

# Кварк-глюонные представления об адронных взаимодействиях и данные LHC

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НИИЯФ МГУ

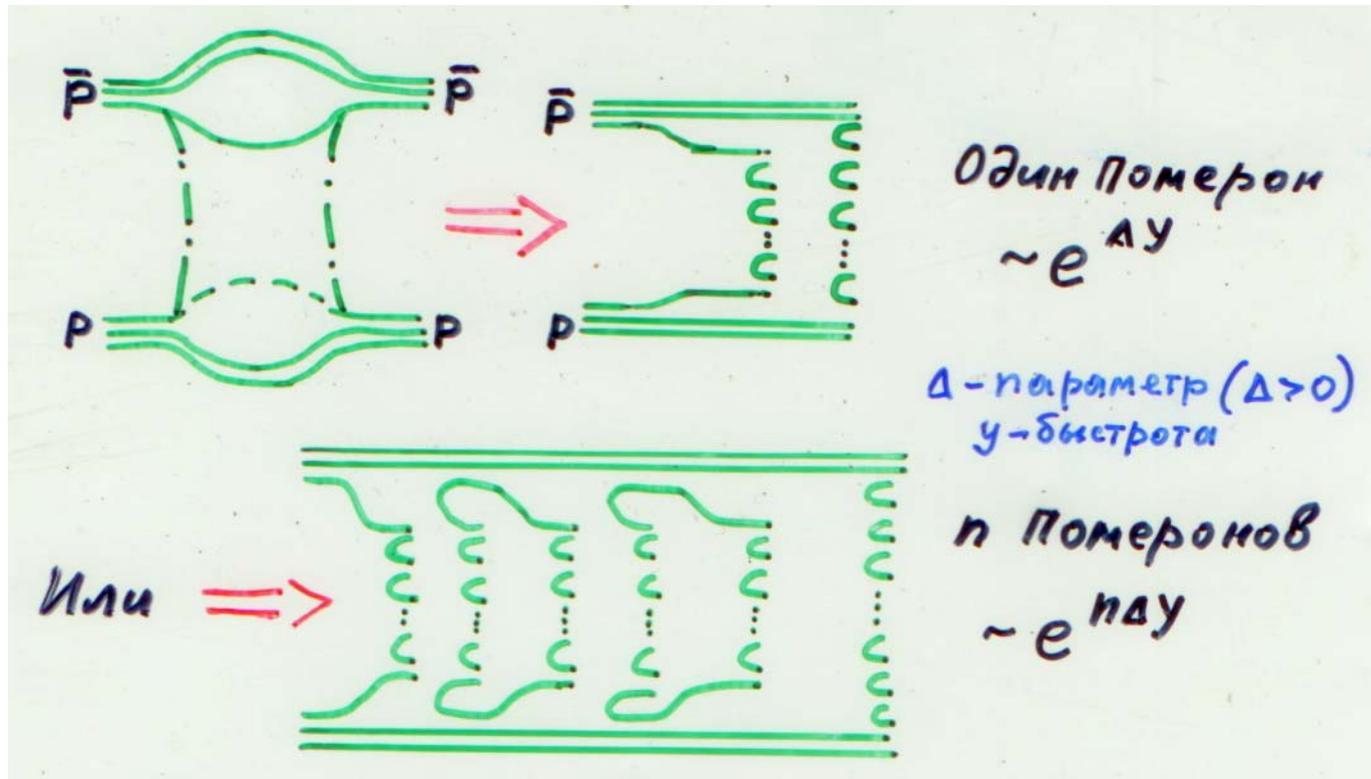
04.10.2011

# План

- 1. Реализация кварк-глюонной картины взаимодействия
- 2. Воспроизведение экспериментальных данных
- 3. Данные LHC относительно p-p взаимодействий
- 4. Взаимодействия тяжёлых ионов на LHC
- 5. О бозоне Хиггса

Модель QGS / Кайдалов и Тер-Мартirosян, 1982 г/ – основана на  $1/N_f$  разложении в QCD и использует реджеонное описание обмена помероном – феноменологическим объектом, представляющим элементарное взаимодействие. Основная идея модели – мягкое адронное взаимодействие может быть описано диаграммами цилиндрического типа. (при  $E > 100$  ГэВ)

Параметры померона находят, фитируя экспериментальные данные.



В представлении прицельного параметра обмен помероном описывается амплитудой:

$$f_{ab}^p(S, \vec{b}) = i \frac{\gamma_a \gamma_b}{\lambda_{ab}} \exp\left(\Delta y - \frac{\vec{b}^2}{4\lambda_{ab}}\right) \equiv i \chi_{ab}^p(S, \vec{b})$$

где  $\vec{b}$  – прицельный параметр,

$S$  – квадрат полной энергии в системе центра масс,

$$y = \ln S$$

$\Delta = \alpha_p(0) - 1$ ,  $\alpha_p(0)$  – интерсепт,

$$\lambda_{ab} = R_a^2 + R_b^2 + \alpha_p'(0)$$

$\alpha_p(0)$  и  $\alpha_p'(0)$  – параметры померонной траектории,

$\chi_{ab}^p(S, \vec{b})$  – померонный эйконал,

$\gamma_{a(b)}$  и  $R_{a(b)}^2$  описывают вершину взаимодействия померон-адрон.

Определение параметров – по фите  $\sigma^{tot}(S)$  и  $B(S)|_{t=0}$

$\Delta$  по данным ISR составляет  $\sim 0.07$ . По результатам SPS  $\Delta$  увеличивается

до 0.12 – 0.14 (с изменением других параметров).

С ростом энергии растёт роль полужестких процессов

Фитирование  $\sigma$  требует  $\Delta \approx 0.12 - 0.14$

Но:  $\left. \frac{d\sigma}{dy} \right|_{y=0} (S)$  требует  $\Delta \approx 0.20 - 0.25$

Партонная эволюция во взаимодействующих адронах может быть разделена на две части: мягкий каскад, характеризующийся малыми передачами импульса  $Q^2 \leq Q_0^2$ , и жесткий каскад  $Q^2 > Q_0^2$ , который описывать пертурбативно. Жесткий эйконал может быть сведен к выражению:

$$\chi_{ab}^{hard}(S, \vec{b}) = r^2 \int dy_1 dy_2 \chi_{ab}^p(e^{y_1+y_2}, \vec{b}) \sigma_{hard}(e^{y-y_1-y_2}, Q_0)$$

где  $y_{1(2)}$  – быстроты, соответствующие концам померонов,  $\sigma_{hard}$  – сечение жесткого партонного взаимодействия,  $\chi_{ab}^p$  – обычный мягкий эйконал (1) и величина  $r^2$  – фитируемый параметр, связанный с плотностью партонов. Учет жестких процессов обеспечивает дополнительный рост сечений и инклюзивных спектров частиц в центральной области.

Сечения различных процессов можно получить,  
вводя

$$\chi_{ab} \Rightarrow \chi_{ab}^p + \chi_{ab}^{hard}$$

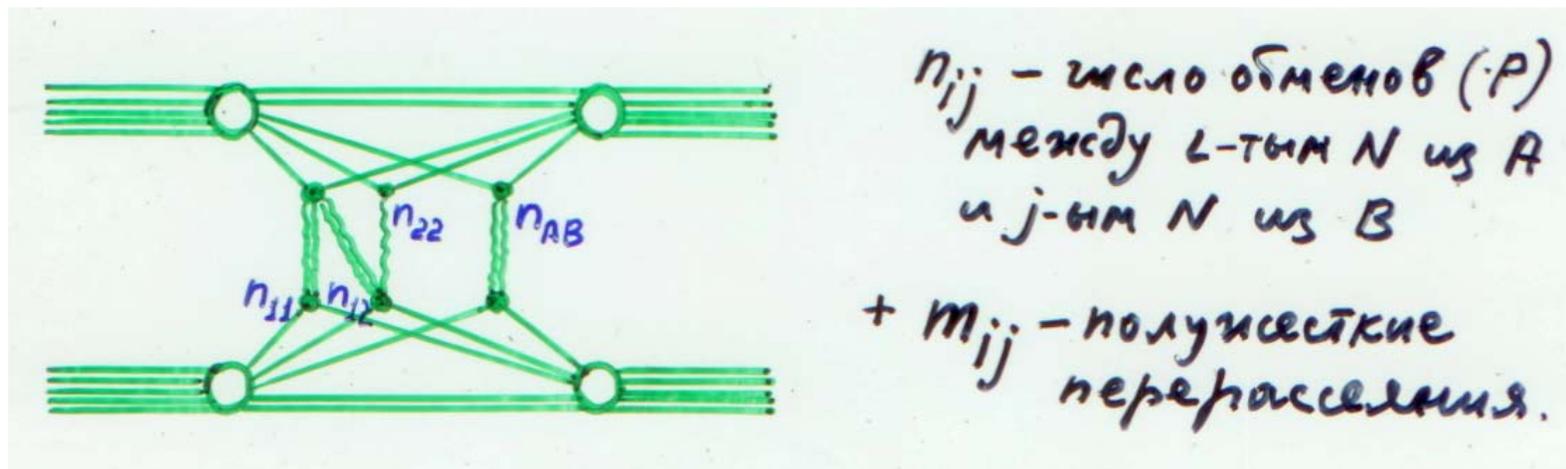
Например,

$$\sigma_{ab}^{tot}(S) = \frac{2}{C_{ab}} \int d^2\vec{b} \left\{ 1 - \exp(-C_{ab} [\chi_{ab}^p(S, \vec{b}) + \chi_{ab}^{hard}(S, \vec{b})]) \right\}$$

$C_{ab}$  — коэффициент ливневого усиления.

# Взаимодействие ядро-ядро

Глауберовский подход. Померонное описание амплитуды нуклон-нуклонного рассеяния. Метод Грибова учёта неупругого экранирования и процессов дифр. диссоциации. Новых параметров не возникает, исключая описание распределения нуклонов в ядре.



