A PROPOSAL TO MEASURE THE SPIN-DEPENDENT STRUCTURE FUNCTIONS OF THE NEUTRON AND THE PROTON AT HERA

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PRC / DESY
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THE HERMES COLLABORATION

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Universität Marburg
Massachusetts Institute of Technology
New Mexico State University
Universität München
Stanford University
Universita di Torino
TRIUMF\University of Alberta\Simon Fraser University
College of William and Mary

16 institutes / 65 physicists

Canada
Germany
Italy
United States

Basic idea:

- Scatter longitudinally polarised electrons in HERA from polarised nucleons

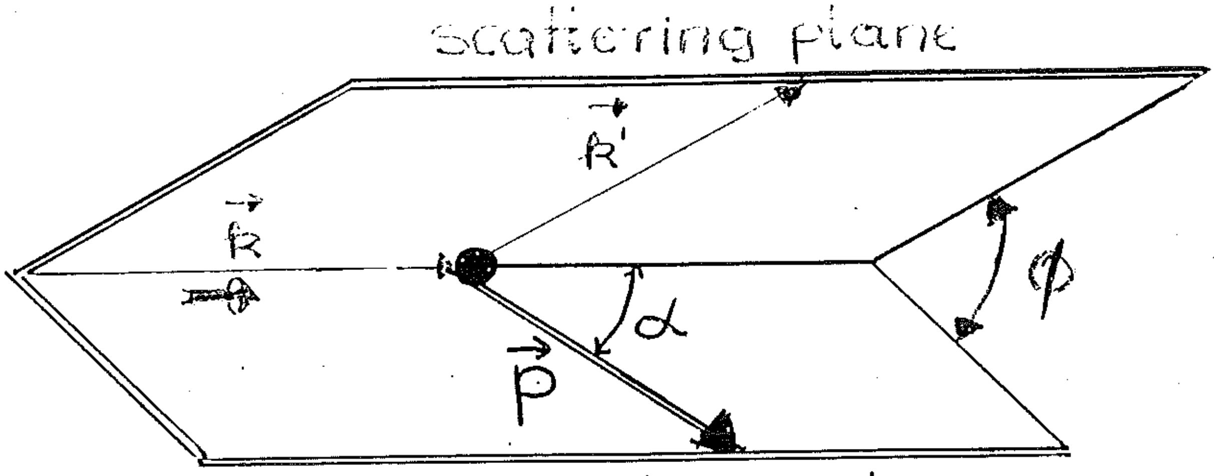
- Use internal polarised gas target (H, D, ^{3}He)

- Use storage cell to increase target density by factor of 100 compared to free atomic beam

⇓

First precision measurement of spin dependent structure function

Polarised lepton nucleon scattering



Polarisation plane

$$\left.\frac{d^3\sigma(\alpha)}{dx\,dy\,d\phi}\right|_{\substack{\uparrow \\ (e)}} = \frac{d^3\bar{\sigma}}{dx\,dy\,d\phi} \overset{+}{(-)} \frac{d^3\sigma^*(\alpha)}{dx\,dy\,d\phi}$$

$\uparrow$ $\sim f(F_1, F_2)$ $\qquad$ $\uparrow$ $\sim f(g_1, g_2)$

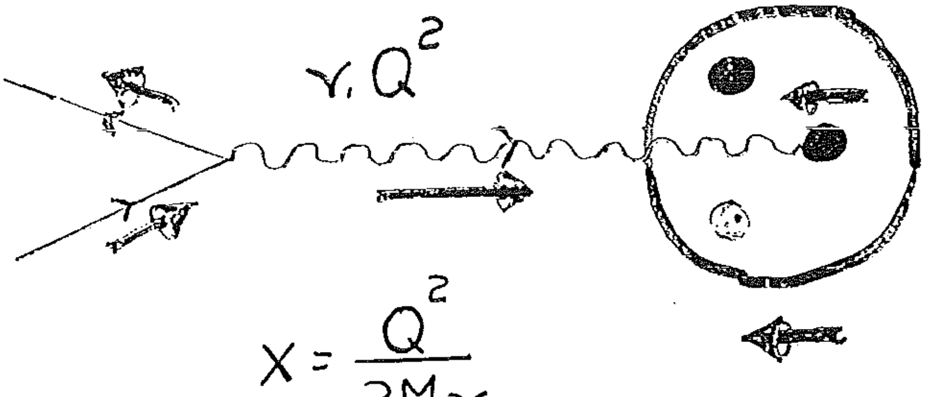
$$\frac{d^3\sigma^*(\alpha)}{dx\,dy\,d\phi} \sim \cos\alpha \cdot \{a \cdot g_1(x) + b\,g_2(x)\} - \cos\phi \,\sin\alpha \cdot c\left\{\frac{y}{2} g_1(x) + g_2(x)\right\}$$

$a \gg b$ $\qquad$ $y = \frac{\nu}{E}$

$\alpha = 0°$: measure dominantly $g_1(x)$

$\alpha = 90°$: " both $g_1(x), g_2(x)$

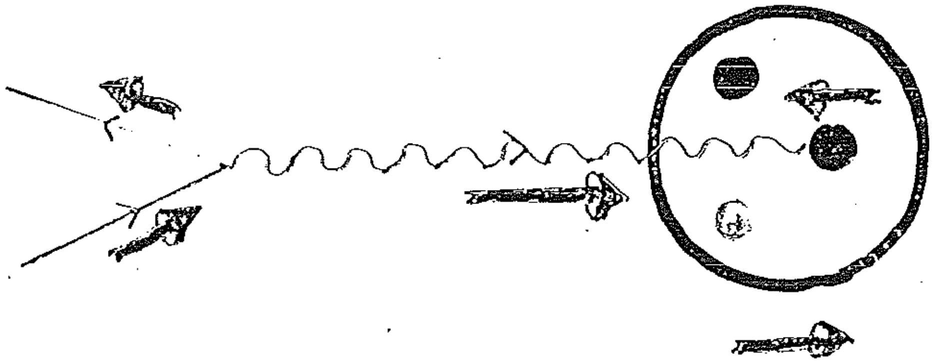
Asymmetries: $A = \dfrac{\sigma(\alpha+\pi) - \sigma(\alpha)}{\sigma(\alpha+\pi) + \sigma(\alpha)}$



$q^+(x, Q^2)$

$x = \frac{Q^2}{2M\nu}$

$\sigma^{\uparrow\downarrow}(\alpha = \pi)$



$q^-(x, Q^2$

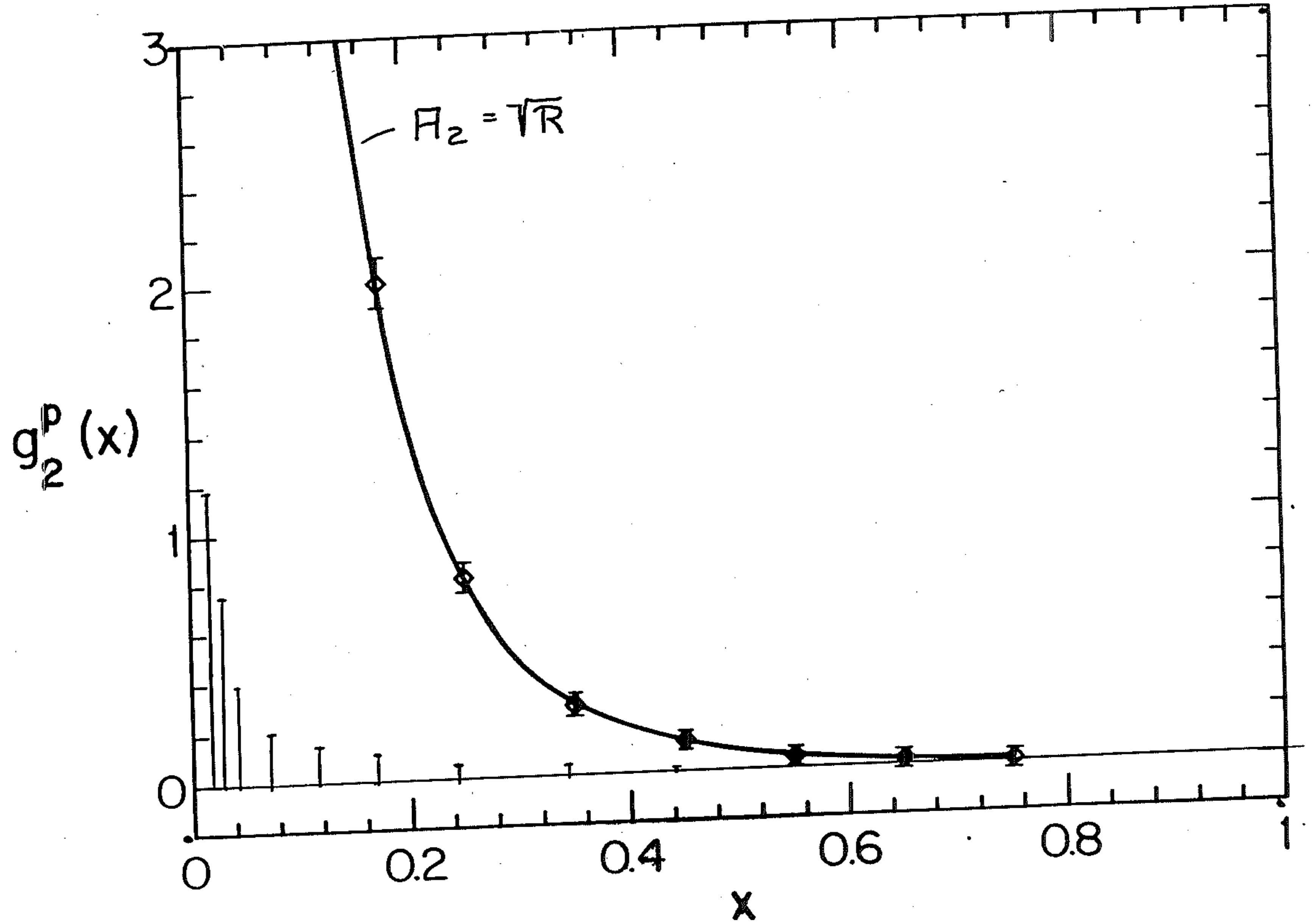
$\sigma^{\uparrow\uparrow}(\alpha = 0)$

$$\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow} \sim \boxed{g_1(x, Q^2) = \frac{1}{2}\sum_f e_f^2 \{q^+(x, Q^2) - q^-(x, Q}$$

$$\Delta q_f = \int_0^1 \{q_f^+(x) - q_f^-(x)\}\, dx$$

$$\Delta q_f \cdot 2M \cdot S_\mu = \langle p, S | \bar{q}_f \gamma_\mu \gamma_5 q_f | p, S$$

