Higher twist from the isolated particle yield

High-pT Physics at LHC, Grenoble'13

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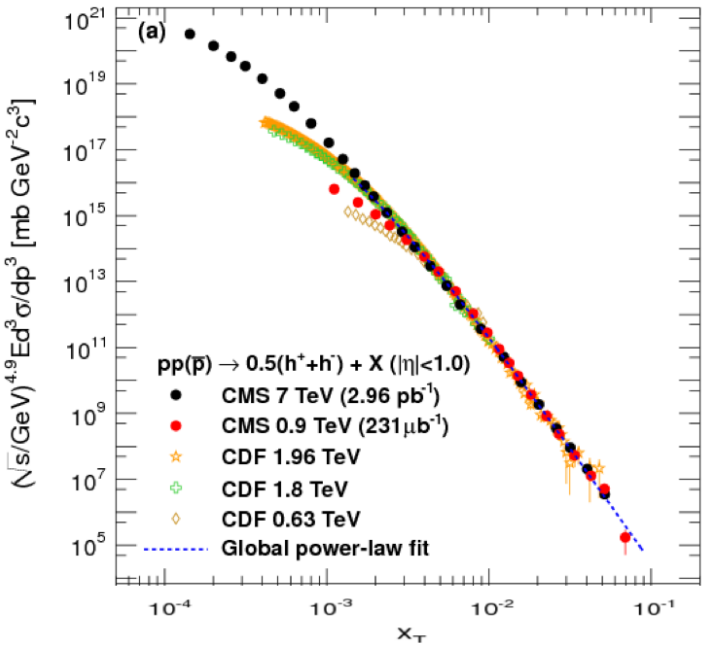
Introduction: x_T Scaling

Factorization of inv. cross section by dimensional analysis

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^n}F\left(\frac{p_T}{\sqrt{s}}\right) = \frac{1}{\sqrt{s}^n}G(x_T), n++=4$$



$x_T = \frac{2p_T}{\sqrt{s}}$

$F\left(\frac{p_T}{\sqrt{s}}\right)$ & $G(x_T)$ dimensionless scaling functions
(Left fig. [JHEP 1108:086,2011])

QCD has Λ_{QCD}, α_s, etc $\implies n > 4$.

At $\sqrt{s}_{LHC}$ pQCD predicts $n \approx 5\ldots6$.

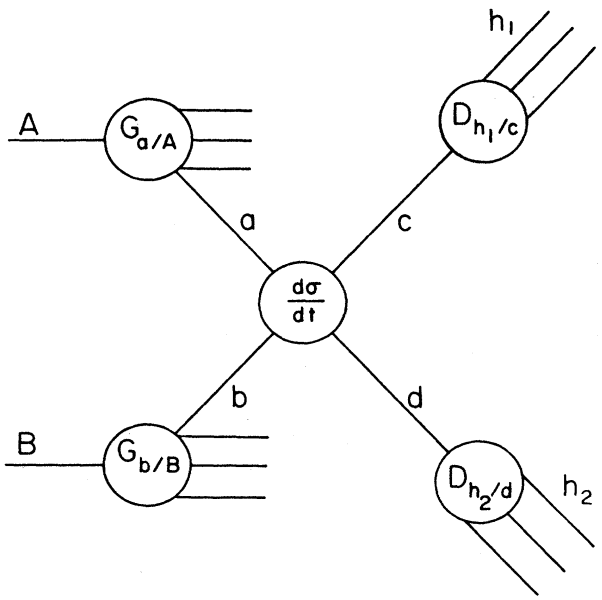
n obtained σ^{inv} with two different $\sqrt{s}$

$$n(x_T,\sqrt{s}_1,\sqrt{s}_2) = \frac{\ln(\sigma^{inv}(x_T,\sqrt{s}_2)/\sigma^{inv}(x_T,\sqrt{s}_1))}{\ln(\sqrt{s}_1/\sqrt{s}_2)}.$$

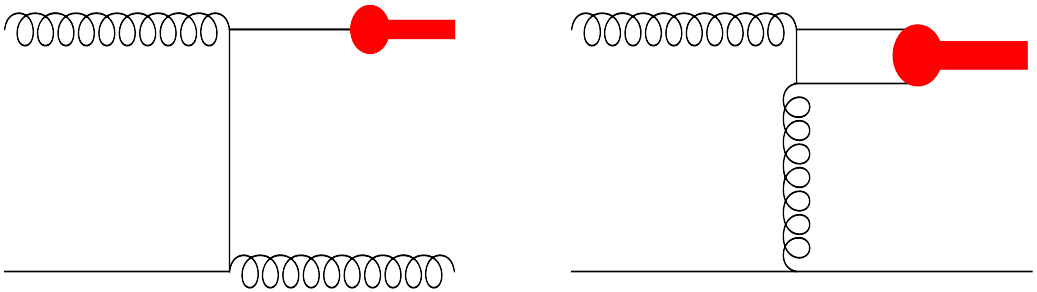
Scaling exponent & "twist"

Leading-twist (LT) processes = particle produced by fragmentation
$\Longrightarrow$ $n \approx 5 \ldots 6$ (NLO pQCD at LHC energies)

Higher-twist (HT) processes = particle produced directly in the subprocess
$\Longrightarrow$ n significantly larger (low-p_{T} phenomenon)



Leading-twist process



Left: Leading-twist, Right: Direct Higher-twist

HT prediction for RHIC and LHC

Prediction bands by F.Arleo et al. [PRL. 105 (2010) 062002]

$\Delta^{\text{fit}} = n_{\text{measured}} - n_{\text{NLO}} =$ "(LT+HT) - LT"

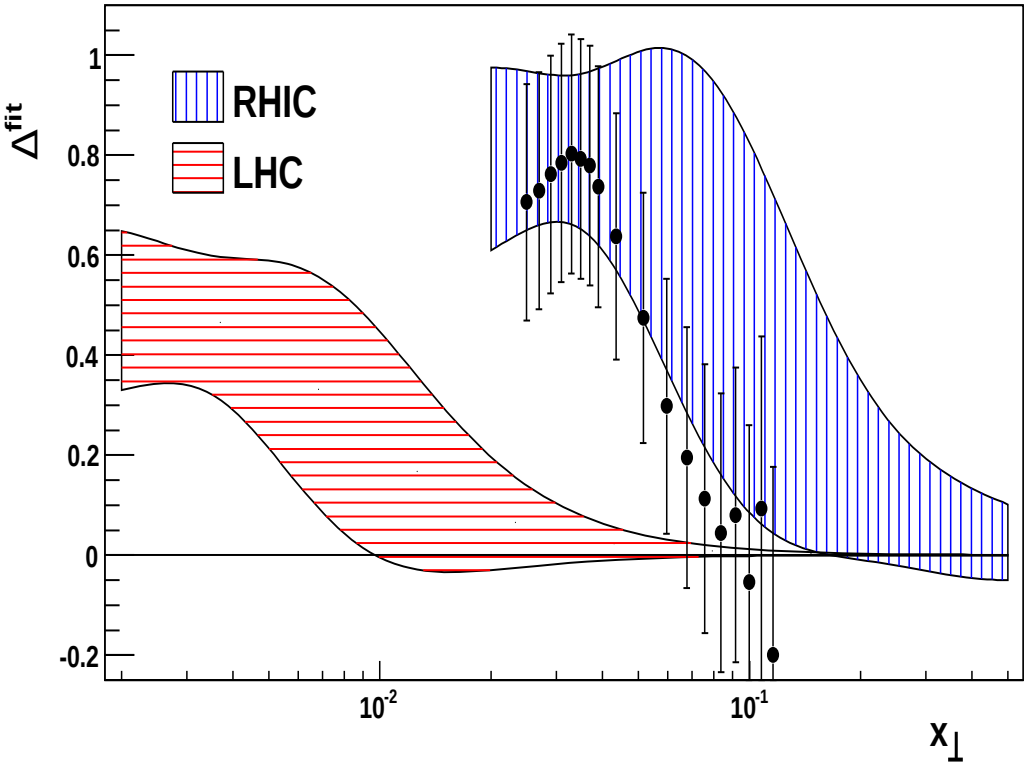
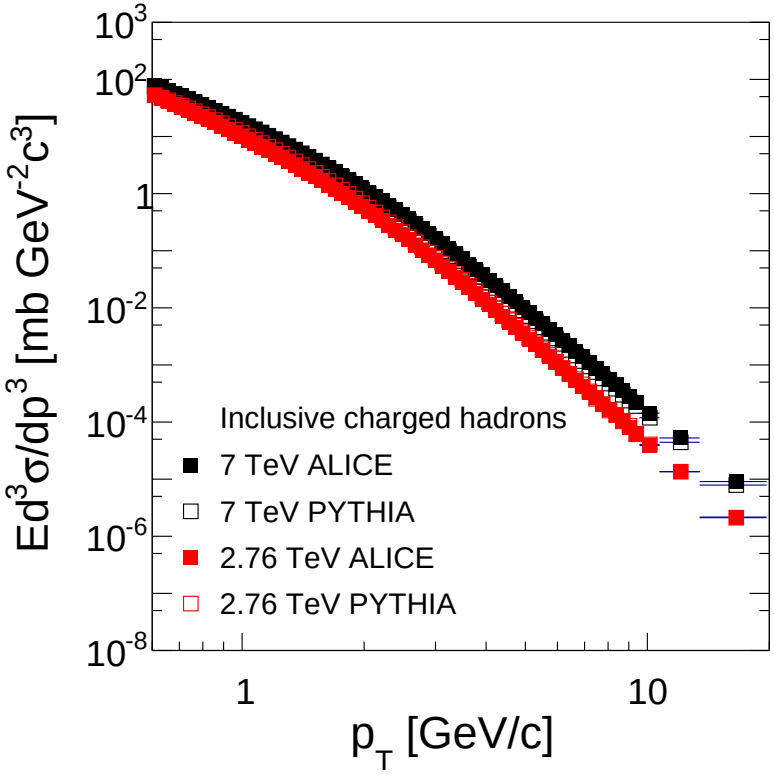


