Searches for New Physics at HERA

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- **The idea(s)**
- **Searches for events with leptons (l,nu)**
  - **and possible interpretations (top,H++)**
- **Searches for new physics signals within specific models**
  - **SUSY, f***
- **Searches for complex topologies**
- **Conclusions**

Many thanks to:
E.Perez, E.Sauvan,M.Klein, H1,HERA

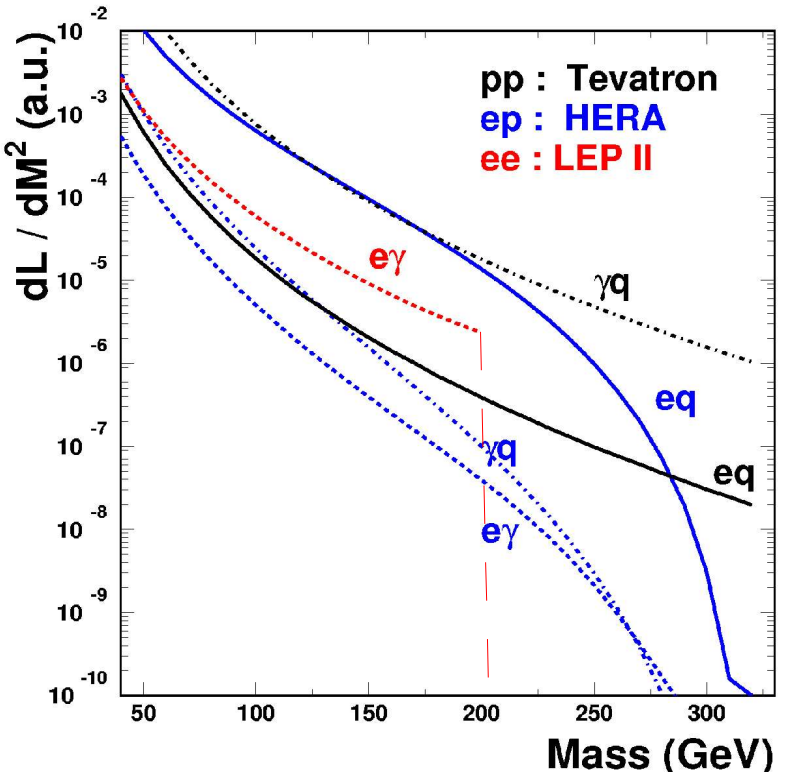
New physics at HERA

- Matter substructure -> revealed in DIS (another Q2 jump)
- New particles from partons fusion
  - SM boson are “t”-ed, cannot help with pair production
  - New bosons are needed/ particles produced singly
  - Most favourable coupling is eq

$$\sigma_c \sim \hat{\sigma}_{ab\to c}\frac{dL}{d\hat{s}}$$

$$\frac{dL}{ds} = \frac{1}{s}\int_{\frac{\hat{s}}{s}}^{1}\frac{dx_a}{x_a}f_A(x_A,\hat{s})f_B\left(\frac{\hat{s}}{sx_A},\hat{s}\right)$$

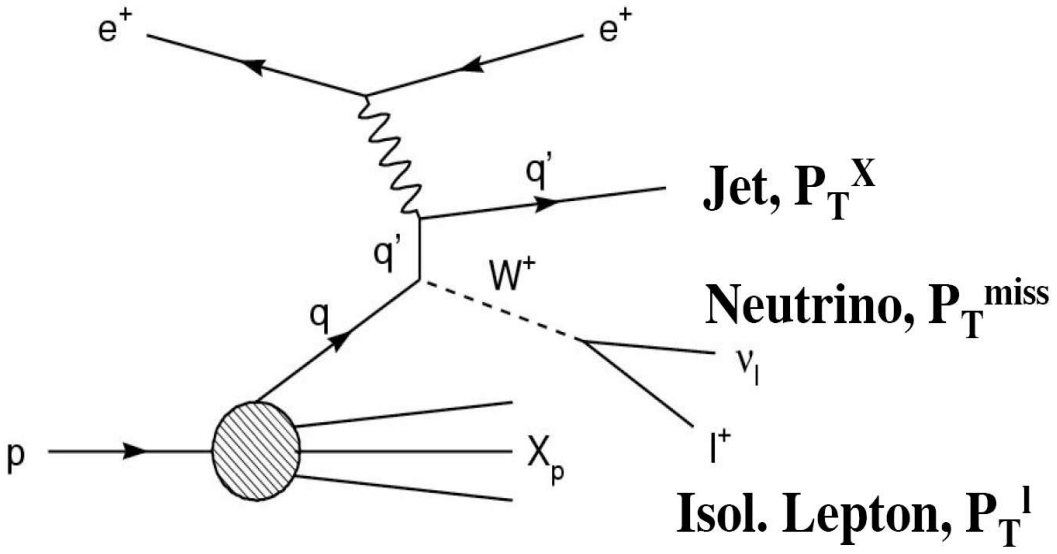
- The ingredients:
  - parton luminosity
    - HERA collides beyond LEP
  - cross-section
    - depend on the underlying physics
  - backgrounds
    - HERA has less than Tevatron

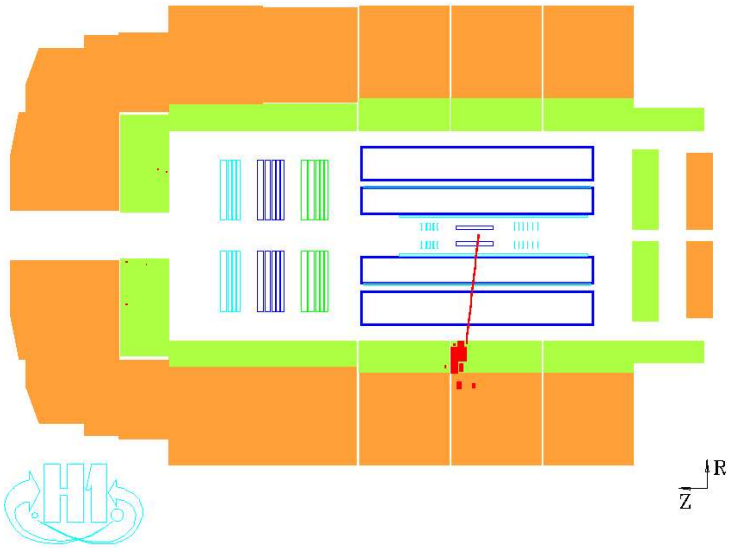


Explore new territory, one goal, two ways

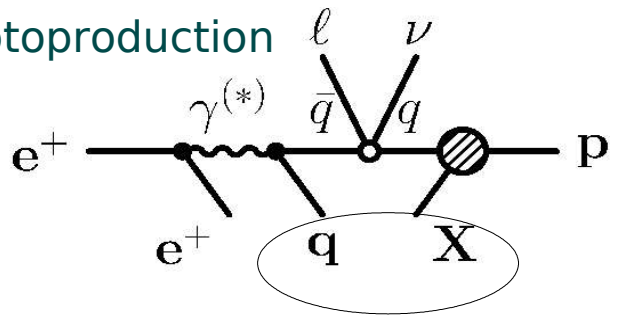
- 1) Check models, verify predicted signatures and phase space
  - extensive cross checks should be available
  - if no signal: quantify the non-observation in a concrete way (limits)
  - comparison to other experiments/colliders
- 2) Look into data vs. SM
  - play with topology to reduce the SM background
  - reveal the anomalies above a small SM contribution
- All should come around together though
  - I'll start with 2) “rare topologies”

Isolated electrons or muons and P_T^{miss} in H1





W photoproduction



hadronic system typically "quiet"

Backgrounds: CC+fake lepton
NC,pairproduction+fake Ptmiss
jets

Total Cross Section ~1.2 pb
=> ~5 events/100pb^{-1}with e or μ

[Hadronic channel is difficult due to QCD background.]

Measured at HERA by H1:

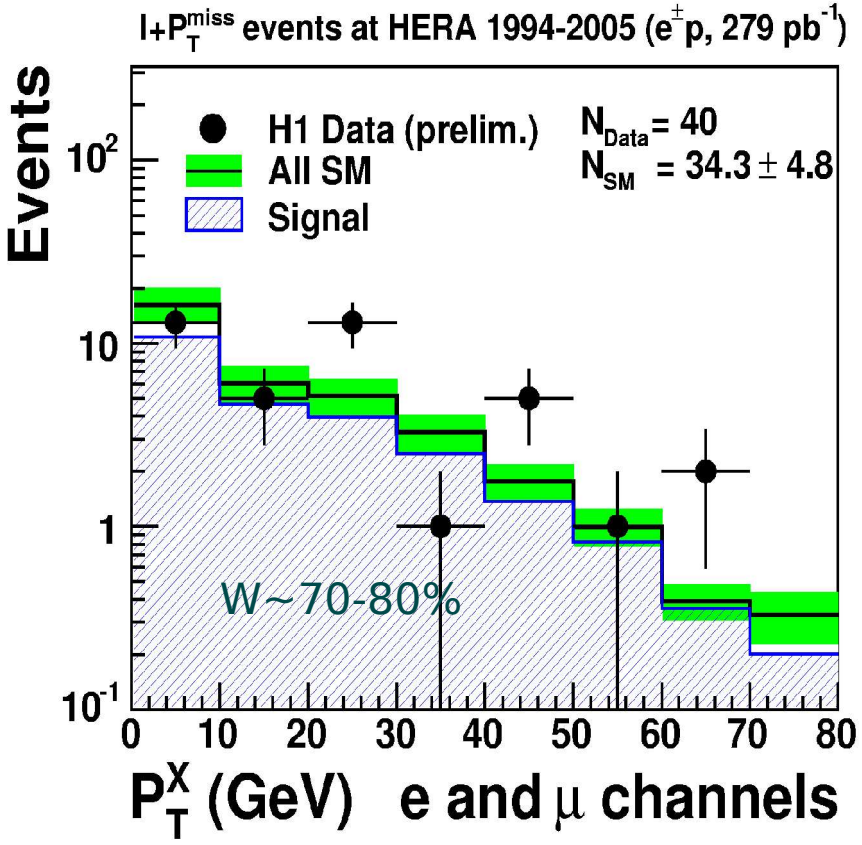
$5° < \theta_l < 140°$; $P_T^l > 10$ GeV; $P_T^{\rm miss} > 12$ GeV and $D_{jet} > 1.0$

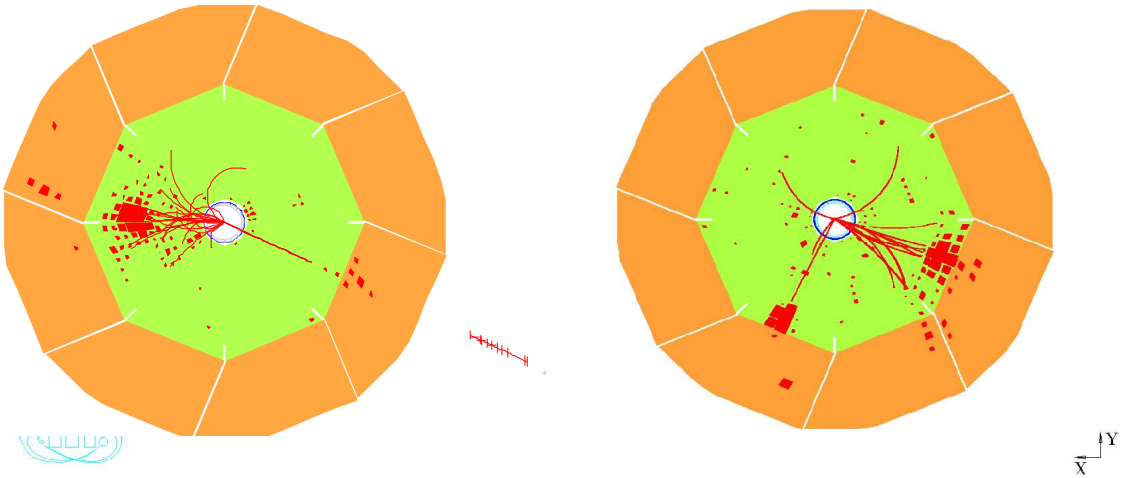
	Measured	SM NLO
$P_T^X < 25$ GeV	$0.146 \pm 0.081 \pm 0.022$	0.194 ± 0.029
$P_T^X > 25$ GeV	$0.164 \pm 0.054 \pm 0.023$	0.043 ± 0.007

