Thoughts & questions on primordial k_T

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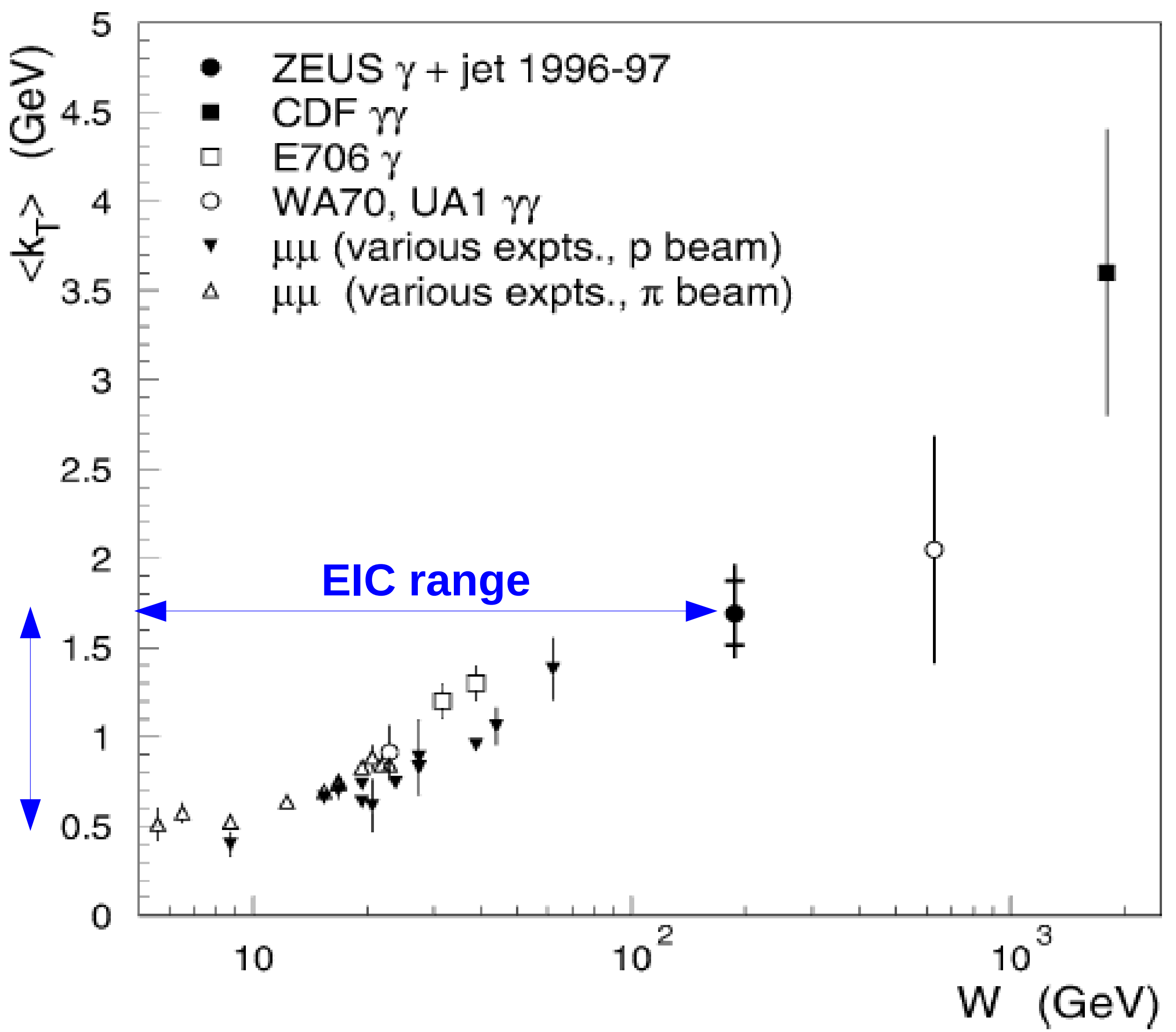
Motivation

- DIS & especially DY & other pp data imply that "intrinsic" k_T grows with s and/or Q^2
  - Pythia 6.4 default RMS k_T is 2 GeV!
  - Often attributed to improperly modeled QCD effects: parton shower details or higher order hard QCD
- In DIS, unlike in pp, we can distinguish between intrinsic non-perturbative k_T and p_T due to QCD radiation. Let's measure it!
- Intrinsic k_T would be clearly also be valuable to compare in ep and eA to look at saturation effects.

Running of "k_T"

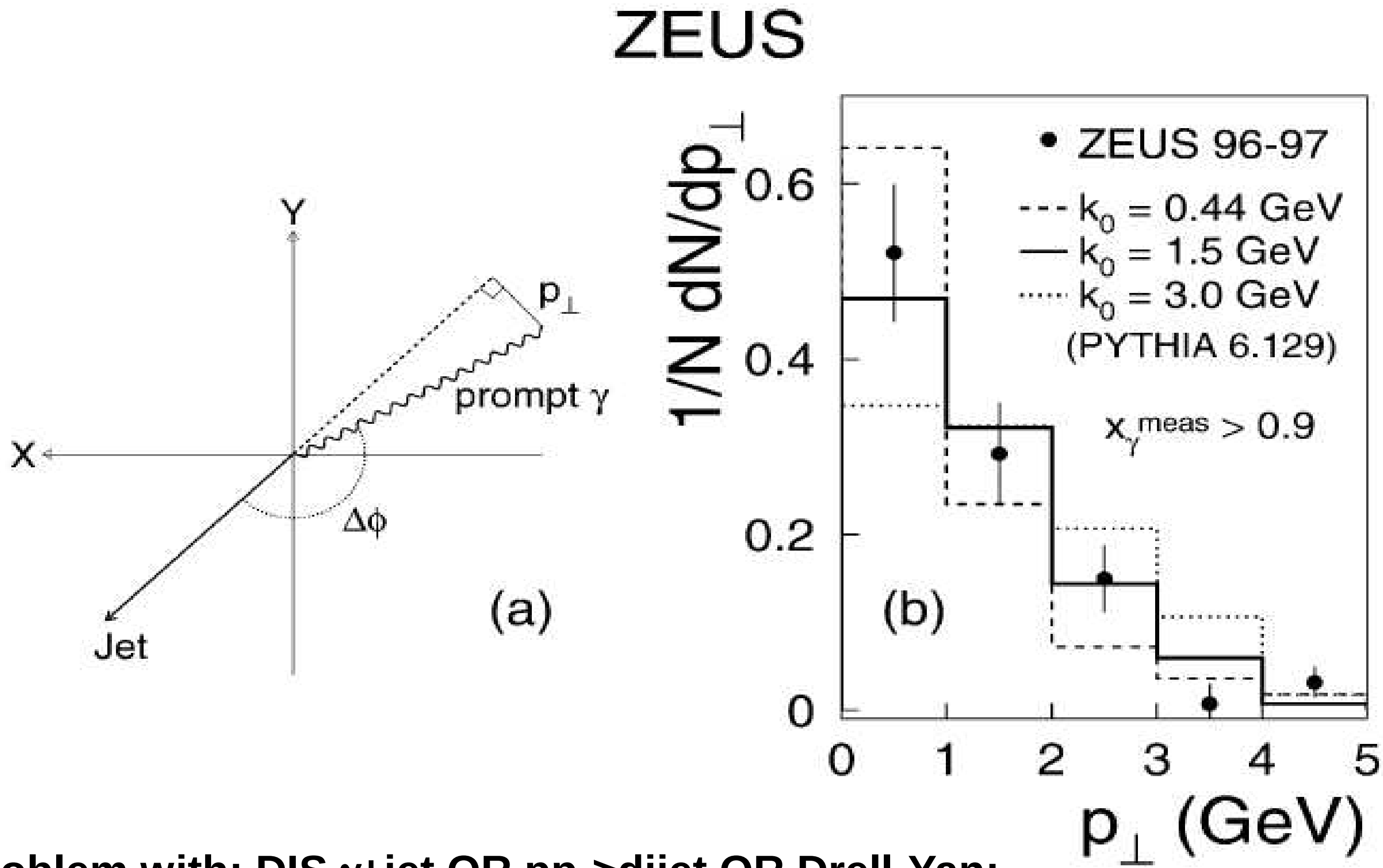
ZEUS Collaboration / Physics Letters B 511 (2001) 19–32



Note: Gaussian: $\langle k_T \rangle = \mathrm{sqrt}(\pi/4) * k_T^{rms}$

ZEUS ignores the target remnant

ZEUS Collaboration / Physics Letters B 511 (2001) 19–32

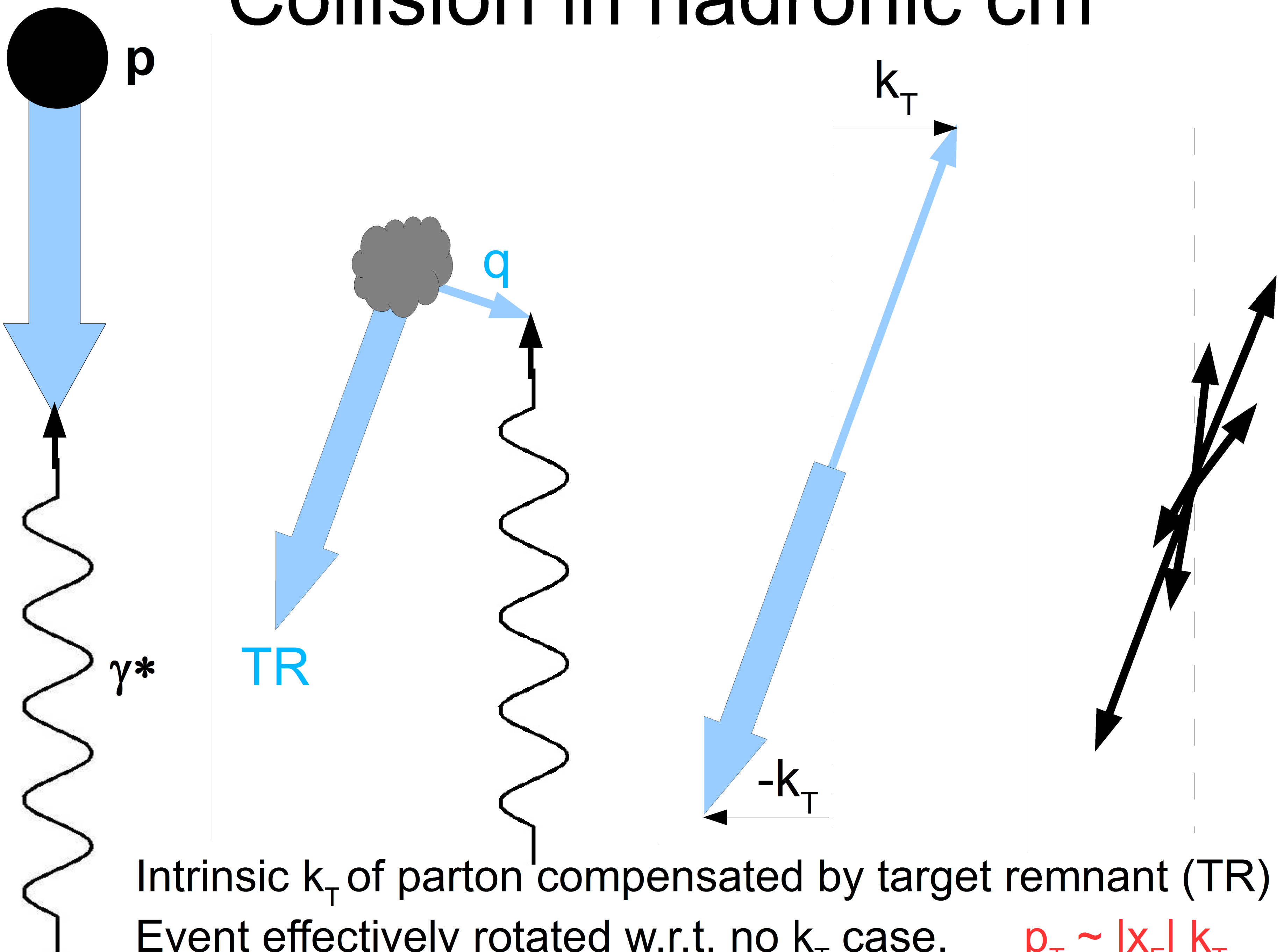


Common problem with: DIS γ+jet OR pp->dijet OR Drell-Yan:

Very <u>subtle</u> differences between intrinsic k_T and gluon radiation

We need something that smacks you in the face a bit more...

