Proiectul: PN 19 06 01 03
Faza: nr. 8
Programe de calcul pentru studiul unor observabile cu ajutorul modelelor fenomenologice la energii relativiste si ultrarelativiste - Partea I
Termen de incheiere a fazei: 9.12.2021

December 7, 2021

Cuprins

- Introducere
- Modele teoretice utilizate
- Rezultate
- Concluzii

Introducere

- Generatorii de evenimente - simuleaza ciocnirile dintre particule prin procedee Monte Carlo
- Este redata structura evenimentelor similar cu ce se observa experimental - milioane de evenimente sunt generate
- Se construiesc marimi numite observabile fizice analizand evenimentele generate - programe de calcul

- Conditii extreme de temperatura si presiune ale materiei nucleare - formarea unei noi stari a materiei, plasma Quark-Gluon (QGP)
- Ciocniri de ioni grei - se observa fenomene considerate a fi semnaturi ale formarii QGP (de ex. "flow")
- Fenomene similare - observate in ciocniri proton-ion greu si chiar proton-proton
- Teoretic:
  - - modele care se bazeaza pe ipoteza crearii QGP
  - - modele alternative - nu necesita formarea QGP

Modele teoretice utilizate

Ciocniri pp

PYTHIA8 versiunea 8306

Un eveniment PYTHIA standard este generat în trei pasi: nivelul de proces, nivelul partonic si nivelul hadronic.

Nivelul de proces: procesele sunt clasificate ca fiind "QCD hard" sau "QCD soft".

Nivelul partonic:implica corectiile procesului "hard", include interactiunea multipartonica (MPI) ramasitele de fascicul, radiatia de stare initiala si finala si reconectarea culorilor(CR).

Nivelul hadronic se ocupa cu hadronizarea, precum si cu efectele posthadronizarii, cum ar fi dezintegrarea si reimprastierea hadronilor.

Are un numar foarte mare de parametri configurabili care sunt potriviti pe un set de date experimentale in asa-numitele "Tunes".

Procese noi, menite sa explice fenomene observate experimental mai ales odata cu pornirea LHC au fost implementate in ultimii ani si acestea pot fi activate optional.

EPOS-LHC

Modelul EPOS este un model core-corona, ceea ce înseamna ca sistemul format este construit dintr-o portiune de miez densa si o coroana mai diluata. Starea initiala este modelata de formarea de "ladder"-uri de partoni (o reprezentare a MPI) astfel ca rezulta câmpuri de culoare numite tuburi de flux, care nu sunt foarte diferite de "string"-urile din modelul PYTHIA. Miezul se formeaza în regiunile în care densitatea de tuburi de flux este peste un anumit prag, în timp ce restul (de obicei limitat la regiunile periferice ale sistemului de ciocnire) alcatuiesc corona. Partea de miez se extinde hidrodinamic si în cele din urma hadronizeaza prin hadronizare colectiva, în timp ce corona se va fragmenta prin fragmentare de "string"-uri. In EPOS-LHC nu a fost efectuata o hidrodinamizare completa In schimb, este utilizata o parametrizare pentru a simula miscarea colectiva al hadronilor.

