Physics & Detector Studies

For the NLC

C Battag
May 24, 1999
Physics with High Energy e⁺e⁻ Colliders

A series of workshops to study the physics potential of High Energy e⁺e⁻ Colliders, held in preparation for the 1996 Snowmass Study.

- Organizational Meeting at Yale, Feb 11, 1995
- Set up Physics Working groups
- Series of Workshops
  1. Estes Park, Colorado, June 23-25, 1995
  2. Fermilab, Nov 16-18, 1995
  3. SLAC, Feb 29-March 2, 1996
  4. Brookhaven Natl Lab, May 6-8, 1996
- Snowmass Study, June 24-July 12, 96
Detector & Collider Parameters
used for Snowmass 96

1. Detector Parameters

For most of the studies carried out for SNOWMASS 96 we used the parameters of the SLD.

LEF, LSc. type detectors are almost good enough to do the job, although many things will have to be different.

2. Linear collider Parameters

Initially 500 GeV $5 \times 10^{33}$ /cm$^2$/sec

Adiabatically 1 TeV $\geq 10^{34}$ /cm$^2$/sec

Upgrade 1.5 TeV $\geq 10^{34}$ /cm$^2$/sec

A 1.5 TeV LHC has a similar reach in Mass scales as the LHC.
SUSY Discovery Reach at the LHC or an NLC

\[ \tan \beta = 2 \quad \mu < 0 \]
Organizing Committee

Of the

Worldwide Study of Physics and Detectors

For Future Linear e+e- Colliders

Co-chairs:

Charles Baltay
Yale University

Sachio Komamiya
University of Tokyo

Dave Miller
UC London

Alan Astbury
TRIUMF (Canada)

Jonathan Bagger
Johns Hopkins (USA)

Paul Grannis
SUNY, Stonybrook (USA)

Steve Olsen
U. of Hawaii (USA)

Charles Prescott
SLAC (USA)

Shinhong Kim
Tsukuba U. (Japan)

Sun Kee Kim
U. of Seoul (Korea)

Takayuki Matsui
KEK (Japan)

G.P. Yeh
Taiwan

Tao Huang
U. of Beijing (China)

Michael Danilov
ITEP (Russia)

Rolf Heuer
CERN/DESY (Germany)

Marcello Piccolo
Frascati (Italy)

Francois Richard
Orsay (France)

Ron Settles
Munich (Germany)
WORKING GROUPS

Detector Simulations
1. Simulations, Generators, and Performance Studies

Detector Groups
2. Vertex detectors
3. Tracking
4. Particle ID and other specialized detectors
5. Calorimetry
6. Muon detector
7. Data acquisition and triggering

Physics Groups
8. Higgs
9. SUSY
10. Other new particles and alternative theories
11. Top physics
12. QCD, two photon
13. Precision electroweak and strong gauge interactions

Groups Joint with Machine People
14. e-e-, e gamma, gamma gamma options
15. Interaction region, backgrounds
### Working Group International Contact Persons

1. **Detector & Physics Simulations**  
   M. Pohl     Mike Peskin     Keisuke Fujii

2. **Vertex Detector**  
   C. Damerell  Jim Brau     Sugimoto

3. **Tracking**  
   R. Settles   Keith Riles   D-H Zhang

4. **Particle I.D. and other specialized detectors**  
   T. Behnke    Hitoshi Yamamoto    Z-G Zhao (IHEP)

5. **Calorimetry**  
   S. Bertolucci  Frank Porter   G. W-S Hou

6. **Muon Detector**  
   M. Piccolo    Dave Koltick    z-s zhu

7. **Data Acquisition and Trigger**  
   P. LeDu       Tony Barker     I. H. Park

8. **Higgs**  
   E. Gross      Rick Van Kooten  Satoru Yamashita

9. **SUSY**  
   U. Martyn    Teruki Kamon    C-S Li (Beijing)

10. **Other New Particles and Alternative Theories**  
    G. Wilson    Slawek Tkaczyk   C. S. Kim

11. **Top Physics**  
    M. Martinez  David Cinabro   Xiu-Miu Zhang

12. **QCD, Two Photon**  
    P. Burrows   Bruce Schumm    Yuan-Han Chang

13. **Electroweak, Strong Gauge Interactions**  
    K. Moenig    Tim Barklow     A. Miyamoto

