Energy-energy correlators with archived ALEPH e^+e^- data

Yi Chen (Vanderbilt U.) , Hannah Bossi (MIT)
Yen-Jie Lee (MIT)

Miniworkshop on CMS gluon charge analysis and ALEPH results

MIT, Cambridge, MA, US

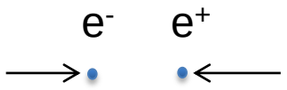
28th February, 2024

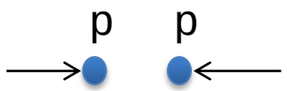
MIT HIG group's work was supported by US DOE-NP

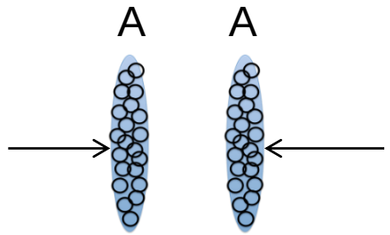
Motivation

- Monte Carlo generators such as PYTHIA 6, PYTHIA 8, SHERPA and HERWIG are tuned with hadronic event shape observables and hadron spectra in $e^+ e^-$
  - Then used to predict the jet spectra and substructure in more complicated hadron collisions

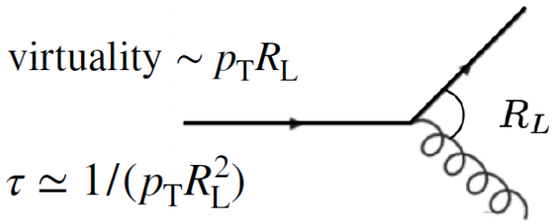
- **EEC in e^+e^-:**
  - New tool for α_s extraction
  - Test on pQCD and compared to event generators.
  - Utilize the new jet clustering tools developed after LEP operation
  - Revisit EEC with fine binning and extended it to full event.
  - Reference of pp

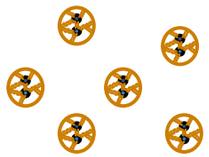




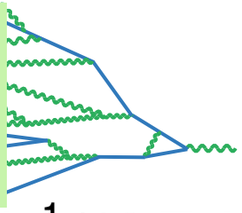


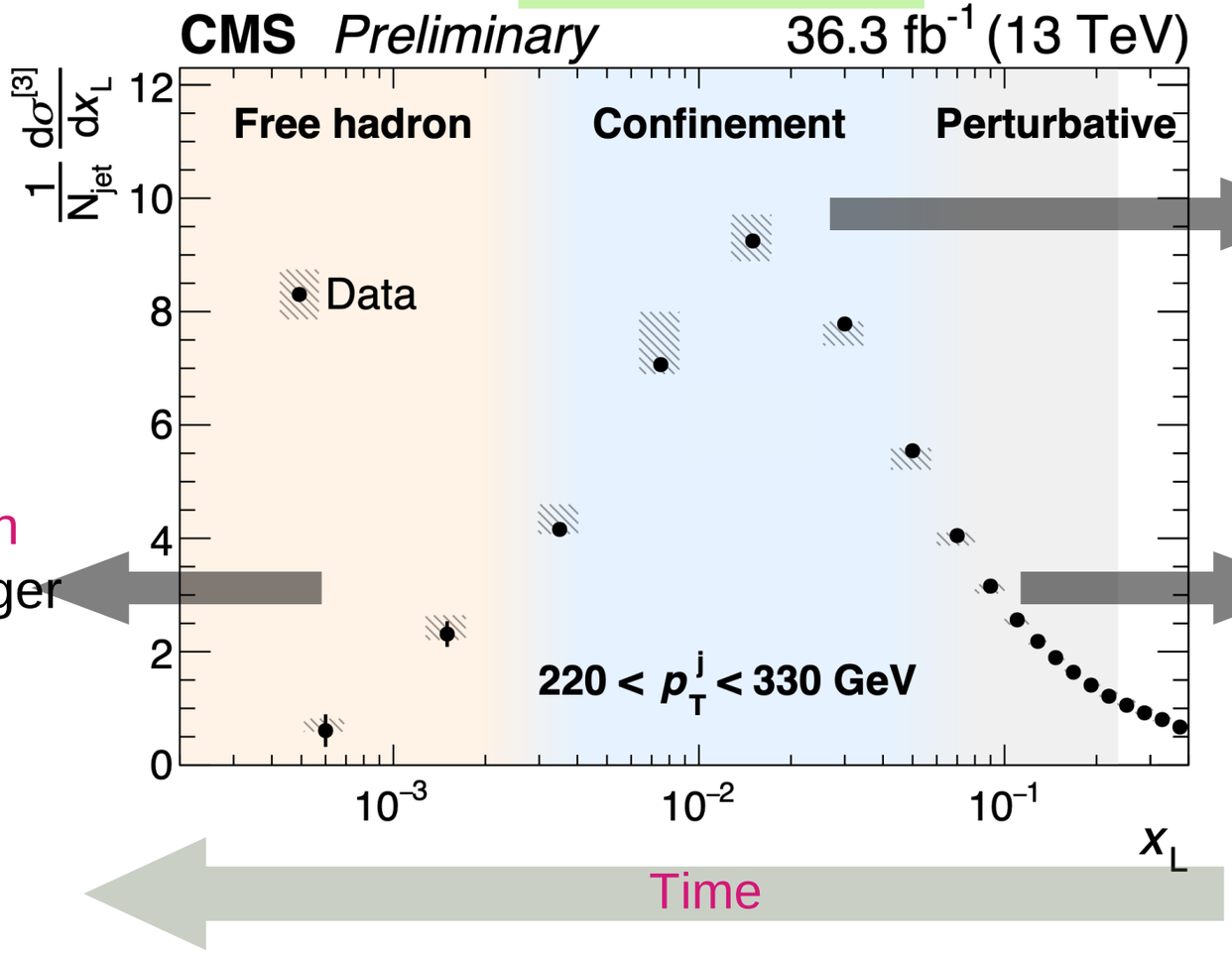
Unfolded E2C in pp at 13 TeV





Confinement



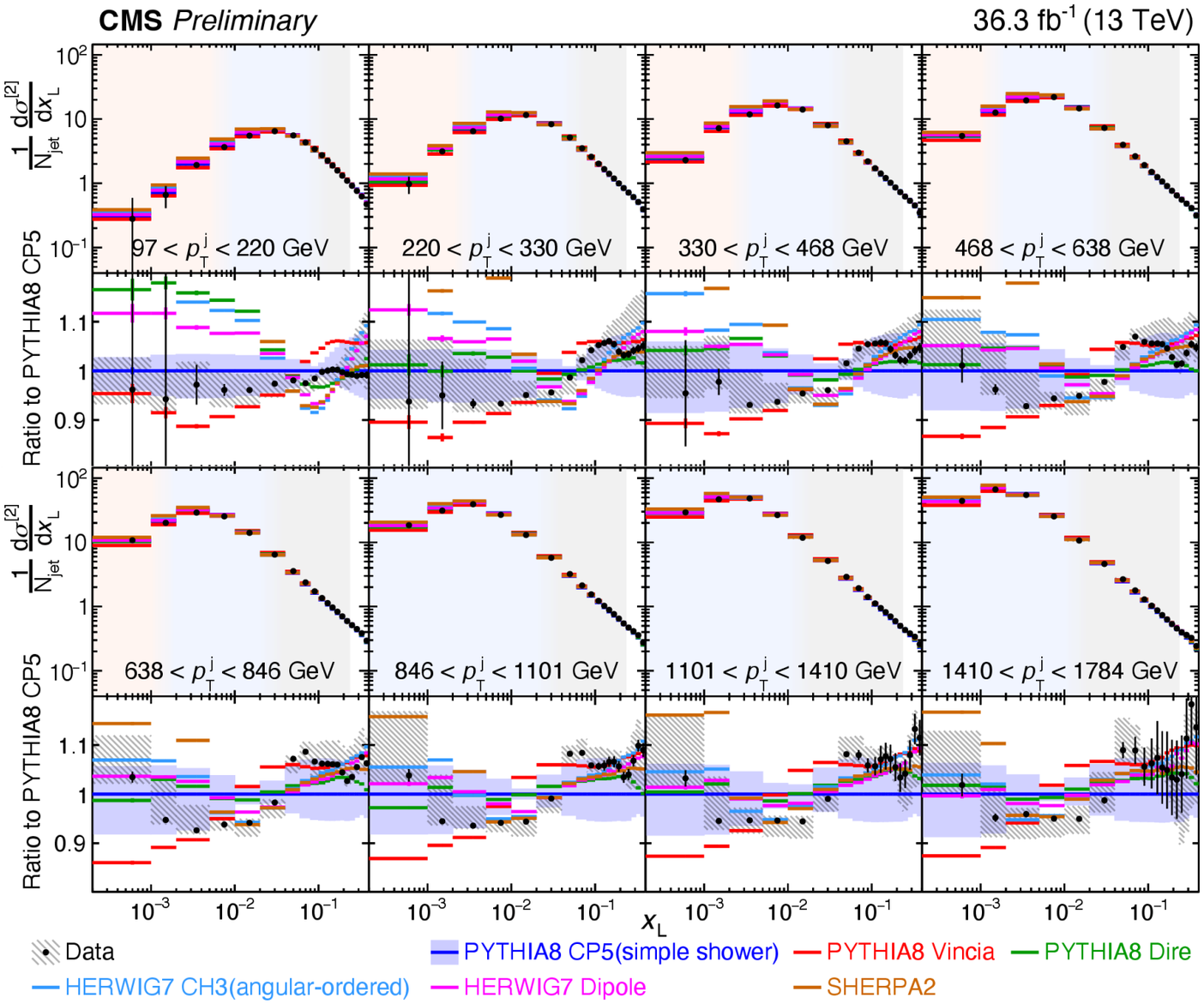


Phase transition
from parton to hadron

Non-interacting hadron
random distribution integer
power-law scaling

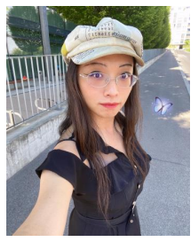
Interacting partons non-integer scaling

Unfolded E2C vs MC Generators in pp at 13 TeV



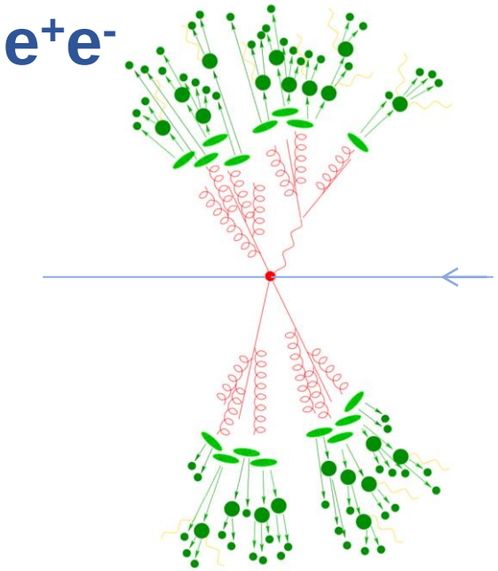
- Results compared to PYTHIA8, HERWIG and SHERPA2
- None of the generator fully describes the E2C data
- Spread of the predictions from generators at the 10-20% level
- Peak position at around $p_T X_L \sim$ 2-3 GeV

Energy-energy correlators in e^+e^-



Yi Chen (Vanderbilt U.)

