The Abdus Salam International Centre for Theoretical Physics

7th International Workshop on Multiple Partonic Interactions at the LHC (Trieste, Italy, November 22-27, 2015)

CMS Experiment at LHC, CERN
Data recorded: Thu Sep 13 05:21:23 2012 CEST
Run/Event: 202792 / 1737666483
Lumi section: 918
Orbit/Crossing: 240400935 / 1986

Jet effects in high multiplicity pp events

Antonio Ortiz

Work in collaboration with: Gyula Bencedi, Héctor Bello and Satyajit Jena

November 25, 2015

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Wigner

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Outline

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- Introduction
- Tools
- Particle production as a function of the event multiplicity and hardness
- Energy dependence
- Summary

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INTRODUCTION

Introduction

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- Small systems (like those produced in pp and p-Pb collisions) have attracted the attention of the heavy ion community because:
  - In high multiplicity events, sQGP-like signatures have been found (flow & long range azimuthal correlations)
  - The origin of such effects is still unknown
  - More differential studies are needed

Introduction

A hydro-inspired model (Blast-Wave):

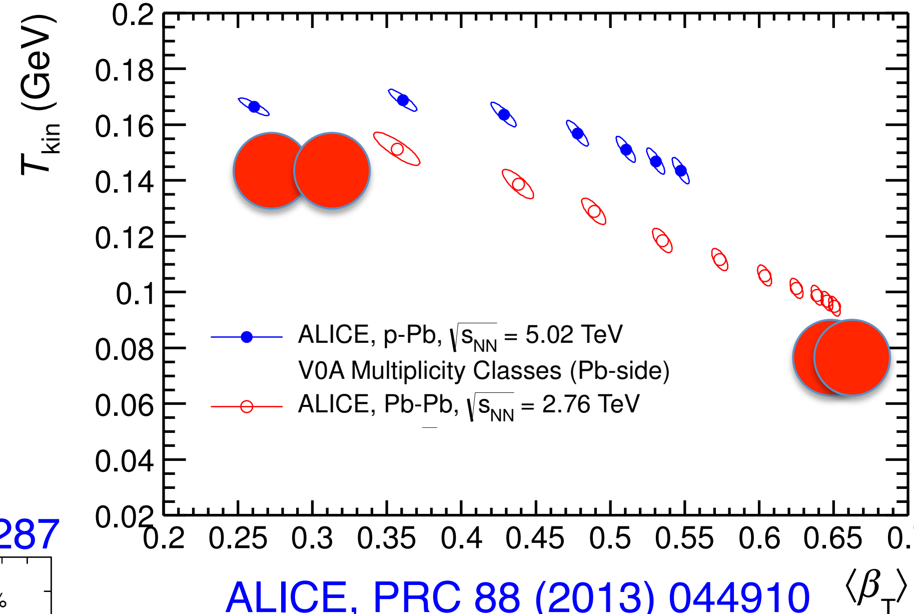
$$\frac{1}{p_{\mathrm{T}}}\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}} \propto \int_0^R r\,\mathrm{d}r\, m_{\mathrm{T}} I_0\left(\frac{p_{\mathrm{T}}\sinh\rho}{T_{\mathrm{kin}}}\right) K_1\left(\frac{m_{\mathrm{T}}\cosh\rho}{T_{\mathrm{kin}}}\right)$$

$$\rho = \tanh^{-1}\beta_{\mathrm{T}} = \tanh^{-1}\left(\left(\frac{r}{R}\right)^n \beta_{\mathrm{S}}\right)$$

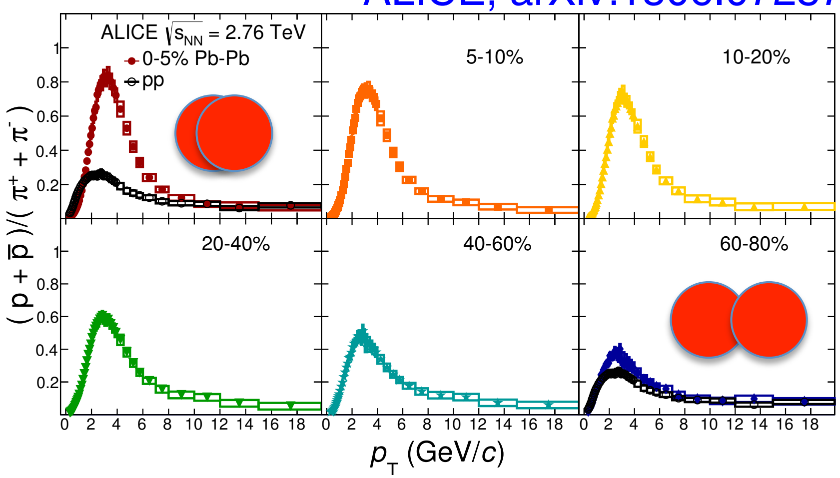
Describes the p_{T} spectra of identified hadrons in:

- p-Pb and Pb-Pb data

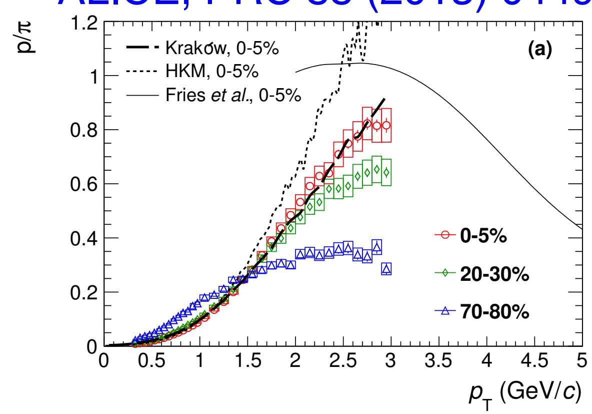
ALICE, PLB 728 (2014) 25-38



ALICE, arXiv:1506.07287



ALICE, PRC 88 (2013) 044910



Introduction

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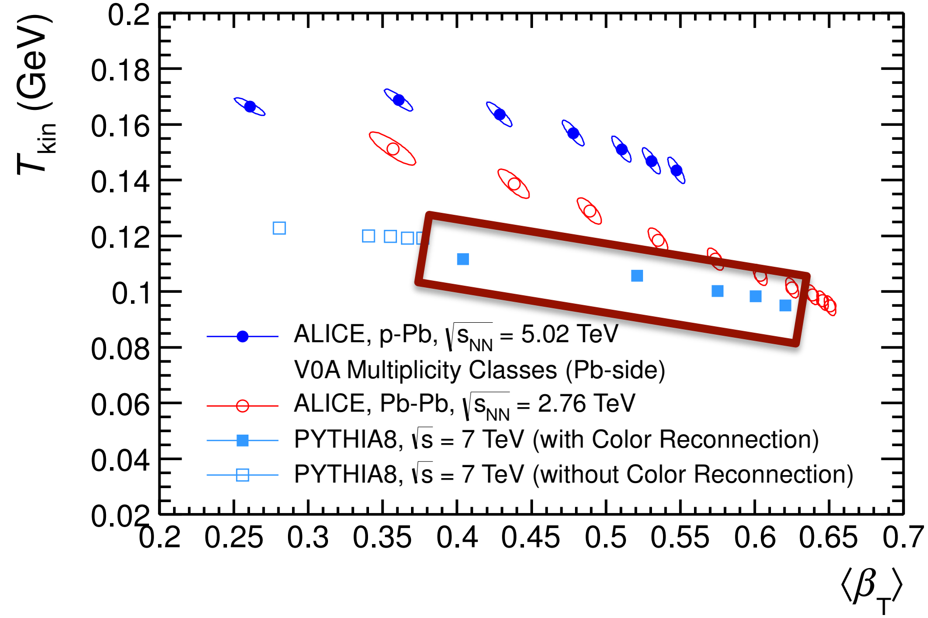
$$\rho = \tanh^{-1}\beta_{\mathrm{T}} = \tanh^{-1}\left(\left(\frac{r}{R}\right)^n \beta_{\mathrm{S}}\right)$$

Describes the p_{T} spectra of identified hadrons in:

- p-Pb and Pb-Pb data
- Also the p_{T} distributions generated with Pythia (where no hydrodynamical evolution is assumed)

ALICE, PLB 728 (2014) 25-38



- It has been discussed that color reconnection (CR) produces radial flow-like patters due to boosted strings

G. Paić, E. Cuautle, P. Christiansen, I. Maldonado and A. O., PRL 111 (2013) 042001

Introduction

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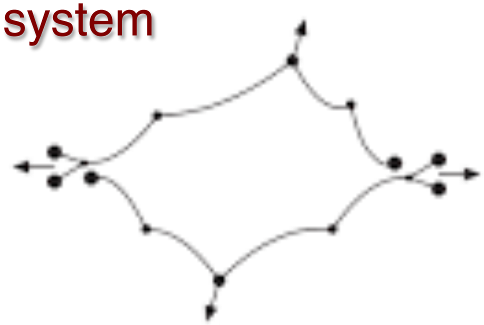
* Figure taken from: G. Gustafson, Acta Phys. Polon. B40, 1981 (2009)

1st partonic system



Introduction

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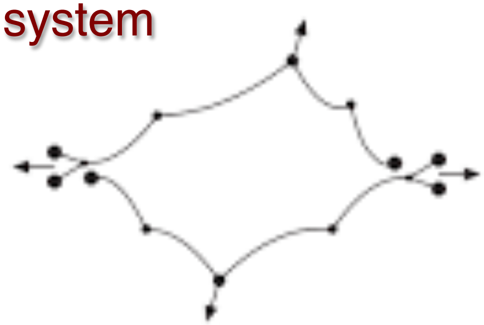
1st partonic system



+2nd partonic system

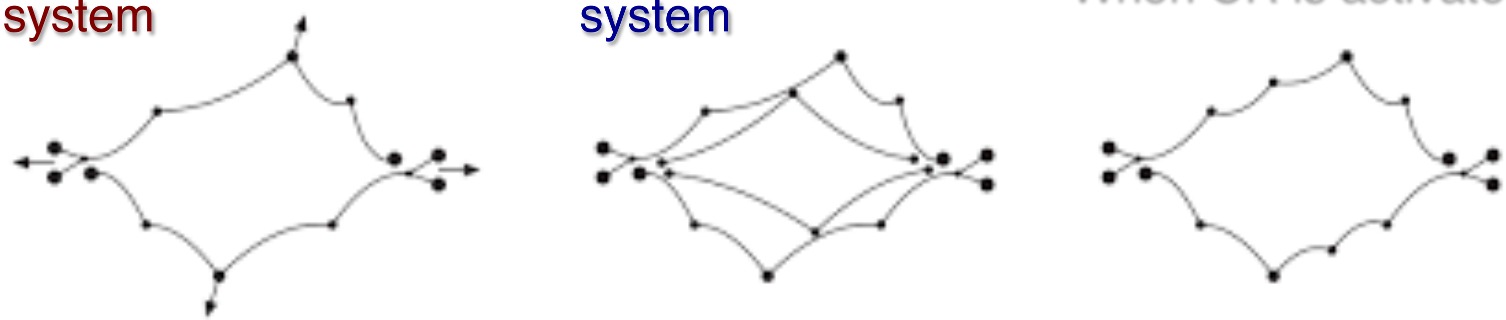
Introduction

* Figure taken from: G. Gustafson, Acta Phys. Polon. B40, 1981 (2009)

1st partonic system

+2nd partonic system

When CR is activated



Introduction

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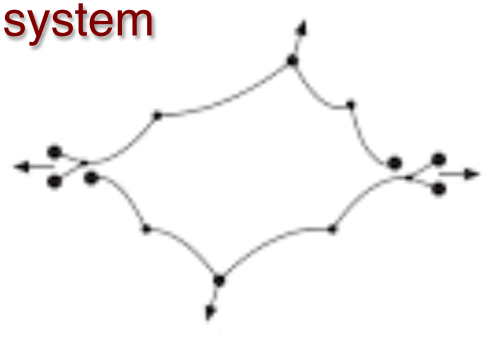
1st partonic system



+2nd partonic system

When CR is activated

This was the focus of this work: PRL 111 (2013) 042001

- The more N_{MPI} the higher the flow-like effect

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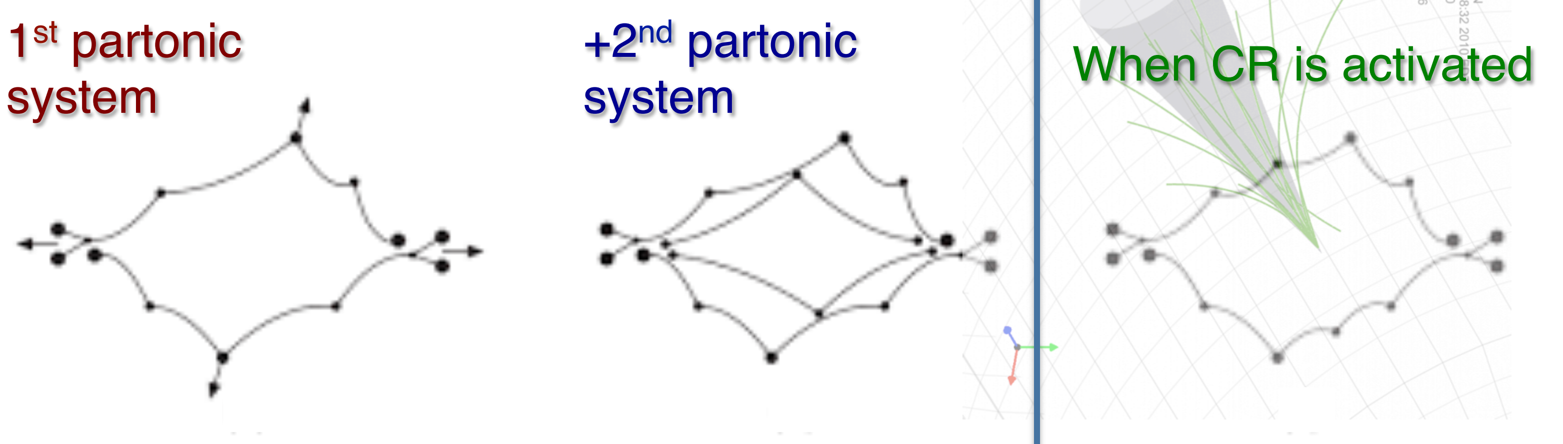
* Figure taken from: G. Gustafson, Acta Phys. Polon. B40, 1981 (2009)



Due to the large N_{MPI} a high p_T jet in the event is expected (high probability):

- Can we quantify the effects of the high p_T jets?
- I would expect a higher boost with increasing the parton p_T

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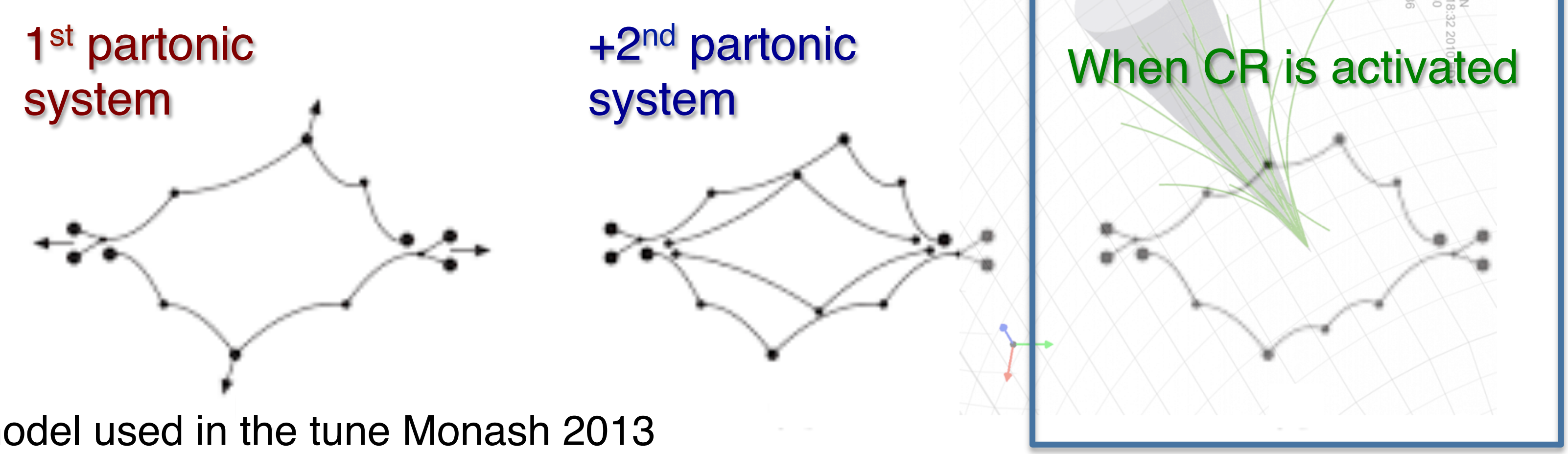

