Measurement of parton shower observables with OPAL

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and the OPAL collaboration

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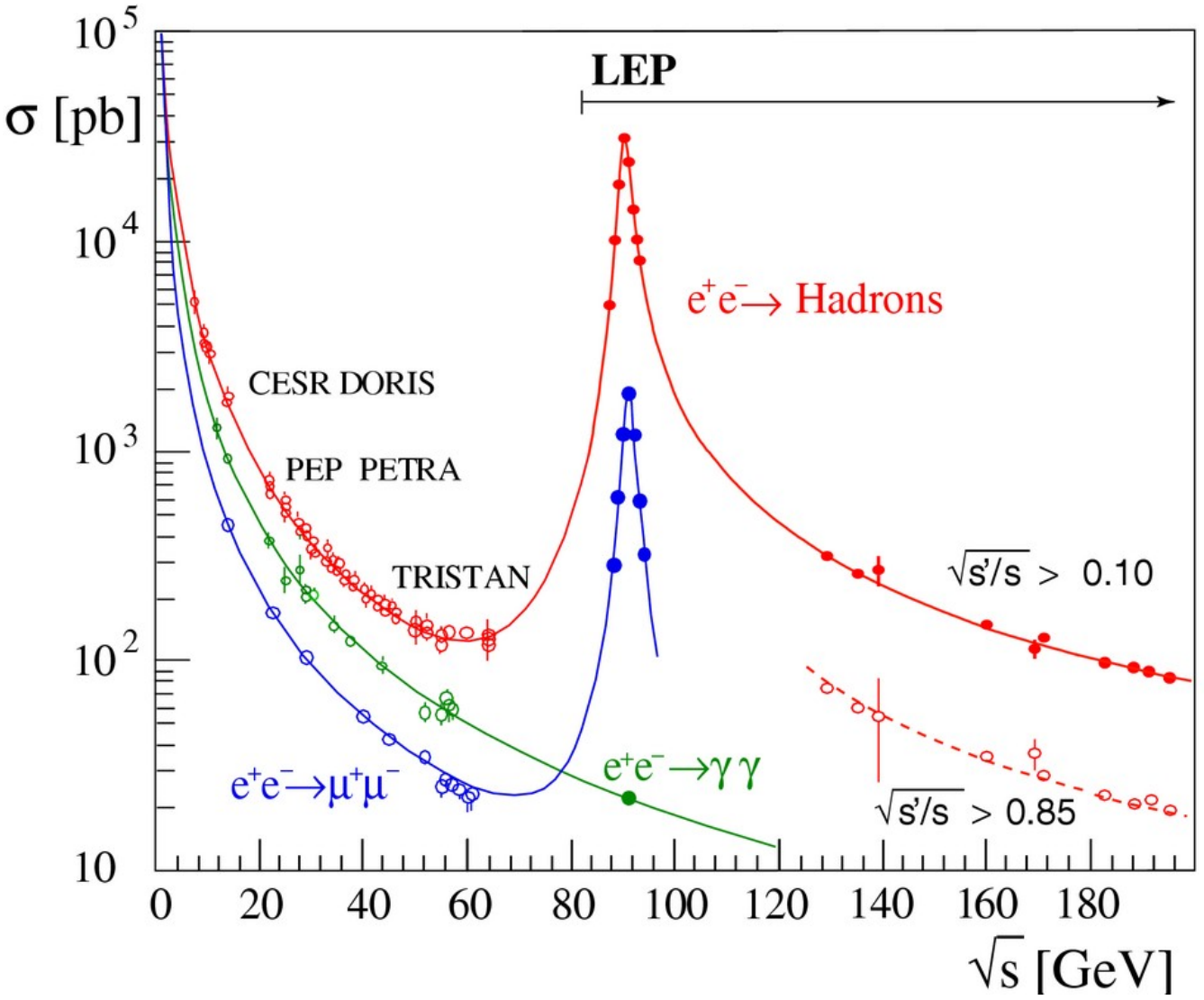
Motivation

- Hot topic: (N)NLO automation in MC
  - Consistent matching to parton shower
  - Parton shower integral component of prediction
  - Parton shower vs LL / NLL / SLL?
- Many new parton shower models
  - Herwig++, Pythia8, Sherpa, VINCIA, ...
- Can we discriminate models with data?
  - Construct special observables in e^+e^- to hadrons 4-jet final states

