NNLO Corrections to Event Orientation in $e^+e^- \to 3$ Jets
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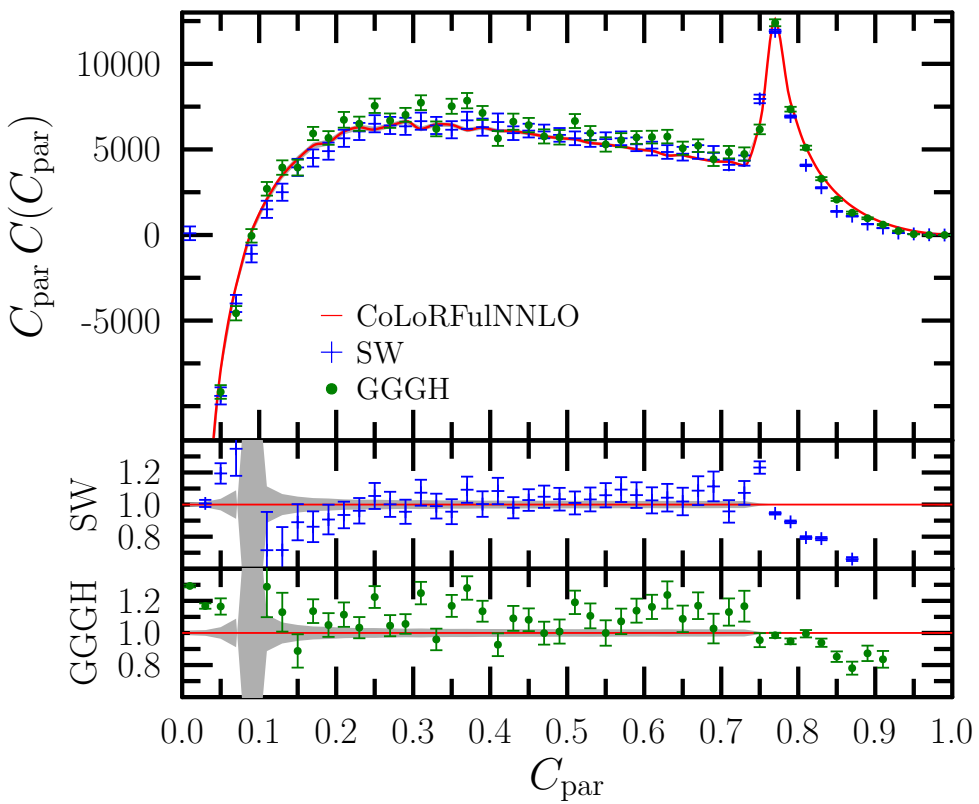
Outline

NNLO QCD Fixed-Order Predictions for $e^+e^- \to \gamma/Z \to 3$ Jets

Fixed-order predictions for canonical event shapes:

- Antenna subtraction [S. Weinzierl (2009), Gehrmann-DeRidder et.al (2007) EERAD3]
- CoLoRFulNNLO [Del Duca et.al(2016)]



E.g:

$$C_{par} = \frac{3}{2} \frac{\sum_{i,j} |\vec{p}_i||\vec{p}_j| \sin^2 \theta_{ij}}{\left(\sum_i |\vec{p}_i|\right)^2}$$

[Del Duca et.al (2016)]

Event Shapes in e^+e^- annihilation

Event shapes have been calculated to NNLO QCD accuracy

- Canonical Event Shapes include:
  - Thrust, heavy jet mass, wide and total jet broadening, two-to-three jet transition variable y_{23}
- Recently extended by:
  - Jet cone energy fraction and energy-energy correlation [Del Duca et.al (2016)]
  - Energy-energy correlation at NNLO+NNLL [Tulipant et.al (2017)]

Expanded perturbatively, an event shape variable y is given by:

$$\frac{1}{\sigma_0}\frac{\mathrm{d}\sigma}{\mathrm{d}y} = \left(\frac{\alpha_s}{2\pi}\right)\frac{\mathrm{d}A}{\mathrm{d}y} + \left(\frac{\alpha_s}{2\pi}\right)^2\frac{\mathrm{d}B}{\mathrm{d}y} + \left(\frac{\alpha_s}{2\pi}\right)^3\frac{\mathrm{d}C}{\mathrm{d}y} + \mathcal{O}(\alpha_s^4) + \cdots,$$

with two-jet cross section σ_0.