In the CR model used in the tune Monash 2013 (Mo2013), an MPI system with a scale p_{T} of the hard interaction (normally $2 \rightarrow 2$) can be merged with one of a harder scale with a probability that is:

$$P(p_{\mathrm{T}}) = \frac{(RR \times p_{\mathrm{T0}})^2}{(RR \times p_{\mathrm{T0}})^2 + p_{\mathrm{T}}^2}$$

Reconnection Range (*RR*): 0-10

Tune Monash 2013: $RR \mathrm{x} p_{\mathrm{T0}} \approx 3$

http://home.thep.lu.se/~torbjorn/pythia82html/Welcome.html

Introduction

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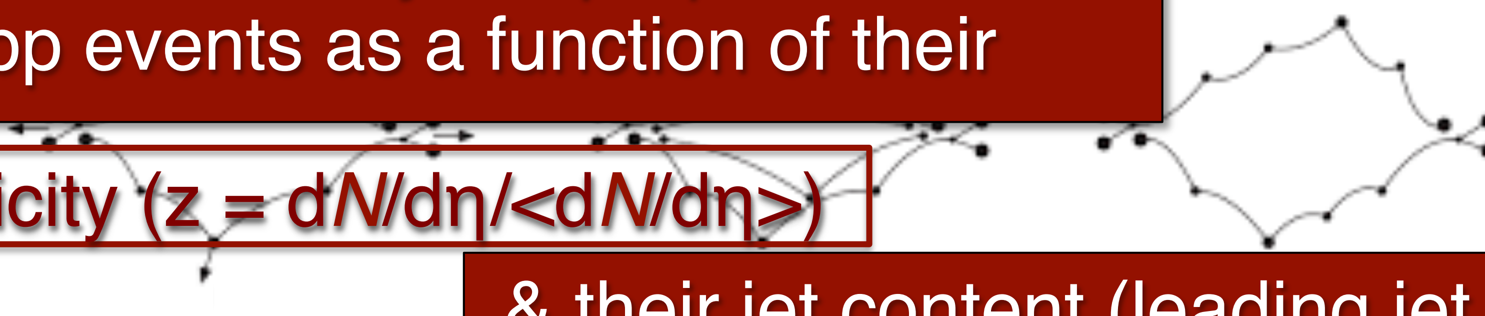

This work: study the properties of the pp events as a function of their

multiplicity ($z = dN/d\eta/\langle dN/d\eta \rangle$)

& their jet content (leading jet p_T)

Tools

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- Generator: **Pythia 8.212**, T. Sjöstrand et. al, CPC191 (2005) 159
  - Tune Monash 2013, P. Skands, EPJC74 (2014) 8, 3024
  - 900M events
    - 7 TeV (reference), 0.9 TeV, 2.76 TeV and 13 TeV
- Jet Finder: **FastJet 3.1.3**, M. Cacciari et al., EPJC72(2012)1896
  - Anti-k_T algorithm
  - R=0.4
  - p_T^{min} = 5 GeV
  - Visible particles (Pythia definition) are considered for the jet reconstruction

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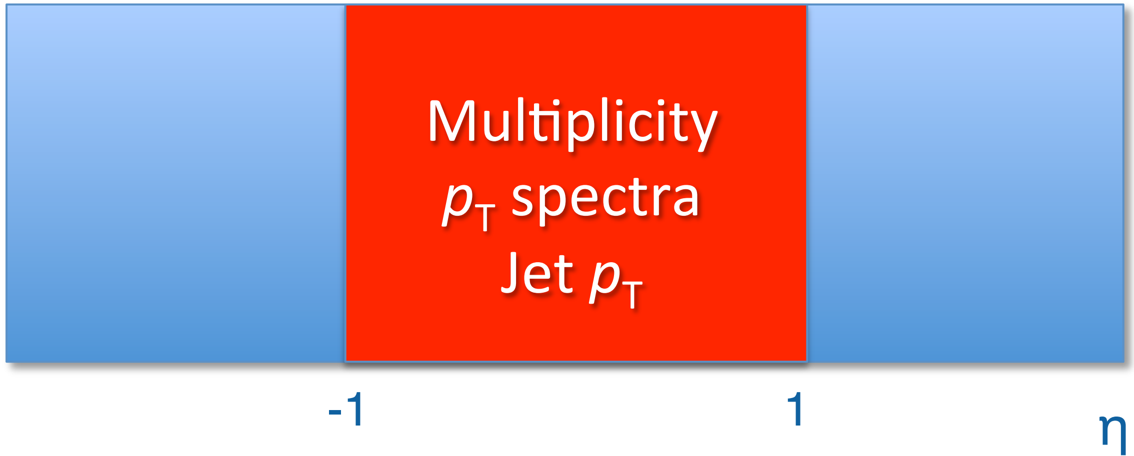
INCLUSIVE PARTICLE PRODUCTION AS A FUNCTION OF THE EVENT MULTIPLICITY AND HARDNESS



* The underlying event contribution to the jet p_T was not studied, because we are only interested in the event classification

INCLUSIVE PARTICLE PRODUCTION AS A FUNCTION OF THE EVENT MULTIPLICITY AND HARDNESS

p_T^{jet} vs. multiplicity

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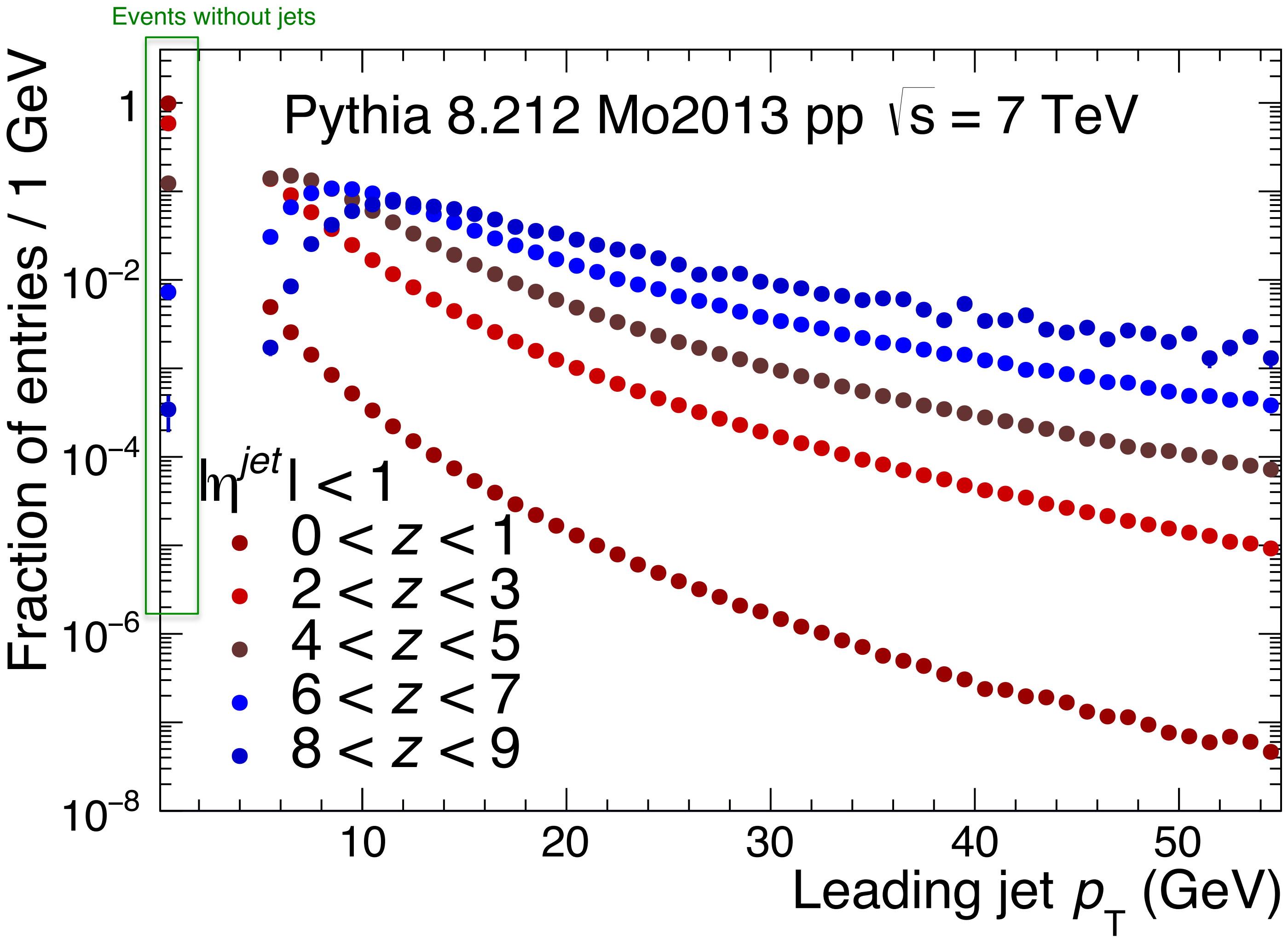

$\langle z \rangle$	$\langle p_T^{jet} \rangle$ (GeV)
0.5	7.09
1.5	7.49
2.5	7.83
3.5	8.48
4.5	9.55
5.5	11.1
6.5	13.2
7.5	15.85

The higher the event multiplicity the higher the average p_T^{jet}

p/π vs. p_T (low multiplicity)

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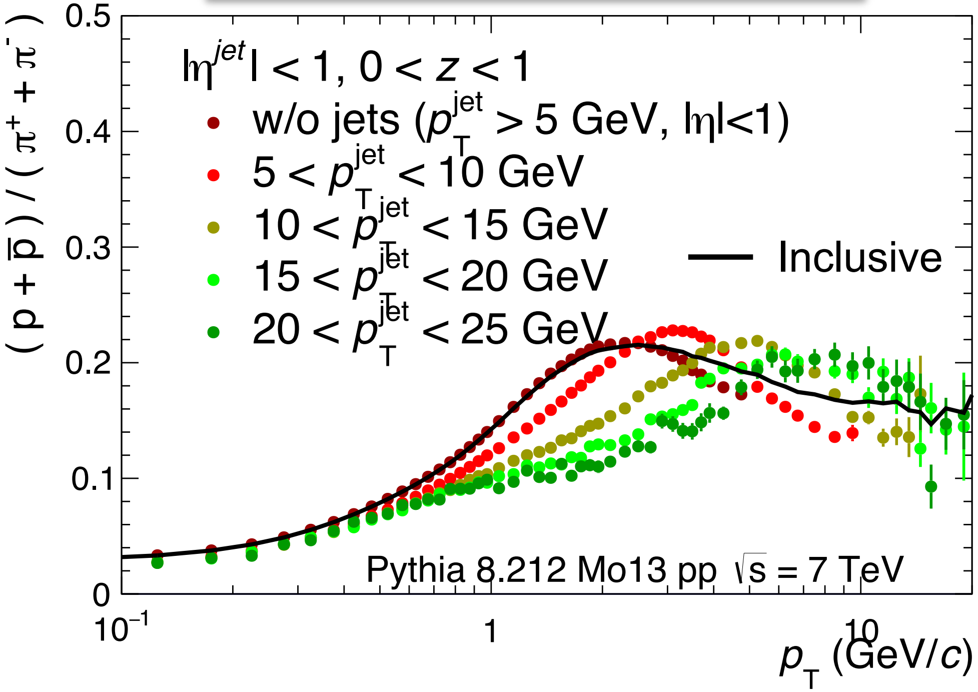
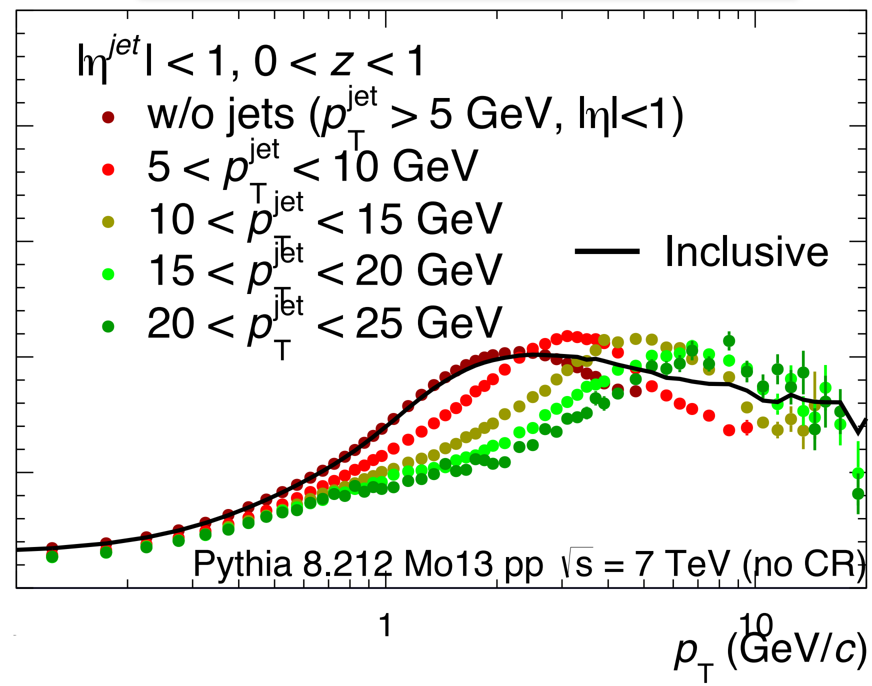
With Color Reconnection



Without Color Reconnection



p/π vs. p_T (low multiplicity)

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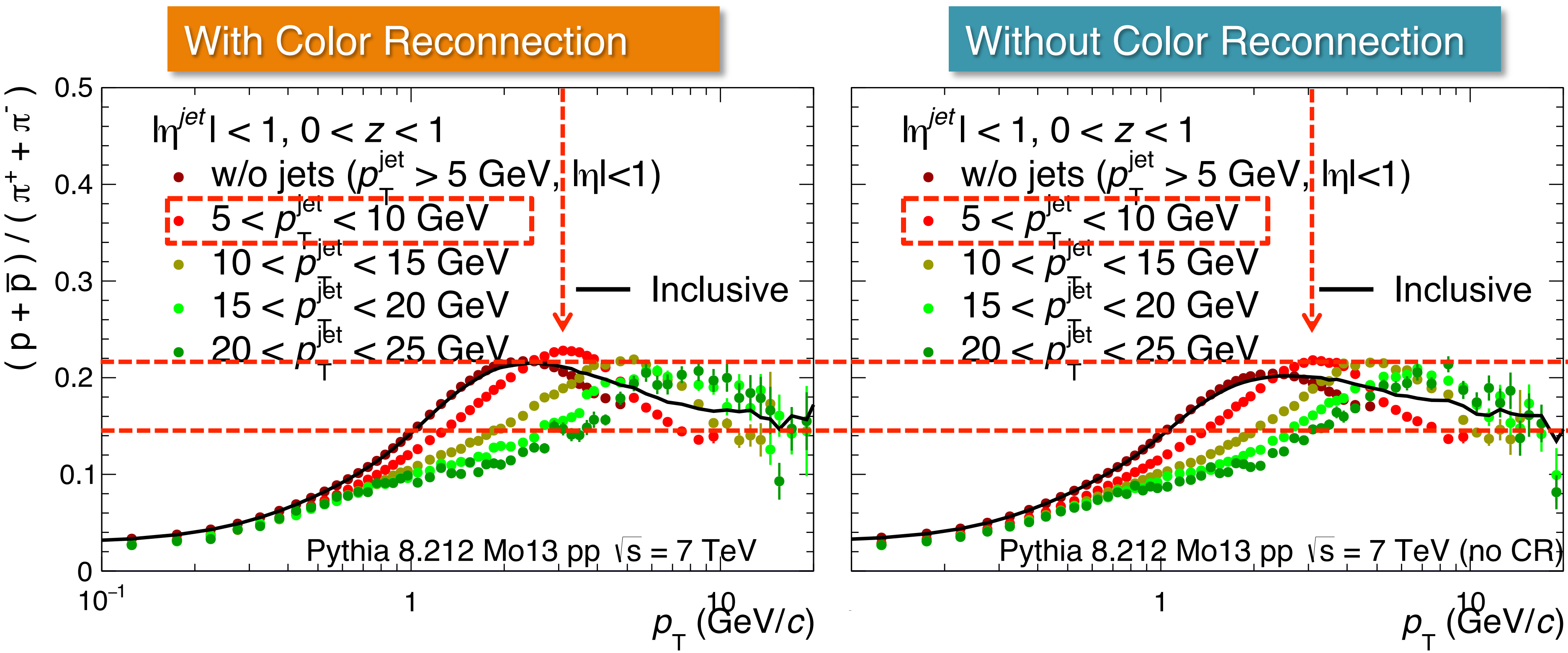

- CR effects are observer for $p_T^{jet} < 10$ GeV

p/π vs. p_T (low multiplicity)