Монте-Карловский генератор QGSJET включает

Взаимодействия адронов с различными мишенями от протона до железа

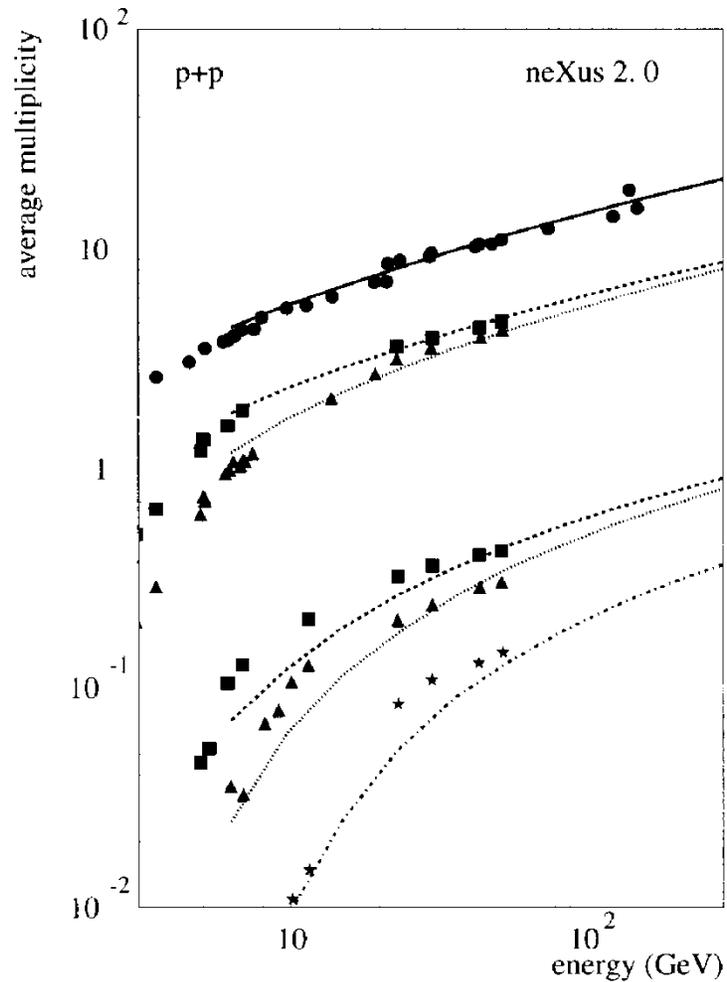
Взаимодействия ядро-ядро (до Fe-Fe), включая фрагментацию  
 спектаторной части ядра.

QGSJET входит в состав программных комплексов CORSIKA и AIRES

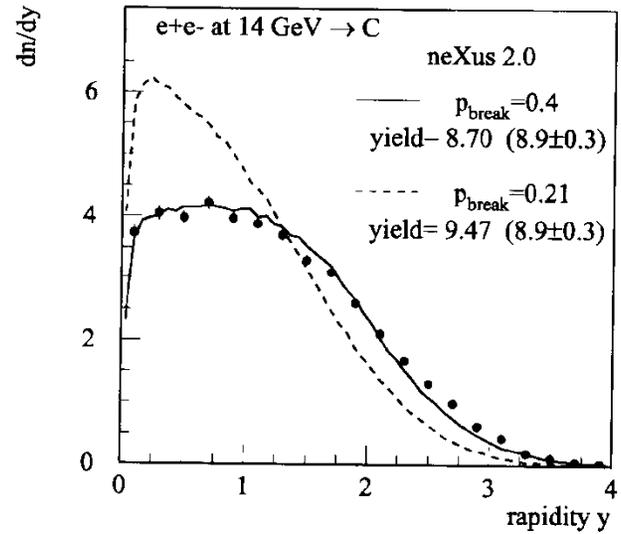
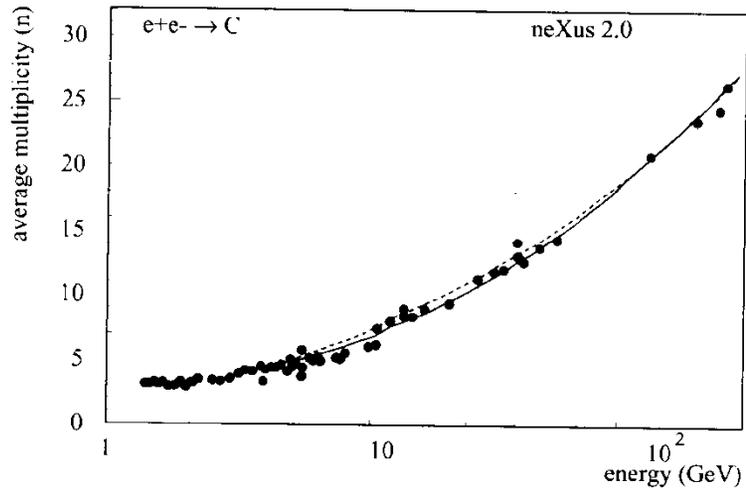
$\sqrt{s}$ (GeV)	$\sigma_{in} (mb)$		$n_{ch}$	
	эксп	теор	эксп	теор
53	35.3±0.4	35.7	12.5±0.2	14.2
546	48.4±1.0	49.7	30.4±0.3	30.5
1800	60.3±2.4	60.7	36.6±0.9	36.9

$\sigma_{AB}^{prod}$  при 200 GeV/nucleon, mb

A+B	27+16	27+32	64+32
теор	1455	1880	2643
эксп	1460±240	1740±120	2640±190



Множественность вторичных частиц  
(все заряженные, пионы, каоны, антипротоны)



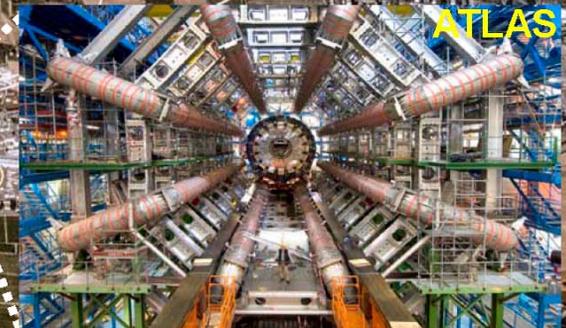
Средняя множественность и распределение по множественности заряженных частиц

# With LHC we are entering a New Era in Fundamental Science

The Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is a turning point in modern physics.



The exploration of a new energy frontier just started



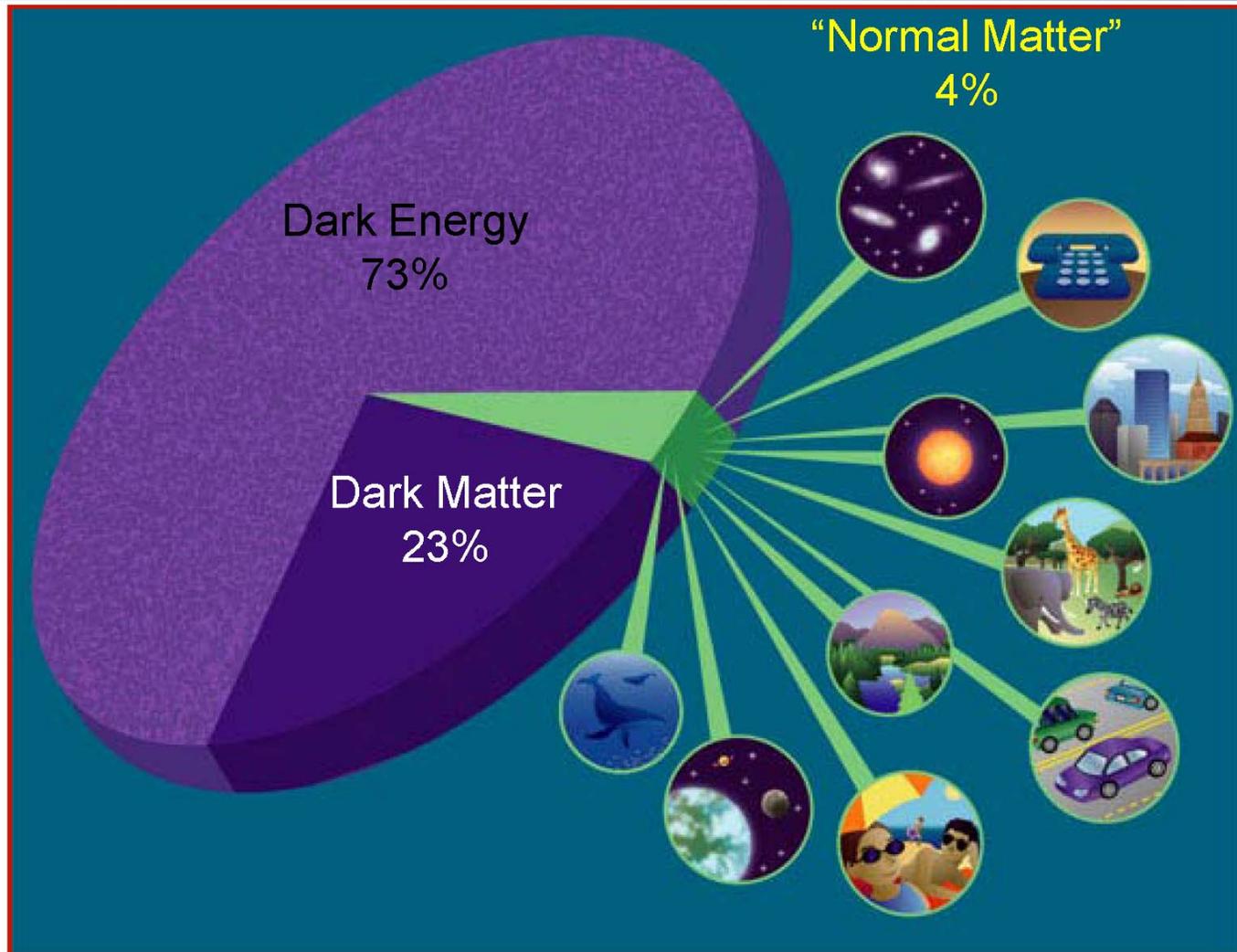
# Why everything is so complex?

