EPAC08
Genoa
June 23 to
June 27 2008

Prospects for a Large Hadron-electron Collider (LHeC) at the LHC

John Dainton

Cockcroft Institute and Univ Liverpool, UK

1. Leptons and Quarks at the Terascale
2. The LHeC
3. Summary

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LHeC @ EPAC08

F Bordry, H-H Braun, O S Brüning, H Burkhardt, A de Roeck, R Garoby, T Linnecar, K-H Mess, J Osborne, L Rinolfi, D Schulte, R Tomas, J Tuckmantel, F Zimmermann (CERN, Geneva), A Eide (EPFL, Lausanne), F J Willeke (BNL, NY), S Chattopadhyay, J Dainton (Cockcroft Institute and Univ. Liverpool), M Klein (Univ. Liverpool), B Holzer (DESY, Hamburg), A Vivoli (LAL, Orsay), S Sultansoy (TOBB ETU, Ankara), A K Ciftci (Univ. Ankara), H Aksakal (Univ. Nigde)

http://www.lhec.org.ac.uk

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1. Leptons and Quarks at the Terascale

Why Leptons ↔ Quarks ?

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- how are leptons and quarks related ?

THE UNCONFINED QUARKS AND GLUONS

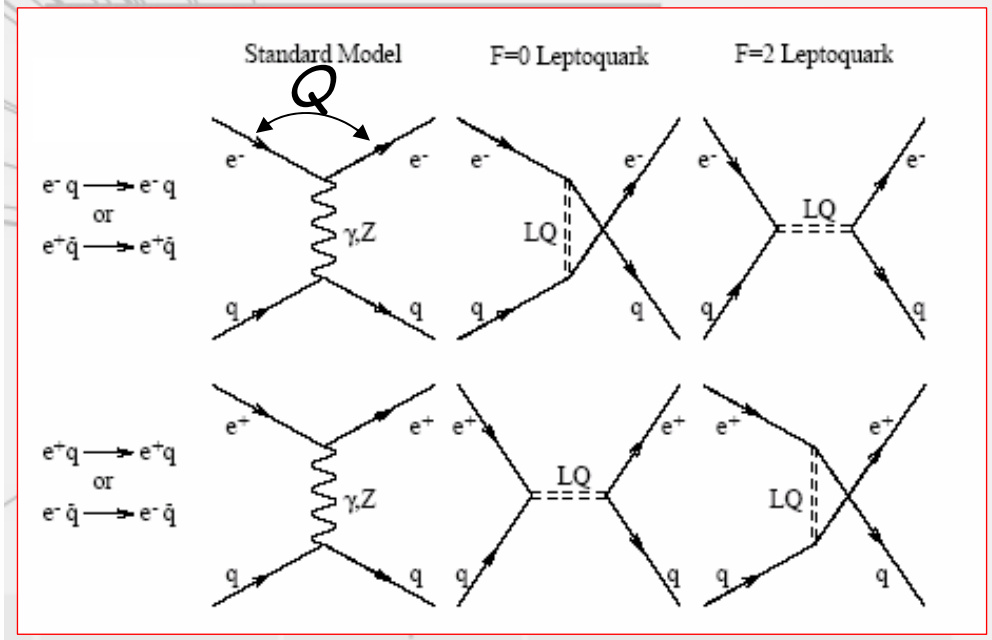
Abdus Salam

International Centre for Theoretical Physics, Trieste, Italy and Imperical College, London, England

1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

ICHEP76 Tblisi



- put them together at the highest energy in the finest detail $\Delta x \Delta Q \sim \hbar$

ep @ 100 GeV: 25 years on

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- Genova 1983
  - HERA collider begins construction
  - meeting to discuss experiments
  - 2 collaborations formed: H1 and ZEUS
- DESY Hamburg 1992
  - HERA *ep* collider begins data-taking
    triumph of accelerator physics
    world's first energy-frontier collider of different particle species
- Dallas ICHEP conference 1992
  - first results → unique $eq \leq 300$ GeV (~ $1 fb^{-1}$)
- DESY Hamburg 2007
  - last collisions and last data taken

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A "100 GeV" scale precision Collider HERA @ DESY

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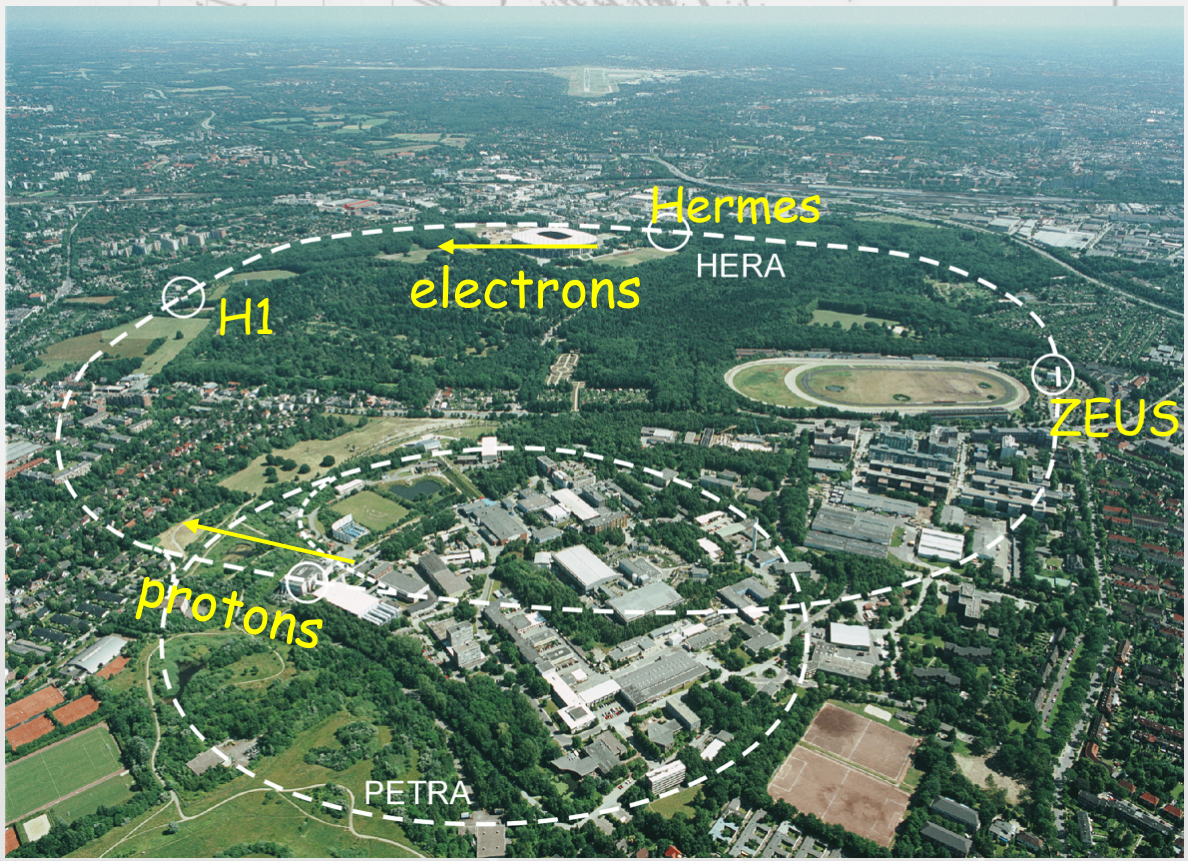
- accelerate beams to "head-on" collision
  27.6 GeV electrons + 920 GeV protons

HERA
DESY
Hamburg



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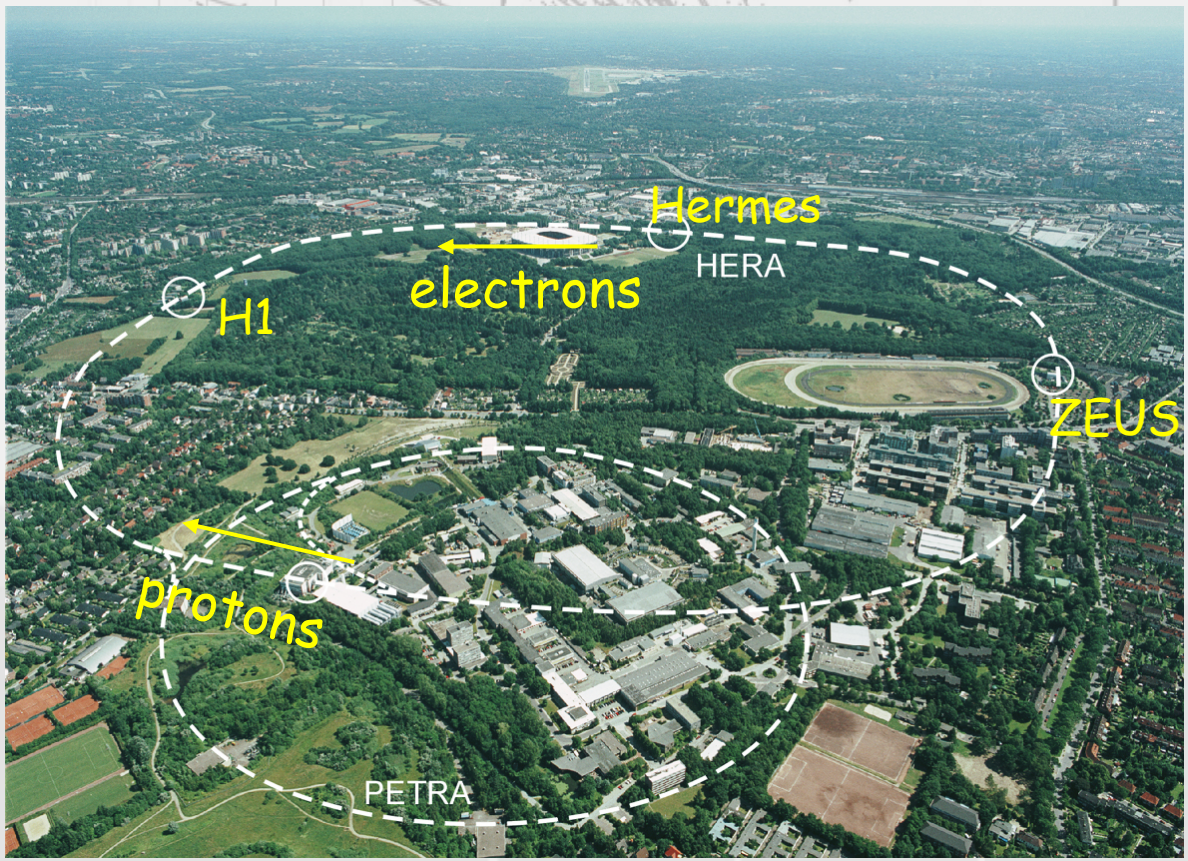
- challenge: different particle species *ep* in collision

27.6 GeV electrons + 920 GeV protons ← *uud* +sea

lepton

HERA
DESY
Hamburg



HERA
+
1992-2007
RIP

Phenomenology

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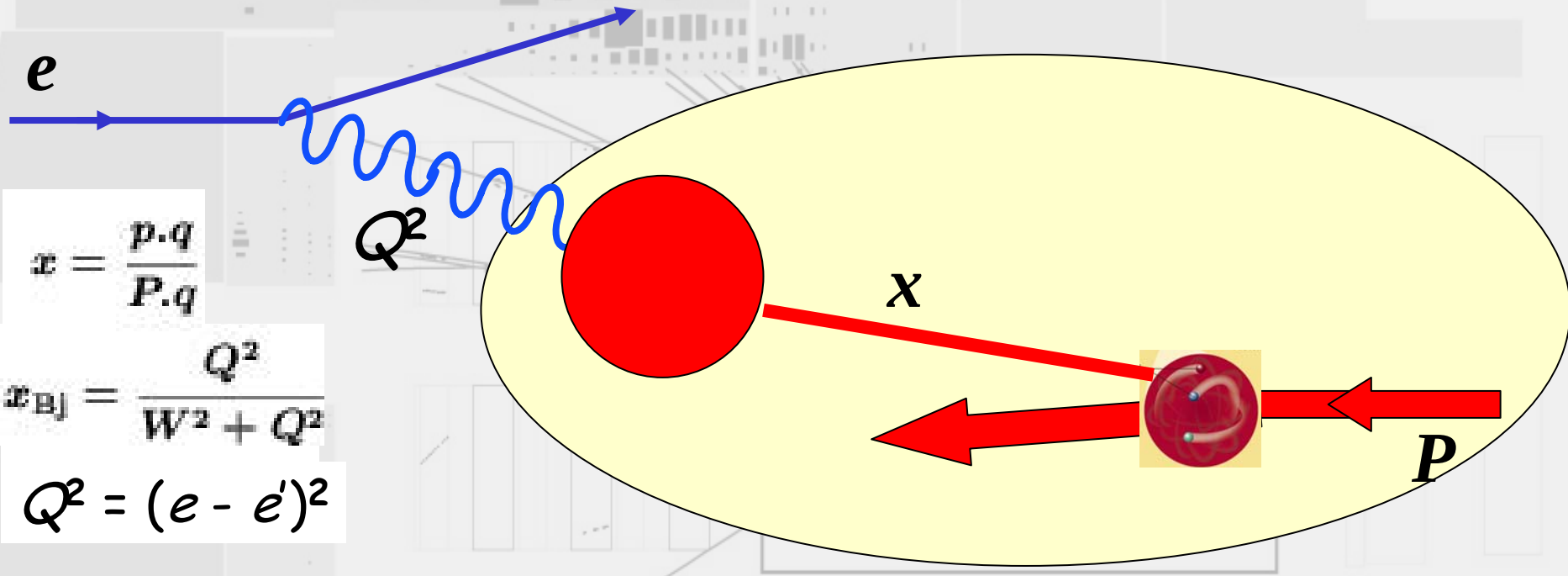


$$x = \frac{p.q}{P.q}$$

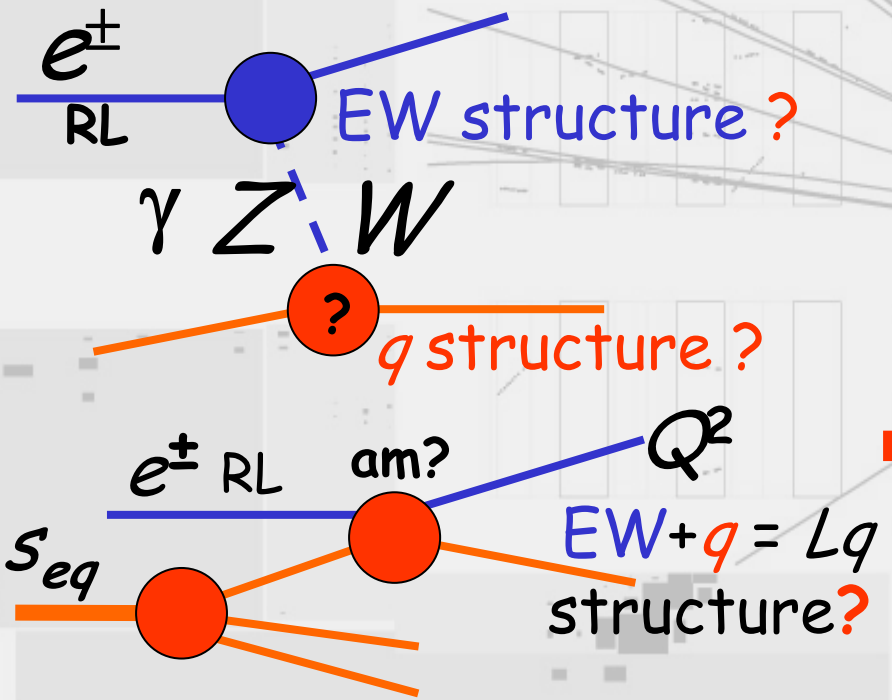
$$x_{Bj} = \frac{Q^2}{W^2 + Q^2}$$

$Q^2 = (e - e')^2$

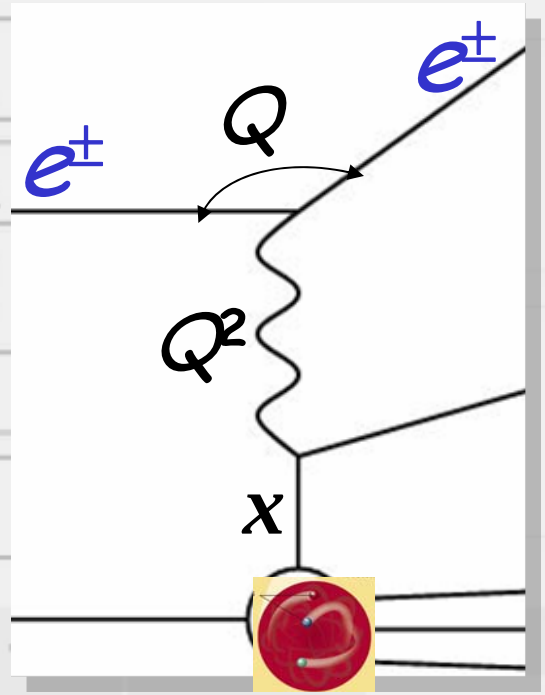
- $x \rightarrow$ fractional momᵐ of struck piece of hadron
  - $\rightarrow$ "inelasticity" of struck parton
  - $\rightarrow$ how "far removed from parent hadron properties" is parton