too high

H1 Collab., V. Andreev et al., Phys. Lett. B561 (2003) 241

(Anomalous) W production

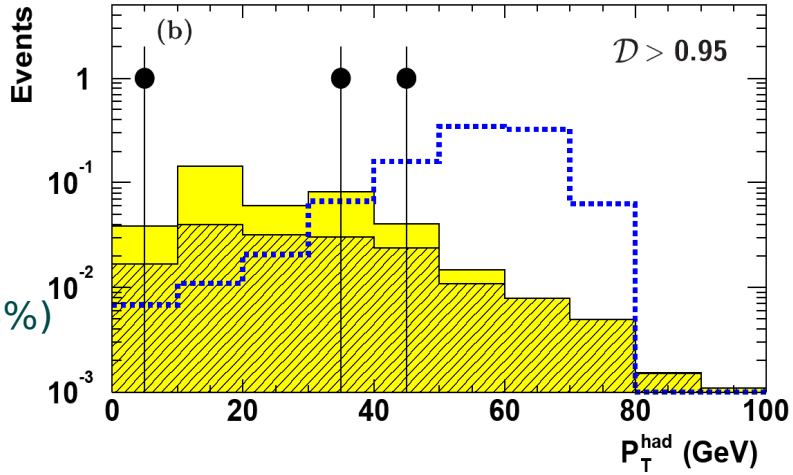




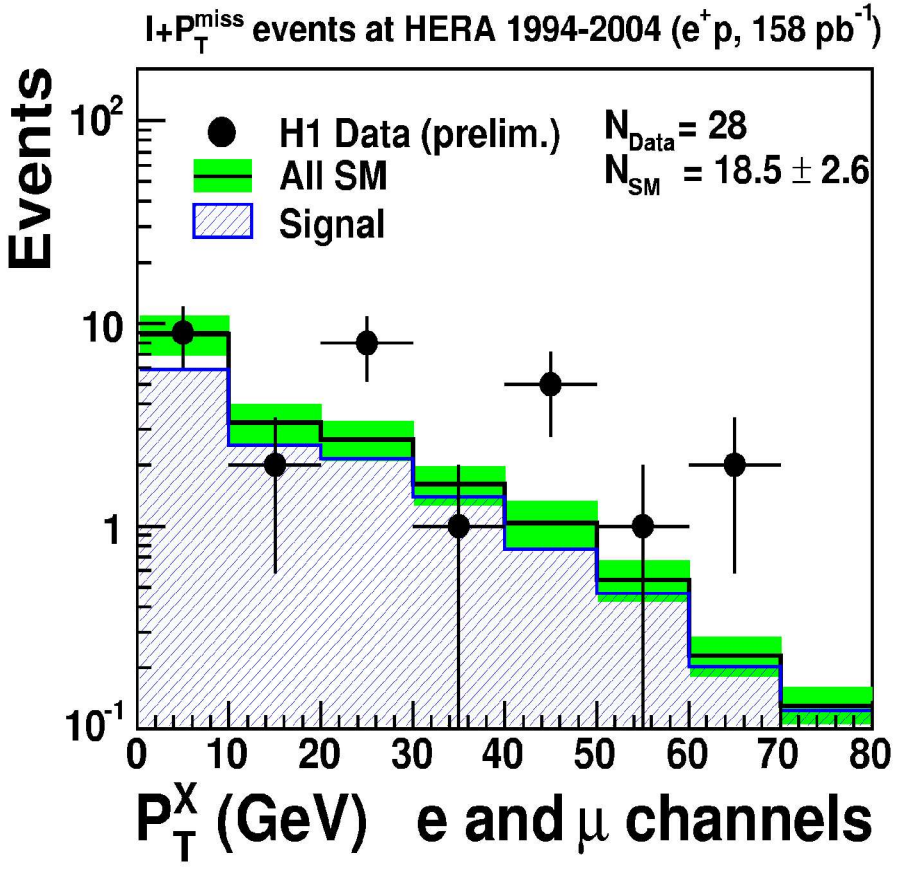
ZEUS tau search PTX>25 GeV
2/0.2 (no event found by H1)

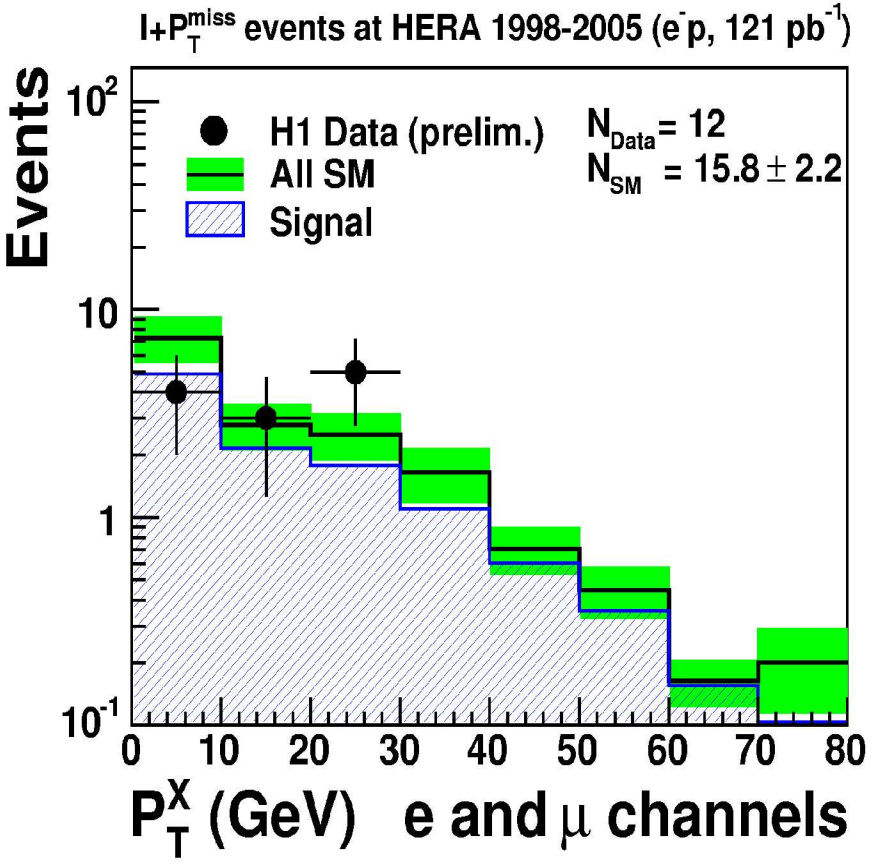
P_T^X > 25 GeV	e channel	μ channel	Combined e & μ
H1 94-05 211 pb-1	11 / 4.7 ± 0.9	6 / 4.3 ± 0.7	17 / 9.0 ± 1.5
ZEUS 99-04 106 pb-1	1 / 1.5 ± 0.2		

ZEUS previous search
(130pb^{-1},HERA I) 7/5.7 (e,μ) (W:45%)



The e-beam charge dependence



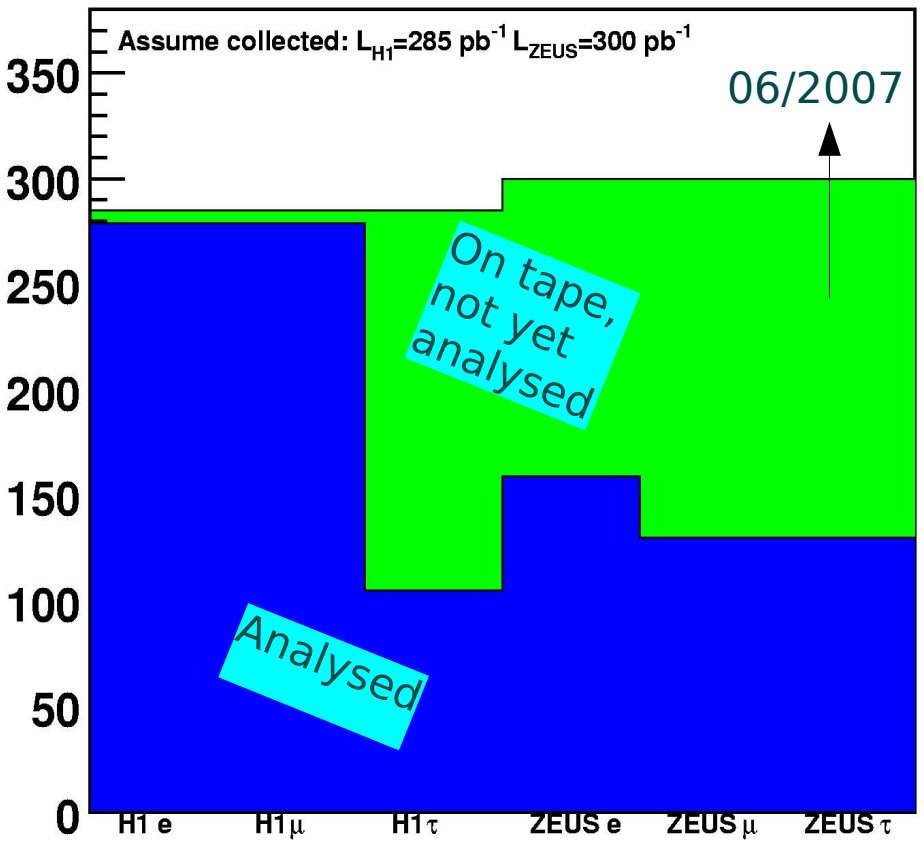


Is this an asymmetry? Still consistent with a statistical fluctuation so far.

P_T^X > 25 GeV	e channel	μ channel	Combined e and μ channels	
H1 e^+p data 158 pb^{-1}	9 / 2.3 ± 0.4	6 / 2.3 ± 0.4	15 / 4.6 ± 0.8	3.4σ
H1 e^-p data 121 pb^{-1}	2 / 2.4 ± 0.5	0 / 2.0 ± 0.3	2 / 4.4 ± 0.7	
H1 $e^\pm p$ data 279 pb^{-1}	11 / 4.7 ± 0.9	6 / 4.3 ± 0.7	17 / 9.0 ± 1.5	

Future data sample vs. significance

Lumi $l+P_T^{miss}$ analyses (e+p and e-p)



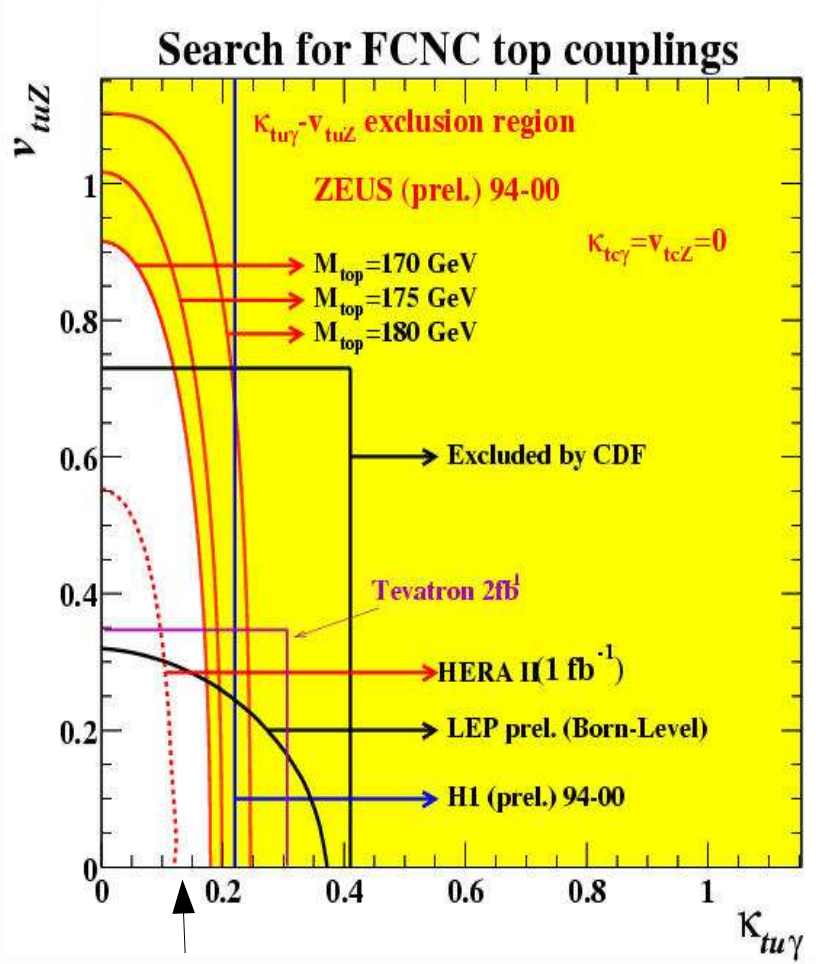
PTX>25 GeV 11/4.7 6/4.3 0/0.5 4/5.5 5/2.8 2/0.2

- **A lot of potential for this study**
- **If the effect is in e^+p collisions: doubling the e^+p lumi :**
  - **H1->5σ**
  - **H1+ZEUS may approach 4σ**

