H1 analyses of J/psi and related

Meeting on EIC quarkonium measurement plans

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Outline

- H1 papers on Quarkonia - overview
- The H1 experiment
- Electron and muon identification
- J/psi trigger strategies in H1
- Two examples of J/psi papers

- Analysis possibilities in H1

H1 papers on Quarkonia

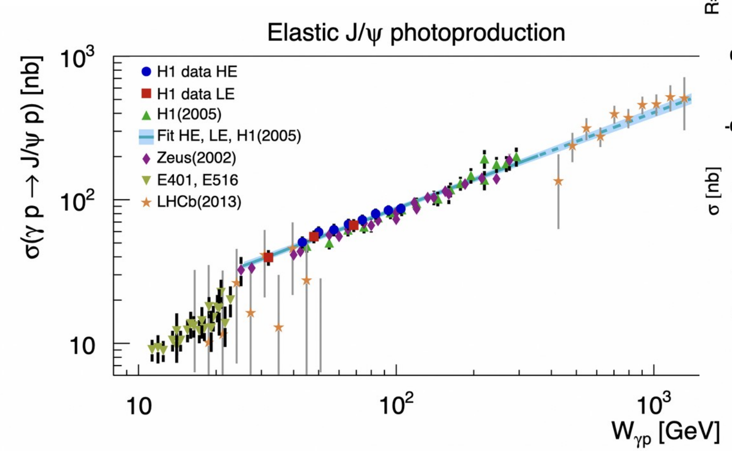
	DIS			Photoproduction			Comment
	DESY-96-023	μ,e	3 pb^{-1}	DESY-94-153	μ,e	0.3 pb^{-1}	(observation)
diffractive				DESY-96-037	μ,e	3 pb^{-1}	1994 run
	DESY-99-026	μ,e	27 pb^{-1}	DESY-00-037	μ,e	27 pb^{-1}	HERA-I, e-p
				DESY-03-061	μ	78 pb^{-1}	high |t| only
	DESY-05-161	μ,e	55 pb^{-1}	DESY-05-161	μ,e	55 pb^{-1}	HERA-I, e+p
				DESY-13-058	μ,e	130 pb^{-1}	HERA-II, new track trigger
				DESY-13-058	μ,e	10 pb^{-1}	
psi', Y	DESY-99-026	μ,e	27 pb^{-1}	DESY-97-228	μ,e	4 pb^{-1}	1994 run
				DESY-00-037	μ,e	27 pb^{-1}	HERA-I, e-p
				DESY-02-075	μ,e	77 pb^{-1}	HERA-I
inelastic	DESY-99-026	μ,e	27 pb^{-1}	DESY-96-037	e	3 pb^{-1}	1994 run
	DESY-02-060	μ,e	77 pb^{-1}	DESY-02-059	μ	77 pb^{-1}	HERA-I
	DESY-09-225	μ,e	315 pb^{-1}	DESY-09-225	μ	165 pb^{-1}	HERA-II

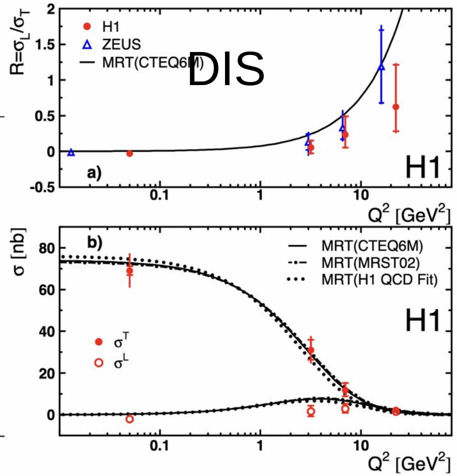
Selection of some physics results

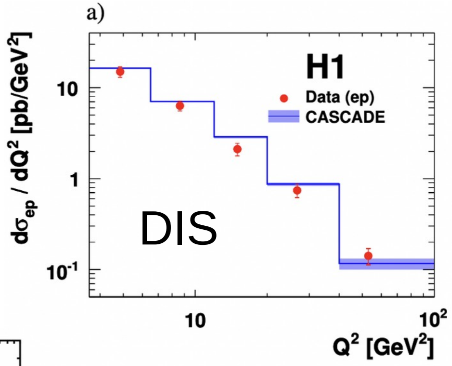
- Diffractive J/psi (2005 and 2013)

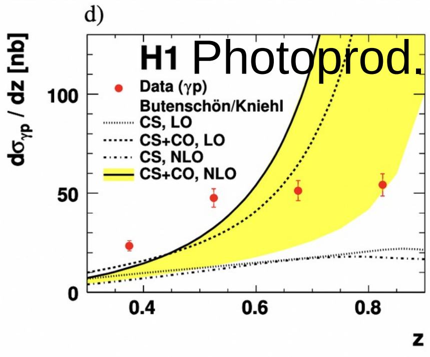
  Photoproduction (2013): description by Regge-inspired fits

