Potential H1 or ZEUS analyses in 2022++

HERA 4 EIC workshop

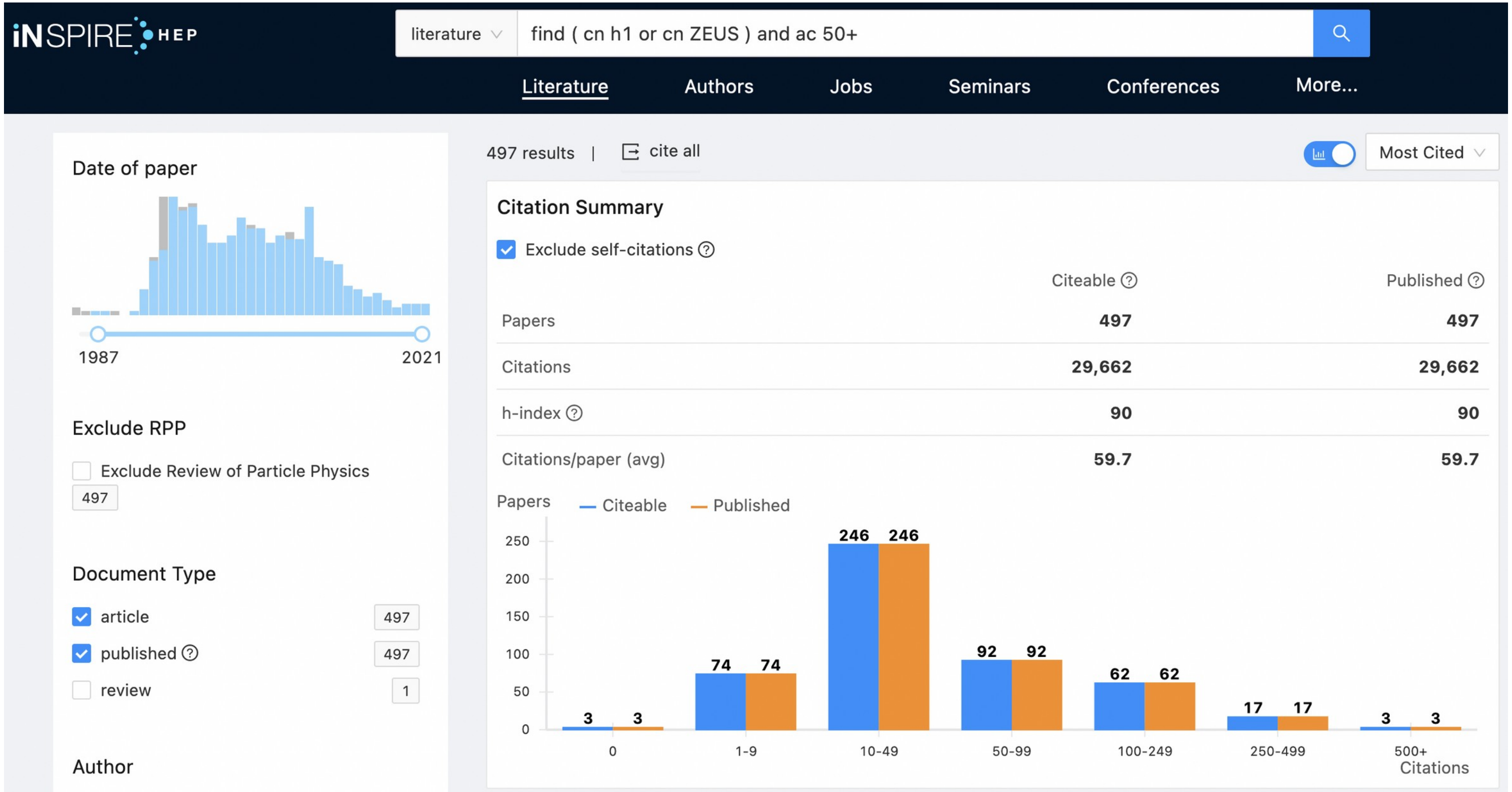
Stefan Schmitt

Disclaimer: this talk is not on behalf of H1 or ZEUS, it reflects my personal opinions only.
Please apologize for any imbalance between presenting H1 and ZEUS results and/or plans, I simply know the H1 perspective better.

Outline

- H1 and ZEUS publications over time
- HERA strategy for future analyses:
  looking back at the HERA symposium 2014
- An (incomplete) selection of possible future analysis topics

