

Effect of Fiducial Cuts on Energy-Energy Correlators

Where did the rest of my events go?

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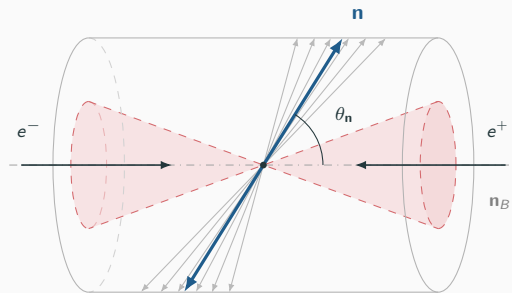
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with Johannes K. L. Michel and Wouter J. Waalewijn

Take home message

- I. We study EECs. Detector acceptance forces a cut on the **event-shape axis**. Current procedure: data inside the rejected region are "restored" using a Monte Carlo efficiency factor, but we need **precision** physics!
- II. Decompose the angular dependence of the EEC to **two structure functions**.
- III. The axis cut is *not* the dominant acceptance effect: **particle-level cuts** have an order of magnitude larger effect.



axis inside the red cones
 $\Rightarrow$ event rejected

Proposal: Use all-order structure of QCD to rigorously extrapolate data into the detector blind spots.

What is an Energy–Energy Correlator (EEC)?

Definition

$$\frac{d\Sigma}{dz} \equiv \sum_{a,b} \int d\sigma \frac{E_a E_b}{Q^2} \delta\left(z - \frac{1 - \cos\theta_{ab}}{2}\right)$$

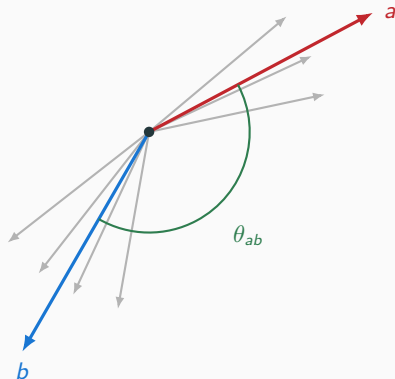
$$\frac{d\text{EEC}}{dz} \equiv \frac{1}{\sigma} \frac{d\Sigma}{dz}$$

Angular variable $z = \frac{1 - \cos\theta_{ab}}{2} \in [0, 1]$

$z \ll 1$ collinear region

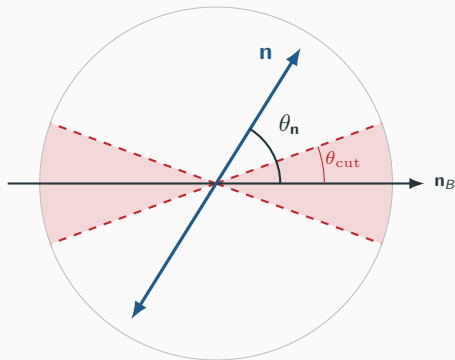
$1 - z \ll 1$ back-to-back region

$z \sim 1$ bulk



Acceptance cuts

Detector acceptance and the event-axis cut



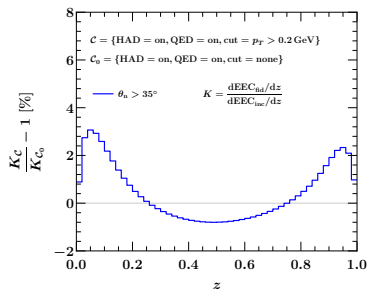
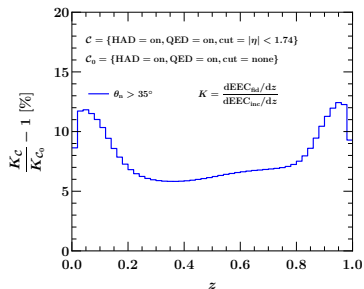
Coverage degrades in the forward region, so existing e^+e^- analyses require the oriented **event-shape axis $\mathbf{n}$** to lie centrally:

$$|\cos \theta_{\mathbf{n}}| \leq \cos \theta_{\text{cut}}$$

- ALEPH analysis: sphericity axis $\theta_{\text{cut}} \approx 35^\circ$
- SLD analysis: thrust axis $\theta_{\text{cut}} \approx 45^\circ$

The measured EEC is a **fiducial** quantity: the published “fully corrected” result needs an extrapolation to the full phase space.

