Particle production mechanisms in hadron collisions

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Introduction

Physics motivations at LHC

ヒッグス粒子を見つけなければ！

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もしかしたら標準模型を超える物理に遭遇するかも！

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Physics motivations at LHC

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もしかしたら標準模型を超える物理に遭遇するかも！

B中間子が大量に生成するぜ！

世界最高温度のQGPの研究が出来る！

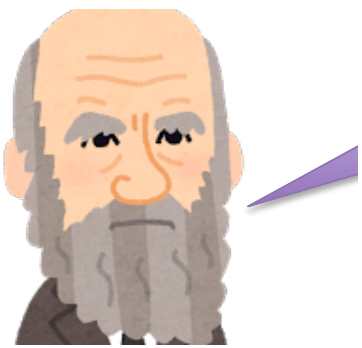
QCD in pp at LHC

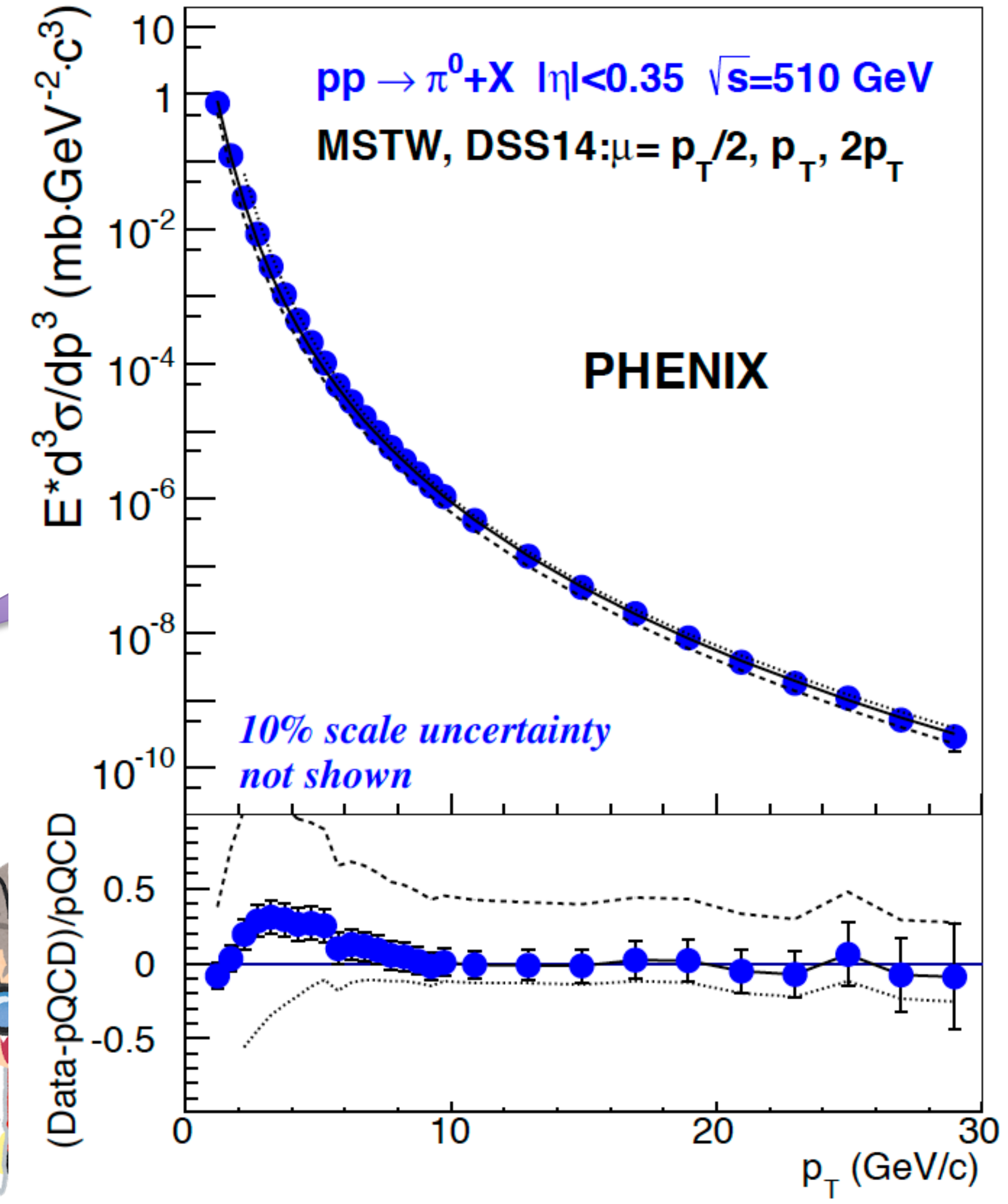
バックグランド

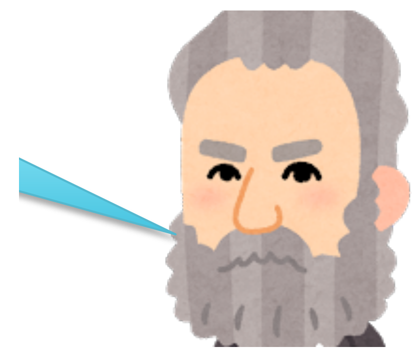
バックグランド

（ほとんど）バックグランド

ただの基準値。

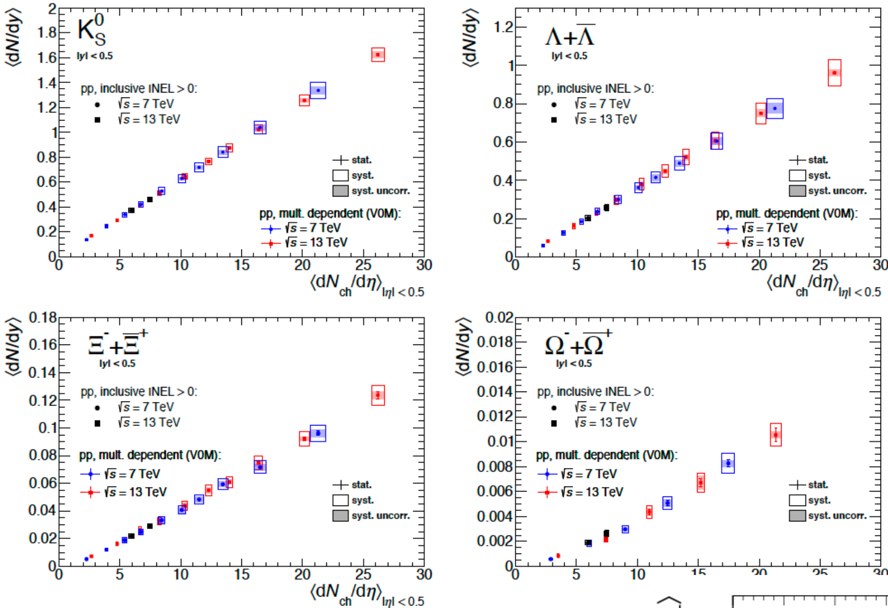


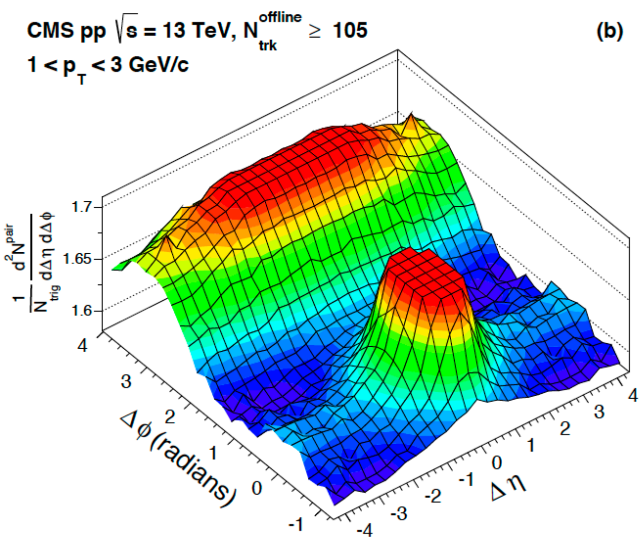

pp → π⁰+X |η|<0.35 √s=510 GeV
MSTW, DSS14:μ= p_T/2, p_T, 2p_T
PHENIX
10% scale uncertainty
not shown
E*d³σ/dp³ (mb·GeV⁻²·c³)
10
1
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
(Data-pQCD)/pQCD
0.5
0
-0.5
0
10
20
30
p_T (GeV/c)

