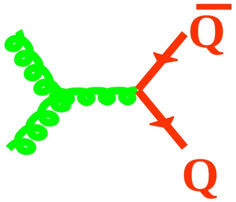
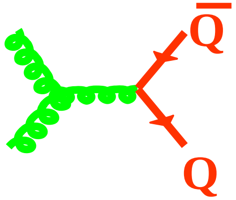


Heavy Quark Monte Carlo generation in ALICE

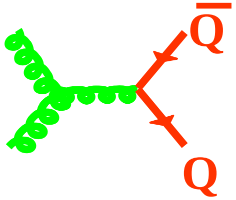
Andrea Dainese - University of Padova

Nicola Carrer - CERN



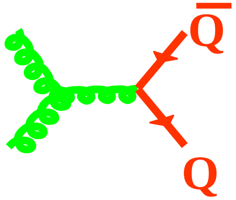
Outline

- Which baseline for ALICE HVQ simulations?
- Charm and Beauty cross sections at NLO
  - Extrapolation to Pb-Pb
- HVQ in PYTHIA: comparison with NLO & tuning
  - Pb-Pb & pp
  - Fragmentation model
- HVQ in HERWIG
- A PDF feature: limited extension at low x
- Conclusions



Which baseline?

- **pQCD** to describe **HVQ production in nucleon-nucleon** collisions
- Include in the baseline only well established nuclear effects
  - Nuclear shadowing
  - Intrinsic k_t
- Keep into account ALICE acceptance
  - **Sensitivity to low p_t !**

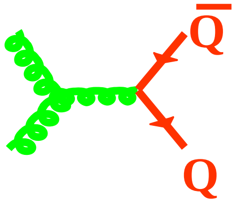


NLO pQCD *(Mangano-Nason-Ridolfi)*

- Exact at NLO
- Does not diverge as $p_t \rightarrow 0$
- Large dependence on choice of scale (especially at low p_t)
- Not an event generator

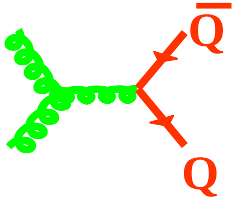
Parton shower models *(PYTHIA, HERWIG)*

- Not exact at NLO
  - Take into account multiple gluon radiation
- Divergences at $p_t \rightarrow 0$
- Implemented as event generators
- Many parameters



Baseline definition

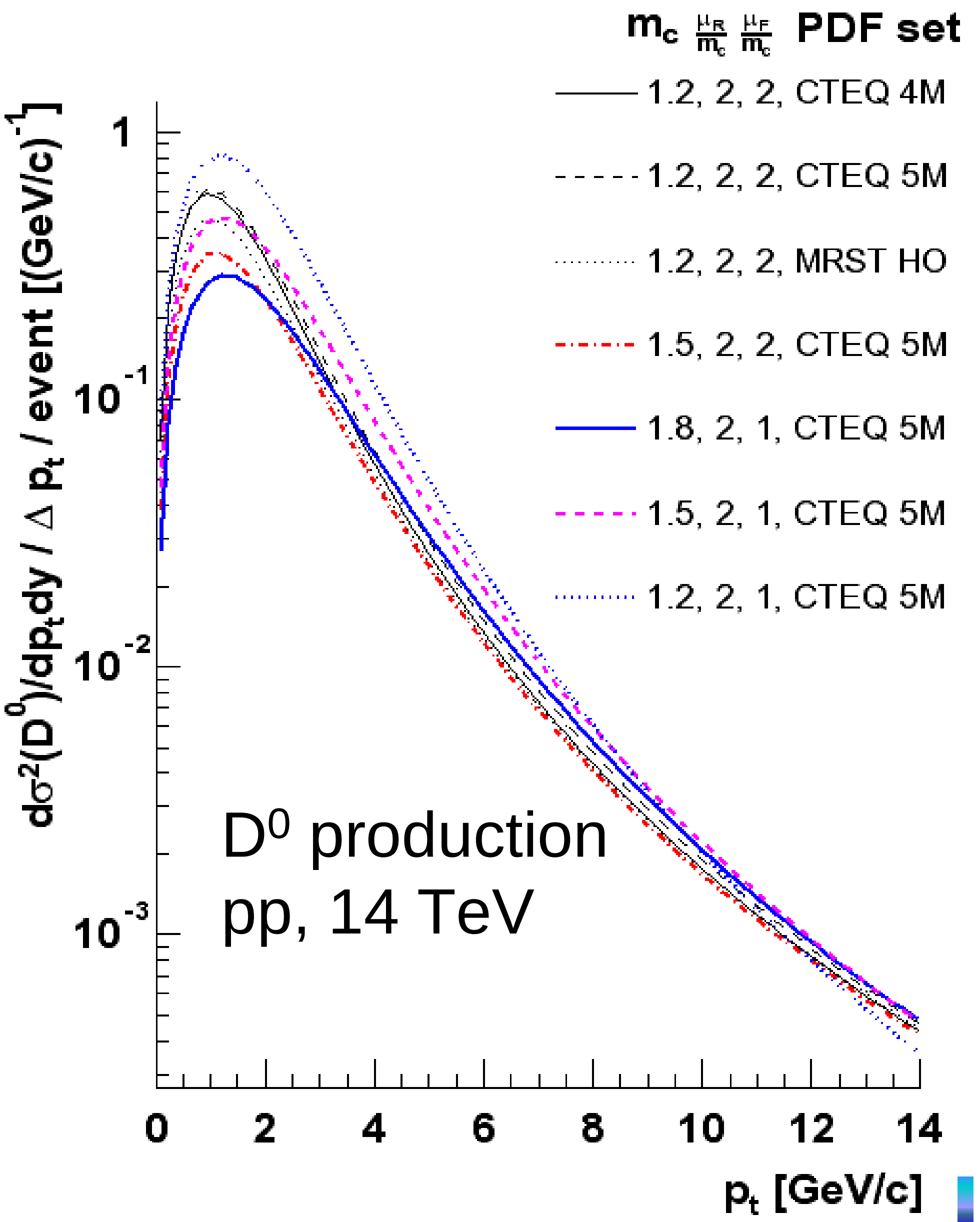
- **Reference rates and spectra from NLO calculation**
  - “reasonable” values for masses and scales
  - average of results with different PDF sets
  - EKS98 for shadowing effect
  - “reasonable” values for intrinsic k_t broadening
  - extrapolation to pA and AA using Glauber model
- Event generation using PS generator (PYTHIA) **tuned to match NLO pQCD results for Q single-inclusive p_t distributions**



Cross sections at NLO in NN

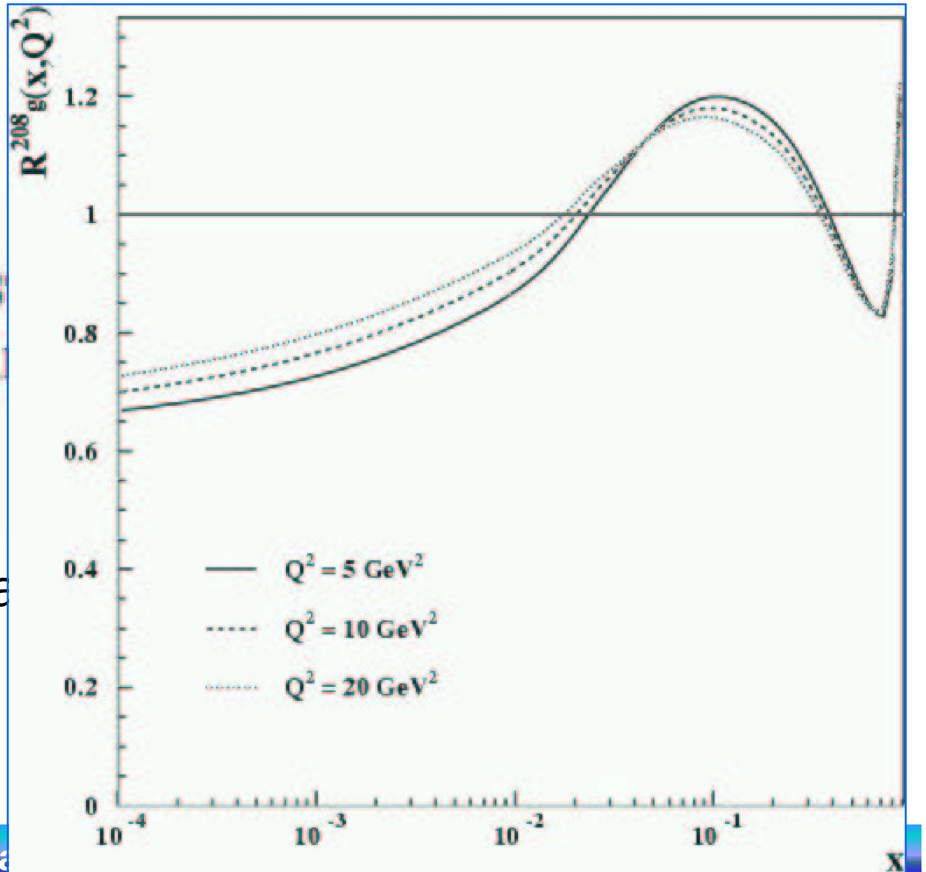
- Theoretical error from scan
  large uncertainty (f
  of masses and sca

parameters		5.5 TeV	14 TeV
$\sigma_{pp}^{c\bar{c}}[mb]$	$m_c = 1.5$ GeV $\mu_R = m_c$ $\mu_F = 2m_c$	8.0	15.2
	$m_c = 1.2$ GeV $\mu_R = m_c$ $\mu_F = 2m_c$	14.9	26.7
	$m_c = 1.8$ GeV $\mu_R = m_c$ $\mu_F = 2m_c$	4.7	9.4
	$m_c = 1.5$ GeV $\mu_R = 2m_c$ $\mu_F = 2m_c$	4.0	7.4
$\sigma_{pp}^{b\bar{b}}[mb]$	$m_b = 4.75$ GeV $\mu_R = m_b$ $\mu_F = m_b$	0.20	0.48
	$m_b = 4.5$ GeV $\mu_R = m_b$ $\mu_F = m_b$	0.23	0.56
	$m_b = 5$ GeV $\mu_R = m_b$ $\mu_F = m_b$	0.17	0.42
	$m_b = 4.75$ GeV $\mu_R = 0.5m_b$ $\mu_F = 2m_b$	0.34	0.90
	$m_b = 4.75$ GeV $\mu_R = 2m_b$ $\mu_F = 0.5m_b$	0.082	0.17



