

Searches for New Physics in ep Collisions at HERA



*XXXIX Rencontres de Moriond
on Electroweak Interactions
and Unified Theories*



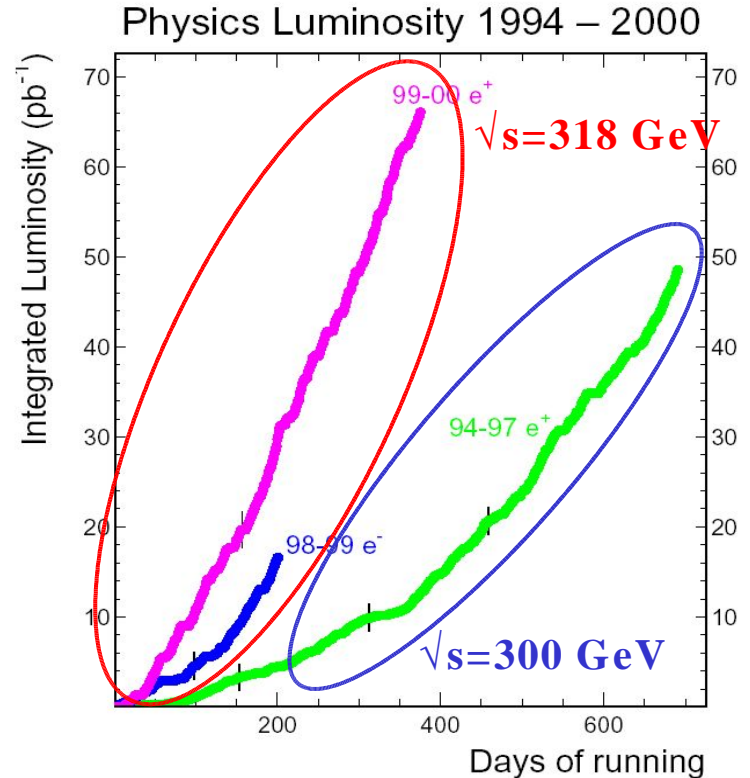
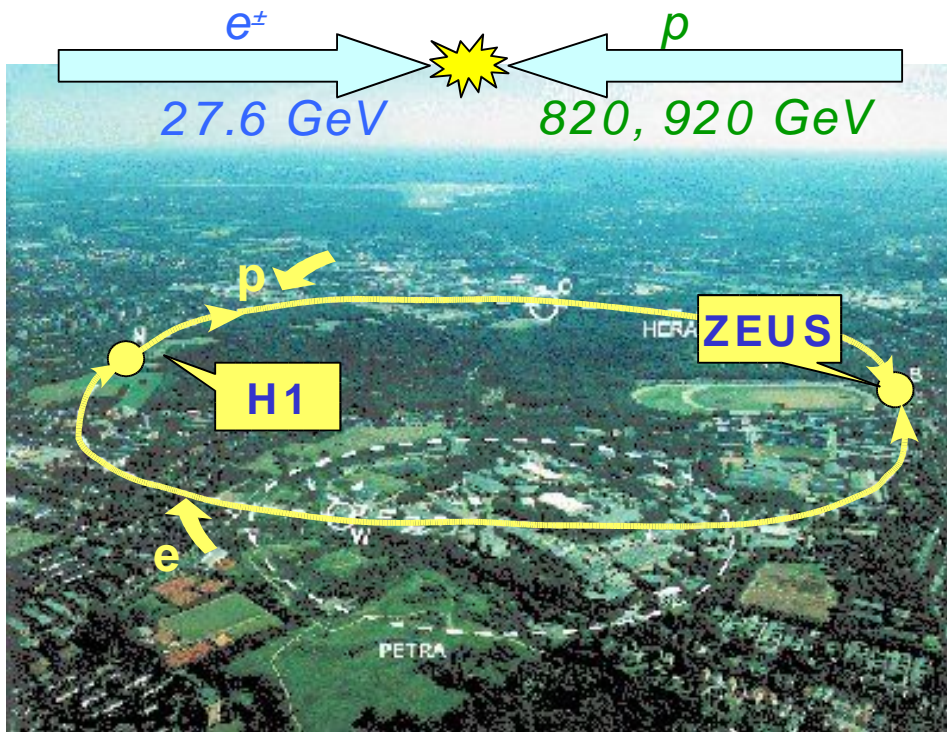
*La Thuile, Aosta Valley, Italy,
March 21-28, 2004*

Bob Olivier, DESY

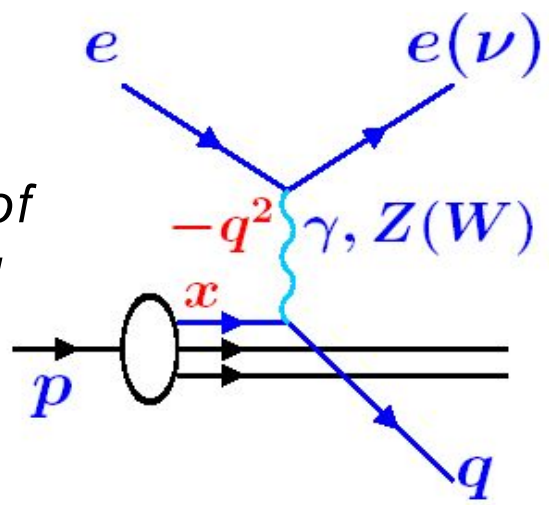
on behalf of H1 and ZEUS collaborations



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

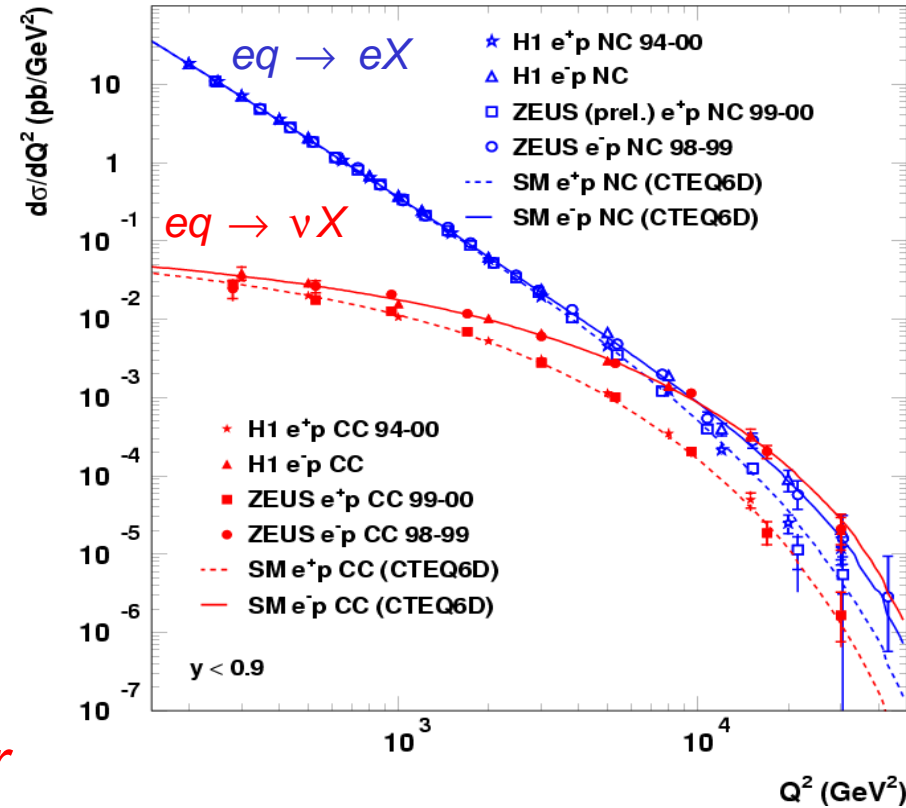
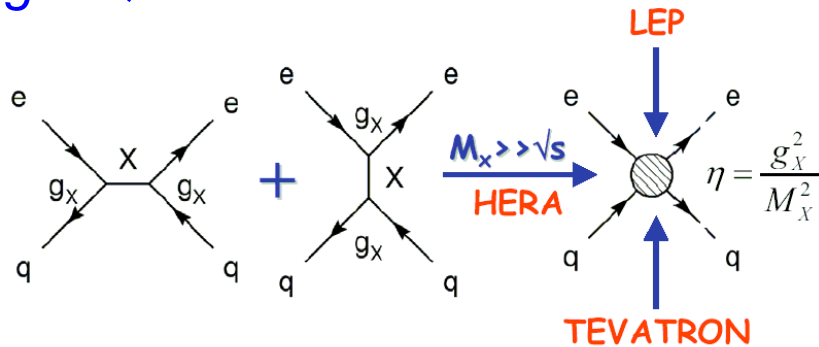
Exclusive final states

