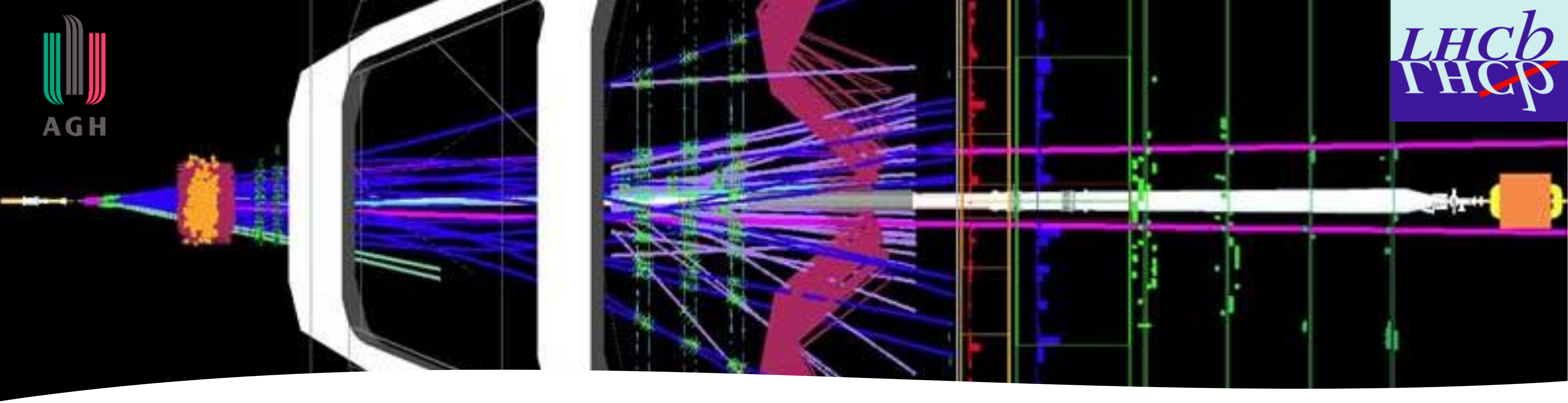


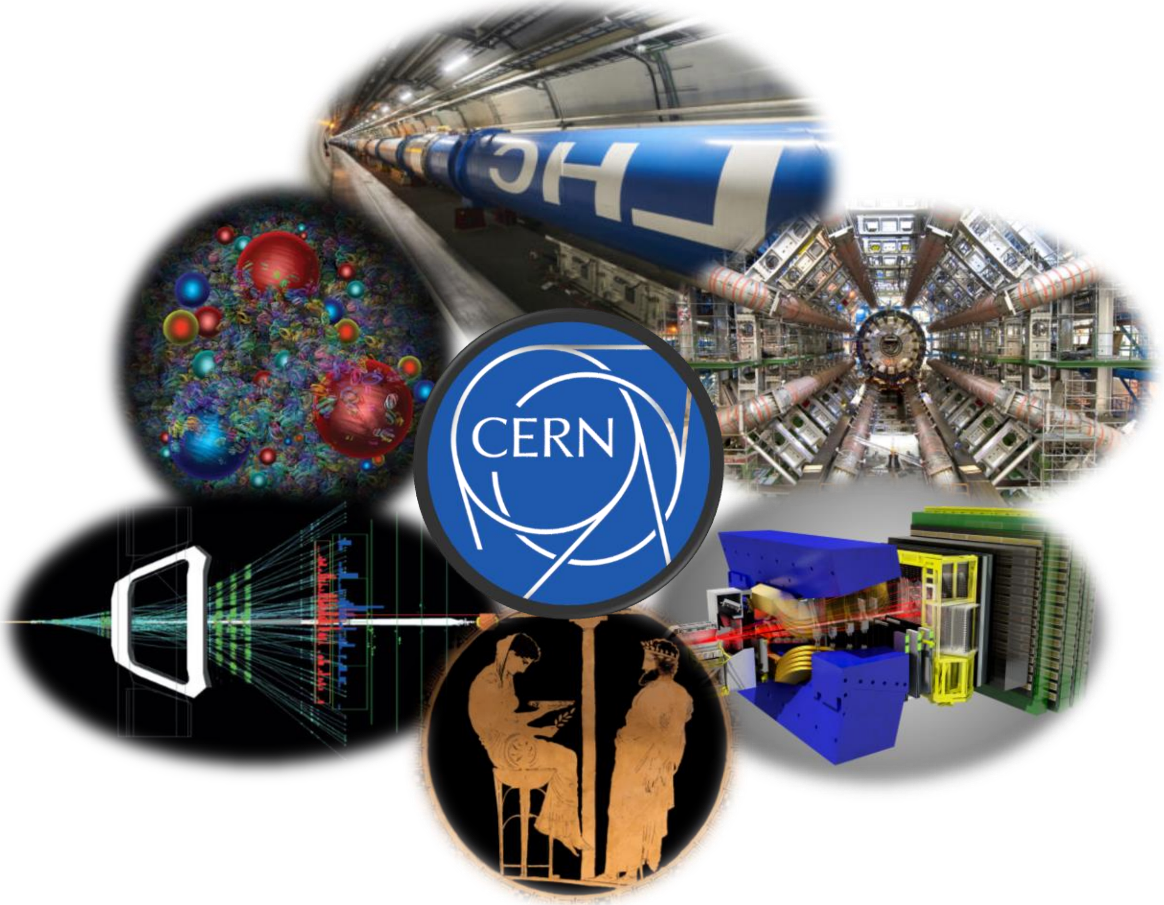
Impact of Pythia parameters on multiplicity of particles in proton-proton collisions at LHC energies

