Future of DIS Summary

Conveners: Paul Laycock, Cyrille Marquet, Anna Stasto

Talks in the session

- Yuji Goto
- Abhay Deshpande
- Will Brooks
- Peter Kostka
- Anselm Vossen
- Paul Reimer (1+1ewk)
- Oleg Denisov
- Matthew Lamont (2)
- Alberto Martinez
- Cyrille Marquet
- Heidi Schellman
- Olaf Behnke
- Krzysztof Kutak
- Nestor Armesto
- Juan Rojo
- Eva-Maria Kabuss
- Leonard Gamberg
- Georges Azuelos (ewk)
- Uta Klein (ewk)
- Krishna Kumar (ewk)
- Ilan Ben-Zvi
- John Jowett
- Sergey Levonian
- Yuhong Zhang
- Tanja Horn (spin)
- Jianwei Qiu (spin*)
- Alexei Prokudin (spin)
- Michael Klasen (spin*)
- Akitomo Enokizono
- Thia Keppel
- Sebastien Procureur

14 in-person + 16 EVO + 3 canceled = 33 total

* summarized in the spin session

What is the Future ?

LHeC

High energies

New physics: leptoquarks, excited fermions,compositeness, SUSY. Small x , saturation, diffraction, hard QCD, electroweak

LHeC, EIC, MINERvA, COMPASS, E-906/Seaquest

Various targets and projectiles

Nuclear structure, medium modification of parton fragmentation and hadron formation. Neutrino interactions. Small x and high parton density.

EIC, COMPASS

Spin

Relation between SIDIS and DY, Sivers func. Boer-Mulders func, 3-dim. imaging. Exclusive processes, GPD's, TMD's etc.

LHeC

LHeC

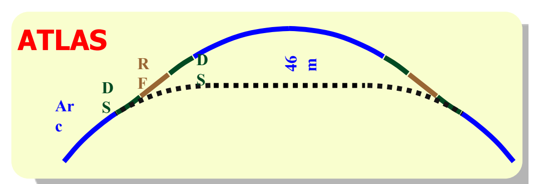
LHeC is a proposed colliding beam facility at CERN. It will collide the existing LHC 7 TeV proton beam with the new electron beam. The operation of LHeC will be simultaneous with the existing proton-proton LHC experiments.

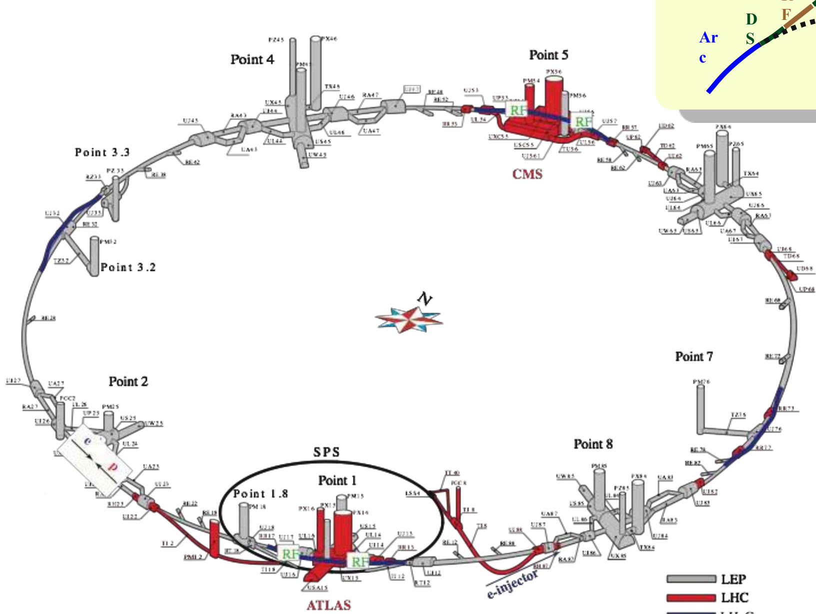
Machine design

Ring-Ring

Overall Layout and Bypasses

e-p/A experiment could be at IP2 (shown) or IP8





"LeR" = electron ring of LHeC

To be done:

Detailed design of CMS and ATLAS bypasses and integration into optics

Bypass design:

- shutdown time
- cost for tunnel
- match LHC and LeR circumference ? Or leave ΔC ~ 1 m ?

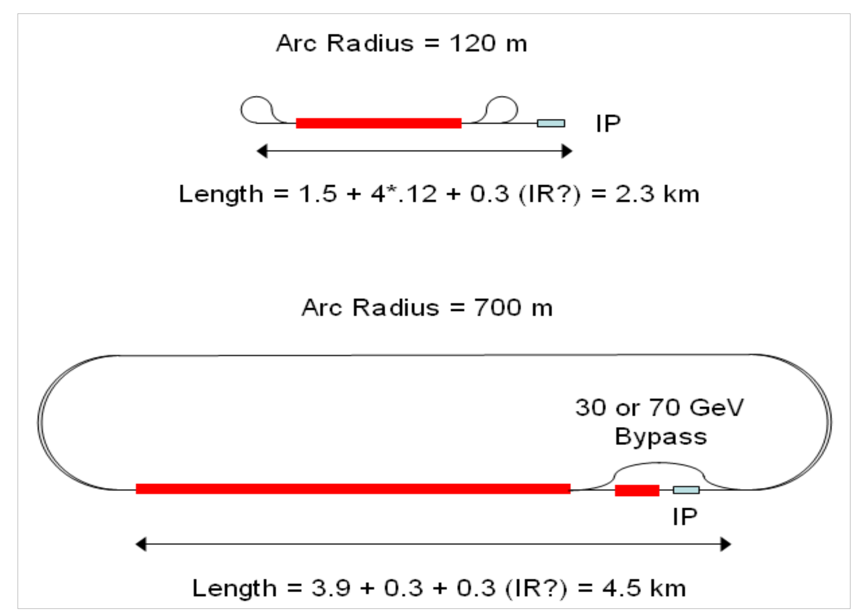
Higher luminosity

Lower energy

Lower power

Linac-Ring

Two LINAC Configurations [CERN-SLAC]



60 GeV
31 MV/m, pulsed
two passes

60 GeV
13 MV/m CW ERL
4 passes

140 GeV
31 MV/m, pulsed
2 passes

Lower luminosity

Higher energy

Higher power

Talk by John Jowett

Detector design

Luminosity and acceptance depend of course on the type of physics program one wants to focus on.

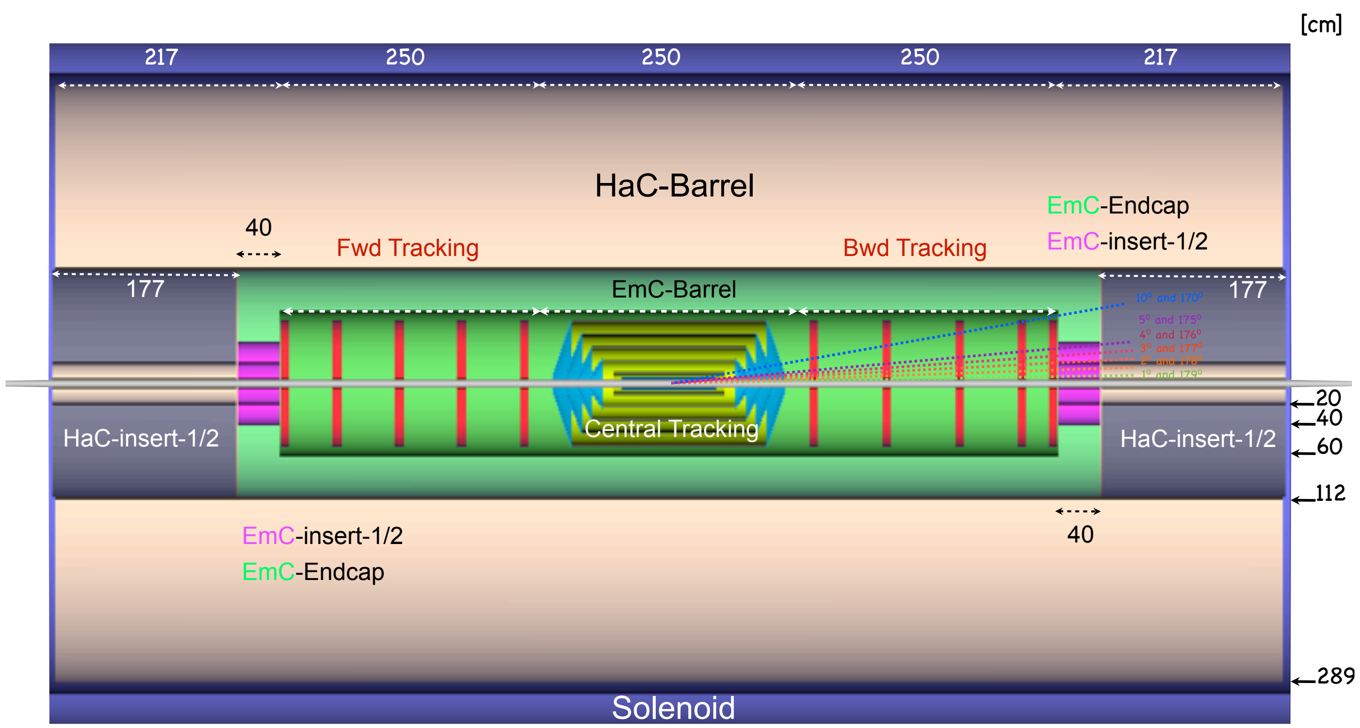
$1^o - 179^o$ acceptance (9 units in η)

at $L = 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

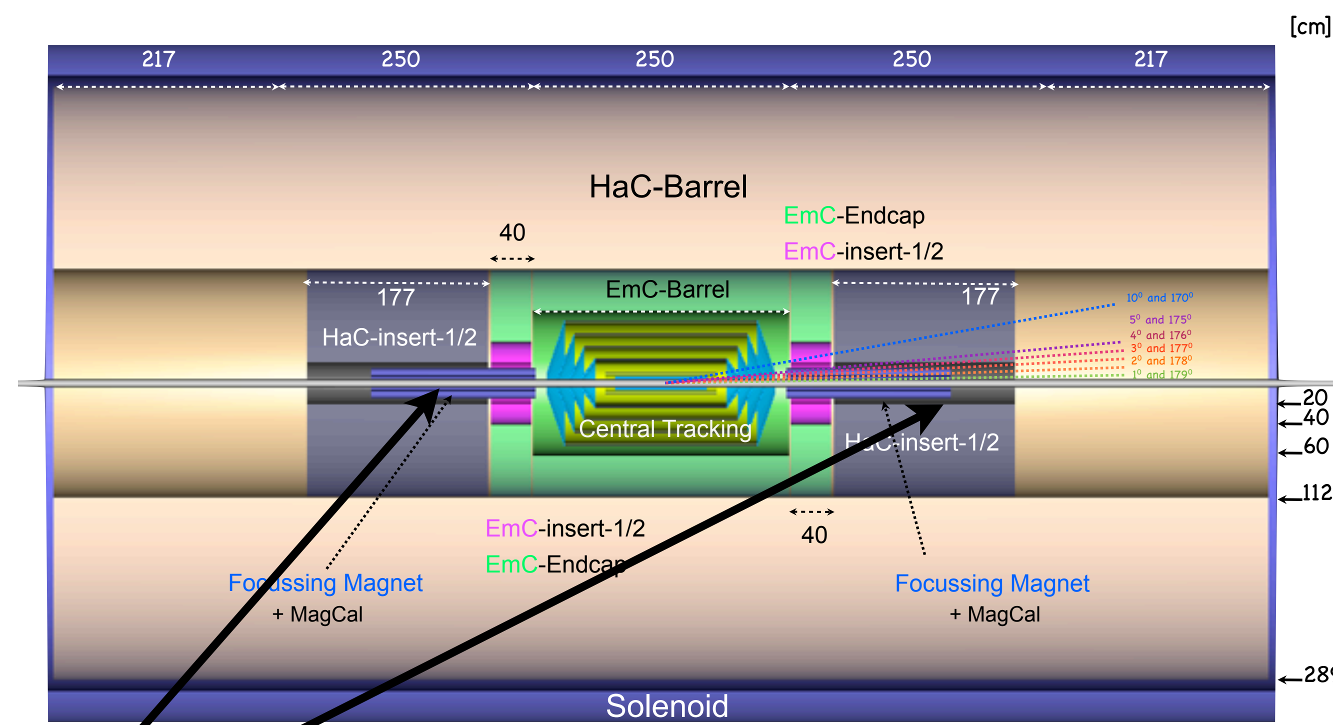
$10^o - 170^o$ acceptance (5 units in η)

at $L = 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

The Detector - Low Q² Setup



The Detector - High Q² Setup



strong focusing magnet system

Talk by Peter Kostka

LHeC

The Detector - Low Q^2 and eA

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=11.8m, 3.5T)
[Return Fe not drawn]

Central Detector

Pixels
Elliptic beam pipe (~3cm - or smaller)

Silicon (fwd/bwd+central)
[Strip or/and Gas on Slimmed Si Pixels]
[0.6m radius for 0.03% * p_t in 3.5T field]

El.magn. Calo (Pb,Scint. $30X_0$)
Hadronic Calo (Fe/LAr; Cu/Brass-Scint. 9-12λ)

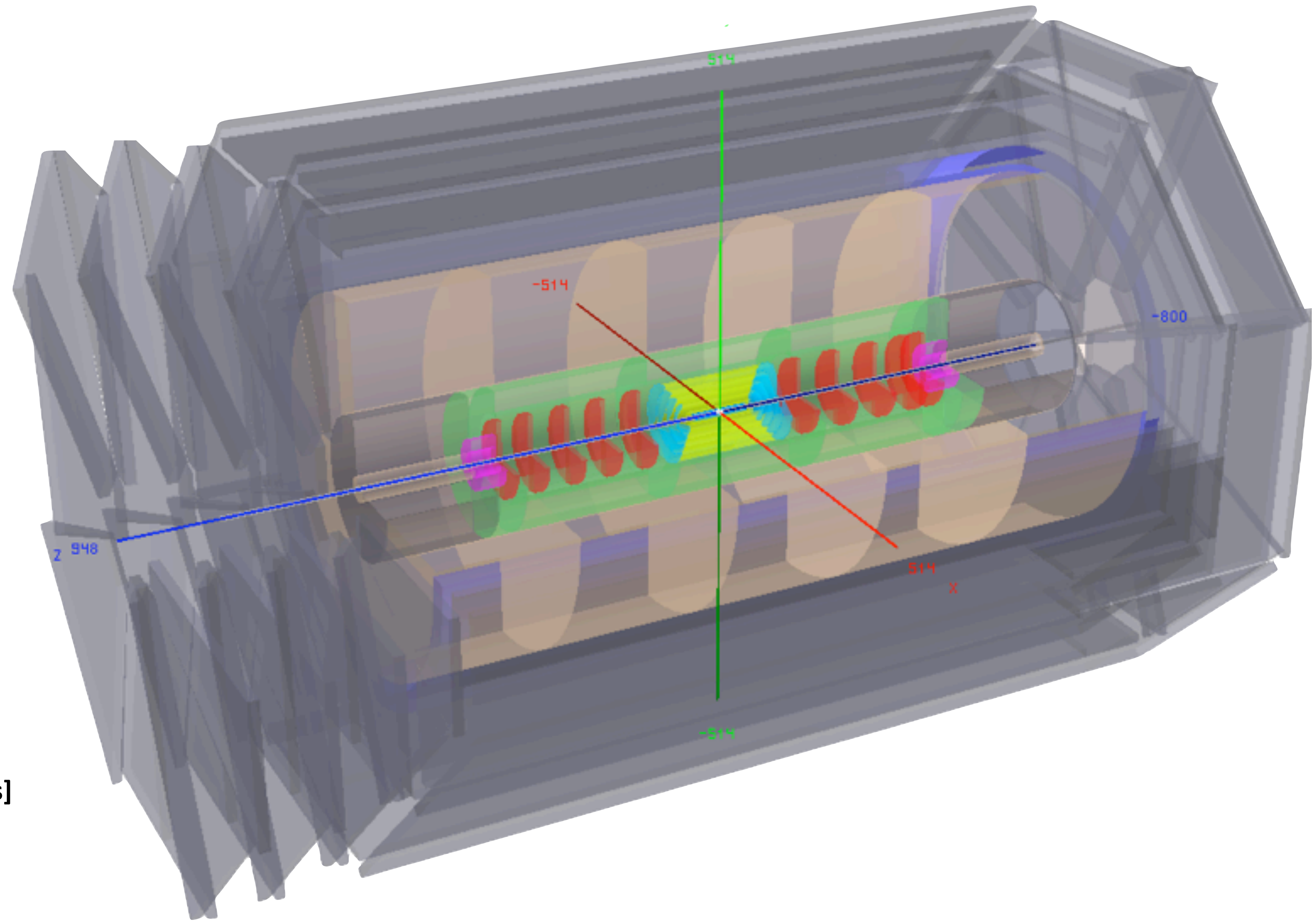
Fwd Detectors

(down to 1°)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]

Calice (W/Si); dual ReadOut - Elm Calo
FwdHadrCalo:
Cu/Brass-Scintillator

Bwd Detectors

(down to 179°)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]
Cu/Brass-Scintillator,
Pb-Scintillator (SpaCal - hadr, elm)

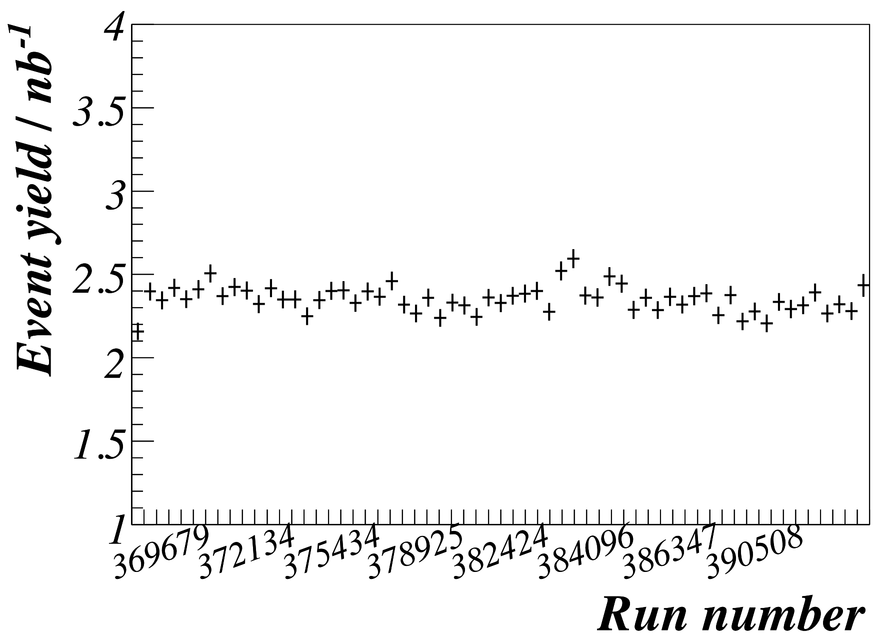


Talk by Peter Kostka

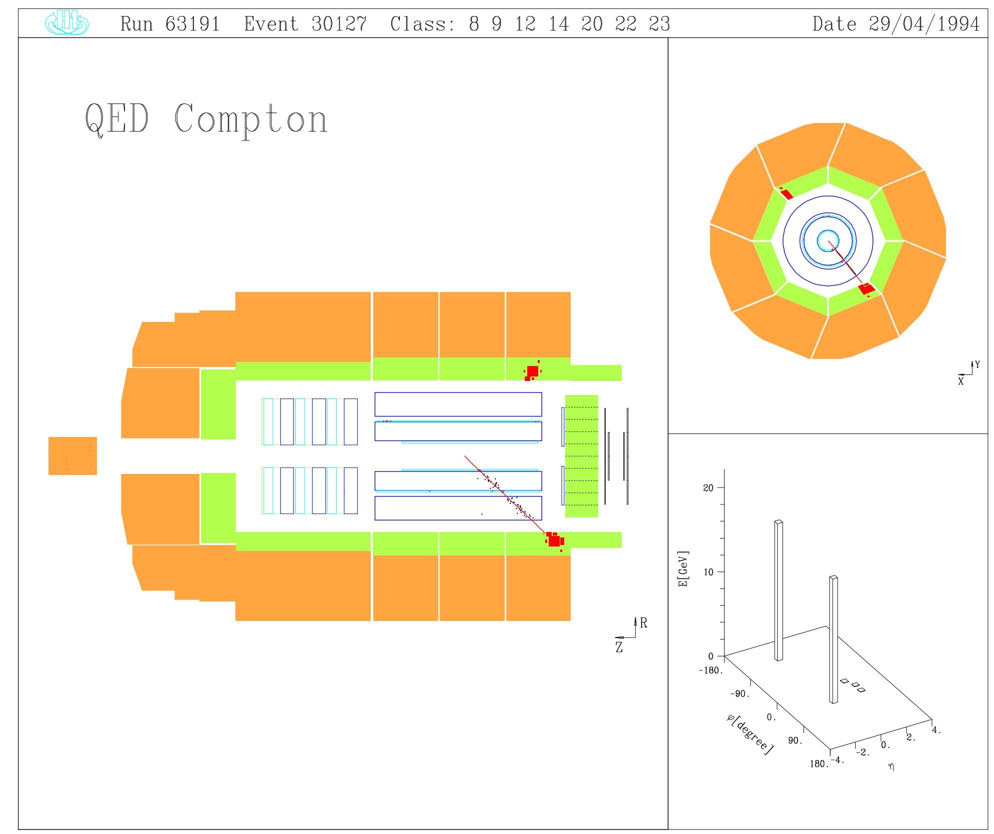
LHeC

Luminosity measurement at LHeC

10 **Examles from HERA**



High Q^2 NC DIS



Precision: $1-2\%$ (F_2), 2% (QEDC)

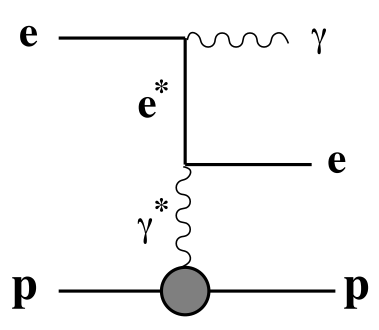
LHeC MC study: (using H1 analysis strategy)

Generator:	DJANGOH ($0.05 < y < 0.6$)	COMPTON MC (elastic part)
high Q^2 setup:	$\sigma_{vis} \simeq$ 10 nb	$\sigma_{vis} \simeq 0.025$ nb
low Q^2 setup:	$\sigma_{vis} \simeq 150$ nb	$\sigma_{vis} \simeq 3$ nb
Rate (stat.err):	$1.5-10$ Hz ($\delta\mathcal{L} \simeq 1\%$/hour)	$0.025-0.03$ Hz ($\delta\mathcal{L} \simeq 0.5\%$/month)

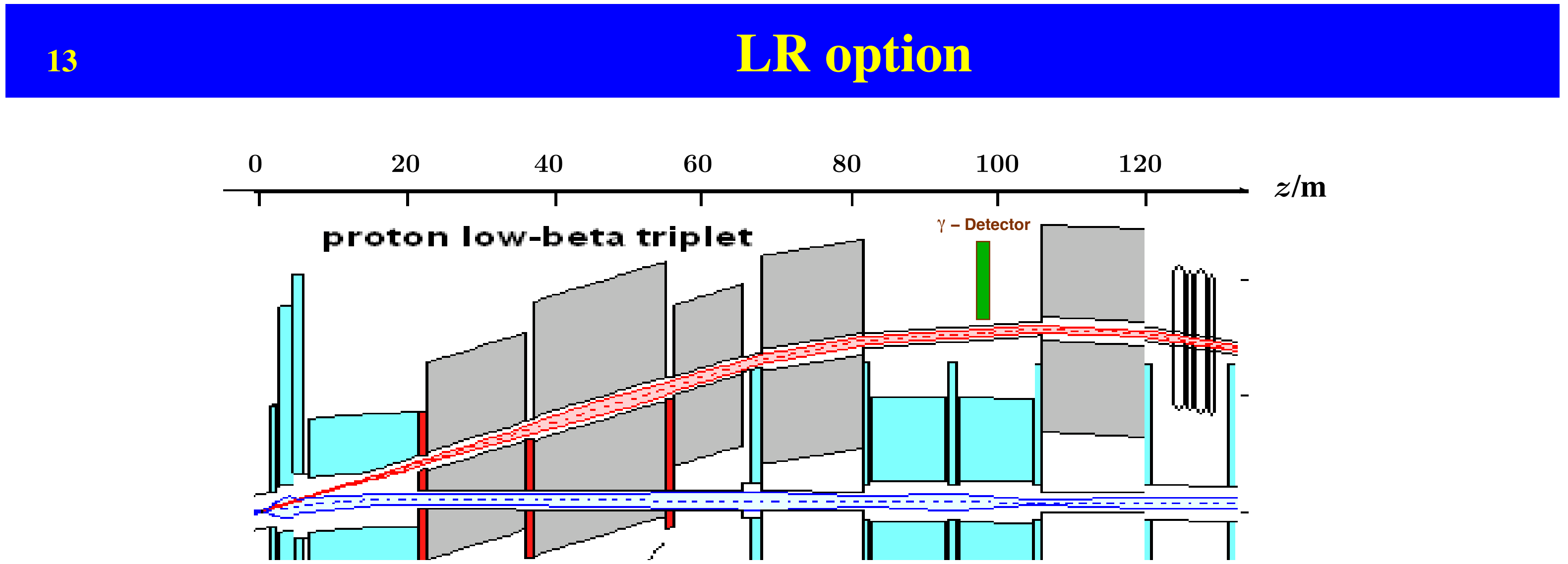
- Good control of the e-beam optics at the IP is essential to monitor acceptances of the tunnel detectors at 5% level

