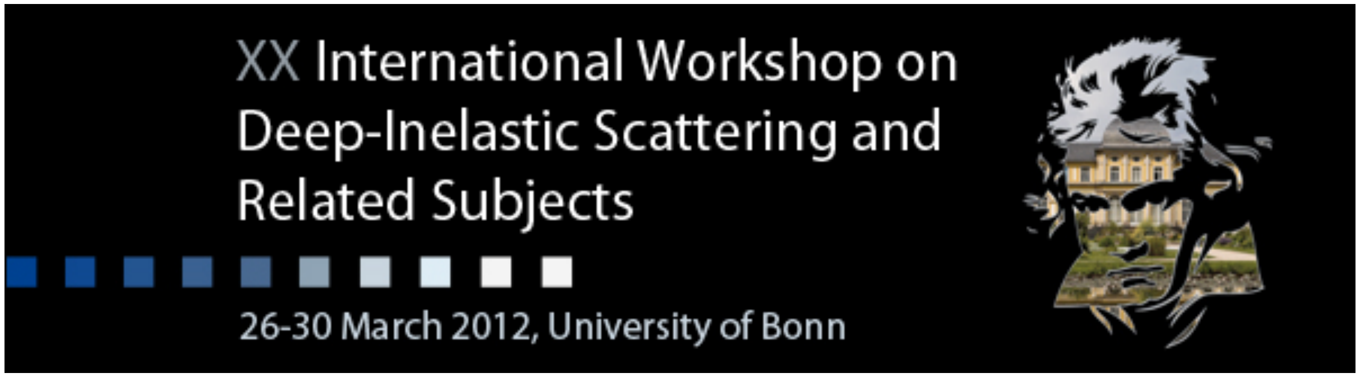
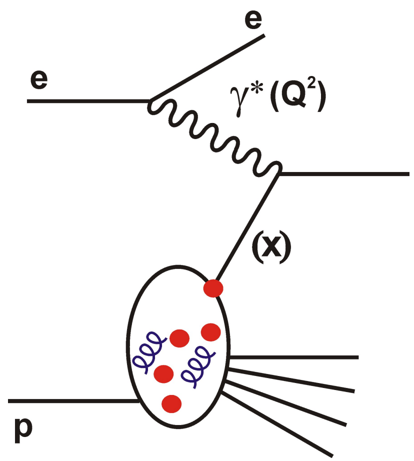
Future of DIS
Part II: "Europe"

Paul Newman
Birmingham University

Summary Talk from
DIS 2012 (Bonn)

Fri 30 March 2012





... or to be more precise ...

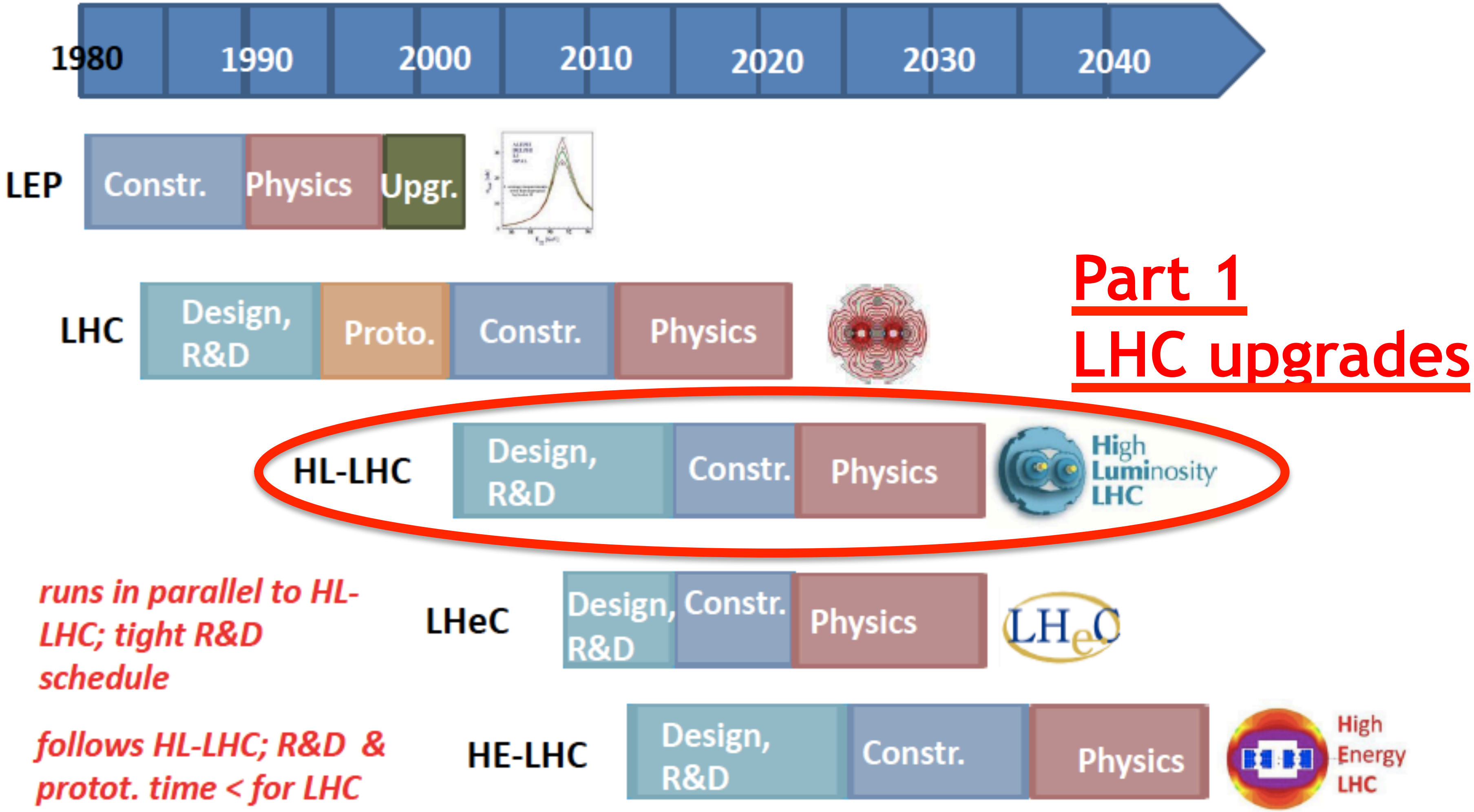
The Large Hadron Collider
VS
The Future

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

CMS

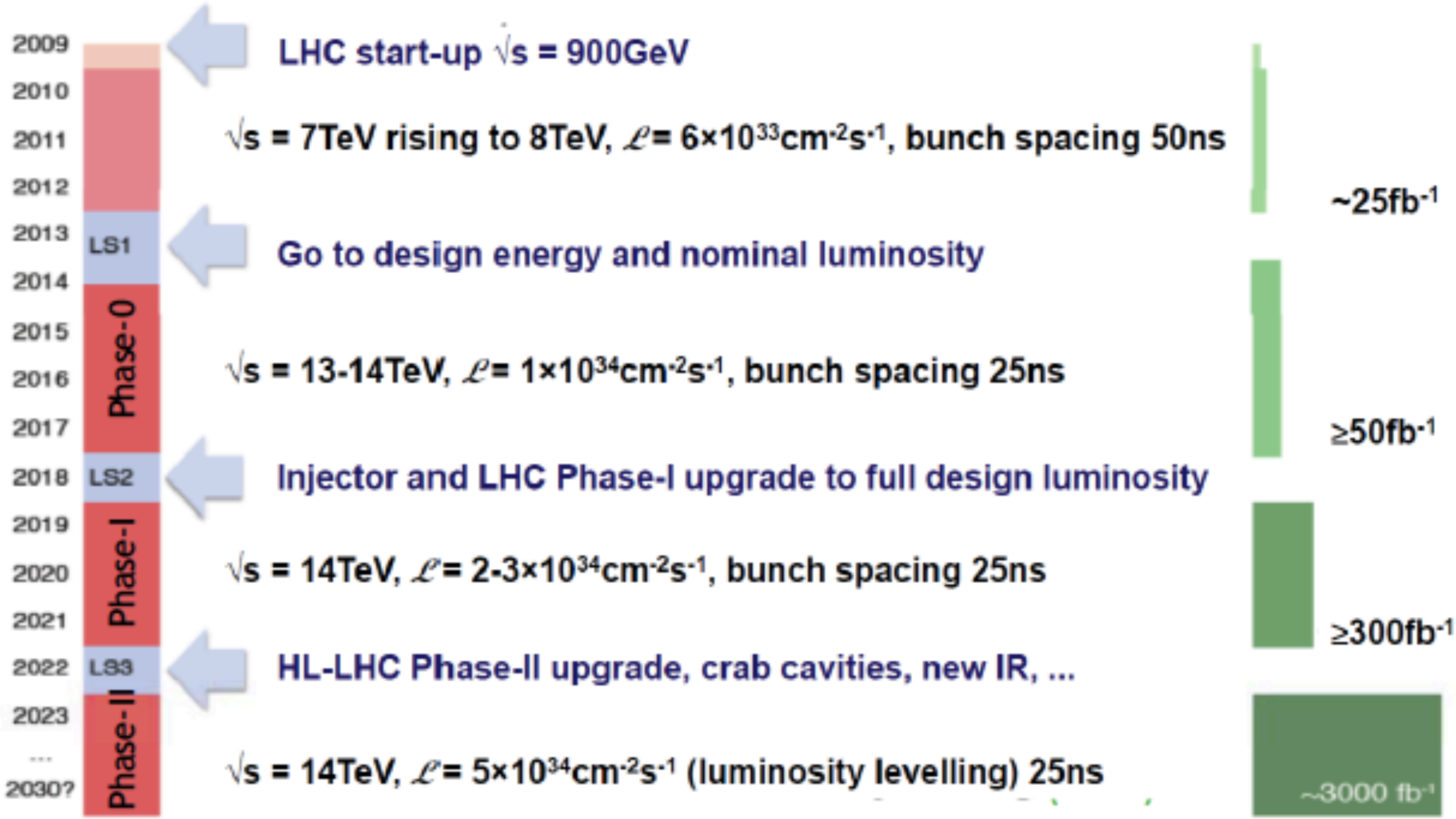
Compact Muon Solenoid

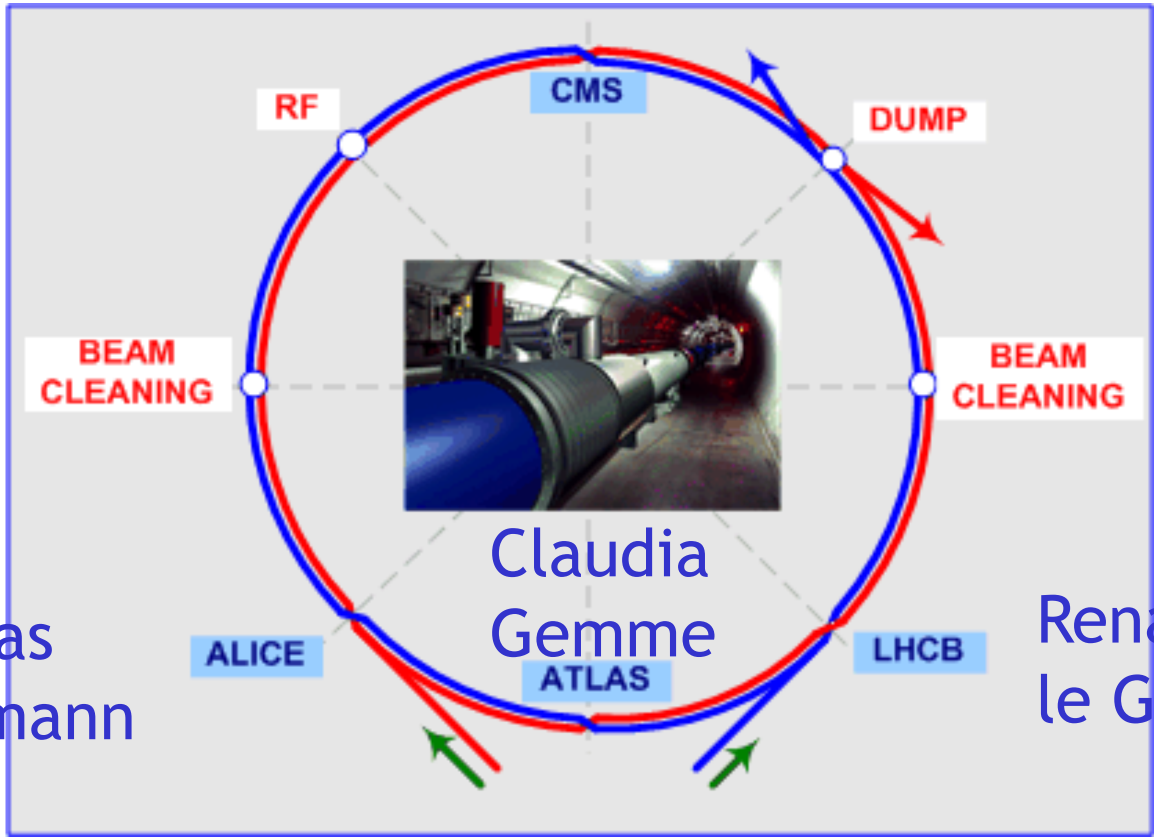
time line of CERN HEP projects



2012 Chamonix LHC Performance workshop summary (Rossi)

LHC Schedule





Claudia Gemme

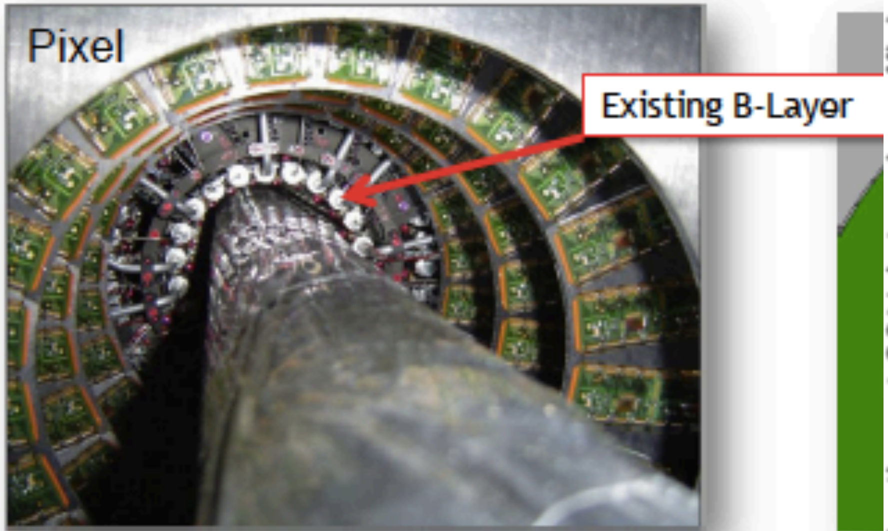
Thomas Peitzmann

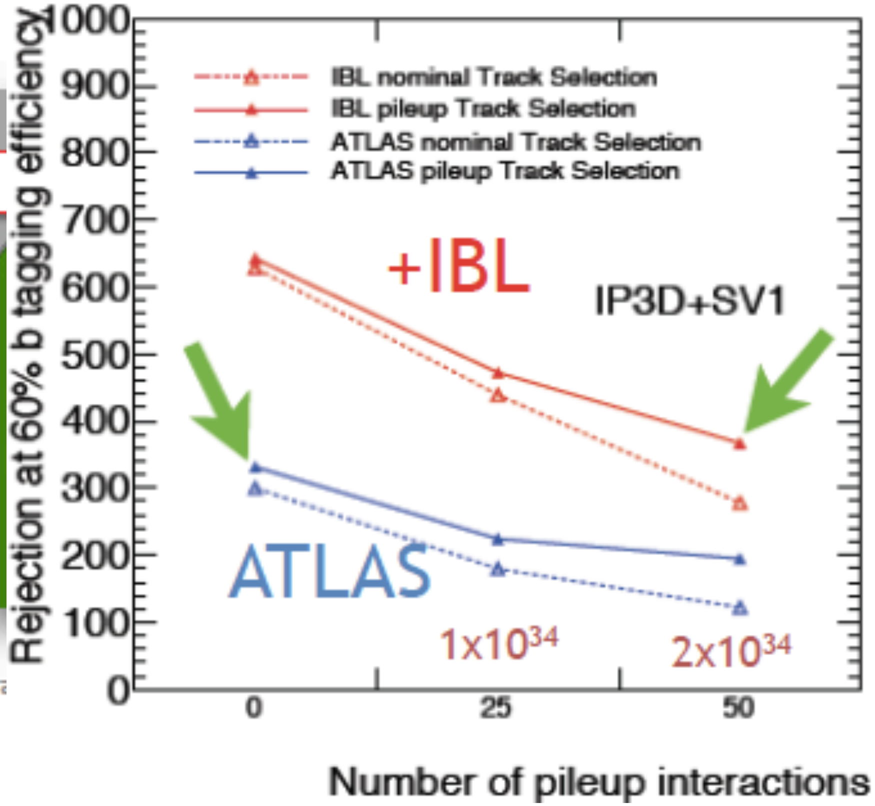
Renaud le Gac

- 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 2×10^{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
  - $<r_{sens}>$ = 33 mm vs present 50.5 mm→ smaller beam pipe radius (29→ 25 mm).





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.

