Calorimeter Options for Large Acceptance PVDIS Setup

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Outline

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1. Motivation
2. Apparatus
   - Requirements and options
   - Solenoidal Large Intensity Device (SoLID)
3. Calorimeter Options

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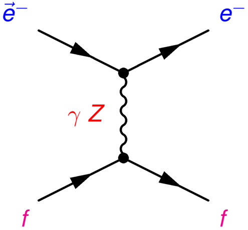
Parity Violation in Electron Scattering at $Q^2 \ll M_Z^2$



Polarized beam on **Unpolarized target**

$$\sigma \propto |A_\gamma + A_{weak}|^2 \sim |A_\gamma|^2 + 2A_\gamma A^*_{weak} + \ldots$$

$$A_{RL} = \frac{\sigma_R - \sigma_L}{\sigma_R - \sigma_L} \sim \frac{A_{weak}}{A_\gamma} \propto \frac{G_F Q^2}{4\pi\alpha}\mathbf{g}$$

$\mathbf{g} = g_A^e G_V^T \pm g_V^e G_A^T$, depend on $\sin^2\theta_W$, kinem.

for $f \equiv l^\pm$ $\mathbf{g} \propto (1 - 4\sin^2\theta_W) < 0.05$

Observable $A \sim 10^{-7} - 10^{-3}$, sensitive to:

- Electroweak coupling: $\Rightarrow$ CM tests
  Magnification: $\sin^2\theta_W \sim 0.23 \Rightarrow \delta(\sin^2\theta_W) \sim 0.02\frac{\delta(A)}{A}$
- Target structure $\Rightarrow$ unusual FF, PDF combinations

PV DIS Asymmetry

$$\mathcal{L}^{eHadron} = \frac{G_F}{\sqrt{2}} \sum_i (C_{1i} \cdot j_A^e \cdot j_V^i + C_{2i} \cdot j_V^e \cdot j_A^i)$$

where i are partons (quarks)

$$C_{1q} = 2g_A^e g_V^i = -C_{1\overline{q}} \approx -t_{3iL} + 2Q_{ei}s_W^2$$
$$C_{2q} = 2g_V^e g_A^i = +C_{2\overline{q}} \approx -t_{3iL}(1-4s_W^2)$$

Cahn,Gilman 1978

$$A_{PV} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}[a(x) + Y(y) \cdot b(x)]$$

$$Y(y) = \frac{1-(1-y)^2}{1+(1-y)^2}, \quad y = \frac{\nu}{E}, \quad x = x_{Bj}$$

$$a(x) = \sum_i f_i(x) C_{1i} Q_{ei} / \sum_i f_i(x) Q_{ei}^2$$
$$b(x) = \sum_i f_i(x) C_{2i} Q_{ei} / \sum_i f_i(x) Q_{ei}^2$$

$f_i(x)$ - quark distribution functions

Isoscaler target

Deuterium: $f(x)$ largely cancel

$q^{\pm} \equiv q \pm \overline{q}$ in proton

$$a(x) = \frac{3}{10}(2C_{1u} - C_{1d})(1 + R_s(x))$$
$$b(x) = \frac{3}{10}(2C_{2u} - C_{2d})(1 - R_a(x))$$

$$\left.\begin{aligned} R_s(x) &= \frac{2s^+}{u^+ + d^+} \\ R_a(x) &= \frac{\overline{u}+\overline{d}}{u^+ + d^+} \end{aligned}\right\} \xrightarrow{large\ x} 0$$

$$A_{PV}(x, Q^2)/Q^2 \xrightarrow{large\ x} \mathcal{A}(y)$$

Corrections from:

- s-quarks, sea-quarks
- target mass
- higher twists

Prescott 1979 $s_W^2 = 0.22 \pm 0.02$ using SM

Measurements of the weak charges C_{1q}, C_{2q}

Existing measurements:

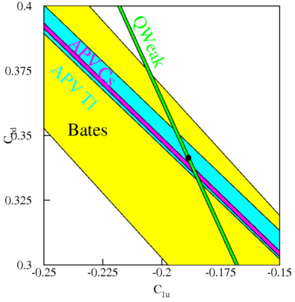
- PV-elastic in $e^- p, d, Be, C$ at Bates, Mainz, JLab
- PV-DIS in $e^- d$, $\mu^{\pm} C$ at SLAC, CERN
- Atomic PV experiments

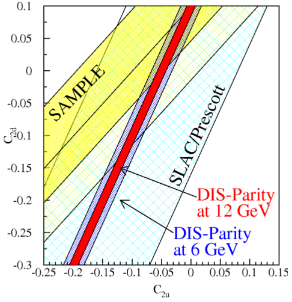
Planned measurements:

- PV-DIS in $e^- d$ at Jlab 6 GeV (Hall A) $x \sim 0.3$
- PV-DIS in $e^- d$ at Jlab 12 GeV (Hall C) $x \sim 0.3$

Remember NUTEV!

Credit to P.Reimer et al





Program of PV DIS Study

Strategy

- Study hadronic physics first
- Use the hadronic results to measure the axial couplings

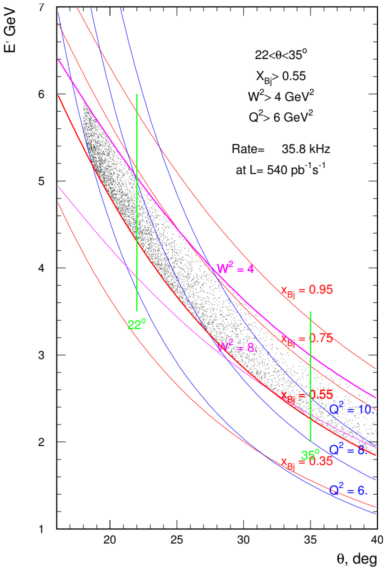
Required precise kinematics and broad range

- Two beam energies: $11, 8.8$ GeV
- Measure A_D in narrow bins of x, Q^2 with 1% precision
- Study the $A_D(Q^2)$ at $0.3 < x < 0.6$ to constrain HT
- Search for CSV with $A_D(x)$ in $0.5 < x < 0.7$
- Use $x > 0.4$, high Q^2, Y data to measure C_{2q}

Requires:

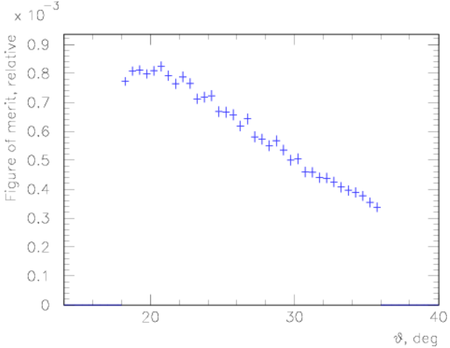
A large acceptance and high rate magnetic spectrometer

DIS Parity Violation at $X > 0.6$ at 12 GeV



Motivation: CSV, d/u, high twists

$A \approx 10^{-4} \cdot Q^2 \sim 0.7 \cdot 10^{-3}$



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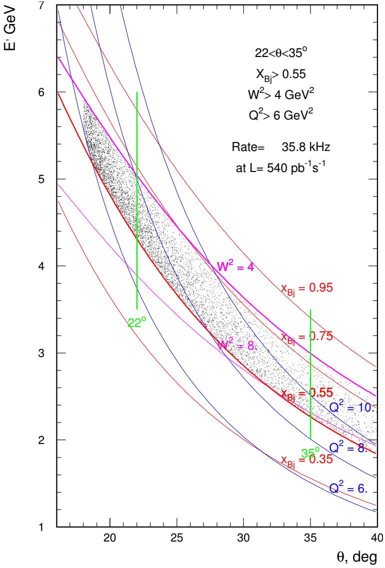

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Kinematics and Rates

- $22^\circ < \theta < 35^\circ$, $W^2 > 4$
- 50 μA, 40 cm LH $0.54\mathrm{fb}^{-1}\mathrm{s}^{-1}$
- Rate 34kHz $X > 0.55$
- Rate 8.7kHz $X > 0.65$

acceptance = 100%, eff=50%

- 1% stat $\Rightarrow 2 \cdot 10^{10}$ events
- $X > 0.55$: 13 days
- $X > 0.65$: 40 days

Other Potential Experiments

Experiments considered at 12 GeV

- SIDIS: transversity, etc. 2 paricles to detect
- $\gamma p \to J/\Psi p$ photoproduction close to threshold
- DVCS $e^- p \to e^- \gamma p, e^- l^+ l^- p,$?

