Elastic Z^0 production at HERA

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on behalf of
ZEUS collaboration

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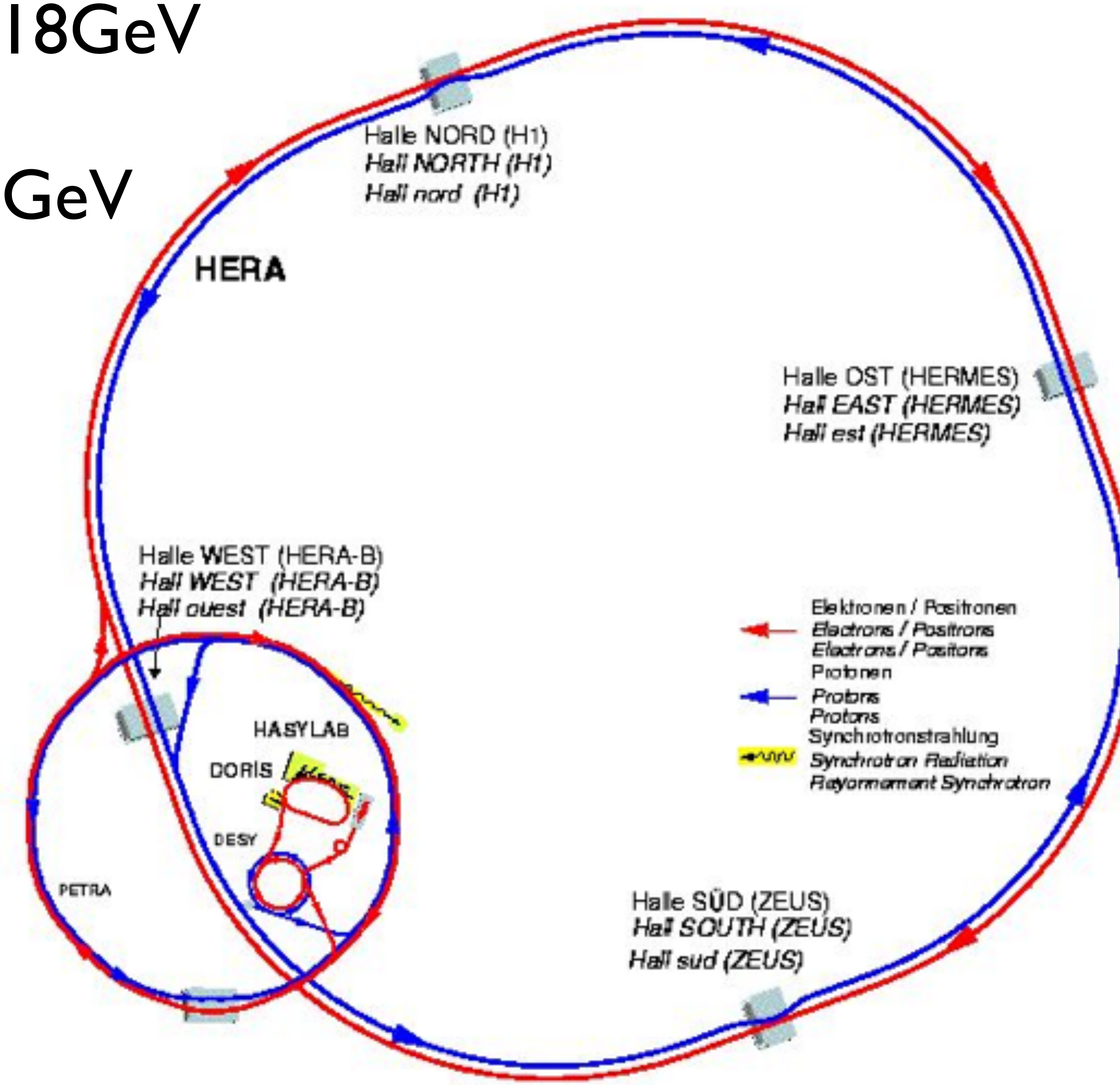
XX International Work on Deep Inelastic Scattering and Related Subjects
@University of Bonn

Topics

- HERA and ZEUS detector
- Motivation
- Monte Carlo Simulation
- Data-driven background estimation
- Fitting result
- Systematic
- Summary