Talk by Sergey Levonian

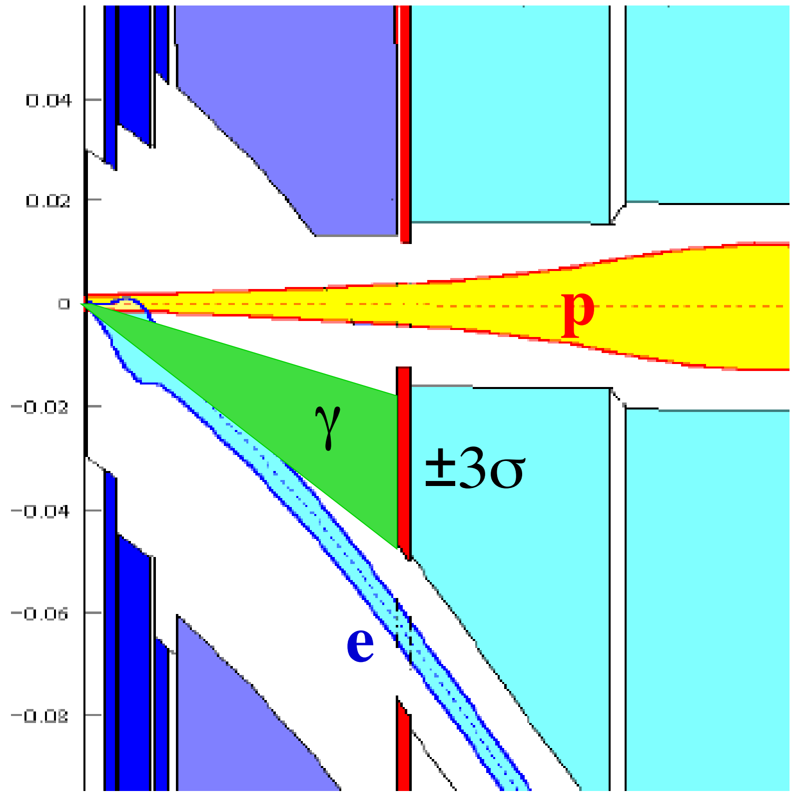
Luminosity measurement at LHeC



B-H process: $\sigma(E > 8) = 112$mb
(poles in both e^* and γ^* propagators)



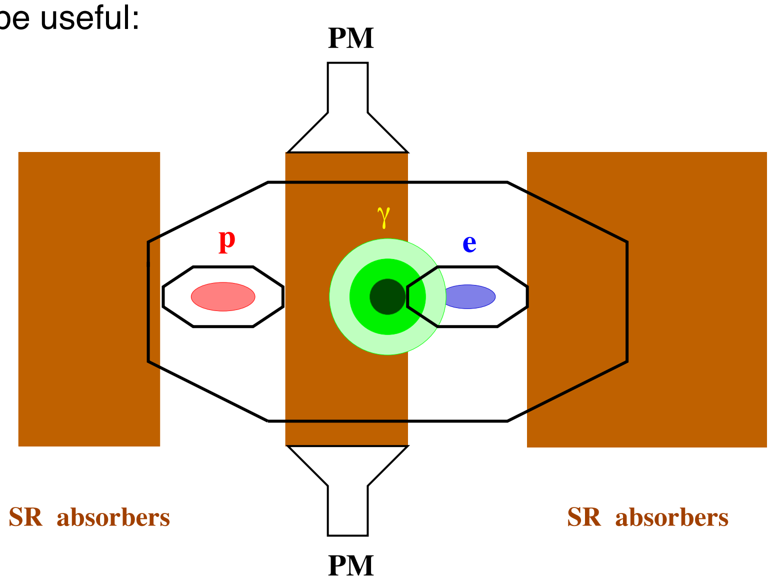
RR option



- BH spot at the hottest place

BH-photon detector integrated into SR absorber

- Cooling system with $10-15$ cm long water bath acting as Čerenkov radiator for BH γ's
- Radiation hard, (almost) insensitive to SR
- Optimisation of crossing angle might be useful:
  Version **A:** acceptance $\simeq (84 \pm 2)\%$
  Version **B:** acceptance $\simeq (10 \pm 1)\%$
- Exact BH counter design and R/O still to be worked out
- Accurate acceptance control requires precise beam tilt monitoring (10-15% of the x-angle)



$\delta L = 3 - 10\%$

Talk by Sergey Levonian

What are the running scenarios?

Simulated Default Scenarios, April 2009

Max Klein

http://hep.ph.liv.ac.uk/~mklein/simdis09/lhecsim.Dmp.CC, readfirst

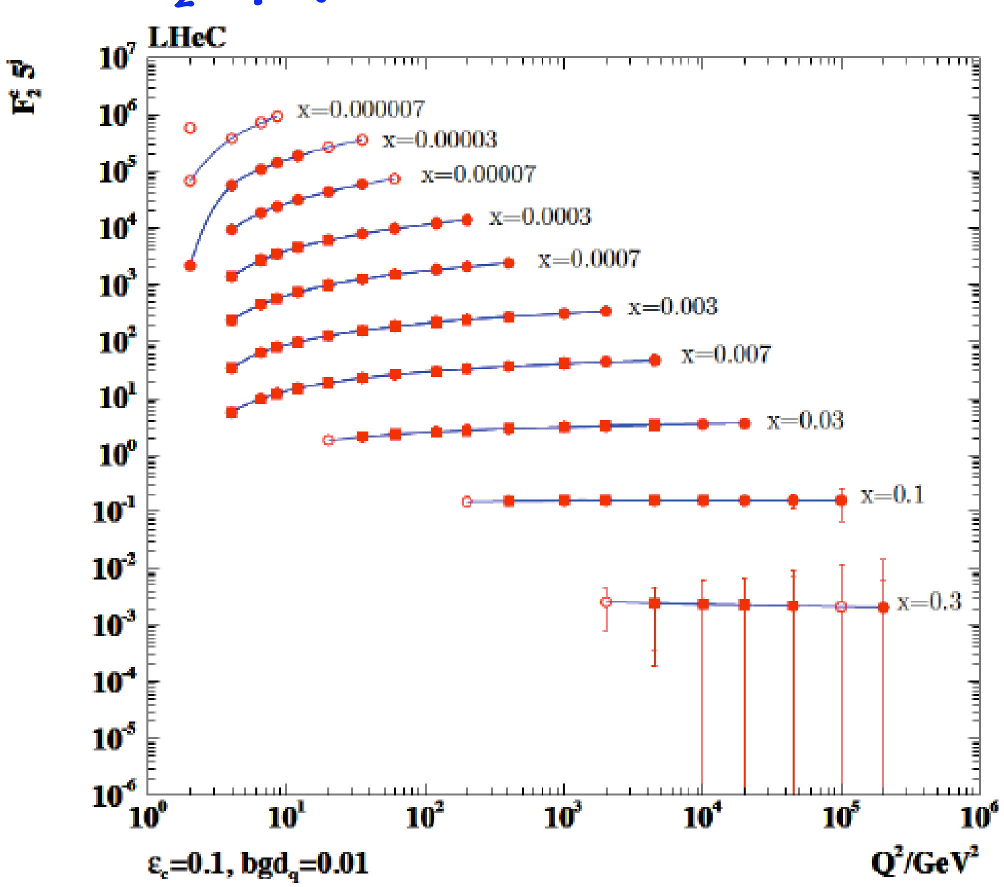
config.	E(e)	E(N)	N	∫L(e^+)	∫L(e^-)	|Pol|	L/10^{32}	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

LHeC Unfolding the parton structure of the proton

The LHeC has the potential to completely unfold the partonic content of the proton: u,d, c,s, t,b and the gluon in an unprecedent kinematic range. This is based on inclusive NC, CC cross sections complemented by heavy quark identification. The (almost) whole p structure which the LHC assumes/needs to know will become accuralely determined.

F_2^{cc} projected LHeC results (only QPM like part):

Max Klein



Systematic error dominates (so far 3%)

Precise measurement near threshold and up to 10^5 GeV²

F_2^{cc} will become precision testing ground for QCD and proton structure

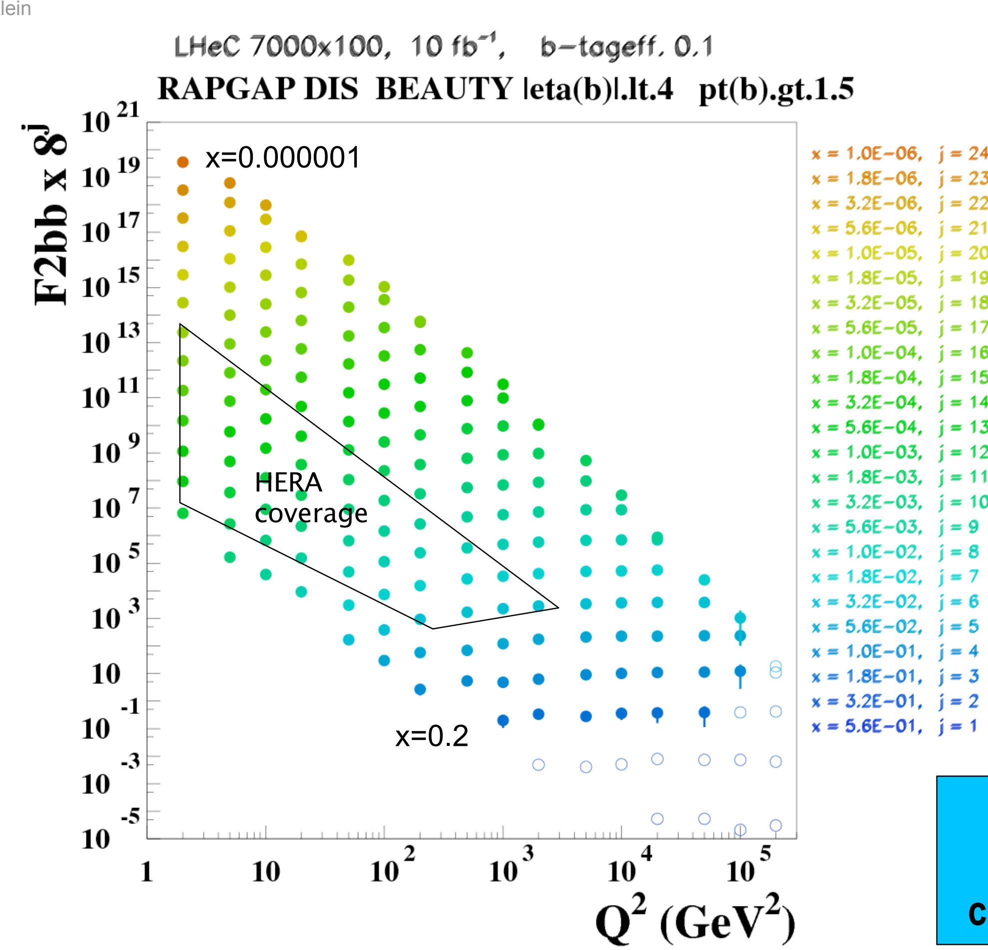
open: 1°

closed: 10°

box: 1 TeV

xF_3, $F_2^{cc,\gamma Z}$? → charm NC couplings

20



Beauty in DIS

O.B.

Largely extended phasespace compared to HERA

Talk by Olaf Behnke

Constraining the PDFs

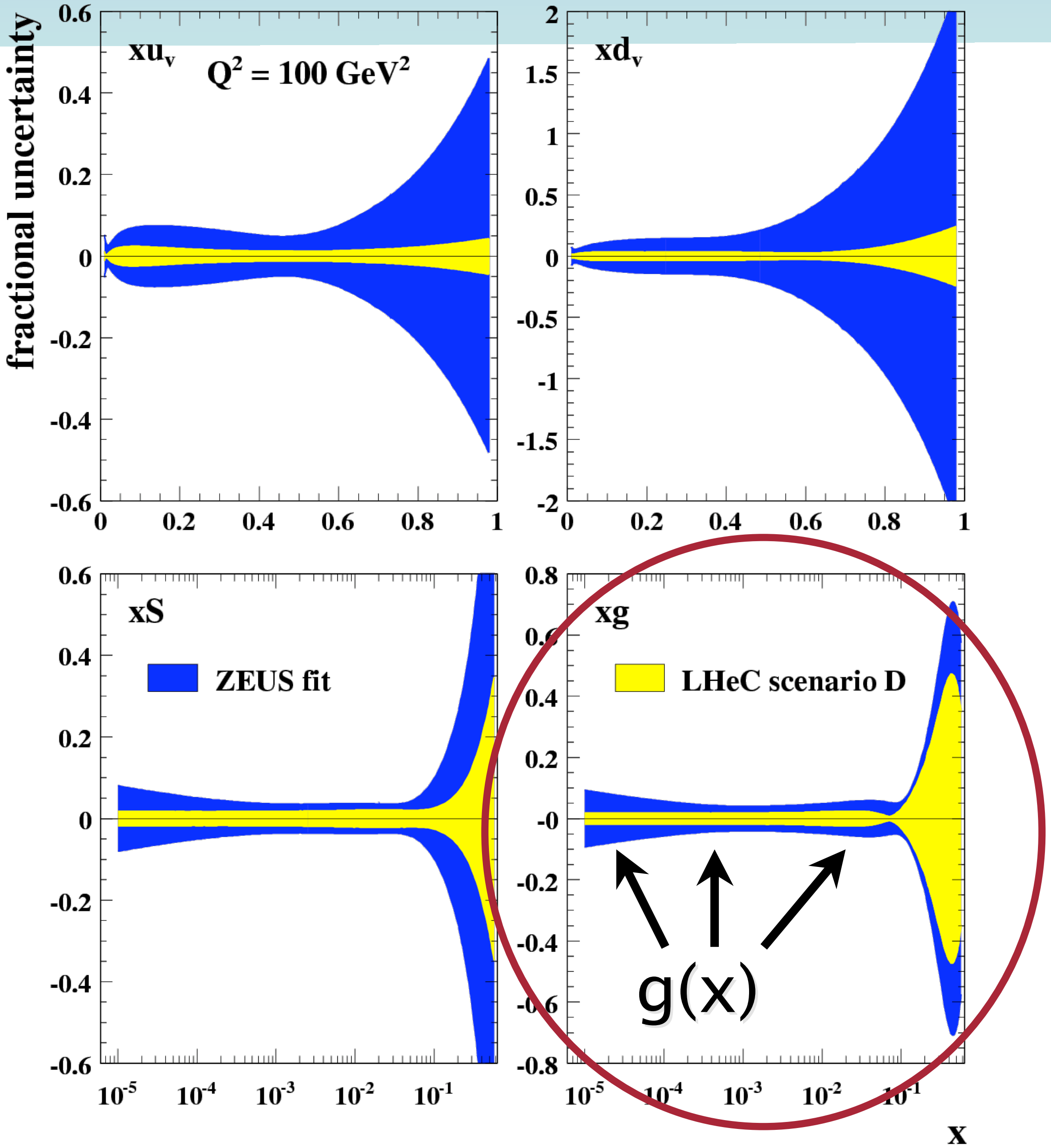
Proton PDFs

Claire Gwenlan

» only PDF parameters free (LHeC **NC** and **CC** $e^{\pm}p$ included)

$Q^2 = 100$ GeV^2

scenario D



Looks very promising, model and parameterisation uncertainties to be studied

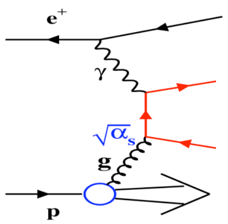
☺ ☺ ☺

Talk by Olaf Behnke

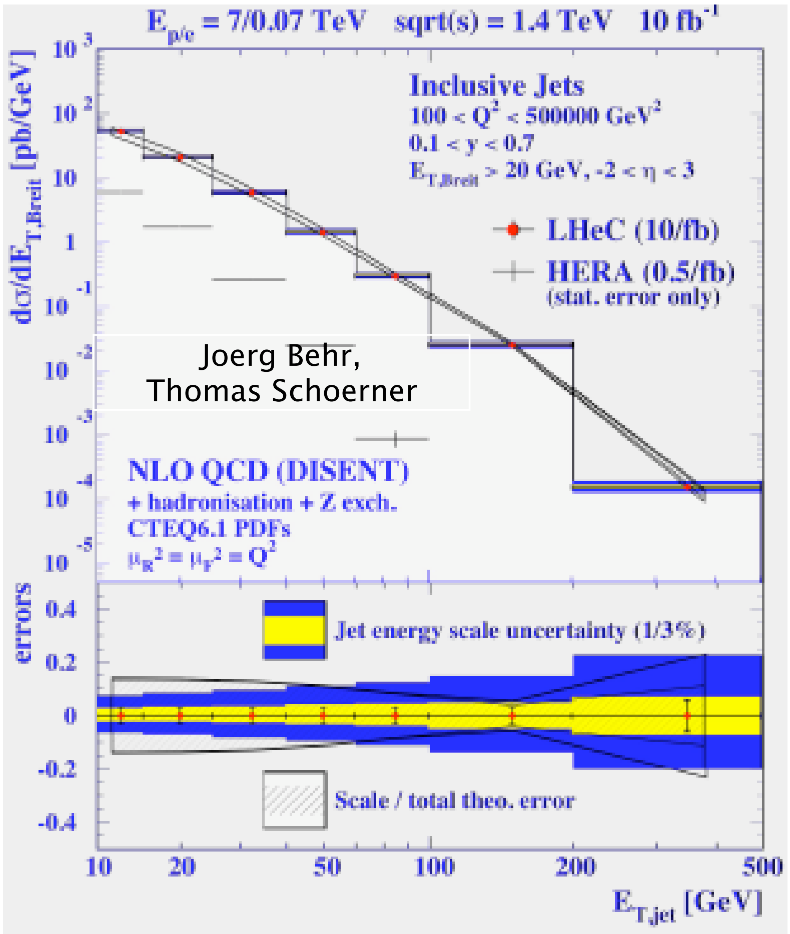
Hard QCD

The LHeC is the ultimate clean precision tool for hard QCD physics:
- **α_s measurements at the permille level from inclusive and jet data**
- **charm and beauty: understand/control the treatment of mass in pQCD calculations**
- **High pt jets: also sensitive to proton and photon structure**

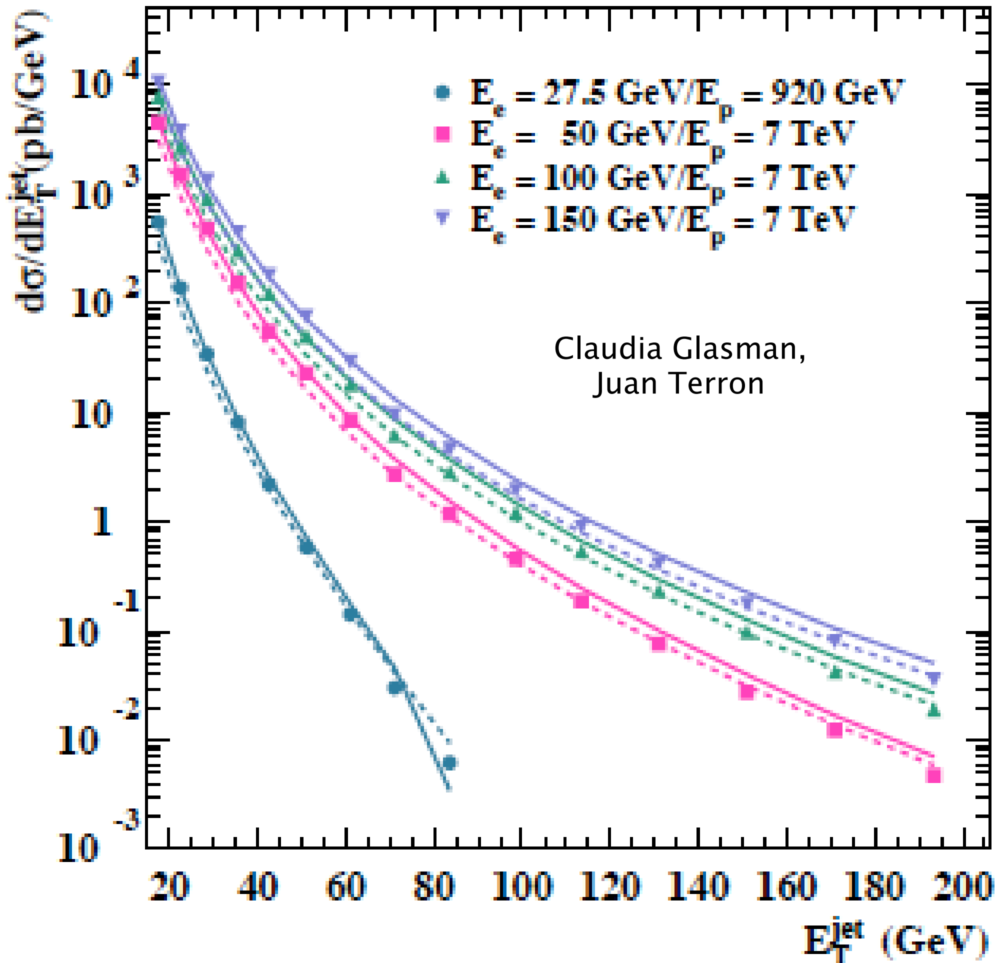
Jet production



DIS



Photoproduction



Reach scales up to 2m_t where change of $1/\alpha_s$ slope is expected

Talk by Olaf Behnke

LHeC

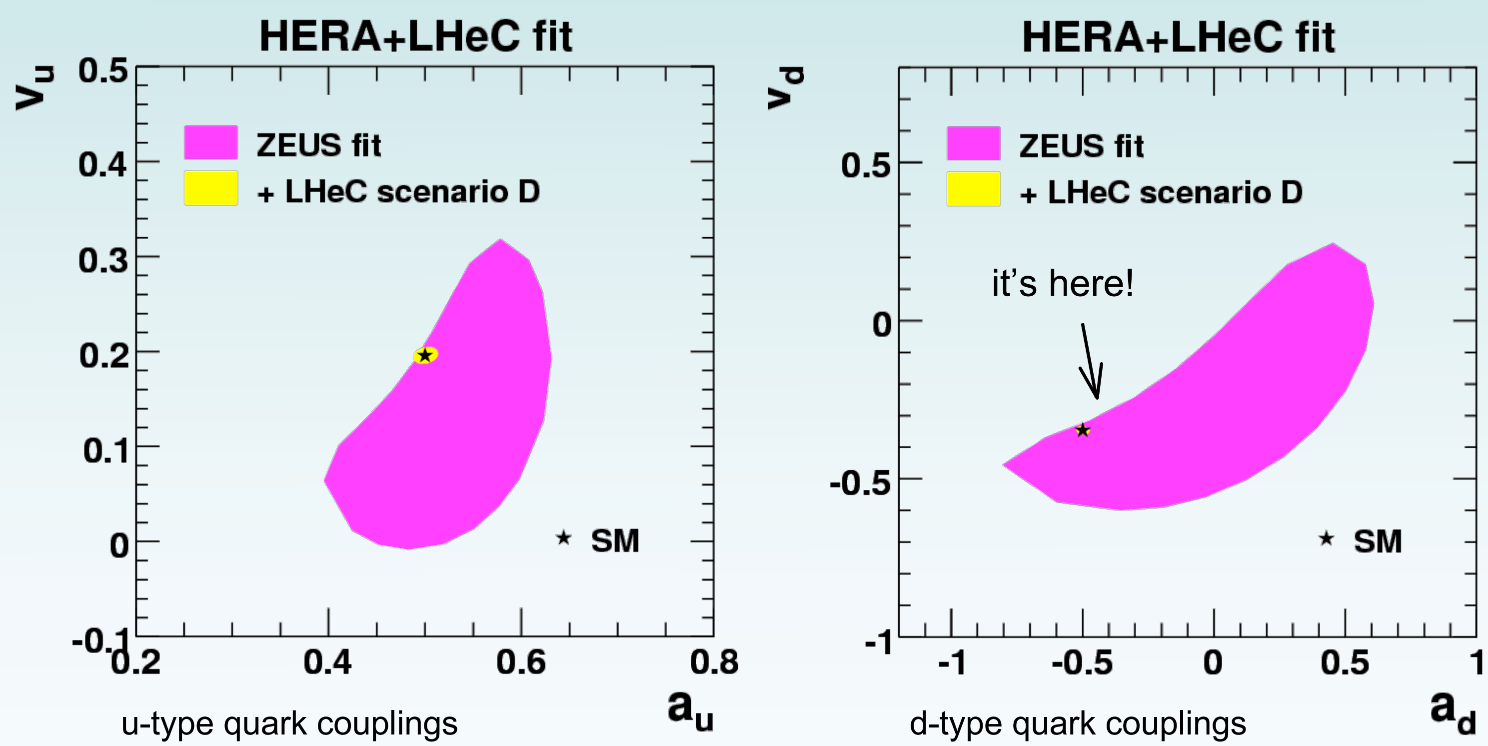
Electroweak Physics

Electroweak high precision SM tests in the t-channel, especially for and with u and d quarks