Phenomenology

- $Q^2 \rightarrow$ -(4-momentum xfer)^2
  $\rightarrow$ Q resolves spatial detail $\Delta x \Delta Q \sim 0.2$ GeV·fm



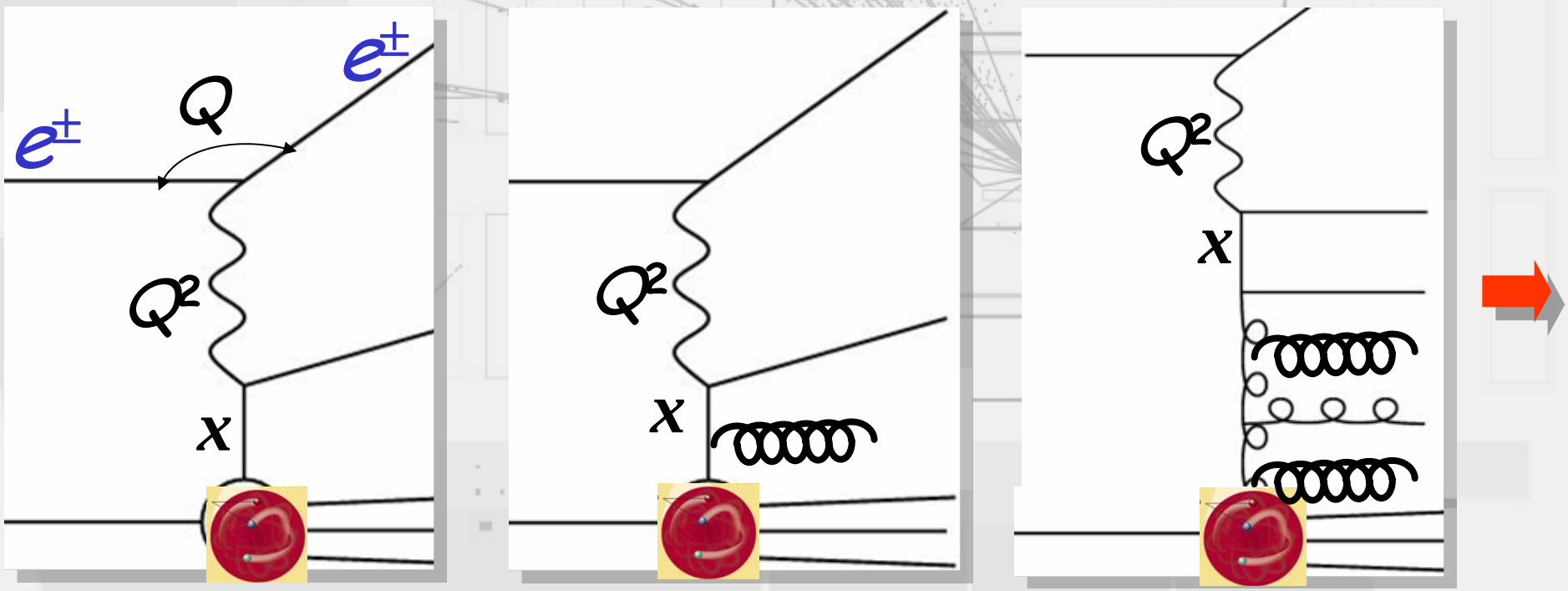
HERA @ 300 GeV



↳ no evidence for sub-structure of q e γ Z W @ HERA

Phenomenology

- $x \rightarrow$ fractional momᵐ of struck piece of hadron
  $\rightarrow$ "inelasticity" of struck quark
  how "far removed from parent properties"



increasing x

low x physics

A "100 GeV" scale precision Collider HERA @ DESY

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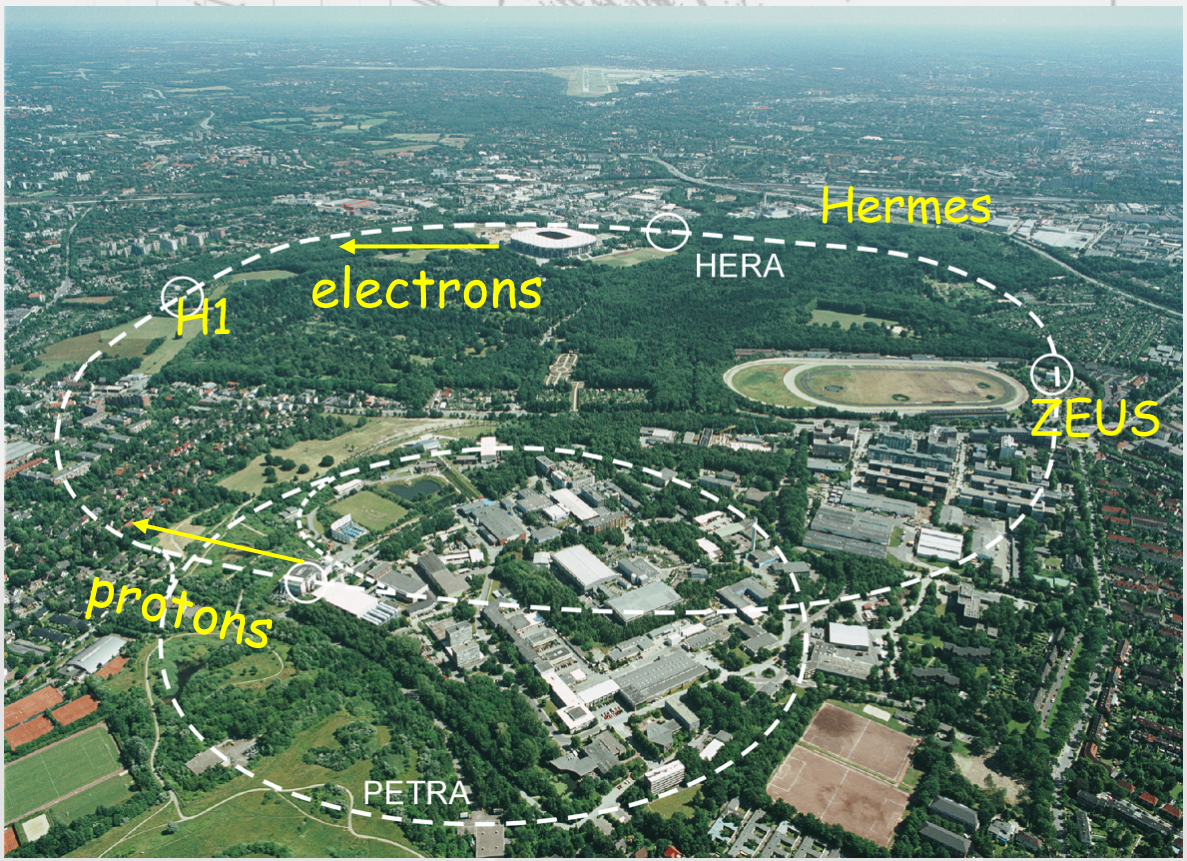
- challenge: different particle species *ep* in collision

27.6 GeV electrons + 920 GeV protons ← *uud* +sea

lepton

HERA
DESY
Hamburg



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- challenge: different particle species *ep* in collision
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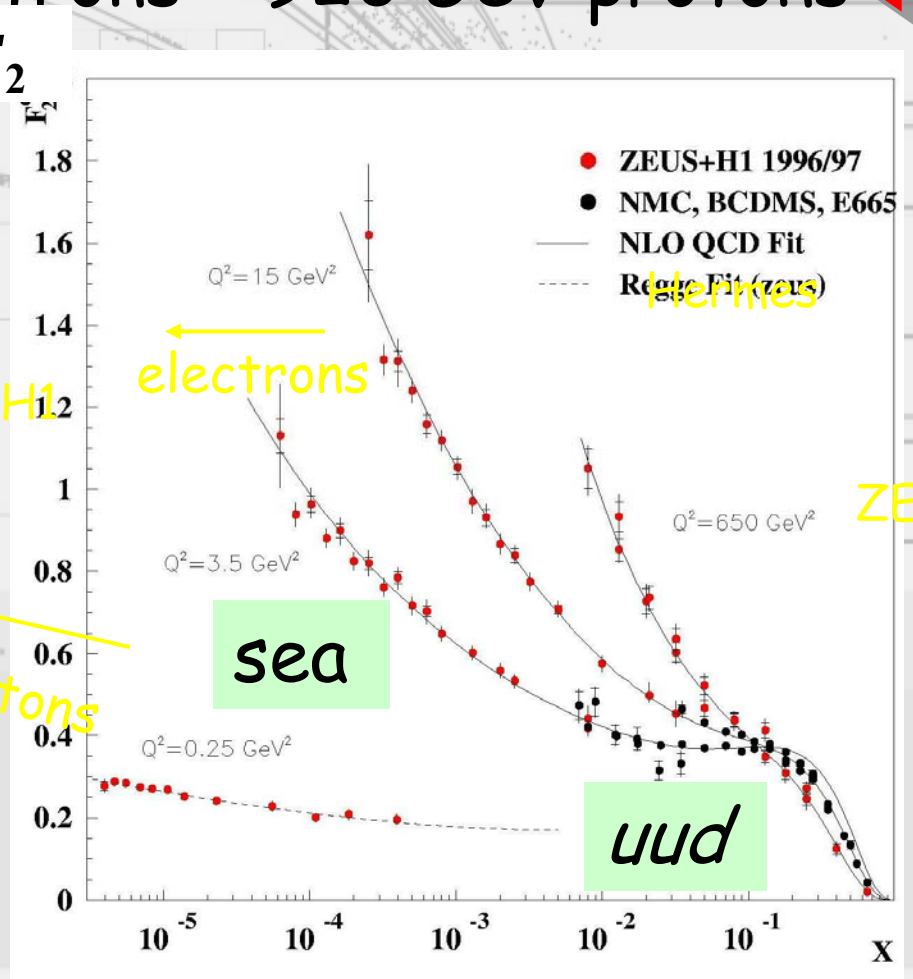
lepton



HERA

- low x
  - steep rise of *q* density
  - for ever ?

HERA
+

1992-2007
RIP

EPAC08
1st post HERA

HERA: *Lq* physics @ 100 GeV?

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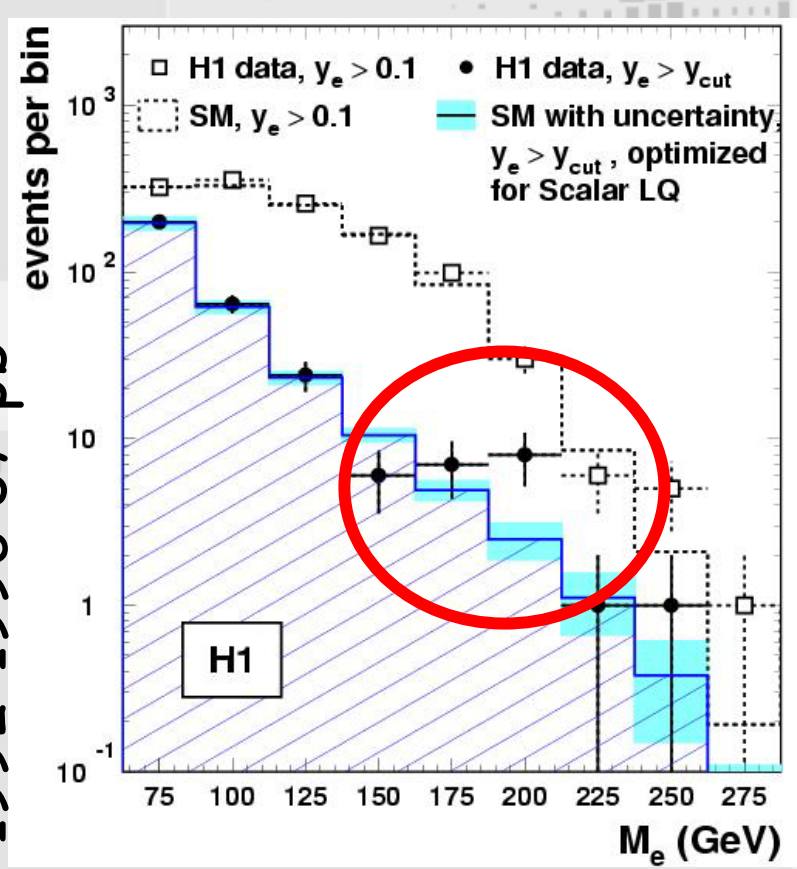
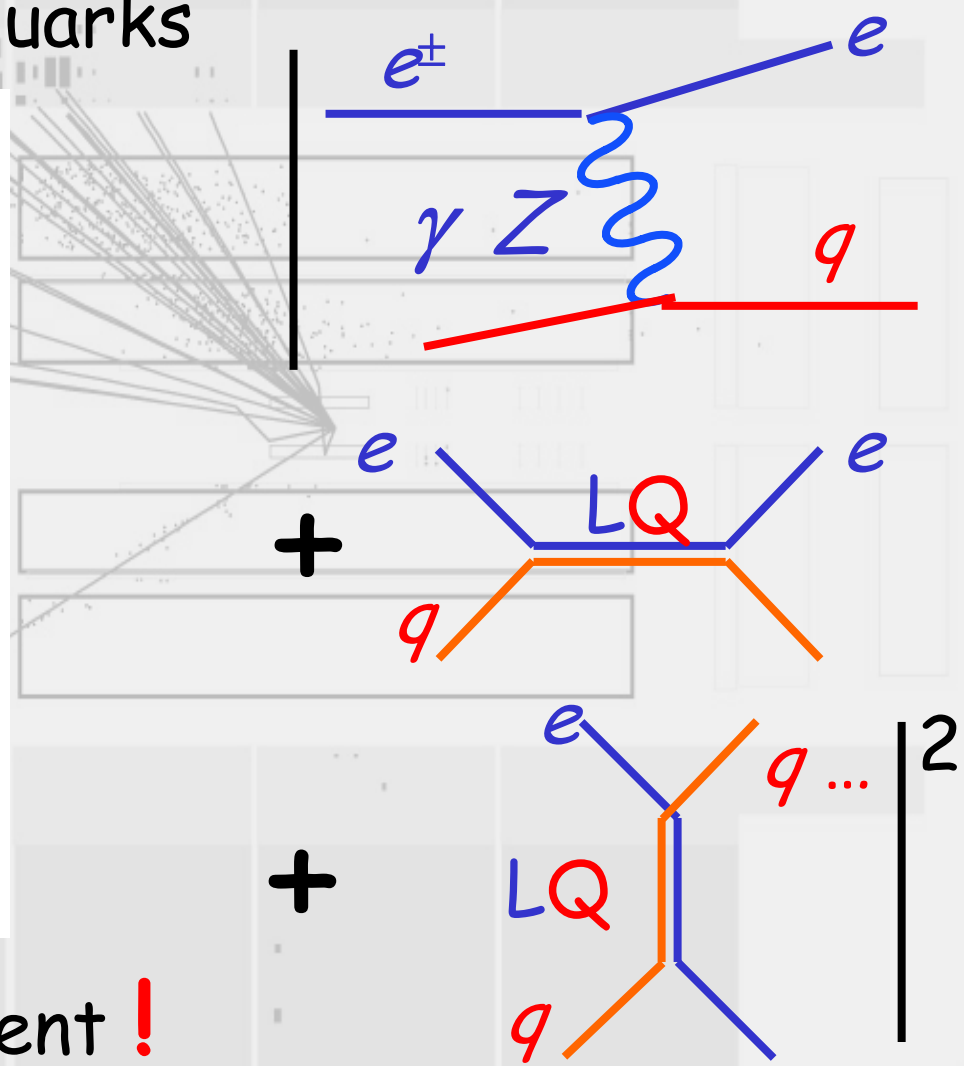
- new *eq* physics - leptoquarks



experiment #1
1992-1996 37 pb-1



- SM theory ↔ experiment !

