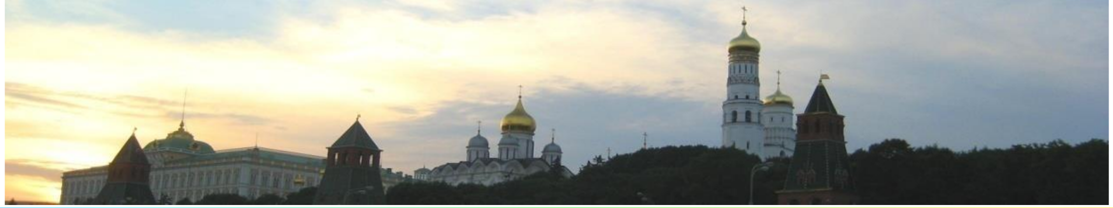
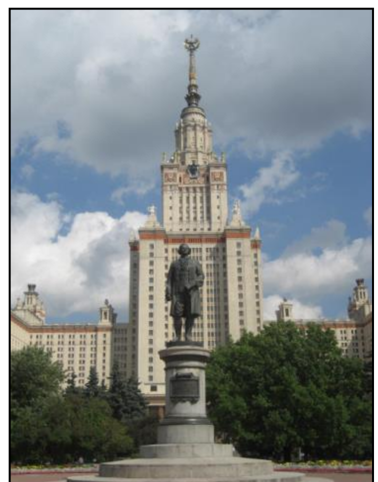


Self-similarity of Jet and Top quark production at Tevatron and LHC

M. Tokarev[*] & I. Zborovsky[**]
T.Dedovich[*]

[*]Joint Institute for Nuclear Research, Dubna, Russia
[**]Nuclear Physics Institute, Řež, Czech Republic

1913-1993



1711-1765

16th Lomonosov Conference on Elementary Particle Physics
MSU, Moscow, Russia, August 22 - 28, 2013

Contents

- Introduction (motivation & goals)
- z-Scaling (principles, ideas, definitions,…)
- Flavor independence of Ψ(z)
- Self-similarity:
  - Top-quark production at Tevatron & LHC
  - Jet production at RHIC, Tevatron & LHC
- Conclusions

z-Scaling - Universality & Saturation

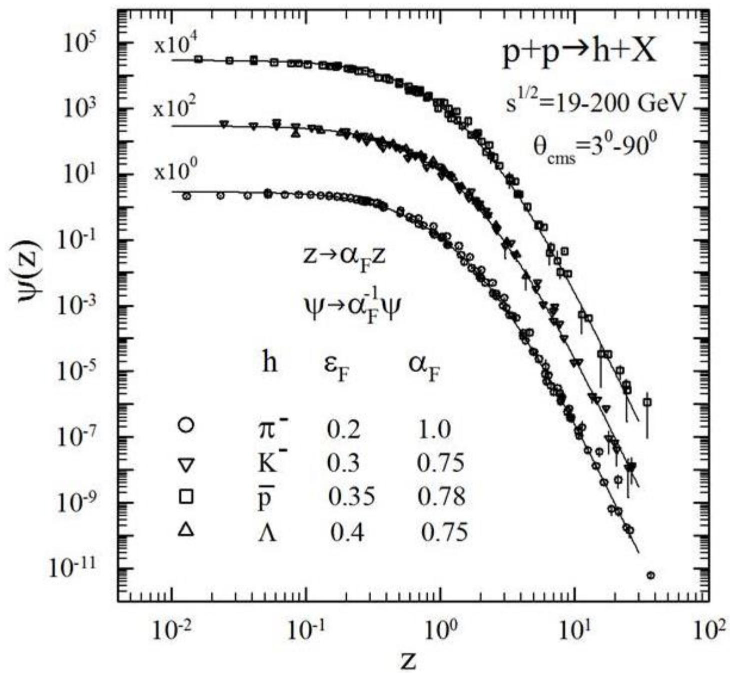
Inclusive cross sections of π^-, K^-, $\bar{p}$, Λ in pp collisions

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.
Universality classes – hadron species (ε_F, α_F).

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,…)

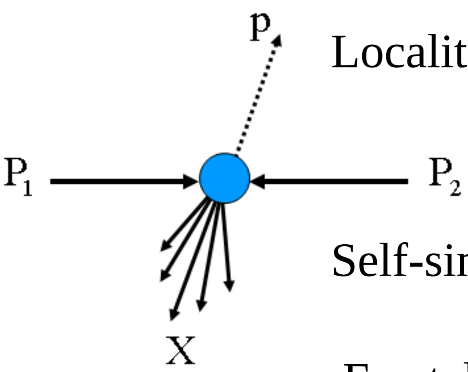
Analysis of new experimental data on p_T-spectra of top-quark and & jet production in $p\bar{p}$ and pp collisions obtained at Tevatron and LHC to verify properties of z-scaling.

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

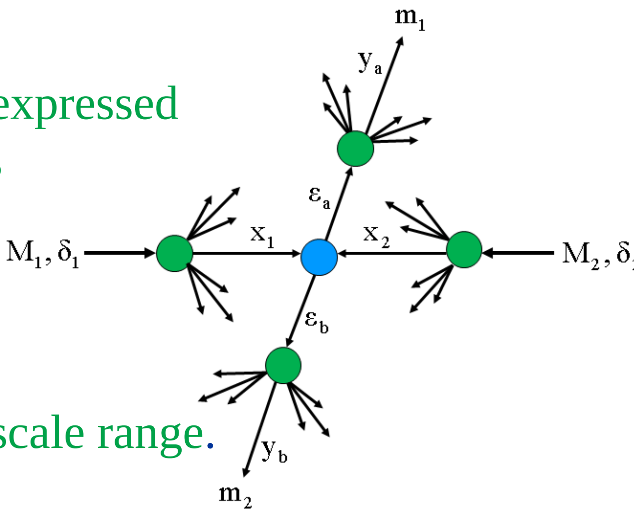
Principles: locality, self-similarity, fractality



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.

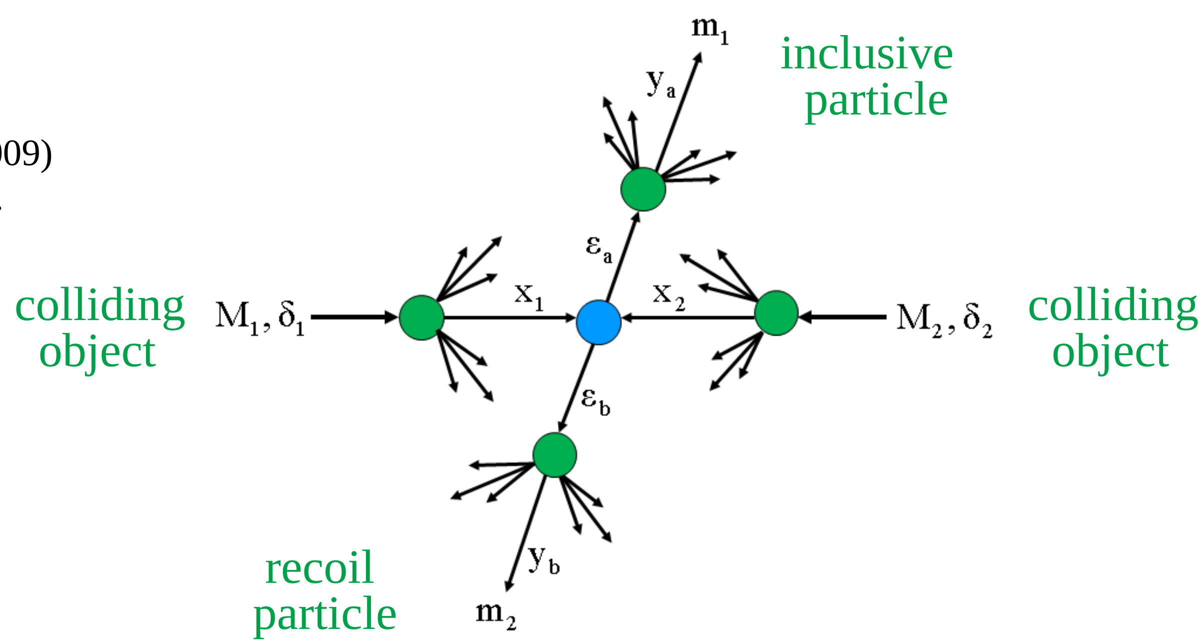


Hypothesis of z-scaling :

$s^{1/2}$, 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):

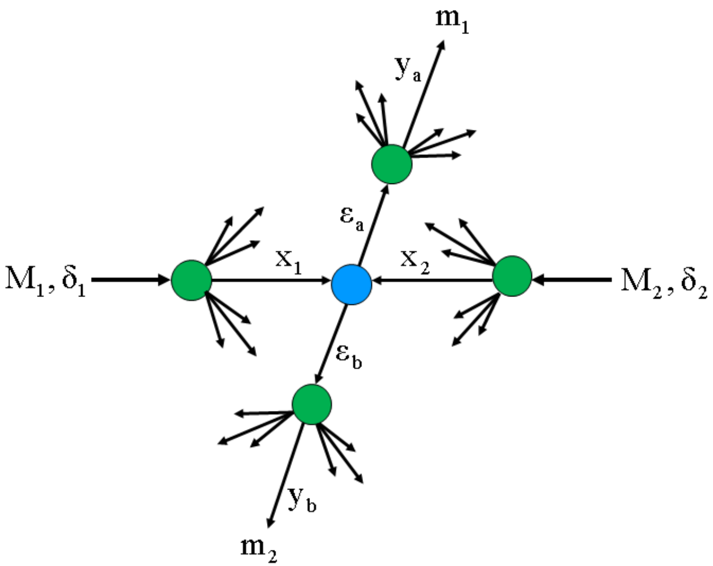
$$(x_1P_1+x_2P_2-p/y_a)^2 = M_X^2$$

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

z as self-similarity parameter

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

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



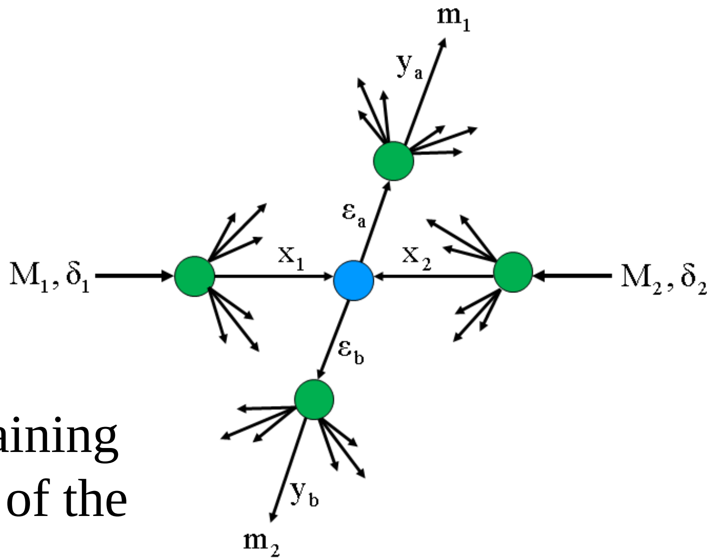
- Ω^{-1} is the minimal resolution at which a constituent subprocess can be singled out of the inclusive reaction
- $s_\perp^{1/2}$ is the transverse kinetic energy of the subprocess consumed on production of m_1 & m_2
- $dN_{ch}/d\eta|_0$ is the multiplicity density of charged particles at $\eta = 0$
- 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

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

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

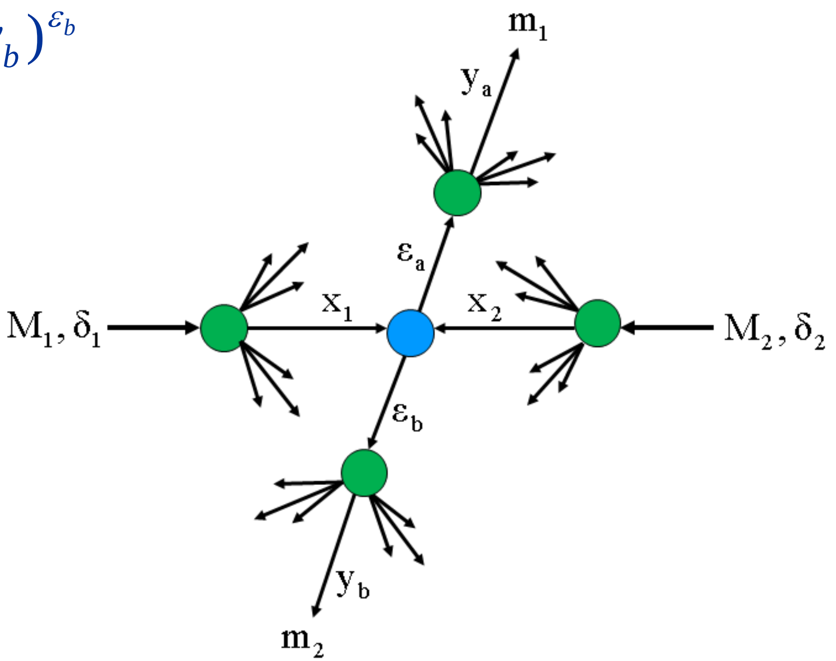
The fractal measure z diverges as the resolution Ω^{-1} increases.

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:

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

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



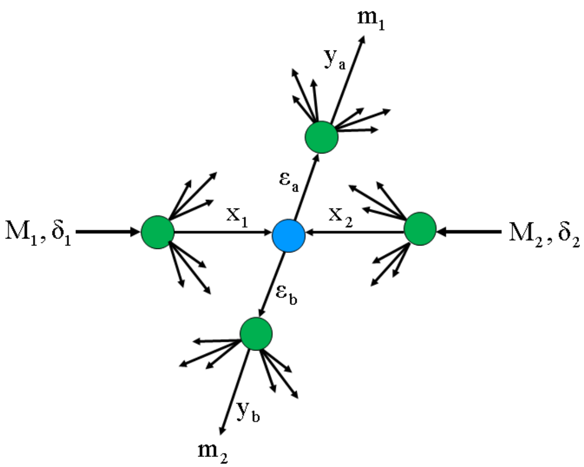
Momentum conservation law

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

Recoil mass

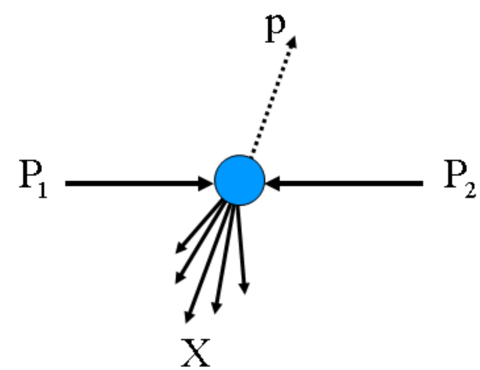
$$M_X = x_1M_1+x_2M_2+m_2/y_b$$

Scaling function $\Psi(z)$



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

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



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

- 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

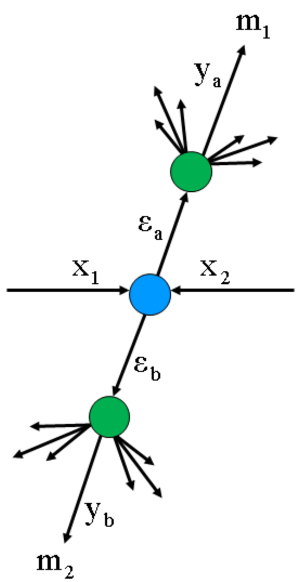
The scaling function $\Psi(z)$ is probability density to produce an inclusive particle with the corresponding z.

