Searches for New Physics in ep Collisions at HERA

XXXIX Rencontres de Moriond
on Electroweak Interactions
and Unified Theories

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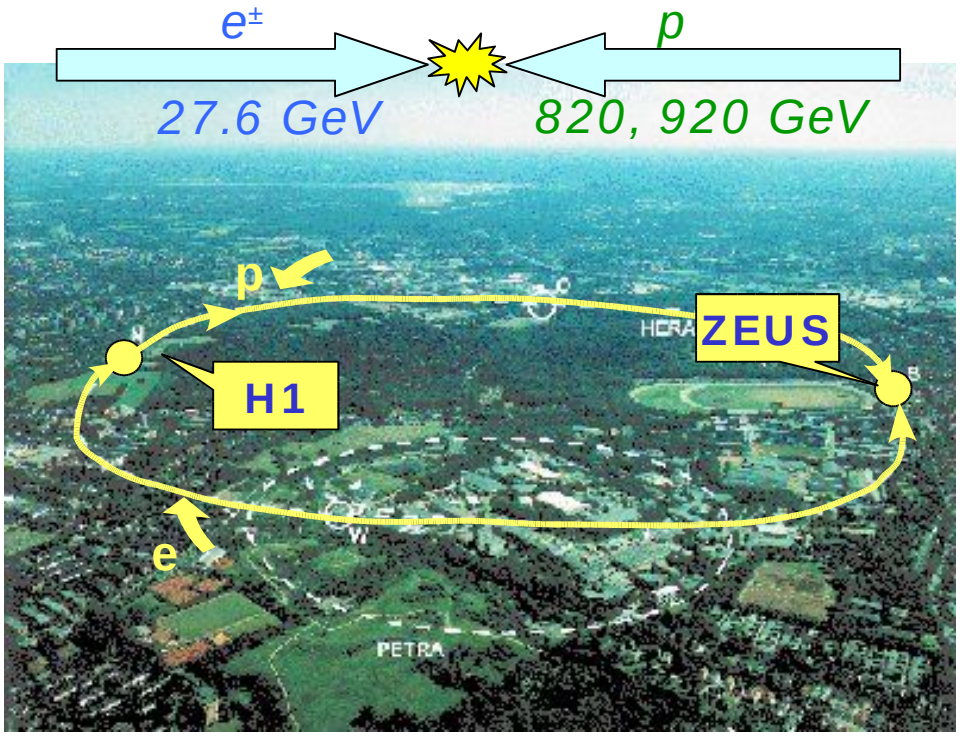
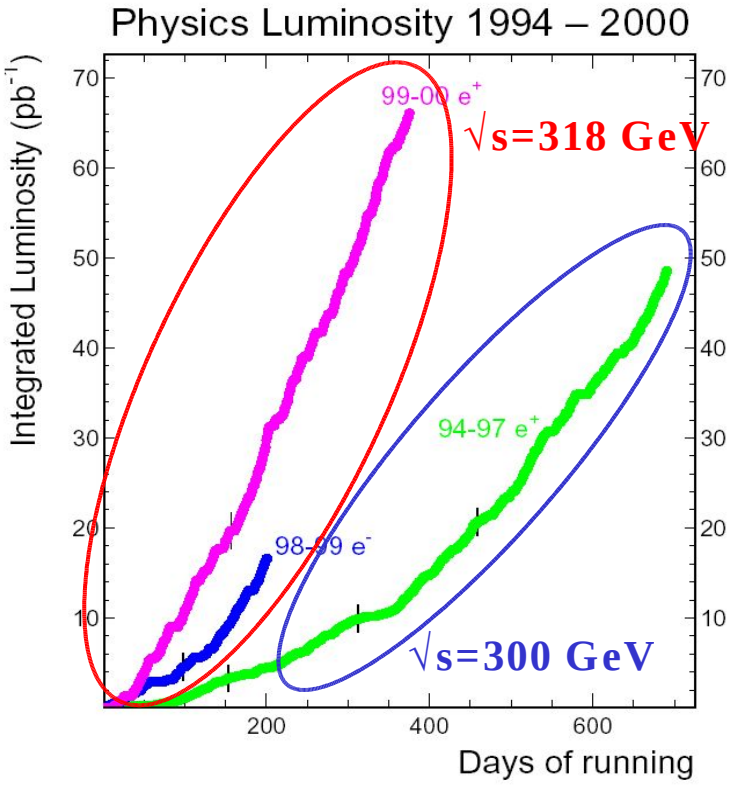
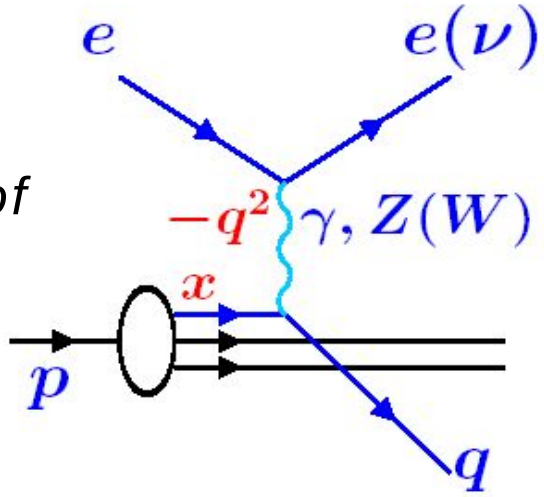
on behalf of H1 and ZEUS collaborations

The HERA Collider





$Q^2 = -q^2$ *virtuality of exchanged boson*



- *HERA I Data sample:*
  - e^+p @ $\sqrt{s}$= 300 GeV : 40 pb^{-1}
  - e^+p @ $\sqrt{s}$= 318 GeV : 66 pb^{-1}
  - e^-p @ $\sqrt{s}$= 318 GeV : 16 pb^{-1}
- *Two colliding experiments: ZEUS, H1*
- *HERA II data taking on-going*

Beyond SM searches at HERA I

Searches for new Resonances or Contact-Interactions

- *Leptoquark*
- *Lepton Flavour Violation*
- *Contact Interaction*
- *Quark Radius*
- *Extra-dimension*
- *Excited Fermion*
- *SUSY in MSSM R_p conserving model*
- *SUSY in R_p violating model*

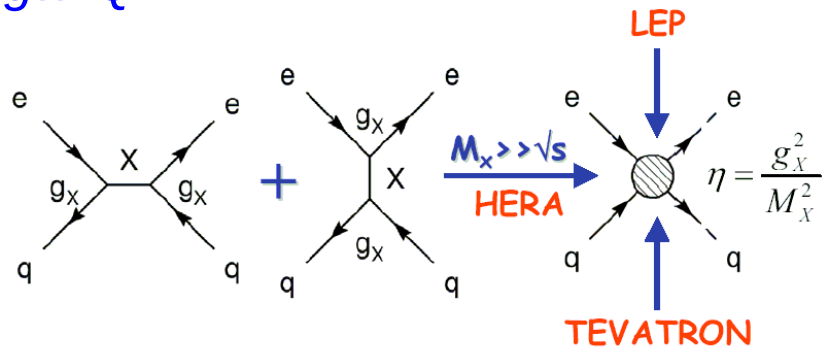
Exclusive final states

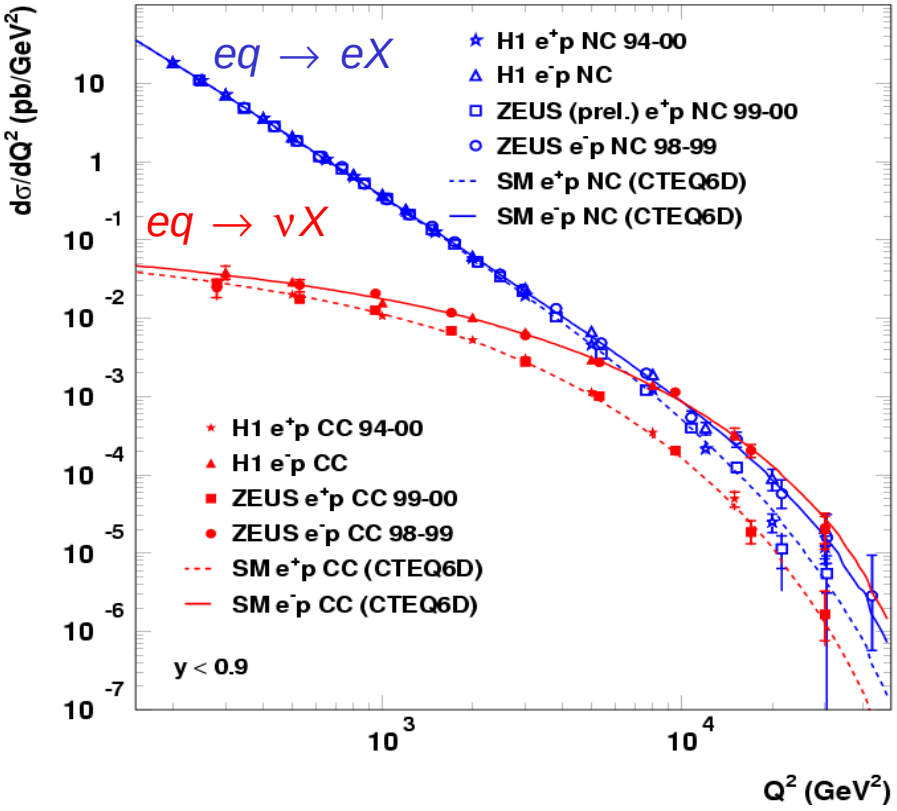
- *Isolated e, μ, τ and missing p_T*
- *Single-top limits*
- *Multi electron, multi muon events*
- *Doubly-charged Higgs limtis*
- *General search*
- *Magnetic Monopoles*

In red the topics covered in this talk

Contact Interaction: Introduction

- *Large Q^2 covered by HERA up to $4 \cdot 10^4$ GeV^2*
- *New physics would produce deviations from SM prediction at high Q^2*





CI: Quark radius form factor

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2}\left(1 - \frac{1}{6}R^2Q^2\right)^2$$

$R_q < 0.85 \times 10^{-16}$ cm *(ZEUS)*

$R_q < 1.0 \times 10^{-16}$ cm *(H1)*

CI: Compositeness

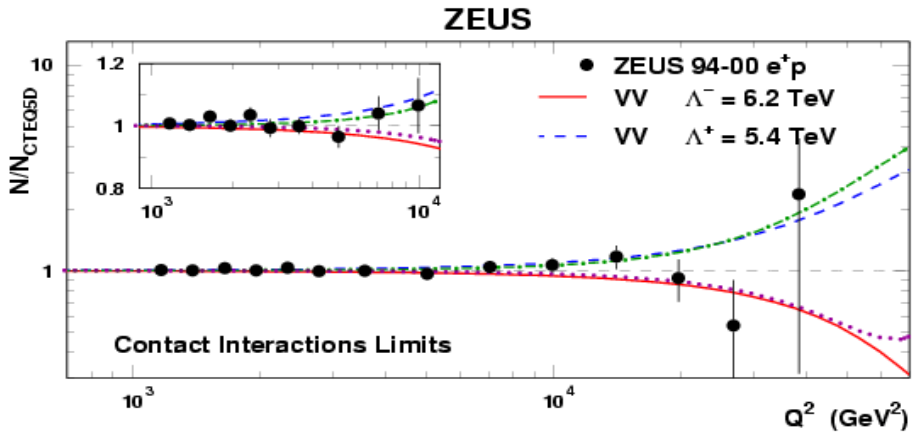
Effective Lagrangian: (vector term only) $\eta_{ij}^{q} = \pm\epsilon_{ij}\frac{4\pi}{\Lambda^2}$