Nuclear effects

- Shadowing (EKS98):
  - AA: reduction of 35% for charm and 20% for beauty
  - pA: reduction of 80% for charm and 10% for beauty
  - effect **localized in p_t < 4-5 GeV/c**



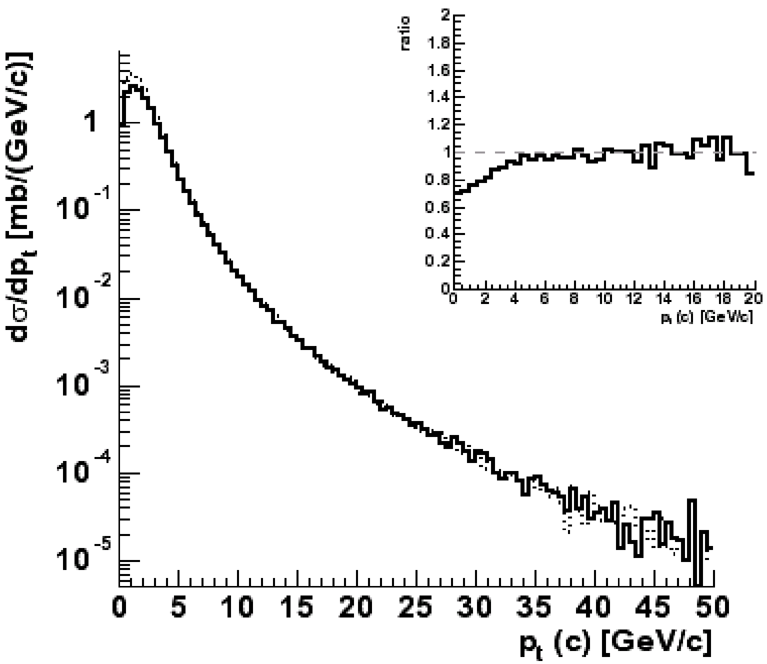
- Intrinsic k_T (from R. Vogt):

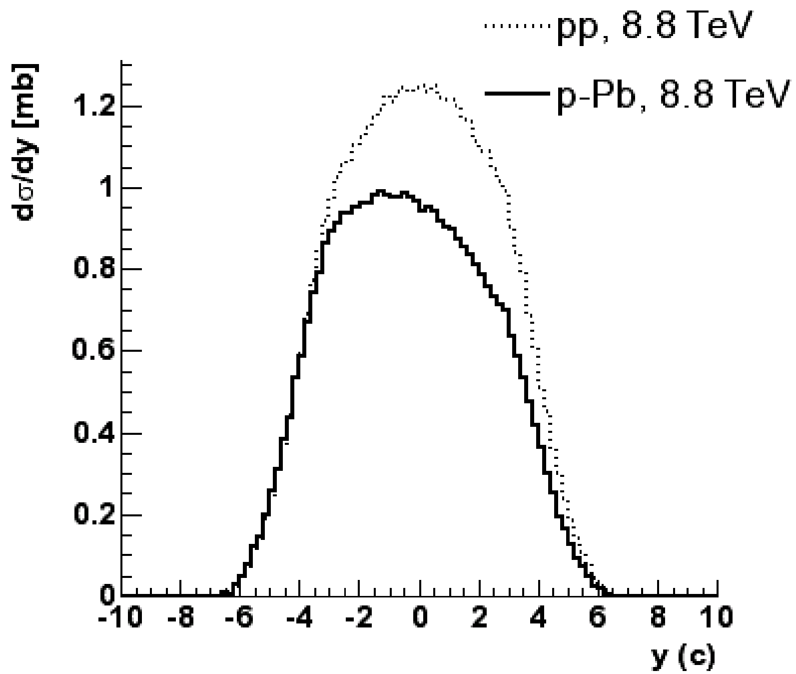
Intrinsic p_t	
from gaussian distr. with mean 0	MS
sigma [GeV/c]	PA

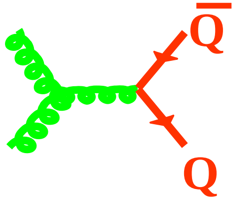
  - large effect on Δφ Q-Qbar (see la

HVQ Yields and Spectra

	Charm			Beauty		
system	pp	p–Pb	Pb–Pb	pp	p–Pb	Pb–Pb
centrality	min.-bias	min.-bias	centr. (5%)	min.-bias	min.-bias	centr. (5%)
$\sqrt{s_{NN}}$	14 TeV	8.8 TeV	5.5 TeV	14 TeV	8.8 TeV	5.5 TeV
$N^{Q\overline{Q}}$/ev	0.16	0.78	115	0.0072	0.029	4.56
$C_{\rm shad}$	1	0.80	0.65	1	0.90	0.84



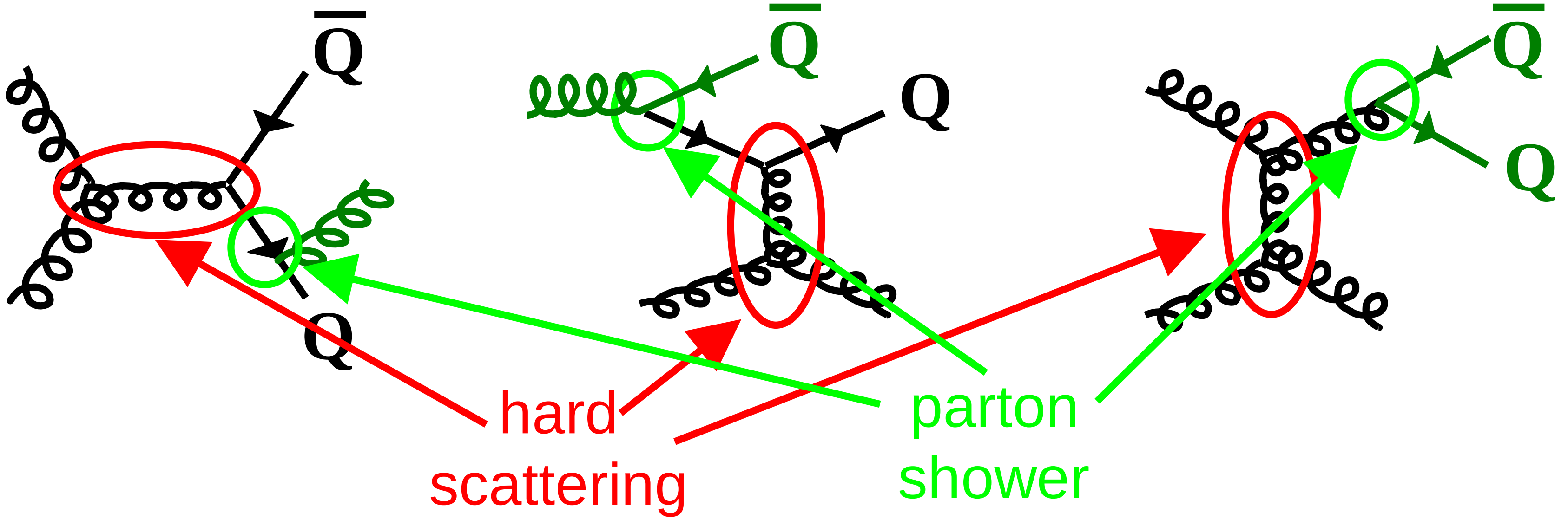




Heavy Quarks in Parton Shower Event Generators: PYTHIA HERWIG

Classification of the processes

Pair Creation (PC) **Flavour Excitation (FE)** **Gluon Splitting (GS)**



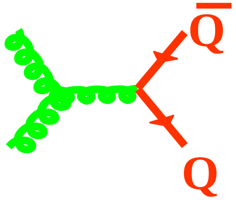
- Hard scattering: LO graph
- Processes classified w.r.t. # HVQs in hard scattering final state
- No double counting because hard scattering is the process with largest virtuality