Only $q_f^p(x)$



3
2
1
0
$g_2^p(x)$
$A_2 = \sqrt{R}$
0
0.2
0.4
0.6
0.8
1
x

Complication:

- virtual γ has transverse and <u>longitudinal</u> polarisation
- quarks have <u>mass</u> and <u>transverse momenta</u>

⇕

$$\boxed{g_2(x)}$$

From OPE:

Wandzura, Wilczek
Shuriak, Vainshtein
Jaffe

$$\boxed{g_2(x) = -g_1(x) + \int_x^1 \frac{dz}{z} g_1(z) + \tilde{g}_2(x)}$$

↑ Quark-Gluon-Corr.
(twist-3 operator)

Experimentally completely unknown!

Furthermore:

Deuteron is Spin-1 target

↷ two more spin dependent structure functions: $b_1(x)$, $\Delta(x)$

No experimental information

Predicted to be small.

First exploratory measurement!

Sum Rules:

① **Bjorken (66)** Fundamental!

$$\int_0^1 dx \left(g_1^p(x) - g_1^n(x)\right) = \frac{1}{6}\left|\frac{g_A}{g_V}\right|_{np} * \text{QCD Korr.}$$

$$= 0.191 \pm 0.003$$

g_A, g_V: weak coupl. const. | from Gamow-Telle β-decay

Experimentally untested!

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② **Ellis-Jaffe** – SU(3)

$$\int_0^1 dx\, g_1^{p,(n)}(X) = \frac{1}{12}\left|\frac{g_A}{g_V}\right|_{np} \left\{ {}^{+}_{(-)} 1 + \frac{5}{3}\cdot\frac{3F-D}{F+D} \right\} * \text{QCD} \ldots$$

↓ $\Delta S = 0$, $F/D = 0.63$

$$\stackrel{p}{=} 0.189 \pm 0.007$$

$$\left(\stackrel{(n)}{=} -0.002 \pm \ldots\right)$$

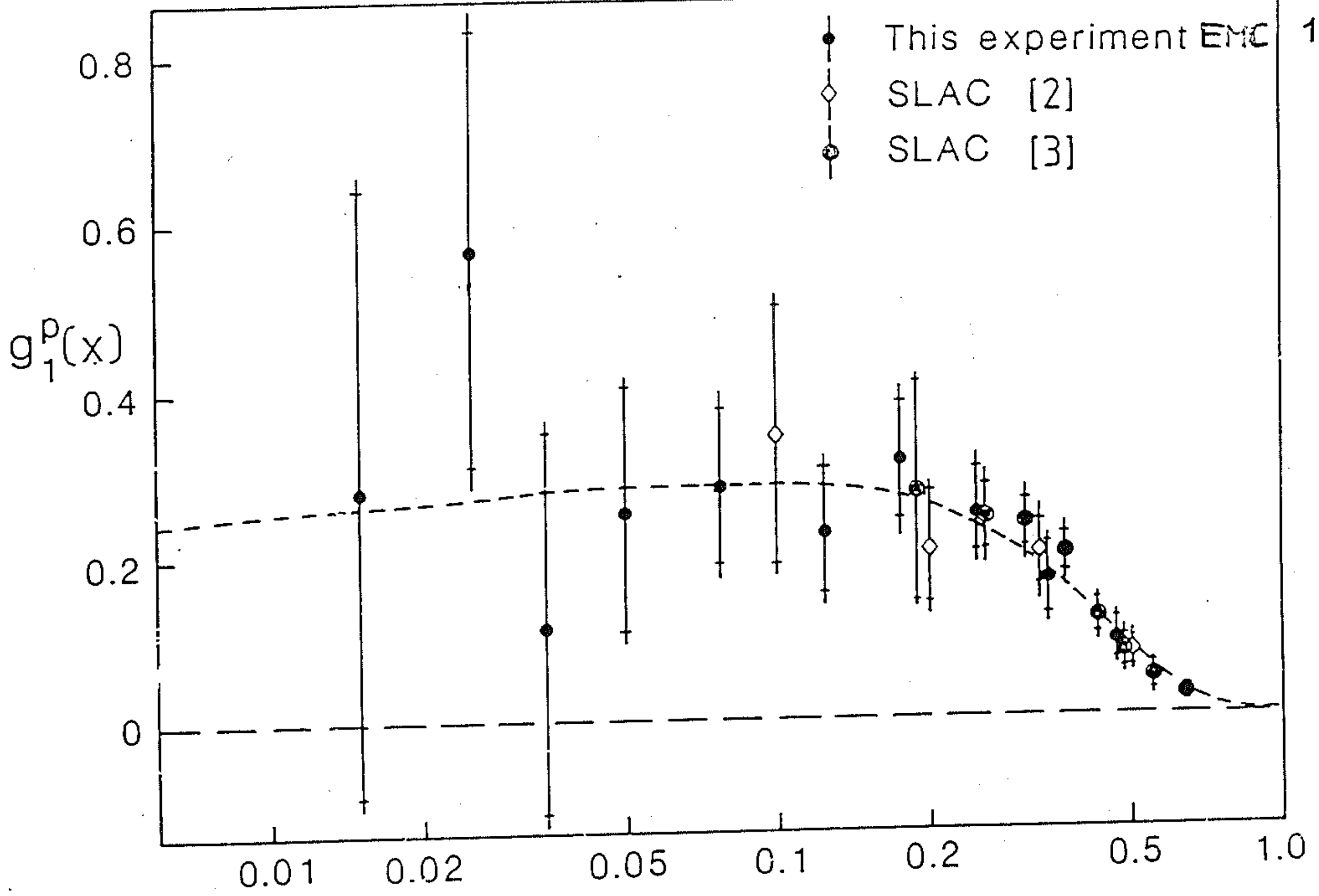
F, D: SU(3) coupling const.; baryon dec

np: F+D; Λp: F+$\frac{1}{3}$D; ΣΛ: F−$\frac{1}{3}$D

$f(NH_3) = \frac{3}{17}$

$f(C_4H_9OH) = $ [illegible]

J. Ashman et. al, Nucl. Phys. B328 (89) 1.



$$\delta A_{\gamma^*} = \frac{1}{\sqrt{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}} \left(f_N \cdot P_B \cdot P_T \cdot D \right)^{-1}$$

$f(NH_3) = \frac{3}{17}$

$f(C_4H_9OH) =$ [illegible]

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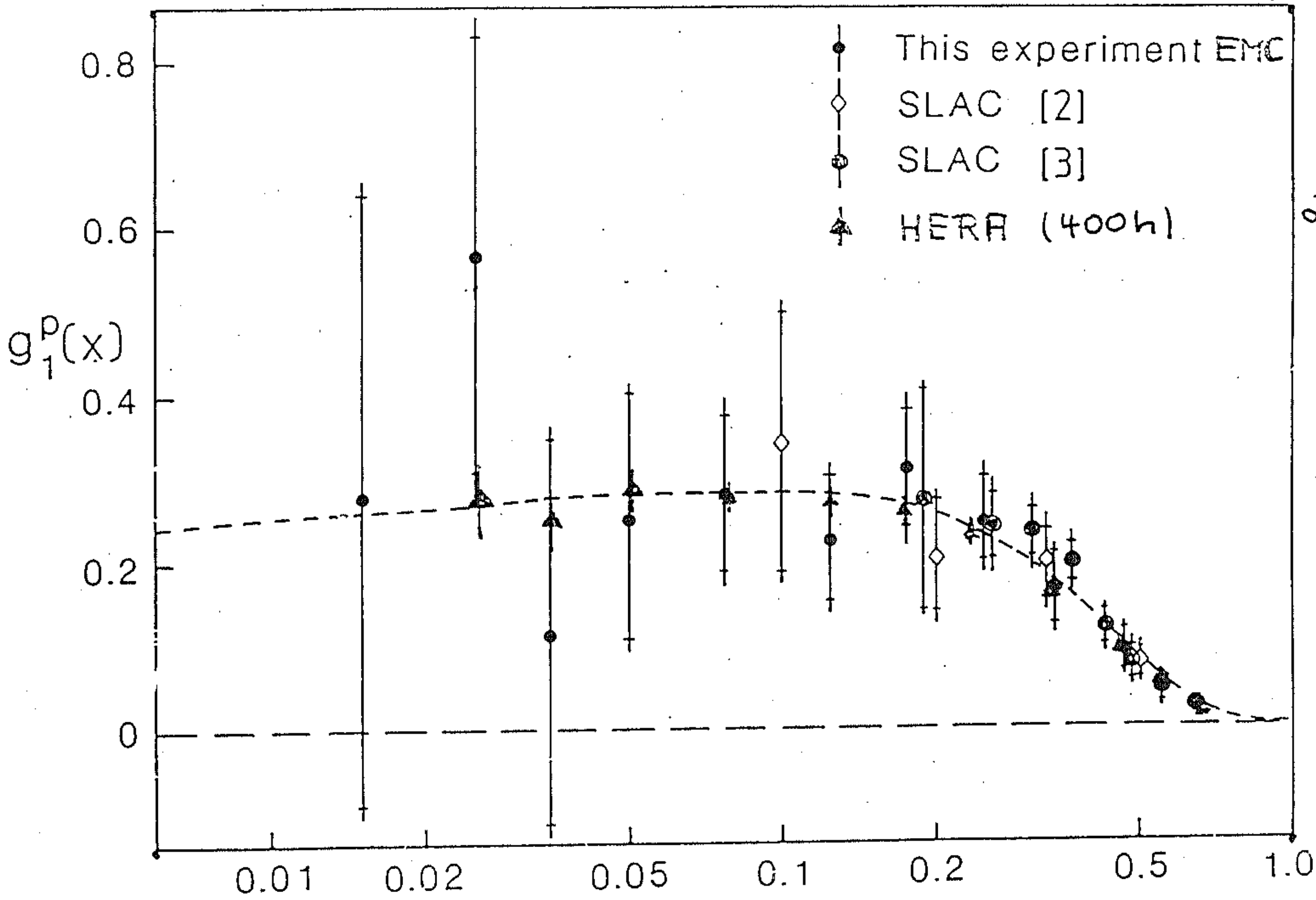


