EIC Collaboration Meeting
Stony Brook University
December 7-8th 2007

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LHeC Status

John Dainton

Cockcroft Institute and Univ Liverpool,
Daresbury Science and Innovation Campus, GB

with and for the
LHeC steering group

1. Why?
2. LHeC Physics - some snapshots
3. Machine
4. Experiment
5. When: Towards a CDR

http://www.lhec.org.uk

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1.Why?

Why? The Energy Frontier

- 1968-1986

pp

Drell Yan
charm
W,Z
jets

lh

quarks
neutral currents
singlet e_R
asymptotic freedom

e⁺e⁻

charm
3 colours
gluon

$SU(2)_L \times U(1)$
QCD

Why? The Energy Frontier

- 1986-2010
  Fermi scale

pp
b quark
t quark
M_W
(TeVatron)

lh
spacelike EW
strong interaction
high density QCD
c,b in hadrons
(HERA)
ν mass

e^+e^-
M_Z , $\sin^2\theta$, 3 ν
h.o. EW (*t*,*H* ?)
(LEP/SLC)
CKM
(*B*-factory)

Standard
Model

Why? The Energy Frontier

- 2008-2033?
  Terascale

pp
TeV discovery ?
Higgs?
new particles?
new symmetries?
(LHC)

lh
TeVdiscovery
& precision ?
particles ?
symmetries ?
dense QCD
(LHeC)

e⁺e⁻
$t\bar{t}$
discovery &
precision ?
spectroscopy
Higgs ?
(ILC/CLIC)

Beyond
Standard
Model

new physics

Why? The Matter Frontier

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- 2008-2033? chromodynamic creation ?

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

lA
QCD dof @ extremes
strong QCD $\leftrightarrow 1_c$
(LH*e*C)

matter creation
new physics

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

Why: Leptons ↔ Quarks ?

- how are leptons and quarks related ?

THE UNCONFINED QUARKS AND GLUONS

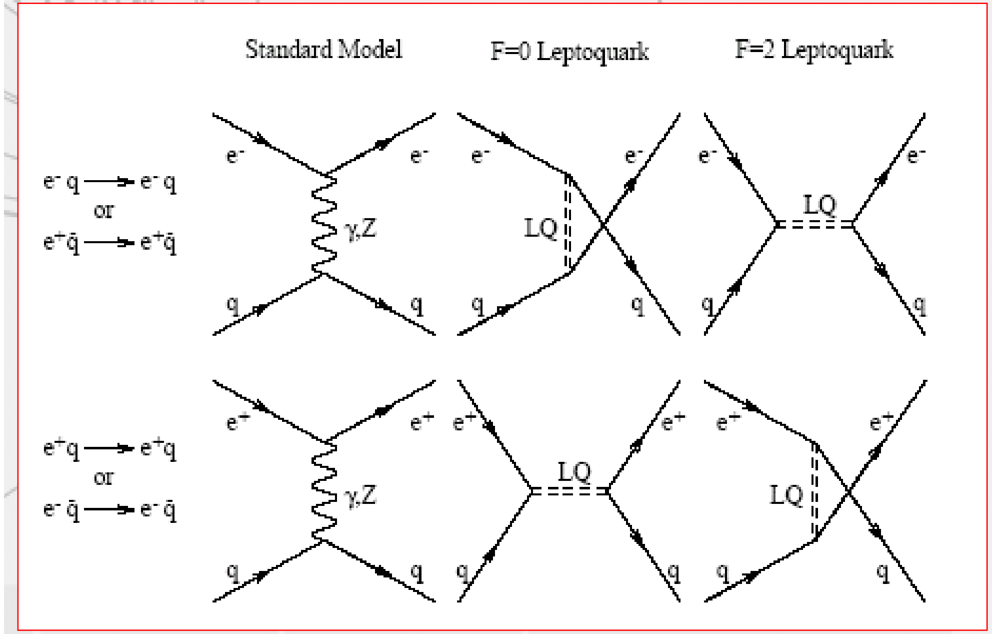
Abdus Salam

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?

ICHEP86 Berkeley



- put them together at the highest energy in the finest detail

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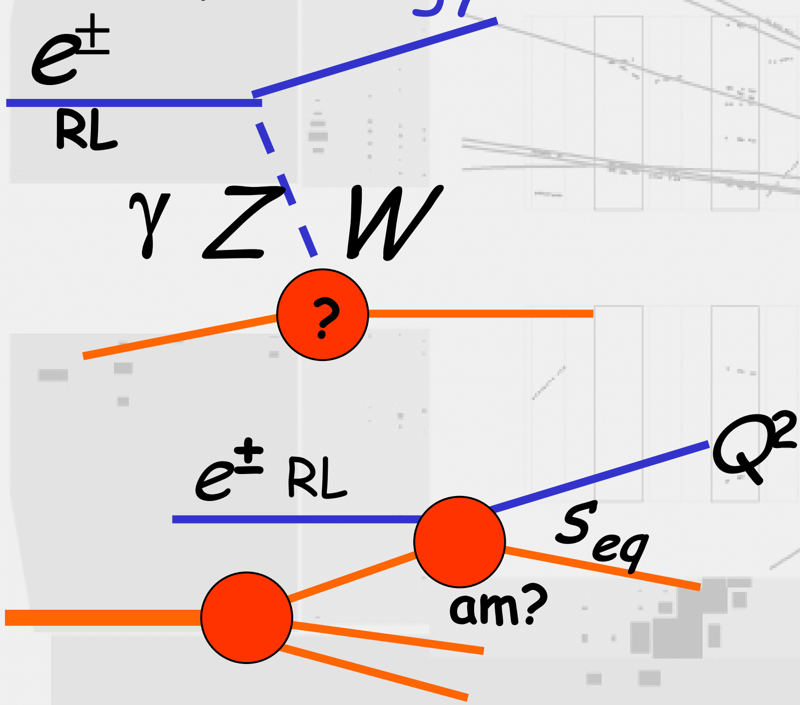
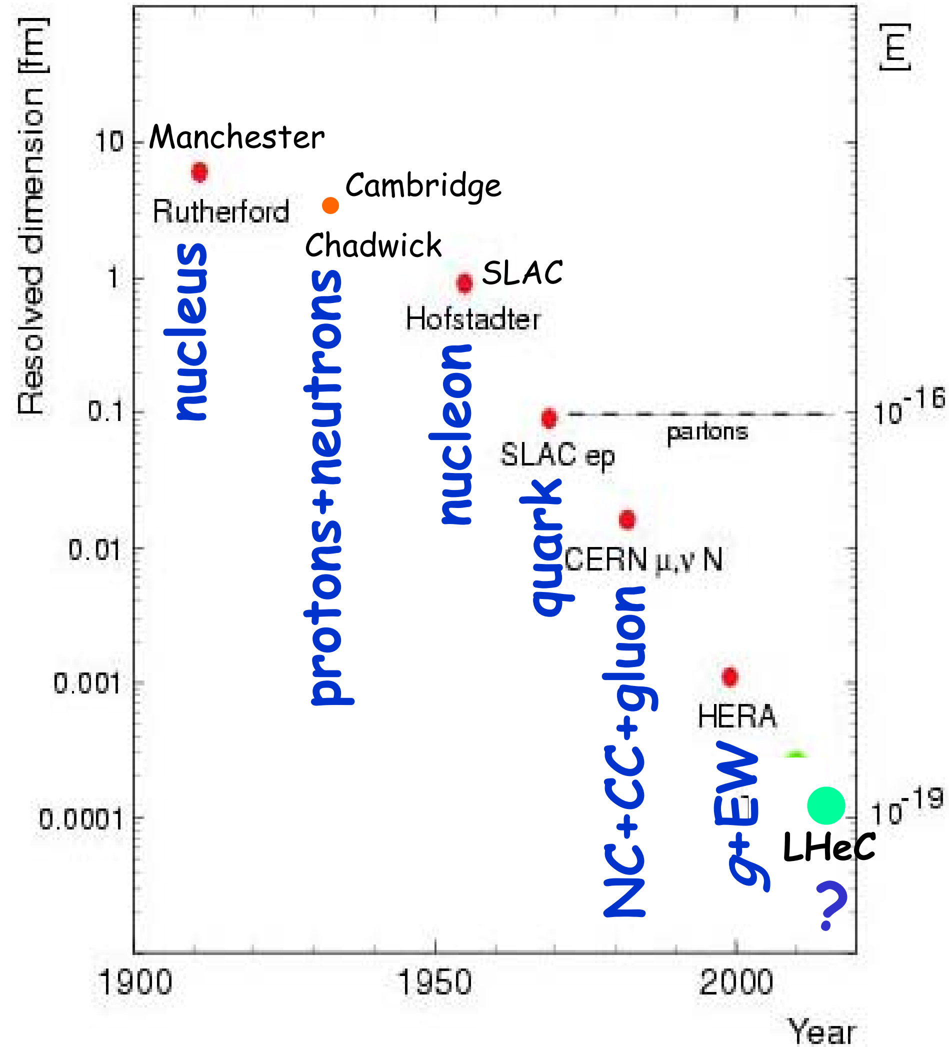
Lepton+quark @ TeV

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

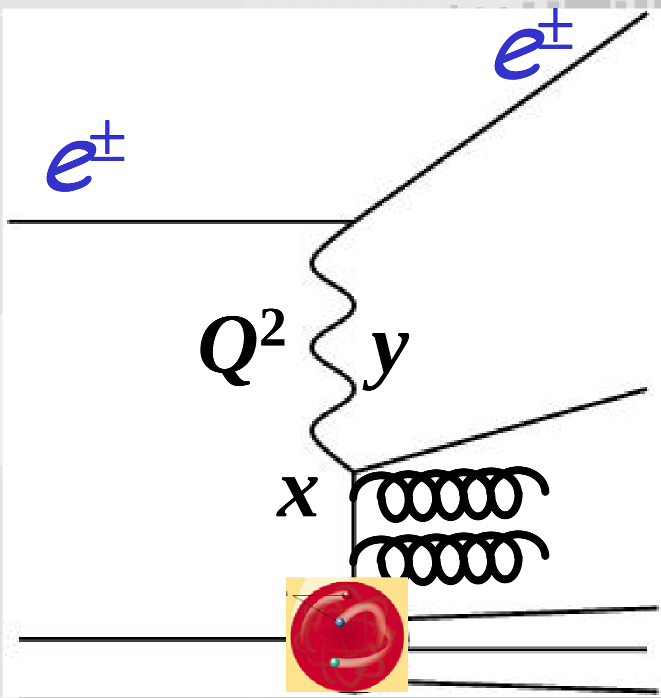




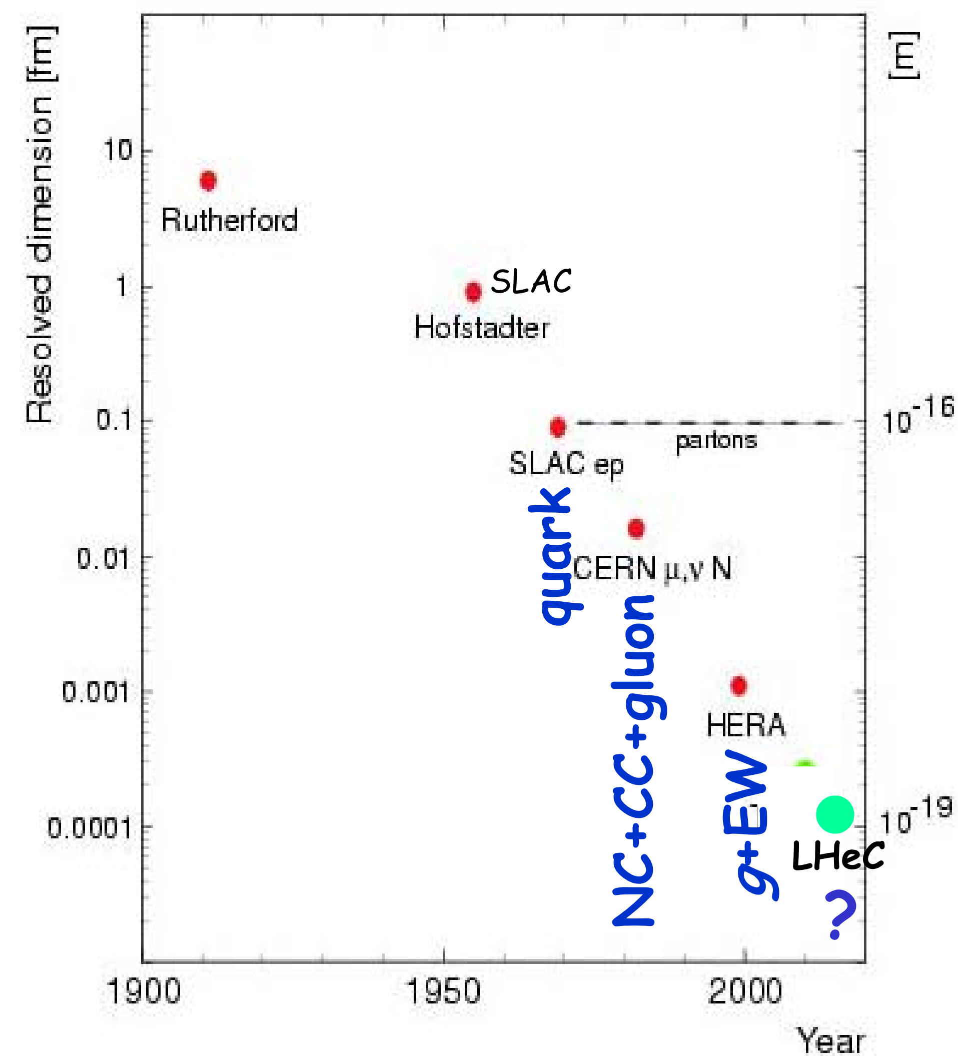
SM + new *Lq* physics
@ ~ 0.0001 fm ?

Why: Structure @TeV

- unique chiral probe @ 0.0001 fm ?



QCD



SM + q structure
@ ~ 0.0001 fm ?

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Why? The Scope

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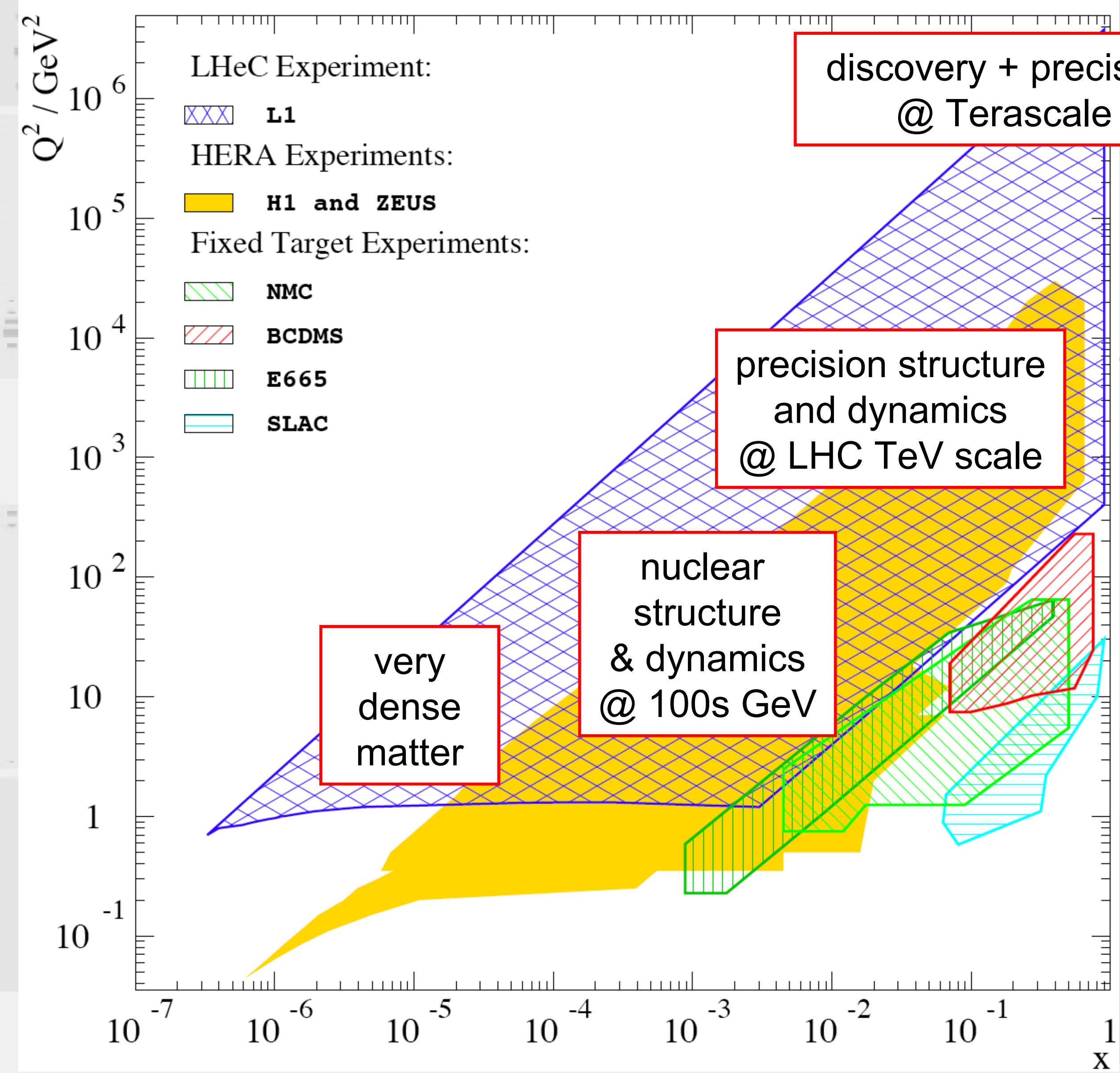

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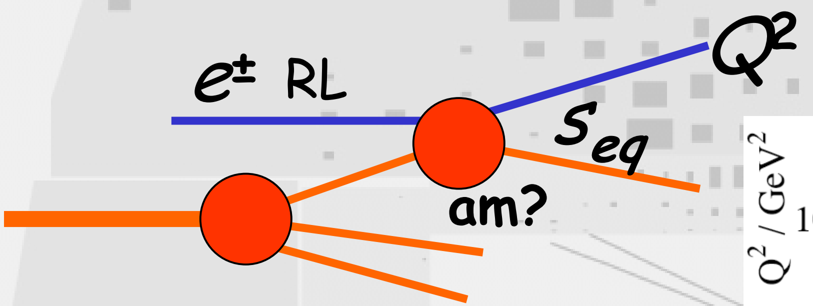
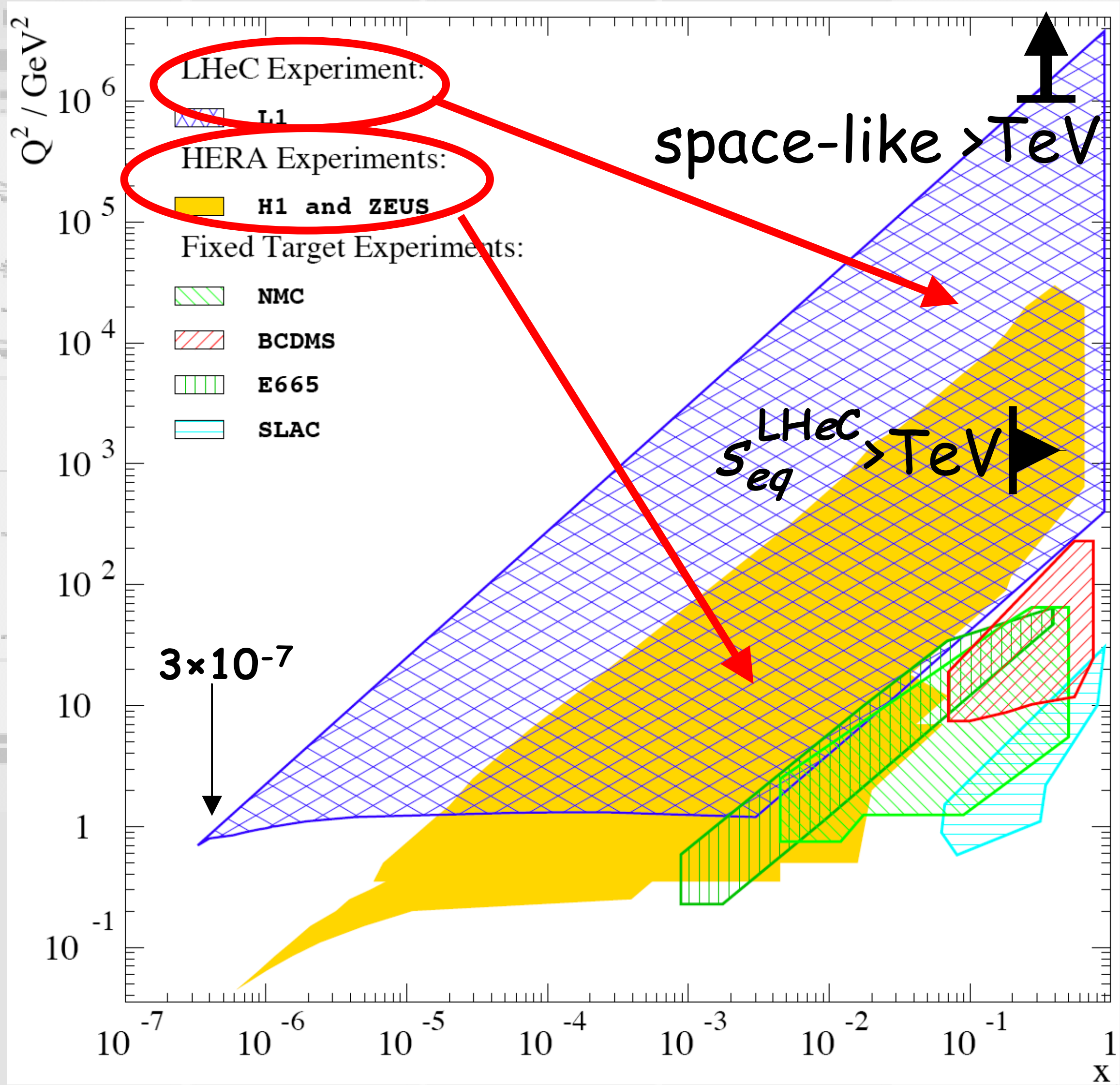
TeV eq Kinematic Reach



- 2007: HERA
  - $Q^2 \leq 30{,}000\ \mathrm{GeV}^2$
  - $s_{eq} \sim (300\ \mathrm{GeV})^2$ in $\boxed{\sim 0.7\ \mathrm{am}}$
- ≥20..?: LHeC
  - $Q^2 \leq 4\times10^6\ \mathrm{GeV}^2$
  - $s_{eq} \leq (4000\ \mathrm{GeV})^2$ in $\boxed{\sim 0.1\ \mathrm{am}}$!



Why: Dense Colour ?

Most of the mass of ordinary matter is concentrated in protons and neutrons. It arises from ... [a] ... profound, and beautiful, source.

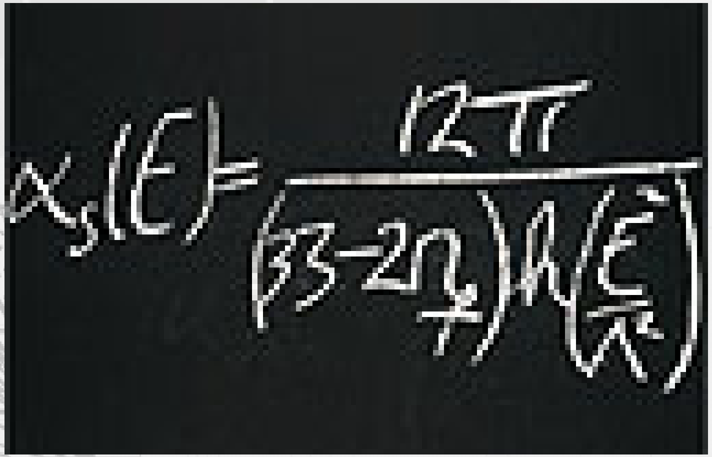
Numerical simulation of QCD shows that if we built protons and neutrons in an imaginary world with no Higgs mechanism – purely out of quarks and gluons with zero mass – their masses would not be very different from what they actually are. Their mass arises from pure energy, associated with the dynamics of confinement in QCD according to the relation $m=E/c^2$. This profound account of the origin of mass is a crown jewel in our Theory of Matter.

Frank Wilcek CERN October 11, 2000

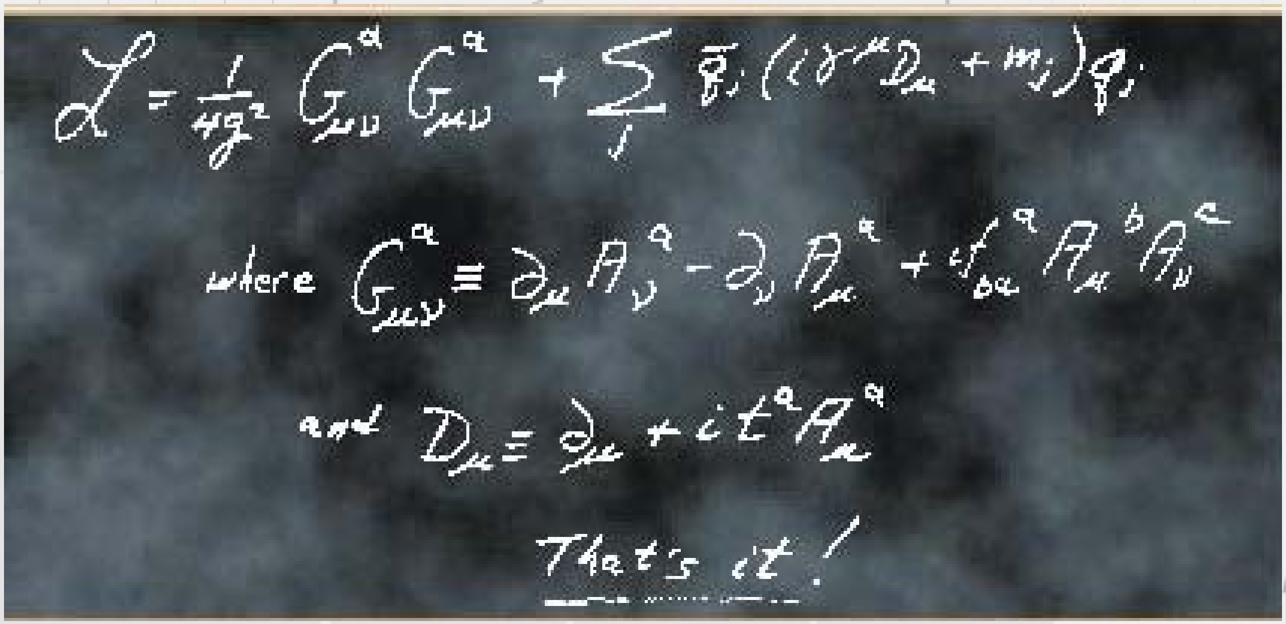
- probe hadronic matter at highest parton density

QCD is headline stuff !

