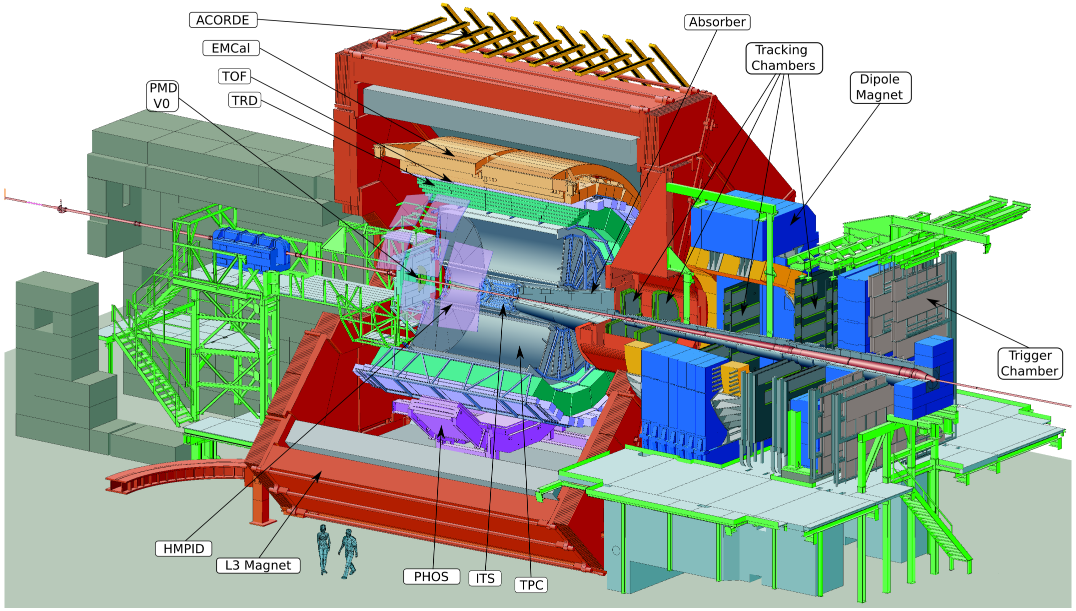
First glance at hard scattering phenomena with ALICE at LHC

Jan Rak for the ALICE collaboration



JYVÄSKYLÄN YLIOPISTO
University of Jyväskylä

ALICE

HELSINKI INSTITUTE OF PHYSICS

“Rediscovery” of (p)QCD in ALICE

2009 and 2010 $p+p$ runs at

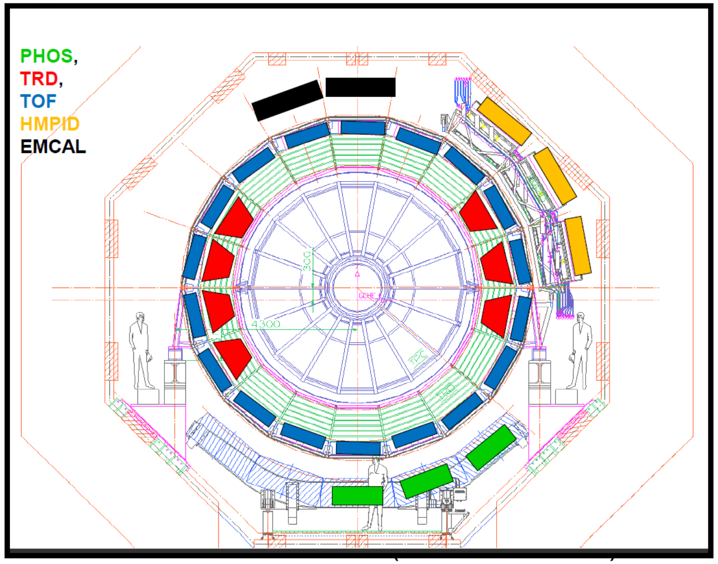
$\sqrt{s}$=0.9 TeV (10x10^6 events)

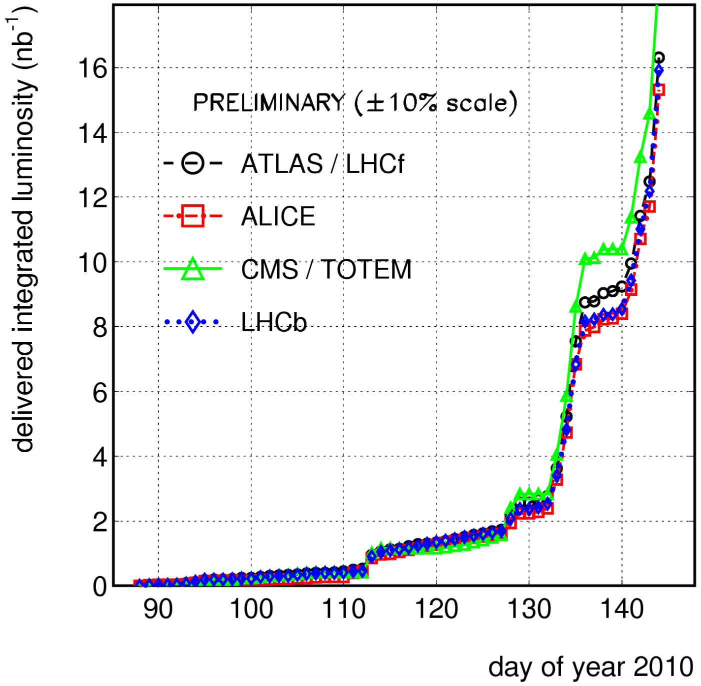
$\sqrt{s}$=7.0 TeV (300x10^6 events)

excellent test bench for pQCD study:

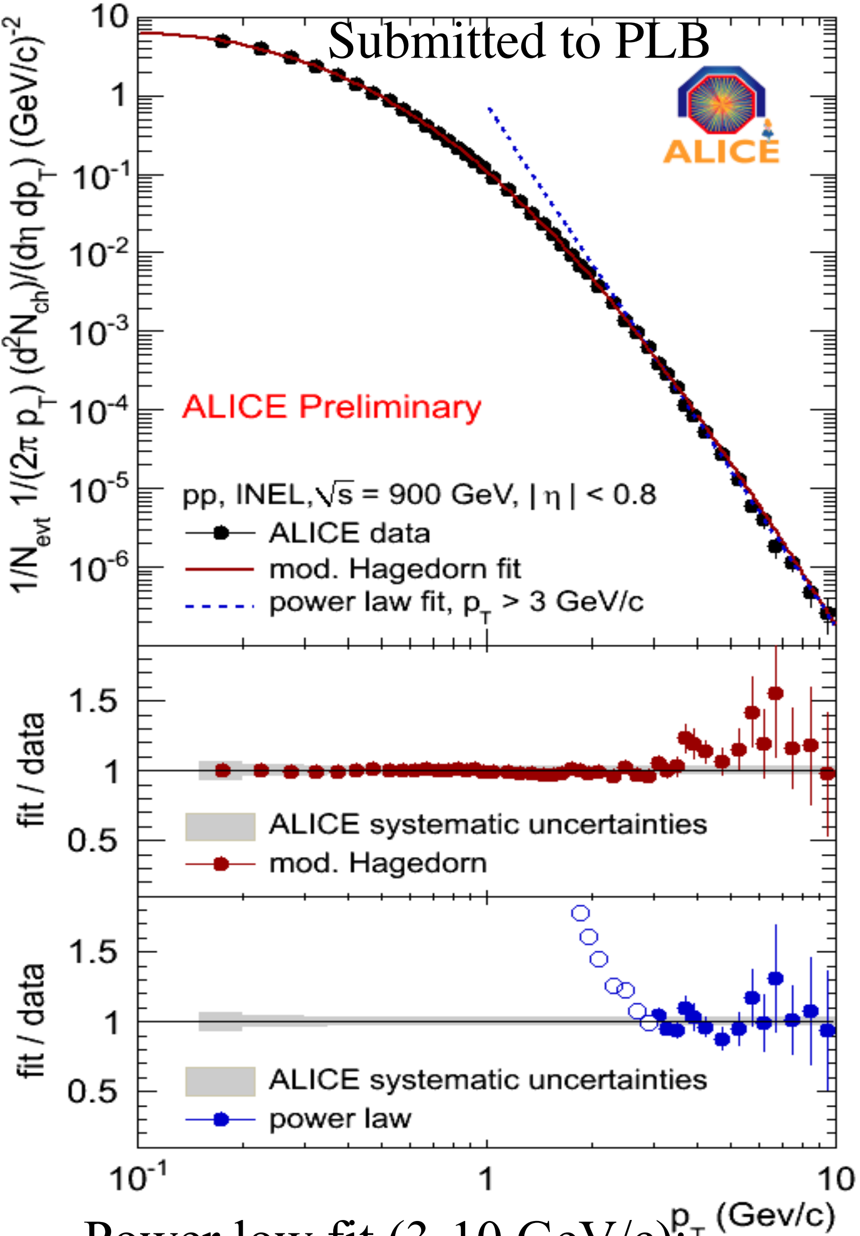
–Highest Center of Mass energy -> lowest x_B reach -> factorization, pQCD evolution etc.

