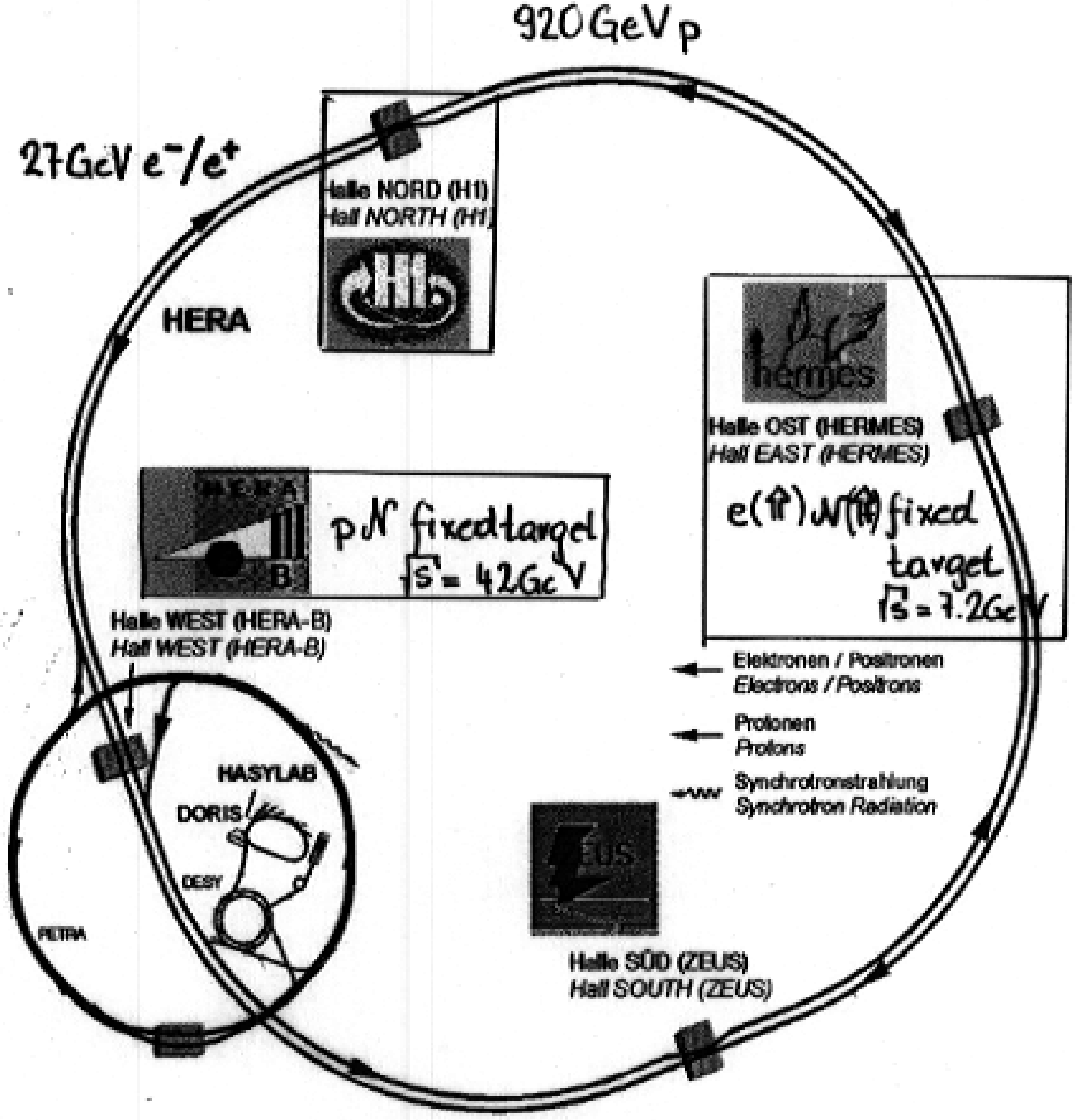
Status of HERA and its Detectors

5-10-99
ICFA

Robert Klanner
Hamburg University

(1) HERA
(2) HERA-B
(3) HERMES
(4) H1 and ZEUS



H1 and ZEUS e p collider: $\sqrt{s} = 320$ GeV

(1) HERA: Status and Plans

History:

1976 1^{st} ideas (B. Wiik + al.)

1981 proposal

• 1992 first luminosity for H1 and ZEUS

• 1995 start HERMES ($e\Uparrow \cdot N\Uparrow$)

1997 achieve design $\mathcal{L}_{ep} \simeq 1.5 \cdot 10^{31}\, cm^{-2} s^{-1}$

• 1999 start HERA-B ($p \cdot N$ for $\not{C}\not{P}$ in B-sector)

2000 luminosity upgrade (aim factor $\simeq 4.7$)

> 2001 high luminosity running

Performance:

running $\varepsilon \approx 40 \cdots 68\%$ (includes 20% - injection + acceleration)

1993 → 1997 e^+p running *)

1998 → mid '99 e^-p running

mid '99 back to e^+p running (for physics reasons mainly)

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*) for e^-p: positively charged dust (?)

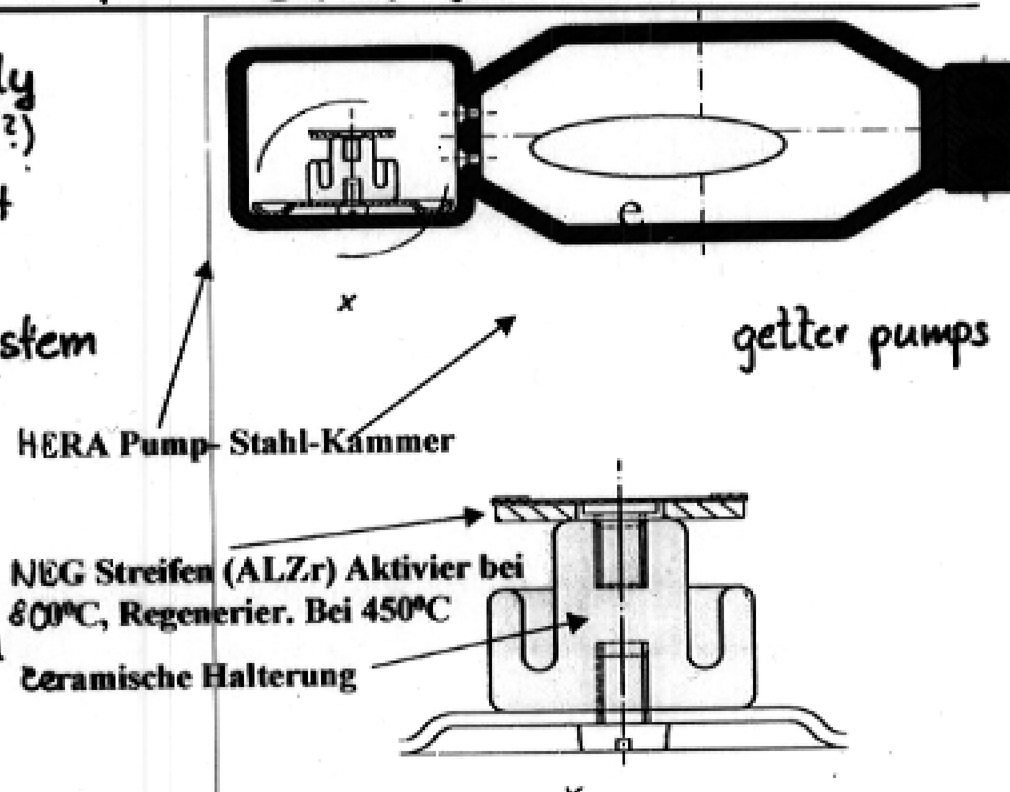
→ τ_e breakdown at $\boxed{I_{e^-} \gtrsim 25\,mA}$

→ e-vacuum system replaced in '98!

↓

vacuum o.k.

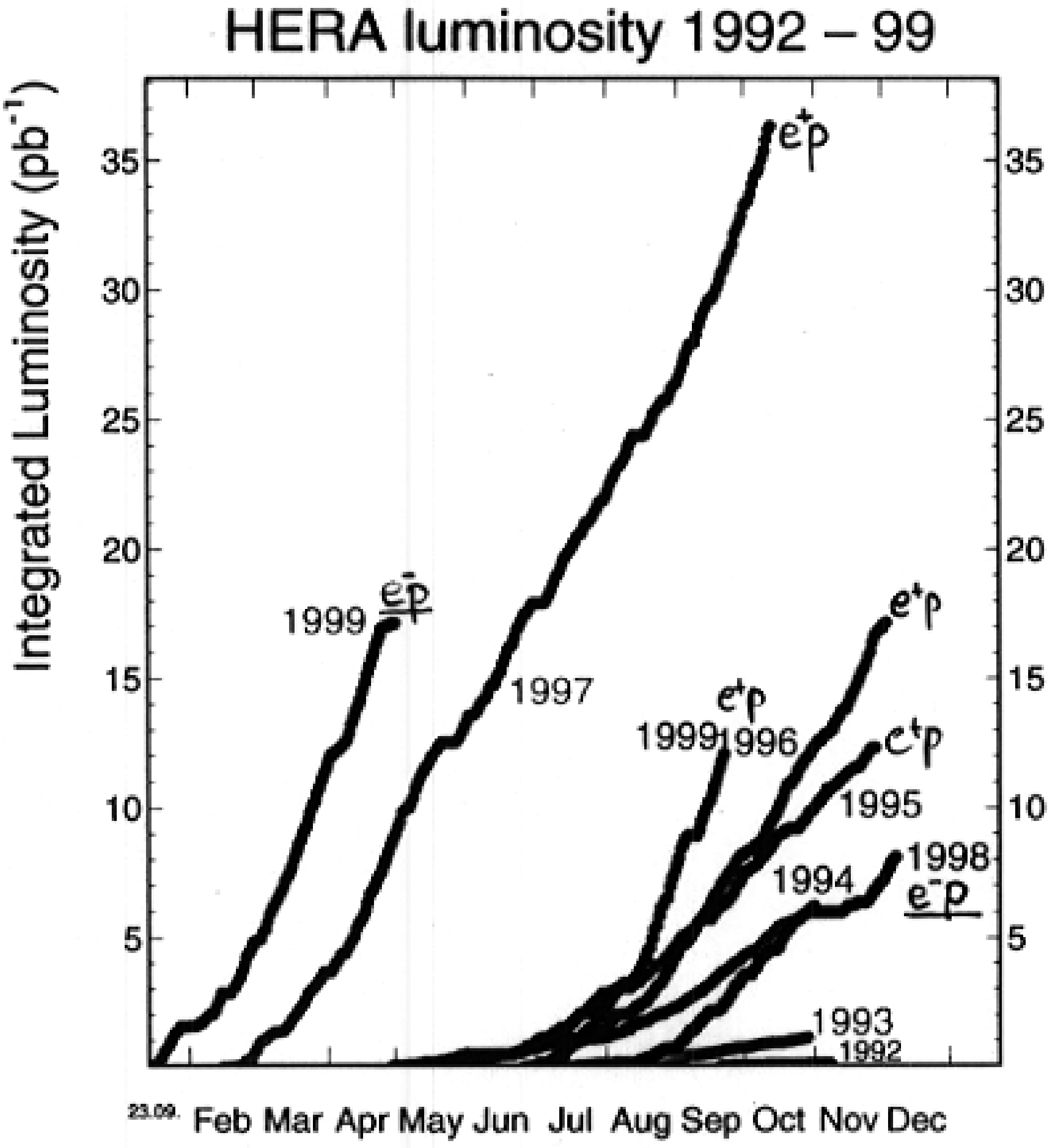
$\boxed{I_{critical} > 40\,mA}$



+ many steady improvements e.g. RF, SC-RF, PS, NC-magnets...

Hera: e-p luminosity delivered:

e^+p: $84\,pb^{-1}$
e^-p: $26\,pb^{-1}$



e - longitudinal polarisation:

routinely: 50-60%

(during e-p luminosity operation)

2000: HERA Luminosity upgrade

$$\mathcal{L} \propto \underbrace{\frac{N_p}{\varepsilon_p}} \cdot \underbrace{I_e} \cdot \underbrace{\frac{1}{\sqrt{\beta^*_{xp} \cdot \beta^*_{yp}}}}$$

p-beam brightness (DESY III space charge) (beam-beam tuneshift)

R-F power

p-β-functions (apertures low β-Quads) (chromaticity).

- move superconducting magnets inside detectors for e-p beam separation and focusing
- more compact e-low β quadrupoles
- new type of septum quads.

Status:

Lattice, optics, accelerator physics: stable, good solutions

room temperature magnets: big fraction produced, delivered excellent field quality

superconducting magnets: new 3d ultrasonic bond (BNL) works well, good field, critical path.

vacuumsystem: in production

cryogenic supplies: tendering in progress

instrumentation, survey systems: in production

➡ ready for start shutdown in May 2000

Longer term options:

eA .... crude estimates have been done for light N

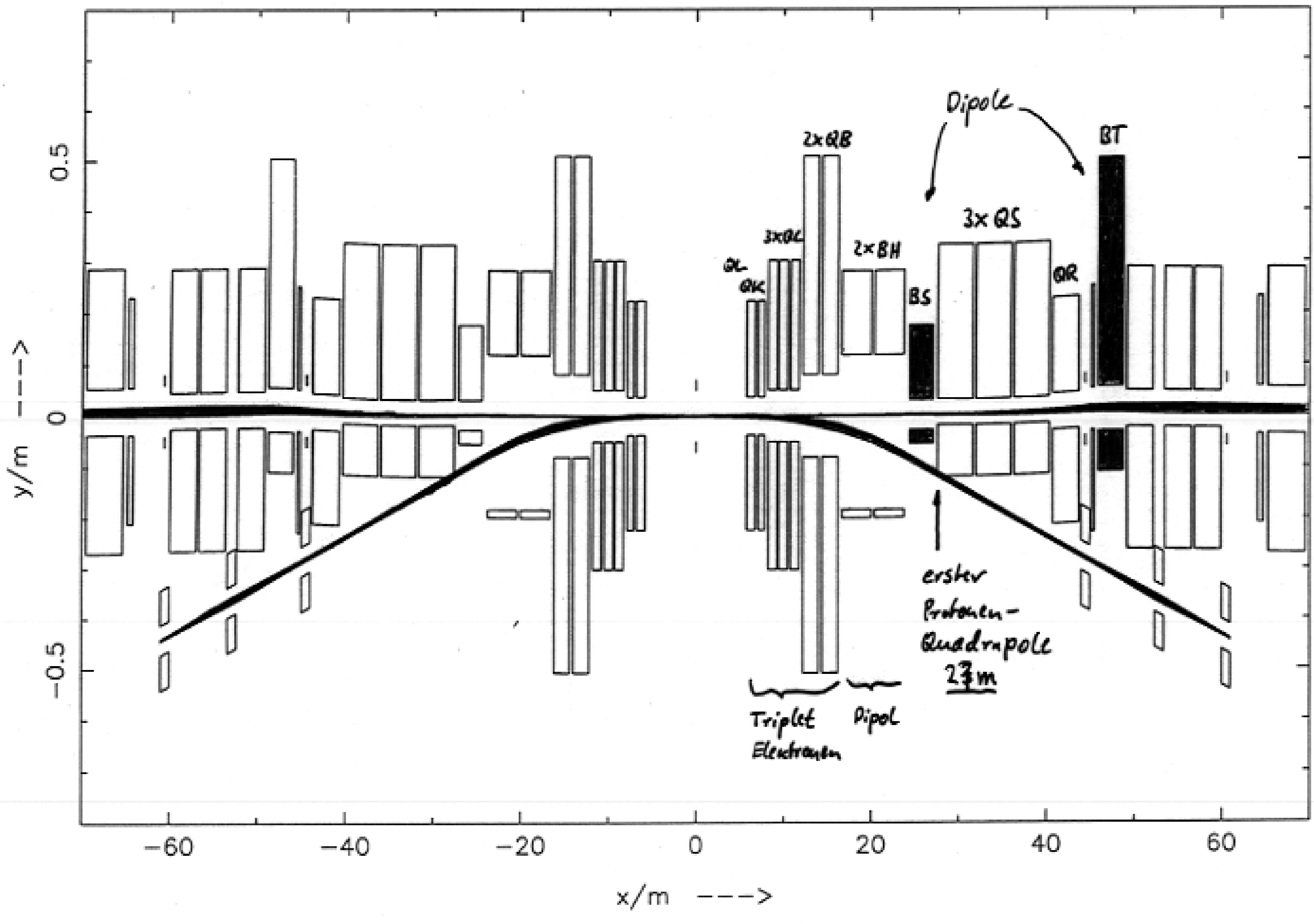
ep(↑)..... difficult, but appears feasible
big effort, see how RHIC does.

strongly linked to TESLA.

