Geometrical scaling at the LHC

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Conclusions

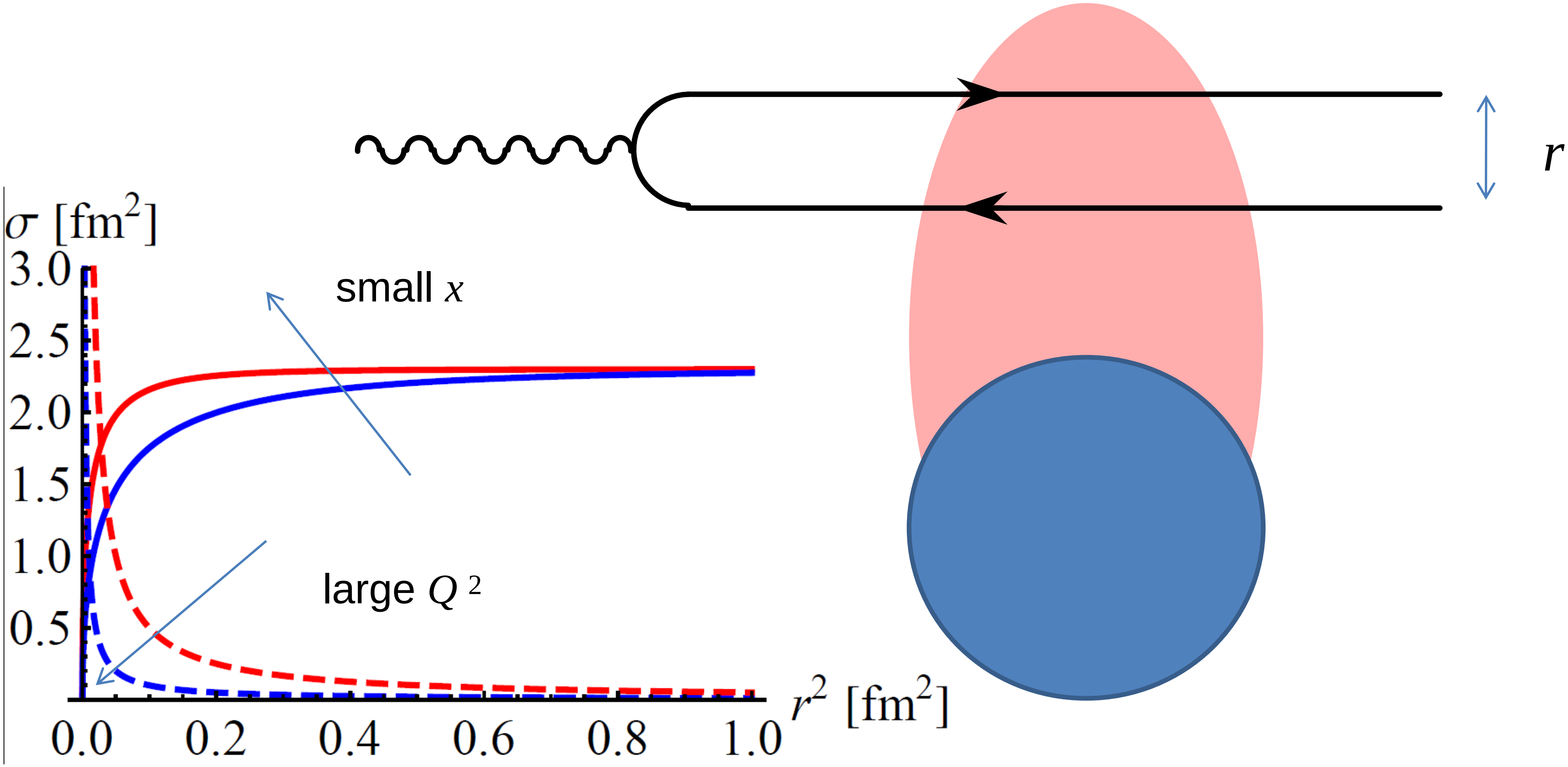
Transverse momentum spectra at the LHC exhibit
geometrical scaling

$$\frac{dN_{\rm ch}}{dy\,dp_{\rm T}^2}(s, p_{\rm T}) = \frac{1}{Q_0^2}F(\tau)$$

Larry McLerran, Michal Praszalowicz:
Acta Phys.Polon.B41:1917-1926,2010, e-Print:**arXiv:1006.4293** [hep-ph];
to be published in: **Acta Phys.Polon.B42,** e-Print:**arXiv:1011.3403** [hep-ph],
Michal Praszalowicz:
e-Print: **arXiv:1101.0585** [hep-ph]

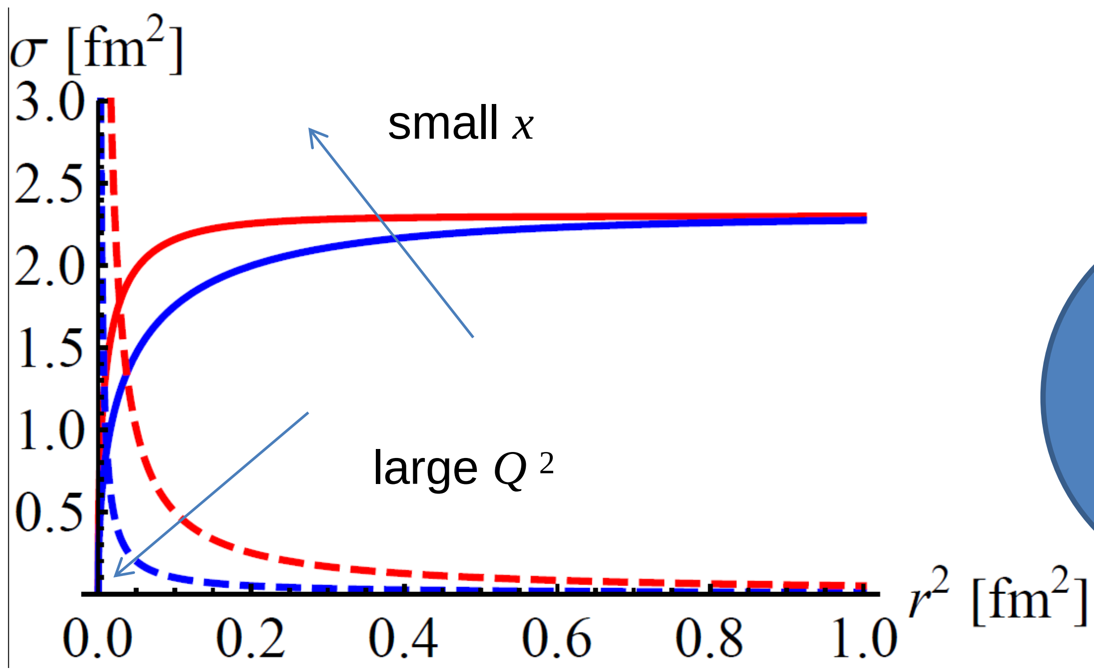
Golec-Biernat Wüsthoff Model

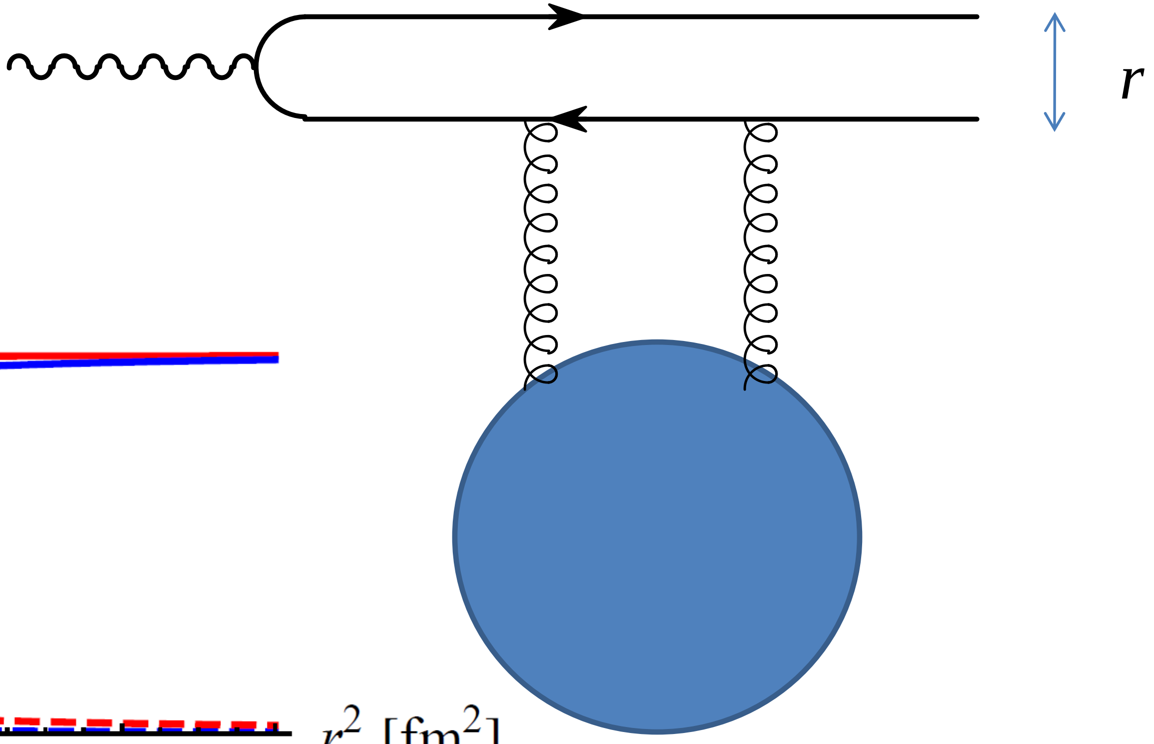
$$\sigma_{\gamma^* p} = \int dr^2 \left|\psi(r, Q^2)\right|^2 \sigma_{dP}(r^2 Q_s^2(x)) \qquad Q_s^2 = Q_0^2 (x_0/x)^\lambda$$



Golec-Biernat Wüsthoff Model

$$\sigma_{dP}(r^2 Q_s^2(x)) \;\sim\; r^2 \alpha_s(\mu_r^2)\, xG(x,\mu_r^2) \sim x^{-\lambda}$$





