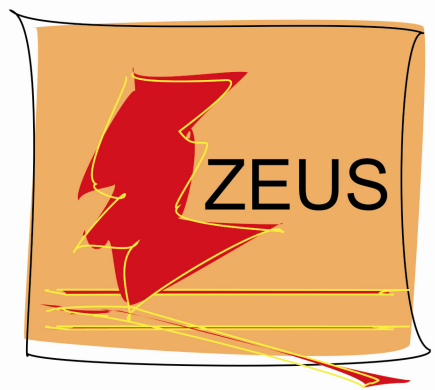
Search for New Physics at HERA

Yongdok Ri (KEK) on behalf of the H1 and ZEUS collaborations



- Introduction of HERA
- Model dependent search
- Model independent search
- Summary

LES RENCONTRES DE PHYSIQUE DE LA VALLEE D'AOSTE

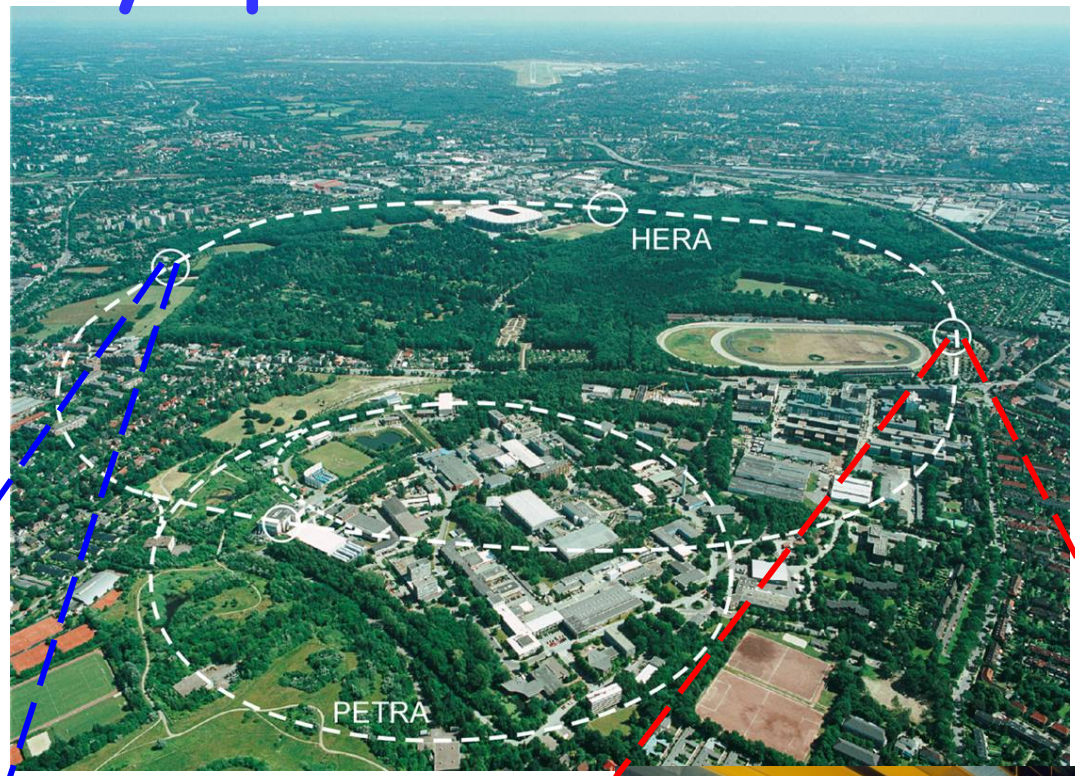
March 1 – 7, 2009, La Thuile, Aosta Valley, Italy

