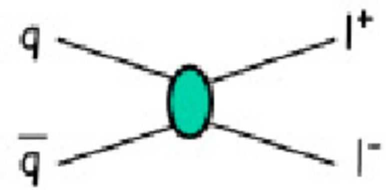
Similarly, excited neutrinos

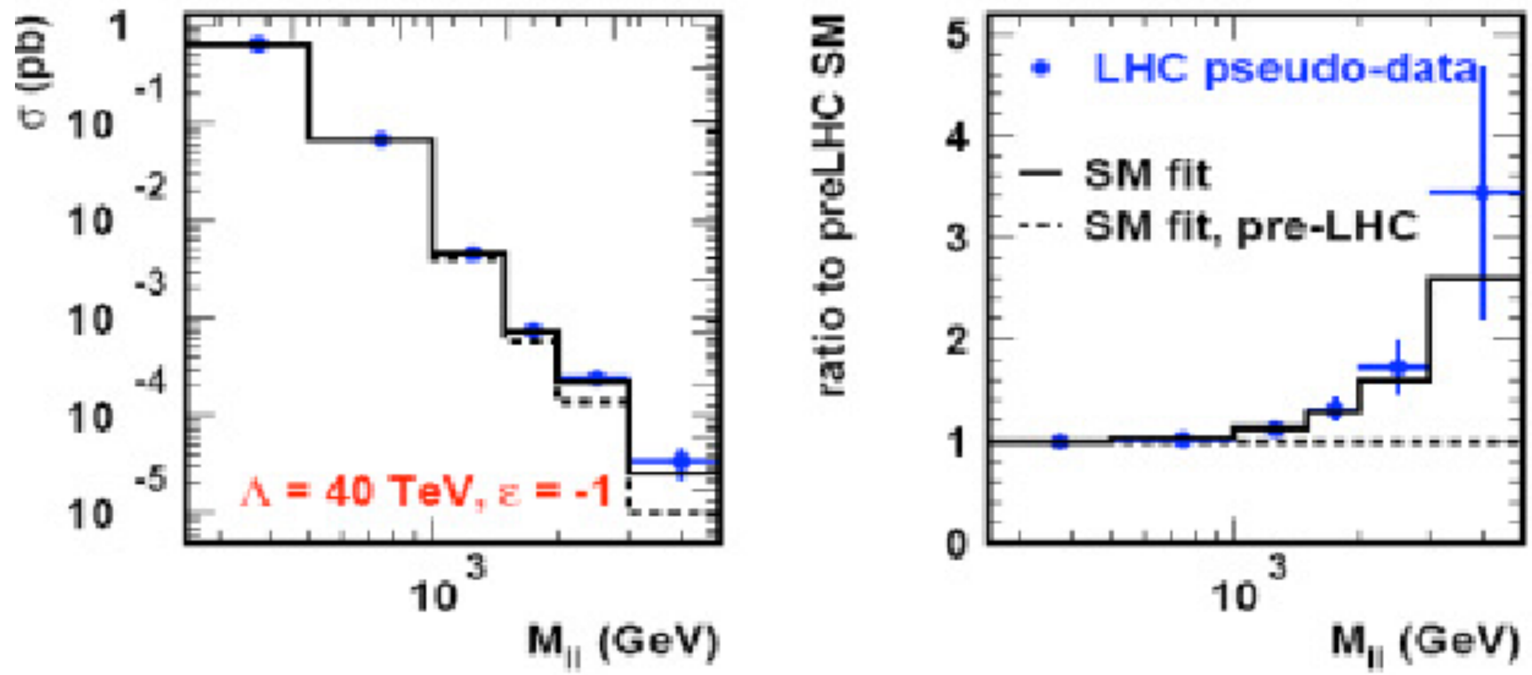


# Complementarity between LHC and LHeC

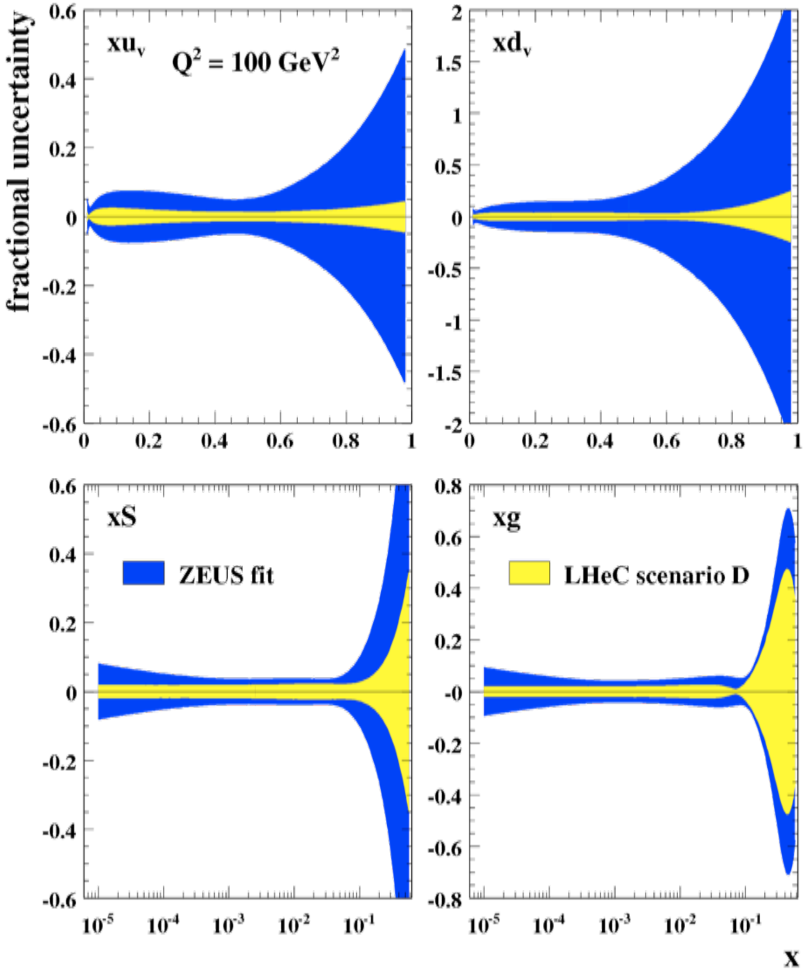
Contact interaction term introduced in LHC pseudo-data for high mass Drell-Yan

