Geometrical scaling in high energy collisons and its breaking

Michał Praszałowicz
Jagellonian University
Kraków, Poland

„Geometrical Scaling”

J. Dias de Deus, Nucl. Phys. B 59 (1973) 231;
A.J. Buras, J. Dias de Deus, Nucl.Phys. B 71 (1974) 481;
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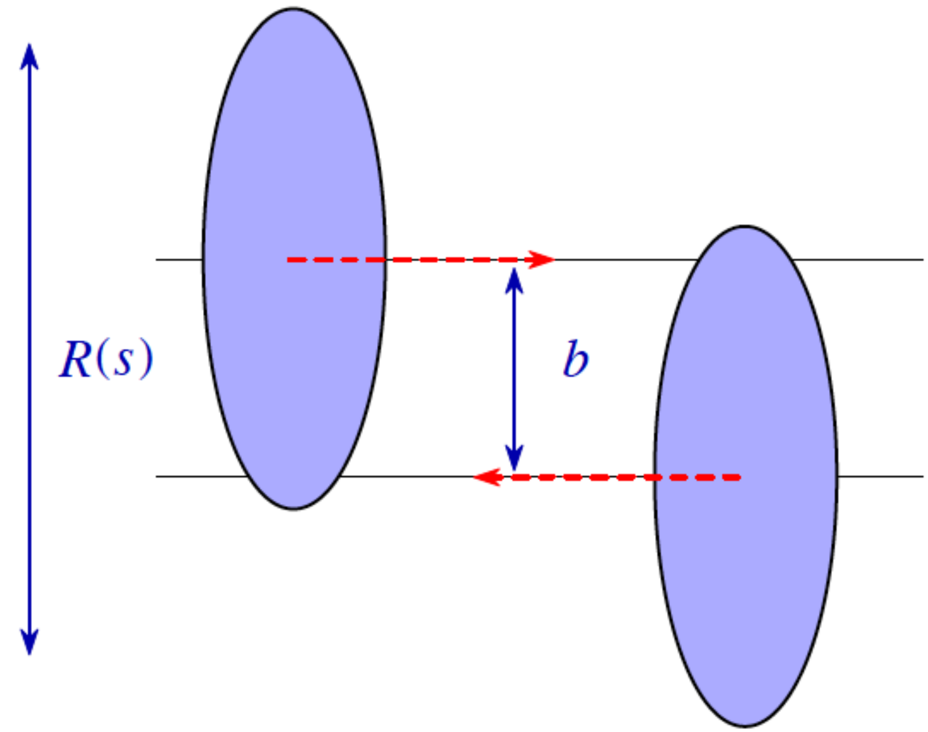
J. Dias de Deus, Acta Phys. Polon. B 6 (1975) 613.

$$A(b,s) = A(b/R(s))$$



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Geometric scaling for the total γ^* p *cross-section in the low* x *region.*
A.M. Stasto, K. J. Golec-Biernat , J. Kwiecinski PRL 86 (2001) 596-599
M. P. and T. Stebel JHEP (2013) 1303 090, 1304 169

$$\sigma_{\gamma^* p} \sim \frac{F_2(x, Q^2)}{Q^2} = \sigma_0 \mathcal{F}\left(\frac{Q^2}{Q^2_{\mathrm{sat}}(x)}\right)$$

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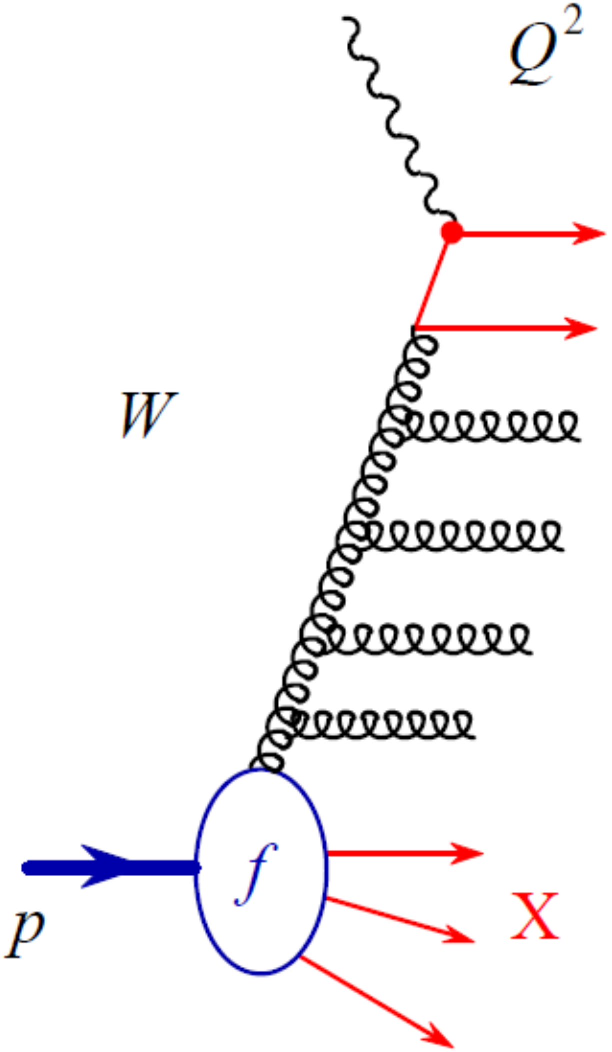
L. McLerran, M. P. Acta Phys.Polon.B41:1917,2010, B42:99,2011
M. P. Phys.Rev.Lett.106:142002,2011, Acta Phys.Pol. B42 (2011) 1557-1566
Phys.Rev. D87 (2013) 071502(R)
L. McLerran, M.P. and B. Schenke, arXiv:1306.2350 [hep-ph] (Nucl. Phys. A)

$$\frac{dN_{\rm ch}}{d\eta dp_{\rm T}^2}(s,p_{\rm T}) = \frac{1}{Q_0^2}\mathcal{F}\left(\frac{p_{\rm T}^2}{Q_{\rm sat}^2(s)}\right)$$

Geometrical scaling in DIS at low *x*



$$dP \sim \frac{\alpha_s C_R}{\pi^2} \frac{d^2 k_T}{k_T^2} \frac{d\xi}{\xi}$$

Resumations:

$$\int \frac{d^2 k_T}{k_T^2} \quad \rightarrow \quad \ln Q^2$$

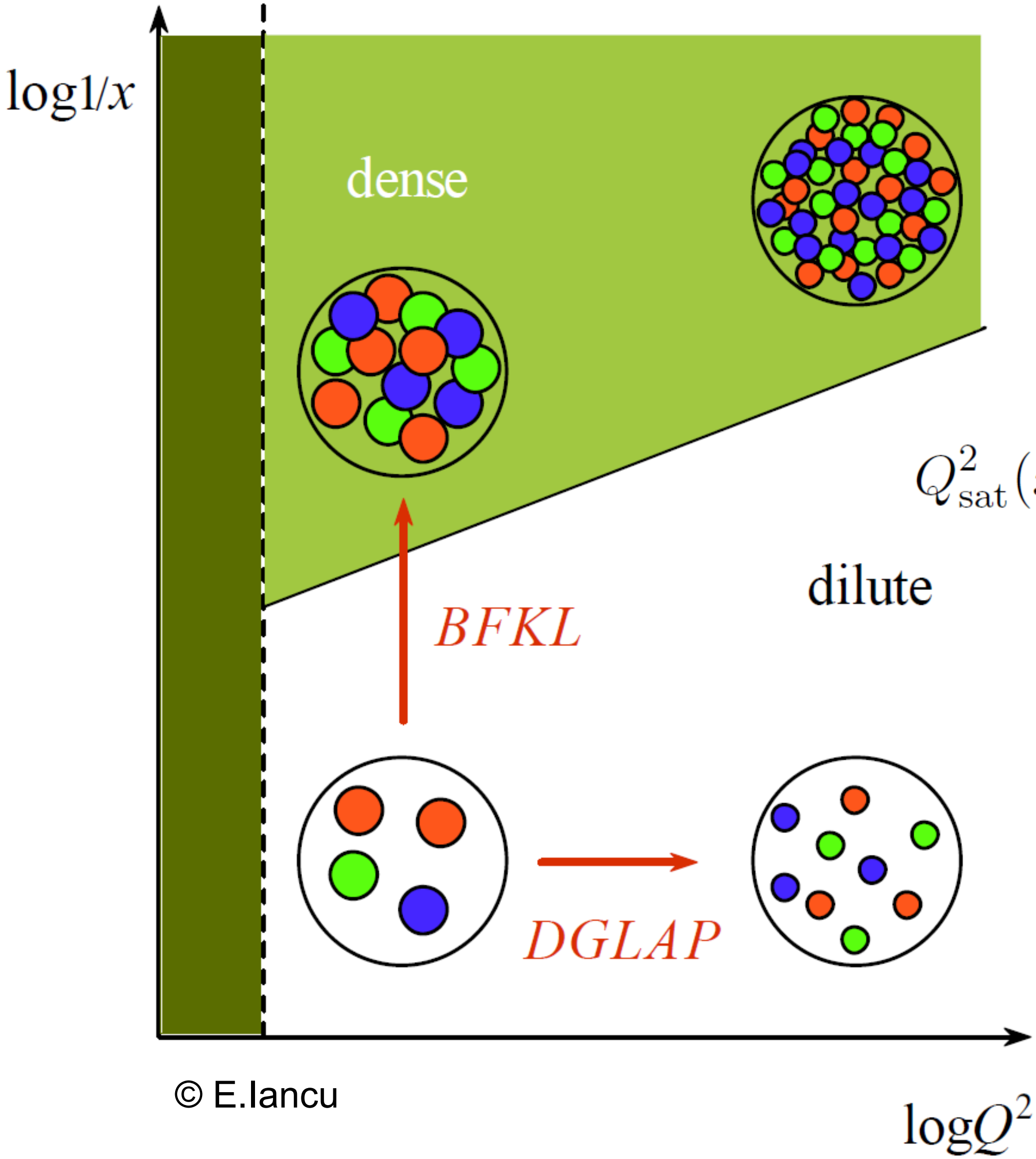
$$\sum \alpha_S^n \ln^n Q^2 \quad \rightarrow \quad \text{DGLAP}$$