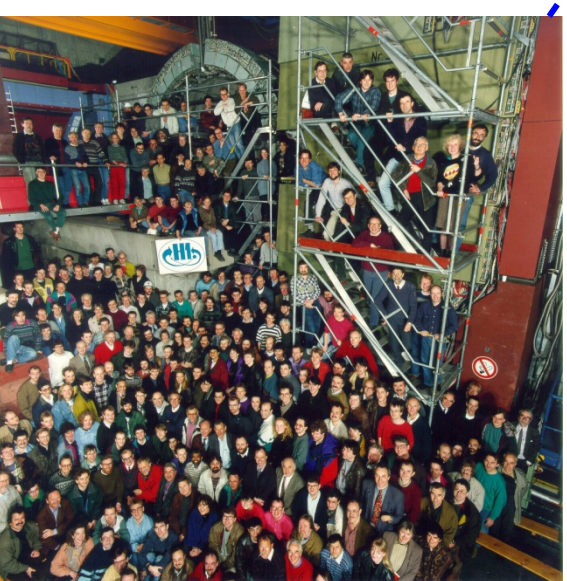
The world only ep collider HERA

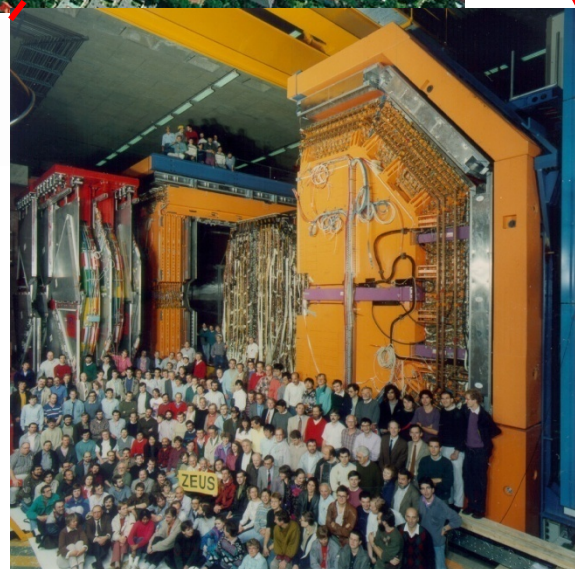
DESY, Hamburg

~6.3km circumference

$e^{\pm}$	27.5GeV
p (up to)	920GeV
$\sqrt{s}$	318GeV

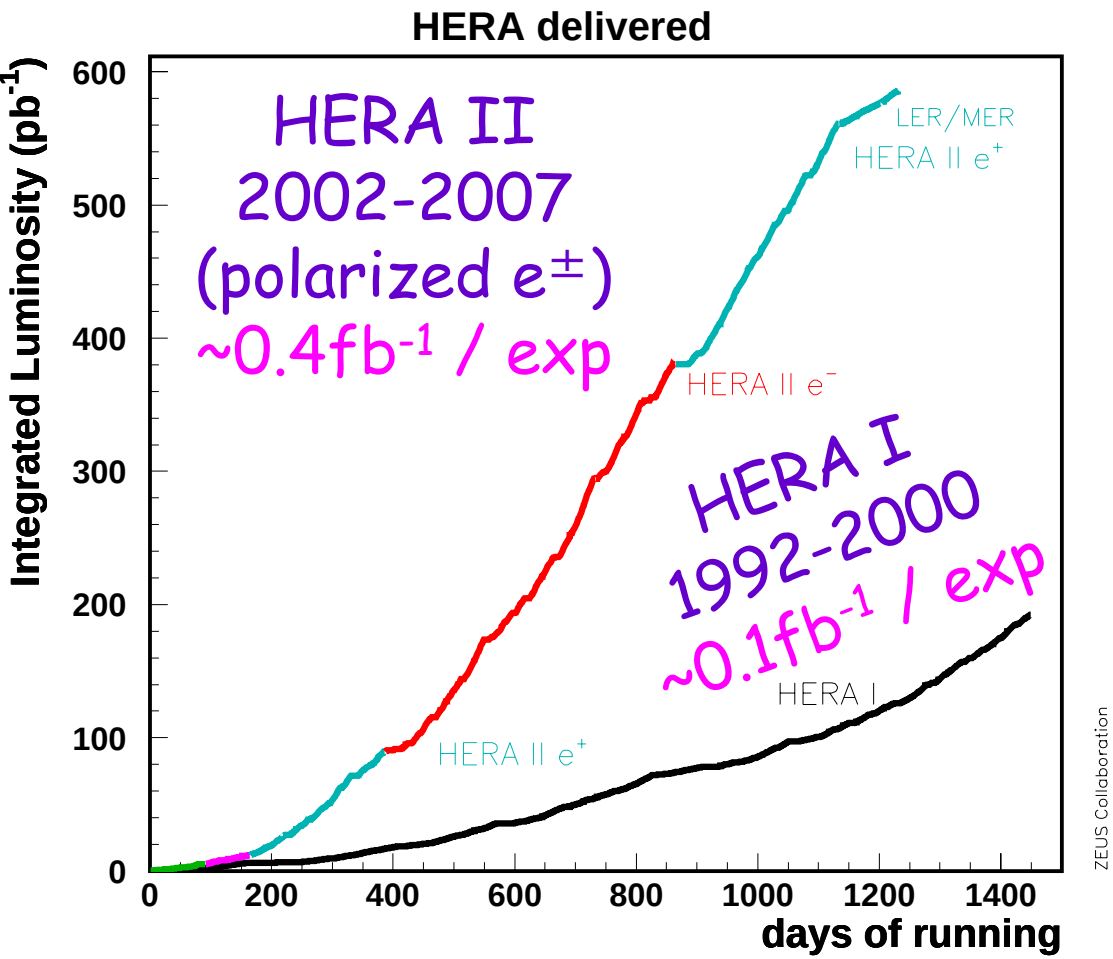






Two collider experiments : **H1 and ZEUS**

HERA operation



Started on summer 1992

and ceased in June 2007

Successful 16 years

Upgrade in 2000/2001

HERA I + HERA II

~0.5 fb^{-1} / experiment

H1 + ZEUS ~1fb^{-1}

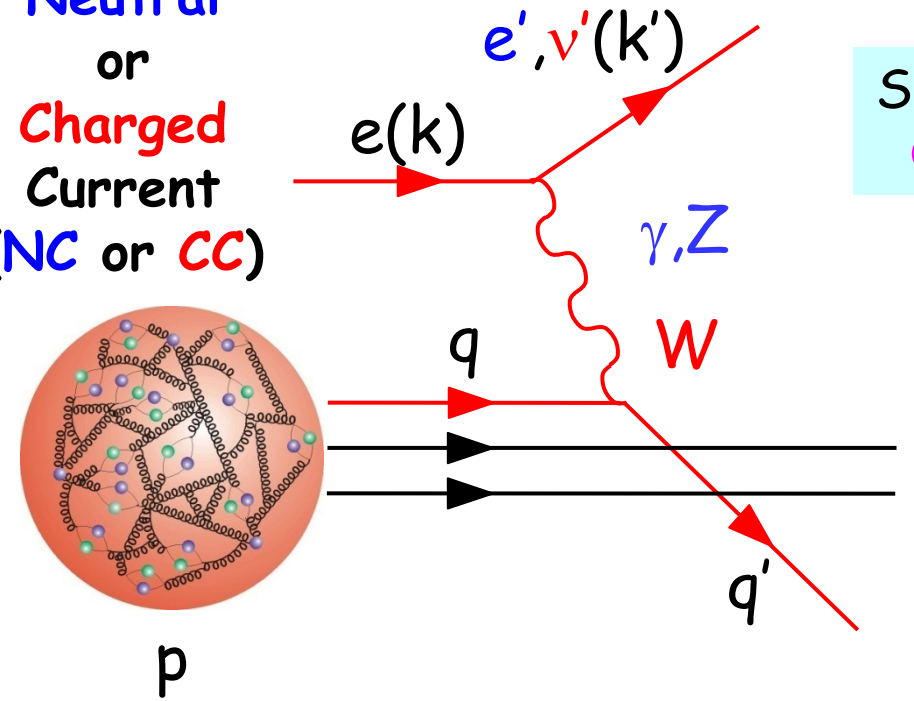
Deep Inelastic Scattering at HERA

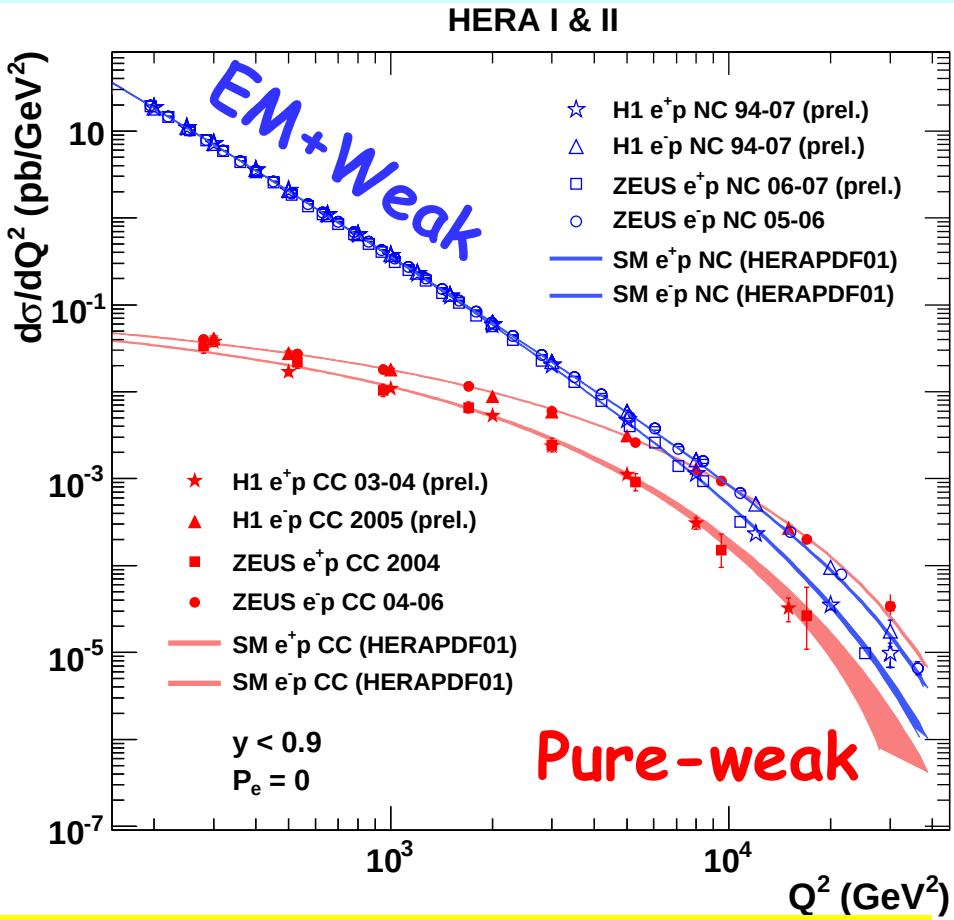
HERA = e-q collider

4-mom transfer squared, $Q^2=(k-k')^2$,
= spatial resolving power

Simultaneous NC/CC investigation up to
Q^2~40,000GeV^2 ⇔ 0.001 proton size

Neutral
or
Charged
Current
(NC or CC)





Low-Q^2 : measure PDFs

↓ QCD evolution

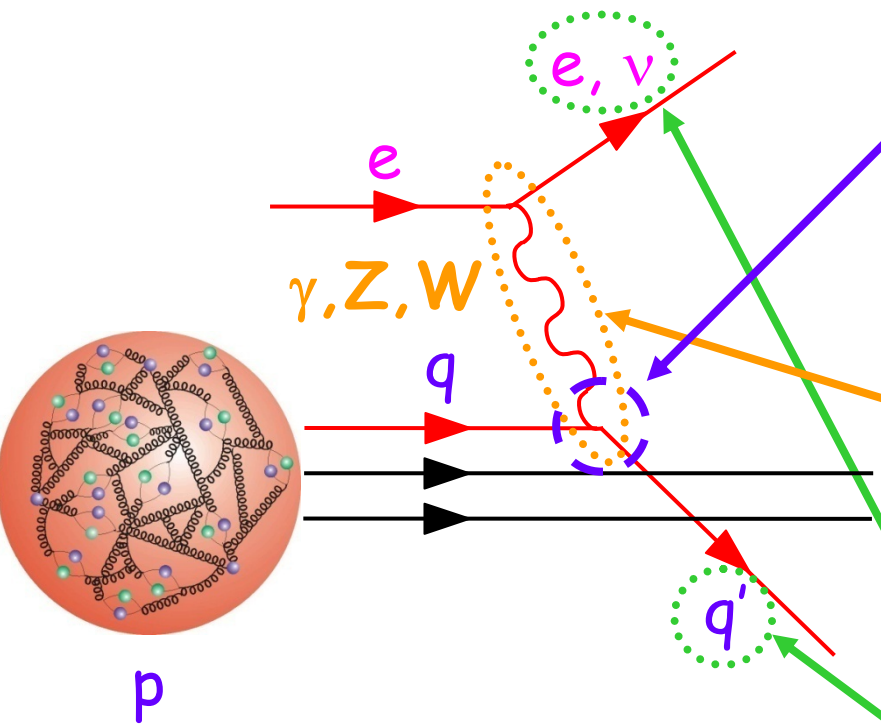
High-Q^2 : Investigate fundamental e-q scattering

New physics would appear at short distance. Let's search!

Model dependent search

1. HERA is a giant electron-microscope

Quark structure



2. If new interaction between e-q scattering

Contact Interaction

3. If fermion is composite

Excited fermion (e,ν,q)

Are quarks really point-like?

- Remember Hofstadter's form-factor measurement

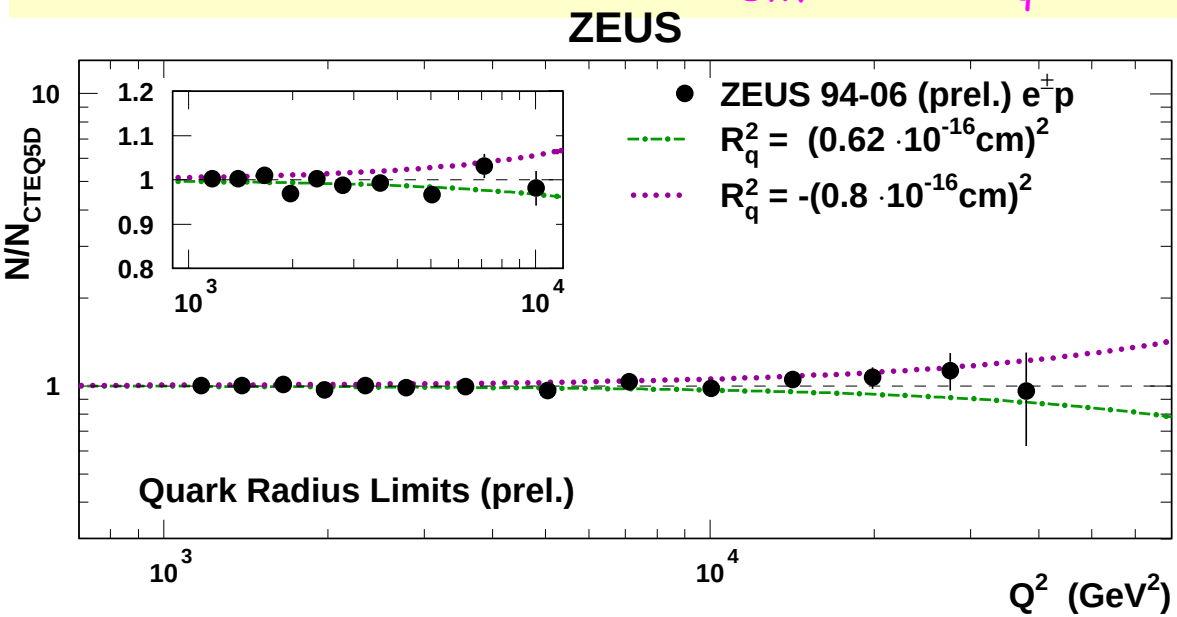
Decrease from $\sigma_{ep}^{elastic}$ at large scattering angle (high Q^2)
→ Discovery of Proton substructure = not point-like

