Polarised Positron Workshop Meeting
Cockcroft Institute
March 28th 2008

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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?

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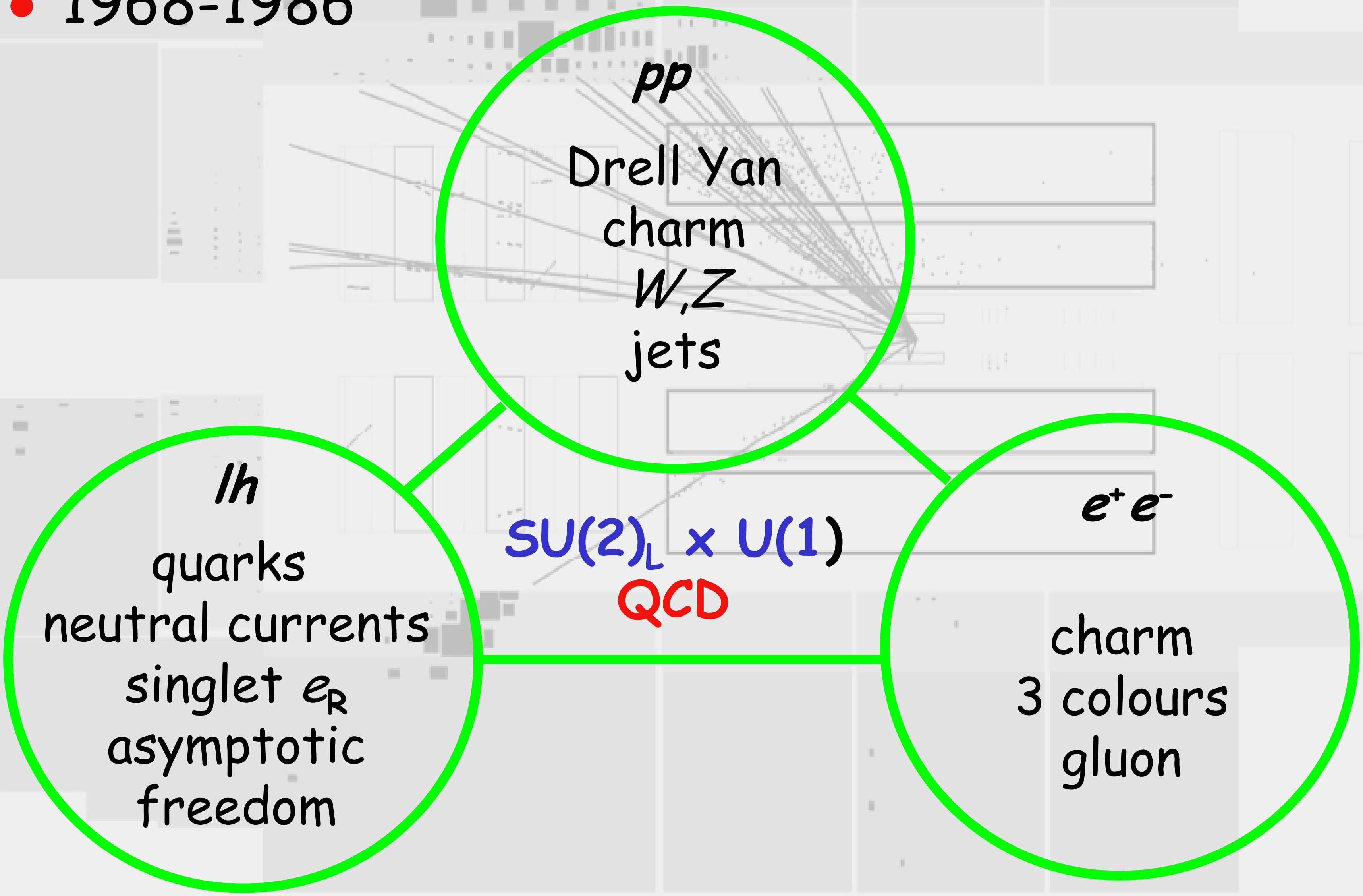
Why? The Energy Frontier

- 1968-1986



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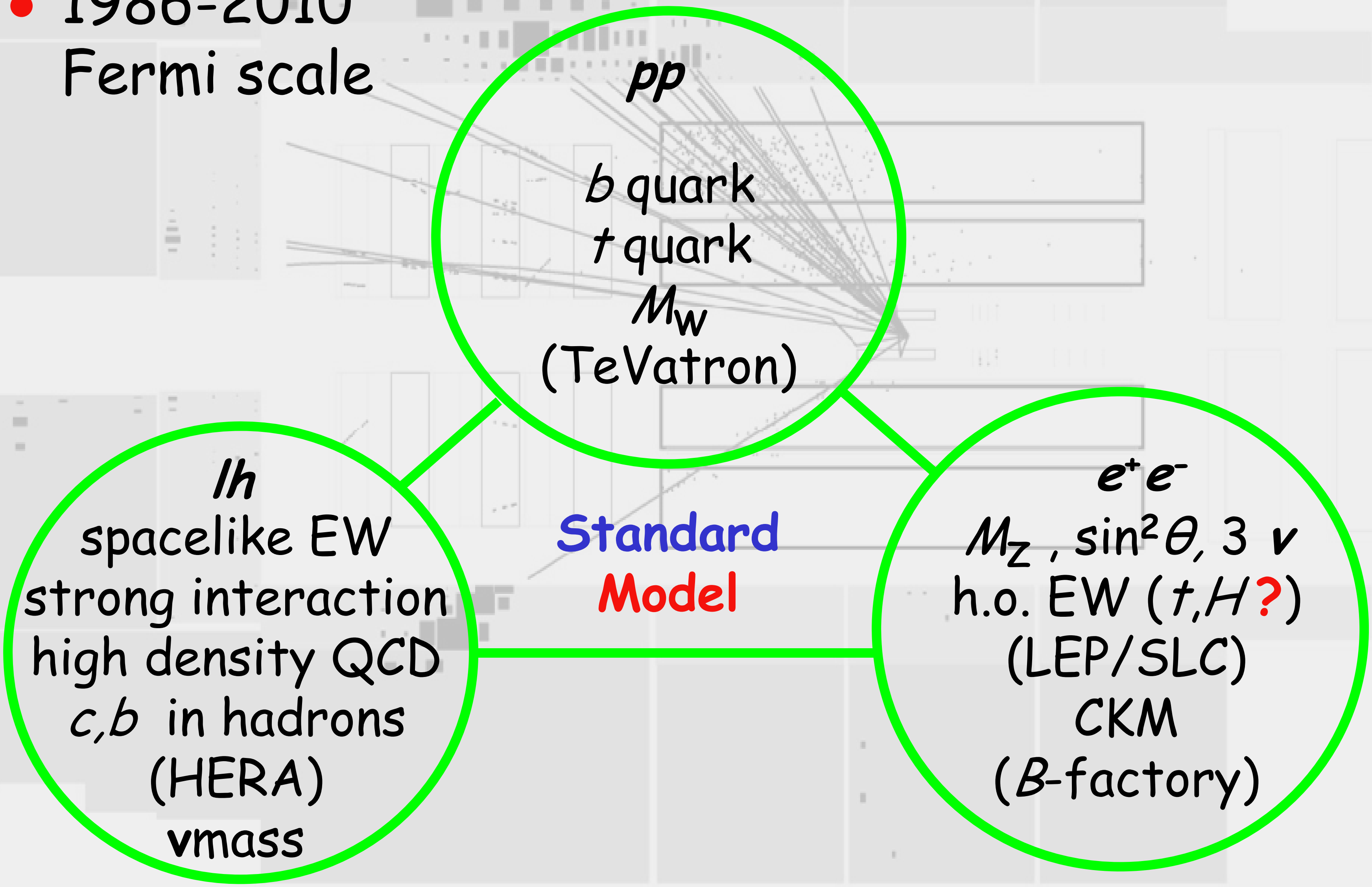
Why? The Energy Frontier

- 1986-2010
  Fermi scale



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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

- 2008-2033? chromodynamic creation ?

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

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

matter creation
new physics

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

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Why:
Leptons ↔ Quarks ?

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- how are leptons and quarks related ?

THE UNCONFINED QUARKS AND GLUONS

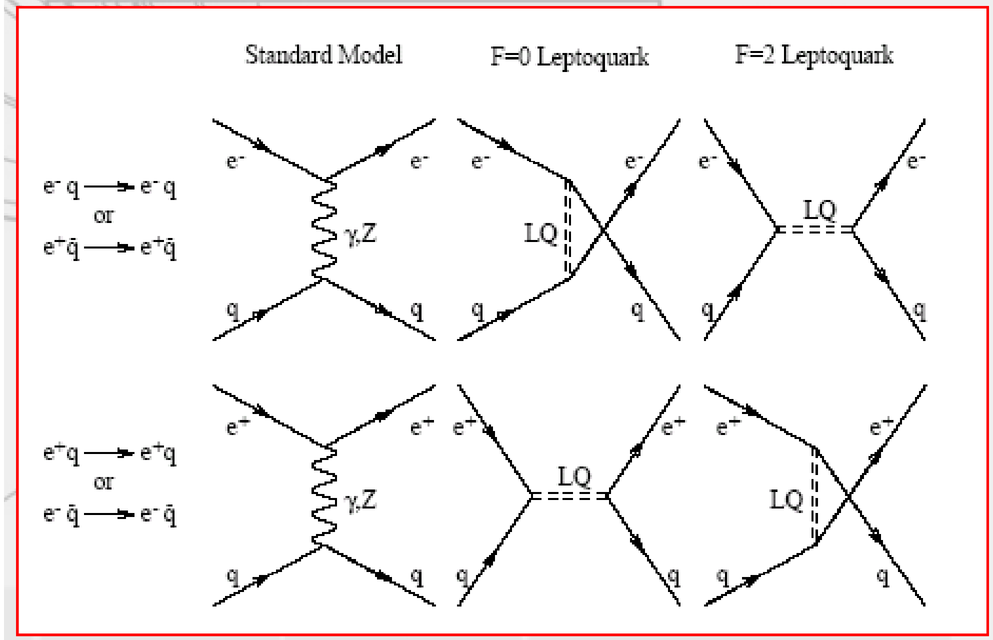
Abdus Salam

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

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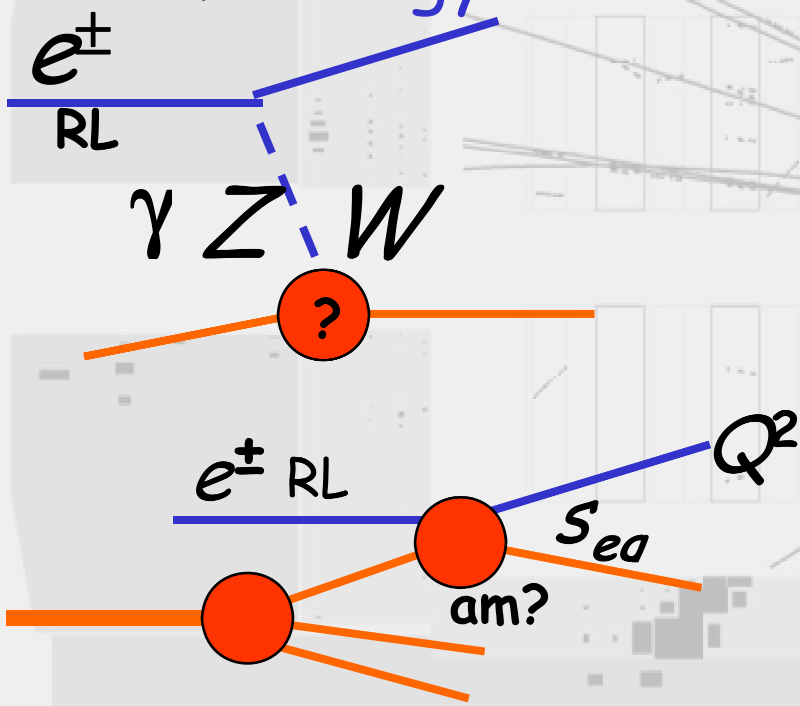
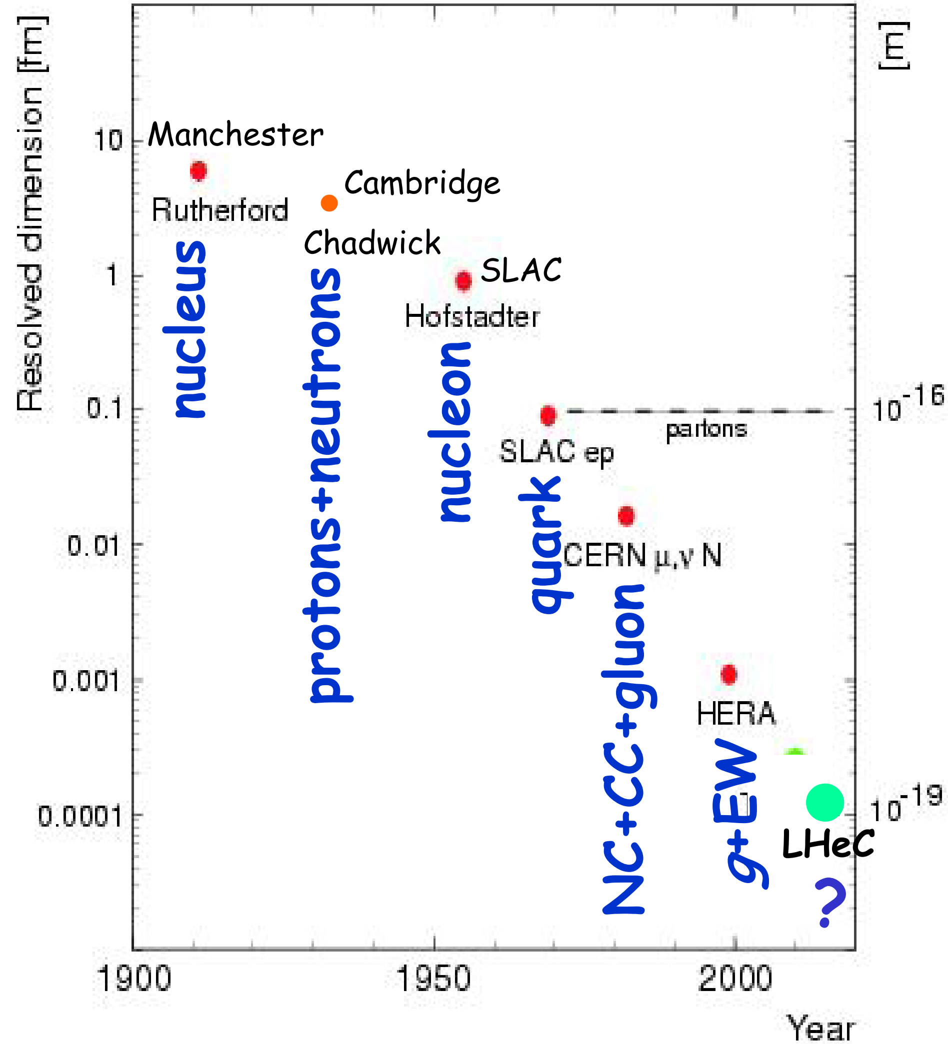
Lepton+quark @ TeV

- unique chiral probe @ 0.0001 fm ?
- 70 $e^{\pm} \otimes p$ 7000 GeV
  cm energy < 1.4 TeV



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



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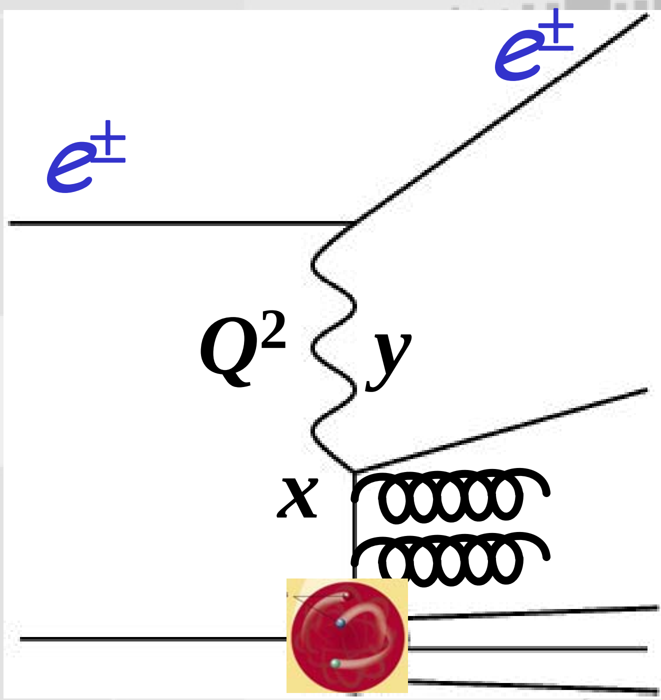
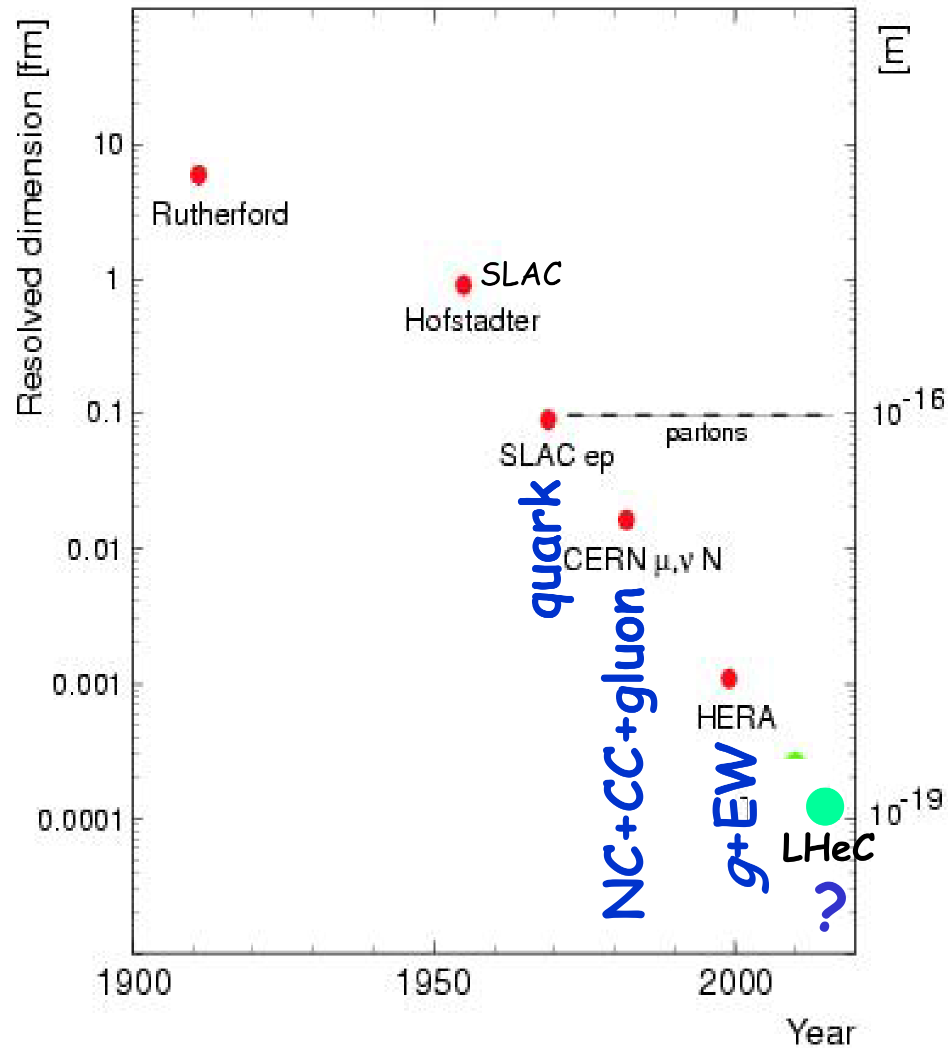
Why: Structure @TeV

- unique chiral probe @ 0.0001 fm ?

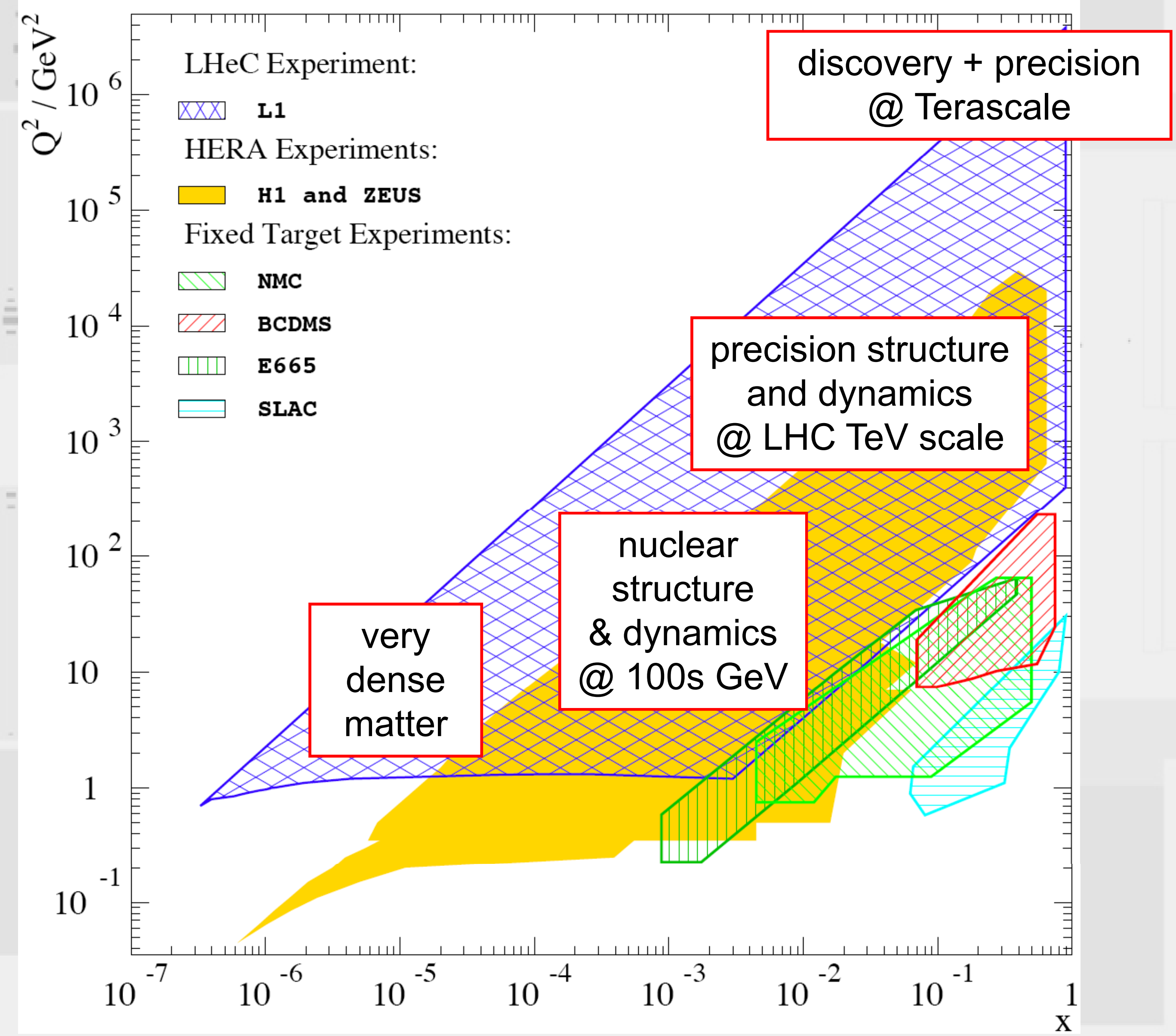


QCD

SM + q structure @ ~ 0.0001 fm ?



Why? The Scope



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TeV *eq* Kinematic Reach

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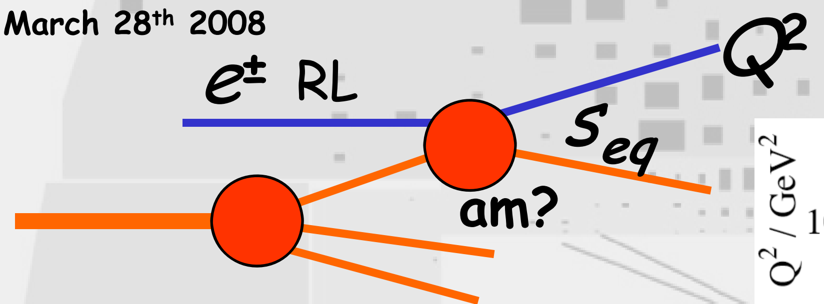
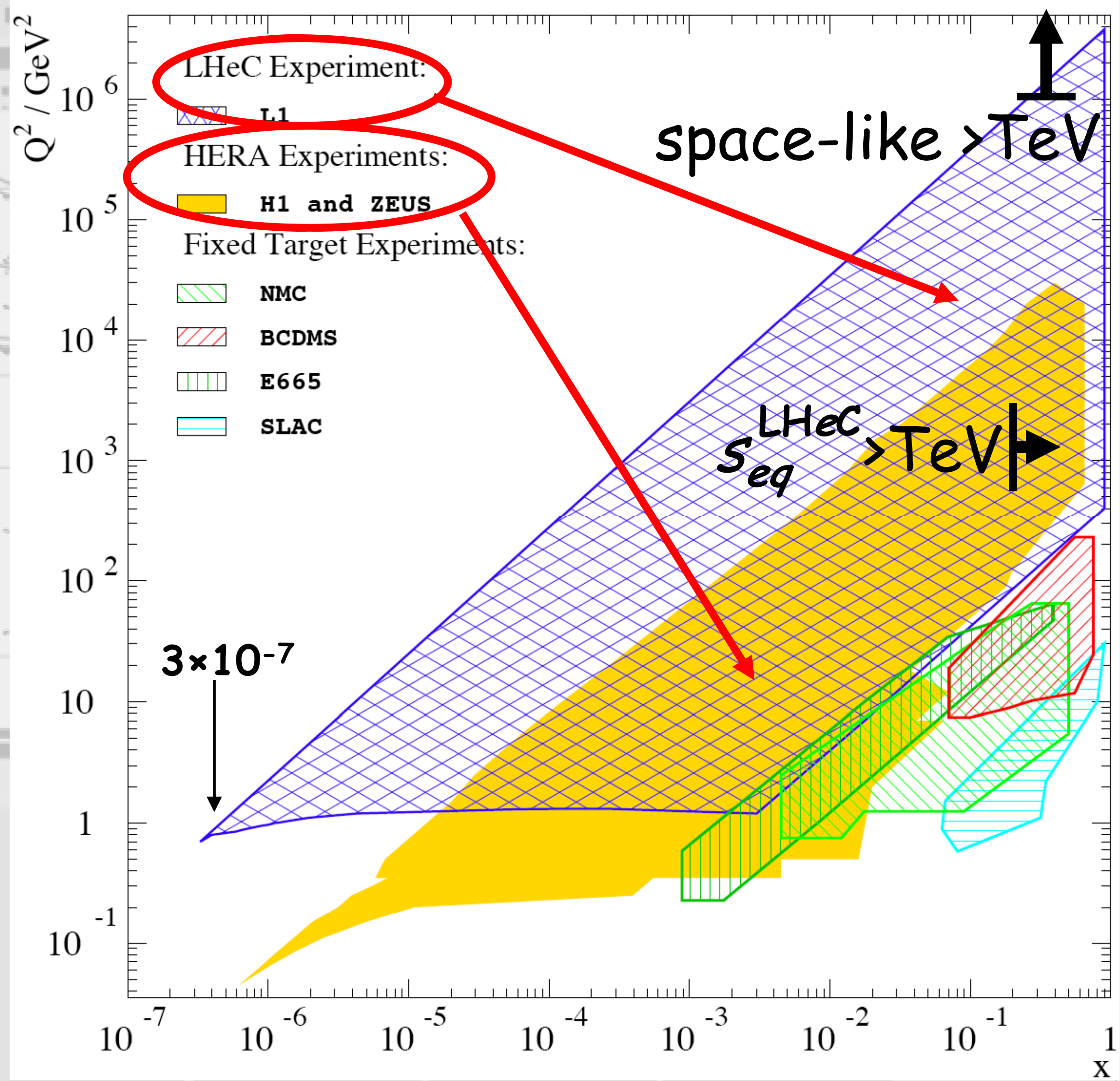


- 2007: HERA
  - $Q^2 \leq 30{,}000\ \mathrm{GeV}^2$
  - $s_{eq} \sim (300\ \mathrm{GeV})^2$ in ~ 0.7 am
- ≥20..?: LHeC
  - $Q^2 \leq 4\times10^6\ \mathrm{GeV}^2$
  - $s_{eq} \leq (4000\ \mathrm{GeV})^2$ in ~ 0.1 am !



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 !

