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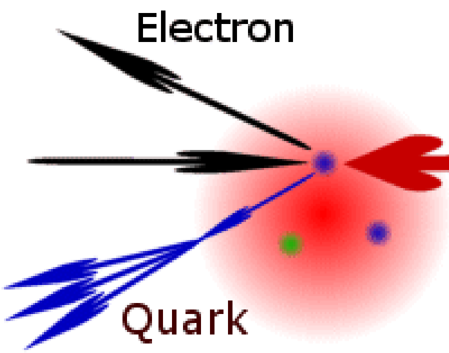
Elastic Z^0 Production @ HERA

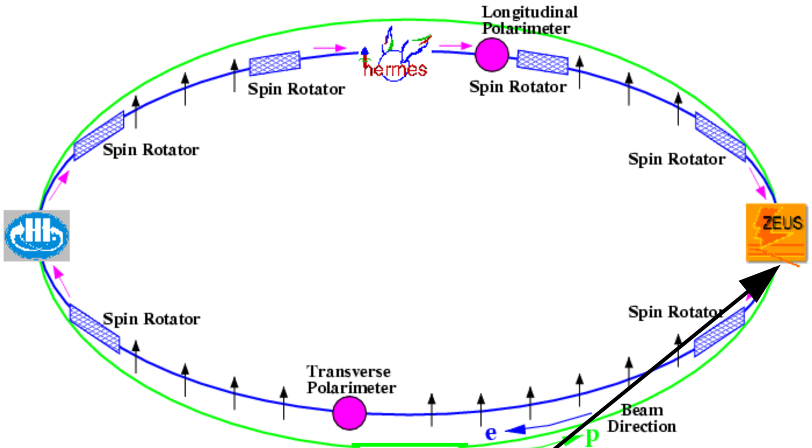
K. Wichmann on behlaf of the ZEUS Collaboration

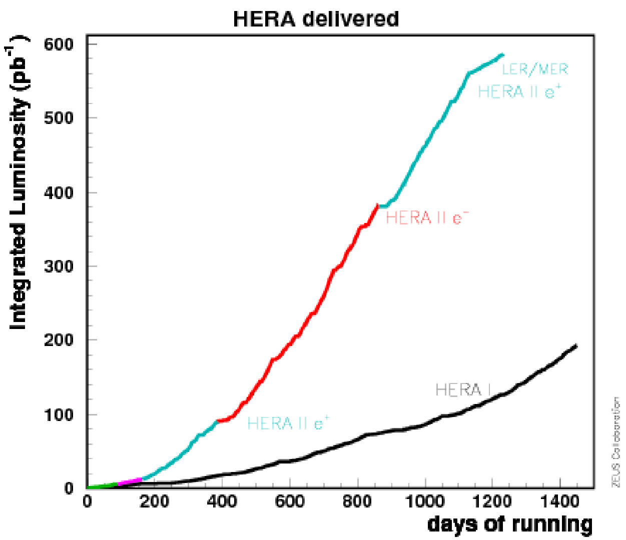
- HERA Accelerator & ZEUS Detector
- Z^0 @ HERA
- Search Strategy
- Results

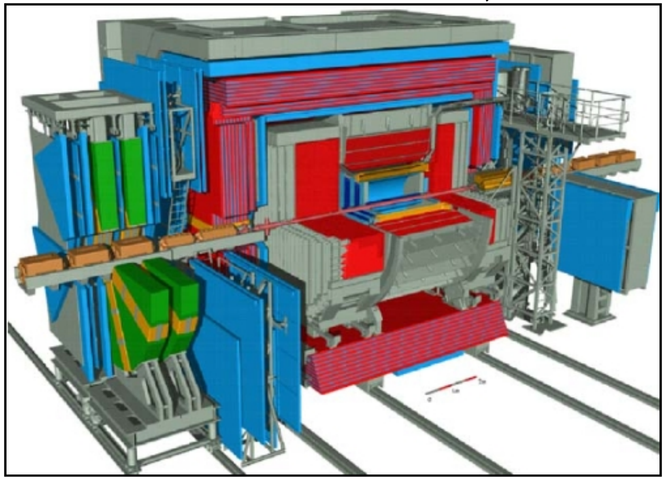
HERA Accelerator



- HERA: ep collider, $\sqrt{s}$ = 320 GeV
- From 2003 polarised lepton beam
- 2 colliding beams experiments: H1 & ZEUS
- **collected 0.5 pb^{-1}/exp of luminosity in 1992-2007**