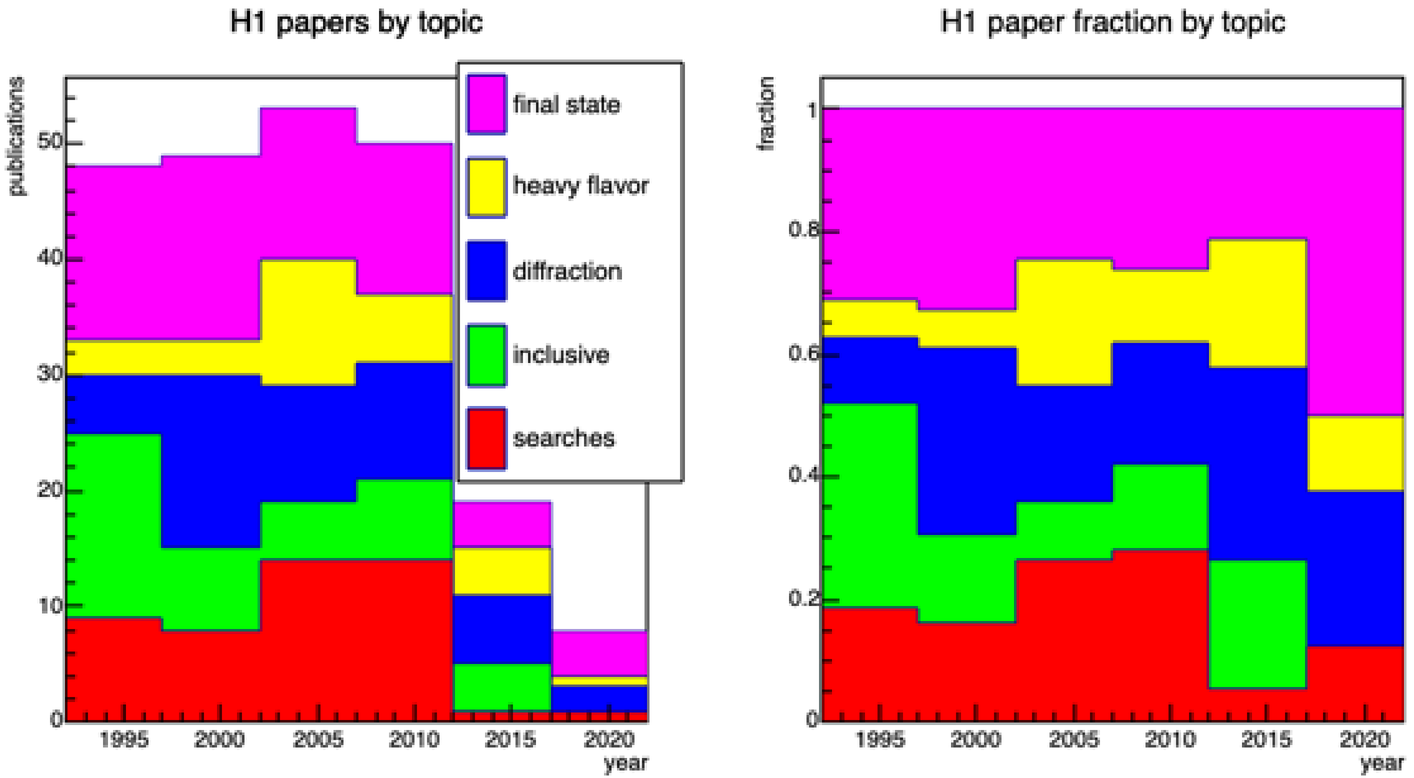
H1 and ZEUS publications - inspire



- Three 500+ papers after excluding self-citations
- Inclusive DIS papers are on top of the list
- Next in citations:
  - Diffraction F_2^D
  - J/ψ, DVCS, light VM
  - Total cross-sec
  - Charm
  - Jets

H1 publications: topics over time

- H1 publications and topics as a function of time
- 15 years after end of experiment: still having 2 papers per year
- Last years: increasing fraction of analyzers looking at final states (jets, event shapes, charged particles, etc)



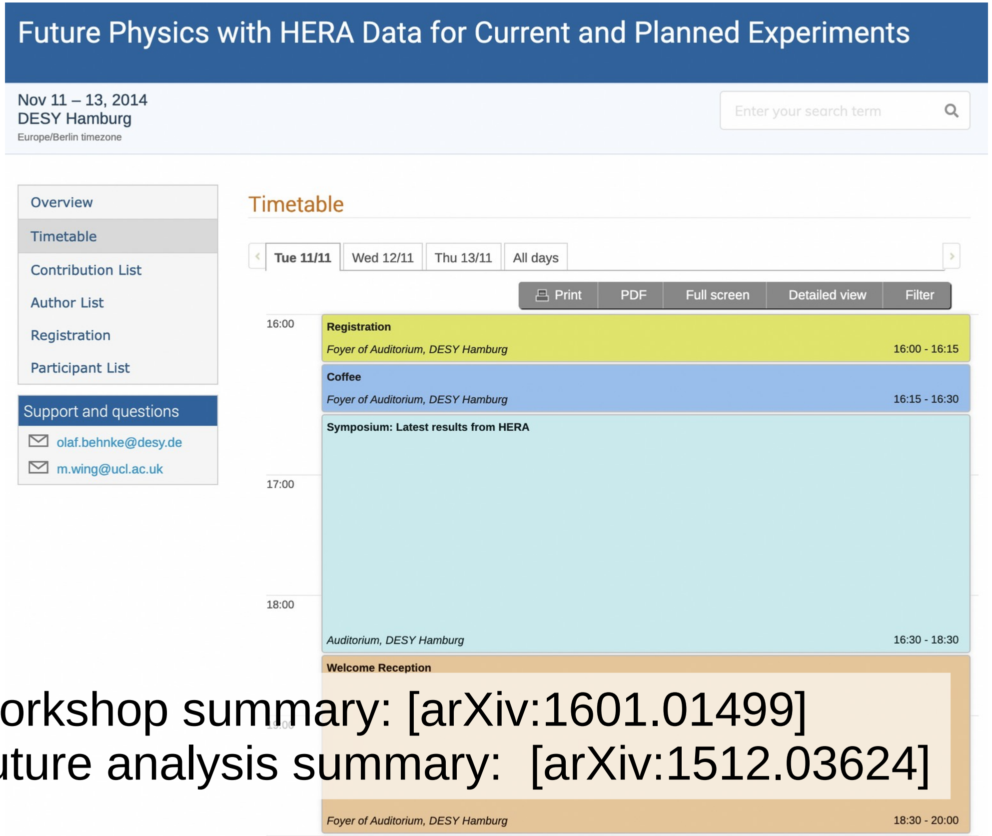
Recap: survey of analyses ideas in 2014

- Symposium in November 2014 with all three HERA experiments

  “Future physics with HERA Data for Current and Planned Experiments”

  https://indico.desy.de/event/10523/

- Goal: collect analysis ideas for the HERA data-preservation phase
- Talks by the experiments and interested theorists → similar to the present workshop
- Where do we stand 7 years after?



Workshop summary: [arXiv:1601.01499]
Future analysis summary: [arXiv:1512.03624]

Ideas in 2014 and resulting publications

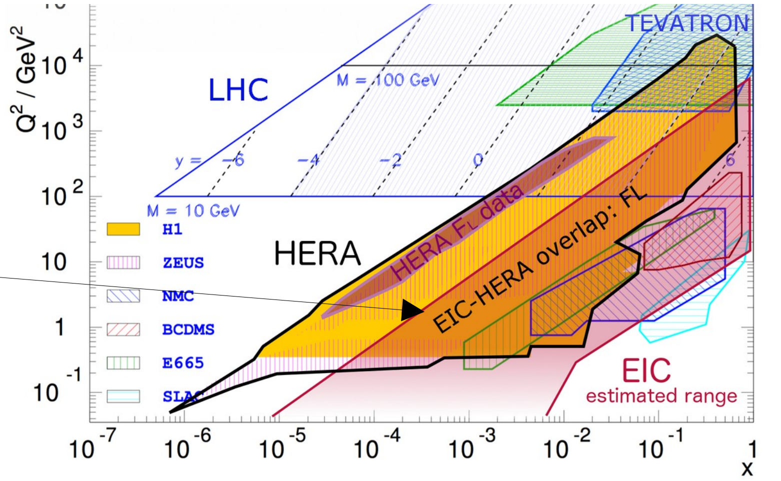
- A quick look at the 2014 slides
- Overall, many of the 2014 open topics were addressed in subsequent papers, so the workshop was a real success