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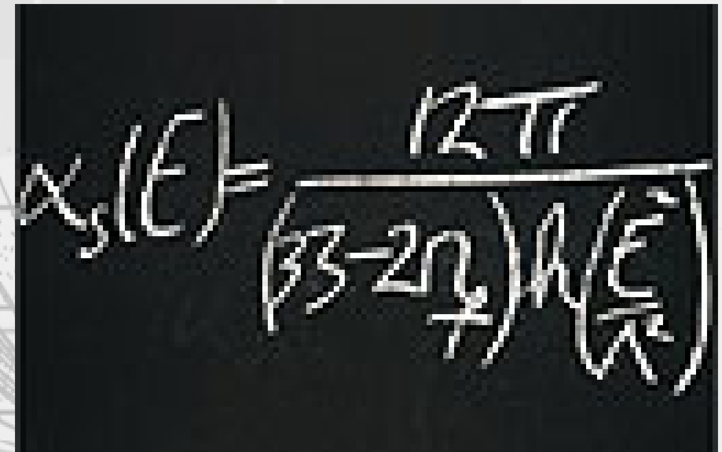
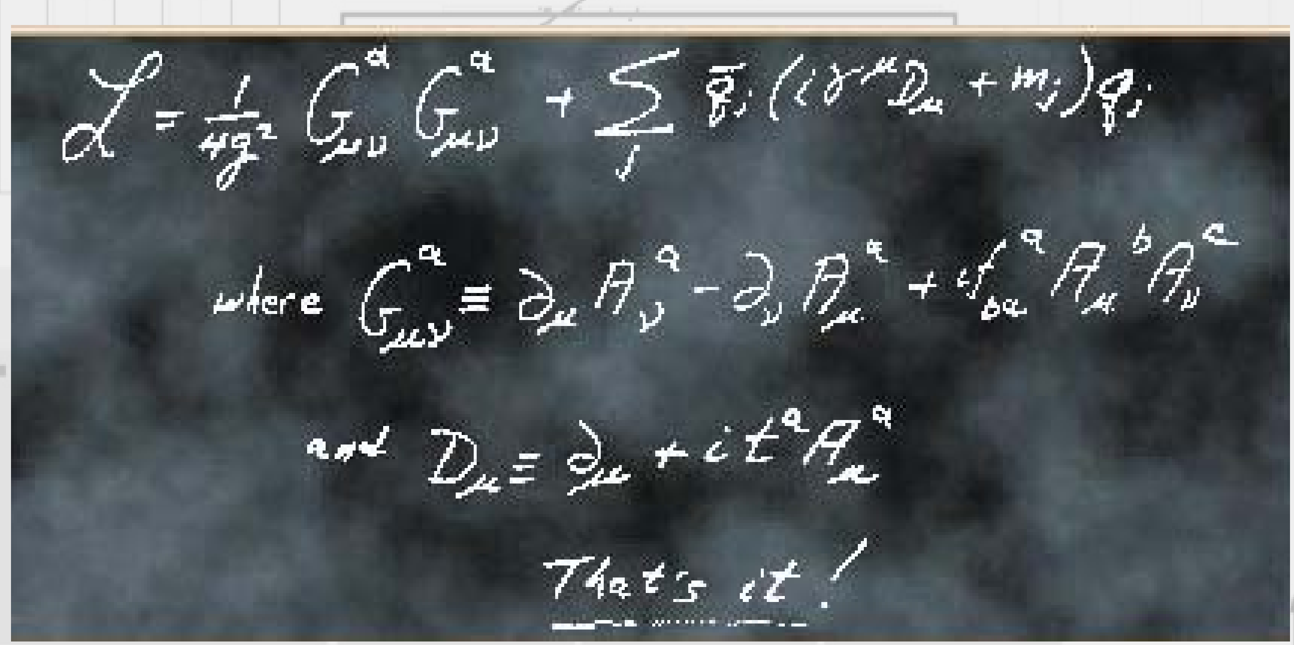
- found on a Guardian newsaper web page



- found on Frank Wilcek's blackboard



TeV *ep* Kinematic Reach ty

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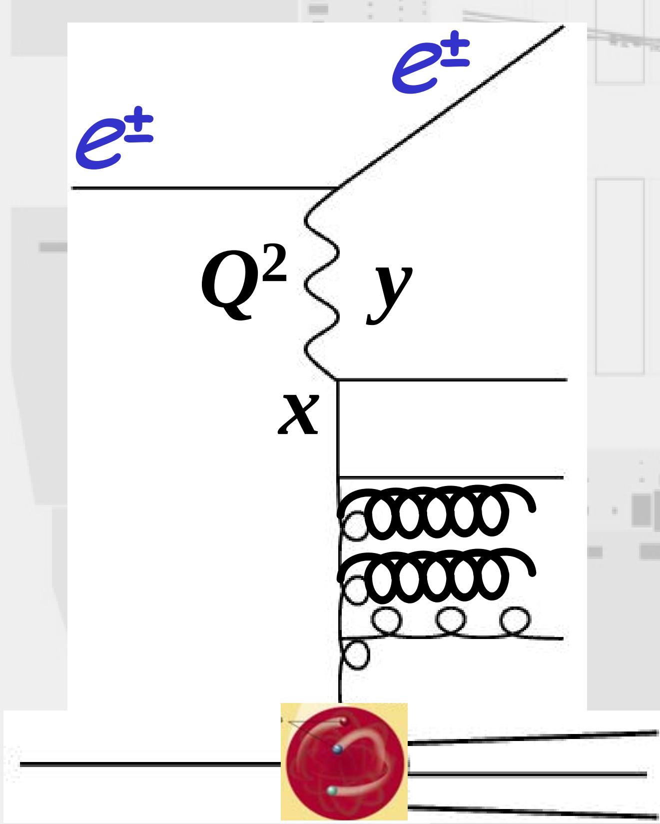
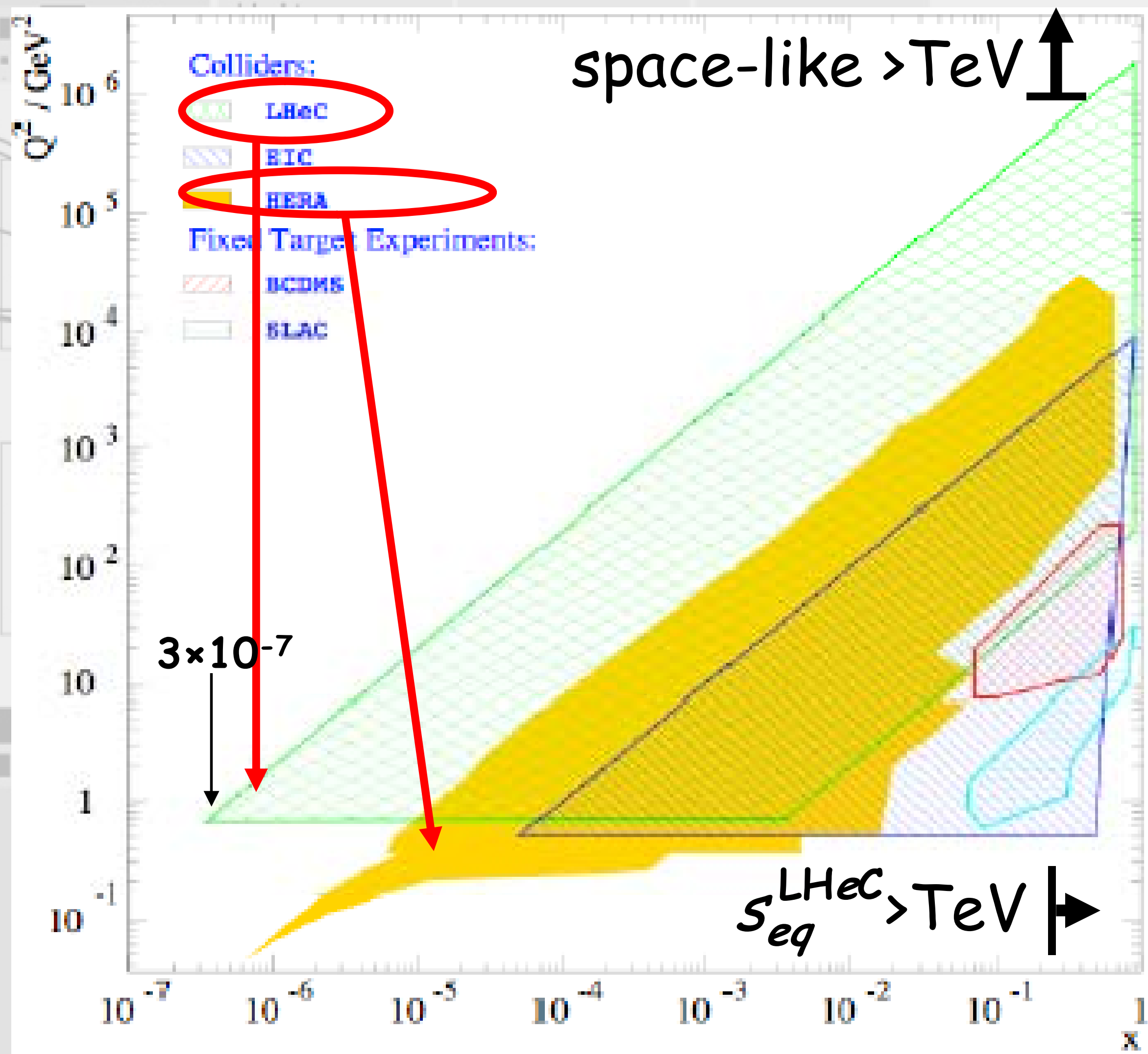
- 2007: HERA / 2016?: LHeC
  - $Q^2 \geq 1$ GeV^2
  - $x_{Bj} \geq 5\times10^{-5}$ / 5×10^{-3}

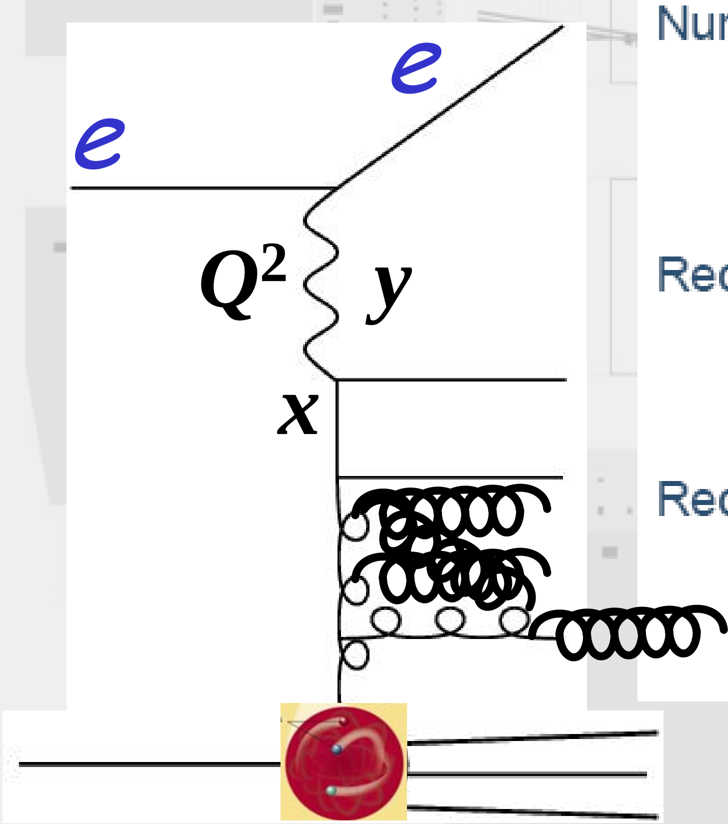




Gluon recombination

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

- $Q^2 \rightarrow$ 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

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Lepton+quark @ TeV

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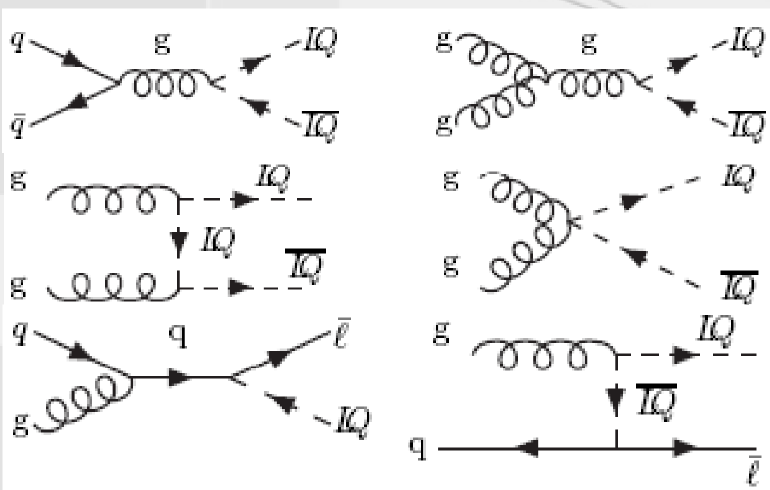
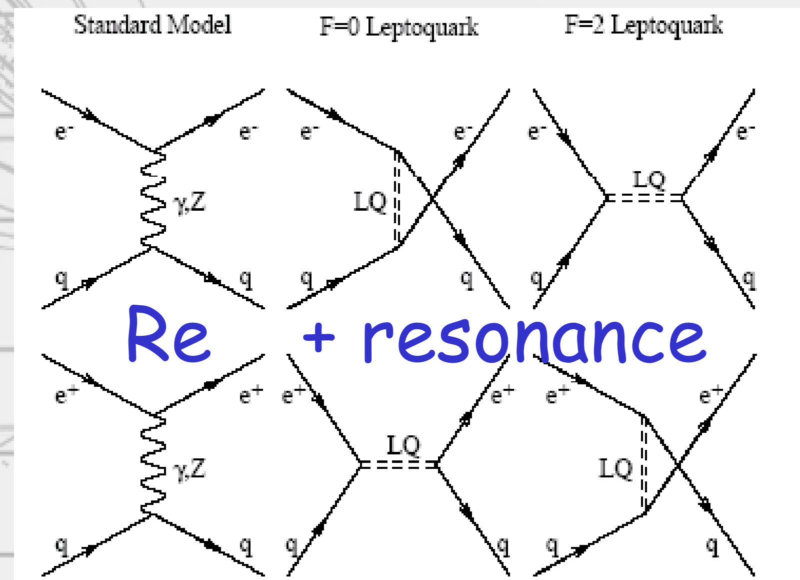
- leptoquark systems – new physics + SM

LHC

LHeC





Re + resonance

LHC	LHeC
SM (hadronic) + signal	SM (electroweak) + signal
Lq & *LqLq* production	*Lq* formation
$\sigma \sim$ few × 0.1 fb (Λ=0.1)	$\sigma \sim$ 100 fb (Λ=0.1)

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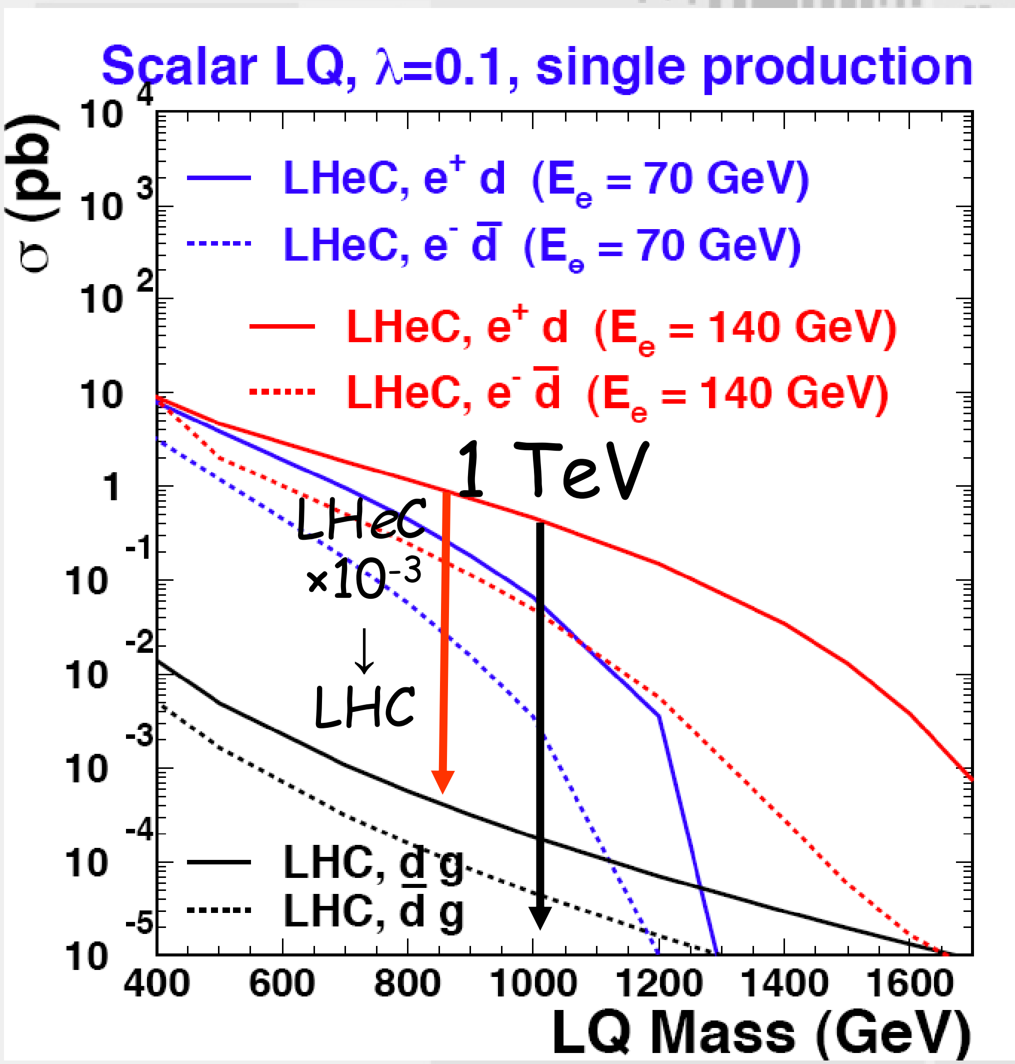

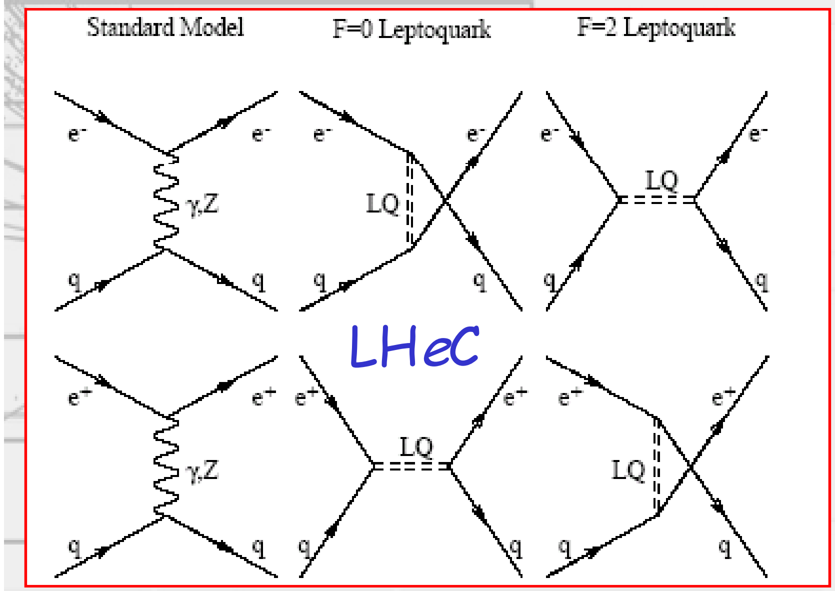

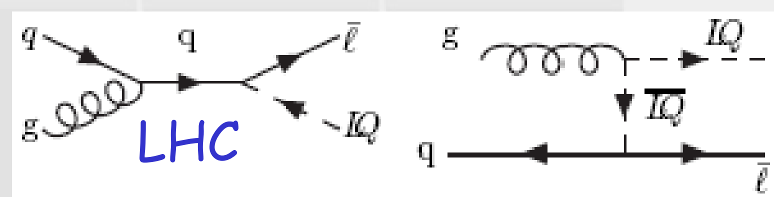

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Lepton+quark @ TeV

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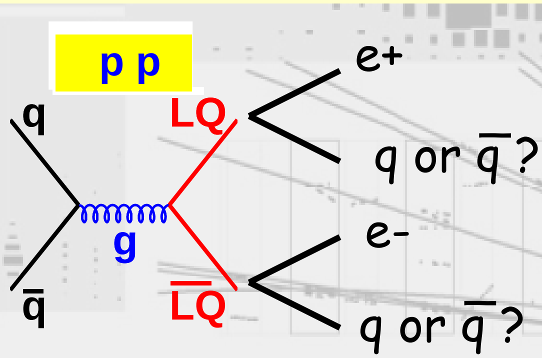
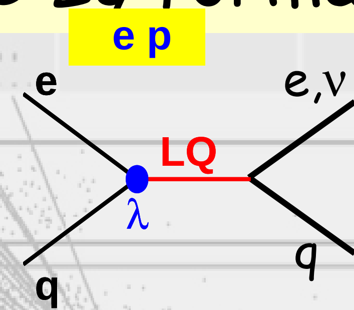
LHC *Lq* pairs+decay



LHeC *Lq* formation+decay



e+ F=0
e- F=2

fermion number

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

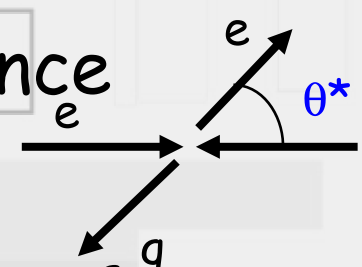
spin parity and chirality

production mechanism ?

disentangle mass spectrum ?

defined formation (e_{LR})
→ precision BRs (NC CC)

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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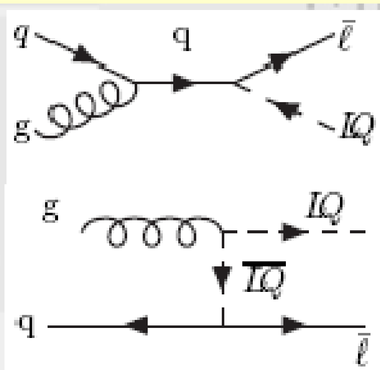
LHC *Lq* +decay

fermion number



spin parity and chirality

$gq \rightarrow Lq\,\bar{l}$

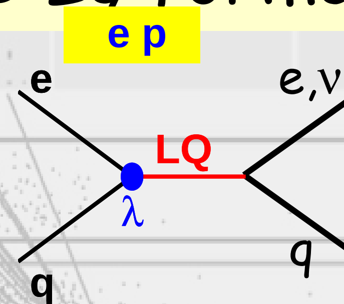
production mechanism ?

disentangle mass spectrum ?

experim! signature

jet + leptons

LHeC *Lq* formation+decay



e+ F=0
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defined formation (e_{LR})
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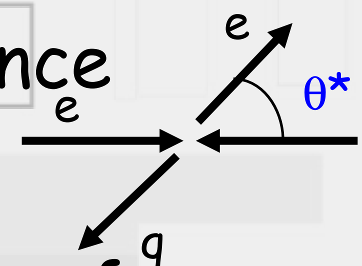

unique PWA

SM + signal + interference

jet+lepton+p_T balance
jet +p_T imbalance

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Unification ?

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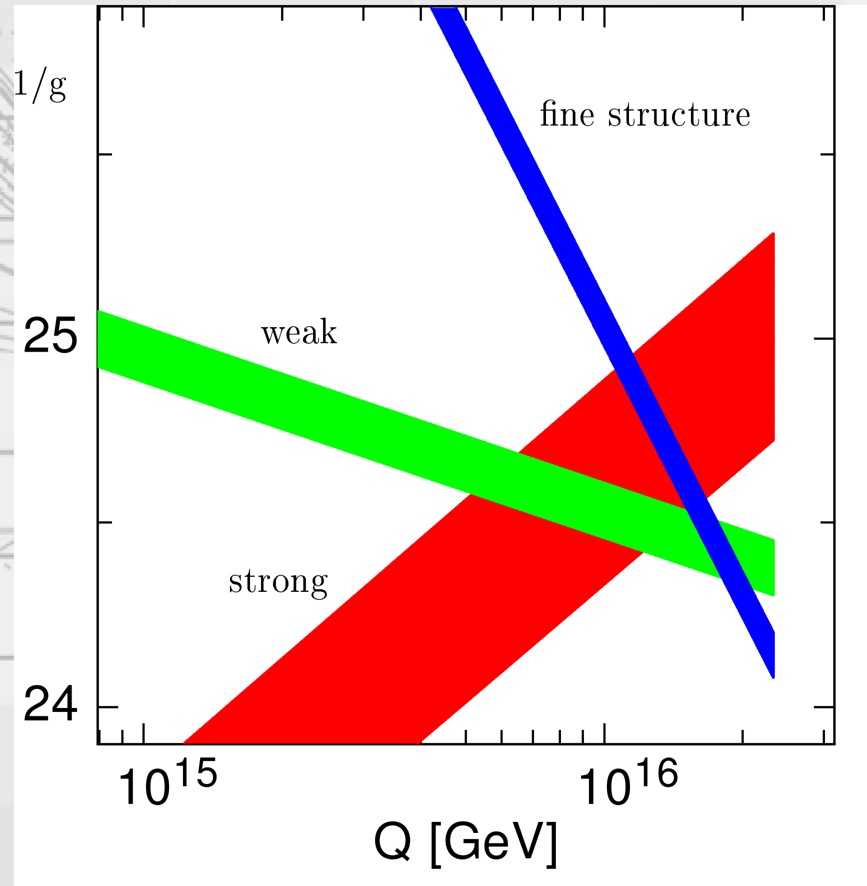
- precision → QCD at highest energy
- short distance structure of SM+
  - 2007 → @ 10^{-3} ppm
  - 2007 G_F @ 10 ppm
  - 2007 G @ 0.1%
  - 2007 α_s @ 1-2%
  - LHeC + detector → α_s @ few ‰



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

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Lepton-Parton and Parton-Parton ?

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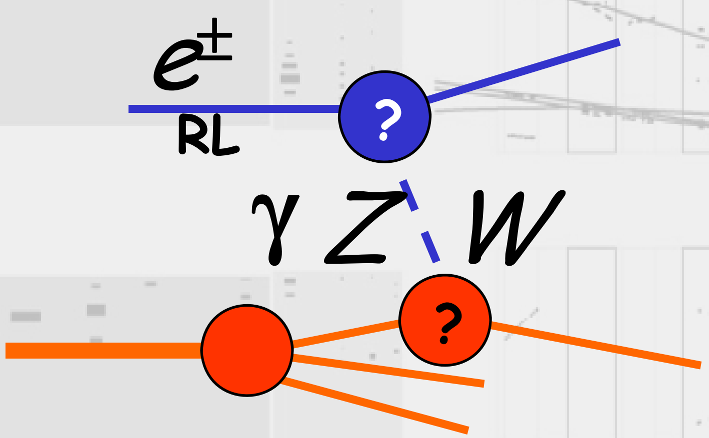
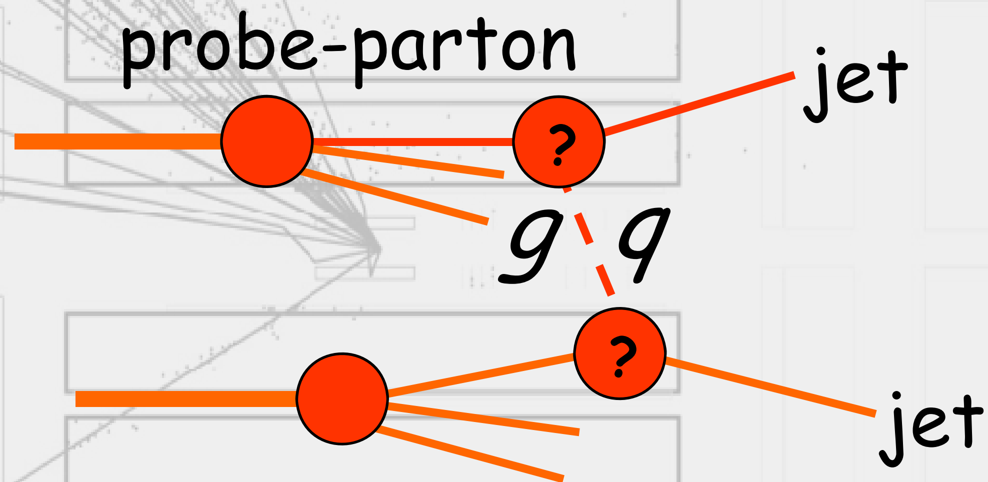
- $ep \rightarrow eX$



- LH*e*C energy scale:
  70⊗7000 GeV

probe = $e^{\pm}$

- $pp \rightarrow$ (jet+jet)X



- *pp* energy scale:
  7000⊗7000 GeV

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

$x_{probe/p}$ = 0.01

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LHC probe parton

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

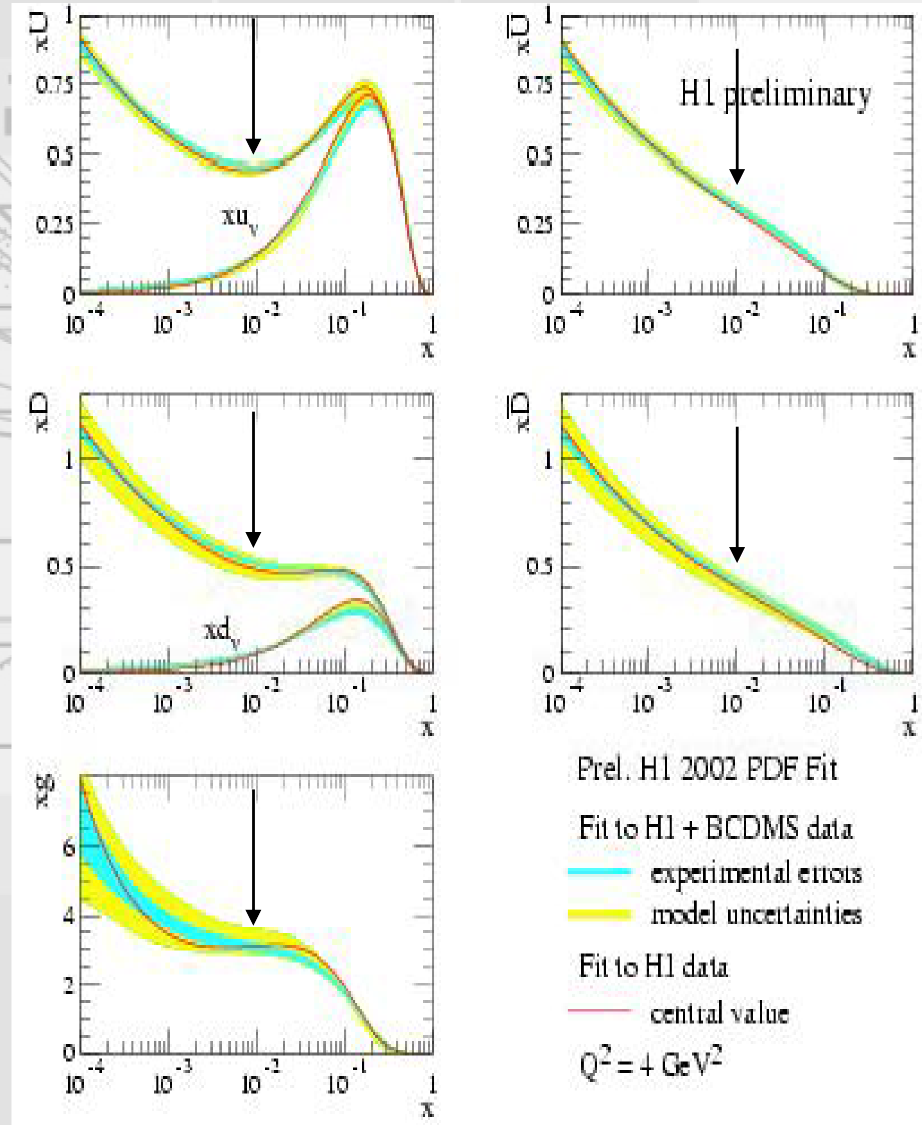
    $g : q \sim 2{:}1$ mixed

- 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

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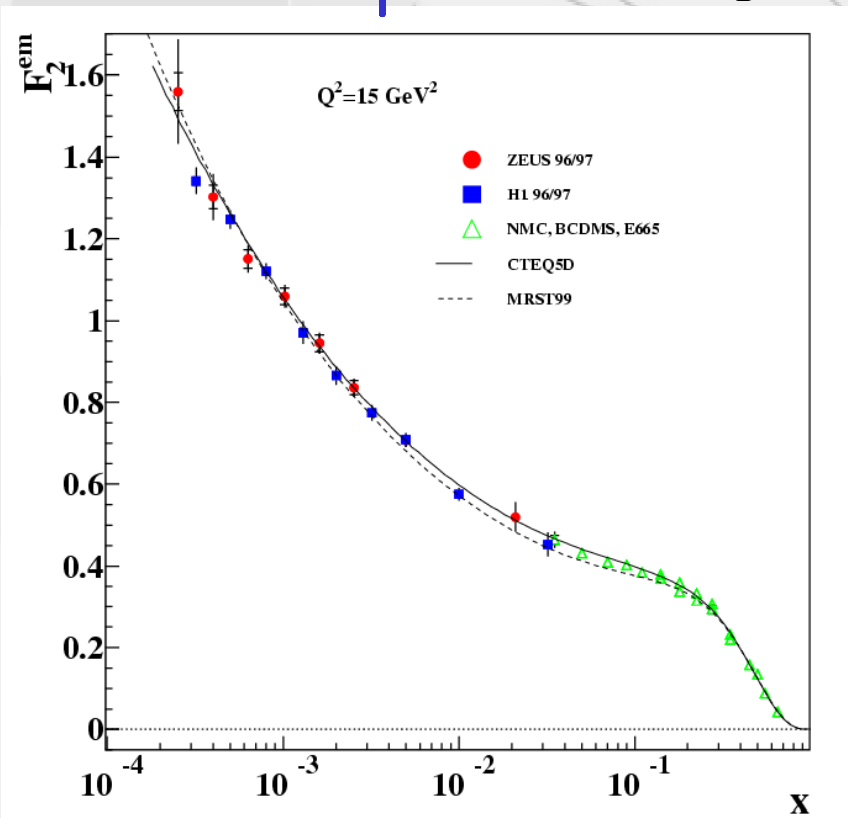
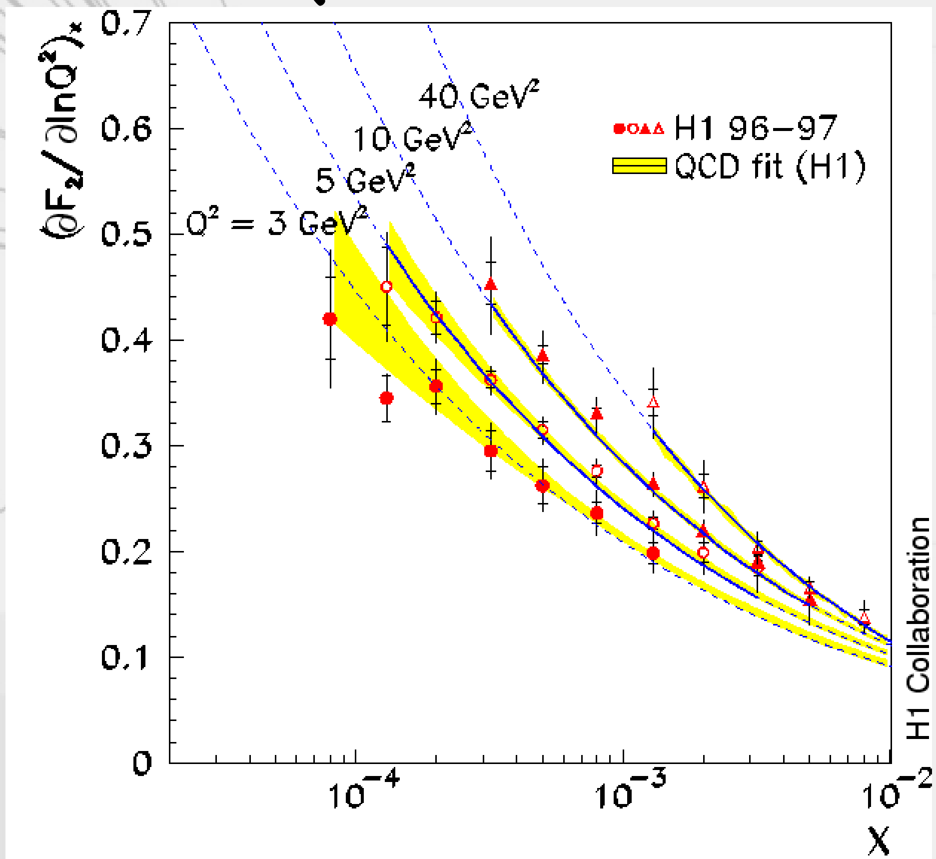
- low-x rise of F_2
  - HERA: precision @ $x > 10^{-4}$ @ Q^2=10 GeV^2





