Tracker Performance Benchmarks for High-pT Tracks

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ALCPG Winter Workshop @ SLAC
January 7, 2004
Performance Benchmarks

- How do we know a detector design is “good enough”?
- As good as possible is not necessarily the right answer
  - Resources are always limited
  - Heroic efforts in one system can lead to performance compromises in other systems
  - The most successful detectors are usually those whose design is well matched to the physics

- Performance benchmarks can play a useful role in deciding whether a design is good enough

- For the outer tracker, need performance benchmarks for:
  - Momentum resolution for high-pT tracks – focus of this talk
  - Momentum resolution for low-pT tracks (especially for b/c tagging)
  - Long-lived decays (KS, new physics)
  - Coverage (this is one case where “as much as possible” applies)
Z Mass Resolution

- Providing good $Z \rightarrow \mu\mu$ mass resolution is a natural benchmark for high-pT tracker performance
  - Reconstruct ZH events
  - New physics may produce Z’s
  - The Z is the only known high mass state that can be fully reconstructed in an exclusive final state

- Z mass resolution dominated by tracker r-phi resolution
  - Multiple scattering, angle errors are small contributions

- As an example, look at the Z mass resolution for SiDet
  - “Circle” fit to expected hit resolutions
  - Includes correlated multiple scattering errors
  - Momentum resolution agrees with Bruce Schumm’s calculations to within ~20%
  - Assume symmetric Z decays with both muons in the x-y plane
Z Mass Resolution
Symmetric Z decay in x-y plane

- 7 um, 0.5% RL/layer
- 14um, 1.0% RL/layer
A Look at ZH kinematics

- How does excellent Z mass resolution translate into Higgs mass resolution?
- If initial state is known, Higgs mass can be determined from Z kinematics
  - For CM frame
    \[ m_H^2 = E_{CM} (E_{CM} - 2E_Z) + m_Z^2 \]

- To estimate the Higgs mass resolution, assume that
  - Collisions take place in CM frame with beam energy known
  - Assume Z decays symmetrically with both leptons in the x-y plane (\( \theta = 90^\circ \))

- Parameterize tracker momentum resolution as
  \[ \sigma_{p_T} = \alpha p_T^2 \]

- Extract Higgs mass resolution
  \[ \sigma(m_h) = \frac{\alpha (E_{cm}^2 + m_Z^2 - m_h^2)(E_{cm}^2 - 3m_Z^2 - m_h^2)}{8\sqrt{2m_h E_{cm}}} \]
ZH Missing Mass Resolution

Symmetric Z decay in x-y plane, tracker resolution of $\sigma(p_T) = 2.4 \times 10^{-5} p_T^2$

![Graph showing Higgs Mass Resolution](image)

- $E_{cm} = 300$ GeV
- $E_{cm} = 400$ GeV
- $E_{cm} = 500$ GeV

Higgs Mass Resolution (GeV) vs. Higgs Mass (GeV)
ZH Missing Mass Resolution

Symmetric Z decay in x-y plane, tracker resolution of $\sigma(p_T) = 4.2 \times 10^{-5} p_T^2$

- $E_{cm} = 300$ GeV
- $E_{cm} = 400$ GeV
- $E_{cm} = 500$ GeV

Higgs Mass Resolution (GeV)

Higgs Mass (GeV)
What About Beam Energy Spread?

- Initial state has neither fixed energy nor at rest in the detector frame due to beam energy spread
- Get beam energy spread from Mike Woods’ talk at the Cornell meeting
  » http://www.slac.stanford.edu/xorg/lcd/ipbi/cornell03/Woods_energy.ppt
  » Does not include ISR or beamstrahlung (Woods: will add low energy tail)
- For the Higgs missing mass resolution, the variation in initial state energy is dominant
  » Effect of a moving CM depends on decay angle, negligible for decays in the x-y plane
  
  \[ \sigma(m_h) = \frac{\left(E_{cm}^2 + m_h^2 - m_Z^2\right)}{2m_h E_{cm}} \sigma(E_{cm}) \]
NLC-500 Results

[Graphs showing distributions and scatter plots related to NLC-500 results.]
TESLA-500 Results

1. Incident Electron Energy (GeV)
2. Positron Energy (GeV) vs. Z (um)
3. $\sqrt{s}$ vs. Interaction Time
4. $\sqrt{s'}$ (GeV)
ZH Missing Mass Resolution - NLC
Symmetric Z decay in x-y plane, perfect tracker with 0.3% energy spread

Higgs Mass Resolution (GeV)

Ecm = 300 GeV
Ecm = 400 GeV
Ecm = 500 GeV

Higgs Mass (GeV)
ZH Missing Mass Resolution - Tesla
Symmetric Z decay in x-y plane, perfect tracker with 0.1% energy spread

Higgs Mass Resolution (GeV)
- Ecm = 300 GeV
- Ecm = 400 GeV
- Ecm = 500 GeV

Higgs Mass (GeV)
Conclusions

- Good Higgs missing mass resolution requires good tracker resolution
  - Missing mass resolution substantially poorer than Z mass resolution
  - For CM energies well above threshold:
    \[ \sigma(m_h) \approx \frac{E_{cm}^2}{2m_Z m_h} \sigma(m_Z) \]

- Beam energy spread contributes to the missing mass resolution
  - For NLC, detector resolution contribution roughly matches resolution contribution from beam energy spread for “less aggressive” SiDet parameters
  - For Tesla, detector resolutions appear to dominate
Open Questions

- Effect of ISR and beamstrahlung on missing mass resolution

- Would a kinematic fit help?
  - Use b directions as kinematic constraints
  - 0C fit when you allow for energy spread in beams
  - Can we determine b-quark directions accurately enough to improve resolution?
  - Now have to worry about FSR, clustering issues, etc.