B. Holzer

present

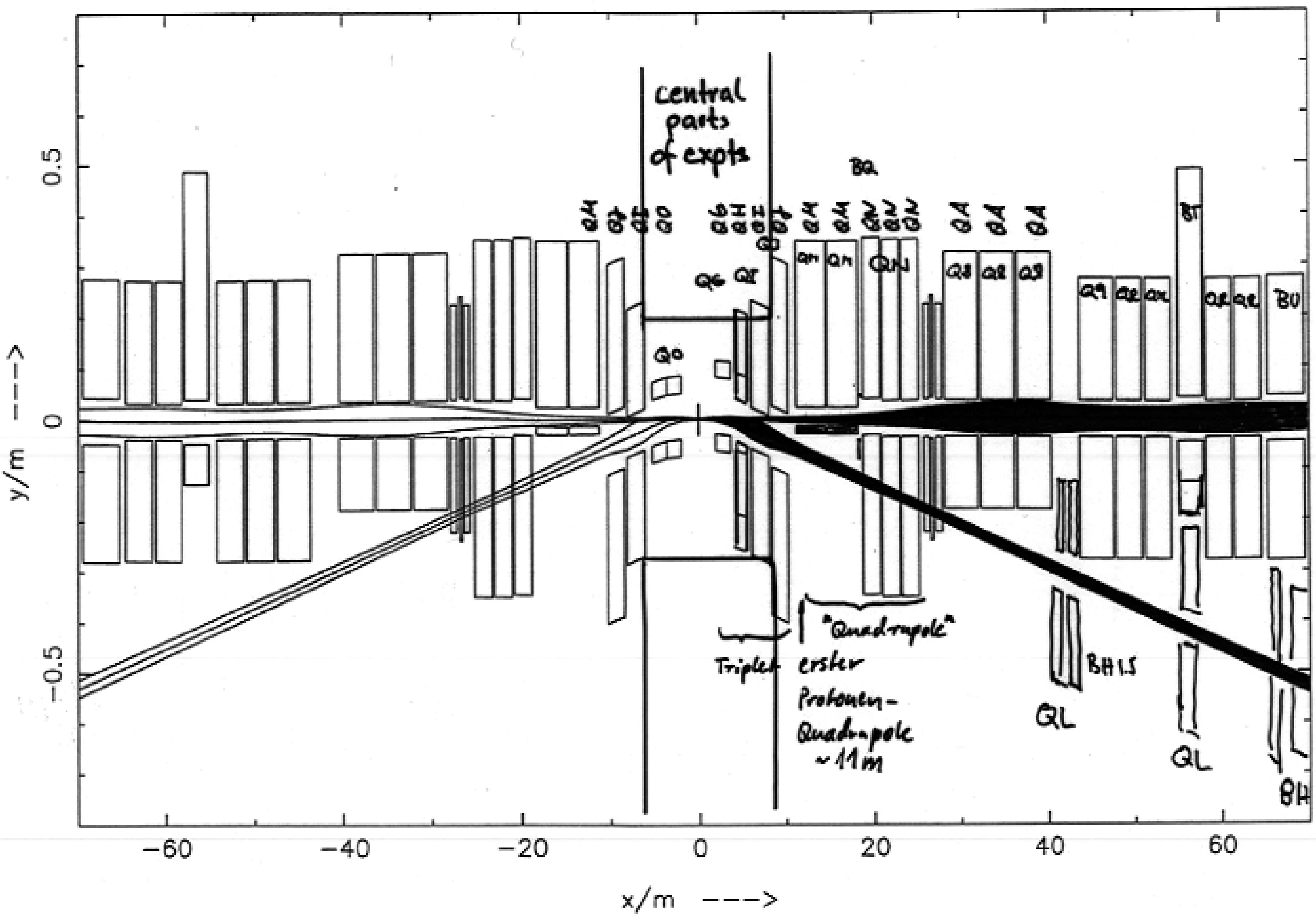
gegenwärtige HERA-WECHSELWIRKUNGSZONE



after 2000

Neue HERA–Wechselwirkungszone,

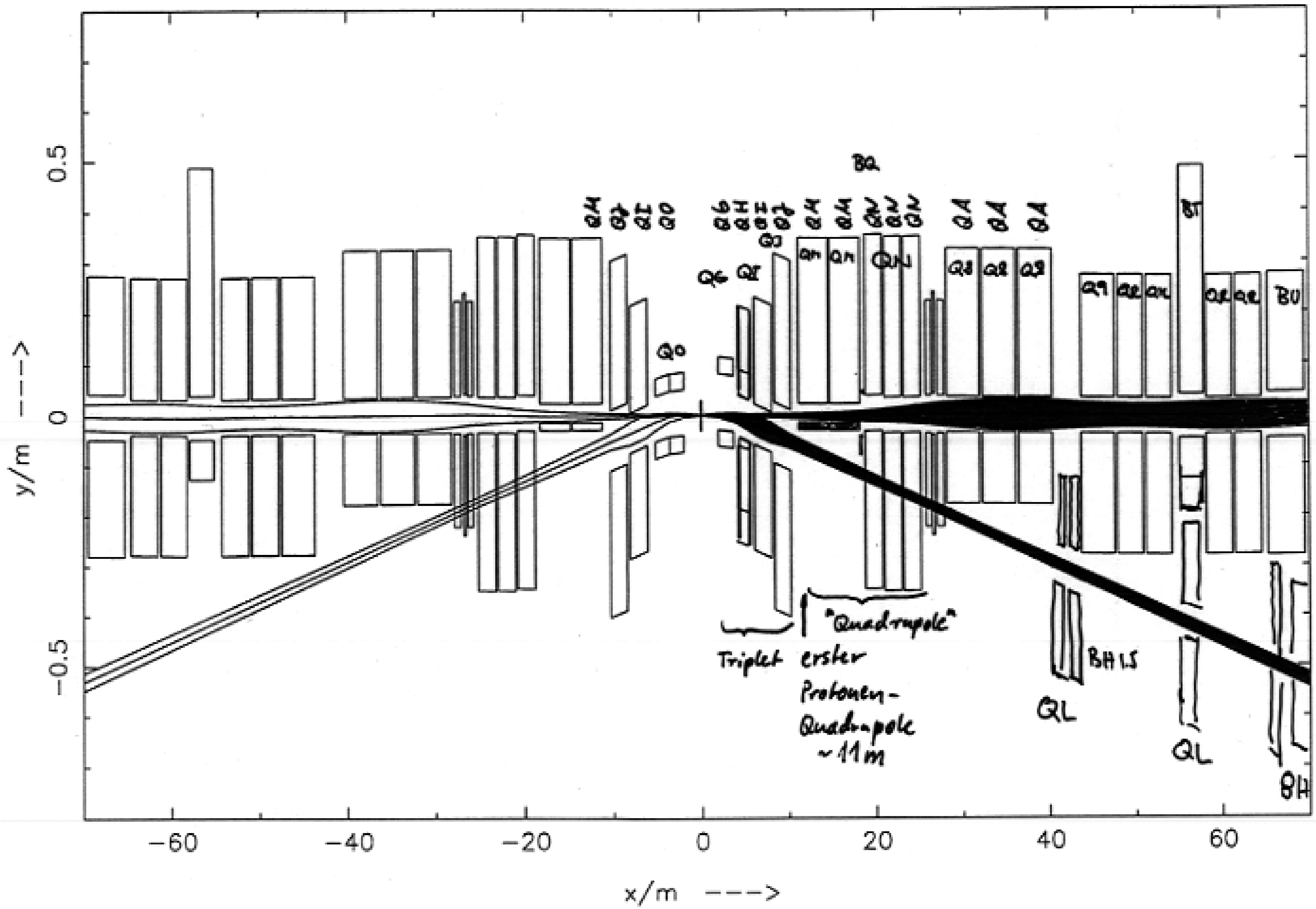
B. Holzer



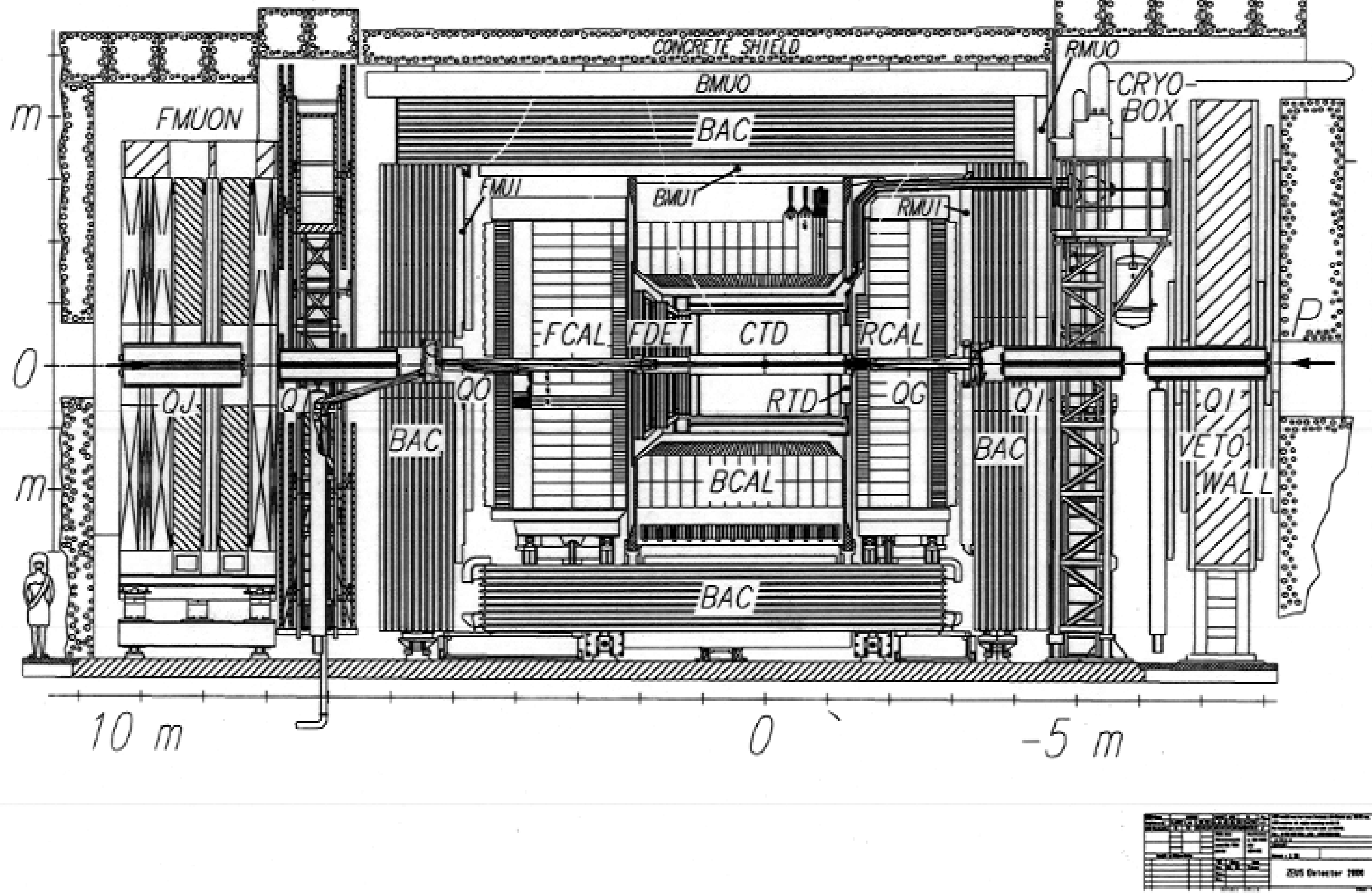
B. Holzer

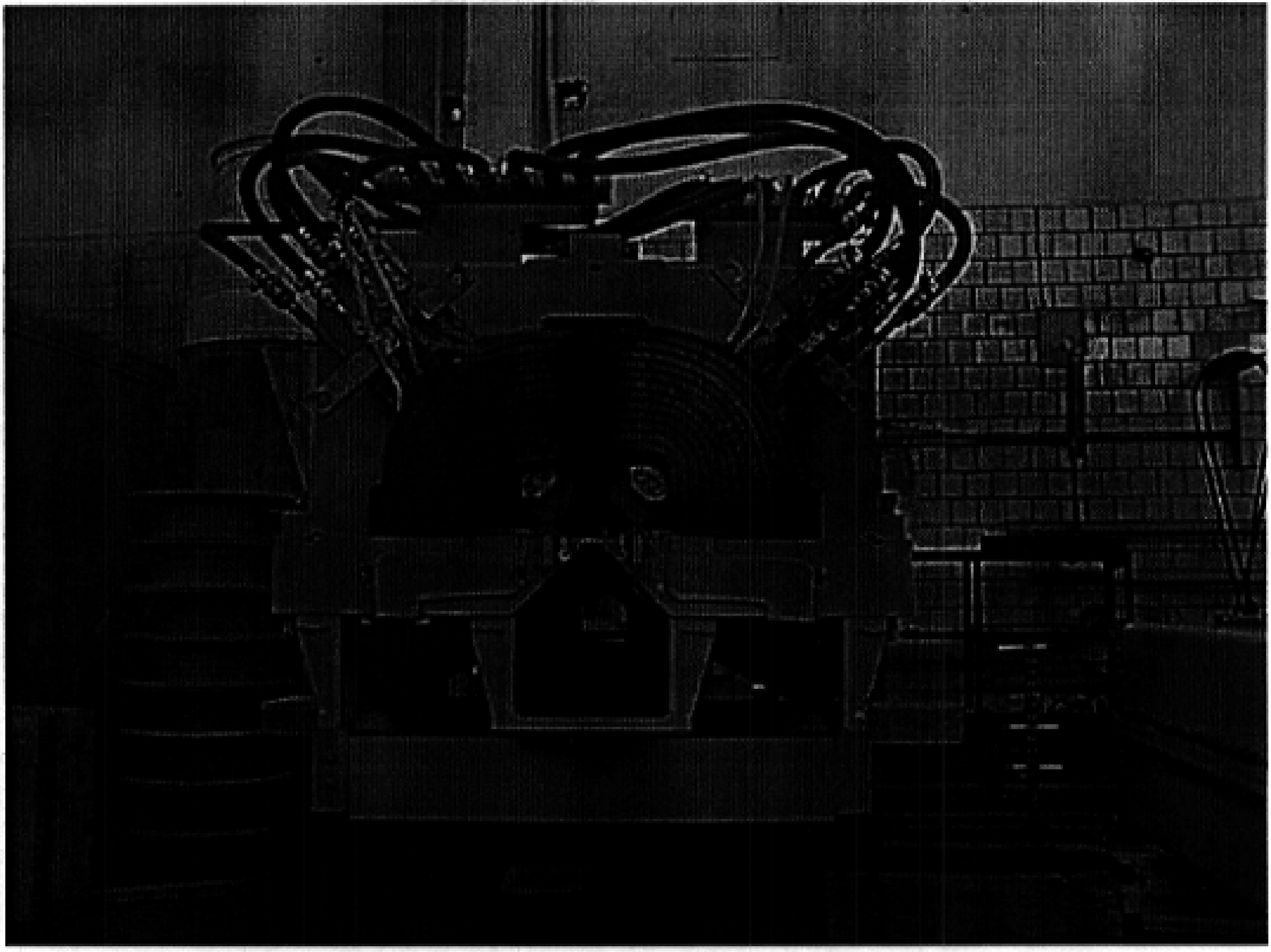
afki 2000

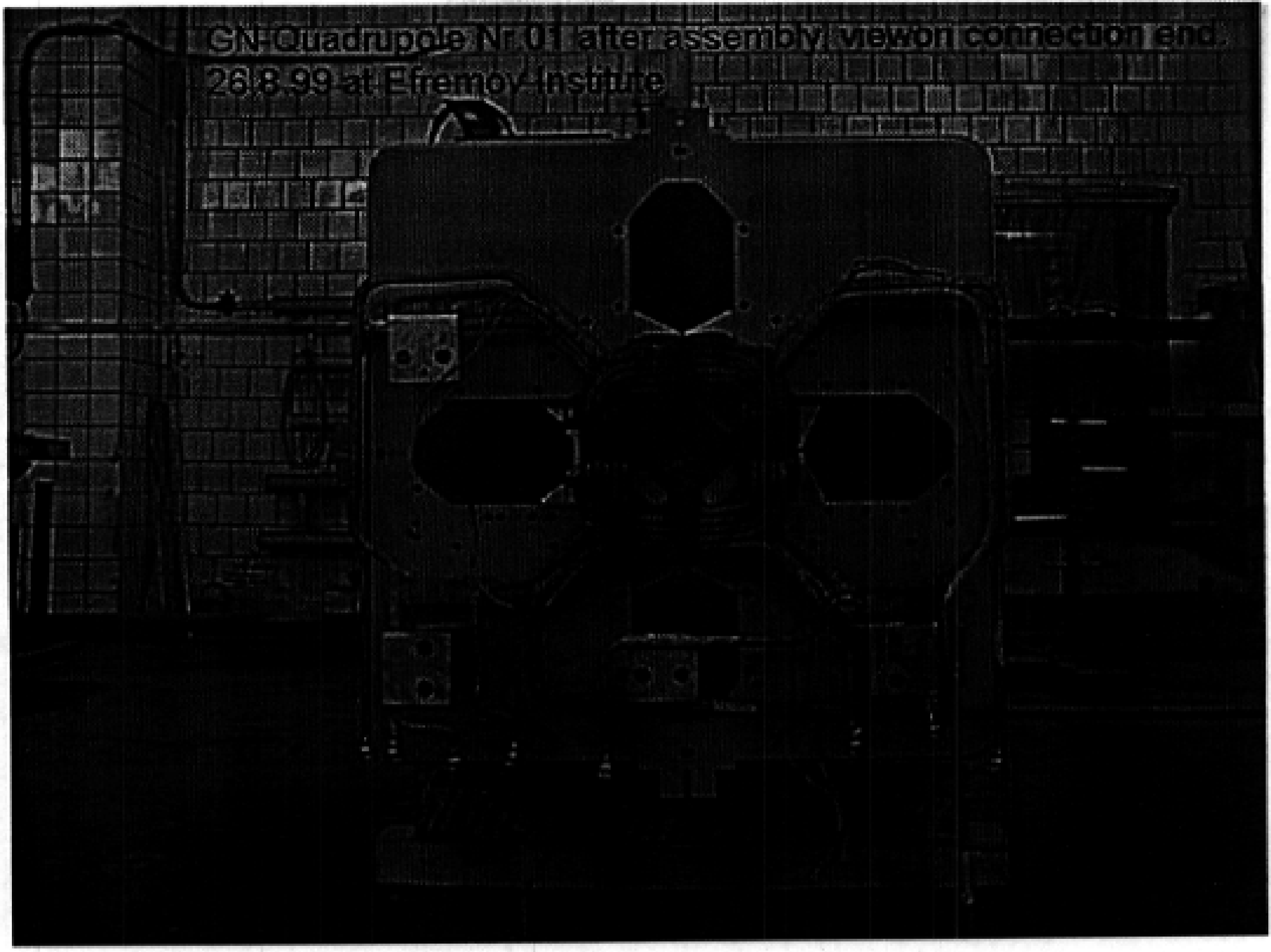
Neue HERA–Wechselwirkungszone.



Overview of the ZEUS Detector
(longitudinal cut)

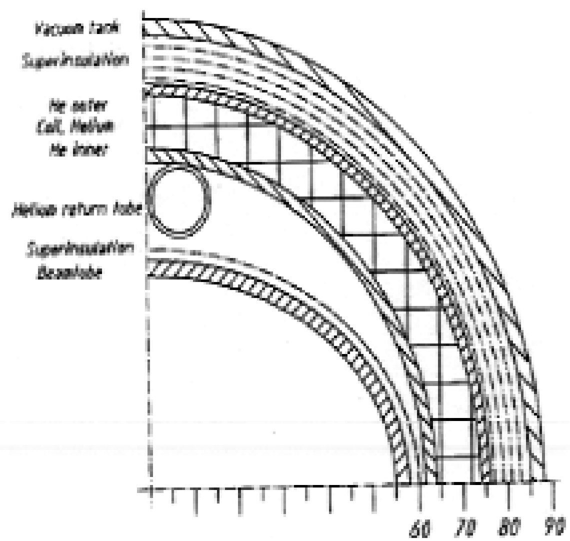


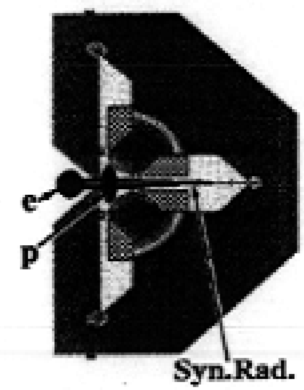


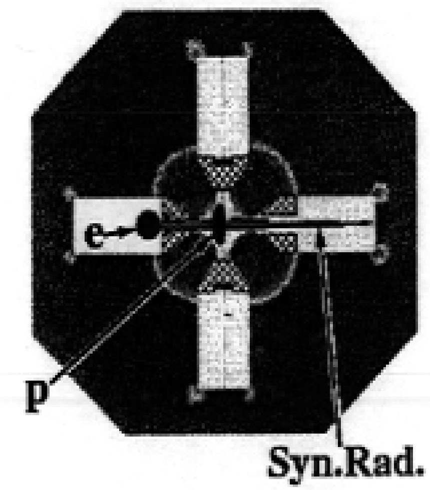


GN-Quadrupole Nr 01 after assembly, viewon connection end
26.8.99 at Efremov Institute

Unconventional Magnet Design







- Superconducting Quadrupole inside Detector provideearly separation and focusing for e-Beam
- Half Quadrupole with Cut-out mirror plate provide early vertical focusing for the p-beam
- Septum Coil Quad provide space for horizontslly large p-beam

(2) Hera-B:

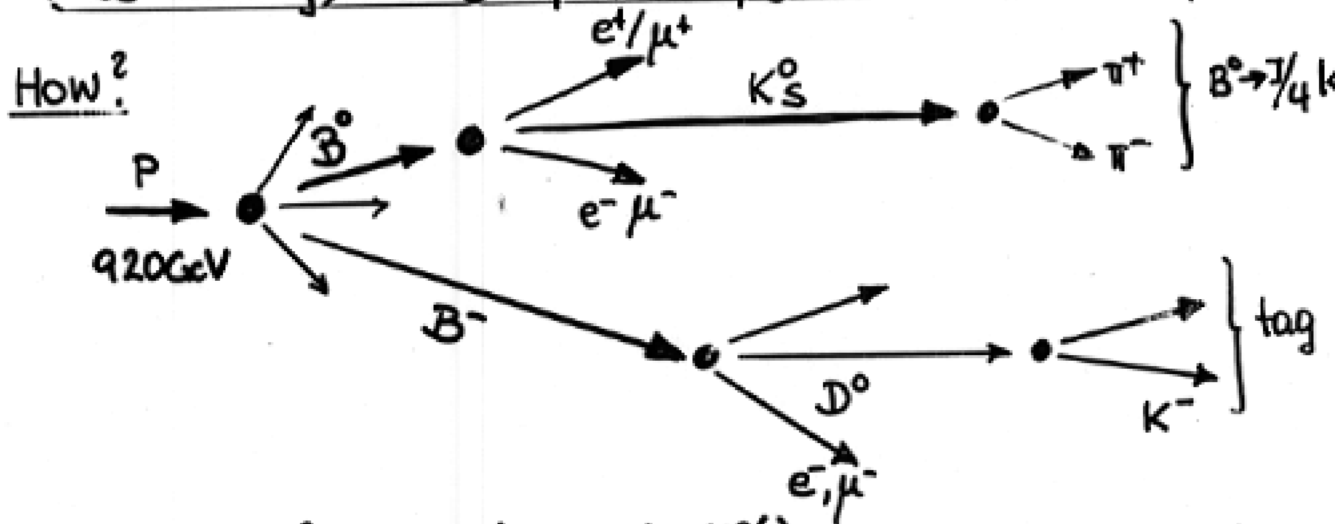
Heavy flavour physics in $p\mathcal{N}$-interactions at $\sqrt{s} = 42\,GeV$
(fixed target experiment with protons $E_p = 920\,GeV$)

Goal #1: CP-violation in $B^0 \to J/\psi + K^0_s$

* $\not{CP}$ in other modes: $B^0 \to \pi^+\pi^-$, $J/\psi + \rho^0$, $\psi' K^0_s, \ldots$
  $B^0_s \to \rho^0 K^0_s$

B^0_s-mixing, B/Λ_B-spectroscopy and decays, hadr. product

How?



tag by $\begin{cases} \text{lepton charge } (\varepsilon = 16\%) \\ \text{K-charge } (\varepsilon = 46\%) \\ \text{vertex charge } (\varepsilon \approx 96\%) \end{cases}$

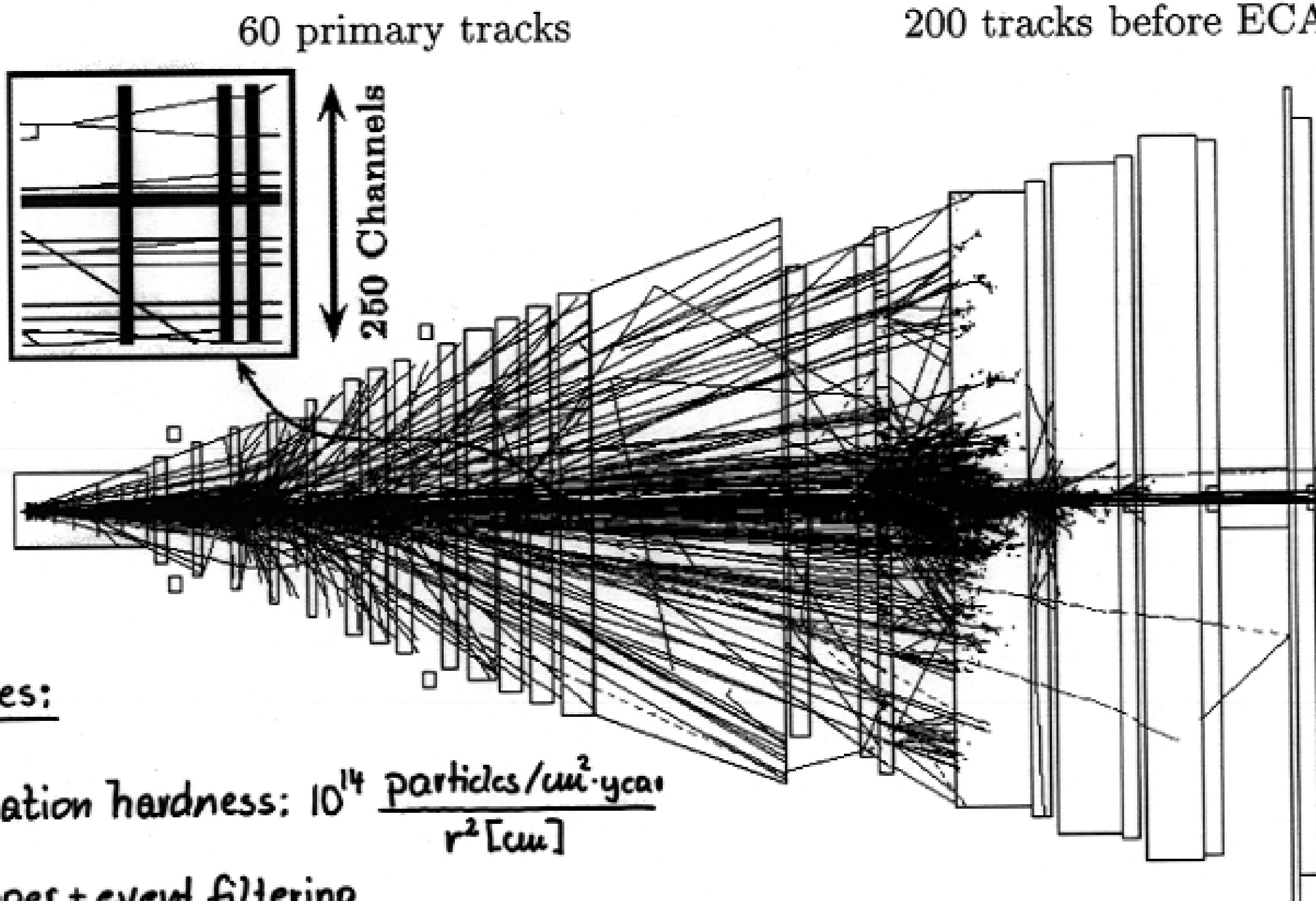
compare decay rates $\begin{matrix} B^0 \\ \bar{B}^0 \end{matrix} \to J/\psi(\ell^+\ell^-) + K^0_s(\pi^+\pi^-)$

$$\text{efficiency} = \frac{\text{measured golden events}}{\text{interaction}} \sim \underline{4 \cdot 10^{-12}} \;!!!$$

$$\varepsilon: \begin{cases} \dfrac{\sigma_{b\bar{b}}}{\sigma_{inel}} * 2 * \text{Prob}(b \to B^0) \simeq \underline{0.8 \cdot 10^{-6}} \\ BR(B \to J/\psi \cdot K^0_s) \cdot BR(J/\psi \to \ell^+\ell^-) \cdot BR(K^0_s \to \pi^+\pi^-) \simeq \underline{3.5 \cdot 10^{-5}} \\ \varepsilon(\text{trigger, reconstruction, vertex}) \simeq \underline{0.17} \end{cases}$$

for $\delta(\sin 2\beta) = 0.13 \Rightarrow$ 1500 events $\Rightarrow 4 \cdot 10^{14}$ i.a (1 year at 40 MHz)