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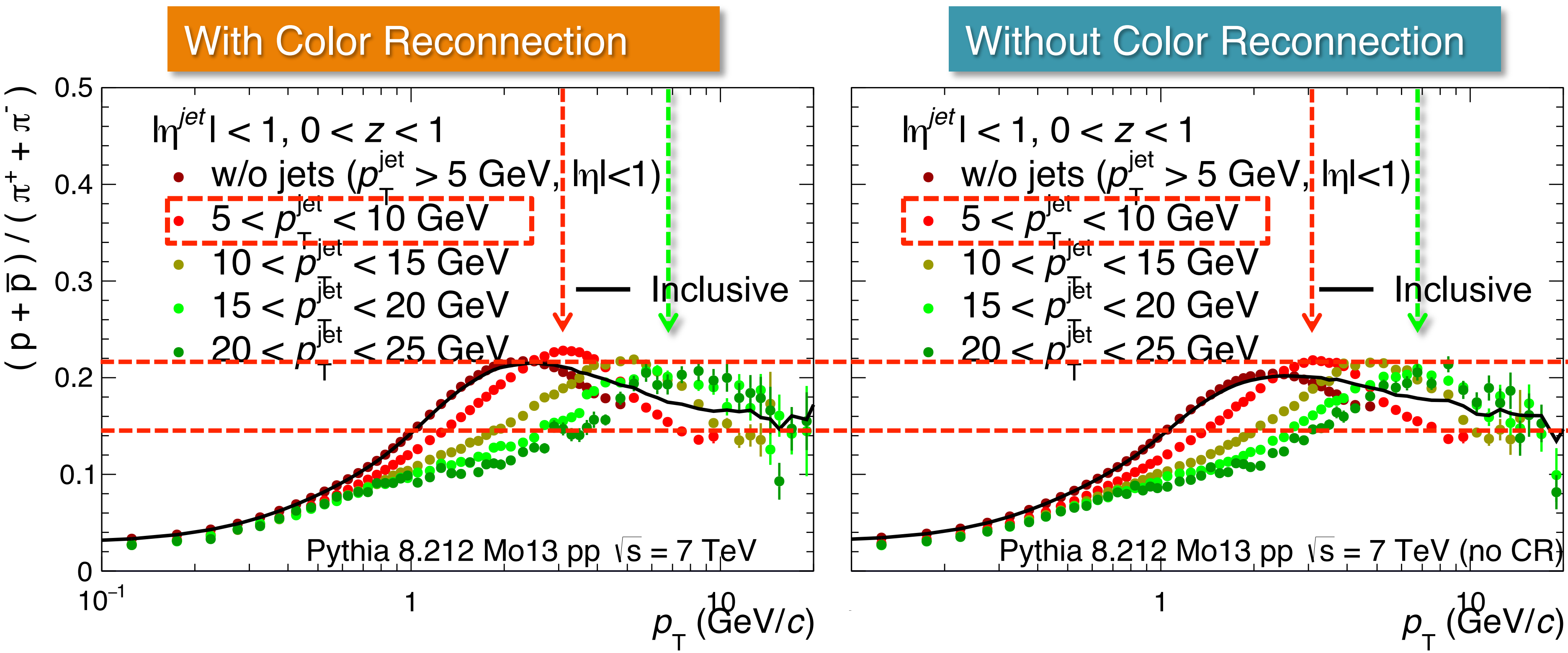

- CR effects are observer for $p_T^{jet} < 10$ GeV
- The position of the peak is shifted to higher p_T when p_T^{jet} increases. The shift is accompanied by an increase of $<\beta_T>$

p/π vs. p_T (low multiplicity)

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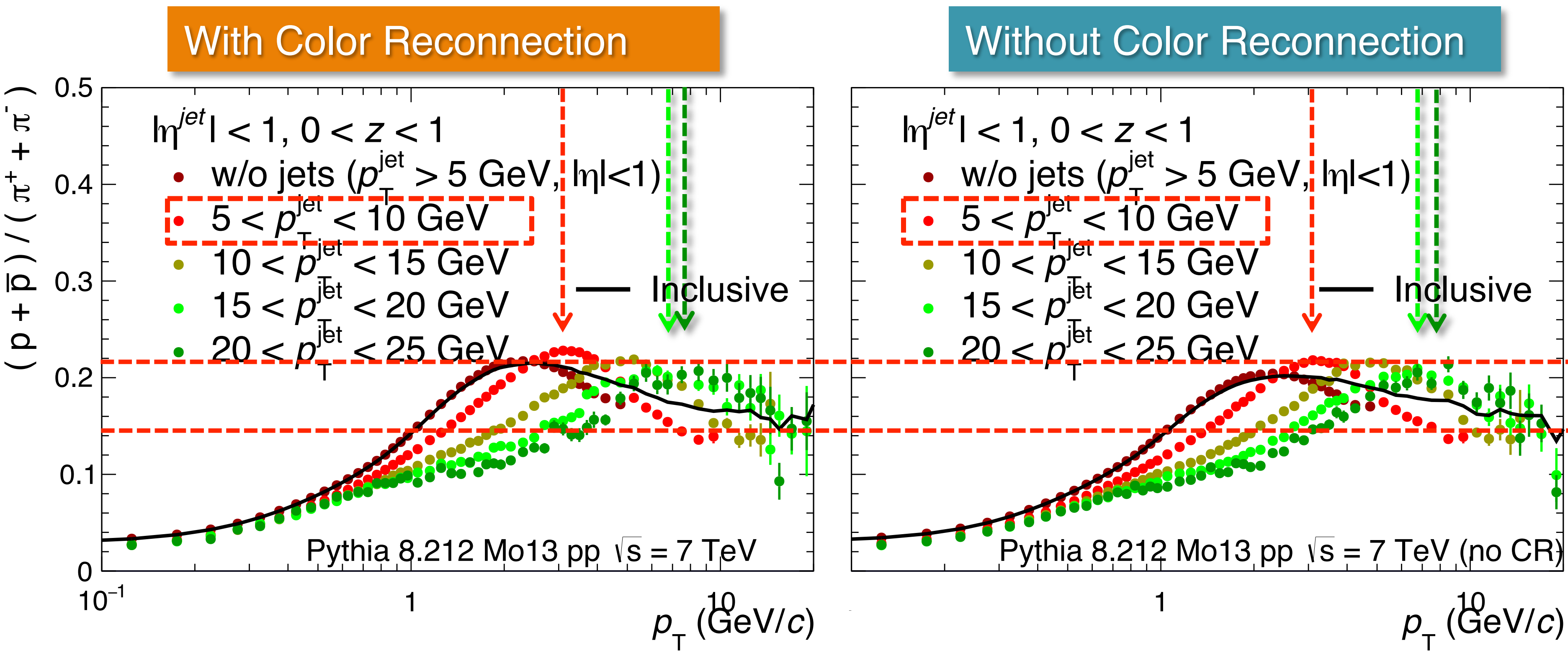

- CR effects are observer for $p_T^{jet} < 10$ GeV
- The position of the peak is shifted to higher p_T when p_T^{jet} increases. The shift is accompanied by an increase of $<\beta_T>$ (from Blast-Wave analysis)
  - The effect is very small for $p_T^{jet} > 15$ GeV

p/π vs. p_T (low multiplicity)

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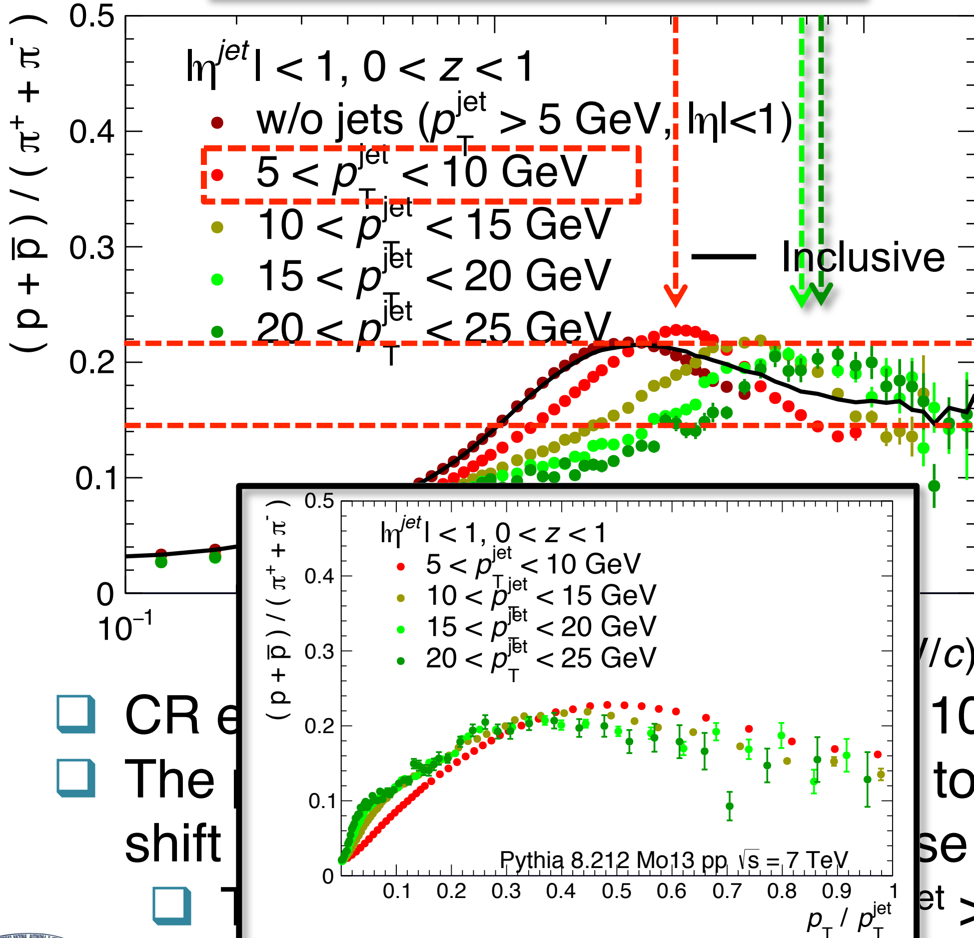
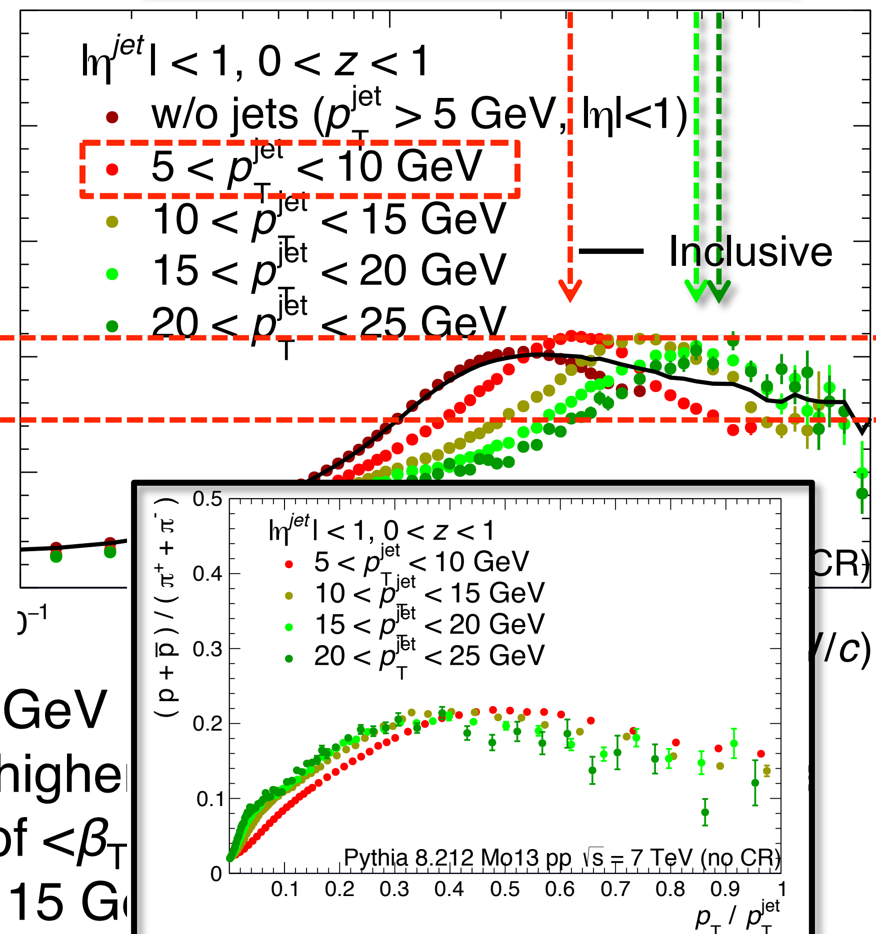
This is a FF effect (p/π vs. p_T/p_T^{jet} is ≈p_T^{jet} independent)

With Color Reconnection



Without Color Reconnection



- CR e ... 10 GeV
- The ... to highe... shift ... se of <β_T
  - T... et > 15 G...

p/π vs. p_T (high multiplicity)

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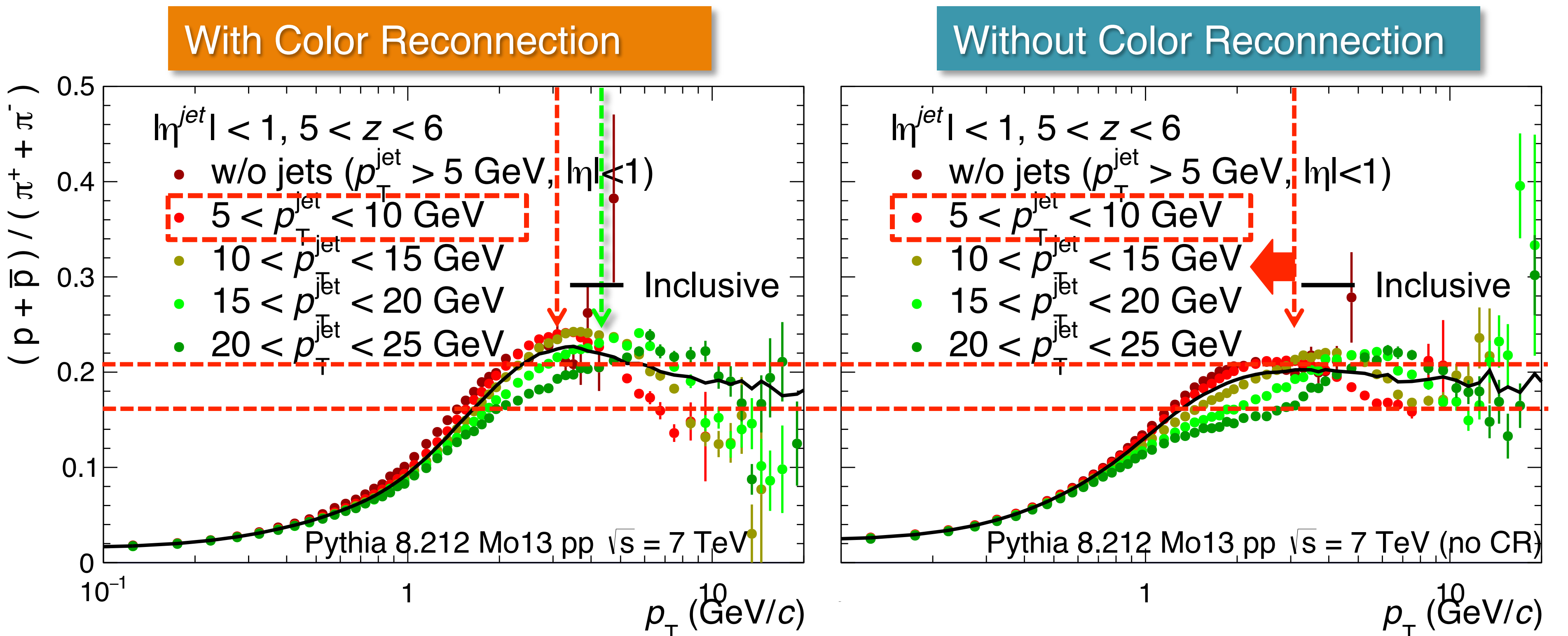

- Larger enhancement with respect to the the case without CR
- With CR, jet effects (peak position) are smaller than in the low N_{ch} case
  - Dominated by underlying event

p/π vs. p_T (high multiplicity)