  DIS (2005): reasonable predictions for some aspects of the data







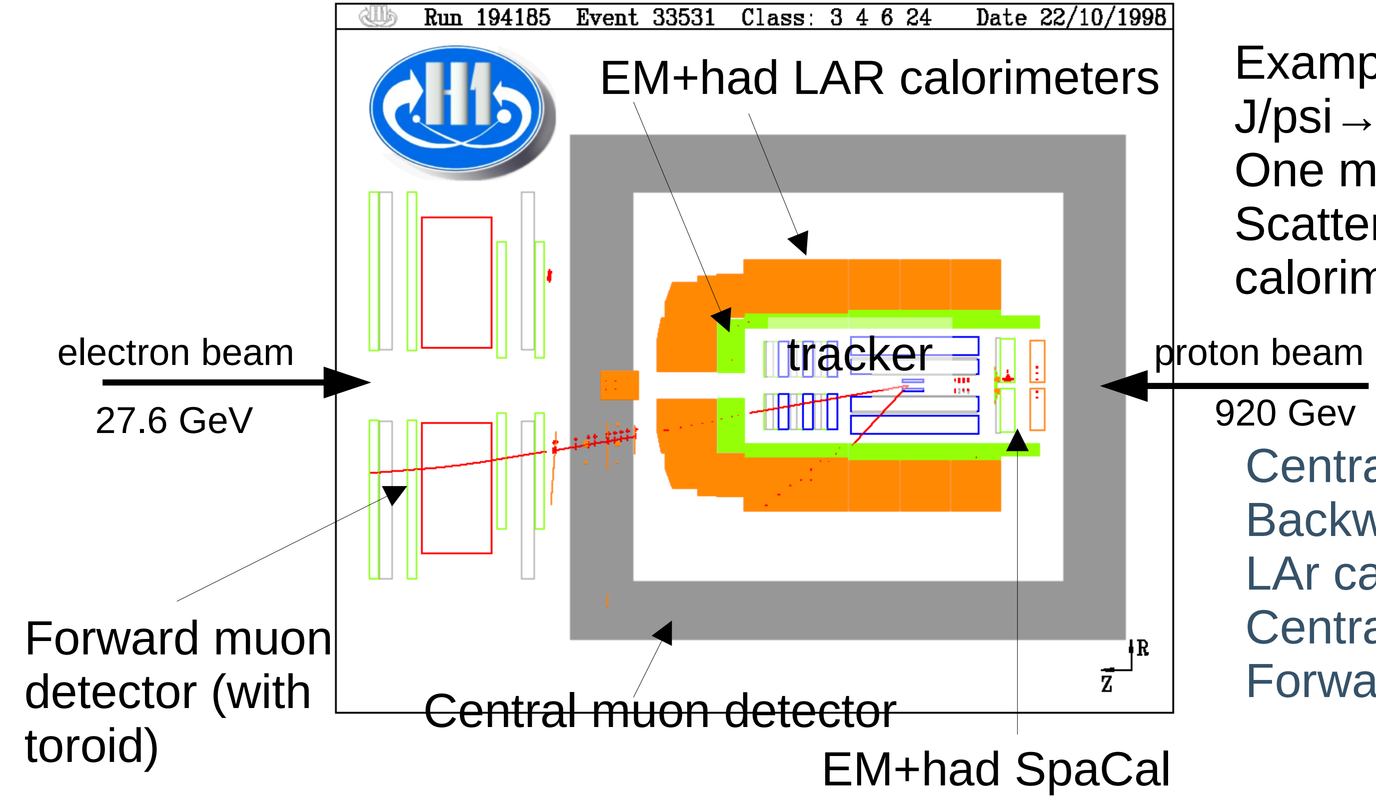


- Inelastic J/psi (2009)

  At the time, no calculation existed for DIS. MC works reasonably

- Calculations for photo-production did not work very well

The H1 detector



Example event display of diffractive J/psi → $\mu^+\mu^-$
One muon in forward muon detector.
Scattered Electron in backward calorimeter

Central tracker: 15°<θ<165°
Backward calorimeter: 155°<θ<175°
LAr calorimeter: 3°<θ<155°
Central muon detector: 5°<θ<175°
Forward muon detector: 3°<θ<18°

H1 electron identification (calorimeter)

- Standard H1 electron finder is based on isolated calorimeter clusters
- Work very well for scattered electron, match regions where trigger is efficient
- LAr: trigger+finder 100% efficient for P_T>10 GeV

  → Q^2>150 GeV^2, y<0.7
- SpaCal: trigger+finder 100% efficient for E>10 GeV

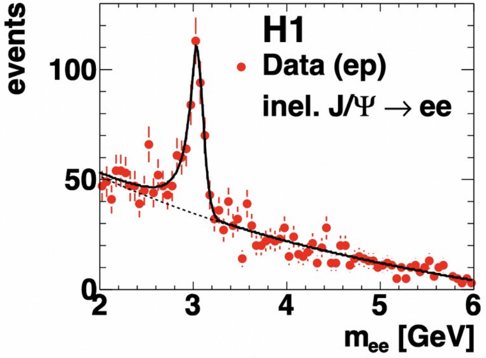
  → 5<Q^2<100 GeV^2, y<0.6

- Electron finder also works well for thresholds below the (standard) DIS triggers
  - LAr: P_T>5 GeV
  - SpaCal: E>2 GeV
- For non-isolated, low P_T objects (such as inelastic J/psi), the standard electron finder is not the best choice

H1 electron identification (track+calo, low P_T)

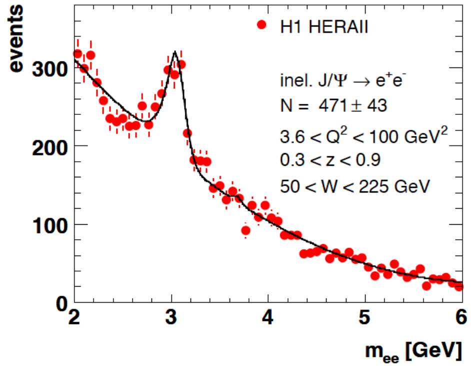
- Developed in 2009: electron finder based on track and LAr calorimeter
- Originally designed for open beauty analysis
  - Uses neural networks to combine track and calorimeter properties
  - Low P_T threshold
  - Works for electron in jets