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

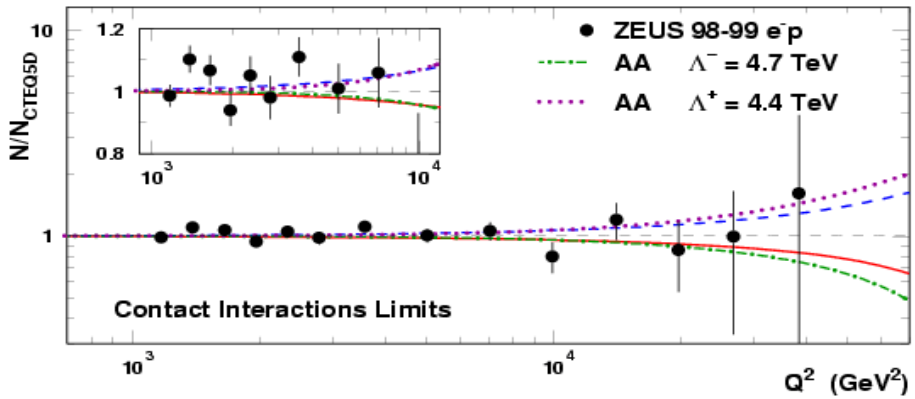
Λ compositeness scale

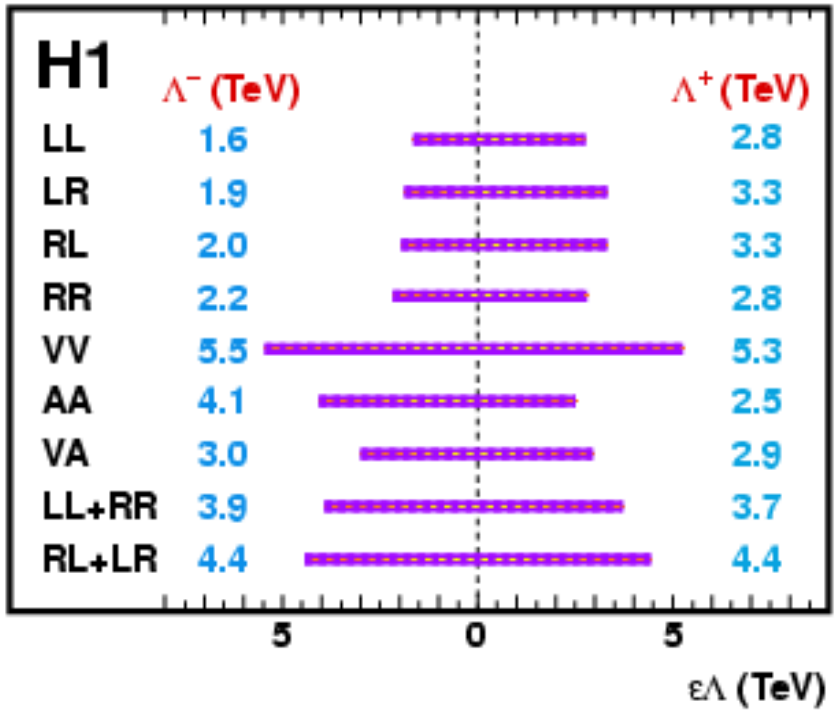
$\varepsilon = 0,1$ (terms considered one by one)

$\varepsilon_{LL} = \varepsilon_{LR} = \varepsilon_{RL} = \varepsilon_{RR}$



$\varepsilon_{LL} = -\varepsilon_{LR} = -\varepsilon_{RL} = \varepsilon_{RR}$



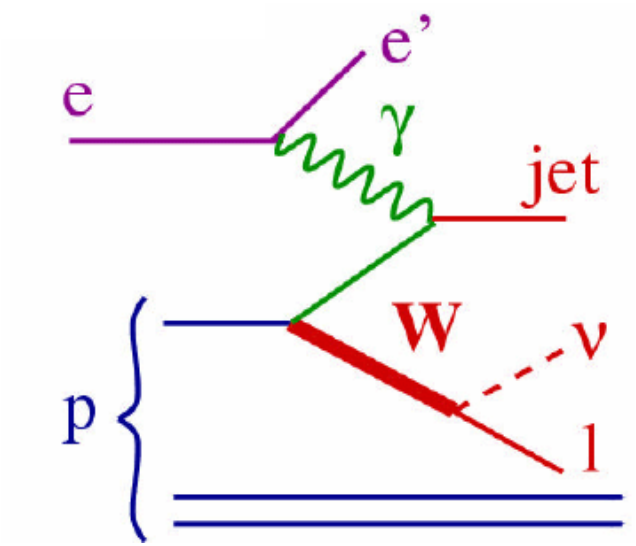


Curves are 95% CL exclusion limits for positive (+Λ) or negative (–Λ) interference term

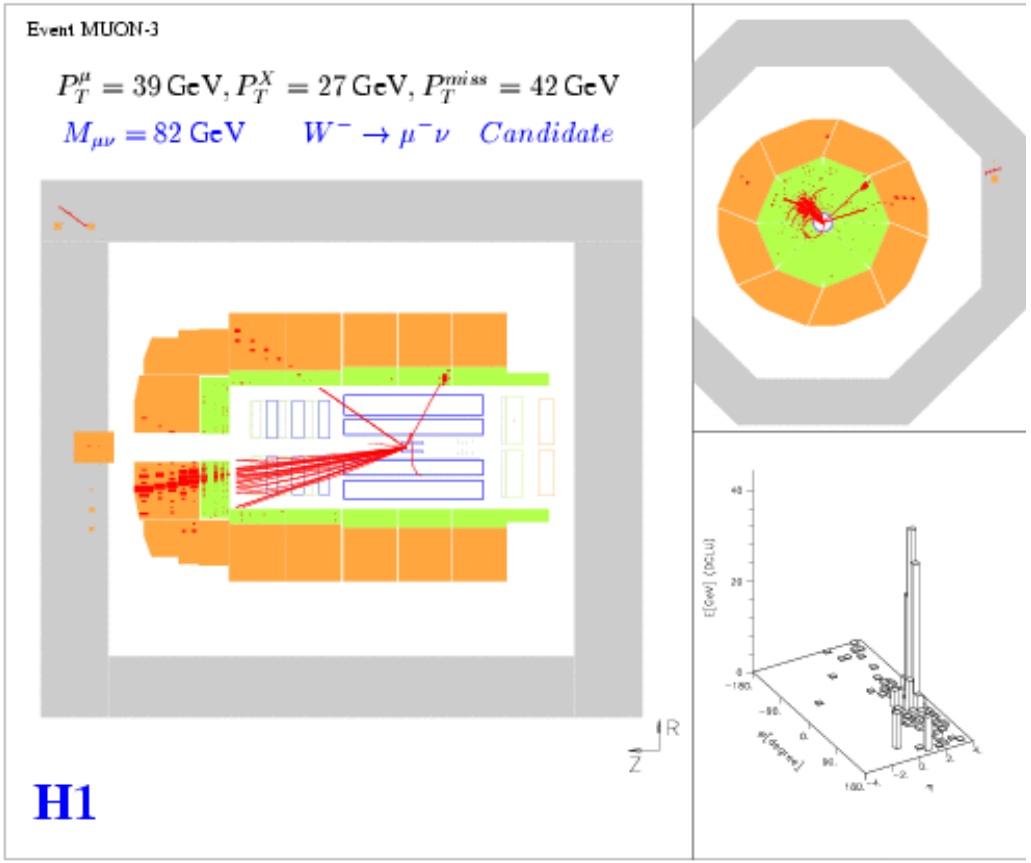
Isolated leptons and missing p_T

Events Topology:

- *High p_T lepton (p_T > 5, 10 GeV)*
- *Missing P_T (> 20, 25 GeV)*
- *Jet*



$e^+p \to e^+\mu^- X$



Dominant SM process is W production: $\sigma(ep \to e\,W^{\pm} X) \sim 1$ *pb*

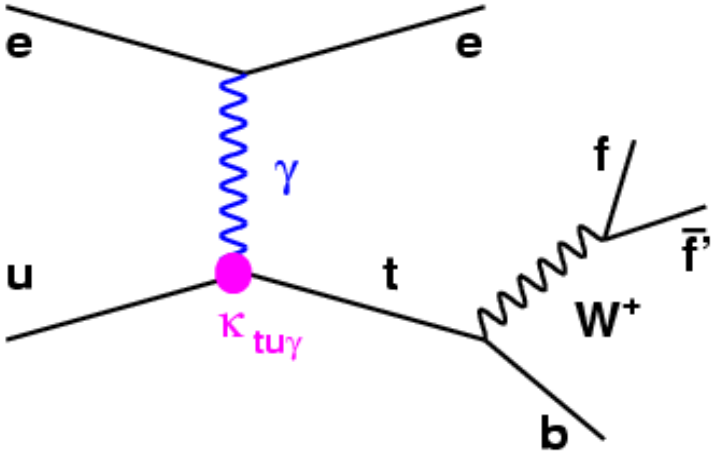
Isolated leptons and missing p_T (2)

		Electrons		Muons		Taus	
H1 118 pb^{-1}	P_T^X cut	Obs.	SM	Obs.	SM	Obs.	SM
	$P_T^X > 25$ GeV	5	1.76 ± 0.30	6	1.68 ± 0.30		
	$P_T^X > 40$ GeV	3	0.66 ± 0.13	3	0.64 ± 0.14		
ZEUS 130 pb^{-1}	$P_T^X > 25$ GeV	2	$2.9^{+0.59}_{-0.32}$	5	2.75 ± 0.21	2	0.20 ± 0.05
	$P_T^X > 40$ GeV	0	$0.94^{+0.11}_{-0.1}$	0	$0.95^{+0.14}_{-0.1}$	1	0.07 ± 0.02

- *H1: observe 6 spectacular events with e or μ and $P_T^X > 40$ GeV*
- *ZEUS: events agree with SM, 2 intriguing events*
- *Is the excess in e^+p collision at high p_T^X new physics?*
- *Single top production*

  via anomalous magnetic and vector

  FCNC top coupling $k_{tu\gamma}$, v_{tuZ}
- *SM cross-section ~ 1fb^{-1}*



Search for Single Top

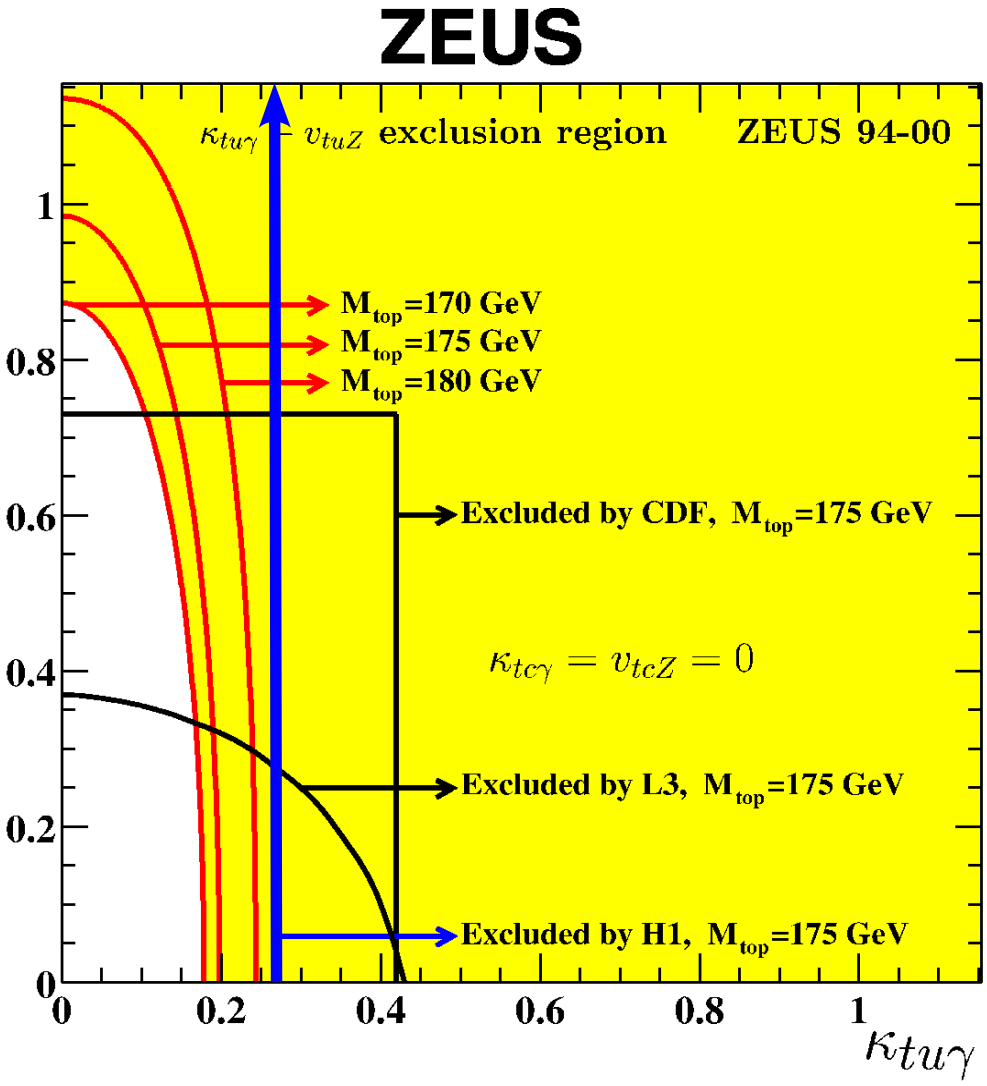
- *H1 observe excess in leptonic channel (e+ μ)*