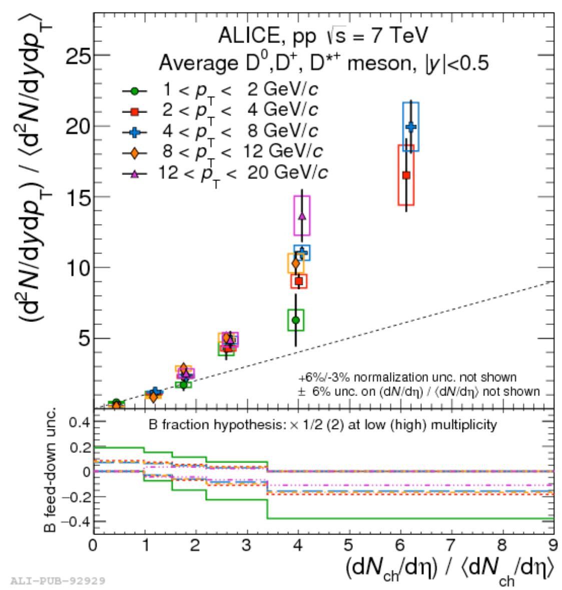


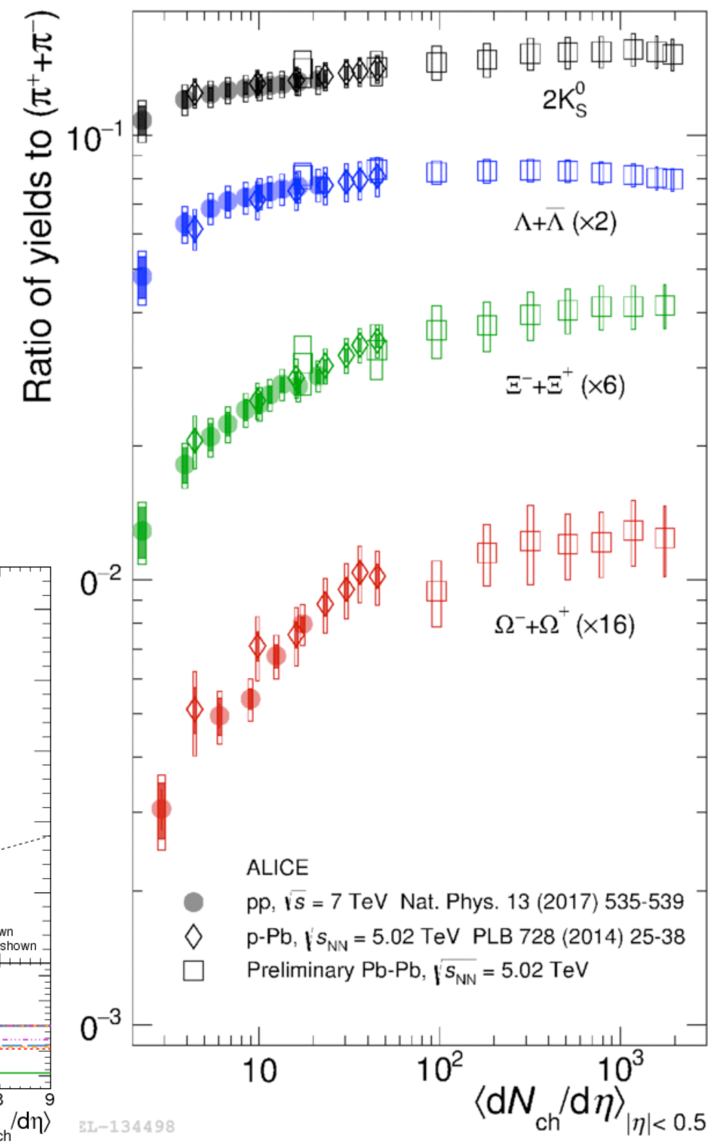
でも・・・

Unexpected results in pp





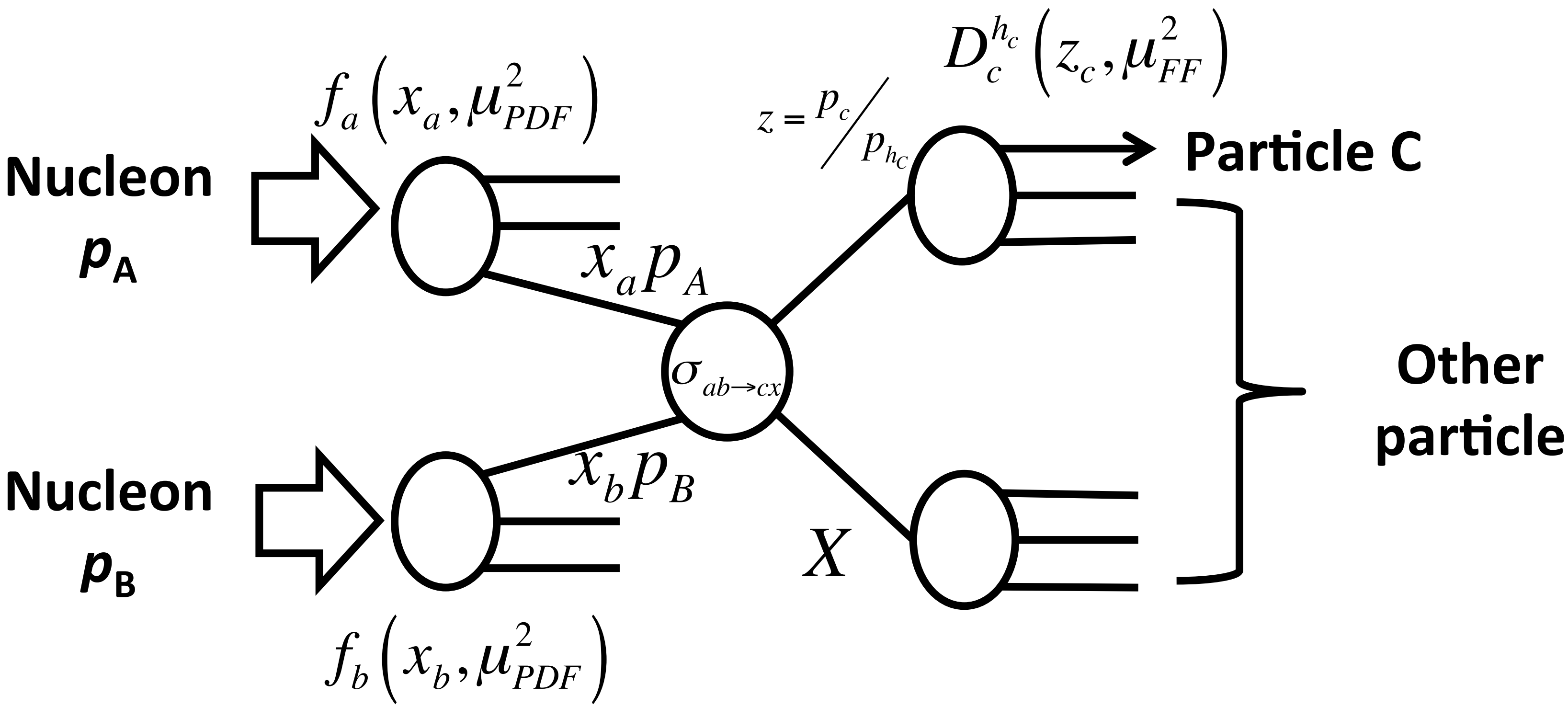




Particle production

- Factorization Theorem

$$d\sigma_{AB\to h_cX} = f_a\left(x_a,\mu^2_{PDF}\right)\otimes f_b\left(x_b,\mu^2_{PDF}\right)\otimes d\hat{\sigma}_{ab\to cx}\otimes D_c^{h_c}\left(z_c,\mu^2_{FF}\right)$$



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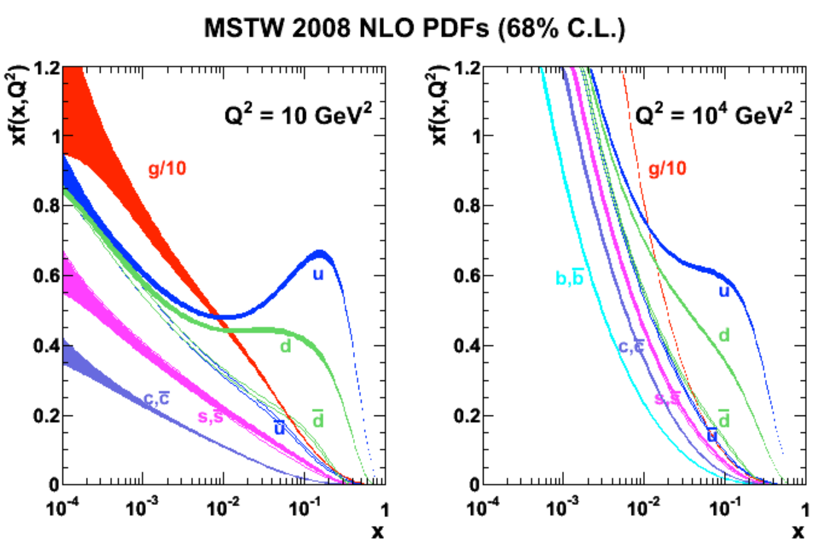
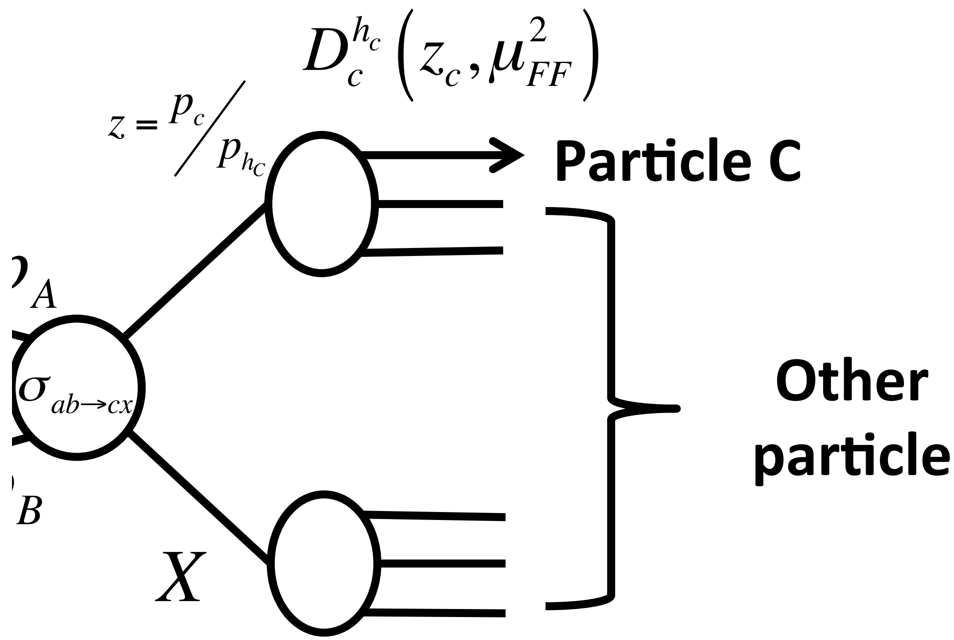


