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Jeju Island, South Korea
August 29 – September 2 2016

Top-Quark p_T-Spectra at LHC and Flavor Independence of z-Scaling

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[**] NPI Řež, Czech Republic

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- Introduction (motivation & goals)
- z-Scaling (principles, ideas, definitions,…)
- Properties of z-Scaling
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- Conclusions

Fundamental principles and symmetries

"Fundamental symmetry principles dictate the basic laws of physics, control the structure of matter, and define the fundamental forces in Nature."

Leon M. Lederman

Self-similarity is a property of physical phenomena and the principle to construct theories.

Top flavor is a fundamental property of quark and has relevance to the structure of the momentum space at small scales.

Top physics is a pillar of the current research program in HEP and provide stringent tests of SM.

z-Scaling - Universality & Saturation

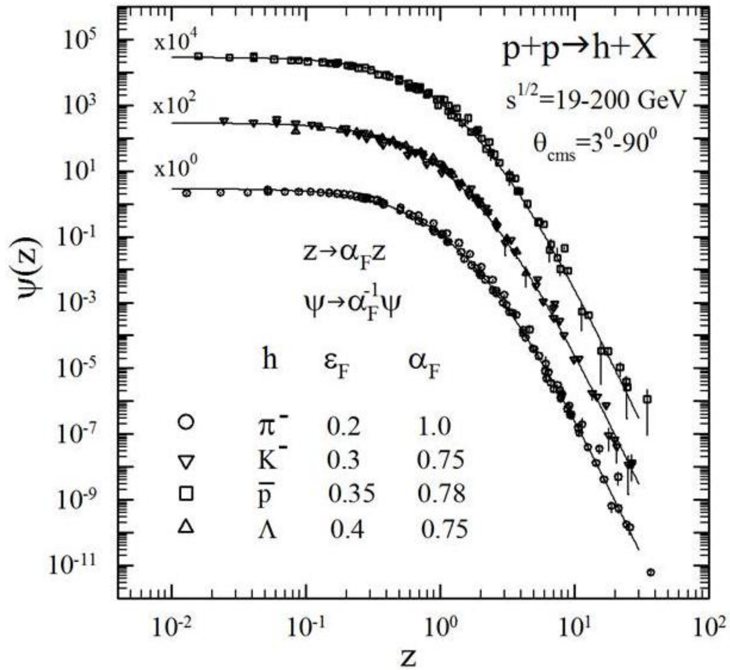
Inclusive cross sections of π^-, K^-, $\bar{p}$, Λ in pp collisions

FNAL:
PRD 75 (1979) 764

ISR:
NPB 100 (1975) 237
PLB 64 (1976) 111
NPB 116 (1976) 77
(low p_T)
NPB 56 (1973) 333
(small angles)

STAR:
PLB 616 (2005) 8
PLB 637 (2006) 161
PRC 75 (2007) 064901

Saturation at low z



Power law at high z

Energy scan of spectra
at U70, ISR, S$\bar{p}$pS, SPS, HERA, FNAL(fixed target), Tevatron, RHIC, LHC

MT & I.Zborovsky
T.Dedovich
Phys.Rev.D75,094008(2007)
Int.J.Mod.Phys.A24,1417(2009)
J. Phys.G: Nucl.Part.Phys. 37,085008(2010)
Int.J.Mod.Phys.A27,1250115(2012)
J.Mod.Phys.3,815(2012)

- Energy & angular independence
- Flavor independence (π, K, $\bar{p}$, Λ)
- Saturation for $z < 0.1$
- Power law $\Psi(z) \sim z^{-\beta}$ for high $z > 4$

Scaling – "collapse" of data points onto a single curve.

Motivation & Goals

Development of z-scaling approach for description of hadron, direct photon and jet production in inclusive reactions to search for signatures of new physics (phase transitions, quark compositeness, extra dimensions, black holes, fractality of space-time, complementary restrictions for theory,…)

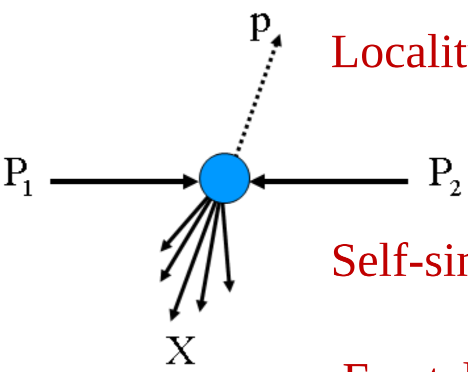
Analysis of new experimental data on p_T-spectra of top-quark production in $p\bar{p}$ and pp collisions obtained at Tevatron and LHC to verify properties of z-scaling.

It concerns to

- Properties of sub-structure of the colliding objects, interactions of their constituents, and fragmentation process at small scales.
- Fractal properties of flavor (u,d,s,c,b,t)
- Fundamental principles (self-similarity, scale relativity, fractality, Lorentz invariance,…)
- Origin of mass, spin, charge,…, fractal topology of space-time,…

z-Scaling

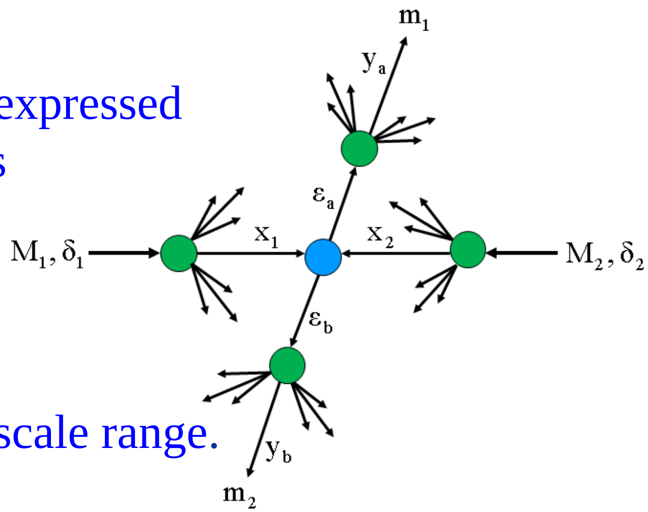
Principles: locality, self-similarity, fractality



Locality: collisions of hadrons and nuclei are expressed via interactions of their constituents (partons, quarks and gluons,...).

Self-similarity: interactions of the constituents are mutually similar.

Fractality: self-similarity is valid over a wide scale range.

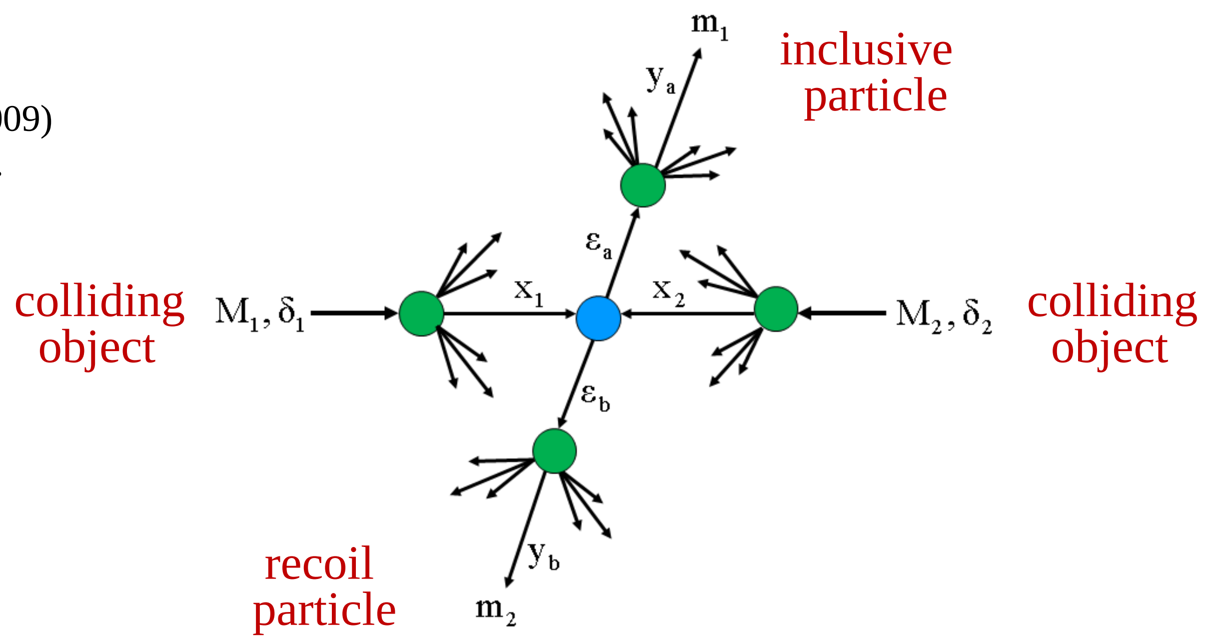


Hypothesis of z-scaling :

$s^{1/2}$, p_T, θ_{cms}	Inclusive particle distributions can be described in terms of constituent sub-processes and parameters characterizing bulk properties of the system.	x_1,x_2,y_a,y_b $\delta_1,\delta_2,\varepsilon_a,\varepsilon_b,c$
$Ed^3\sigma/dp^3$	Scaled inclusive cross section of particles depends in a self-similar way on a single scaling variable z.	$\Psi(z)$

Locality of hadron interactions

M.T. & I.Zborovský
Part.Nucl.Lett.312(2006)
PRD75,094008(2007)
Int.J.Mod.Phys.A24,1417(2009)
J.Phys.G: Nucl.Part.Phys. 37,085008(2010)



Constituent subprocess

$$(x_1M_1) + (x_2M_2) \Rightarrow (m_1/y_a) + (x_1M_1+x_2M_2+m_2/y_b)$$

Kinematical condition (4-momentum conservation law):