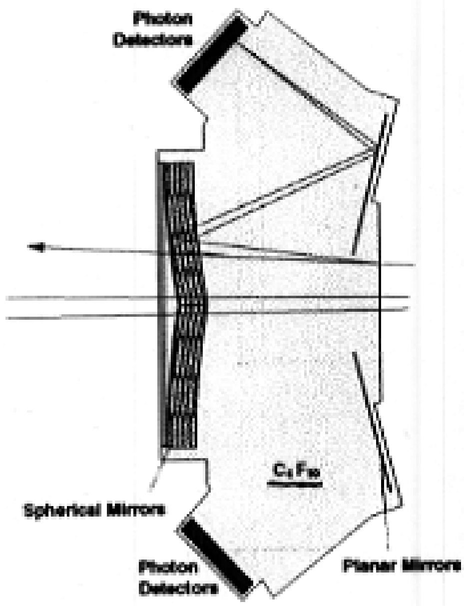
A typical event consisting of 4 interactions at 10MHz

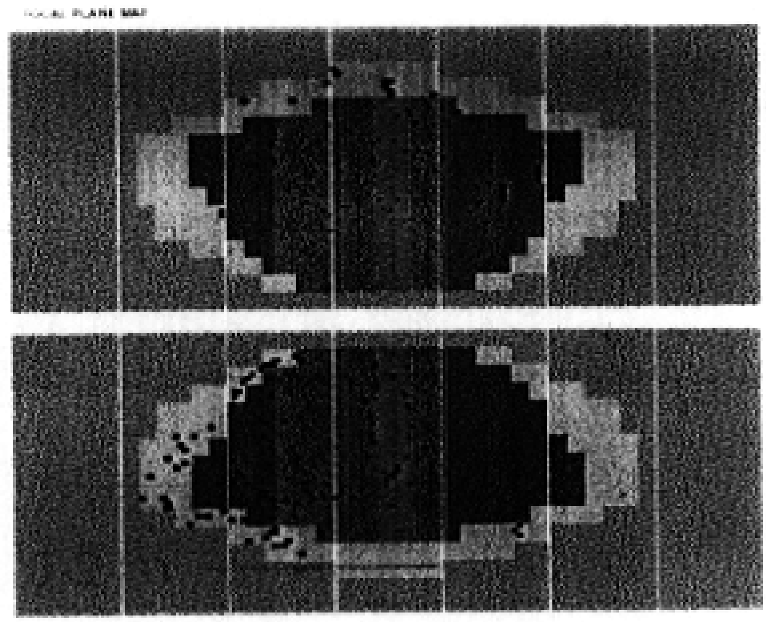


Challenges:

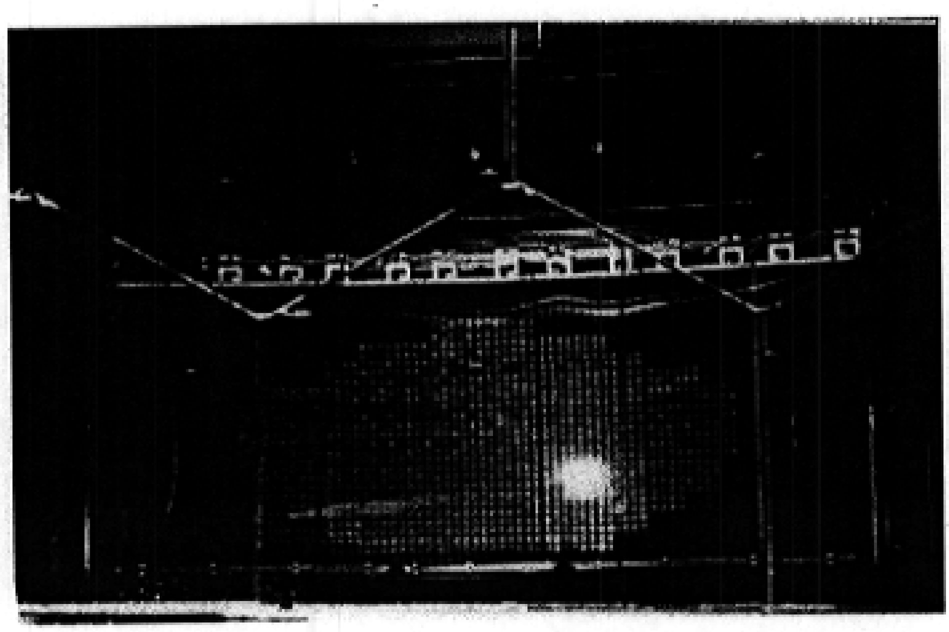
- radiation hardness: $10^{14} \frac{\text{particles}/\text{cm}^2\cdot\text{year}}{r^2[\text{cm}]}$
- trigger + event filtering

RICH Detector





Light yield: 35 γ/ $\beta = 1$ ring (as expected)



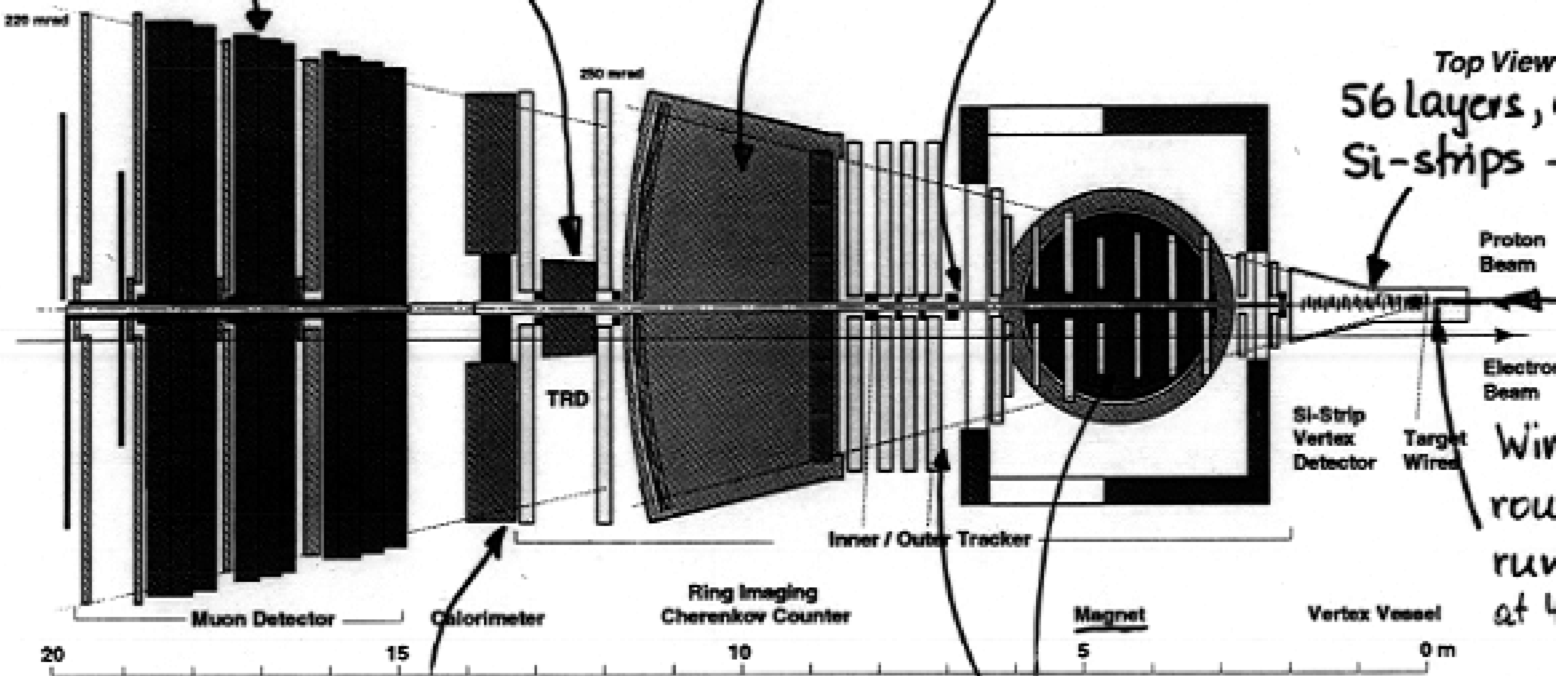
<u>TRD</u>: straws, 100% ready

<u>RICH</u>: C_4F_{10} + mirrors + PMTs beautiful performance 35 γ's for $\beta = 1$ ring

<u>Inner tracker</u>: MSGCs with Gem-amplifier; still rate related effects but workable, 50% built and 20% installed

<u>Muon</u> system: 95% installed

56 layers, double sided Si-strips - ready



920 GeV protons

Wire target routinely running at 40 MHz

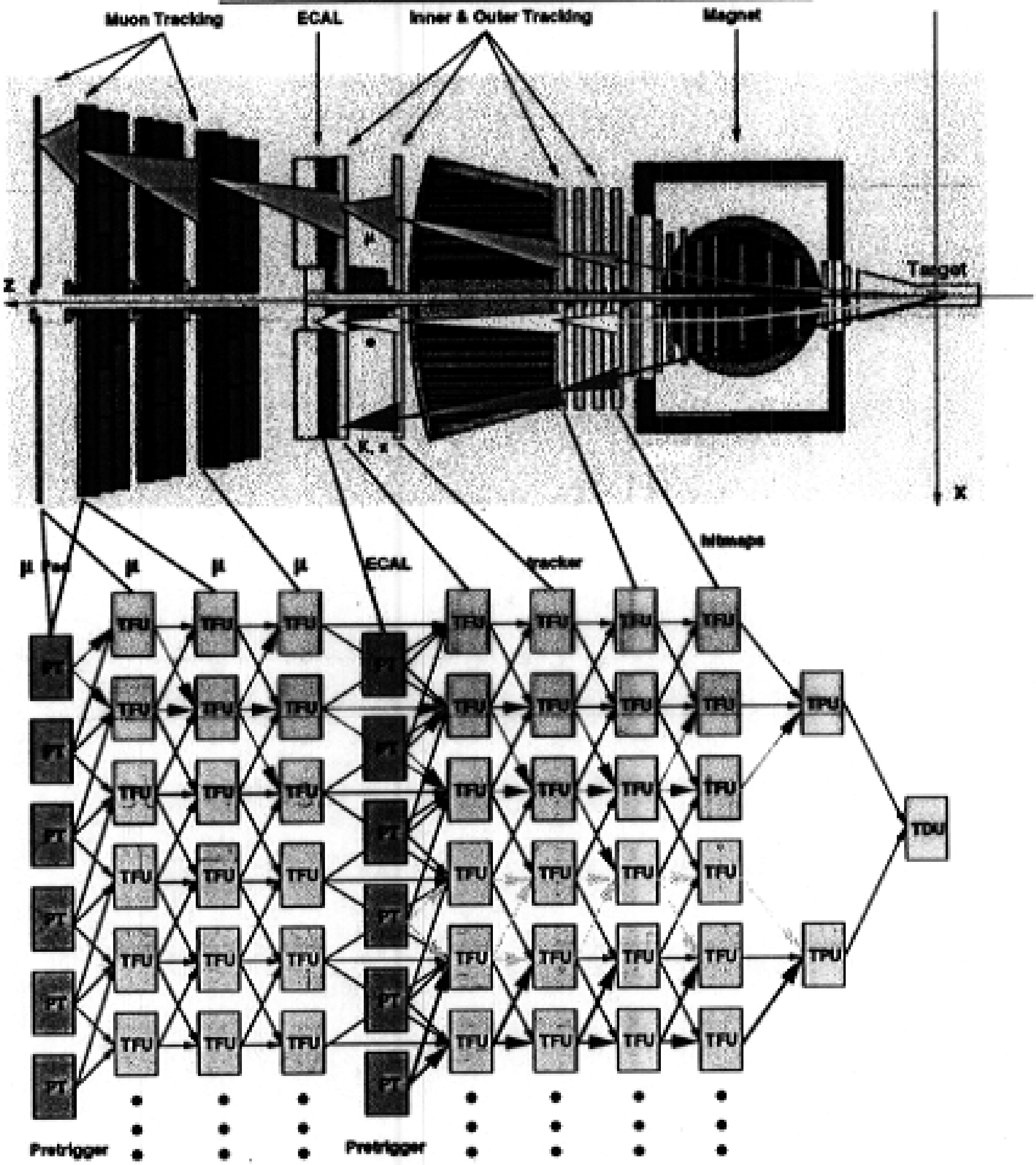
DAQ: running

<u>ECAL</u>: Pb-SCI-shashlik - 100% installed good performance, calibration in progress.

<u>Outer tracker</u>: large (3m x 6m) honeycomb chambers; initial aging solved by Au-coating and change of gas: Ar-CO_2-CF_4 - 60% installed

Trigger: new territory ⟺ critical path item
first level triger

Hardware "Kalman" filter



higher level triggers + offline software in good shape.

SPENGLER@HB-SUR03, SEP01/17:54

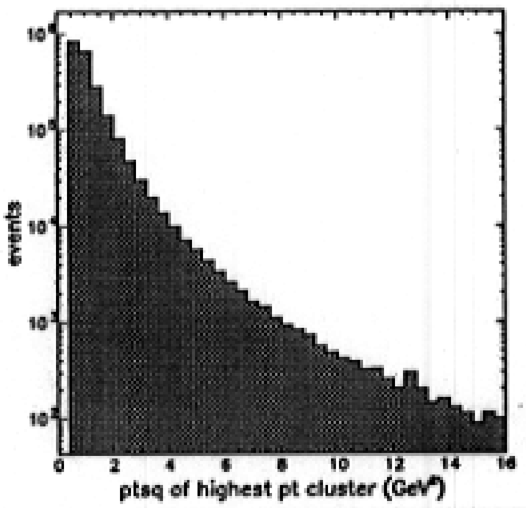
Trigger tests

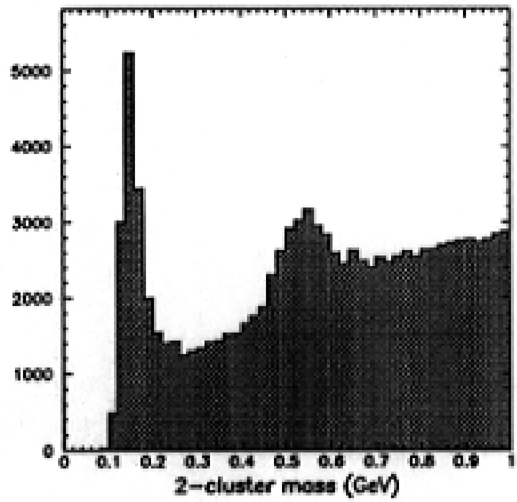
Cal pretrig: 1 cluster, $p_t > 1.3\,\mathrm{GeV}$

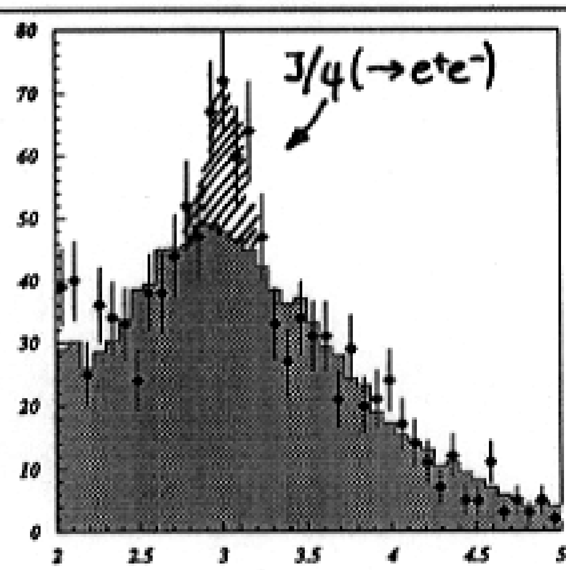
2LT: 2 ecal clusters, $p_t > 1.0\,\mathrm{GeV}$,

2-cluster mass $> 2.2\,\mathrm{GeV}$

Online monitor plots







2-cluster mass (GeV) ⟶

Offline: Points: Require VDS hits associated with clusters. Histo: require no VDS hits

Summary: Hera-B major technological challenge + time pressure ➡ unpleasant surprises which required significant additional R+D

Nearly complete by end 1999 with aim to start physics program in early 2000

(3) HERMES: disentangling the nucleon spin

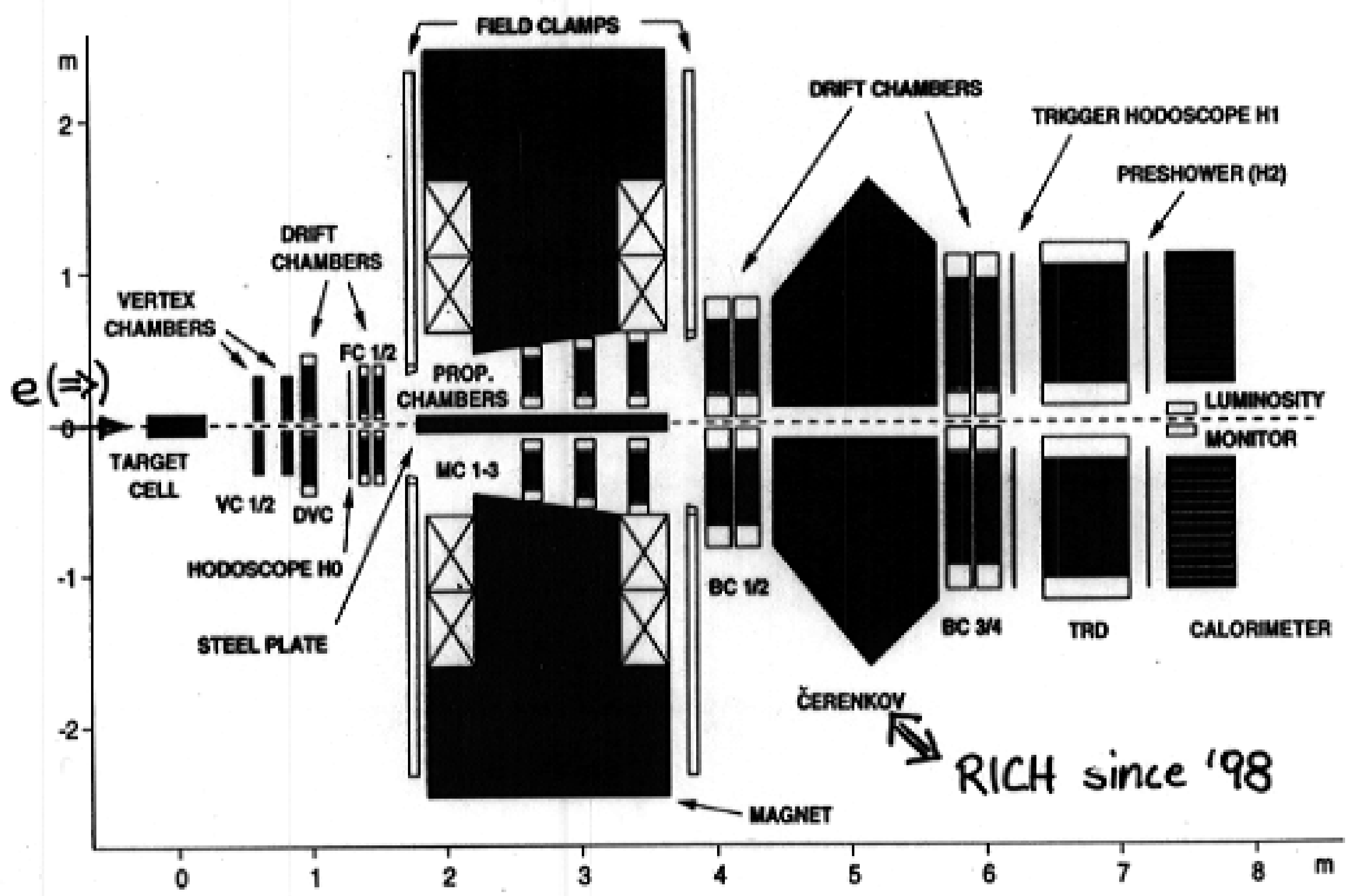
$$J = \tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_z$$

quarks   gluons   ang. momentum

Novel techniques:

- longitudinally polarised $e(\uparrow)$ - 27.5 GeV - P_e: 50-60% in e-HERA
- internal storage cell with polarised gas atoms
  ^1H, ^2H, ^3He: ^1H: $P_T = 86\%$ @ $0.7 \cdot 10^{14}$ atoms/cm²
  ^3He: $P_T = 46\%$ @ $3.3 \cdot 10^{14}$ atoms/cm²
- open, large acceptance spectrometer with particle id.