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

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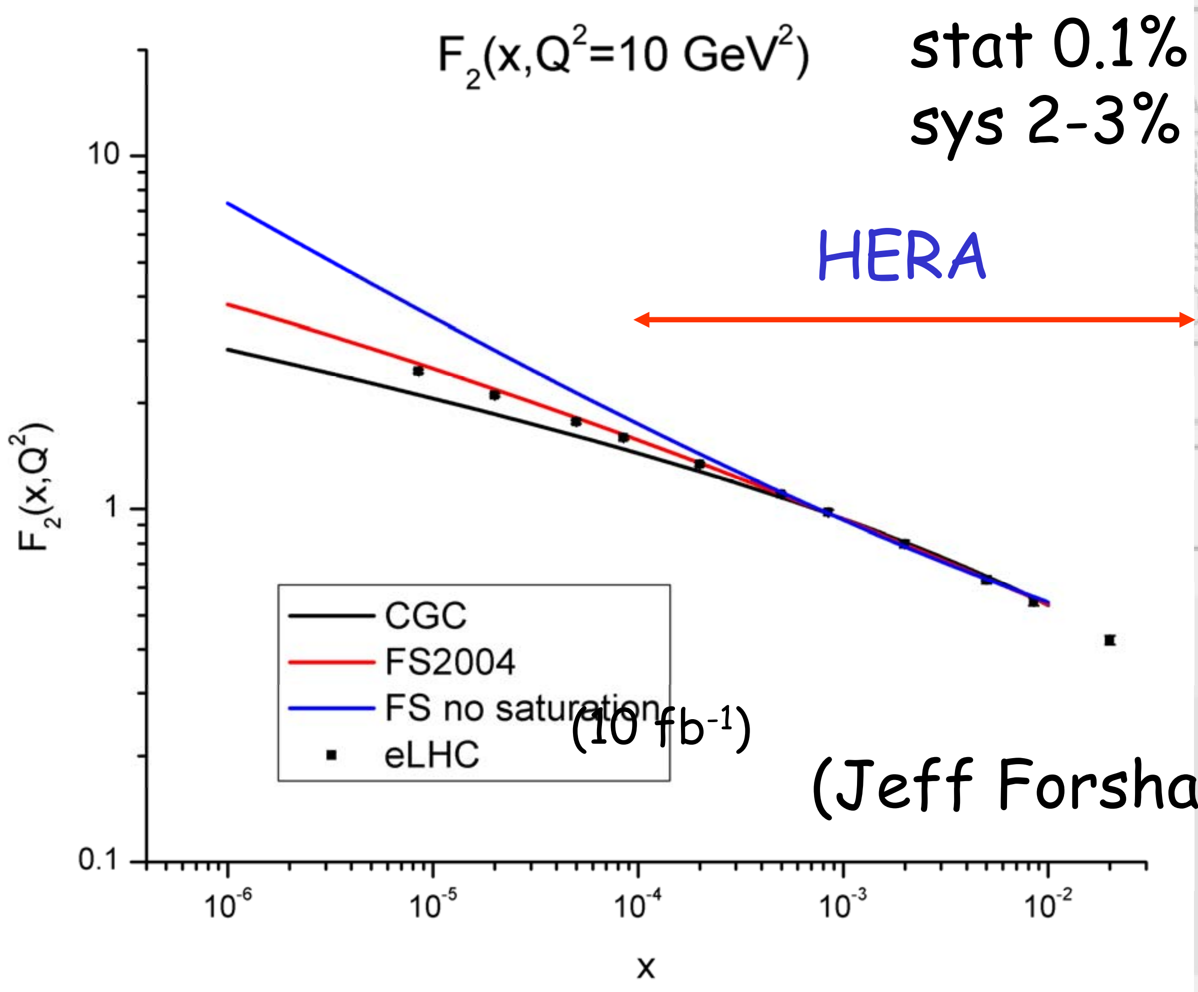
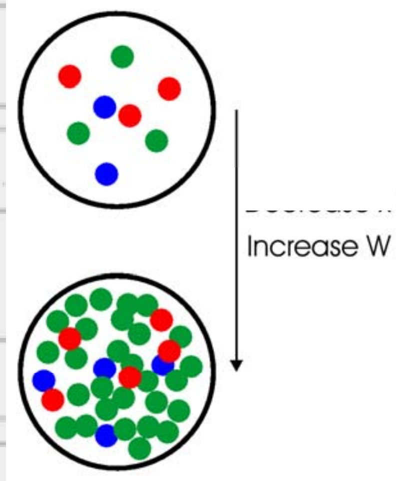
Gluon recombination @ LHeC

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





(Jeff Forshaw)

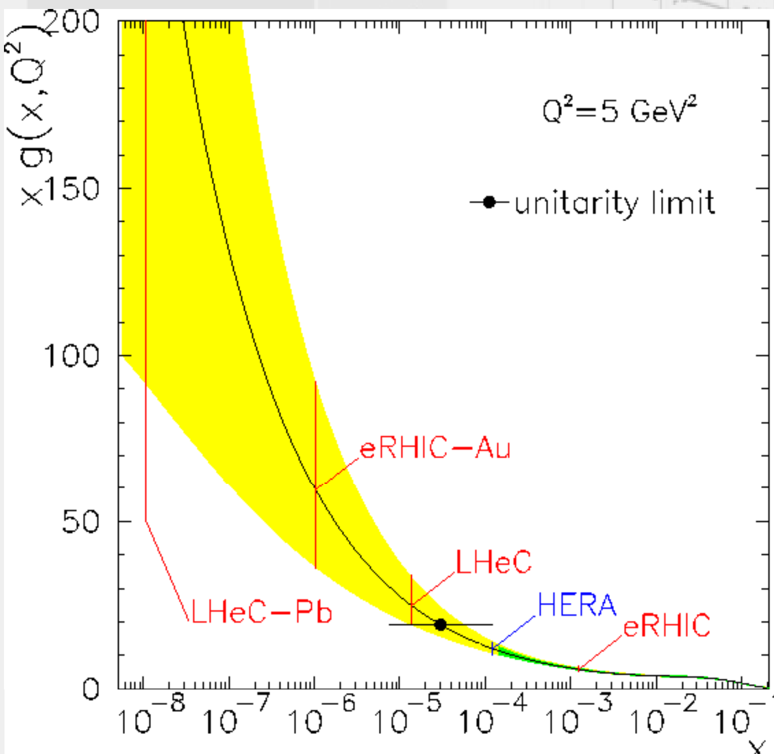
- LHeC "nails" saturation

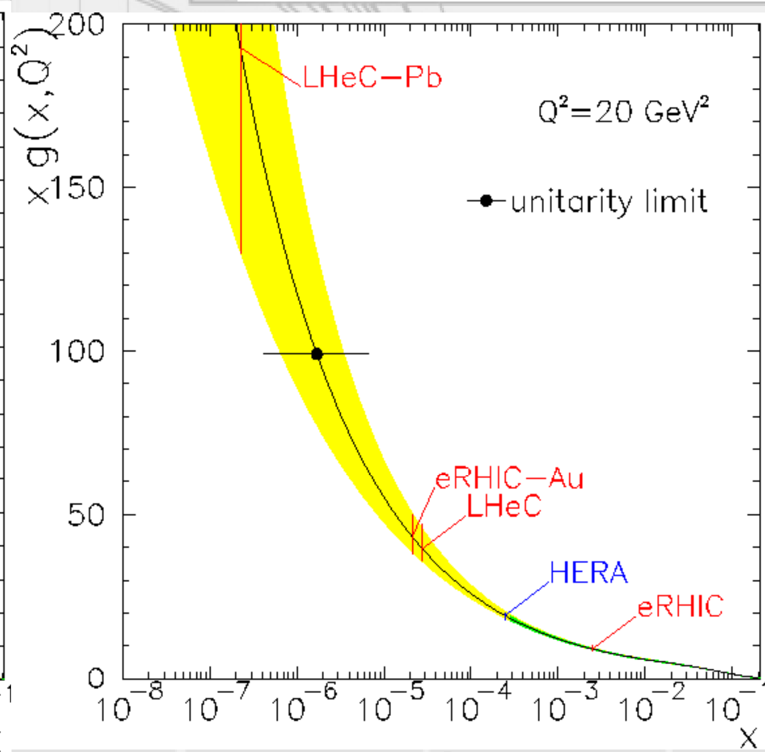
Gluon recombination @ LHeC

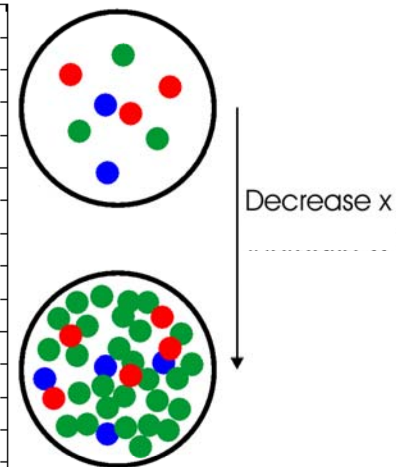
- *ep* saturation $Q^2 \leq 5\ GeV^2$

  eA saturation $Q^2 \leq 20\ GeV^2$

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



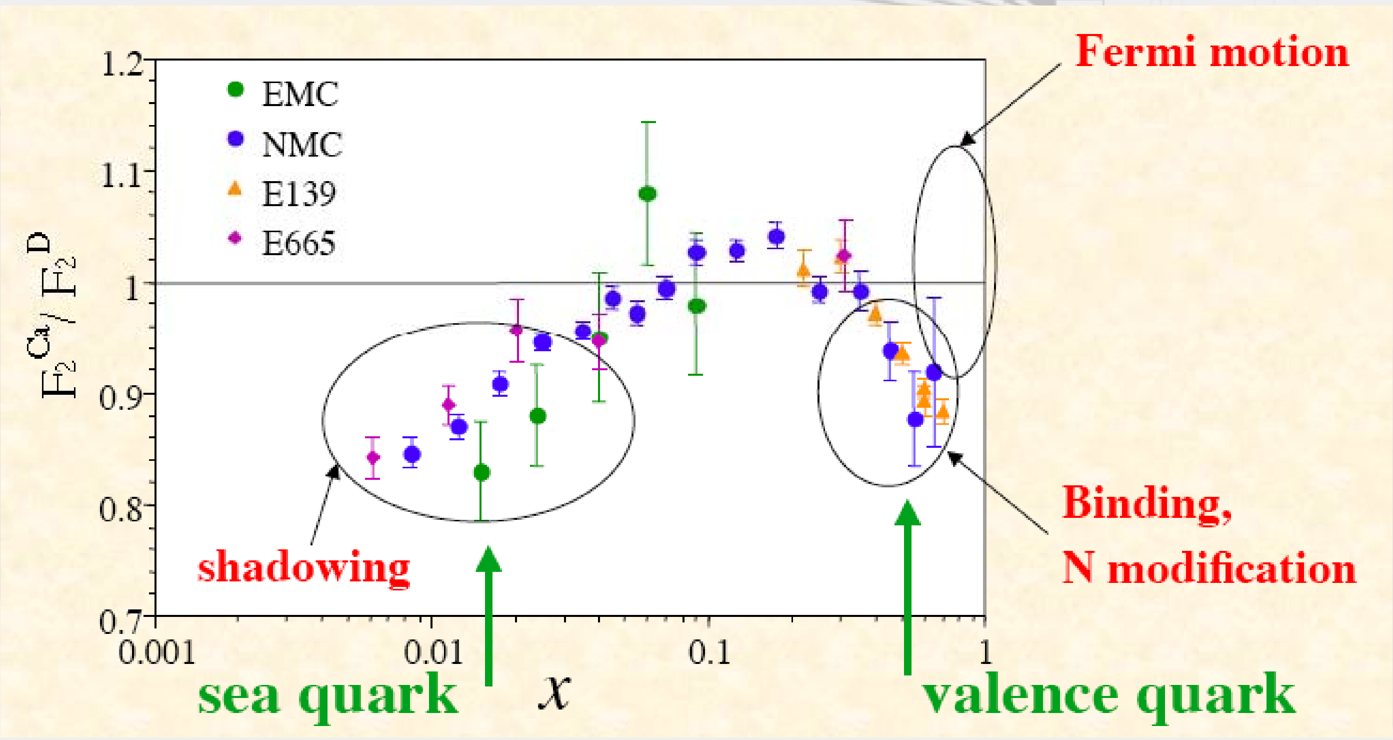




- LHeC “nails” saturation

Partons in Nuclear Matter

- 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 $x > 0.01$



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1_c dynamics in p and A

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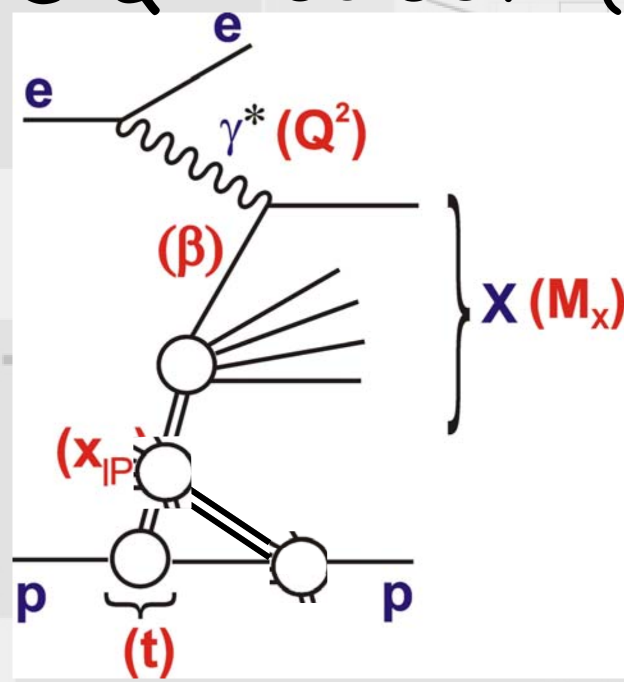
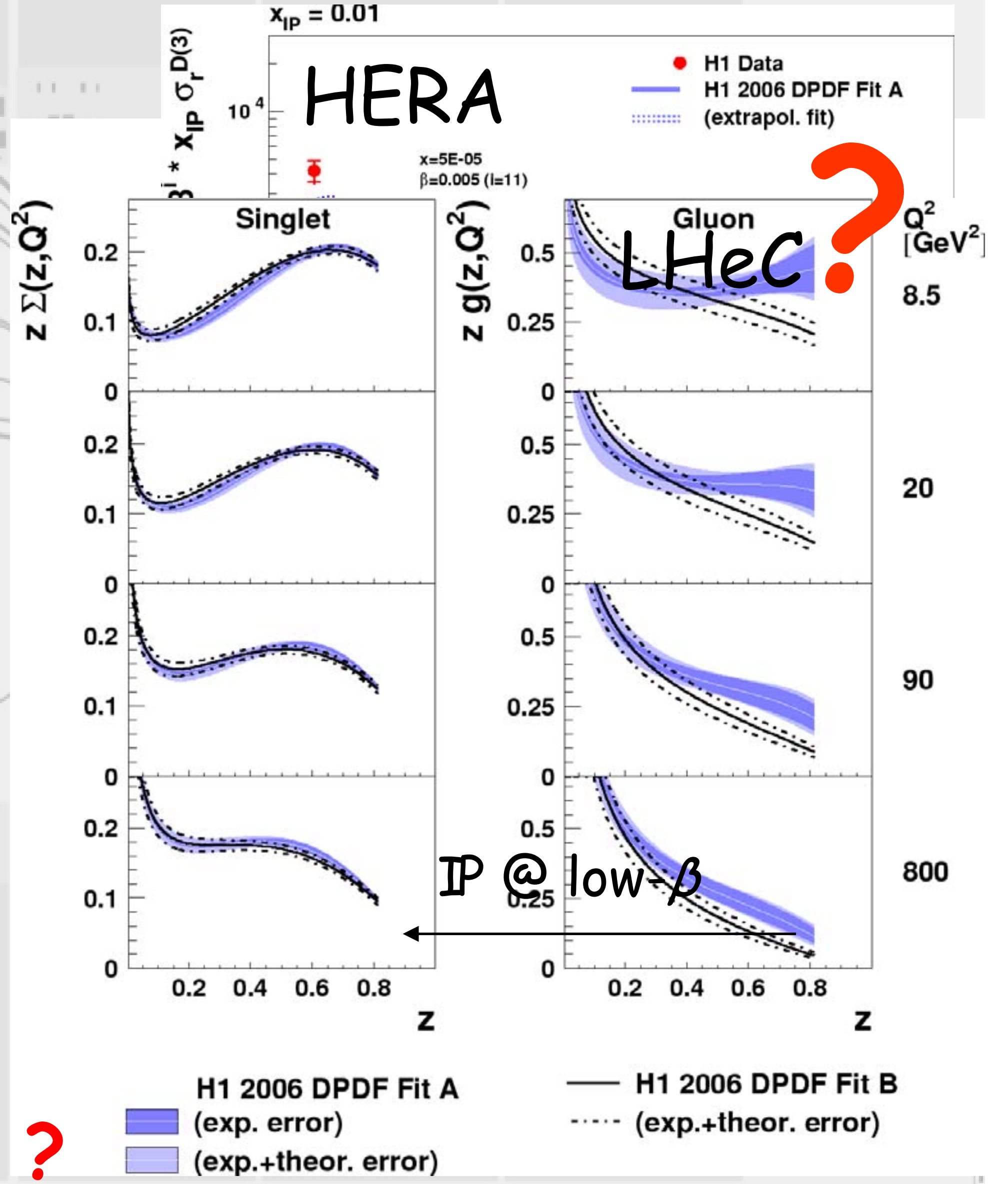
- low-x reach at LHeC
  precision @ $x > 10^{-4}$
  @ $Q^2 = 250\ \mathrm{GeV}^2$ ($x = \beta x_{I\!P}$)

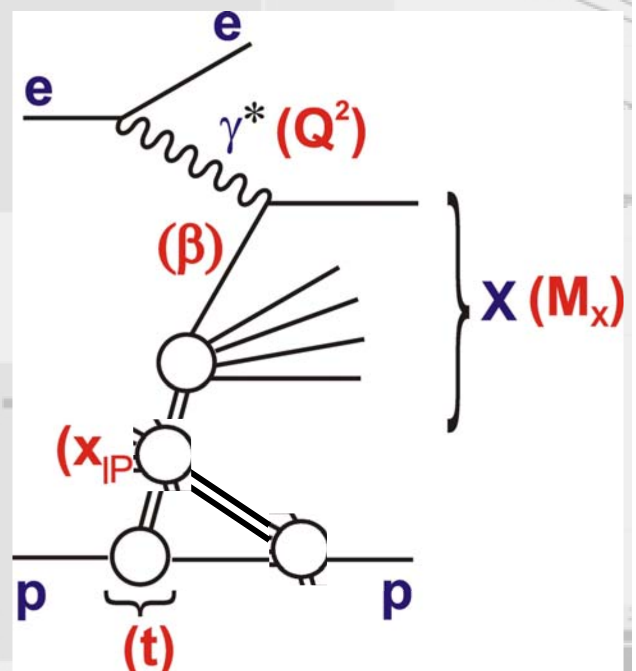


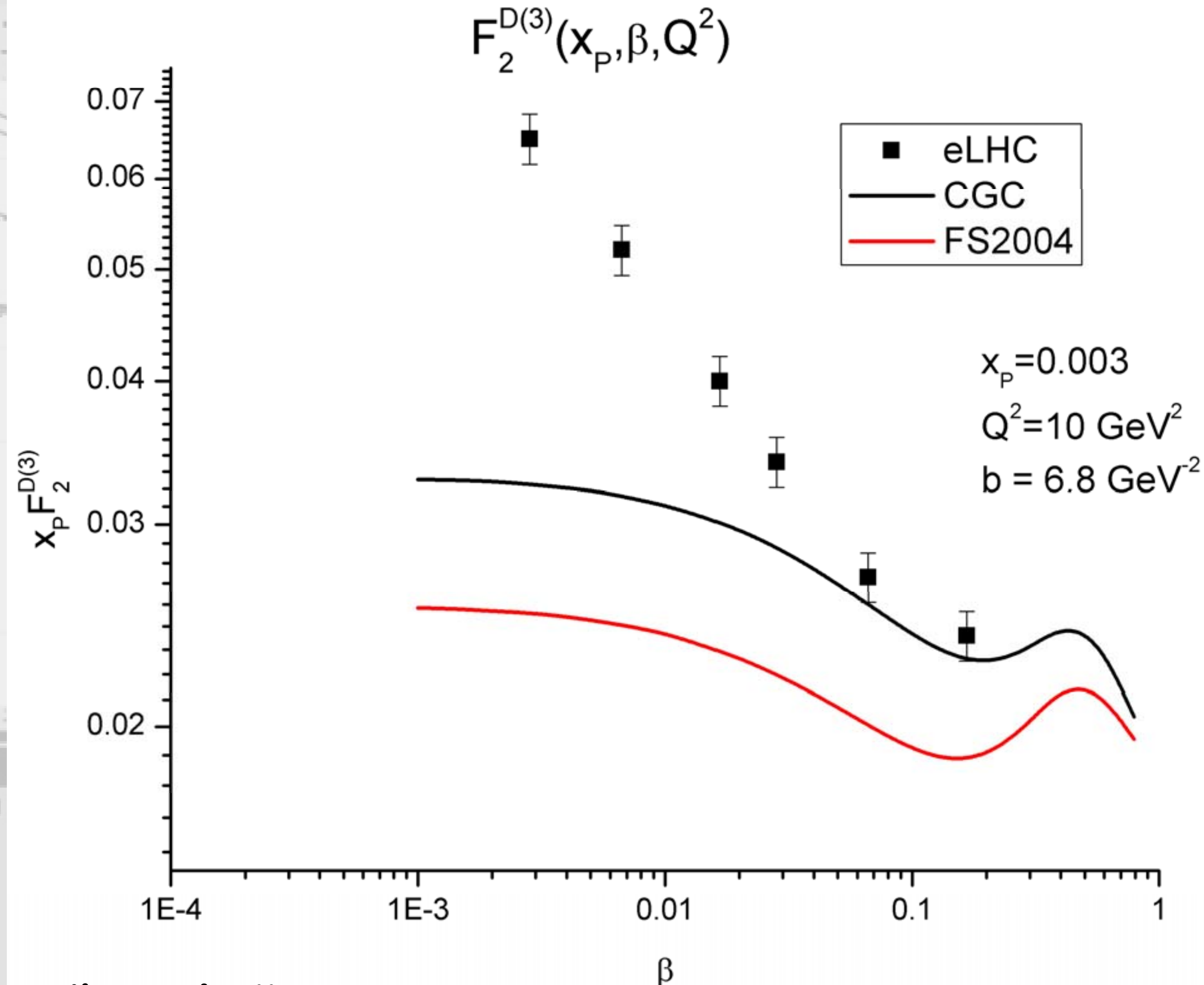


- low x physics of $I\!P$
  $I\!P$ in $I\!P$: triple $I\!R$
  QCD → reggeon calculus ?

1_c dynamics in *p* and *A*

- low-*x* ℙ physics at LH*e*C





- LH*e*C diffraction “nails” saturation

1_c dynamics in *p* and *A*

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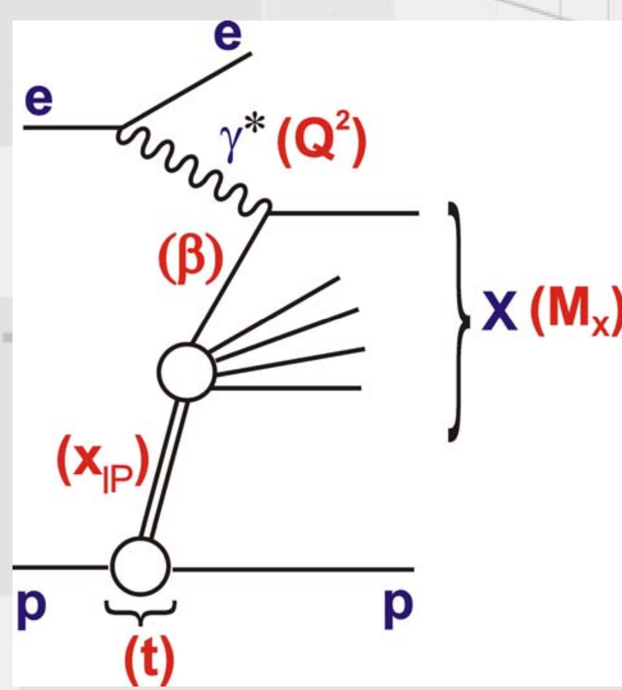
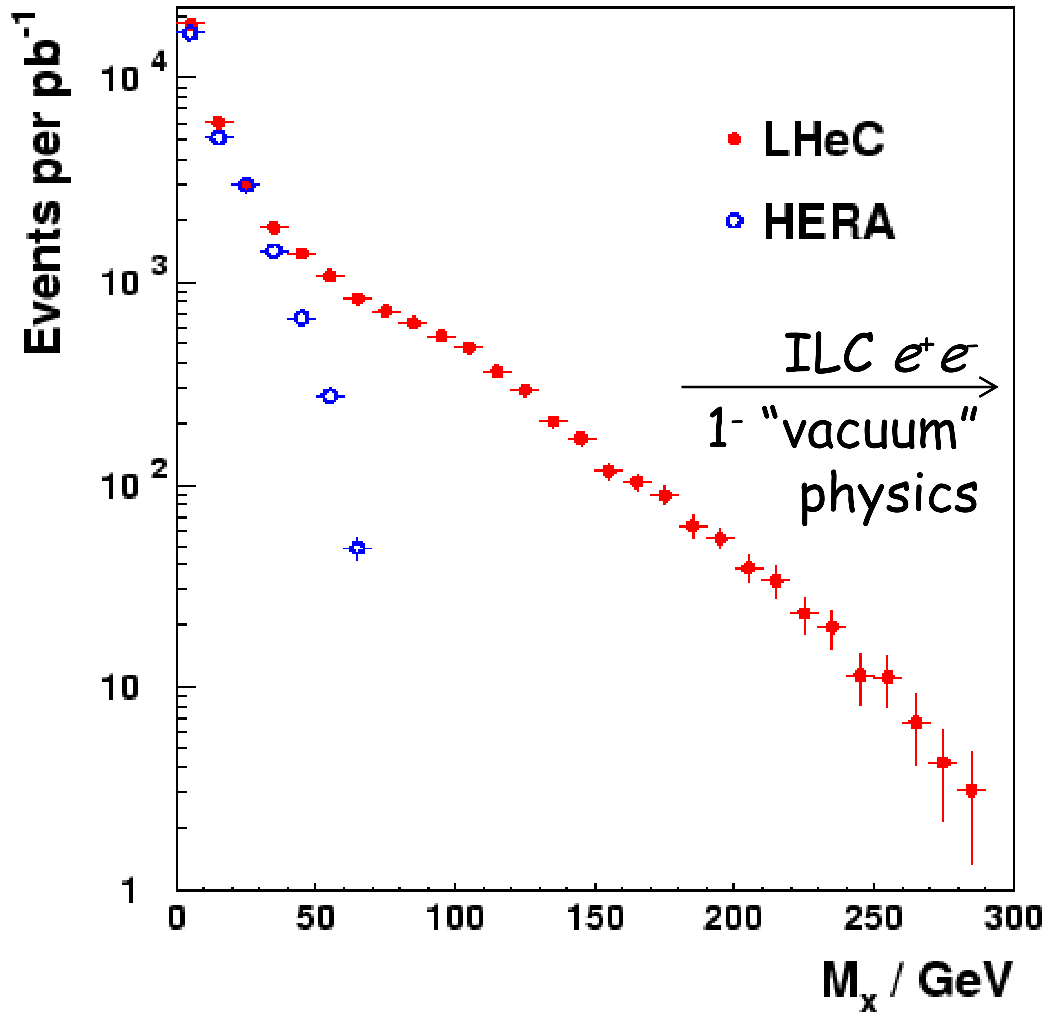
- IP physics at LH*e*C
  0^+ "vacuum" physics



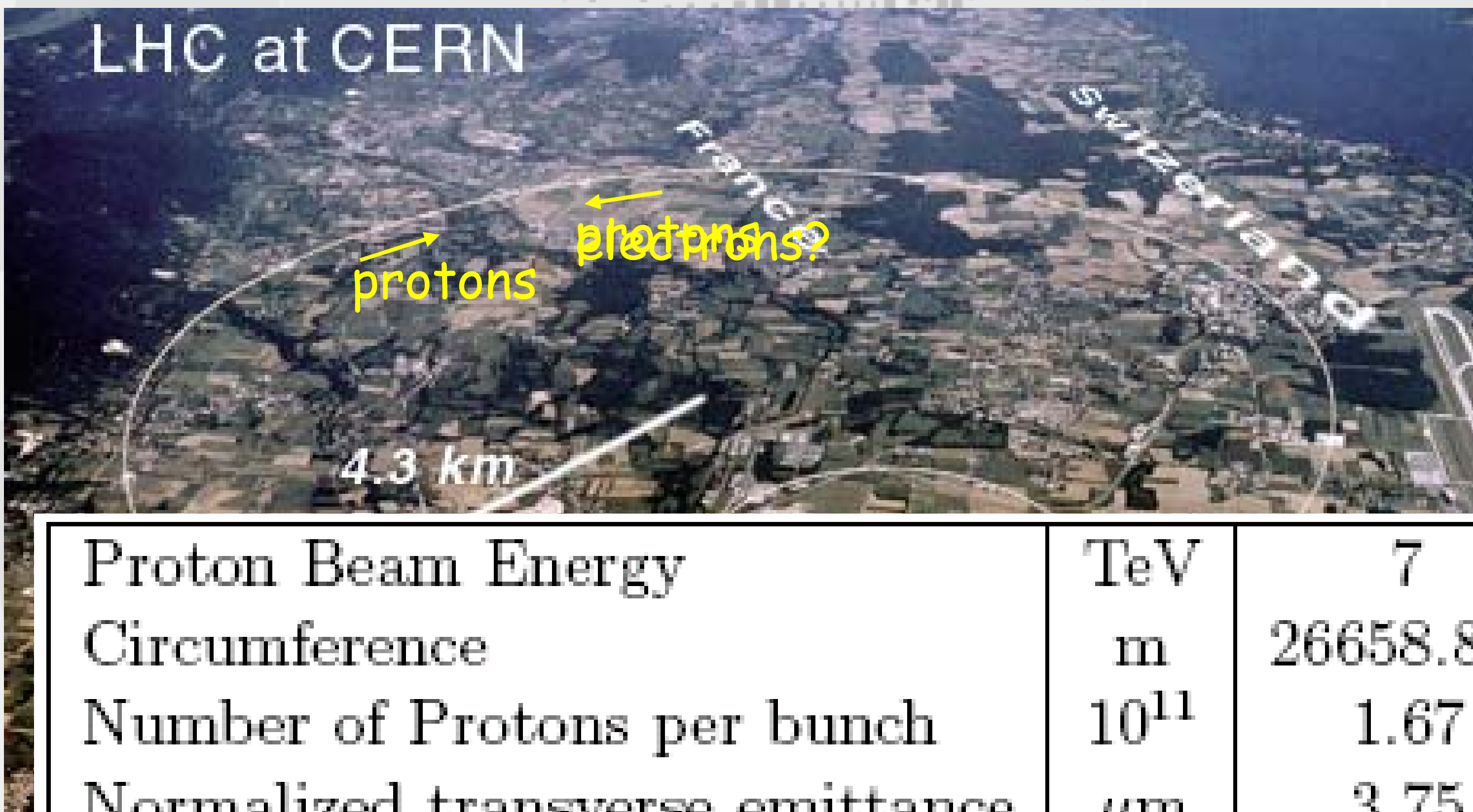


- eIP physics @ 1 TeV / γ*IP physics 5 ≤ Q^2 ≤ 100 GeV: leptopomerons ?