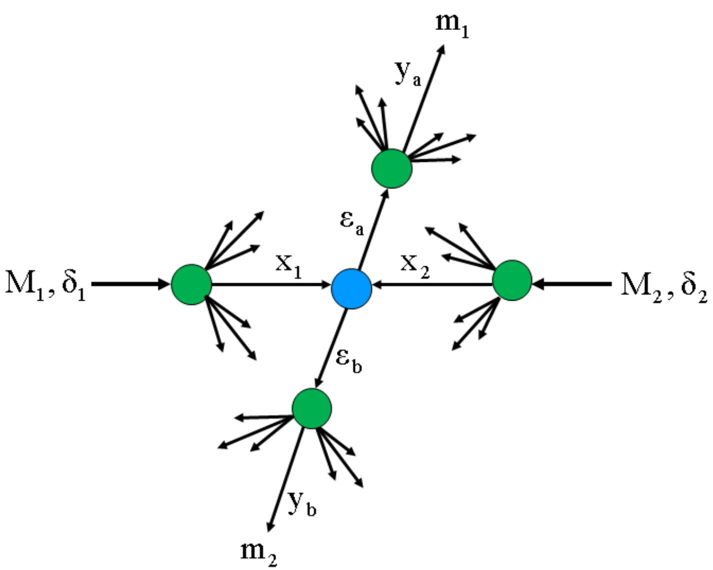
$$(x_1P_1+x_2P_2-p/y_a)^2 = M_X^2$$

Recoil mass: $M_X= x_1M_1+x_2M_2+m_2/y_b$

z as self-similarity parameter

$$z = z_0 \cdot \Omega^{-1}$$

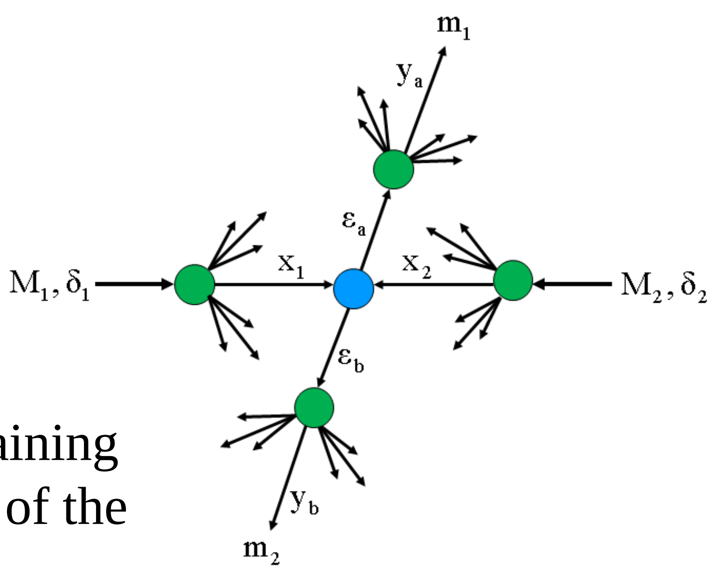
$$z_0 = \frac{s_\perp^{1/2}}{(dN_{ch}/d\eta|_0)^c m}$$



- Ω^{-1} is the minimal resolution at which a constituent subprocess can be singled out of the inclusive reaction
- $s_\perp^{1/2}$ is the transverse kinetic energy of the subprocess consumed on production of m_1 & m_2
- $dN_{ch}/d\eta|_0$ is the multiplicity density of charged particles at $\eta = 0$
- c is a parameter interpreted as a "specific heat" of created medium
- m is an arbitrary constant (fixed at the value of nucleon mass)

z as fractal measure

The fractality is reflected in definition of z



$$z = z_0 \cdot \Omega^{-1}$$

$$\Omega = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}(1-y_a)^{\varepsilon_a}(1-y_b)^{\varepsilon_b}$$

Ω is relative number of configurations containing a sub-process with fractions x_1, x_2, y_a, y_b of the corresponding 4-momenta

δ_1, δ_2, ε_a, ε_b are parameters characterizing structure of the colliding objects and fragmentation process, respectively

Ω^{-1} (x_1, x_2, y_a, y_b) characterizes resolution at which a constituent sub-process can be singled out of the inclusive reaction

$$z(\Omega)|_{\Omega^{-1}\to\infty} \to \infty$$

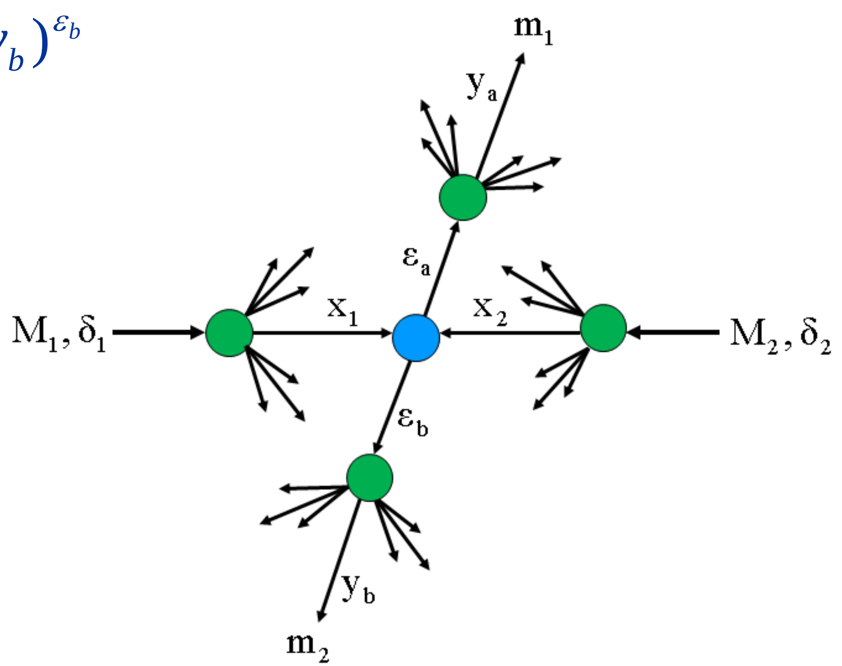
The fractal measure z diverges as the resolution Ω^{-1} increases.

Momentum fractions x_1, x_2, y_a, y_b

Principle of minimal resolution: The momentum fractions x_1, x_2 and y_a, y_b are determined in a way to minimize the resolution Ω^{-1} of the fractal measure z with respect to all constituent sub-processes taking into account 4-momentum conservation:

$$\Omega = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}(1-y_a)^{\varepsilon_a}(1-y_b)^{\varepsilon_b}$$

$$\begin{cases} \partial\Omega/\partial x_1 \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \\ \partial\Omega/\partial x_2 \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \\ \partial\Omega/\partial y_b \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \end{cases}$$



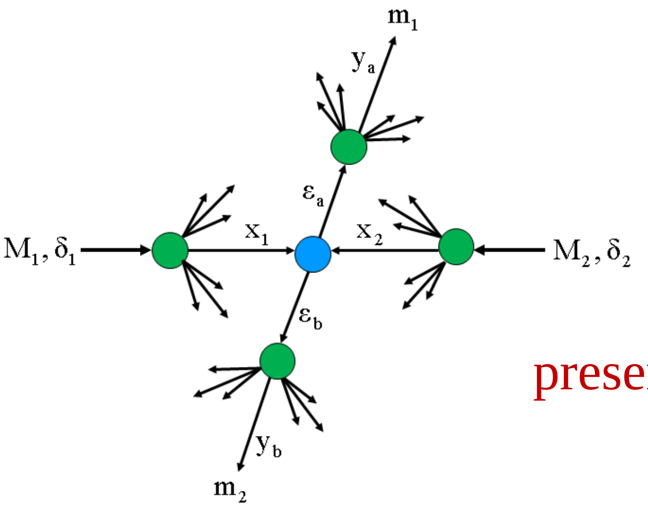
Momentum conservation law)

$$(x_1P_1+x_2P_2-p/y_a)^2 = M_X^2$$

Recoil mass

$$M_X = x_1M_1+x_2M_2+m_2/y_b$$

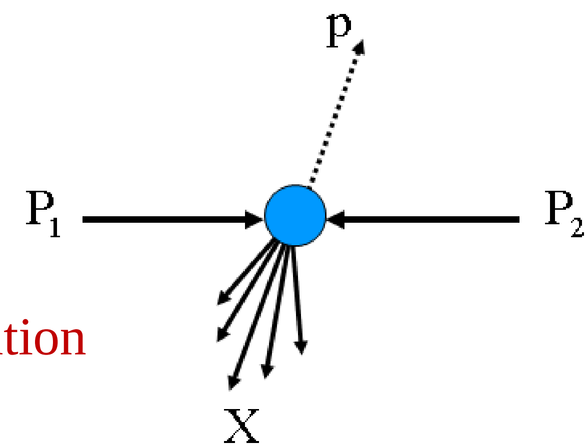
Scaling function Ψ(z)



$$\int_0^{\infty} \Psi(z)dz = 1$$

Scale transformation
preserves the normalization condition

$$z \to \alpha_F z, \quad \Psi \to \alpha_F^{-1} \Psi$$



$$\Psi(z) = \frac{\pi}{(dN/d\eta)\cdot\sigma_{inel}} \cdot J^{-1} \cdot E\frac{d^3\sigma}{dp^3} \quad \Longleftrightarrow \quad \int E\frac{d^3\sigma}{dp^3} dy d^2p_{\perp} = \sigma_{inel} \cdot N$$

- σ_{in} - inelastic cross section
- N - average multiplicity of the corresponding hadron species
- $dN/d\eta$ - pseudorapidity multiplicity density at angle θ (η)
- $J(z,\eta;p_T^2,y)$ - Jacobian
- $Ed^3\sigma/dp^3$ - inclusive cross section

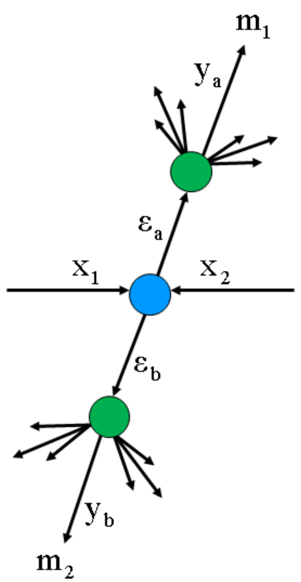
The scaling function Ψ(z) is probability density to produce an inclusive particle with the self-similarity parameter z.

Transverse kinetic energy $\sqrt{s_\perp}$

$$s_\perp^{1/2} = \underbrace{y_1(s_\lambda^{1/2} - M_1\lambda_1 - M_2\lambda_2) - m_1}_{\text{energy consumed for the inclusive particle } m_1} + \underbrace{y_2(s_\chi^{1/2} - M_1\chi_1 - M_2\chi_2) - m_2}_{\text{energy consumed for the recoil particle } m_2}$$

energy consumed for the inclusive particle m_1

energy consumed for the recoil particle m_2



Fraction decomposition: $x_{1,2} = \lambda_{1,2} + \chi_{1,2}$

$$\lambda_{1,2} = \kappa_{1,2}/y_1 + \nu_{1,2}/y_2$$

$$\chi_{1,2} = (\mu_{1,2}^2 + \omega_{1,2}^2)^{1/2} \mp \omega_{1,2}$$

$$\omega_{1,2} = \mu_{1,2}U, \quad U = \frac{\alpha - 1}{2\sqrt{\alpha}}\xi, \quad \alpha = \frac{\delta_2}{\delta_1}$$

$$\xi^2 = (\lambda_1\lambda_2 + \lambda_0)/[(1-\lambda_1)(1-\lambda_2)]$$

$$\kappa_{1,2} = \frac{(P_{2,1}p)}{(P_2P_1)}, \quad \nu_{1,2} = \frac{M_{2,1}m_2}{(P_2P_1)}$$

$$\mu_{1,2}^2 = \alpha^{\pm 1}(\lambda_1\lambda_2 + \lambda_0)\frac{1-\lambda_{1,2}}{1-\lambda_{2,1}}$$

$$\lambda_0 = \bar{\nu}_0/y_2^2 - \nu_0/y_1^2$$

$$\bar{\nu}_0 = \frac{0.5m_2^2}{(P_1P_2)}, \quad \nu_0 = \frac{0.5m_1^2}{(P_1P_2)}$$

$$s_\lambda = (\lambda_1P_1 + \lambda_2P_2)^2$$

$$s_\chi = (\chi_1P_1 + \chi_2P_2)^2$$

The scaling function $\Psi(z)$ and self-similarity parameter z are expressed via Lorentz invariants.