e^+e^- annihilation to hadrons



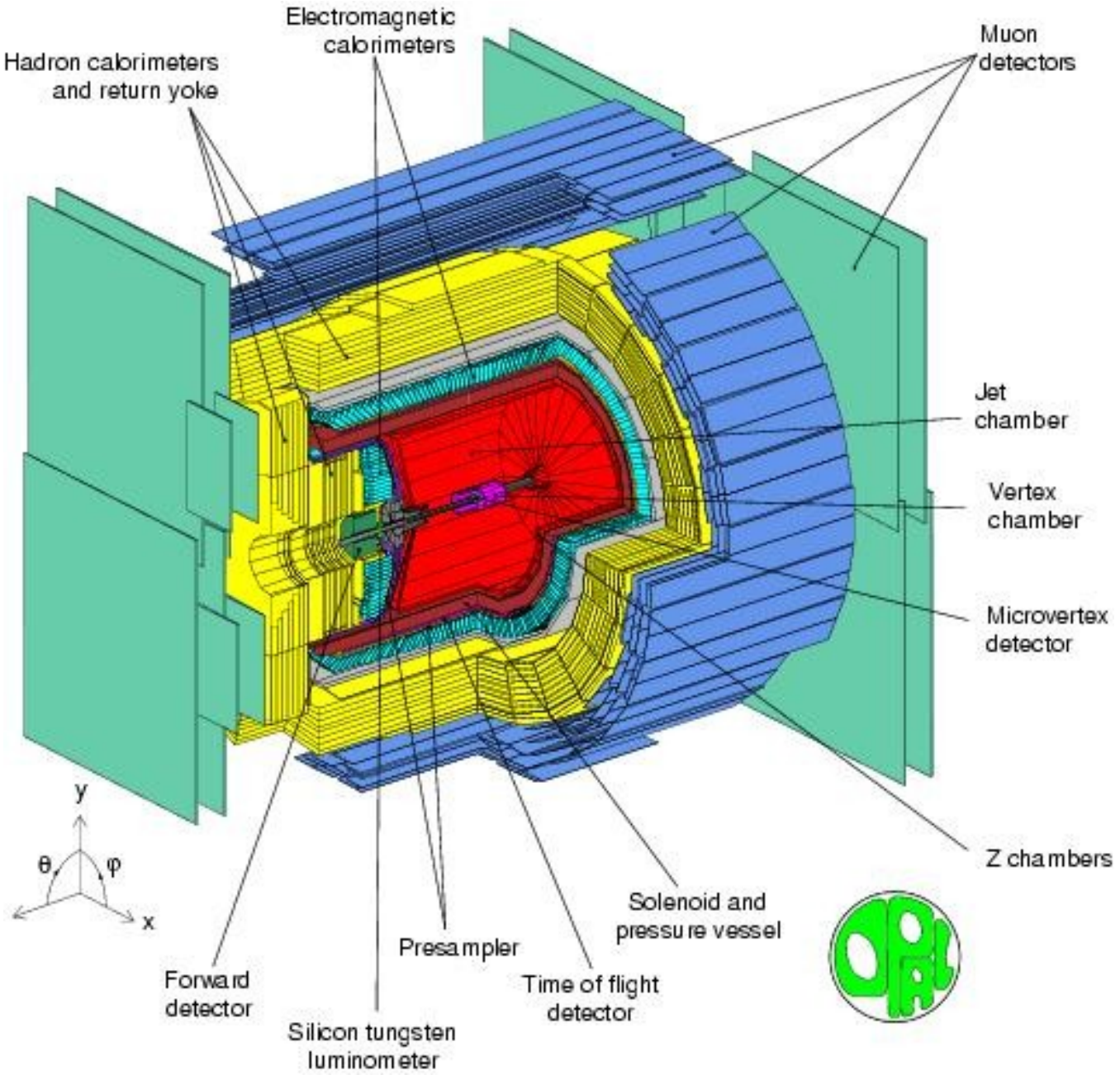
Almost ideal to study QCD effects

Good statistics

No IS interference

Clean environment

The OPAL experiment

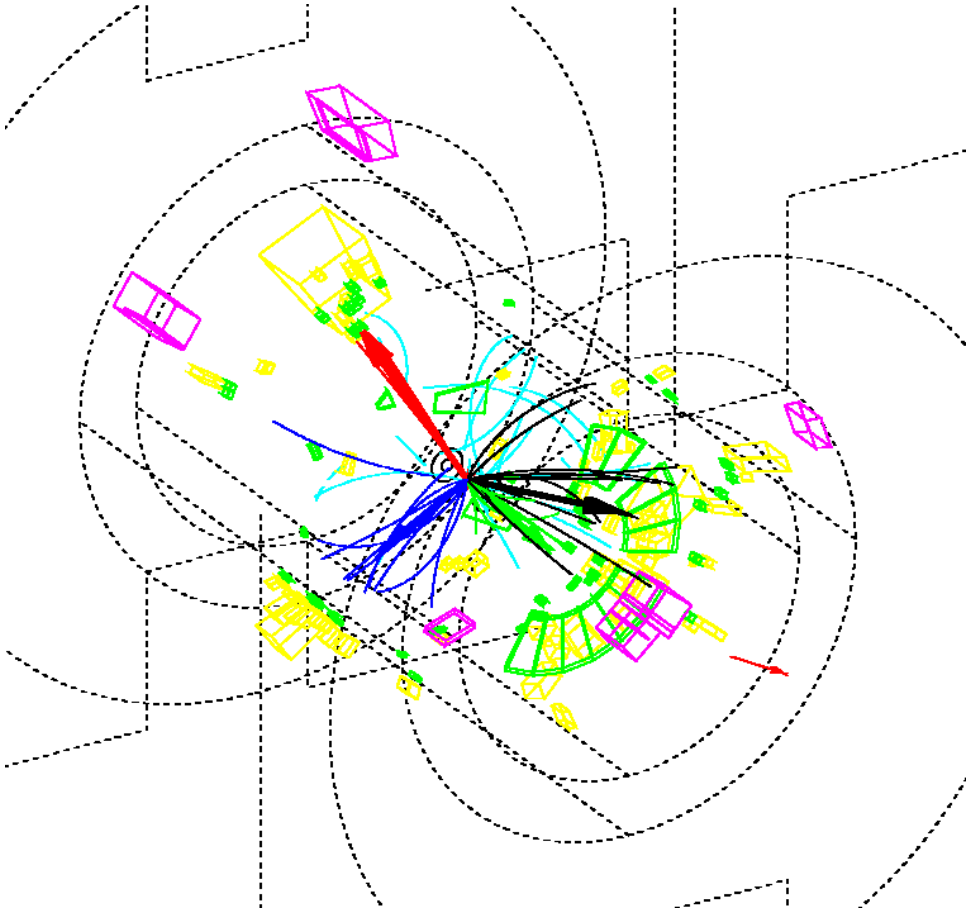


1989 to 2000 at LEP

Use calibration data taken on the Z peak during LEP 2 (1996-2000) period; 14.7/pb

Best detector and simulations

4-jet event selection



Select 4-jet events using
Durham iterative jet clustering

$y_{ij} = 2\min(E_i,E_j)^2(1-\cos\theta_{ij})/s$

Require $y_{43} > 0.0045$

4-jet topology observables

We use four observables after energy ordering the 4 jets, and placing cuts on interjet angles to force 1st jet to recoil against ~collinear 2nd and 3rd jets

θ_{14}: angle between 1st and 4th jet

θ^*: $\theta_{24} < \pi/2$; $\theta^* = \theta_{24} - \theta_{23}$ opening angle difference

$C_2^{(1/5)}$: 2-point energy correlation double ratio, sensitive to collinear structure

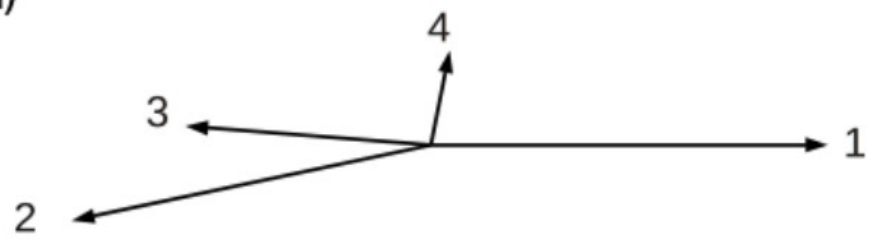
$\rho = (M_L/M_H)^2$: ratio of hemisphere masses