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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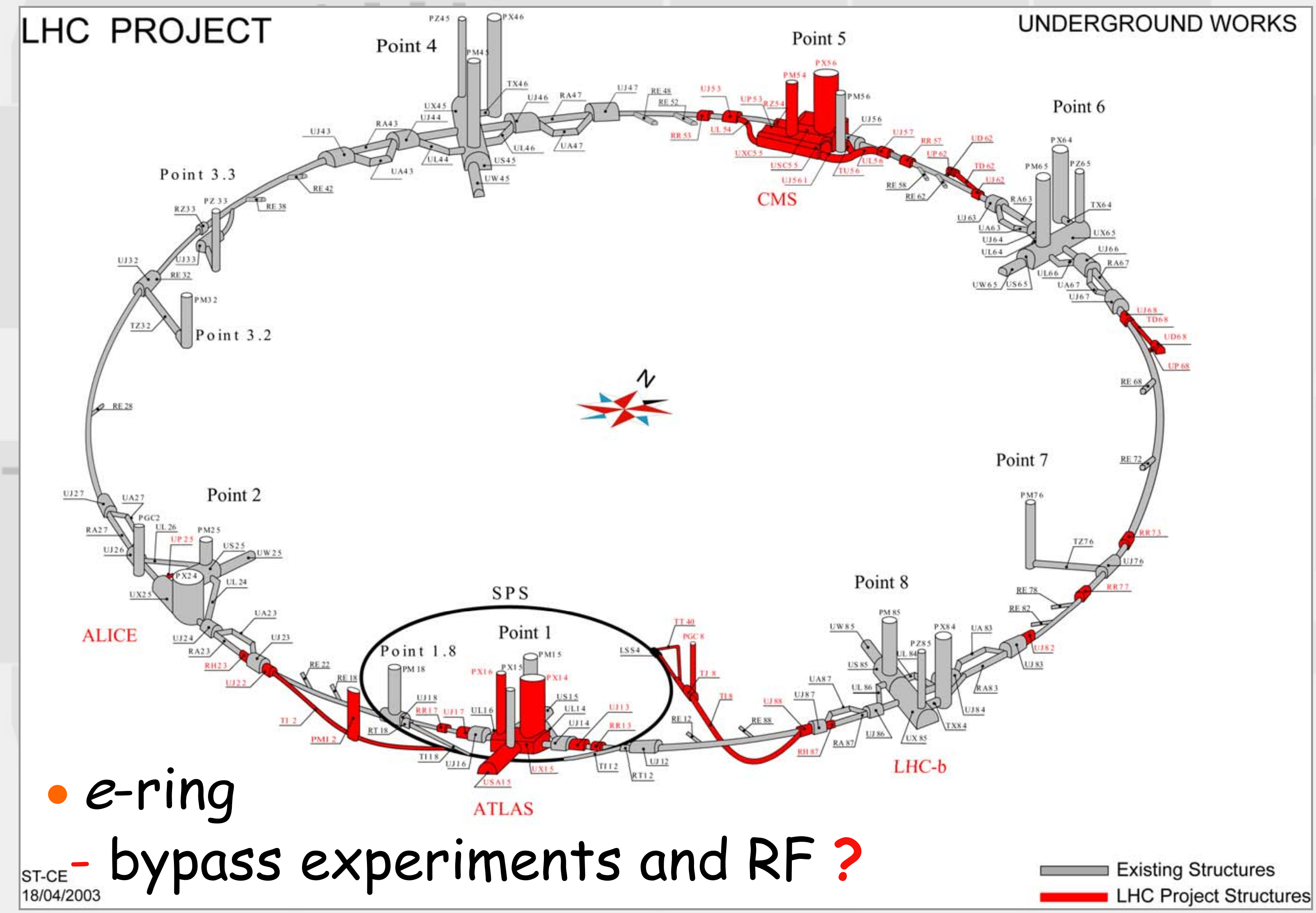

- e-ring
  - bypass experiments and RF ?

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ep Collisions

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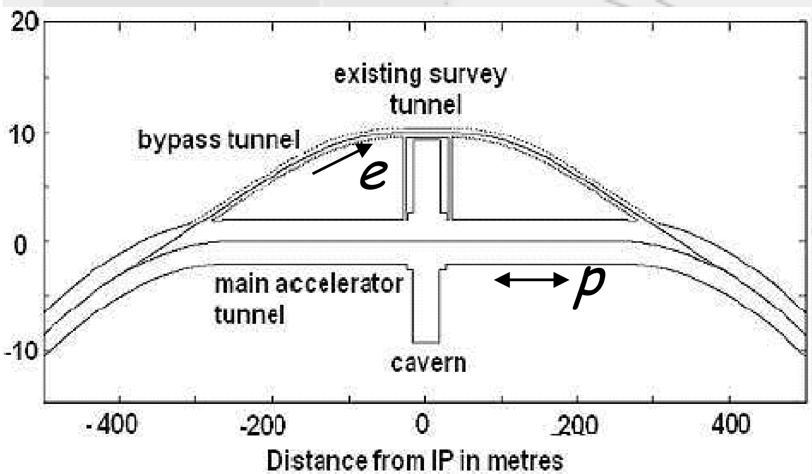
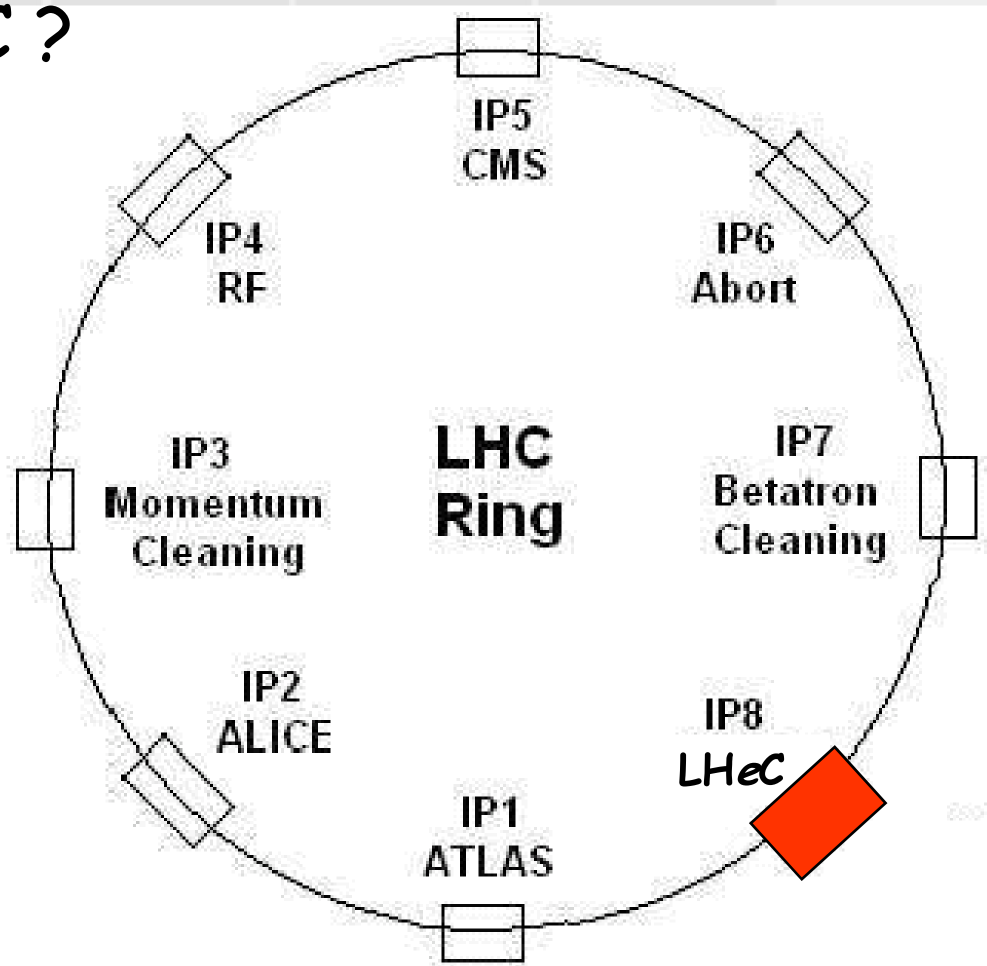
- after *B* physics @ LHC ?





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

↳ *ep* alongside *pp* data-taking @ LHC

F Willeke (DESY and BNL)

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Luminosity: *e*-Ring

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

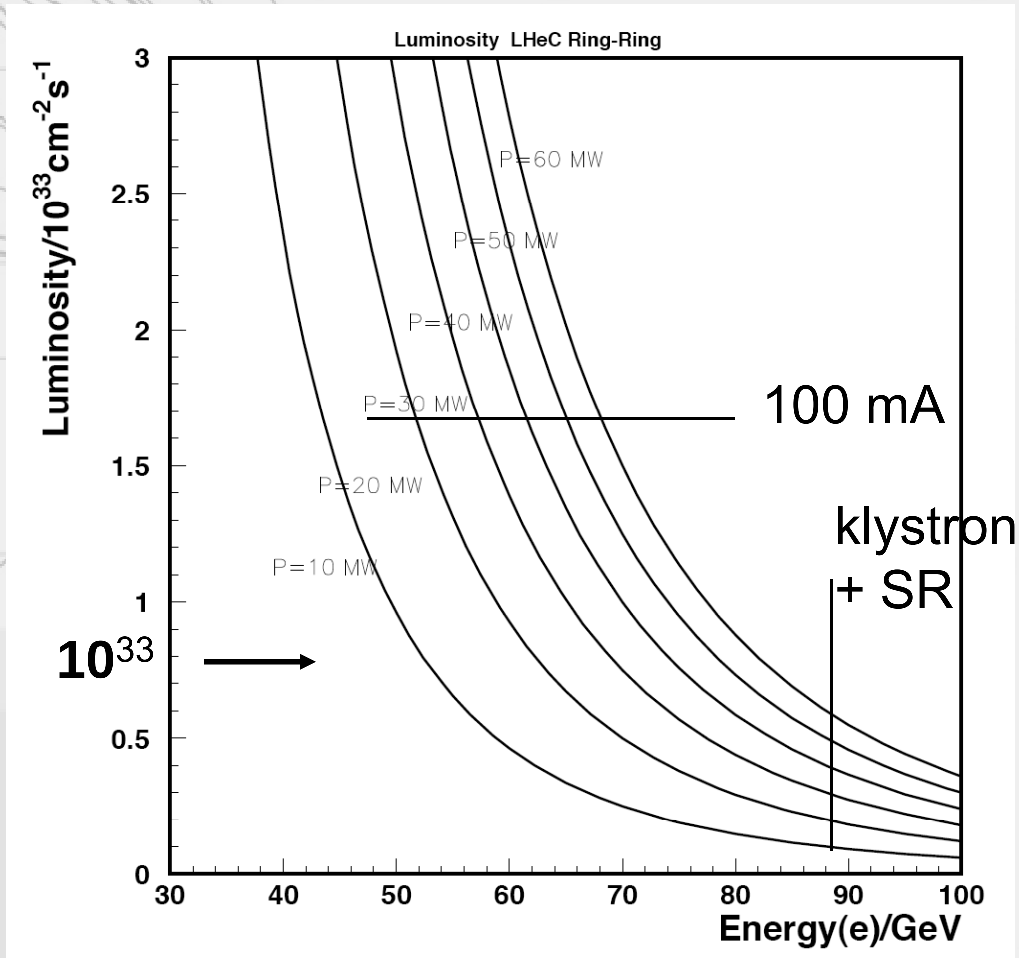
$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

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

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

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

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

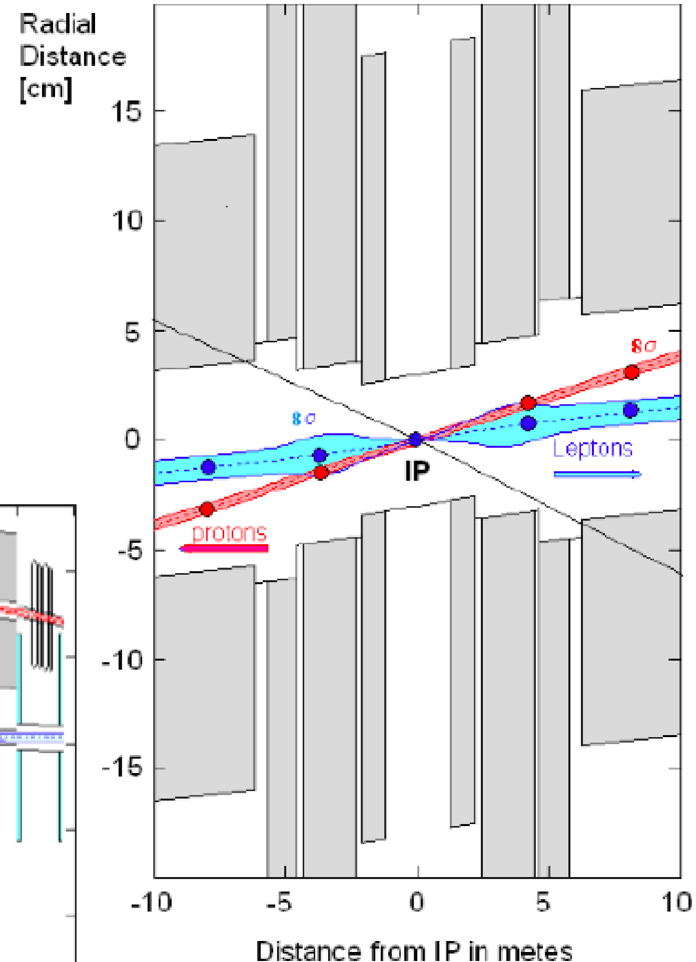


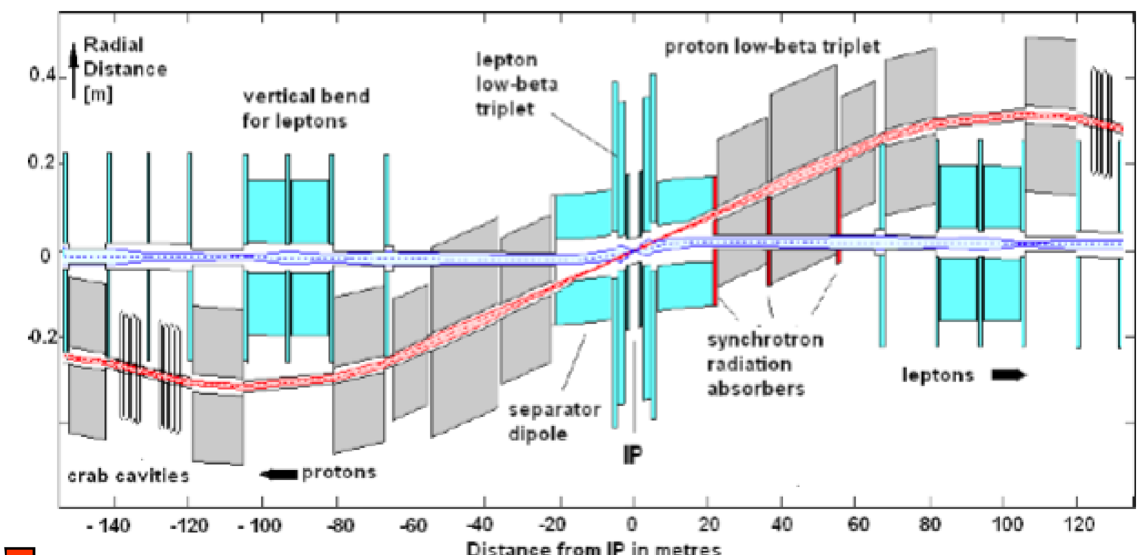
cf also A.Verdier 1990, E.Keil 1986

e-Ring IR

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	$10^{33}\text{cm}^{-2}\text{s}^{-1}$	1.1	





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

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e-ring

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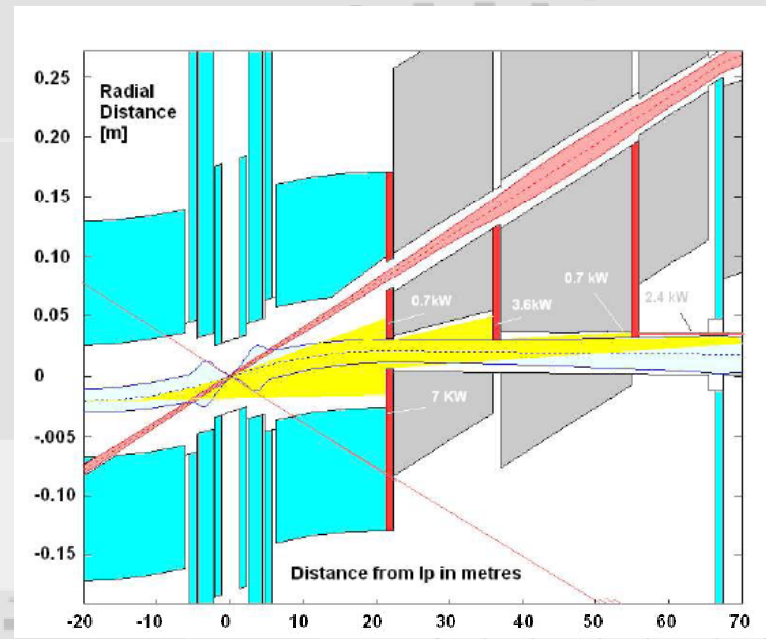
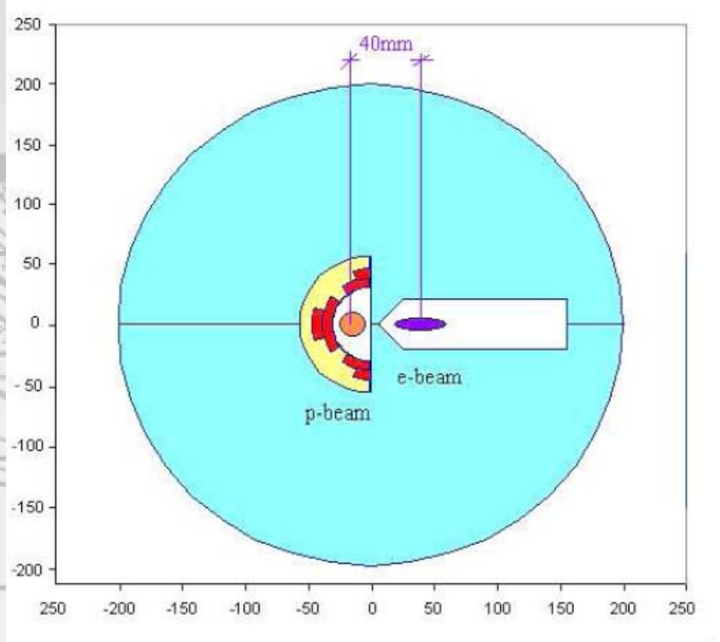


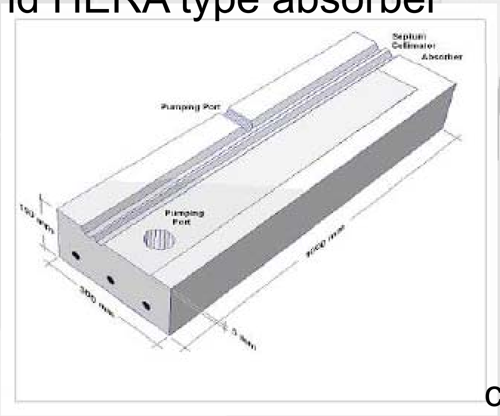


Synchrotron radiation fan

and HERA type absorber

$9.1kW$

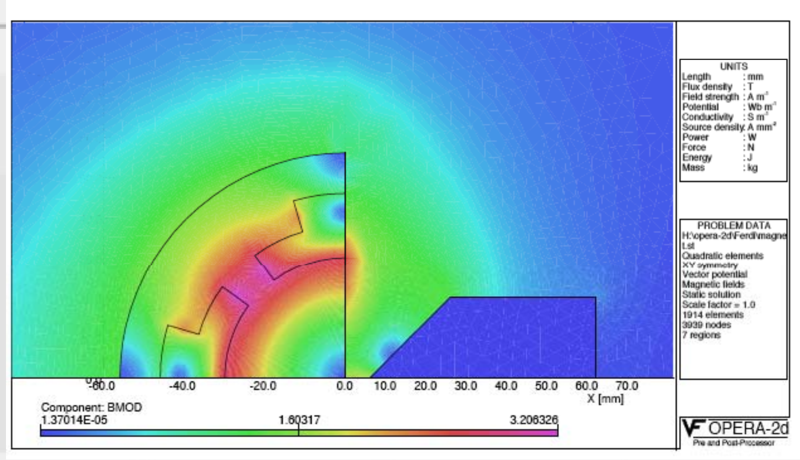
$E_{crit} = 76keV$



100W/mm^2

cf also W.Bartel Aachen 1990

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



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e-ring Issues

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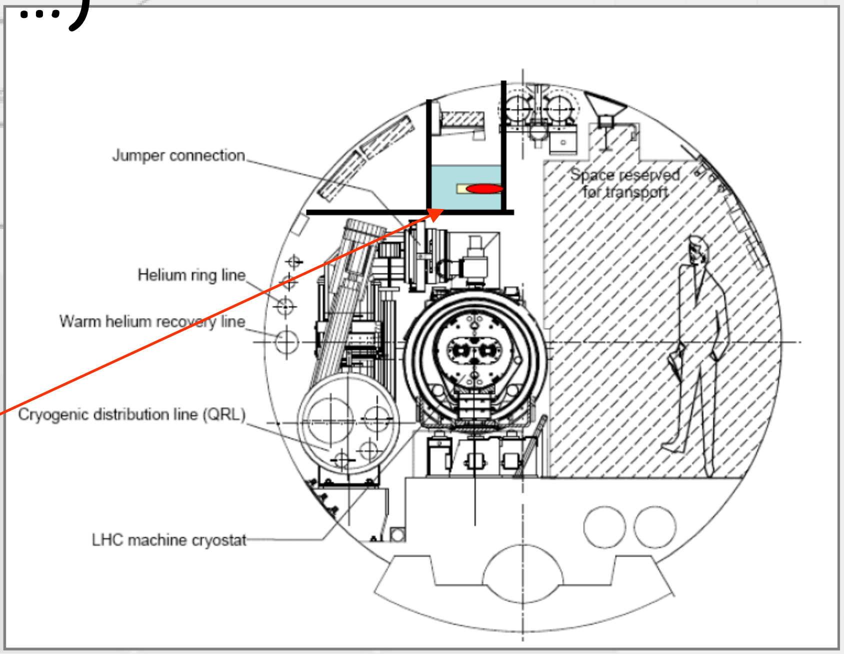
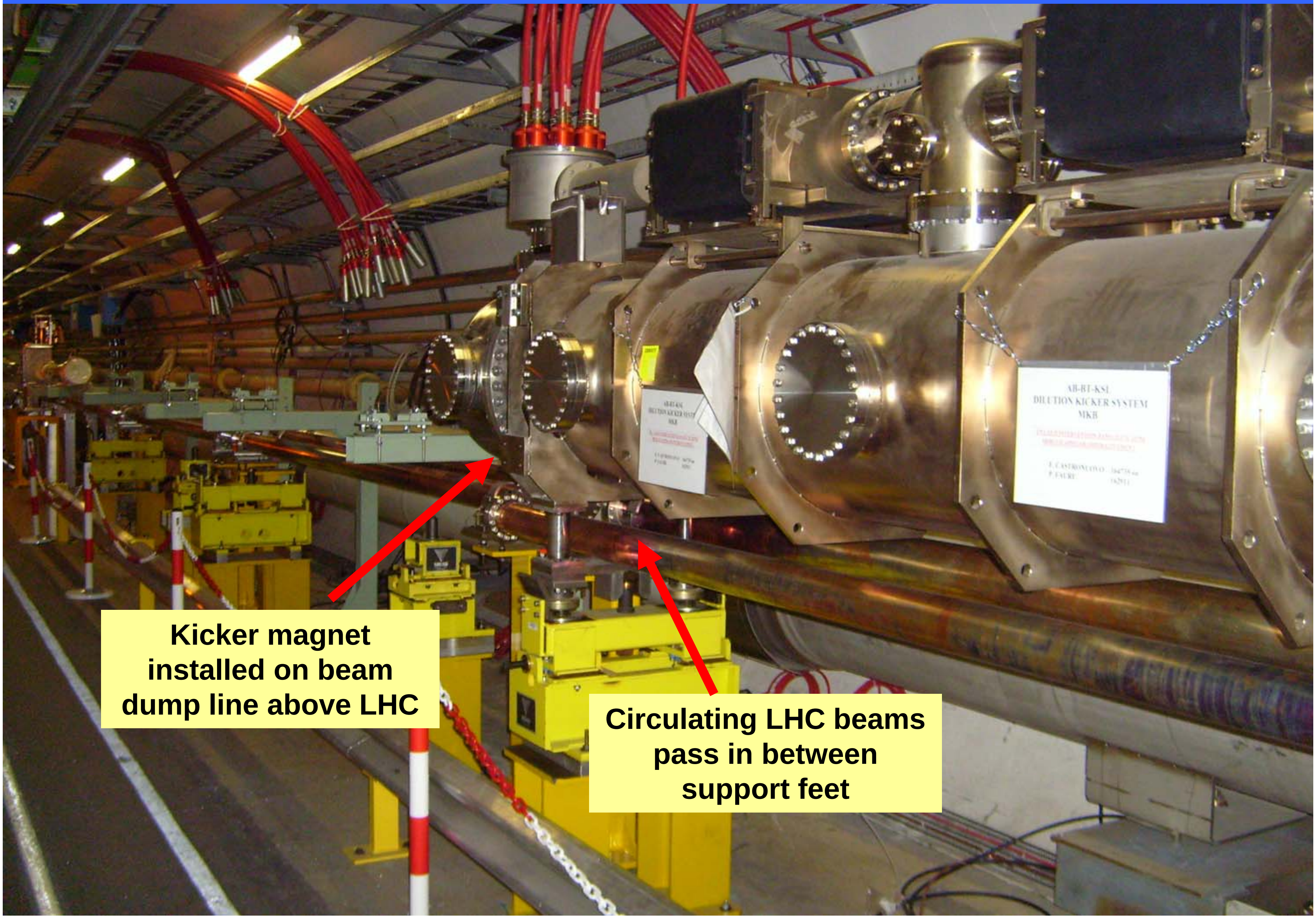
- power: 25 ns → nx40 MHz RF I < 100 mA
  60 klystrons @ 1.3MW, coupler 0.5MW, 66% effy
  extra RF in bypasses
- injection: 1.4×10^{10} *e* in 2800 bunches
  (LEP2 4×10^{11} in 4)
  energy < 20 GeV (ELFE, KEK …)
- SR → LHC magnets:
  water cooling+Pb
- bypasses: ATLAS CMS + RF
  → ~500m from arcs
  ~ -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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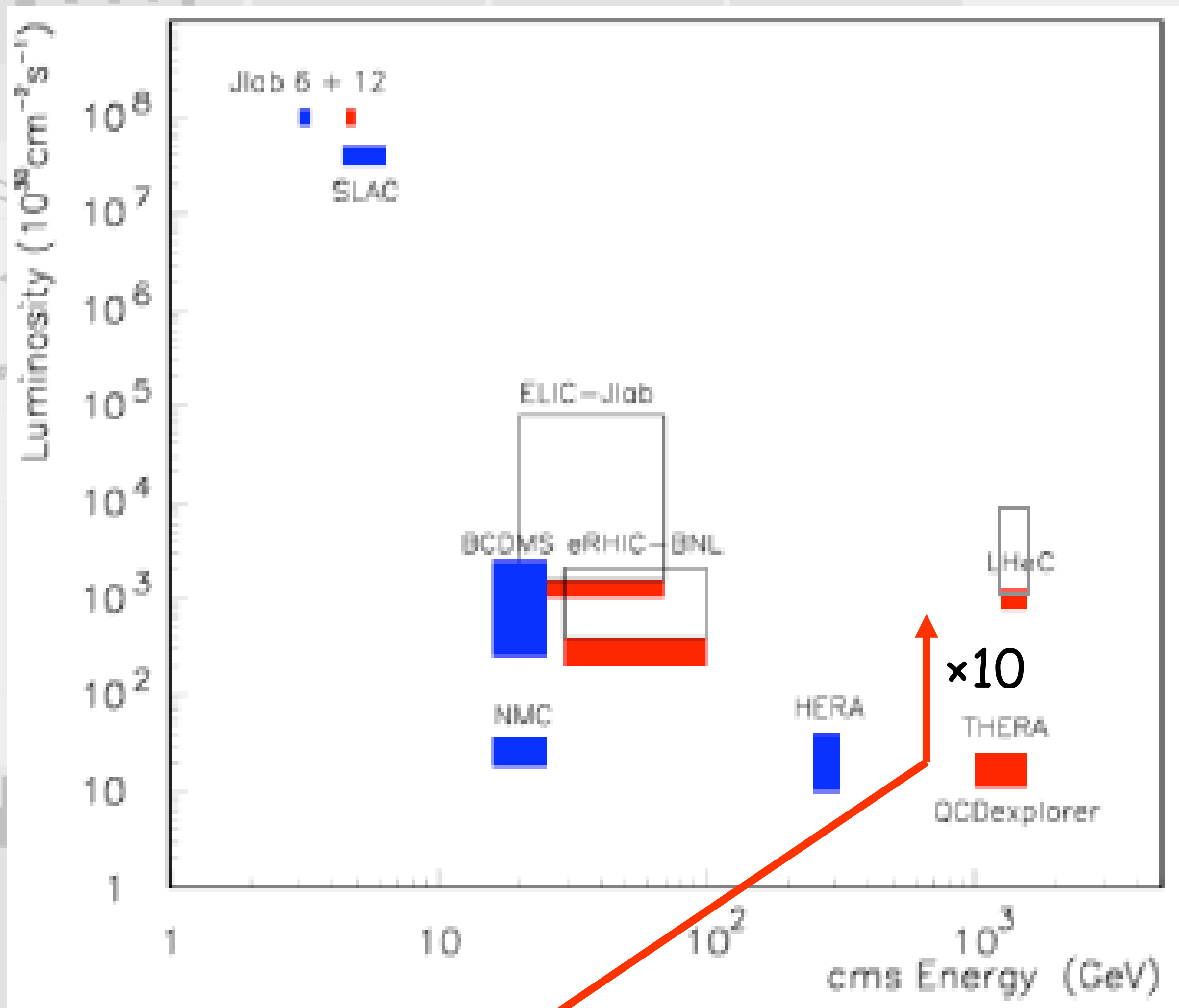
- astounding !
- ×10² L_{NMC} μp @ 0.01 fm
- L_{eRHIC} $e_{pol}p_{pol}$ eA @ 0.007 fm
- ×10² L_{HERA} $e_{pol}p$ @ 0.001 fm
- L_{LHeC} $e^{\pm}p$ eA @ 0.00014 fm



indisputably a next step ?

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e-linac + LHC

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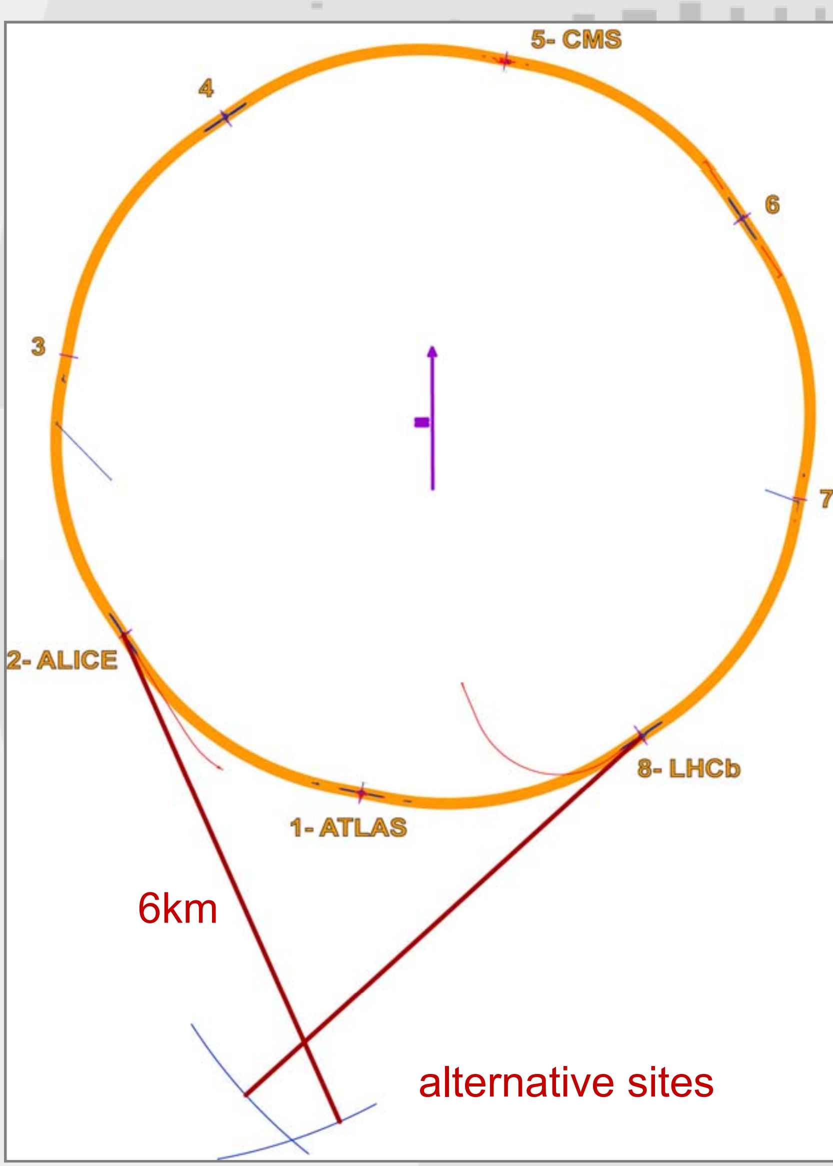


		ring-linac pulsed		ring-linac, cw, ~99% energy recovery	
	units	e-	p	e-	p
energy	GeV	70	7000	70	7000
punch population	10^{10}	2	17	2	17
σ_z	cm	0.03	7.55	0.03	7.55
beam current (pulsed)	mA	101	858	101	858
emittance $\varepsilon_{x,y}$	nm	0.5, 0.5			
$\beta^*_{x,y}$	cm	15, 15			
spacing	ns	25			
e-linac/ring 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.