110 days

$I_e = 60\,mA$

$\mathcal{L} = 3 \times 10^{31}\,cm^{-2}s^{-1}$

$P^B = 0.5$

$P^T = 0.8$

$f(H) = 1$!

$$\delta A_{\gamma^*} = \frac{1}{\sqrt{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}} \left(f_N \cdot P_B \cdot P_T \cdot D \right)^{-1}$$

Result:

$$\Gamma_1^p = \int_0^1 dx\, g_1^p(x) = 0.126 \pm 0.010 \pm 0.015 \quad \text{(EMC+SLAC)}$$

E.J. = 0.189

↓ Bjorken S.R

$$\Gamma_1^n = \int_0^1 dx\, g_1^n(x) = -0.065 \pm$$

?

Consequences:

$$\left(\langle S_z\rangle^p = \tfrac{1}{2}\right); \quad \langle S_z\rangle_{q_f} = \tfrac{1}{2}\left(\Delta q_f + \Delta\bar{q}_f\right); \quad F/D = 0.63$$

$$\langle S_z\rangle_u = 0.391 \pm \ldots, \quad \langle S_z\rangle_d = -0.236 \pm \ldots, \quad \langle S_z\rangle_s = -0.095$$

↓

- $\langle S_z\rangle_{quarks} = 0.060 \pm 0.047 \pm 0.069$

Fraction of nucleon spin originating from quark spins is only 10 ± .. % !

Also from $\gamma p \to \gamma p$

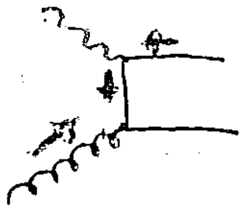
- (strange) sea is polarised antiparallel to proton spin !

? What is origin of proton spin ?

'Spin crisis'

Explanations:

- EMC result wrong (low x problem? $x \to 0$
- Perturbative QCD wrong
- Bjorken S.R. violated
- Isospin breaking $m_d > m_u$
- Higher Twist effect - Drell, Hearn, Gerasimo
- SU(3) not applicable
- $\langle S_z \rangle^p$ dom. angular orbital momentum: Δ
  (Skyrme model)
- Gluon effect
  (Adler, Bell, Jackiw anomaly ; $\partial_\mu A_0^\mu \sim \varepsilon^{\mu\nu\rho\sigma} F_{\mu\nu}$



$$\Delta q = \Delta \tilde{q} \overset{!}{-} \frac{\alpha_s(Q^2)}{2\pi} \Delta g(Q^2)$$

$$\curvearrowright \Delta g \simeq 5 \simeq -\Delta L_g$$

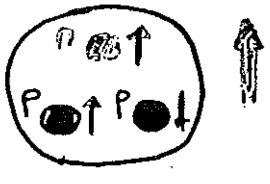
- Small η'-Nucleon coupling
-
-

Whole excitement based on one (badly known) number : $\boxed{\Gamma_1^p}$

⬇

For a better understanding we have to measure <u>x dependence</u> of

- $g_1^p(x)$ (with much better statistical and systematic accuracy than EMC)
- $g_1^n(x)$
  - deuteron $\quad g_1^n(x) = g_1^d(x) - g_1^p(x)$
    ($\mu^d = .974(\mu^p + \mu^n)$)
  - ^3He
    ($\mu^{^3He} = 1.112\mu^n$)



- $g_2^{p,n}(x)$

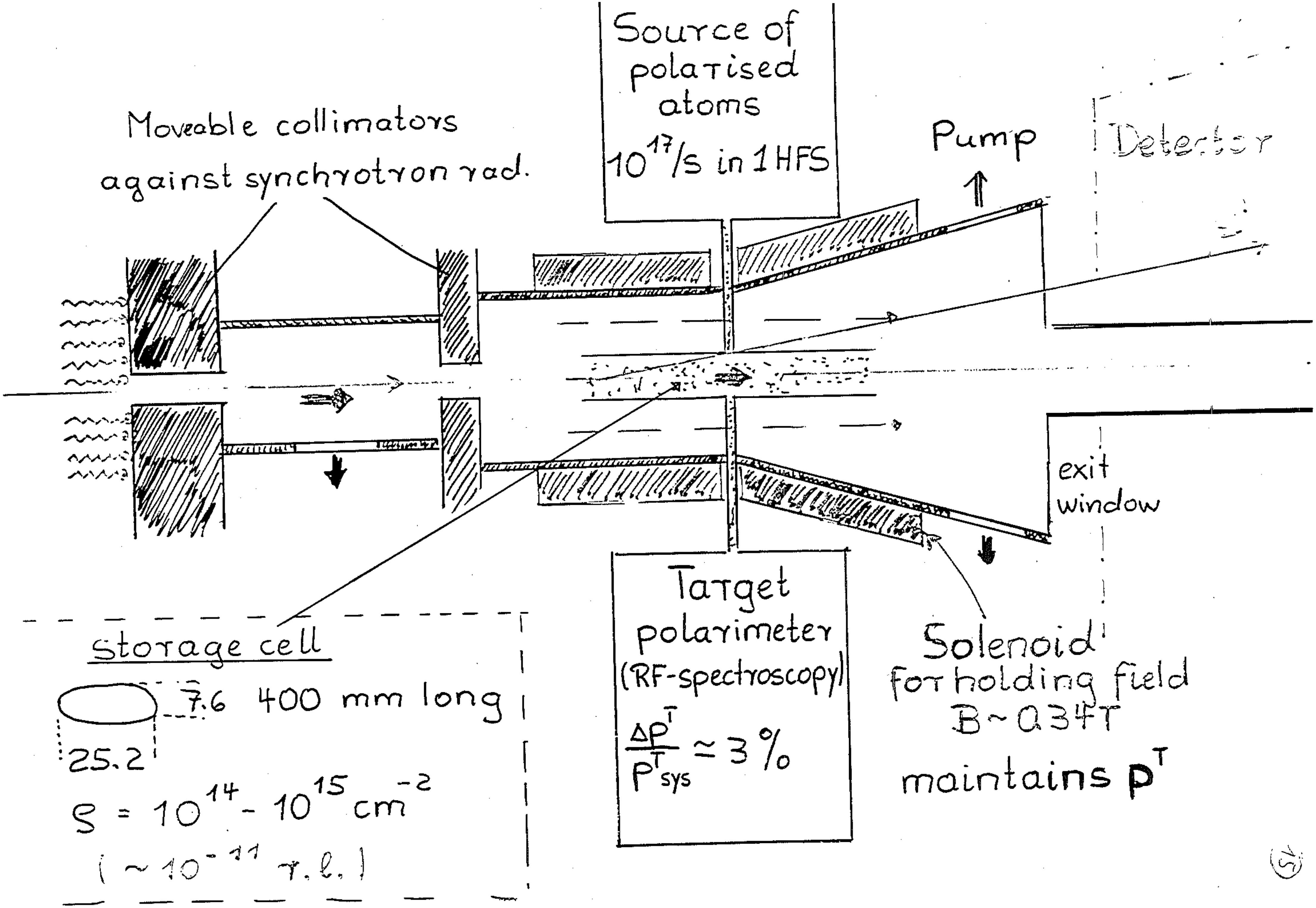
- Stringent test for models
- Determination of pol. quark distr.
- Precise test of Bjorken S.R.