Event Shapes in e^+e^- annihilation

Resummation known for:

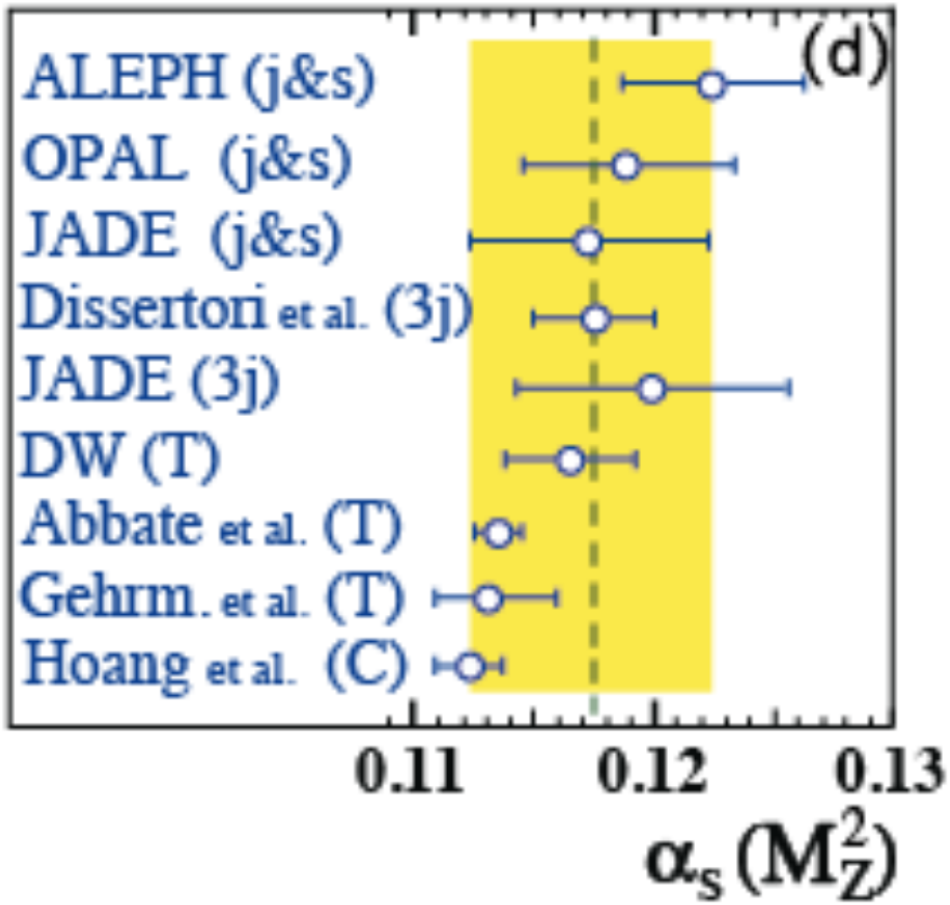
- continuously global, rIRC safe event-shape observables up to N^2LL [Banfi et.al (2014)] (ARES)
- N^3LL for $(1-T)$ and C apart from four-loop cusp anomalous dimension.[Hoang et.al (2014)]

NLO Electro-weak corrections known for

- $\mathcal{O}(\alpha^3\alpha_s)$ corrections to three-jet production ES [Denner et.al (2010)]
- Alternatively use OpenLoops+SHERPA.

Extraction of $\alpha_s(M_Z)$ from Event Shapes

[Bethke,Salam,Dissertori ('15)]



- Event shapes are used to determine value of $\alpha_s(M_Z)$
- Extractions from NNLL(N3LL)+NNLO event shapes are in tension with lattice calculations!

Is There Room for Improvement?