Hannah Bossi (MIT)



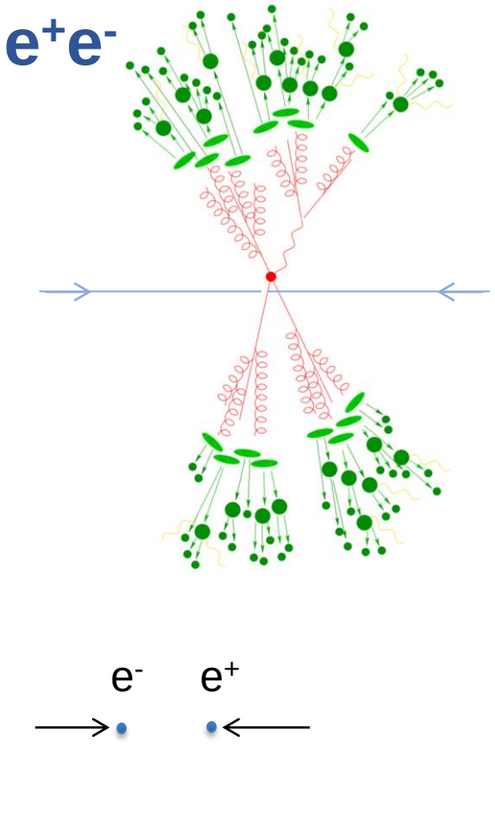
Jet in Electron-Positron Annihilation

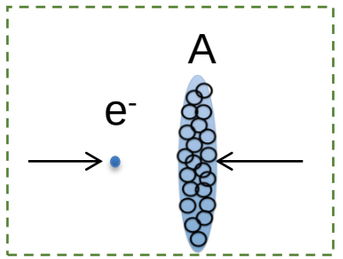
- Jets in e^+e^- with identical algorithms as those used in hadron colliders are of great interest
  - No gluonic initial state radiation
  - No complications of parton distribution functions
  - No beam remnants and multi-parton interactions

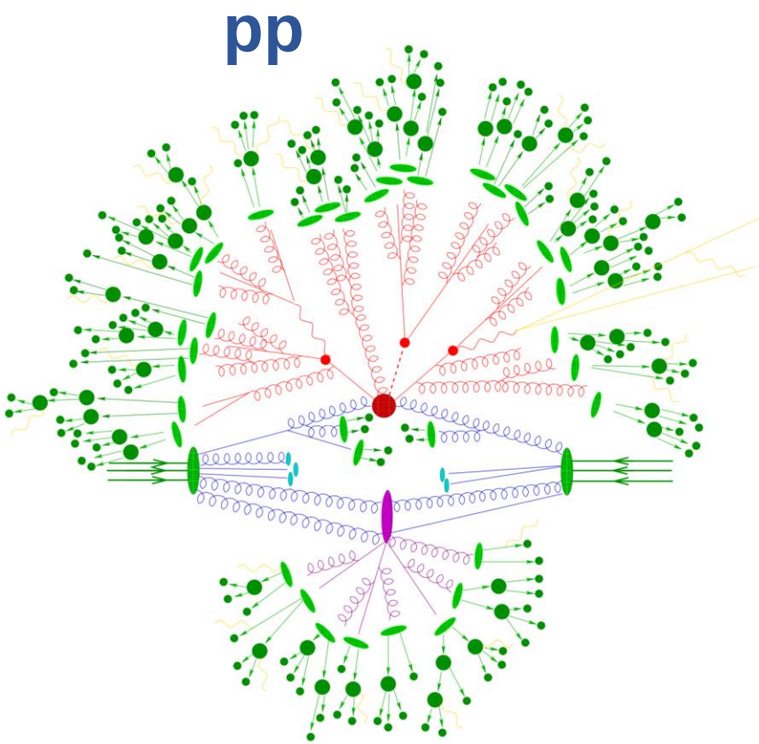
  → Cleanest test of pQCD and phenomenological models

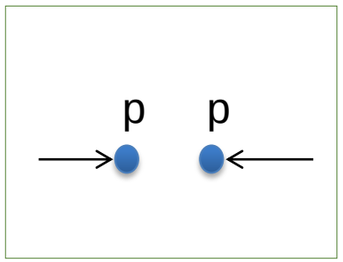
- Serve as a reference for the **pp** and future **EIC** measurements

- Inform the QCD studies at the future FCC.









Definition of EEC in e^+e^-

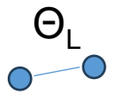
- No Jet reconstruction, Full event

$$\frac{1}{N_{event}} \frac{d(\sum E_i E_j / E^2)}{d\theta_L}$$

Yi Chen (Vanderbilt U.)

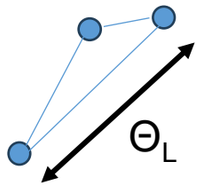
  - Sum over pairs of charged particles in the event
  - Normalize by total energy E in the event (91.2 GeV by definition in LEP1)
  - **Θ_L is the opening angle (in rad.)** as opposed to the R_L or x_L which is eta-phi
  - Average over all events considered

E2C



- Similar for 3-particle or higher correlators
  - For N-particle correlators, **Θ_L is defined as the largest angle of the pairs**

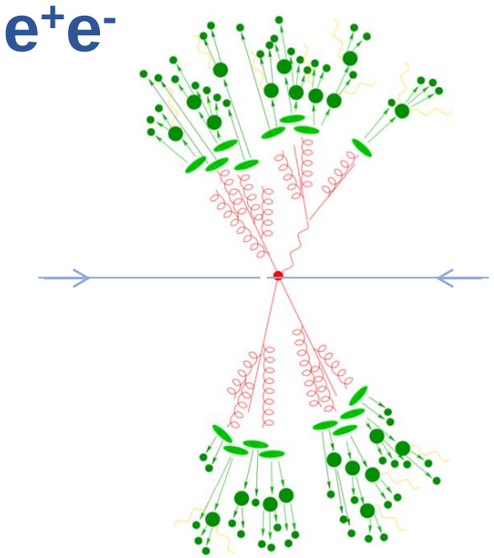
E3C

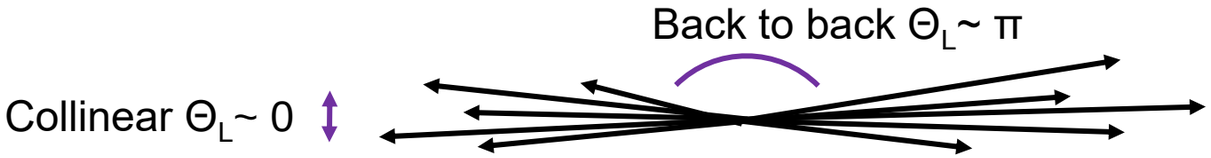


EEC in e^+e^-: Extending to back-to-back region

- Back-to-back (Sudakov Limit)
  - At $\Theta \sim \pi$
  - Study correlations of the full set of particles, not just those within jets
- **Not possible to explore with jet substructure**
  - Presents a unique opportunity in e^+e^-!
- Important ingredient into theory calculations to control non-perturbative effect
- Similar to collinear limit, this can also be used to study confinement transition and strong coupling constant

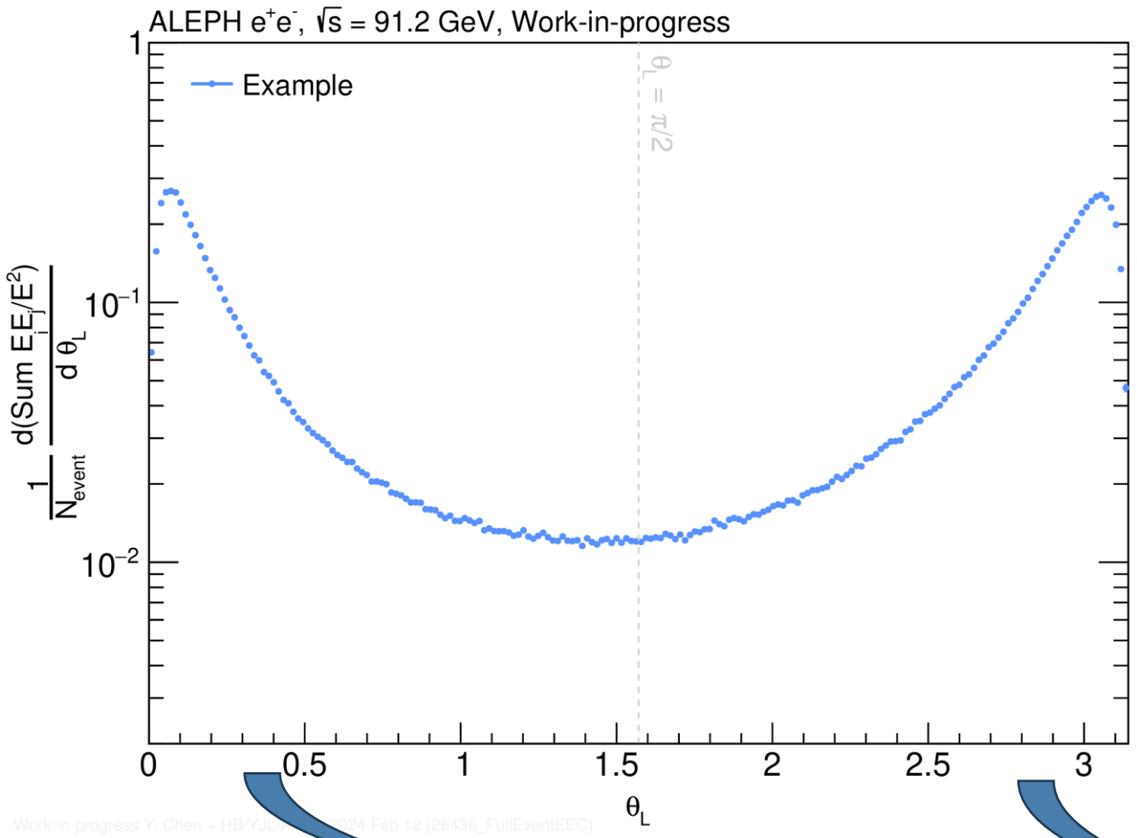
Yi Chen (Vanderbilt U.)

