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(on behalf of the
ZEUS collaboration)

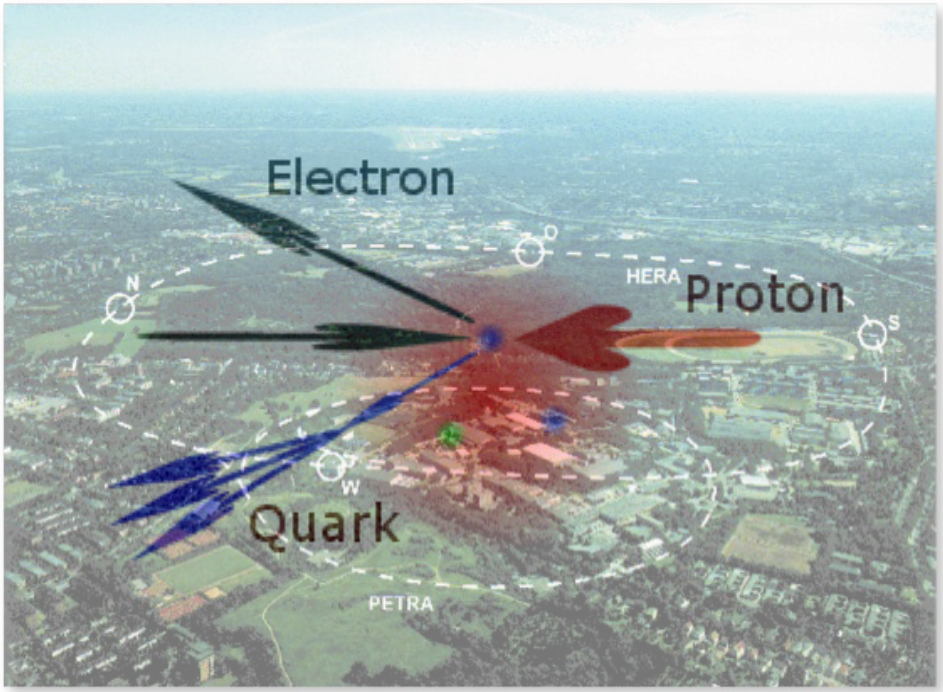
Elastic Z^0 production at HERA

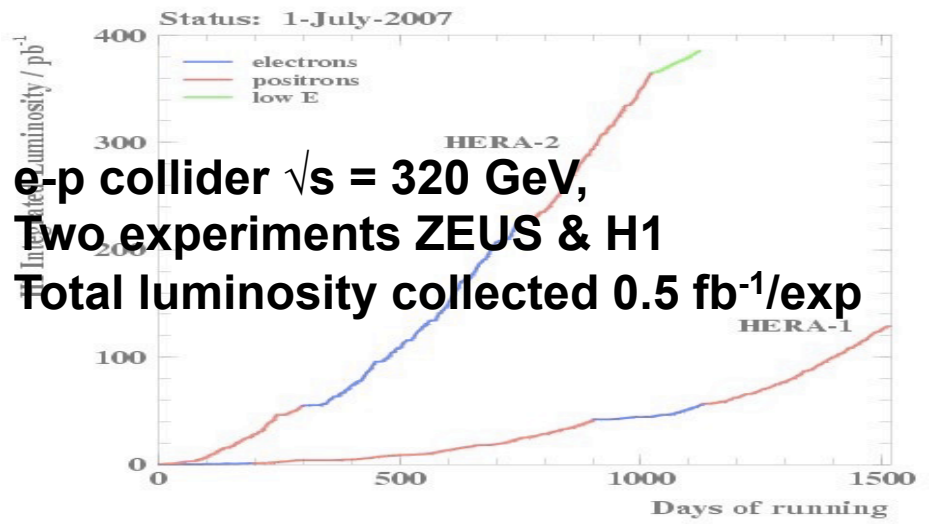
- HERA and ZEUS
- EW bosons@HERA
- Z^0 Search strategy
- Background estimation
- Results

available as Phys. Lett. B718 (2013) 915

HERA

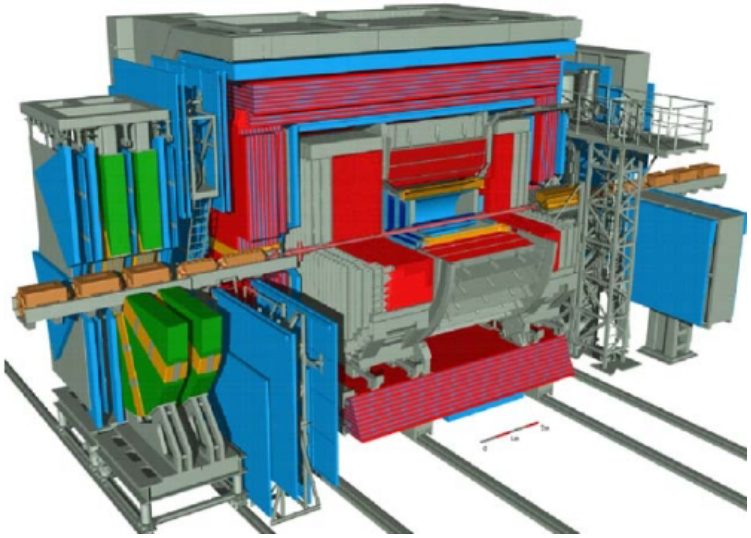
HERA-1 (1993-2000) ≃ **120** pb-1
HERA-2 (2000-2007) ≃ **380** pb-1





e-p collider √s = 320 GeV,
Two experiments ZEUS & H1
Total luminosity collected 0.5 fb^{-1}/exp