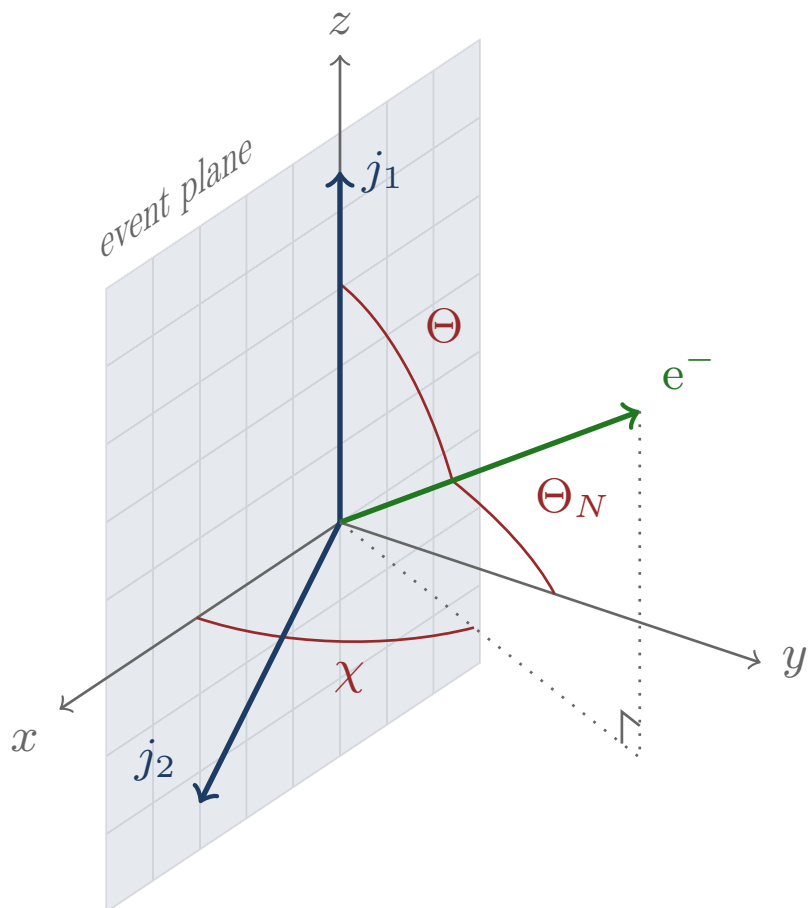
Calculations of standard programs have been run with idealised lepton kinematics and for full 4π angular coverage:

$\rightarrow$ Lepton kinematics can be averaged out!

- Data has to be corrected for limited detector acceptance to match theoretical prediction
- SLD [hep-ex/9608016] found NLO effects to be small!

To be really precise, i.e. per-mille level, theoretical predictions should mirror experimental measurements:
$\rightarrow$ compare distributions in fiducial region
$\rightarrow$ use event orientations to get an indication for size of effects!

Event Orientation in e^+e^- Annihilation



For three jet final states, event orientations are defined by:

- Θ, Θ_N, χ

Full lepton kinematic has to be considered in calculations!

NNLOJET: $e^+e^- \to 3$ jets

Event orientations were calculated using the NNLOJET program.
NNLOJET is:

- A semi-automated Monte Carlo for NNLO QCD phenomenology
- Employs the antenna subtraction formalism
- Includes a variety of processes at NNLO:

Processes

- pp→H+ jet [arXiv:1607.08817]
- pp→Z + jet [arXiv:1607.01749]
- DIS dijets [arXiv:1606.03991],
- pp→dijets[arXiv:1611.01460]
- $e^+e^- \to 3$ jets [arXiv:1709.01097],

NNLOJET is interfaced to APPLfast program to generate grids for $\alpha_s(M_Z)$ and PDF fits [H1 et.al(2017)].

Experimental measurements of event orientations

Event orientation variables for exclusive three-jet final states were measured at

- The Stanford Linear Detector(SLD) at SLC,
- L3 at LEP,

colliding electron and positron beams each with energy $M_Z/2$.

Jets are found using the JADE algorithm with parameter y_{cut}.

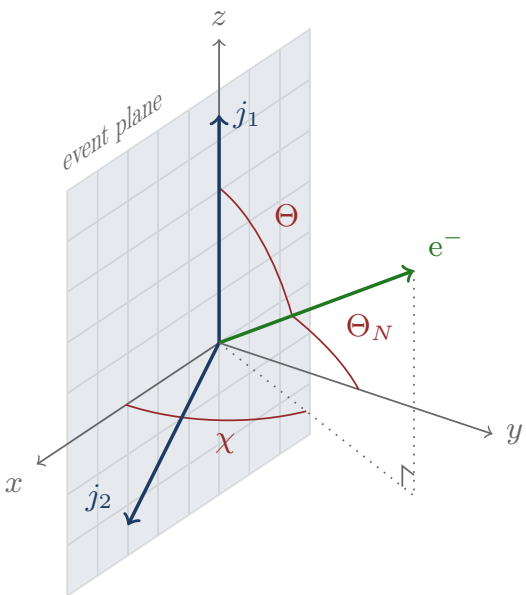
- L3 obtained two measurements:
  1. For a range; $0.02 < y_{cut} < 0.05$
  2. For a fixed coarse jet resolution; $y_{cut} = 0.25$
- SLD used $y_{cut} = 0.02$