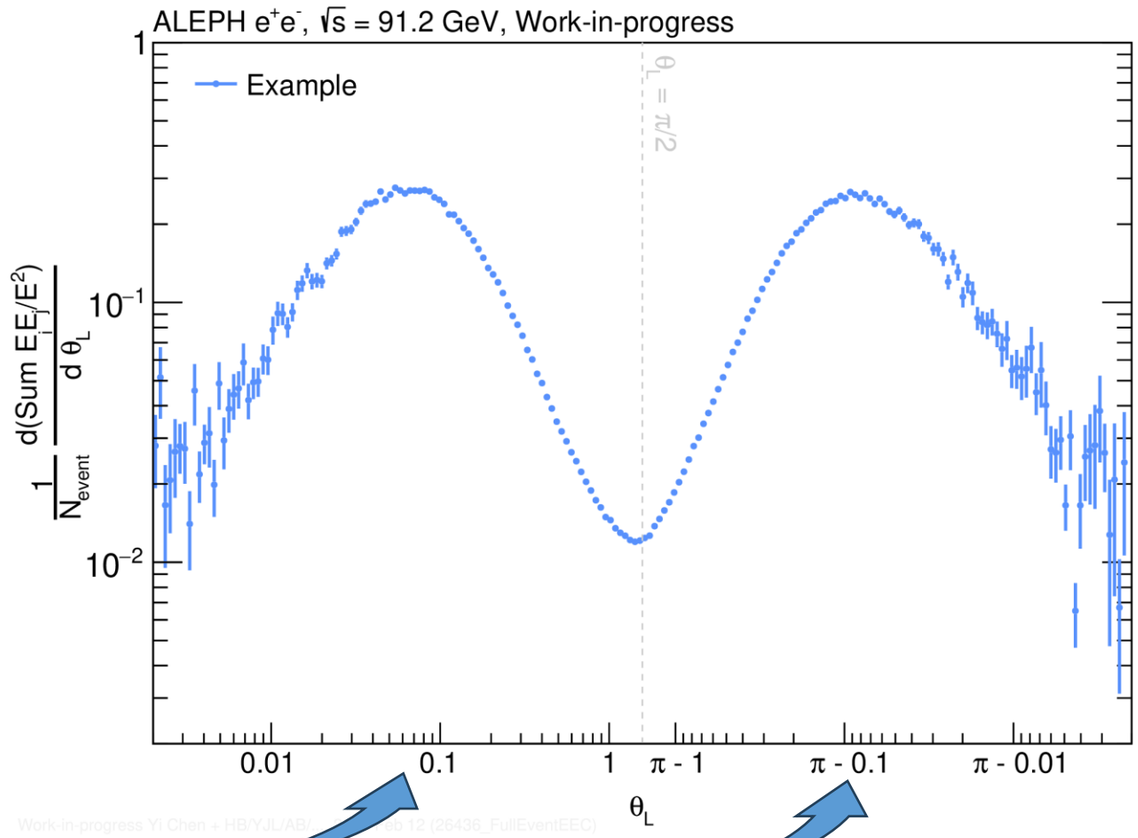




2-Particle EEC (E2C) from Archived MC

- Presented in double-log-x scale to focus on the tail region



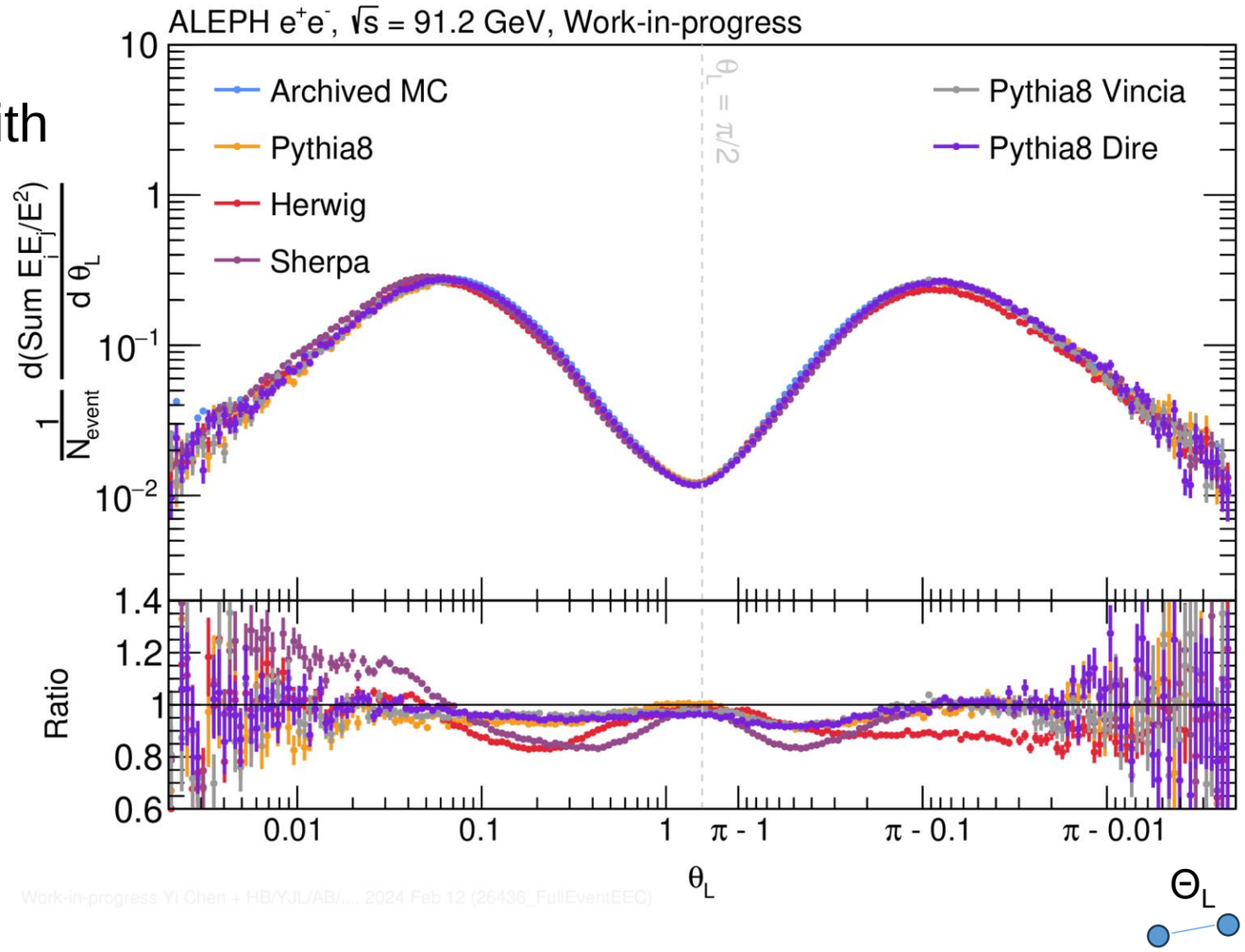


Log scale [0,π/2]

Flipped log scale π-[0,π/2]