–Preparing the stage for Heavy Ion physics – nuclear modification of parton properties in excited nuclear medium

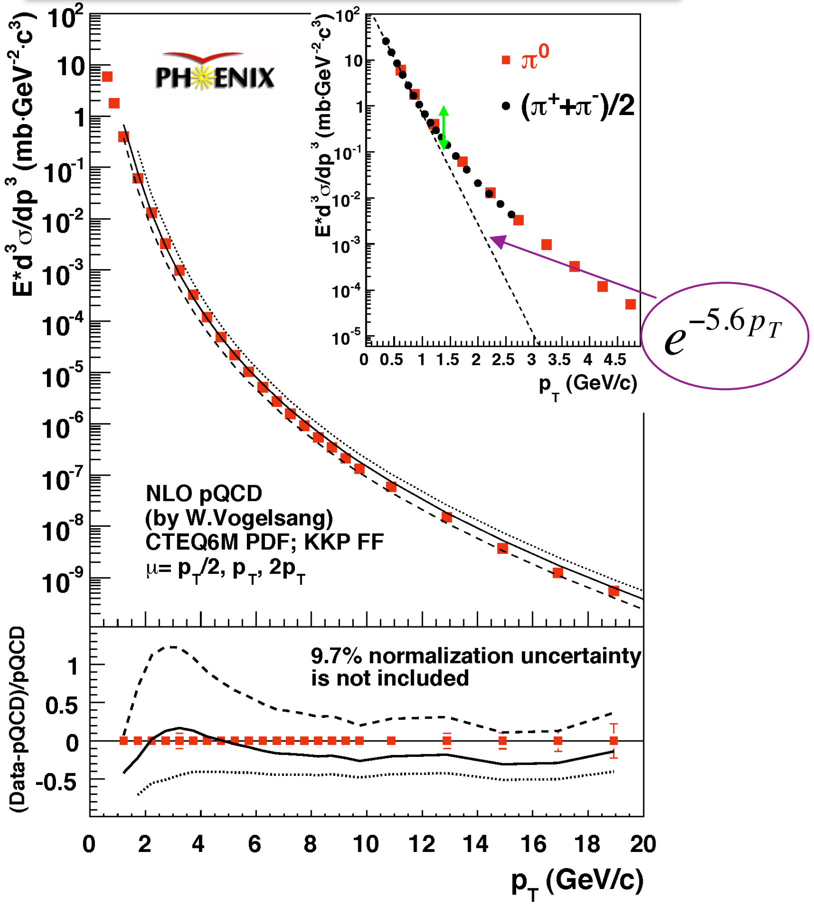




Inclusive charged distributions (INEL)


Submitted to PLB

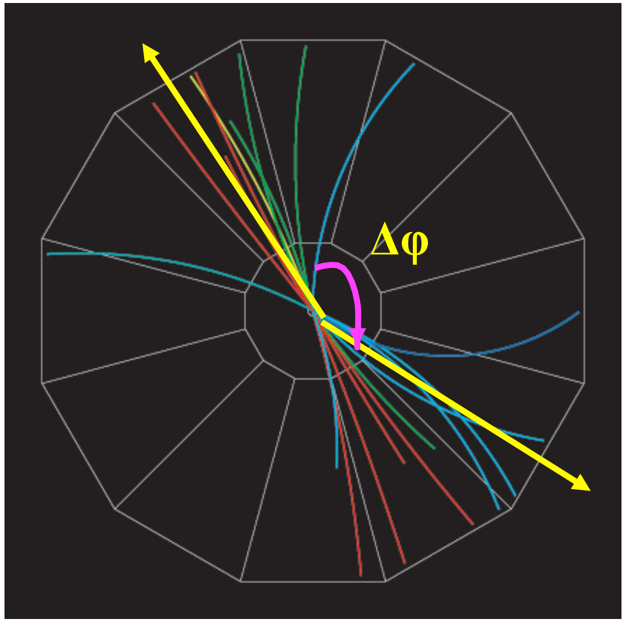
J.Phys.Conf.Ser. 69 (2007) 012035
hep-ph/0702083



- NLO agreement
- Turn over from soft to power law around p_T ~ 3 GeV/c. Soft/hard interplay.

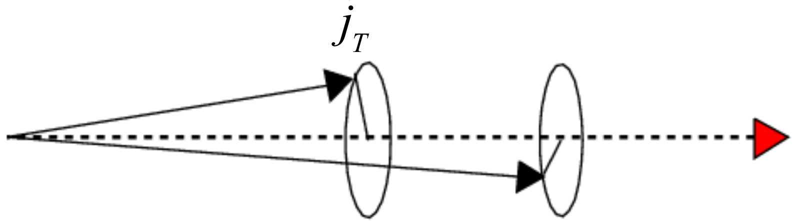
Power low fit (3-10 GeV/c):

More exclusive observables
Leading particle azimuthal correlations

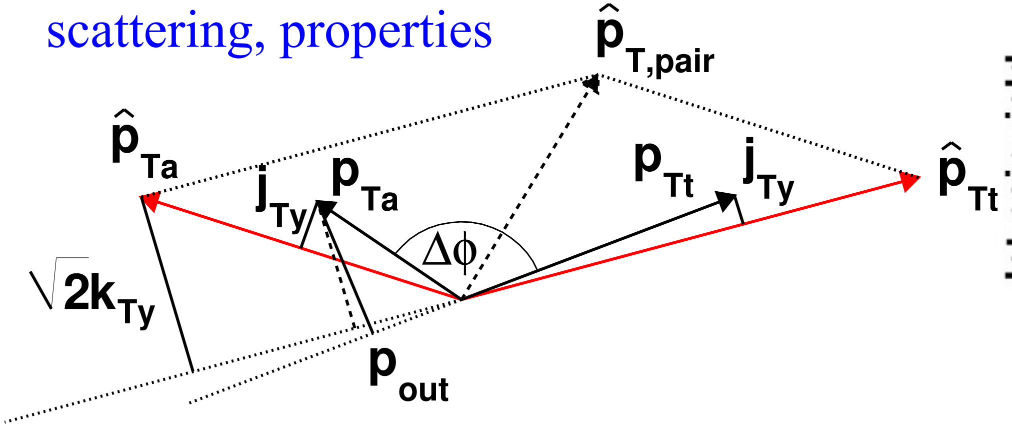


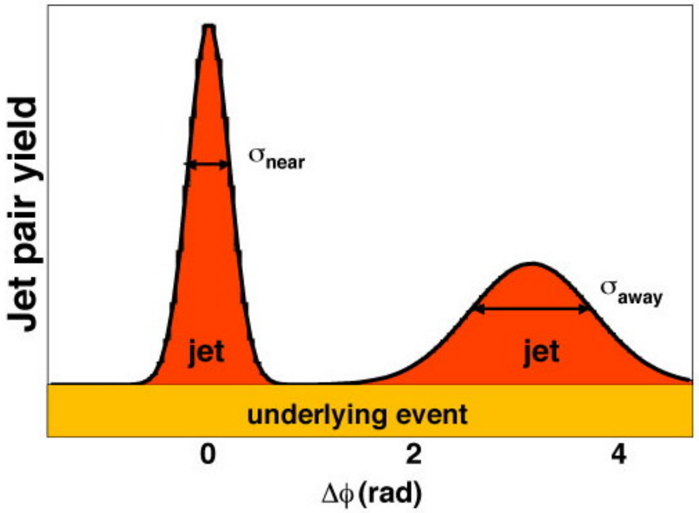
Leading particle approximates the jet thrust.

- –Near side (intra-jet): “Single” jet properties



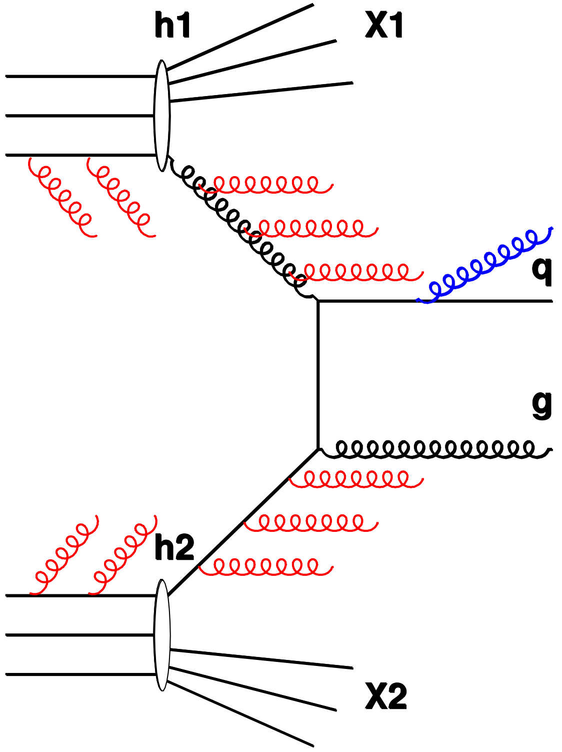
- –Away side (inter-jet): Di-jet, hard scattering, properties





Soft + hard QCD radiation
k_T phenomenology

$$q + g \rightarrow q + g$$



Back-to-back balanced

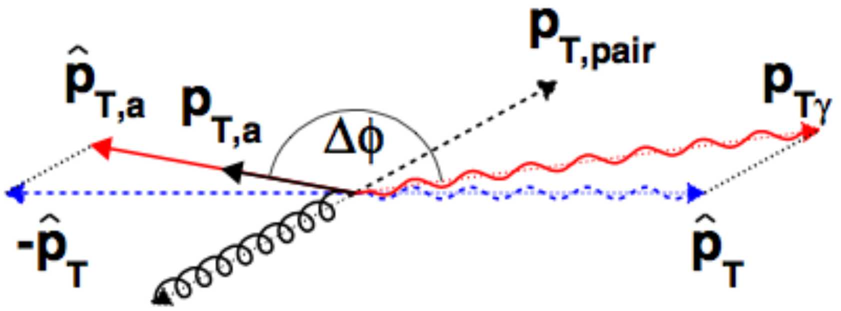
$$\frac{d\sigma}{d\Delta\varphi} = \delta(\varphi - \pi) \qquad \left.\frac{d\sigma}{d\hat{q}_T}\right|_{p_{T\gamma}} = \delta(\hat{q}_T - p_{T\gamma})$$

Soft QCD radiation

$$\frac{d\sigma}{d\Delta\varphi} \propto Gauss(\Delta\varphi) \qquad \left.\frac{d\sigma}{d\hat{q}_T}\right|_{p_{T\gamma}} \propto Gauss(p_{T\gamma})$$