Properties of $\Psi(z)$ in pp & $p\bar{p}$ collisions

- Energy independence of $\Psi(z)$ ($s^{1/2} > 20$ GeV)
- Angular independence of $\Psi(z)$ ($\theta_{cms}=3^0$-90^0)
- Multiplicity independence of $\Psi(z)$ ($dN_{ch}/d\eta=1.5$-26)
- Power law, $\Psi(z) \sim z^{-\beta}$, at high z ($z > 4$)
- Flavor independence of $\Psi(z)$ ($\pi, K, \varphi, \Lambda, .., D, J/\psi, B, \Upsilon, \ldots$, top)
- Saturation of $\Psi(z)$ at low z ($z < 0.1$)

These properties reflect self-similarity, locality, and fractality
of the hadron interaction at constituent level.
It concerns the structure of the colliding objects, interactions
of their constituents, and fragmentation process.

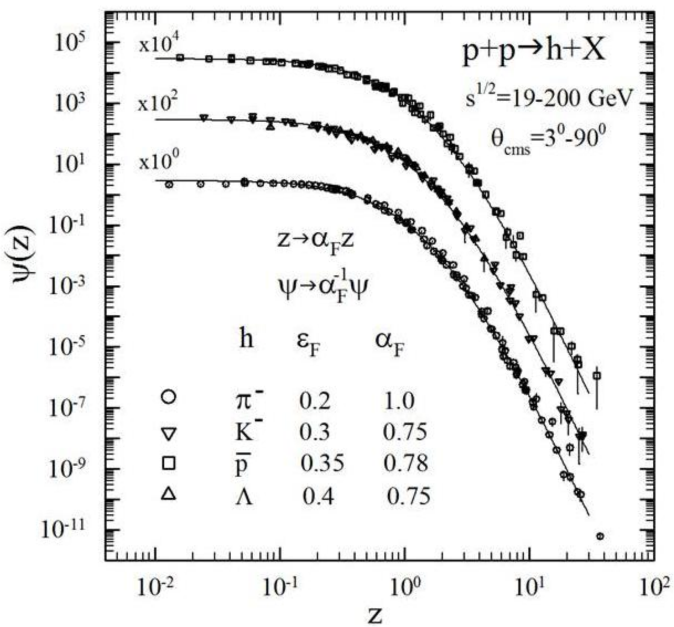
M.T. & I.Zborovsky
Phys.At.Nucl. 70,1294(2007)
Phys.Rev. D75,094008(2007)
Int.J.Mod.Phys. A24,1417(2009)
J. Phys.G: Nucl.Part.Phys. 37,085008(2010)
Int.J.Mod.Phys. A27,1250115(2012)
…………………

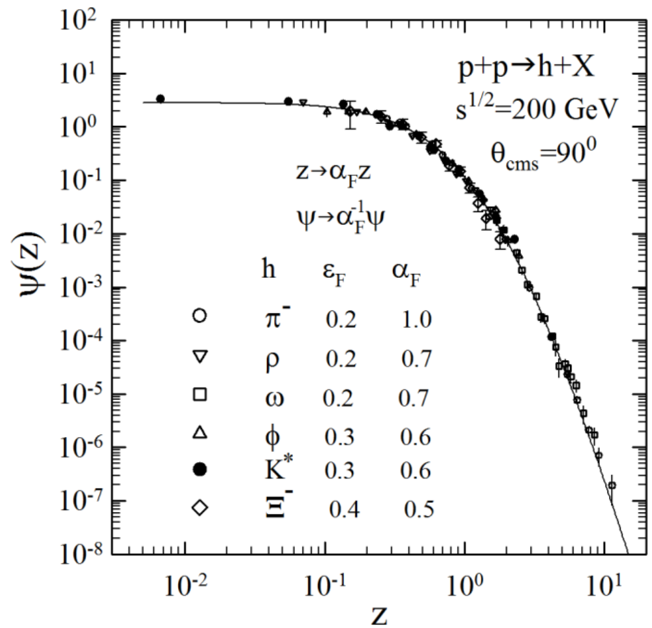
z-Scaling before LHC

Flavor independence of $\Psi(z)$ at RHIC

$\pi^-, \rho, \omega, \phi, K^*, \Lambda, \Xi, J/\psi$, D, B, Υ

M.T. & I.Zborovský
Int.J.Mod.Phys.
A24,1417(2009)





STAR:
PRL 92 (2004) 092301
PLB 612 (2005) 181
PRC 71 (2005) 064902
PRC 75 (2007) 064901

PHENIX:
PRC 75 (2007) 051902

- Energy independence
- Angular independence
- Flavor independence
- Saturation for $z < 0.01$

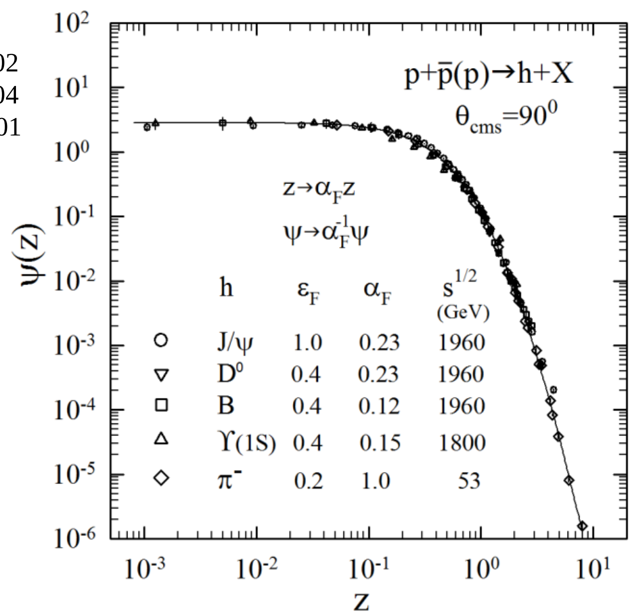
- Power law $\Psi(z) \sim z^{-\beta}$ at large z
- ε_F, α_F independent of p_T, $s^{1/2}$

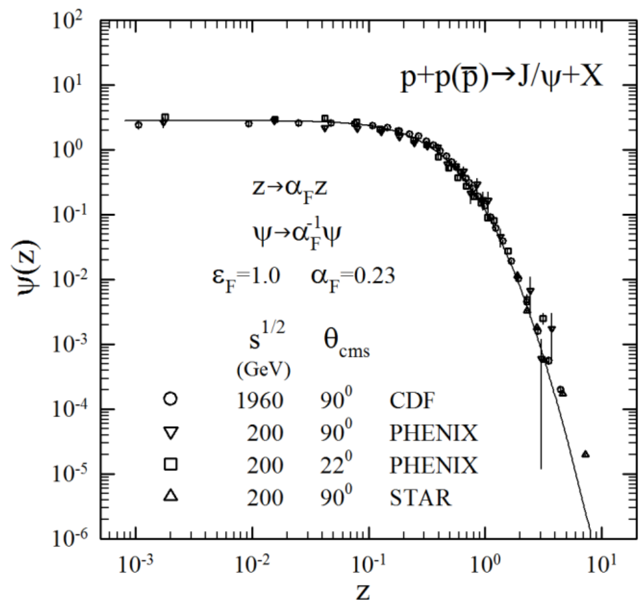
Self-similarity of particle formation with various flavor content.

Flavor independence of $\Psi(z)$ at Tevatron

π^-, ρ, ω, ϕ, K^*, Λ, Ξ, J/ψ, D, B, Υ

CDF:
PRL 88 (2002) 161802
PRL 91 (2003) 241804
PRD 71 (2005) 032001





CDF:
PRD 71 (2005) 032001
PHENIX:
PRL 98 (2007) 232002
STAR:
Z.Tang
J.Phys.G35:104135, 2008

- Energy & angular independence
- Saturation of $\Psi(z)$ for $z < 0.1$
- Flavor independence of $\Psi(z)$
- Extra large $\varepsilon_F=1$ for J/ψ

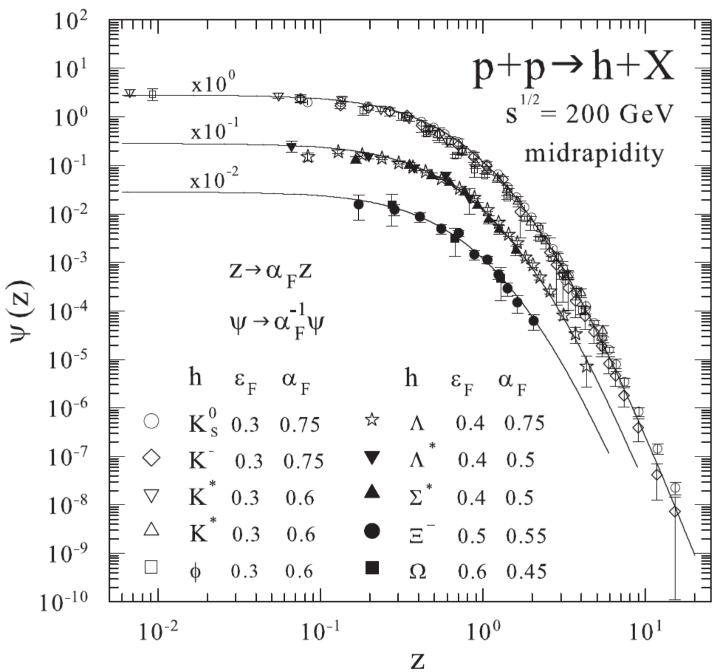
Self-similarity of strangeness production in pp at RHIC

Universality: flavor independence of the scaling function

M.T.& I.Zborovský
Int.J.Mod.Phys.
A24,1417(2009)

Solid line for π^- meson is a reference curve
$\varepsilon_\pi = 0.2, \quad \alpha_\pi = 1$

K^0_S, K^-, K^*, ϕ, Λ, Ξ, Ω, Σ^*, Λ^*



M.T. & I.Zborovský
SQM'15
Dubna, Russia, 2015
HSQCD'16
Gatchina, Russia, 2016

STAR:
PRL 92 (2004) 092301
PRL 97 (2006) 132301
PLB 612 (2005) 181
PRC 71 (2005) 064902
PRC 75 (2007) 064901
PRL 108 (2012) 072302

PHENIX:
PRC 75 (2007) 051902
PRD 83 (2011) 052004
PRC 90 (2014) 054905

- Energy independence
- Angular independence
- Flavor independence
- Saturation for $z < 0.01$