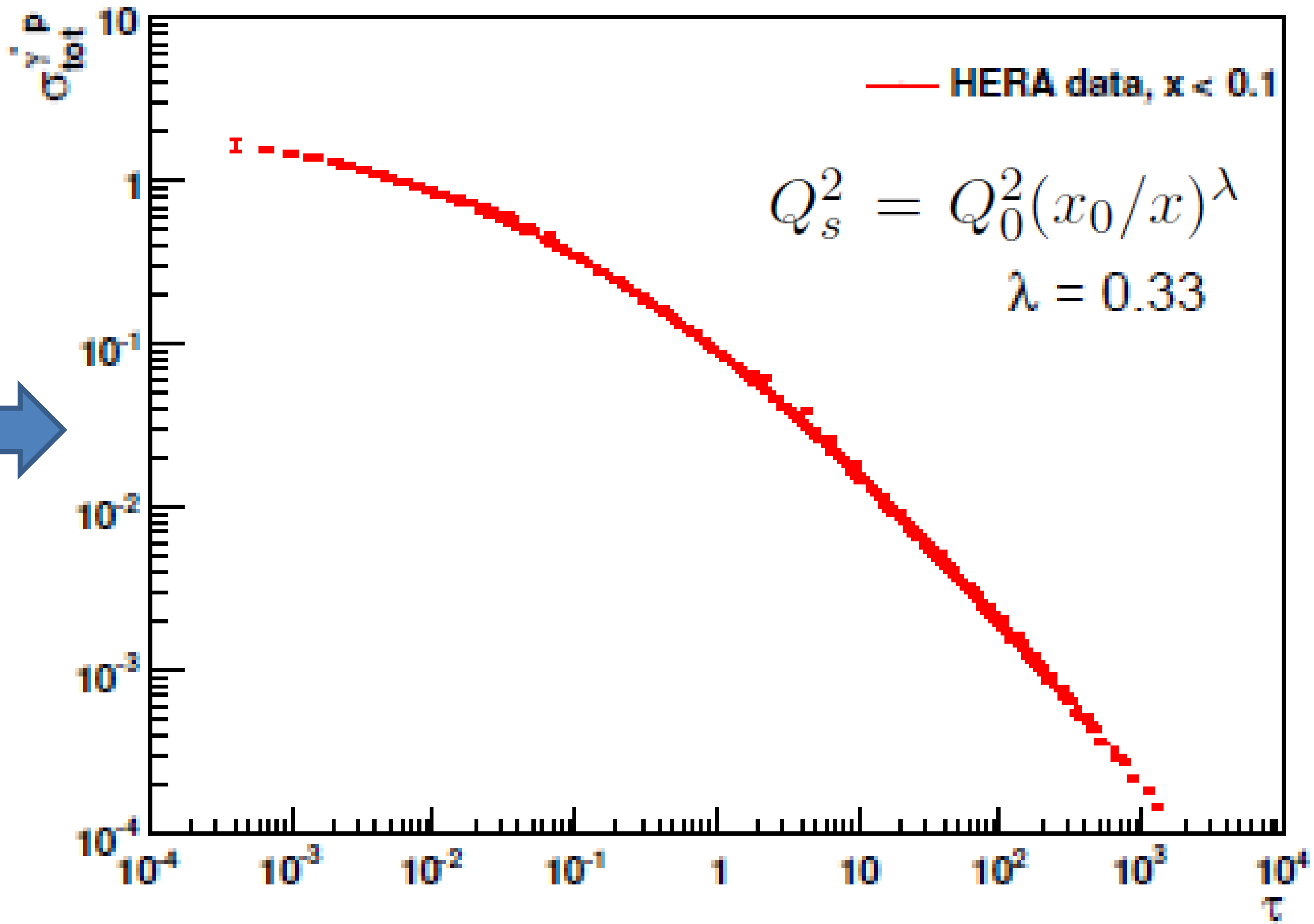
Geometrical Scaling

$$\sigma_{\gamma^* p} = \int dr^2 \left|\psi(r, Q^2)\right|^2 \sigma_{dP}(r^2 Q_s^2(x))$$

$$\boxed{\sigma_{\gamma^* p} \quad = \quad \sigma_{\gamma^* p}\left(\frac{Q_s(x)}{Q}\right)}$$

HERA data and DGLAP evolution: Theory and phenomenology.
F. Caola, S. Forte, J. Rojo **arXiv:1007.5405** [hep-ph]

A. M. Stasto, K. J. Golec-Biernat and J. Kwiecinski, Phys. Rev. Lett. **86**, 596 (2001) [arXiv:hep-ph/0007192].



$$\mathrm{Log}(\ Q^2/Q_s^2(x)\ )$$

Saturated gluonic matter at the LHC

„Old”, conventional physics with a new tool:

Saturated gluonic matter at the LHC

„Old", conventional physics with a new tool:

$$Q_s^2 = Q_0^2 (x_0/x)^\lambda$$

Geometrical scaling of p_T distributions

$$\frac{dN_{\rm ch}}{dy\,dp_{\rm T}^2}(s,p_{\rm T}) = \frac{1}{Q_0^2}F(\tau)$$

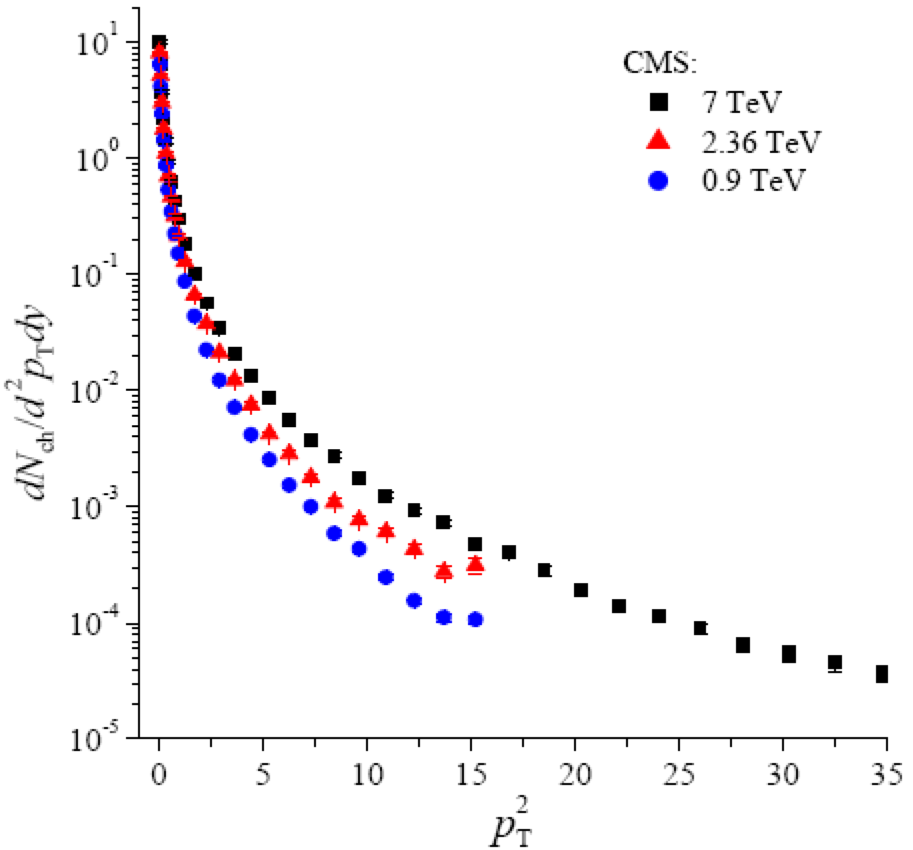
multiplicity distribution is a universal function of scaling variable τ

$$Q_{\rm sat}^2(x) = Q_0^2\left(\frac{1}{x_0}\frac{p_{\rm T}}{\sqrt{s}}\right)^{-\lambda}$$

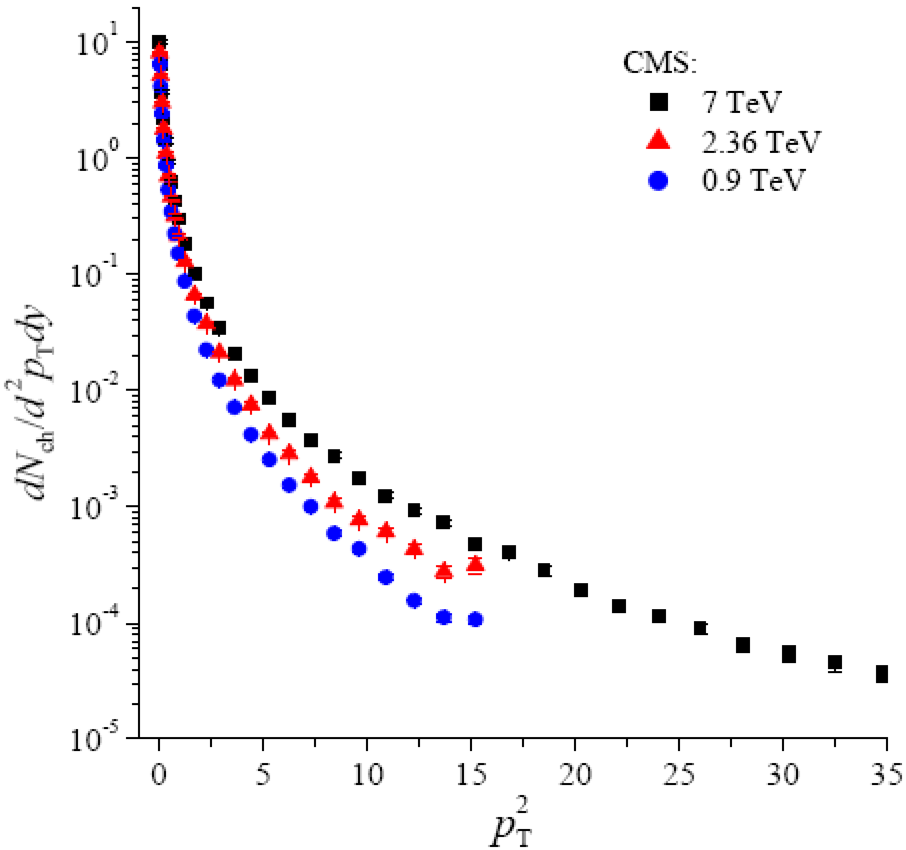
$$\tau = \frac{p_{\rm T}^2}{Q_{\rm sat}^2(p_{\rm T}/\sqrt{s})} = \frac{p_{\rm T}^2}{1\,{\rm GeV}^2}\left(\frac{p_{\rm T}}{\sqrt{s}\times 10^{-3}}\right)^{\lambda}$$