ZEUS



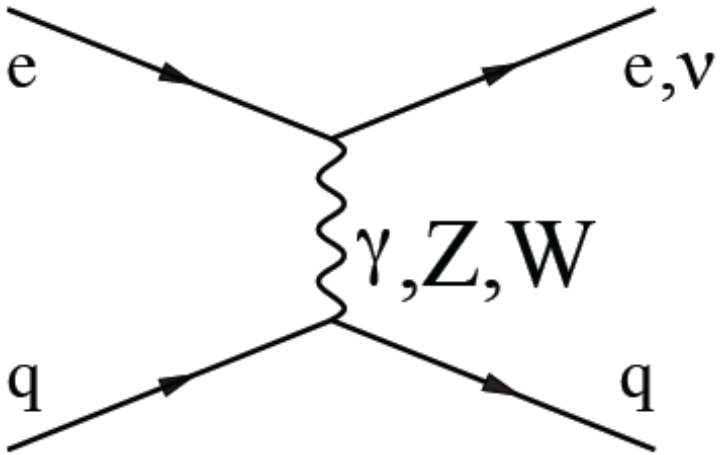
General-purpose 4π detector

- **High resolution calorimeter with compensating Uranium absorber**
- **Electron:** $\sigma(E)/E = \dfrac{0.18}{\sqrt{E(GeV)}}$
- **Hadron:** $\sigma(E)/E = \dfrac{0.35}{\sqrt{E(GeV)}}$

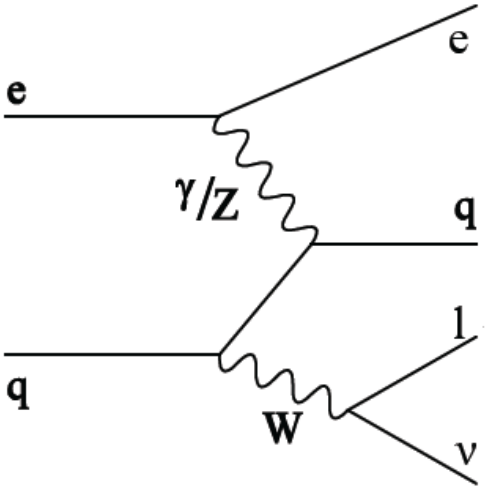
EW Bosons at HERA

Relevant for NC/CC processes at high-Q2 (t-channel off-shell exchange)

Study them in SM

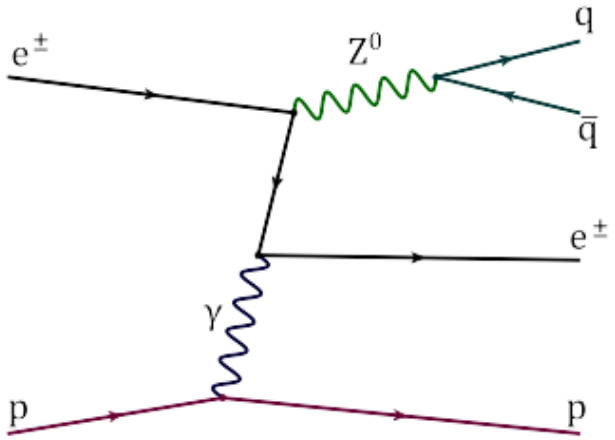


Only sub-leading production via radiation from quark/lepton lines

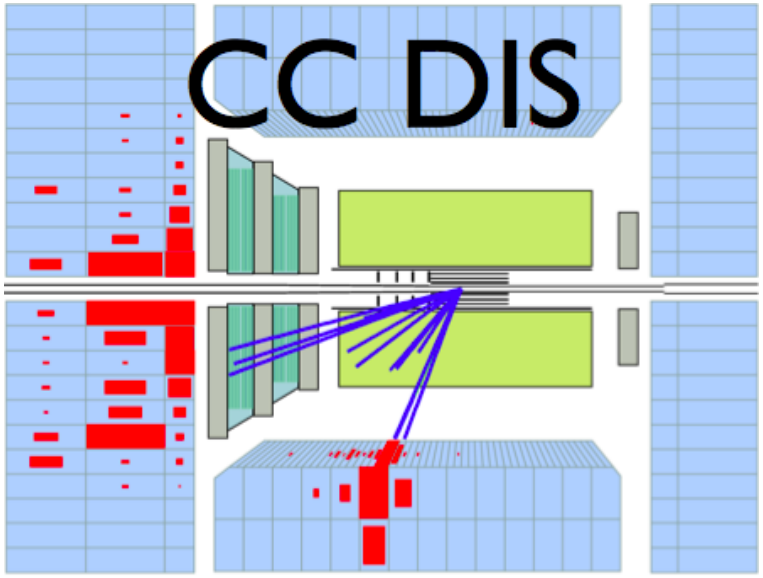


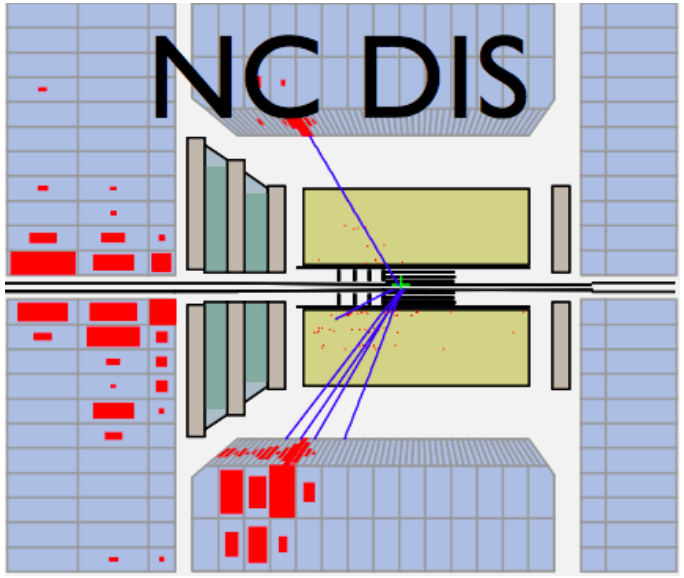
H1 and ZEUS, JHEP 1003 (2010) 035:
σ(ep→W±X)=1.06±0.17(stat⊕syst) pb