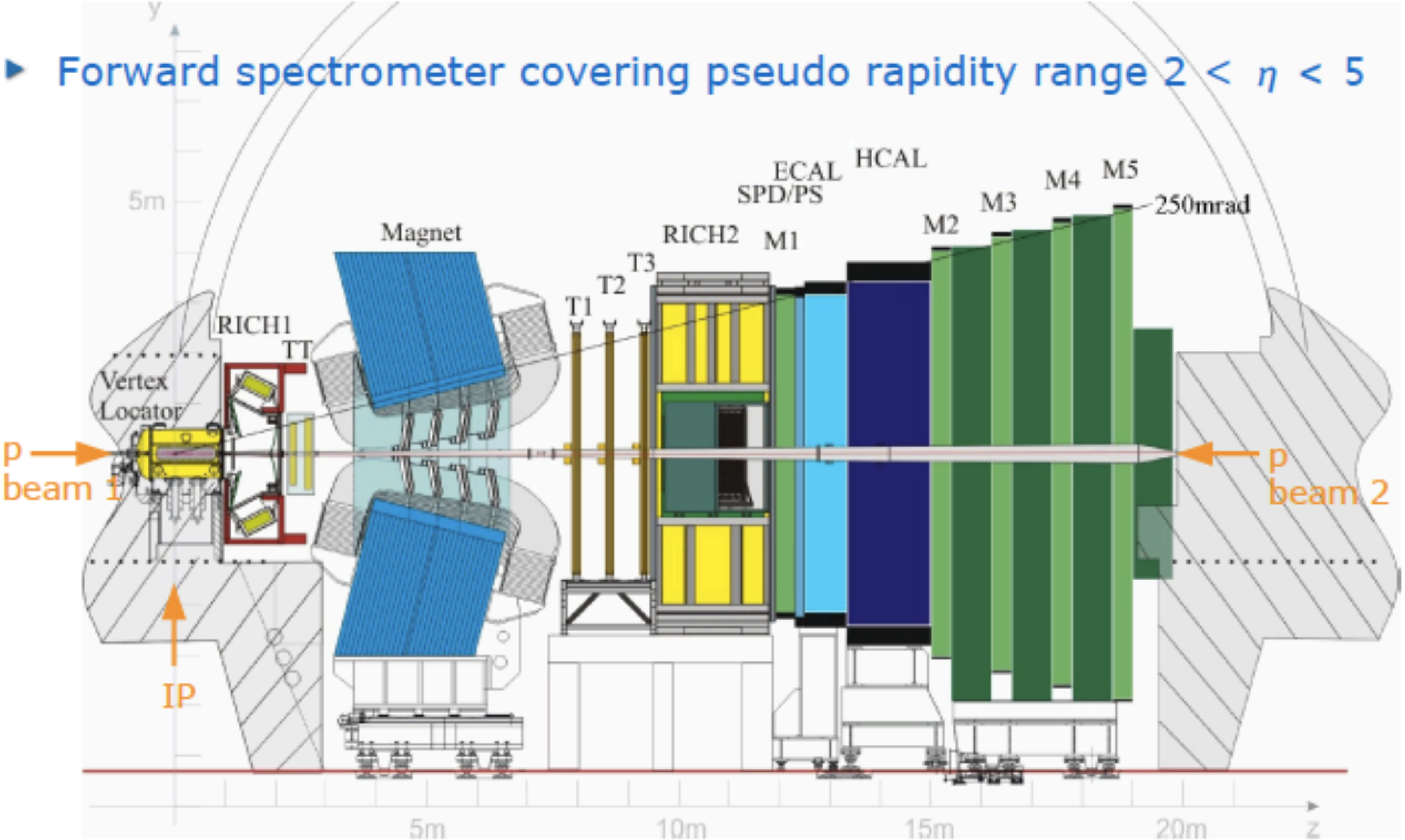
✓ ATLAS: Challenge of peak luminosity exceeding design luminosity

- 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 $2 < \eta < 5$

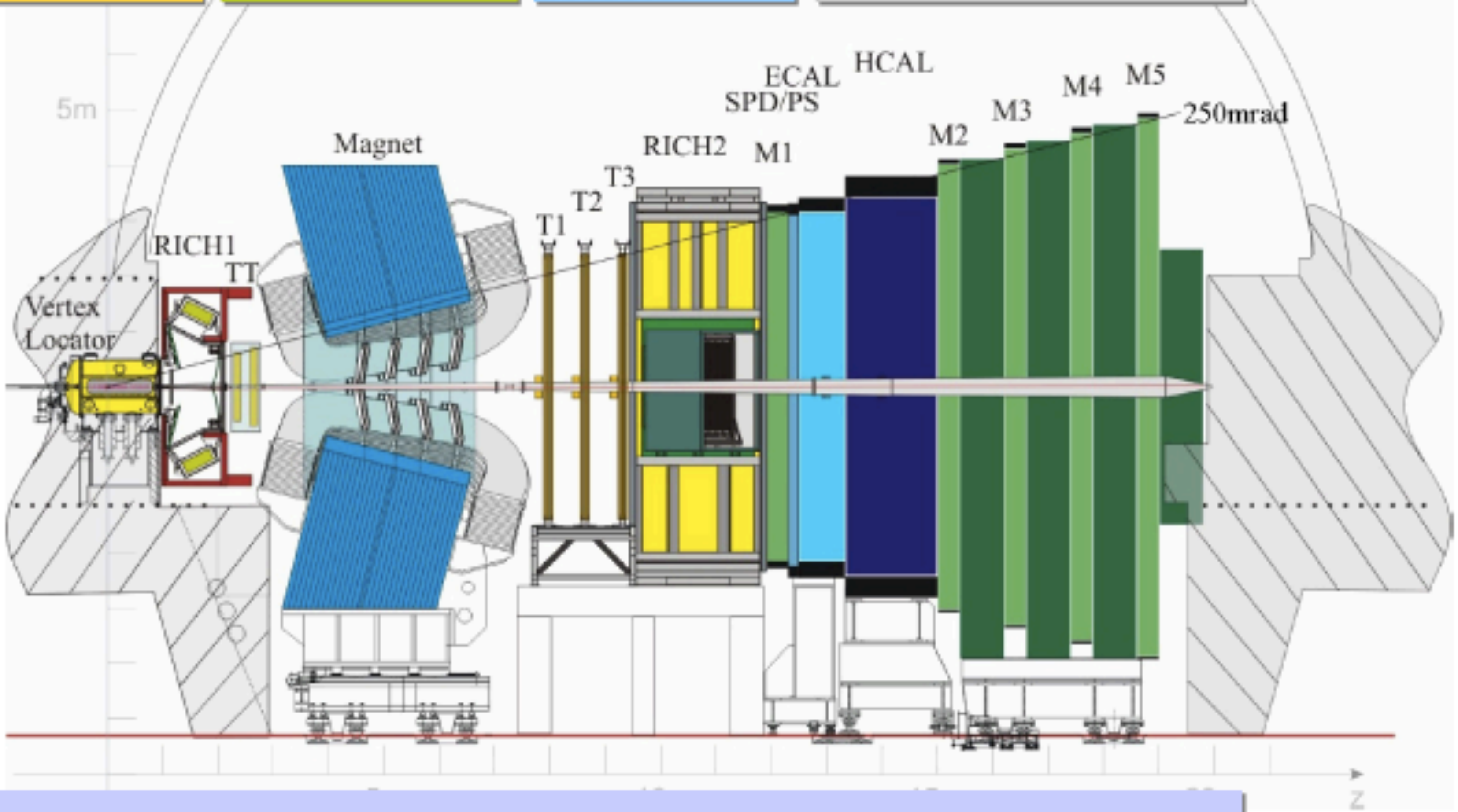


<u>More details:</u> The LHCb detector at LHC, JINST **3** (2008) S08005

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

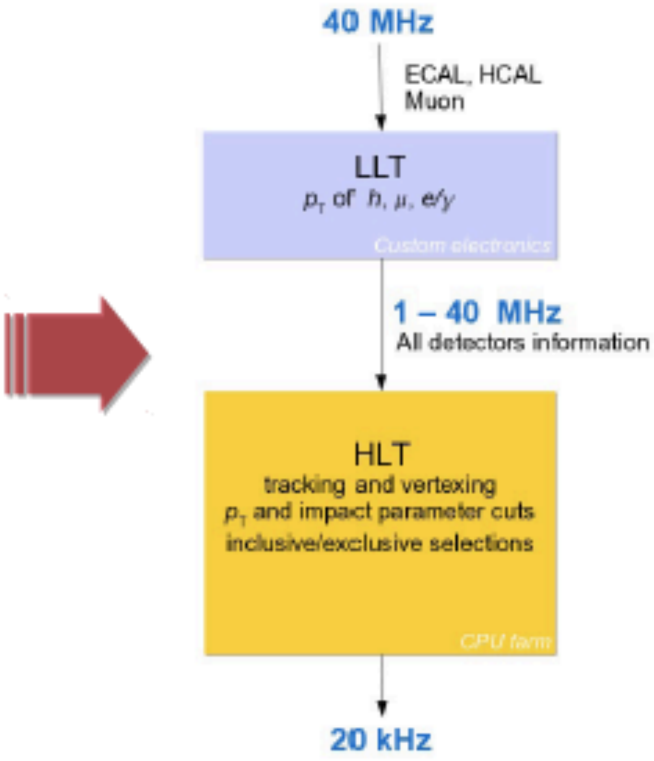


Replace all the front-end electronics + DAQ network

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

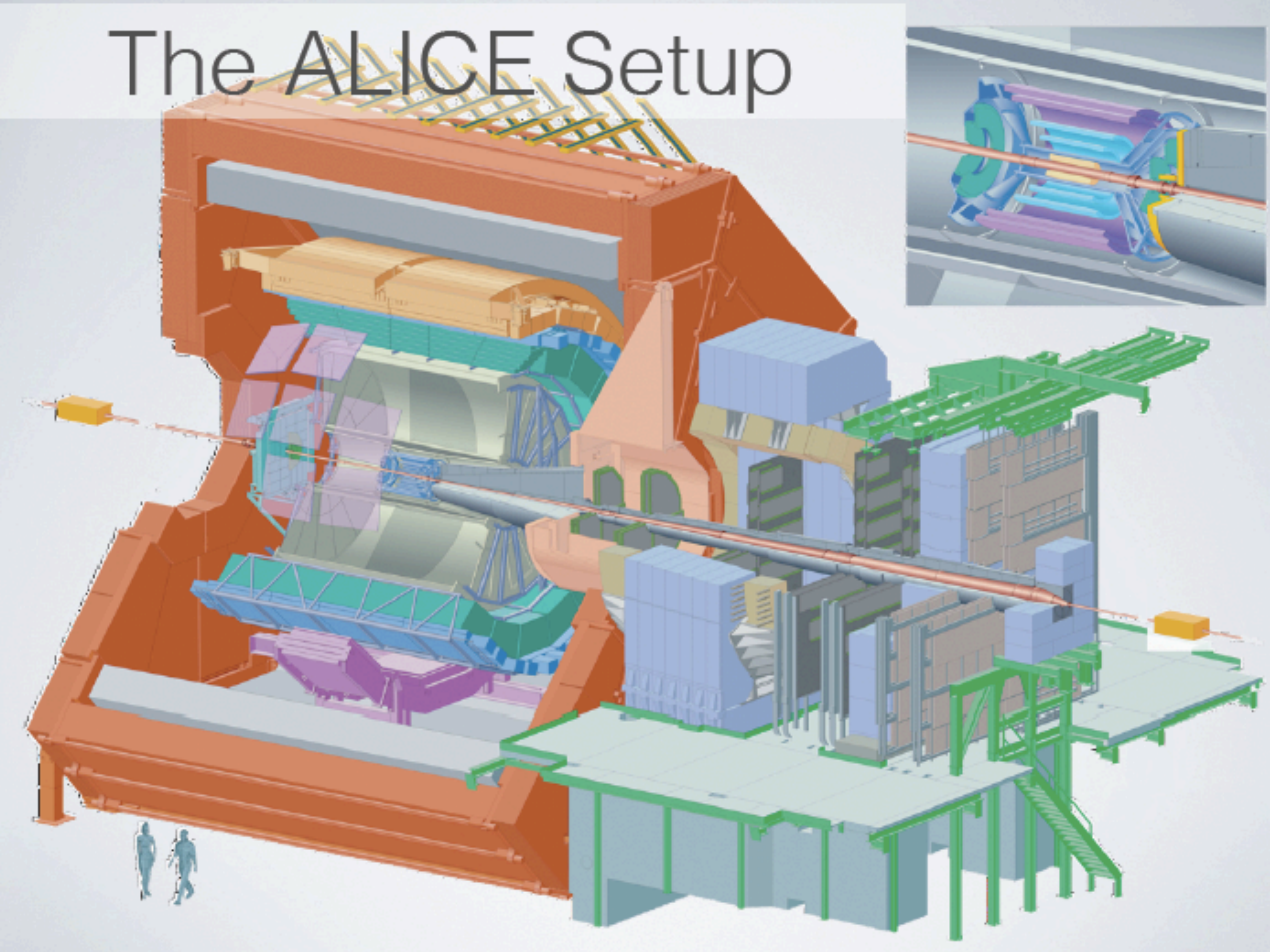
LLT efficiencies

- 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

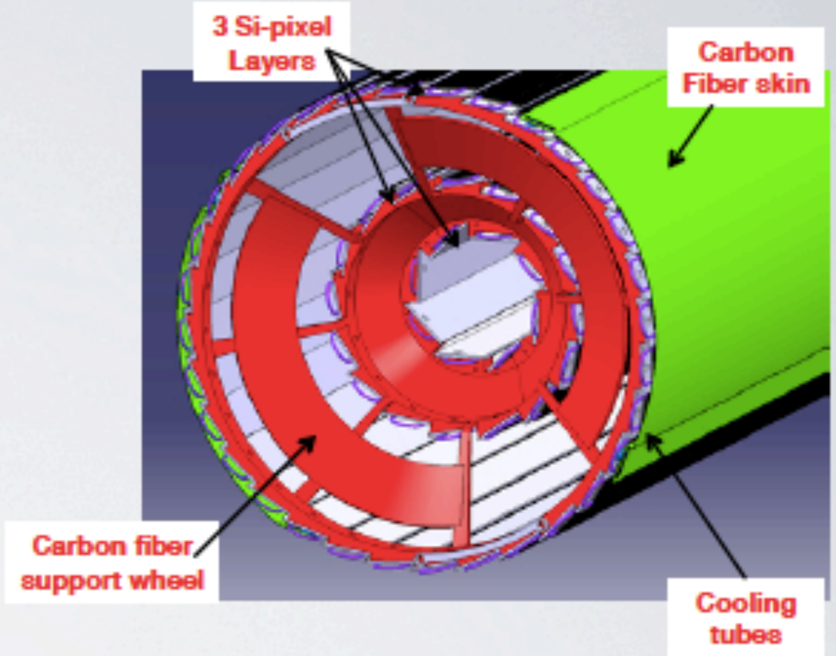
- advanced probes are rare, but essentially "untriggerable"
  - rare low momentum signals
- current experimental setup is rate-limited
  - e.g. intrinsic limit of current TPC (gated operation)
- basic strategy:
  - enhance rate capabilities (50kHz Pb+Pb, ≈2MHz p+p)
    - upgrade TPC (GEMs), readout of 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

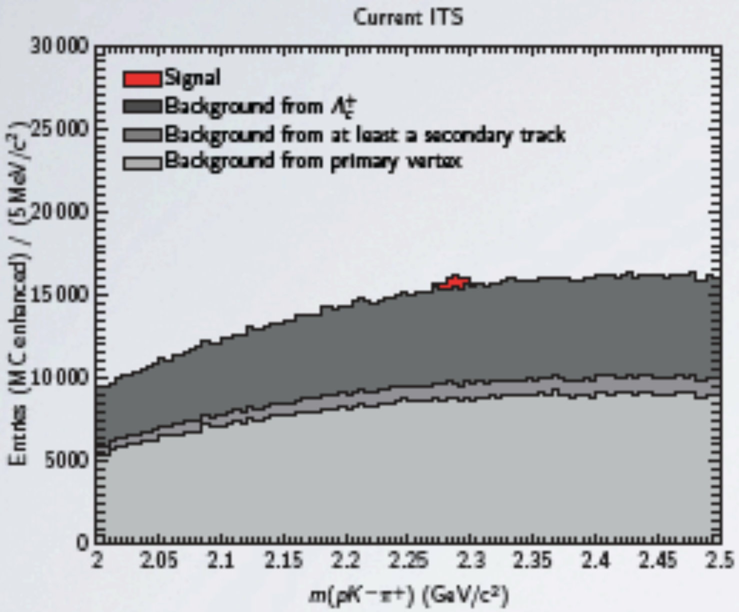
- new strip detector
  - smaller cell size (half length)
  - new front-end chip
    - CMOS 0.13 μm
    - on-chip ADC

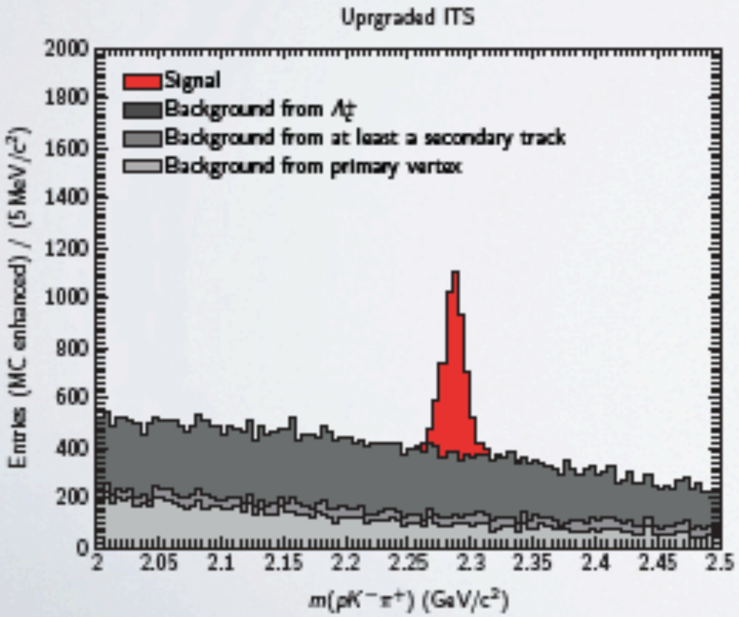


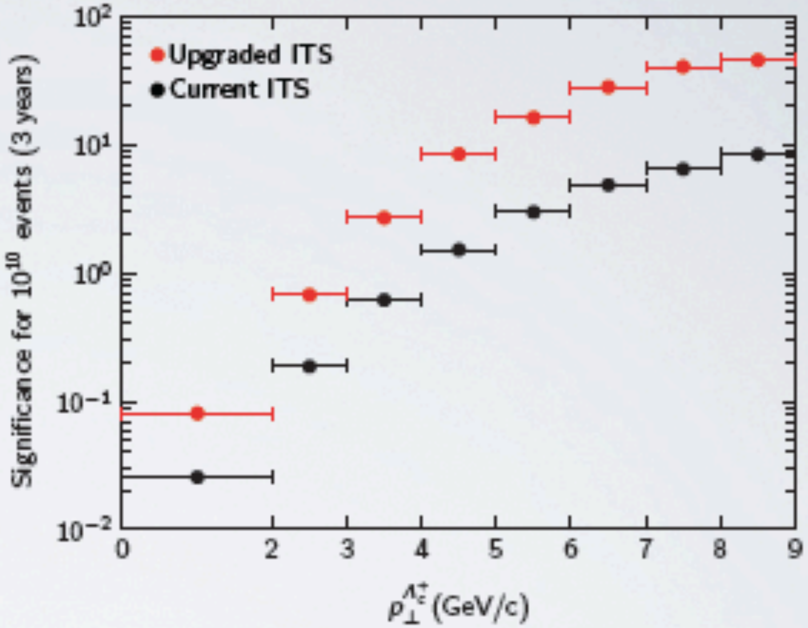
final draft of CDR, endorsed internally in ALICE