Asymmetries: $N_l/N_r = \sum_{xi<x0} n_i / \sum_{xi>x0} n_i$

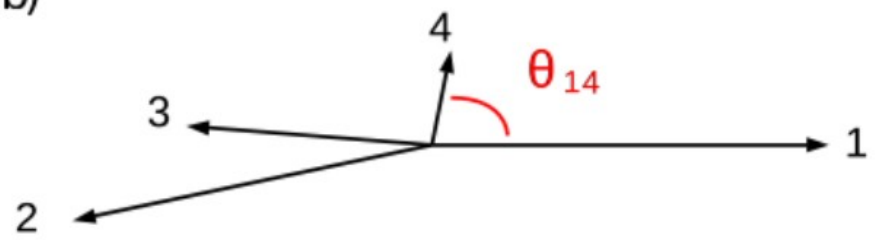
[N. Fischer, S. Gieseke, S. Plätzer, P. Z. Skands, Eur. Phys. J. C74(2014) 2831]

4-jet topology observables

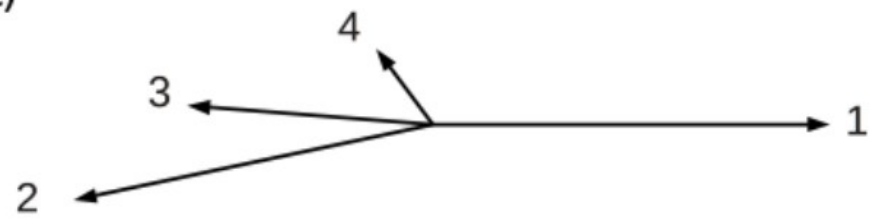
a) $\theta_{12} > 2\pi/3;\ \theta_{13} > 2\pi/3;\ \theta_{23} < \pi/6$



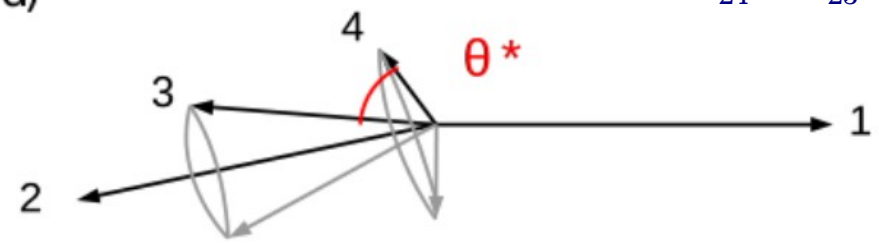
b)



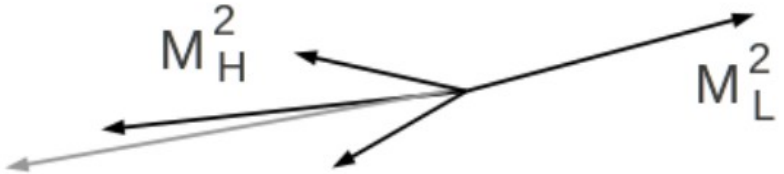
c) $\theta_{12} > 2\pi/3;\ \theta_{13} > 2\pi/3;\ \theta_{23} < \pi/6;\ \theta_{24} < \pi/2$



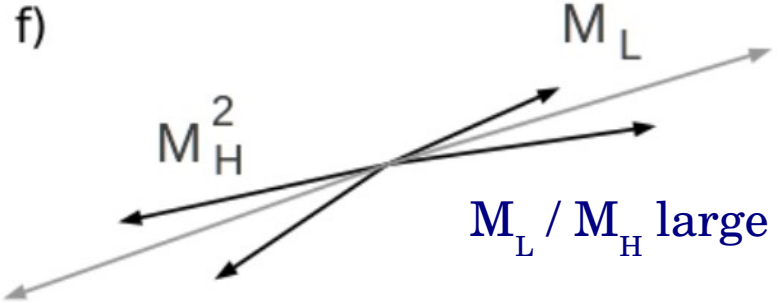
d) $\theta^* = \theta_{24} - \theta_{23}$



e) M_L / M_H small

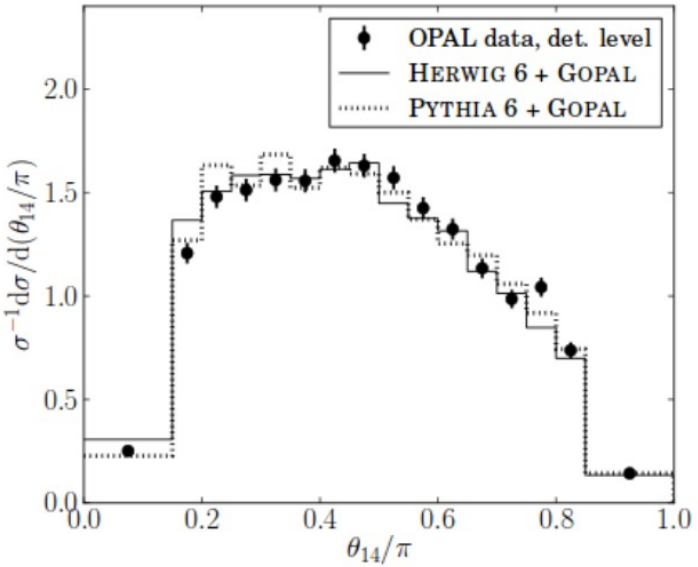


f)