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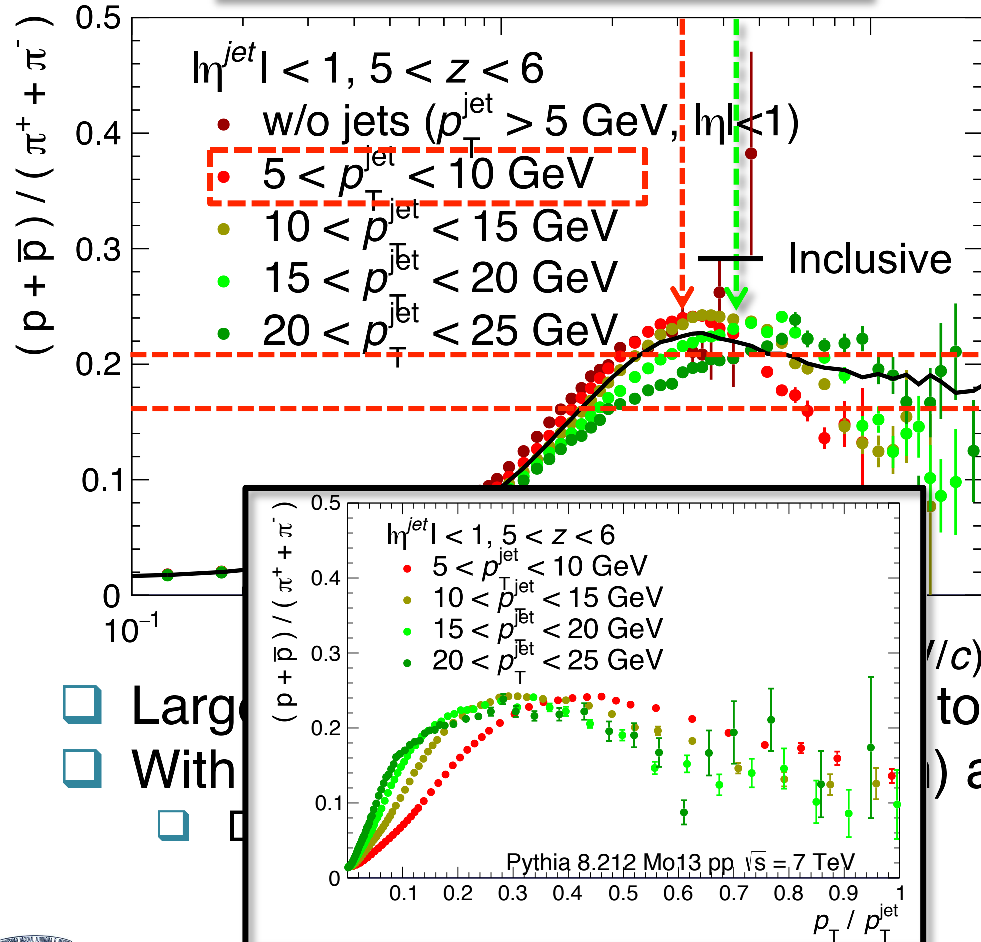
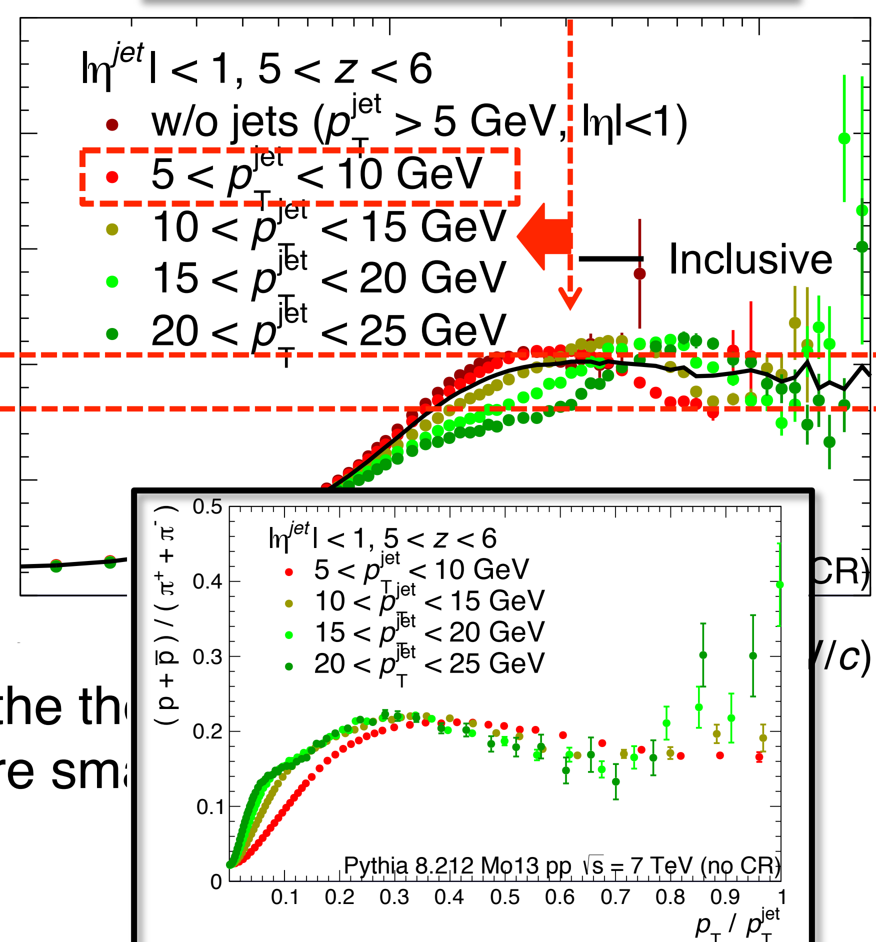
Without CR: p/π vs. p_T/p_T^{jet} is ≈p_T^{jet} independent (FF)

With Color Reconnection



Without Color Reconnection



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- With…) are sma…
  - D…

Study of the inclusive light flavored hadron production

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Results from the Blast-Wave analysis are presented, for this a simultaneous fit of the BW function to the the p_T spectra is performed in order to extract $<\beta_T>$. The fitting ranges are the following:

π	K	K^0_S	p	ϕ	Λ	Ξ	Ω
0.5-1.0	0.3-1.5	0.3-1.5	0.8-2.0	0.8-2.0	1.0-2.1	1.2-2.6	1.3-2.8

p_T ranges (GeV/c)

(Same p_T ranges as in: G. Paić, E. Cuautle and A. O. NPA 941 (2015) 78-86, where the p_T spectra in high multiplicity events were described by BW model within 10%)

Without Jets

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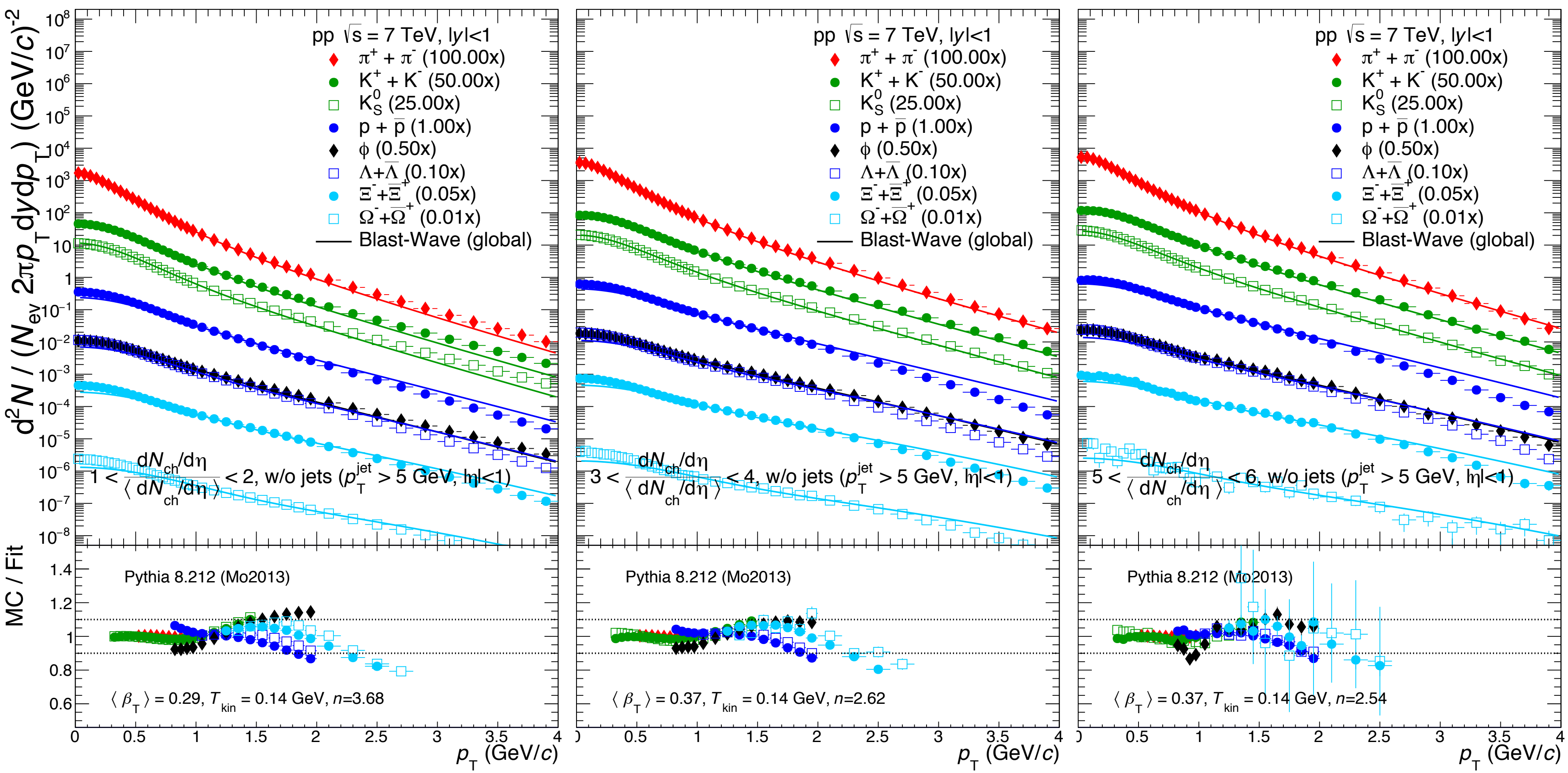
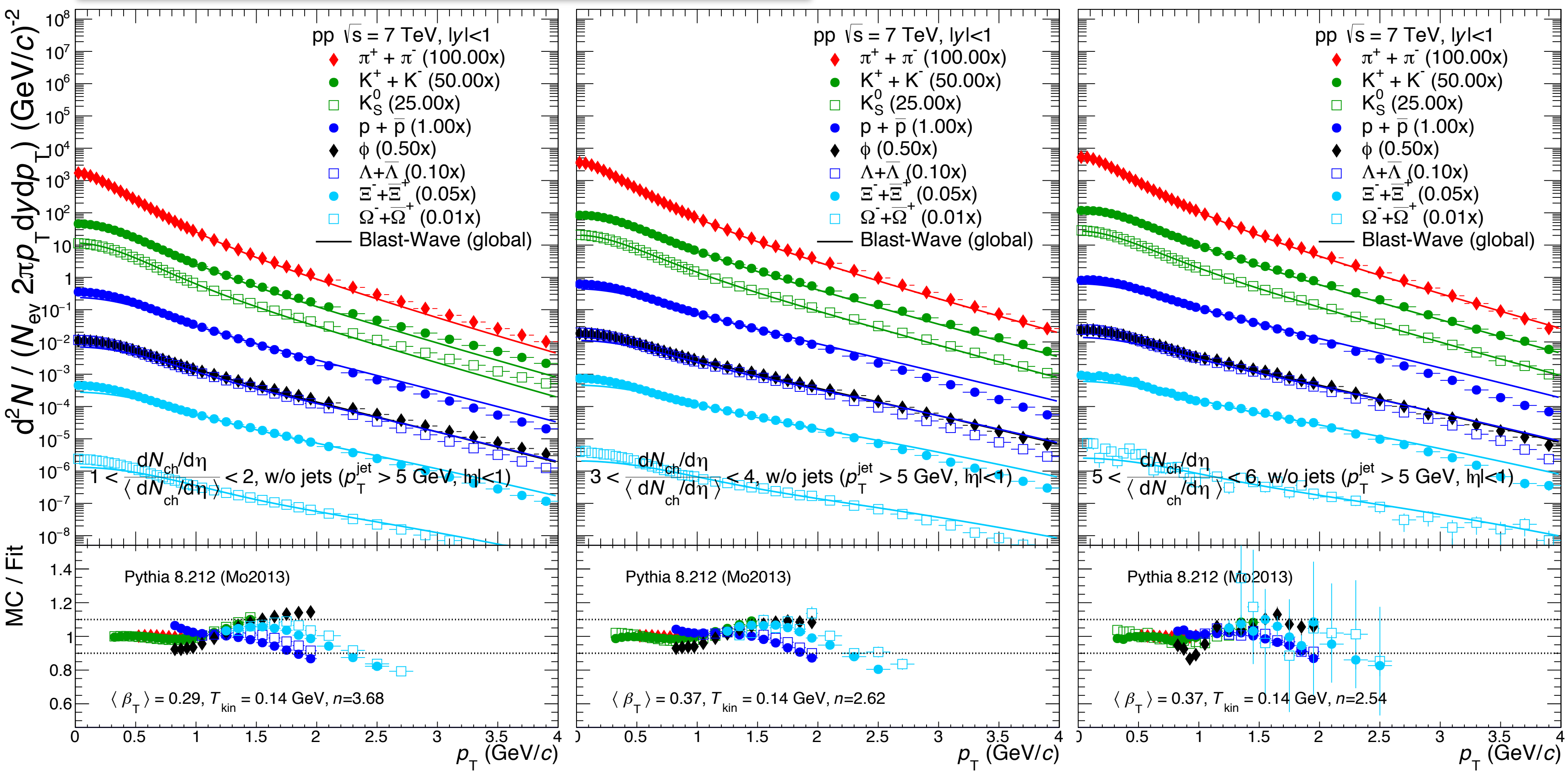


Without Jets

$<\beta_T>\approx 0.34$, $<T_{kin}>\approx 0.14$, $<n>\approx 2.94$



$<N_{ch}>_{|\eta|<1}\approx 16.23$ $<N_{ch}>_{|\eta|<1}\approx 38.02$ $<N_{ch}>_{|\eta|<1}\approx 59.58$

Without Jets

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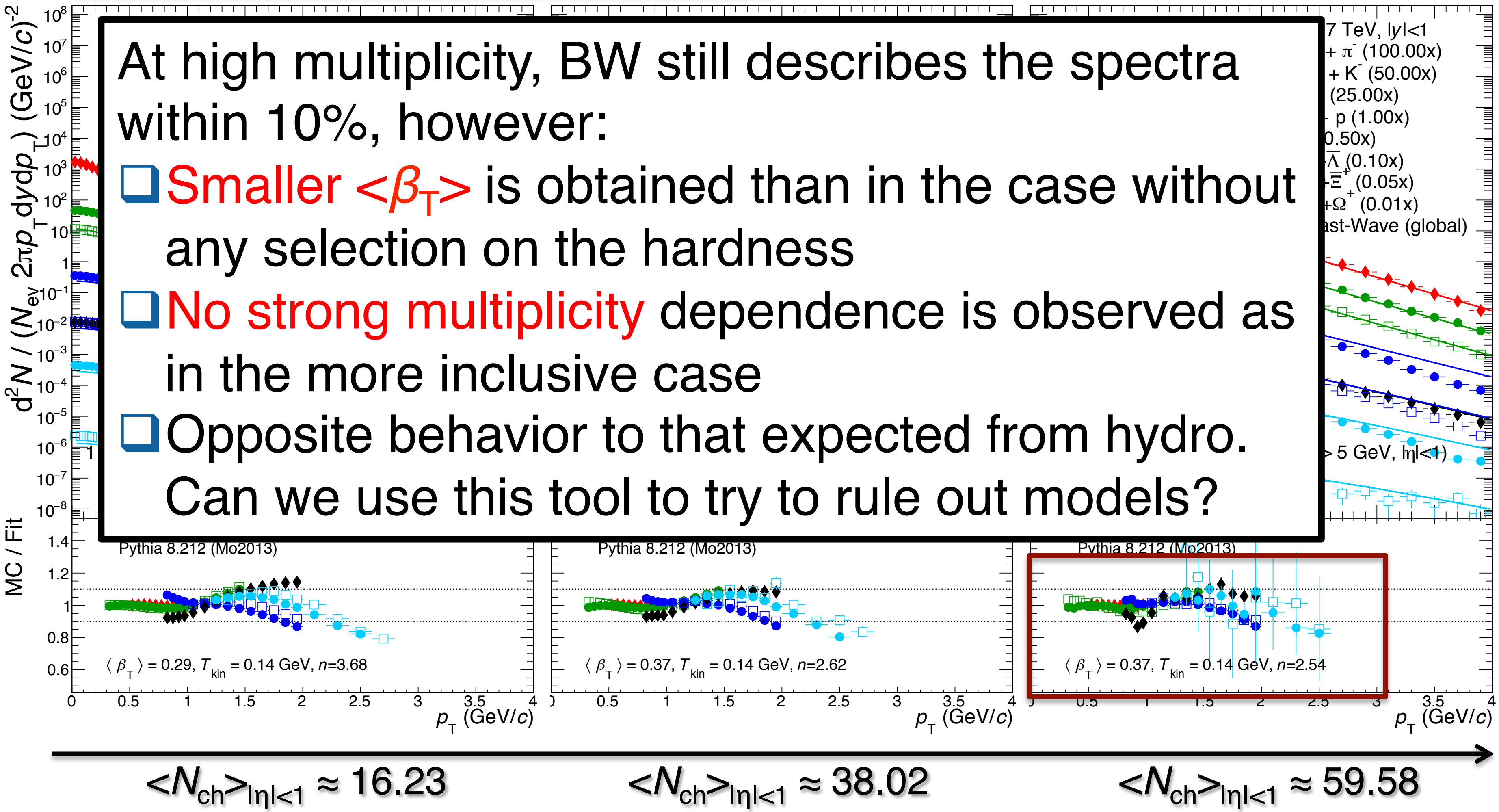
$\langle \beta_T \rangle \approx 0.34$, $\langle T_{kin} \rangle \approx 0.14$, $\langle n \rangle \approx 2.94$



At high multiplicity, BW still describes the spectra within 10%, however:

- Smaller $\langle \beta_T \rangle$ is obtained than in the case without any selection on the hardness
- No strong multiplicity dependence is observed as in the more inclusive case
- Opposite behavior to that expected from hydro. Can we use this tool to try to rule out models?