  → Such a workshop can be of great use – I am glad we have a similar type of meeting today
- Next slides: an incomplete look at possible future analyses

Ideas presented in 2014	Papers, Analyses 2015++
inclusive	
EW fit	DESY-16-039 (ZEUS)
	DESY-18-080 (H1)
High-x data	DESY-20-048 (ZEUS)
charm in CC	DESY-19-054 (ZEUS)
diffraction	
DPDF fit	H1prelim-19-013 (H1)
Vector mesons	DESY-15-120 rho+n (H1)
	DESY-20-080 rho (H1)
	preliminary psi'/psi (ZEUS)
Hadronic final states	
HERA-II precision jet data	DESY-16-200 (H1)
NNLO jet analysis	DESY-17-137 (H1)
	DESY-21-201 (H1+ZEUS)
prompt photons	DESY-17-077 (ZEUS)
	DESY-17-212 (ZEUS)
event shapes	H1prelim-21-032 (H1)
	H1prelim-22-033 (H1)
pentaquark	DESY-16-065 (ZEUS)
heavy flavour	
charm in diffraction	DESY-17-043 (H1)

Future analysis ideas - inclusive

- F_L data combination
  - Could also be used to prepare for extracting F_L from HERA+EIC



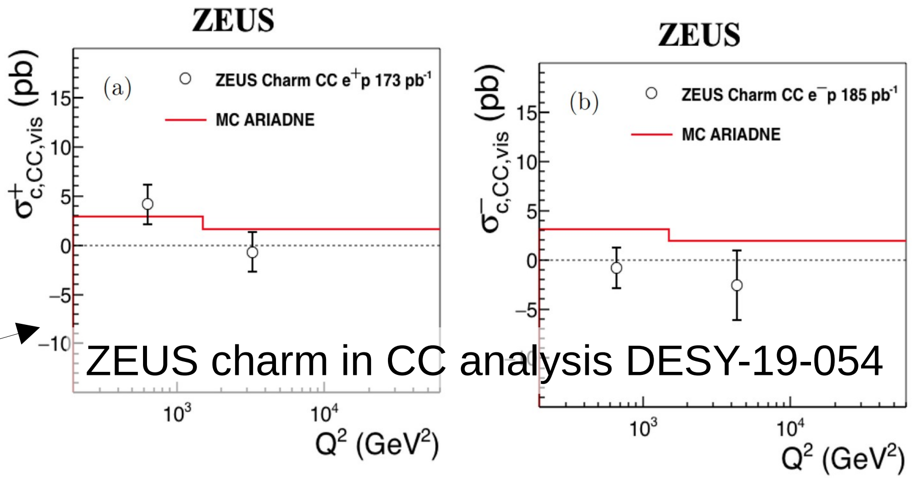
- Extend phase-space of traditional inclusive analyses
  - High-x (ZEUS paper)
  - Profit from improved reconstruction methods (talks by Owen and Alan)

- Revisit radiative corrections
  - HERA method: radiative corrections. Best choice for EIC?

    → HERA measurements, where photon radiation is part of the results?

Future analysis ideas - PDF

- Photon in the proton (from μ+μ- pair production?)
- Photon structure – from photoproduction of jets or charged particles → HERA-II sample
- Strange sea
  - ZEUS paper. H1 could try charm in CC (thesis exists)
  - Other idea: can ϕ production be used?



ZEUS charm in CC analysis DESY-19-054

H1 thesis T. Zimmermann (2008), using muons

$F_c = 9.5 \pm 8.9 \pm 3.0\ \%$ for e^+p and

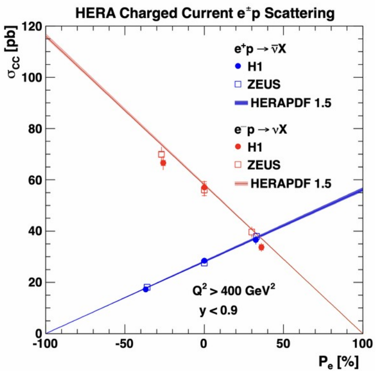
$F_c = 4.4 \pm 6.9 \pm 2.6\ \%$ for e^-p. Compatible with zero

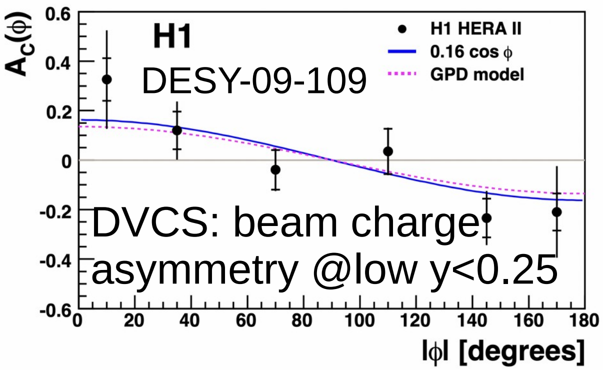
Lifetime analysis was not successful at the time (T.Zimmermann). Could possibly try with track-based electron finder.