$$\int \frac{d\xi}{\xi} \quad \rightarrow \quad \ln W$$

$$\sum \alpha_S^n \ln^n W \quad \rightarrow \quad \text{BFKL}$$

Saturation

small x
large W



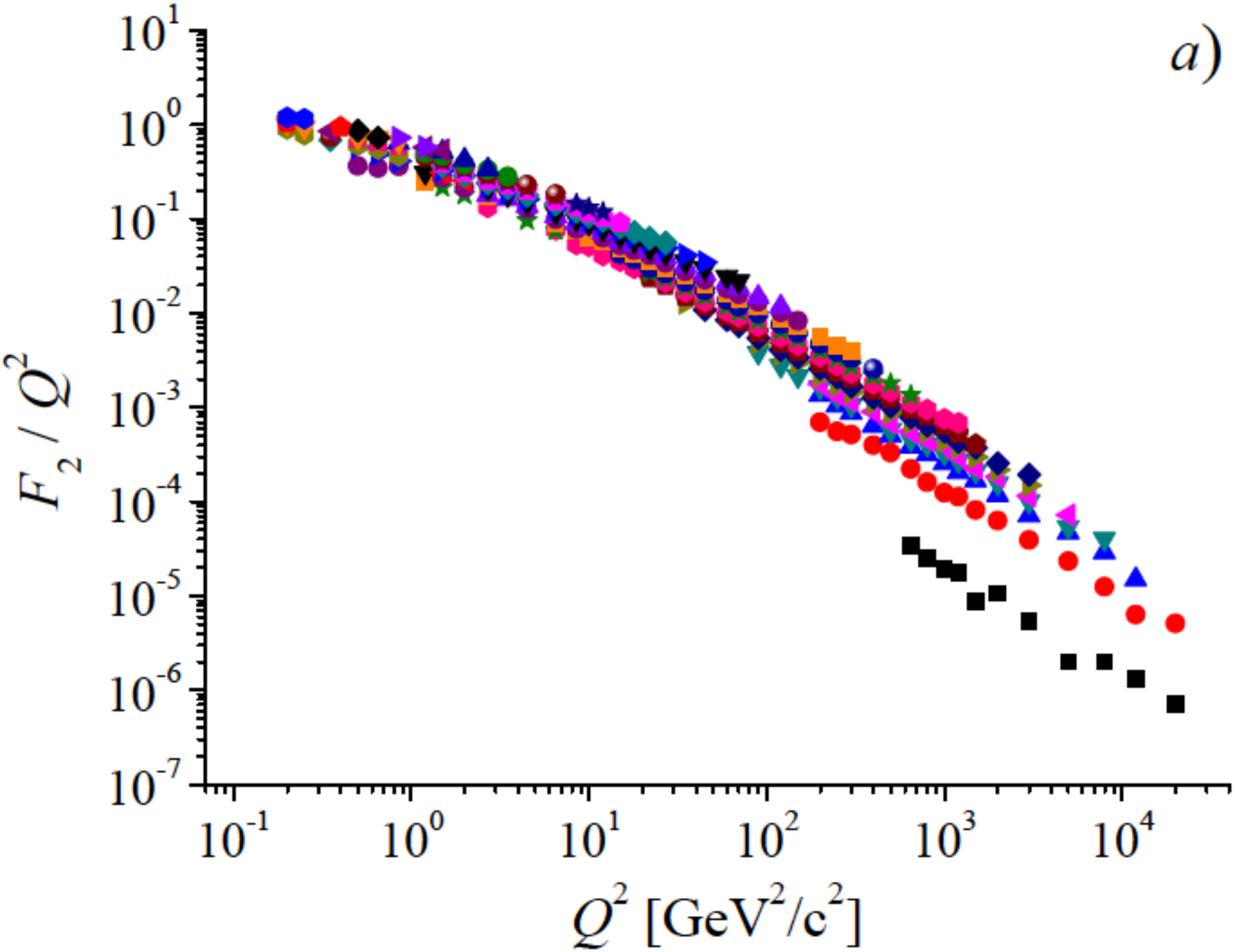
$$Q^2_{\rm sat}(x) = Q_0^2 \left(\frac{x}{x_0}\right)^{-\lambda}$$

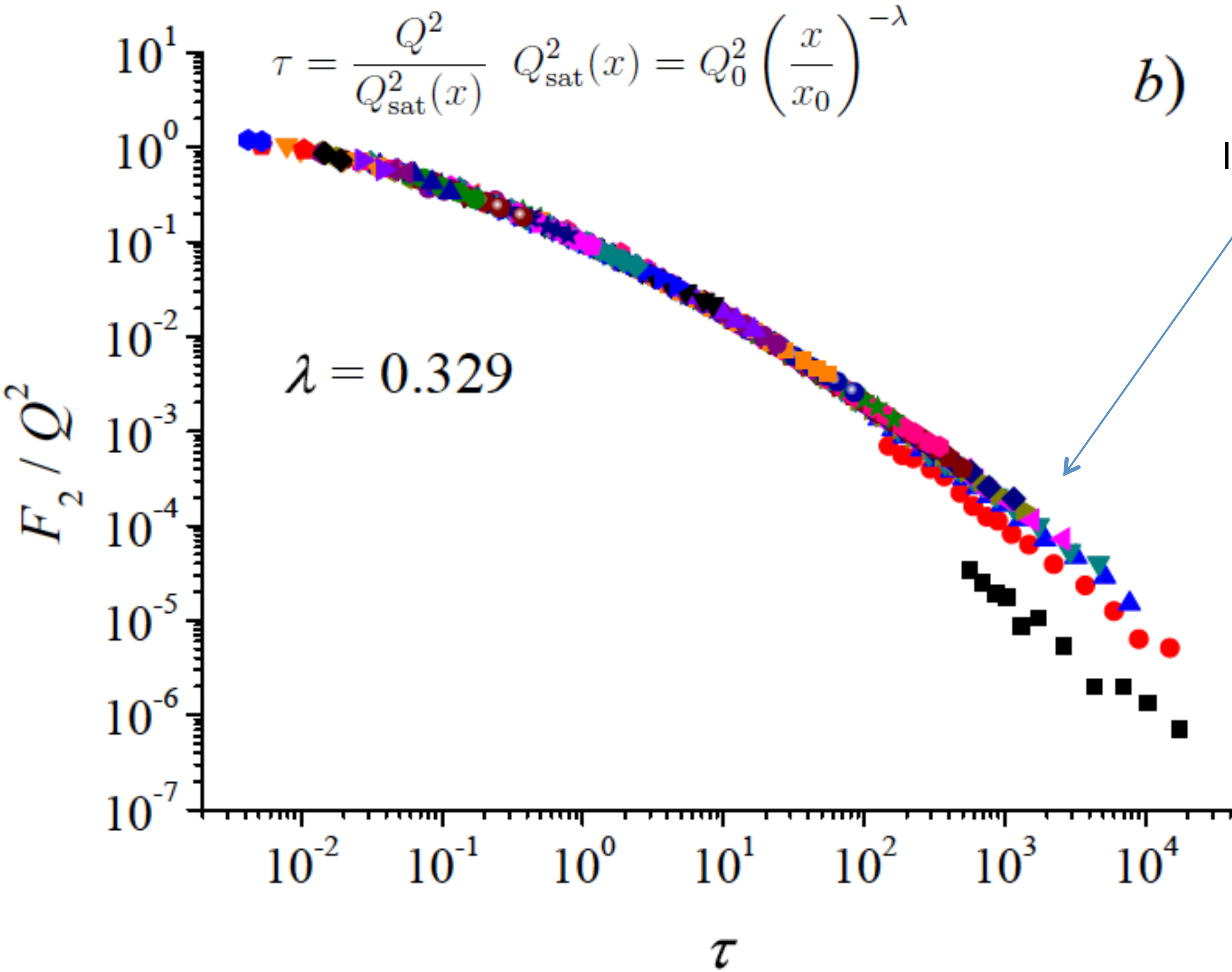
large x
small W

Geometrical Scaling in DIS

$$\sigma_{\gamma^* p}(x, Q^2) = \sigma_{\gamma^* p}\left(\frac{Q^2}{Q^2_{\mathrm{sat}}(x)}\right)$$

Combined HERA data 2009 for e⁺





$\tau = \frac{Q^2}{Q^2_{\rm sat}(x)}$ $Q^2_{\rm sat}(x) = Q^2_0 \left(\frac{x}{x_0}\right)^{-\lambda}$
b)
large x
$\lambda = 0.329$
F_2 / Q^2
τ
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Domain of GS in DIS

$$\lambda = 0.329 \pm 0.005$$

$$\text{up to } \; x = 0.08 \; (!)$$

Saturated gluonic matter at the LHC

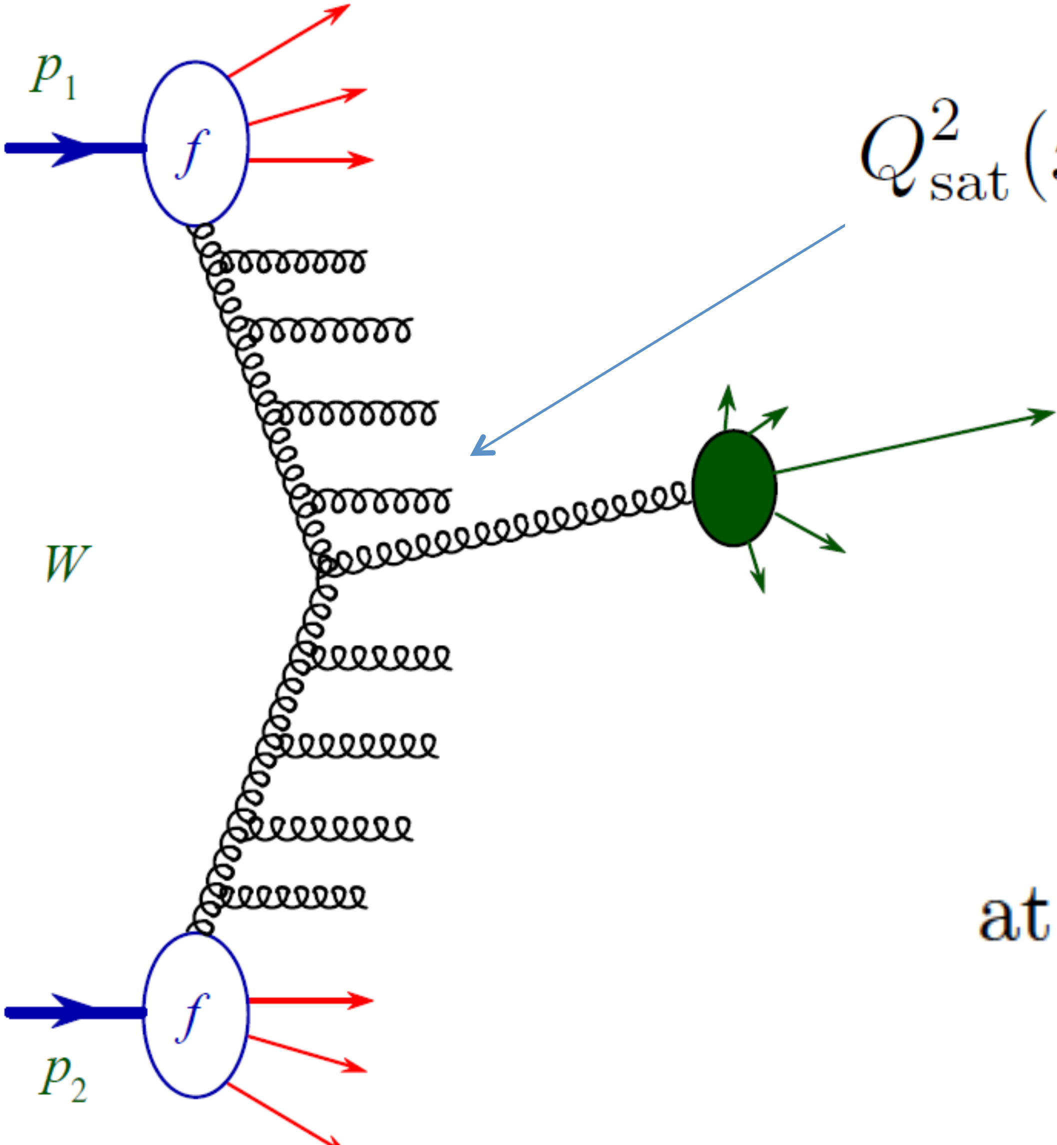
„Old", conventional physics with a new tool:

Saturated gluonic matter at the LHC

„Old”, conventional physics with a new tool:

$$Q^2_{\mathrm{sat}}(x) = Q^2_0 \left(\frac{x}{x_0} \right)^{-\lambda}$$

p-p at the LHC



$$Q^2_{\rm sat}(x) = Q^2_0 \left(\frac{x}{x_0}\right)^{-\lambda}$$

$$x = \frac{p_{\rm T}}{W} e^{\pm y}$$

at the LHC $y \sim 0$

Geometrical scaling of p_T distributions

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

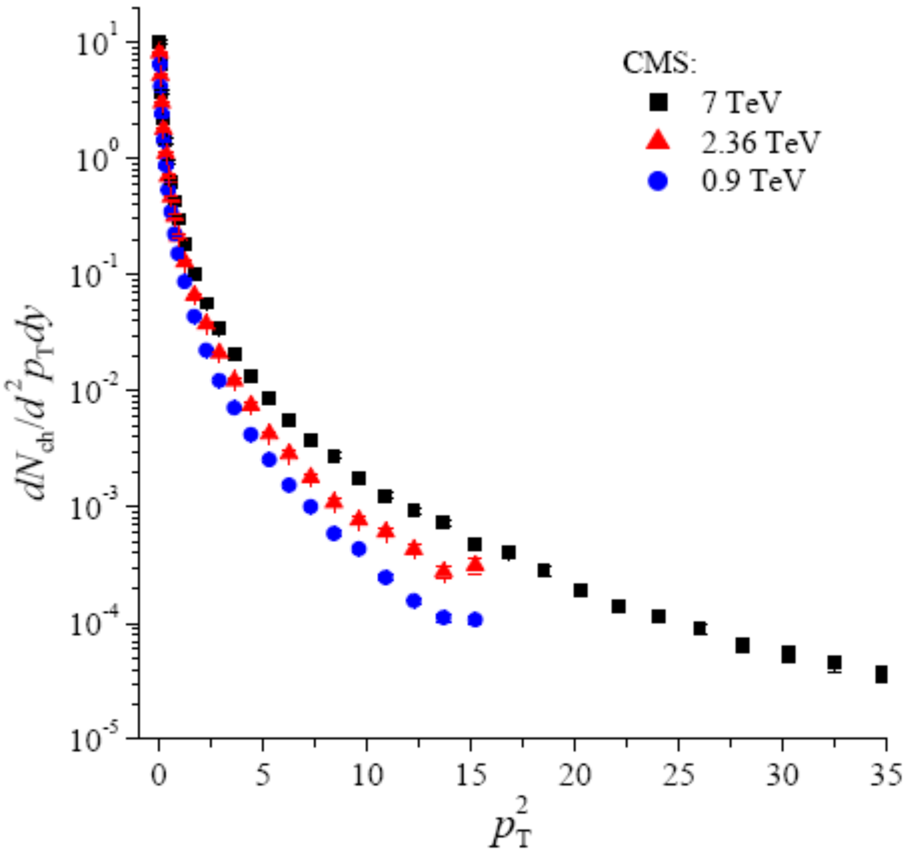
multiplicity distribution is a universal function of scaling variable τ

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

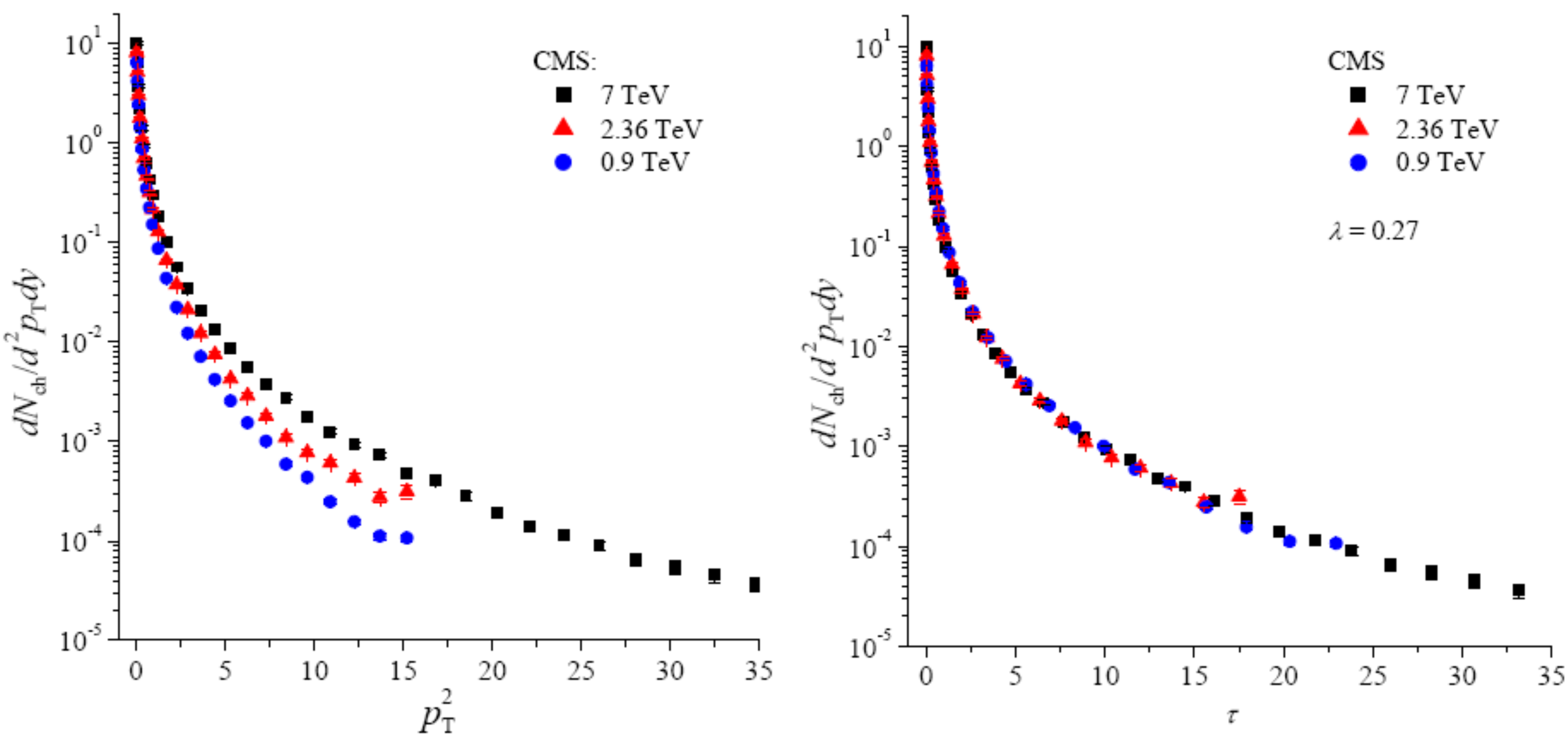
$$\tau = \frac{p_{\rm T}^2}{Q_{\rm sat}^2(p_{\rm T}/\sqrt{s})} = \frac{p_{\rm T}^2}{1\,{\rm GeV}^2} \left(\frac{p_{\rm T}}{\sqrt{s} \times 10^{-3}} \right)^{\lambda}$$

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

Geometrical scaling of p_T distributions

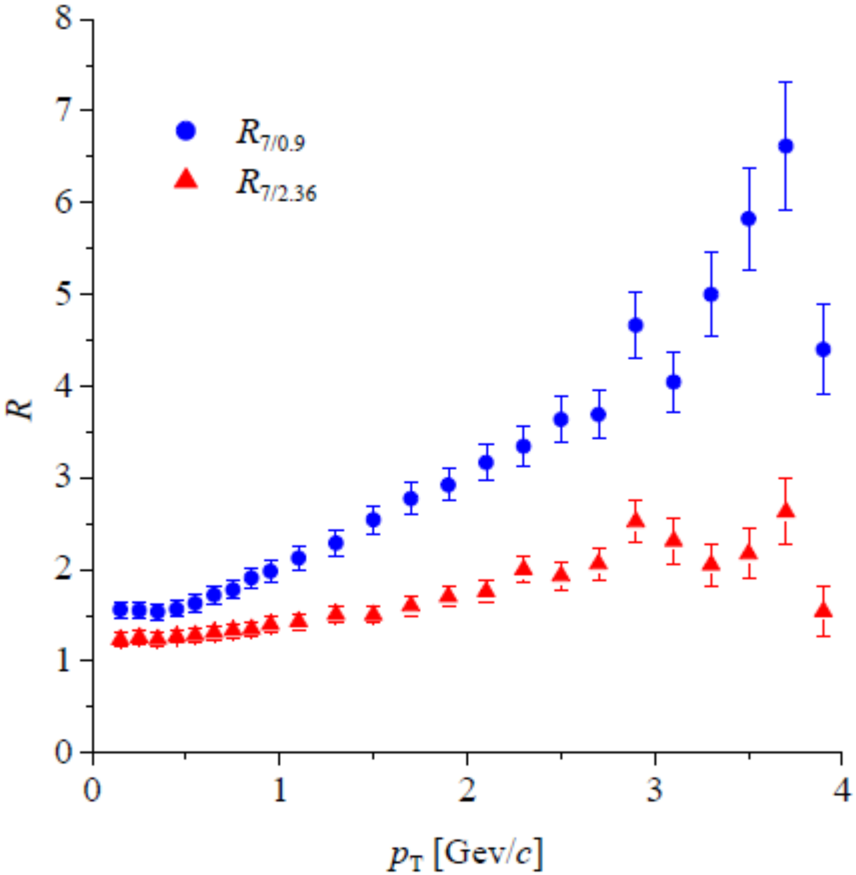


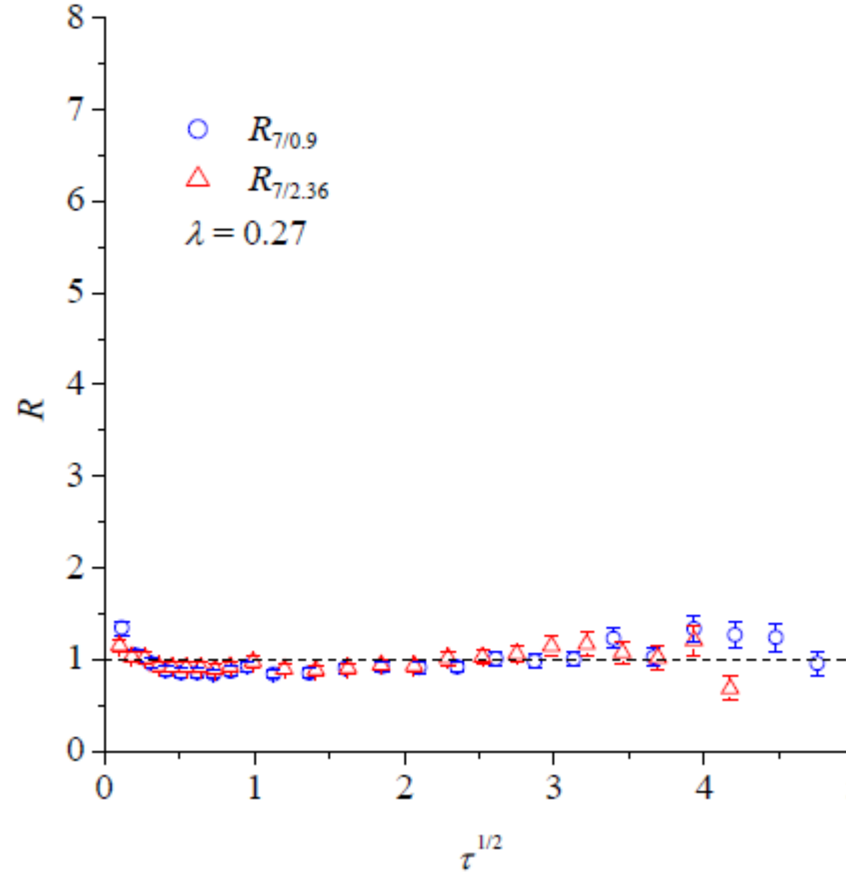
Geometrical scaling of p_T distributions