Saliha Bashir

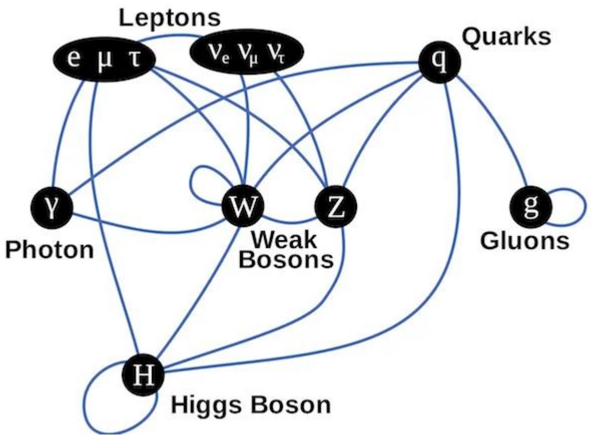
10.06.2022

Outline

- Motivation
- Monte Carlo Event Generators
- Particle flow in data and MC
- Quantum Chromodynamics (QCD)
- Pythia and Modelling of an event in Pythia
- Pythia parameters for Multiparton Interactions
- Results from impact of Pythia parameters on Multiplicity
- Summary and Conclusion
- Future work

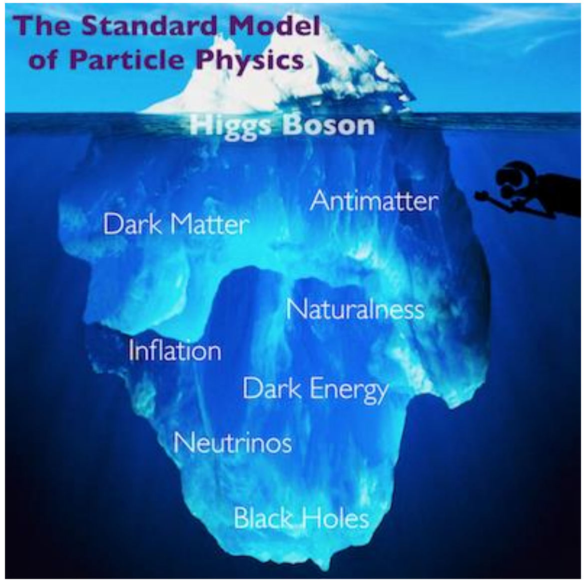


Motivation

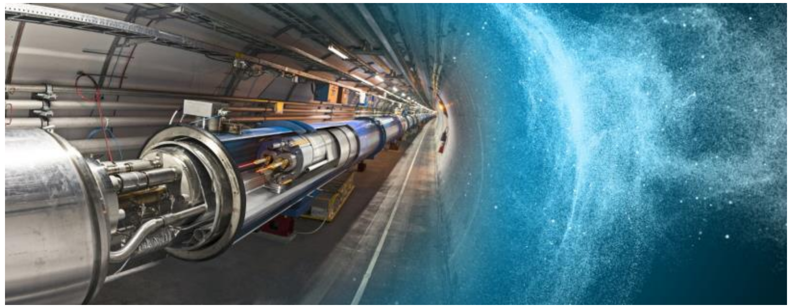