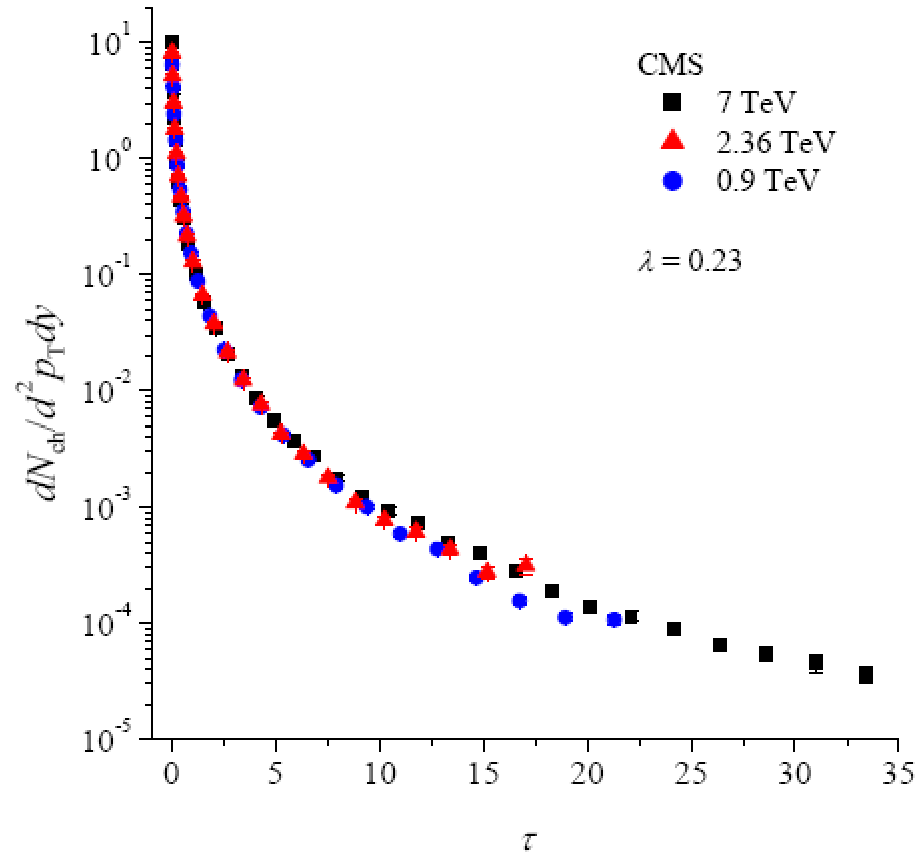
note that for $\lambda = 0$ scaling variable $\tau = p_T^2$