Electroweak physics: quark couplings to Z0

scenario D: $P_e = \pm 0.9$

comparison with **ZEUS fit** (base to which LHeC pseudo-data added)



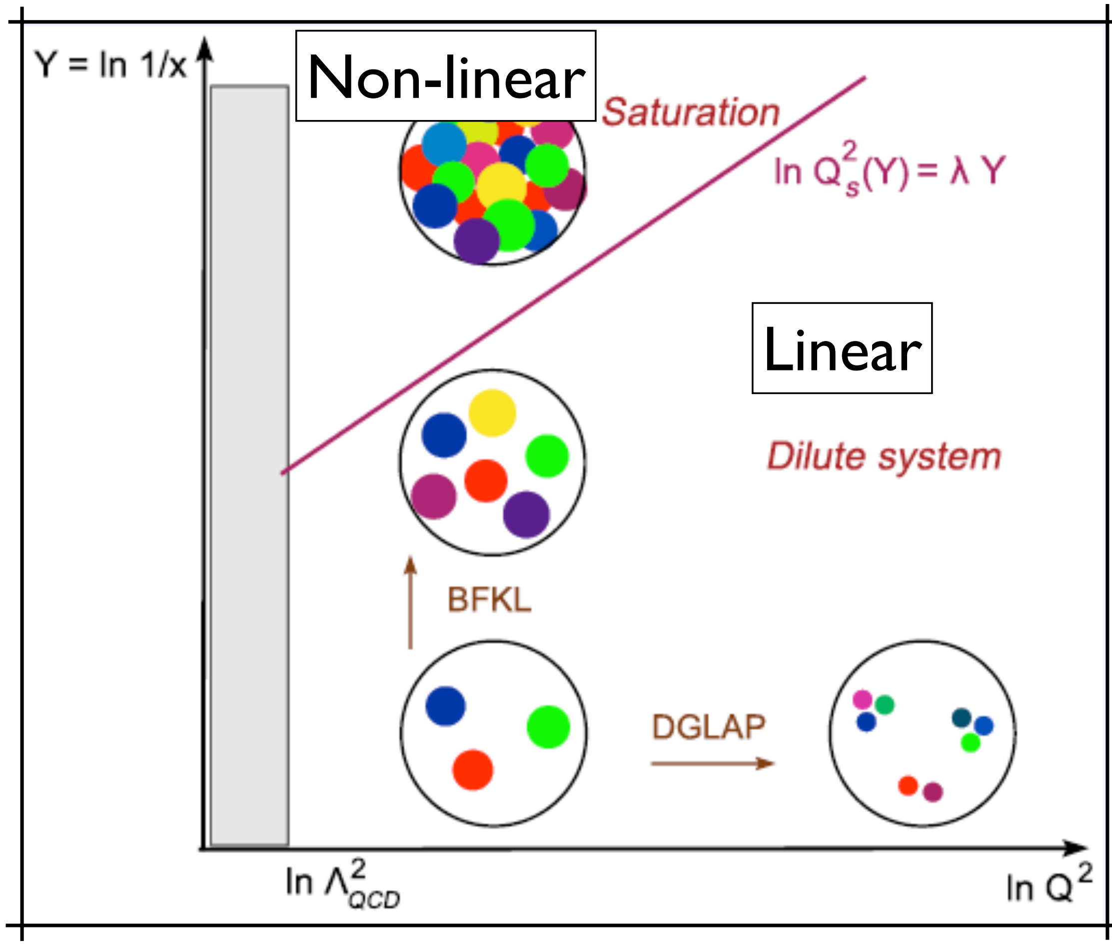
Claire Gwenlan 9

LHeC (and HERA) especially sensitive to u and d couplings: expect deviations from SM for these couplings e.g in Leptophobic Z' models

LHeC is electroweak precision machine.

Talk by Olaf Behnke

Theory: high-energy QCD



Where do the available experimental data lie?

Our aims: understanding

- The implications of unitarity in a QFT.
- The behavior of QCD at large energies / hadron wave function at small x.
- The initial conditions for the creation of a dense medium in heavy-ion collisions: nuclear WF + initial stage.

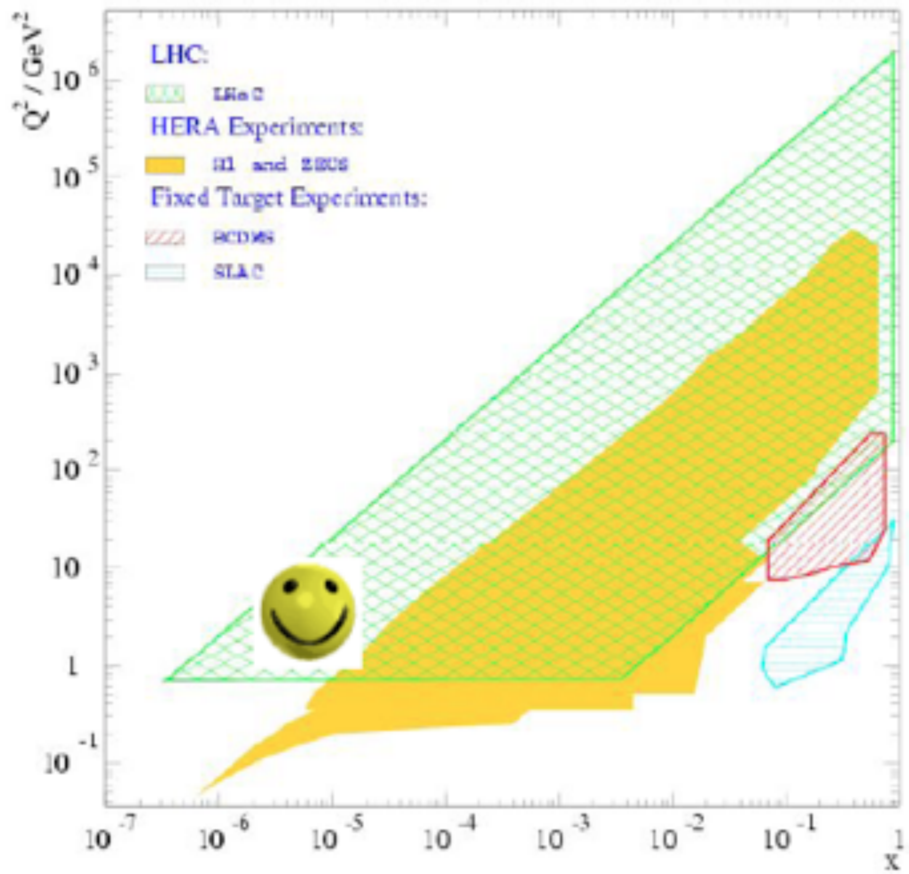
Interesting problems at small x:

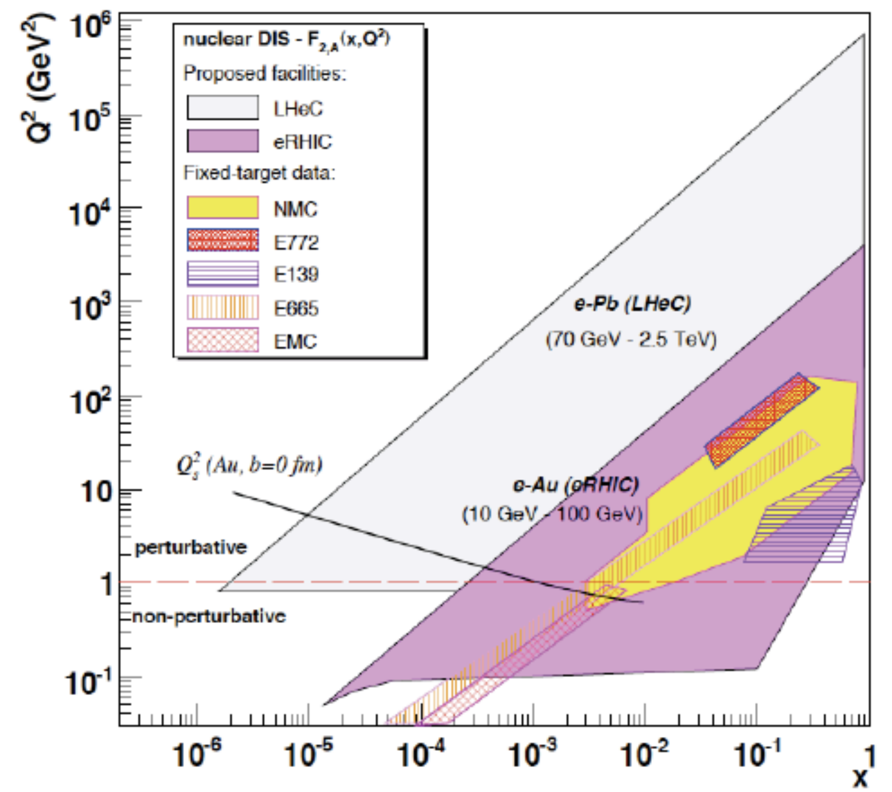
Saturation, diffraction, DIS on nuclei — *Talk by Nestor Armesto*

Parton dynamics, forward jets — *Talk by Krzysztof Kutak*

Kinematics:

ep

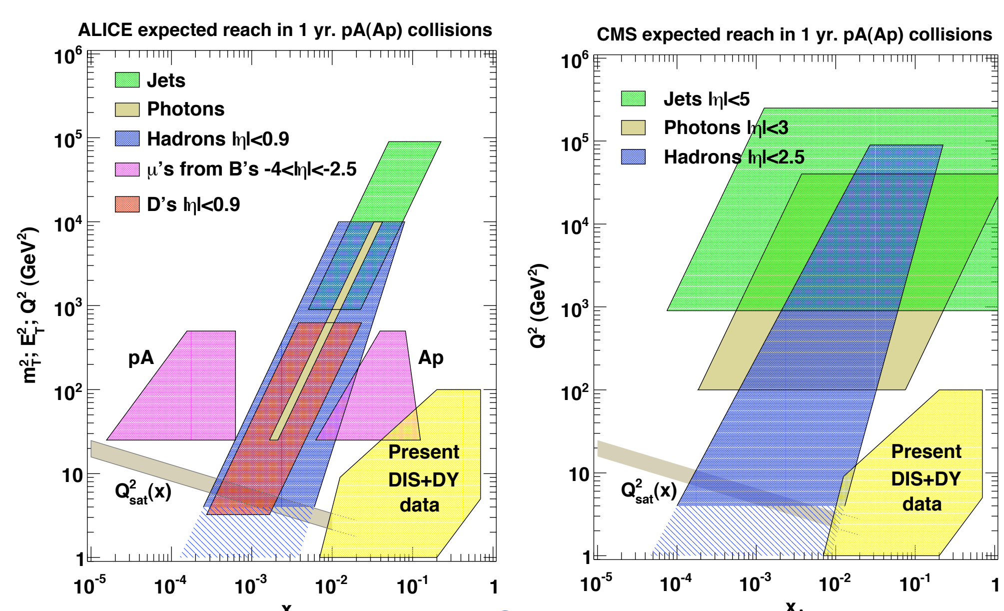




eA

- ep: access to the perturbative region below x ~ a few 10^{-5}.
- eA: new realm.
- No small-x physics without ~

1 degree acceptance.



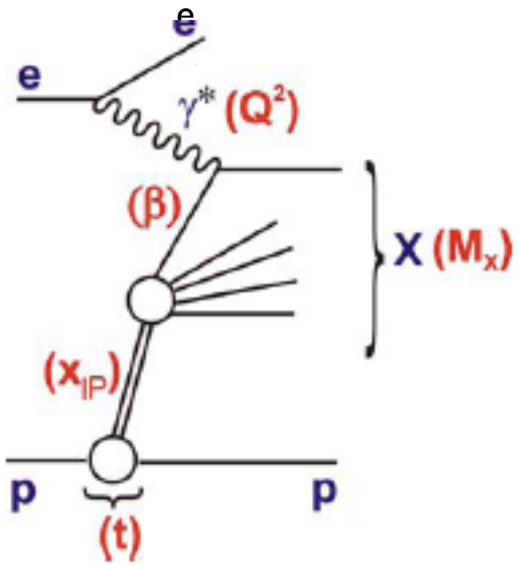
Small-x physics at the LHeC: 2. Inclusive observables.

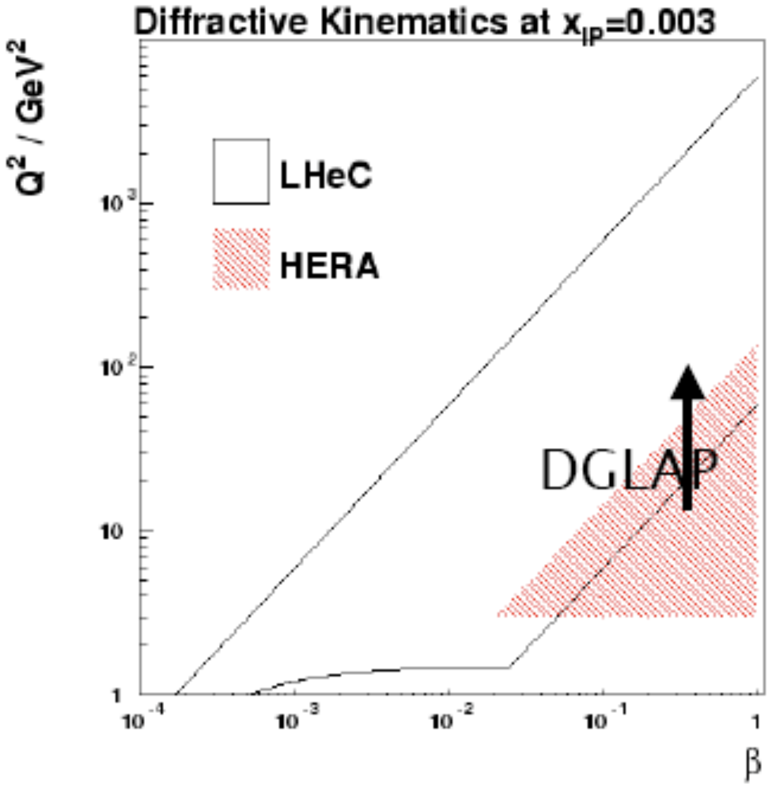
Salgado

Talk by Nestor Armesto

Diffraction at LHeC

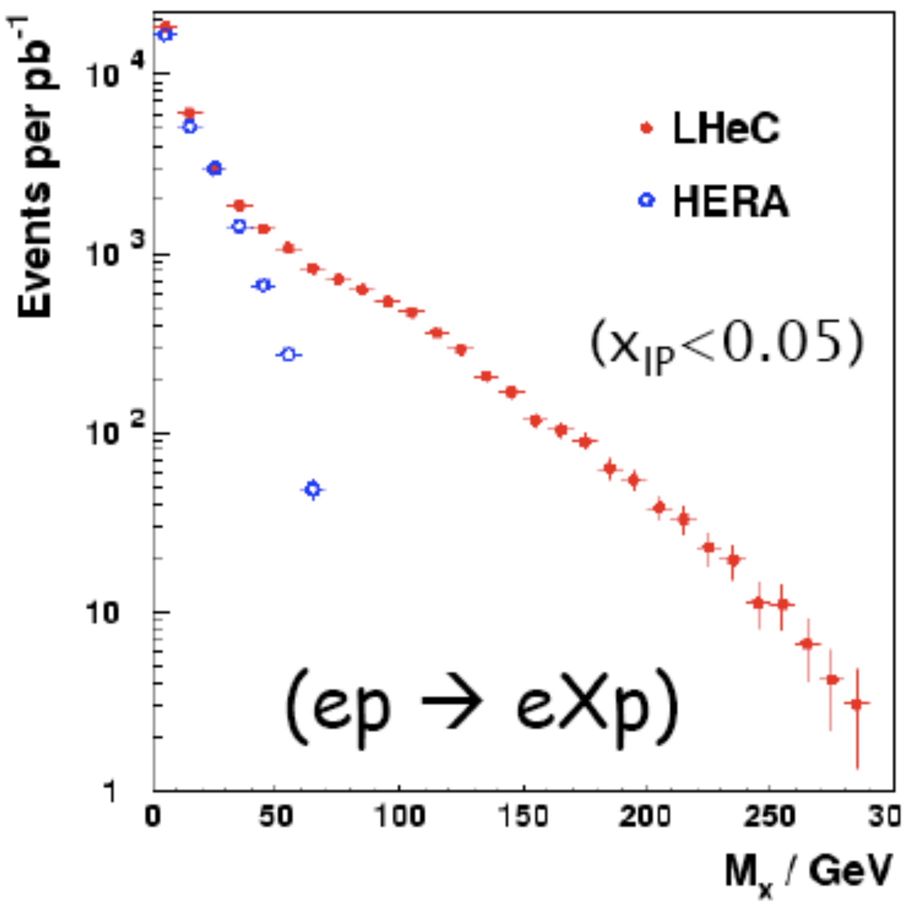
ep diffractive pseudodata:





- Large increase in the M^2, $x_P=(M^2-t+Q^2)/(W^2+Q^2)$, $\beta=x/x_P$ region studied.

[RAPGAP simulation]

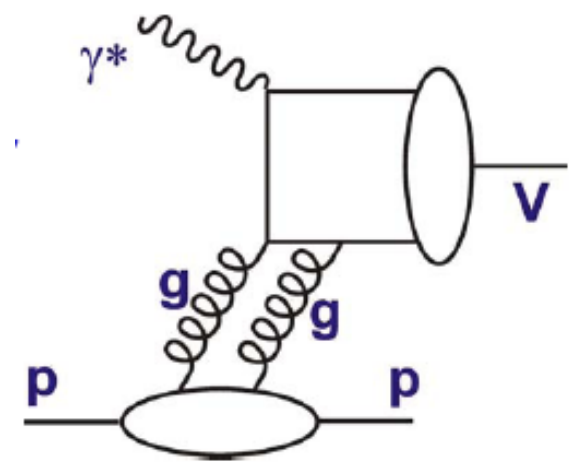


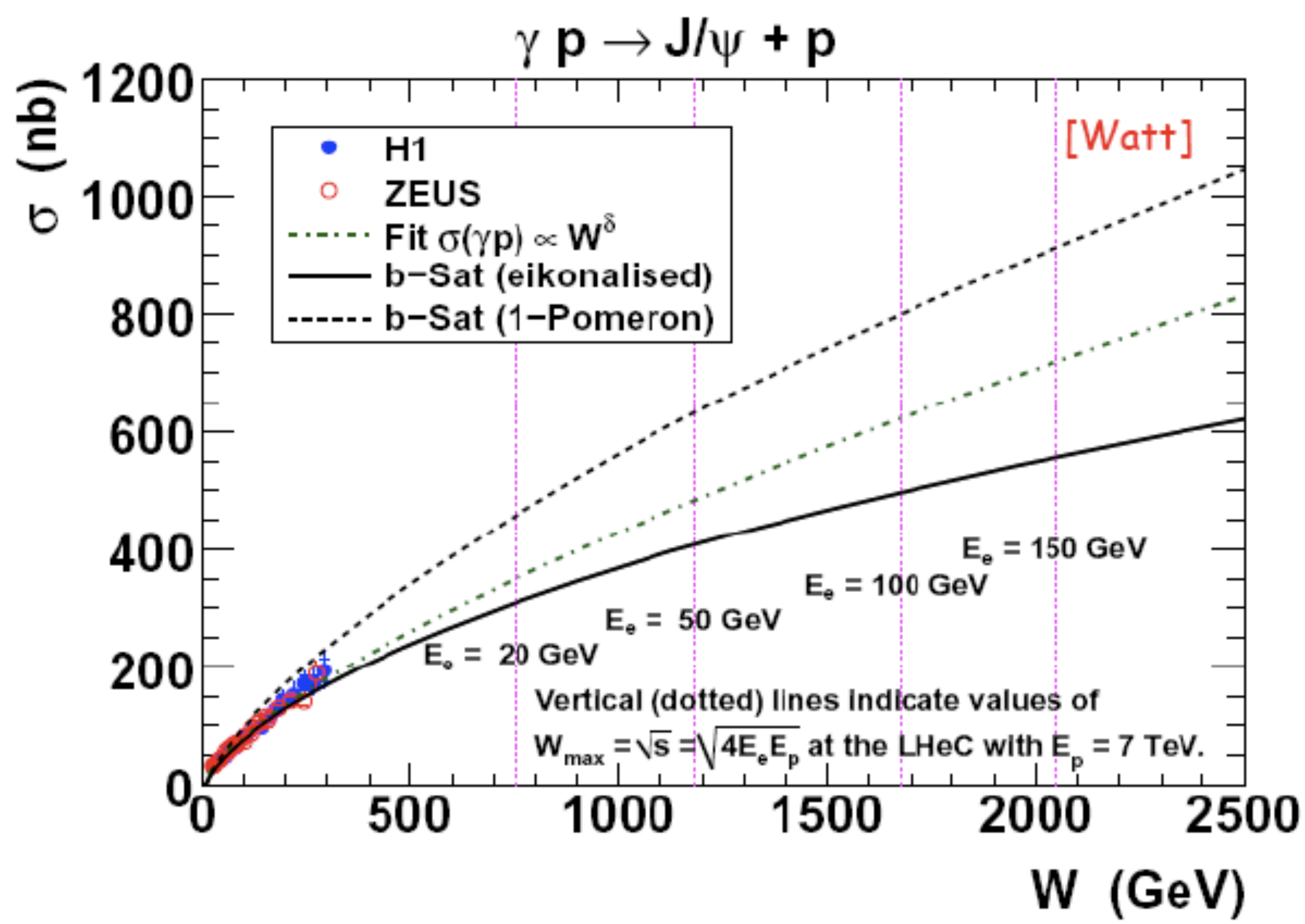
Fantastic increase in kinematics coverage wrt to HERA at LHeC

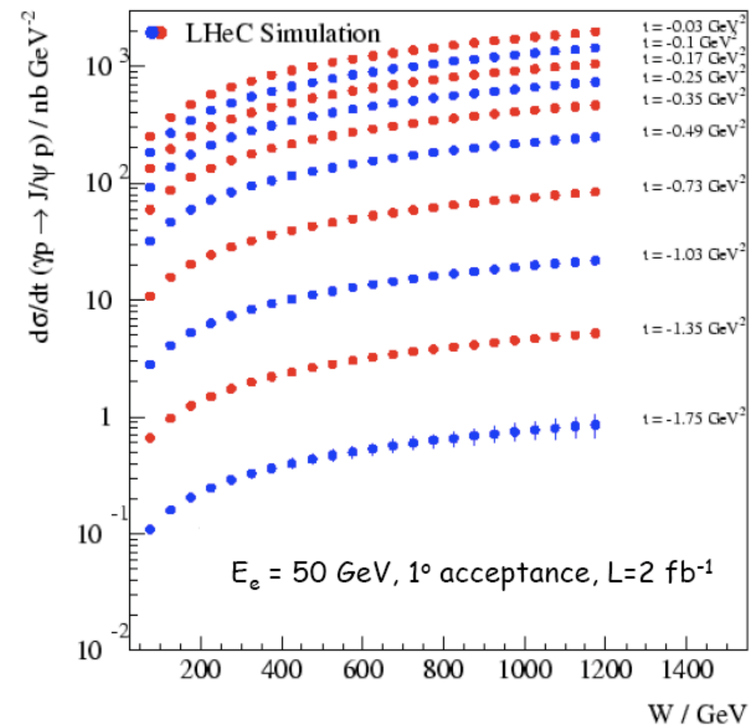
Talk by Nestor Armesto

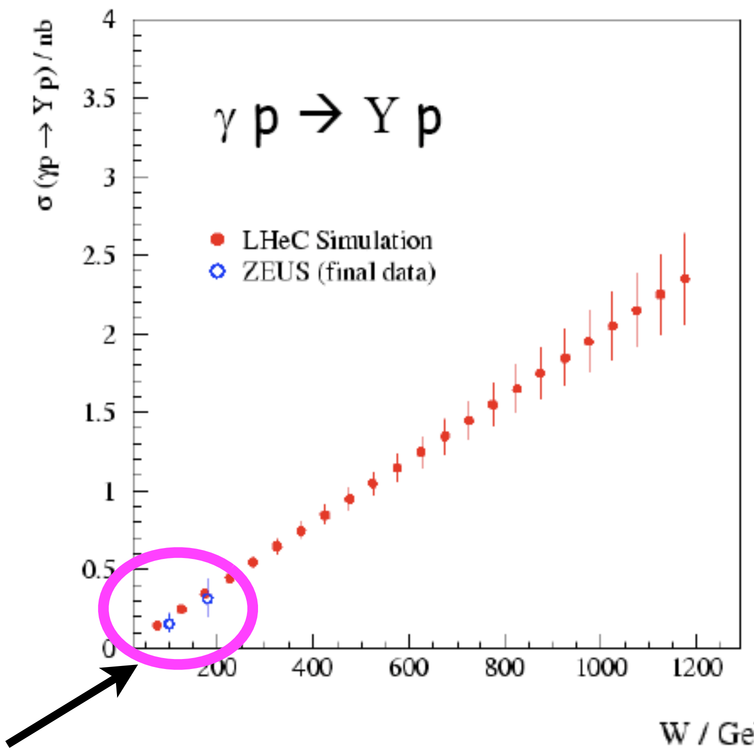
Elastic vector meson production:

- Most promising!!!