- found on a Guardian newsaper web page



- found on Frank Wilcek's blackboard



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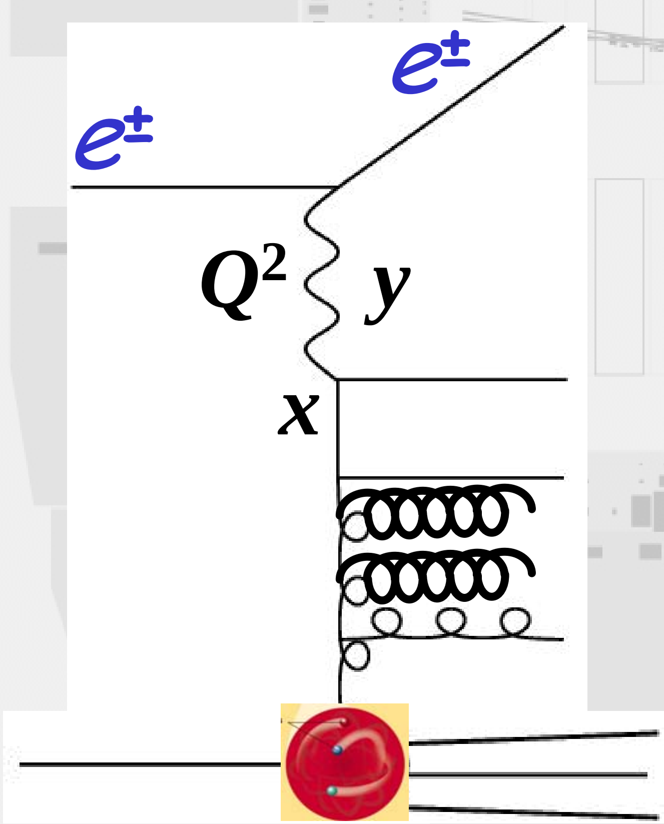
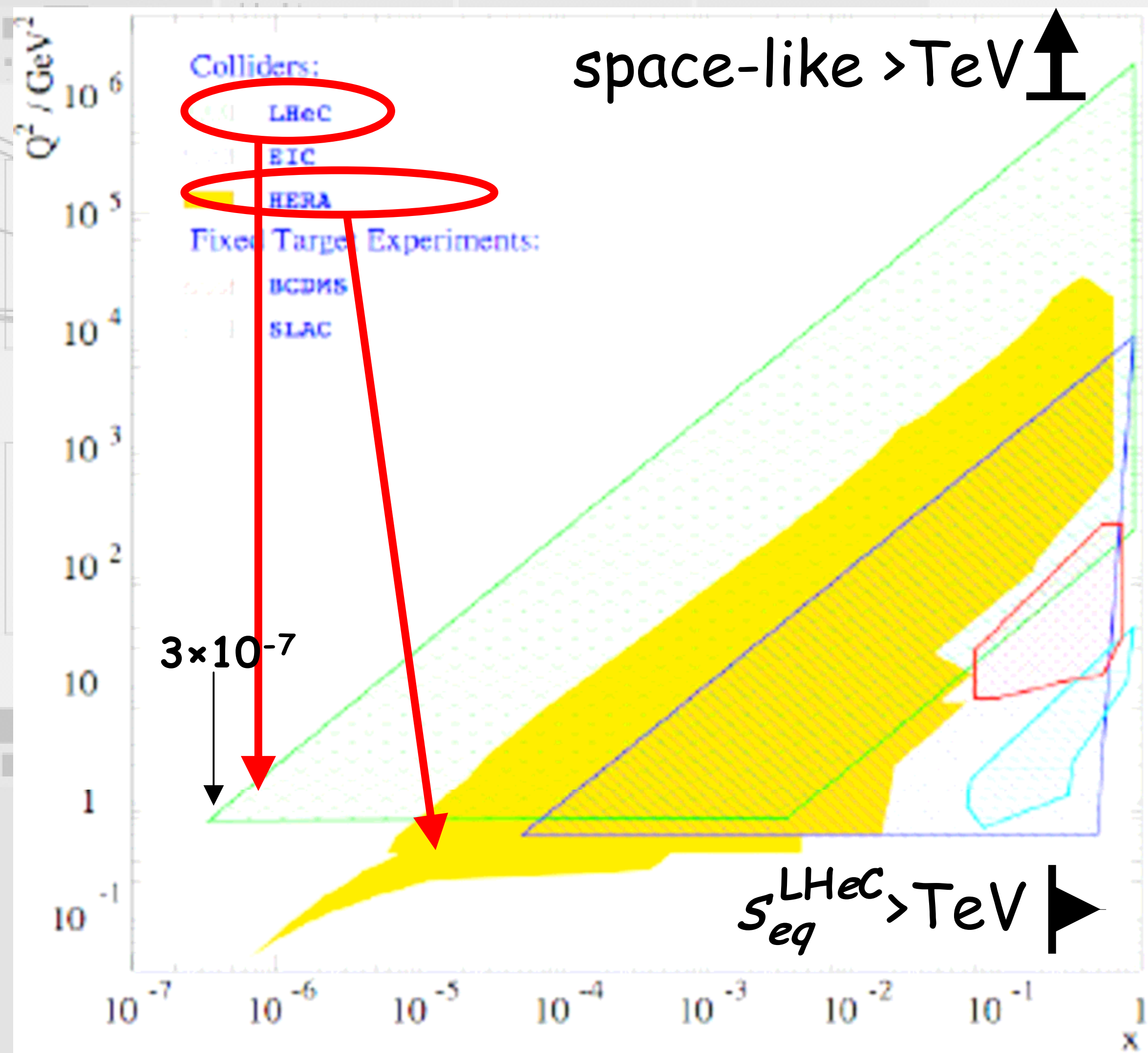
TeV *ep* Kinematic Reach

- 2001:HERA / 2016?:LHeC
  - $Q^2 \geq 1$ GeV^2
  - $x_{Bj} \geq 5\times10^{-5}$

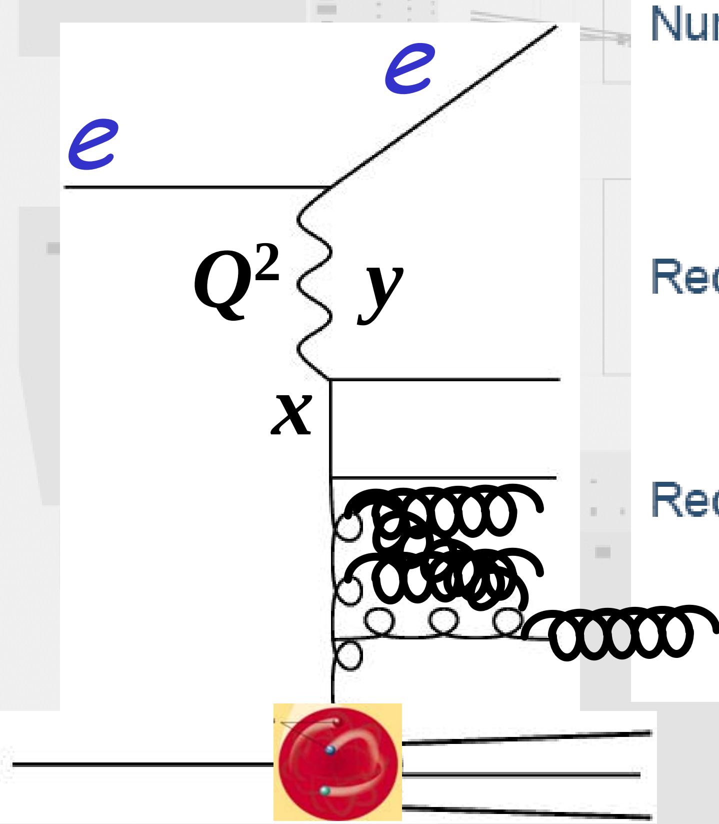




Gluon recombination

- $\geq 20..?$: LHeC
  - $Q^2 \geq 1$ GeV^2
  - $x_{Bj} \geq 5\times10^{-7}$

- $Q^2 \rightarrow$ size of gluons
- $x_{Bj} \rightarrow$ phase space for gluons



Number of gluons per unit area:

p and A

$$\rho \sim \frac{xG_A(x,Q^2)}{\pi R_A^2}$$

Recombination cross-section:

$$\sigma_{gg\rightarrow g} \sim \frac{\alpha_s}{Q^2}$$

Recombination happens if $\rho\sigma_{gg\rightarrow g} \gtrsim 1$, i.e. $Q^2 \lesssim Q_s^2$, with:

$$Q_s^2 \sim \frac{\alpha_s xG_A(x,Q_s^2)}{\pi R_A^2} \sim A^{1/3}\frac{1}{x^{0.3}}$$

low x large nuclei

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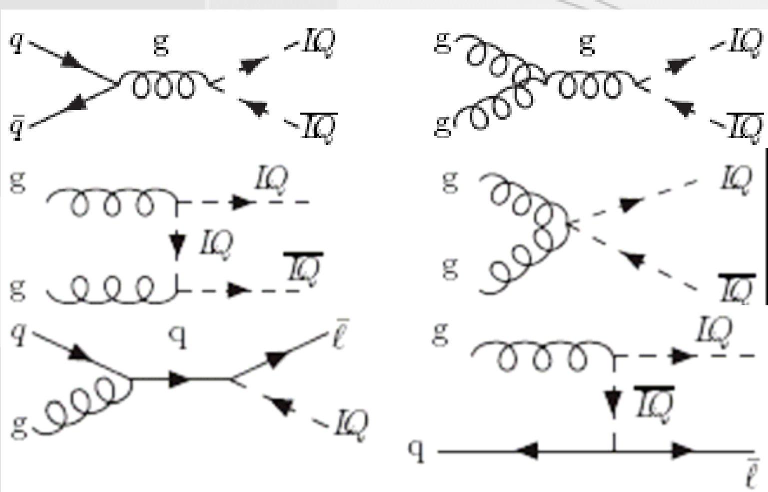
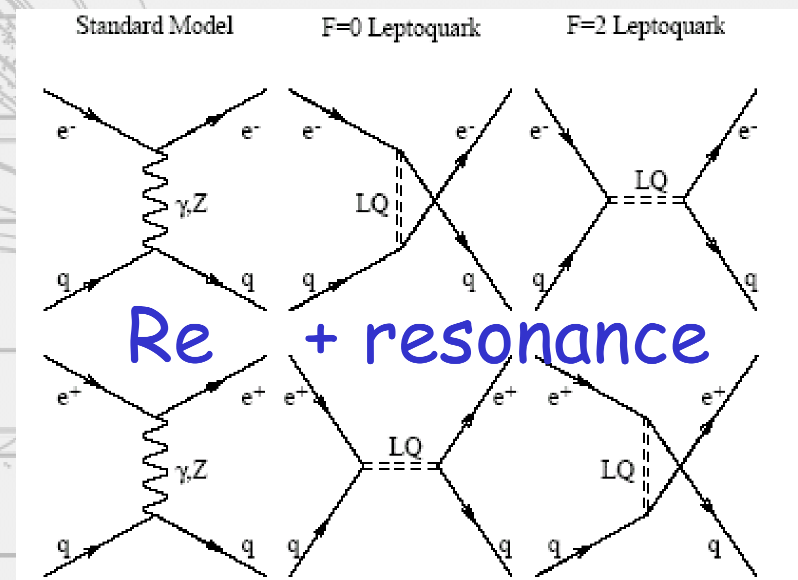
2.LHeC physics
- some snapshots

Lepton+quark @ TeV

- leptoquark systems – new physics + SM

LHC | LHeC





LHC	LHeC
SM (hadronic) + signal	SM (electroweak) + signal
Lq & *LqLq* production	*Lq* formation
σ ~ few × 0.1 fb (Λ=0.1)	σ ~ 100 fb (Λ=0.1)

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Lepton+quark @ TeV

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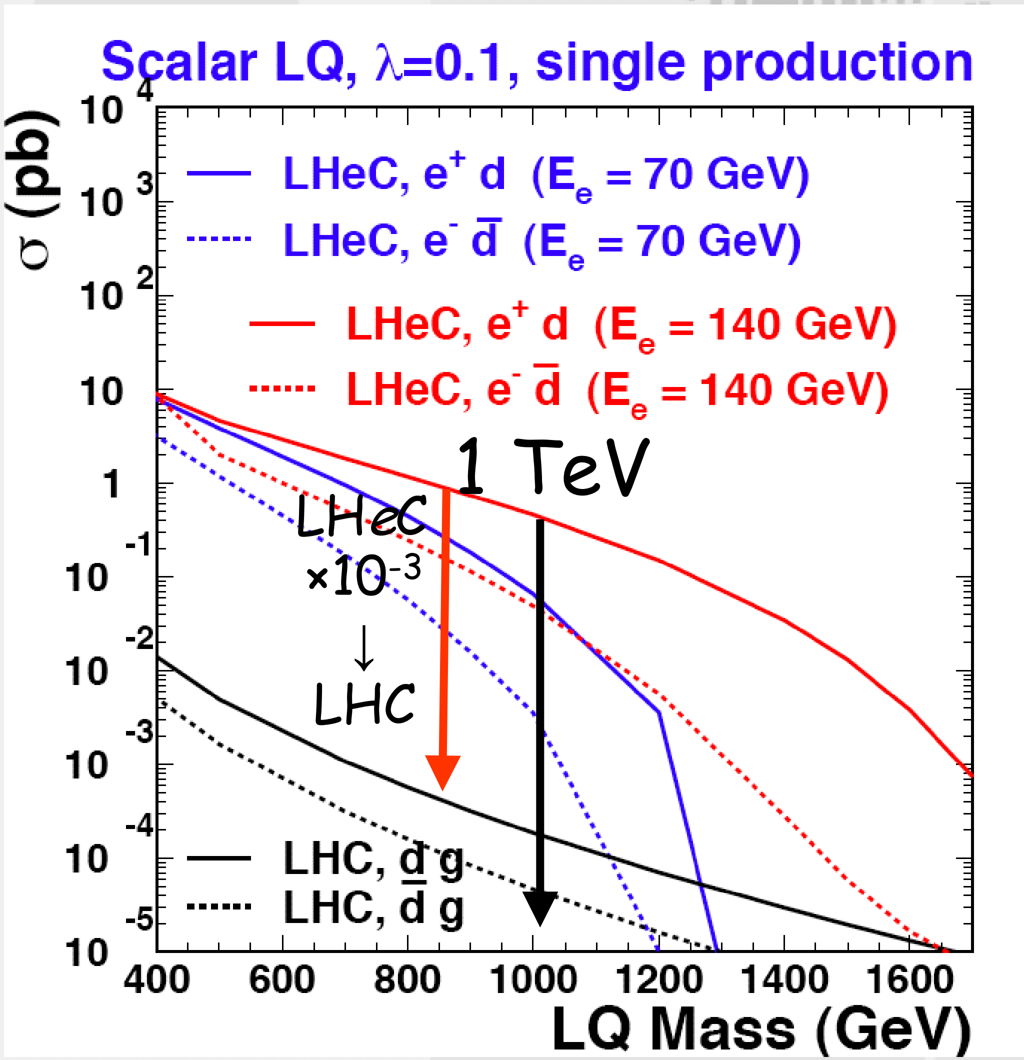
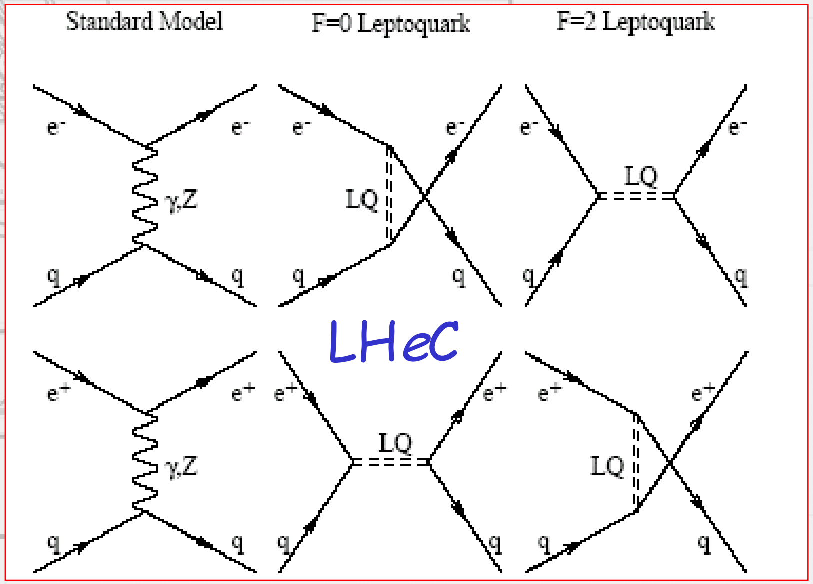
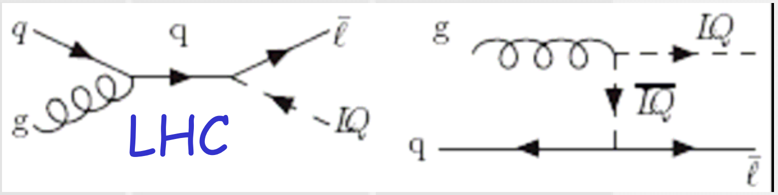
- leptoquark systems – new physics +SM







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Lepton+quark @ TeV

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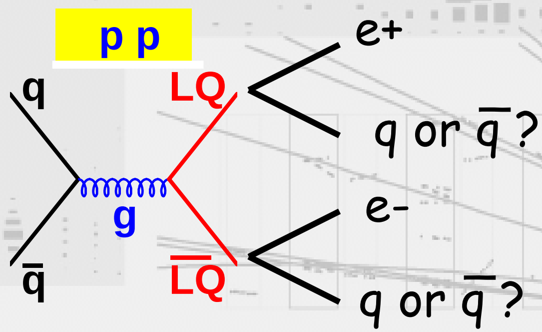
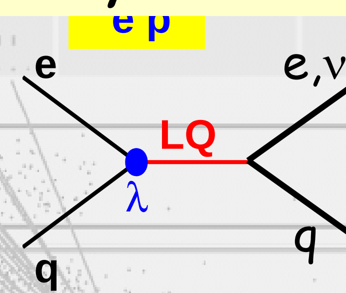
LHC *Lq* pairs+decay

LHeC *Lq* formation+decay





e+ F=0

e- F=2

fermion number

defined formation (e_{LR})

→ precision BRs (NC CC)

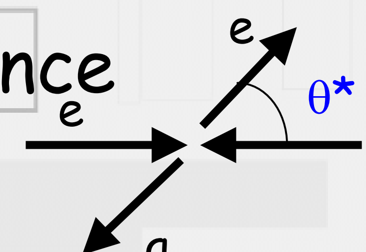
spin parity and chirality

$\bar{q}q \rightarrow g \rightarrow \bar{L}q\, Lq$

production mechanism ?

disentangle mass spectrum ?

inclusive coherence



unique PWA

SM + signal + interference

experim! signature

jets + leptons

jet+lepton+p_T balance

jet +p_T imbalance

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Lepton+quark @ TeV

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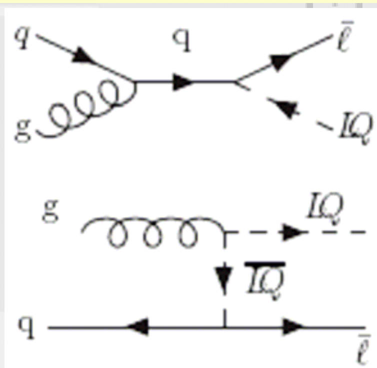
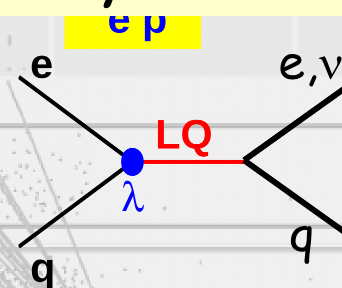
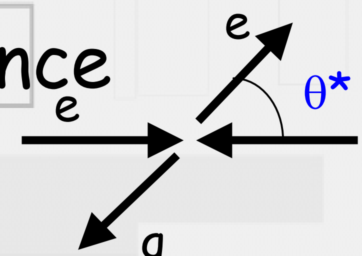
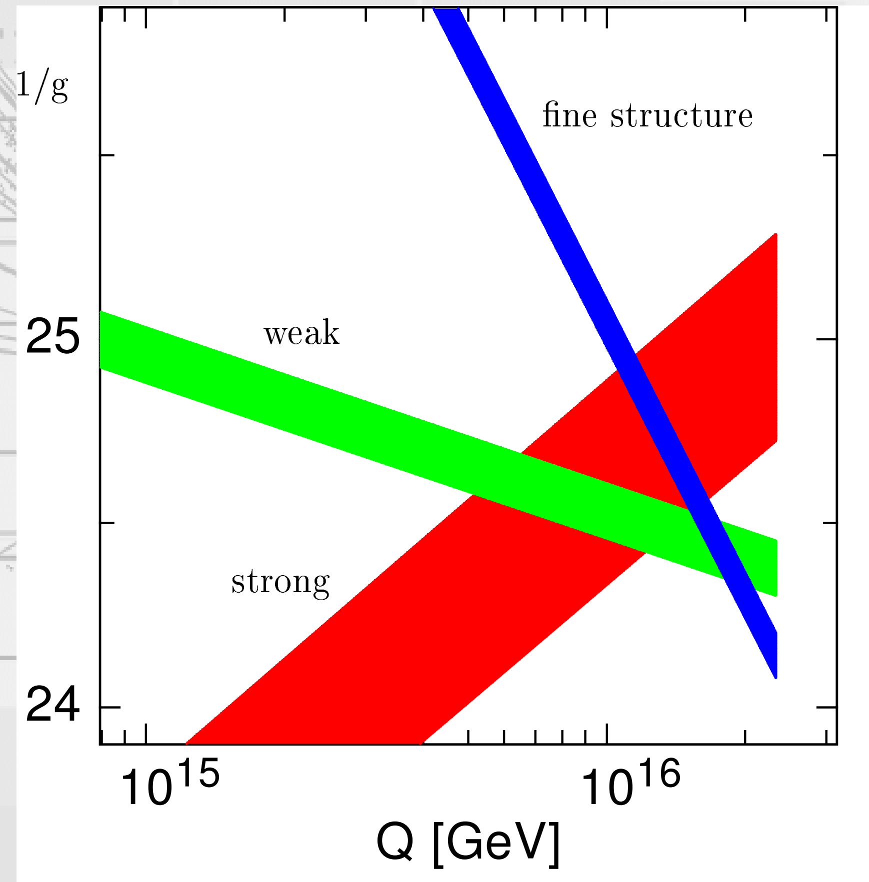
	LHC *Lq* +decay	LHeC *Lq* formation+decay
fermion number		 $e+$ F=0, $e-$ F=2
spin parity and chirality	$gq \rightarrow Lq\,\bar{l}$ production mechanism ? disentangle mass spectrum ?	defined formation (e_{LR}) $\rightarrow$ precision BRs (NC CC) inclusive coherence unique PWA SM + signal + interference 
experim! signature	jet + leptons	jet+lepton+p_T balance jet +p_T imbalance

Unification ?

- precision → QCD at highest energy
- short distance structure of SM+
  - 2007 → @ 10^{-3} ppm
  - 2007 G_F @ 10 ppm
  - 2007 G @ 0.1%
  - 2007 α_s @ 1-2%
  - LHeC + detector → α_s @ few ‰



precision → extrapolation → discovery
probe new chromodynamic physics - beyond SM ?

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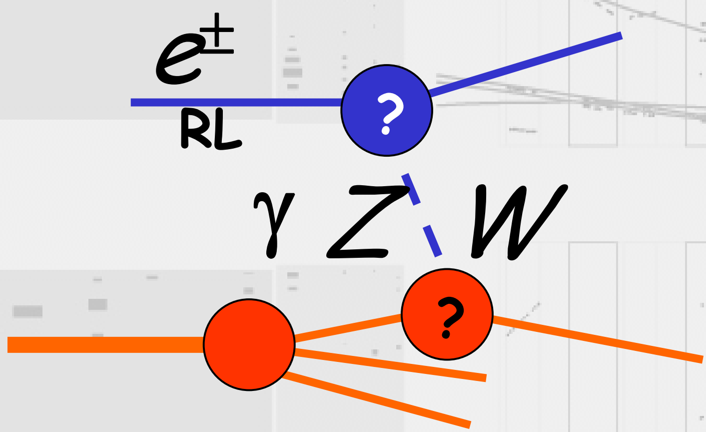
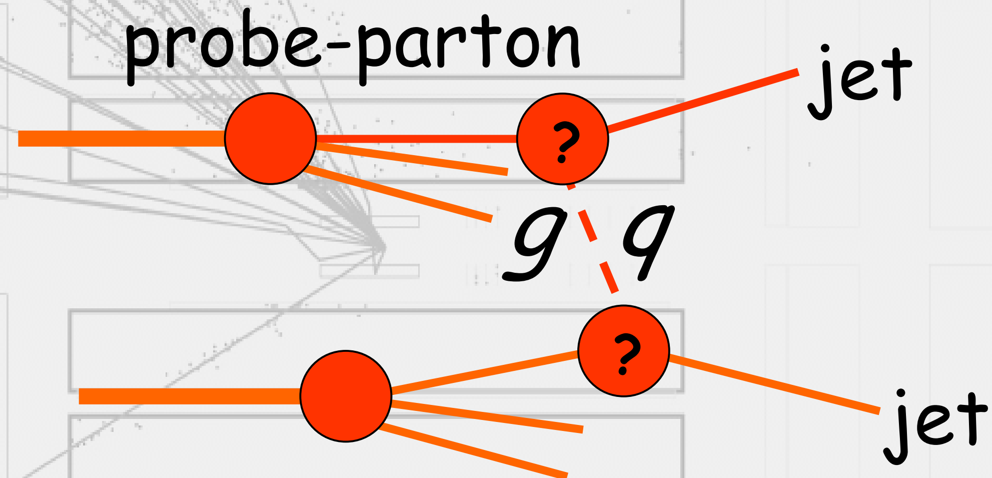
Lepton-Parton and Parton-Parton ?

- $ep \to eX$



- LH*e*C energy scale: 70⊗7000 GeV

- $pp \to (\mathrm{jet{+}jet})X$



- *pp* energy scale: 7000⊗7000 GeV

probe+*p* at LH*e*C scale

probe = $e^{\pm}$

$x_{\mathrm{probe}/p} = 0.01$

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LHC probe parton

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- probe-parton @ $x \le 0.01$
  - $xq = xU + xD + x\bar{U} + x\bar{D}$

