Transparencies of Talk given at the 2nd Topical Seminar on Perspectives for Experimental Apparatus at Future High Energy Machines

E. Malamud
5/23/86
Institut de Physique Nucléaire
Université de Lausanne

SÉMINAIRE DE PHYSIQUE NUCLEAIRE

23 Mai 1986 à 16h00
Salle BSP 626

Compte rendu de la conférence de Miniato 1986

2nd TOPICAL SEMINAR on PERSPECTIVES for EXPERIMENTAL APPARATUS at
FUTURE HIGH ENERGY MACHINES

Prof. Ernest Malamud
Université de Lausanne
2nd TOPICAL SEMINAR on

PERSPECTIVES FOR EXPERIMENTAL APPARATUS
at FUTURE HIGH ENERGY MACHINES
San Miniato, Italy  May 5-9, 1986

≤ 75 physicists / 10 countries
≤ 25 industry representatives / 16 companies
~ 100 participants

48 talks
2 round table discussions
  • calorimetry
  • HEP ↔ Industry
  1 parallel session

≤ ≈ 30 h.

- CALORIMETRY
- CENTRAL VERTEX DETECTORS
- Non-accelerators
- Status of new accelerators
- Particle identification at super high energy
- Trans Rad
- Summary, Miscell.
• At the conference various applications were discussed:
  • Non-accelerator (e.g. ICARUS)
  • Fixed target (e.g. HELIOS)
  • Colliders

• Detectors for colliders all have a similar configuration:

...important parameters
  • size
  • time structure
  ...influence design of inner layers

...Diagram:

- Interaction Region
- Microvertex
  - Ap
  - Flavor
  - Silicon, Drift
- Charged particle tracking
  - DWF, MuPC's
- Particle Identification
  - TRD, RICH
- Magnet (or) NonMagnet
- Calorimetry
  - EM
  - Had
- Muons

• For most of the major collider detectors there was a report on at least one portion of the detector.

• Copies of transparencies from a few talks and some commercial brochures available.
SPS Collider $\frac{P}{315} \xrightarrow{215} \frac{P}{3 \times 10^{29}} \frac{3 \times 10^{30}}{(ACOL)}$

UA1

UA2

Tevatron I $\frac{P}{900} \xrightarrow{800} \frac{P}{(1000)_{(1000)}}$

$\frac{H}{\text{TEST}} \frac{1}{\geq 10^{30}}$

CDF

DØ

SLC $\frac{e^{-}}{50} \xrightarrow{e^{+}} \frac{50}{50}$

Mark II

SLD

LEP $\frac{e^{-}}{50} \xrightarrow{e^{+}} \frac{50}{50}$

L3

DELPHI

OPAL

ALEPH

HERA $\frac{P}{820} \xrightarrow{30\ (38)} \frac{e^{-}}{1.5 \times 10^{31}}$

H1

ZEUS

$\frac{?}{SSC} \frac{?}{20000} \xrightarrow{20000} \frac{?}{(250 \times 10^{6})}$

$\frac{?}{LHC} \xrightarrow{?} \frac{?}{6000} \xrightarrow{6000}$

$\frac{?}{COLLIDING\ LINACS} \xrightarrow{e^{-}} \frac{e^{+}}{1000} \xrightarrow{1000}$

$10^{32}-10^{33}$
PLAN FOR SEMINAR.

1 - CALORIMETRY
   Rather general remarks

2 - VERTEX/CENTRAL DETECTORS

3 - SILICON STRIP DETECTORS
   (based on excellent review talk by
    P. Horisberger, CERN)

4 - PARTICLE IDENTIFICATION AT
    SSC ENERGIES

5 - NON-ACCELERATOR PHYSICS
   "Review of review talks"
   • J. Emmein, Saclay
   • E. Fiorini, Milan
1. **CALORIMETRY**

Some obvious remarks on the importance of calorimetry:

1. *Energy (momentum) measurement.*

   - Magnet + Chambers \( \frac{\Delta p}{p} = k_1 p \) [gives sign]
   - Calorimeter \( \Delta E/E = k_2 / \varepsilon^{1/2} \)

   These are equal at \( p = E = (k_2 / k_1)^{2/3} \)

   Generally 50 - 100 GeV

2. Calorimeters dominate all of the new large detectors and generally represent > 50% of cost

3. There are 5 "elementary" particles to detect at very high energy:
   - \( \nu \)
   - \( e \)
   - \( \nu \rightarrow \text{missing } p_t \)
   - quarks \( \rightarrow \text{Jets} \rightarrow e/\pi = 1.000 \)
   - \( \mu \)
In general, a calorimeter consists of alternating layers of

Passive material
Active material - readout medium

In separate talks various calorimeters were described having different combinations:

<table>
<thead>
<tr>
<th>Passive</th>
<th>Active (Sampling)</th>
<th>Combined Passive, active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>Scintillator - PM</td>
<td>BGO</td>
</tr>
<tr>
<td>Copper</td>
<td>Scintillator - PD</td>
<td>Lead-glass tube</td>
</tr>
<tr>
<td>Uranium</td>
<td>Silicon</td>
<td>(liquid Ar (SSe)</td>
</tr>
<tr>
<td></td>
<td>liquid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Room temp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TMS, TMP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Plastic fibers)</td>
<td></td>
</tr>
</tbody>
</table>

and their relative advantages and disadvantages were discussed in terms of:
- Performance. Energy, spatial resolution ($\pm$, L)
- Compactness, Hermeticity ($\nu$'s)
- Cost, ease of construction
- Control of systematic errors
- Radiation resistance
Silicon calorimetry

Application: EM calorimetry
- low noise $\rightarrow$ can use for low E
- E linearity 47 MeV/GeV
- Fast $\leq$ 10 ns for 300 μm thick
- Compact, geometry flexible
- Low voltage
- active layer thin $\rightarrow$ poor E-resolution $0.17 - 0.20 \sqrt{E}$
- expensive

\[
\begin{array}{ccc}
W & \text{CERN-SICAPo} & \frac{t(\text{active})}{\mu} \\
? & \text{ICRR Tokyo} & 70,200 \text{ Pb} \\
U & \text{ICR - Hamburg \, \, \, ZEUS} & 1000 \text{ (Li-dr) FD} \\
Pb & \text{Hamburg \, H1 phy} & 200 \text{ surf. barrier FD} \\
\end{array}
\]

$A \, (cm^2)$

25

38

530
Physics aspects of high resolution calorimetry

Talk by R. Wigmans, CERN.

\[ \sigma \left( \frac{\Delta E}{E} \right) = a + \frac{b}{E^{1/2}} \]

OFFSET TERM DOMINATES AT HIGH ENERGY.

\( a = 0 \) if \( e/\pi = 1.000 \) \((b = 0.3 \text{ to } 0.5)\)

This can be demonstrated by looking in detail at the equations for longitudinal shower development.

\[ a \]

\[ e/\pi \]

In a general calorimeter \( e/\pi \neq 1 \).

How to make \( e/\pi = 1 \)?

Passive material - Uranium - Fission
Lead - spallation products

\[ \rightarrow \text{neutrons} \]

Active material - if there are free p's

\[ \rightarrow \text{np elastic scattering} \]

\[ \text{large } \sigma \text{ at low } E \]

Free protons

1. Scintillator
2. in TMS, TMP
3. add CH₄ to Ar

(1) less n-induced fission
(2) n captured close to point

non-sampling of production
Wigams has studied shower processes (especially the crucial part < 1 MeV) by neutron activation.

He cuts up his calorimeter in pieces and determines the E/L distribution of different isotopes.

For any given combination of passive/active (free p)
he can "tune" E/π to 1.000 by adjusting tp, ta

Round table discussion
What is the ultimate achievable resolution?

Passive. U.
Intrinsic spread in binding E \sim \sqrt{E/\Delta E} \sim 0.18/\sqrt{E}
Sampling \sim 0.18/\sqrt{E}

Active. Free p \rightarrow E/\pi = 1.000.
Suppose E > 1 TeV?
\sigma (\Delta E/E) \leq 1 \%

Systematics may limit any further gain
- Stability - ion chamber better (but slower)
- Radiation damage
- Calibration, monitoring in a large system
2. VERTEX/CENTRAL DETECTORS

SOME FACTORS INFLUENCING DESIGN:

(1) Size of interaction region

\[ \sigma_x \sim \sigma_y \sim \sigma_z \]

SLC \quad 1-2 \ \mu m

SSC \quad 5 \ \mu m \quad + \ cm.

Tevatron I \quad \geq 60 \ \mu m \quad + 10 \ \text{cm.}

(2) Accelerator time structure

Several \( 10^4 \) analog channels \( \rightarrow \) power dissipation in readout electronics

time between crossings

SLC \quad 5556 \ \mu \text{sec.} \ (180 \ 	ext{pps})

LEP \quad 22 \ \rightarrow \ 11 \ \mu \text{sec.}

Tevatron I \quad 6.9 \ \rightarrow \ 1.2 (?)