Example of a leading-order diagram of Z^0 boson production and subsequent hadronic decay



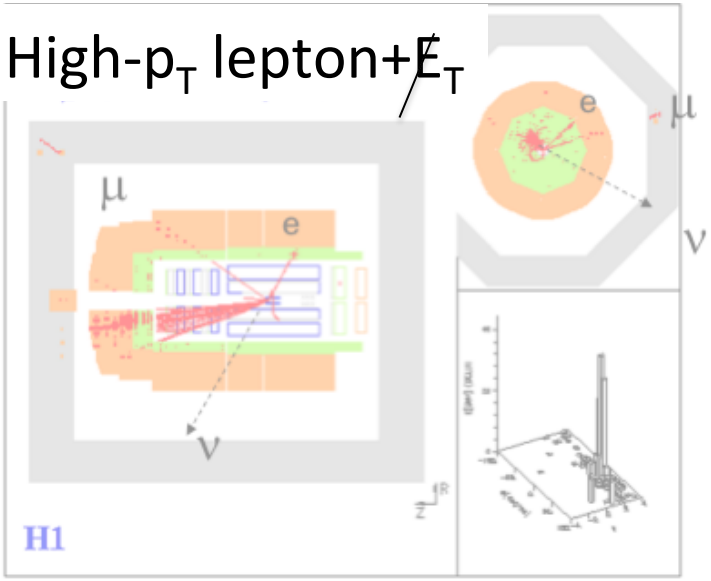
ZEUS, Phys. Lett. 680 (2009) 13 for Z→l+l-:
not conclusive





(via virtual W and Z contributions)

High-p_T lepton+$\not{E}_T$



Real W production

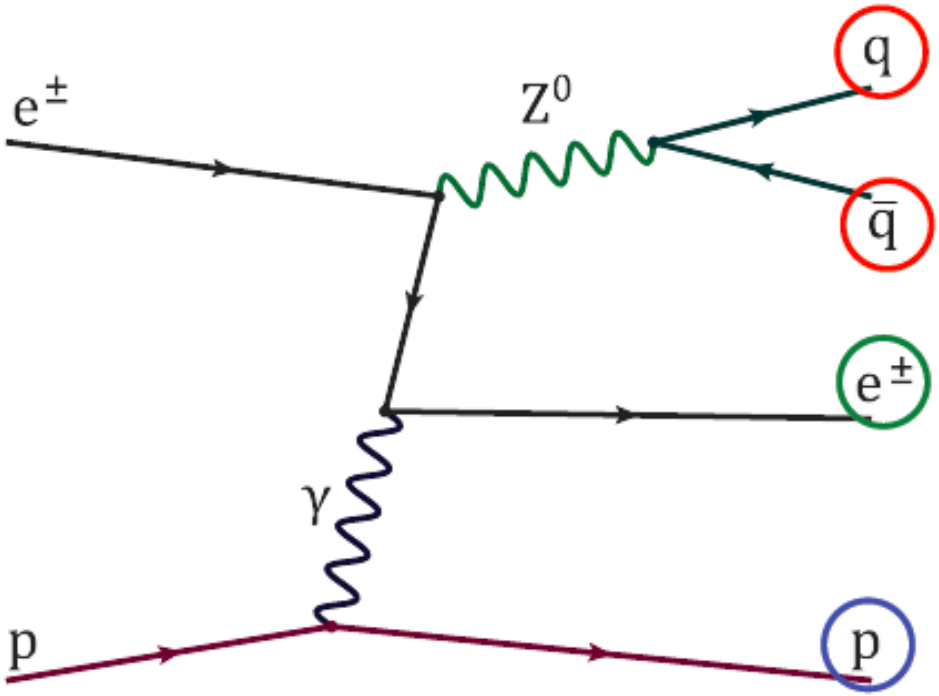
Accomplish HERA EW-study by measuring Z production

Cross-section 0.4 pb-1 expected from SM
Smallest cross section measured at HERA!

Z^0 search strategy

Hadronic Z^0 decays → highest branching ratio
(very large QCD multi-jet background)

Elastic (and quasi-elastic) Z^0 production: ~ 0.16 pb
(expected better S/B ratio)
by requiring MAX η pseudorapidity of CALORIMETER energy deposit