- Power law $\Psi(z) \sim z^{-\beta}$ at large z
- ε_F, α_F independent of p_T, $s^{1/2}$

Self-similarity of K_S^0 production in pp & p$\bar{\text{p}}$

Sp$\bar{\text{p}}$S, Tevatron, RHIC, LHC

$\sqrt{s}$=200-7000 GeV

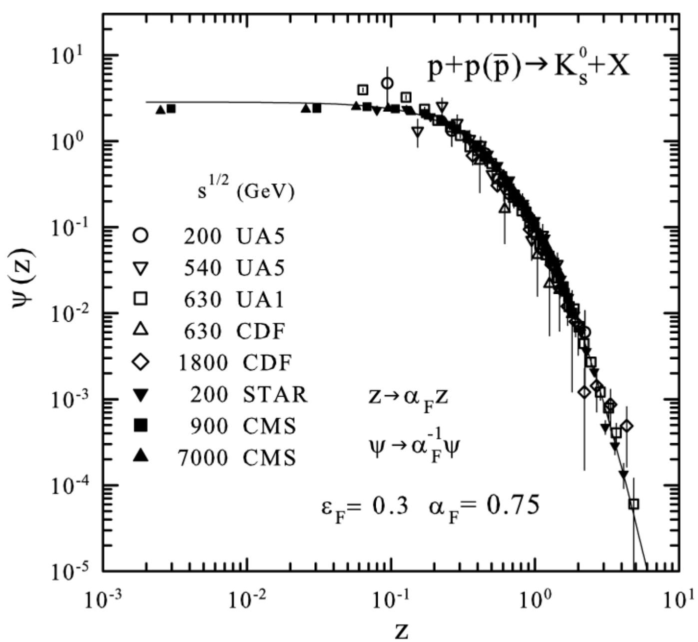
CERN: UA5
PLB 199 (1987) 311
NPB 258 (1985) 505

CERN: UA1
PLB 366 (1996) 441

FNAL: CDF Coll.
PRD 40 (1989) 3791

RHIC: STAR Coll.
PRC 75 (2007) 064901

LHC: CMS Coll.
J. High Energy Phys.05 (2011) 064



M.T. & I.Zborovský
ISMD'11
Miyajima Island,
Japan, 2011

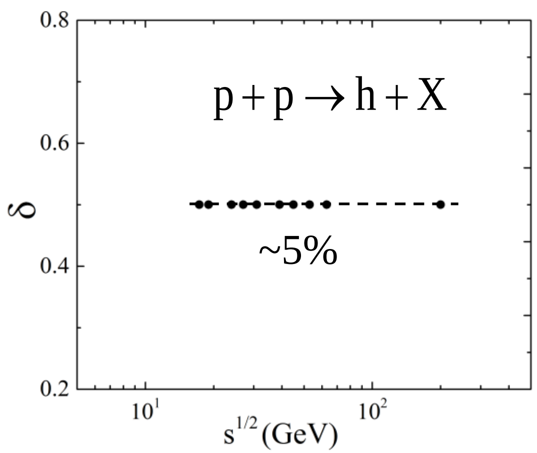
Solid line for π^- meson is a reference curve
$\varepsilon_\pi = 0.2, \quad \alpha_\pi = 1$

- Energy independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for $z < 0.01$
- Shape of $\Psi(z)$ is the same in p$\bar{\text{p}}$ and pp

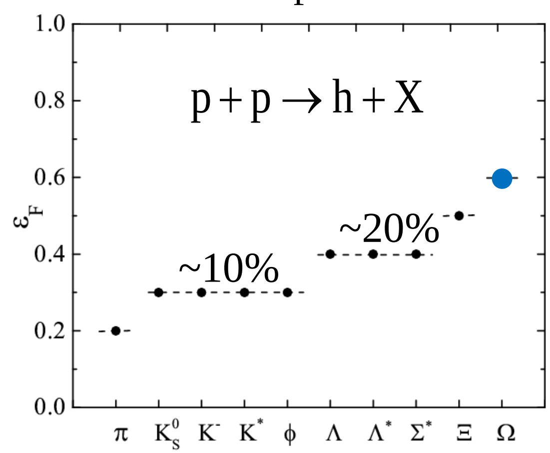
Model parameters: δ, ε_F, c

Parameters δ, ε_F, c are found from
the scaling behavior of Ψ as a function of self-similarity variable z

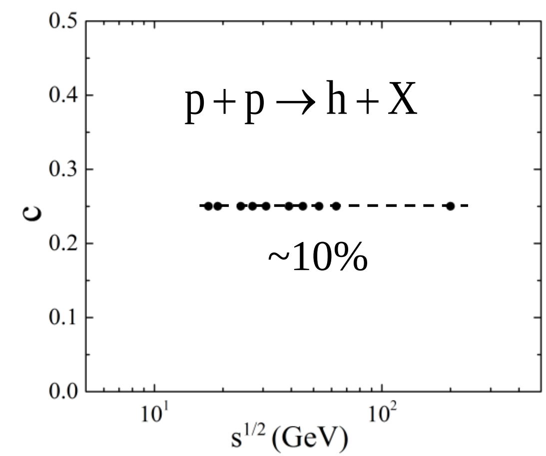
Proton fractal dimension — δ



Fragmentation dimension — ε_F



"Specific heat" — c

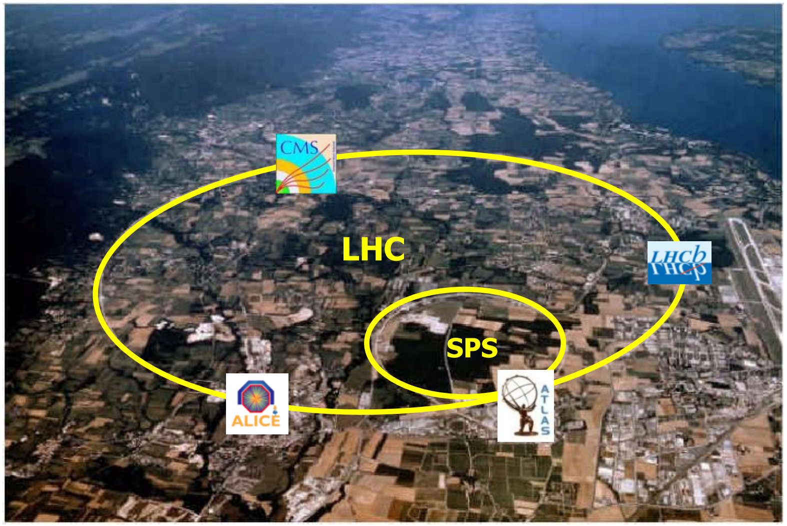


- δ, ε_F, c are independent of $\sqrt{s}$, p_T
- ε_F depends on flavor

A discontinuity and strong correlation of the model parameters could give indication on new physics in pp collisions:
Search for phase transition, critical point …. with strange probes.

What about self-similarity and flavor independence of Ψ(z) for top quark production in pp collisions at LHC ?

CERN



Top quark production and decay

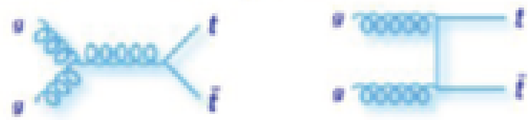
Top-quark discovery

1995

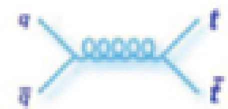
CDF Collab. F.Abe et al.
Phys. Rev. Lett. 74 (1995)2626.
DØ Collab. S.Abachi et al.
Phys. Rev. Lett. 74(1995)2632.

$m_t \approx 170$ GeV

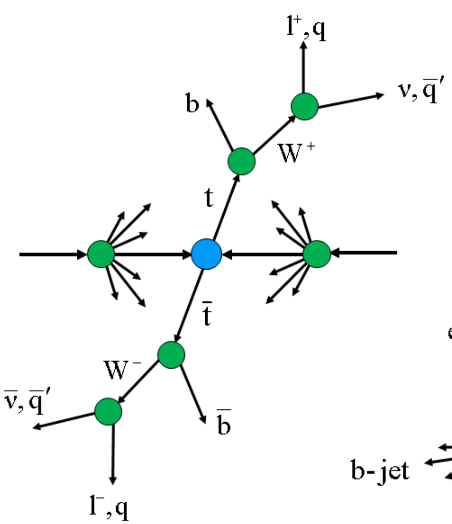
Gluon fusion

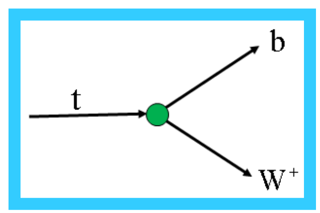


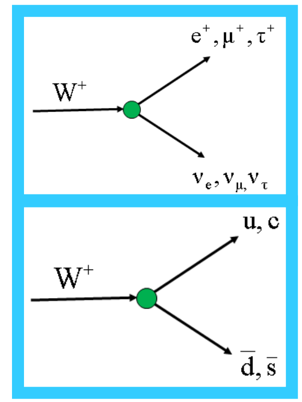
Quark-antiquark annihilation



		Gluon fusion	Quark-antiquark annihilation
LHC	13 TeV	~ 90%	~10%
LHC	7,8 TeV	~ 85%	~15%
Tevatron	1.96 TeV	~ 15%	~85%