7 new layers, nearest at 2.2 cm from beam

Example: Charmed Baryons





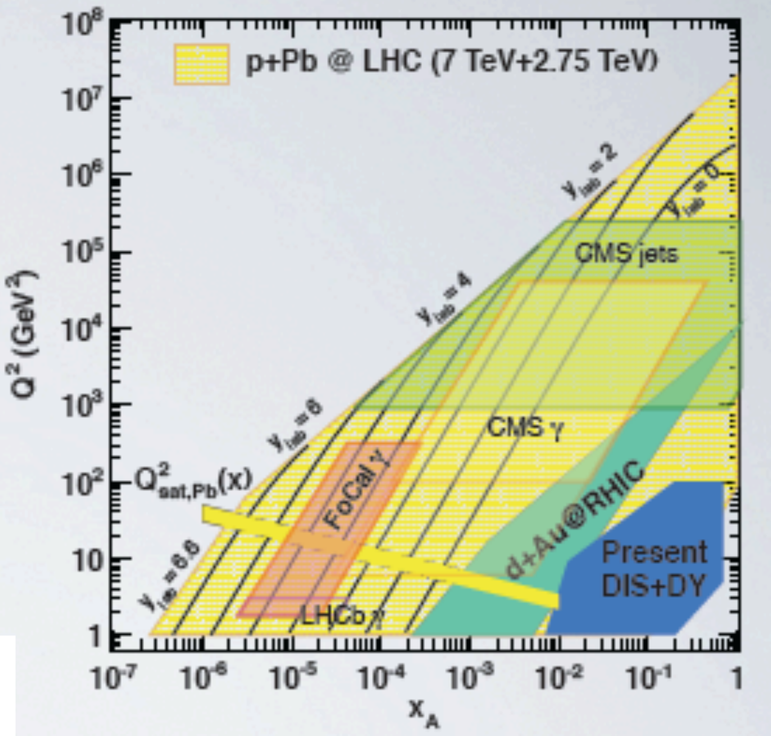


M. Mager

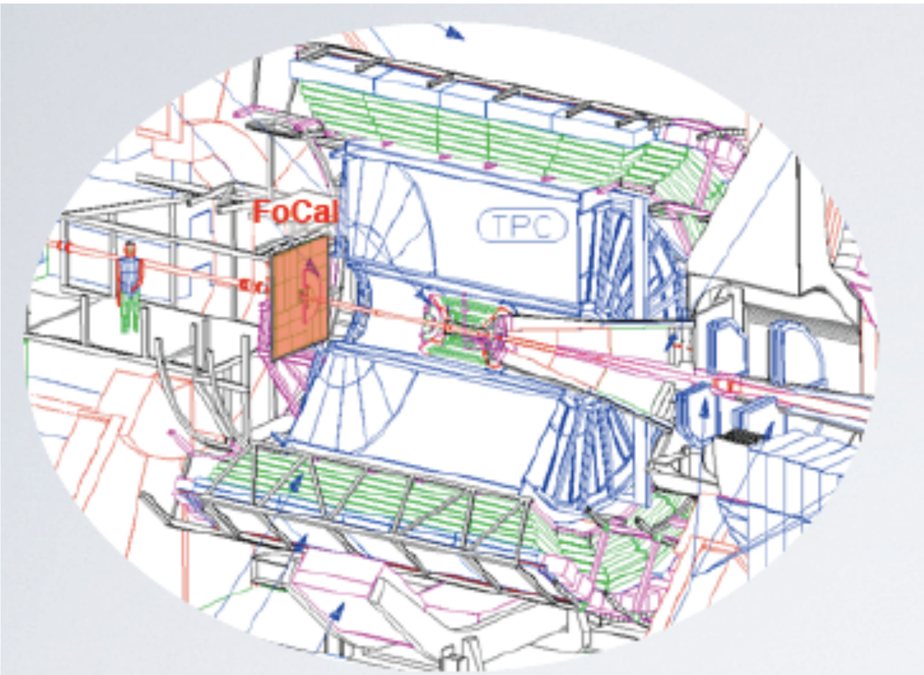
- strong advantage of new ITS for both S/B and significance
- optimization studies ongoing

Small Bjorken-x

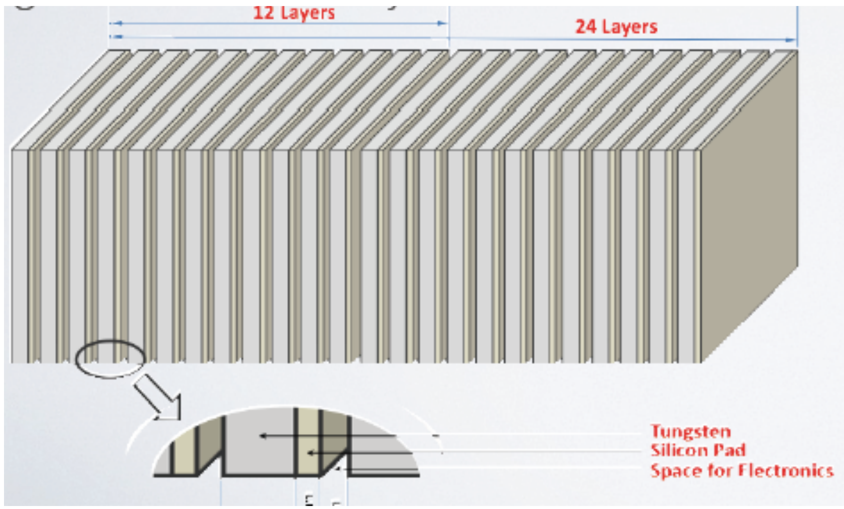
- physics at small x / large y enters new regime
- ALICE has the opportunity for a substantial upgrade at large rapidity



$2.5 < \eta < 4.5$



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} $cm^{-2}s^{-1}$

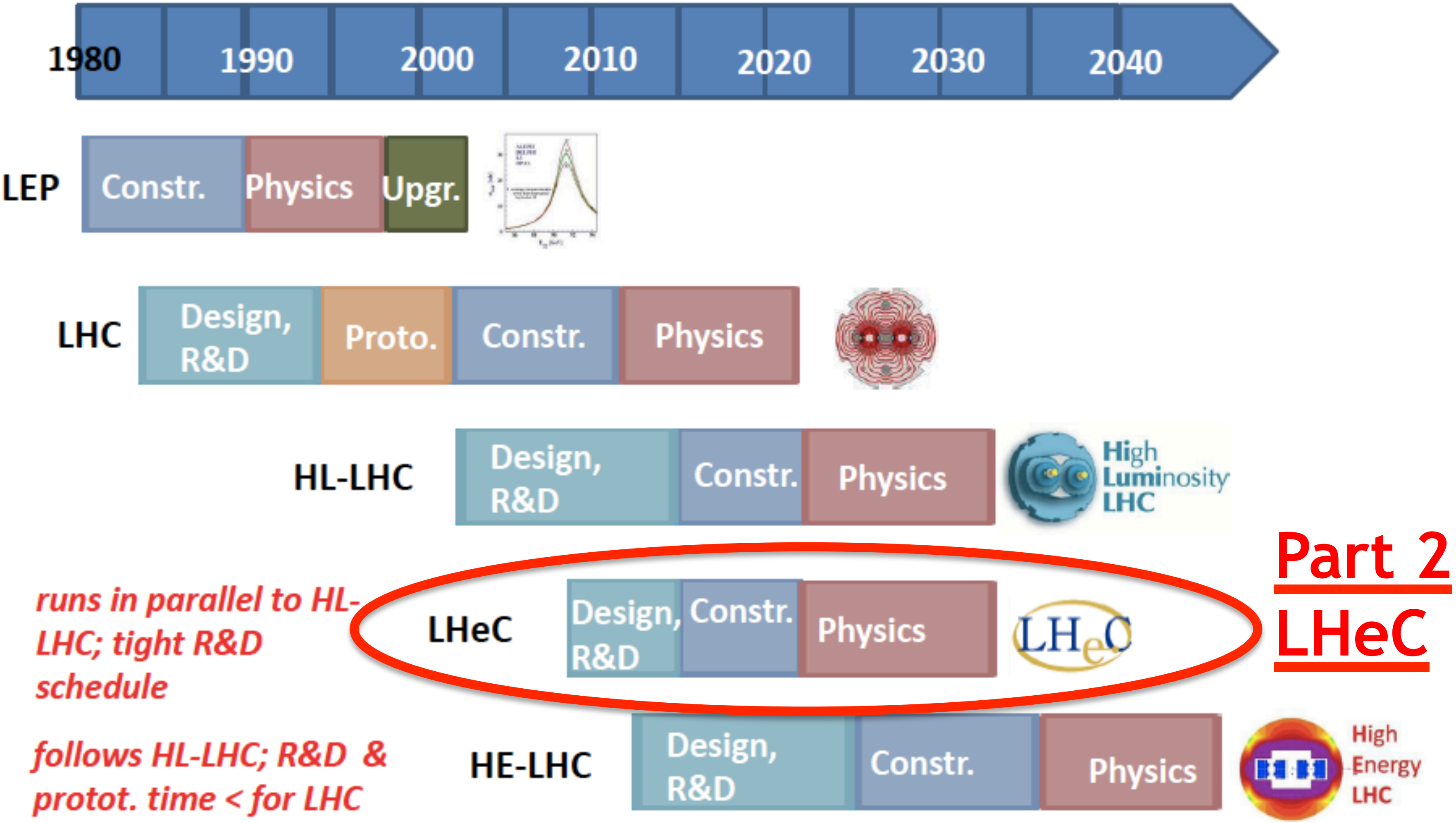
Shutdown: 18 Months

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

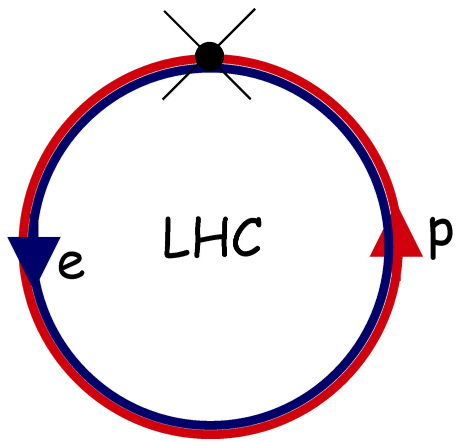
LHeC Study Group

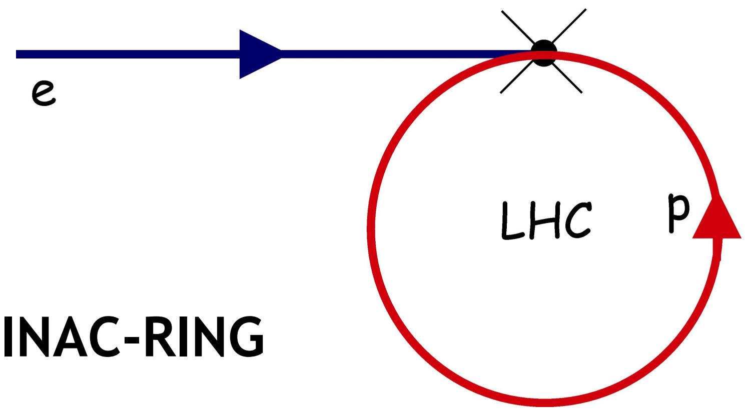
J. Abelleira Fernandez[10,15], C.Adolphsen[39], S.Alekhin[40,11], A.N.Akai[01], H.Aksakal[30], P.Allport[17], J.L.Albacete[37], V.Andreev[25], R.B.Appleby[23], N.Armesto[38], G.Azuelos[26], M.Bai[47], D.Barber[11], J.Bartels[12], J.Behr[11], O.Behnke[11], S.Belyaev[10], I.BenZvi[47], N.Bernard[16], S.Bertolucci[10], 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

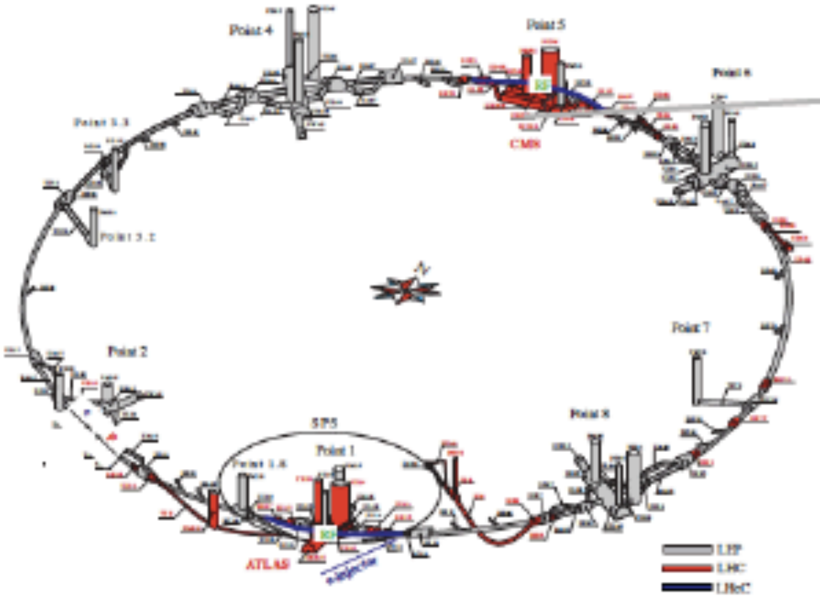


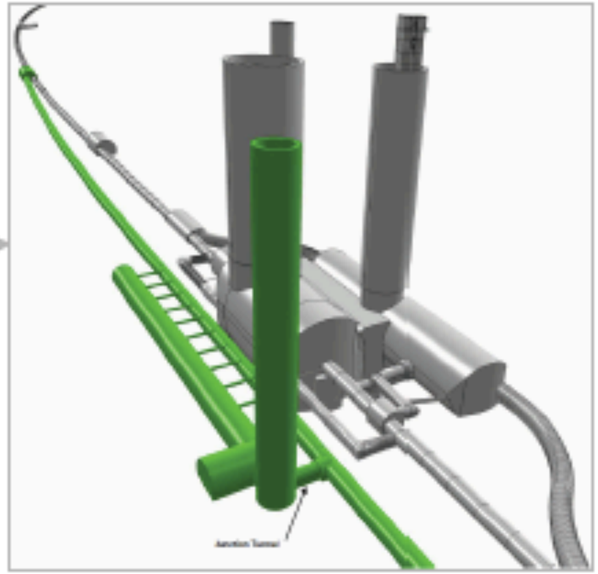


LINAC-RING

Baseline solutions exist in both versions

e Ring- p/A Ring





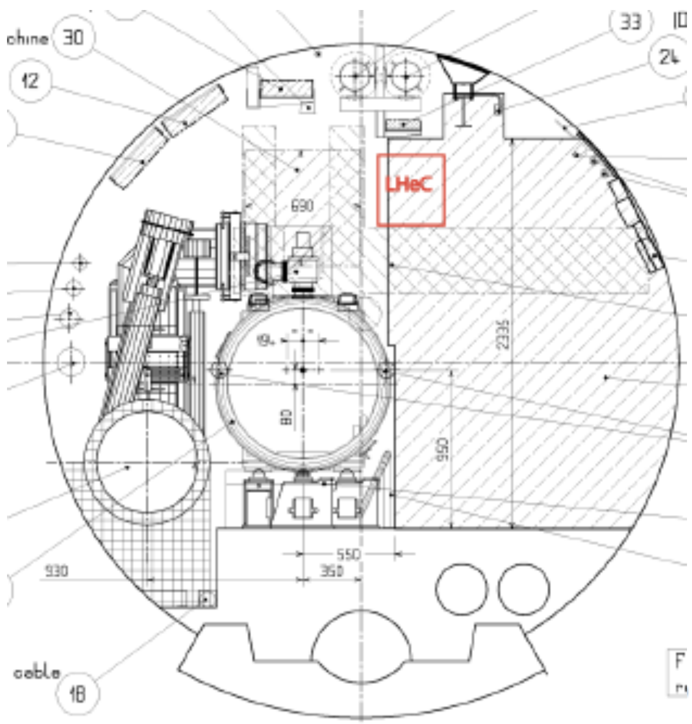
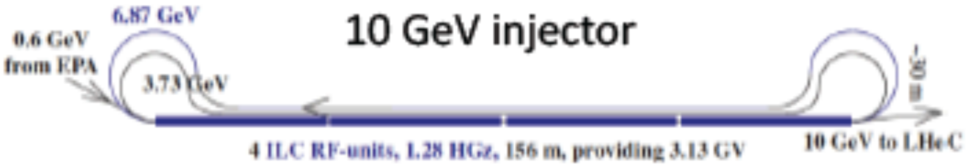


Figure 1: Schematic Layout of the LHC (grey/red) with the bypasses of CMS and ATLAS for the ring electron beam (blue) in the RR version. The e injector is a 10 GeV superconducting linac in triple racetrack configuration which is considered to reach the ring via the bypass around ATLAS.

10 GeV injector



Magnets for Electron Ring

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

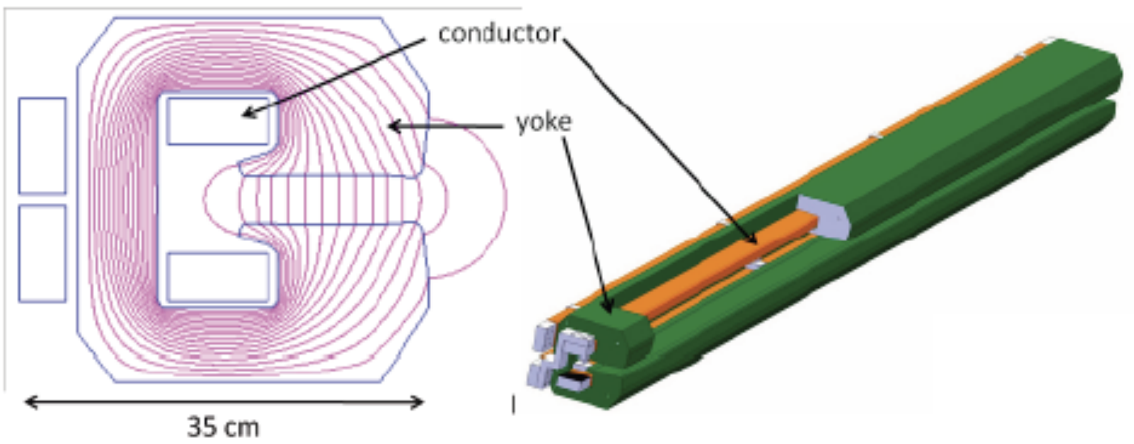


Fig. 2. Field lines and artistic view of a LHeC arc dipole.