- *Is this single top via FCNC?*
- ✔ *If yes*
  $\sigma(ep \to etX) \sim 0.29 + 0.15/-0.14$ pb
- ✔ *If not upper limit*
  on $k_{tu\gamma} < 0.27$ @ 95% CL

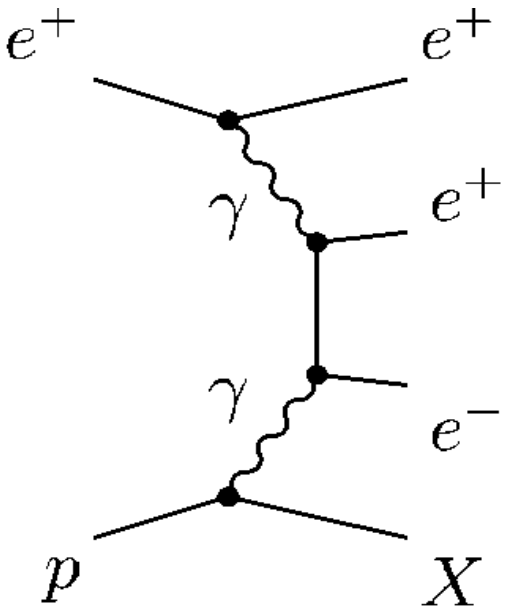
- *ZEUS:*

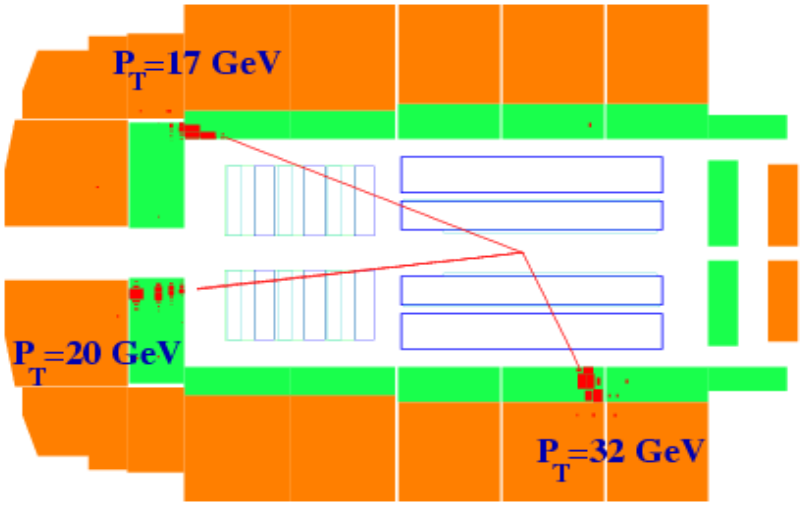
Good agreement with SM

- $\sigma(ep \to etX)$
  < 0.225 pb @ 95% CL
- *Z-exchange evaluated*
  → *limit-curve*



Search for multi lepton events





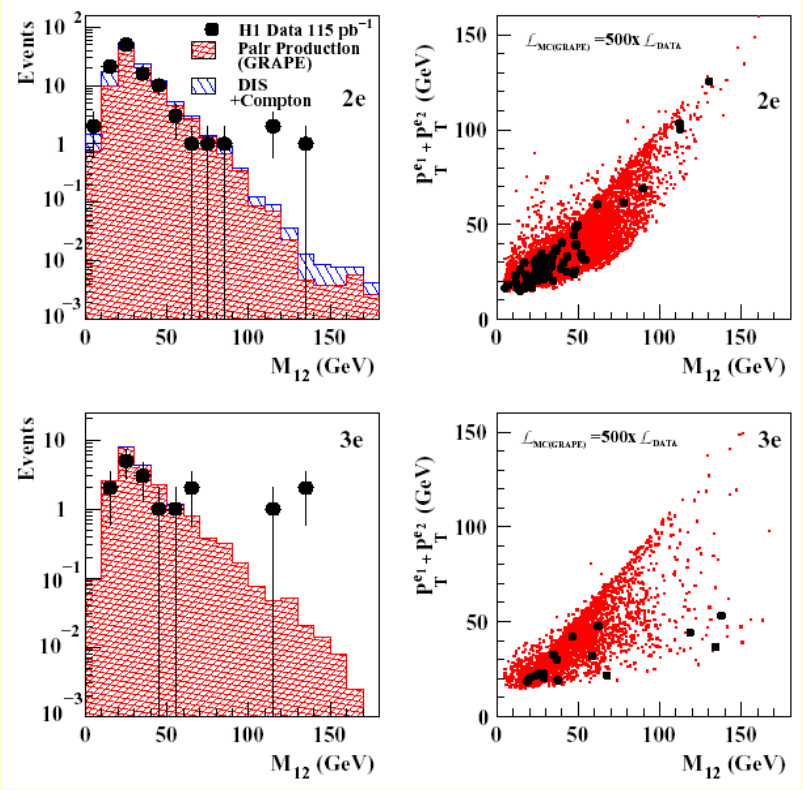
Very clean process which can be sensitive to new physics at high di(tri)-lepton invariant mass

Selection:

- *2 or 3 isolated leptons (ee, eee, μμ, μμe)*
- *p_T > 5 GeV and 10 GeV*
- *3^{rd} electron with E_e > 5 GeV*

Multi lepton events

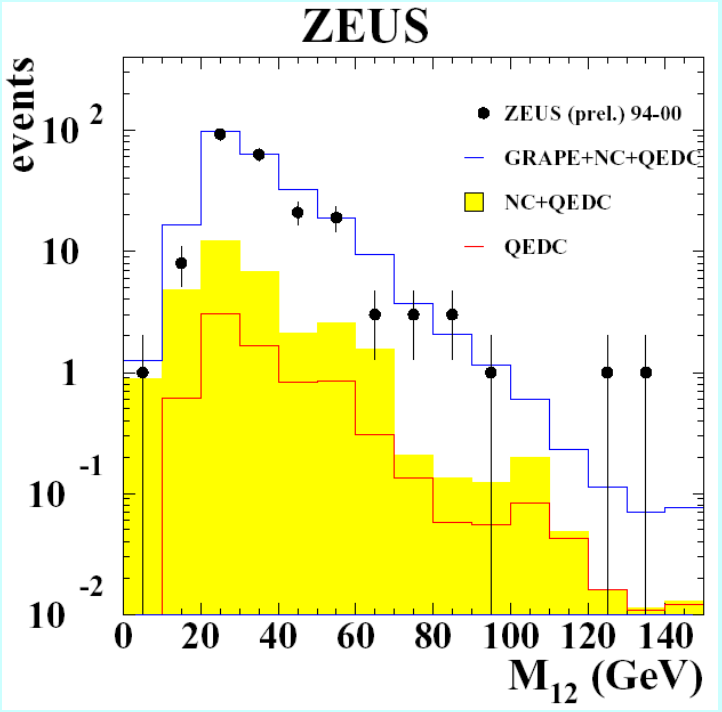
H1



Sample	Data	SM
2e Total	108	117±8.6
3e Total	17	20.3±2.1
2e M_{12}>100 GeV	3	0.30±0.04
3e M_{12}>100 GeV	3	0.23±0.04

6 outstanding events M_{12} > 100 GeV

ZEUS



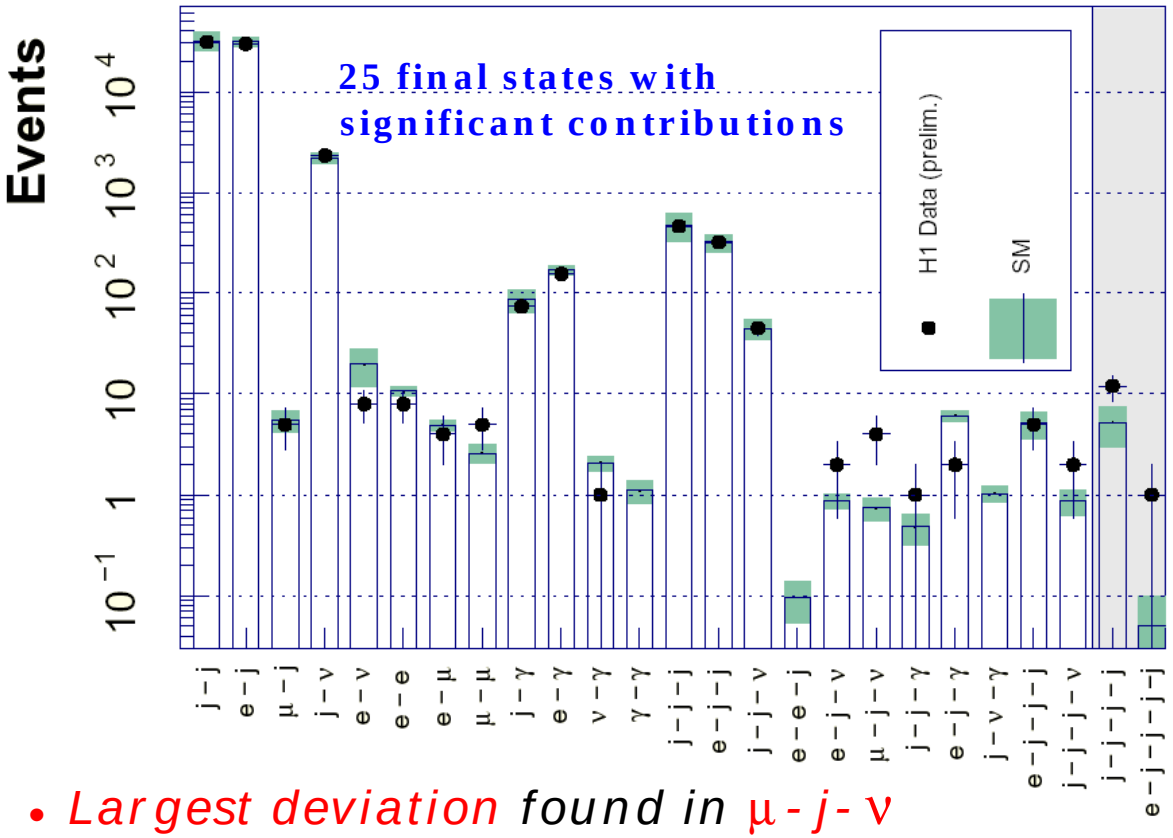
Sample	Data	SM
2e Total	191	213.9±3.9
3e Total	26	34.7±0.5
2e M_{12}>100 GeV	2	0.77±0.08
3e M_{12}>100 GeV	0	0.37±0.04

