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The triply heavy baryons

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Introduction

- Heavy quarks: *c*, *b* and *t* quarks.

  But *t* is short lived and so does not take part in hadronazation. Therefore, only *c* and *b* quarks will form the triply heavy baryons.

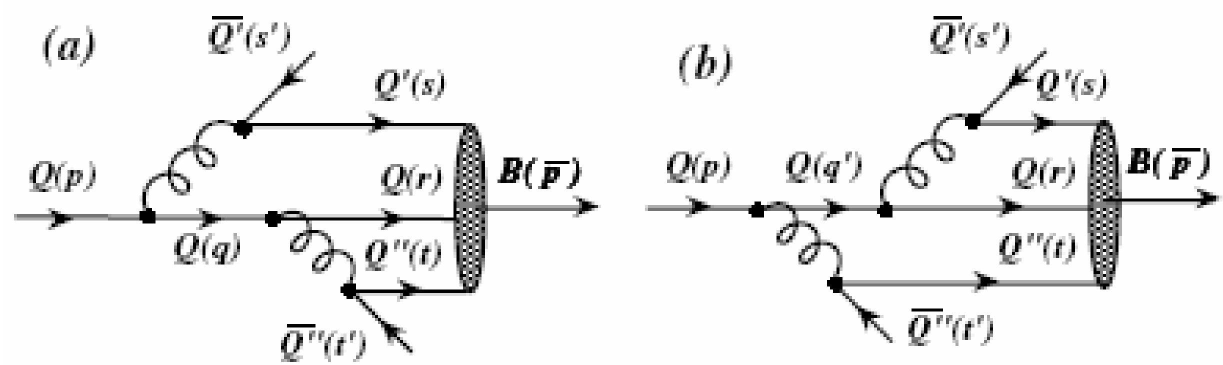
- Heavy baryons

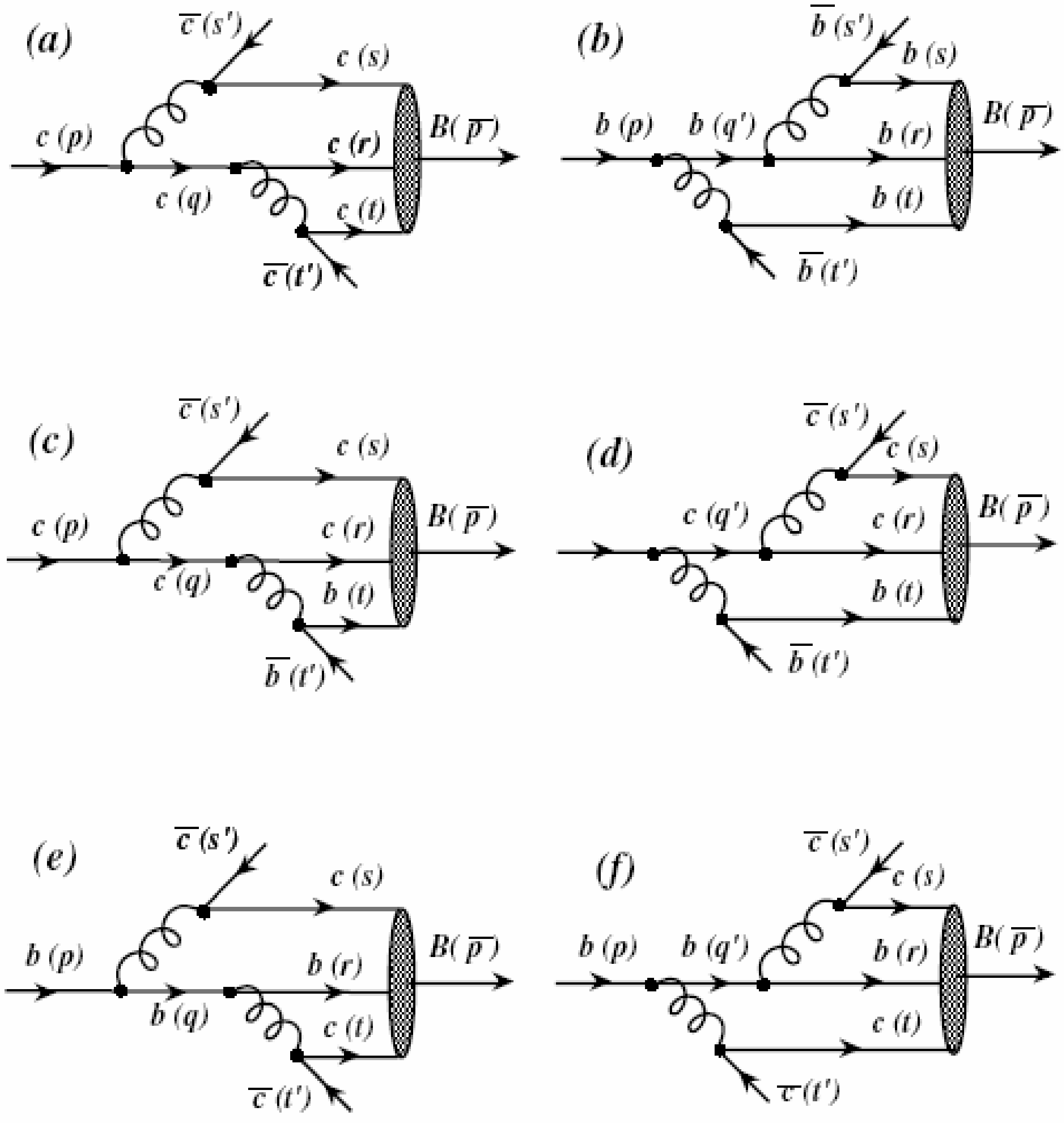
  Heavy baryons are put into three categories according to their iso-spin.

