The TESLA vertex detector as physics tool

Thorsten Kuhl
DESY Hamburg
Contents

- Physics motivation
- Experimental environment
- Tool for vertexing : ZVTOP
- Studies at ECM=91.2 GeV (benchmark)
- Neural Net: b and c selection
- Detector optimization
- Back to physics at 500 GeV
People involved

- Chris Damerell, RAL
- Nicolo de Groot, Bristol
- Matthew Wing, Bristol
- Stefania Xella Hansen, RAL
- TK
Physics motivation

Discovery and high precision physics:
- Higgs boson sector
- SUSY
- Gauge boson couplings
- Giga-Z
- ...

Detector requirements:
- 10 times better than LEP and LHC
- Example: charm tagging
TESLA

- Energy: \( \leq 500 \) GeV (first stage)
- Luminosity: \( \sim 500 \) fb\(^{-1}\)/y
- Bunch spacing: 337 ns
- Bunch train: 950 \( \mu \) s
- Beam spot: 5 \( \times \) 553 nm
- Beam pipe radius: 1.4 cm
Background

- Beamstrahlung
- Mostly electron pairs from photon conversion
- Define inner radius
TESLA detector concept

- Excellent tracking devices:
  \[ \sigma_{IP(r-\phi)} \leq 5 \mu m \]
  \[ \delta(1/p_t) \leq 5 \times 10^{-5} \text{(GeV)} \]

- High 3d granularity --> tracking calorimeter
- Excellent energy flow
  \[ \delta E/E \approx 0.3/\sqrt{E/\text{GeV}} \]
- Excellent angular coverage

Magnetic Field: 4 Tesla
TESLA Vertex Detector

- High track density in jets --> smallest possible pixels
- Inner layer close to beam pipe (1.4cm)
- Good angular coverage (VTX+FTD)
- Stand alone track reconstruction
- Low material (<<0.5 X^0)
- Four different concepts for pixel detector:
  - CCD
  - Depfet
  - Hybrit-APS
  - Monolit-APS

http://hepwww.rl.ac.uk/damerell//International_VTX_R&D.htm
CCD Vertex Detector

- 5 layer vertex detector
- Size: 20x20 cm²
- Most inner layer: R=1.5 cm
- 900 Megapixel
- Bunch train structure: Continuos readout
- Resolution:

\[ \sigma_{\text{IPr } \phi} = \left(4.20 \oplus \frac{4.00}{(p/\text{GeV}) \sin^{3/2}(\theta)}\right) \text{ m} \]

Thorsten Kuhl

Vertex 2002, 05.11.2002
Detector Simulation

- Full Simulation:
  - Brahms
  - Based on Geant 3

- Fast Simulation:
  - Simdet
  - Smearing based on Brahms parametrisation

Thorsten Kuhl

Vertex 2002, 05.11.2002
Vertex reconstruction tool: ZVTOP
• **SLD Vertex finder** (Nucl.Instrum.Meth.A388:247-253,1997)
• Tracks are described as Gaussian probability tubes
• Look for overlapping regions
• These are seed vertices (and IP)

Thorsten Kuhl

Vertex 2002, 05.11.2002
Track Attachment

- Cascade decays $b \rightarrow c \rightarrow s$: several seed vertices
- Start: Vertex with biggest D
- Attach reasonably close tracks
Application to TESLA: Vertex Mass

- Use all tracks from secondary vertex
- Calculate invariant mass
- Correct for missing $p$

$$M_{pt} = \sqrt{M_{Vtx}^2 + P_t^2 + |P_t|}$$

Cut at $M_{pt} = 2$ GeV:

- b-Efficiency: 55%
- b-Purity: 97%

SLD (barrel only):
- Efficiency: 52%
- Purity: 98%

Horsten Kuhl

Vertex 2002, 05.11.2002
Exclusive B-decay reconstruction

High track quality selection:

- Track-vertex assignment: 92.4% Efficient, 99.1% Pure!
- Reconstruct decay chain: $B \rightarrow D^{*+} \rightarrow D^0$

Resolution: 1 MeV

LEP: histogram width (6-7 MeV)
Exclusive B decay reconstruction

... or even $B^+ \rightarrow D^{**0} \rightarrow D^+ \rightarrow D^0$

- **Opal**: 3.5 Mevents (4 years of LEP I)
- **TESLA**: 1 Mevents (1/4 day of Giga-Z)

Thorsten Kuhl

Vertex 2002, 05.11.2002
High efficiency:

Neural Net selection
TESLA neural net

Introduction:

- Based on topological vertexing (ZVTOP):
  - Corrected vertex mass
  - Decay length / decay length significance
  - Vertex momentum
  - Vertex probability

- Additional trackwise information
  - IP joint probability (Aleph)

