

# Implementing $\phi$ asymmetry & $k_T$ theory with LEPTO

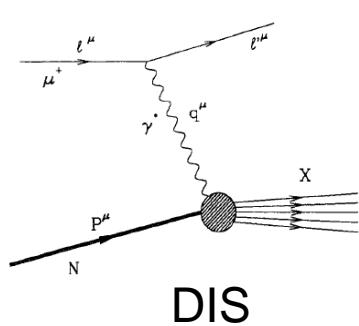
Mark D. Baker

(& Elke-Caroline Aschenauer)

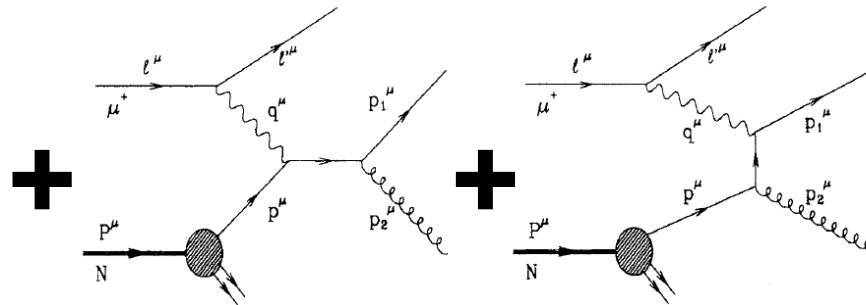
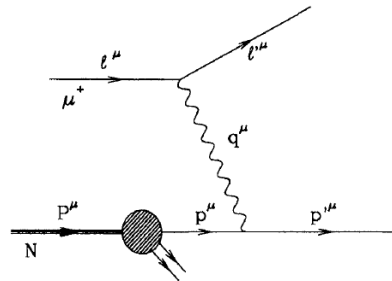
BNL

16-DEC-2010

# 0<sup>th</sup> and 1<sup>st</sup> order Matrix Elements + Parton Shower for fragmentation

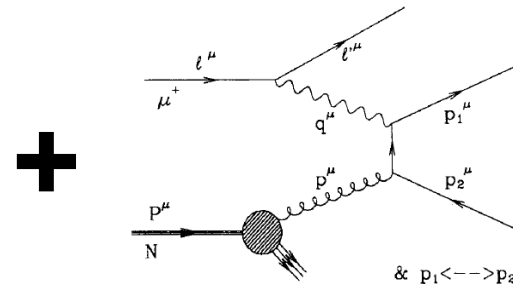


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LEPTO used as a basis for :

- PEPSI
- DJANGO
- ...



Photon-Gluon Fusion

# LEPTO version 6.5.1

- `/afs/rhic.bnl.gov/eic/PACKAGES/LEPTO-32BIT`
  - Installed by Elke & Mark
    - After finding and fixing a bug affecting “LFRAME=4”.
  - Links to Pythia 5.7.24, LHAPDF5.8.4, Jetset 7.4.08
  - Example steering routines available already
  - General steering routine shortly
- Fixing Lepto bug in PEPSI and DJANGO also
- `.../eic/PACKAGES/LEPTO-PHI-32BIT` (from Mark)
  - Lepto with Generalized Cahn effect
  - Available shortly (running in a private area)
- Many options
  - Various PDFs (through LHAPDF)
  - $F_L$  from QCD, TMC (Target M Corr.), HT
  - Intrinsic Charm

# LEPTO-PHI-32BIT

- Generalized Cahn effect

( $\phi$  asymmetry due to primordial partonic  $k_T$ )