Tuning of PYTHIA parameters

- Comparison at the bare quark level

<u>Heavy Quarks in PYTHIA:</u>

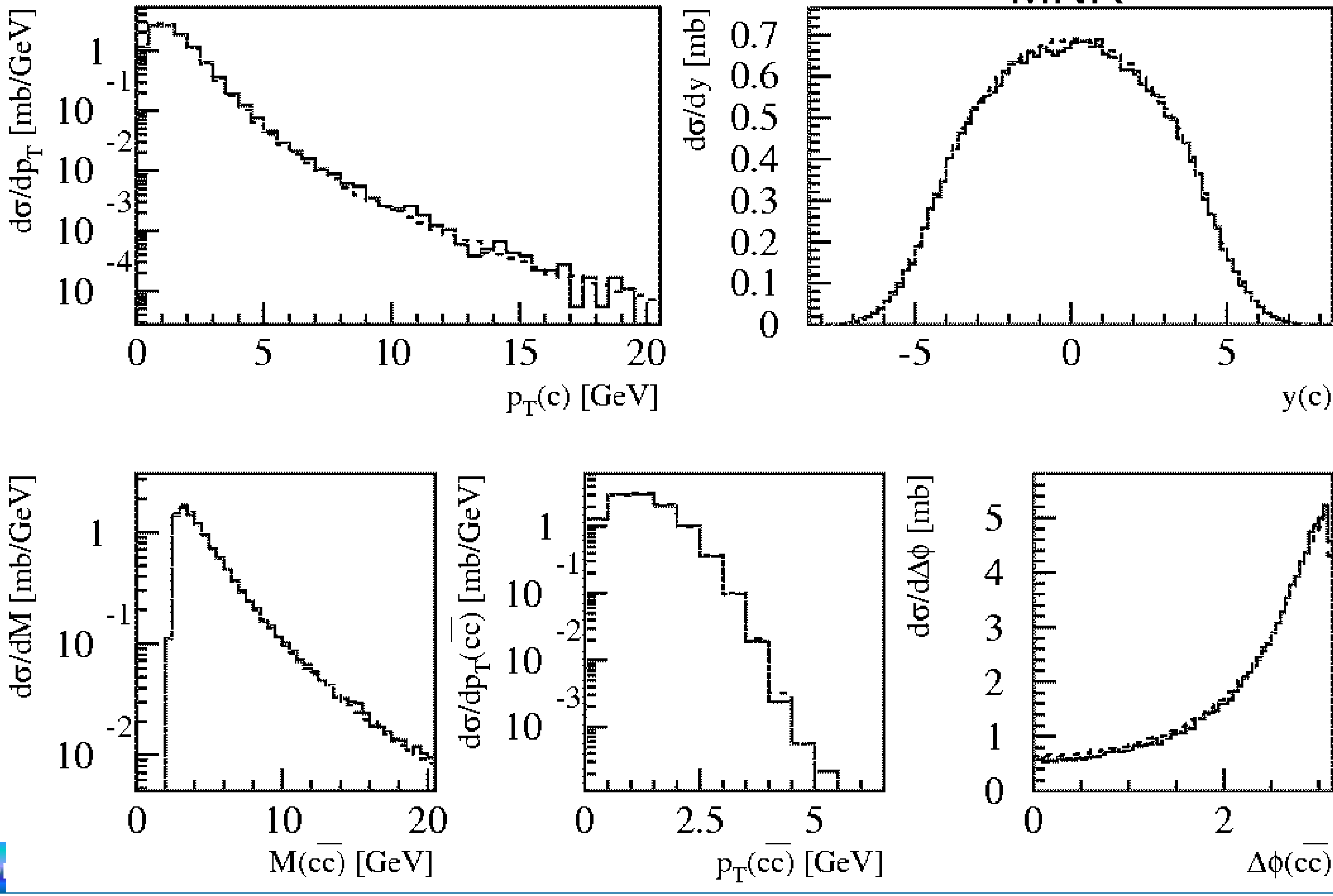
- MSEL = 4/5 $\longrightarrow$ <u>Leading Order</u> processes
  - settings corresponding to MNR
  - good agreement with MNR LO
- MSEL = 1 $\longrightarrow$ initial and final state <u>Parton Shower</u> processes describe contributions above LO
  - agreement with MNR NLO less good
  - parton shower processes $\neq$ NLO processes
  - massless Matrix Elements! cross section diverges at $p_t^{hard} \longrightarrow 0$
  - Tuning of parameters less "physics inspired"
  - Main parameter tuned: min. p_t^{hard} (2.1 GeV/c for c, 2.75 GeV/c for b)