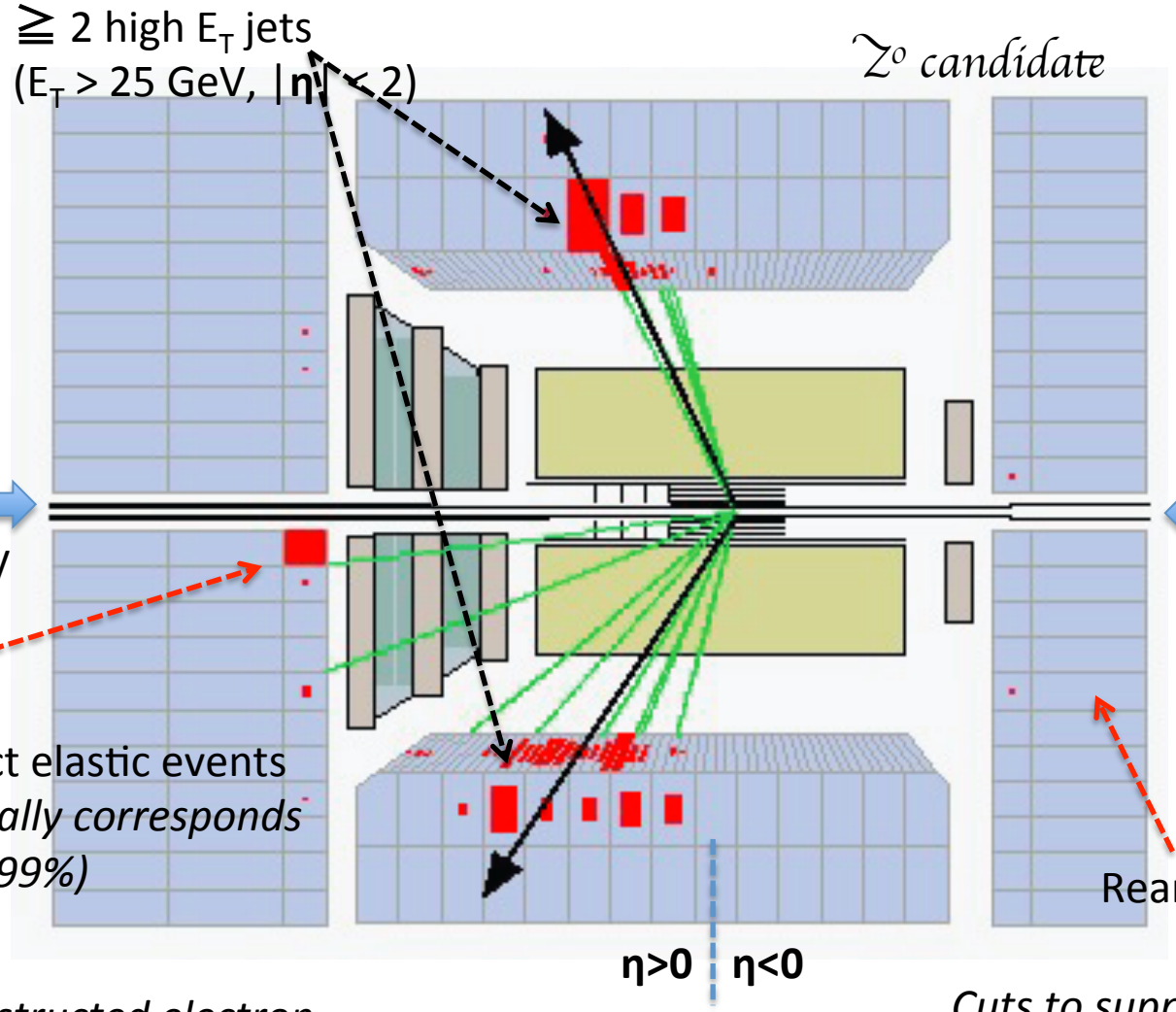


2 (or more) high-ET jets

beam-electron back-scattered to forward (proton) direction

p or p*: no proton remnant in detector

Event selection



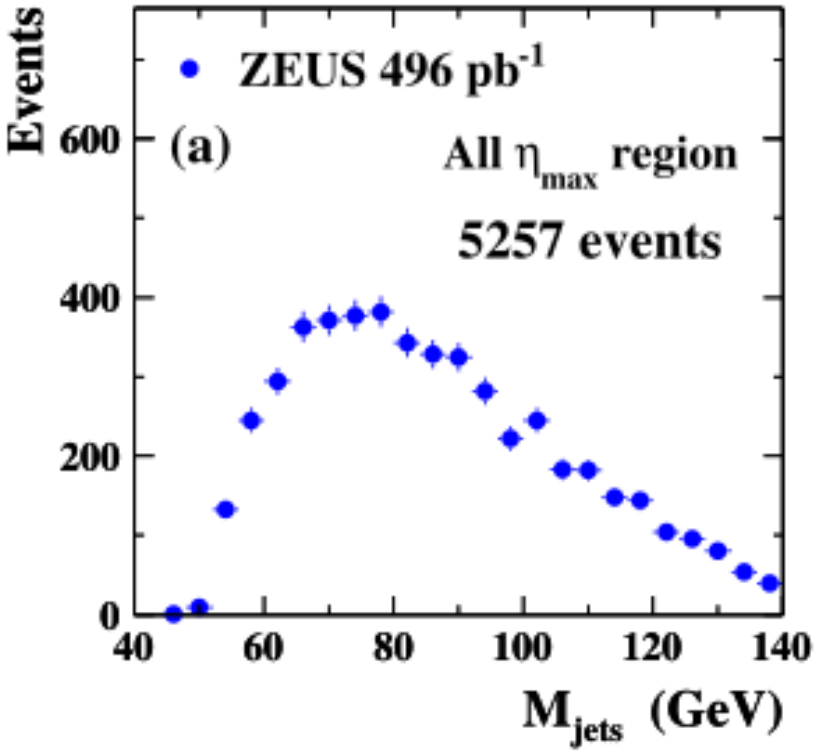
At most 1 reconstructed electron with ϑ<80 degrees