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

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

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

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

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

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

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

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

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

$$s_\lambda = (\lambda_1 P_1 + \lambda_2 P_2)^2$$

$$s_\chi = (\chi_1 P_1 + \chi_2 P_2)^2$$

The scaling variable z and scaling function $\Psi(z)$ are expressed via Lorentz invariants.

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

- Energy independence of Ψ(z) ($s^{1/2} > 20$ GeV)
- Angular independence of Ψ(z) ($\theta_{cms}=3^0$-90^0)
- Multiplicity independence of Ψ(z) ($dN_{ch}/d\eta=1.5$-26)
- Power law, Ψ (z) $\sim z^{-\beta}$, at high z ($z > 4$)
- Flavor independence of Ψ(z) (π,K,φ,Λ,..,D,J/ψ,B,ϒ,…, top)
- Saturation of Ψ(z) at low z ($z < 0.1$)

These properties reflect self-similarity, locality, and fractality
of the hadron interaction at a 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)
…………………

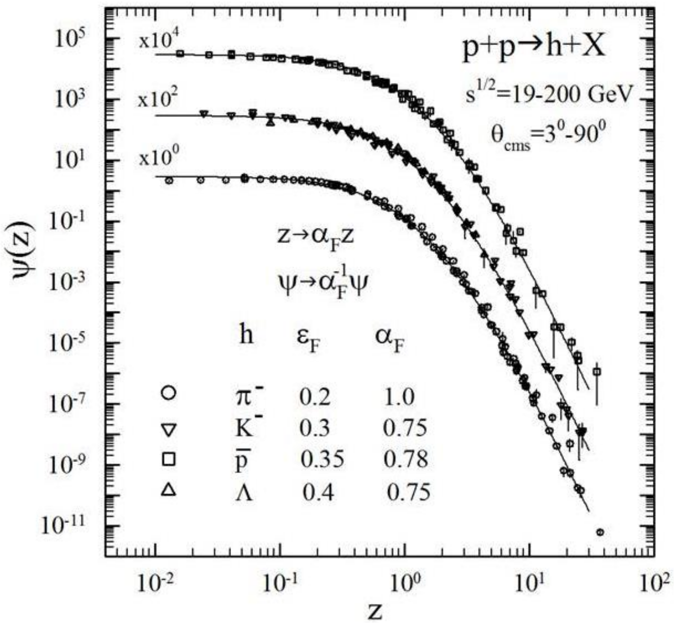
Flavor independence of Ψ(z) at RHIC

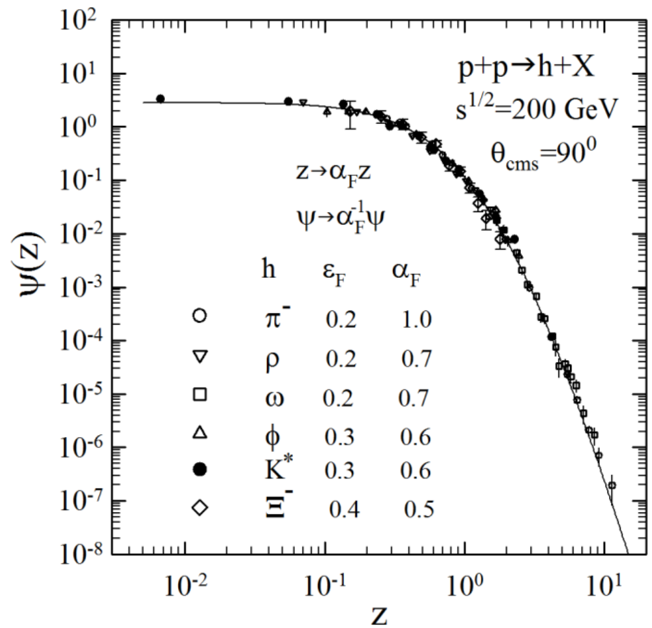
M.T. & I.Zborovský
Int.J.Mod.Phys. A24,1417(2009)

π^-, ρ, ω, ϕ, K*, Λ, Ξ, J/ψ, D, B, ϒ

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 $z < 0.01$

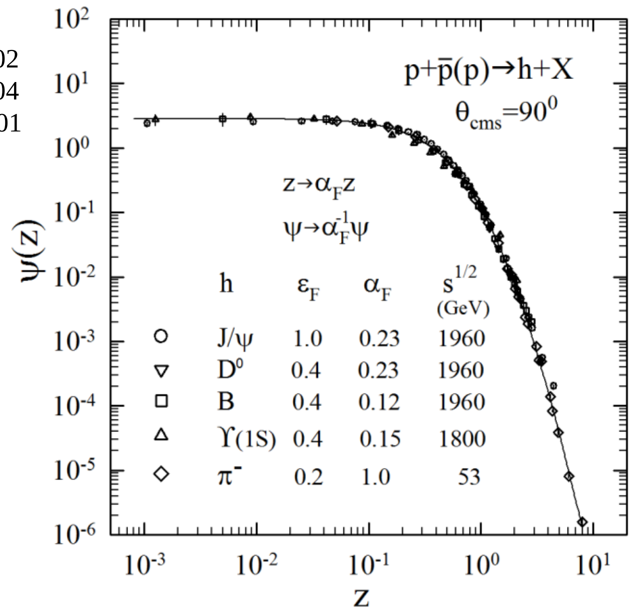
- Power law $\Psi(z) \sim z^{-\beta}$ at large z
- ε_F, α_F independent of p_T, $s^{1/2}$

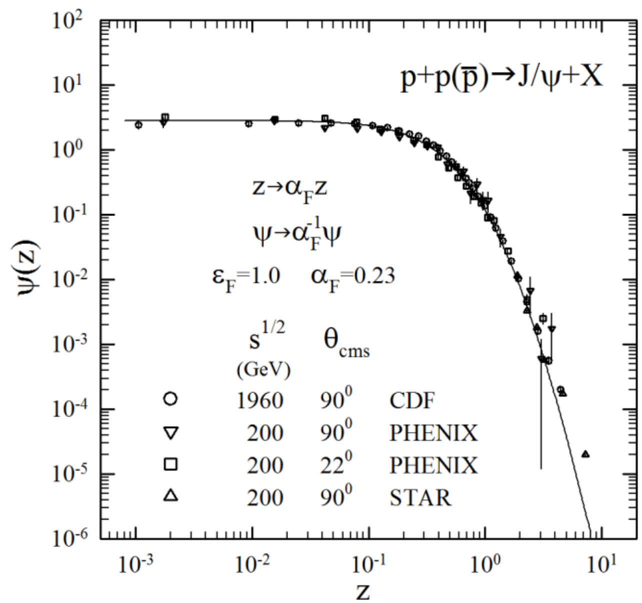
Self-similarity of particle formation with various flavor content.

Flavor independence of Ψ(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 Ψ(z) for $z < 0.1$
- Flavor independence of Ψ(z)
- Extra large $\varepsilon_F=1$ for J/ψ

Flavor independence of Ψ(z) at Sp$\bar{p}$S, Tevatron, RHIC, LHC

π^-, K_S^0

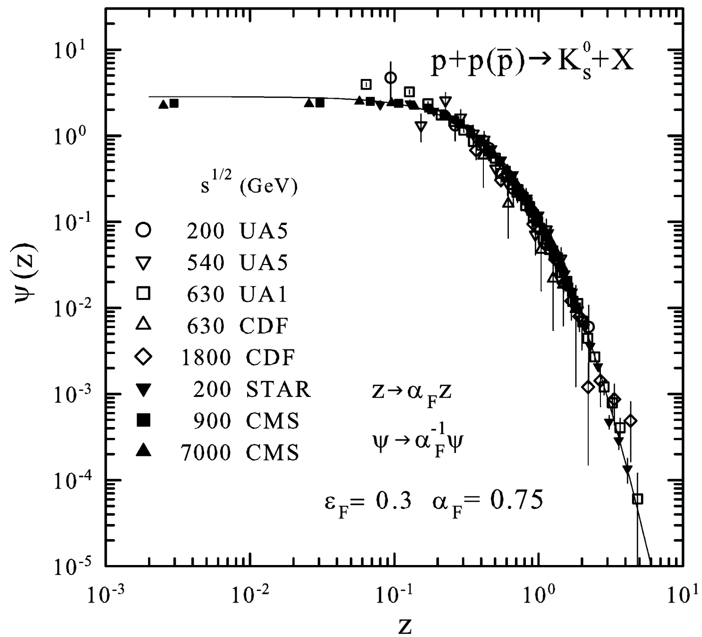
CERN: UA5
PLB 199 (1987) 311
NPB 258 (1985) 505

CERN: UA1
PLB 366 (1996) 441

FNAL: CDF Coll.
PRD 40 (1989) 3791

RHIC: STAR Coll.
PRC 75 (2007) 064901

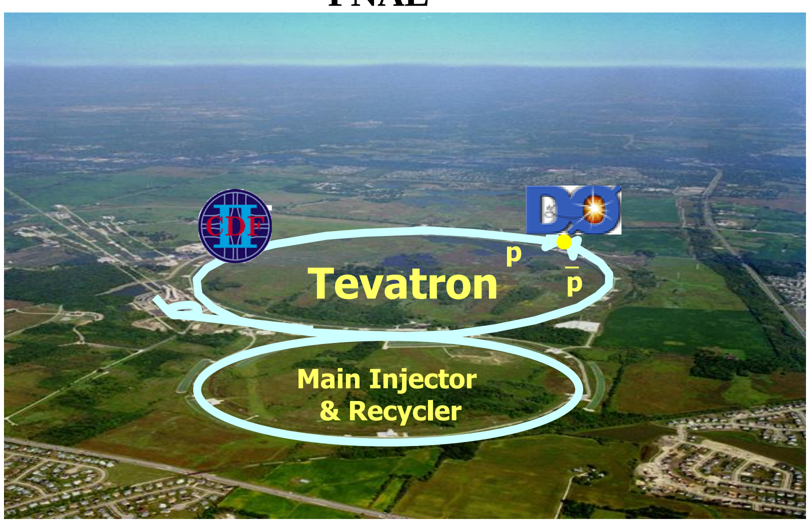
LHC: CMS Coll.
J. High Energy Phys.05 (2011) 064



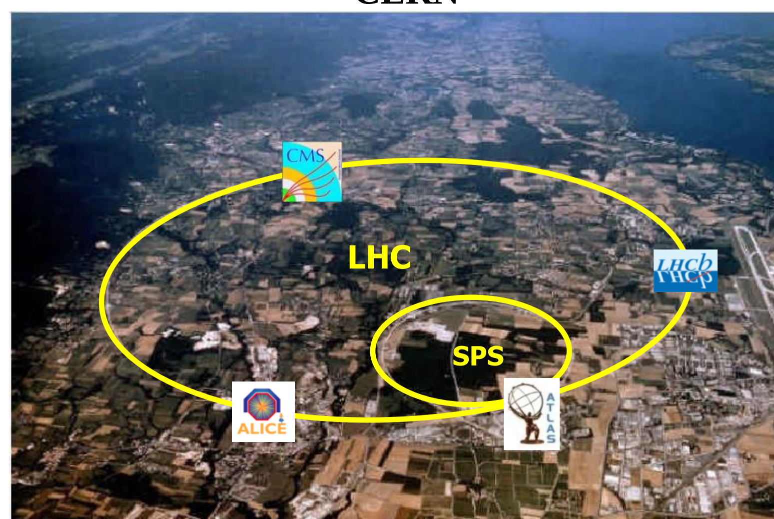
- Energy independence of Ψ(z)
- Saturation of Ψ(z) for z < 0.01
- Shape of Ψ(z) is the same in p$\bar{p}$ and pp

What about flavor independence of $\Psi(z)$ for top quark production in $p\bar{p}$ & pp collisions at Tevatron and LHC ?

FNAL



CERN

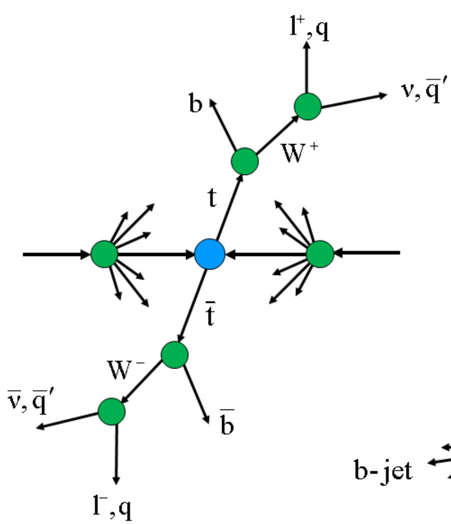


Top quark production and decay

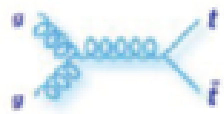
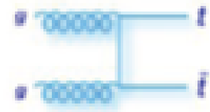
Top-quark discovery
1995

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

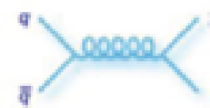
$m_t \approx 170$ GeV



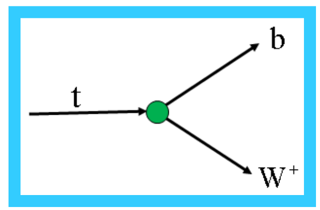
Gluon fusion

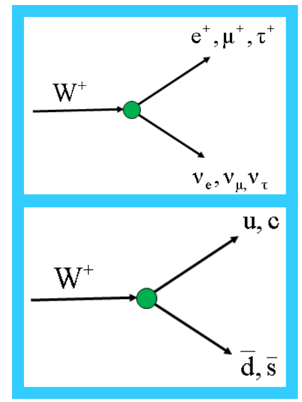



Quark-antiquark annihilation



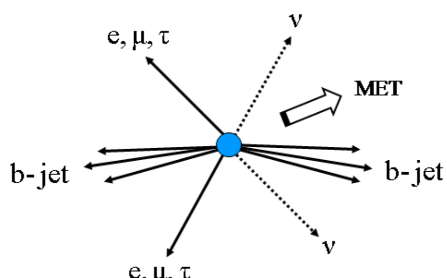
		Gluon fusion	Quark-antiquark annihilation
LHC	7 TeV	~ 85%	~15%
Tevatron	1.96 TeV	~ 15%	~85%





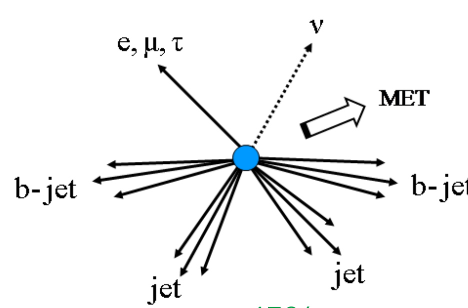
W decay modes
leptons
jets

dileptons



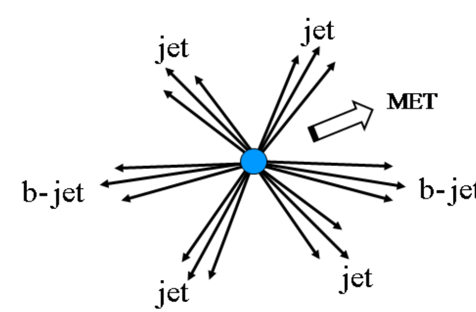
~9%

lepton+jets



~45%

all hadronic

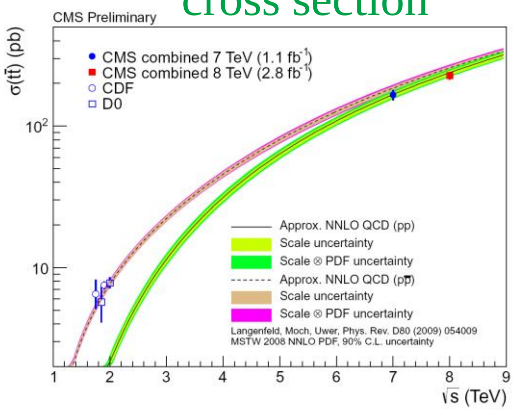


~46%

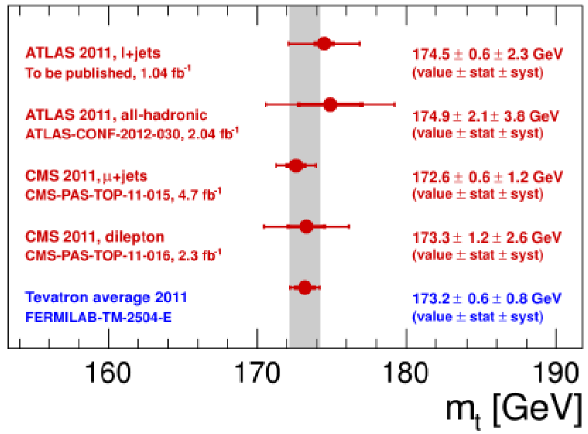
T. Muller, IHEP2012, Melbourne, Australia
S.Strandberg , EPSHEP 2013, Stockholm, Sweden