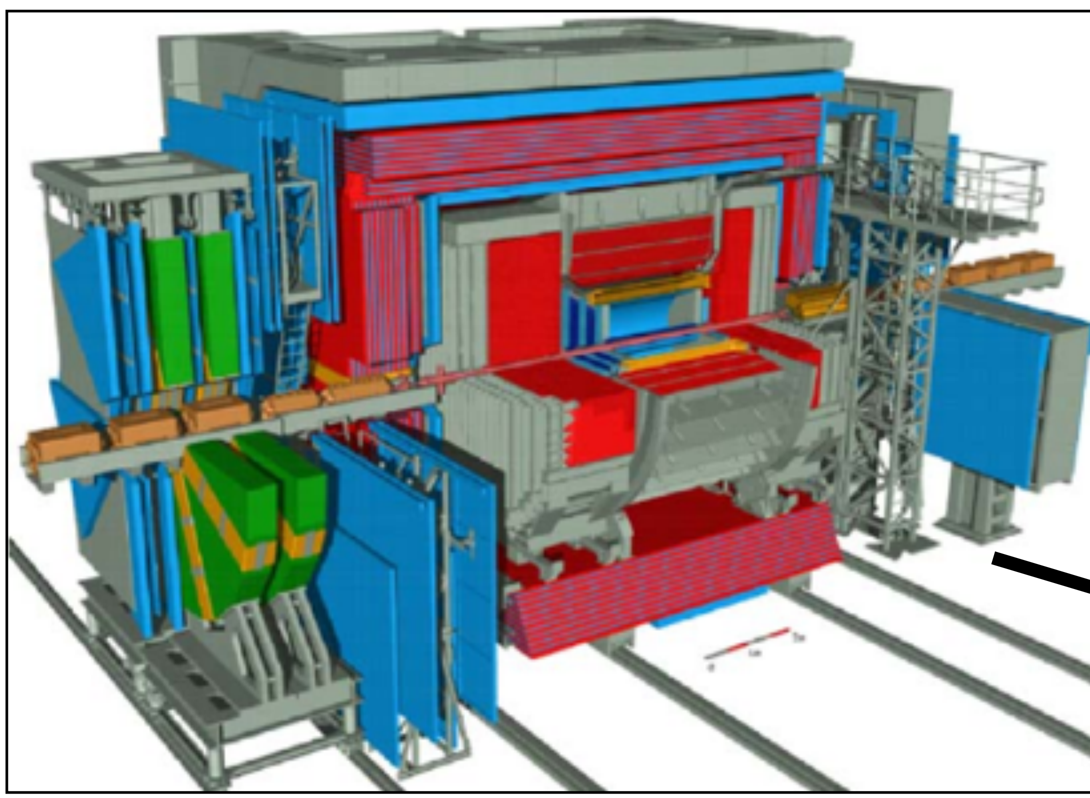
HERA

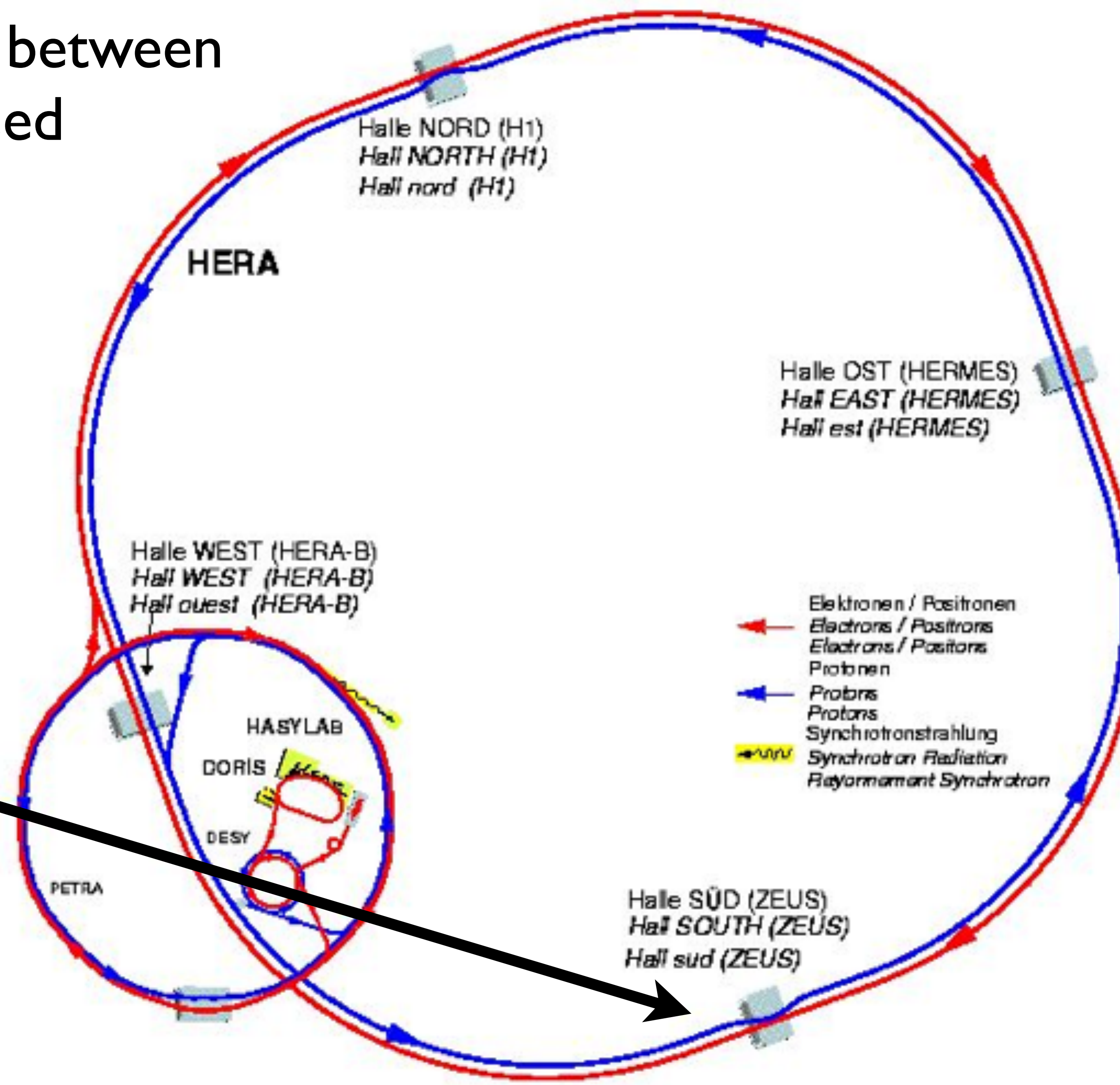
- Unique ep collider at DESY
- Operated during 1992-2007
- Center-of-mass energy: 318GeV
  proton:920GeV
  electron(positron):27.5GeV