- At HERA, analogous search for quark down to ~10^{-3}fm

If charge distribution of quark (R_q) is finite, cross section deviates from SM (sees small coupling)

$$\sigma=\sigma_{SM}\times(1-\langle R_q\rangle^2 Q^2/6)^2$$

assuming electron is point-like



No deviation → set limit on R_q (95% CL)

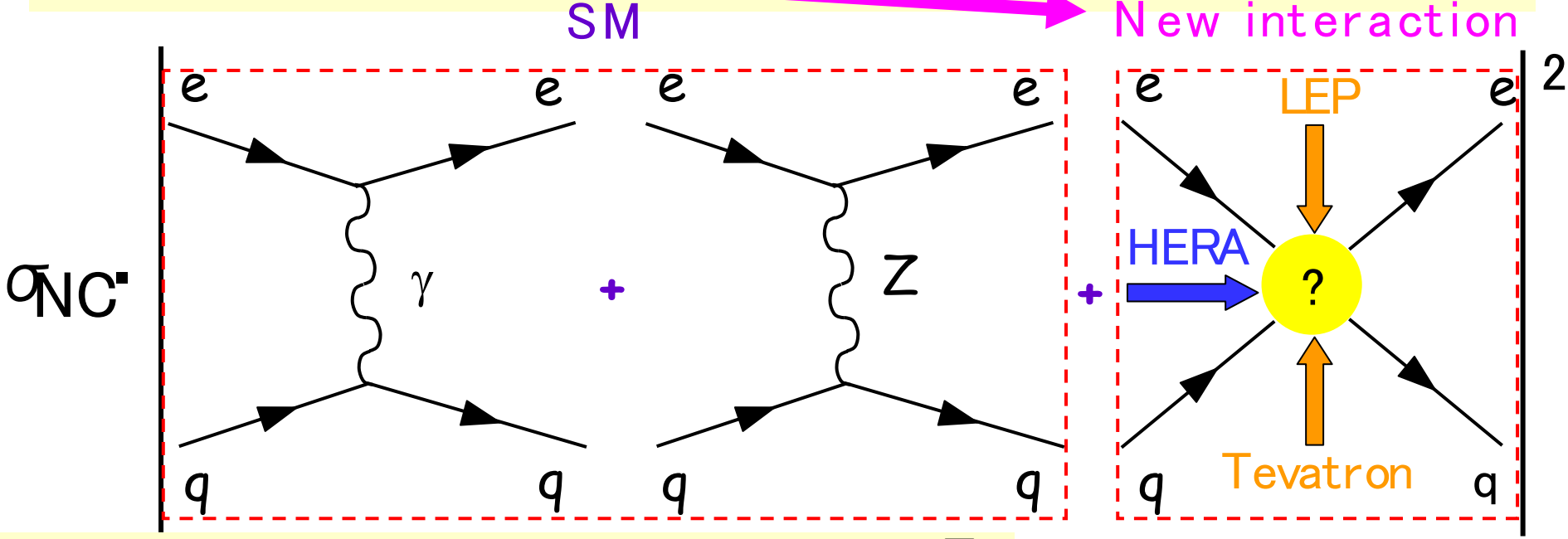
ZEUS : R_q<0.62*10^{-3}fm

H1 : R_q<0.74*10^{-3}fm

Contact Interactions (CI)

•Physics at much higher energy scale is described by four-fermion CI at low energy limit, remember early days of weak int., i.e. $G_F \sim e^2/\sin^2\theta_W M_W^2$.

•Various new physics, e.g. new gauge bosons, large extra dimensions, composite fermions, heavy leptoquarks, … would add new term



•Physics at energy scale larger than $\sqrt{s}$ modifies σ via virtual effects

Search at HERA is complementary

Considered CI models

•Effective Laglangian for vector eeqq CIs :

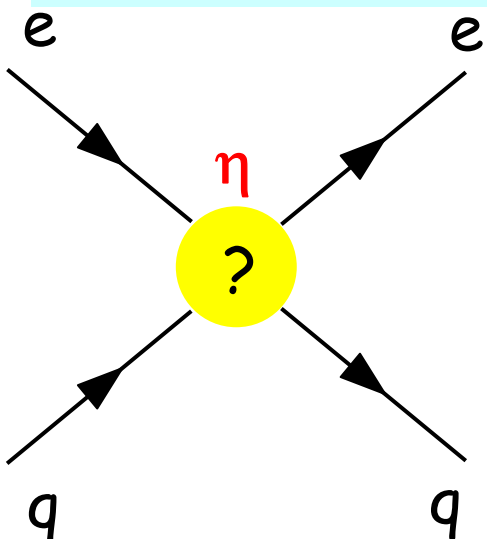
$$L_{CI} = \sum_{i,j=L,R}^{q=u,d} \eta_{ij}^{q} (\bar{e}_i \gamma^{\mu} e_i)(\bar{q}_j \gamma_{\mu} q_j)$$

Coupling : $\eta = \pm 4\pi / \Lambda^2$

Λ : **new physics scale**

Different η sign makes different SM-CI interference

Each model assumes different chiral structure,



given by a set of 8 coefficients

e:L or R
q:L or R
q:up or down

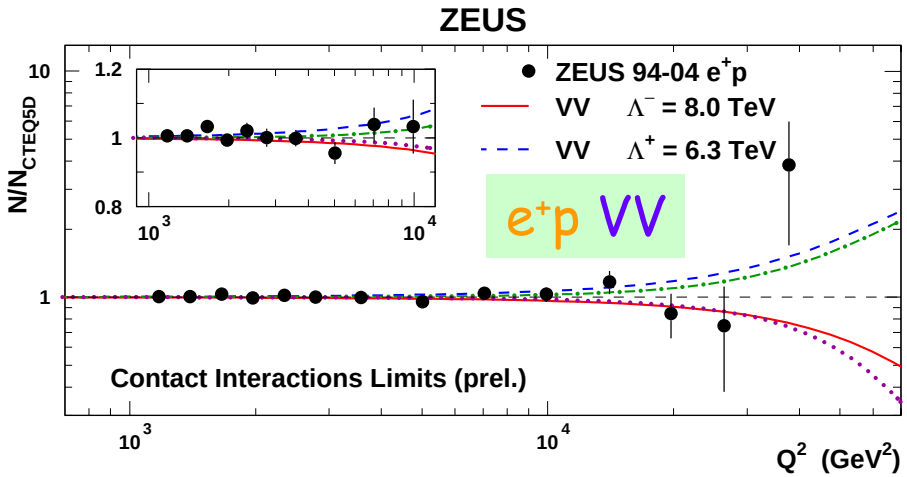
Models conserving parity:

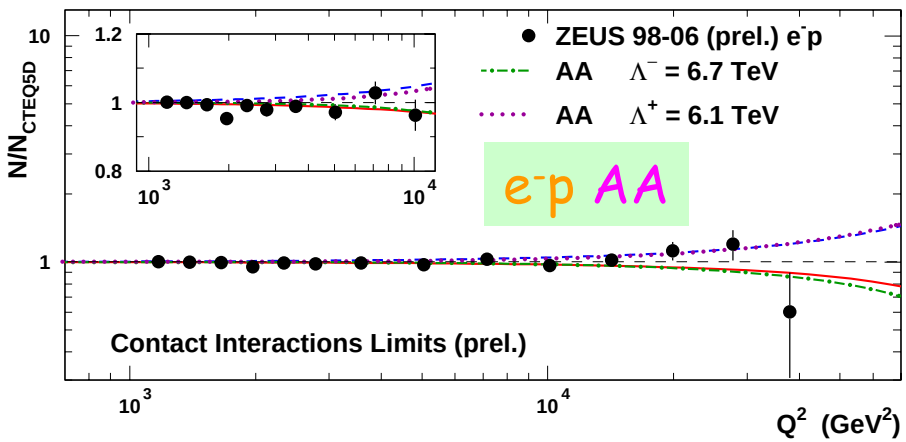
Model	η_{LL}^{ed}	η_{LR}^{ed}	η_{RL}^{ed}	η_{RR}^{ed}	η_{LL}^{eu}	η_{LR}^{eu}	η_{RL}^{eu}	η_{RR}^{eu}
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1					$+\eta$	$-\eta$		
U2					$+\eta$		$+\eta$	
U3					$+\eta$			$+\eta$
U4						$+\eta$	$+\eta$	
U5						$+\eta$		$+\eta$
U6							$+\eta$	$-\eta$

Models violating parity:

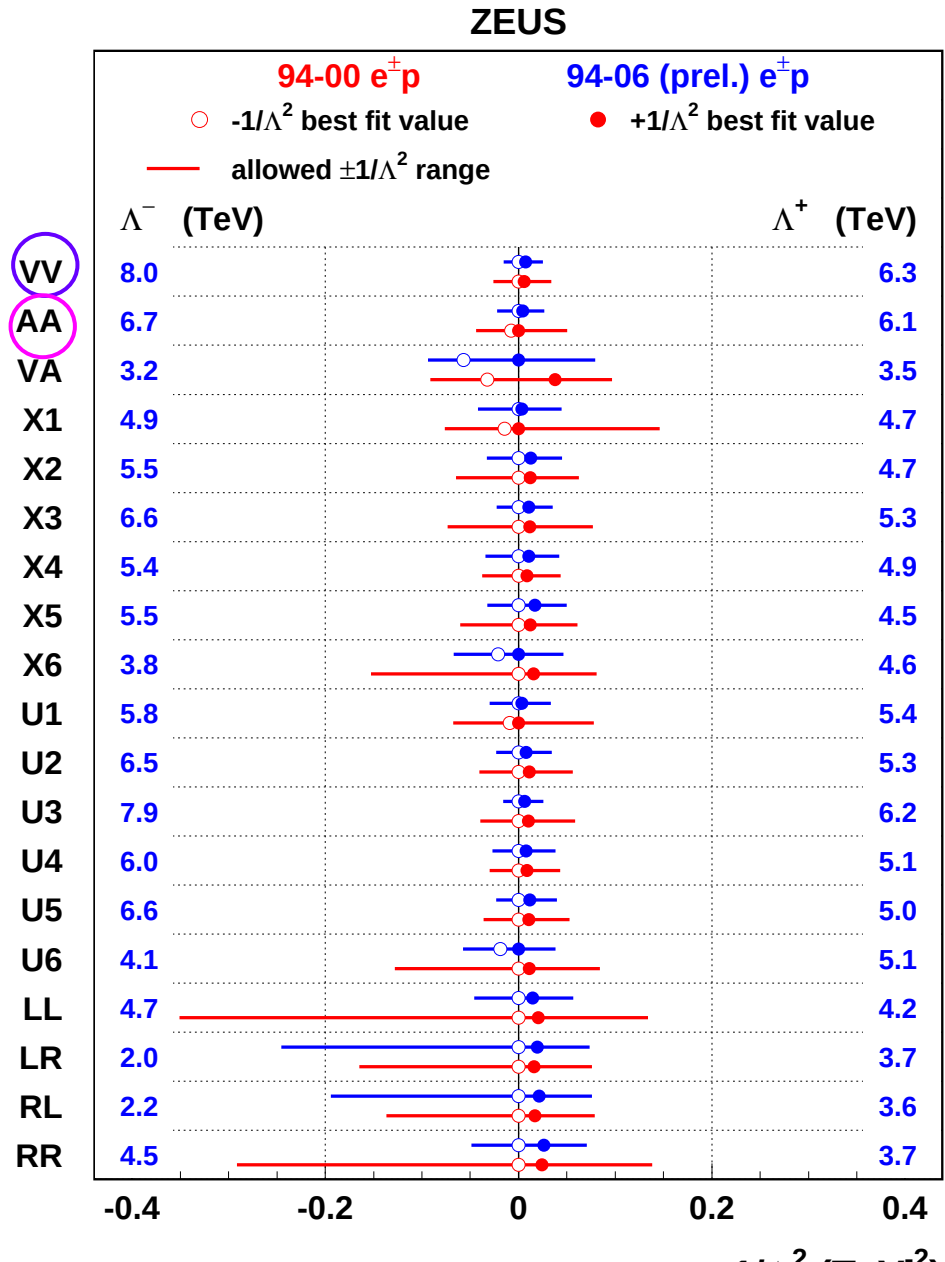
LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$

CI search results





ZEUS (94-06) : Λ>2.0-8.0TeV
H1 (HERA I): Λ>1.6-5.5TeV
at 95% CL

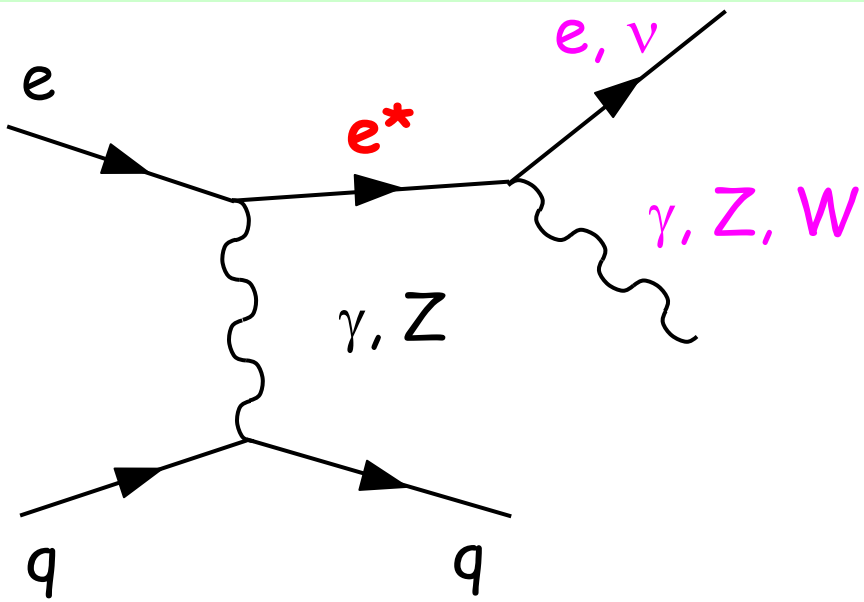


Excited fermion

•Possible origin of three-family structure and mass hierarchy of fermions → Compositeness model of fermions

•Excited leptons and quarks could radiate gauge bosons (Analogy : Composite matter has excited states which become stable with emission, e.g. excited atom emits X-ray)
→ Search mass resonance in fermion+boson pair

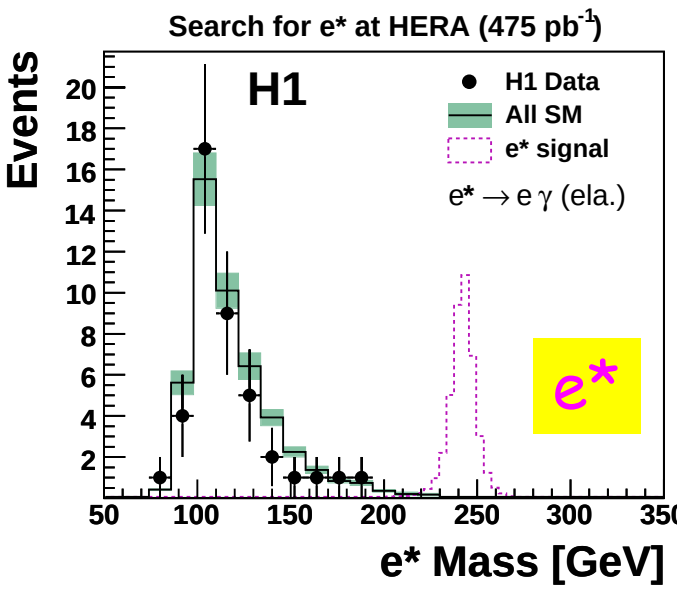
Example diagram of e* production

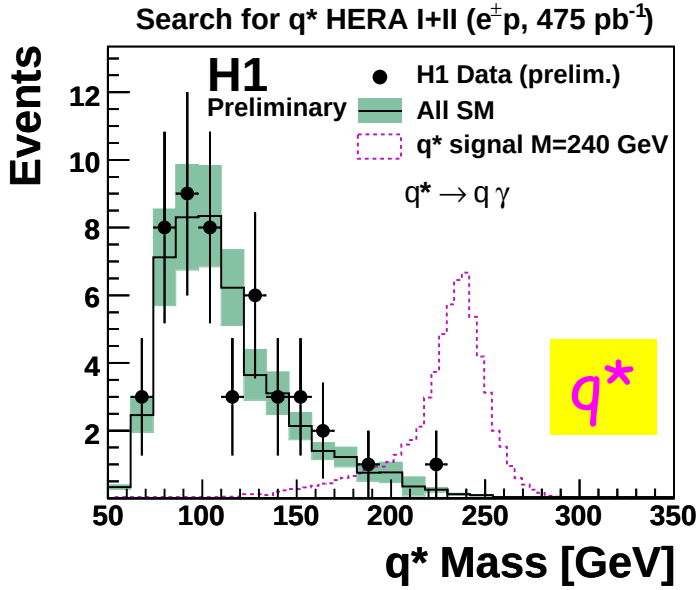


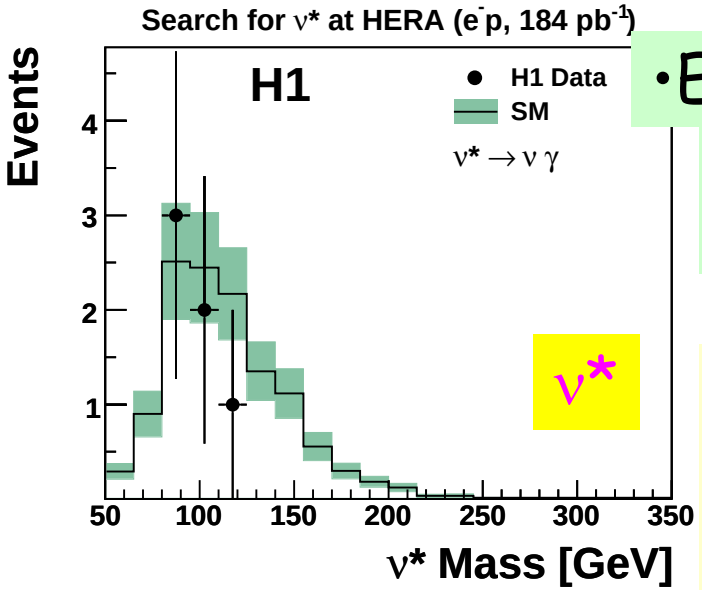
- $e^* \rightarrow e\gamma, eZ, \nu W$
- $\nu^* \rightarrow \nu\gamma, \nu Z, eW$
- $q^* \rightarrow q\gamma, qZ, qW$

with subsequent hadronic or leptonic decays of W and Z are considered.