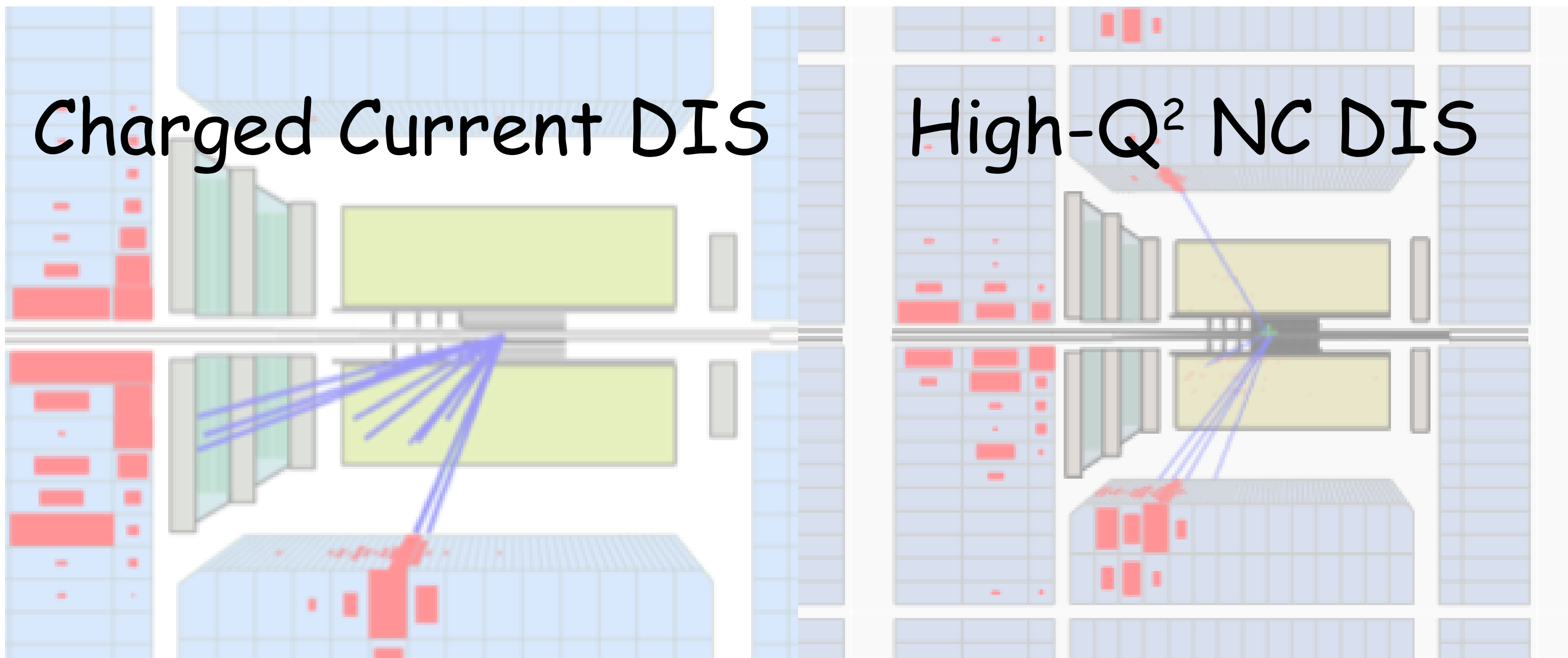


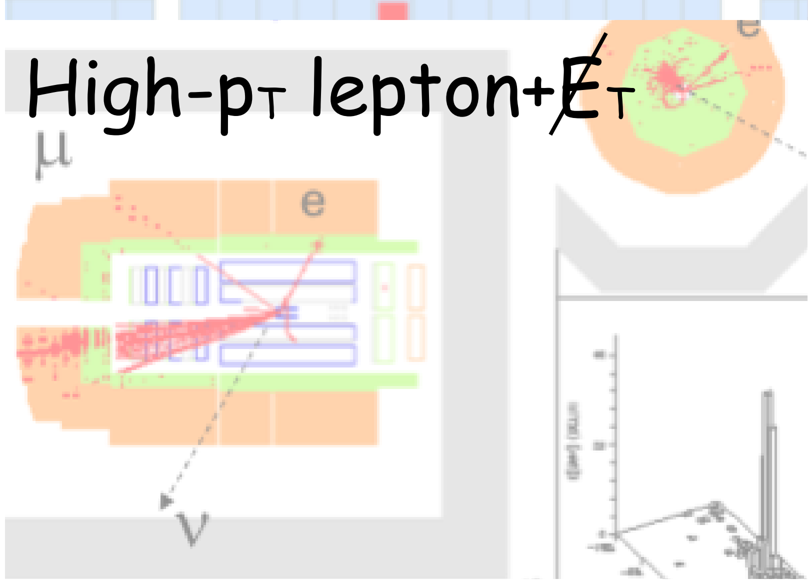


- ZEUS: general purpose detector at HERA
- High resolution uranium compensating calorimeter
  - electron $\sigma(E)/E = 0.18/\sqrt{E}$
  - hadrons $\sigma(E)/E = 0.35/\sqrt{E}$