Ratios of p_T spectra

quality of GS can be examined by looking at the ratios:





small increase with τ

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

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

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

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

integral over $d\tau$ is energy independent

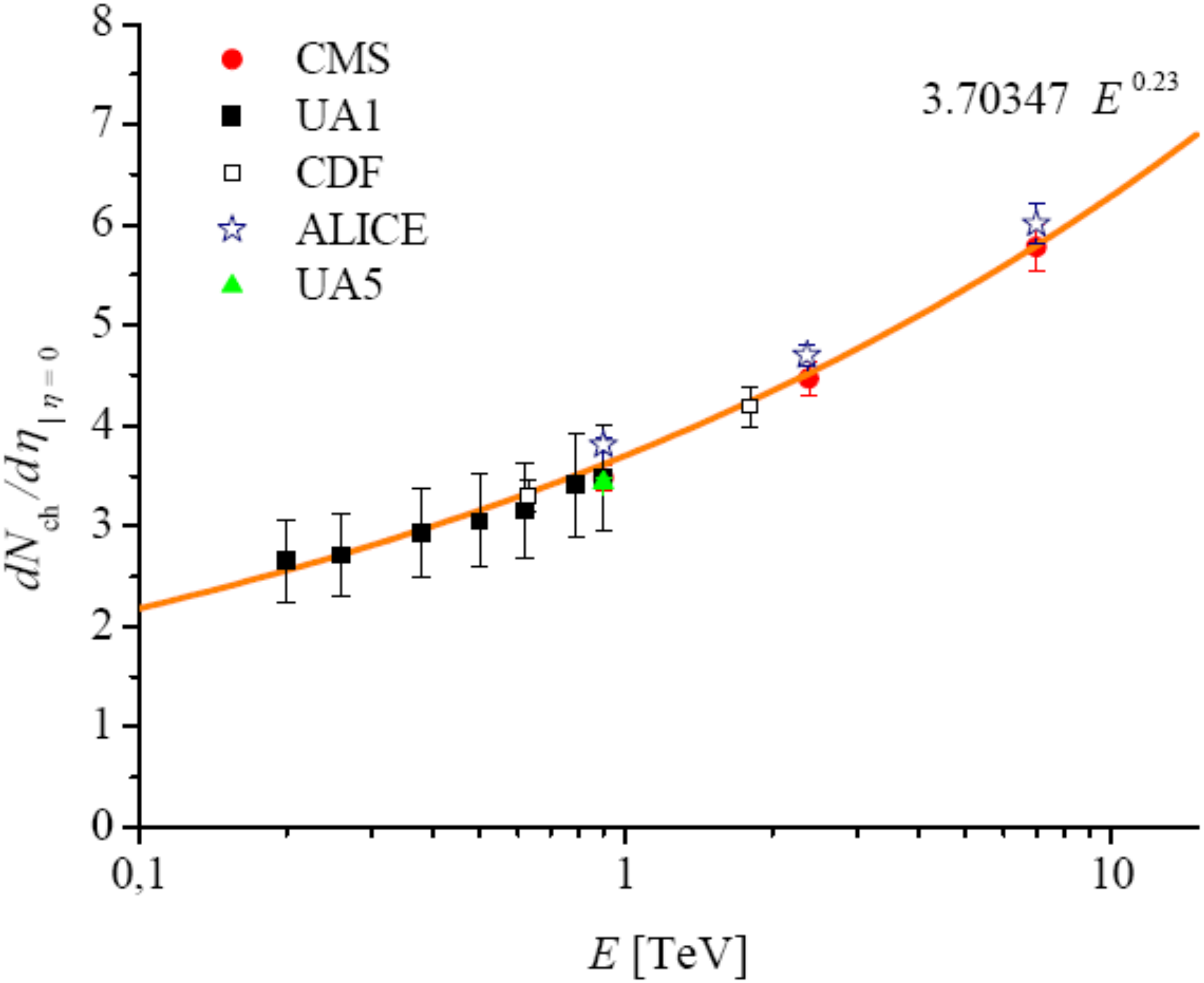
$$W \sim \sqrt{s}$$

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

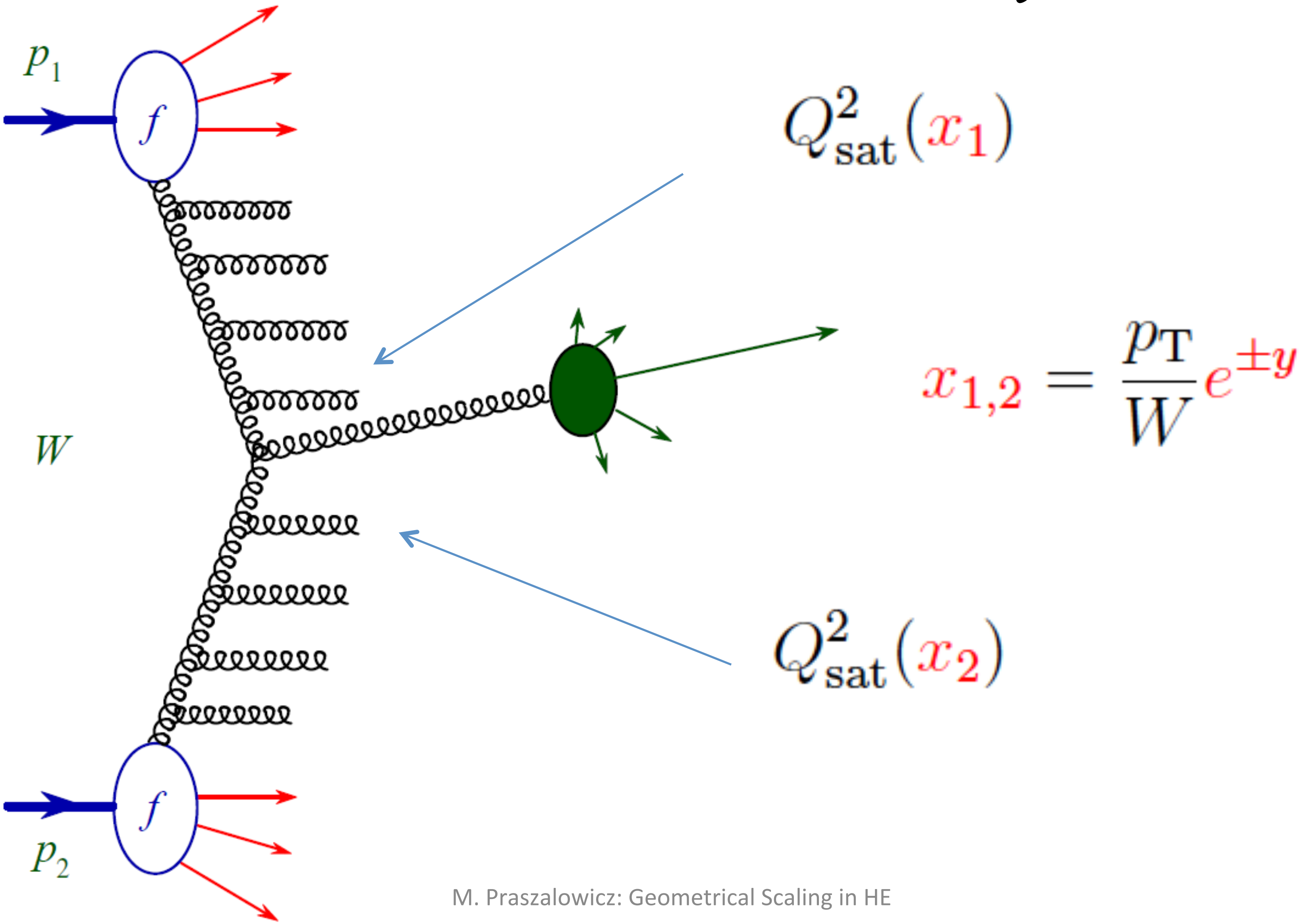
effective growth of multiplicity is slower than λ

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

Multiplicity from GS



p-p at forward rapidity $y > 0$



Kinematical range of GS in pp

$$x_1 < x_{\max}$$

$$p_{\mathrm{T}\max}(W, y) < x_{\max} W e^{-y}$$

Kinematical range of GS in pp

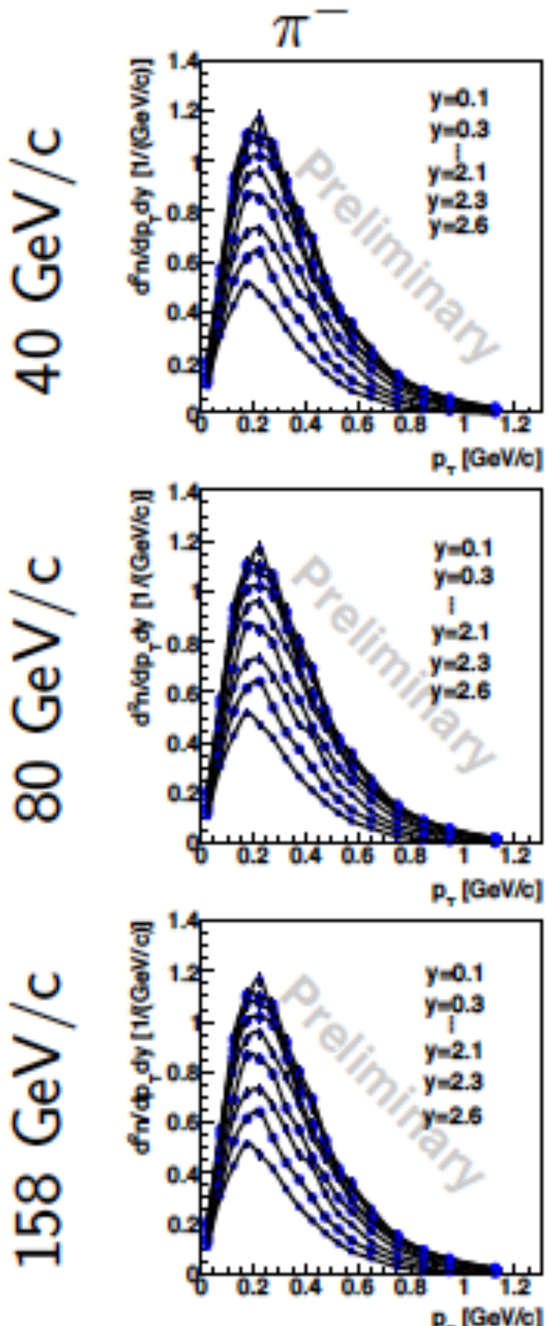
$$x_1 < x_{\rm max}$$

$$p_{\rm T max}(W, y) < x_{\rm max} W\, e^{-y}$$

transverse momentum schould be larger
than some nonperturbative scale Λ

$$p_{\rm T min} > \Lambda$$

NA61 Shine data



9th Polish Workshop on Relativistic Heavy-Ion Collisions
"From p-p to p-Pb and Pb-Pb collisions"