• We are trying to solve some of the main puzzles of nature

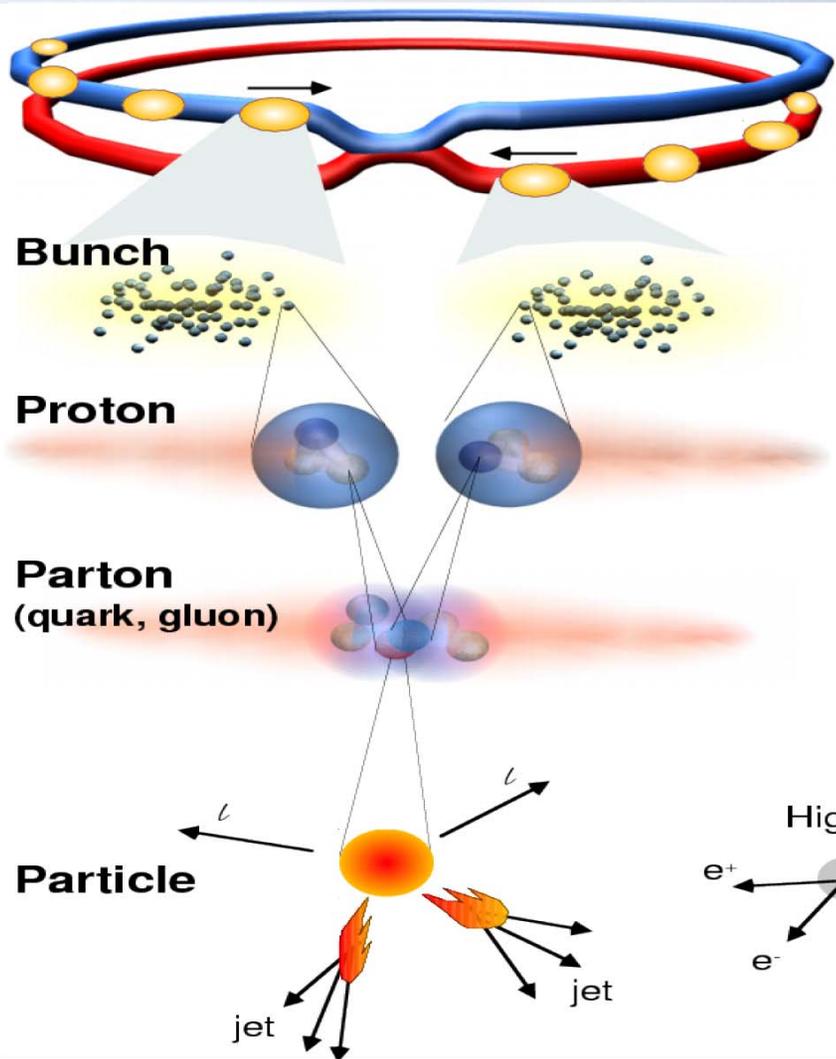
- What is the origin of mass: **Higgs Scalar Field?**
- What is the dark matter that keeps together the clusters of galaxies: **Gas of Heavy Neutralinos?**
- What is the origin of the large asymmetry between matter and anti-matter in the Universe: **New Generation of Quarks? Large CP violating effects?**
- What was the state of matter in the very first instants after the Big-Bang: **Quark Gluon Plasma?**
- Why gravity is so weak: **Extradimensions?**

• The answer to some of these questions is probably hidden in the so far un-explored multi-TeV region made accessible by LHC

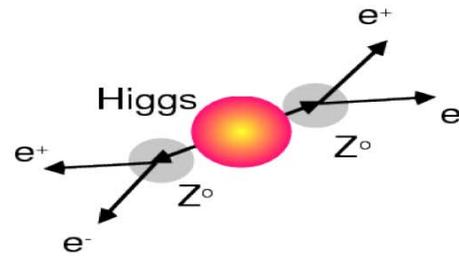
# The picture of our immense ignorance



# LHC pp operations in 2011



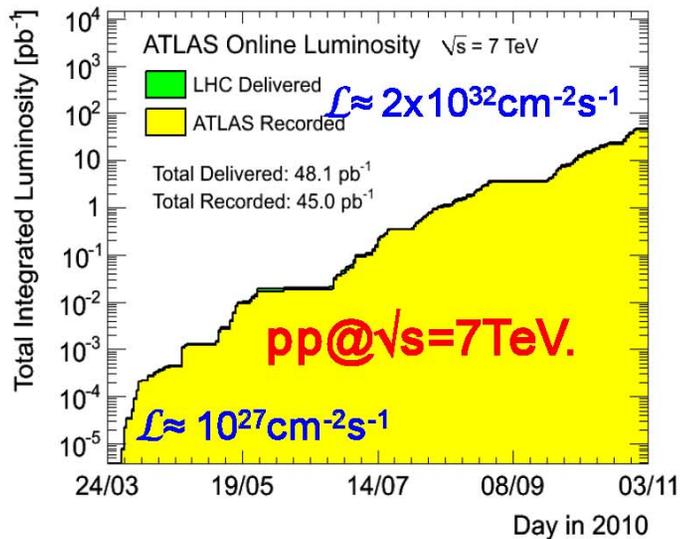
<b>Proton-Proton</b>	1404 x 1404 bunches
Protons/bunch	$1.25 \times 10^{11}$
Beam energy	3.5 TeV
Luminosity	$2.1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
Crossing rate	80MHz
Collisions $\approx$	$10^7\text{-}10^8 \text{ Hz}$



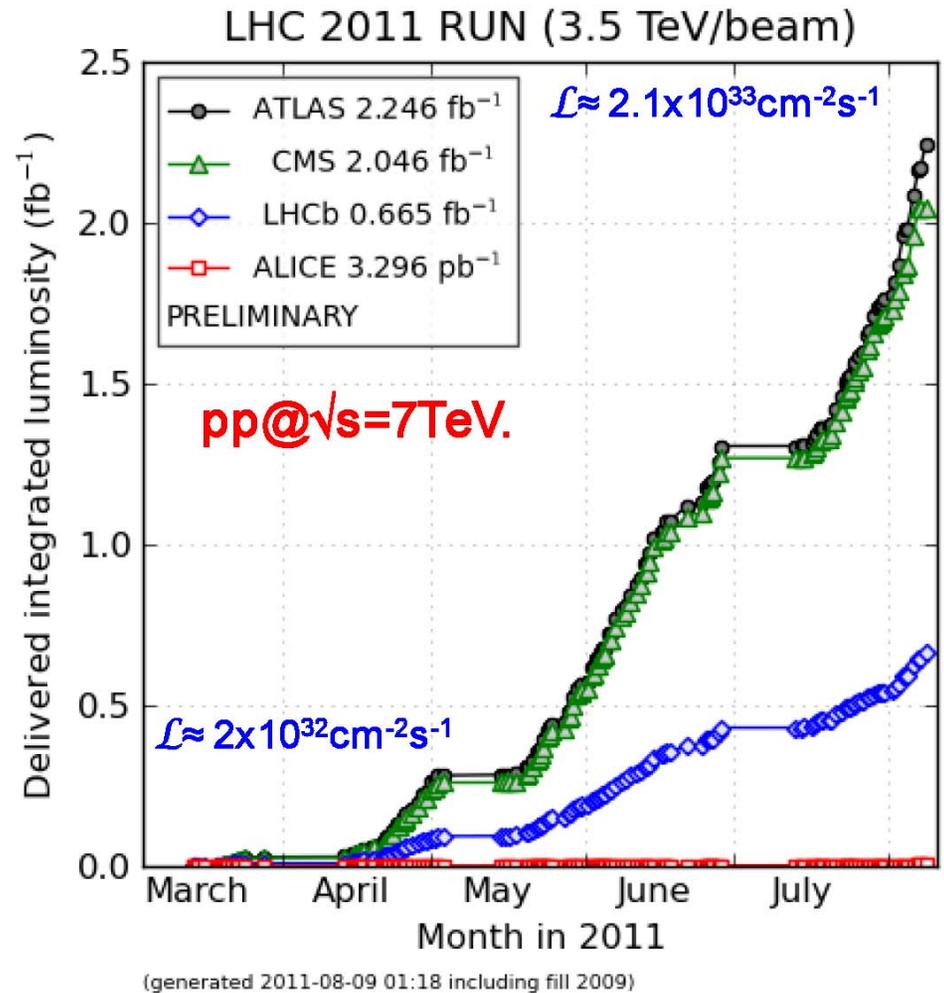
Higgs

SUSY.....

# LHC pp operations



Excellent LHC performance in 2011. The goal of the whole 2011 achieved in the first three months. Another factor 2 gained in the last 3 weeks. New record of instantaneous luminosity achieved every week. Good perspective to get additional factors by November.



# Comparison of hadronic interaction models with LHC data

#1169  
Pierog

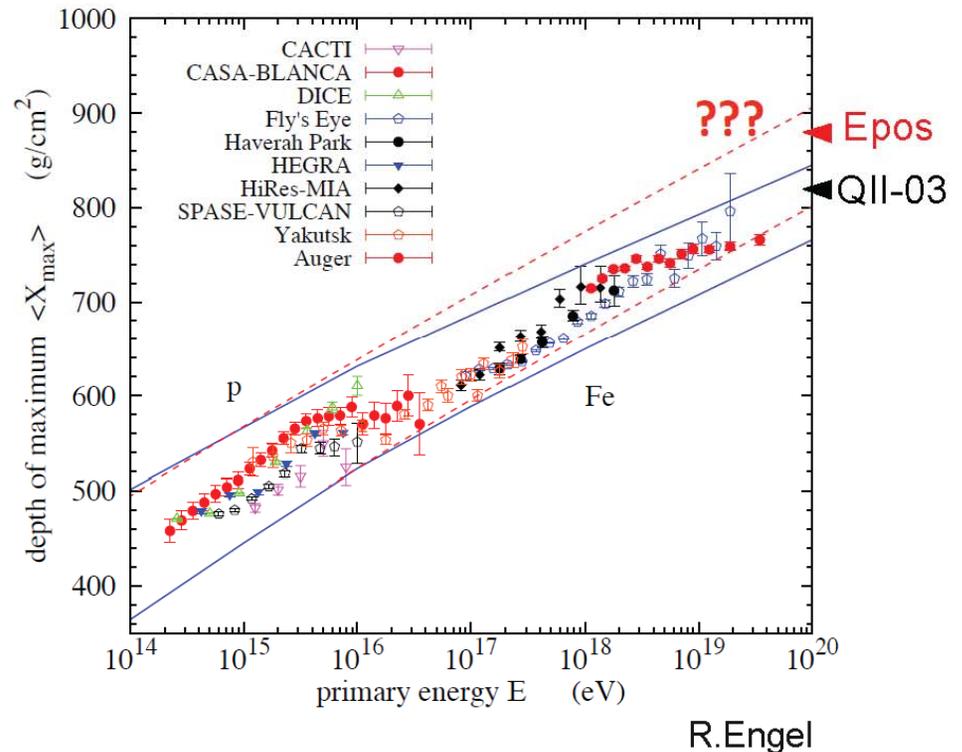
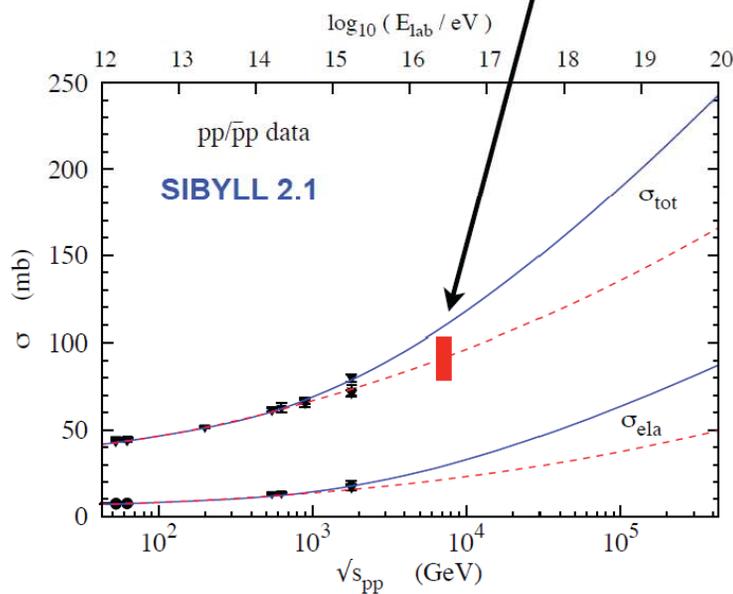
## LHC p-p cross section: change in $X_{\max}$