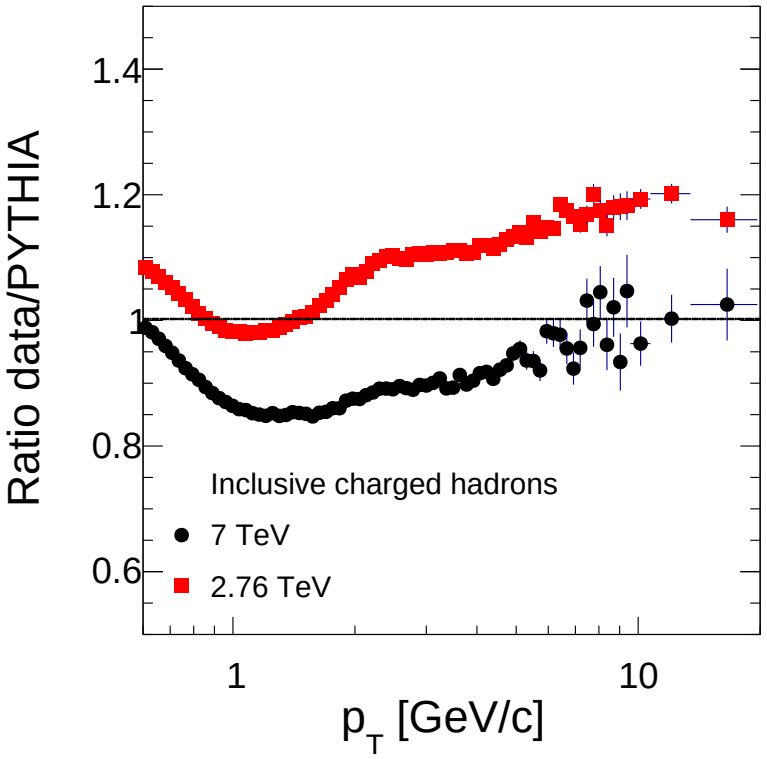
FIGURE : Prediction of Δ^{fit} based on a global fit of RHIC and Tevatron data with preliminary data points from PHENIX. [F.Arleo, Moriond 2010]

Non-zero Δ^{fit} data points $\Longrightarrow$ A hint of HT at RHIC data?

ALICE DATA VS. PYTHIA8

Inclusive charged hadrons at 7 TeV and 2.76 TeV





Left: Data & PYTHIA8 inclusive invariant p_T distributions of charged hadrons

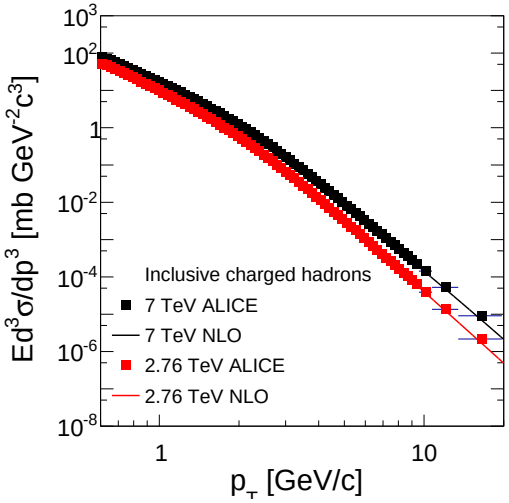
Right: Data/PYTHIA8 ratio. PYTHIA describes the inclusive spectra within 20%

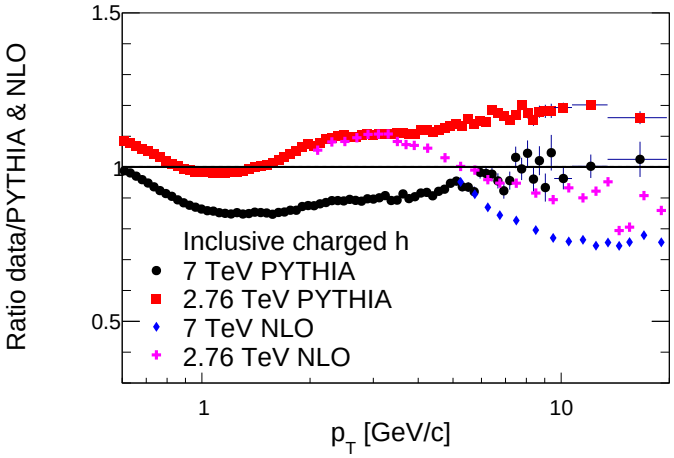
* finite tracking efficiency included in PYTHIA8

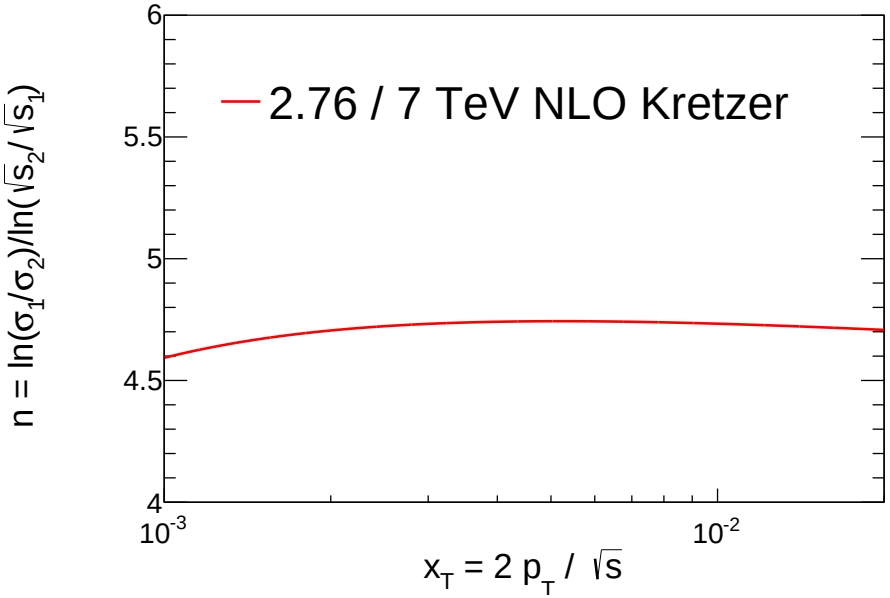
ALICE DATA VS. NLO

ALICE inv. cross sections with NLO (DSS FF) [arXiv:1307.1093], NLO overpredicts the data by a factor two (See backup).