Geometrical scaling of p_T distributions

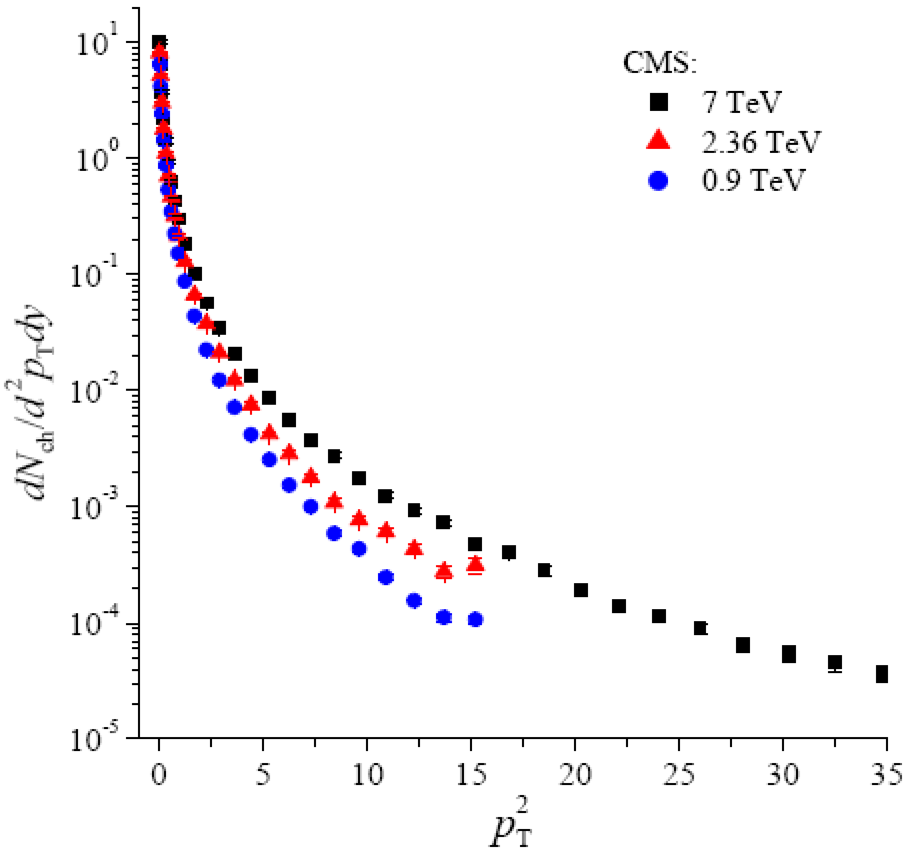


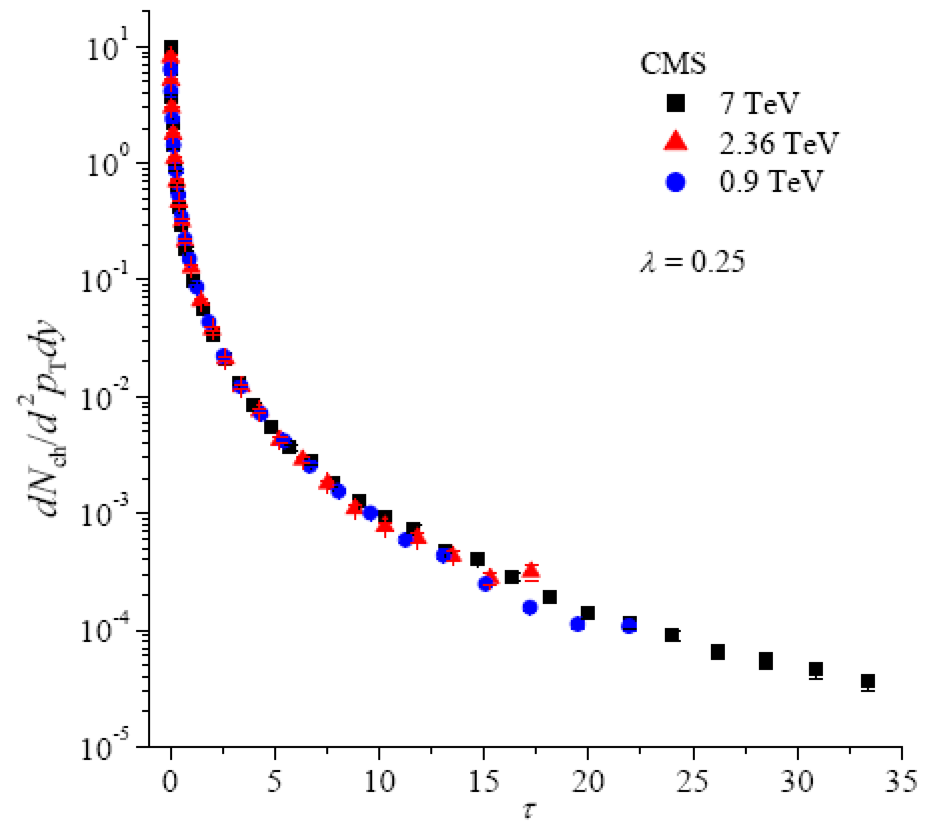
Geometric scaling of p_T distributions



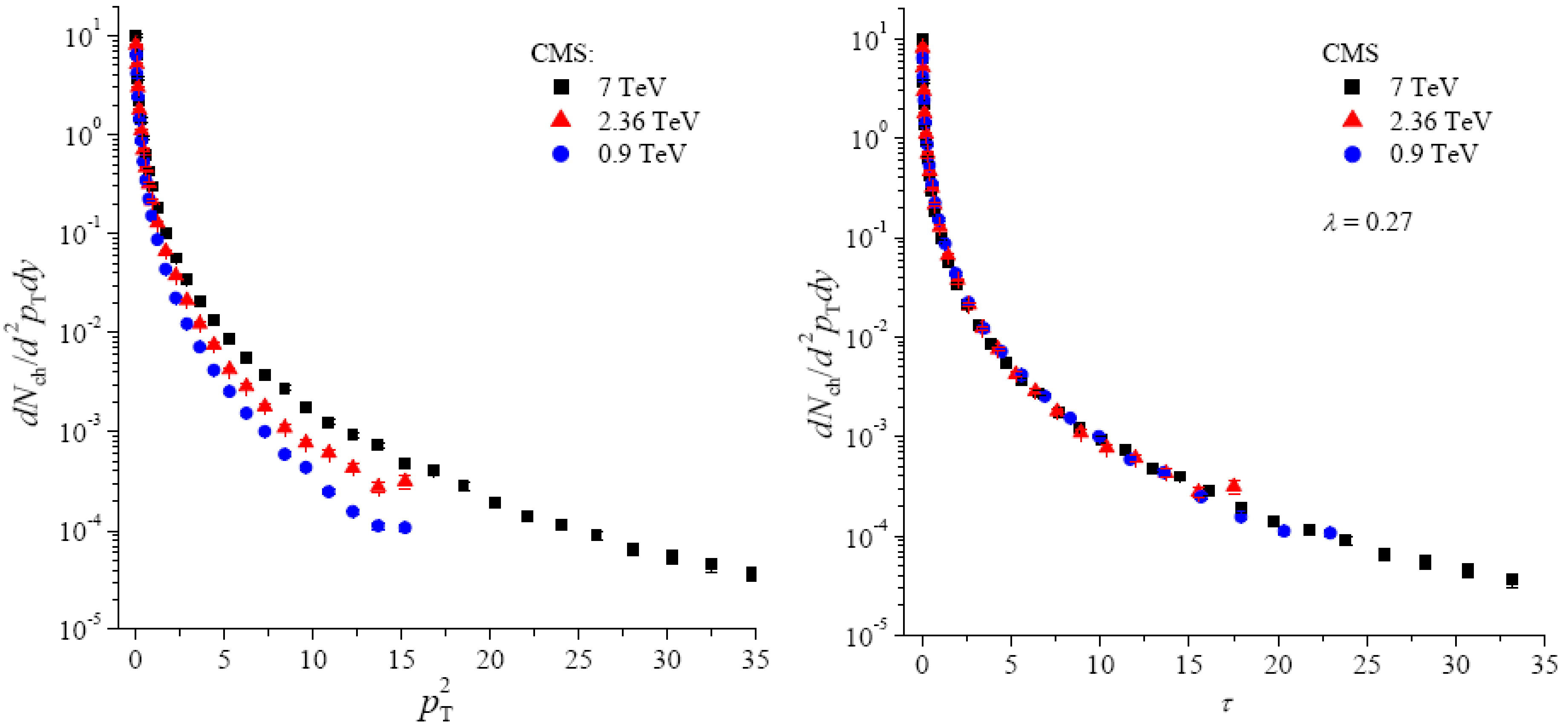


Geometric scaling of p_T distributions





Geometric scaling of p_T distributions



Geometric scaling of p_{T} distributions

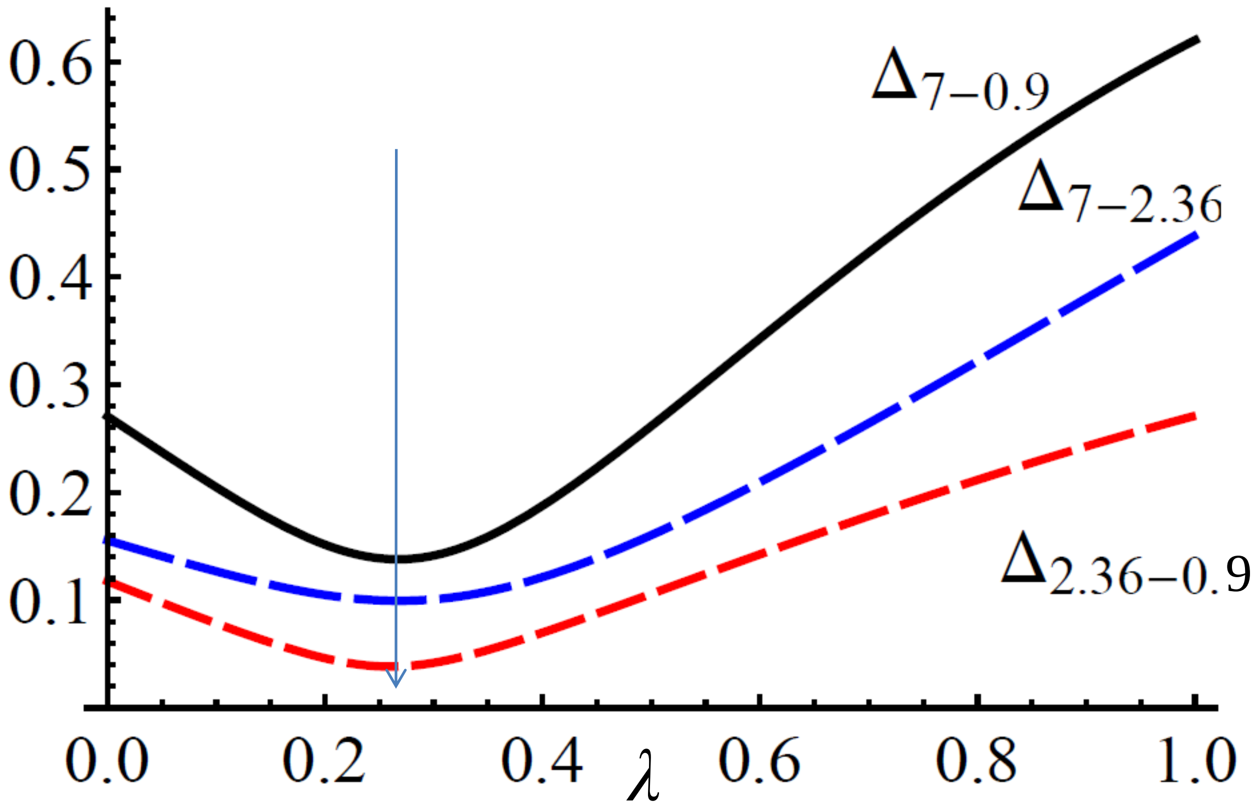
sensitivity to power λ

$$Q^2_{\mathrm{sat}}(x) = Q_0^2 \left(\frac{1}{x_0} \frac{p_{\mathrm{T}}}{\sqrt{s}} \right)^{-\lambda}$$

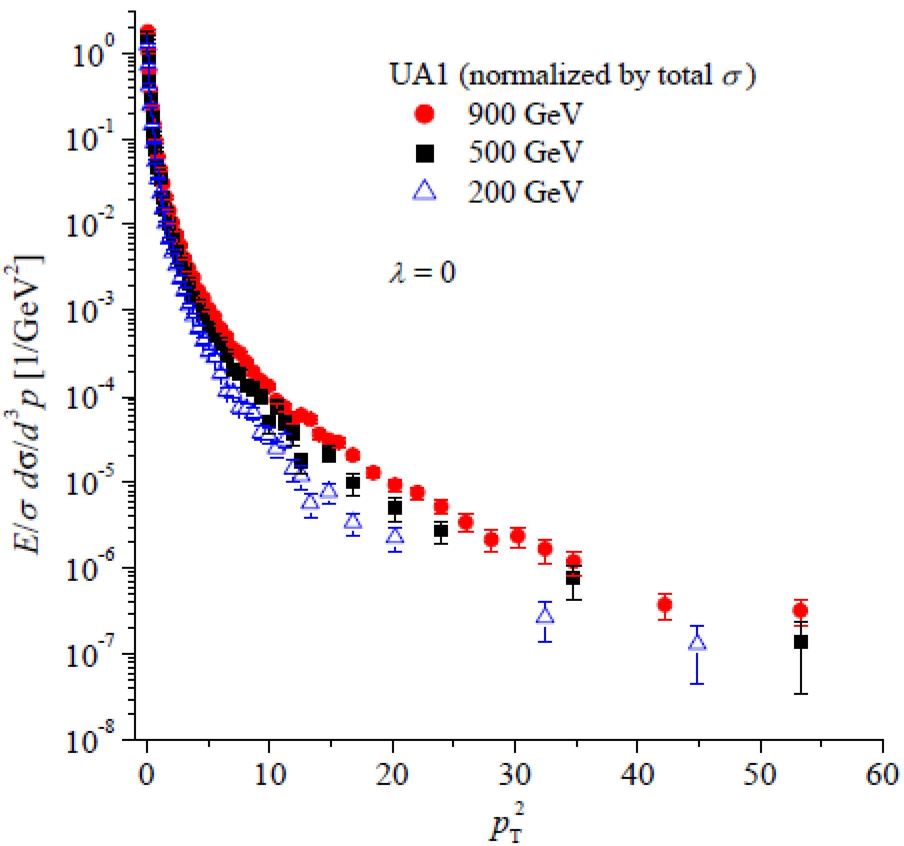
$$\sigma^2_{E_1-E_2} = \int_0^{\tau_{\max}} \left(\left.\frac{dN_{\mathrm{ch}}}{d\eta d\tau}\right|_{E_1} - \left.\frac{dN_{\mathrm{ch}}}{d\eta d\tau}\right|_{E_2} \right)^2 d\tau$$

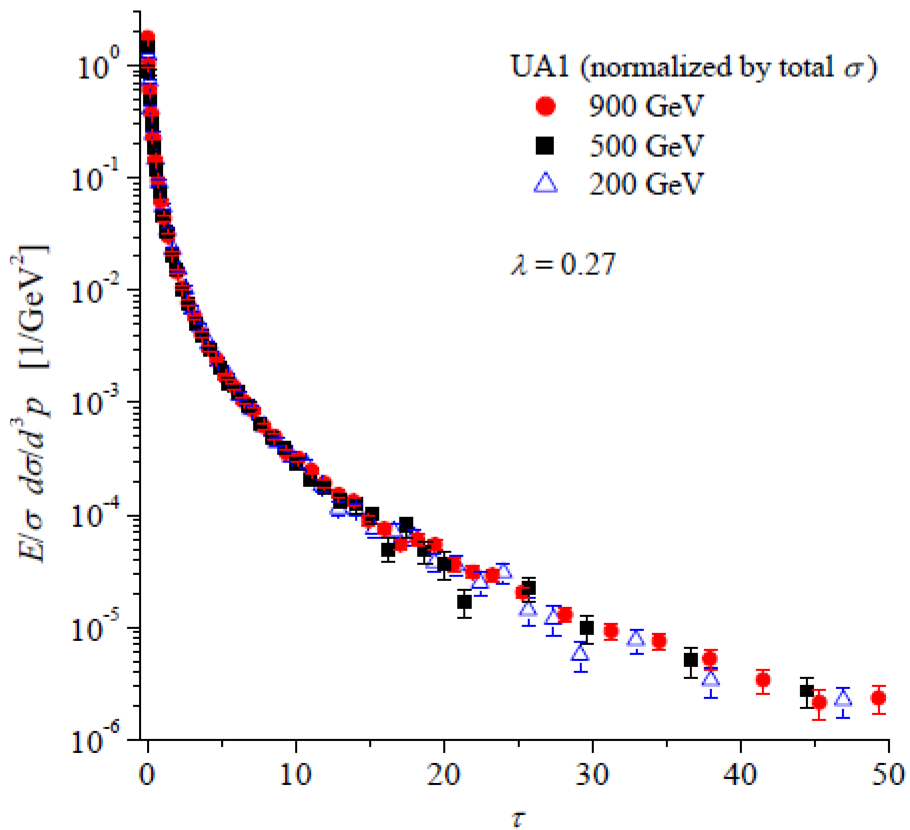
Geometric scaling of p_T distributions

sensitivity to λ



Geometric scaling of p_T distributions at SPS energies





Geometrical scaling of p_{T} distributions

$$\frac{dN_{\mathrm{ch}}}{dy\,dp_{\mathrm{T}}^{2}} = \frac{1}{Q_0^2} F(\tau) \quad \Rightarrow \quad \frac{dN_{\mathrm{ch}}}{dy} = \int \frac{dp_{\mathrm{T}}^{2}}{Q_0^2} F(\tau)$$

$$\tau = \frac{p_{\mathrm{T}}^{2}}{Q_0^2} \left(\frac{p_{\mathrm{T}}}{W}\right)^{\lambda/2}$$

$$W \sim \sqrt{s}$$

Geometrical scaling of p_{T} distributions

$$\frac{dN_{\mathrm{ch}}}{dy\,dp_{\mathrm{T}}^2} = \frac{1}{Q_0^2}F(\tau)$$

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$$\tau = \frac{p_{\mathrm{T}}^2}{Q_0^2}\left(\frac{p_{\mathrm{T}}}{W}\right)^{\lambda/2}$$