Luminosity: Linac-Ring

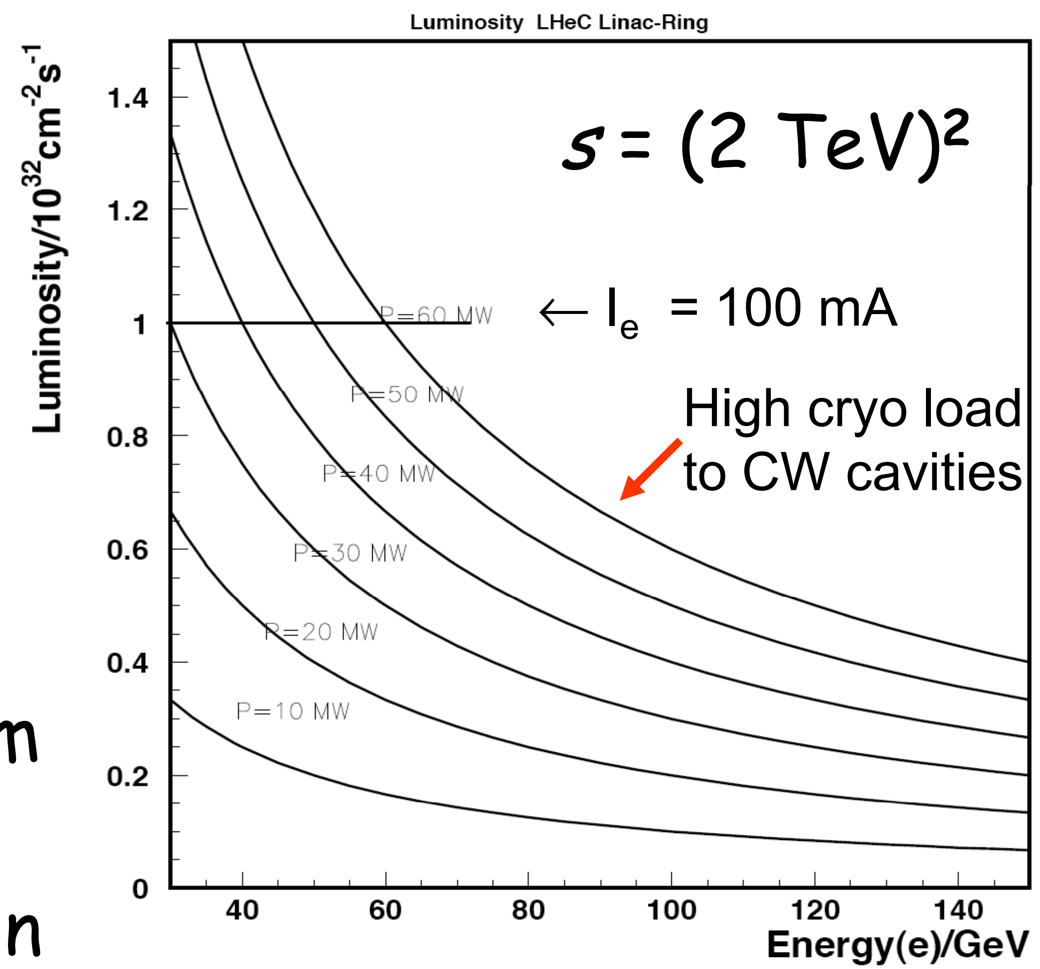
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 1 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1} \quad I_e = 100 mA \cdot \frac{P}{MW} \cdot \frac{GeV}{E_e}$$

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

$N_p = 1.7 \cdot 10^{11}$

$\beta^* = 0.15 m$

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



→ 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 ?

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eRHIC and ERL

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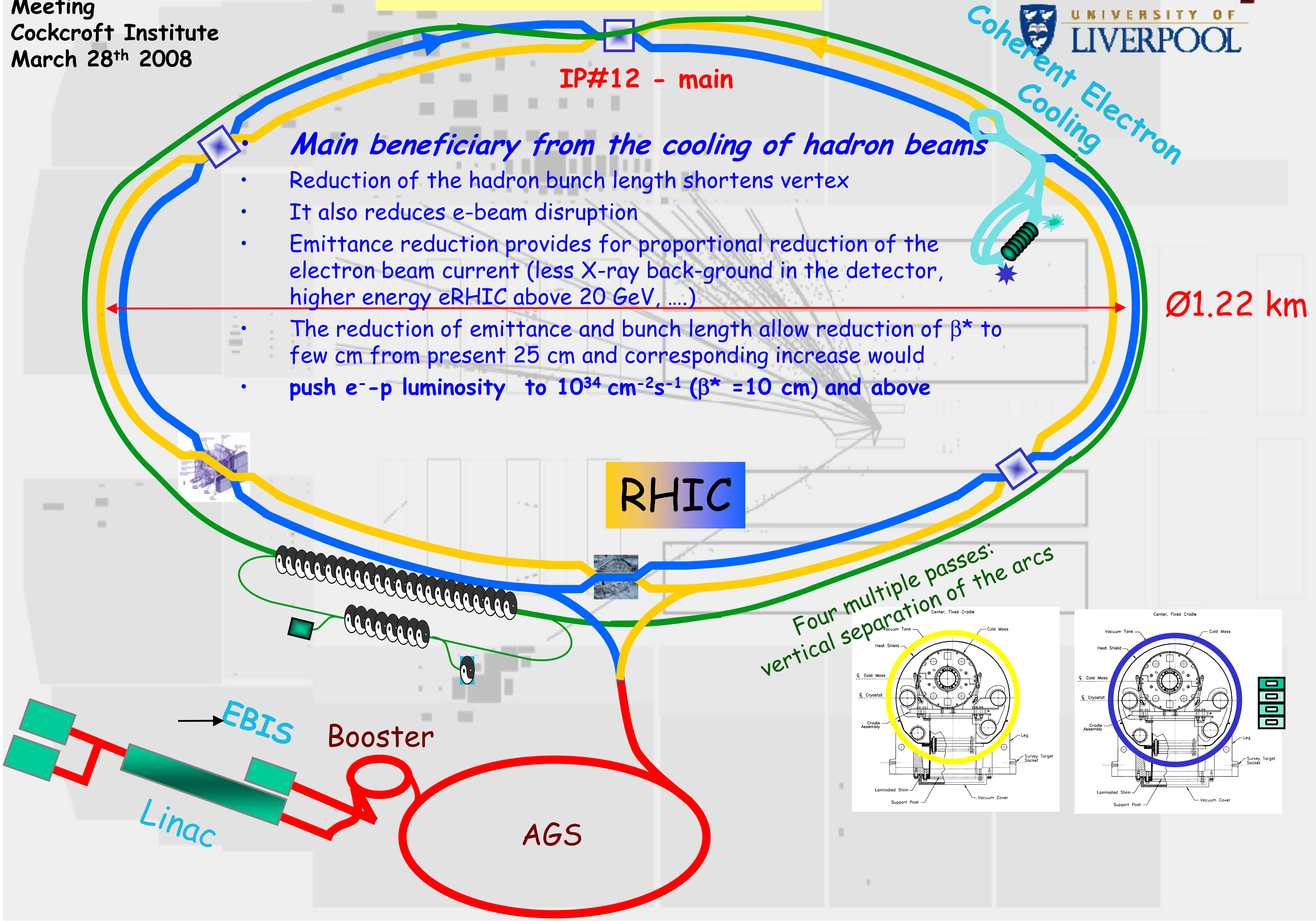
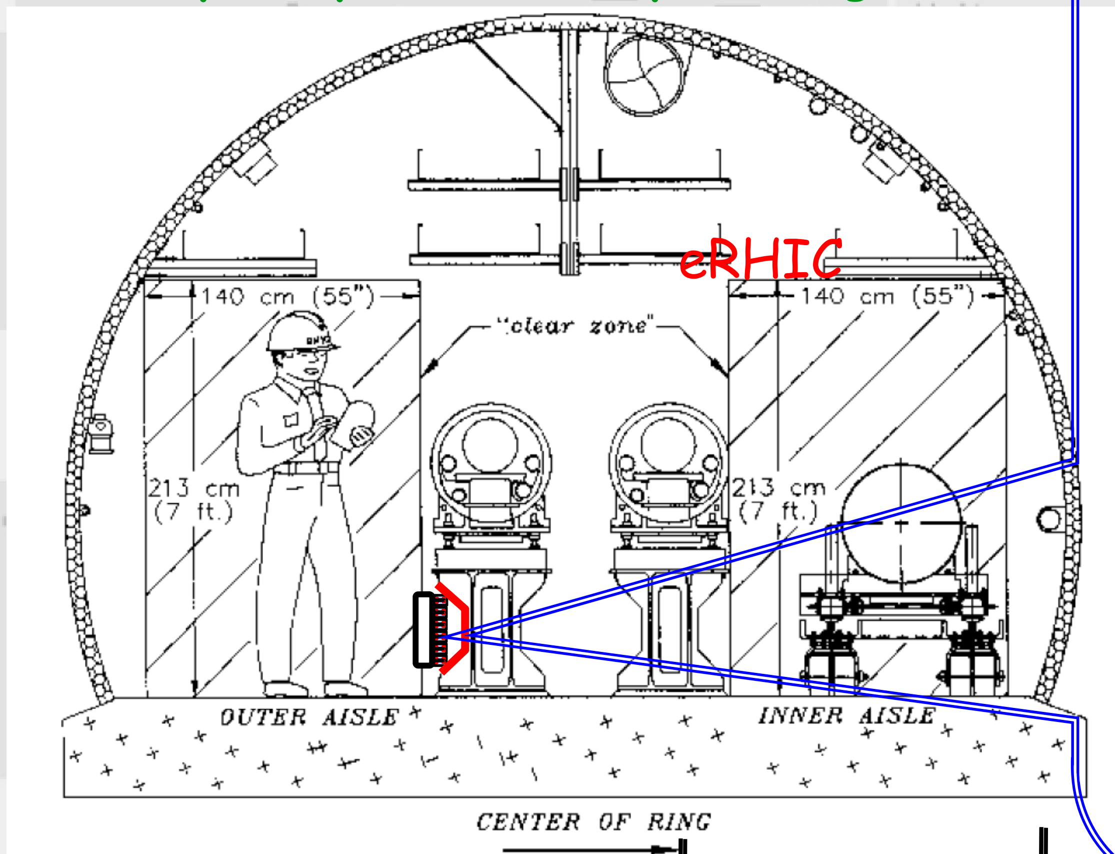
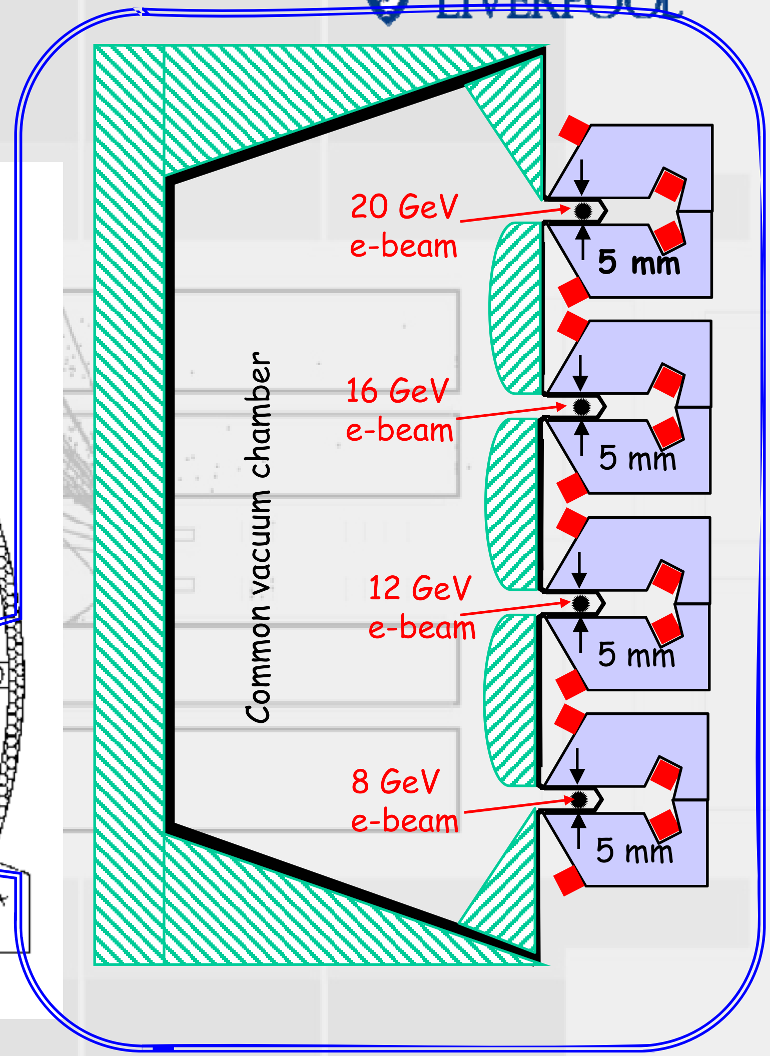


- ***Main beneficiary from the cooling of hadron beams***
- Reduction of the hadron bunch length shortens vertex
- It also reduces e-beam disruption
- Emittance reduction provides for proportional reduction of the electron beam current (less X-ray back-ground in the detector, higher energy eRHIC above 20 GeV, ….)
- The reduction of emittance and bunch length allow reduction of β* to few cm from present 25 cm and corresponding increase would
- **push e^--p luminosity to 10^{34} $cm^{-2}s^{-1}$ (β* =10 cm) and above**

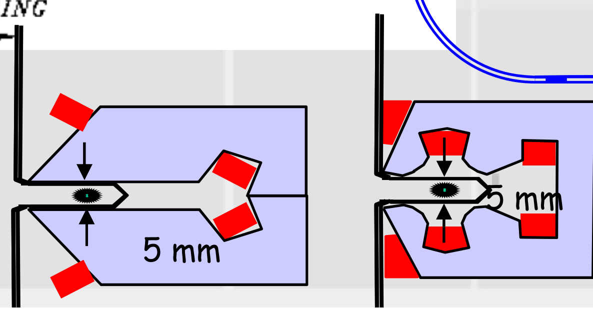
eRHIC loop magnets

- Small gap provides for low current
- Very low power consumption magnets





C- Dipole



C-Quad

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ERL spin transparency

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Bargman, Mitchel,Telegdi equation

$$\frac{d\hat{s}}{dt} = \frac{e}{mc}\hat{s}\times\left[\left(\frac{g}{2}-1+\frac{1}{\gamma}\right)\vec{B} - \frac{\gamma}{\gamma+1}\left(\frac{g}{2}-1\right)\hat{\beta}(\hat{\beta}\cdot\vec{B}) - \left(\frac{g}{2}-\frac{\gamma}{\gamma+1}\right)[\vec{\beta}\times\vec{E}]\right]$$

$$a = g/2 - 1 = 1.1596521884\cdot 10^{-3}$$

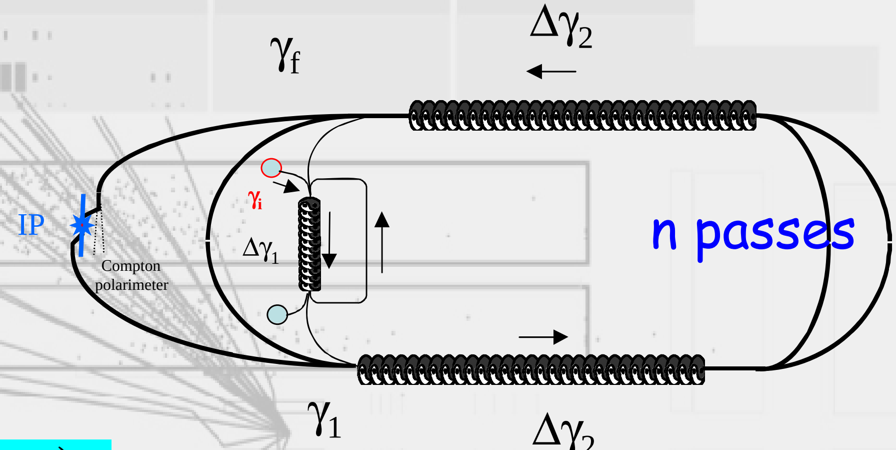
$$\hat{\mu} = \frac{g}{2}\frac{e}{m_o}\hat{s} = (1+a)\frac{e}{m_o}\hat{s}; \qquad \nu_{spin} = a\cdot\gamma = \frac{E_e}{0.44065[GeV]}$$

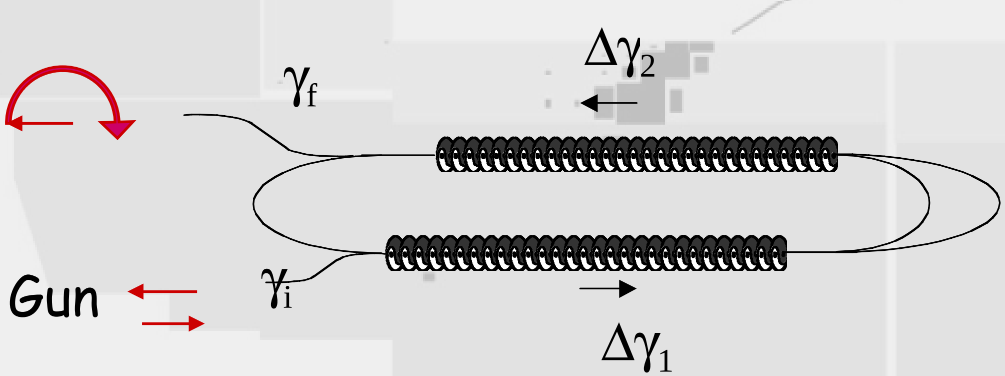
$$\Delta\varphi = a\cdot\gamma\theta$$

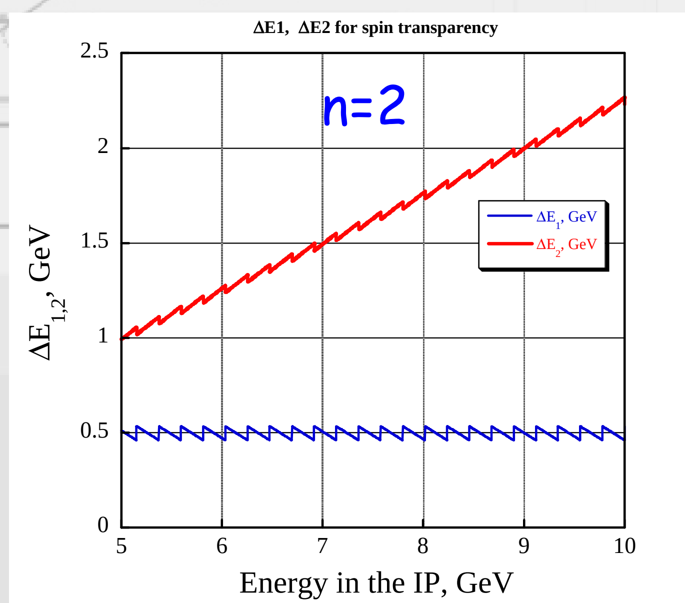
Total angle $\varphi = \pi a\cdot(\gamma_i(2n-1) + n(\Delta\gamma_1\cdot n + \Delta\gamma_2(n-1))$

Has solution for all energies!

$$\begin{cases} \gamma_i + 2\cdot(\Delta\gamma_1+\Delta\gamma_2) = \gamma_f \\ a\cdot(\gamma_i(2n-1) + n(\Delta\gamma_1\cdot n + \Delta\gamma_2(n-1)) = N \end{cases}$$







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Ring-Ring LHeC is limited by power of synchrotron radiation from the e-beam!

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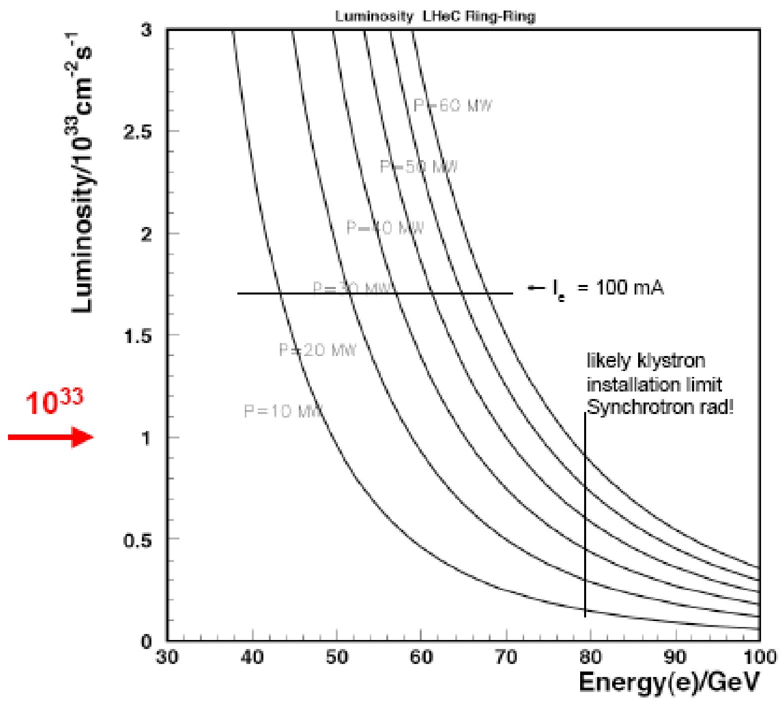
Luminosity: Ring-Ring

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

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



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

10^{33} can be reached in RR
E_e = 40-80 GeV & P = 5-60 MW.

HERA was 1-4 10^{31} cm^{-2} s^{-1}
huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region for 10^{33} : 50 MW, 70 GeV

May reach 10^{34} with ERL in bypasses, or/and reduce power.
R&D performed at BNL/eRHIC

cf also A.Verdier 1990, E.Keil 1986

M.Klein, ecfa07 talk

For linac-ring LHeC a pulsed linac with 0.5% duty factor (1 msec, 5 Hz) without energy recovery considered

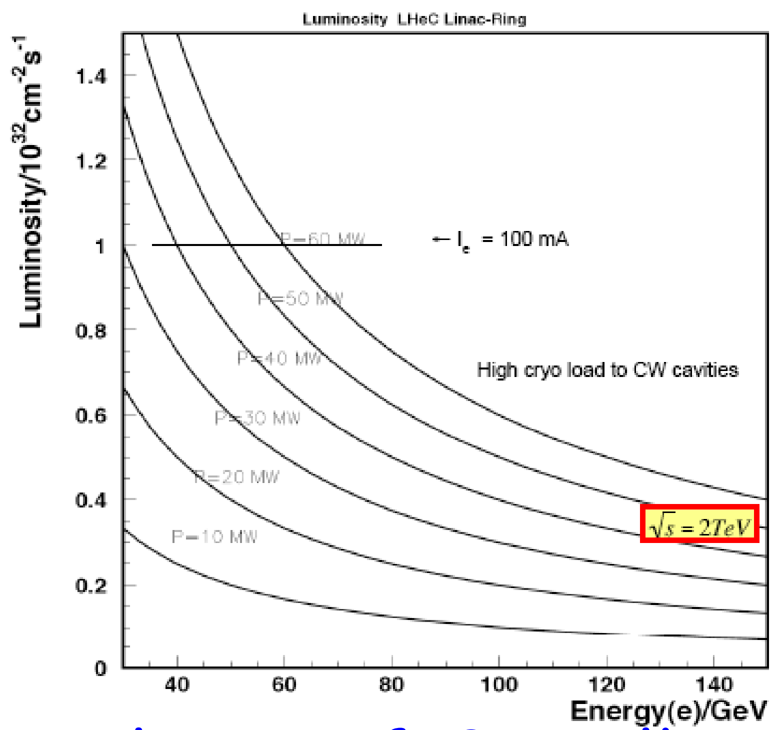
Luminosity: Linac-Ring

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

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

$N_p = 1.7 \cdot 10^{11}$

$\beta^* = 0.15 m$



$$I_e = 100 mA \cdot \frac{P}{MW} \cdot \frac{GeV}{E_e}$$

LHeC as Linac-Ring version can be as luminous as HERA II:

4 10^{31} can be reached with LR:
E_e = 40-140 GeV & P=20-60 MW
LR: average lumi close to peak

140 GeV at 23 MV/m is 6km +gaps

Luminosity horizon: high power:
ERL (2 Linacs?)

M.Klein, ecfa07 talk

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ERL based LHeC

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	Electrons	Protons Cooling/no Cooling
Energy	140 GeV	7 TeV
N per bunch	$0.088\ 10^{11}$	$1.7\ 10^{11}$
Rep rate, MHz	40	
Beam current, mA	5.6	1090
Norm emittance, μm	6	0.3 / 3.8
β*, m	1.3	0.5
ξ* D	6.3 *.14*	**0.0006/ 0.0001**
Luminosity, x 10^{34} cm^{-2} sec^{-1}	**0.24 / 0.06**	
Loss for SR, MW	67	Kink Λ=0.03

Hard radiation may be a problem

ERL based LHeC

- Luminosity $3{\cdot}10^{34}$ cm^{-2} sec^{-1} at all energies of e-beam (probably will be limited by burn-off of the proton beam)
  Or "ring-ring" luminosity of 10^{33} cm^{-2} sec^{-1} with 3 mA electron beam current and 2.2 MW loss for SR
- e-beam current is low (because of the cooling!)
- If further reduction of β* is possible, L~ 10^{35} is feasible
- Higher energies of electrons are possible
- e-Beams with very low emittance are possible -> larger β* for electron - easier optics, longer detectors, less synch modulation effects….
- 140 GeV, 5 mA e-beam and luminosity of $4{\cdot}10^{33}$ cm^{-2} sec^{-1}
- Tiny beam pipe to "thru-pass" pp IR regions ?

Low *e*-current

$$\xi_p = \frac{N_e}{\gamma_p} \cdot \frac{r_p}{4\pi\varepsilon_p} = \frac{N_e \cdot r_p}{4\pi\varepsilon_{p\ norm}};$$

- Normalized emittance of electrons ~ 3 μm is possible - no problems to match the proton beam
- @ 100 GeV, γ_e=2 10^5 ~ 300 γ_p , i.e. proton normalized emittance can be as low a 0.01 μm
- $N_e \sim \varepsilon_{norm}$
- ~ ε_{norm} : 3.8μm -> 0.1μm : N_e=4 10^9
- I_e= 20 mA, SR_{loss}=57 MW (the same as Ring-Ring with 100 x luminosity!)

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Other considerations

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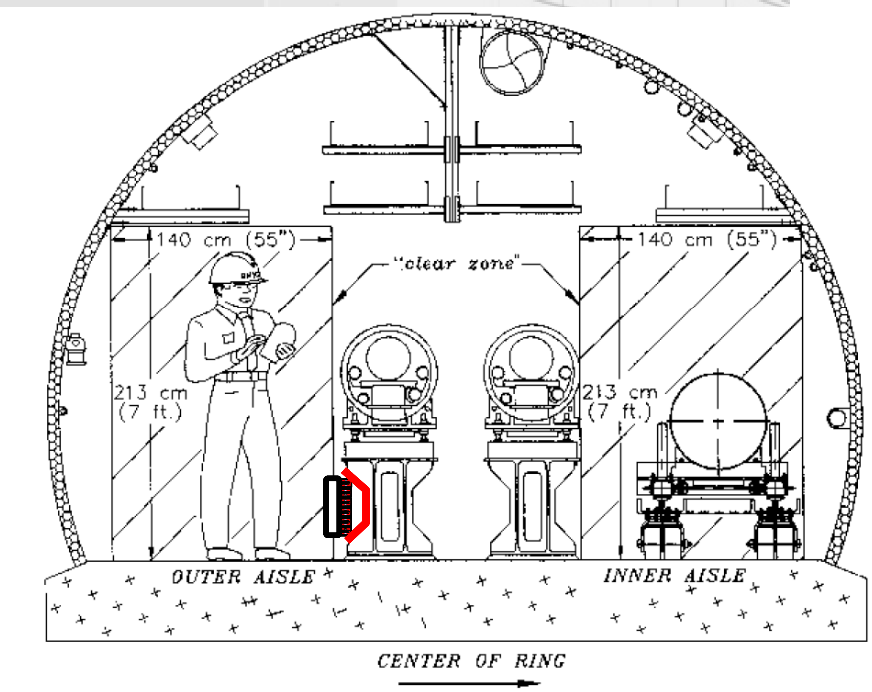
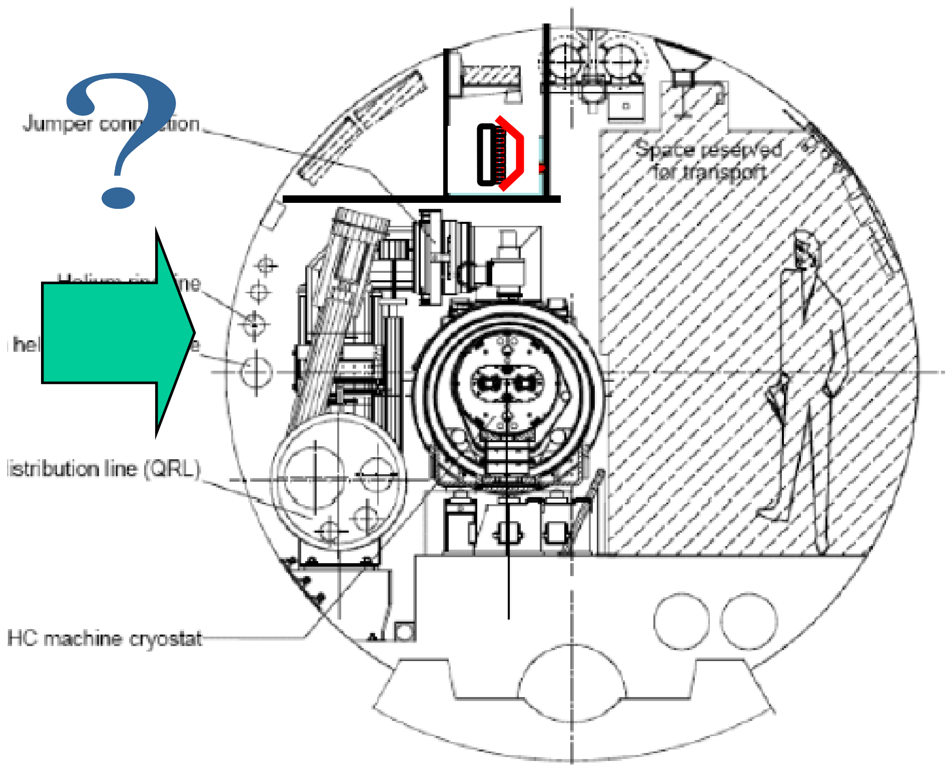
- May (for the most part) fit inside the LHC tunnel.

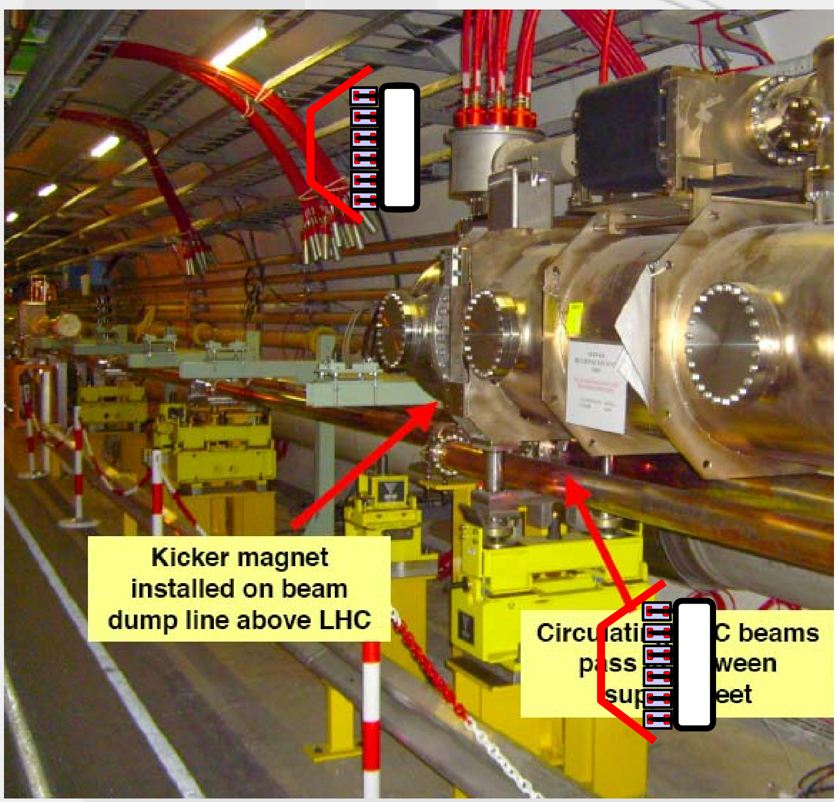


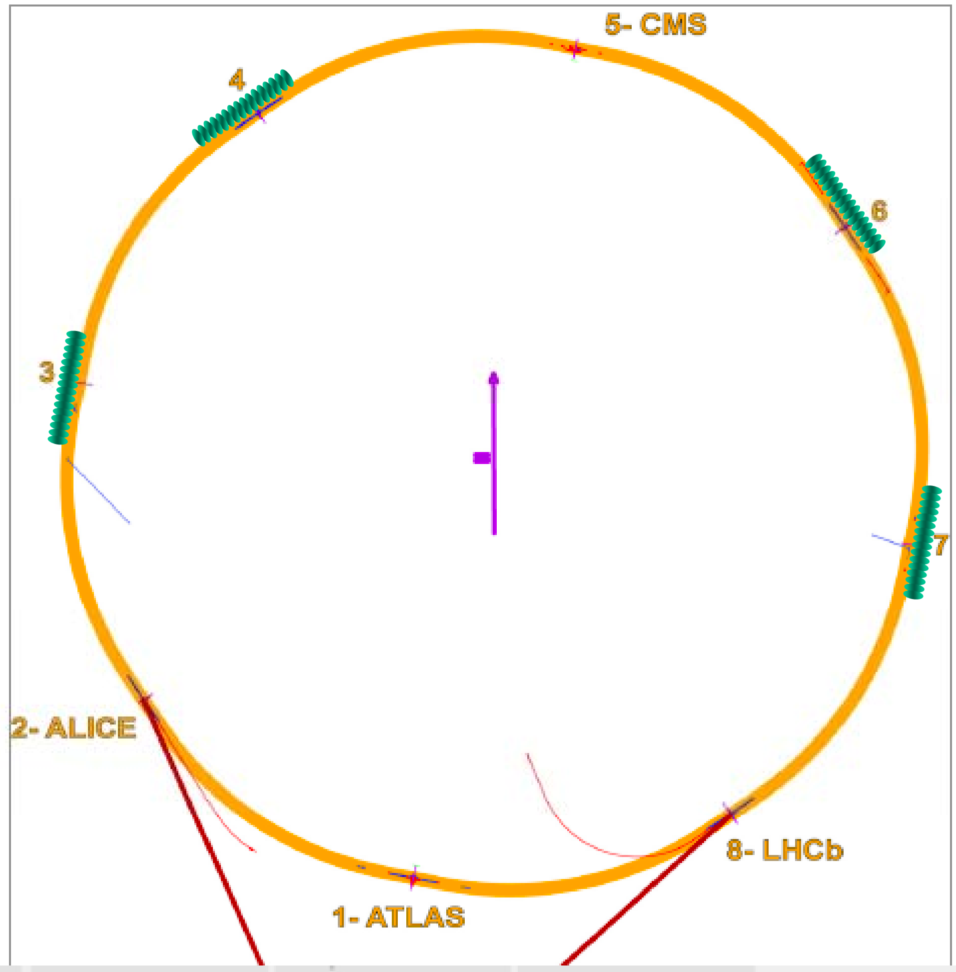


- Tiny *e* beam pipe to thru-pass *pp* IRs ?