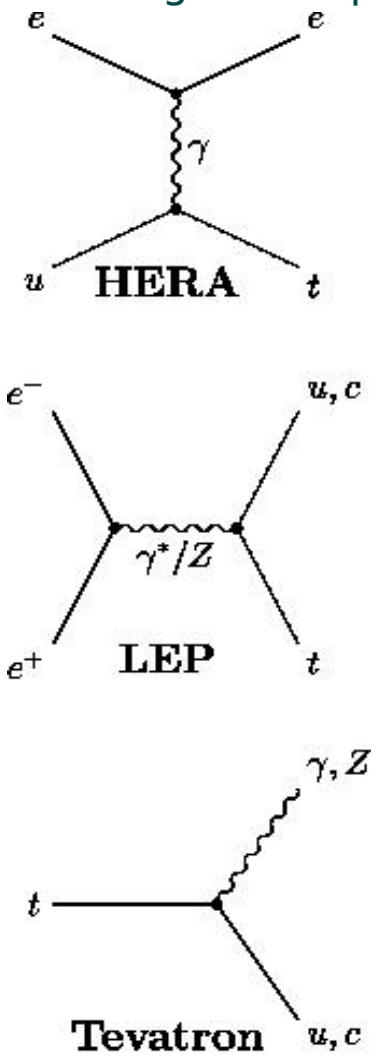
Coherent effort needed

Anomalous top

Possible explanation of high PT W production

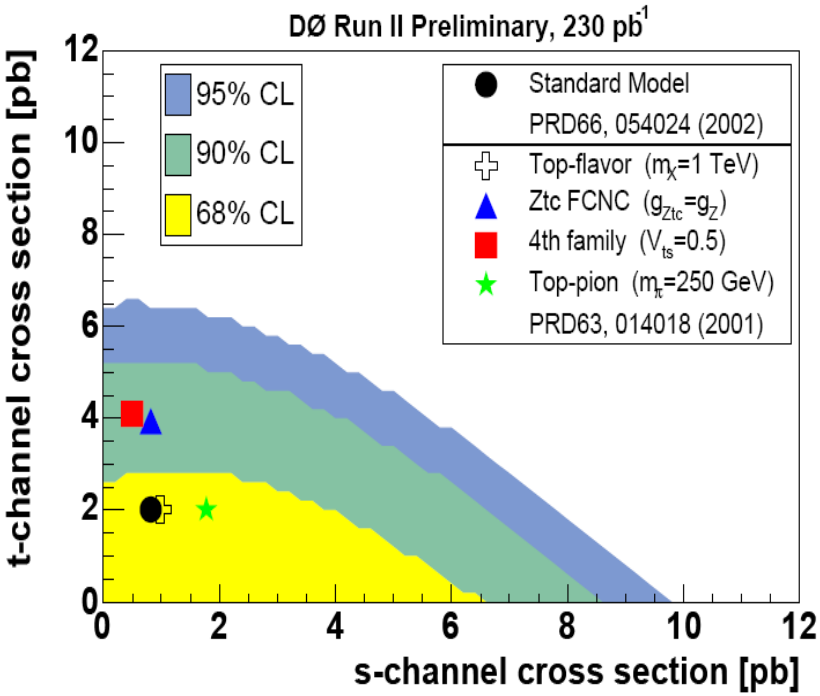


HERA is competitive



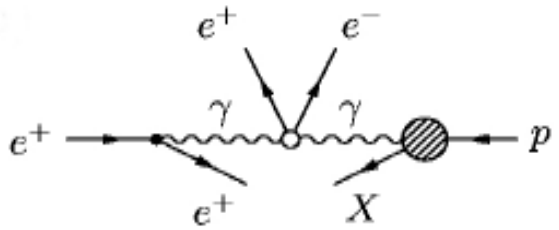
(or a la LEP: single top)

Possible impact in single top at Tevatron k~0.2 => 1pb



This hypothesis cannot explain e+/e- difference,
if an anomalous single top signal is observed at Tevatron,
it may provide an useful cross-check of its nature

Events with at least two charged leptons (e or μ)

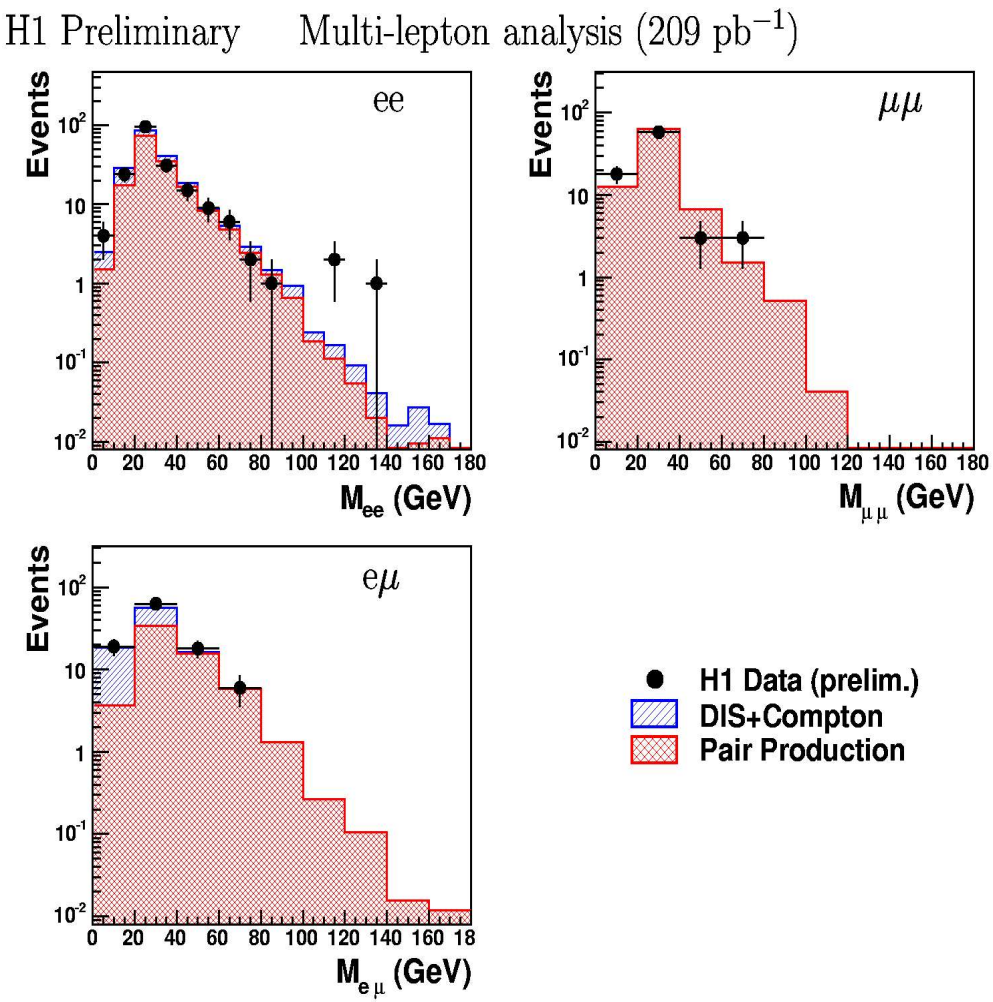


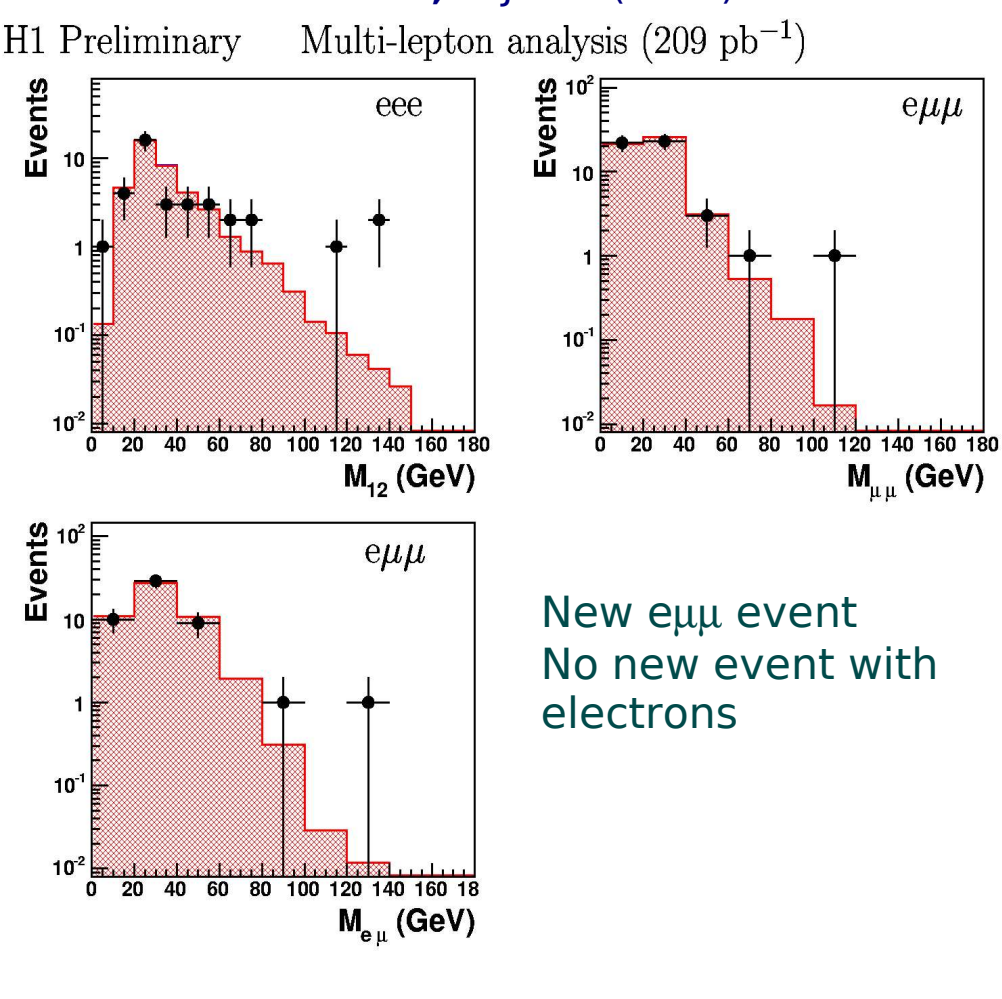
H1 94-00 data obs. / exp.

selection \ expt	H1 (115 pb^{-1})
2e, M_{12} > 100 GeV	3 / 0.30 ± 0.04
3e, M_{12} > 100 GeV	3 / 0.23 ± 0.04

Analysis extended to all pairings/ HERA II (209 pb^{-1})

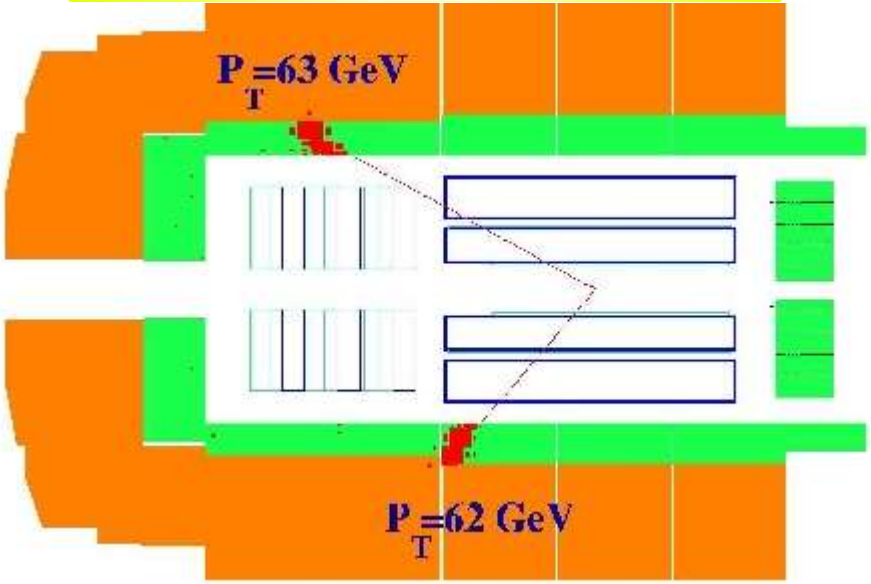
H1, EPJ C31 (2003) 17

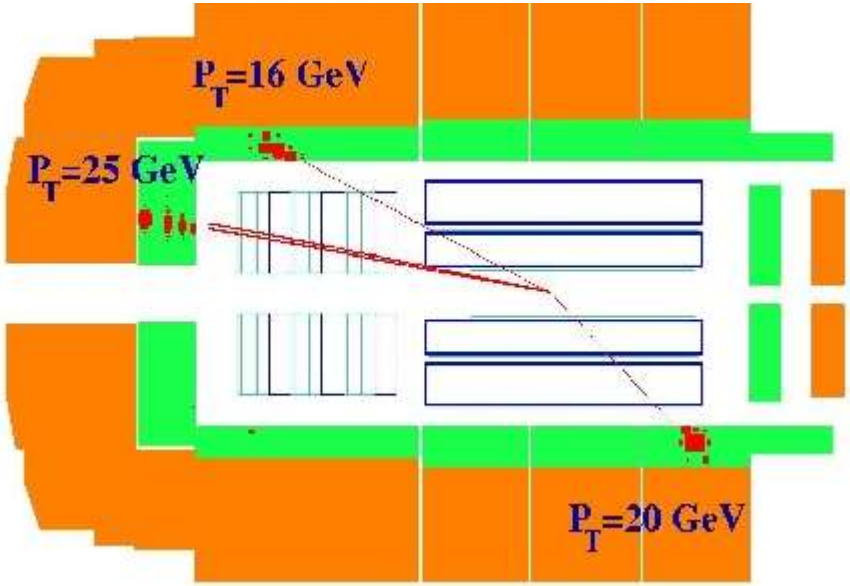




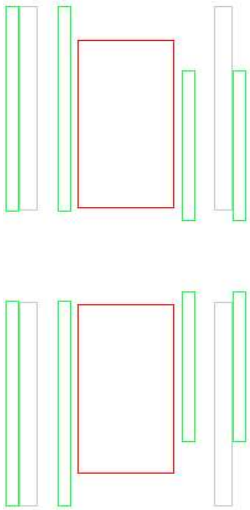
New eμμ event
No new event with electrons