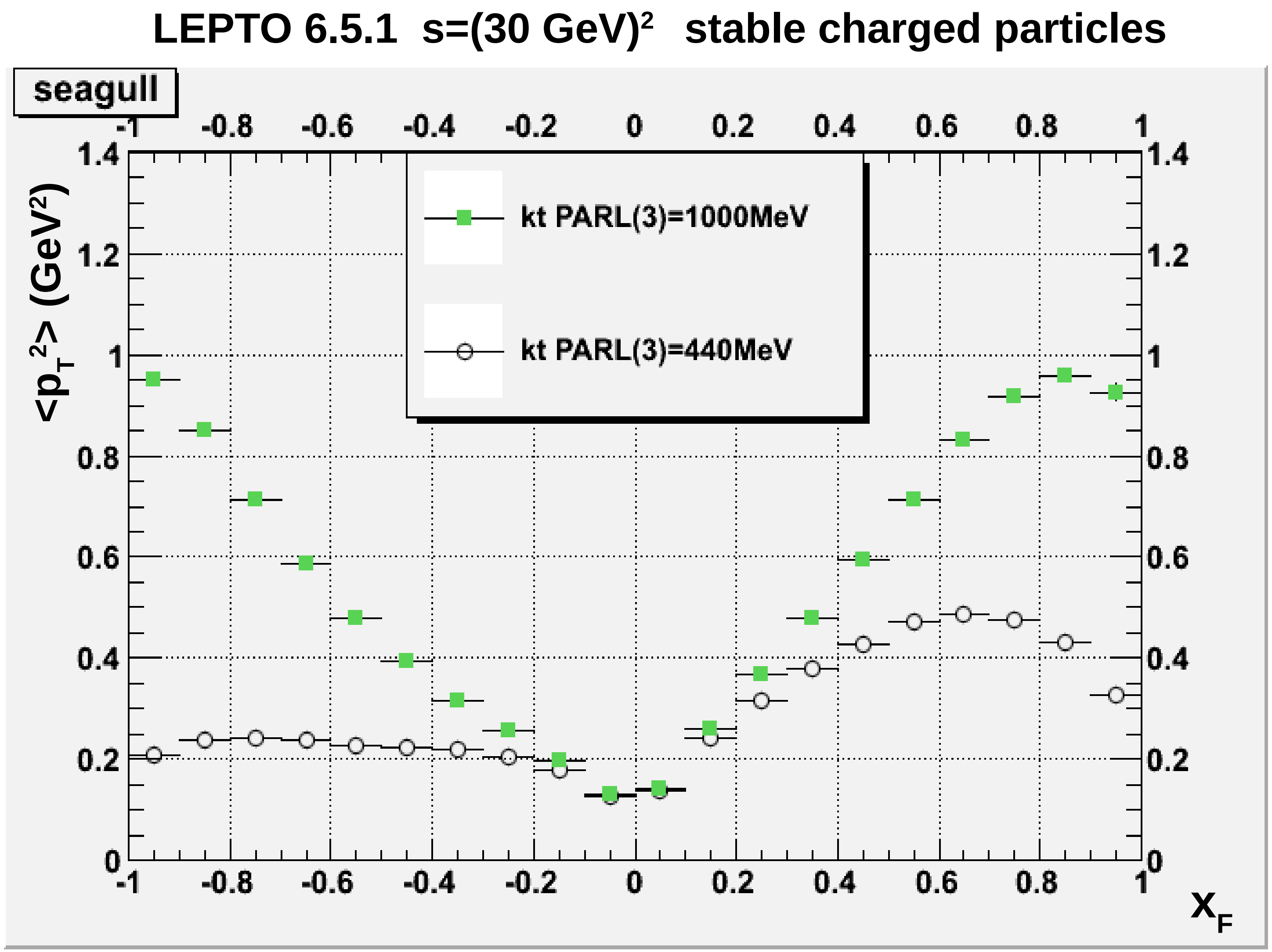
Collision in hadronic cm

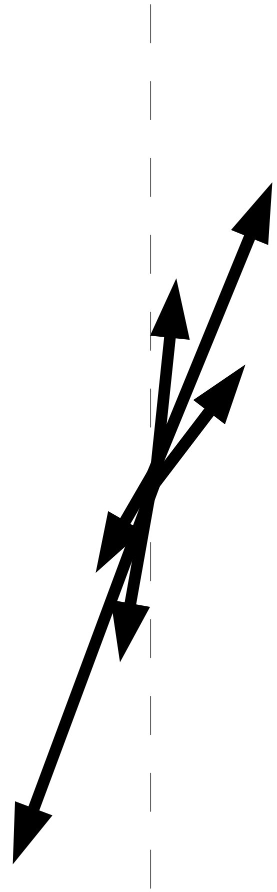


Intrinsic k_T of parton compensated by target remnant (TR)