Requirements

Acceptance

- Working at $\mathcal{L} \sim 0.54 \mathrm{fb}^{-1}\mathrm{s}^{-1}$
- $E' > 1.5$ GeV to remove low energy e^-, π^-
- $E' < \infty$ no line of sight, to remove γ
- $\sigma E'/E' < 2\%$ energy resolution
- $\Delta\Omega > 0.3 str$ solid angle
- PID $e/\pi \sim 10^5$
- Trigger rate $<$20 kHz/DAQ

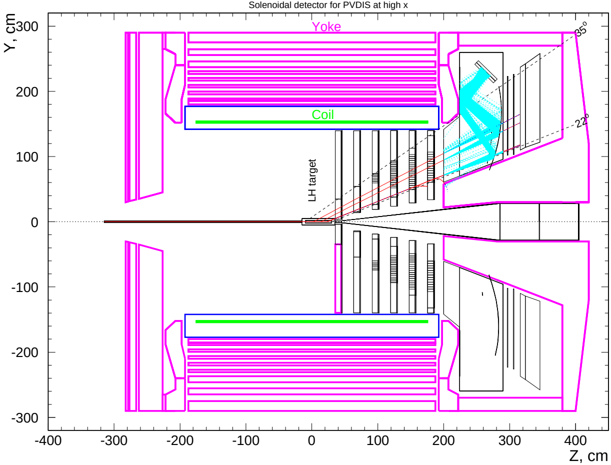
If it were easy - would have been done somewhere

Options

Several options have been considered:

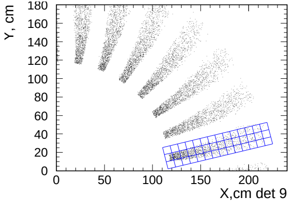
- Large solenoidal spectrometer
  a magnet leased from BaBar/CLEO/CDF...
- Double-todoid spectrometer
- Others - much lower acceptance ...

Solenoidal Large Intensity Detector (SoLID)



BeBar magnet
Altered yoke

Calorimeter
$>$200 krad/year
$50\% \times 15$ m^2 = 7 m^2
pre/shower
Magnetic field
$\sim$0.01 T



EM calorimeters with optical readout

Material	Density g/cm^3	X_0 cm	R_M cm	λ_I cm	Refr. index	τ ns	Peak λ nm	Light yield	$\frac{N_{p.e.}}{GeV}$	rad	$\frac{\sigma E}{E}$
Crystals											
NaI(Tl)**	3.67	2.59	4.5	41.4	1.85	250	410	1.00	10^6	10^2	$1.5\%/E^{1/4}$
CsI *	4.53	1.85	3.8	36.5	1.80	30	420	0.05	10^4	10^4	$2.0\%/E^{1/2}$
CsI(Tl)*	4.53	1.85	3.8	36.5	1.80	1200	550	0.40	10^6	10^3	$1.5\%/E^{1/2}$
BGO	7.13	1.12	2.4	22.0	2.20	300	480	0.15	10^5	10^3	$2.\%/E^{1/2}$
$PbWO_4$	8.28	0.89	2.2	22.4	2.30	5/39%	420	0.013	10^4	10^6	$2.0\%/E^{1/2}$
						15/60%	440				
						100/01%					
LSO	7.40	1.14	2.3		1.81	40	440	0.7	10^6	10^6	$1.5\%/E^{1/2}$
PbF_2	7.77	0.93	2.2		1.82	Cher	Cher	0.001	10^3	10^6	$3.5\%/E^{1/2}$
Lead glass											
TF1	3.86	2.74	4.7		1.647	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF-5	4.08	2.54	4.3	21.4	1.673	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
SF57	5.51	1.54	2.6		1.89	Cher	Cher	0.001	10^3	10^3	$5.0\%/E^{1/2}$
Sampling: lead/scintillator											
SPACAL	5.0	1.6				5	425	0.3	10^4	10^6	$6.0\%/E^{1/2}$
Shashlik	5.0	1.6				5	425	0.3	10^3	10^6	$10.\%/E^{1/2}$