1. Λ_c, Λ_b, … I=1
2. Ξ_{cc}, Ξ_{cb}, … I=½
3. Ω_{ccc}, Ω_{ccb}, Ω_{cbb}, Ω_{bbb} I=0

Fragmentation functions

- Calculate the following pair of diagrams for each baryon state in leading order.





(a)
$\bar{c}\,(s')$
$c\,(s)$
$B(\bar{p})$
$c\,(p)$
$c\,(r)$
$c\,(q)$
$c\,(t)$
$\bar{c}\,(t')$
(b)
$\bar{b}\,(s')$
$b\,(s)$
$B(\bar{p})$
$b\,(p)$
$b\,(q')$
$b\,(r)$
$b\,(t)$
$\bar{b}\,(t')$
(c)
$\bar{c}\,(s')$
$c\,(s)$
$B(\bar{p})$
$c\,(p)$
$c\,(r)$
$c\,(q)$
$b\,(t)$
$\bar{b}\,(t')$
(d)
$\bar{c}\,(s')$
$c\,(s)$
$B(\bar{p})$
$c\,(q')$
$c\,(r)$
$b\,(t)$
$\bar{b}\,(t')$
(e)
$\bar{c}\,(s')$
$c\,(s)$
$B(\bar{p})$
$b\,(p)$
$b\,(r)$
$b\,(q)$
$c\,(t)$
$\bar{c}\,(t')$
(f)
$\bar{c}\,(s')$
$c\,(s)$
$B(\bar{p})$
$b\,(p)$
$b\,(q')$
$b\,(r)$
$c\,(t)$
$\bar{c}\,(t')$

$$D_{c\to\Omega_{ccb}}(z,\mu_\circ)=\frac{\pi^4\alpha_s(2m_1)^2\alpha_s(2m_2)^2f_B^2C_F^2m_2^2}{128a^2m'^4zf^6(z)g^2(z)}\{6-\beta-\gamma+\alpha^3(1+\gamma)+4a^4(\alpha-1)[-2+\alpha(\beta-1)+\beta+\gamma]$$
$$+\alpha^2(4+5\beta+3\gamma)+\alpha(7+6\beta+5\gamma)+8a^3[5+\beta+\alpha^2(6+9\beta)+\alpha(7+7\beta+\gamma)]$$
$$+2a[66+23\beta+27\gamma+\alpha^3(1+\gamma)+\alpha^2(52+37\beta+19\gamma)+\alpha(115+70\beta+57\gamma)]$$
$$+a^2[182+71\beta+71\gamma+5\alpha^3(1+\gamma)+\alpha^2(168+141\beta+47\gamma)+\alpha(311+198\beta+133\gamma)]\}.$$