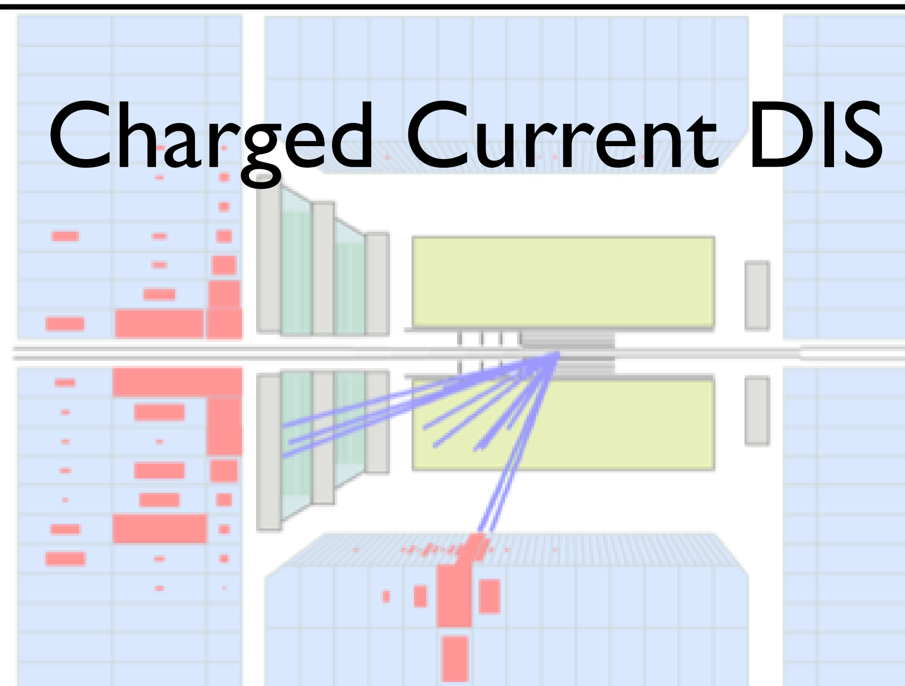
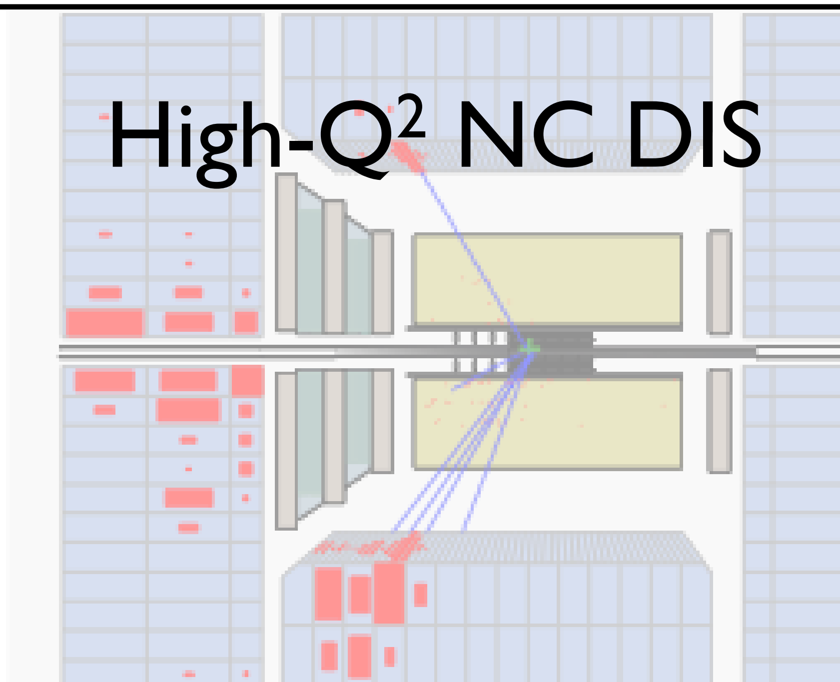
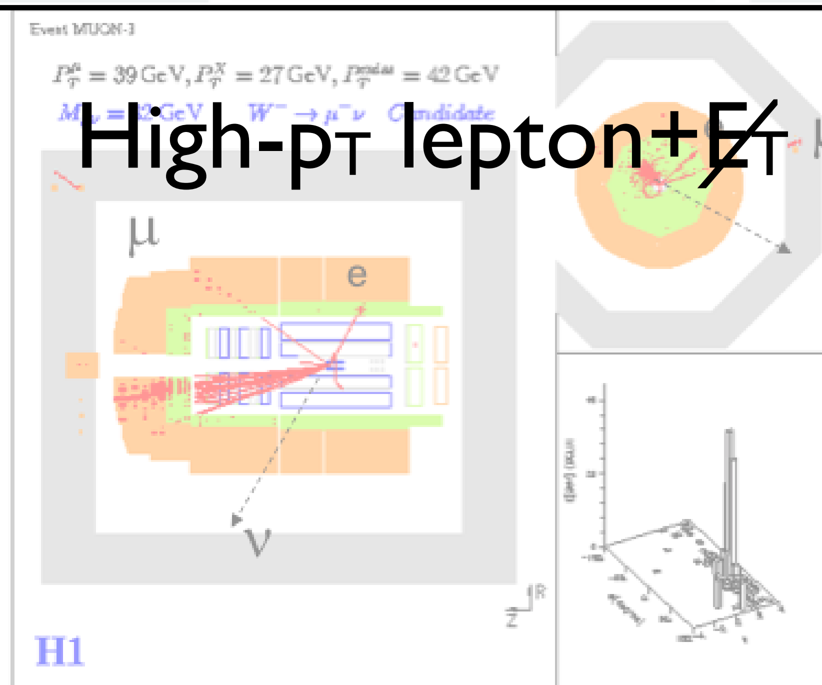
ZEUS detector

- General purpose detector at HERA
- High resolution calorimeter using Uranium absorber
  - electron $\sigma\left(\mathrm{E}\right)/\mathrm{E}=0.18/\sqrt{\mathrm{E}}$
  - hadrons $\sigma\left(\mathrm{E}\right)/\mathrm{E}=0.35/\sqrt{\mathrm{E}}$
- 496 pb^{-1} data collected between 1996 and 2007 were used in this analysis