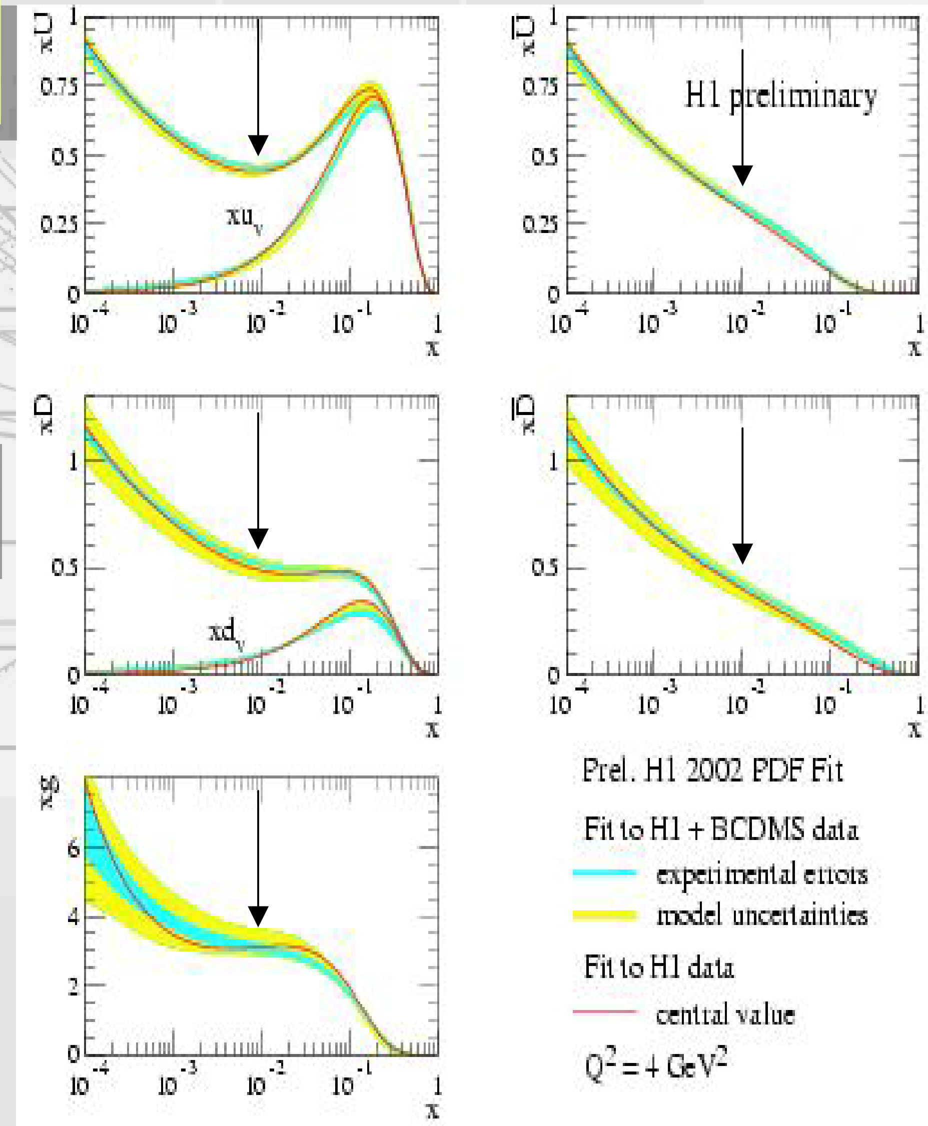
    $g:q \sim 2{:}1$ mixed

- probe-parton @ $x \gg 0.01$

    $g:q \to 0$ all quark

"mixed" LHC probe
@ LH*e*C energy

q LHC probe
@ LHC top energy



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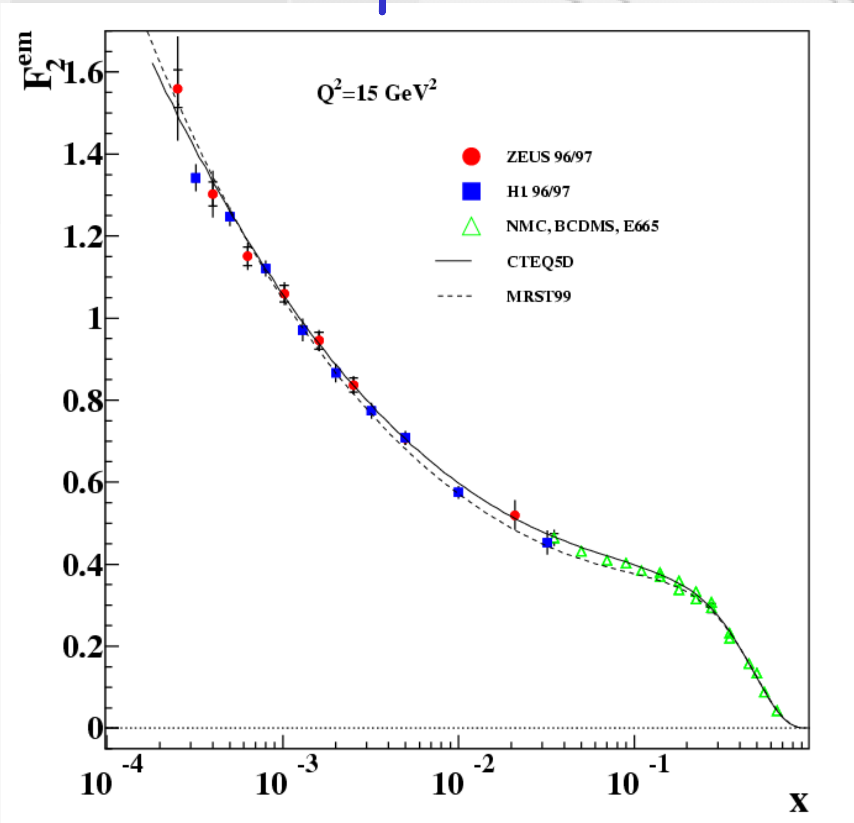
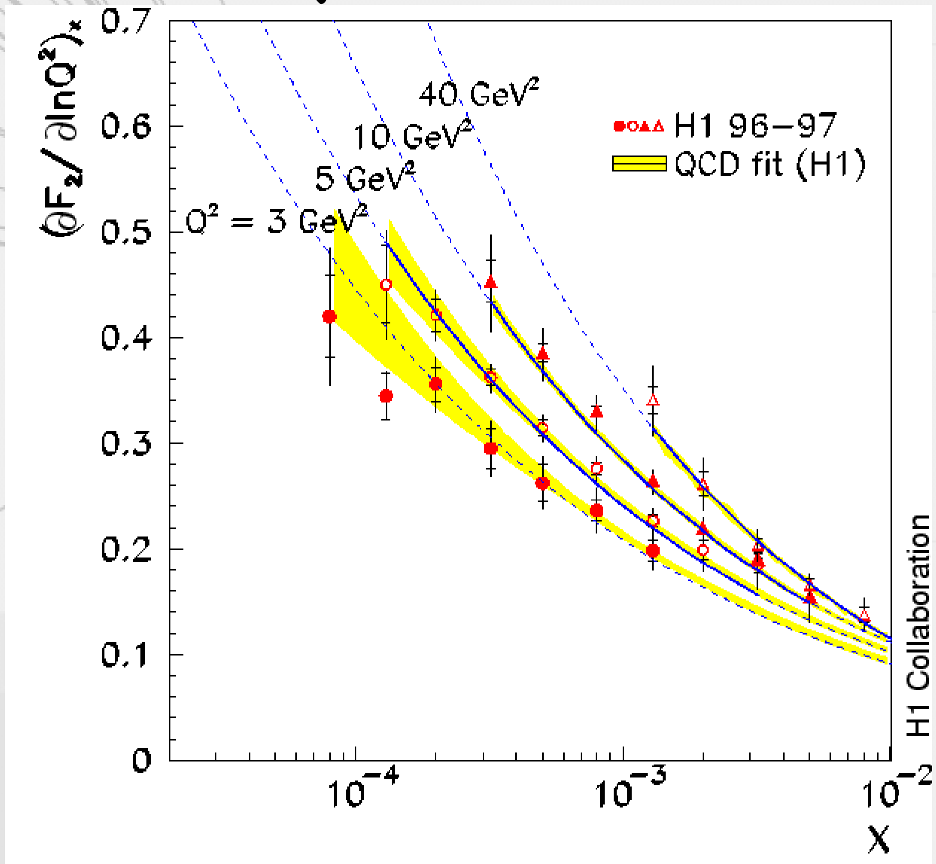
Gluon recombination @ HERA

- low-x rise of F_2
  - HERA: precision @ $x > 10^{-4}$ @ Q^2=10 GeV^2

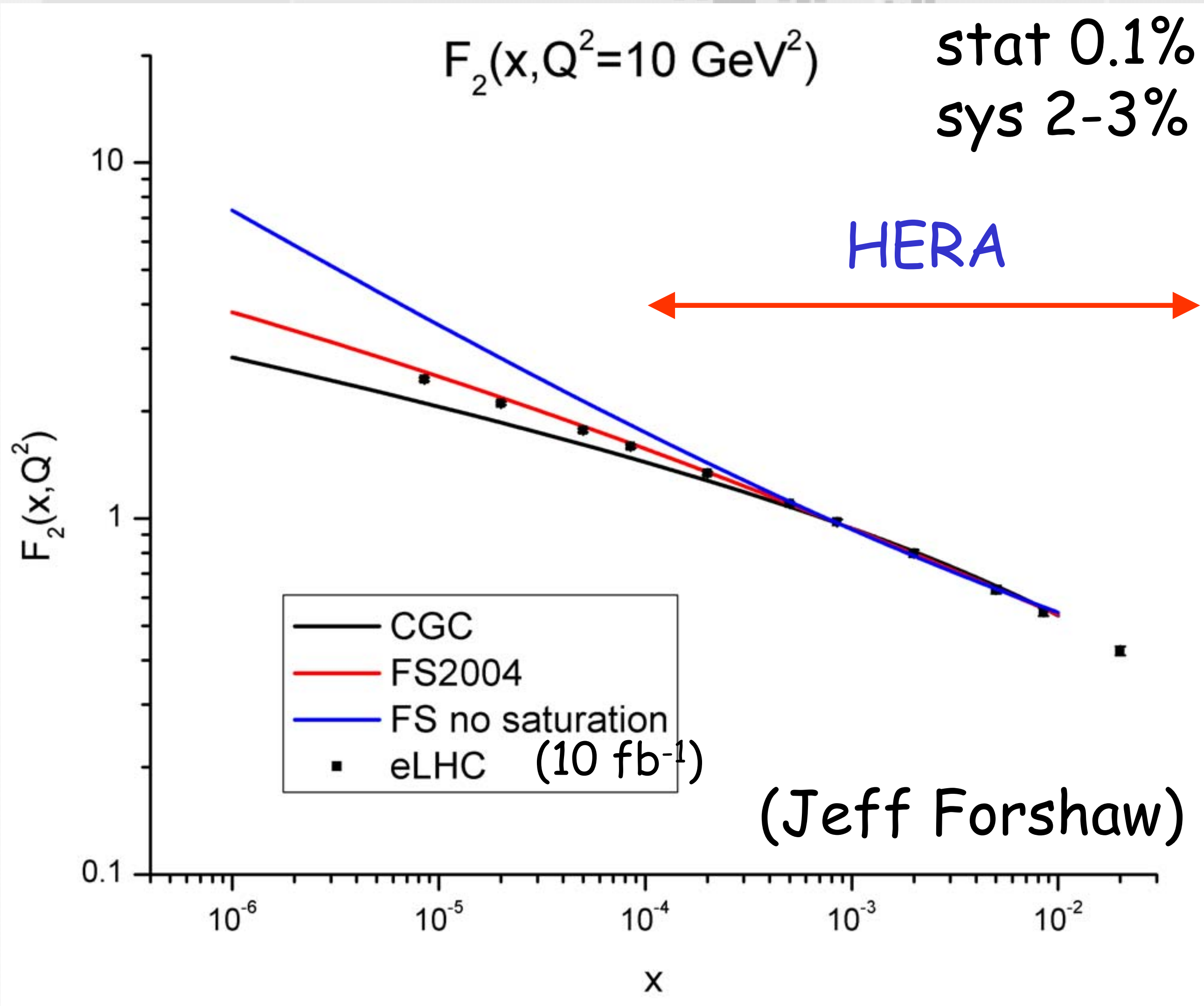




- relentless rise of
  quark (F_2) and gluon $^{\partial F_2}/_{\partial \ln Q^2}$

Gluon recombination @ LHeC

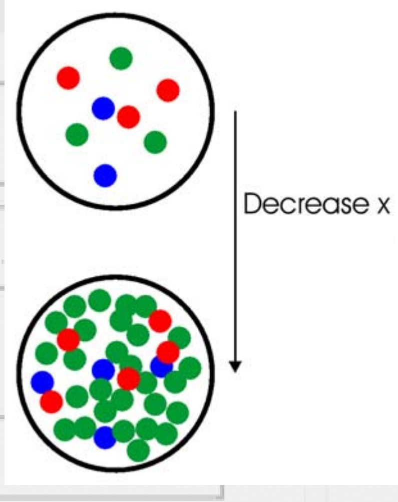
- low-x rise of F_2
  - LHeC: precision @ $x > 10^{-4}$ @ Q^2=250 GeV²



stat 0.1%
sys 2-3%

(10 fb^{-1})

(Jeff Forshaw)



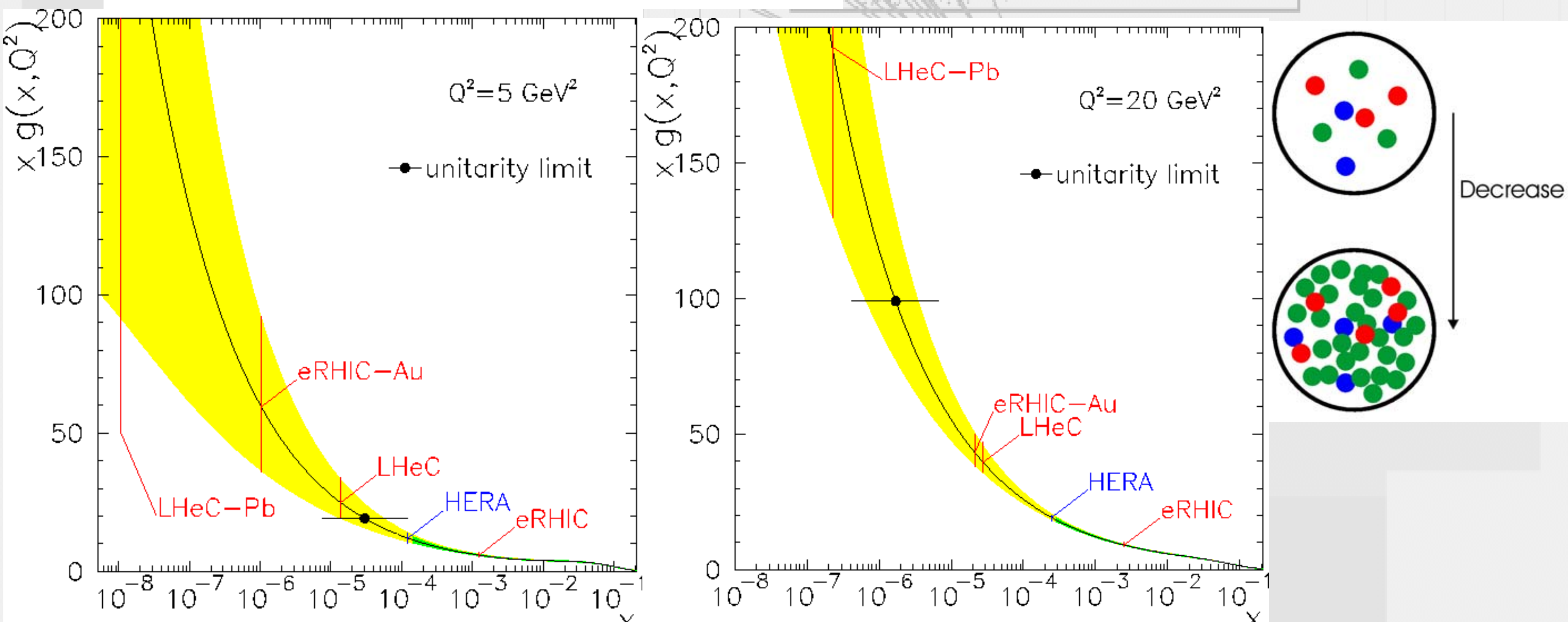
- LHeC "nails" saturation

Gluon recombination @ LHeC

- *ep* saturation $Q^2 \leq 5$ GeV²

  eA saturation $Q^2 \leq 20$ GeV²

$$Q_s^2 \sim \frac{\alpha_s x G_A(x, Q_s^2)}{\pi R_A^2} \sim A^{1/3} \frac{1}{x^{0.3}}$$



- LHeC "nails" saturation

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Partons in Nuclear Matter

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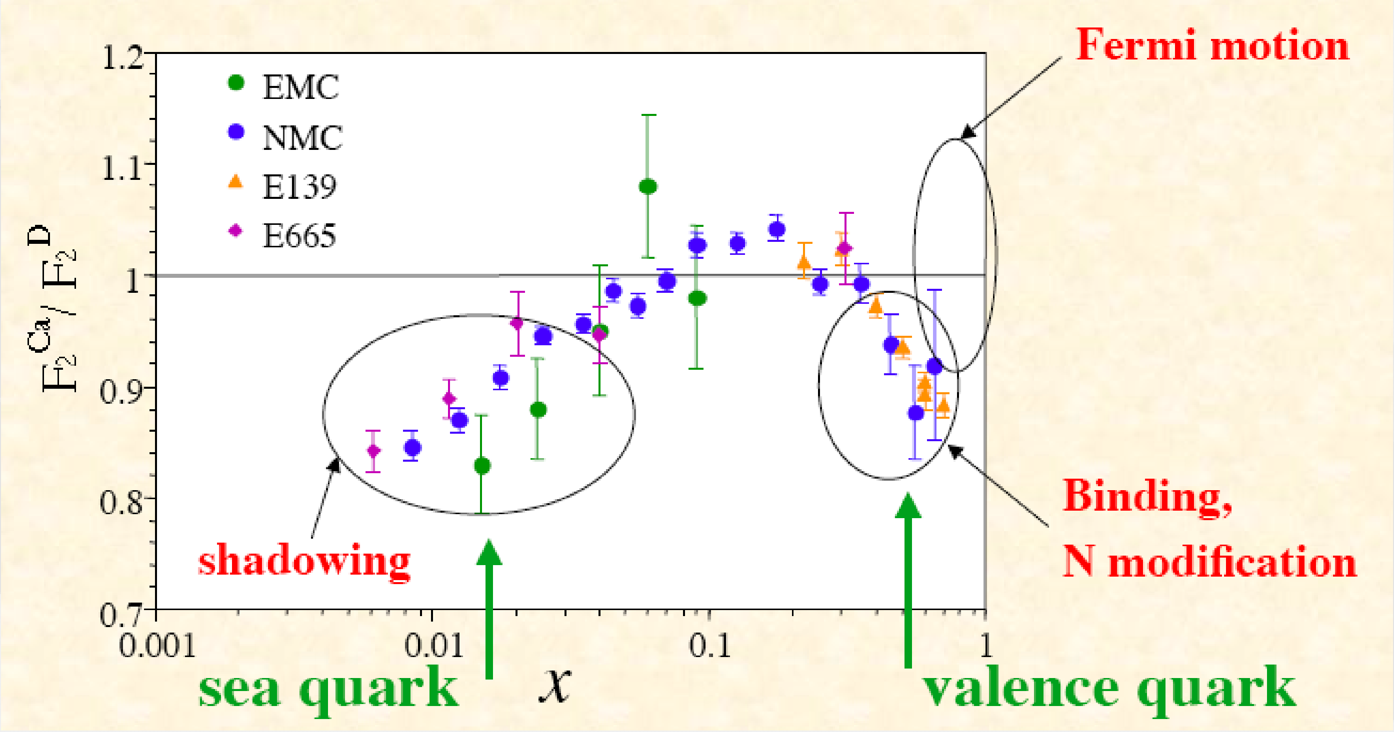
- fundamental to origin of mass in Universe (Wilczek)
  - from nucleon valence to QCD-field dominated ($x\downarrow$)
  - increasing number of valence partons ($A\uparrow$)
- very limited, but tantalising, old data
  - $Q^2 < 1$ GeV^2 $x > 0.01$

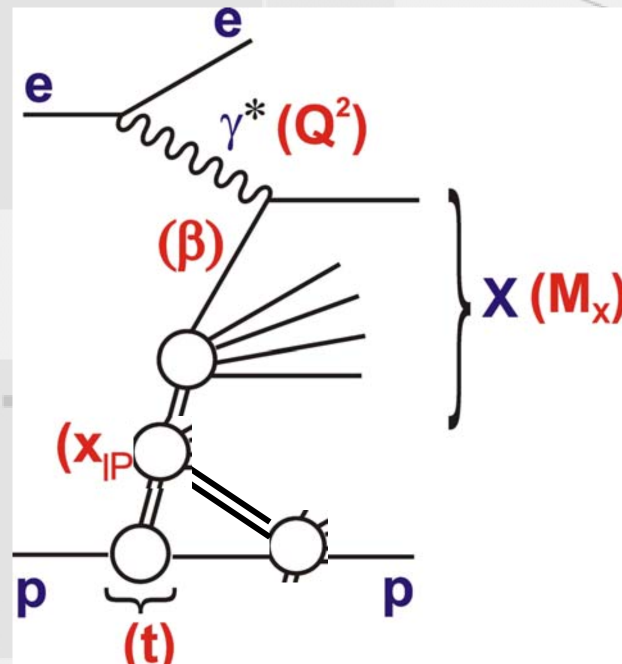


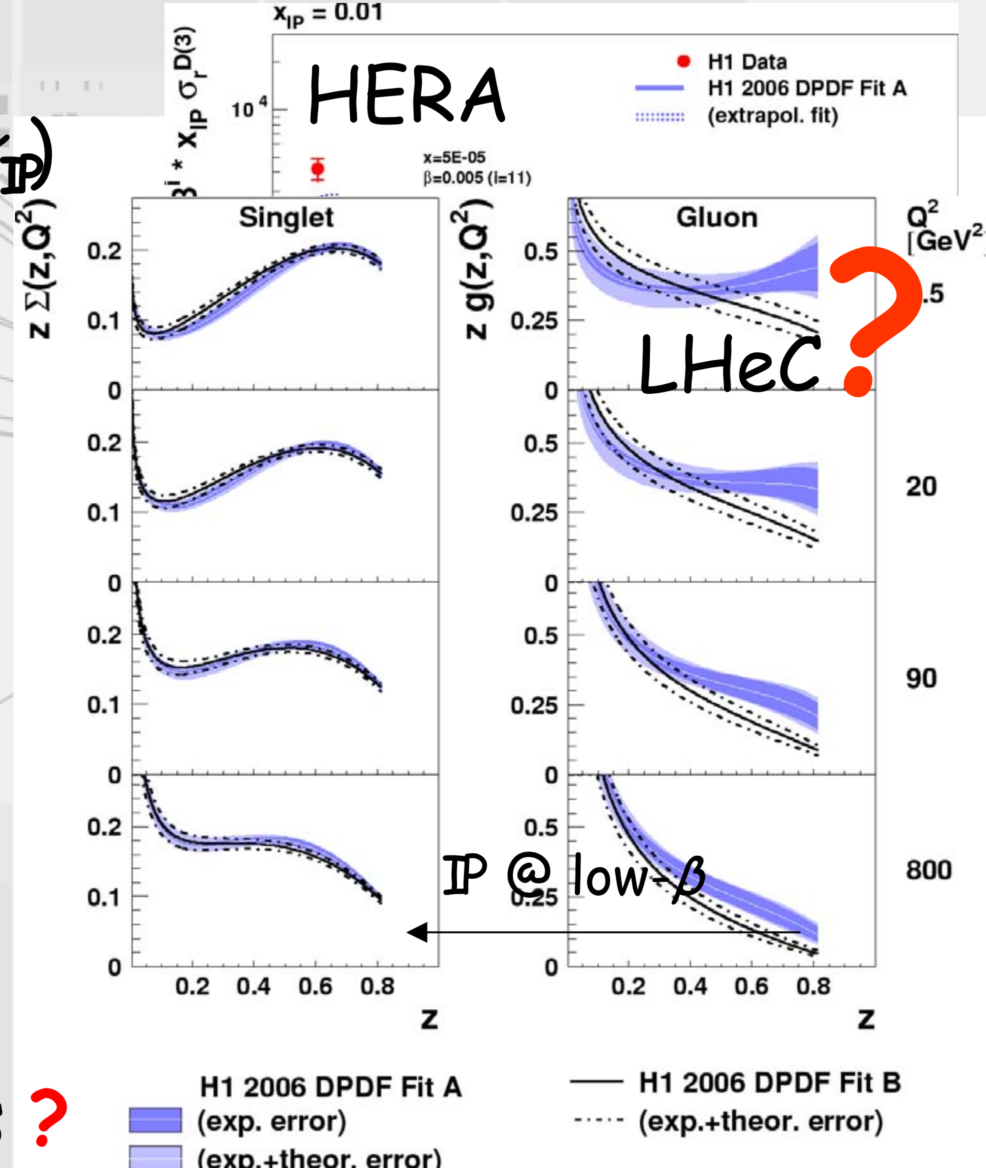
1_c dynamics in p and A

- low-x reach at LHeC

  precision @ $x > 10^{-4}$

  @ Q^2=250 GeV² ($x = \beta x_{I\!P}$)





- low x physics of $I\!P$

  $I\!P$ in $I\!P$: triple $I\!R$

  QCD → reggeon calculus ?

1_c dynamics in *p* and *A*

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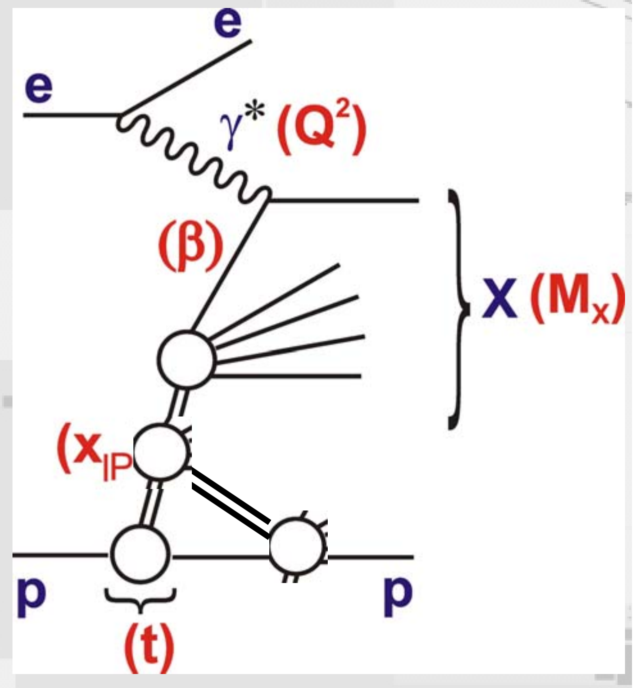
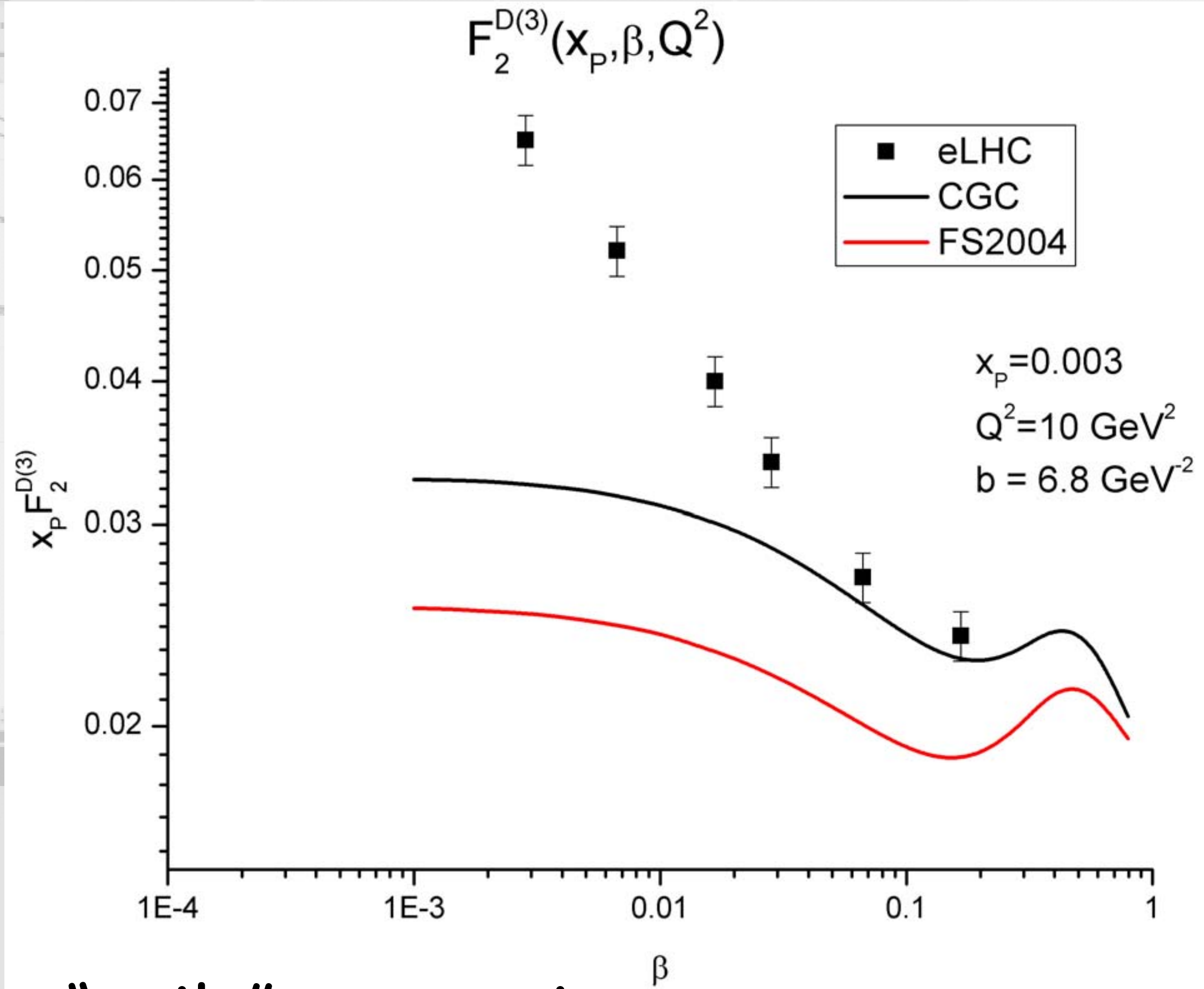
- low-*x* IP physics at LH*e*C