Cuts to suppress low-Q2 NC and photo-production

Remaining background: diffractive multi-jet production

Elastic and quasi-elastic selection

Multi-jet sample dominated by QCD background,
no (negligible) Z^0 signal



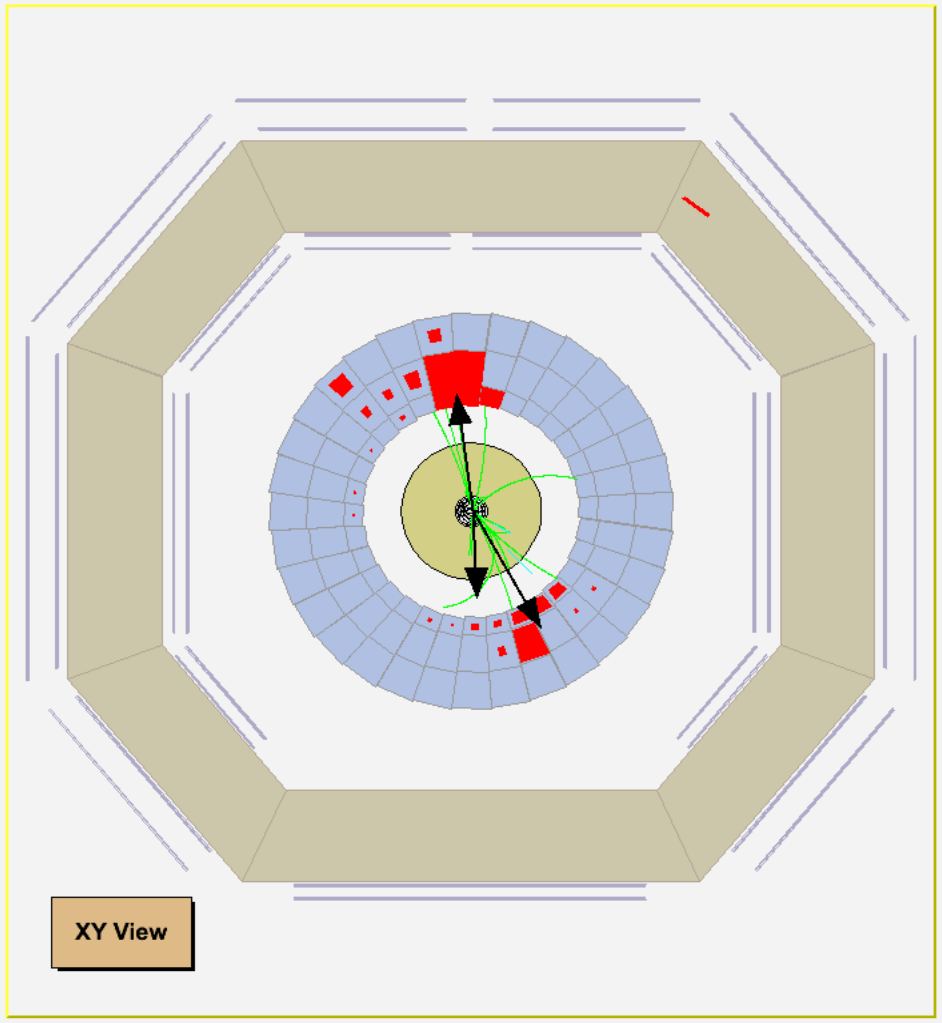
All Data Sample, 0.5 fb^{-1} :
5257 selected events with

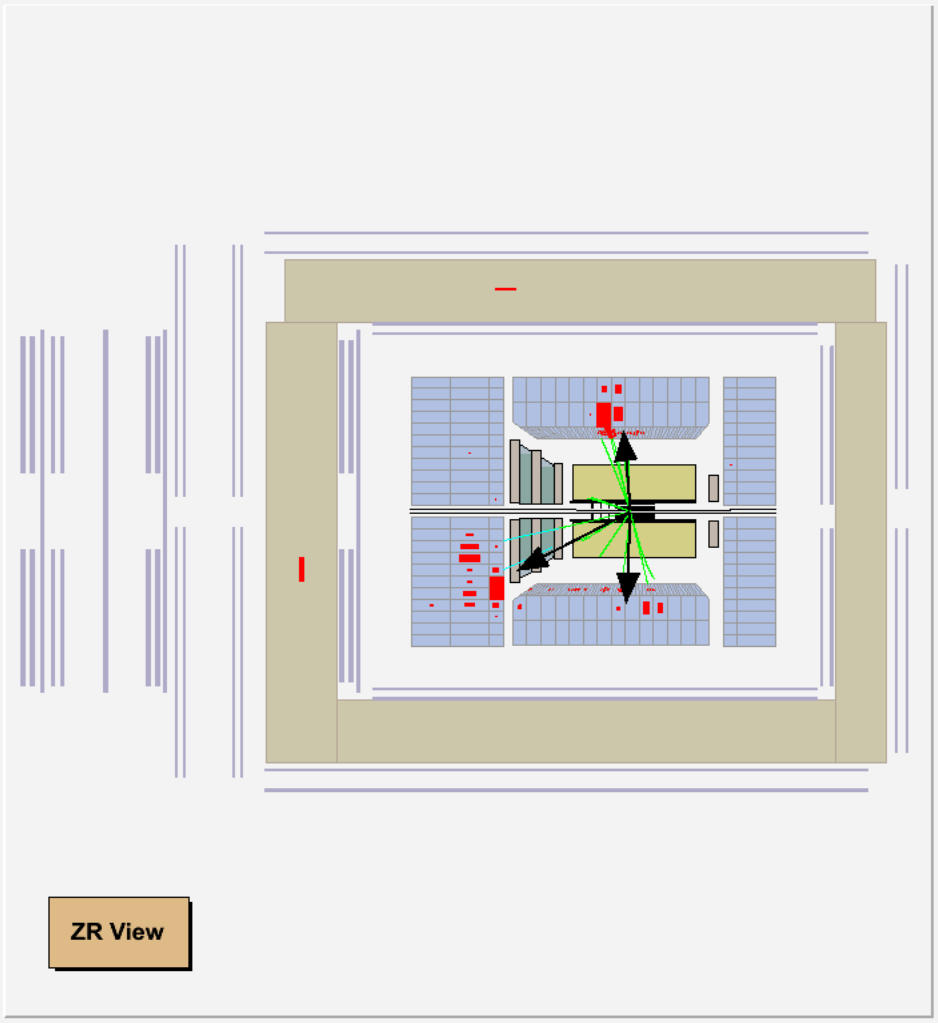
- 2525 evts with $\eta_{max}>4.2$
- 1743 evts with $4.0 < \eta_{max} < 4.2$
- 918 evts with $3.0 < \eta_{max} < 4.2$

Use η_{max} for elastic selection:

- pseudorapidity of the energy deposit in the calorimeter closest to the proton beam direction, calculated from CAL cells with E > 400 MeV

$$\eta_{max} < 3.0$$

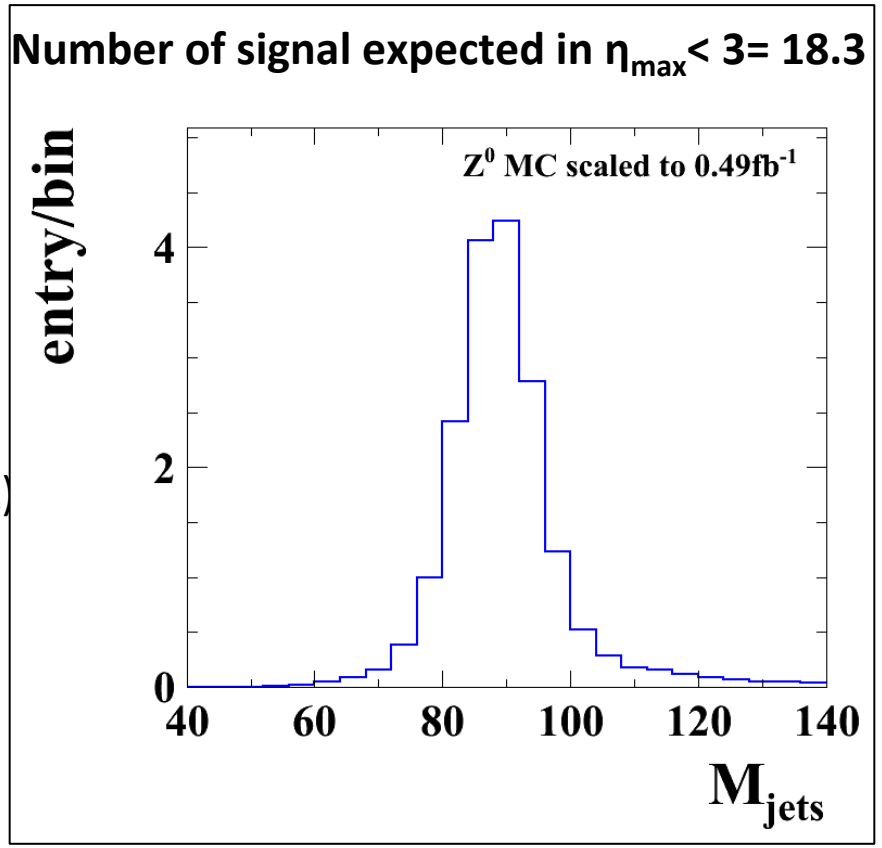




Typical candidate: M=91.8GeV, η_{max}=2.34

Monte Carlo simulations

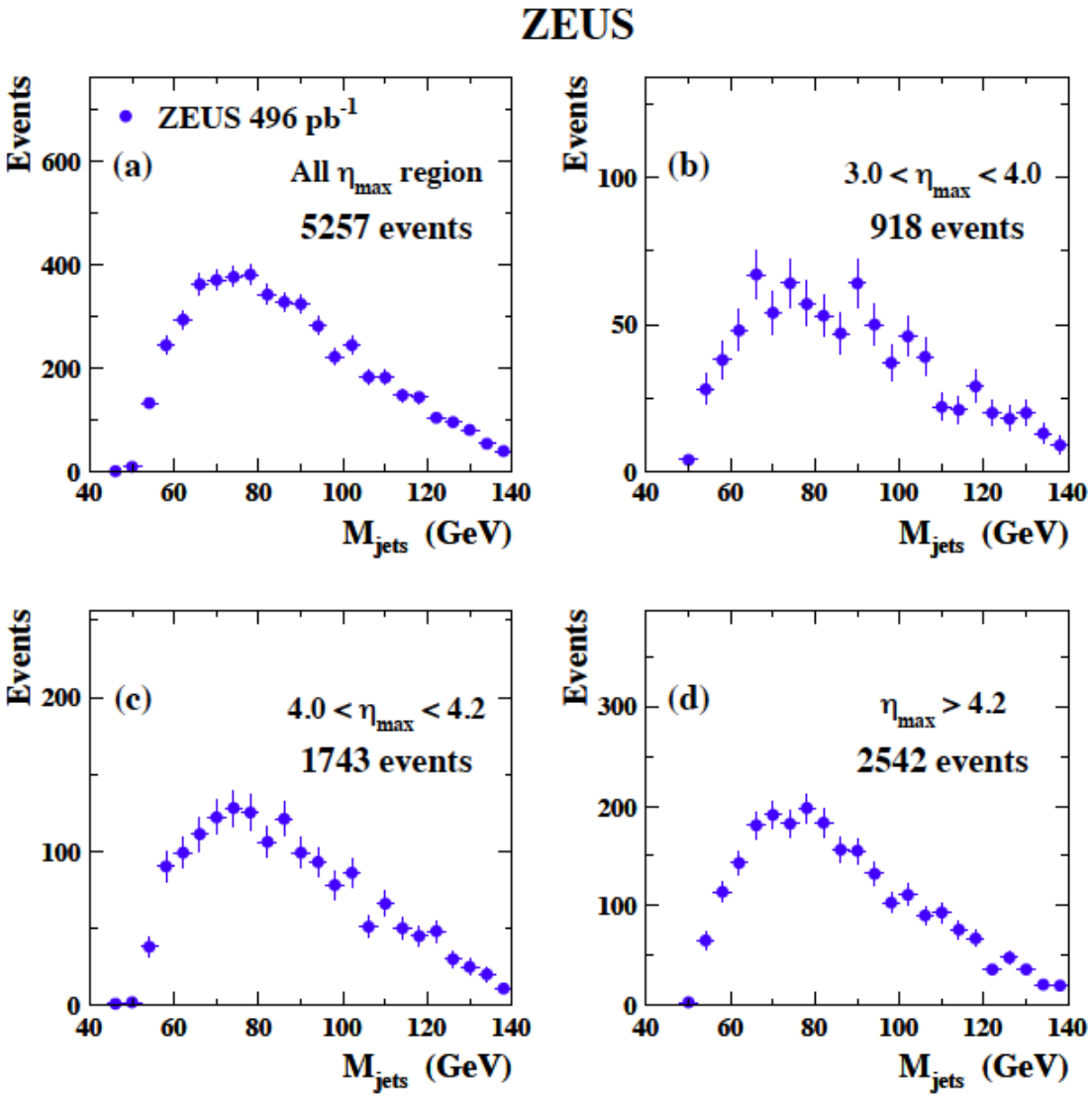
- **EPVEC used for signal**
  - Baur, Vermaseren and Zeppenfeld (1992)
  - Interfaced to PYTHIA+JETSET
- **Elastic and quasi-elastic ep→ep(p*) Z: 0.16 pb**
  - Selection acceptance ~22%, expect 17.9 events
- **Inelastic processes: 0.24 pb**
  - DIS (**$\gamma^* p \rightarrow Z^0 X$**) and resolved php ($\gamma p \rightarrow (qq \rightarrow Z^0) X$)
  - Selection acceptance <1%, expect 0.4 events
- **Do not use background MC**
  - Tail of high-E_T diffractive DIS, hard to model
  - Use data-driven estimation (next slide)