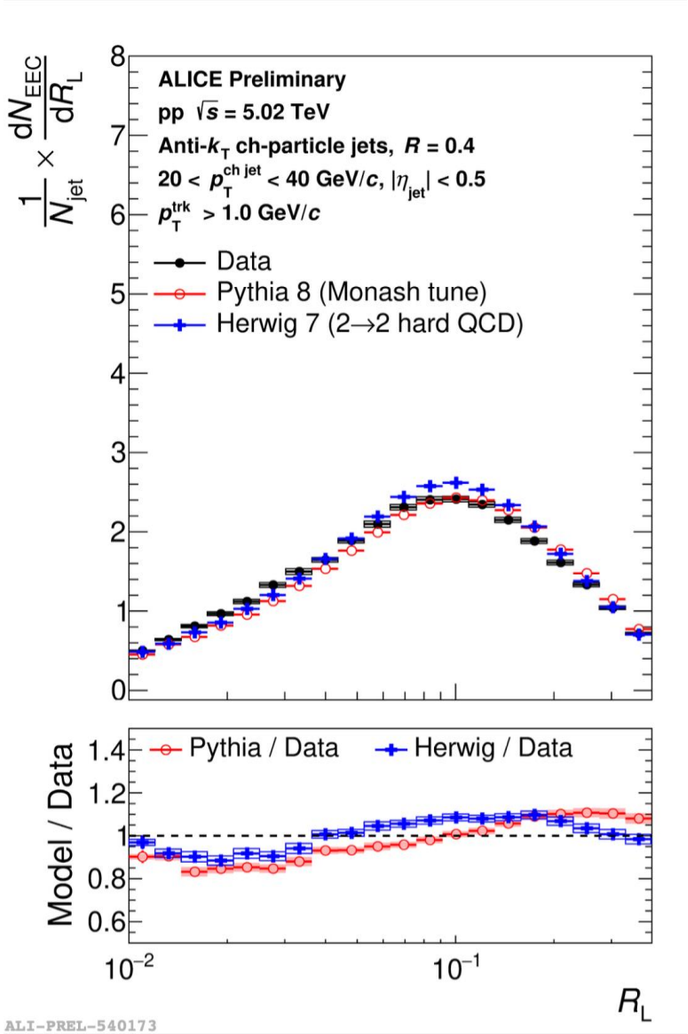
E2C from MC Generators

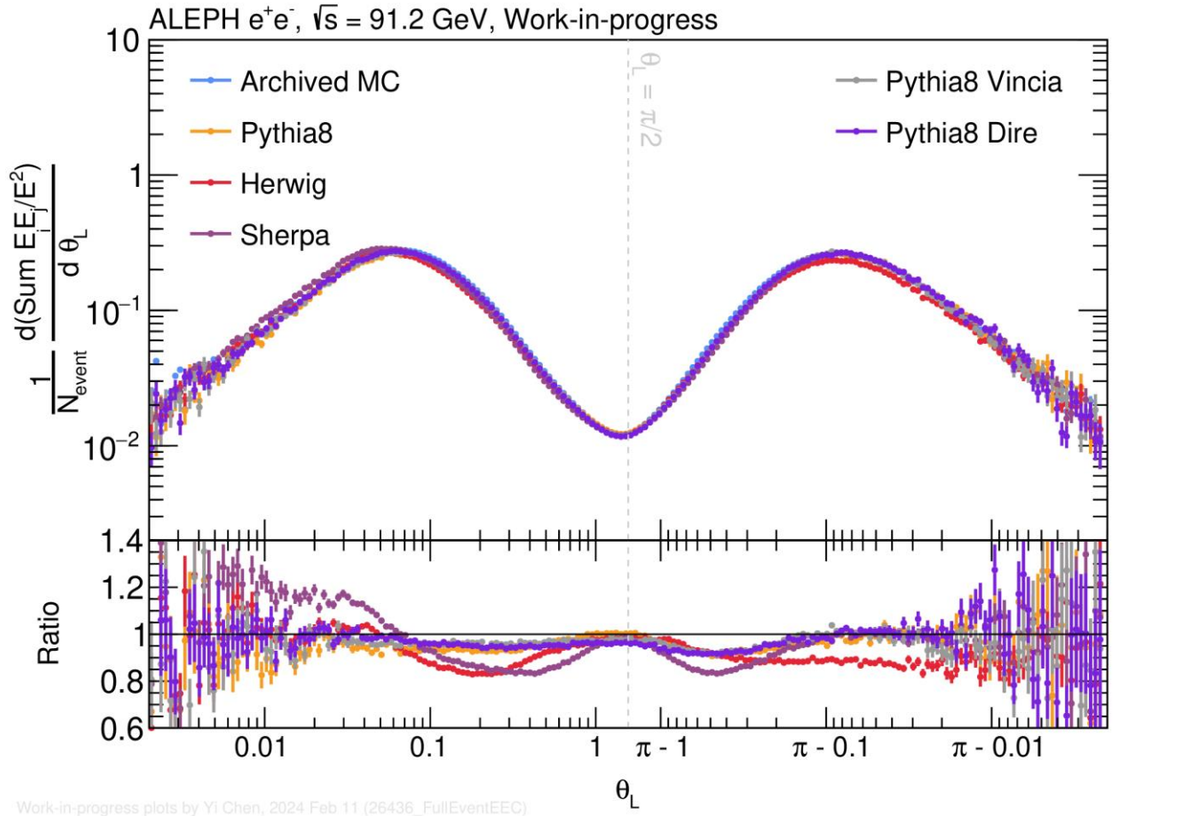
- Dominant structures
  - Dijet back to back
  - Left peak is what people are familiar with
  - No reason to be symmetric a priori
- Left peak (collinear)
  - Parton shower region
    - Different shower, different slope
  - Hadronization region
    - MCs roughly parallel to each other
  - Peak location
    - Correspond to 45 GeV scale
    - Different MC are a bit different
- Right peak (back-to-back)
  - Also a peak and transition between Sudakov limit and parton shower



Comparison with ALICE pp

- Agreement between pp and Pythia 8 or Herwig is at the level of 20%

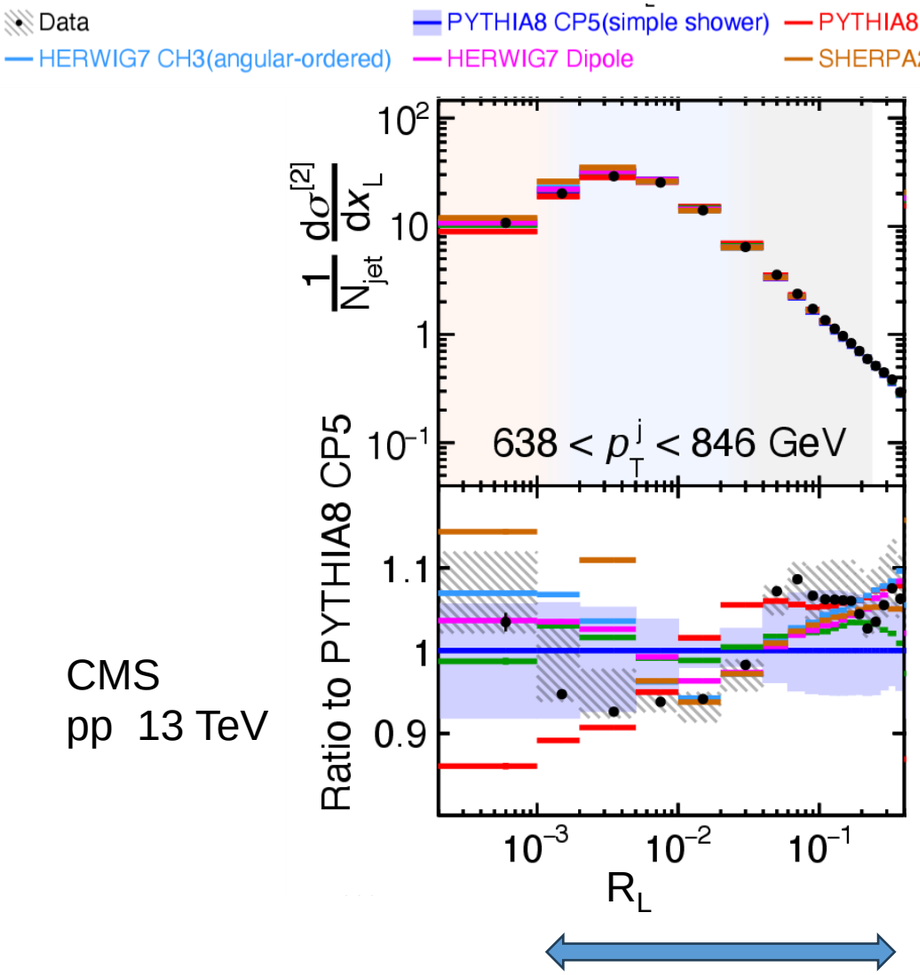


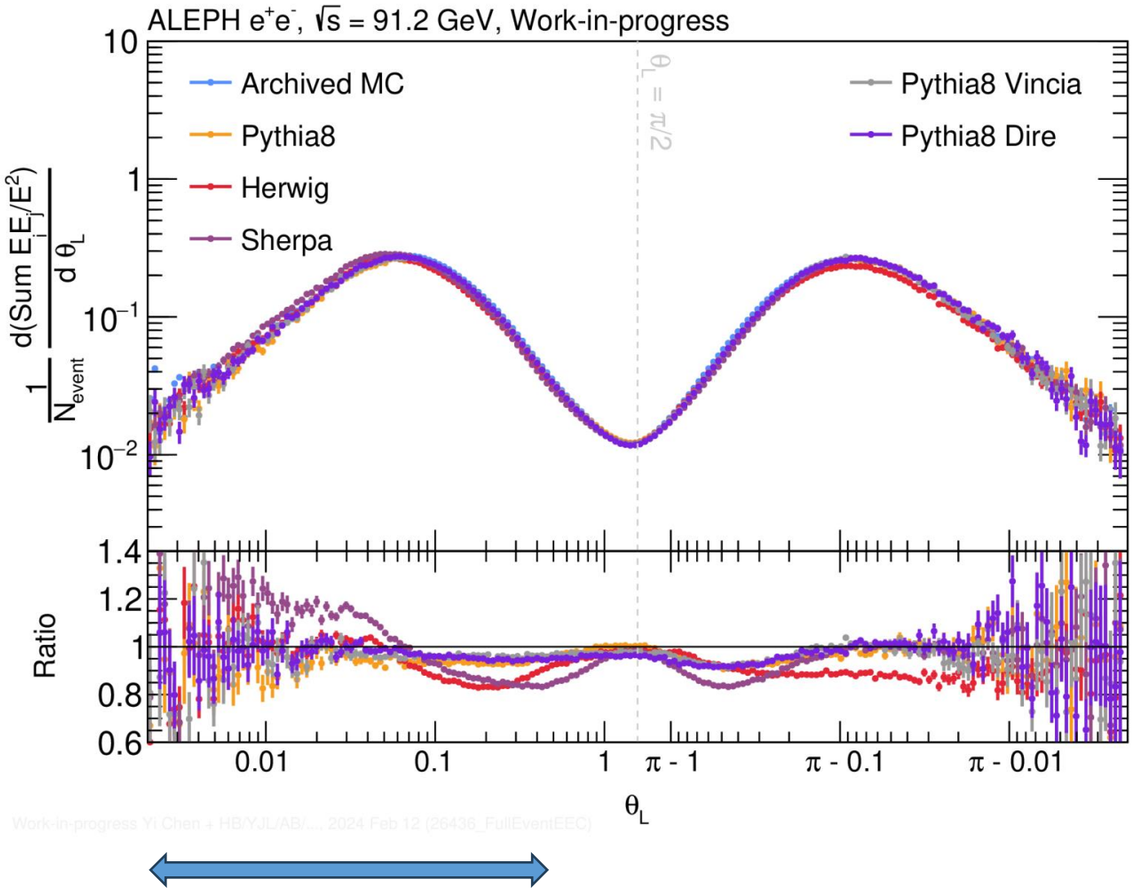


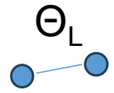
E2C from MC in pp and e^+e^-

- Similar MC hierarchy between e^+e^- generators and pp generators (SHERPA->HERWIG->PYTHIA)
- Larger x_L not comparable due to jet boundary effects in pp measurement