Event effectively rotated w.r.t. no k_T case. $p_T \sim |x_F|\, k_T$

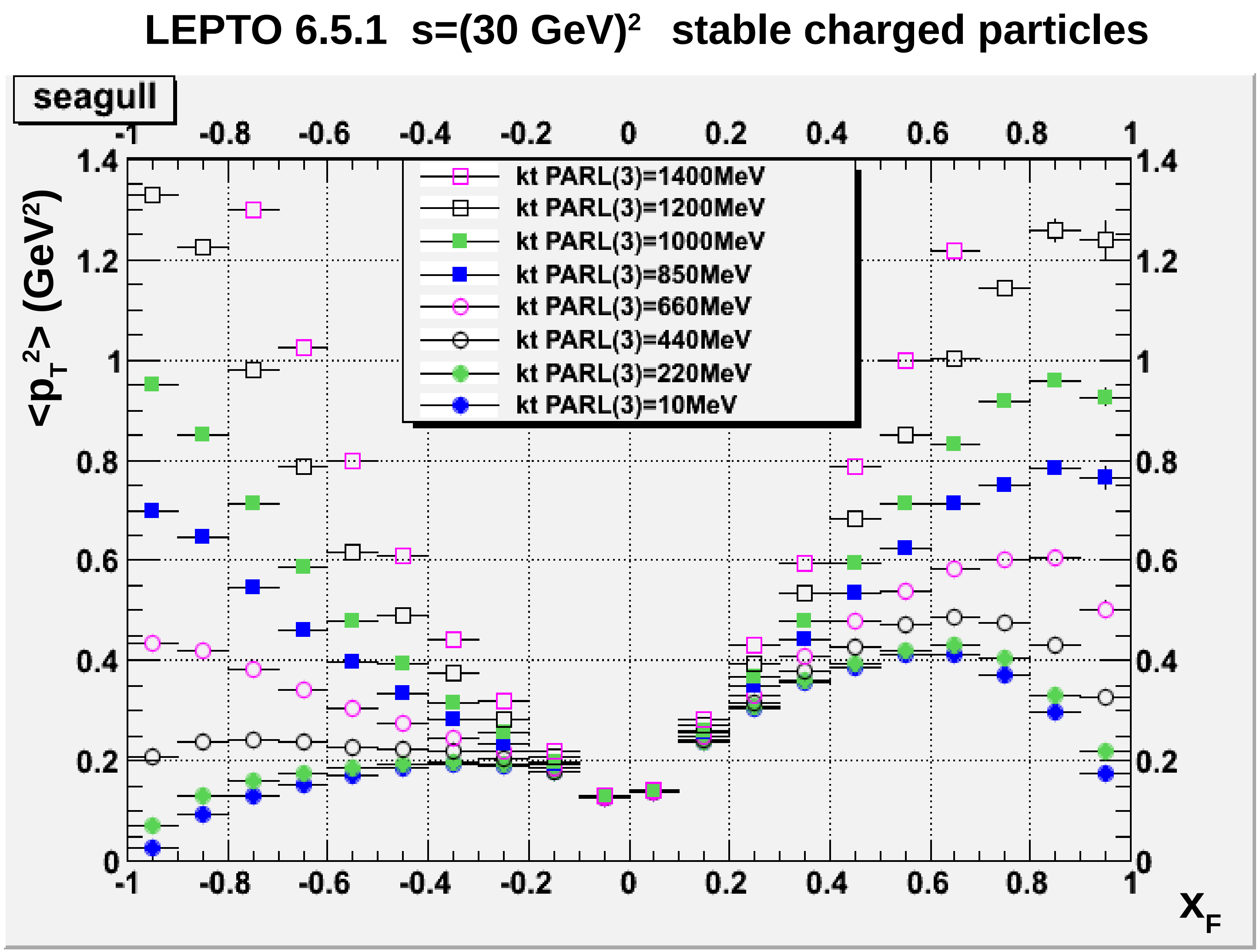
Primordial k_T shows up at high $|x_F|$

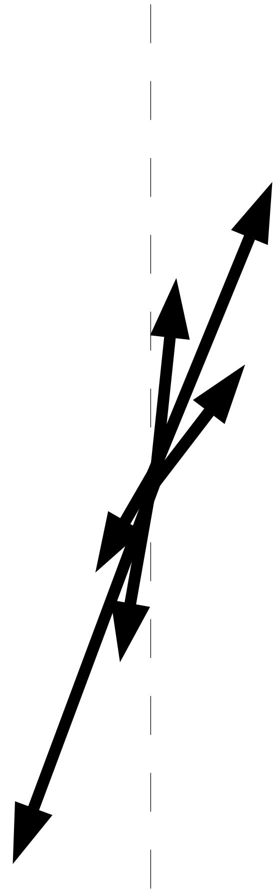




Contribution from primordial k_T to p_T is roughly $\propto |x_F|$

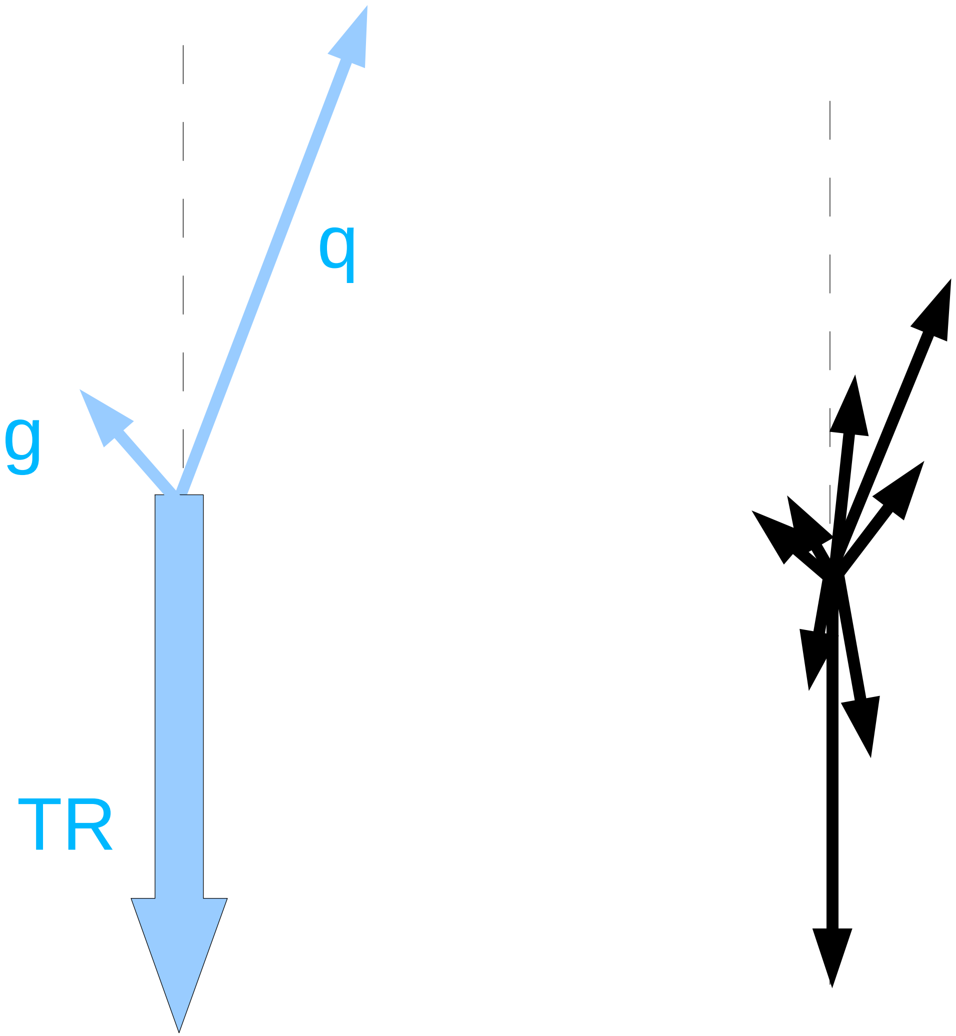
Primordial k_T shows up at high $|x_F|$





Contribution from primordial k_T to p_T is roughly $\propto |x_F|$

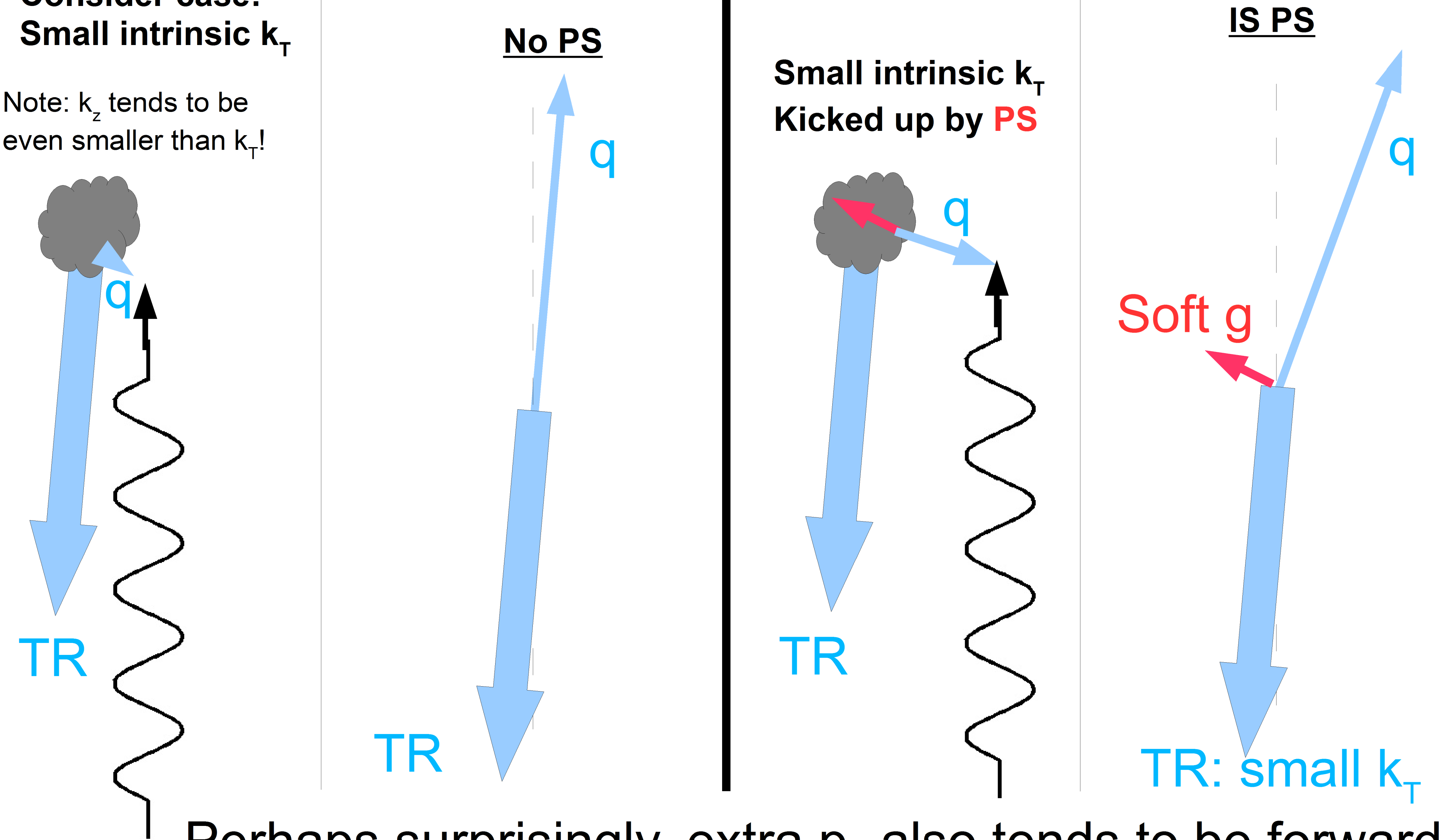
QCD effects in hadronic cm



Hard QCD (and FS Parton Shower) increases p_T at forward x_F

What about Init. State Parton Shower?

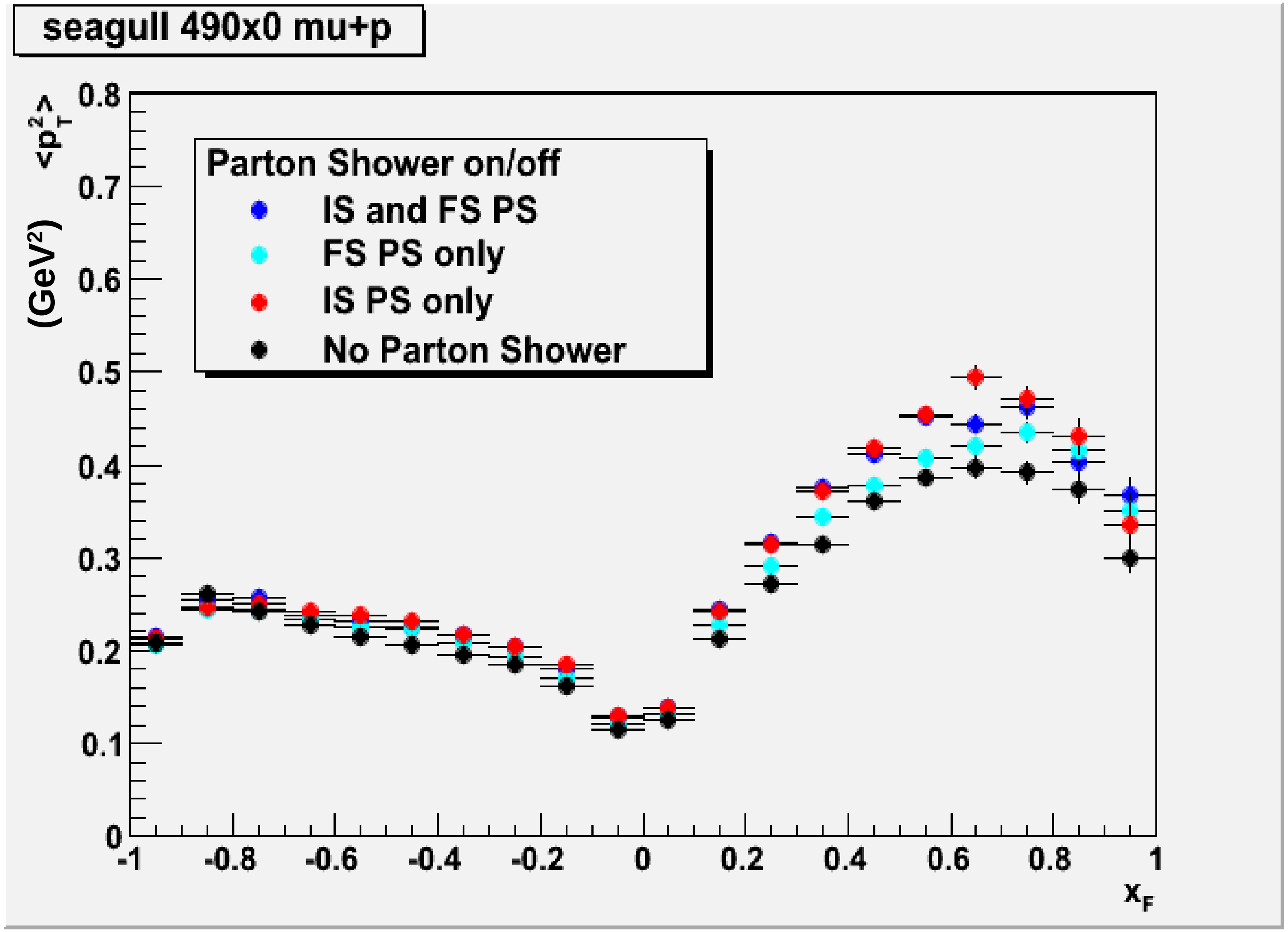
Consider case:
Small intrinsic k_T



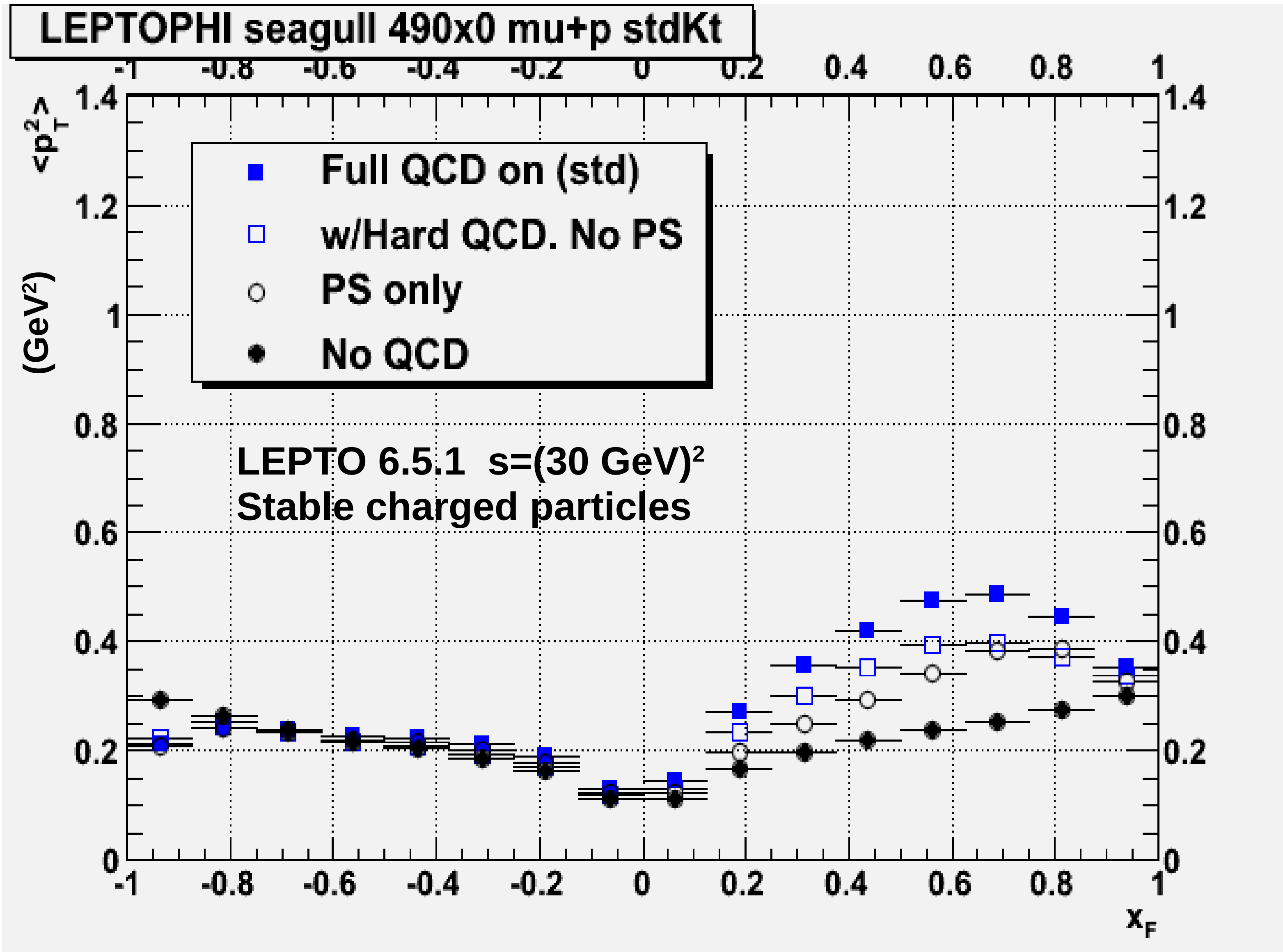
Perhaps surprisingly, extra p_T also tends to be <u>forward</u>

Parton Showers mostly contribute at forward x_F

LEPTO 6.5.1 $s=(30\ GeV)^2$ Stable charged particles



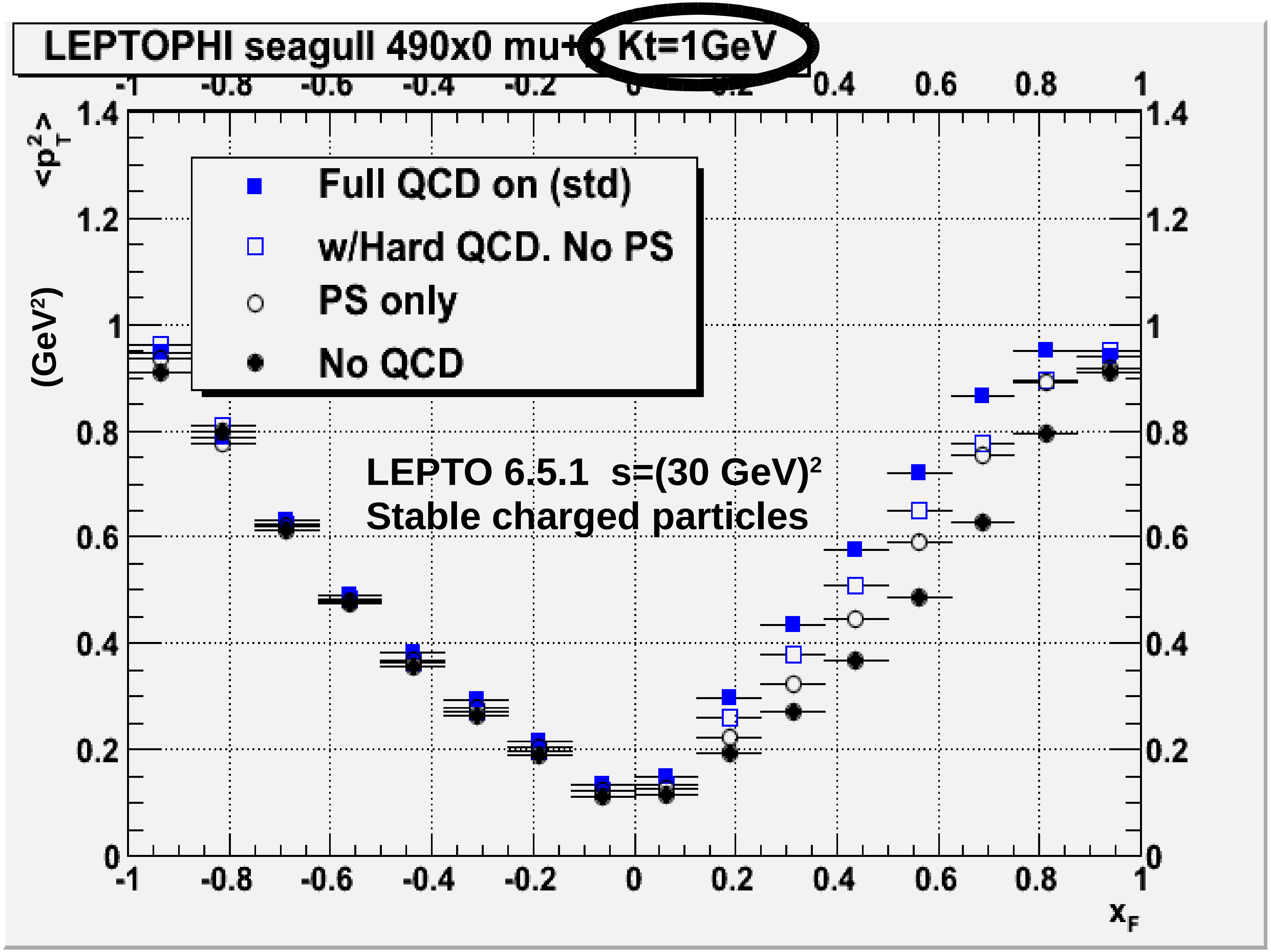
QCD, in general, shows up at forward x_F



