Large Hadron Electron Collider

Progress Report to ECFA

ep at 100 times the luminosity and Q^2 and 1/x as compared to HERA
eA at 10^4 times an extended kinematic range

Max Klein

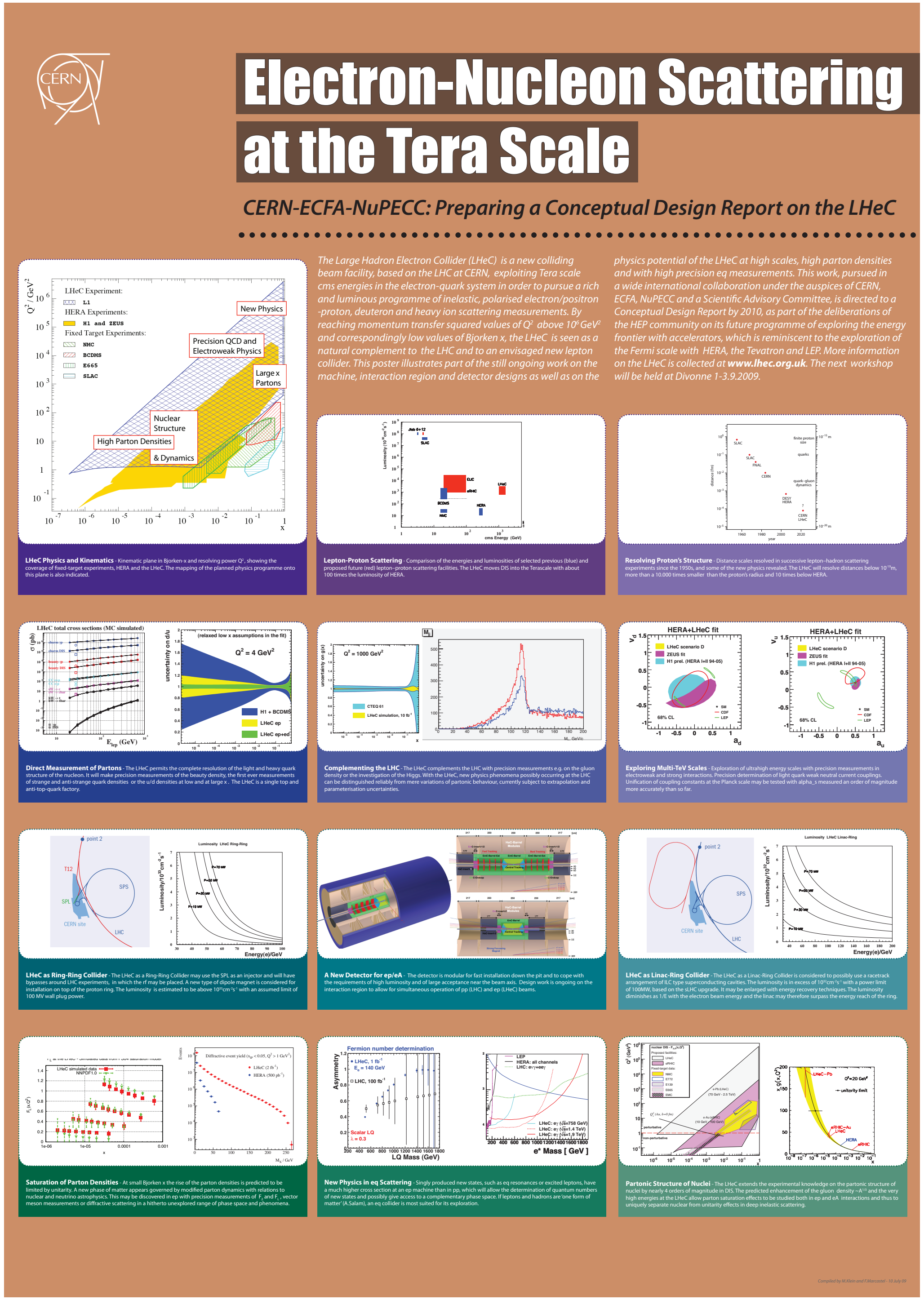
for the LHeC Group

DRAFT 25.11.
11.45 am

UNIVERSITY OF LIVERPOOL

CERN Geneva 27. November 2009

www.lhec.cern.ch



Electron-Nucleon Scattering at the Tera Scale

CERN-ECFA-NuPECC: Preparing a Conceptual Design Report on the LHeC

The Large Hadron Electron Collider (LHeC) is a new colliding beam facility, based on the LHC at CERN, exploiting Tera scale cms energies in the electron-quark system in order to pursue a rich and luminous programme of inelastic, polarised electron/positron -proton, deuteron and heavy ion scattering measurements. By reaching momentum transfer squared values of Q^2 above 10^6 GeV^2 and correspondingly low values of Bjorken x, the LHeC is seen as a natural complement to the LHC and to an envisaged new lepton collider. This poster illustrates part of the still ongoing work on the machine, interaction region and detector designs as well as on the physics potential of the LHeC at high scales, high parton densities and with high precision eq measurements. This work, pursued in a wide international collaboration under the auspices of CERN, ECFA, NuPECC and a Scientific Advisory Committee, is directed to a Conceptual Design Report by 2010, as part of the deliberations of the HEP community on its future programme of exploring the energy frontier with accelerators, which is reminiscent to the exploration of the Fermi scale with HERA, the Tevatron and LEP. More information on the LHeC is collected at ***www.lhec.org.uk****. The next workshop will be held at Divonne 1-3.9.2009.*

LHeC Physics and Kinematics - Kinematic plane in Bjorken-x and resolving power Q^2, showing the coverage of fixed-target experiments, HERA and the LHeC. The mapping of the planned physics programme onto this plane is also indicated.

Lepton-Proton Scattering - Comparison of the energies and luminosities of selected previous (blue) and proposed future (red) lepton–proton scattering facilities. The LHeC moves DIS into the Terascale with about 100 times the luminosity of HERA.

Resolving Proton's Structure - Distance scales resolved in successive lepton–hadron scattering experiments since the 1950s, and some of the new physics revealed. The LHeC will resolve distances below 10^{-19}m, more than a 10.000 times smaller than the proton's radius and 10 times below HERA.

Direct Measurement of Partons - The LHeC permits the complete resolution of the light and heavy quark structure of the nucleon. It will make precision measurements of the beauty density, the first ever measurements of strange and anti-strange quark densities or the u/d densities at low and at large x. The LHeC is a single top and anti-top-quark factory.

Complementing the LHC - The LHeC complements the LHC with precision measurements e.g. on the gluon density or the investigation of the Higgs. With the LHeC, new physics phenomena possibly occurring at the LHC can be distinguished reliably from mere variations of partonic behaviour, currently subject to extrapolation and parameterisation uncertainties.

Exploring Multi-TeV Scales - Exploration of ultrahigh energy scales with precision measurements in electroweak and strong interactions. Precision determination of light quark weak neutral current couplings. Unification of coupling constants at the Planck scale may be tested with alpha_s measured an order of magnitude more accurately than so far.

LHeC as Ring-Ring Collider - The LHeC as a Ring-Ring Collider may use the SPL as an injector and will have bypasses around LHC experiments, in which the rf may be placed. A new type of dipole magnet is considered for installation on top of the proton ring. The luminosity is estimated to be above 10^{33}cm^{-2}s^{-1} with an assumed limit of 100 MV wall plug power.

A New Detector for ep/eA - The detector is modular for fast installation down the pit and to cope with the requirements of high luminosity and of large acceptance near the beam axis. Design work is ongoing on the interaction region to allow for simultaneous operation of pp (LHC) and ep (LHeC) beams.

LHeC as Linac-Ring Collider - The LHeC as a Linac-Ring Collider is considered to possibly use a racetrack arrangement of ILC type superconducting cavities. The luminosity is in excess of 10^{32}cm^{-2}s^{-1} with a power limit of 100MW, based on the sLHC upgrade. It may be enlarged with energy recovery techniques. The luminosity diminishes as 1/E with the electron beam energy and the linac may therefore surpass the energy reach of the ring.

Saturation of Parton Densities - At small Bjorken x the rise of the parton densities is predicted to be limited by unitarity. A new phase of matter appears governed by modified parton dynamics with relations to nuclear and neutrino astrophysics. This may be discovered in ep with precision measurements of F_2 and F_L, vector meson measurements or diffractive scattering in a hitherto unexplored range of phase space and phenomena.

New Physics in eq Scattering - Singly produced new states, such as eq resonances or excited leptons, have a much higher cross section at an ep machine than in pp, which will allow the determination of quantum numbers of new states and possibly give access to a complementary phase space. If leptons and hadrons are 'one form of matter' (A.Salam), an eq collider is most suited for its exploration.

Partonic Structure of Nuclei - The LHeC extends the experimental knowledge on the partonic structure of nuclei by nearly 4 orders of magnitude in DIS. The predicted enhancement of the gluon density ~$A^{1/3}$ and the very high energies at the LHeC allow parton saturation effects to be studied both in ep and eA interactions and thus to uniquely separate nuclear from unitarity effects in deep inelastic scattering.