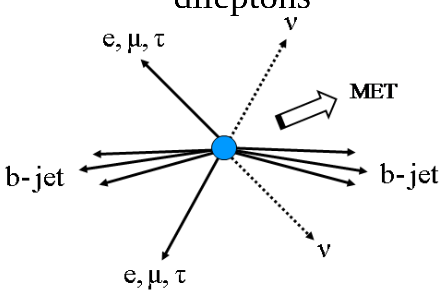






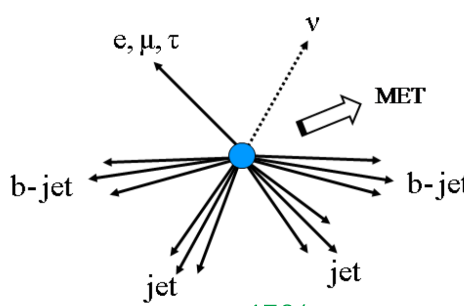
W decay modes
leptons
jets

dileptons



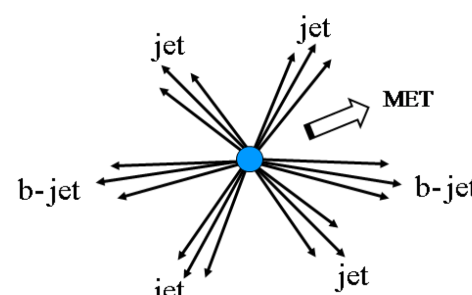
~9%

lepton+jets



~45%

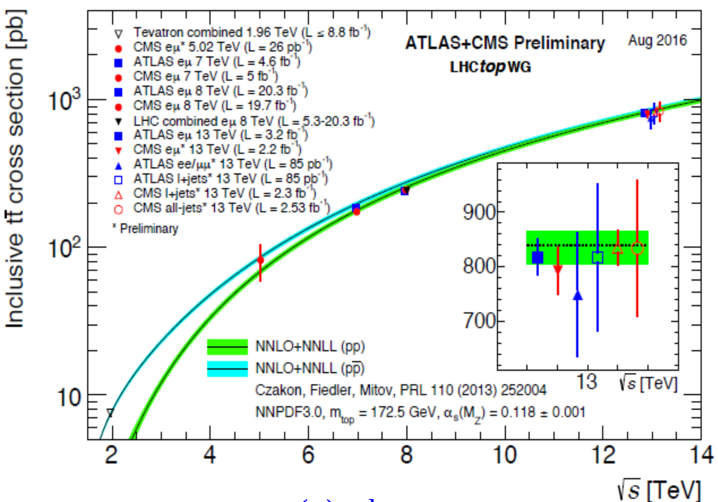
all hadronic



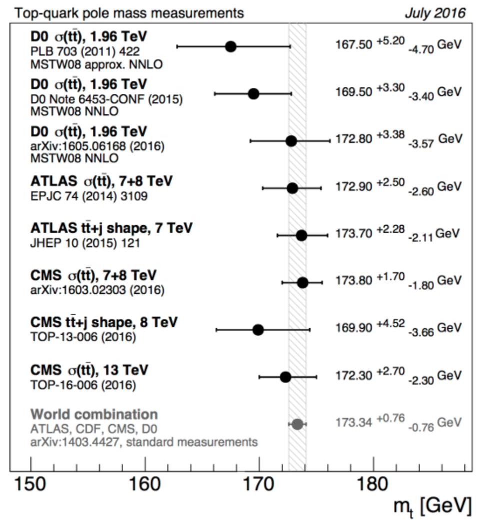
~46%

Top quark properties: mass, charge, spin, width, lifetime, …

cross section

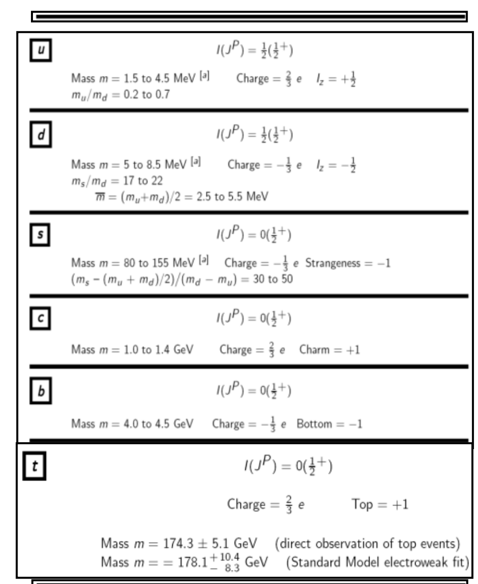


mass



electric charge +2/3e
color triplet
spin 1/2
topness +1
full width 2.00±0.47 GeV
lifetime ~3.29·10^{-25} s
decay (Br ≈ 100%) W→ bt

3 generations of quarks



$\sigma(tt)$, pb

CMS	13 TeV	793 ± 8 ± 38 (2.2 fb^{-1})
ATLAS	13 TeV	803 ± 7 ± 27 (3.2 fb^{-1})
CMS	8 TeV	244.9 ± 1.4 ± 6.3 (19.7fb^{-1})
ATLAS	8 TeV	242.4 ± 1.7 ± 5.5 (20.2 fb $^{-1}$)
LHCb	8 TeV	289 ± 43 ± 40 (2.0 fb^{-1})
CMS	7 TeV	173.6 ± 2.1 ± 4.5 (5.0 fb^{-1})
ATLAS	7 TeV	182.9 ± 3.1 ± 4.2 (4.6 fb $^{-1}$)
LHCb	7 TeV	239 ± 53 ± 33 (1.0 fb^{-1})
CMS	5 TeV	82 ± 20 ± 5 (26 pb^{-1})

m_t , GeV/c^2
CDF+DØ+CMS+ATLAS
173.34 ± 0.27± 0.71 GeV/c^2
arXiv:1403.4427

Top quark is a complementary probe to search for new physics:

$t\to Wb$, V_{tb} ,V_{ts} ,V_{td} , FCNC:$t\to Zc(u)$, $t\to(Z,q,g)\gamma$, tagged jets, t-$\bar{t}$, t-$\bar{b}$ resonances, A_C , A_{FB} , A_{CP} , t-$\bar{t}$ spin correlations, polarization,…

Jay Howarth
(for ATLAS Collab.)
ICHEP2016, Chicago,USA

Michelangelo L. Mangano
ICHEP2016, Chicago,USA

Georgios Daskalakis
(for CMS Collab.)
ICNFP2016, Crete,Greece

Alberto Orso Maria Iorio
(for the ATLAS, CMS, and LHCb Collab.)
DIS2016, Hamburg, Germany

Antonio Limosani
(for ATLAS Collab.)
ICHEP2016, Chicago,USA

J.Fernandez
(for ATLAS,CDF,CMS,DØ Collab.)
LHCP16, Lund, Sweden

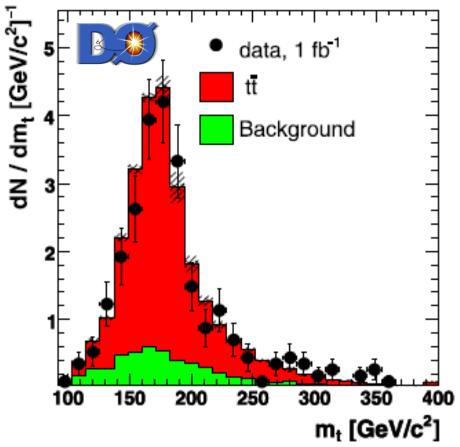
JINR

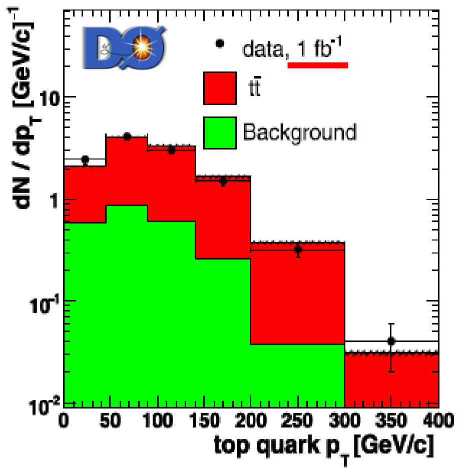
Top flavor & z-Scaling

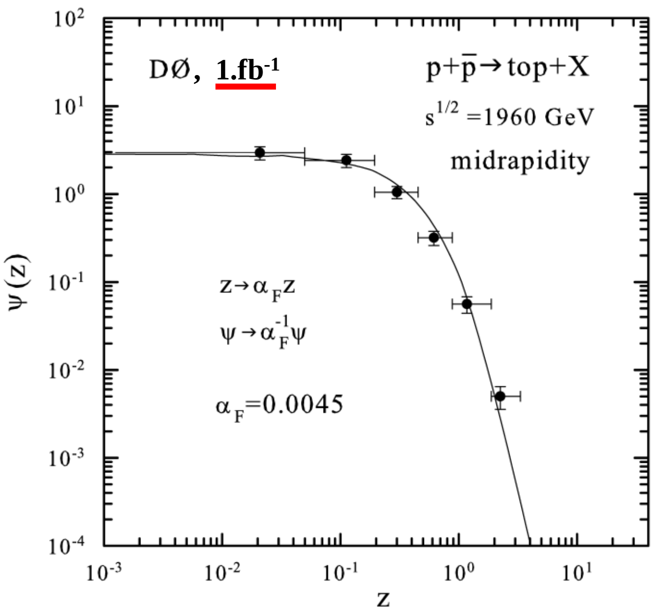
$p\bar{p}$ & pp @ 1.96,7,8 TeV
low integral luminosity

Self-similarity of top quark production at Tevatron

DØ Collaboration V.M. Abazov et.al.
Phys.Lett. B 693 (2010) 515.







M.T. & I.Zborovský
JINR E2-2012-12
J.Mod.Phys. 3(2012)815

- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

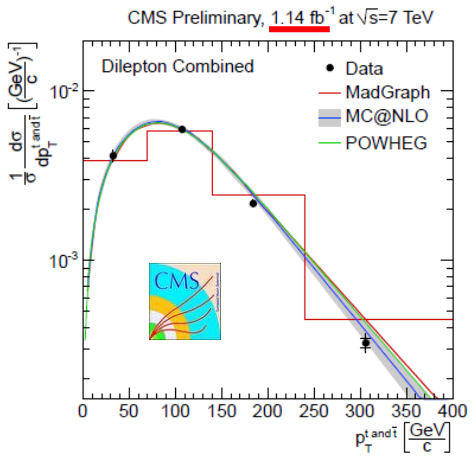
Very small energy loss in the elementary $t\bar{t}$ production process.

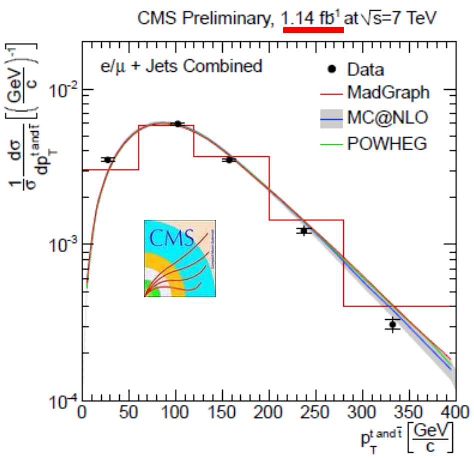
- Measurements of p_T and m_T distributions
- Probing large momentum $20<p_T< 400$ GeV/c
- NLO, NNLO, MC@ NLO , m_t =170 GeV

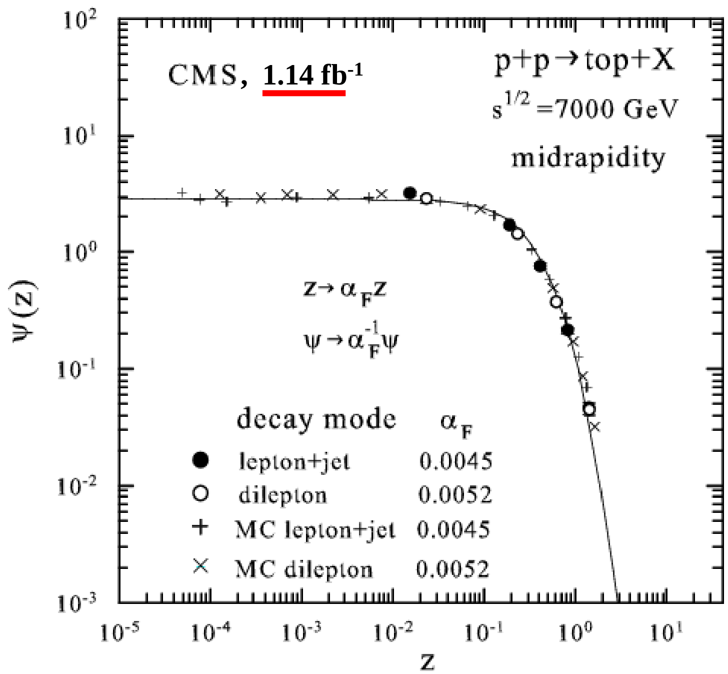
DØ data confirm self-similarity of top quark production in $p\bar{p}$.