Expected resolution much better than ever !
(compared to di-jet resolutions of other detectors)

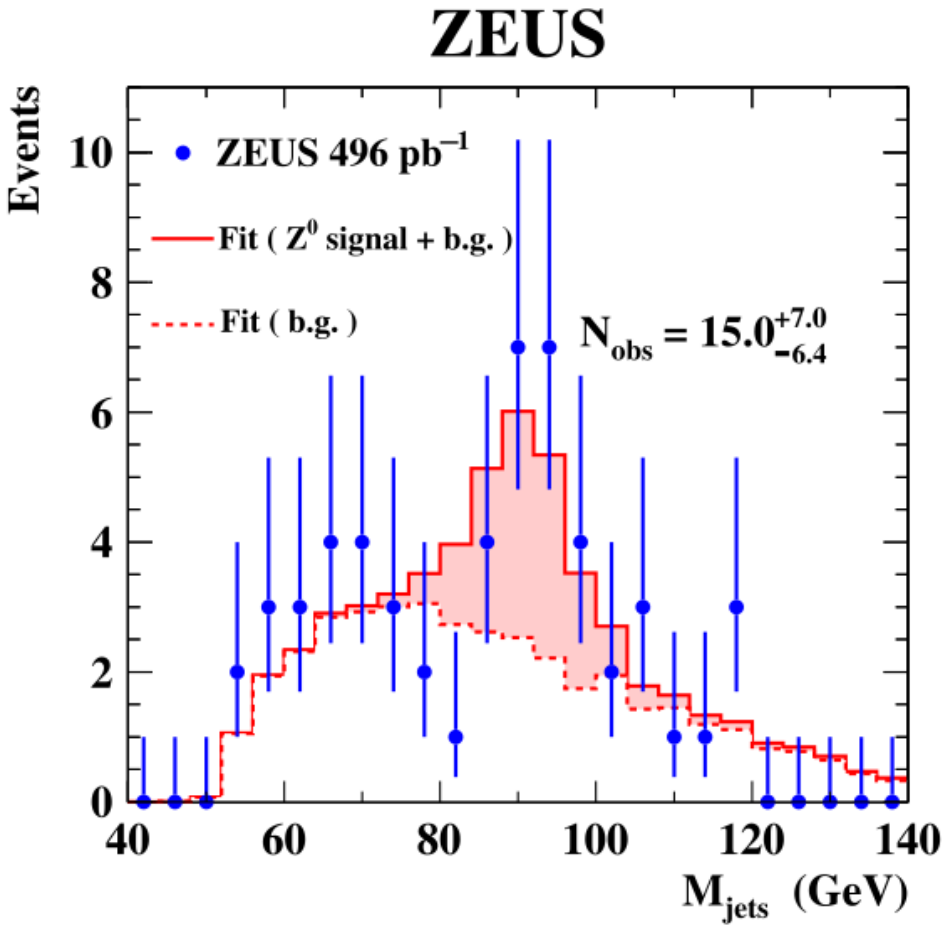
Bck-shape estimation (data driven)

- invariant mass shape has little η_{max} dependence
- Use invariant mass distribution
- background shape-template from data in $\eta_{max} > 4$ region
- signal shape-template from EPVEC MC
- Fit signal region ($\eta_{max} < 3$) with templates



Results

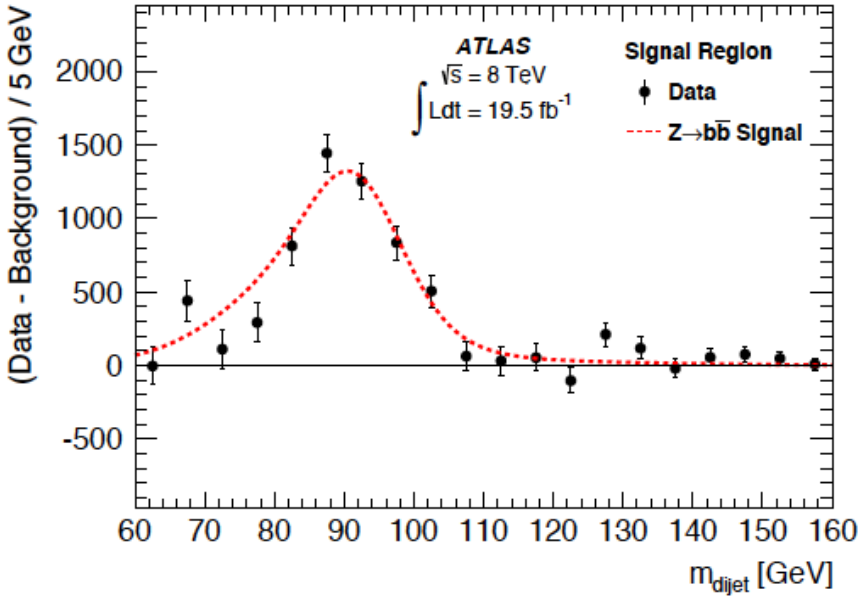
Di-Jet invariant mass after $\eta_{max} < 3$ cut