- Preliminary simple test with Sibyll on cross section ONLY
  - ➔ lower cross section → heavier composition with FD

ALICE  $\sigma_{\text{ine}} = (72.7 \pm 1.1 \pm 5.1) \text{ mb}$

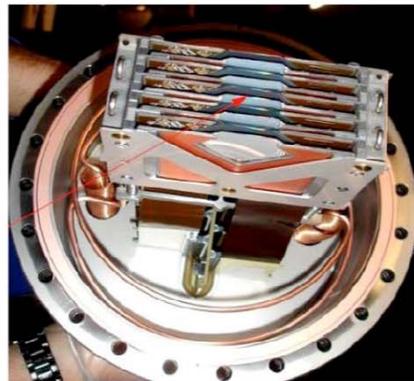
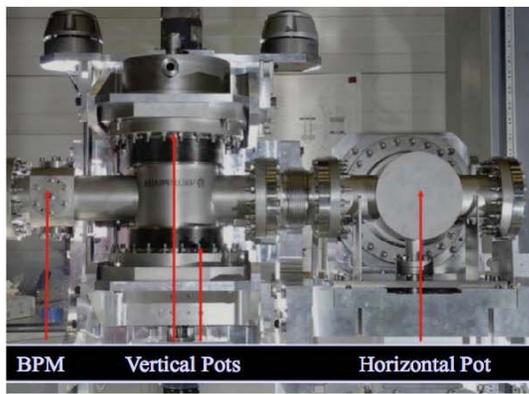
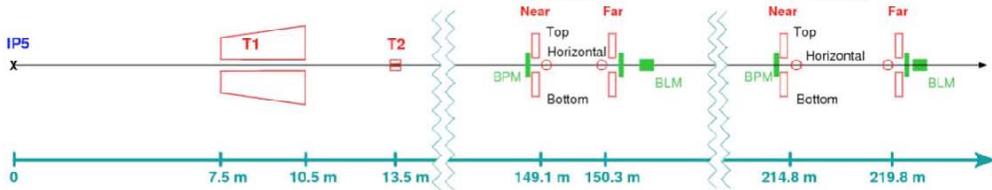
LHC: ATLAS  $\sigma_{\text{ine}} = (69.4 \pm 2.4 \pm 6.9) \text{ mb}$