$$W \sim \sqrt{s}$$

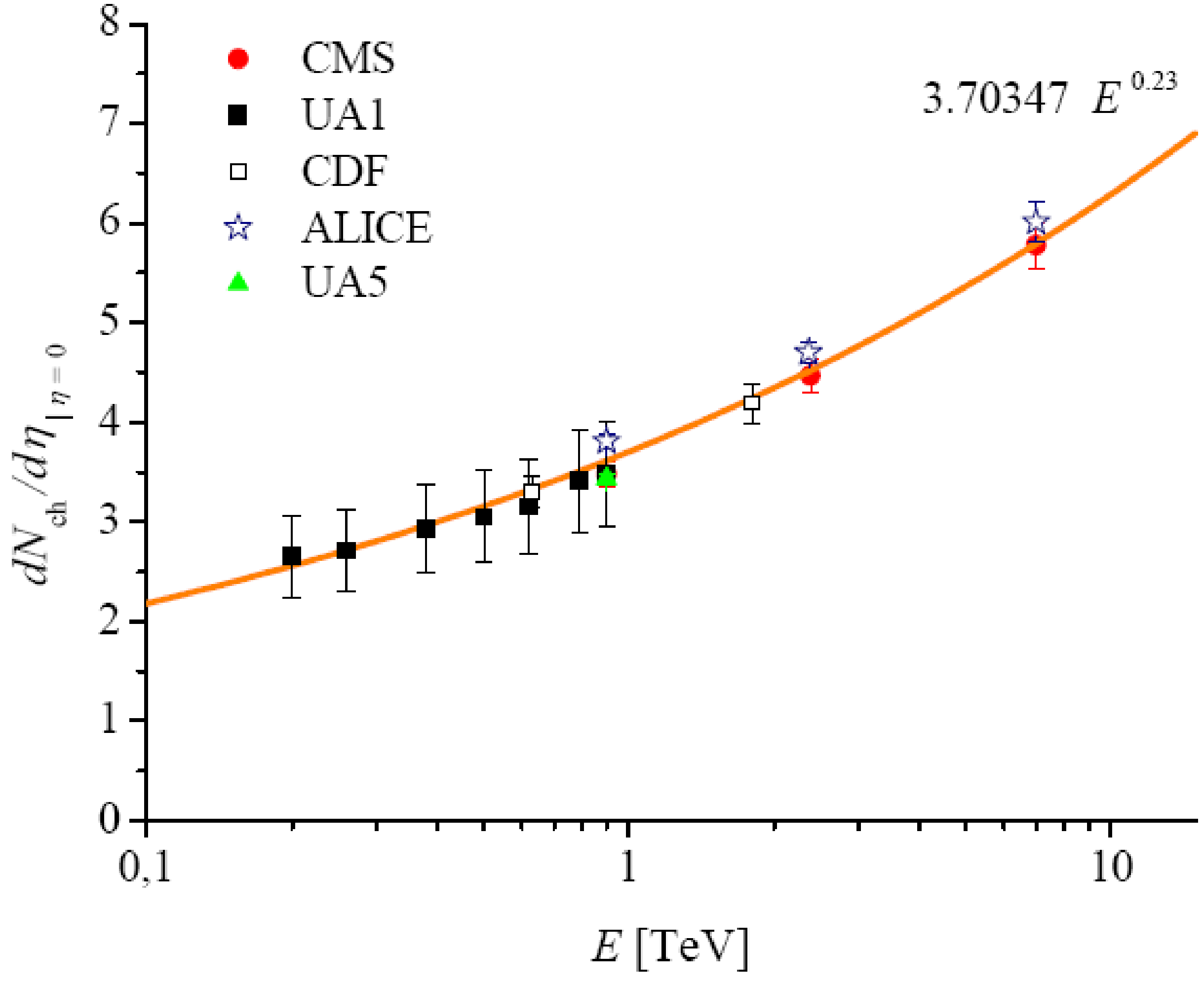
integral over $d\tau$ is energy independent

$$\frac{dp_{\mathrm{T}}^2}{Q_0^2} = \frac{2}{2+\lambda}\left(\frac{W}{Q_0}\right)^{\frac{2\lambda}{2+\lambda}} \tau^{-\frac{\lambda}{2+\lambda}}\,d\tau$$

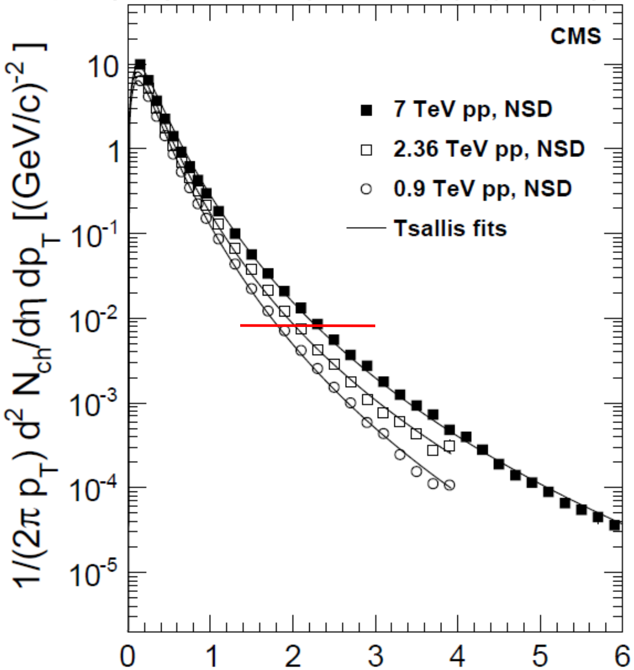
effective growth of multiplicity is slower than λ

$$\boxed{\lambda_{\mathrm{eff}} = \frac{2\lambda}{2+\lambda} < \lambda}$$

Multiplicity from GS



Geometrical scaling of p_T distributions

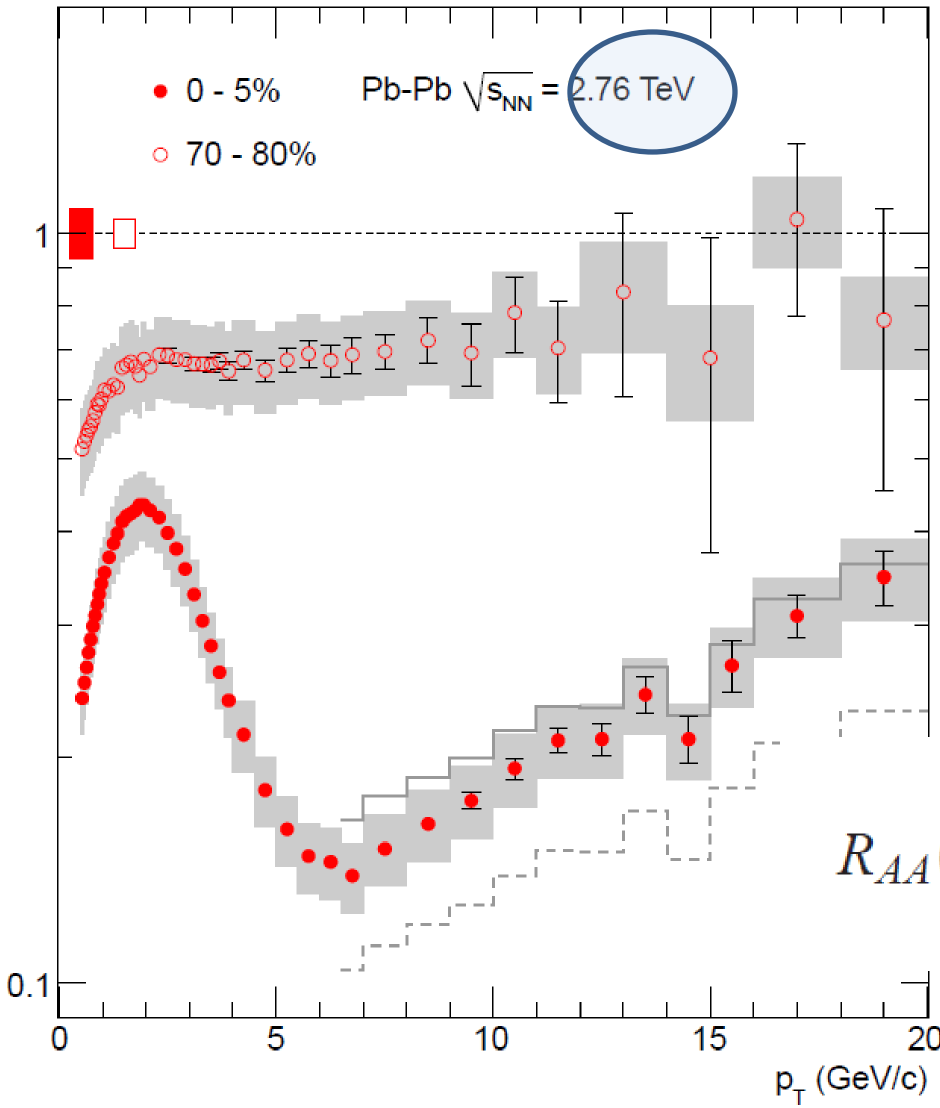


Predicting multiplicity distributions for other energies: 2.76, 10, 14 etc. TeV

$$\frac{dN_{ch}}{d\eta d^2 p_{\mathrm{T}}}(p_T(W_2), W_2) = \frac{dN_{ch}}{d\eta d^2 p_{\mathrm{T}}}(p_T(W_1), W_1)$$

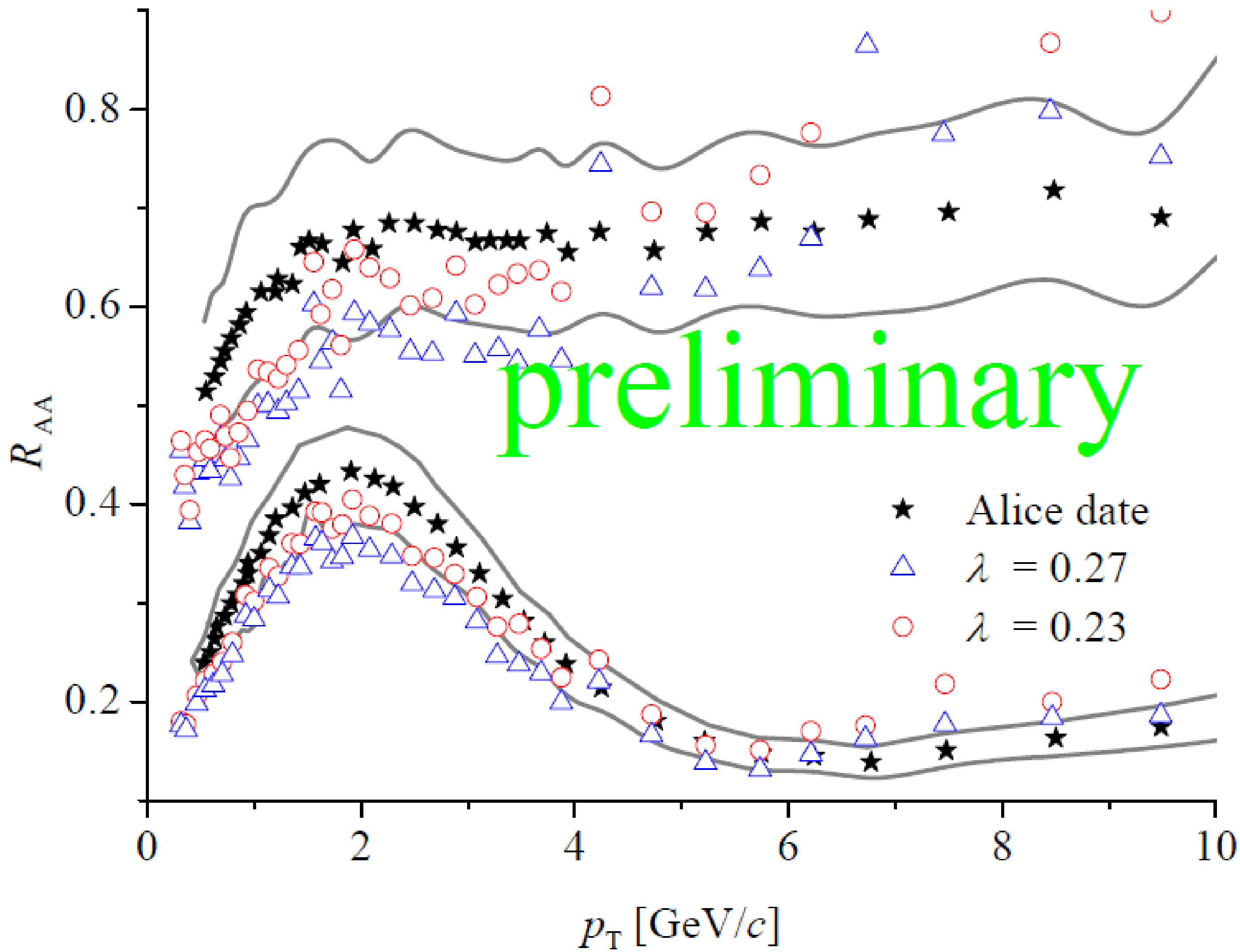
$$p_{\mathrm{T}}(W_2) = p_{\mathrm{T}}(W_1)\left(\frac{W_2}{W_1}\right)^{\lambda/(\lambda+2)}$$