24-25 November 2012 *Collegium Maius, Jagiellonian University*
Poland timezone

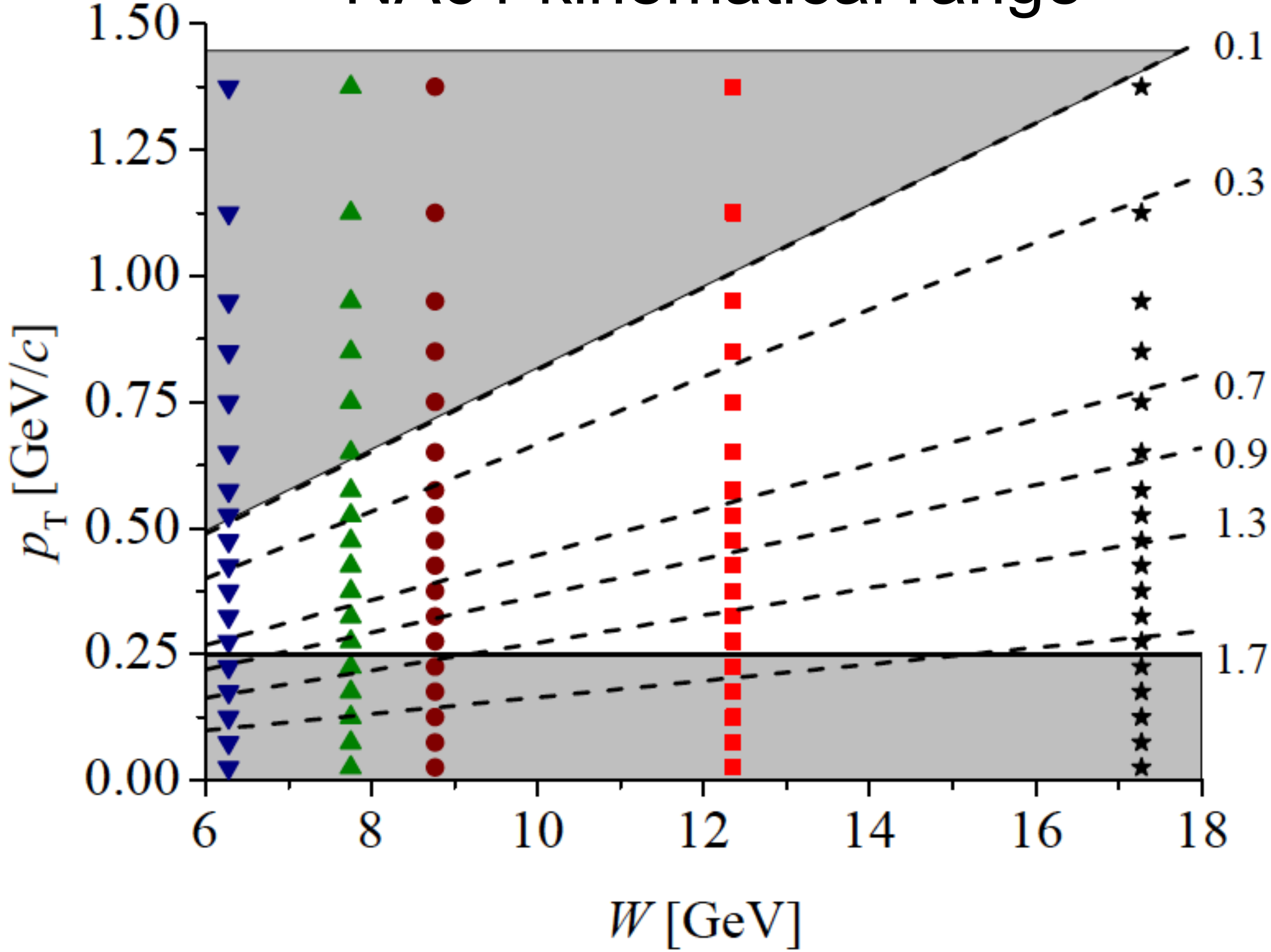
Hadron spectra: p+p vs. Pb+Pb at the SPS energies

Szymon Puławski
for NA61/SHINE Collaboration

University of Silesia, Katowice

- Data analyzed:
  - p+p @ 20 GeV/c ($\sqrt{s} = 6.2$ GeV): $1.3 \cdot 10^6$ events
  - p+p @ 31 GeV/c ($\sqrt{s} = 7.7$ GeV): $3.1 \cdot 10^6$ events
  - p+p @ 40 GeV/c ($\sqrt{s} = 8.8$ GeV): $5.2 \cdot 10^6$ events
  - p+p @ 80 GeV/c ($\sqrt{s} = 12.3$ GeV): $4.3 \cdot 10^6$ events
  - p+p @ 158 GeV/c ($\sqrt{s} = 17.3$ GeV): $3.5 \cdot 10^6$ events

NA61 kinematical range



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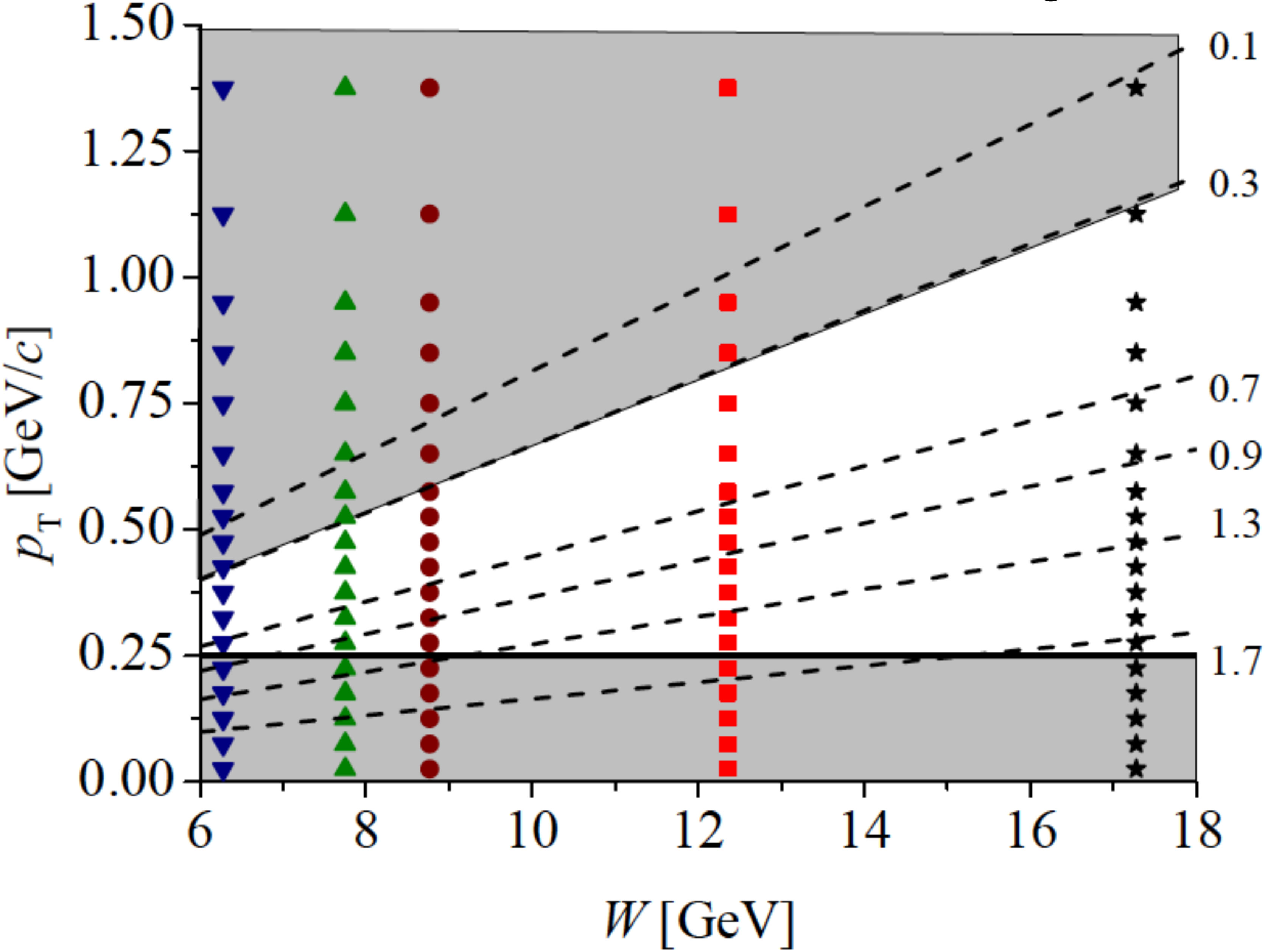

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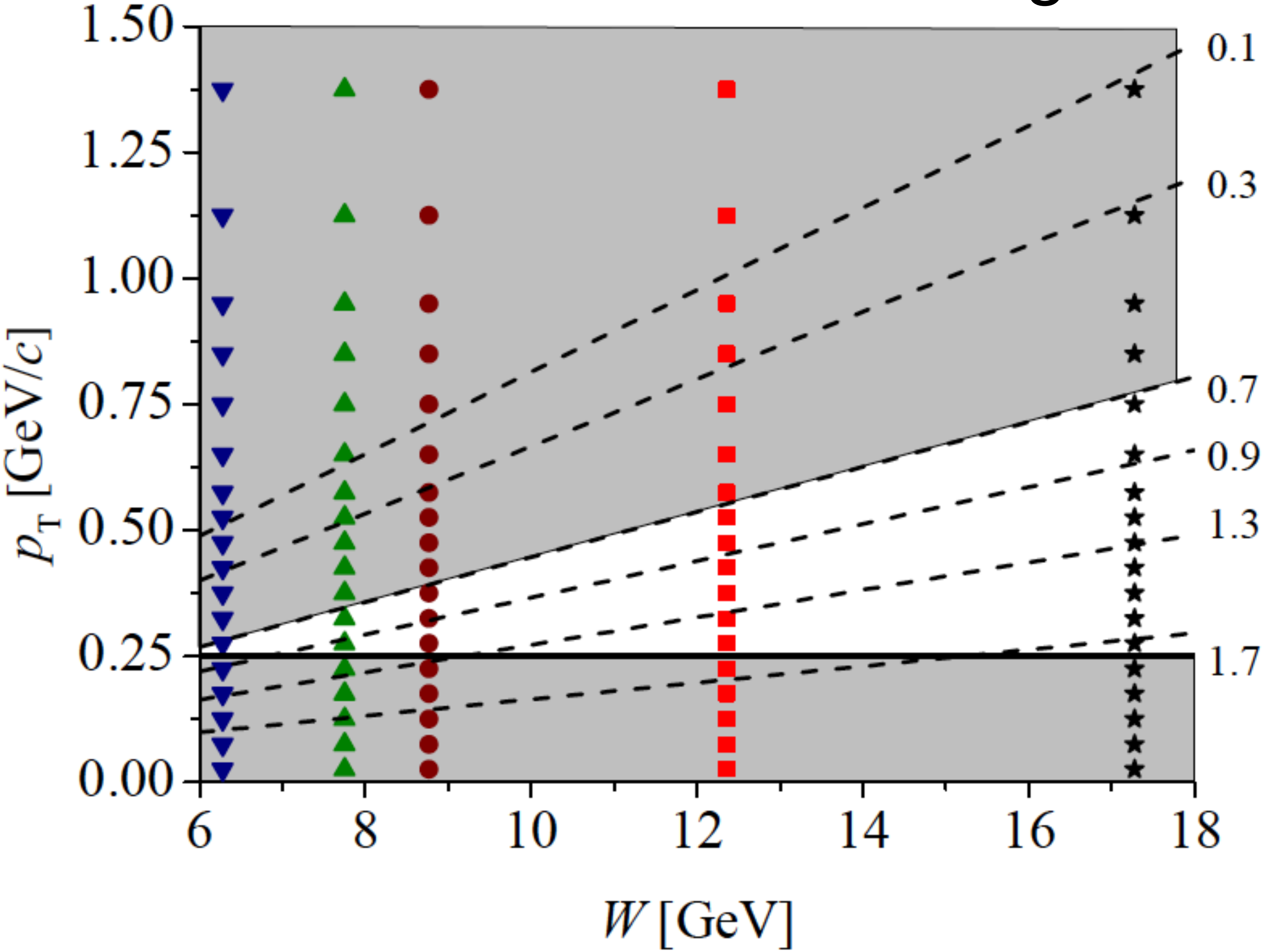