2009: arxiv:1002.0234



Inelastic J/psi with new electron finder

2008: thesis M.Steder

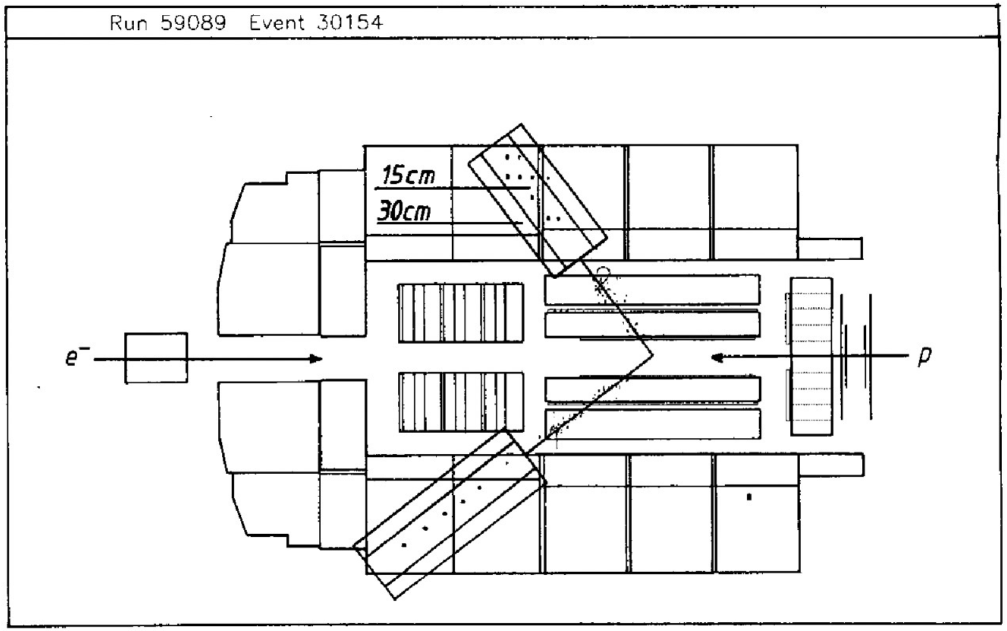


Inelastic J/psi without new electron finder

Selected analyses with new electron finder:
Inel. J/psi: Eur.Phys.J.C68 (2010) 401 [arxiv:1002.0234]
b→e: Eur.Phys.J.C72 (2012) 2148 [arxiv:1206.4346]
Diffractive J/psi: Eur.Phys.J.C73 (2013) 2466 [arxiv:1304.5162]
Thesis on new electron finder: M. Sauter (2009) [link]

H1 muon identification

- Muon identification:
  - Fwd muon system
  - Muon chamber +central track
  - Calorimeter +central track
- Muon chambers are reached in H1 only for approximately P_T>1.5 GeV
- Calorimeter discriminator inputs:
  - Energies in cylinders r=15,30 cm
  - Distance of clusters from calorimeter impact point

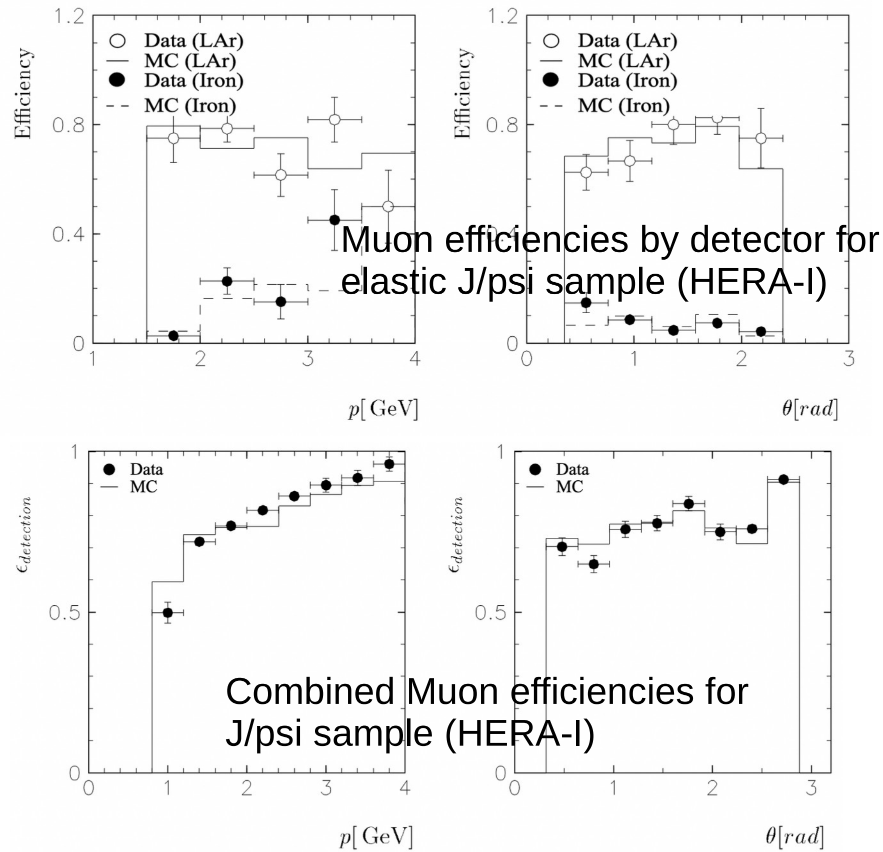


Example: J/psi→ $\mu^+\mu^-$ energy deposits in the LAr calorimeter
Thesis G. Schmid (1994) [link]

H1 muon identification efficiencies for J/psi

- Technical note describes algorithm and HERA-I efficiency in great detail
- HERA-II efficiencies can be found in the corresponding publications and theses on diffractive and inelastic J/psi [link to theses]
- Low P_T: calorimeter dominates
- Both detectors contribute equally at high P_T

HERA-I: technical note H1-IN 97-518
HERA-II theses: M.Steder (Hamburg, 2008)
and F.Huber (Heidelberg, 2012)



Muon efficiencies by detector for elastic J/psi sample (HERA-I)

Combined Muon efficiencies for J/psi sample (HERA-I)

