Physics at HERA

Summer Student Lectures
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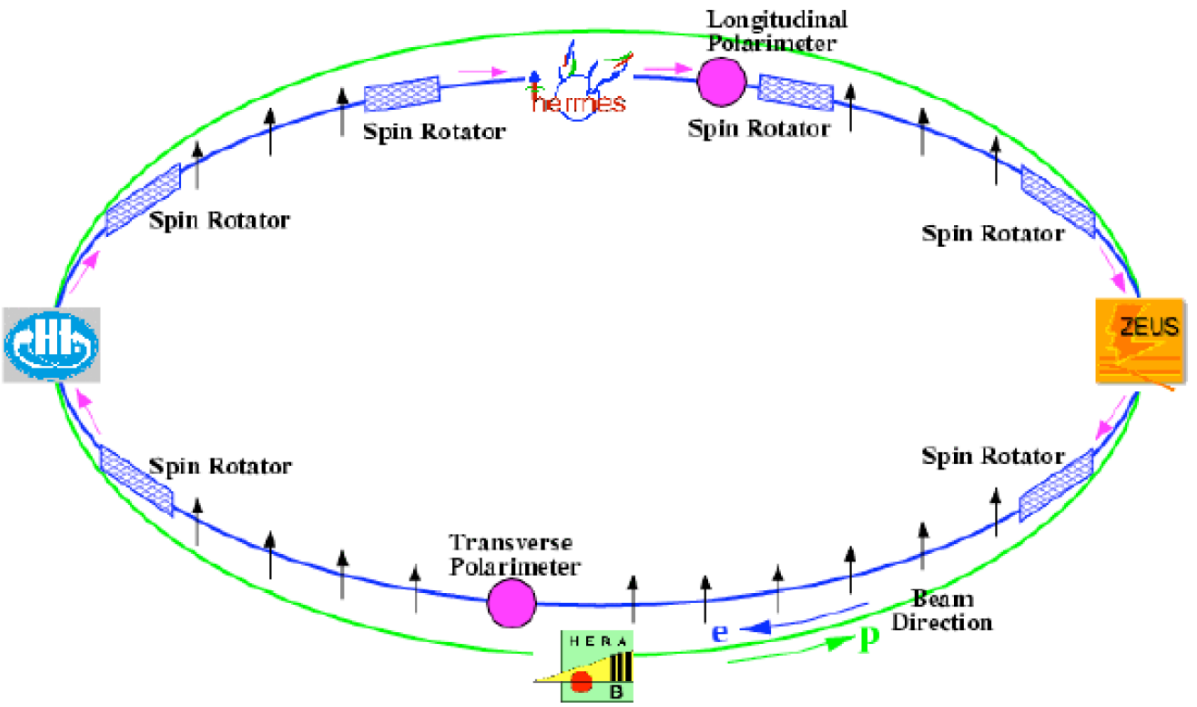
Overview Part 3

- Polarization
  - CC and Polarization
  - Proton Spin Measurements by HERMES
- Exotics
  - Model Dependent Searches
  - Model Independent Searches

Polarization

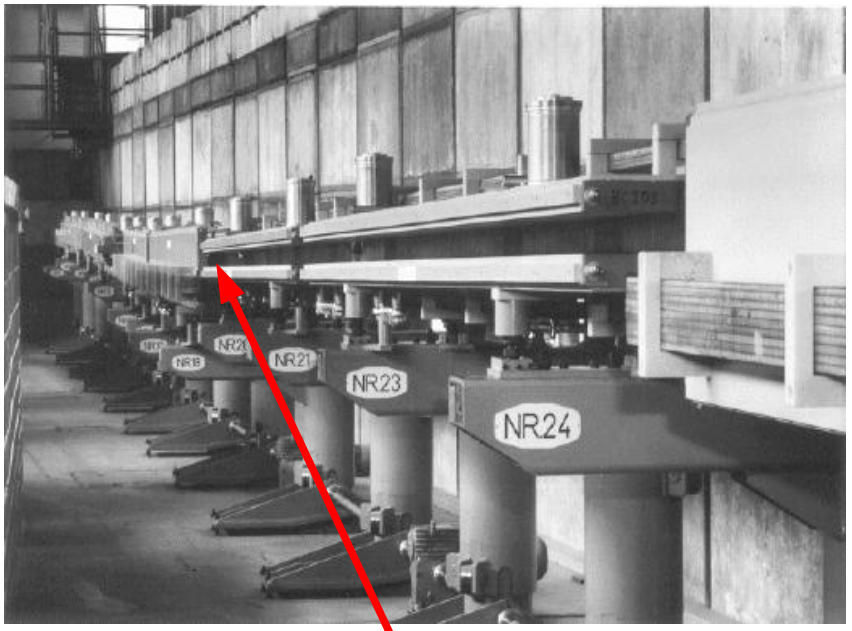
Polarization @ HERA

$$P_e = \frac{N_{RH} - N_{LH}}{N_{RH} + N_{LH}}$$



- transverse polarization builds up in ~40 minutes through synchrotron radiation (Sokolov-Ternov effect)
- spin rotators flip transverse ⟶ longitudinal before experiments and back after

Polarization @ HERA



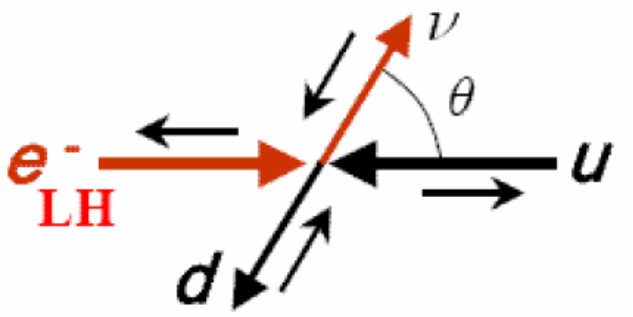
spin rotator

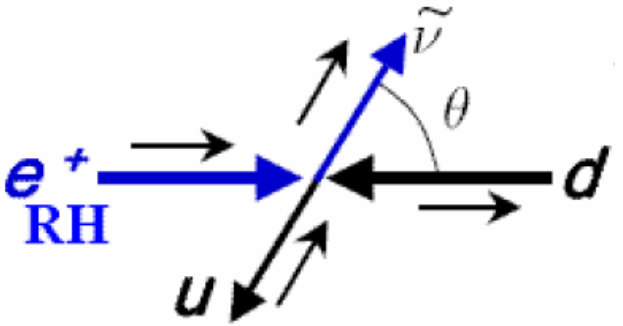
CC & Polarization

- CC cross section depends on longitudinal electron/positron polarization P_e

$$\frac{d^2\sigma^{\pm}_{CC}}{dx\,dQ^2}(P_e) \approx (1 \pm P_e)\frac{G_F^2}{4\pi x}\cdot\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \cdot Y_+ W_2^{\pm}$$

- reason: *W* boson couples only to left-handed (LH) particles and right-handed (RH) antiparticles:





CC: Polarization Dependence

- Standard Modell expectation:

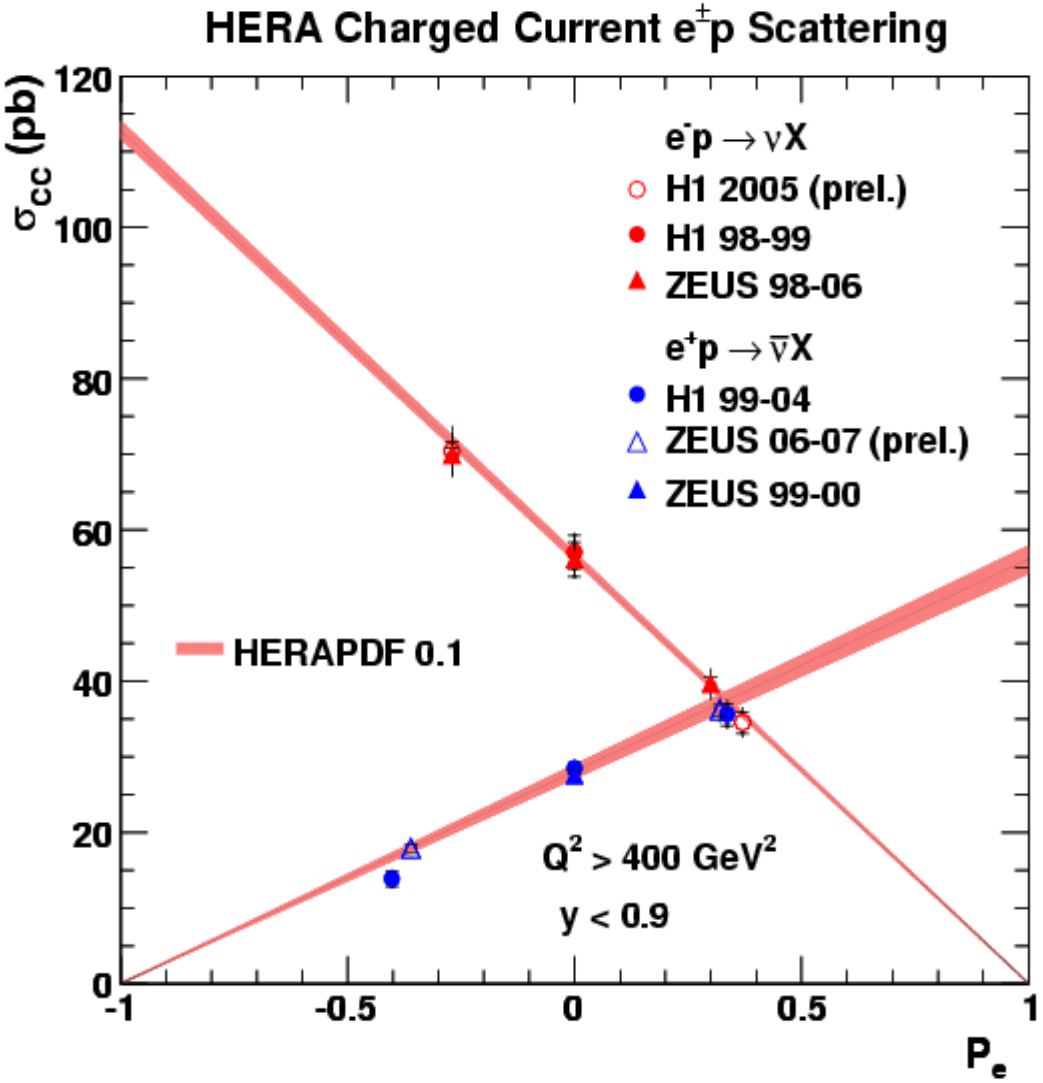
$$\sigma^{-}_{CC}(P_e=+1) = 0$$

$$\sigma^{+}_{CC}(P_e=-1) = 0$$

- experimental result: (H1)

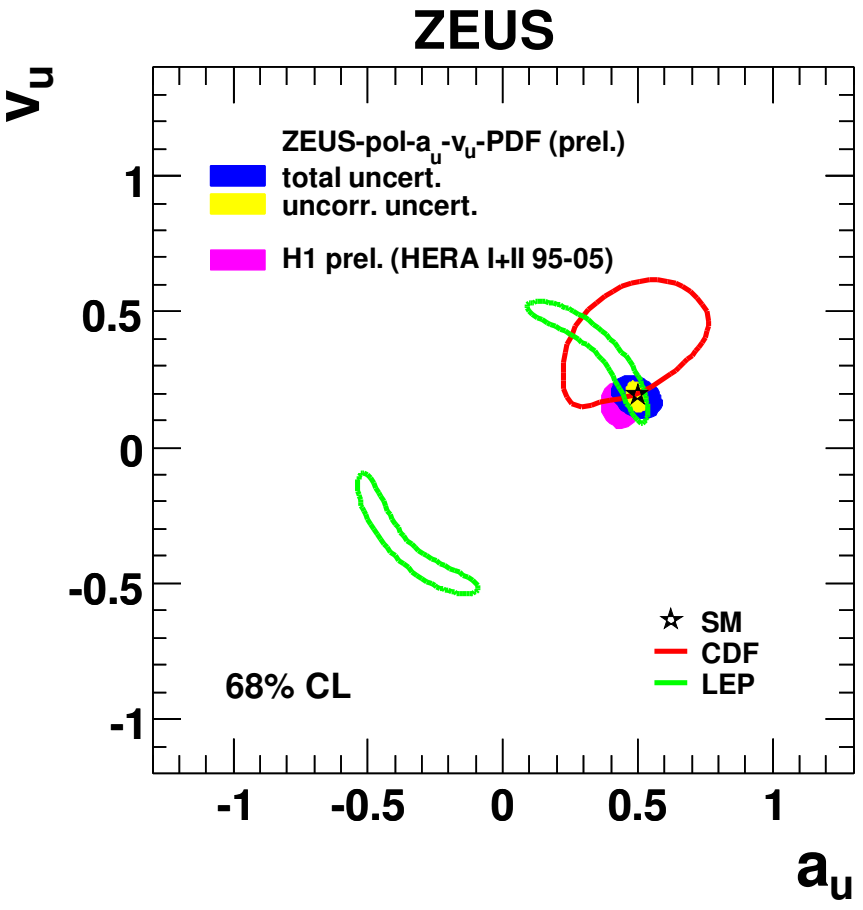
$$\sigma^{-}_{CC}(+1) = -0.9 \pm 2.9_{stat} \pm 1.9_{syst} \pm 1.9_{pol} \text{ pb}$$