Compiled by M.Klein and F.Marcastel - 10 July 09

Recent Developments

2008

September	Divonne workshop; NuPECC Meeting at Glasgow
October	ICFA Seminar at SLAC
November	**ECFA Plenary at CERN**
December	Convenor's Meeting at CERN

2009

March	Visit at SLAC [Linac]
April	DIS09 at Madrid: LHeC premeeting, parallel, SAC plenary panel (M.K. arXiv:0908.2877 [hep-ex])
April	PAC09 at Vancouver - Papers, Talk, Proceedings
May	Visit at BNP Novosibirsk [Ring Magnets]
June	Low x / HPD meeting at CERN, pre-Blois
July	Talk and Poster at EPS09 and Lepton-Photon
September	Divonne II (CERN-ECFA-NuPECC Workshop)
October	NuPECC Long Range Planning Workshop

Conceptual Design Report
Large Hadron Electron Collider (LHeC) at CERN

DRAFT - February 2009

Extended version by Mid December09

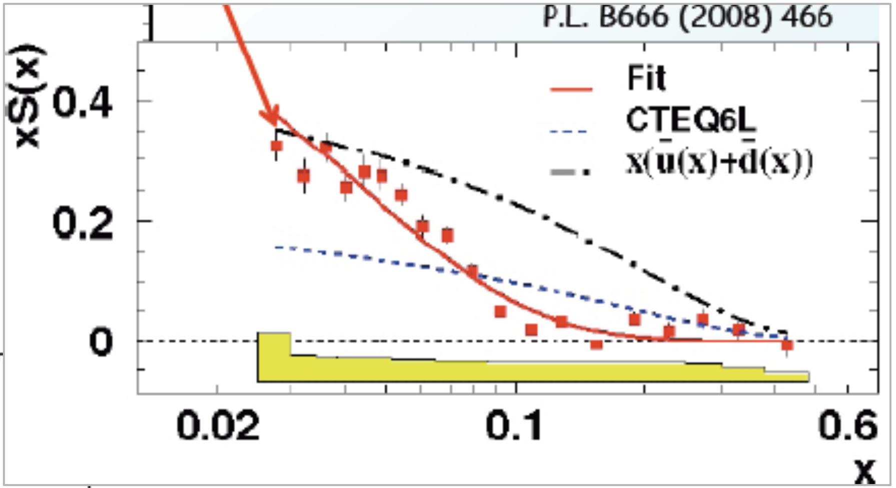
Physics Programme of the LHeC

- \+ Unfolding completely the **parton structure of the proton** (neutron and photon) and search for sub-substructure down to ten times below HERA's limit
- \+ Sensitive exploration of **new symmetries and the grand unification** of particle interactions with electroweak and strong interaction measurements of unprecedented precision.
- \+ Search for and exploration of **new, Terascale physics**, in particular for singly produced new states (RPV SUSY, LQ, excited fermions) complementary to the LHC
- \+ Exploration of **high density matter** [low x physics beyond the expected unitarity limit for the growth of the gluon density]
- \+ Unfolding the substructure and parton dynamics inside nuclei and the study of **quark-gluon plasma** matter by an extension of the kinematic range by four orders of magnitude.

Huge amount of studies done and ongoing. Follows one example per point each

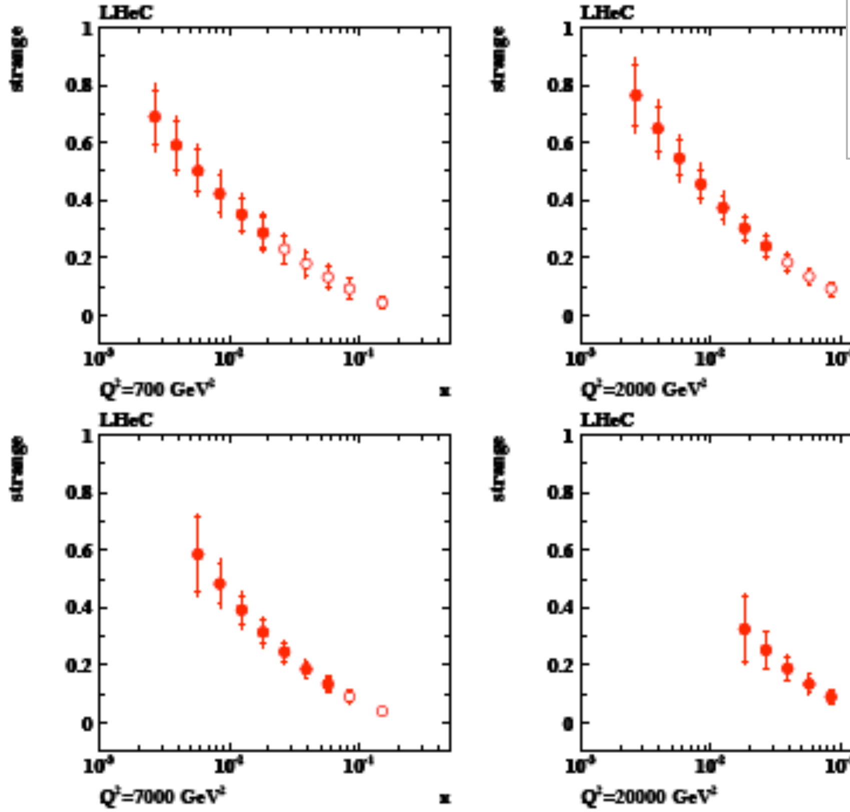
Anti-Strange Quark Distribution

s not measured with H1,ZEUS
HERMES (N_K): s much larger
dimuon data: s ≠ sbar?



HERMES, K.Rith EPS09

Q^2~ 1 GeV^2



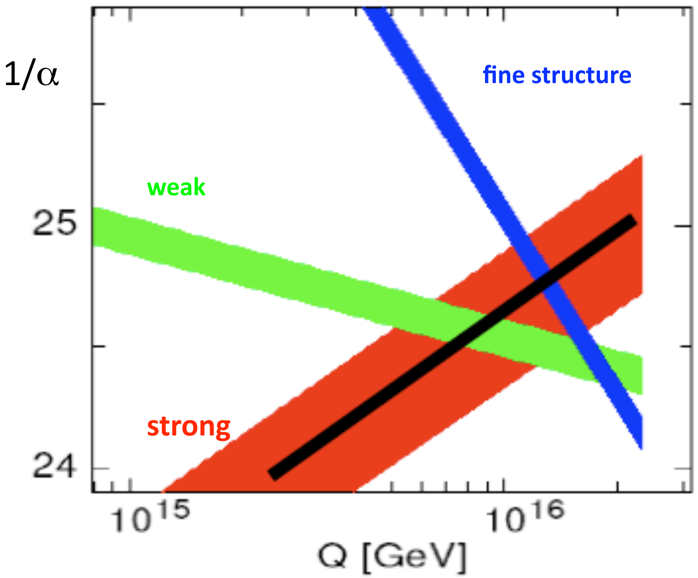
$W^- sbar \rightarrow cbar$
$1 fb^{-1}$
$\varepsilon_c = 0.1$
$\varepsilon_q = 0.01$
$\delta_{syst} = 0.1$
$\circ - \vartheta_h \geq 1^o$
$\bullet - \vartheta_h \geq 10^o$

W,Z sensitive to s

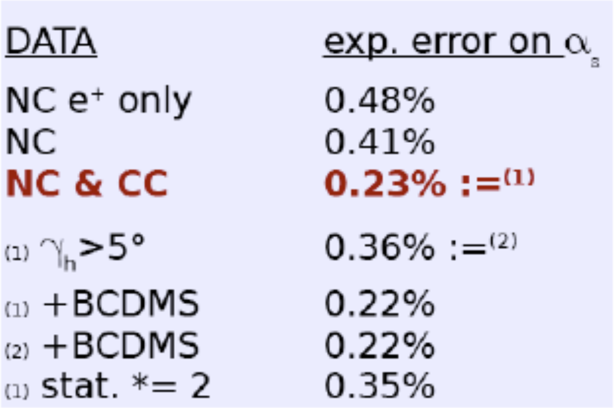
LHeC: measure both strange and anti-s with high precision for the first time

Strong Coupling Constant

Simulation of α_s measurement at LHeC



MSSM - B.Allnach et al, hep-ex/0403133



DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h>5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

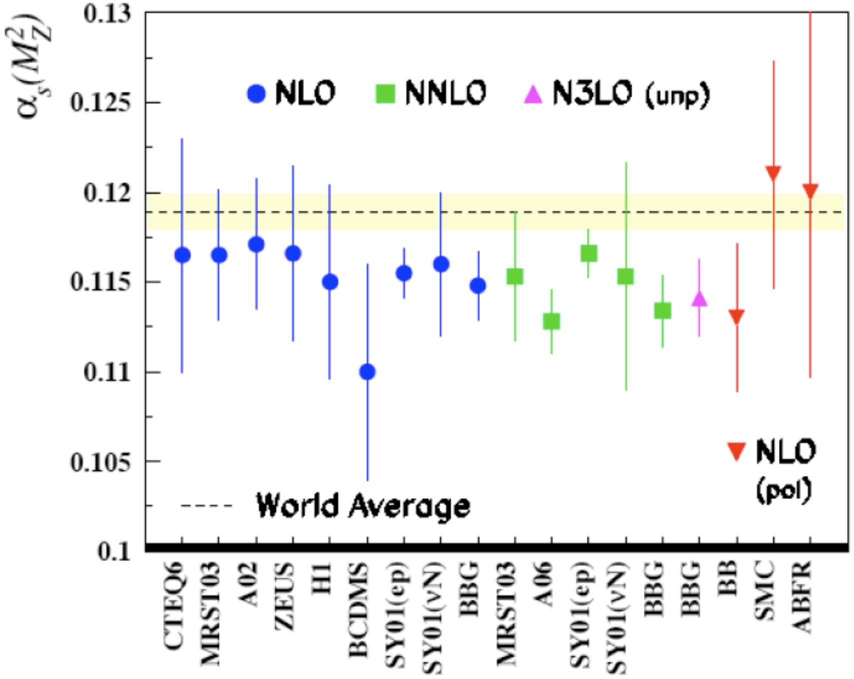
T.Kluge

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

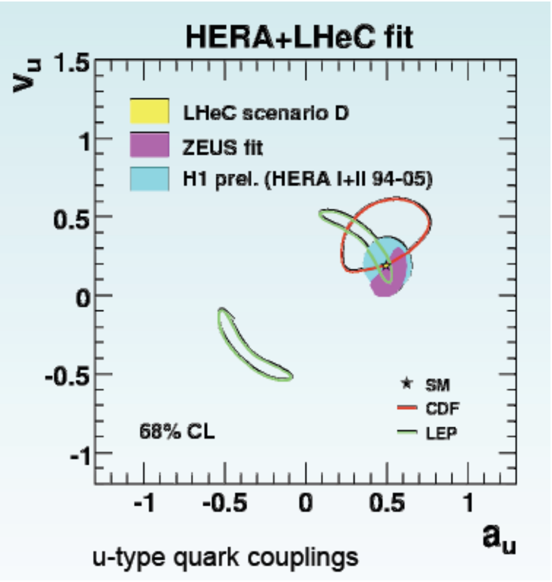
DIS tends to be lower than world average

LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD

Blumlein et al '06

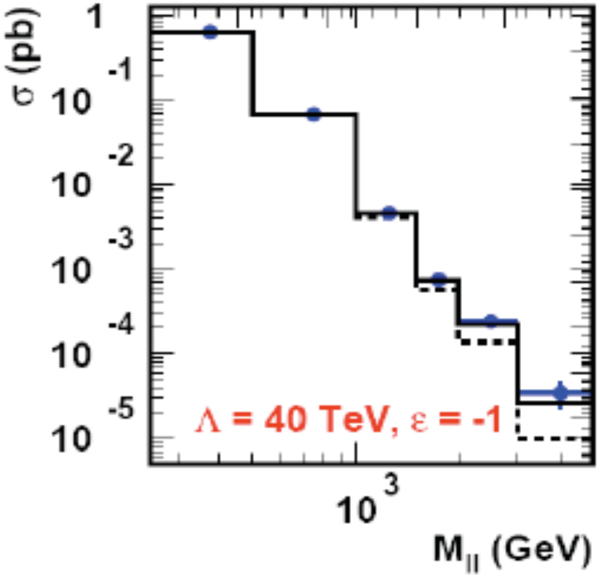


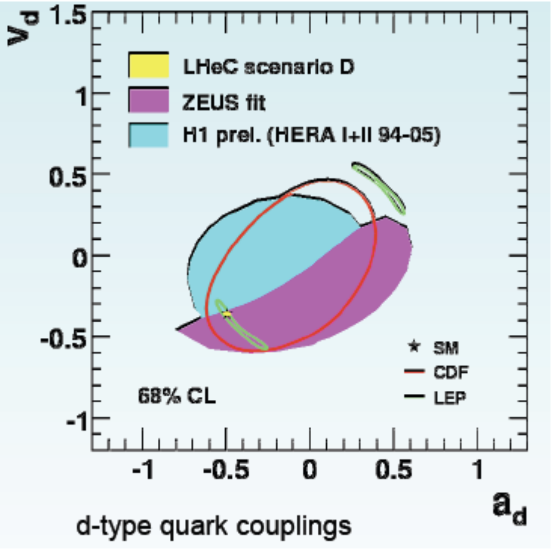
Exploration of High Scales

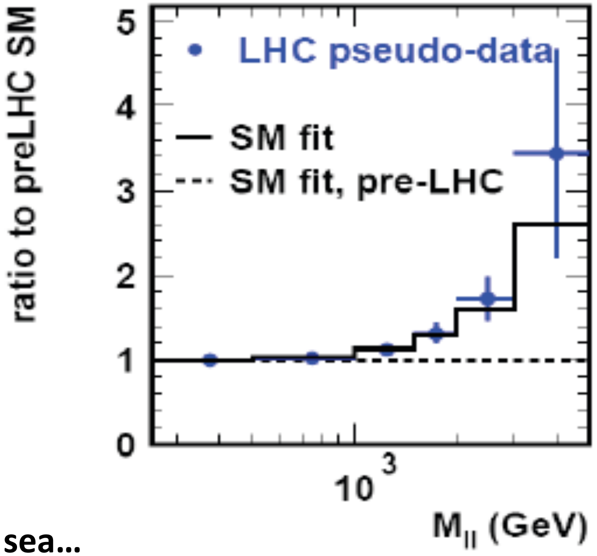


Precision measurement of NC couplings: access to new el.weak physics

C.Gwenlan, M.K.



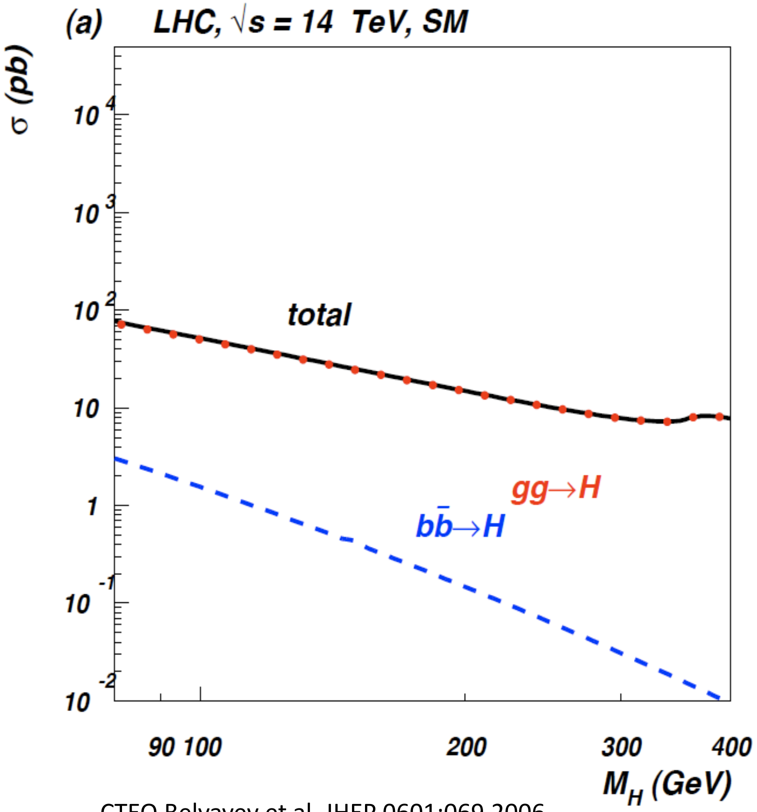




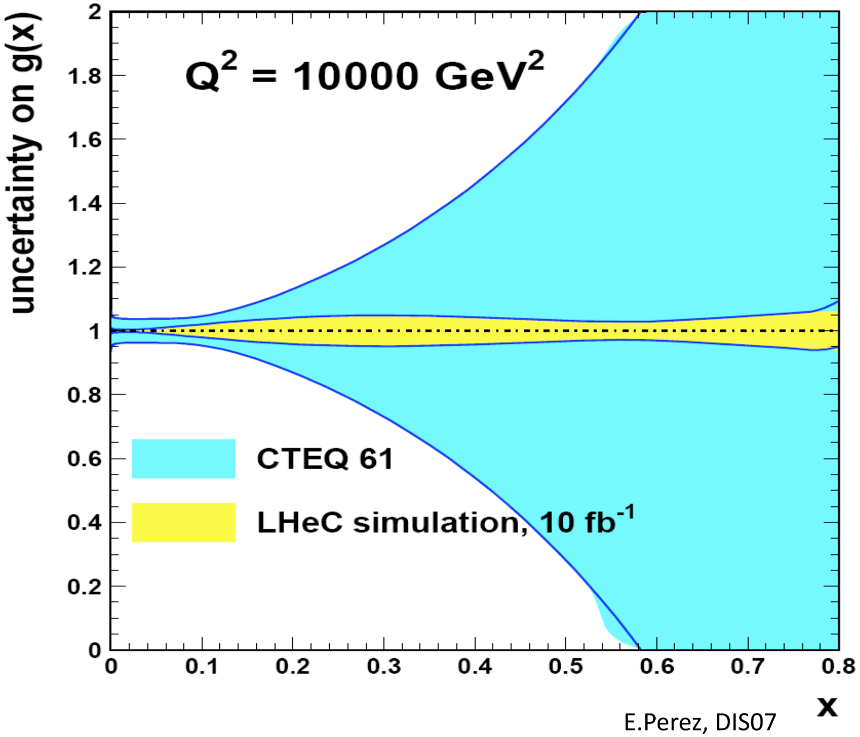
CI study:
LHeC ‘freezes’ the pdfs
This allows new physics to be revealed.
HERA+BCDMS: reshuffle the sea…

E.Perez

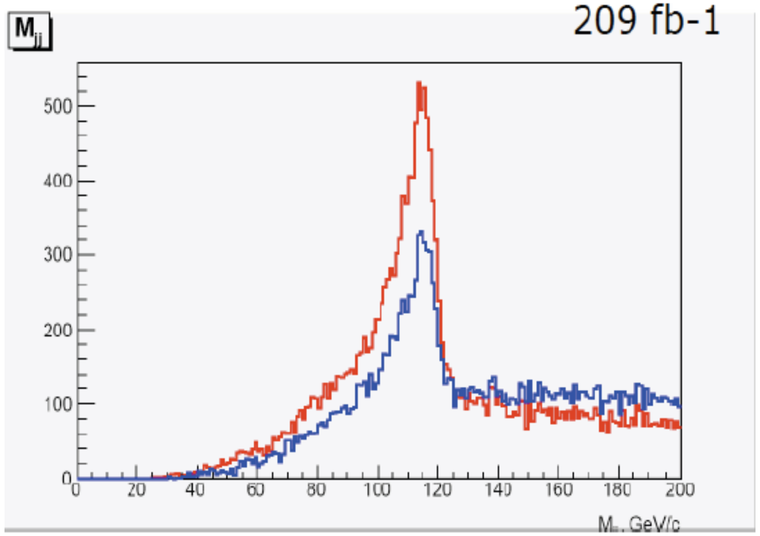
Gluon - SM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006