HERMES Proposal

- Use internal gastarget with large fraction f of polarizable nucleons
  ($f^{H} = 1$; $f^{D} = 1$; $f^{^3He} \simeq \frac{1}{3}$)
  $P^T(H) = P^T(D) \simeq 0.8$; $P^T(^3He) \simeq 0.5$
- Produce required target density by thin walled storage cell.
  $\rho = 10^{14}\,cm^{-2}\,(H) \rightarrow 10^{15}\,cm^{-2}\,(^3He)$
- Longitudinally polarised e^- in HERA $\Rightarrow$ $\mathcal{L} = 0.4 - 3 \times 10^{32}\,cm^{-2}s^{-1}$
- Flip targetspin frequently : O(s

⬇

High statistical and systematic accuracy


Moveable collimators
against synchrotron rad.
Source of
polarised
atoms
10^17/s in 1 HFS
Pump
Detector
exit
window
Target
polarimeter
(RF-spectroscopy)
$\frac{\Delta P^T}{P^T}_{sys} \simeq 3\%$
Solenoid
for holding field
B ~ 0.34T
maintains P^T
Storage cell
7.6 400 mm long
25.2
$\varsigma = 10^{14} - 10^{15}\ cm^{-2}$
(~ 10^{-11} r.l.)

beam lifetime

$$(\rho \cdot \ell)_{H\text{-}Target} \simeq 3 \times 10^{-8}\,\text{mbm}\ (N_2\text{-eq}$$

$$\simeq 0.2\,\%\ (\rho \cdot \ell)_{Ring}$$

$$\tau(H\text{-}Target) \simeq 400\,h \gg \tau_{Ring}$$

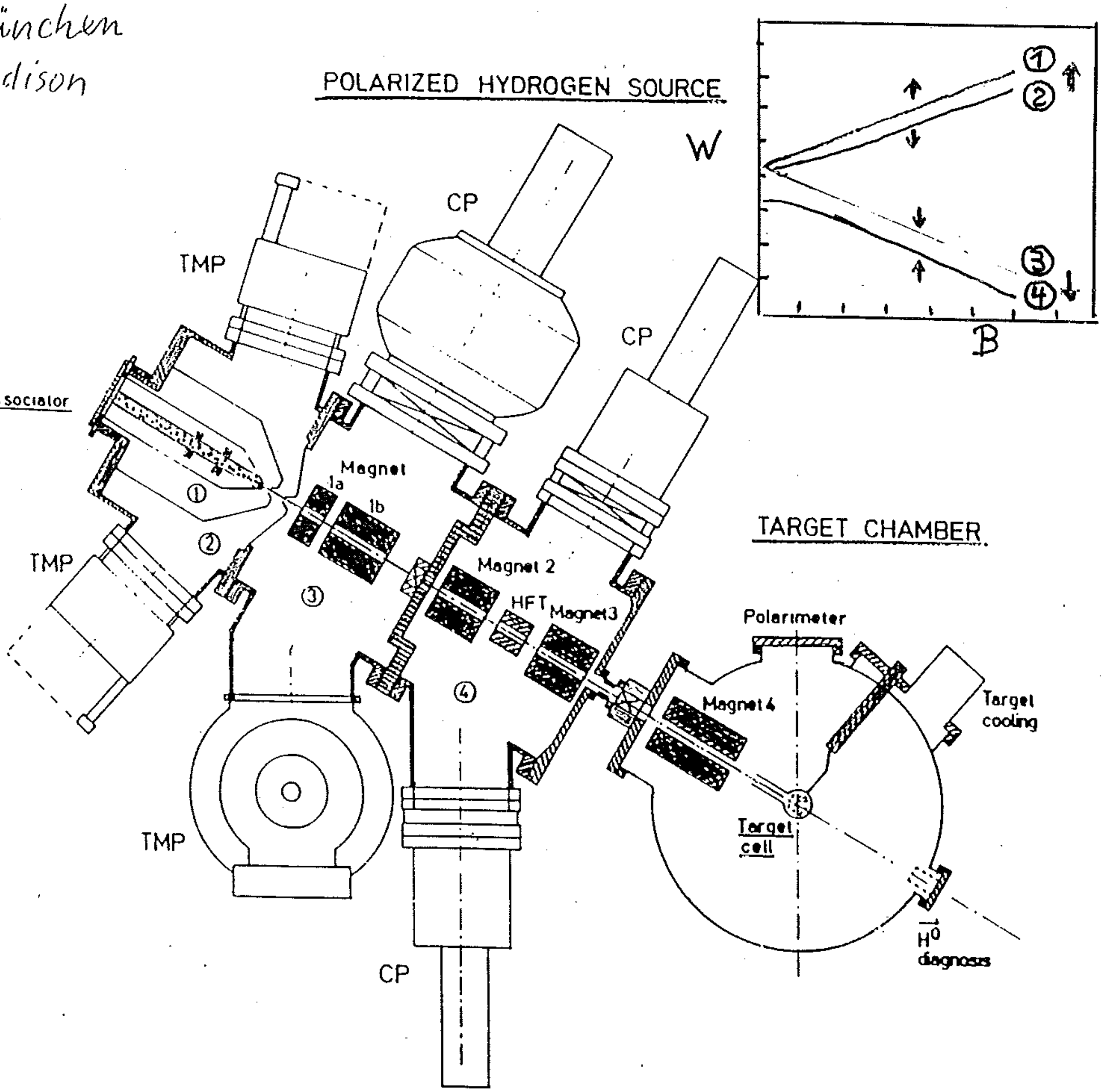
$$\tau(^3He) \simeq 50\,h$$

↷ negligible impact !

Internal polarized hydrogen target

FILTEX (TSR / LEAR)

Heidelberg
Marburg
München
Madison



Source:
- Goal is to produce $10^{17}/s$ in $|m_J\ m_I\rangle = |\frac{1}{2}\ \frac{1}{2}\rangle$
- Gas flow up to 5 mb ℓ/s H_2
- Total H_2 pumping speed $\sim 16\,000\ \ell/s$
  clean vacuum system.
- Sextupole magnets with $B_0 = 1.5\ T$.

Status H/D source

- Source is operational
  (without sextupoles; delivery → 4/90)

- Many systematic studies performed
  - degree of dissociation
  - velocity distribution
  - attenuation at high gas flow

- Present estimate: $> 6.5 \times 10^{16}/s$
  (into acceptance of storage cell)

  (Already factor 2-3 higher than best sou

  Number based on measurements and (very) conservative assumptions

- Several improvements possible
  ↷ $10^{17}\,s^{-1}$ realistic
  (in continuous mod

Target polarisation

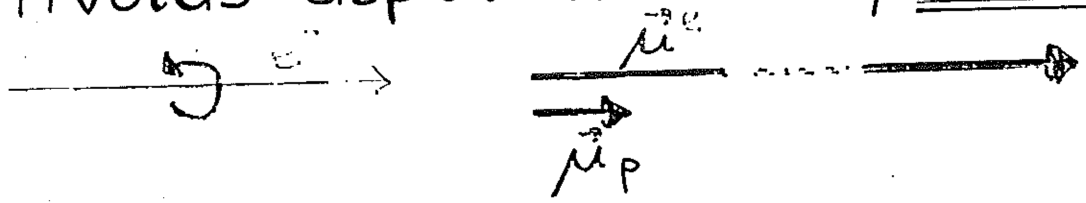
Expect : $\boxed{p^T(H,D) \approx 0.8}$ (From source > .95)

For this we require :

- Magnetic holding field: $B_H \approx .34T$

  Decouples $\vec{\mu}_p, \vec{\mu}_e$

  Avoids depolarisation by **bunch field**



— — — —

Studied in detail by calculations (incl. MC sim.)

— — —

- Coating of cell walls (dryfilm, Al_2O_3 ...)

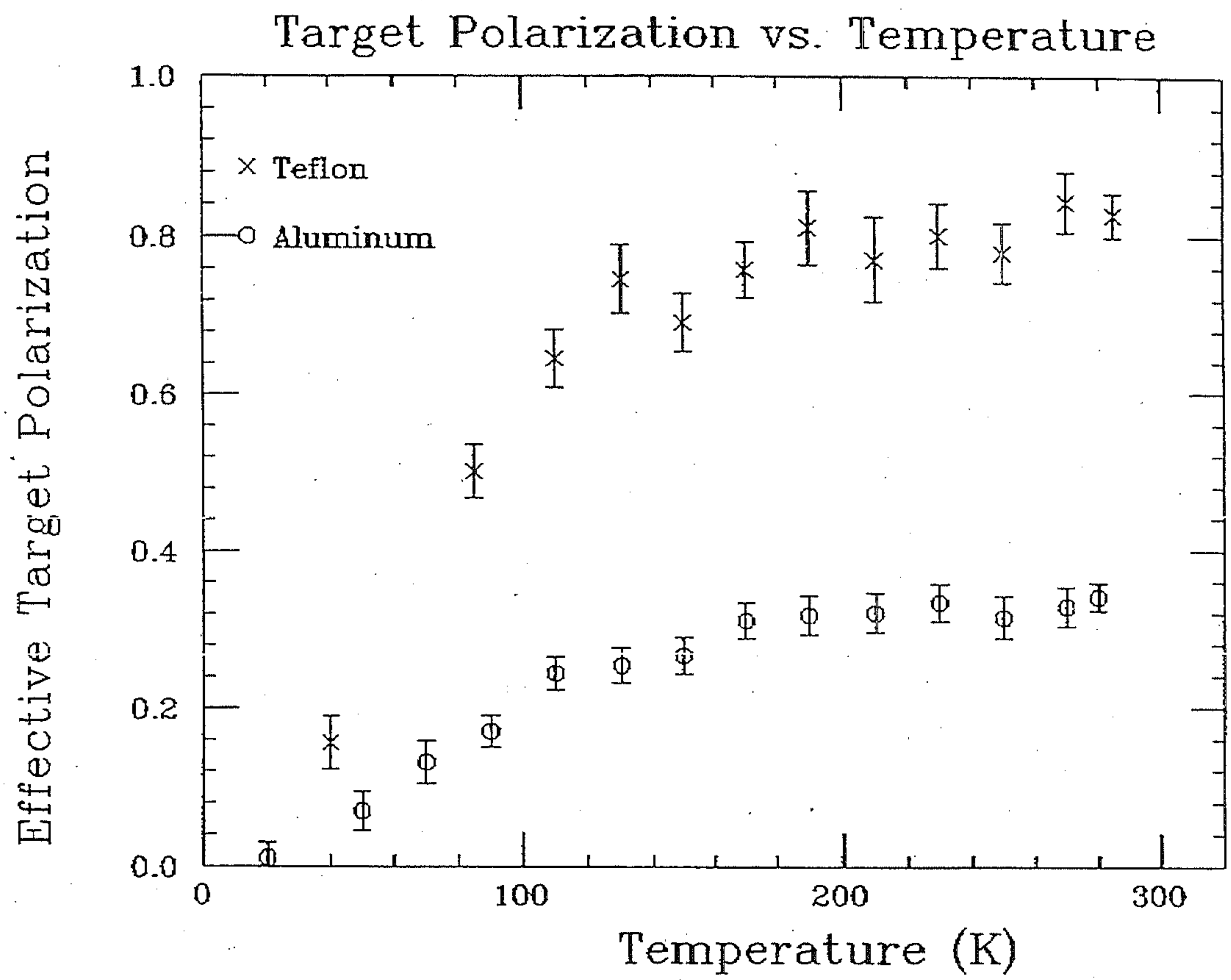
  Avoids depolarisation by **wall bounces**

— — — —

Experimentally investigated at ANL, MPI, Madison

No problems observed with storage cell installed for several months in VEPP-3

ANL - Novosibirsk expt.