CMS  $\sigma_{\text{ine}} = (68 \pm 3 \pm 4) \text{ mb}$

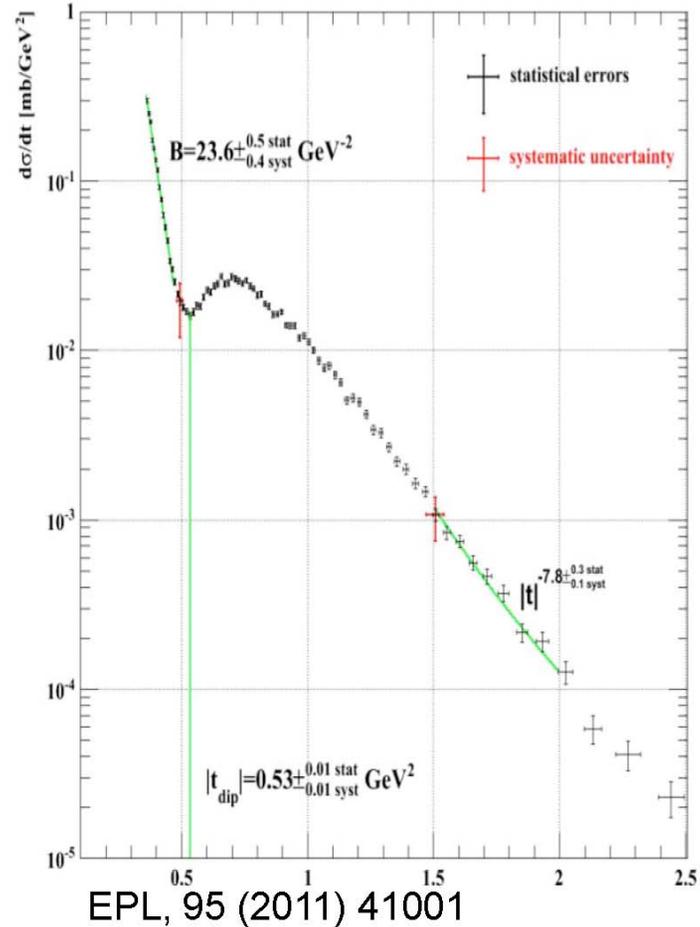


# Totem $\sigma_{\text{elastic}}$ and $\sigma_{\text{tot}}$

$3.1 \leq \eta \leq 4.7$     $5.3 \leq \eta \leq 6.5$

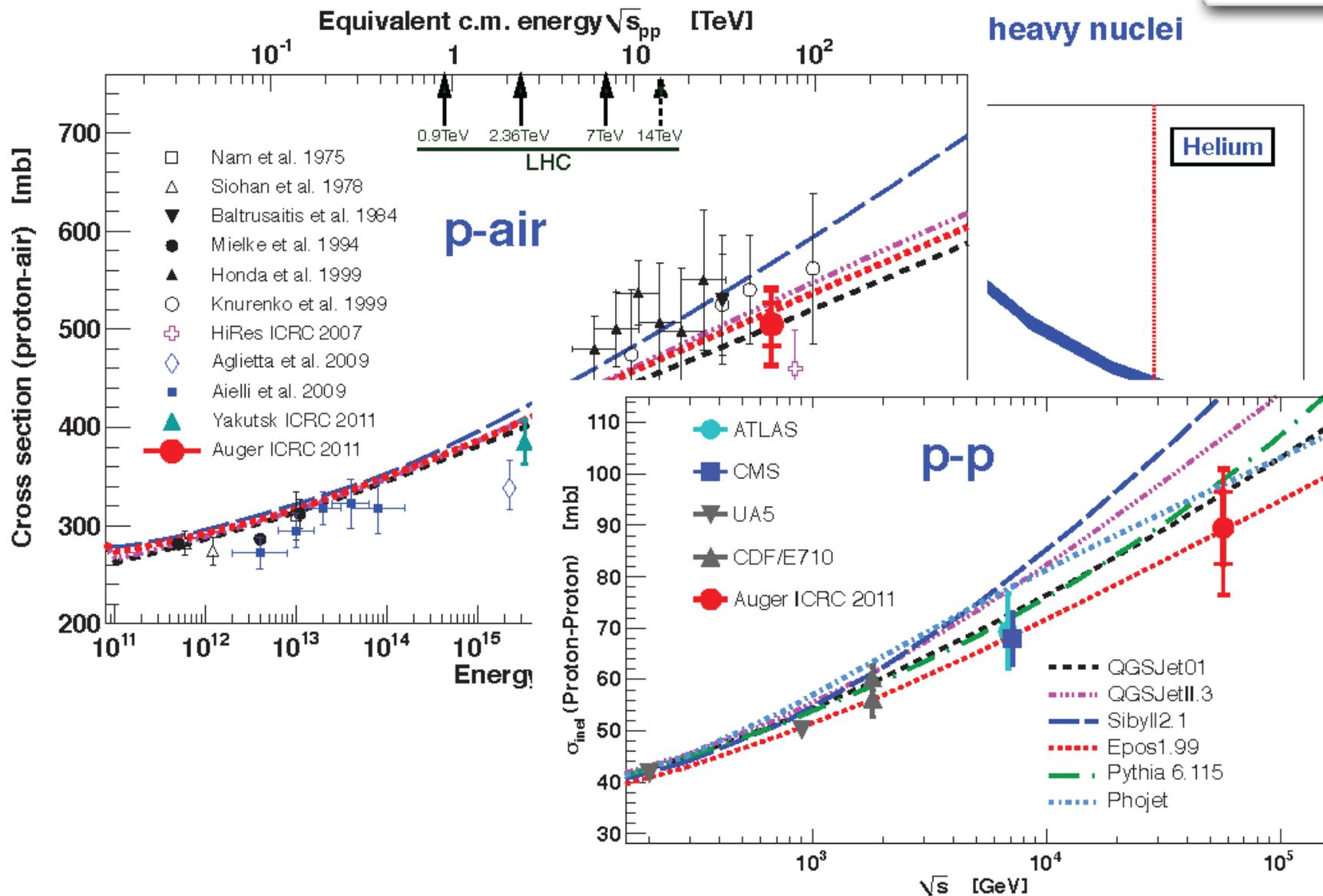


**Very preliminary pp differential cross section**



# Estimation of the proton-air cross section with the Pierre Auger Observatory

#946  
Ulrich

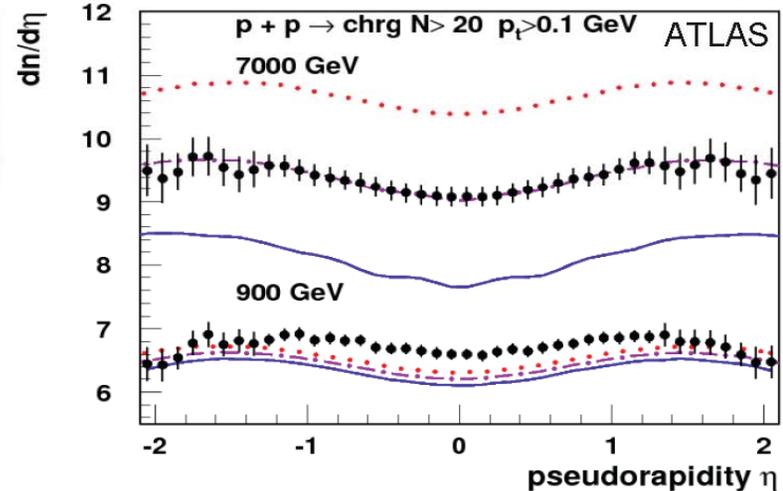
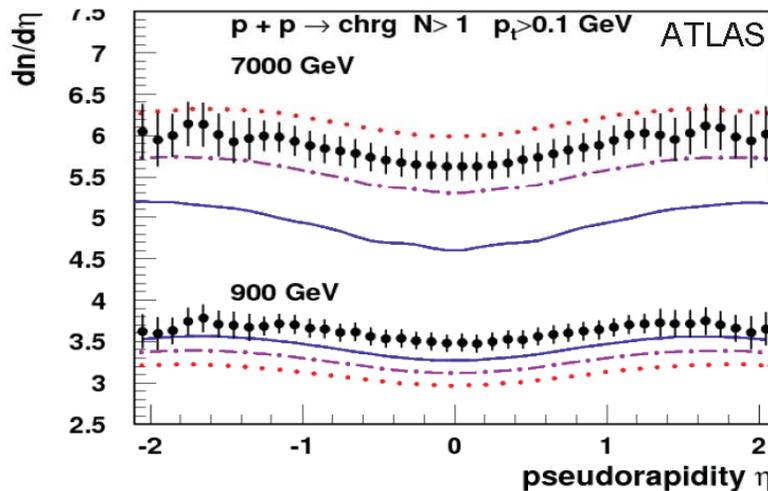
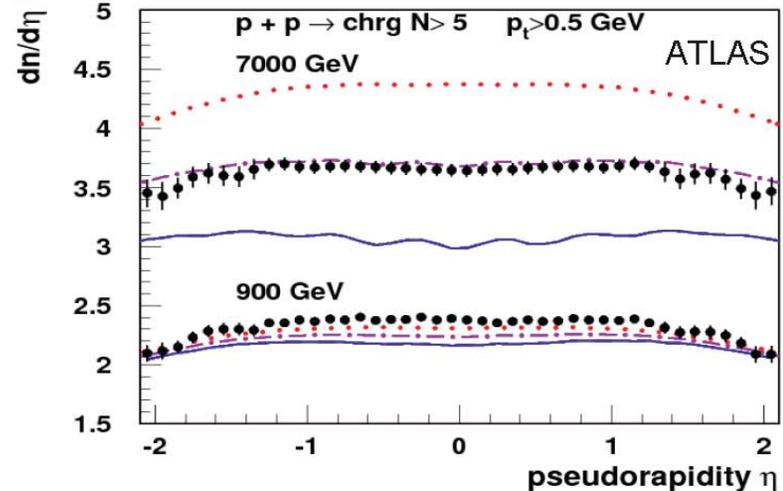
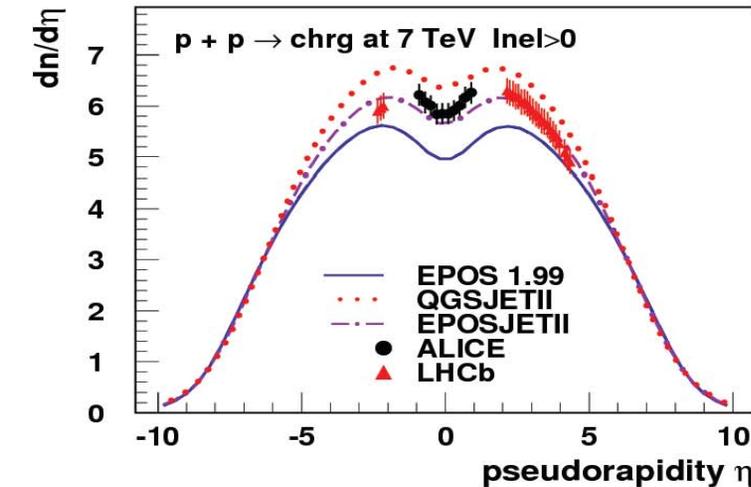


# Comparison of hadronic interaction models with LHC data

$$\eta = -\ln \left[ \tan \left( \frac{\theta}{2} \right) \right]$$

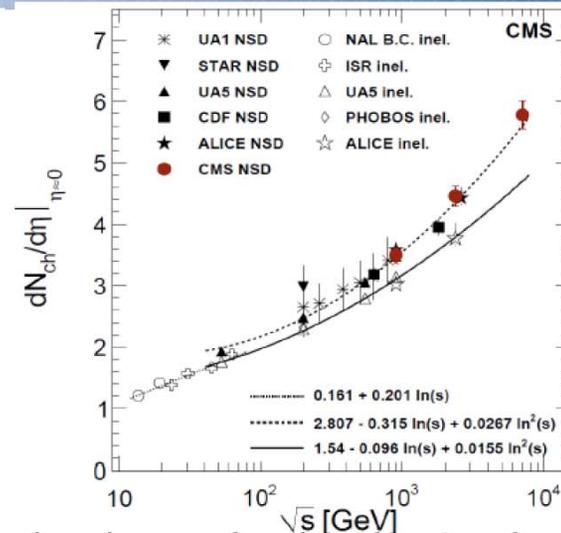
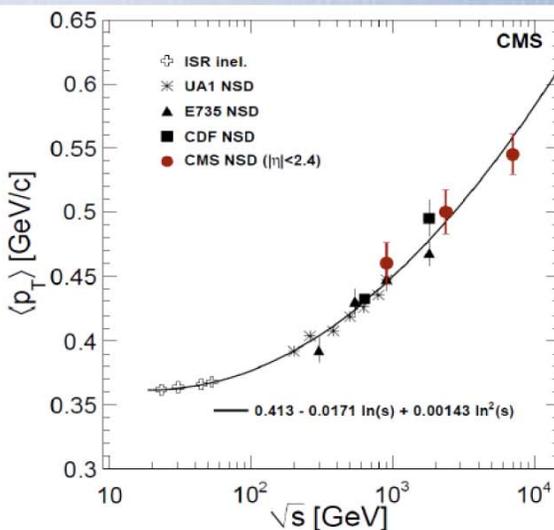
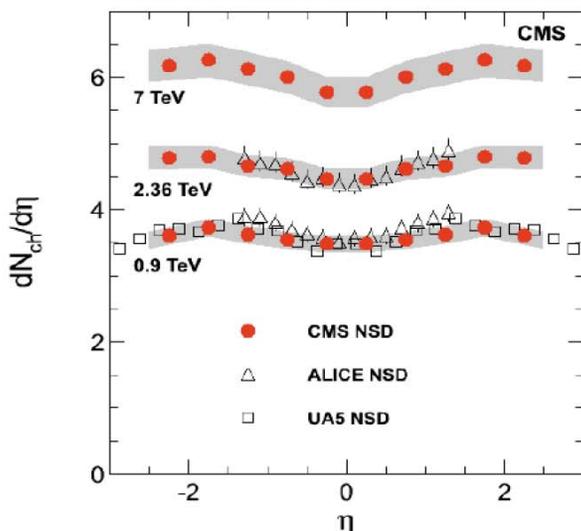
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## Pseudorapidity distributions



EPOSJETII=(EPOS 1.99+QGSJETII-03)/2 is **NOT** a new model !

# Minimum bias and soft QCD

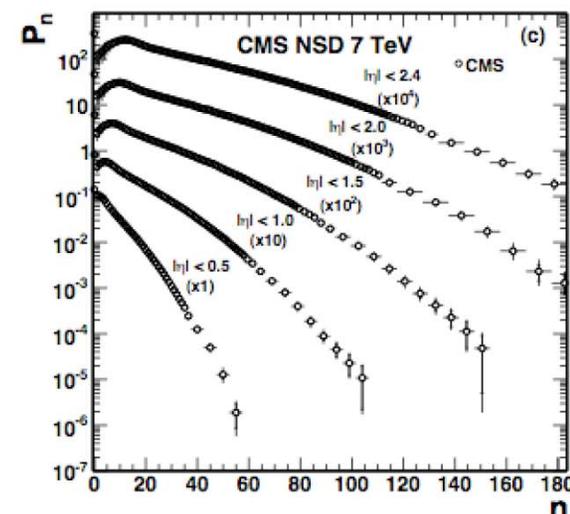
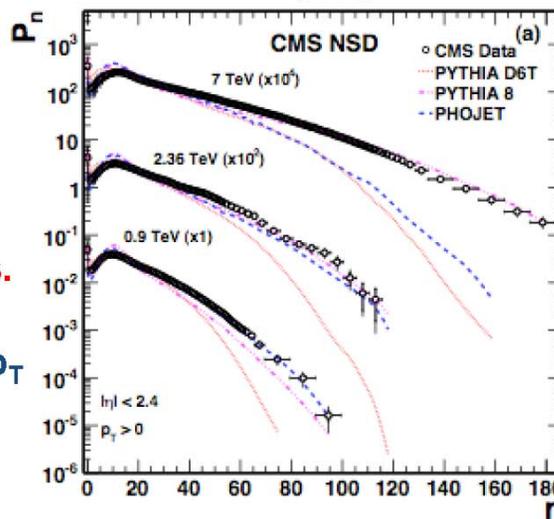


Measurements at 0.9, 2.36 and 7 TeV. Careful check of the scaling of particle multiplicity and  $\langle p_T \rangle$  vs energy.

**Rise of the particle density in data stronger than extrapolations from lower energies and model predictions.**

Careful tuning effort of the MC generators. Marginal impact on high  $p_T$  physics.