Future analysis ideas - polarisation

- HERA lepton beam was polarized, but has not been used much by H1 and ZEUS
- Electroweak effects have been measured only in:
  - Charged current
  - gamma/Z interference
- Analysis ideas: beam polarization also should be visible in DVCS and diffractive DIS vector-mesons

Charged current wrt polarisation (H1/ZEUS summary plot)

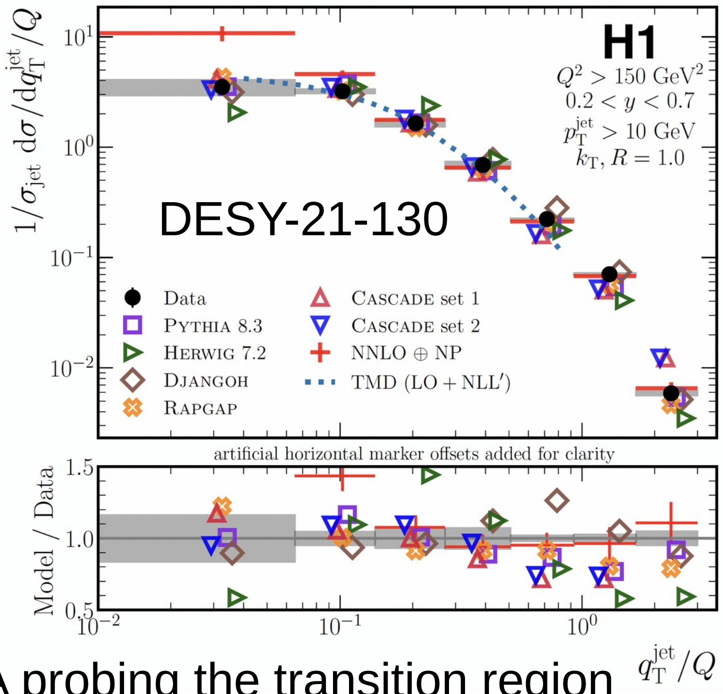




Could also measure polarization asymmetry. For H1, high y region 0.3<y<0.7 looks most promising.

Future analysis ideas – jets and event shapes

- Theory advances have triggered new analysis → stay tuned
- Recent examples and ideas
  - Lepton-jet decorrelation → TMD
  - Triple-differential event shapes → PDF and α_S (talk by Daniel)
  - Groomed event shapes: transition between fragmentation and hard QCD (talk by Henry)

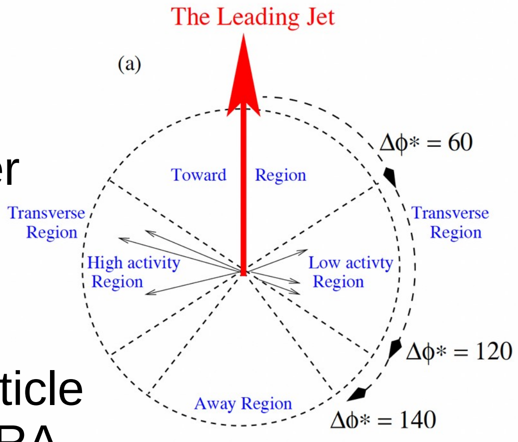


HERA probing the transition region between collinear QCD and TMDs

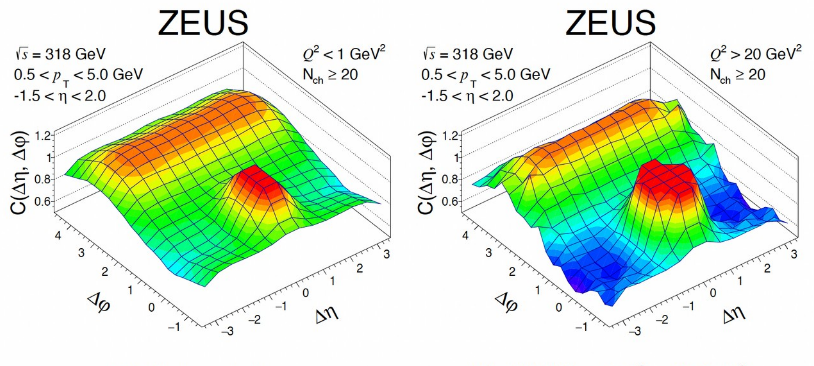
Future analysis ideas – hadronic final states

- Examples:
  - Underlying event
  - Particle azimuthal correlations (talks by Chuan and Dhevan)
  - Jet substructure (talks by Vinicius and Mriganka)
  - Semi-inclusive DIS: leading hadrons, multi-differential
  - Multiplicities/entanglement (Zhoudunming)
- HERA data $\rightarrow$ tune MC for EIC and LHC
- Make sure our results are in RIVET

H1prelim-07-032 underlying events, promising but never published



DESY-21-099: particle correlations at HERA

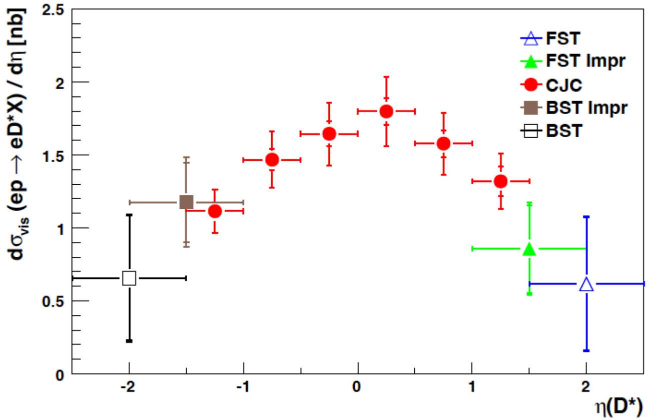


(a) *Photoproduction.* (b) *NC DIS with $Q^2 > 20\ GeV^2$.*

Future analysis ideas – heavy flavour

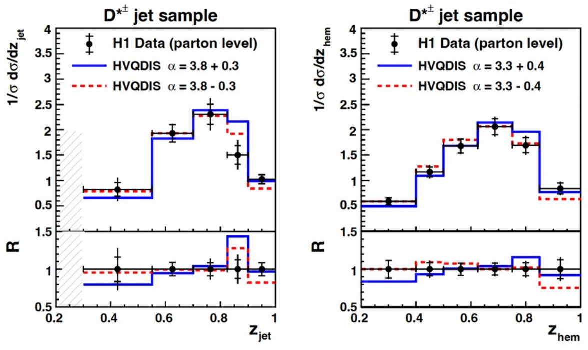
- Joint H1+ZEUS paper on inclusive charm and beauty → is there more to come?
- Ideas from 2014 (Achim’s slides):
  - Look at forward muons (intrinsic charm?)

    H1: use Fwd/Bwd Silicon?
  - Multi-differential analyses
  - Improved charm fragmentation (HERA-II DIS data analysis?)