SPS-ACOL \quad 3.8 \ \mu \text{sec.}

SSC \quad > 13 \ \mu \text{sec}

(3) Beam pickup:

e.g. TeV I \quad \rightarrow \quad 10^{12} \text{protons} \quad \land \quad I_{pk} = 160 \ \text{a.}

1 \text{ns bunch}

UAI \quad \rightarrow \quad 10^{11} \text{protons}

\[ \text{p.m. 4 mv} \quad \text{signal 5 mv} \]

Carbon fibre vacuum

Aluminised

Successful operation of Si-strip detectors in vacuum

Tevatron (DSSA) small angle scattering.

beam \ \sum \ \text{Det.} \ \rightarrow

\text{RF shield}

(4) Total \( L \). At \( 3 \times 10^{30} \) (ACOL) \quad 2 \times 10^{6} \text{cCompound part.-/sec.}
Selections from 3 interesting talks:

1. The UA1 Central Detector at Present and Future Luminosities. V. Vuillemin, CERN.
   - An "old" detector running into trouble as \( \mathcal{L} \) is raised.

2. The Spiral Projection Chamber. U. Grestaldi
   - "ASTERIX" at LEAR
   - "OBELIX" at LEAR
   - \( p\bar{p} \) GAS JET EXPERIMENT IN FERMILAB ACCUMULATOR

   Talk at IPN-Lausanne by
   John Peoples, E-760 (Tevatron I project manager) JUNE 4 (Wednesday)
   - Similar geometry at DØ, SLD (?) ... etc.

3. High Resolution Particle Tracking in Scintillating Glass Fiber Trackers. J. Knobly, CERN
   - compare to Plastic Fibers (UA2 upgrade)
   - besides application as trackers, fibers might be used in calorimetry
Due to long electron drift paths and high gas gain \(10^5\), UA1 will face 2 major problems:

1. Track distortions due to space charge, caused by +ve ions.
   Main problem is in large horizontal gaps near the beam.

\[
\begin{align*}
\text{Extrapolate:} & \quad I_D = 200 \text{ mA} \\
& \quad I_c = 70 \text{ mA}
\end{align*}
\]

Track distortions can be parameterized as a function of \(I_D\), but become unacceptably large \((> 500 \mu A)\) at these currents.
UA1 CENTRAL DETECTOR

CABLES

HALF MAGNET

FIXED END CAP

MOBILE END CAP

SUPPORT

VACUUM PIPE

L = 6 meters
6 half-cylinders
All wires horizontal

GAS Ar-Ethane 40/60 (V: 25 m³)
GAIN ~10⁵
v₀ 50μm/ns

- wires along magnetic field
- planes of wires arranged to optimize
  N(hits) / track
- measurement of 3 coordinates + dE/dx
Typical hits recorded for a UA1 event (Megatek display)
General characteristics of the detector

<table>
<thead>
<tr>
<th>Type</th>
<th>Drift chamber with charge division readout of the second coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas mixture</td>
<td>Argon (40%) + ethane (60%)</td>
</tr>
<tr>
<td>Drift field and gap length</td>
<td>1.5 kV/cm, 18 cm</td>
</tr>
<tr>
<td>Drift velocity</td>
<td>5.3 cm/microsec</td>
</tr>
<tr>
<td>Drift angle</td>
<td>23° at B = 0.7 T</td>
</tr>
<tr>
<td>Anode plan arrangement</td>
<td></td>
</tr>
<tr>
<td>a) Distance between sense wires</td>
<td>10 mm</td>
</tr>
<tr>
<td>b) Wire length</td>
<td>80 cm min., 220 cm max.</td>
</tr>
<tr>
<td>c) Sense wire charac.</td>
<td>35 microns Ni-Cr streched at 80 g</td>
</tr>
<tr>
<td>d) Field wire charac.</td>
<td>100 microns gold-plated Cu-Be stretched at 200 g</td>
</tr>
<tr>
<td>Cathode plane structure</td>
<td>5 mm</td>
</tr>
<tr>
<td>a) Distance between wires</td>
<td>150 microns gold-plated Cu-Be stretched at 200 g</td>
</tr>
<tr>
<td>b) Wire characteristics</td>
<td></td>
</tr>
<tr>
<td>Total number of wires</td>
<td>22800</td>
</tr>
<tr>
<td>Total number of sense wires</td>
<td>6110</td>
</tr>
</tbody>
</table>

Working voltages:

\[
\begin{align*}
V_D &= 26 \text{ kV} \\
V_C &= 2.7 \text{ kV} \\
V_F &= 2.0 \text{ kV}
\end{align*}
\]

E field at surface of wires

\[
\begin{align*}
E_s &= 210 \text{ kV/cm} \\
E_c &= 33 \text{ kV/cm} \\
E_f &= 2.7 \text{ kV/cm}
\end{align*}
\]
An obvious way to solve these problems is to lower the gas gain.