Hard NLO radiation

$$\frac{d\sigma}{d\Delta\varphi} \propto \frac{1}{\Delta\varphi^{-n}} \qquad \left.\frac{d\sigma}{d\hat{q}_T}\right|_{p_{T\gamma}} \propto \frac{1}{p_{T\gamma}^{-n}}$$

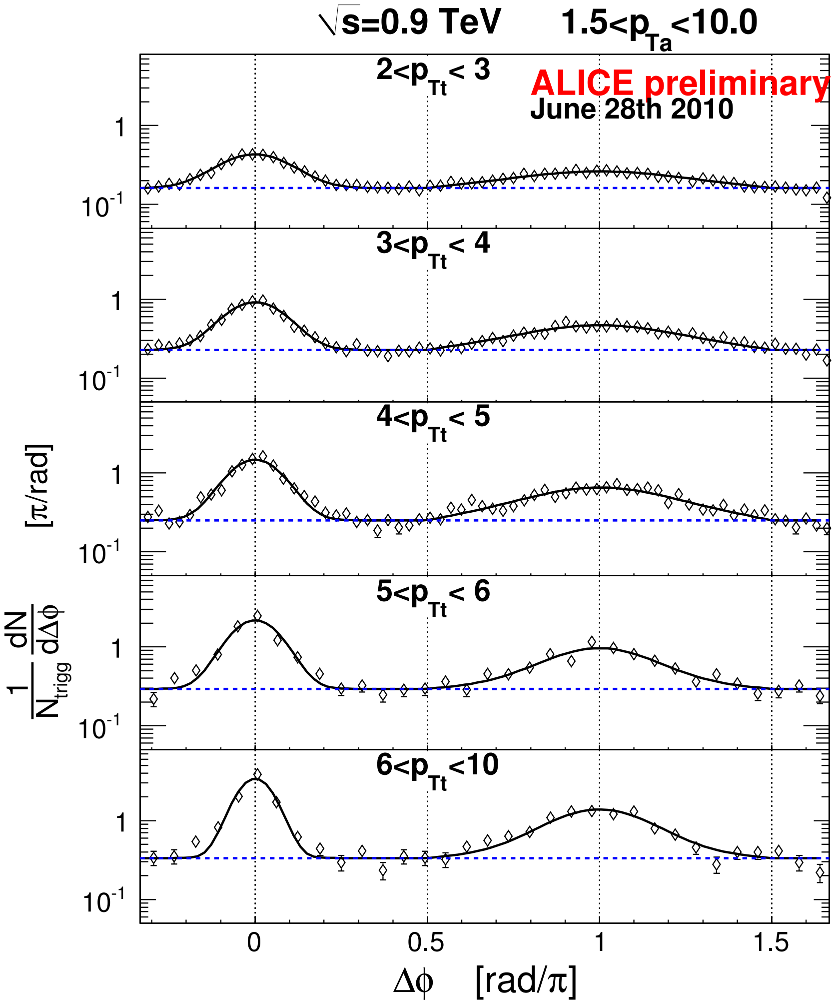


Resummation we.g. A. Kulesza, G. Sterman, and W. Vogelsang, Nucl. Phys.**A721, C591 (2003)**

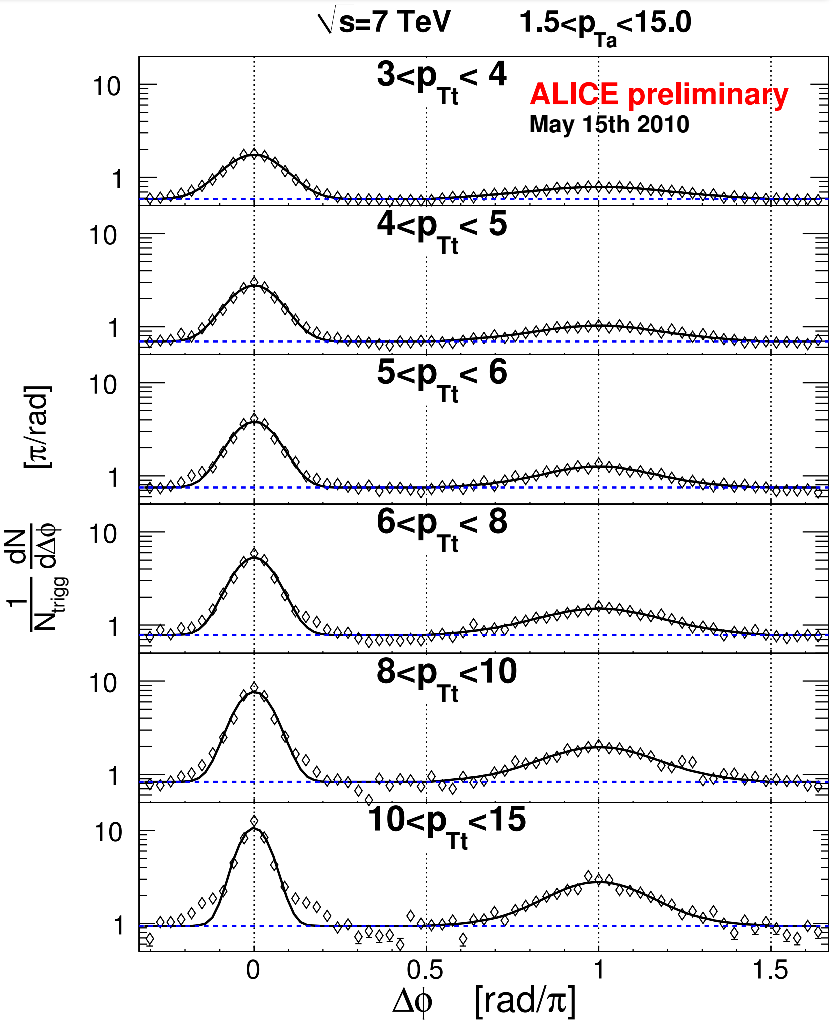
$$\left\langle k_T^2 \right\rangle = \left\langle k_T^2 \right\rangle_{INTRINSIC} + \left\langle k_T^2 \right\rangle_{RADIATIVE} + \left\langle k_T^2 \right\rangle_{NLO}$$