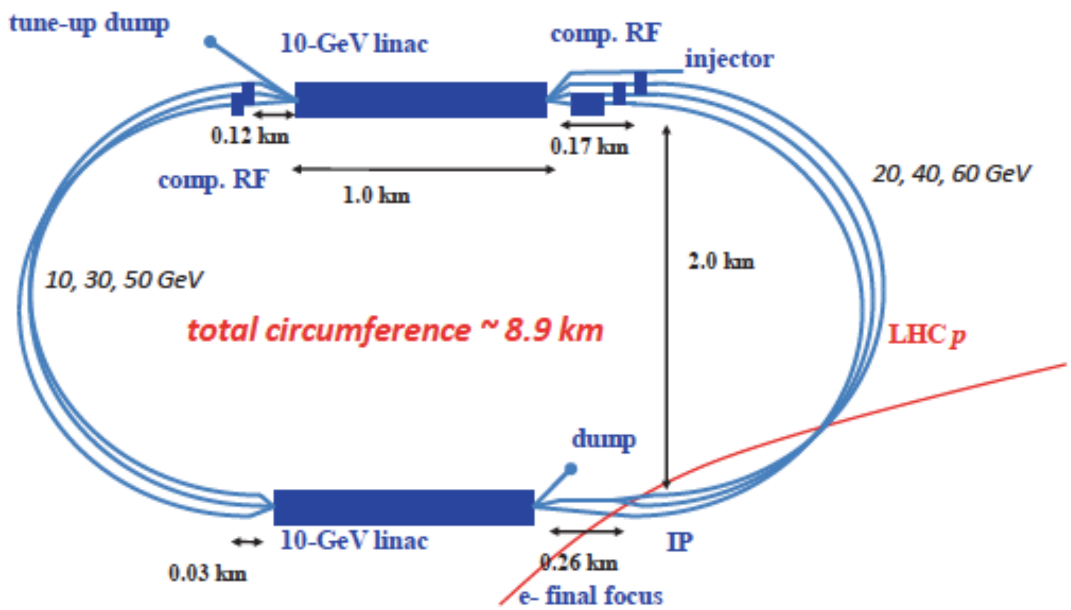
Prototypes (Novisibirsk)

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

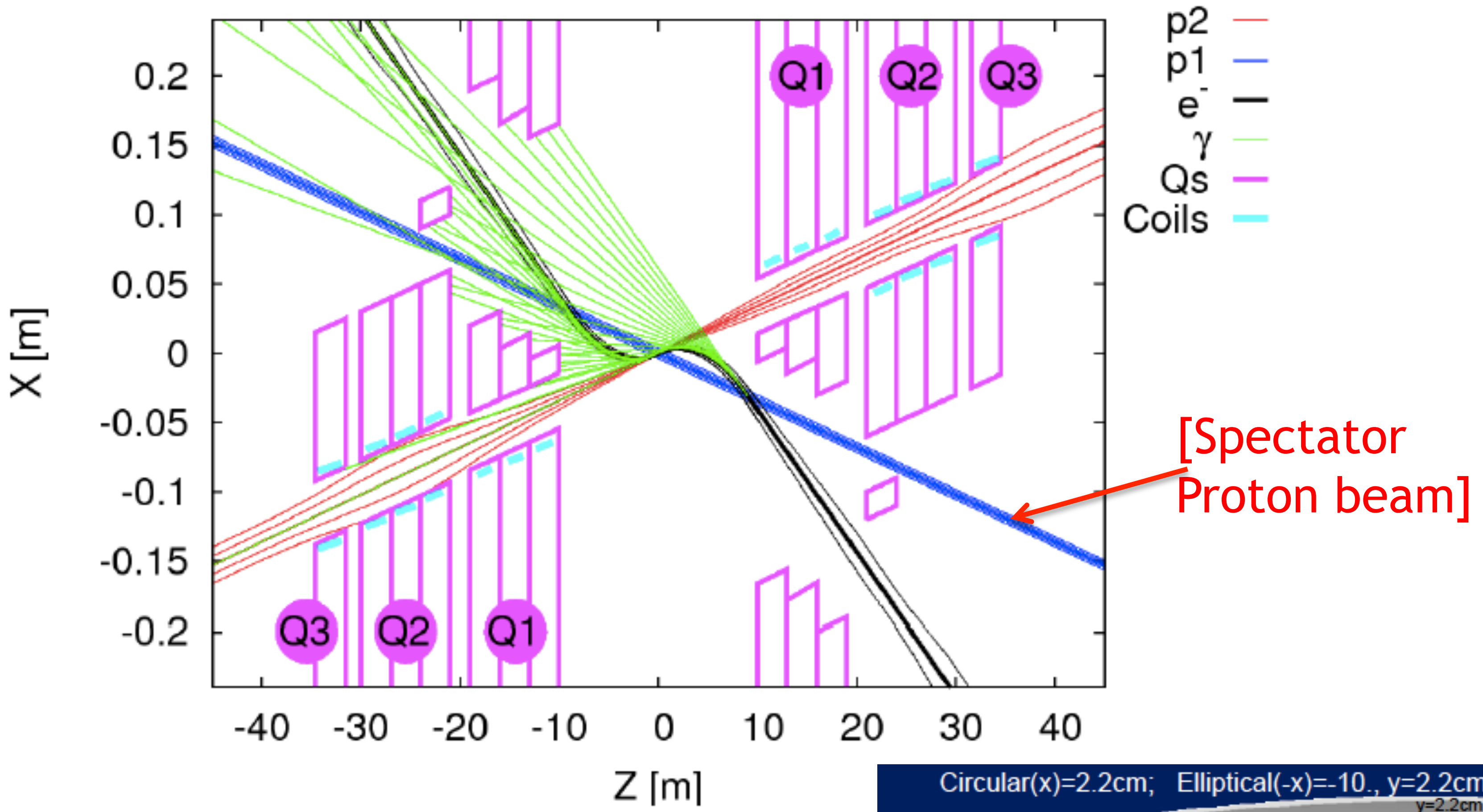


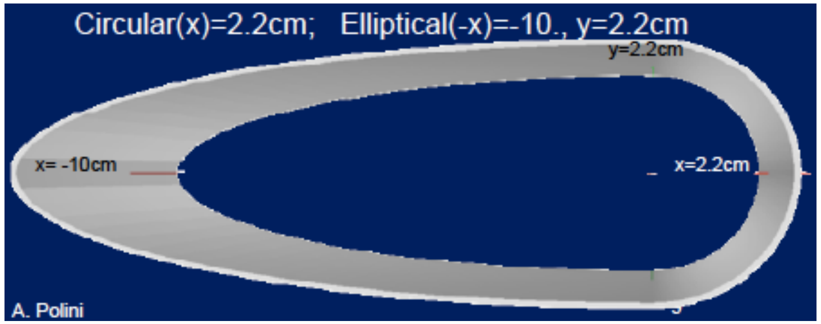
Baseline design:

- 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)

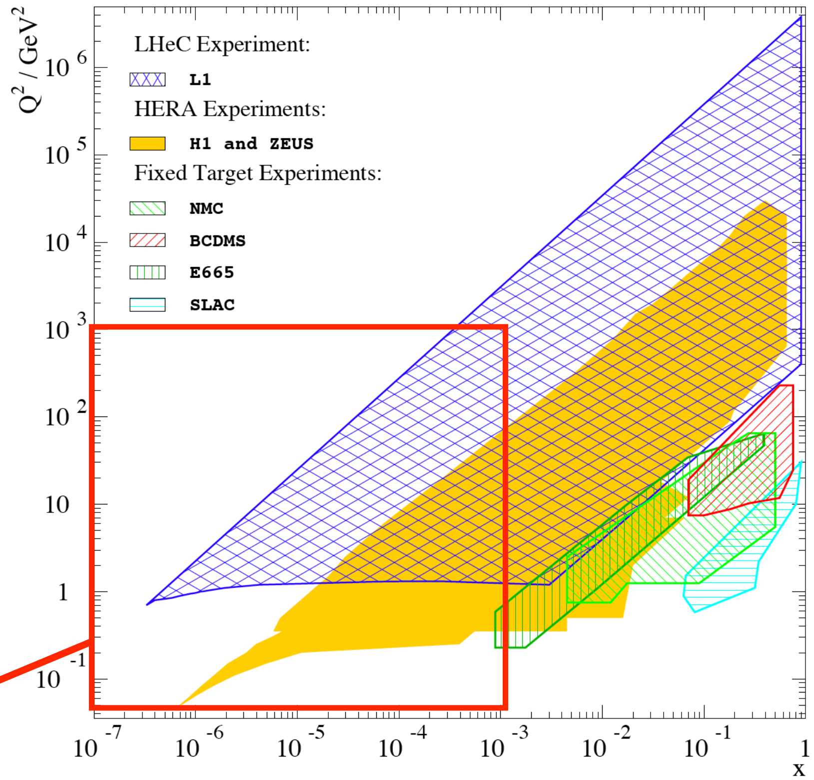


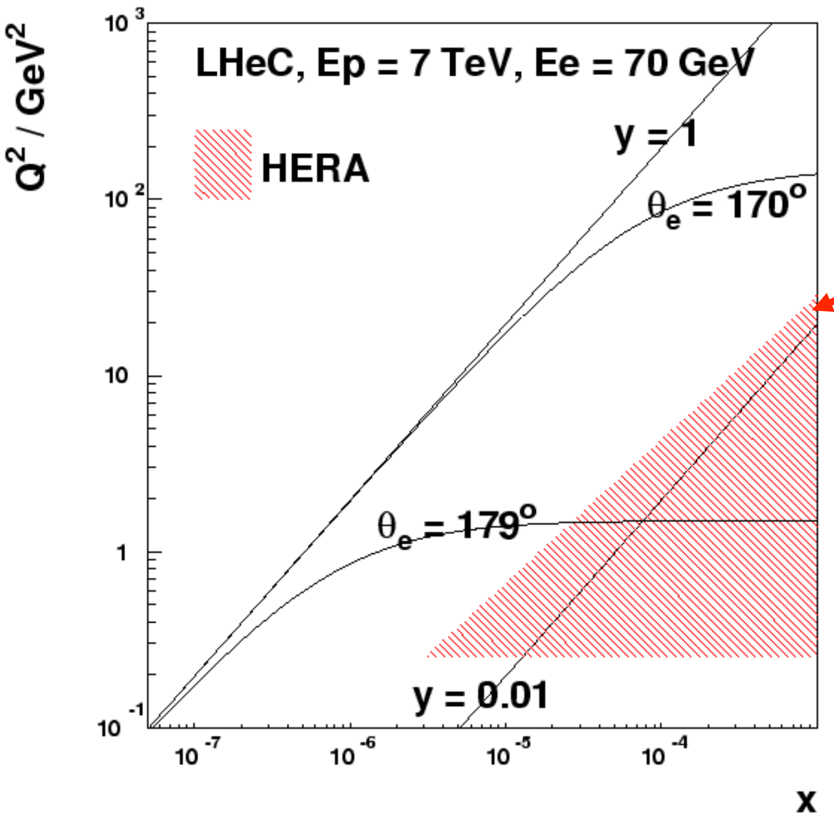


- 2 x 9m dipole magnets (0.3T) through detector region bend electrons into head-on collisions
- Synchrotron fan can be absorbed, but has implications for beampipe design

Detector Acceptance Requirements

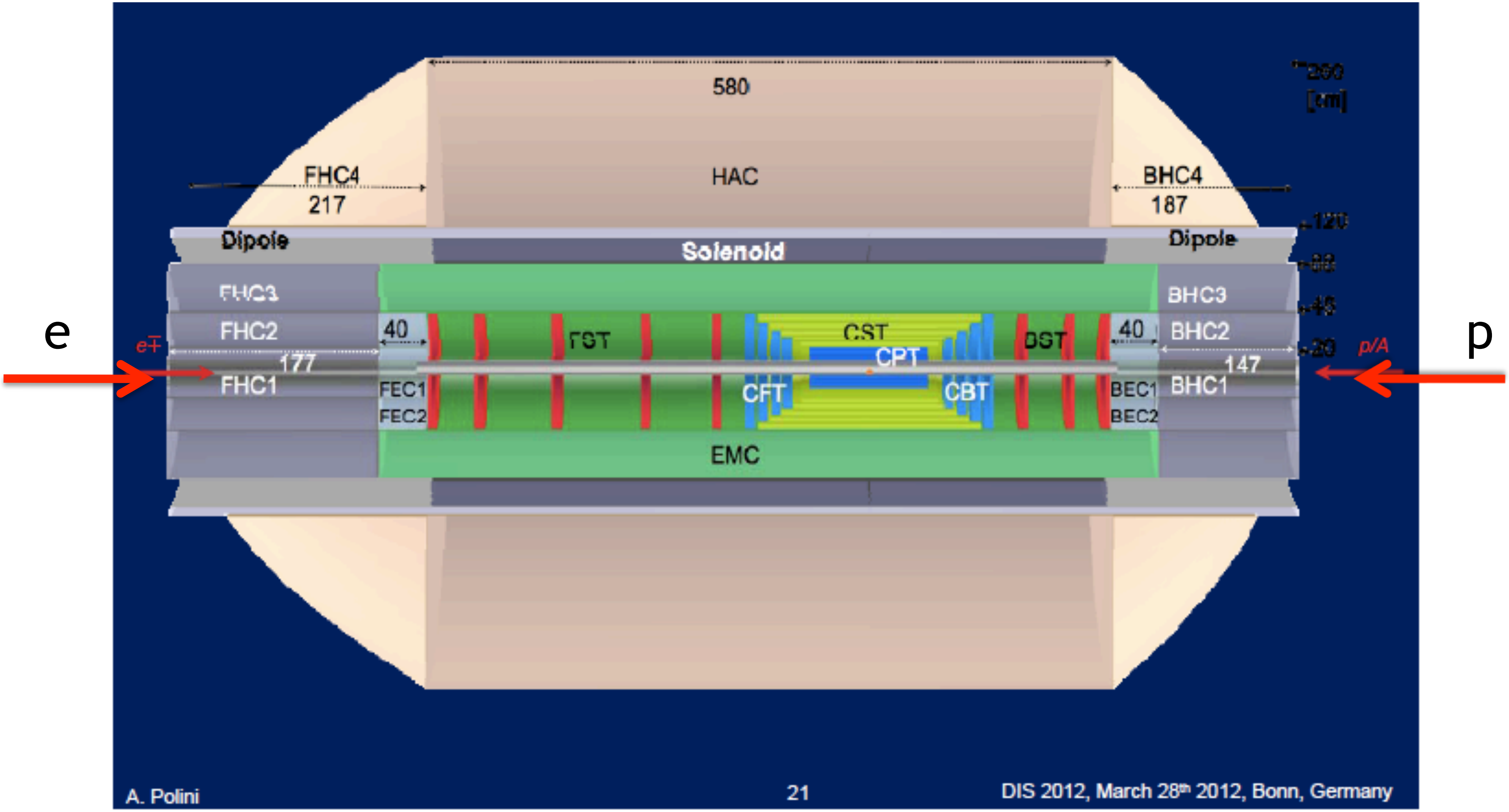
Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°





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

Central Detector (Alessandro Polini)

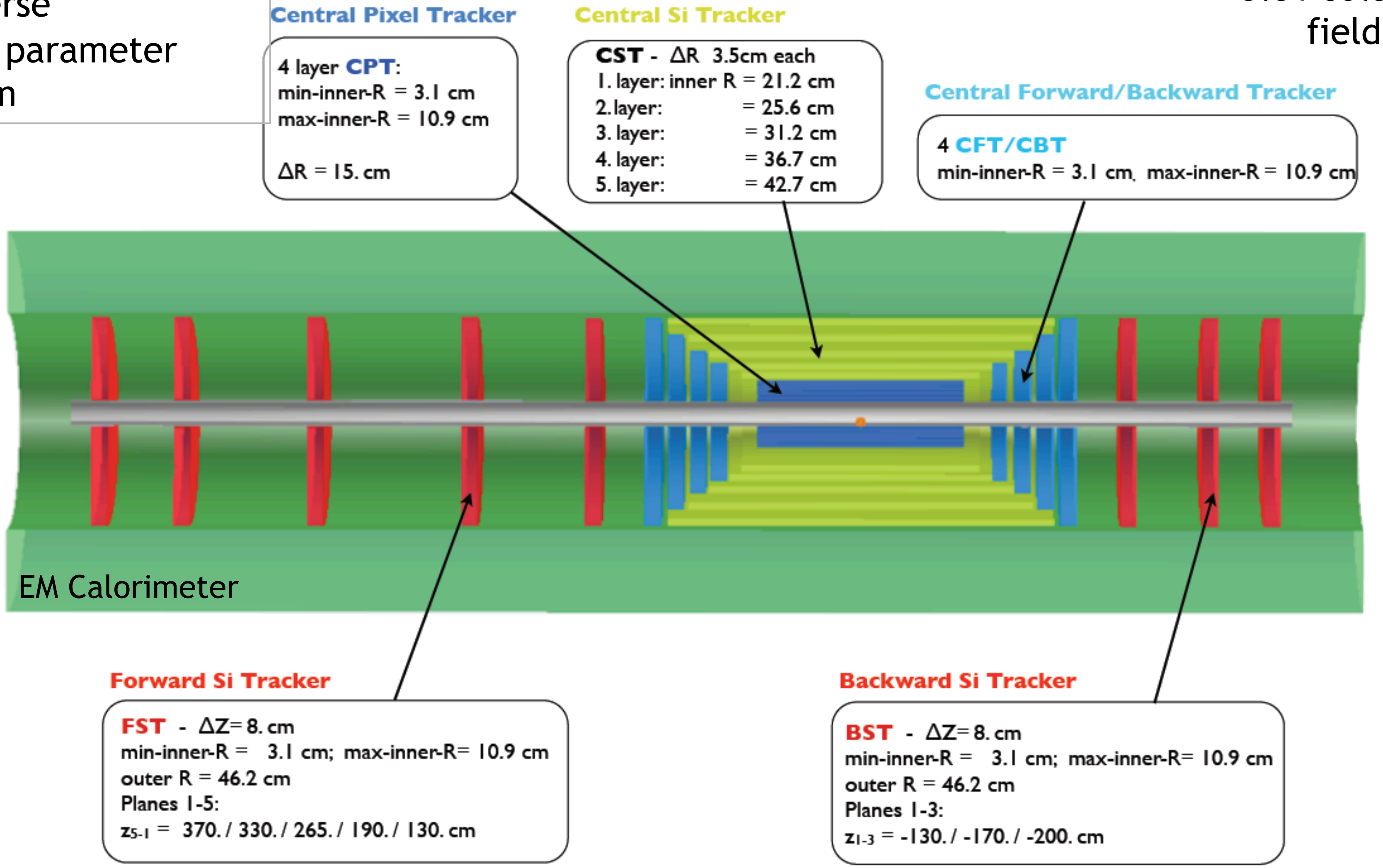


Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m² [CMS 21 x 15m², ATLAS 45 x 25 m²]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Tracking Region