CMS
pp 13 TeV

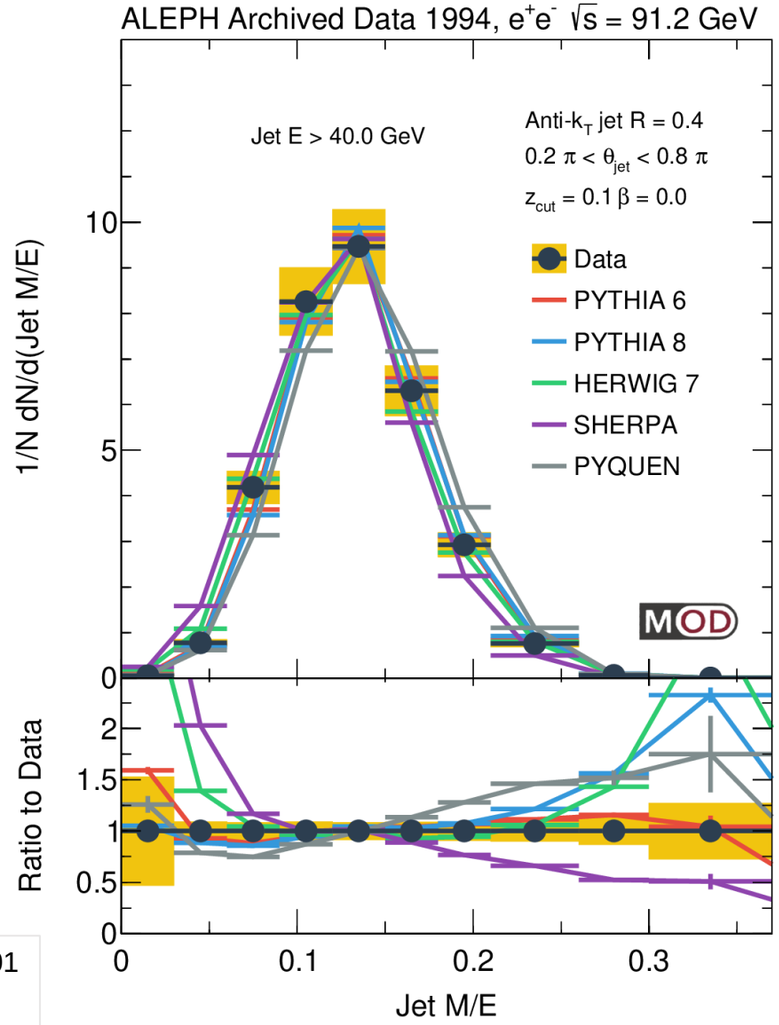


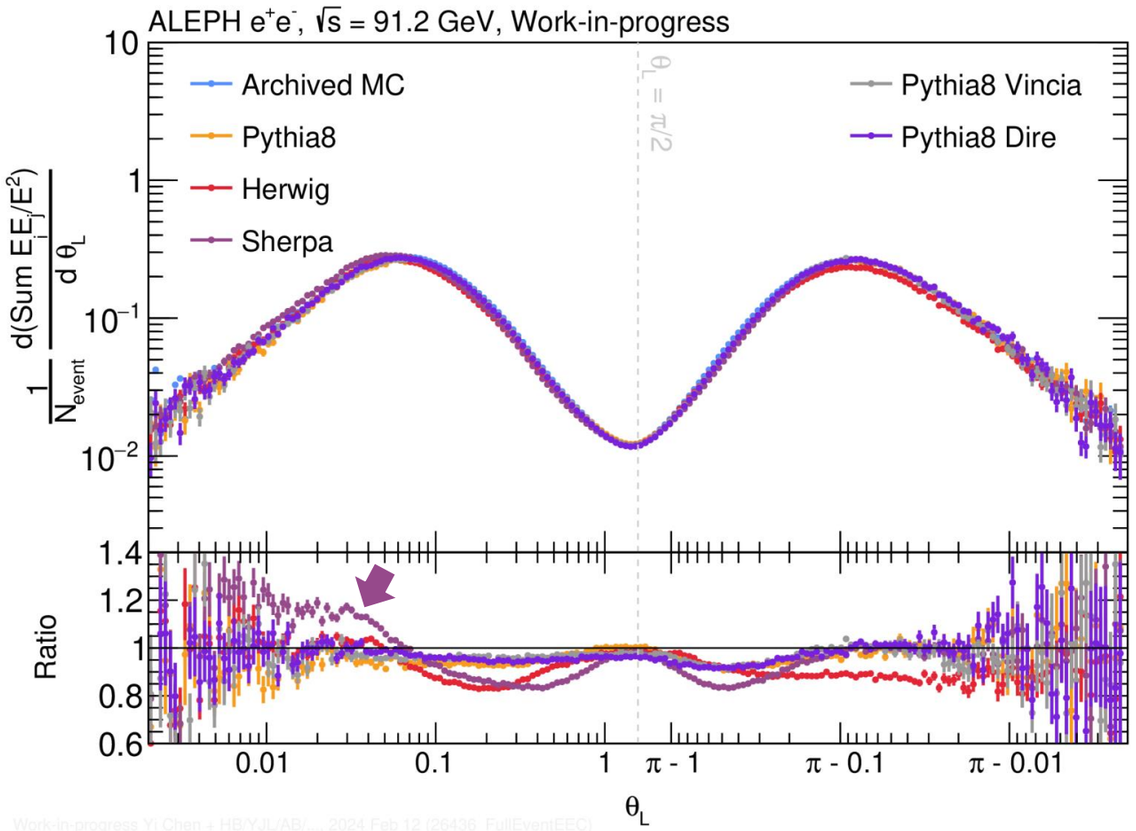




Comparison between E2C with Jet Mass

- Mass scale for SHERPA is smaller --> smaller SHERPA angular scale in EEC

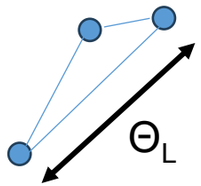


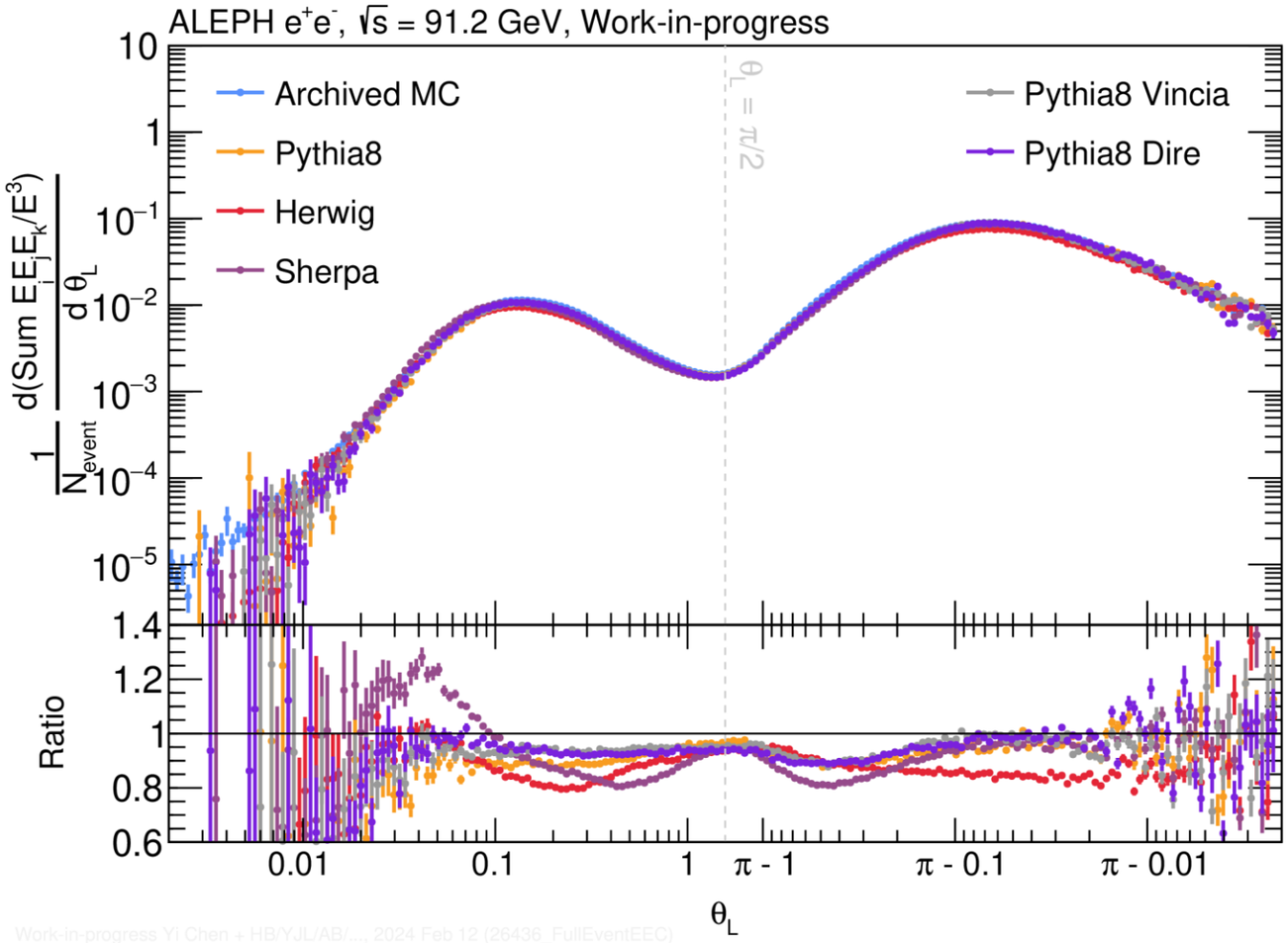


MITHIG-MOD-21-001
arXiv:2111.09914
JHEP 06 (2022) 008

3-particle EEC (E3C) from MC in e^+e^-

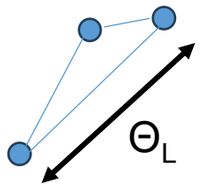
- E3C is by definition not symmetric
  - Due to intrinsic max(pair)
  - Other variants of E3C are possible
- At the away-side
  - Dominant contribution from **dijet**
  - Mostly 1 particle from one shower + 2 particles from the other shower
- Agreement between MC generators similar to E2C:
  - The predictions differ by up to 20%!