CF 0.9 and 7 TeV

$\sqrt{s}$= 900 GeV

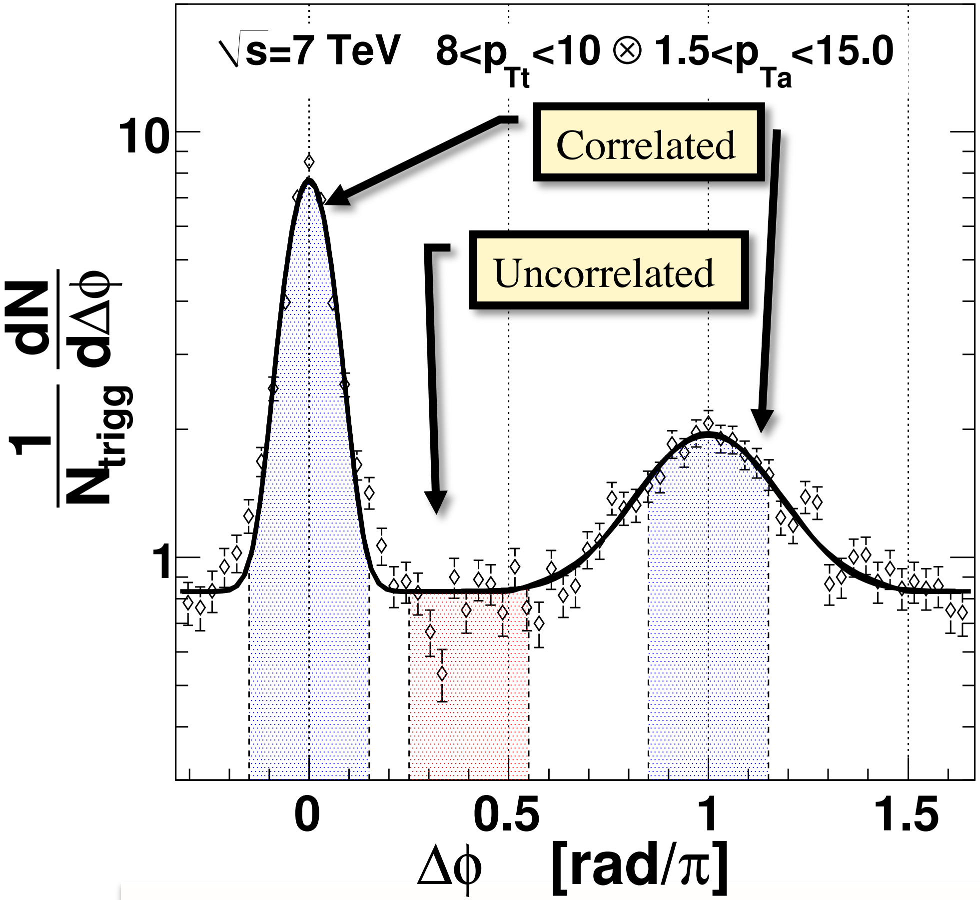


$\sqrt{s}$ = 7 TeV



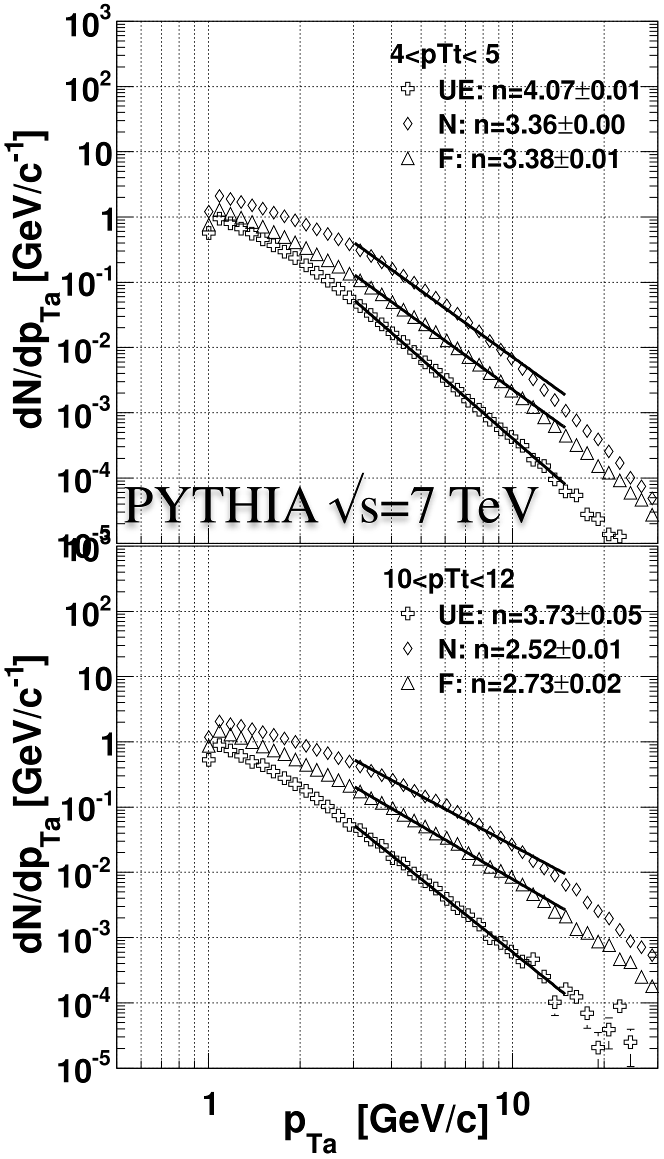
Large statistics allows up to 30 GeV/c of the trigger particle.

(Un)correlated p_T distributions



Three $\Delta\phi$ regions:

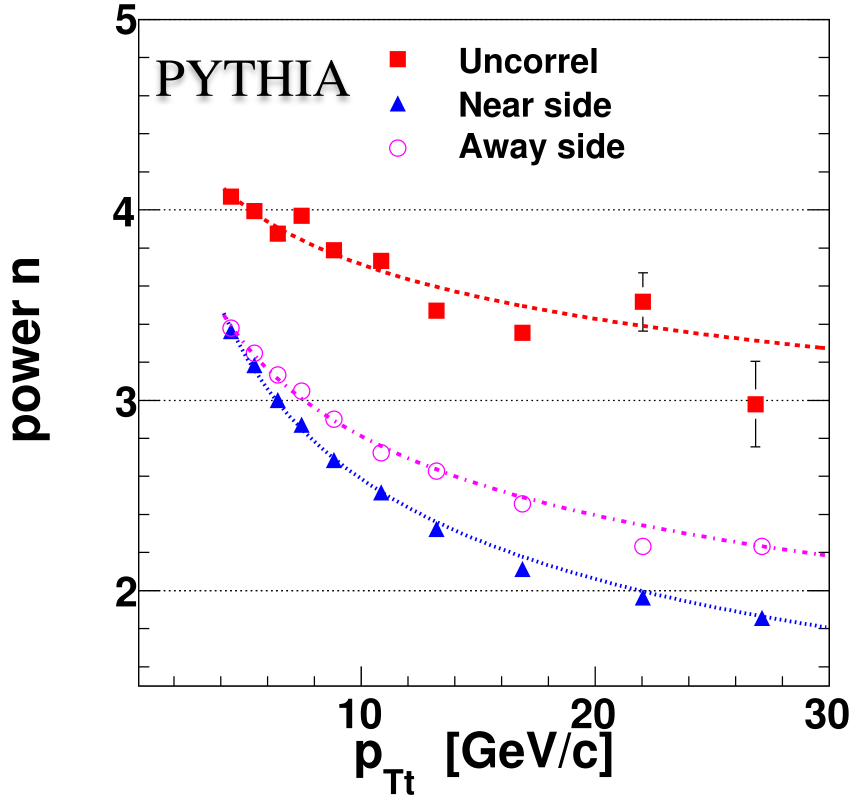
1. Uncorrelated $0.25<\Delta\phi<0.55$ rad/π
2. Near side $-0.15<\Delta\phi<0.15$ rad/π
3. Away side $0.85<\Delta\phi<1.15$ rad/π



Power law fit in 3-15 GeV/c range

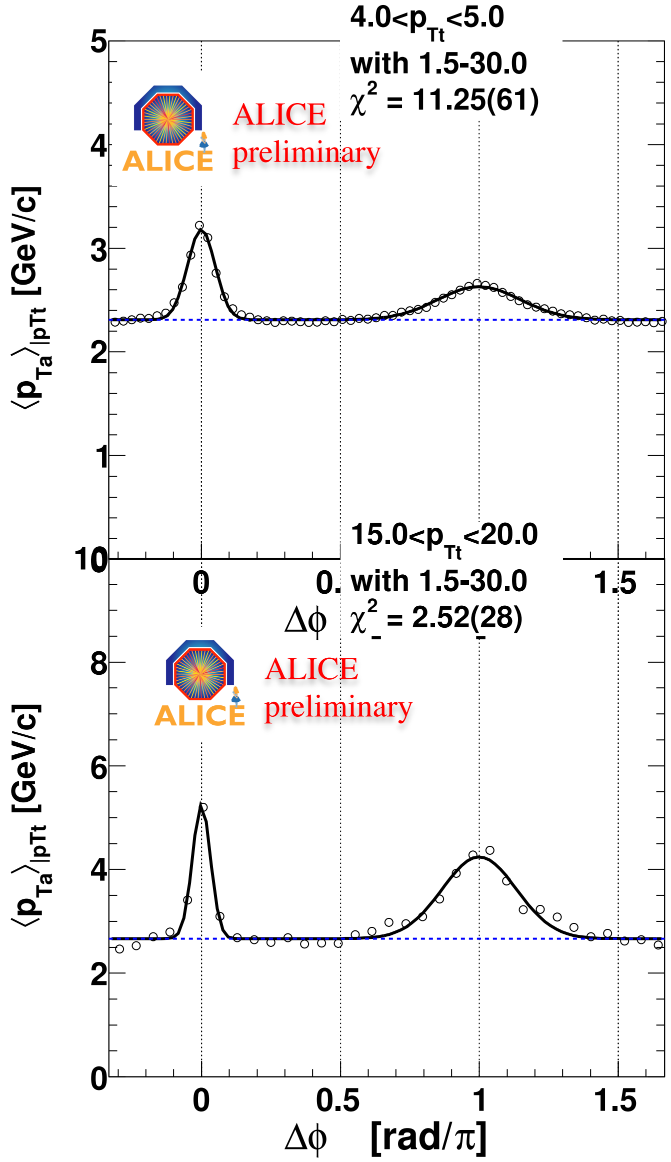
Initial state radiation

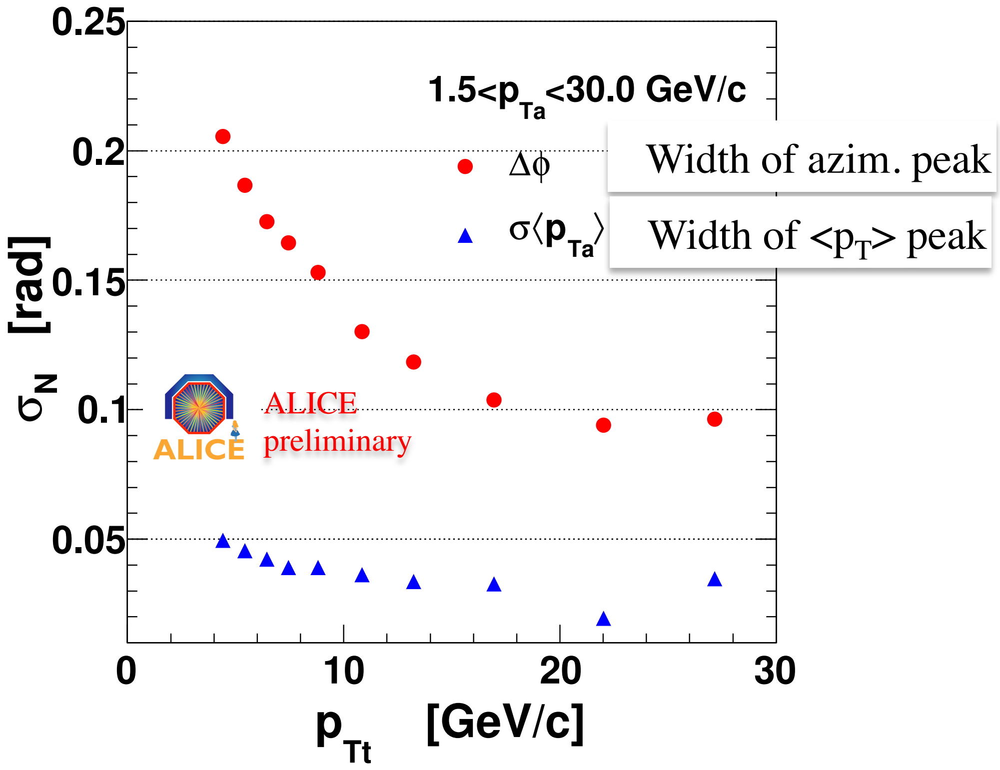
- Uncorrelated p_{Ta} distribution
  - Power law n~4. If purely Underlying Event then it should be p_{Tt} independent. Dashed line power law fit.
- Near side p_{Ta} distribution
  - Becomes harder with p_{Tt}
- Away side p_{Ta} distribution
  - Becomes harder with p_{Tt}

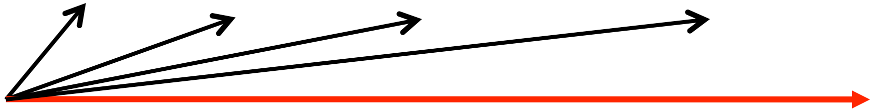


Because the uncorrelated (in azimuth) yield is, at least partially, correlated in p_T it hints the contribution of Initial State Radiation in addition to the Underlying Event source.