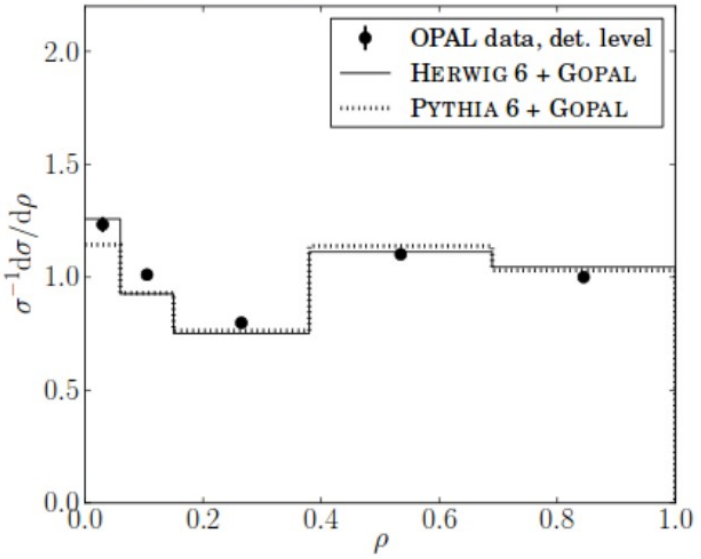


Detector level

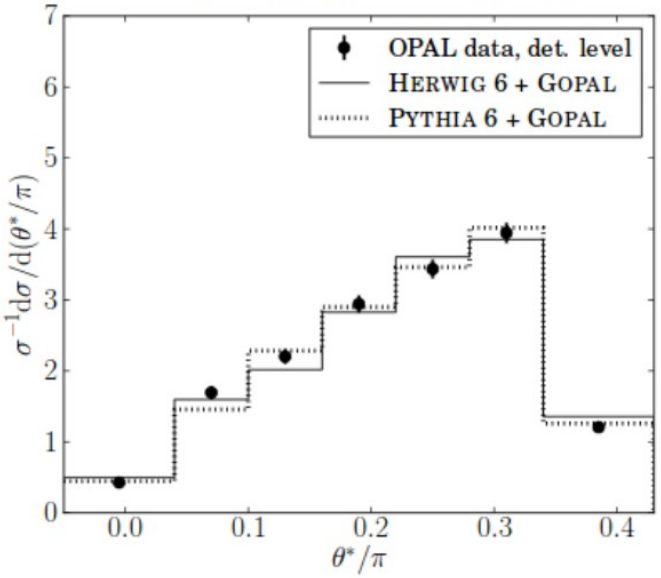
a) Angle between 1st and 4th jet, θ_{14}/π



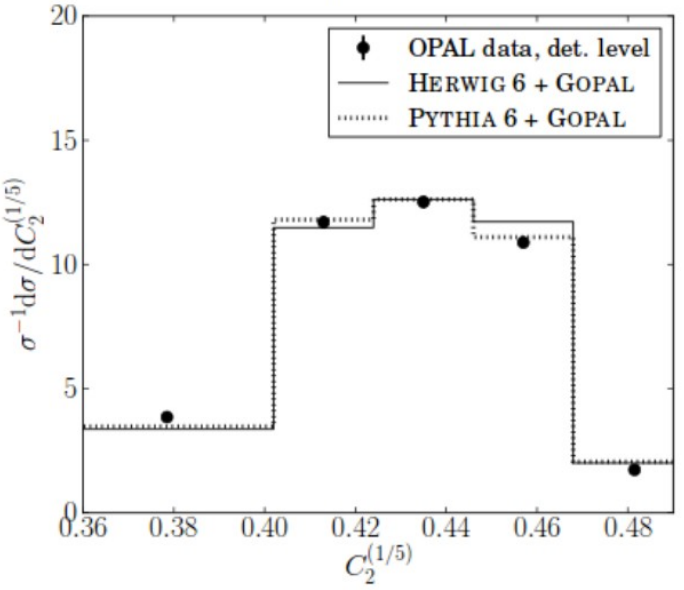
b) Ratio of jet masses, ρ



c) Difference in opening angles, $\theta^* = \theta_{24} - \theta_{23}$



d) 2-point double ratio, $C_2^{(1/5)}$



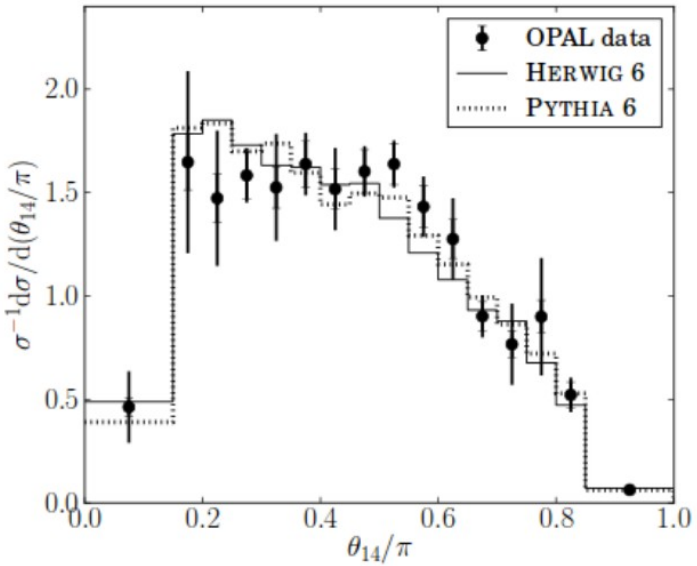
Old OPAL MC with G3 detector simulation ok for data

Unfold exp. effects using iterative Bayesian method

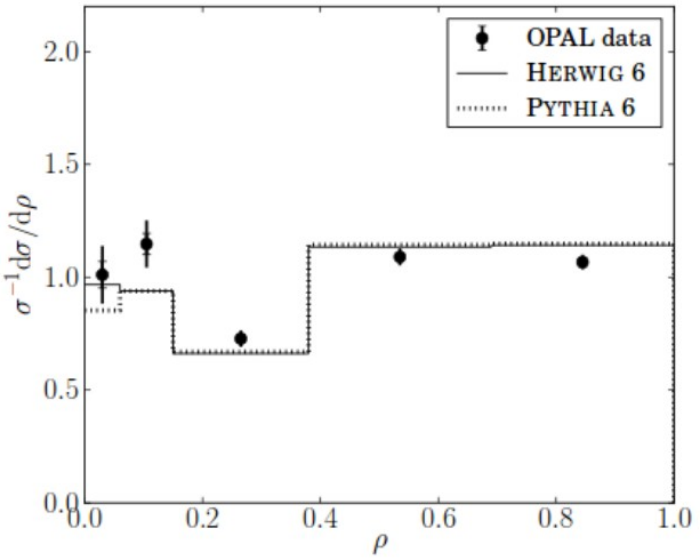
stat. errors only!