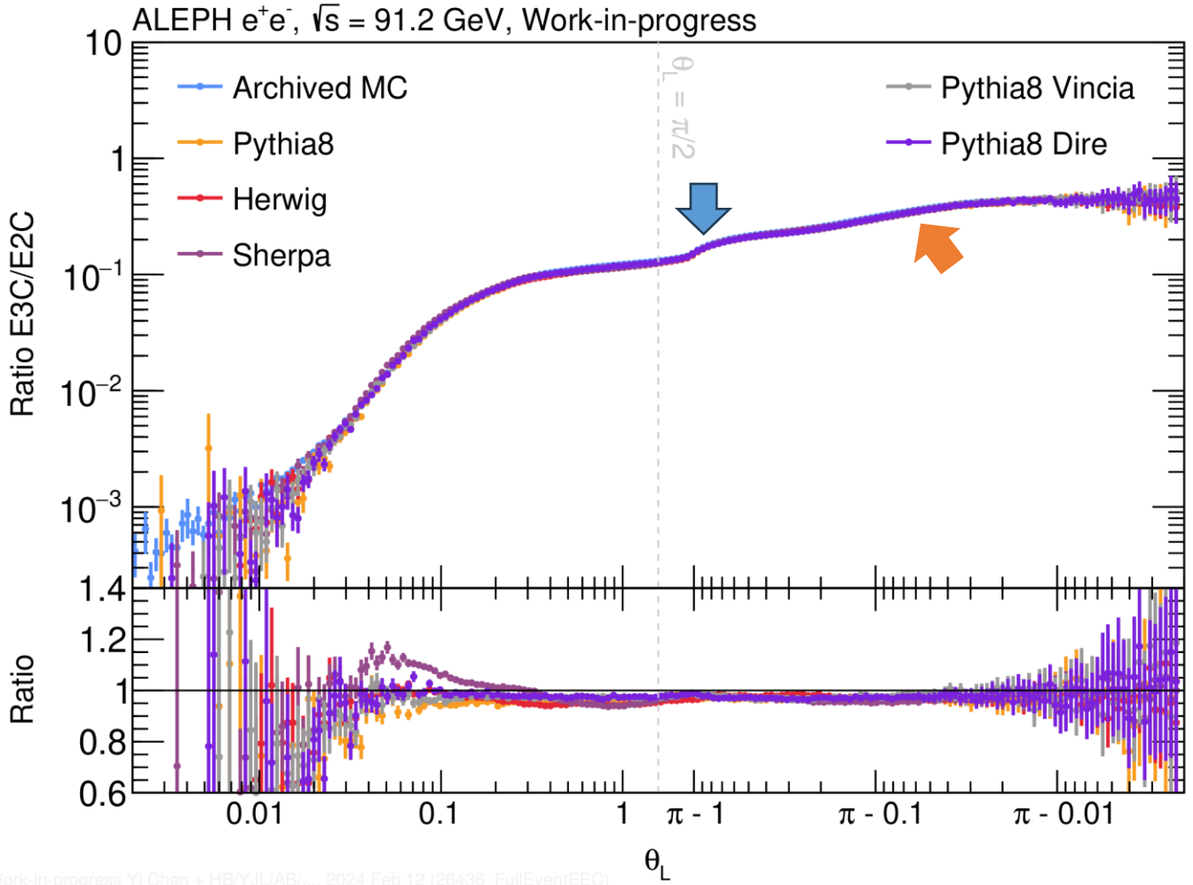




E3C / E2C in e^+e^- at 91 GeV

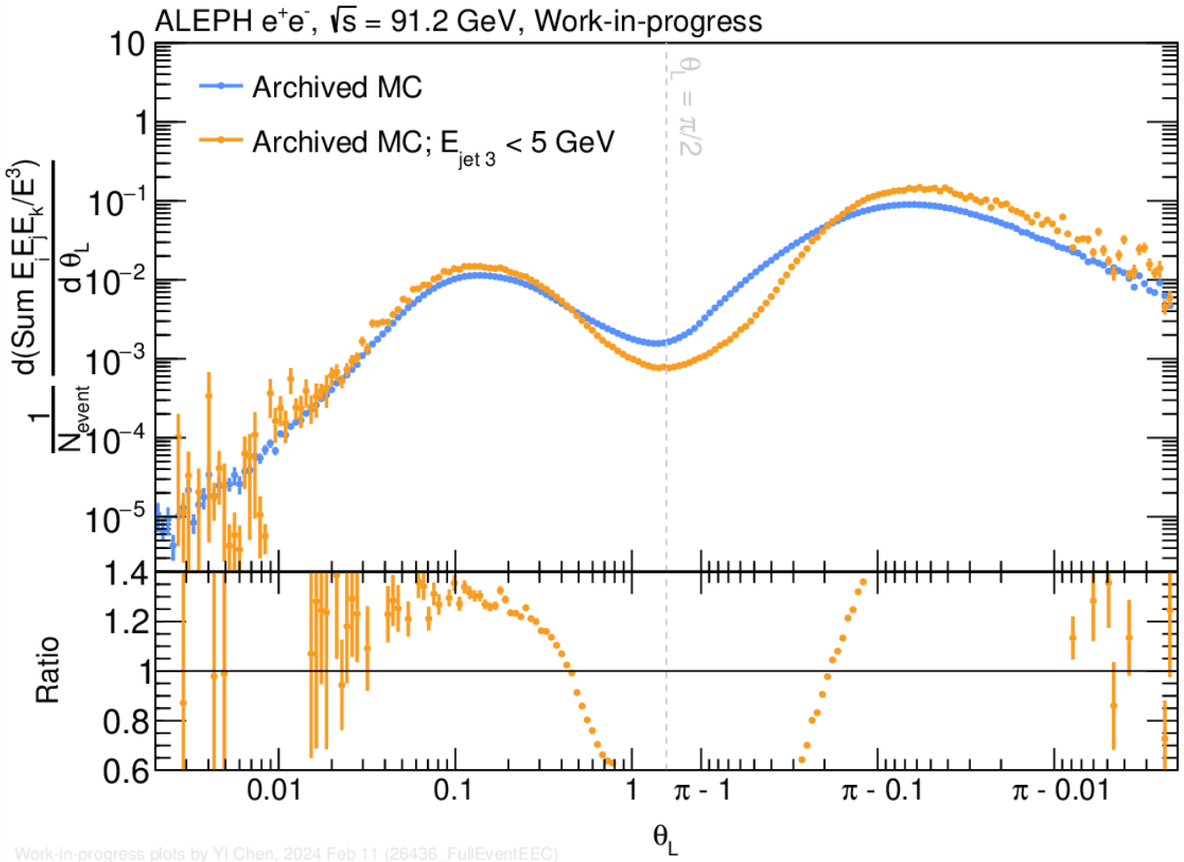
- Observe non-trivial slope in the hadronization region
  - Away-side ($\Theta_L > \pi/2$) region: roughly flat
  - A small structure around $2\pi/3$:
    - Reject **3-jet** event removes this particular structure
  - Further increase beyond $2\pi/3$: **di-jet**
- MCs agree with each other within 5-10%
  - Except for the small angle region of SHERPA