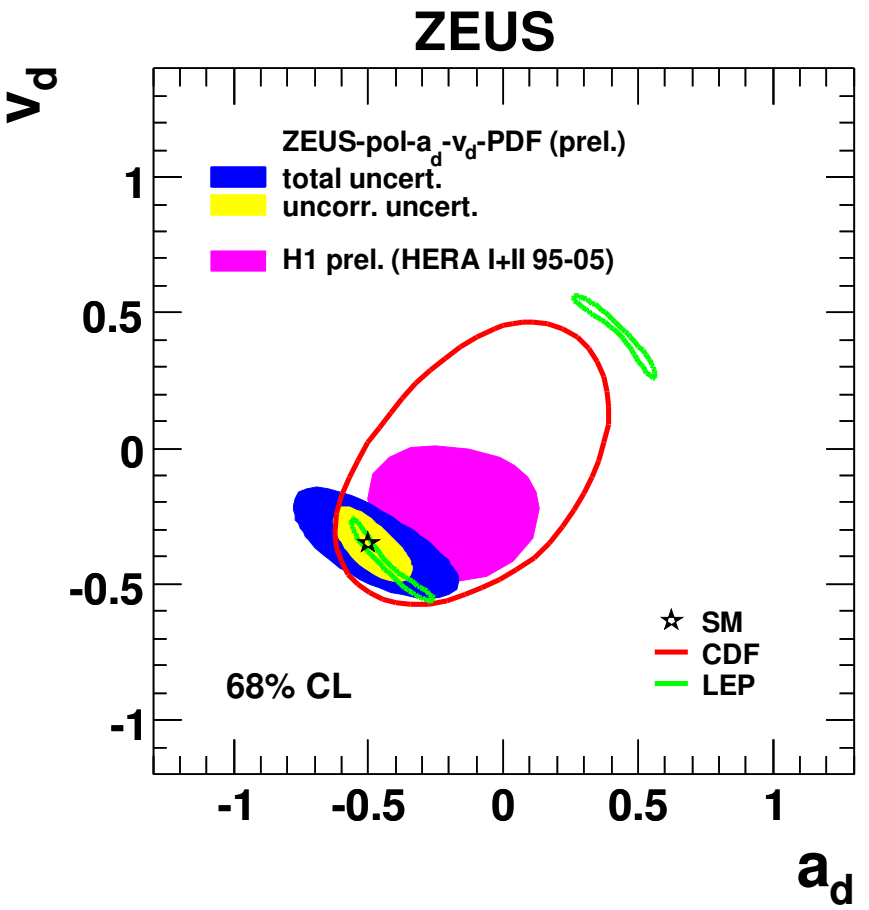
$$\sigma^{+}_{CC}(-1) = -3.9 \pm 2.3_{stat} \pm 0.7_{syst} \pm 0.8_{pol} \text{ pb}$$



Electroweak Parameters: Z^0 Couplings

polarization also allows better sensitivity to vector and axial-vector couplings of *up*- and *down*-type quarks to the Z^0





The spin of the proton

- spin: very important quantity in quantum physics with properties of angular momentum
- spin-½ paricles (fermions):
  - fundamental constituents of matter: quarks, leptons
  - proton, neutron
- spin-½ responsible for stability of matter (Pauli-principle): „No two spin-½ particles can occupy a state where all quantum numbers are identical.“

Spin and Magenetic Moment

Magnetic moment $\vec{\mu} = g(e/2M)\vec{s}$

Pointlike fundamental fermions: $s = \frac{1}{2}$, $g=2$, $\langle\mu_F\rangle = (e_F/2m_F)\,\hbar$

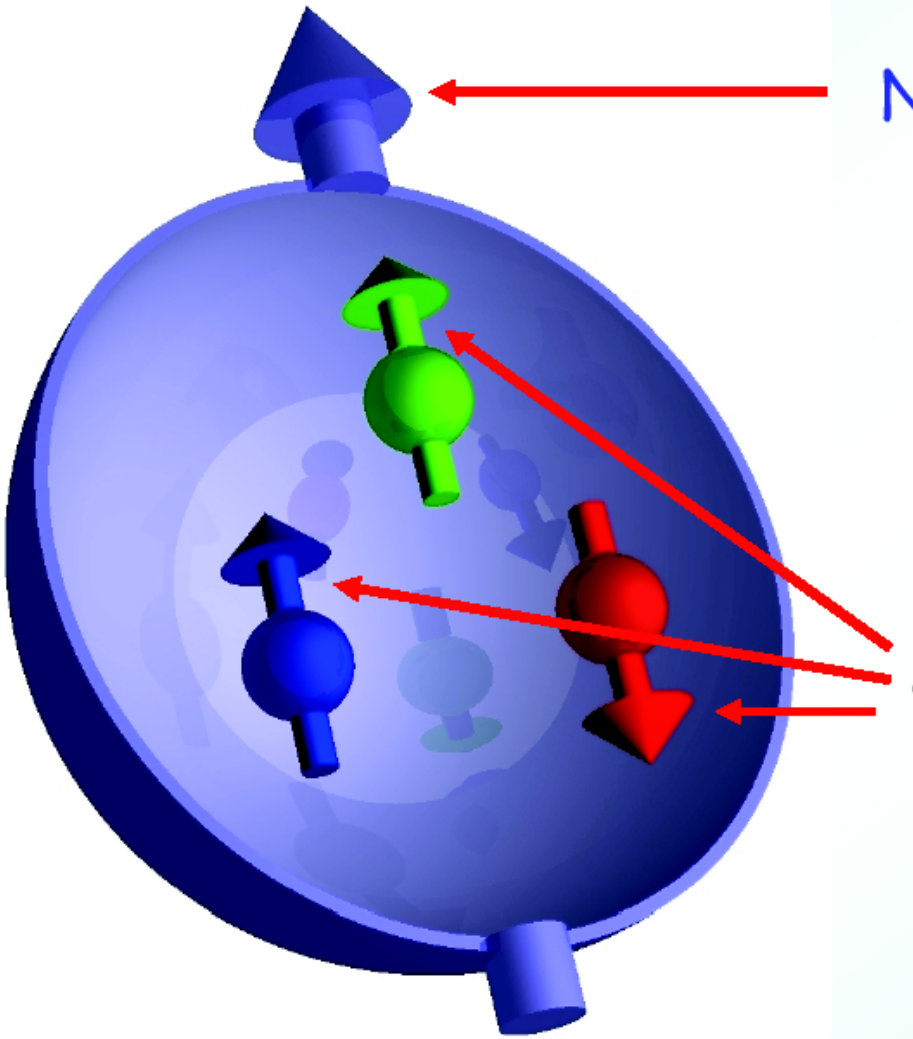
- Proton p: $s = \frac{1}{2}$, $g^p = 5{,}46$
- Neutron n: $s = \frac{1}{2}$, $g^n = -3{,}82$

$g^{p,\,n} \neq 2$, $\langle\mu^n\rangle \neq 0$

- p, n are not fundamental and pointlike
  $\sqrt{\langle r^2\rangle} \cong 0{,}84 \cdot 10^{-15}$ m
- p, n are composite systems

slides by K. Rith

Constituent Quark Model



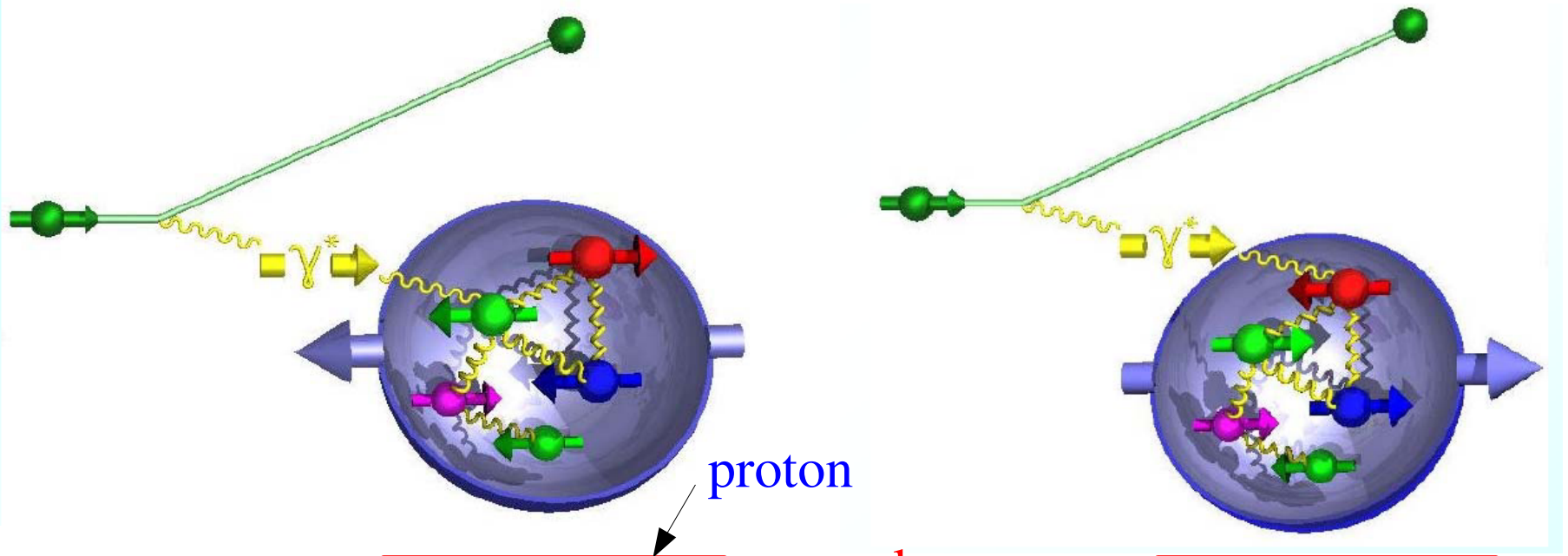
Nucleon Spin

$$\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma$$

Contribution of quark spins:

$$\Delta\Sigma = 1$$

Quark helicity distributions



$$\Delta q(x) = q^+(x) - q^-(x)$$

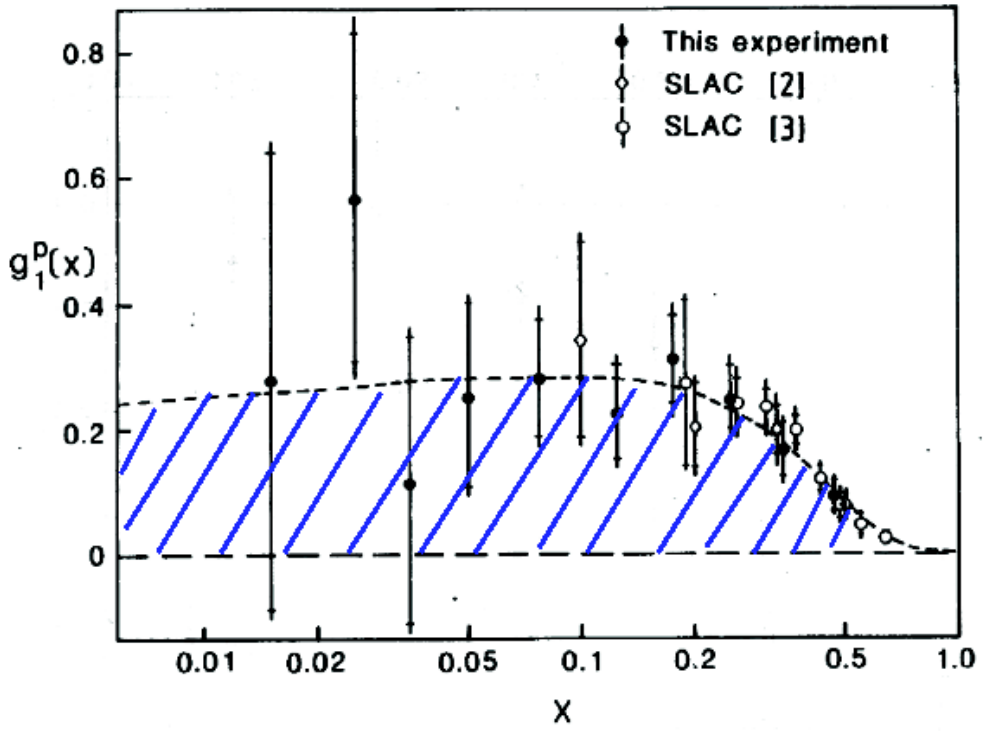
$$\Delta q = \int_0^1 \Delta q(x)\, dx$$

$$\Delta\Sigma = \sum_q \Delta q$$

$$g_1(x) = \tfrac{1}{2} \sum_q e_q^2 \Delta q(x)$$

$$\Gamma_1 = \int_0^1 g_1(x)\, dx$$

EMC result of $g_1(x)$



Consequence (1987):