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

In red the topics covered in this talk

Contact Interaction: Introduction

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



CI: Quark radius form factor

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

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

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

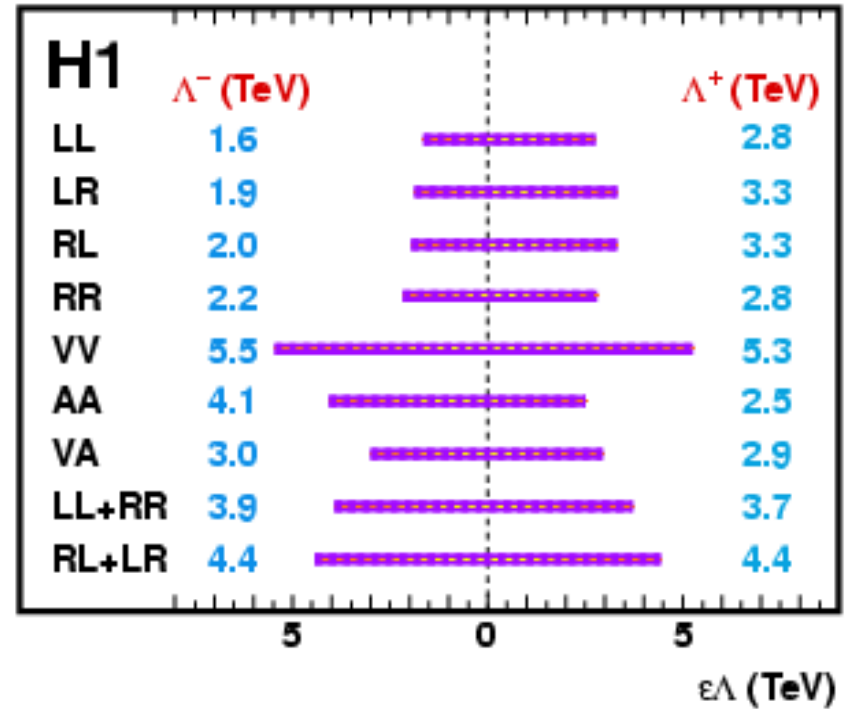
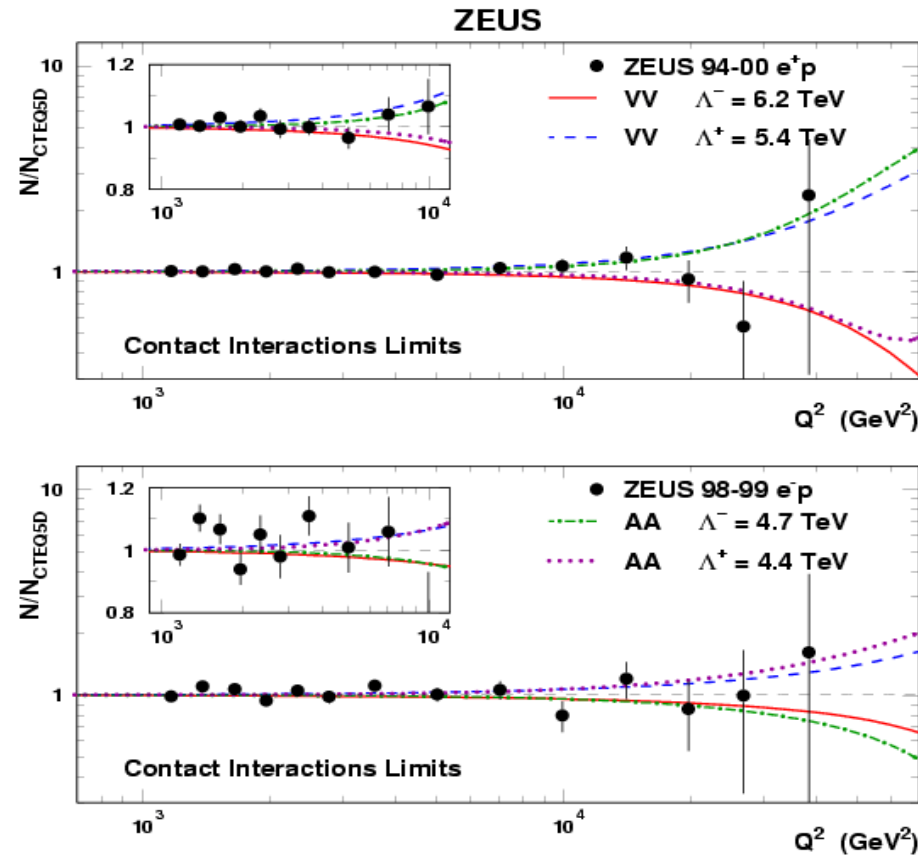
CI: Compositeness

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

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

Λ compositeness scale
 $\epsilon = 0, 1$ (terms considered one by one)

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

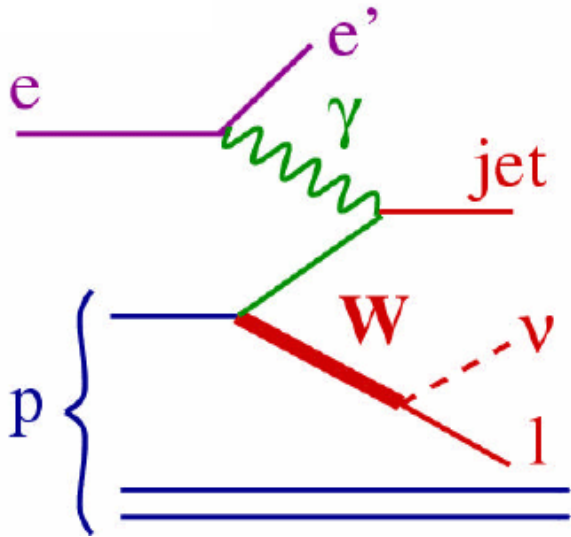


Curves are 95% CL exclusion limits for positive (+ Λ) or negative (- Λ) interference term

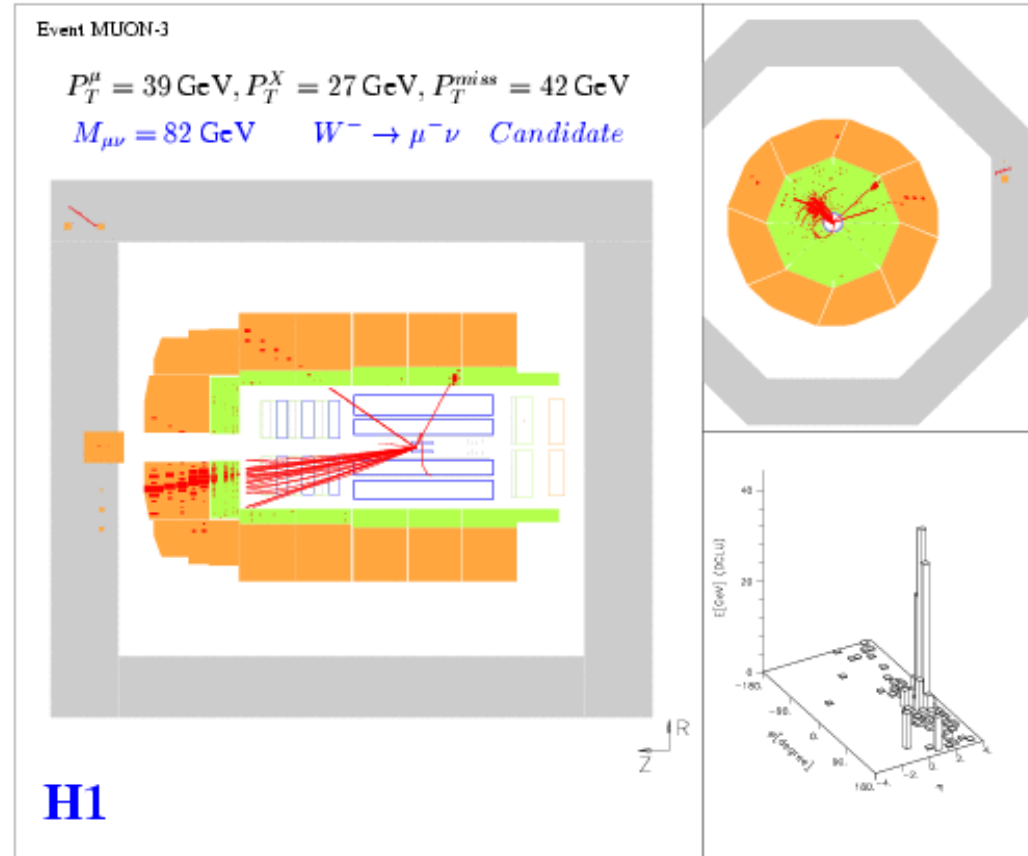
Isolated leptons and missing p_T

Events Topology:

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



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

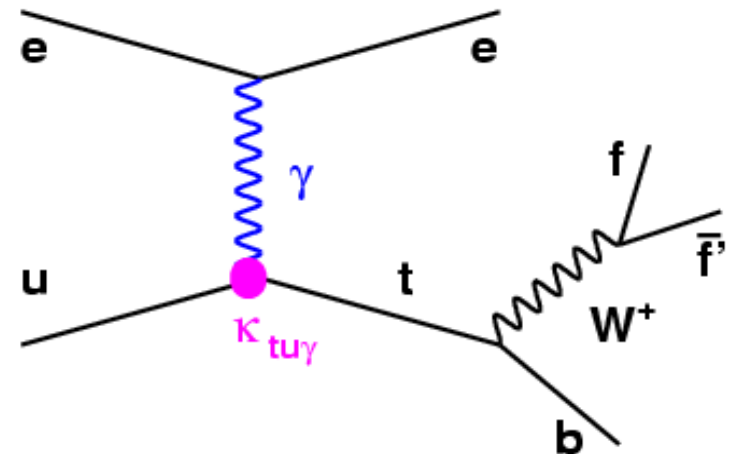


Dominant SM process is W production: $\sigma(ep \rightarrow e W^\pm X) \sim 1$ pb

Isolated leptons and missing p_T (2)

	P_T^X cut	Electrons		Muons		Taus	
		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

- 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 $\sim 1\text{fb}^{-1}$



Search for Single Top

- H1 observe **excess** in **leptonic** channel ($e + \mu$)

ZEUS

- Is this single top via FCNC?