$15 < p_T^{Jet} < 20$ GeV

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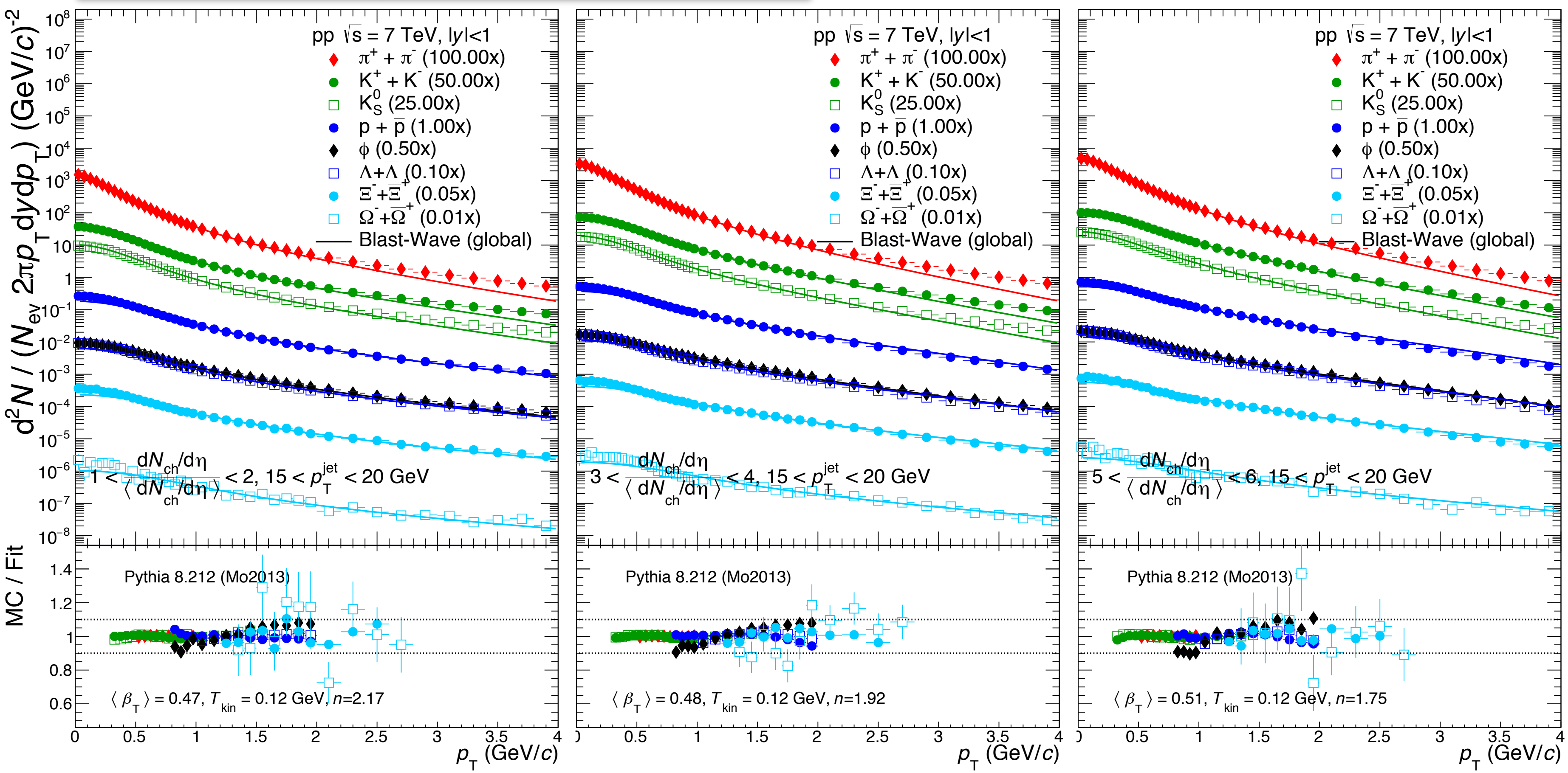
$<\beta_T>\approx 0.48$, $<T_{kin}>\approx 0.12$, $<n> \approx 1.94$



$<N_{ch}>_{|\eta|<1} \approx 16.23$ $<N_{ch}>_{|\eta|<1} \approx 38.02$ $<N_{ch}>_{|\eta|<1} \approx 59.58$

$15 < p_T^{Jet} < 20$ GeV

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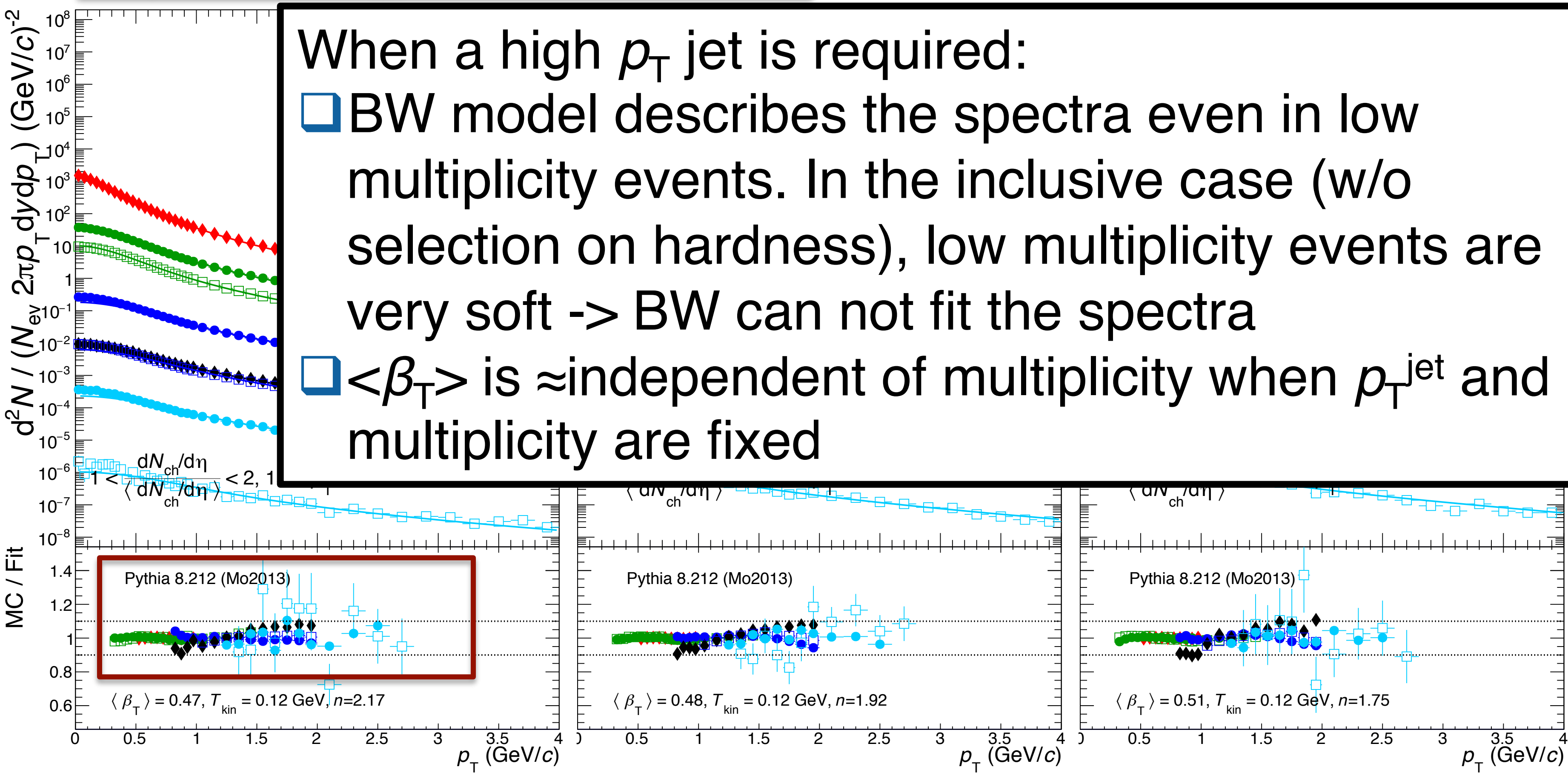

When a high p_T jet is required:

- BW model describes the spectra even in low multiplicity events. In the inclusive case (w/o selection on hardness), low multiplicity events are very soft -> BW can not fit the spectra
- $<\beta_T>$ is ≈independent of multiplicity when p_T^{jet} and multiplicity are fixed

$<N_{ch}>_{|\eta|<1} \approx 16.23$ $<N_{ch}>_{|\eta|<1} \approx 38.02$ $<N_{ch}>_{|\eta|<1} \approx 59.58$

15 < p_T^{Jet} < 20 GeV

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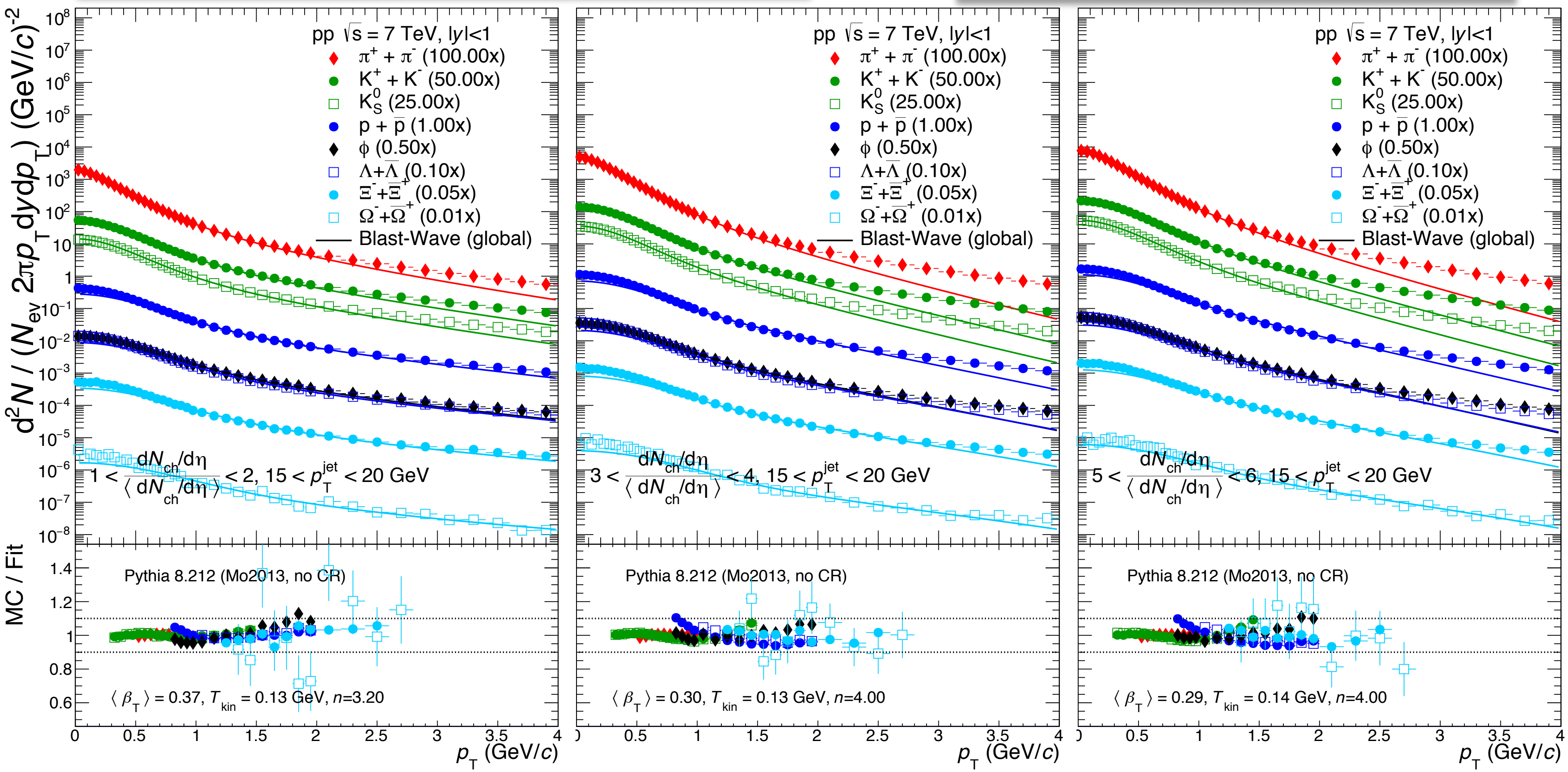
Smaller $\langle\beta_T\rangle \approx 0.32$ & larger $\langle n \rangle \approx 3.7$

Without Color Reconnection



Slight increase of $\langle\beta_T\rangle$

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ENERGY DEPENDENCE

$15 < p_T^{Jet} < 20$ GeV

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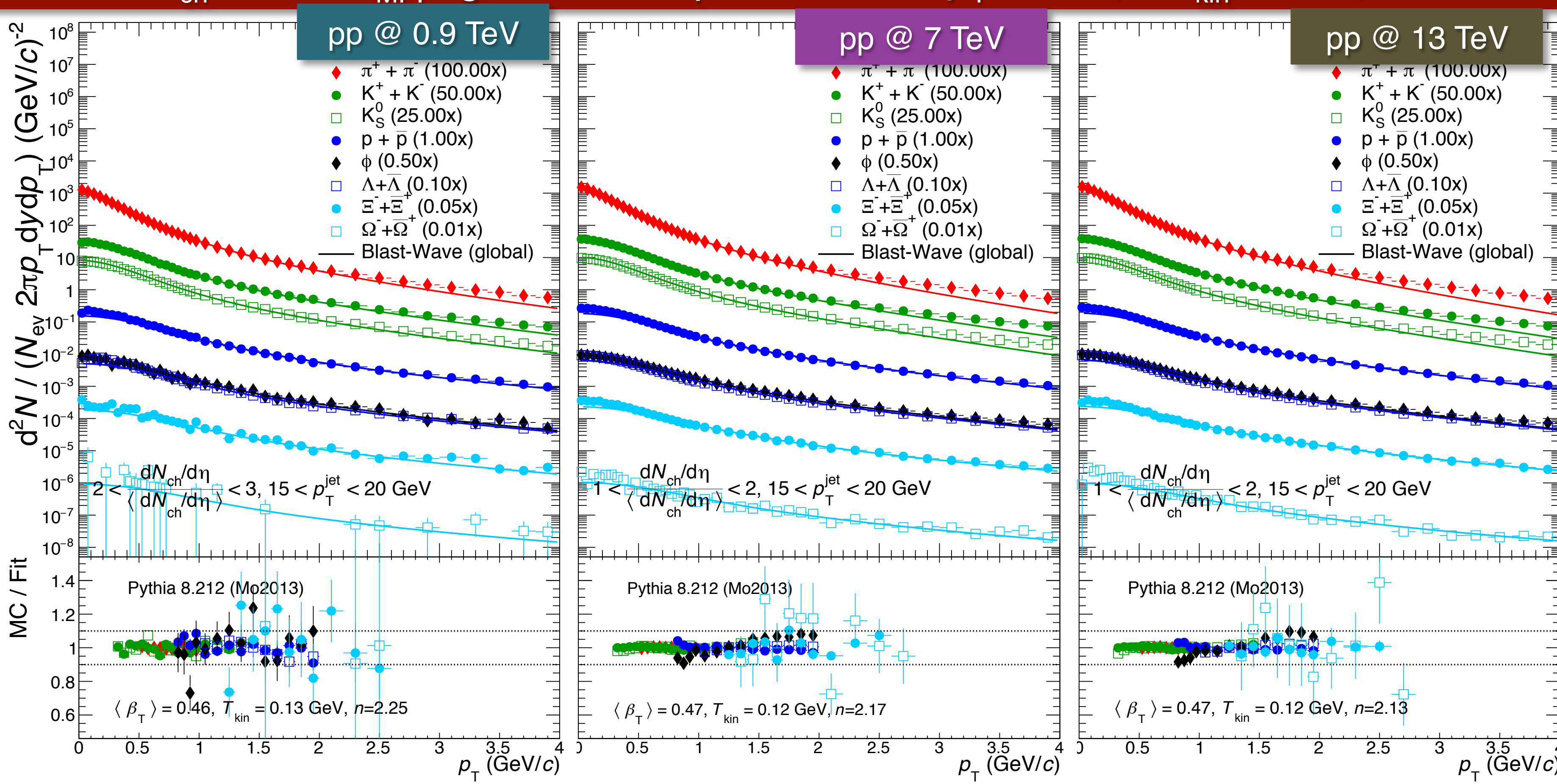
Similar $\langle N_{ch} \rangle$ and $\langle N_{MPI} \rangle$ gives similar parameters: $\langle \beta_T \rangle \approx 0.47$, $\langle T_{kin} \rangle \approx 0.12$, $\langle n \rangle \approx 2.18$