	QPM:
$\Delta u \cong 0{,}78$	4/3
$\Delta d \cong -0{,}47$	-1/3
$\Delta s \cong -0{,}19$	0

1) Quark-'Sea' is negatively polarised

2) $\Delta\Sigma = \Delta u + \Delta d + \Delta s =$
$= 0{,}12 \pm 0{,}09 \pm 0{,}14$ — 1

Contribution of Quark Spins to Nucleon-Spin very small

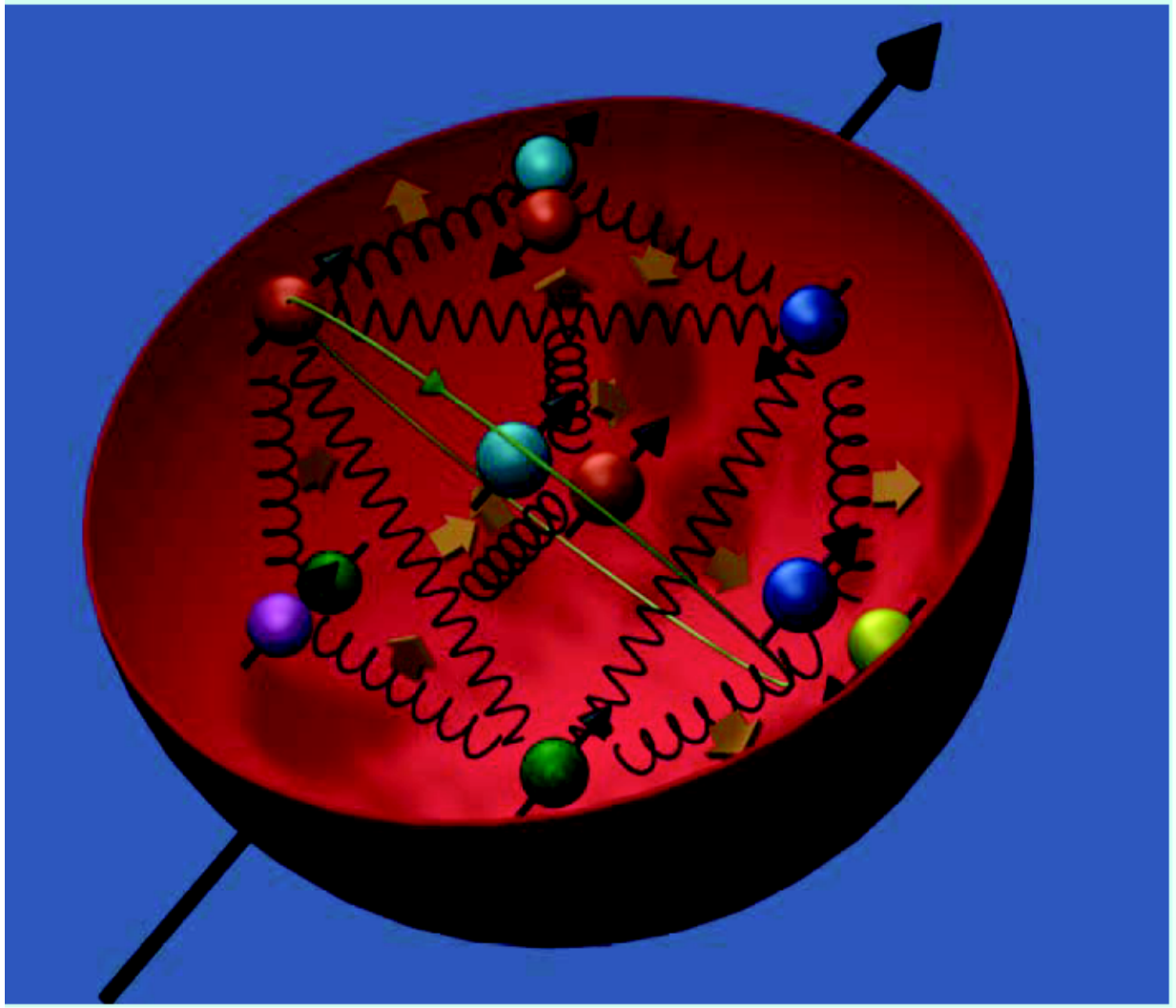
Spin-'crises'

$\Gamma_1^p = 0{,}126 \pm 0{,}010 \pm 0{,}015$

J. Ashman et al., PL B 206 (1988) 364 (1403 Cit.)

J. Ashman et al. Nucl. Phys. B 328 (1989) 1 (1207 Cit.)

Nucleon Spin in QCD



$\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma$ (Quark spins)

$+\ \Delta G$ (Gluon spins)

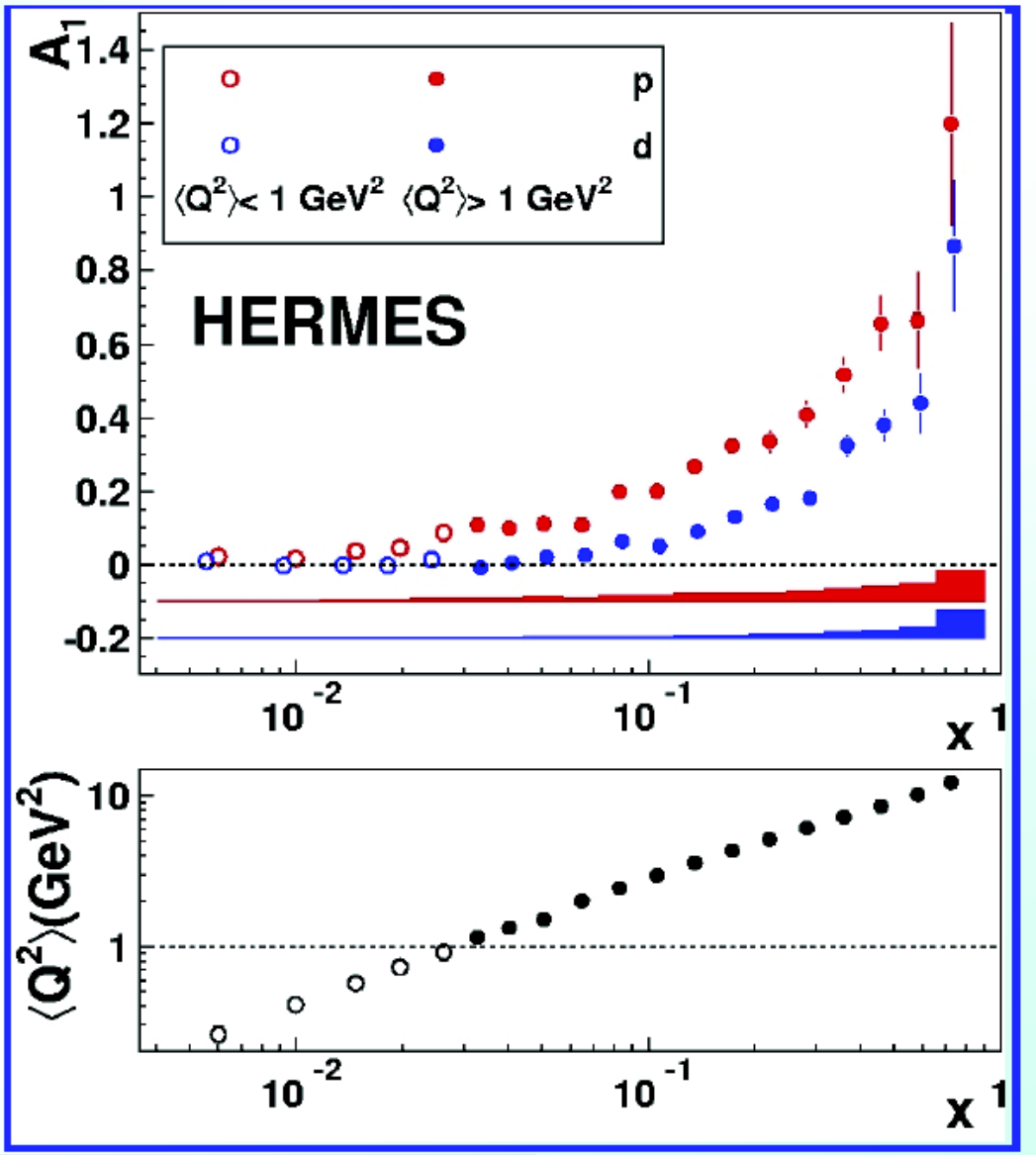
$+\ L_q + L_g$

(Orbital angular momenta)