- LH*e*C diffraction "nails" saturation

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1_c dynamics in *p* and *A*

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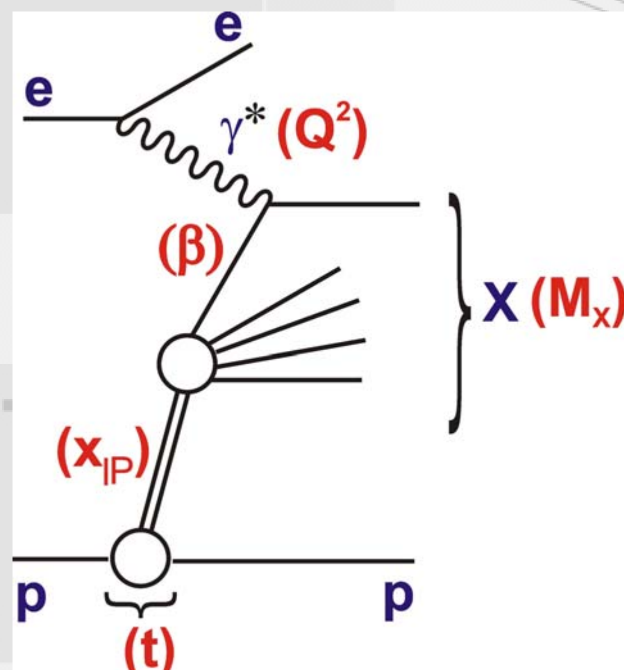
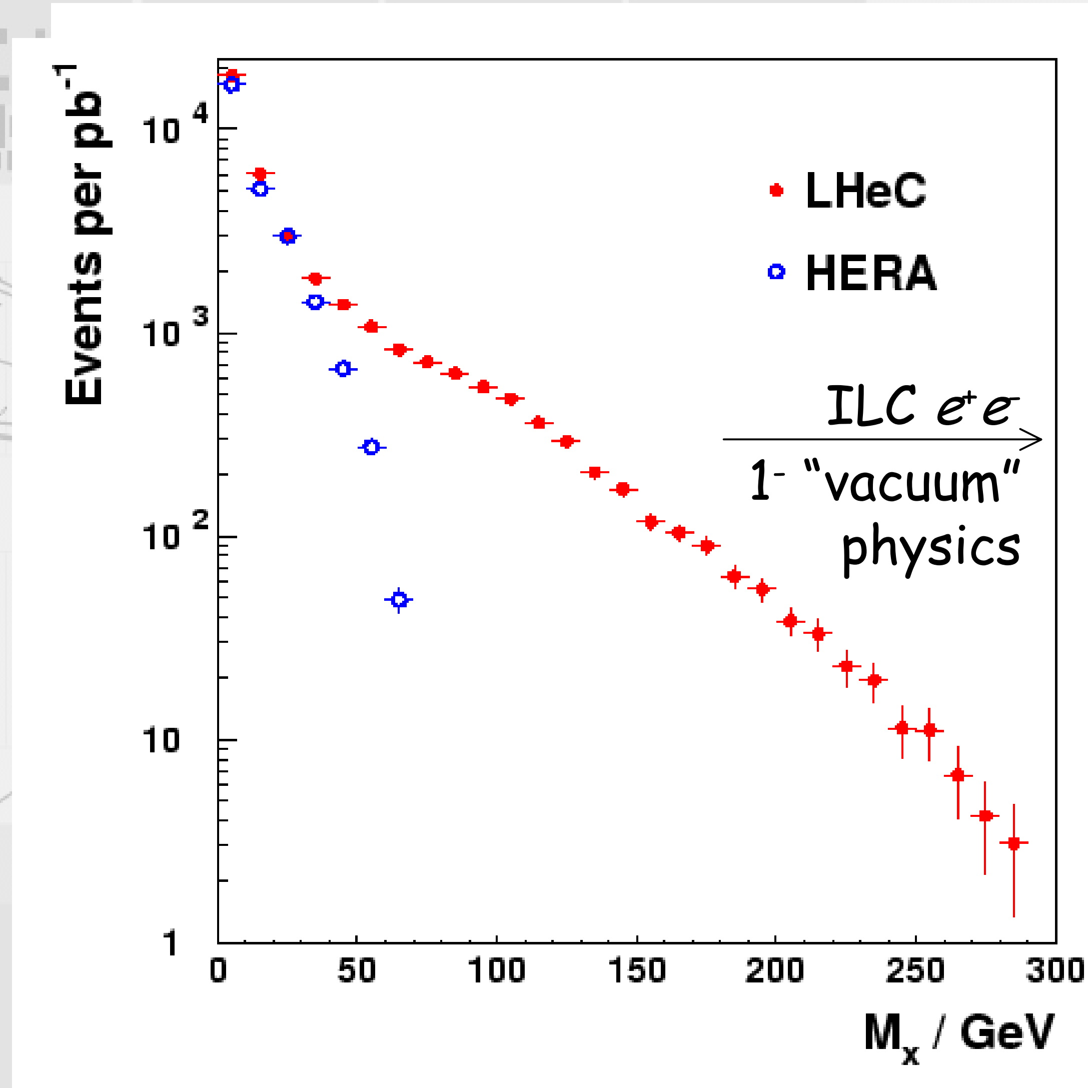
- IP physics at LH*e*C
  0^+ "vacuum" physics



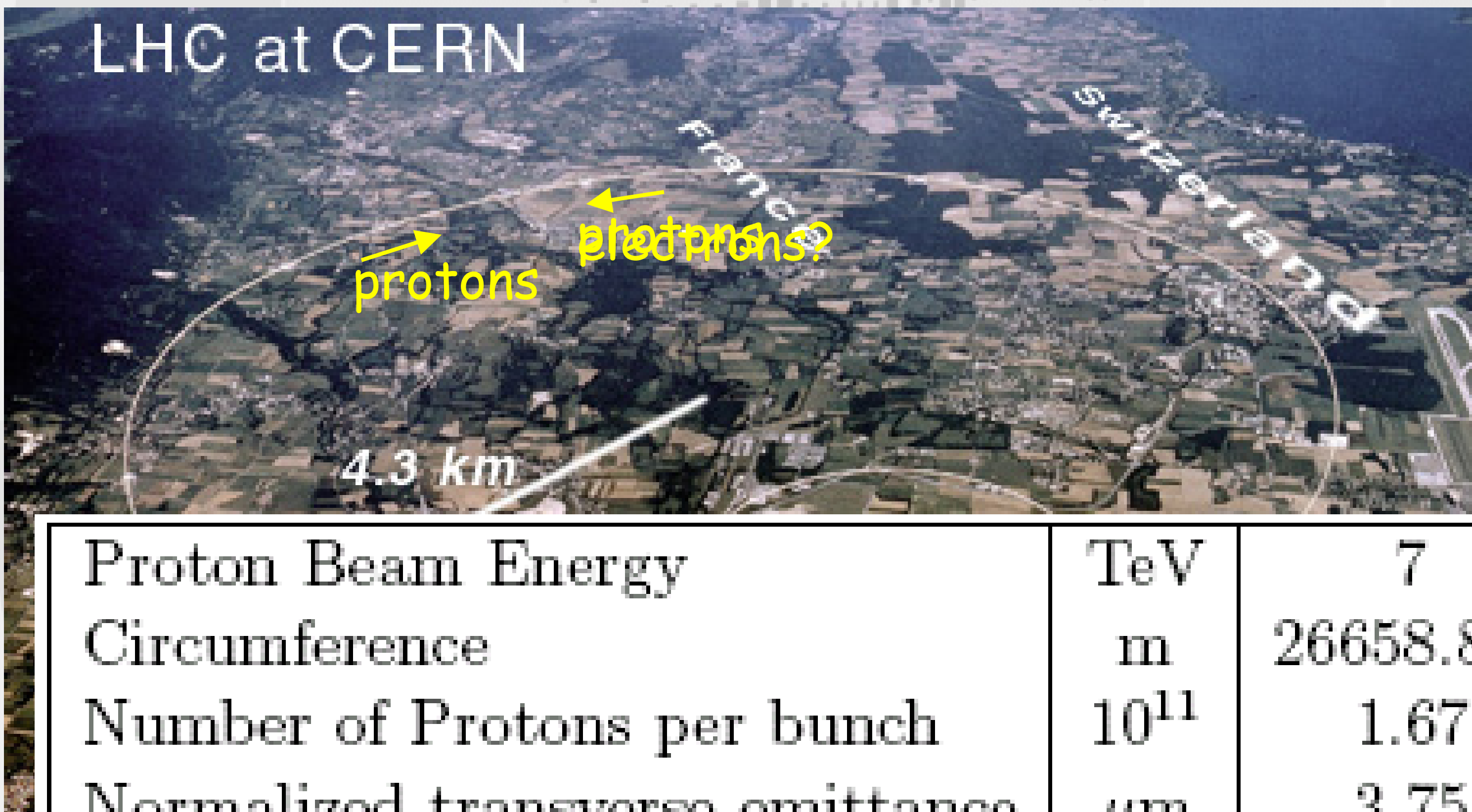


- γ*IP physics … GeV: leptopomerons ?

3.Machine

Proton beam

- "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	

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LHC

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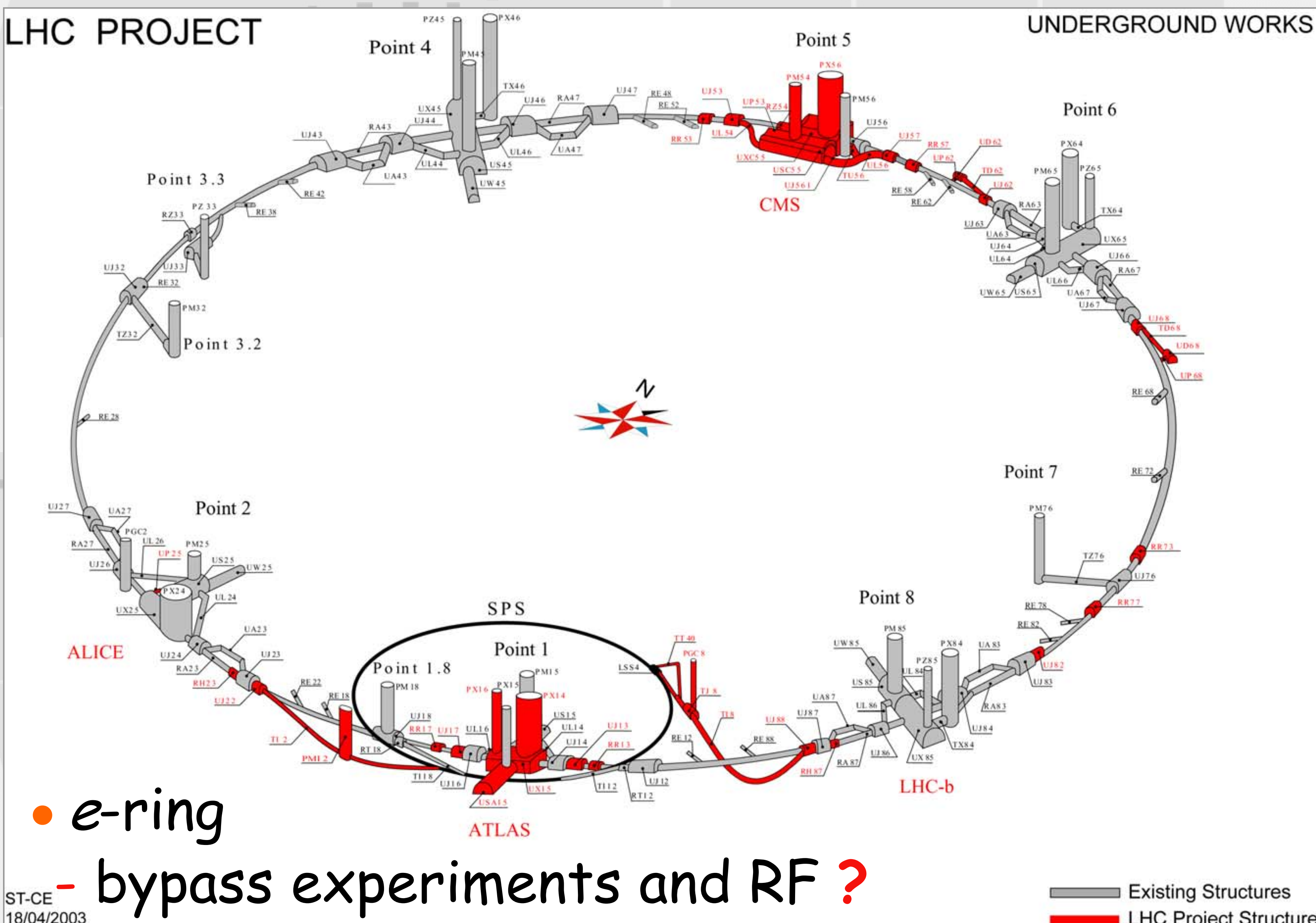

- *e*-ring
  - bypass experiments and RF ?

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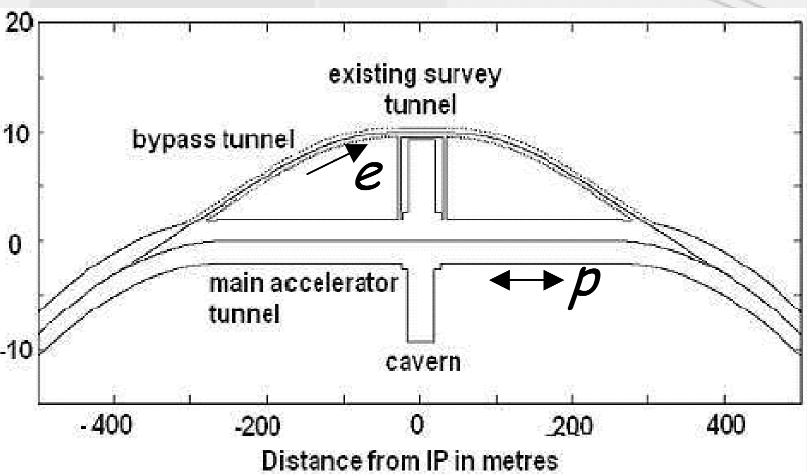
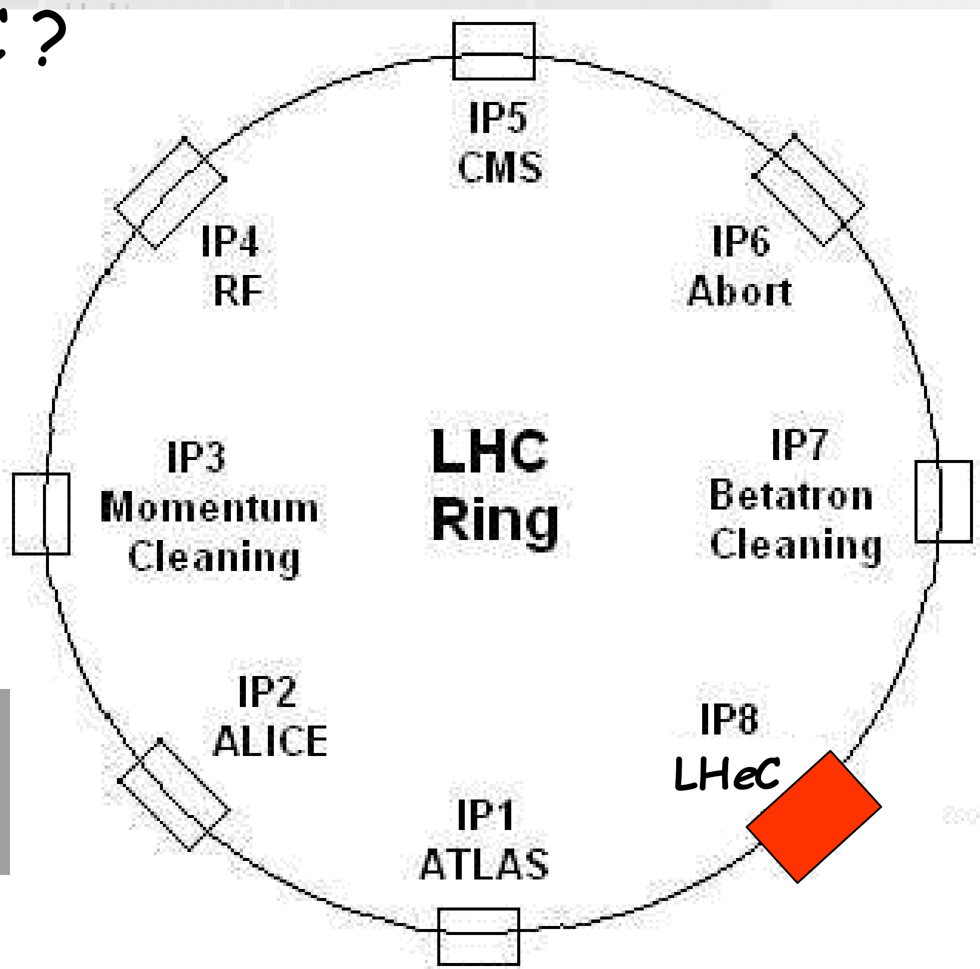
ep Collisions

- after *B* physics @ LHC ?





civil engineering
tunnel >2×250m×2m Ø @IP

ep alongside *pp* data-taking @ LHC

Luminosity: *e*-Ring

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$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.3 10^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

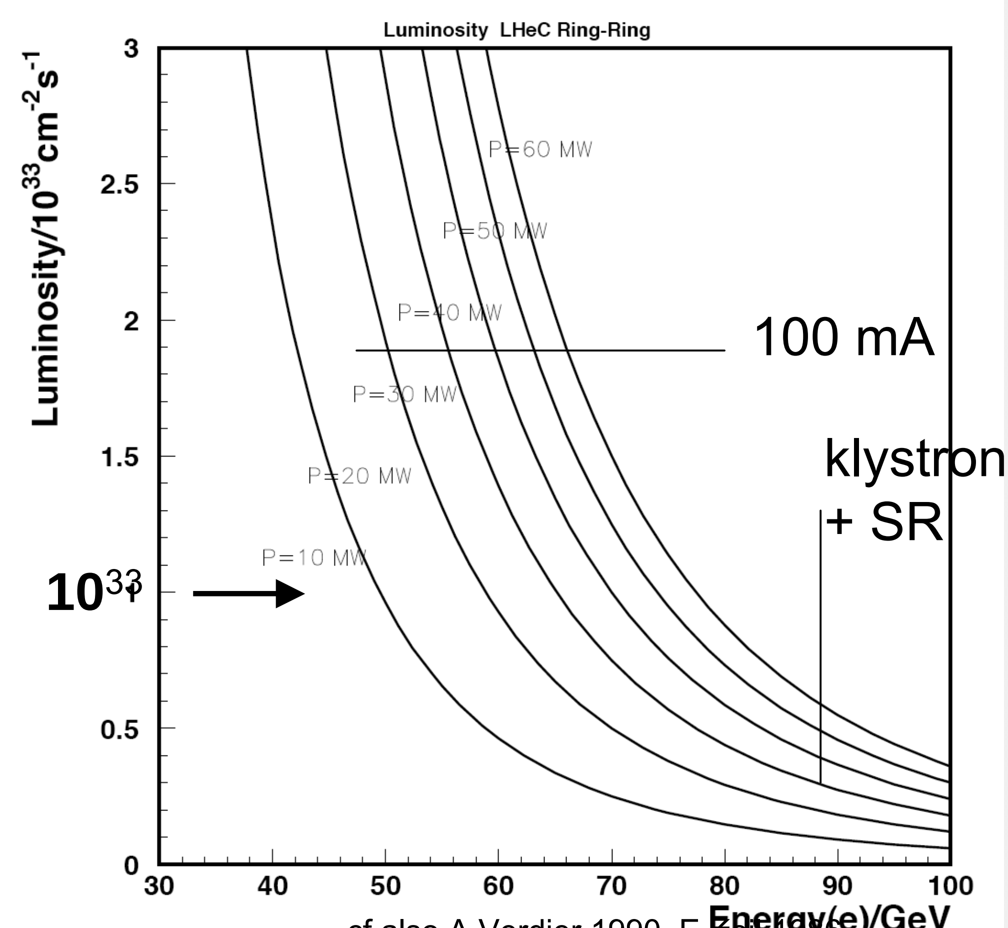
$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

$$\varepsilon_{pn} = 3.8\mu m \qquad \beta_{px} = 1.8m$$

$$N_p = 1.7 \cdot 10^{11} \qquad \beta_{py} = 0.5m$$

$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$

- *e*-ring
  - 10^{33} cm^{-2}s^{-1}
  - E_e < 80 GeV
  - power P < 60 MW
  - ERL → 10^{34}cm^{-2}s^{-1} ? (eRHIC)



cf also A.Verdier 1990, E.Keil 1986

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e-Ring IR

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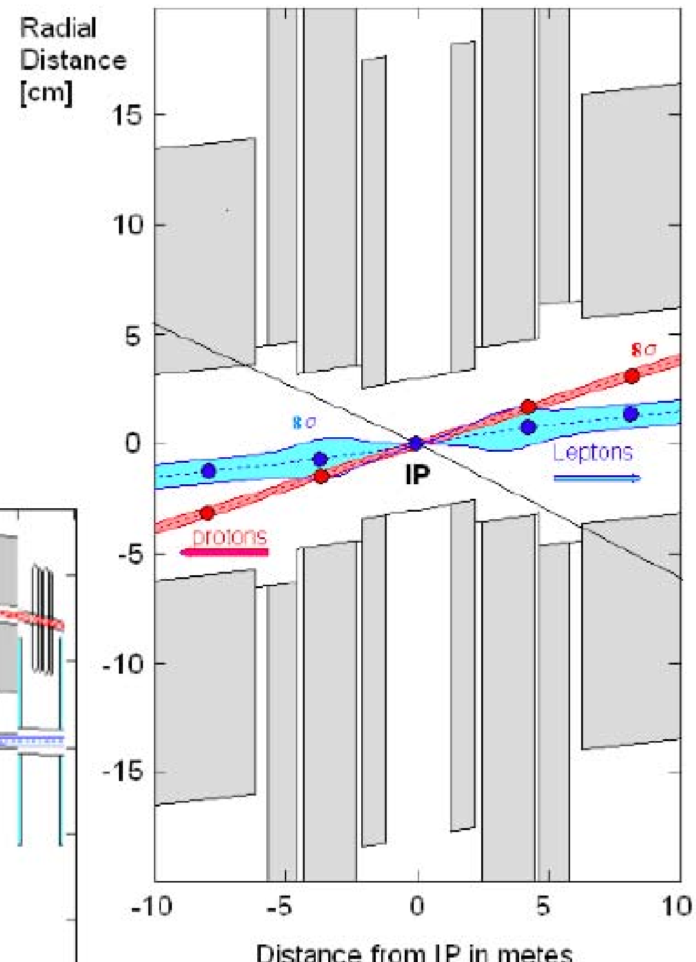
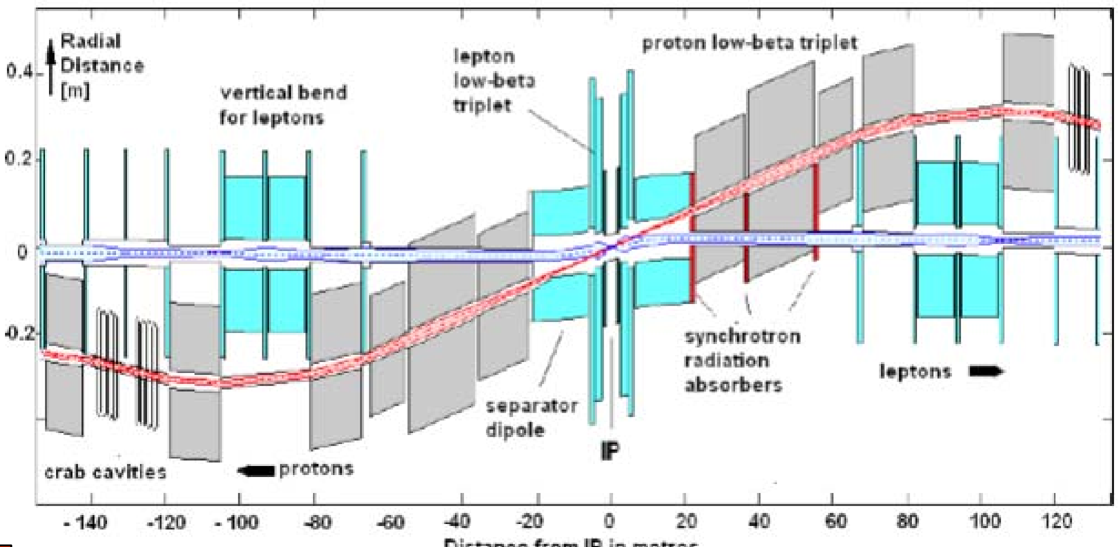
Table 3: *Main Parameters of the Lepton-Proton Collider*

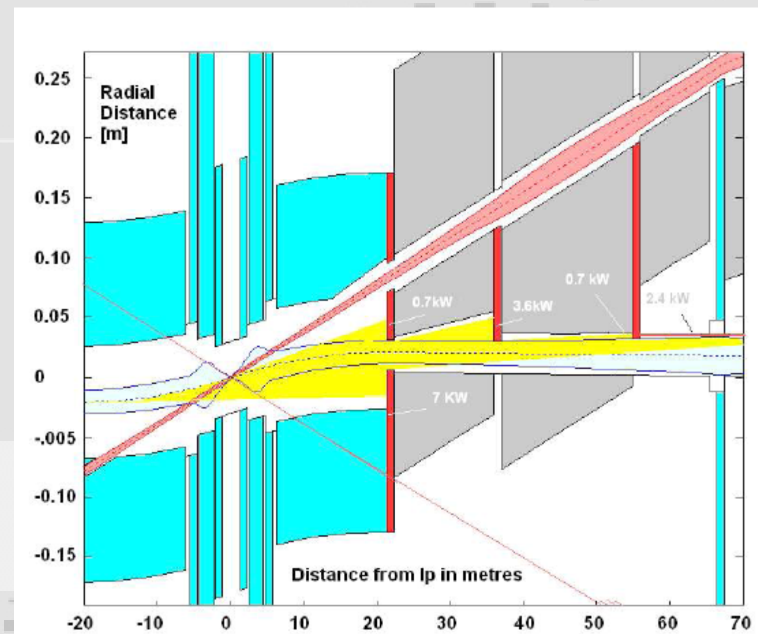
Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6 \cdot 10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.1	