$*$ - hygroscopic

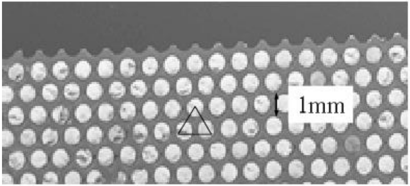
Energy resolution

- Fluctuations of the track length (EM): $\frac{\sigma E}{E} \simeq \frac{0.005}{\sqrt{E}}$
- Sampling fluctuations (EM): $\frac{\sigma E}{E} \simeq \frac{\sqrt{E_c \cdot t}}{\sqrt{E}}$, where t is the layer thickness in X_0 (B.Rossi),
  $\sim \frac{0.1 \cdot \sqrt{t}}{\sqrt{E}}$ for lead absorber ($t > 0.2$) $> \frac{0.05}{\sqrt{E}}$
- Statistics of the observed signal (EM): $\frac{\sigma E}{E} > \frac{0.01}{\sqrt{E}}$
- Noise, pedestal fluctuations $\frac{\sigma E}{E} < \frac{0.01}{E}$
- Calibration drifts $\frac{\sigma E}{E} \sim 0.01$ for a large detector

Ideally, a large sampling calorimeter may have $\frac{\sigma E}{E} \simeq \frac{0.05}{\sqrt{E}} \oplus 0.01$

SpaCal (CERN, Frascatti, Hall D)

scintillating fibers / lead matrix



- Volume: Fiber/Pb/glue 48%/42%/10%
- $X_\circ = 1.2$ cm
- 5 g/cm^3

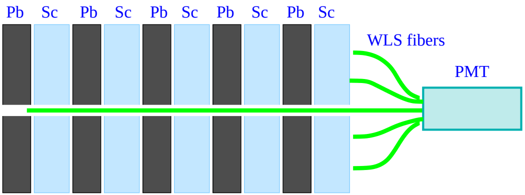
- CERN - original R&D
- KLOE (DAFNE) - 5000 PMTs
- KLOE $\sigma E/E \approx 5.7\%/E^{1/2}$
- KLOE $\sigma\tau \approx 50/E^{1/2} + 50$ ps

Critical for this resolution:

- uniformity
- fibers collected to the Ph.Det.
- Ph.Det. surface: 50%
  PMTs only? Mag. field?

Shashlyk Calorimeter

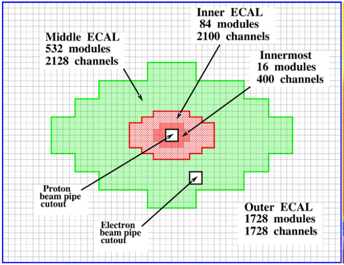
- Pb + scintillator sandwitch
- WLS fibers to the Ph.Det.
- Ph.Det. surface $\sim$ 1%

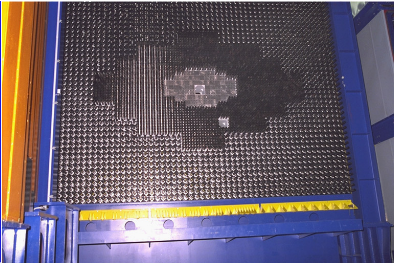


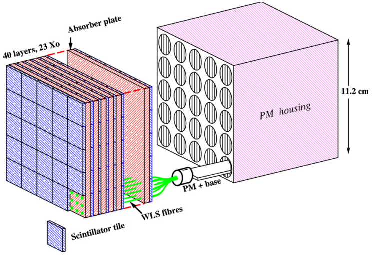
- HERA-B: PMTs
  $\frac{\sigma E}{E} \simeq \frac{0.12}{\sqrt{E}} \oplus 0.014$
- KOPIO: APDs
  $\frac{\sigma E}{E} \simeq \frac{0.03}{\sqrt{E}} \oplus 0.020$