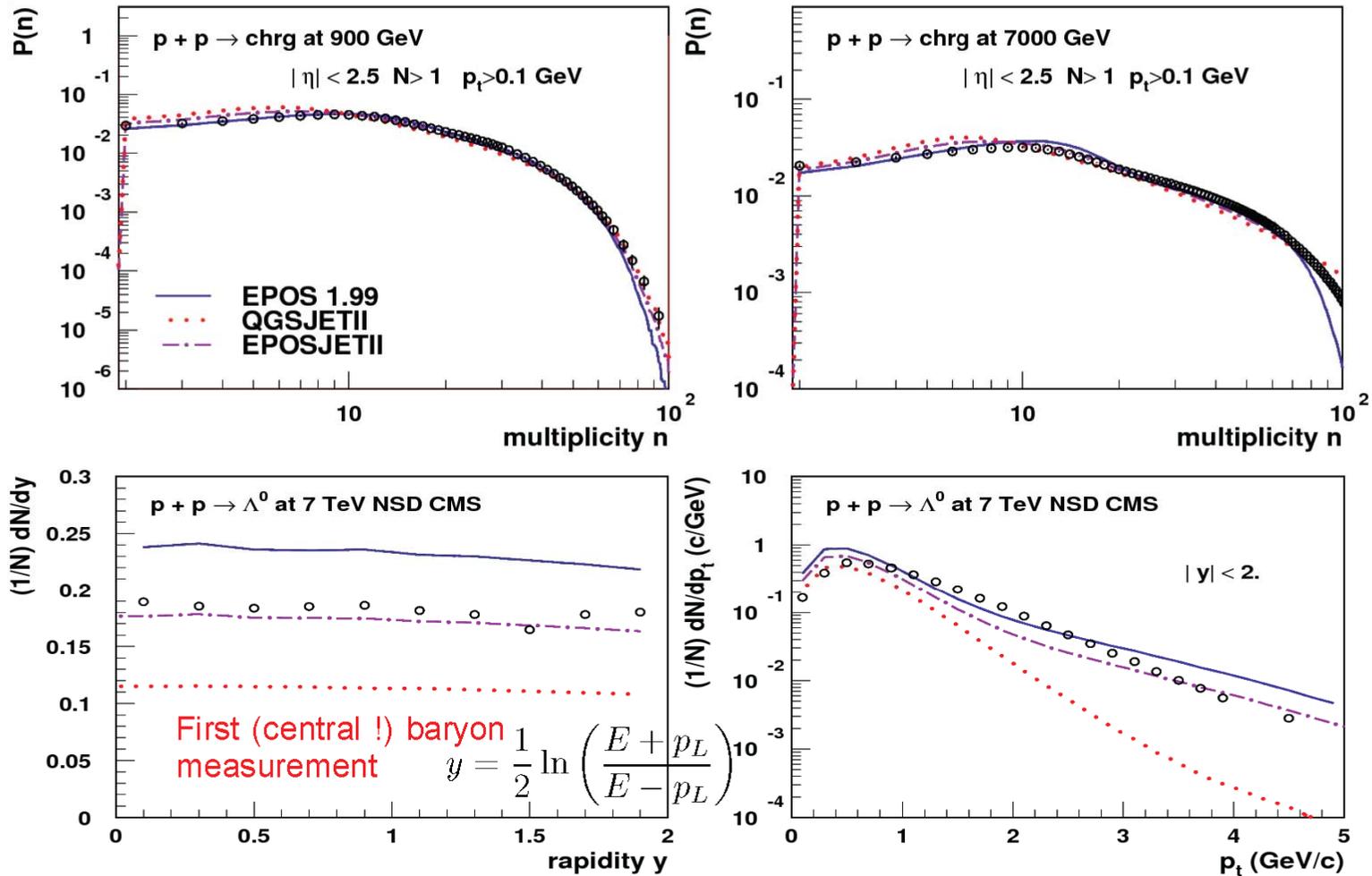
*Phys. Rev. Lett.* 105 (2010) 032001;  
arXiv:1005.329; arXiv:1011.5531;



# Comparison of hadronic interaction models with LHC data

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## Multiplicity and Lambda distributions

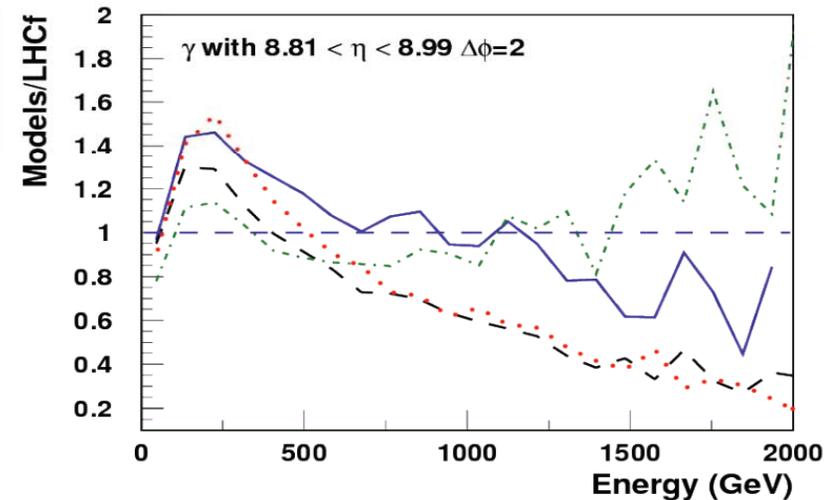
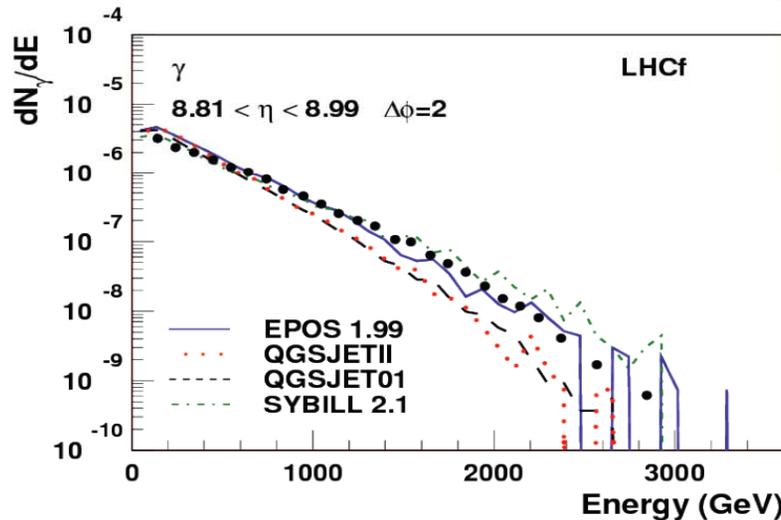
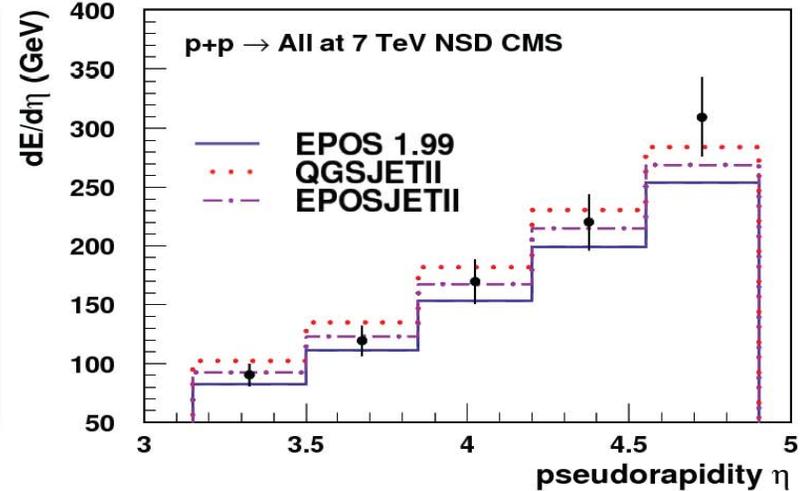
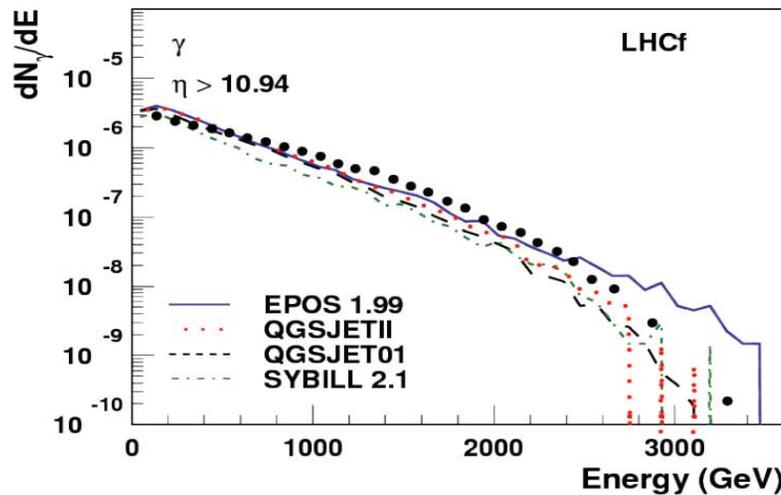


- Data well bracketed by EPOS 1.99 and QGSJETII-03
- ➔ Both models are needed !

# Comparison of hadronic interaction models with LHC data

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## Forward spectra



● Fitting of LHCf data  $\rightarrow$  effect on air shower development under investigation

# Basic Idea

Compress large amount of energy in a very small volume

→ produce a “fireball” of hot matter:

temperature  $O(10^{12} \text{ K})$

–  $\sim 10^5 \times T$  at centre of Sun

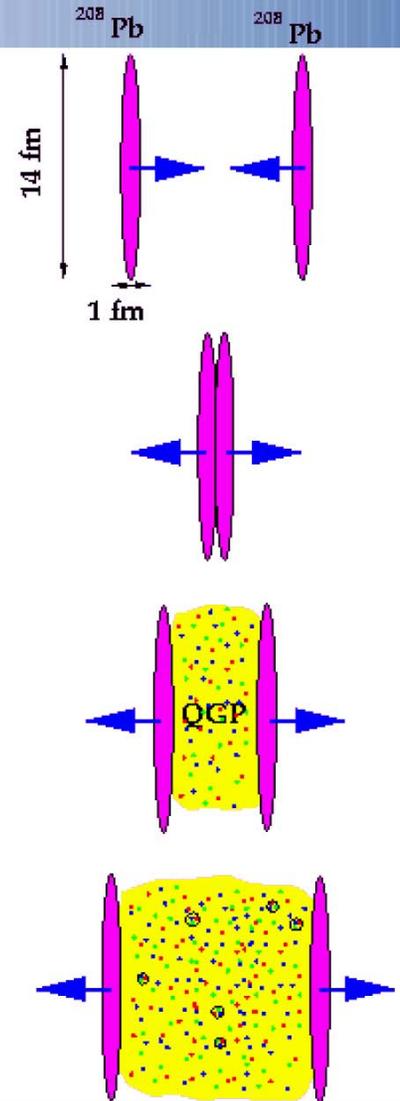
–  $\sim T$  of universe @  $\sim 10 \mu\text{s}$  after Big Bang

• how does matter behave under such extreme conditions?