J/psi Trigger strategies in H1

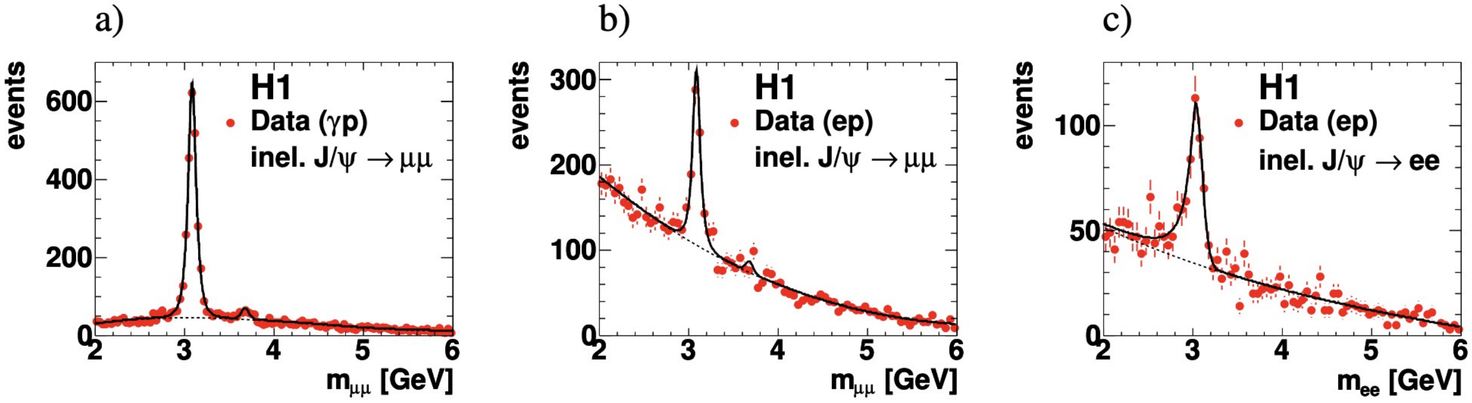
- DIS: inclusive trigger on scattered electron – all J/psi data recorded
- Photoproduction: trigger on J/psi signature, more difficult
  - Inelastic J/psi $\rightarrow \mu^+\mu^-$: signal in muon detector plus high P_T central track

    No trigger strategy for inelastic J/psi $\rightarrow e^+e^-$
  - Diffractive J/psi: use Fast Track Trigger to select low multiplicity events

    Before 2005 (no fast track trigger): using other, less efficient trigger strategies

Trigger strategy enforced the use of muon channel for inelastic J/psi photoproduction

Inelastic J/psi in DIS and γp (2009)



- photoproduction: use only muons

  (lack of trigger for J/psi → e^+e^- as discussed on prev. sllide)

- DIS: both electron and muon pairs

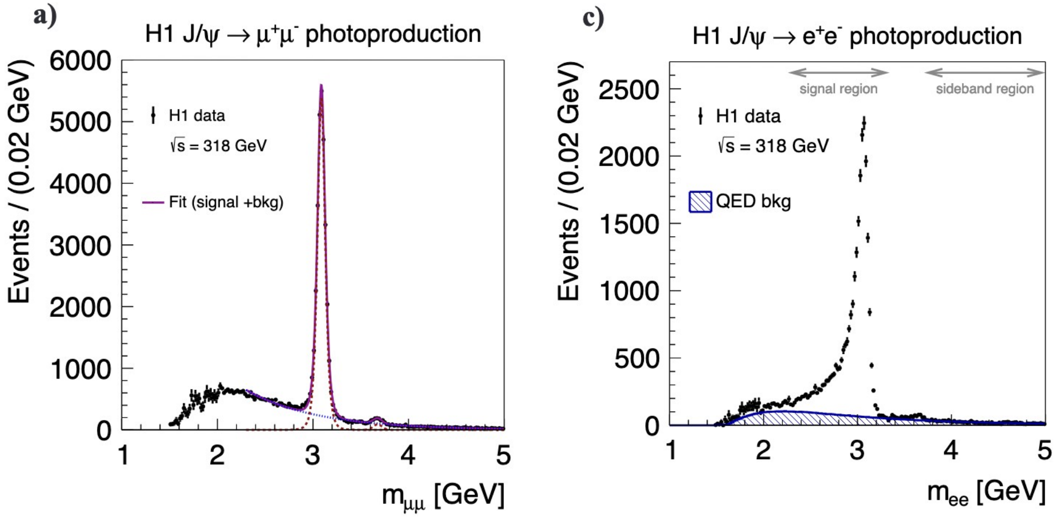
- J/psi counting: fit of signal+bgr
- For electron, fit function accounts for radiative tail [hep-ex/0505008]

Eur.Phys.J.C68 (2010) 401 [arxiv:1002.0234]
PhD: M. Steder (Hamburg, 2008) [link]

Diffractive J/psi photoproduction (2013)

- Trigger: two oppositely charged tracks with P_T>800 MeV
  - Uses the FastTrackTrigger, operational 2005-2007
- Analysis cuts: require empty calorimeter (diffraction)
- Identify the two tracks as either electrons or muons

Eur.Phys.J.C73 (2013) 2466 [arxiv:1304.5162]
PhD: F.Huber (Heidelberg 2012) [link]



- Muon counting: fit of signal+background (bgr dominated by π pair production)
- Electron counting: no fit, subtract MC prediction (QED lepton pair production)

Summary on H1 electron and muon ID

- Large number of J/psi analyses from H1, mainly on HERA-I data
- Muon-ID:
  - For P_T<1.5, make use of calorimeter with its longitudinal segmentation
  - For P_T>1.5, include muon chambers to reach best efficiency
- Electron-ID:
  - Calorimeter-based for isolated, large P_T objects
  - Backward direction: SpaCal for isolated electrons with E>2 GeV
  - Track+calorimeter with neural network for non-isolated objects at low P_T