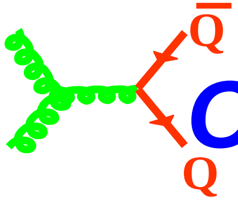


MNR vs. PYTHIA: LO

$$gg \to c\bar{c}$$

—— PYTHIA
- - - - MNR



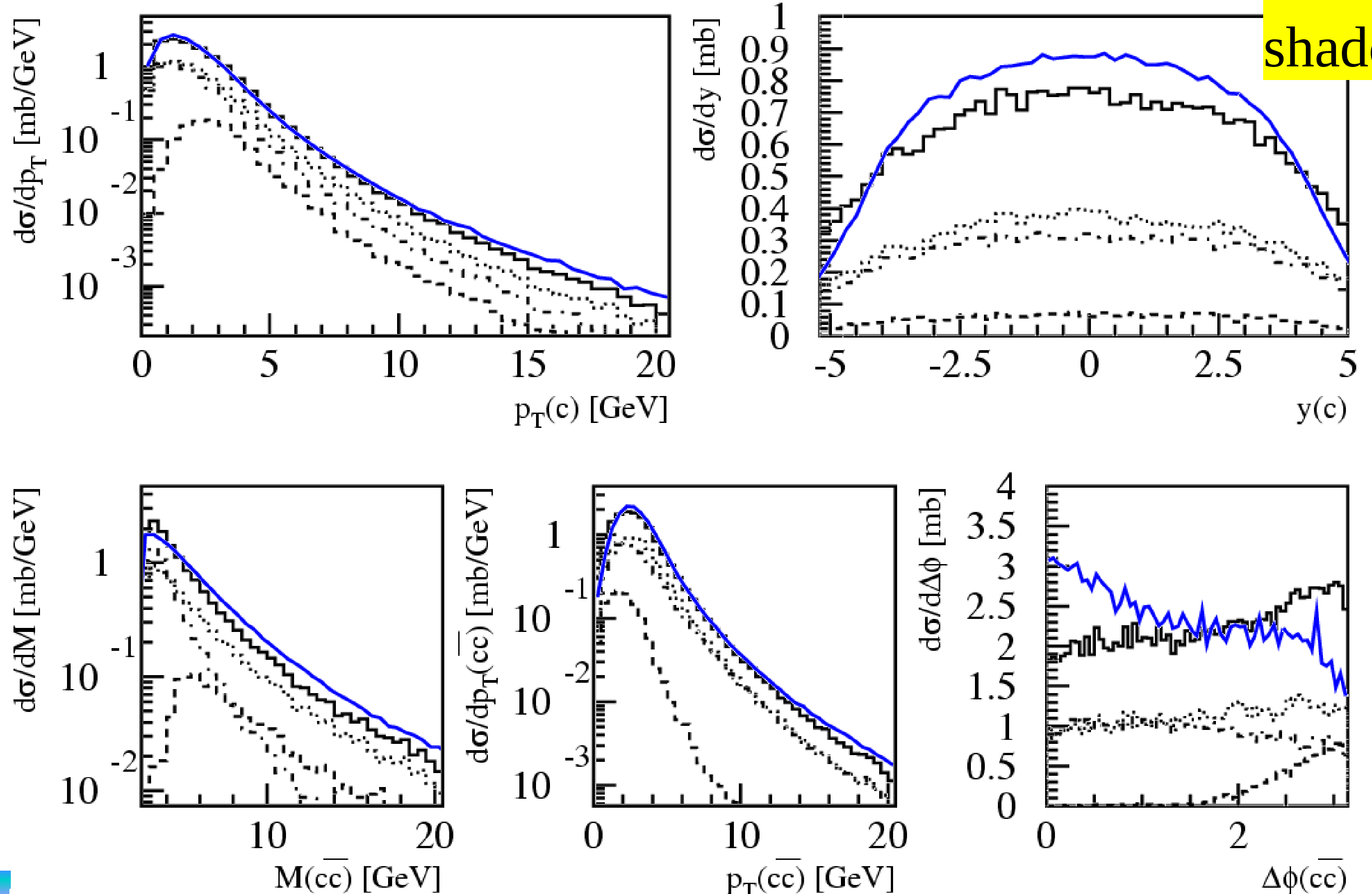


Charm NLO: (Pb-Pb)/N_{coll} 5.5 TeV

MNR —— Pythia

- - - - pair creation
.... flavour excitation
-·-·-· gluon splitting
—— TOTAL

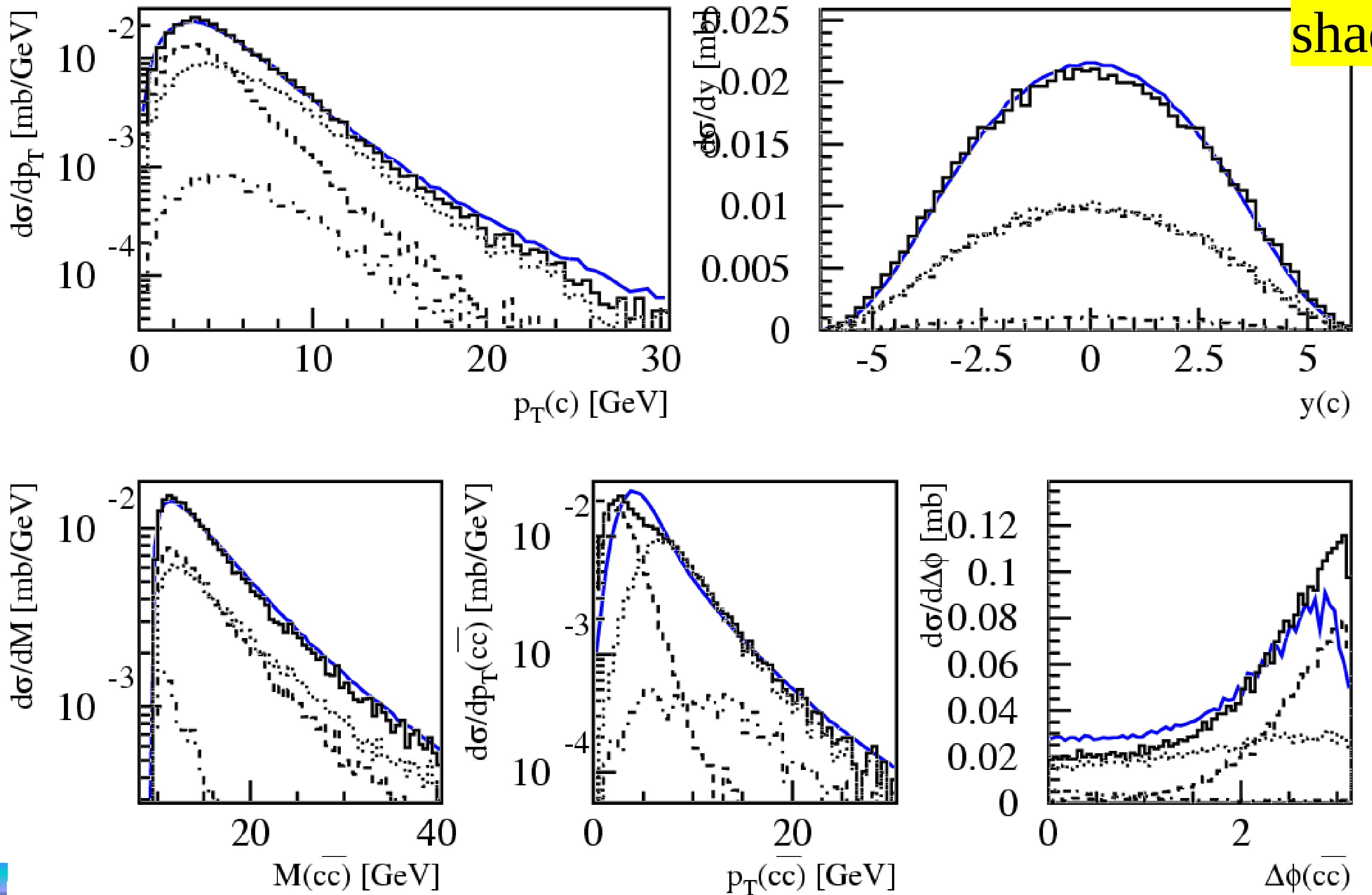
Include shadowing

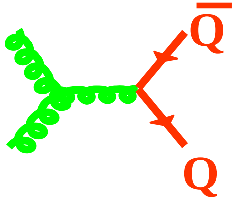


Beauty NLO: (Pb-Pb)/N_{coll} 5.5 TeV

MNR —— Pythia
- - - pair creation
.... flavour excitation
-·-·- gluon splitting
—— TOTAL