✓ If yes

$$\sigma(ep \rightarrow etX) \sim 0.29 + 0.15 / - 0.14 \text{ pb}$$

✓ If not upper limit

$$\text{on } k_{t\gamma} < 0.27 \text{ @ 95\% CL}$$

- **ZEUS:**

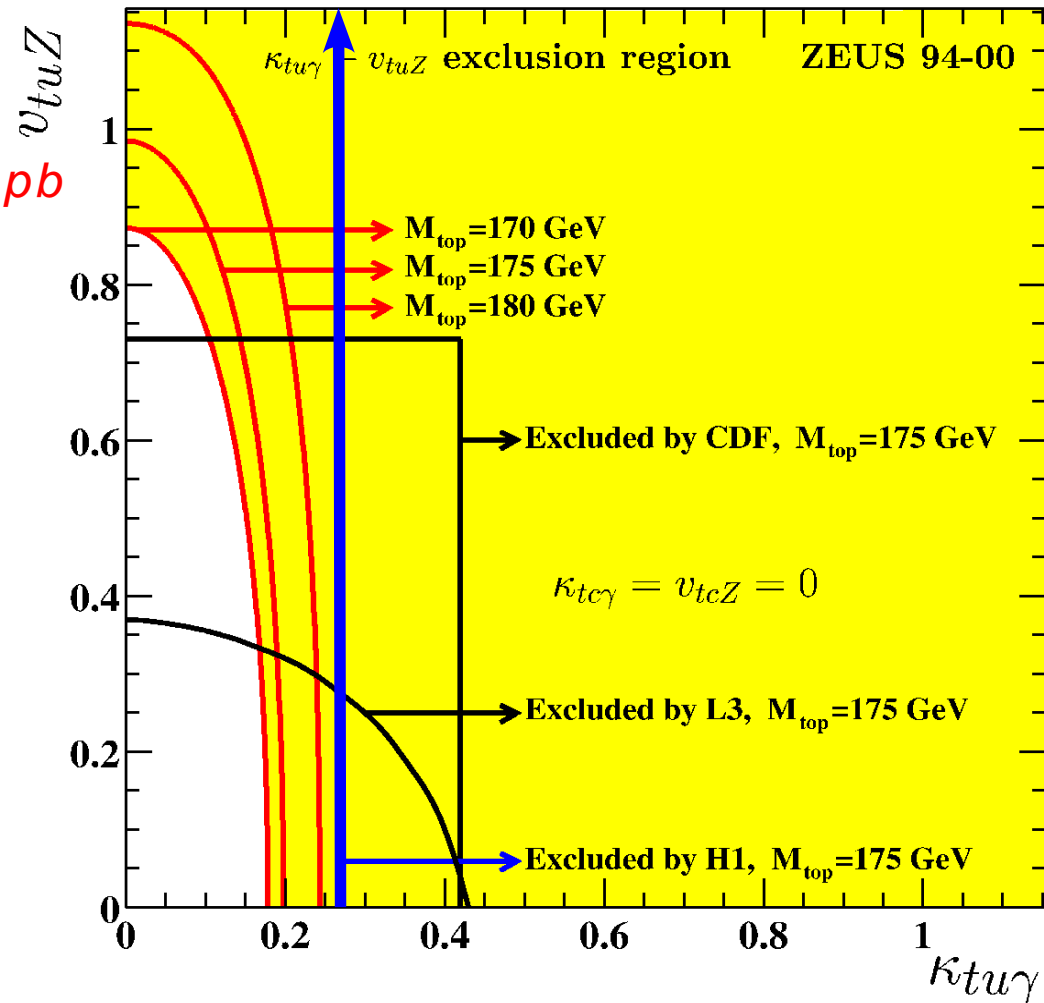
Good agreement with SM

- $\sigma(ep \rightarrow etX)$

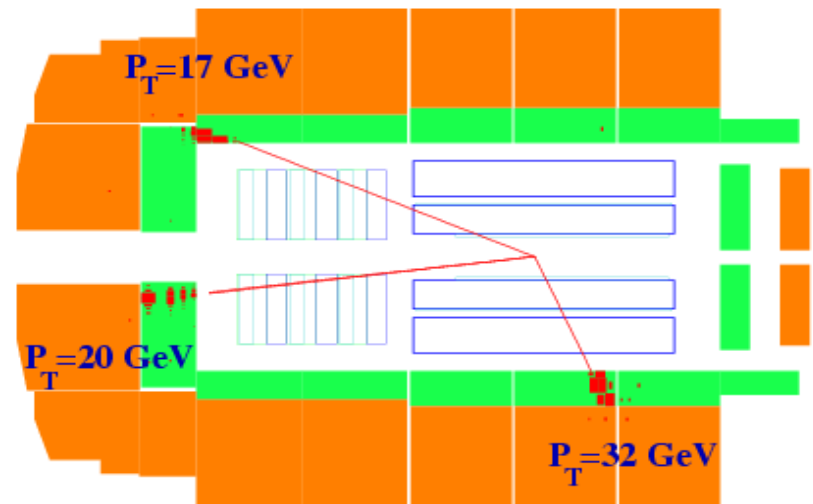
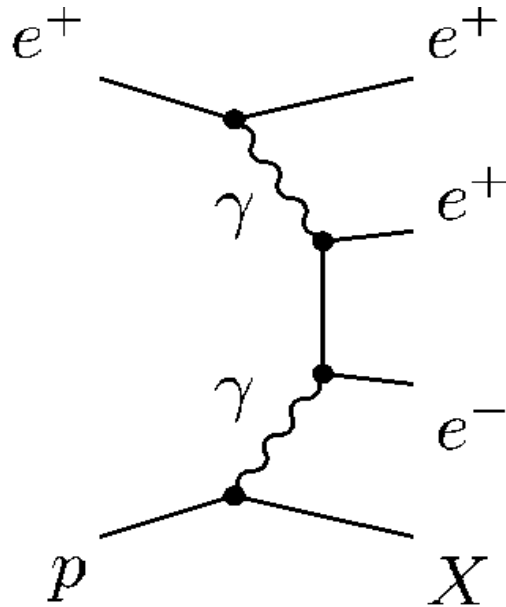
$$< 0.225 \text{ pb @ 95\% CL}$$

- Z-exchange evaluated

→ limit-curve



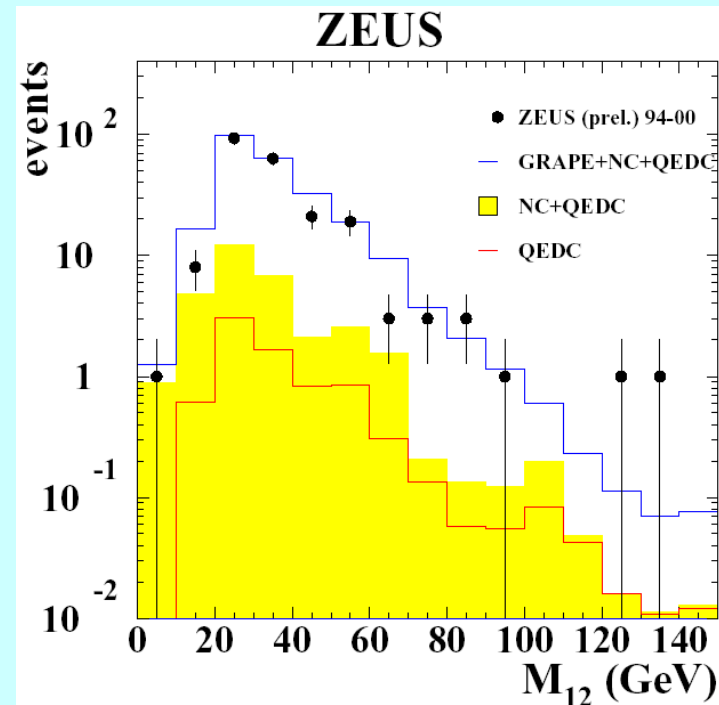
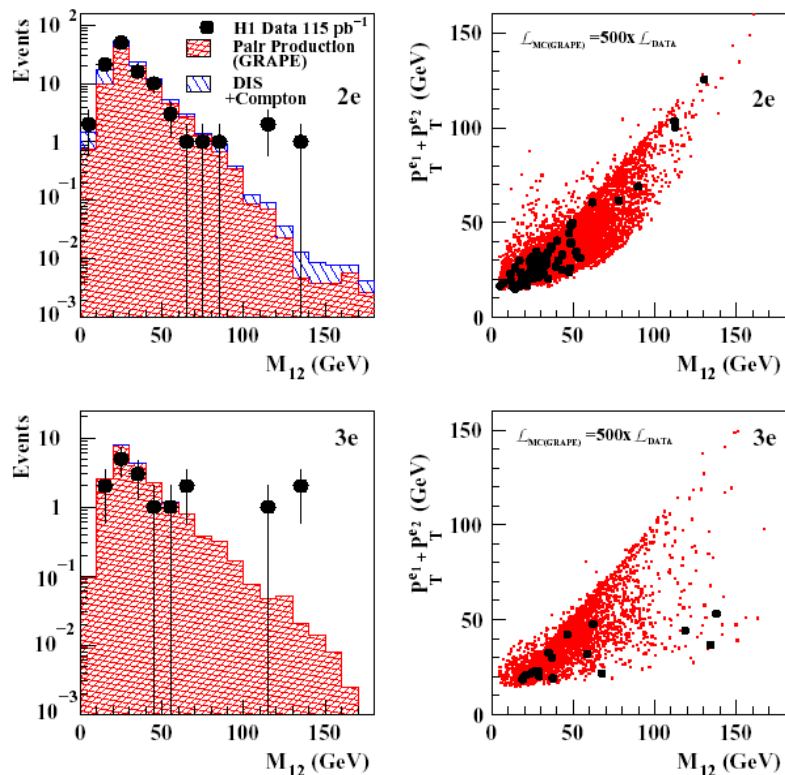
Search for multi lepton events



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 , $\mu\mu$, $\mu\mu e$)
- $p_T > 5 \text{ GeV}$ and 10 GeV
- 3rd electron with $E_e > 5 \text{ GeV}$



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

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

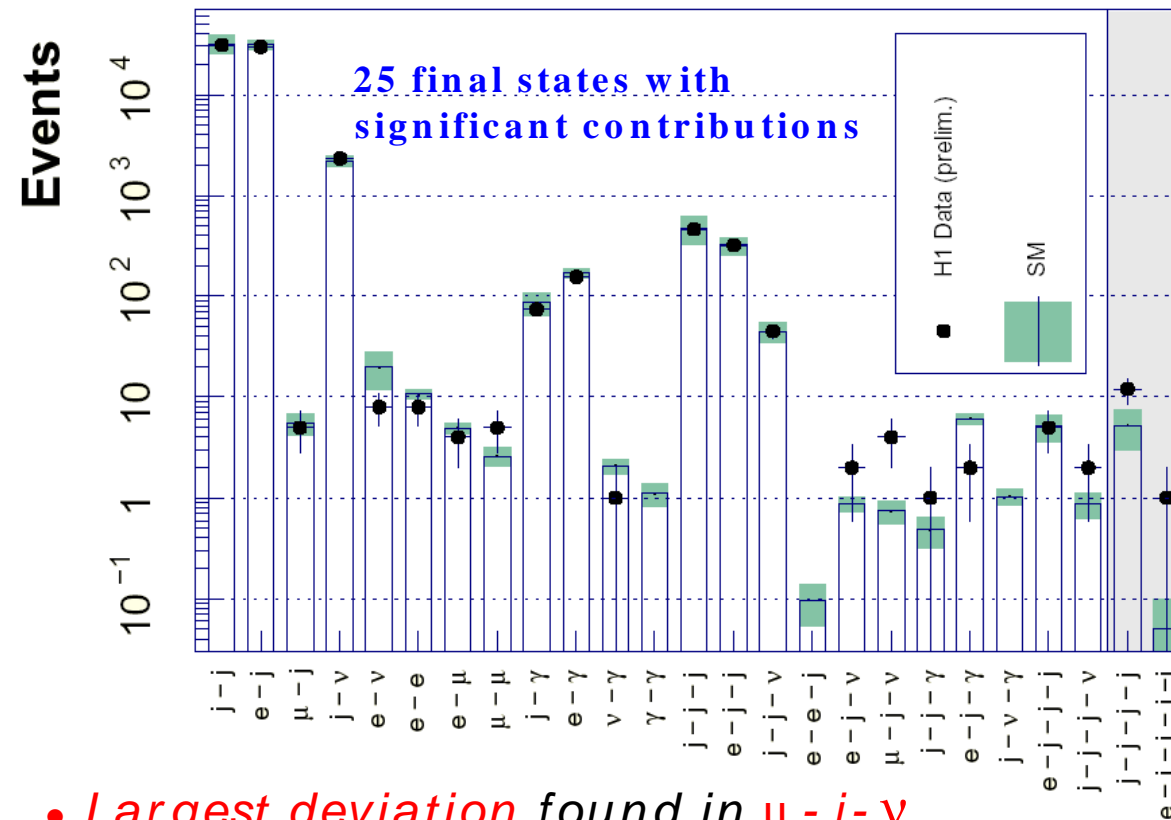
6 outstanding events $M_{12} > 100$ GeV

Good agreement with SM

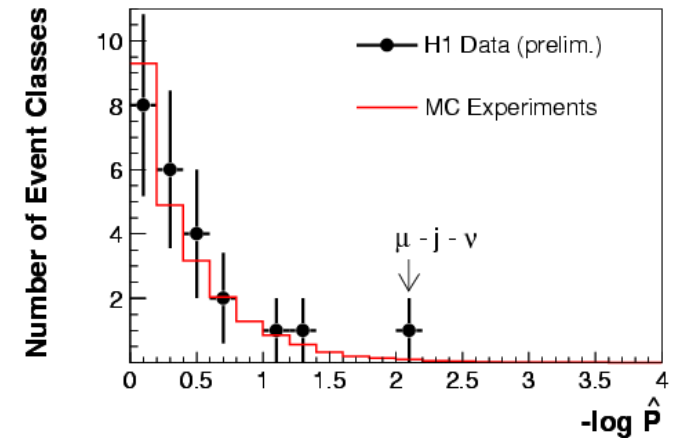
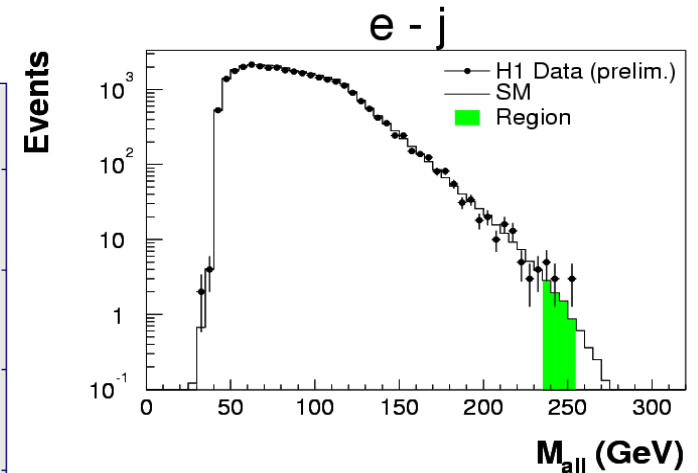
$\mu\mu$, $\mu\mu e$ final states: good agreement with SM (1 $\mu\mu$ event w/ $M > 100$ GeV)