$$f_b\left(x_b,\mu_{PDF}^2\right)$$



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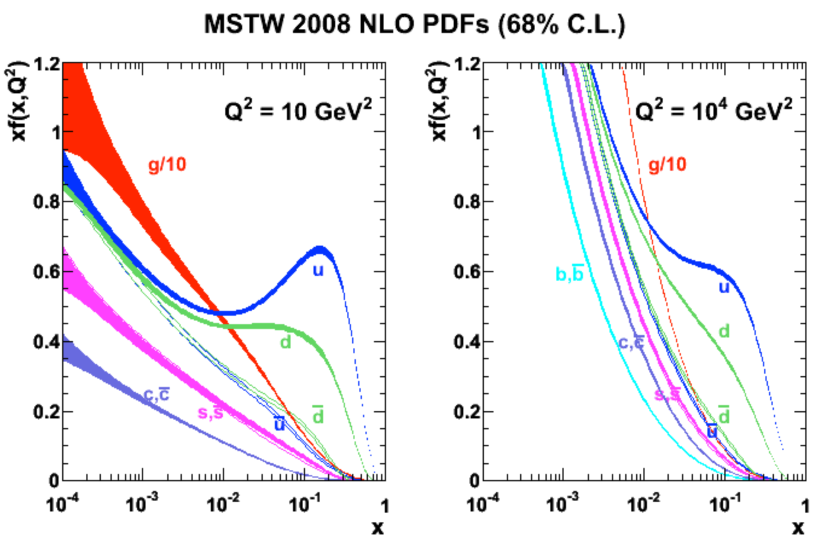
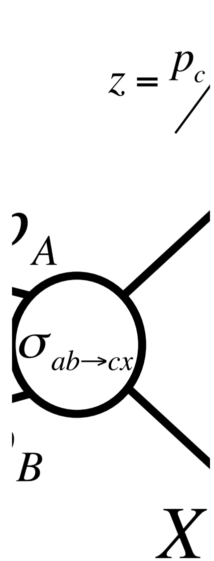
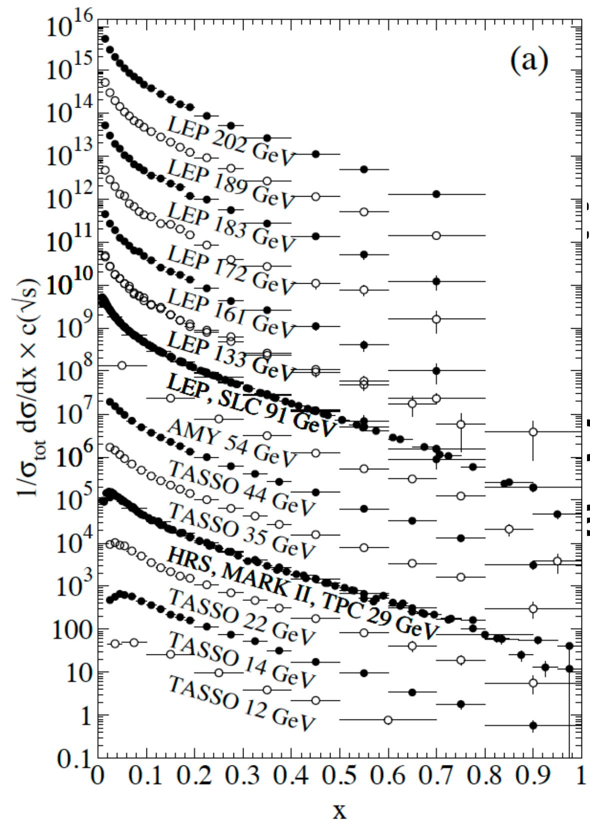


$$f_b\left(x_b,\mu_{PDF}^2\right)$$





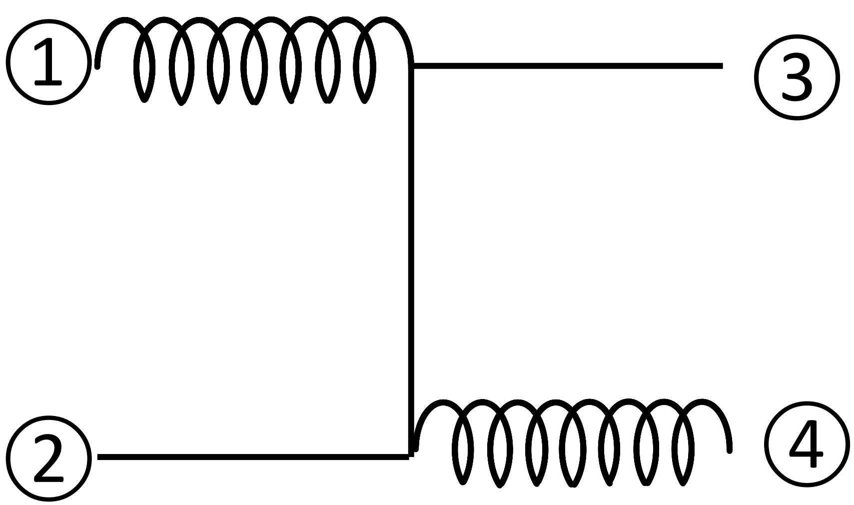
Other
article

QCD subprocess

- Hard scattering in conventional pQCD

$$E\frac{d^3\sigma}{dp^3}(AB \to CX) = \frac{d^3\sigma}{p_T dp_T dy d\varphi} = \frac{1}{p_T^{2n_{active}-4}} F\left(\frac{p_T}{\sqrt{s}}\right)$$

  – n_{active} is the number of fields participating to the hard process
  – $p_T/\sqrt{s} \propto x_T$



2→2 sub-process

Jet or direct photon

$n_{active} = 4 \rightarrow 2n_{active} - 4 = 4$

x_T scaling

$$\sqrt{s}^{\,n} E\frac{d^3\sigma}{dp^3}(AB \rightarrow CX) = \left(\frac{\sqrt{s}}{p_T}\right)^n F\left(\frac{p_T}{\sqrt{s}}\right) = \left(\frac{2}{x_T}\right)^n F'\left(x_T\right) = G\left(x_T\right)$$

$$n = 2n_{active} - 4$$

$$x_T = \frac{2p_T}{\sqrt{s}}$$

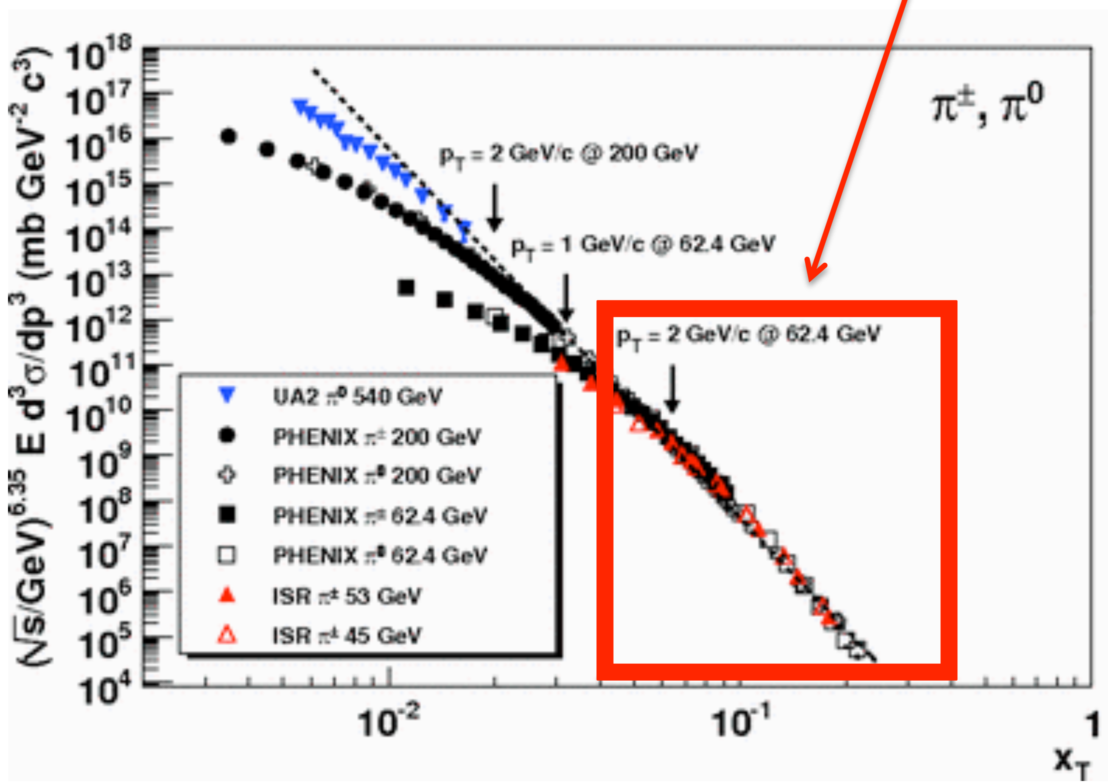
x_T scaling

$$\sqrt{s}^{\,n} E\frac{d^3\sigma}{dp^3}(AB\rightarrow CX)=\left(\frac{\sqrt{s}}{p_T}\right)^n F\left(\frac{p_T}{\sqrt{s}}\right)=\left(\frac{2}{x_T}\right)^n F'(x_T)=G(x_T)$$

$$n=2n_{active}-4$$

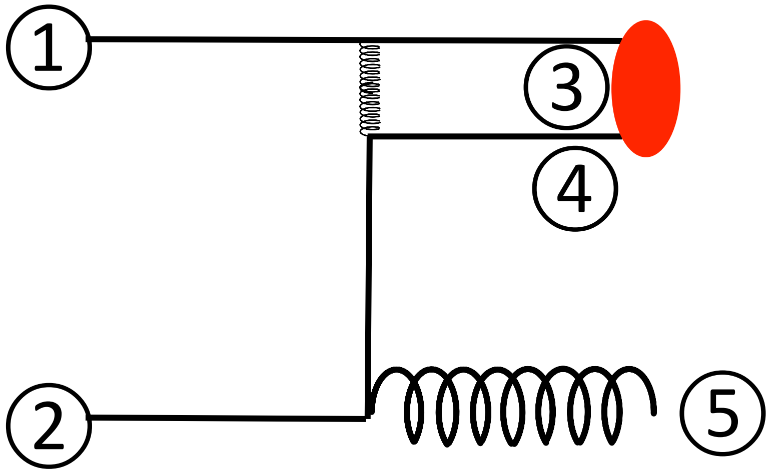
$$x_T=\frac{2p_T}{\sqrt{s}}$$

NOT depend on collision energy!



Direct hadron production

Meson production

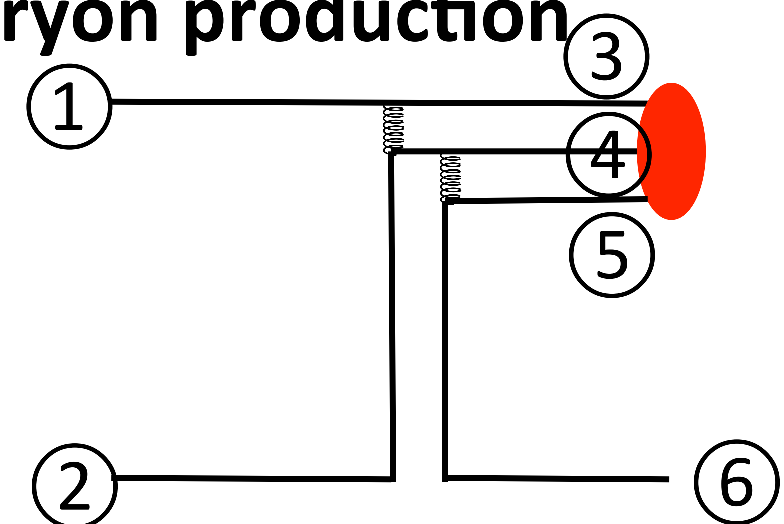


Direct meson production

$n_{\mathrm{active}} = 5 \rightarrow 2n_{\mathrm{active}} - 4 = 6$

$$E\frac{d^3\sigma}{dp^3}(AB \rightarrow CX) = \frac{1}{p_T^{6}} F\left(\frac{p_T}{\sqrt{s}}\right)$$