The HERMES Experiment

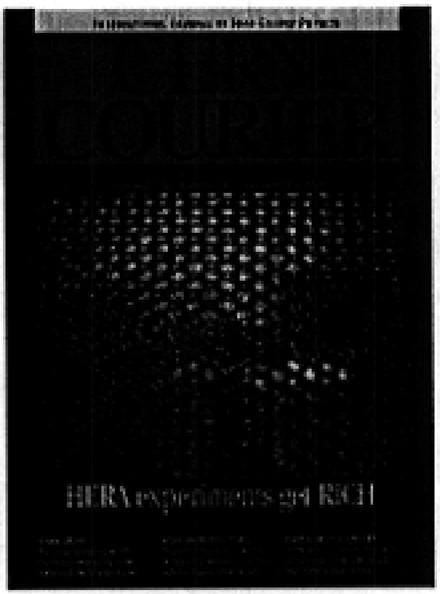


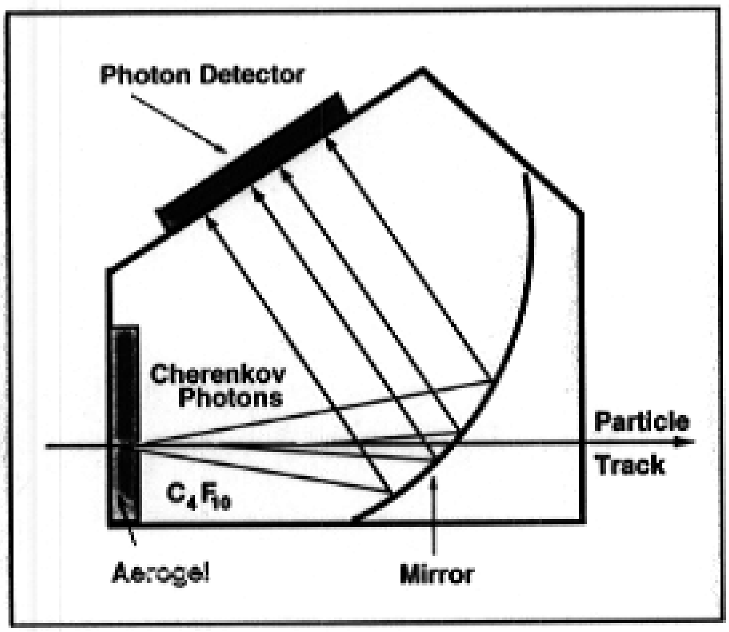
- apparatus performs very well.

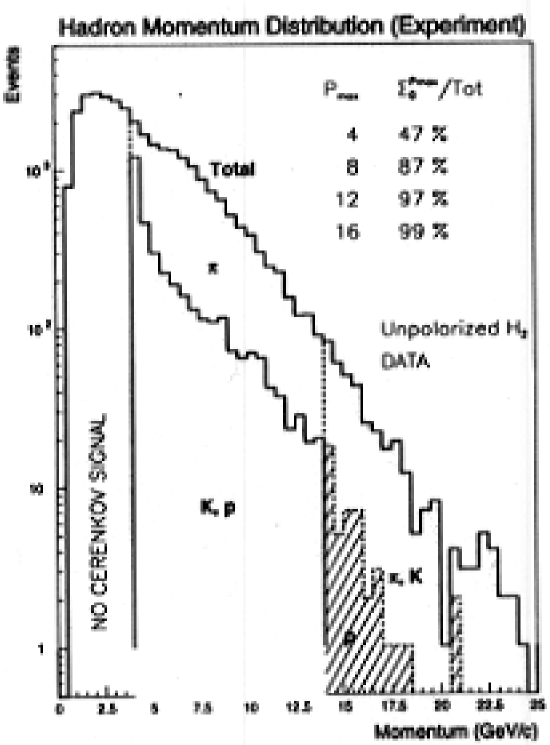
3.2

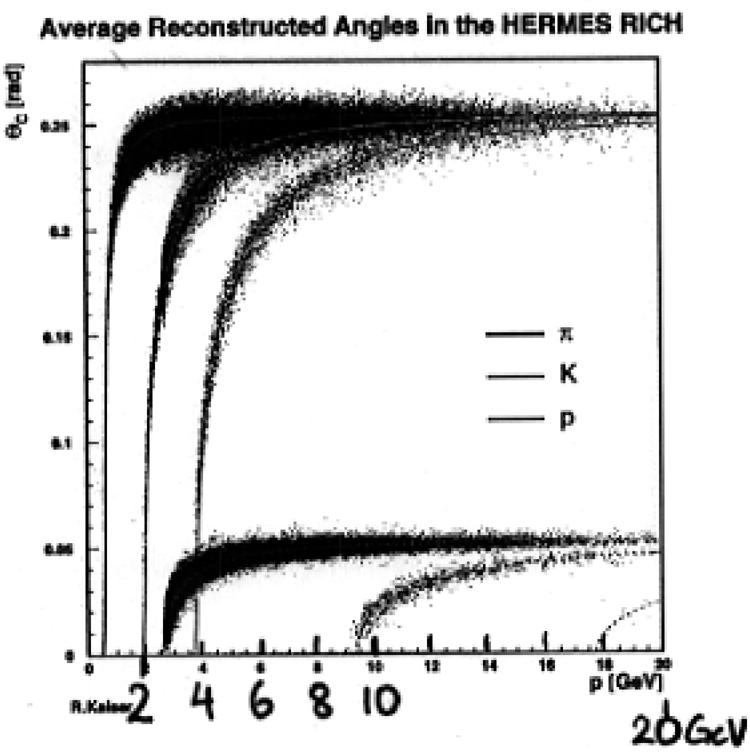
The RICH Detector

Installed in 1998, the RICH detector employs a dual radiator system and an array of 4000 PMT's to allow separation of π, K, and p across the full momentum range of 1 - 20 GeV/c.









Demonstrating the technique:

- measurement of the inclusive spin structure func. $\boxed{g_1^{N}}$ using longitudinally polarised N-target

$$A_{\parallel} = \frac{N^{\uparrow\downarrow}\mathcal{L}^{\uparrow\uparrow} - N^{\uparrow\uparrow}\mathcal{L}}{N^{\uparrow\downarrow}\mathcal{L}_p^{\uparrow\uparrow} + N^{\uparrow\uparrow}\mathcal{L}_p}$$

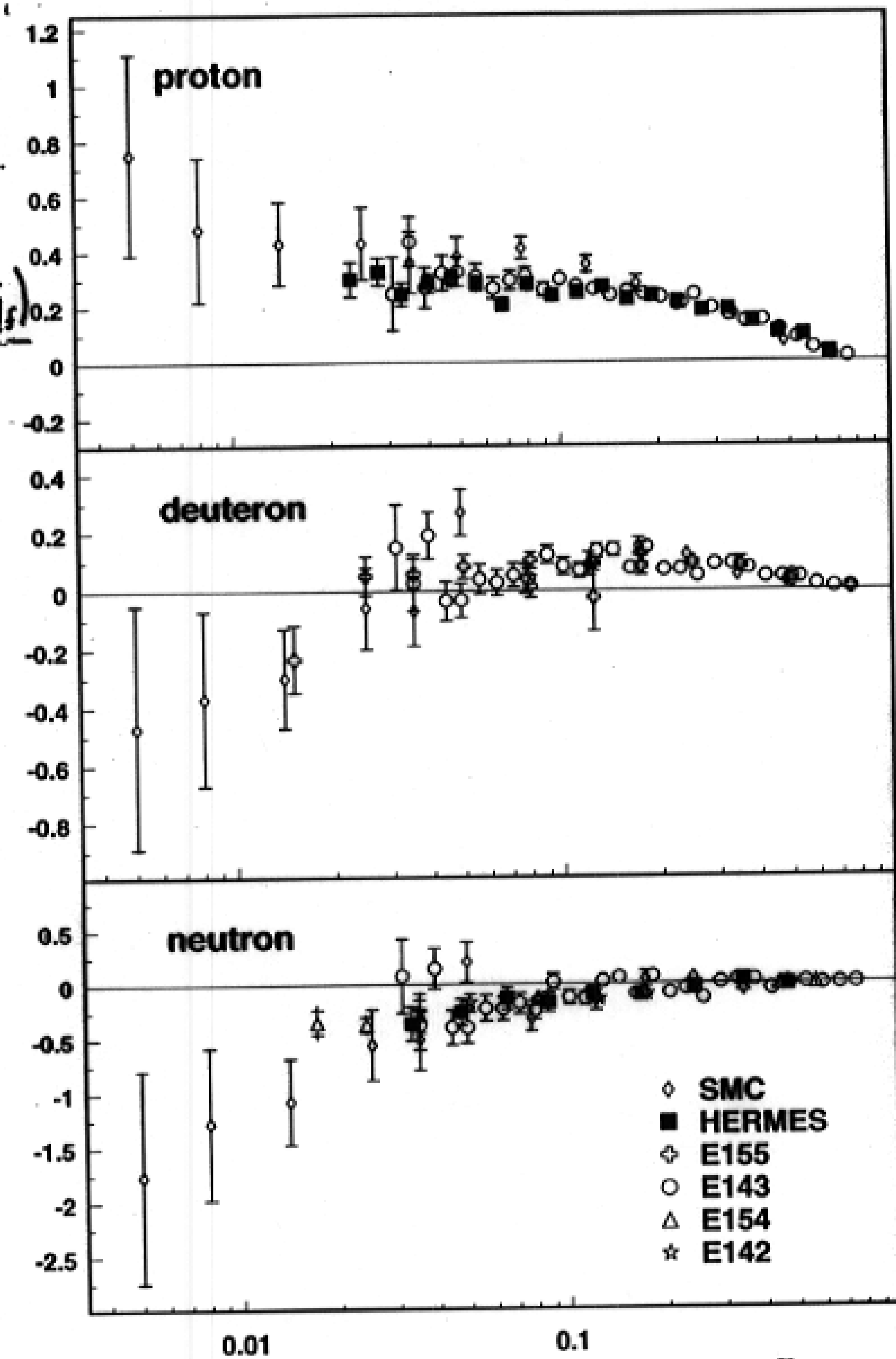
N^i... rates
$\mathcal{L}^i$... Luminosity
$\mathcal{L}_p^i$... Luminosity polaris. weighted

$g_1(x,Q^2)$

QPM: $= \frac{1}{2}\sum e_f^2(\Delta q_f + \Delta\bar{q}_f)$

$\Downarrow$

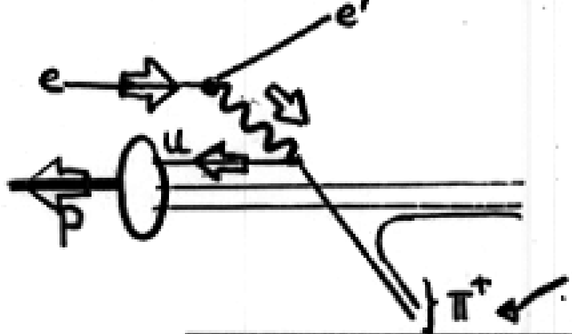
technique demonstrated



$\frac{g_1}{F_1} \approx A_{\parallel}$

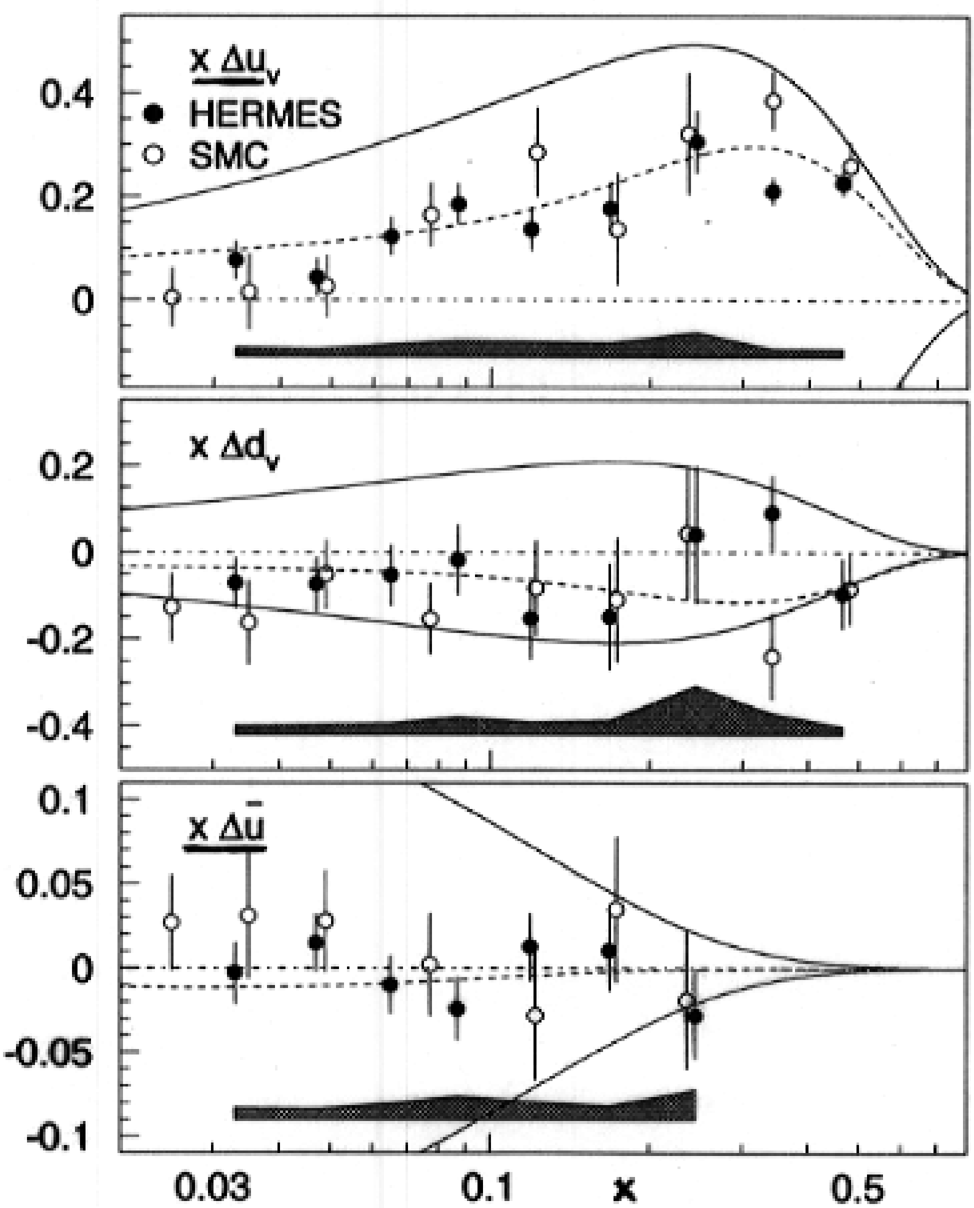
Polarised semi-inclusive DIS

➡ flavour decomposition of quark polarisation



{ tag flavour of scattered quark
{ via hadron in fragmentation region

Valence- and Sea Quark Distributions



$Q^2 = 2.5\,\mathrm{GeV}^2$

—— positivity limit

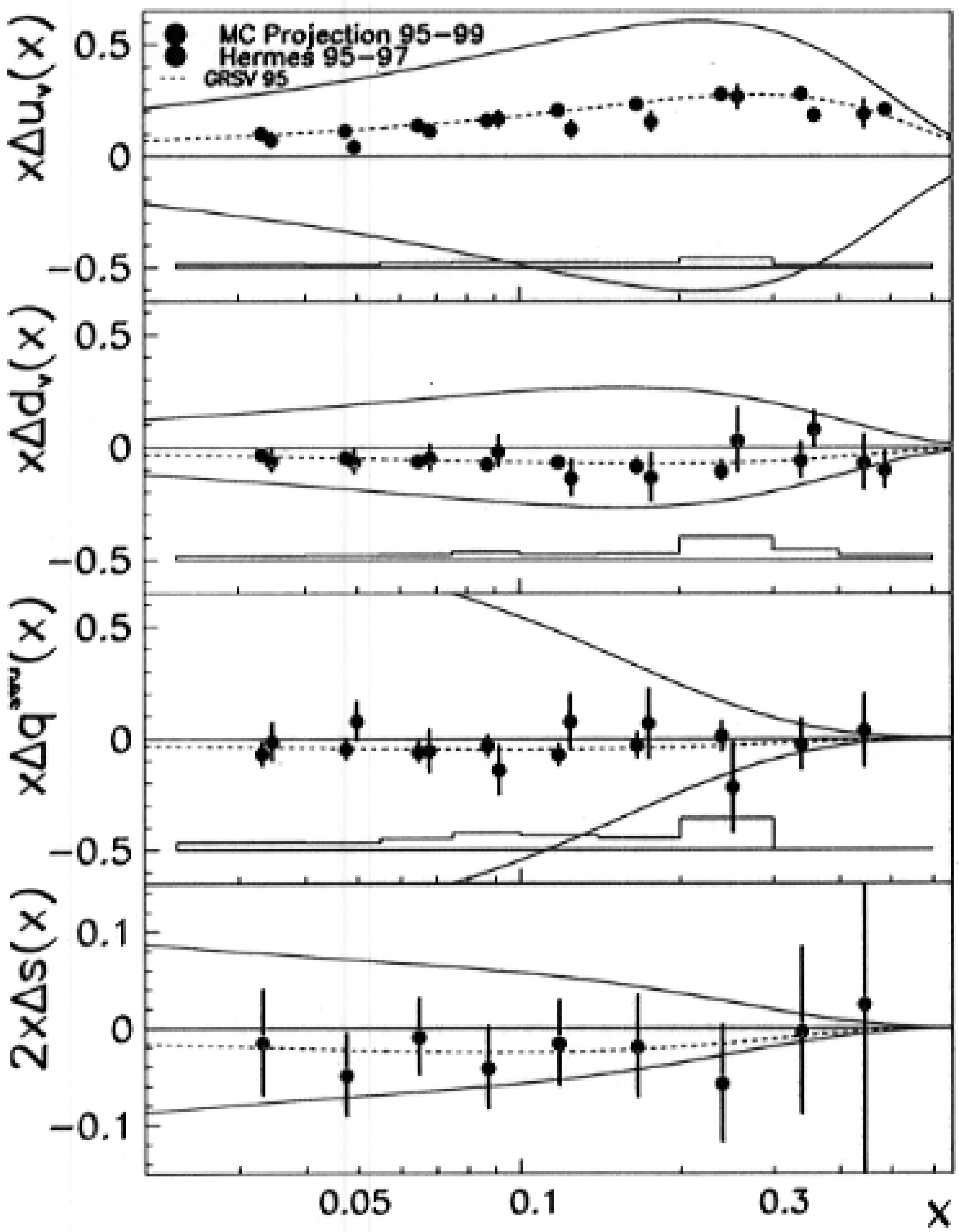
- - - - QCD à la Gehrmann + Stierling

(assume: $\Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}$)

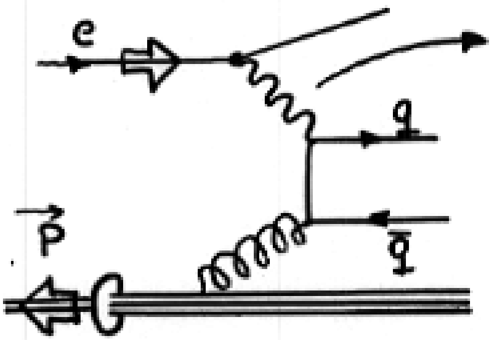
3.4

Projections up to 2000

hermes



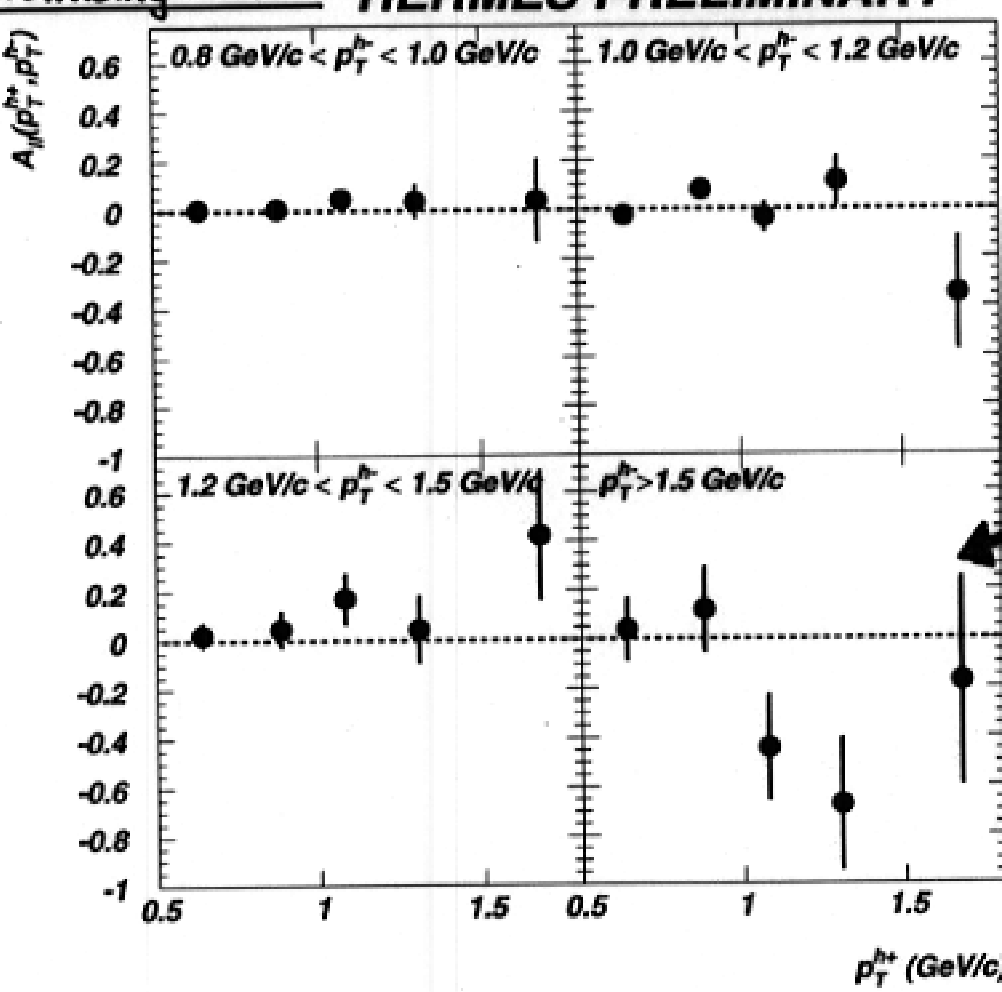
Towards the gluon polarisation measurement ΔG



γ^* $Q^2 \simeq 0$ (photoproduction)

- select "high"-p_T h^+ and h^-
- measure asymmetry $A_{\parallel}(p_T^{h^+}, p_T^{h^-})$

first promising results: **HERMES PRELIMINARY**



negative asymmetry!