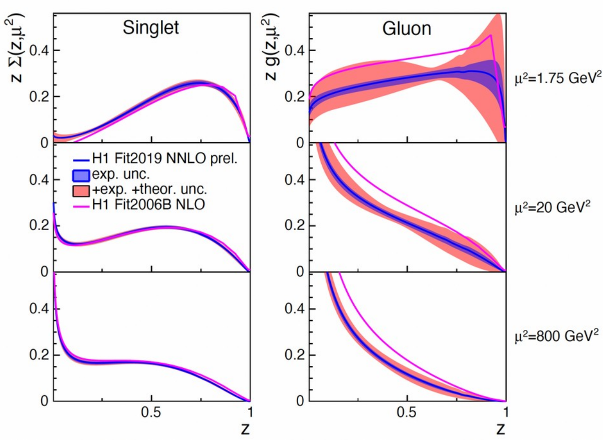
H1 thesis I. Glushkov (2008) showing potential of Fwd and Bwd silicon trackers for D*

DESY-08-080 D* fragmentation function from HERA-I sample $2<Q^2<100$ GeV²



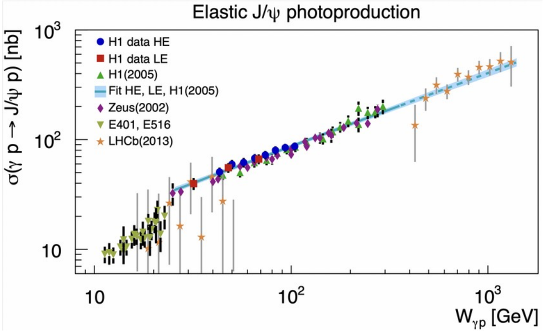
Future analysis ideas - diffraction

- H1+ZEUS data combination F_2^D ?
- New DPDF (H1 preliminary result)
- Further analyses with forward neutron (e.g. HERA-II - high Q^2)
- Vector mesons in DIS (HERA-II), multi-differential J/psi?
- Odderon searches HERA-II
- Talks by Mark, Alessia, Bjoern, Sergey



H1prelim-19-013
DPDF fit @NNLO
Includes HERA-II data, inclusive+jets

DESY-13-058 J/psi photo-production
Potential to analyze decay angles and the large DIS sample



Summary

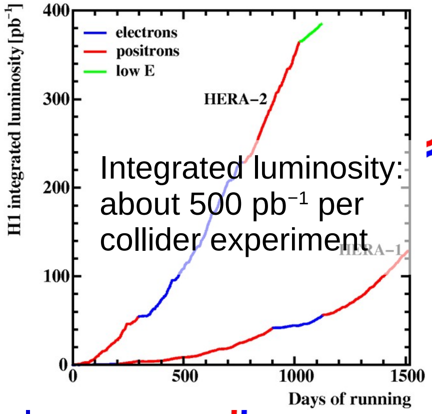
- 30 years after the start of HERA and 15 years after end of data taking, we are still discussing exciting analysis opportunities

  → **data preservation at DESY and MPI really paid off**
- In view of the EIC HERA data can be used to
  - Explore areas of physics which have been neglected in the past
  - Answer specific questions in corners of the accessible phase space
  - Help to establish the better possible MC models for ep and eA
  - Provide “real” data analyses for studenst while ramping up the EIC
- **Looking forward to have an exciting workshop with detailed discussions of analysis opportunities**

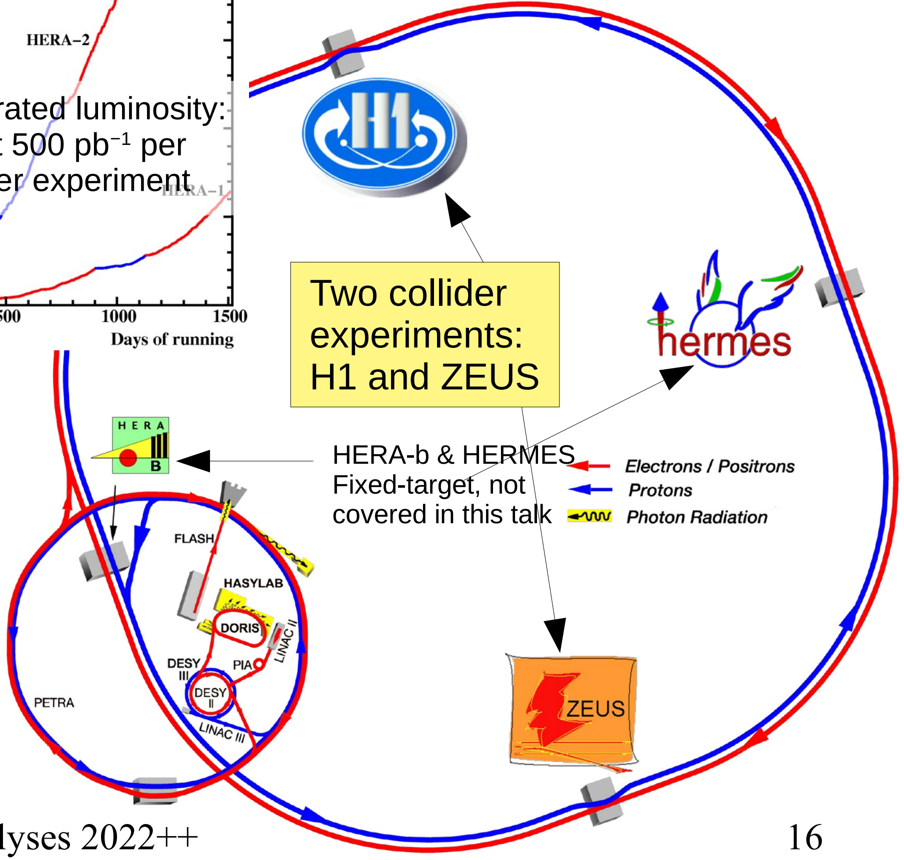
Backup slides

The HERA collider

- Operated from 1992 to 2007
- Circumference 6.3 km
- Electrons or positrons colliding with protons
- Proton: 460-920 GeV, Leptons 27.6 GeV
- Peak luminosity ~7×10^{31} $cm^{-2}s^{-1}$
- Lepton beam polarisation up to 40-60% (Sokolov-Ternov effect, rise-time ~30 minutes)