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

cross section



mass

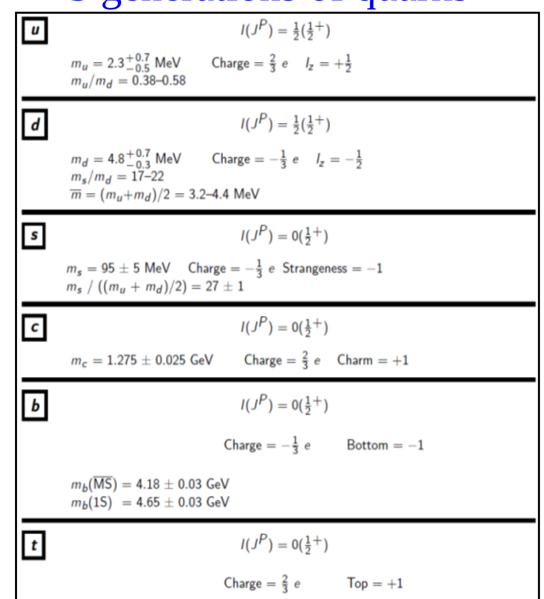


electric charge	+2/3e
color triplet	
spin	1/2
topness	+1
full width	2.00±0.47 GeV
lifetime	$\sim 3.29\cdot 10^{-25}$ s
decay (Br ≈ 100%)	$W\rightarrow bt$

	$\sigma(tt)$, pb	
CMS	8 TeV	227 ± 3 ± 11
ATLAS	7 TeV	177 ± 3 ± 7
CMS	7 TeV	165.8 ± 2.2 ± 10

	m_t, GeV/c^2
CDF+D0	173.2 ± 0.6 ± 0.8 GeV/c^2
CMS+ATLAS	173.3 ± 0.5 ± 1.3 GeV/c^2
CDF	172.85 ± 0.71 ± 0.85 GeV/c^2

3 generations of quarks


u
$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$
$m_u = 2.3^{+0.7}_{-0.5}$ MeV Charge $= \frac{2}{3}\,e$ $I_z = +\frac{1}{2}$
$m_u/m_d = 0.38$–0.58

d
$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$
$m_d = 4.8^{+0.7}_{-0.3}$ MeV Charge $= -\frac{1}{3}\,e$ $I_z = -\frac{1}{2}$
$m_s/m_d = 17$–22
$\overline{m} = (m_u+m_d)/2 = 3.2$–$4.4$ MeV

s
$I(J^P) = 0(\frac{1}{2}^+)$
$m_s = 95 \pm 5$ MeV Charge $= -\frac{1}{3}\,e$ Strangeness $= -1$
$m_s\,/\,((m_u+m_d)/2) = 27 \pm 1$

c
$I(J^P) = 0(\frac{1}{2}^+)$
$m_c = 1.275 \pm 0.025$ GeV Charge $= \frac{2}{3}\,e$ Charm $= +1$

b
$I(J^P) = 0(\frac{1}{2}^+)$
Charge $= -\frac{1}{3}\,e$ Bottom $= -1$
$m_b(\overline{MS}) = 4.18 \pm 0.03$ GeV
$m_b(1S) = 4.65 \pm 0.03$ GeV

t
$I(J^P) = 0(\frac{1}{2}^+)$
Charge $= \frac{2}{3}\,e$ Top $= +1$

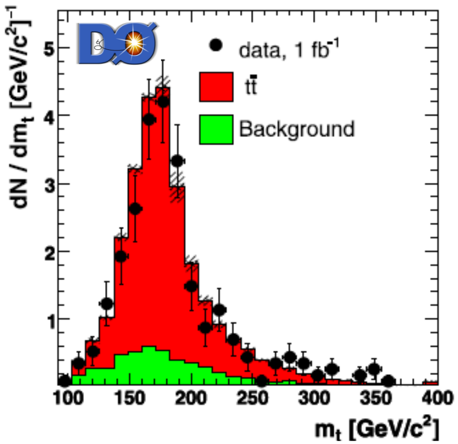
$t\rightarrow Wb$, V_{tb}, V_{ts}, V_{td}, Flavor Changing Neutral Current in non SM top decays: $t\rightarrow Zc(u)$, $t\rightarrow(Z,q,g)\gamma$, tagged jets, $t\text{-}\bar{t}$, $t\text{-}\bar{b}$ resonances, A_{FB}, A_C, $t\text{-}\bar{t}$ spin correlations ,…

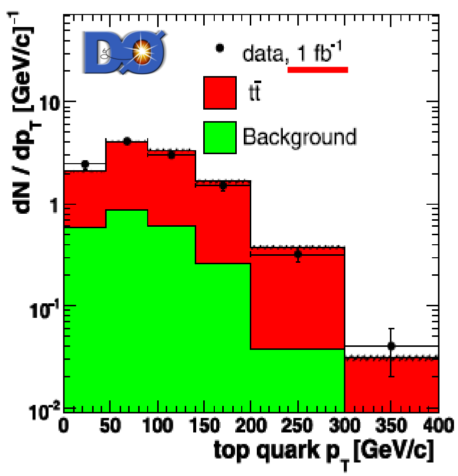
arXiv:1107.5255
arXiv:1205.2175
arXiv:1207.6758
ATLAS-CONF-2012-095
ATLAS-CONF-2012-024
CMS PAS TOP-12-001
CMS PAS TOP-11-024

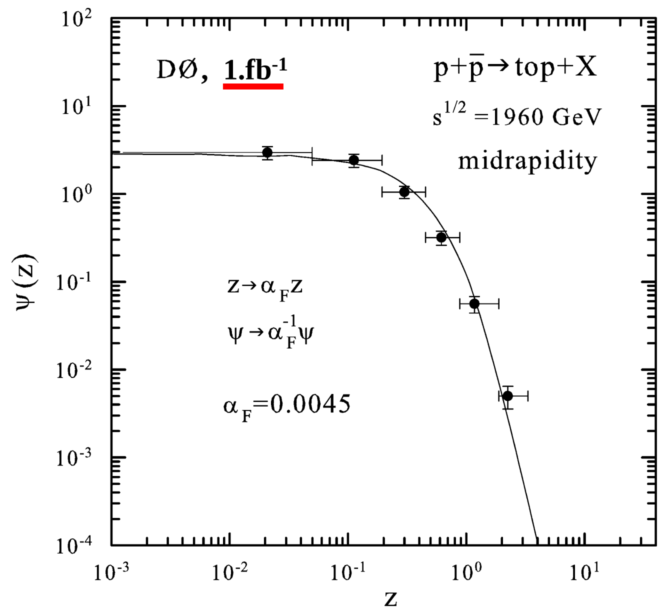
Top quark is a complementary probe to search for new physics using heavy flavour.

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" $c = 0.25$

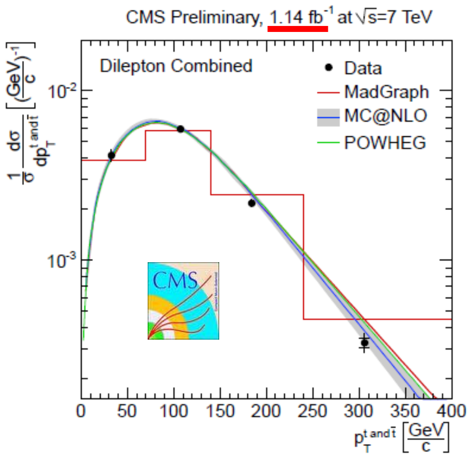
Very small energy loss in the elementary $t\bar{t}$ production process.

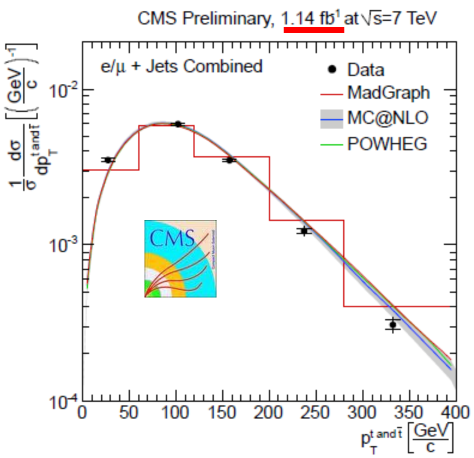
- Measurements of p_T and m_T distributions
- Probing large momentum $20 < p_T < 400$ GeV/c
- NLO, NNLO, MC@ NLO , m_t =170 GeV

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

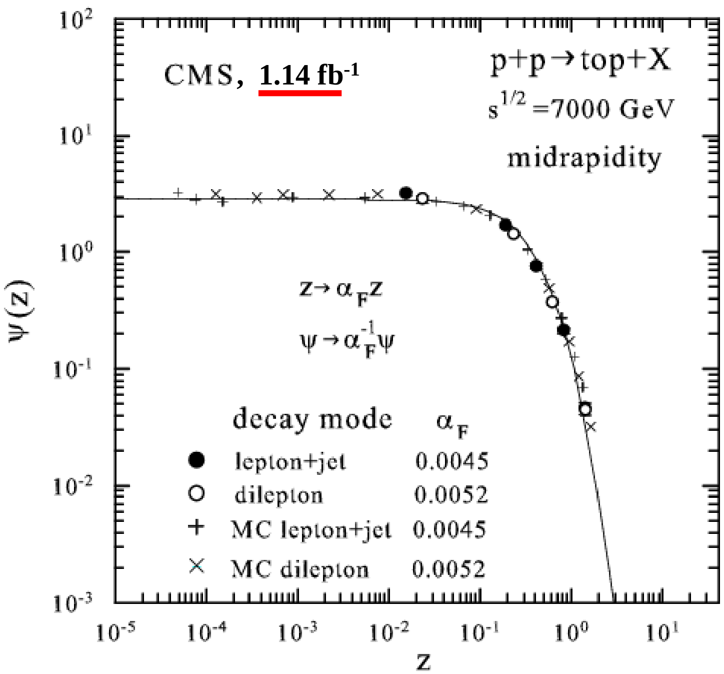
Self-similarity of top quark production at LHC

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





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



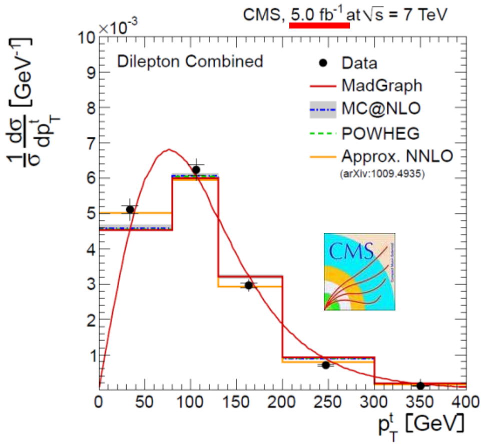
M.T. & I.Zborovský
ISMD’12
Kielce, Poland,2012

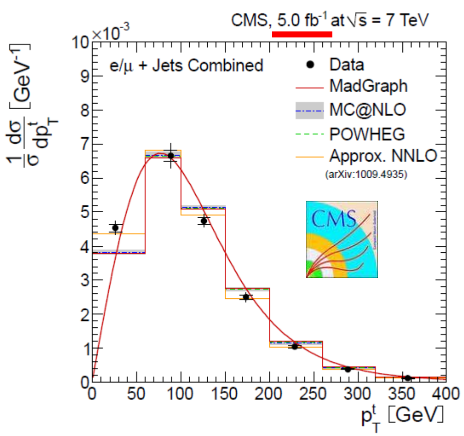
- Flavor independence of Ψ(z)
- Saturation of Ψ(z) for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- “Specific heat” $c = 0.25$

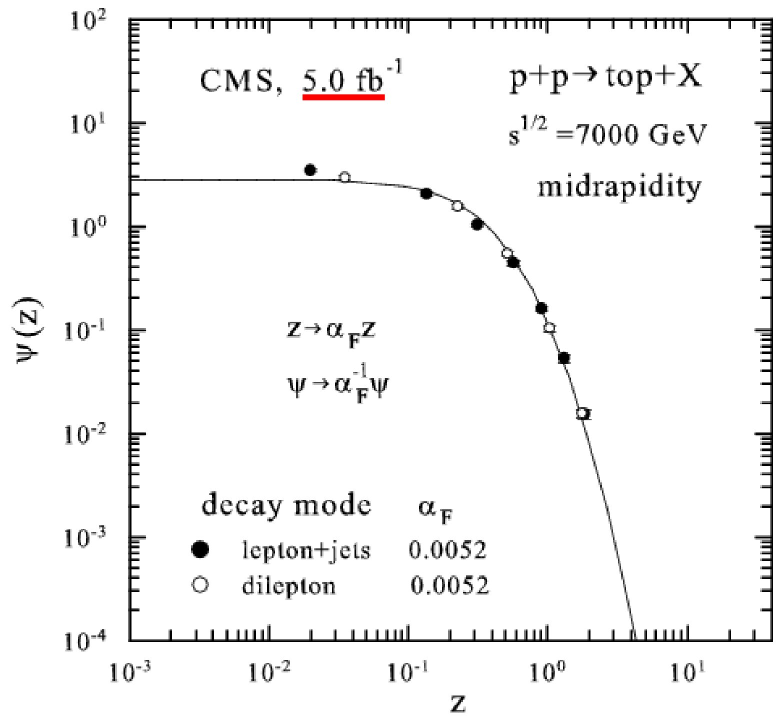
CMS data confirm self-similarity
of top quark production in pp

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







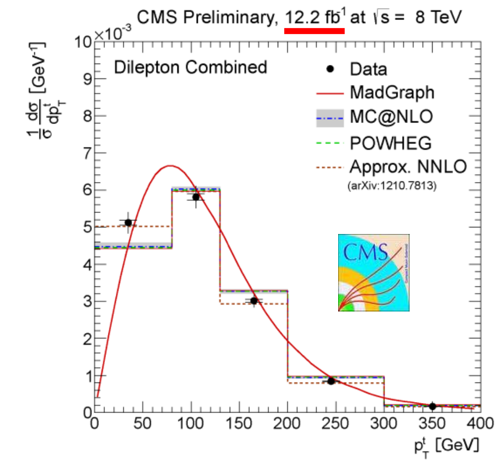
- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