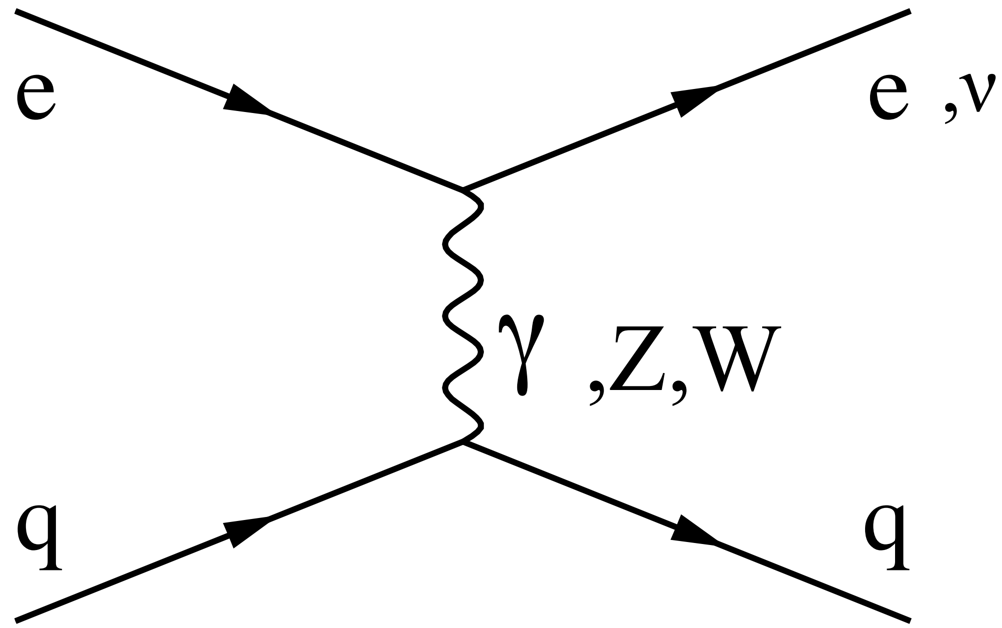




Electroweak Bosons at HERA

	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?**

Lepton-Hadron collision -DIS



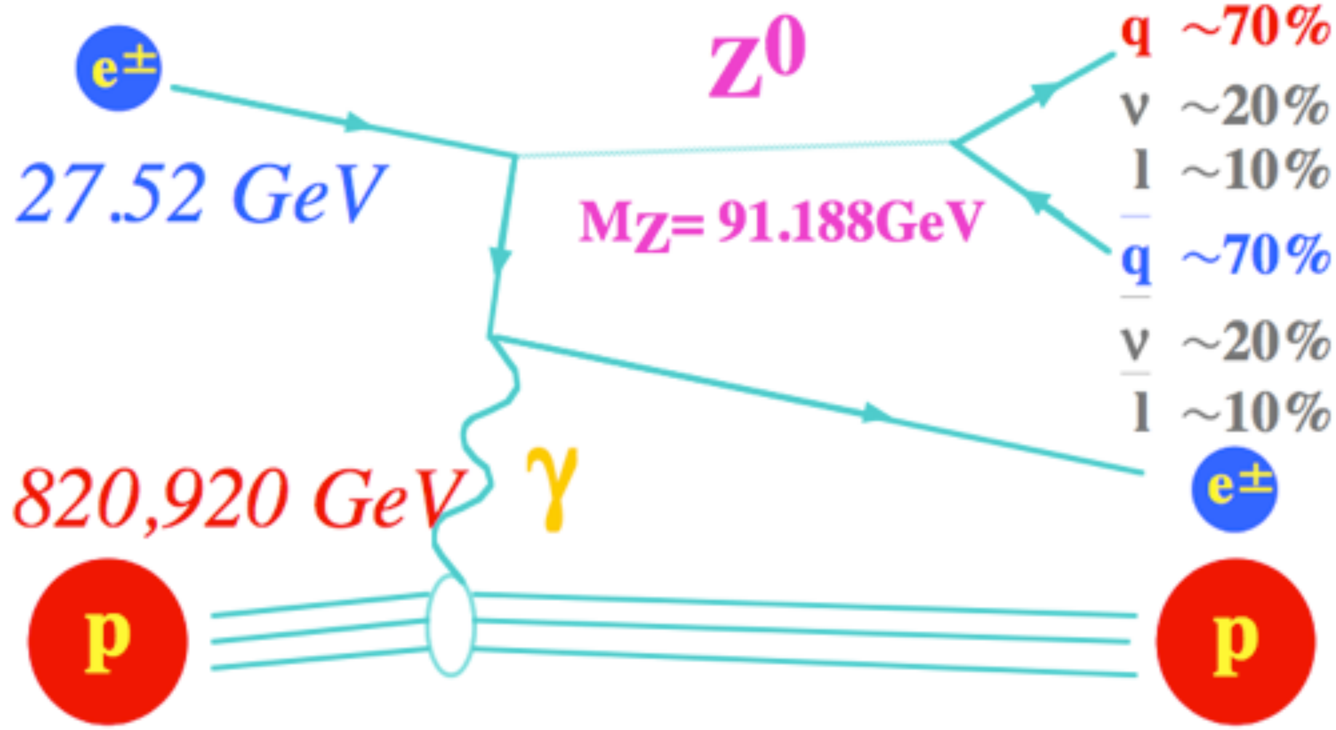
- Mainly t-channel exchange of gauge bosons
- No s-channel Drell-Yan production $q\bar{q}\rightarrow Z$ (unlike hadron colliders)
- On-shell W/Z production by radiation from quark/lepton lines
  - small cross section
- W boson cross section is measured to be