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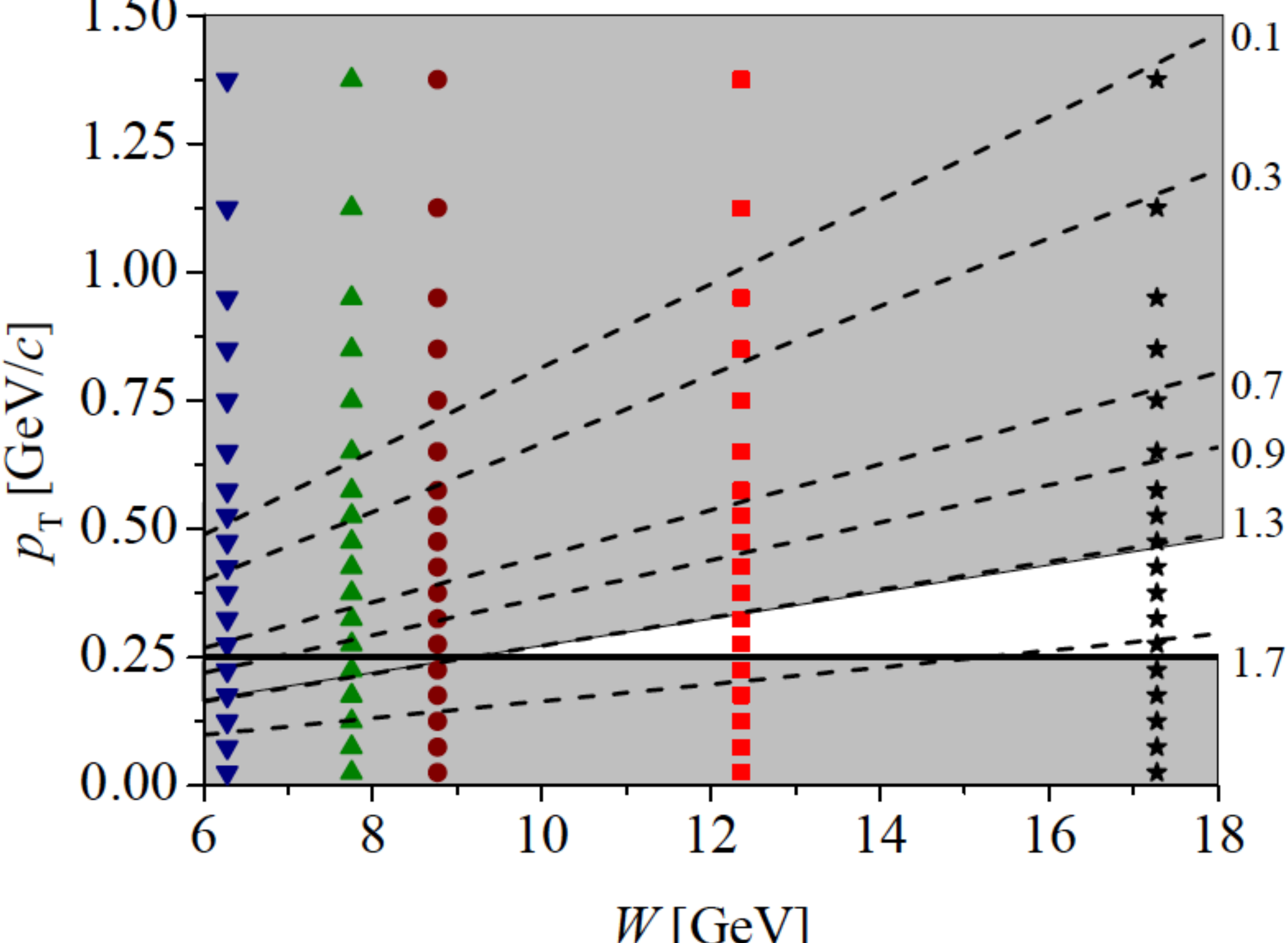
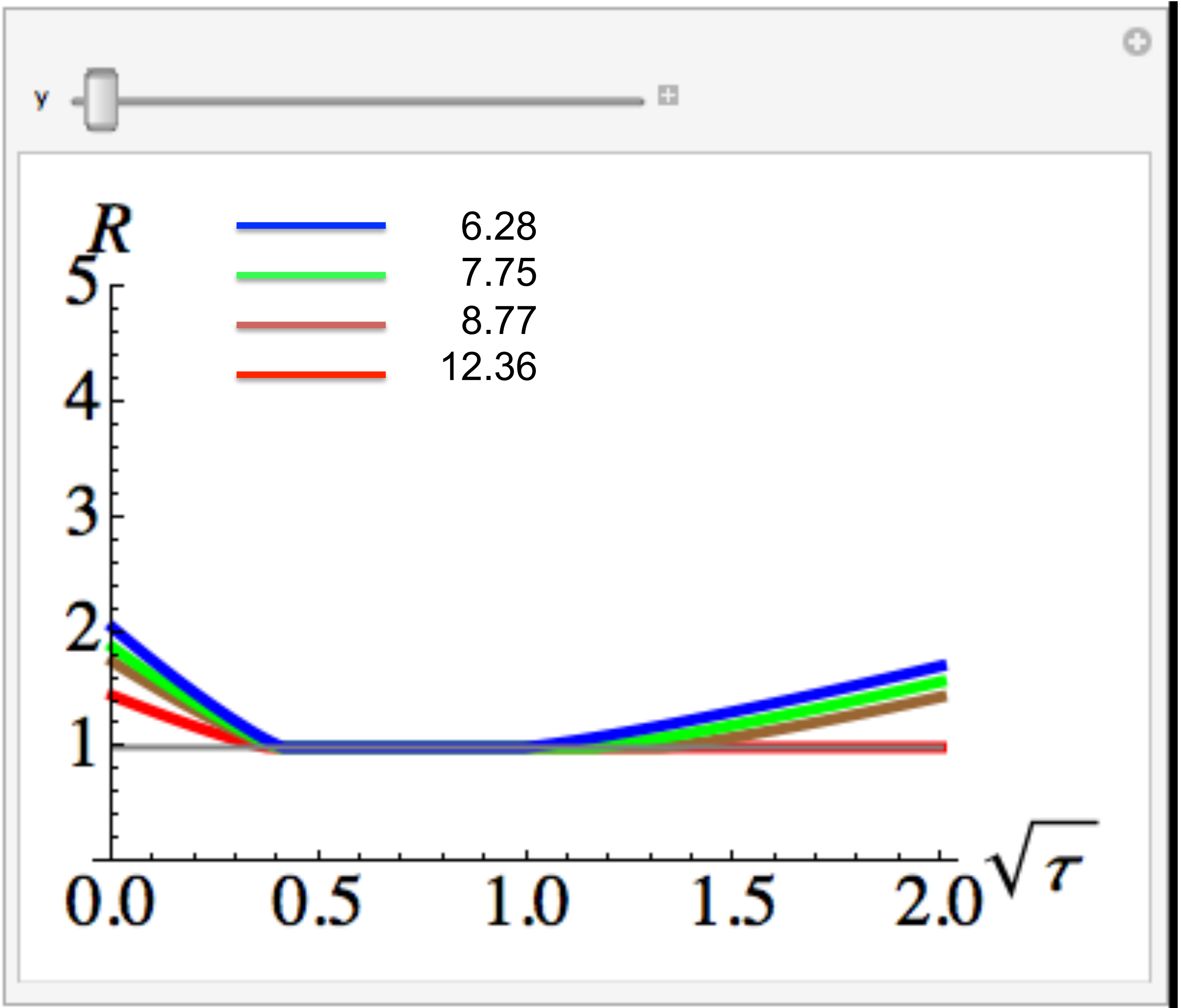
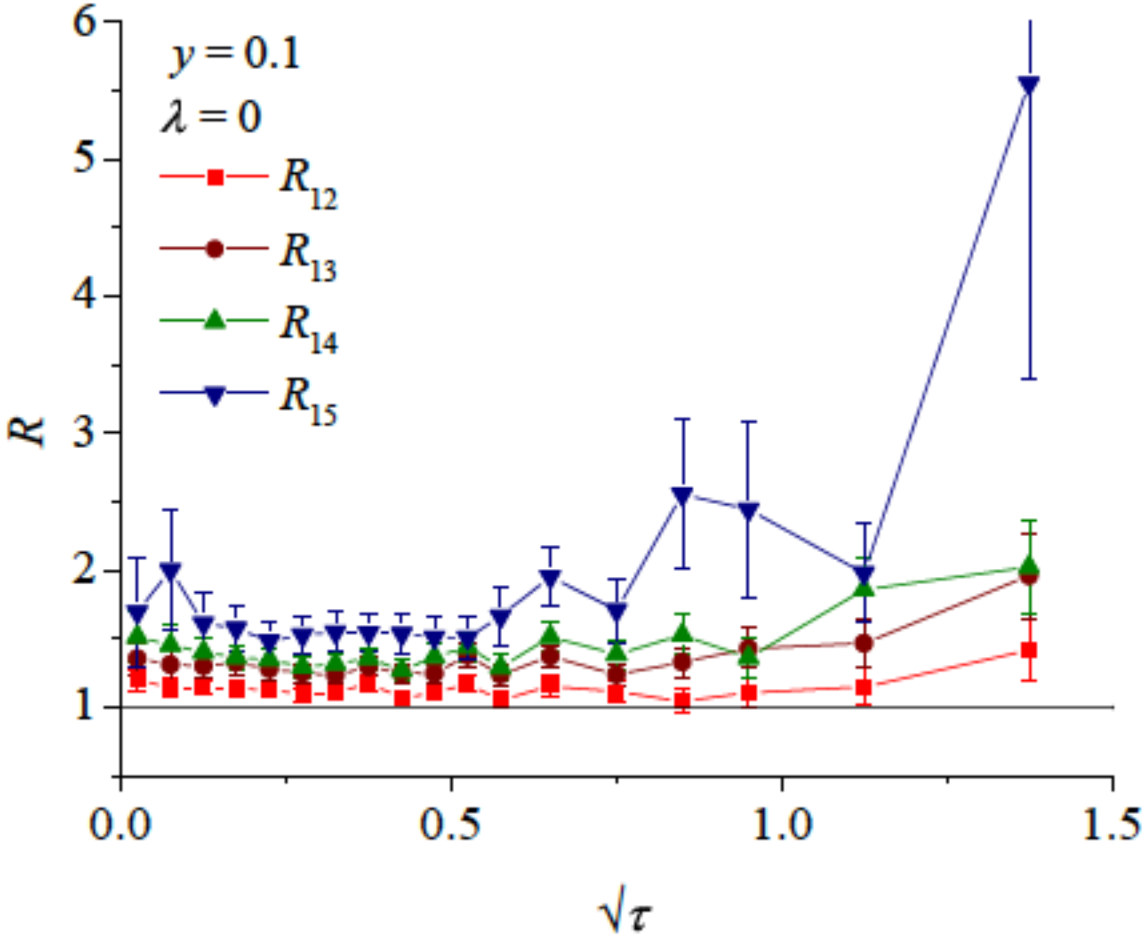
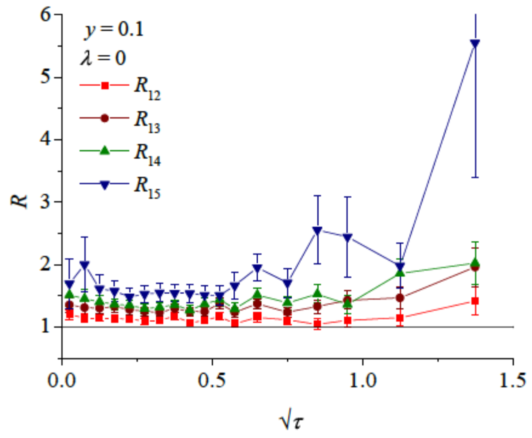