- $\Delta g/\theta$ becomes worse (change div.)
  \[ \times 5 \] (prop. change)
- Need to modify electronics

<table>
<thead>
<tr>
<th>$E$</th>
<th>gain</th>
<th>$I_D$</th>
<th>dist.(worst)</th>
<th>$\Delta g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3 \times 10^{29}$</td>
<td>$10^5$</td>
<td>20</td>
<td>190 μm</td>
<td>1.5% x l \rightarrow 3.3 cm max.</td>
</tr>
<tr>
<td>$3 \times 10^{30}$</td>
<td>$10^5$</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$3 \times 10^{30}$</td>
<td>$2 \times 10^4$</td>
<td>40</td>
<td>380 μm</td>
<td>10% \rightarrow 20 cm.</td>
</tr>
</tbody>
</table>

(2) Detector Aging

Comparison of Sept. '83 and Dec. '85 data shows no aging effect even in "hottest" region. \[ \int G dt = 1 \text{ coul/meter}. \]

Using source and small test chamber, they observed degradation in chamber characteristics for \[ \int G dt > 7 \text{ coul/m}. \]

By adding 0.8% Ethanol leakage current stopped

Present R&D

Use laser induced ionization (∞ p) to map long range distortions repeatedly. Problem is to find a suitable "doping seed".

SPIRAL PROJECTION CHAMBER (Gastaldi)

Coated with uniform high resistive conductive layer

- Field shaping end caps
- Internal, external cylinders

\[ E \propto \frac{1}{r} \quad \text{(like a cylindrical capacitor)} \]

Inner cylinder can be conical.

Characteristics:

1. Magnification (for tracks near inner radius)
2. Cylindrical symmetry
   Equal \( \Delta \phi \), towers
3. Can be very long
4. Wires, mechanics, electronics at outside radius (away from radiation)
5. Interesting option:
   HIGH DENSITY RADIAL PROJECTION CHAMBER
Spiral Protection Chamber

- Chamber Frame
- Sense Wire
- Field Wire
- Drift Cell
- External Cathode
- Beam Pipe
- Field Shaping End Cap
- Negative High Voltage Electrode (internal cathode)
$K^+ K^- \pi^+ \pi^-$ event
$K^\pm/\pi^\pm$ identification by $dE/dx$

in the ASTERIX SPC

up to $\sim 350$ MeV/c

$dE/dx$ vs $K$ separation in the ASTERIX experiment.
HIGH DENSITY RADIAL SPIRAL PROJECTION CHAMBER
3. FIBERS FOR TRACKING (Kirkby)

APPLICATIONS

(1) Live targets. Direct observation of \( \tau, c, b \ldots \) decay.
\[ 10^{-13} \text{ sec.} \rightarrow \text{impact parameters } \sim 30 \mu \]

(2) Precise tracking.
Small size can reduce overall detector size.

CHARACTERISTICS and CRITERIA

(1) Single track resolution. \( \sigma \sim 10 \mu \).

(2) \( \sigma \) 2-hit \( \sim 100 \mu \).

(3) Rate. \( 1 - 10 \times 10^6 \)

(4) Radiation resistance

(5) Low mass

(6) Radiation resistance

PLASTIC

Light yield
Long life
\( \text{min} \, D \sim 1000 \mu \)

Low mass \( x_0 = 44 \, \text{cm} \)

important
to try and
reduce

GLASS

poor light yield
Short lives
\( D \sim 30 \mu \! \)
Radiation resistant
High mass \( x_0 = 9.8 \, \text{cm} \)
PRINCIPLE OF OPERATION

a) SOLID SCINTILLATOR

b) SCINTILLATING FIBRE BUNDLE (FIBRES PERPENDICULAR TO TRACK)

LONGITUDINAL OPTICAL IMAGE

c) SCINTILLATING FIBRE BUNDLE (FIBRES PARALLEL TO TRACK)

TRANSVERSE OPTICAL IMAGE
INDIVIDUAL FIBRE

ABSORPTION

TRAPPING CONE
(2.8% x 4π str
EACH DIRECTION)

n = 1.58

n = 1.49

SCINTILLATING CORE (GS1 GLASS)

OPTICAL CLADDING

EXTRA MURAL ABSORBER (EMA)

PARTICLE

5.5 μ

28.5 μ

5.5 μ
Current measurements and $R > D$.

1. GSI scintillating glass.
   
   Cerium doped. Has $\text{Ce}_2\text{O}_3$ (4%) (scintillator).

2. Attenuation length
   
   Poor transmission may be due to some $\text{Ce}_2\text{O}_3$ $\rightarrow$ Ce $\text{O}_2^+$ (oxidation)
   
   Could be controlled during manufacture.

   For fiber bundles $\lambda \approx 2.5$ cm.