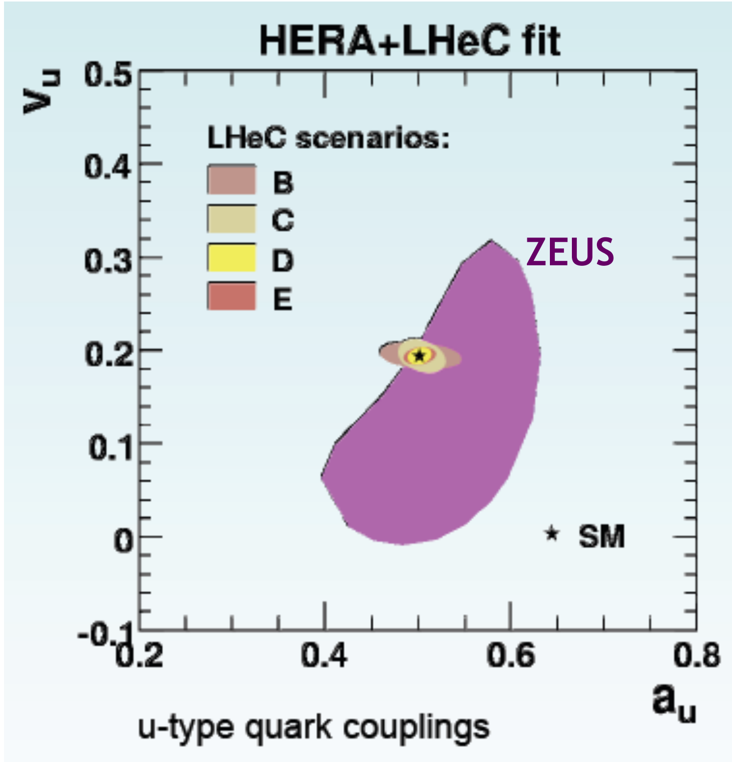


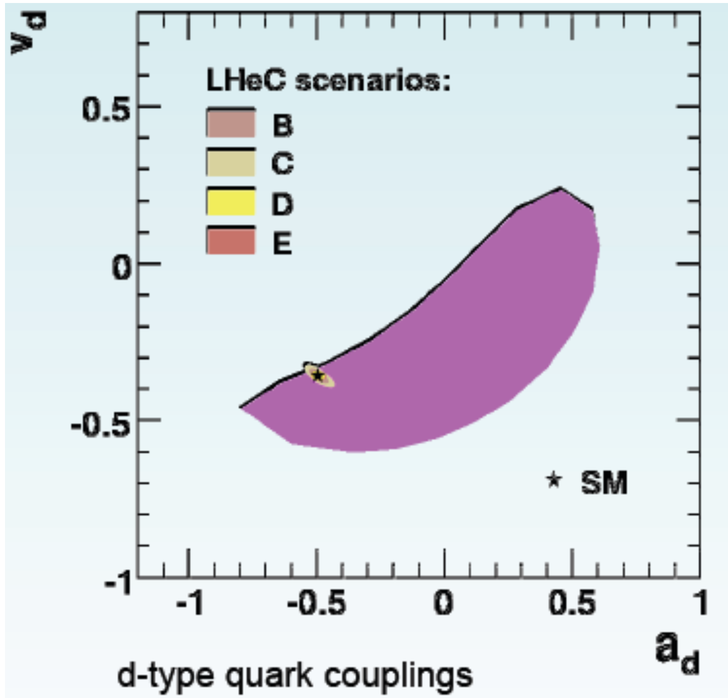




- Even if new physics looks rather different from SM, wide range of high x BSM effects can be accomodated in DGLAP fits due to poor current high x PDF constraints