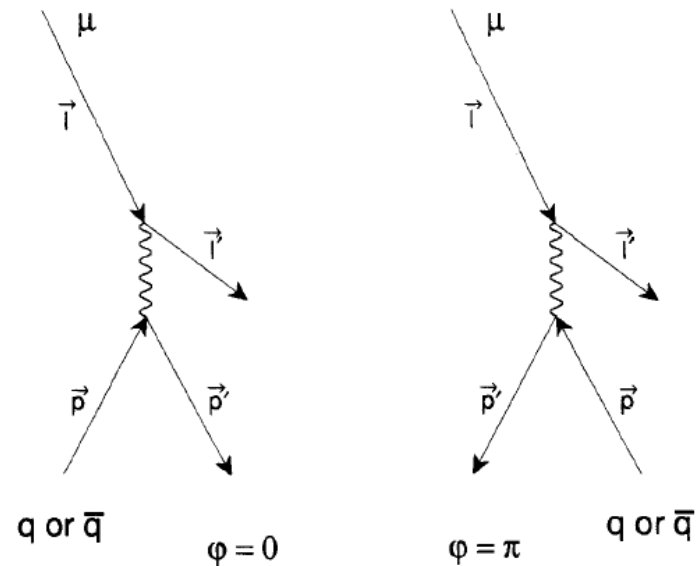
MDB PhD Thesis (MIT, 1993)

<http://www.rhic.bnl.gov/~baker/eRHIC/MDBThesis/AzimuthalAsymmetry.pdf>

- Generalized to all orders of  $k_T/Q$
- Generalized to include  $k_T$  at  $O(\alpha_s)$ 
  - Joshipura & Kramer with errors fixed

# Two pictures of the Cahn effect

## Kinematic



UNFAVORED

FAVORED

$$\sigma \sim s^2 + u^2$$

$\phi=\pi$  is more collinear: higher  $s, u$

## Polarization

Even for unpolarized lepton+proton,  
 $\gamma^*$  remembers lepton scattering plane.

Key to relationship with Collins, Sivers etc.

# Generalization to all $k_T/Q$

<http://www.rhic.bnl.gov/~baker/eRHIC/MDBThesis/AzimuthalAsymmetry.pdf>

Cahn

$$A = [1 + (1 - y_{B_j})^2],$$

$$B = -4 \frac{k_{\perp}}{Q} (2 - y_{B_j}) \sqrt{1 - y_{B_j}},$$

$$C = 4 \frac{k_{\perp}^2}{Q^2} (1 - y_{B_j}).$$

$$\frac{dN}{d\varphi} \sim A + B \cos \varphi + C \cos 2\varphi,$$

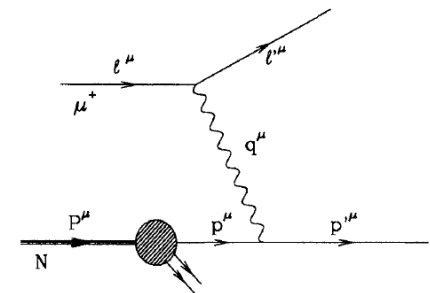
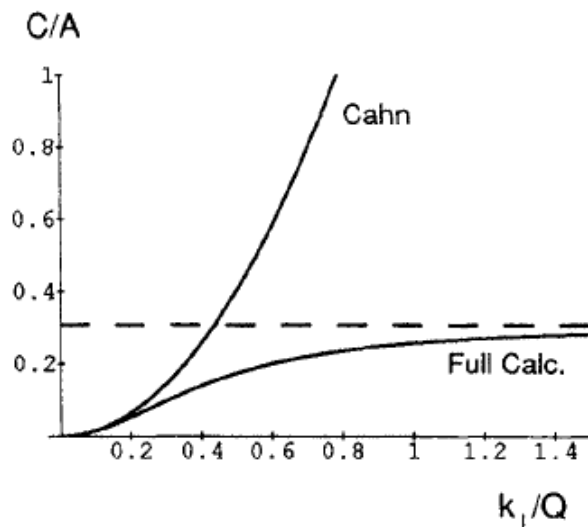
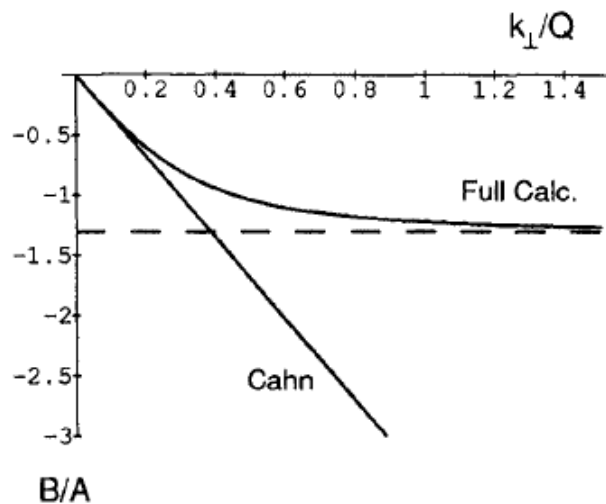
Full (Baker)