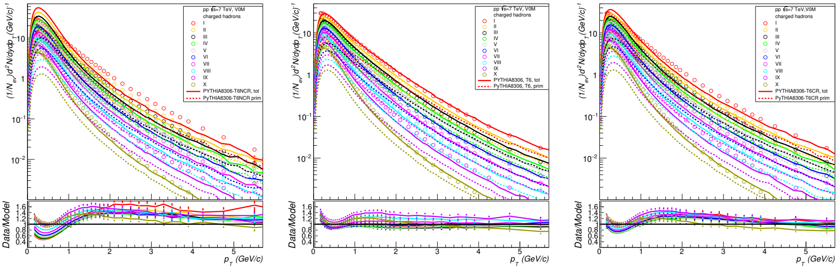
Ciocniri A-A

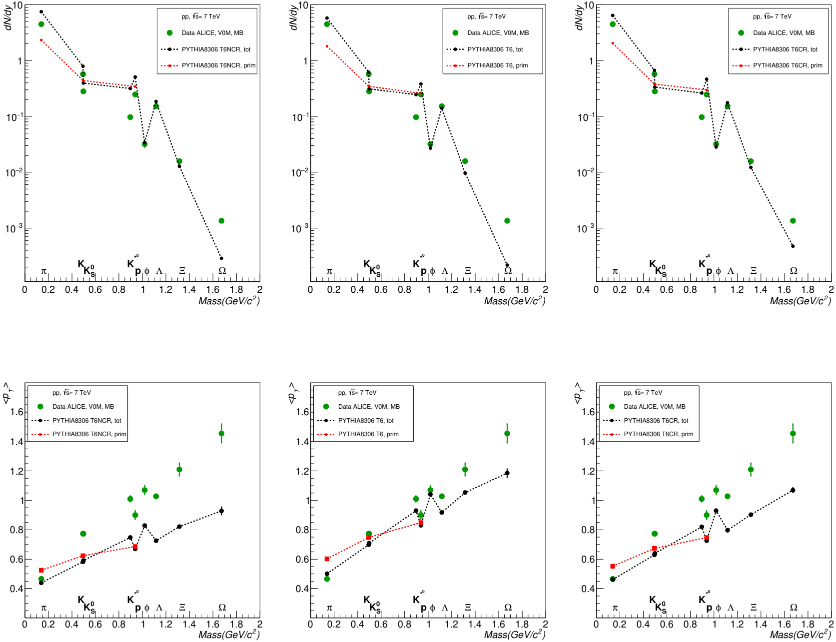
TRAJECTUM

Codul este scris în C++ si încorporeaza calculul conditiilor initiale, faza prehidrodinamica, faza hidrodinamica, si formarea de particule în interiorul unui singur executabil. In plus, pentru fiecare dintre aceste componente o clasa de baza specifica interfata cu care componenta comunica cu celelalte componente. In acest fel, devine posibil sa existe mai multe versiuni pentru fiecare componenta, pe care utilizatorul le poate schimba dupa cum doreste. Interfata comuna garanteaza ca, indiferent de alegerea facuta de utilizator, componenta va interactiona consistent cu celelalte. In plus, TRAJECTUM interogheaza fiecare componenta aleasa care sunt parametrii necesari pentru a functiona corect si verifica fisierul de parametri specificat de utilizator pentru a citi acesti parametri. Continutul final de particule serveste ca exemplu al afirmatiei ca toate componentele interactioneaza corect în mod automat. In implementarea curenta este posibila alegerea pentru continutul de particule final utilizarea codurilor UrQMD sau SMASH.

Rezultate

- Activitati:
  - peste 180 de milioane de evenimente generate
  - programe de calcul pentru construirea observabilelor fizice teoretice
  - comparatia cu observabile masurate experimental - date publicate de colaborarea ALICE
    - distributii de impuls transversal si influenta rezonantelor
    - observabile derivate din distributiile de impuls transversal
- Studii complementare in sprijinul indeplinirii obiectivelor specifice din cadrul colaborarilor ALICE si CBM:
  - comparatia rezultatelor experimentale obtinute in studii multi-diferentiale ale produsilor rezultati in ciocniri pp la energiile LHC - analize in curs de desfasurare in grupul ALICE din IFIN-HH
  - studiul sistematic al proprietatilor de scalare ale hadronilor produsi in interactii pp si A-A
  - prezicerea unor observabile de interes la experimentul CBM


pp √s=7 TeV, V0M
charged hadrons
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306-T6NCR, tot
PyTHIA8306-T6NCR prim
PYTHIA8306, T6, tot
PYTHIA8306, T6, prim
PYTHIA8306-T6CR, tot
PyTHIA8306-T6CR prim
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)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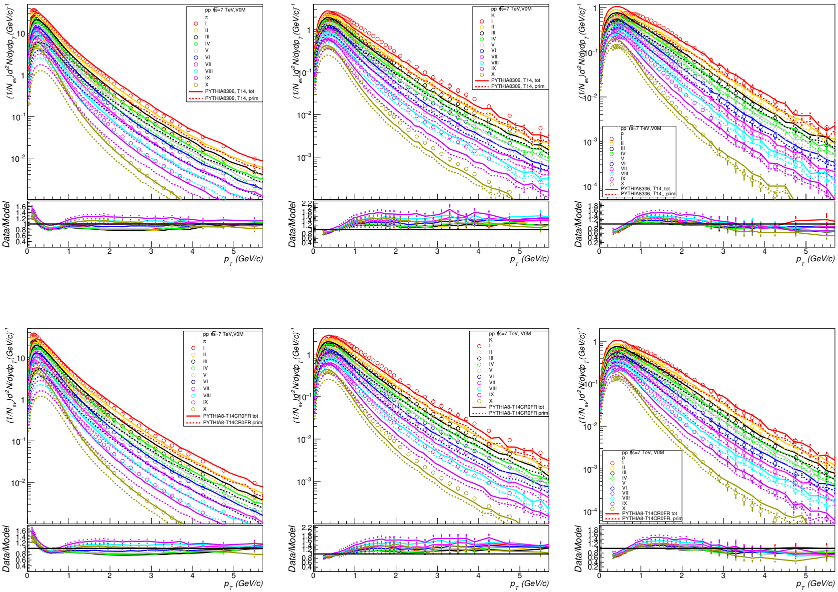
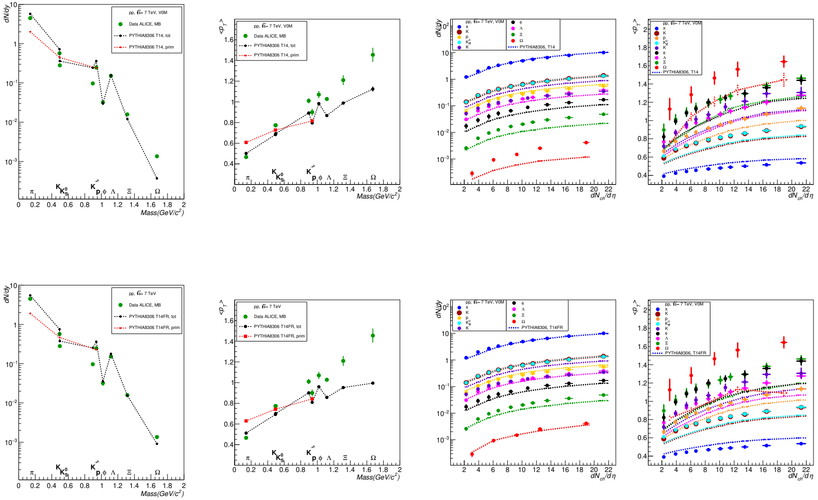
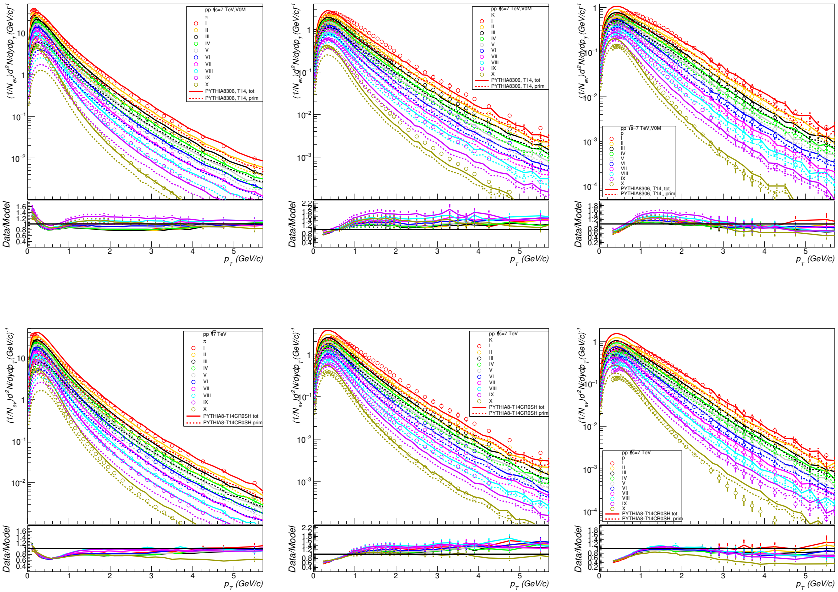
PYTHIA8306 T6NCR, tot
PYTHIA8306 T6NCR, prim
PYTHIA8306 T6, tot
PYTHIA8306 T6, prim
PYTHIA8306 T6CR, tot
PYTHIA8306 T6CR, prim
dN/dy
<p_T>
Mass(GeV/c^2)
π K K_S^0 K^*0 p φ Λ Ξ Ω