Hadron (particle) level

a) Angle between 1st and 4th jet, θ_{14}/π



b) Ratio of jet masses, ρ



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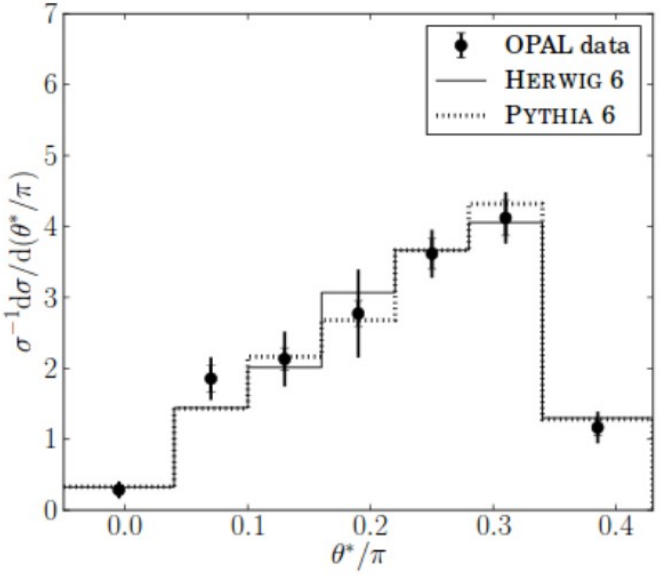

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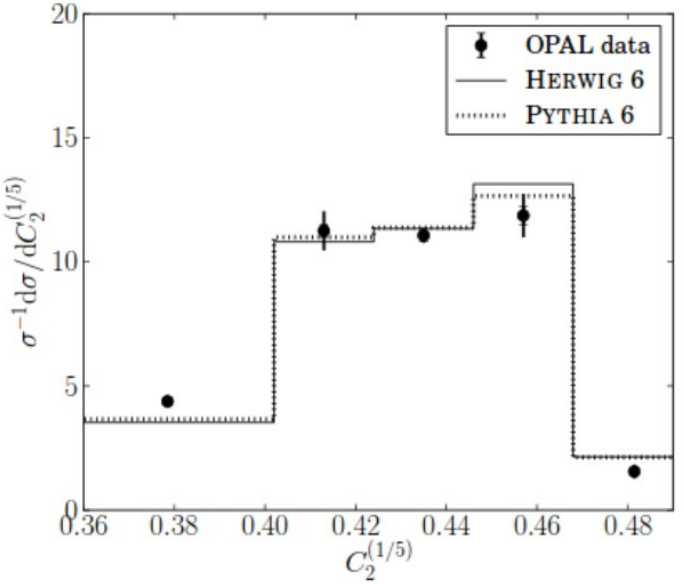


After unfolding exp. Effects

Old OPAL MCs ok to model data

Exp. systematics dominated by underlying model difference

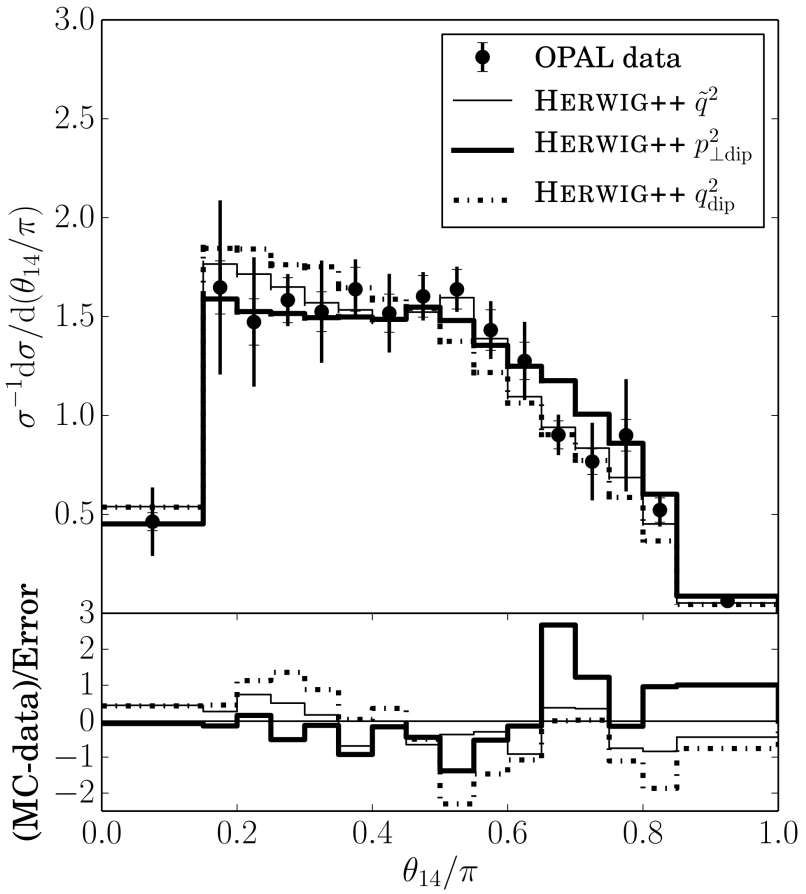
Modern MC parton showers

- Herwig++ variants
  - $q^{\sim 2}$ ordering, DGLAP splitting, global recoils, LO ME corr.
  - $p_{t,dip}^2$ ordering, CS dipoles, local recoils
  - q^2 ordering, CS dipoles, local recoils, less coherence
- Pythia8 variants
  - $p_{t,ant}^2$ ordering, antenna functions, local recoils (VINCIA)
  - m_{ant}^2 ordering, antenna functions, local recoils (VINCIA)
  - $p_{t,evol}^2$ ordering, DGLAP splitting, local recoils, LO ME corr., ang. veto

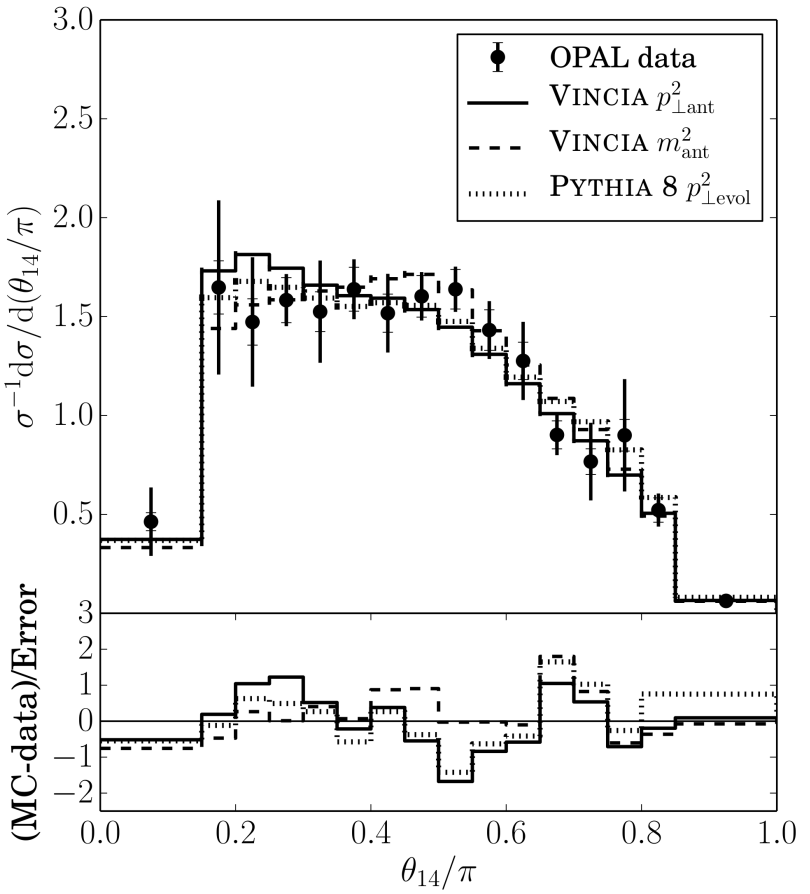
All MCs tuned to same LEP1 data using rivet+professor!