Angular ordering





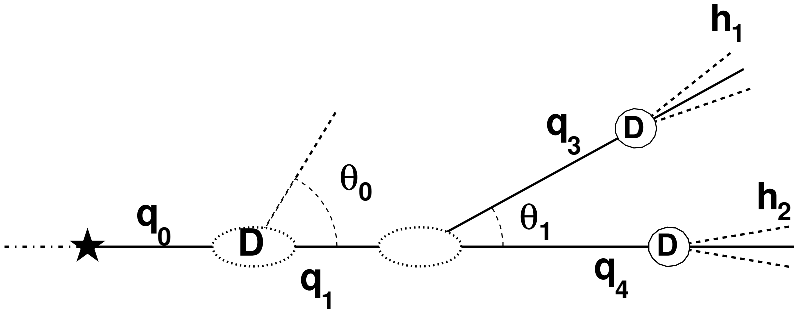


Relative jet-fragmentation transverse momentum is p_{Tt} independent. It reflects the color coherence (destructive interference)

Phys.Rev. D78, 014019 (2008), arXiv:0712.2212

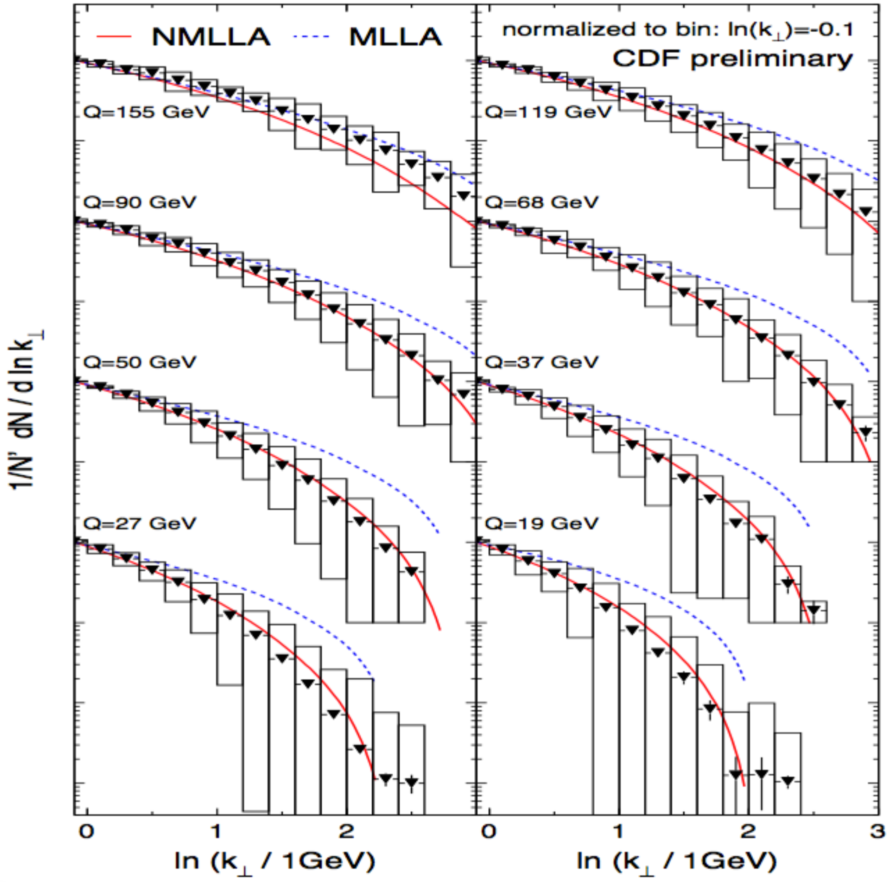
Color coherence – angular ordering

- Modified Leading Logarithmic Approximation (MLLA)
  - destructive interference of the small angle radiation



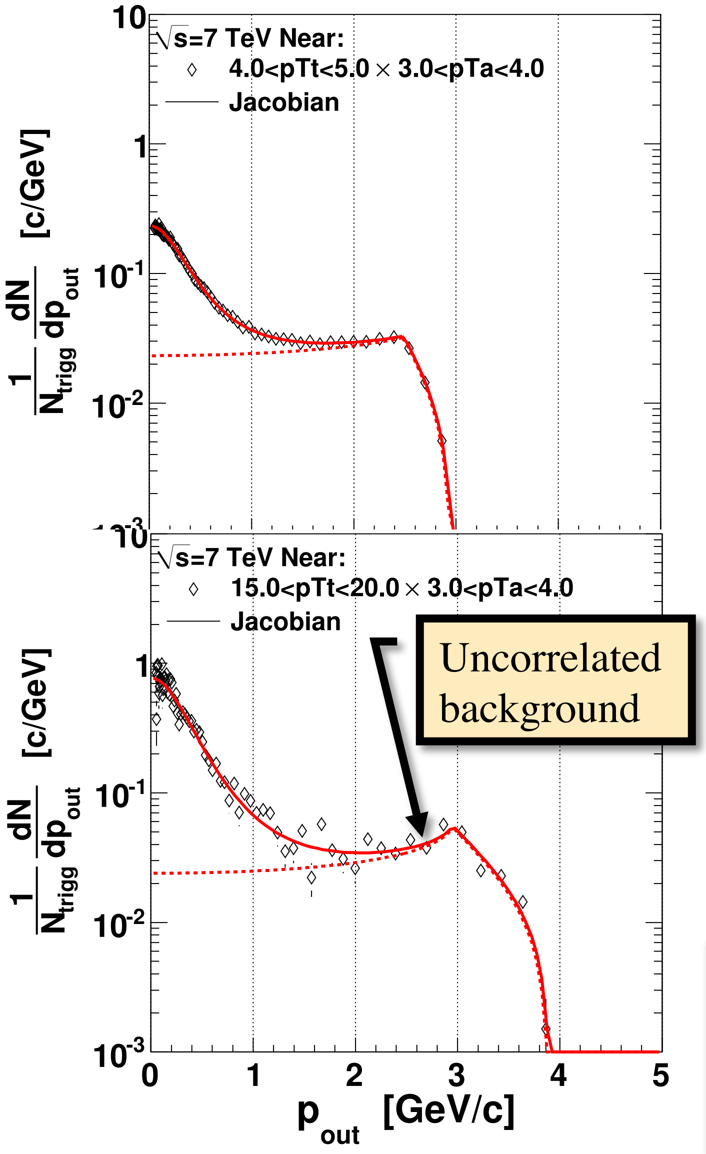
Dokshitzer, Y. L. et al: Hard Processes in QCD Phys.Rept., 1980, 58, 269-395

Fong Phys.Lett., 1989, B229, 289

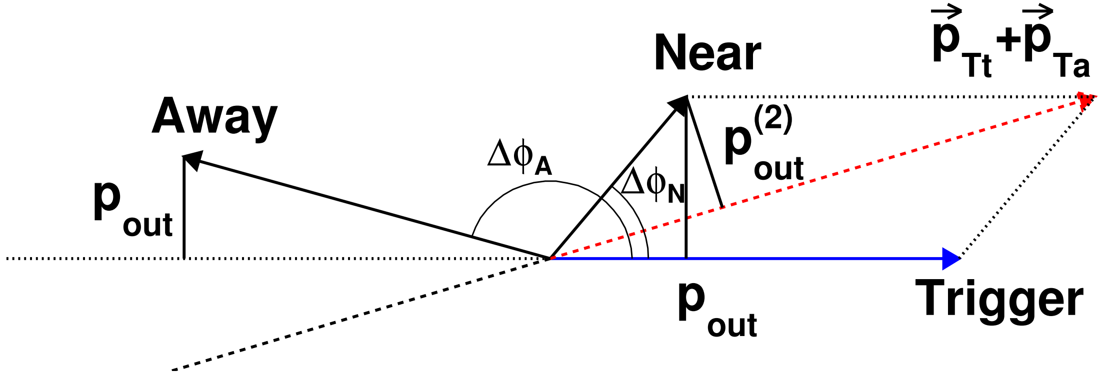


CDF collaboration, S. Jindariani, A. Korytov, A. Pronko, k⊥ Distributions of Particles in Jets at CDF, CDF reportCDF/ANAL/JET/PUBLIC/8406 (March 2007)

$p^{(2)}_{out}$ distributions



Uncorrelated background



$\frac{dN}{dp_{out}}$ for an UE distrib ($dN/d\Delta\phi$ = const) $\frac{dN}{dp_{out}} = \frac{dN}{d\Delta\phi}\frac{1}{p_{Ta}\cos\Delta\phi} = \frac{1}{\sqrt{p_{Ta}^2 - p_{out}^2}}$

However, p_{Ta} is measured in finite bin so the pro UE p_{out} distribution reads

$$\frac{dN}{dp_{out}} = \int_{pTa1}^{pTa2} \frac{p_{Ta}^{-n}}{\sqrt{p_{Ta}^2 - p_{out}^2}} dp_{Ta} \quad \text{for } p_{out} < p_{Ta1} \quad \text{where } p_{Ta1} < p_{Ta} < p_{Ta2}$$

$$\frac{dN}{dp_{out}} = \int_{pout}^{pTa1} \frac{p_{Ta}^{-n}}{\sqrt{p_{Ta}^2 - p_{out}^2}} dp_{Ta} \quad \text{for } p_{Ta1} < p_{out} < p_{Ta2} \text{ and 0 otherwise.}$$