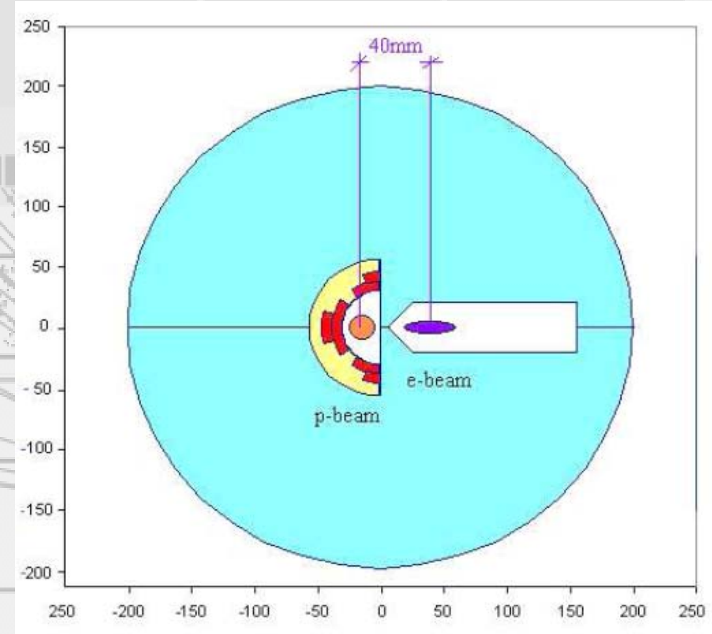




simultaneous *pp* (*AA*) and *ep* (*eA*)

e-ring





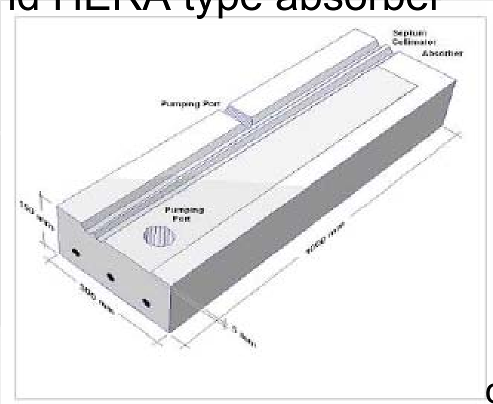
Synchrotron radiation fan

and HERA type absorber

$9.1kW$

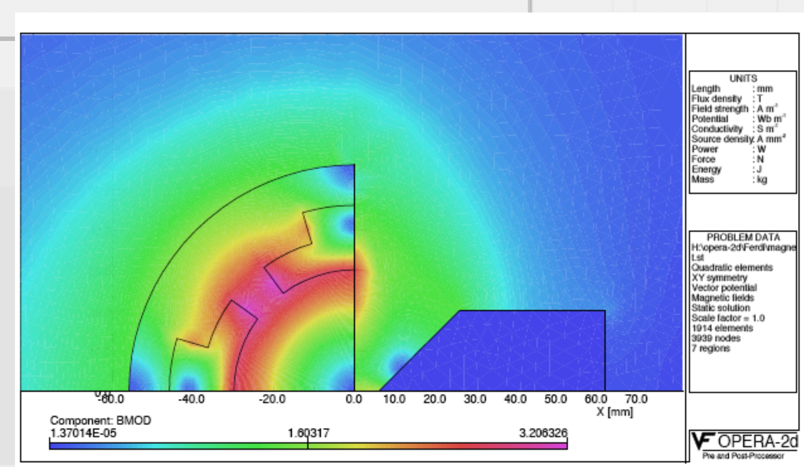
$E_{crit} = 76keV$

First p beam lens: septum quadrupole.
Cross section and Field calculation



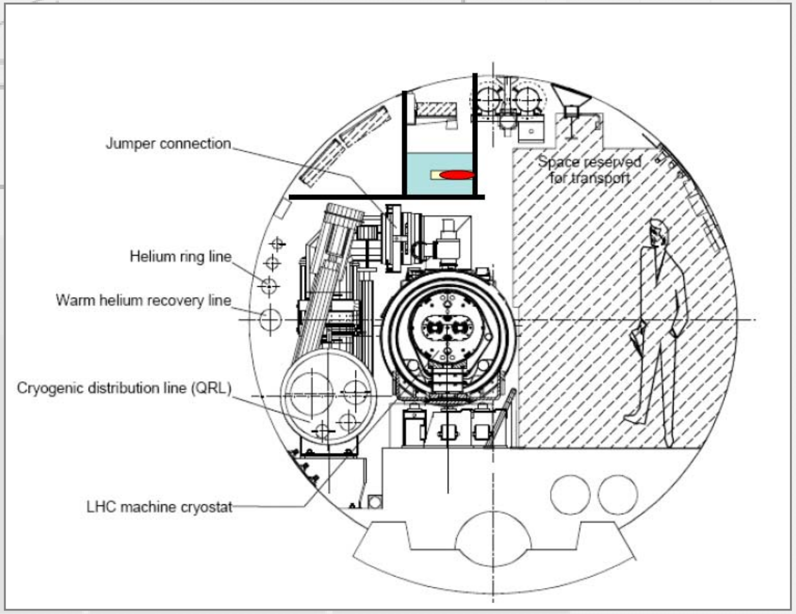
100W/mm^2

cf also W.Bartel Aachen 1990

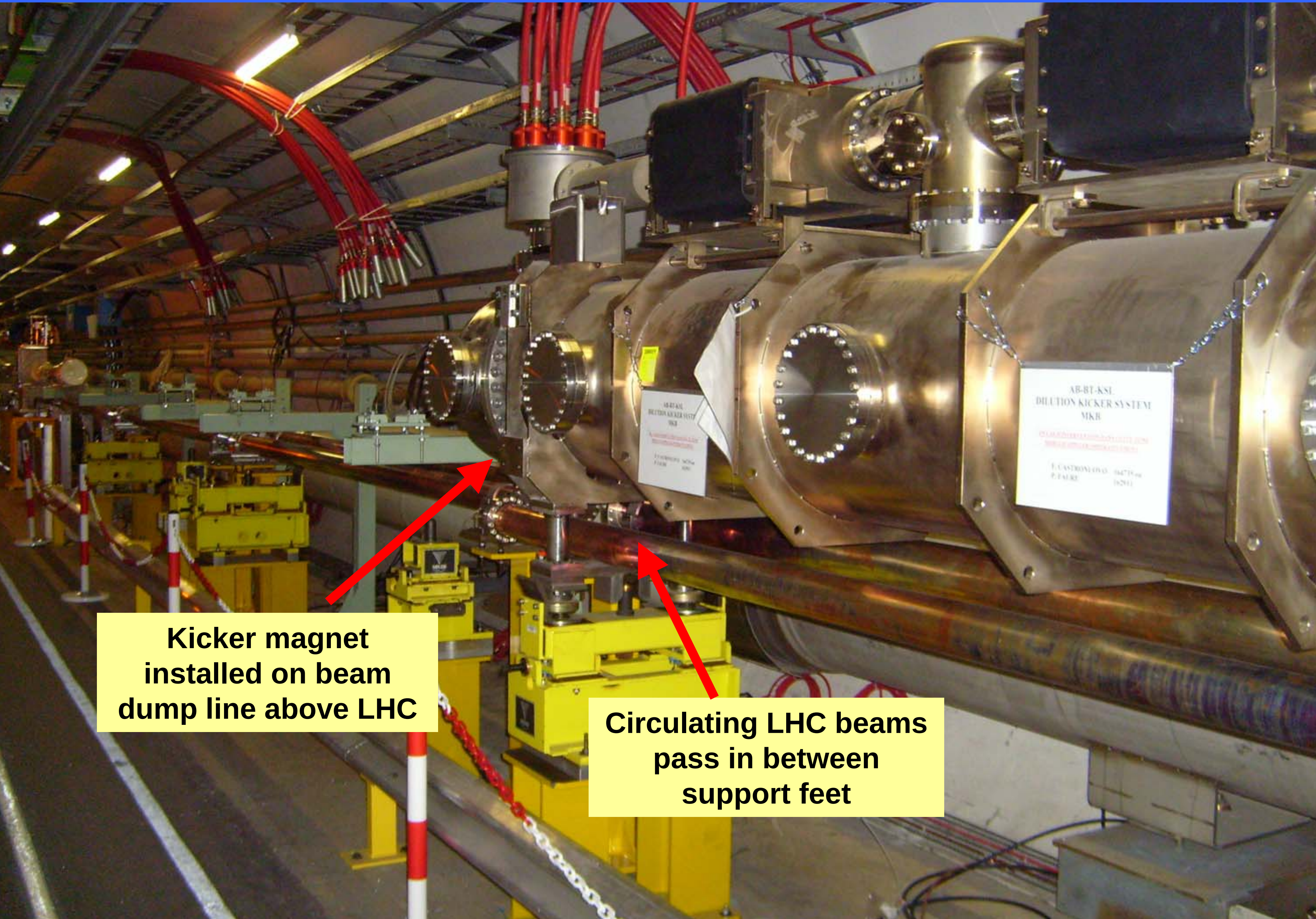


e-ring Issues

- power: 25 ns → nx40 MHz RF I < 100 mA
  60 klystrons @ 1.3MW, coupler 0.5MW, 66% effy
  extra RF in bypasses
- injection: 1.4×10^{10} *e* in 2800 bunches (LEP2 4 10^{11} in
  energy can be < 20 GeV (ELFE, KEK ...)
- SR → LHC magnets: water cooling+Pb
- bypasses: ATLAS CMS + RF
  → ~500m from arcs
  ~ -20cm radius of *e*-ring
- space: above LHC



Equipment above installed LHC beamlines….



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$e^{\pm}p$ Luminosity

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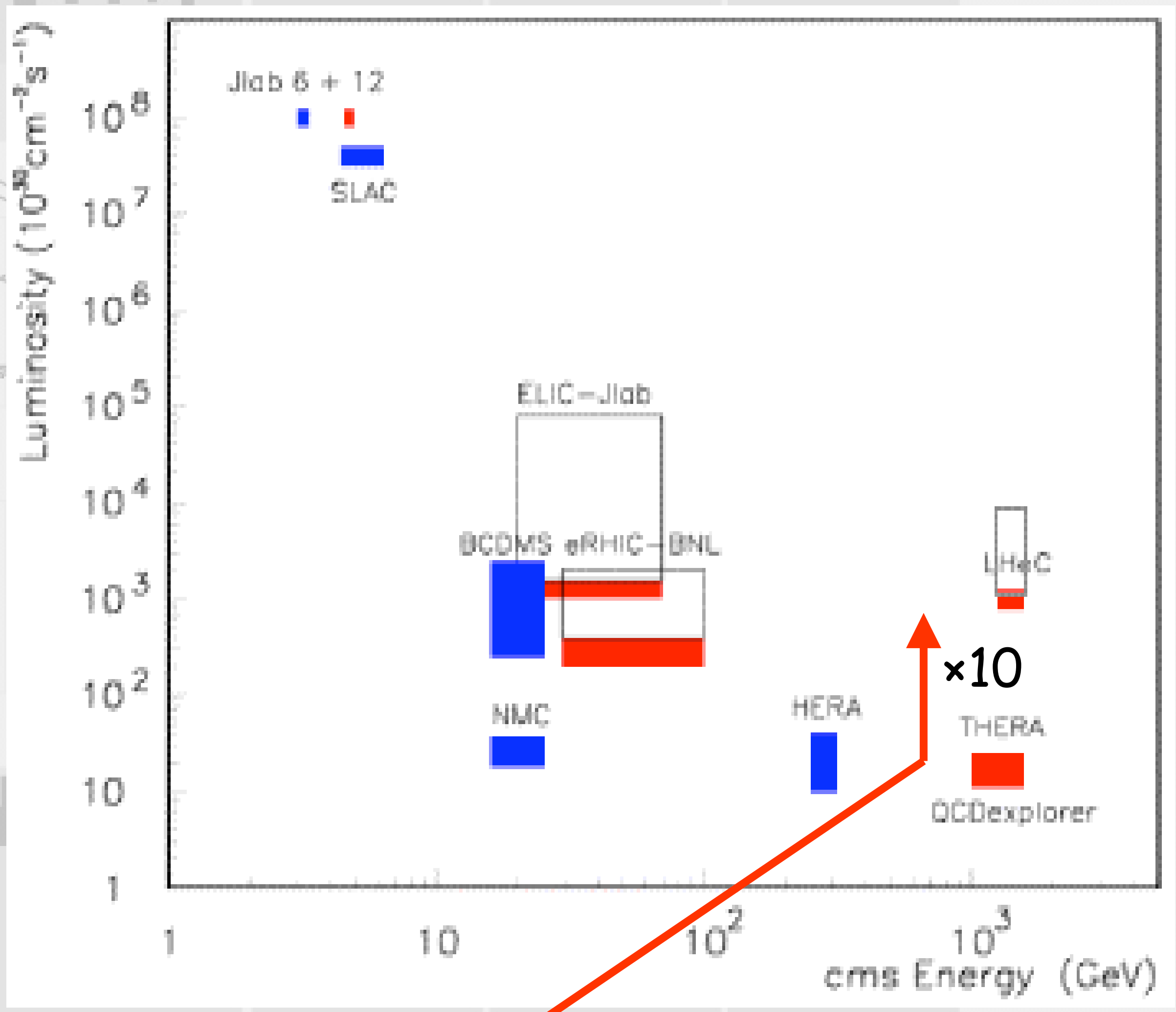
- astounding !

- $\times 10^2\ \mathcal{L}_{NMC}\ \mu p$ @ 0.01 fm
- $\mathcal{L}_{eRHIC}\ e_{pol}p_{pol}\ eA$ @ 0.007 fm
- $\times 10^2\ \mathcal{L}_{HERA}\ e_{pol}p$ @ 0.001 fm
- $\mathcal{L}_{LHeC}\ e^{\pm}p\ eA$ @ 0.00014 fm



indisputably a next step ?

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e-linac + LHC

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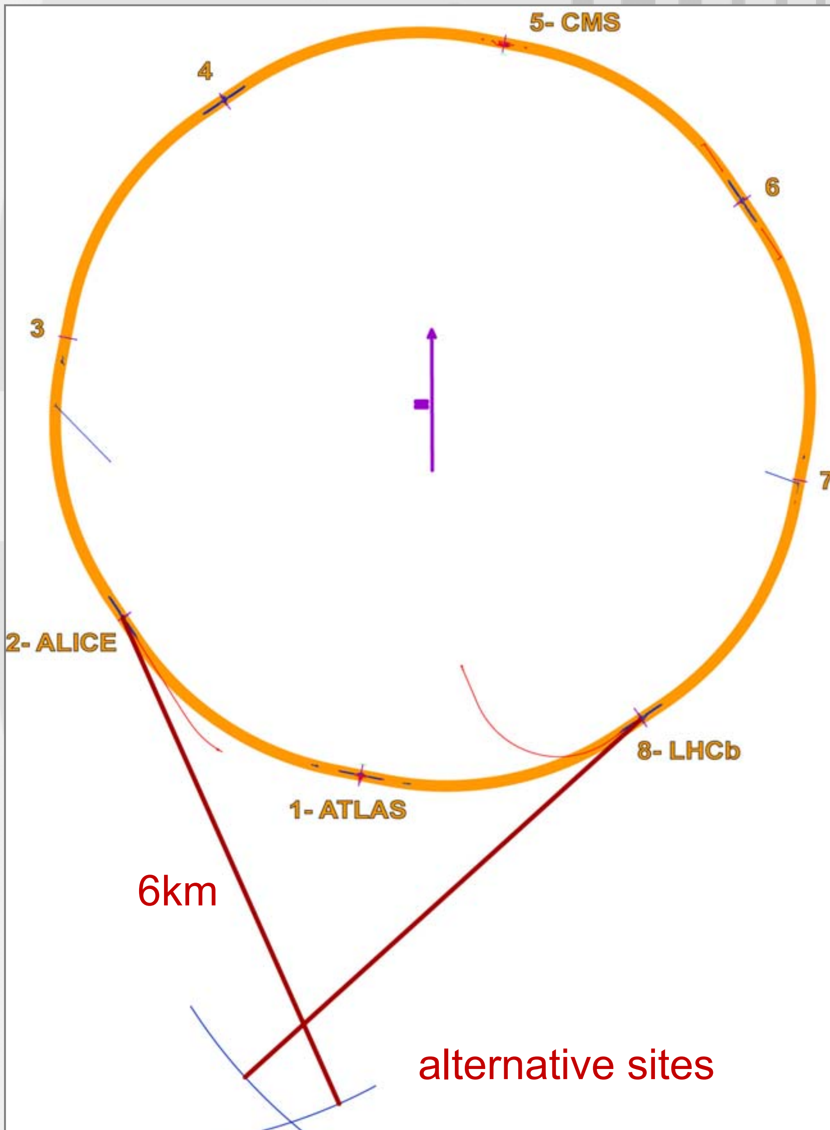

		ring-linac pulsed		ring-linac, cw , ~99% energy recovery	
	units	e-	p	e-	p
energy	GeV	70	7000	70	7000
punch population	10^{10}	2	17	2	17
σ_z	cm	0.03	7.55	0.03	7.55
beam current (pulsed)	mA	101	858	101	858
emittance $\varepsilon_{x,y}$	nm	0.5, 0.5			
$\beta^*_{x,y}$	cm	15, 15			
spacing	ns	25			
e-linac/ring length	km	3.5		7 (2 linacs)	
e- pulse length		1 ms		cw	
repetition rate		5 Hz		continuous	
e- beam power	MW	35		7000	
peak luminosity	**10^{32} cm^{-2}s^{-1}**	**0.6**		**2x110**	

S. Chattopadhyay (Cockcroft), F.Zimmermann (CERN), et al.

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Luminosity: Linac-Ring

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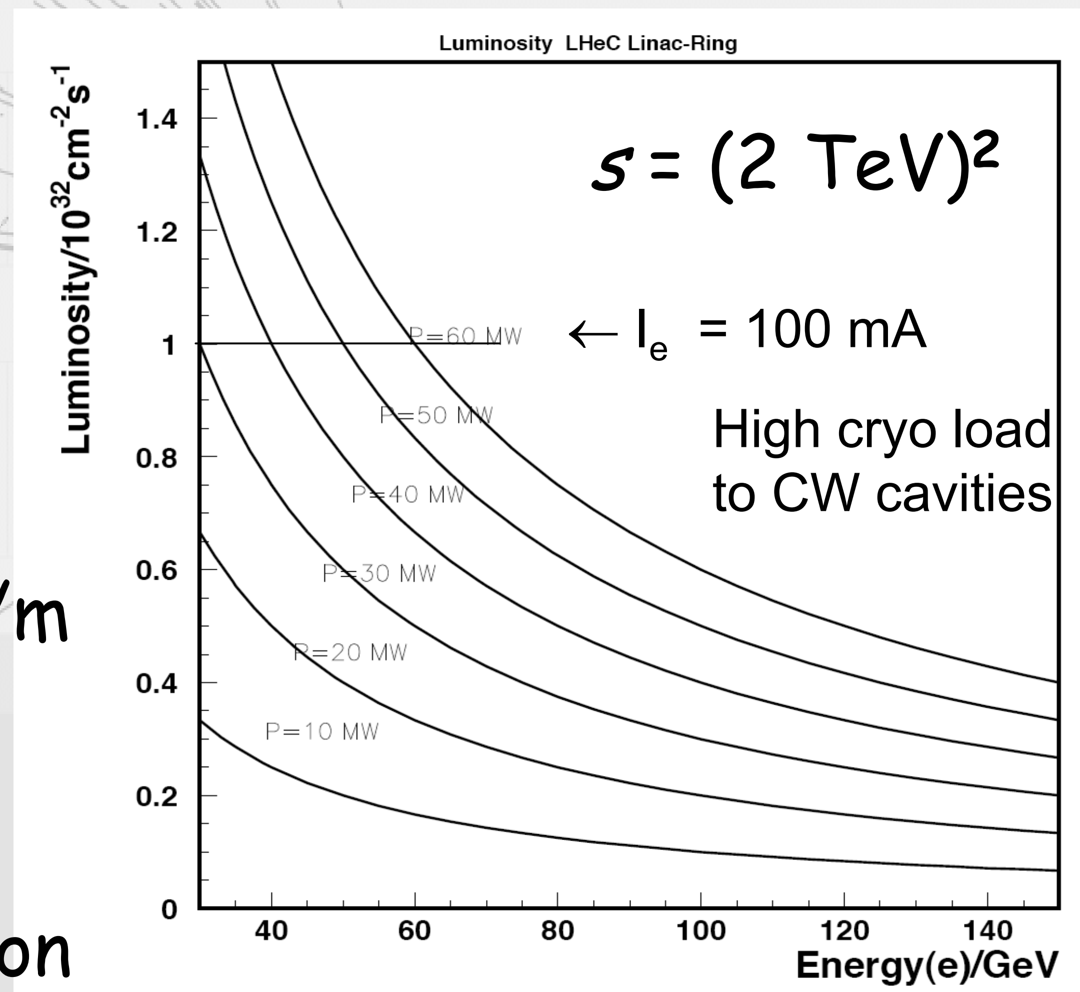
$$L=\frac{N_p\gamma}{4\pi e\varepsilon_{pn}\beta^*}\cdot\frac{P}{E_e}=1\cdot10^{32}\cdot\frac{P/MW}{E_e/GeV}cm^{-2}s^{-1}\qquad I_e=100mA\cdot\frac{P}{MW}\cdot\frac{GeV}{E_e}$$

$\varepsilon_{pn}=3.8\mu m$

$N_p=1.7\cdot10^{11}$

$\beta^*=0.15m$

- e-linac
  - 10^{32} cm^{-2}s^{-1} ~HERA
  - E_e < 140 GeV (\$s)
  - power *P* < 60 MW
  - 6 km+gaps @23 MV/m
  - ERL → ? cm^{-2}s^{-1} 2 linacs



↳ lumi + energy horizon

Linac-Ring & Ring-Ring

	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	6	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]

Machine

- ring-ring
  - stupendous lumi (~ LHC)
  - energy horizon ~ 1.2TeV
  - civil engineering impact on LHC
  - *e*-polarisation (Sokolov-Ternov)
  - *ep* (*eA*) with *pp* (*AA*)
- linac-ring
  - moderate (~HERA) lumi (~ LHC)
  - energy horizon ~ multi-TeV
  - less civil engineering impact on LHC
  - *e*-polarisation (source: e^+?)
  - *ep* (*eA*) with *pp* (*AA*)

- LHC upgrade: cost ?

4.Experiment

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Sensitivity

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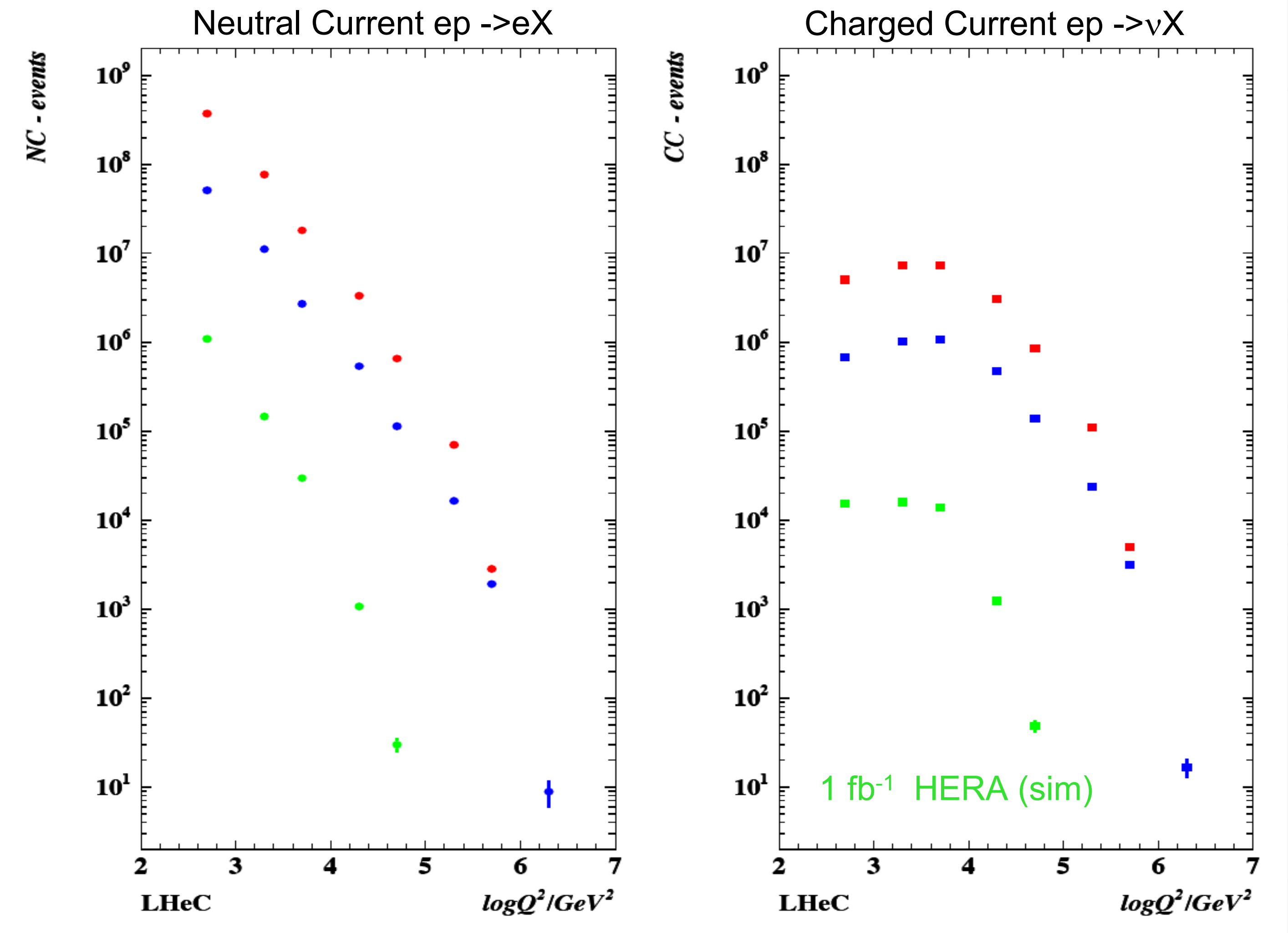
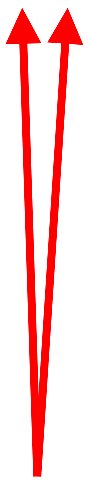
- rates: energy can win you TeV² in Q^2

100 fb^{-1} 70 GeV *e*-ring

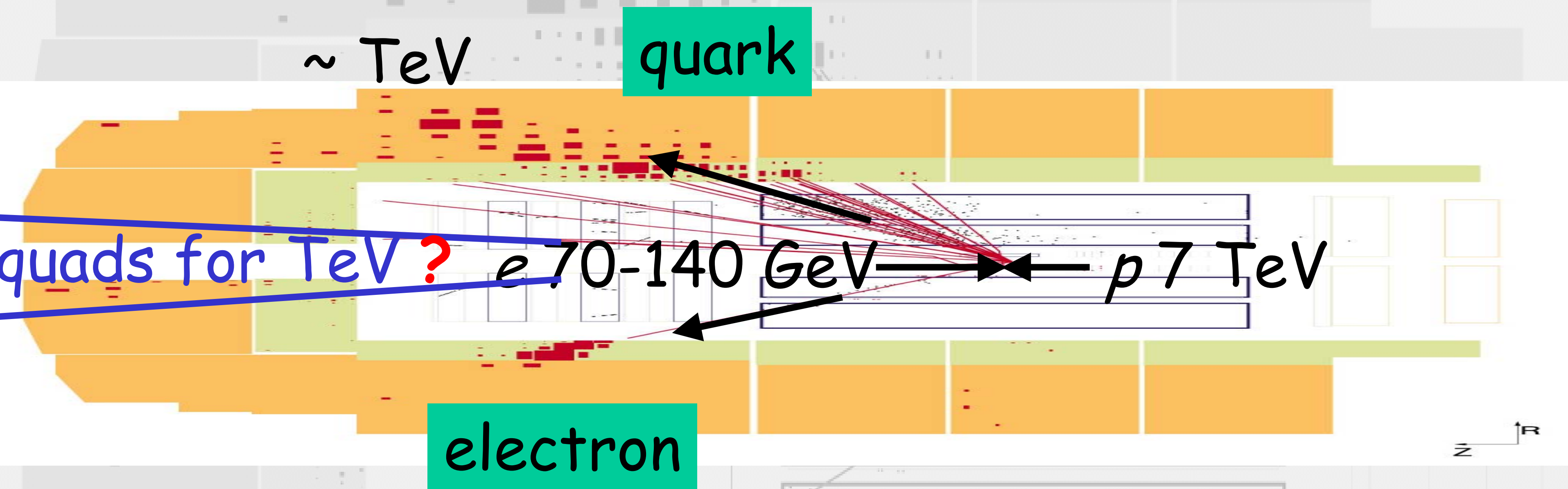
10 fb^{-1} 140 GeV *e*-linac





Asymmetric Collider

- asymmetric beam momenta: LHeC



- "forward" hemisphere detection to multiTeV
  topological challenge
  precision challenge

- "backard" hemisphere detection to fewx10 GeV

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IR Kinematics

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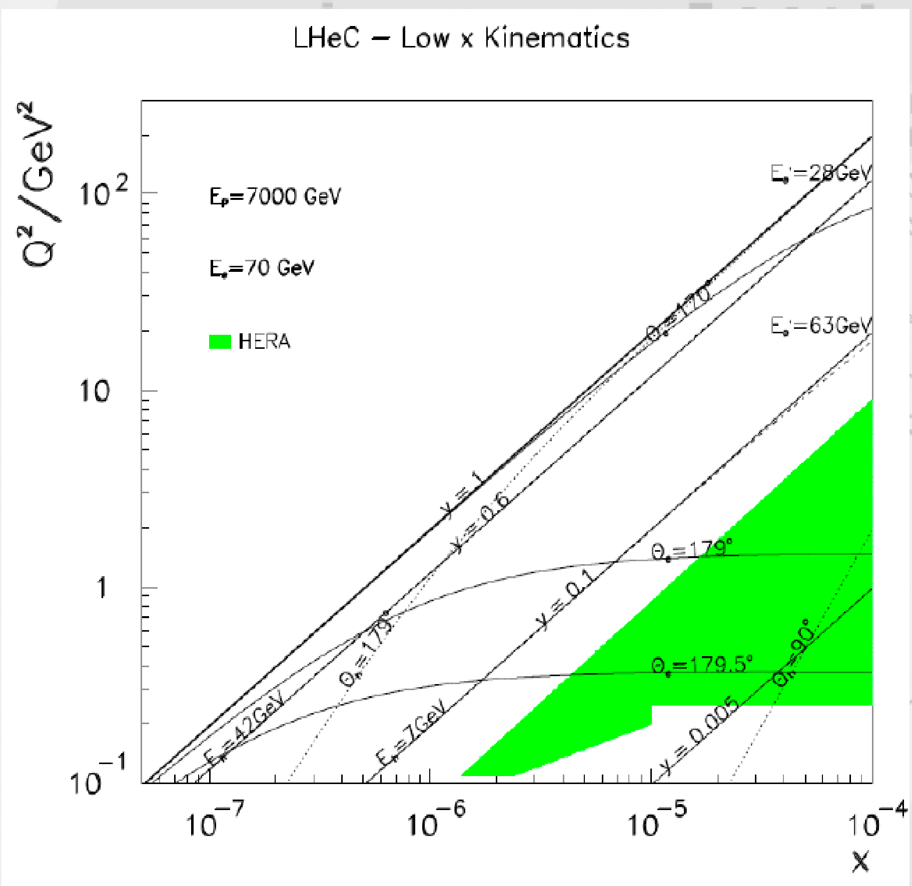

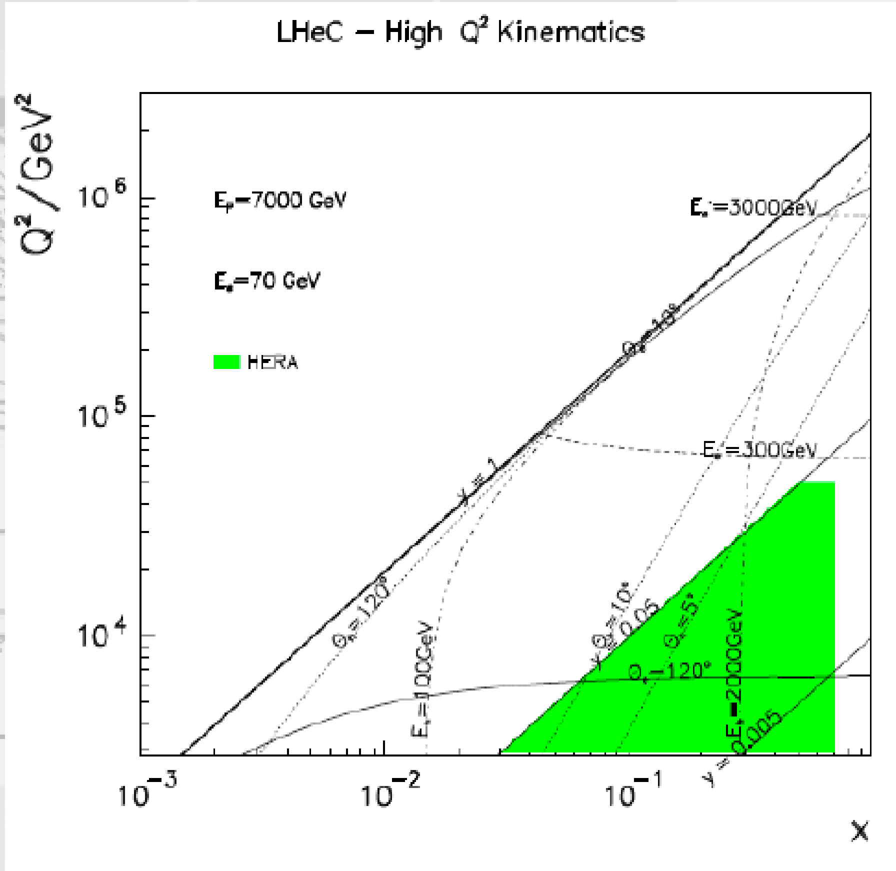

- backward e
  forward remnant 1_c
- forward TeV hadrons

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ep is precision @ every scale