Here NLO with Kretzer FF is used, describes the data within 25%. Calculation by H.Paukkunen, Jyväskylä.





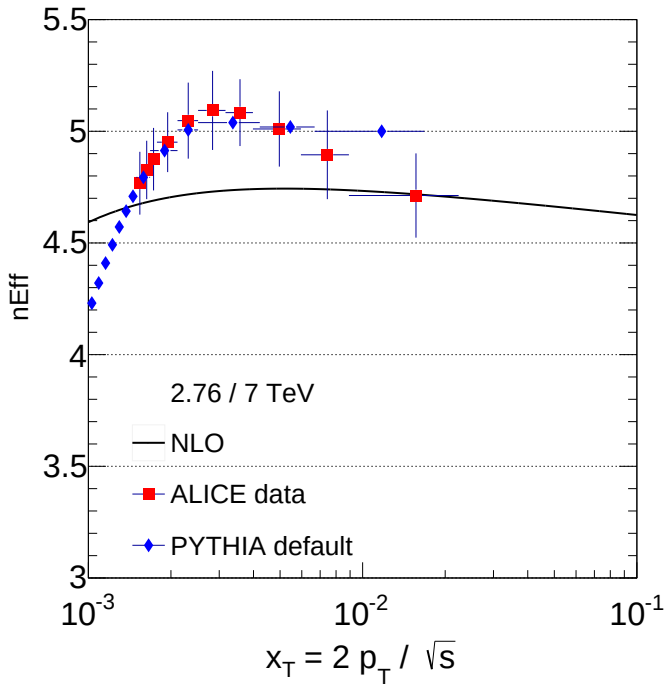


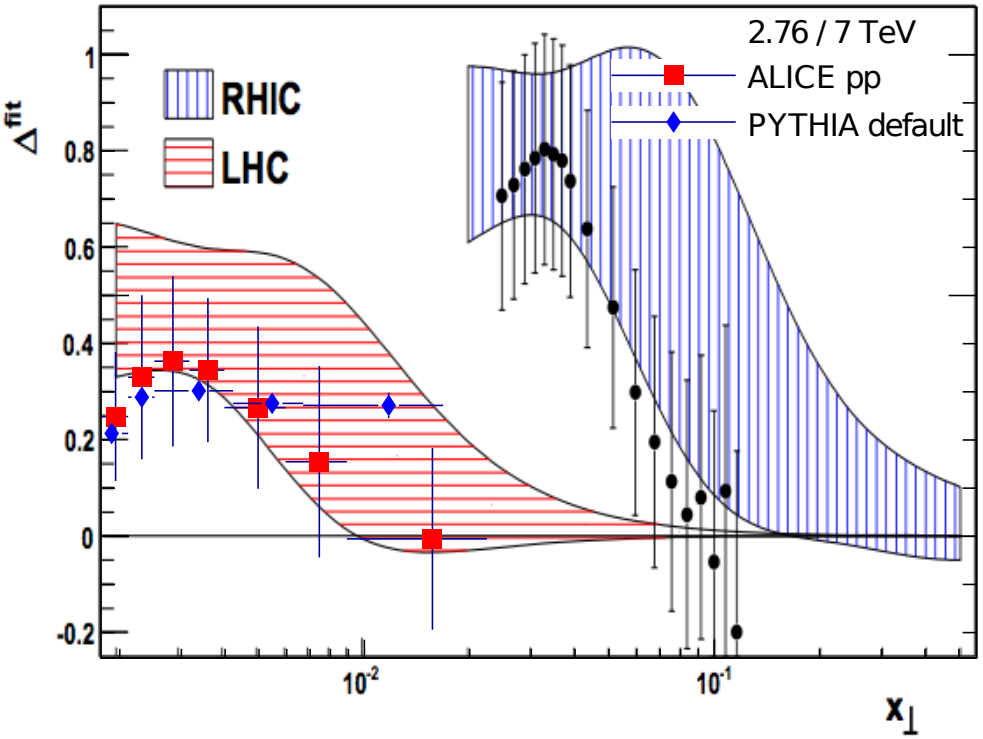
n obtained from NLO

Scaling exponents vs. predictions

Left: n from NLO, ALICE data and PYTHIA8

Right: Δn to NLO.





Remarks:

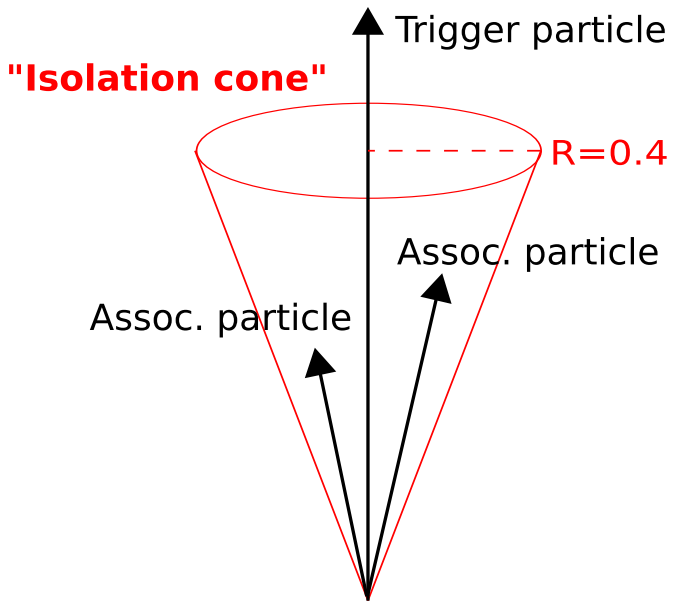
1) Data points seem to agree with LHC prediction
2) Non-zero Δn even from PYTHIA8 which has no Higher Twist processes.

HT Prediction for Isolated Particles

It is suggested by F.Arleo et al. [PRL. 105 (2010) 062002] that isolation cuts should enhance the fraction of HT processes

Hadrons from direct production (HT) are expected to be accompanied with less hadronic activity than jets.

I aim to verify this using PYTHIA8.