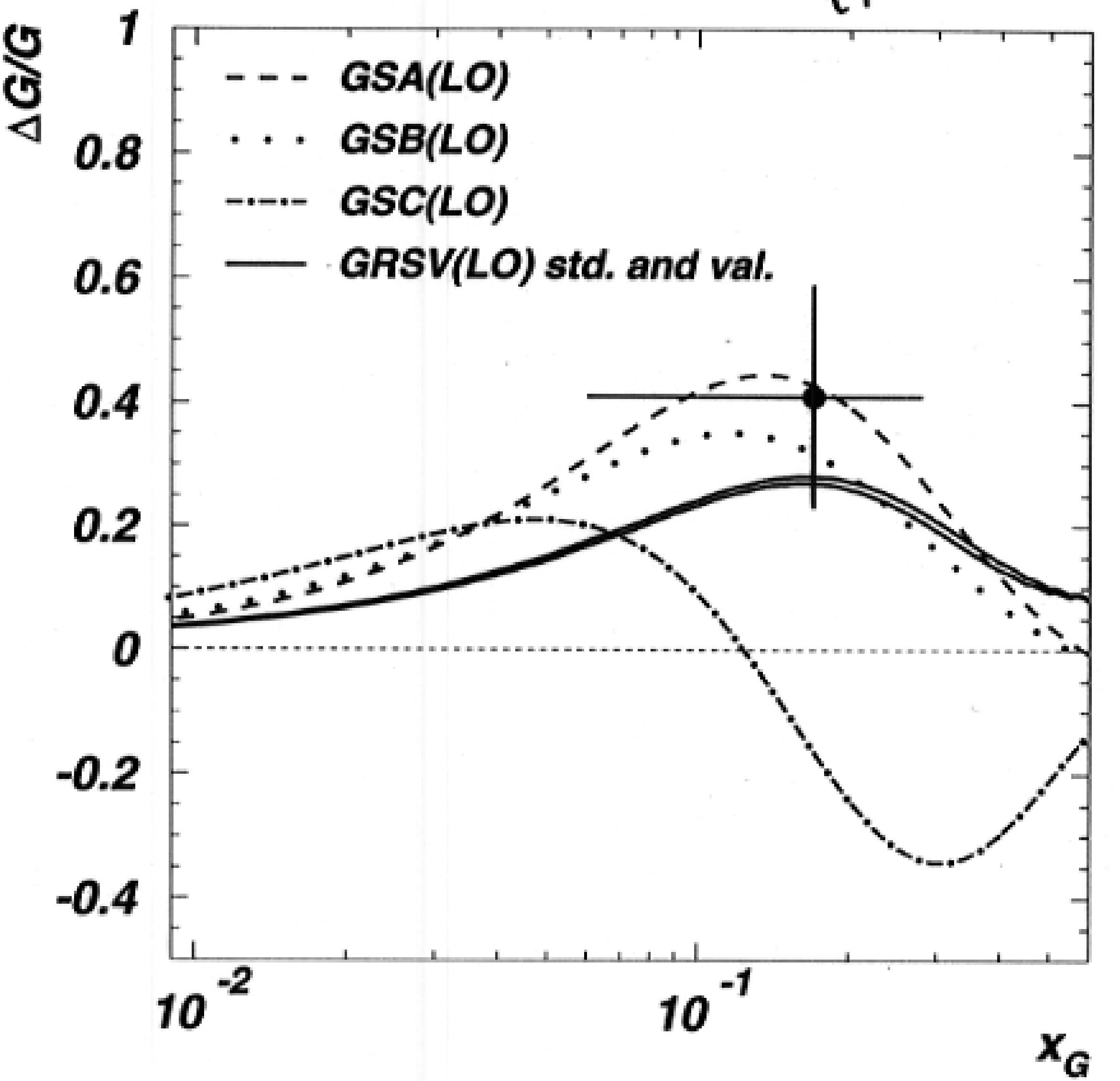
systematic error ≈ 8 % of measurement

checks that have been performed on the data:

- $e^+ - h^+$ misidentification.
- particle identification cut variation.
- momentum ($\sim z$) cut variation.
- consistent result obtained using identified pions only

Comparison to Phenomenological Fits

$\boxed{\frac{\Delta G}{G} = 0.41 \pm 0.18 \pm 0.03 \pm \text{theory}^{?}}$ $\begin{cases} \langle x_G \rangle = 0.17 \\ \langle \hat{p}_T^2 \rangle = 2.1\,\text{GeV}^2 \end{cases}$



Error bar includes only statstical and experimental systematic uncertainties. Unknown theoretical uncertainty from contribution and spin asymmetry of anomalous photon and NLO QCD corrections. If only a dilution, value of $\Delta G/G$ will increase but significance of deviation from zero will not change.

More HERMES physics results:

- spin-azimuthal asymmetries (e.g. sensitive to relativistic spin orbit effects)
- ρ^0- production (σ, decay angular distributions, spin-correlations, coherence effects)..
- A- dependence of $R = \frac{\sigma_L}{\sigma_T}$

Future program:

- improve accuracy of flavour decomposition and ΔG using longitudinally polarised targets

- transversely polarised targets (^1H, ^2H tested $\simeq P_T \simeq 90\%$): measurement of h_1 (third leading-twist SF besides F_1 and g_1)

- unpolarised targets:
  study of Λ^0 - polarisation
  nuclear effect for vector-meson production.

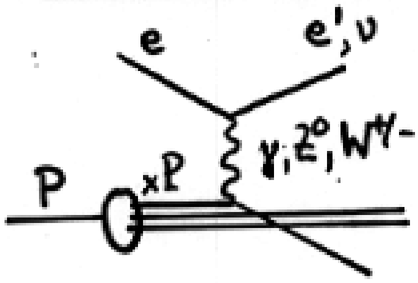
(4) Collider experiments H1 and ZEUS

• $\int$luminosity recorded:

	H1	ZEUS
e^+p	$\sim 47\,pb^{-1}$	$57\,pb^{-1}$
e^-p	$18\,pb^{-1}$	$17\,pb^{-1}$

➡ upgrade 2000 $\times \sim 4.7\,\mathcal{L}_i$

• kinematic domain: x, Q^2

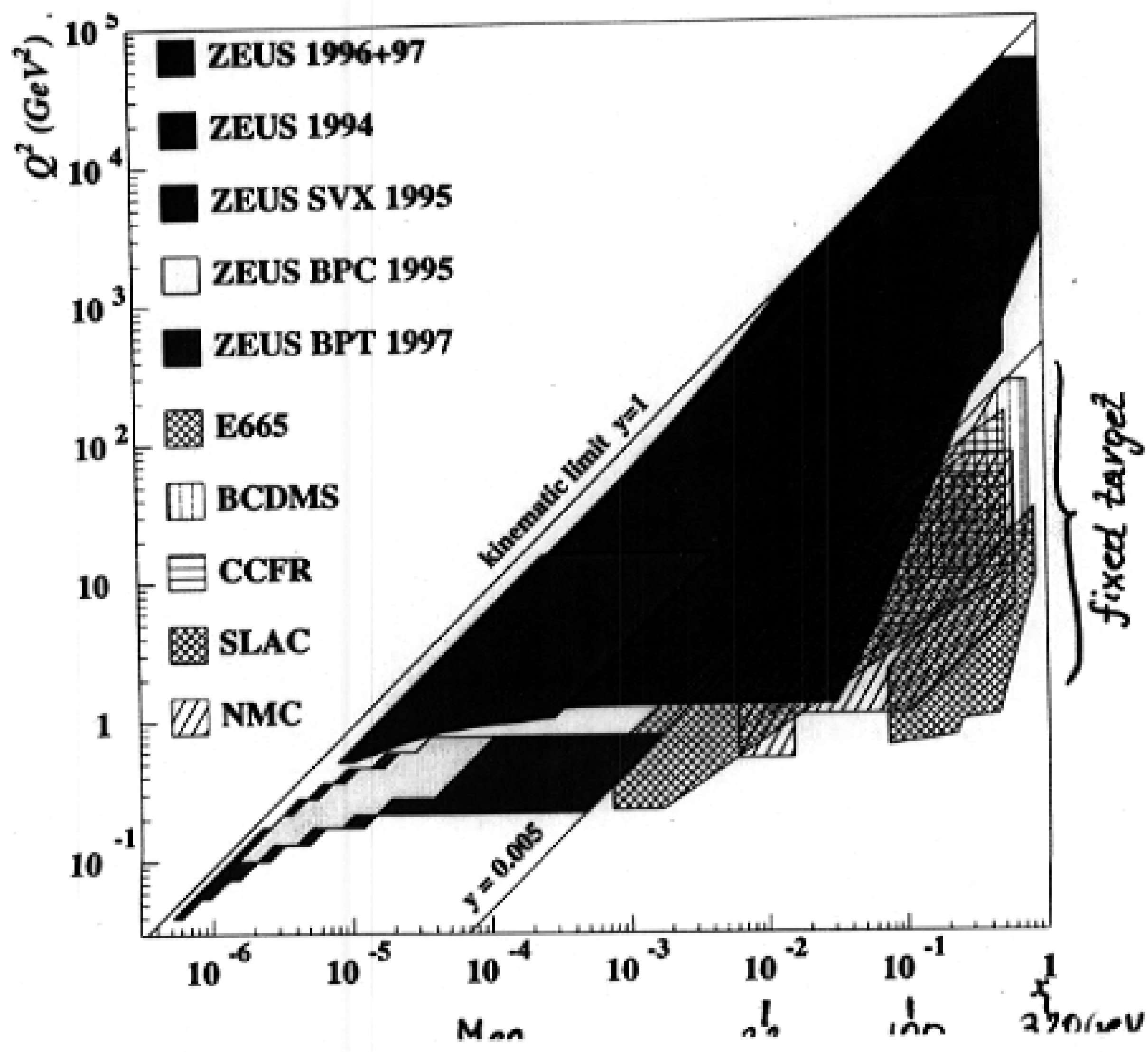


NC: • $Q^2 \simeq 0$: photoproduction $W_{\gamma p} \simeq 300\,$GeV

NC: • $Q^2 = \mathcal{O}(0.1-1\,GeV^2)$: transition to perturbative QCD

NC+CC: • $Q^2 \gtrsim 1-10^5\,GeV^2$: structure proton, p-QCD, EW in space-like region, beyond SM searches.

$M_{eq} = \sqrt{x \cdot s_{ep}} = \sqrt{x} \cdot 320\,GeV$

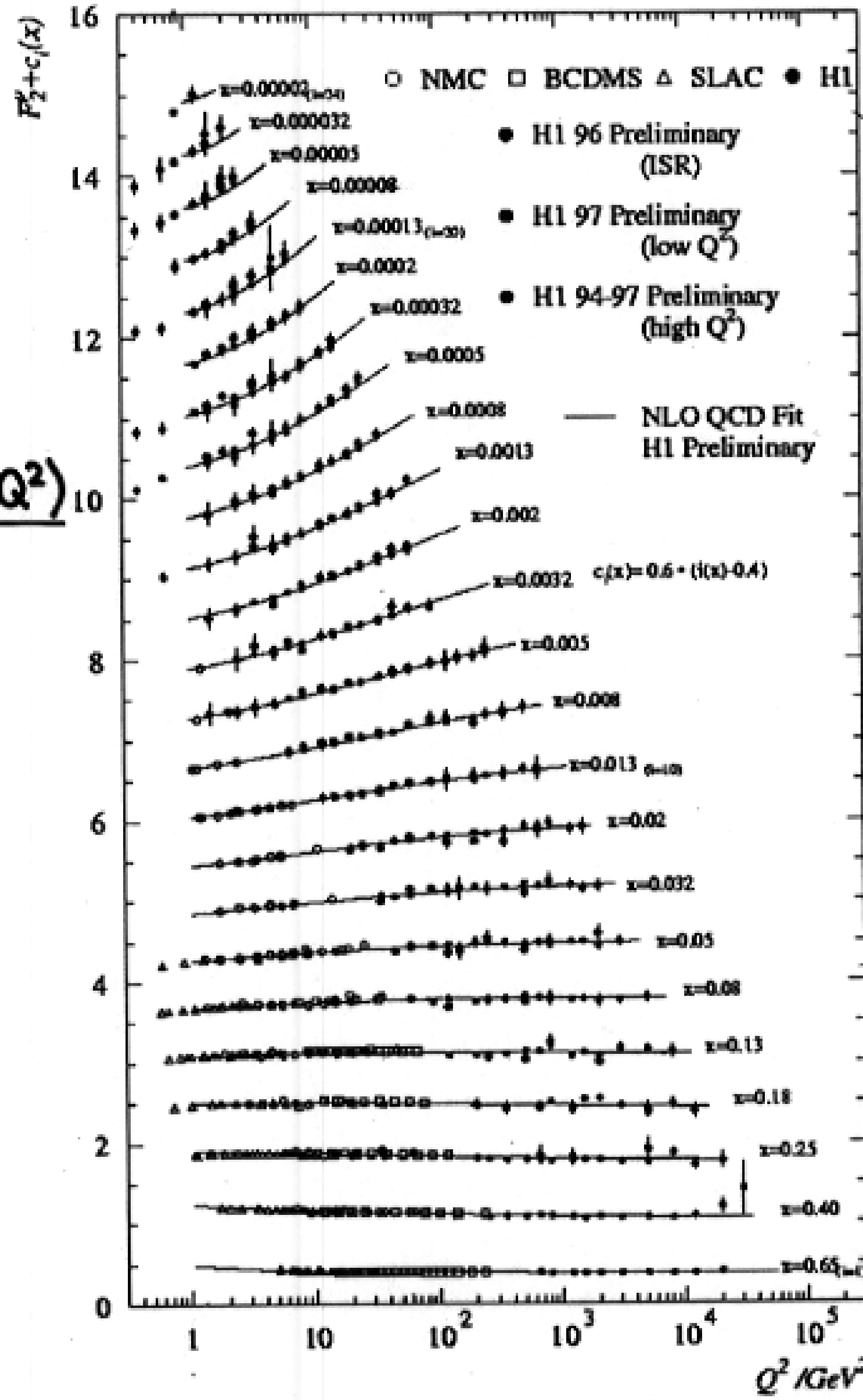


F_2 structure function of proton

$\delta F_2 \simeq 3\text{-}5\%$ - for $Q^2 \gtrsim 1000\,\mathrm{GeV}^2$ statistics limited

Luminosity upgrade

$F_2(x,Q^2)$



Scaling violation by gluons

Bjorken scaling

- NLO p-QCD evolution describes data for $Q^2 \gtrsim 1\,\mathrm{GeV}^2$
- at low x and $Q^2 \gg 1\,\mathrm{GeV}^2$ increase in parton density

e.g. for $Q^2 = 20\,\mathrm{GeV}^2$
($\delta r \simeq 1/20\, r_{proton}$)

	$5\cdot10^{-4} < x < 5\cdot10^{-3}$	$x > 0.6$
$q\bar{q}$	~ 10	~ 2.4
g	~ 30	~ 1.8

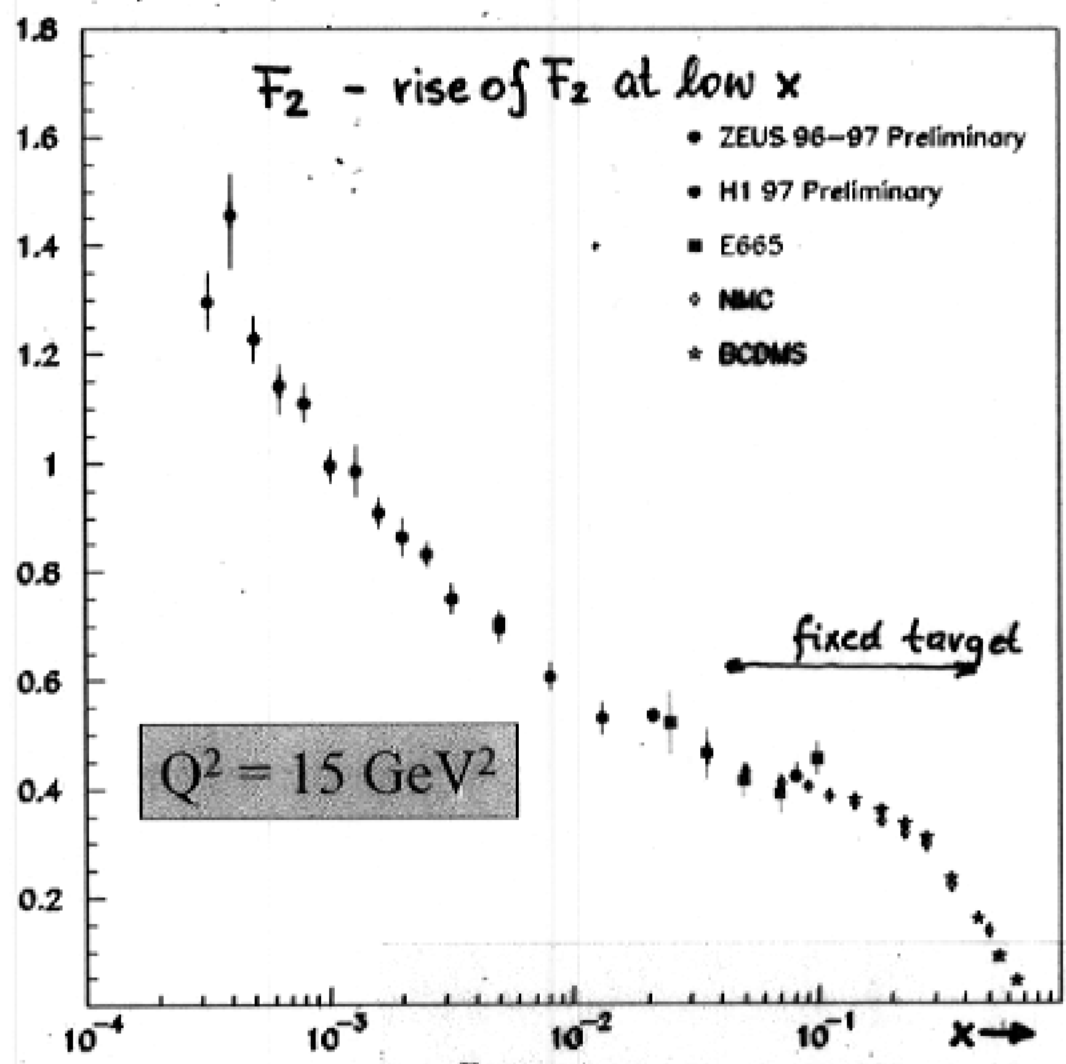
from scaling violations:

$$\frac{dF_2(x,Q^2)}{d\ln Q^2}$$

$$\Downarrow$$

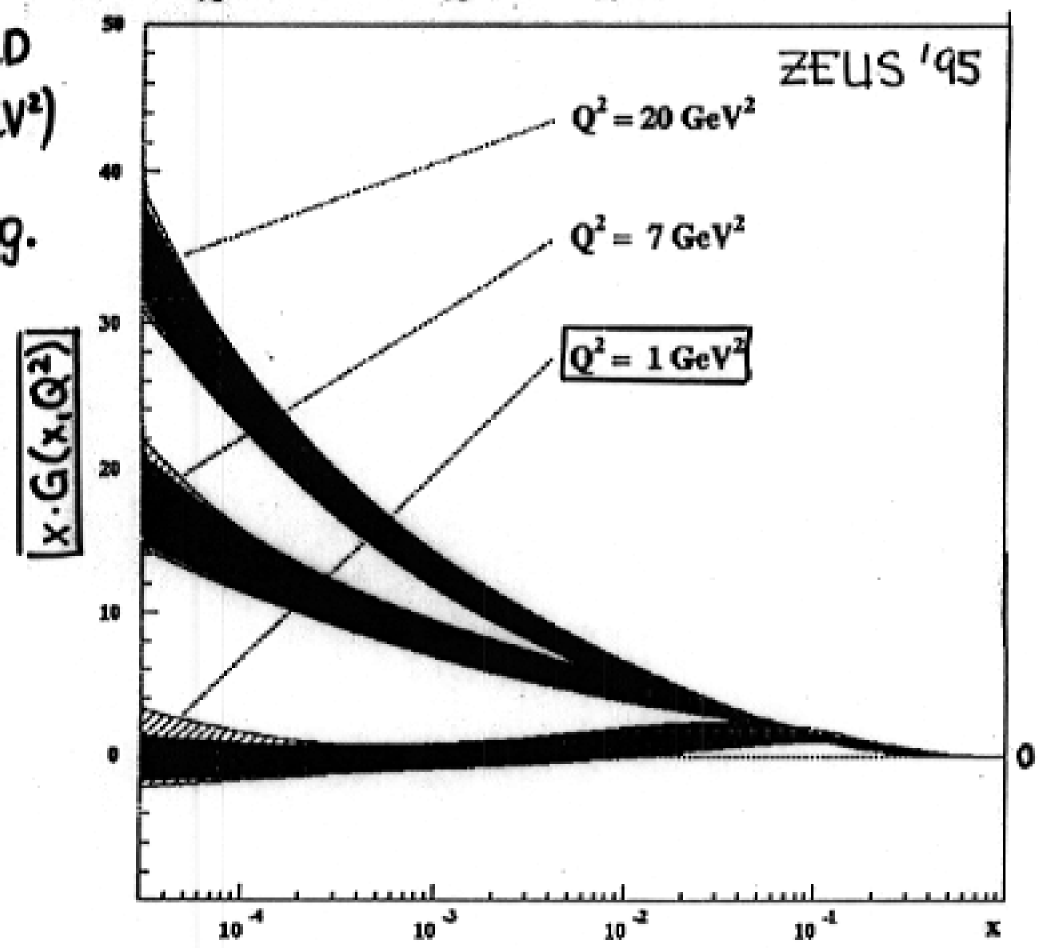
$$\boxed{G(x,Q^2)}$$

values compatible with other determinations (jets, charm, ...).