$$A = [1 + (1 - y_{B_j})^2] \left( \frac{1}{\xi'^2} + \xi'^2 \frac{k_{\perp}^4}{Q^4} \right) + 8(1 - y_{B_j}) \frac{k_{\perp}^2}{Q^2},$$

$$B = -4 \frac{k_{\perp}}{Q} \left( \frac{1}{\xi'} + \xi' \frac{k_{\perp}^2}{Q^2} \right) (2 - y_{B_j}) \sqrt{1 - y_{B_j}},$$

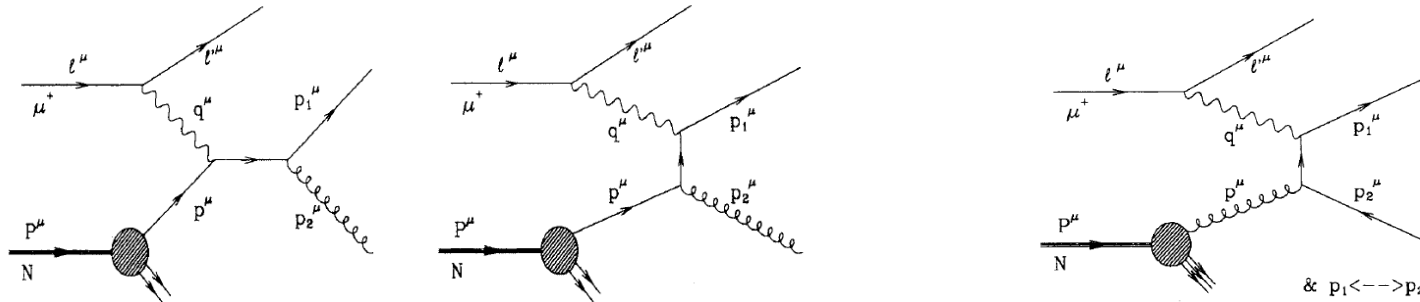
$$C = 4 \frac{k_{\perp}^2}{Q^2} (1 - y_{B_j}).$$

$$\xi' = \left( \frac{1}{2} + \frac{1}{2} \sqrt{1 + \frac{4k_{\perp}^2}{Q^2}} \right)^{-1}$$