3. Radiation test: $10^8$ rad. ($\equiv 100$ years

   "Weak" yellow

   10 cm. from SSS

   Followed by temperature annealing (not possible with plastic)

4. Read out (oversimplified)

   ![Diagram of readout process]

   1 ms gate

   $10^5$ gain

5. Track residuals $\sigma = 25 \mu m$, 2-σ res. 80 μm.
Some examples

5 ceV/c π⁻ beam

18 mm

no EMA → noise
EMA, → less noise

2 hits/mm
3. SIlicon Strip Detectors

- Another rapidly evolving technology
- The main challenge lies in the area of electronics
- Motivation: same as for fiber tracking
  - Secondary vertices
  - Improve $\Delta p/\rho$ $\rightarrow$ reduce size of detector
- Other advantages of silicon:
  - Primary ionization localized
    - $\delta$ rays < 1 $\mu$m (cf. gas several mm.)
  - Precise structure using well developed IC technology
  - $\delta E = 3.6$ eV/eh pair $\rightarrow$ large charge statistics
  - Signal collection $\sim 20$ nsec. (holes)
  - Electrical signals can be directly interfaced and processed
- Size limited by largest round silicon rods
  - 2" 50 mm
  - 3" 75 mm
  - 4" 100 mm
\[
\left( \frac{\Delta p}{p} \right)^2 = \left( 0.4 \% \right)^2 + (1 \%)^2

\]

Note compactness of detector

- GAS JET (direction into paper)
- SILICON MICRO-STRIP TRACKER (barrel: 3 z layers, end-cap: 3 x-y layers)
- STRAW CHAMBER (barrel: 8 z layers, end-cap: 4 x-y layers)
- FAST RICH (liquid C\textsubscript{6}H\textsubscript{6}, radiator)
- BGO ELECTROMAGNETIC CALORIMETER (photodiode readout)
- SUPERCONDUCTING SOLENOID (6 Tesla)
- FLUX RETURN (restricted to top and bottom sides of detector)
Diode Strip Structure

Silicon planar process
Start with $\geq 10$ K-2 cm n-doped
Ion implant
Metallization etc.

Resolution determined by
- Landau fluctuations, 8-rays, inclined tracks, $8$
- Strip pitch, readout (inter-strip capacitance charge division)

Typical thickness 300 $\mu$m, $(0.3 \% L_{rad})$

Too wide
Charge interpolation not possible

Too narrow
Electronic noise
OBSERVED CHARGE DISTRIBUTION

OF MICROSTRIP COUNTERS (KENNER)

\[ U = 120 \text{ VOLTS} \]
\[ H = 0 \text{ TESLA} \]
\[ \Gamma = 6 \mu\text{m} \]

\[ U = 200 \text{ VOLTS} \]
\[ H = 0 \text{ TESLA} \]
\[ \Gamma = 4.5 \mu\text{m} \]

\[ U = 120 \text{ VOLTS} \]
\[ H = 1.68 \text{ TESLA} \]

\[ U = 120 \text{ VOLTS} \]
\[ H = -1.68 \text{ TESLA} \]

E. BEAU et al.
NA32. 200 GeV/π

25 μm PITCH  EVERY STRIP READ OUT

(MICRON)
64 mm x 60 mm
bias ~ 50V

σ = 2.6 ± 0.1 μm

PREDICTED - MEASURED COORDINATE

σ VS. PULSE HEIGHT

σ VS. BIAS VOLTAGE
Evolution of electronics

**chan.**

<table>
<thead>
<tr>
<th></th>
<th>100 - 1000</th>
<th>Fixed target</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCRETE COMPONENTS PC BOARD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYBRIDS</td>
<td>1 - 10 K</td>
<td>Fixed target</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collider</td>
</tr>
<tr>
<td>VWSI (Microplex)</td>
<td>100 K</td>
<td>Collider</td>
</tr>
</tbody>
</table>

Application to collider experiments

Several important differences:

- # of channels 10 - 100 X more
- mechanical structure holding the detectors must be light
- ---- but also precise! survey difficult
Secondary vertex resolution
for 30-40 GeV $D \rightarrow K\pi^+$ etc. ($\Delta z > 3-4$ mm)

$\Delta z = 130 \ mu$
What is Micoplex? (CERN, SLAC)

Example (DELPHI)

- 1280 ch.
- 4 M-strip detector

10 multiplex VLSI chips soldered directly to detector

- 128 chs. Low noise amps.
- Read out serially. (few MHz)
- Shift register

1280 chs → 1 twisted pair

SLAC - pulsed analog power → reduce total P. (10/μsec)

- amp. rise time 20 nsec
- Storage cap memory time > 50 msec.

Future directions:

- reduce power
- Circuit protect (large detector capac. ≈ 100's of pF)
- More pre-processing on chip
MARK II - MICROVERTEX DETECTOR

UNIV. OF HAWAII, UC SANTA CRUZ, SLAC

(COMBINED R&D WITH CERN ON VLSI READ OUT CHIP)

MICRO-MEEX

SILICON MICROSTRIP DETECTOR INSIDE PRECISE GASEOUS DRIFT CHAMBER.