$$D_{b\to\Omega_{ccb}}(z,\mu_\circ)=\frac{\pi^4\alpha_s(2m_1)^4f_B^2C_F^2}{64a^6m'^2zf'^6(z)g'^2(z)}\{3\alpha'^2(1+3\beta')+a\alpha'[-5+\alpha'^2-4\beta'+2\alpha'(8+9\beta')]+14a^5\gamma'$$
$$+2a^4(12+5\beta'+\gamma'+12\alpha'\gamma')+a^2[2-\beta'+\alpha'^2(21+10\beta')+\alpha'(36+34\beta'-3\gamma')+\alpha'^3\gamma']$$
$$+a^3[20+6\beta'-\gamma'+11\alpha'^2\gamma'+4\alpha'(11+5\beta'+3\gamma')]\}.$$

$$D_{Q\to\Omega_{QQQ}}(z,\mu_\circ)=\frac{\pi^4\alpha_s(2m_Q)^4f_B^2C_F^2}{256m_Q^2zf^6(z)g^2(z)}$$
$$\times\{46+15\beta+15\gamma+\alpha^3(1+\gamma)$$
$$+\alpha^2(40+37\beta+11\gamma)$$
$$+\alpha(75+50\beta+33\gamma)\},$$

The fragmentation probabilities.

Process	F.P.	$\langle z \rangle(\mu_\circ)$
$c \longrightarrow \Omega_{ccc}$	2.789×10^{-5}	0.521
$c \longrightarrow \Omega_{ccb}$	2.475×10^{-6}	0.490
$b \longrightarrow \Omega_{ccb}$	2.183×10^{-4}	0.634
$b \longrightarrow \Omega_{bbb}$	6.459×10^{-7}	0.534
$b \longrightarrow \Omega_{cbb}$	5.290×10^{-6}	0.562
$c \longrightarrow \Omega_{cbb}$	1.086×10^{-7}	0.482

Calculation of the cross sections (LHC)

Use the factorization procedure

$$\frac{d\sigma}{dp_T}[pp \to \Omega_{QQ'Q''}(p_T) + X] = \sum_{i,j} \int dx_1 dx_2 dz f_{i/p}(x_1, \mu) f_{j/p}(x_2, \mu) \{\hat{\sigma}[ij \to Q(p_T/z) + X, \mu] D_{Q \to \Omega_{QQ'Q''}}(z, \mu)\}$$

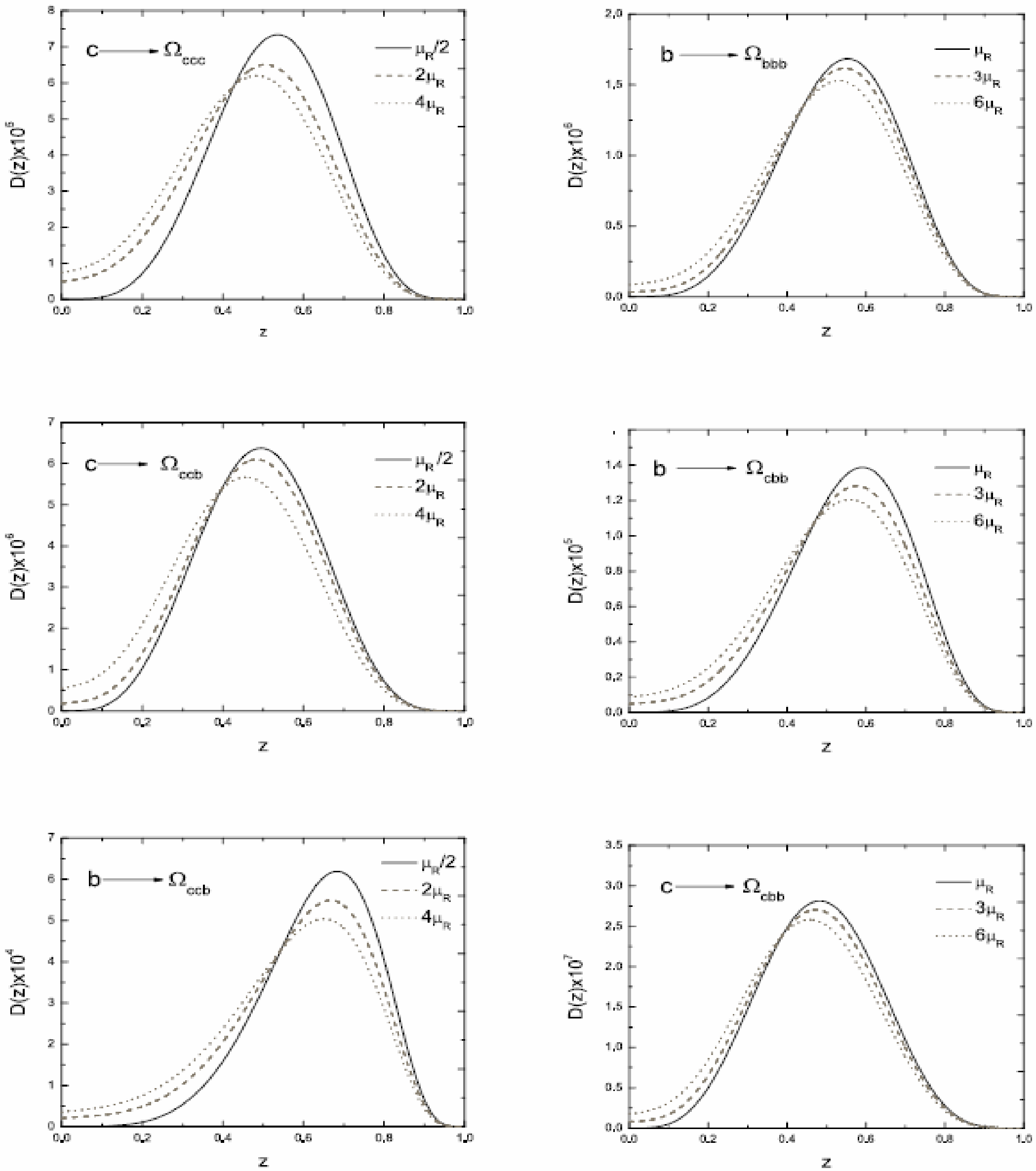
Need to evolve the fragmentation functions up to factorization scale using A.P. equation