Plots for  $y=0.5$

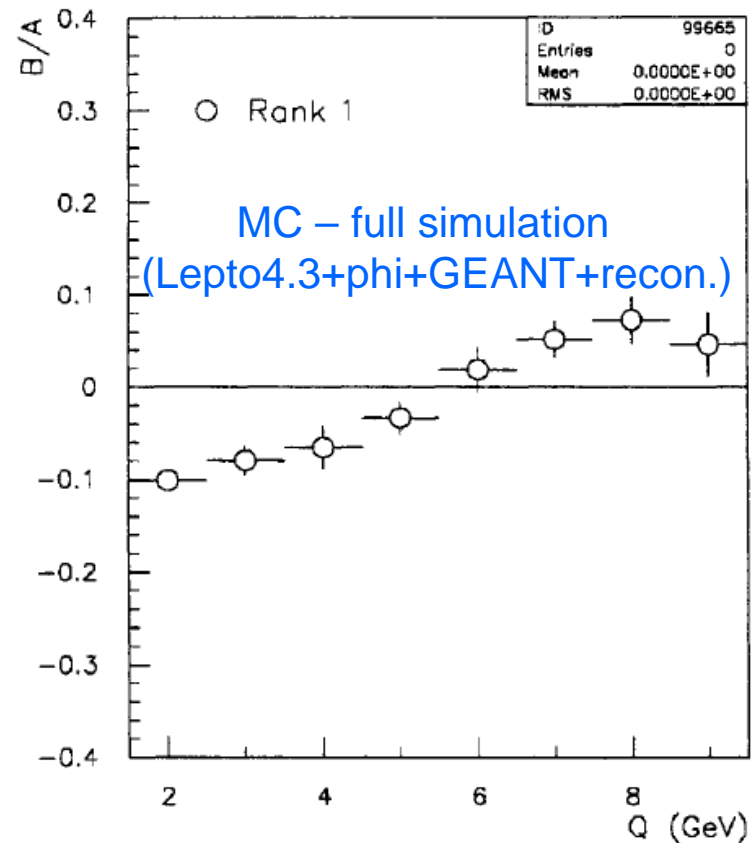
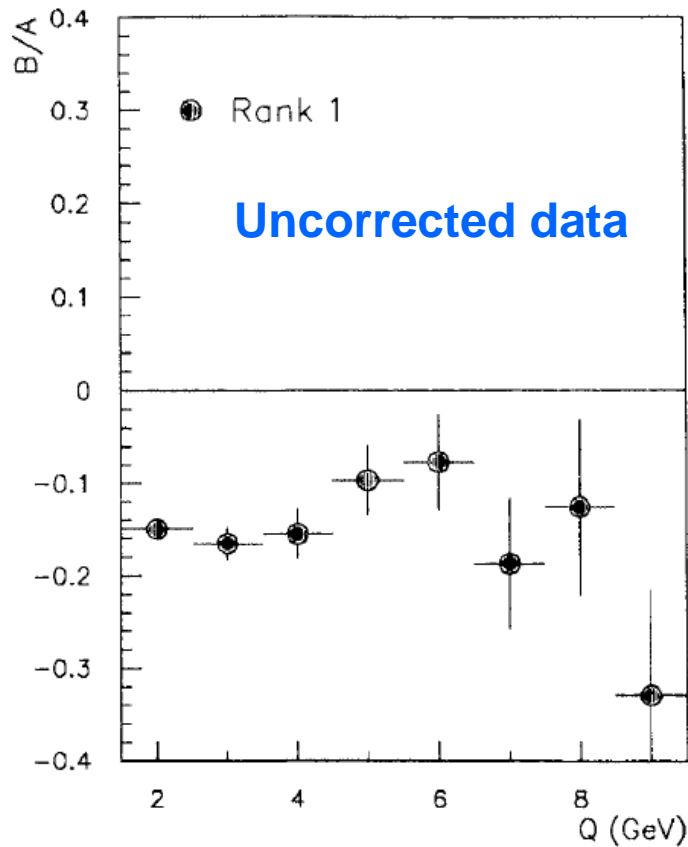
# $O(\alpha_s)$ with $k_T$



- Straightforward but algebraically involved.
  - Two azimuthal angles
- Joshipura and Kramer, J. Phys. G8 (1982) 209
  - But see MDB Thesis for error fixes