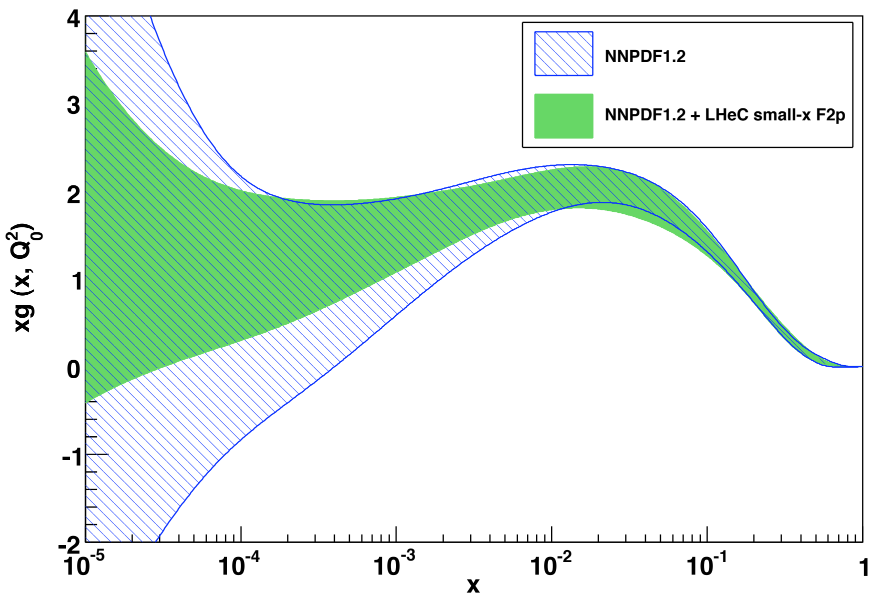


HERA data

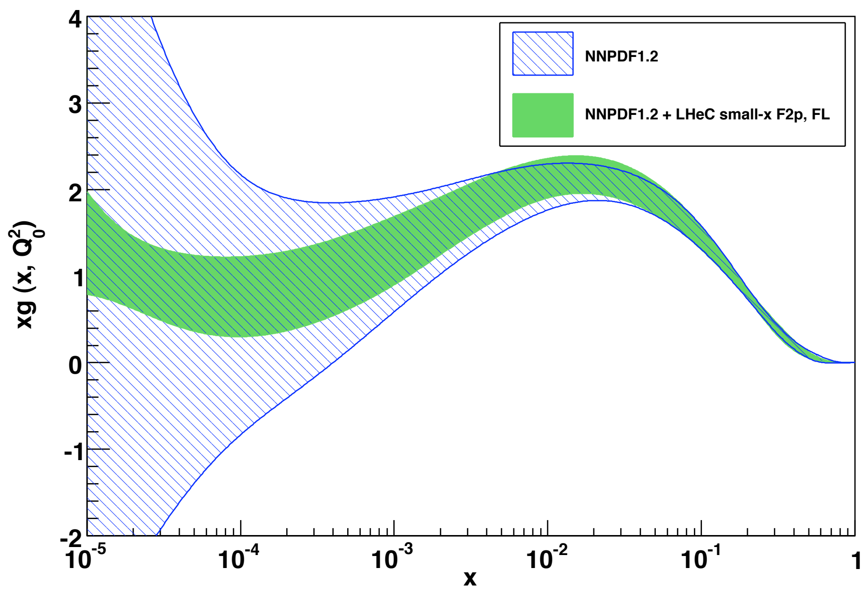
Talk by Nestor Armesto

LHeC Constraining the PDFs by LHeC

Gluon uncertainties with small-x F_2^p LHeC data only



Gluon uncertainties with small-x F_2^p and F_L^p LHeC data

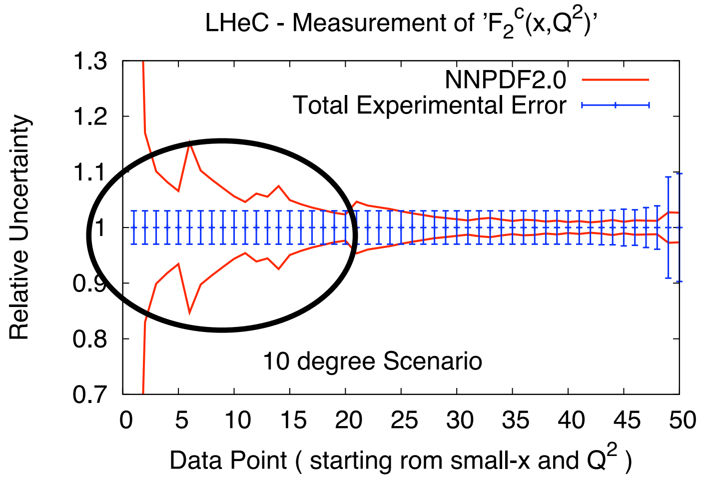


Modest error reduction of gluon at small-x, need F_L for more

→ Sizable error reduction of gluon at small-x requires LHeC F_L data

Can use charm in the analysis. Does that give comparable constraint?

Small-x,Q^2 F_2^c measurements will provide very important constraints on the small-x gluon



Conclusions from this analysis:

- Strong constraint on **gluon at small-x** (scenarios C,D,E)
  $\Longrightarrow$ Opening up of a new kinematic region
- Impact on **strangeness** (scenario B) concentrated at small-x
  $\Longrightarrow$ Exclusive charm production ($sW \to c$) pins downs small-x strangeness
- **Valence distributions** mostly unaffected
  $\Longrightarrow$ Strong constraints from fixed target and Drell-Yan data
- F_2^c very important measurement
  $\Longrightarrow$ Sizable constraints on the low-x gluon
  Complements the potential of $F_L(x, Q^2)$ measurements

Talk by Juan Rojo

Light Higgs boson at the LHeC

Talk by Uta Klein

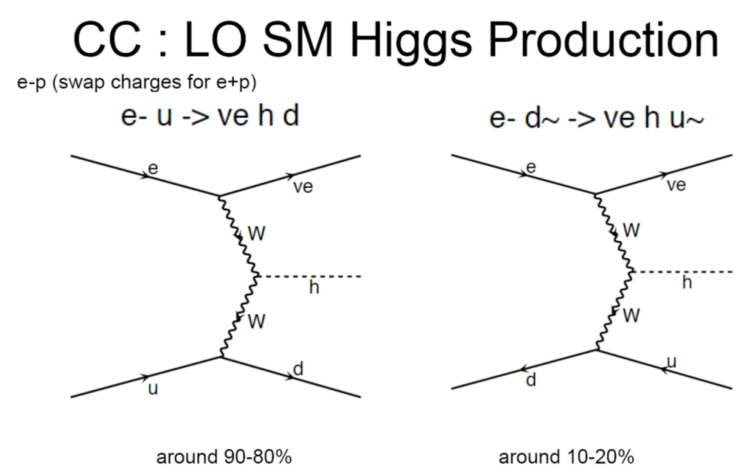
At LHC: Even after the Higgs discovery at LHC the measurement of the Yukawa couplings can be very challenging.

At LHeC: A precision ep collider machine can add on a valuable information w.r.t. LHC. Example: Yukawa couplings.

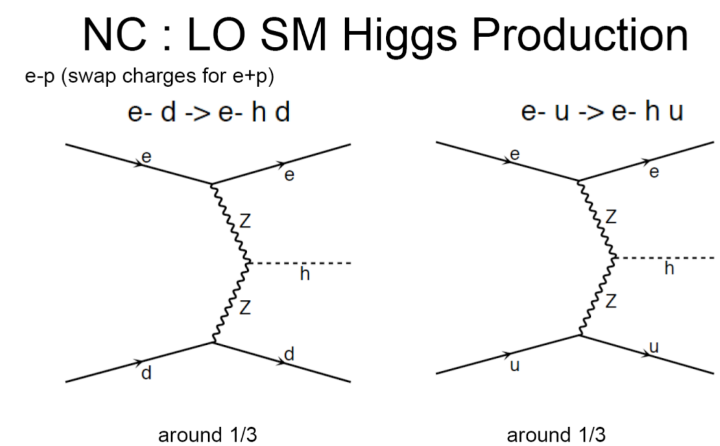
$$\sqrt{s} = 1 - 2\ \mathrm{TeV}$$

ep

~ 200 fb

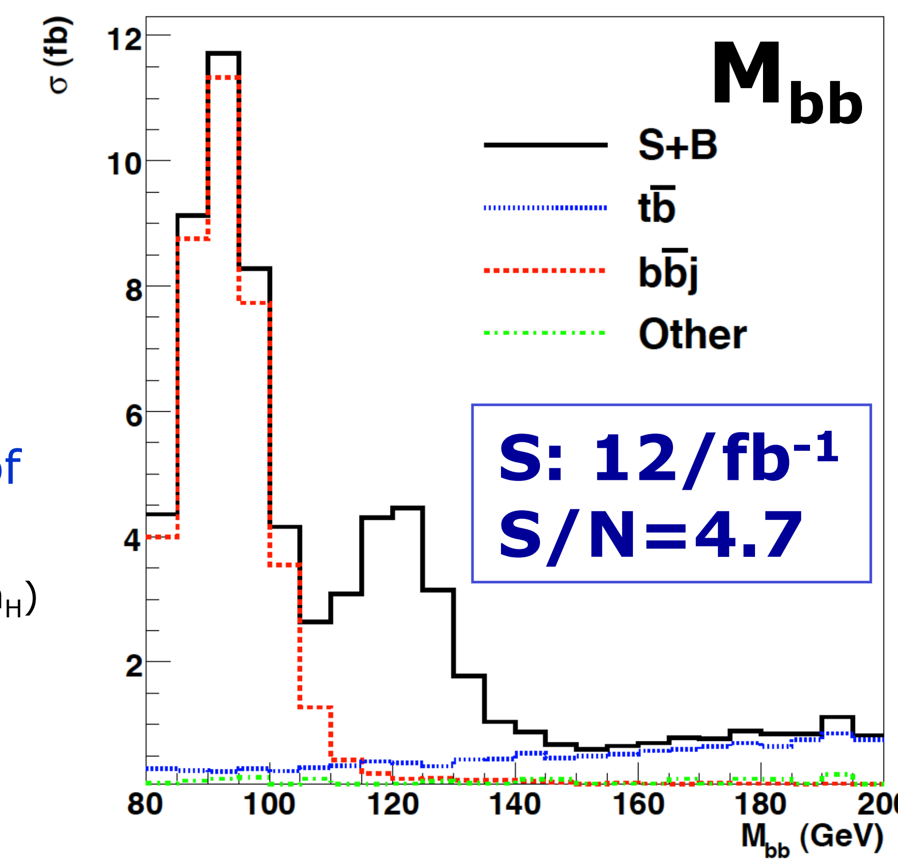


~ 50 fb (Z heavier than W and couplings to fermions smaller)



Look at bbar + forward jet :

- m_H=120 GeV, ep: 140 Gev X 7000 GeV using Madgraph and DECAY
- generated parton energies and angles smeared by resolutions, e.g. δE_{had}=60% yields δm_H=7% (w/o angular smearing)
- 60% b-tagging efficiceny applied on b-quarks and rejection factors of 10 and 100 for c and light quarks, resp., for $|\eta|<2.5$
- require mass of 2 b-partons to be within 120±10 GeV (assume known m_H)
- tag the forward spectator parton within $1<\eta<5$ and $p_T>30$ GeV
- high invariant mass of H-candidate and spectator jet, $M_{HJ}>250$ GeV



Physics BSM

Talk by Georges Azuelos

What can we gain by having ep collider?

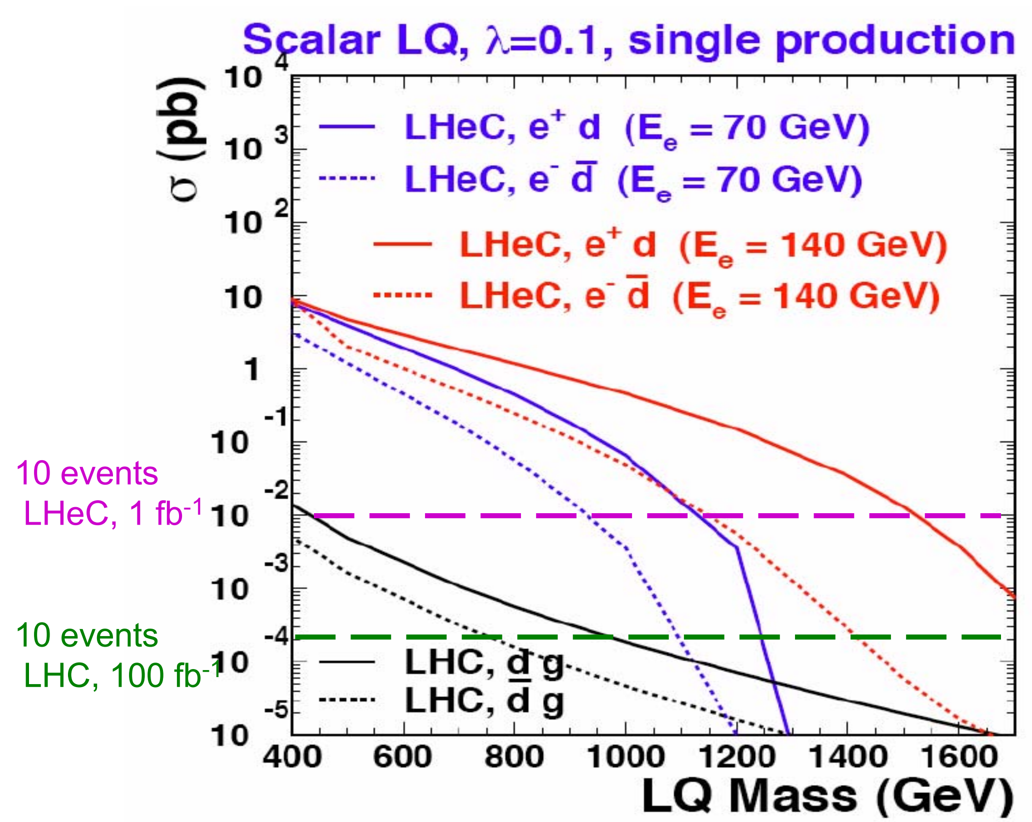
- **LHeC can complement LHC in understanding new physics phenomena**
- **more precision and more complete interpretation of LHC discoveries**

Examples of new physics that can be explored at LHeC:

- Leptoquarks
- Contact interactions
- Excited fermions
- Compositeness
- Heavy leptons

Leptoquarks:

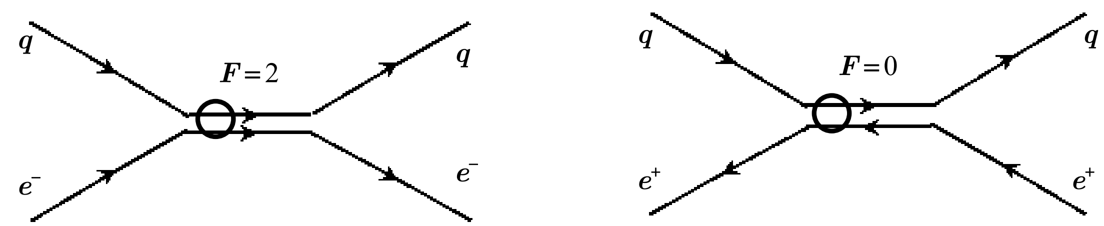
Cross sections generally higher than at LHC

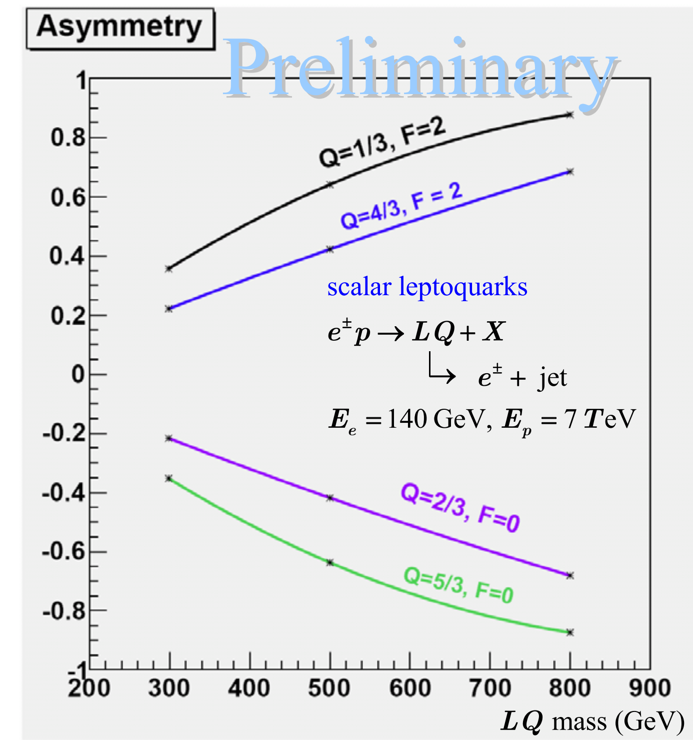


LHeC Leptoquarks

- Quantum numbers and couplings:
  - **F: fermion number can be obtained from asymmetry in single LQ production, since q have higher x than $\bar{q}$**

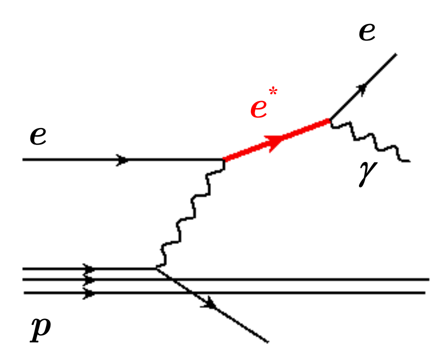
$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$



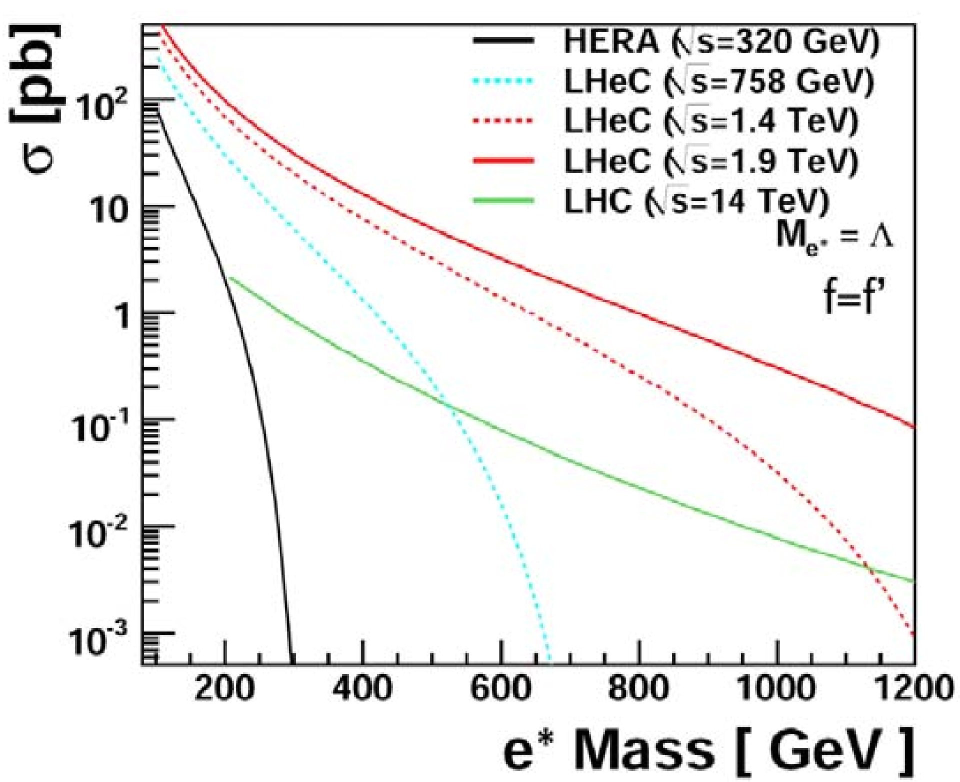


Excited leptons

LHeC could extend the reach for excited electrons, in the e-γ mode

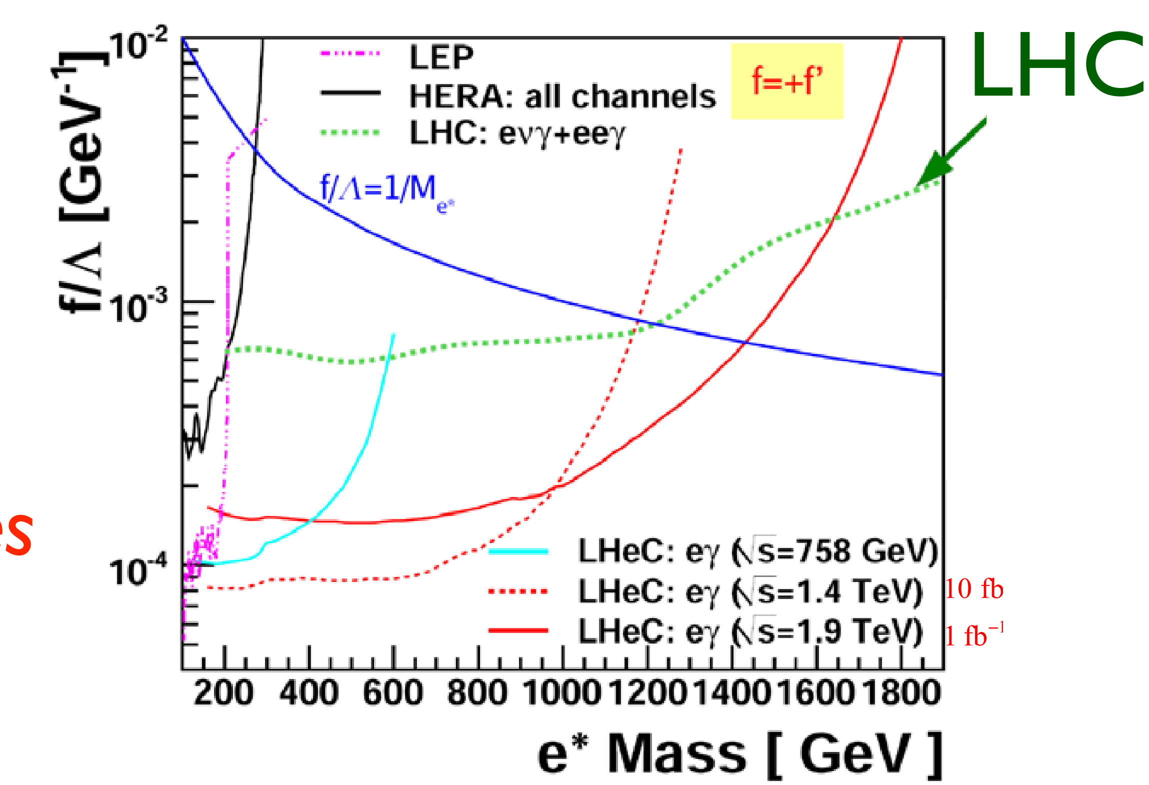


single production cross section



Talk by Georges Azuelos

sensitivity reach to masses and couplings



LHeC news

CDR completion in 2010 - milestones:

- topical meetings
- first draft - summer 2010
- final draft - fall 2010
- Report and Discussion at Divonne III
  (the 3rd CERN-ECFA-NuPECC workshop on the LHeC)
  28.-30.10.2010

The CDR is open for contributions on the design of
- the accelerator,
- the detector,
- the interaction region

and the three physics topics:
- precision QCD and electroweak interactions
- new physics beyond the standard model
- physics at high parton densities

It is also open for expressions of interest.