Integrated luminosity: about 500 pb^{-1} per collider experiment



Two collider experiments: H1 and ZEUS

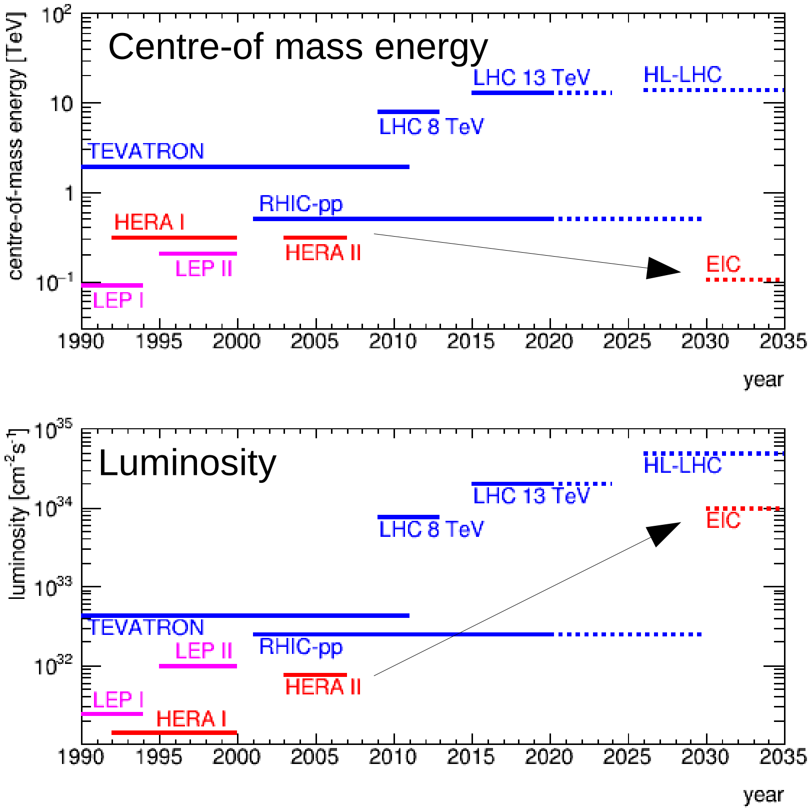
HERA-b & HERMES Fixed-target, not covered in this talk

HERA compared to other colliders

- HERA at construction time: energy frontier (E_p~Tevatron, E_e~ ½ LEP)

  Detectors were designed for discoveries, not so much for precision

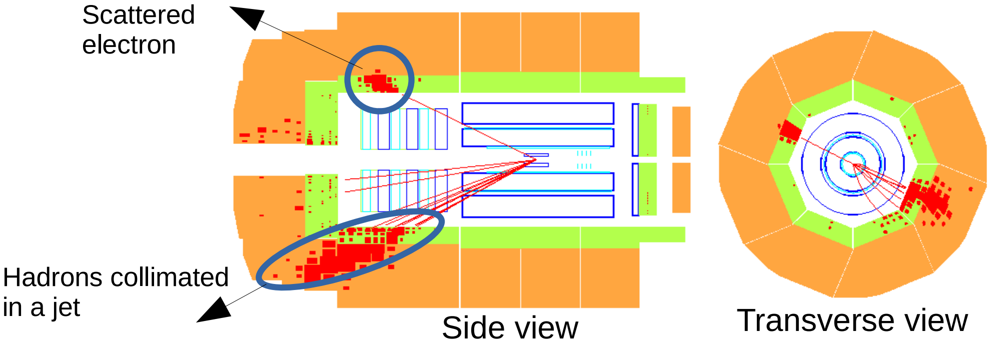
- EIC compared to HERA:
  - Reduced center-of-mass energy ×0.3
  - Much higher luminosity ×100
  - Better lepton polarisation
  - Target polarisation
  - Heavy targets
  - Much improved detectors: tracking, acceptance, particle identification, forward detectors, ...



Processes studied at the HERA collider

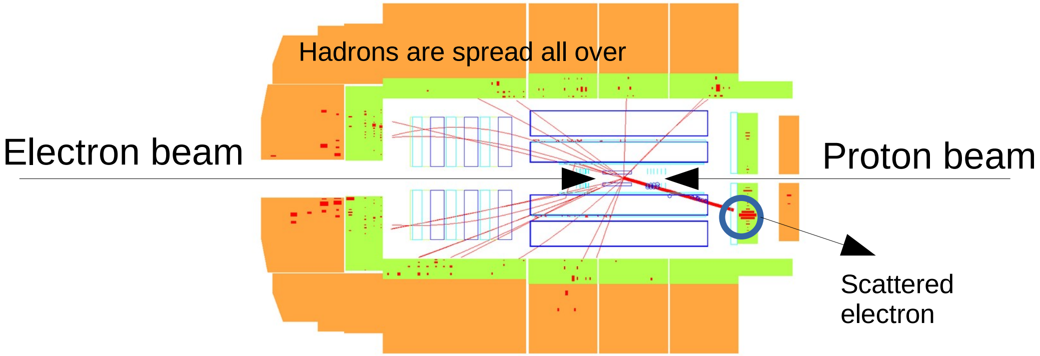
HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

- Neutral Current DIS (Deep Inelastic Scattering)
  - electron in main detector
- Charged current DIS
  - neutrino with high transverse momentum (escapes detection)
- Photoproduction
  - Electron scattered at very low angle (dedicated low-angle detector or not detected)



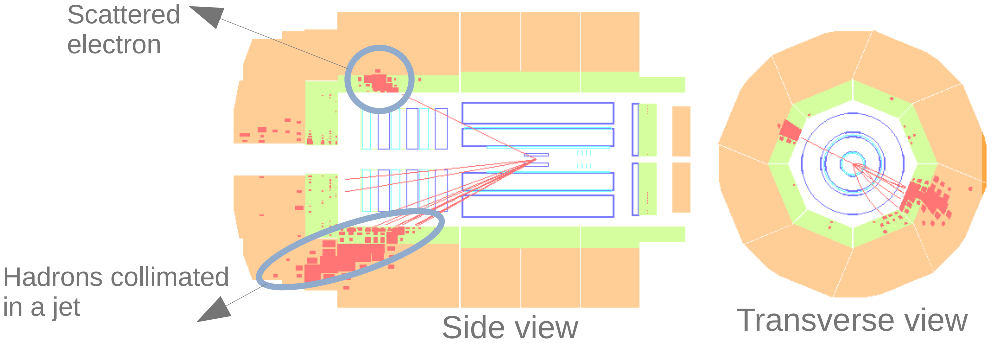
Large electron scattering angle (rare event)