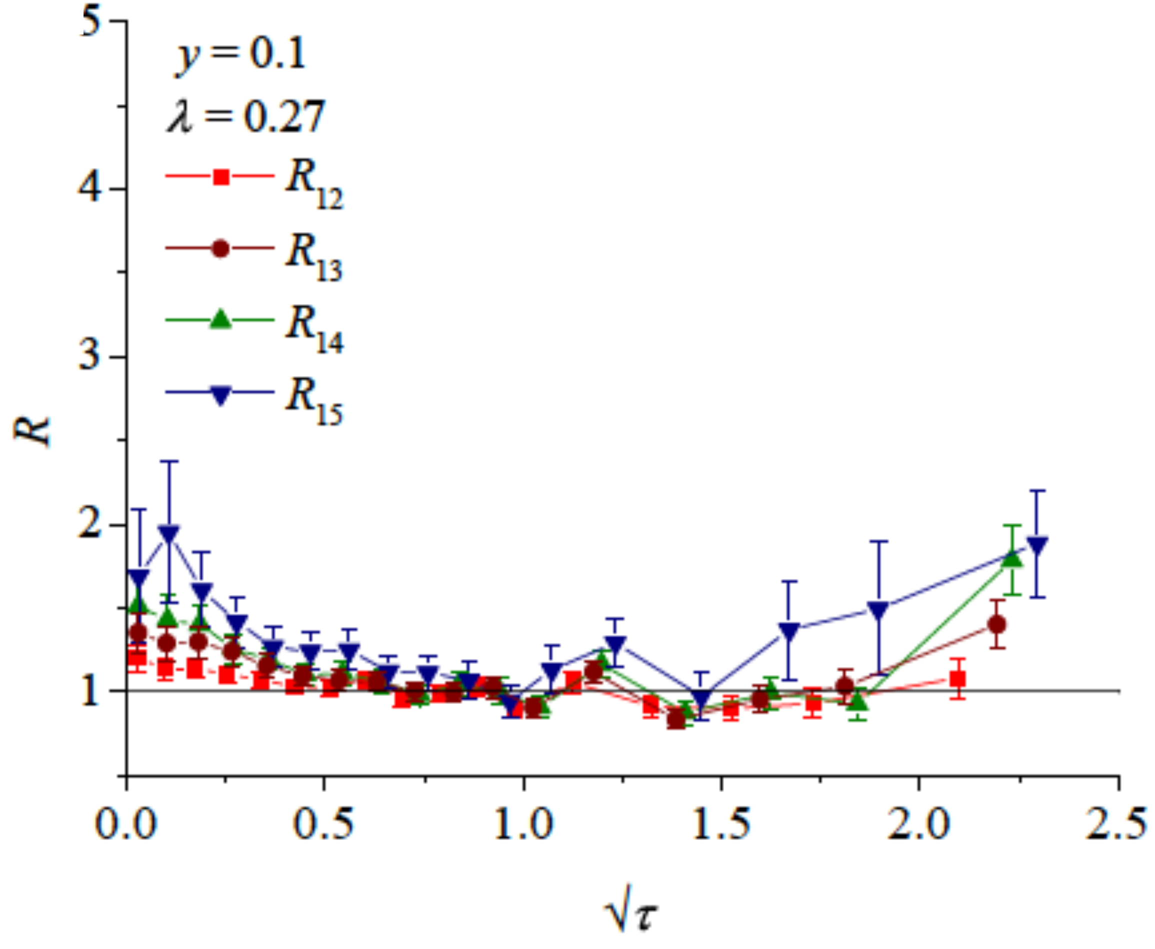

y
R
6.28
7.75
8.77
12.36
5
4
3
2
1
0.0
0.5
1.0
1.5
2.0
$\sqrt{\tau}$



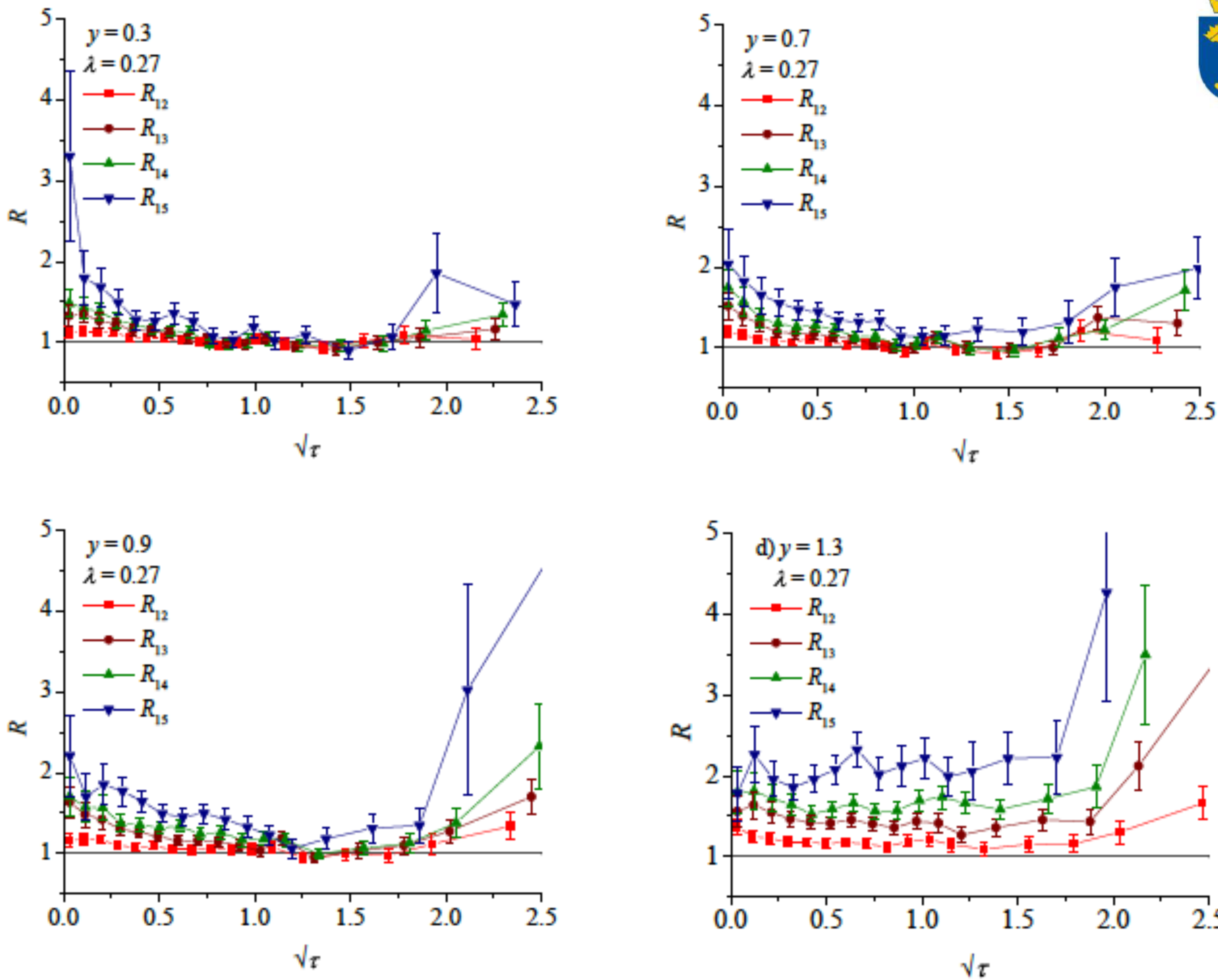
y = 0.1
λ = 0
R12
R13
R14
R15
R
√τ
6
5
4
3
2
1
0.0
0.5
1.0
1.5



y = 0.1
λ = 0
R12
R13
R14
R15
R
√τ

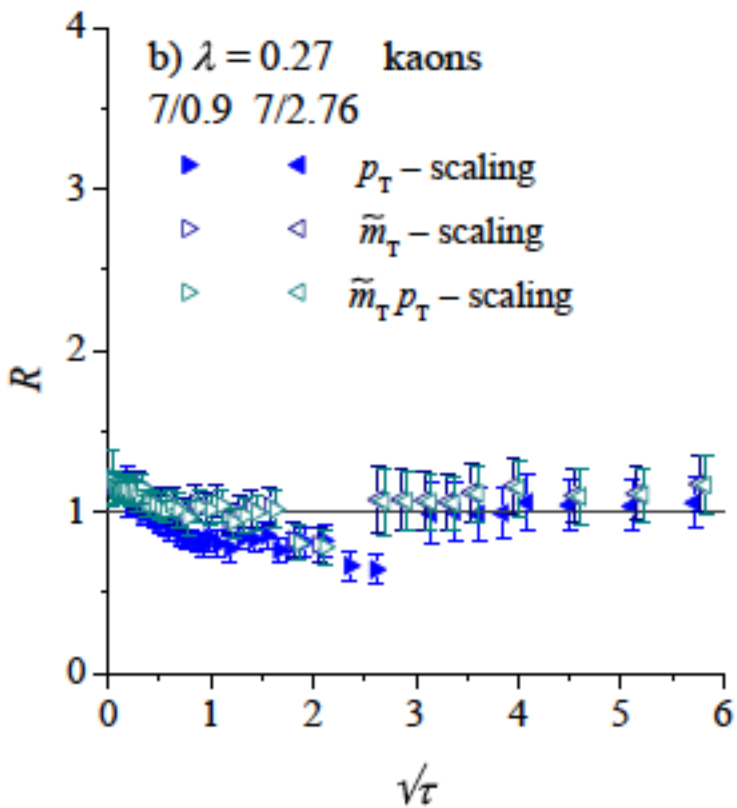


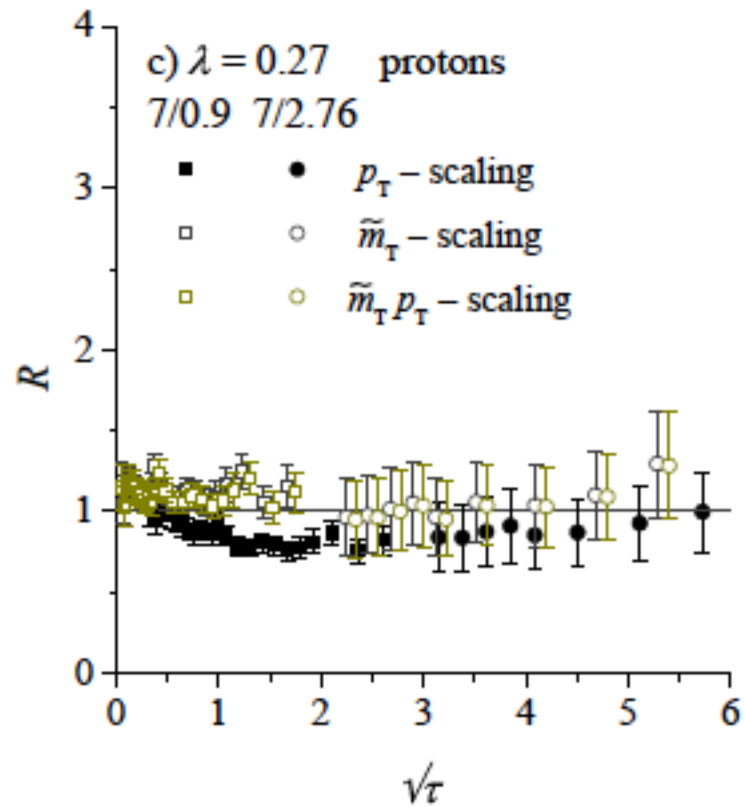
y = 0.1
λ = 0.27
R12
R13
R14
R15
R
√τ


y = 0.3
λ = 0.27
R12
R13
R14
R15
R
√τ
y = 0.7
λ = 0.27
R12
R13
R14
R15
R
√τ
y = 0.9
λ = 0.27
R12
R13
R14
R15
R
√τ
d) y = 1.3
λ = 0.27
R12
R13
R14
R15
R
√τ

GS for identified particles

$$\tau_{p_{\rm T}} = \frac{p_{\rm T}^2}{Q_{\rm s}^2} = \frac{p_{\rm T}^2}{Q_0^2}\left(\frac{p_{\rm T}}{W}\right)^{\lambda} \quad \Rightarrow \quad \tau_{\tilde{m}_{\rm T}} = \frac{\tilde{m}_{\rm T}^2}{Q_0^2}\left(\frac{\tilde{m}_{\rm T}}{W}\right)^{\lambda}$$





Summary

- GS in DIS works for rather high Bjorken x
- GS works also for charge particles in pp
- GSV is found for $y \neq 0$ in agreement with expectations
- GS for identified particles in $m_{\mathrm{T}} - m$

Universal shape of GS
connection with Tsallis-like parametrization
relation to unitegrated [illegible]
GS in HI
A dependence of the saturation scale
centrality dependence
why pp lambda is different than in DIS?
quantitative analysis is needed

Why does this work?