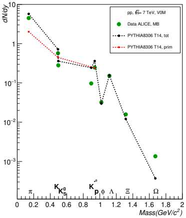


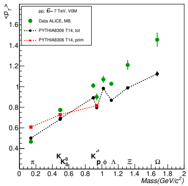
pp √s=7 TeV,V0M
π
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306, T14, tot
PYTHIA8306, T14, prim
K
p
PYTHIA8-T14CR0FR tot
PYTHIA8-T14CR0FR prim
pp √s=7 TeV, V0M
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)

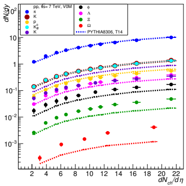

pp, √s= 7 TeV, V0M
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
dN/dy
<p_T>
Mass(GeV/c^2)
π K K_S^0 K* p φ Λ Ξ Ω
PYTHIA8306, T14
dN_ch/dη
pp, √s= 7 TeV
PYTHIA8306 T14FR, tot
PYTHIA8306 T14FR, prim
PYTHIA8306, T14FR

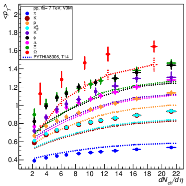


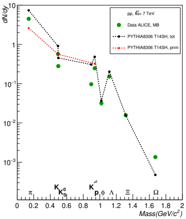
pp √s=7 TeV,V0M
π
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306, T14, tot
PYTHIA8306, T14, prim
K
p
PYTHIA8306, T14,, prim
pp √7 TeV
pp √s=7 TeV
PYTHIA8-T14CR0SH tot
PYTHIA8-T14CR0SH prim
PYTHIA8-T14CR0SH, prim
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)

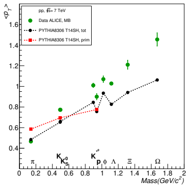

dN/dy
pp, √s = 7 TeV, V0M
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
π
K
K^0_S
K^{*0}
p
φ
Λ
Ξ
Ω
Mass(GeV/c²)

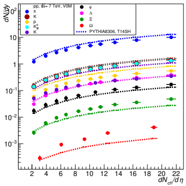

<p_T>
pp, √s = 7 TeV, V0M
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
π
K
K^0_S
K^{*0}
p
φ
Λ
Ξ
Ω
Mass(GeV/c²)