Target Polarization vs. Temperature
Teflon
Aluminum
Effective Target Polarization
Temperature (K)
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300

^{3}He - Target (Caltech, MIT)

Method: Optical pumping
+ Metastability exchange

Due to closed e^--shell

↷ much smaller effects on polarisation by bunch field and wall bounces

↷ small holding field sufficient

Routinely achieved polarisation: $P^{^3He} = 0.$

Status:

- Closed cell target operational
- First experiment starts this weekend

Installation in HERA

East Hall : spinrotators already foresee

Require modification of beamline

- Separation between e and p

- Synchrotron radiation

Due to magnet geometry and optics not possible to shield storage cell and detector sufficiently by collimators

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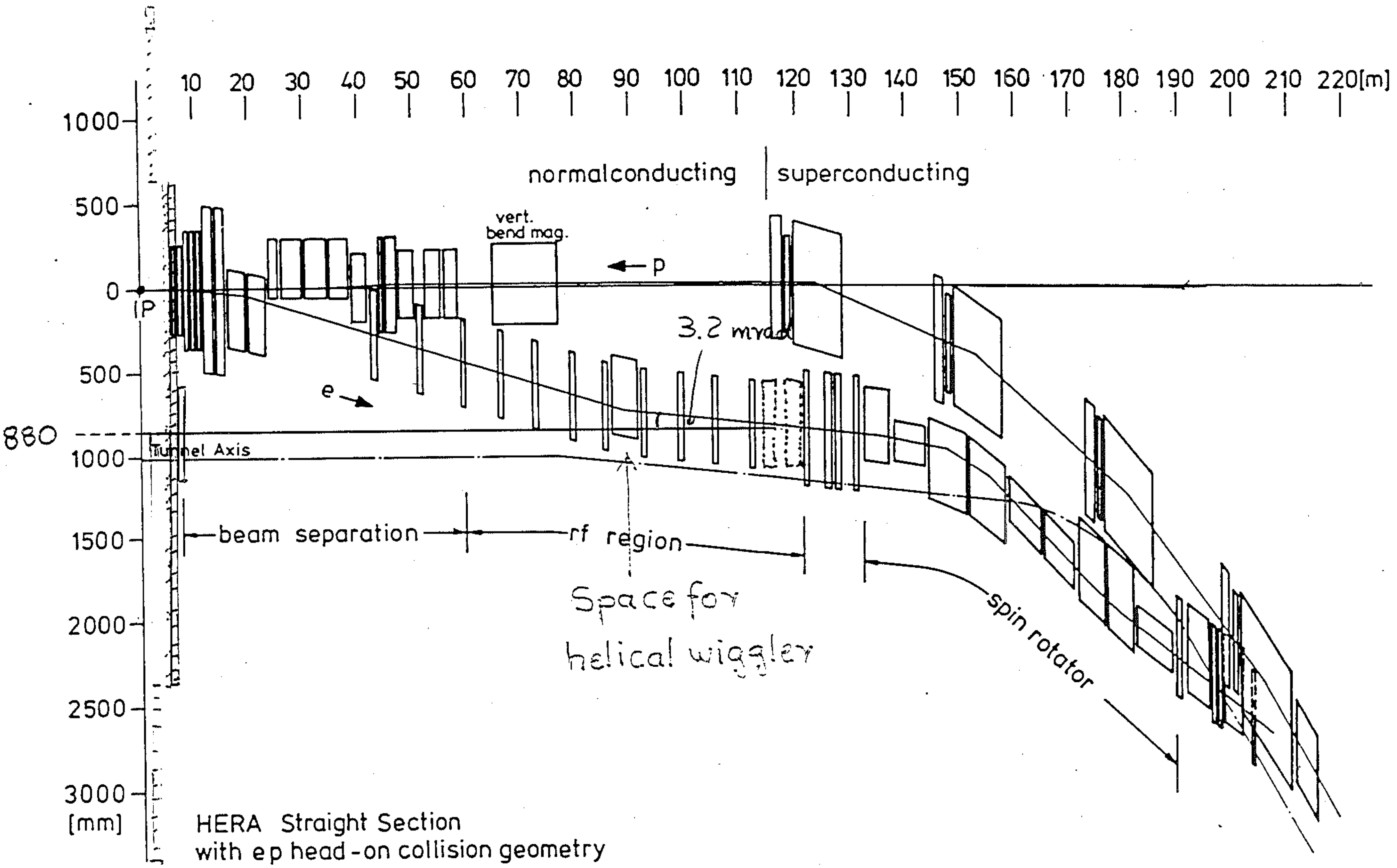
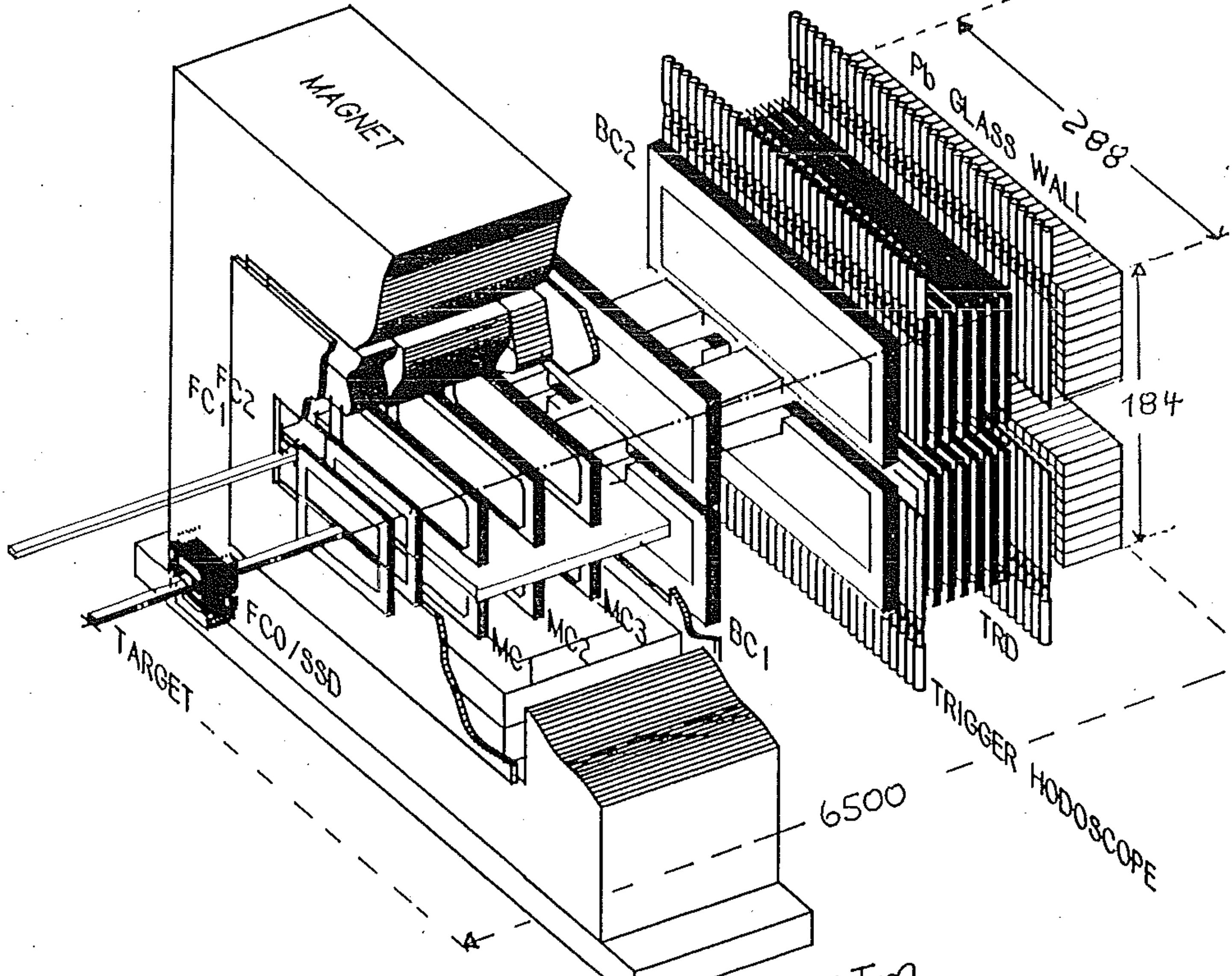
Targetdensity too small by factor ~ 1(