Electroweak Bosons @ HERA

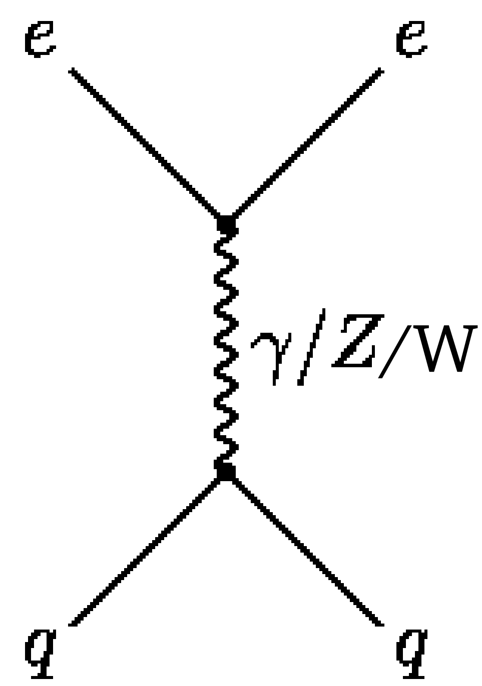
	W	Z
Virtual	Charged Current DIS	High-Q^2 NC DIS
Real	High-p_T lepton+$\not{E}_T$	**Missing piece in HERA EW program?**





Electroweak Bosons Production @ HERA

- Dominant process at HERA: Deep Inelastic Scattering (DIS)
- Electroweak bosons production
  - Mainly t-channel exchange
  - unlike at hadron colliders: no s-channel Drell-Yan production qq→Z
- W/Z produced on-shell by radiation from quark/lepton lines -> small cross section



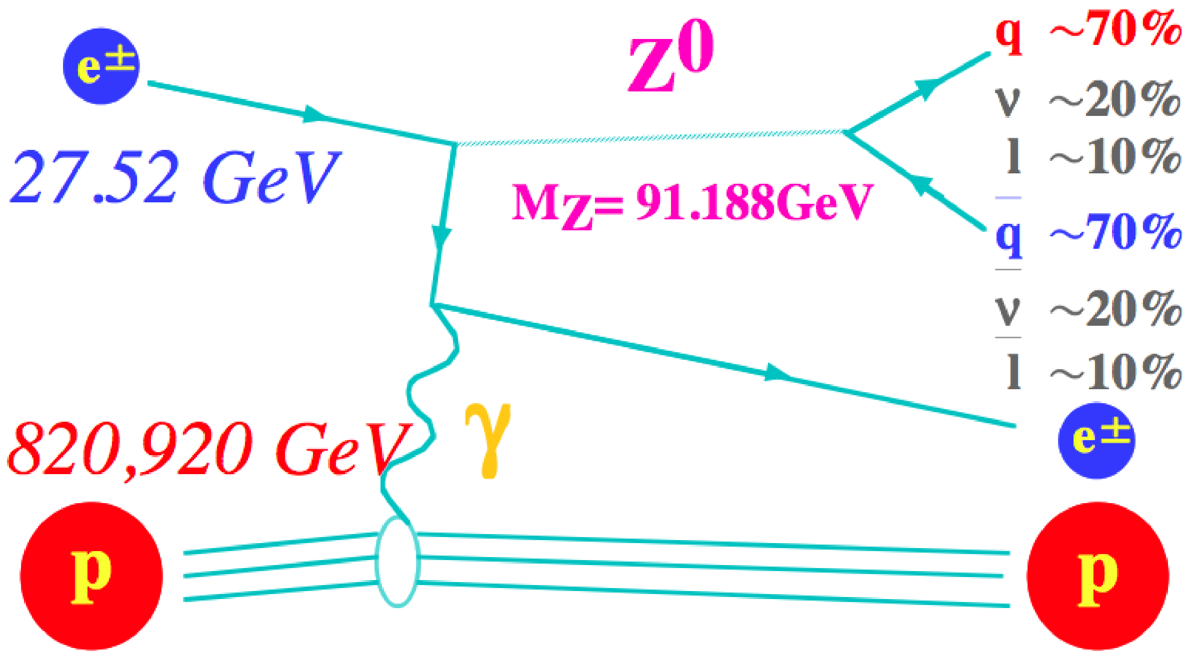
- W boson cross section is measured to be:

$$\sigma_{(ep\to WX\to l\nu X)} = 1.06 \pm 0.16\,(\text{stat.}) \pm 0.07\,(\text{syst.})\ \text{pb.}$$

The H1 and ZEUS collaborations, JHEP 3 1-19(2010)