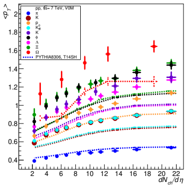

dN/dy
pp, √s = 7 TeV, V0M
π
K
p
K^0_S
K*
φ
Λ
Ξ
Ω
PYTHIA8306, T14
$dN_{ch}/d\eta$

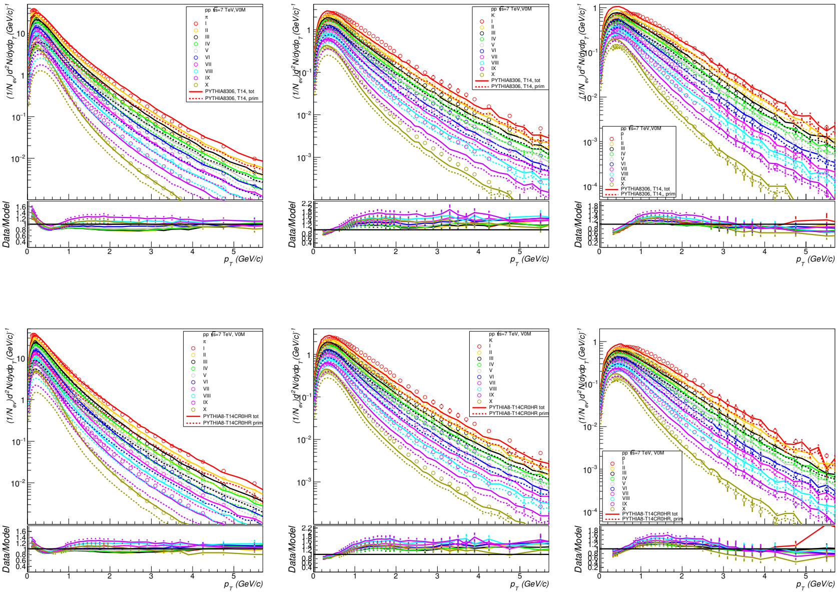

<p_T>
pp, √s = 7 TeV, V0M
π
K
p
K^0_S
K*
φ
Λ
Ξ
Ω
PYTHIA8306, T14
$dN_{ch}/d\eta$


dN/dy
pp, √s = 7 TeV
Data ALICE, MB
PYTHIA8306 T14SH, tot
PYTHIA8306 T14SH, prim
π
K
K^0_S
K^{*0}
p
φ
Λ
Ξ
Ω
Mass(GeV/c²)

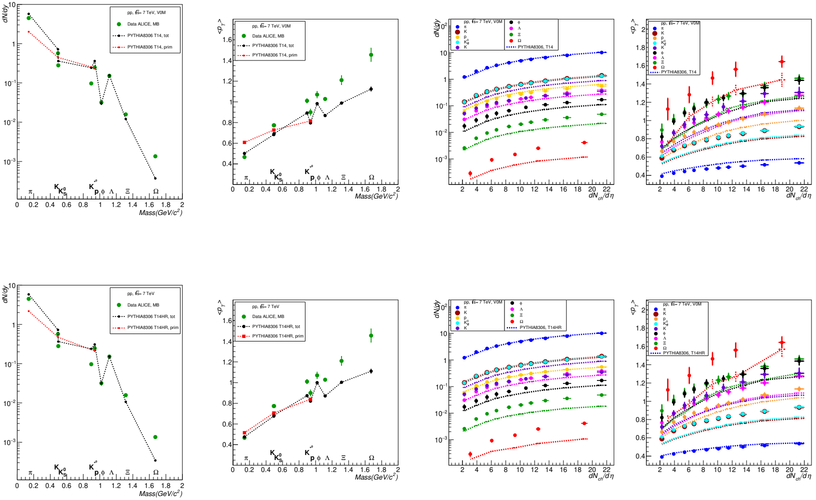

<p_T>
pp, √s = 7 TeV
Data ALICE, MB
PYTHIA8306 T14SH, tot
PYTHIA8306 T14SH, prim
π
K
K^0_S
K^{*0}
p
φ
Λ
Ξ
Ω
Mass(GeV/c²)

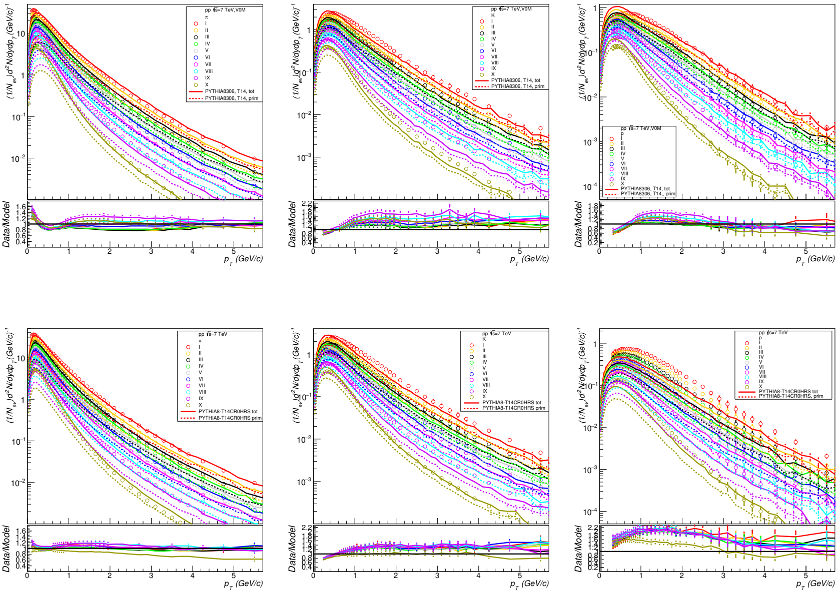

dN/dy
pp, √s = 7 TeV, V0M
π
K
p
K^0_S
K*
φ
Λ
Ξ
Ω
PYTHIA8306, T14SH
$dN_{ch}/d\eta$


<p_T>
pp, √s = 7 TeV, V0M
π
K
p
K^0_S
K*
φ
Λ
Ξ
Ω
PYTHIA8306, T14SH
$dN_{ch}/d\eta$