Mass distribution of fermion+boson pair







- Only fγ decay mode is shown
- M_{f^*}=240GeV (arbitrary norm.)
- No excess → set limits

- Effective Laglangian for f-f* interaction

$$L_{int.} = \frac{1}{2\Lambda}\overline{F_R^*}\sigma^{\mu\nu}\left[gf\frac{\tau^a}{2}W^a_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu} + g_s f_s\frac{\lambda^a}{2}G^a_{\mu\nu}\right]F_L + h.c.$$

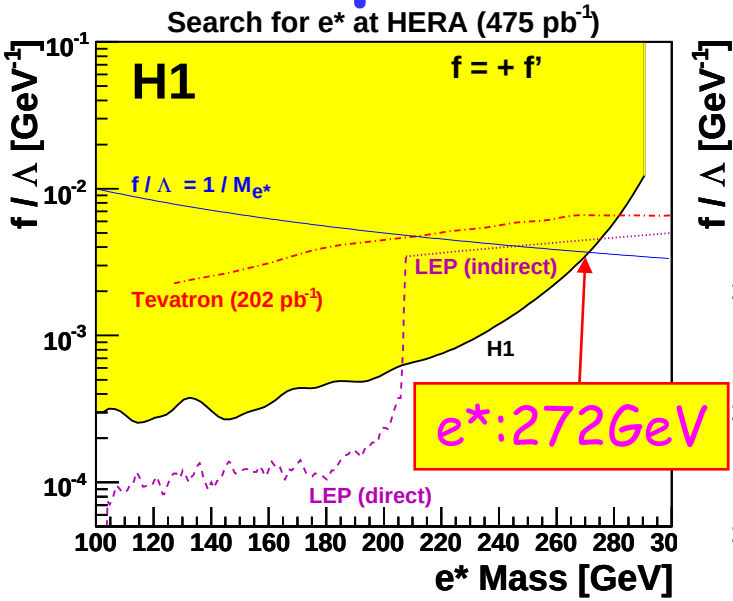
SU(2) U(1) SU(3)

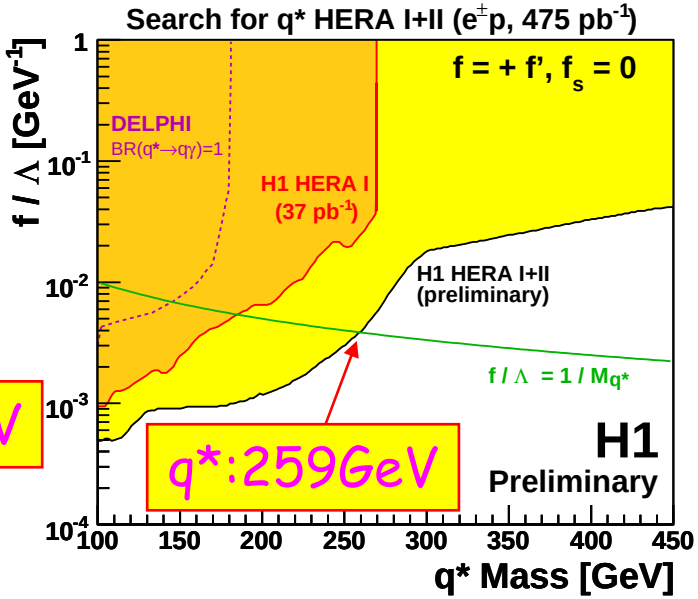
Unknown parameters for Excited fermion

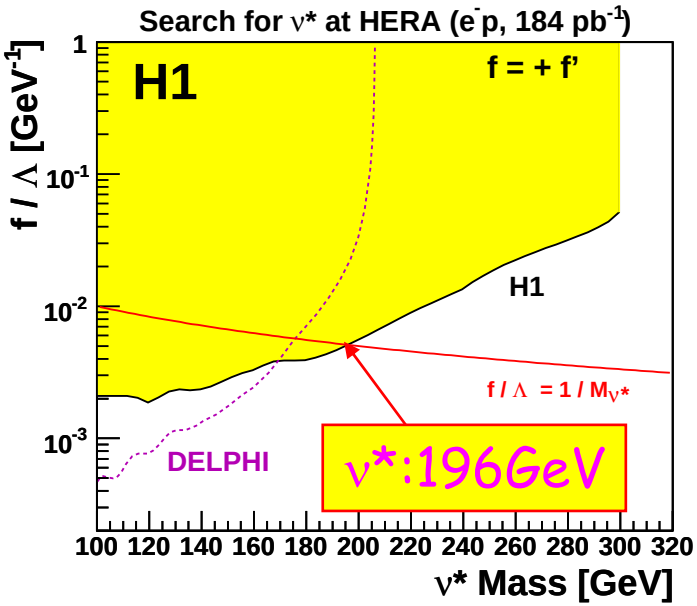
- f, f', f_s : coupling associated to 3 gauge bosons
- Λ : Energy scale of compositeness

For given M_{f^*} and relation f, f' and f_s, σ only depends on f/Λ

Mass dependent exclusion limits on f/Λ at 95% CL







- Assumption f=+f'
(f=-f' also derived for ν*, not shown)

HERA's unique sensitivity

e^* : $M_{e^*} > \sim 200$GeV & $f/\Lambda < \sim 3*10^{-3}$

ν^* : $M_{\nu^*} > \sim 200$GeV

q^* : $M_{q^*} > \sim 180$GeV,

and $f_s=0$ only tested at HERA

Complementary to LEP and Tevatron

Model independent search

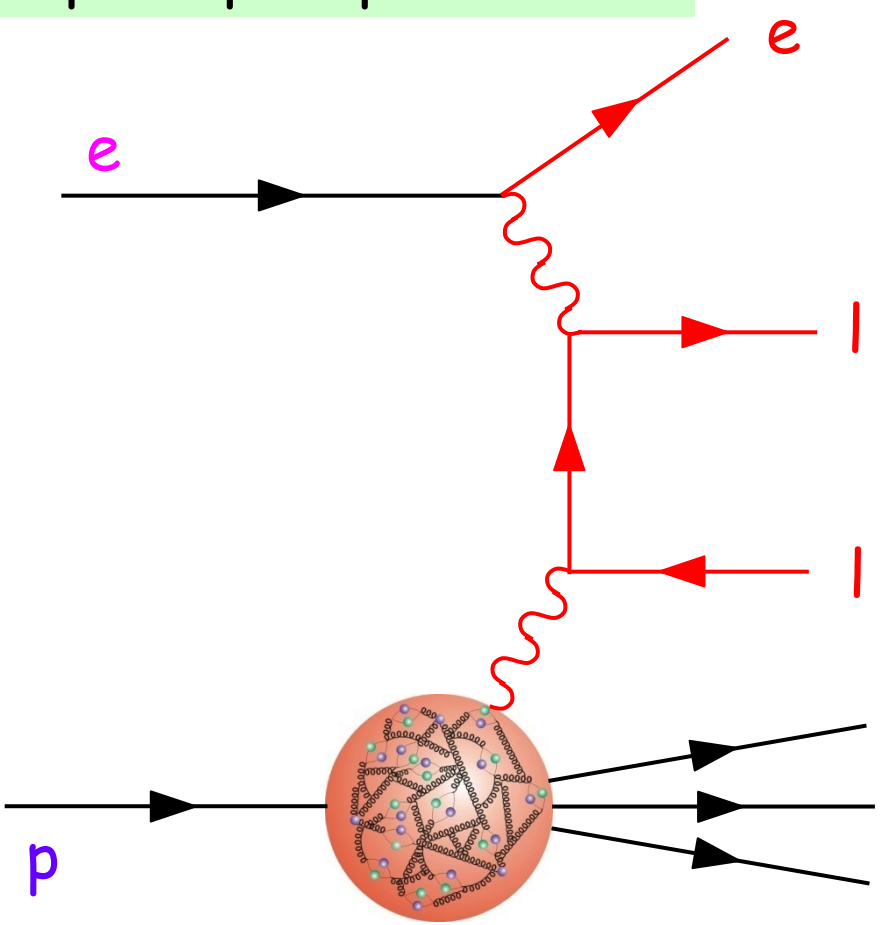
- Signature based search by looking for deviations from SM in various topologies.
- Don't rely on any a priori definition of new physics
- Following type of event is interesting :
  - Rare event
  - Accurately calculable process
  - Having experimentally clean signature

Presented are :

1. Multi-lepton events
2. Isolated lepton + missing p_T event
3. General search

Multi-lepton events

Example diagram of lepton-pair production



- Dominant process is γ-γ, i.e. QED process → accurately calculable

- Production of high p_T lepton is rare and clean signature

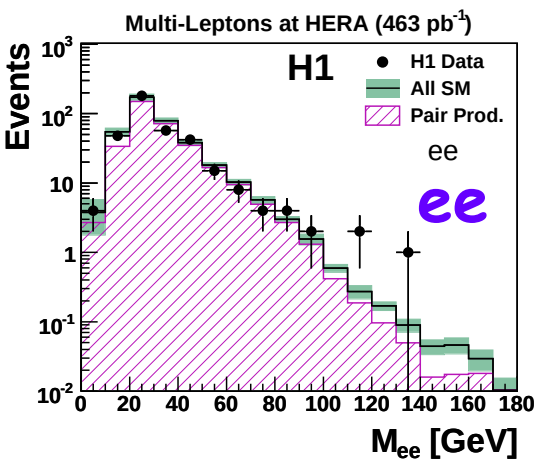
←New particle could be produced

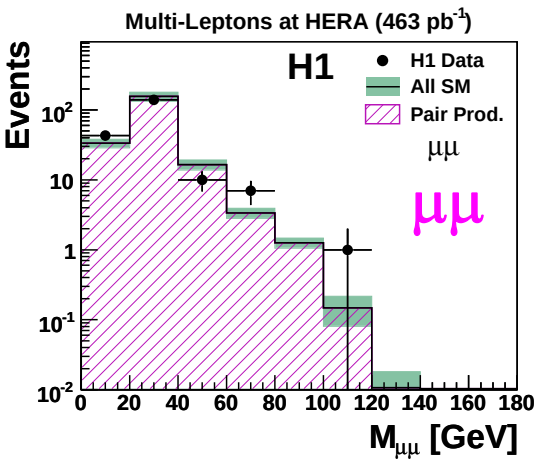
Search for multi-lepton events at high invariant mass