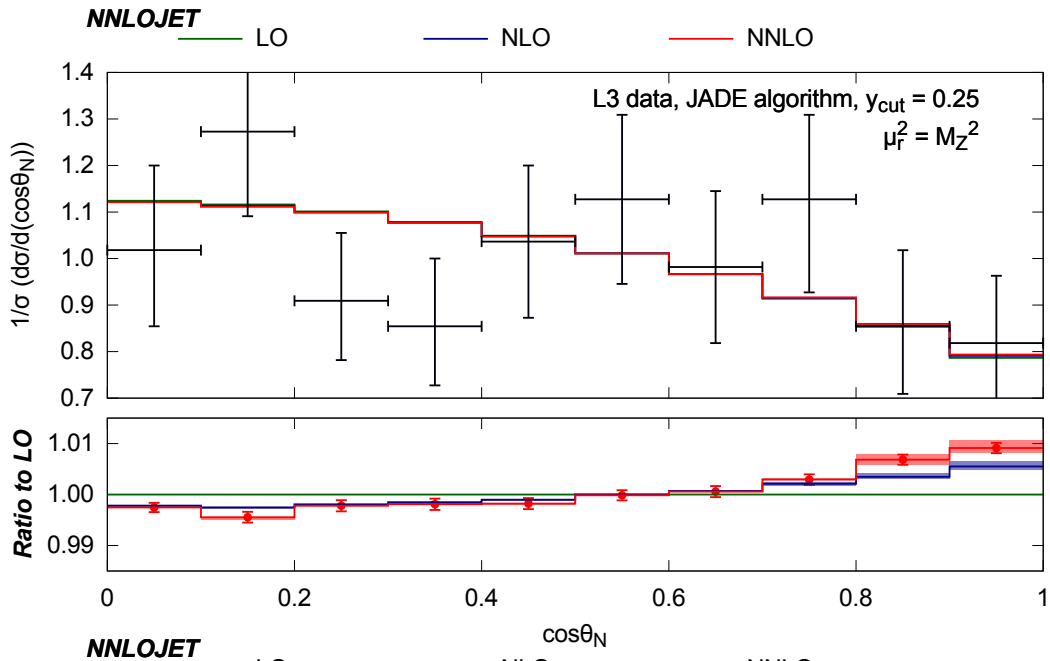
All data:

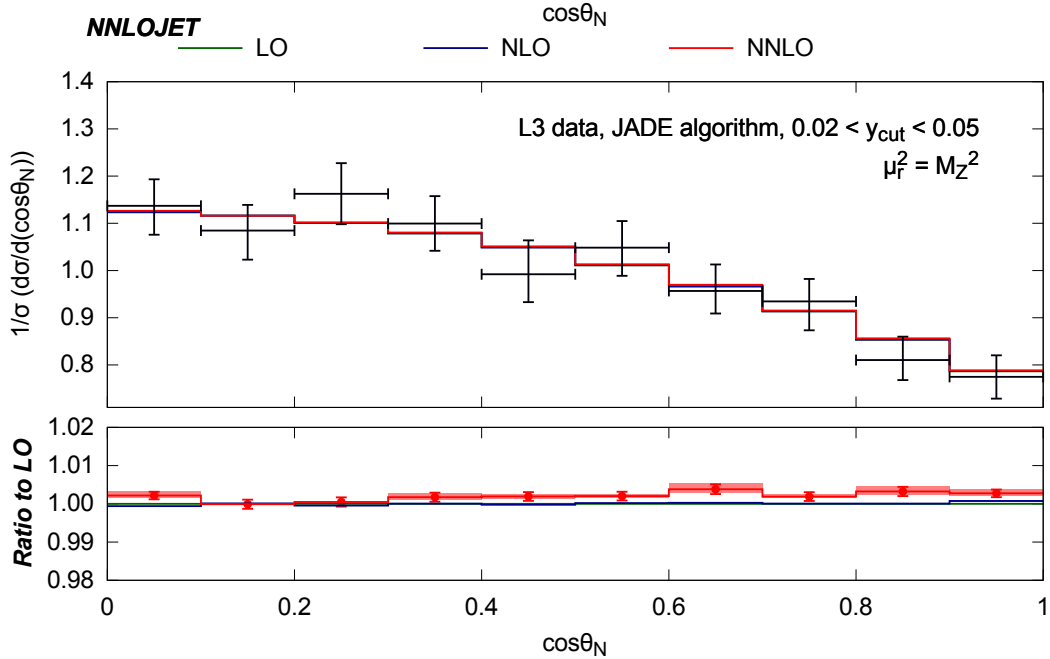
- Corrections to 4π acceptance: only relevant in endpoint bins of event orientation distributions.
- normalised to the three-jet cross section
  1. distributions integrate to unity by construction.
  2. leading order is independent of α_s.