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 $\mu - j - \nu$



Super - Symmetry Models

Mechanism of SUSY breaking
unknown: different models

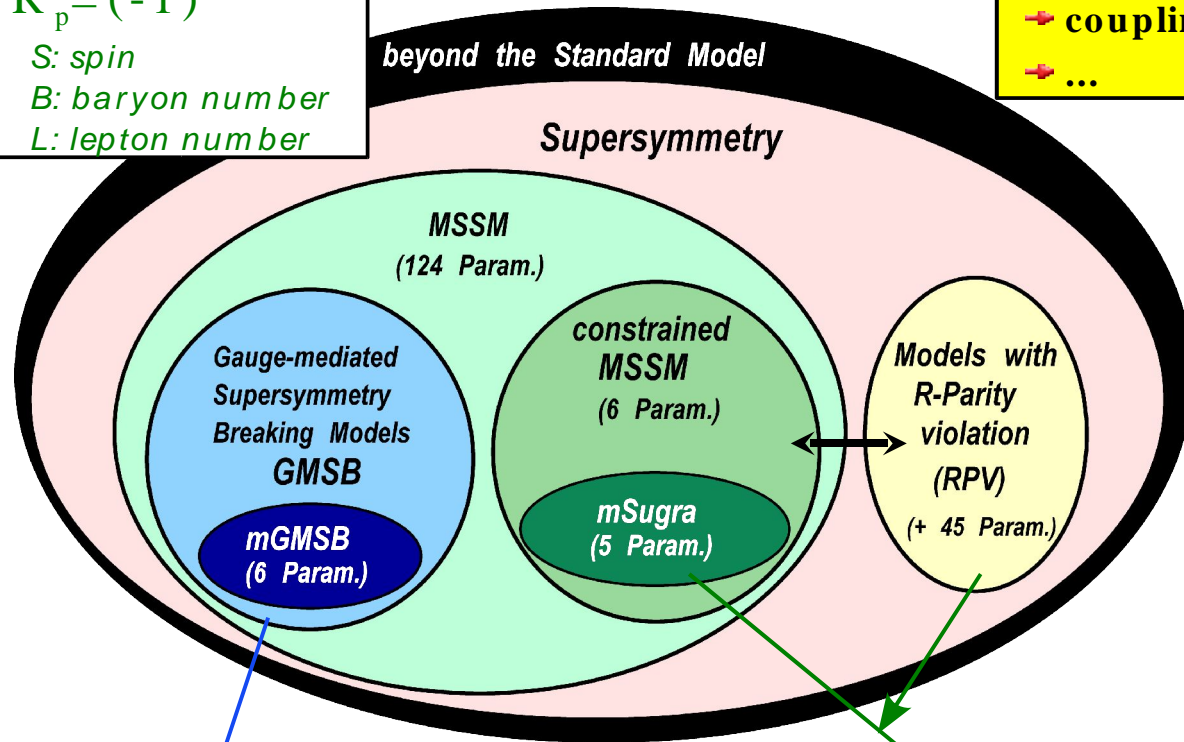
$$R_p = (-1)^{2S+3B+L}$$

S: spin

B: baryon number

L: lepton number

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



Lightest SUSY Particle, *LSP*:

MSSM: lightest neutralino
GMSB: gravitino

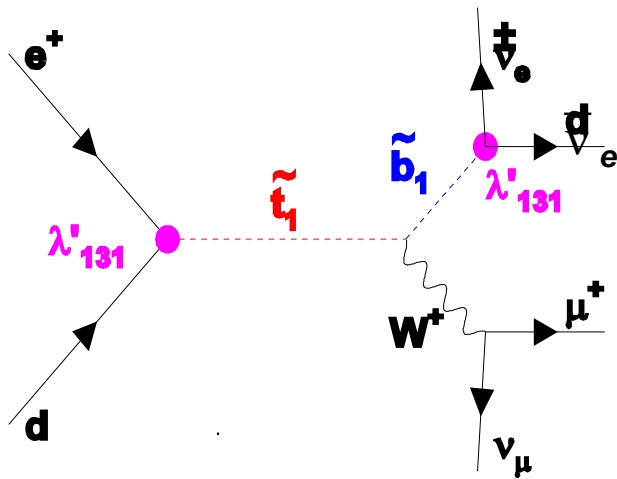
HERA searches:

RPV+MSSM: squarks
RPV+GMSB: gravitino

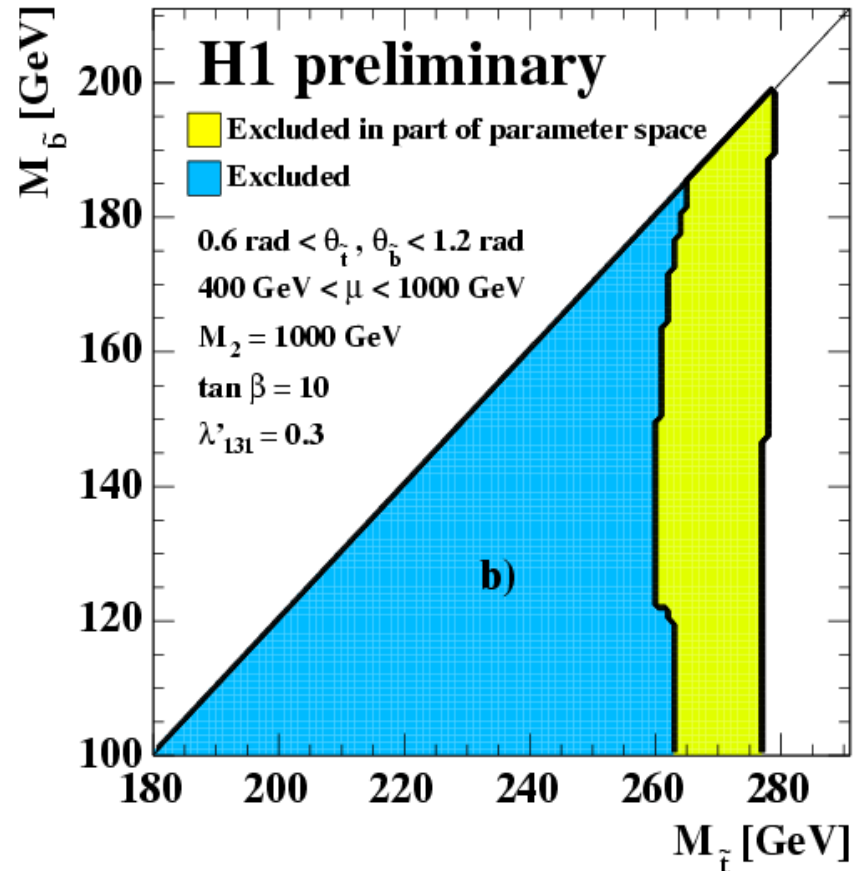
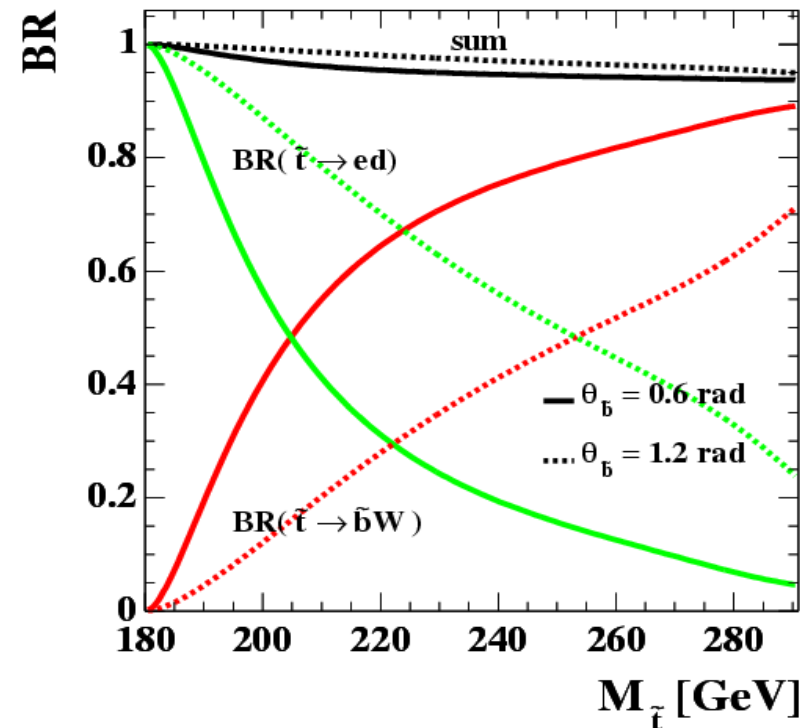
Communication via
gauge bosons

Communication
with our visible
world via gravity

Bosonic Stop Decay

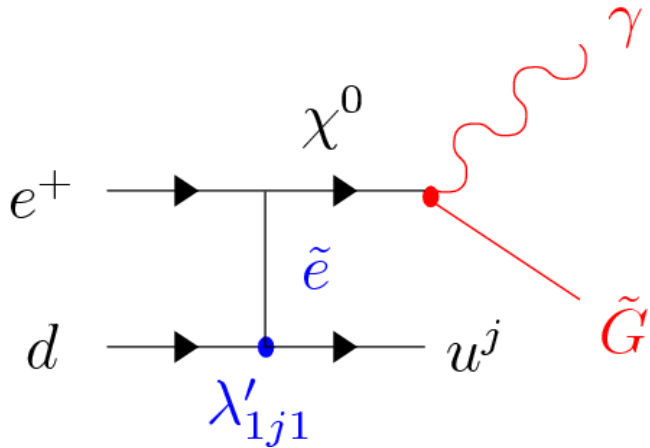


Bosonic decays contribute if allowed kin.
 Possible scenario : $m(\text{sbottom}) < m(\text{stop})$
 and main decay mode of b_1 is $b_1 \rightarrow \nu d$
 Signature: $l + \text{jet} + P_{T,miss}$