Other considerations

- Is there room for linac in the straights?





Conclusions: ERL

- ERL seems to be the most promising approach for high energy, high luminosity electron-ion and polarized electron-proton collider
- It can take advantage of any ring-ring concept and go further
- Presently there is no show-stoppers but a significant amount of R&D
- At BNL the R&D ERL tests in 2009, MIT's progress with developing high current polarized gun, prototyping of small gap magnets will next step-stones towards QCD factory at BNL.
- LHeC based on this principle reach 10^{34}-10^{35} level of luminosity

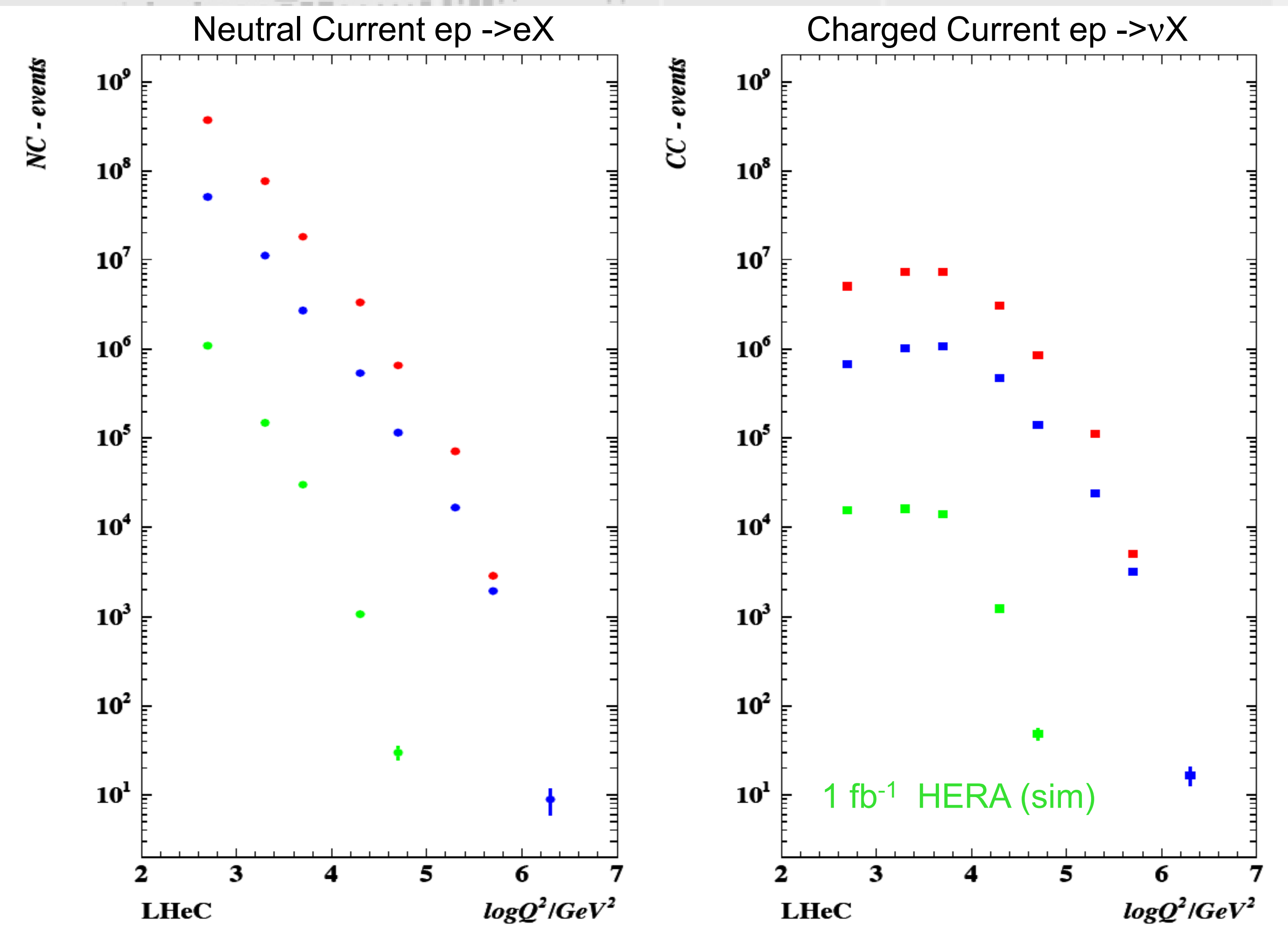
4. Experiment

Sensitivity

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

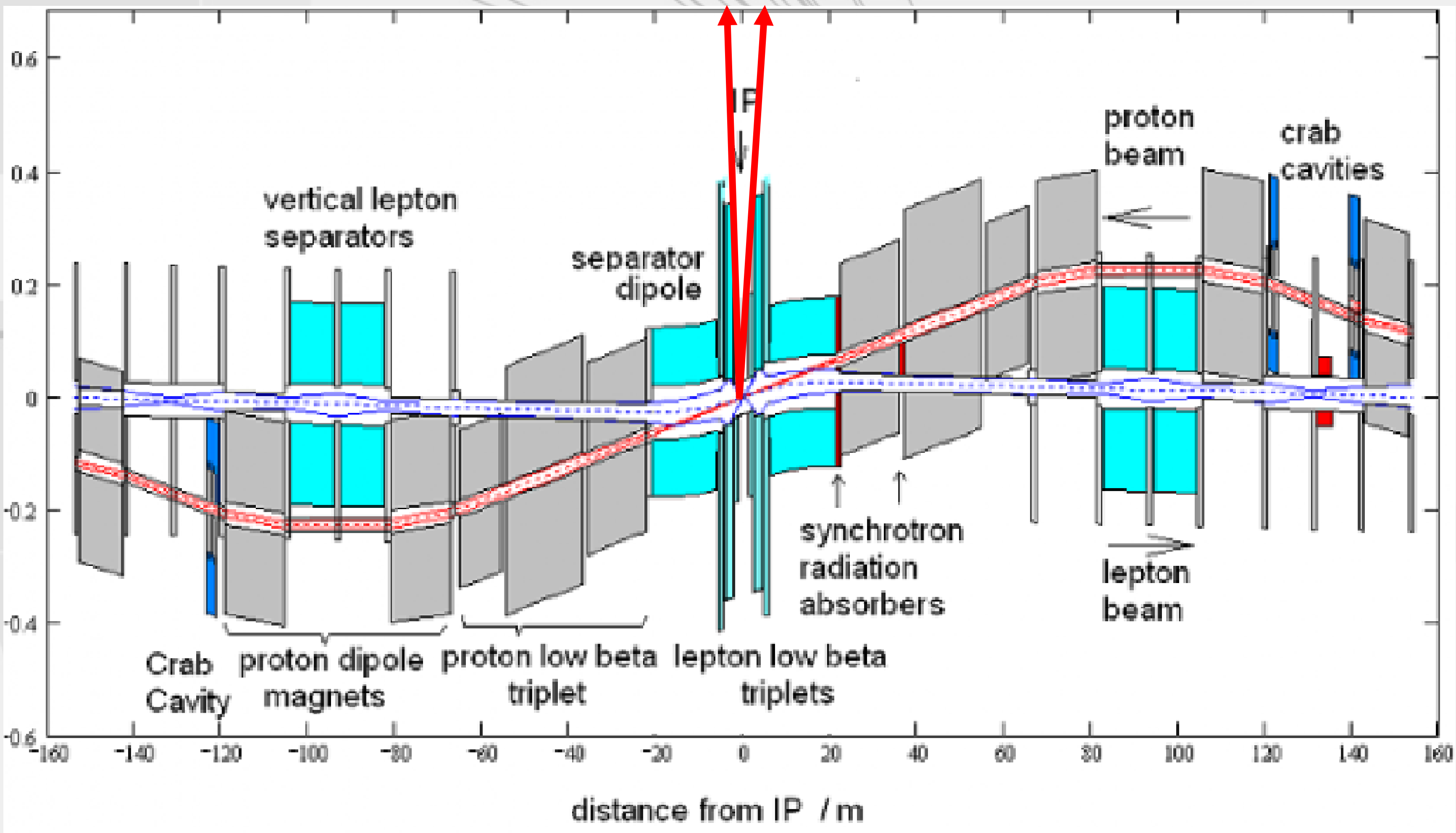
100 fb^{-1} 70 GeV *e*-ring

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



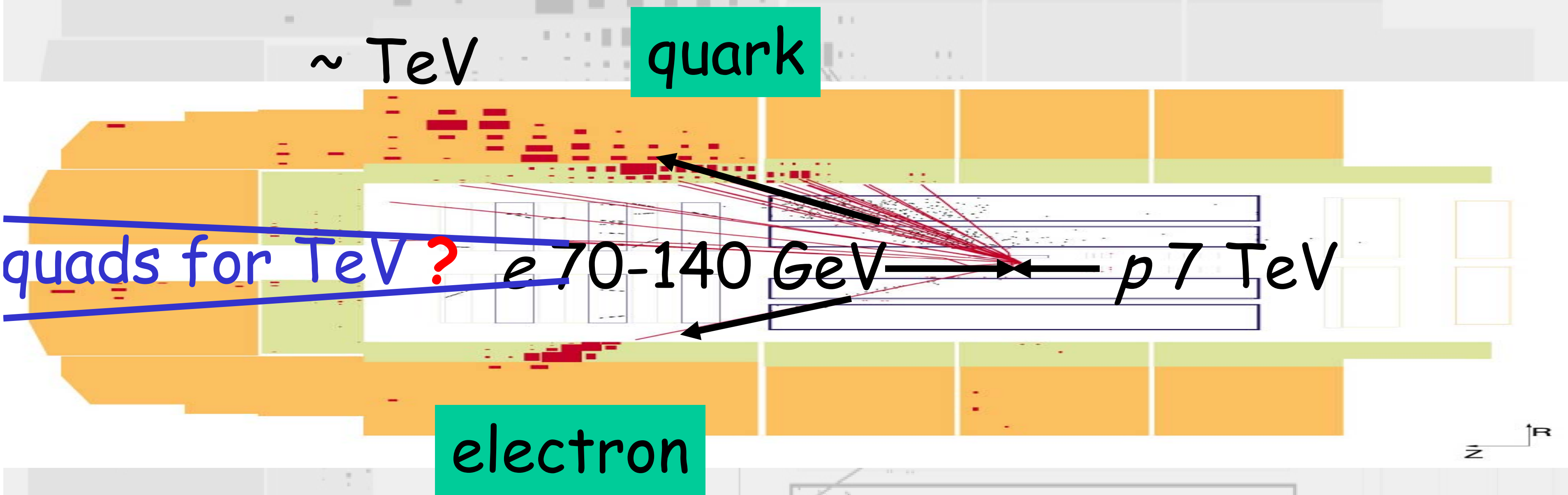
IR and Experiment

- IR ±many m
- IR ≥9.4° around beam



Asymmetric Collider

- asymmetric beam momenta: LH*e*C



- "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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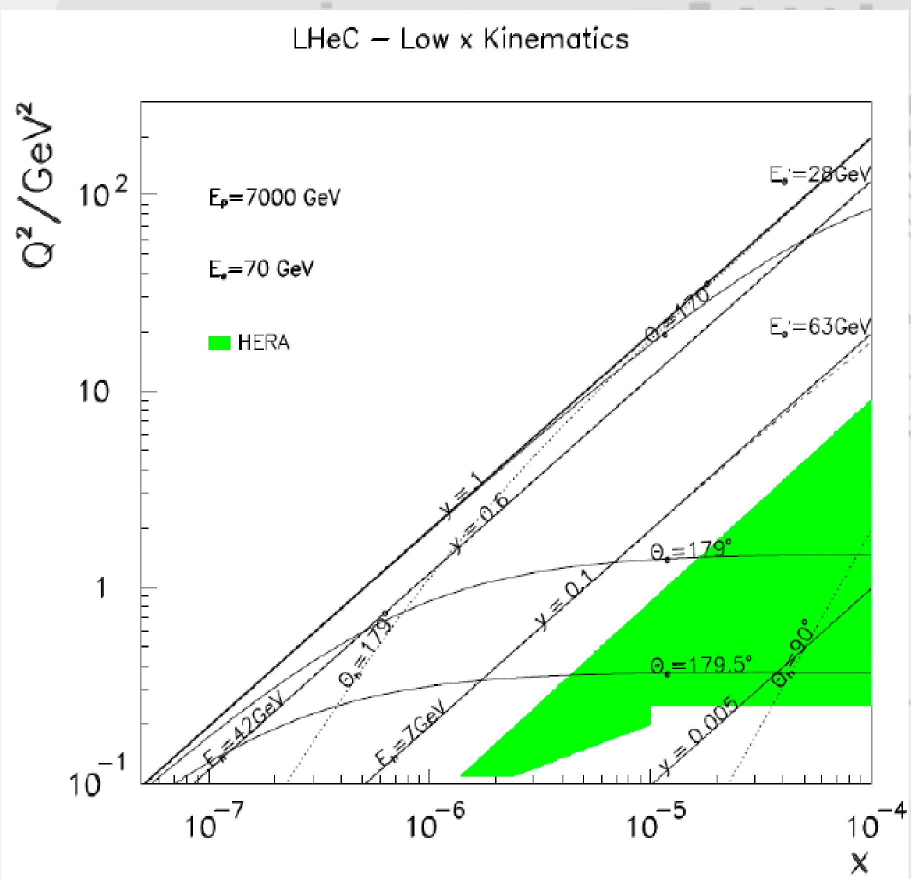

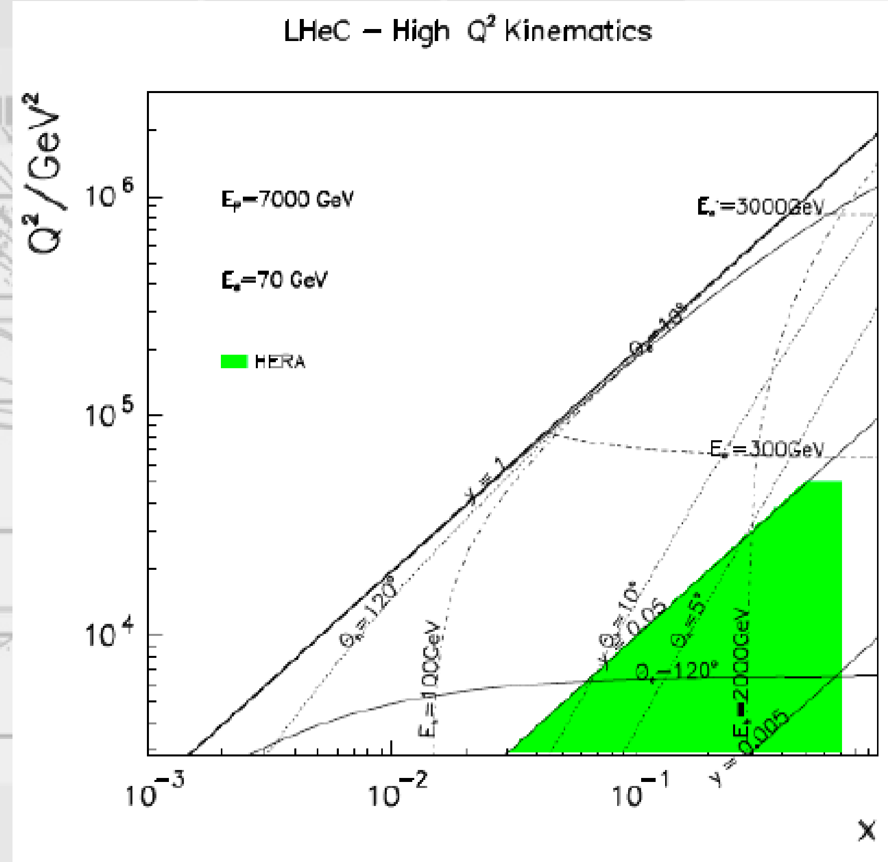

- backward e
- forward remnant 1_c
- forward TeV hadrons

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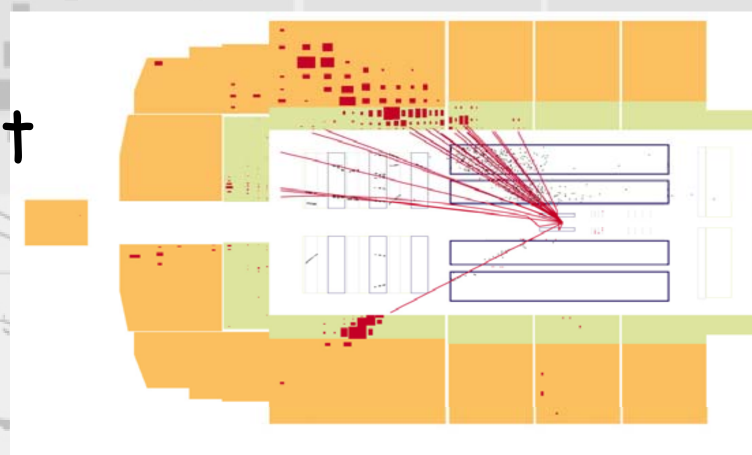
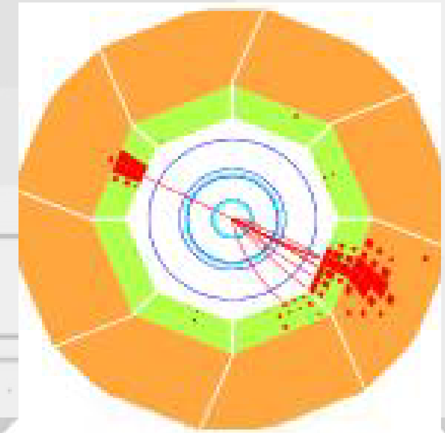
ep is precision @ every scale

- Neutral Current

  $ep \rightarrow eX$

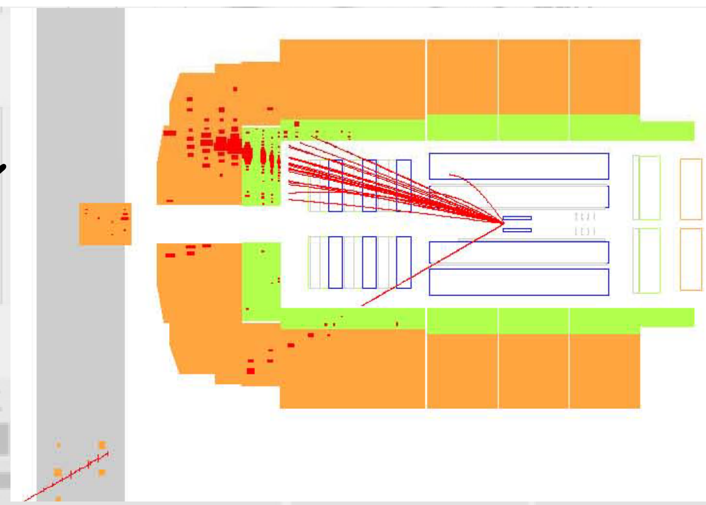
  ~~p_{Tmiss}~~

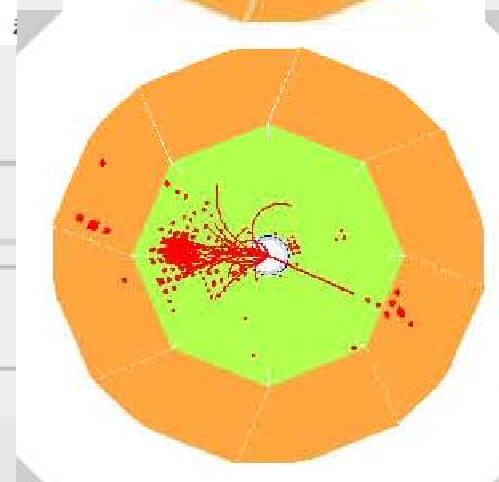




- $ep \rightarrow ?+\text{lepton}+X$

  p_{Tmiss} + lepton





- precision @ TeV scale of lepton+quark

  $eq \; \nu q \; \tau q$ 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 September 8+9 Divonne CH
- 2009: workshop II
  LHeC CDR [LHC Committee]
- 2011: LHeC 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.

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LHeC Scientific Advisory Committee

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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)

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

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4. Summary

Now

- LHeC $70\text{-}140_e \otimes 7000_p$ GeV
  - can be built
  - has startlingly good luminosity ≥ 10^{34} $cm^{-2}s^{-1}$
    grows with LHC *pp* luminosity
  - extends substantially, uniquely, and with synergy to LHC_{TeV} discovery physics
  - probes chromodynamics
    @ new density frontier
    in uniquely comprehensive manner *ep eA*
    with unchallengable precision
    synergetically with LHC *pp pA AA*

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Proposal to ECFA

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As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms syst[illegible] It accesses high parton densities 'beyond' what is expec[illegible] the unitarity limit. Its physics is thus fundamental and[illegible] be further worked out, also with respect to the fin[illegible] LHC and the final results both from the Tevatron ar[illegible].

First considerations [illegible]**ng and a linac-ring accelerator layout lead to a**[illegible]**ted combination of energy and luminosity for** [illegible]**on physics,** exploiting the latest developments i[illegible] and detector technology.

It is thus pr[illegible] **to hold two workshops (2008 and 2009), under the auspic**[illegible] **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

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Lepton + quark @ TeV

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- energy for
  - TeV *eq* discovery
  - extreme chromodynamics

LHeC and LHC

- precision for
  - TeV *eq* discovery
  - *eq* understanding
  - extreme chromodynamics

LHeC and ILC/CLIC

- luminosity for
  - TeV *eq* discovery

LHeC and LHC

- energy range for
  - QCD phase equilibria

LHeC RHIC FT LHC

Extras

Lepton Ring

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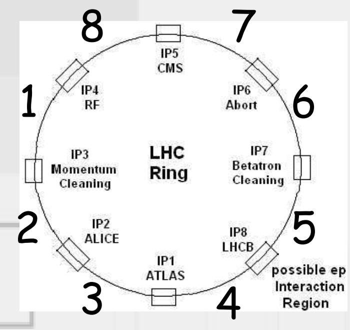

- in LEP tunnel … so like LEP
  - FODO in eight arcs
    β-tron phase advance φ_H=108° φ_V=90°
  - bending radius 3133.3 m
  - $(\delta E/E_{beam})_{rms} = 1.1\times10^{-3}$
  - SR 26 W/cm (E_c=254 KeV)
  - scRF @ 1GHz resonators @ 12 MV/m
    100 m structure = 670 cells
    - sync. phase 31°
    - bucket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

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Interaction Region

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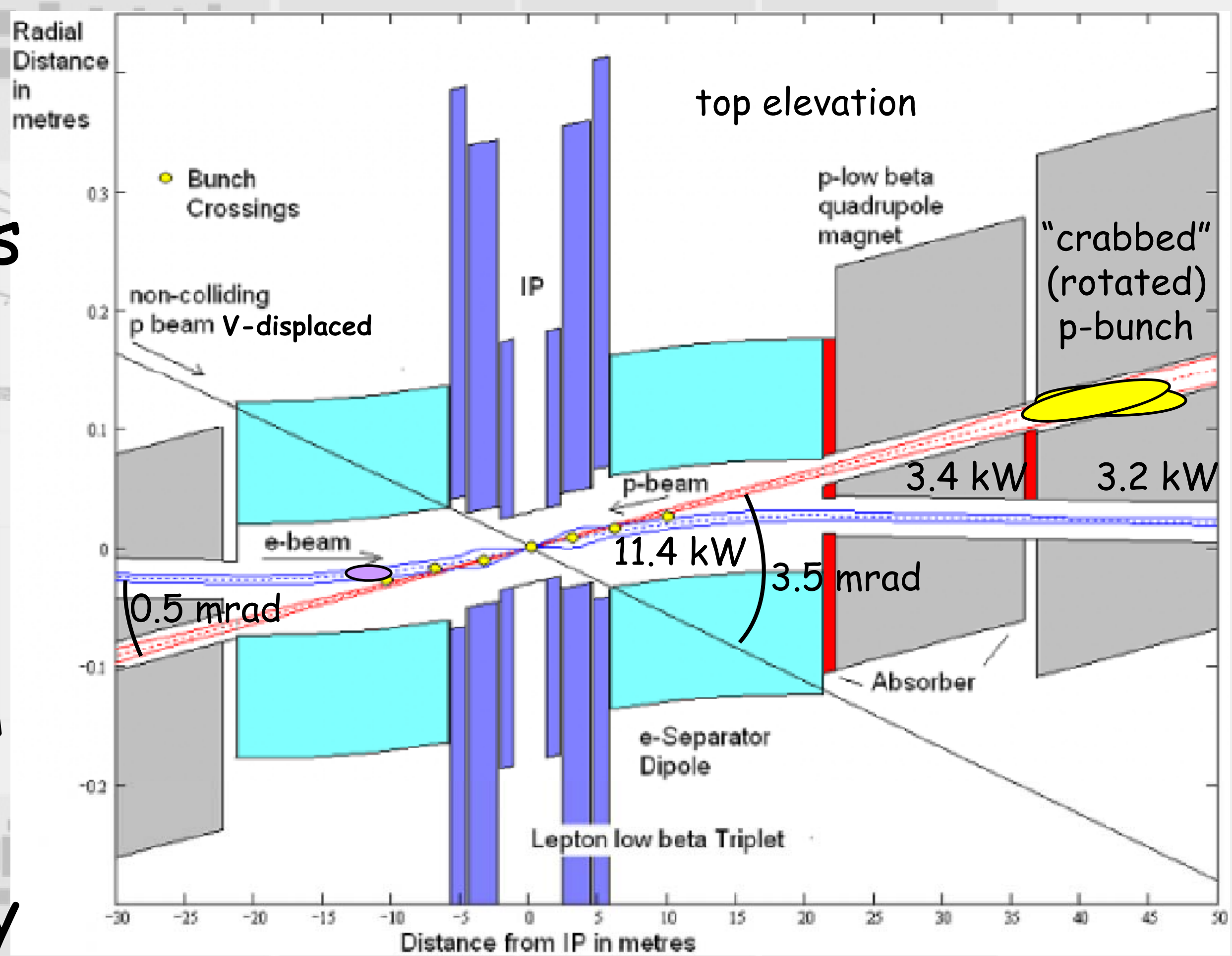
- highest lumi
  - low β_e
    - close sc quads
  - low X-ing angle
    - "hard" bend
    - 8σ beam sep^{n}
  - SR fan
    - □ sc *p*-beam « HERA
  - "crab" RF cavity *p*-bunch rotation
- 1° beam access = low-lumi/low-*x* option (cf HERA)



Operational Luminosity

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

↳ operational luminosity

I_e= 74mA, N_p= 1.68 10^{11}, γ_p = 7460, ϵ_p= 0.5 nm

ϵ_{xe}= 25 nm, ϵ_{ye} = 5 nm and $R = 0.89$

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

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Polarisation @ LHeC

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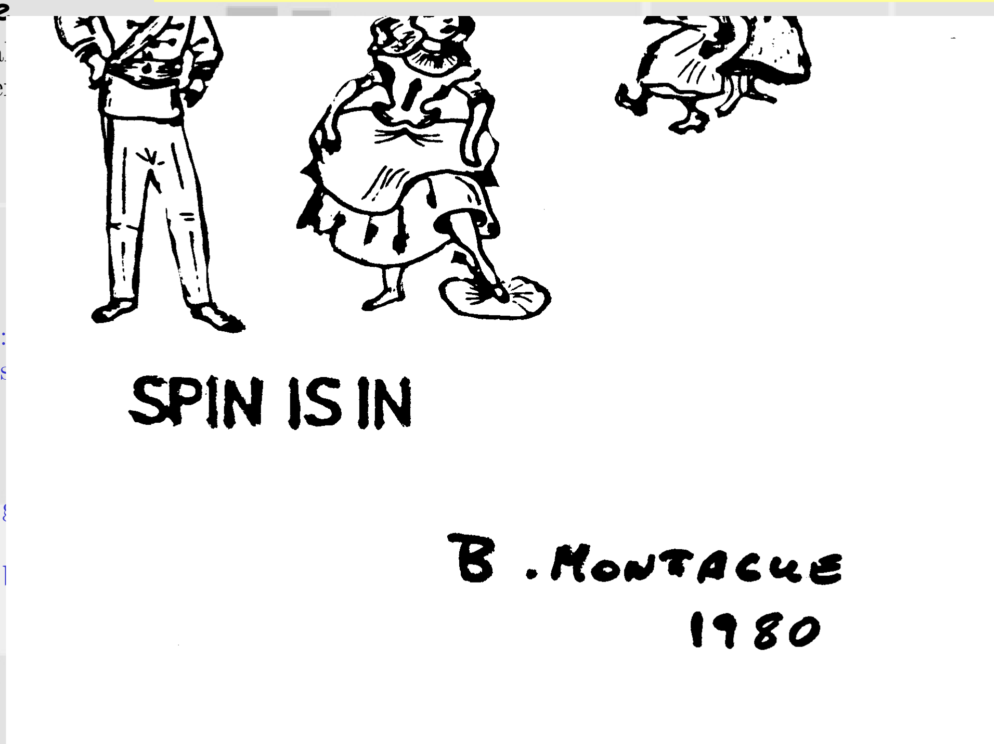
Barber

Recall ... well under...



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:

- Need very good alignment — better than at LEP.

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

- Siberian Snakes to suppress the effect of energy spread and synchrotron motion on spin motion?
- Overall, roughly at each energy:

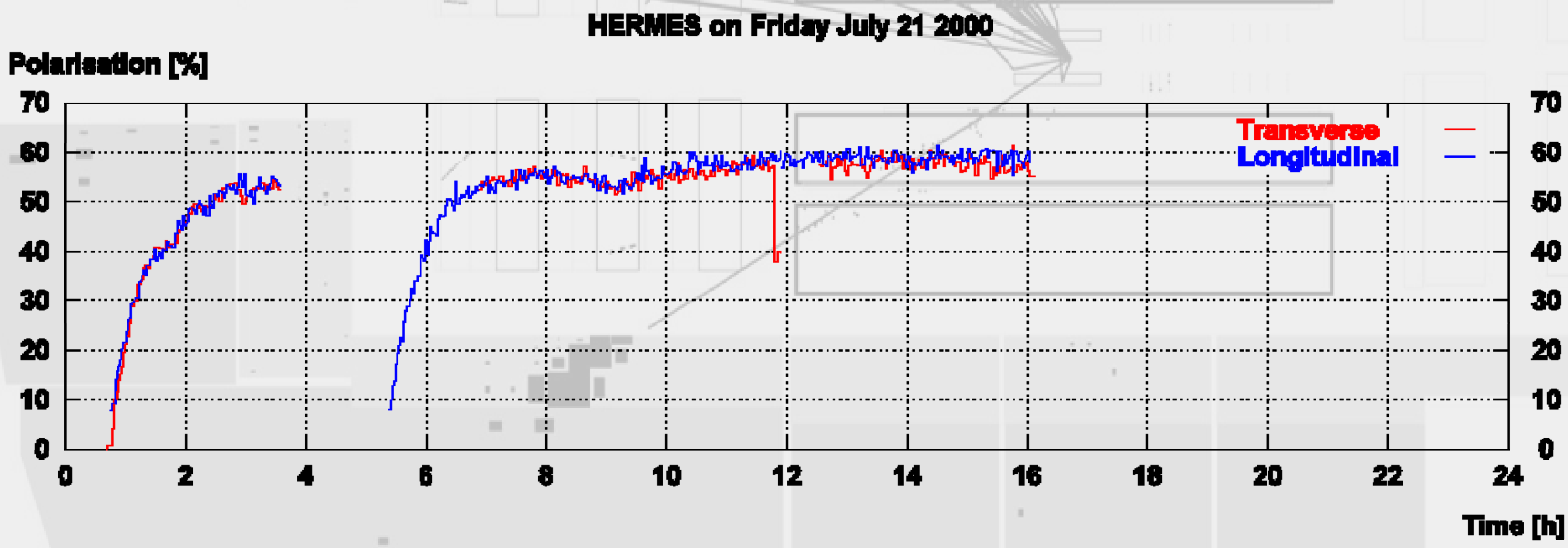
These are essential in proton rings to suppress depolarising resonances during acceleration (e.g., RHIC).