E.Perez, DIS07



In SM Higgs production is gluon dominated

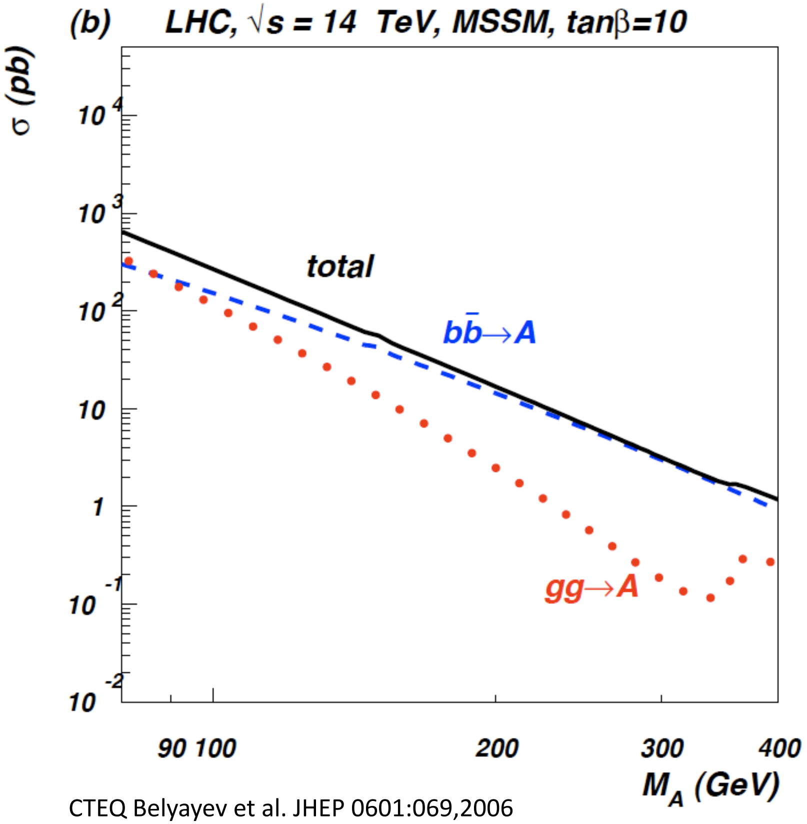
LHeC: huge x,Q^2 range for xg determination

WW to Higgs fusion has sizeable ep xsection

U.Klein
B.Kniehl
M.Kuze
E.Perez

Cf Divonne 09 for QCD bgd studies + btagging

Beauty - MSSM Higgs

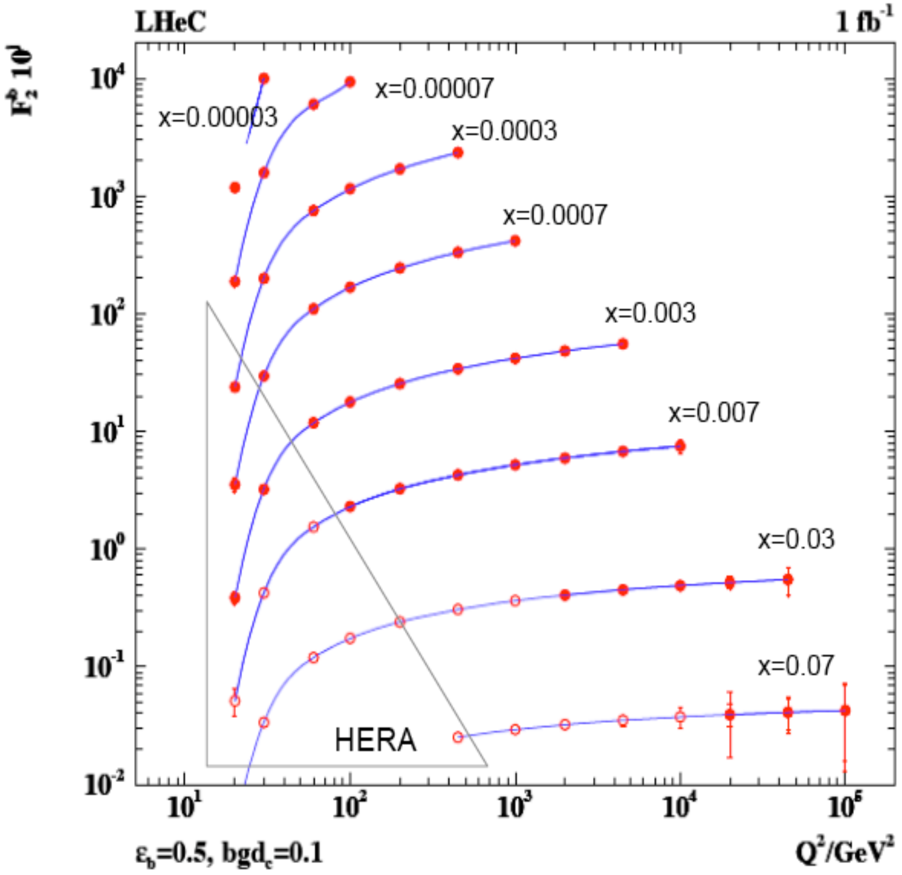


CTEQ Belyayev et al. JHEP 0601:069,2006

In MSSM Higgs production is b dominated

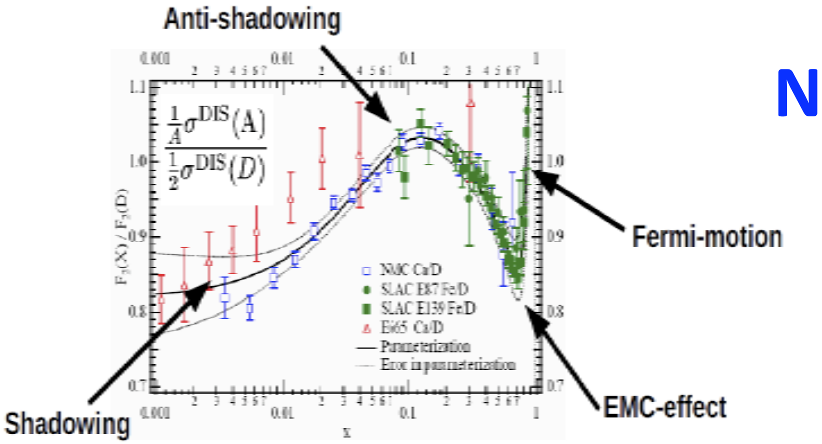
First measurements of b at HERA can be turned to precision measurement of b-df.

LHeC: higher fraction of b, larger range, smaller beam spot, better Si detectors

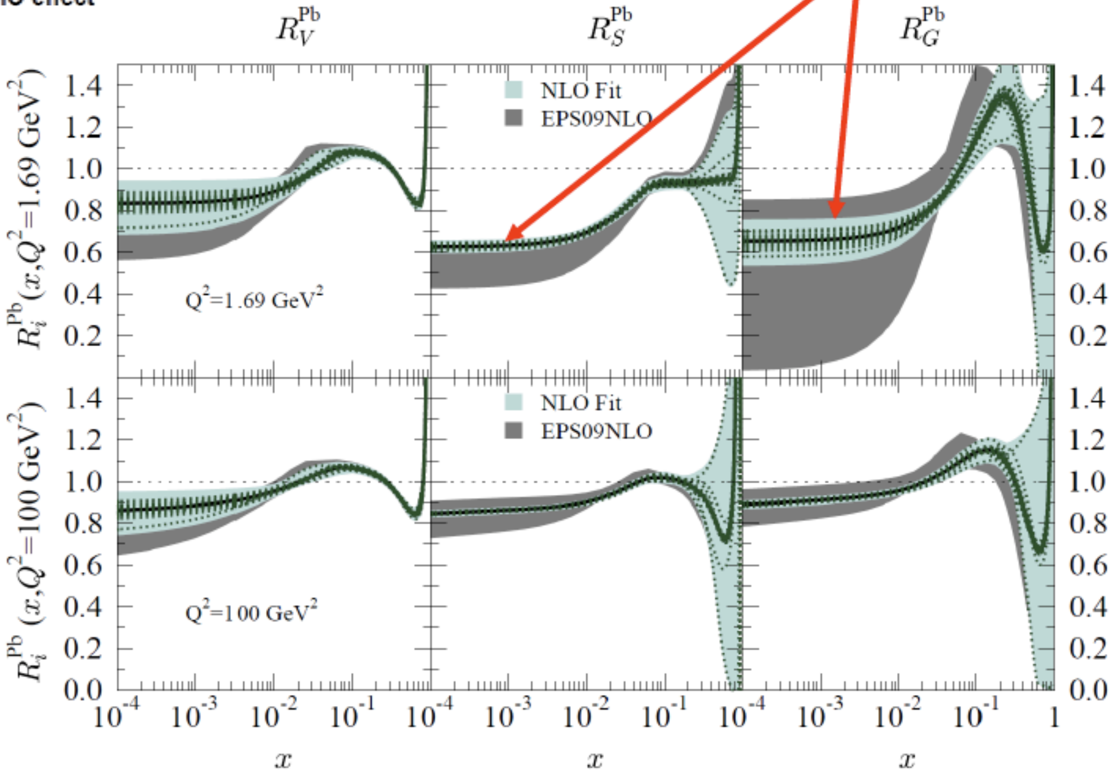


MK, A.Mehta (DIS07)

Nuclear Parton Distributions



Study using eA LHeC pseudodata
Quantitative improvement, but
based on DIS `DATA' for the 1st time



K.Eskola, H.Paukkunen, C.Salgado, Divonne09

Fermi motion ← p tagging

p, D, Ca, Pb

LHeC will have immense impact on the partonic structure of nuclei

→A complete determination of nPDFs in grossly extended range, into nonlinear regime
→ Determination of the initial state of the Quark Gluon Plasma