14. **e-e-, eγ, yy Options**  
    V. Telnov    Karl Van Bibber  T. Takahashi

15. **Interaction Regions, Backgrounds**  
    O. Napoly    Tom Markiewicz  Toshiaki Tauchi
American Working Group Interim Organizers

Paul Grannis & Charles Baltay, Coordinators

1. Detector & Physics Simulations
   Mike Peskin, Tim Barklow, Richard Dubois
2. Vertex Detector
   Jim Brau
3. Tracking
   Keith Riles, Dean Karlen, Chris Hearty
4. Particle I.D.
   Hitoshi Yamamoto, Richard Stroynowsky
5. Calorimetry
   Frank Porter, Ray Frey
6. Muon Detector
   Dave Koltick
7. Data Acquisition/Electronics
   Tony Barker, Bob Jacobsen
8. Higgs
   Rick Van Kooten, Bill Marciano
9. SUSY
   Teruki Kamon, Bob Hollebeek, H. Murayama, U. Nauenberg
10. Other New Particles
    Slawek Tkaczyk, Joanne Hewett
11. Top Physics
    David Cinabro, Dave Gerdes, Andreas Kronfeld
12. QCD, Two Photon
    Bruce Schumm, Lance Dixon
13. Electroweak, Strong Gauge Interactions
    Tim Barklow, Mike Peskin
14. e-e-, ey, yy Options
    Karl Van Bibber, Clem Heusch, Les Rosenberg
15. Interaction Regions, Backgrounds
    Tom Markiewicz, Stan Hertzbach

First name on each line agreed to serve as the International Contact person.
DESIGN "S"
QUADRANT VIEW
(AS OF 10 DEC. 1998)

MUON DETECTOR/IRON

HADRONIC CALORIMETER

MAGNET COIL

ELECTROMAGNETIC CALORIMETER

CENTRAL TRACKER

VERTEX DETECTOR
### e^+e^- COLLIDER DETECTOR - Revised 121198 DESIGN S

<table>
<thead>
<tr>
<th>Component</th>
<th>Radius (cm) Min</th>
<th>Radius (cm) Max</th>
<th>Axial (cm) Min</th>
<th>Axial (cm) Max</th>
<th>ZI (cm) Min</th>
<th>ZI (cm) Max</th>
<th>Technology</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex Detectors</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>12.5</td>
<td>CCD</td>
<td></td>
<td></td>
<td>4.5μ+5.5μ / psin^3/2</td>
</tr>
<tr>
<td>Central Tracking</td>
<td>10</td>
<td>75</td>
<td>0</td>
<td>120</td>
<td>Si u strips</td>
<td></td>
<td></td>
<td>(delta) P^2-6x10^6 high p</td>
</tr>
<tr>
<td>ECals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(delta) P/P-0.4% low p</td>
</tr>
<tr>
<td>Barrel</td>
<td>75</td>
<td>110</td>
<td>0</td>
<td>155</td>
<td>Tungsten/Si pads</td>
<td></td>
<td></td>
<td>(delta) E/E- 12%/ (root) E +1%</td>
</tr>
<tr>
<td>End Cap</td>
<td>20</td>
<td>75</td>
<td>120</td>
<td>155</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coil Magnet</td>
<td>110</td>
<td>140</td>
<td>0</td>
<td>155</td>
<td>SC Solenoid</td>
<td></td>
<td></td>
<td>6 Tesla</td>
</tr>
<tr>
<td>HCal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrel</td>
<td>140</td>
<td>250</td>
<td>0</td>
<td>265</td>
<td>Cu/Scintillator</td>
<td></td>
<td></td>
<td>(delta) E/E-50%/ (root) E +2%</td>
</tr>
<tr>
<td>Endcap</td>
<td>20</td>
<td>140</td>
<td>155</td>
<td>265</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron/Muon Detectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrel</td>
<td>250</td>
<td>370</td>
<td>0</td>
<td>265</td>
<td>Fe/gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endcap</td>
<td>20</td>
<td>370</td>
<td>265</td>
<td>385</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Vertex Detector** - as in Snowmass