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

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

- σ(Z) is expected to be ~0.4pb

Z^0 Search strategy

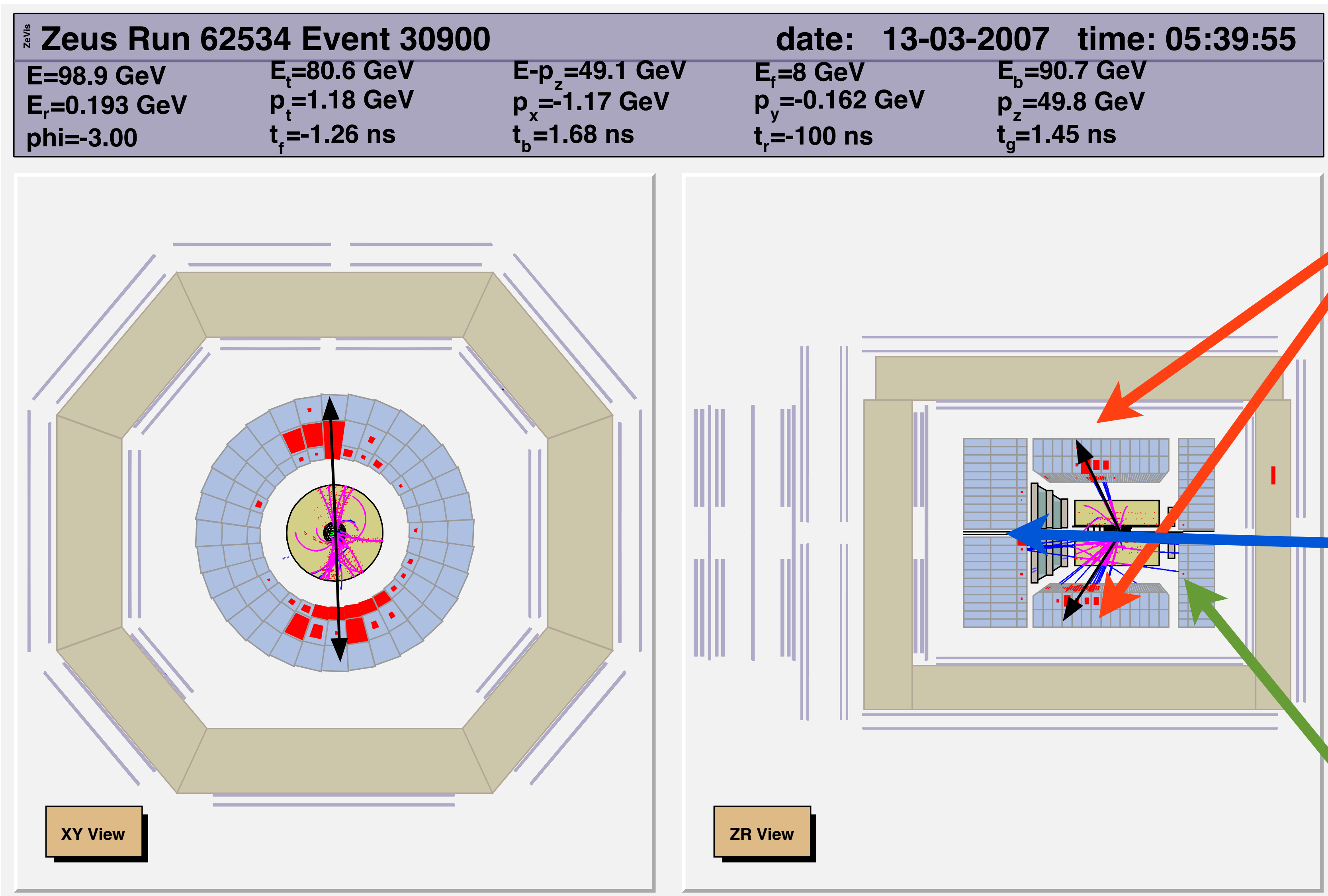


elastic Z^0 diagram, hadronic channel

- Leptonic decays have too small branching ratio => **Hadronic decays** (But very large QCD dijet bg)
- Target: **elastic production**(~0.16pb), expecting larger S/N

Z^0 Search strategy(cont'd)