- σ(Z) is expected to be ~ 0.4pb

Elastic Z^0 Production

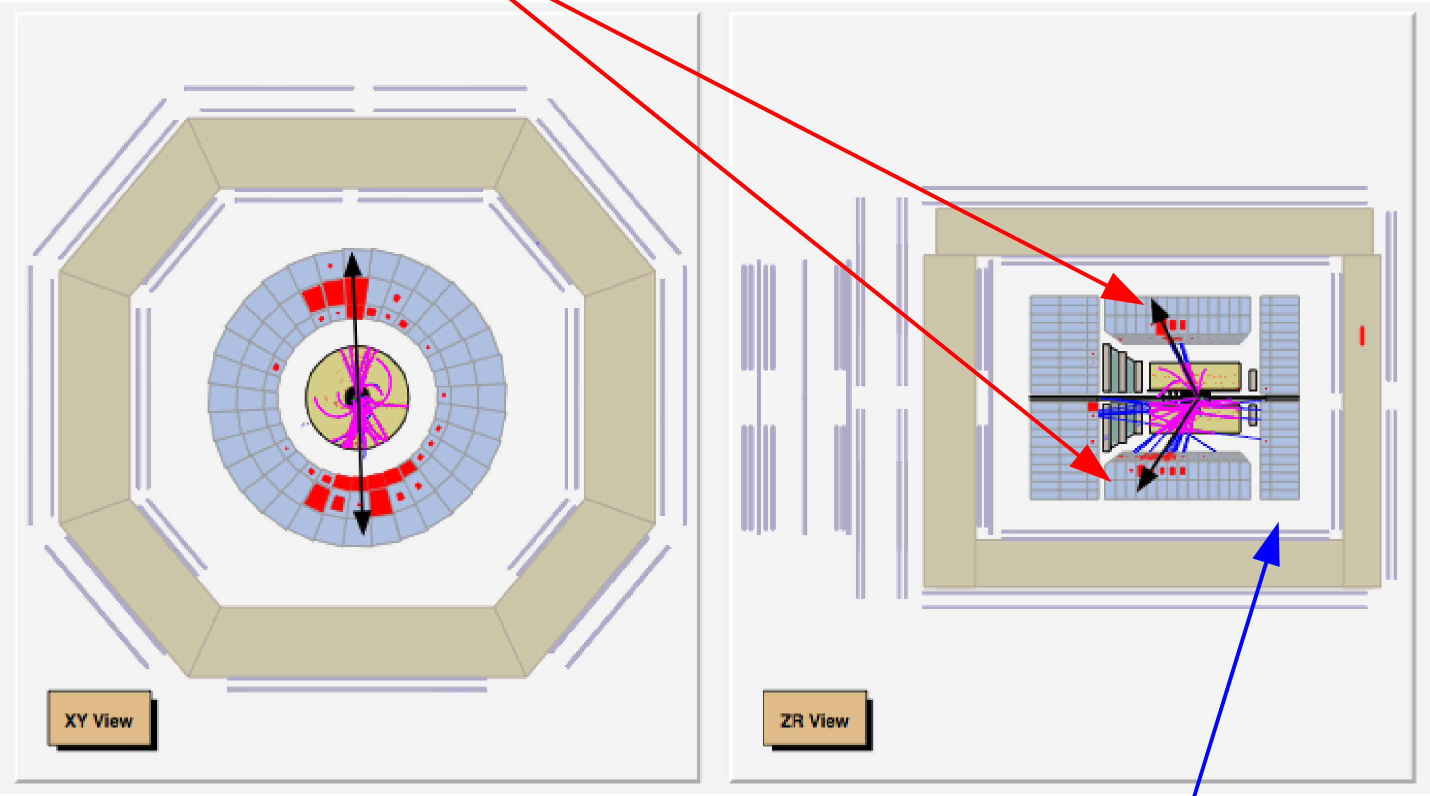


elastic Z^0 diagram, hadronic channel

- **Hadronic Z^0 decays** → highest branching ratio (leptonic too small)
  - very large QCD multi-jet background
- **Elastic Z^0 production**: ~0.16 pb
  - expected better S/B ratio

Event Selection

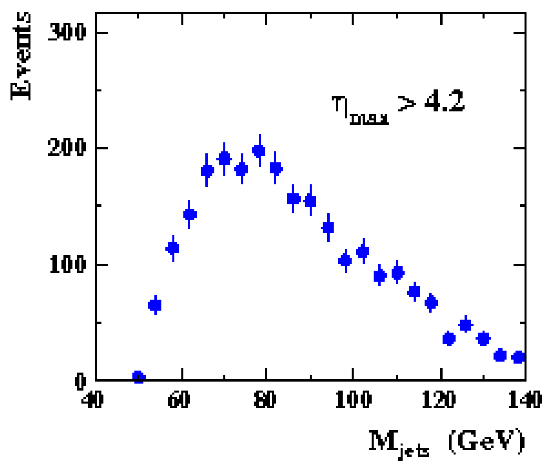
- **Select events with at least 2 jets & calculate invariant mass from all jets with E_T>4GeV & |η|<2**
  - at least 2 high E_T jets (E_T > 25 GeV)



to discriminate signals from low-Q^2 NC:
RCAL veto
E-Pz peak at 55 GeV, cut 50 < E-pz < 64 GeV