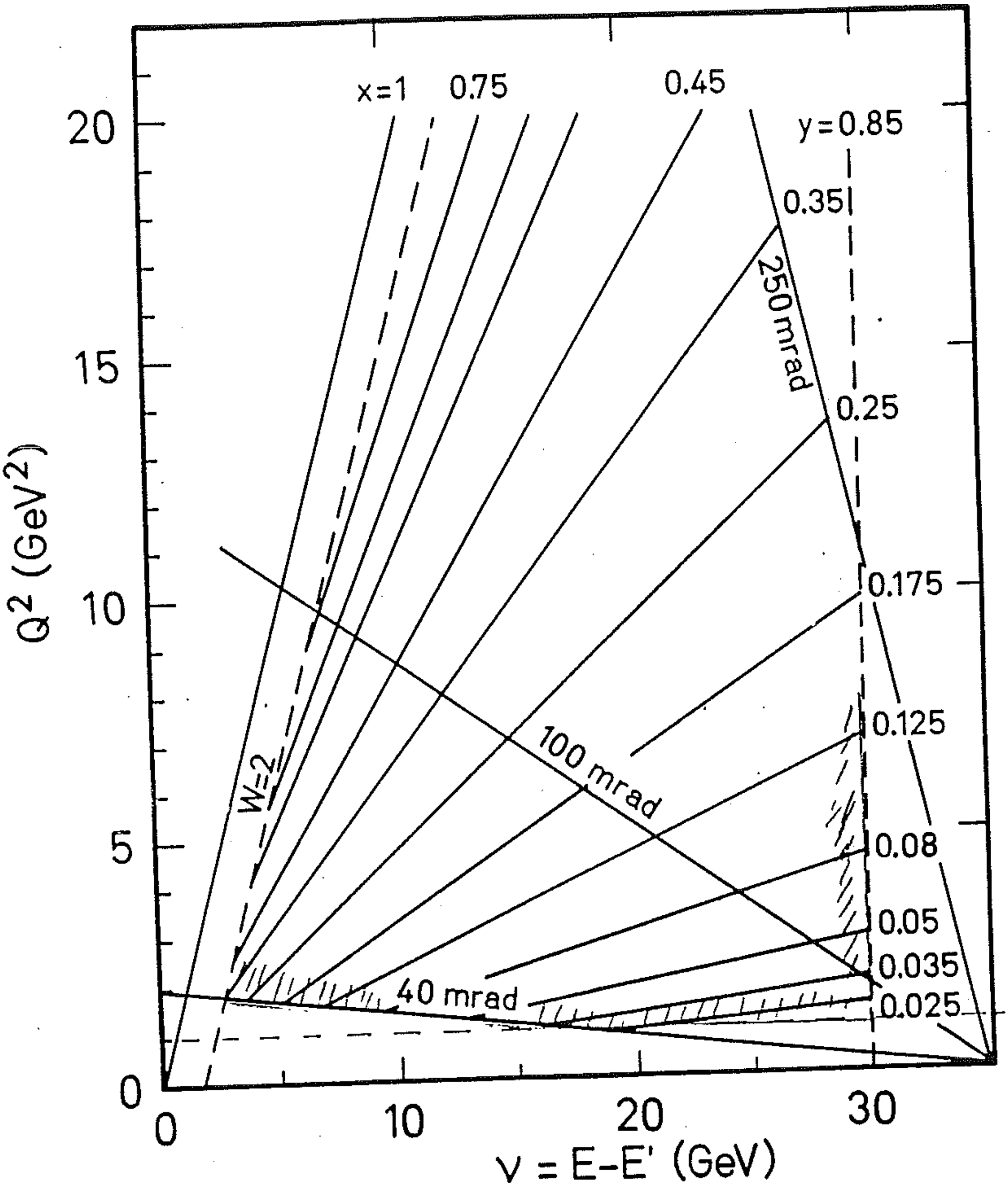
HERA Straight Section
with ep head-on collision geometry
(p-4 α-Lattice)
(e-2 α-Lattice)

HERMES



$\int B\,dl = 1.5\,Tm$

Angular acceptance
$40 < \Theta_e < 250$ mrad



Cuts: $Q^2 > 1\ GeV^2$
$y < 0.85$
$W > 2\ GeV$

$R(^3He) \sim 10.2\ s^{-1}$

Tracking:

Determination of E', θ_e, vertex

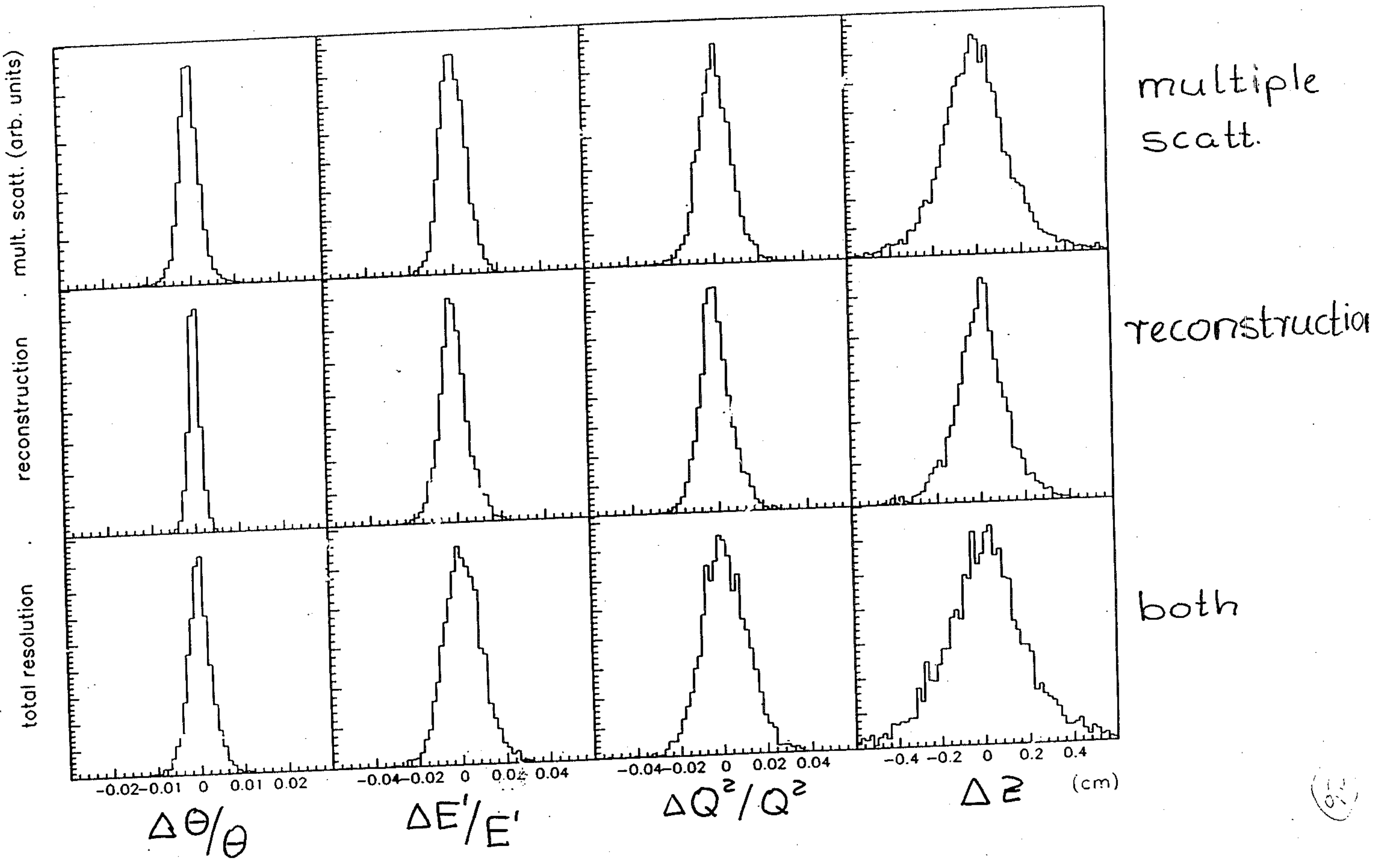
Detector	SSD silicon (TORINO)	FC0 drift (TRIUMF)	FC1-2 drift (MIT)	MC1-3 prop. (ANL)	BC1-4 drift (MPI)
wire spacing (mm)	0.115	4	7	2	10
resolution (mm)	0.05	< 0.2	< 0.2	1	< 0.2

Resolutions dominated by multiple scattering and straggling

$$\frac{\Delta E'}{E'} \sim 0.7 - 1.7\% \;;\; \frac{\Delta Q^2}{Q^2} < 1.5\% \;;\; \frac{\Delta x}{x} \sim 1\text{-}8\%$$

Vertex: $\sigma_z \sim 5\,\text{mm}$

$\sigma_r \sim 0.3\,\text{mm}$



mult. scatt. (arb. units)
reconstruction
total resolution
multiple scatt.
reconstructio
both
-0.02 -0.01 0 0.01 0.02
-0.04 -0.02 0 0.04
-0.04 -0.02 0 0.02 0.04
-0.4 -0.2 0 0.2 0.4
(cm)
ΔΘ/Θ
ΔE'/E'
ΔQ²/Q²
Δz

Calorimeter (Los Alamos, Caltech, Illinois, New Mexi

Purpose:

- Trigger on electrons with $E' > 4.5$ Ge
- Suppress pions

↳ Need good energy resolution

Dimensions (each half): $288 \times 72\ cm^2$

32×8 elements of $9 \times 9 \times 41$ cm

Preferred option: Dense Pb glass (SF57-D

(well understood)

$\frac{\sigma_E}{E} \sim 3.6\%/\sqrt{E} + C\%$ ($C \approx 3\%$)

(Move behind shielding if not data taking)