Baryon production



Direct baryon production

$n_{\mathrm{active}} = 6 \rightarrow 2n_{\mathrm{active}} - 4 = 8$

$$E\frac{d^3\sigma}{dp^3}(AB \rightarrow CX) = \frac{1}{p_T^{8}} F\left(\frac{p_T}{\sqrt{s}}\right)$$

Extraction of the exponent *n*

- From x_T scaling

$$\sqrt{s}^{\,n} E \frac{d^3\sigma}{dp^3}(AB \rightarrow CX) = \boxed{G(x_T)}$$

Constant for several collision energies

- $G(x_T)$ is constant

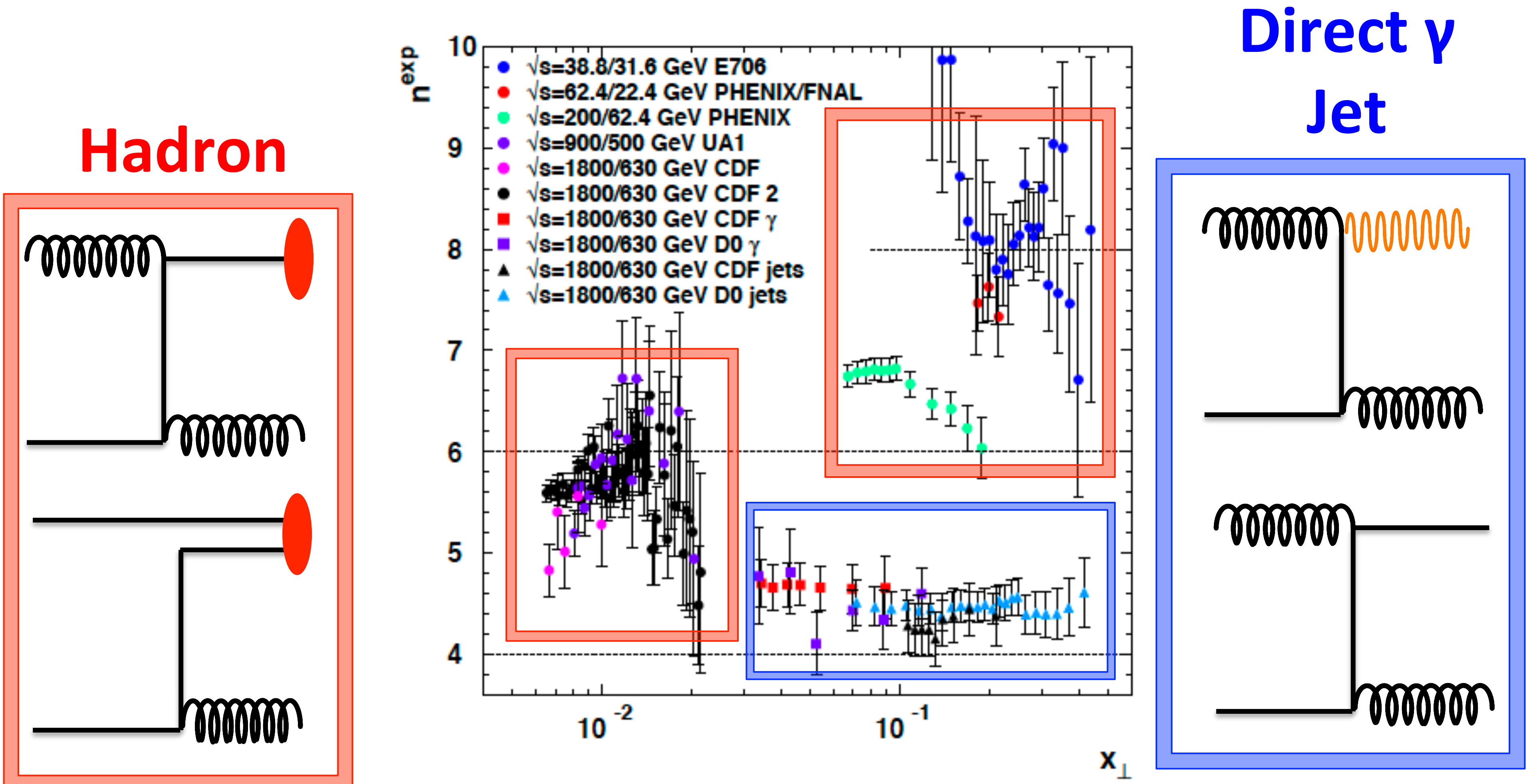
$$\sqrt{s_1}^{\,n} E \frac{d^3\sigma}{dp^3}(AB \rightarrow CX) = \sqrt{s_2}^{\,n} E \frac{d^3\sigma}{dp^3}(AB \rightarrow CX)$$

$$\boxed{n = -\frac{\ln\left[\sigma_1^{inv}\left(x_T, \sqrt{s_1}\right) / \sigma_2^{inv}\left(x_T, \sqrt{s_2}\right)\right]}{\ln\left(\sqrt{s_1} / \sqrt{s_2}\right)}}$$

NOTE: $\sqrt{s_1} \sim \sqrt{s_2}$ is better to cancel several higher order effects

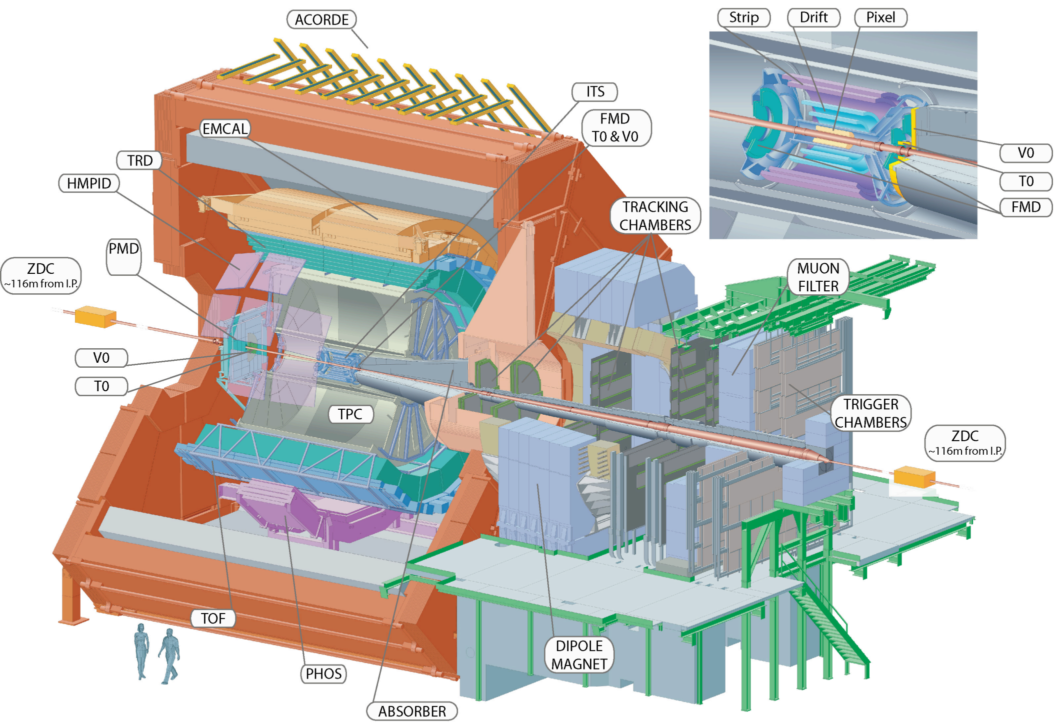
Exponent *n* in experiment

- Exponent n is measured at 22.4 GeV to 1.8 TeV

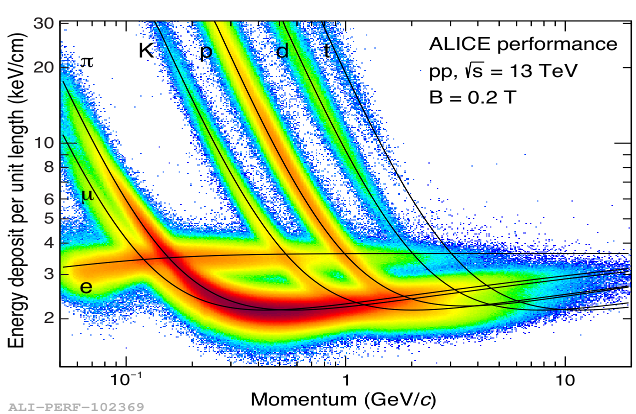


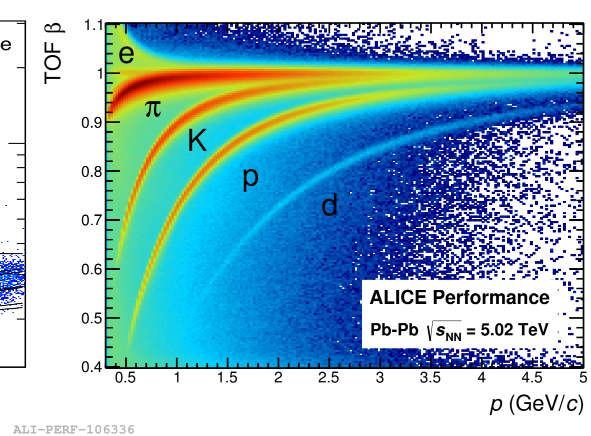
Neutral meson measurement with the ALICE detector

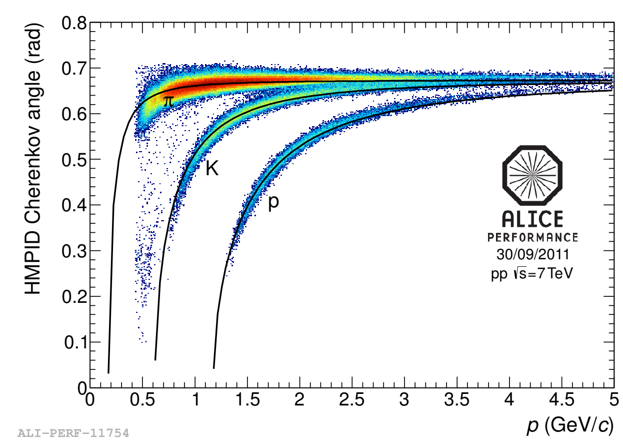
ALICE @ LHC



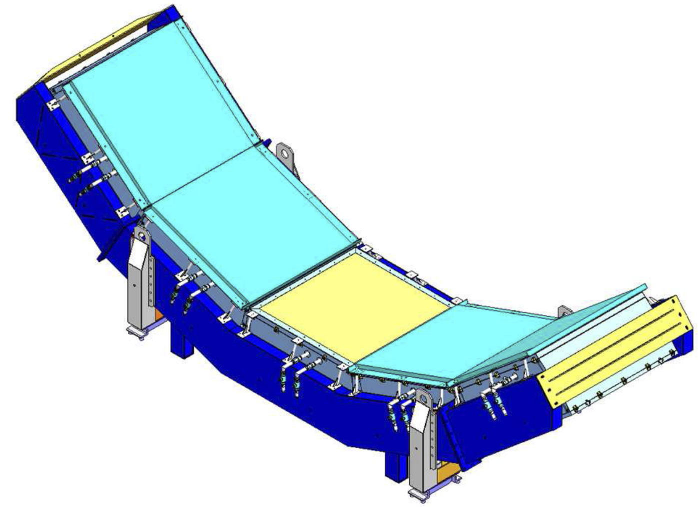
- Central detectors
  - ITS: Particle DCA
  - TPC: Tracking + PID
  - TOF: PID
  - HMPID: PID
  - TRD: electron ID
  - EM Calorimeter: 5 MeV – 80 GeV
- Forward detectors
  - Muon: Tracking muon ID