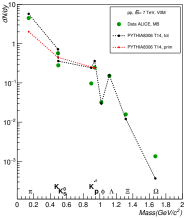


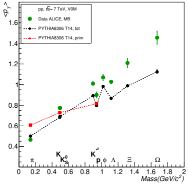
pp √s=7 TeV,V0M
π
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306, T14, tot
PYTHIA8306, T14, prim
K
p
PYTHIA8306, T14,, prim
pp √s=7 TeV, V0M
PYTHIA8-T14CR0HR tot
PYTHIA8-T14CR0HR prim
PYTHIA8-T14CR0HR, prim
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)


pp, √s= 7 TeV, V0M
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
pp, √s= 7 TeV
PYTHIA8306 T14HR, tot
PYTHIA8306 T14HR, prim
PYTHIA8306, T14
PYTHIA8306, T14HR
dN/dy
$<p_T>$
Mass(GeV/c^2)
$dN_{ch}/d\eta$



pp √s=7 TeV,V0M
π
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306, T14, tot
PYTHIA8306, T14, prim
K
p
PYTHIA8306, T14,, prim
pp √s=7 TeV
PYTHIA8-T14CR0HRS tot
PYTHIA8-T14CR0HRS prim
PYTHIA8-T14CR0HRS, prim
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)


pp, √s= 7 TeV, V0M
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
dN/dy
Mass(GeV/c^2)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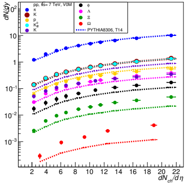
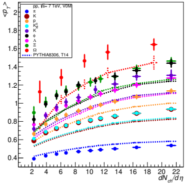
Data ALICE, MB
PYTHIA8306 T14, tot
PYTHIA8306 T14, prim
<p_T>
Mass(GeV/c^2)


pp, √s= 7 TeV, V0M
PYTHIA8306, T14
dN/dy
dN_ch/dη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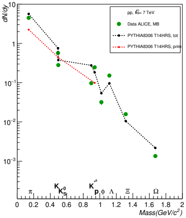
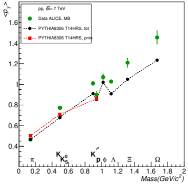
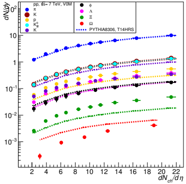
PYTHIA8306, T14
<p_T>
dN_ch/dη


pp, √s= 7 TeV
Data ALICE, MB
PYTHIA8306 T14HRS, tot
PYTHIA8306 T14HRS, prim
dN/dy
Mass(GeV/c^2)


pp, √s= 7 TeV
Data ALICE, MB
PYTHIA8306 T14HRS, tot
PYTHIA8306 T14HRS, prim
<p_T>
Mass(GeV/c^2)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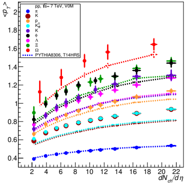
PYTHIA8306, T14HRS
dN/dy
dN_ch/dη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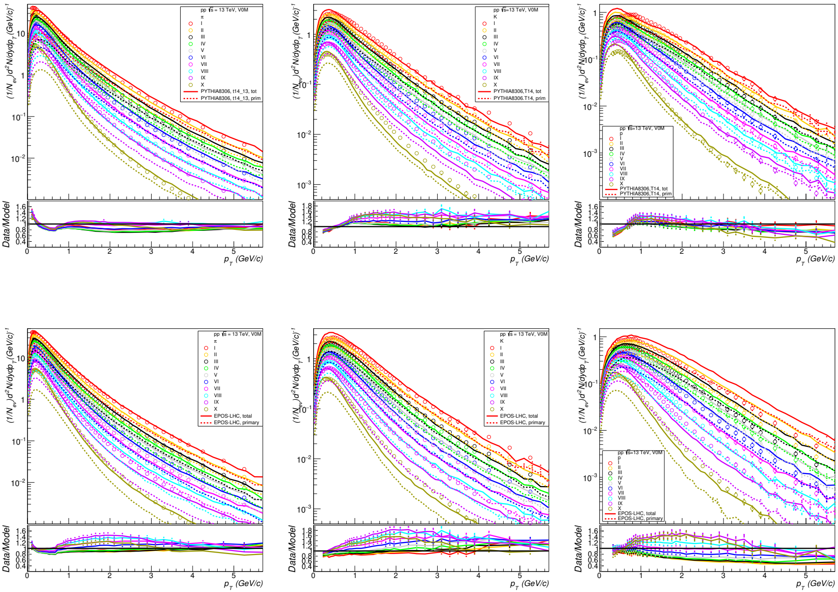
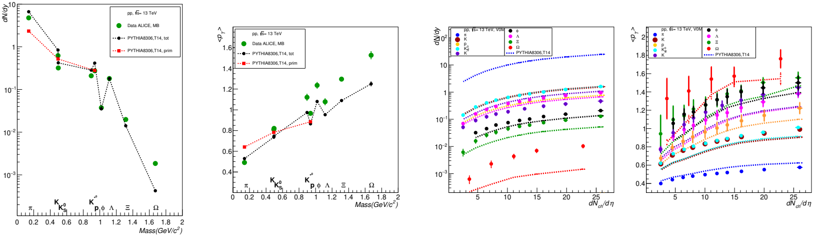
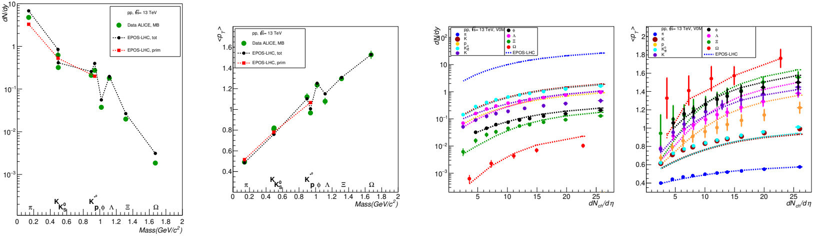
PYTHIA8306, T14HRS
<p_T>
dN_ch/dη