Standard Model: Most Successful Theory

Physics beyond Standard Model must exist

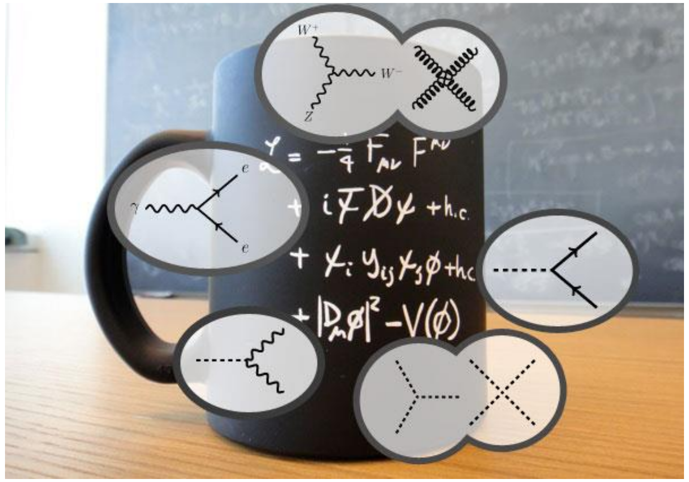


LHC

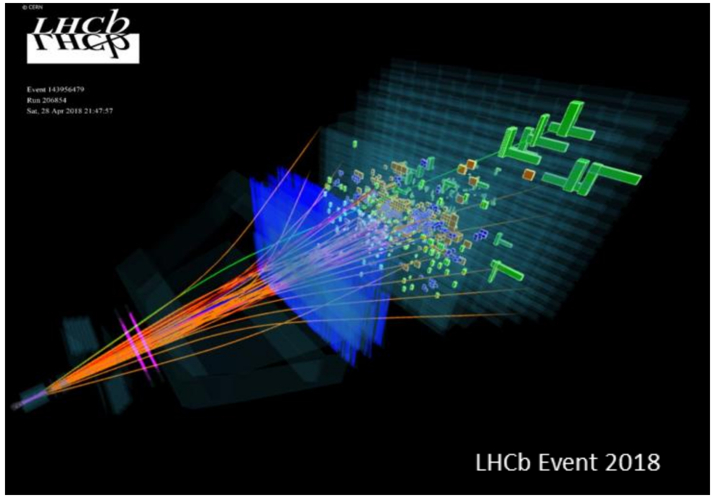


Motivation: Mote Calo Event Generators (MCEG)

There is a huge gap between a one-line formula of a fundamental theory, like the Lagrangian of the SM, and the experimental reality that it implies



Data Makes you smarter



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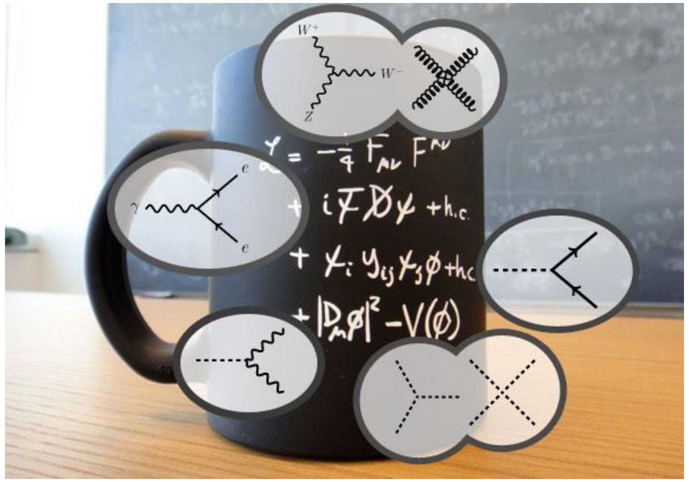

