Thoughts on Track-Based Observables

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Bringing Theory Closer to Experiment?

Goal of "Truth Objects":

Common language between experimental measurements and theoretical predictions
Very important task! (Sorry I can't be there to discuss in person)

Experimental Need:

Truth objects close enough to reconstructed objects to minimize unfolding uncertainties

Theoretical Needs:

Particle-based (not parton-based) to allow for later hadronization improvements
Infrared and collinear (IRC) safe to allow comparisons to fixed-order calculations

Experimental/Theoretical Opportunity:

Leverage theoretical insights on IRC unsafety to confront experimentally clean measurements with minimal unfolding?

Track-Based Observables

Obvious Experimental Advantages:

Excellent momentum/angular resolution for charged particles
Immediate control over pileup from vertexing
Smaller unfolding uncertainties than calorimeter-based measurements (right?)

Obvious Theoretical Challenge:

Not collinear safe; ill-defined in perturbation theory. E.g. $\rho^0 \to \pi^+ \pi^-$

Why Bother?

For dijet resonance searches, track jets give poor invariant mass resolution
For dark matter searches, tracks alone give poor missing momentum resolution
Calorimeters are there for a reason!

Promising Application for Track-Based Observables:

Precision/legacy standard model measurements, especially in high pileup environment

Some Personal Perspective

Experience with ALEPH:

I am trying to perform new event shape measurements on the Z pole
Fantastic archival "particle flow" data from ALEPH
Opportunities to do new e^+e^- measurements while waiting for ILC/CepC/FCC-ee

My Frustrations:

Very easy to make all sorts of measurements on particle flow objects
Very easy to do detector unfolding using "matrix method" (ALEPH recommended)
Very hard to match published systematic uncertainties!

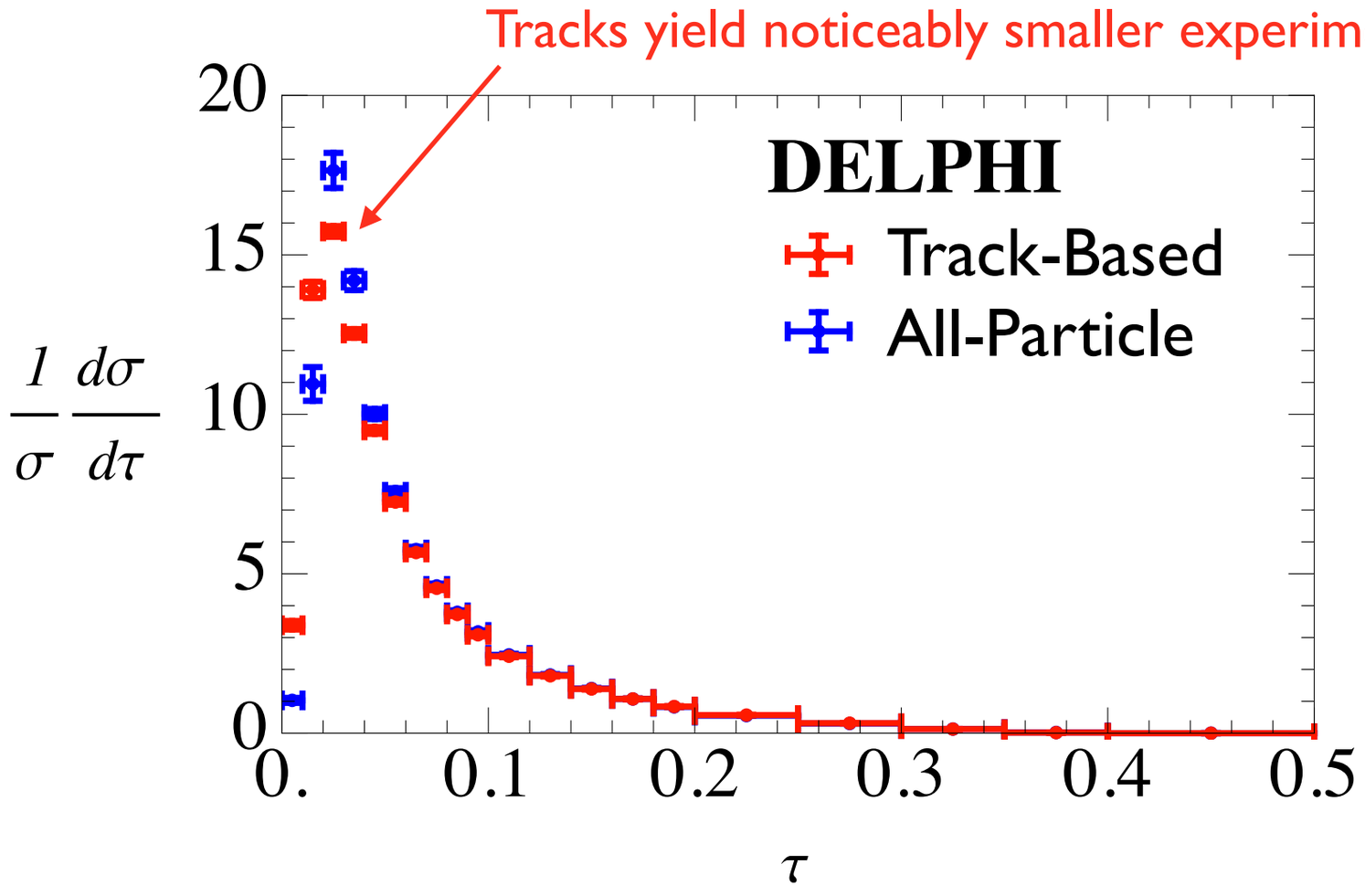
Key Challenge:

ALEPH cannot measure arbitrarily soft particles
Monte Carlo includes arbitrarily soft particles
Straight unfolding underestimates uncertainties in soft regime (bias to Monte Carlo)
Only recourse: use many Monte Carlo programs to cover soft uncertainties

Great Opportunity:

Systematic uncertainties seem to be dominated by soft neutrals
My analysis would be much easier with track-only event shapes!

Revisiting Thrust at LEP

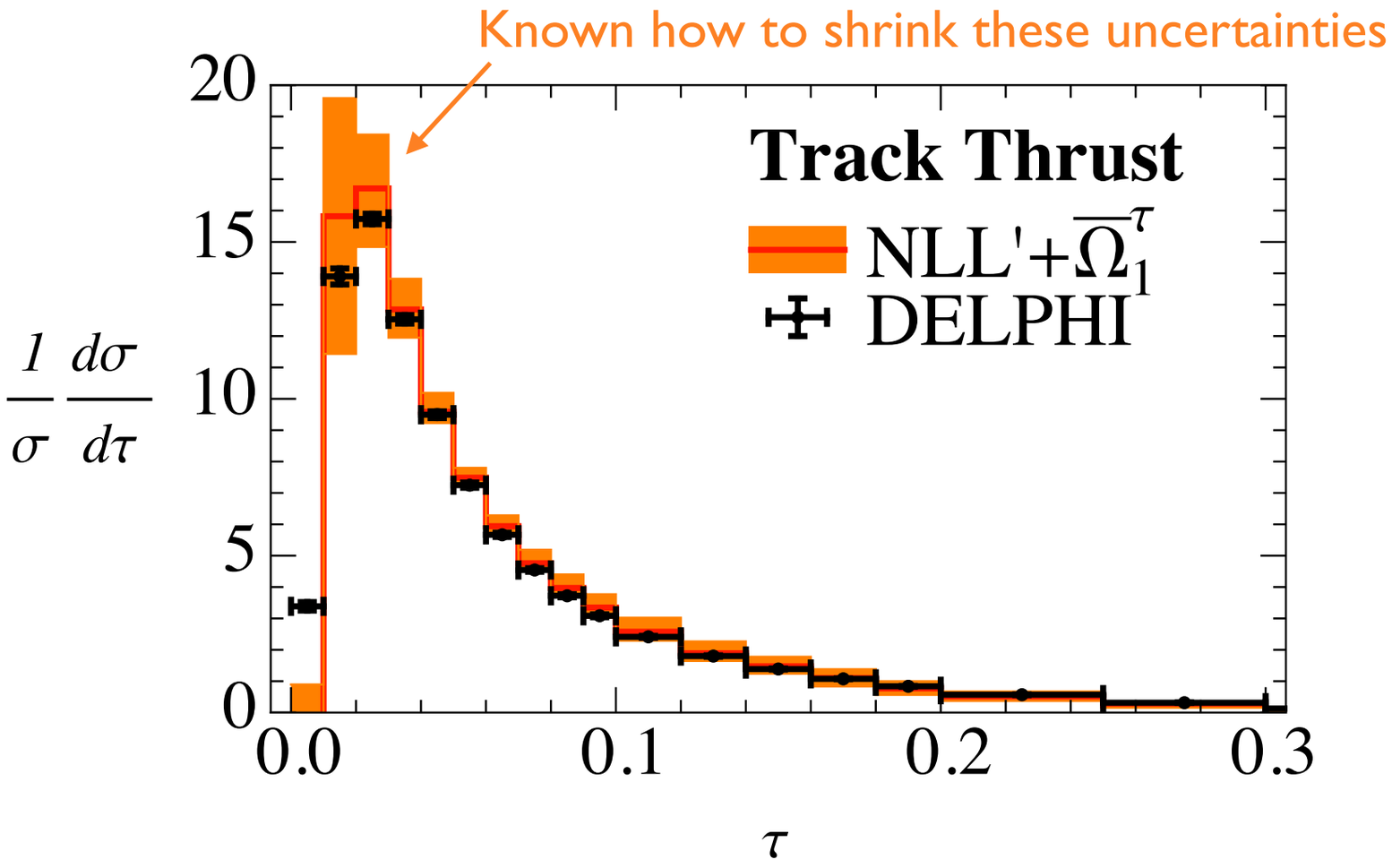


All-particle thrust is currently used for precision α_s extraction

Track-based thrust should improve result… if theory is up to the task

Revisiting Thrust at LEP

Theory *is* up to the task!



This is track-based calculation only at NLL'
State of the art for all-particle is N^{3}LL', possible for track-based as well

[Chang, Procura, JDT, Waalewijn, 1306.6630]