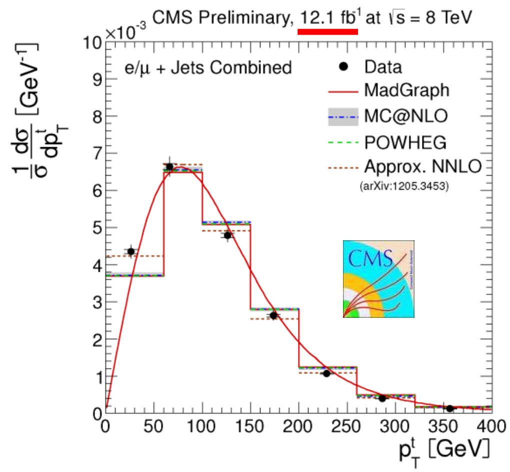
CMS data confirm self-similarity
of top quark production in pp

CMS Collaboration,
CMS-PAS-TOP-11-013

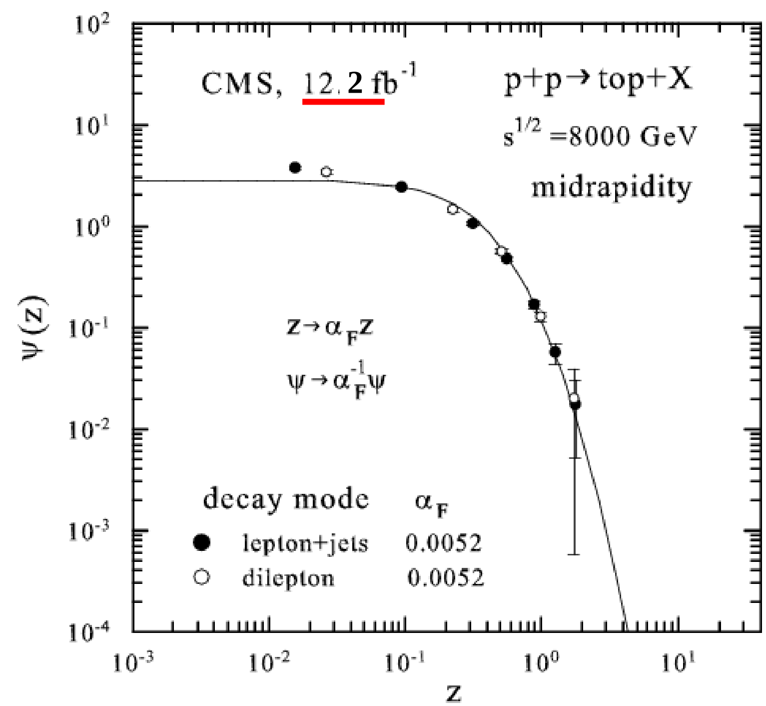
Self-similarity of top quark production at LHC

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

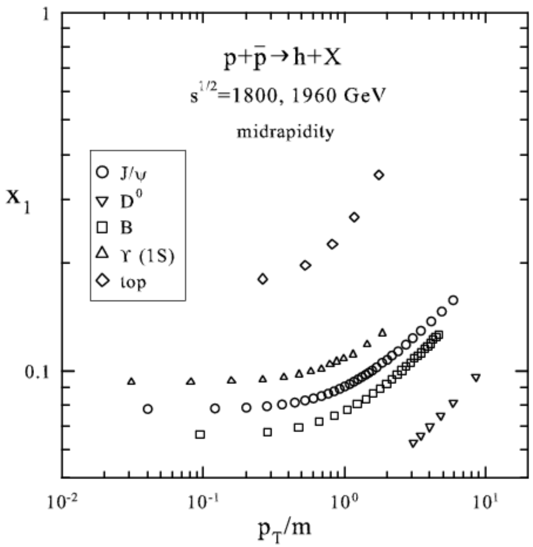


- Flavor independence of $\Psi(z)$
- Saturation of $\Psi(z)$ for or $z < 0.1$
- Fractal dimensions $\delta = 0.5$, $\varepsilon_{top} = 0$
- "Specific heat" $c = 0.25$

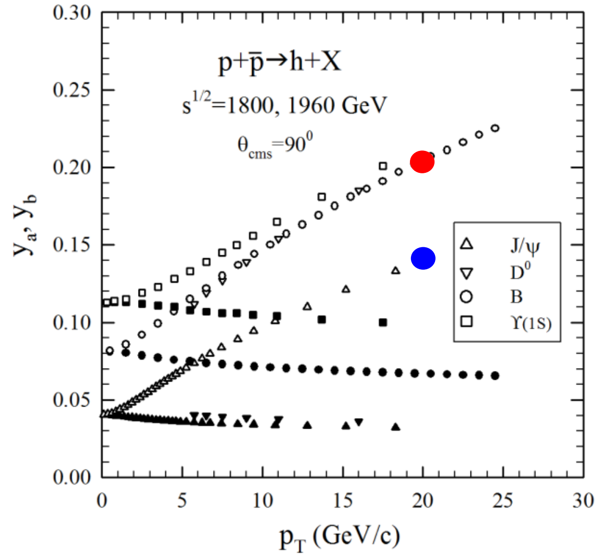
CMS data confirm self-similarity
of top quark production in pp

Microscopic scenario of constituent interactions

Fraction x_1 vs. p_T/m



Energy loss $\Delta E/E \sim (1-y_a)$



$p_T \approx 20$ GeV/c

Y, B, D
80% energy loss
$q \approx 100$ GeV/c

J/ψ
84% energy loss
$q \approx 142$ GeV/c

top
≈ 0 % energy loss
$q \approx 20$ GeV/c

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

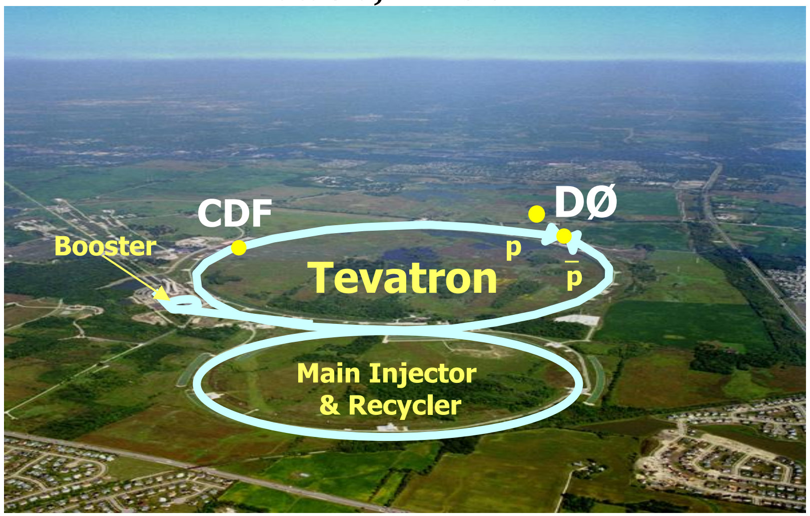
Negligible energy loss → high sensitivity to

- structure of colliding objects (dimensions δ_1, δ_2)
- constituent interactions ("specific heat" c)
- transition of point-like massless top to massive top ($m_{top} \approx m_{Au}$)

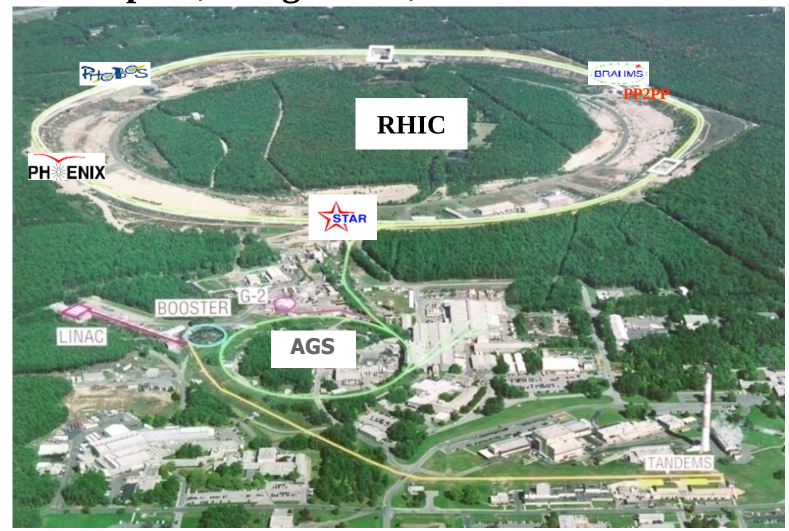
Verification of universality of $\Psi(z)$ shape over a wide z-range .

Jets at Hadron Colliders

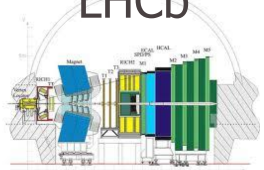
Batavia, Illinois



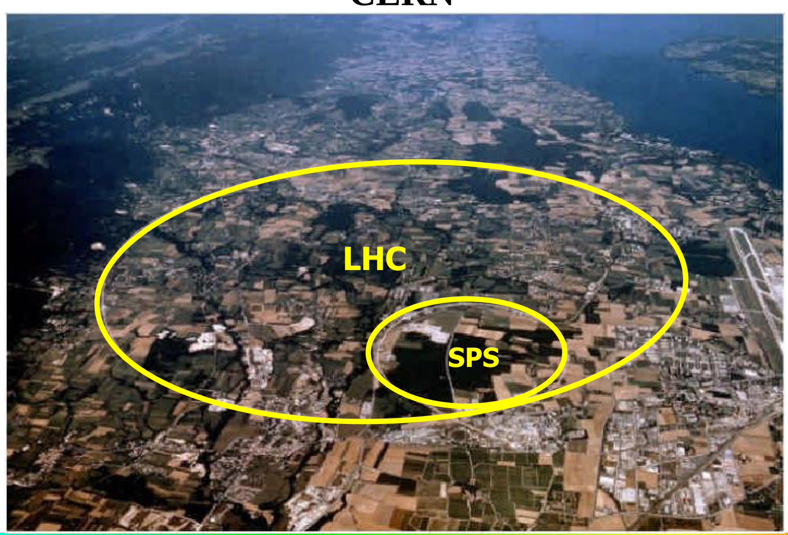
Upton, Long Island, New York



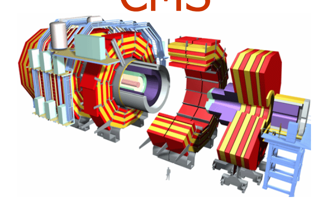
LHCb



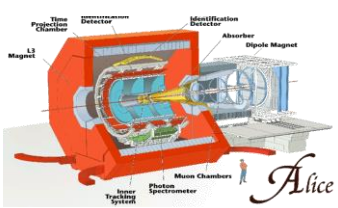
CERN



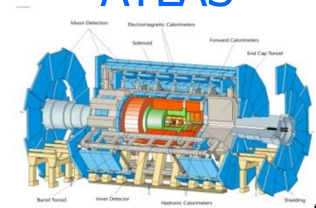
CMS



ALICE

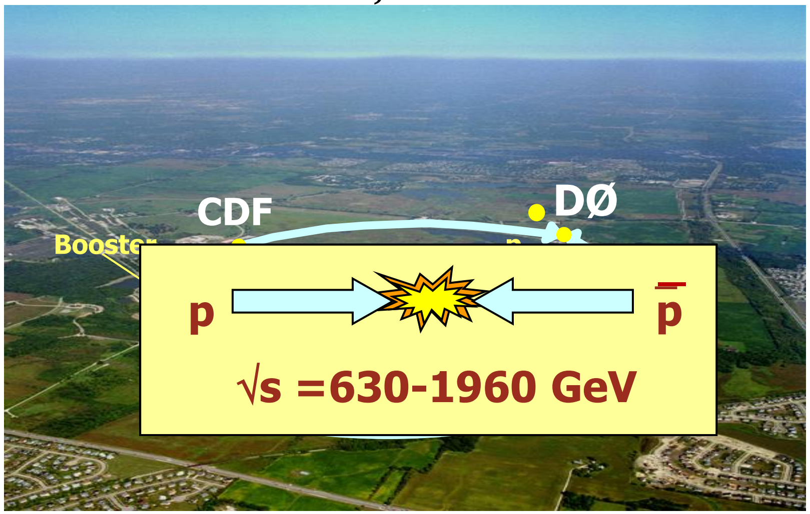


ATLAS

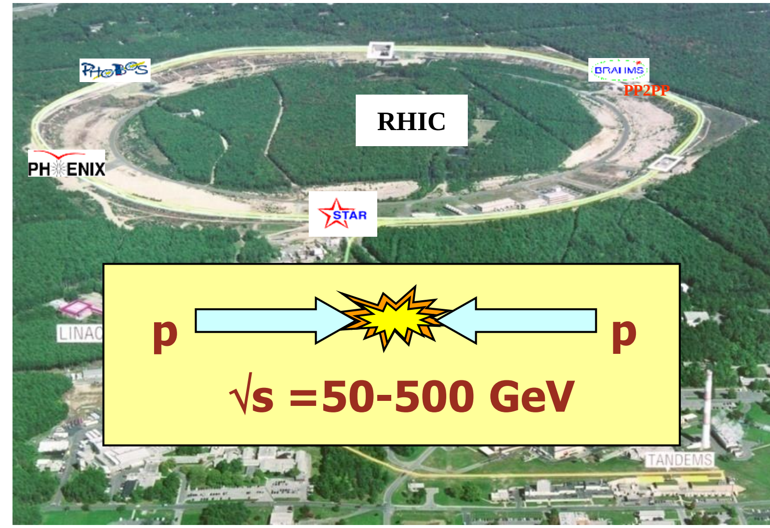


Jets at Hadron Colliders

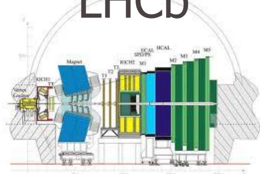
Batavia, Illinois



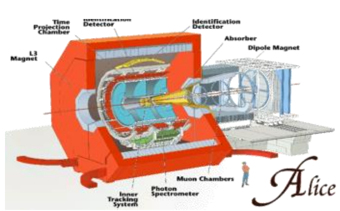
Upton, Long Island, New York



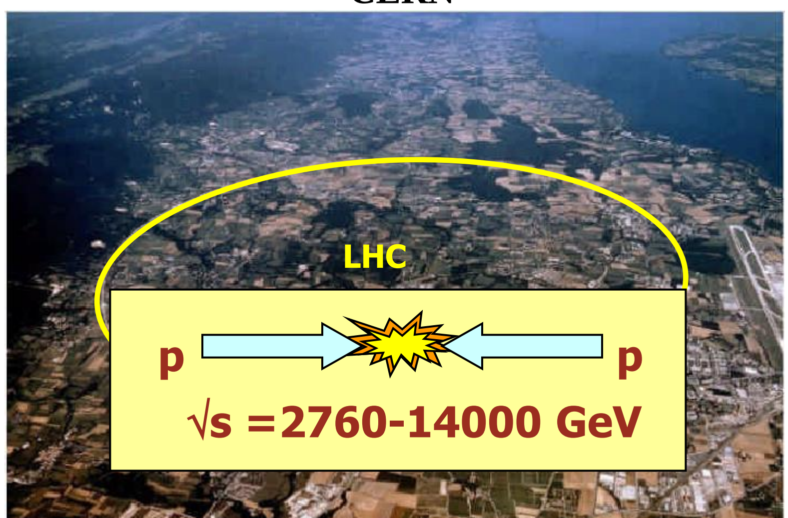
LHCb



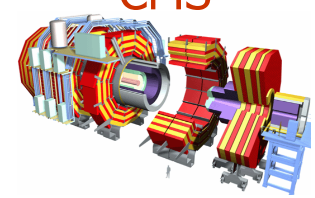
ALICE



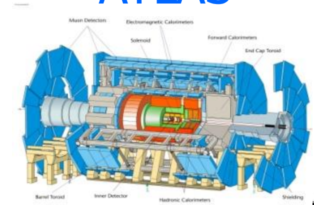
CERN



CMS



ATLAS



Jet measurements at HCs are precisely test of theory

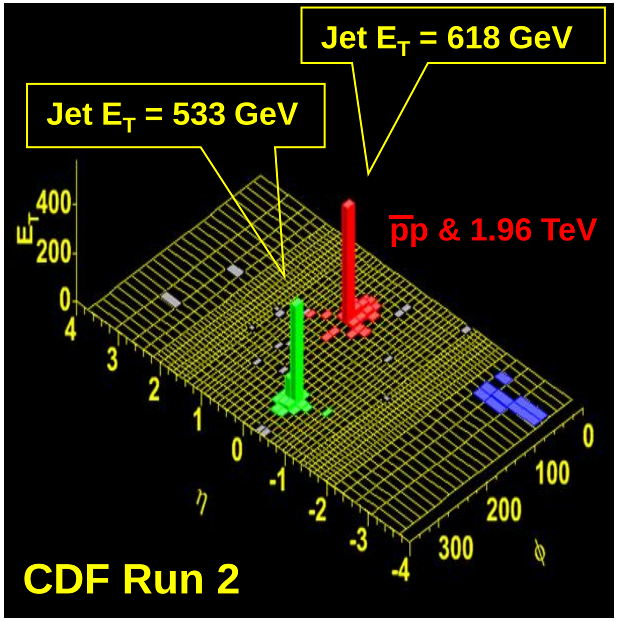
What is jet ?