Search for Superlight Gravitinos

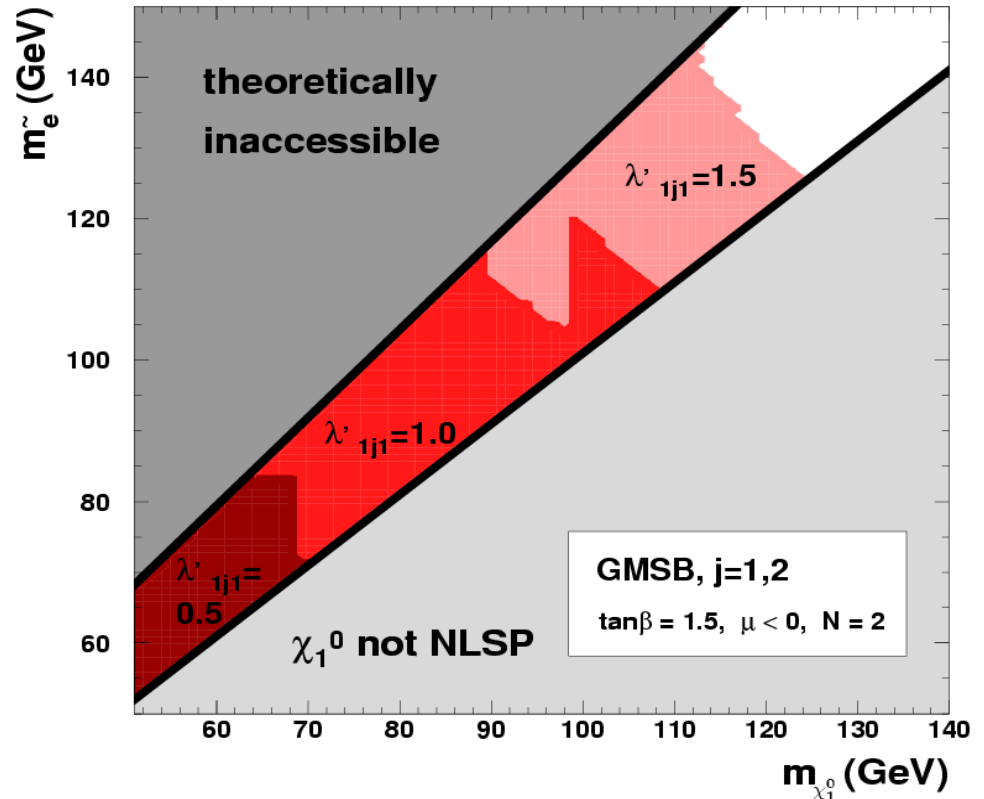
SUSY RPV + GMSB scenario:



Gravitino LSP, χ^0 NSLP
 $m(\text{squarks}) > m(\text{sleptons})$

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

H1 e^+p preliminary



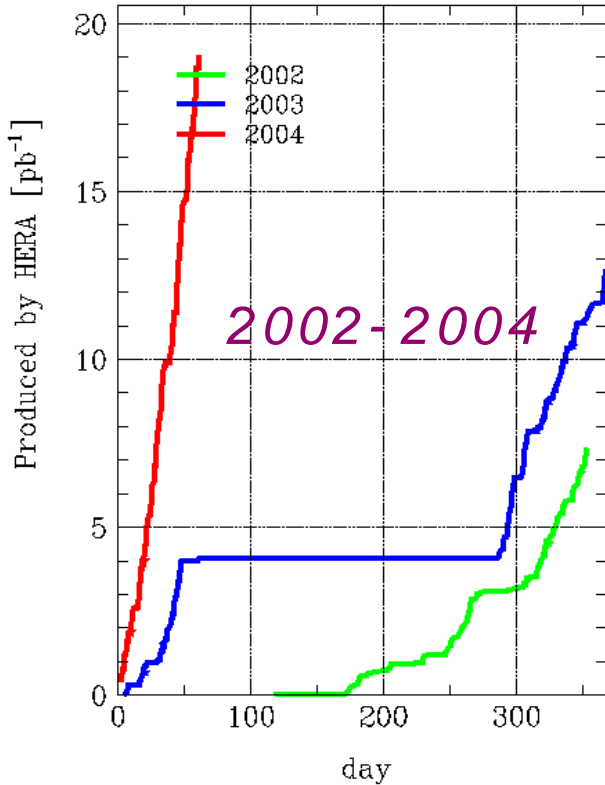
Limits independent of the squark masses

- *Typical LEP limits on sleptons are $\sim 90 - 100$ GeV*

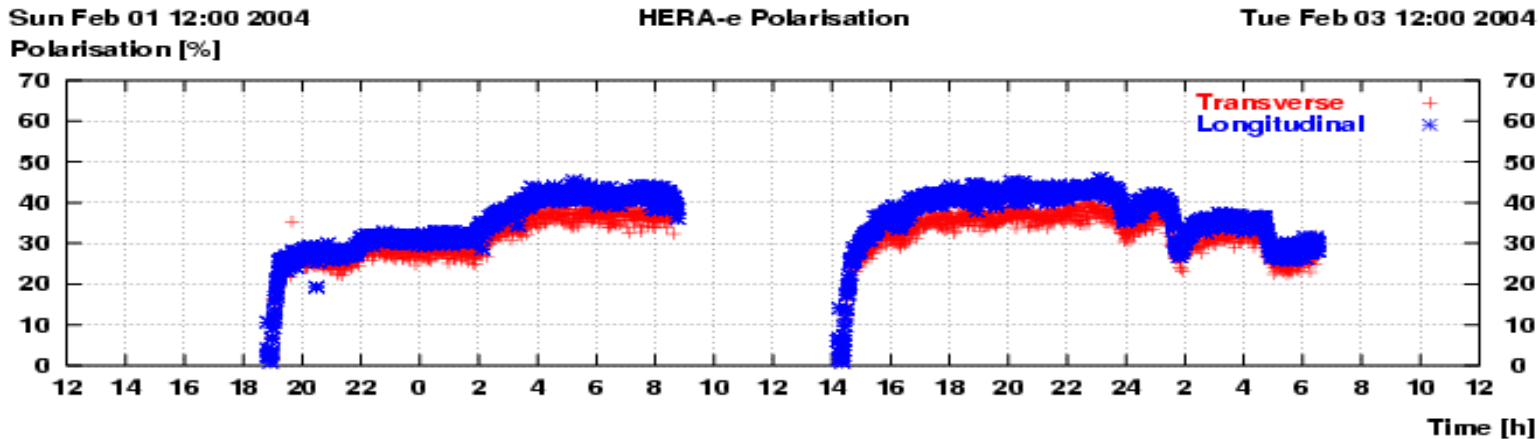
Conclusions

- *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 $M_{ee} > 100 \text{ GeV}$*
- *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 $\sim 30 \text{ pb}^{-1}$ of luminosity in 2003/4*
 - *Inst. luminosity ($3 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$) higher than HERA I*
 - *Longitudinal polarization $\sim 30\text{-}50\%$*

Outlook: HERA II

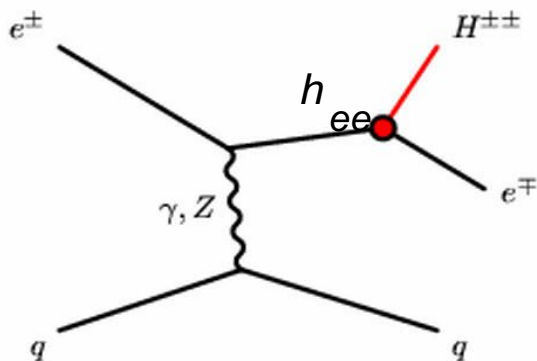


- HERA II delivered $\sim 30 \text{ pb}^{-1}$ of luminosity in 2003-2004
- Instantaneous luminosity ($3 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$) already higher than HERA I
- Longitudinal electron polarization $> 30\%$