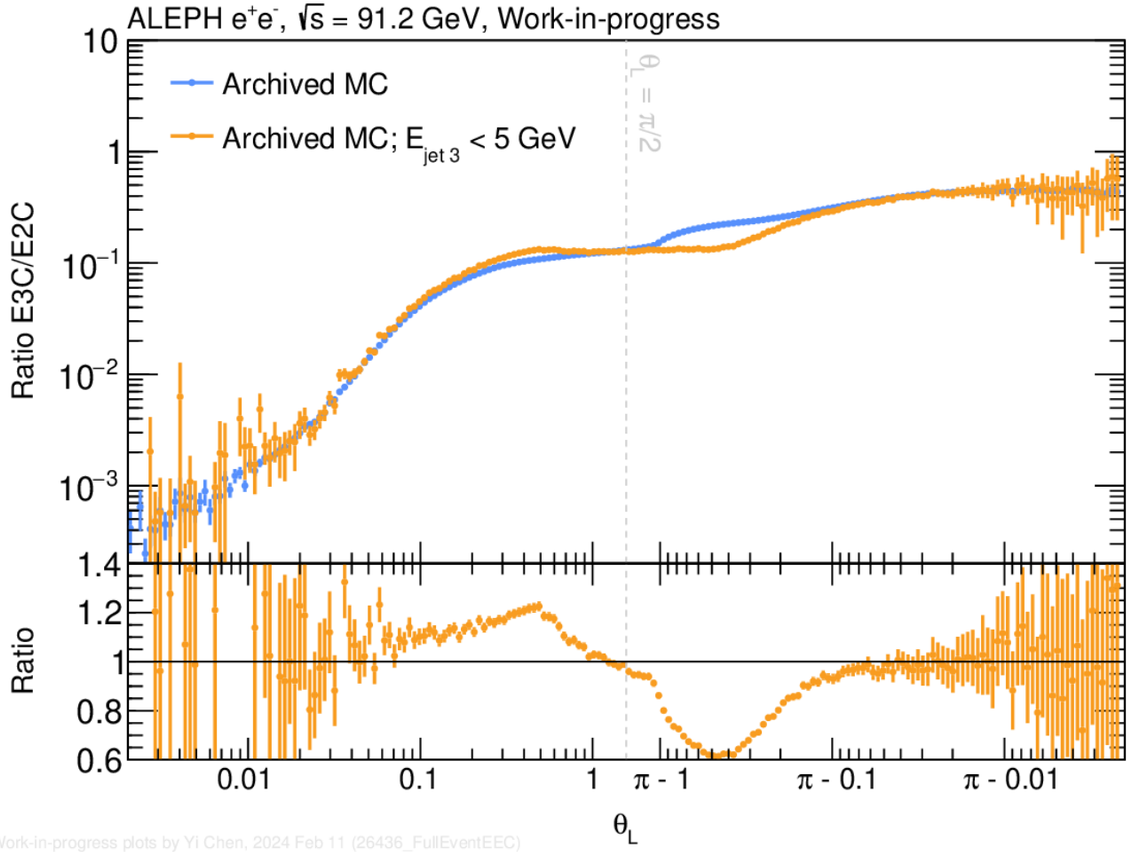


Rejecting 3-jet events in EEC's

E3C

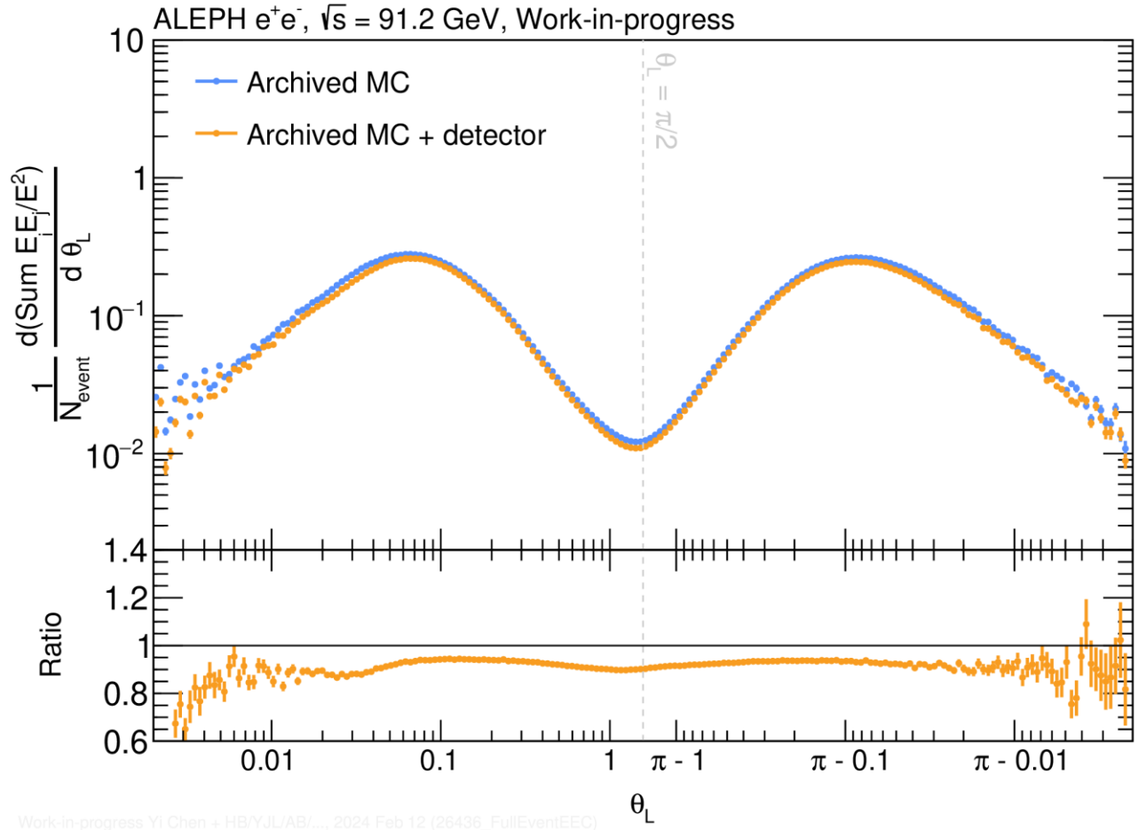


E3C/E2C

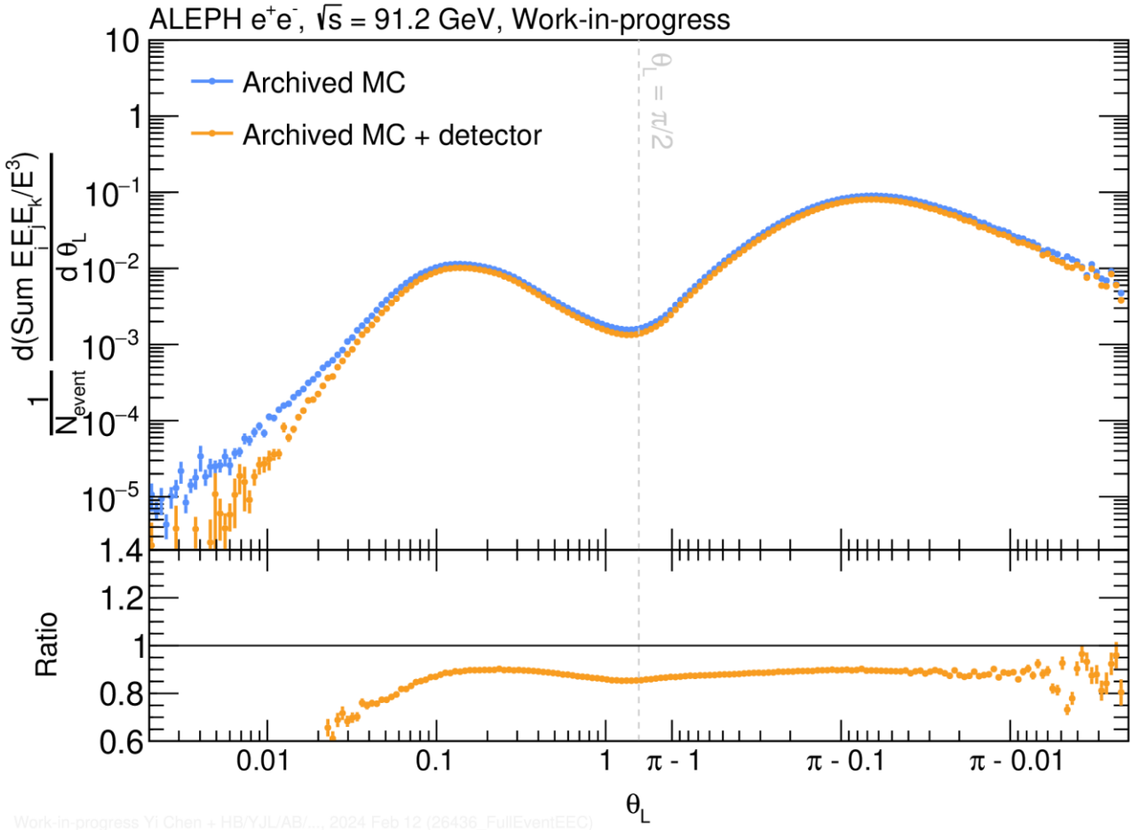


Detector Effects based on Archived ALEPH MC

- Will we be able to measure the correlators? **Yes!**
- Generator- and detector-level results are similar over a large phase space