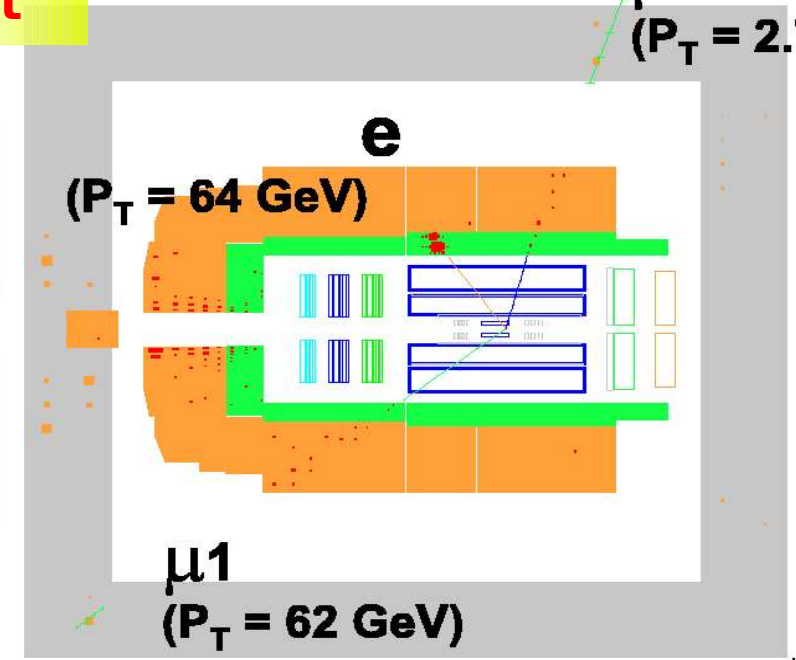
2e/3e events at high mass

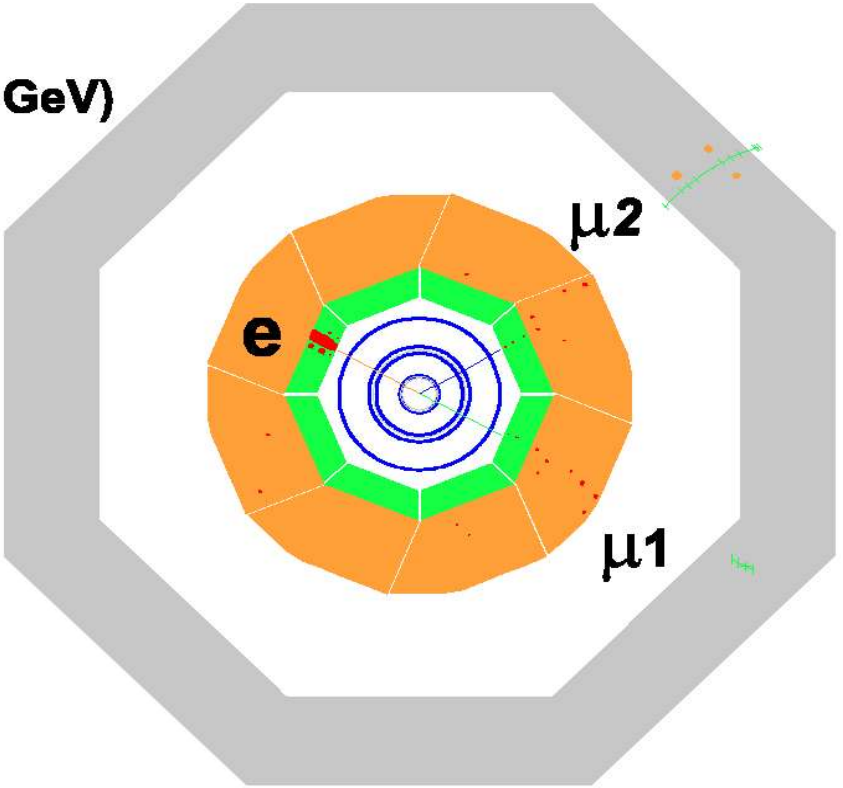




eμμ event



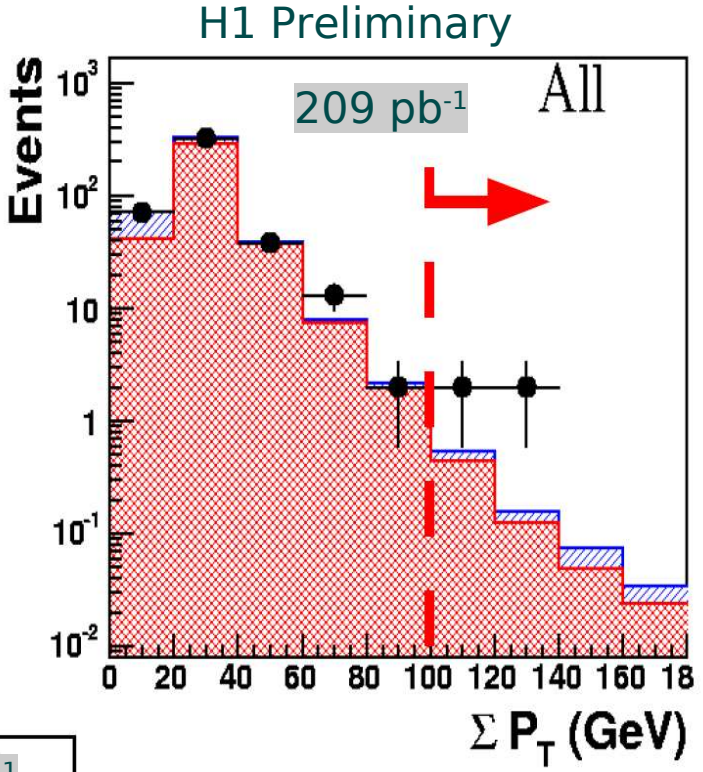


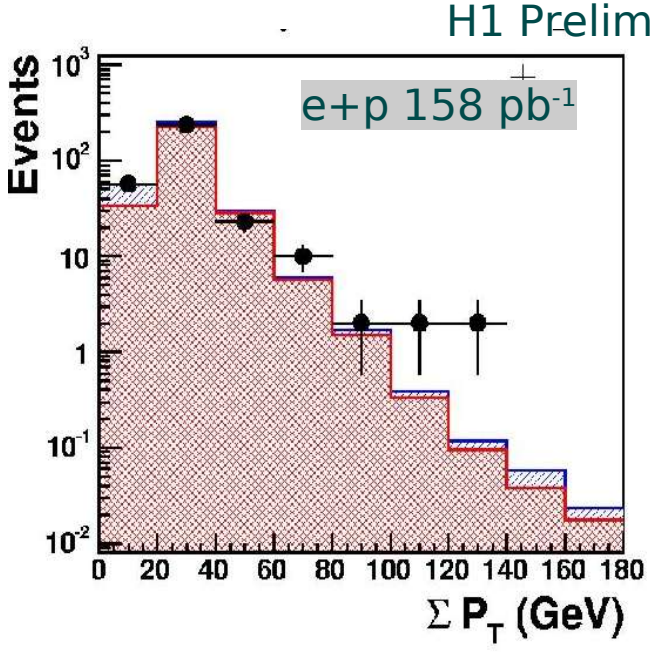


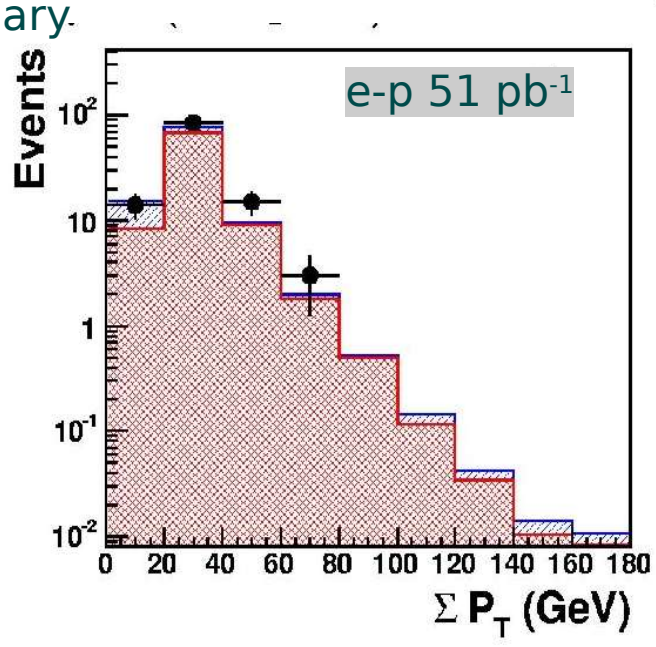
R
Z
Y

P_T Scale of multi-lepton events

- Check the scale of the multi-lepton production
- Scalar transverse momentum
- 4/0.81±0.17 for ΣP_T>100 GeV
- (high ΣP_T events appear in e^+p collisions)