# $Q^2$ dependence of asymmetry

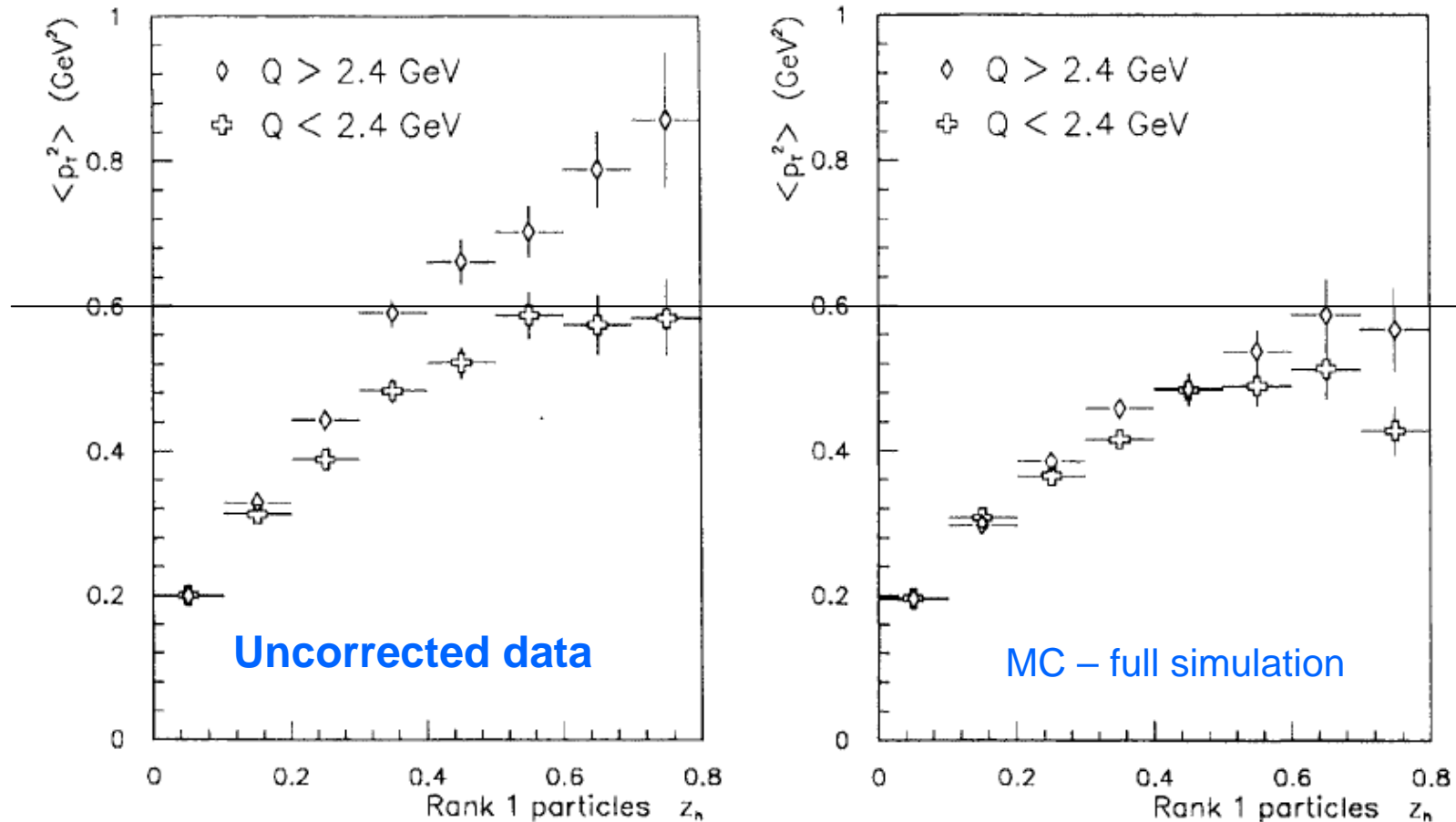
FNAL E665 (490 GeV fixed target) - note: EMC result is similar



For fixed  $k_T$ , Cahn effect should vanish at high  $Q^2$   
Does this mean that  $k_T$  grows with  $Q^2$ ?