→ study the fireball properties

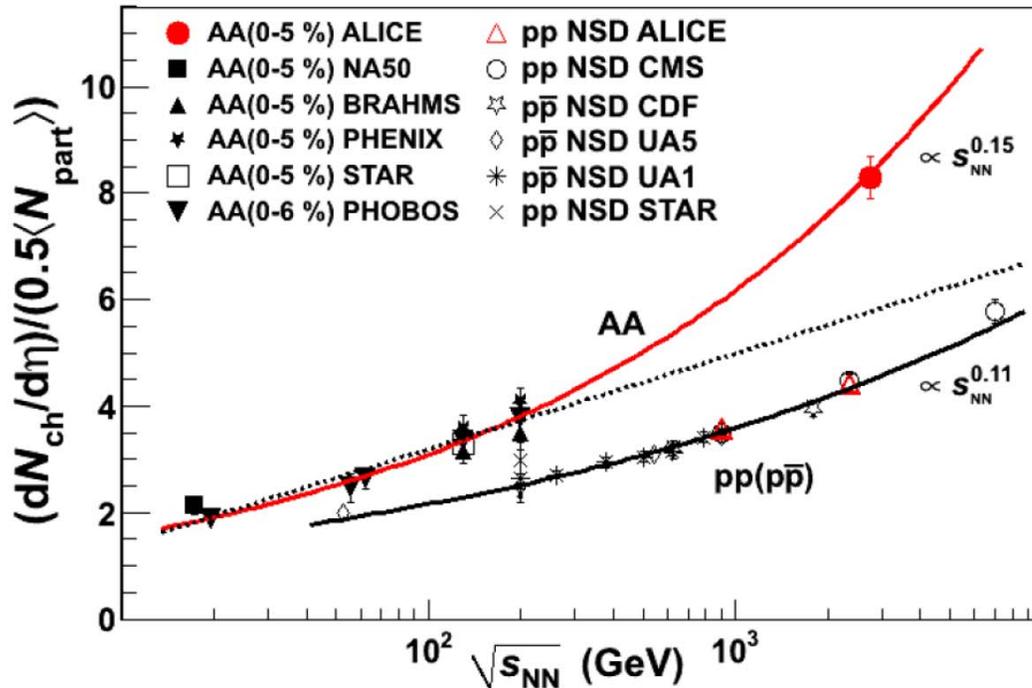
→ QCD predicts state of deconfined quarks and gluons (Quark-Gluon Plasma)

→ Look at the new state of matter in full detail



# Charged Particle Multiplicity

most central collisions: ~ 1600 charged particles per unit of  $\eta$



log extrapolation fails (finally!)

2.2 x central Au+Au  
( $\sqrt{s_{NN}}=0.2$  TeV)

1.9 x pp (NSD)  
( $\sqrt{s_{NN}}=2.36$  TeV)

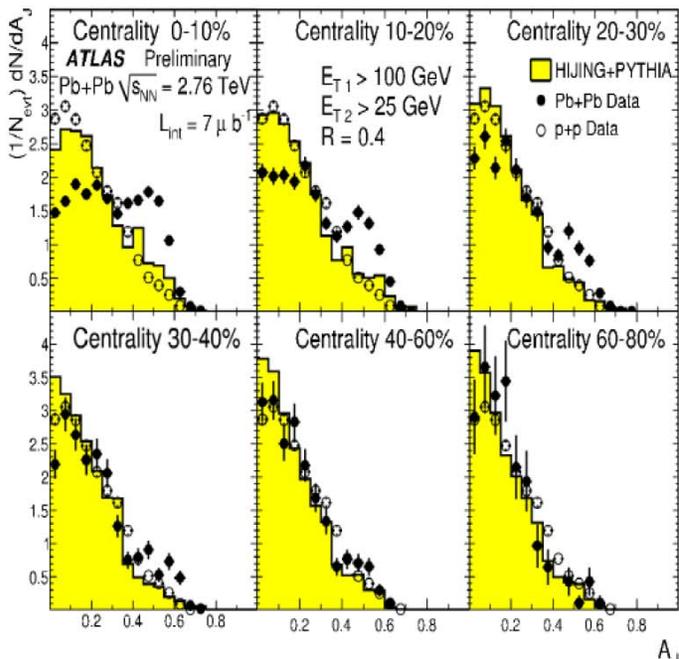
ALICE: PRL105 (2010) 252301

$\sqrt{s_{NN}}=2.76$  TeV Pb+Pb, 0-5% central,  $|\eta|<0.5$

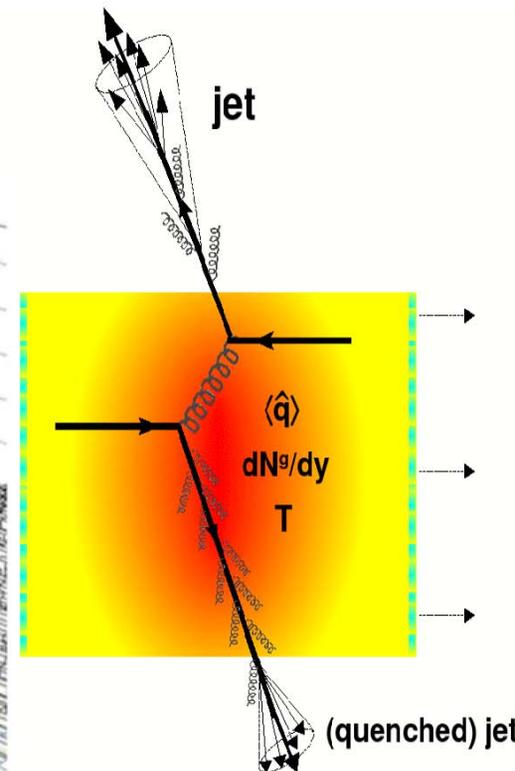
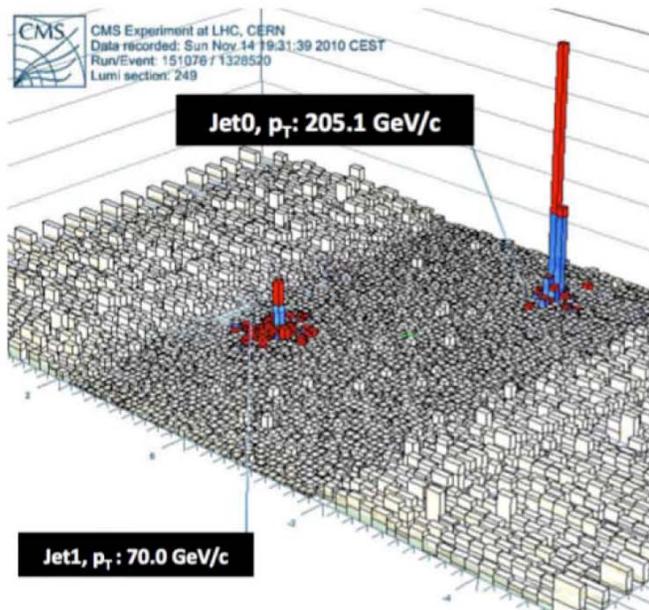
2  $dN_{ch}/d\eta / \langle N_{part} \rangle = 8.3 \pm 0.4$  (sys.)

# Jet-quenching

**First direct evidence of strong jet quenching observed in LHC HI collisions by ATLAS and CMS.**



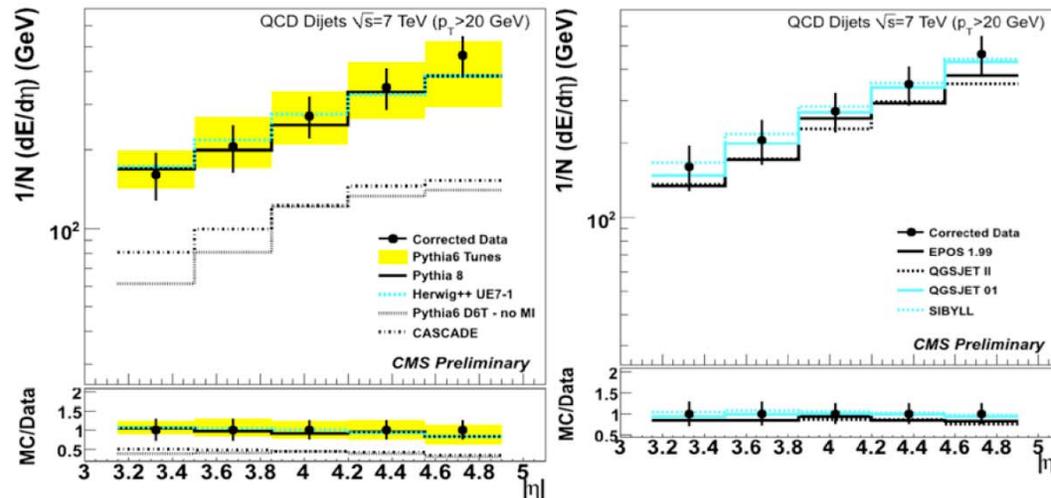
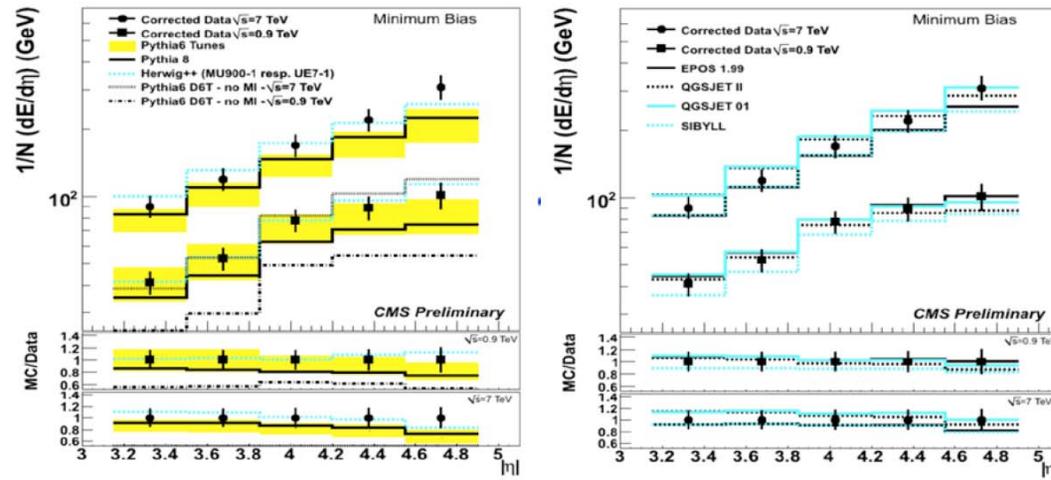
Indirect evidence of strong jet quenching measured at RHIC in single particle spectra and particle correlations.