Particle-level cuts



- $|\eta| < \eta_{\text{cut}}, \quad p_T > p_{T,\text{cut}}$

applied *before* the axis and the EEC are computed.

⇒ Particle-level cuts are the **largest** acceptance effect.

Shift of the efficiency factor K ($\theta_{\text{cut}} = 35^\circ$):

- $|\eta| < 1.74$: **$\mathcal{O}(10\%)$**
- $p_T > 0.2 \text{ GeV}$: **$\mathcal{O}(4\%)$**
- event-axis cut: up to **1%**
- hadronization: $\lesssim 0.1\%$
- QED radiation: noise

Current practice: a Monte Carlo efficiency factor

The published inclusive result is the fiducial measurement times a bin-by-bin MC efficiency factor:

$$\frac{d\text{EEC}_{\text{inc}}^{\text{exp}}}{dz} = \frac{d\text{EEC}_{\text{fid}}^{\text{exp}}(\theta_{\text{cut}})}{dz} \times \underbrace{\left[\frac{d\text{EEC}_{\text{inc}}^{\text{MC}}}{dz} / \frac{d\text{EEC}_{\text{fid}}^{\text{MC}}(\theta_{\text{cut}})}{dz} \right]}_{K^{-1}(\theta_{\text{cut}})}$$

Percent-level data are corrected by a factor whose accuracy is not constrained by the measurement itself and its systematic uncertainty cannot be assessed.

Example: in the bulk the EEC starts at $\mathcal{O}(\alpha_s)$: an η cut changes it by $\sim 10\%$ at that order

$$\frac{d\text{EEC}(|\eta| < \eta_{\text{cut}})/dz}{d\text{EEC}/dz} \propto 1 + \underbrace{\mathcal{O}(10\%)}_{\mathcal{O}(\alpha_s): \text{MC } \checkmark} + \underbrace{\mathcal{O}(1\%)}_{\mathcal{O}(\alpha_s^2): \text{uncontrolled}}$$

Symmetry fixes the angular dependence

$$\frac{d^2\Sigma_{\text{fid}}}{dz d\cos\theta_n} = \frac{3}{8}(1 + \cos^2\theta_n) \frac{d\Sigma_U(Q, z)}{dz} + \frac{3}{16}(1 - 3\cos^2\theta_n) \frac{d\Sigma_O(Q, z)}{dz}$$

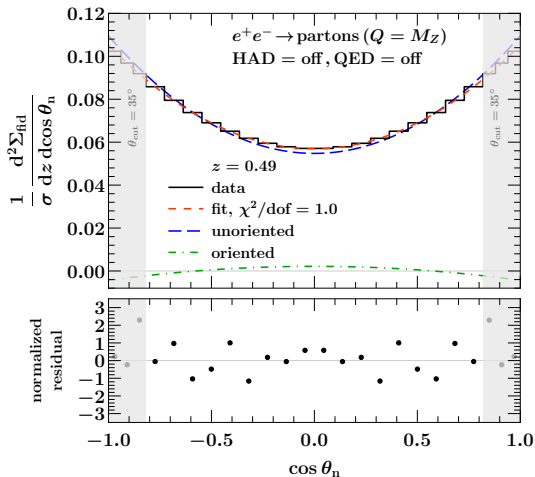
- Holds **to all orders in α_s** , at hadron level, for **any** event axis.
- Removing the cut leaves only the unoriented term: $d\Sigma_{\text{inc}}/dz = d\Sigma_U/dz$.