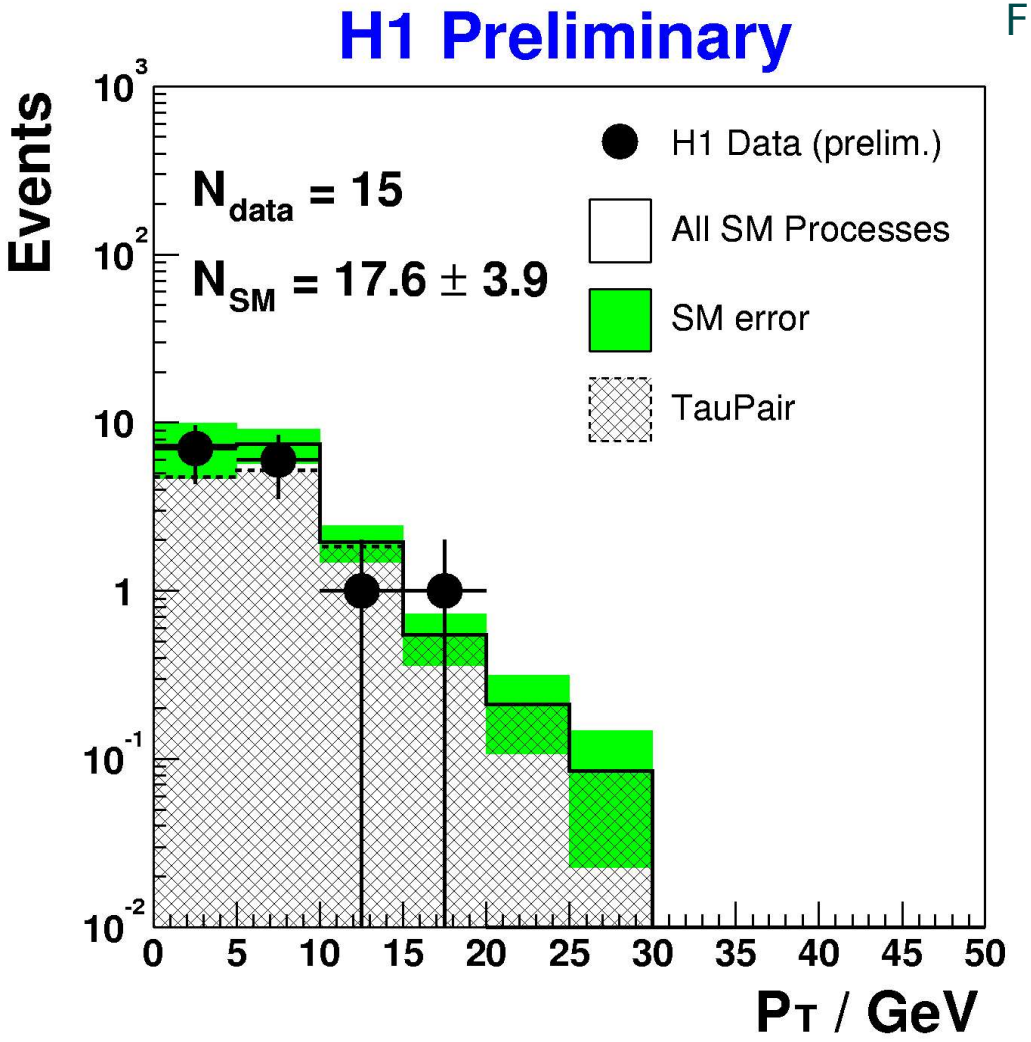


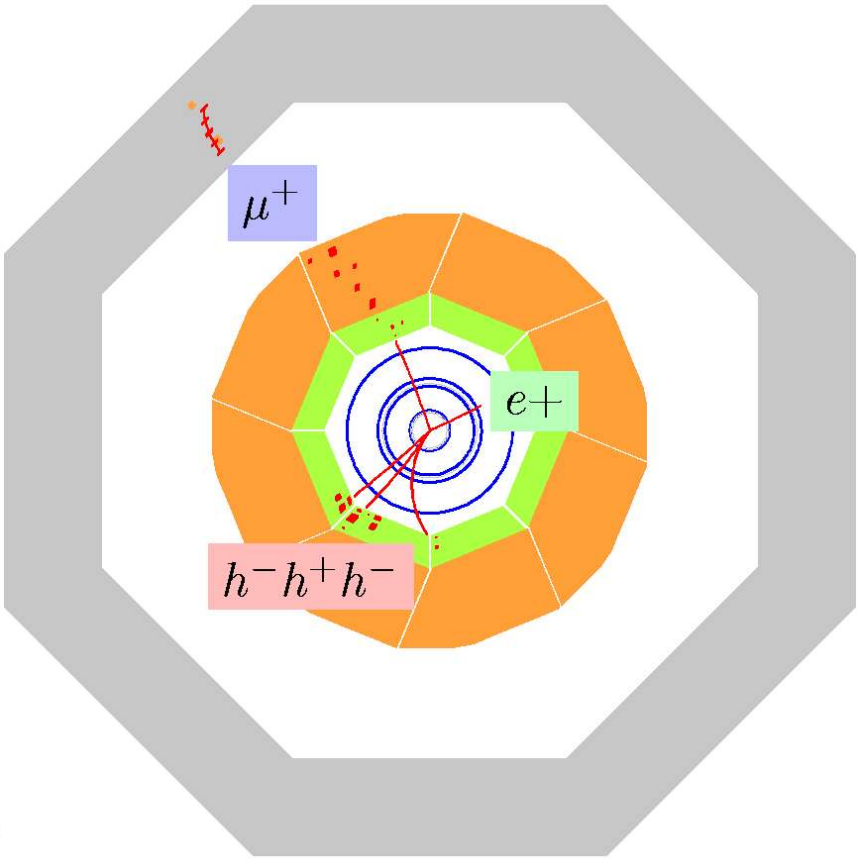


Events with tau leptons detected at HERA

Apply a multivariate analysis to separate signal from background

First measurements of tau leptons at HERA



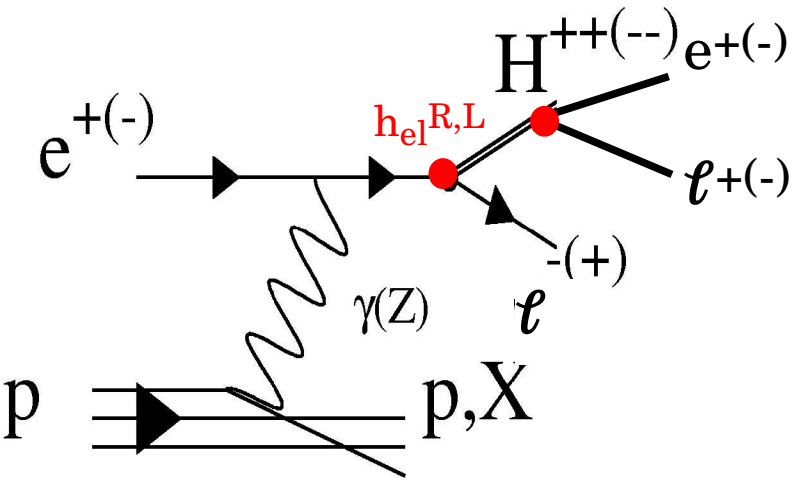


Doubly charged Higgs boson

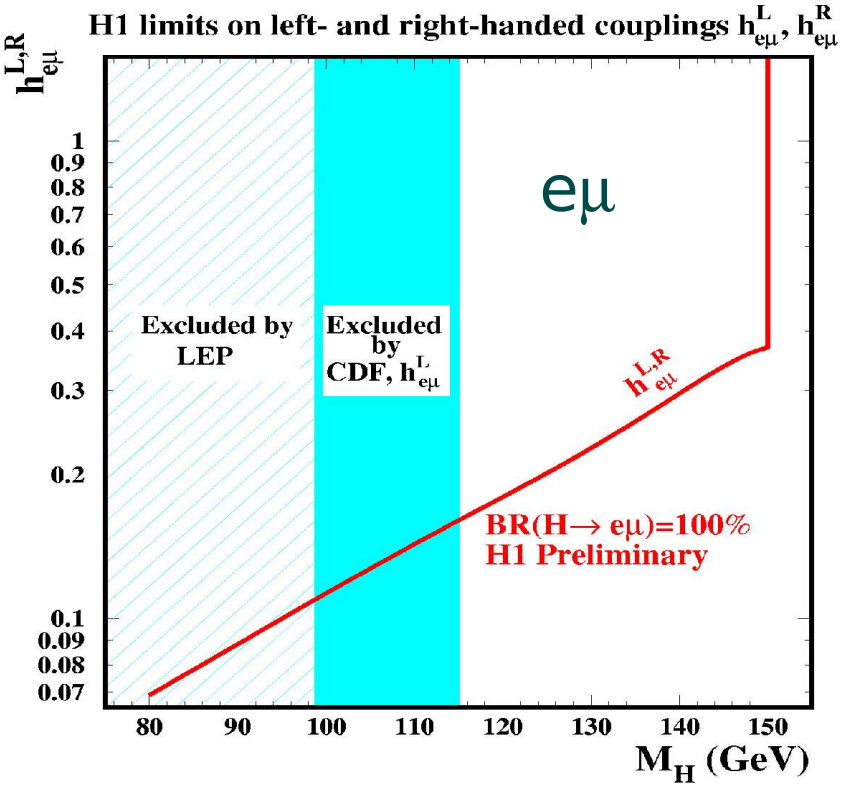
- In extension to SM: $H^{\pm\pm}$ appears in Higgs triplet(s) of non-zero hypercharge
- Left-right symmetries: $SU(2)_R \times SU(2)_L \times U(1)_B$
- vev might give mass to Majorana neutrinos

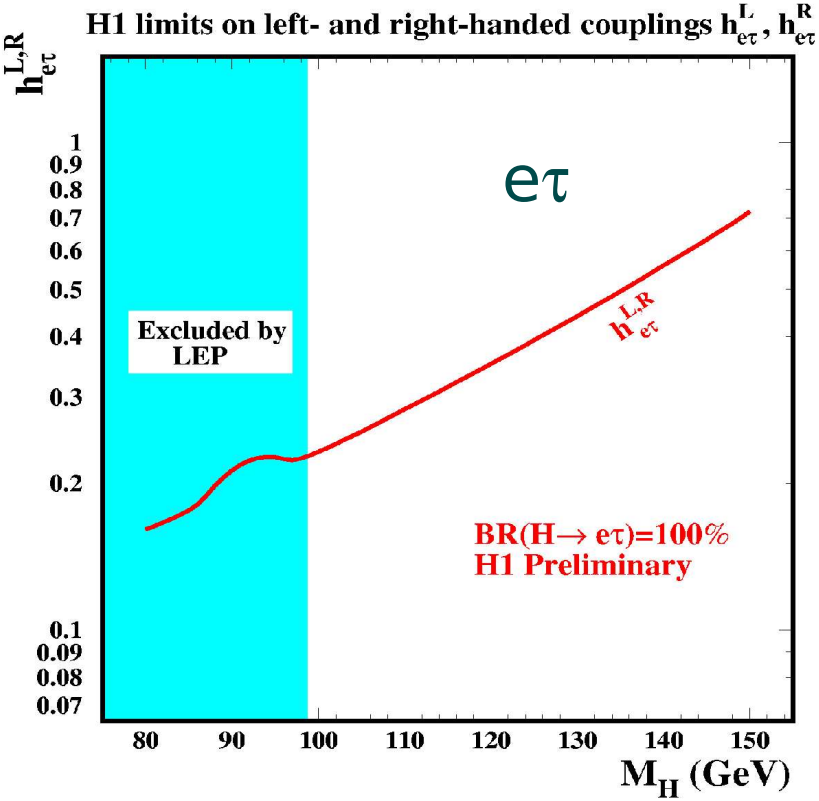
➔ Only couplings to leptons $h_{ll}^{R,L}$

➔ One dominant coupling: $h_{el} \gg 0$



observed multi-lepton events not likely H++





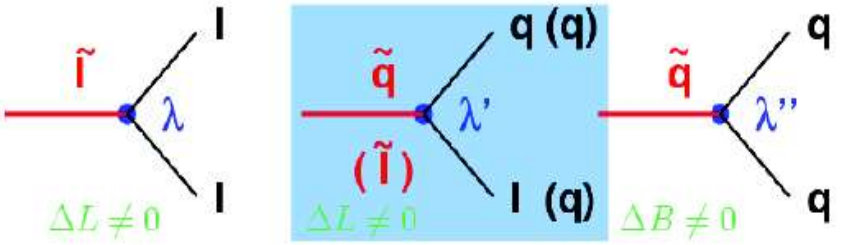
Unique sensitivity at HERA

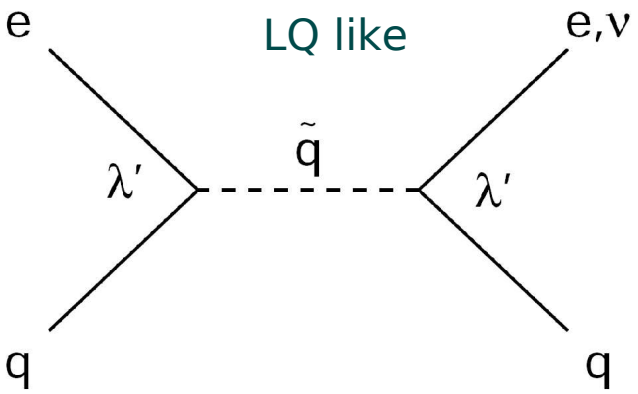
Supersymmetry

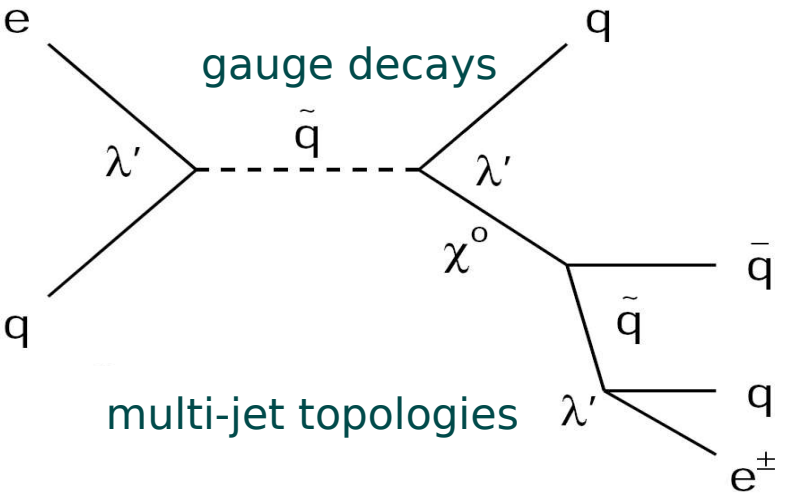
- Unify internal and space-time symmetry, commute spin, i.e. fermions<=>bosons
- every internal degree of freedom induce new “s”partner
  - ex. $q \Rightarrow \tilde{q}_L, \tilde{q}_R$
- Production of new particles at colliders
- R_p =1(SM) -1(sparticles)