Basic physics: only the struck, accelerated, parton radiates

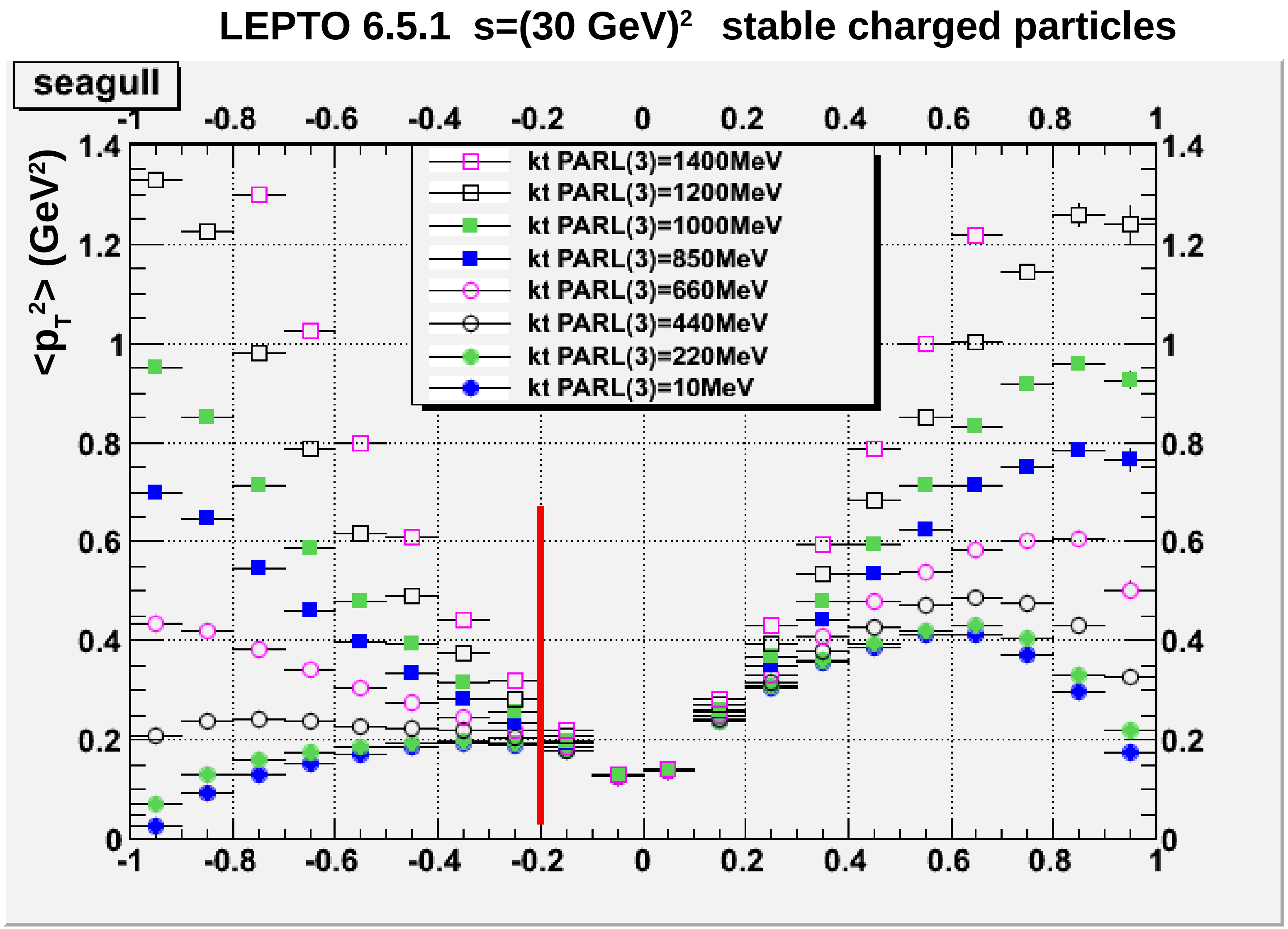
QCD shows up at forward x_F

GeV²



Basic physics: only the struck, accelerated, parton radiates

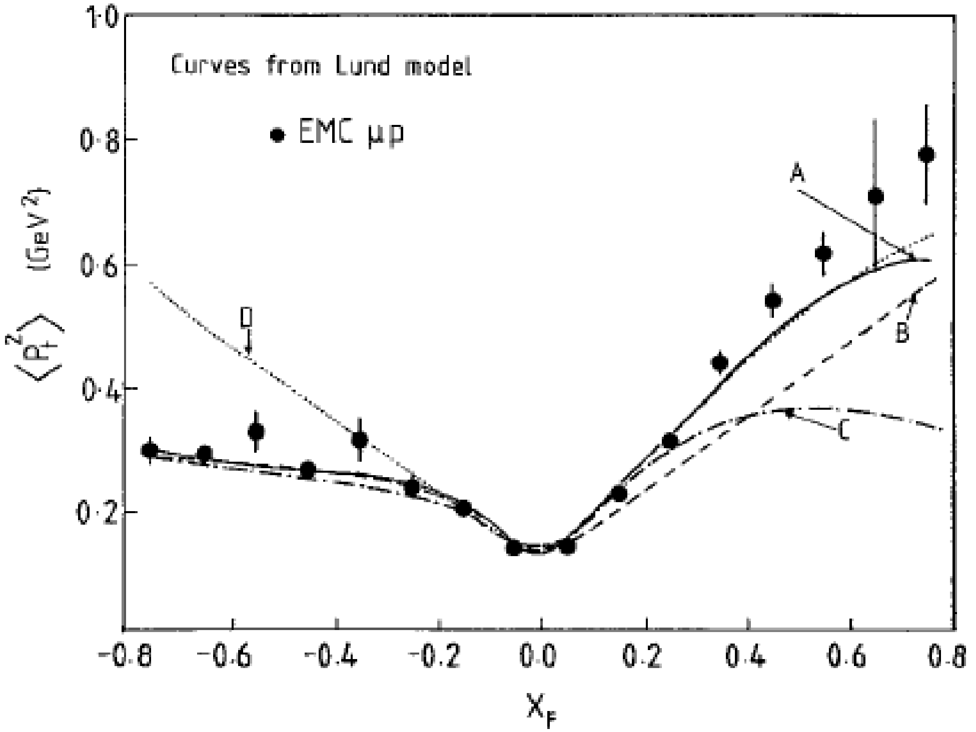
Primordial k_T cleanest at x_F<-0.2

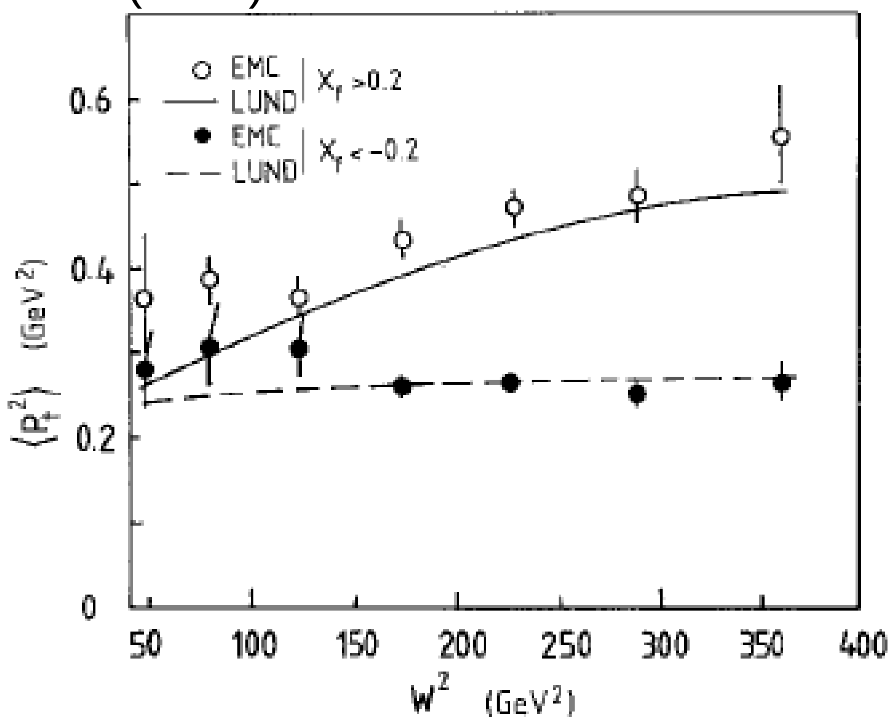


Also shows up at x_F>0.2, especially for larger values of k_T

EMC singles data

EMC Collaboration, ZPC 36 (1987) 527





A: Standard LEPTO w/ k_T^{RMS} = 0.44 GeV (hard & soft QCD on)
B: Hard gluons off, soft still on
C: Soft gluons off, hard still on
D: Like case C, but w/ k_T^{RMS} = 0.88 GeV

0.88 GeV of kT looks VERY different than 0.44 GeV + soft QCD

Conclusion (singles)

- Intrinsic k_T of struck parton:
  - Is reflected in the target remnant as well as struck parton (both forward and negative x_F)
  - Impacts hadron p_T like $|x_F|\ k_T$
- Dynamical p_T from soft or hard QCD shows up primarily forward (γ^* direction in hadronic cm)
- Therefore intrinsic k_T cleanest at x_F<-0.2
- Huge difference in seagull plot for rms k_T of 0.44 GeV vs. 1.0 GeV

Next step: correlations

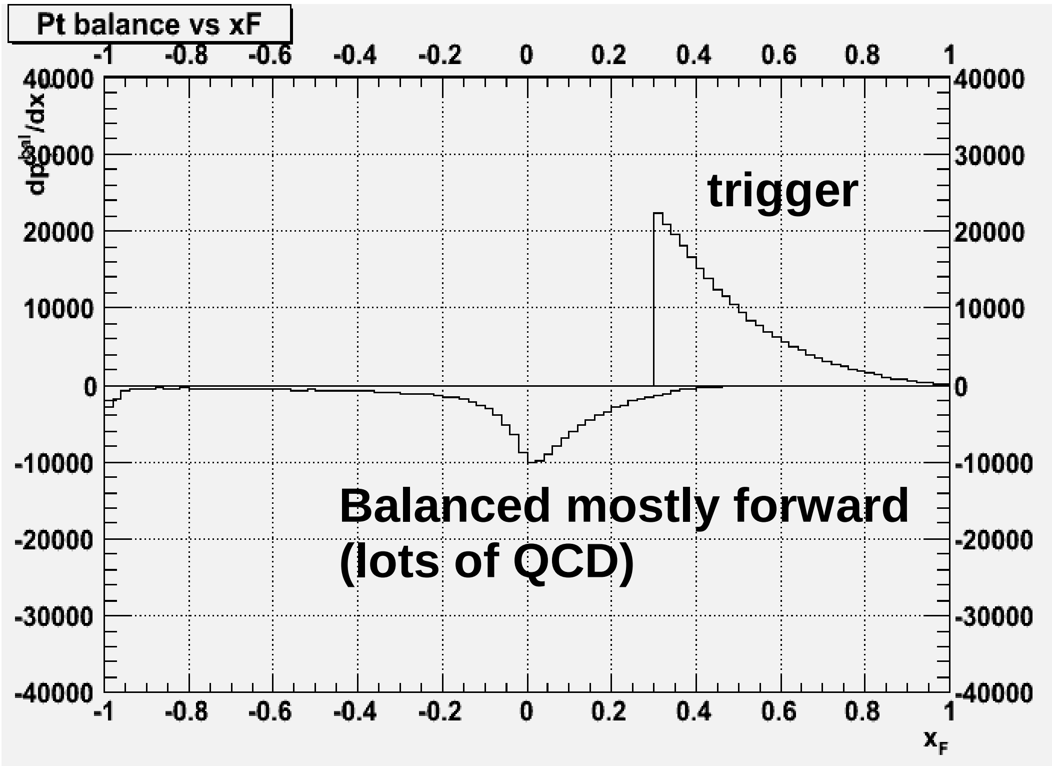
- Forward p_T is a mix of k_T and QCD
- For eA, intranuclear cascading (INC) will ALSO contribute at large negative x_F.
  - Simulate impact of this, of course...
- But we have MORE information.
  - Intrinsic k_T shows up forward and backward and equal and opposite
  - INC should primarily affect x_F<-0.2 and not x_F>0.2
  - QCD is forward, not backward.