Alternative: Pb-Scint. fibers

(high radiation resistance: Mrc

New device, further studies need

(this spring)

Pion rejection: Online ~ 20

Offline ~ 300

TRD (TRIUMF / Alberta / Simon Fraser)

6 modules (each half) – length 60 cm ; 70×240 cm^2

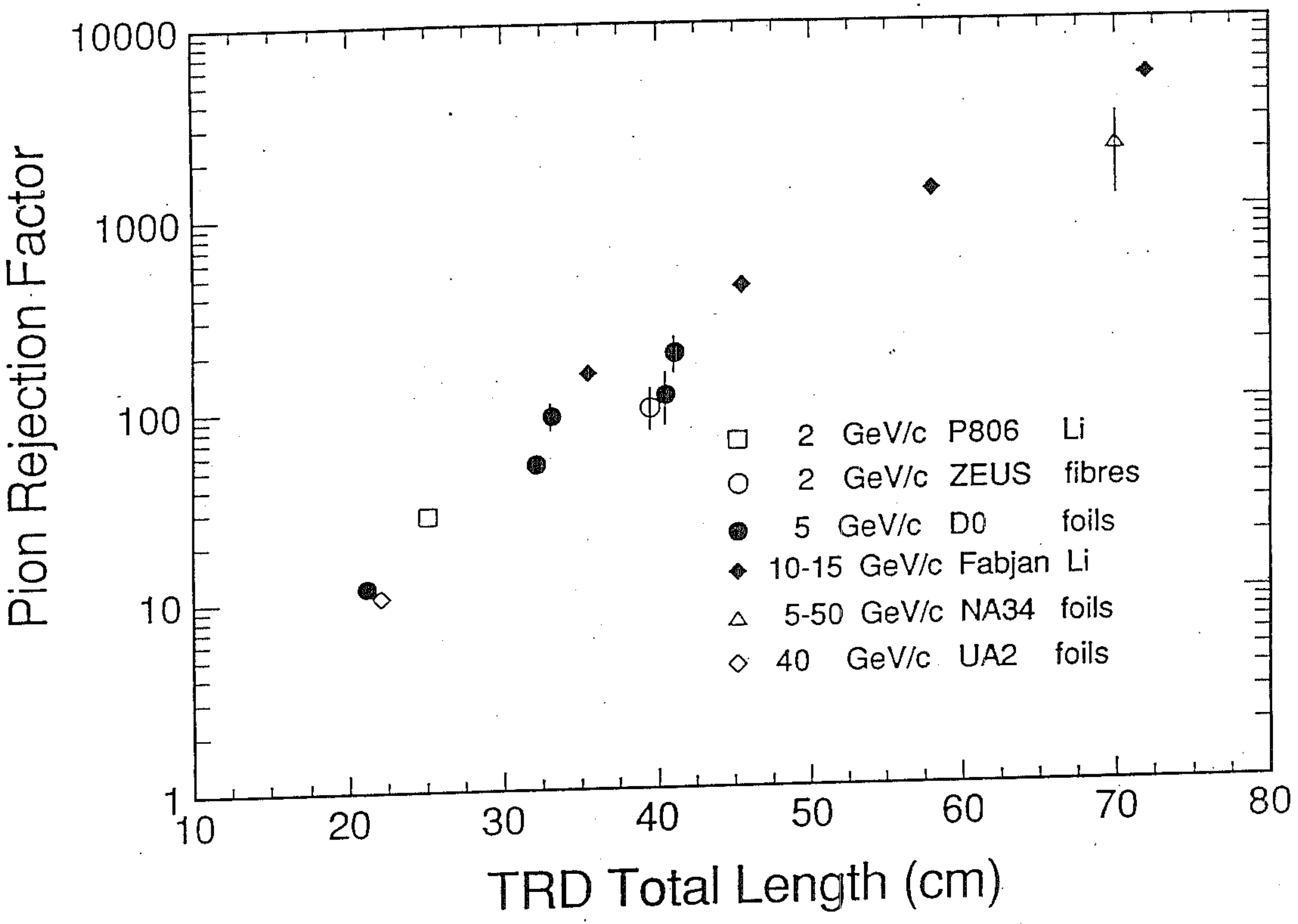
Radiator (6.5 cm) : polypropylene fibers felt ; 20 μm ; ρ = 0.12 g/cm^3
He ; (similar to ZEUS)

X-ray det. (2.5 cm) : cell size : ± 14.3 mm ; vert.
gas : Xe + 10% quench
(recirculate, purify)
Measure total charge (FERA

Option:
Second level trigger : Calorimeter + TRD

- Scan through Calorimeter once
  Look for segment cluster (vert. rows)
- For each cluster scan through TRD ;
  Sum ADC's of appropriate region.

Pion rejection : On-line : 10
Off-line : 100 (Q-likelyhood)


Pion Rejection Factor
10000
1000
100
10
1
10
20
30
40
50
60
70
80
TRD Total Length (cm)
2 GeV/c P806 Li
2 GeV/c ZEUS fibres
5 GeV/c D0 foils
10-15 GeV/c Fabjan Li
5-50 GeV/c NA34 foils
40 GeV/c UA2 foils

Expected trigger rates $R(^3He)$

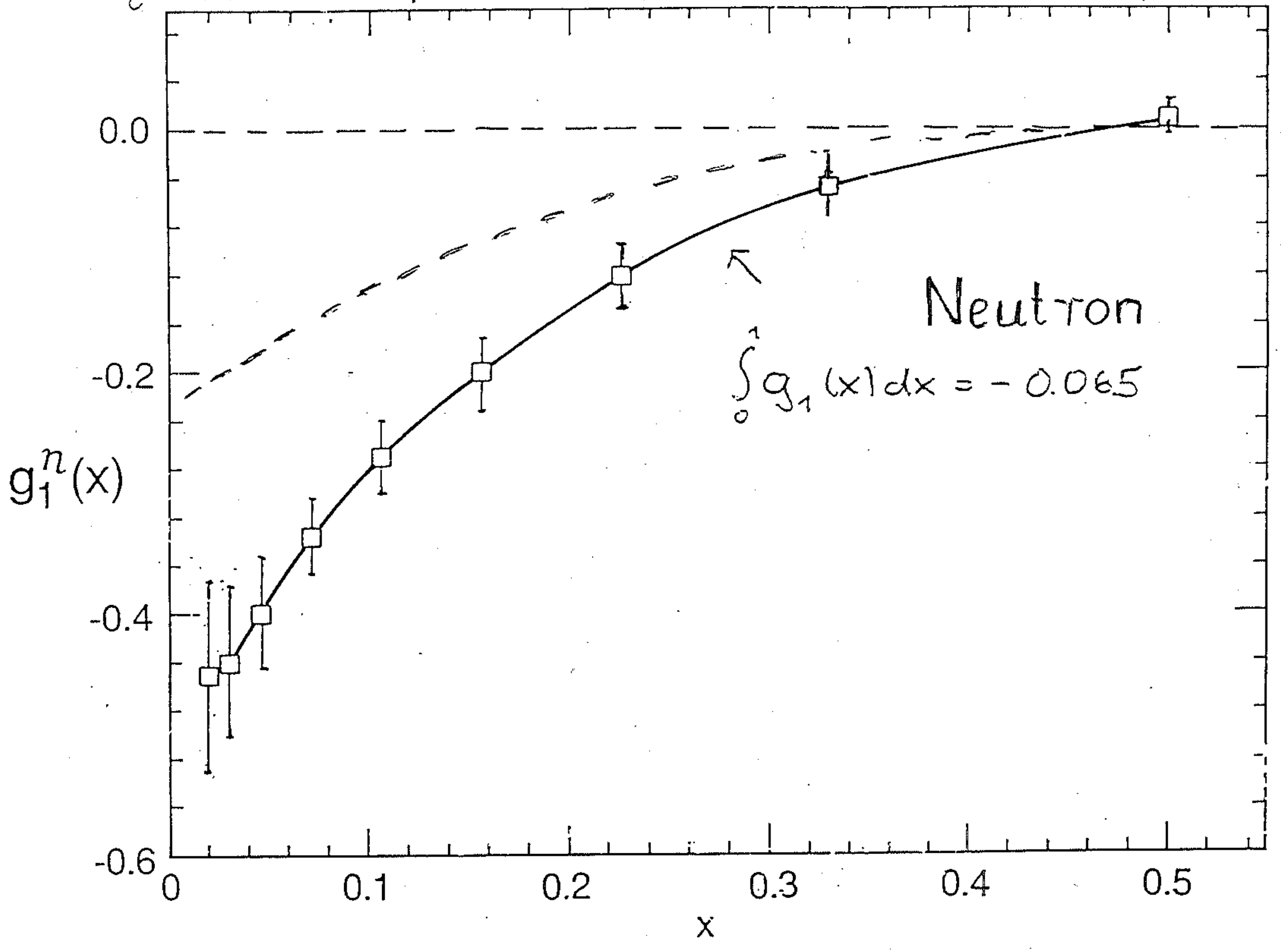
$\mathcal{L} = 3 \times 10^{32}\ cm^{-2} s^{-1}$; $E = 35\ GeV$, $I = 60mA$