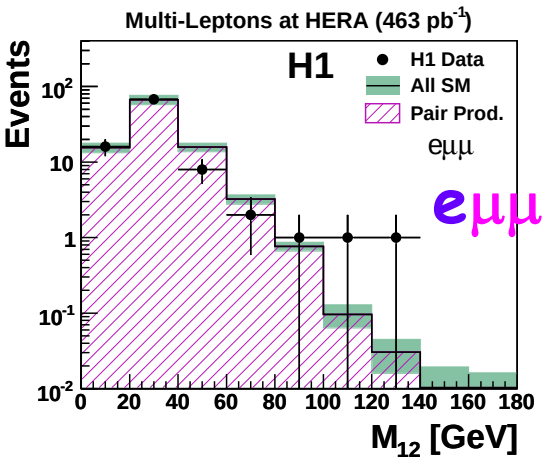
Scattered electron escapes the detector for almost all cases, thus :
two leptons (+ 1e)

Various e and μ channels

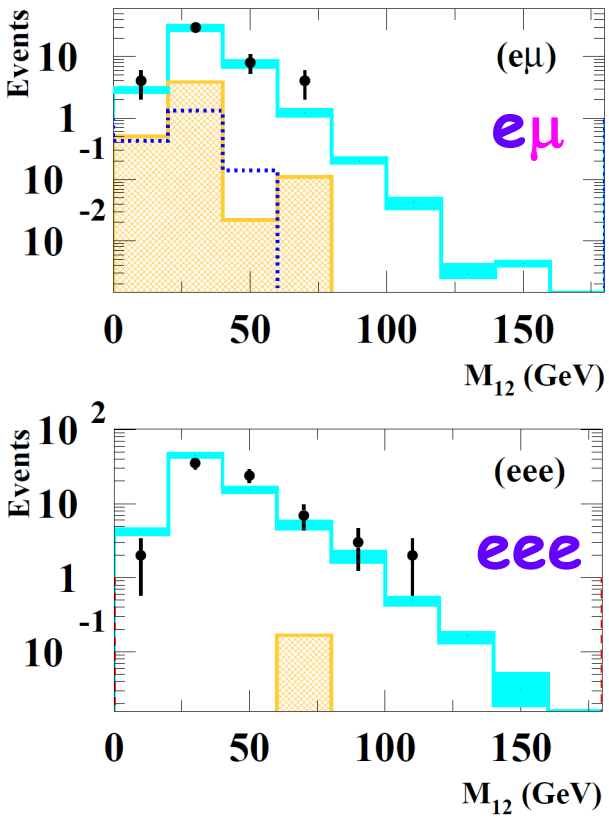
0.46fb^{-1}







0.48fb^{-1}

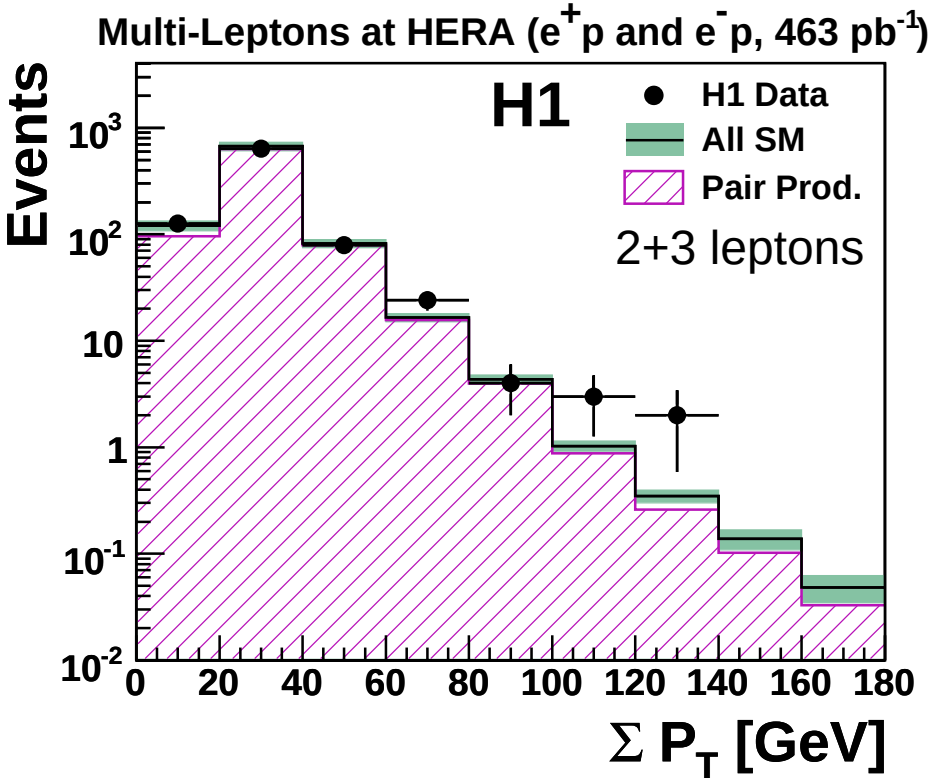


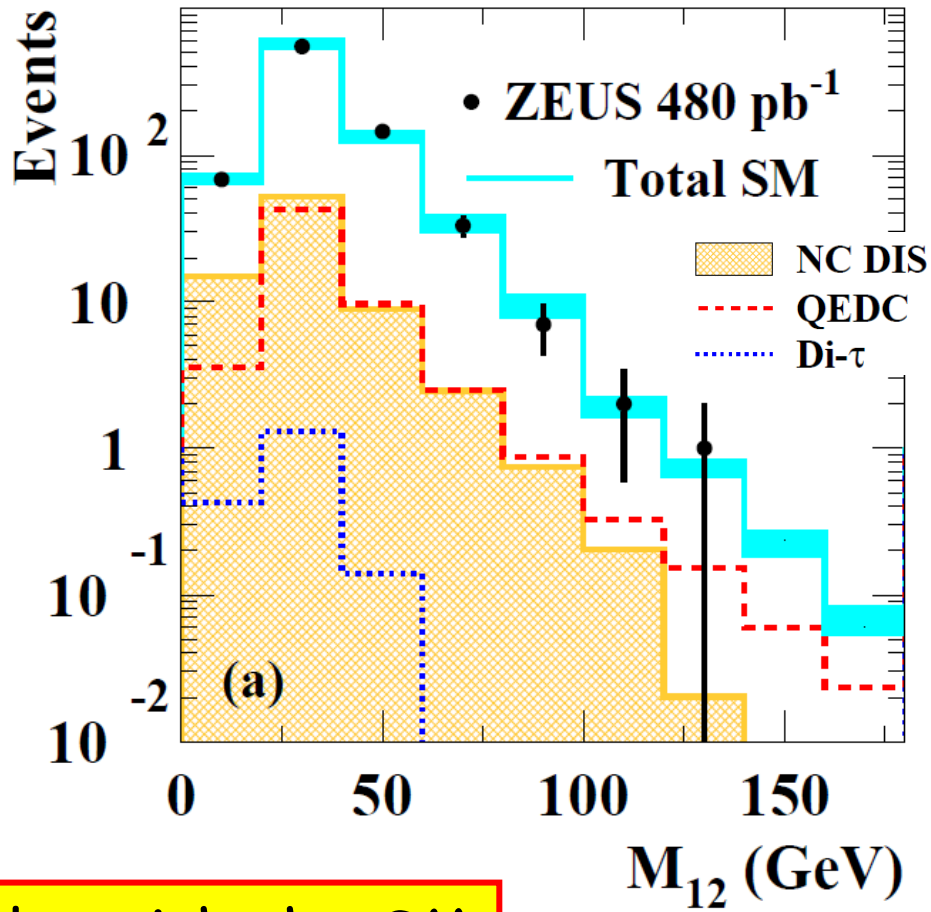
Topologies with e or μ :
ee, eμ, μμ, eee, eμμ

Both experiments finished their analysis using full data

Hottest ZEUS results!
Released very recently.

Combined results for e and μ channels





Consistent results with the SM

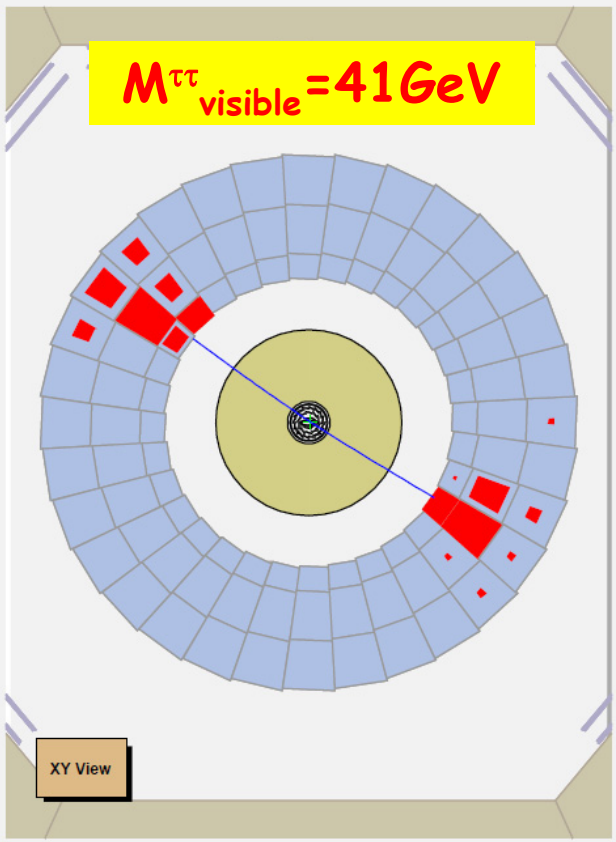
Combination of H1 and ZEUS results is ongoing