- Better high x precision at high lumi LHeC could disentangle …

# PDFs & EW Couplings




Using ZEUS fitting code, HERA + LHeC data … EW couplings free

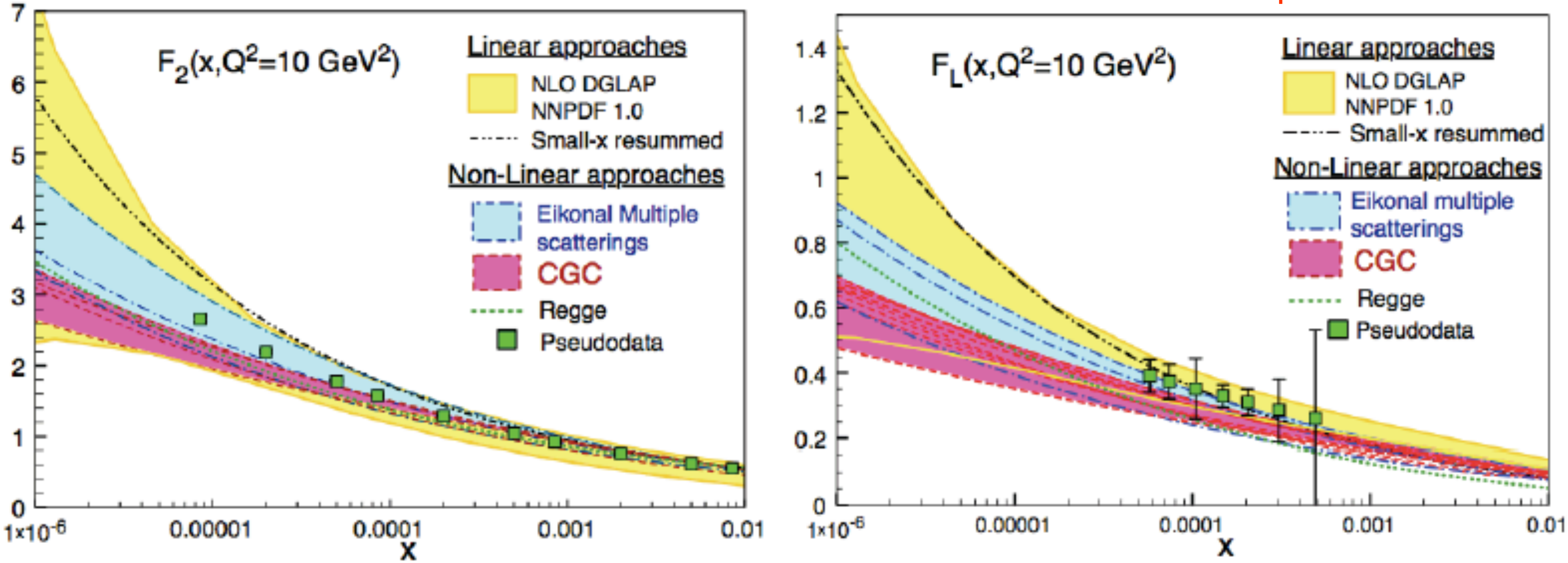
$E_e$ = 100 GeV, L = 10+5 fb$^{-1}$, P = +/- 0.9