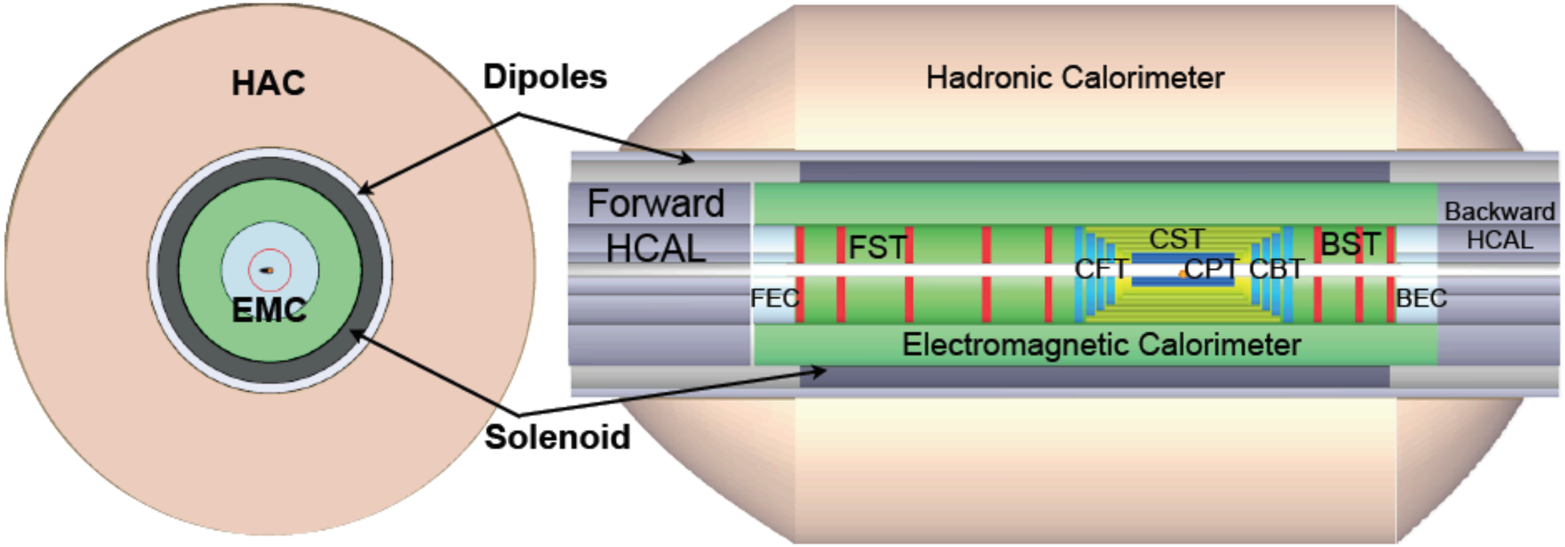
Transverse momentum
$\Delta p_t/p^2_t \rightarrow 6\ 10^{-4}\ GeV^{-1}$
transverse
impact parameter
→ 10µm

[encased in
3.5T solenoid
field]



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

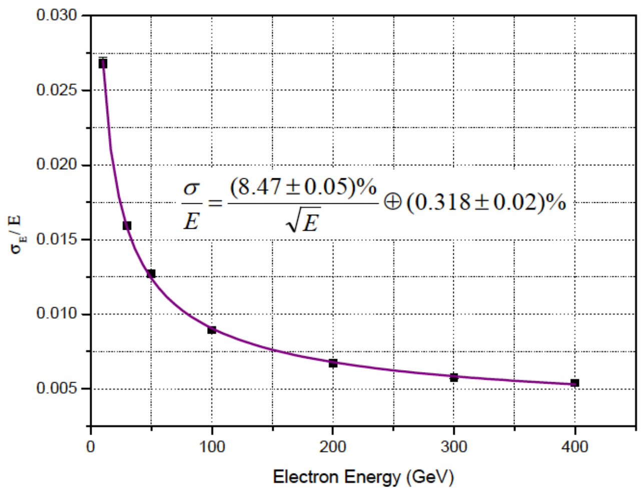
Calorimeters

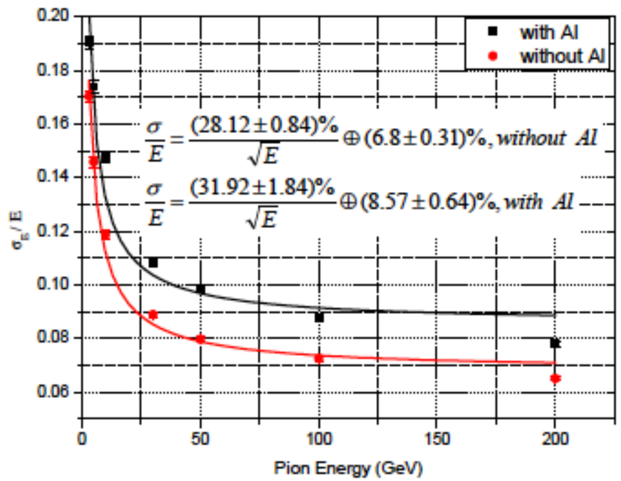


Liquid Argon EM Calorimeter [accordion geometry, inside coil]

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

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



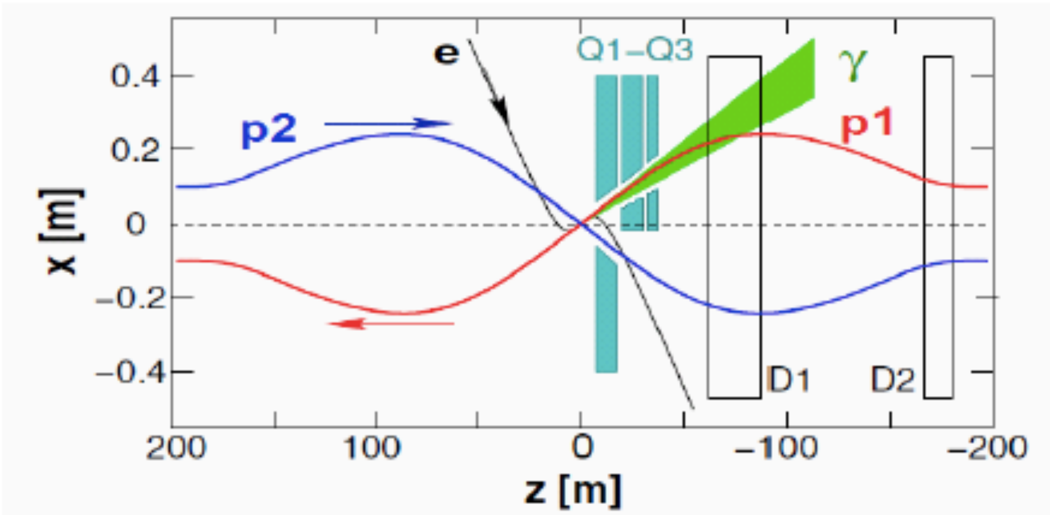


Fwd / Bwd Detectors (Armen Bunyatyan)

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



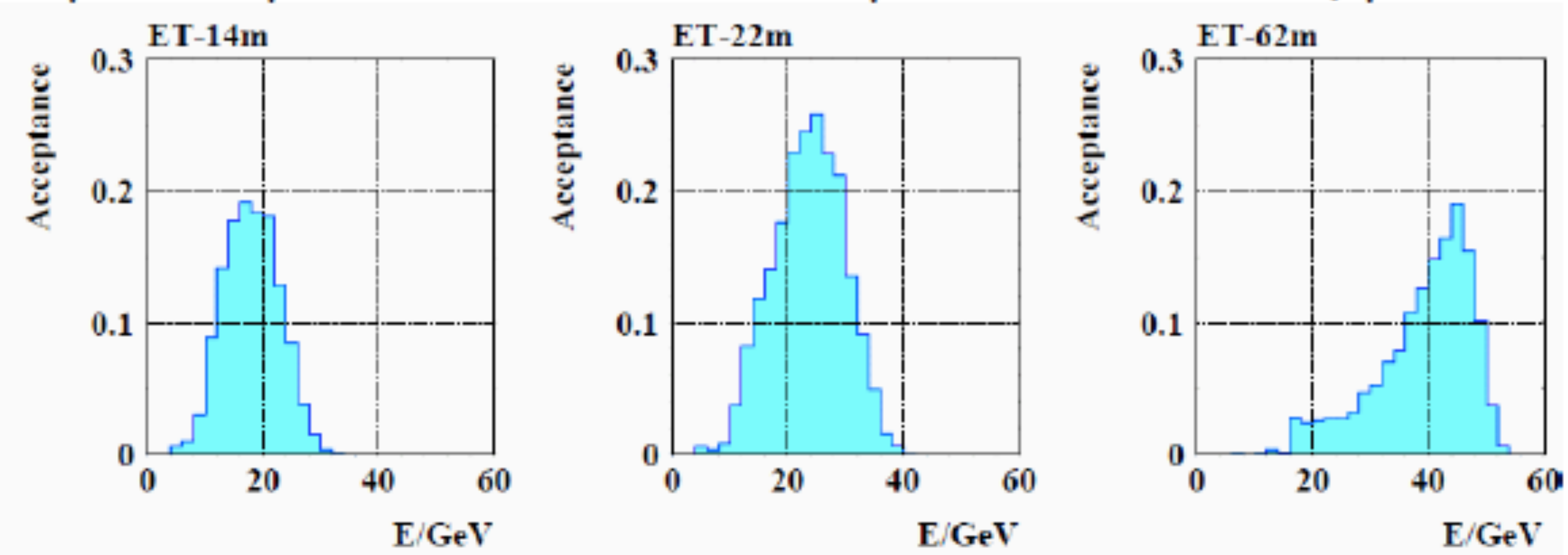
Main limitation – geometrical acceptance, defined by the aperture of Q1-Q3.
May be need to split dipole D1 to provide escape path for photons.
Geometrical acceptance of 95% is possible, total luminosity error δL=1%.

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 γp background to DIS)

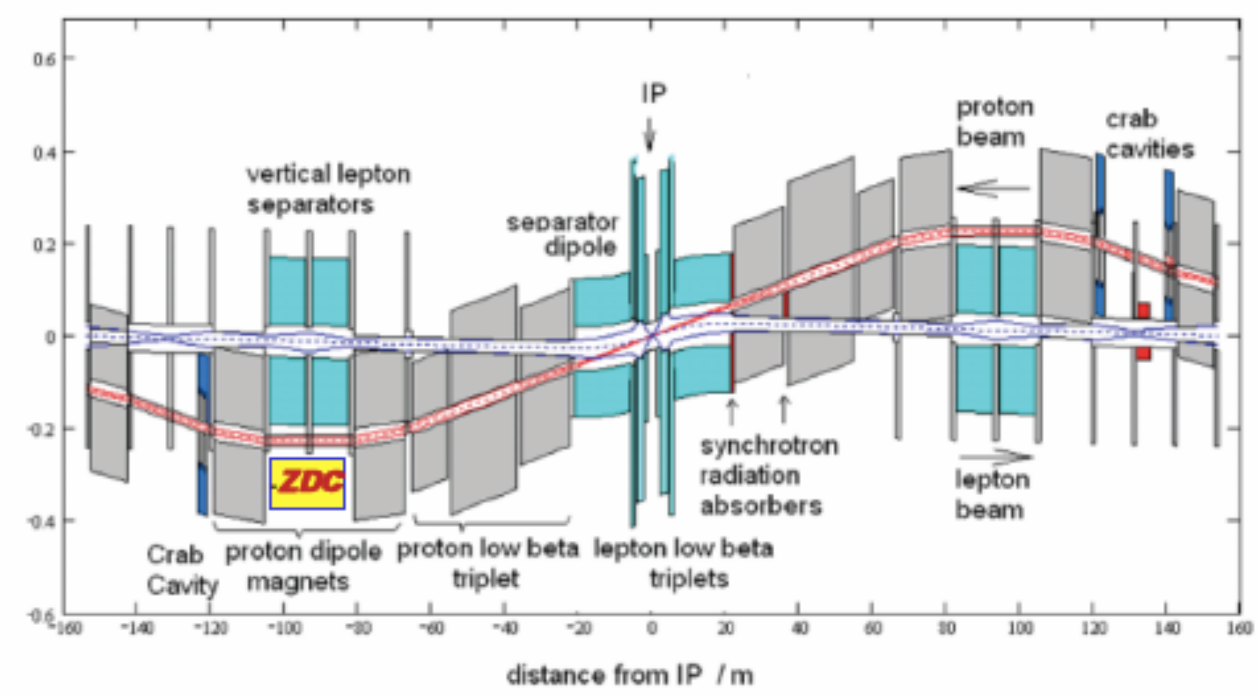
Clean sample – background from e-gas can be estimated using pilot bunches.
Three possible positions simulated→ acceptances reasonable (up to 20÷25%)



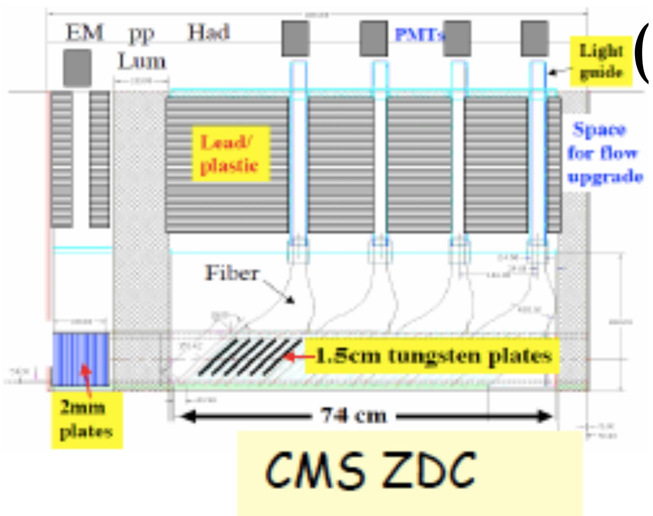
Acceptance depends on the distance of the detector from the e-beam axis and on the details of the e-beam optics (beam tilt, trajectory offset)

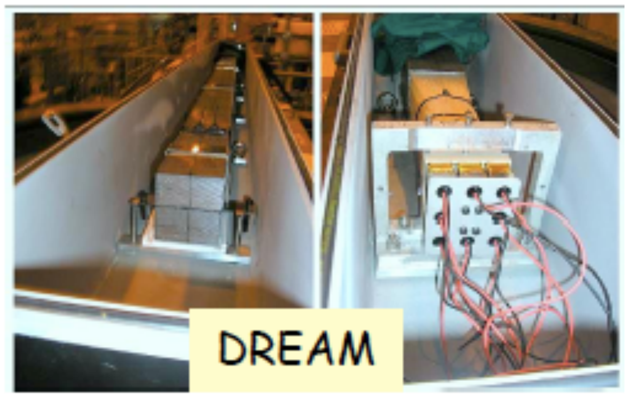
Need a precise monitoring of beam optics and accurate position measurement of the e-tagger to control geometrical acceptance to a sufficient precision
(e.g. 20μm instability in the horizontal trajectory offset at IP leads to 5% systematic uncertainty in the visible cross section)

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)

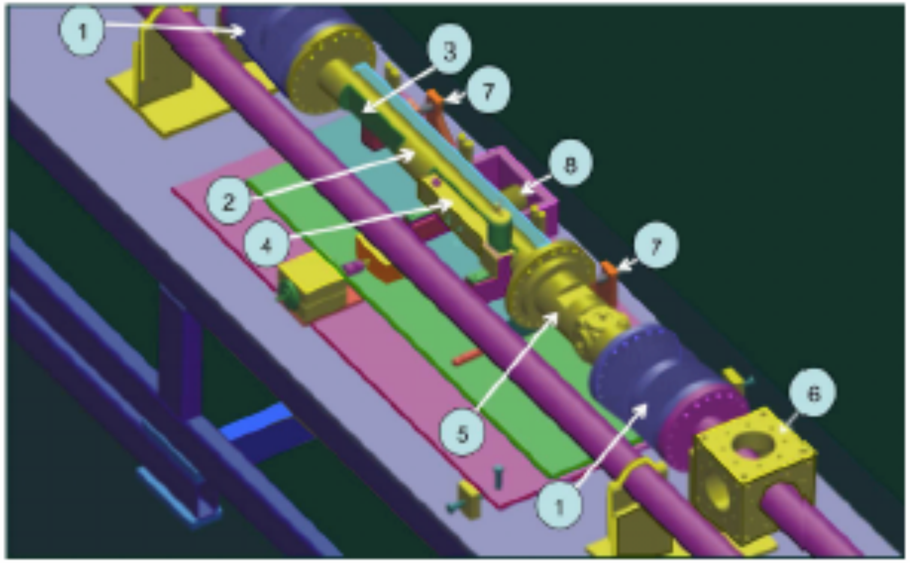
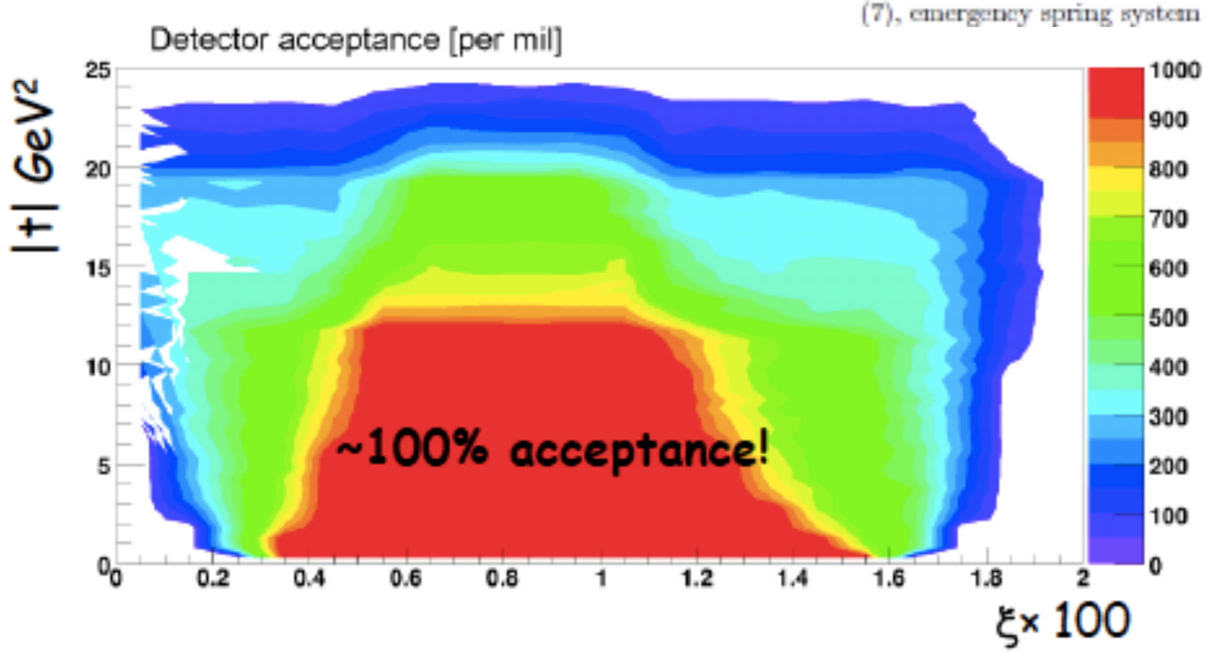


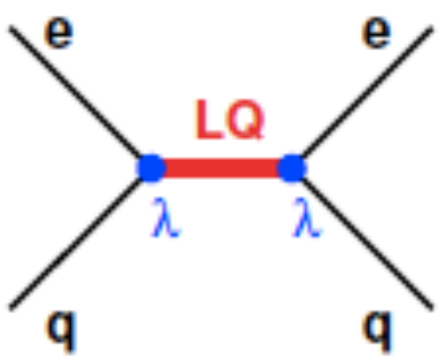
Figure 3.2: Top view of one detector section: bellows (1), moving pipe (2), Si-detector pocket (3), timing detector (4), moving BPM (5), fixed BPM (6), LVDT position measurement system (7), emergency spring system (8).