Backup Slides

Search for Doubly Charged Higgs



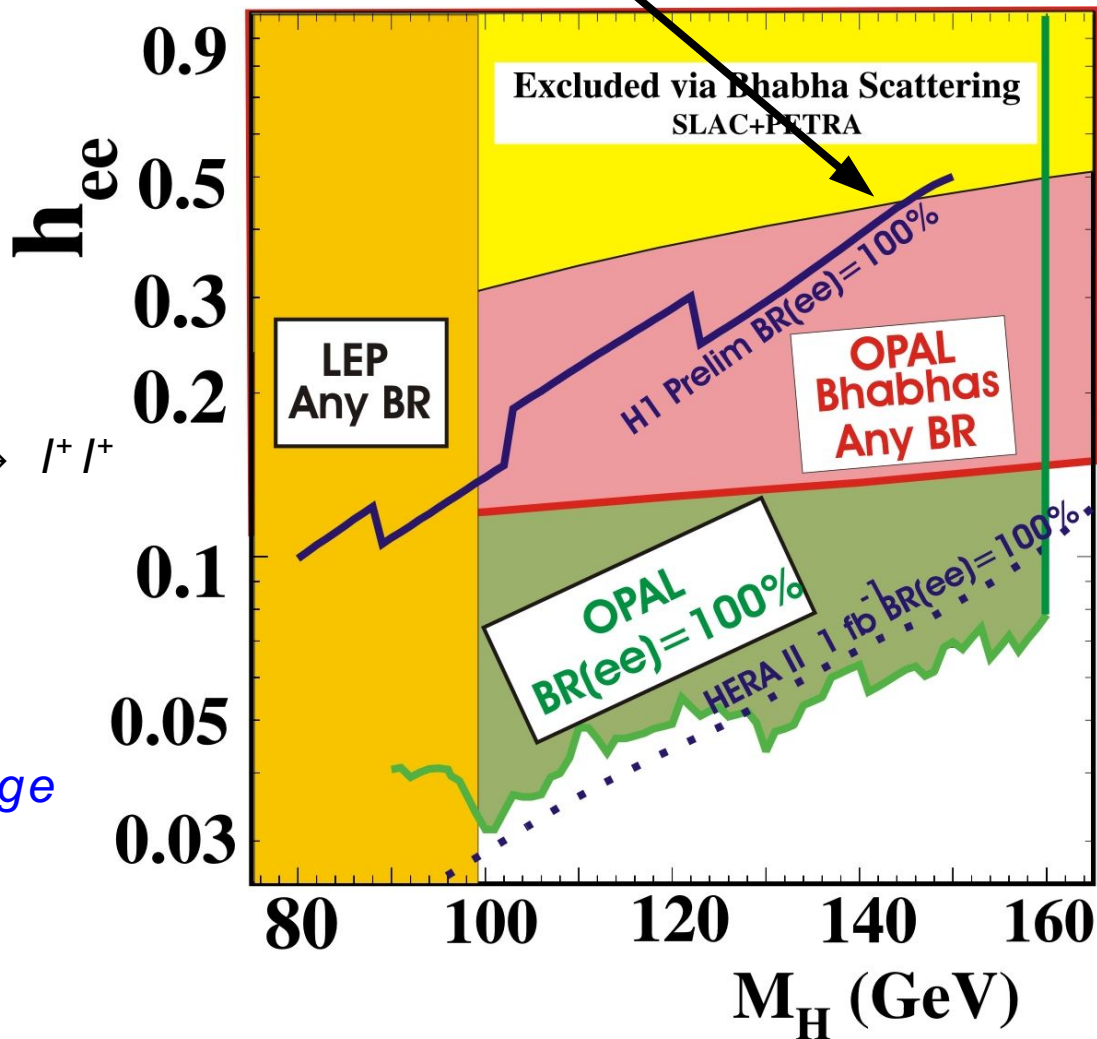
single production at HERA

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

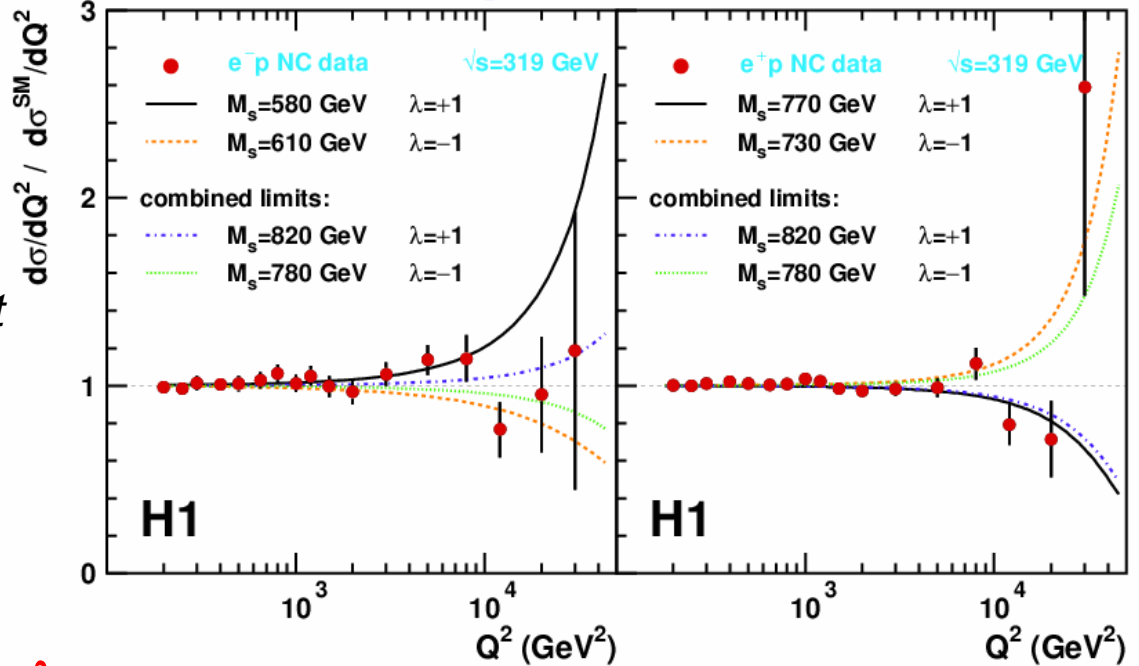
$$-M_p^2 = R^n M_s^{2+n}$$

- 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

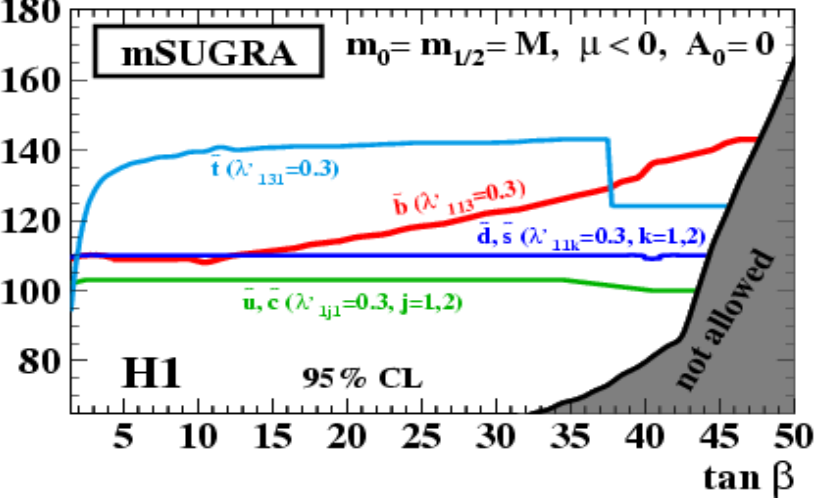
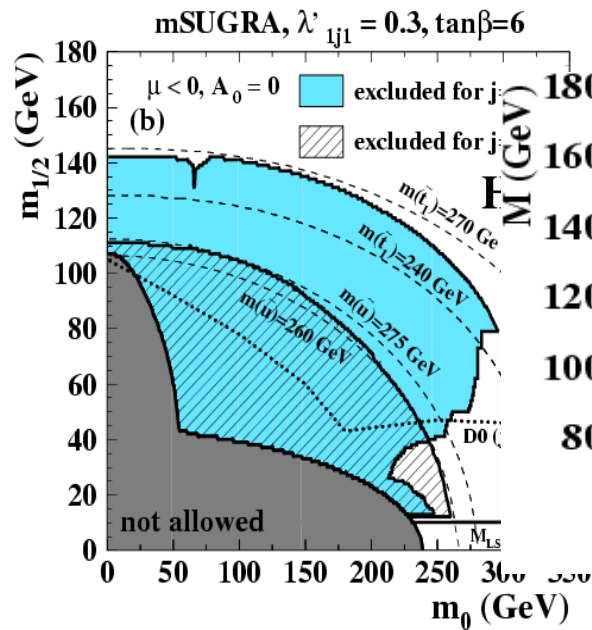
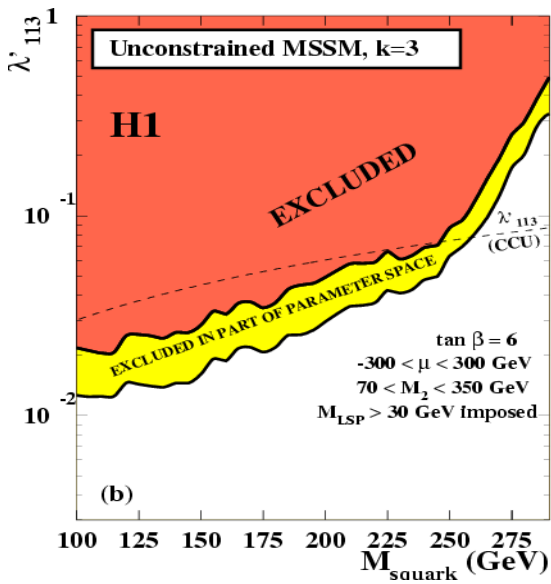
– Effective coupling $\eta_G = \lambda / M_s^4$

Large Extra Dimensions



Limits	H1	ZEUS
$\lambda=-1$	0.78 TeV	0.82 TeV
$\lambda=+1$	0.82 TeV	0.81 TeV

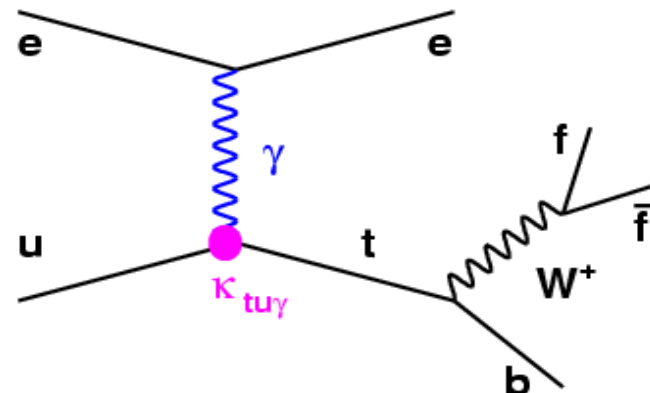
Squarks



Isolated leptons and missing p_T (2)

	P_T^X cut	Electrons		Muons		Taus	
		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 $\sim 1\text{fb}^{-1}$



Single top: semi-leptonic decays

- **ZEUS**: no events with $P_T^X > 40$ GeV

- **H1**: further cuts to select top

- Only positive leptons

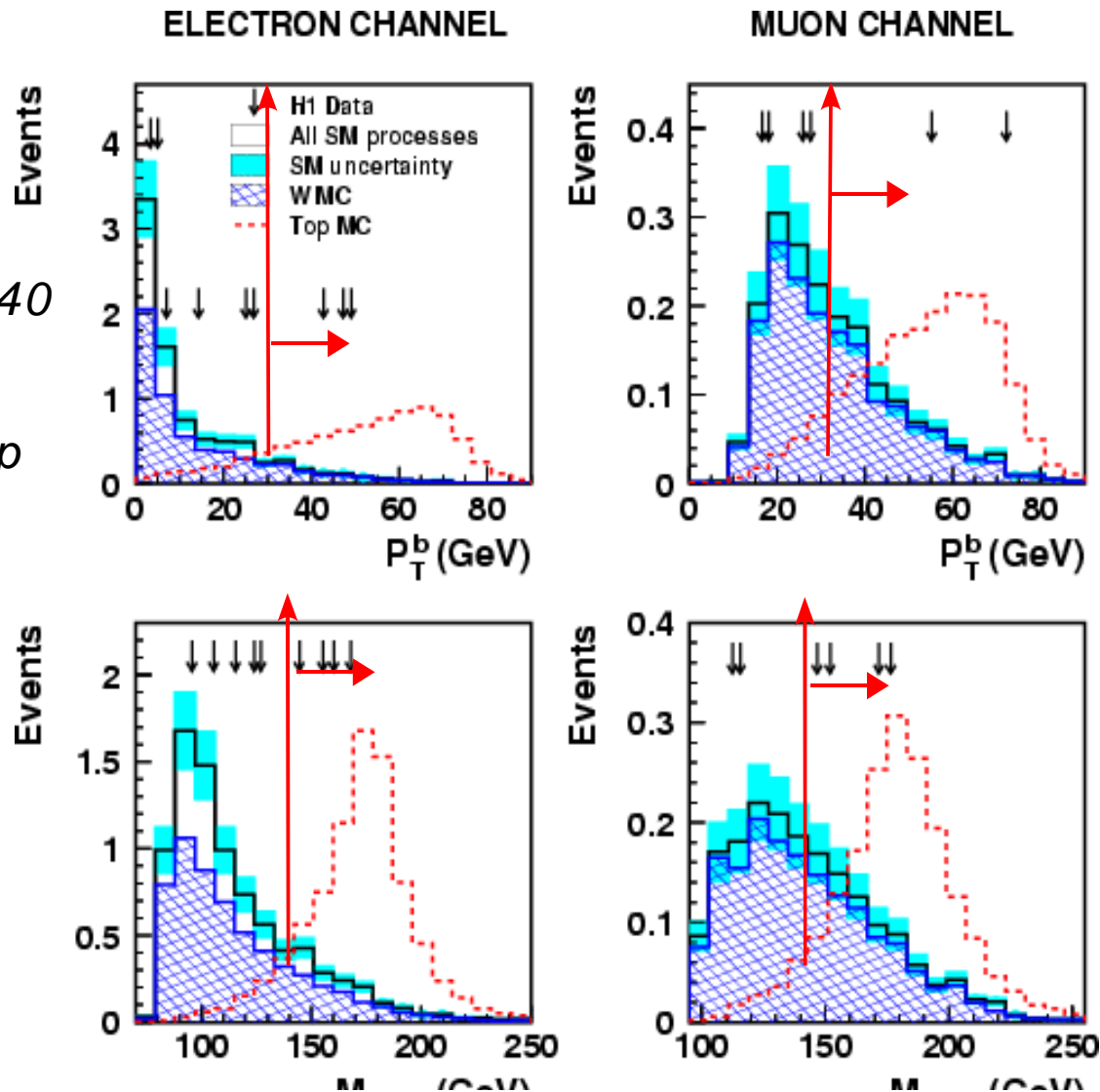
- $P_t^{jet} > 30$ GeV, $M_{lvb} > 140$ GeV