Physics – Work in Progress

Various subjects are being completed

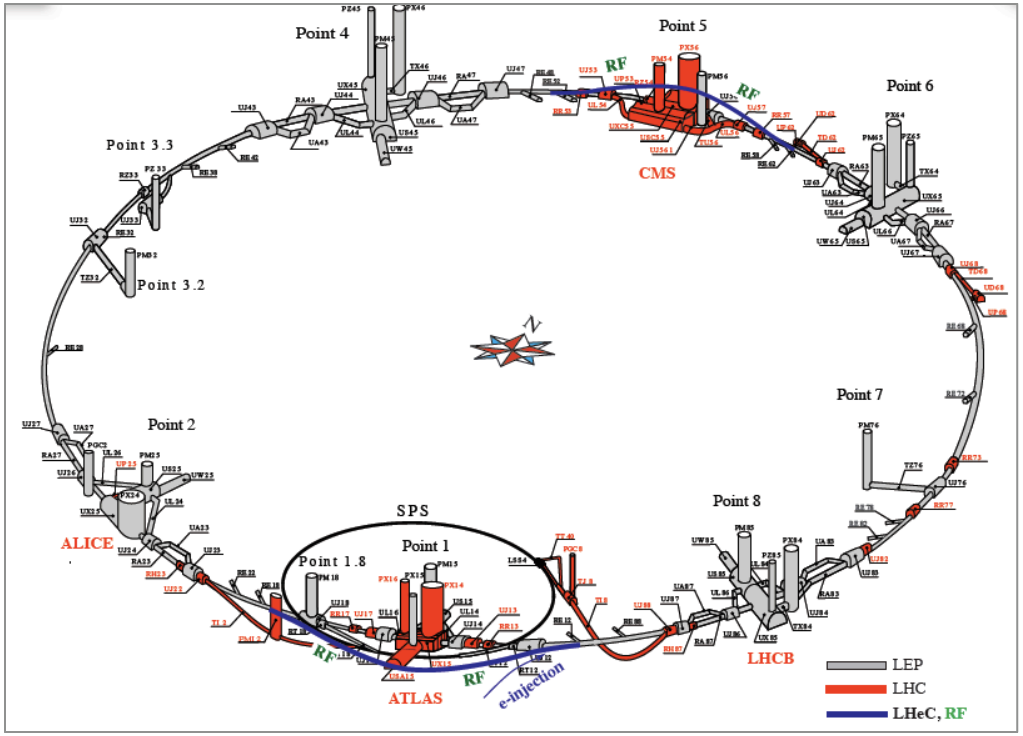
Higgs background
Single top reconstruction
RPVSUSY
4th generation fermions
Photoproduction (real and virtual)
…

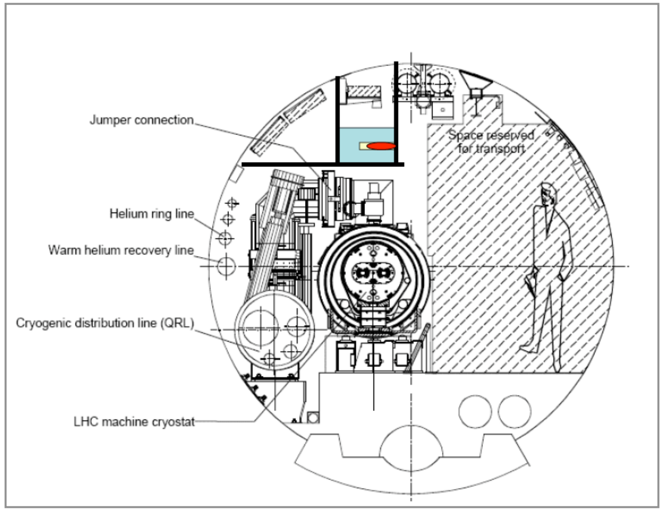
Closer link to detector (Simulation efforts)

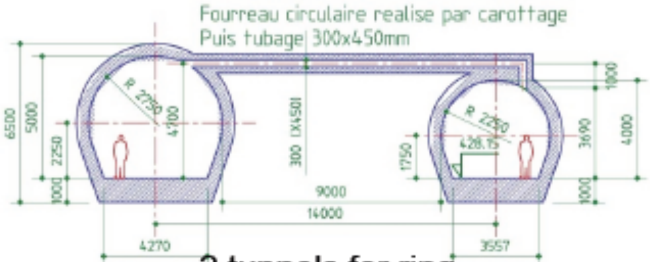
Closer look to LHC-LHeC-ILC/CLIC complementarity

A headline: The world's new microscope?

Ring-Ring ep/eA





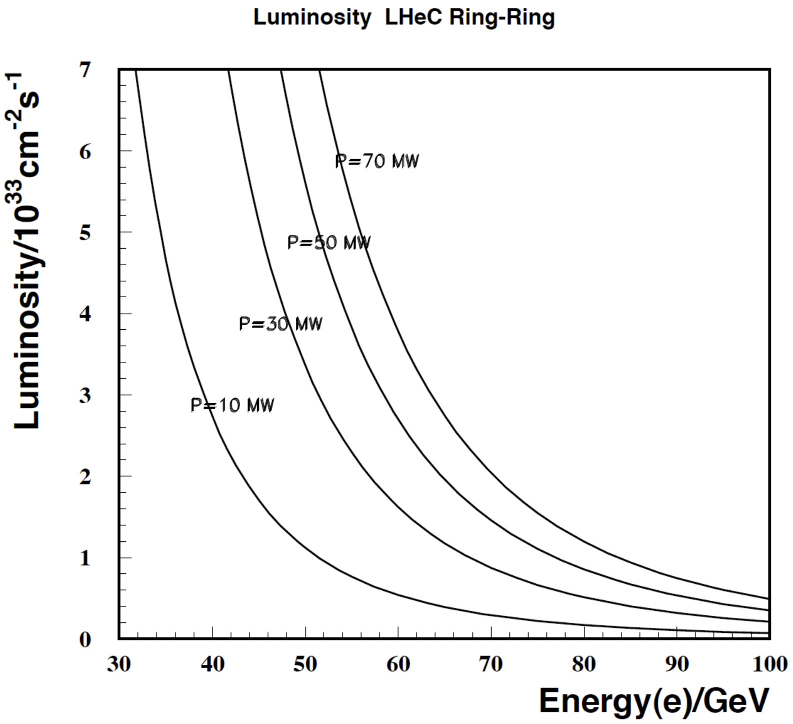


2 tunnels for ring
and shielded rf

E_e=10 … 80 GeV. $L_{ep}\sim10^{33}$cm^{-2}s^{-1} (100 times HERA)

1/x and $Q^2\sim10^{4(2)}$ times larger in eA (ep) than so far

RR Luminosity and Parameters

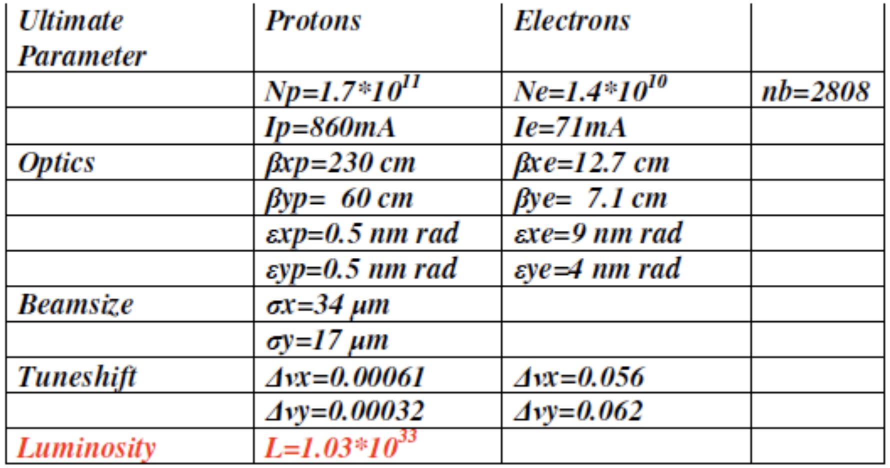


Luminosity for e±p safely above $10^{33}cm^{-2}s^{-1}$

Used “ultimate” LHC beam parameters

Energy limited by injection and rf (<80 GeV)

Power limit set to 100 MW,
below assumed 14 MW beam power only



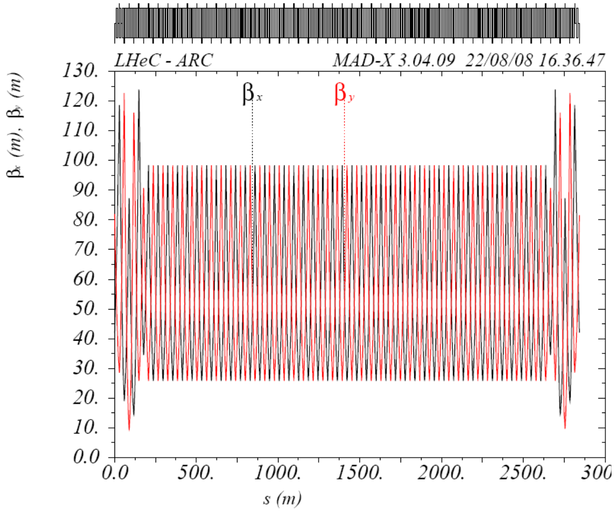
Ultimate Parameter	*Protons*	*Electrons*	
	*Np=1.7*10¹¹* $N_p=1.7*10^{11}$	$N_e=1.4*10^{10}$	*nb=2808*
	Ip=860mA	*Ie=71mA*	
Optics	*βxp=230 cm*	*βxe=12.7 cm*	
	βyp= 60 cm	*βye= 7.1 cm*	
	εxp=0.5 nm rad	*εxe=9 nm rad*	
	εyp=0.5 nm rad	*εye=4 nm rad*	
Beamsize	*σx=34 μm*		
	σy=17 μm		
Tuneshift	*Δνx=0.00061*	*Δνx=0.056*	
	Δνy=0.00032	*Δνy=0.062*	
Luminosity	$L=1.03*10^{33}$		