$\rightarrow$Look order-by-order for size of corrections.

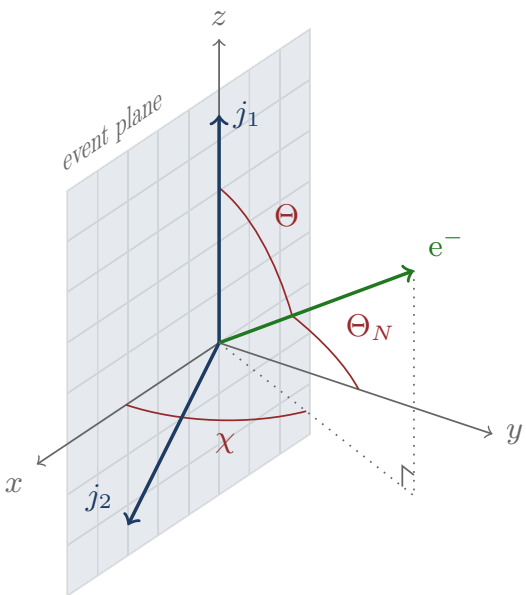
Results for Θ_N: Coarse vs Fine Jet Resultion

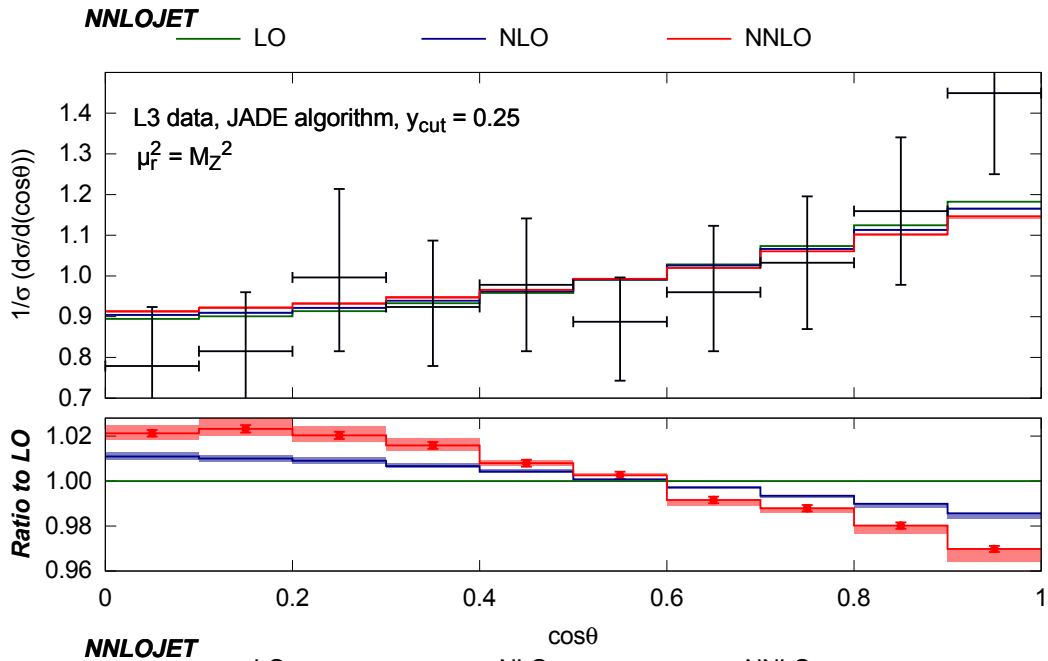


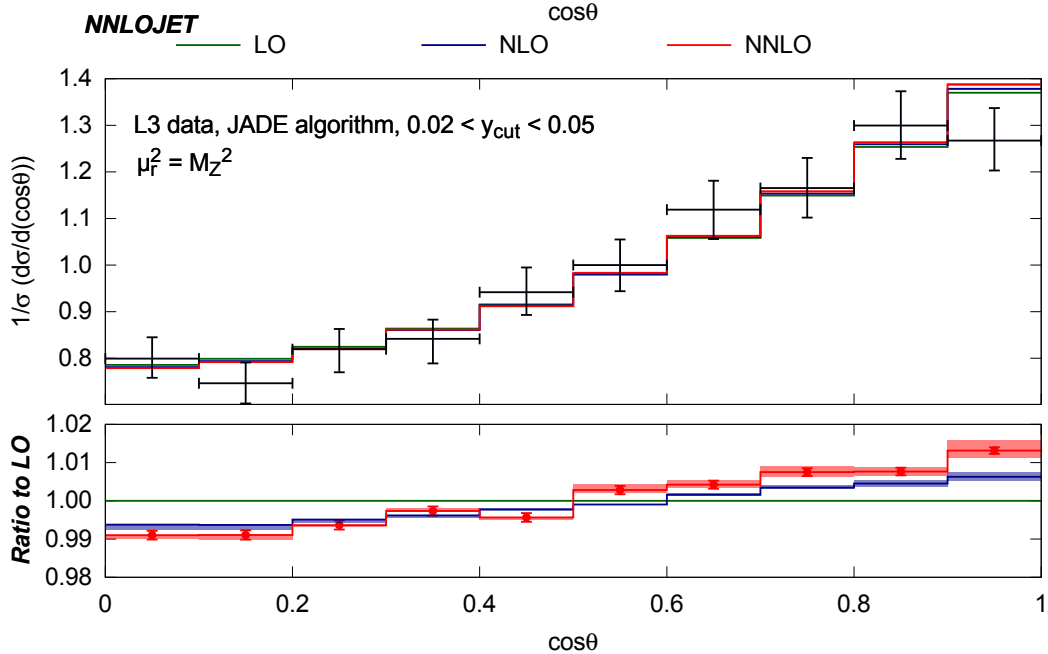




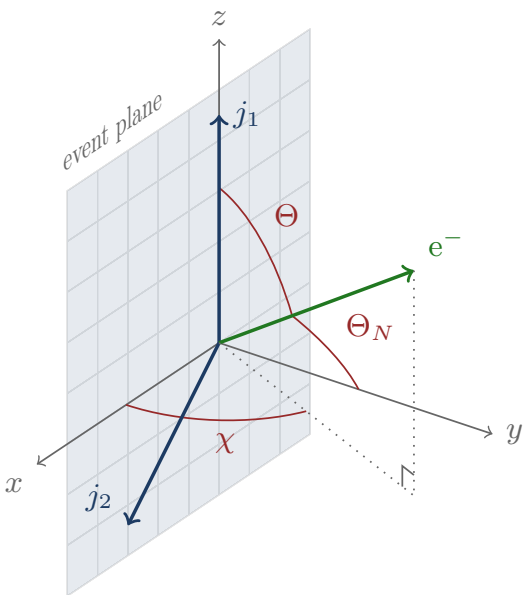
Results for Θ: Coarse vs Fine Jet Resultion