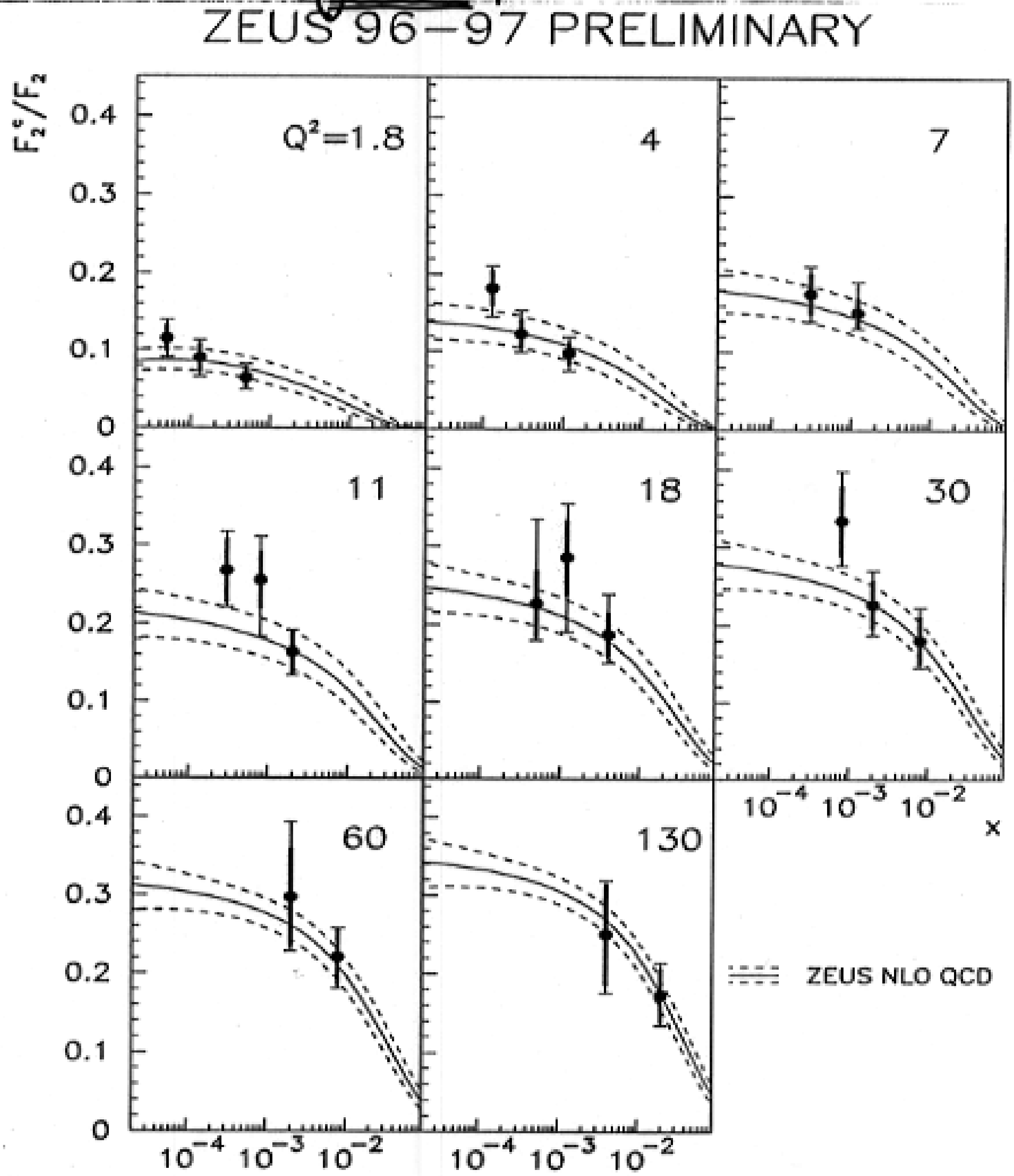


limit of p-QCD validity $\mathcal{O}(1\,\text{GeV}^2)$

$G(x,Q^2) \rightarrow$ neg.



Gluon content of proton - F_2^{charm}



I direct measurement via $ep \to e' D^*$

prediction using $G(x, Q^2)$ from Q^2-evolution of F_2

N.B. $\frac{\sigma_{charm}}{\sigma_{tot}} \simeq 25\%$ for $x \simeq 10^{-3}$ and $Q^2 \gtrsim 30 \, GeV^2$

Diffraction

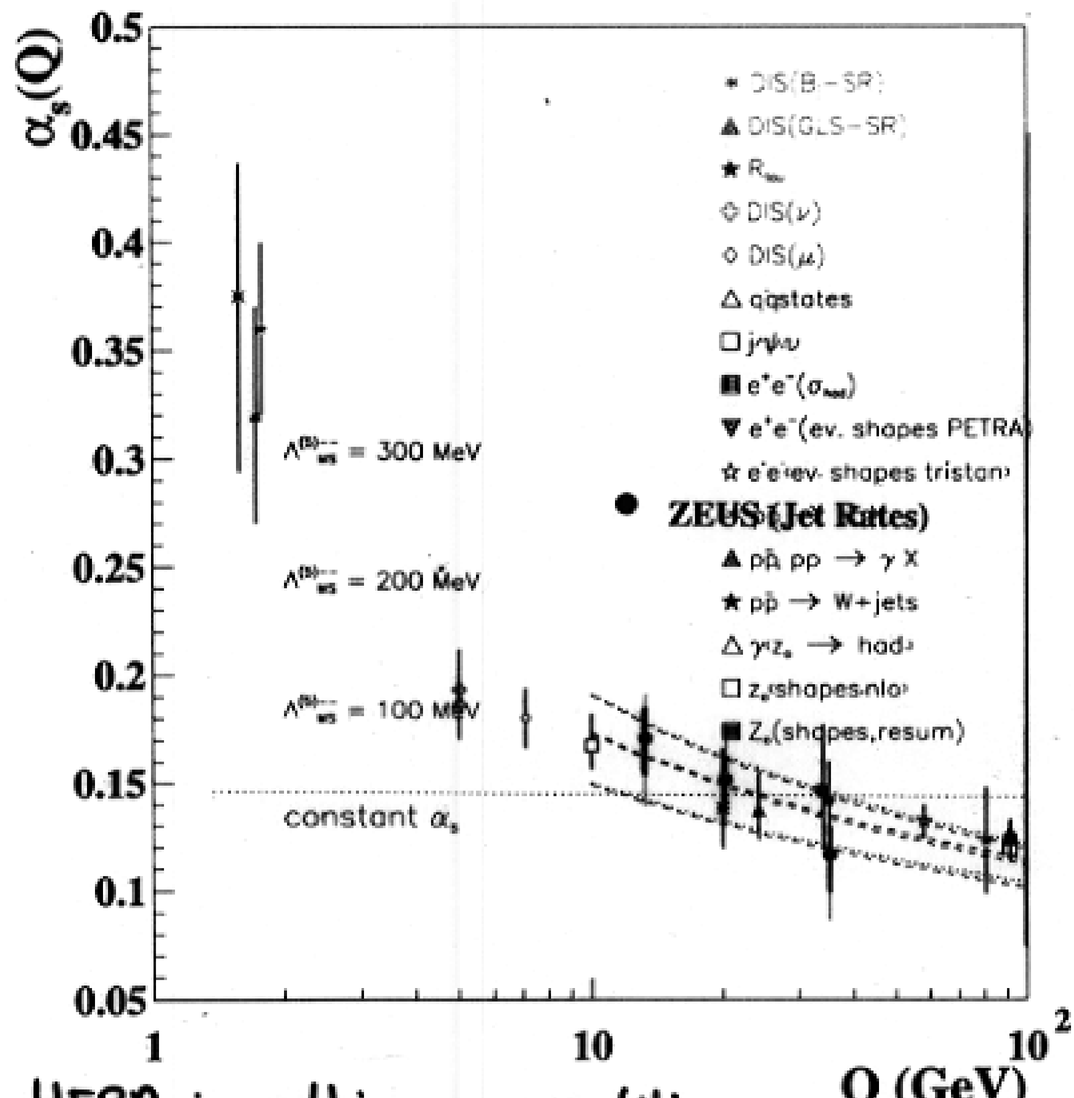
strong coupling constant α_s

- large reach in scale (e.g. Q^2) → running α_s in single expt.
- many different methods
  - jet counting
  - event shapes
  - scaling violation (at high x where quarks dominate
    ➡ precision measurement after lumin. upgrade)
    (with stat. error of 0.001).
  - ......

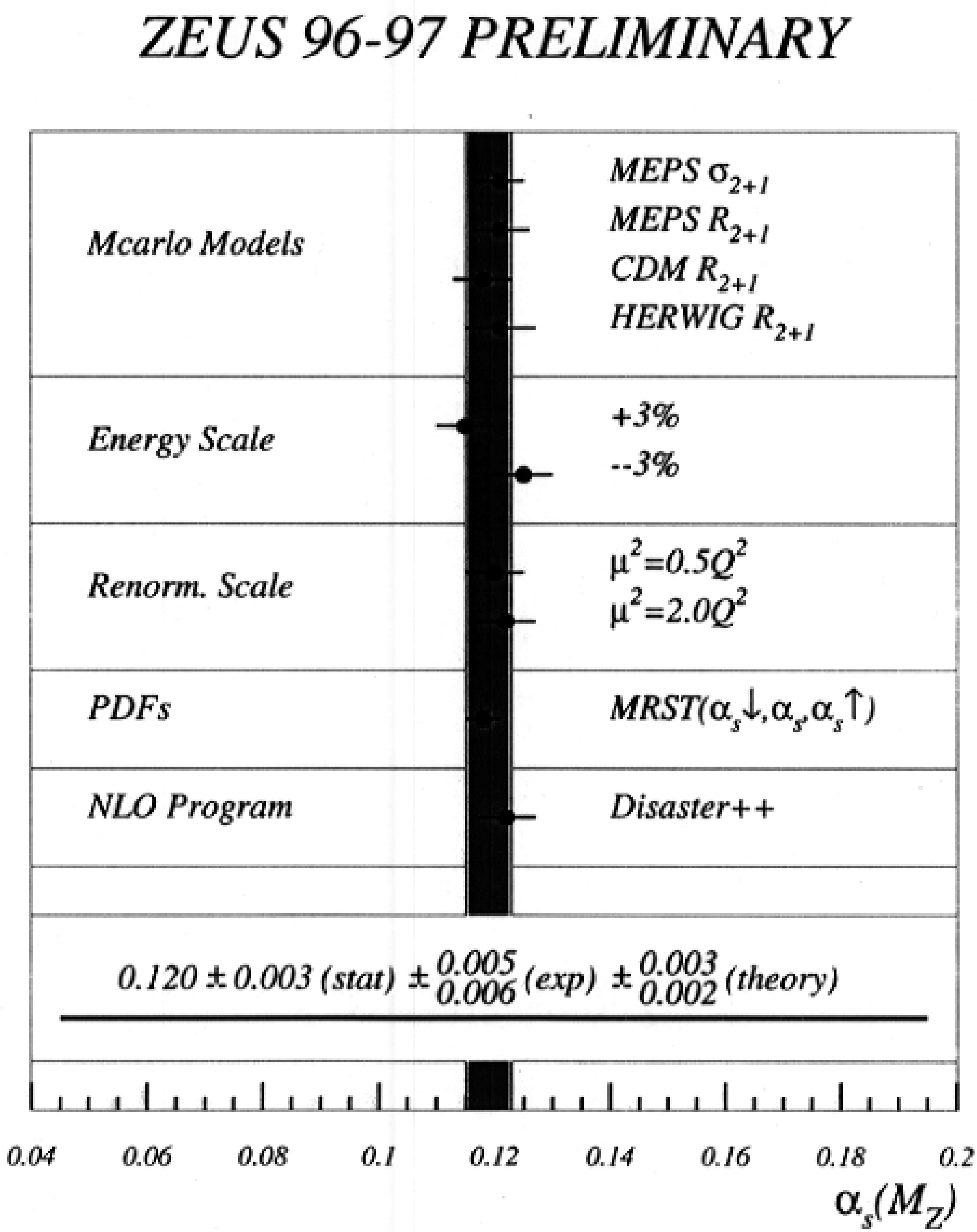
example from di-jet events ZEUS '96/'97-data preliminary

$$\boxed{\alpha_s(M_Z) = 0.120 \pm 0.003(st.) \pm 0.005(exp.) \pm 0.003(th.)}$$

(world average '98: 0.119 ± 0.004)



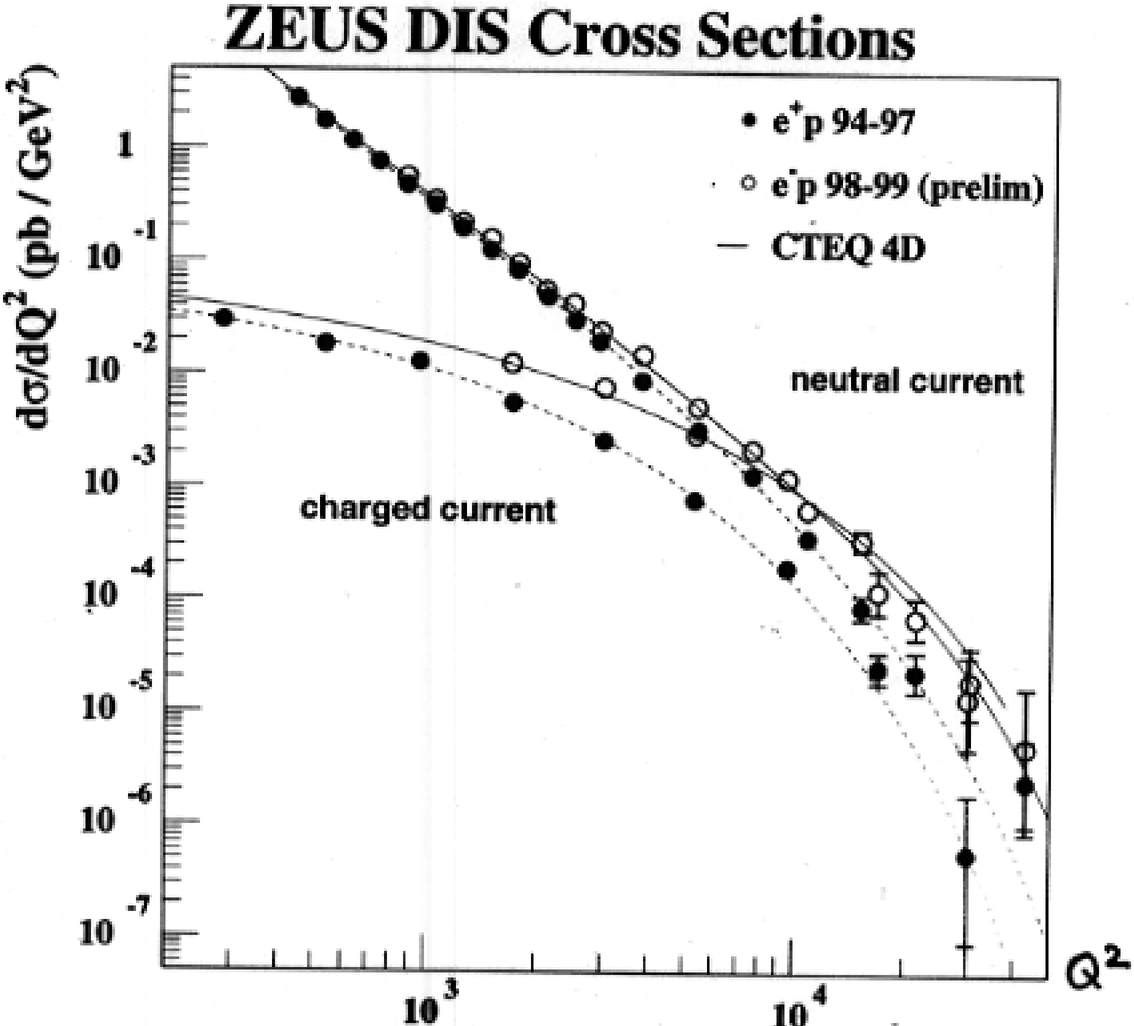
⇨ HERA is getting competitive



ZEUS 96-97 PRELIMINARY
Mcarlo Models
MEPS σ_{2+1}
MEPS R_{2+1}
CDM R_{2+1}
HERWIG R_{2+1}
Energy Scale
+3%
--3%
Renorm. Scale
$\mu^2=0.5Q^2$
$\mu^2=2.0Q^2$
PDFs
MRST($\alpha_s\downarrow,\alpha_s,\alpha_s\uparrow$)
NLO Program
Disaster++
$0.120 \pm 0.003\ (stat) \pm^{0.005}_{0.006}\ (exp) \pm^{0.003}_{0.002}\ (theory)$
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
$\alpha_s(M_Z)$

NC- and CC-scattering at the electroweak scale

from ~48pb^{-1} e^+p and 16pb^{-1} e^-p data:



- agreement with SM-predictions (> 6 orders of magn.)
  (→ extraction of u,d with minimal assumptions for $x \to 1$)
  ➡ luminosity upgrade (events + $e^{+/-}$-polarisation)

- EW-unification: $\underline{\sigma_{em} \simeq \sigma_{weak}}$
- sensitivity to EW-effects:
  - CC: $\boxed{\begin{aligned} M_{Prop} &= 80.9 \pm 3.3(st.) \pm 1.7(syst.) \pm 3.7(pdf) \text{ H1} \\ &= 81.4 \pm 2.7(st.) \pm 2.0(syst.) \pm 3.3(pdf) \text{ ZEUS} \end{aligned}}$

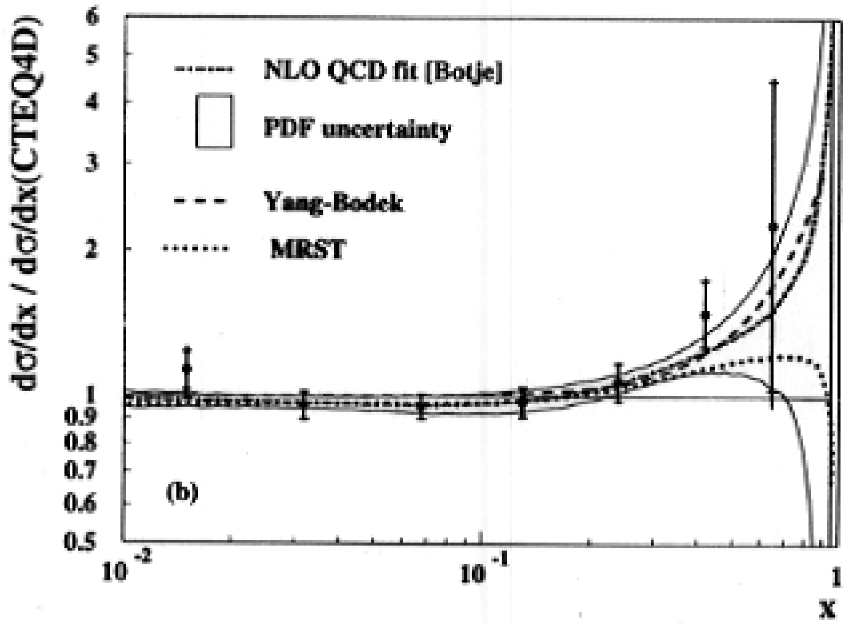
M_W(spacelike) agrees with M_W(timelike)

important test of universality of the SM

- limits on anomalous couplings in space-like region

4.5

Parton Densities at High x



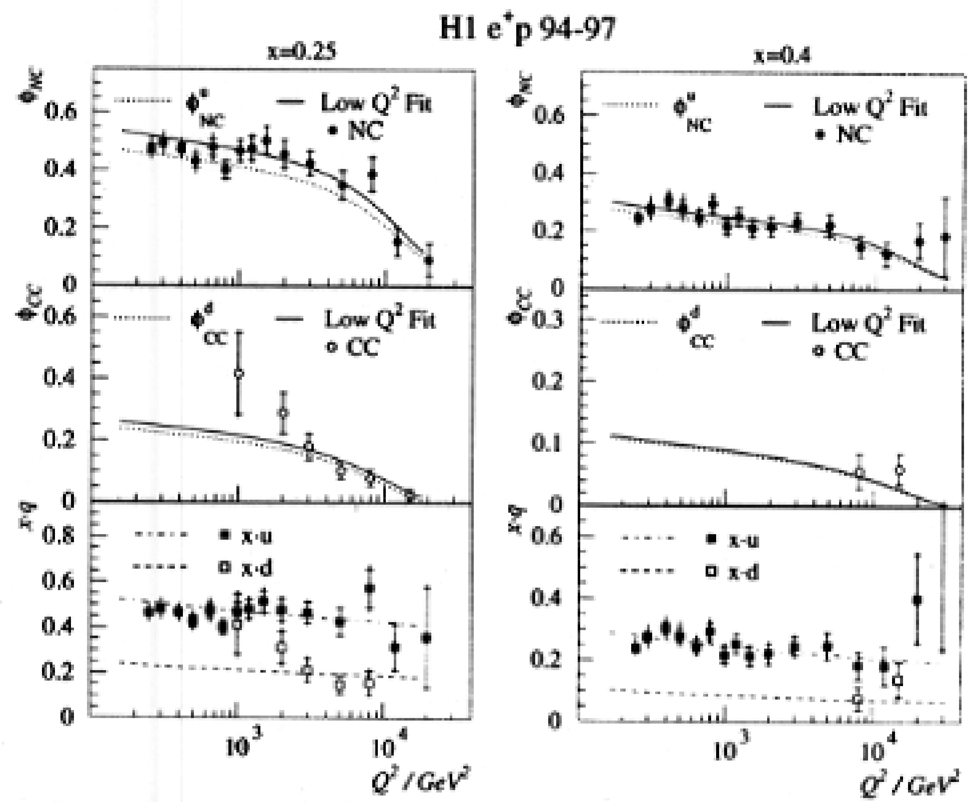
Parton densities at high x (especially d) poorly constrained ($F_2^d \to F_2^{p+n}$ needs e.g. nuclear binding corrections)

$\lim_{x\to 1} d/u = 0$?? 0.2 ??

At HERA : start to distinguish u and d in a single experiment !

$$\Phi_{NC} \sim (1+(1-y)^2)\sum e_i^2 x q_i$$

$$\Phi_{CC} \sim x\bar{u} + (1-y)^2 xd$$

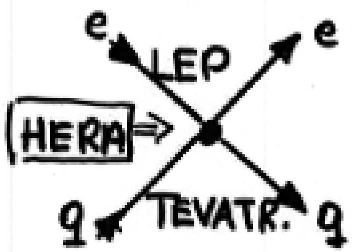


⇒ Extraction of u, d at high x possible with minimal assumptions !
Promising with $\nearrow \mathcal{L}$! ... And still more with $\vec{e}$!

Physics beyond the SM - complementary to LEP/FNAL

- unexpected phenomena
- leptoquarks, leptogluons
- lepton flavour violation
- excited leptons
- SUSY (R-conserving and R-violating)
- contact interactions / substructure
- .....