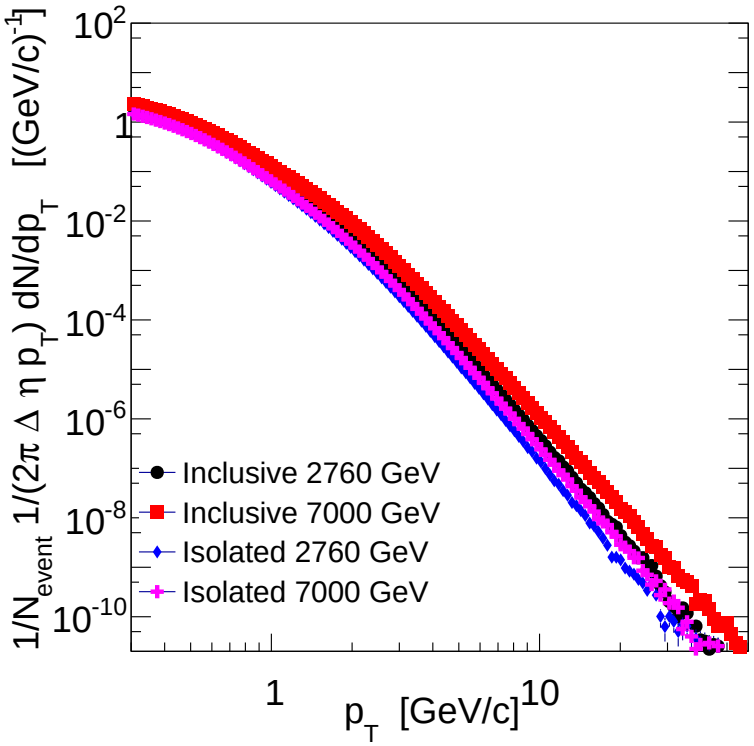


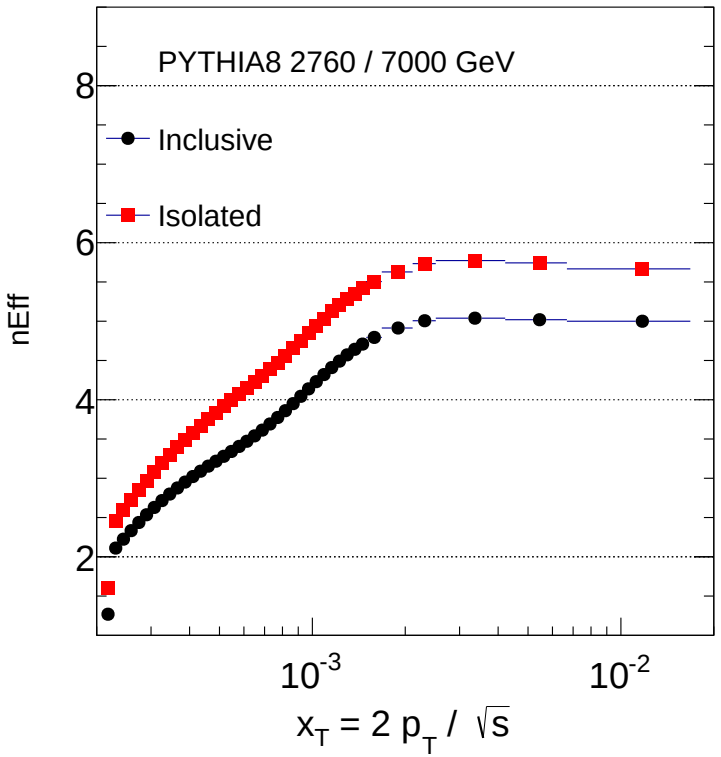
Isolation cut:

- Calculate $\sum p_{\mathrm{T}}$ of associated particles inside the cone
- If the sum is smaller than pre-defined limit, the particle is isolated
- I used cone with radius R=0.4 in η-ϕ
- The $\sum p_{\mathrm{T}}$ was required to be less than 10% of the trigger p_{T}

ISOLATED n FROM PYTHIA8

Below is the n of inclusive (black) and isolated spectra from PYTHIA8.





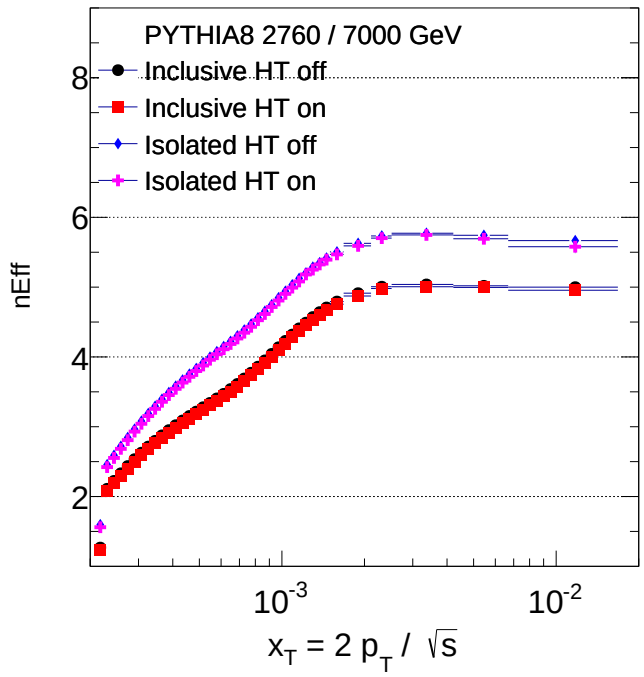
The isolation cut increases n, even in PYTHIA8 without HT. This suggests a kinematical bias caused by the isolation itself.

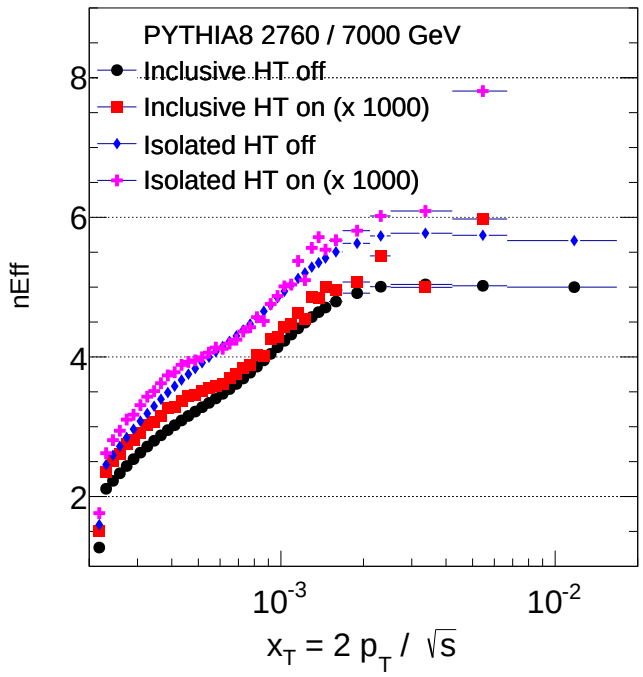
HT implementation for PYTHIA8

With help of T.Sjöstrand, I added a HT process [Phys.Rev.D23,99] to PYTHIA8.

$$(\mathrm{q\,g} \to \mathrm{q}\pi) \qquad \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}} = \frac{\pi(\alpha_s(p_\mathrm{T}))^3}{\hat{s}^2}\frac{1}{4\pi}\frac{s_0}{\hat{s}}F(\cos\theta), \tag{1}$$

with HT scale $s_0 = 16\pi^2 f_\pi^2$, $f_\pi = 93$ MeV and $F(z = \cos\theta) = \frac{2}{27}(1-z)\left(1 + \frac{4}{(1+z)^2}\right)$





Left: HT as in [Phys.Rev.D23,99] **Right**: HT multiplied by 1000 to magnify effect

With this implementation, the effect of HT to n is very weak, even when enhanced by factor of 1000.