- The invariant mass is calculated by using all of jets with E_T>4GeV & |η|<2



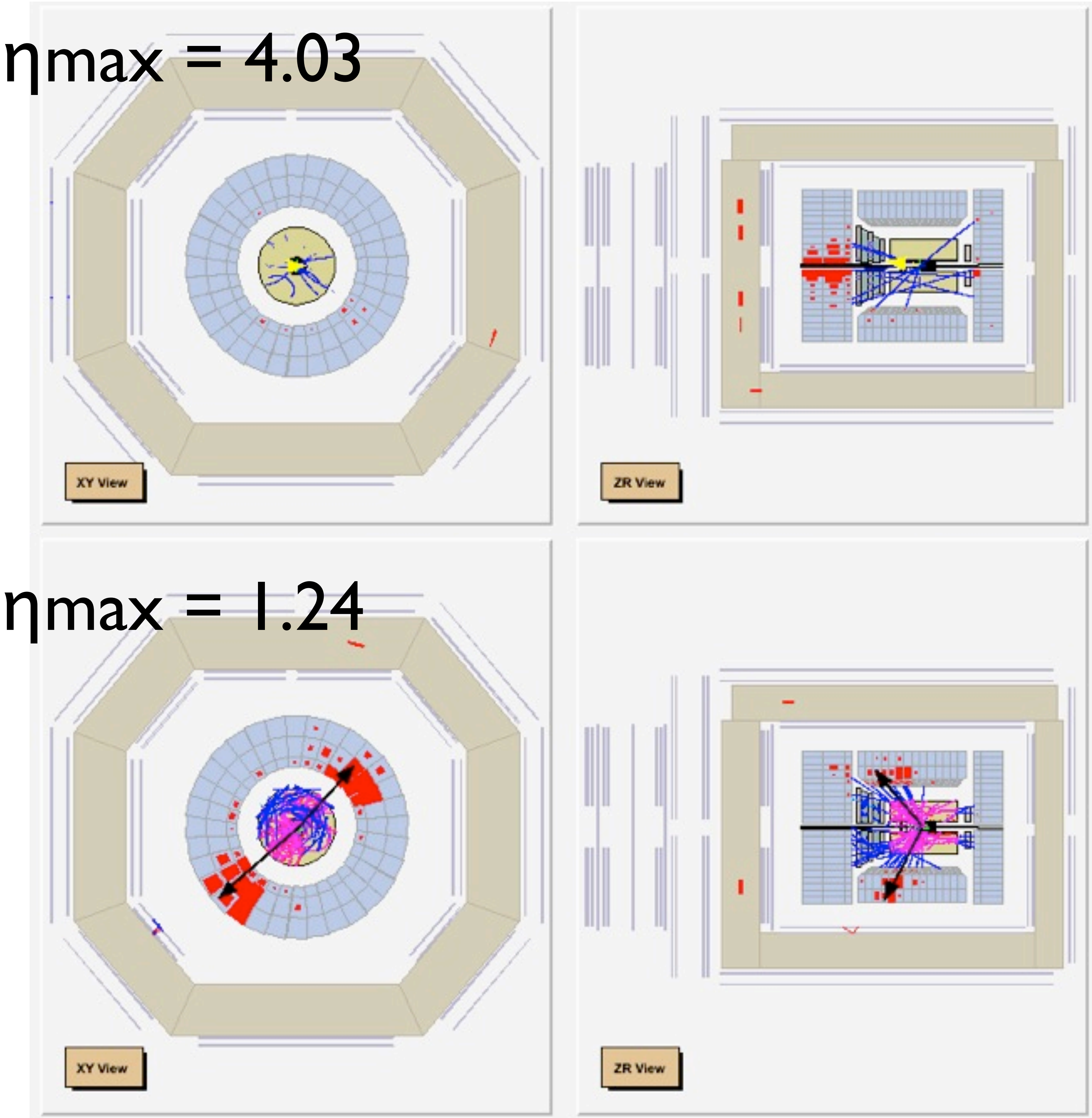
≧2 large E_T jets
(E_T>25GeV)

η_{max} < 3
to select elastic events

RCAL veto

E-Pz peaks at 55GeV
to discriminate signals from low-Q^2 NC

η_{max}



SM cross section and MC selection acceptance

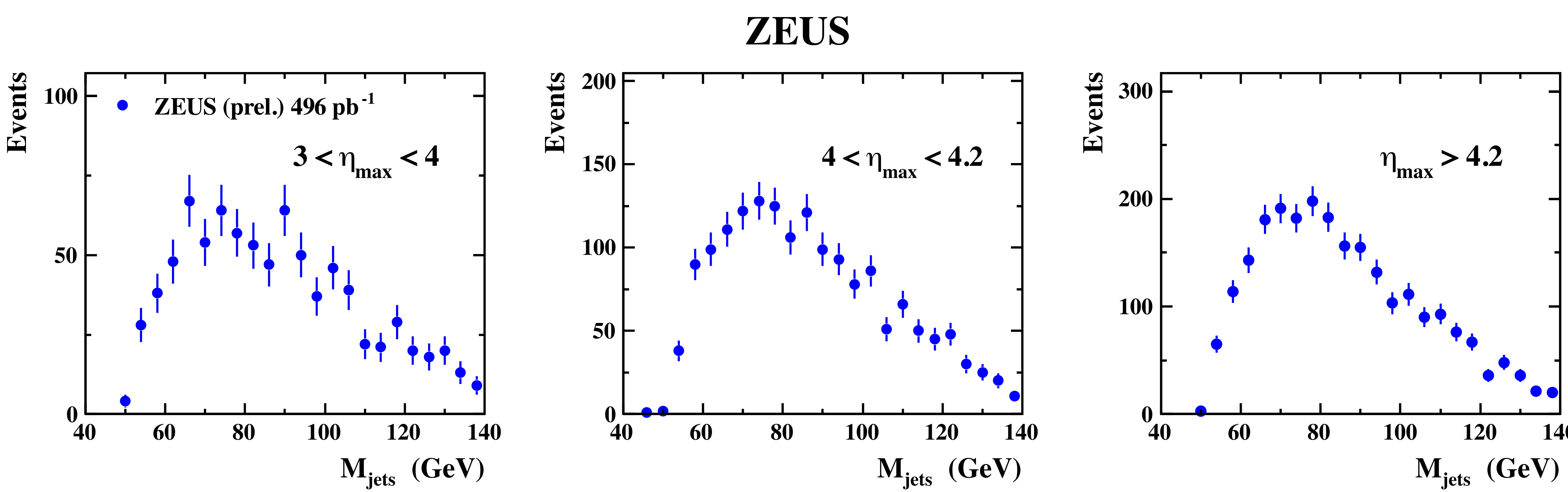
- MC samples are generated with EPVEC interfaced with Pythia hadronic fragmentation

	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

- Total cross section is 0.40pb
- Total expected #of events after all selection: 18.3
- Total acceptance 0.094 (0.22 for ‘elastic’)
- This analysis aims to measure the ‘elastic’ cross section
- The invariant mass distribution with MC is used as signal shape template

Data driven b.g. shape estimation

- M_{jets} in several η_{max} slices (after all selection)
- No significant difference was found



Background template is made from all of data in η_{max}>3

=> Fit the final sample data with signal(MC)+b.g.(Data) shape template

How to obtain cross section

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

2. χ^2 is defined to be:

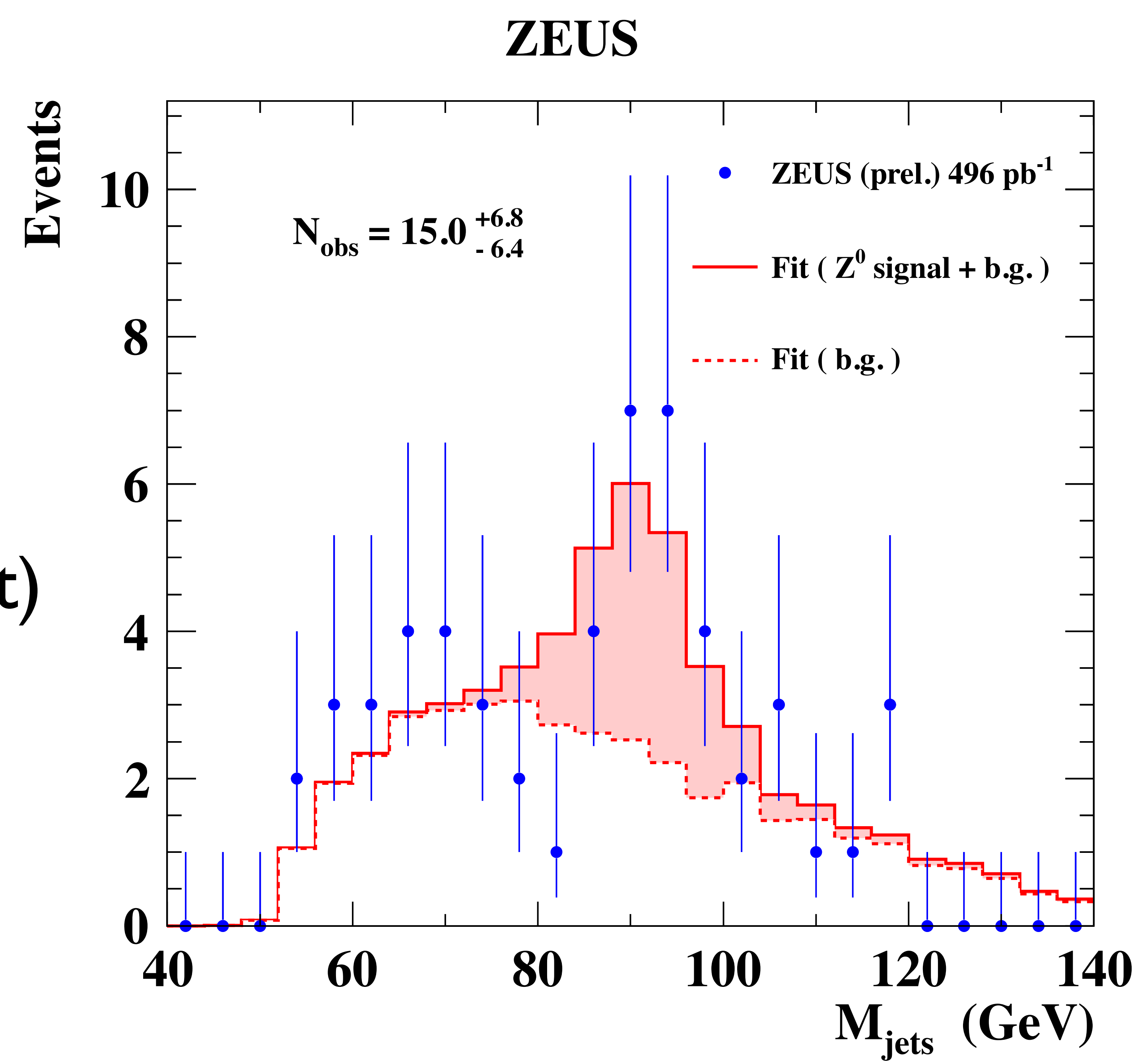
   $$\chi^2 = -2\sum_i log\frac{\mathcal{L}(N_{ref,i}, N_{obs,i})}{\mathcal{L}(N_{obs,i}, N_{obs,i})}$$

3. Find (a, b, e) to minimize χ^2

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

Fitting result

- Best fit result;
  - signal normalization parameter 'a': **0.82** (with +2.8% energy shift)



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

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

Systematics

Source	errors on xsection
$E_{T,jet}$ scale ±3%	(+2.1%, -1.7%)
elastic selection uncertainty	(+36.5%, -28.6%)
b.g. shape uncertainty	±1.5%
Luminosity	±1.9%
TOTAL	(+36.6%, -28.8%)

Elastic selection cut(η_{max}<3) uncertainty

- Elastic events with forward scattered electron(η_e>3) in the calorimeter are removed by η_{max}<3
  (events with the election passing though
  the forward beam pipe are accepted)