- maximum likelihood fit with signal and background templates *(χ^2/ndf = 17.6/22)*
- mass peak shift due to energy scale fitted as a nuisance parameter **ε** (σ_ε=3%, the fit gave **ε**=3±2%)
- 15.0+7.0−6.4 events observed *(signal with 2.3 σ significance)*

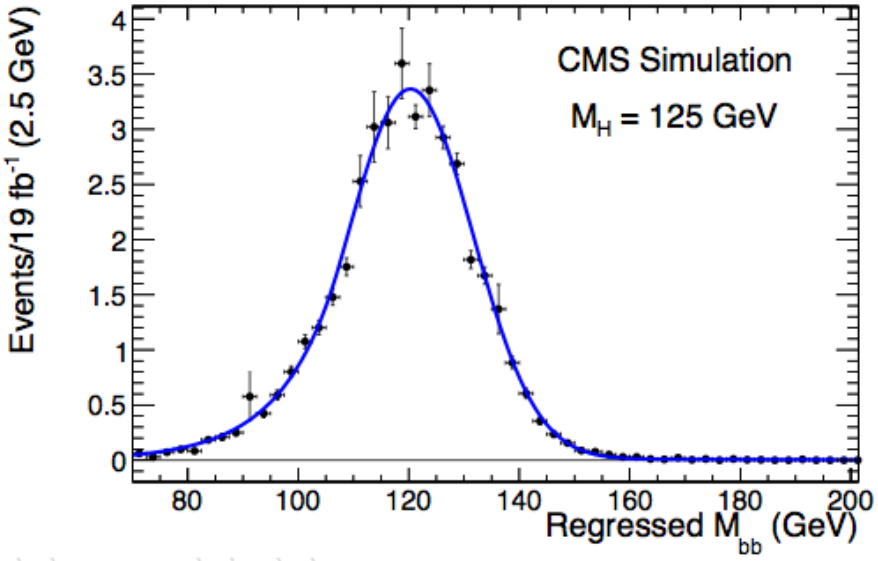
Shown excellent resolution of ZEUS uranium calorimeter

Hadronic Z^0 mass resolutions at LHC



ATLAS result on $Z^0 \rightarrow b\text{-}\bar{b}$
arXiv:1404.7042

CMS result on $Z^0 \rightarrow b\text{-}b$
arXiv:1403.3047



CMS template for $H \rightarrow b\text{-}\bar{b}$
CMS-PAS HIG-13-011
Archive Id: 184550P
(courtesy of the CMS Collaboration)

Cross-section estimation

Systematic uncertainties: total (+7.2, −6.2)%

- acceptance change by ±3% energy scale: (+2.1, −1.7)%
- η_{max} cut varied by ±0.2: (+6.4, −5.4)%
- using different η_{max} slices for background template: ±1.5%
- signal template peak width (6 GeV) smeared: negligible
- luminosity: ±2%

Resulting (quasi-)elastic Z^0 cross section

$$\sigma(ep \to eZ_0 p^{(*)}) = 0.13 \pm 0.06\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ \text{pb}$$

- consistent with SM prediction 0.16 pb
- first measurement of on-shell Z^0 cross section in ep collisions!

Summary

A search for on-shell Z^0 production in ~0.5 fb-1 ep collisions at HERA using ZEUS detector

- Used hadronic decay for Z^0
- (quasi-)elastic process aimed to suppress QCD backgrounds.
- **Excellent resolution of ZEUS uranium calorimeter**

First measurement of Z^0 production in ep collisions

$$\sigma(ep \to eZ^0 p^{(*)}) = 0.13 \pm 0.06\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ \text{pb}$$

- In agreement with SM elastic cross section of 0.16 pb
- Electroweak bosons at HERA fully exploited

BACKUP

Used data periods and luminosity

- Data collected between 1996 and 2007
- Total integrated luminosity : 496 pb**-1**
- Average polarisation is less than 1%
  (the effect is neglected in this analysis)

	proton beam energy (GeV)	luminosity (pb**-1**)	
96/97 e+	820	38.6	HERA-I total 121
98/99 e−	920	16.7	
99/00 e+		65.9	
03/04 e+		41.0	HERA-II total 375
04/05 e−		135.1	
06 e−		55.2	
06/07 e+		143.8	

Event selection (496 pb^{-1}): results

- **Trigger mainly based on CAL E_T**
- **Jets defined by k_T algorithm**

– at least 2 jets with ET > 25 GeV, $|\eta| < 2$. $\Delta\Phi_{12} > 2$ rad

– use all jets (ET > 4GeV, $|\eta| < 2$) for invariant mass

– remove jet if it overlaps with e/γ within R < 1

- **At most 1 electron in detector**

– $E_e > 5$ GeV, isolation, track match if in tracking coverage

–$\theta_e < 80^0$ required (reject low-Q2 NC b.g.)

- **No particles in rear (electron beam) direction**

– ERCAL < 2GeV

– 50 < Σ(E-pZ) < 64 GeV (sum over all CAL deposits)

***kT* cluster algorithm** in the longitudinally invariant inclusive mode. The algorithm was applied to the energy clusters in the CAL after excluding those associated with the scattered-electron candidate. Energy corrections were applied to the jets in order to compensate for energy losses in the inactive material in front of the CAL.

Cuts against cosmics and beam-gas

Reject events if any of the following conditions are met:

- $|Z_{vtx}| > 50cm$
- jets with $175 < \theta_1+\theta_2 < 185^0$ and $\Delta\Phi_{12} > 175^0$
- $|t_u-t_d| > 6$ ns (up-down timing difference in BCAL)
- $E_T^{miss} > 25$ GeV
- $N^{trk}_{vtx} < 0.25*(N^{vtx}_{all}-20)$ (vertex tracks and all tracks)