Contact: working group convenors and steering group (klein@ifh.de)

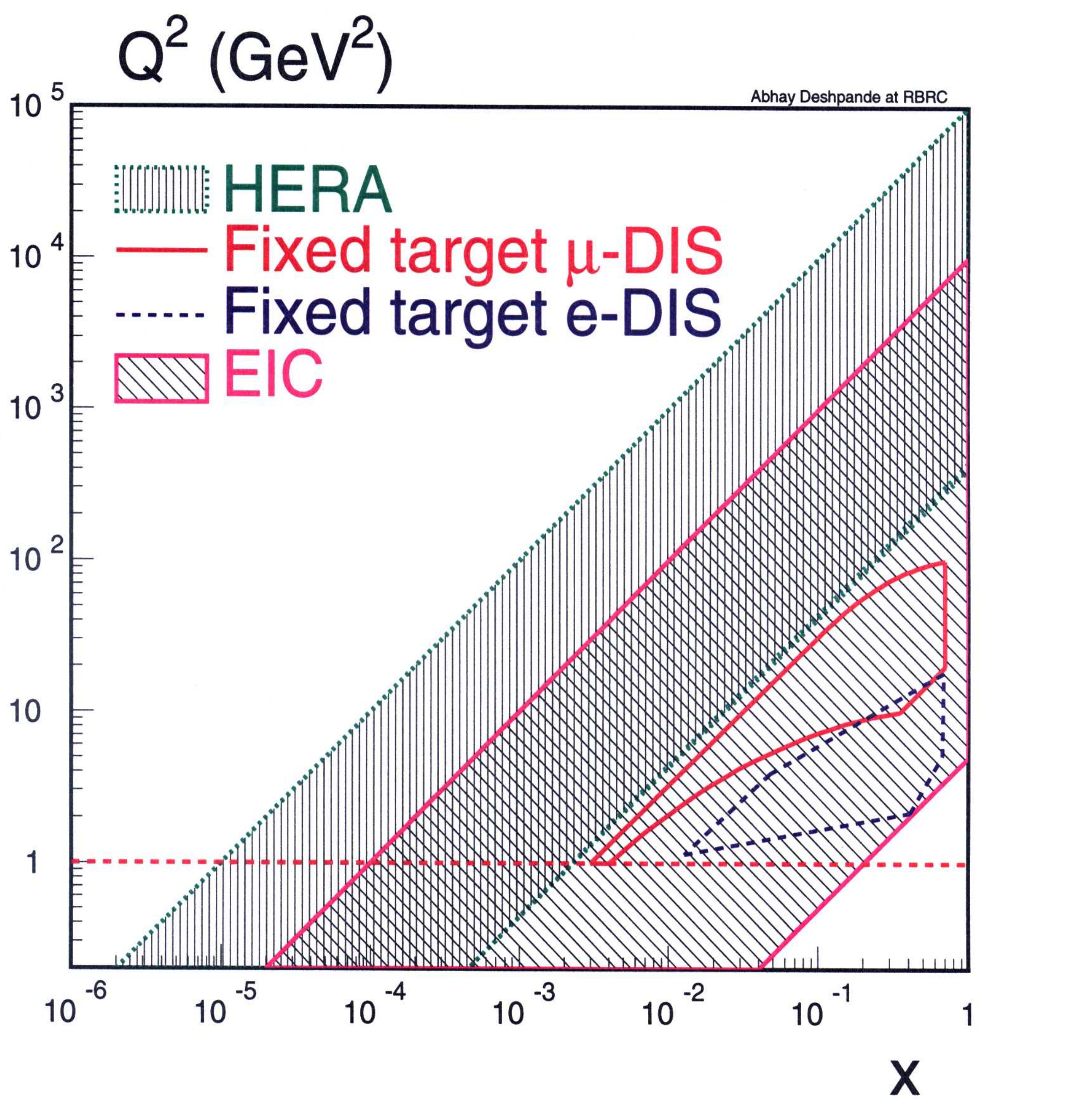
the web page of all LHeC is http://www.lhec.org.uk

the web page of all project meetings is http://indico.cern.ch/categoryDisplay.py?categId=1874

EIC

Talk by Abhay Deshpande

EIC in the US: Basic Parameters



- E_e=10 GeV (5-20 GeV variable)
- E_p=250 GeV (50-250 GeV Variable)
- Sqrt(S_{ep}) = 30-100 GeV
- $X_{min} = 10^{-4}$; $Q^2_{max} = 10^4$ GeV
- Beam polarization ~ 70% for e,p
- Luminosity $L_{ep} = 10^{33-34}$ cm^{-2}s^{-1}
- Aimed Integrated luminosity:
  - 50 fb^{-1} in 10 yrs (100 x HERA)
  - Possible with 10^{33} cm^{-2}s^{-1}

Nuclei:

- p->U; E_A=20-100 GeV
- Sqrt(S_{eA}) = 12-63 GeV
- $L_{eA}/N = 10^{33}$ cm^{-2}s^{-1}

Scientific Frontiers Open to EIC

Polarized Beams

- Nucleon Spin structure
  - Polarized quark and gluon distributions
    - Longitudinal spin structure (Low x critical)
    - Transverse spin structure (wide Q^2 arm critical)
  - Correlations between partons (T. Horn's talk)
    - Exclusive processes --> Generalized Parton Distributions
  - Precision measurements of QCD and of EW parameters in SM (K. Kumar's Talk)

- Un-polarized Nucleon Structure (M. Lamont's talk)
  - Understanding confinement with low x/lowQ^2 measurements
  - Un-polarized quark and gluon distributions
- Nuclear Structure, role of partons in nuclei
  - Confinement in nuclei through comparison e-p/e-A scattering
- Hadronization in nucleons and nuclei & effect of nuclear media
  - How do knocked off partons evolve in to colorless hadrons

{ W. Brooks' talk }

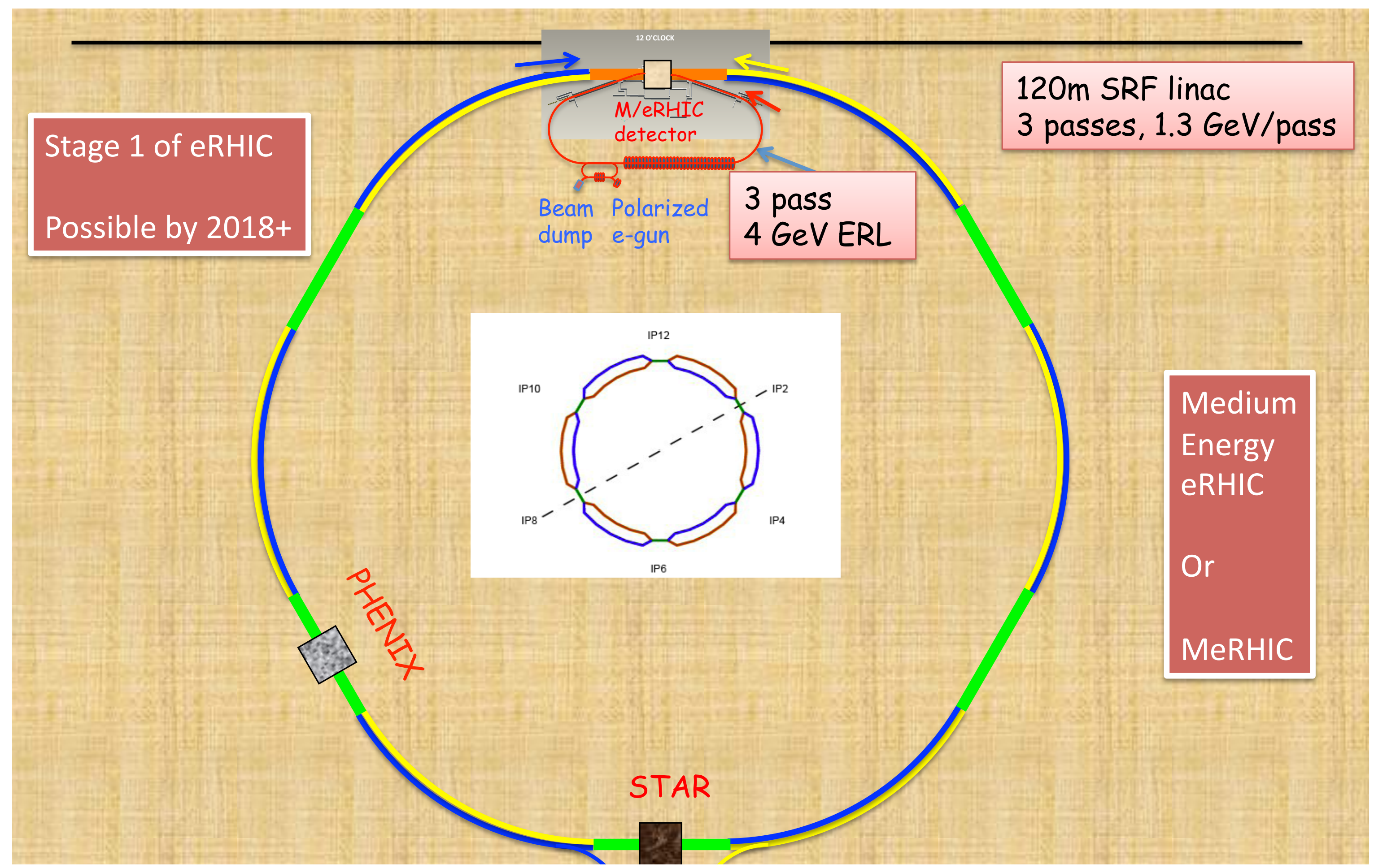
- Partonic matter under extreme conditions (M. Lamont's talk)
  - For various A, compare e-p/e-A

Proton & Nuclear Beams

Talk by Abhay Deshpande

EIC-eRHIC Stage I

- **MeRHIC**: Medium Energy eRHIC
  - Both Accelerator and Detector are located at IP2 (or IP12) of RHIC
  - 4 GeV e^- x 250 GeV p (63 GeV c.m.), L ~ 10^{32}-10^{33} cm^{-2} sec^{-1}
  - 90% of hardware will be used for HE eRHIC



Machine parameters:

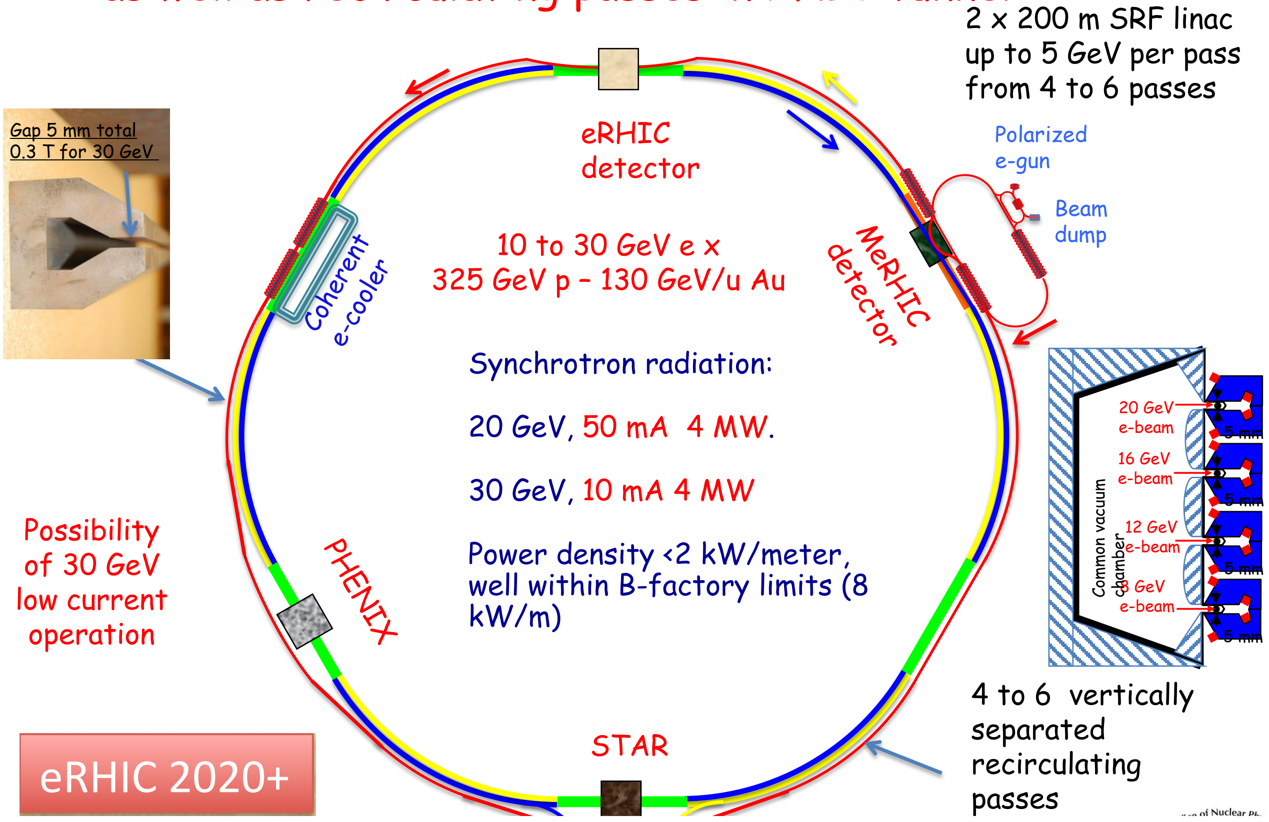
	not cooled		With cooling	
	p	e	p	e
Energy, GeV	250	4	250	4
Number of bunches	111		111	
Bunch intensity, 10^{11}	2.0	0.31	2.0	0.31
Bunch charge/current, nC/mA	32/320	5/50	32/320	5/50
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.5	7.3
rms emittance, nm	9.4	9.4	0.94	0.94
beta*, cm	50	50	50	50
rms bunch length, cm	20	0.2	5	0.2
beam-beam for p /disruption for e	1.5e-3	3.1	0.015	7.7
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93		9.3	

Talk by Abhay Deshpande

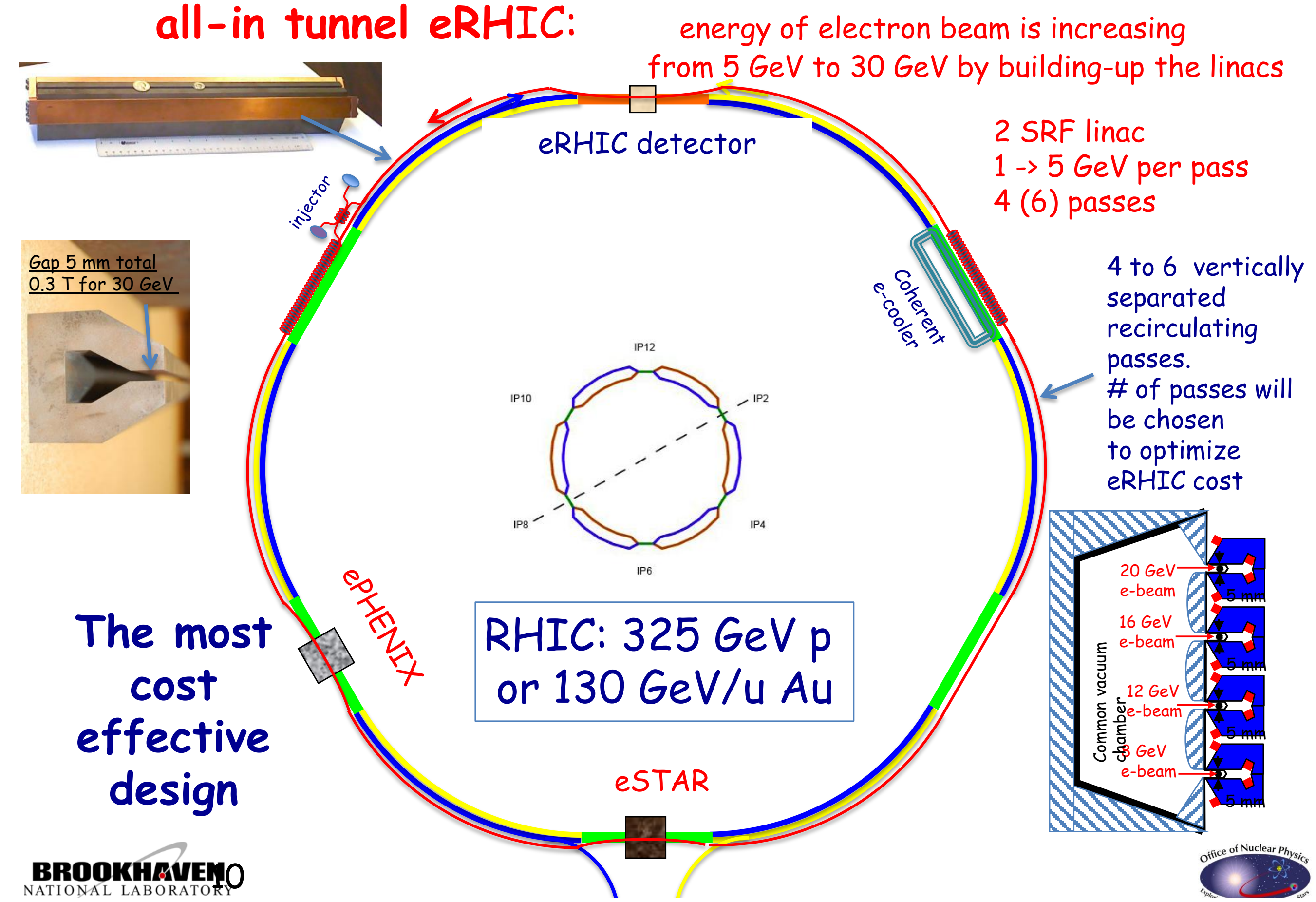
Talk by Ilan Ben-Zvi

EIC-eRHIC Stage 2: higher energy *Talk by Ilan Ben-Zvi*

High energy stage of eRHIC: by adding additional linacs as well as recirculating passes in RHIC tunnel



Staging approach under consideration presently: staging all-in tunnel eRHIC:



The most cost effective design

BROOKHAVEN NATIONAL LABORATORY 10

	eRHIC IR1		eRHIC IR2	
	p /A	e	p /A	e
Energy (max), GeV	325/130	20	325/130	20
Number of bunches	166	74 nsec	166	74 nsec
Bunch intensity (u) , 10^{11}	2.0	0.24	2.0	0.24
Bunch charge, nC	32	4	32	4
Beam current, mA	420	50	420	50
Normalized emittance, 1e-6 m, 95% for p / rms for e	1.2	25	1.2	25
Polarization, %	70	80	70	80
rms bunch length, cm	4.9	0.2	4.9	0.2
β*, cm	25	25	5	5
Luminosity, $cm^{-2}s^{-1}$	2.8×10^{33}		1.4×10^{34}	

Energy Recovery Linac
Test Facility
Start Comissioning 2011

EIC-ELIC at JLAB   Medium Energy Stage

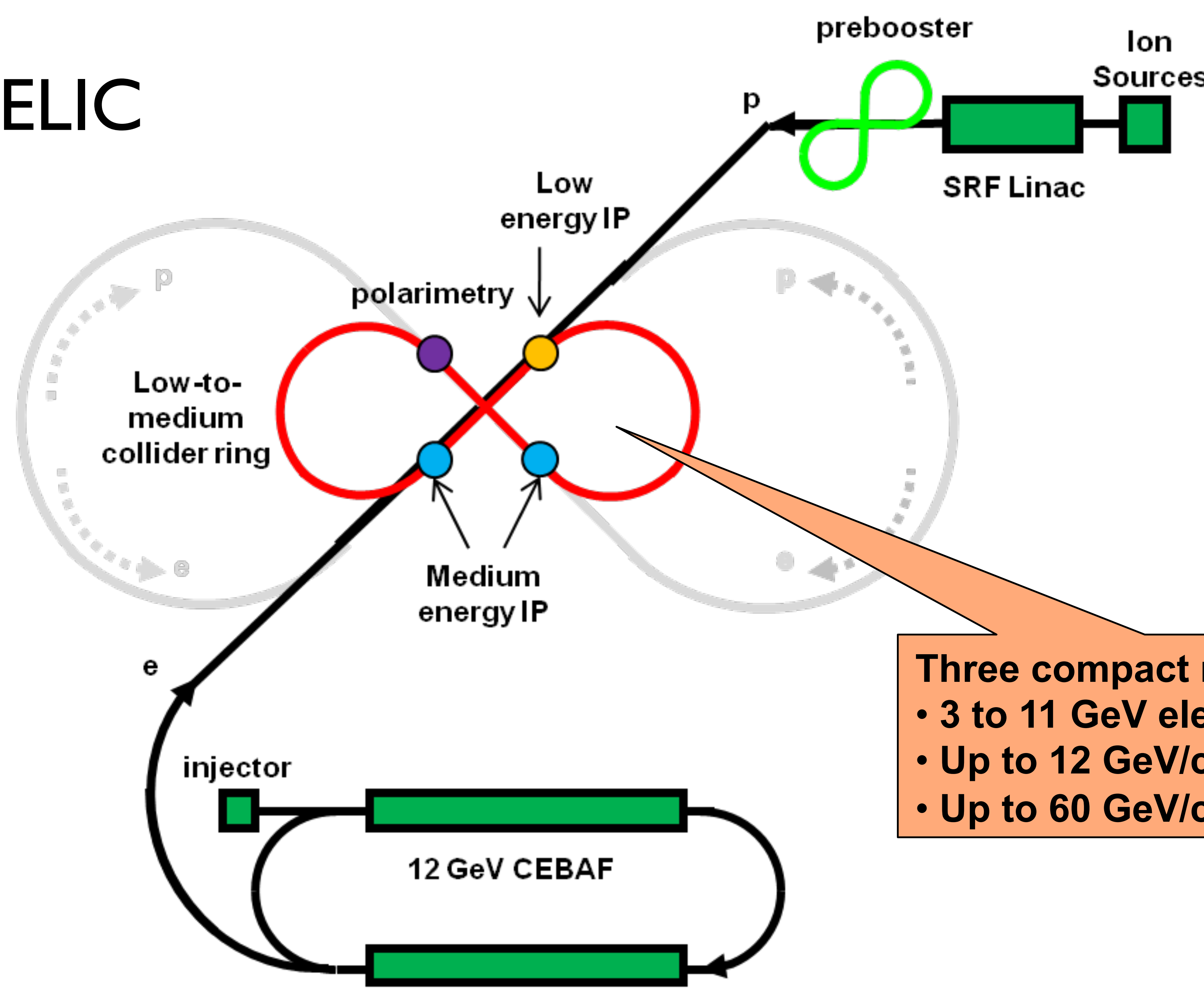
Design goals for ELIC

- ultra high luminosity (up to 10^{35}) in multiple detector regions
- very high polarization (>80%) for both electron & light ions