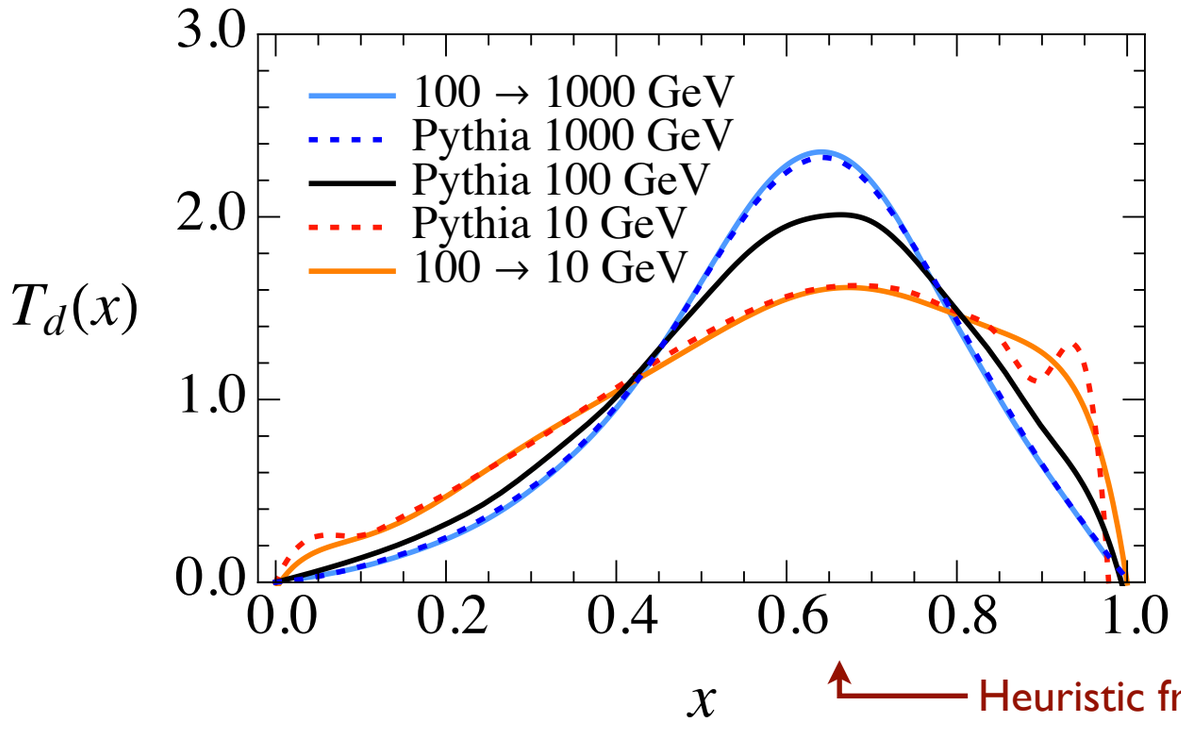
Introducing "Track Functions"

Recall Parton Distribution Functions:

Fraction of hadron's energy carried by one parton
Non-perturbative objects extracted from data; absorb collinear singularities
Use perturbative DGLAP evolution to extrapolate to higher scales

Track Functions:

Fraction of parton's energy carried by charged particles
Theoretically just like PDFs! (Non-perturbative object with perturbative evolution)



E.g. Down Quark Track Function

Black: Pythia at 100 GeV
Solid: Evolved to 10 GeV, 1000 GeV
Dashed: Pythia at 10 GeV, 1000 GeV

[Chang, Procura, JDT, Waalewijn, 1303.6637]

Which Tracks to Count?

Truth Tracks?

Do you count only detector stable particles? Which lifetime cut?
Do you reconstruct B mesons? D mesons? Remove $K_S \to \pi^+ \pi^-$?

Good News!

Track functions work with any consistent definition of "truth tracks"

Important Subtleties:

Must use definition based only on particle ID, not particle momentum
Must use consistent definition for extraction and application
Because of hadron masses and nonperturbative effects, corrections of order Λ_{QCD}/Q

Open Question:

Can we adapt track function to include absolute minimum p_T cut?
(Important to further mitigate unfolding issues)

Questions to the Workshop

To Experimentalists:

Improvement in precision enough to justify track-based measurements?
Really easier to unfold track jets, or still complications?
Pileup mitigation enough to consider track-based measurements?

To Theorists:

In principle, can automatically handle track functions at NLO. Worth the effort?
In principle, can extract track functions using similar framework to PDFs. Worth the effort?
Clearly IRC safe should be focus. Worth thinking about some collinear unsafe calculations?

Some Cases to Consider:

Dijet kinematics with track jets
W/Z + N jet staircase plots with track jets
Track jet vetos for exclusive Higgs processes
Track-based jet/event shapes

My Bottom Line

Important to measure/calculate legacy cross sections with minimal unfolding from detector to truth

Track-Based Observables:

Best example I can think of where unfolding should be minimal

Track Functions:

Theoretically as robust as PDFs

If we didn't have calorimeters, track functions would be essential!

Can generalize to handle other collinear unsafe measurements (i.e. CMS's p_T^D)

Trade Offs:

Calorimeters are there for a reason! Track-based measurements lose information

Tracking is very precise! Track-based measurements ideal for precision, esp. with pileup