Elastic Selection

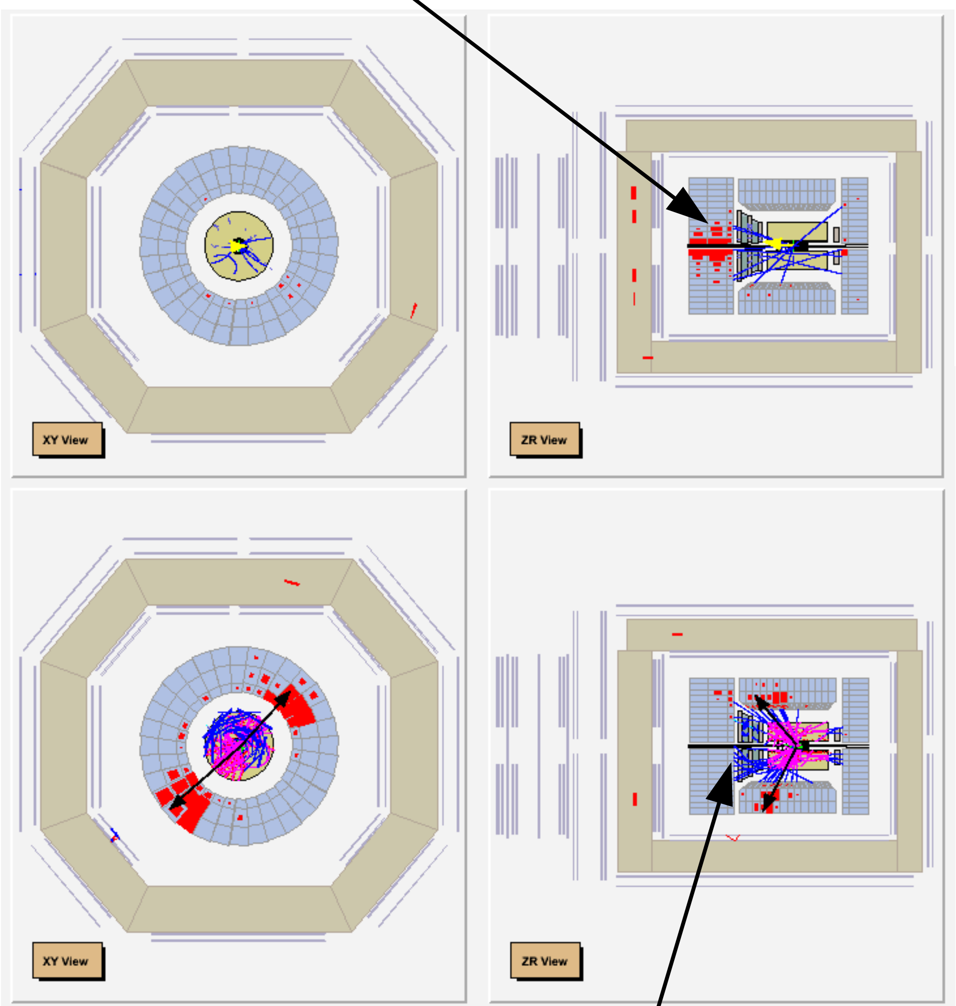
- Multijet sample dominated by QCD background: no Z^0 signal