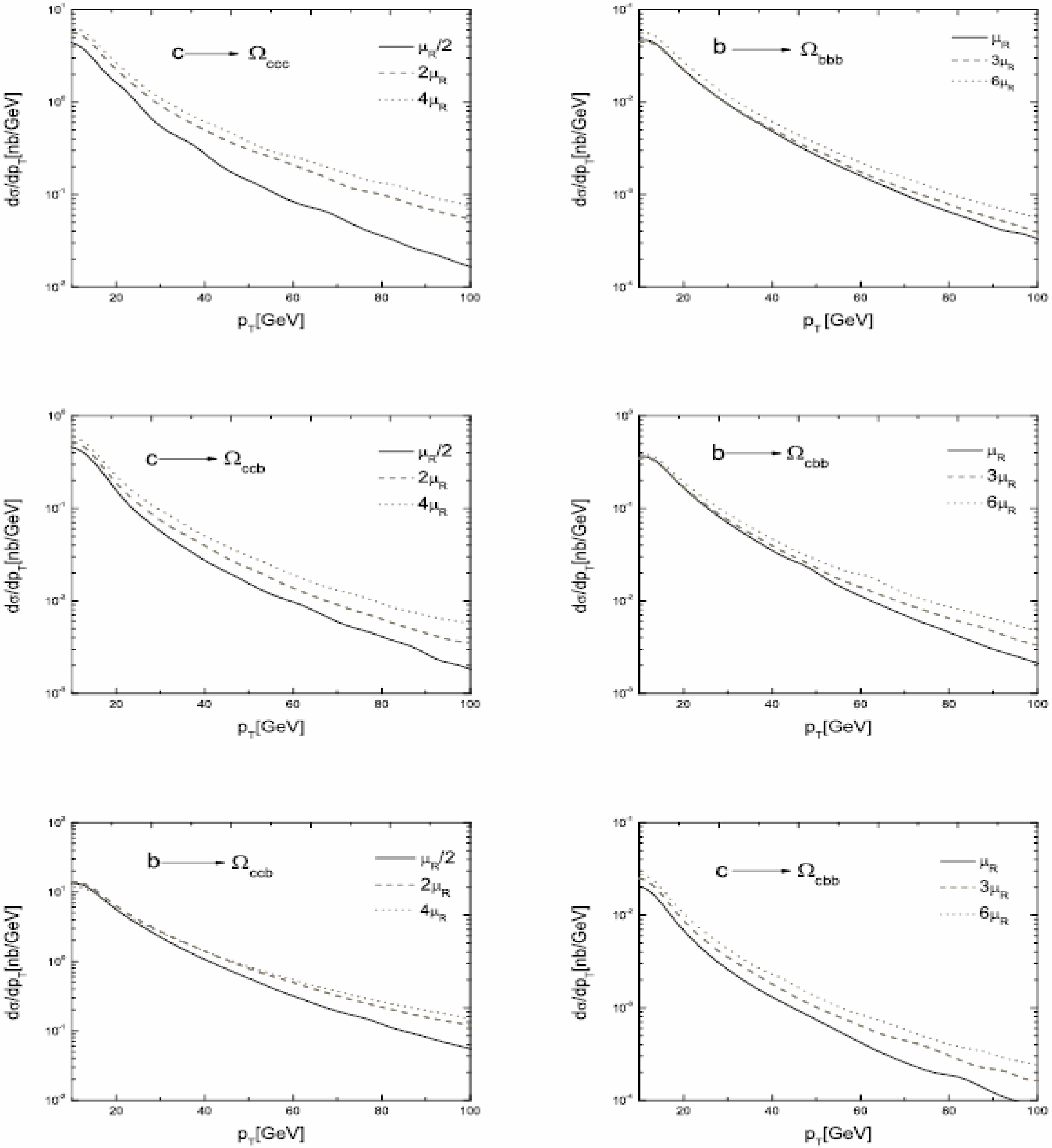
$$\mu \frac{\partial}{\partial \mu} D_{Q \to H}(z, \mu) = \int_z^1 \frac{dy}{y} P_{Q \to Q}(z/y, \mu) D_{Q \to H}(y, \mu)$$