θ_{14}

a) Angle between 1st and 4th jet, θ_{14}, HERWIG++



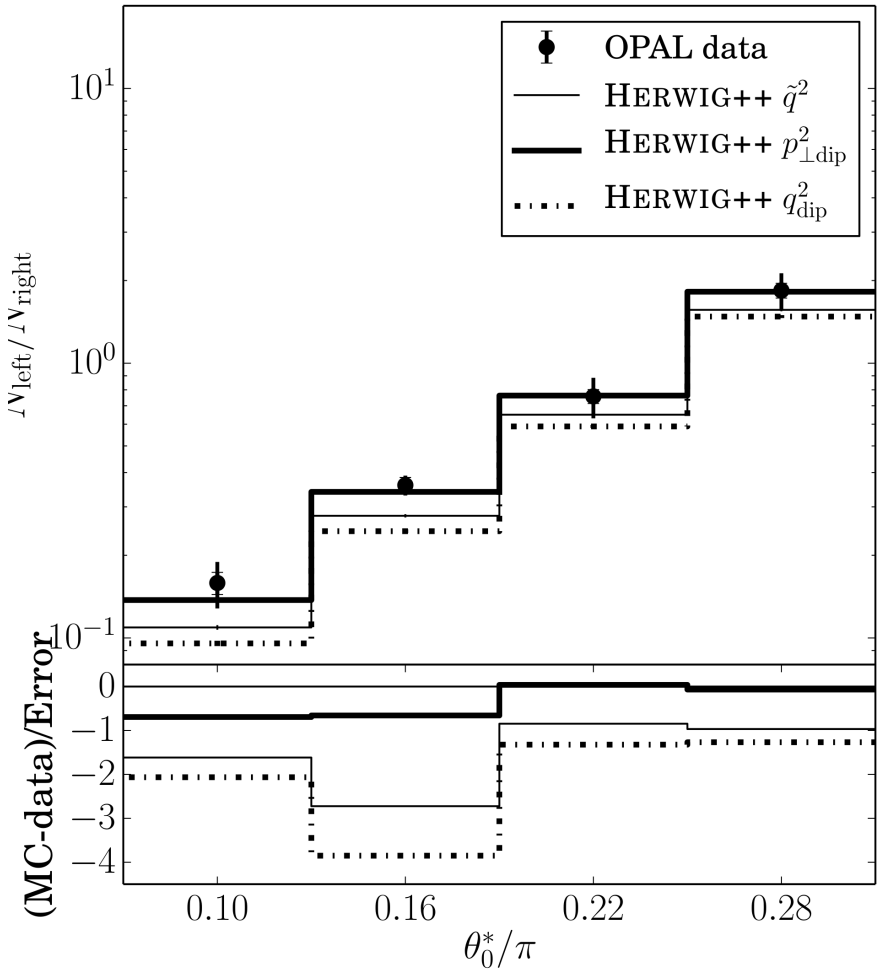
b) Angle between 1st and 4th jet, θ_{14}, VINCIA, PYTHIA 8



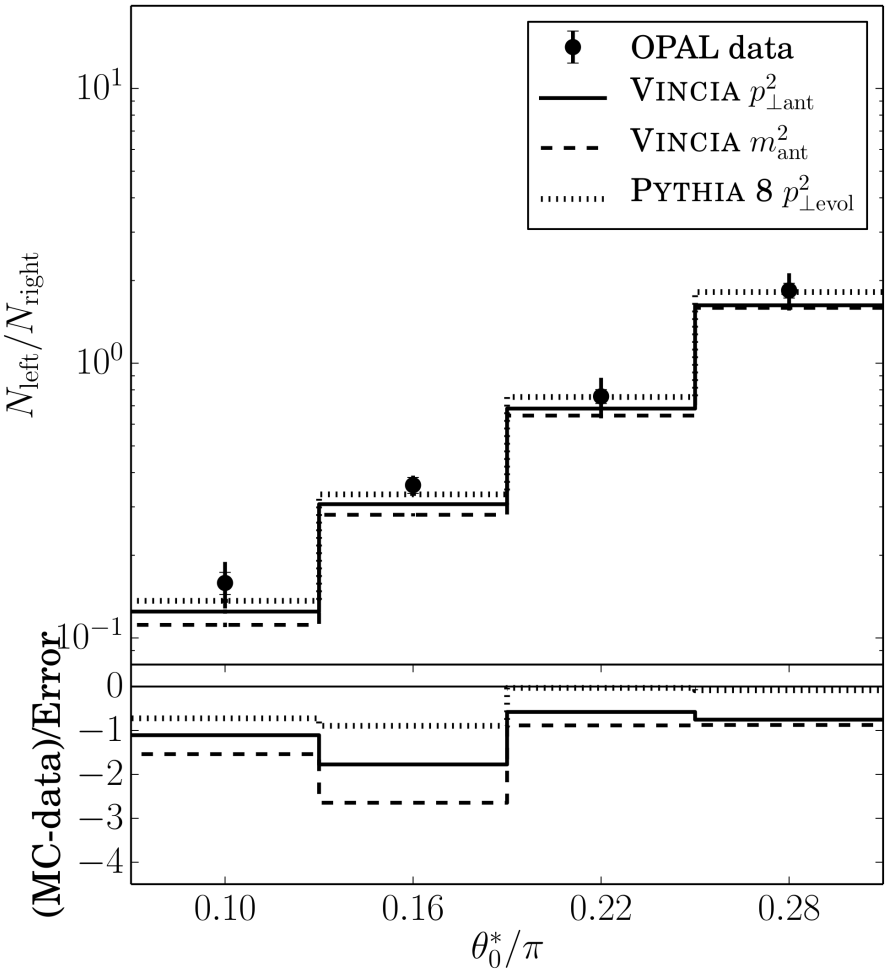
All MC models agree with data (Herwig++ $p_{t,dip}^{\ 2}$ marginal)