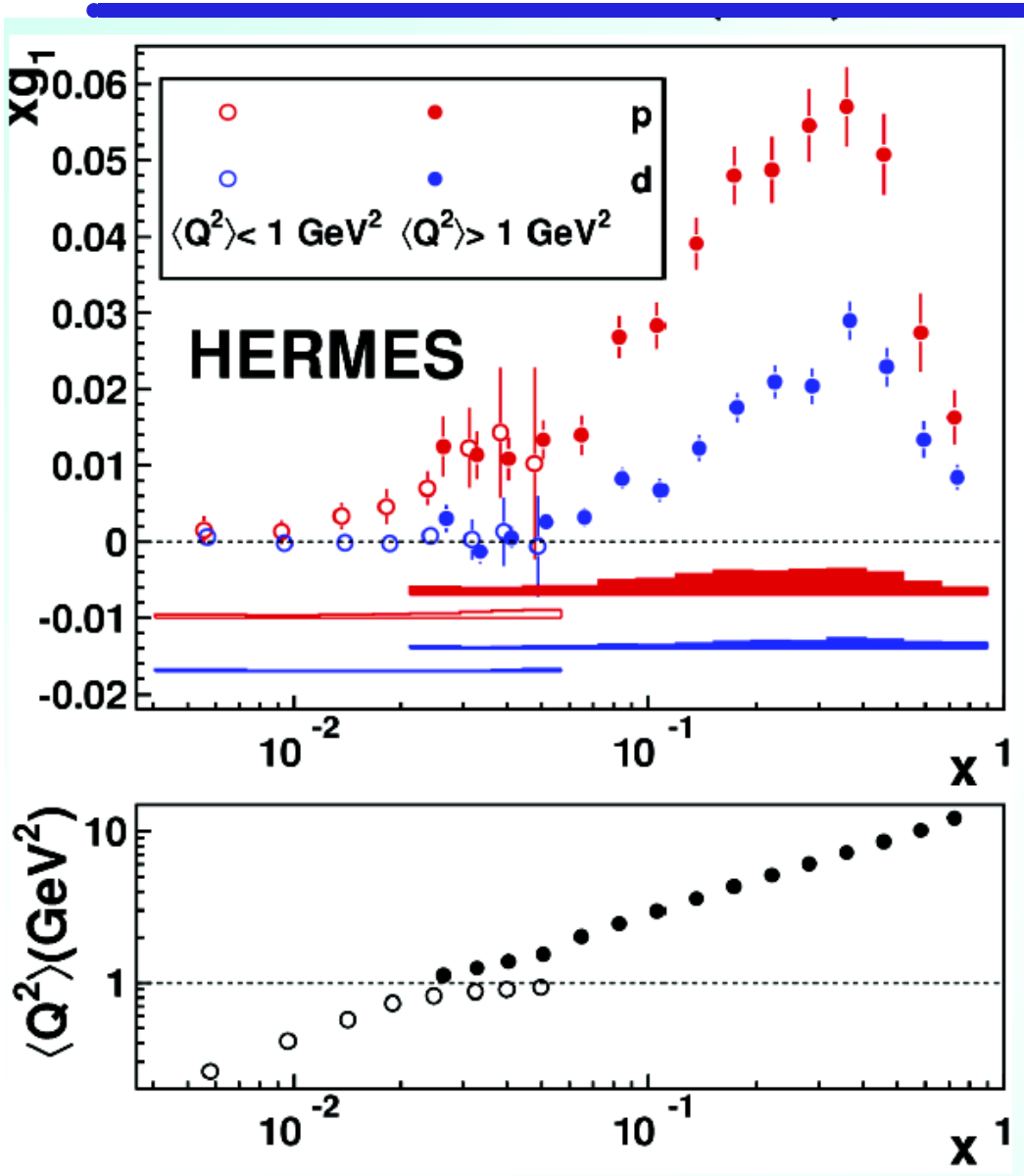
Asymmetry $A_1 = g_1/F_1$

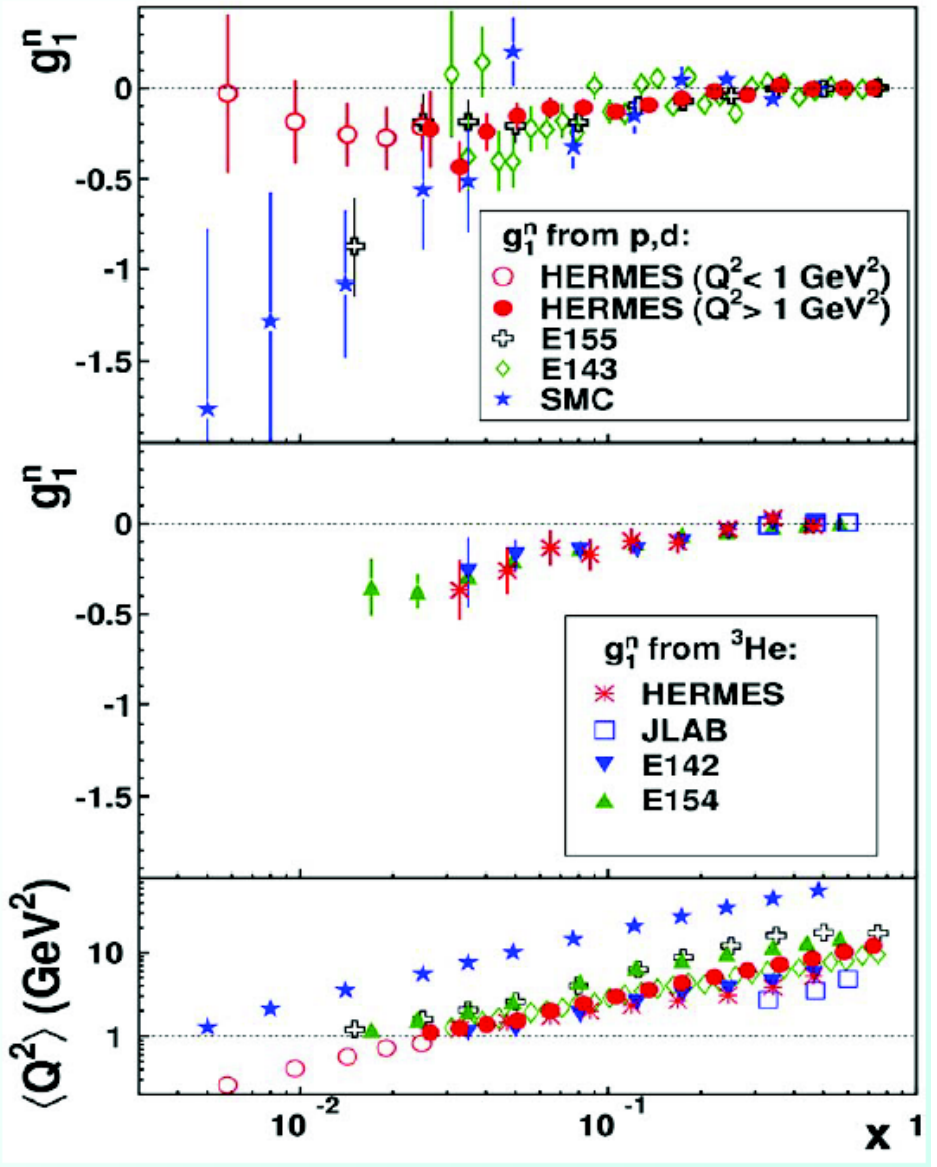
beam target

$$A_1(x) \cong \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}} \cong \frac{\sum_q e_q^2 \Delta q(x)}{\sum_q e_q^2 q(x)} = \frac{g_1(x)}{F_1(x)}$$

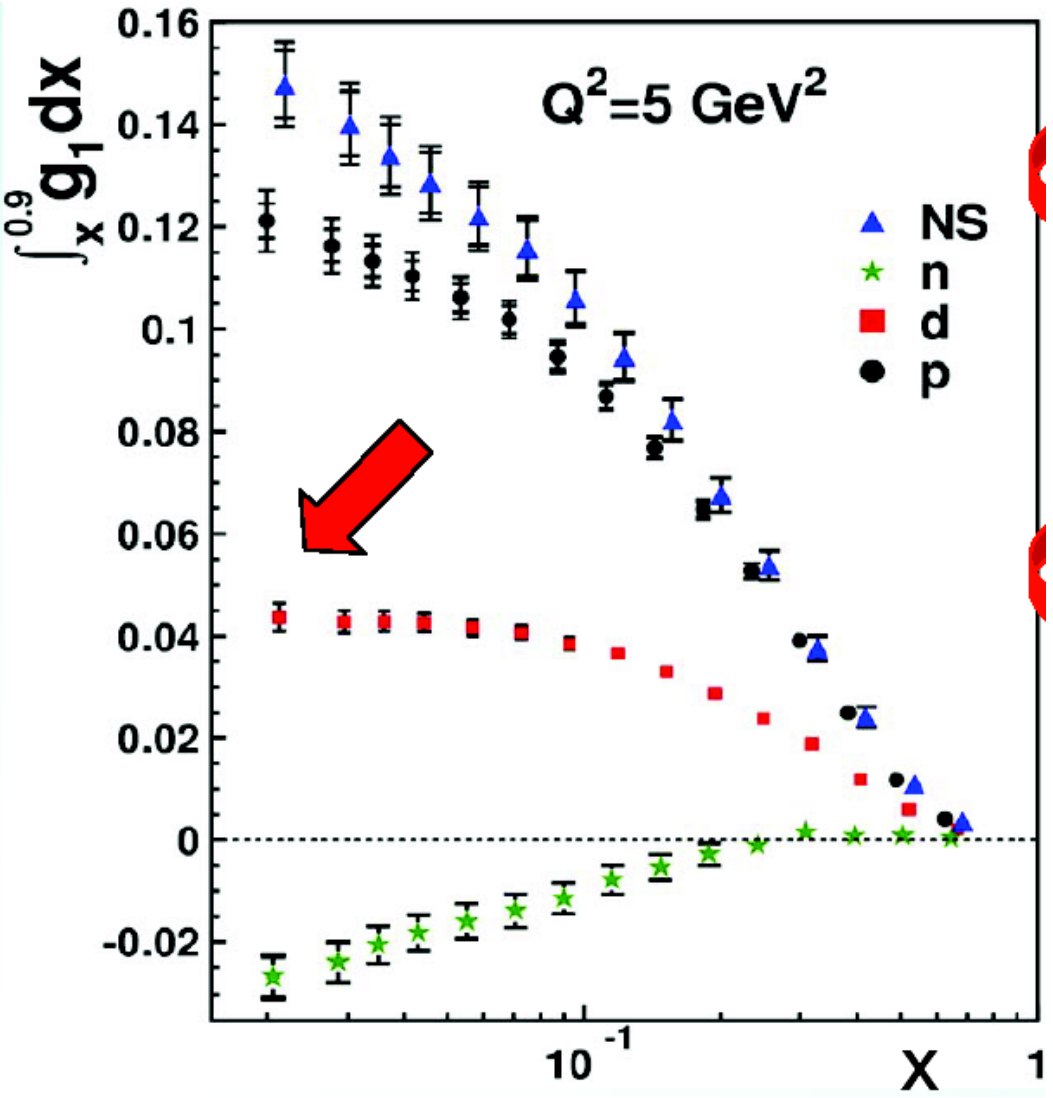


$g_1(x)$


xg1
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
p
d
⟨Q²⟩< 1 GeV²
⟨Q²⟩> 1 GeV²
HERMES
10 -2
10 -1
1
x
⟨Q²⟩(GeV²)
10
1
10 -2
10 -1
1
x


g1n
0
-0.5
-1
-1.5
g1n from p,d:
HERMES (Q²< 1 GeV²)
HERMES (Q²> 1 GeV²)
E155
E143
SMC
g1n
0
-0.5
-1
-1.5
g1n from ³He:
HERMES
JLAB
E142
E154
⟨Q²⟩ (GeV²)
10
1
10 -2
10 -1
1
x

Determination of $\Delta\Sigma$

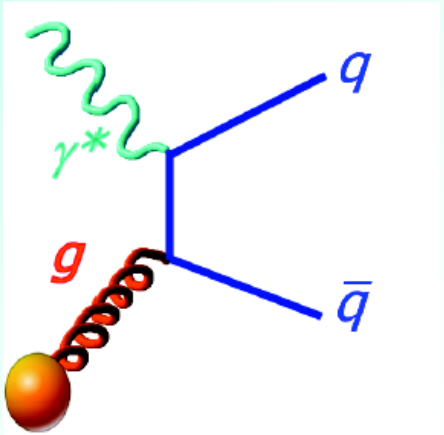


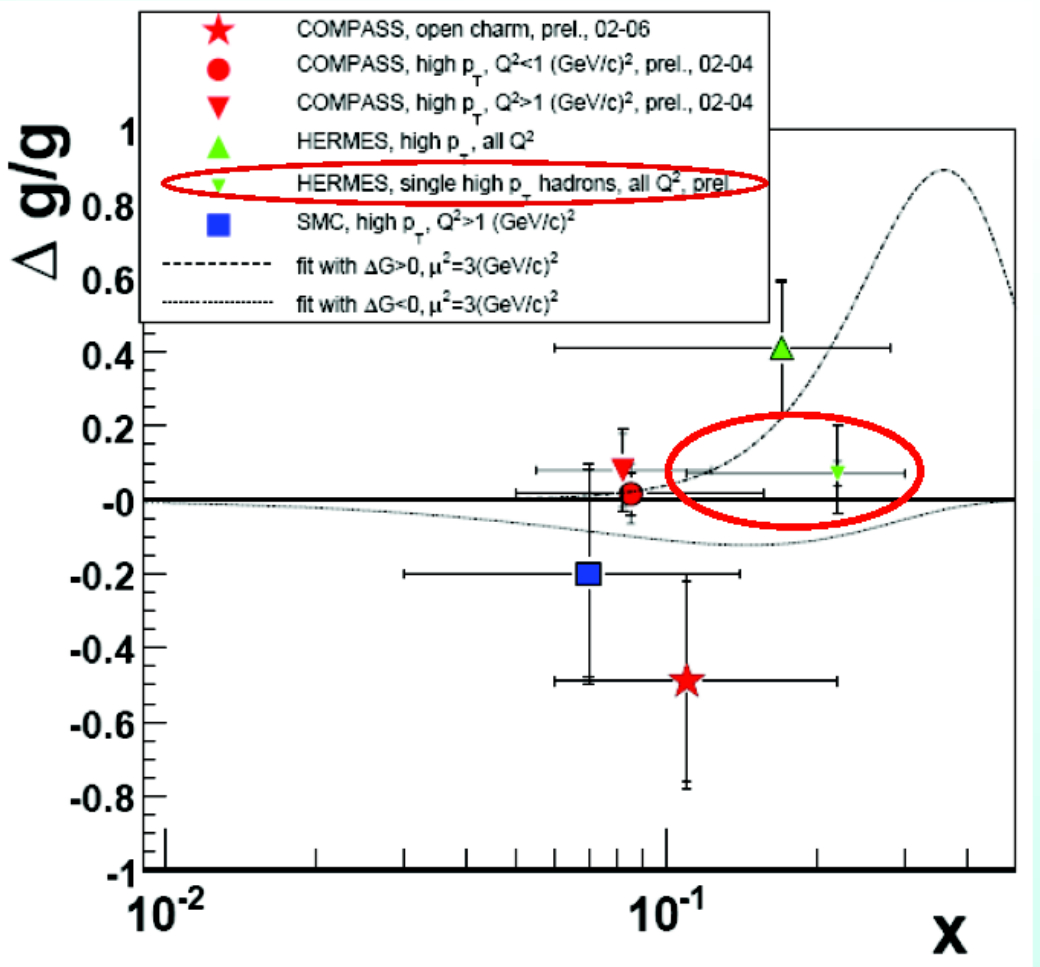
most precise determination comes from deuteron data