HERA: *Lq* physics @ 100 GeV?

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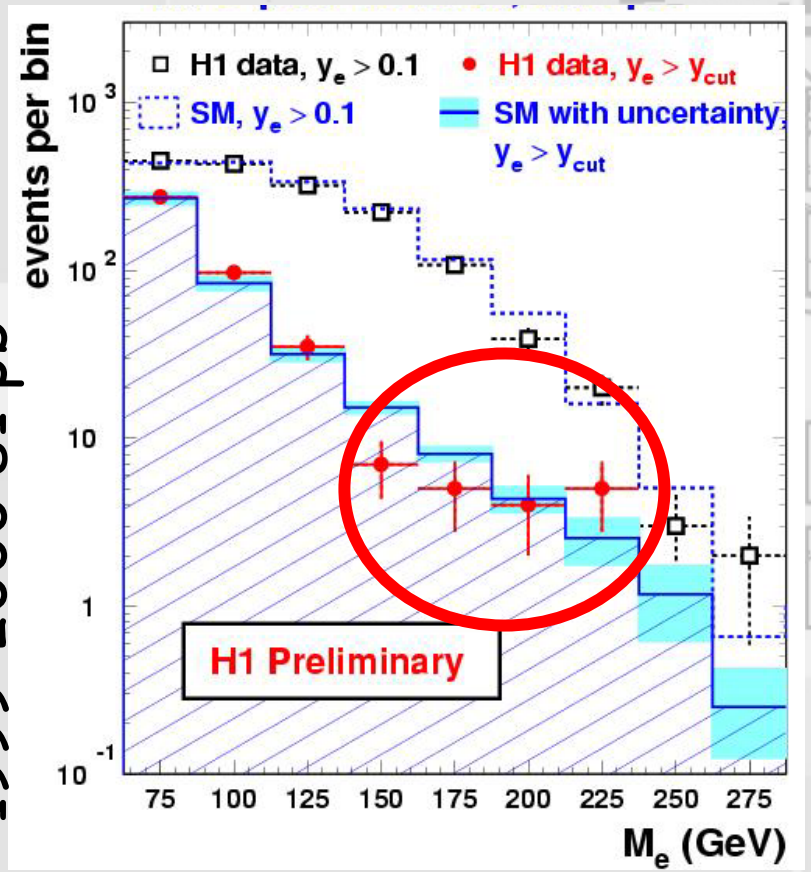
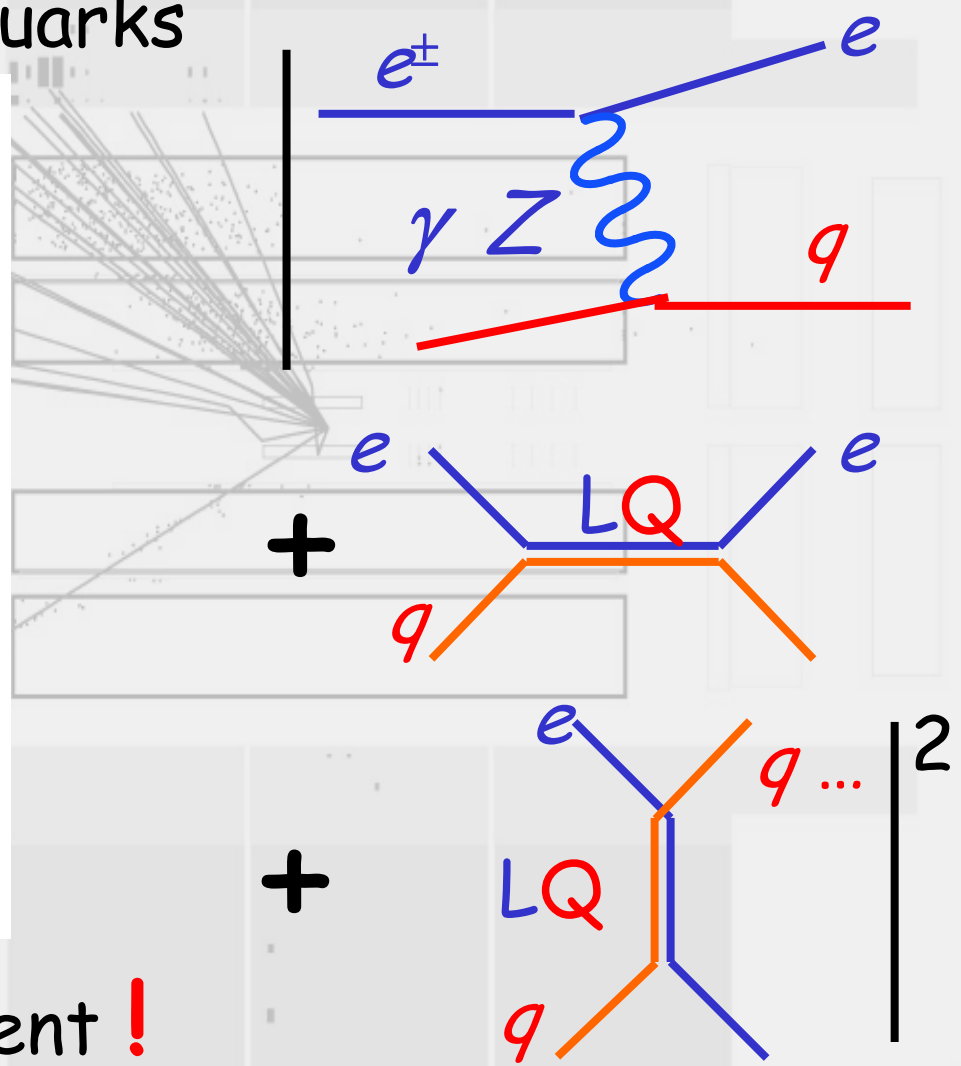
- new *eq* physics - leptoquarks



experiment #2
1999-2000 81 pb-1



- SM theory ↔ experiment !

HERA: *Lq* physics @ 100 GeV?

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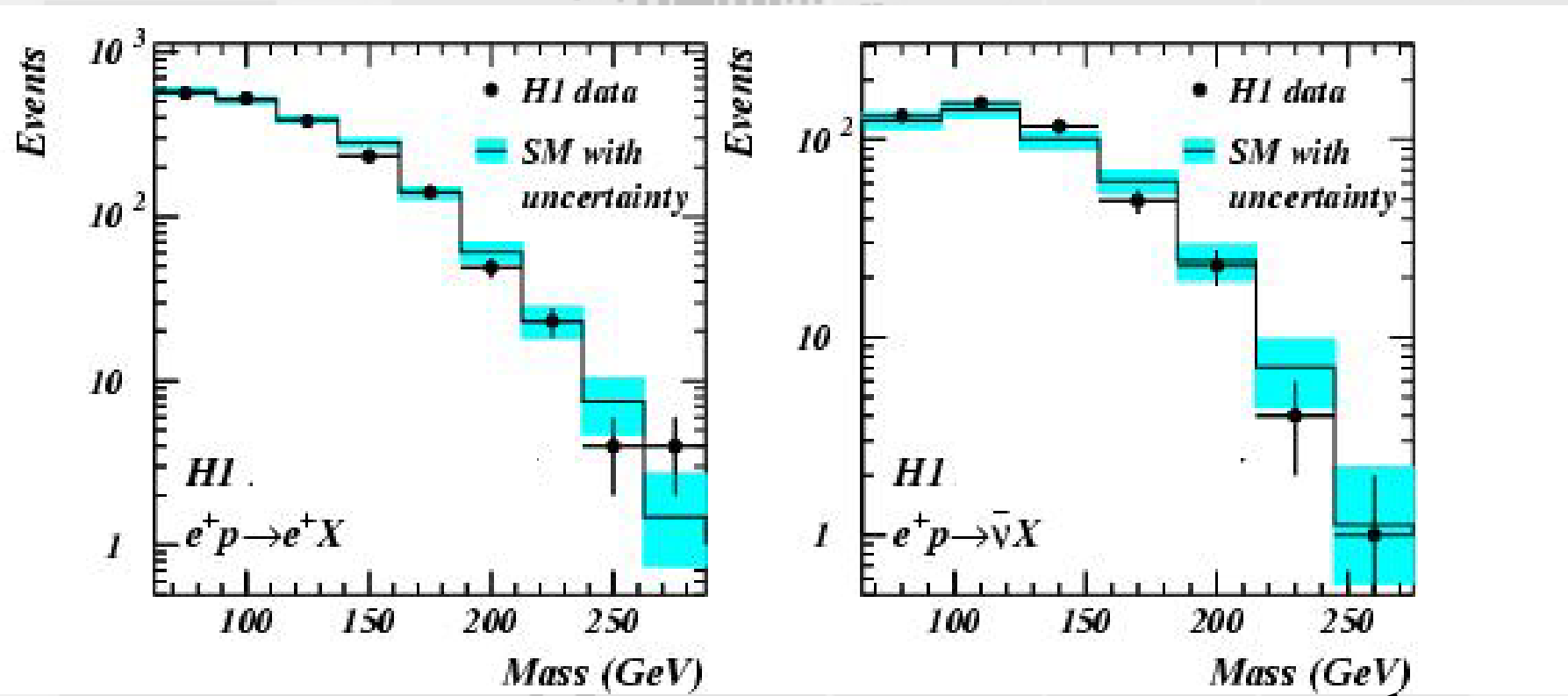
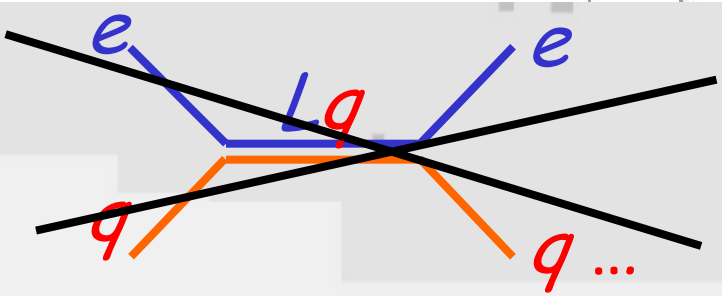
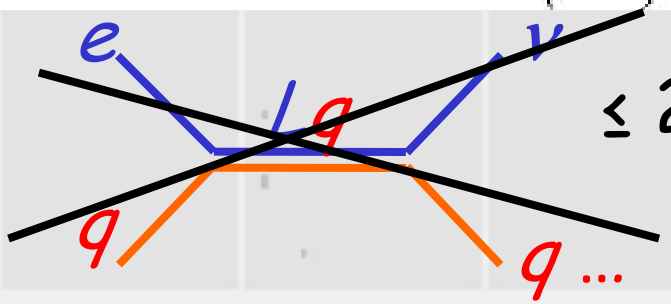
- new *eq* physics – 1992-2000 120 pb^{-1}







≤ 200 GeV
TeV ?

HERA: Quarks @ 100 GeV ?

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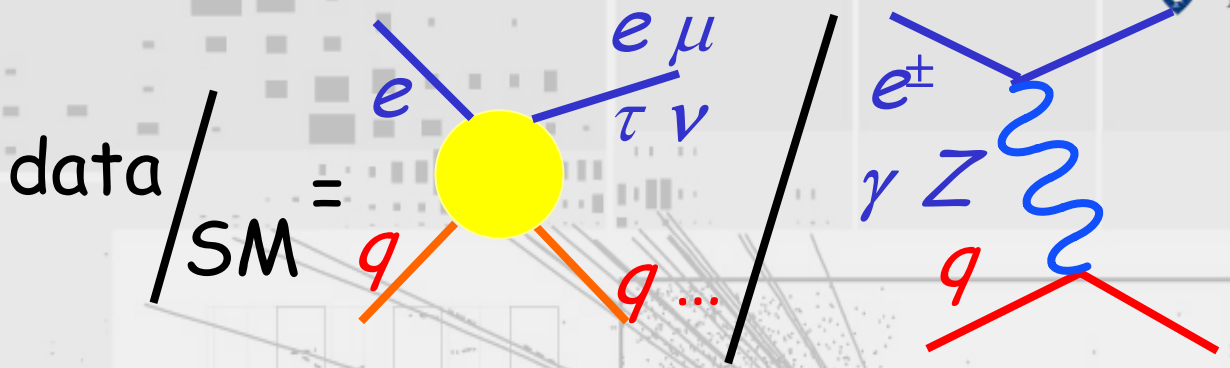

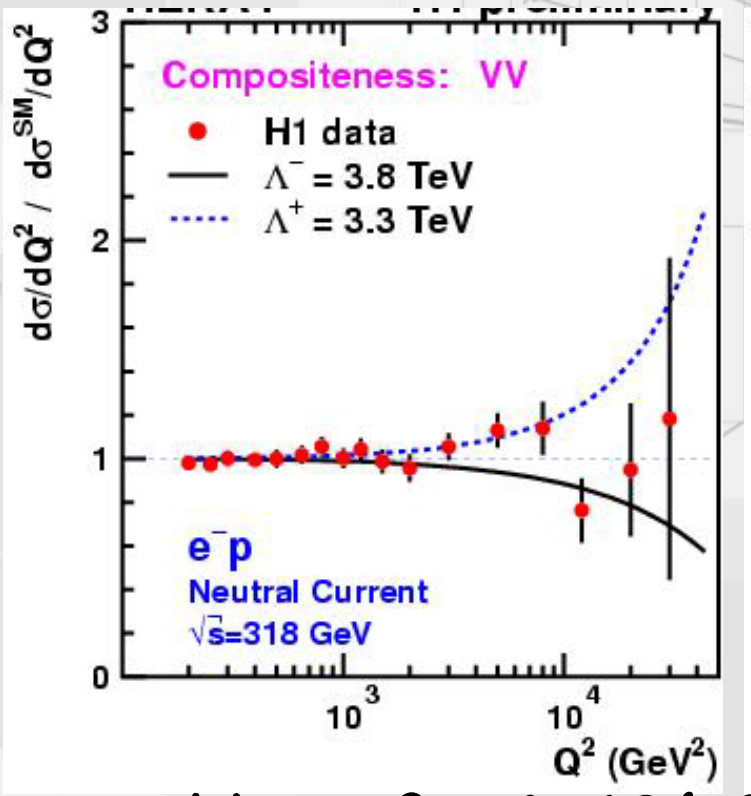

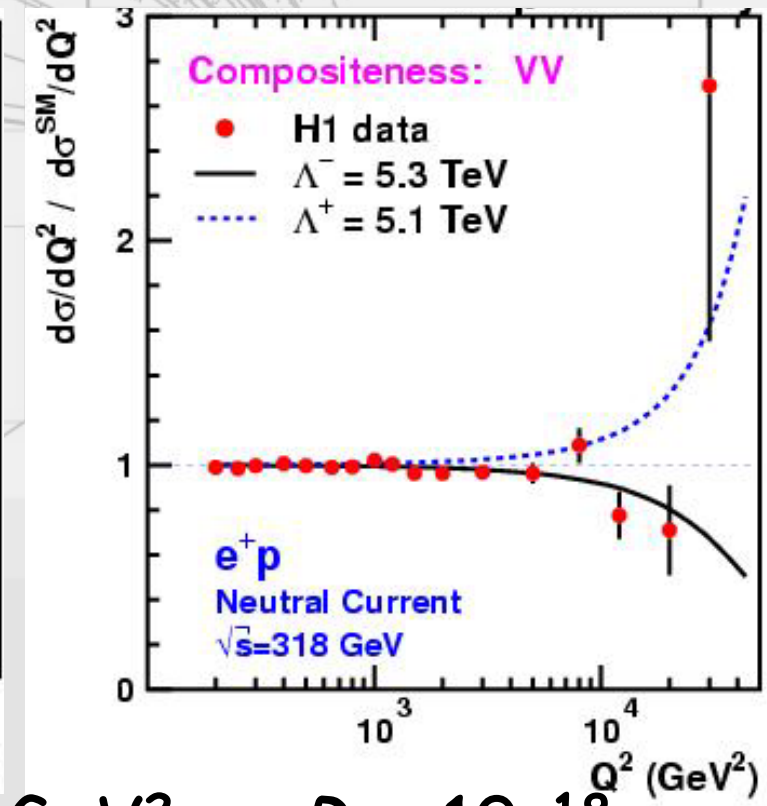

- point-like $Q^2 \leq 4 \times 10^4$ GeV^2 $\rightarrow$ $R_q < 10^{-18}$ m = 1 am

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A "TeV" scale precision Collider LHeC @ DESY