- 3 different classes
  - Only primary vertex found
  - Also one secondary vertex found
  - Three or more vertices found
NN: Benchmarking at 91.2 GeV

Why 91.2 GeV?
- Benchmark
- Comparison TESLA to LEP/SLD
- Giga-Z option

b-Net:
- Efficiency: 80%
- Purity: 90%
- Equal performance of SLD central detector

c-Net:
- Efficiency: 40%
- Purity: 80%
- 2-3 times better than SLD
Summary: Vertexing at the Z-Peak

- **ZVTOP**: Very efficient vertex finder
- **N-Net selection**: Very good flavor separation
- **B-Tagging**:
  - Efficiency 60(90)%, 98(80)% Purity
  - As good as SLD for a much bigger range; important for searches in multi jet final states
- **C-Tagging**:
  - Efficiency 40%, 80% Purity
  - Much better than SLD

**TESLA Vertex detector** is a great tool for vertexing which a very good angular coverage
Optimize Detector configurations
Detector dependence

Comparison:
  CCD
  “Standard”
Configuration:
  • 5 Layers

Worst case configuration:
  • Remove inner layer
  • Double sensor thickness

Thorsten Kuhl
Detector dependence (cont.)

- ZVTOP- Performance: Number of vertices

- Slightly worse but rather robust

Thorsten Kuhl

Vertex 2002, 05.11.2002
Neural Net Comparison

- 5 layer
- 4 layer/ double thickness

- B-Tag: again robust
- C-tag really suffers mainly because of the 2/3 of c-quark events with no vertex found; short lived D^0's which are very sensitive to impact parameter resolution

Thorsten Kuhl
Vertex charge for B's

- Fraction of correct reconstructed charge Vs b-net output
- 4-Layer: ~6% less efficient

Huge factor in multijet final states!

Thorsten Kuhl

Vertex 2002, 05.11.2002
Vertex charge for c's

- Fraction of correct reconstructed charge vs D+ efficiency of NN
- Drop because of poorly reconstructed D's
Summary: Detector Configurations

Comparison of 4 thick Vs 5 thin layers:
Flavor tagging:
- b-tagging efficiency very robust
- c-tagging performance drops rapidly
- b-charge reconstruction efficiency drops by ~5 %

Other issues:
- Stand alone pattern recognition much more difficult
- Material: more multiple scattering and more photon conversion background in outer detectors
Flavor tagging
at
500 GeV
Neural Net for 500 GeV

c-Net:
- Efficiency (fixed): 40%
- Purity: 80% → 95%
- Purity (fixed): 60%
- Efficiency: 60% → 80%

Much improved w/r/t 91.2 GeV!
B/c separation excellent!

b-Net:
- Purity (fixed): 90%
- Efficiency: 80% → 65%

Thorsten Kuhl
Vertex 2002, 05.11.2002
NN 500 GeV cont.

Why this poor b-Net performance at 500 GeV ???

Different flavor composition
- Gluon splitting to b and c is enhanced

Performance equal to 91.2 GeV !!!

Thorsten Kuhl
Tagging in multi jet final states at 500 GeV
Jetwise flavor tagging

Why ???
Multi jet final states:
- Z-Pairs
- Top-Pairs
- Higgs searches
- SUSY-searches

Problems:
- Jet-track assignment

Performance drops by ~5-10%

Thorsten Kuhl
Verify fast simulation

- Simdet: high statistic analysis (~1000 times faster)
- Compare with full simulation Brahms
- General agreement better than 10%
- Simdet a bit optimistic
- Needs some fine tuning but surprisingly good without

Thorsten Kuhl

Vertex 2002, 05.11.2002
NN as tool: 4-jet 2-b final states

- Higgsstrahlung HZ --> bbqq
- 2b+ Signal efficiency: 80%
- Non b efficiency: 2.5%
NN as tool: 4 jet 4-b final states

- SUSY searches AH
- Sum of the two 2-jet masses before/after B-Tag
- 4-b Efficiency: $\sim 60\%$
- 2-b Efficiency: $\sim 4\%$
- 0-b Efficiency: $\sim 0.1\%$

Thorsten Kuhl
Vertex 2002, 05.11.2002
Summary: Tagging at 500 GeV

b-Tagging:
  - As good as for 91.2 GeV

c-Tagging:
  - Much improved because of boost

Multi jet final state:
  - Jetwise tag ~5-10% less efficient hemisphere tag
  - Fast simulation verified
  - Excellent tool for searches

Excellent tool at high energy!
Summary

- TESLA vertex detector: Excellent physics tool
- 4 R&D projects with different sensors
- Show CCD detector results as example
- Excellent tagging performance for b and especially for c at low and high energy
- Excellent tool for (Higgs) searches
- Comparison 5 to 4 layer: Importance of fifth layer shown for c-tag and vertex charge