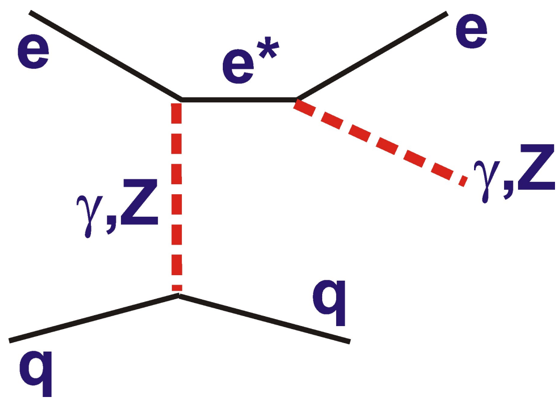


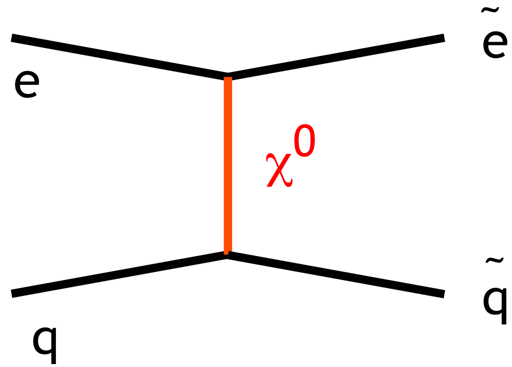
Physics Programme

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

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







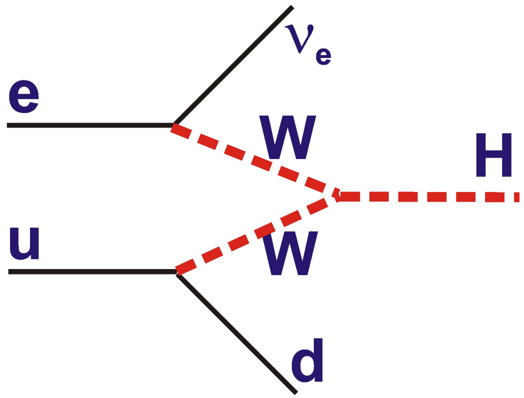
• LHeC enhances LHC discovery potential by clarifying signals

→ Quantum Number Determinations

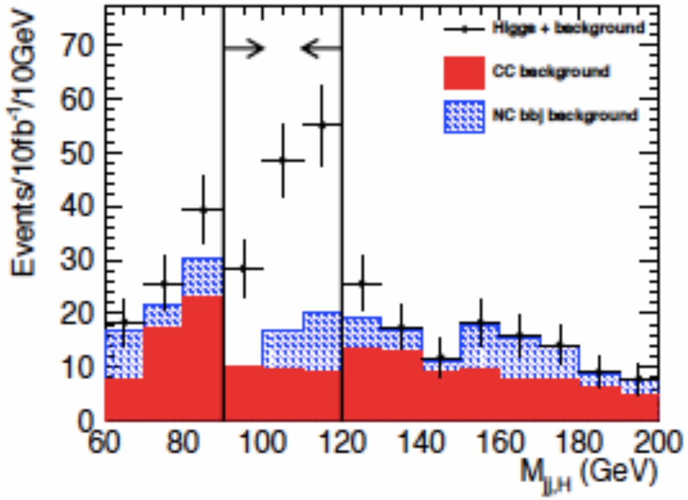
→ Reducing uncertainties due to PDFs / QCD modelling

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

Anomalous Higgs Couplings (Rohini Godbole)



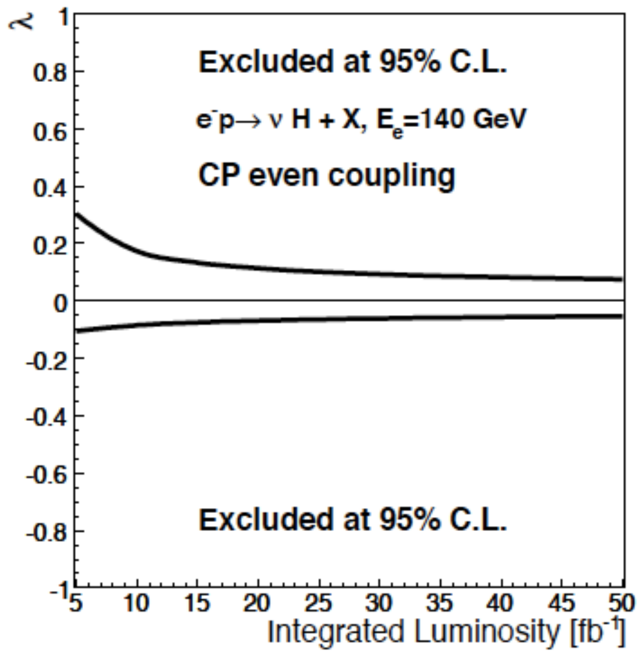
Clean signal to identify Higgs production via WW fusion (and decay to b-bbar) $H + j + E_t^{miss}$

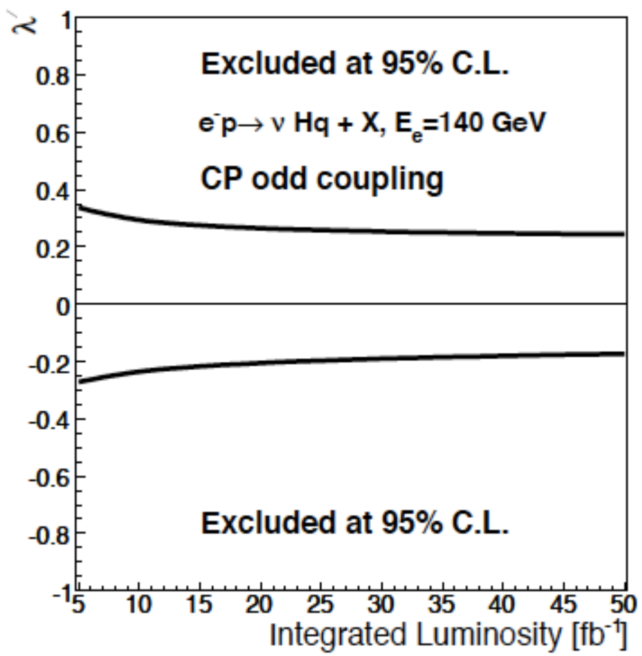


~ 100 events / year after cuts (S/B = 1.8)

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 γ 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

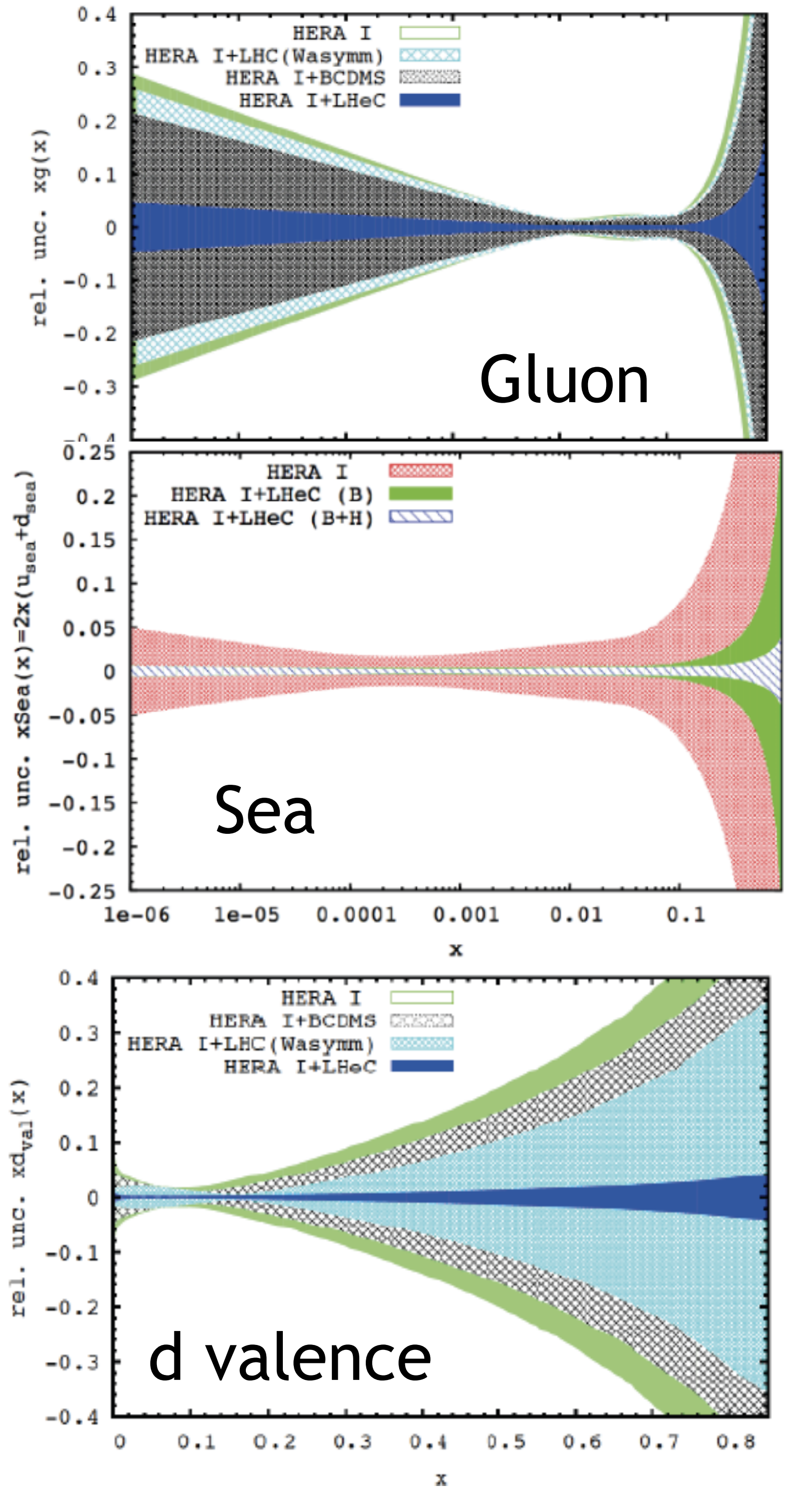
Full simulation of inclusive NC and CC DIS data, including systematics → NLO DGLAP fit using HERA technology…

… 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)

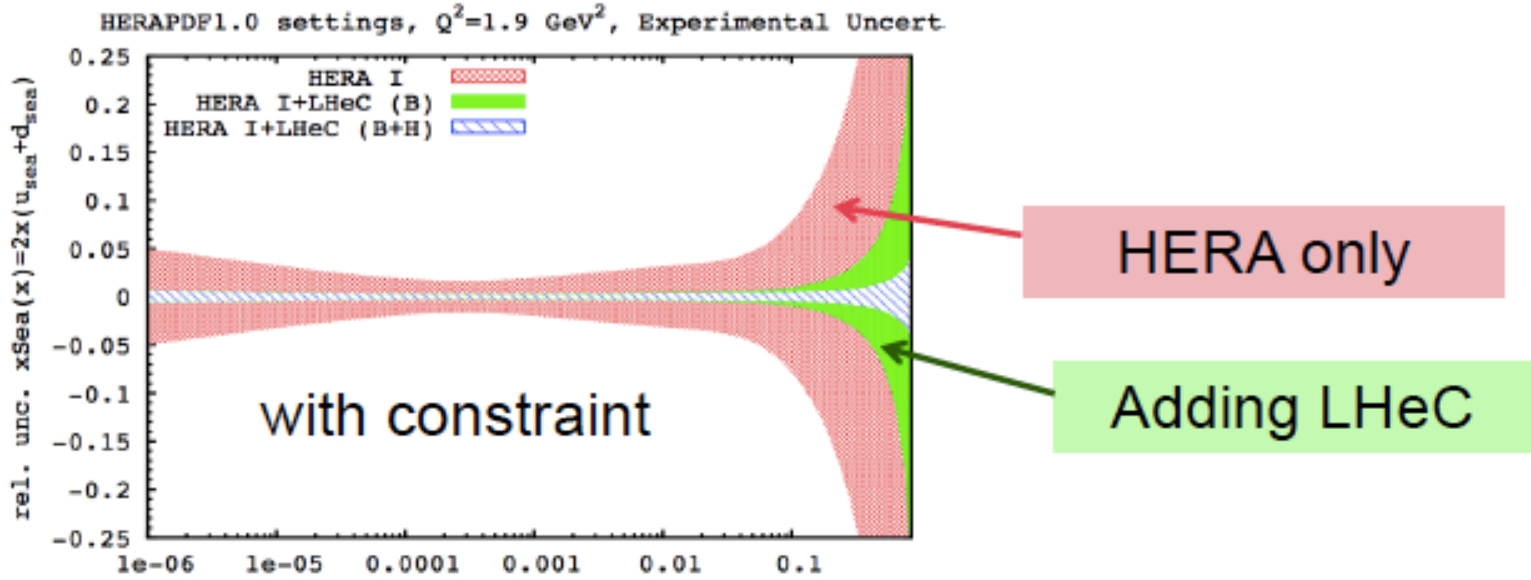
… precise light quark vector, axial couplings, weak mixing angle