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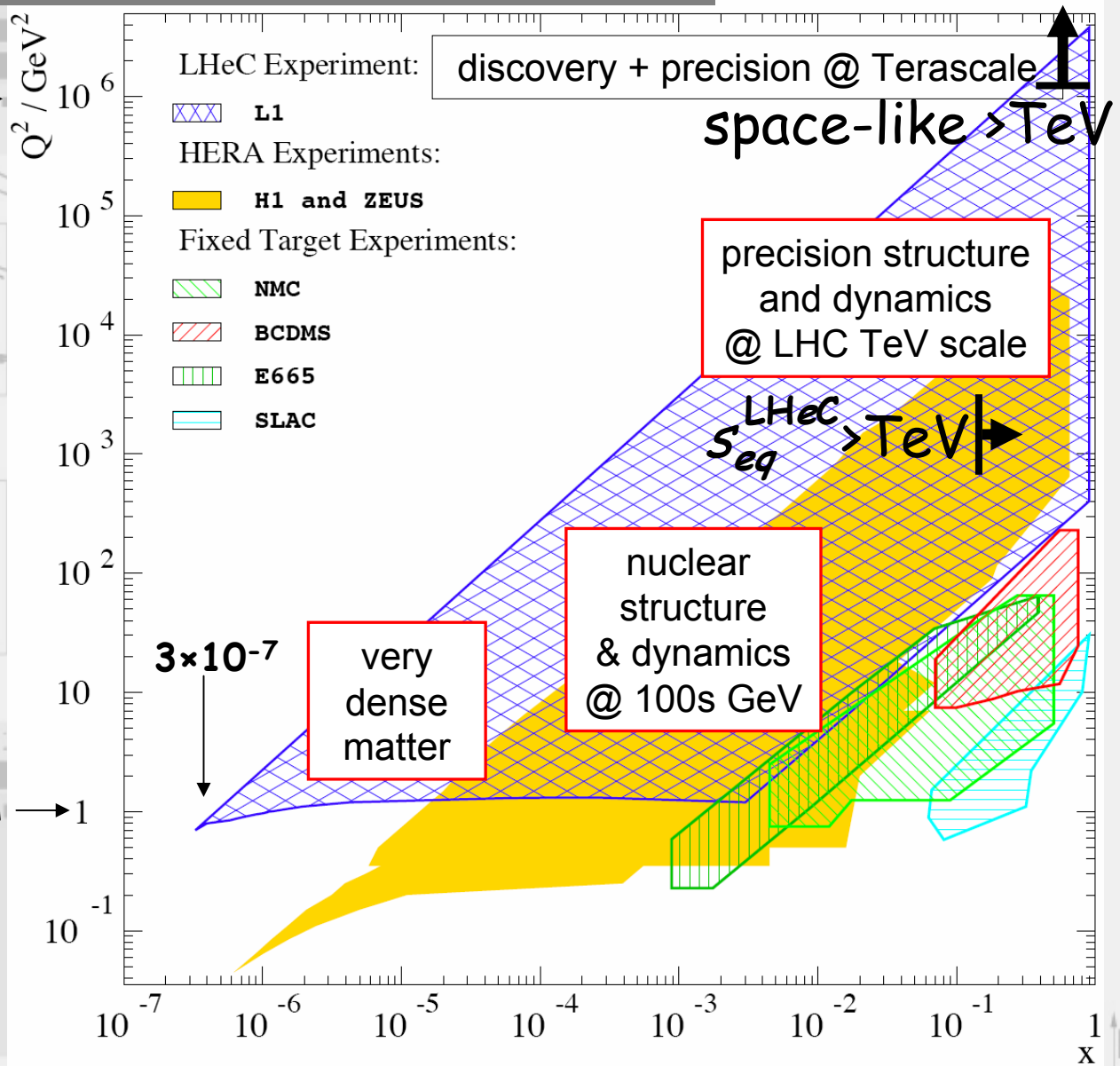
- 70 ⊗ 7000 GeV
  $e \otimes p$ or ion A
  - cm energy 1400 GeV
- e-ring ⊗ LHC
- e-linac ⊗ LHC



Lepton+quark @ TeV

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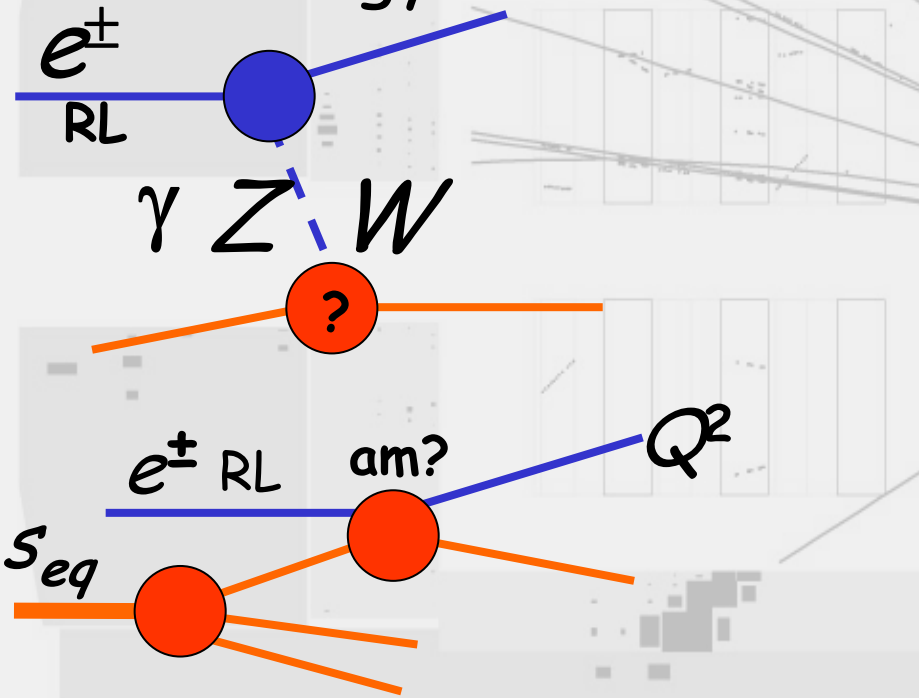
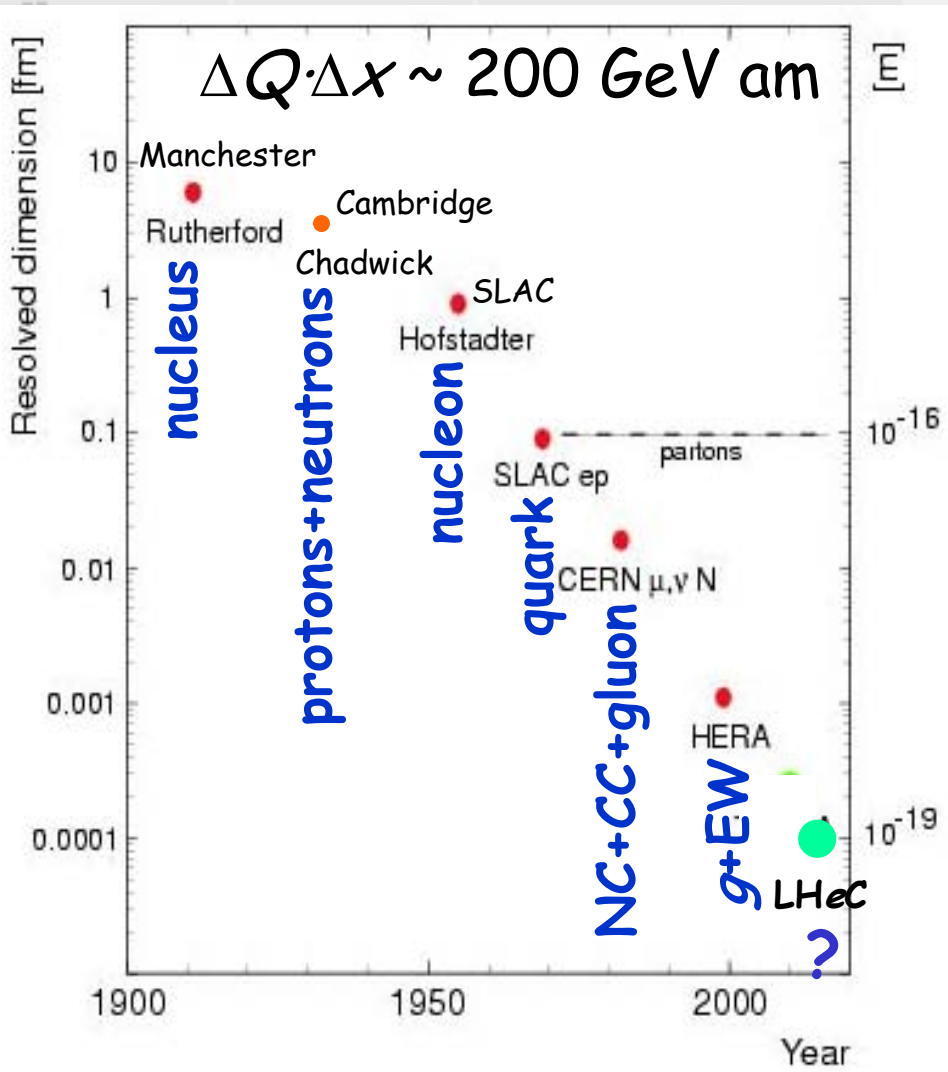
- unique chiral probe @ 0.0001 fm ?
- 70 $e^{\pm} \otimes p$ 7000 GeV
  cm energy 1400 GeV



SM + new *Lq* physics
@ ~ 0.0001 fm ?



Lepton+quark @ TeV

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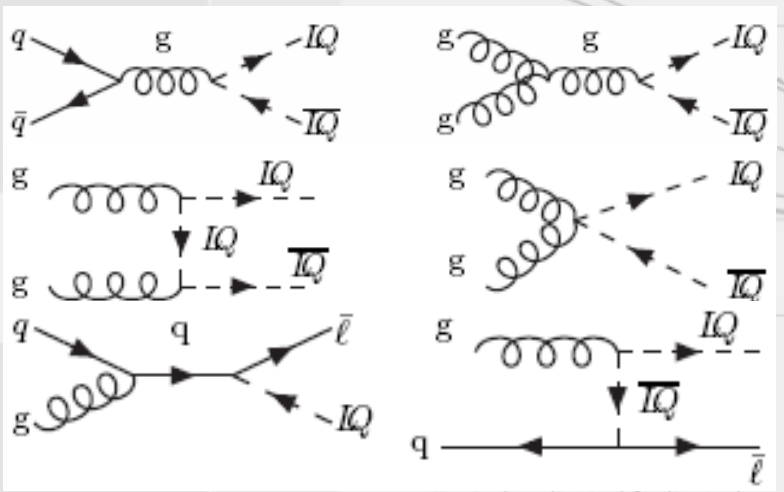
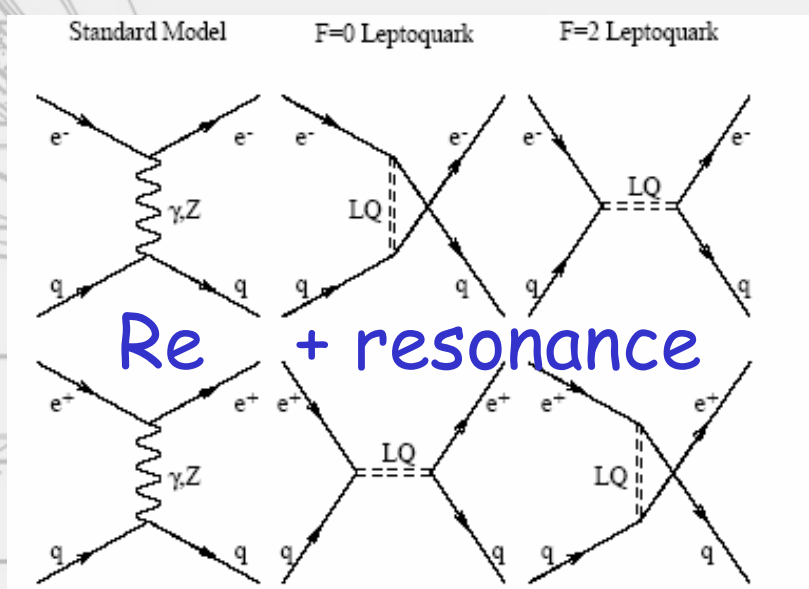
- leptoquark systems – new physics + SM

LHC



LHeC



SM (hadronic) + signal

Lq & *LqLq* production

σ ~ few × 0.1 fb (Λ = 0.1)

SM (electroweak) + signal

Lq formation

σ ~ 100 fb (Λ = 0.1)

Lepton+quark @ TeV

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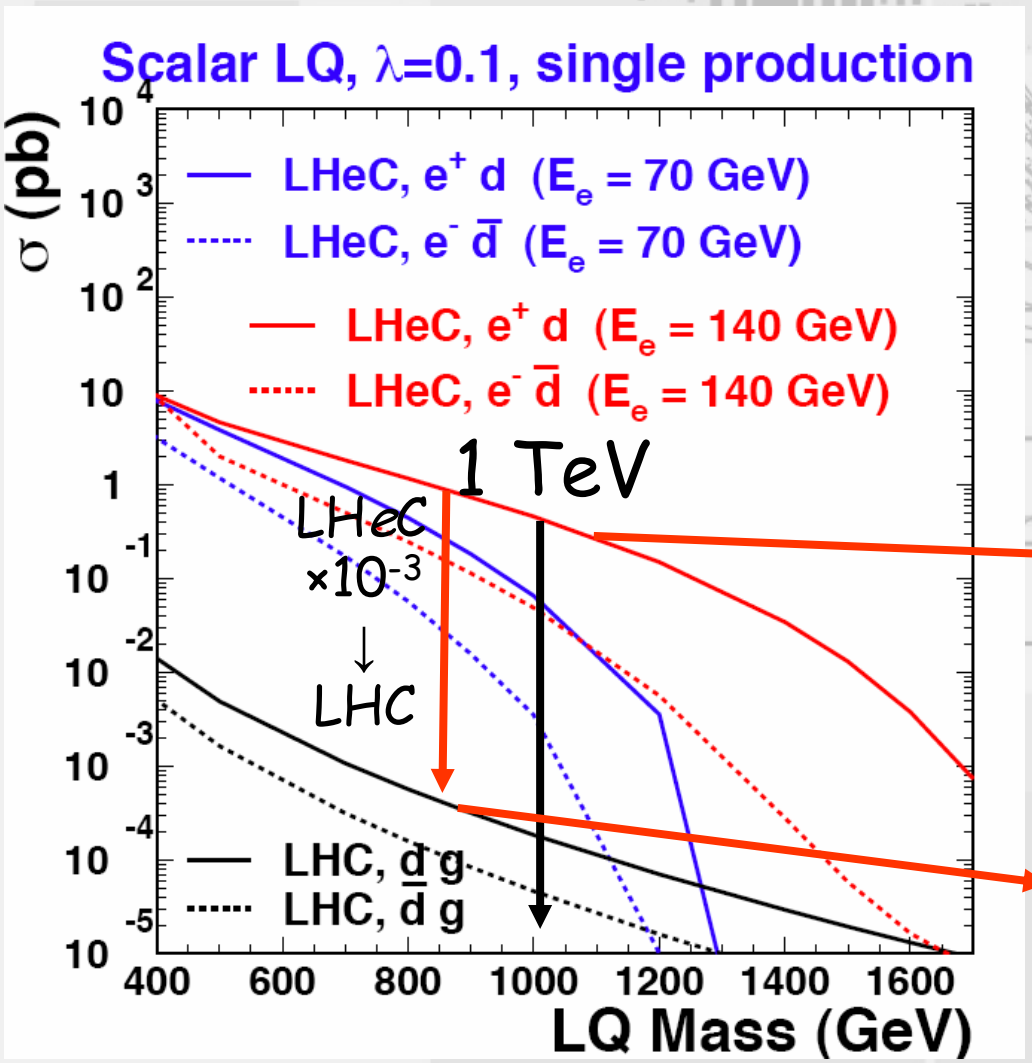
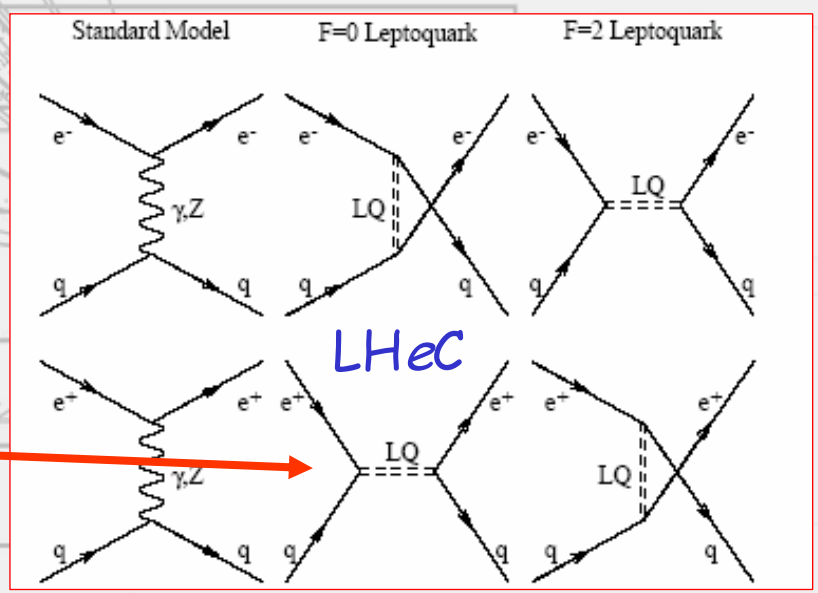
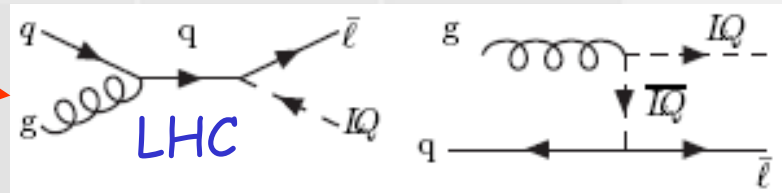
- leptoquark systems – new physics +SM