# “Seagull” plot is also $Q^2$ dependent



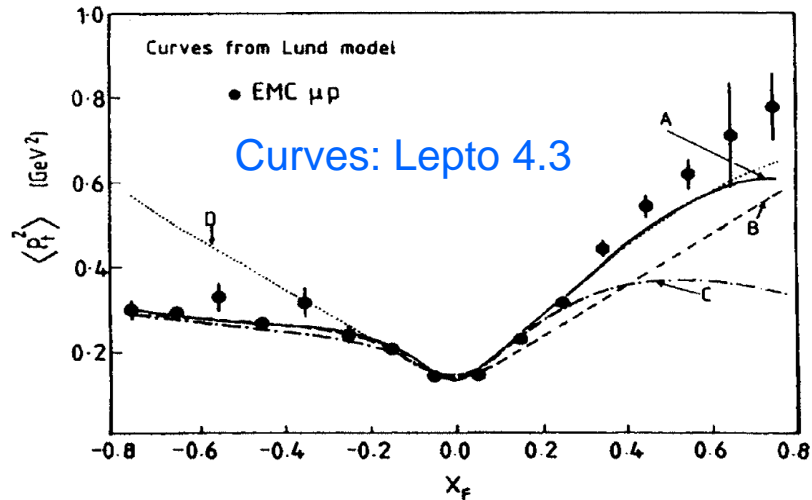
Tune  $k_T(Q)$  for a better description of data?

# Tuning $k_T$

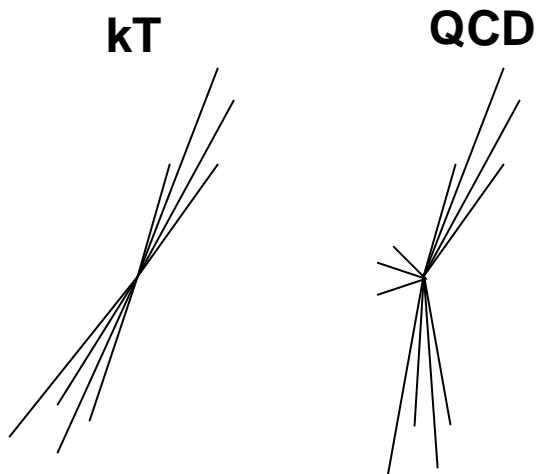
- Default  $k_T$  settings are independent of  $Q^2$  and fairly modest:  $\langle k_T^2 \rangle = (0.44 \text{ GeV})^2$ 
  - Strong partonic  $\phi$  asymmetry almost completely washed out by hadronization
    - Old-style LUND/JETSET in LEPTO 4.3
    - parton shower in LEPTO 6.5.1.
  - Don't really match data
- How can we understand spin-related  $\phi$  asymmetry if we don't understand the unpolarized result?

# Separating QCD and $k_T$

EMC, Z. Phys. C 36 (1987) 527



- Primordial parton  $k_T$  (in the “wavefunction”) leads to front-back symmetric  $p_T$   
**Curve D:  $\langle k_T^2 \rangle = (0.88 \text{ GeV})^2$  & QCD OFF**
- QCD radiation affects only the forward (accelerated) partons  
**Curve A:  $\langle k_T^2 \rangle = (0.44 \text{ GeV})^2$  & QCD ON**



- We can also try to reconstruct the jet directions directly using:
  - Leading particles (forward/backwards)
  - Jet recon. algorithms (e.g. **Anti- $k_T$**  )



# Conclusion & Plans

- Conclusions
  - Straight LEPTO and phi-asymmetric LEPTO will be in “PACKAGES” soon.
  - Primordial partonic  $k_T$  and  $\phi$  asymmetry not that well understood yet.
- Plans
  - Finalize LEPTO release and tune  $k_T(Q)$
  - Perhaps study  $p_T$ -imbalance of dijets to distinguish QCD Compton vs.  $k_T$