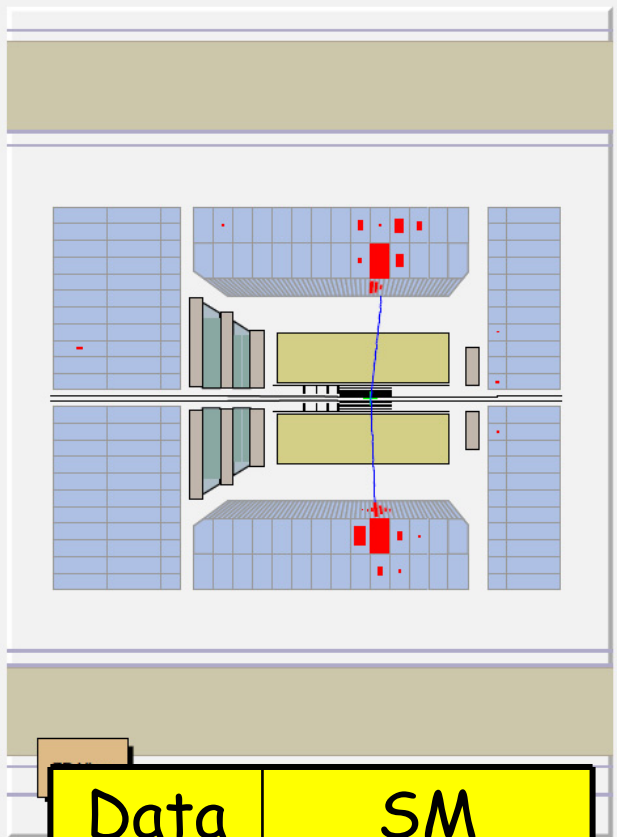
τ-pair production

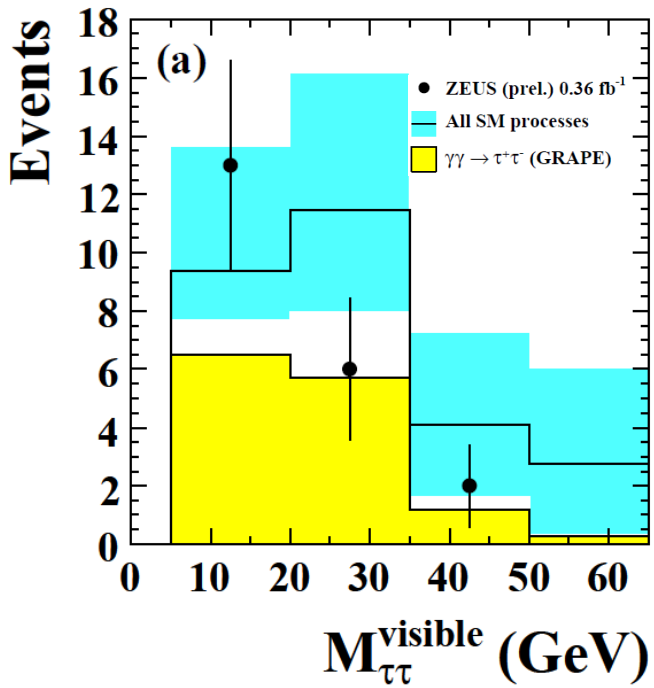
Hadronic channel is important, i.e. BR($\tau \to \nu_\tau$+hadrons)>60%, but challenging

Discriminate from QCD-induced jets

- low mass
- low multiplicity
- pencil-like







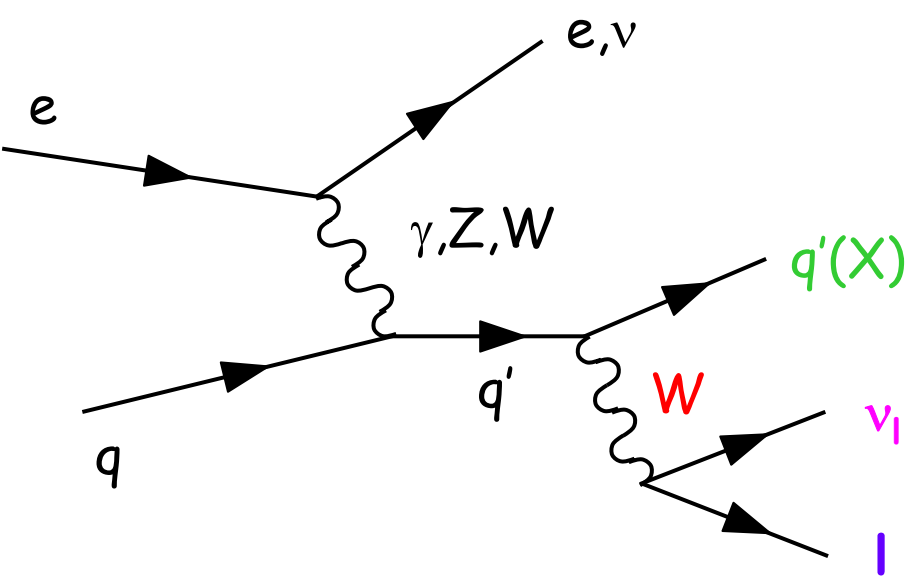
Data	SM
21	$27.2^{+7.1}_{-6.3}$

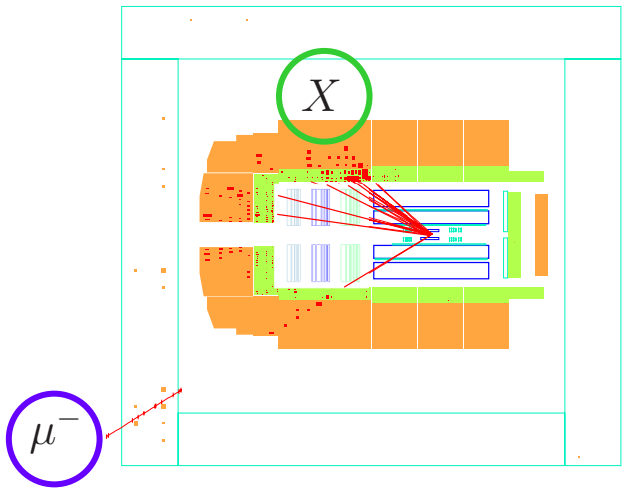
Good agreement with SM

Isolated lepton + missing p_T event

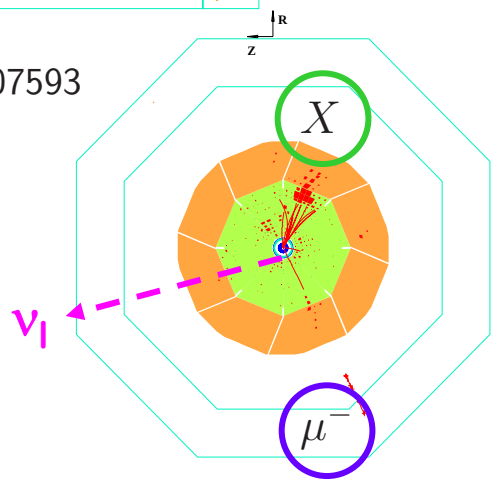
- For NC or CC DIS, either isolated lepton or missing p_T
- Events having both topologies are very rare
- In the SM, main source is **W production**

Example diagram of W production





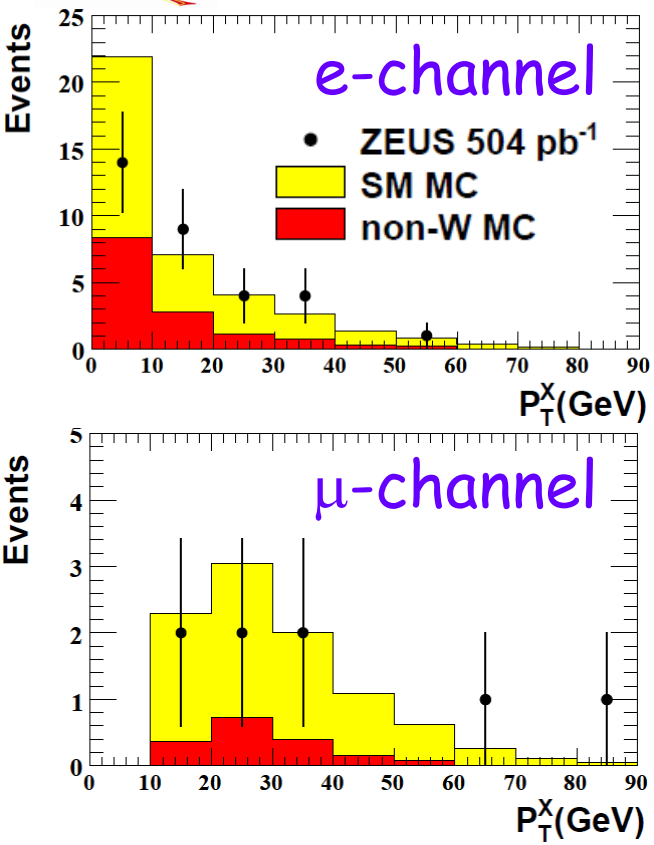
Run 473929 Event 107593



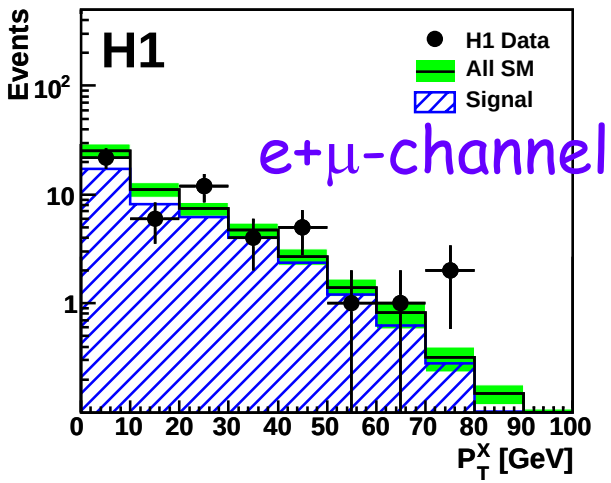
High hadronic $p_T^X > 25$GeV

H1 and ZEUS results using full data

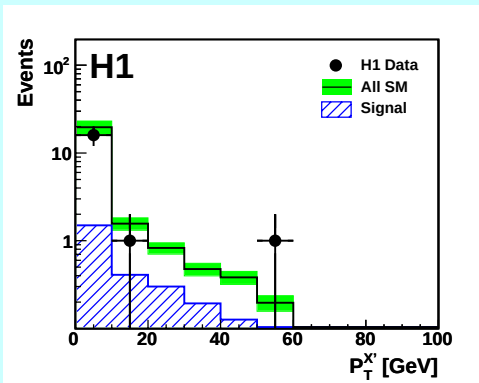
ZEUS 0.50fb^{-1}



H1 0.47fb^{-1}



H1 also performed τ-channel and agreement with SM is confirmed :