- 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

$\eta_{max} < 3.0$

$\eta_{max} = 4.03$



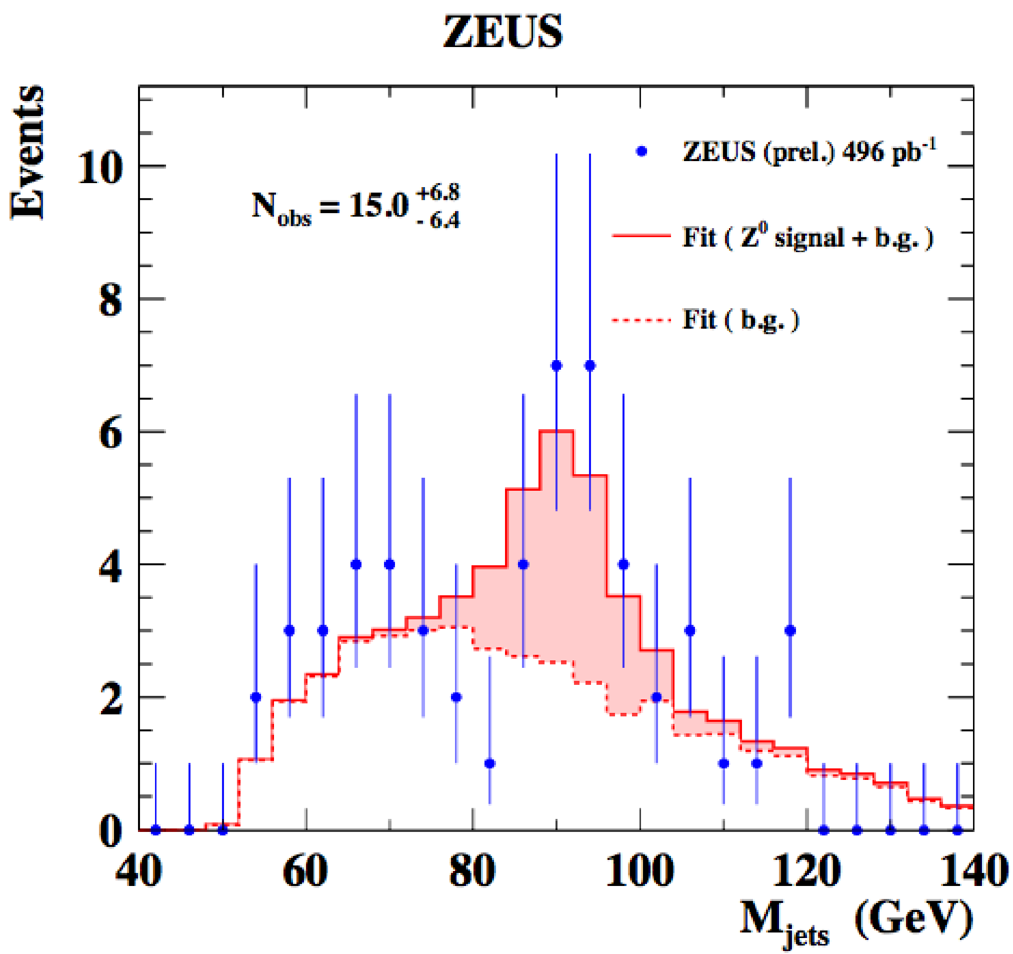
elastic event: $\eta_{max} = 1.24$

Z^0 Mass Peak

- **496 pb^{-1} data collected in years 1996-2007 used in this analysis**
  - shows excellent resolution of ZEUS uranium calorimeter

15 events observed (+6.8, -6.4 events)

- Details of fit and cross section determination described in next slides



Cross Section Calculation

Fit the data with shape templates of signal(MC) + bg(data, η_{max} > 3)

1. Define the reference number, $N_{ref,i}$, for each bin *i* in 40 < M < 140 GeV

$$N_{ref,i} = aN^{MC}_{signal,i}(e) + bN^{data}_{bg,i}$$

(e: energy shift parameter allowed in ±3%)

1. χ^2 is defined as:

$$\chi^2 = -2\sum_i log\frac{\mathcal{L}\left(N_{ref,i}, N_{obs,i}\right)}{\mathcal{L}\left(N_{obs,i}, N_{obs,i}\right)}$$

2. Find (a, b, e) to minimize χ^2

3. The best fit 'a' gives the ratio between observed and SM cross section i.e. we can get $\sigma_{obs} = a\sigma_{SM}$

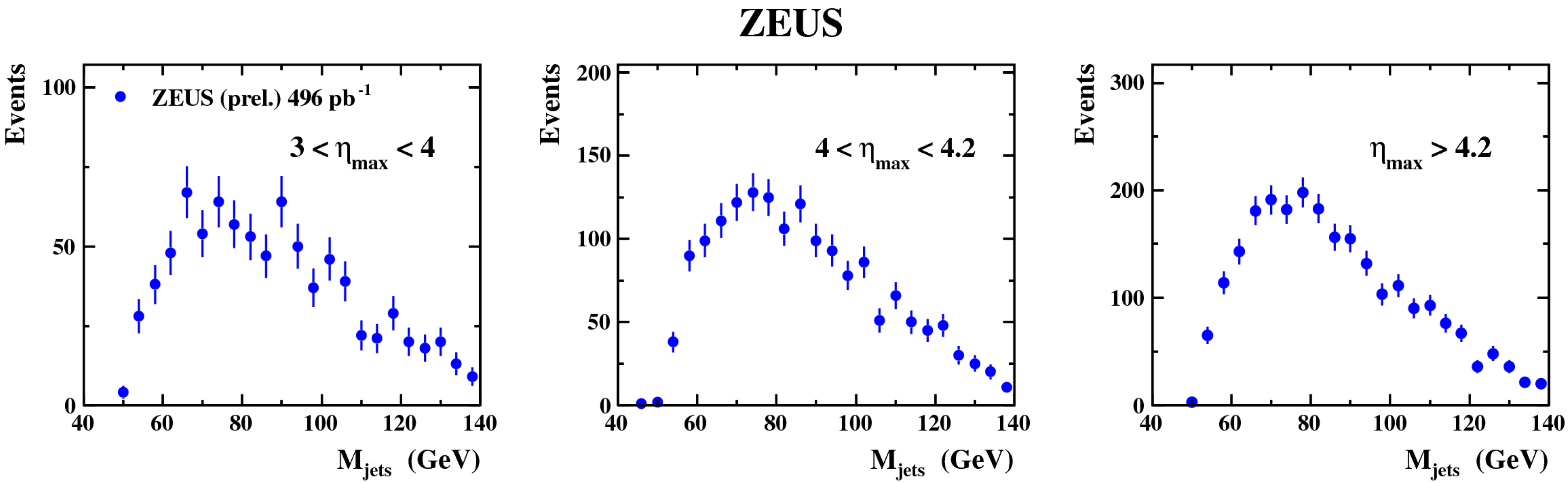
Number of Signal Events from MC

- EPVEC Monte Carlo interfaced with Pythia hadronic fragmentation
  - Total cross section: 0.40 pb
- This analysis aims to measure the 'elastic' cross section
  - Elastic cross section: 0.16 pb
  - Expected # of elastic events after all selection cuts: 17.9
  - Acceptance for elastic production: 0.22
- Invariant mass distribution with MC used as signal shape template

	cross section [pb]	selection acceptance	expected #of events(xsec×acc×lumi)
elastic	0.163 (total 'elastic')	0.22	17.9
inelastic	0.236 (total 'inelastic')	0.0035	0.4