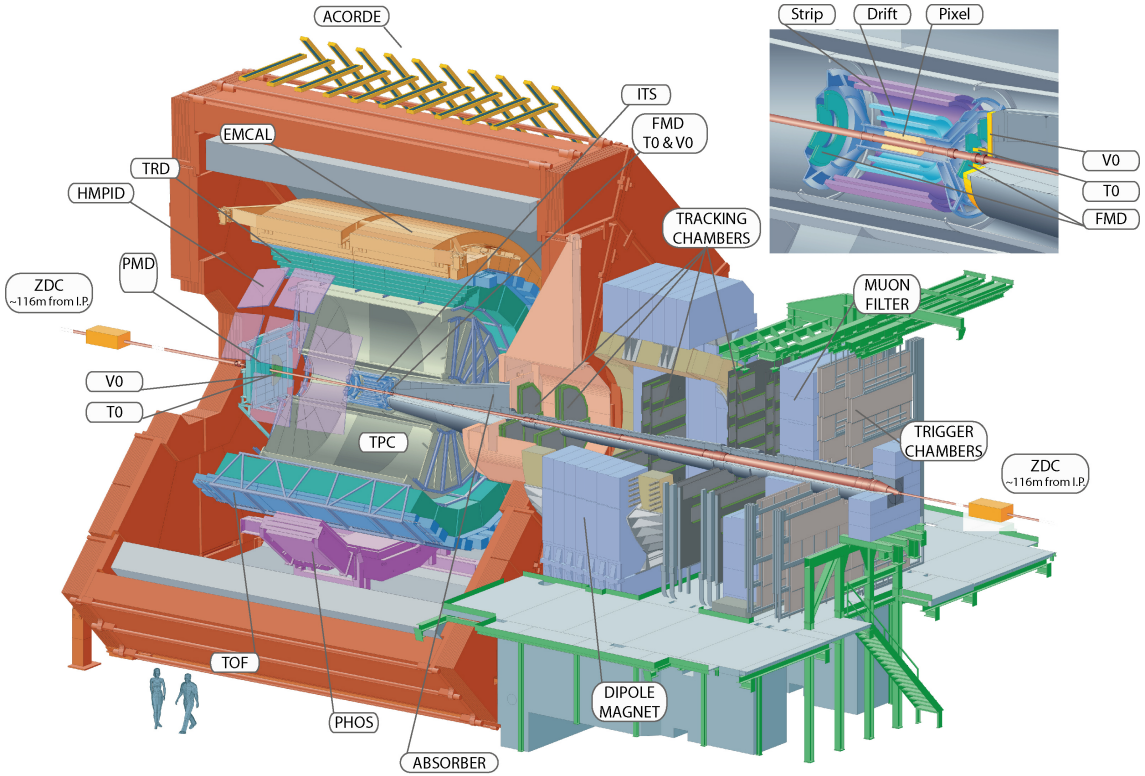
Conclusion

- The x_{T} scaling exponents n for inclusive charged hadrons were extracted from ALICE pp data, PYTHIA and NLO at $\sqrt{s} = 7$ TeV and 2.76 TeV.
- The Δn results are in agreement with HT predictions from F.Arleo et al.
- Isolation cuts increase n due to a kinematical bias.
- Even when multiplied by 1000, the direct $\pi^{\pm}$ production as described in [Phys.Rev.D23,99] is barely visible on n at LHC energies in PYTHIA8.
- The HT PYTHIA implementation suggests that the direct pion production HT contribution is very small at LHC energies

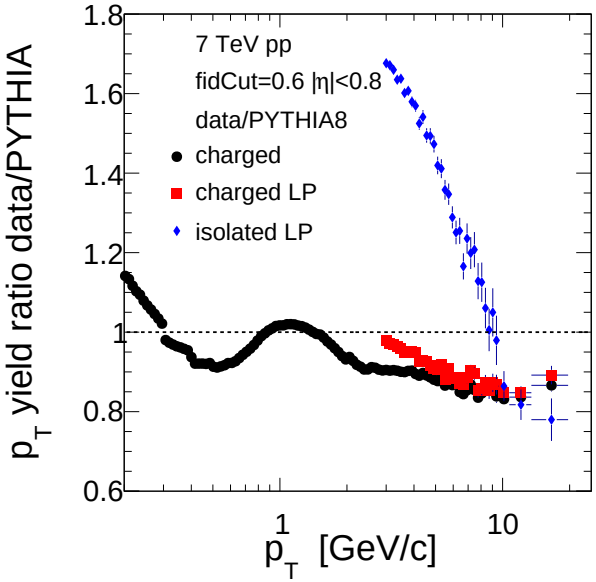
Backup slides

The ALICE Experiment

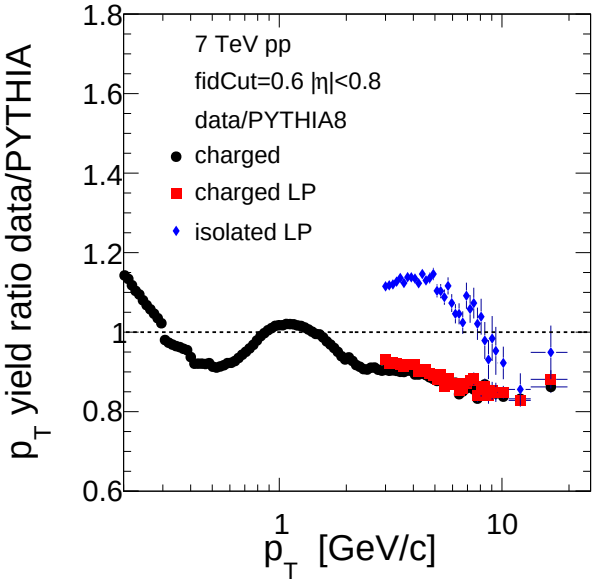
Part of the Large Hadron Collider (LHC) at CERN, Switzerland.
Designed for heavy-ion collisions, but has also a *pp* program.
Excellent particle identification cabability, down to even $p_{\mathrm{T}} = 100$ MeV/c.



- For the isolation checking in PYTHIA, we wanted to mimick the low p_{T} performance of a real detector.
- This was done by removing particles from the PYTHIA event randomly according to the efficiency curve.
- When obtaining the p_{T} spectra, the inverse of the efficiency was used to recover the lost particles, like in the real data.
- After this, the isolated spectra were in better agreement. Figures below are 7 TeV data/PYTHIA ratios before (left) and after (right) the effi was applied in PYTHIA.