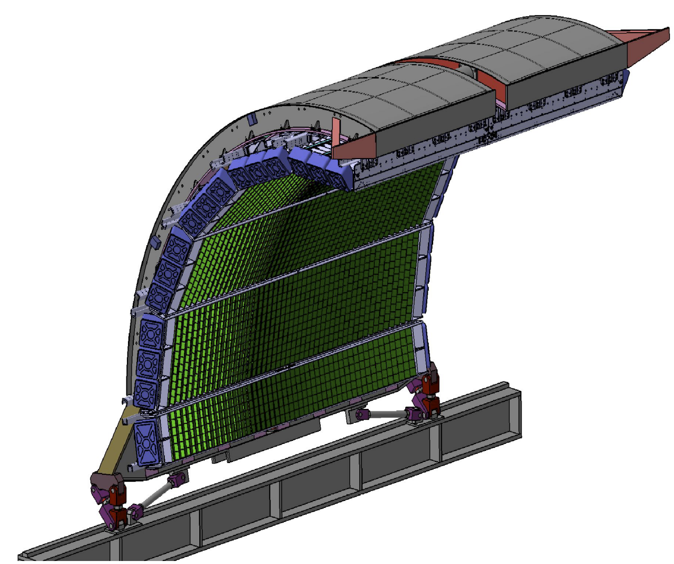




Photon reconstruction (1)

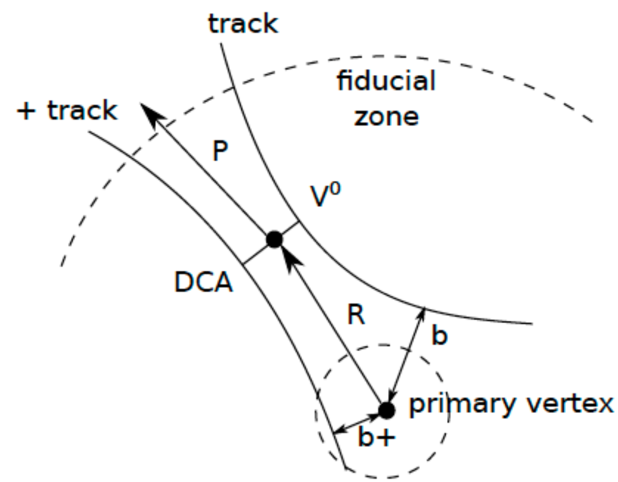


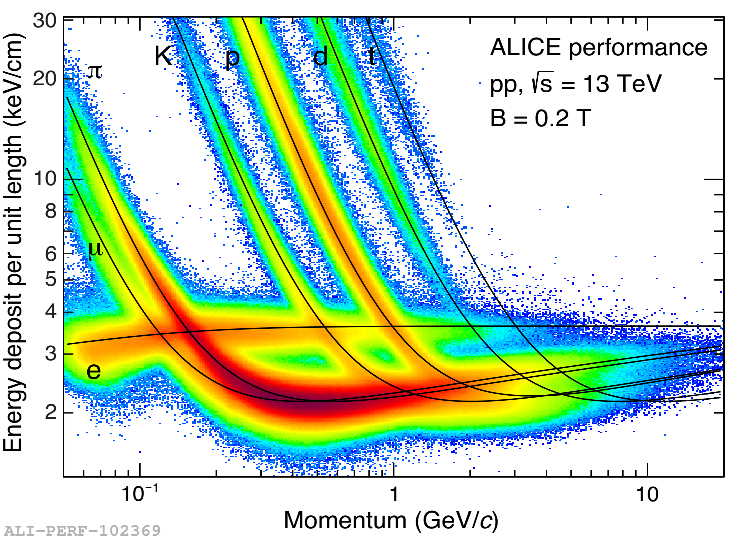
- PHOS
  - Lead Tungstate Crystal ($PbWO_4$)
  - Cell dimensions:
    - $\Delta\eta \times \Delta\varphi = 0.004 \times 0.004$
  - Energy resolution:
    - $\sigma_E / E = 1.8\% / E \oplus 3.3\% / \sqrt{E} \oplus 1.1\%$
  - $|\eta| < 0.12, \Delta\varphi = 60^\circ$
- EMCal
  - Shashlik calorimeter (leads/scintillator × 77)
  - Cell dimensions:
    - $\Delta\eta \times \Delta\varphi = 0.0143 \times 0.0143$
  - Energy resolution:
    - $\sigma_E / E = 4.8\% / E \oplus 11.3\% / \sqrt{E} \oplus 1.7\%$
  - $|\eta| < 0.67, \Delta\varphi = 100^\circ$

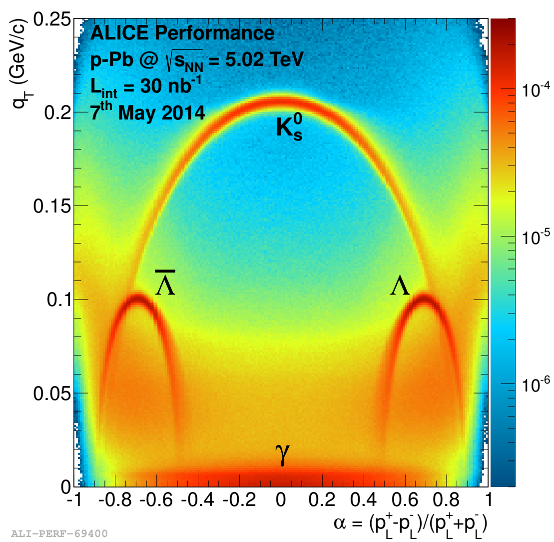


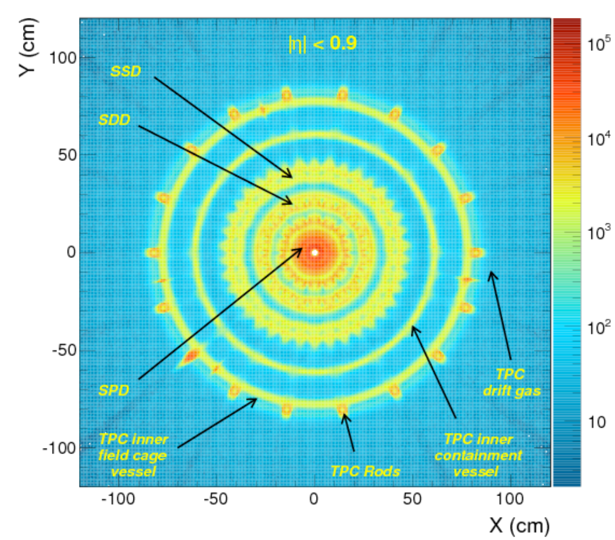
Photon reconstruction (2)

- Photon Conversion Method (PCM)
  - Select electron candidates with TPC dE/dx
  - Pair of electron and positron with large impact parameter
  - DCA between the pair (V0 finding)
  - Armenteros-Podolanski-Plot
- Performance
  - $|\eta| < 0.9, 0 < \varphi < 2\pi$
  - Purity > 99%