Contact interactions - search for new physics » s_{Hera}



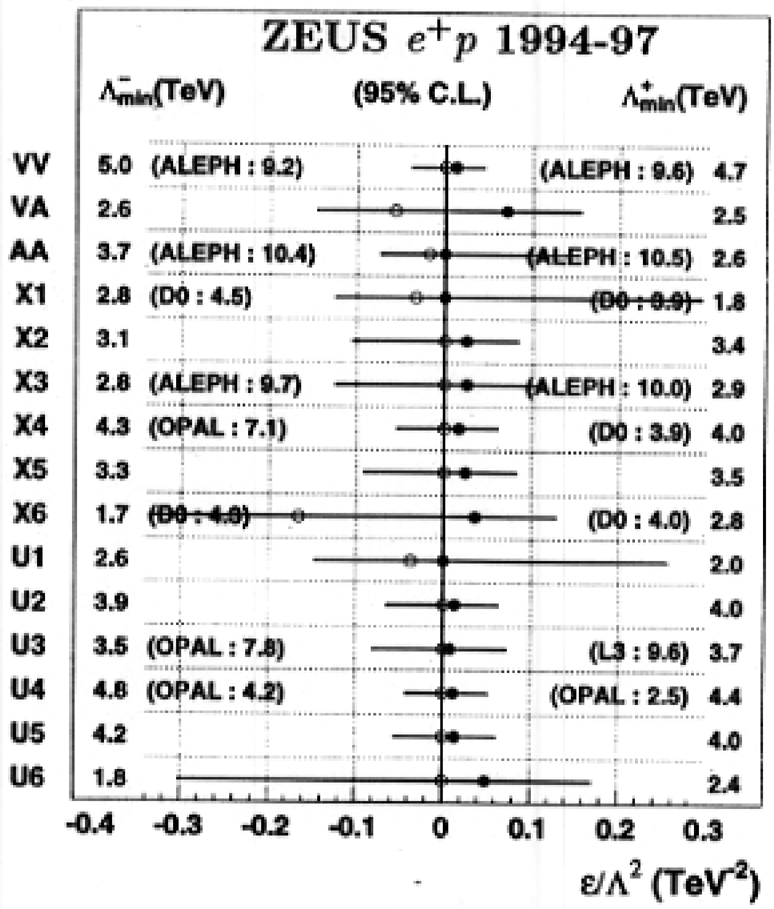
only vector terms

$$\boxed{\mathcal{L}_{CI} = \sum \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i)\cdot(\bar{q}_j \gamma_\mu q_j)}$$

$\left(\eta_{..} \begin{matrix} >0 \\ 0 \\ <0 \end{matrix}\right)$

interference CI ⊗ DIS

➡ modifies $d^2\sigma/dx\,dQ^2$



- 15 (×2) scenarios constrained by ZEUS
- horizontal bars show 95% CL limits

- limits range $\boxed{\text{from 1.7 TeV to 5 TeV}}$

- NB : LEP (EPS'99) limits rely on flavor symmetry hypothesis
- (Prel.) constraints on chiral models ($\not{F}$) by H1 (useful for combination)

Leptoquarks and the high x, Q^2 excess in $e^+p \to e^+X$

		$\mathcal{L}$ [pb^{-1}]	$Q^2 > 15000$		$M_{eh} = 187$-212 GeV; $y > 0.4$	
			N_{obs}	N_{SM}	N_{obs}	N_{SM}
H1	94-96	14	12	4.7±0.8	7	0.95±0.18
	94-97	37	22	14.8±2.1	8	3.01±0.54

			$Q^2 > 35000$	
			N_{obs}	N_{SM}
ZEUS	94-96	20	2	0.15±0.01
	94-97	47	2	0.29±0.02

→ excess remains, but significance is decreasing

+ no significant deviations from SM in e^-p and CC

→ set upper limits; e.g first generation leptoquarks

for BRW-LQ + $\lambda = \sqrt{4\pi\alpha_{em}}$: M_{LQ} > up to (95% CL) F=0 275/284 GeV (S/V); F=2 290 GeV (S)

TeVatron:

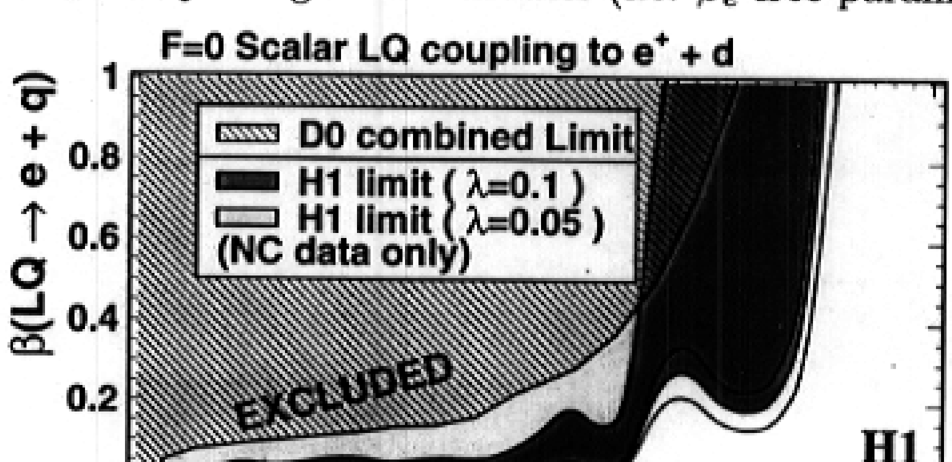
$\mathcal{B}$	D0	CDF	Combined
$\mathcal{B} = 1$	$M > 225$GeV	$M > 213$GeV	$\boxed{M > 242\text{GeV}}$
$\mathcal{B} = 0.5$	$M > 204$GeV	$M > 184$GeV*	-
$\mathcal{B} = 0$	$M > 79$GeV	-	-

Lower Limit 95% CL * $e\nu jj$ only

All numbers for NLO calculations with $Q^2 = 4M^2_{LQ}$ evolution

$\Longrightarrow$ Discovery reach at HERA requires small $\beta = \beta(LQ \to eq)$
e.g. $\beta <\sim 0.4$ for $M_{LQ} \sim 200$ GeV

HERA's Sensitivity in "generic" models (i.e. β_e free parameter)



luminosity upgrade → discovery potential for low β

Lepton flavour violation (LFV)

No events $ep \to \mu + \text{jet} + X$ or $\to \tau + \text{jet} + X$ with kinematic properties of $2 \to 2$ body process found

⇨ stringent limits for LFV-leptoquarks ($m < \sqrt{s_{Hera}}$)

⇨ stringent limits for LFV interactions ($m \gg \sqrt{s_{Hera}}$).

H1: $e \leftrightarrow \tau$ $\quad \sigma_{eq_i \to \tau q_j} \propto \left(\frac{\lambda_{1i} \cdot \lambda_{3j}}{M^2_{LQ}}\right)^2$ $\quad$ **F = 0**

BEST EXCLUSION UPPER LIMITS ON $\boxed{\frac{\lambda_{1i}\ \lambda_{3j}}{M^2_{LQ}}\ (\text{in } 10^{-4}\ \text{GeV}^{-2})}$

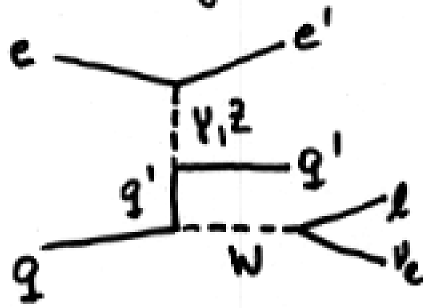
FOR LEPTON FLAVOUR VIOLATING LEPTOQUARKS

$q_i\ q_j$	$S_{1/2,L}$	$S_{1/2,R}$	$\tilde{S}_{1/2,L}$	$V_{0,L}$	$V_{0,R}$	$\tilde{V}_{0,R}$	$V_{1,L}$
1 1	$\tau \to \pi e$ 0.0032 H1: 0.046	$\tau \to \pi e$ 0.0016 H1: 0.037	$\tau \to \pi e$ 0.0032 H1: 0.062	G_F 0.002 H1: 0.015	$\tau \to \pi e$ 0.0016 H1: 0.015	$\tau \to \pi e$ 0.0016 H1: 0.013	G_F 0.002 H1: 0.0060
1 2	ZEUS: 0.12 H1: 0.047	$\tau \to Ke$ 0.05 H1: 0.038	$\tau \to Ke$ 0.05 H1: 0.063	$\tau \to Ke$ 0.03 H1: 0.017	$\tau \to Ke$ 0.03 H1: 0.017	ZEUS: 0.10 H1: 0.014	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-6} H1: 0.0065
1 3	•	$B \to \tau \bar{e} X$ 0.08 H1: 0.065	$B \to \tau \bar{e} X$ 0.08 H1: 0.065	$B \to l\nu X$ 0.02 H1: 0.020	$B \to \tau \bar{e} X$ 0.04 H1: 0.020	•	$B \to l\nu X$ 0.02 H1: 0.020
2 1	ZEUS: 0.34 H1: 0.15	$\tau \to Ke$ 0.05 H1: 0.095	$\tau \to Ke$ 0.05 H1: 0.12	$\tau \to Ke$ 0.03 H1: 0.020	$\tau \to Ke$ 0.03 H1: 0.020	ZEUS: 0.10 H1: 0.023	$K \to \pi\nu\bar{\nu}$ 2.5×10^{-6} H1: 0.010
2 2	$\tau \to e\gamma$ 0.03 H1: 0.18	$\tau \to e\gamma$ 0.02 H1: 0.10	ZEUS: 0.48 H1: 0.13	ZEUS: 0.25 H1: 0.024	ZEUS: 0.25 H1: 0.024	ZEUS: 0.31 H1: 0.034	ZEUS: 0.13 H1: 0.014
2 3	•	$B \to \tau \bar{e} X$ 0.08 H1: 0.14	$B \to \tau \bar{e} X$ 0.08 H1: 0.14	$B \to l\nu X$ 0.02 H1: 0.035	$B \to \tau \bar{e} X$ 0.04 H1: 0.035	•	$B \to l\nu X$ 0.02 H1: 0.035
3 1	•	$B \to \tau \bar{e} X$ 0.08 H1: 0.16	$B \to \tau \bar{e} X$ 0.08 H1: 0.16	V_{ub} 0.002 H1: 0.022	$B \to \tau \bar{e} X$ 0.04 H1: 0.022	•	V_{ub} 0.002 H1: 0.022
3 2	•	$B \to \tau \bar{e} X$ 0.08 H1: 0.19	$B \to \tau \bar{e} X$ 0.08 H1: 0.19	$B \to l\nu X$ 0.02 H1: 0.026	$B \to \tau \bar{e} X$ 0.04 H1: 0.026	•	$B \to l\nu X$ 0.02 H1: 0.026
3 3	•	ZEUS: 0.72 H1: 0.23	ZEUS: 0.72 H1: 0.23	$\tau \to e\gamma$ 0.51 Z H1: 0.045	$\tau \to e\gamma$ 0.51 Z H1: 0.045	•	ZEUS: 0.38 H1: 0.045

- Many indirect bounds considerably improved (also in some cases for $e \leftrightarrow \mu$)
- High discovery potential for LFV LQs with $M \gg \sqrt{s}$

W-production at HERA

main diagram:



$\sigma_{ep \to eW^{\pm}X} \simeq 1\,\mathrm{pb}$

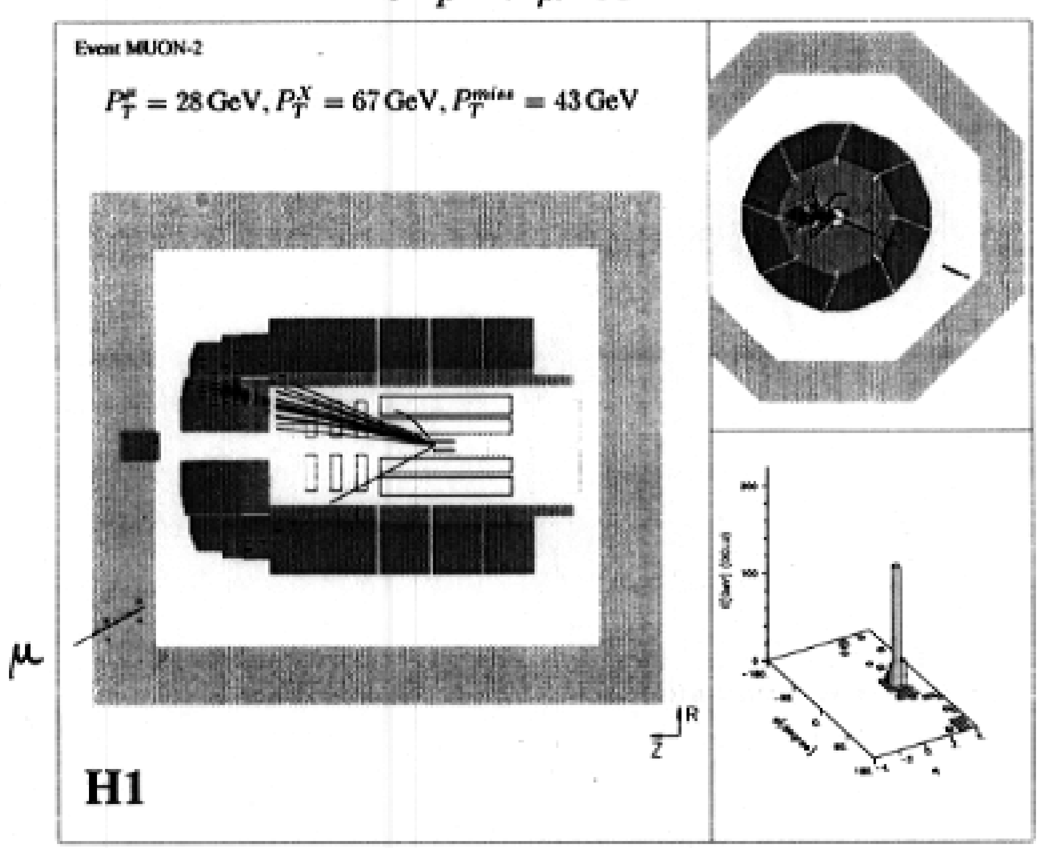
at present $\mathcal{L}$ expect few events $W \to e\,\nu_e$, $\mu\,\nu_\mu$

signature: high p_T isolated lepton
+ missing $|\vec{p}_T|$ from ν

		ZEUS		H1	
		N_{obs}	$N_{exp}(N_W)$	N_{obs}	$N_{exp}(N_W)$
e^+p	$W \to e$	3	$3.2 \pm 0.3\,(2.1)$	1	$2.4 \pm 0.5\,(1.7)$
	$W \to \mu$	0	$1.4 \pm 0.2\,(0.8)$	5	$0.8 \pm 0.2\,(0.5)$
e^-p	$W \to e$	2	$0.8 \pm 0.4\,(0.3)$	0	$1.0 \pm 0.2\,(0.6)$
	$W \to \mu$	0	$0.8 \pm 0.1\,(0.3)$	0	$0.4 \pm 0.1\,(0.2$

- events clean and well measured
- signal? ➡ need more $\mathcal{L}$ (in part. e^-p).

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

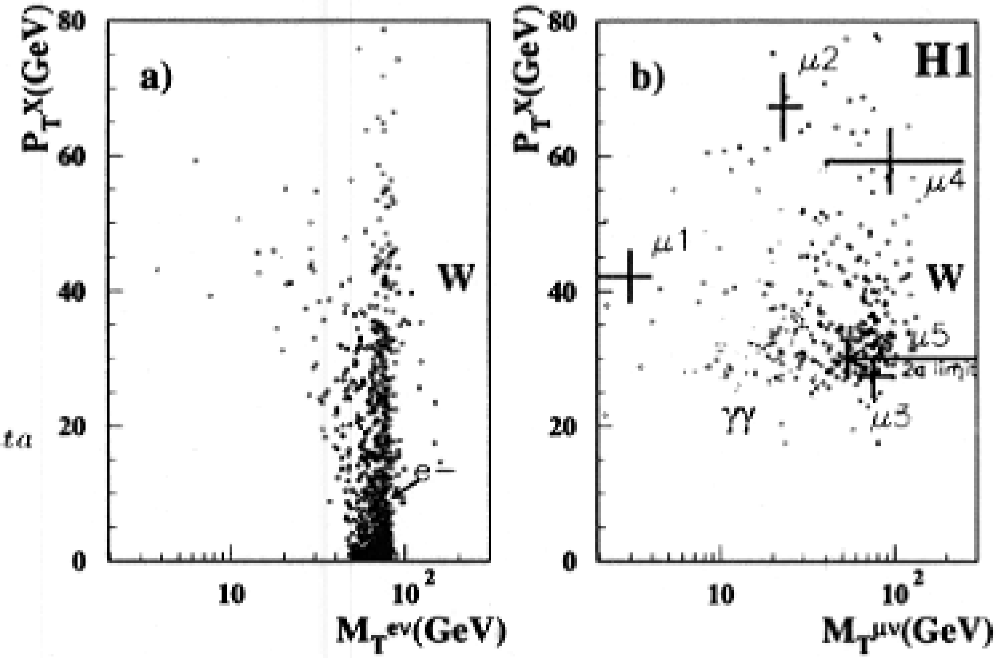


4.9(

High P_T Isolated Leptons

H1 Observation vs. W prod expectation: (e^+ data)

$\mathcal{L}_{MC}$ $\sim$ $500 \times \mathcal{L}_{data}$

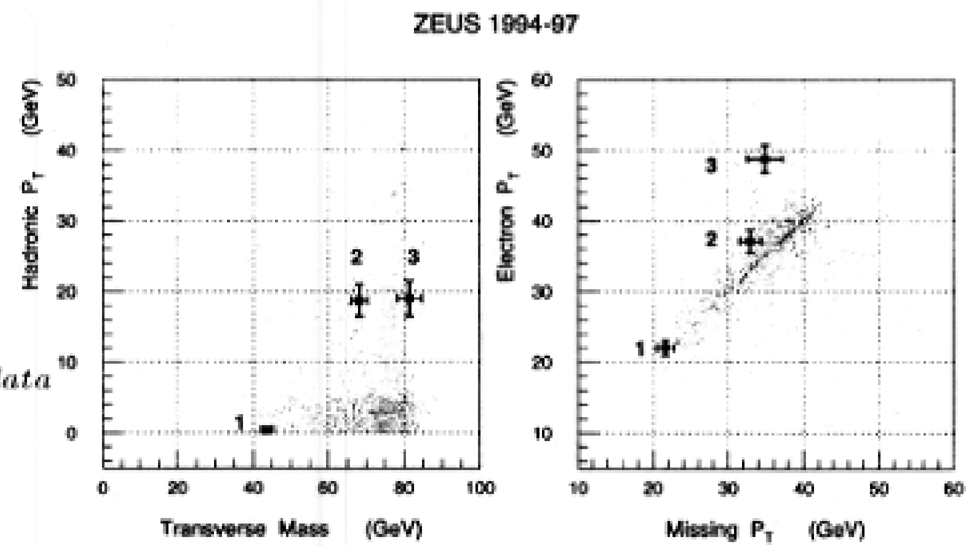


NB : μ_3 contains electron ! , μ_5 : charge not determined

3 events at high $P_{T,had}$ (H1 Collab., Euro. Phys. J C5 (1998) 575.)

ZEUS Observation vs. NC and W prod. expectation: (e^+ data)

$\mathcal{L}_{MC}$ $\sim$ $1000 \times \mathcal{L}_{data}$



2 events at high $P_{T,had}$ (ZEUS Collab., DESY-99-054)

$\Rightarrow$ few W candidates show an abnormally large hadronic recoil !

Next steps (tentative planning)

1999: → mid. Dec. e^+p 27.5 x 920 GeV
2000: mid Jan - April ? – " –
2000: May : begin shutdown for

HERA upgrade:
- increase $\mathcal{L}$ by factor ≈ 4.7
- spin rotators for H1 + ZEUS (HERMES)
  ⇨ e^+_L, e^+_R, e^-_L, e^-_R

- H1 and ZEUS modifications + upgrade

2001: run-in
after run-in phase expect ≈ 150 pb^{-1}/year.

? running strategy ?

$e^-_{L,R}\,p$ ~ 2x200 pb^{-1} 2-3 years
$e^+_{LR}\,p$ – " – 2-3 years

- possibly F_L measurement after high luminosity run

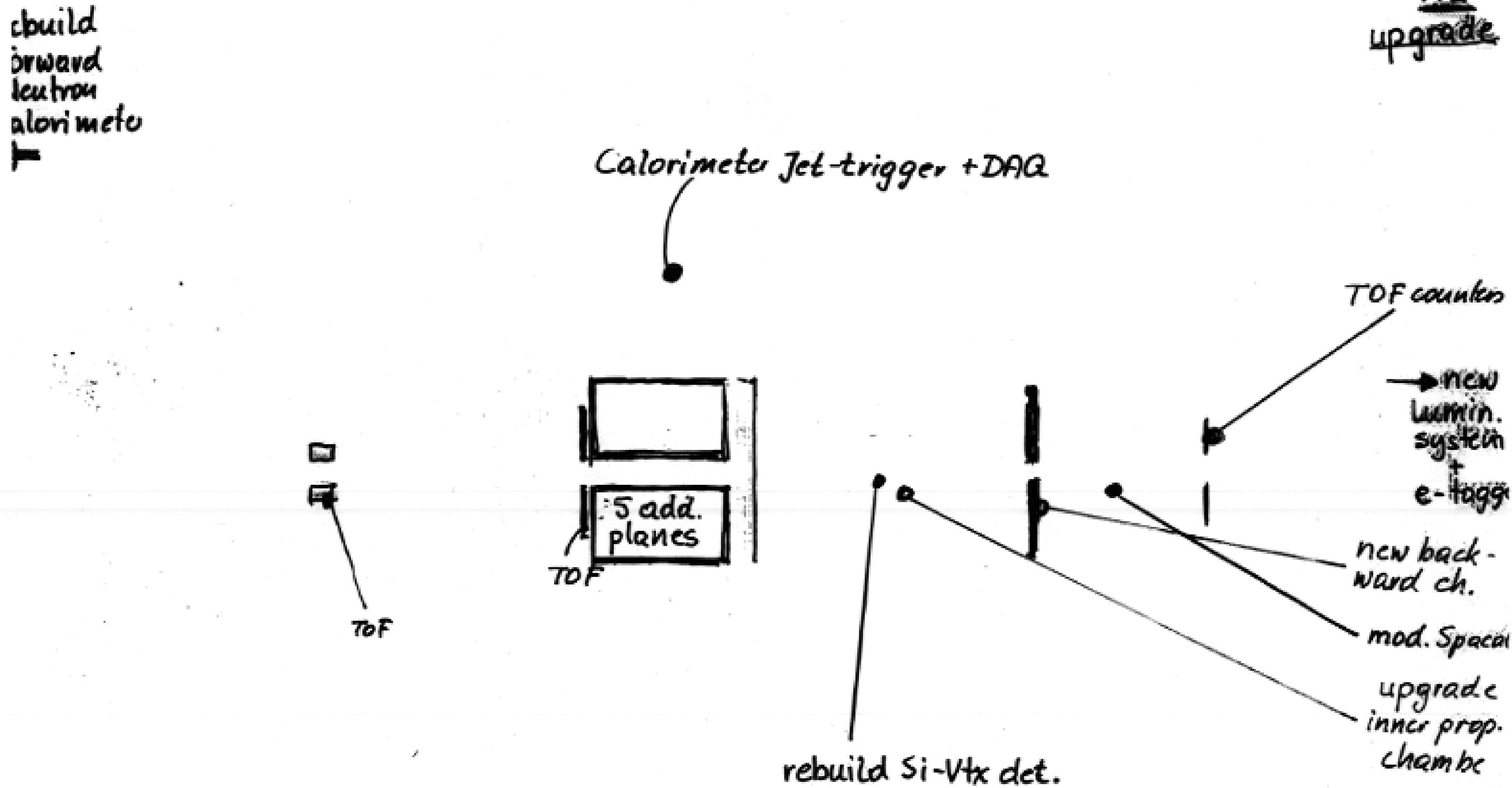
$(E_e = 27.5\,GeV) \cdot (E_p = 250, 350, 450, 820, 920\,GeV)$
? 1 year ?