Include shadowing

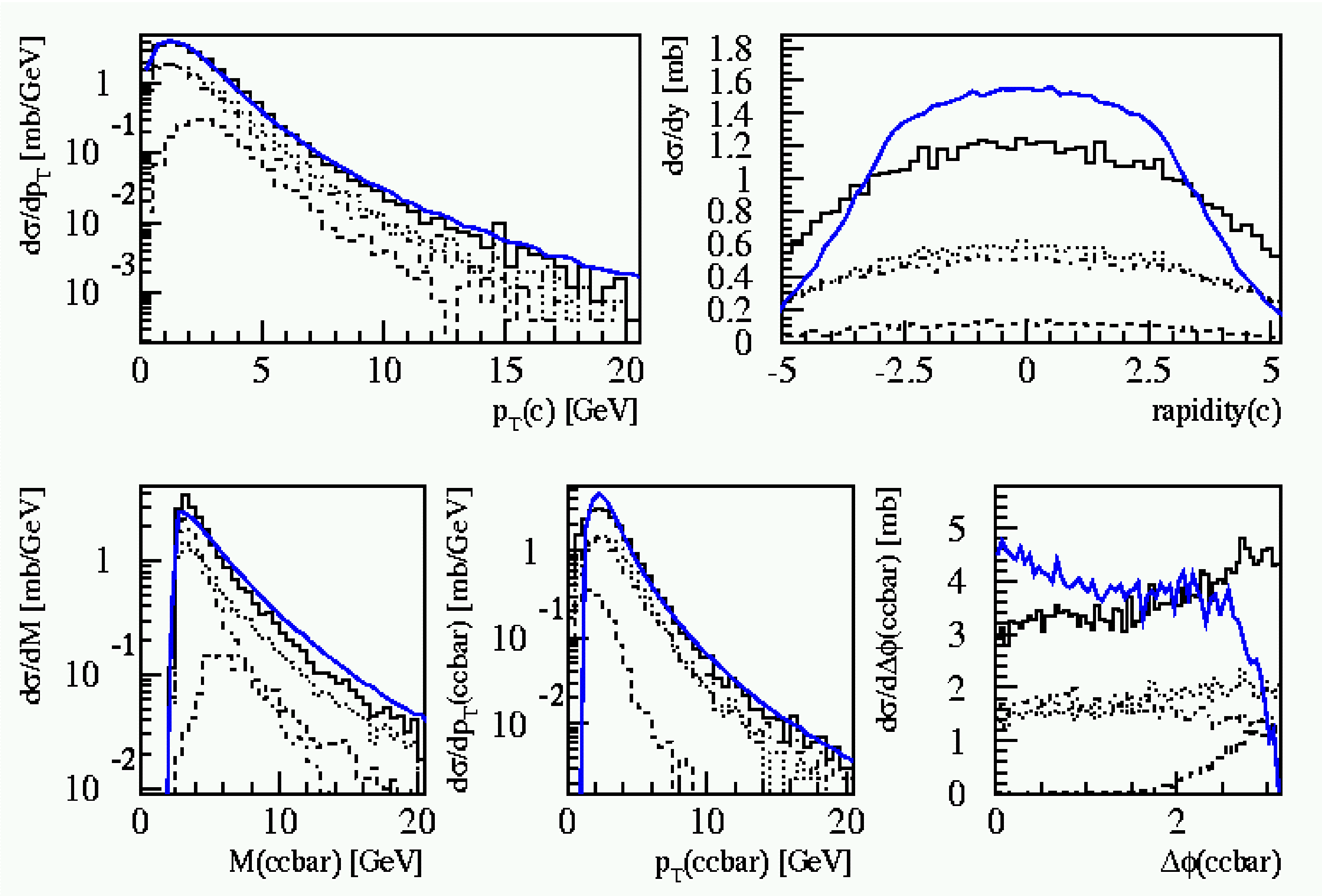


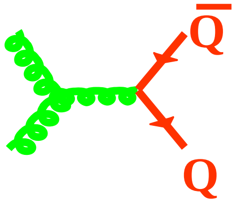


Charm NLO: pp 14 TeV

MNR —— Pythia

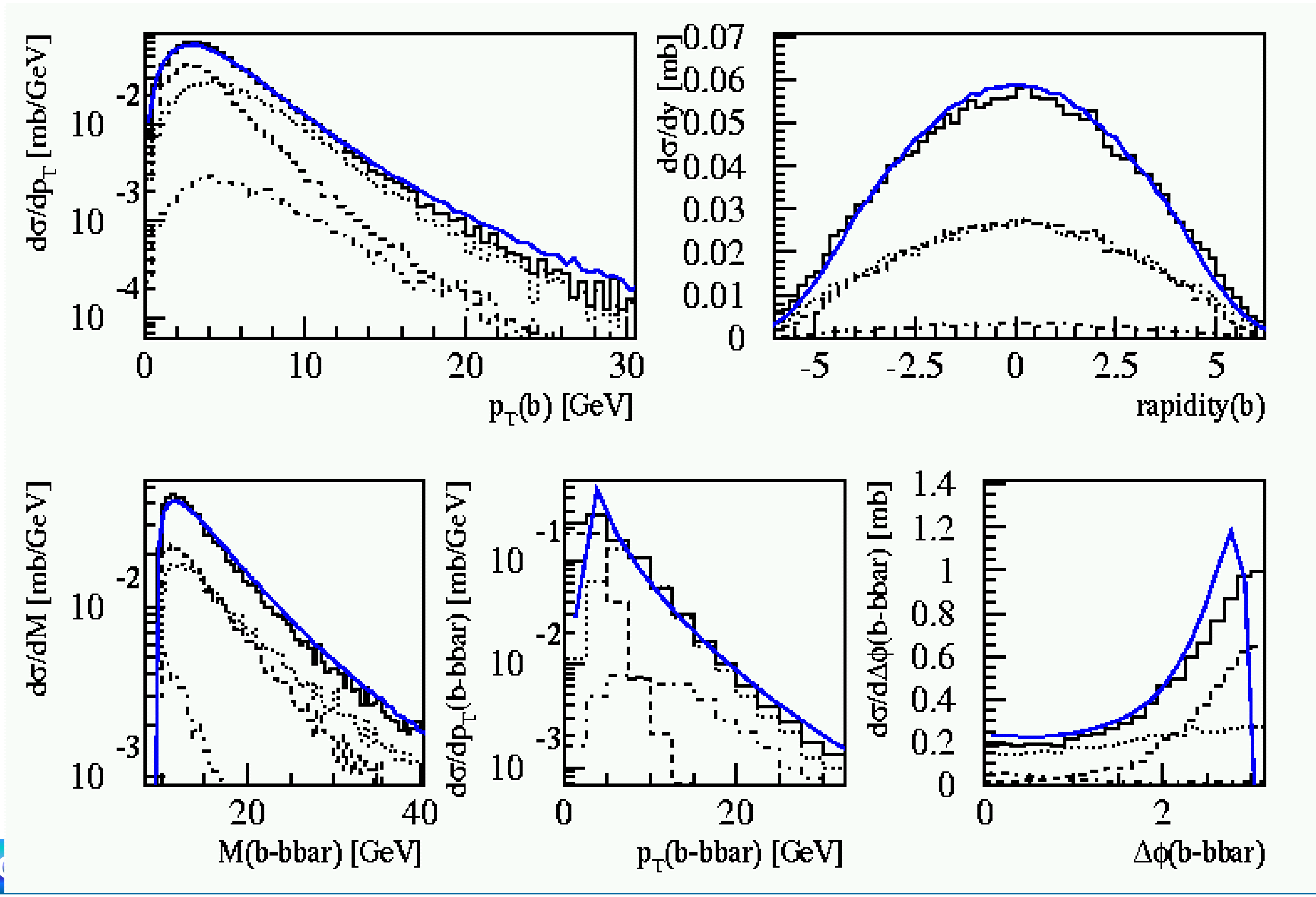
- - - - pair creation
.... flavour excitation
-·-·-· gluon splitting
—— TOTAL





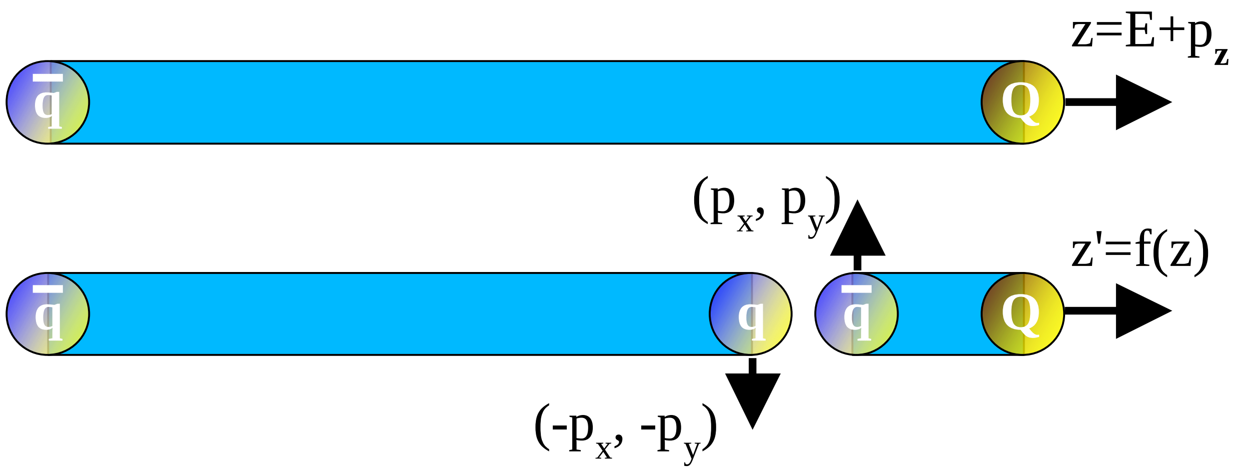
Beauty NLO: pp 14 TeV

MNR ——— Pythia
- pair creation
- flavour excitation
- gluon splitting
- TOTAL



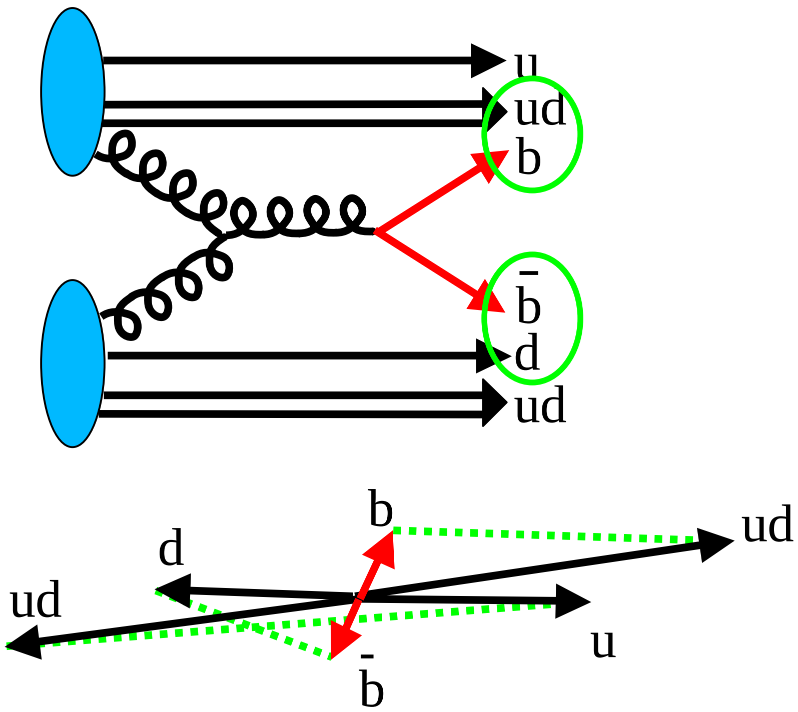
Fragmentation in PYTHIA

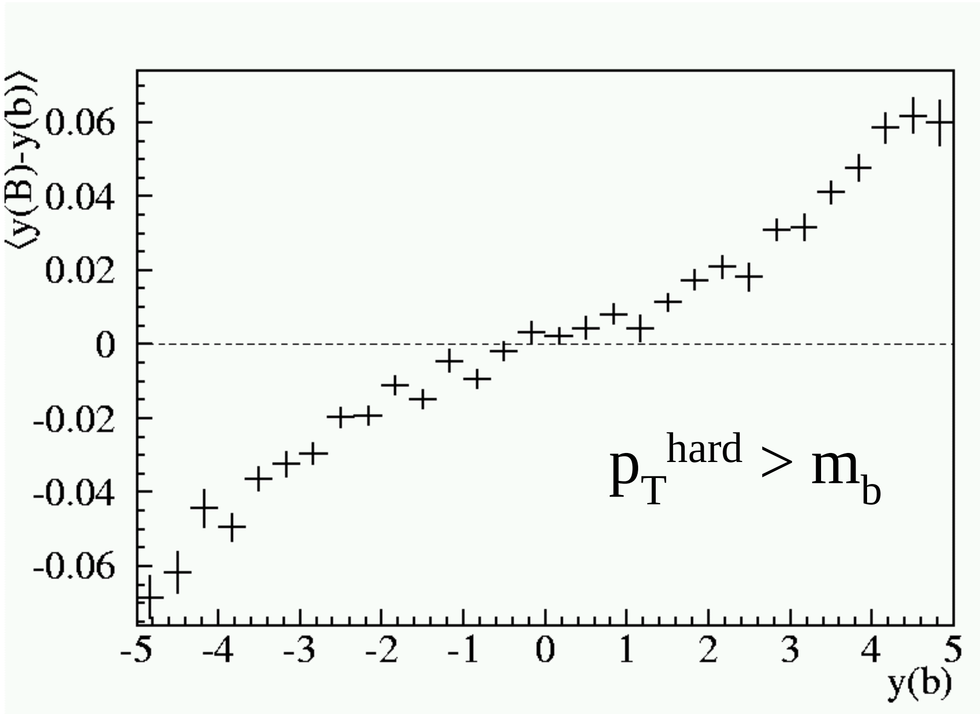
- Use default parameters
- Lund string fragmentation model
  - longitudinal fragmentation:
    - Lund symmetric fragmentation function
    - Modified to account for harder spectra in HVQ fragmentation
  - transverse momentum pick-up
    - $\sigma(p_x) = \sigma(p_y) = 230$ MeV/c