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

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

e Ring – Optics

Optics in the arcs



β functions for LHeC - 2008

dispersion was 50-90cm

and horiz. emittance 22 nm

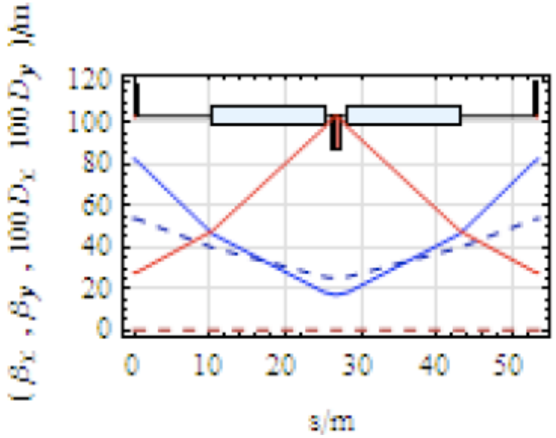
384 60m long cells

2009: optimisation of FODO cell

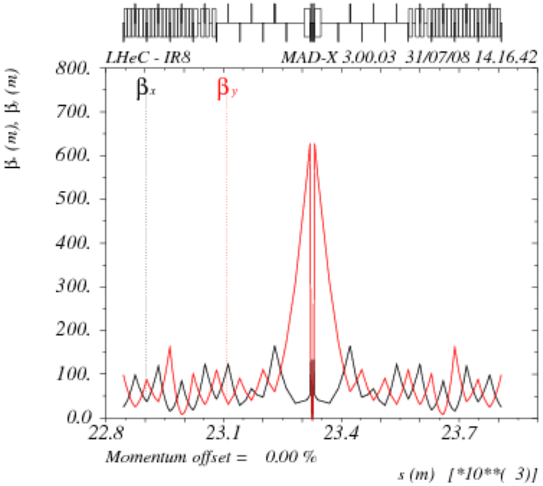
Dispersion reduced to 20-50cm

emittance ε_x=7.5nm ε_y=3.7 nm

MEDIUM FIELD STRENGTH SOLUTION



FODO optimisation

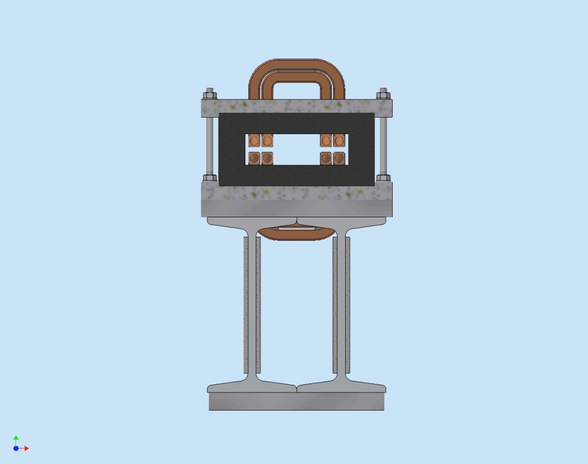


“inner” triplet focus
β_x=7.1cm β_y=12.7cm

Mini beta design

Dipole magnets

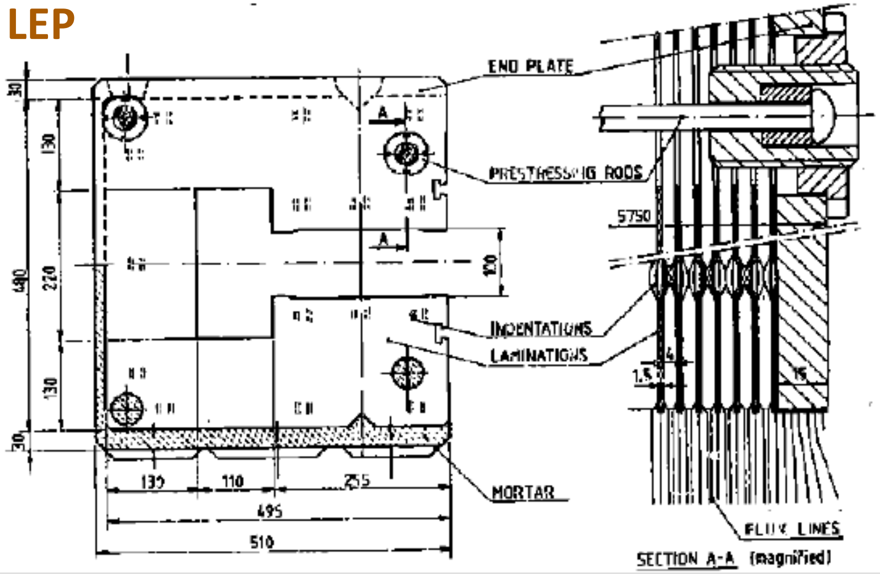
Nominal current at B=0.135 T	A	937
Conductor size (height x width) Diameter of cooling hole	mm	13x13 10
No. of turns		4
Turn length	m	60
Gap height	mm	36
Temperature rise	Deg. C	12
Water flow rate throw all the magnet (P=5 bar)	l/min	7
Total weight	kg	<3500
Maximuum vertical sagitta	mm	0.05



O-shaped magnet with ferrite core
P. Vobly et al Novosibirsk, D. Tommasini, J.Jowett CERN

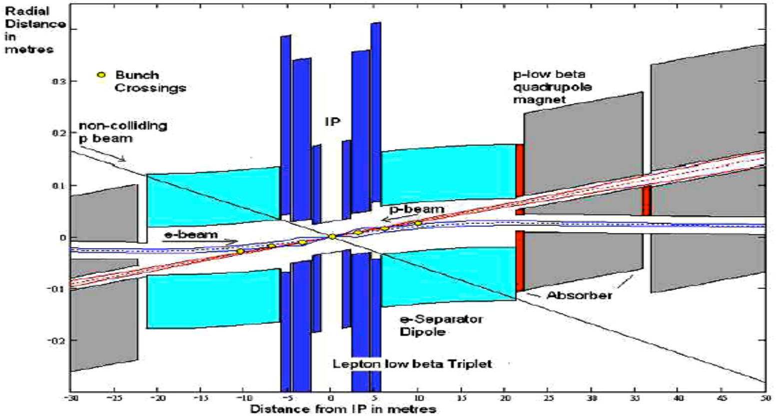
Prototype design under way at BNP Novosibirsk, May 2010

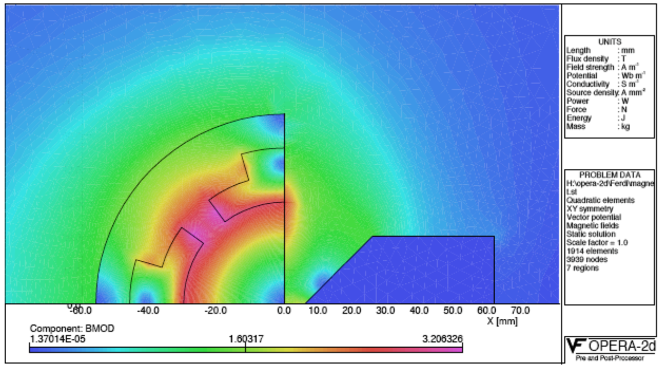
LEP



Ring – Work in progress

Interaction region design



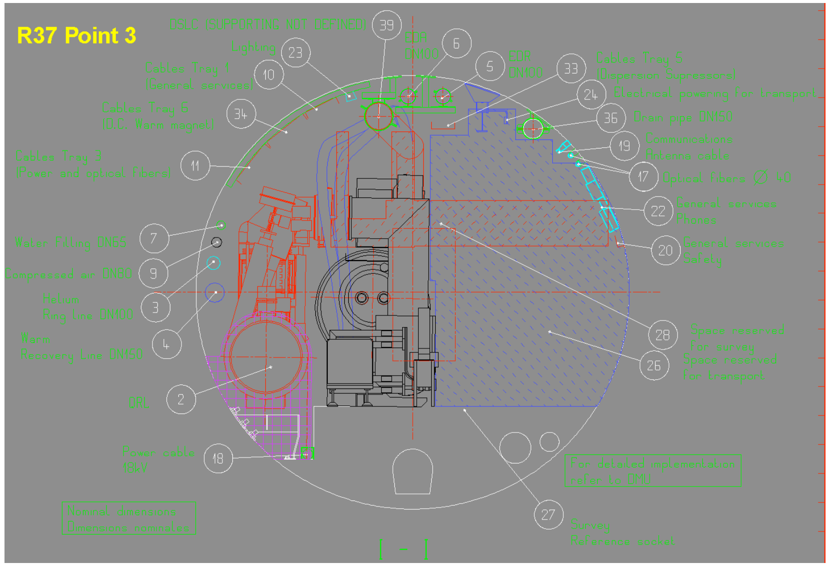


B.Holzer, B.Nagorny, U.Schneekloth, F.Willeke et al

Installation study

Systematic investigation of clashes with LHC installation and possible ways ‘around’