Also: Weak mixing angle at TeV scales

# Extrapolating HERA models of $F_2$

With 1 $fb^{-1}$ (1 month at $10^{33}$ $cm^{-2}$ $s^{-1}$), $F_2$ stat. < 0.1%, syst, 1-3%

$F_L$ measurement to 8% with 1 year of varying $E_e$ or $E_p$




NLO DGLAP uncertainties explode @ low x and $Q^2$

- 'Modern' dipole models, containing saturation effects & low x behaviour derived from QCD give a much narrower range
- … we should be able to distinguish between different models for the onset of saturation effects

# Design Parameter Summary

**RR**= Ring - Ring
**LR** =Linac -Ring

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

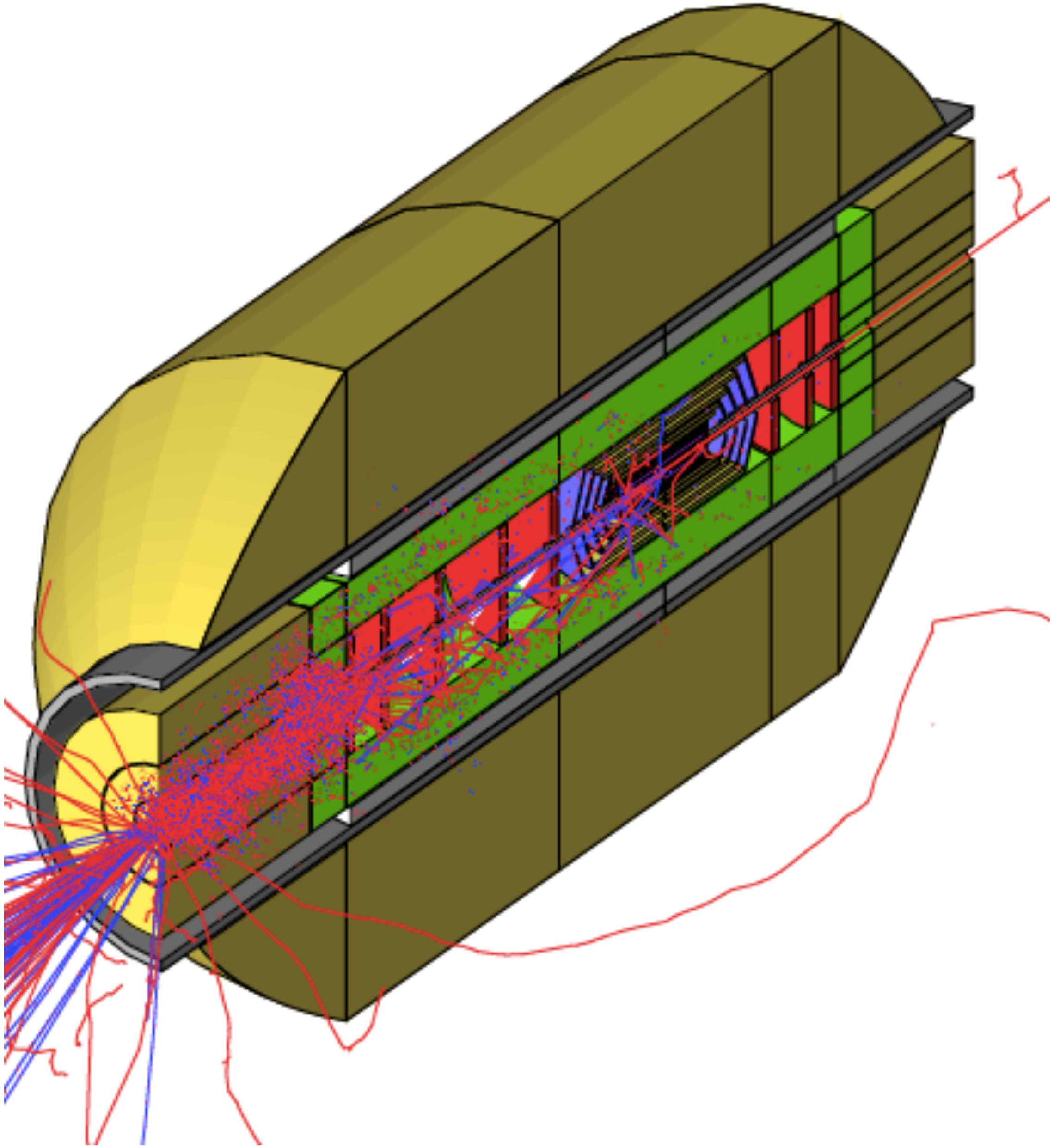
| proton beam | RR | LR |
|---|---|---|
| bunch pop. [$10^{11}$] | 1.7 | 1.7 |
| tr.emit.$\gamma\varepsilon_{x,y}$ [μm] | 3.75 | 3.75 |
| spot size $\sigma_{x,y}$ [μm] | 30, 16 | 7 |
| $\beta^*_{x,y}$ [m] | 1.8,0.5 | 0.1 |
| bunch spacing [ns] | 25 | 25 |