6.3 mm 35 mm 25 mm readout pitch

*Detectors will be cut from 4'' wafers (under development)
ALEPH (MPI, Duisberg, PISA)

Double sided readout for \( r-\phi \) and \( r-z \)

**FIG. 6** \( r-z \) READ-OUT
CDF (Fermilab)
(PISA)

- 4 layers (will use 4" wafers)
- pitch 25 μm
- readout pitch: layers 1, 2 50 μm, 3, 4 100 μm

Performance:
1. Short-lived particles. At 10 GeV/c $\sigma_p < 20 \mu$m.
2. Improved $\frac{\Delta p}{p}$: $0.001 p$ at 10 GeV/c
   $0.005 p$ with vertex detector
Charge Coupled Devices

1. Read out device for high data rates (delay line).

2. Directly as a detector.
   - 2 dimensional $\rightarrow$ space points
   - Typical pixel size: $22 \mu m \times 22 \mu m$
   - $t \sim 15 \mu s$ (so signal is $\frac{1}{20}$ Micro strip det)
   - For low noise needs cooling (LHe, N$_2$)

Major Problems:
- No fast clear
- Stays sensitive during readout.

Advantage of space points

![Graph showing advantage of space points with labeled points 1 to 8 and an event marked as NA32 event.]
Single track 0.5 m x 5 m
Double track separation in space 40 m

40%2 EFFICIENT FOR IONIZING PARTICLES.

High information density allows spurious hits

3 PHASE CHARGE TRANSPORT IN CCDS
CCD MICROVERTEX DETECTOR FOR SLD

OPERATION OF CCD'S AND THEIR READ OUT CONSTRAINTS

MATCH NICELY WITH SLC OPERATIONS

< 180 pps

USE CCD'S WITH:

22 μm → 22 μm PIXEL SIZE

385 x 596 PIXELS → 8.5 mm x 12.7 mm SIZE

READ OUT AT ~4 MHz → ~50 μsec

~ 0.6% LOSS

5 CCD'S PER LADDER
PLANNED INITIALLY WITH END CARDS.

120° → 25° 1 HIT
120° → 30° 2 HITS

60.4 MM

SEAM PIPE RADIUS → 10
SILICON DRIFT CHAMBER

characteristics

- Drift velocity $2 \text{m}/\text{ns}$
  \[ E = 150 \text{ V/cm} \]
- Requires very uniform doping (sensitive to radiation damage?)
- $1 \text{ cm}$ coord. from drift time $\sim 20 \mu \text{s}$
- $1 \text{ cm}$ coord. from pad interpol. $\sim 20 \mu \text{s}$
- Double track separation $500 \mu \text{m}$ in space

Proposed for UA6 upgrade.
2 measuring stations in front of magnet
4. PARTICLE IDENTIFICATION
AT SSC ENERGIES

Very abbreviated version of talk by T. Ypsilantis.

SSC Detector concept (non-conventional)

Spherical to minimize RICH surface area

---

EM/HAD CALORIMETER

Fully Active
Liquid Ar

20 samples in depth
no sampling fluctuations
\( \frac{e^+}{\pi^-} = 1 \)
Fast < 10 ns.

---

RICH 4 m.

---

106 channels

---

Silicon tracking

Super cond. coil
Super cond. mag. shield

Beam
Ring Imaging Čerenkov Counter  RICH

(1) Resolution obtained with DELPHI prototypes for both liquid/gas radiators agrees with predictions.

(2) After some algebra he derives:

$$p^2 = \frac{100 N_0 L}{\sigma \sqrt{N}} (m_K^2 - m_\pi^2)$$

$$N_0 = 150 \text{ cm}^{-1} \text{ for TMAE radiator, best possible mirrors, and best quartz window.}$$

Suppose we choose $\sigma = 4.2 \text{ SD}$

This $\Rightarrow$ that 1% of the time $\pi/K$ misidentification will occur.

Next choose desired $N$ of p.e.

\text{e.g. } N = 25.

With this choice a 4 meter long counter will separate $\pi/K$ (99% prob) up to 257 GeV.
(3) The RICH counter can also be thought of as a $\delta$ measuring device.

$$\frac{\Delta \delta}{\delta^3} = \frac{5 \times 10^{-3}}{\sqrt{N}} \frac{1}{\gamma_T^2} \quad \gamma_T = \frac{\eta}{\sqrt{n^2 - 1}}$$

For present design, $N = 25$ p.e.

$\delta_T = 50 \quad \eta - 1 = 2.6 \times 10^{-4}$ \hspace{1em} (He/Ne)

$$\frac{\Delta \delta}{\delta} = 4.7\% \quad \text{at} \quad \delta = 3.16 \quad (44 \text{ GeV} \pi)$$

(4) Particle direction measured with precision.