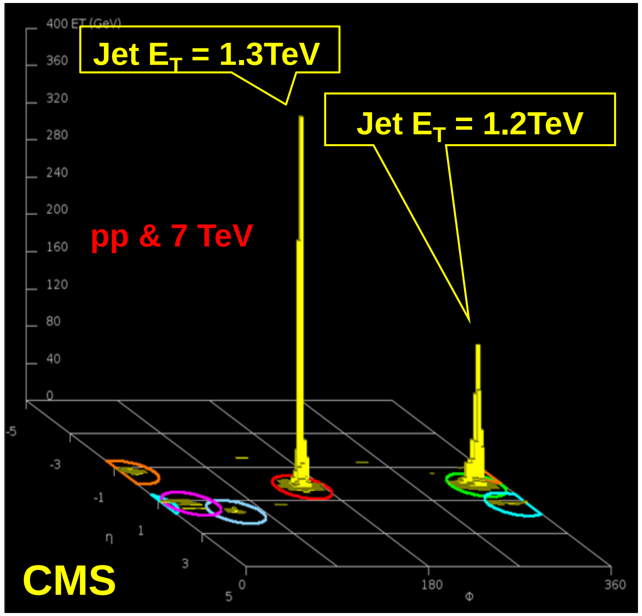
- Jet is strong correlated group of particles in space-time.
- Jet is a product of hard scattering of hadron constituents.
- Definition of jet in experiment and theory is a basis for understanding of transition mechanism from quark and gluon to hadronic degrees of freedom.
- QCD evolution schemes based on DGLAP, BFKL, CCFM equations are widely used.
- Large systematic errors in theoretical calculations is due to uncertainties of pdf's and mainly to gluon distribution function.

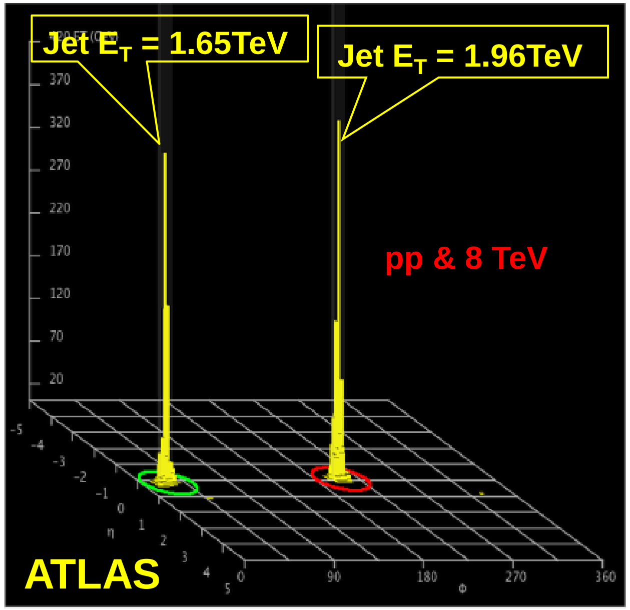
Experimental verification and QCD test of z-scaling of jet production in hadron collisions to search for new phenomena and establish new constraints (gluons, Q^2-evolution etc.) on theory.

Jets at Tevatron and LHC

Jets in 2-D space {η,φ}



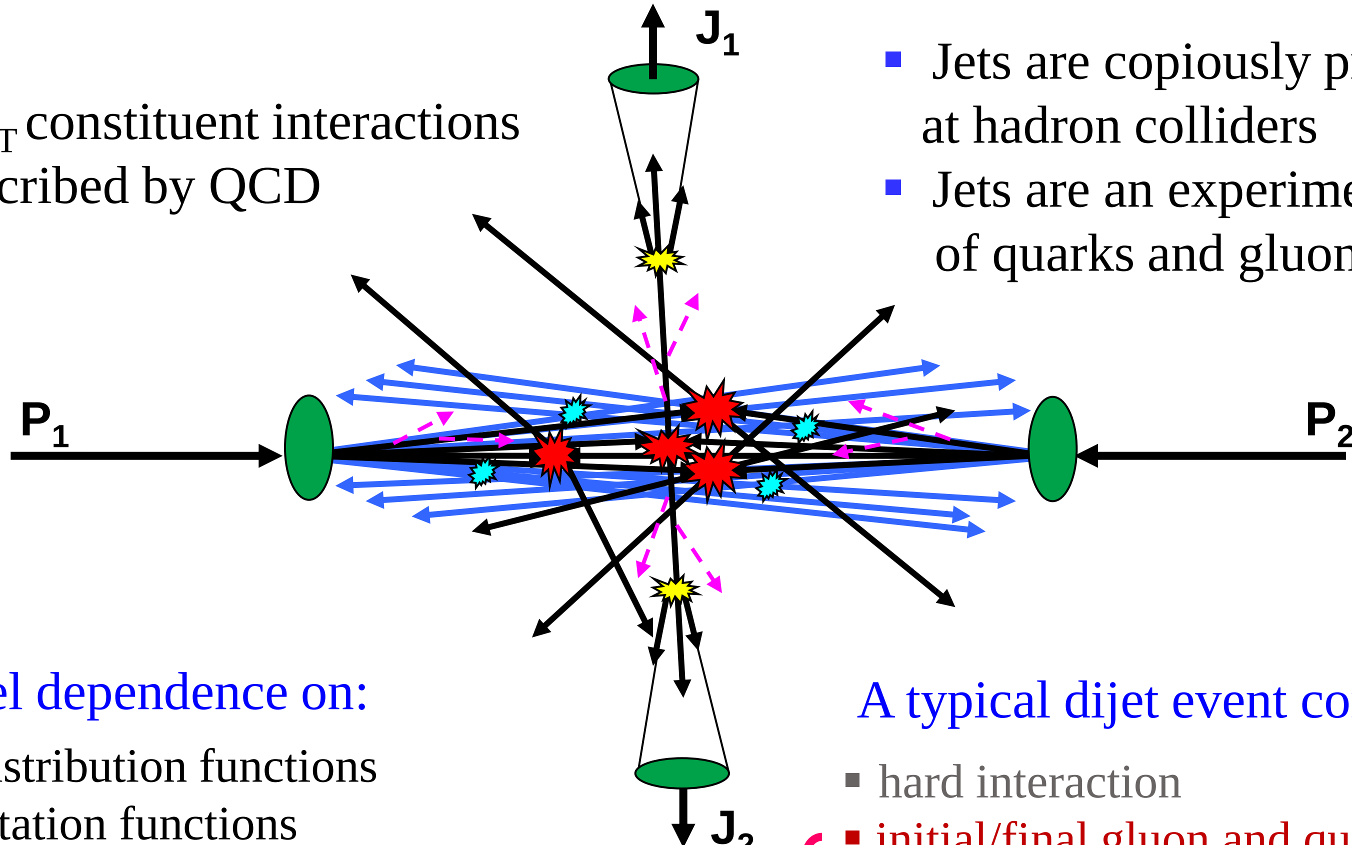




Experimental verification and QCD test of z-scaling of jet production in hadron collisions to search for new phenomena and establish new constraints (gluons, Q^2-evolution etc.) on theory.

Jet Topology

- High-p_T constituent interactions are described by QCD



- Jets are copiously produced at hadron colliders
- Jets are an experimental signature of quarks and gluons

Model dependence on:

- Parton distribution functions
- Fragmentation functions
- Higher order corrections
- Renormalization, factorization and fragmentation scales
- QCD evolution scheme

A typical dijet event consists of:

- hard interaction
- initial/final gluon and quark radiation
- secondary semi-hard interactions
- interaction between remnants
- hadronization
- jet formation

Underlying event

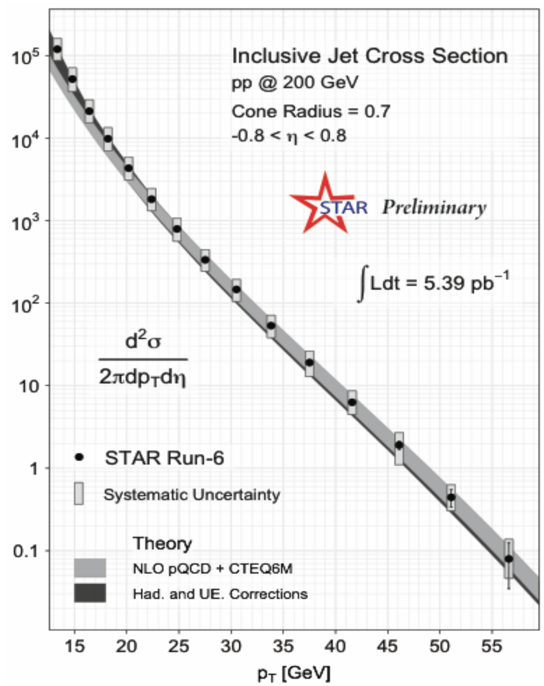
Jets at ISR, FNAL, Sp$\bar{p}$S, RHIC & z-Scaling

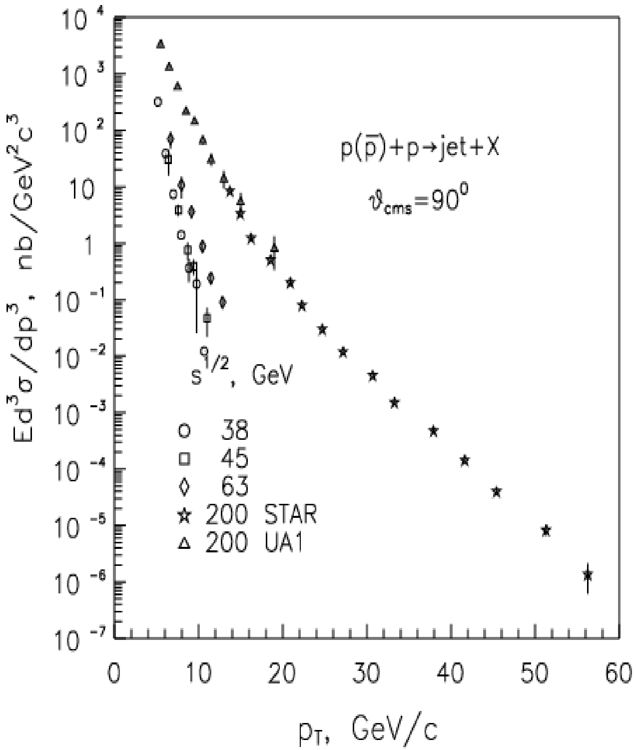
BNL: STAR
M.Calderon,
Extrem QCD, San Carlos,
Mexico, July 18-20, 2011

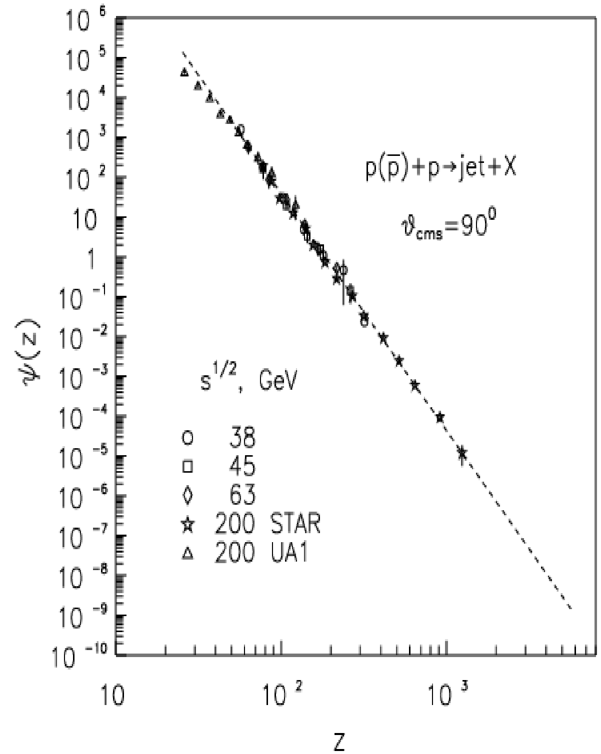
CERN: AFS
PLB118(1982)185
PLB118(1982)193
PLB123(1983)133

FNAL: E557
PRD41 (1980) 1371
Fermilab-Pub-90/22E (1990)