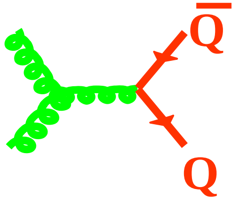


Beam-drag effect

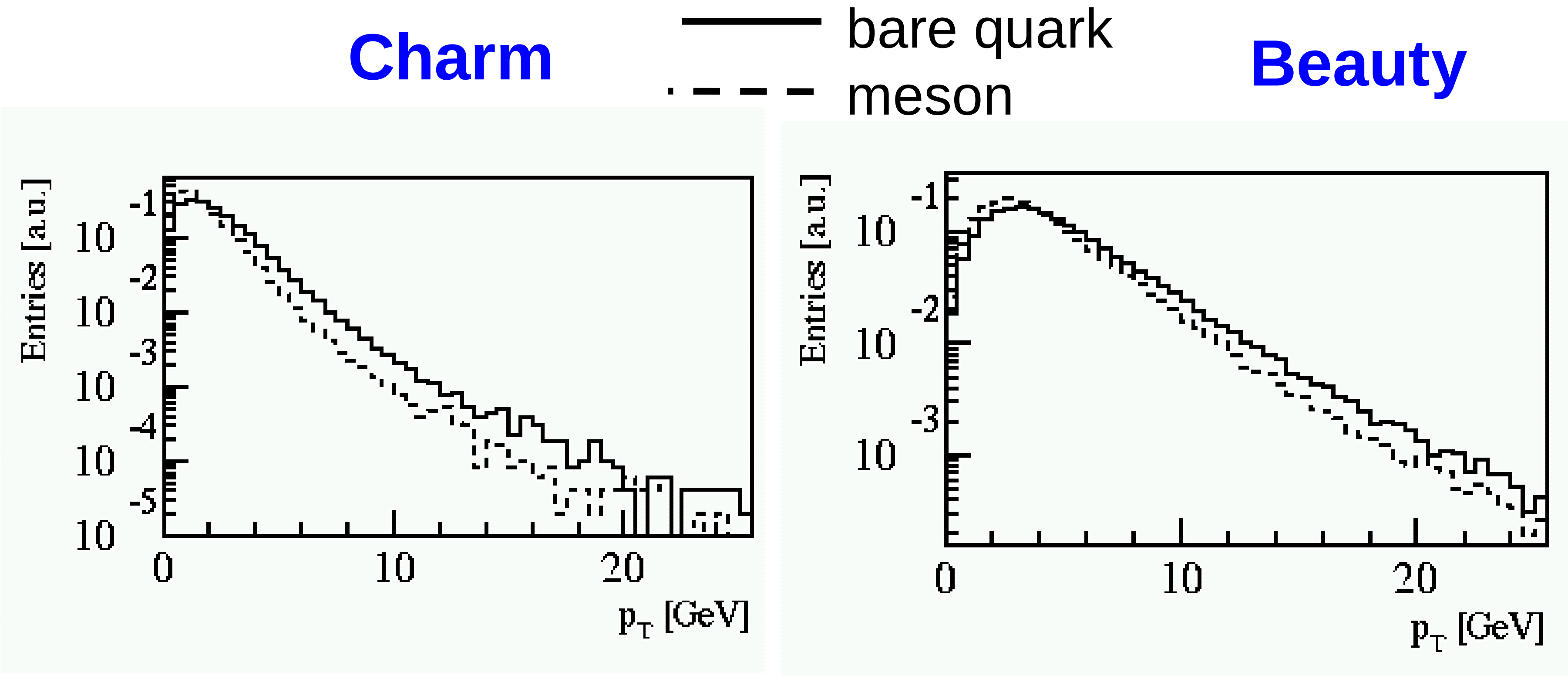
- Simple LO graph, no shower







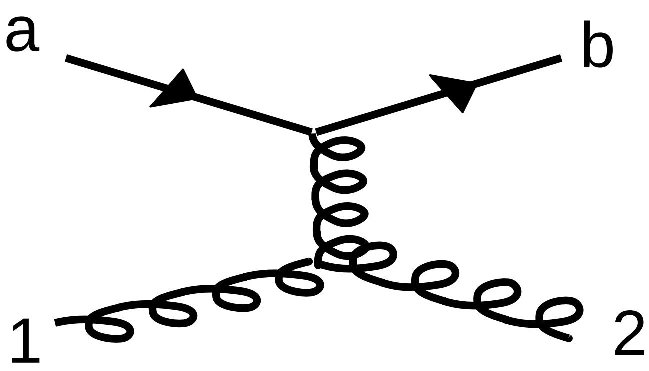
Effect of fragm. on spectra

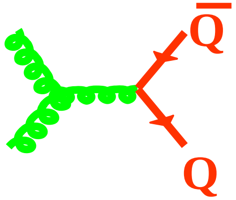


- Average p_t-reduction:
  - 25% for charm
  - 15% for beauty

Heavy Quarks in HERWIG

- As in PYTHIA: pair creation, flavour excitation, gluon splitting
- Pair creation AND flavour excitation use massive Matrix Element
- Kinematis for FE as if PC:
  - $1 + 2 \rightarrow a + b$ $\qquad m_1 = m_2 = 0, \quad m_a = m_b = m_Q$