$\tau_{dep}^{-1} \propto$ (a polynomial in ξ^N) $\times\, \tau_{st}^{-1}$

- But in electron rings they kill the S-T effect if the synchrotron radiation is evenly distributed around the ring!!!
- But longitudinal polarization at the IP: the polarization vector must be rotated into the longitudinal direction before an IP and back to the vertical afterwards ===> spin rotators.
- Depolarization can be strongly enhanced by misalignments, regions where the polarization is not vertical, spin rotators etc, etc.....
- Can an arrangement be found based on a normal snake layout combined with the synchrotron radiation from bends?

What's been achieved

- Sokolov-Ternov + spin-rotators @ HERA



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What's been achieved

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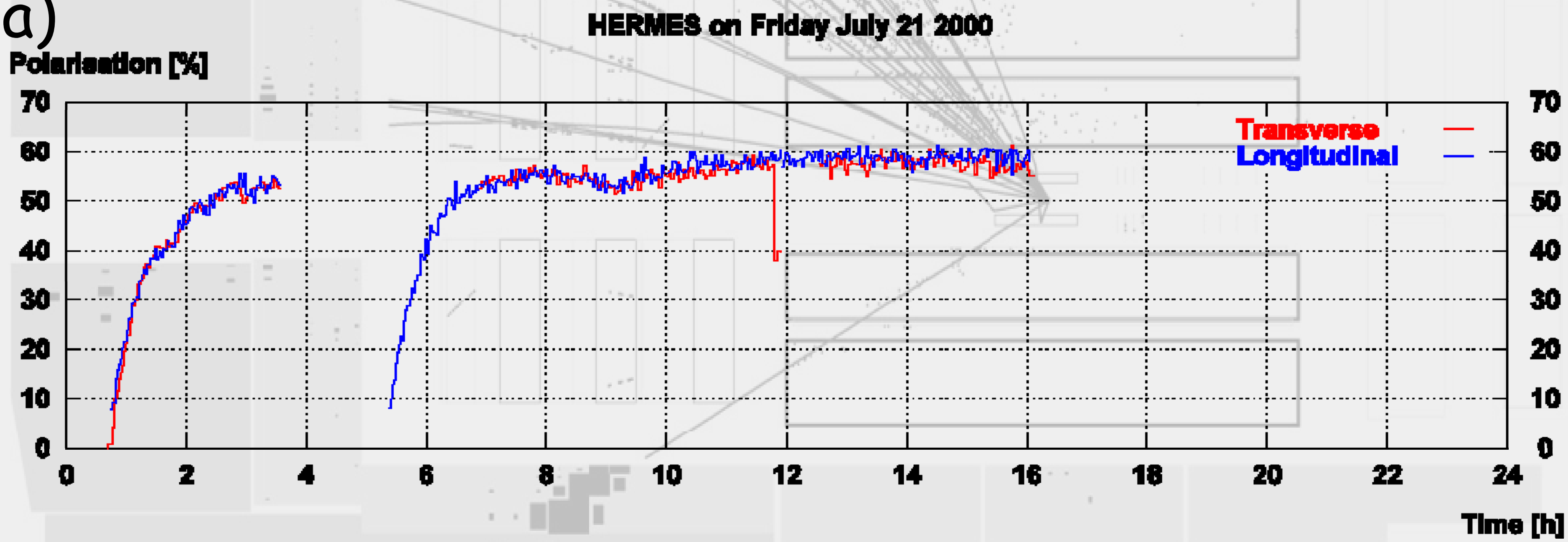
a)



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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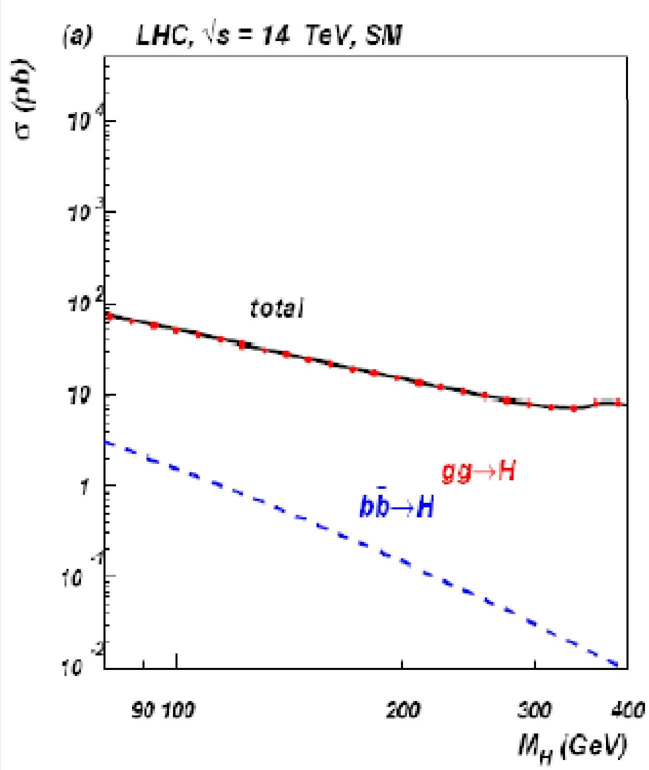
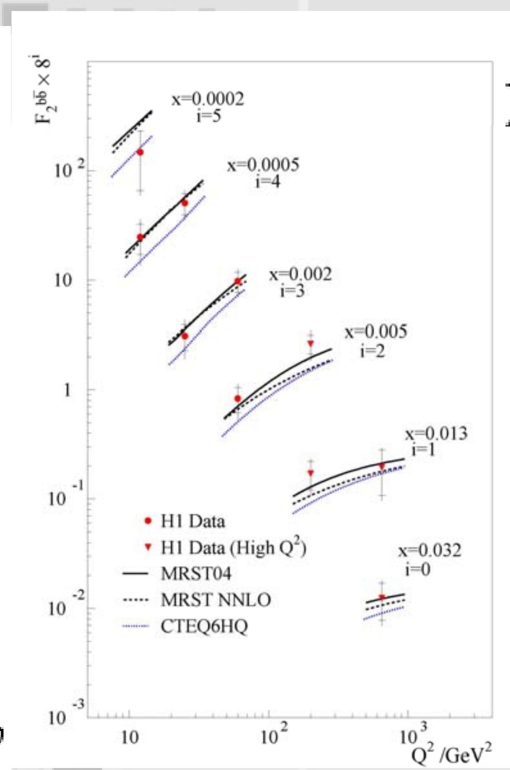
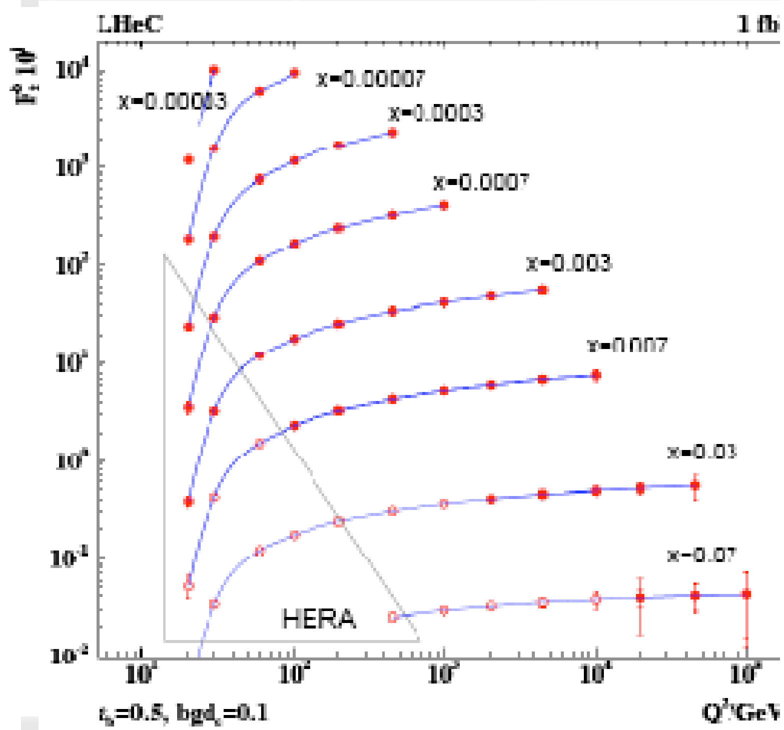
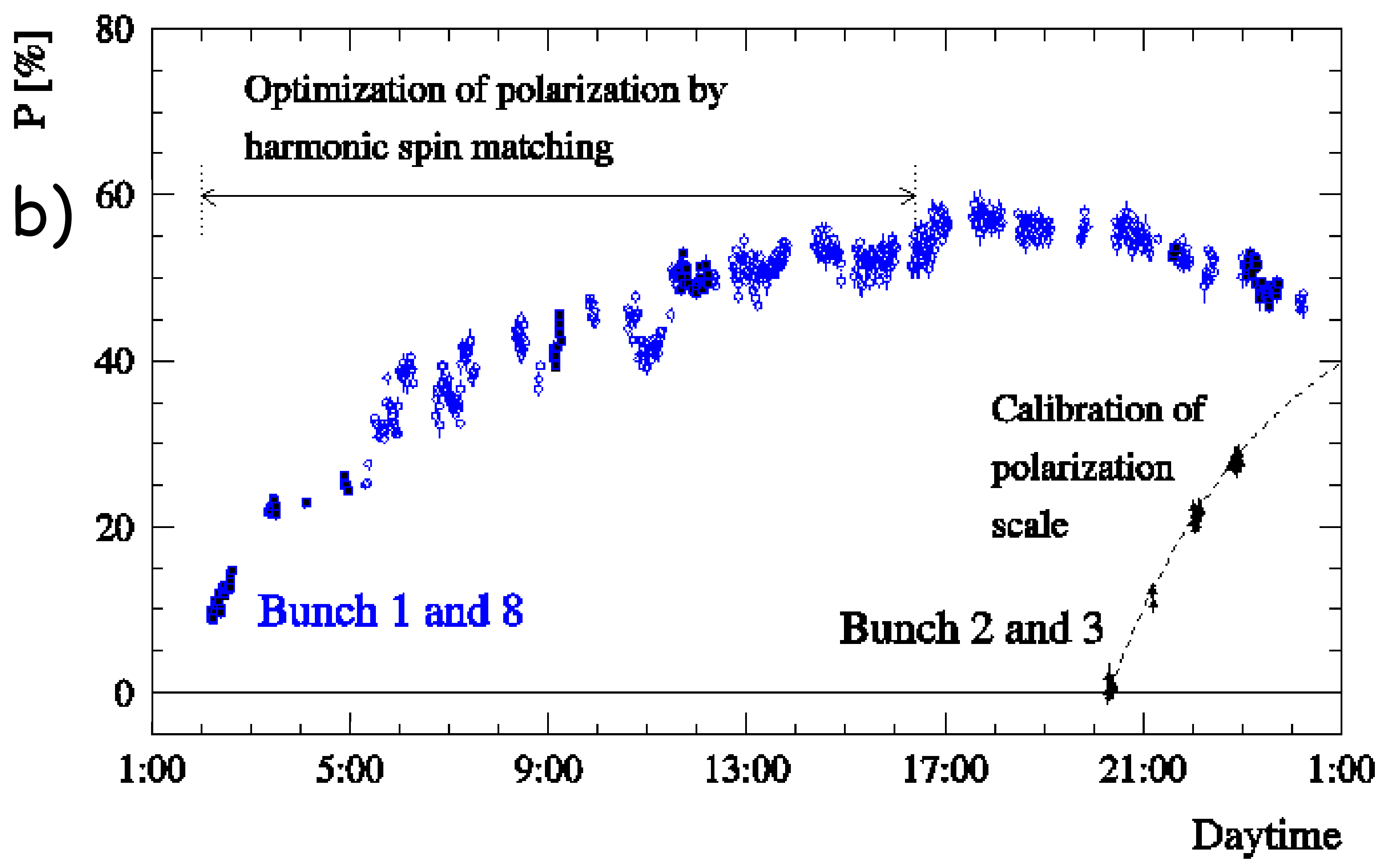






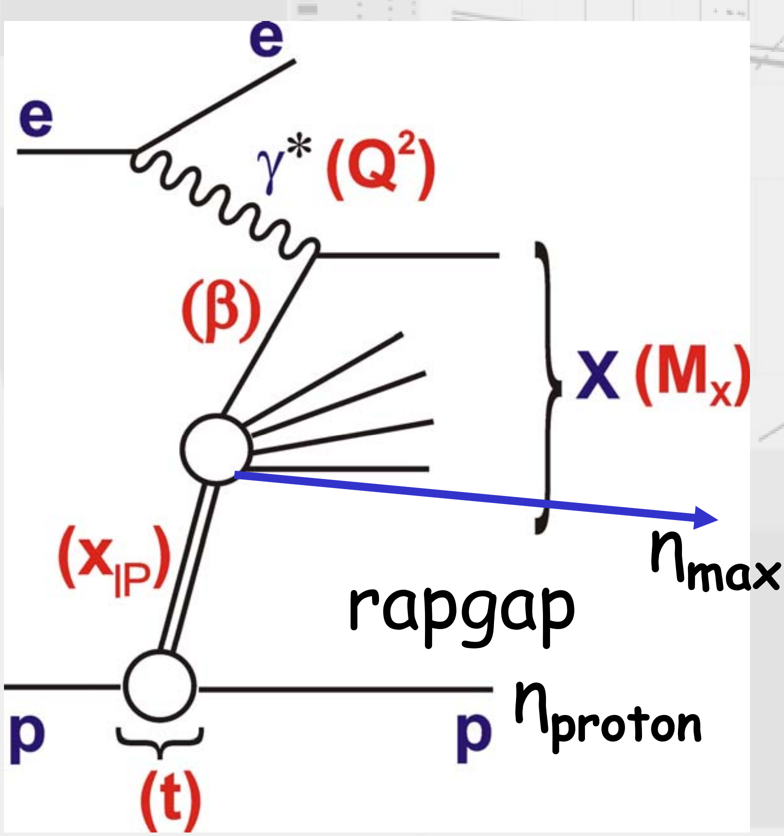
What's been achieved

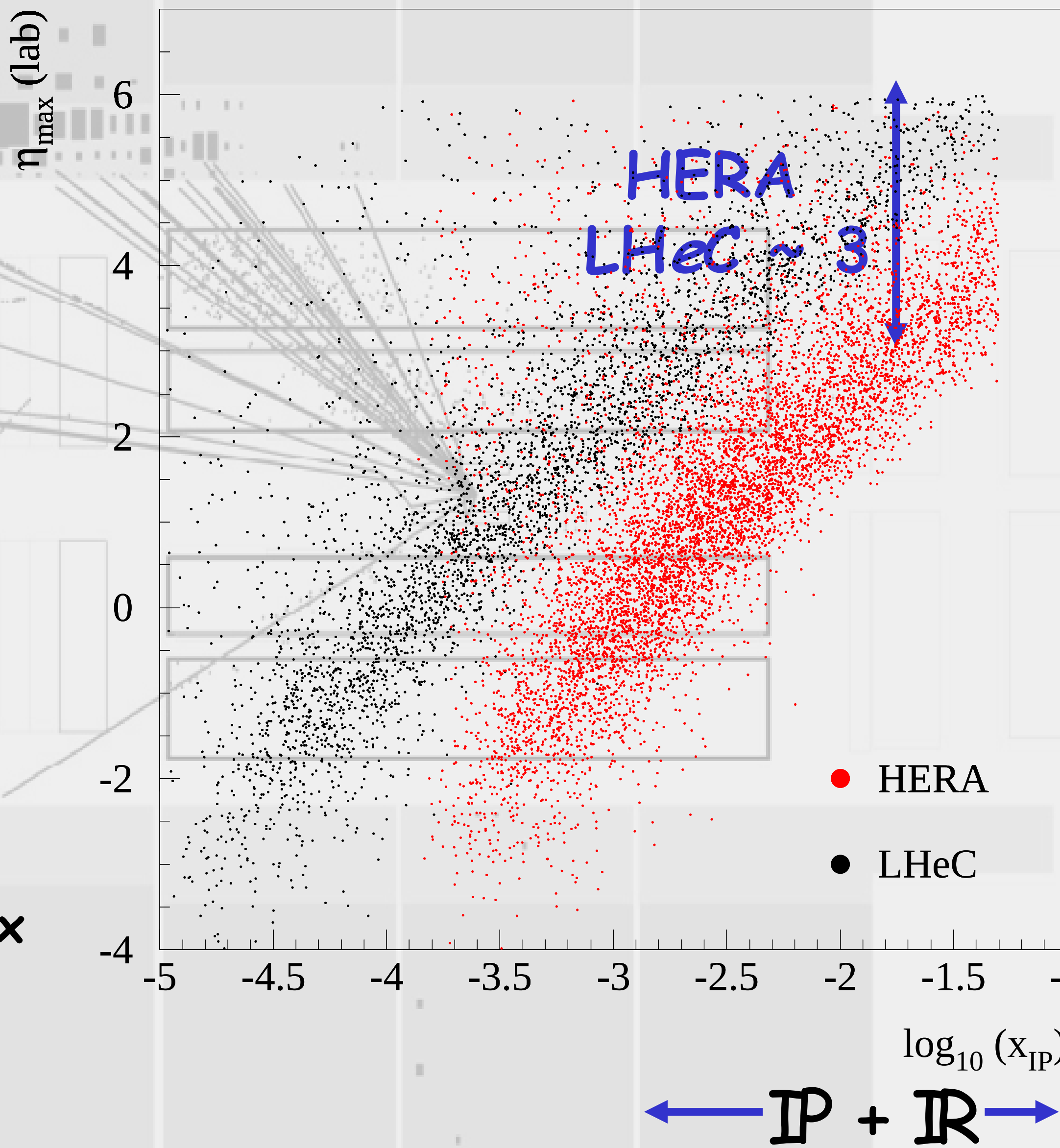
- Sokolov-Ternov @ $LEP_{70\ GeV}$



Diffraction and Rapgap

- rapgap @ LHeC ?





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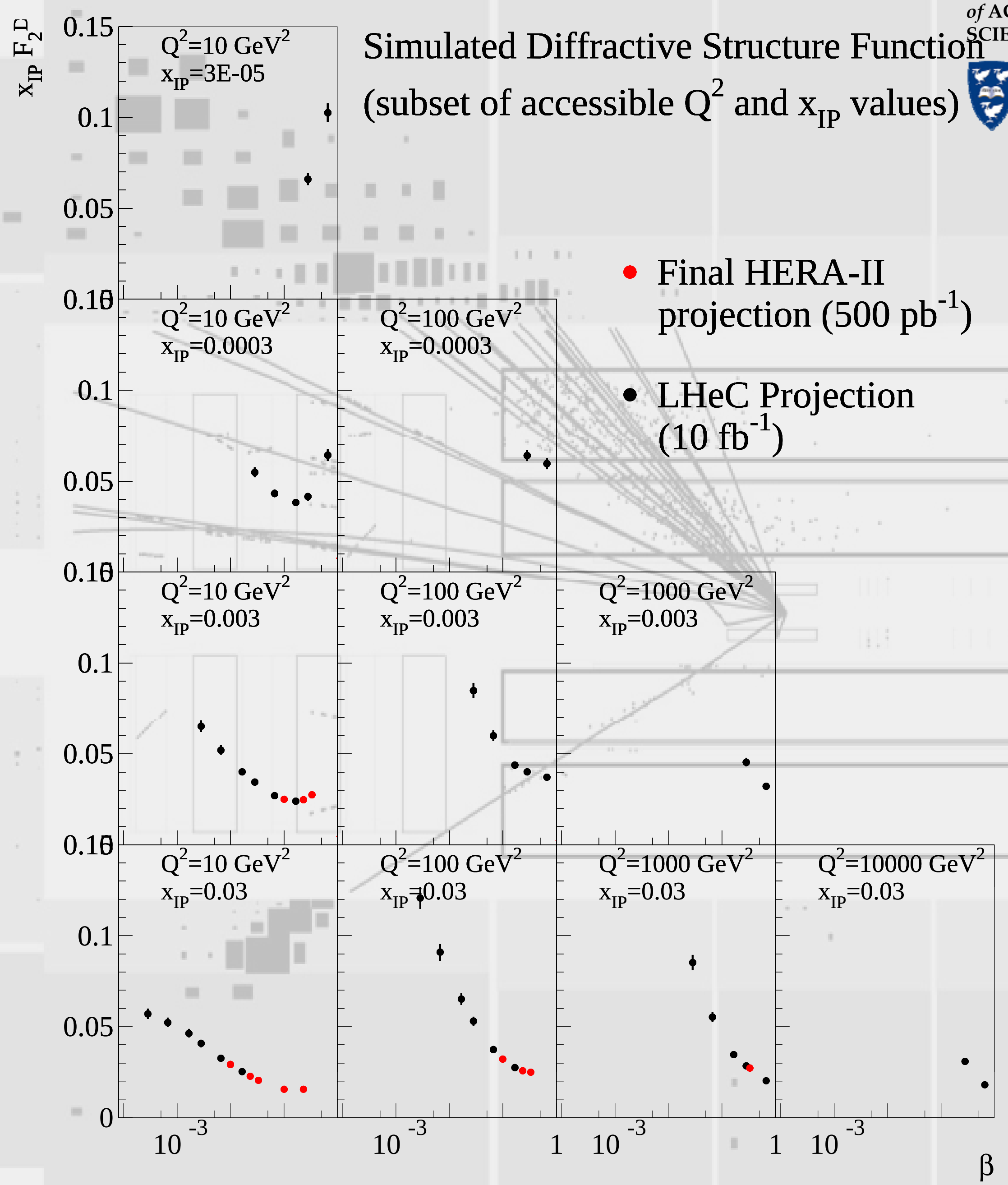
Simulated Diffractive Structure Function
(subset of accessible Q^2 and x_{IP} values)



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Acceptance and Measurement

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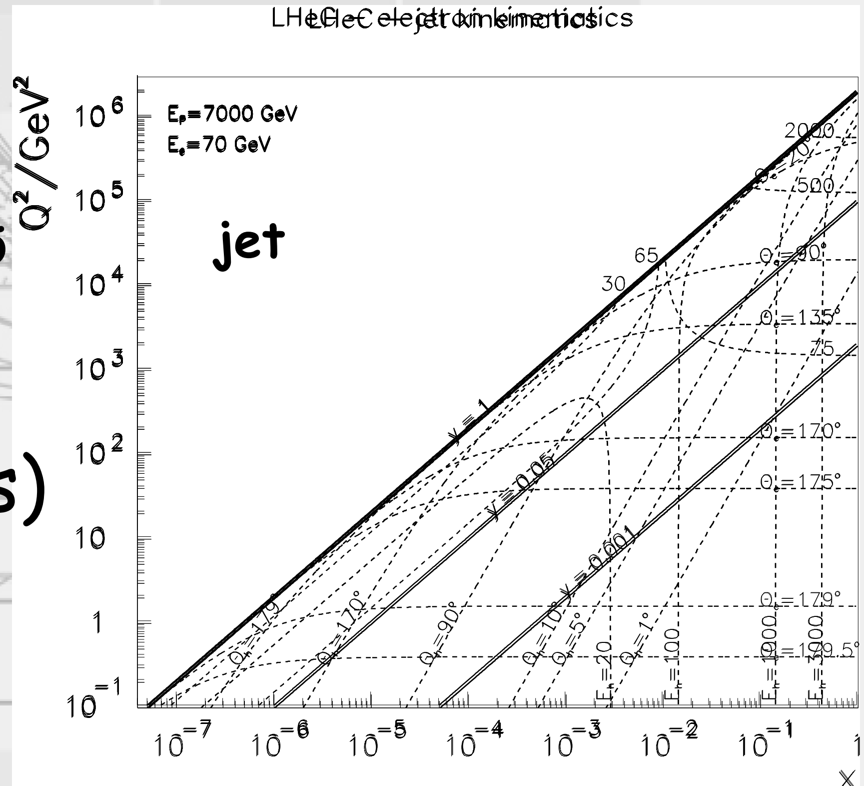
- 70   7000 GeV
- high lumi quads (±10° bp)
  $Q^2_e > 100$ GeV² $x > 3\times10^{-5}$
- few GeV ≤ $E_{h,e}$ ≤ few TeV
- low lumi for low x (no quads)
  $1 < Q^2 < 100$ GeV²
  $x < 3\times10^{-5}$
  "forward" hadrons:
  "forward rapgap" instrumentation



precision e/had-measurement
$170 < \theta_e < 179°$ $170 < \theta_h < 179°$

!

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Rate

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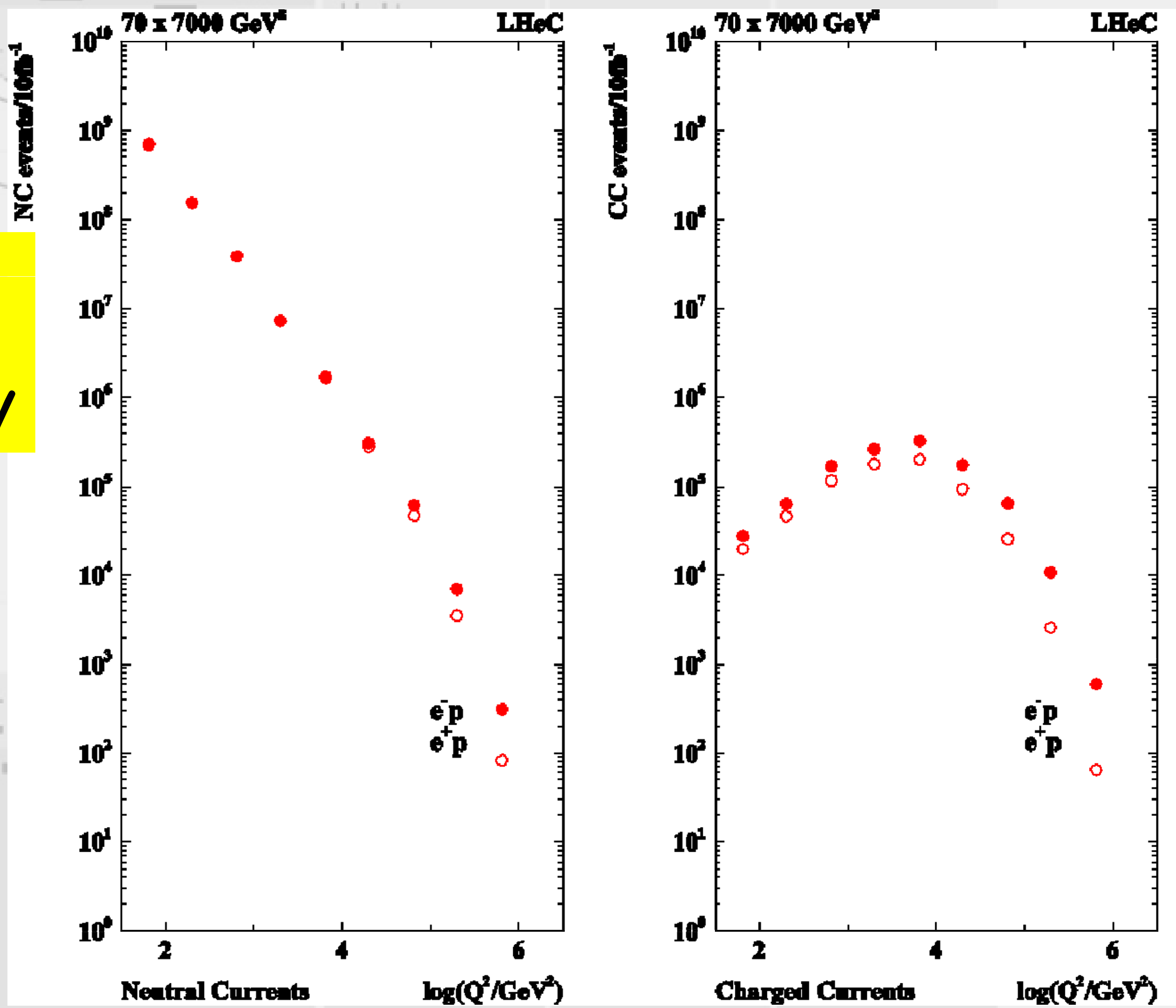
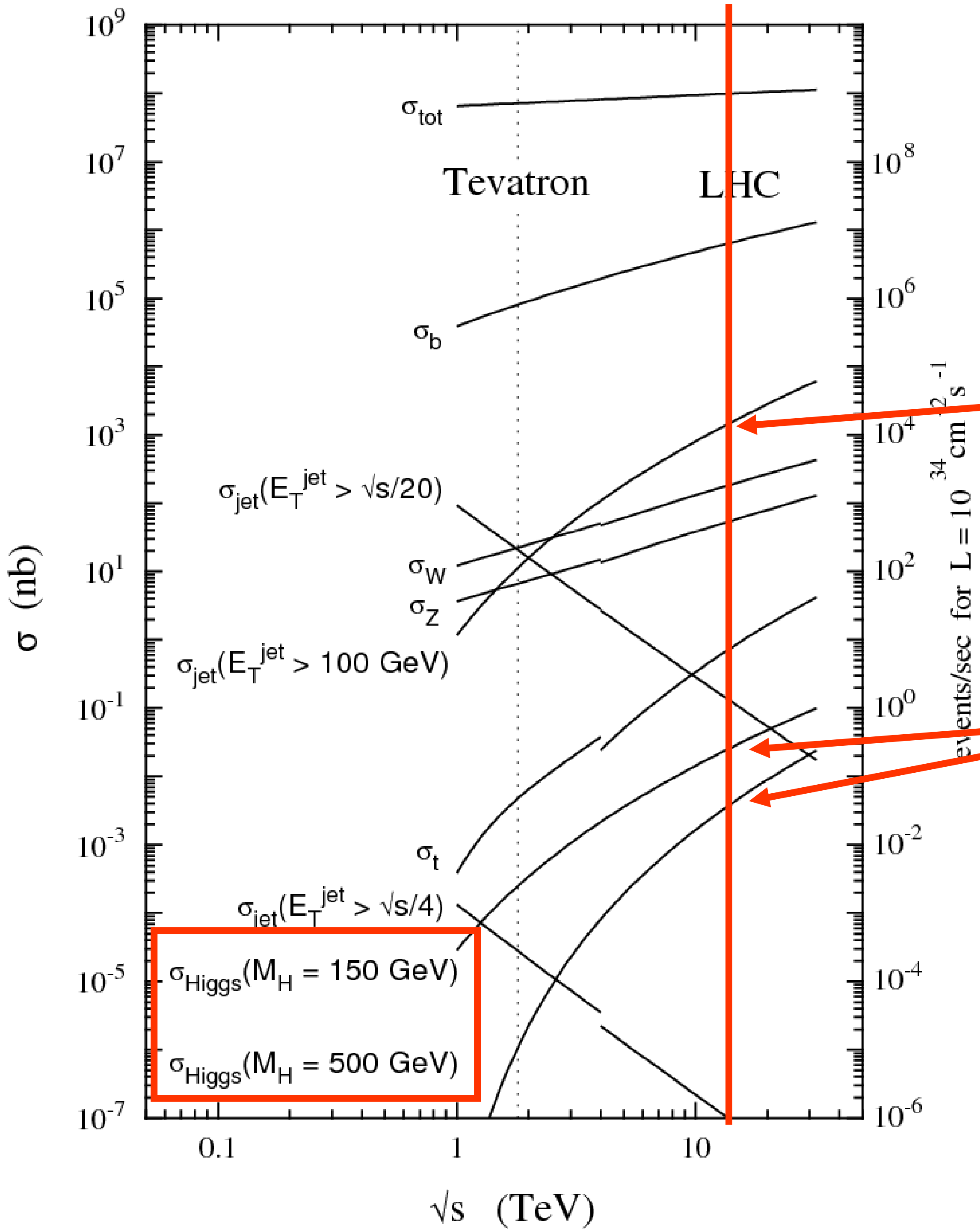
- $100/10\ fb^{-1}$
  $= 100/3 \times$ LHeC y