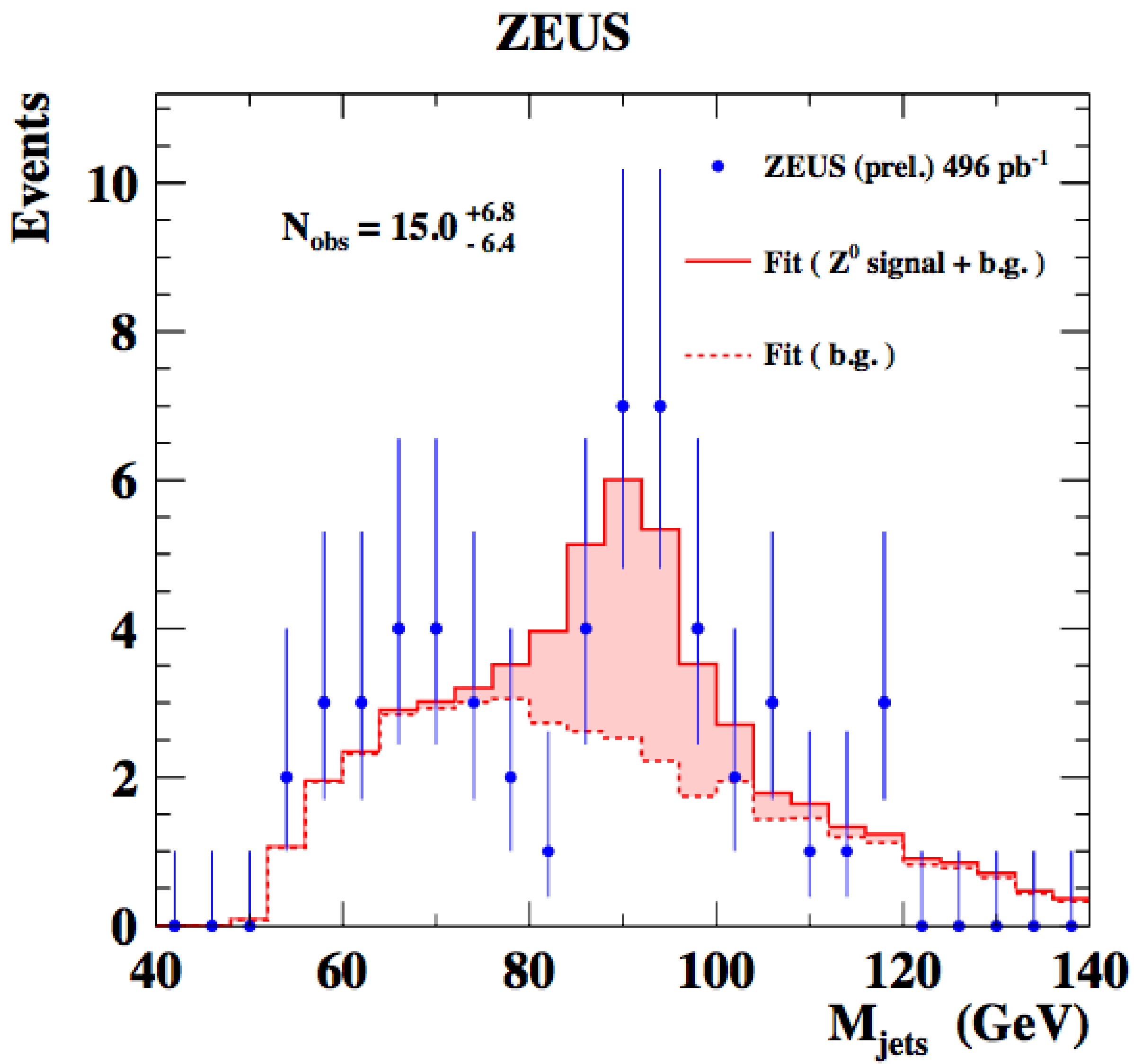
Number of Background Events from Data

- Background studied in data (after all selection cuts) for different slices of η_{max}
  - No difference in shape observed
  - Data for $\eta_{max} > 3$ used for background template



Fit final data sample with signal (MC) + BG (Data) shape templates

Elastic Z^0 Production Cross Section



$$\sigma_{obs}\left(ep \rightarrow ep^{(*)}Z^0\right) = 0.133^{+0.060}_{-0.057}\,(\text{stat.only})\ \text{pb}$$