- 5 layers of CCD's: 0.12 per x_0 layer
- radii of layer:
  - 1: 1.2cm, +/- 2.5 cm long
  - 2: 2.4cm, +/- 5 cm long
  - 3: 3.6cm, +/- 7.5 cm long
  - 4: 4.8cm, +/- 10 cm long
  - 5: 6.0cm, +/- 12.5 cm long
- CCD's: 20 u x 20u pixels
- point error ~ 5u

**Central Tracker**

- Silicon u strips
- Layer: 1: 14 cm = +/- 1.2 m
EM Calorimeter

Tungsten/Silicon pad readout

Tungsten $x_0 = 0.35 \text{cm}$, (lambda) $= 9.6 \text{cm}$

Structure:

- 50 layers: 2 mm Tungsten
- 3 mm Si pad readout

Total thickness 25 cm

100 mm of Tungsten/3.5 mm $= 29 x_0$ total, 1 (lambda)

Segmentation: 1.5 cm x 1.5 cm pads

1.5 mrad x 15 mrad

50 longitudinal layers

Hadronic Calorimeter

Copper/Scintillator towers

Cu (lambda) $= 14.8 \text{cm}$

Copper

38 layers of: 20 mm Copper

5 mm Scintillator

Total thickness 95 cm = 5.1 lambda

EM + Had Calorimeter 6.1 lambda

EM Calorimeter: 1% of $X_0$ per layer

Muon detectors: 10 Iron plates, 10 cm thick each
10 cm thick Fe plates with gas chambers inside in 2 cm gaps.

Continus pad structure of hadron calorimeter for tailcatcher.

Position resolution

- 10 layers • 1 cm in theta direction
- 2 layers • 1 cm in Z direction

Last Modified: 12/14/98 21:43
### e^+e^- COLLIDER DETECTOR Revised 12/98 - DESIGN L

<table>
<thead>
<tr>
<th>Component</th>
<th>Radius Min (cm)</th>
<th>Axial Min</th>
<th>ZI Max</th>
<th>Technology</th>
<th>Performance</th>
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</thead>
<tbody>
<tr>
<td>Vertex Detectors</td>
<td>2.5</td>
<td>10</td>
<td>0</td>
<td>15</td>
<td>CCD</td>
</tr>
<tr>
<td>Central Tracking</td>
<td>25</td>
<td>200</td>
<td>0</td>
<td>300</td>
<td>TPC</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140u, 144 points</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(delta)P/P^2=5x10^6 high p</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(delta)P/P=0.1% low p</td>
<td></td>
</tr>
<tr>
<td>ECal Barrel</td>
<td>200</td>
<td>250</td>
<td>0</td>
<td>350</td>
<td>Pb/scintillator</td>
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<tr>
<td>End Cap</td>
<td>25</td>
<td>200</td>
<td>300</td>
<td>350</td>
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<tr>
<td>ECal</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>HCal Barrel</td>
<td>250</td>
<td>370</td>
<td>0</td>
<td>470</td>
<td>Pb/Scintillator</td>
</tr>
<tr>
<td>Endcap</td>
<td>25</td>
<td>250</td>
<td>350</td>
<td>470</td>
<td></td>
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<tr>
<td>HCal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coil Magnet</td>
<td>370</td>
<td>450</td>
<td>0</td>
<td>470</td>
<td>SC Solenoid</td>
</tr>
<tr>
<td>Iron/Muon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 (lambda) thick</td>
</tr>
<tr>
<td>Barrel</td>
<td>450</td>
<td>620</td>
<td>0</td>
<td>470</td>
<td></td>
</tr>
<tr>
<td>Endcap</td>
<td>25</td>
<td>620</td>
<td>470</td>
<td>670</td>
<td></td>
</tr>
</tbody>
</table>

**Vertex Detector**

5 layers of CCD's

radius layer 1 2.5cm, +/- 5 cm long

2

3 evenly spaced

4

5 10 cm, +/- 20 cm long

total length 40 cm of outer layer

**Central Tracker**

TPC - assume 144 points on a track (active region 27-190 cm)

point accuracy 140u
gas thickness 0.01 $X_0$

Calorimeter - Pb/scintillator (a la JLC design)