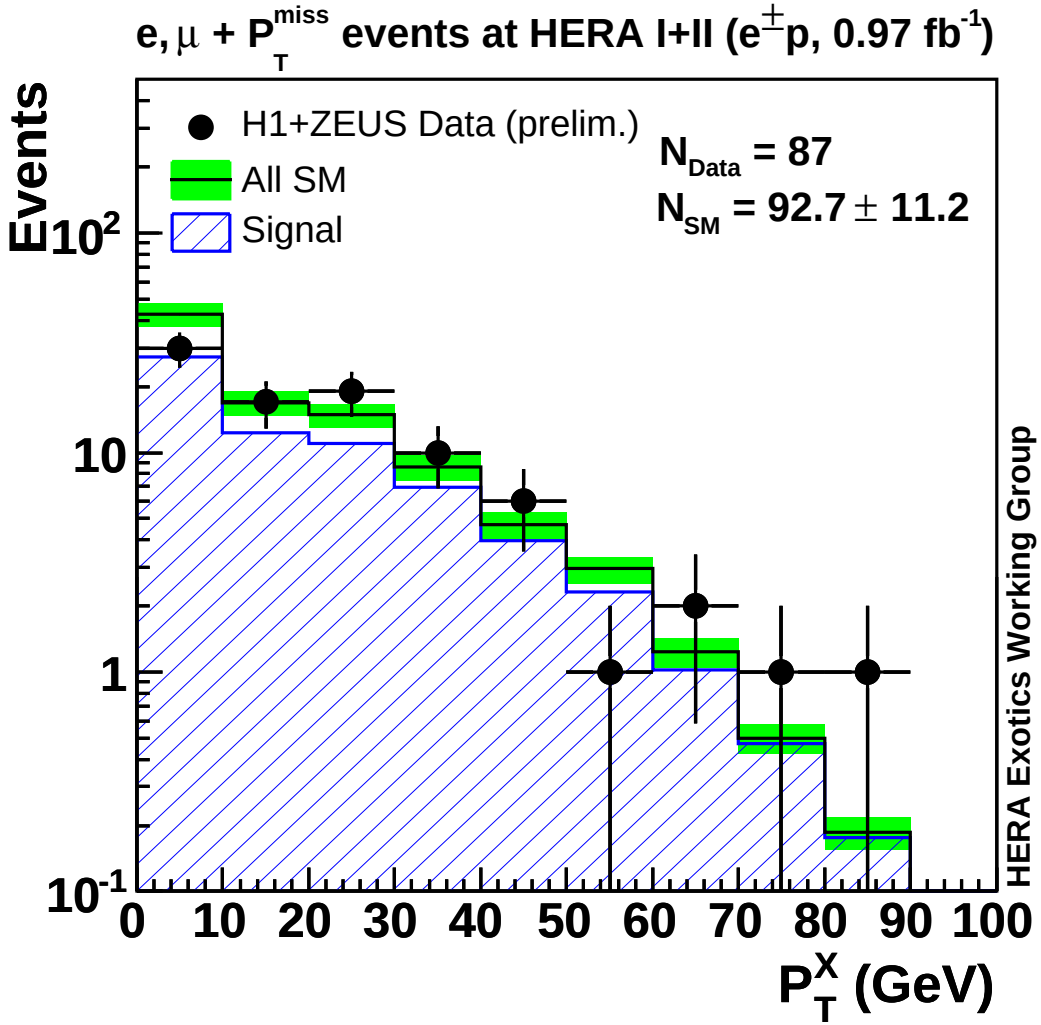
- No significant deviation from SM
- Measure W production cross section

H1	$1.14 \pm 0.25(\text{stat.}) \pm 0.14(\text{syst.})\text{pb}$
ZEUS	$0.89^{+0.25}_{-0.22}(\text{stat.}) \pm 0.10(\text{syst.})\text{pb}$
SM	$1.3 \pm 0.2\text{pb}$

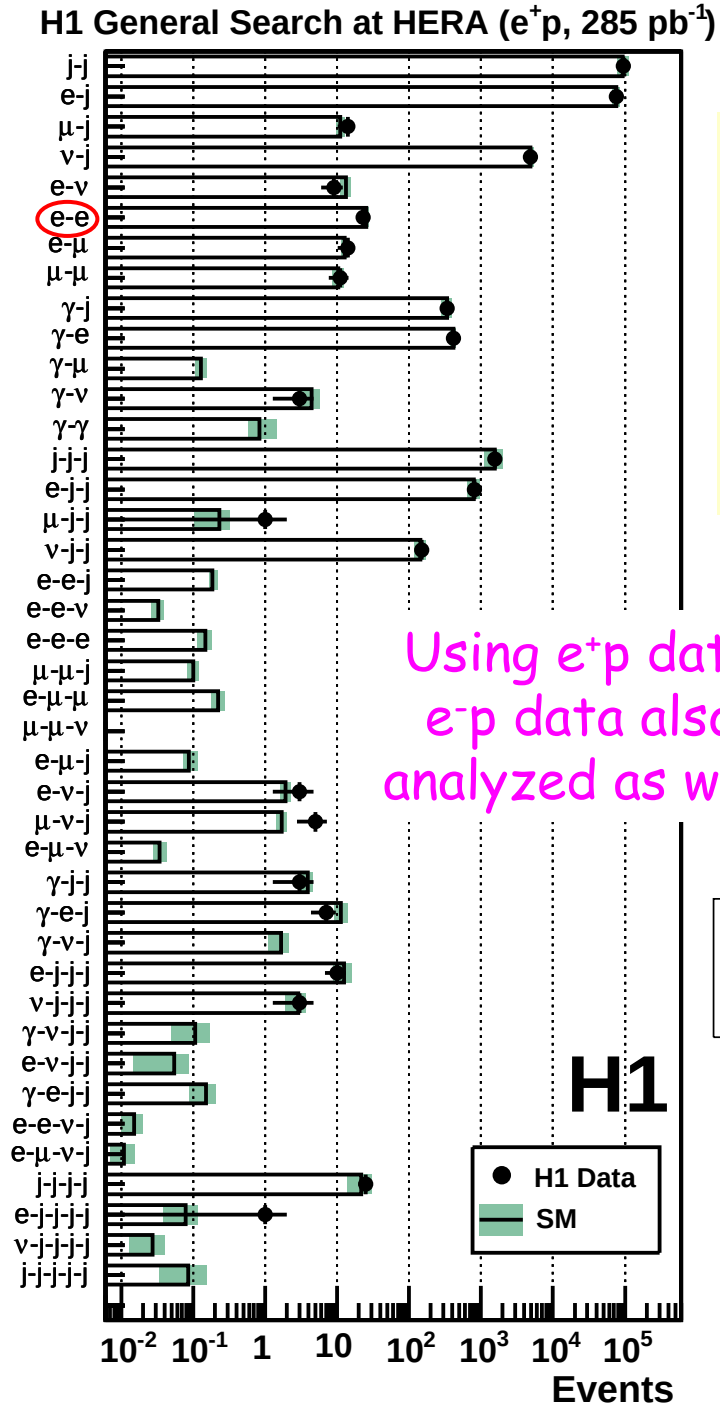
H1+ZEUS combined result

H1 and ZEUS combined in common phase space

(note: Shown is based on preliminary results.)



Combination using final results is ongoing



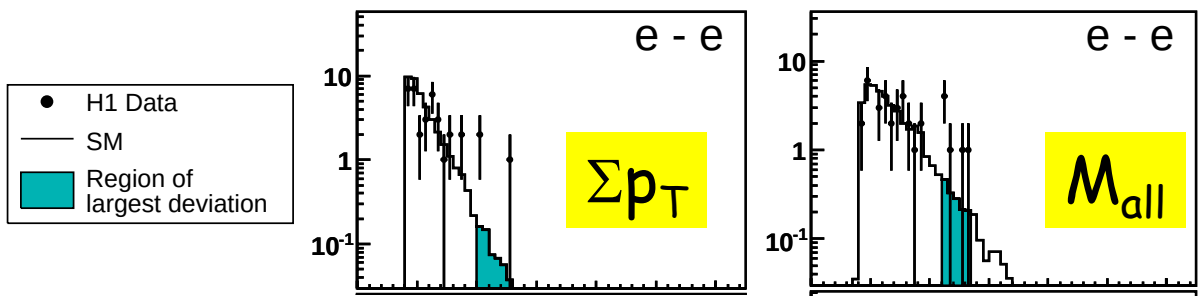
General search

- Investigate final states with high-p_T(>20GeV) objects : e, γ, μ, ν, jet

- At least one event is found in 27 topologies for $e^{\pm}p$ data

Using e^+p data e^-p data also analyzed as well

- Deviation from SM is searched for in distributions of scalar sum of p_T and invariant mass M_{all}



High-p_T SM phenomena at HERA are well understood

Summary

•The only ep collider, HERA, finished 16 years of successful data taking, and ~1fb^{-1} data were taken by H1+ZEUS.

•HERA provides the unique and complementary sensitivity to new physics. In this talk, recent results of :

quark form factor, contact interactions, excited fermions, multi-leptons, isolated lepton+p_T^{miss}, general search

were presented.

•Generally good agreement with the SM
even at new kinematic domain explored by HERA

•Searches at HERA are being finalized for each H1 and ZEUS, and to gain higher sensitivity,
combination of results by two experiments is ongoing.