$$R_P = (-1)^{3B+L+2S}$$

$$W_{\not R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$







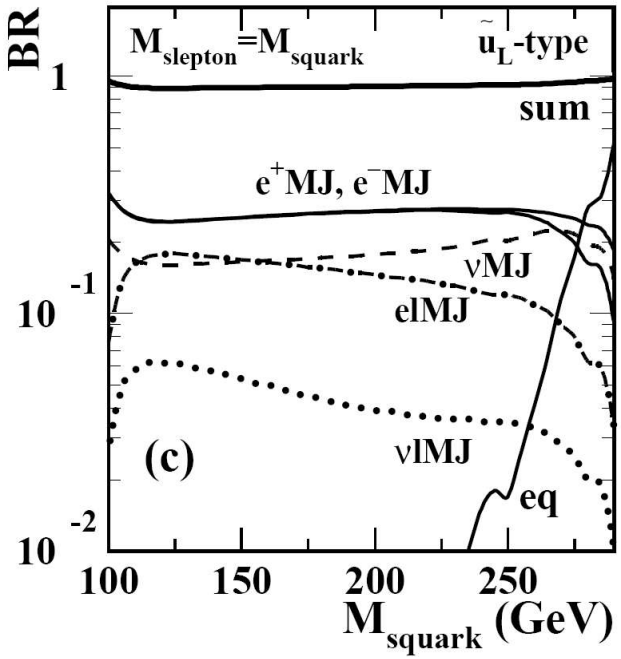
$e^+ d \to \tilde{u}_L^j$ via λ'_{1j1}

$e^- u \to \tilde{d}_R^k$ via λ'_{11k}

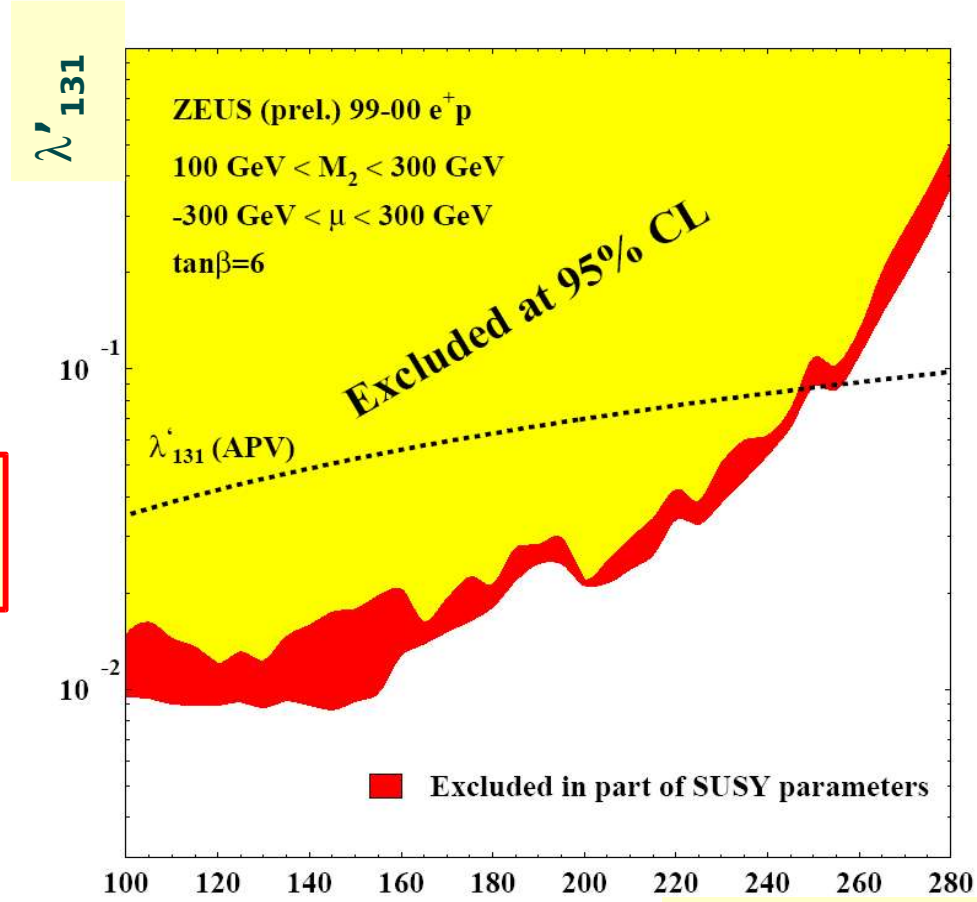
e^+ and e^- probe different squarks & couplings

Constraints within the MSSM

- H1, EPJ C36 (2004) 425 : all squark types, all decay modes
- ZEUS Prelim stop $\rightarrow$ eq and stop $\rightarrow$ b χ_+



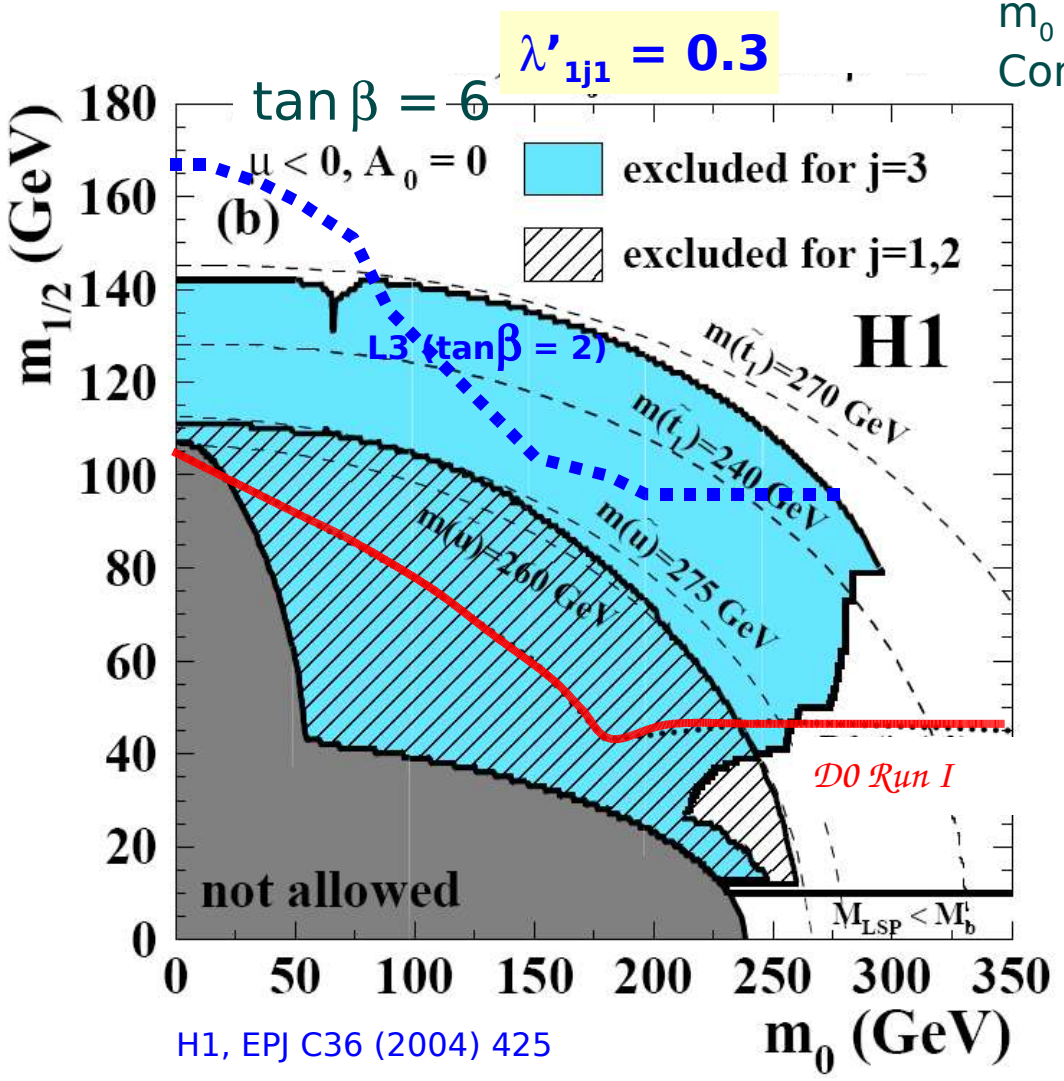
"Unconstrained model" :
sfermion & gaugino sectors are not related,
i.e. M_f are free parameters



- For $\lambda' = 0.3$ ($\lambda'^2 / 4\pi = \alpha_{em}$):
  squarks ruled out up to ~270 - 280 GeV

HERA's sensitivity extends
beyond the indirect limits
from low energy exp.

HERA mSUGRA



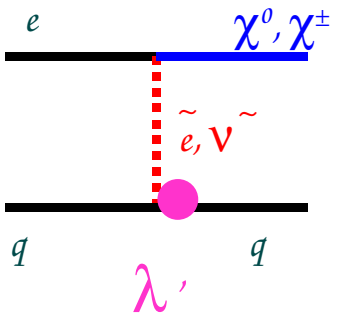
H1, EPJ C36 (2004) 425

Contrained model : only 5_{susy} parameters;
m_0 (scalars) $m_{1/2}$(fermions) mass parameters
Compare with other experiments

Intermediate m_0:
-not excluded at LEP
-difficult at Tevatron (E_t^{miss}+jets)
runII mass sensitivity up to 200-250 GeV

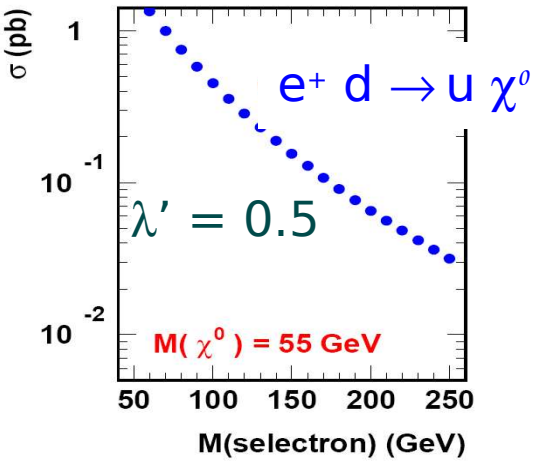
Discovery potential for RpV stop
at HERA with larger luminosity

If squarks are very heavy ?
SUSY in t-channel



Gaugino production via slepton exchange.

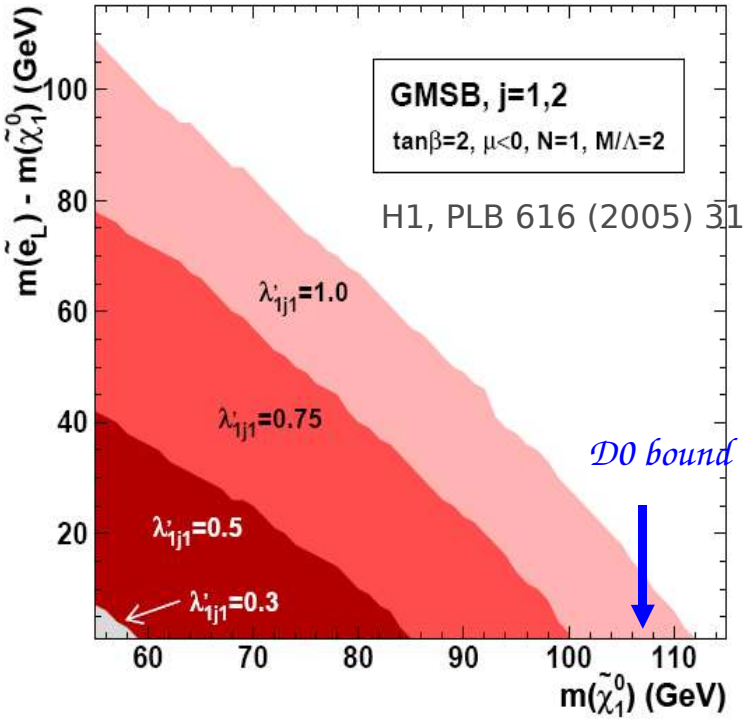
Considered at HERA in two scenarios :



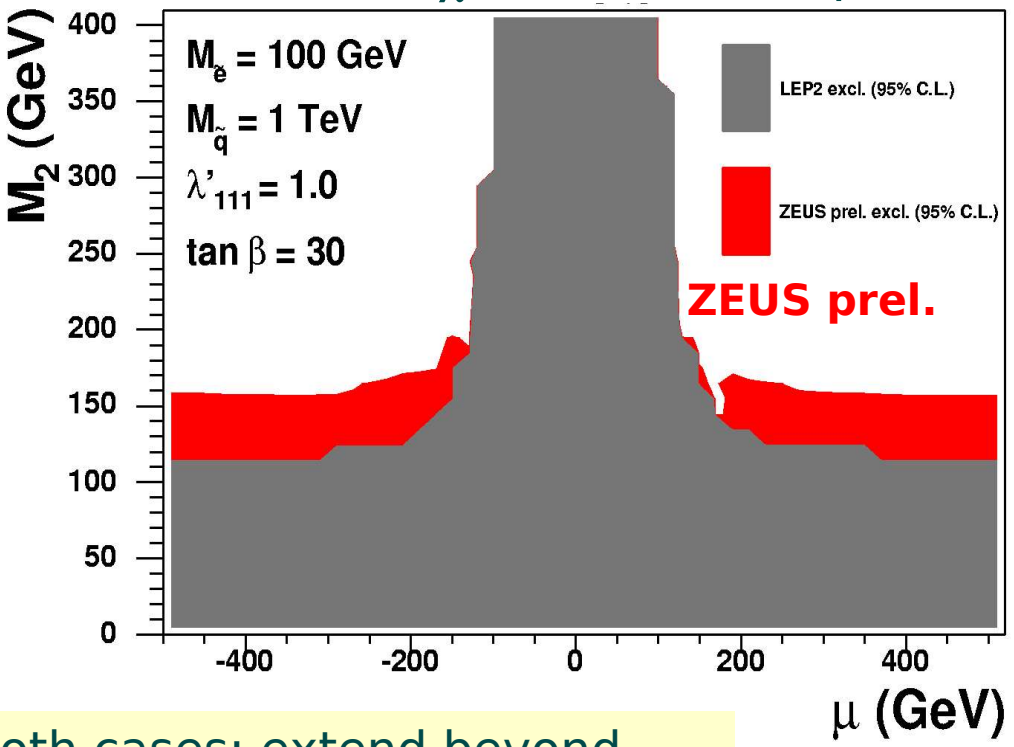
"GMSB" like :