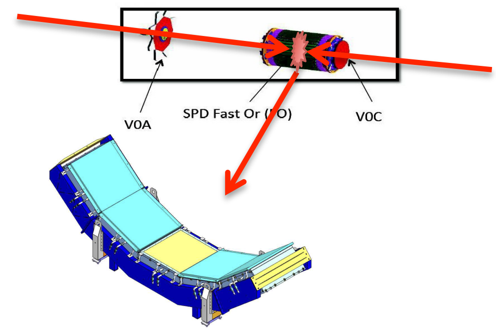


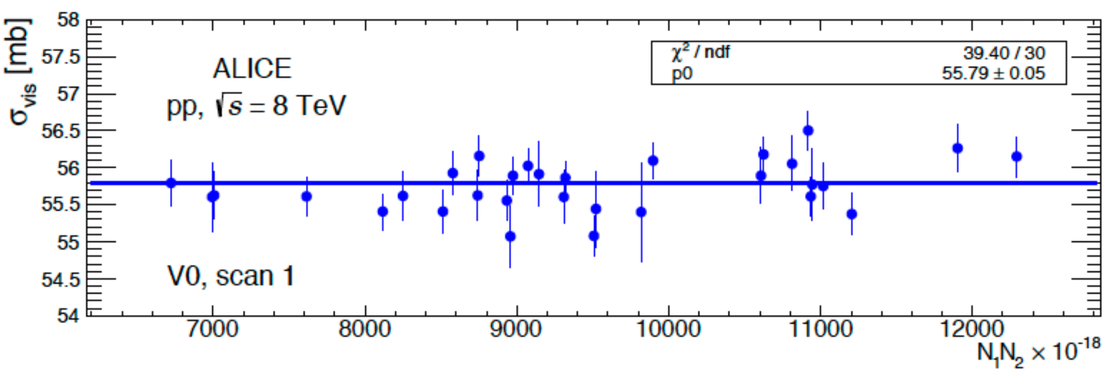


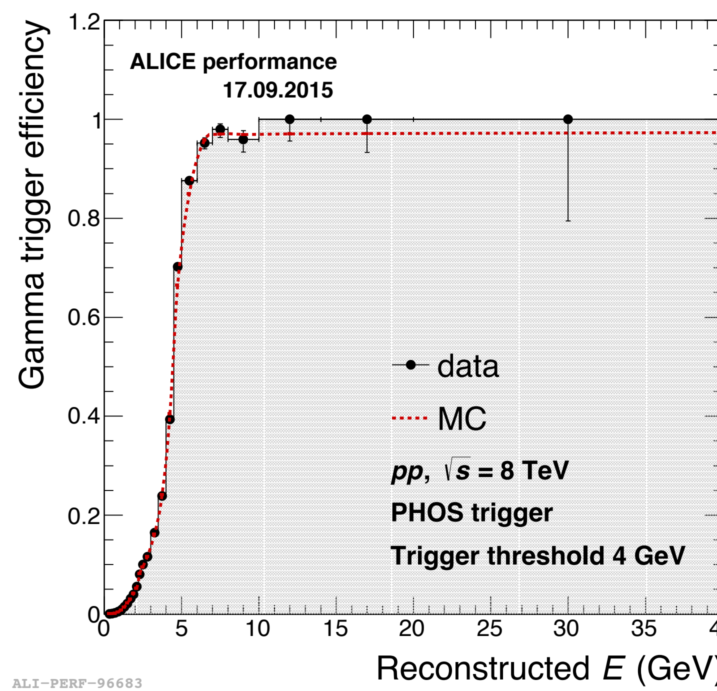


Data sample

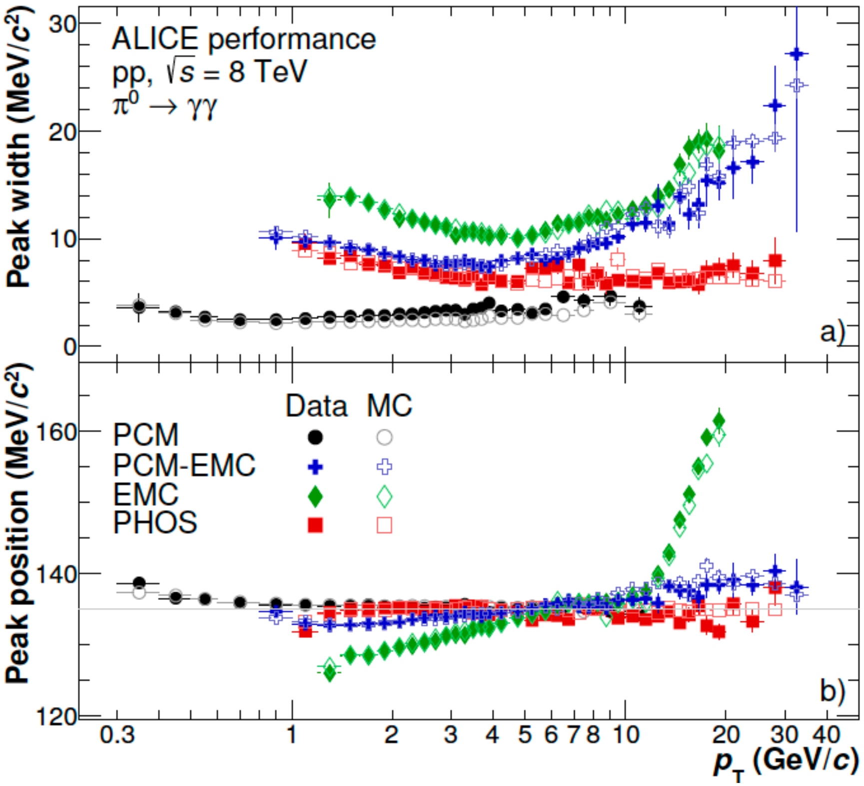
- proton-proton @ 8 TeV (2012)
- Min-bunch crossing: 50 ns = 20M Hz
- The collision probability / BC @ ALICE: 1 – 5 %
- Minimum-bias trigger
  - Coincidence V0-A and V0-C
  - 76% efficiency for the inelastic cross section
  - σ_{pp}^{MB} = 55.7 mb (vdM scan technique)
- PHOS-trigger
  - L0-trigger: E_{th} = 4 GeV
    - Rejection factor to MB: ~10000
- EMCal-trigger
  - L0-trigger: E_{th} = 2 GeV
    - Rejection factor to MB: ~70
  - L1-trigger: E_{th} = 4 GeV
    - Rejection factor to MB: ~ 12000

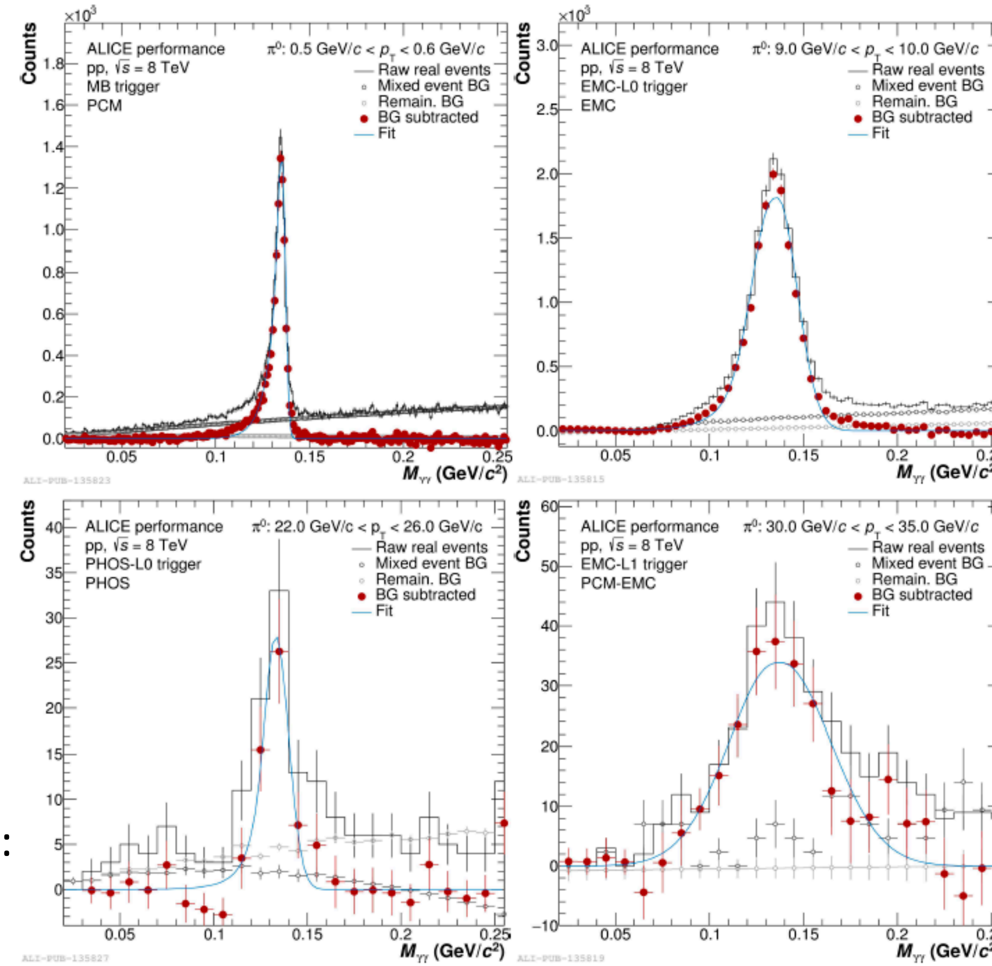






Neutral meson reconstruction





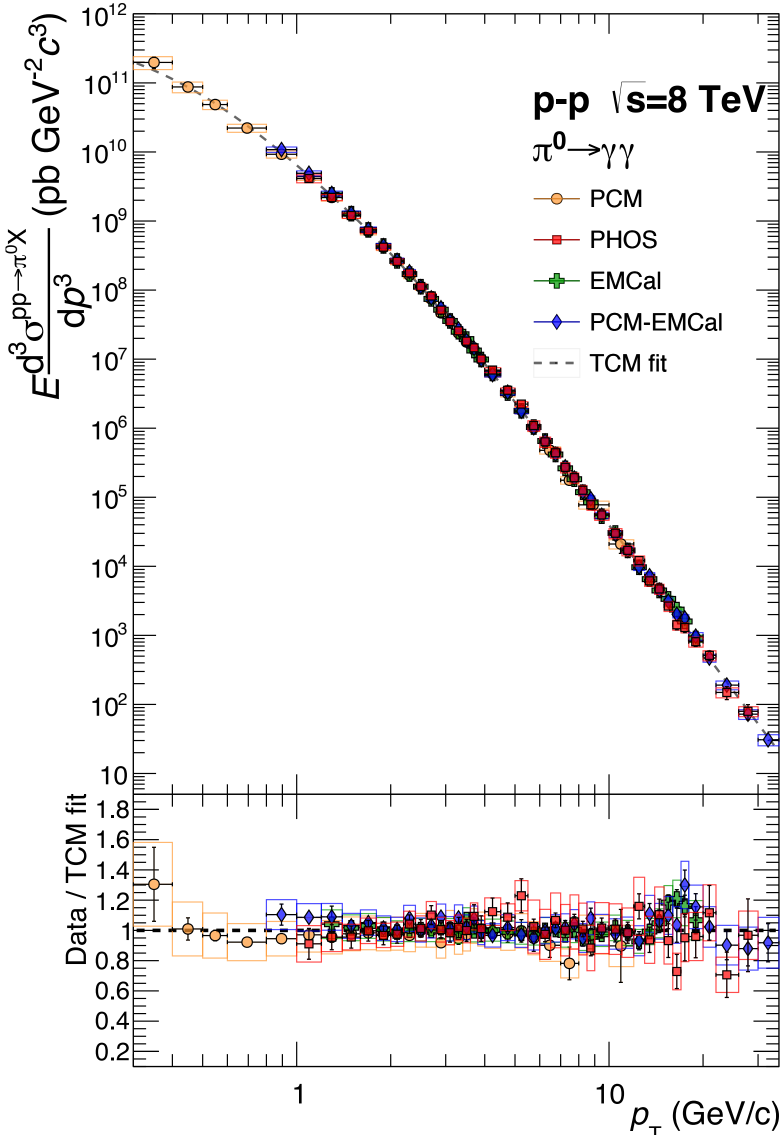
- Invariant mass of two photon candidate:

$$M_{\gamma 1\gamma 2} = \sqrt{2E_{\gamma 1}E_{\gamma 2}\left(1-\cos\theta_{\gamma 1\gamma 2}\right)}$$

- Event mixing for uncorrelated background
- Fit with gauss + low mass tail
- Paring two photons from PHOS / PCM / EMCal / PCM-EMCal hybrid

Results

Full corrected cross section



$$E\frac{d^3\sigma}{dp^3} = \frac{1}{2\pi p_T} \frac{\sigma_{pp}^{MB_{AND}}}{N_{evt}^{i}} \frac{\left(1 - F_{Secondary}\right)}{Br(h \to \gamma\gamma)} \frac{1}{Acc \cdot \varepsilon} \frac{\Delta N^h}{\Delta\eta\Delta\varphi}$$