θ^* Asymmetry

c) Asymmetry for θ^*, HERWIG++



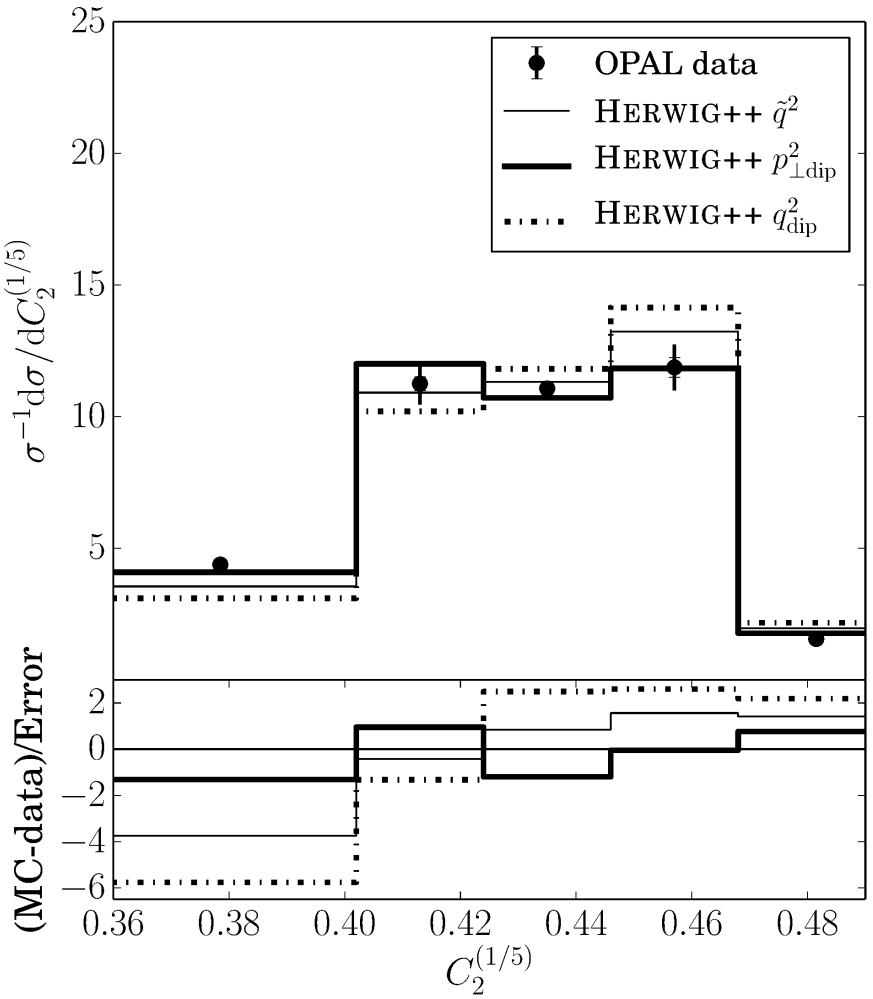
d) Asymmetry for θ^*, VINCIA, PYTHIA 8



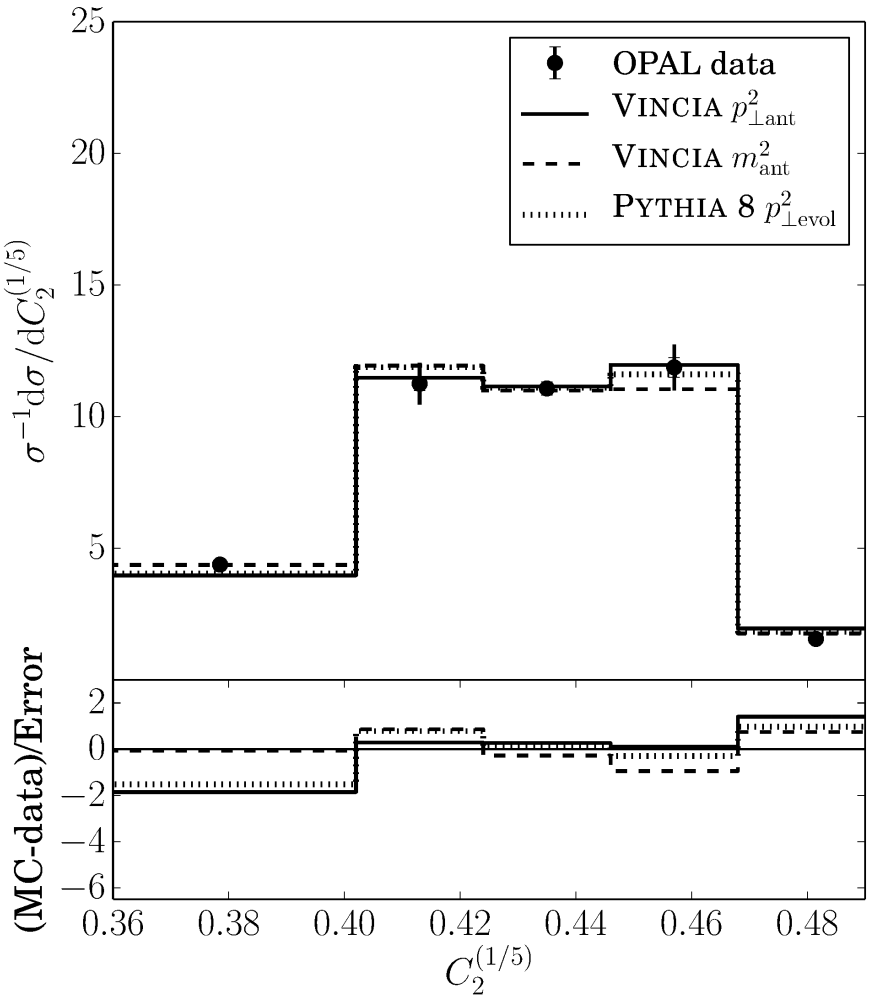
All models ok, except Herwig++ q^2 (less coherence)