Consistent with SM elastic cross section $\sigma_{SM}\left(ep \rightarrow ep^{(*)}Z^0\right) = 0.16\text{pb}$

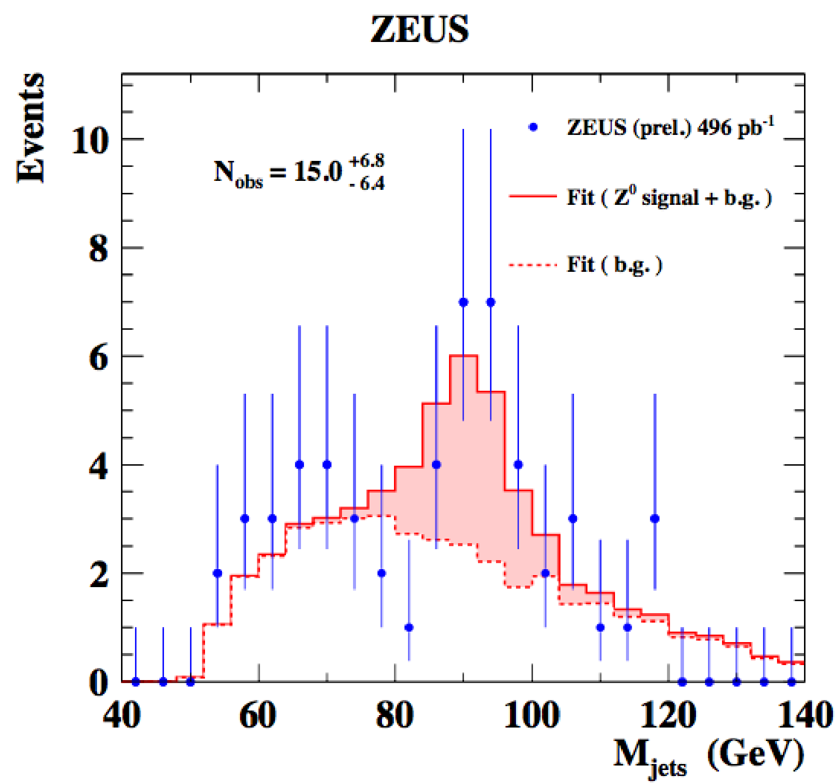
Systematic Uncertainty

- Systematic uncertainty estimated in conservative way (preliminary)
- Measurement dominated by statistical errors

Source	Errors on xsection
$E_{T,jet}$ scale ±3%	(+2.1%, -1.7%)
Elastic selection uncertainty	(+36.5%, -28.6%)
BG shape uncertainty	±1.5%
Luminosity	±1.9%
TOTAL	(+36.6%, -28.8%)

Final Results

- Z^0 elastic cross section was measured for a first time in ep collisions by ZEUS experiment
  - Smallest cross section measured @ HERA
  - Demonstrates excellent resolution of ZEUS uranium calorimeter
  - Electroweak bosons fully exploited
  - In agreement with SM elastic cross section of 0.16 pb



$$\sigma_{obs}\left(ep \rightarrow ep^{(*)}Z^0\right) = 0.133^{+0.060}_{-0.057}\,(\text{stat.})^{+0.049}_{-0.038}\,(\text{syst.})\ \text{pb}$$

Backup Slides

How to obtain cross section

Fit the data with shape templates of signal(MC) + bg(data, ηmax>3)

1. Define reference number at each bin i, $N_{ref,i}$ (i: 40-140GeV)

$$N_{ref,i} = aN^{MC}_{signal,i}(e) + bN^{data}_{bg,i}$$

- $N^{MC}_{signal,i}(e)$ is signal expectation at bin i in $\eta_{max} < 3$ region.
  e is parameter of energy shift, $e = [-0.03, 0.03]$ and $M_{jets} = (1+e) \times M_{jets}$
- $N^{data}_{bg,i}$ is number of background at bin i in $\eta_{max} > 3$ region.

2. Calculate log-likelihood, LLH, by summing over all bins

$$LLH = \sum_i A_i + \left(\frac{e}{\sigma_e}\right)^2$$

$\left(\frac{e}{\sigma_e}\right)^2$ is a penalty term. $(\sigma_e = 0.03)$

$$A_i = \begin{cases} 2N_{ref,i} - 2N_{obs,i} + 2N_{obs,i}log\left(\frac{N_{obs,i}}{N_{ref,i}}\right) & (\text{if } N_{obs,i} > 0) \\ 2N_{ref,i} - 2N_{obs,i}] & (\text{if } N_{obs,i} = 0) \end{cases}$$

3. a, b and e are free parameters. Iterate and find the best fit (a, b, e) giving minimumLLH

4. The best fit 'a' gives the ratio between observed and SM cross-section i.e. we can get $\sigma_{obs}=a\sigma_{SM}$

Courtesy of T. Nobe