Small electron scattering angle (frequent event)



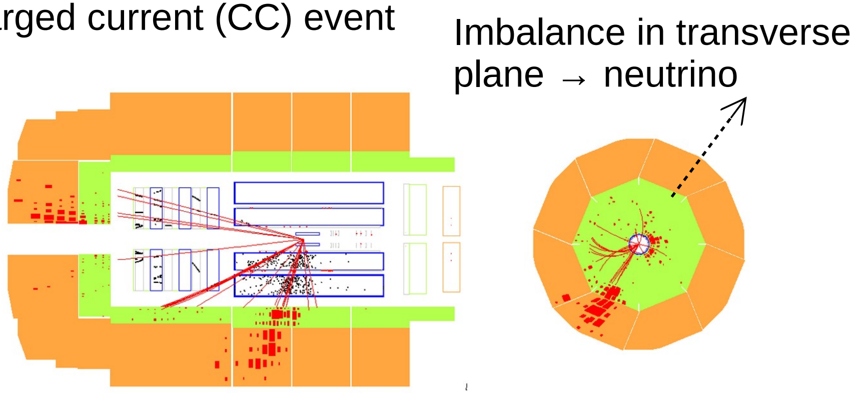
Processes studied at the HERA collider

- Neutral Current DIS
  - electron in main detector
- Charged current DIS
  - neutrino with high transverse momentum (escapes detection)
- Photoproduction
  - Electron scattered at very low angle (dedicated low-angle detector or not detected)



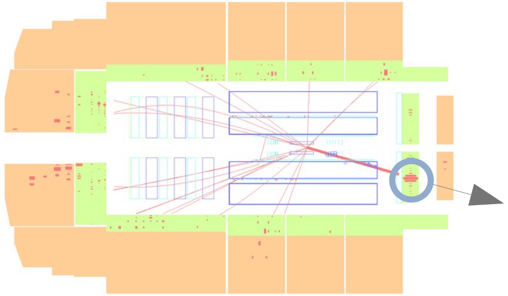
Neutral current (NC) event

Charged current (CC) event



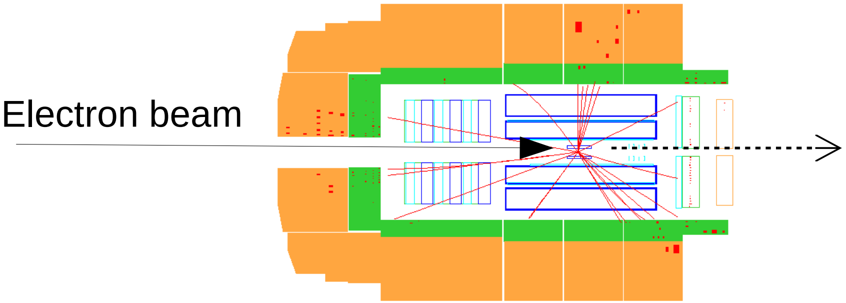
Processes studied at the HERA collider

- Neutral Current DIS
  - electron in main detector
- Charged current DIS
  - neutrino with high transverse momentum (escapes detection)
- Photoproduction
  - Electron scattered at very low angle (not detected or scattered into dedicated low-angle tagger)



Neutral current (NC) event

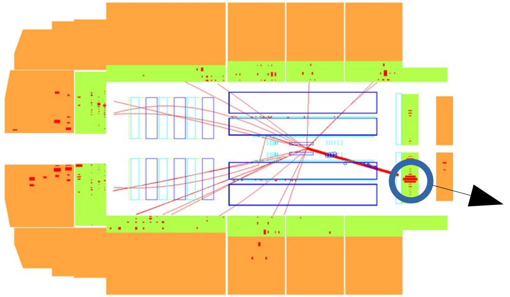
Photoproduction (most frequent type of event)



Photoproduction and DIS

- **Main kinematic variable: negative four-momentum squared $Q^2 = -(e-e')^2$**
- Q^2 provides a natural hard scale for perturbative calculations
- Deep-inelastic scattering (**DIS**): $Q^2 \gg 0$
  - Perturbative QCD applicable

- **Photoproduction**: $Q^2 \sim 0$
  - Perturbative QCD works only if there is another hard scale (jet, heavy quark, etc)

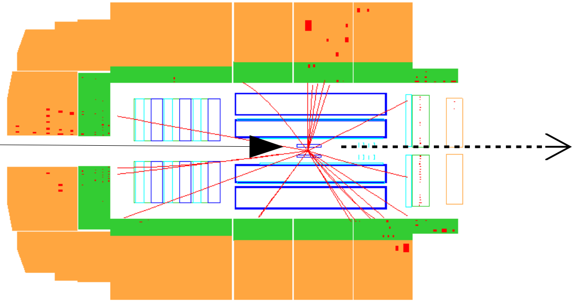


Scattered electron in detector

Neutral current (NC) event

Photoproduction (most frequent type of event)

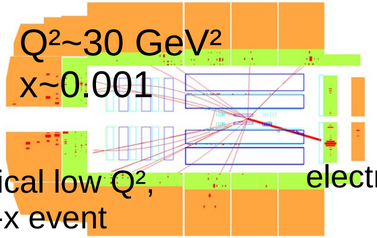
Electron beam



Scattered electron is not detected

Neutral current DIS kinematics at HERA

- Kinematic variables: Q^2, x, y, $Q^2=sxy$
- Determine from 4-vectors of beam particles e, p, scattered electron e' and hadronic final state X