Measuring the EEC *double differentially* in z and $\cos\theta_n$ determines both structure functions from data inside the acceptance. The unoriented one is the full-phase-space EEC.

Same logic as the Drell–Yan angular coefficients $A_0, \dots, A_7$: **standard since the Tevatron**.

ATLAS, EPJC 86 (2026) 483 CMS, arXiv:2604.25678

Defiducialization on Pythia data



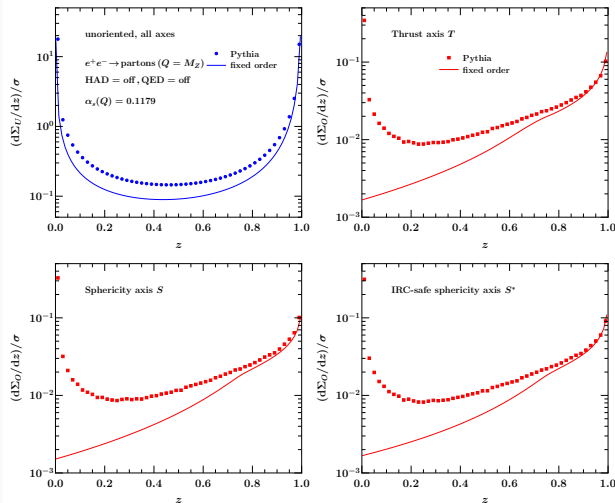
The fit uses **only the accepted region** (white).

- **blue**: unoriented harmonic $\propto 1 + \cos \theta_n^2$
- **green**: oriented harmonic $\propto 1 - 3 \cos \theta_n^2$

The fitted $d\Sigma_U/dz$ is proportional to the full-phase-space EEC, obtained **without an efficiency factor**.

The oriented EEC at $\mathcal{O}(\alpha_s)$

Structure functions: fixed order vs Pythia

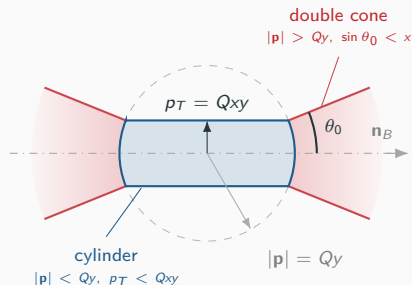


Fit the two harmonics to Pythia at each z , and compare with the $\mathcal{O}(\alpha_s)$ result.

- **Unoriented:** singular at both ends.
- **Oriented:** at small z Pythia's oriented function reflects the shower/resummation.

Particle-level cuts

Removing the particle cuts



Tie the two cuts together: $\sin \theta_0 = x$,
 $p_{T,\text{cut}} = Q \times y$.

Removed region = double cone $\cup$ cylinder.

ALEPH: $\eta_{\text{cut}} \simeq 1.74$, $p_{T,\text{cut}} = 0.2 \text{ GeV}$

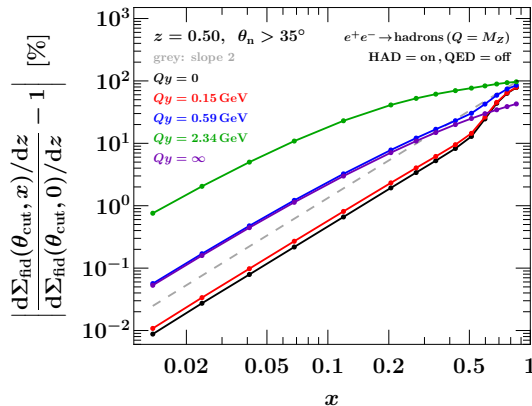
$\Rightarrow x \simeq 0.34$, $y = 6.4 \times 10^{-3}$, $Qy \simeq 0.59 \text{ GeV}$

We can prove that

$$\frac{d\Sigma_{\text{fid}}(\theta_{\text{cut}}, x, y)}{dz} = \frac{d\Sigma_{\text{fid}}^{(0)}(\theta_{\text{cut}})}{dz} + x^2 \frac{d\Sigma_{\text{fid}}^{(2)}(\theta_{\text{cut}}, y)}{dz} + \mathcal{O}(x^3)$$

and the offset is the fiducial EEC *free of particle-level cuts*.