Efficiency not taken into account

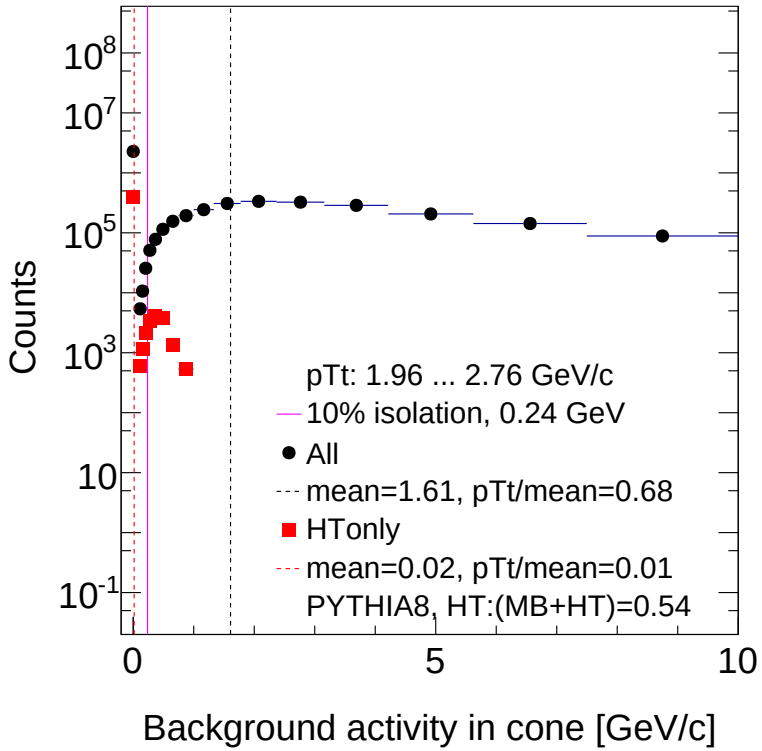


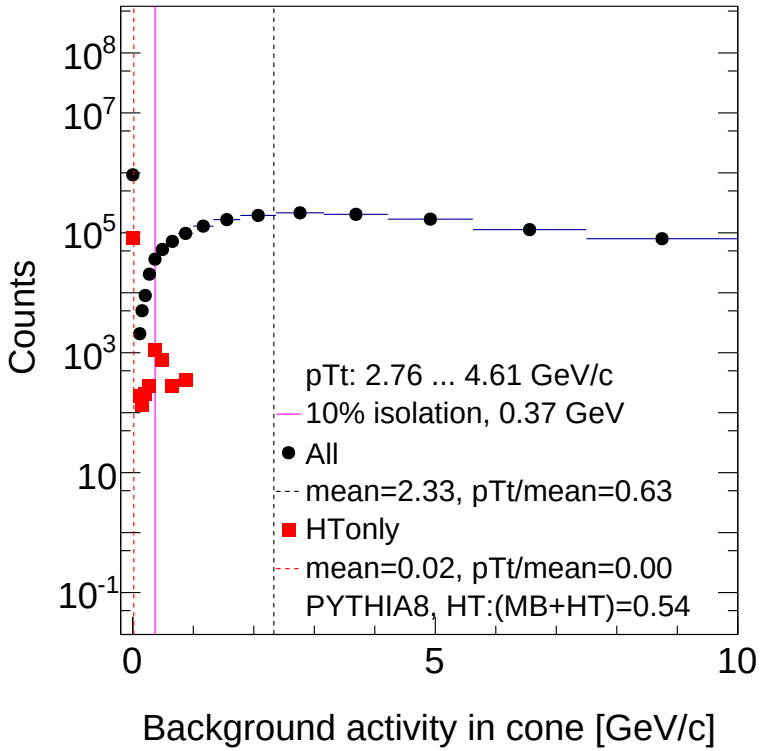
Efficiency taken into account

Background activity plots

PYTHIA8 ISR=FSR=MPI=kT=off

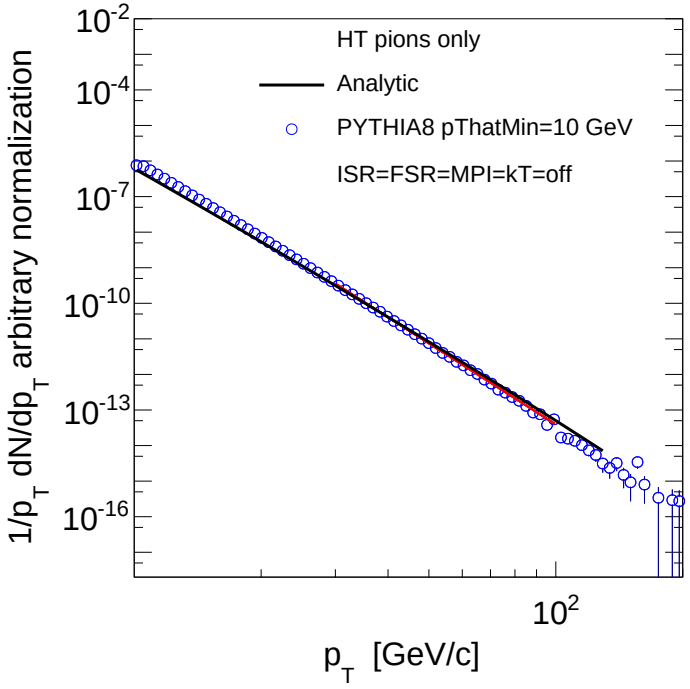
Activity in a R=0.4 cone for HT pions and all hadrons