$C_2^{(1/5)}$

a) 2-point double ratio, $C_2^{(1/5)}$, HERWIG++



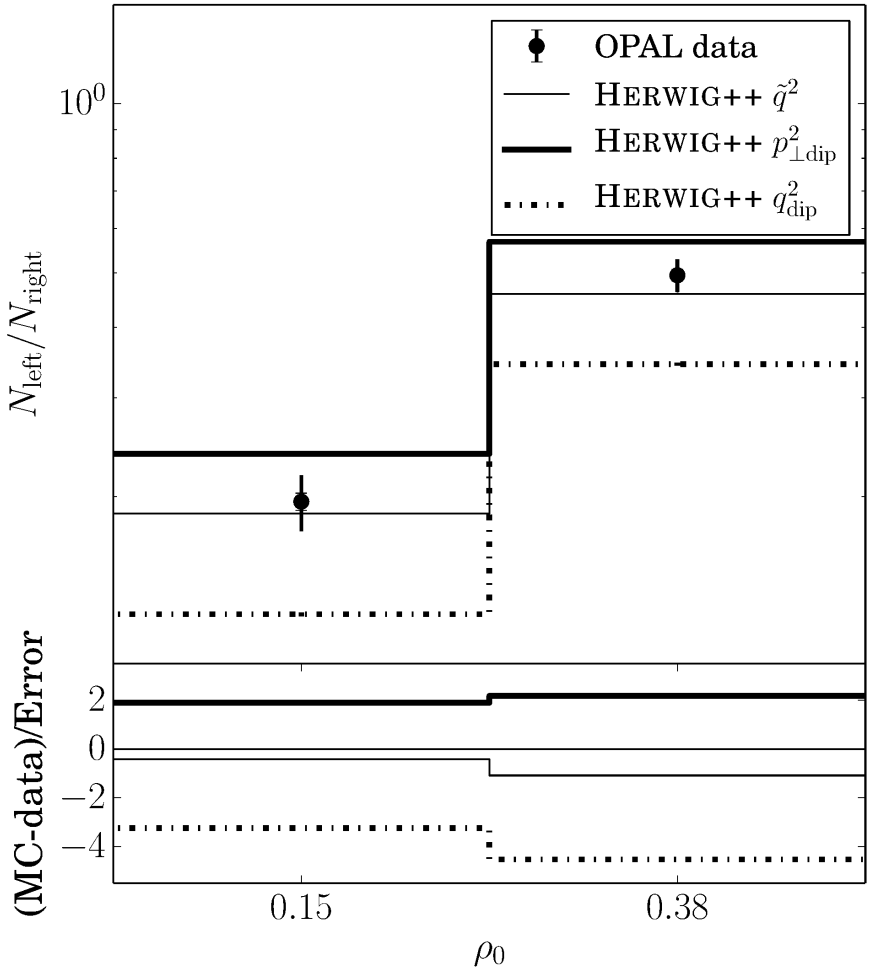
b) 2-point double ratio, $C_2^{(1/5)}$, VINCIA, PYTHIA 8



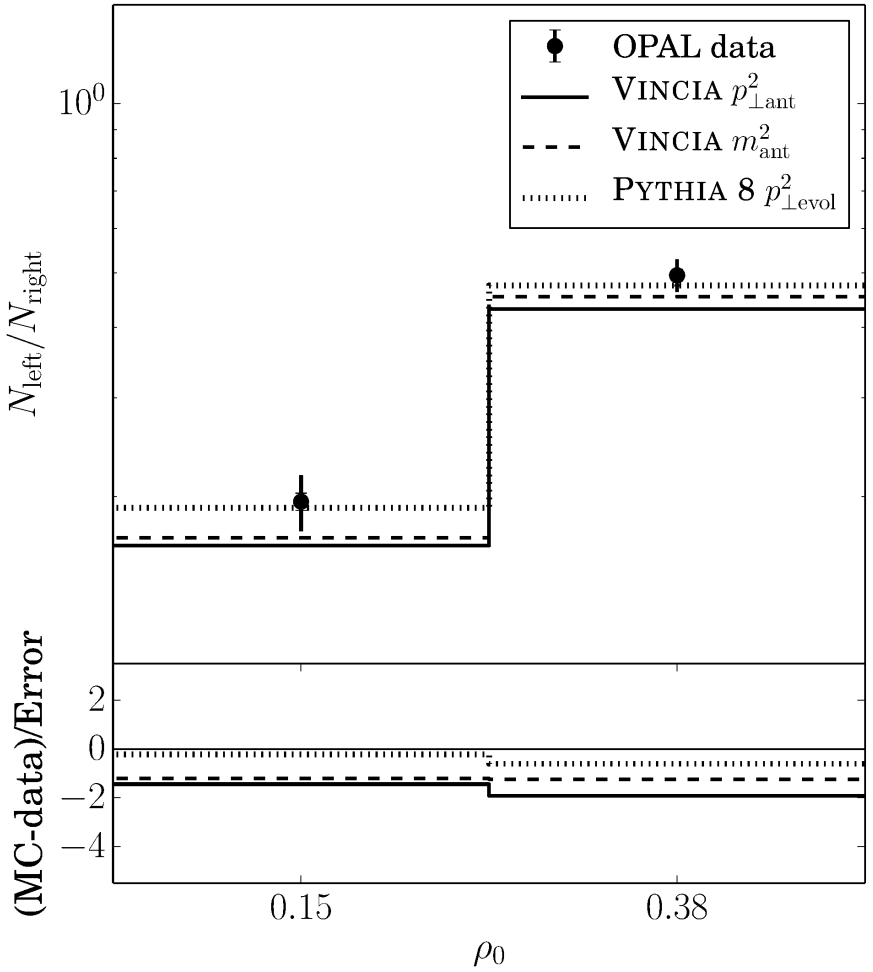
MC ok, except Herwig++ q^2

$\rho = (M_L/M_H)^2$ Asymmetry

c) Asymmetry for ρ, HERWIG++



d) Asymmetry for ρ, VINCIA, PYTHIA 8



MC models ok, except Herwig++ q^2, Pythia8 variants slightly better than Herwig++ variants

Conclusion

- New observables sensitive to parton shower development measured
- Comparison with modern MC models
  - models broadly ok, coherence needed
  - interesting model differences observed
  - Pythia8/VINCIA with p_t based evolution fare best
- Different hadronisation models, would like to repeat with all shower models with same hadronisation model