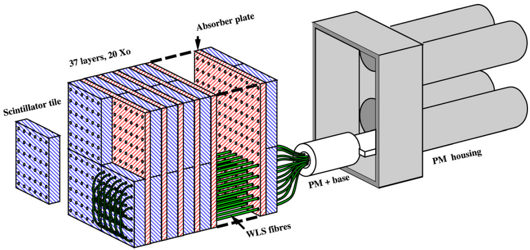
HERA-B Calorimeter

NIMA 580, 1209 (2007)





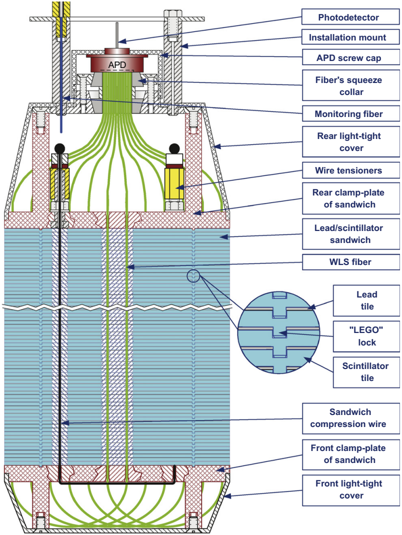




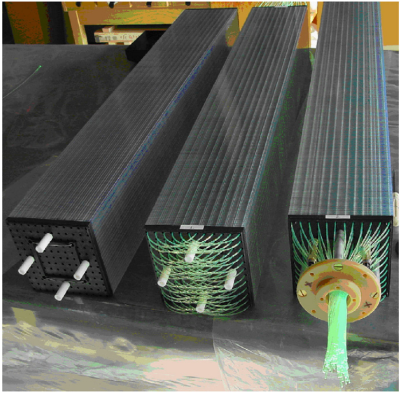
HERA-B Calorimeter (continue)

Parameter	Inner	Middle	Outer
Channels	2100	2128	1728
Cell size	2.23 cm	5.59 cm	11.18 cm
Absorber	W-Ni-Fe	Pb	Pb
$X_\circ$	0.558 cm	1.675 cm	1.675 cm
Moliere	1.24 cm	4.15 cm	4.15 cm
Depth in $X_\circ$	23	20	20
Volume Abs/Sc	2.2:1	1:2	1:2
WLS	Kuraray Y-11	BCF-91A	BCF-91A
p.e./GeV	130	800	1300
krad/year	5000	400	100
$\frac{\sigma E}{E}$	$\frac{0.21}{\sqrt{E}} \oplus 0.012$	$\frac{0.12}{\sqrt{E}} \oplus 0.014$	$\frac{0.11}{\sqrt{E}} \oplus 0.014$
$\sigma X, Y$ cm	$\frac{1.25}{\sqrt{E}} \oplus 0.022$	$\frac{1.37}{\sqrt{E}} \oplus 0.028$	$\frac{2.17}{\sqrt{E}} \oplus 0.028$

KOPIO Calorimeter



NIMA 584, 291 (2008)



KOPIO Calorimeter (continue)

Cell size	11 cm
Absorber	Pb 0.275 mm × 300
Scintillator	BASF143E 1.5 mm
Hole	1.3 mm
Fiber	1.0 mm Y11-200 MS
Fibers/module	72×1.5 m
Fibers bunch OD	1.4 cm
$X_\circ$	3.49 cm
Moliere	5.98 cm
Density	2.75 g/cm^3
Depth in $X_\circ$	16
Total depth	65 cm
krad	100
APD	API OD=16 mm QE=94%
p.e./GeV	60000
$\frac{\sigma E}{E}$	$\frac{0.028}{\sqrt{E}} \oplus 0.020$
σt, ps	$\frac{72}{\sqrt{E}} \oplus \frac{14}{E}$

Jefferson Lab