# CMS Measurements of the Energy Flow

## EF in Minimum Bias Events

- HERWIG
  - $\sqrt{s}$  dependent tunes work
- PYTHIA
  - large spread between tunes
  - even LHC tunes do not work well
- Cosmic Ray generators
  - work pretty well w/o extra tuning !!!



## EF in Di-Jet Events $p_t > 20$ GeV

- HERWIG
  - $\sqrt{s}$  dependent tunes work
- PYTHIA
  - tunes cover data
- Cosmic Ray MCs
  - describe data

CMS-PAS-FWD-10-11

# $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ (ATLAS)

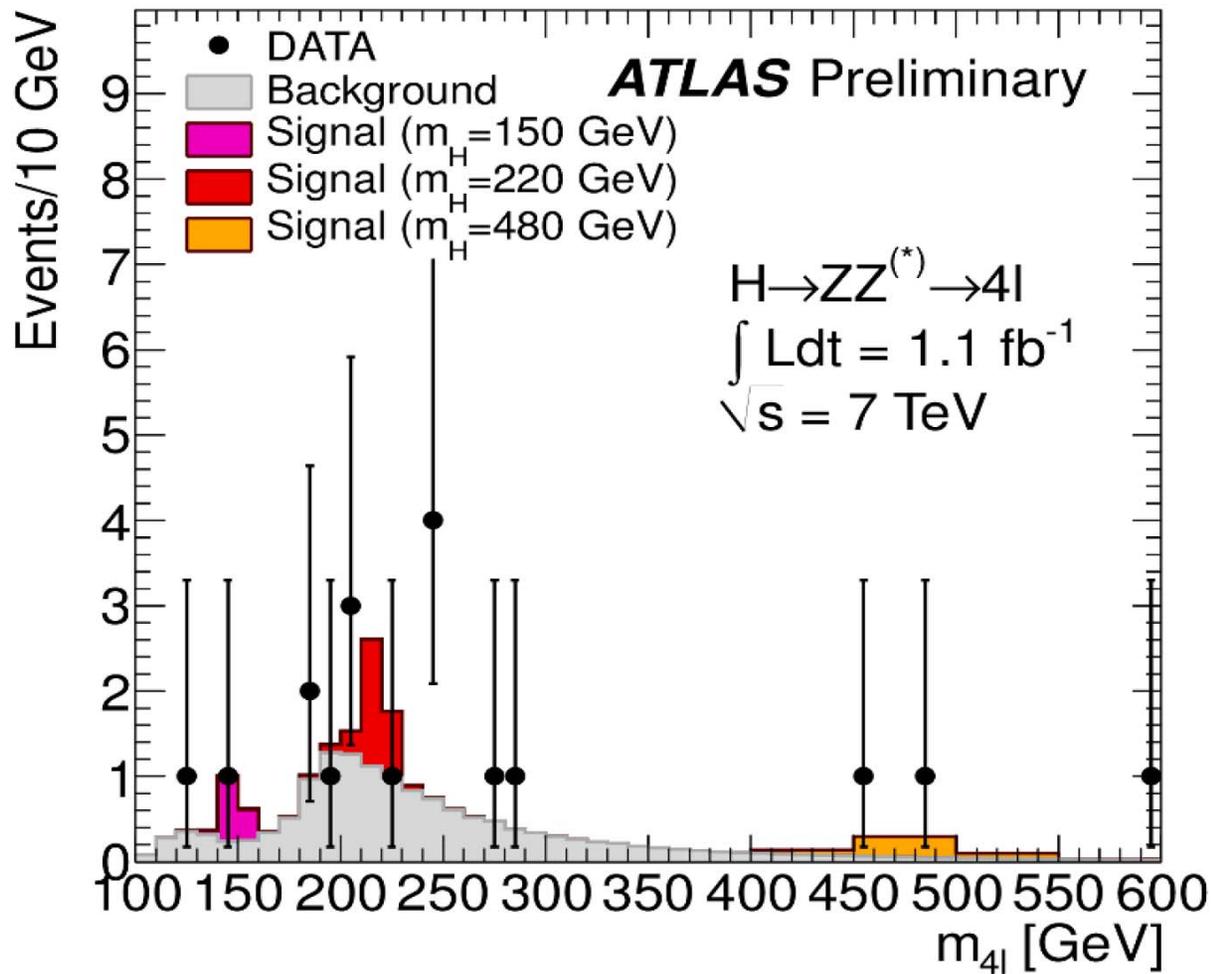
Excellent mass resolution and signal/background

Low product branching ratio

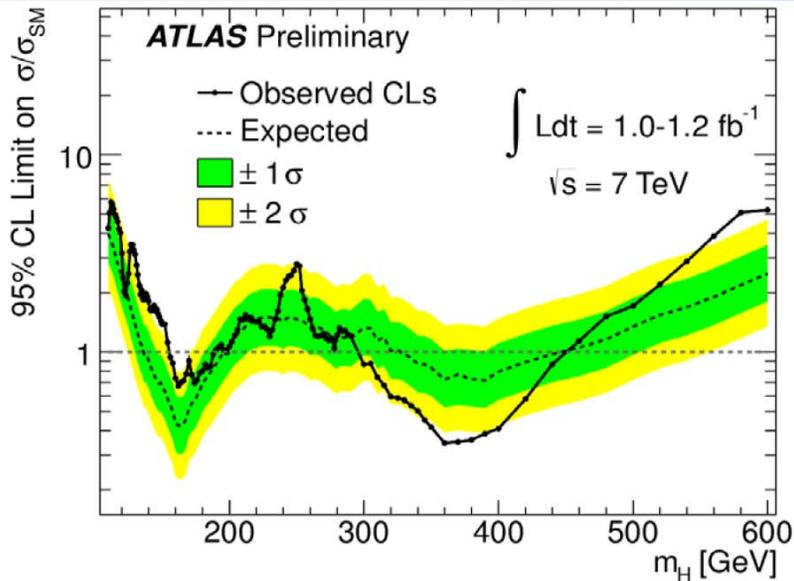
Useful below ZZ threshold

Leptons 3 and 4 down to 7 GeV

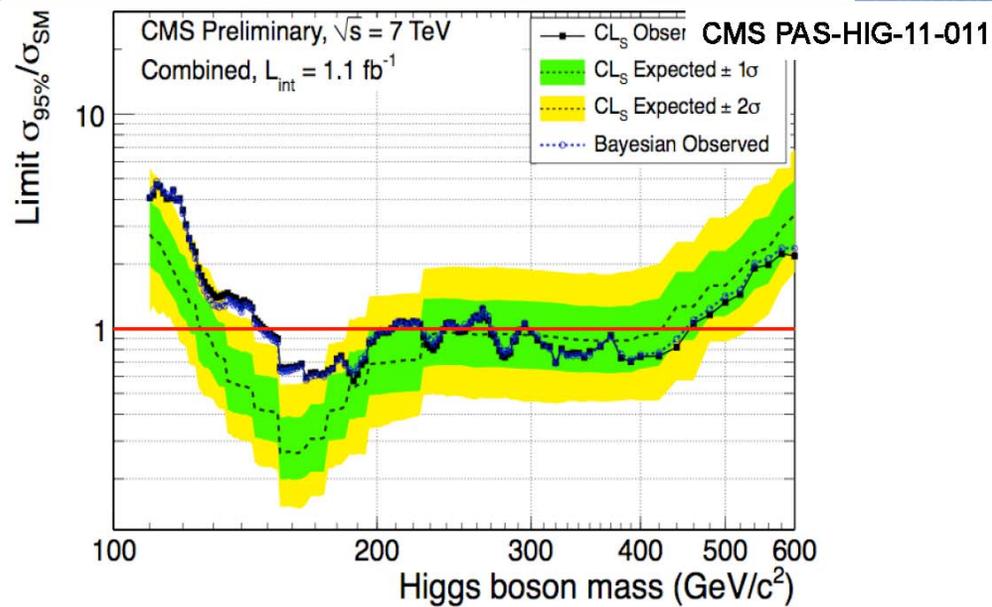
Low and high-mass selections - divide at 180 GeV



# SM Higgs exclusion limits



**ATLAS Observed exclusion: 155-190 GeV  
 + 295-450 GeV**



**CMS Observed exclusion: 149-206 GeV  
 + 300-440 GeV**

In the low mass part (114-149 GeV) we see a couple of interesting regions showing excesses larger than  $3\sigma$  (local significance without correction for LEE effects). Further study with the new data we are collecting will hopefully tell us if we are seeing a background fluctuation or a first sign of the Higgs boson.

# Conclusion

- LHC operations are proceeding very well.
- Plenty of new physics results are being produced by all LHC experiments.
- Unfortunately no evidence for physics beyond the Standard Model so far.
- New exclusion limits for the SM Higgs have been recently produced by ATLAS and CMS. Intriguing excess in data is present in the low mass region. With the data we will collect in the next few months we hope we'll be able to distinguish between the possible interpretations: the production of a Higgs boson or a statistical fluctuation of the background.

Спасибо за внимание