For $N = 25$, $\gamma_T = 50 \quad \Delta \Theta = 20 \text{ mrad}$.

Use $\delta$ to help tracking \hspace{1em} (modulo mass)

(5) Readout requirements:

$A = 50 \text{ m}^2 \quad 50 \times 10^6 \text{ pixels} \hspace{1em} (1 \text{ mm}^2)$

at 10 pixels/pad $\rightarrow 5 \times 10^6$ pads!
5. NON-ACCELERATOR PHYSICS

Important questions discussed in 2 excellent review talks by Fiorini and Ernwein:

(1) Why is the solar $\nu$ flux as measured by Davis low?

(2) Are there $\nu$ oscillations?

(3) Is the $\nu$-mass $\neq 0$?

(4) Are nucleons stable?

(5) Is there some new, unexplained particle coming from the X-ray source Cygnus-X?

There is only time to repeat their main conclusions.
Solar Neutrino Flux at TAU

Line Sources: (cm$^{-2}$ sec$^{-1}$)
Continuum Sources: (cm$^{-2}$ sec$^{-1}$ MeV$^{-1}$)

Neutrino Energy (MeV)

10$^{-5}$ 10$^{-4}$ 10$^{-3}$ 10$^{-2}$ 10$^{-1}$

0.1 0.3 1 3 10

pp 13N $^7$Be $^7$Be $^8$B pep
Davis (BNL) experiment.

\[ E_\nu > 1 \text{ MeV} \]
\[ \nu_e + ^{37}\text{Cl} \rightarrow ^{37}\text{Ar} + e^- \]
\[ \rightarrow 35 \text{ day } T \]

Theory/Exp = 3 !

Why ?
- Solar, Medw. Wrong
- \( \nu^- \) Oscillations

\[ \nu_e \rightarrow \nu_\mu \text{ on way from } 0 \rightarrow \oplus \]

However, most 0 \( \nu \)'s below E
detectable by Davis.

New experiments being prepared (no results yet)

(1) GALLIUM.

\[ \nu_e + ^{71}\text{Ga} \rightarrow ^{71}\text{Ge} + e^- \]
\[ \rightarrow 11.4 \text{ days} \]
\[ E_\nu > 233 \text{ keV}, \text{ collect } 70\% \text{ of } \nu \text{'s from solar pp cycle.} \]

3 experiments:
- GALLEX. Gran Sasso tunnel.
  GeCl in HCl \rightarrow GeH_4 \text{ gas}
- GALLIUM US CANadian
- BARSAM (USSR)
  must remain metallic!
  melt \rightarrow blow gas through it
MAJOR ADVANTAGE: Calibration Source

Cr-51 source
access port

80
70
60

30 t Ga-level

Cr-51 source

-80
-70
-60

240 m³/h
22°C

sparger
air lift

technical
hood

8 m

0.25 m

ventilation channel
spill tray

1 m

GALLEX TARGET TANK
(2) Look for Tc (Technicium) in Mo (Molybdenum) bearing rock

\[ ^{98}Xe + ^{93}Mo \rightarrow ^{97}Tc + e^- \]

\[ \text{Need to look at thousands of tons to be sensitive.} \]

(3) Sunbury Mine

\[ \nu_e + e^- \rightarrow \nu_e + e^- \]

\[ \nu_e + (pn) \rightarrow \nu_e + n + c \]

1000 tons

\[ \text{Surrounded by PM's.} \]

(4) ICARUS - Liquid-A

\[ \nu_e + e^- \rightarrow 2\bar{\nu}_e + e^- \]

TPC type detector

\[ \nu_e + ^{40}Ar \rightarrow e^- + ^{40}K \]
Neutrino oscillations

e.g. $\bar{\nu}_e = \nu_1 \cos \alpha + \nu_2 \sin \alpha$
$\nu_\mu = -\nu_1 \sin \alpha + \nu_2 \cos \alpha$

Experiments have been done at
- Accelerators (incl. $\pi$-factories)
- Underground
  Byproduct of solar $\nu_\tau$ p-decay
- Reactors $\bar{\nu}_e$

No evidence for oscillations

Neutrino Masses

$\mu < 270 \text{ keV}$
$\tau < 56 \text{ MeV}$
$\nu_e \ ?$

$^3\text{H} \rightarrow ^3\text{He} + e^- + \bar{\nu}_e$ Use Kurie plot to measure end point.