$\Delta\Sigma = 0.330 \pm 0.025$ (exp.) ± 0.011 (theory) ± 0.028 (evol.)

for comparison:
EMC: $\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14$

Determination of Δg/g





$\langle \mu^2 \rangle = 1.35$ GeV²

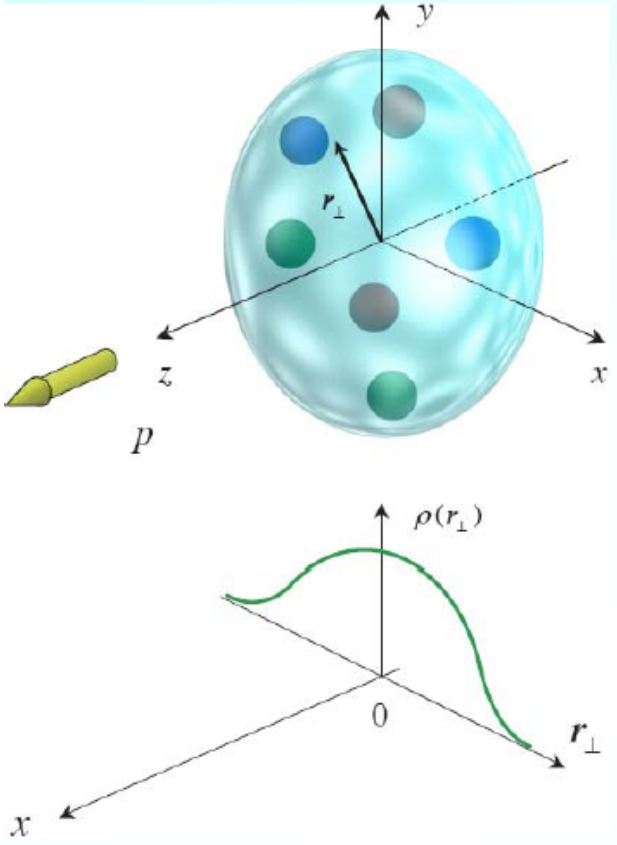
$$\Delta g/g(x,\mu^2) = 0.071 \pm 0.034^{(stat)} \pm 0.010\ (sys\text{-}exp)\ ^{+0.127}_{-0.105}\ (sys\text{-}model)$$

Nucleon Spin

- origin still unclear
  - Δq cotributes ~1/3
  - Δg contribution seems to be very small
  - ➔ but very low x not yet measured
- contribution of orbital angular momentum?
  - ➔ Deeply Virtual Compton Scattering, Generalised Parton Distributions

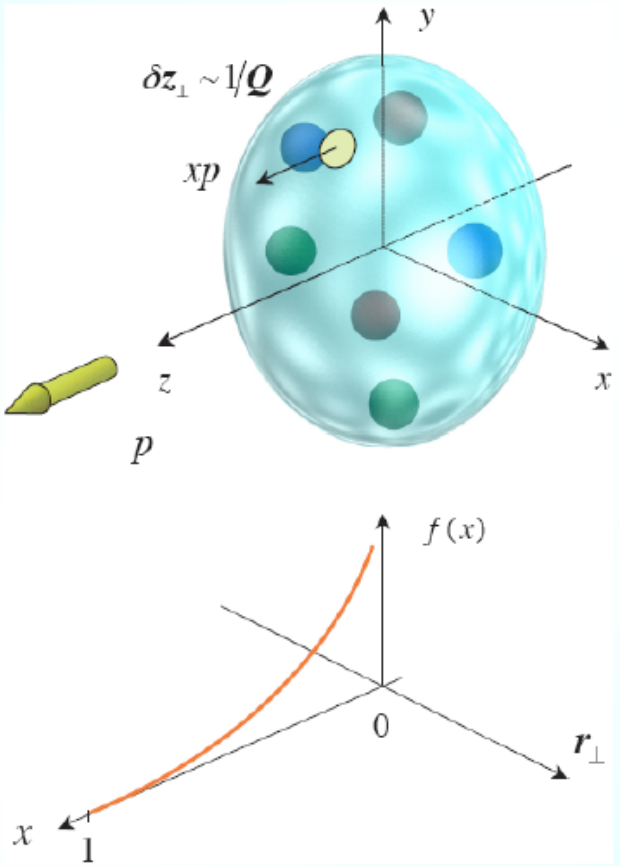
Generalised Parton Distributions

Formfactors:



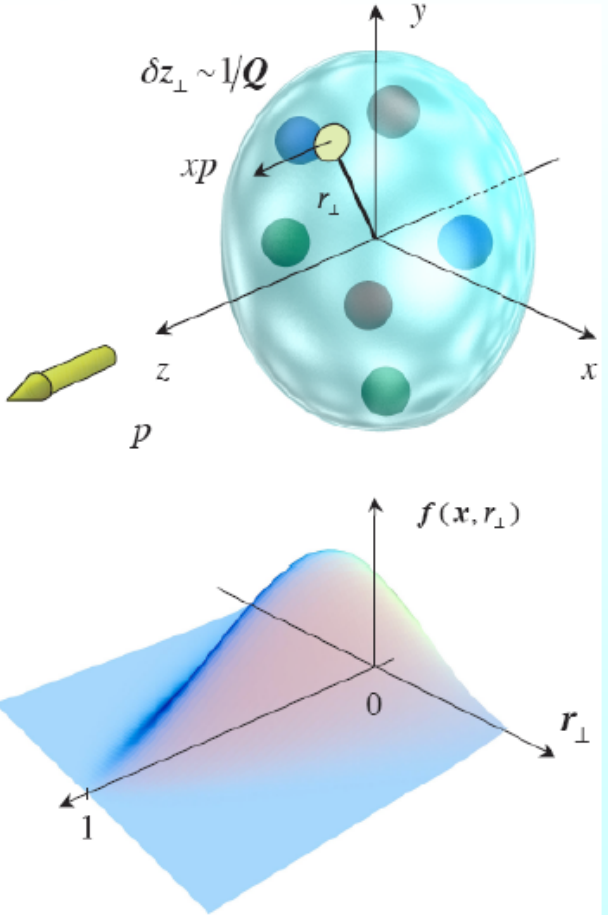
Fouriertransform of e.g. a radial charge distribution

PDFs:



Number density of quarks with longitudinal momentum fraction x

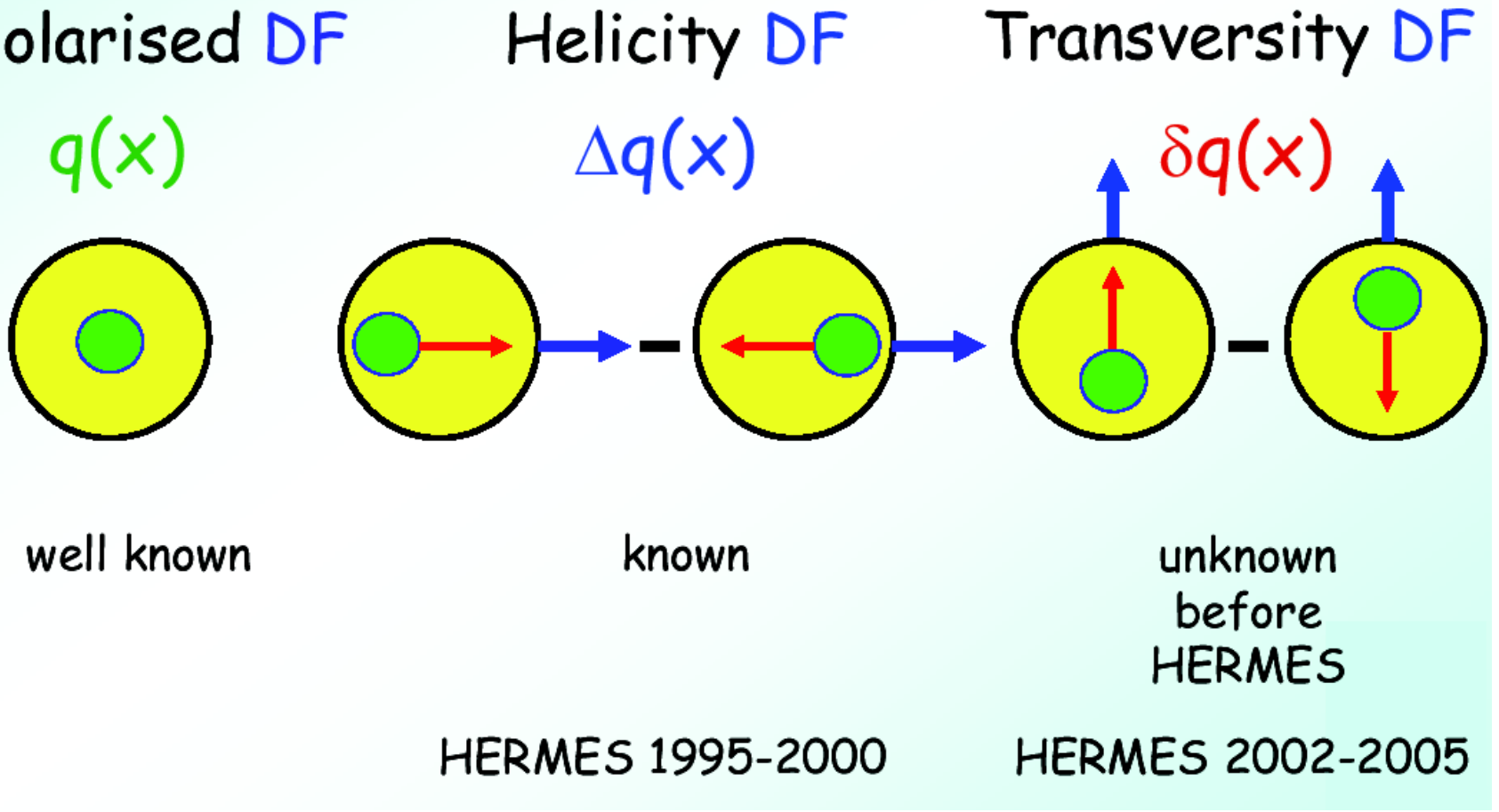
GPDs:



Generalised description in 2+ 1 dimensions

Transversity

For a complete description of momentum and spin distribution of the nucleon at leading-twist: 3 distribution functions (DF)