Summary on Trigger and Analysis limitations

- **Trigger limitations** for inelastic J/psi photo production:
  - only muon chamber based trigger was available

    → in H1, the muon chambers were essential for this type of analysis
- **Acceptance limitations** of central tracker (not discussed in detail)
  - Small W (proton direction): muons only (forward muon detector)
  - High W (electron direction): electrons only (SpaCal calorimeter)
- **Mass reconstruction** with a fit works best for tracks from muons, because of the radiative tail in electron channel

  Diffractive J/psi→ee: perfect modelling of (QED) background, no fit required

Outlook: analysis possibilities in H1

- H1 welcomes new members
- Members join as individuals, no (financial) commitment involved
- We already have several new collaborators from the US, analyzing properties of the hadronic final state
- **Vector mesons are presently not covered in H1 → interesting opportunity to back-up your EIC studies with data**

Example uncovered analysis:

- J/psi in diffractive DIS:

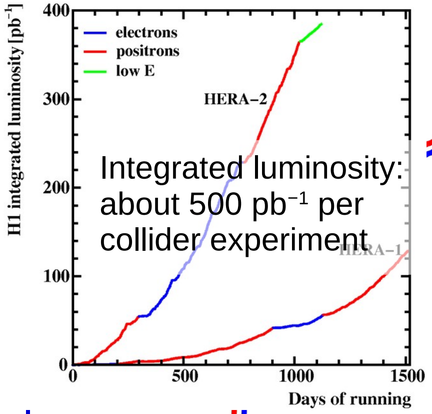
  HERA-II data have not been analyzed (this is 80% of the available data!)
- Novelty aspect: lepton beam was polarized at HERA II, could measure spin transfer

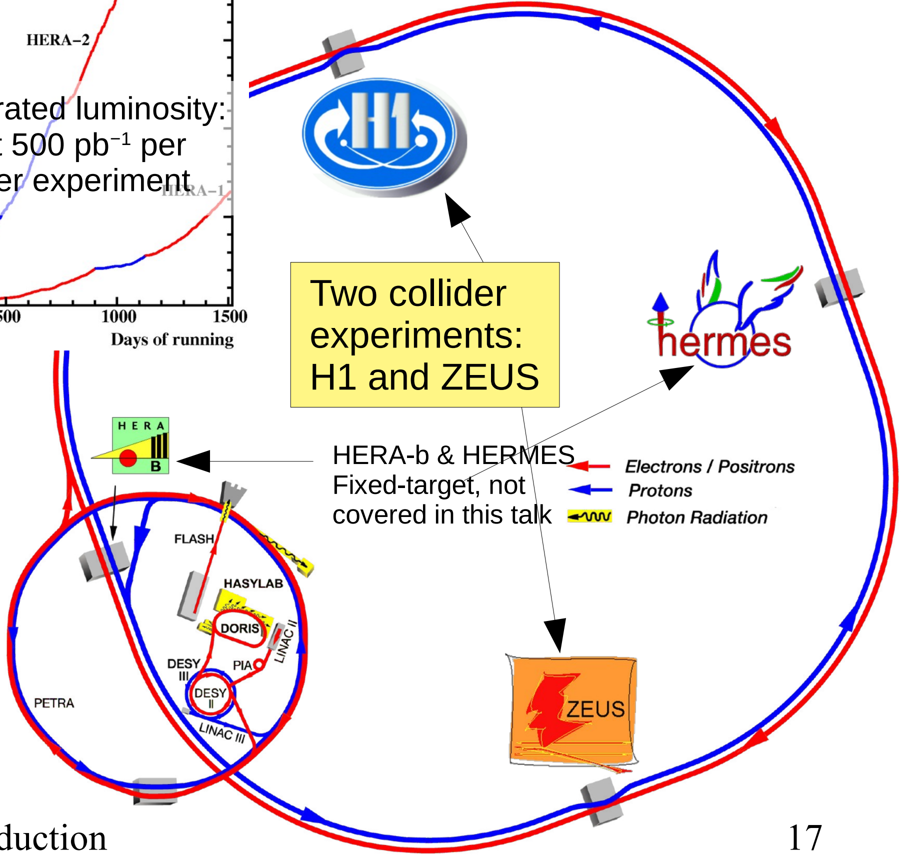
Contact sschmitt@mail.desy.de for details

Backup

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)