5 events (3e,2 μ) – SM 1.31 ± 0.22

Top efficiency:

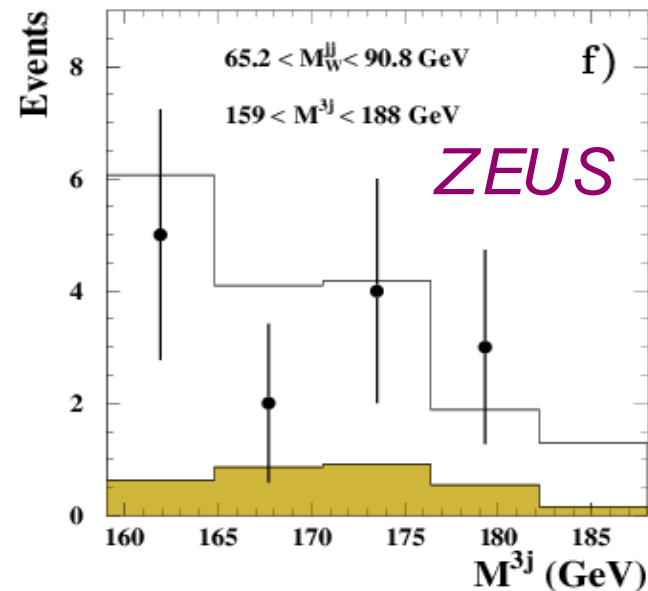
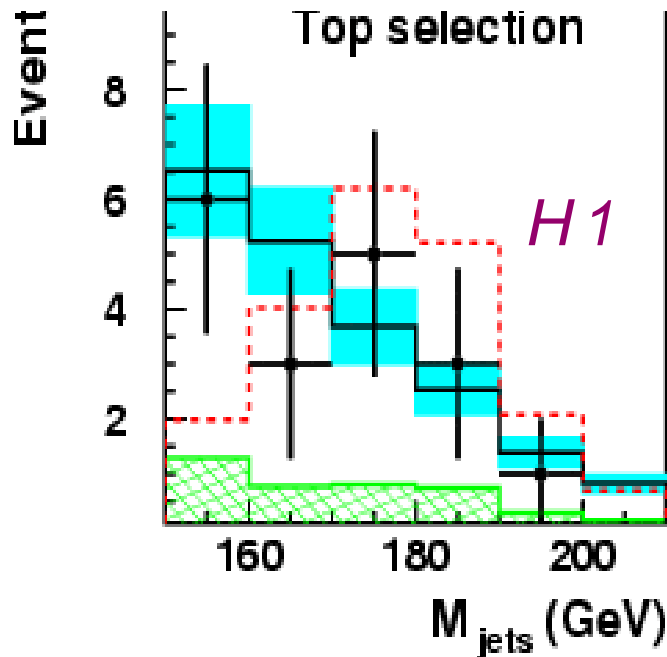
36% electron

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

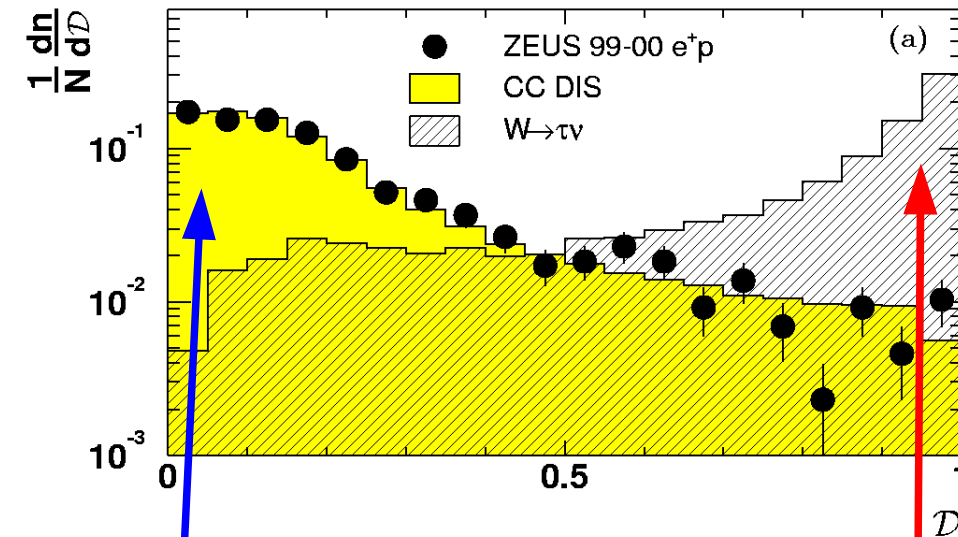


Both experiments agree with SM in the hadronic channel

Isolated τ events

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

ZEUS



$D=0$: QCD jets

$D=1$ tau jets

Isolated τ events

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

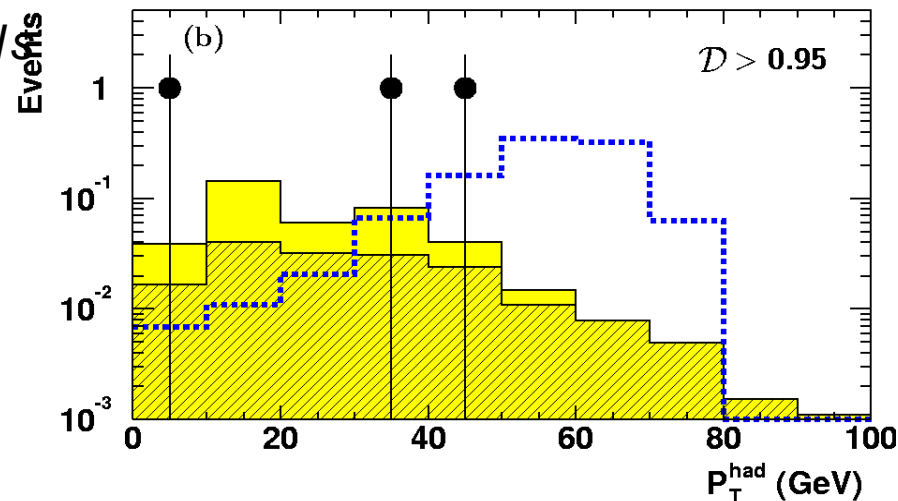
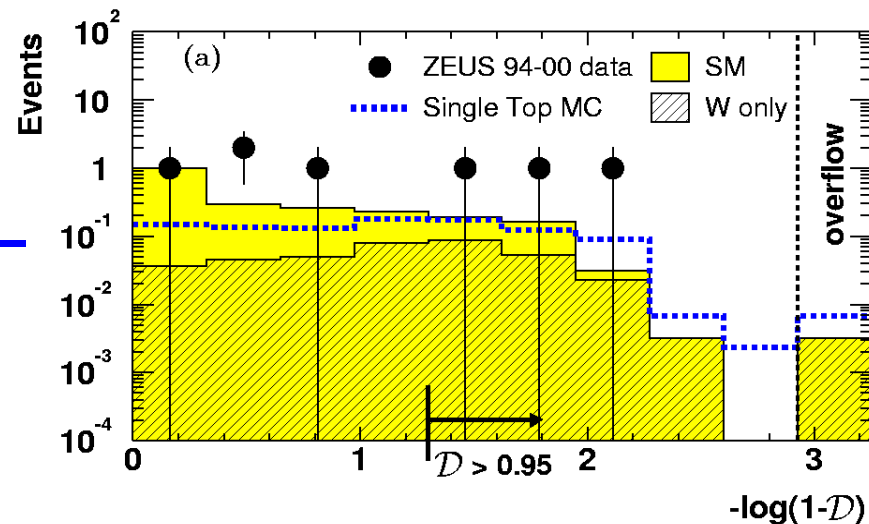
Cut	Data	SM
$\phi_{aco} > 8^\circ$	7	$2.2^{+0.39}_{-0.58}$
$D > 0.95$	3	$0.40^{+0.12}_{-0.13}$
$P_T^x > 25$ GeV	2	0.20 ± 0.05

(Prob. statistical fluctuation 1.8%)

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

\Rightarrow unlikely to be single top

ZEUS

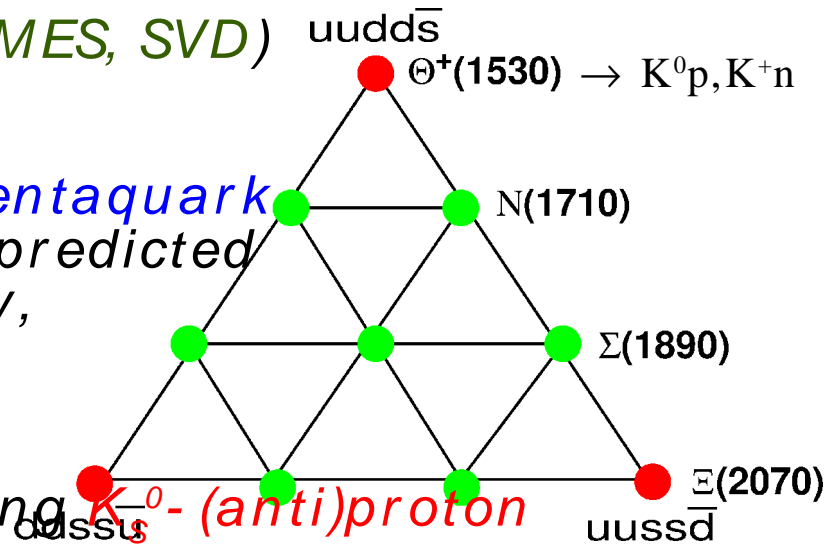


Search for $K^0_s p$ resonance

- 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 resonance: K^0_s selection