Nuclear modification factor



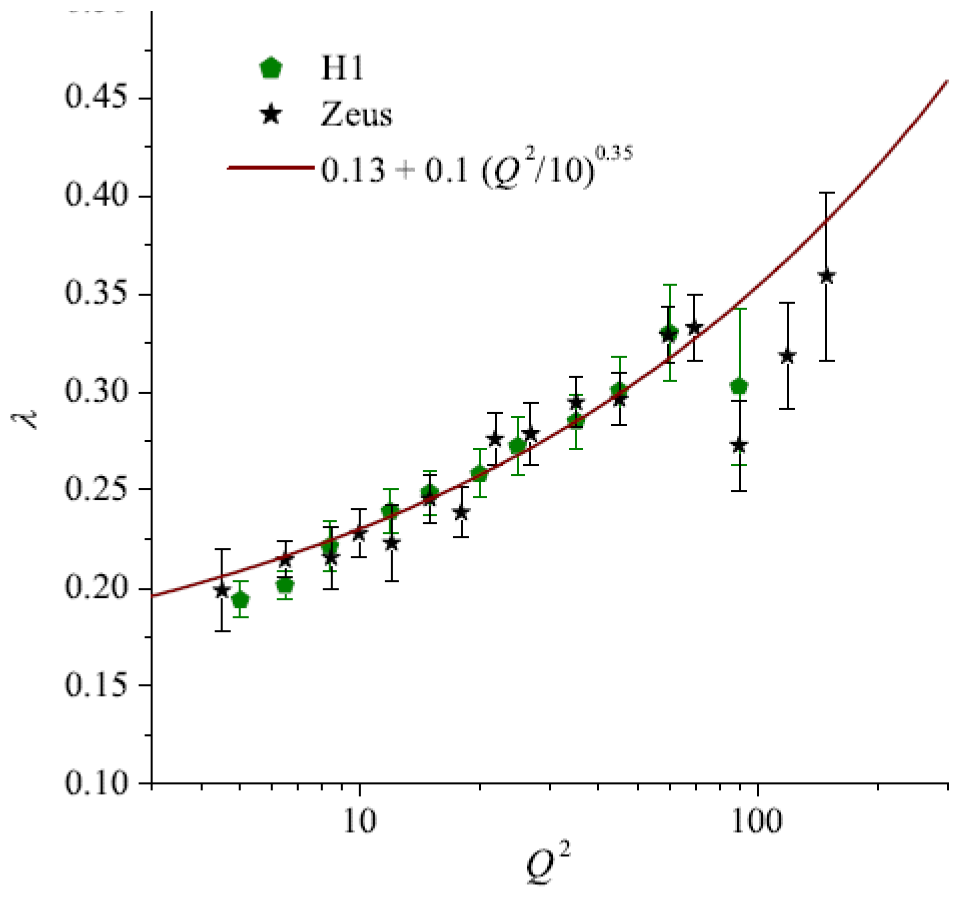
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{\mathrm{ch}}^{AA}/d\eta\, dp_T}{\langle N_{\mathrm{coll}}\rangle\, (1/N_{evt}^{pp})\, d^2N_{\mathrm{ch}}^{pp}/d\eta\, dp_T}$$

Nuclear modification factor



Geometrical Scaling with $\lambda(Q^2)$

$$F_2(x, Q^2) \sim \sigma_0 Q^2_{\rm sat} \sim \frac{1}{x^{\lambda(Q^2)}}$$



H. Kowalski, L.N. Lipatov, D.A. Ross, G. Watt, Eur.Phys.J.C70:983-998,2010.

Geometrical Scaling with $\lambda(Q^2)$

$$p^2_{1\,\mathrm{T}}\left(\frac{p_{1\,\mathrm{T}}}{W_1}\right)^{\lambda(\alpha p^2_{1\,\mathrm{T}})} = p^2_{2\,\mathrm{T}}\left(\frac{p_{2\,\mathrm{T}}}{W_2}\right)^{\lambda(\alpha p^2_{2\,\mathrm{T}})}$$

Geometric Scaling with $\lambda(Q^2)$

$$p_{1\,\mathrm{T}}^2 \left(\frac{p_{1\,\mathrm{T}}}{W_1}\right)^{\lambda(\alpha p_{1\,\mathrm{T}}^2)} = p_{2\,\mathrm{T}}^2 \left(\frac{p_{2\,\mathrm{T}}}{W_2}\right)^{\lambda(\alpha p_{2\,\mathrm{T}}^2)}$$

for slowly varying λ we can solve above eq. bin by bin

Geometric Scaling with $\lambda(Q^2)$

$$p_{\mathrm{T}}(W_2) \;\; = \;\; p_{\mathrm{T}}(W_1)\left(\frac{W_2}{W_1}\right)^{\lambda/(\lambda+2)}$$

for slowly varying λ we can solve above eq. bin by bin

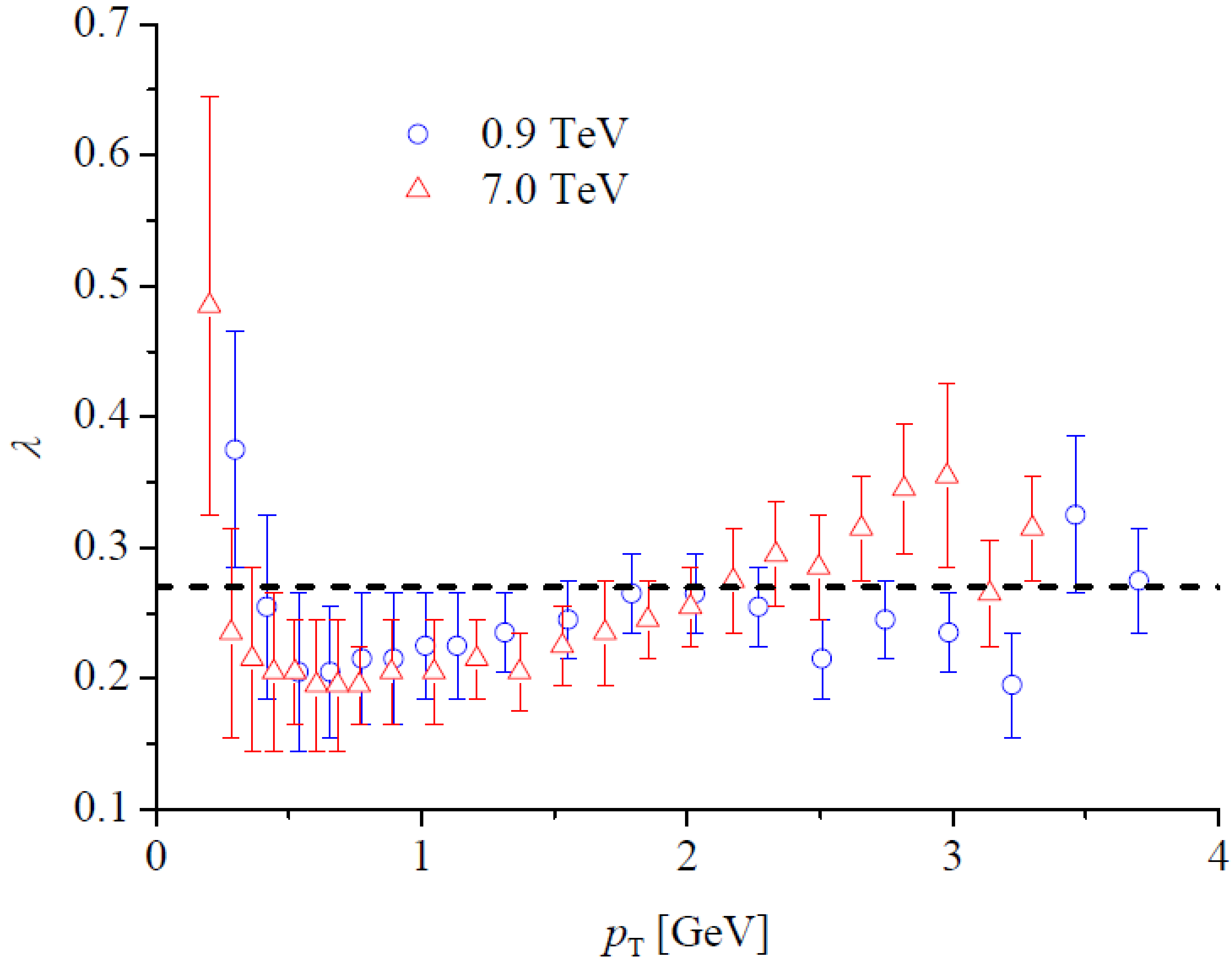
Geometric Scaling with $\lambda(Q^2)$

$$p_{\mathrm{T}}(W_2) \;=\; p_{\mathrm{T}}(W_1)\left(\frac{W_2}{W_1}\right)^{\lambda/(\lambda+2)}$$