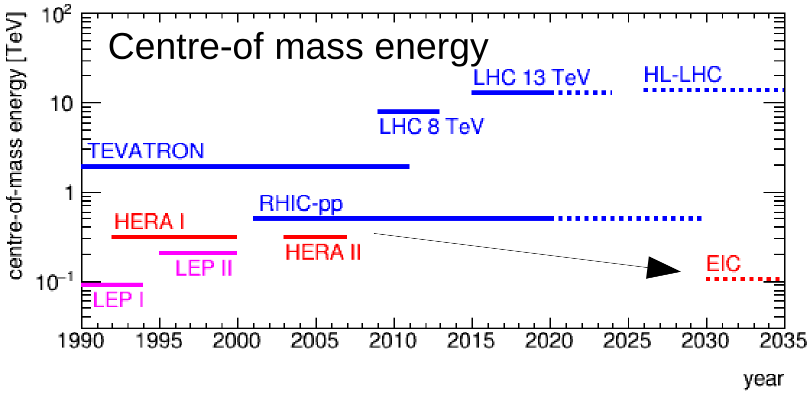


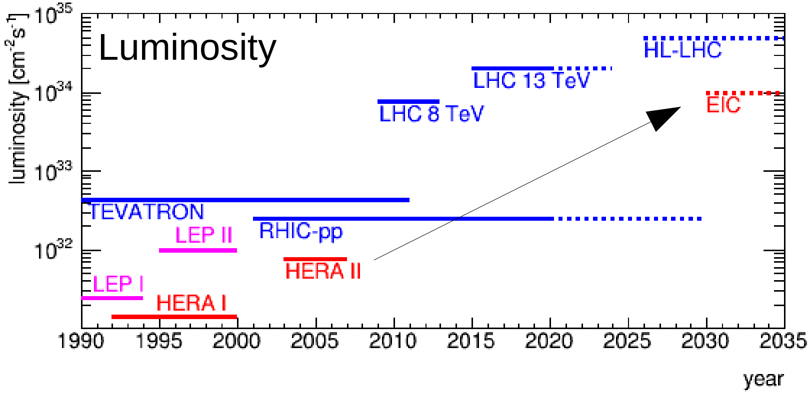
HERA compared to other colliders

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

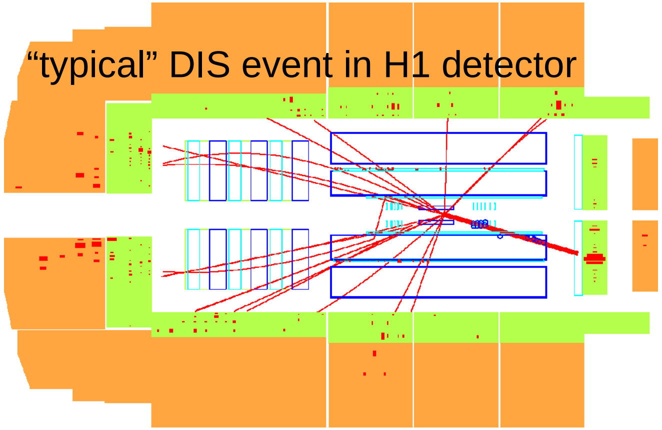
  Detectors were designed for discoveries, not so much for precision

- 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, ...