$\chi \to \gamma +$ gravitino, i.e. $\gamma + E_{T,miss}$

$\to$ study of radiative CC DIS

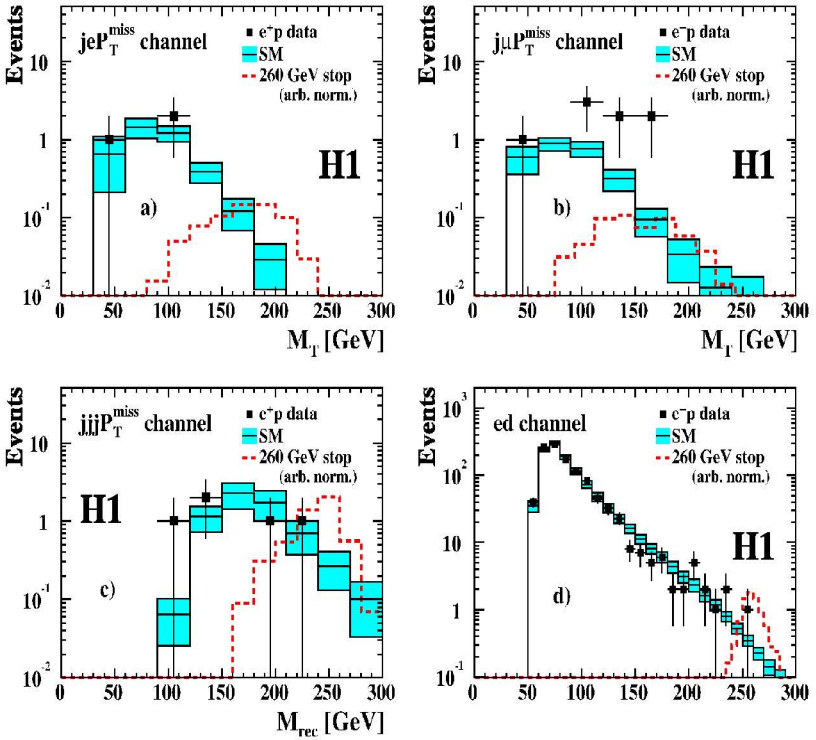


"mSUGRA" like : $\chi \to$ e or ν + 2 quarks

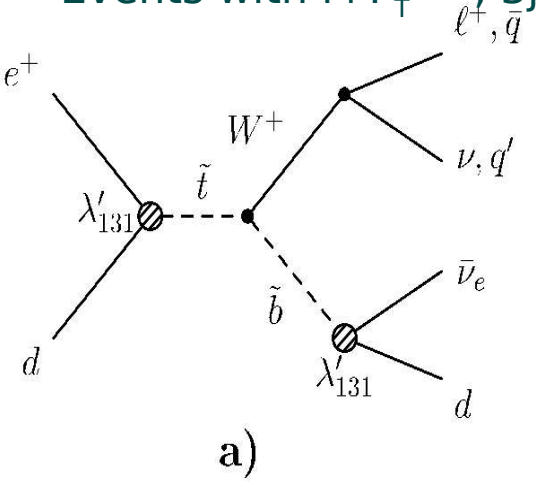


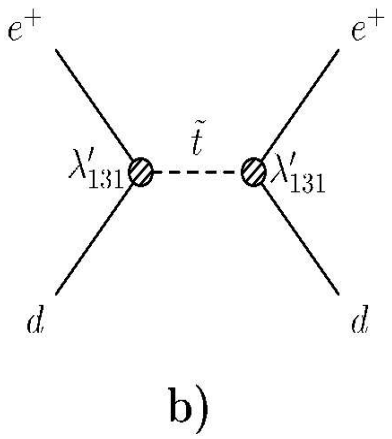
In both cases: extend beyond limits set by LEP/Tevatron.

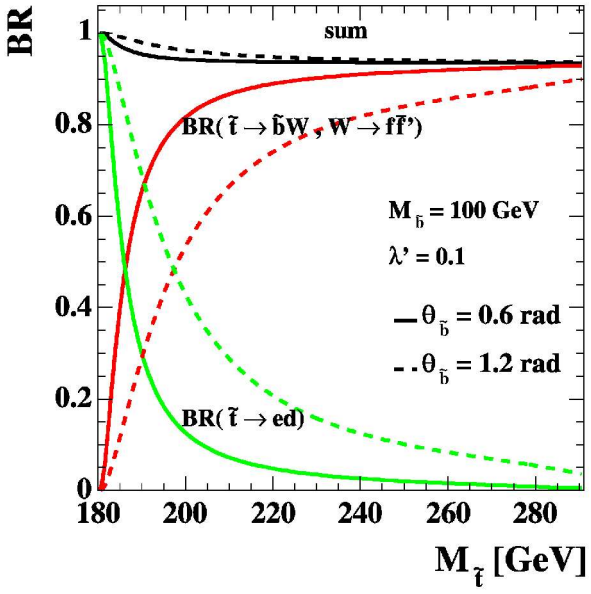
If the stop is heavier than sbottom

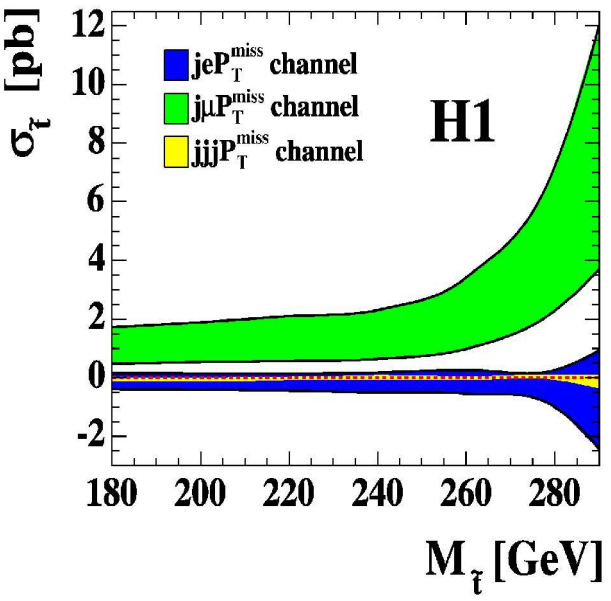


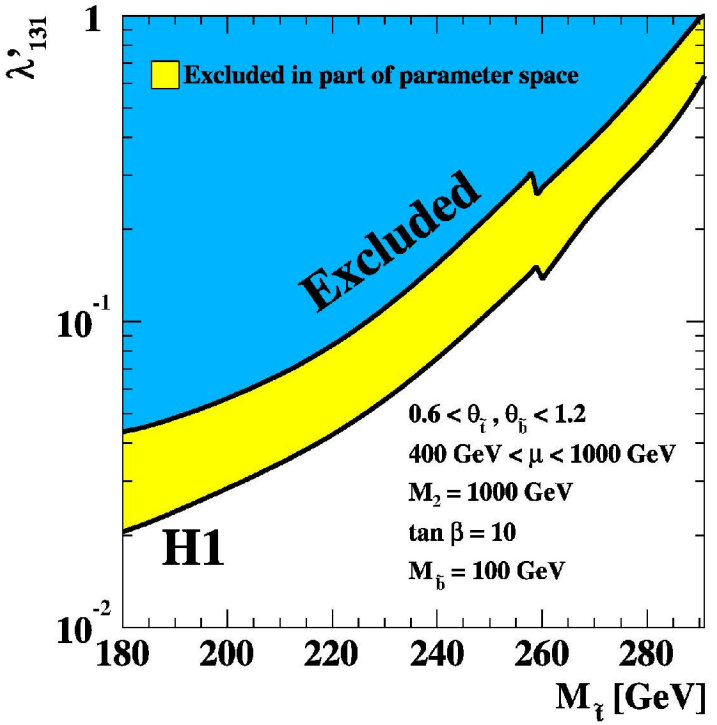
Events with l+P$_T^{miss}$, 3jets+P$_T^{miss}$







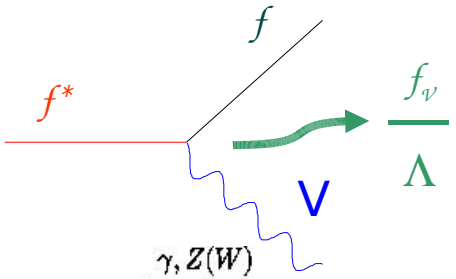




Search for lepton-boson resonances

Unambiguous signature for matter substructure:
direct observation of excited states

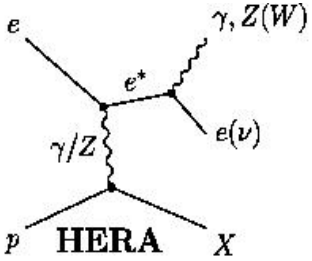
Hagiwara et al, ZPC 29 (1985) 115.
Boudjema et al, ZPC 57 (1993) 425.