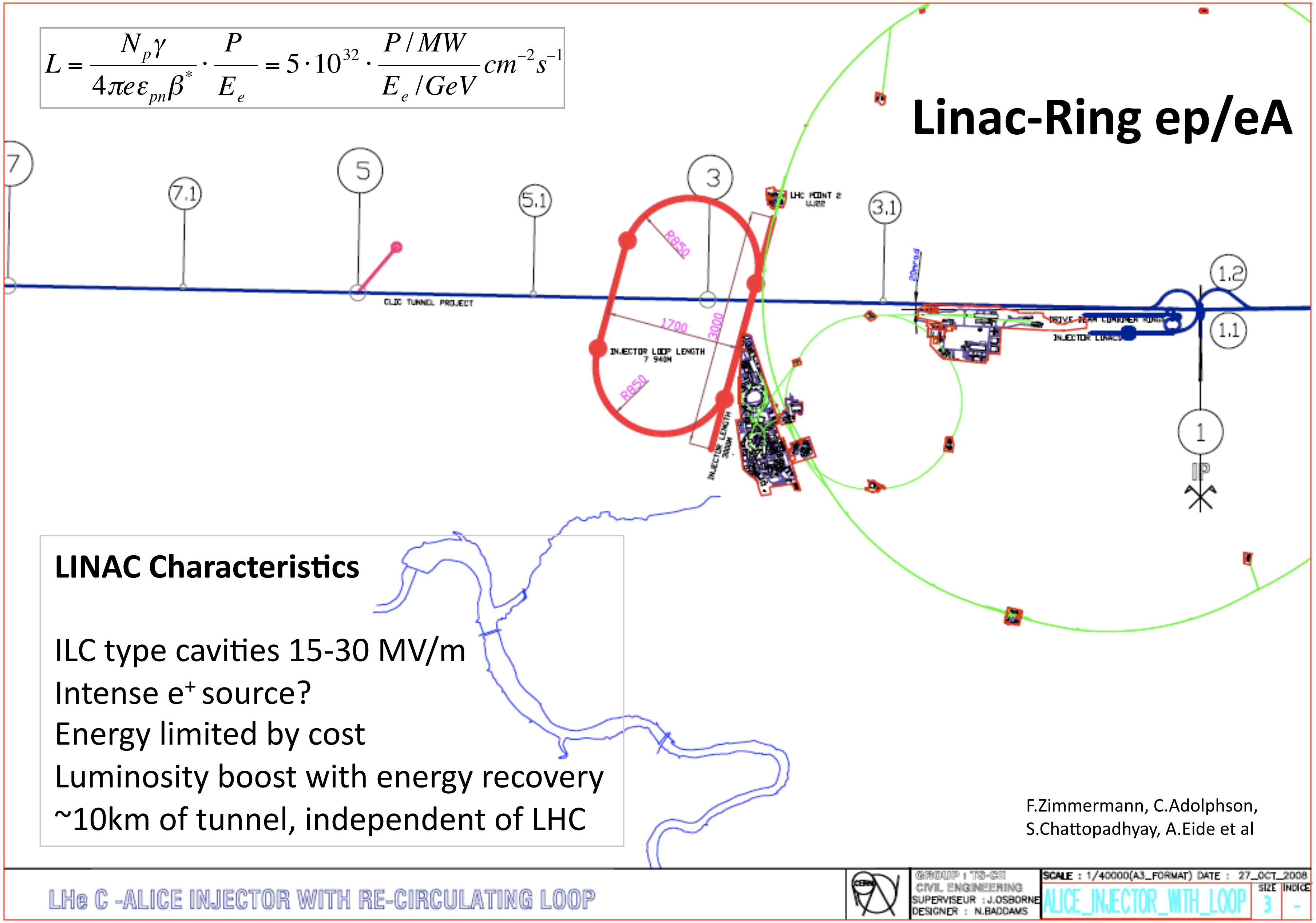
Kh Mess, Y.Muttoni et al



Polarisation

Linac-Ring ep/eA

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$



LINAC Characteristics

ILC type cavities 15-30 MV/m

Intense e$^+$ source?

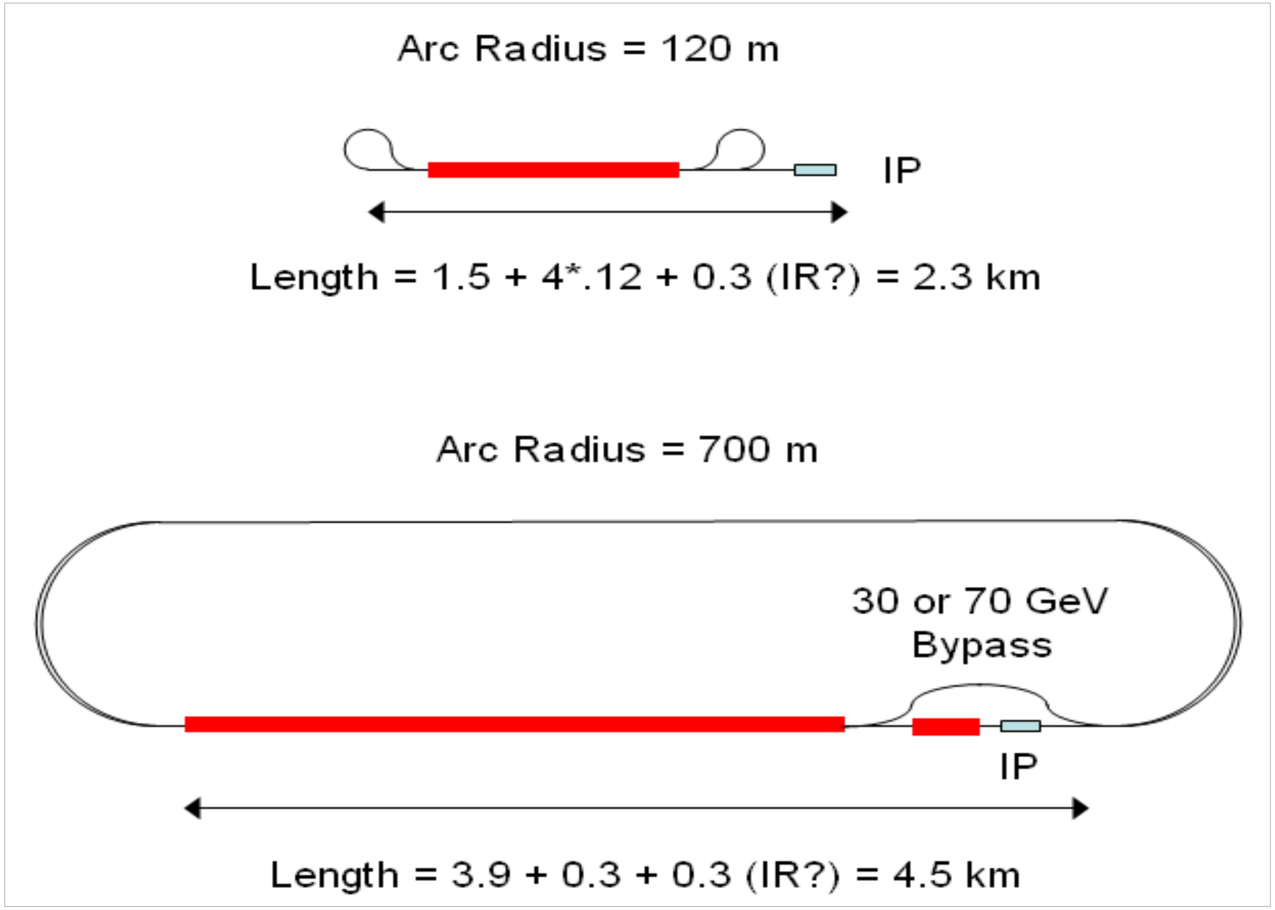
Energy limited by cost

Luminosity boost with energy recovery

~10km of tunnel, independent of LHC

F.Zimmermann, C.Adolphson,
S.Chattopadhyay, A.Eide et al

Three LINAC Configurations



60 GeV
31 MV/m, pulsed
two passes. 2 10^{32}

60 GeV
13 MV/m CW ERL
4 passes 3 10^{33}

140 GeV
31 MV/m, pulsed
2 passes 2 10^{32} $cm^{-2}s^{-1}$

C.Adolphson (SLAC), F.Zimmermann (CERN) et al

A slide on LINAC design work

Being done with Frank

A slide on LINAC work in progress

Being done with Frank

LHeC Detector: version for low x and eA

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn,
2 coils w/o return Fe studied]

Central Detector

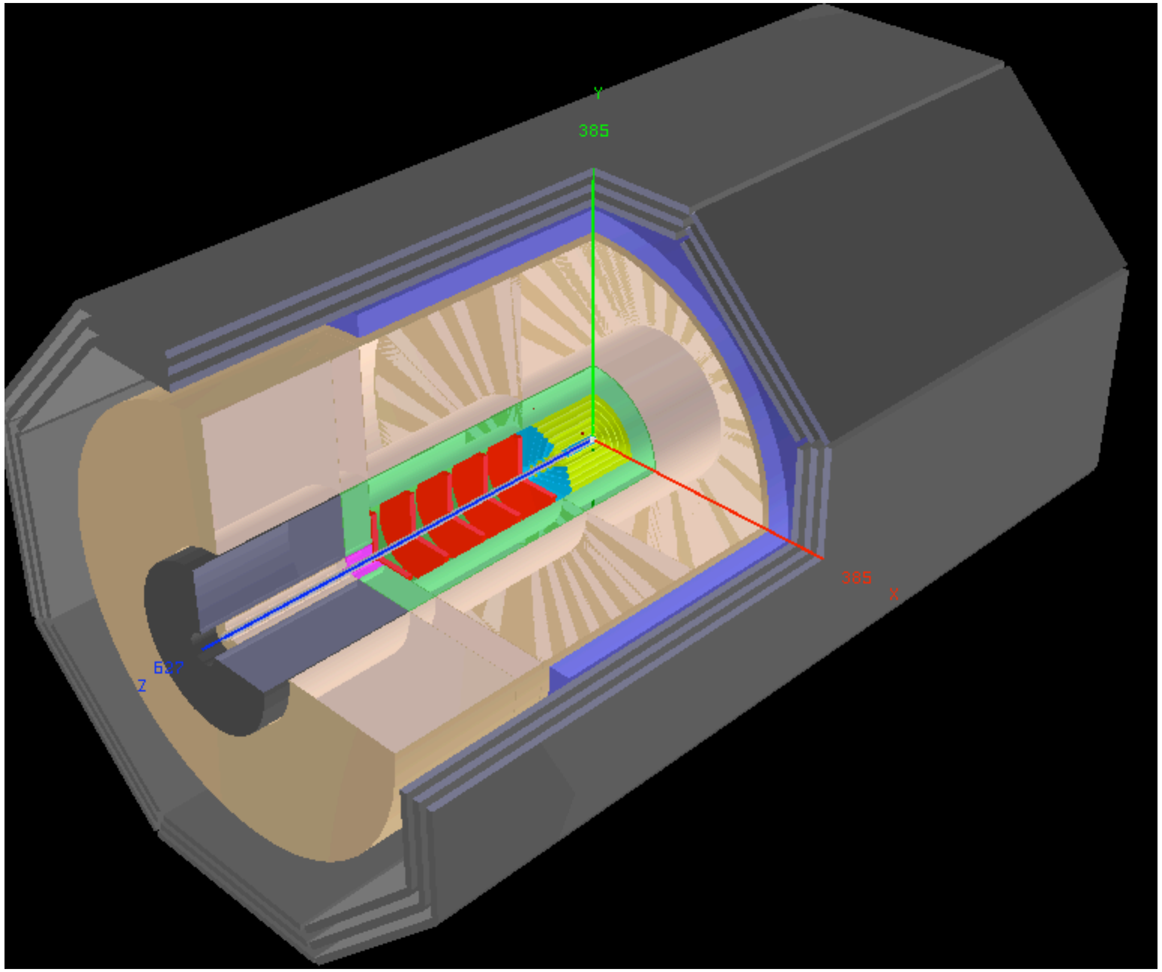
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)



Pkostka, A.Pollini et al., April2009

Extensions in fwd direction (tag p,n,d) and backwards (e,γ) under study.