Exotics or Beyond the Standard Modell

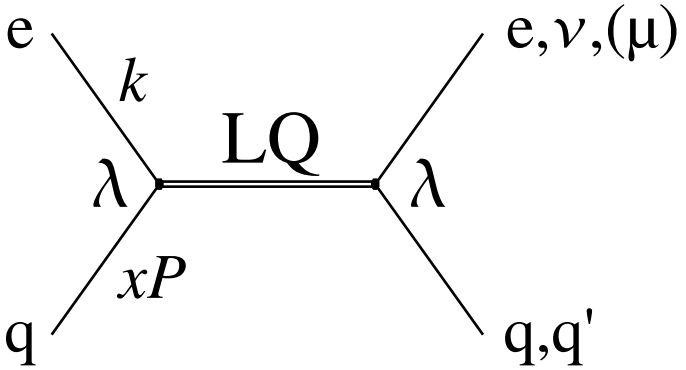
New Particles

many theories predict more particles than the SM:

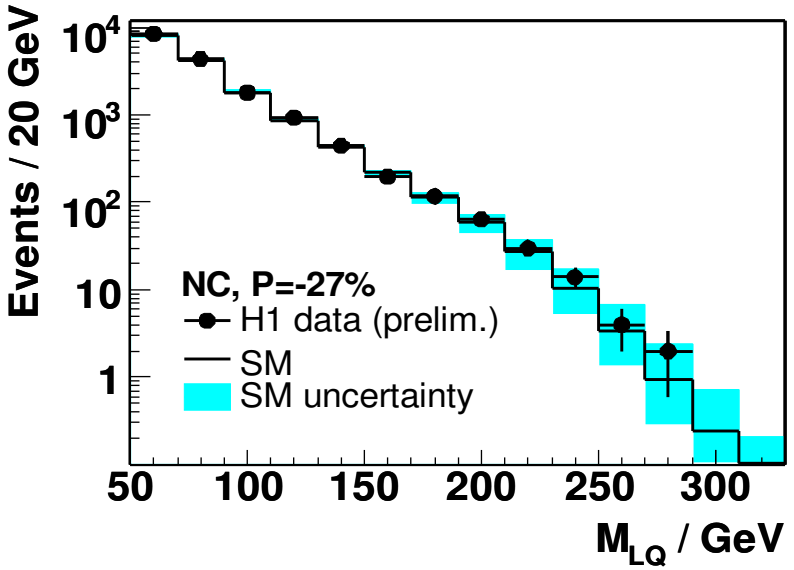
- SUSY:
  - every Standard Model particle has a supersymmetric partner
  - fermion partners are bosons, boson partners fermions
- leptoquarks
  - particle with lepton and quark properties
  - can be produced resonantly in *ep* collisions
- ... exited fermions, contact interactions, large extradimensions ...

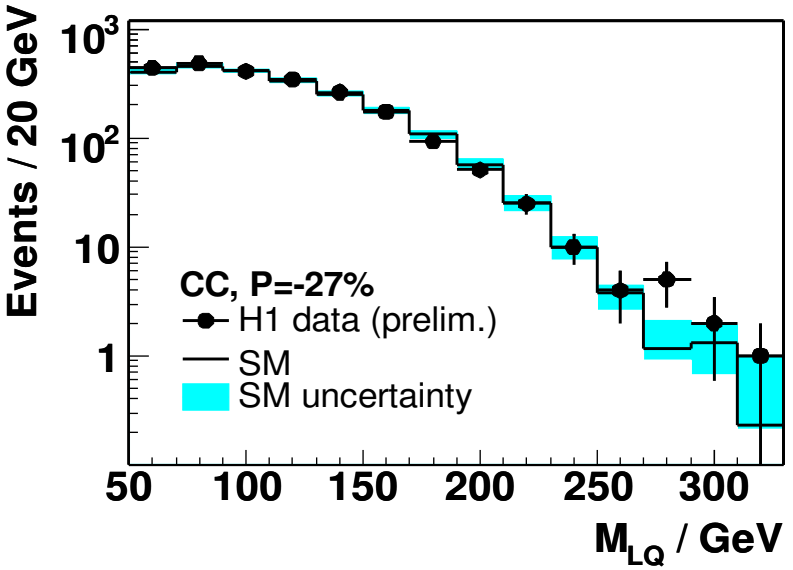
but experimentally search also model-independent!

Leptoquarks

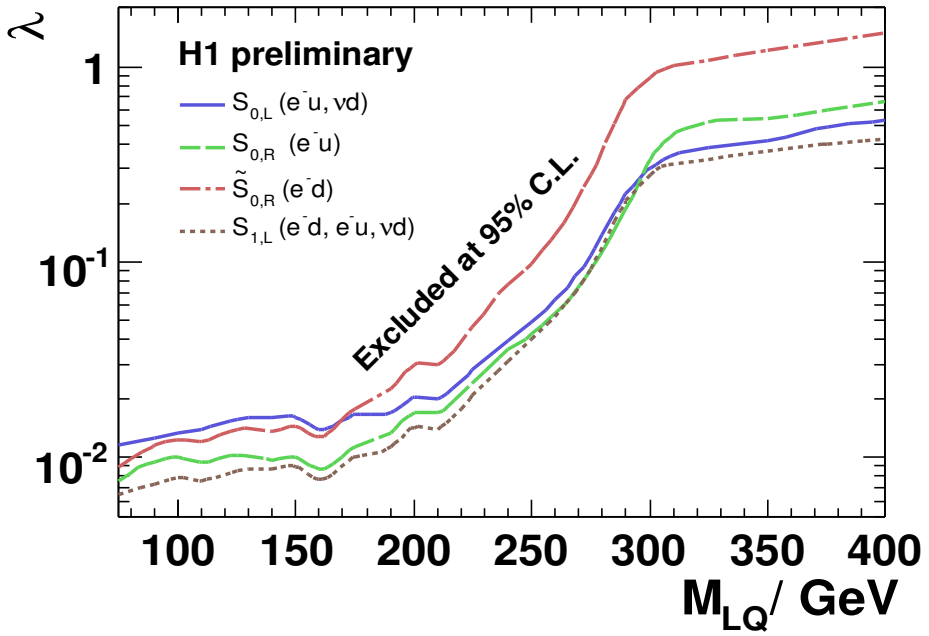


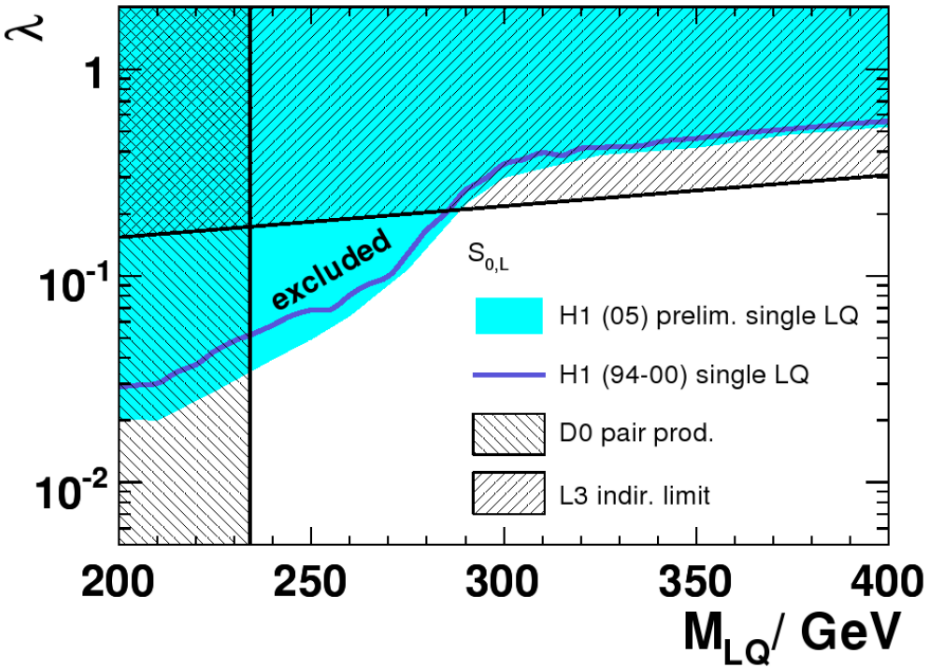
- can look the same as NC or CC process
- $M_{LQ}^2 = (xP + k)^2 = xs$
- compare measured cross section with SM expectation
- derive limits on coupling λ



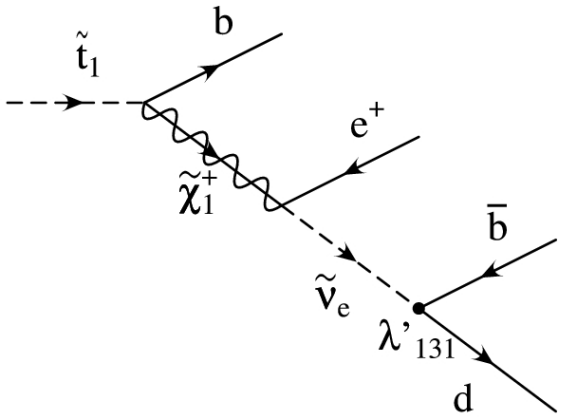


Limits on Leptoquarks



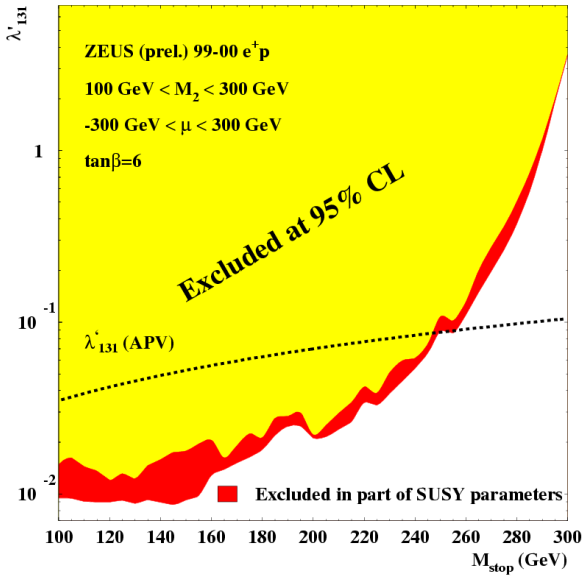


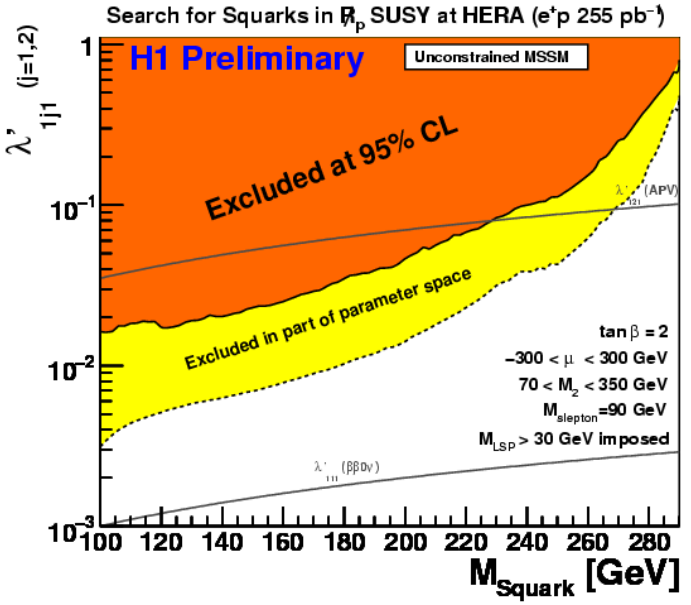
SUSY

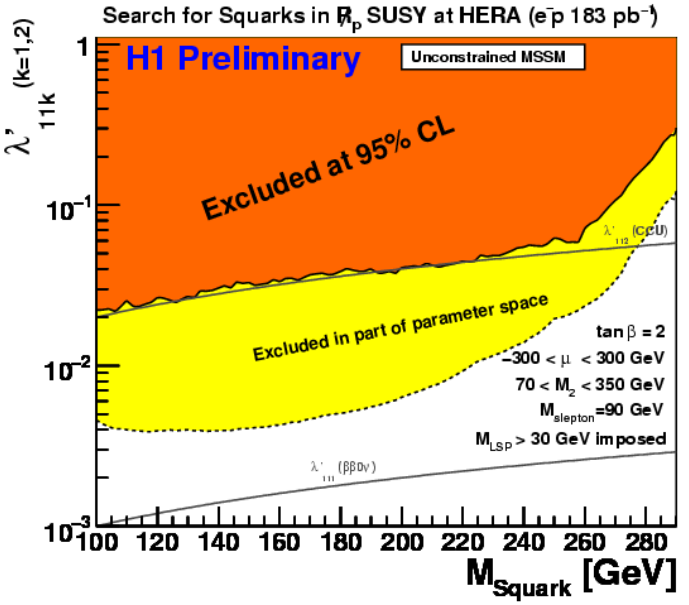


- R parity violation: single SUSY particle can be produced
- limits depend on many parameters (masses, couplings)
- example: stop