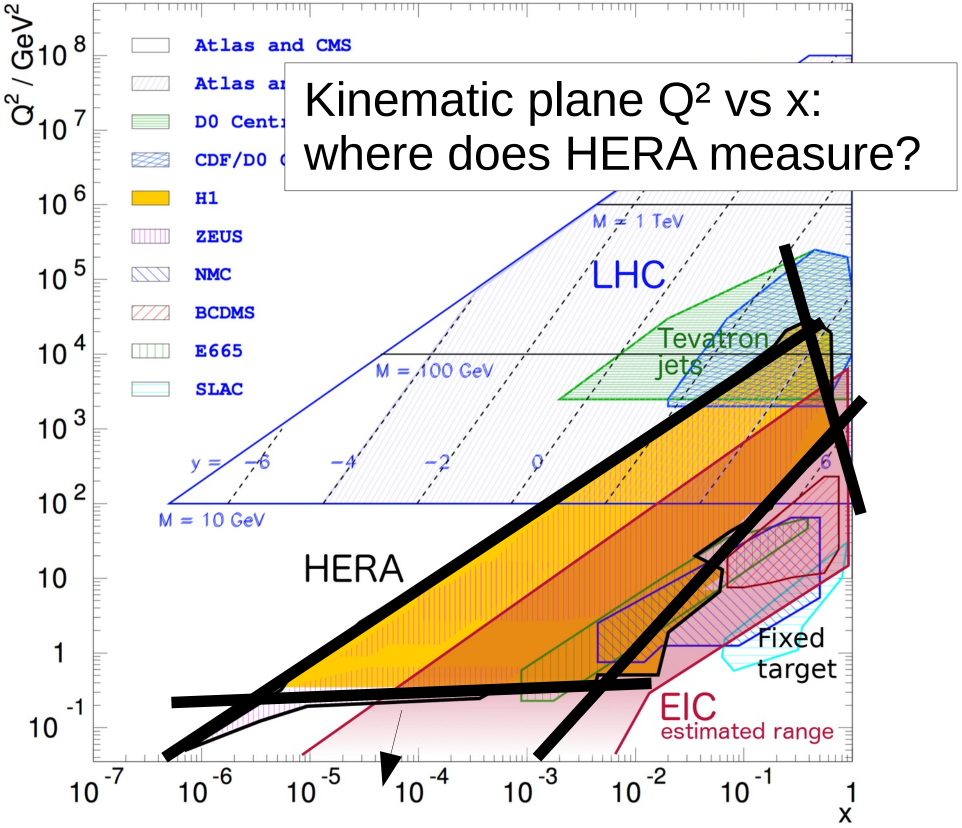


Typical low Q^2, low-x event

$$y_e=1-\frac{(e'p)}{(ep)},\ y_h=\frac{(Xp)}{(ep)}$$

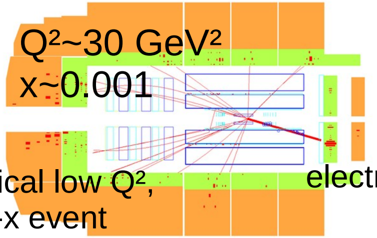
$$Q^2=\frac{p_T^2}{1-y},\ x=\frac{Q^2}{sy}$$

- "Electron" method: $y=y_e$ and $p_T=p_{T,e}$
- At low y, the electron method is limited by energy resolution, initial and final state radiation
  → use $y=y_h$ (sigma method)
- Other methods also in use: double-angle, etc



Neutral current DIS kinematics at HERA

- Kinematic variables: Q^2, x, y, $Q^2=sxy$
- Determine from 4-vectors of beam particles e, p, scattered electron e' and hadronic final state X



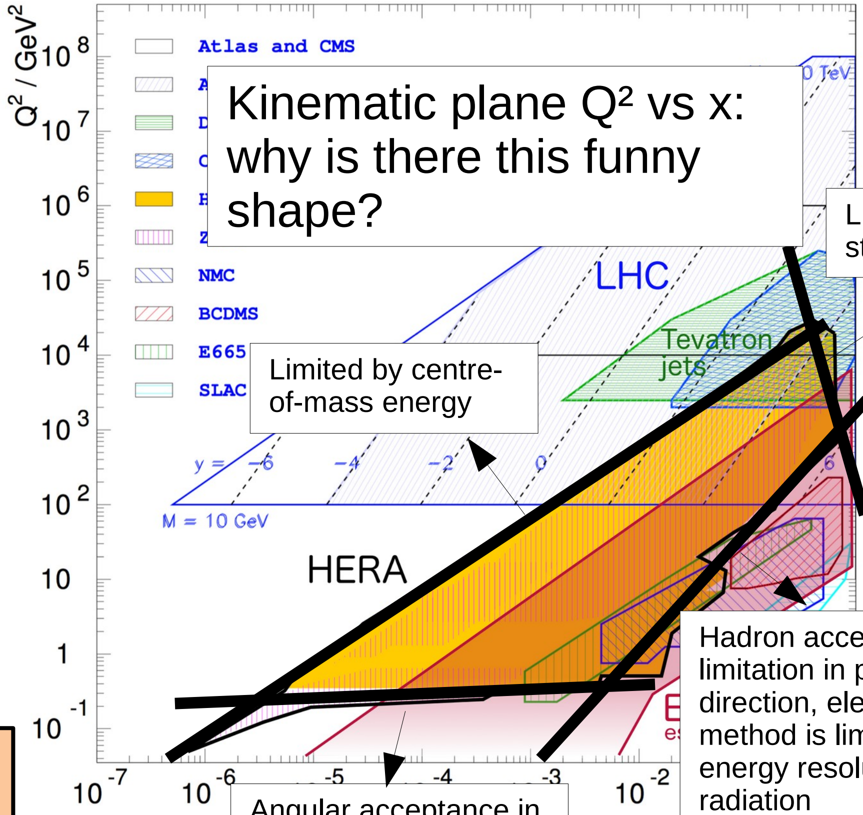
Typical low Q^2, low-x event

$$y_e = 1 - \frac{(e'p)}{(ep)},\; y_h = \frac{(Xp)}{(ep)}$$

$$Q^2 = \frac{p_T^2}{1-y},\; x = \frac{Q^2}{sy}$$

- “Electron” method: $y=y_e$ and $p_T=p_{T,e}$
- At low y, use $y=y_h$ (sigma method) → hadrons contributing to y_h have to be within detector acceptance → low y / high x is not accessible

HERA is “low-x” because of acceptance limitations in the forward (proton) direction



Kinematic plane Q^2 vs x: why is there this funny shape?

Limited statistics

Limited by centre-of-mass energy

Angular acceptance in electron direction

Hadron acceptance limitation in proton direction, electron method is limited by energy resolution & radiation
HERA = low-x