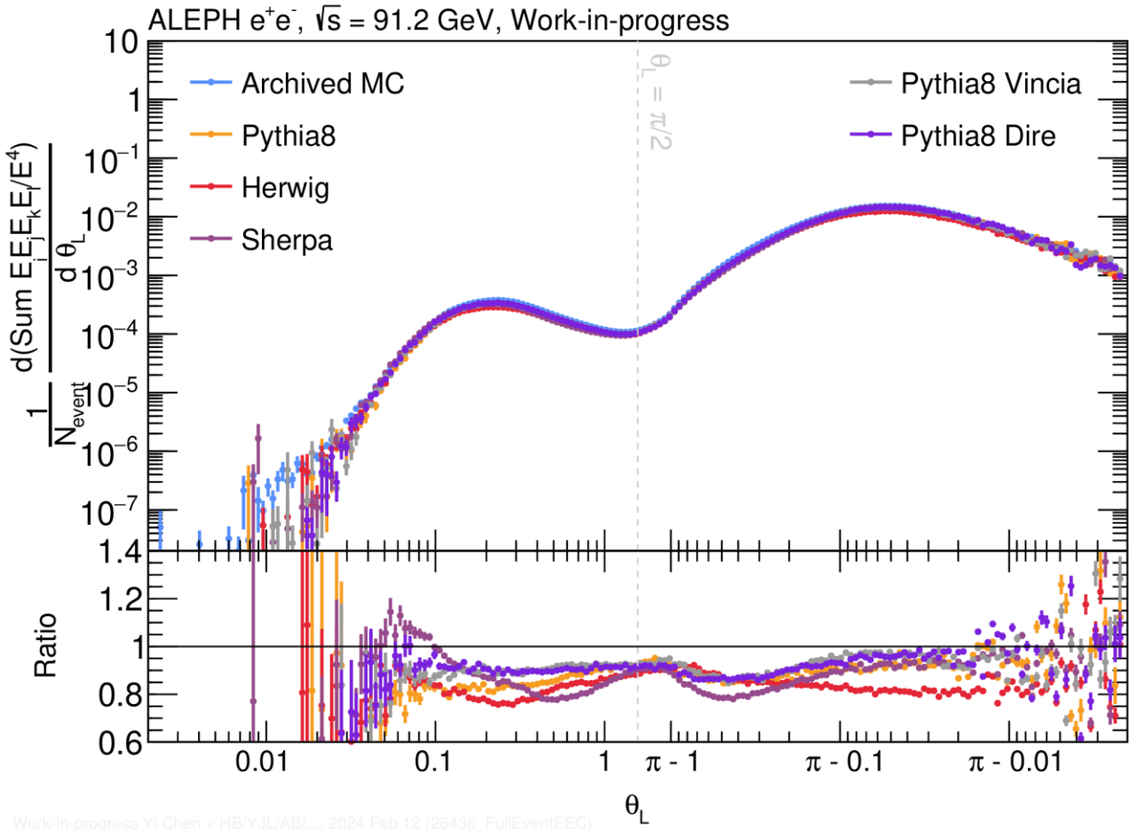
E2C

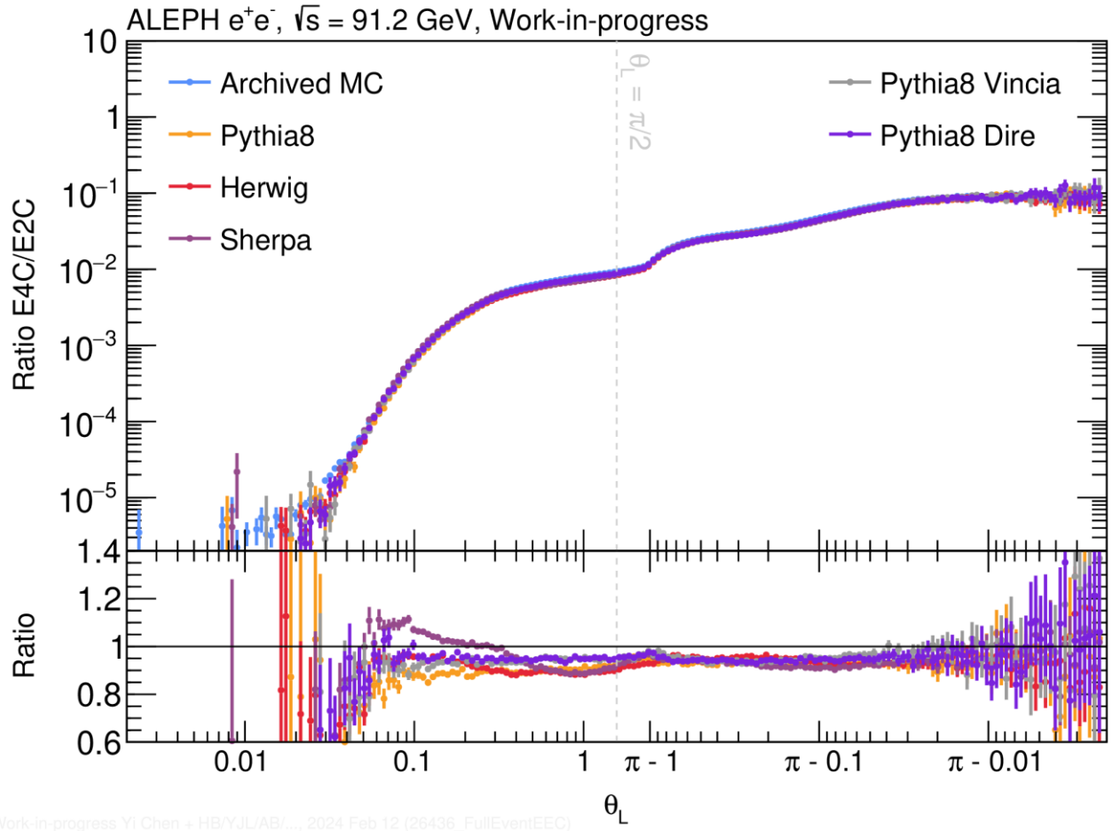


E3C

E4C and E4C/E2C ratio in e^+e^-

- Predictions of E4C and E4C/E2C from event generators



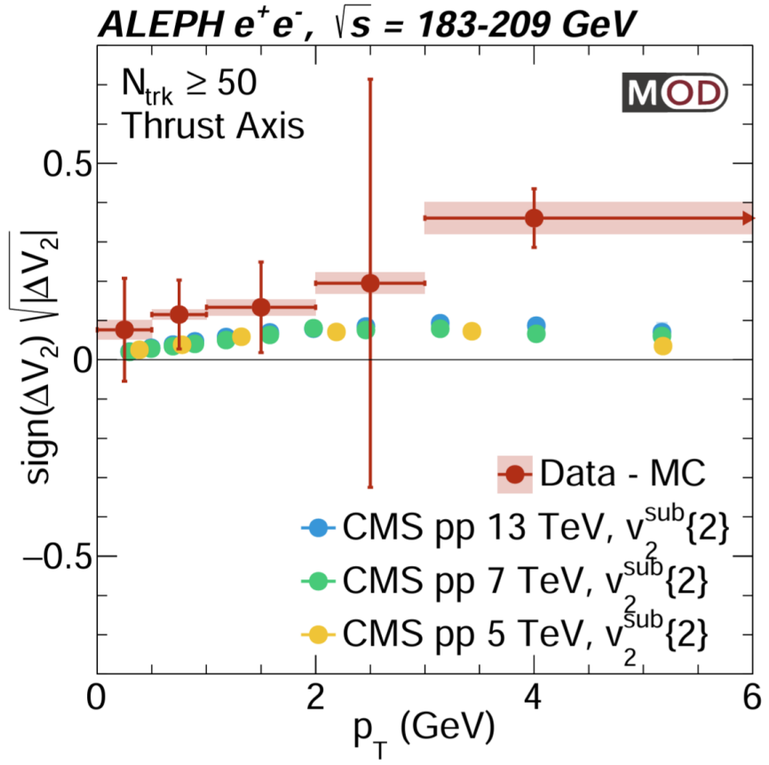


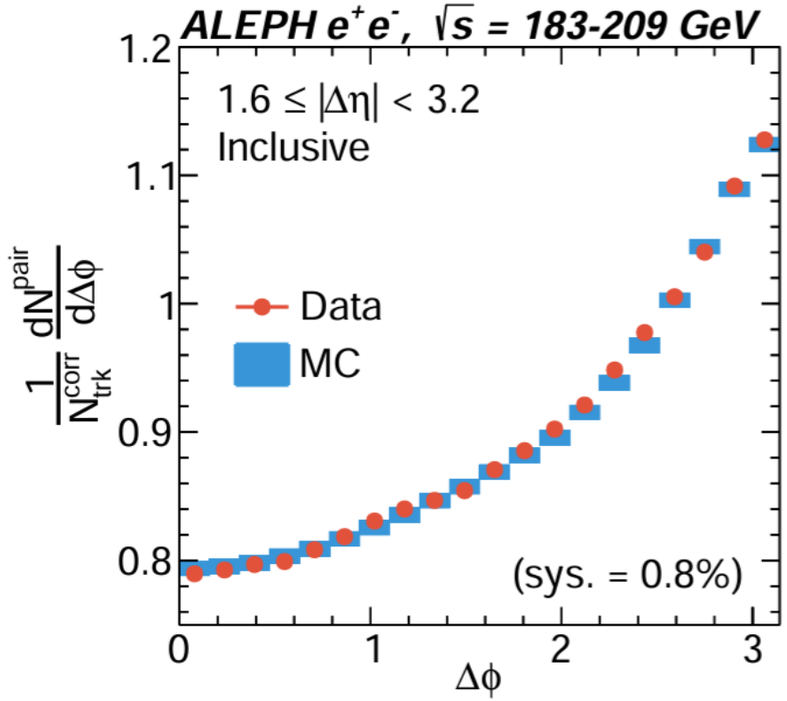
- Feasibility check of data analysis in progress

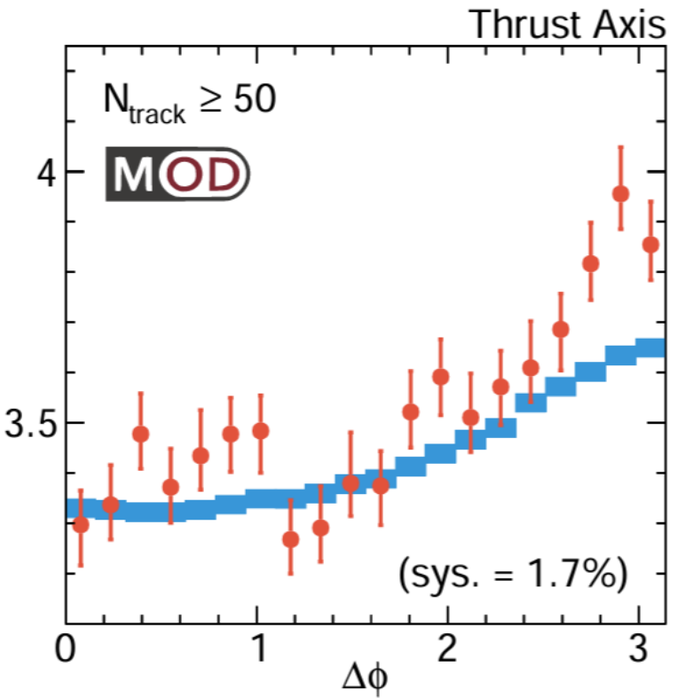
Observable Wishlist in e^+e^-

- Two point and higher particle correlator (EnC) and their ratios
  - How high can we go??
- Charged Correlators (plus/minus) and Charge-Weighted Correlators
  - Probes correlations between charges, modification of scaling behavior, and changes in hadronization transitions
- E^nE^m Correlators
  - Potentially useful for suppressing soft radiation & studying transition region
- … also a lot of other possibilities
  - (As usual we have way too many interesting observables to measure)

Flow-like Correlation in e^+e^- at LEP2 Energies







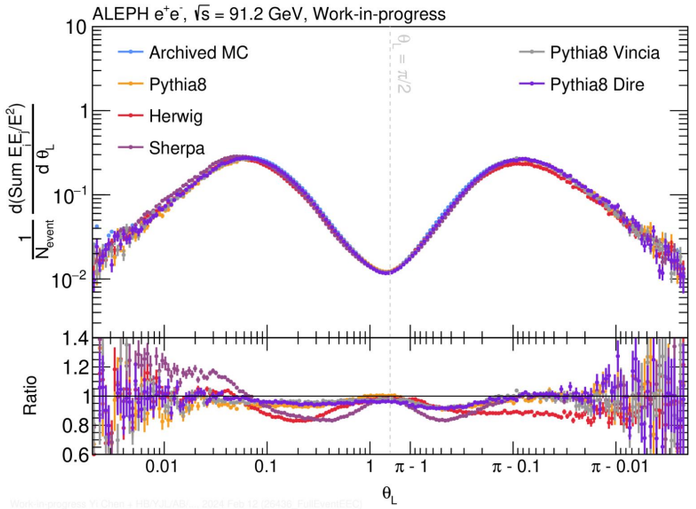
- Long-range correlation in e^+e^- collisions!
  - Not described by ALEPH archived MC
- May be interesting to study EEC with archived MC in different multiplicity intervals

MIT-MOD-23-001
arXiv: 2312.05084
Submitted to PRL

Yu-Chen "Janice" Chen (MIT)

Summary

- e^+e^- EEC with archived ALEPH data
  - Feasible to measure it with archived ALEPH data
  - Full event analysis without jet
  - First exploration of the back-to-back region
  - Up to 20% spread across MC generators
    - Identify interesting length scales related to Z mass, 2 and 3 jet event
    - Collinear regions are consistent with our understanding in pp
- Many interesting ideas to come!



Acknowledgement

We would like to thank **Roberto Tenchini** and **Guenther Dissertori** from the ALEPH collaboration for the useful comments and suggestions on the use of ALEPH archived data.

We would like to thank **Ian Moult, Felix Ringer**, **Jesse Thaler, Andrew Lakoski, Liliana Apolinário, Ben Nachman, Camelia Mironov, Jing Wang** for the useful discussions on the analysis.

The MIT group's work was supported by US DOE-NP

Backup slides

Rejecting 3-jet events in EEC's