ZEUS



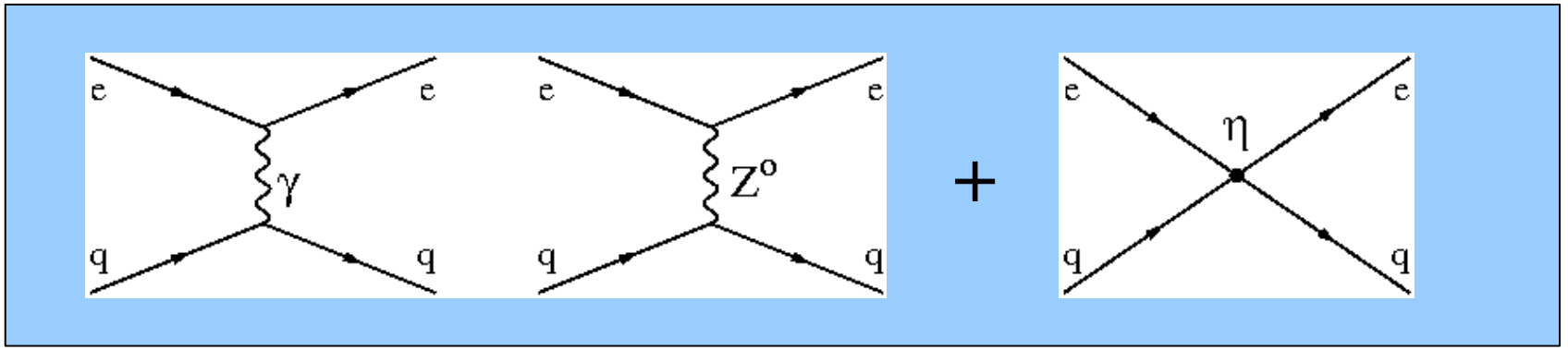




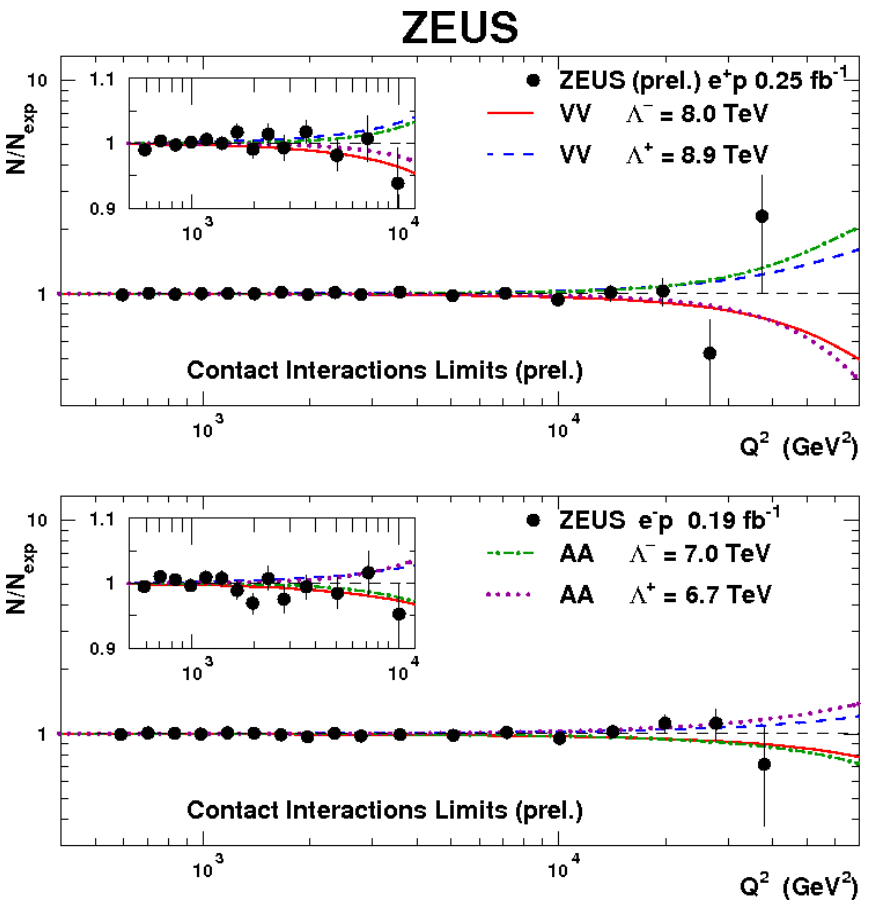
Contact Interactions

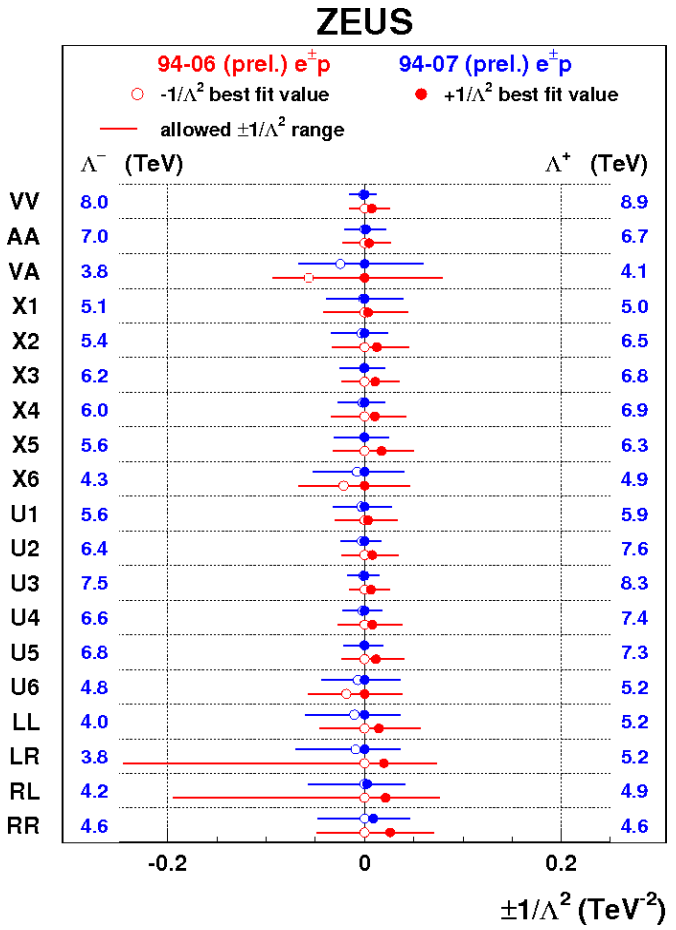
- New interactions at higher scale ($\Lambda >> \sqrt{s}$) can be effectively described at lower energies as 4-fermion *eeqq* Contact Interactions
- Reminder: before W and Z^0 were discovered, weak interactions ($\Lambda \approx M_W$) were described as 4-fermion Contact Interactions with Fermi constant $G_F = g^2/M^2_W$

➔ Contact Interactions would modify the DIS cross section



Contact Interactions





- No sign for Contact Interactions found
- masses much larger than √s excluded

ZEUS (94-07 data):
Λ> 3.8 - 8.9 TeV

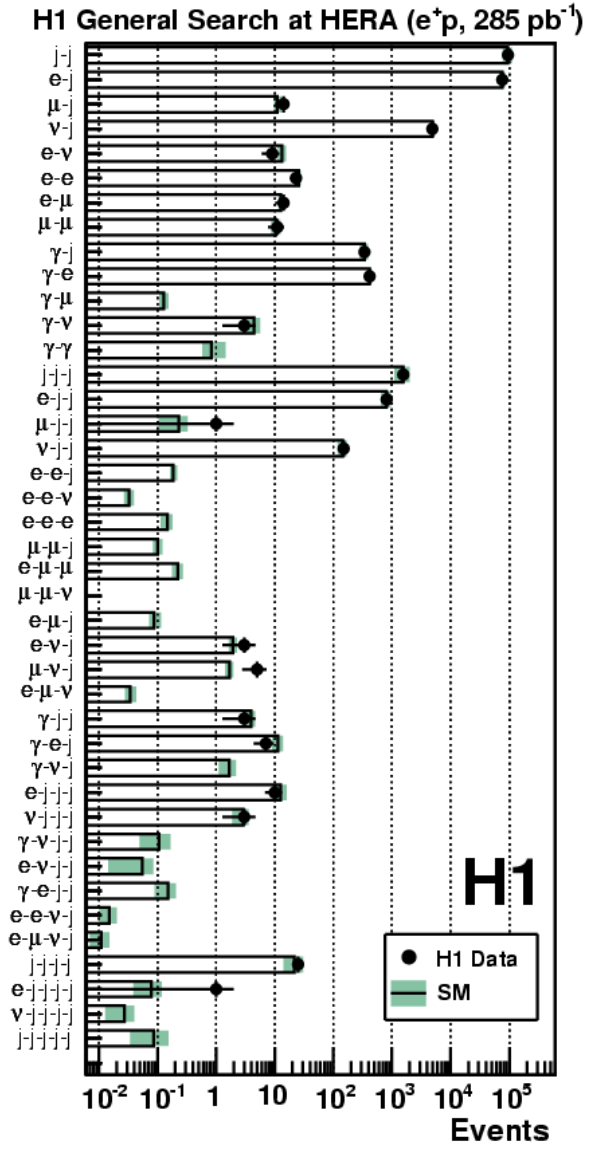
General Searches

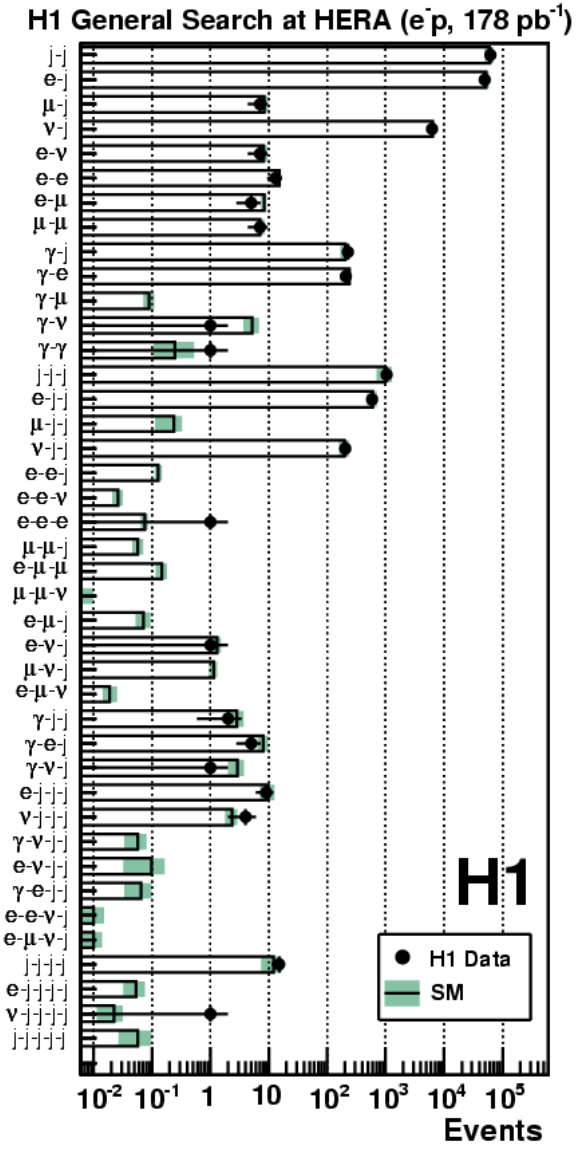
- idea: new particles have typically large mass