Low-x @ TeV

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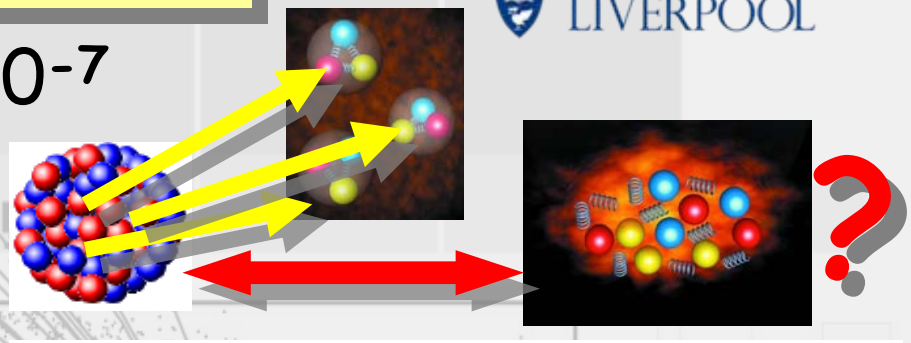
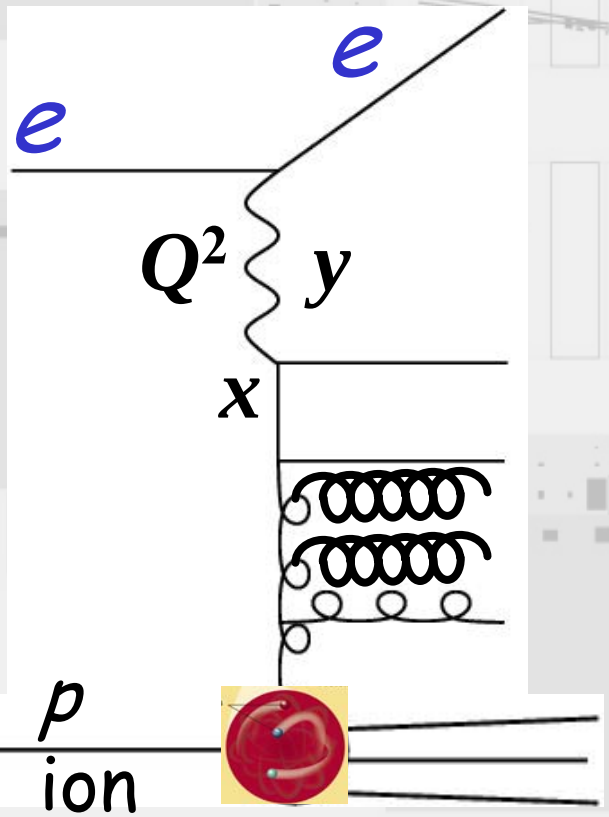
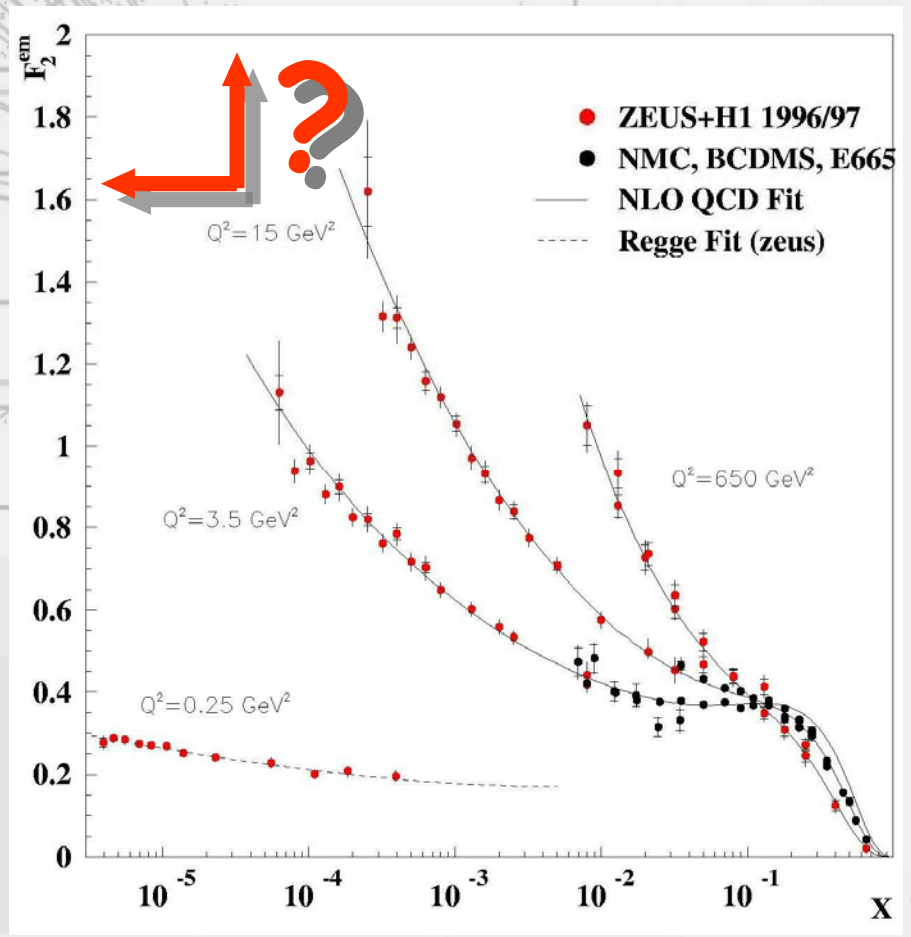
- LHeC: $Q^2 \geq 1\ GeV^2$ $x \geq 5\times10^{-7}$
  - parton recombination
  - "saturation"
  - dense hadronic matter







Low-x @ TeV

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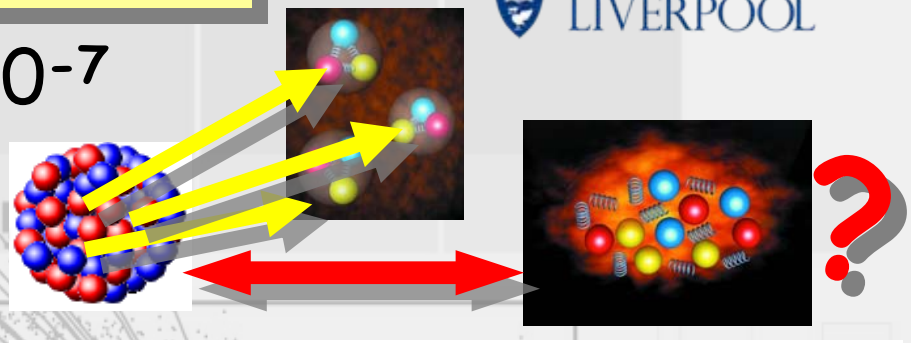

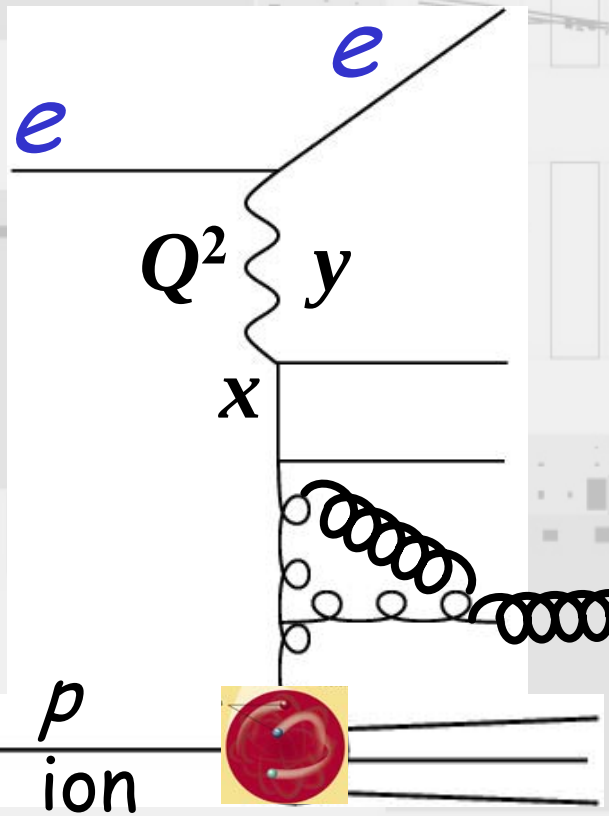

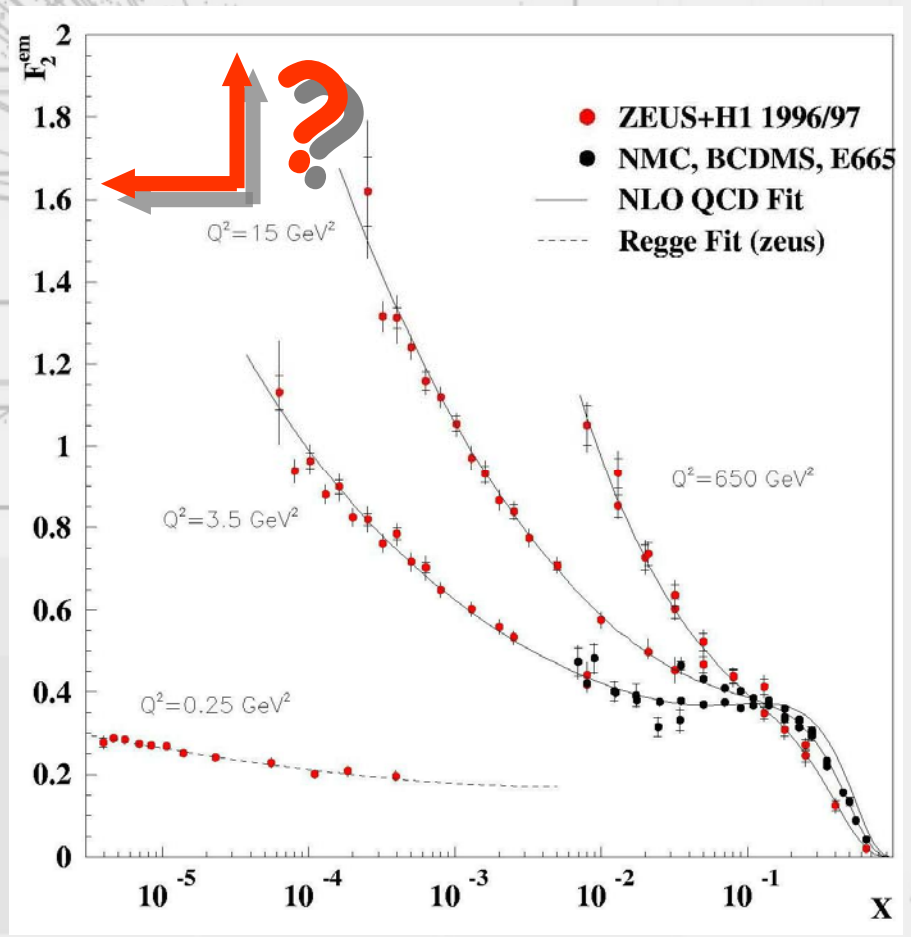

The Energy Frontier

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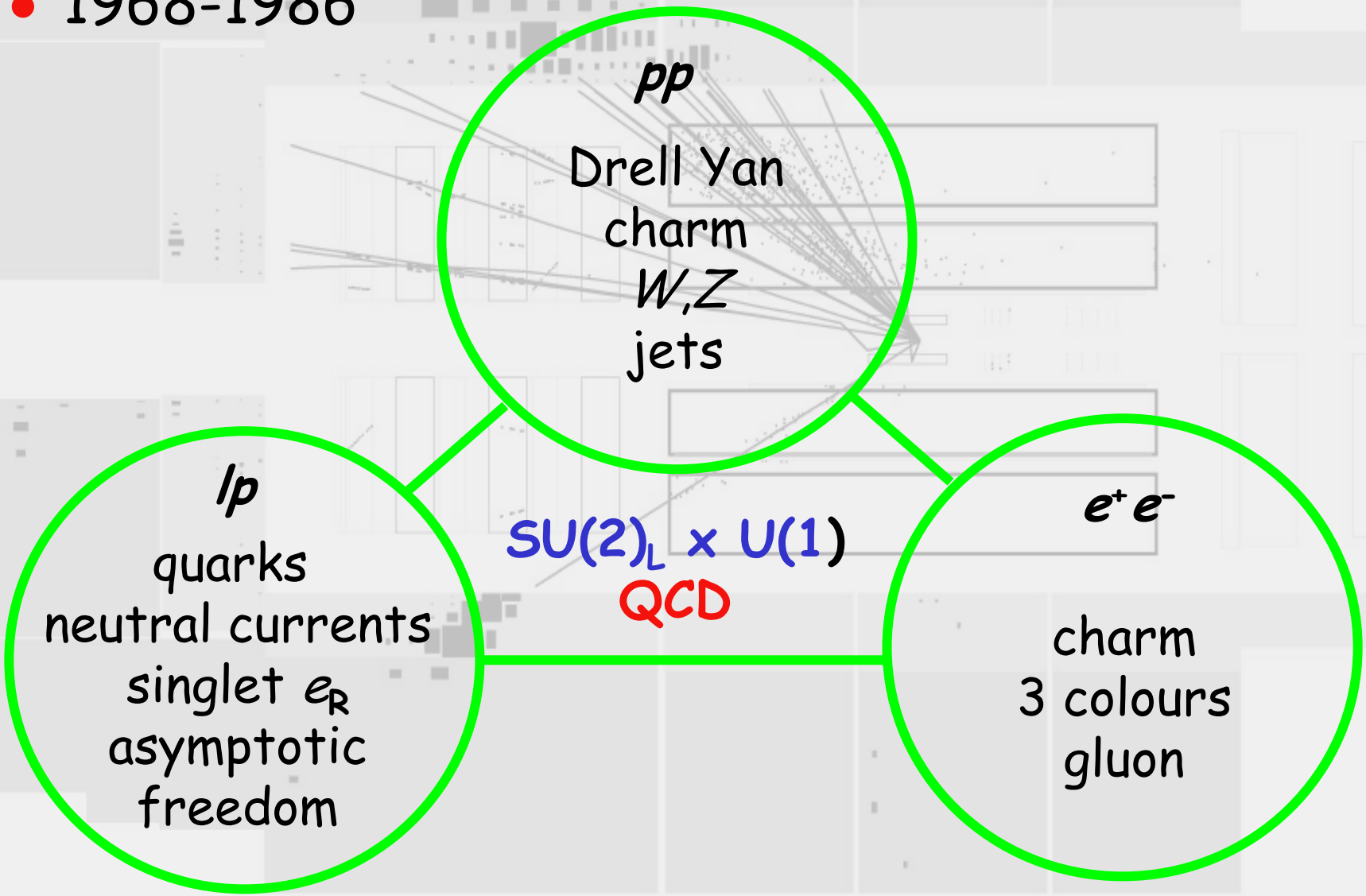
- 1968-1986