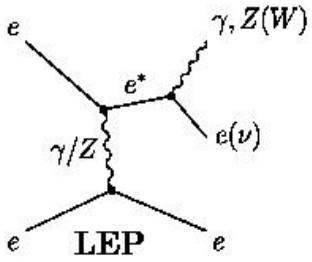


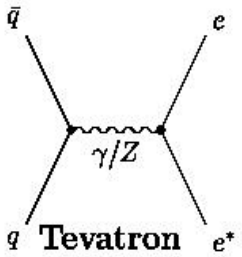
$\Lambda \approx$ compositeness scale

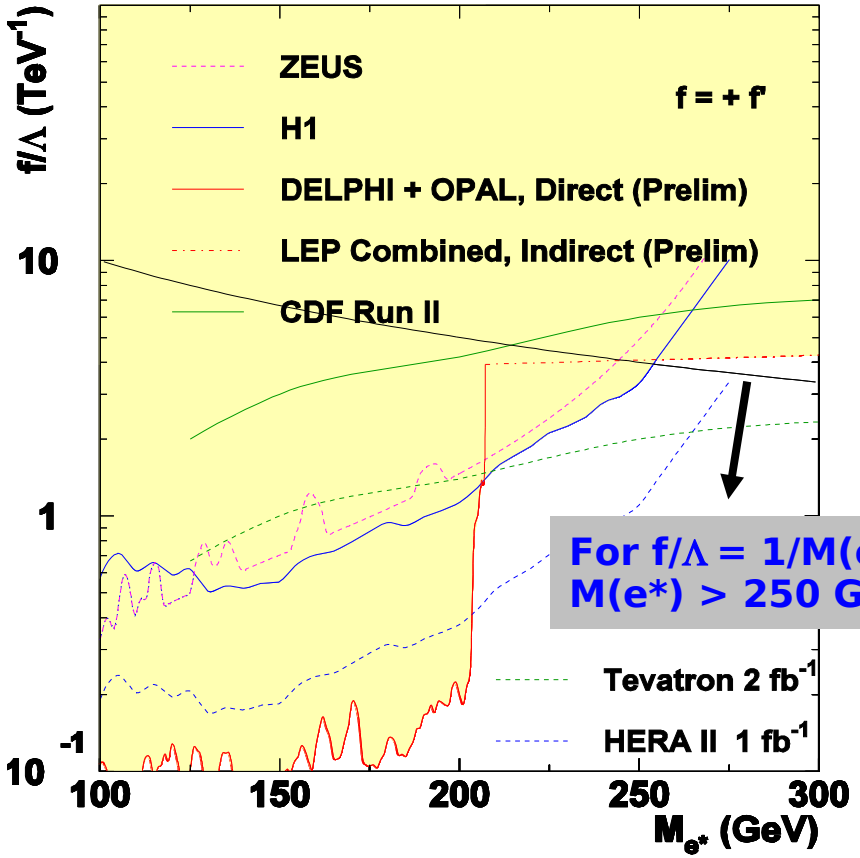
Relative strength

γ, Z, g : couplings f, f ', f_s

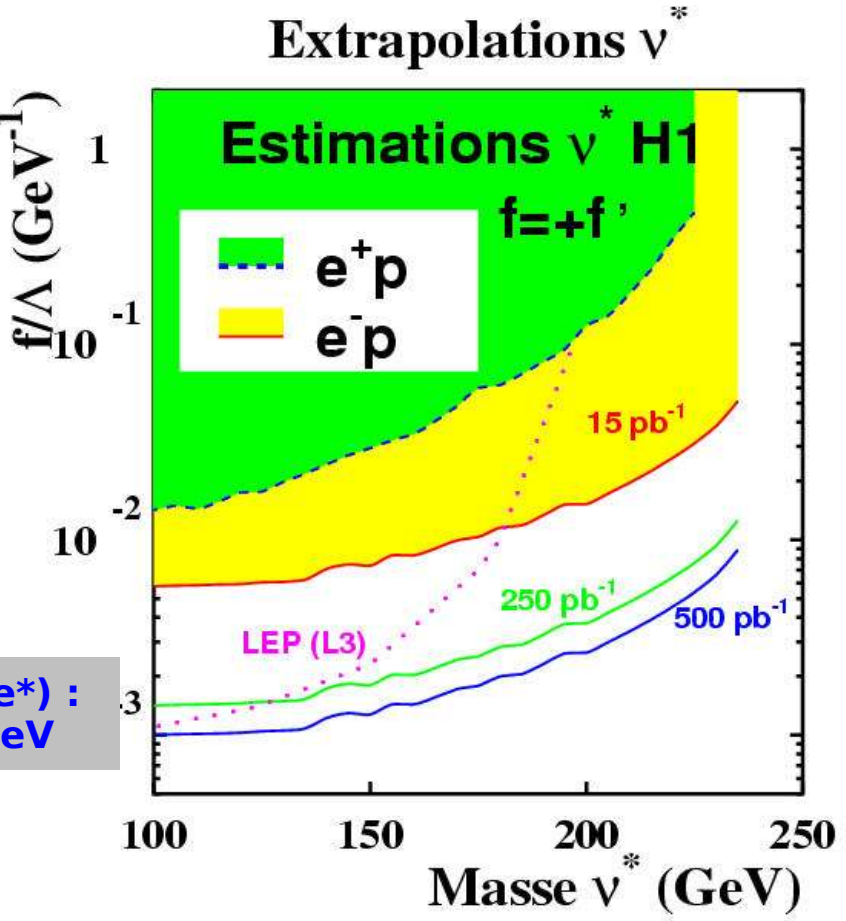








For f/Λ = 1/M(e*) :
M(e*) > 250 GeV

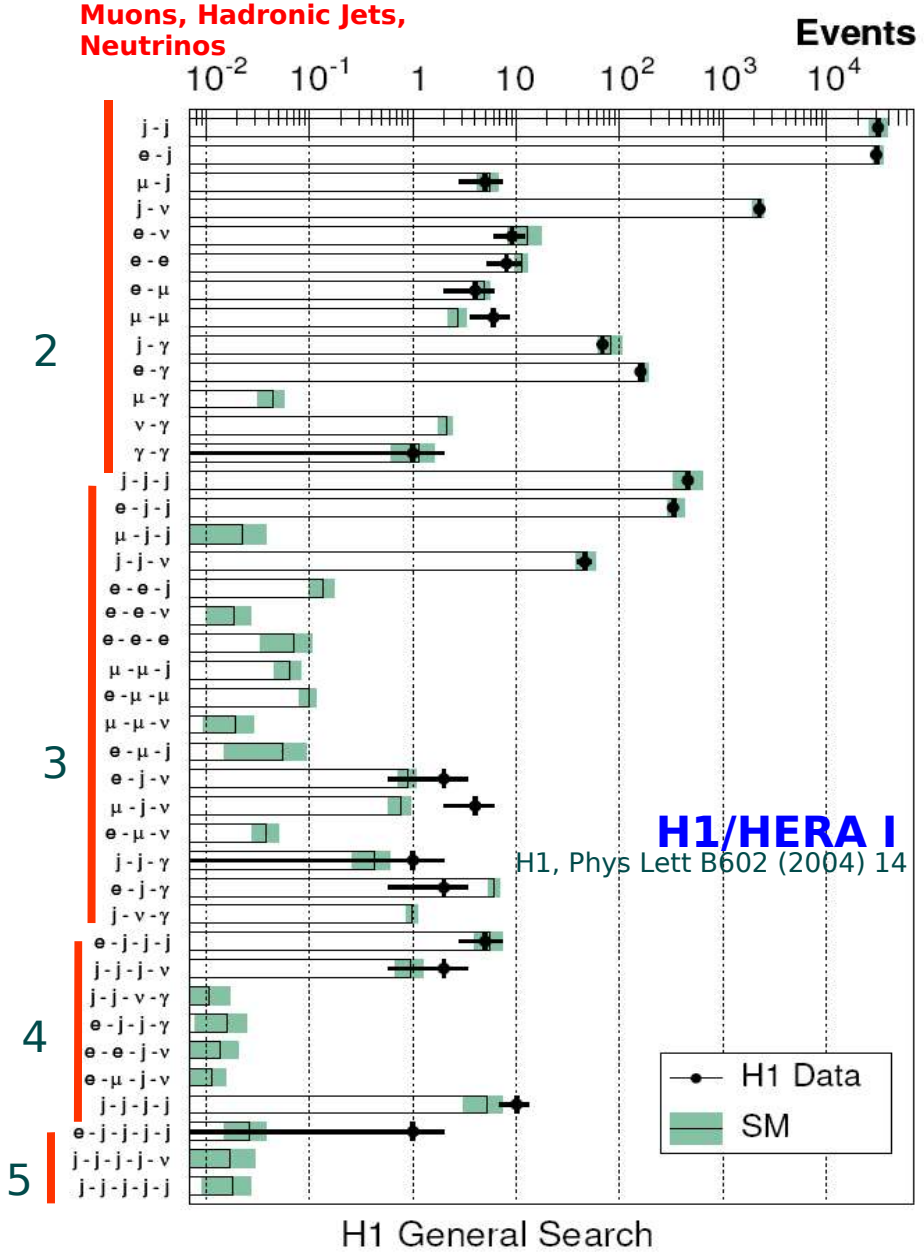


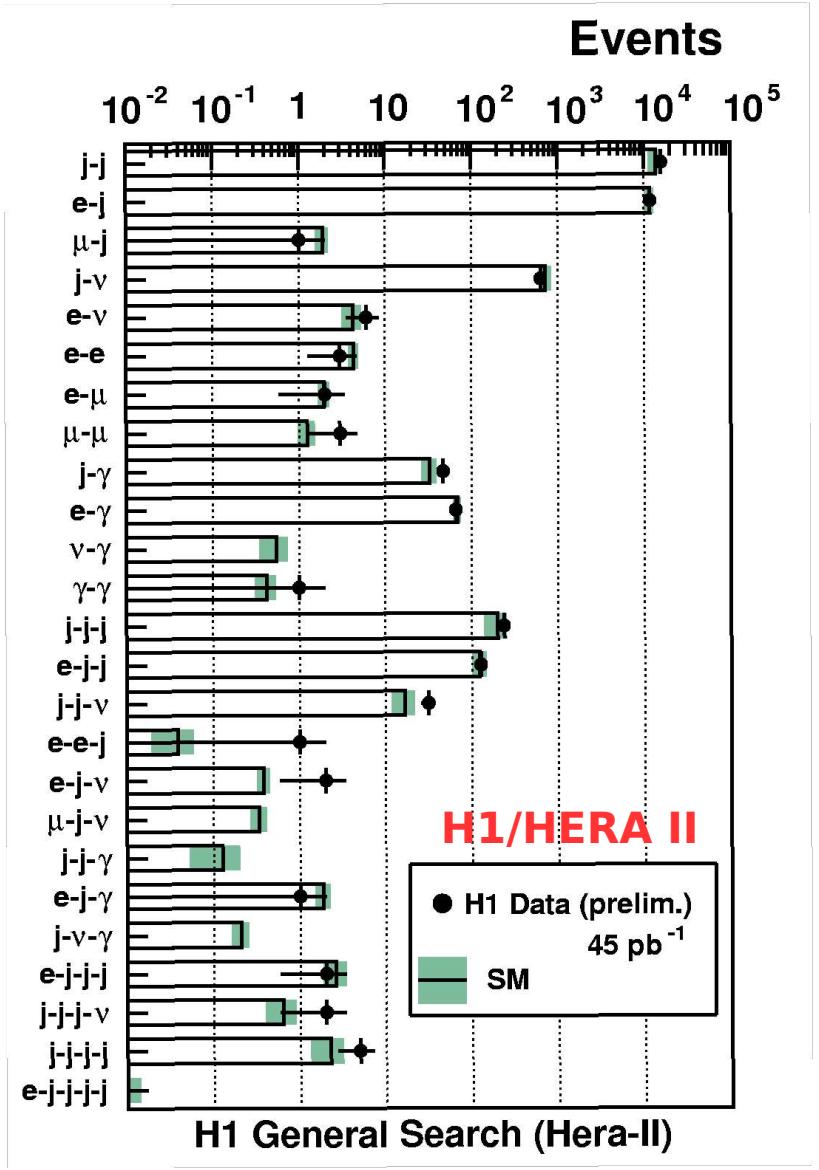
Surprises in e^-p data?

“Signature Based” Searches for NP

- Search for isolated particles at high PT:
  - **Electrons ,Photons,**
  - **Muons, Hadronic Jets,**
  - **Neutrinos**

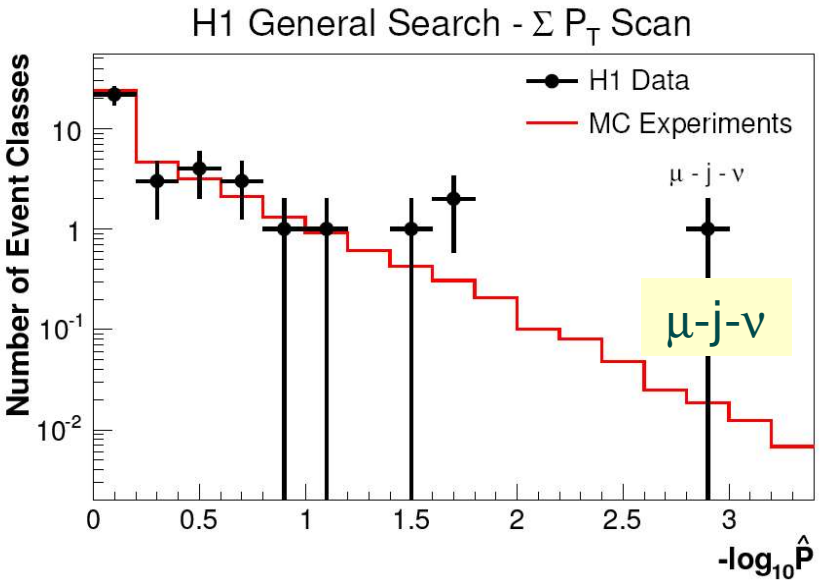
Unique phase space:
PT>20 GeV
10<theta<140





The effectiveness of a general search

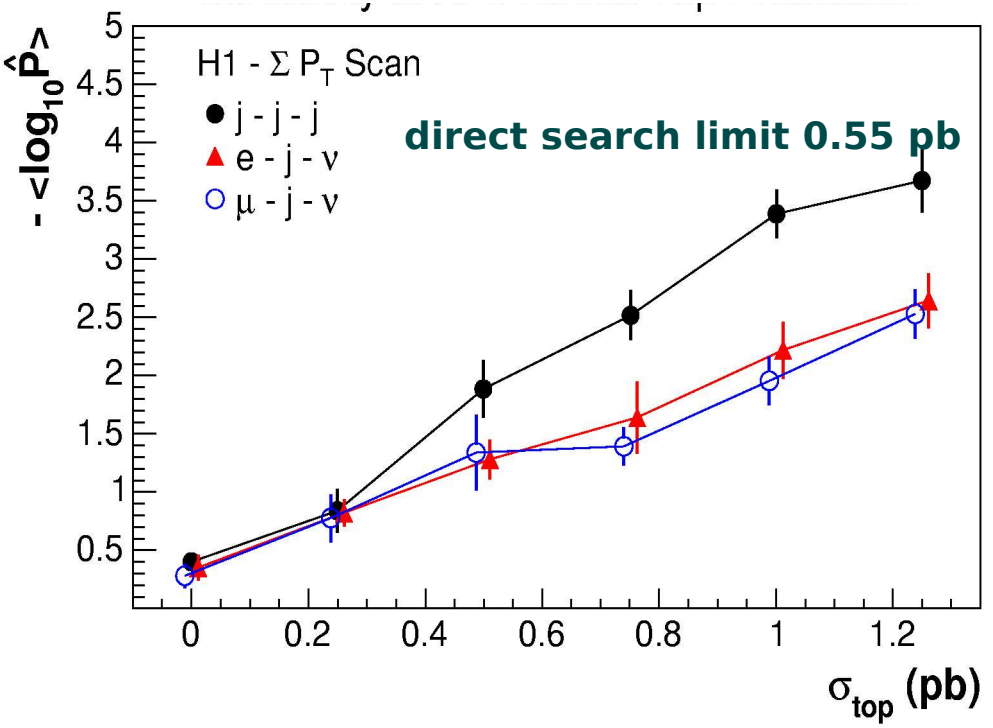
Classify observed events
Search for fluctuation in M/PT spectra
with a statistical unbiased method



overall very good agreement H1 data / SM
retrieves the "lepton-jet-$E_{T,miss}$" and "multi-electron" anomalies

Sensitivity to BSM signals (example->)

SM Physics and detector under control
Ideal analysis to update "on-line"



Perspective H1/HERA

- A large part of the lumi is (still) ahead
- HERA is a unique collider and has discovery windows (SUSY,top,f*,H++)
- There are a few intriguing fluctuations, we need final word with most precise analysis
  - expect significant increase (x2) in e+p data
- H1 goals:
  - analyse with full statistics isolated leptons and multileptons
  - survey the high PT data with a generic analysis
  - explore sensitivity windows, have clear message to the following HEP programs