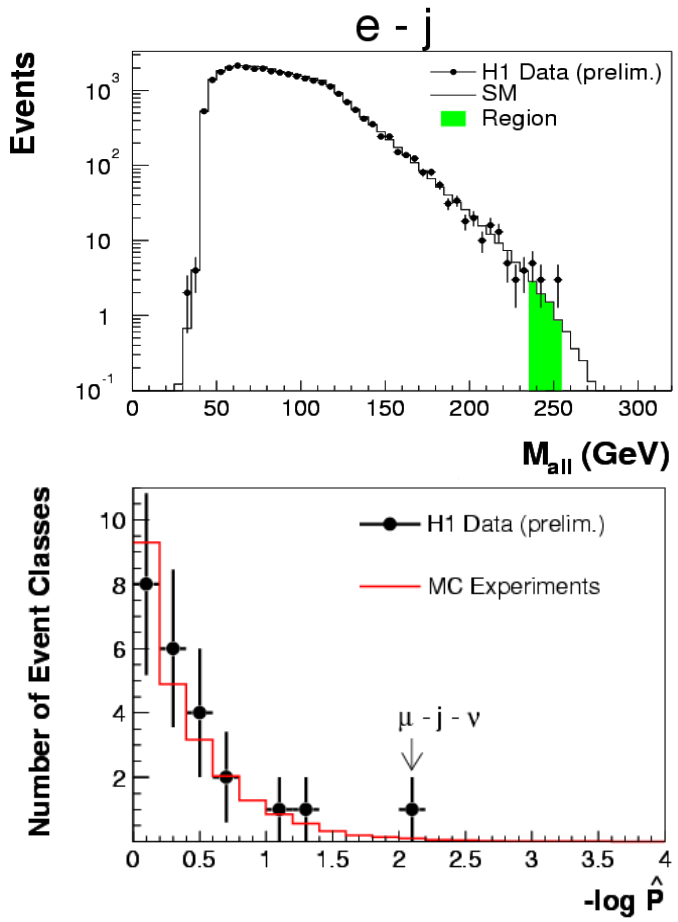
Good agreement with SM

μμ, μμe final states: good agreement with SM (1 μμ event w/ M>100 GeV)

General Search (H1)

- Select events with at least 2 isolated object with $P_T > 20$ GeV
- Object are: e, μ, j , γ and ν or non interacting particle
- $\hat{P}$ statistical estimator to look for large deviation from SM in M_{all} and ? p_T





- Largest deviation found in μ - j - ν

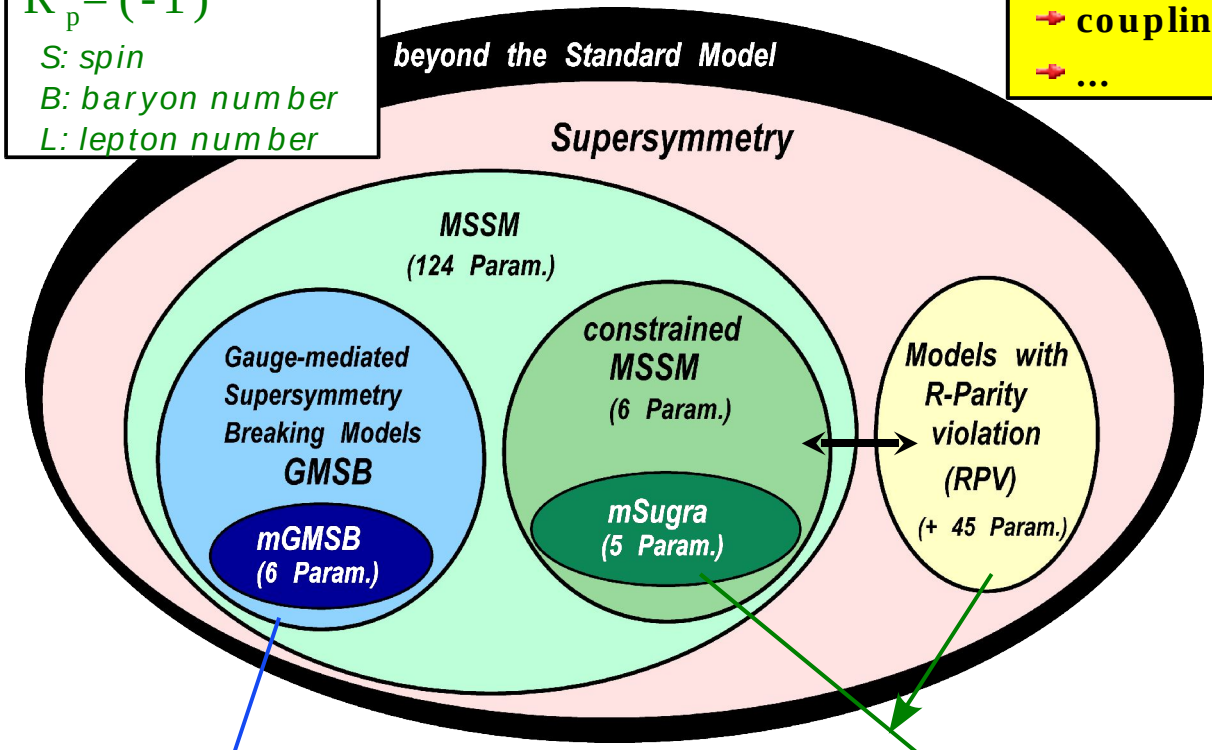
Super-Symmetry Models

Mechanism of SUSY breaking unknown: different models

- symmetry between fermions and bosons
- cancels quadratic divergences in higgs mass
- fine tuning problem
- hierarchy problem
- coupling unification
- ...

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

S: spin
B: baryon number
L: lepton number



Communication via gauge bosons

Communication with our visible world via gravity

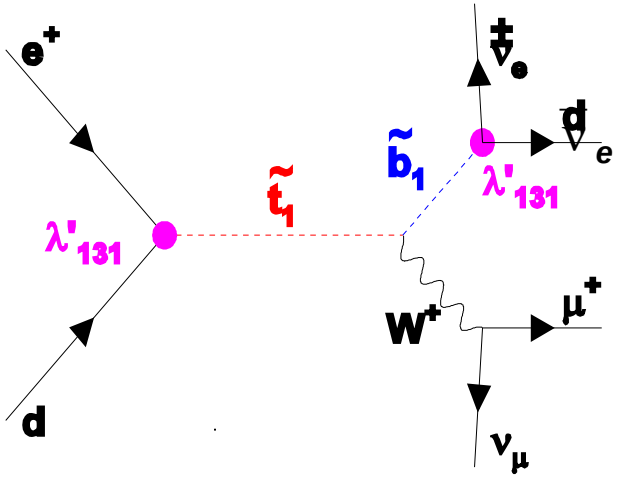
Lightest SUSY Particle, LSP:

MSSM: lightest neutralino
GMSB: gravitino

HERA searches:

RPV+MSSM: squarks
RPV+GMSB: gravitino

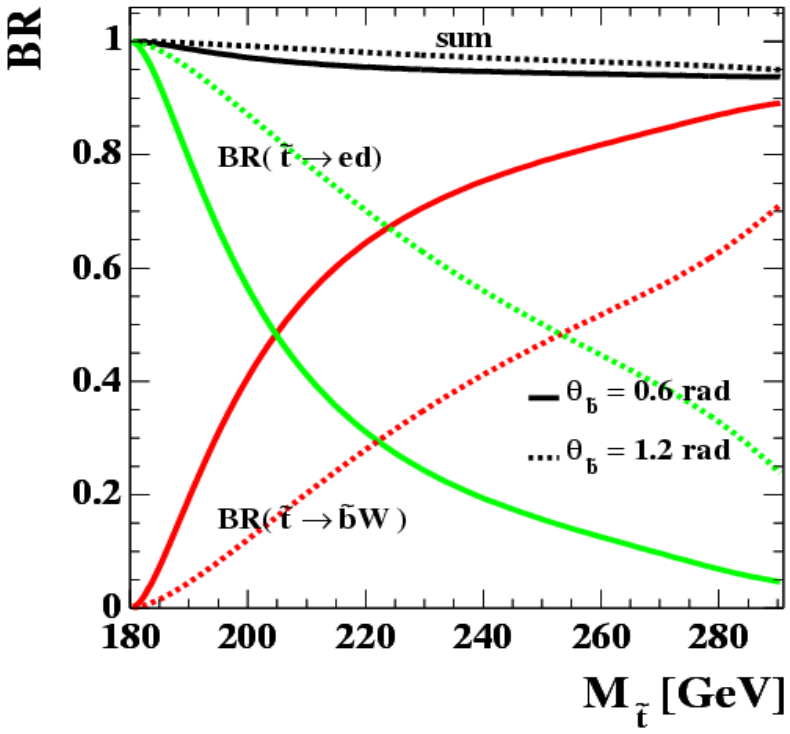
Bosonic Stop Decay

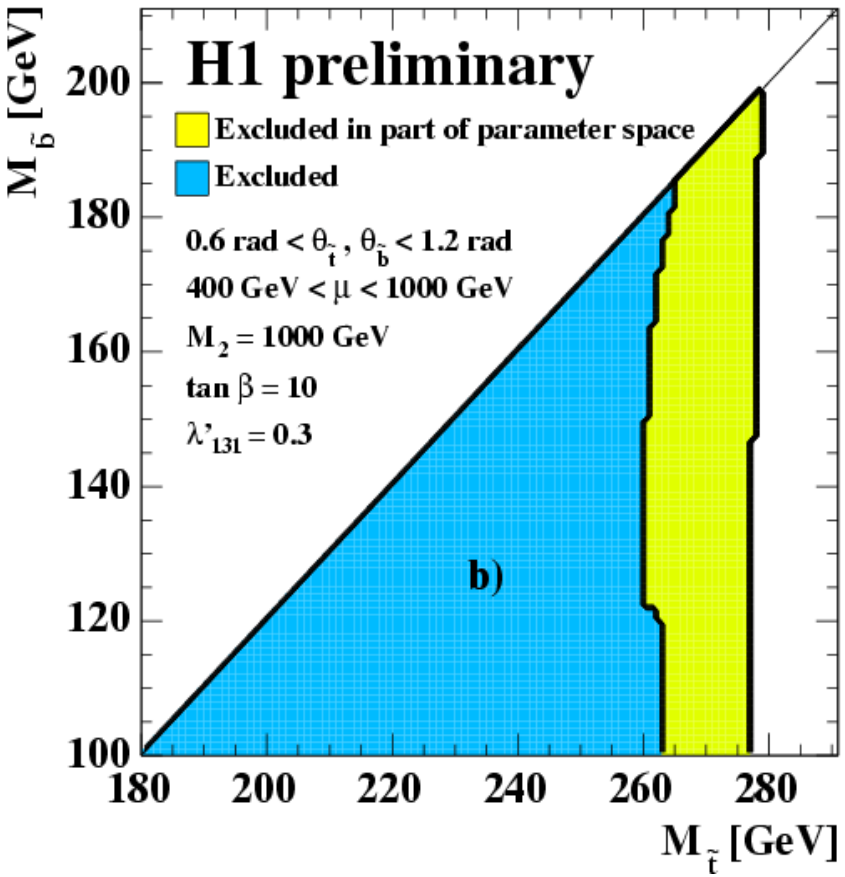


Bosonic decays contribute if allowed kin.