- Acceptance of η_{max}<3 cut for elastic events=67%

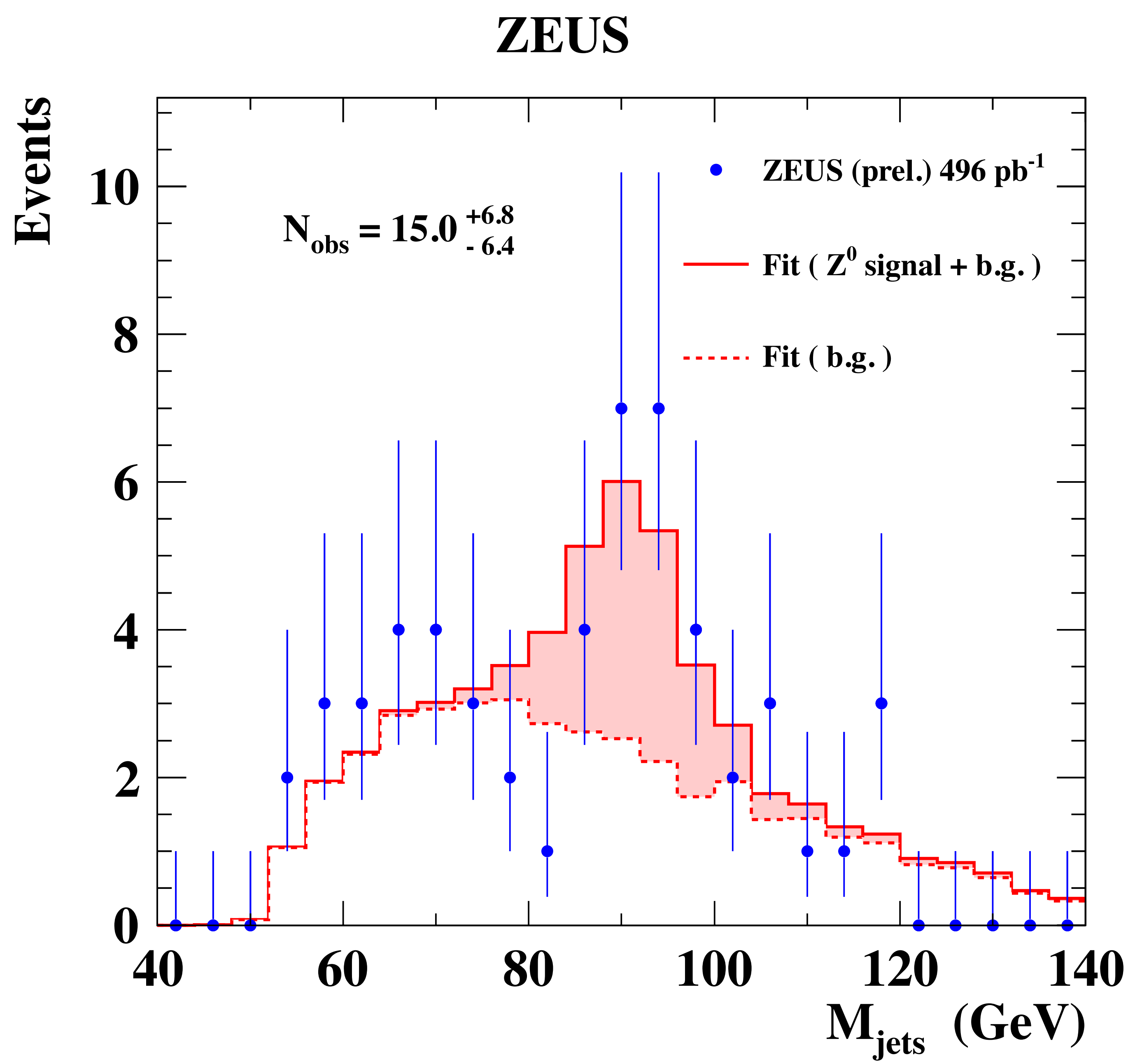
- Lower side of systematics is very conservatively estimated by assuming 100% acceptance of η_{max} cut for elastic events
  (Acceptance gain = +40% => Systematic for xsec= -28.6%)

- Upper side of systematic is estimated by changing to calculate ηmax by using all CAL cells with MC
  (nominally using cells with E>400MeV)
  (Acceptance loss = -26.8%=>Systematic for xsec = +36.5%)

Result and summary

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

- Elastic Z^0 cross section in ep collision was measured.
- The result agrees with SM cross section of 0.16pb



backup

Cut flow chart

Trigger requirement	
Select $Z^0 \rightarrow qq$	Number of jets >= 2 $E_{T,2nd\ jet}$ > 25GeV $\lvert\eta_{jet}\rvert < 2$ $\lvert\Delta\varphi_{2jets}\rvert$ > 2rad
Select elastic Z^0 production	50 < E-Pz < 64GeV θe < 80°or no electron found E_{RCAL} < 2GeV ηmax < 3 (ηmax: calculated from >400MeV cells)
Cosmic rejection	|Zvtx| < 50cm & Chivtx >= 0 Reject if 175°<θjet1 + θjet2 < 185° only if |φjet1 - φjet2| > 175° Cc_pt < 25 GeV |Cal_tu - Cal_td| < 6ns only if (Cal_tu_E>4GeV AND Cal_td_E > 4GeV)
di-electron rejectrion	Reject if there are 2 or more EM candidates which satisfy EmProb > 0.0001& Ee > 5GeV & EmENin < 5GeV (no EM track requirements)
NC diffractive rejection	If there is EM candidate which satisfies EmProb > 0.0001 & Ee > 5GeV & EmENin < 5GeV and if there is jet which satisfy dR(jet and EM) < 1 neglect the jet and use another jet to reconstruct mass
Beam gas rejection	Ntrkvtx > 0.25*(Trk_ntracks - 20)

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 $\sigma_{obs} = a\sigma_{SM}$

Used data period and luminosity

- Data collected between 1996 and 2007
- Total integrated lumi.: **496pb^{-1}**

	proton beam energy [GeV]	lumi. [pb^{-1}]	
06/07 e+	920	143.8	HERA-II total 375
06 e-		55.2	
04/05 e+		135.1	
03/04 e-		41.0	
99/00 e+		65.9	HERA-I total 121
98/99 e-		16.7	
96/97 e+	820	38.6	

Systematics estimation jet energy uncertainty

- Assume ±3% jet energy shift with MC

	selection acceptance			systematic error for xsec	
	nominal	Ejet +3%	Ejet -3%		
(quasi-)elastic	0.224	0.228 (+1.7%)	0.219 (-2.0%)	+2.1% -1.7%	+2.1% -1.7%
inelastic (DIS+resolved)	0.00353	0.00360 (+2.0%)	0.00351 (-1.6%)	+1.6% -1.9%	

Systematic estimation Background 'shape' uncertainty

- Tried to use partial slices of η_{max} as a background template
- $3<\eta_{max}<4$: Background shape in this region is significantly affected by part of signal
  => This slice is not used.
- Systematic=±1.5%

	Signal(MC)/Data in 80-100GeV
nominal($\eta_{max}>3$)	0.37%
$3<\eta_{max}<4$	2.6%
$4<\eta_{max}<4.2$	0.40%
$\eta_{max}>4.2$	0.19%
$\eta_{max}>4$	0.27%