Transverse momentum balance

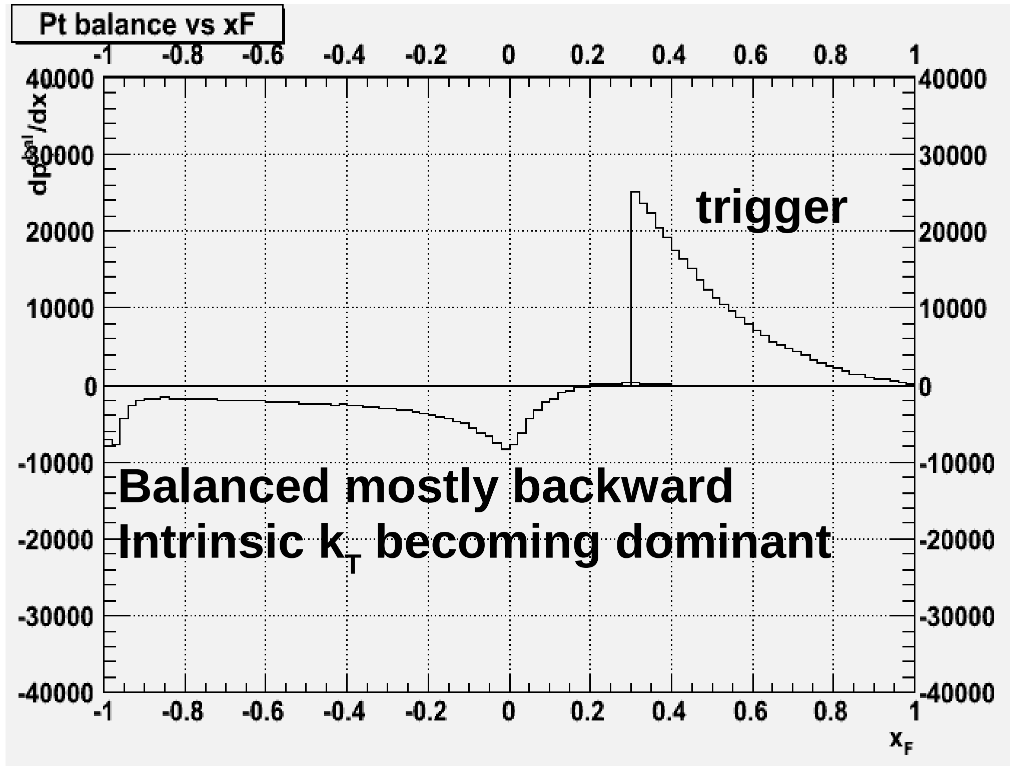
- Trigger particle:
  - Leading (largest x_F) particle with $x_F>0.3$
  - Anti-leading (largest $-x_F$) particle with $x_F<-0.3$.
- Define the p_T direction of this leading particle as p_x. Plot the integral of p_x of all other particles as a function of x_F (or y^*).

Transverse momentum balance

RMS k_T=0.44 GeV



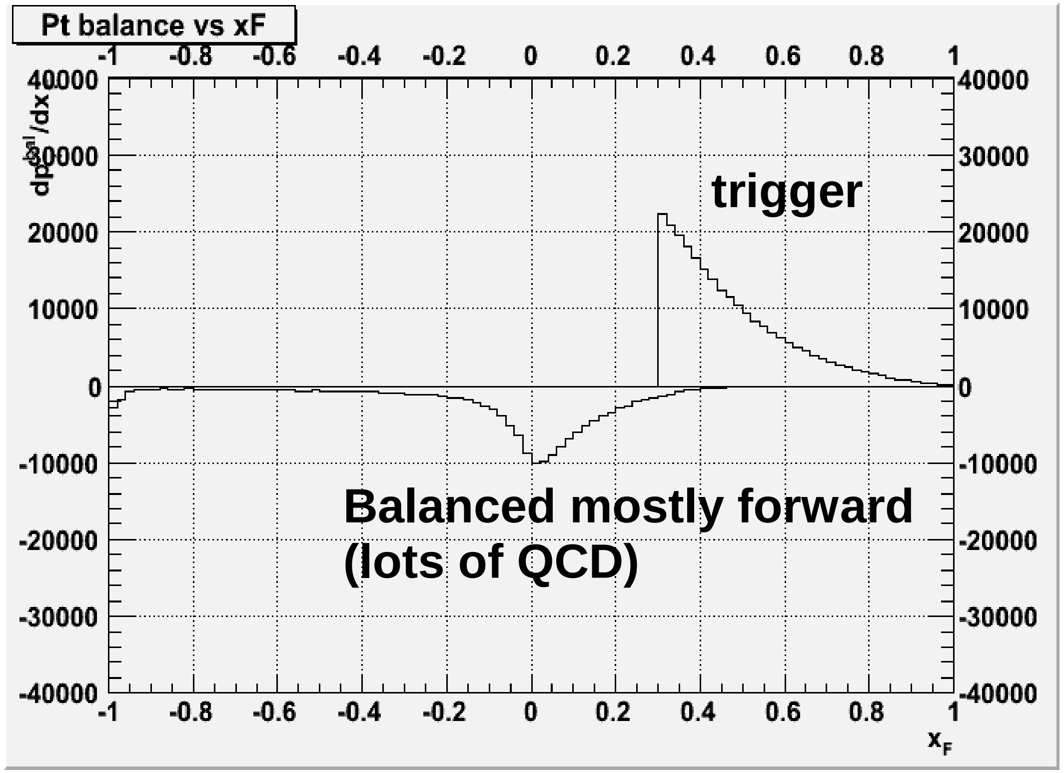
RMS k_T=1.0 GeV



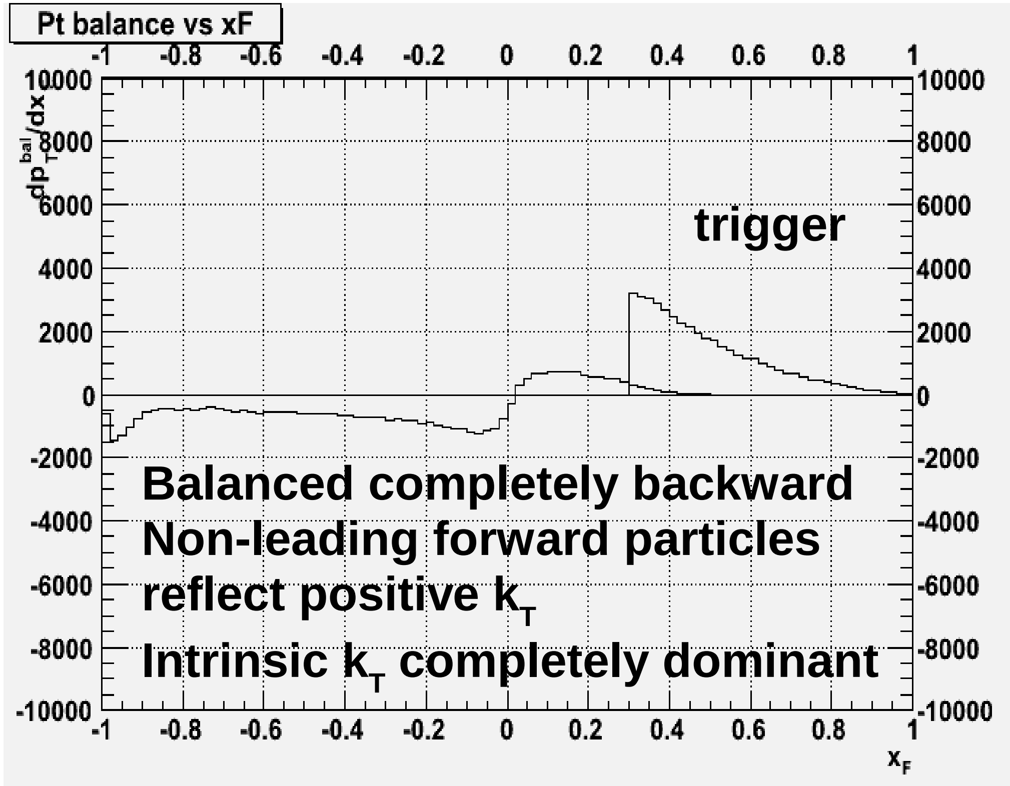
Note: These should be normalized by $1/N_{ev}$ and bin size Δx_F

Transverse momentum balance

RMS k_T=0.44 GeV



RMS k_T=2.0 GeV



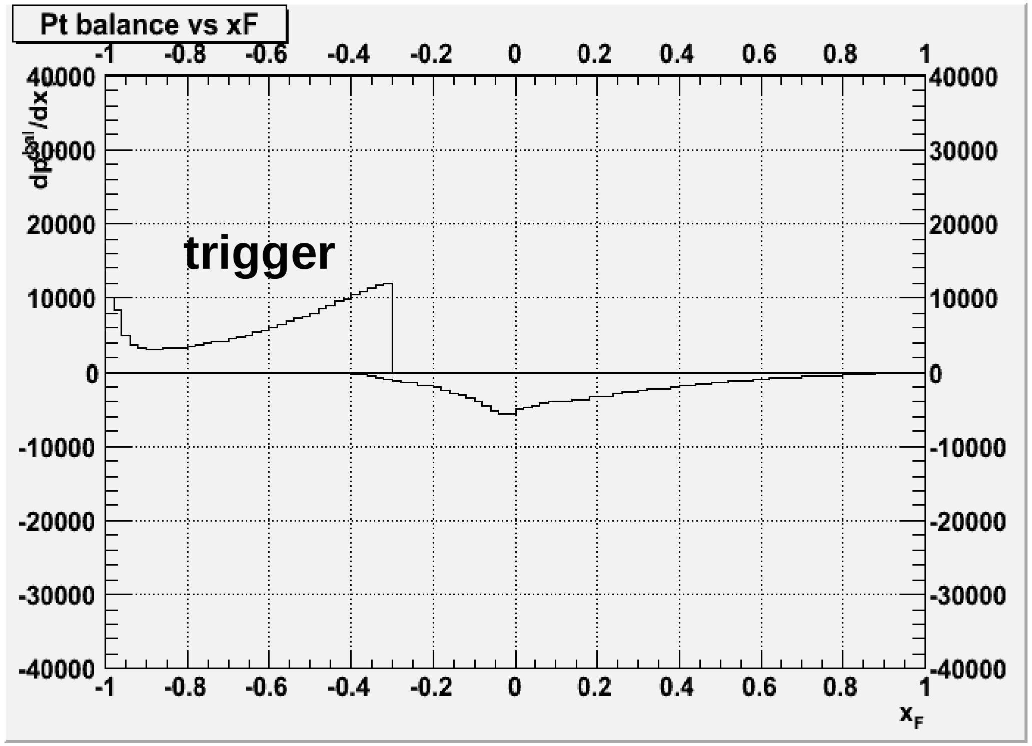
Note: These should be normalized by $1/N_{ev}$ and bin size Δx_F