Validation: the x^2 law

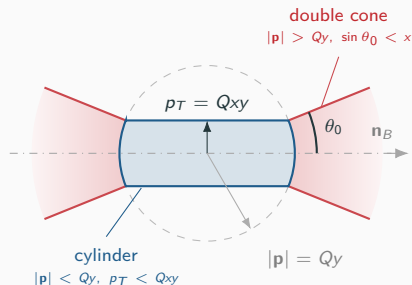


Fit each curve to $A + Bx^n$ at small x :

Qy	$x \leq 0.12$	$x \leq 0.041$
0	1.990(6)	2.002(12)
0.15 GeV	1.989(5)	2.006(10)
0.59 GeV	1.869(1)	1.940(2)
2.34 GeV	1.577(1)	1.717(1)
∞	1.861(1)	1.936(1)

✓ Predicted x^2 law confirmed: $n \rightarrow 2$ as the window shrinks.

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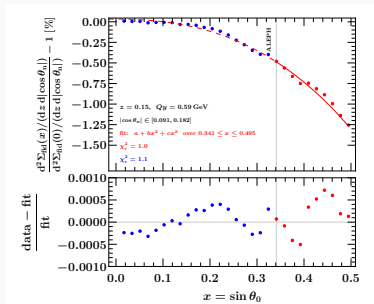
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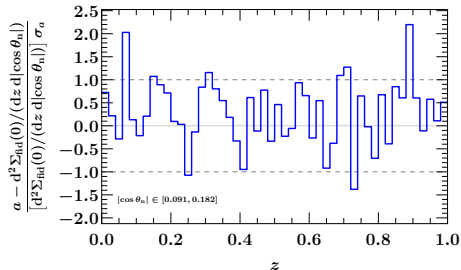
and the offset is the fiducial EEC *free of particle-level cuts*.

The proposal: measure the EEC at a few $x > x_{\text{nominal}}$ at fixed y , fit to the power law, keep the offset and apply the harmonic fit.

Extrapolating from inside the acceptance

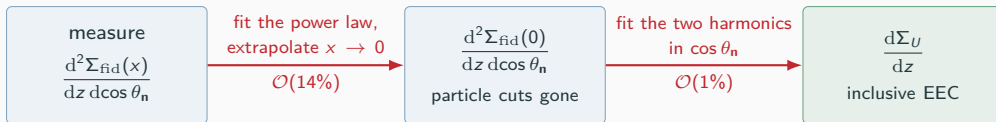


- Cuts can only be made *larger*: measure at $x \geq x_{\text{ALEPH}}$ only (red).
- Fit $a + bx^2 + cx^3$ there, extrapolate to $x = 0$.
- Blue: $x < x_{\text{ALEPH}}$, is a **black box** in data.



It works! We get closure.

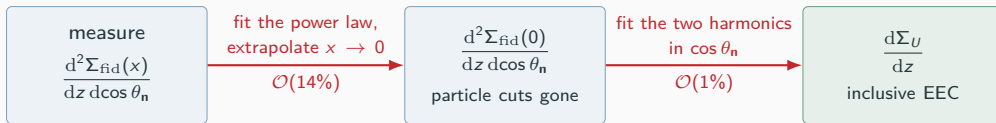
Summary



Every step uses **only data inside the acceptance**, no MC efficiency factor anywhere.

We can fully control for both axis and particle-level cuts
using all-order theory and making smart use of data.

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Thank you!