Completion of the CDR

Steps to go in 2010

1. Finalise physics and technical studies
2. DIS09 [April2010] and IPACC Japan [May2010]
3. Draft CDR June 2010
4. Divonne III – Updates and Discussion with referees
5. November 10: Final report to ECFA
6. Submit CDR to CERN, ECFA, NuPECC

Thanks to many colleagues impossible to listing here, to you, NuPECC and to CERN:

LHeC barack 561 in a protected area

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Swapan Chattopadhyay (Cockcroft)
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Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
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Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Committee

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)

Working Group Convenors

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
Peter Kostka (DESY),
Rainer Wallny (UCLA),
Alessandro Polini (Bologna)

New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

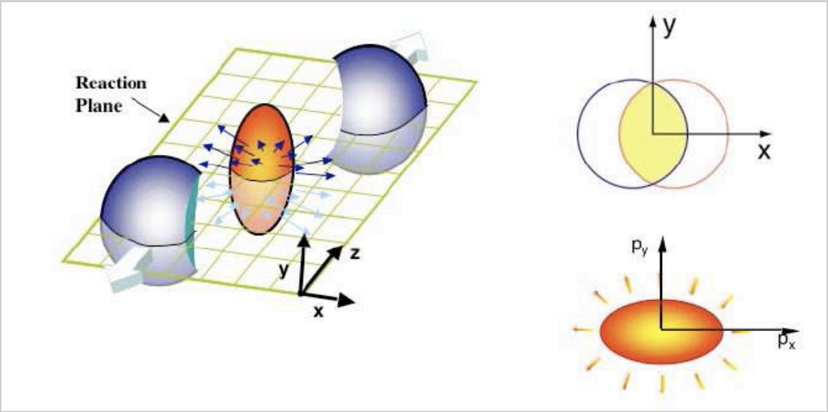
Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)

Physics at High Parton Densities
Nestor Armesto (CERN),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

Backup slides

Quark Gluon Plasma

Landau 1953. **RHIC**: QGP strongly coupled plasma with liquid behaviour
instead of weakly interacting gas of partons



M.Tannenbaum, Rept.Prog.Phys 65 (2006) 2005

Related to cold atoms and to superstring theory [AdS/CFT]

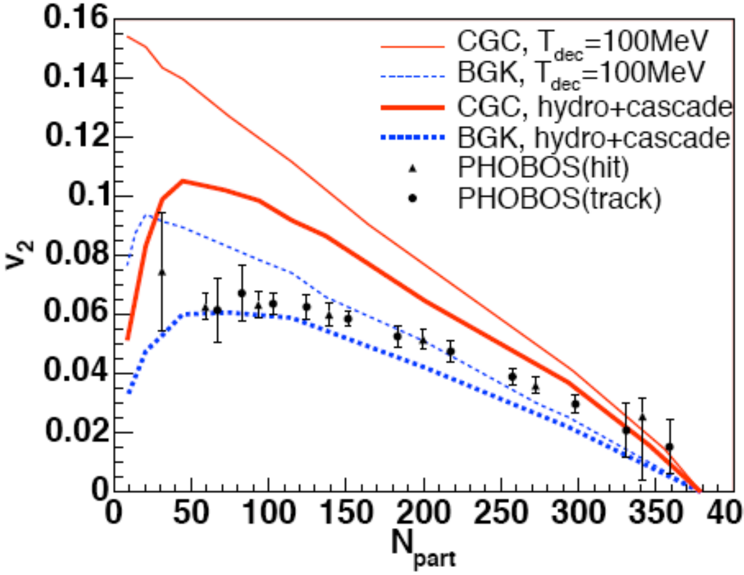
Collective flow in non-central collisions anisotropic

Anisotropy proportional to 1/viscosity of fireball, dominantly elliptic ("v_2" coefficient)

QGP most perfect liquid – smallest shear viscosity/entropy

Conclusions depend on initial fireball eccentricity

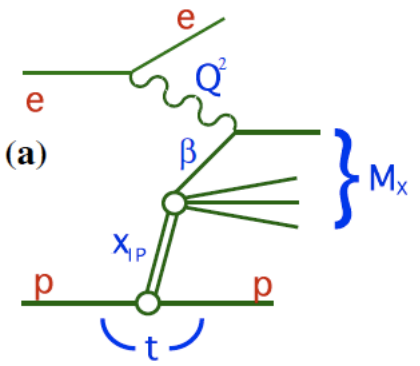
eA to measure the initial conditions of QGP.

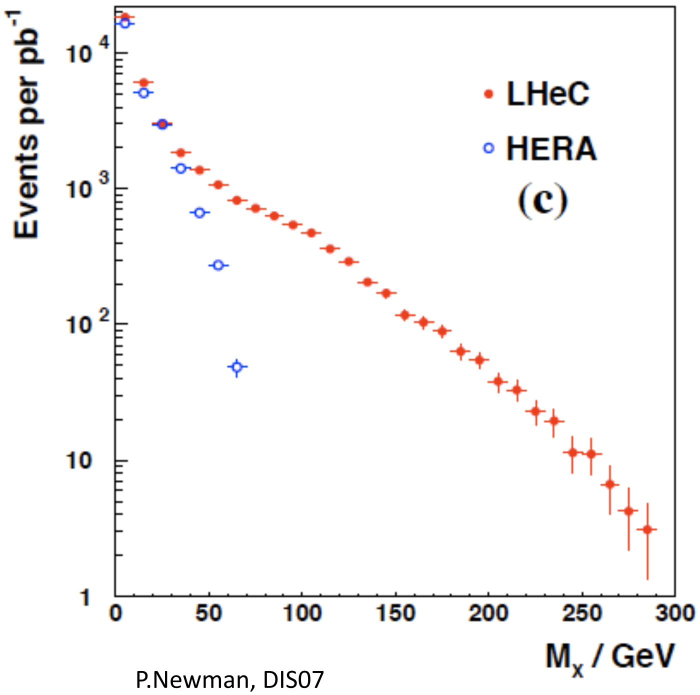


Hirano et al, Phys.Lett.B636(2006)299

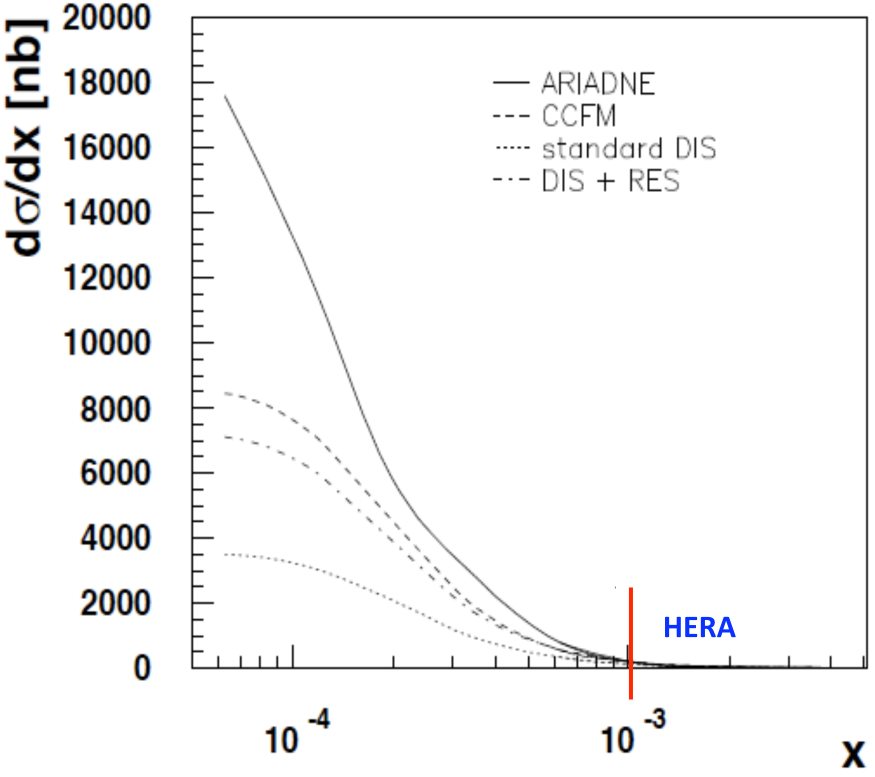
U.Heinz arXiv:0907.4256 (nucl.th)

Quark-Gluon Dynamics - Diffraction and HFS (fwd jets)





P.Newman, DIS07



H.Jung, L.Loennblad, THERA study

Diffraction to accompany (SUSY) Higgs fwd physics at LHC

Understand multi-jet emission (unintegr. pdf's), tune MC's
At HERA resolved γ effects mimic non-kt ordered emission
Crucial measurements for QCD, and for QCD at the LHC