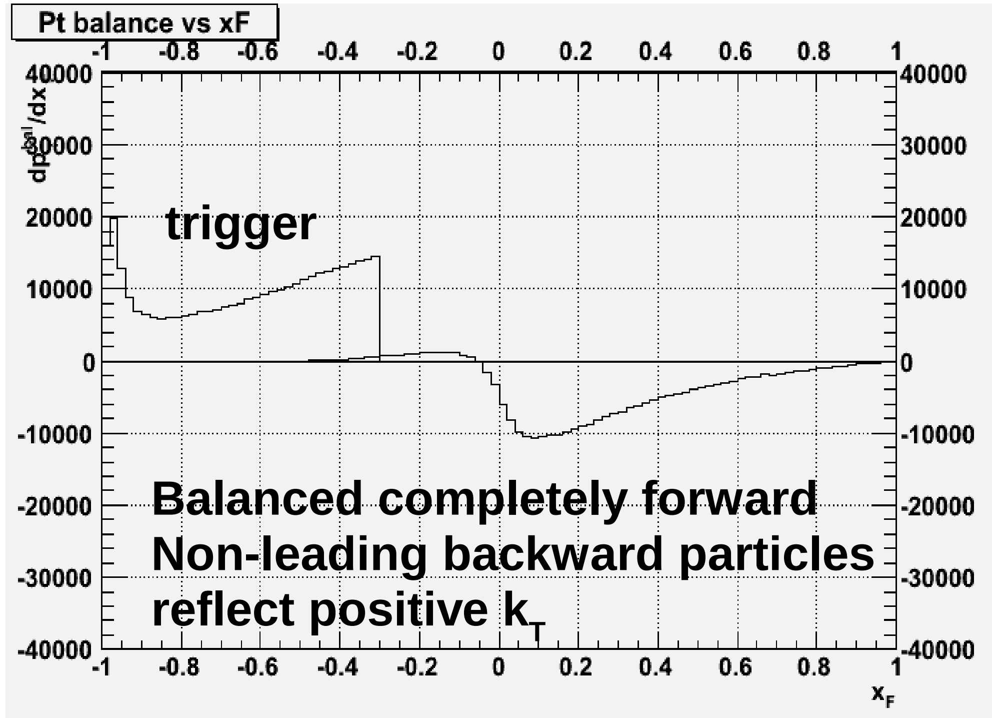
Transverse momentum balance

Triggered by target anti-leading particle

RMS k_T=0.44 GeV **RMS k_T=1.0 GeV**

Intrinsic k_T already dominant





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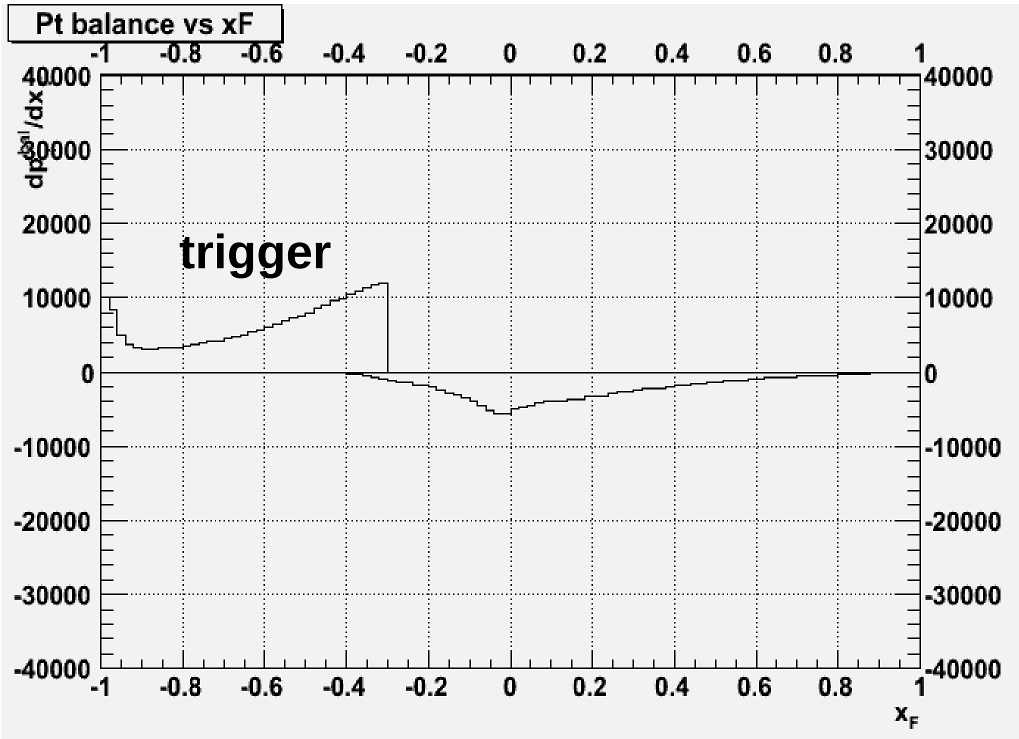
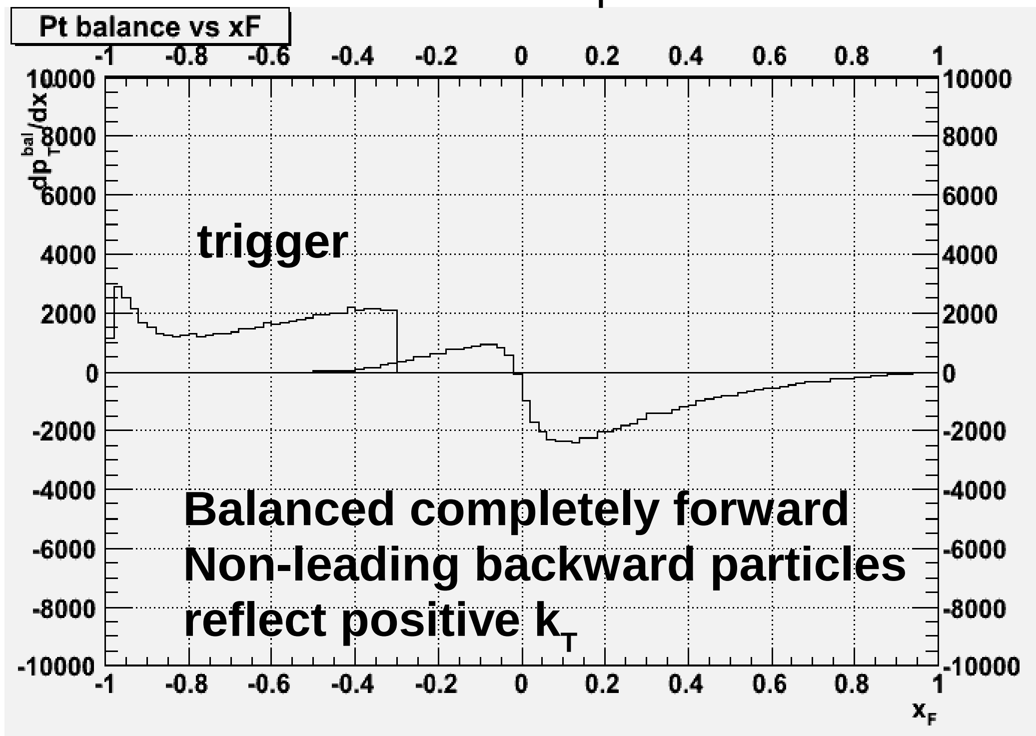
Transverse momentum balance

RMS k_T=0.44 GeV



RMS k_T=2.0 GeV

Intrinsic k_T dominant



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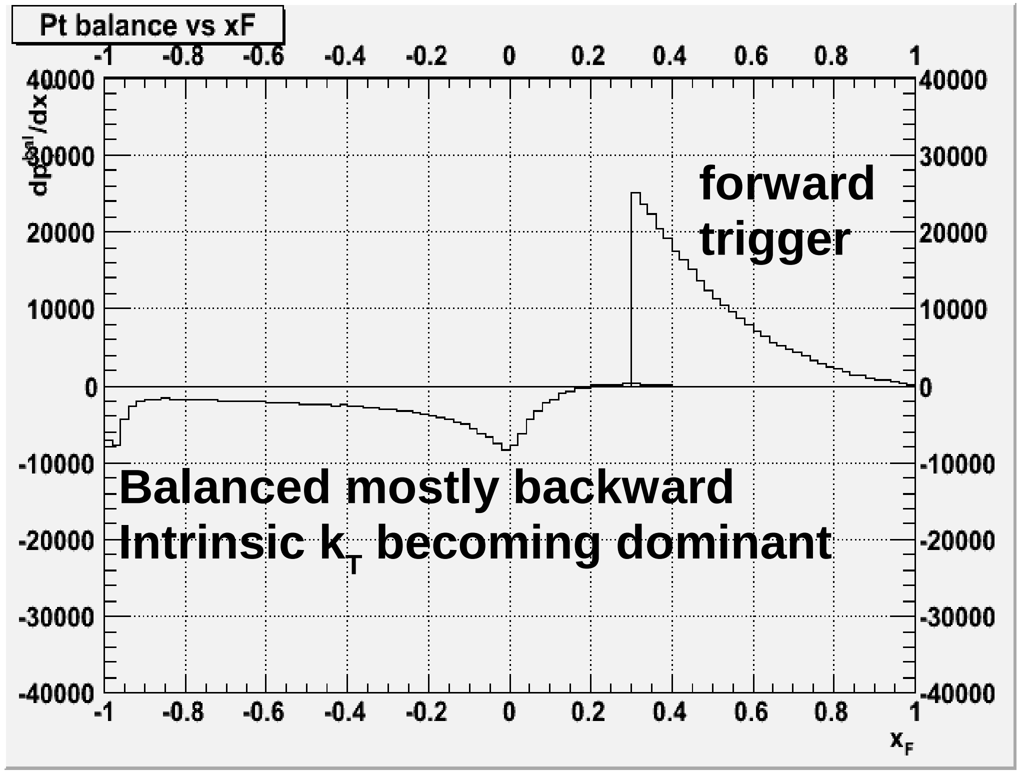
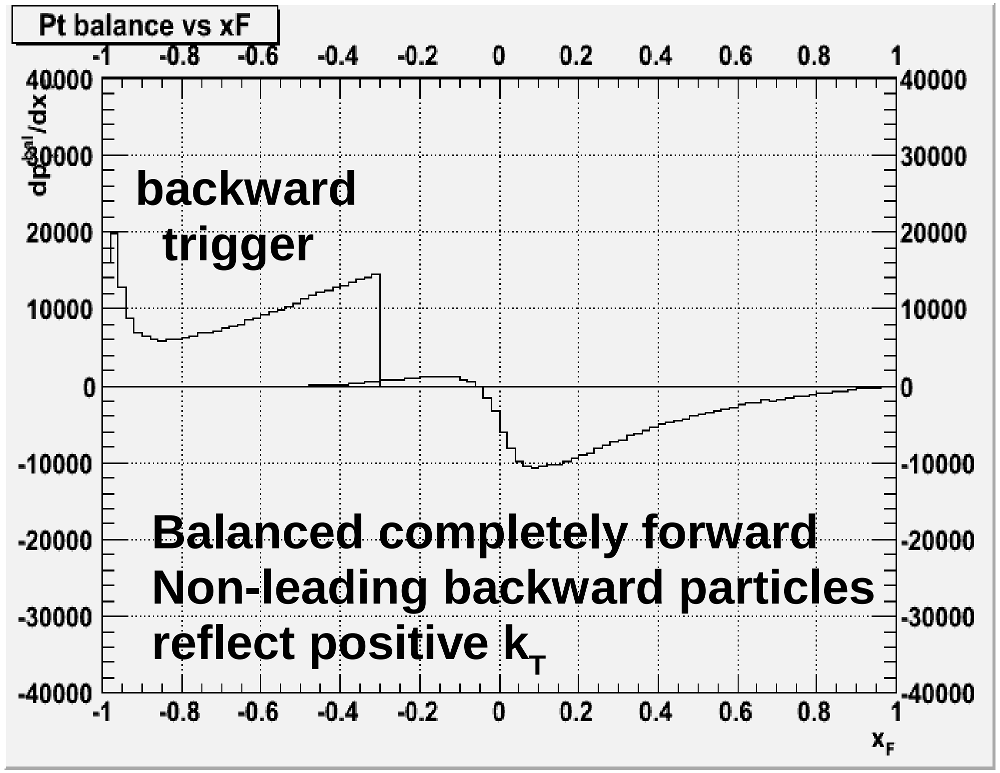
Transverse momentum balance

RMS k_T=1.0 GeV



RMS k_T=1.0 GeV



Note: These should be normalized by $1/N_{ev}$ and bin size Δx_F

Intrinsic k_T already dominant

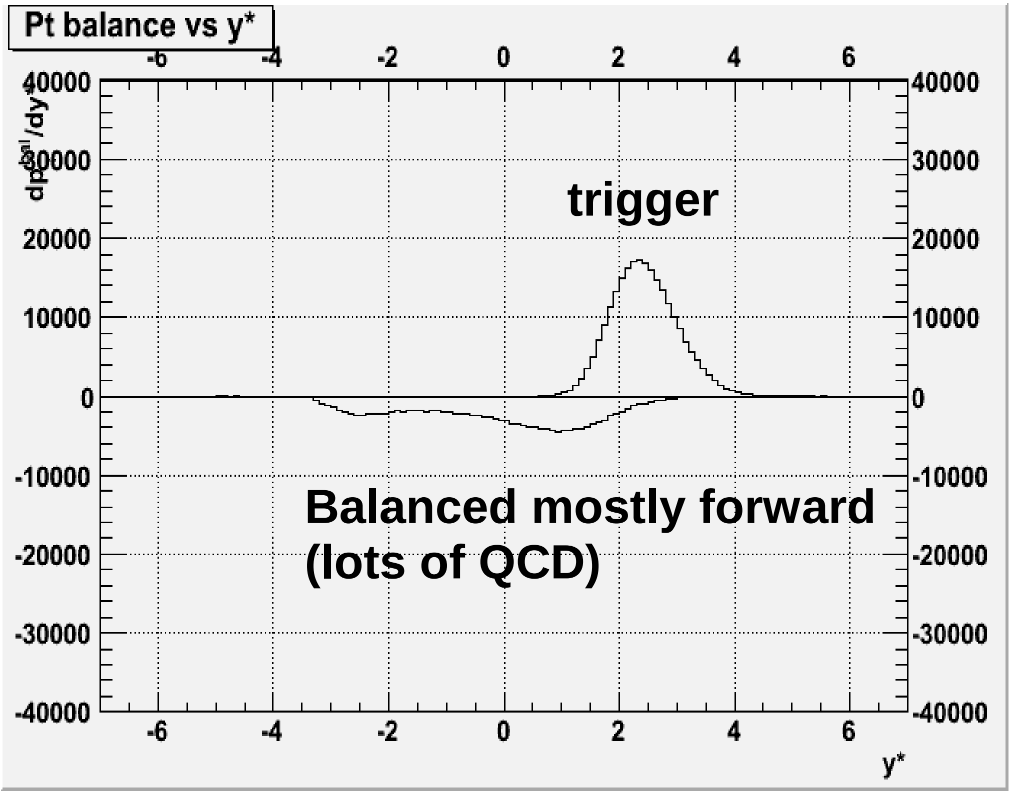
For k_T=1.0 GeV, we can see that the forward trigger p_T is still a mix of k_T and QCD,
While for the backward trigger, the p_T is dominated by k_T.