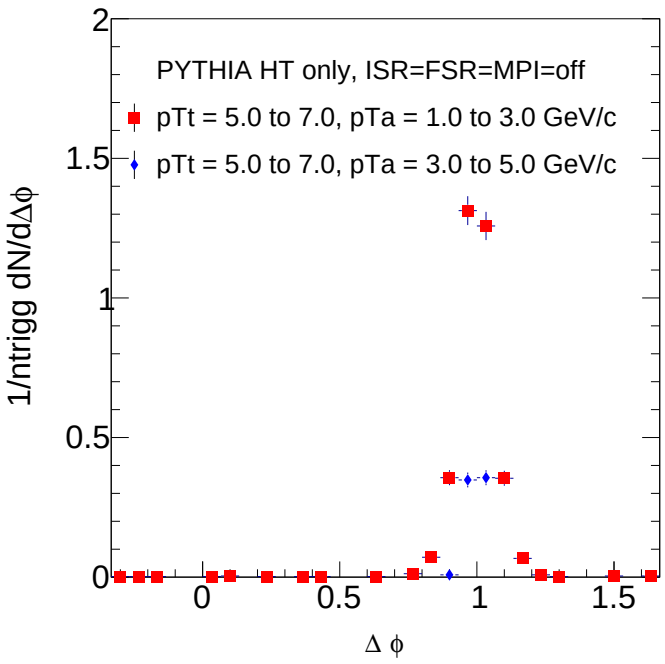


Very hard to distinguish HT from all hadrons with isolation cut

HT in PYTHIA8



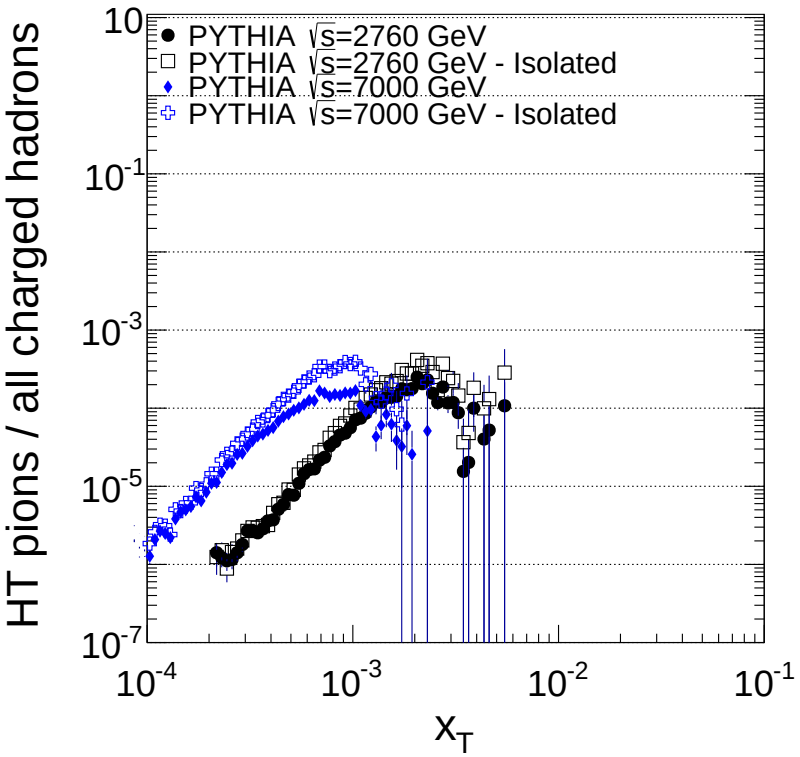
p_T analytical & PYTHIA8

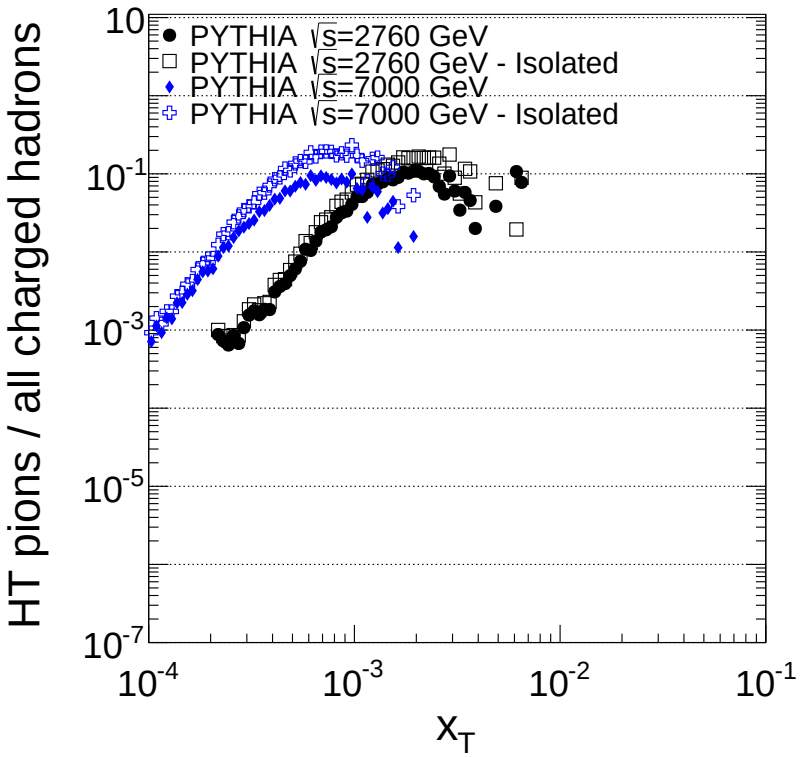


HT pion correlation function

HT in PYTHIA8

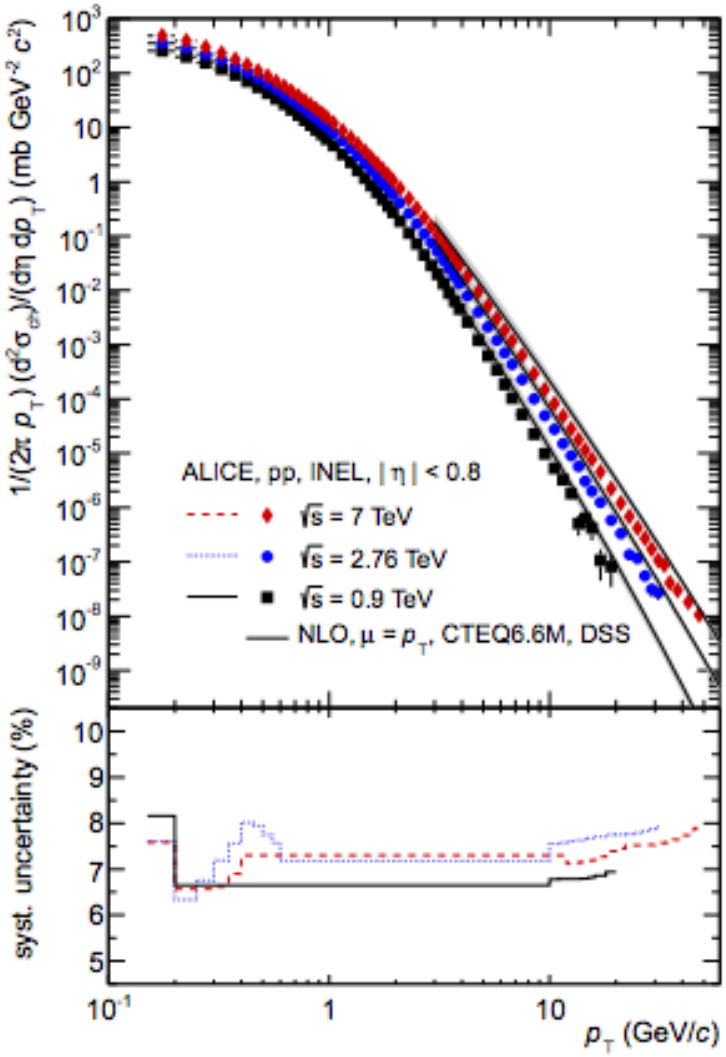
Ratio of HT pions / all charged hadrons

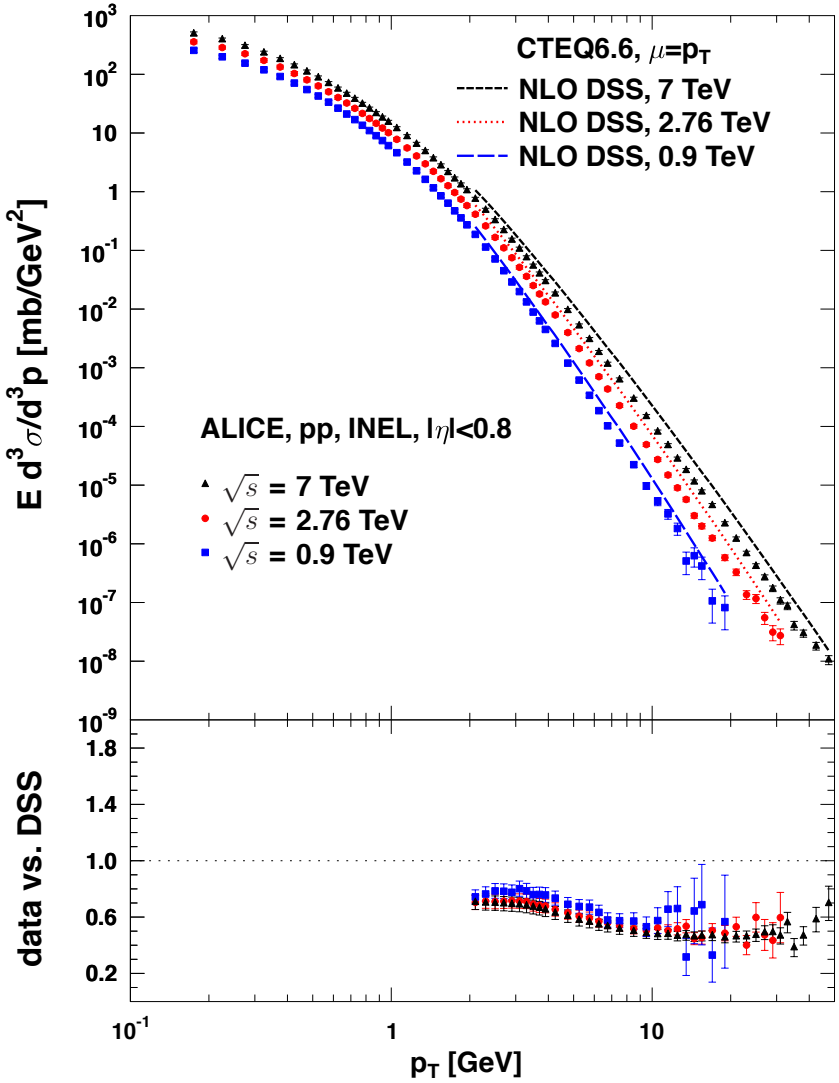




Left: HT as in [Phys.Rev.D23,99] **Right**: HT multiplied by 1000 to magnify effect