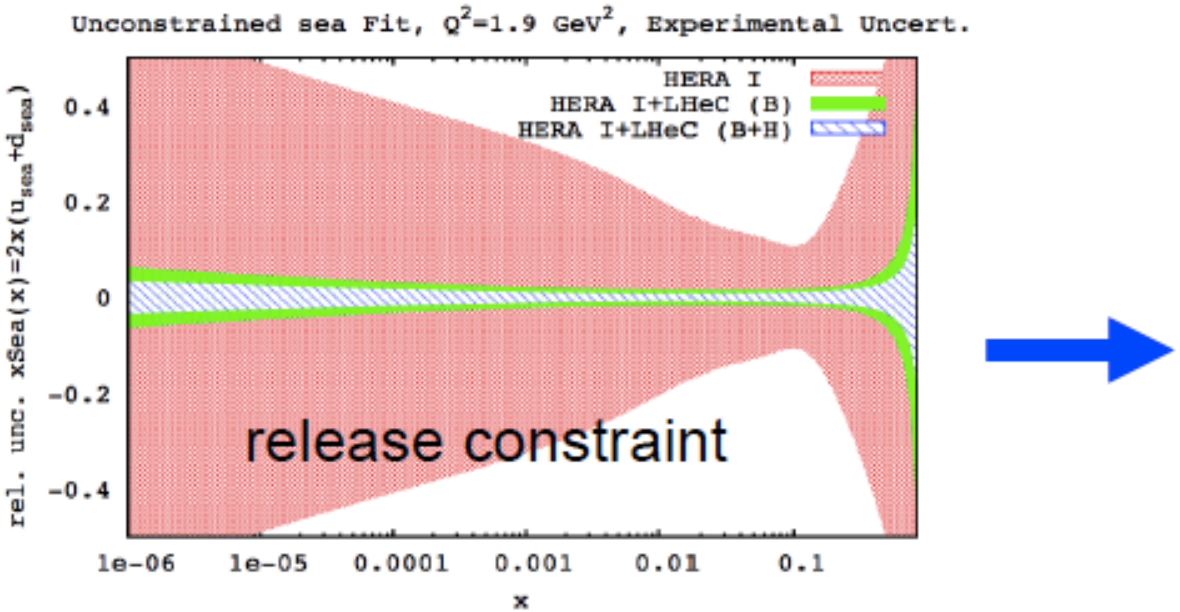
… full flavour decomposition



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

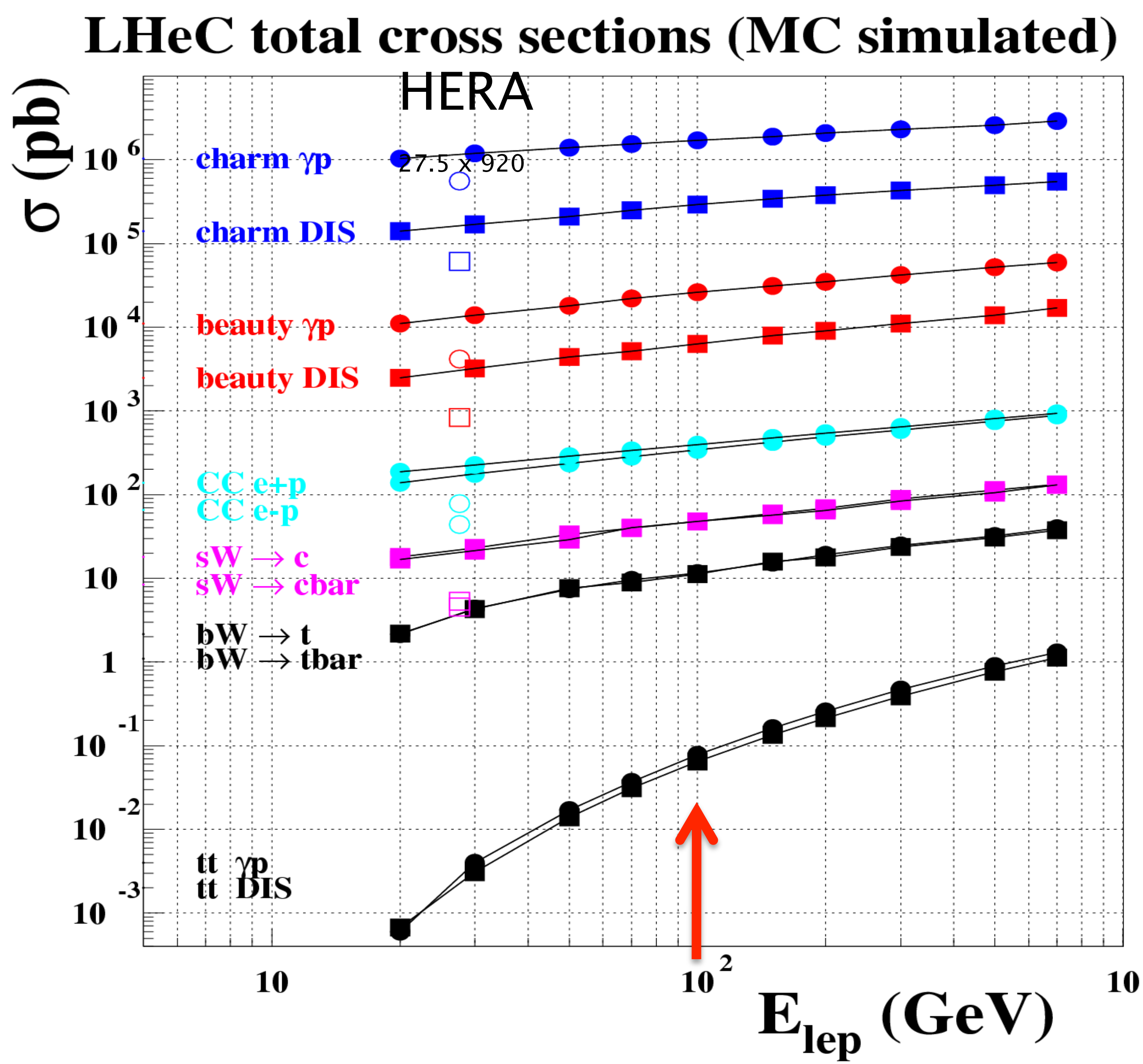
Voica Radescu





With LHeC can get rid of such assumptions

Cross Sections and Rates for Heavy Flavours



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

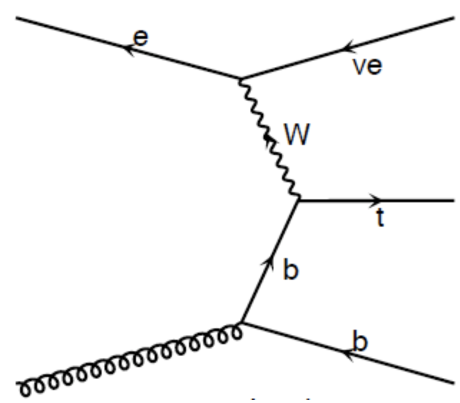
Beauty $[10^{8} / 10\ fb^{-1}]$

cc

sW → c $[4.10^{5} / 10\ fb^{-1}]$

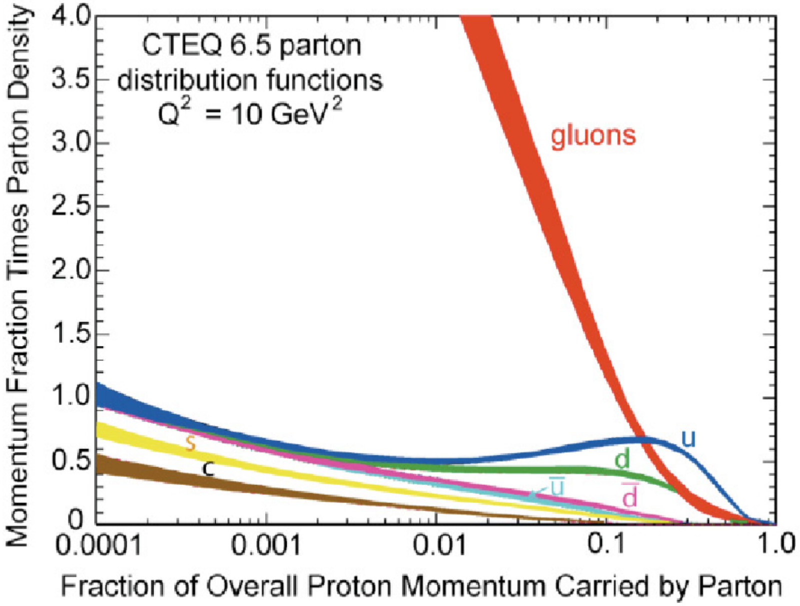
bW → t $[10^{5} / 10\ fb^{-1}]$

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

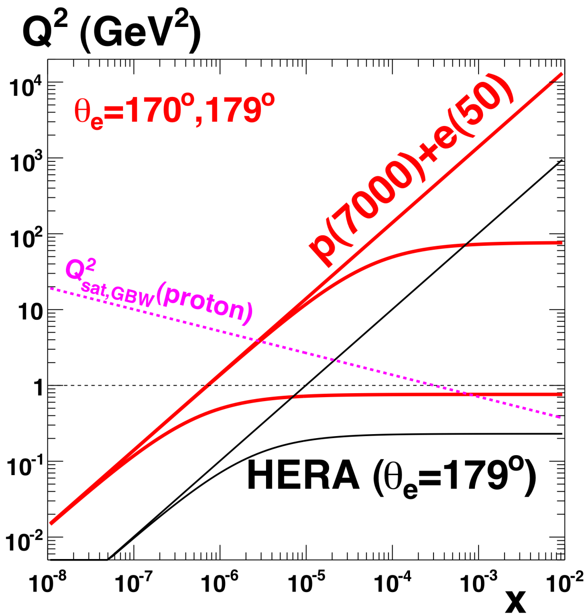


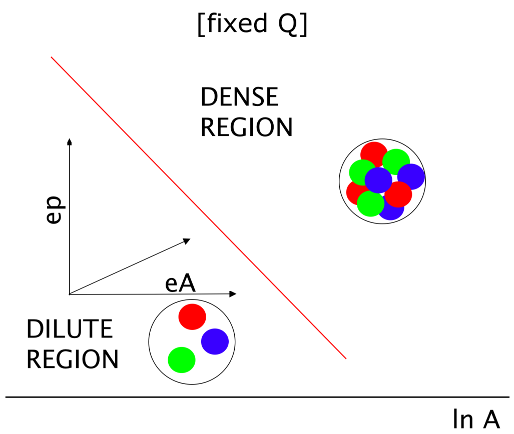
c.f. luminosity of ~10 fb^{-1} per year …

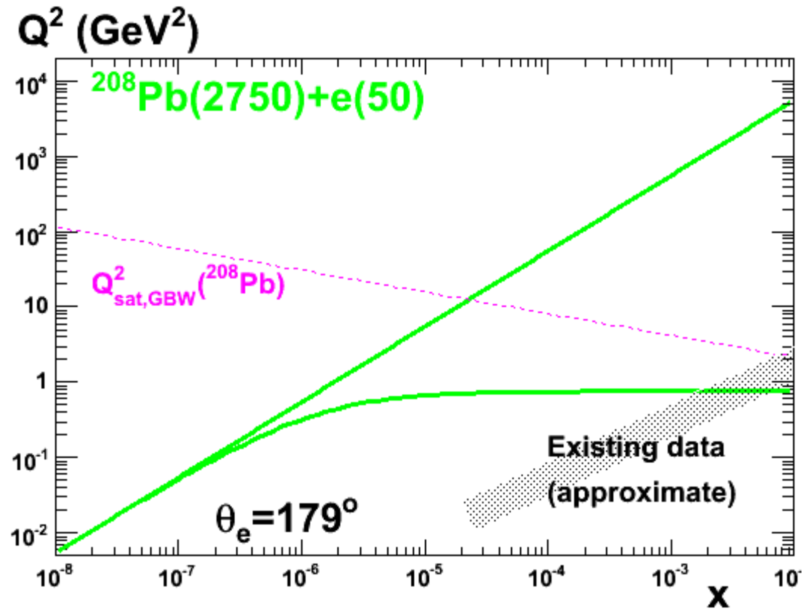
Low-x Physics / Parton Saturation (Nestor Armesto and Anna Stasto)



- 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 …



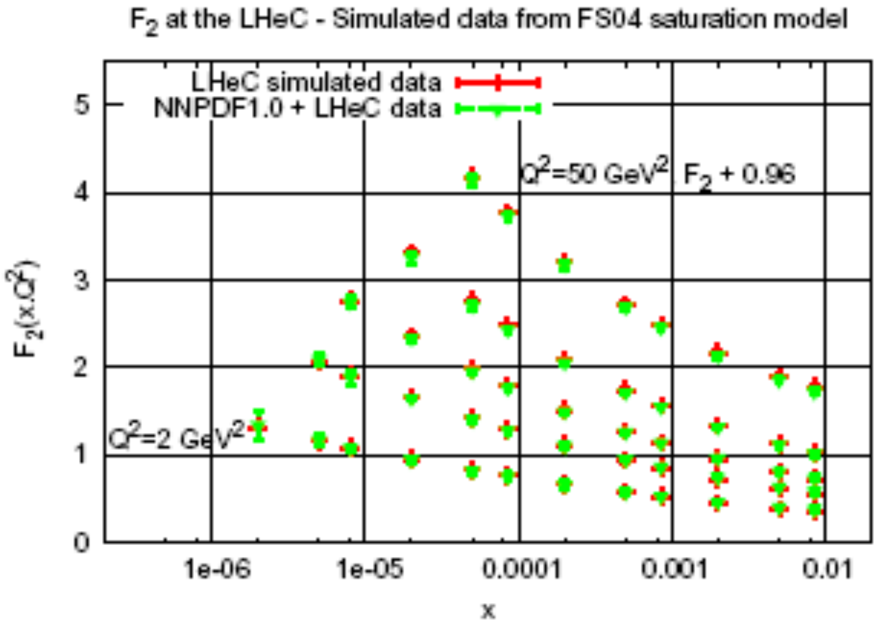


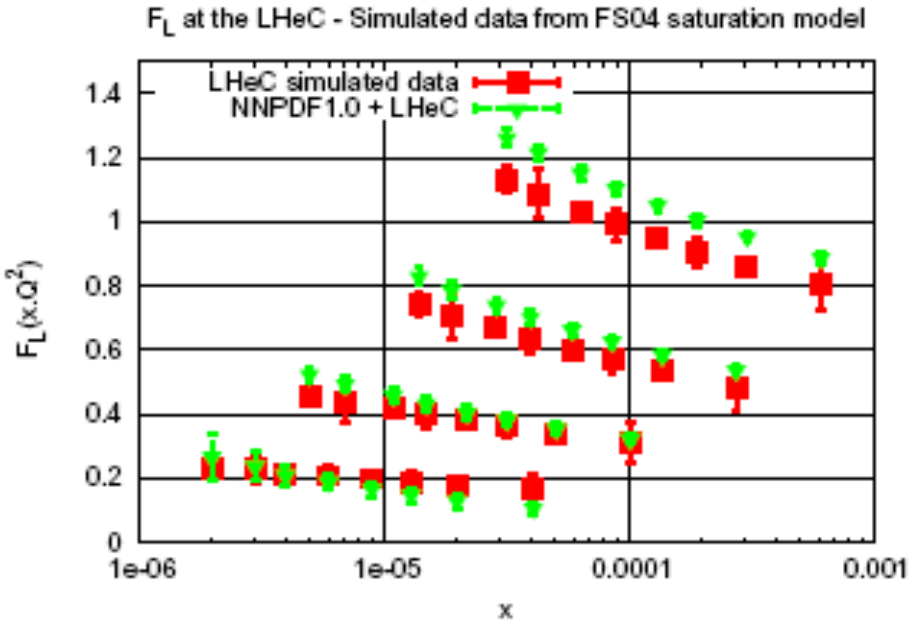


Can Parton Saturation be Established in ep @ LHeC?

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

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

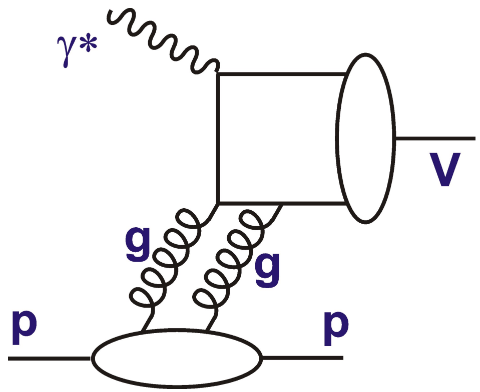




Conclusion: clearly establishing non-linear effects needs a minimum of 2 observables … (F_2^c may work in place of F_L)…

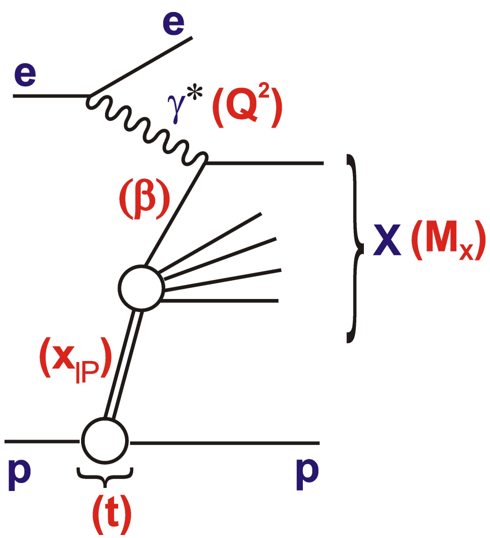
Exclusive / Diffractive Channels and Saturation

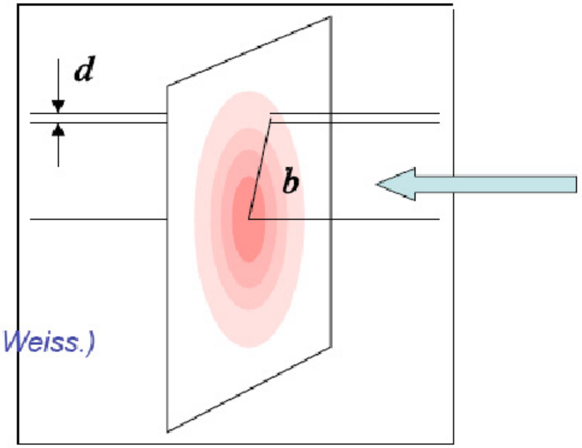
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon



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

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



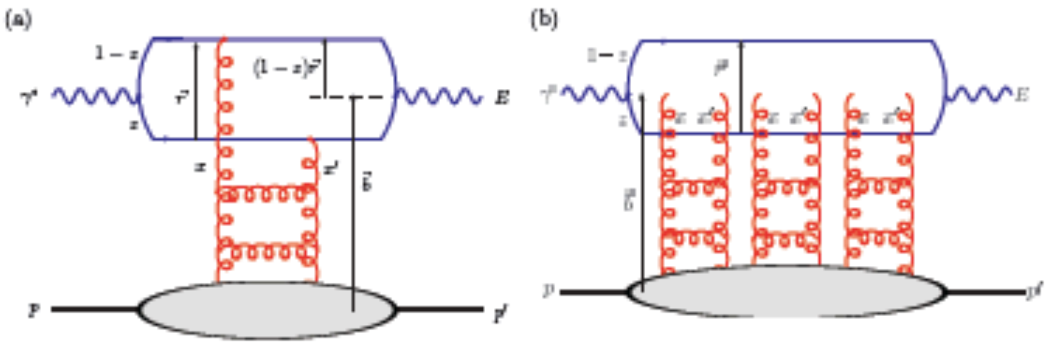


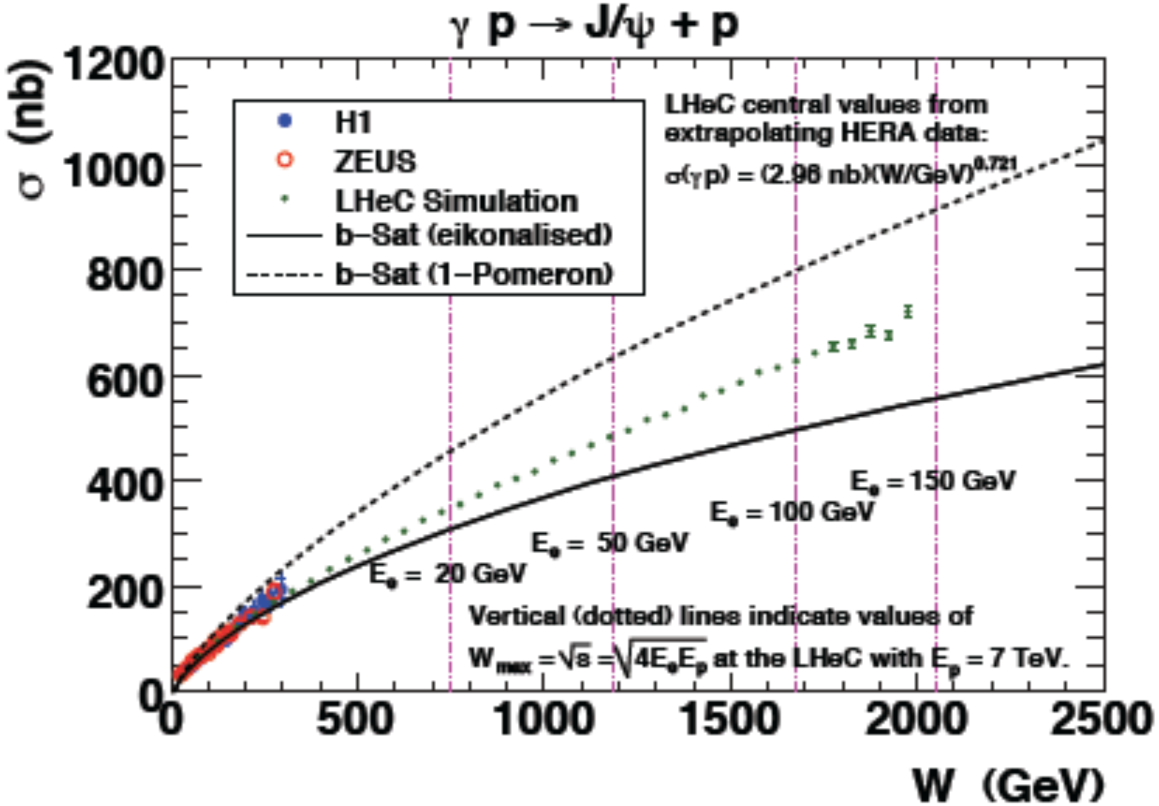
(figure from C. Weiss.)