Reminder: variables

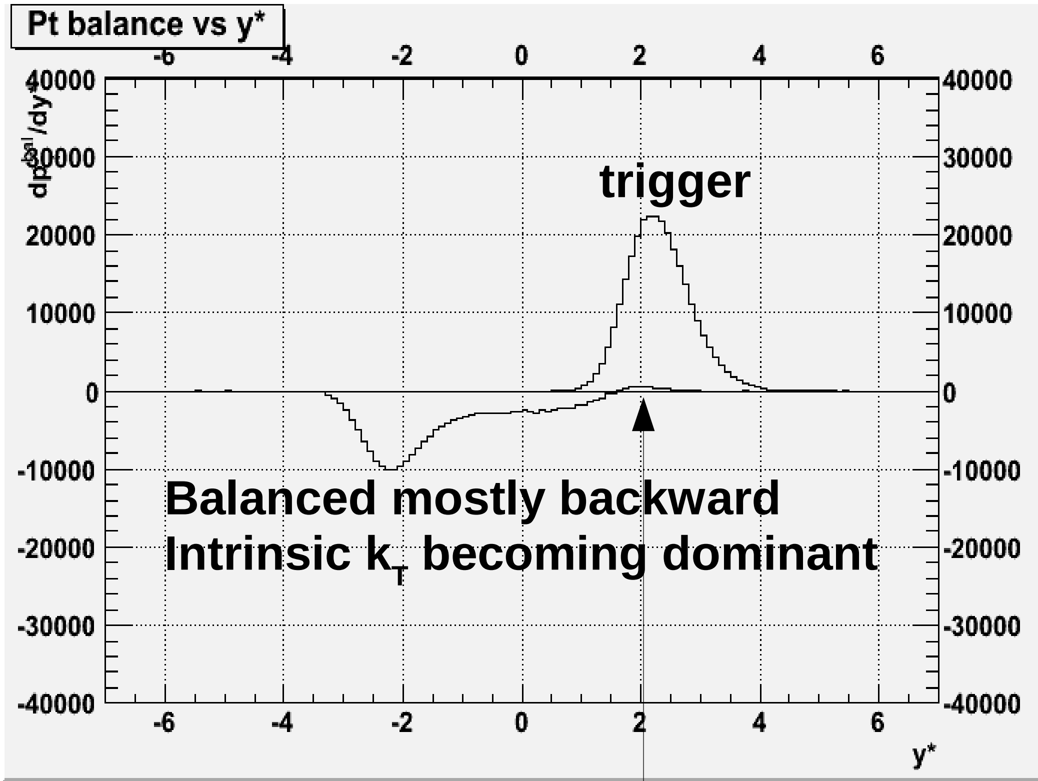
- Hadronic (γ*p) cm with + z along γ* direction.
  - Feynman x: $x_F = 2\ p_z\ /\ W$
  - Cm rapidity: $y^* = 0.5 \ln [(E+p_z)/(E-p_z)]$
- For reasons I don't fully understand, y* seems more incisive with relatively clear “peaks” for the QCD and k_T compensation– and was used by EMC:
  - Triggered on x_F and plotted vs. y*...

Transverse momentum balance

RMS k_T=0.44 GeV



RMS k_T=1.0 GeV

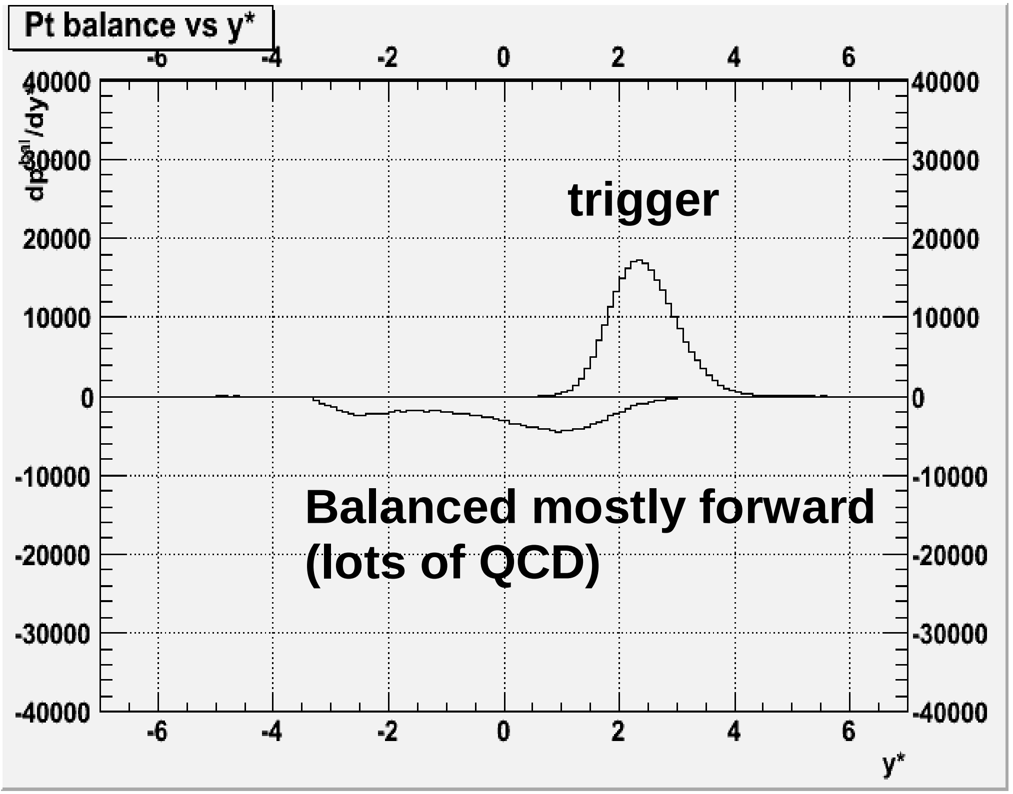


Note: These should be normalized by $1/N_{ev}$ and bin size Δy^*

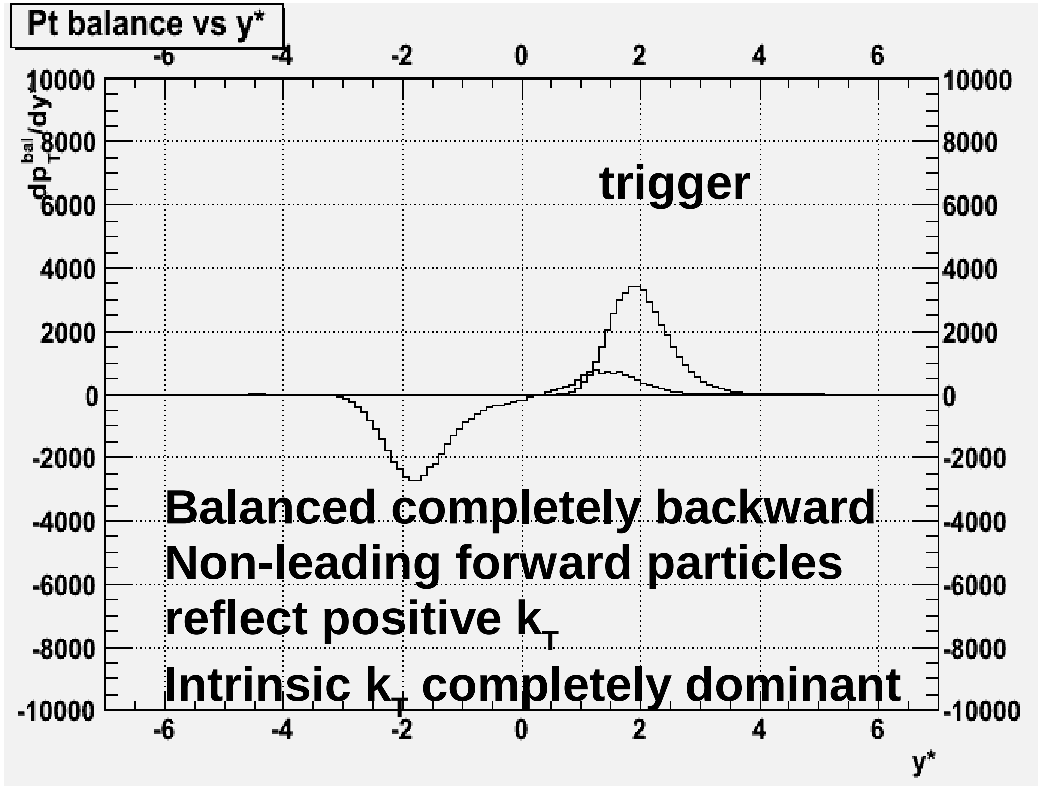
Very forward particles reflect positive k_T

Transverse momentum balance

RMS k_T=0.44 GeV



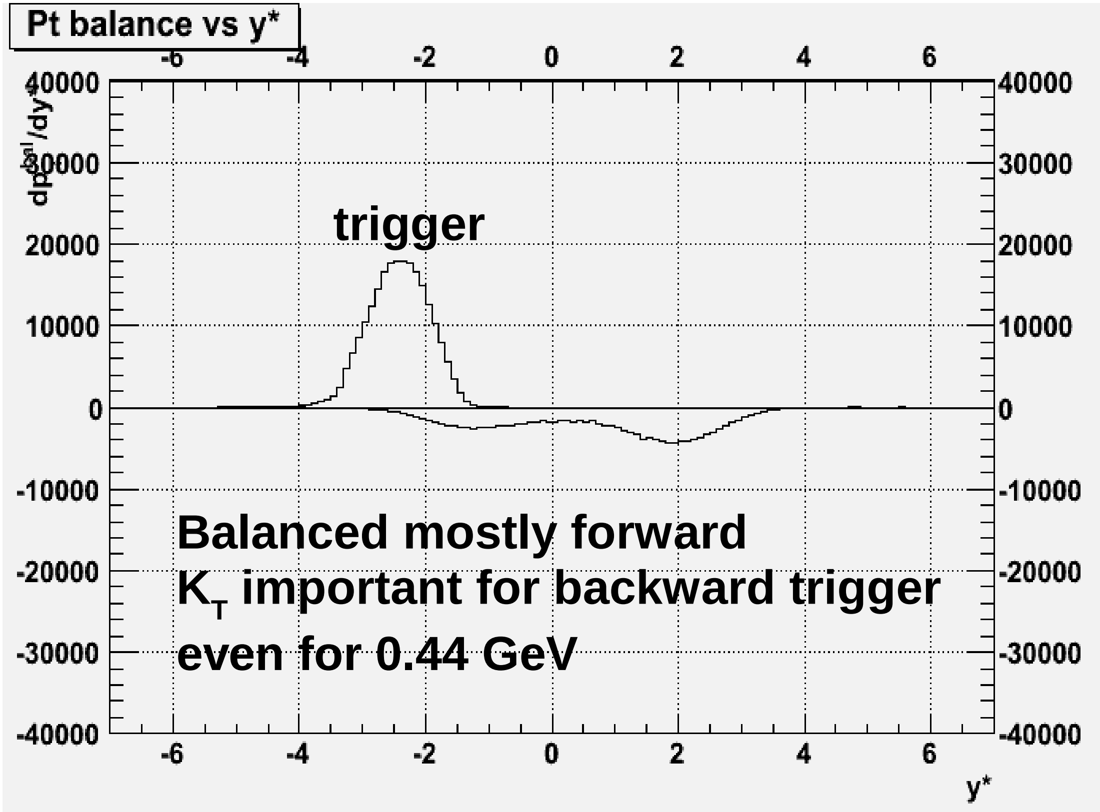
RMS k_T=2.0 GeV



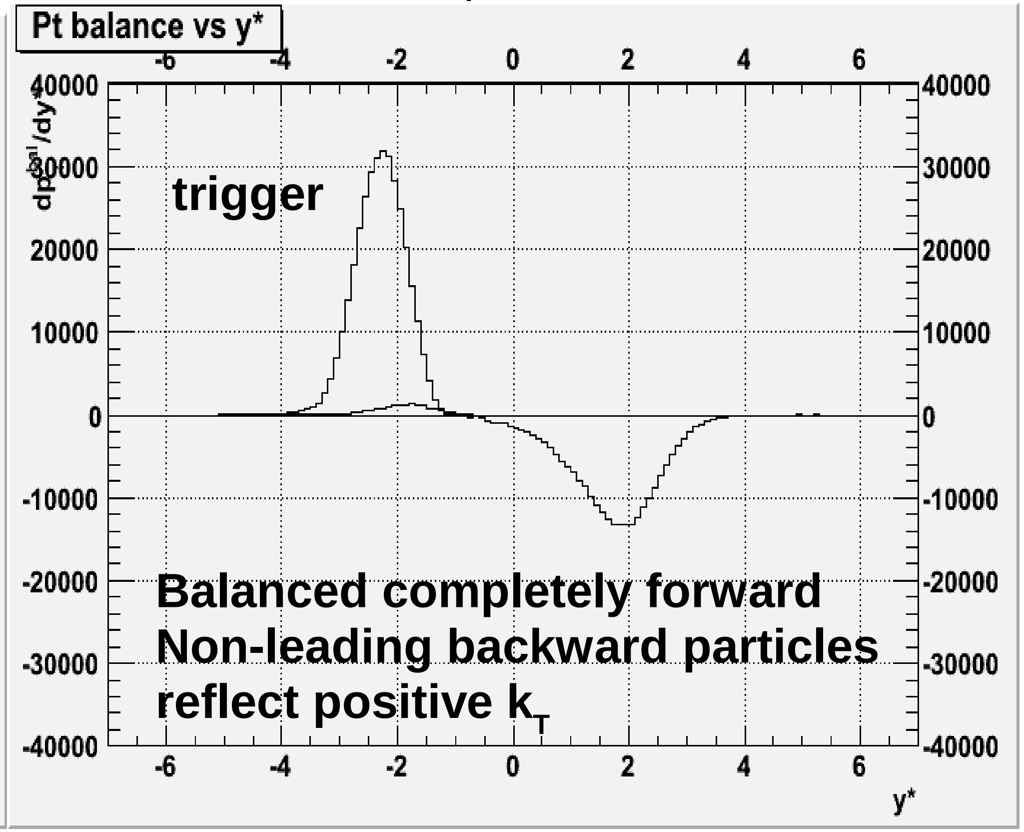
Note: These should be normalized by $1/N_{ev}$ and bin size Δy