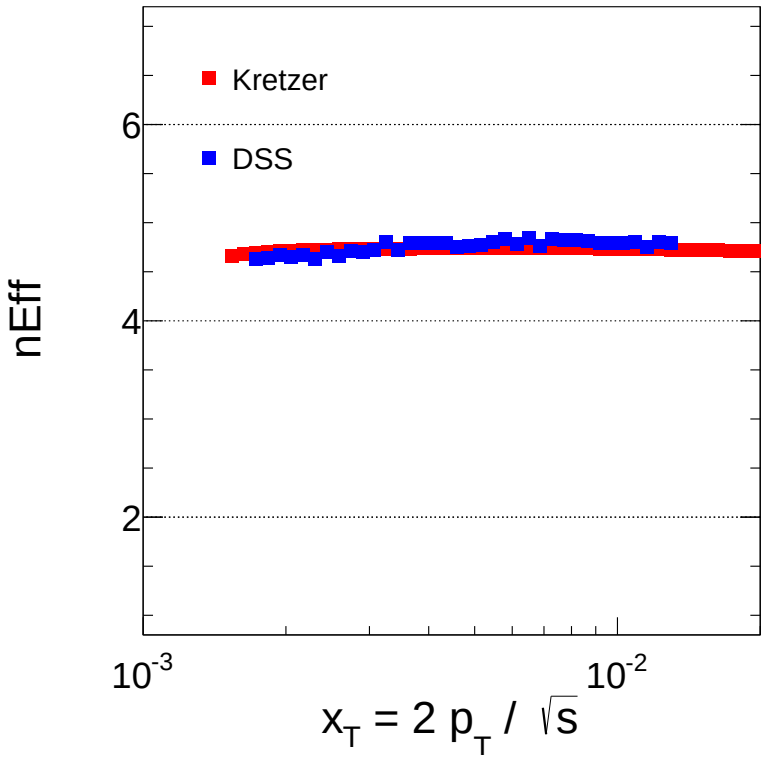
ALICE and NLO p_T

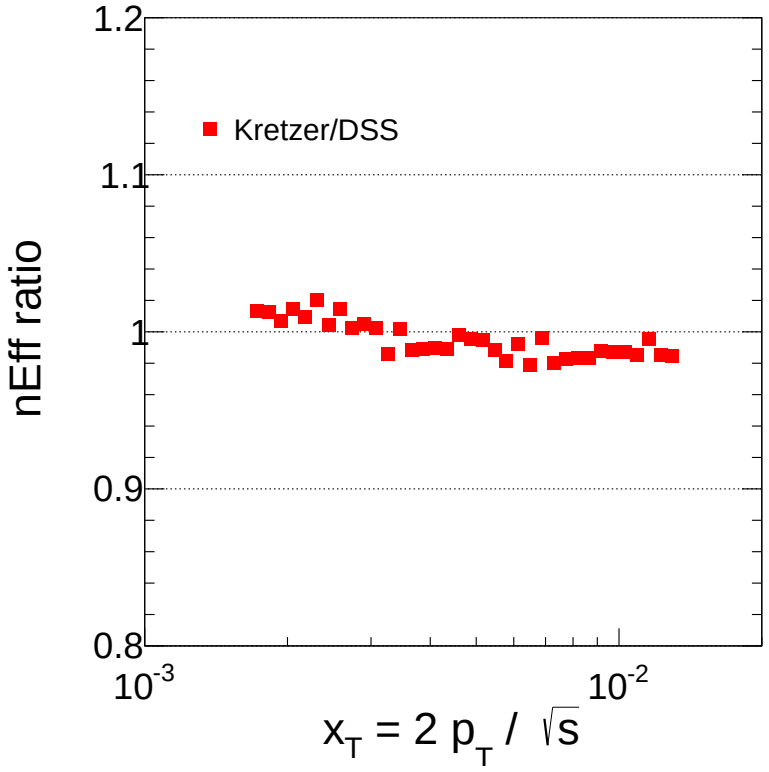




Left: Fig. from [arXiv:1307.1093] **Right**: From H.Paukkunen, Jyväskylä

FF AND n





Left: n with DSS and Kretzer FF **Right**: Ratio Kretzer/DSS NLO spectra

from H.Paukkunen, Jyväskylä

Toy Monte Carlo model

To study the role of kinematics further, a toy Monte Carlo model was made in the spirit of Bjorken's Parent-Child-Relationship [Phys.Rev.D8,4098 (1973)]

$$\frac{1}{p_{\mathrm{T}}}\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} = \int f_q(p_{\mathrm{Tq}}) \cdot D(z)\frac{1}{z^2}\mathrm{d}z \sim \frac{1}{p_{\mathrm{T}}^a}\int_{x_{\mathrm{T}}}^1 z^{a-2}D(z)\mathrm{d}z,$$

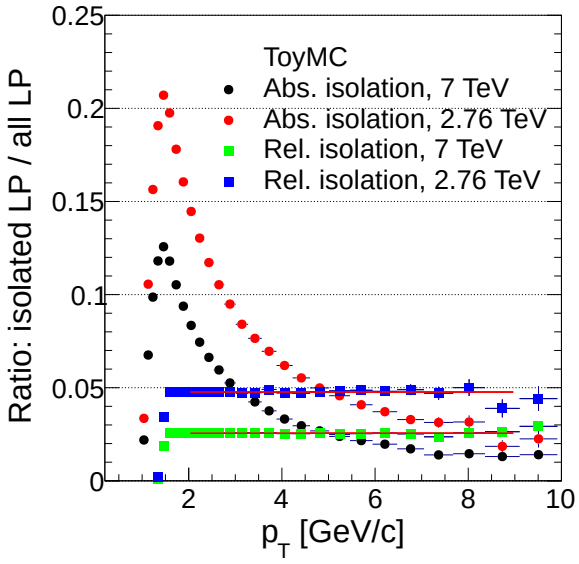
where $z = p_{\mathrm{T}}/p_{\mathrm{Tq}}$, $D(z)$ is the fragmentation function (FF) and $f_q(p_{\mathrm{Tq}})$ is the final parton spectrum.

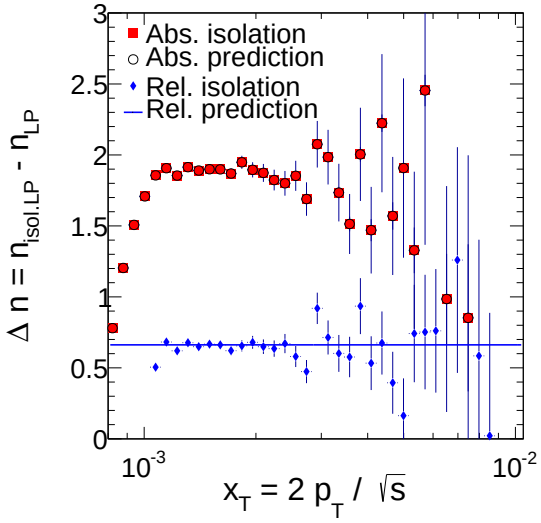
The spectra of isolated hadrons was needed, so a Monte Carlo cascade process was used instead of integration:

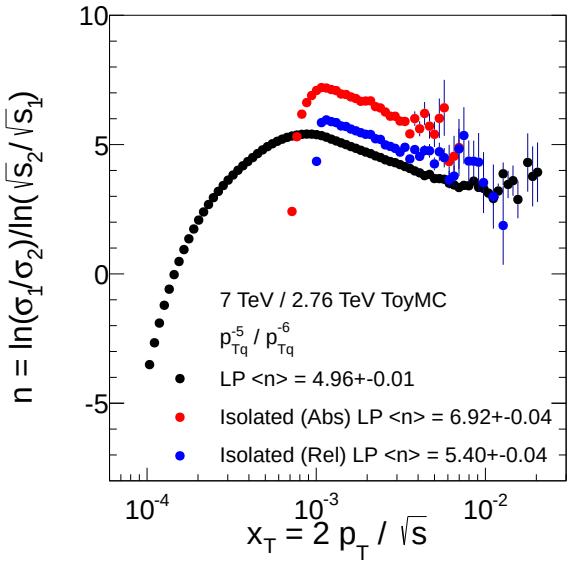
- Parton momentum p_{Tq} is sampled from power law
  - $f_q(p_{\mathrm{Tq}}) \sim p_{\mathrm{Tq}}^{-6}$ for "2.76 TeV"
  - $f_q(p_{\mathrm{Tq}}) \sim p_{\mathrm{Tq}}^{-5}$ for "7 TeV"
- z is sampled from the approximation of FF, $\exp(-8.2 \cdot z)$
- $p_{\mathrm{T}} = z \cdot p_{\mathrm{Tq}}$ is saved and subtracted from the p_{Tq}

Now the scaling exponent n could be extracted from the hadron spectra.

Toy MC - Δn prediction (relative isolation)







Fractions f of isolated particles with the relative cut:
$f_1 = 0.0257(1)$, green points at 7 TeV
$f_2 = 0.0478(1)$, blue points at 2.76 TeV

$$\Delta n_{\text{pred.}} = \frac{\ln(f_1\sigma_1/f_2\sigma_2)}{\ln(\sqrt{s_2}/\sqrt{s_1})} - \frac{\ln(\sigma_1/\sigma_2)}{\ln(\sqrt{s_2}/\sqrt{s_1})} = \frac{\ln(f_1/f_2)}{\ln(\sqrt{s_2}/\sqrt{s_1})}$$

$\Longrightarrow$ non-zero Δn just from the isolation probabilities!