$\langle N_{ch} \rangle_{|\eta|<1} \approx 15.65$
$\langle N_{MPI} \rangle \approx 3.53$

$\langle N_{ch} \rangle_{|\eta|<1} \approx 17.72$
$\langle N_{MPI} \rangle \approx 4.14$

$\langle N_{ch} \rangle_{|\eta|<1} \approx 18.35$
$\langle N_{MPI} \rangle \approx 4.26$

Spectral shapes

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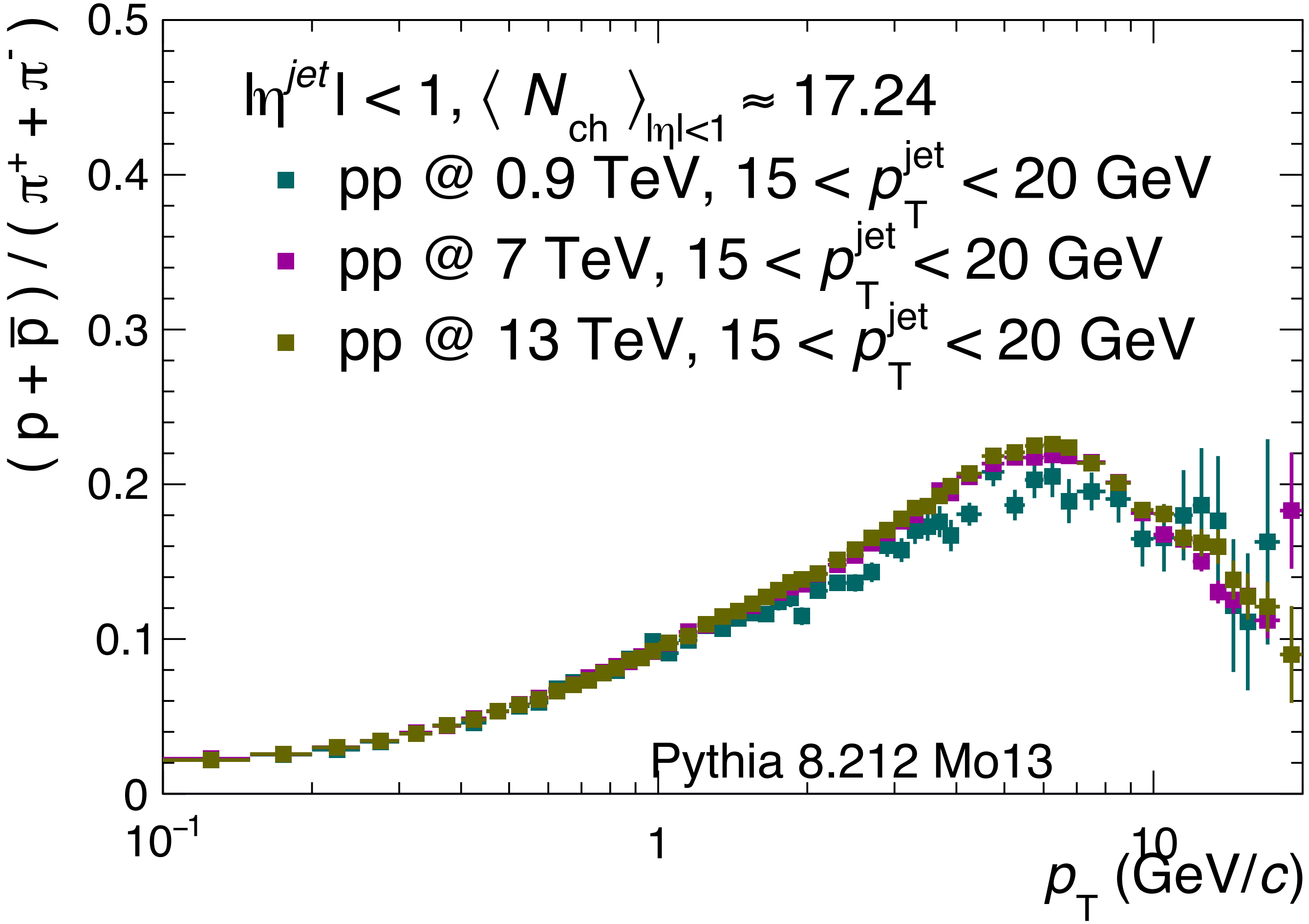

Proton-to-pion ratio show little or no dependence with $\sqrt{s}$
(p_T position of the peak is the same for the three colliding systems)

Spectral shapes

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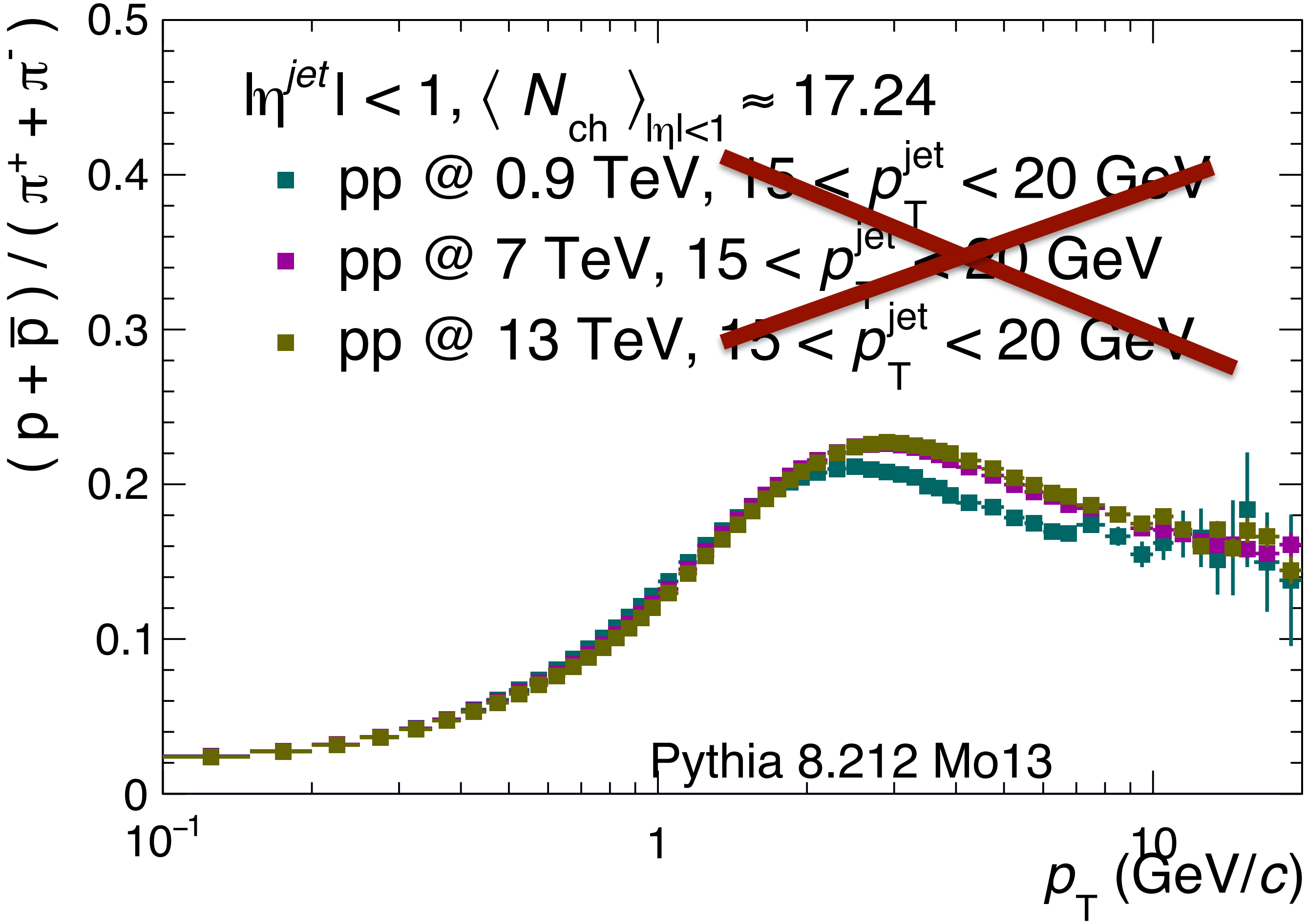

Without the jet requirement, the ratios look more different due to the different jet biases

Summary

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- In Pythia, MPI (semi-hard and hard partonic scatterings) and CR produce flow-like effects
- The result of the interaction between the soft and hard component could be used as a tool to validate or rule out models which produce flow(-like) effects in small systems, e.g. hydro vs. color reconnection (important for HI physics)
- Same physics is obtained when a selection on multiplicity and hardness is implemented

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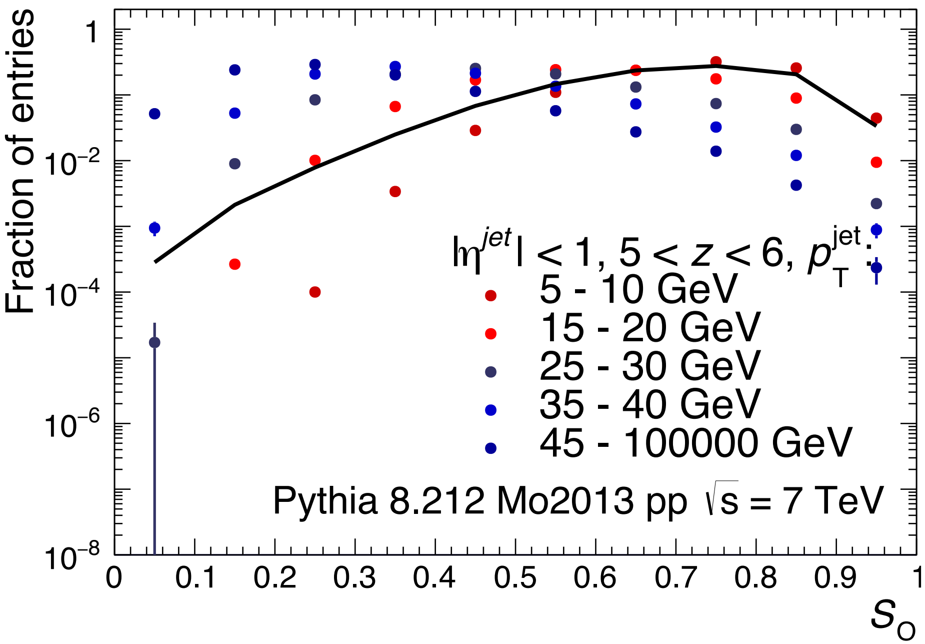
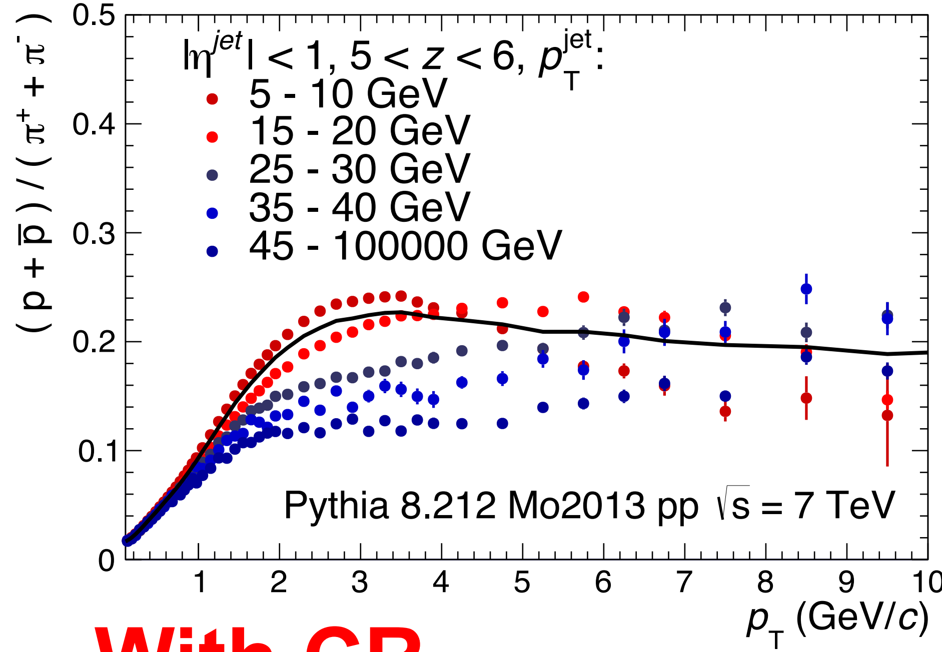
Guy Paić, Peter Christiansen, Andreas Morsch and Eleazar Cuautle are acknowledged for the useful discussions

BACKUP

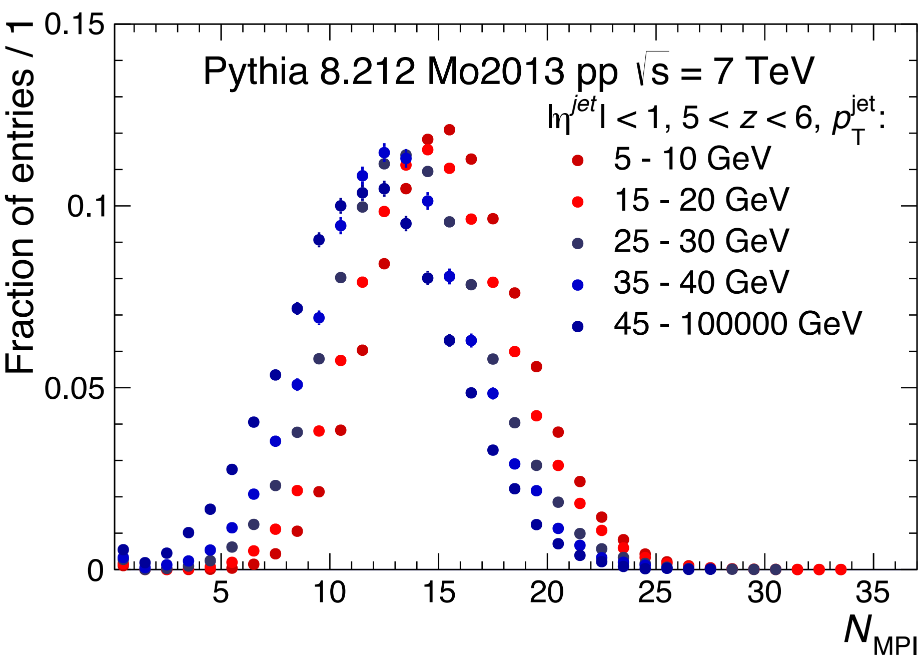


Fraction of entries
S_O
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV

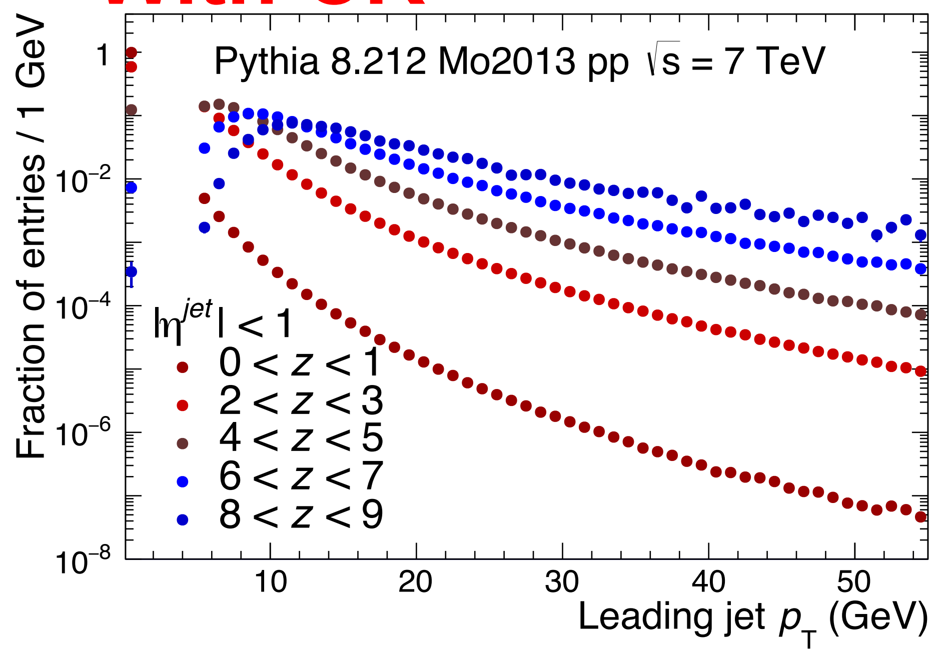


$(p + \bar{p}) / (\pi^+ + \pi^-)$
p_T (GeV/c)
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV

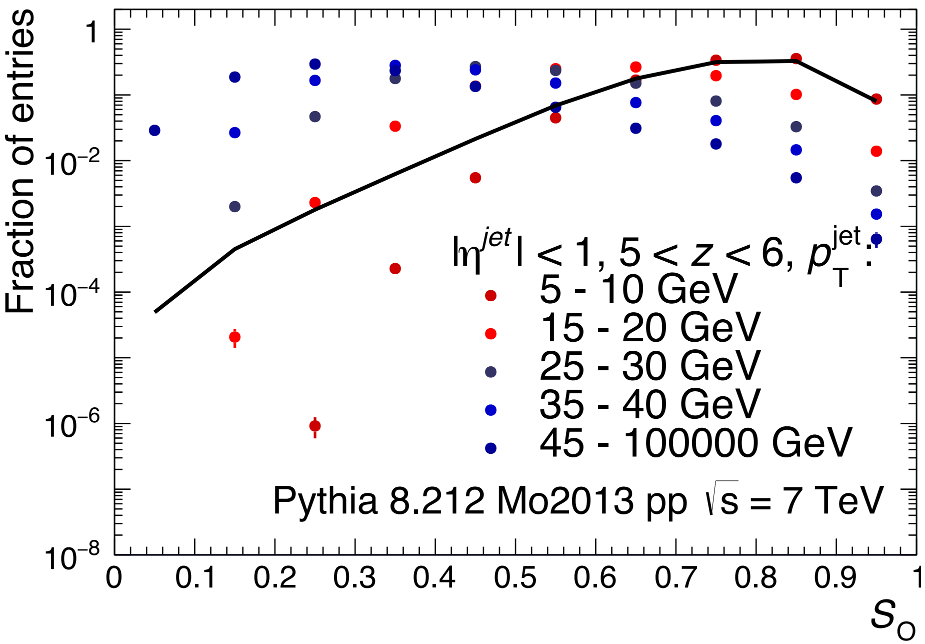
With CR

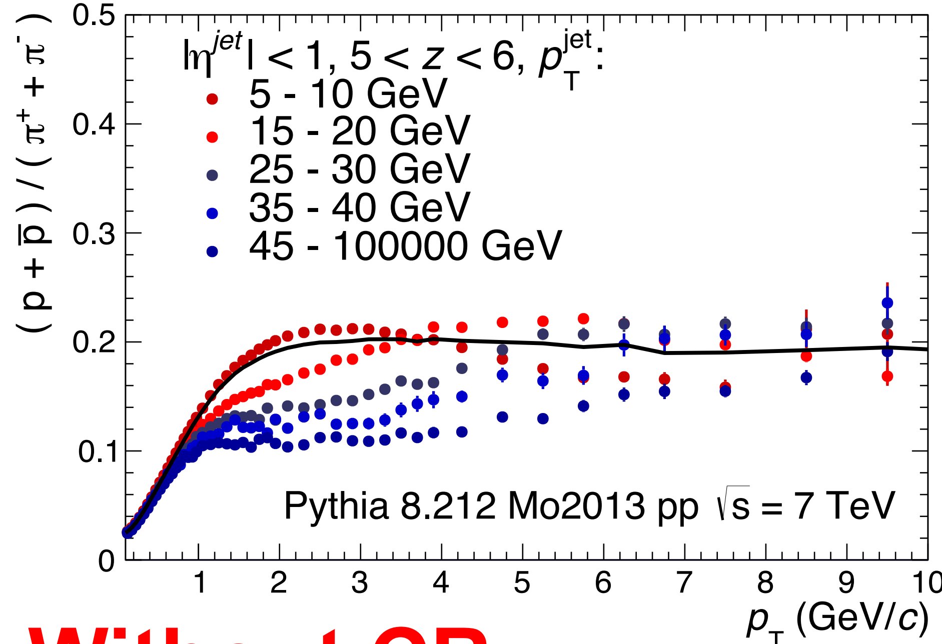


Fraction of entries / 1
N_{MPI}
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV

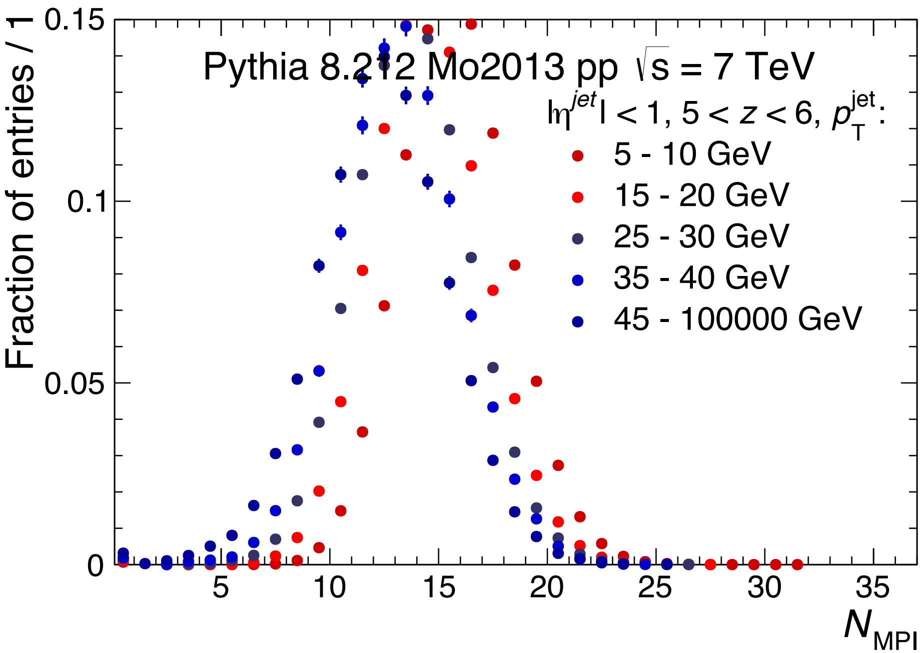


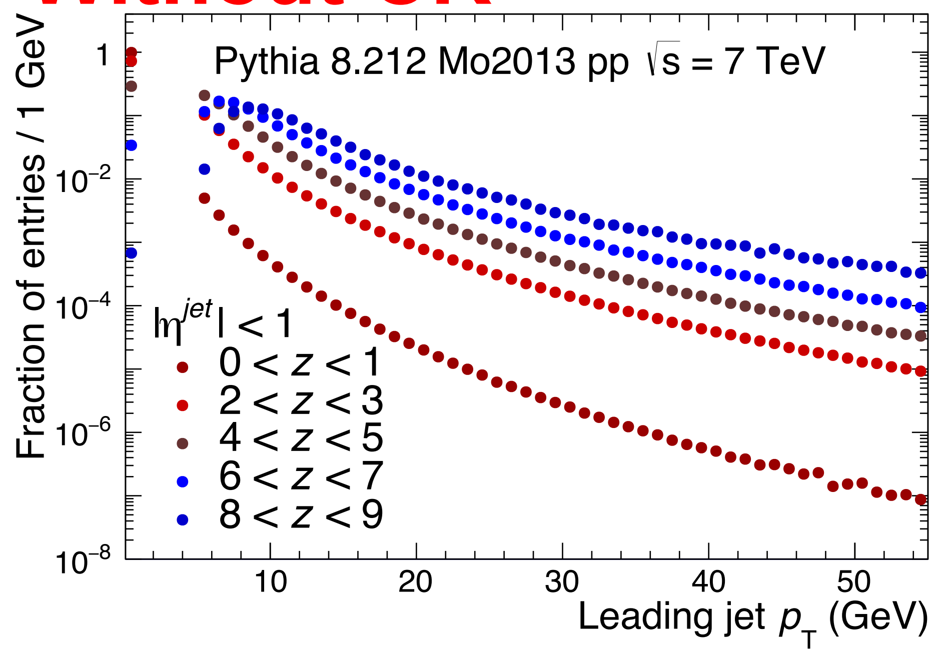
Fraction of entries / 1 GeV
Leading jet p_T (GeV)
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
$|\eta^{jet}| < 1$
$0 < z < 1$
$2 < z < 3$
$4 < z < 5$
$6 < z < 7$
$8 < z < 9$


Fraction of entries
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
S_O


$(p + \bar{p}) / (\pi^+ + \pi^-)$
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
p_T (GeV/c)

Without CR


Fraction of entries / 1
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
$|\eta^{jet}| < 1$, $5 < z < 6$, p_T^{jet}:
5 - 10 GeV
15 - 20 GeV
25 - 30 GeV
35 - 40 GeV
45 - 100000 GeV
N_{MPI}


Fraction of entries / 1 GeV
Pythia 8.212 Mo2013 pp $\sqrt{s}$ = 7 TeV
$|\eta^{jet}| < 1$
$0 < z < 1$
$2 < z < 3$
$4 < z < 5$
$6 < z < 7$
$8 < z < 9$
Leading jet p_T (GeV)

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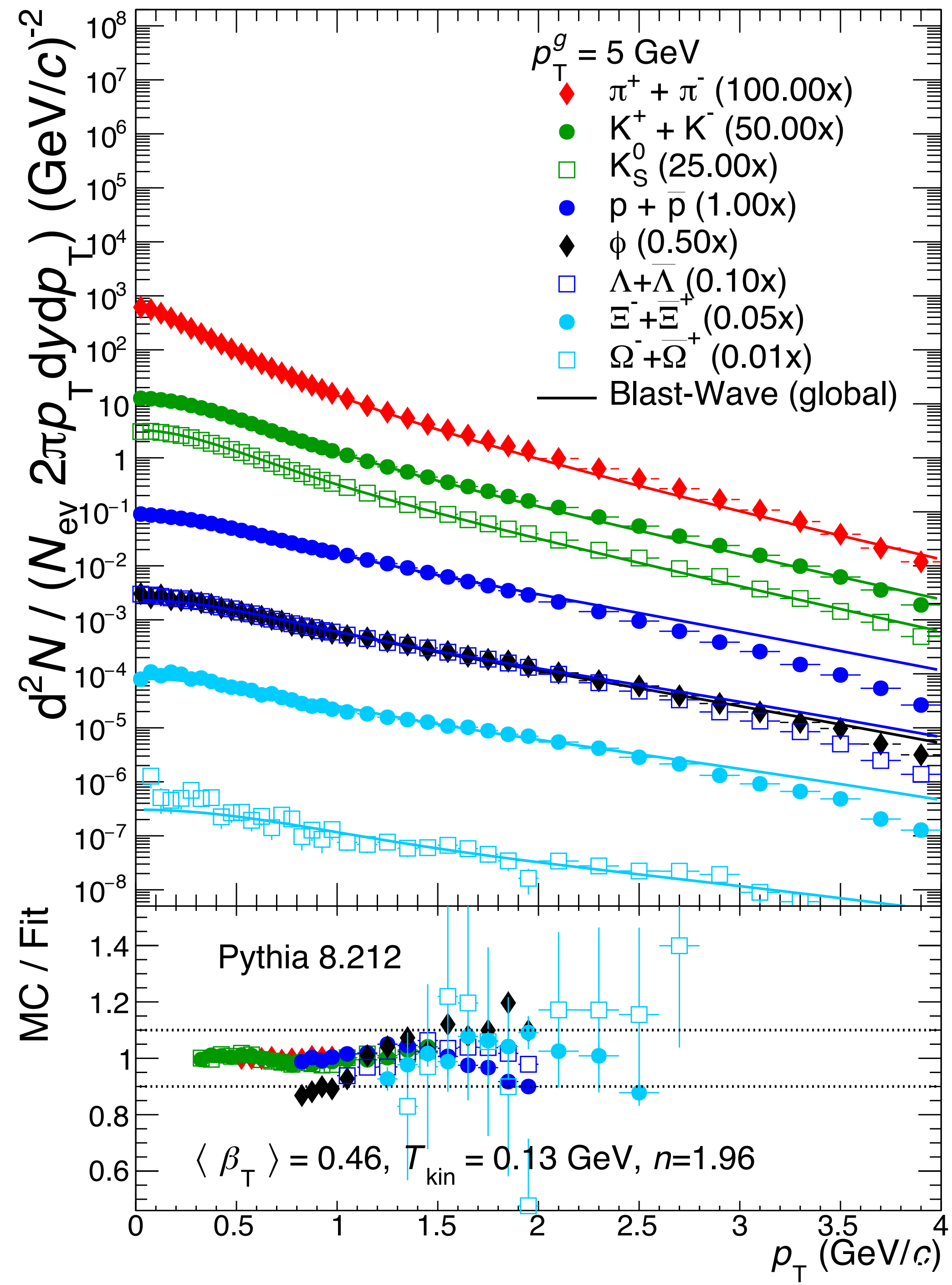
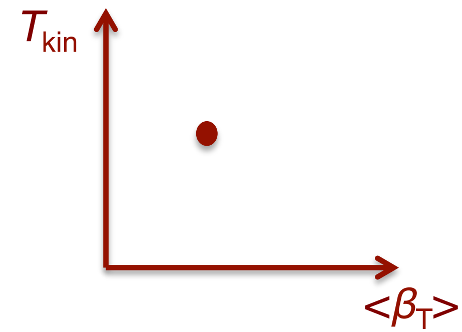
HADRONIZATION IN A CLEAN PARTONIC CONFIGURATION





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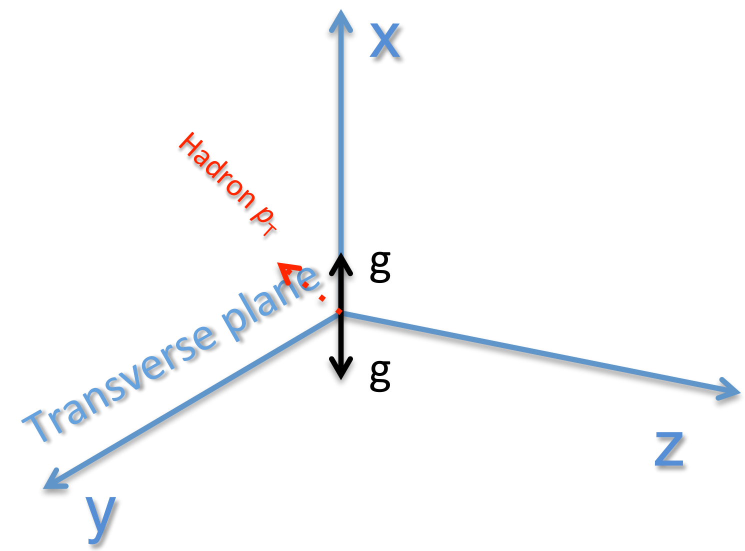
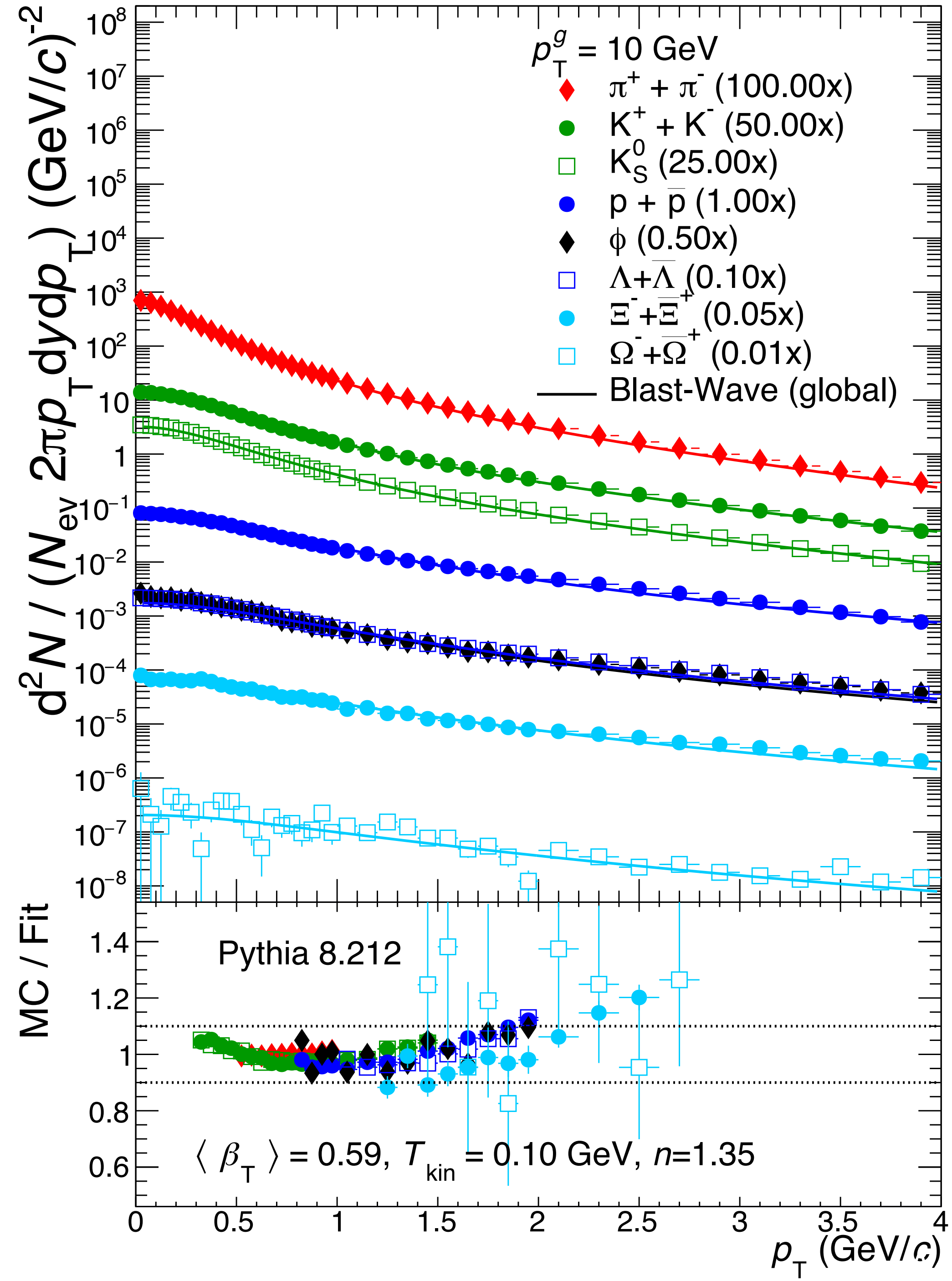