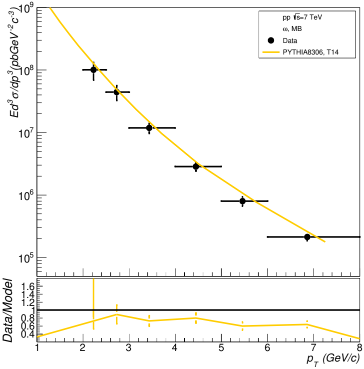

pp √s = 13 TeV, V0M
π
I
II
III
IV
V
VI
VII
VIII
IX
X
PYTHIA8306, t14_13, tot
PYTHIA8306, t14_13, prim
pp √s=13 TeV, V0M
K
PYTHIA8306,T14, tot
PYTHIA8306.T14, prim
pp √s=13 TeV, V0M
p
PYTHIA8306,T14, tot
PYTHIA8306,T14, prim
EPOS-LHC, total
EPOS-LHC, primary
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
Data/Model
p_T (GeV/c)

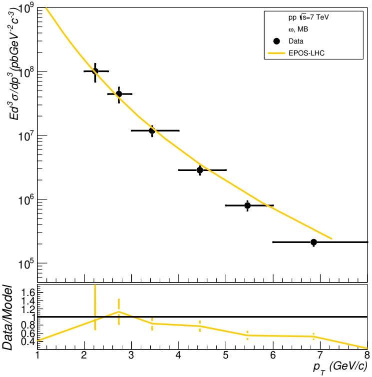


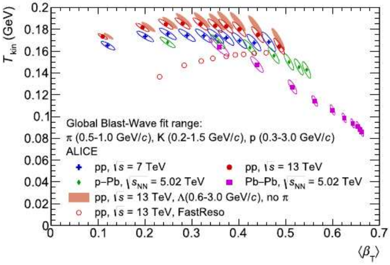
pp, √s= 13 TeV
Data ALICE, MB
PYTHIA8306,T14, tot
PYTHIA8306,T14, prim
dN/dy
<p_T>
Mass(GeV/c^2)
pp, √s= 13 TeV, V0M
PYTHIA8306,T14
dN_ch/dη



pp, √s= 13 TeV
Data ALICE, MB
EPOS-LHC, tot
EPOS-LHC, prim
dN/dy
<p_T>
Mass(GeV/c^2)
pp, √s= 13 TeV, V0M
EPOS-LHC
dN_ch/dη

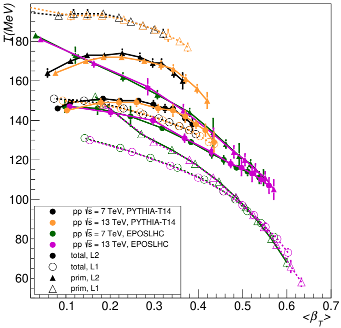

pp √s=7 TeV
ω, MB
Data
PYTHIA8306, T14
Ed^3σ/dp^3(pbGeV^-2c^-3)
Data/Model
p_T (GeV/c)

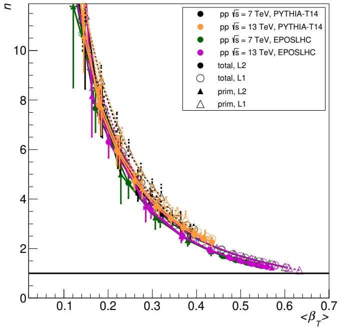

pp √s=7 TeV
ω, MB
Data
EPOS-LHC
Ed^3σ/dp^3(pbGeV^-2c^-3)
Data/Model
p_T (GeV/c)

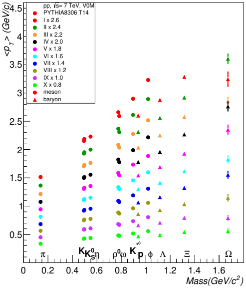


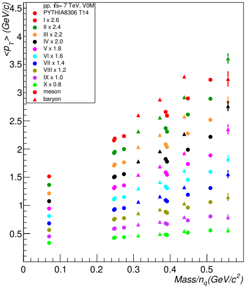
L1: π, K,p 0-2 GeV/c

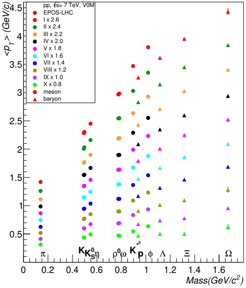
L2: π, 0.5-1 GeV/c; K, 0.2-1.5 GeV/c; p, 0.3-3 GeV/c

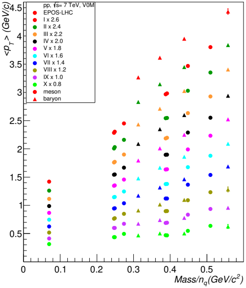


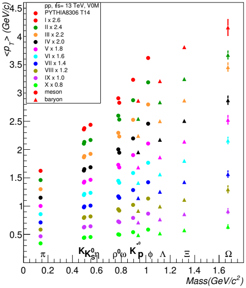


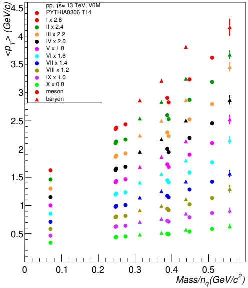

pp, √s= 7 TeV, V0M
PYTHIA8306 T14
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
$\langle p_T \rangle$ (GeV/c)
π
K K_S^0 η
ρ^0 ω
K^{*0} p
φ
Λ
Ξ
Ω
Mass(GeV/c^2)