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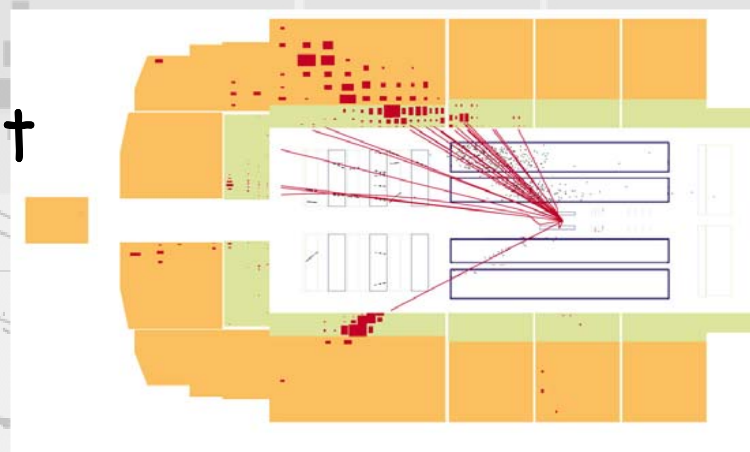
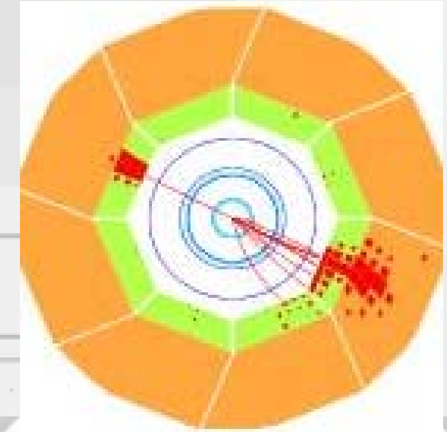
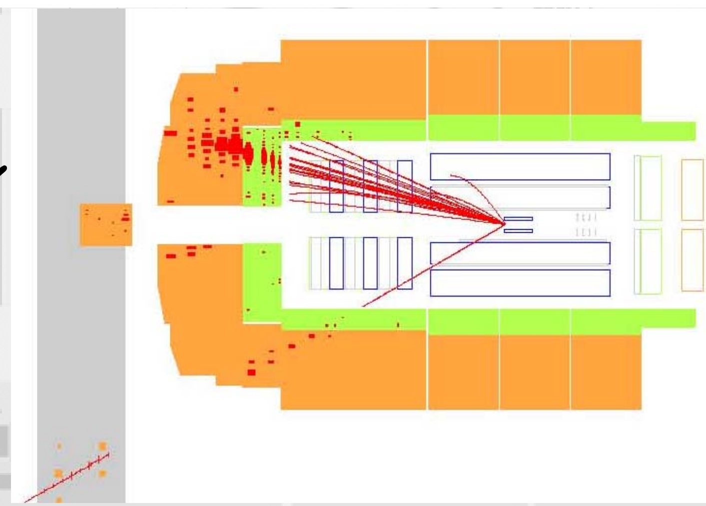
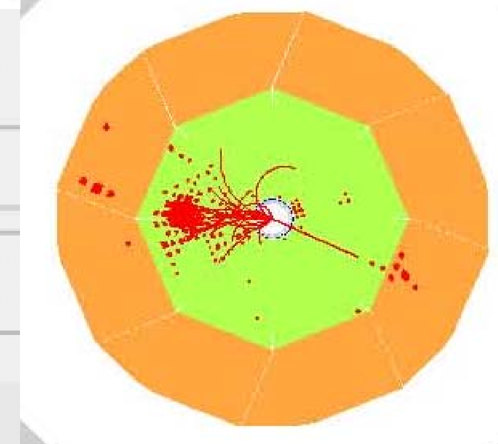
- Neutral Current
  $ep \to eX$
  $\cancel{p_{T}}$miss

- $ep \to ? + \text{lepton} + X$
  $p_{T\text{miss}}$ + lepton

- precision @ TeV scale of lepton+quark

eq νq τq cf HERA

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5. When?

Towards a CDR

Timeline

- 2007: form working groups + steering committee ✔
  initial meeting of conveners + committee ✔
  SAC overview ✔
- 2007/8: ECFA/CERN endorsement "work out" ✔
- 2008: workshop I
- 2009: workshop II
  LH*e*C CDR [LHC Committee]
- 2011: LH*e*C TDR
  - construction 8 years ?
  - impact on LHC: civil engineering + installation *e*-ring and *e*-linac
  - be aware of CLIC progress

WG Structure

- accelerator (injector, ring or linac)
  Oliver Bruening (CERN) JBD (CI)
- interaction region (+ small angle detectors) — tba
- infrastructure — CERN + tba
- detector — tba
- the new physics — tba
- precision QCD and electroweak — tba
- physics of high parton density — tba

CDR

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.

Interaction Region and Forward Detectors

Design of IR (LR and RR), integration of fwd 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 Interaction

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.

LHeC Scientific Advisory Committee

Experimentalists

Joel Feltesse (Saclay/DESY)
Aharon Levy (Tel Aviv)
Allen Caldwell (MPI München) Chair
Roland Horisberger (PSI)
Richard Milner (MIT)
John Dainton (Univ Liverpool)

Accelerator

Stephen Myers (CERN)
Swapan Chattopadhyay (Cockcroft Inst)
Roland Garoby (CERN)
Ferdy Willeke (DESY/BNL)
A Skrinsky (Budker)

Theory

Guido Altarelli (Roma)
Lev Lipatov (Petersburg)
Stan Brodsky (SLAC)
John Ellis (CERN)
Frank Wilczek (MIT)

Labs

Jos Engelen (CERN)
Young-Kee Kim (Fermilab)
Rolf Heuer (DESY)
Peter Bond (BNL)

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Steering Group

Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

- setting up WGs + workshop I

4. Summary

Now

- LHeC $70\text{-}140_e \otimes 7000_p$ GeV
  - can be built
  - has startlingly good luminosity $\geq 10^{32}$ cm^{-2}s^{-1}
    grows with LHC *pp* luminosity
  - extends substantially, uniquely, and with synergy to LHC$_{\text{TeV}}$ discovery physics
  - probes chromodynamics
    @ new density frontier
    in uniquely comprehensive manner *ep eA*
    with unchallengable precision
    synergetically with LHC *pp pA AA*

Proposal to ECFA

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results both from the Tevatron and from HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity for lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

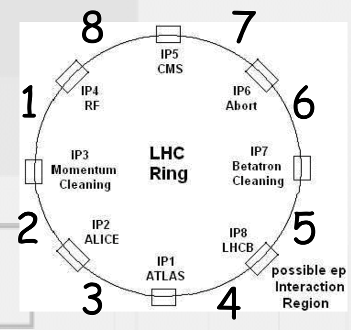
Endorsed by ECFA
November 30th 2007

Lepton + quark @ TeV

- **energy** for — **LHeC and LHC**
  - TeV *eq* discovery
  - extreme chromodynamics
- **precision** for — **LHeC and ILC/CLIC**
  - TeV *eq* discovery
  - *eq* understanding
  - extreme chromodynamics
- **luminosity** for — **LHeC and LHC**
  - TeV *eq* discovery
- **energy range** for — **LHeC RHIC FT LHC**
  - QCD phase equilibria

Extras

Lepton Ring

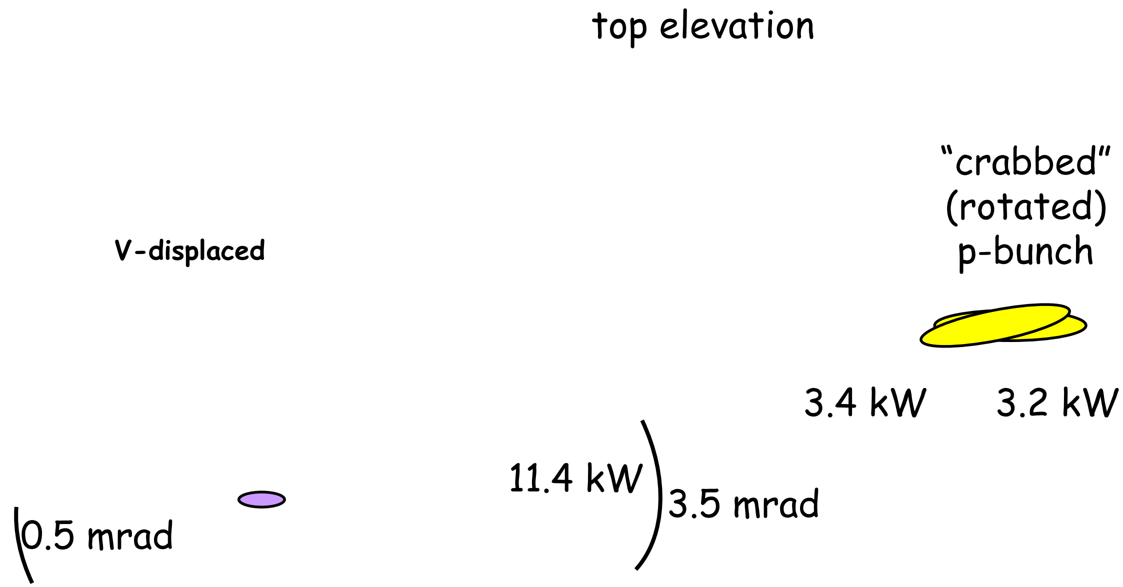


- in LEP tunnel … so like LEP
  - FODO in eight arcs
    β-tron phase advance φ_H=108° φ_V=90°
  - bending radius 3133.3 m
  - $(\delta E/E_{beam})_{rms} = 1.1\times10^{-3}$
  - SR 26 W/cm (E_c=254 KeV)
  - scRF @ 1GHz resonators @ 12 MV/m
    100 m structure = 670 cells
    - sync. phase 31°
    - bucket takes 10× $(\delta E/E_{beam})_{rms}$
  - unlikely *e*-beam instability
    single bunch current modest
    impedance « LEP

LEP=9 W/cm
HERA=13.5 W/cm

scRF proven
@ > 6 MV/m

- highest lumi
  - low β_e
    - close sc quads
  - low X-ing angle
    - "hard" bend
    - 8σ beam sep$^{\underline{n}}$
- SR fan
  - □ sc p-beam
  - « HERA
  - "crab" RF cavity
    p-bunch rotation



- 1° beam access = low-lumi/low-x option (cf HERA)

Operational Luminosity

- beam-beam
  - "hour-glass"
  - dynamic β: < HERA
  - long range beam-beam (parasitic interactions): marginal ⚠

↳ operational luminosity

$$I_e = 74\text{mA},\ N_p = 1.68\ 10^{11},\ \gamma_t = 7460,\ \epsilon_p = 0.5\ \text{nm}$$

$$\epsilon_{xe} = 25\ \text{nm},\ \epsilon_{ye} = 5\ \text{nm and } R = 0.89$$

$$L = \frac{I_e \cdot N_p \cdot \gamma_p \cdot R}{4 \cdot \pi \cdot e \cdot \sqrt{\epsilon_p \beta_{xp} + \epsilon_{ye}\beta_{ye}} \cdot \sqrt{\epsilon_p \beta_{yp} + \epsilon_{ye}\beta_{ye}}} = 1.04 \cdot 10^{33} cm^{-2} s^{-1}$$

Polarisation @ LHeC

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Barber

Recal… well
unde…

•

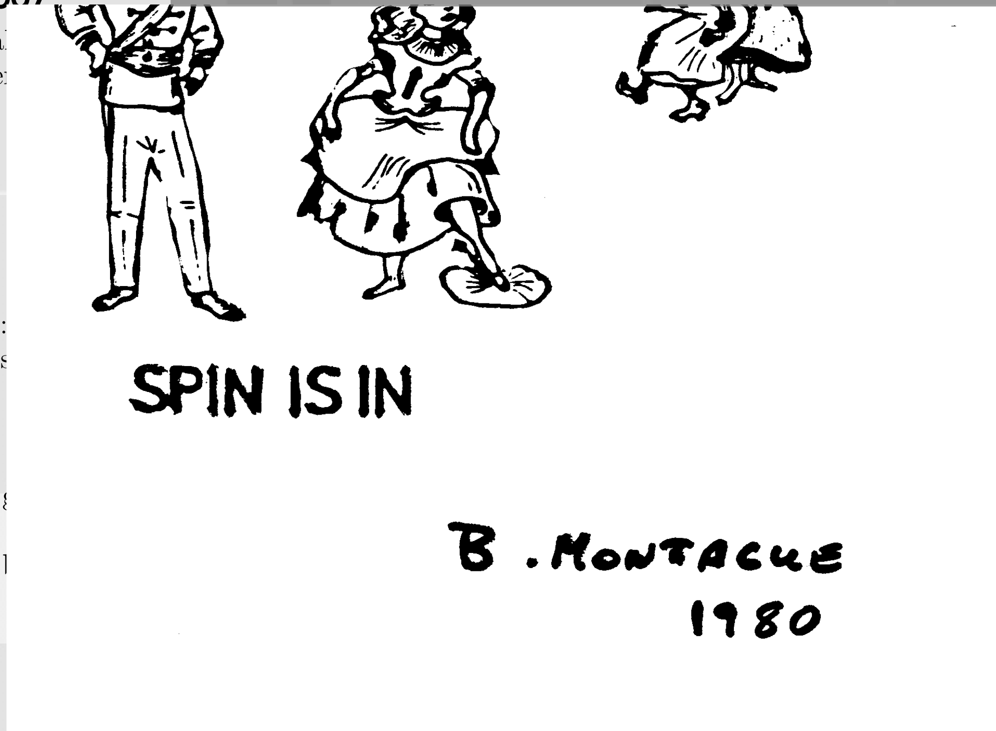
…tron

LEP: …many
hours…

•

The …

The … …polar-



Plan

• Depolarization is worst at RESONANCES:

$$\nu_s = k_0 + k_1 Q_1 + k_2 Q_2 + k_3 Q_3$$

Begin NOW with intense careful study based on experience to investigate tricks.

At high energy the synchrotron sideband resonances take control:

Strength scale : $\xi = (\frac{a\gamma\,\sigma_\delta}{Q_s})^2$

• Need very good alignment - better than at LEP.

• Siberian Snakes to suppress the effect of energy spread and synchrotron motion on spin motion?

• Overall, roughly at each energy:

$$\tau_{dep}^{-1} \propto (\text{a polynomial in } \gamma^{2N}) \times \tau_{st}^{-1}$$

These are essential in proton rings to suppress depolarising resonances during acceleration (e.g., RHIC).

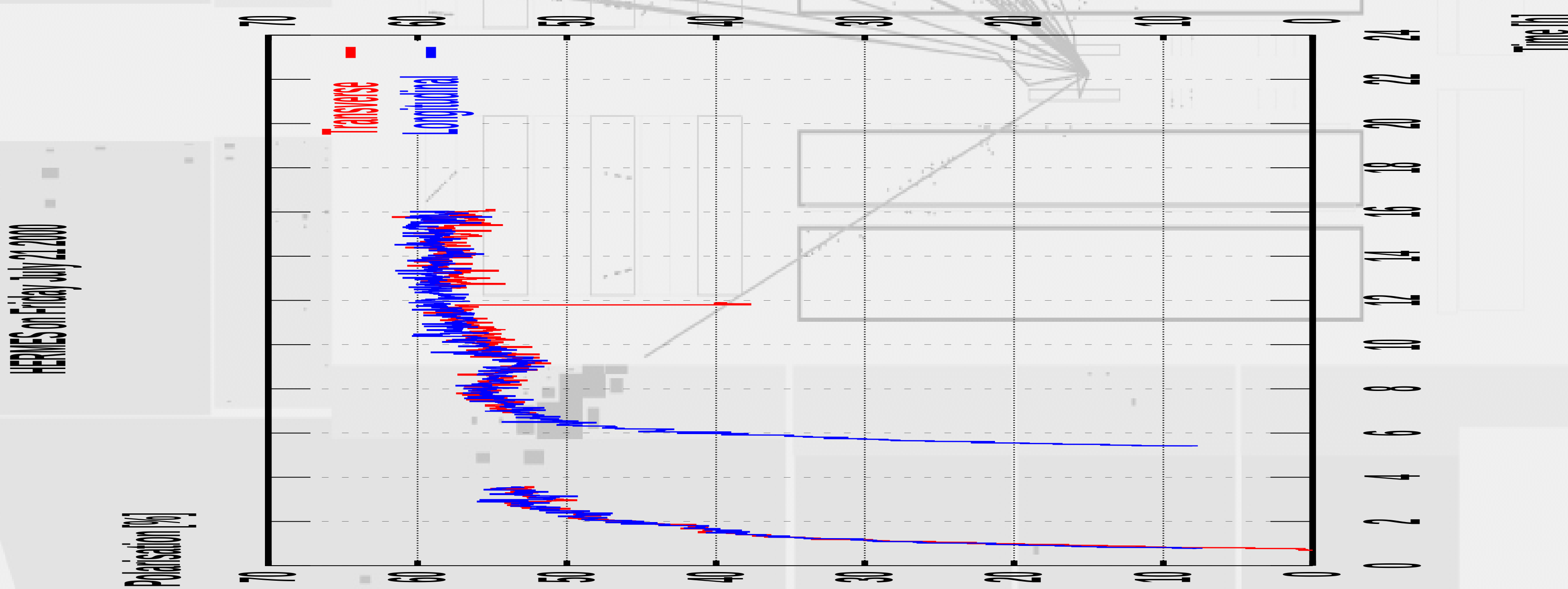
• But in electron rings they kill the S-T effect if the synchrotron radiation is evenly distributed around the ring!!!

• For longitudinal polarization the polarization vector must be rotated into the longitudinal direction before an IP and back to the vertical afterwards ===> spin rotators.

• … rotators etc, etc.....

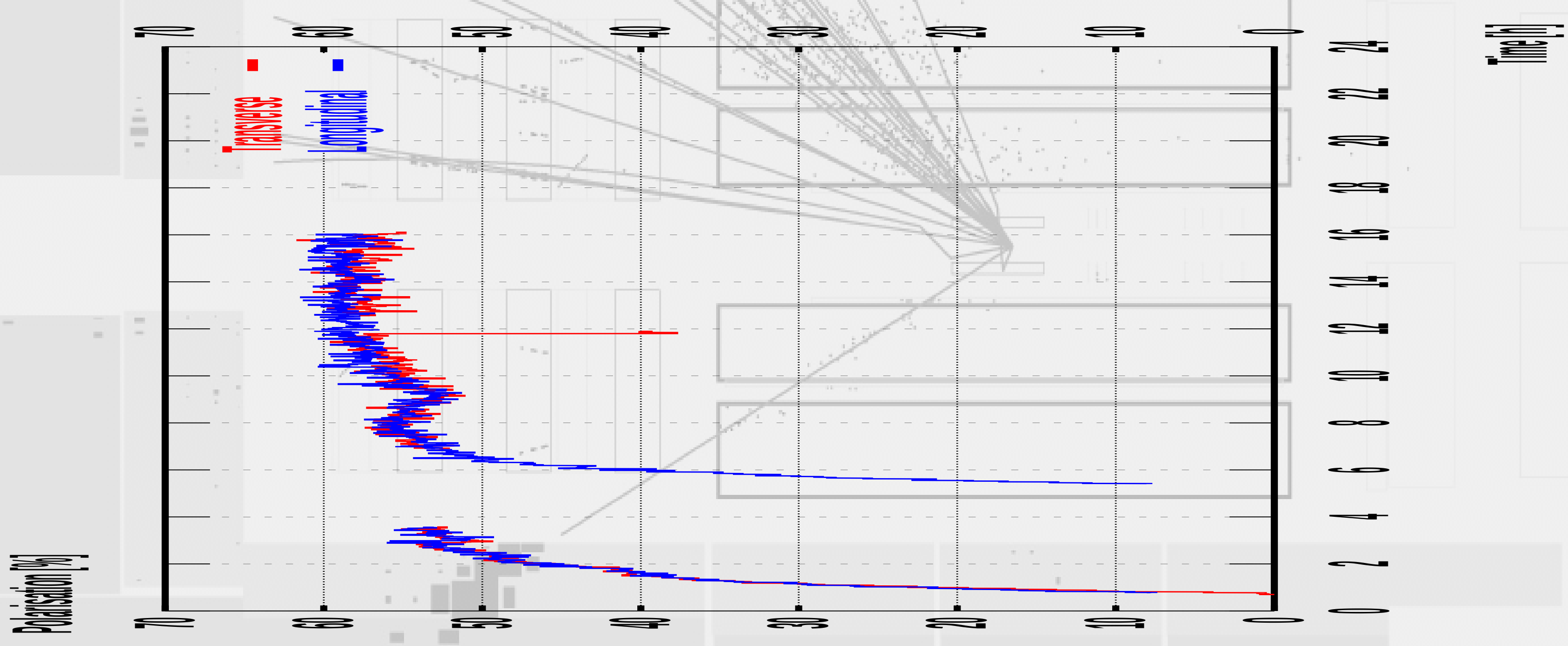
What's been achieved

- Sokolov-Ternov + spin-rotators @ HERA



What's been achieved

a)



LHeC

- tunnel exists (LEP, LHC)
- injection once existed (LEP) ?
- operating *p*-beam (from 2008)
- operating *A*-beam (from 2008)
- *ep eA* operating alongside *pp pA AA*
- *the* TeV *ep* collider !
- "minimal" mods to LHC !

↳

- LHC upgrade
- cost ?

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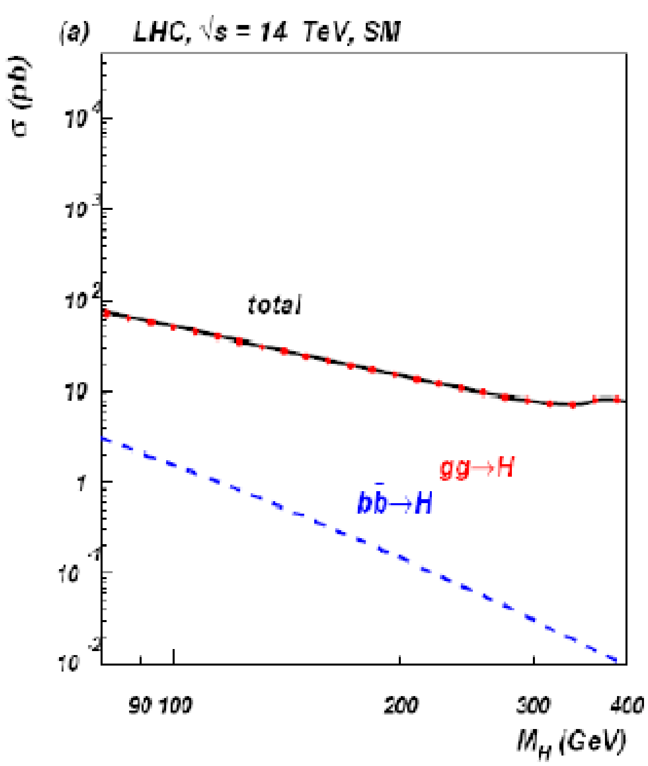
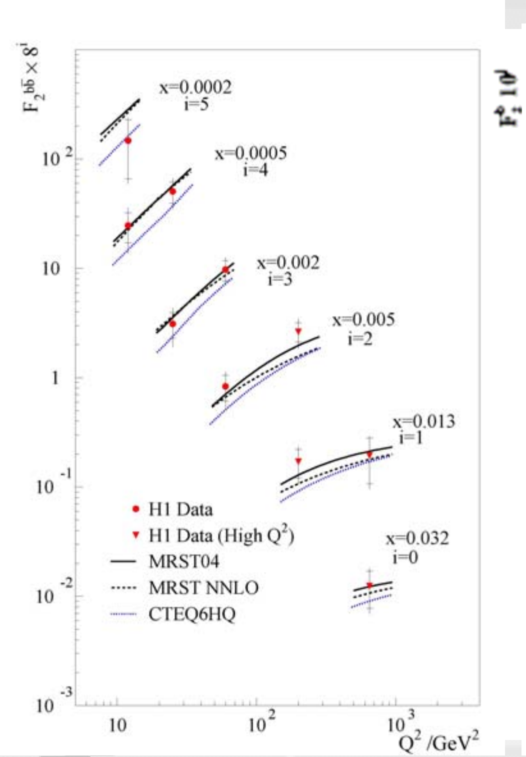
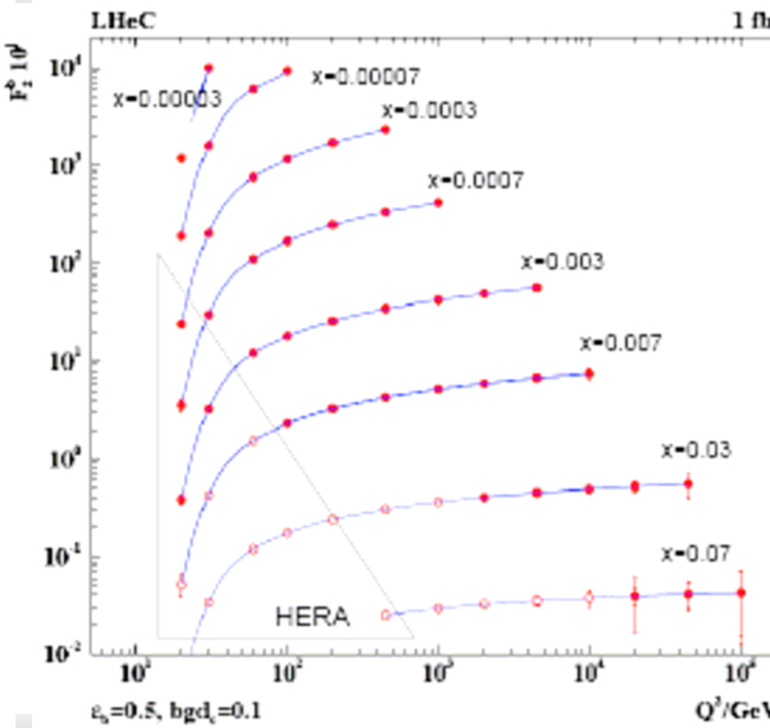
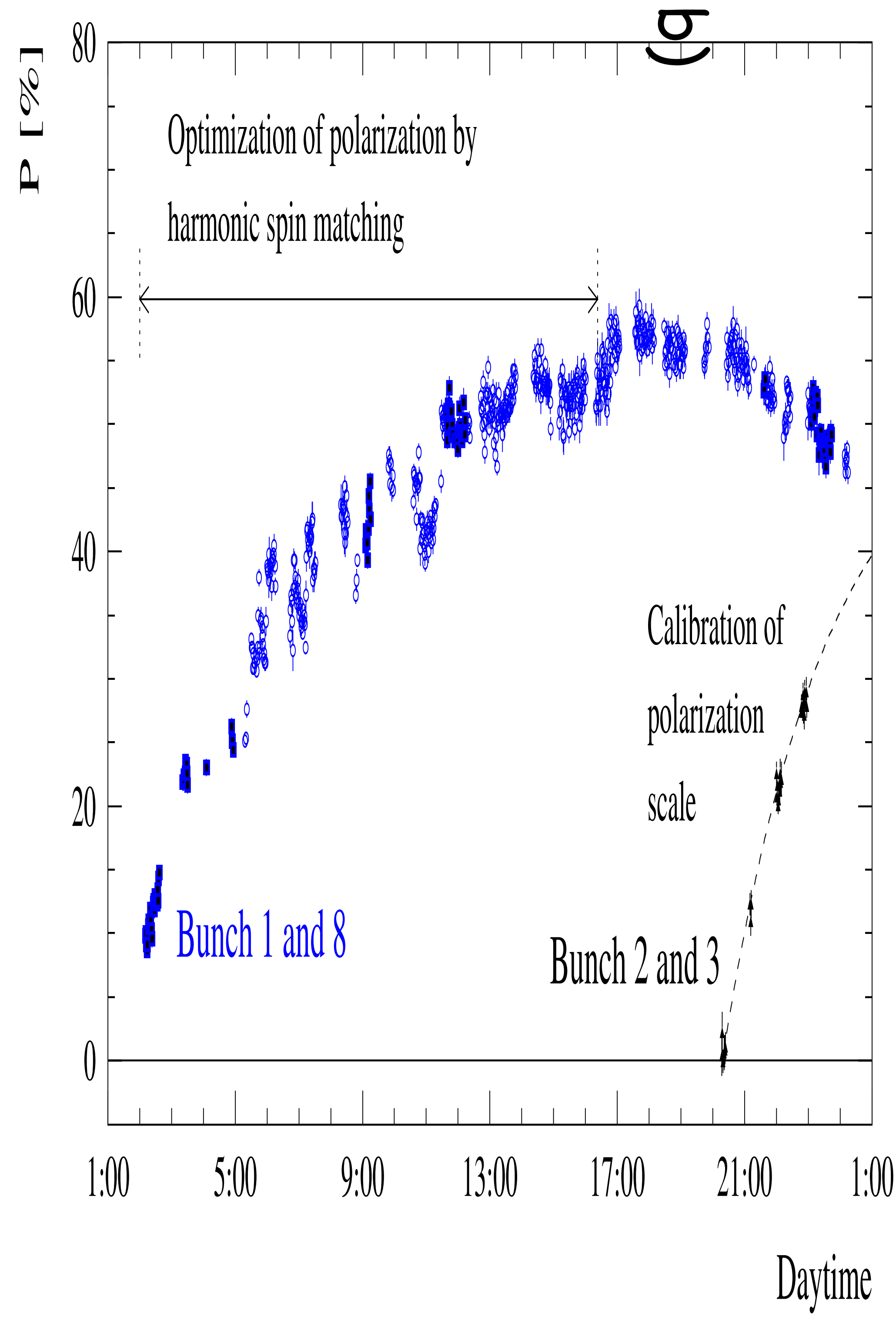






st polarization achieved:



What's been achieved

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Diffraction and Rapgap

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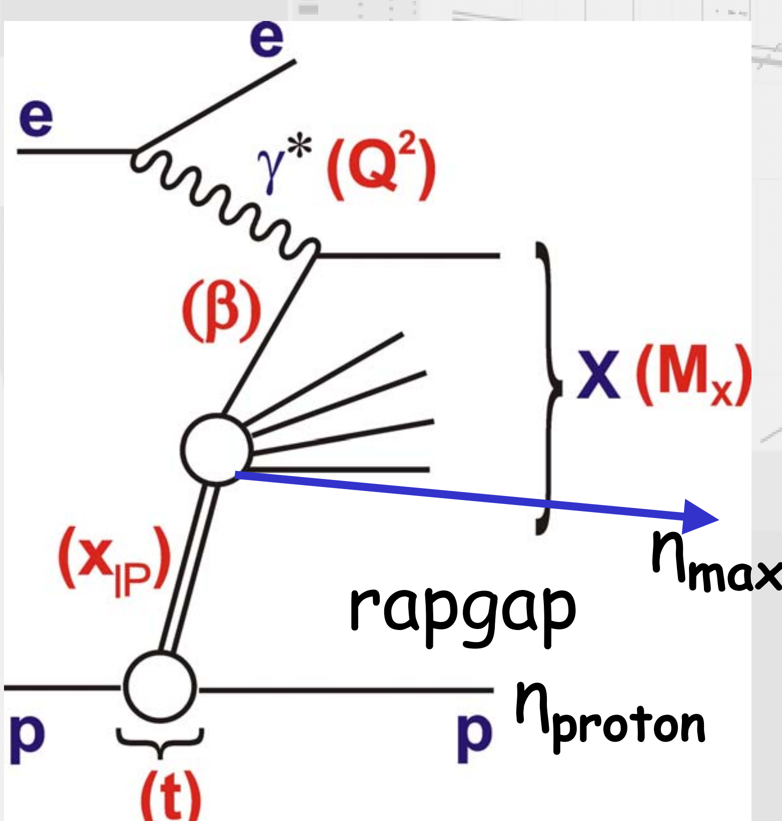
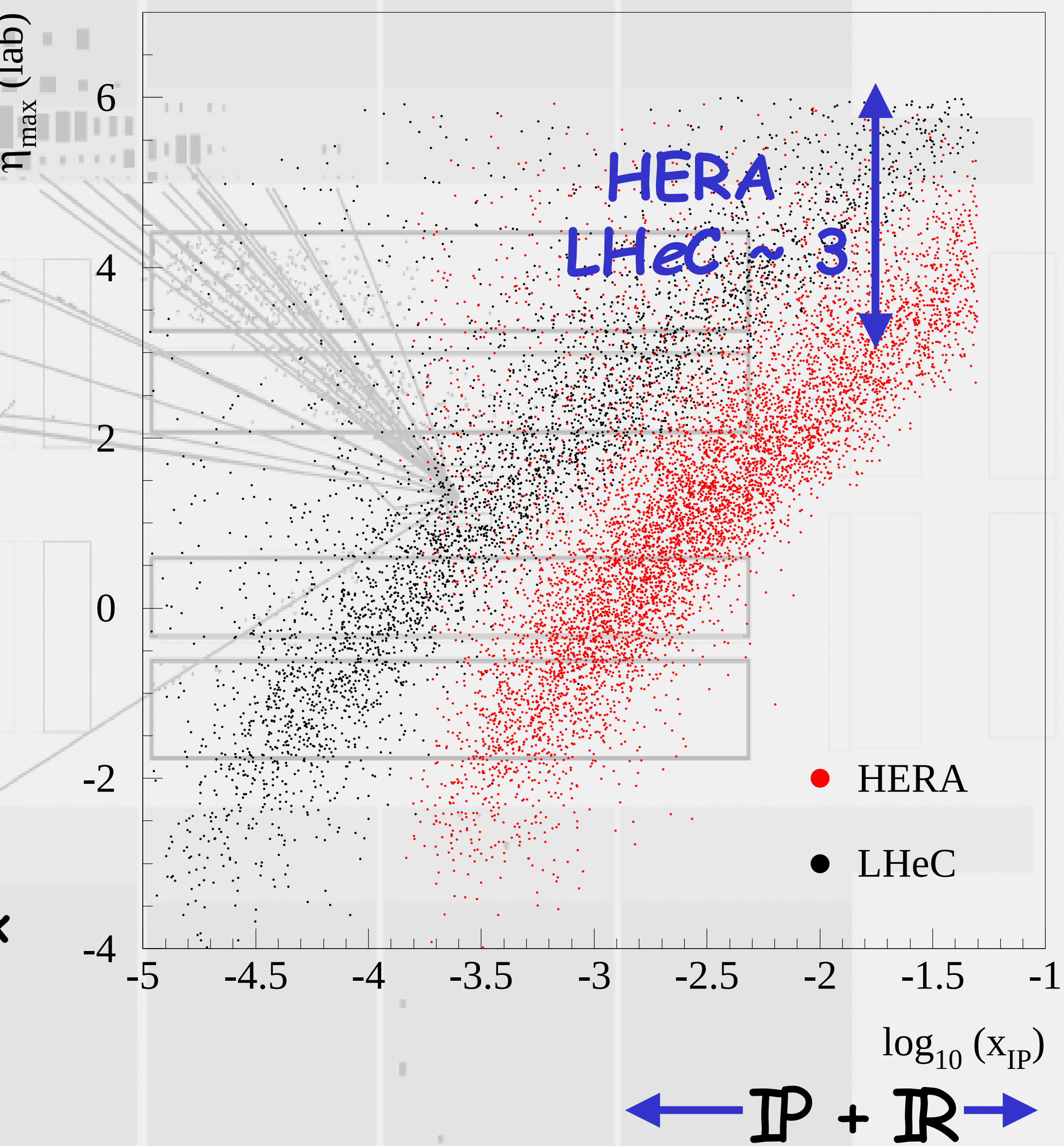
- rapgap @ LHeC ?





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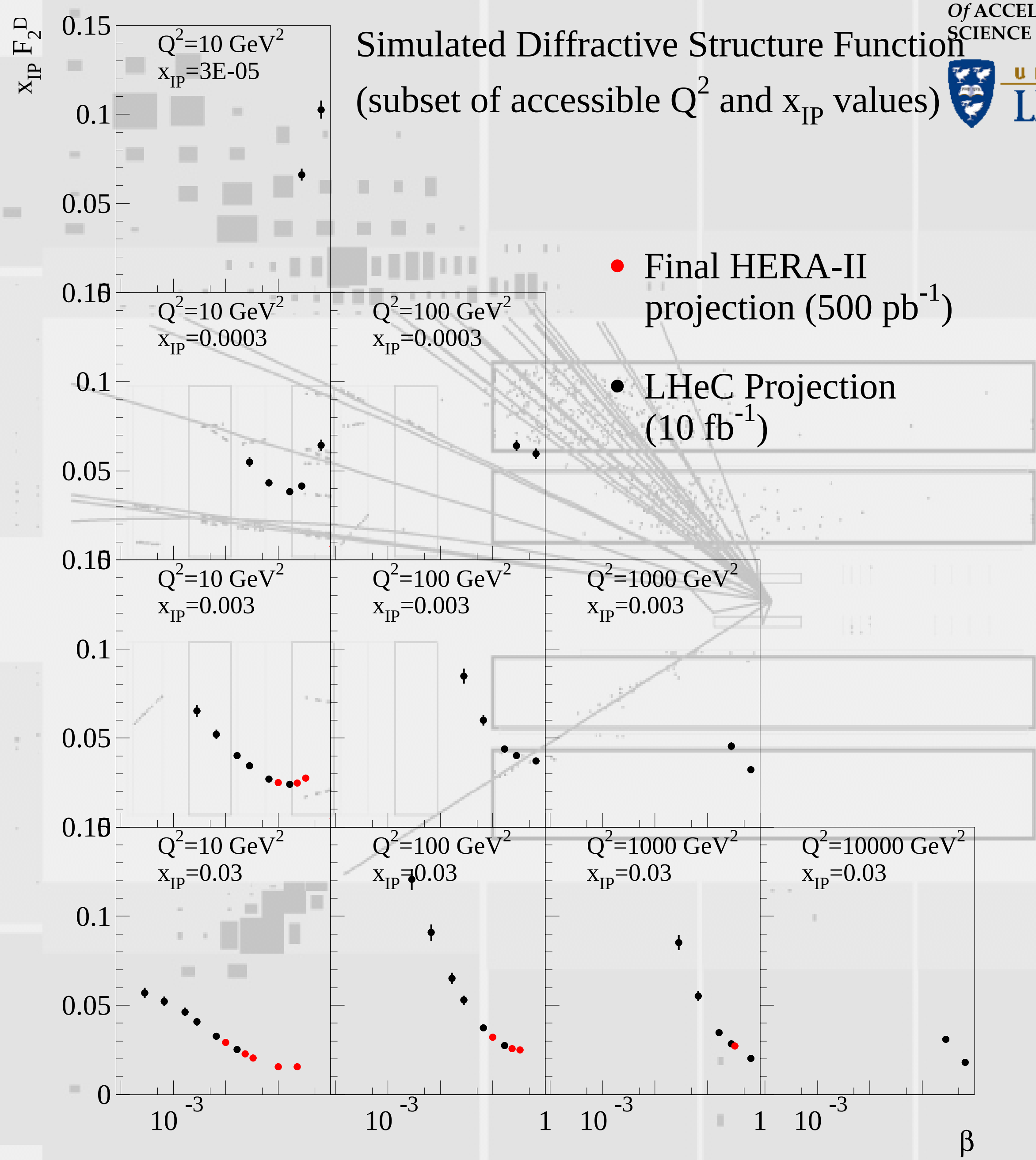
Simulated Diffractive Structure Function
(subset of accessible Q^2 and x_{IP} values)



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Acceptance and Measurement

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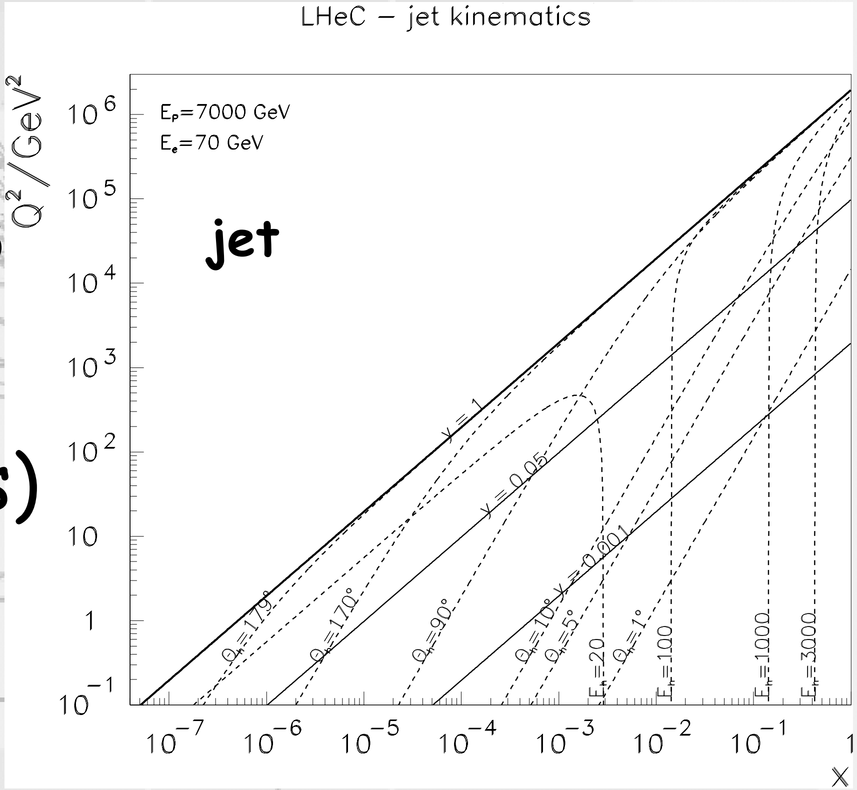
- 70 7000 GeV
- high lumi quads (±10° bp)
  $Q^2_e > 100$ GeV² $x > 3\times10^{-5}$
- few GeV ≤ $E_{h,e}$ ≤ few TeV
- low lumi for low x (no quads)
  $1 < Q^2 < 100$ GeV²
  $x < 3\times10^{-5}$
  "forward" hadrons:
  "forward rapgap" instrumentation
  precision e/had-measurement
  $170 < \theta_e < 179°$ $170 < \theta_h < 179°$!

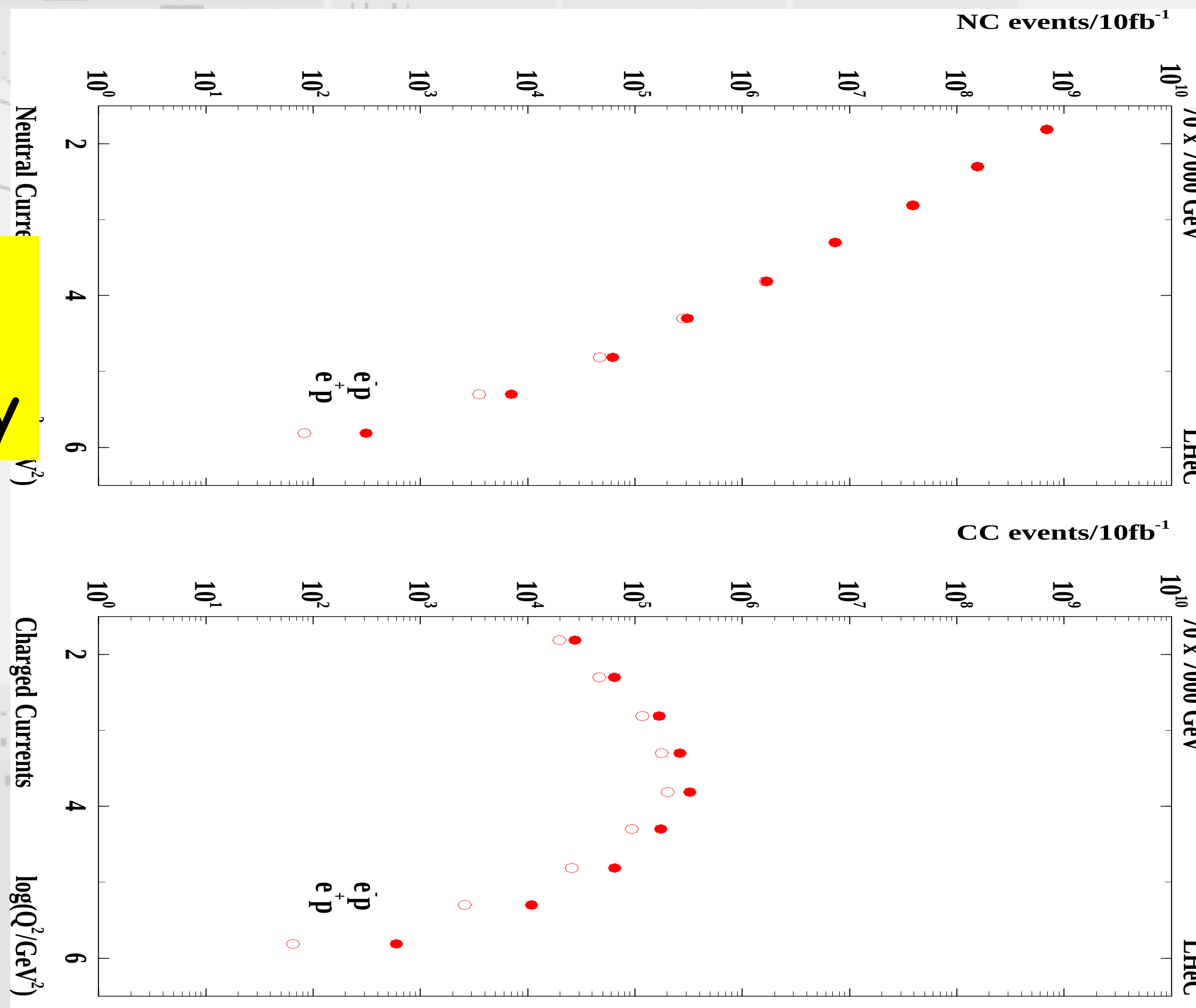


Rate

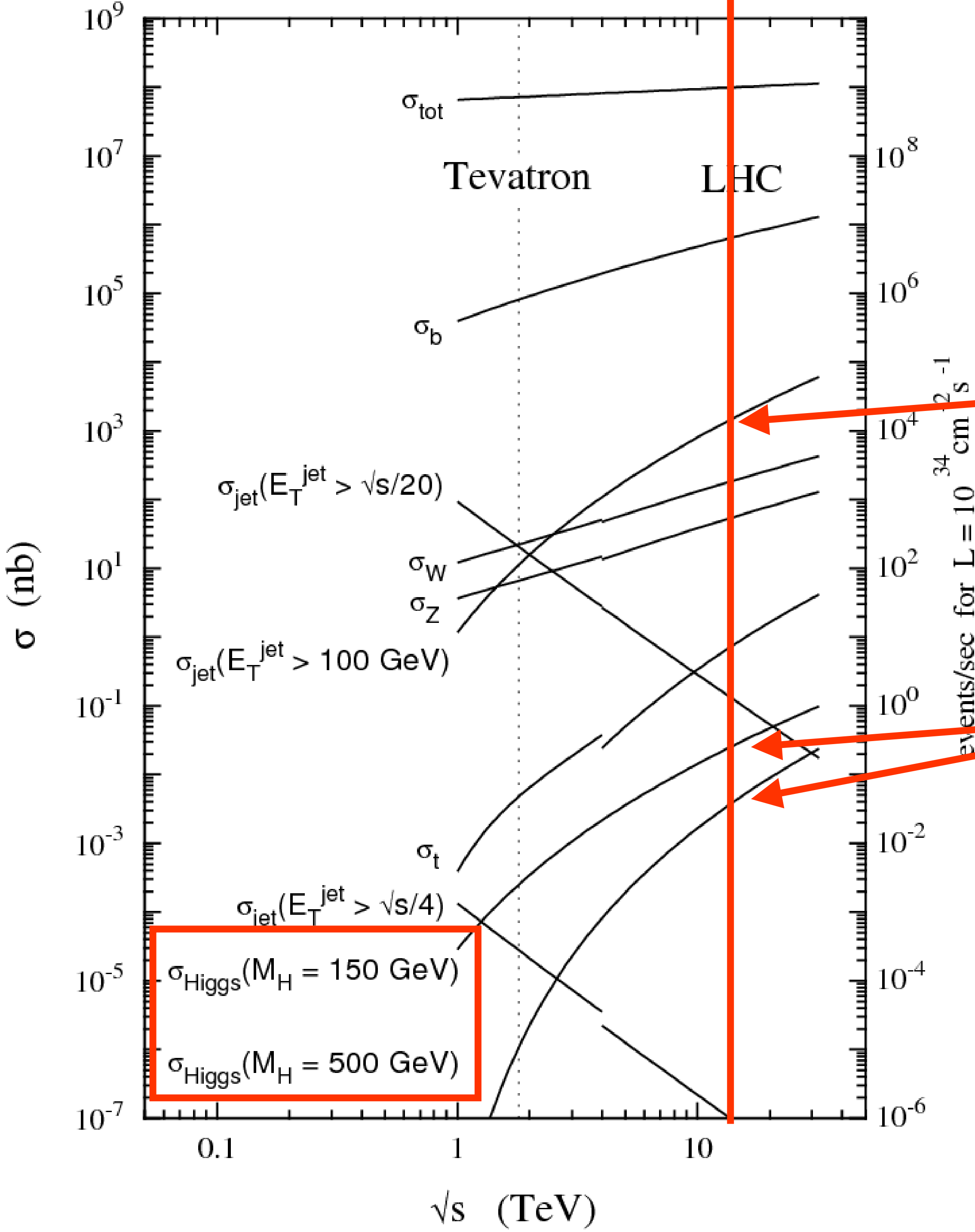
- 100/10 fb^{-1}

  = 100/3×LHeC y

@ Q^2 = 1 TeV^2



Needle in a haystack…

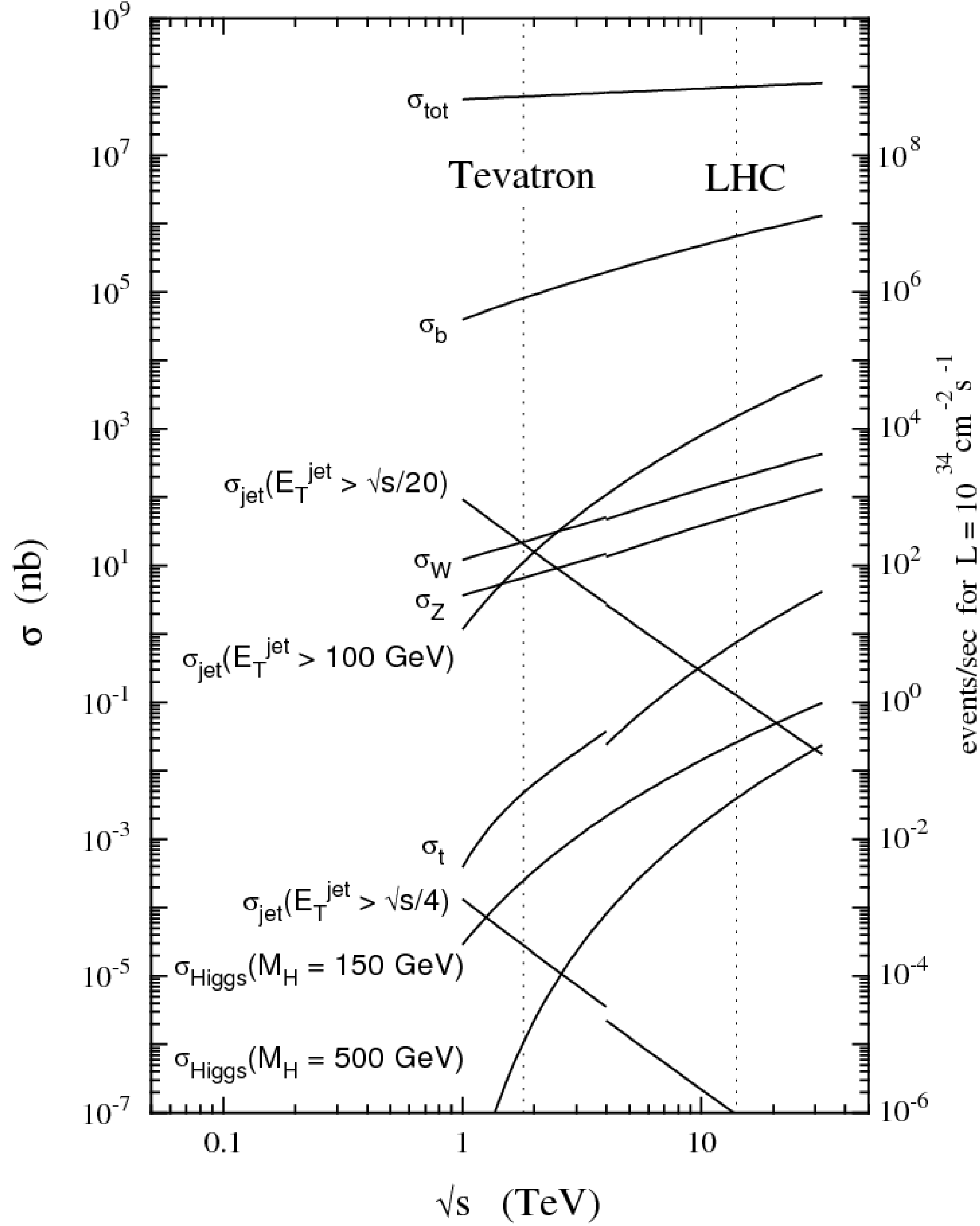


QCD jet production at high energy

Higgs production

Need to use signatures with small backgrounds:
- **Leptons**
- **High-mass resonances**
- **Heavy quarks**

to avoid being overwhelme


Tevatron
LHC
σ_tot
σ_b
σ_jet(E_T^jet > √s/20)
σ_W
σ_Z
σ_jet(E_T^jet > 100 GeV)
σ_t
σ_jet(E_T^jet > √s/4)
σ_Higgs(M_H = 150 GeV)
σ_Higgs(M_H = 500 GeV)
σ (nb)
√s (TeV)
events/sec for L = 10^34 cm^-2 s^-1
0.1
1
10