Self-similarity of top quark production at LHC

Differential production cross sections
as a function of the transverse momentum
of the top quarks p_T







M.T. & I.Zborovský
ISMD'12
Kielce, Poland, 2012

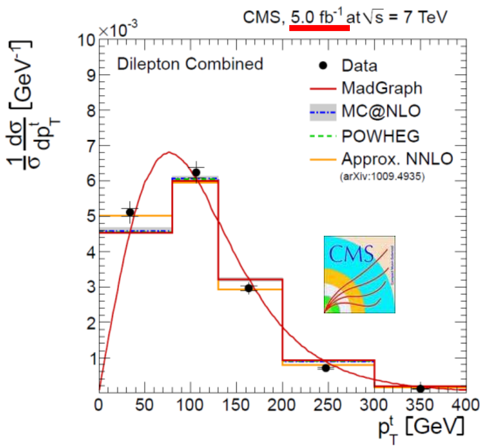
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

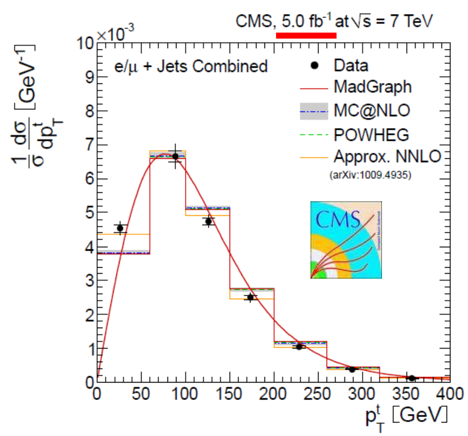
CMS data confirm self-similarity of top quark production in pp

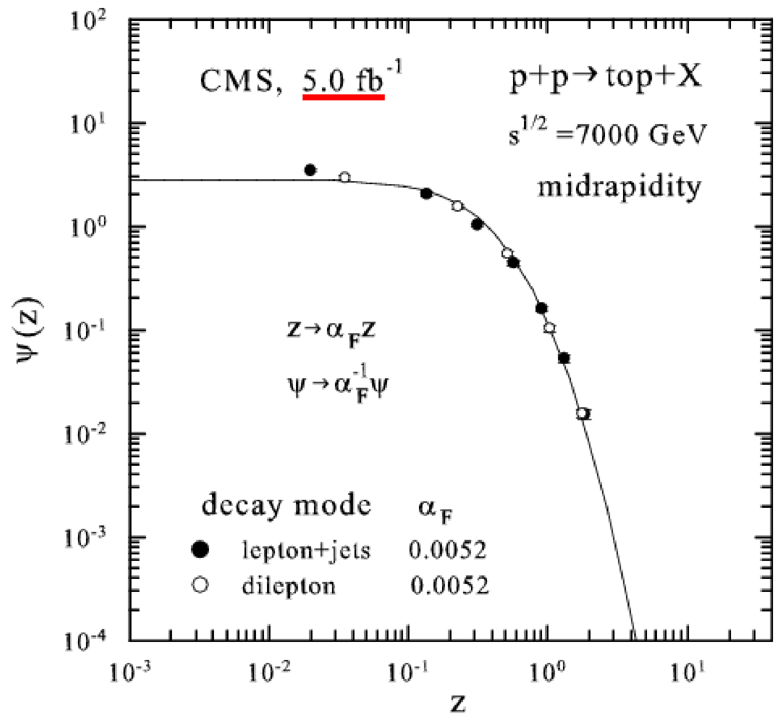
CMS Collaboration,
CMS-PAS-TOP-11-013 (2011)

Self-similarity of top quark production at LHC

Differential production cross sections as a function of the transverse momentum of the top quarks p_T







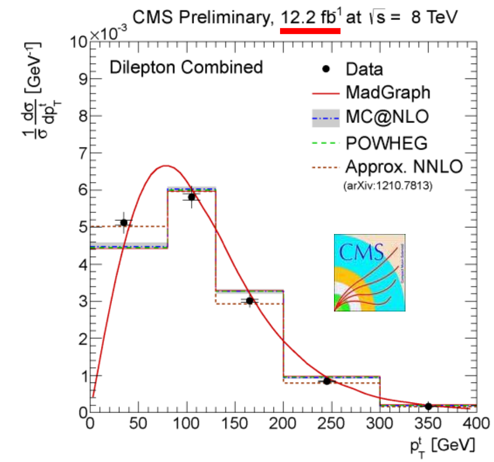
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

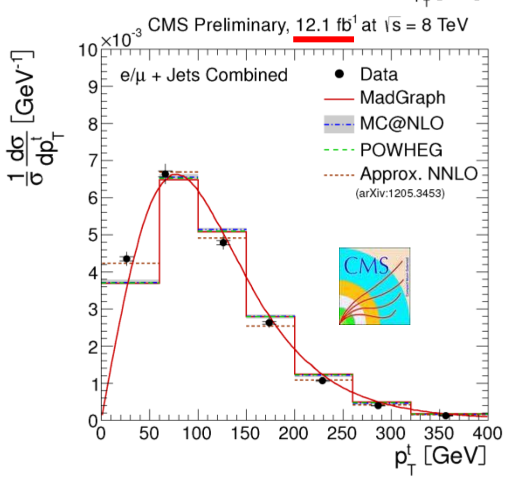
CMS data confirm self-similarity of top quark production in pp

CMS Collaboration,
CMS-PAS-TOP-11-013
Eur.Phys.J.C73(2913)2339

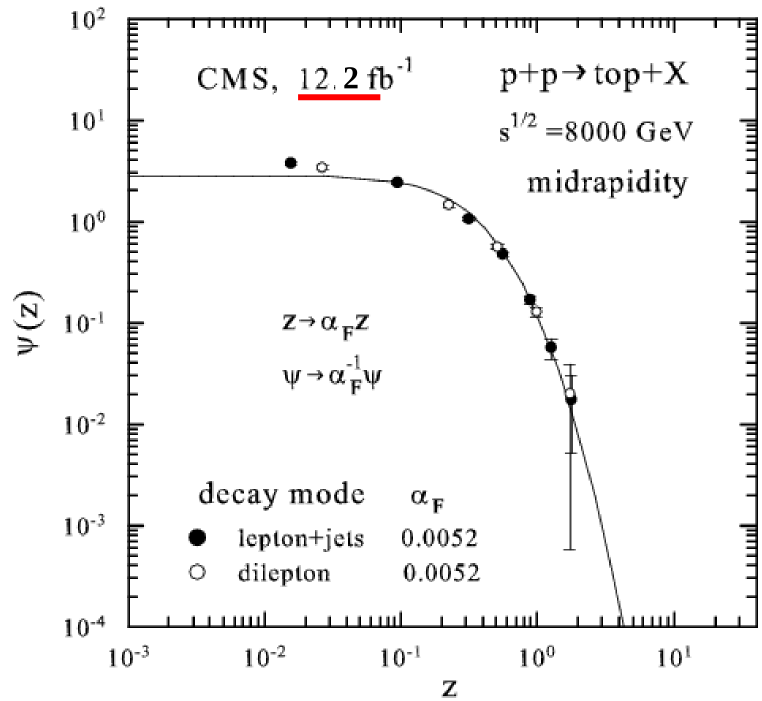
Self-similarity of top quark production at LHC

Differential production cross sections
as a function of the transverse momentum
of the top quarks p_T





CMS Collaboration,
CMS PAS TOP-12-027
CMS PAS TOP-12-028



- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

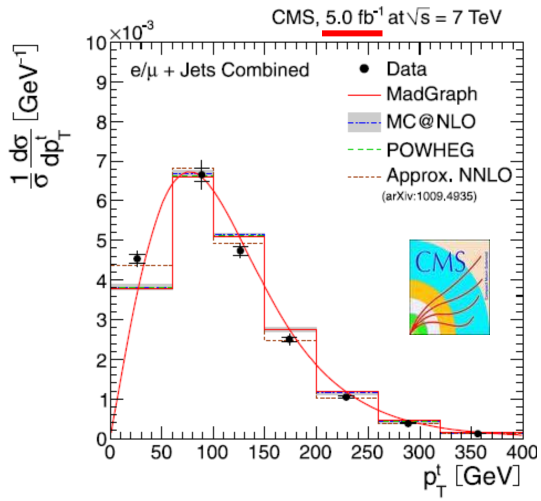
CMS data confirm self-similarity of top quark production in pp