@ $Q^2 = 1\ TeV^2$



Needle in a haystack…

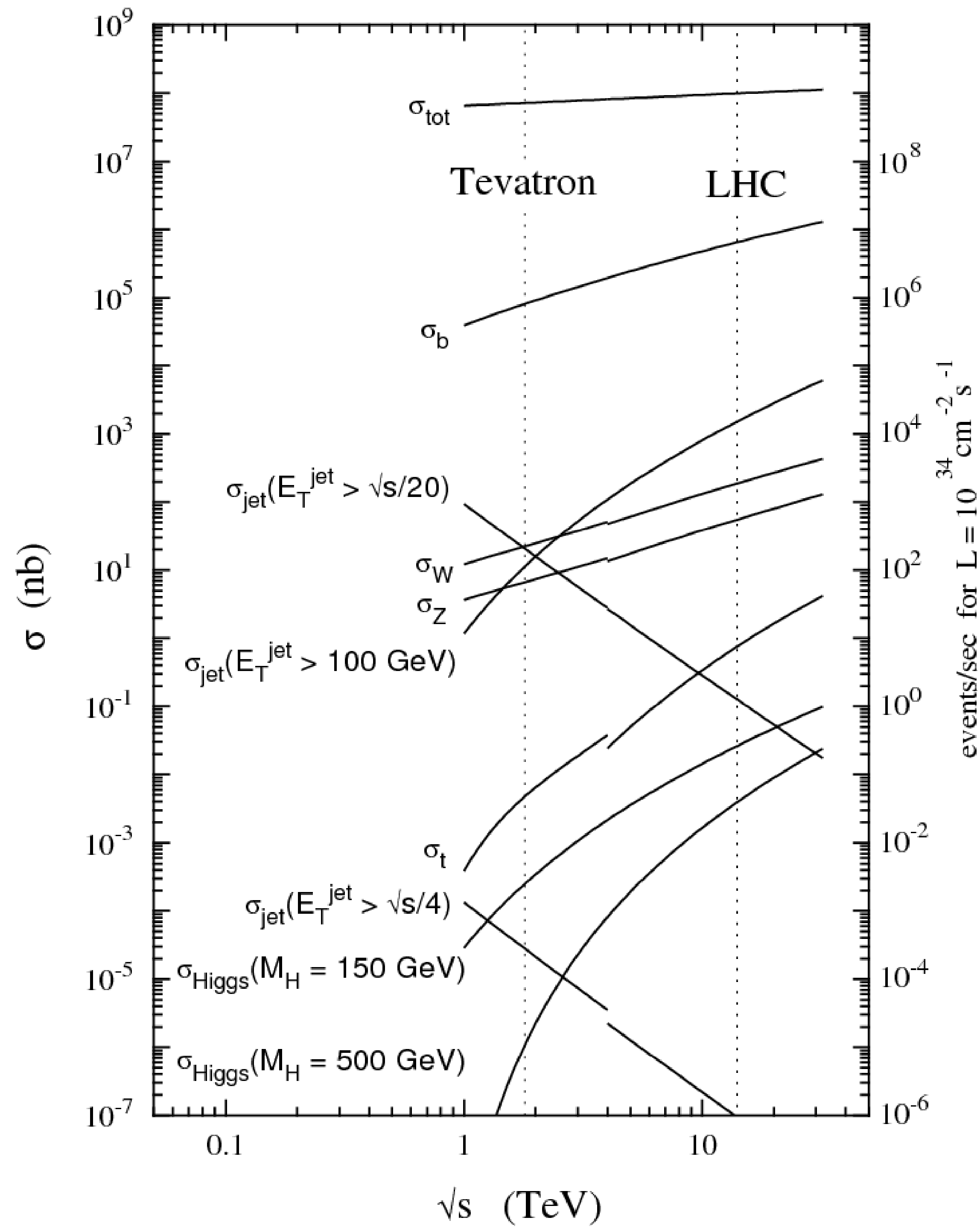


QCD jet production at high energy

Higgs production

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

to avoid being overwhelmed



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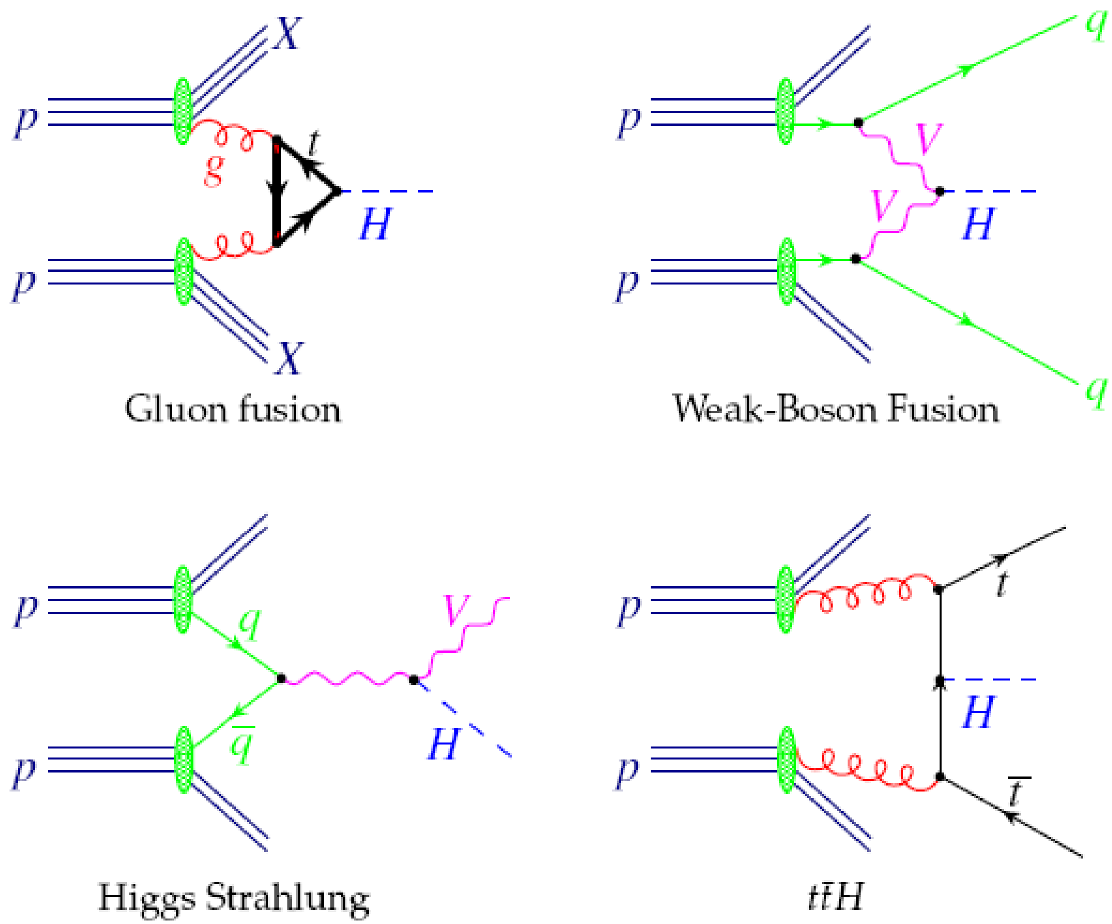
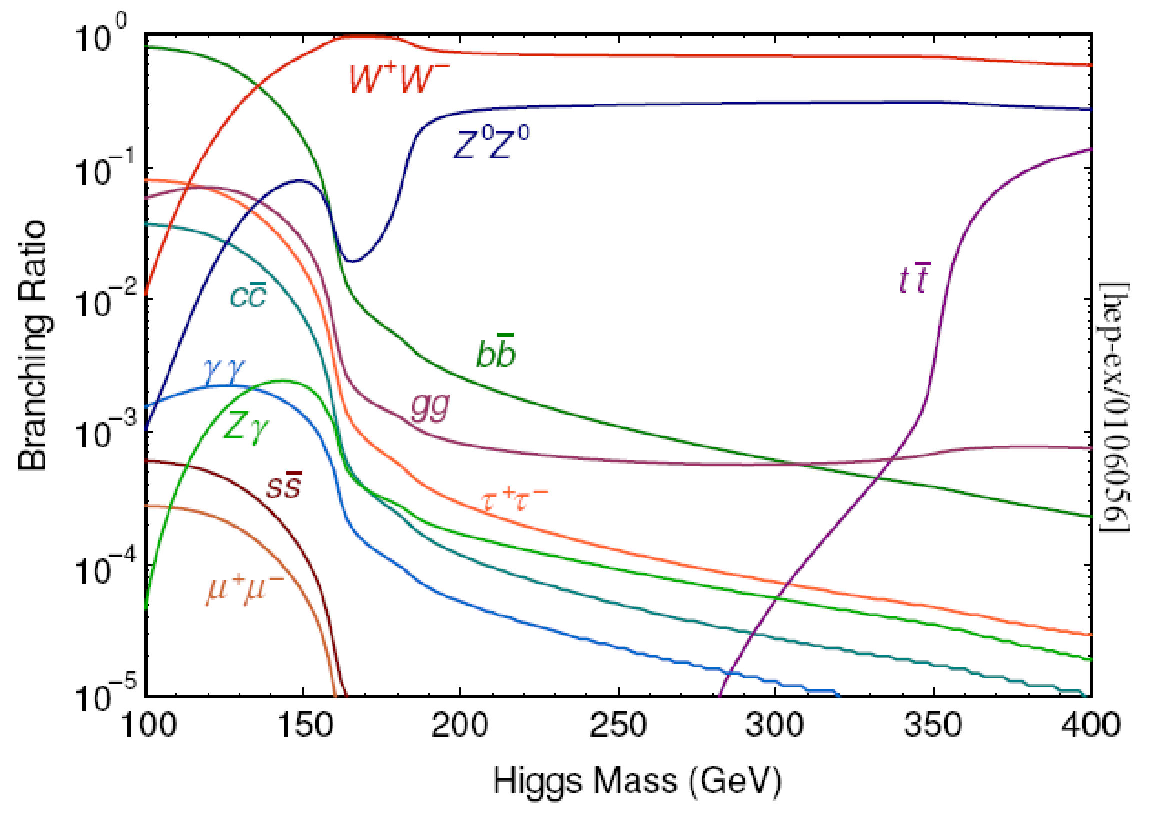
Producing a Higgs



- Higgs couplings ∝ **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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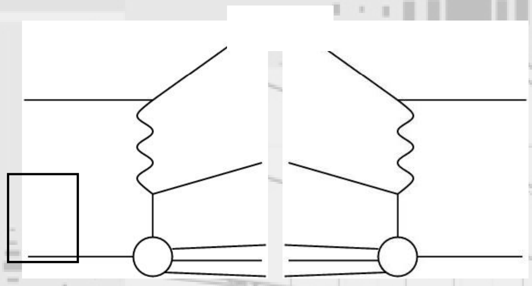
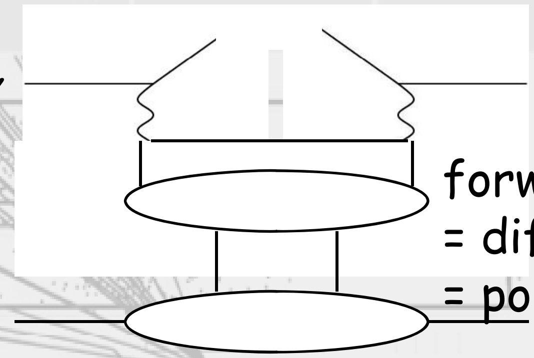
a) 

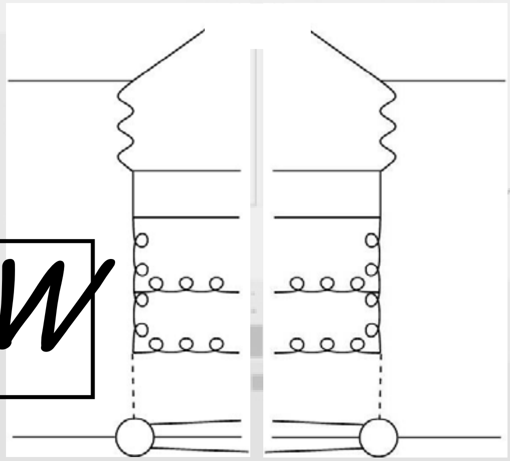
large W =

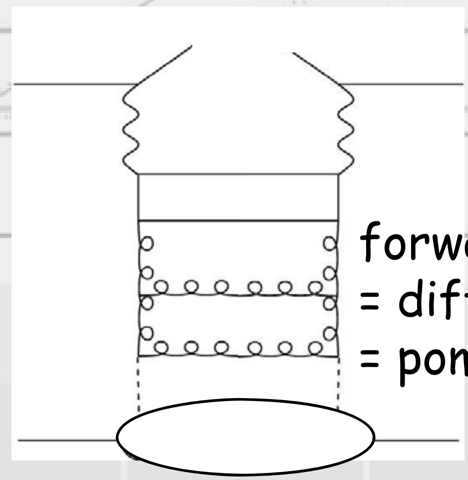


W

forward elastic
= diffraction
= pomeron

b) W





forward elastic
= diffraction
= pomeron

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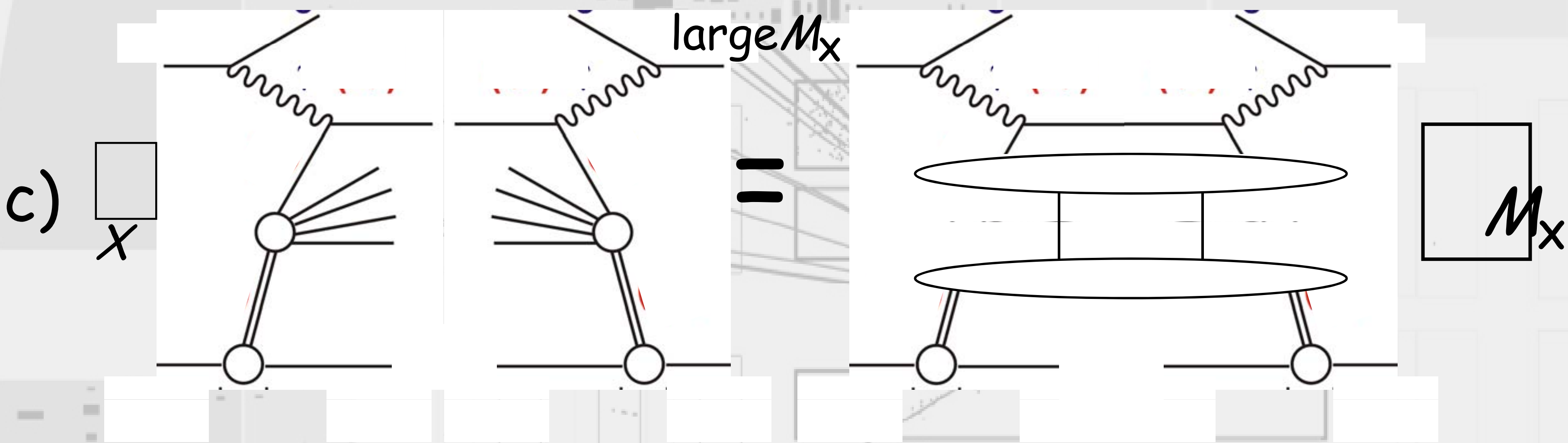

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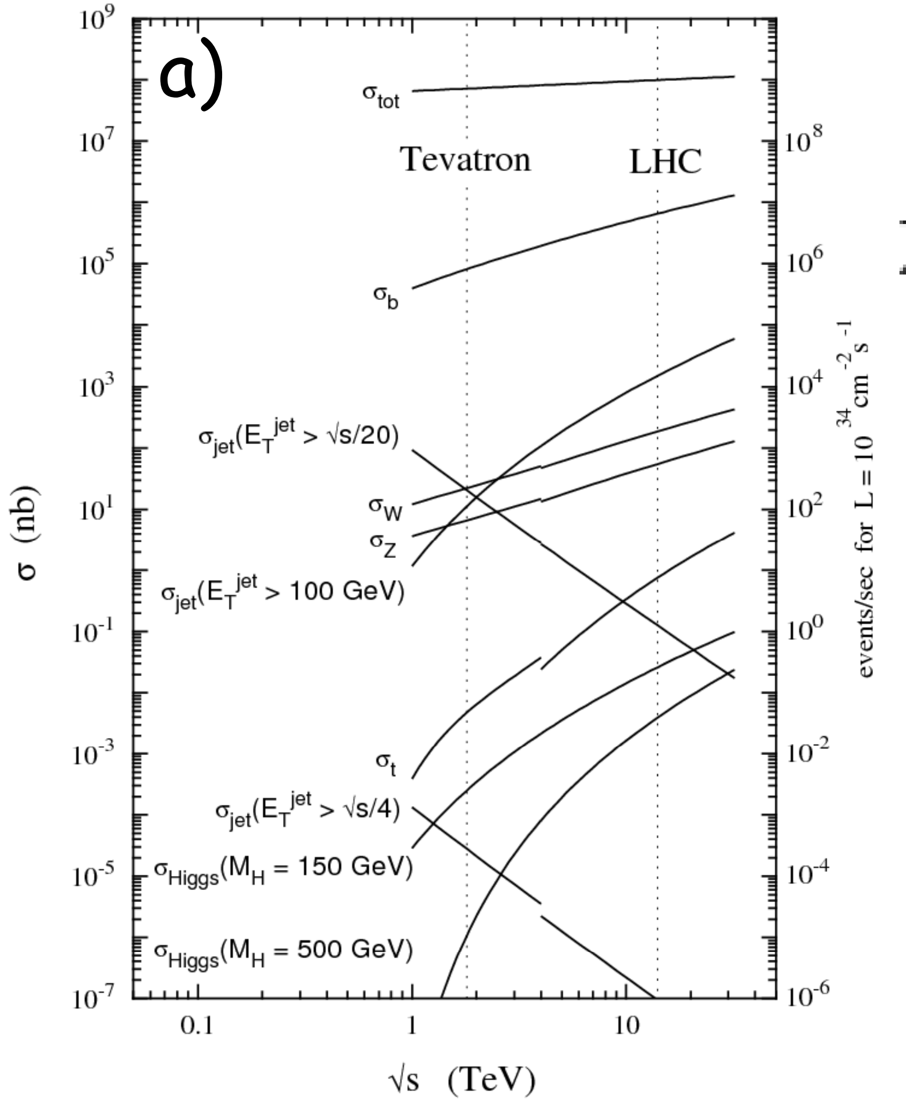

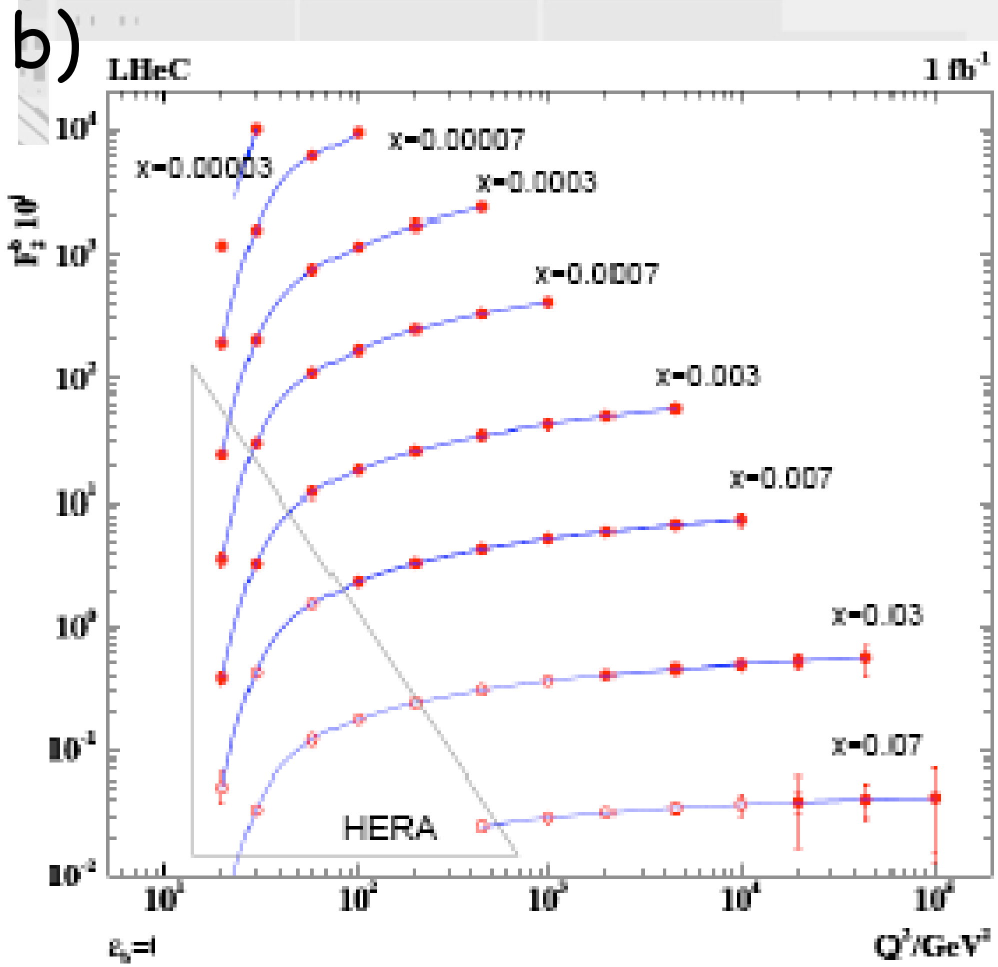

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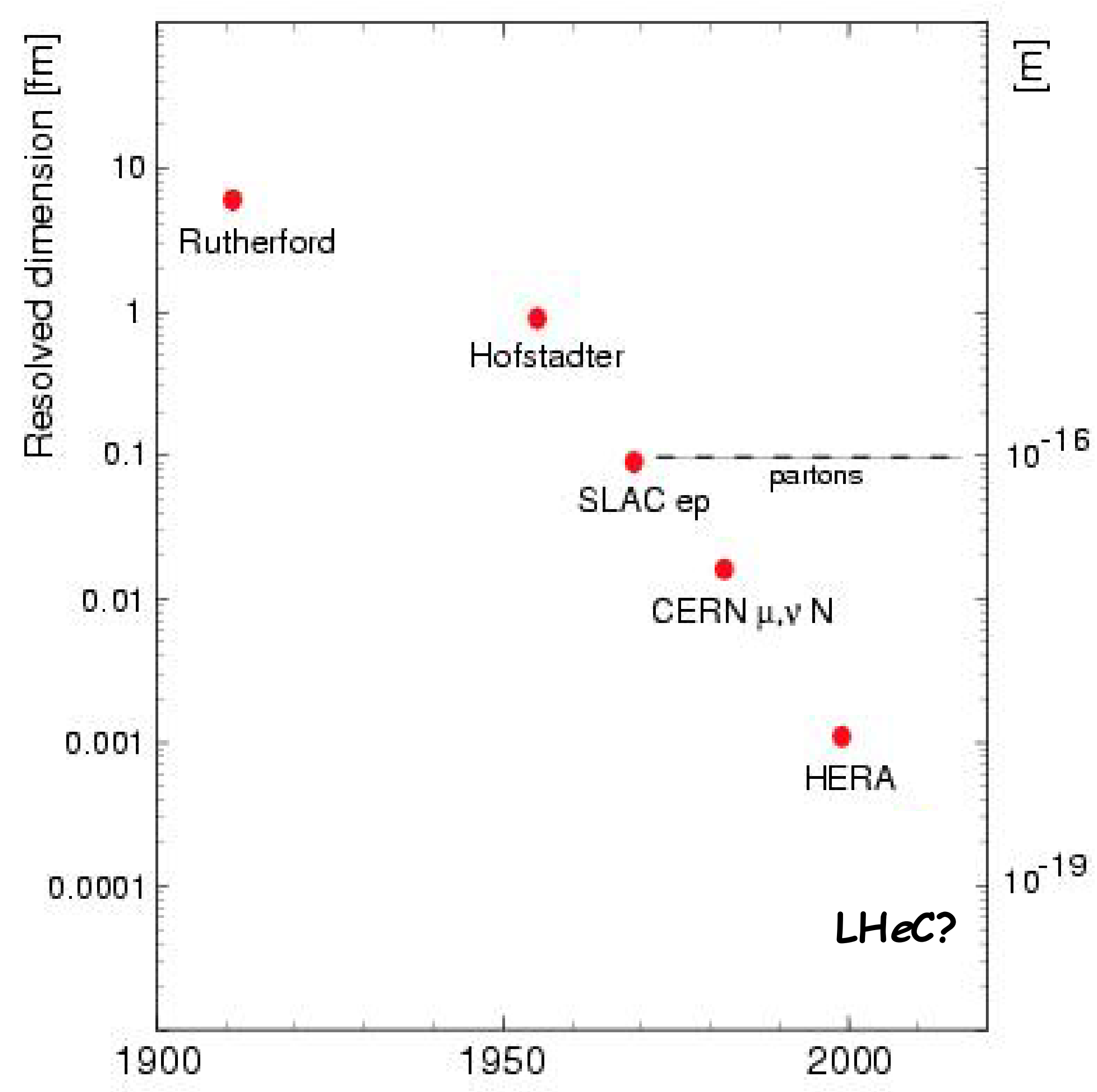

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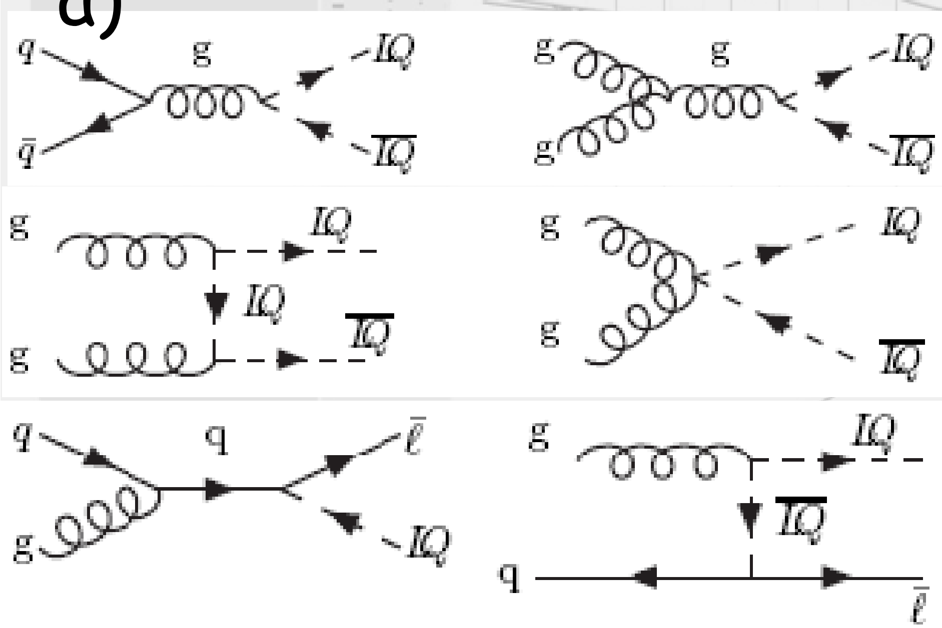
a)



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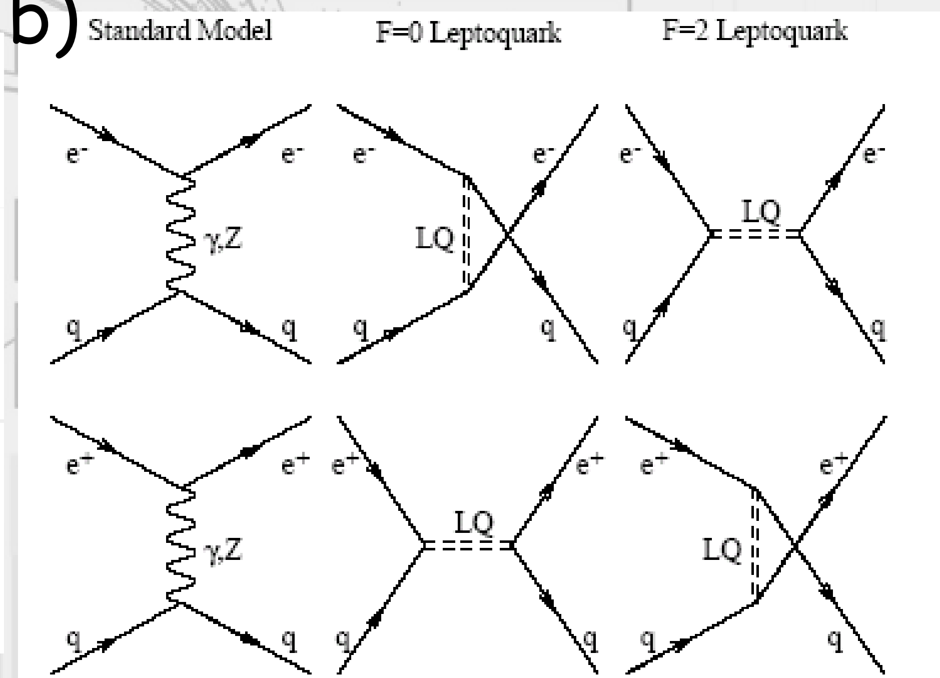

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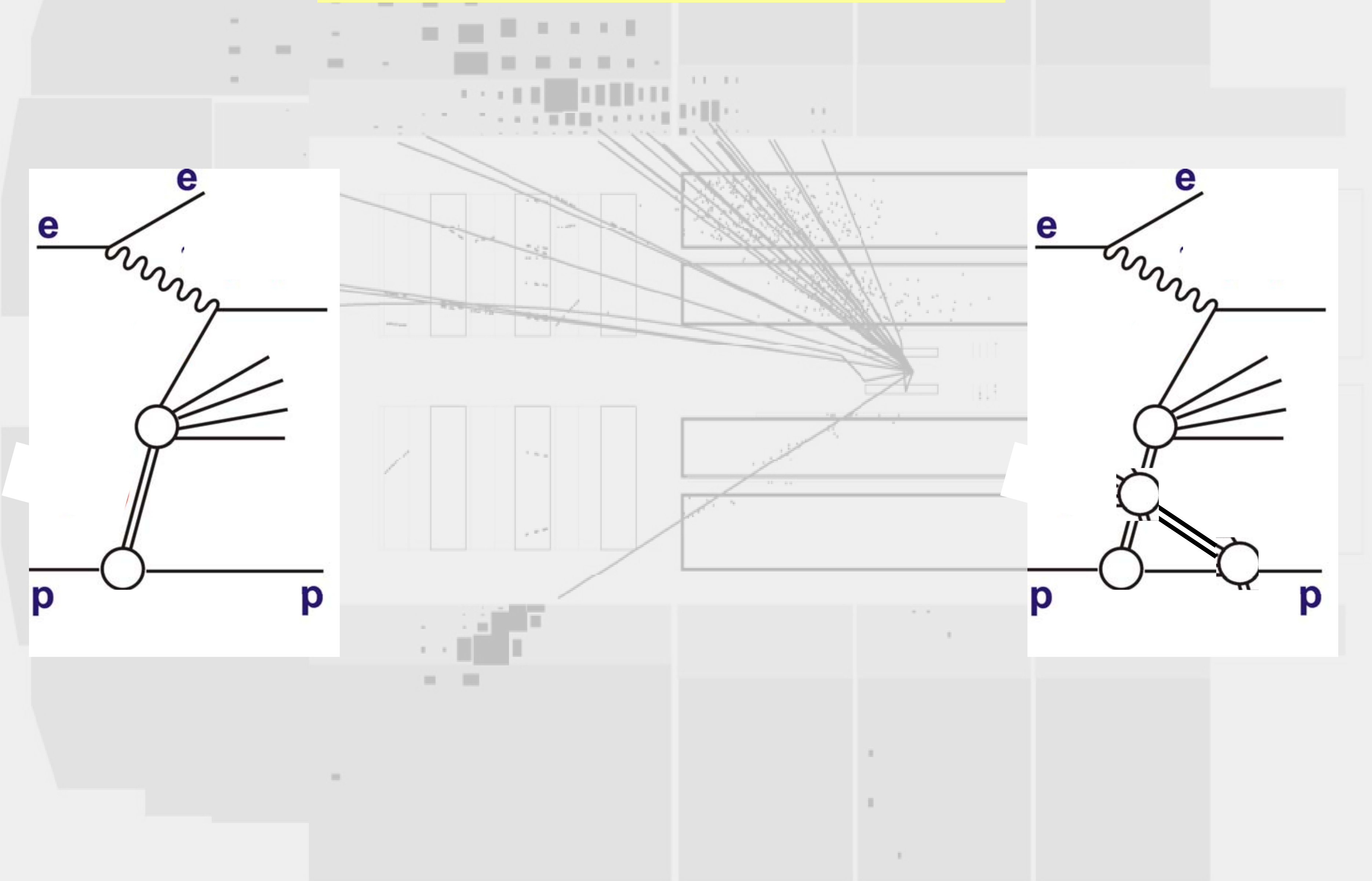

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