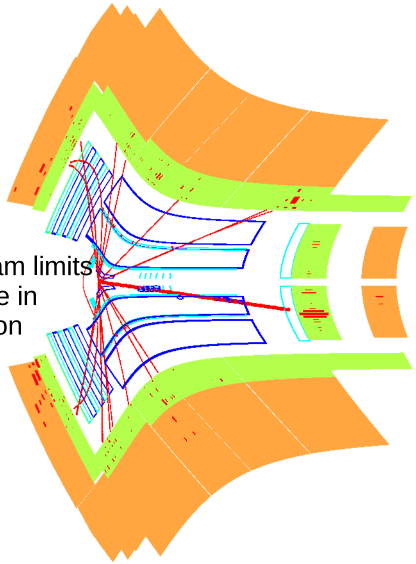


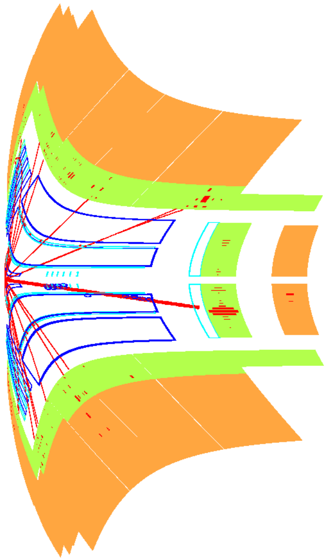


HERA boost visualized



Proton beam limits acceptance in target region





E_e=27.6 GeV E_p=920 GeV

Laboratory system

E_e=160 GeV E_p=160 GeV

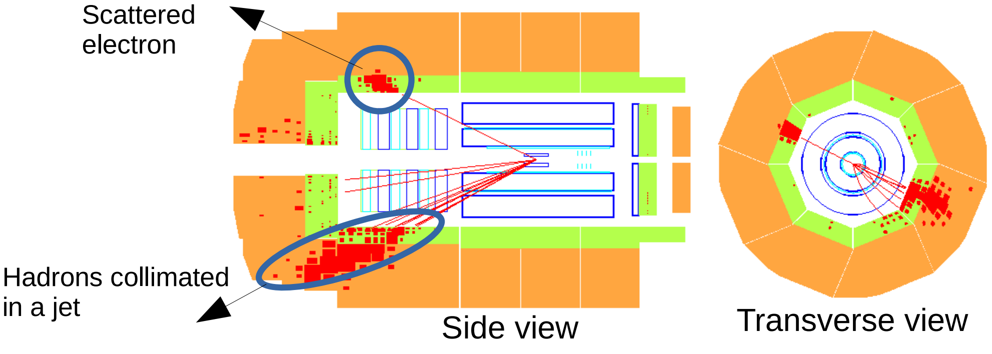
ep center-of-mass system

E_e=54000 GeV

Proton rest-frame
c.f. fixed-target experiment

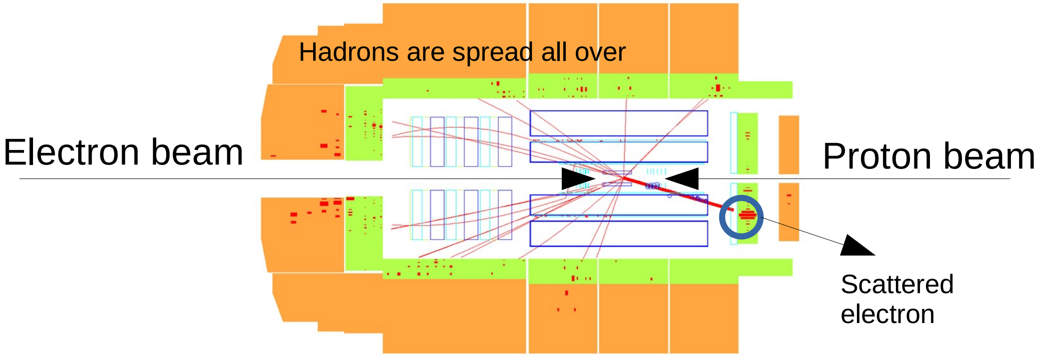
Processes studied at the HERA collider

- 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
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  - neutrino with high transverse momentum (escapes detection)
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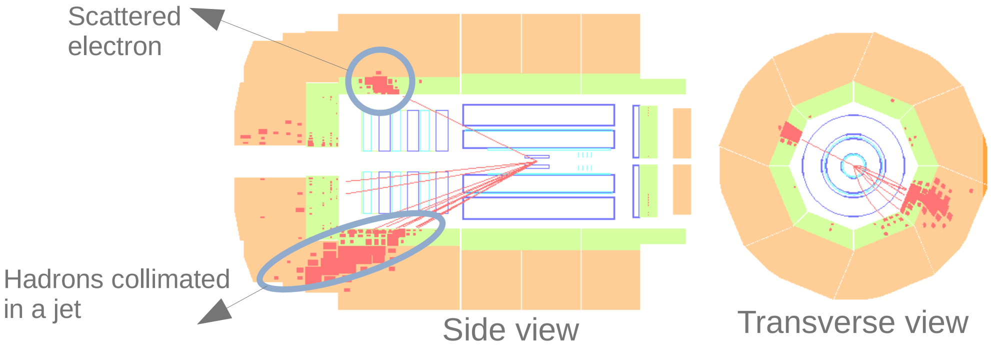
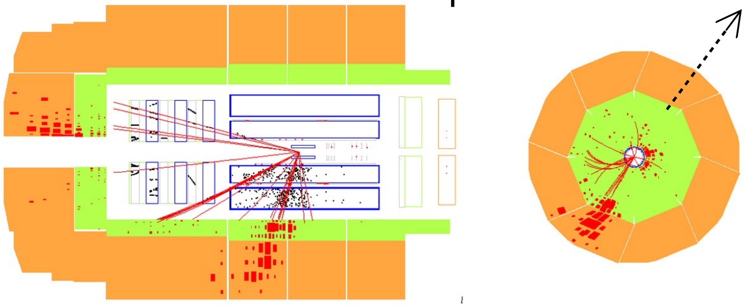


Neutral current (NC) event

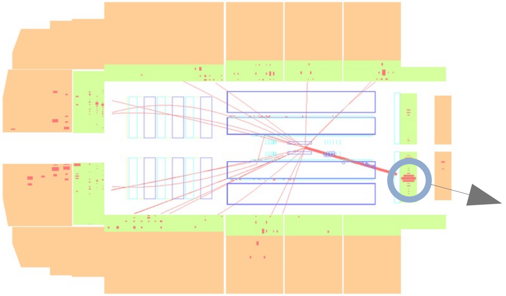
Charged current (CC) event

Imbalance in transverse plane → neutrino



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)

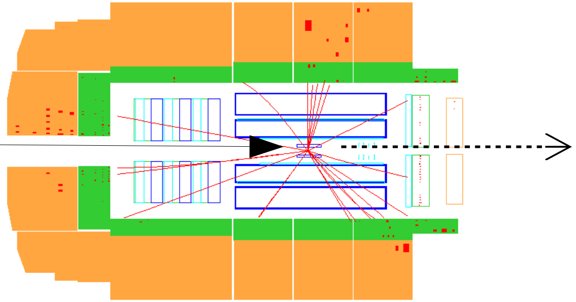


Scattered electron in detector

Neutral current (NC) event

Photoproduction (most frequent type of event)

Electron beam

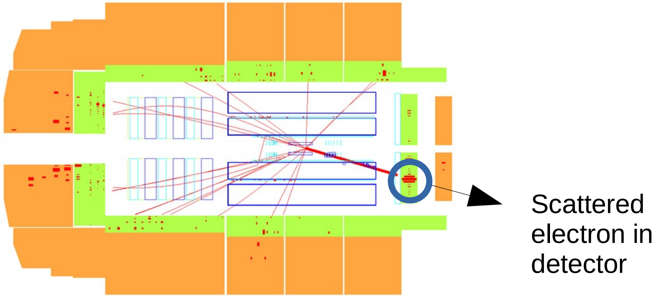


Scattered electron is not detected

Photoproduction and DIS

- **Main kinematic variable: negative four-momentum squared Q²= −(e-e')²**
- Q² 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)



Neutral current (NC) event

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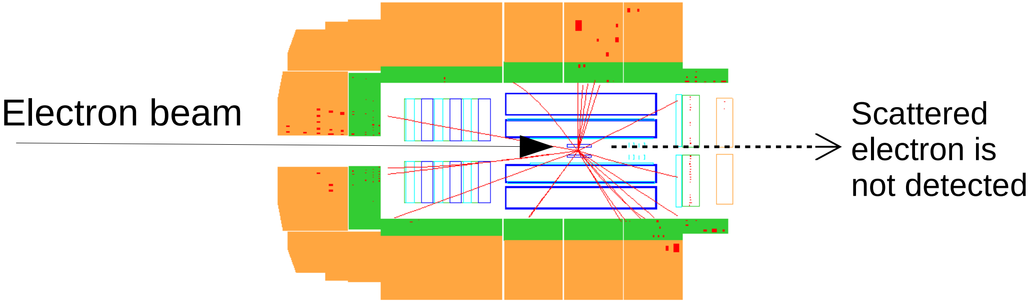
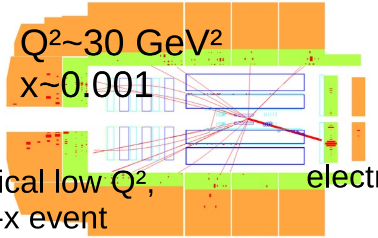