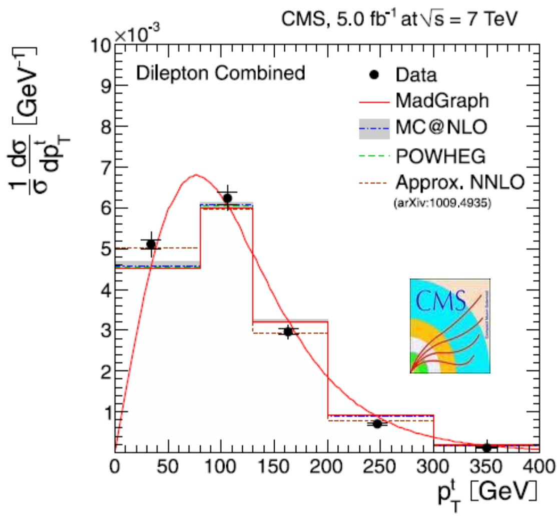
Top flavor & z-Scaling

$p\bar{p}$ & pp @ 1.96,7,8,13 TeV

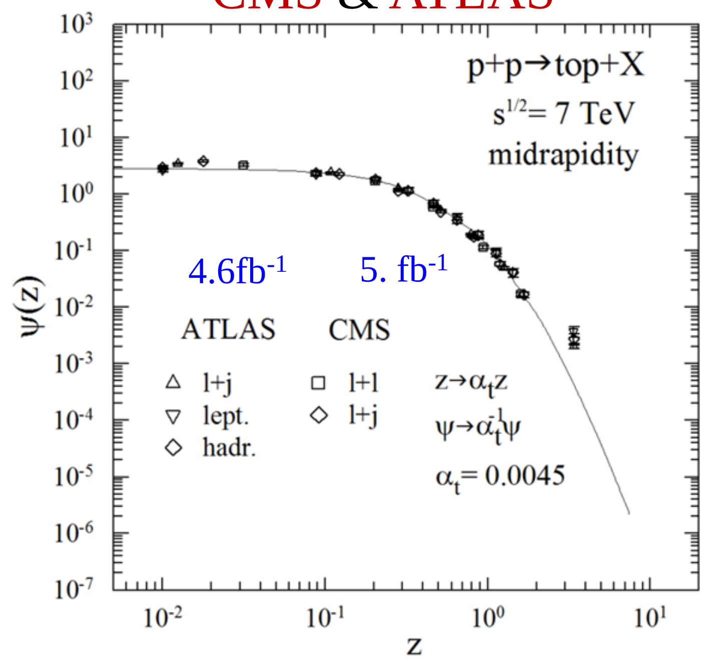
high integral luminosity

Self-similarity of top quark production at LHC @ 7 TeV





CMS & ATLAS



ATLAS
Phys. Rev. D90 (2014) 072004
JHEP 06 (2015)100

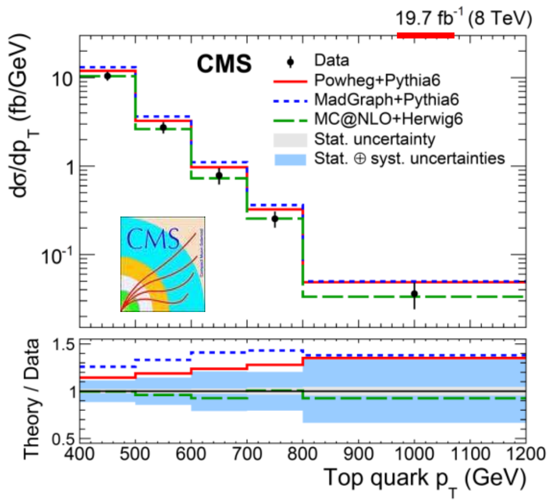
CMS
EPJC 73(2013)2339

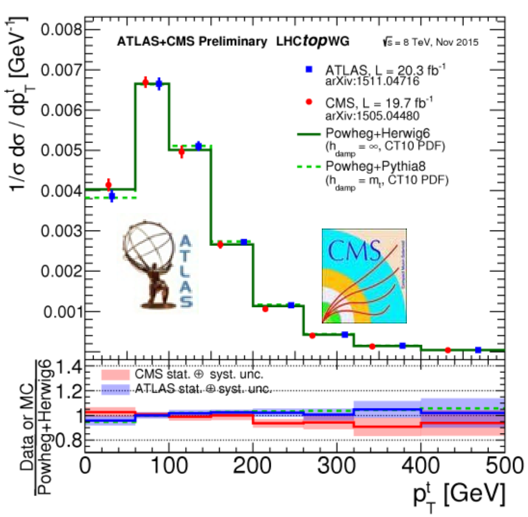
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

CMS & ATLAS data confirm self-similarity of top quark production in pp

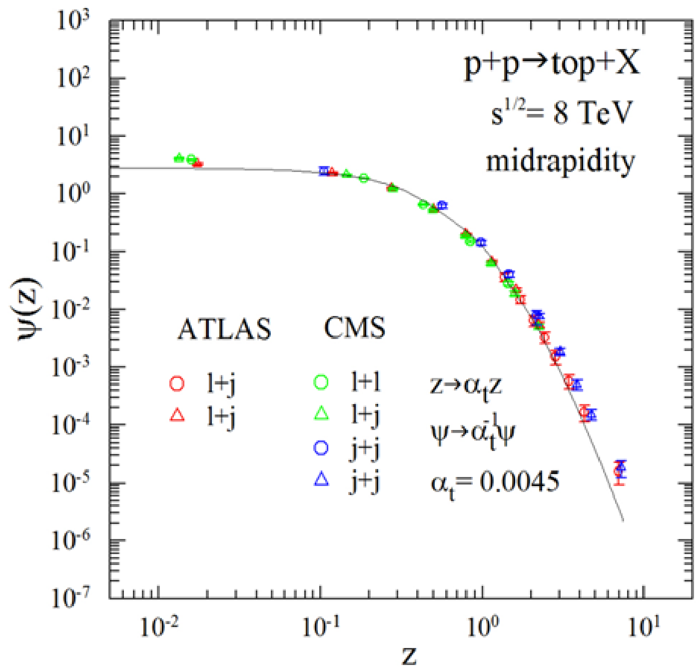
Self-similarity of top quark production at LHC @ 8 TeV

Differential production cross sections
as a function of the transverse momentum
of the top quarks p_T





CMS & ATLAS



ATLAS
Phys.Rev.D93(2016)032009
arXiv:1511.04716

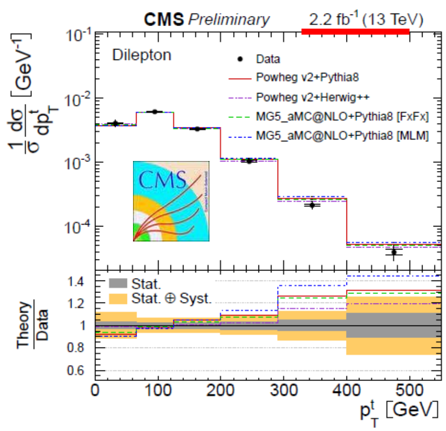
CMS
EPJC 75(2015)542
EPJC76(2016)128
arXiv:1505.04480
arXiv:1605.00116

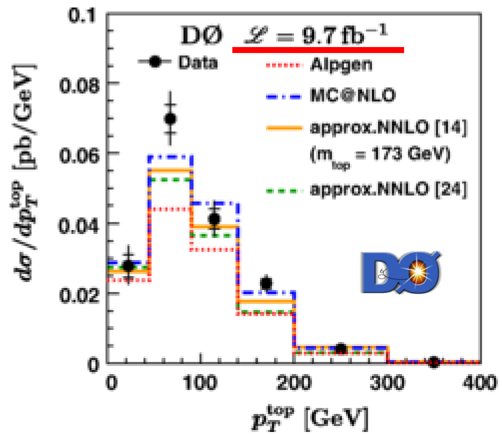
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

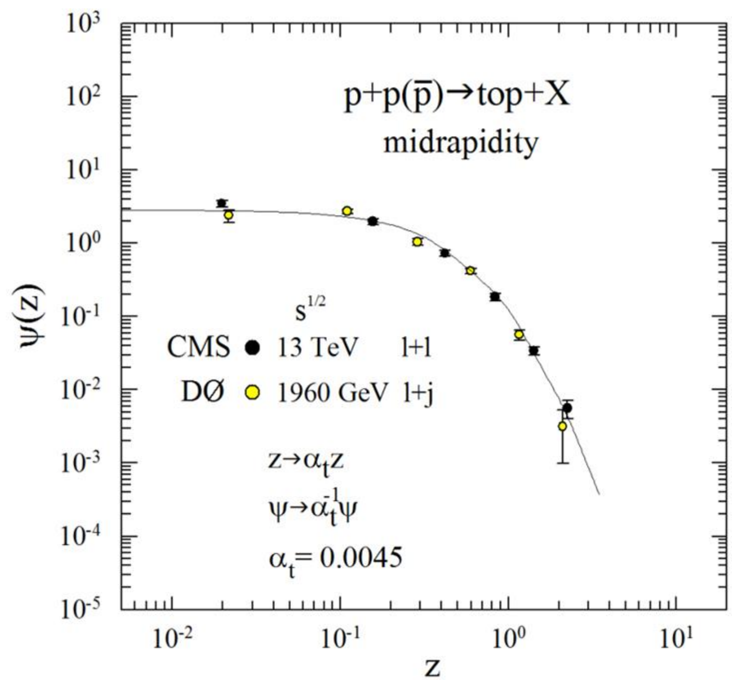
CMS & ATLAS data confirm self-similarity of top quark production in pp

Self-similarity of top quark production at LHC @ 13 TeV

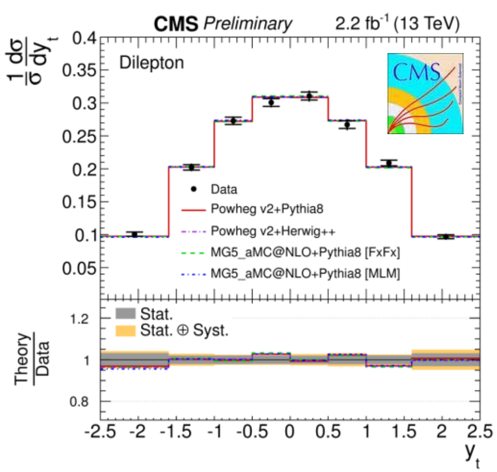
Differential production cross sections
as a function of the transverse momentum of the top quarks p_T

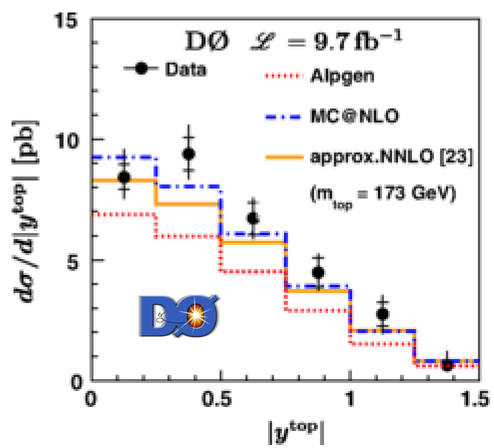






Differential production cross sections
as a function of the rapidity of the top quarks y





- Energy independence of $\Psi(z)$
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

CMS-PAS TOP-16-011
DØ PRD 90 (2014) 092006

CMS & DØ data confirm self-similarity
of top quark production in pp & p$\bar{\text{p}}$

Self-similarity of top quark production in pp

Self-similarity parameter

$$z = z_0 \Omega^{-1}$$

$$z_0 = \frac{s_\perp^{1/2}}{(dN_{ch}/d\eta|_0)^c m_N}$$

$$\Omega = (1-x_1)^{\delta}(1-x_2)^{\delta}(1-y_a)^{\varepsilon_F}(1-y_b)^{\varepsilon_F}$$