Summary

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Backup Slides

GS in HI: *A* dependence

$$\text{transverese parton size } s \sim \frac{\pi}{Q^2}$$

$$\text{cross section } \sigma \sim \alpha(Q^2)\frac{\pi}{Q^2}$$

$$\text{nucleus transverse size } S_A \sim \pi R_A^2$$

$$\text{critical \# partons} \sim \frac{S_A}{\sigma} \sim \frac{Q^2 R_A^2}{\alpha(Q^2)}$$

Saturation starts when # of partons in the nucleus N_A is equal to the critical # S_A/σ

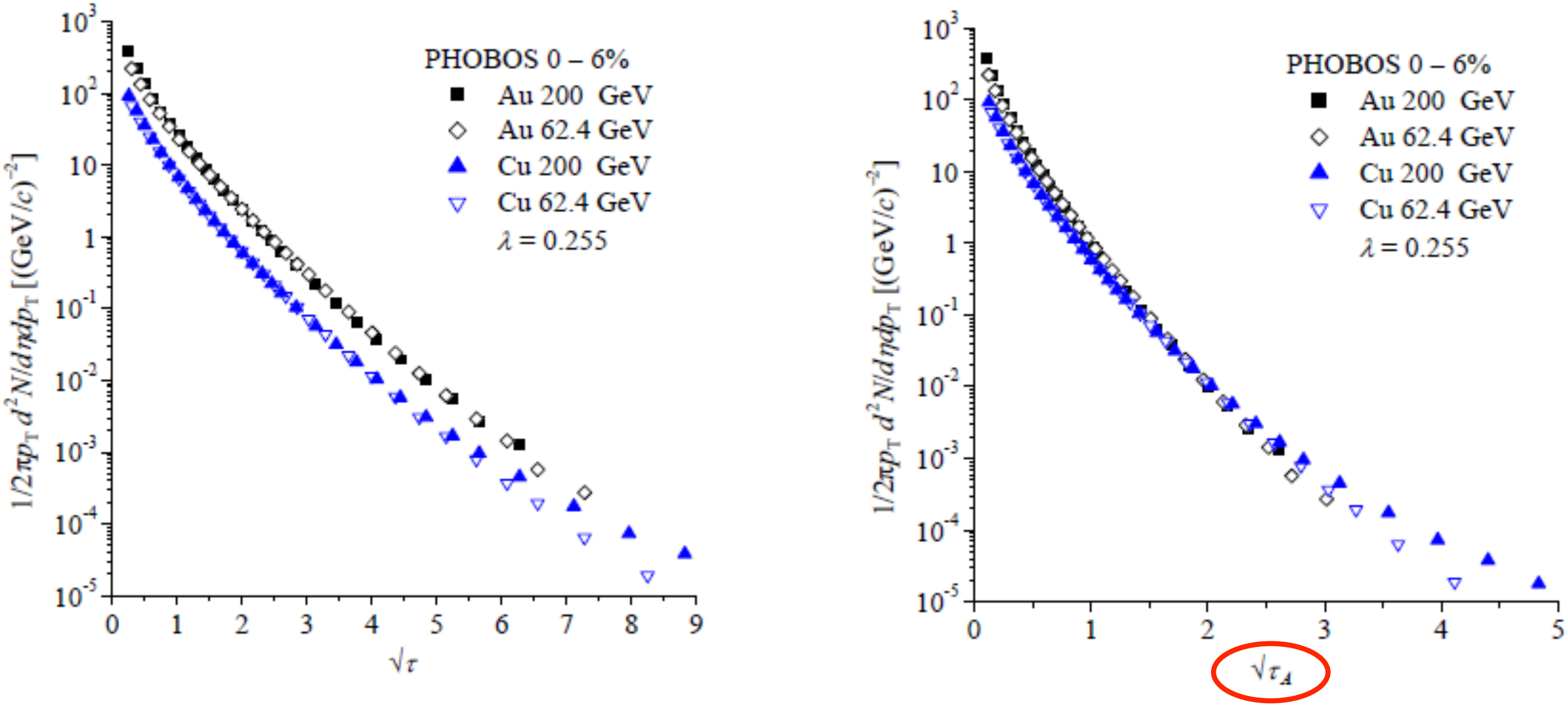
$$N_A \sim \frac{S_A}{\sigma} \implies Q^2_{\text{sat}} \sim \alpha(Q^2)\frac{N_A}{R_A^2} \sim \frac{A}{A^{2/3}} \sim A^{1/3}$$

$$Q^2_{A\,\text{sat}} \sim A^{1/3} Q^2_{\text{sat}}$$

GS in HI: *A* dependence

B. B. Back *et al.* [PHOBOS Collaboration], Phys. Rev. Lett. **94** (2005) 082304 [arXiv:nucl-ex/0405003].

B. Alver *et al.* [PHOBOS Collaboration], Phys. Rev. Lett. **96** (2006) 212301 [arXiv:nucl-ex/0512016].

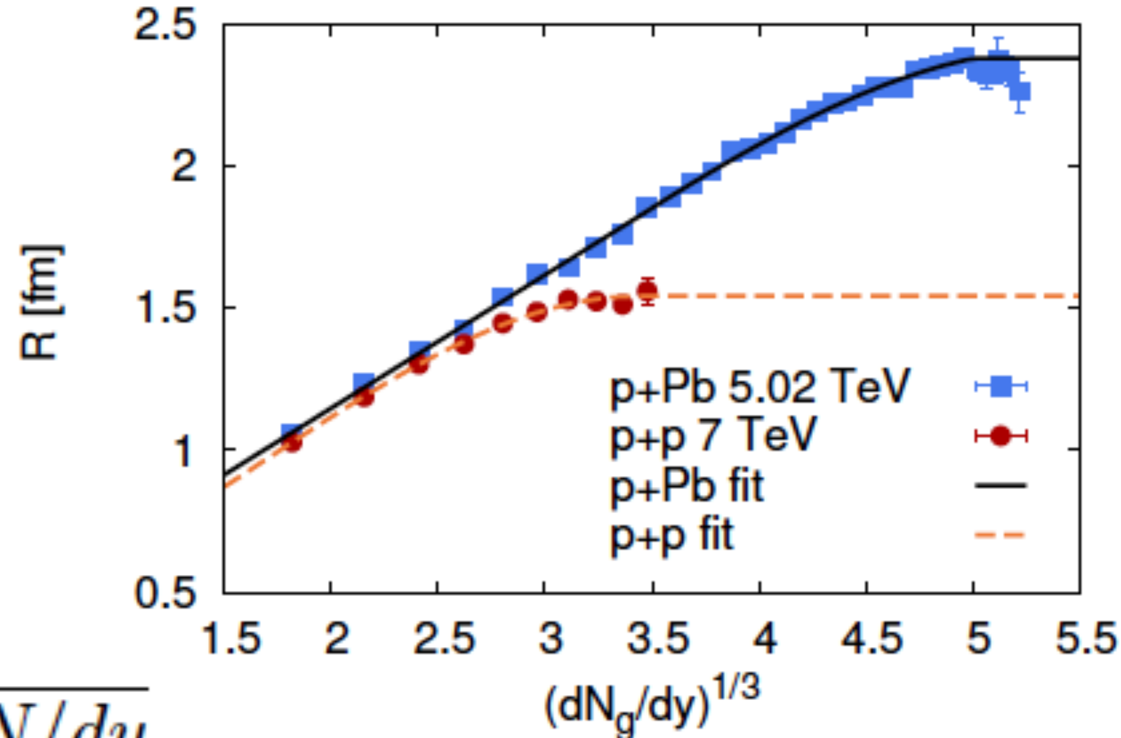


GS in pA

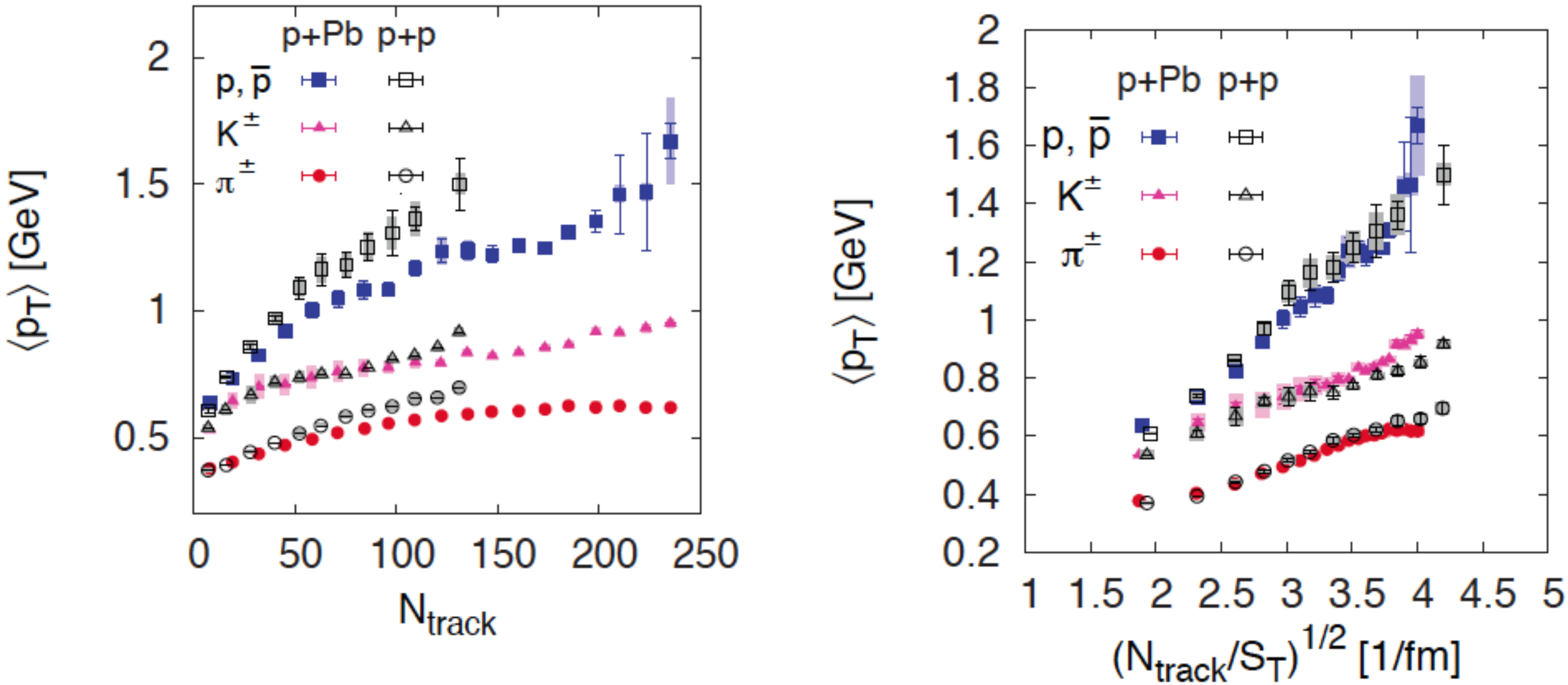
A. Bzdak, B. Schenke, P. Tribedy and R. Venugopalan, arXiv:1304.3403

$$\bar{Q}^2_{\rm sat} \sim \frac{dN}{dy}\frac{1}{S_{\rm T}}$$

$$\langle p_{\rm T}\rangle = A + B\sqrt{dN/dy}$$



GS in pA



L. McLerran, M.P. and B. Schenke, arXiv:1306.2350 [hep-ph] (Nucl. Phys. A)