Data Set

- 121 pb^{-1} , 1996-2000 $e^\pm p$ data @ 300-319 GeV

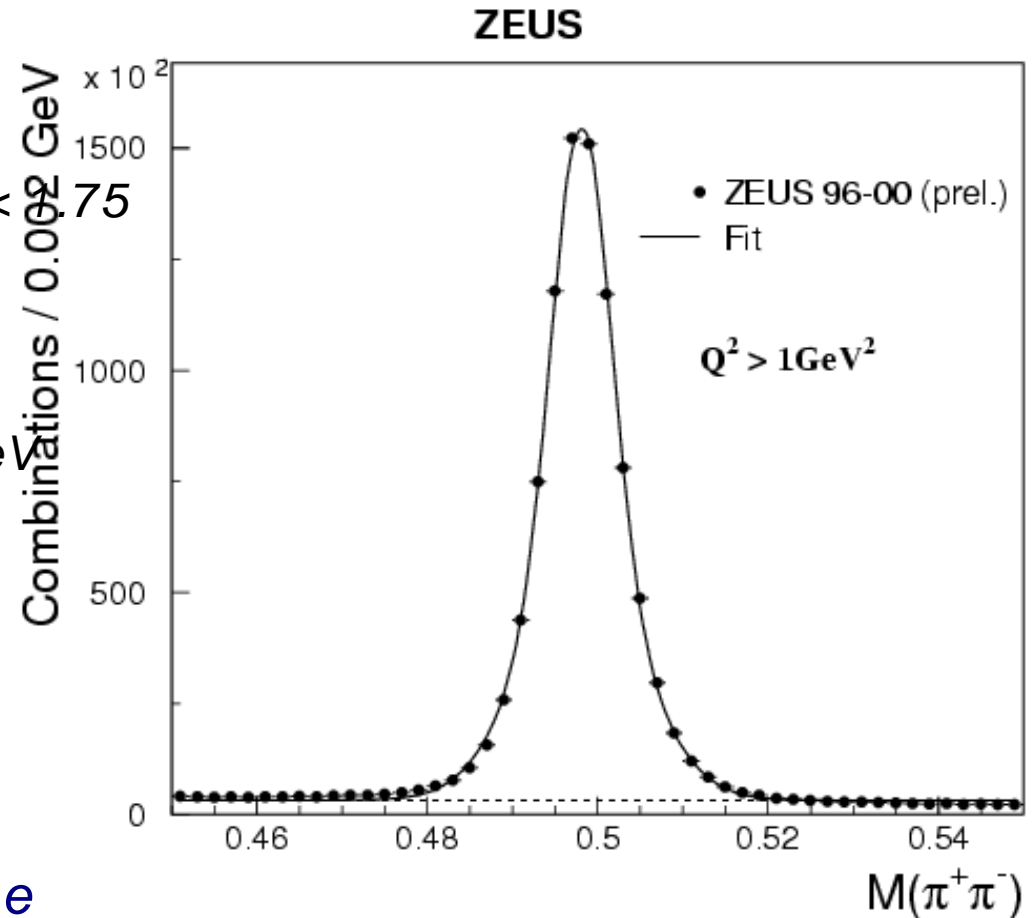
- DIS events $Q^2 > 1 \text{ GeV}$

K^0_s selection: $K^0 \rightarrow ?^+ ?^-$

- CTD tracks, $p_T > 150 \text{ MeV}$, $|\eta| < 0.75$
- K^0_s from secondary vertex
- Photon conversion removed:
 $M(e^+ e^-) < 50 \text{ MeV}$
- Λ 's removed $M(? p) < 1121 \text{ MeV}$
- $p_T(K^0) > 300 \text{ MeV}$; $|\eta(K^0)| < 1.5$

Double Gaussian + linear background fit

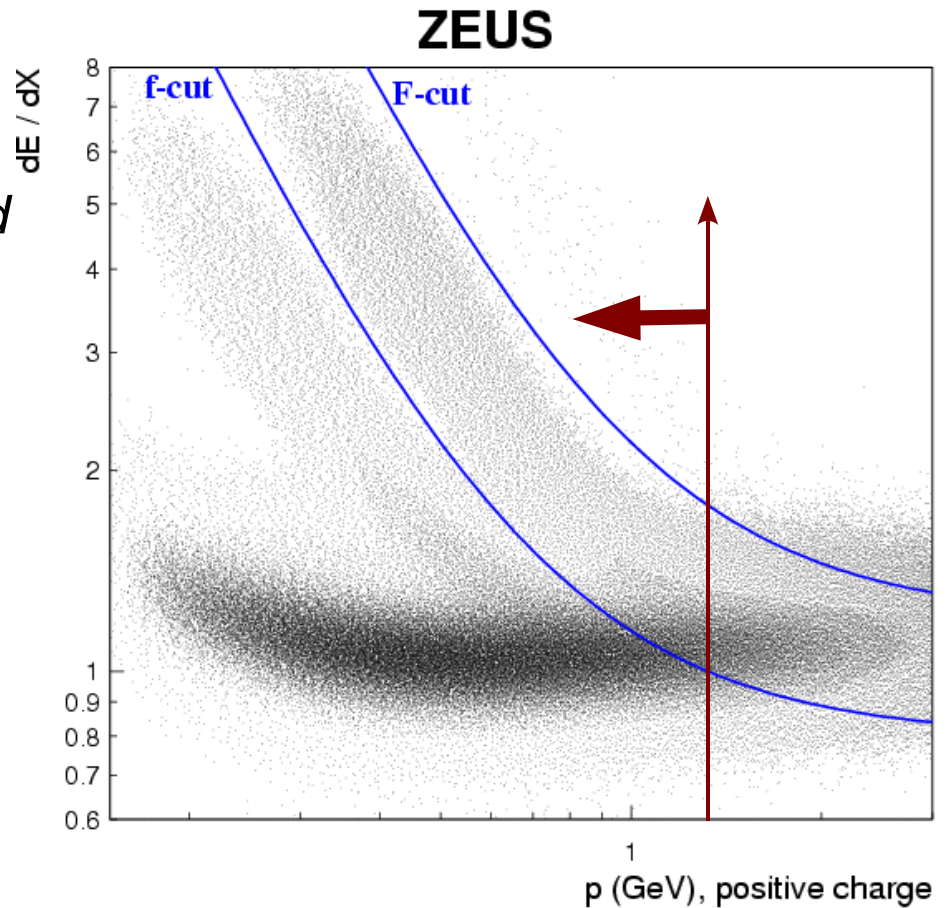
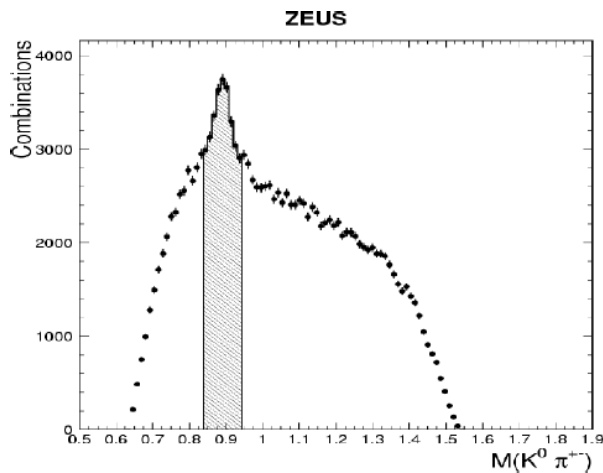
869690 \pm 1016 K^0 candidate
background \sim 6%



Peak at 498.12 ± 0.01 (stat) MeV

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

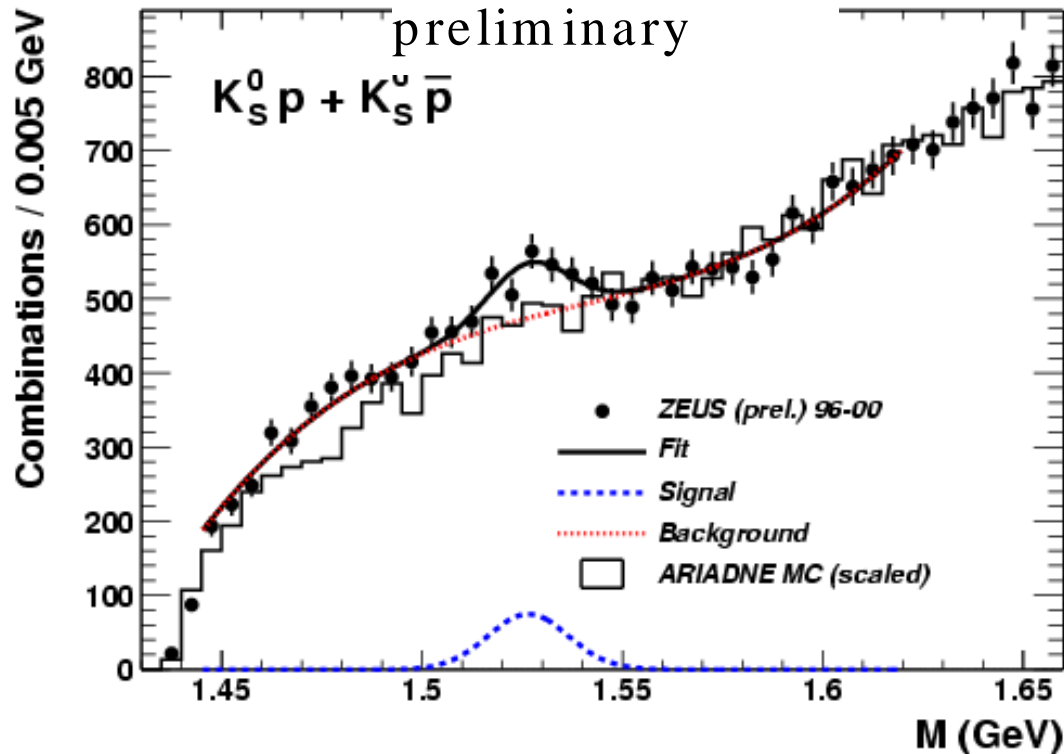
- Most of the signal $p \sim 0.8 - 2$ GeV
- $p < 1.3$ GeV inside dE/dx band
- $E(\text{proton}) > E(K^0)$
- Assign pion mass to proton candidate, reconstruct $K^0?$, reject pions from K^* :
 $800 < M(K^0?) < 980$ MeV



$K_S^0 p(\text{anti-}p)$ invariant mass

Fit: Gaussian + p3 (free parameter)

ZEUS



Combined sample: 372 ± 75 candidates

Peak $1527 \pm 2(\text{stat})$ MeV, width $10 \pm 2(\text{stat})$ MeV

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