Possible scenario : m(sbottom) < m(stop) and main decay mode of b_1 is $b_1 \rightarrow \nu\, d$

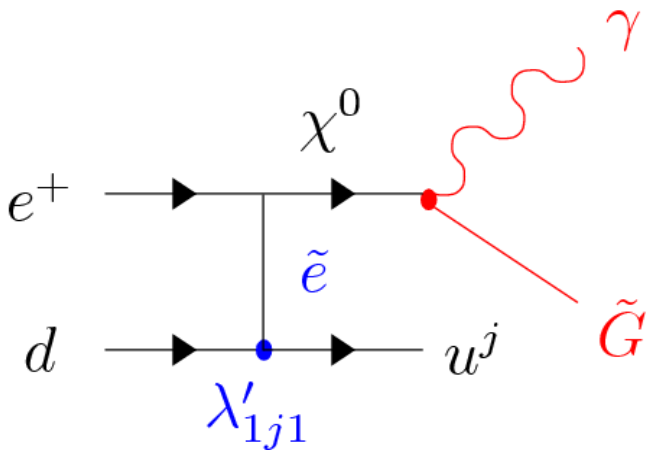
Signature: l + jet + $P_{T,miss}$





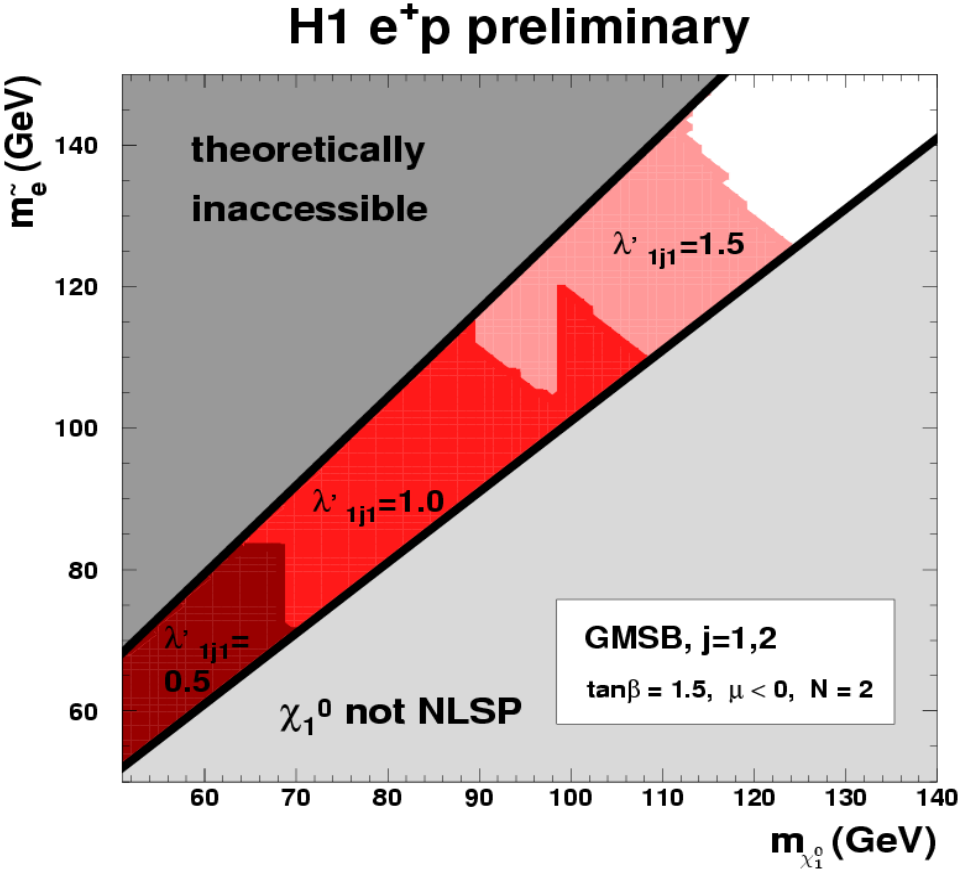
Search for Superlight Gravitinos

SUSY RPV + GMSB scenario:



Gravitiono LSP, χ^0 NSLP
m(squarks) > m(sleptons)

- *Signature: γ + jet + $P_{T,miss}$*
- *1 event found,*
  2.55 ± 1.30 expected



Limits independent of the squark masses

- *Typical LEP limits on sleptons are ~ 90 – 100 GeV*

Conclusions

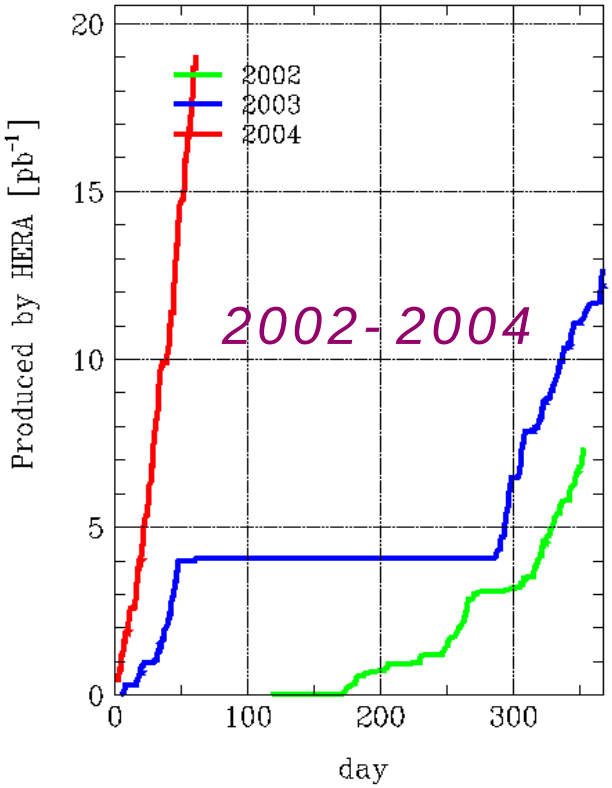
- *HERA is a unique facility to search for new physics and test models (contact-interaction, quark radius, anomalous top production, RPV-SUSY,...)*

- *Outstanding H1 multi-electron events $M_{ee} > 100$ GeV*

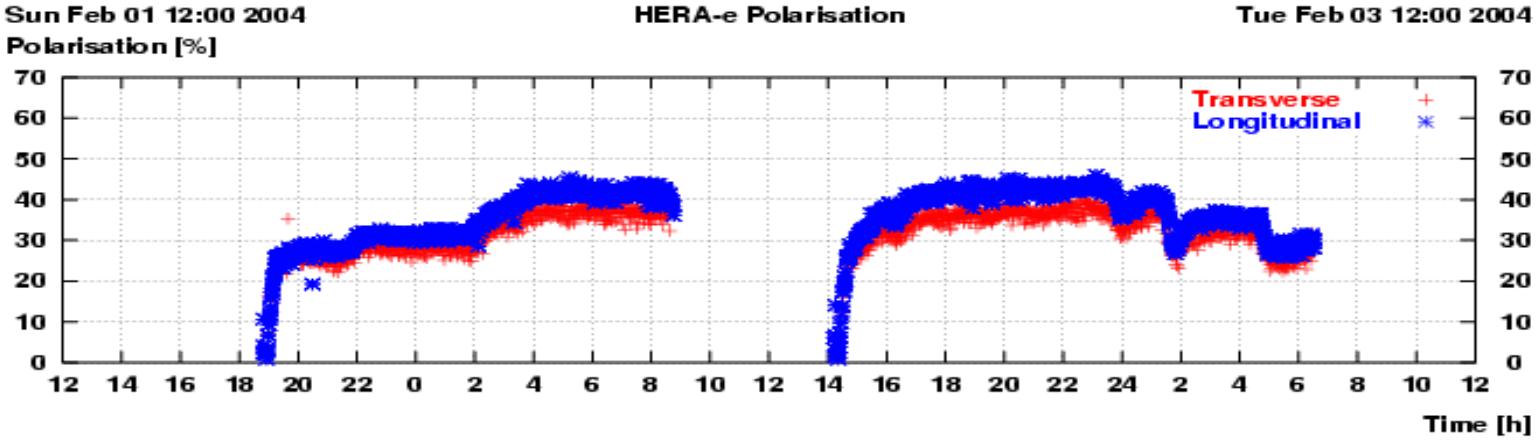
- *Final results on isolated leptons at HERA I:*
  - *Excesss in e, μ channels from H1, in τ channel from ZEUS*
  - *The two results are not easy to explain together*
  - *HERA II will sort out*

- *HERA II plan: x10 more luminosity + e longitudinal polarisation*
  - *HERA II delivered ~ 30 pb^{-1} of luminosity in 2003/4*
  - *Inst. luminosity ($3 \cdot 10^{31}$ $cm^{-2}s^{-1}$) higher than HERA I*
  - *Longitudinal polarization ~ 30-50%*

Outlook: HERA II

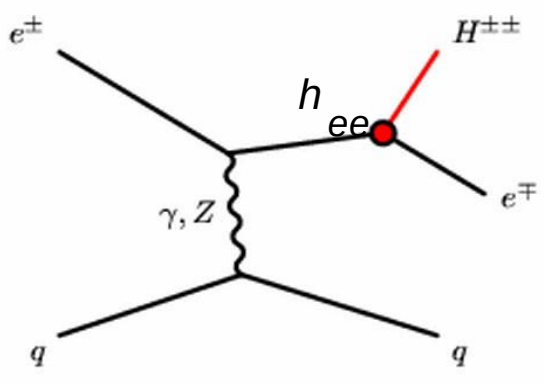


- *HERA II delivered ~ 30 pb^{-1} of luminosity in 2003-2004*
- *Instantaneous luminosity ($3 \cdot 10^{31}$ cm^{-2}s^{-1}) already higher than HERA I*
- *Longitudinal electron polarization > 30%*



Backup Slides

Search for Doubly Charged Higgs



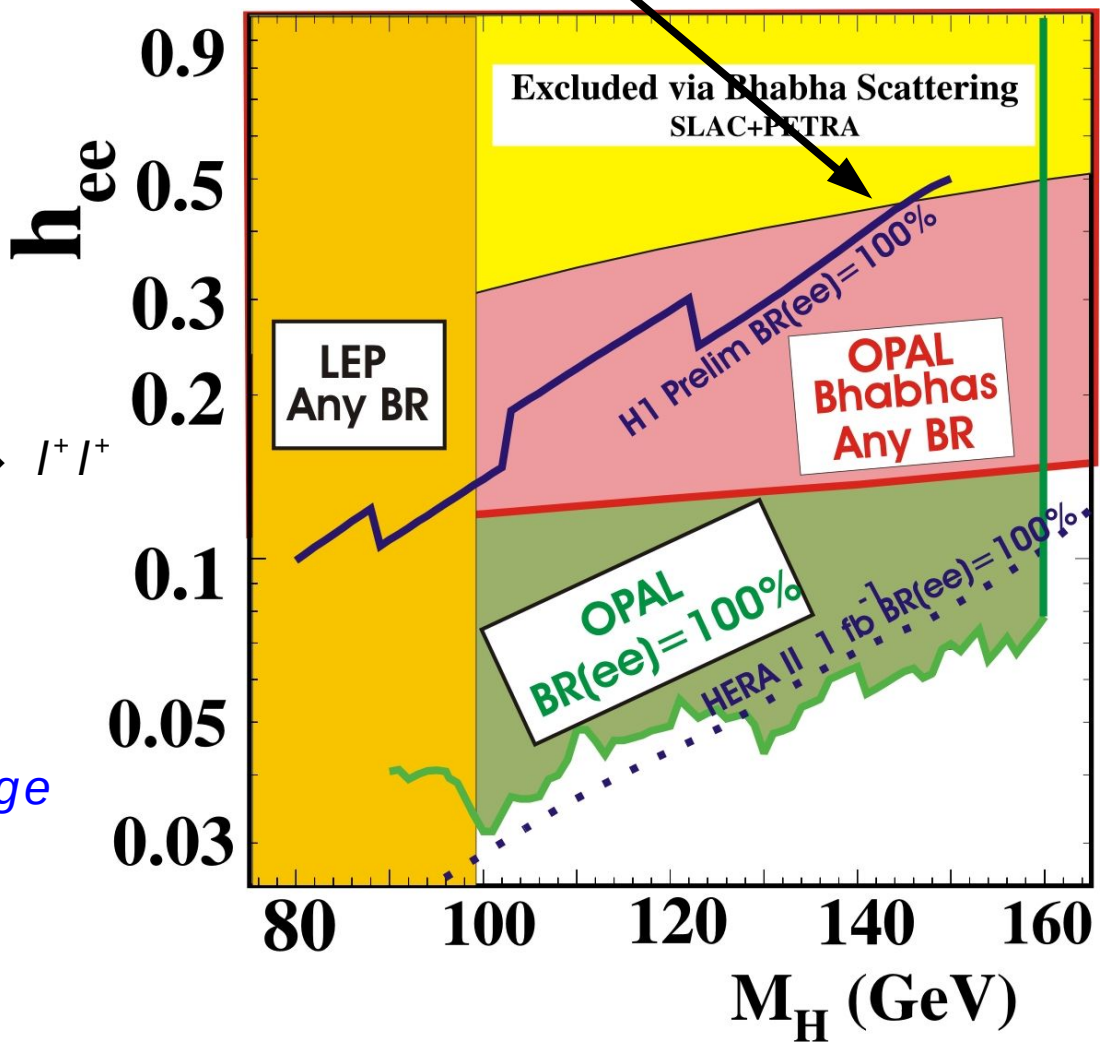
single production at HERA

H^{++} predicted in LR symmetric models

At HERA: $e^+p \rightarrow e^-H^{++}X$, $H^{++} \rightarrow l^+l^+$ $\rightarrow$ multi-lepton final state !
Sensitivity to h_{ee} coupling