Medium energy ELIC

MEIC

Possible 2020+

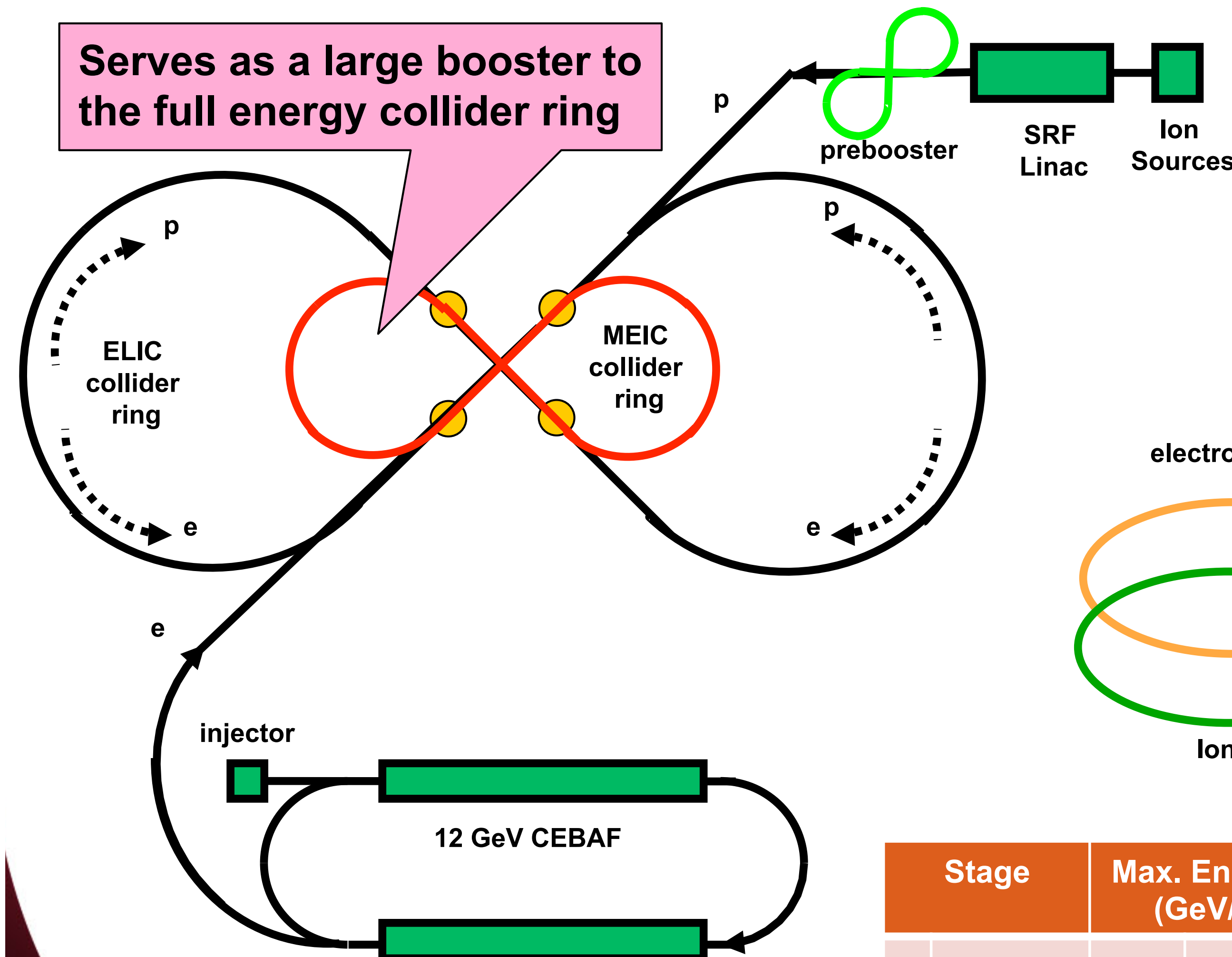


Three compact rings:
- **3 to 11 GeV electron**
- **Up to 12 GeV/c proton (warm)**
- **Up to 60 GeV/c proton (cold)**

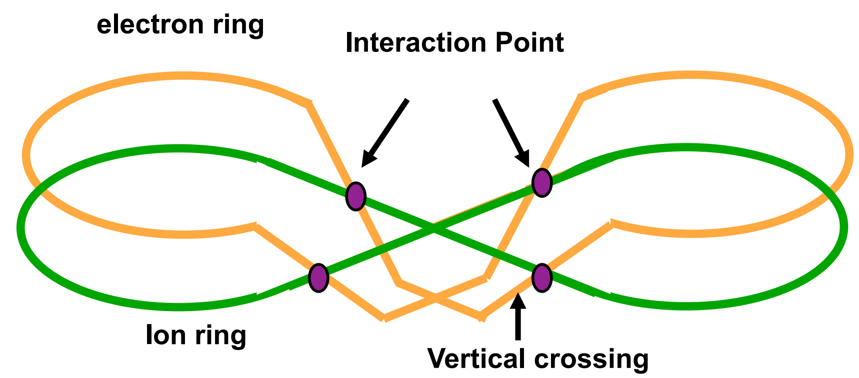
Talk by Yuhong Zhang

EIC-ELIC at JLAB High energy upgrade

Possible 2025+

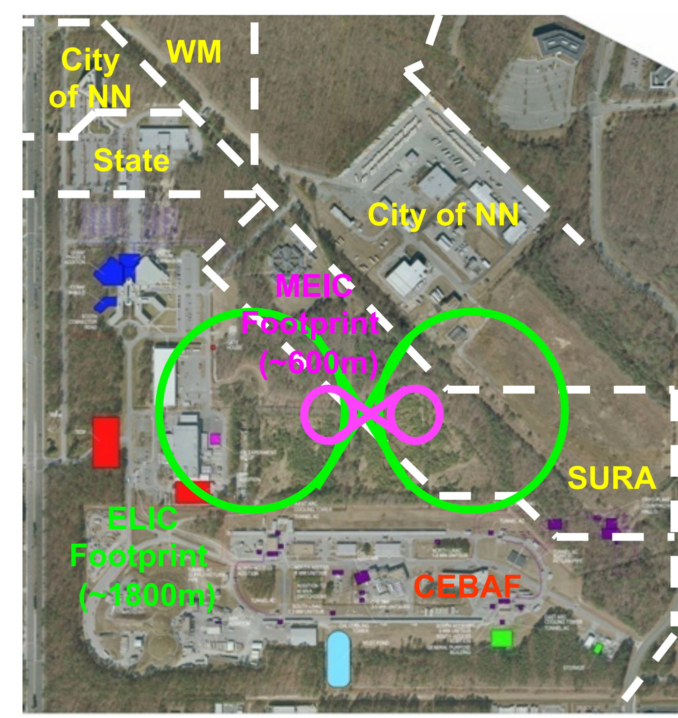


Circumference	m	1800
Radius	m	140
Width	m	280
Length	m	695
Straight	m	306



Satellite view of JLAB with planned facilities for EIC

Stage	Max. Energy (GeV/c)		Ring Size (m)		Ring Type		IP #
	p	e	p	e	p	e	
Low	12	5 (11)	630		Warm	Warm	1
Medium	60	5 (11)	630		Cold	Warm	2
High	250	10	1800		Cold	Warm	4



Jefferson Lab

Talk by Yuhon Zhang

EIC-ELIC at JLAB

Talk by Abhay Deshpande

Talk by Yuhong Zhang

Basic parameters for ELIC

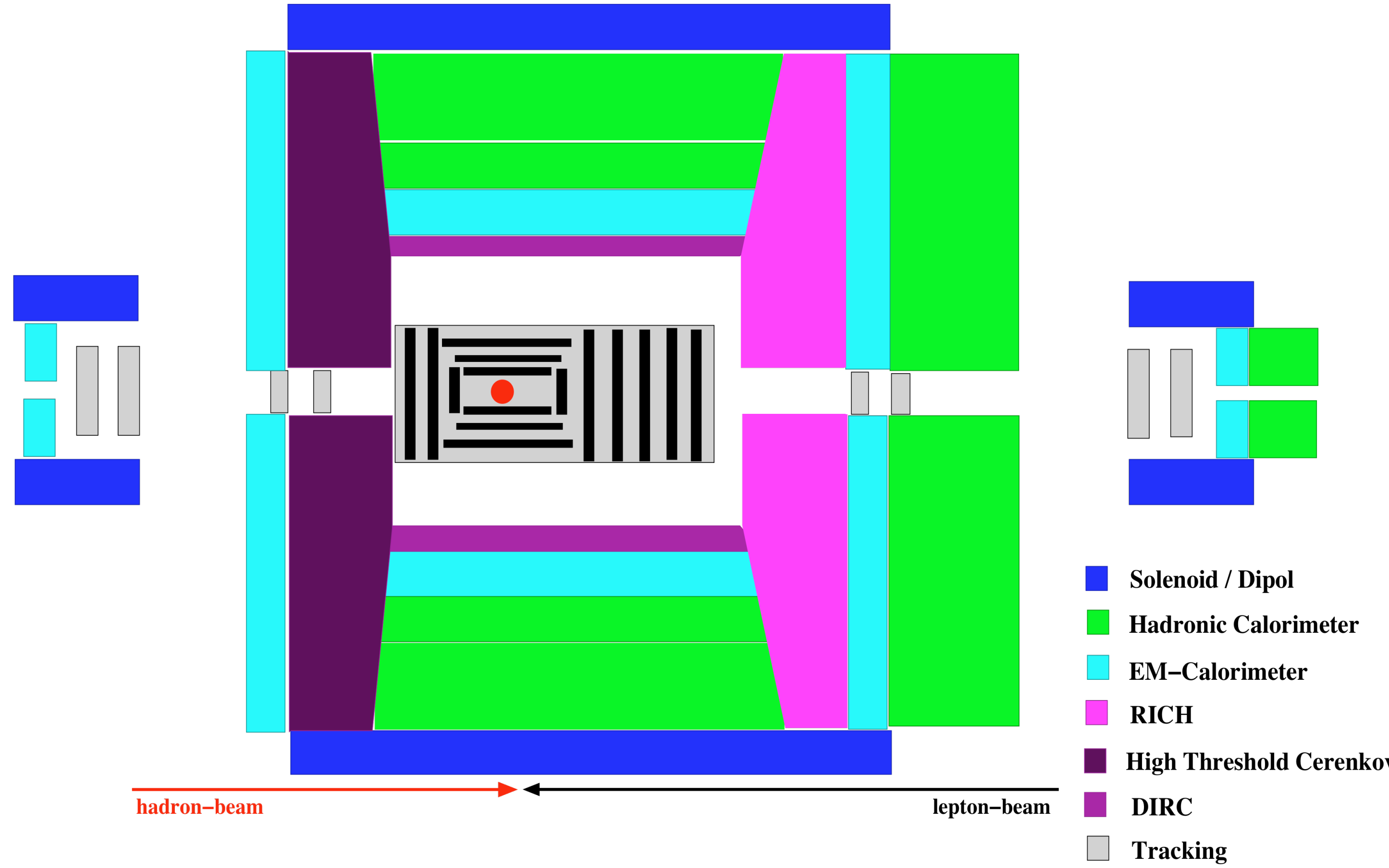
Beam Energy	GeV	250/10	150/7	60/5	60/3	12/3
Collision freq.	MHz			499		
Particles/bunch	10^{10}	1.1/3.1	0.5/3.25	0.74/2.9	1.1/6	0.47/2.3
Beam current	A	0.9/2.5	0.4/2.6	0.59/2.3	0.86/4.8	0.37/2.7
Energy spread	10^{-3}			~ 1		
RMS bunch length	mm	5	5	5	5	50
Horiz. emit., norm.	µm	0.7/51	0.5/43	0.56/85	0.8/75	0.18/80
Vert. emit. norm.	µm	0.03/2	0.03/2.87	0.11/17	0.8/75	0.18/80
Horizontal beta-star	mm	125	75	25	25	5
Vertical beta-star	mm			5		
Vert. b-b tune shift/IP		0.01/0.1	0.015/.05	0.01/0.03	.015/.08	.015/.013
Laslett tune shift	p-beam	0.1	0.1	0.1	0.054	0.1
Peak lumi/IP, 10^{34}	$cm^{-2}s^{-1}$	11	4.1	1.9	4.0	0.59

High energy — Medium energy — Low energy

Detector design for MeRHIC *Talk by Matthew Lamont*

Detector requirements from physics

- e+p physics
  - Need the same detector for inclusive (ep → e'X), semi-inclusive (ep → e'X + hadrons) and exclusive (ep → e'p+π) reactions
    - Need to have a large acceptance (*both* mid- and forward-rapidity)
    - Crucial to have particle identification
      - e, π, K, p, n over wide momentum range and scattering angles
      - excellent secondary vertex resolution (charm)
    - small systematic uncertainty for e/p polarisation measurements
    - small systematic uncertainty for luminosity measurements
- e+A physics
  - most requirements similar to e+p guidelines
  - additional complication arises from the need to tag the struck nucleus in exclusive and diffractive reactions
- Also, important to have the same detector for all energies

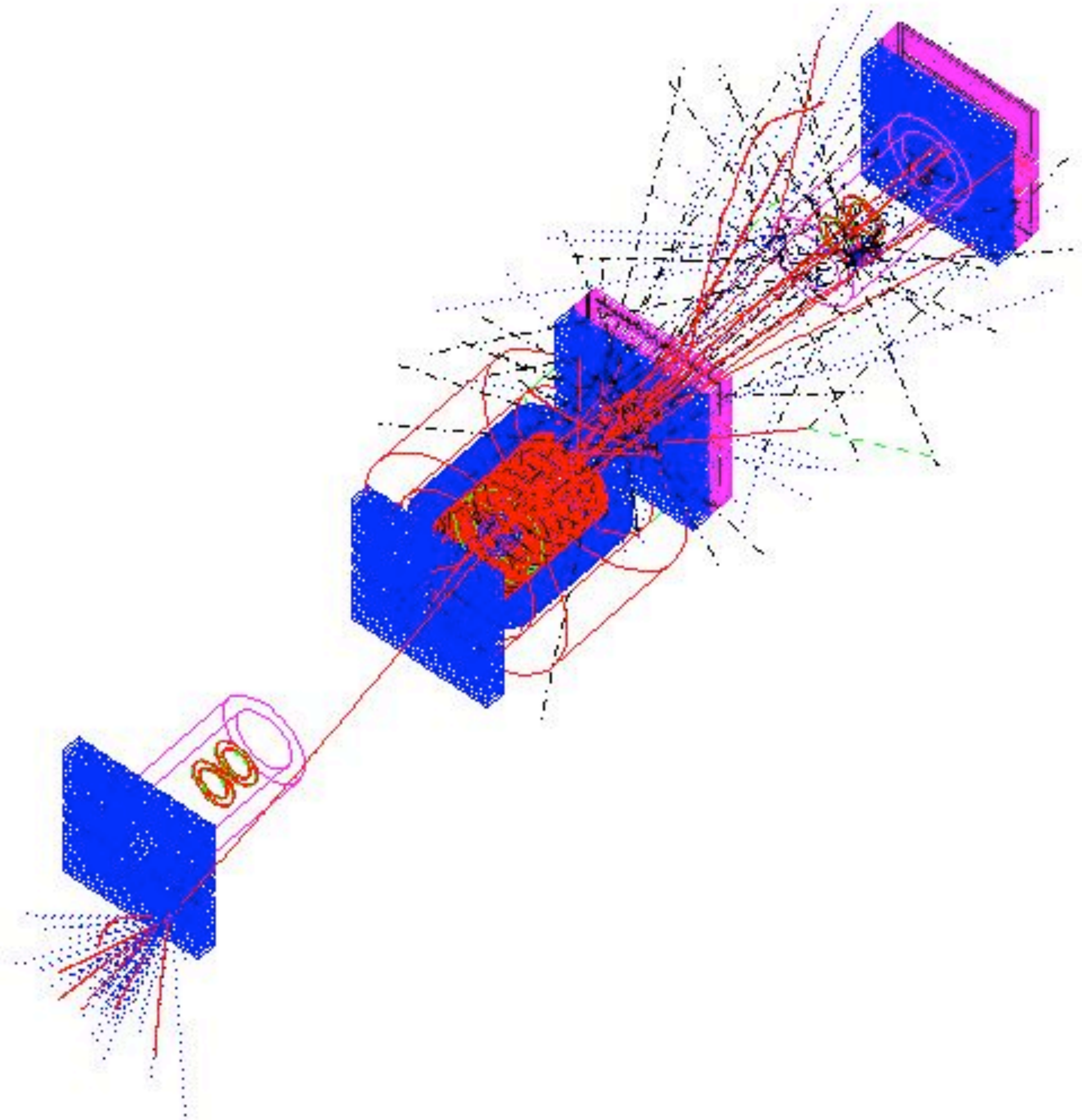


- Dipoles need to have good forward momentum resolution
  - Solenoid has no magnetic field for r → 0
- RICH, DIRC for hadron pid
- High threshold Cherenkov → fast trigger for scattered lepton
- Radiation length very critical → low lepton energies

What about other existing detectors?

- Looking at the possible use of eSTAR and ePHENIX concepts
  - eSTAR looks promising and the STAR geometry is in the same format as what we are using for our other studies
  - a possible ePHENIX is not really viable with the current setup
    - thoughts of a future, upgraded PHENIX are being put forward to deal with jet physics in heavy-ion collisions

MeRHIC detector in Geant 3

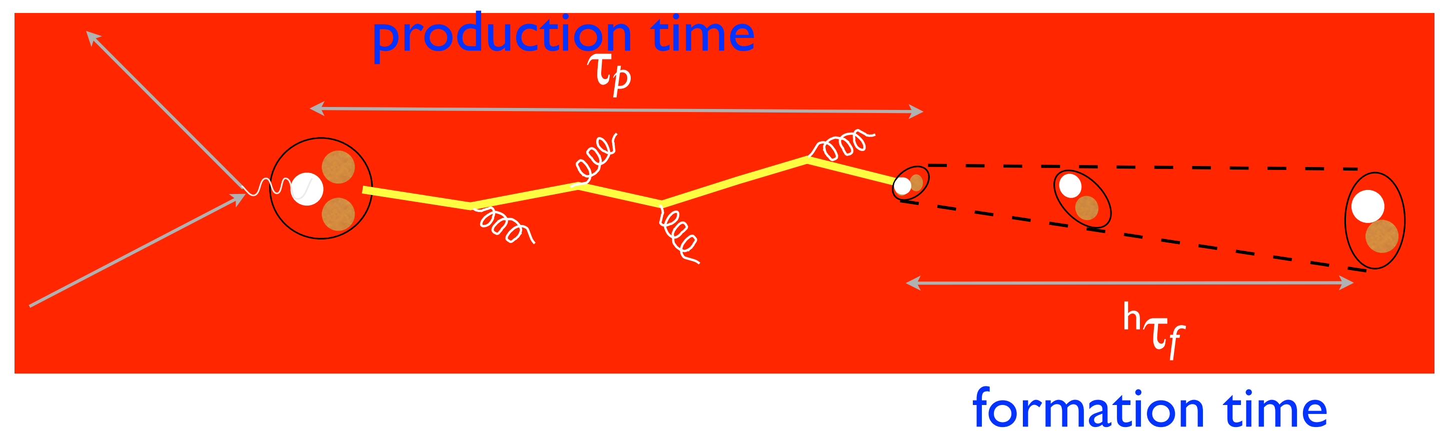


Parton dynamics in nuclear medium

Talk by Will Brooks

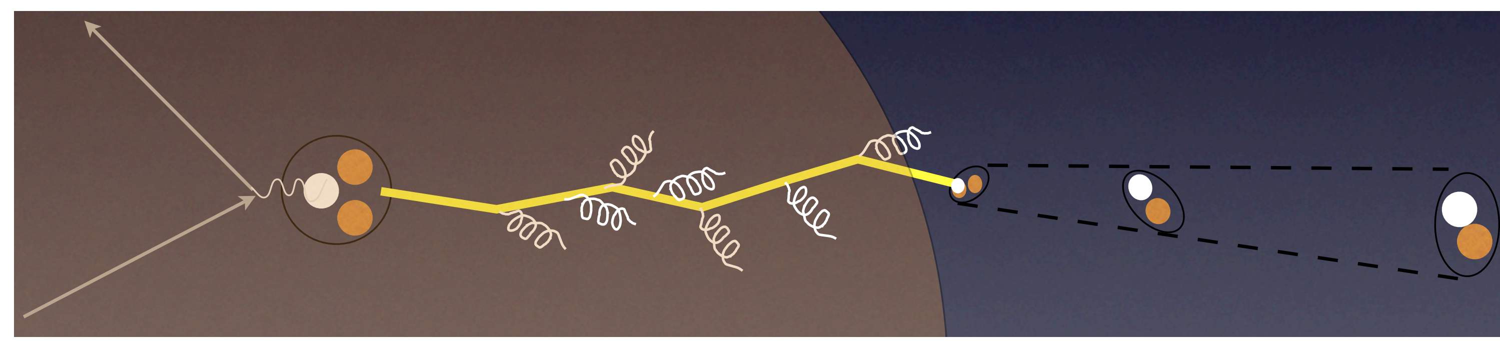
- A high energy eA collider would allow to study the dynamics of hadronization, testing the parton/hadron energy loss mechanism by introducing a length of colored material which would modify its pattern (length/nuclear size, chemical composition).

DIS in vacuum (in practice on a nucleon)



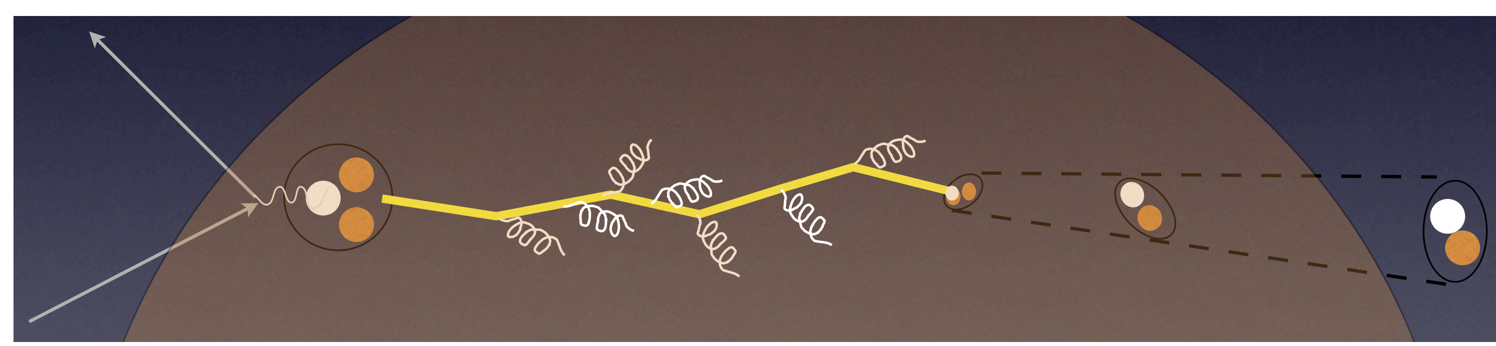
DIS in medium:

Hadron forms outside, high energy, partonic energy loss



or

Hadron forms inside, low energy, prehadron(hadron) absorption.