$\frac{\Delta N^h}{\Delta\eta\Delta\varphi}$: The number of reconstructed π^0

$\sigma_{pp}^{MB_{AND}}$: The cross section of the MB trigger

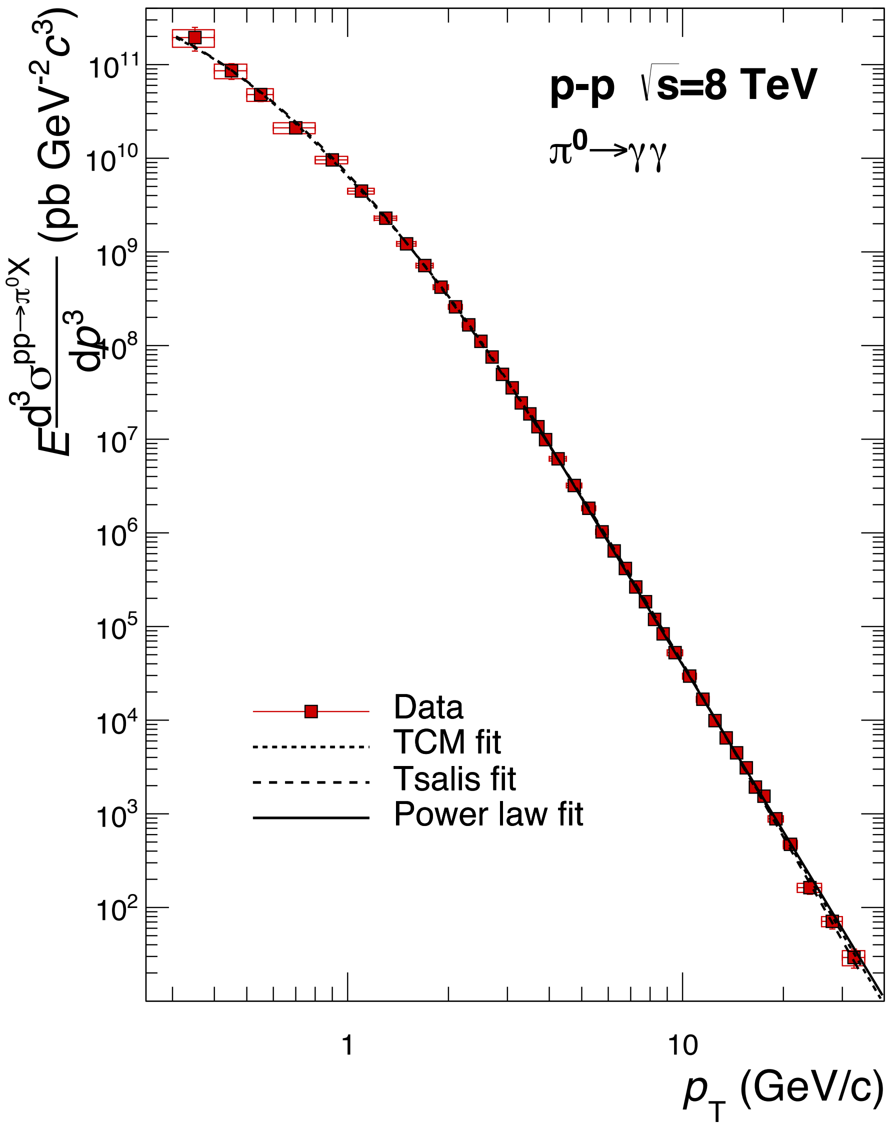
N_{evt}^{i} : The number of analyzed event

$F_{Secondary}$: Fraction of the secondary π^0

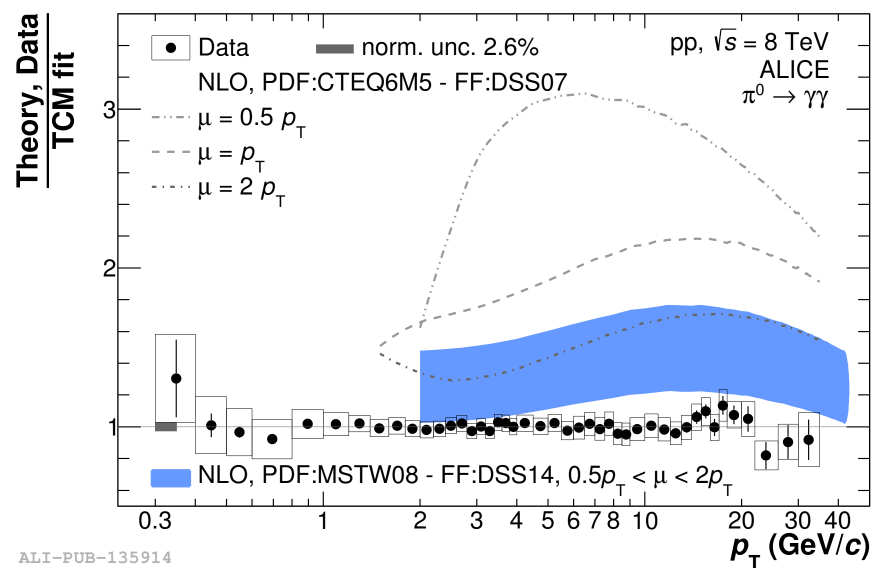
$Br(h \to \gamma\gamma)$: Branching ratio $\pi^0 \to \gamma\gamma$

$Acc \cdot \varepsilon$: acceptance x efficiency

Results: Cross section at 8 TeV



- 0.3 – 35 GeV/c π^0 has been measured by combining all subsystems!
- The pQCD predictions which have been tuned with lower energy results overestimate the spectrum.



Exponent n

- The **π^0** is consistent with the **jet** @LHC energies
- The **π^0** is higher than the **jet** @ RHIC energies

- Almost all neutral pions are generated by the jet fragmentation @ LHC!
- On the other hand, neutral pions are generated by both jet fragmentation and direct hadron production @ RHIC!

Multiplicity dependence

The growth of high p_T region is larger than low p_T.

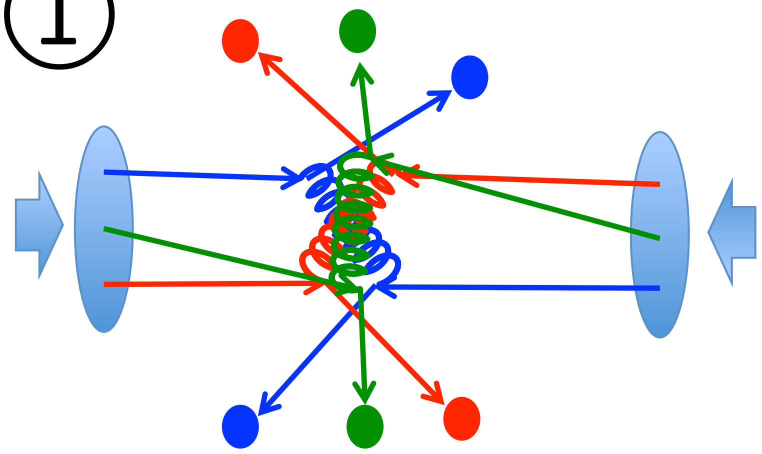
Multiplicity dependence

- The growth of high p_T region is larger than low p_T.

- The CR (Color Reconnection) model describes both high and low p_T growth.

Color reconnection (CR)

①



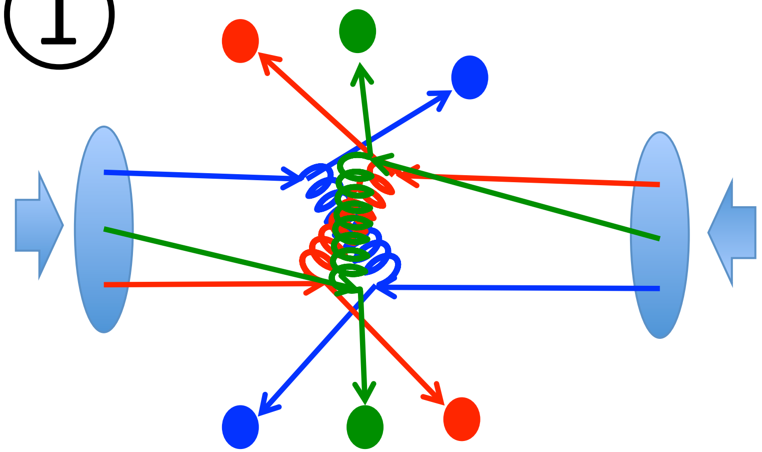
① Multiple Parton Interactions

Color reconnection (CR)

①Multiple Parton Interactions

②Color connection

①



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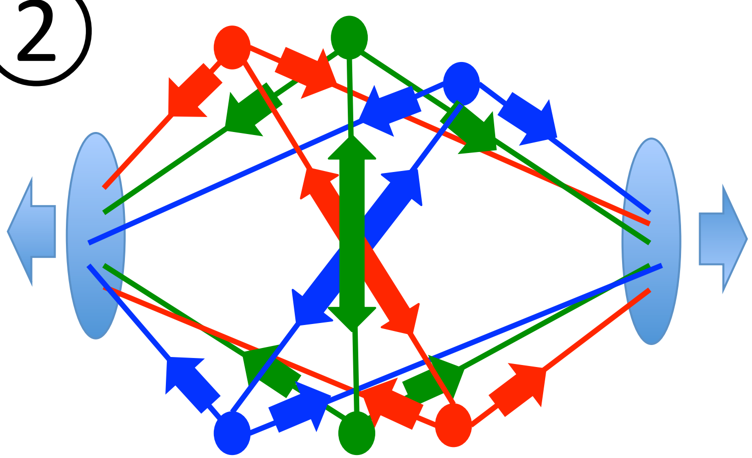

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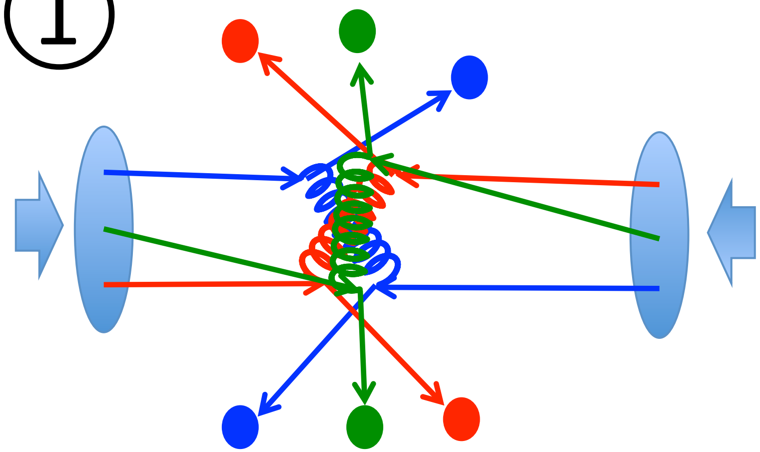