H1 combines e and μ channels
Only one ee event fulfills charge requirement

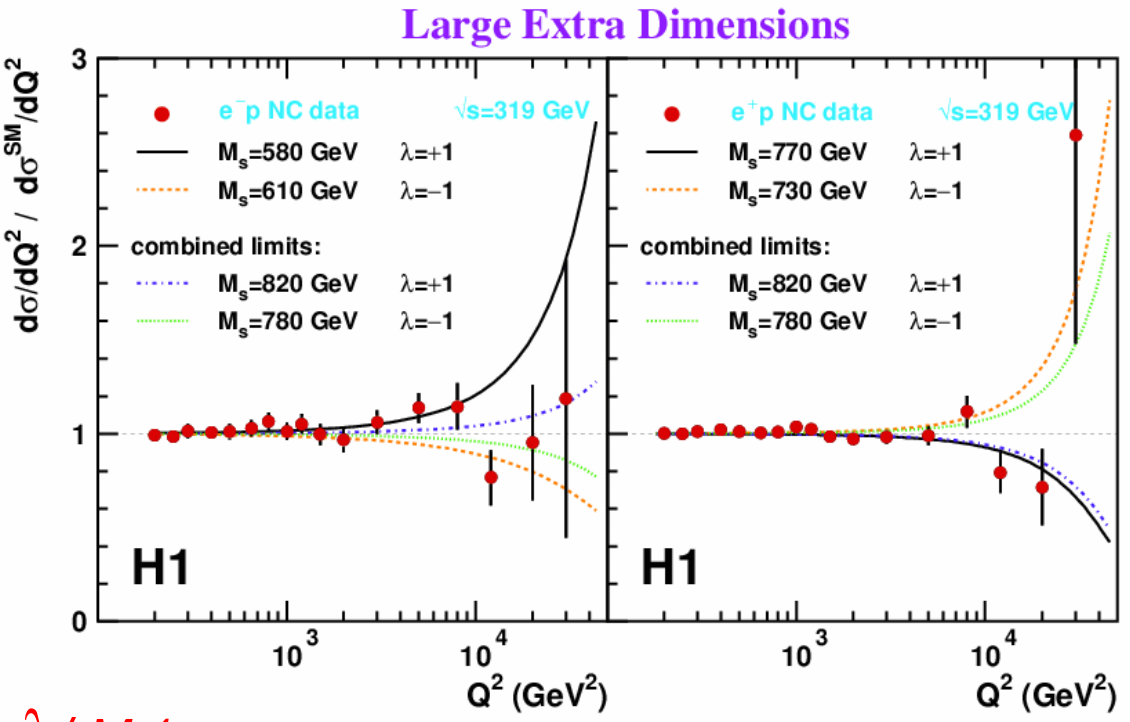
H^{++} interpretation unlikely



CI: Large extra dimensions

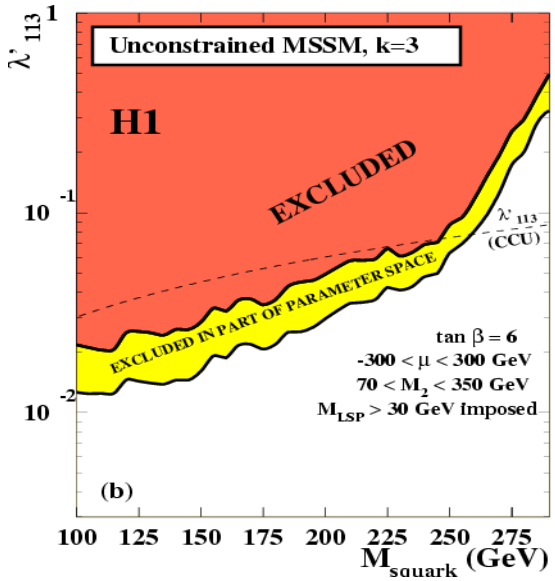
Arkani-Hamed et al. [Phys.Lett. B429, 263 (1998)]:

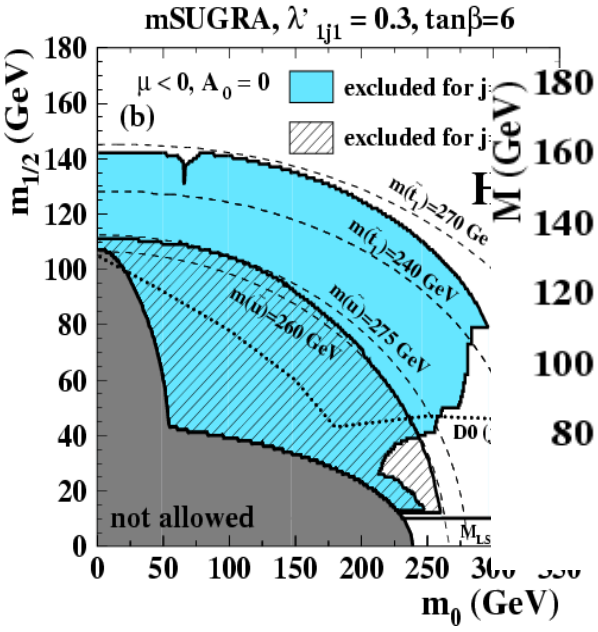
- SM particles propagate in 4-D, gravitons in (4+n)-D
- $M_p^2 = R^n M_s^{2+n}$
  - M_s scale of the 4+n theory (~1 TeV)
  - R = size of n compact extra dimensions
- Virtual Kaluza-Klein "graviton" exchange interferes with γ,Z
- Effective coupling $\eta_G = \lambda / M_s^4$

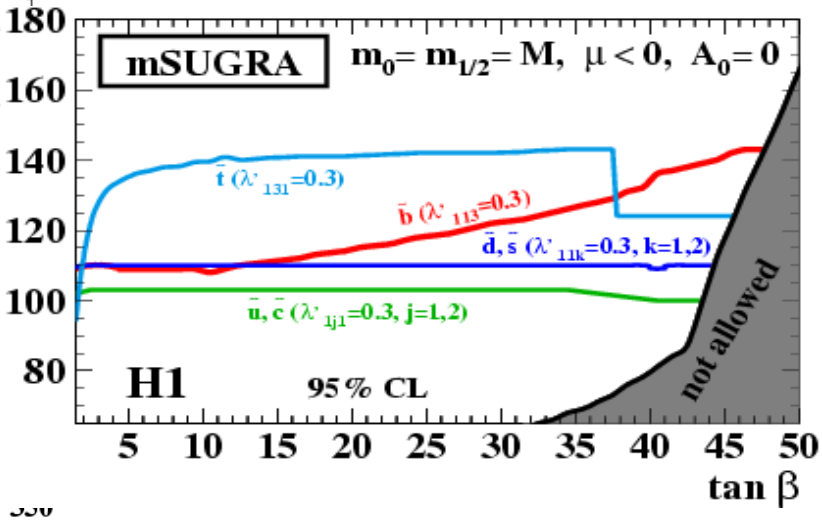


Limits	H1	ZEUS
λ=-1	0.78 TeV	0.82 TeV
λ=+1	0.82 TeV	0.81 TeV

Squarks


Unconstrained MSSM, k=3
H1
EXCLUDED
EXCLUDED IN PART OF PARAMETER SPACE
λ'_{113} ($\bar{c}\bar{c}\bar{u}$)
tan β = 6
-300 < μ < 300 GeV
70 < M_2 < 350 GeV
M_{LSP} > 30 GeV imposed
(b)
λ'_{113}
M_{squark} (GeV)

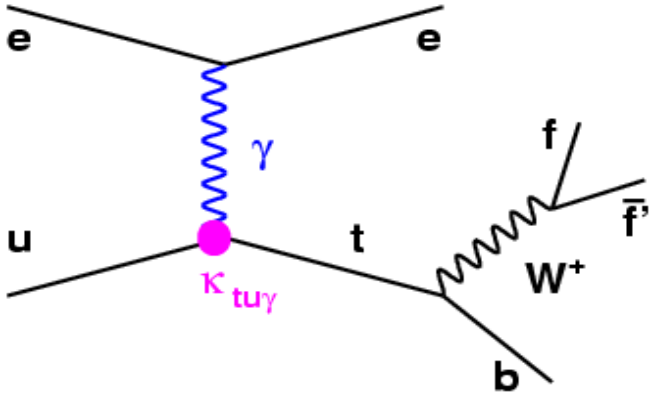

mSUGRA, λ'_{1j1} = 0.3, tanβ=6
μ < 0, A_0 = 0
(b)
excluded for j
excluded for j
$m(\tilde{t}_1)$=270 Ge
$m(\tilde{t}_1)$=240 GeV
$m(\tilde{u})$=275 GeV
$m(\tilde{u})$=260 GeV
D0 (
not allowed
M_{LS}
$m_{1/2}$ (GeV)
m_0 (GeV)


mSUGRA
m_0= $m_{1/2}$= M, μ < 0, A_0= 0
$\bar{t}$ (λ'_{131}=0.3)
$\bar{b}$ (λ'_{113}=0.3)
$\bar{d}$, $\bar{s}$ (λ'_{11k}=0.3, k=1,2)
$\bar{u}$, $\bar{c}$ (λ'_{1j1}=0.3, j=1,2)
H1
95% CL
not allowed
tan β

Isolated leptons and missing p_T (2)

		Electrons		Muons		Taus	
	P_T^X cut	Obs.	SM	Obs.	SM	Obs.	SM
H1 118 pb^{-1}	$P_T^X > 25$ GeV	5	1.76 ± 0.30	6	1.68 ± 0.30		
	$P_T^X > 40$ GeV	3	0.66 ± 0.13	3	0.64 ± 0.14		
ZEUS 130 pb^{-1}	$P_T^X > 25$ GeV	2	2.9 +0.59/-0.32	5	2.75 ± 0.21	2	0.20 ± 0.05
	$P_T^X > 40$ GeV	0	0.94 +0.11/-0.1	0	0.95 +0.14/-0.1	1	0.07 ± 0.02

- *Is the excess in e^+p collision at high p_T^X new physics?*
- *Single top production via anomalous magnetic and vector FCNC top coupling $k_{tu\gamma}$, v_{tuZ}*
- *SM cross-section ~ 1fb^{-1}*