Transverse momentum balance

RMS k_T=0.44 GeV



RMS k_T=1.0 GeV

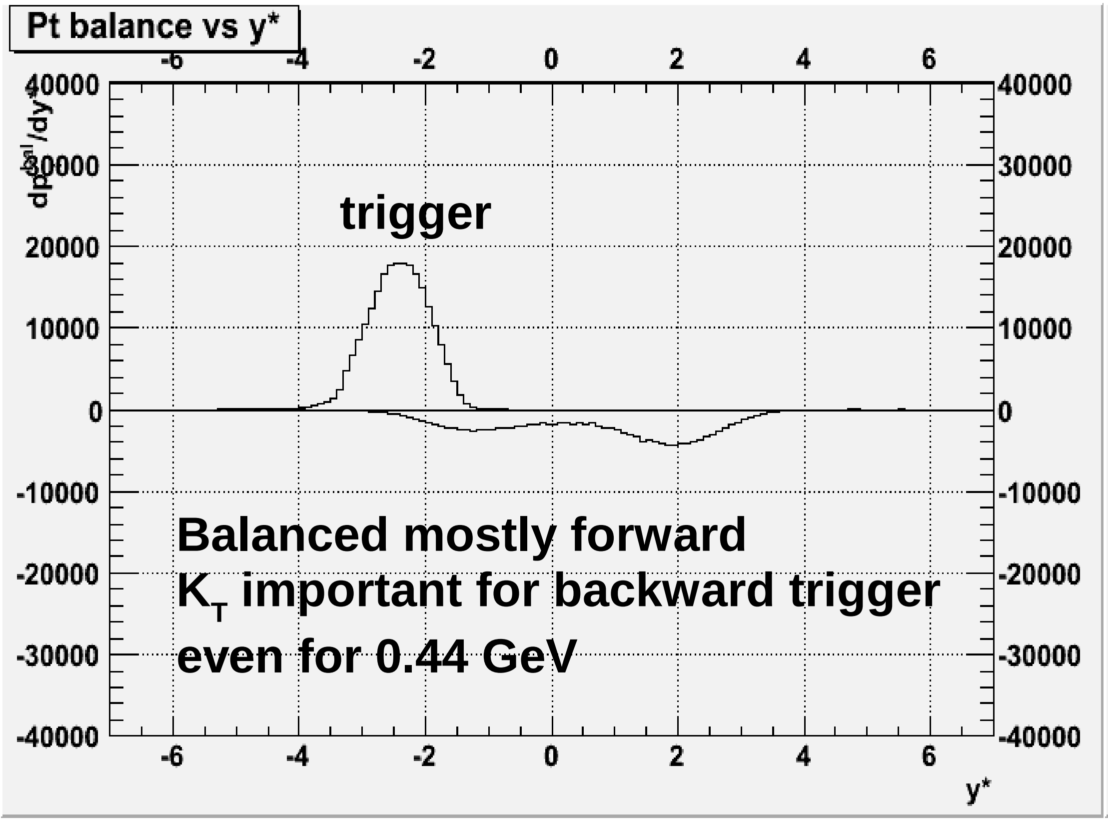


Note: These should be normalized by $1/N_{ev}$ and bin size Δy^*

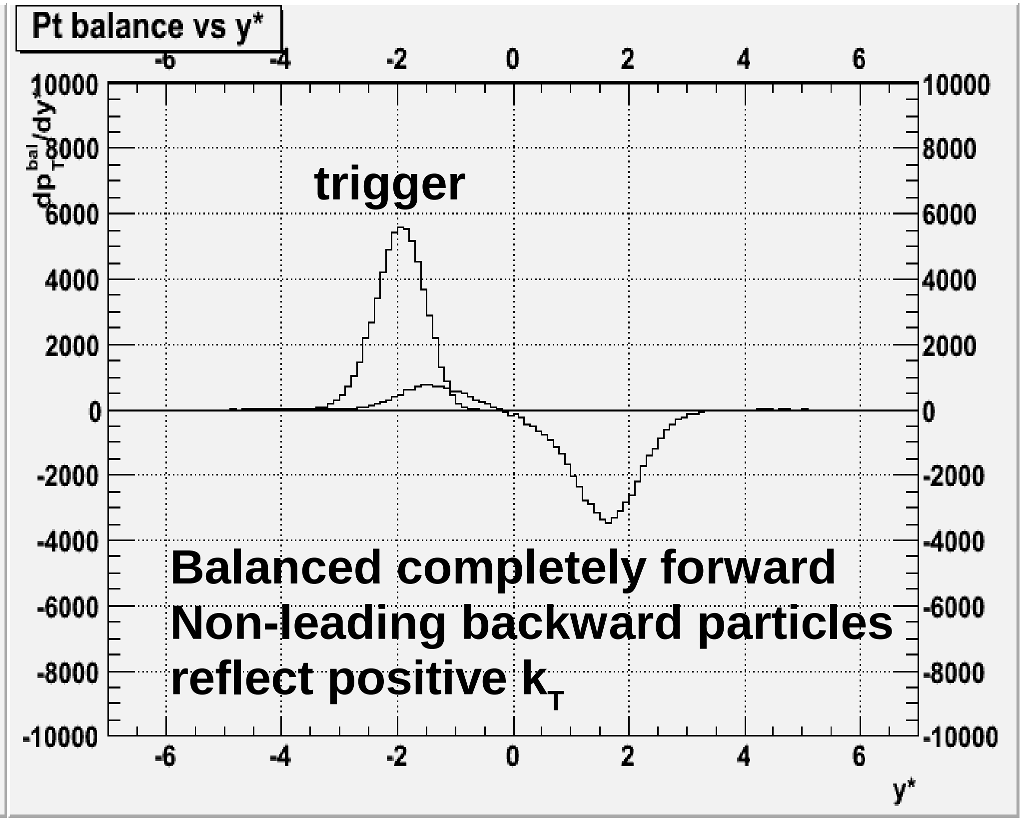
Intrinsic k_T already dominant

Transverse momentum balance

RMS k_T=0.44 GeV



RMS k_T=2.0 GeV



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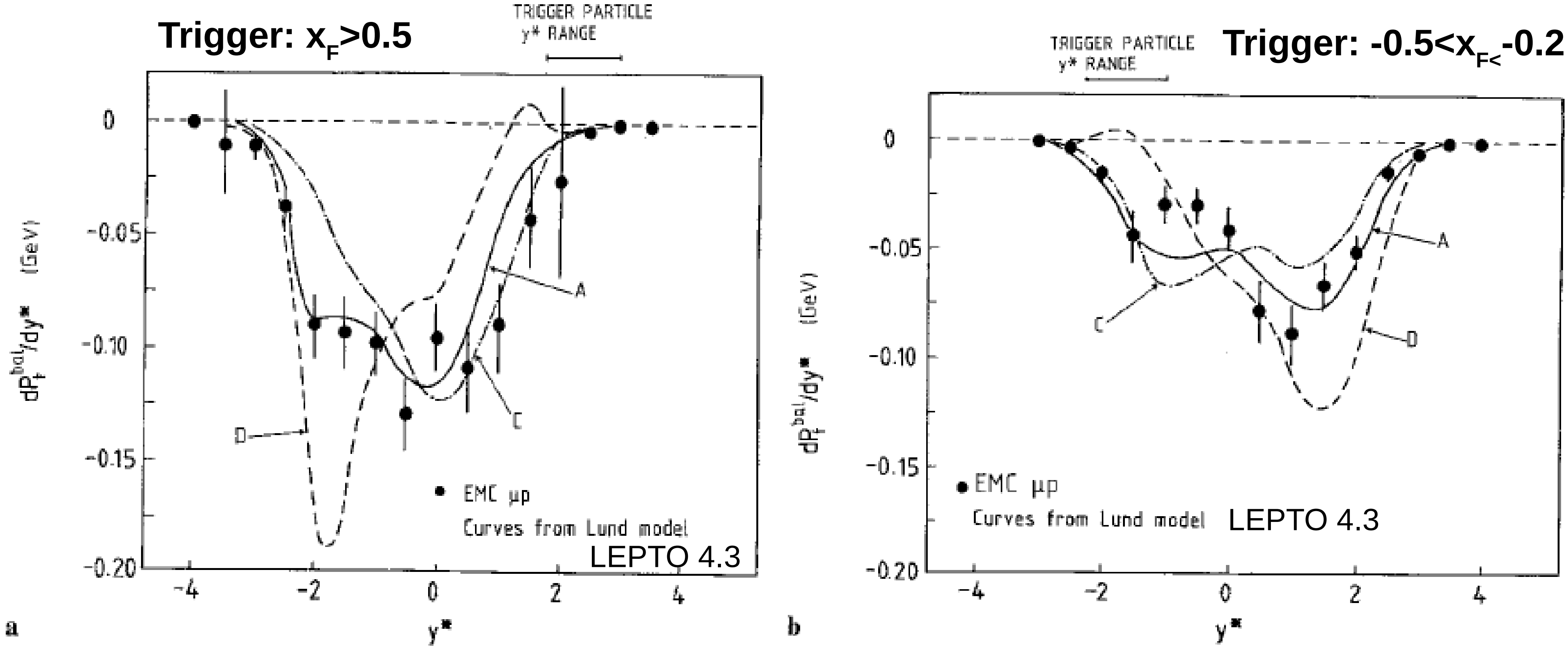
Intrinsic k_T dominant

EMC p_T balance plots

EMC Collaboration, ZPC 36 (1987) 527



A: Standard LEPTO w/ k_T^{RMS} = 0.44 GeV

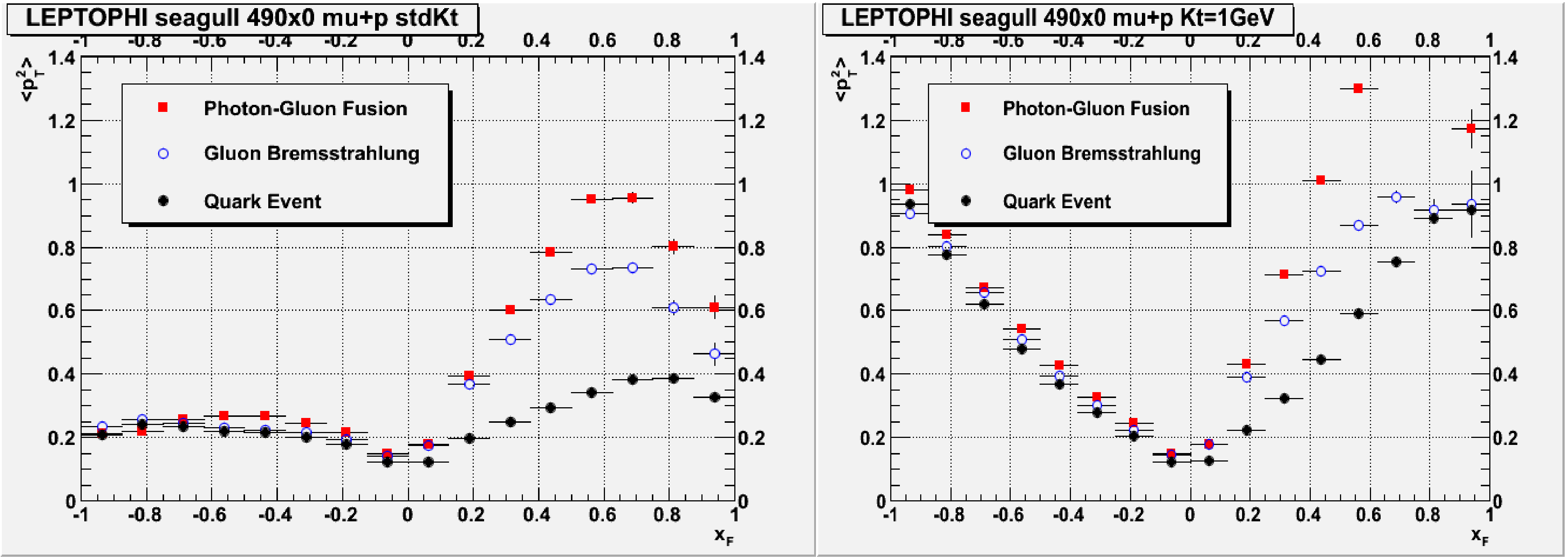
C: Soft gluons off

D: Soft gluons off, but w/ k_T^{RMS} = 0.88 GeV

0.88 GeV of kT looks VERY different than 0.44 GeV + soft QCD
This & the earlier EMC seagull plots were how LEPTO (even 6.5.1) was tuned

Gluon k_T

Gluon and sea quark kT must be highly correlated, but lets look at what might happen if we tag photon-gluon fusion events:



Backward hemisphere very sensitive to kT and doesn't care about subprocess. If gluon and quark kT are different, this is a clear way to see it!

Note: My LEPTO-PHI version has the ability to make gluon kT different than quark kT

Conclusion

- Effect of large intrinsic k_T (1-2 GeV) looks very different from hard or soft QCD effects in DIS:
  - Seagull plots and general p_T at high $|x_F|$
    - Especially $x_F<-0.2$
  - Forward-backward p_T-balance correlations
- For gluon k_T the backward hemisphere is even more critical to use since the forward hemisphere is contaminated with QCD.