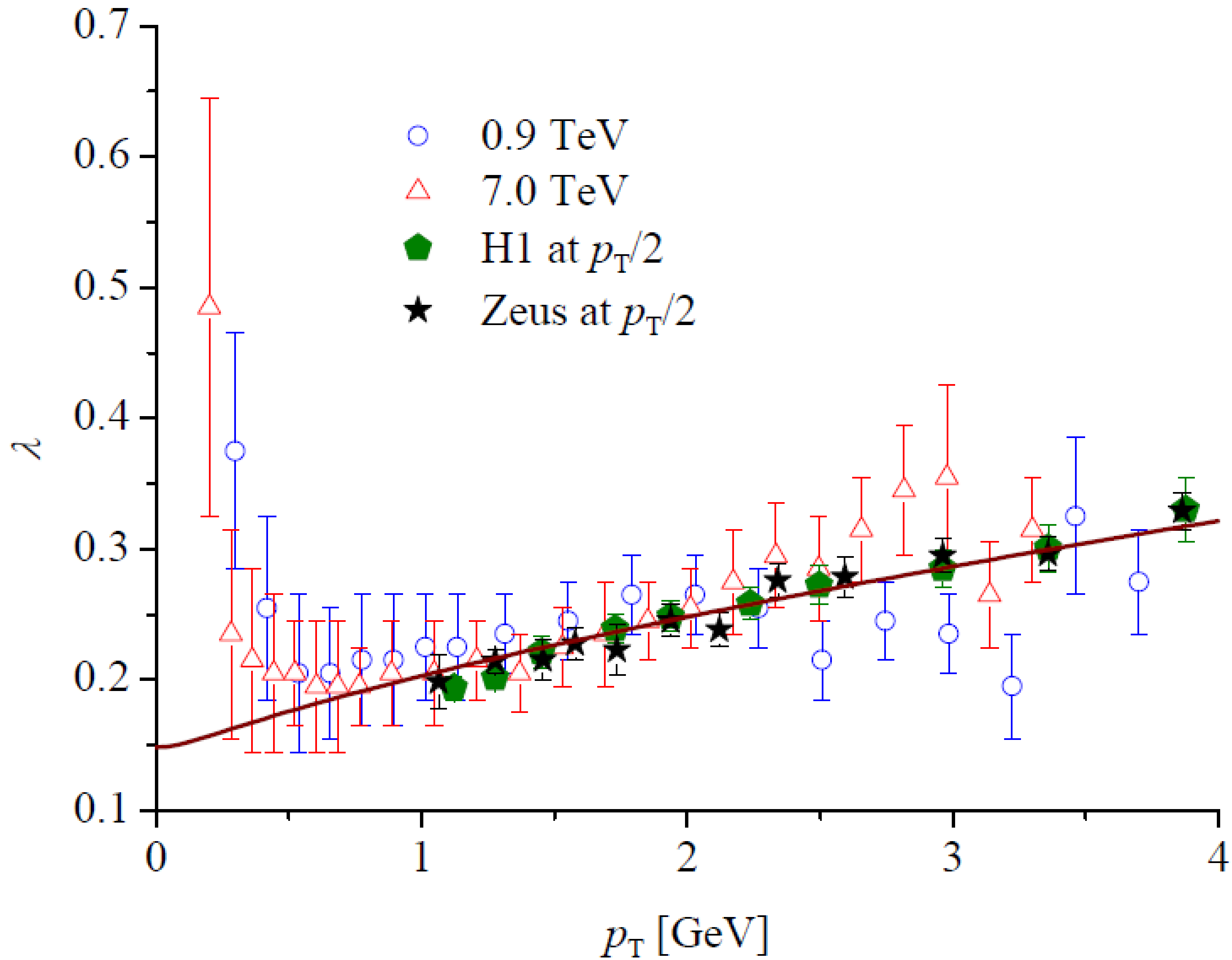
for slowly varying λ we can solve above eq. bin by bin

Take multiplicity distributon at 2.36 TeV as a reference

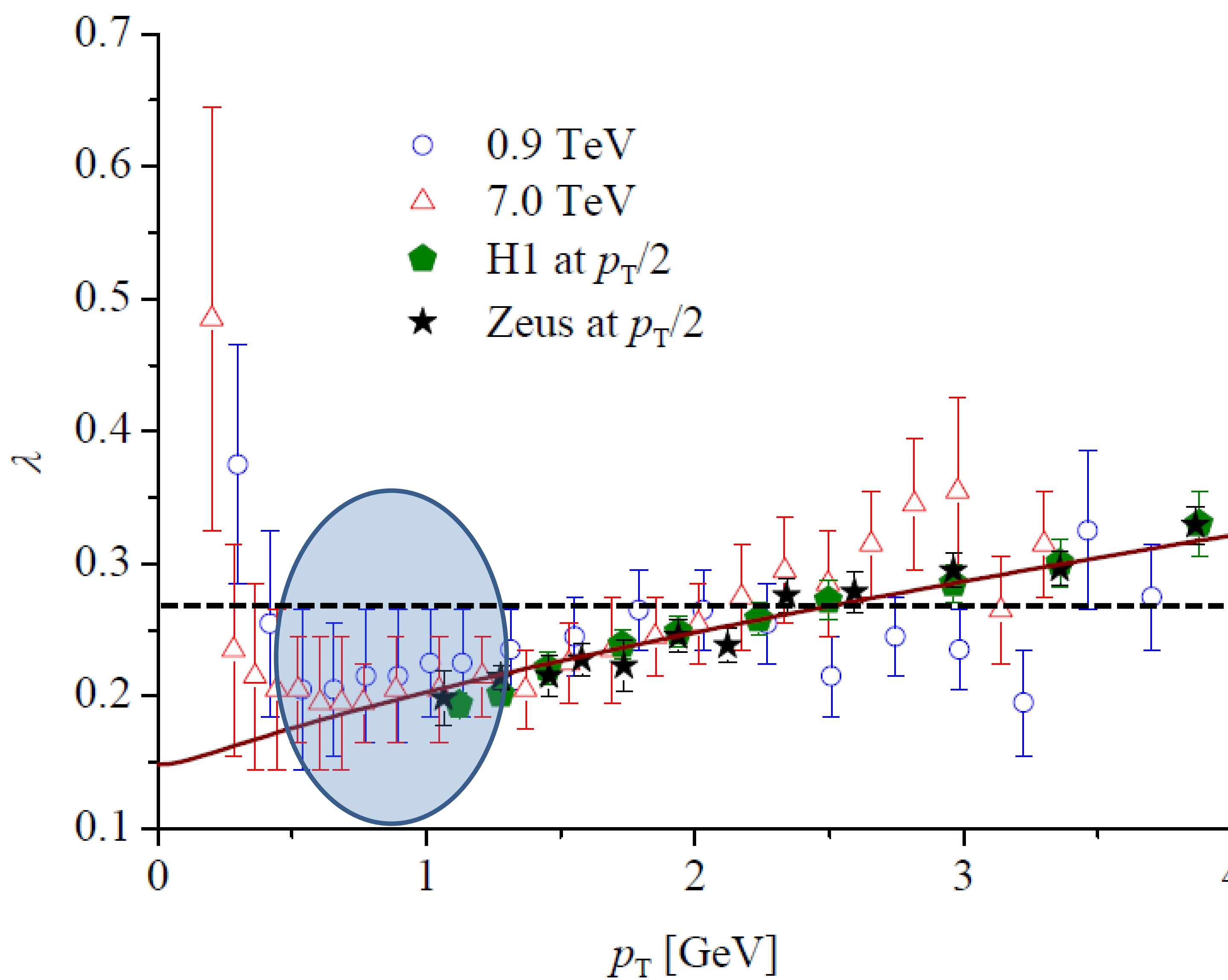
0.9 TeV $\Longrightarrow$ 2.36 TeV $\Longleftarrow$ 7 TeV



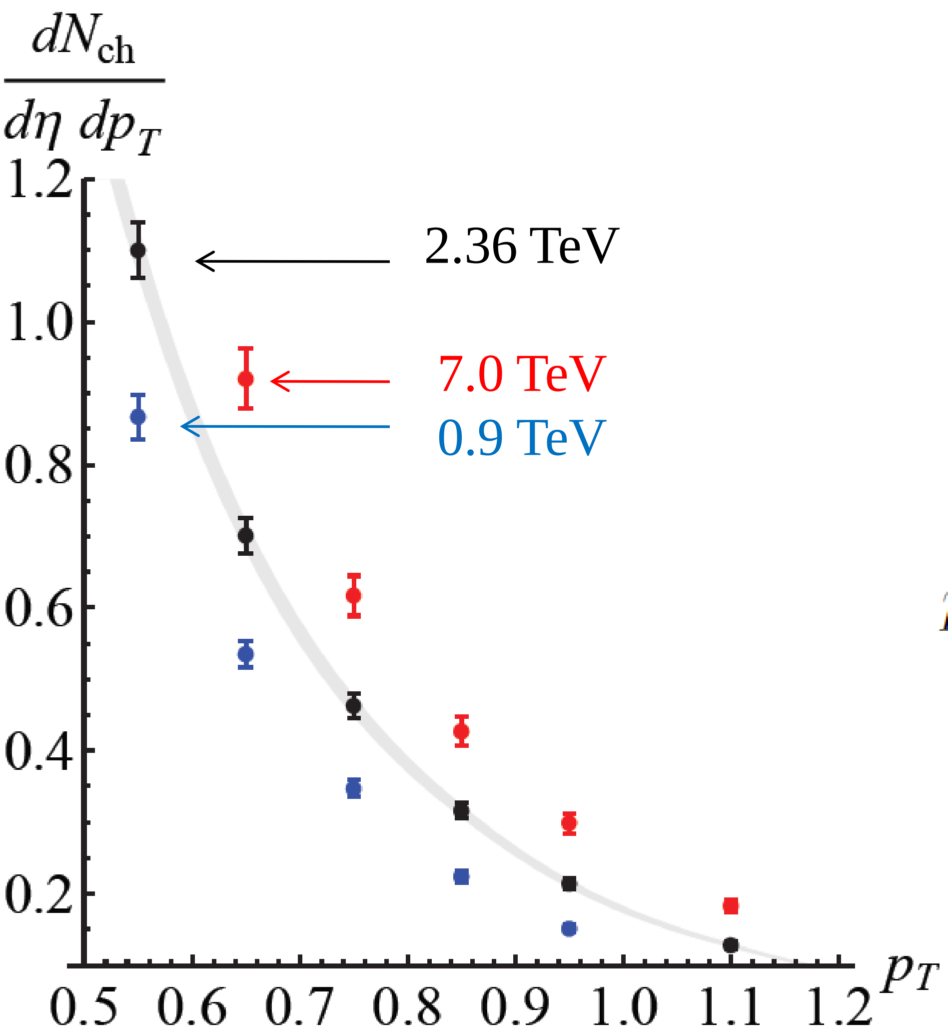
0.9 TeV
7.0 TeV
λ
p_T [GeV]
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4