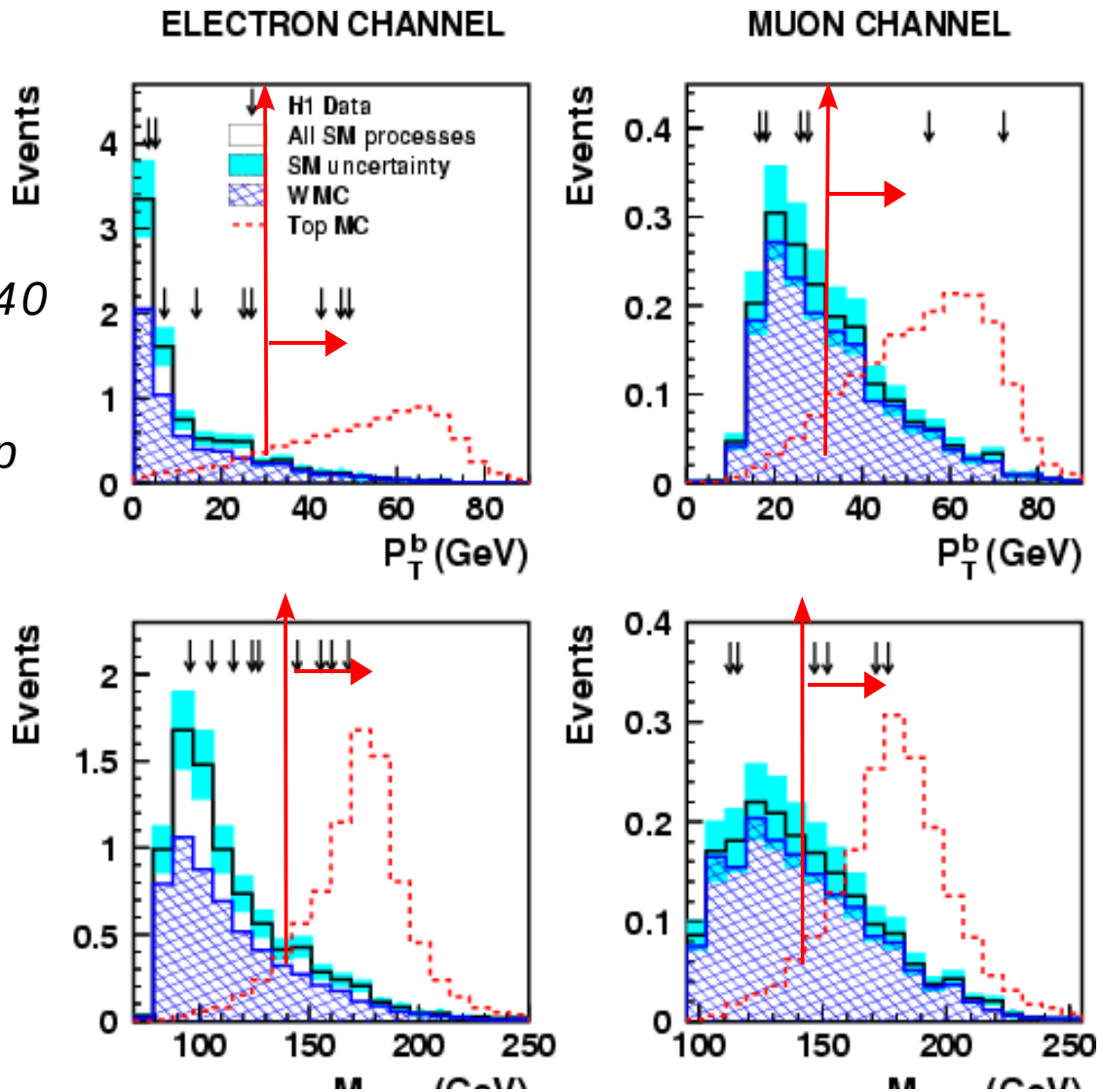


Single top: semi-leptonic decays

- *ZEUS: no events with* $P_T^X > 40$ *GeV*
- *H1: further cuts to select top*
  - *Only positive leptons*
  - $P_t^{jet} > 30$ *GeV,* $M_{lvb} > 140$ *GeV*

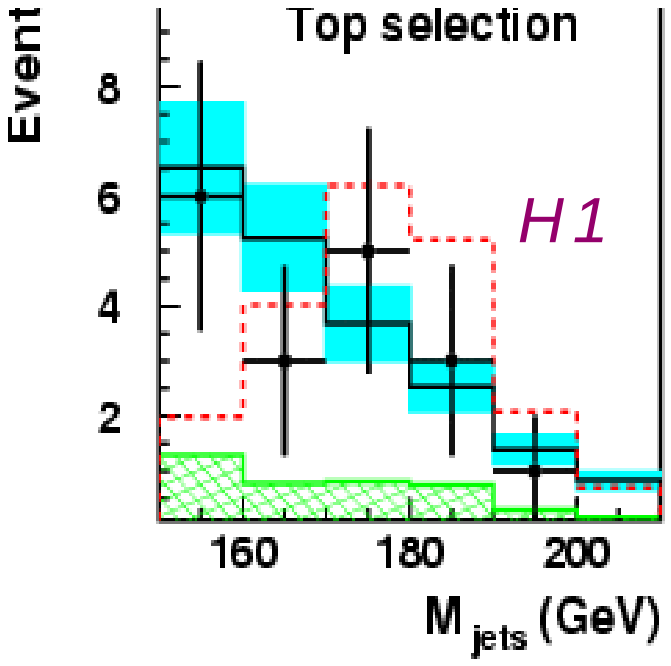
5 events (3e,2μ) – SM 1.31± 0.22

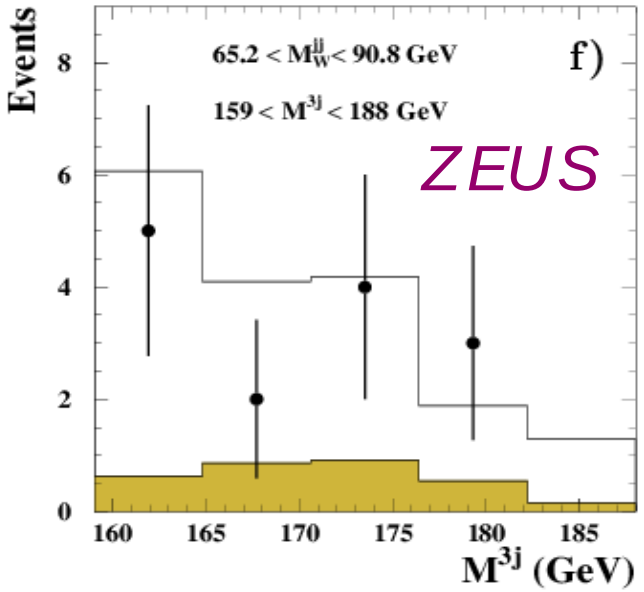
Top efficiency:
36% electron
38% muon



Single top: hadronic decays

Cut	H1	ZEUS
P_T^{jet}	40,30,15 GeV	40,25,14 GeV
W mass window	$65 < M_{jj} < 95$ GeV	$62.5 < M_{jj} < 90.8$ GeV
Top mass window	$150 < M_{jets} < 210$ GeV	$159 < M_{jets} < 188$ GeV

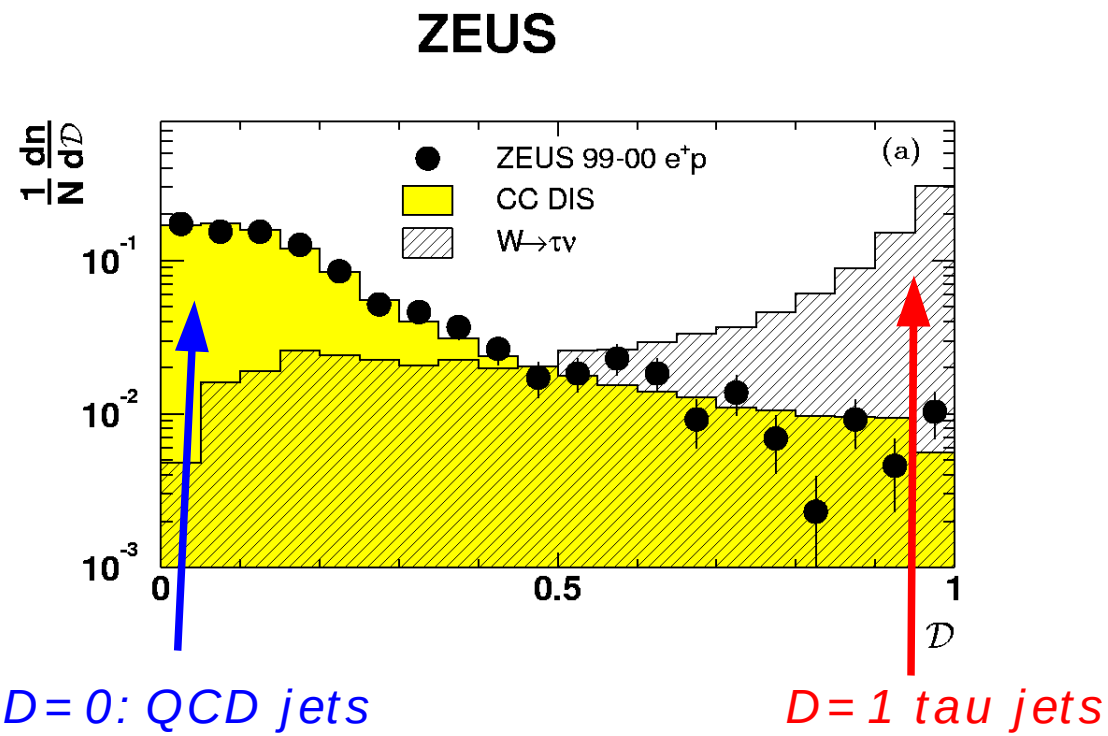




Both experiments agree with SM in the hadronic channel

Isolated τ events

- Extend search for isolated high-p_T leptons and missing p_T to τ-lepton decaying hadronicaly
- τ selected using discriminant D base on jet-shape variable: pencil-like jet, only 1 track in jet

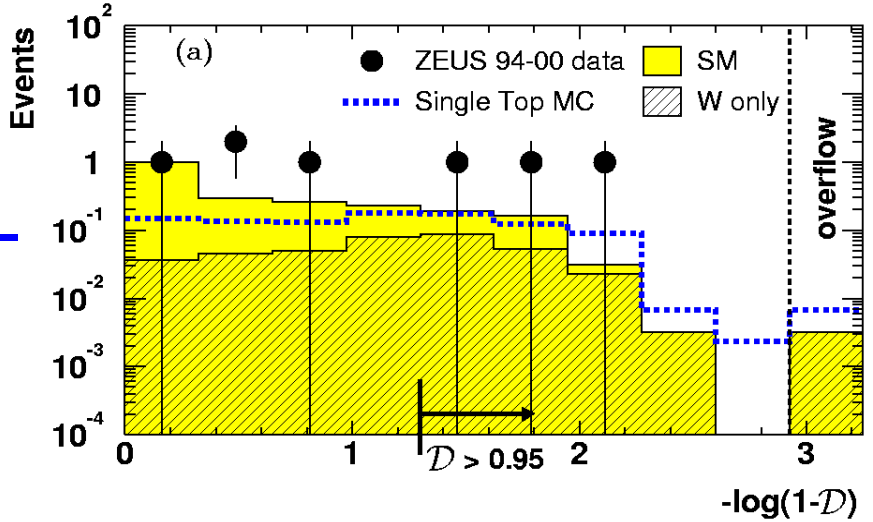


Isolated τ events

- $p_T^{miss} > 20$ GeV
- Isolated track, $p_T^{track} > 5$ GeV

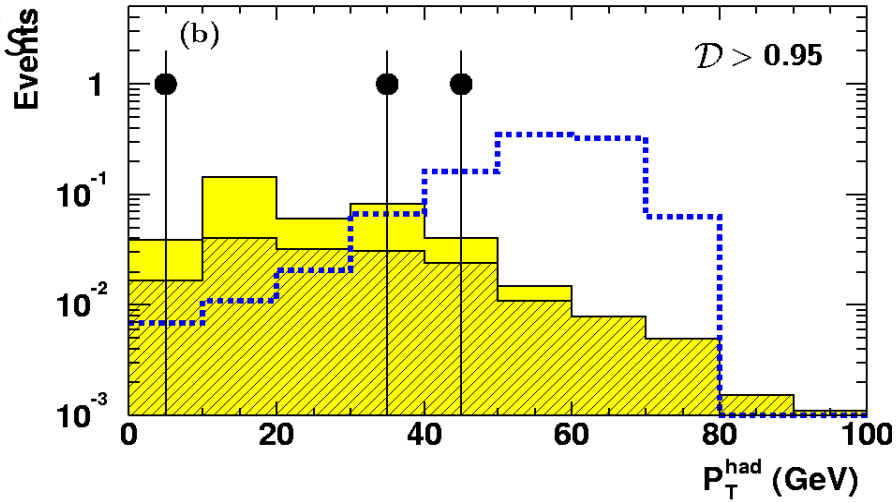
Cut	Data	SM
$\phi_{aco} > 8^0$	7	2.2 +0.39/-0.58
$D > 0.95$	3	0.40 +0.12/-0.13
$P_T^X > 25$ GeV	2	0.20 ± 0.05

(Prob. statistical fluctuation 1.8%)



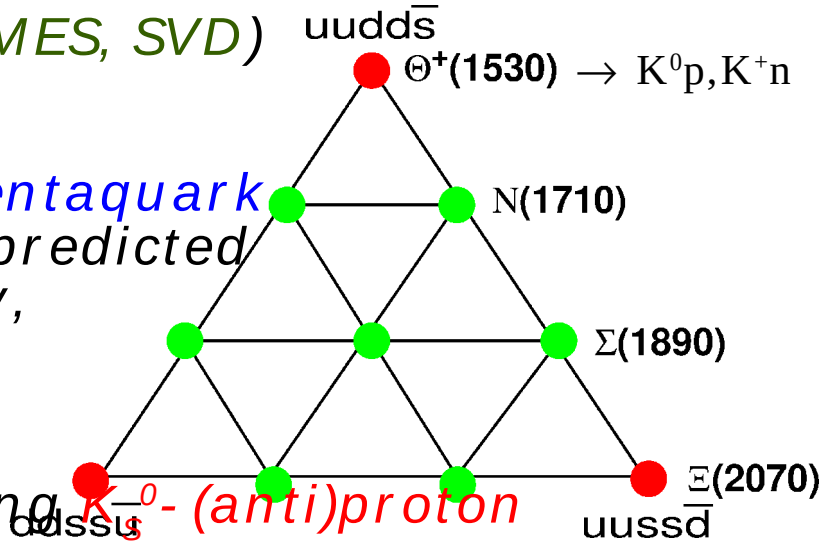
- Not compatible with e/μ/jet channels
- 2 events have opposite charge while top produce anti-lepton (anti-top production highly suppress in ep collision)