$$\mu_\circ = m + M \qquad , \qquad \mu_R = \sqrt{(p_T^Q)^2 + m_Q^2}$$

$$P_{Q \to Q}(x = \frac{z}{y}, \mu) = \frac{4\alpha_s(\mu)}{3\pi} \left(\frac{1+x^2}{1-x}\right)_+$$

$$f_+(x) = f(x) - \delta(1-x)\int_0^1 f(x')dx'$$

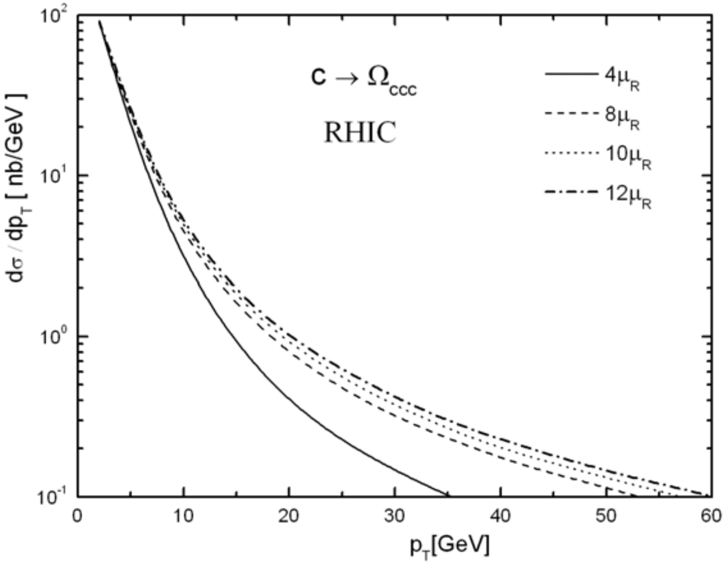

c → Ω_ccc
μ_R/2
2μ_R
4μ_R
D(z)x10^5
z
b → Ω_bbb
μ_R
3μ_R
6μ_R
D(z)x10^6
z
c → Ω_ccb
μ_R/2
2μ_R
4μ_R
D(z)x10^6
z
b → Ω_cbb
μ_R
3μ_R
6μ_R
D(z)x10^5
z
b → Ω_ccb
μ_R/2
2μ_R
4μ_R
D(z)x10^4
z
c → Ω_cbb
μ_R
3μ_R
6μ_R
D(z)x10^7
z