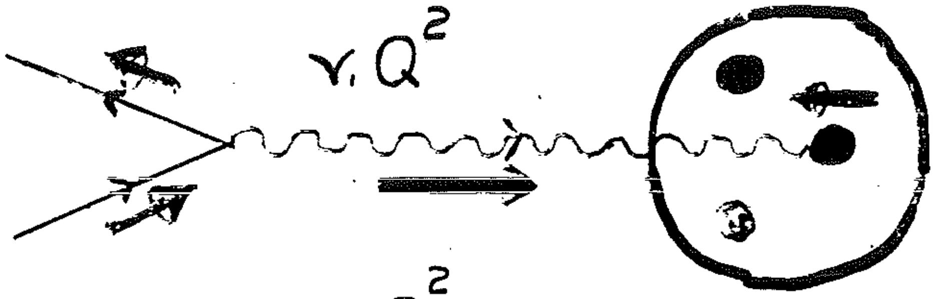
	e DIS + rad.	$\pi^+ + \pi^-$	π^0 $(e^+ + e^-)$	Σ
Flux/s (E > 4.5 GeV)	20	1000	500	
Trig.-1 Calorimeter Hodoscopes	20	50	2	72
Option Trig.-2 + TRD	20	5	2	27
Offline ($Q^2 > 1\ GeV^2$, $y < 0.85$)	10.2	0.003	.4 ↓ $e^+ - e^-$ 0 ± 0.02	10.2

$$R(D) \simeq \frac{1}{4} R(^3He)$$

$$R(H) \simeq \frac{1}{8} R(^3He)$$

HERA { 400 h H, $P^H = 0.8$ + 400 h D, $P^D = 0.8$. $P_B = 0.5$, $Q^2 > 1\,GeV^2$ | μ-CERN: ~20 years

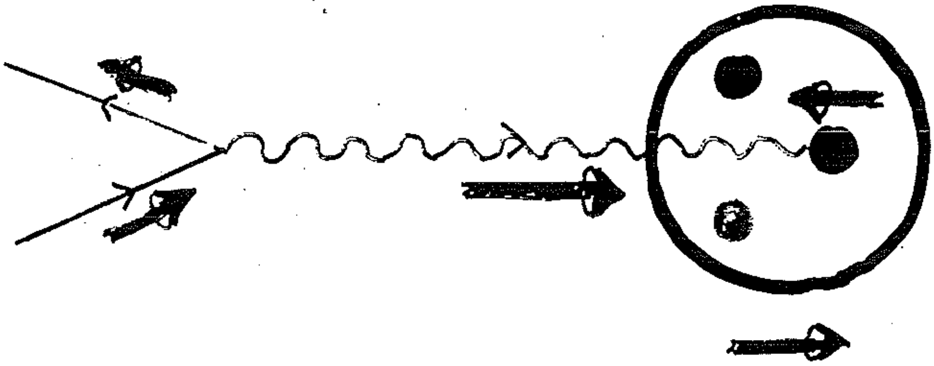




$q^+(x, Q^2)$

$x = \frac{Q^2}{2M\nu}$

$\sigma^{\uparrow\downarrow}(\alpha = \pi)$



$q^-(x, Q^2)$

$\sigma^{\uparrow\uparrow}(\alpha = 0)$

$$\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow} \sim \boxed{g_1(x, Q^2) = \frac{1}{2} \sum_f e_f^2 \{ q^+(x, Q^2) - q^-(x, Q^2) \}}$$

$$\Delta q_f = \int_0^1 \{ q_f^+(x) - q_f^-(x) \} dx$$

$$\Delta q_f \cdot 2M \cdot S_\mu = \langle p, S | \bar{q}_f \gamma_\mu \gamma_5 q_f | p, S \rangle$$

Experimentally: Only $g_1^p(x)$

Anticipated accuracies for Sum Rules

$\mathcal{L}(H) = 3.5 \times 10^{31}\ cm^{-2}s^{-1}$; $p^T(H) = 0.8$

$\mathcal{L}(D) = 7 \times 10^{31}$ " ; $p^T(D) = 0.8$

$\mathcal{L}(^3He) = 30 \times 10^{31}$ " ; $p^T(^3He) = 0.5$

$p^B = 0.5$; $I = 60\ mA$

Main sources for systematic errors:

$\Delta p^B / p^B = 2.5\%$; $\Delta p^T / p^T = \Delta F_2 / F_2 = 3\%$;

$R = \sigma_L / \sigma_T$; rad. corr. ; nuclear effects for ^{3}H

Integr.	value	Target	errors (%) stat.	errors (%) syst
Γ_1^p	0.126	H	2.5	5.2
Γ_1^d	0.061	D	2.5	5.2
Γ_1^n	-0.065	D-H	12	11
"	"	^{3}He	11	7.8
$\Gamma_1^p - \Gamma_1^n$	0.191	2H-D	3.5	6.4
"	"	^{3}He	4.1	4.3

Beam time request

a) Commissioning and checkout of apparatus – parasitically

b) Data taking (in parallel to H1, ZEUS)

6 runs over 2-3 years

Target	Polarisation	Measured quantities
H	→	g_1^p
D	→	g_1^d; g_1^n; $\Gamma_1^p - \Gamma_1^n$; b_1^d
^3He	→	g_1^n; $\Gamma_1^p - \Gamma_1^n$
H	↑	g_2^p
D	↑	g_2^n; Δ^d
^3He	↑	g_2^n

Beam time for anticipated accuracy

$T_{nom} = 400\ h$ (100% eff.)

if: $I = I_{nom} = 60\,mA$; $P^B = P^B_{nom} = 0.5$.

Otherwise: $$T = \frac{I_{nom}}{I} \times \left(\frac{P^B_{nom}}{P^B}\right)^2 \cdot T_{nom}$$

c) If dedicated running would be necessary:

we don't want to give up statistical precision

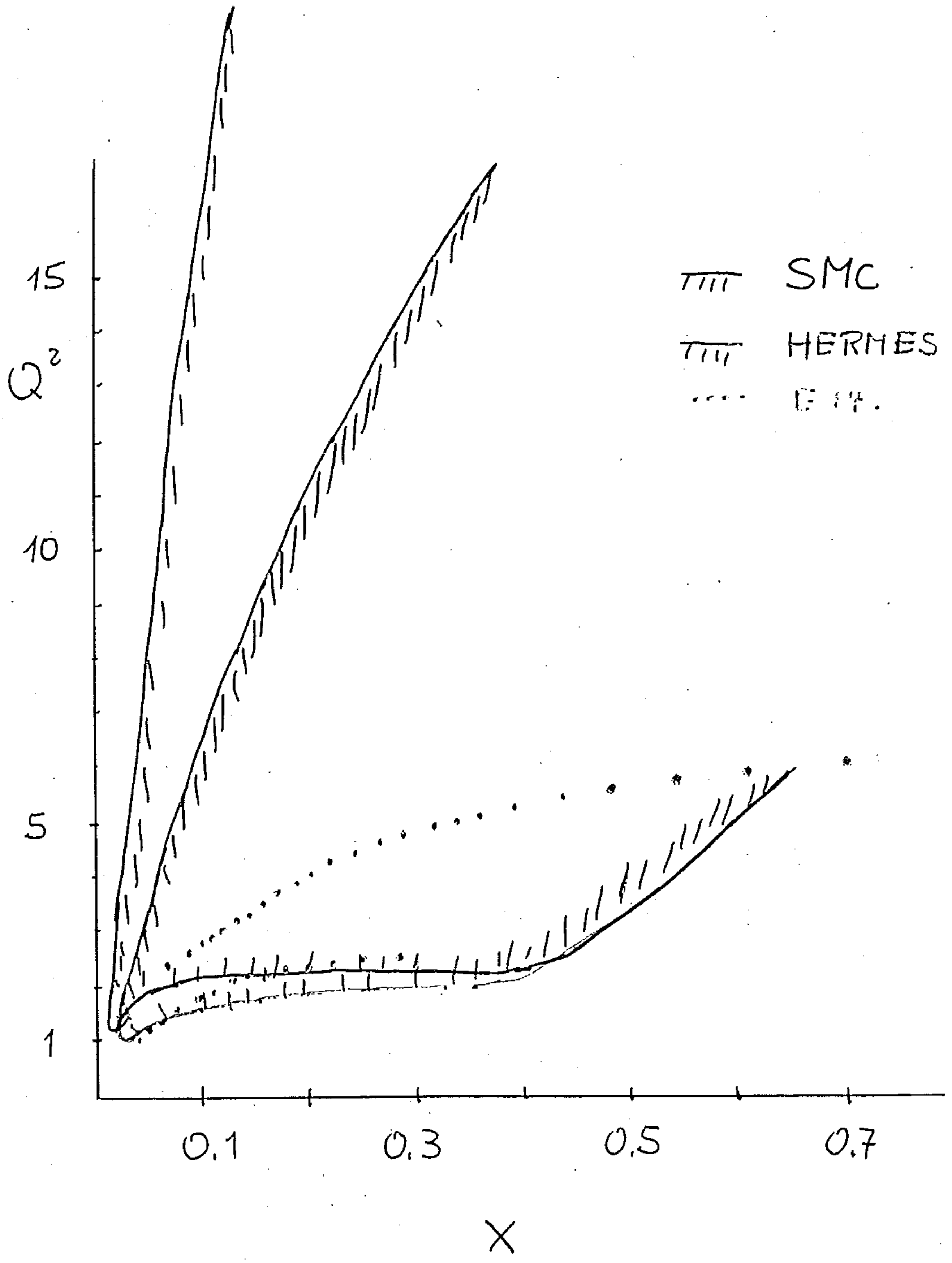
but would be prepared to reduce programme to

4 runs: H$\rightarrow$, D$\rightarrow$, ^{3}He$\rightarrow$

H$\uparrow$

Requests to DESY:

- Modification of beam-line in East
- Moveable platform for detector
- Power supply for magnet
- Shielding of proton beam-line
- Collimator system
- Shielding house for spectrometer
- Compensator for magnetic fields
- General services: electrical, cabling alignment, cooling water..


SMC
HERMES
15
10
5
1
Q²
0.1
0.3
0.5
0.7
X


P.IKTOD
197