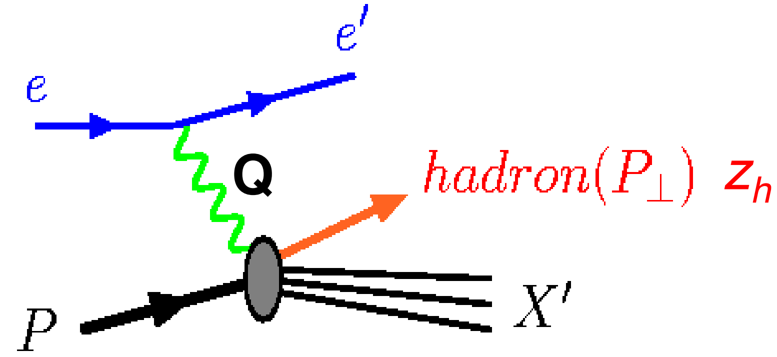
Connection between the transverse momentum broadening in SIDIS and the saturation scale which characterizes the dense medium.

$$\Delta p^2_T = Q^2_s(b,E)$$

Transverse momentum distributions: SIDIS

Talk by Cyrille Marquet

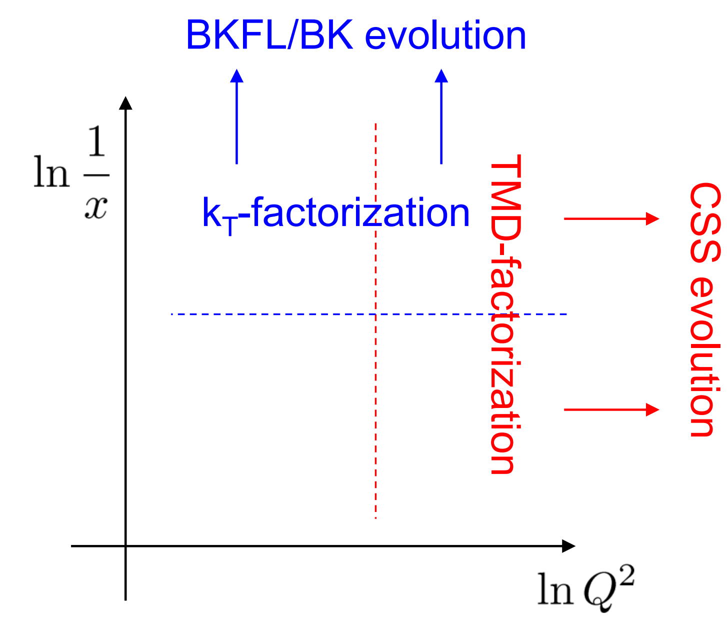
Semi-Inclusive DIS



large Q^2 | small x

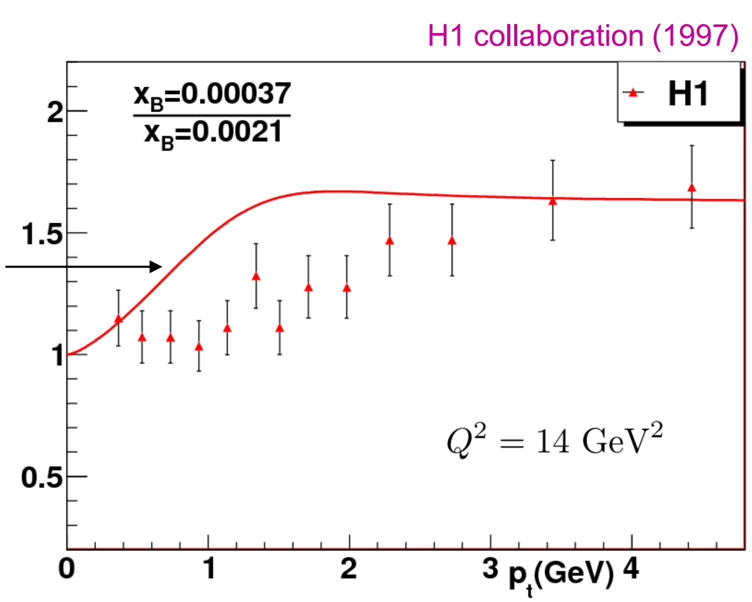
TMD factorization ⟷ **kT factorization**

Exact mapping in the region of overlap:



Can (easily?) incorporate the saturation in the TMD factorization

Theoretical prediction



at future EIC's

the SIDIS measurement provides direct access to the transverse momentum distribution of partons in the proton/nucleus, and the saturation regime can be easily investigated

EIC: nucleon spin

STONY BROOK UNIVERSITY

Nucleon Spin ~~Crisis~~ Puzzle

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_Q + \Delta G + L_G$$

- We know how to measure ΔΣ and ΔG precisely using pQCD in a <u>model independent</u> way
  - ½ (ΔΣ) ~ 0.15 : From fixed target pol. DIS experiments
  - RHIC-Spin: ΔG *not large* as anticipated in the 1990s, but *measurements & precision needed at low & high x*

RHIC spin talks

- Orbital angular momenta: L_Q (L_G?)
  - Through GPDs: Model dependences … other theoretical issues..
  - A lot to learn from the 12 GeV Jlab & the COMPASS program & ongoing theoretical development

GPD talks in Spin WG

- It would be great to have a 3D tomographic image of a proton…. Transverse spin phenomena (TMDs, GPDs: Q & G)

Talk by Abhay Deshpande

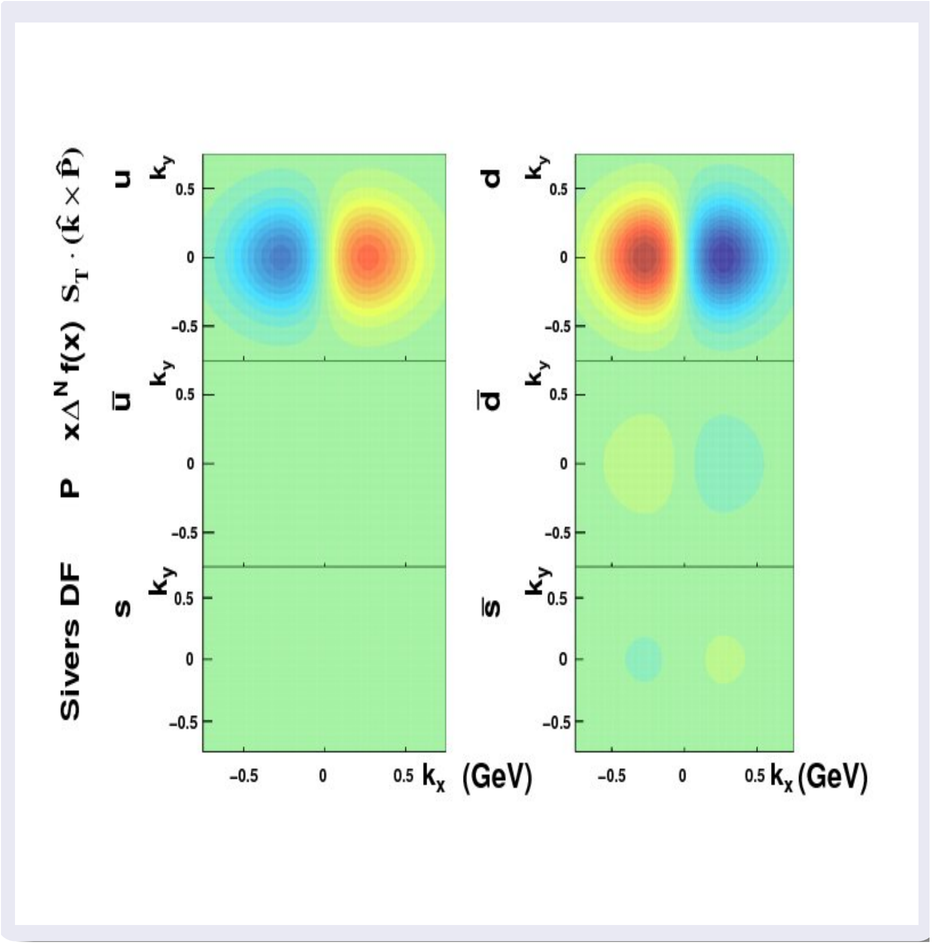
EIC: nucleon spin, GPDs, TMDs

"Usage of high energy unpolarized beams at experimental facilities, such as LHC, undoubtedly has its advantages, but the mass of the proton can be neglected with respect to the energy of the beam. On the contrary if we have polarized beams, then the spin of the proton can never be neglected with respect to the energy. This opens a unique opportunity to study 3 dimensional spin structure of the proton."

Jianwei Qiu, Duke workshop, March 2010.

We will be able to study how partons are distributed inside of the nucleon both in impact parameter Generalised Parton Distributions and momentum Transverse Momentum Dependent distributions space.

Sivers functions for u, d and sea quarks are extracted from HERMES and COMPASS data.

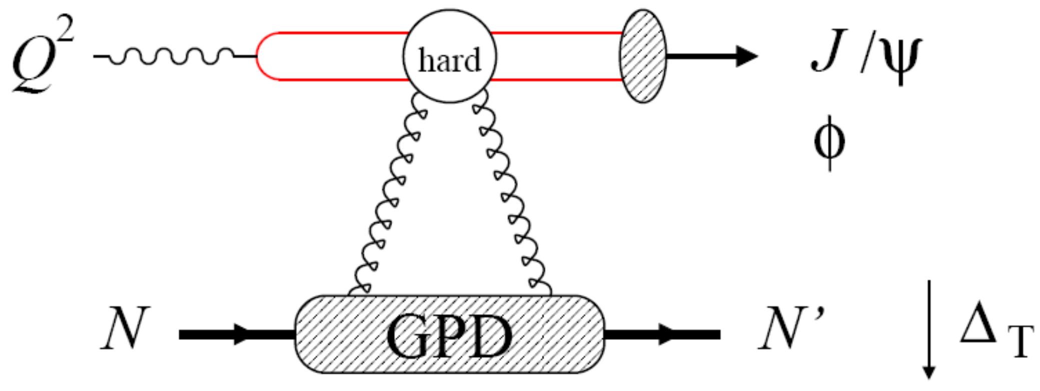


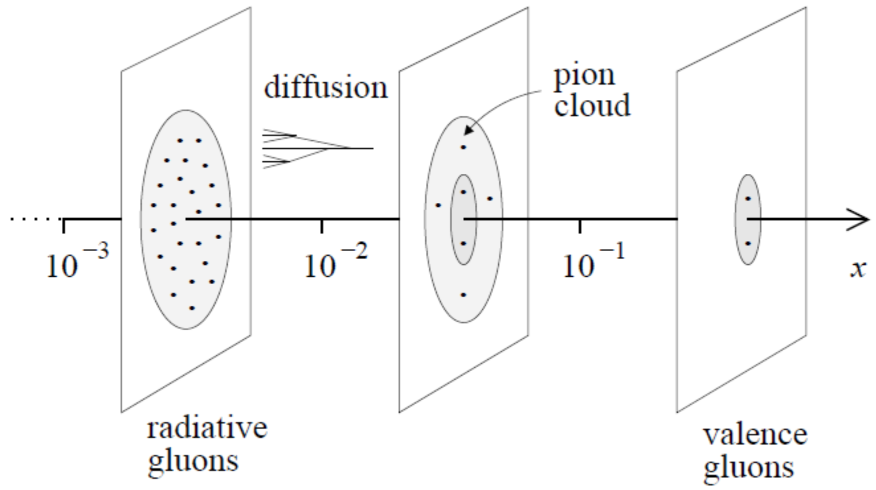
It is possible to extract the three dimensional structure of proton. This can also be performed at EIC.

Talk by Alexei Prokudin

EIC: nucleon spin, GPDs, TMDs

Exclusive reaction:

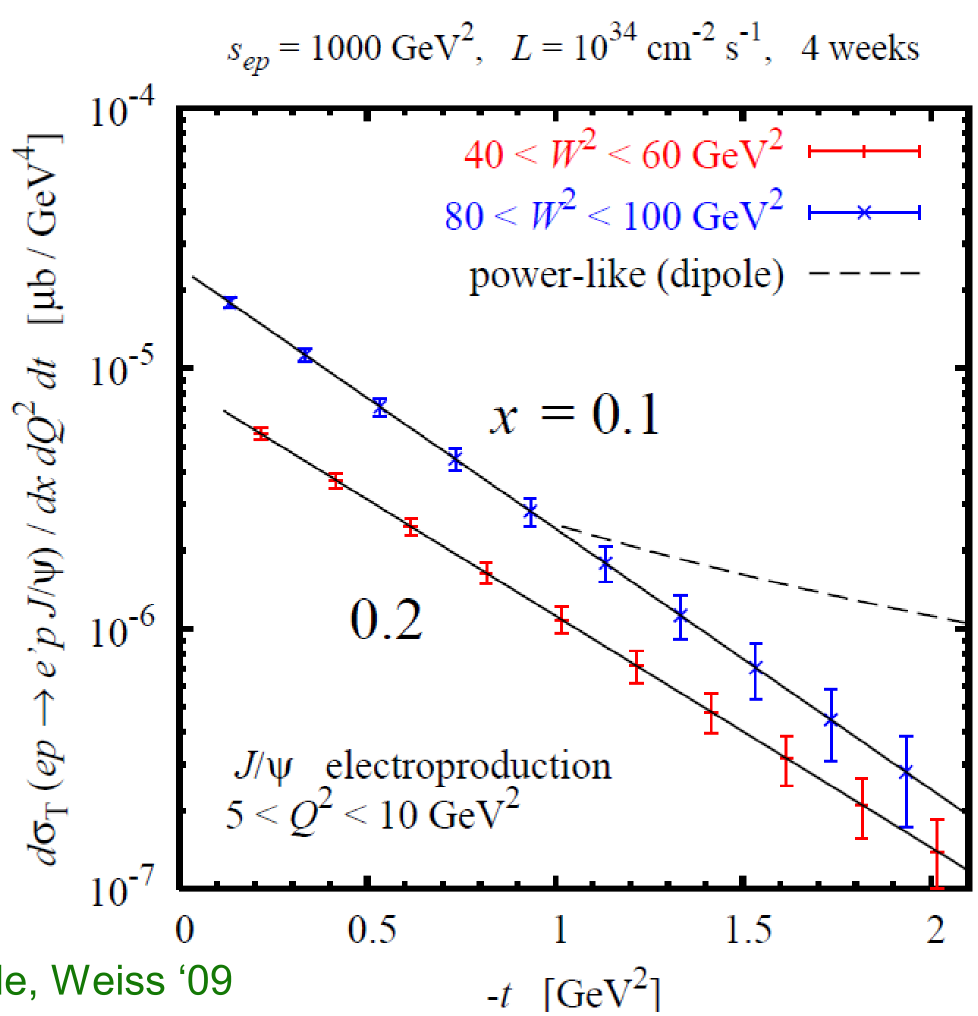




- Transverse spatial distributions from exclusive J/ψ and φ (Q^2>10 GeV^2)
  - Transverse distribution directly from Δ_T dependence

- Imaging requires
  - Full t-distribution for Fourier transform
  - Non-exponential? Power-like at |t|>1 GeV^2?
  - Electroproduction with Q^2>10 GeV^2: test reaction mechanism, compare different channels, control systematics

- Experimentally need:
  - Recoil detection for exclusivity, t-measurements
  - Luminosity ~ 10^{34} for x>0.1, electroproduction, high-t



Hyde, Weiss '09

Tanja Horn

Krishna Kumar

Electroweak Physics at a Future Electron-Ion Collider (EIC)

- ***Lepton-Quark Weak Neutral Current Couplings***
  - EIC with highest luminosities may allow precision beyond planned facilities, both for BSM physics and nucleon stucture
    - *sensitivity would reach beyond 12 GeV JLab program*
    - *interest level might be magnified depending on LHC results and results of the JLab program*
    - *theoretically very clean (e.g. higher twist effects)*
    - *detailed look at experimental systematics needed!*
  - An optimized (smaller) data set with polarized ^{1}H, ^{2}H and ^{3}He
    - *new parity-violating structure functions*
    - *separation of quark helicity distributions from $x = 0.005$ to 0.5*
    - *Possibly critical for disentangling new physics in W asymmetries*
  - e-A with polarized electrons
    - *novel probe of EMC effect?*
    - *available "for free" during e-A running if properly instrumented*

Leonard Gamberg

Final state interactions T-odd TMDs and the transverse structure of hadrons

- It is expected higher luminosity and wider Q^2 range will enable a more precise extraction of TMDs Sivers, Boer-Mulders ,"transversity"....
- Transverse spin physics and TMDs should be a dedicated program program at an EIC
- Extractions of Sivers, Boer-Mulders, Transversity TMD will give us deeper insight into the color and transverse structure of hadrons
- A joint effort of Drell Yan and SIDIS experiments will enable a test the fundamental prediction of "modified universality"

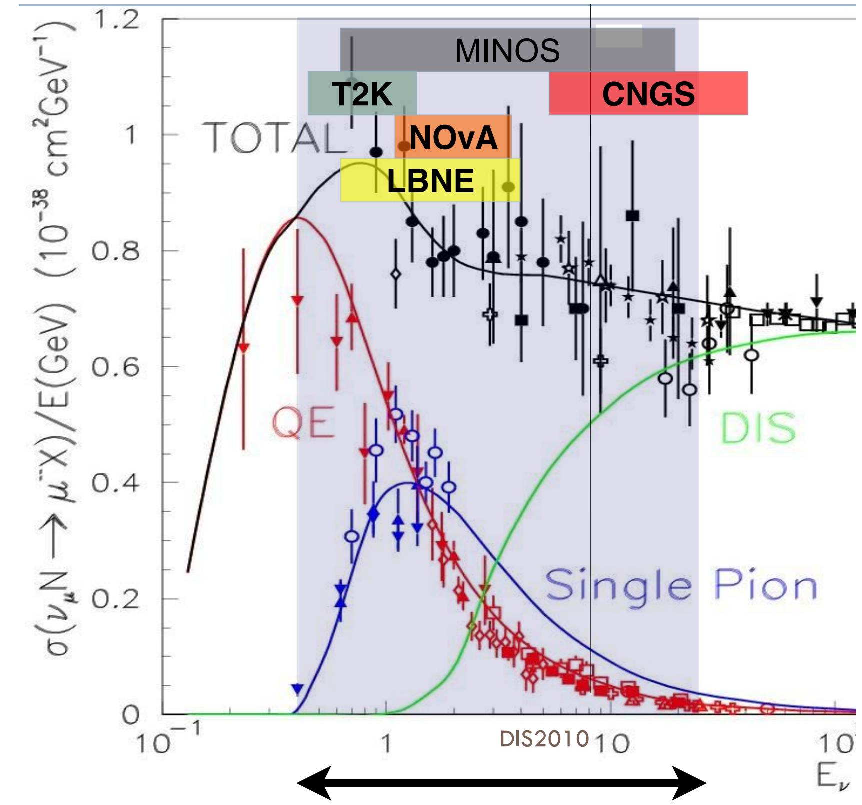
MINERνA

MINERvA

Talk by Heidi Schellman

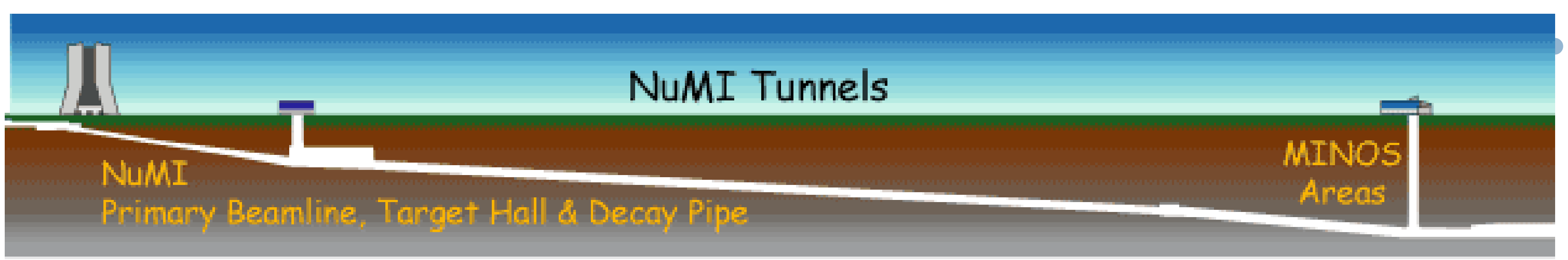
- Goals
  - Basic understanding of neutrino interactions in the 1-10 GeV range.
  - Important inputs for neutrino oscillation experiments

Possible to study wide range of nuclear targets

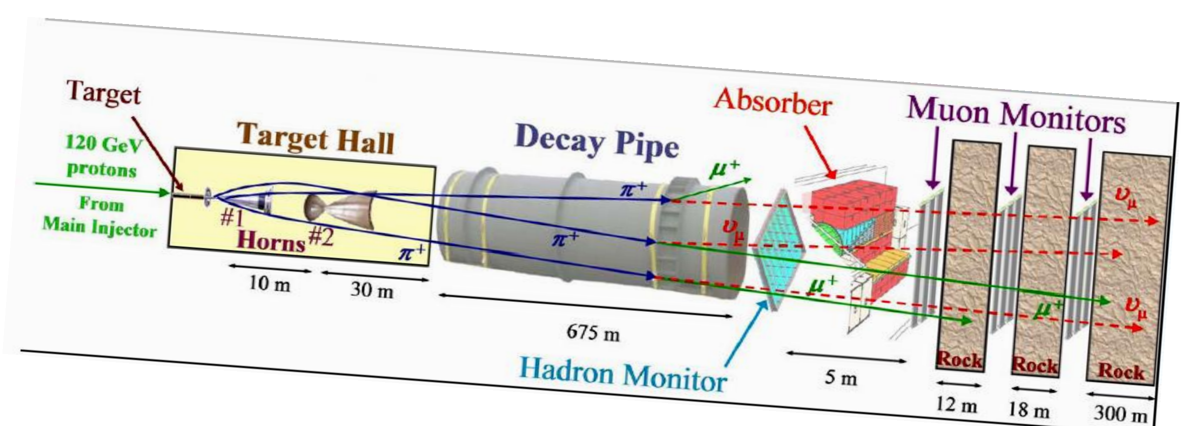


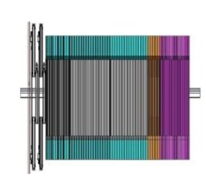
MINERvA range

Experimental setup:

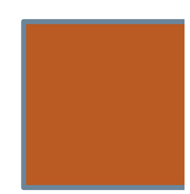


- Study transition between perturbative and nonperturbative QCD regimes





MINERvA

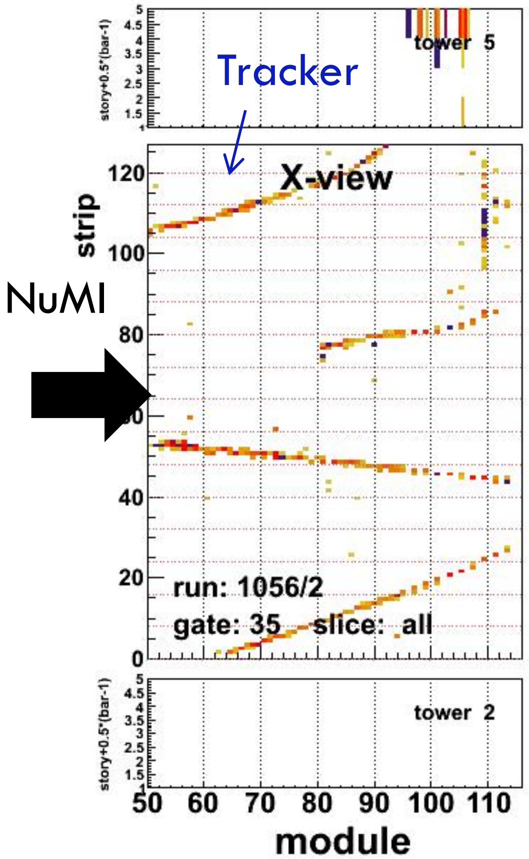


MINOS

Sample events

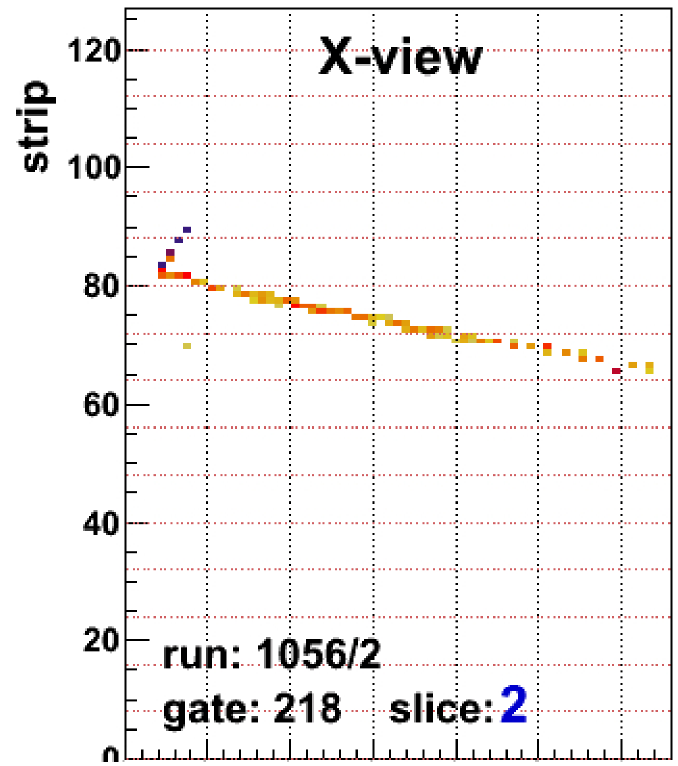
Talk by Heidi Schellman

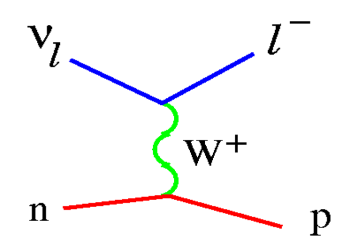
Rock muons



Muons created by the upstream neutrino interactions.

Quasi-elastic candidate





Muon kinematics from angle, range and momentum in MINOS.

Proton kinematics from angle, range.

MINERvA can be sensitive to the A dependence of the inclusive structure functions

- An early look at the data after a run with 60% of the detector shows that the detector works very well. We can distinguish different particle species! We are using these events to tune our calibration and reconstruction algorithms.