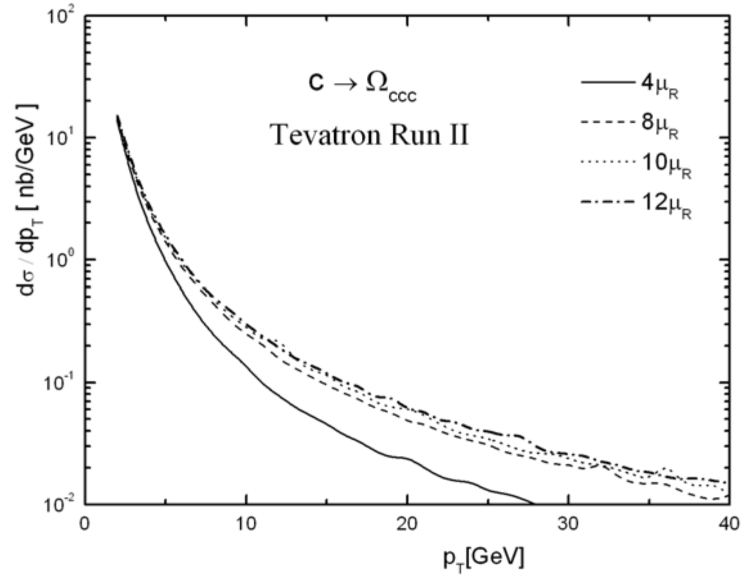
c → Ω_{ccc}
$\mu_R/2$
$2\mu_R$
$4\mu_R$
b → Ω_{bbb}
μ_R
$3\mu_R$
$6\mu_R$
c → Ω_{ccb}
$\mu_R/2$
$2\mu_R$
$4\mu_R$
b → Ω_{cbb}
μ_R
$3\mu_R$
$6\mu_R$
b → Ω_{ccb}
$\mu_R/2$
$2\mu_R$
$4\mu_R$
c → Ω_{cbb}
μ_R
$3\mu_R$
$6\mu_R$
$d\sigma/dp_T$[nb/GeV]
p_T[GeV]
20
40
60
80
100

The total cross sections for different states in various scales at CERN LHC.

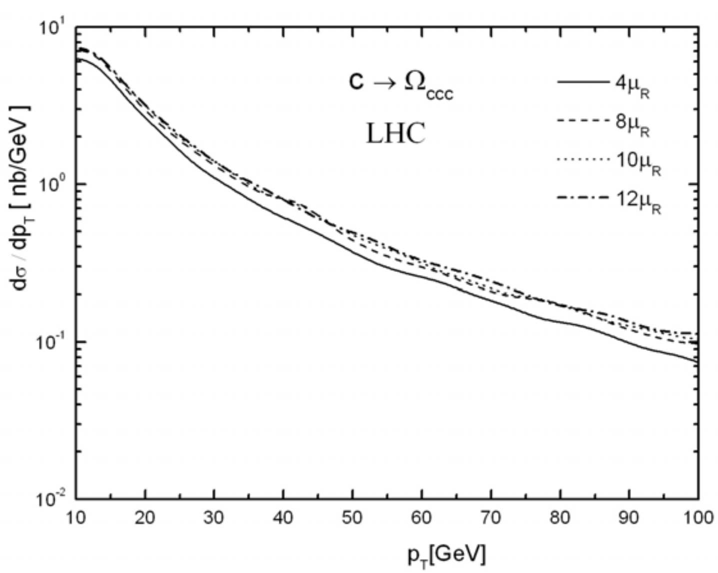
Process of Production	Cross Section [pb] $\mu_R/2$	μ_R	$2\mu_R$	$3\mu_R$	$4\mu_R$	$6\mu_R$	The Ratio $\sigma(Q \to \Omega)/\sigma(Q)$
$c \to \Omega_{ccc}$	301.88		306.99		307.59		1.20×10^{-7}
$c \to \Omega_{ccb}$	26.58		30.03		29.88		1.18×10^{-8}
$b \to \Omega_{ccb}$	2153.08		2155.31		1723.80		3.61×10^{-6}
$b \to \Omega_{bbb}$		6.34	6.38	5.77		8.40	1.36×10^{-8}
$b \to \Omega_{cbb}$		50.30	34.77	47.78		52.34	7.43×10^{-8}
$c \to \Omega_{cbb}$		1.14	1.38	1.47		1.49	5.41×10^{-10}