➔ final state should contain particles with large transverse momentum from the decay

  - jets
  - electrons
  - muons
  - photons
  - neutrinos (missing transverse momentum)

General Searches

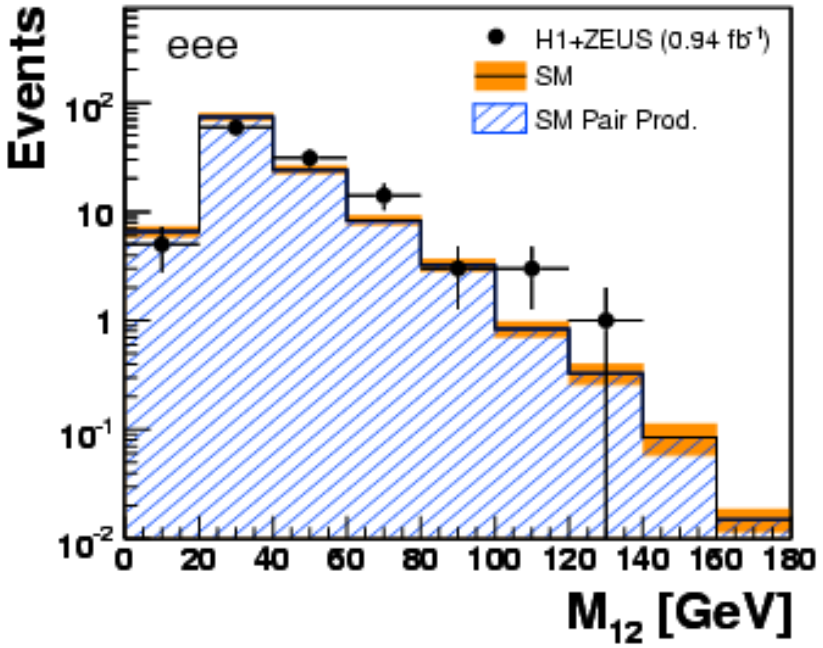


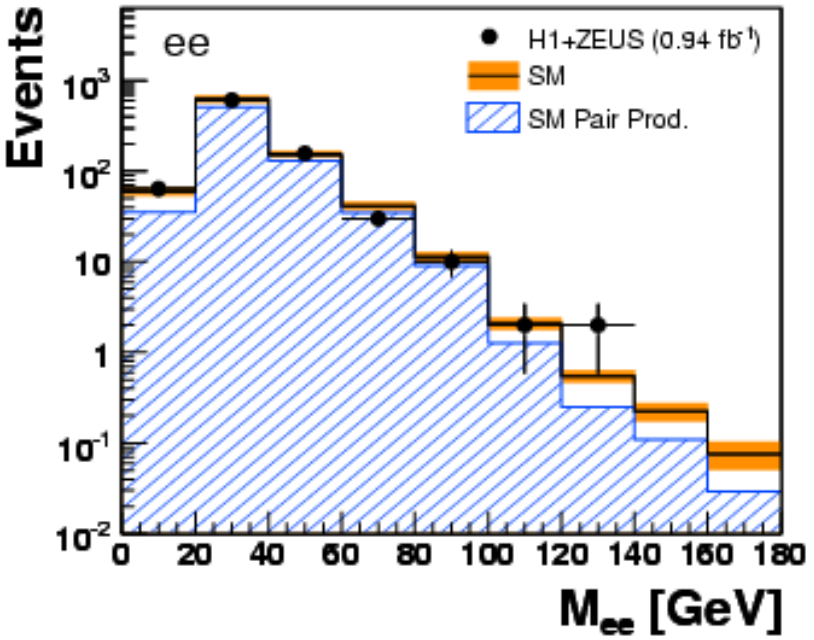


every channel in reasonable agreement with the standard model

Multi-Leptons

in HERA1 a small excess of di- and tri-electron events at high transverse momenta observed by H1

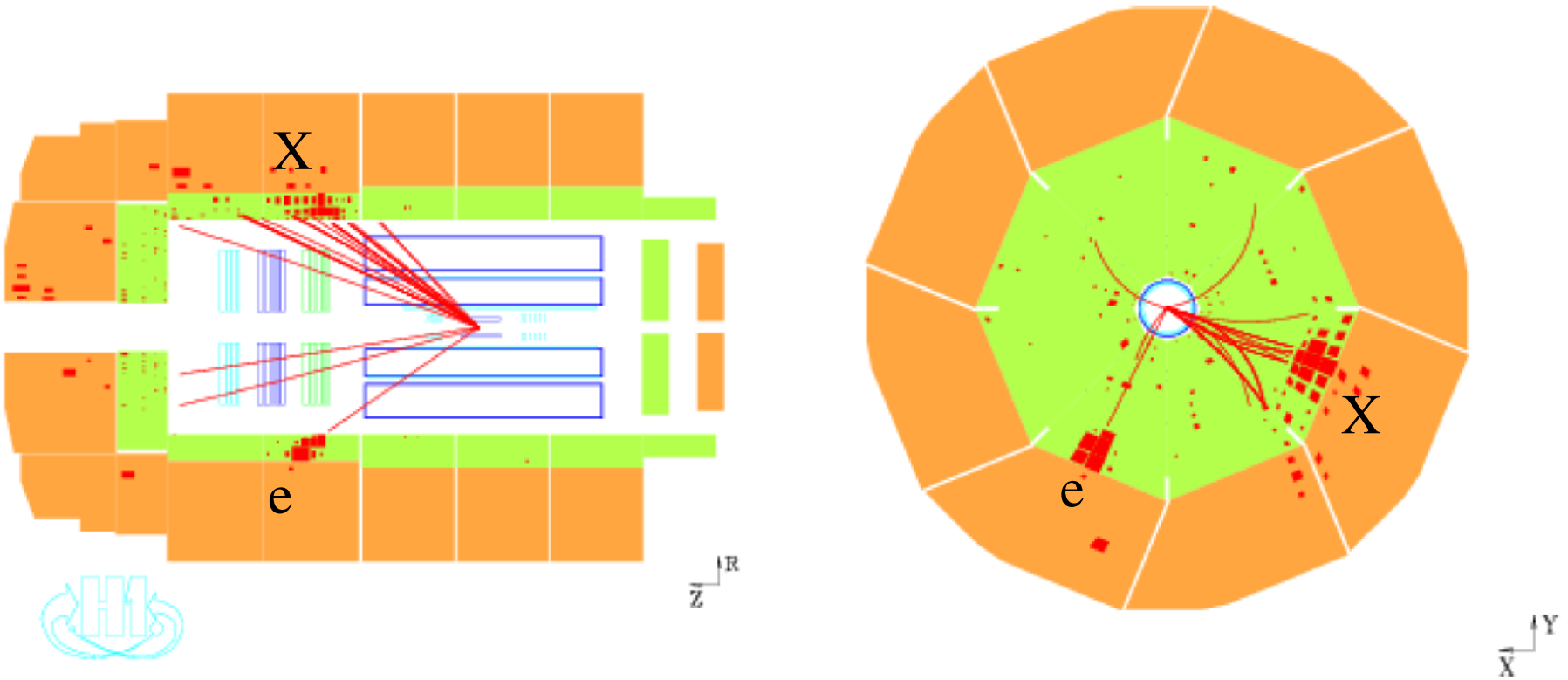




combined HERA (H1+ZEUS HERA1&2) data show no significant excess

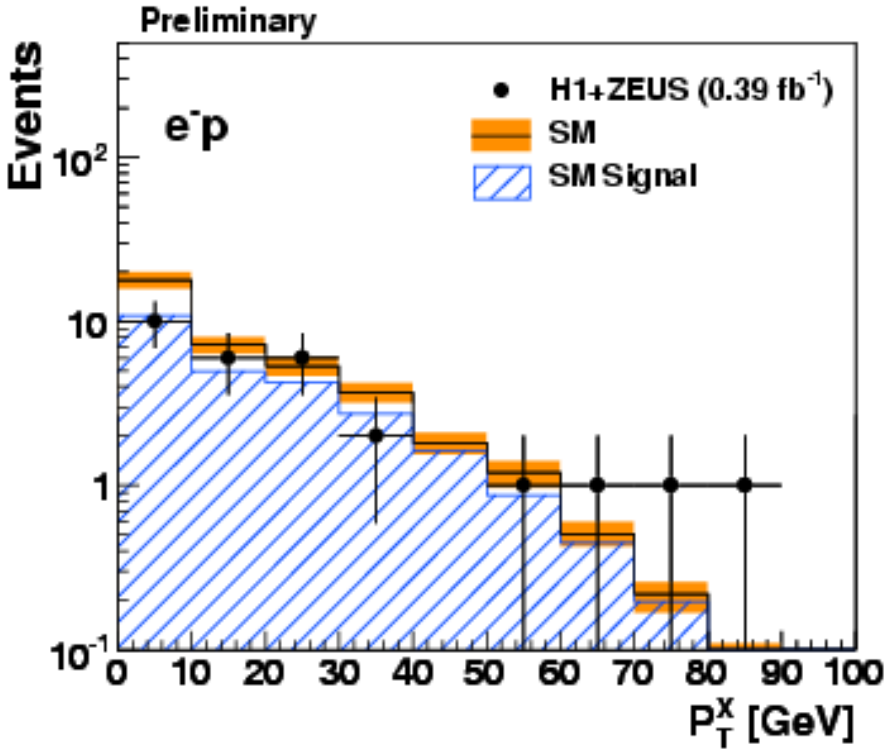
first combined paper by ZEUS & H1

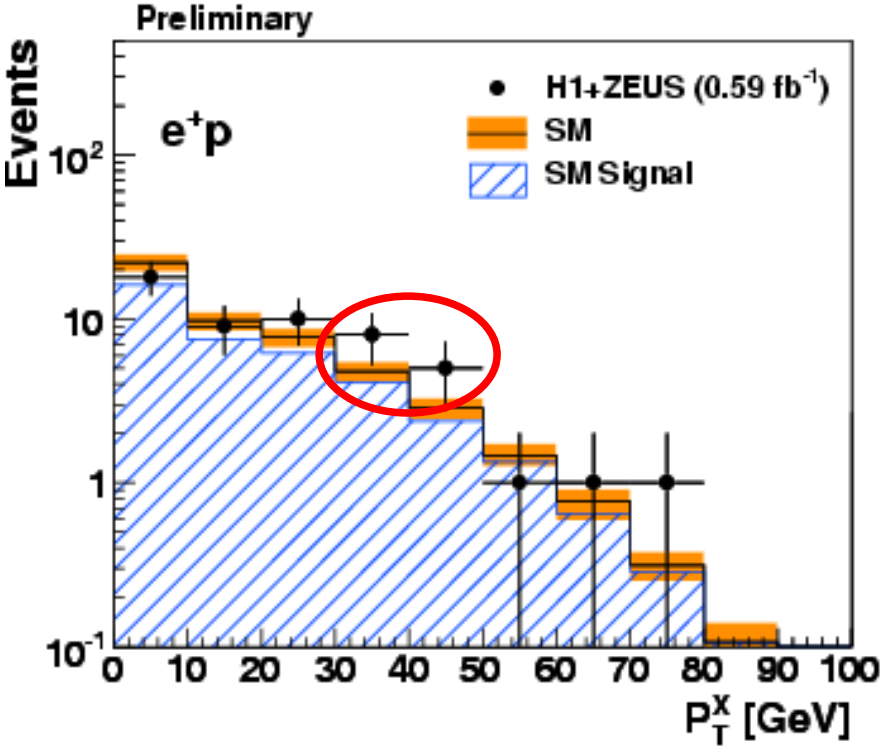
Isolated Leptons and Missing P_T



- spectacular events
- excess in HERA1 data at large transverse momenta of the hadronic system (P_T^X) seen by H1

Isolated Leptons and Missing P_T





- no excess in e^- data
- e^+:H1+ZEUS combined: 1.9 σ excess
- H1 alone: 2.4 σ excess

?

H1+ZEUS Preliminary 1994-2007 e^+p 0.59 fb^{-1}		Data	SM Expectation
Combined	Total	53	49.82 ± 6.18
	$P_T^X > 25$ GeV	23	14.02 ± 1.94