$\boxed{\text{➡ post upgrade running 2001 → 2006 ...}}$

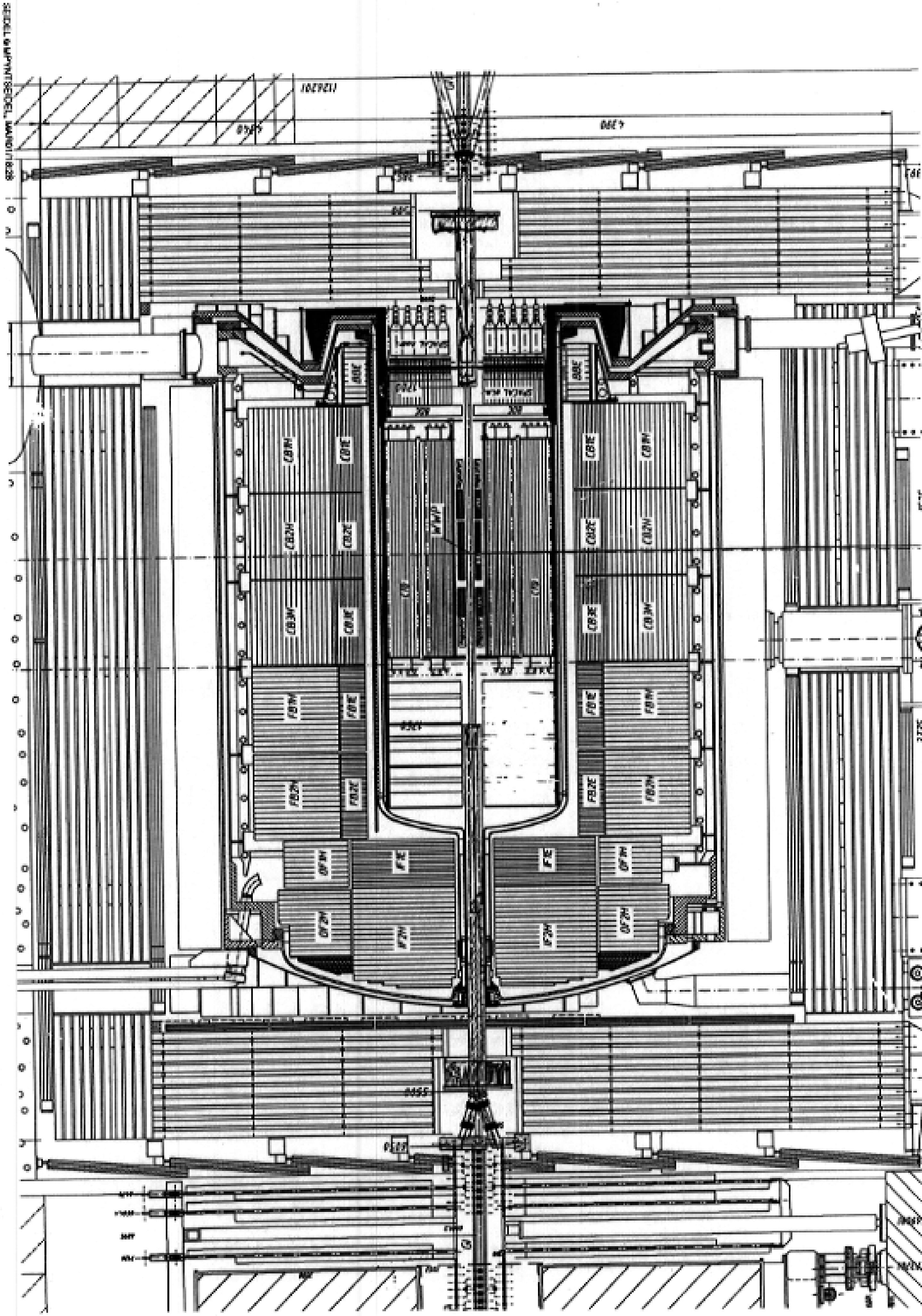
- The 4 HERA experiments run simultaneous (for $E_p = 920\,GeV$)

[Options eA and $e(\Uparrow) \cdot p(\Uparrow)$ are under study, their realisation will depend on their physics potential and on TESLA].

H1 upgrade

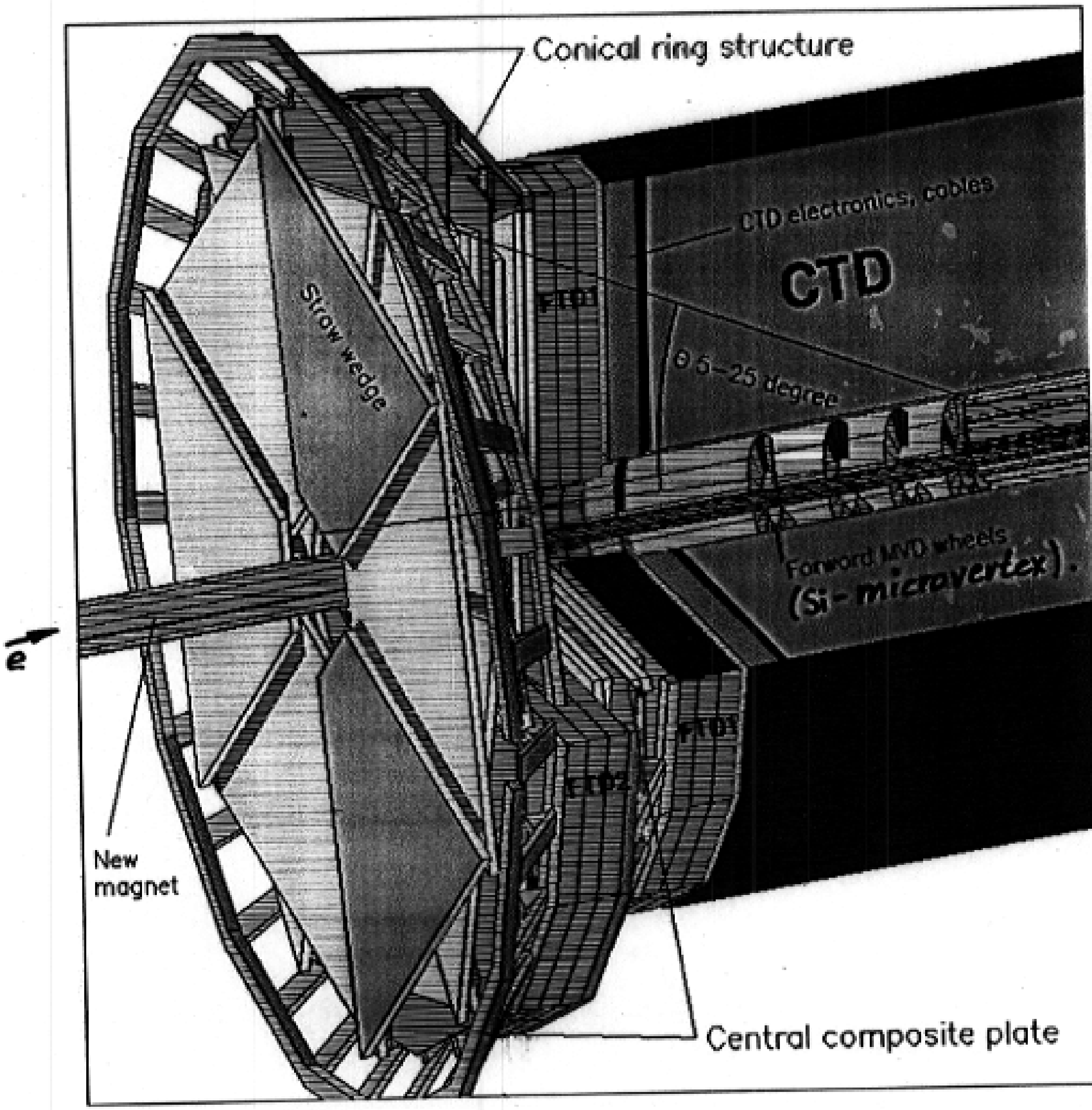


cbuild
orward
leutron
alorimetc
Calorimeter Jet-trigger +DAQ
TOF counters
new lumin. system + e-tagger
5 add. planes
TOF
TOF
new back-ward ch.
mod. Spacal
upgrade inner prop. chamber
rebuild Si-Vtx det.



ZEUS detector upgrade

- improve tracking :
  Si - microvertex detector
  forward straw - tracker



- luminosity measurement system + new γ - tagger
- remove forward proton / neutron / plug - detectors
- + many modifications to bring magnets into detector,
  + new beampipe.

ep physics after HERA-upgrade (H1/ZEUS).

Standard DIS

$e^+_L p$, $e^+_R p$, $e^-_L p$, $e^+_L p$ $\quad$ $\mathcal{O}$(200 pb^{-1} each).

measure for NC: F_2, xF_3, xG_3, xH_3
F_2^{charm}, F_2^{beauty}
(F_L if runs at reduced E_p)

for CC: F_2, xF_3, F_2^{charm}, F_2^{beauty} (F_L)

Q^2 = $10 \to 50\,000$ GeV^2

- separate u,d,s-distributions in p for $x \gtrsim 0.05 \to 1$ (without nuclear effects)
- $G(x,Q^2)$ including the high x ($x \gtrsim 0.1$) region
- precision $\alpha_s(Q^2)$-measurement

  for $\mathcal{L} = 250\,pb^{-1}$: $\delta\alpha_s(stat.) \approx \pm 0.002$ for 3 Q^2-intervals (150 - 300 GeV^2
  300 - 700 GeV^2
  700 - 4000 GeV^2).

- precision measurement of a- and v-couplings of u- and d-quark (e-polarisation gains up to a factor 6 in precision v_q)

Beyond the SM

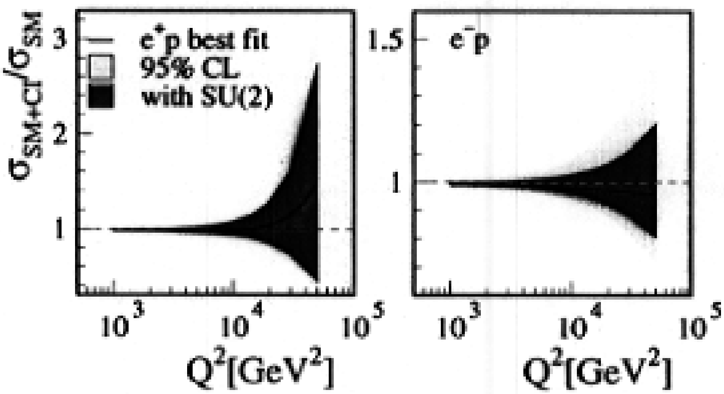
- direct + simple search for right-handed weak current
  (e.g. SM: $\sigma(e^-_R p \to \nu X) = \sigma(e^+_L p \to \bar{\nu} X) = 0$).

- Leptoquarks
- Lepton flavour violation
- SUSY in particular R_p-violating scenario
- ΔR anomalous γWW-coupling

Beyond the Standard Model

How well do present data constrain $\sigma_{NC}(e^+/e^-p)$?

A.F. Zarnecki, hep-ph/9904334



Global fit (HERA, LEP, TeVatron, low energy exp.) $d\sigma/dQ^2$ at $Q^2 > 15000\text{GeV}^2$ allowed to deviate by 40% (e^+ case)

- in e^+p : $\mathcal{L} \sim 100 - 200\text{pb}^{-1}$ needed to observe such a deviation
- e^-p NC DIS : much more constrained by existing data
- significant effects could be seen with $\mathcal{L} \sim 100\text{pb}^{-1}$ and polarized e

Sensitivity to Leptoquark from deviation from σ_{SM}

e.g. for e^+p and 250pb^{-1} (unpol.)

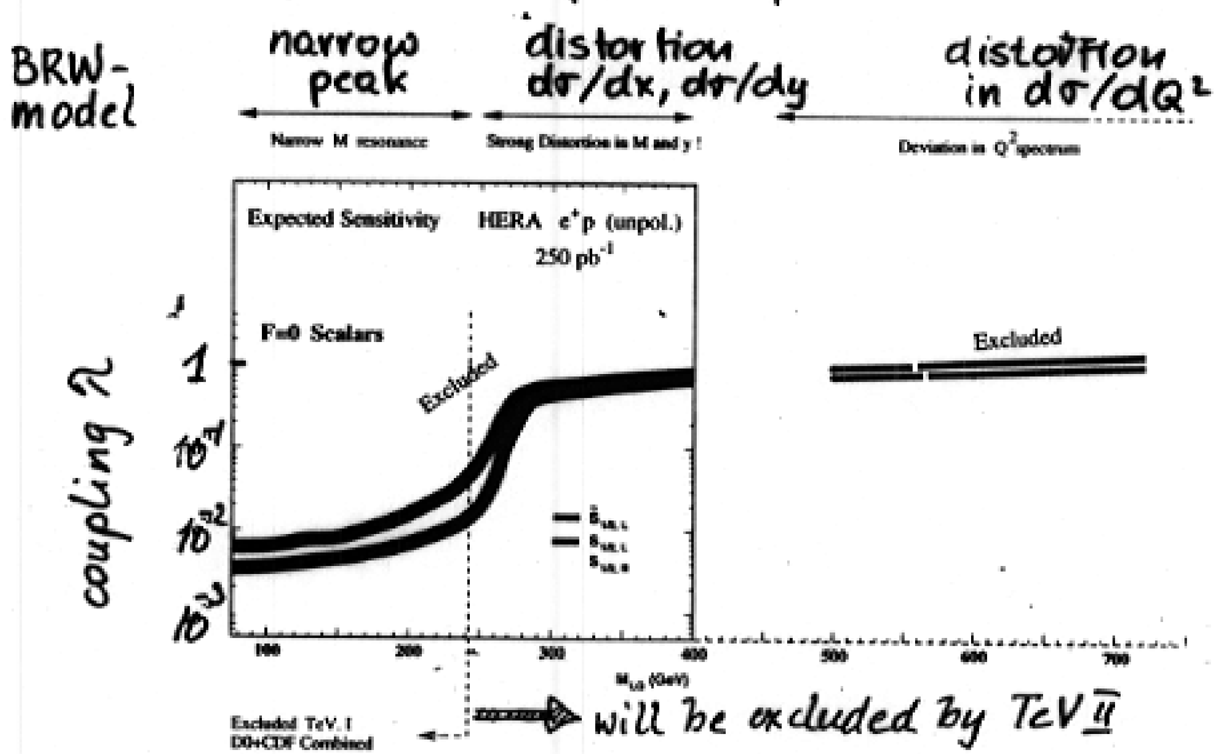
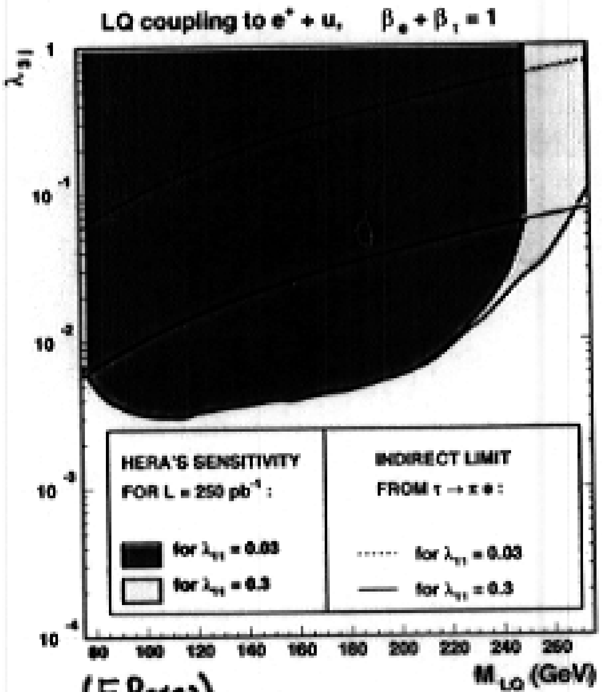


Figure 9. Expected constraints on leptoquarks from HERA$_{II}$ for an integrated luminosity of 250 pb^{-1}. The rejection limit curves are obtained by extrapolating recent HERA direct searches and Contact Interaction results.

! unless $\beta_e = \beta(LQ \to eq) \ll 1$!

Sensitivity to leptoquarks from event signatures

e.g. LQ coupling to first and third generation



(E.Perez).

- For LFV LQs coupling to e and τ : sensitivity far beyond most stringent indirect bounds
- For 1^{rst} generation LQs : discovery potential especially at low β_e

$\boxed{\text{• } ep \text{ collider = best machine to study LQ quantum numbers (single production, sign of } e \text{ beam, polarization,..)}}$

Lepton flavour violation ⟺ SUSY with $\not{R}_p$

additional term in superpotential

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

$\lambda''_{ijk} = 0 \Rightarrow$ baryon number conservation

<u>HERA has a particular sensitivity λ'-couplings</u>

Anomalous coupling at γWW-vertex

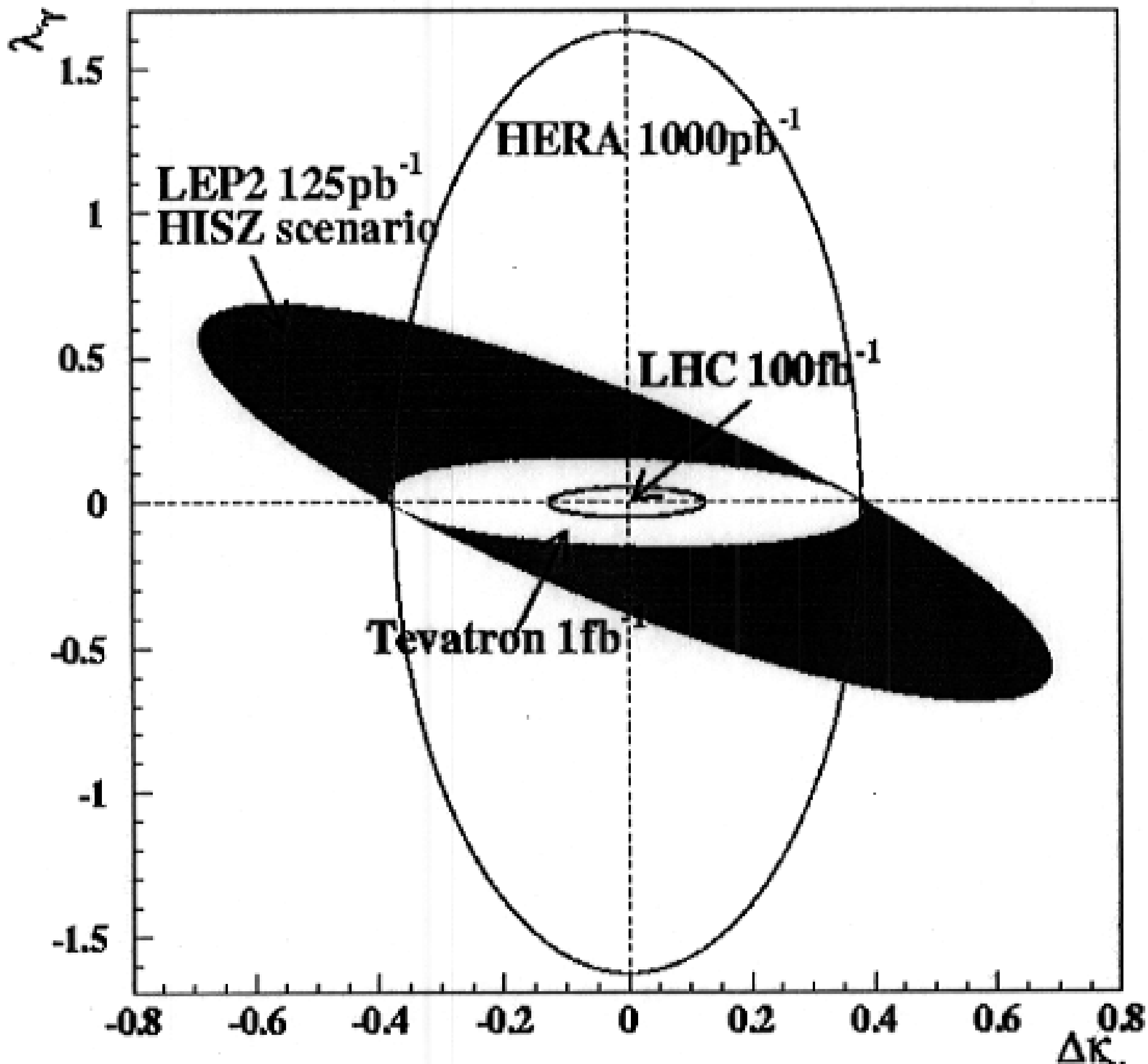
for HERA at $1\,fb^{-1}$ similar sensitivity as Tevatron at $1\,fb^{-1}$ for <u>$\Delta\kappa$</u>.

Future Physics at HERA

Sensitivity to $WW\gamma$ vertex:

Anomalous couplings: $\Delta\kappa_\gamma$, λ_γ parameterise

deviation from Standard Model



Competitive with projected limits from Tevatron and LEP2

Summary

- HERA has achieved design performance
- running experiments perform to specifications
- 2000: luminosity upgrade for ep ➡ x 4.7 in $\mathcal{L}$
  ➡ ~ 150 pb^{-1}/year
- very broad physics program ➡ ≈ 2006

  HERA-B: heavy flavour (b)-physics; $\cancel{CP}$ in B^0

  HERMES: unique program - spin of nucleons

  H1+ZEUS: beyond structure function, low-x-physics, QCD, diffraction some opportunities for physics beyond the Standard Model.
- options eA and e(↑)N(↑) depend on TESLA + physics potential.