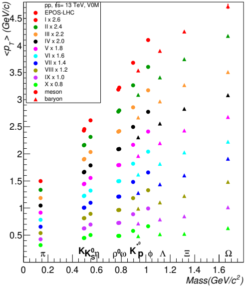

pp, √s= 7 TeV, V0M
PYTHIA8306 T14
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
$\langle p_T \rangle$ (GeV/c)
Mass/n_q(GeV/c^2)

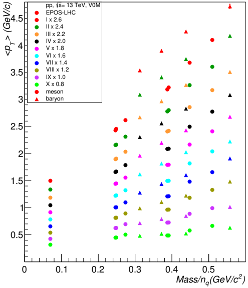

pp, √s= 7 TeV, V0M
EPOS-LHC
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
$\langle p_T \rangle$ (GeV/c)
π
K K_S^0 η
ρ^0 ω
K^{*0} p
φ
Λ
Ξ
Ω
Mass(GeV/c^2)


pp, √s= 7 TeV, V0M
EPOS-LHC
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
$\langle p_T \rangle$ (GeV/c)
Mass/n_q(GeV/c^2)


pp, √s= 13 TeV, V0M
PYTHIA8306 T14
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
<p_T> (GeV/c)
Mass(GeV/c^2)
π K K_S^0 η ρ^0 ω K^*0 p φ Λ Ξ Ω

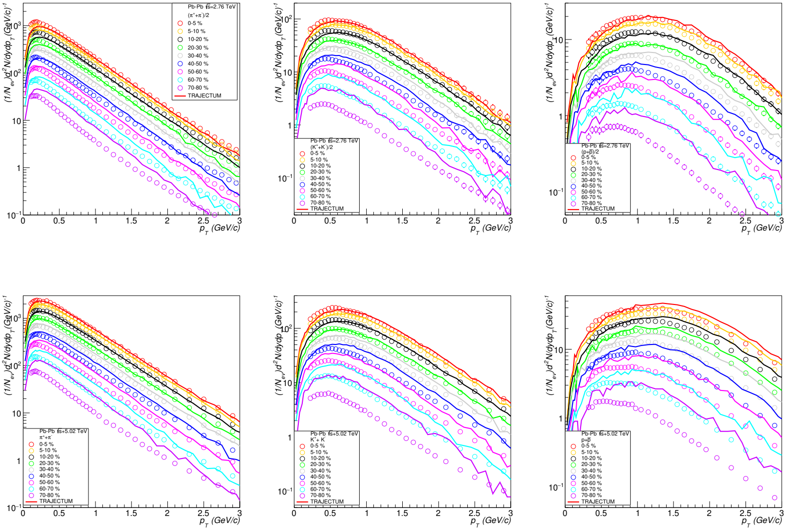

pp, √s= 13 TeV, V0M
PYTHIA8306 T14
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
<p_T> (GeV/c)
Mass/n_q(GeV/c^2)

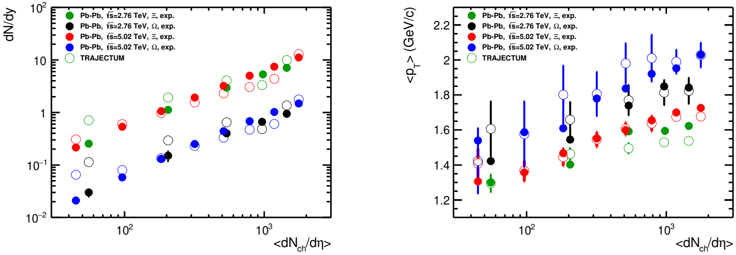

pp, √s= 13 TeV, V0M
EPOS-LHC
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
<p_T> (GeV/c)
Mass(GeV/c^2)
π K K_S^0 η ρ^0 ω K^*0 p φ Λ Ξ Ω


pp, √s= 13 TeV, V0M
EPOS-LHC
I x 2.6
II x 2.4
III x 2.2
IV x 2.0
V x 1.8
VI x 1.6
VII x 1.4
VIII x 1.2
IX x 1.0
X x 0.8
meson
baryon
<p_T> (GeV/c)
Mass/n_q(GeV/c^2)

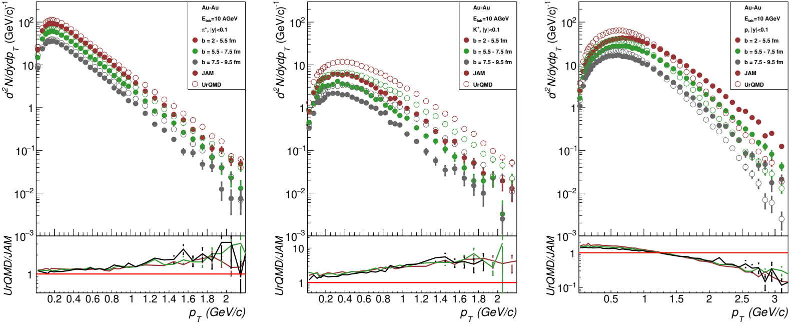
$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$