CERN: UA1
PLB172(1986)461
NPB309(1988)405



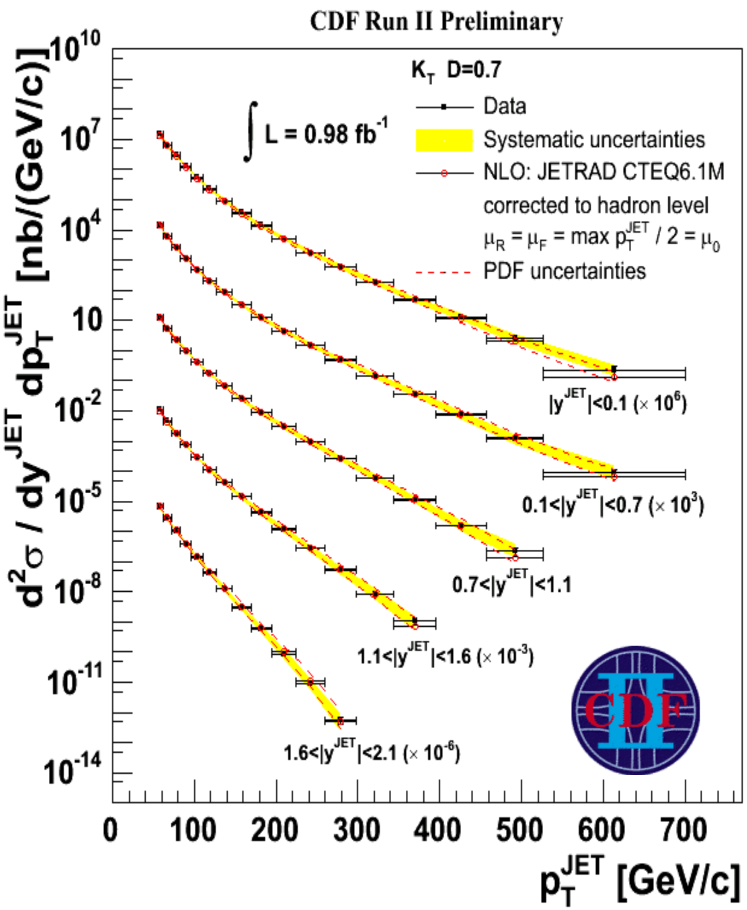


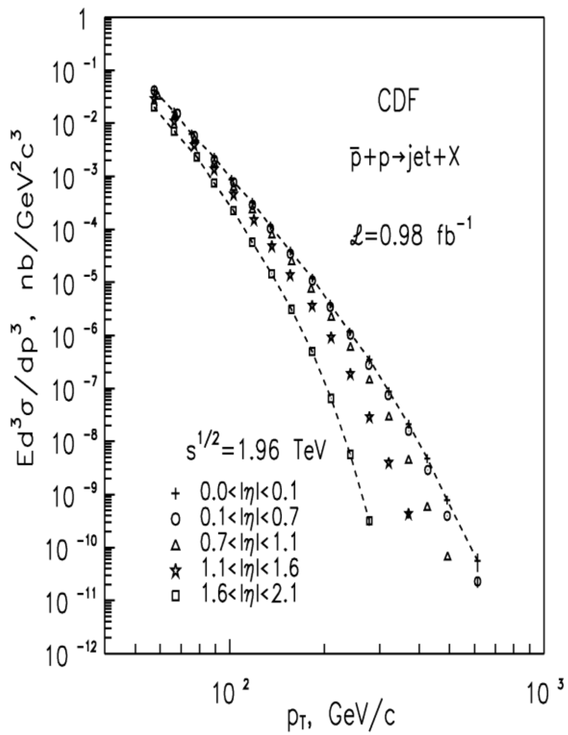


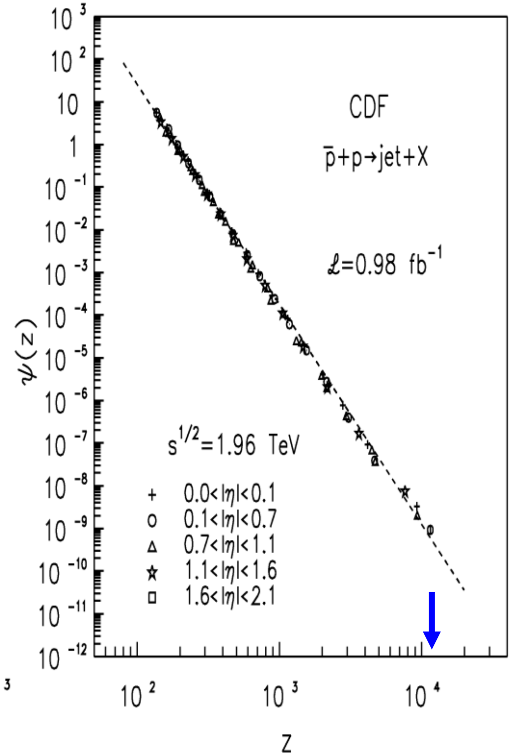
- Energy independence of $\Psi(z)$
- Power behavior of $\Psi(z) \sim z^{-\beta}$, $\beta \approx 5.95$
- RHIC confirms z-scaling found at ISR and FNAL

M.T. & T.Dedovich,I.Zborovsky
Int.J. Mod. Phys.A15 (2000) 3495
Int.J.Mod.Phys.A27(2012)1250115

z-Scaling & Jets at Tevatron in Run II





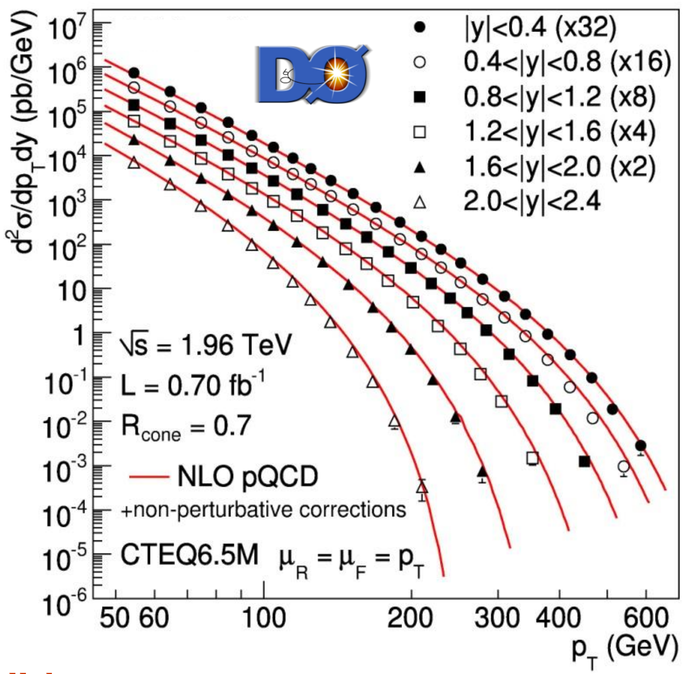


- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$

CDF collaboration
A.Abulencia et al., Phys.Rev.D75, 092006, 2007
T.Aaltonen et al., Phys.Rev.D78, 052006, 2008

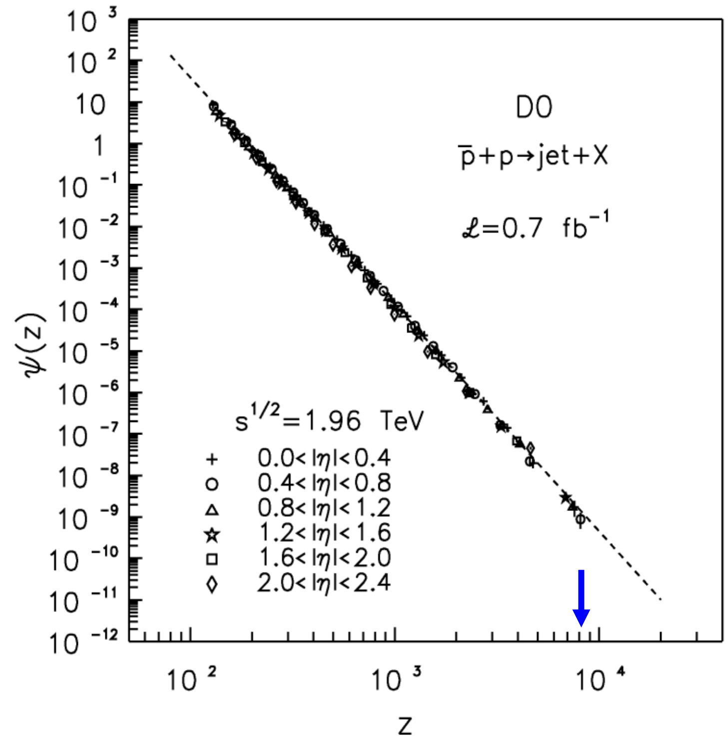
Tevatron data confirm z-scaling in jet production in $\bar{p}p$

z-Scaling & Jets at Tevatron in Run II



DØ Collaboration
V.M.Abazov et al.,
Phys.Rev.Lett.101,062001(2008)

Jet transverse spectra are measured up to 600 GeV/c



- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$

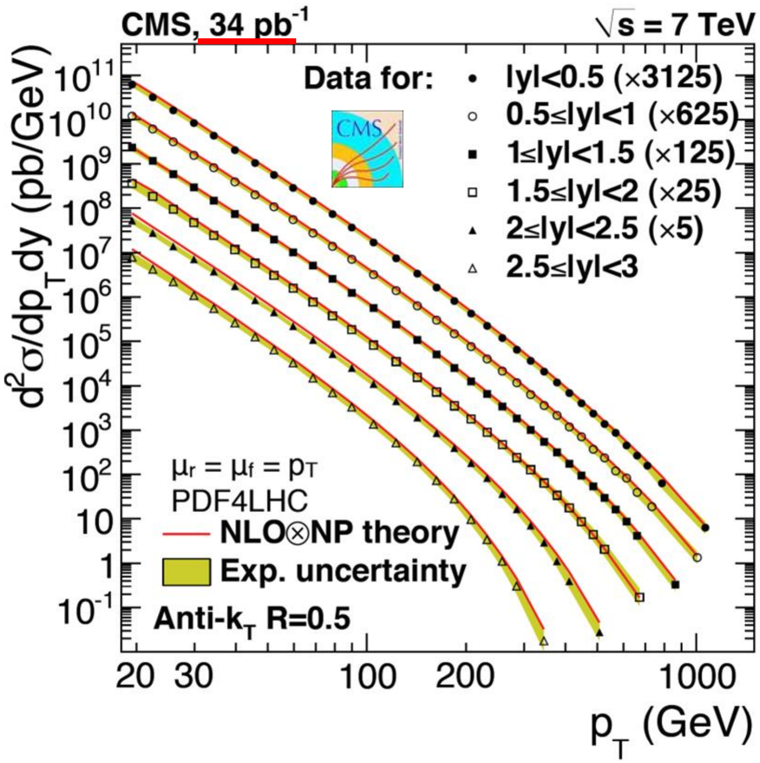
Self-similarity of jet production in proton-antiproton collisions.

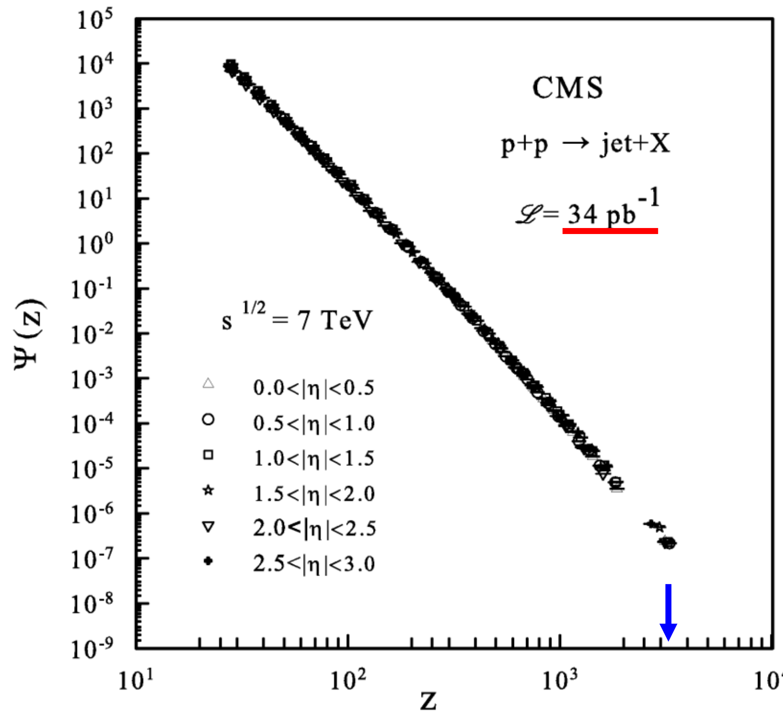
Tevatron data confirm
z-scaling in jet production in $p\bar{p}$ collisions

RHIC data confirm
z-scaling in jet production in pp collisions

What about z-scaling
in jet production in pp collisions at LHC ?

Inclusive Jets at CMS & z-Scaling





MT
T.Dedovich
I.Zborovsky
IJMP A27(2012) 1250115

Measurements of inclusive jet cross sections:

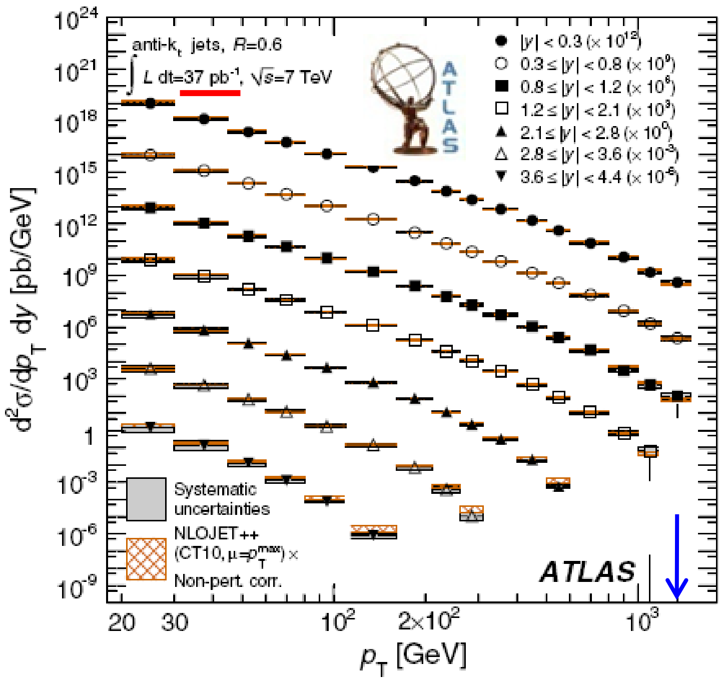
- Probing large momentum $18<p_T<1100$ GeV/c
- Rapidity region $|y| < 3$
- Agreement with NLO pQCD

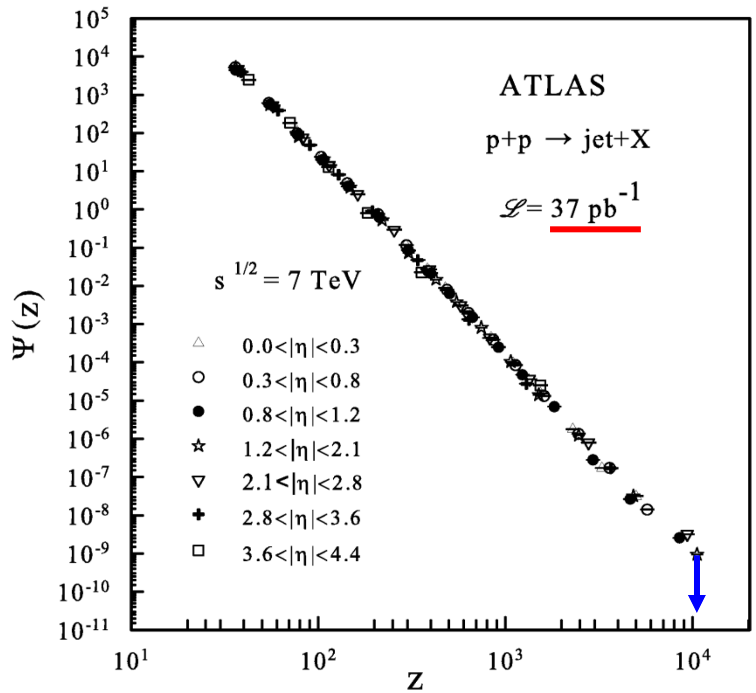
- Angular independence of Ψ(z)
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 3\cdot10^3$
- Self-similarity of jet production

CMS data confirm
z-scaling of jet production in pp

CMS Collaboration,
Phys.Rev.Lett.107 (2011) 132001

Inclusive Jets at ATLAS & z-Scaling





MT
T.Dedovich
I.Zborovsky
IJMP A27(2012) 1250115

Measurements of inclusive jet cross sections:

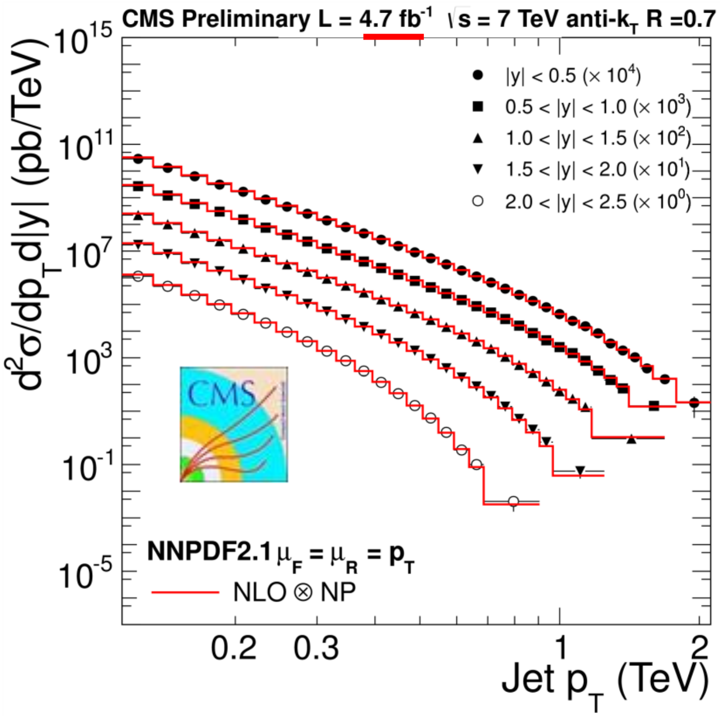
- Probing large momentum $20 < p_T < 1500$ GeV/c
- Rapidity region $|y| < 4.4$
- Agreement with NLO pQCD

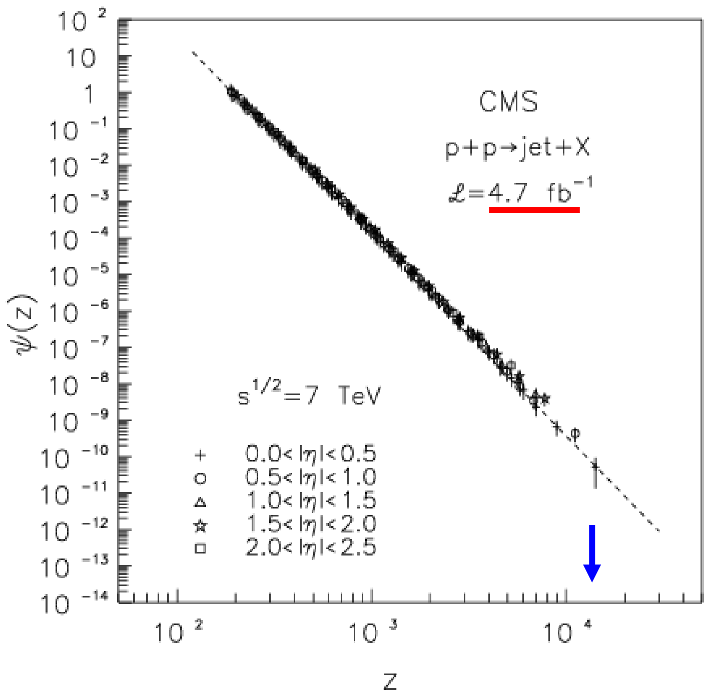
- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 10^4$
- Self-similarity of jet production

ATLAS data confirm z-scaling of jet production in pp

ATLAS Collaboration
G. Aad et al.
Phys. Rev. D 86 (2012) 014022

Inclusive Jets at CMS & z-Scaling





MT
T.Dedovich
I.Zborovsky
HS & QCD , 2012
Gatchina, Russia

Measurements of inclusive jet cross sections:

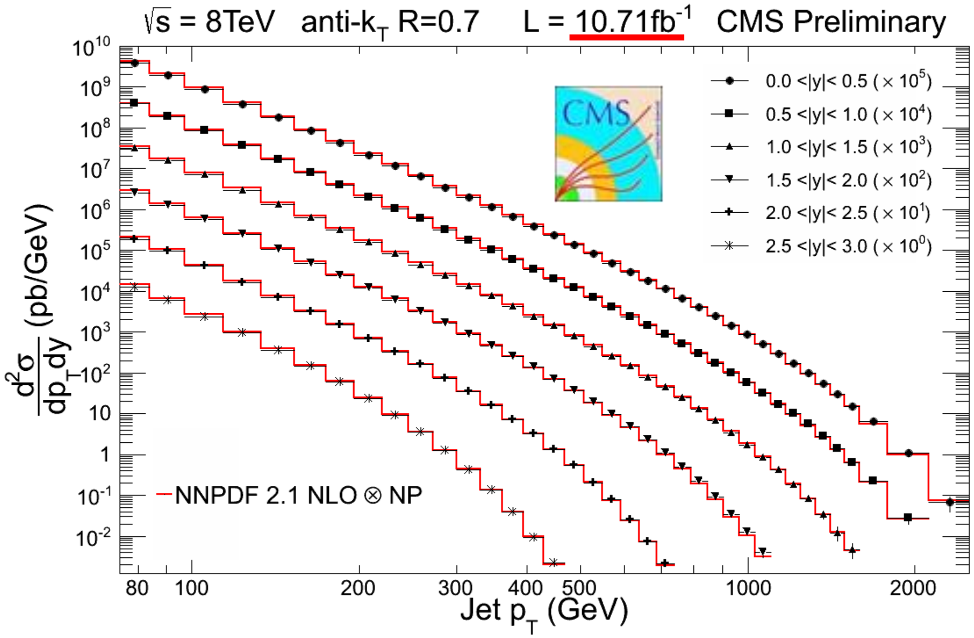
- Probing large momentum $114 < p_T < 2000$ GeV/c
- Rapidity region $|y| < 2.5$
- Agreement with NLO pQCD

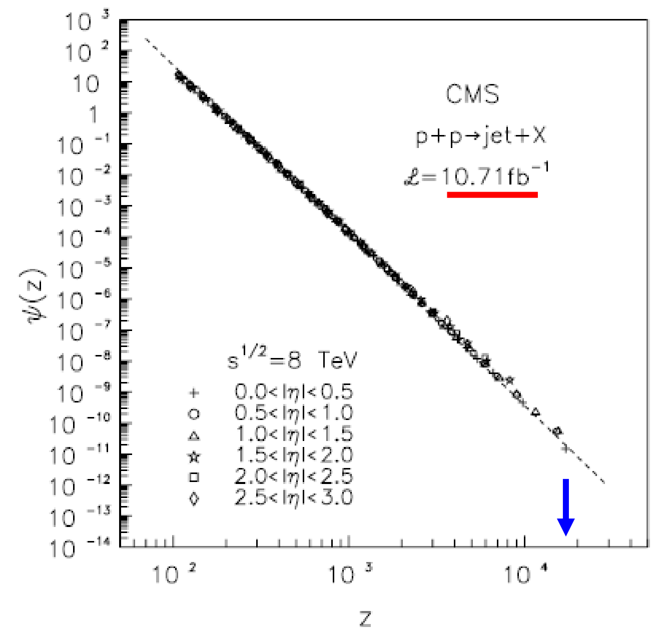
- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 1.3 \cdot 10^4$
- Self-similarity of jet production

CMS data confirms
z-scaling of jet production in pp

CMS PAS QCD-11-004
P.Krieger, "Physics at LHC",
Vancouver, June 4-9, 2012

Inclusive Jets at CMS & z-Scaling





Measurements of inclusive jet cross sections:

- Probing large momentum $74 < p_T < 2500$ GeV/c
- Rapidity region $|y| < 3.0$
- Agreement with NLO pQCD

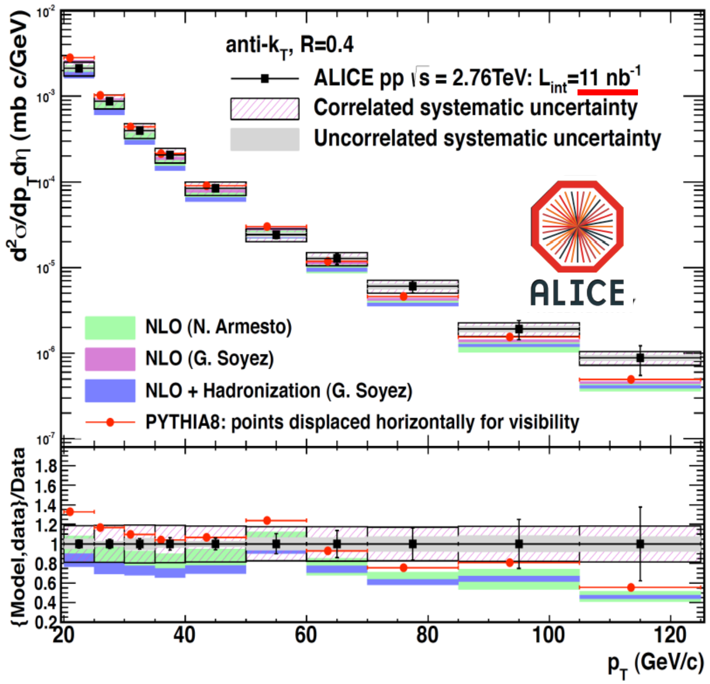
- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 1.7 \cdot 10^4$
- Self-similarity of jet production

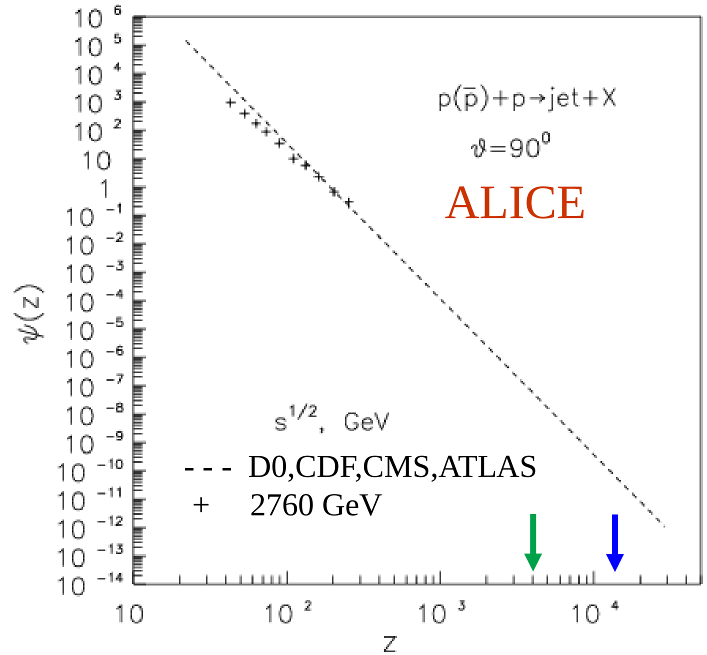
CMS data confirms z-scaling of jet production in pp

CMS-PAS-SMP-12-012

J. R. Dittmann,
"Jet Physics at the LHC & Tevatron",
Barcelona, Spain May 15, 2013

Inclusive Jets at ALICE & z-Scaling





Measurements of inclusive jet cross sections:

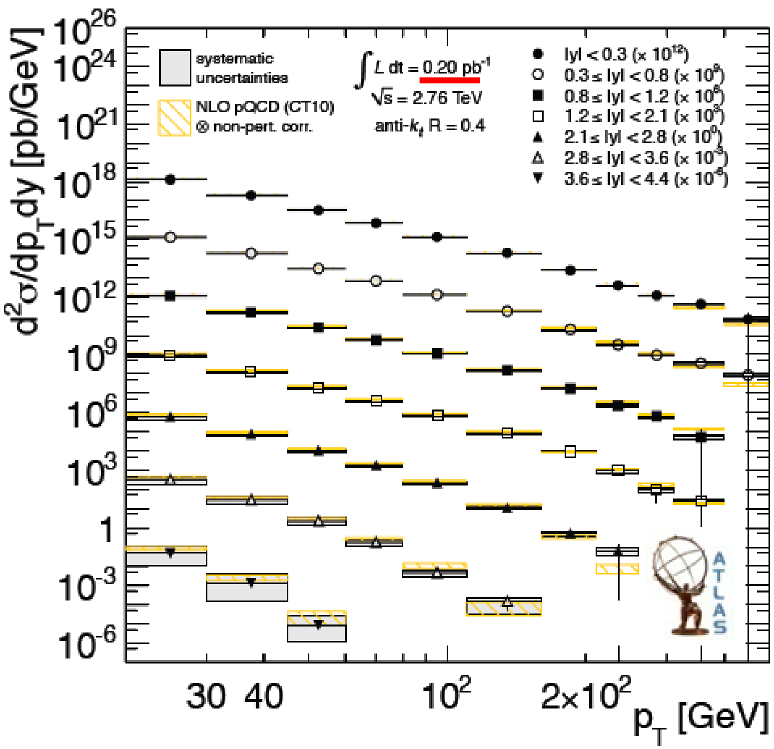
- Probing large momentum $20<p_T< 125$ GeV/c
- Rapidity region $|\eta| < 0.5$
- Agreement with NLO pQCD

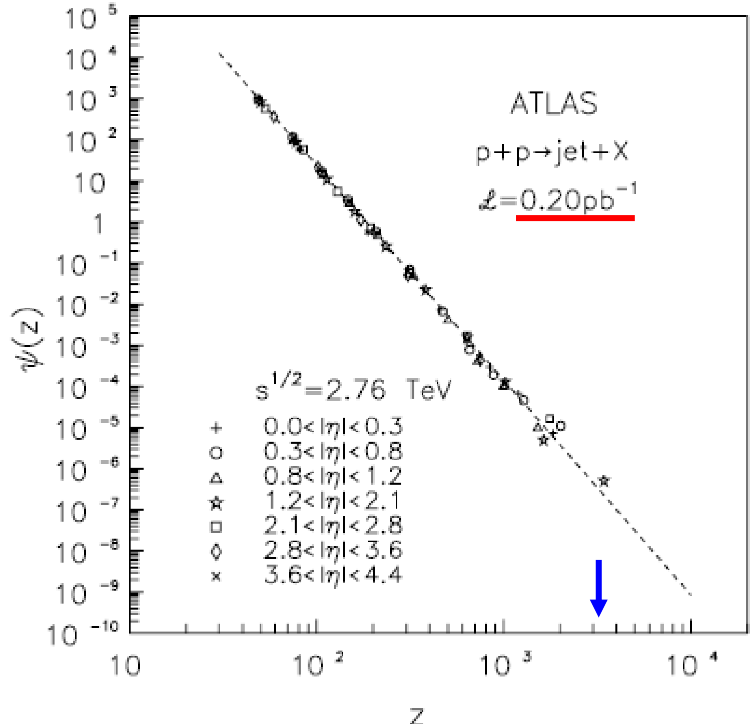
ALICE Collaboration
R.Ma, "Hard Probes 2012" Gagliari, Italy, May 27- June 1, 2012.
Phys. Let. B 722 (2013) 262.

- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 3\cdot10^3$
- Self-similarity of jet production

ALICE data confirm
z-scaling of jet production in pp

Inclusive Jets at ATLAS & z-Scaling





Measurements of inclusive jet cross sections:

- Probing large momentum $20 < p_T < 430$ GeV/c
- Rapidity region $|y| < 4.4$
- Agreement with NLO pQCD

- Angular independence of $\Psi(z)$
- Power law, $\Psi(z) \sim z^{-\beta}$, up to $z \approx 3\cdot10^3$
- Self-similarity of jet production

ATLAS data confirm
z-scaling of jet production in pp

ATLAS Collaboration
CERN-PH-EP-2013-036

Inclusive Jets at ATLAS @ DØ & z-Scaling

DØ Collaboration
B.Abbott et al., Phys.Rev.Lett. 82, 2451 (1999)
B.Abbott et al., Phys.Rev. D64, 032003 (2001)
D.Elvira, Ph.D Thesis Univsodad de Buenos Aires, Argentina (1995).
V.M.Abazov et al., Phys.Lett. B525, 211 (2002)
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ATLAS Collaboration
ATLAS-CONF-2011-047
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Eur. Phys. J. C71(2011) 1512, arXiv:1009.5908.33.
Phys. Rev. D86 (2012) 014022, arXiv:1112.6297
CERN-PH-EP-2013-036

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Phys.At. Nucl. 68, 404 (2005)

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Phys.Part.Nucl.Lett. 3, 312 (2006)

M.T. & I.Zborovsky
High-pT Physics at LHC 09
February 4-7, 2009
Prague, Czech Republic
PoS (High-p_T physics09) 046
M.T. & T.Dedovich, I.Zborovsky
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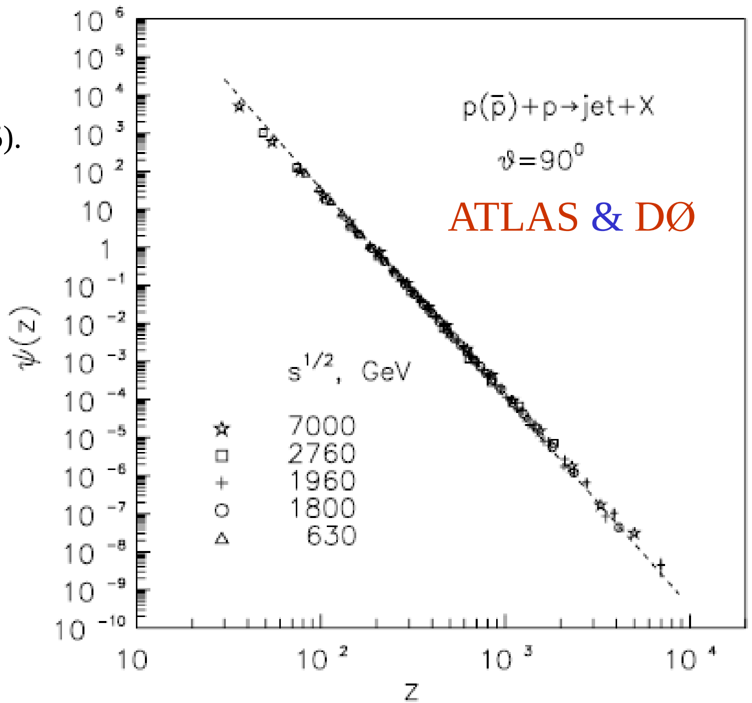

- Energy independence of $\Psi(z)$
- Universality of $\Psi(z)$ in pp & $p\bar{p}$
- Power law of $\Psi(z)$ for $z > 10^2$

ATLAS & DØ data confirm z-scaling
of jet production

Inclusive Jets at CMS @ CDF & z-Scaling

CDF Collaboration
F.Abe et al., Phys.Rev.Lett. 77, 438 (1996).
T.Affolder et al., Phys.Rev. D 64, 032001(2001)
A.Abulencia et al., Phys.Rev.Lett. 96, 122001(2006)
A.Abulencia et al., Phys.Rev. D74, 071103 (2006)
A.Abulencia et al., Phys.Rev. D75, 092006 (2007)
T.Aaltonen et al.,Phys.Rev. D78 ,052006 (2008)

CMS Collaboration,
Phys.Rev.Lett.107,132001,2011
CMS PAS QCD-11-004
P.Krieger, Physics at LHC,
Vancouver, June 4-9, 2012

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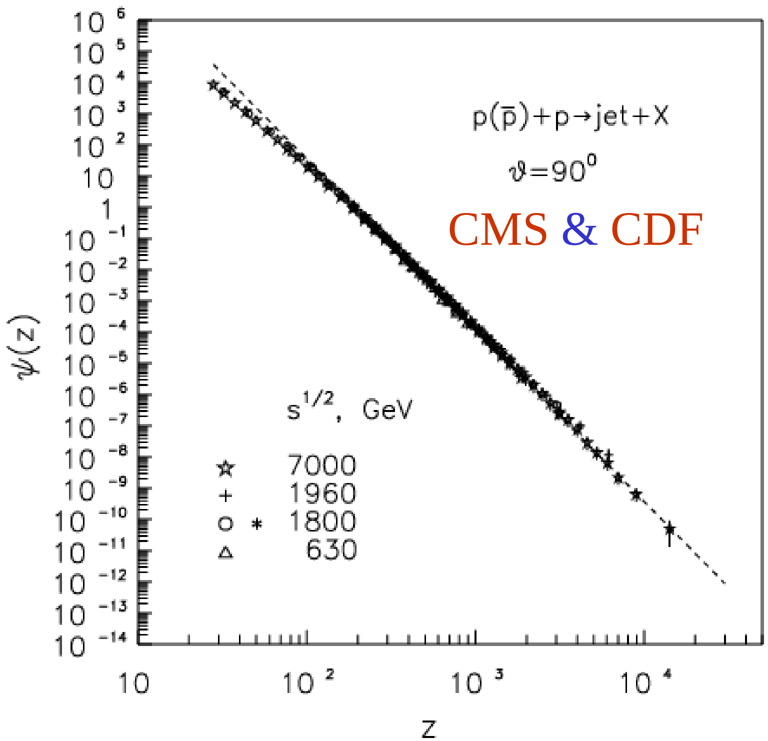

- Energy independence of Ψ(z)
- Universality of Ψ(z) in pp &$p\bar{p}$
- Power law of Ψ(z) for z >10^2

CMS & CDF data confirm z-scaling of jet production

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B.Abbott et al., Phys.Rev.Lett. 82, 2451 (1999)
B.Abbott et al., Phys.Rev. D64, 032003 (2001)
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CMS Collaboration,
Phys.Rev.Lett.107,132001,2011
CMS PAS QCD-11-004
P.Krieger, Physics at LHC, Vancouver, June 4-9, 2012
CMS-PAS-SMP-12-012
J. R. Dittmann, Jet Physics at the LHC & Tevatron, Barcelona, Spain May 15, 2013

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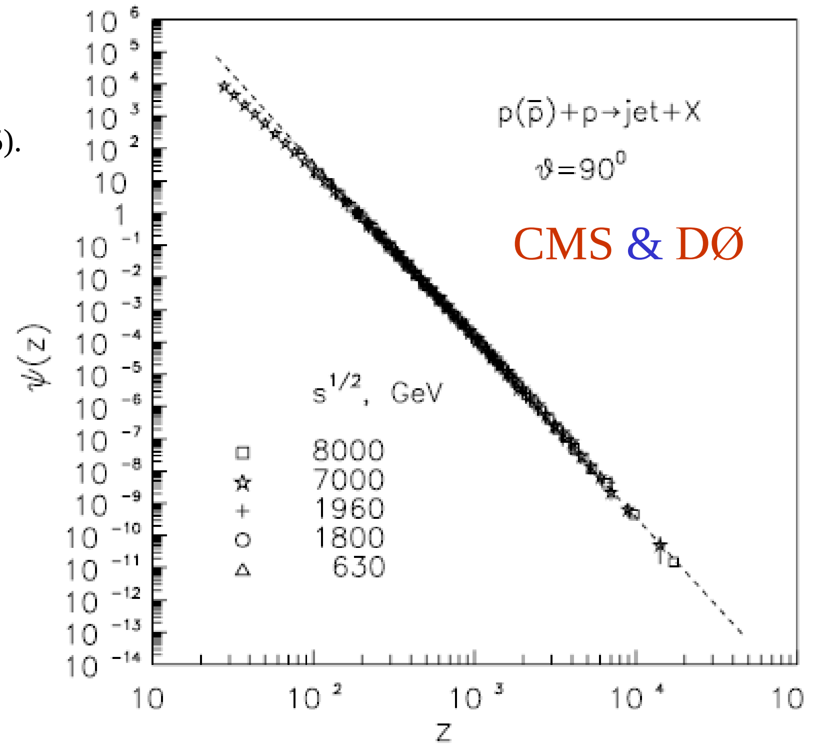


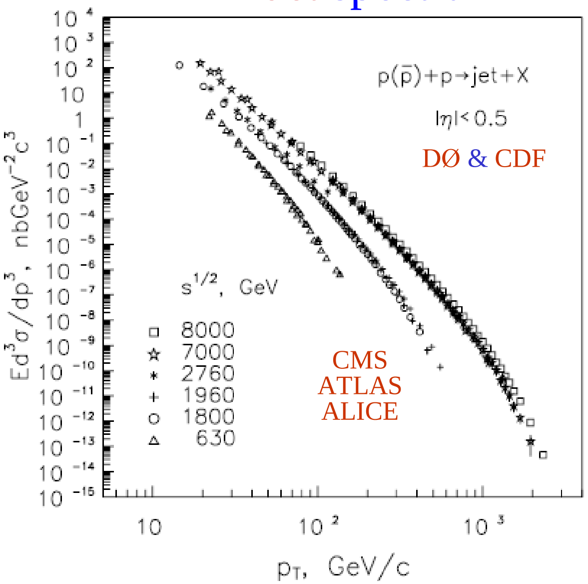
- Energy independence of Ψ(z)
- Universality of Ψ(z) in pp & $p\bar{p}$
- Power law of Ψ(z) for z >10^2

CMS & DØ data confirm z-scaling of jet production

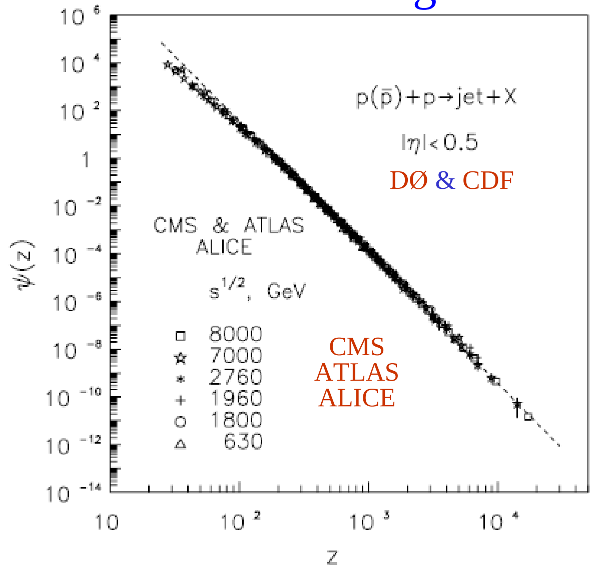
Self-similarity of jet production over a wide scale range

Highest energy - $\sqrt{s}$ = 8 TeV, highest momentum - $p_T \approx 2.4$ TeV/c ,
smallest scale ~ $8\cdot10^{-5}$ fm

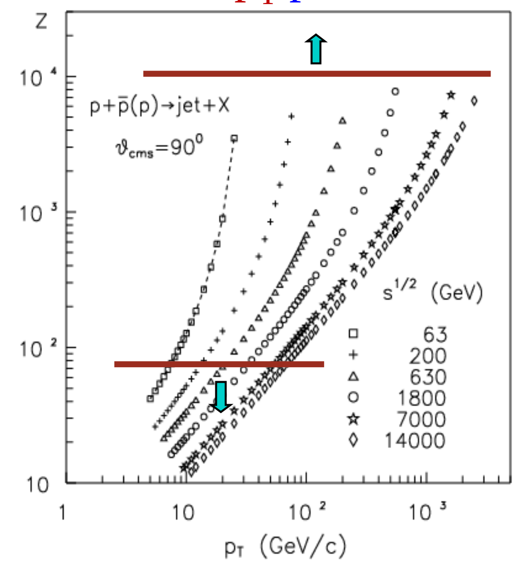
Jet spectra



z-scaling



z-p_T plot



New test of z-scaling at LHC

Structural phenomena ⟺ constituent substructure,…
Collective phenomena ⟺ multiple interactions, phase transitions,…
Self-similarity at small scales ⟺ fractal topology of momentum space,…

Search for new phenomena at LHC

Conclusions I (top quark)

- Results of analysis of Tevatron and LHC data on inclusive transverse momentum spectra of top quarks produced in $p\bar{p}$ and pp collisions at $\sqrt{s}$=1.96 TeV and at $\sqrt{s}$=7 TeV in z-scaling approach were presented.
- New confirmations of z-scaling at LHC (energy and flavor independence, saturation of $\Psi(z)$) were demonstrated.
- z-Scaling of hadron production at high energies manifests self-similarity, locality and fractality of hadron interactions at a constituent level.

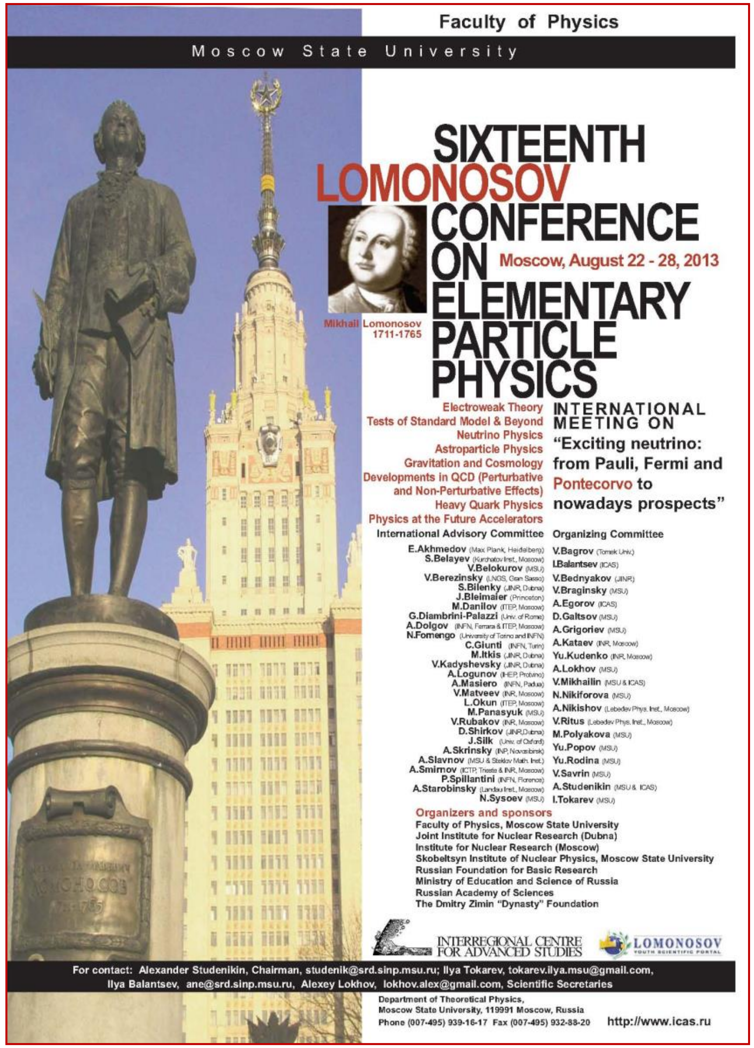
New TeV-energy region is available to understand origin of flavor – u,d,c,s,b,t.

Conclusions II (jets)

- LHC data on jet production in pp collisions at $\sqrt{s}$=2.76, 7, 8 TeV obtained by CMS, ATLAS and ALICE Collaborations were analyzed in the z-scaling approach.
- Results of analysis were compared with the Tevatron data.
- New confirmations of z-scaling properties at LHC (energy and angular independences, power law of $\Psi(z)$) were obtained.
- z-Scaling of jet 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 new physics phenomena in jet production at LHC.

16th Lomonosov Conference on Elementary Particle Physics
MSU, Moscow, Russia, August 22 - 28, 2013



Thank You for Your Attention !