⇒ unlikely to be single top



Search for $K^0_S p$ resonance

- Several *fixed target experiments* observe a narrow baryon $S=+1$ resonance ~ *1530 MeV*, (*LEPS, DIANA, CLAS, SAPHIR, HERMES, SVD*)
- *Observation* compatible with Θ^+ *pentaquark* at *1530 MeV and width < 15 MeV*, predicted in the soliton model by D.Diakonov, V.Petrov and M.Polyakov
- Search of *pentaquark* reconstructing K^0_S- (anti)proton invariant mass
- The search is performed in the *central-tracking region*, where hadron *production is dominated by fragmentation*



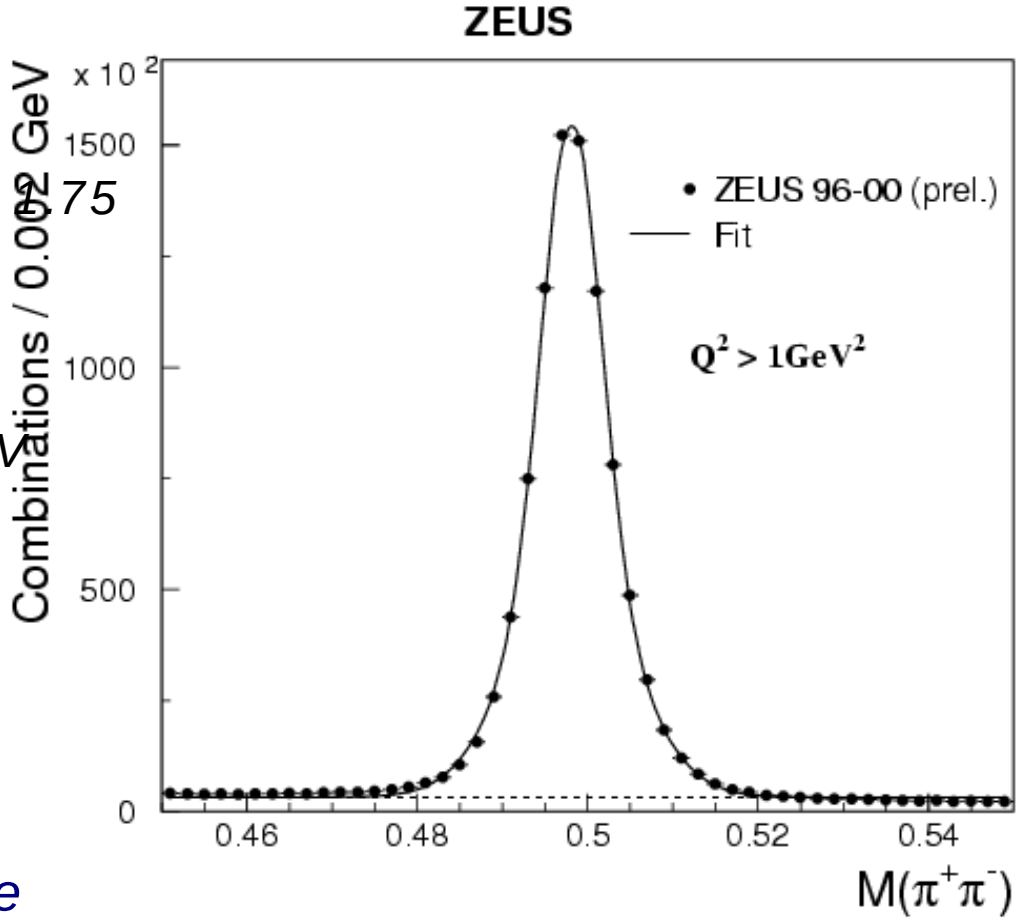
Search for $K^0_S p$ resonance: K^0_S selection

Data Set

- *121 pb^{-1}, 1996-2000 $e^{\pm}p$ data @ 300-319 GeV*
- *DIS events $Q^2 > 1$ GeV*

K^0_S selection: $K^0 \to \pi^+\pi^-$

- *CTD tracks, $p_T > 150$ MeV, $|\eta| < 1.75$*
- *K^0_S from secondary vertex*
- *Photon conversion removed: $M(e^+e^-) < 50$ MeV*
- *Λ's removed $M(\pi p) < 1121$ MeV*
- *$p_T(K^0) > 300$ MeV; $|\eta(K^0)| < 1.5$*



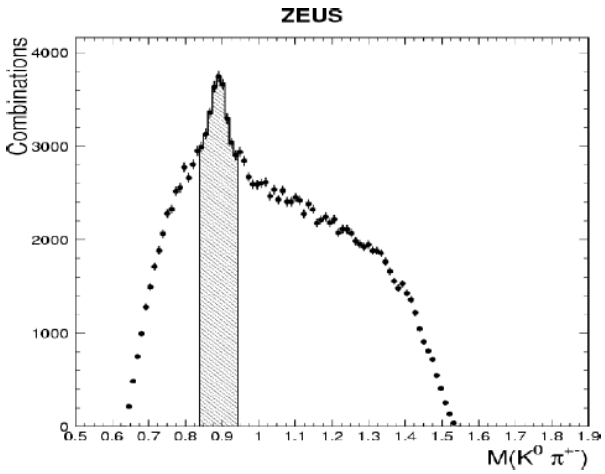
Double Gaussian + linear background fit

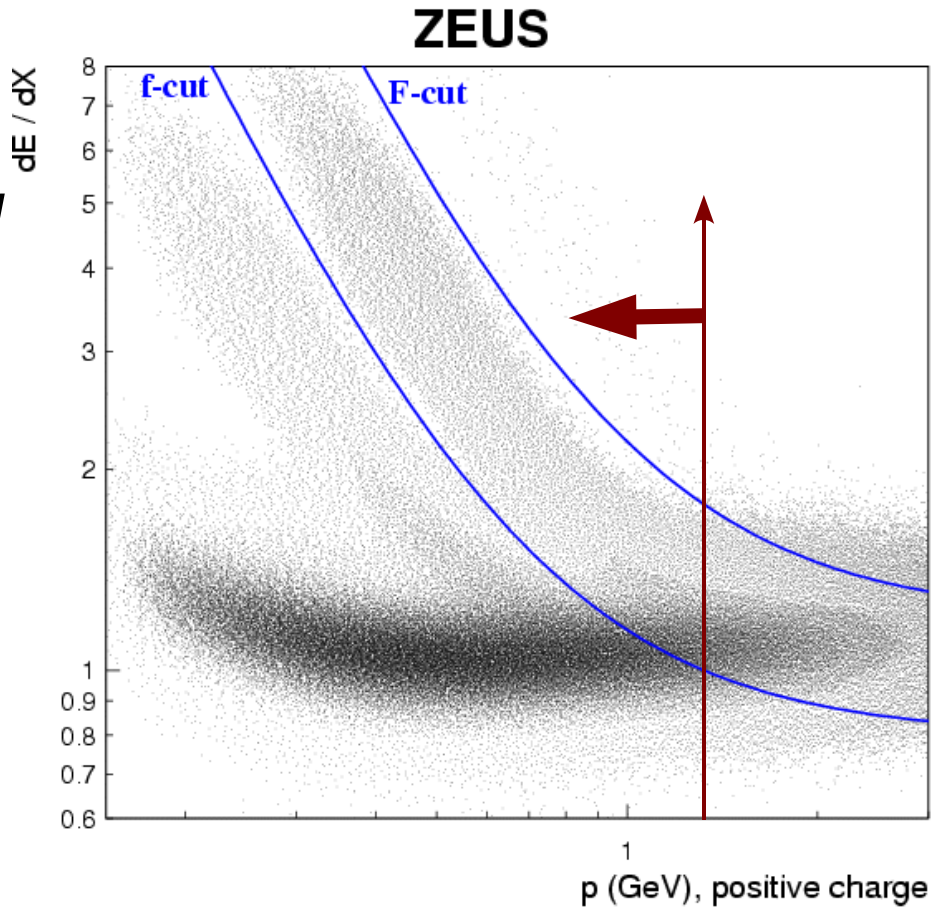
869690 ± 1016 K^0 candidate
background ~ 6%

Peak at 498.12 ± 0.01 (stat) MeV

Search for $K^0_S p$ resonance: p selection

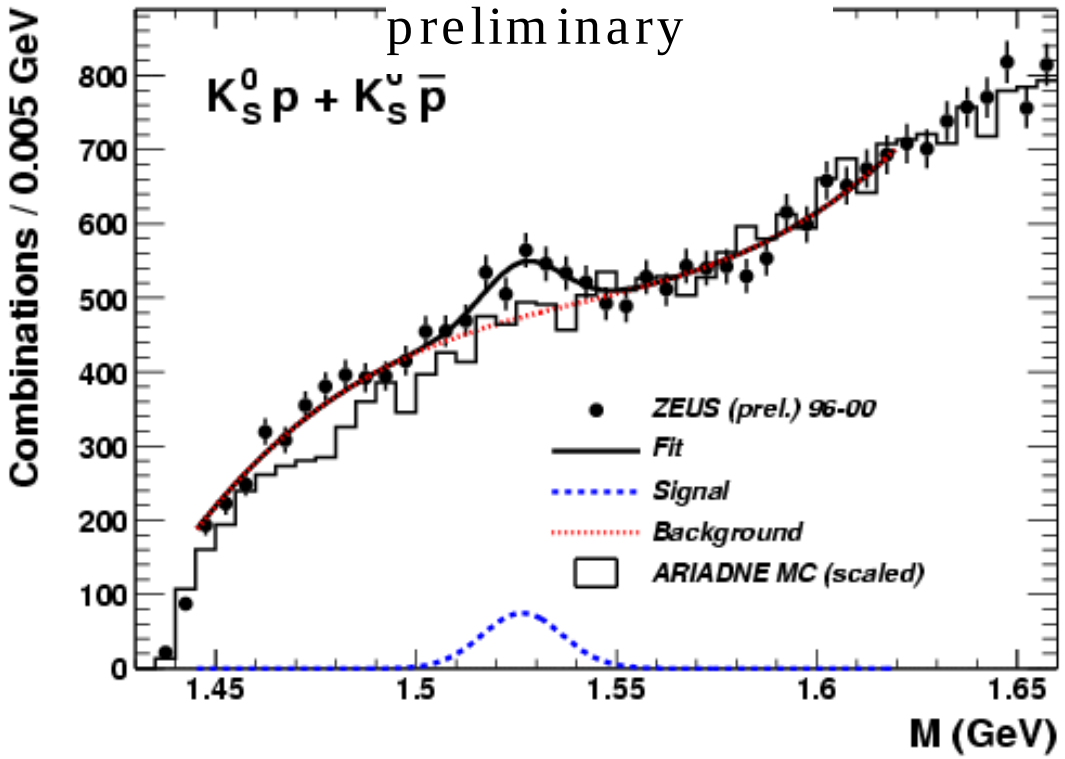
- Most of the signal $p \sim 0.8\text{-}2$ GeV
- $p < 1.3$ GeV inside dE/dx band
- E(proton) > $E(K^0)$
- Assign pion mass to proton candidate, reconstruct K^0?, reject pions from K*: $800 < M(K^0?) < 980$ MeV





$K^0_S p$(anti-p) invariant mass

Fit: Gaussian + p3(free parameter)



Combined sample: 372± 75 candidates

Peak 1527 ± 2(stat) MeV, width 10 ± 2(stat) MeV

(Mass resolution from MC simulation: 4± 1 MeV)