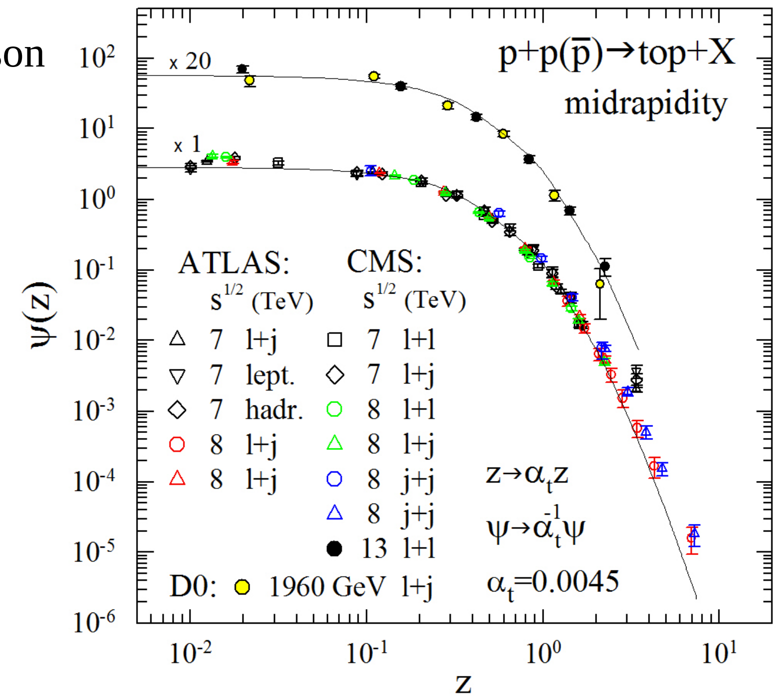
Solid line for π^- meson is a reference curve $\varepsilon_\pi = 0.2, \quad \alpha_\pi = 1$

- $dN_{ch}/d\eta|_0$ - multiplicity density
- c - "specific heat" of bulk matter
- δ - proton fractal dimension
- ε_F - fragmentation fractal dimension

Scaling function

$$\Psi(z) = \frac{\pi}{(dN/d\eta)\cdot \sigma_{inel}} \cdot J^{-1} \cdot E\frac{d^3\sigma}{dp^3}$$

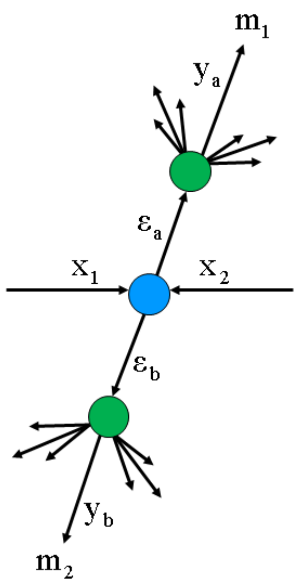
"Collapse" of data points onto a single curve



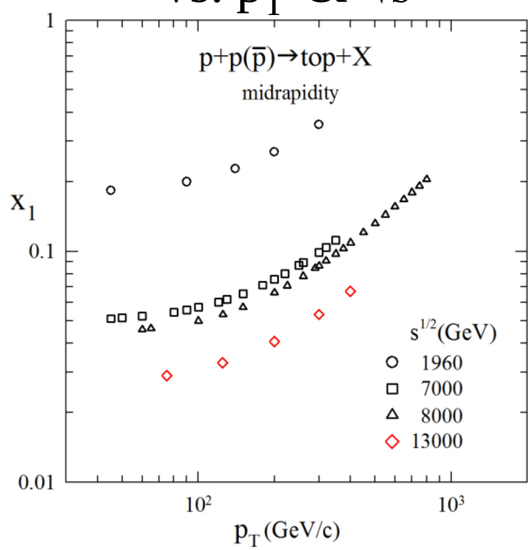
- Energy independence of $\Psi(z)$
- Centrality independence of $\Psi(z)$
- Power law at high z
- Saturation at low z

Universality: the same shape of Ψ both for top and π^- (solid line)

Top production at a constituent level



Momentum fractions
vs. p_T & $\sqrt{s}$



Top quark:

$y_{top} \approx 1,$
$\varepsilon_{top} \approx 0,$
$M_X \approx m_{top}$

$$z = z_0 \Omega^{-1}$$

$$\Omega = (1-x_1)^{\delta}(1-x_2)^{\delta}(1-y_a)^{\varepsilon_F}(1-y_b)^{\varepsilon_F}$$

$$M_X = x_1 M_1 + x_2 M_2 + m_{top}/y_{top}$$

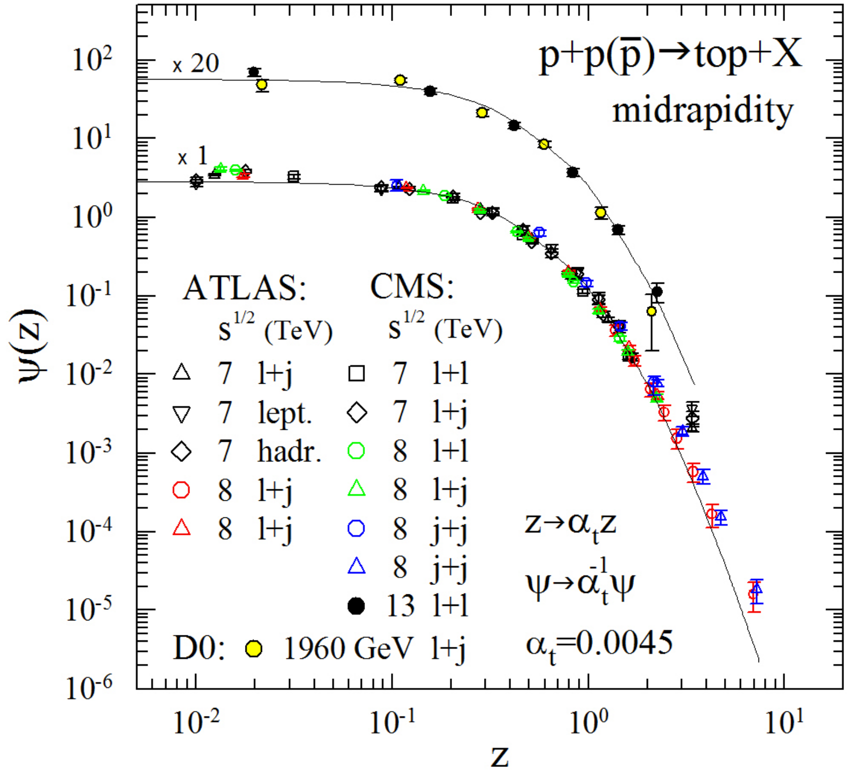
Negligible energy loss $\rightarrow$ high sensitivity at high x_1 to
- structure of colliding objects (dimensions δ_1, δ_2)
- constituent interactions ("specific heat" c)
- transition of point-like massless top to massive top ($m_{top} \approx m_{Au}$)

Verification of universality of $\Psi(z)$ shape over a wide z-range.
Extraction of ε_{top} $\rightarrow$ estimation of energy loss.

Self-similarity of top quark production at LHC @ Tevatron

$s^{1/2}$ (GeV)	
1960	PRD90(2014)092006
7000	PRD90(2014)072004
7000	JHEP06(2015)100
7000	JHEP06(2015)100
7000	EPJC73(2013)2339
7000	EPJC73(2013)2339
8000	PRD93(2016)032009
8000	arXiv:1511.04716
8000	EPJC75(2015)542
8000	EPJC75(2015)542
8000	EPJC76(2016)128
8000	arXiv:1605.00116
13000	CMS TOP 16-011

"Collapse" of data points onto a single curve



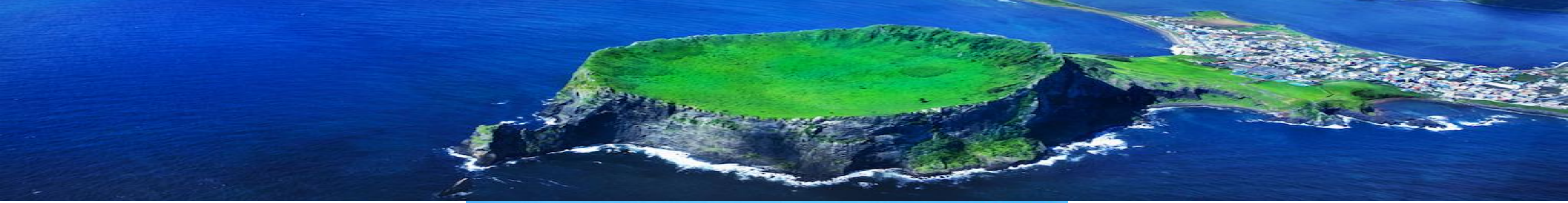
- Energy independence of $\Psi(z)$
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

LHC & Tevatron data confirm self-similarity of top quark production in pp & $p\bar{p}$

Conclusions

- Results of analysis of new LHC data on inclusive transverse momentum spectra of top quarks produced in pp collisions at $\sqrt{s}$=7, 8 and 13 TeV in z-scaling approach were presented.
- New confirmations of z-scaling at LHC (energy and flavor independence, saturation of $\Psi(z)$) were demonstrated.
- DØ data on top transverse momentum spectra in $p\bar{p}$ collisions are in agreement with CMS and ATLAS data in pp collisions.
- z-Scaling of hadron production at high energies manifests self-similarity, locality and fractality of hadron interactions at a constituent level.

New TeV-energy region is available to search for, study and understand new physics phenomena at LHC.



Thank You for Your Attention !

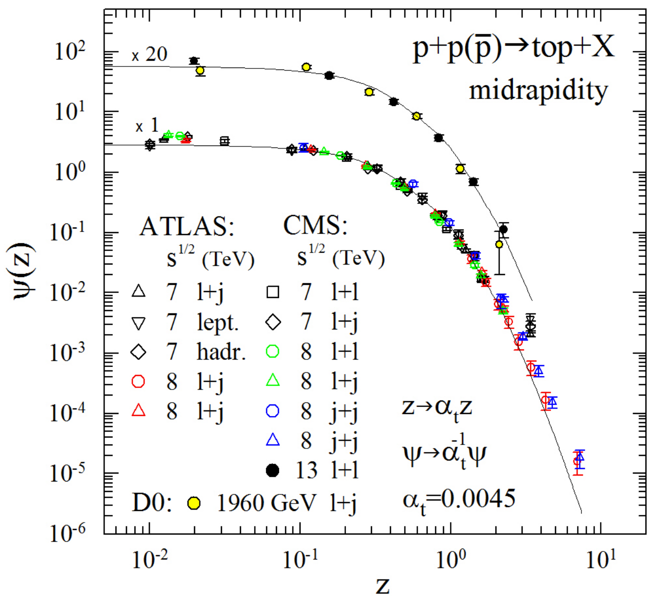
Back-up slides

Top-Quark p_T-Spectra at LHC and Flavor Independence of z-Scaling

M. Tokarev (*JINR, Dubna*) & I. Zborovský (*NPI, Řež*)

Self-similarity of top production at LHC & Tevatron

$s^{1/2}$ (GeV)		
○ (yellow)	1960	PRD90(2014)092006
△	7000	PRD90(2014)072004
▽	7000	JHEP06(2015)100
◇	7000	JHEP06(2015)100
□	7000	EPJC73(2013)2339
◇	7000	EPJC73(2013)2339
○ (red)	8000	PRD93(2016)032009
△ (red)	8000	arXiv:1511.04716
○ (green)	8000	EPJC75(2015)542
△ (green)	8000	EPJC75(2015)542
○ (blue)	8000	EPJC76(2016)128
△ (blue)	8000	arXiv:1605.00116
◆	13000	CMS TOP 16-011



"Collapse" of data points onto a single curve.