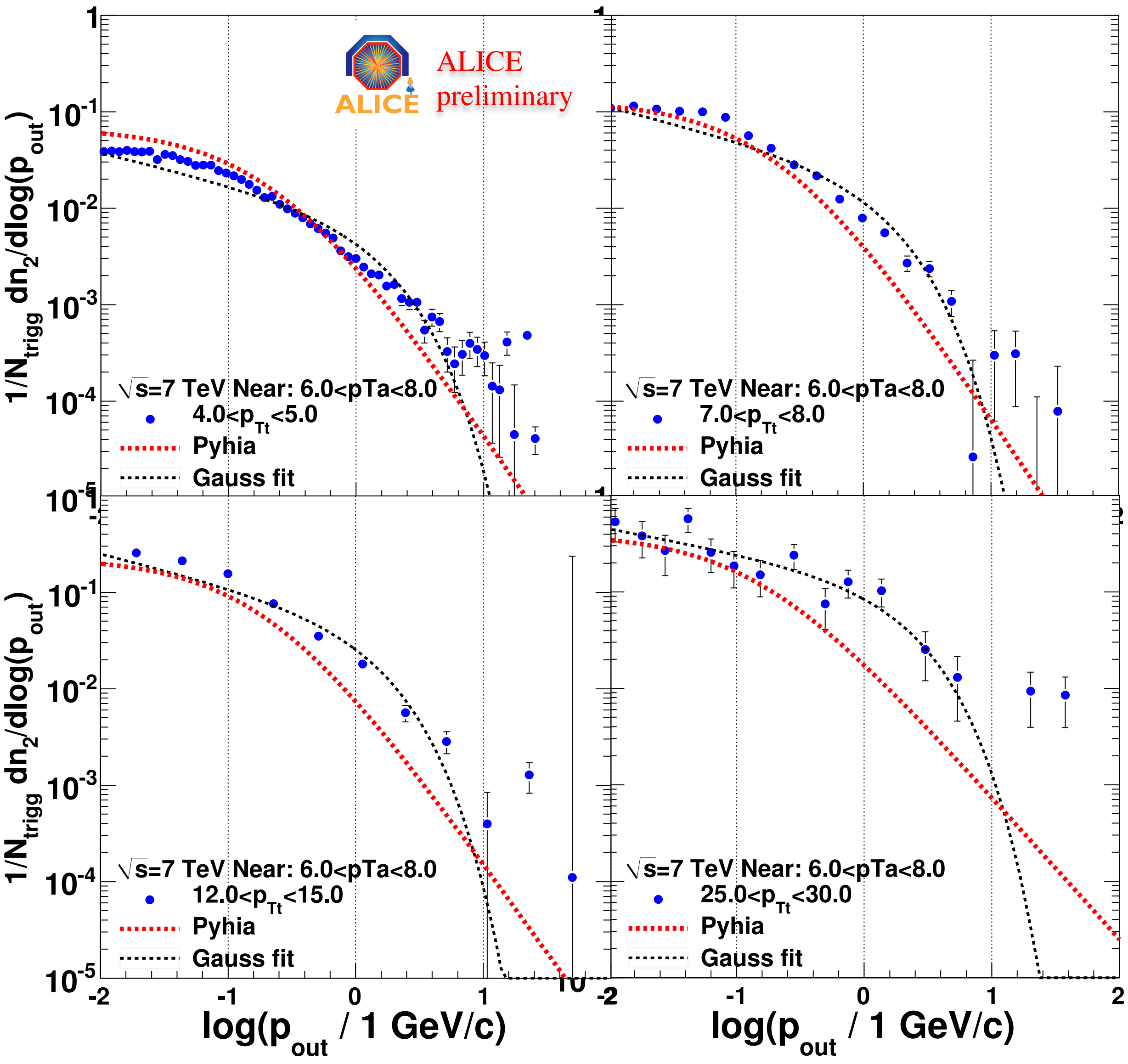
This integral is analytical for integer power n (enough for narrow p_{Ta} bins)

$$\frac{dN}{dp_{out}} = \frac{\sqrt{p_{Ta}^2 - p_{out}^2}\left(p_{out}^2 + 2p_{Ta}^2\right)}{3p_{out}^4 p_{Ta}^3}$$

power $n = 4$ fits the data best

Full azimuthal coverage of ALICE allows precise elimination of the uncorrelated (in azimuth) particles due to the Jacobean peak.

$\sqrt{s}$=7 TeV Near side log(p_{out}) uncorrected distributions

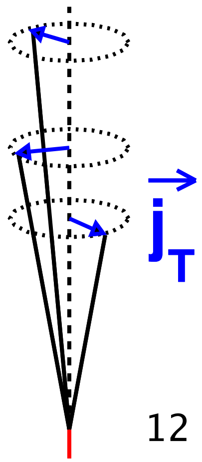


Near side log(p_{out}) distributions manifest the same trend as PYTHIA, however, at high trigger momenta an excess seems to develop.

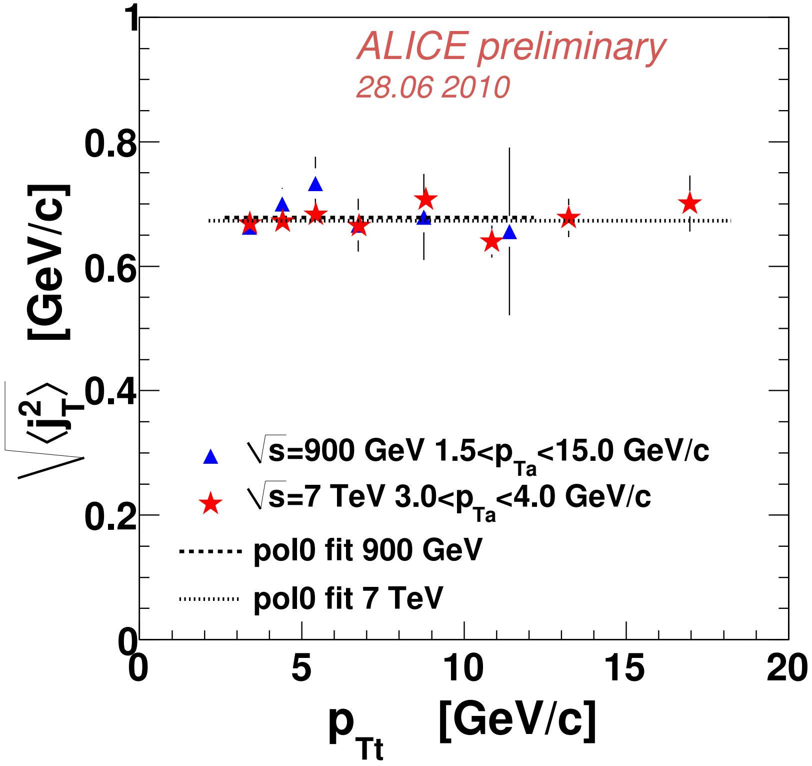
Away side log(p_{out}) under construction.

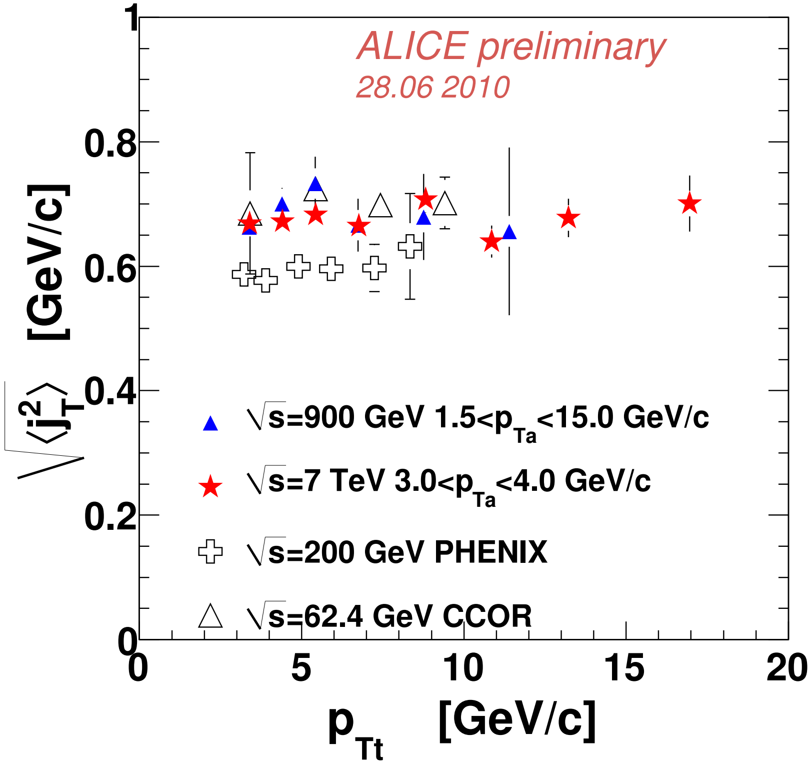
The Gaussian part could be used to quantify the mean jet fragmentation transverse momentum

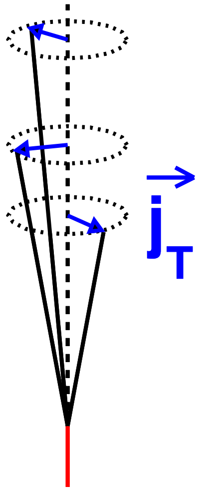
$$\sqrt{\langle j_T^2 \rangle} \propto \sqrt{\langle p_{out}^2 \rangle}$$



Jet-fragmentation transverse momentum







$$\sqrt{\left\langle j_T^2 \right\rangle}_{900\ \mathrm{GeV}} = 678 \pm 12\ \mathrm{MeV/c}$$

$$\sqrt{\left\langle j_T^2 \right\rangle}_{7\ \mathrm{TeV}} = 673 \pm 5\ \mathrm{MeV/c}$$

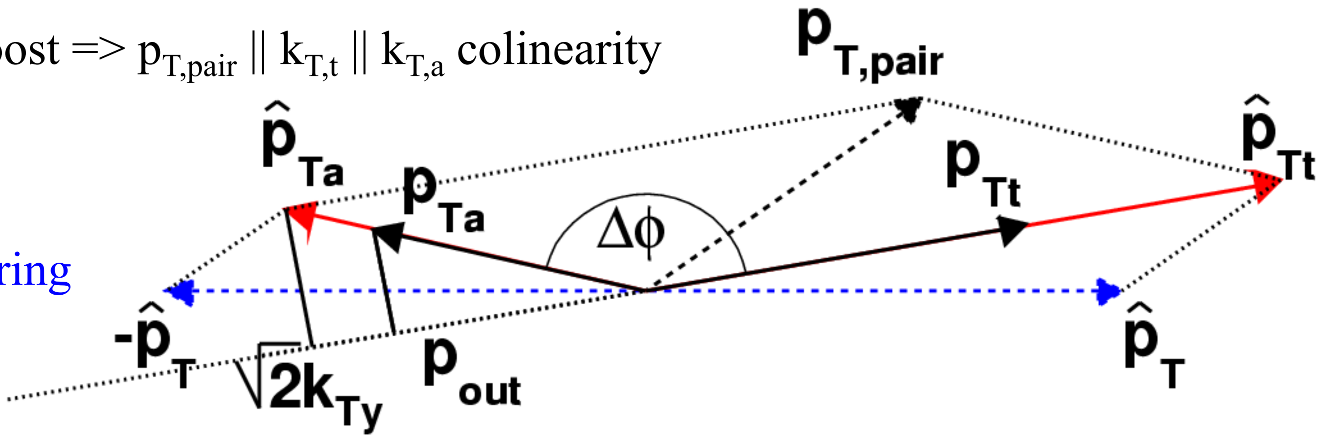
All measurements agree within stat error bars! Systematic errors not shown.