3 experiments have been done
at ITEP (Moscow) Lubimov et al
(1980) $14 \leq m_\nu \leq 46 \text{ ev} \quad 99\% \text{ CL}$
(1983) $m_\nu \geq 2.0 \quad 95\% \text{ CL}$
(1984) $m_\nu \geq 9$
Experimental difficulties

- Molecular effects
- Low counting rates in crucial region

$m_y > 0$
-resolution prefect

$m_y = 0$
-finite resolution

ITEP 1984 Data

KURIE PLOT

- $m_y = 0$
- $m_y = 550 \text{eV}$ (Best Fit)
- Conclude: $m_y > 9 \text{eV}$

$E (\text{eV})$
New experiments cast doubt on ITEP result

1. Los' Alamos

\[ m_{\nu_e} < 36 \text{ eV (95\% CL)} \]

2. \[ \sin^2 \theta < 0.9 \text{ eV (95\% CL)} \]

---

![Graph 1: Tritium Spectrum](image1)

**Source:** Tritium

\[ m_0 = 0 \text{ FIXED} \]

**CH3T Spectrum**

![Graph 2: m_0 = 3.5 eV FIXED](image2)

\[ m_0 = 3.5 \text{ eV FIXED} \]
Nucleon Decay

Is the proton stable?

Age of universe \( \geq 10^{10} \) years

Radio/geochemical \( \geq 10^{27} \) years

\( \text{Th}^{232} \ldots \)

Minimal SU5 but \( 10^{29} \pm 1.4 \) years

\[ p \rightarrow e^+ \pi^0 \]

\[ n \rightarrow e^+ \pi^- \]

Best limit today \( \tau > 3.6 \times 10^{32} \)

for \( p \rightarrow e^+ \pi^0 \)

So minimal SU5 ruled out.

Theory: Other symmetry groups predict
other decay modes and longer lifetimes.

Experiments: More complex decay modes being
studied and sensitivity being improved

Two techniques:

1. Water Cerenkov.

2. Fine grained tracking
   calorimeters (Iron, Gas readout)
## WATER CERENKOV
- $\beta_{\text{th}} > 0.75$
- Homogenous
- Good timing (directionality)
- Good $\Delta E / E$ for showers
- 11% free protons
- Low cost $\rightarrow$ large mass
- Ideal for $p \rightarrow e^+ \pi^0$
- $\delta v_{\text{e}} \sim 7.5 \text{ cm}$

## Fe-gas Sampling Calorimetry
- Get "pictures" good for complex topology
- Denoise $\rightarrow$ small $\rightarrow$ deep
- Sensitive to slow particles
- Nucleon effects larger
- $\delta v_{\text{e}} \sim 1 \text{ cm}$

<table>
<thead>
<tr>
<th></th>
<th>HPW [a]</th>
<th>IMB Water C.</th>
<th>KAMIOKA</th>
<th>KGF</th>
<th>NUSEX Iron cal</th>
<th>FREJU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden (kg/cm²)</td>
<td>1500</td>
<td>1600</td>
<td>2700</td>
<td>7600</td>
<td>5000</td>
<td>4850</td>
</tr>
<tr>
<td>Total/Fiducial Mass (TONS)</td>
<td>700/180</td>
<td>8000/3300</td>
<td>3000/880</td>
<td>140/65</td>
<td>150/130</td>
<td>900/60</td>
</tr>
<tr>
<td>Sensitivity (kiloton/year)</td>
<td>0.13</td>
<td>3.8</td>
<td>1.5</td>
<td>0.25</td>
<td>0.35</td>
<td>0.61</td>
</tr>
<tr>
<td>Number of contained events</td>
<td>0 [a]</td>
<td>401</td>
<td>181</td>
<td>19</td>
<td>37</td>
<td>65</td>
</tr>
<tr>
<td>Number of candidates (background)</td>
<td>0(0.7)</td>
<td>21(20)</td>
<td>5(3)</td>
<td>4(21)</td>
<td>3(1.6)</td>
<td>1(-1)</td>
</tr>
</tbody>
</table>

[a]: events with multiple muon decay only

Under construction: **Soudan 2 (1987-88)**

Under design: **Super-Kamioka**

**Icarus**

Under 1990's.
Conclusions

1. ~10 candidates, have possible
   2) background interpretations

2. Present experiments may reach
   \(10^{32}\) yr. limit after thorough 2)
   background studies

3. Projects for 1990's may reach \(>10^{33}\)
**CYGNUS X-3**

\[ d = 35,000 \text{ L.Y.} \]

- Variable X-ray and radio source (1000:1)
- \( E_x \rightarrow 10^{15} \text{ eV} \)
- \( P = 4.8 \text{ hours} \)
- **Nusser / 1981-84** observed an excess of \( \mu^- \)s coming from direction of Cygnus X-3 when 4.8 hour periodicity used.
- If true these must be secondaries due to some new neutral particle.
- **NUSSEX, FREJUS, OAKSAN, HOMEStAKE, KAMIOKADA, HPW, IMB**
  \[ 1983-86 \] fail to confirm effect.