Include deuterons (new) and lead (exists)

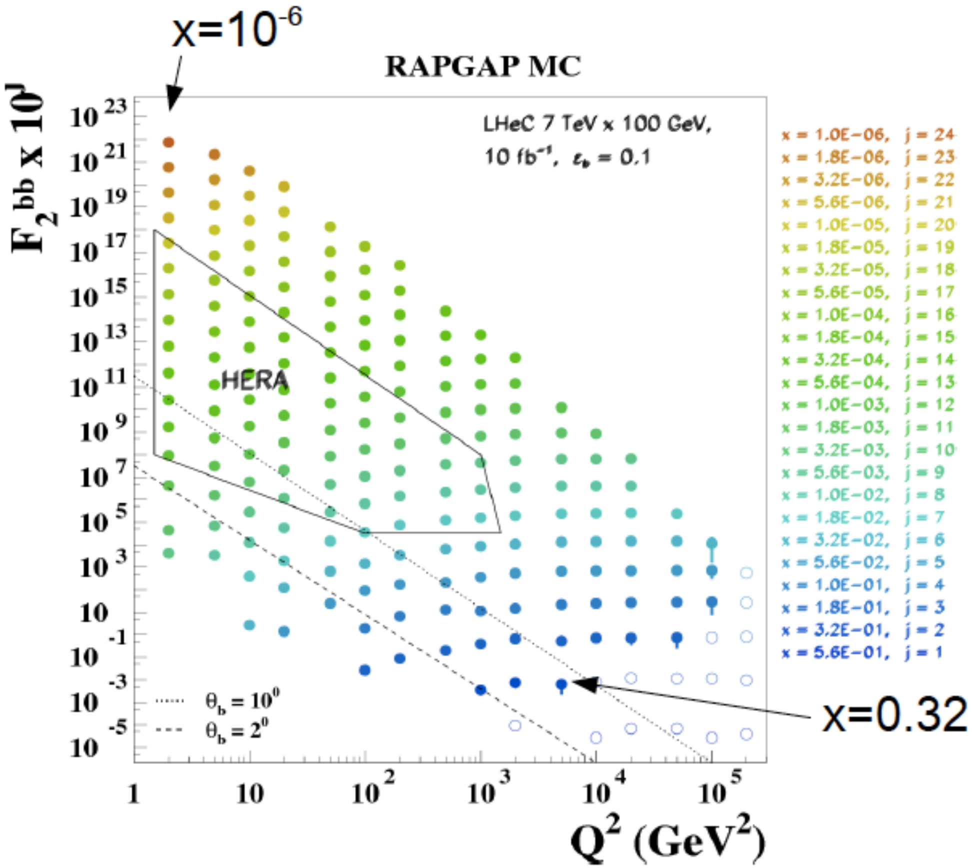
10 $fb^{-1}$ per year looks possible

… ~ 100 $fb^{-1}$ total

# A GEANT4 Simulated High x Event



# Flavour Decomposition

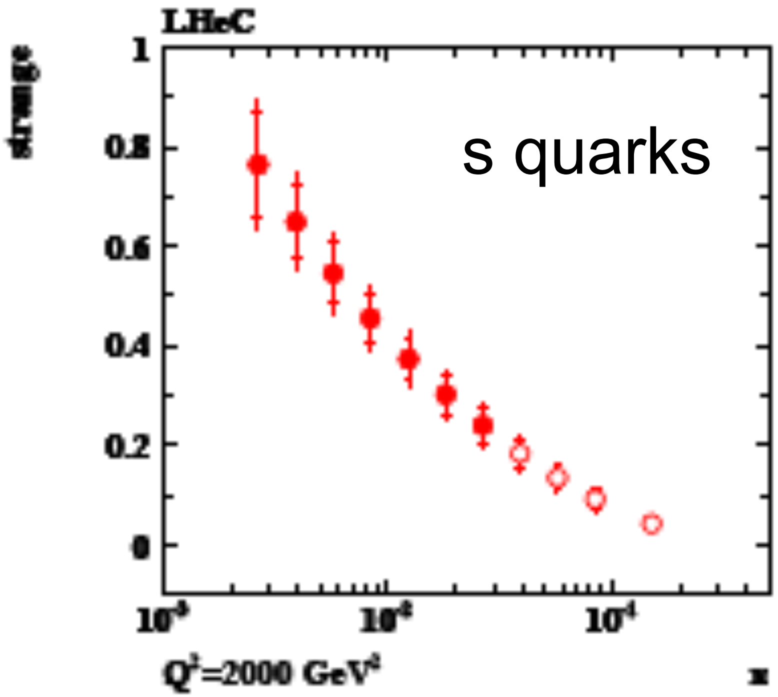



Precision c, b measurements (modern Si trackers, beam spot 15 * 35 $\mu m^2$ , increased HF rates at higher scales).

Systematics at 10% level

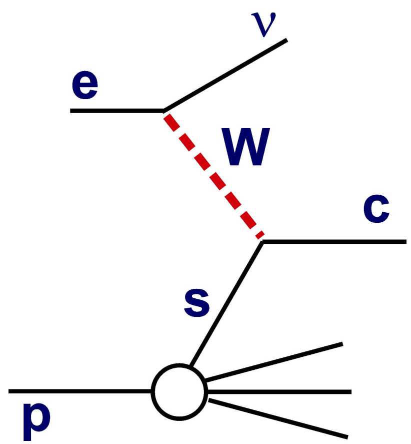
→beauty is a low x observable!

→s, sbar from charged current




● LHeC 10° acceptance

○ LHEC 1° acceptance




(Assumes 1 $fb^{-1}$ and
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag)

# IP Parameters (ERL Option)

| | protons | electrons |
|---|---|---|
| beam energy [GeV] | 7000 | 60 |
| Luminosity [$cm^{-2}s^{-1}$] | $10^{33}$ | |
| normalized emittance $\gamma\varepsilon_{x,y}$ [$\mu$m] | 3.75 | 50 |
| rms IP beam size $\sigma^*_{x,y}$ [$\mu$m] | 7 / 7 | |
| bunch spacing [ns] | 25 or 50 | 50 |
| bunch population | $1.7 \times 10^{11}$ | $2 \times 10^{9}$ |

Energy recovery efficiency = 96%
Power consumption = 100 MW
Lepton polarisation = 80-90%
Positrons tricky …

"Significant room for optimisation beyond CDR phase"