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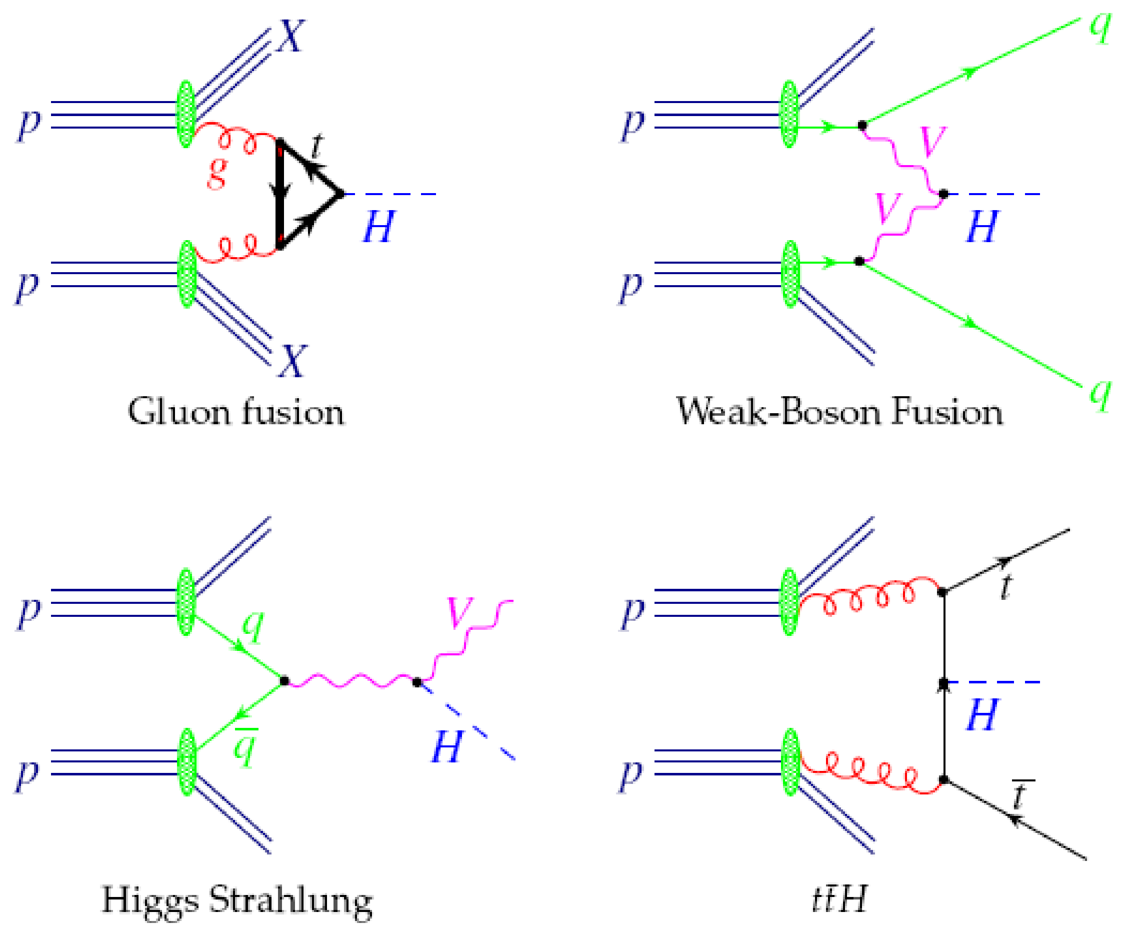
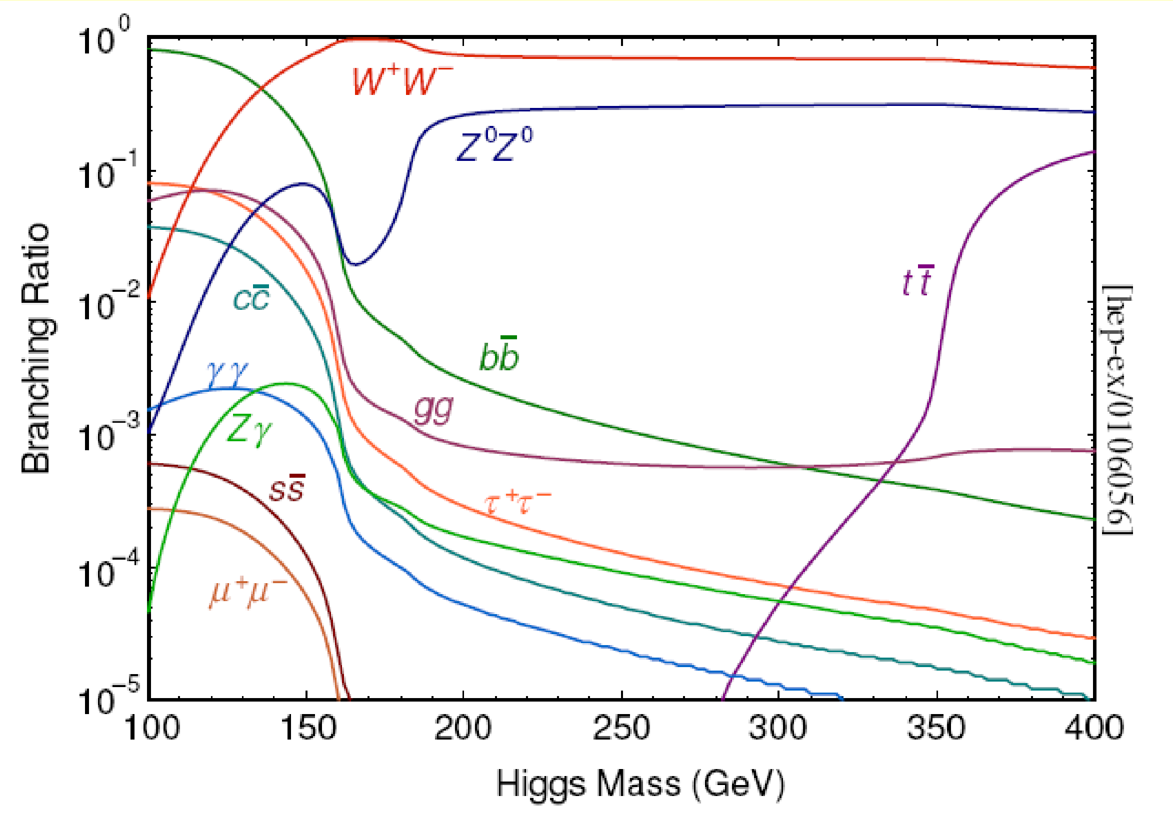
Producing a Higgs



- Higgs couplings $\propto$ **mass**
  - u-ubar ➔ H has very small cross-section
  - Dominant production via vertices coupling Higgs to heavy quarks or W/Z bosons

Decay of the SM Higgs



- Width becomes large as WW mode opens
- Branching ratios change rapidly as new channels become kinematically accessible

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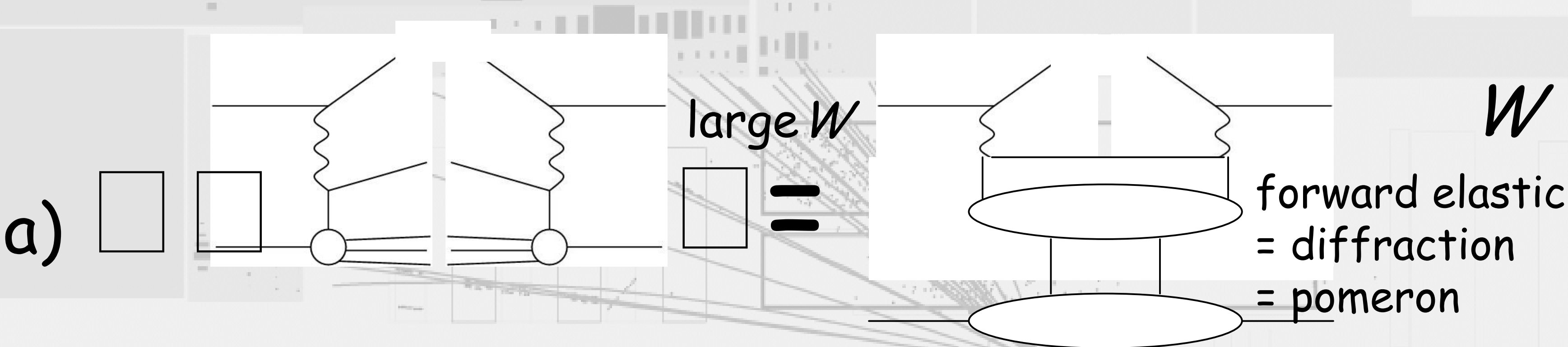
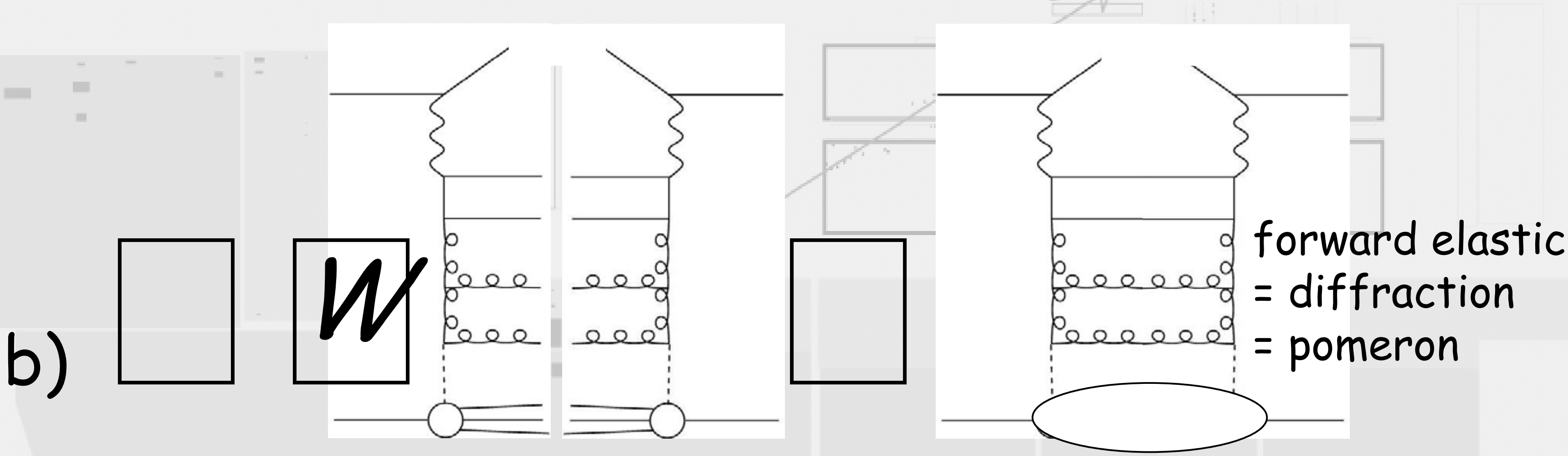
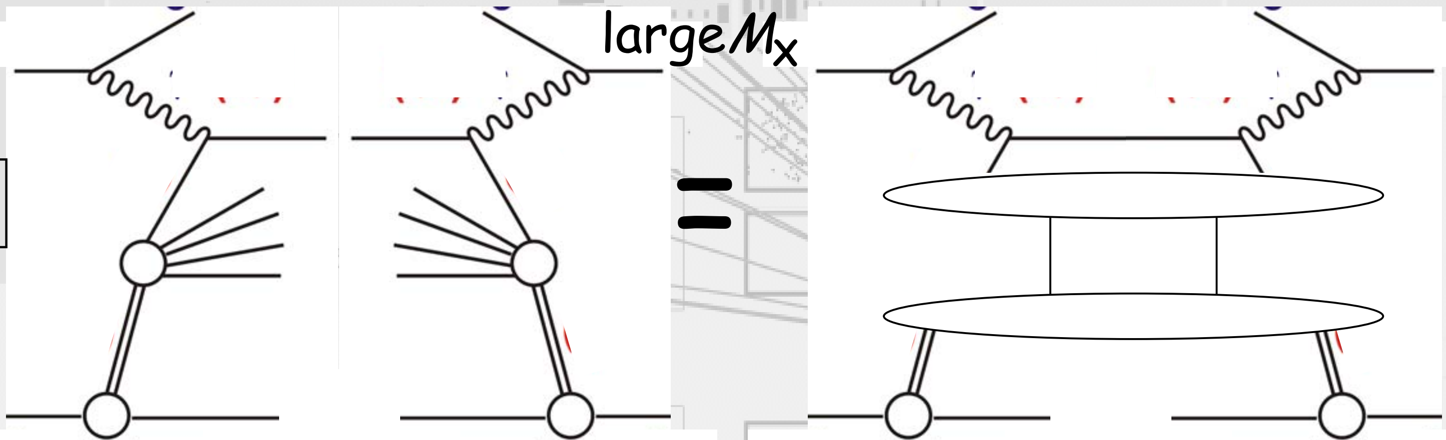




c) x



M_X

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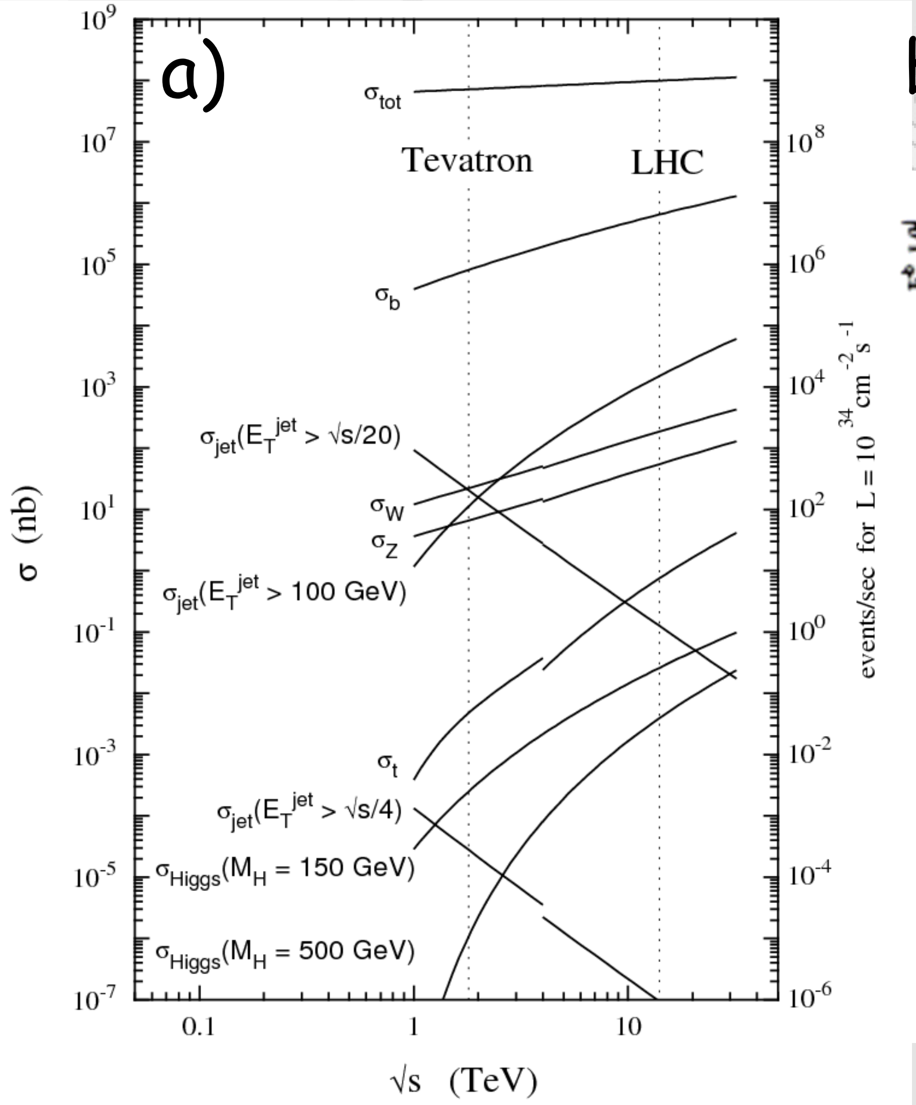

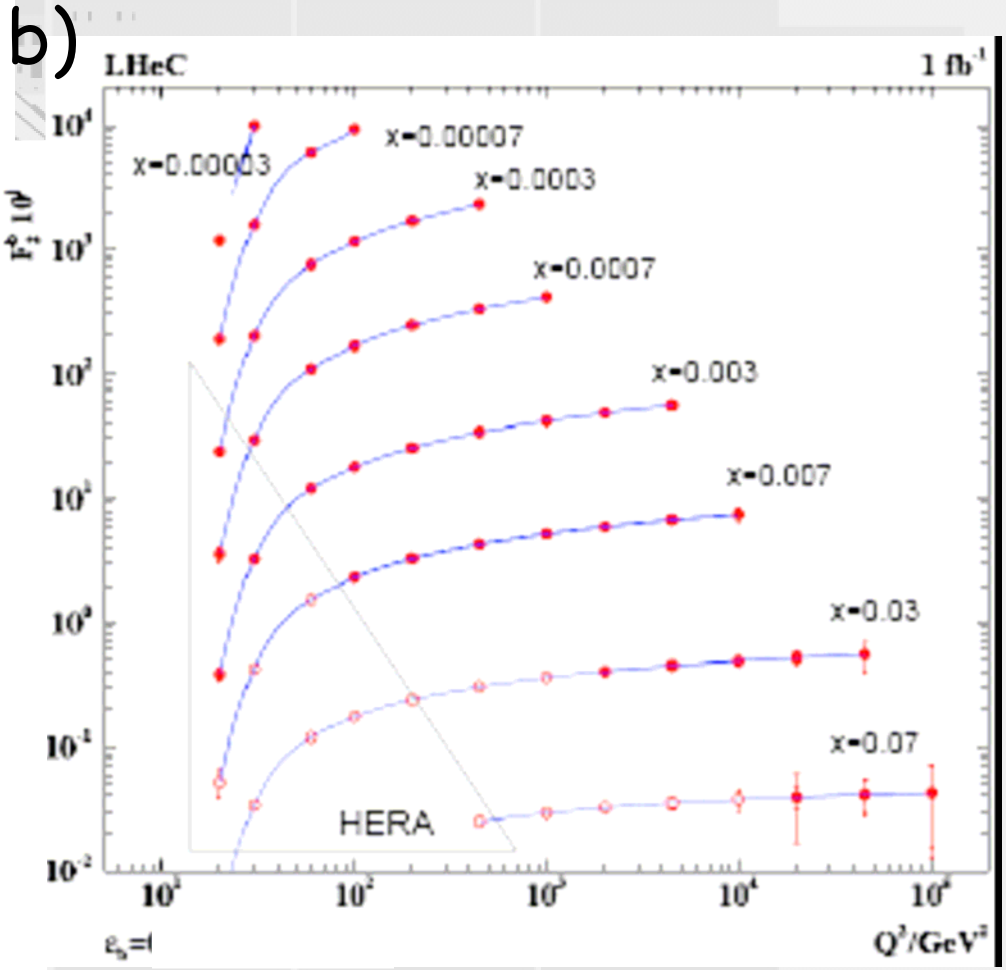

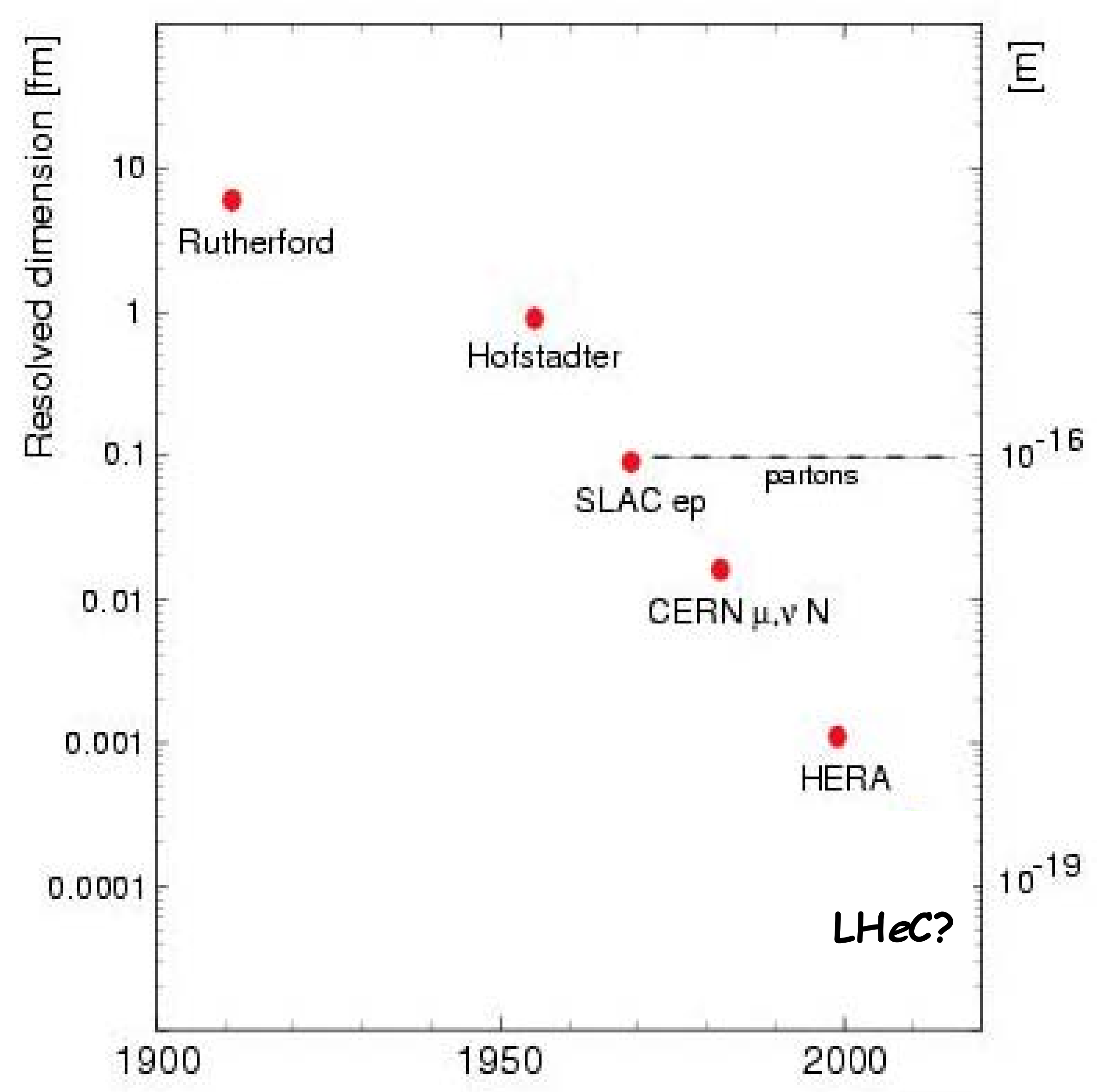
Resolved dimension [fm]
[m]
10
1
0.1
0.01
0.001
0.0001
10^{-16}
10^{-19}
Rutherford
Hofstadter
SLAC ep
partons
CERN μ,ν N
HERA
LHeC?
1900
1950
2000

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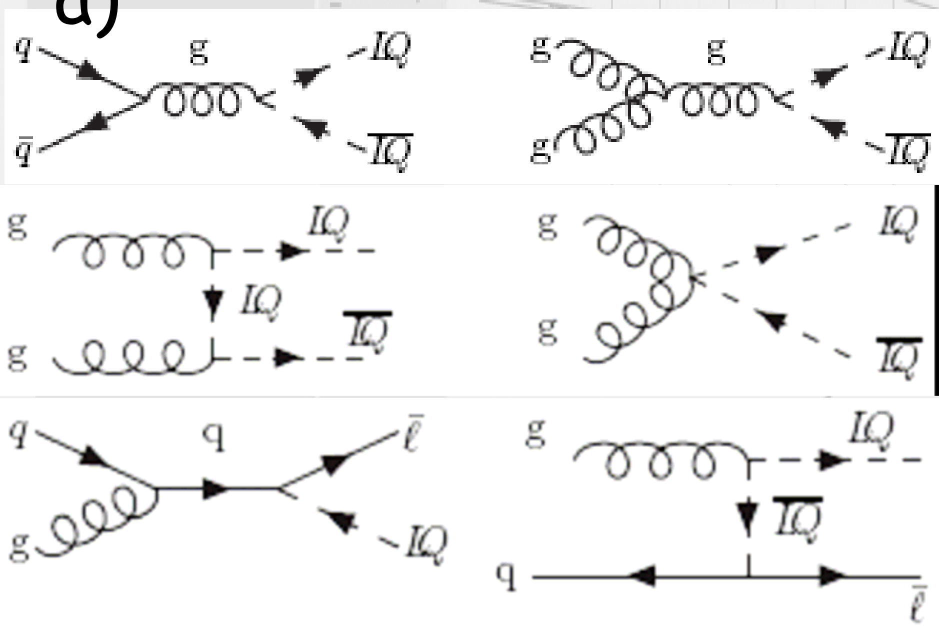
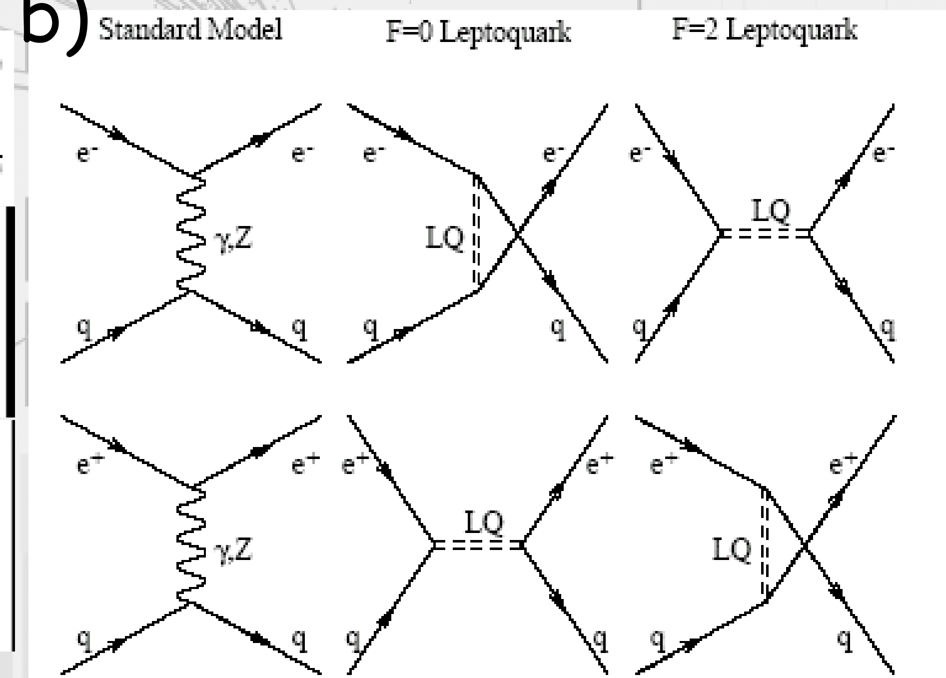
a)



b)



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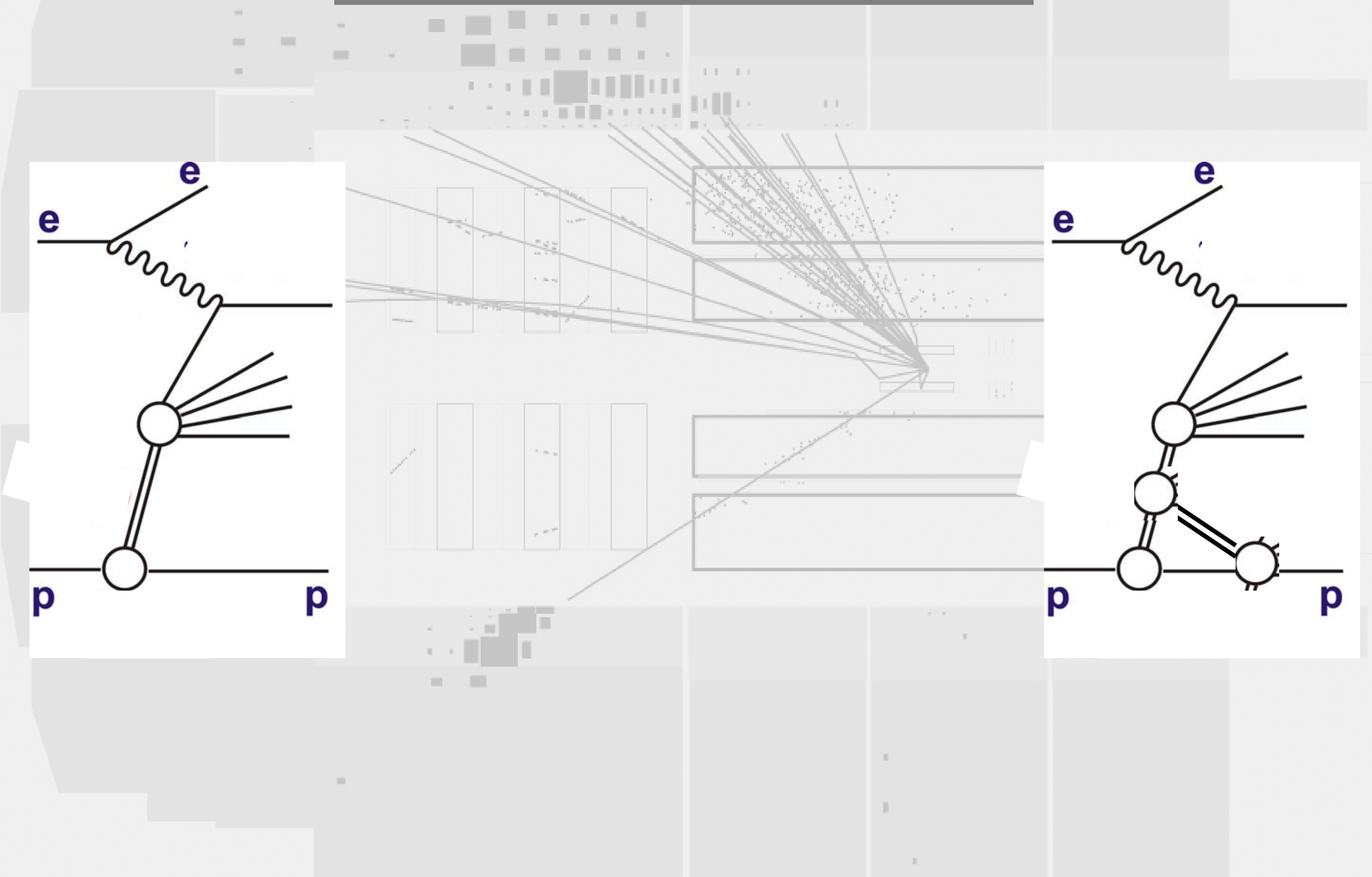

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