The Energy Frontier

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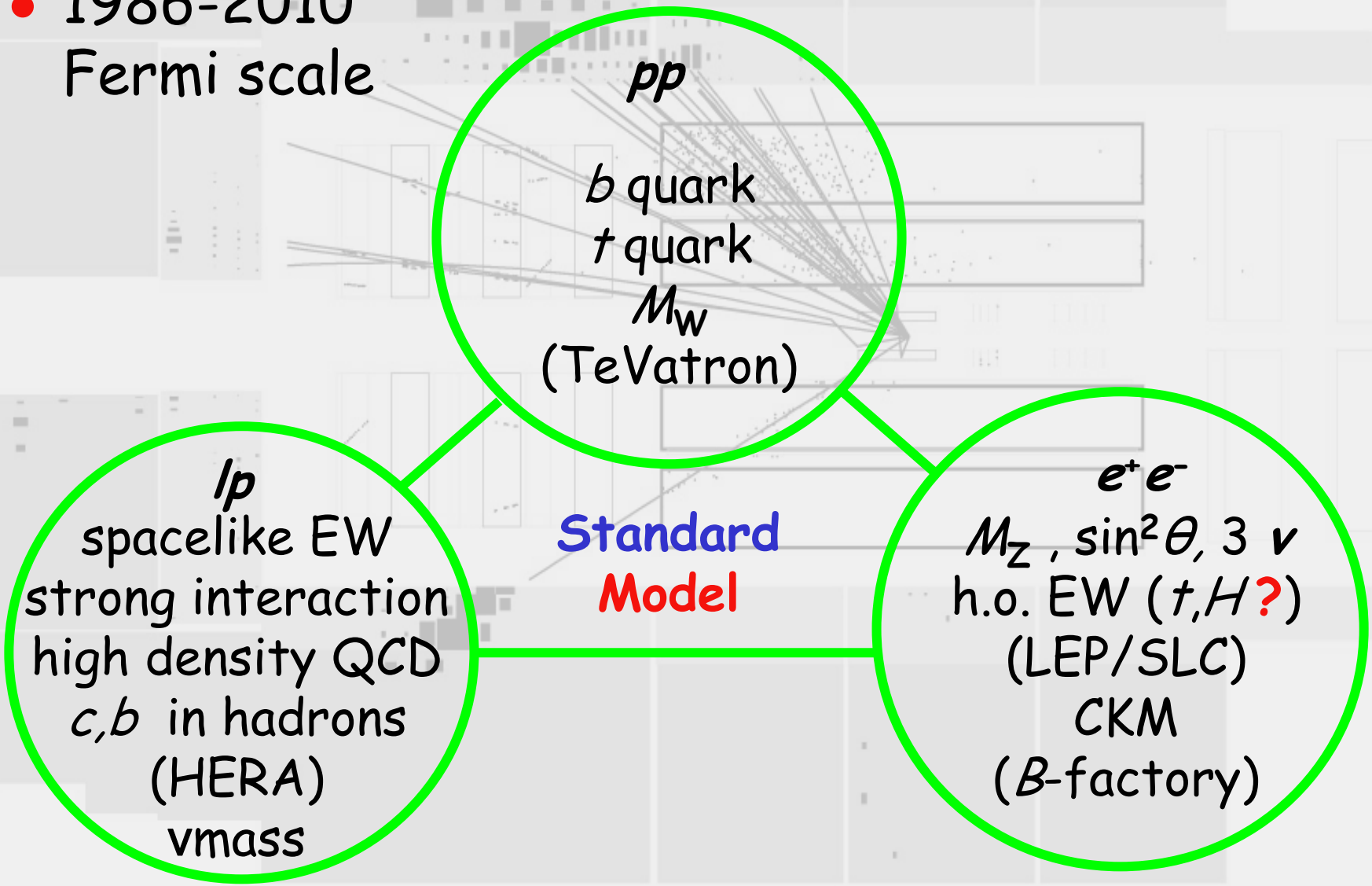
- 1986-2010
  Fermi scale



The Energy Frontier

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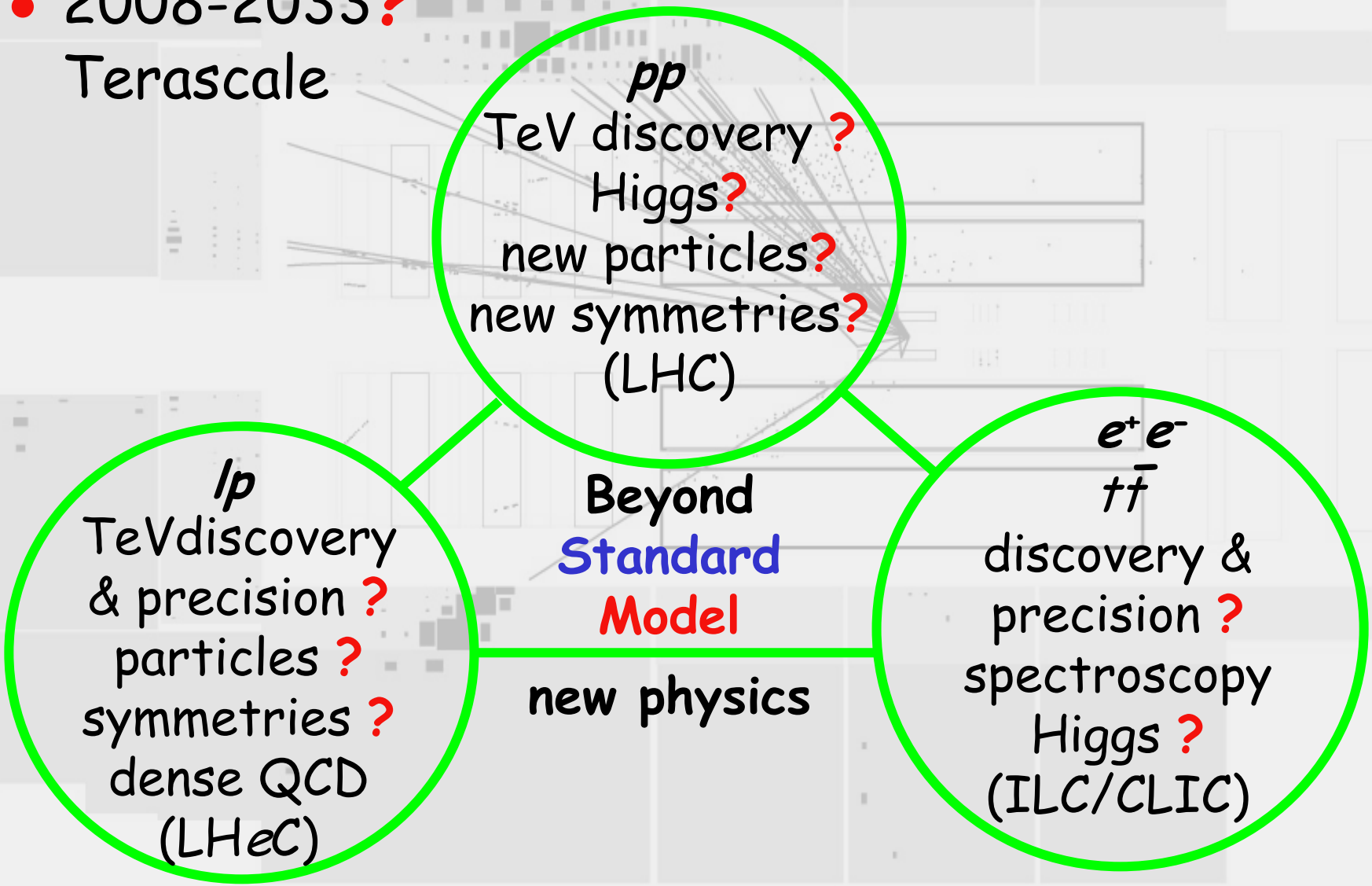
- 2008-2033?
  Terascale



The Matter Frontier

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- 2008-2033?
  chromodynamic
  creation ?
  ion = *A*

AA
QGP ?
QCD phase
equilibria?
nuclear dynamics?
nuclear formation
(LHC)

lA
QCD dof @
extremes
strong QCD ↔ 1_c
(LHeC)

matter creation
new physics

e^+e^-
pQCD
(ILC/CLIC)

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2. The LHeC

Proton beam

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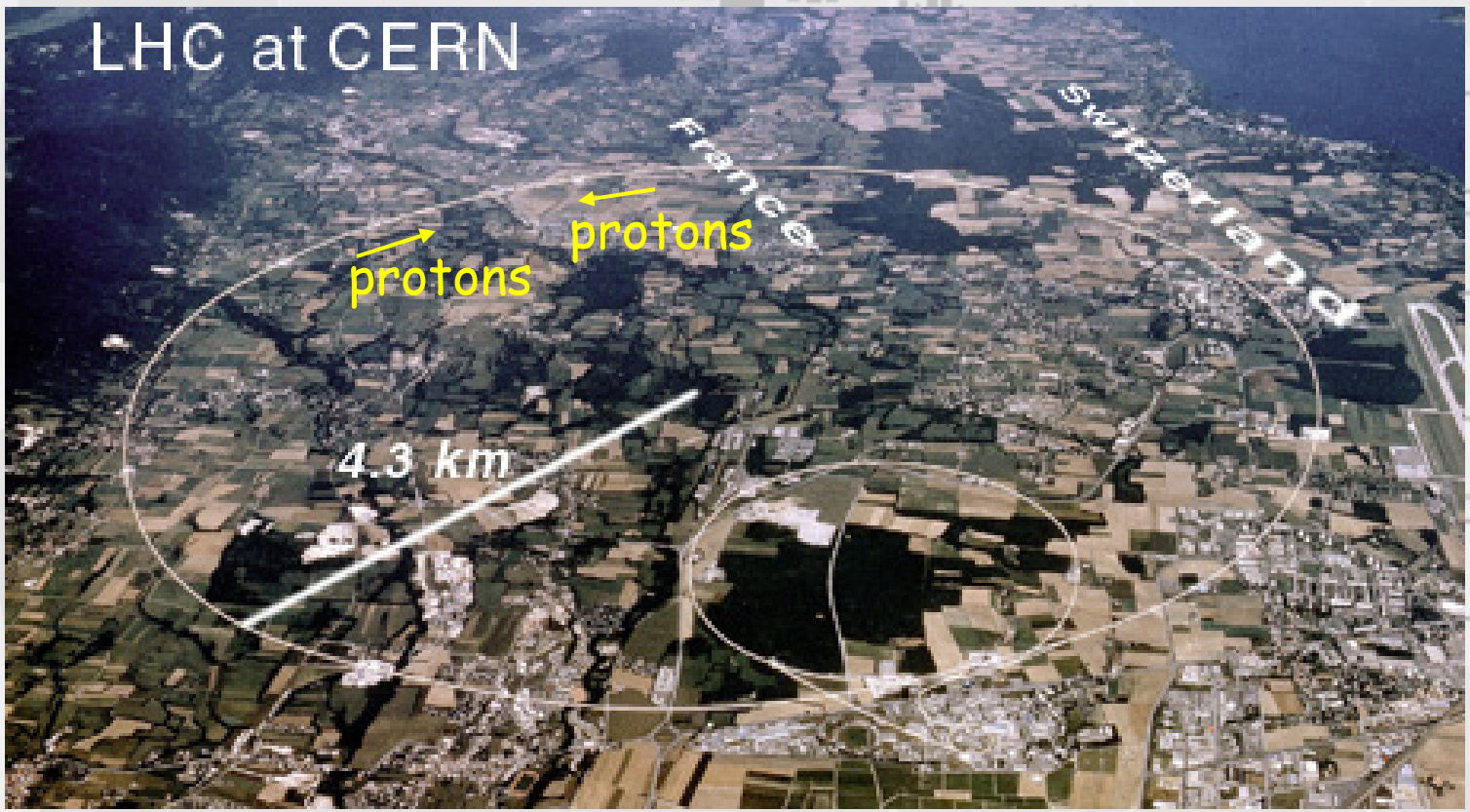
- "standard" LHC protons



Proton beam

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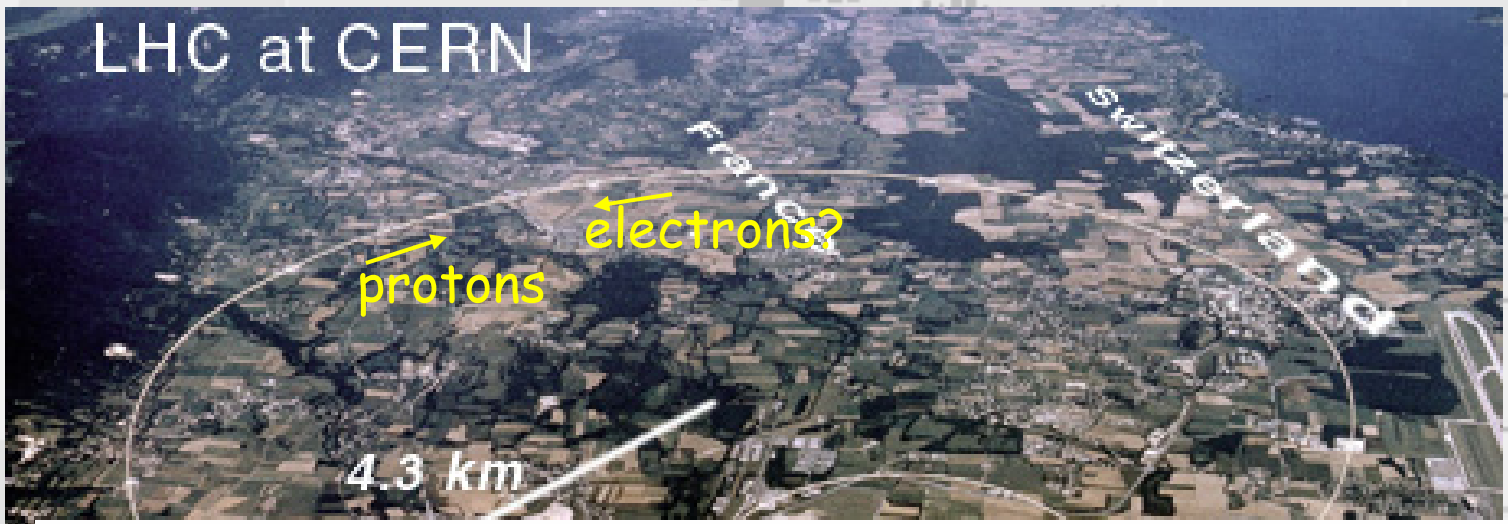
- "standard" LHC protons … with electrons?