Correl. fcn width - k_T and acoplanarity

Lorentz boost => $p_{T,pair} \parallel k_{T,t} \parallel k_{T,a}$ colinearity

Lab frame

Hard scattering rest frame



$$\langle|p_{out}|\rangle = \sqrt{2}\langle|k_{Ty}|\rangle \frac{p_{Ta}}{\langle\hat{p}_{Ta}\rangle} \quad\Rightarrow\quad \sqrt{\langle p_{out}^2\rangle} = \langle z_t\rangle \sqrt{\langle k_T^2\rangle}\,\frac{x_h}{\hat{x}_h}$$

k_T-induced jet imbalance $\hat{x}_h(x_h) = \frac{\hat{p}_{Ta}}{\hat{p}_{Tt}}$ particle pair imbalance $x_h = \frac{p_{Ta}}{p_{Tt}}$

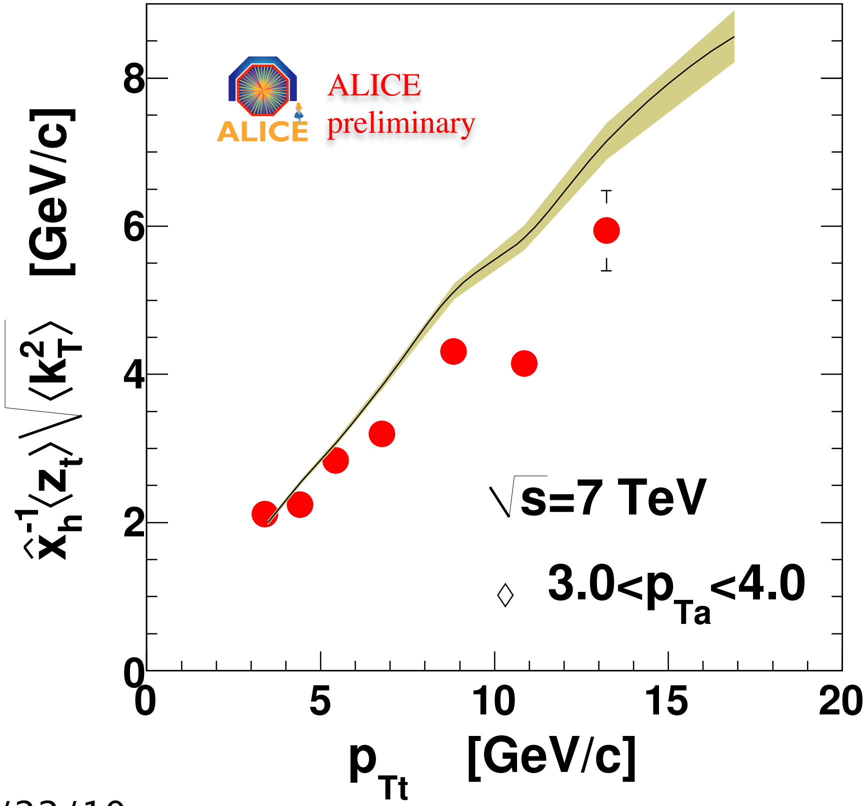
partonic $$\boxed{\frac{\langle z_t\rangle}{\langle\hat{x}_h\rangle}\sqrt{\langle k_T^2\rangle} = \frac{1}{x_h}\sqrt{\langle p_{out}^2\rangle - \langle j_{Ty}^2\rangle(1+x_h^2)}}$$ hadronic

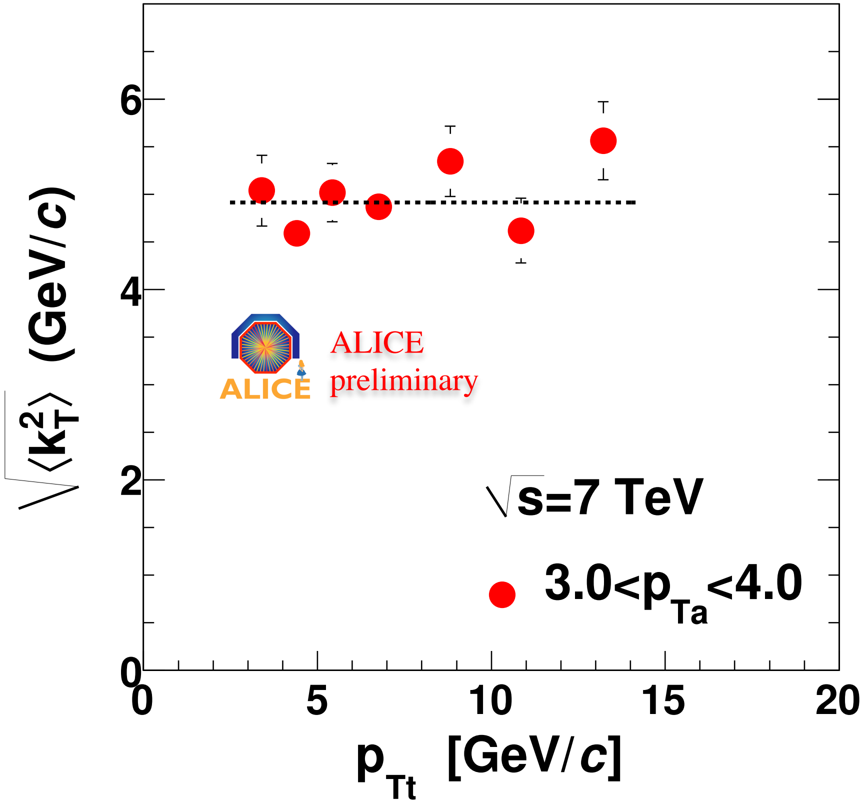
Small pTa bin -> no fluctuations/biases

$$\frac{\langle z_t \rangle}{\langle \hat{x}_h \rangle}\sqrt{\langle k_T^2 \rangle} = \frac{1}{x_h}\sqrt{\langle p_{out}^2 \rangle - \langle j_{Ty}^2 \rangle (1 + x_h^2)}$$

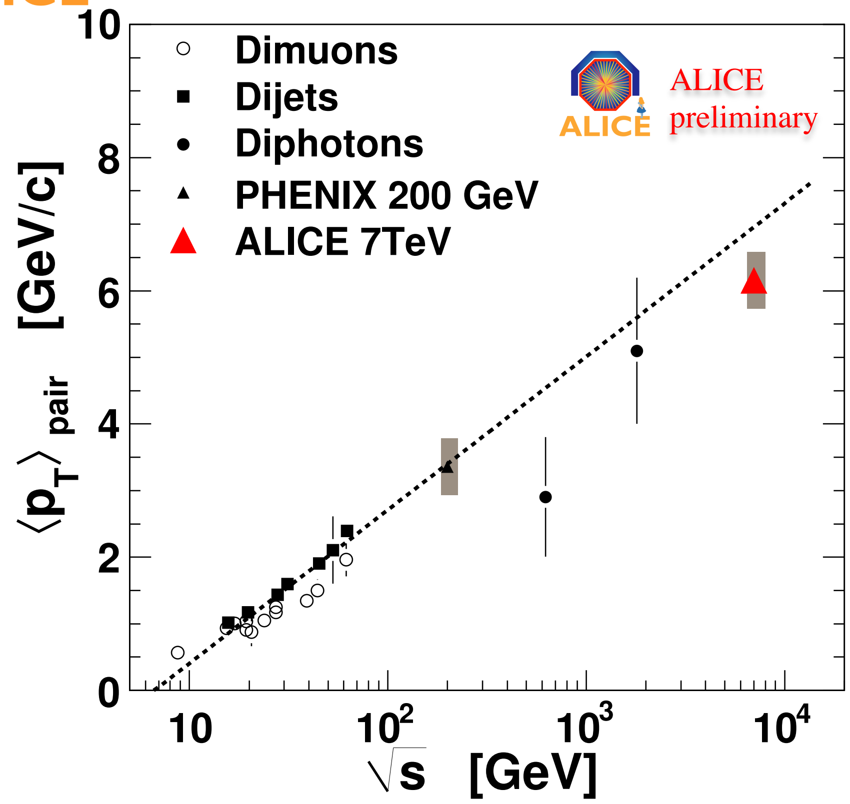
Decomposition analytically.

The only assumption here is a shape of an effective fragmentation function. For details see backup slides.