Neutral current DIS kinematics at HERA

- 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

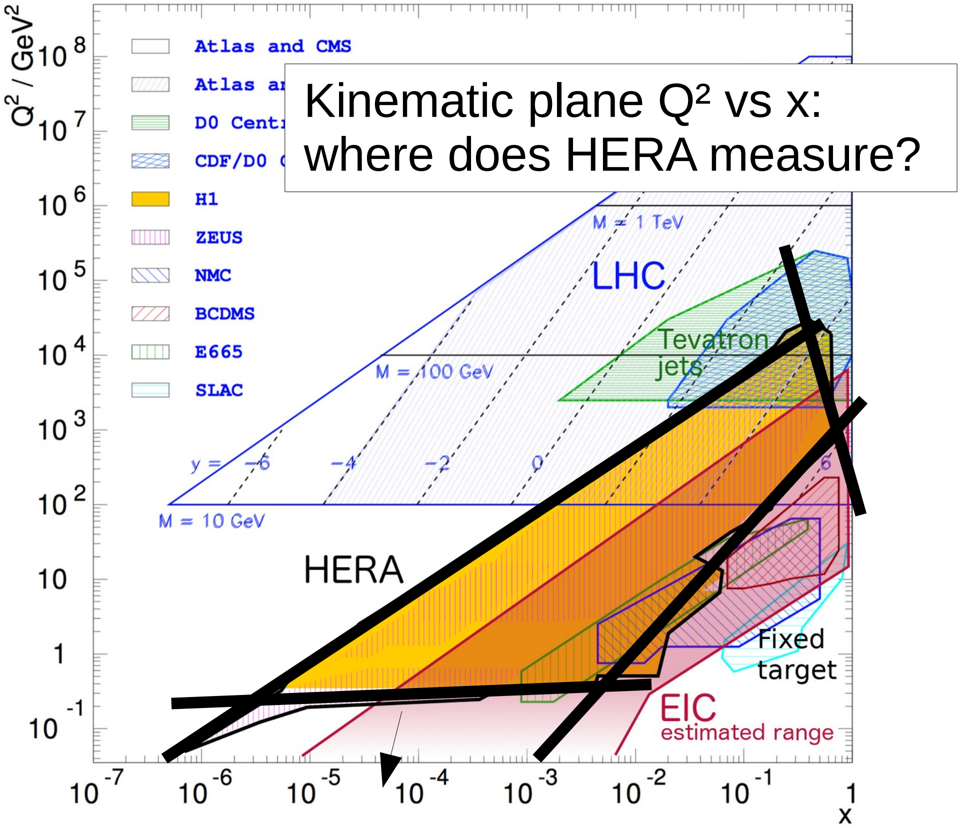


Typical low Q^2, low-x event

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

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

- "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



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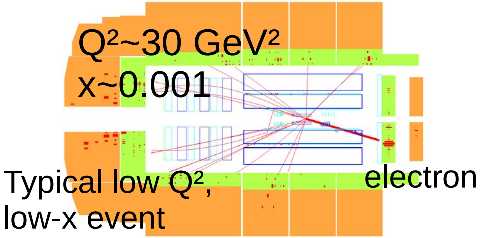

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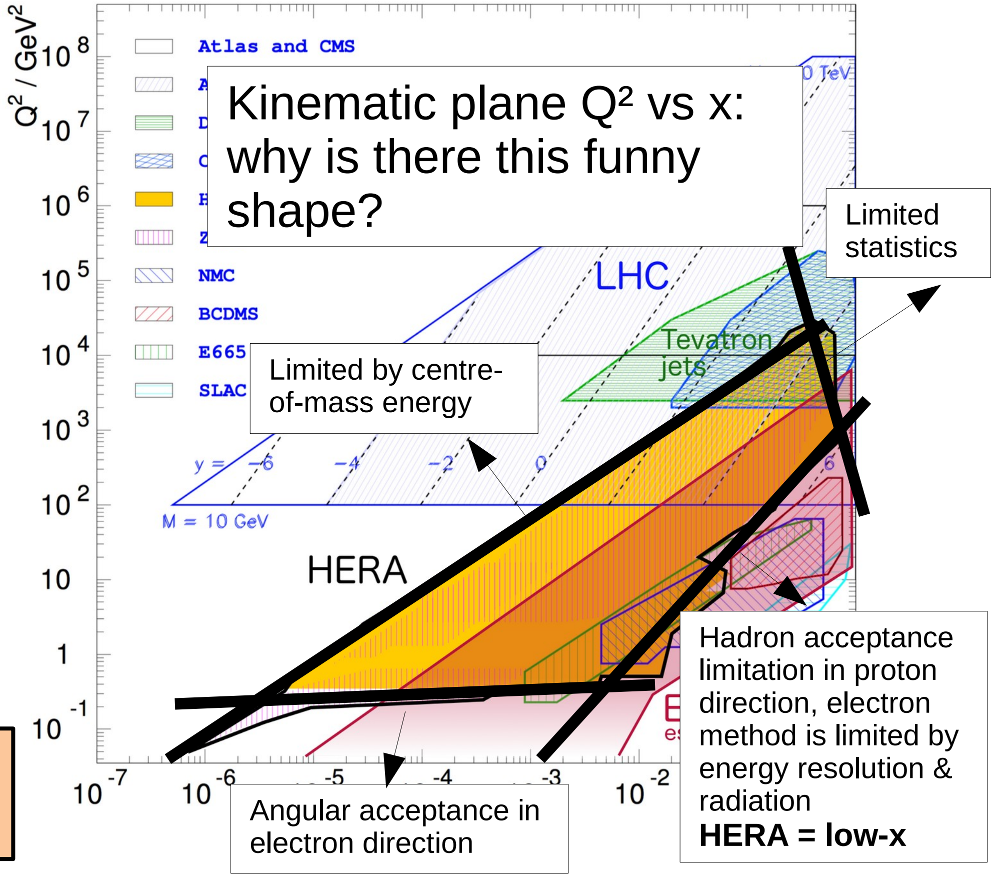
- "Electron" method: $y=y_e$ and $p_T=p_{T,e}$
- At low y, use $y=y_h$ (sigma method) → hadrons contributing to y_h have to be within detector acceptance → low y / high x is not accessible



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