Proton Beam Energy	TeV	7	
Circumference	m	26658.883	
Number of Protons per bunch	10^{11}	1.67	N_p
Normalized transverse emittance	μm	3.75	ε_{pN}
Bunch length	cm	7.55	
Bunch spacing	ns	25	

LHeC ring-ring

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Quantity	unit	$e^{\pm}$	p
Beam energy	GeV	70	7000
Total beam current	mA	74	544
Particles/bunch N_b	10^{10}	1.40	17.0
Horiz. emittance	nm	7.6	0.501
Vert. emittance	nm	3.8	0.501
Horizontal β_x^*	cm	12.7	180
Vertical β_y^*	cm	7.1	50
Energy loss per turn	GeV	0.707	6×10^{-6}
Radiated power	MW	50	0.003
Bunch frequency	MHz	40	
CMS Energy ($\sqrt{s}$)	GeV	1400	
Luminosity $/10^{33}$	$cm^{-2}s^{-1}$	1.1	

LHeC ring-ring

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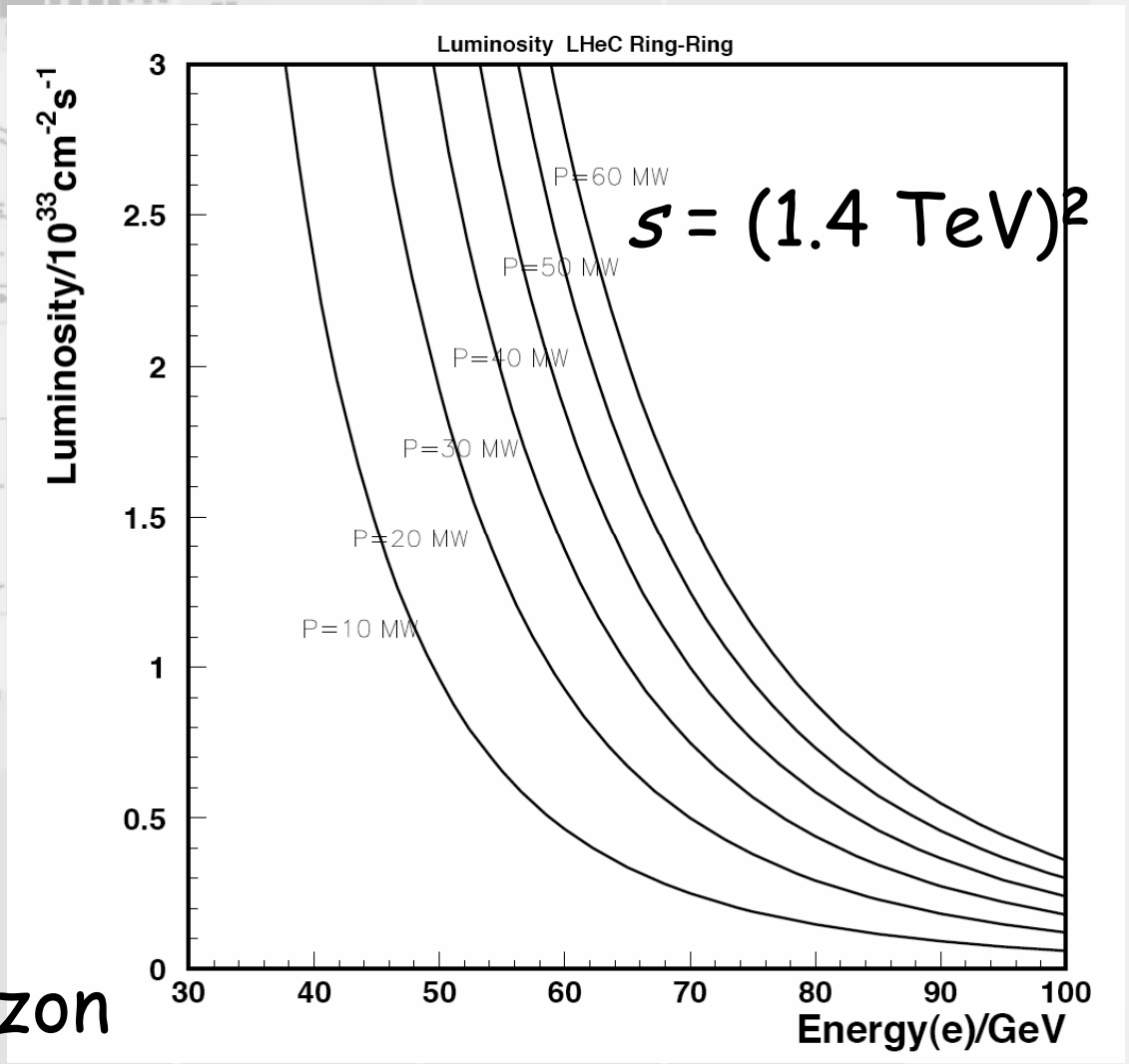
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1} \qquad I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$



- e-ring
  - HERA
    1.4×10^{31} $cm^{-2}s^{-1}$
  - $E_e \leq 70$ GeV ($s)
  - power $P < 60$ MW
  - ERL $\rightarrow$? $cm^{-2}s^{-1}$

↳ lumi + energy horizon

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LHeC ring-ring

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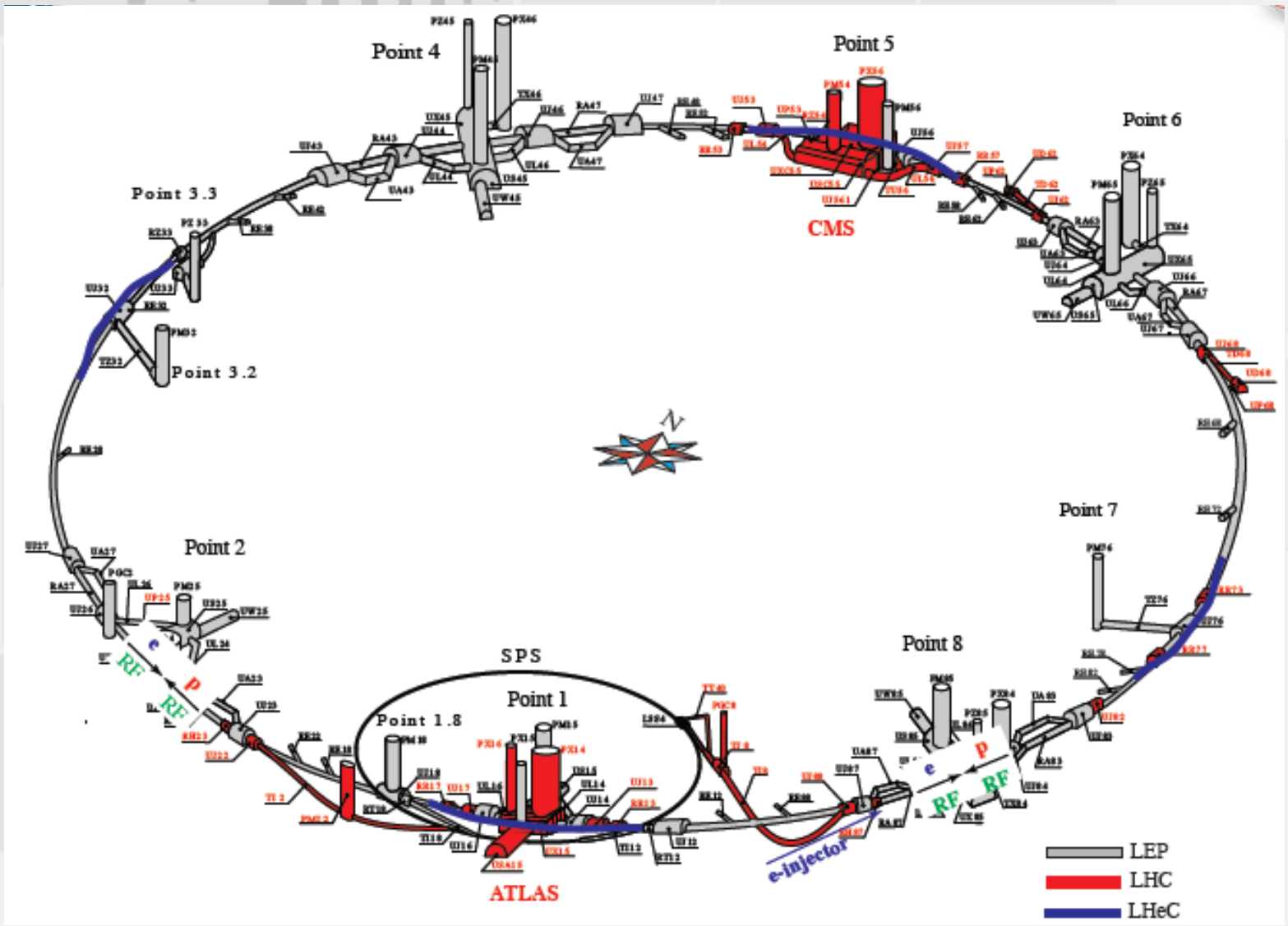

LHeC ring-ring

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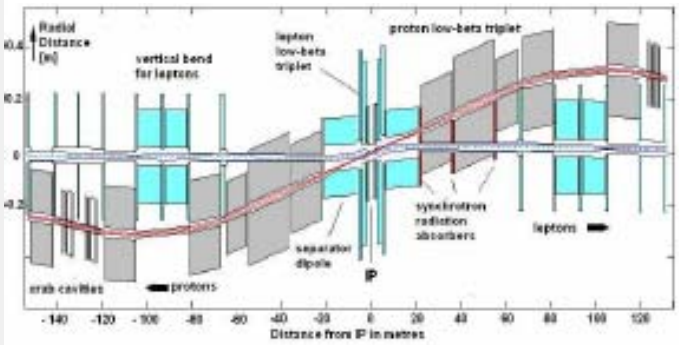
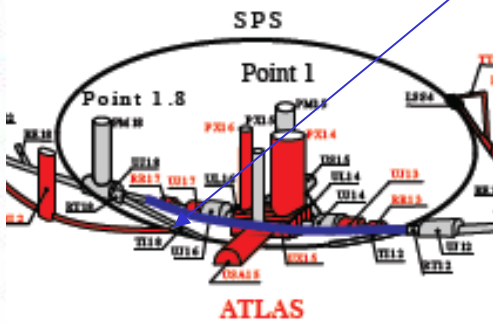
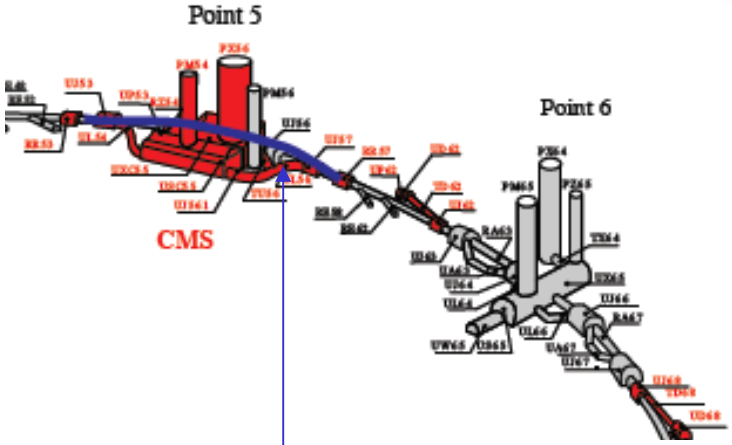
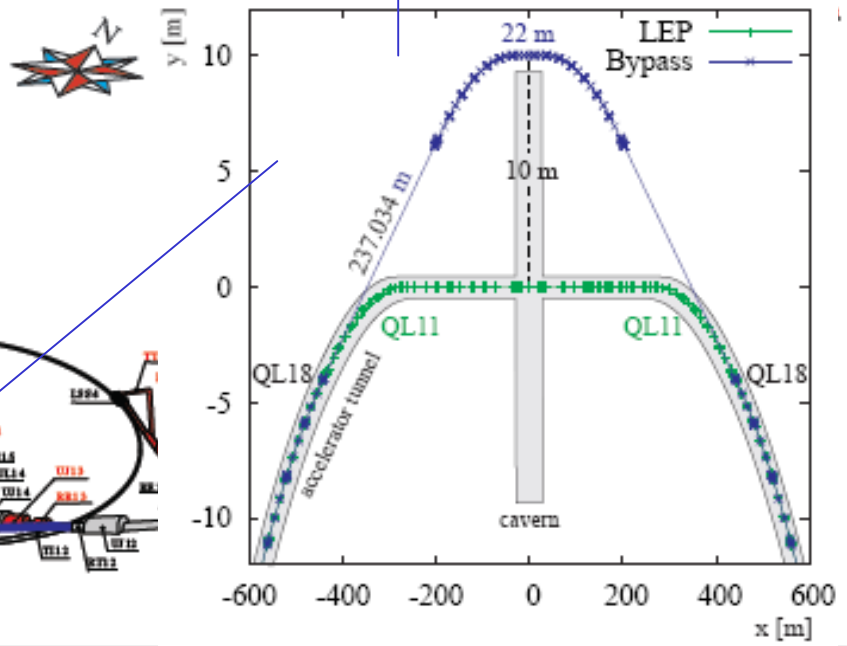
- ring-ring (RR)
  - IR1 IR5 by-pass
  - *ep* 1.1×10^{33} $cm^{-2}s^{-1}$
    ePb 1.1×10^{31} $cm^{-2}s^{-1}$
  - bunch charge < LEP
    injection < 22 GeV (ELFE?)

	IR1/IR5 ATLAS/CMS	IR2 and/ or IR 8	IR3/IR7
Bypass for	Experiments	RF	Collimation
Diameter	4.4/3.8 m	5.50 m	4.2/3.8 m
Length	500 m	500 m	500 m
Separation	10–13 m		









LHeC ring-ring

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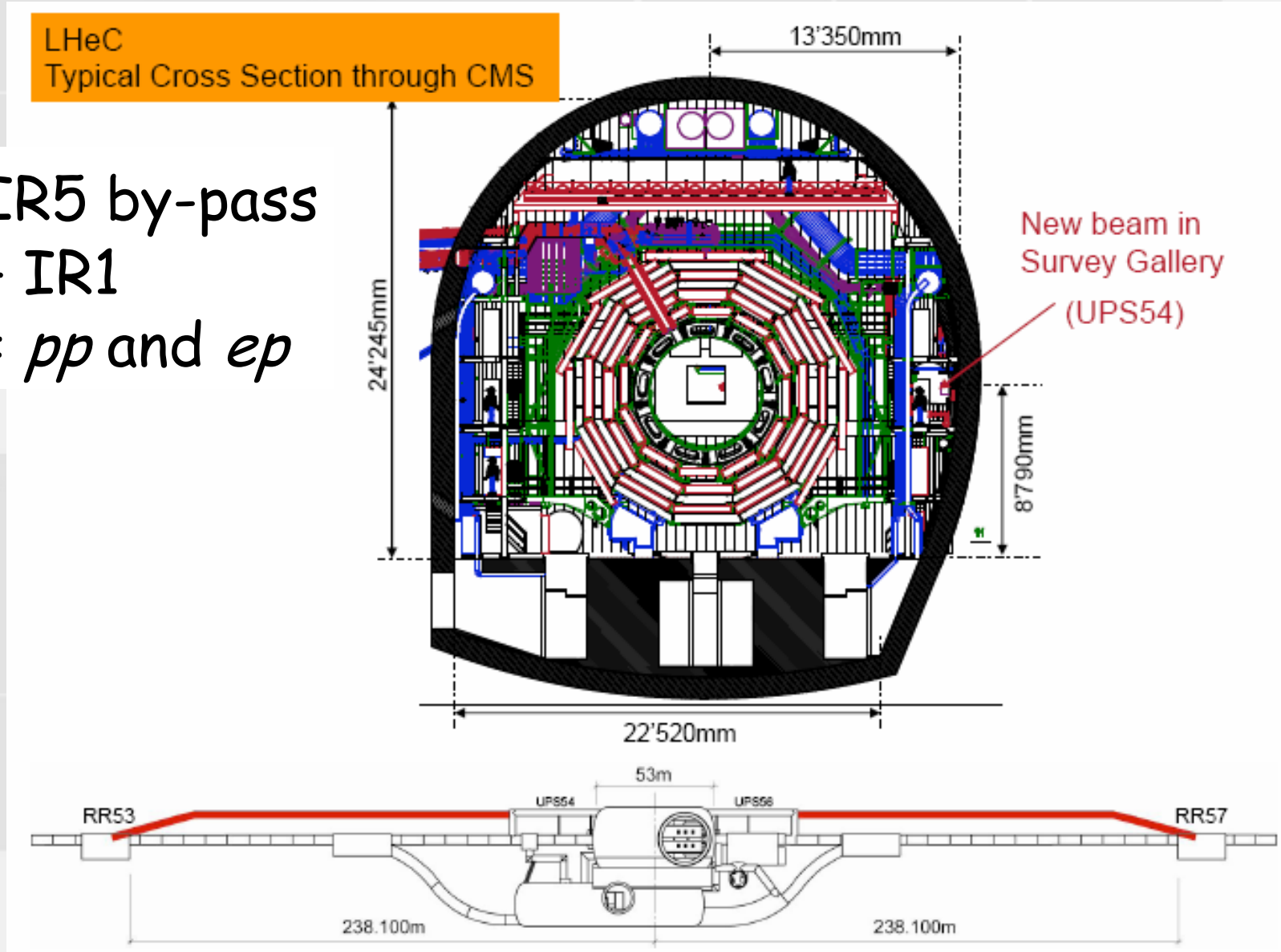
- IR5 by-pass
  + IR1
  = *pp* and *ep*



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- IR5 by-pass survey gallery