World comparison



$$\langle p_{T,\mathrm{pair}} \rangle = \sqrt{2} \times \langle k_T \rangle = \sqrt{\frac{\pi}{2}} \sqrt{\langle k_T^2 \rangle}$$

$$\sqrt{\langle k_T^2 \rangle} = 4.9 \pm 0.1 \text{ GeV/c}$$

PHENIX measured	$\sqrt{\langle k_T^2 \rangle} = 2.68 \pm 0.07 \pm 0.15$ GeV/c
Phys. Rev. D 74, 072002 (2006)	$\langle p_T \rangle_{\mathrm{pair}} = 3.36 \pm 0.09 \pm 0.43$ GeV/c
extrapolation to LHC √s=0.9 TeV:	$\sqrt{\langle k_T^2 \rangle} \approx 3.9$ GeV/c, $\langle p_T \rangle_{\mathrm{pair}} \approx 4.9$ GeV/c
extrapolation to LHC √s=7 TeV:	$\sqrt{\langle k_T^2 \rangle} \approx 5.6$ GeV/c, $\langle p_T \rangle_{\mathrm{pair}} \approx 7.0$ GeV/c

Summary

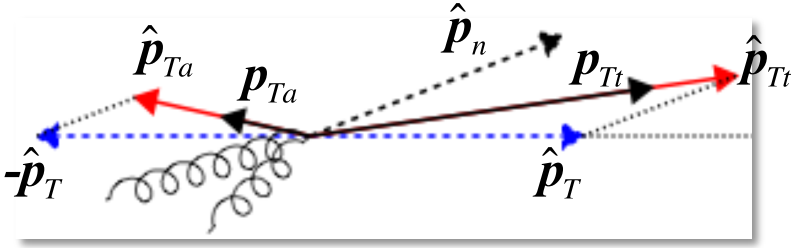
- The leading particle associated yield was analyzed in order to study
  - Initial state and higher order radiation – uncorrelated p_{Ta} distributions
    - Possible hints for NLO phenomena seen in the high trigger p_{Tt} associated p_{out} distributions (excess over PYTHIA)
  - Jet fragmentation:
    - The jet-fragmentation transverse momentum j_T seems to be independent on the trigger particle momentum and the mean value is comparable with lower $\sqrt{s}$ measurements.
  - Di-hadron acoplanarity
    - Mean net parton-pair momentum $p_{T,pair} \sim k_T$ seems to be in a good agreements with the phenomenological extrapolation from lower $\sqrt{s}$ data.

Kinematics

$$\frac{\langle z_t\rangle\left(\sqrt{\langle k_T^2\rangle}, p_{Tt}, p_{Ta}\right)}{\langle \hat{x}_h\rangle\left(\sqrt{\langle k_T^2\rangle}, p_{Tt}, p_{Ta}\right)}\sqrt{\langle k_T^2\rangle} = \frac{1}{x_h}\sqrt{\langle p_{out}^2\rangle - \langle j_{Ty}^2\rangle(1+x_h^2)} \qquad x_h = \frac{p_{Ta}}{p_{Tt}};\quad p_{out} \approx \sigma_{away};\quad j_T \approx \sigma_{near}$$

Assumption (*Phys.Rev.D74:072002,2006 for details*) :

Invariant mass of mass-less partons in hard scattering CMS and in LAB is the same -> non-Gaussian k_T-smearing.



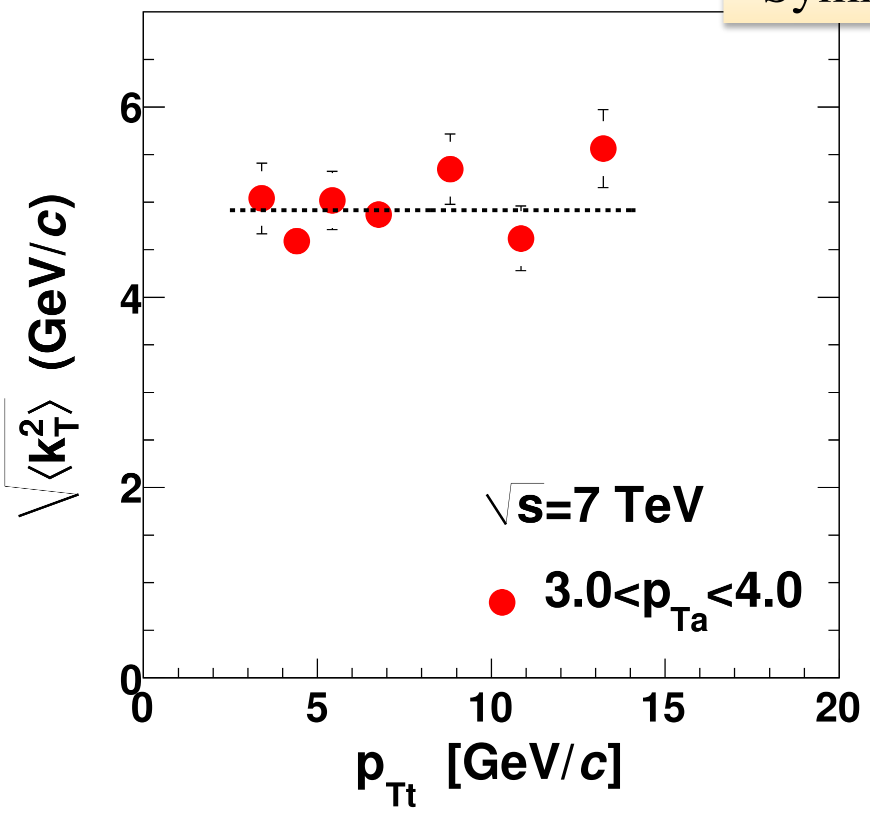
$$\langle z_t\rangle\left(\sqrt{\langle k_T^2\rangle}, p_{Tt}, p_{Ta}\right) = \int_{xTt}^{1} dz_t\, z^{n-1}\cdot D^\pi(z_t)\cdot \Sigma'_Q(z_t)$$

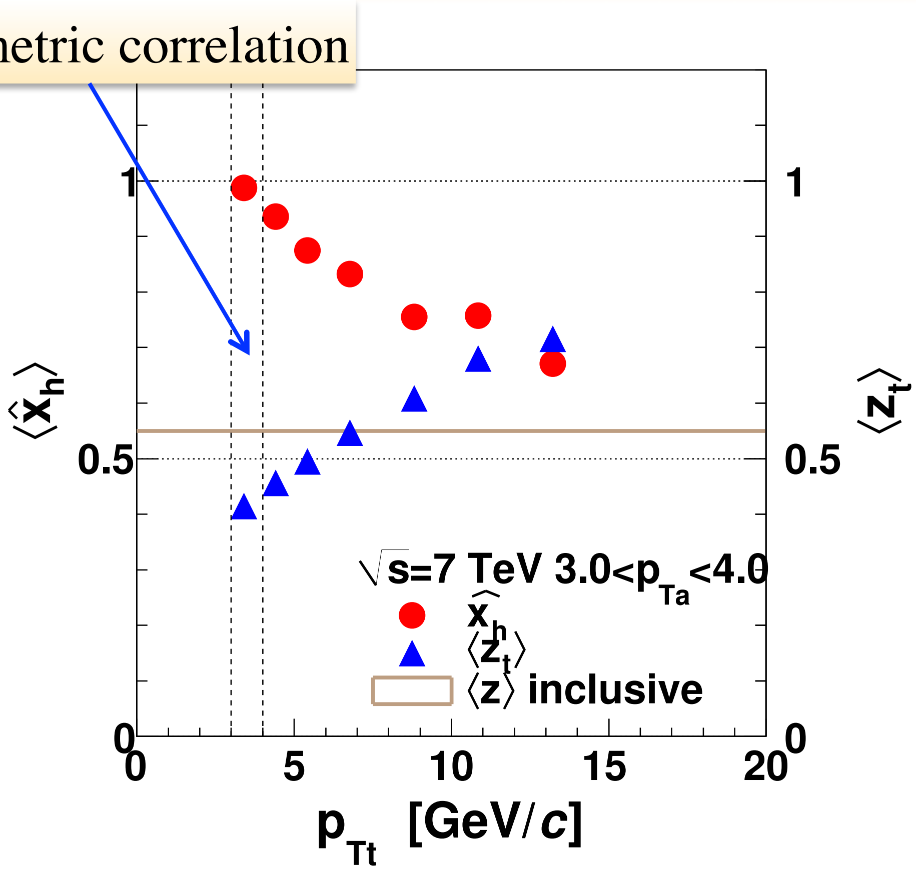
$$\langle \hat{x}_h\rangle\left(\sqrt{\langle k_T^2\rangle}, p_{Tt}, p_{Ta}\right) = \int_{pTt}^{\sqrt{s}/2} d\hat{p}_{Tt}\, \hat{p}_{Tt}^{\,n-1}\cdot D^\pi\left(\frac{p_{Tt}}{\hat{p}_{Tt}}\right)\cdot \Sigma'_Q\left(\frac{p_{Tt}}{\hat{p}_{Tt}}\right)$$

where k_T-smeared parton dist. $\Sigma'_Q(z_t) = \int_0^{\sqrt{s}/2} d\hat{p}_T\, \Sigma_Q(\hat{p}_T)\int_0^{\pi} d\phi\, \hat{p}_n\cdot G\left(\hat{\mathbf{p}}_n, \sqrt{\langle k_T^2\rangle}\right)\cdot D^\pi\left(\frac{p_{Ta}}{\hat{\mathbf{p}}_{Ta}}\right)\cdot\frac{1}{\hat{\mathbf{p}}_{Ta}}$

Sami Rasanen developed new machinery for these integrals

Final values of the kT imbalance function





$\langle z_t \rangle$ trigger particle fraction < $\langle z_{inclusive} \rangle$

imbalance function $\langle \hat{x}_h \rangle = \left\langle \frac{\hat{p}_{T,\text{ASSOC JET}}}{\hat{p}_{T,\text{TRIGGER JET}}} \right\rangle = 1$ when $p_{Ta} = p_{Tt}$