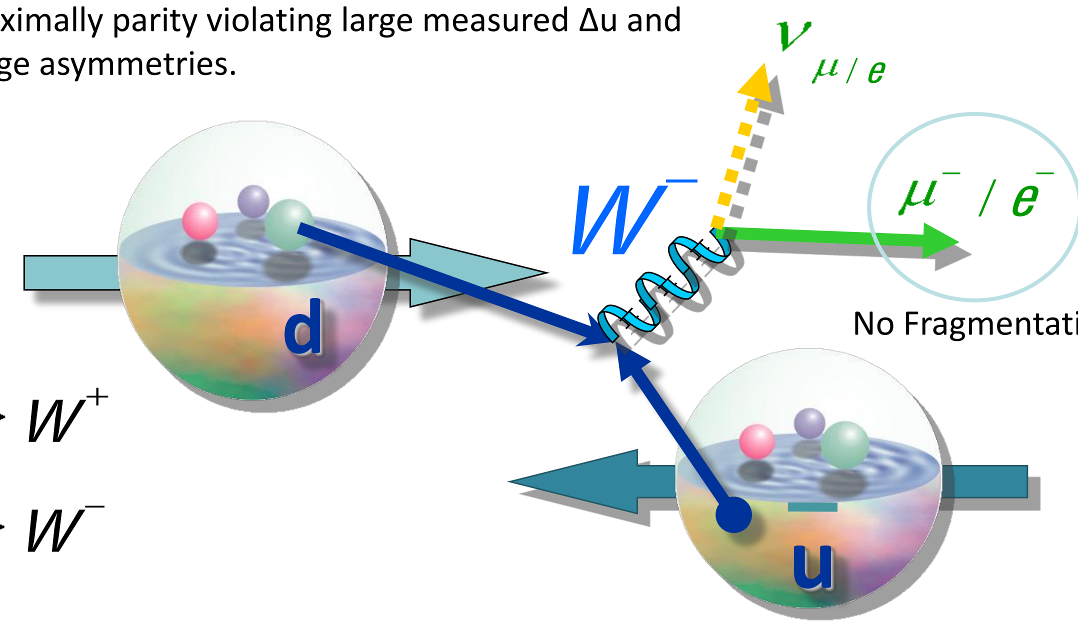
- MINERvA is on its way
- Stay tuned for cross section and exclusive measurements at the next DIS!

Talk by Anselm Vossen

PHENIX Calorimetry and Trigger Upgrades

W Production Basics

Since W is maximally parity violating large measured Δu and Δd *require* large asymmetries.



$$u\bar{d} \rightarrow W^+$$

$$d\bar{u} \rightarrow W^-$$

$$A_L^{W^-} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}} \propto \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

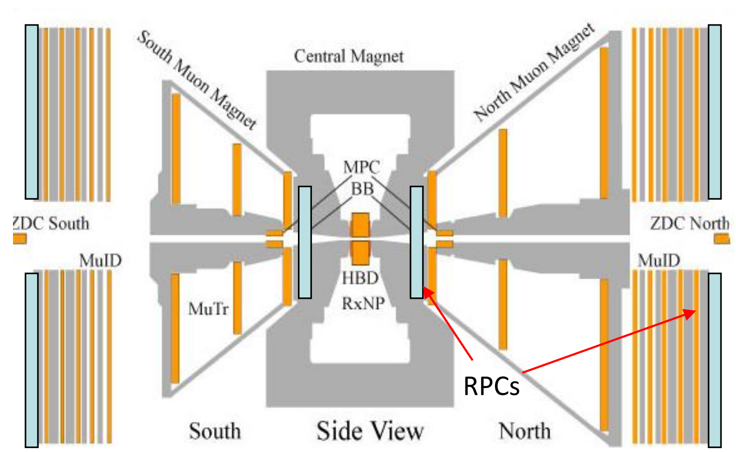
$x_1(x_2)$: momentum fraction of quark in polarized (unpolarized) proton

for W^+ to get $\Delta\bar{d}$ and Δu…

17

Status of Software

- Reconstruction
  - RPC included
  - Offline MuTr stations exists
- Simulation
  - Efficiencies
  - Smearing
    - Momentum
    - Charge identification
  - Background simulation
    - Hadronic background
      - Punch through
      - Decay hadrons faking straight high momentum track
    - S/N assumption: 3:1
      - Reachable with absorber (2011) or future vertex tracker (>2012)
  - Absorber effects
    - Background suppression
    - Impact on momentum reconstruction



RPC3 North Completed Installation

31 31

Talk by Anselm Vossen

COMPASS and DY measurements

Prospects for a DVCS measurement at COMPASS

Talk by Eva-Maria Kabuss

- COMPASS has a great potential in GPD physics
- for exclusive measurements recoil proton detection mandatory

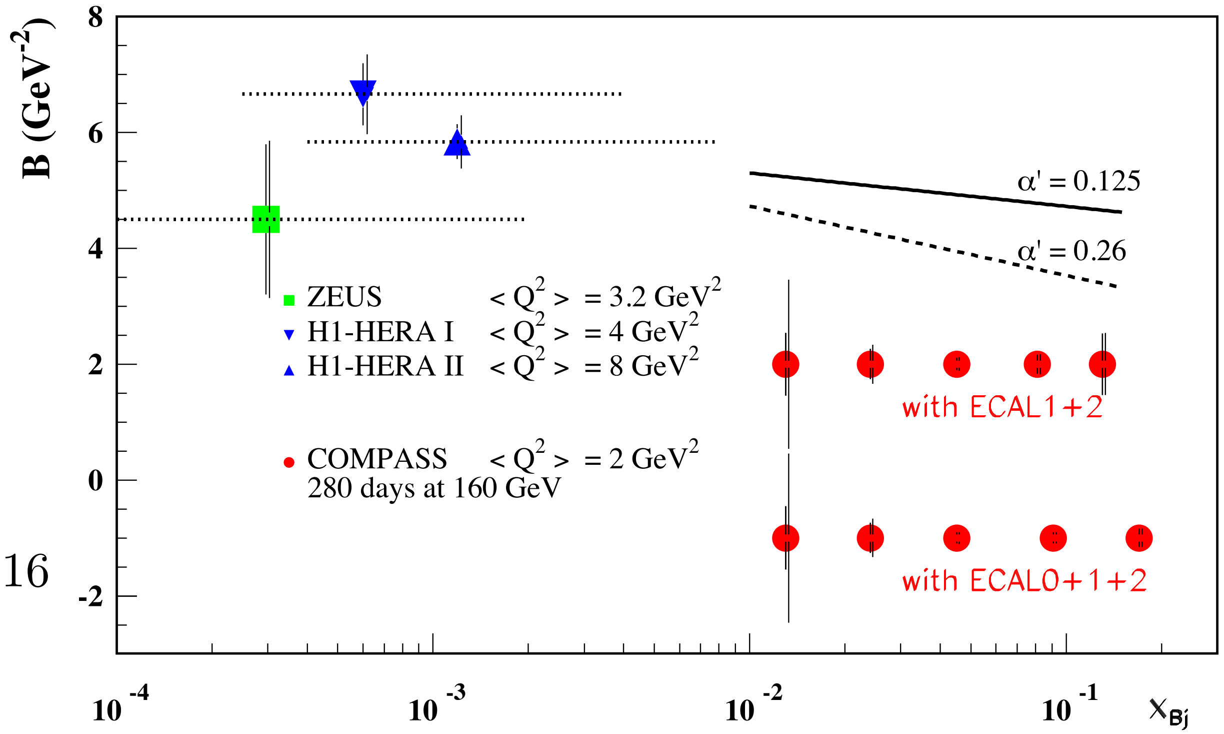
- **unique kinematic range** between HERA and HERMES/JLab
  - intermediate x_{Bj}: $\Longrightarrow$ sea and valence quarks
  - high x_{Bj} limit from acceptance
  - Q^2 up to 8GeV^2 $\Longrightarrow$ limit from cross section with $L = 10^{32}$ cm^{-2}s^{-1}

- **planned measurements:**
  - deeply virtual Compton scattering
  - deeply virtual meson production

projections with 2 years of data
$\varepsilon_{global} = 10\%$
$L = 1222$ pb^{-1}

Transverse imaging

$$d\sigma^{DVCS}/d|t| \propto \exp(-B|t|)$$



- determination of B with 0.1 GeV^{-2} accuracy, α' with 3σ acc. if $\alpha' \geq 0.16$
- no model dependence

Future COMPASS Drell-Yan measurement

Talk by Oleg Denisov

Sivers, Boer-Mulders functions SIDIS ←→ DY

QCD

↓

$\sigma_h \cong \sigma_p \times$ PDF

↓

Direction of the gauge-link of the k_T dependent PDF is process-dependent (gauge-link is resummation of all collinear soft gluons) and it changes to the opposite in SIDIS wrt DY

↓

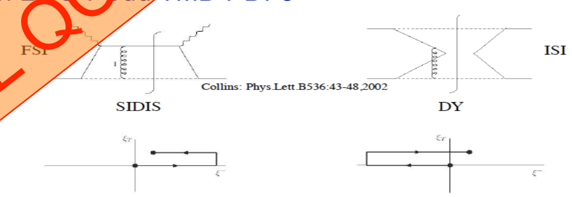
$$f_{1T}^{\perp}(x,\mathbf{k}_T)\Big|_{SIDIS} = -f_{1T}^{\perp}(x,\mathbf{k}_T)\Big|_{DY}$$

$$h_1^{\perp}(x,\mathbf{k}_T)\Big|_{SIDIS} = -h_1^{\perp}(x,\mathbf{k}_T)\Big|_{DY}$$

FUNDAMENTAL QCD TEST

QCD factorization, valid for hard processes only (Q, q_T are large)

Cross-sections are gauge-invariant objects, to provide the gauge invariance of the PDFs the gauge-link was introduced (intrinsic feature of PDF). The presence of gauge-link provides the possibility of existence of non-zero T-odd TMD PDFs



Sivers and Boer-Mulders functions are T-odd, and to provide the time-invariance they change the sign in SIDIS wrt DY due to the opposite direction of the gauge-link

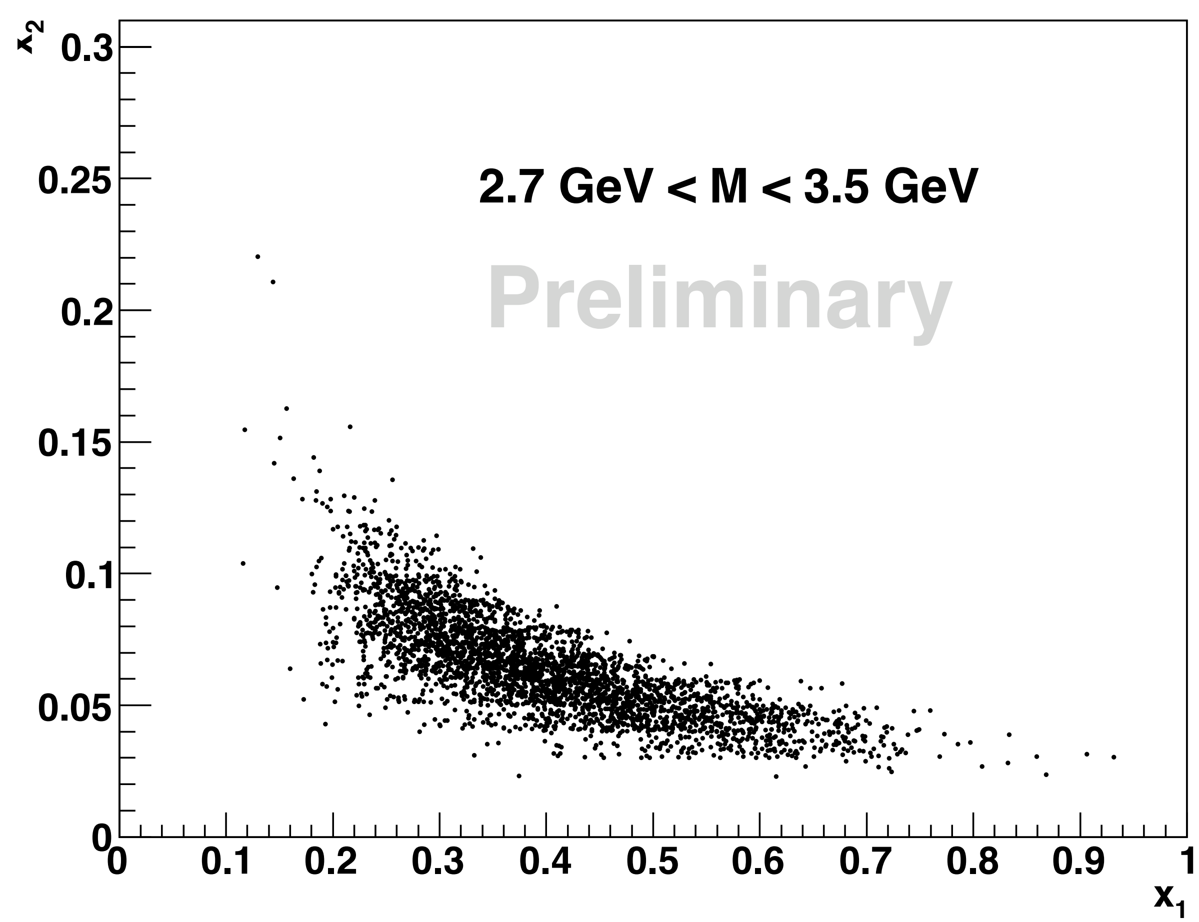
J.C. Collins, Phys. Lett. B536 (2002) 43

J. Collins, talk at LIGHT CONE 2008

- Valence quark range for both J/Psi and DY

$$x_1 = \frac{Q^2}{P_1 q},$$
$$x_2 = \frac{Q^2}{P_2 q},$$
$$x_f = x_1 - x_2,$$

COMPASS DY test run 2009



DY@COMPASS projections I

With a beam intensity $I_{beam} = 6 \times 10^7$ particles/second, a luminosity of $L = 1.7 \times 10^{33}\ cm^{-2}s^{-1}$ can be obtained.

↪ Assuming 2 years of data-taking, one can collect > 200000 DY events in the region $4 < M_{\mu\mu} < 9.$ GeV/c^2.

Feasibility of process has been demonstrated

Polarized Drell-Yan measurement

Talk by Yuji Goto

- Polarized Drell-Yan experiment
  - Not yet done!
  - Many new inputs for remaining proton-spin puzzle
    - flavor asymmetry of the sea-quark polarization
    - transversity distribution
    - transverse-momentum dependent (TMD) distributions
      - Sivers function, Boer-Mulders function, etc.

Sivers function is process dependent. Collins 2002

$$\Delta^N f_{q/p^\uparrow\, DY} = -\Delta^N f_{q/p^\uparrow\, SIDIS}$$

Sivers function measurement

- Sign of Sivers function determined by single transverse-spin (SSA) measurement of DIS and Drell-Yan processes
  - Should be opposite each other
    - Initial-state interaction or final-state interaction with remnant partons
- < 1% level multi-points measurements have already been done for SSA of DIS process
  - x = 0.01 – 0.3 (more sensitive in lower-x region)
- comparable level measurement needs to be done for SSA of Drell-Yan process for comparison

---

- J-PARC proposal
  - Not accepted yet
    - Waiting for FNAL-E906 result for unpolarized measurements
  - 50 GeV beam necessary, polarized-beam necessary
- RHIC
  - Collider experiment
  - Fixed-target (internal-target) experiment
  - Both feasible

Important measurement. Direct verification of the relation between SIDIS and DY.

Measurement of flavor asymmetry of light quark sea

- Naïve Assumption:

$$\bar{d}(x) = \bar{u}(x)$$

- NMC (Gottfried Sum Rule)

$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

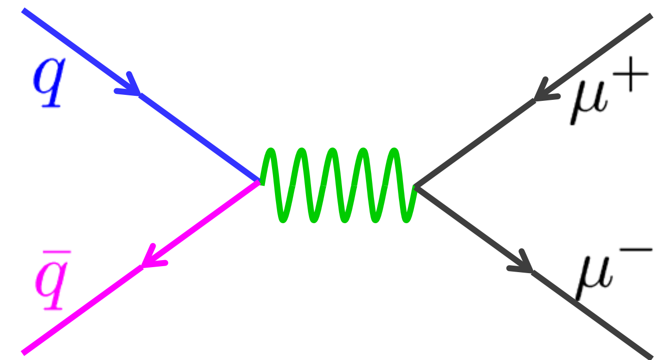
- NA51 (Drell-Yan)

$$\bar{d} > \bar{u} \text{ at } x = 0.18$$

- E866/NuSea (Drell-Yan)

$$\bar{d}(x)/\bar{u}(x) \text{ for } 0.015 \leq x \leq 0.35$$

Drell-Yan scattering:
A laboratory for sea quarks

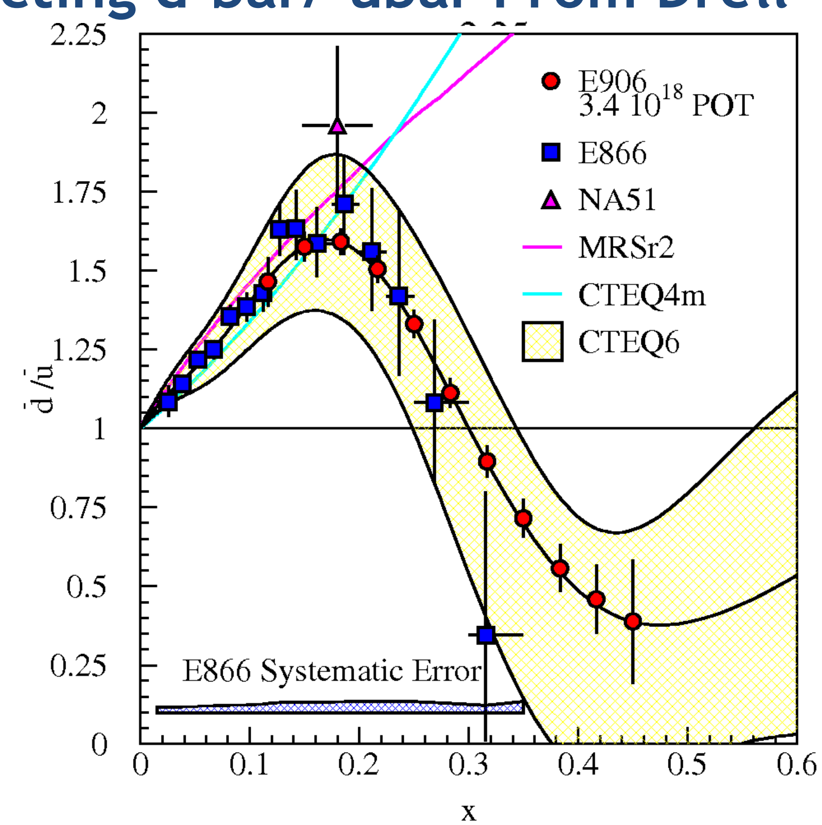


The future:

Fermilab E-906/SeaQuest

- Data in 2010-13
- ^1H, ^2H, and nuclear targets
- 120 GeV proton Beam

Extracting d-bar/-ubar From Drell-Yan Scattering



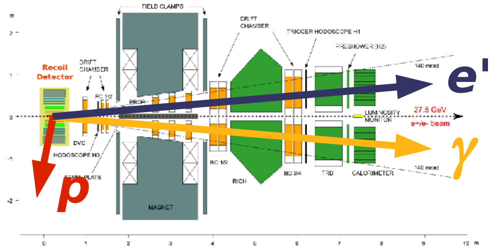
- E906/SeaQuest will extend these measurements and reduce statistical uncertainty.
- E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.

Talk by Paul Reimer

DVCS with Recoil

DVCS analysis with Recoil:

1. Forward Spectrometer:
* Selection of $e\gamma$ topologies.
* Calculate 'missing' p and ϕ.



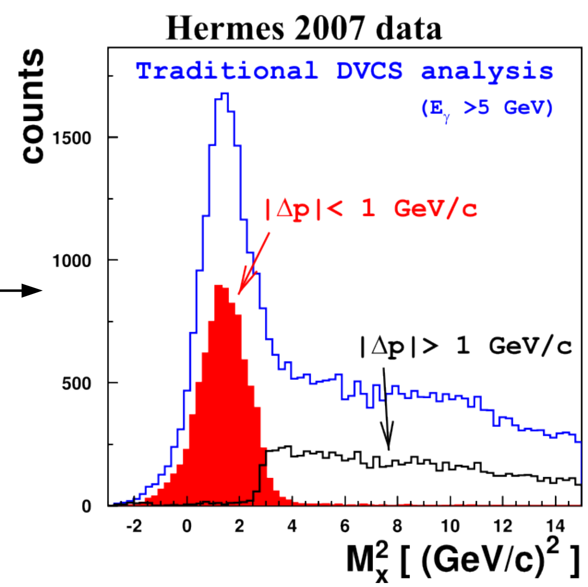
2. Recoil Detector:
* Select proton track candidate.
* Look for "DVCS" correlations:

$$\Delta\phi = \phi_{meas} - \phi_{calc}$$
$$\Delta p = p_{meas} - p_{calc}$$

* **Apply exclusivity cut:**

$$|\Delta p| < 1 GeV/c$$

*Background levels < **1%***



The HERMES Recoil Detector

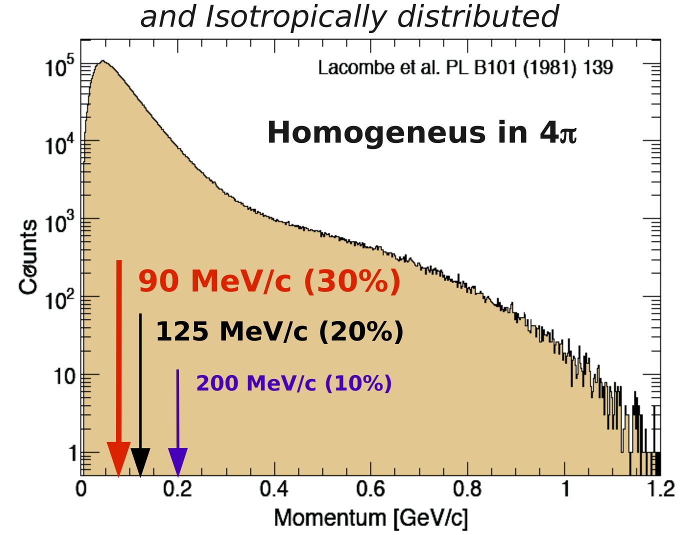
Commissioning Status and Analysis Prospects

Talk by Alberto Martinez

Spectator protons and Recoil

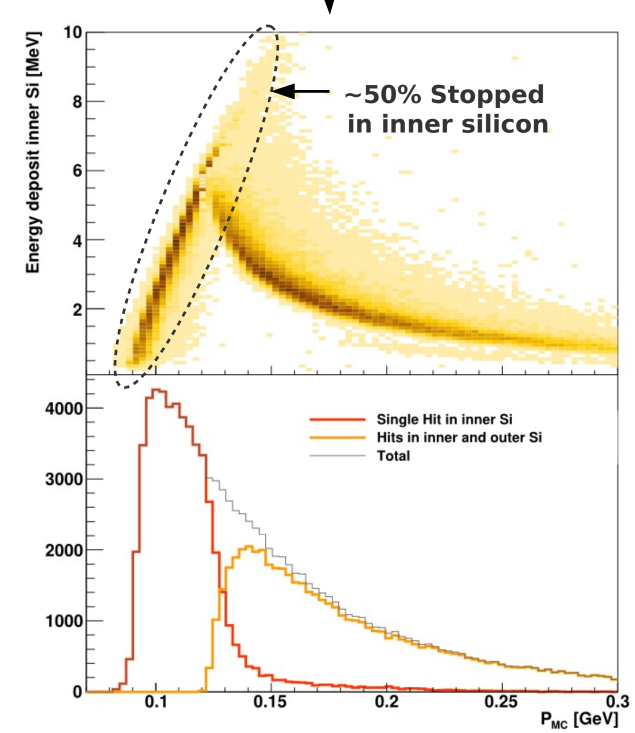
Simple spectator model:
Lacombe et al. PL B101 (1981) 139

Spectator spectrum is at low momentum and Isotropically distributed



* *Minimum momentum **90 MeV/c***
* *Energy acceptance **30%***
* *Geometrical acceptance **57%***

Spectator protons in Recoil Detecor



Accessible spectator spectrum with Recoil Detector: 30 %

We would like to thank:

Organizers for the wonderful conference

All the speakers in the session for contributions

Grazie mille!