	Experiment		Pythia8306-T14		EPOS-LHC	
V0M 2.8 < η < 5.1 & -3.7 < η < -1.7						
1	25.75	0.40	29.02	0.10	28.51	0.10
2	19.83	0.30	23.34	0.04	22.41	0.04
3	16.12	0.24	19.42	0.03	18.18	0.03
4	13.76	0.21	16.59	0.03	15.19	0.02
5	12.06	0.18	14.22	0.02	12.89	0.03
6	10.11	0.15	11.47	0.01	10.39	0.01
7	8.07	0.12	8.80	0.01	7.77	0.01
8	6.48	0.10	6.78	0.008	5.94	0.008
9	4.64	0.07	4.58	0.004	4.11	0.003
10	2.52	0.04	2.70	0.002	2.42	0.002
SPD |η| < 0.8						
1	32.49	0.50	36.83	0.13	35.54	0.13
2	23.42	0.35	26.80	0.05	25.46	0.046
3	18.29	0.28	20.95	0.03	19.68	0.03
4	14.90	0.23	17.30	0.03	16.04	0.02
5	12.90	0.19	14.52	0.02	13.27	0.02
6	10.72	0.16	11.67	0.014	10.43	0.02
7	8.14	0.12	8.90	0.01	8.00	0.01
8	5.95	0.09	6.75	0.008	6.13	0.007
9	3.82	0.06	4.50	0.004	4.26	0.004
10	1.76	0.03	2.14	0.002	2.10	0.001
SPD 0.8 < |η| < 1.5						
1	26.32	0.40	30.22	0.11	30.06	0.11
2	19.51	0.29	24.01	0.04	23.13	0.04
3	15.45	0.23	19.55	0.03	18.72	0.03
4	13.14	0.20	16.56	0.03	15.46	0.02
5	11.63	0.17	14.47	0.02	13.03	0.02
6	9.50	0.14	11.88	0.02	10.70	0.01
7	7.68	0.11	8.96	0.01	8.02	0.01
8	6.35	0.10	7.00	0.01	6.09	0.01
9	4.36	0.06	4.85	0.004	4.51	0.004
10	2.67	0.04	2.82	0.002	2.71	0.002


Pb-Pb √s=2.76 TeV
(π⁺+π⁻)/2
0-5 %
5-10 %
10-20 %
20-30 %
30-40 %
40-50 %
50-60 %
60-70 %
70-80 %
TRAJECTUM
Pb-Pb √s=2.76 TeV
(K⁺+K)/2
Pb-Pb √s=2.76 TeV
(p+p̄)/2
Pb-Pb √s+5.02 TeV
π⁺+π⁻
Pb-Pb √s+5.02 TeV
K⁺+ K
Pb-Pb √s+5.02 TeV
p+p̄
(1/N_ev)d²N/dydp_T (GeV/c)⁻¹
p_T (GeV/c)



dN/dy
Pb-Pb, √s=2.76 TeV, Ξ, exp.
Pb-Pb, √s=2.76 TeV, Ω, exp.
Pb-Pb, √s=5.02 TeV, Ξ, exp.
Pb-Pb, √s=5.02 TeV, Ω, exp.
TRAJECTUM
<dN_ch/dη>
<p_T> (GeV/c)
Pb-Pb, √s=2.76 TeV, Ξ, exp.
Pb-Pb, √s=2.76 TeV, Ω, exp.
Pb-Pb, √s=5.02 TeV, Ξ, exp.
Pb-Pb, √s=5.02 TeV, Ω, exp.
TRAJECTUM
<dN_ch/dη>



Au-Au
E_{lab}=10 AGeV
π^+, |y|<0.1
K$^+$, |y|<0.1
p, |y|<0.1
b = 2 - 5.5 fm
b = 5.5 - 7.5 fm
b = 7.5 - 9.5 fm
JAM
UrQMD
$d^2N/dydp_T$ (GeV/c)$^{-1}$
UrQMD/JAM
p_T (GeV/c)

Concluzii

- Modelul PYTHIA8 cu diferite optiuni descrie destul de bine datele experimentale dar sunt necesare comparatii mai detaliate pe date rezultate din studii multi-diferentiale. Dificultatea consta in potrivirea unei multitudini de parametri in conditiile in care este nevoie sa fie generat un numar foarte mare de evenimente, mai ales in cazul observabilelor diferentiale care necesita o statistica buna, pentru a trage concluzii corecte.
- Modelul EPOS-LHC sau orice model de tip hidrodinamic trebuie de asemenea utilizat pentru o comparatie care sa evidentieze diferentele intre ipotezele fizice al diferitelor modele pe drumul gasirii unei descrieri convingatoare si unitare a fenomenelor care au loc la ciocniri relativiste.
- Structurile teoretice complexe de tip hibrid sunt foarte promitatoare in descrierea datelor experimentale dar folosirea lor nu e triviala pentru ca trebuie cunoscute si manipulate multe tipuri de modele teoretice.

- Studiul influentei dezintegrarii rezonantelor asupra distributiilor de pioni, kaoni si protoni prin modele teoretice arata calitativ ca acestea pot sa explice comportarea datelor experimentale, dar cantitativ poate exista o diferenta. Dificultatea consta in faptul ca modelul trebuie sa descrie foarte bine datele experimentale de la care sa porneasca o indicatie cantitativa corecta asupra contributiei rezonantelor.