Parton-level configurations as direct input for hadronization



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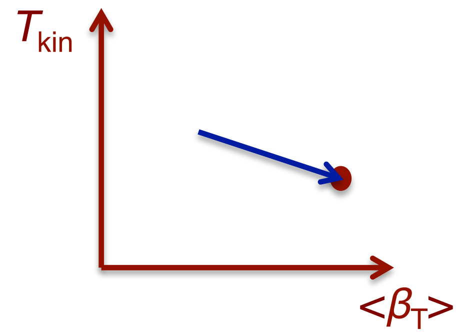
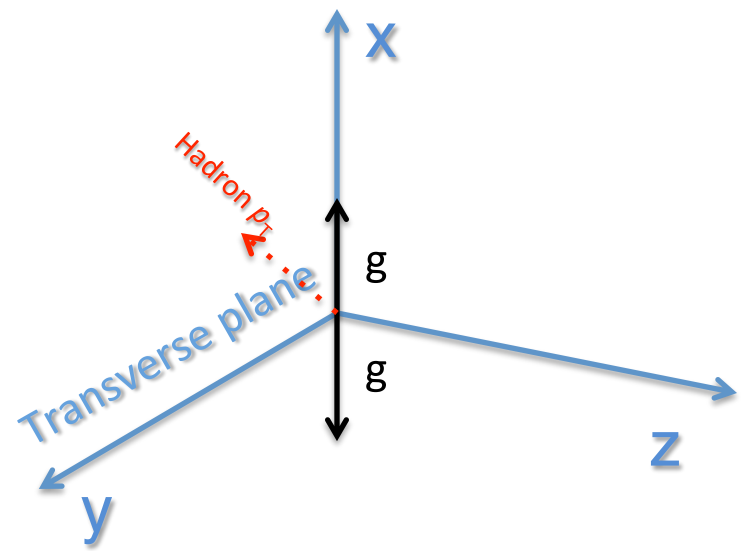
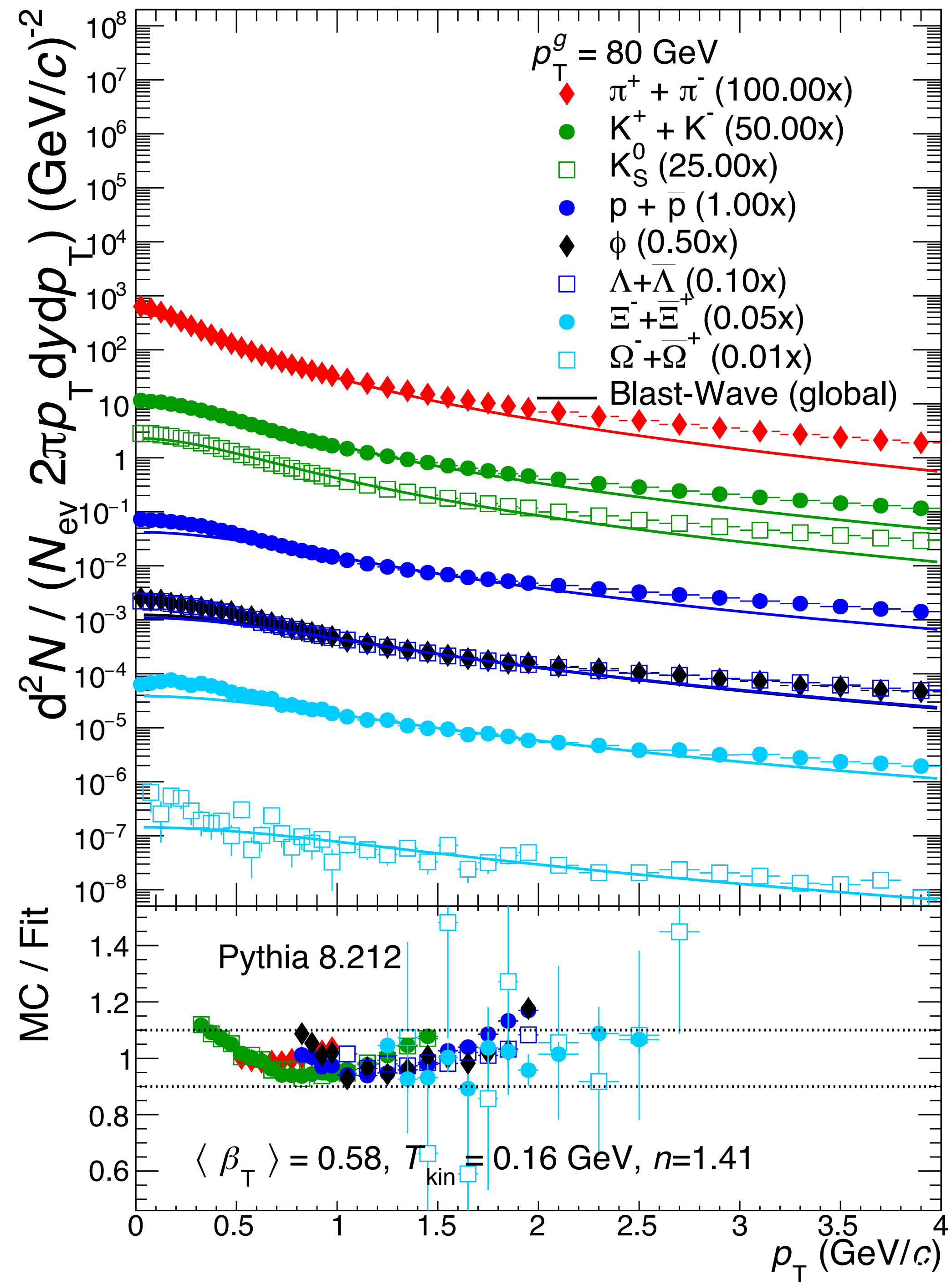
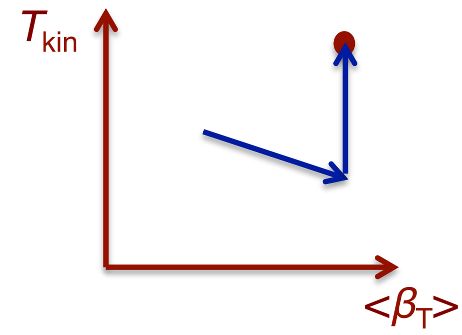




Parton-level configurations as direct input for hadronization





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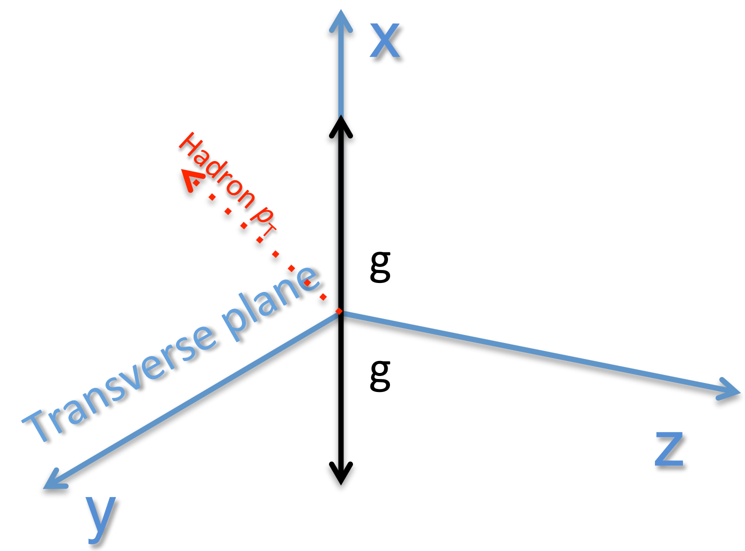

Parton-level configurations as direct input for hadronization

OTHER APPROACHES

Jet effects can be also seen in a more inclusive analysis

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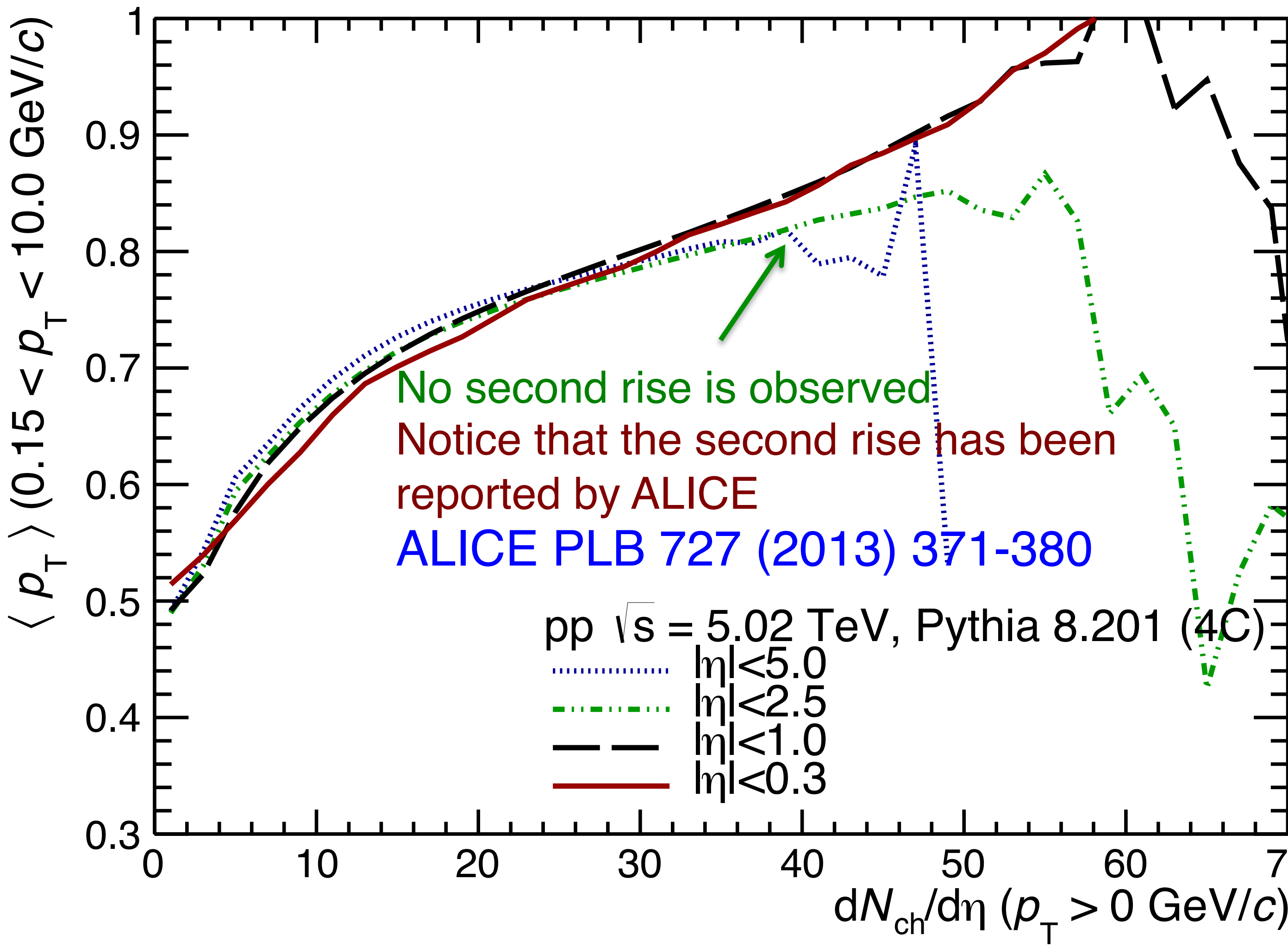

- <p_T> was computed with charged particles within |η|<0.3
- $dN_{ch}/d\eta$ was computed using different η windows

Jet effects can be also seen in a more inclusive analysis

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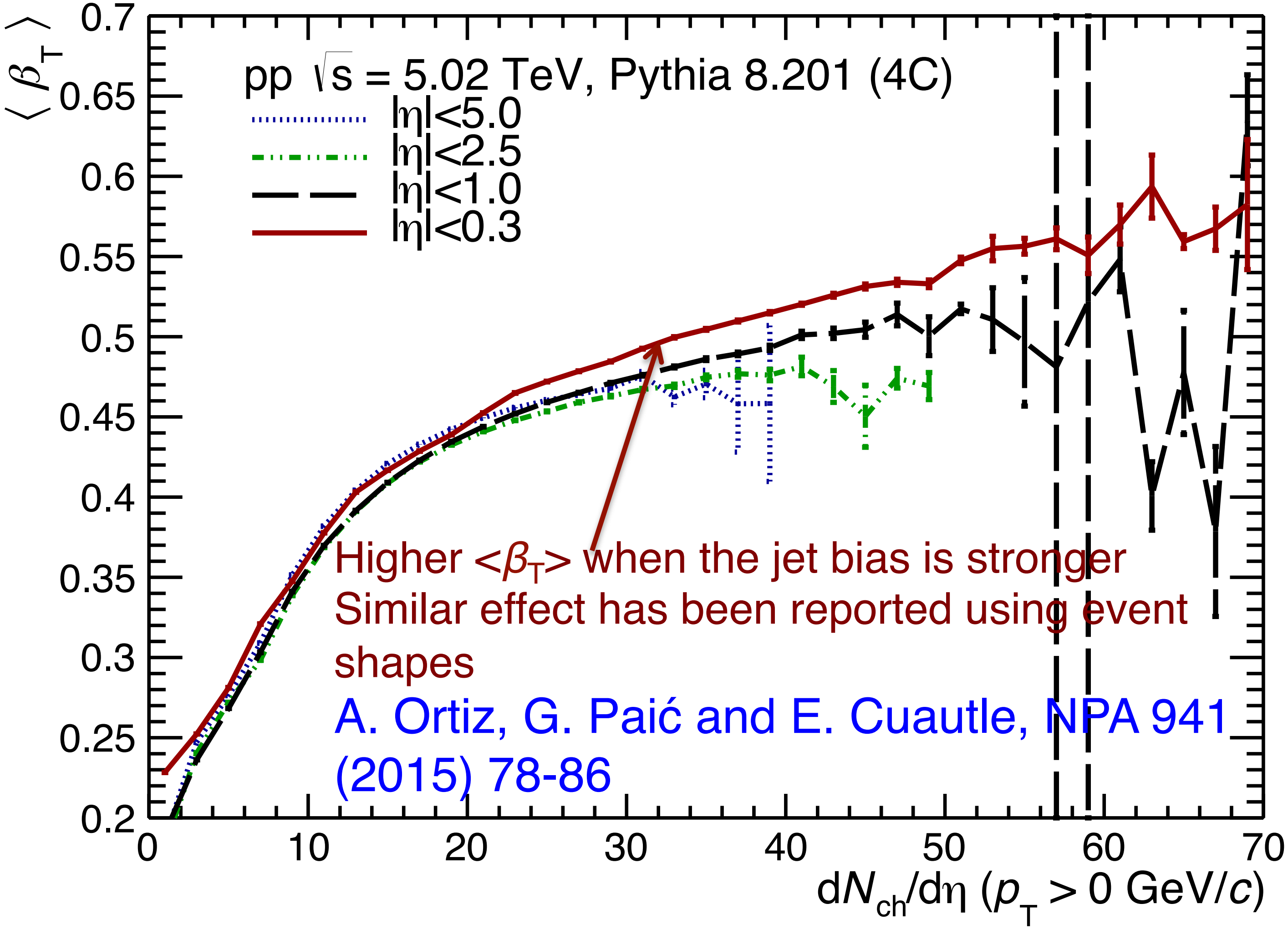

- $\langle \beta_T \rangle$ was computed with charged particles within $|\eta|<0.3$
- $dN_{ch}/d\eta$ was computed using different η windows

PID in charged jets

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Xianguo Lu, for the ALICE Collaboration, NPA 00 (2014), 1-4