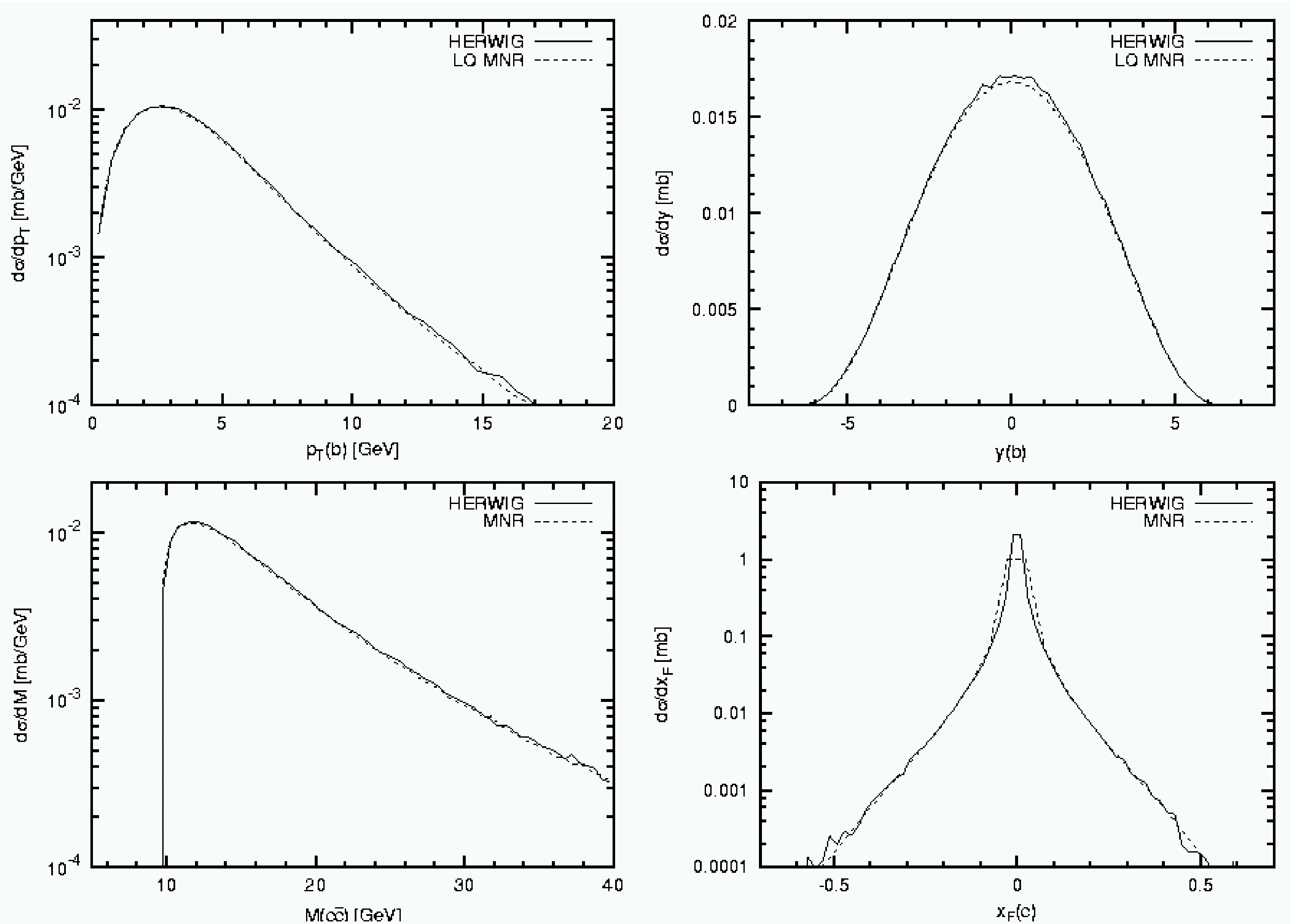


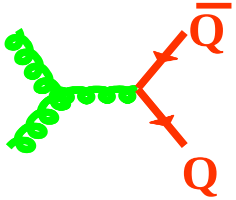


MNR vs. HERWIG: LO

$$gg \to b\bar{b}$$

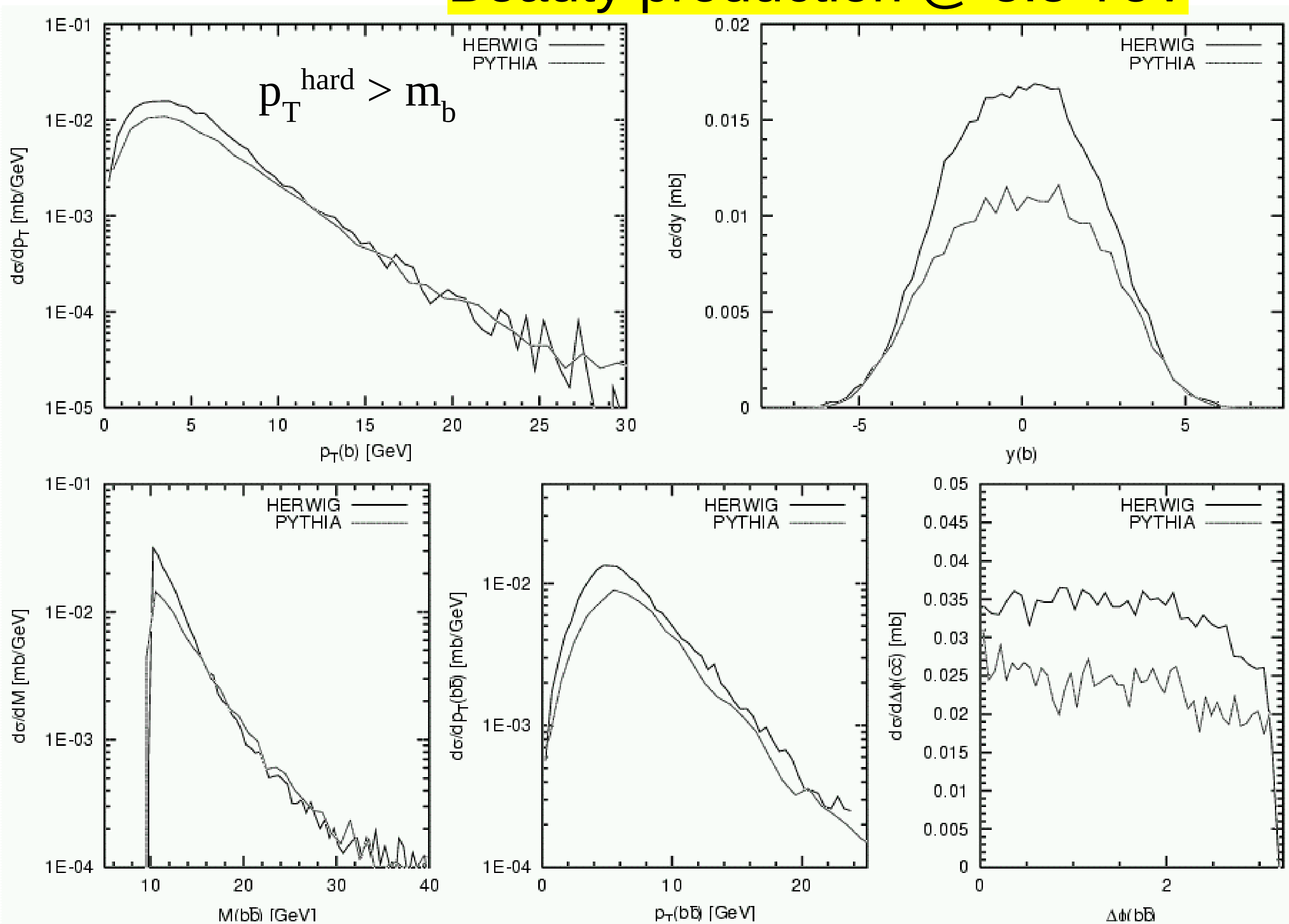
—— HERWIG
- - - - MNR



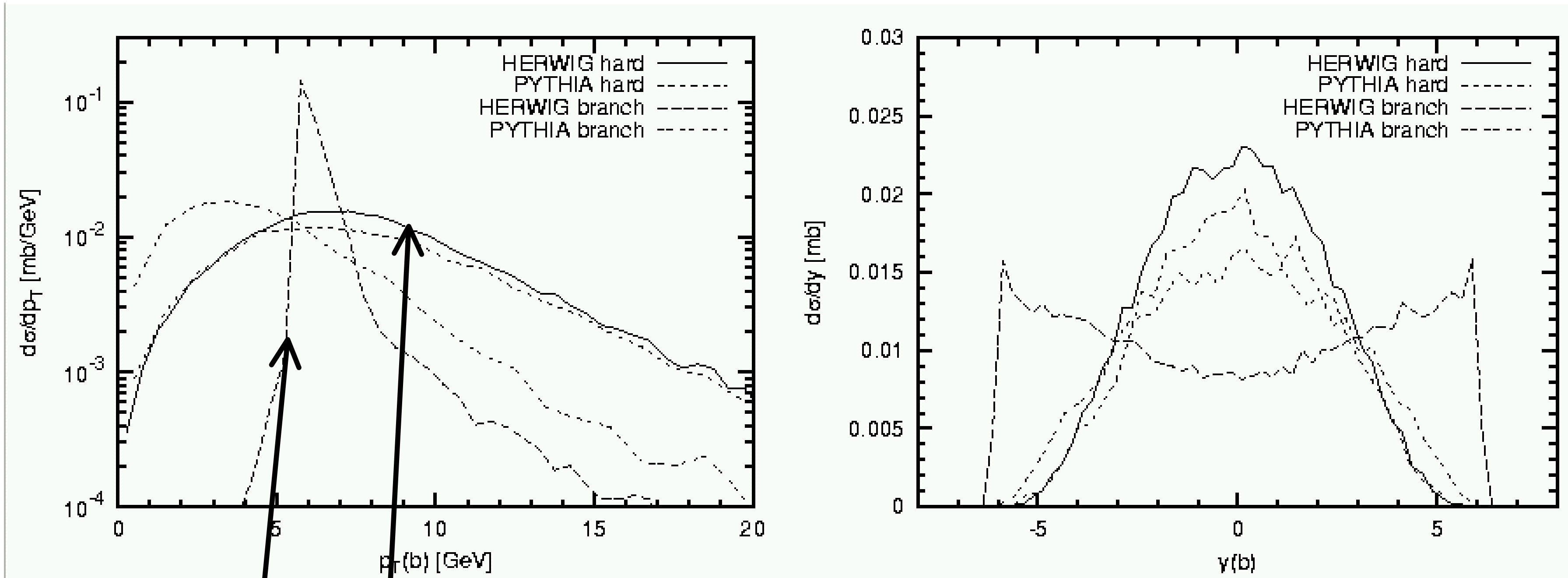


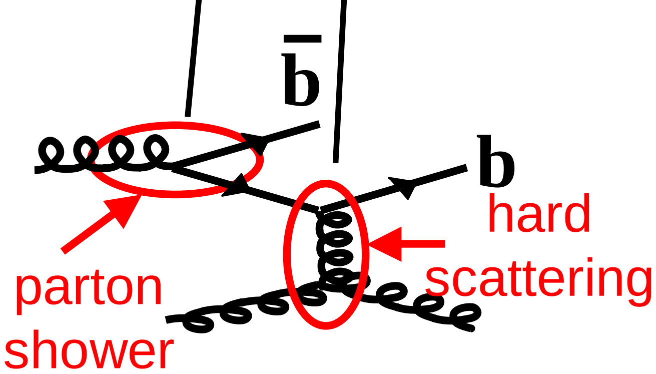
GS: HERWIG vs. PYTHIA

Beauty production @ 5.5 TeV



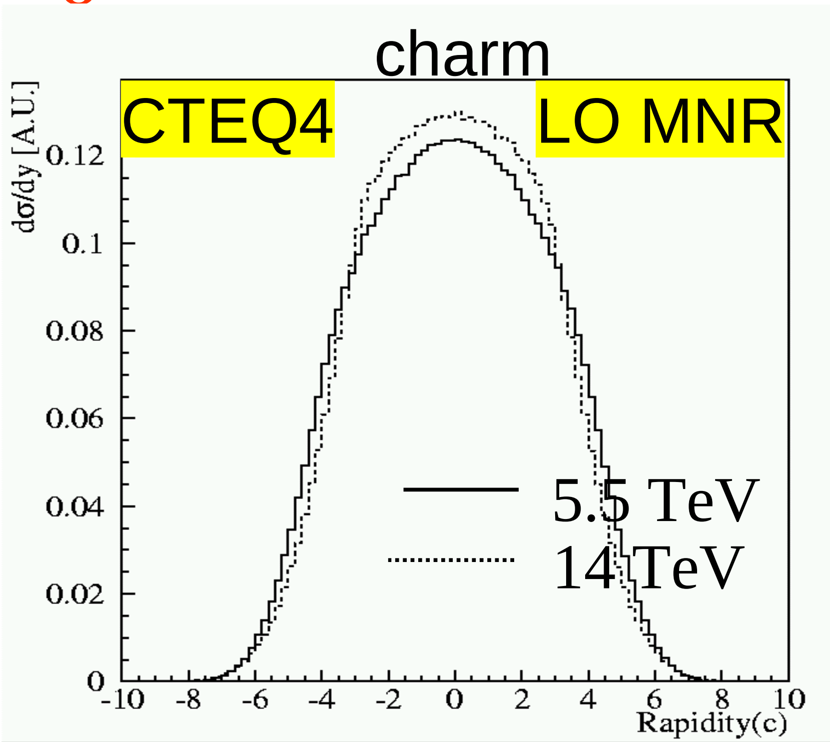
FE in HERWIG

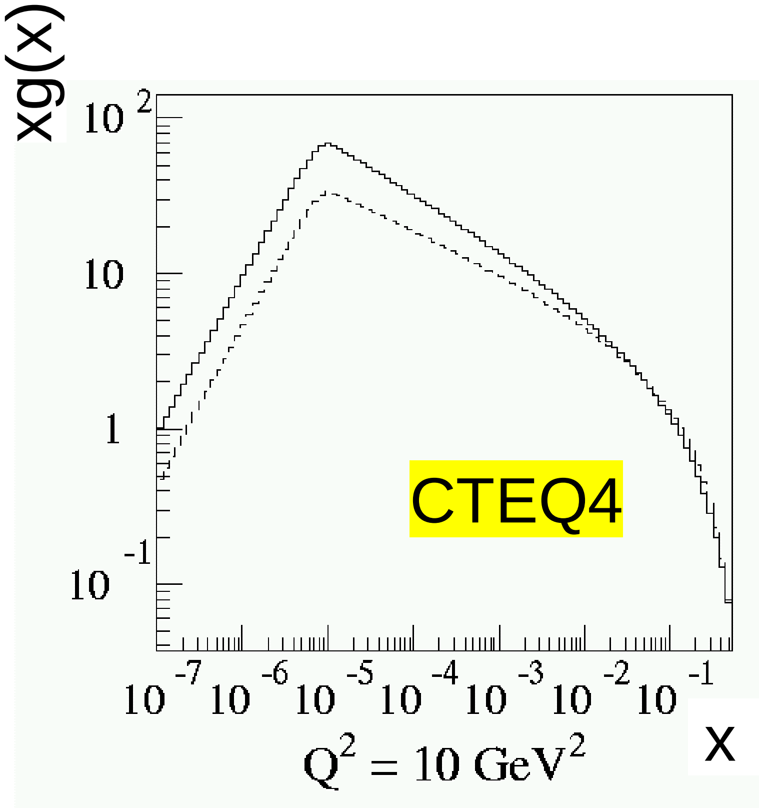




- FE contribution from Herwig is wrong
  - Contribution from PS branching peaked at m_Q

PDF feature (I)





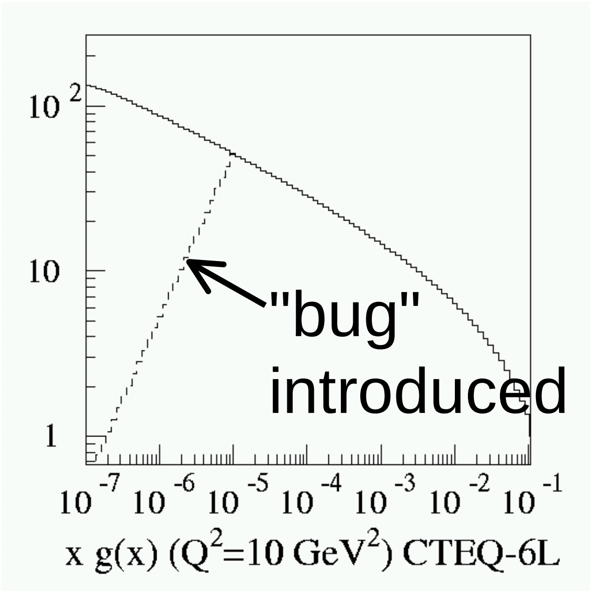
- Rapidity spectrum narrows 5.5→14TeV
- Reason: CTEQ4, CTEQ5, MRST, ...
  - valid x > 10^{-5}, discontinuous behaviour below

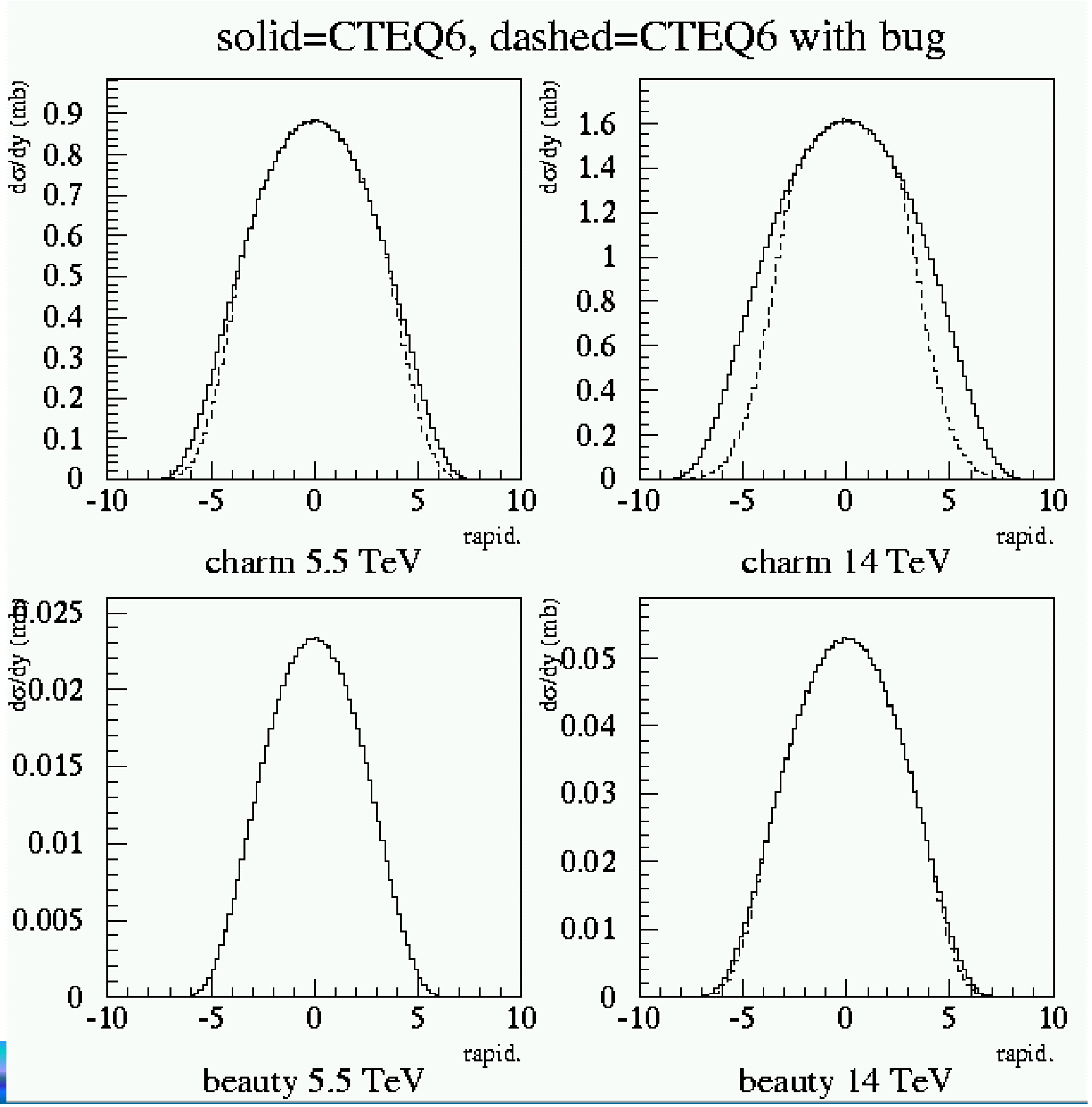
$$\sqrt{s} = 5.5\,\mathrm{TeV},\ y_{c\bar{c}} > 4.3 \quad \rightarrow \quad x_1 < 10^{-5}, x_2 > 0.053$$

$$\sqrt{s} = 14\,\mathrm{TeV},\ y_{c\bar{c}} > 3.4 \quad \rightarrow \quad x_1 < 10^{-5}, x_2 > 0.0082$$

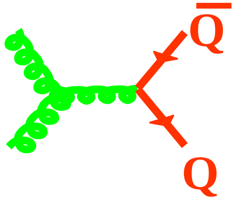
PDF feature (II)

- CTEQ6: calculated $x > 10^{-6}$, extrapolated below





- Effect relevant only for charm @ 14 TeV $|y| > 3.5$



Conclusions

- **Baseline for ALICE HVQ simulations:**
  - **rates from NLO calculations (MNR)**
  - **generation with PYTHIA, tuned to reproduce p_t spectra given by NLO pQCD**
- Determined parameters for generation with PYTHIA (Pb-Pb, p-Pb & pp)
- (PYTHIA) Fragmentation only affects p_t spectra
- HERWIG gives wrong results for flavour excitation