<table>
<thead>
<tr>
<th>Section</th>
<th>Layers</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>40</td>
<td>4mm Pb</td>
</tr>
<tr>
<td>H</td>
<td>120</td>
<td>8mm Pb</td>
</tr>
</tbody>
</table>

Pb: $x_0 = 0.56$ cm (lambda) = 17 cm

EM $40 \times 4 = 160$ mm $\Rightarrow 28 x_0$

Total $40 \times 4 + 120 \times 8 = 16 + 96 = 112$ cm $\Rightarrow 6.6$ (lambda)

Total thickness

<table>
<thead>
<tr>
<th>Section</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>$40 \times 0.5 = 20$ cm</td>
</tr>
<tr>
<td>Had</td>
<td>$120 \times 1 = 120$ cm</td>
</tr>
</tbody>
</table>

(Silicon pads 1 cm x 1 cm after 6th layer of EM) *not implemented in the code*

Segmentation

<table>
<thead>
<tr>
<th>Section</th>
<th>Segmentation</th>
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</thead>
<tbody>
<tr>
<td>EM</td>
<td>.04 x .04 (i.e., 40 mr x 40 mr)</td>
</tr>
<tr>
<td>Had</td>
<td>.08 x .08</td>
</tr>
</tbody>
</table>

Muon detector a la Tesla detector design

- 24 iron plates 5 cm thick each
- 3 cm gaps between plates
- Use RPC detectors
- Pads continuing tower structure of Hadron calorimeter

Position resolution for muon tracking:

- 3 cm wide strips give $\sigma_{(theta)} = 1$ cm in (theta) in each of the 24 gaps
- Every sixth layer to have 3 cm transverse strips to provide $\sigma \approx 1$ cm

Last Modified: 12/14/98 21:46
NLC Detector Designs

DESIGN "S"

Quadrant View

Small Tracker

- Optimized for best Vertex
- Needs large field (4 to 6T)
- Small tracking volume
  - Silicon tracker
- Close to EM Calorimeter
  - Need small Nolier Rod
  - Operation in High Field

Design "L"

Large Tracker

- Optimized for best tracking eff and momentum resolution
- Lower Magnetic Field
  - Further out Vertex Detector
- Large Calorimeter
  - Can be better optimized
    for Hadron Energy Res
- Large Muon System

Two Detectors will be very desirable!

- Complementary detector design choices
- Complementary Physics Capabilities
- Detectors only 5 to 10% of Collider Cost
- Two interaction regions allow implementation of special options like 8τ on one side
  while other side is taking e+e- data
SLD
JLC Detector Design
SDC Detector for the SSC
GEM Detector for the SSC
JLC Detector Design
# Detector Characteristics

<table>
<thead>
<tr>
<th>Detector</th>
<th>Diameter</th>
<th>Length</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLD</td>
<td>9.0 m</td>
<td>9.5 m</td>
<td>57 M 1986 $</td>
</tr>
<tr>
<td>NLC &quot;S&quot;</td>
<td>7.4 m</td>
<td>7.4 m</td>
<td>?</td>
</tr>
<tr>
<td>NLC &quot;L&quot;</td>
<td>13.0</td>
<td>13.4</td>
<td>?</td>
</tr>
<tr>
<td>Tesla Det.</td>
<td>13.0</td>
<td>15.6</td>
<td>?</td>
</tr>
<tr>
<td>JLC Det.</td>
<td>15.0</td>
<td>15.0</td>
<td>?</td>
</tr>
<tr>
<td>SDC</td>
<td>25.2</td>
<td>39.8</td>
<td>584 M 1992 $</td>
</tr>
<tr>
<td>GEH</td>
<td>23.9</td>
<td>38.0</td>
<td>499 M 1990 $</td>
</tr>
<tr>
<td>ATLAS</td>
<td>22.0</td>
<td>28.0</td>
<td>465 M SF</td>
</tr>
<tr>
<td>CMS</td>
<td>15.0</td>
<td>21.6</td>
<td>465 M SF</td>
</tr>
</tbody>
</table>