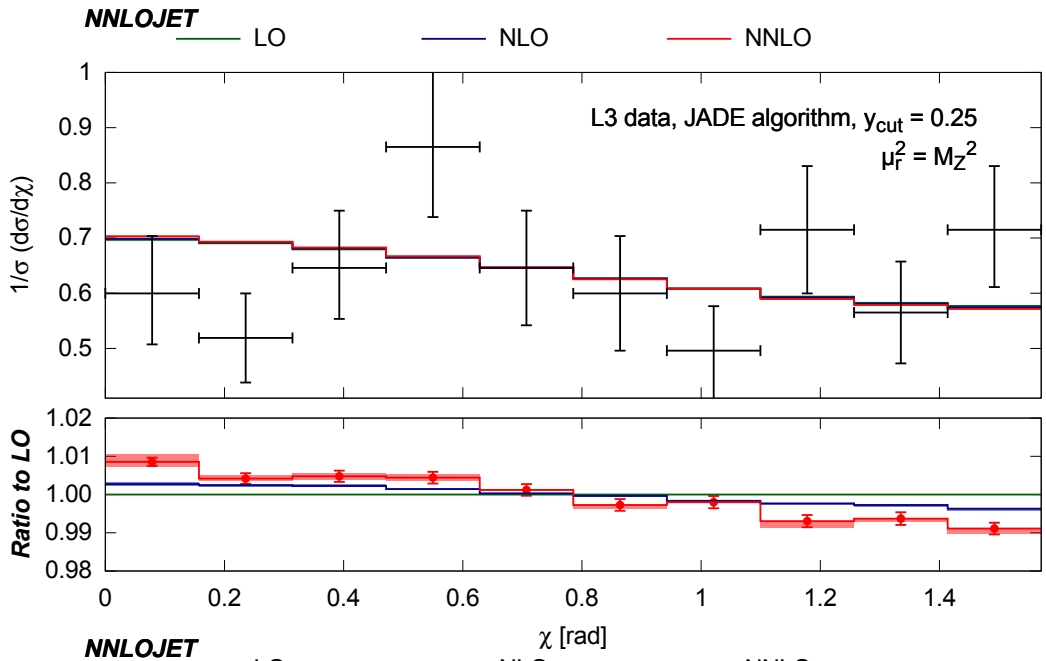


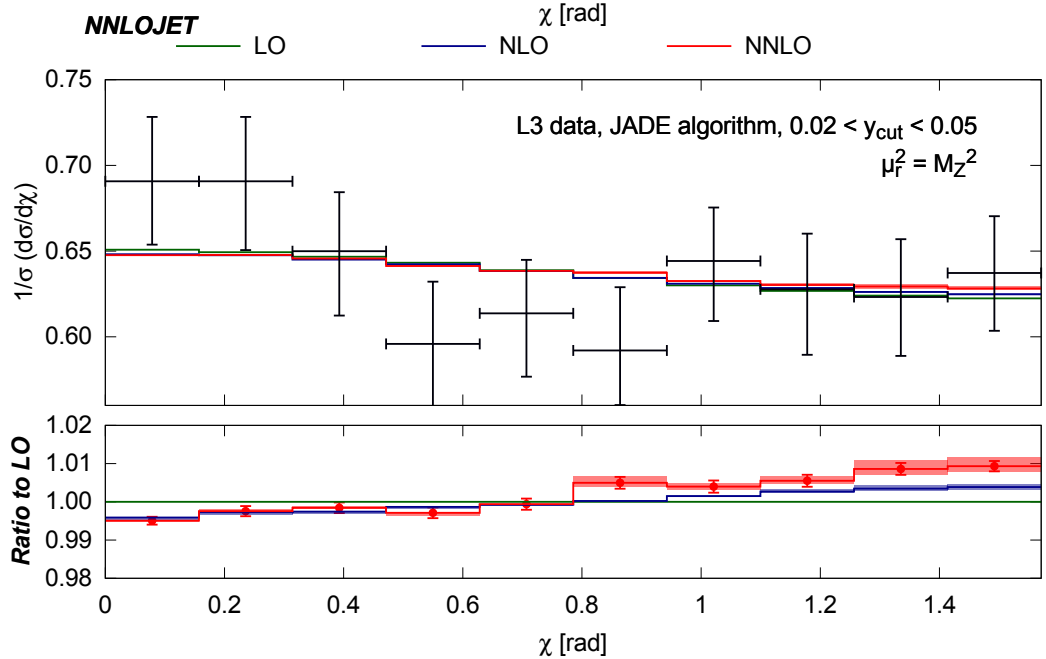




Results for χ: Coarse vs Fine Jet Resultion







Conclusions

We find event orientation variables

- are extremely robust under QCD corrections.
- finer jet resolution has a smaller correction.

Our findings support the validity of applied acceptance corrections at LEP and SLD!

However, to obtain per-mille accuracy at a future linear collider NNLO QCD corrections to event orientations will be important!
$\rightarrow$ compare fiducial cross sections!

Precision QCD Studies at a Future Linear Collider

At a future linear collider our calculation can be used to:

- Combine fixed-order results with N^2LL resummations
- Include NLO EW corrections
  $\rightarrow$ no di-boson veto on data necessary anymore.
- Compare experiment and theory in fiducial region

Results can be used for a precise extraction of $\alpha_s(M_Z)$:

- Non perturbative corrections go as $1/\sqrt{s}$
  $\rightarrow$ NP corrections at future LC smaller than at LEP/LEP2, enables independent $\alpha_s(M_Z)$ extraction.