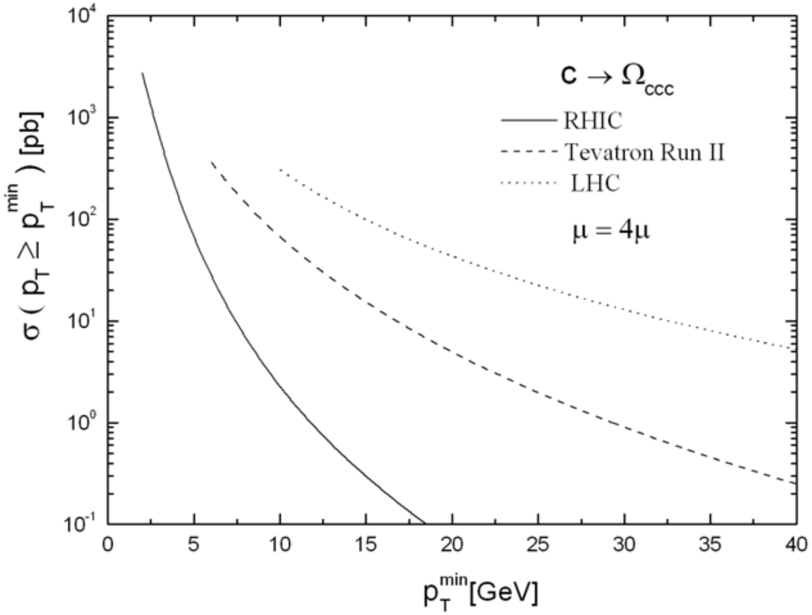
$c \to \Omega_{ccc}$
RHIC
$4\mu_R$
$8\mu_R$
$10\mu_R$
$12\mu_R$
$d\sigma / dp_T$ [nb/GeV]
p_T[GeV]



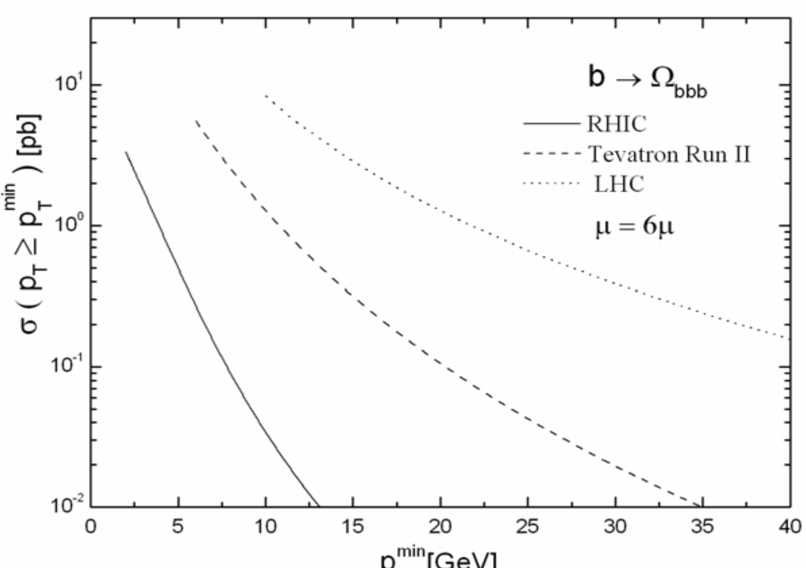
$c \to \Omega_{ccc}$
Tevatron Run II
$4\mu_R$
$8\mu_R$
$10\mu_R$
$12\mu_R$
$d\sigma / dp_T$ [nb/GeV]
p_T[GeV]



$c \to \Omega_{ccc}$
LHC
$4\mu_R$
$8\mu_R$
$10\mu_R$
$12\mu_R$
$d\sigma / dp_T$ [nb/GeV]
p_T[GeV]



$c \to \Omega_{ccc}$
RHIC
Tevatron Run II
LHC
$\mu = 4\mu$
$\sigma\ (\ p_T \geq p_T^{min}\ )$ [pb]
p_T^{min}[GeV]



$b \to \Omega_{bbb}$
RHIC
Tevatron Run II
LHC
$\mu = 6\mu$
$\sigma\ (\ p_T \geq p_T^{min}\ )$ [pb]
p_T^{min}[GeV]

The total cross section in pb for Ω_{ccc} and Ω_{ccc} baryons at different hadron colliders. The accepance cuts are introduced in Table 1.

	RHIC	Tevatron Run II	CERN LHC
$c \to \Omega_{ccc}\ (4\mu_R)$	2758.26	382.938	307.598
$b \to \Omega_{bbb}\ (6\mu_R)$	3.3499	5.91677	8.40254

References:

- M.A. Gomshi Nobary and R. Sepahvand, Phys. Rev. D 71, 043024 (2005), hep-ph/0406148.
- M.A. Gomshi Nobary and R. Sepahvand, Nucl. Phys. B 741, 34 (2006), hep-ph/0508115.