LHeC ring-ring

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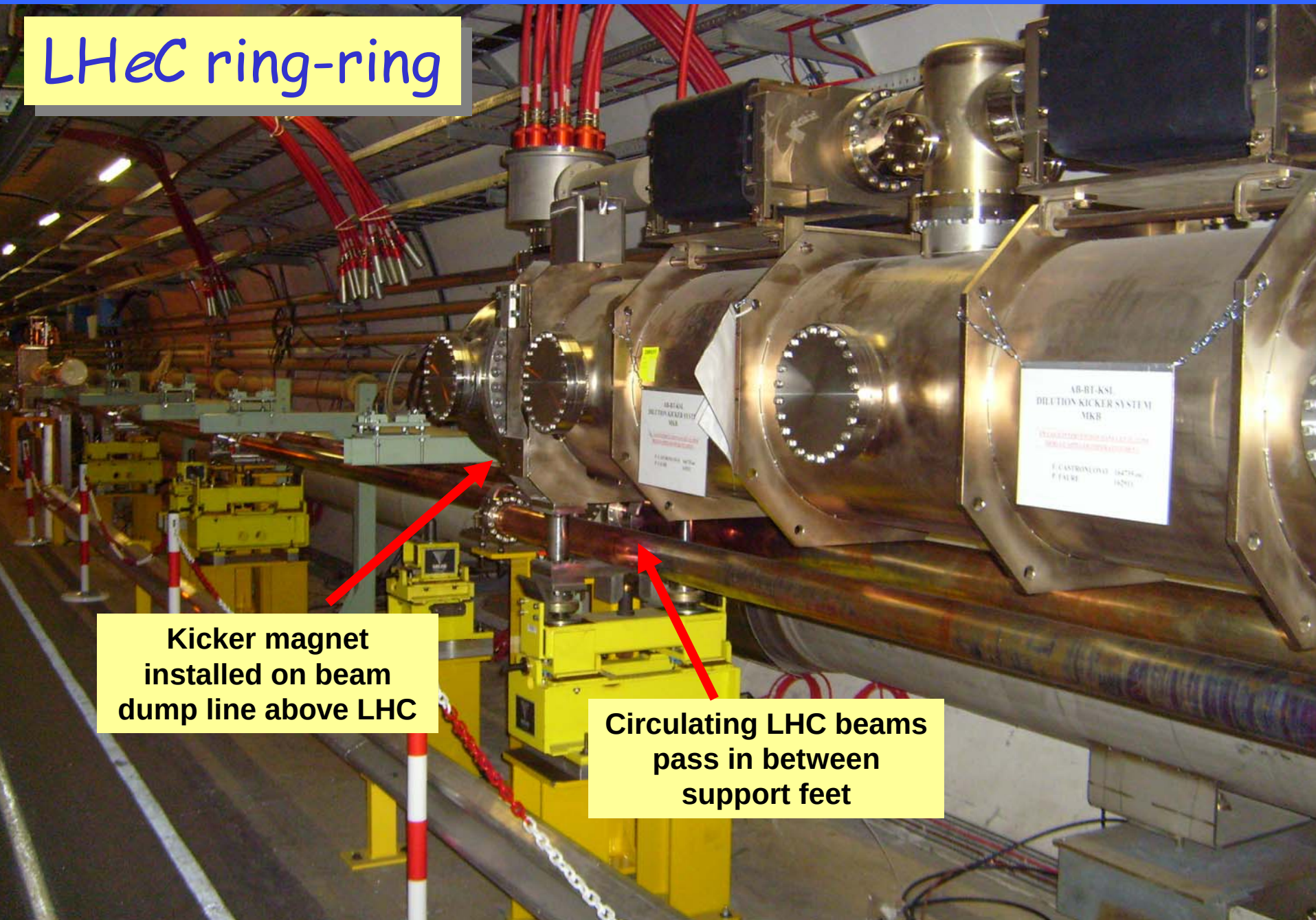
- IR5 by-pass: survey gallery → CMS cavern

Equipment above installed LHC beamlines….



LHeC linac-ring

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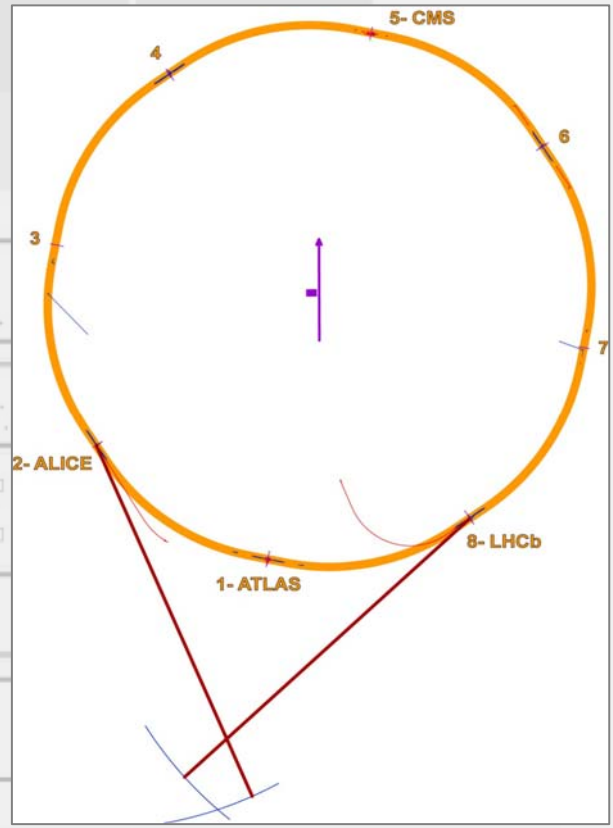
- conceptual layout
  - new linac tunnel
  - ≤ 140 GeV e ⊗ 7 TeV p (≤ 2 TeV)
  - power for TeV → ERL+CW ?
    use CERN rings (incl. LHC!) ?
  - CW or pulsed ?
  - integrated e^+ source



energy [GeV]	20	20	60	60	60	120
option	cw 4-pass	cw 4-p. ERL	cw 4-pass	cw 4-p. ERL	pulsed	pulsed
bunch population $N_{b,e}$ [10^9]	0.06, 0.12*	1.3, 2.6*	0.1, 0.2*	0.3, 0.6*	17, 34*	7, 14*
average current [μA]	400	8650	74	2050	820	340
beam power at IP [MW]	8.0	172	4.5	120	49	48
IP beta function [m]	0.25, 0.098*	0.25, 0.098*	0.74, 0.30*	0.74, 0.30*	0.74, 0.30*	1.72, 0.69*
luminosity [10^{31} cm^{-2}s^{-1}]	2.7, 20*	58, 430*	0.5, 3.7*	14, 100*	5.5, 41*	2.3, 17*
total electrical power [MW]	20	20	20	20	100	100

Linac-Ring

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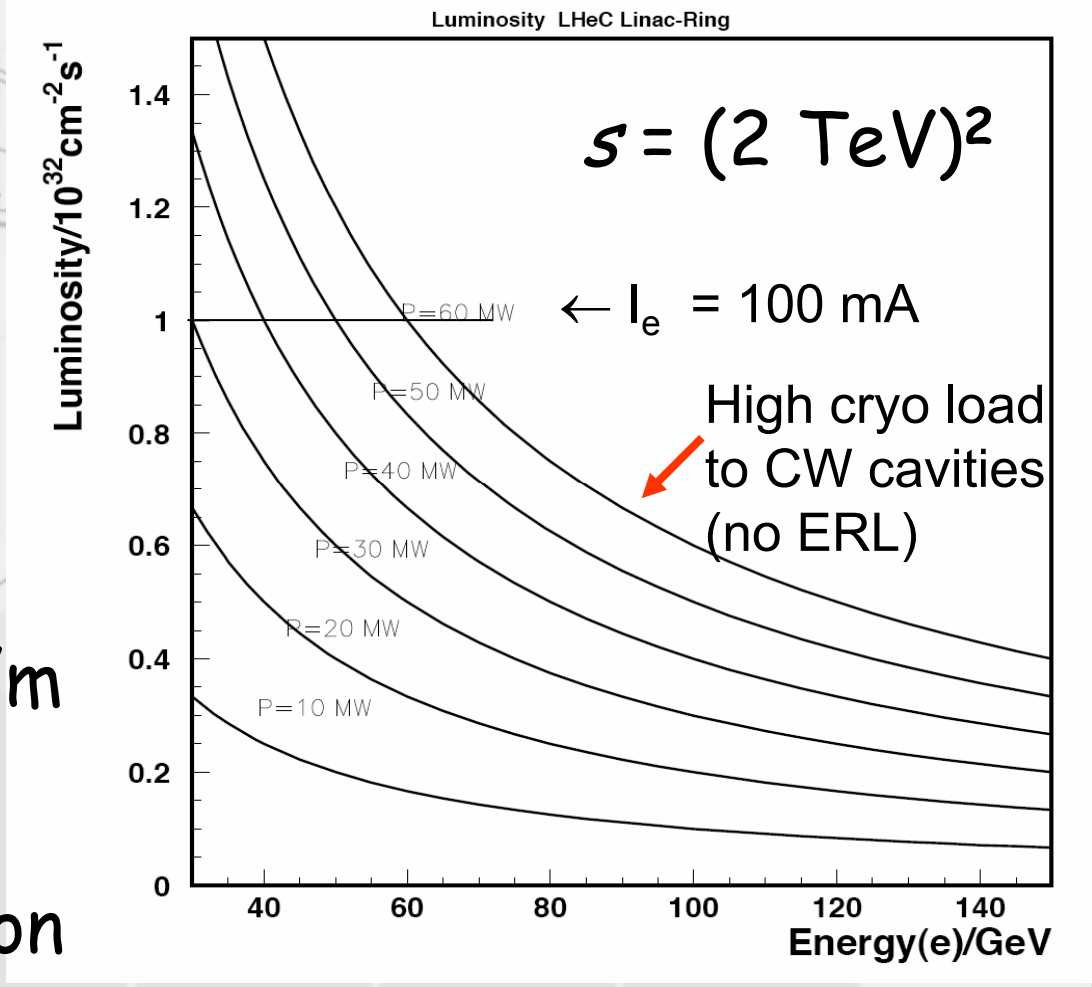
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 1 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1} \qquad I_e = 100mA \cdot \frac{P}{MW} \cdot \frac{GeV}{E_e}$$

$\varepsilon_{pn} = 3.8 \mu m$ $\quad N_p = 1.7 \cdot 10^{11}$ $\quad \beta^* = 0.15m$

- e-linac
  - HERA
  - 1.4×10^{31} $cm^{-2}s^{-1}$
  - E_e < 140 GeV ($s)
  - power P < 60 MW
  - 6 km+gaps @23 MV/m
  - ERL → ? $cm^{-2}s^{-1}$

↳ lumi + energy horizon



LHeC ring-ring

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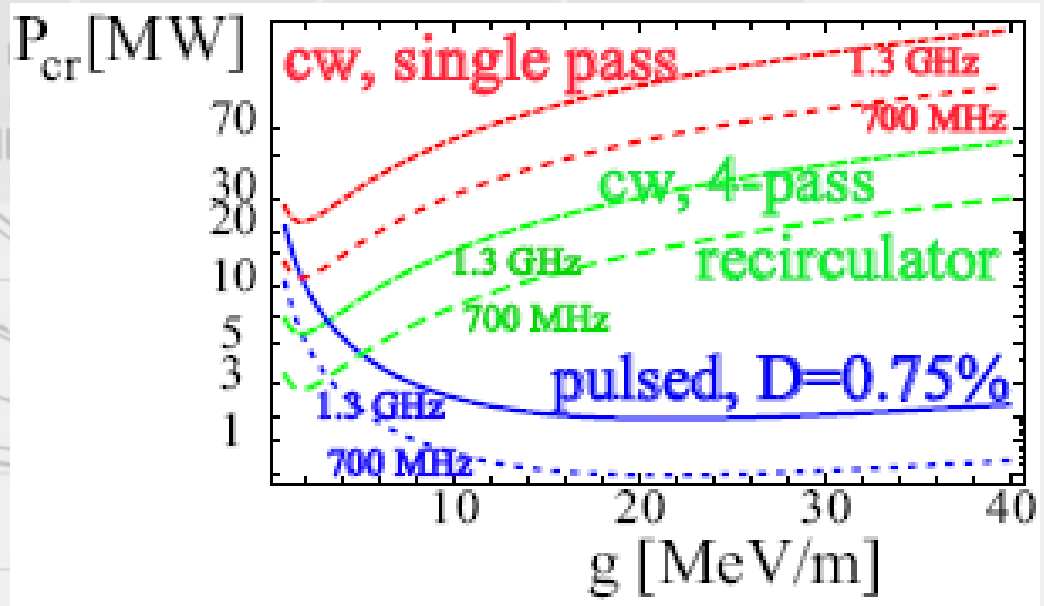
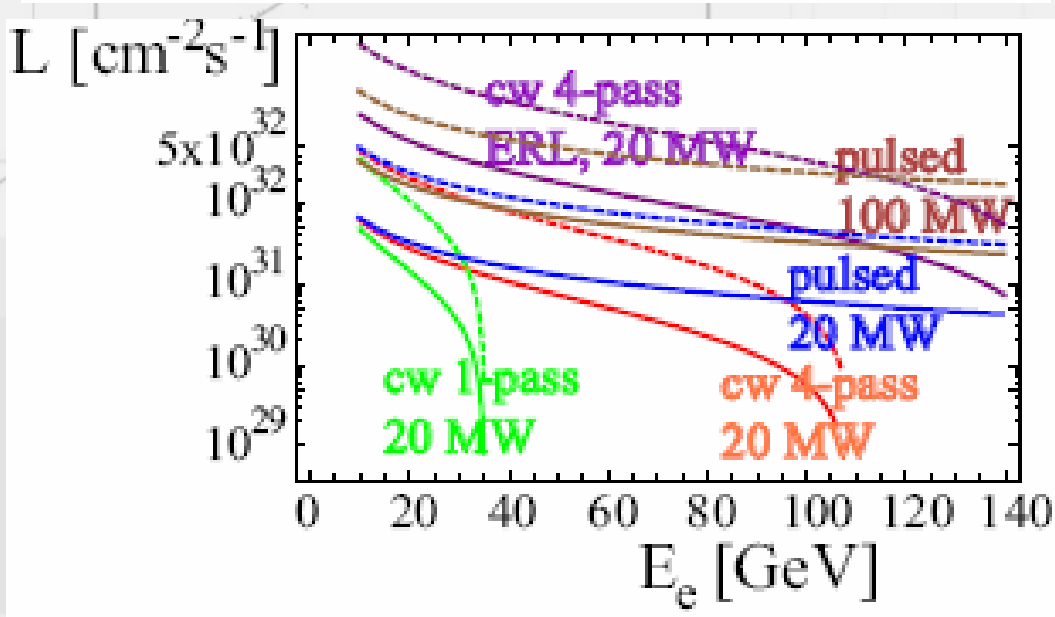
- power consumption
  → ER ?





Linac-Ring and Ring-Ring

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- interruption to *pp* data-taking

	L-R	R-R
Energy / GeV	40-140 …	40-80
Luminosity / 10^{32} cm^{-2} s^{-1}	0.5	10
Mean Luminosity, relative	2	1 [dump at L_{peak} /e]
Lepton Polarisation	60-80%	30% [?]
Tunnel / km	5-9	2.5=0.5 * 5 bypasses ?
Biggest challenge	CW cavities	Civil Engineering Ring+Rf installation
Biggest limitation	luminosity (ERL,CW)	maximum energy
IR	not considered yet one design? (eRHIC)	allows ep+pp 2 configurations [lox, hiq]

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3. Summary

LHeC

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- LHeC is the terascale lepton-quark machine
  - to date most pragmatic means of getting a lepton into a TeV interaction
  - "upgrade of LHC" – simultaneous *pp ep* (*AA eA*)
  - exploits stupendous LHC hadron beams
  - challenges contemporary *e*-beam technology synergies (ERL, linac, low emittance rings)
  - no showstoppers so far
  - CERN ECFA and NuPECC support EIC/eRHIC collaboration
  - evaluation → CDR 2009/2010 → LHCC
  - TDR > 2010 → CDR

→ quarks and leptons; why and how ? When ?

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ECFA/CERN LHeC Workshop.

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Accelerator Design [RR and LR]

Closer evaluation of technical realisation: injection, magnets, rf, power efficiency, cavities, ERL…

What are the relative merits of LR and RR? Recommendation. **Workpackages**

Interaction Region and Forward/Backward Detectors

Design of IR (LR and RR), integration of fwd/bwd detectors into beam line.

Infrastructure Definition of infrastructure - for LR and RR.

Detector Design A conceptual layout, including alternatives, and its performance [ep and eA].

New Physics at Large Scales

Investigation of the discovery potential for new physics and its relation to the LHC and ILC/CLIC.

Precision QCD and Electroweak Interactions

Quark-gluon dynamics and precision electroweak measurements at the TERA scale.

Physics at High Parton Densities [small x and eA]

QCD and Unitarity, QGP and the relations to nuclear, pA/AA LHC and SHEν physics.

Divonne, 1-3.9.08

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ECFA CERN Workshop at Divonne 1-3.9.2008

http://www.lhec.org.uk

Opening

J.Engelen (CERN)
B Fulton (NuPECC)
K.Meier (ECFA)
G.Altarelli (Roma): DIS in the LHC time

1.9. 2pm

Indico=31463

Email:
event-lhec-workshop@cern.ch
Patricia Mage-Granados
Jill Karlson Forestier
Urs Wiedemann
Max Klein

http://indico.cern.ch/event/LHeC_workshop