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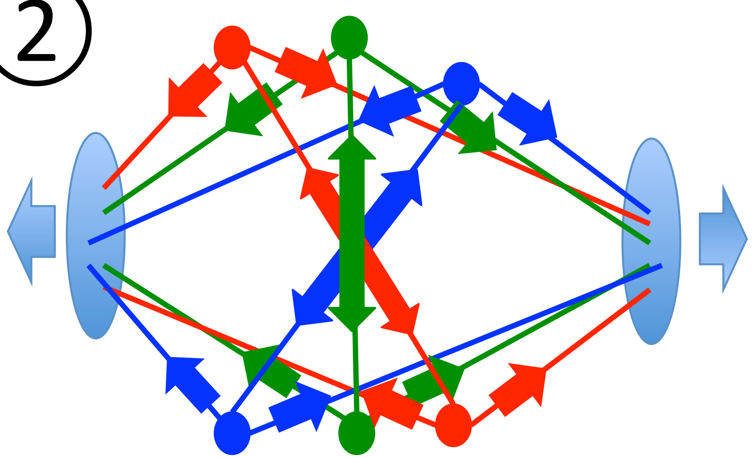

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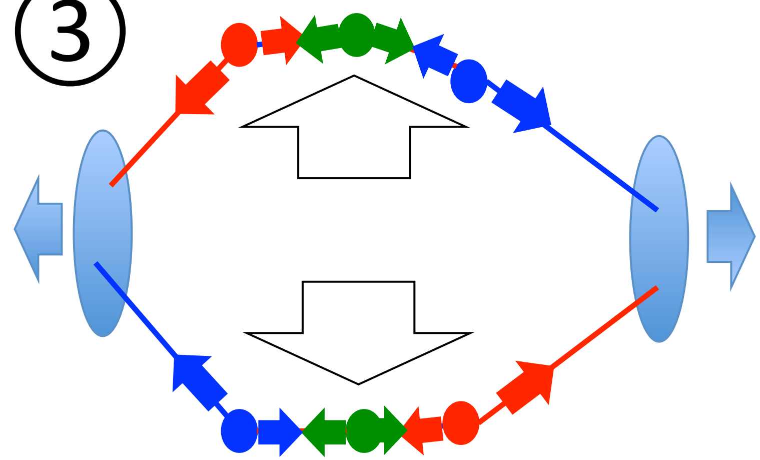


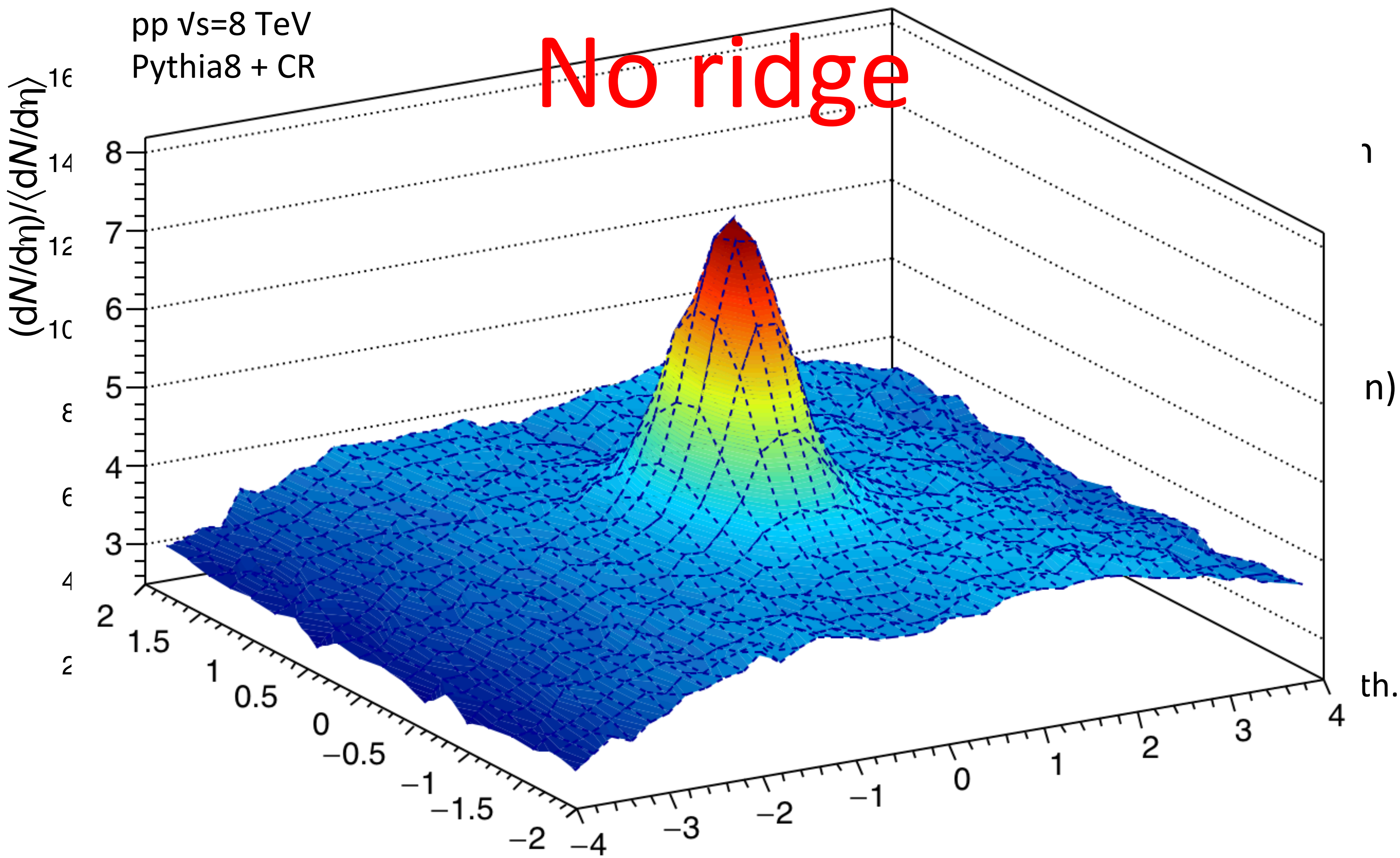
Multiplicity dependence

- The growth of high p_T region is larger than low p_T.

- The CR (Color Reconnection) model describes both high and low p_T growth.

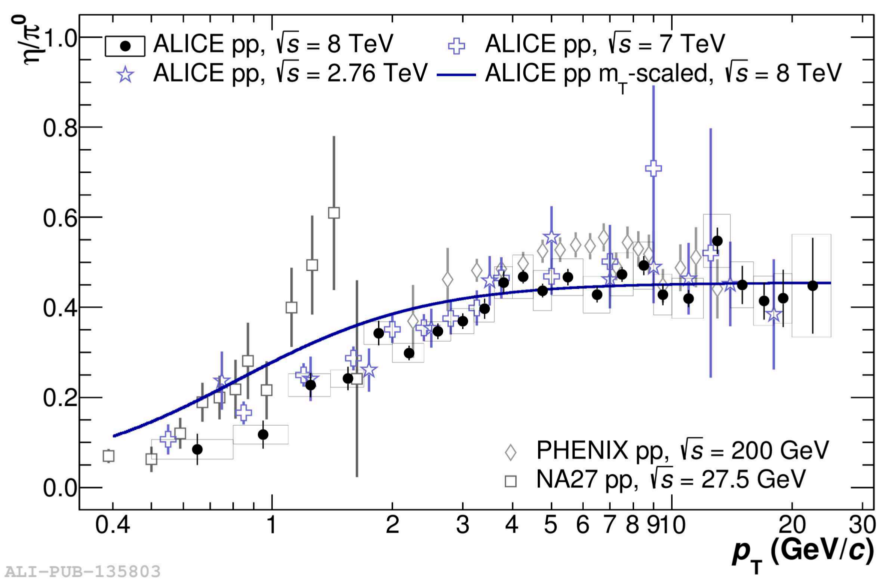
- The CR model describes both light and heavy hadrons growth.

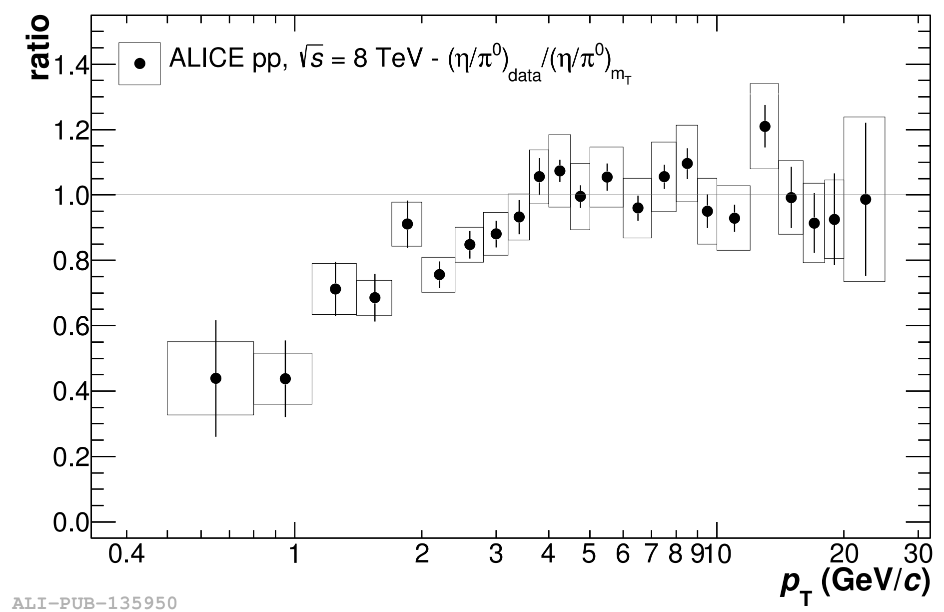
Multiplicity dependence



Results: η to π^0 ratio

- m_T scaling violation! (6.2σ)
- Radial flow?





Summary and conclusion

- Wide p_T range neutral pion cross section in pp collisions at several LHC energies have been measured with the ALICE detector.
- The direct hadron production mechanism can be ignored at LHC collisions energies. On the other hand at RHIC energies, it should be considered.
  - When we compare with the LHC and RHIC results, the differences should be considered.
- The CR model describes the multiplicity dependence of light and heavy hadrons.
  - The CR can not reproduce the ridge…
- The obvious m_T scaling violation has been measured.

LHC-Run1 pp results

x_T scaling

Multiplicity determination