Exclusive diffraction: vector mesons

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

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





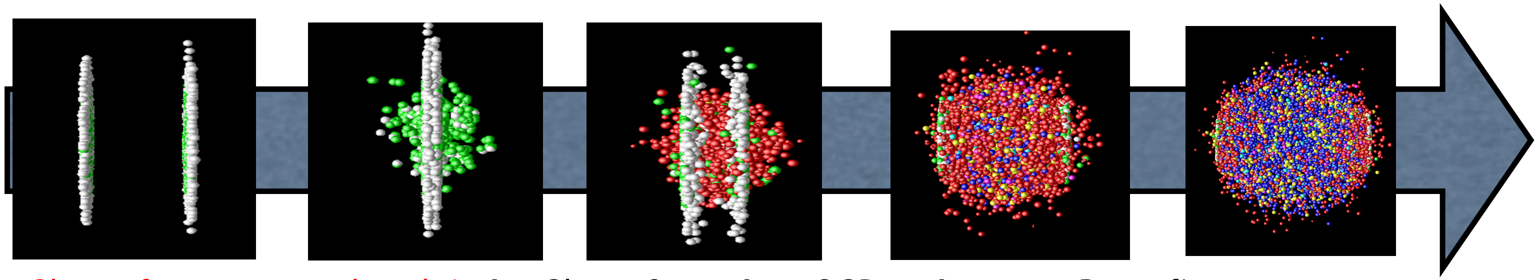
Large effects even for the t-integrated observable.

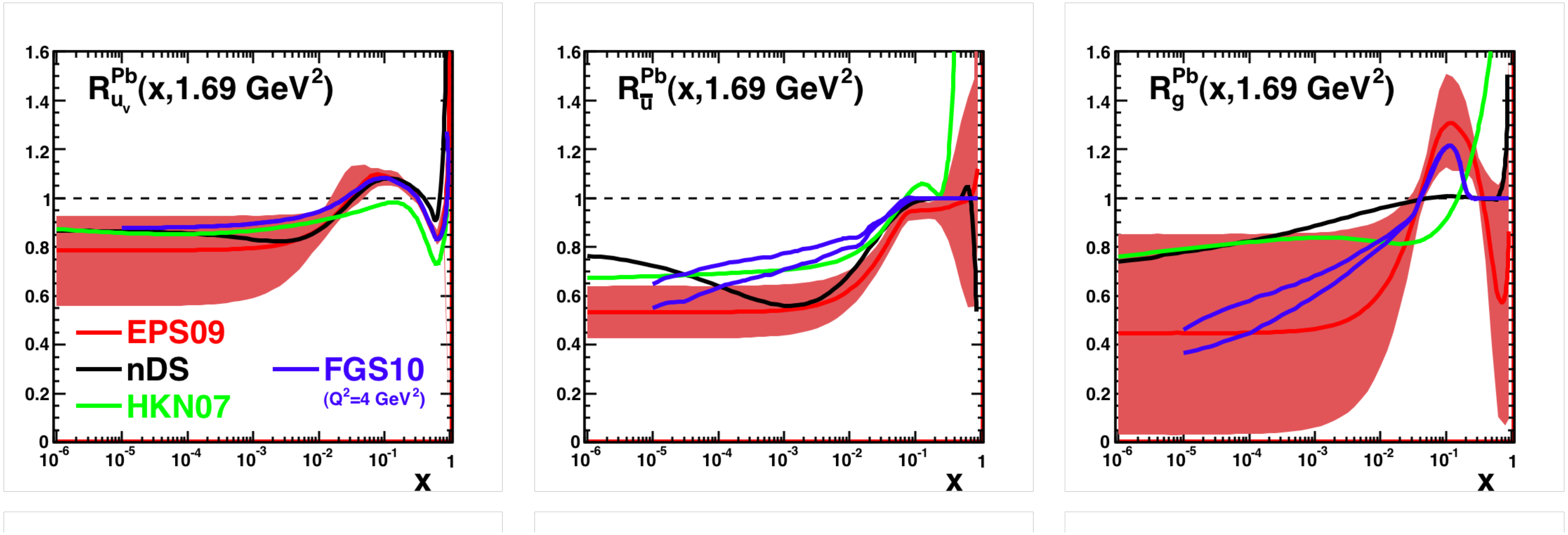
Different W behavior depending whether saturation is included or not.

Simulated data are from extrapolated fit to HERA data

LHeC can distinguish between the different scenarios.

What is Initial State of LHC AA Collisions?

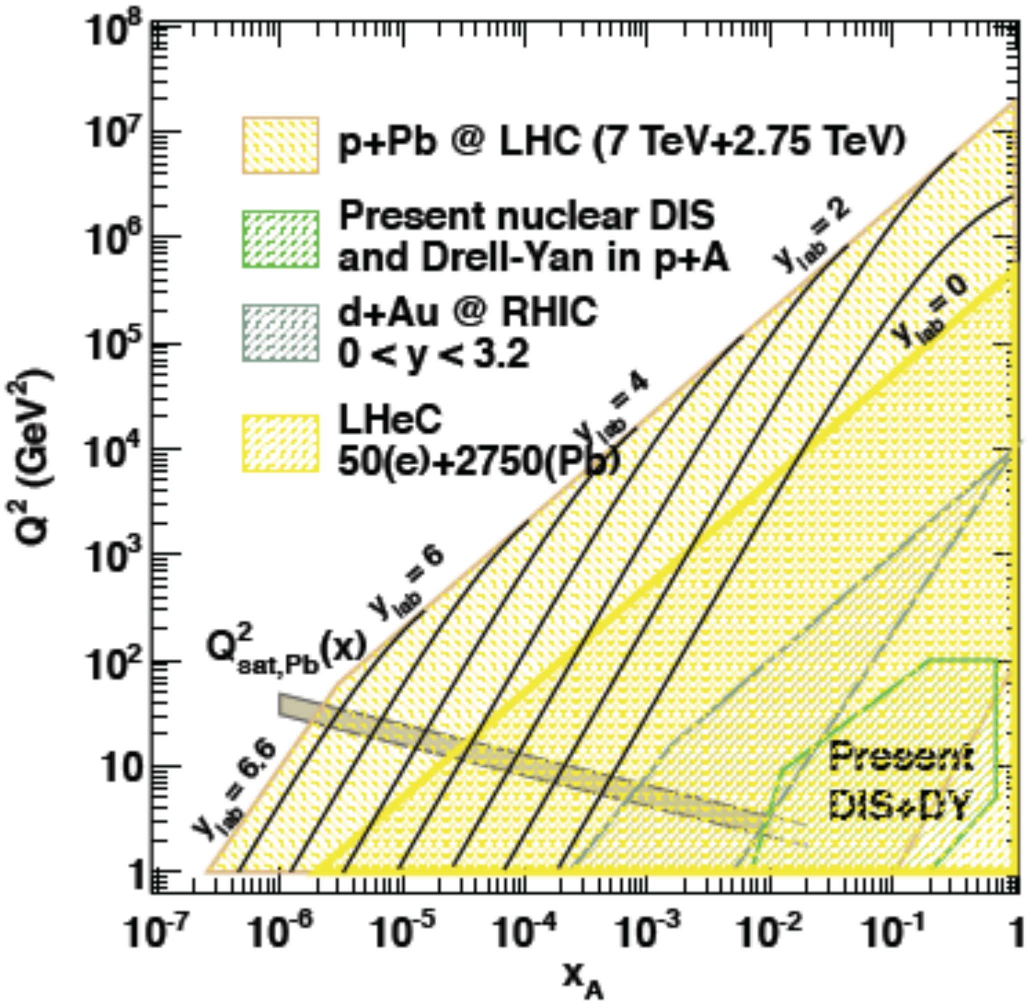




R_i = Nuclear PDF i / (A * proton PDF i)

Nuclear PDFs (Carlos Salgado)

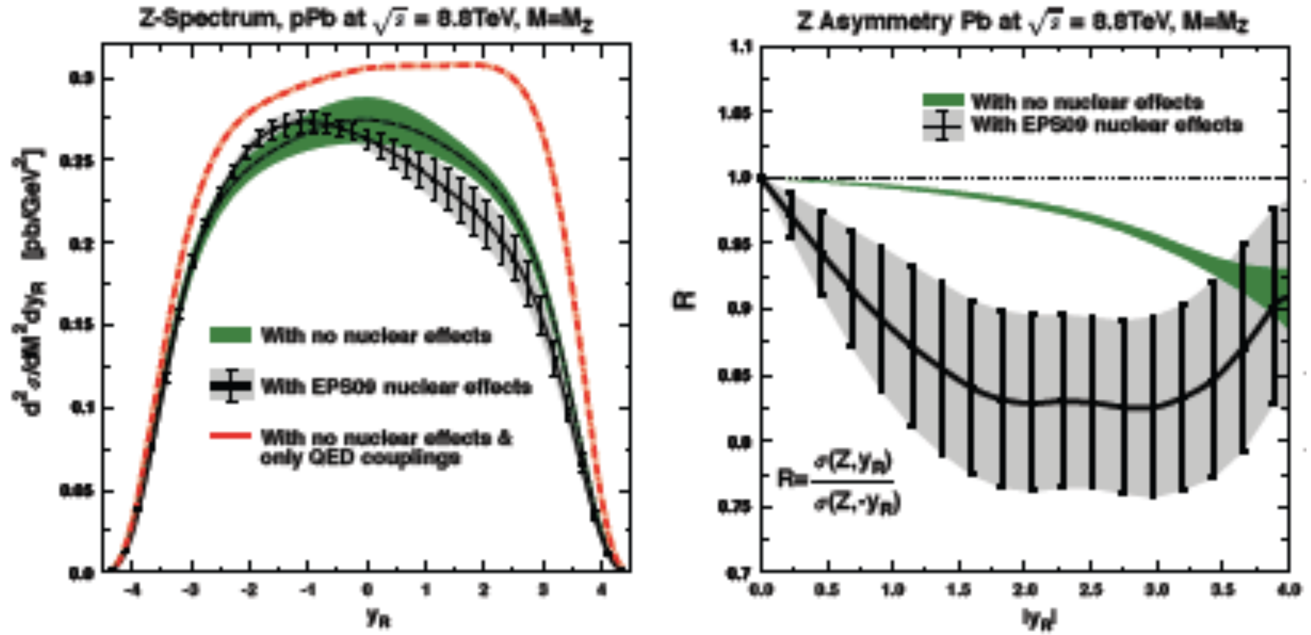
Kinematical reach in nuclear collisions



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

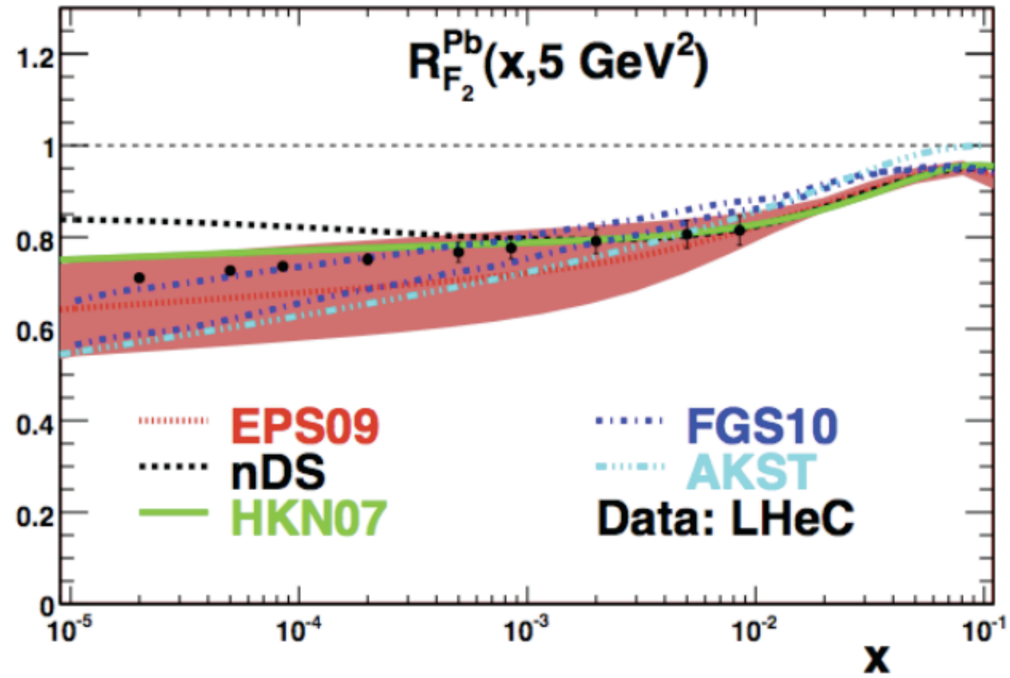
No substitute for low x DIS data

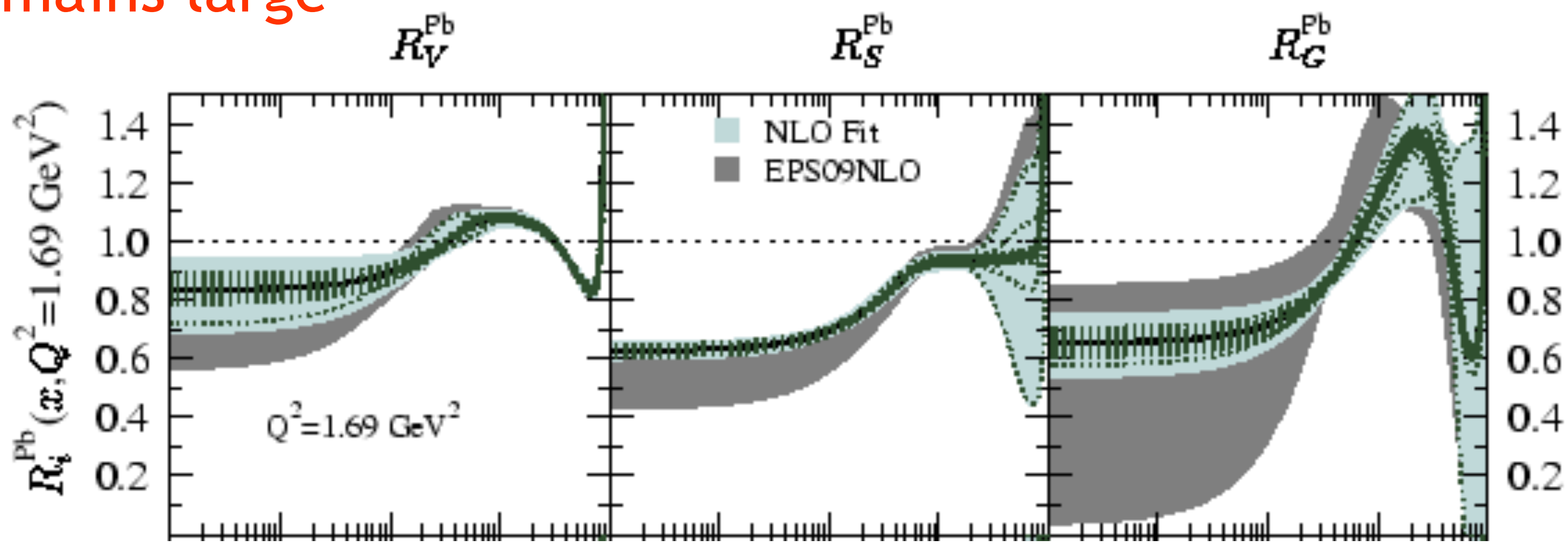
Study of Impact of e-Pb LHC data

- 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



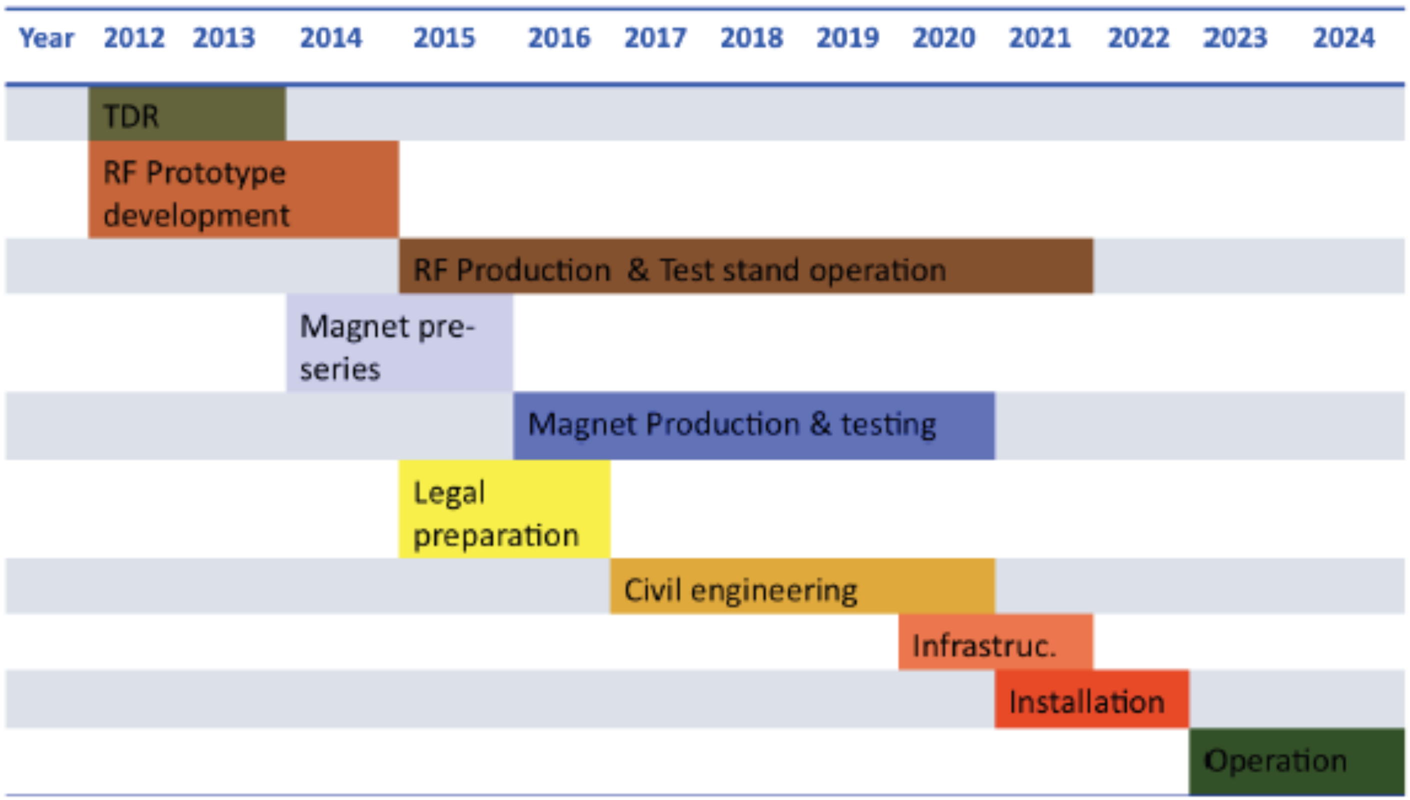


LHeC Physics Studies I didn't cover

eD scattering
α_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 π^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