0.9 TeV
7.0 TeV
H1 at $p_T/2$
Zeus at $p_T/2$
λ
p_T [GeV]
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4



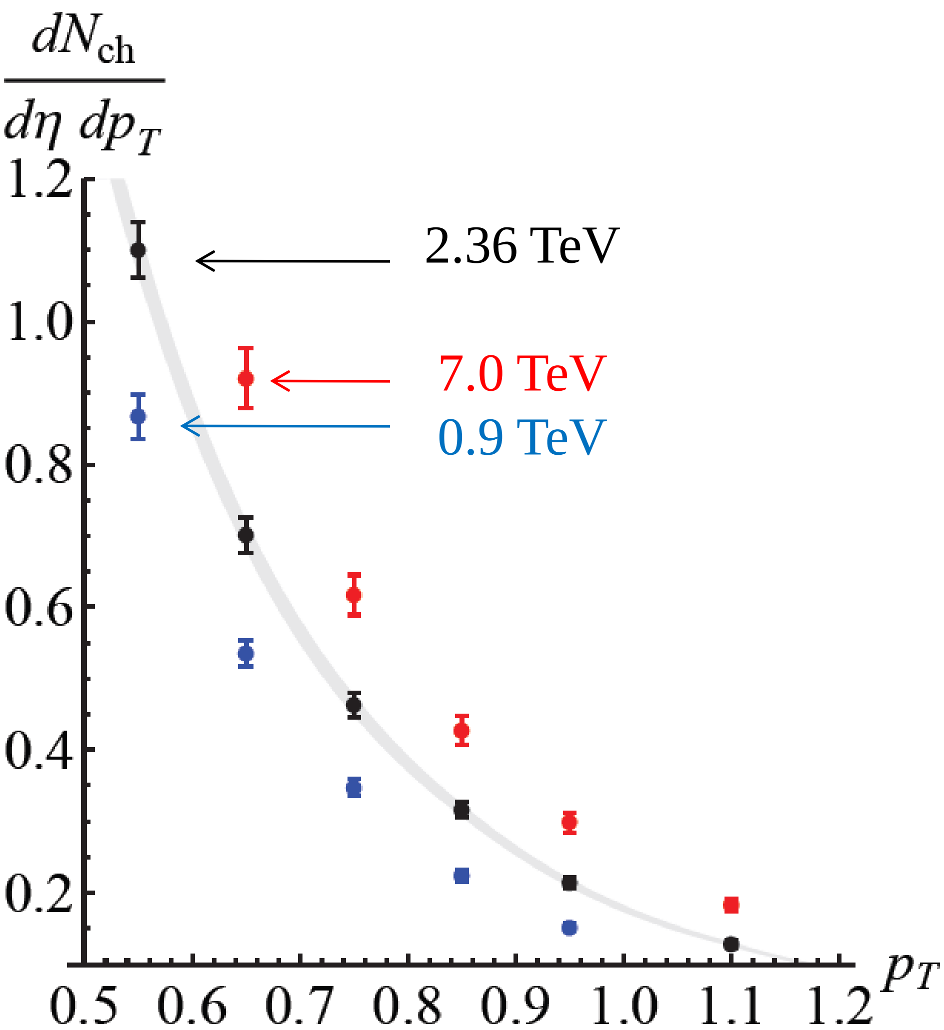
0.9 TeV
7.0 TeV
H1 at $p_T/2$
Zeus at $p_T/2$
λ
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4
p_T [GeV]



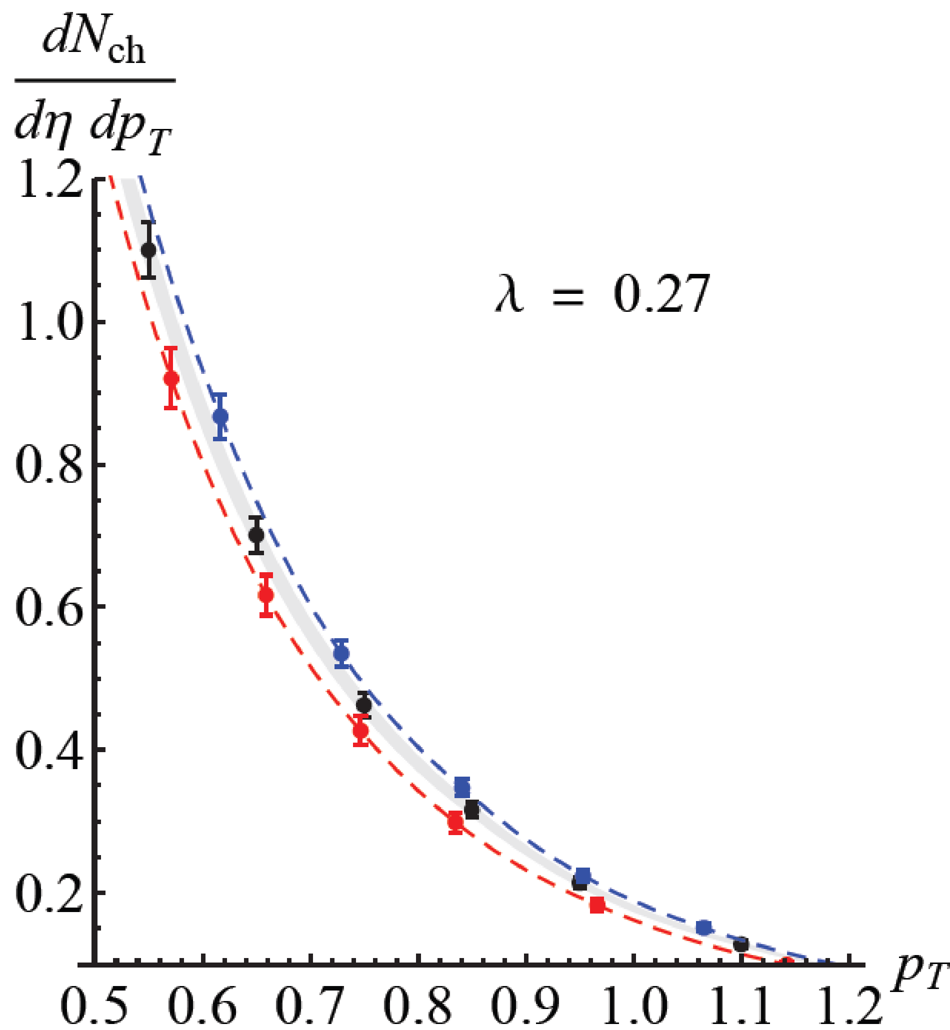
$$p_{\mathrm{T}}(W_2) = p_{\mathrm{T}}(W_1)\left(\frac{W_2}{W_1}\right)^{\lambda/(\lambda+2)}$$

CMS data

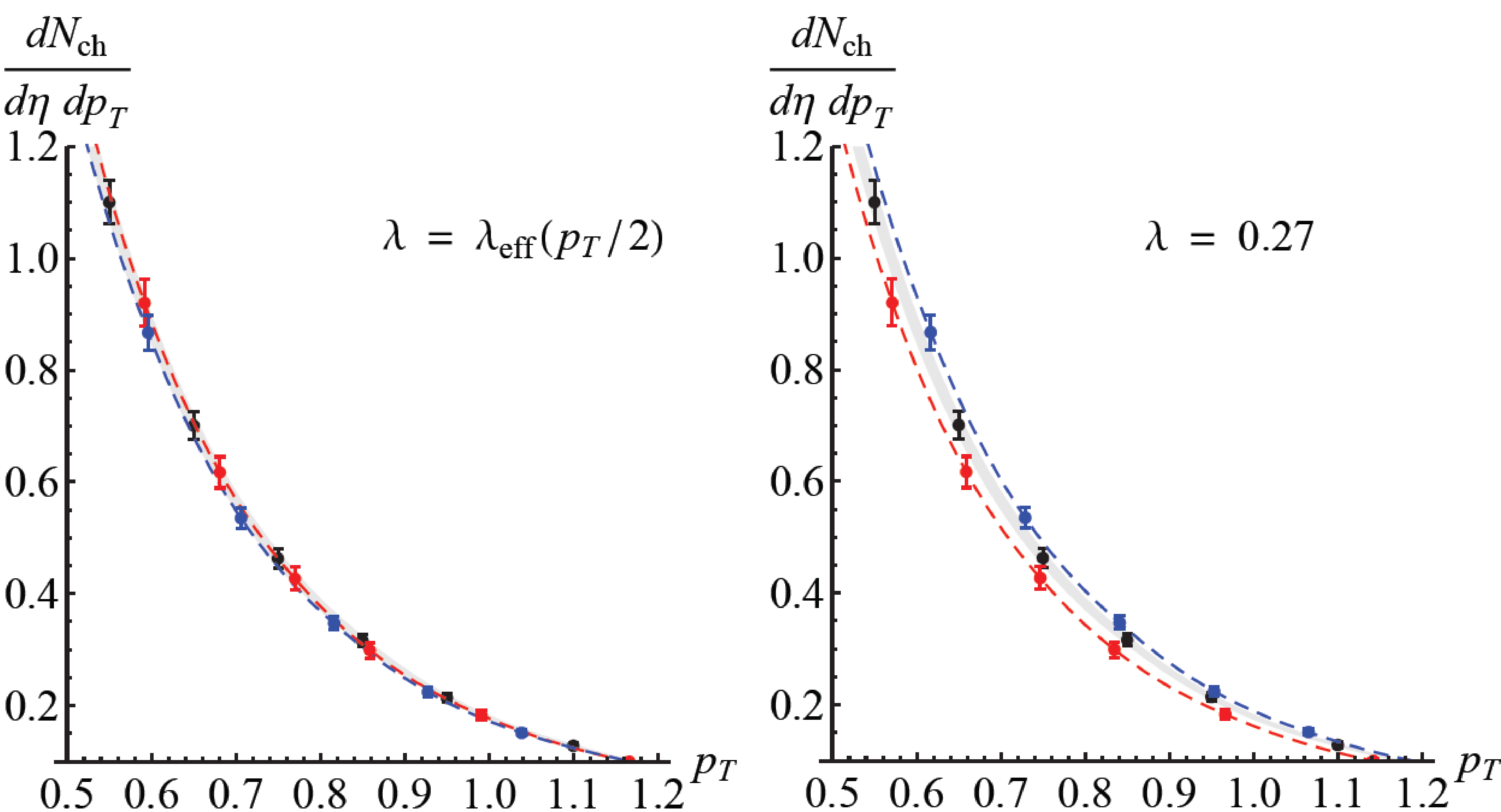
CMS data at 2.36 TeV and rescaled data at 0.9 and 7 TeV



CMS data



CMS data at 2.36 TeV and
rescaled data at 0.9 and 7 TeV



$\frac{dN_{ch}}{d\eta\, dp_T}$
$\lambda = \lambda_{eff}(p_T/2)$
$\lambda = 0.27$
1.2
1.0
0.8
0.6
0.4
0.2
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
p_T

Summary

1. Geometrical scaling in variable $\tau = \frac{p_{\mathrm{T}}^2}{Q_0^2}\left(\frac{p_{\mathrm{T}}^2}{W^2}\right)^{\lambda/2}$
   works very well
   for CMS and also UA1 p_{T} spectra with $\lambda = 0.27$
2. As a consequence $$dN_{\mathrm{ch}}/dy \sim W^{\lambda} \langle p_{\mathrm{T}} \rangle \sim W^{\lambda_{\mathrm{eff}}/2}$$
   where $$\lambda_{\mathrm{eff}} = \frac{2\lambda}{2+\lambda} < \lambda.$$
3. p_{T} dependent λ improves GS
4. $\lambda(p_{\mathrm{T}}) = \lambda_{\mathrm{DIS}}(p_{\mathrm{T}}/2)$

Summary

1. Geometrical scaling in variable $\tau = \frac{p_{\mathrm{T}}^2}{Q_0^2}\left(\frac{p_{\mathrm{T}}^2}{W^2}\right)^{\lambda/2}$ works very well for CMS and also UA1 p_{T} spectra with $\lambda = 0.27$
2. As a consequence $dN_{\mathrm{ch}}/dy \sim W^{\lambda} \; \langle p_{\mathrm{T}} \rangle \sim W^{\lambda_{\mathrm{eff}}/2}$ where
$$\lambda_{\mathrm{eff}} = \frac{2\lambda}{2+\lambda} < \lambda.$$
3. p_{T} dependent λ improves GS
4. $\lambda(p_{\mathrm{T}}) = \lambda_{\mathrm{DIS}}(p_{\mathrm{T}}/2)$
5. Why it does work?