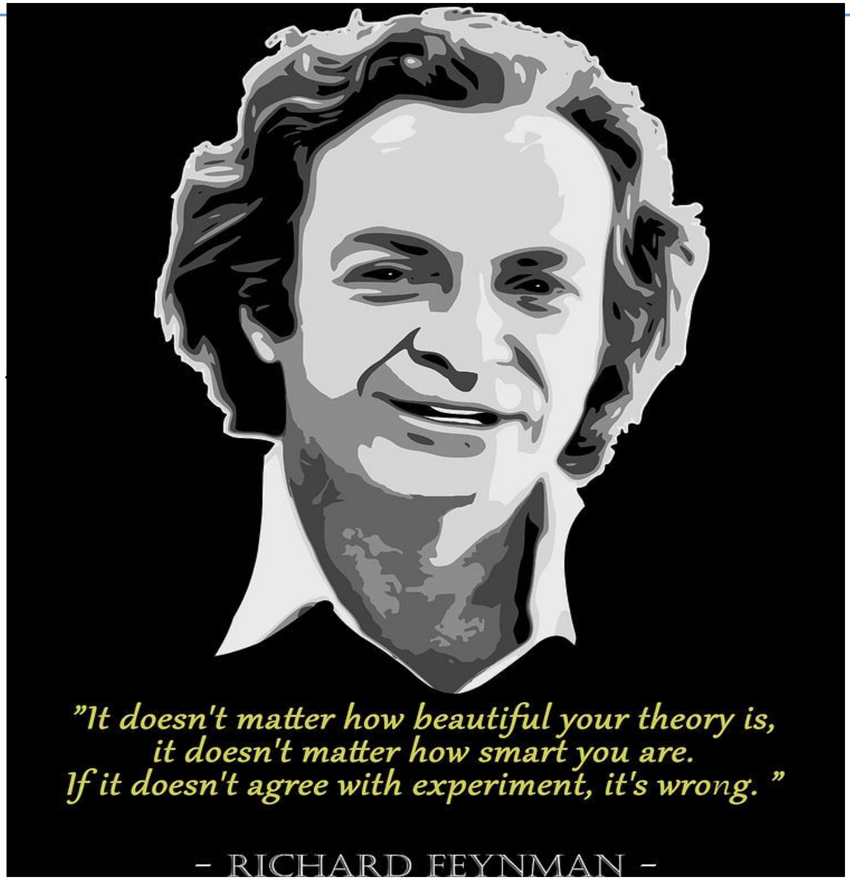

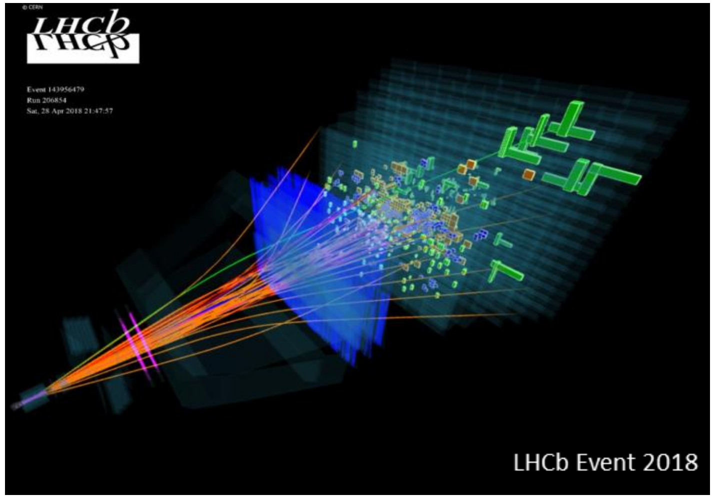

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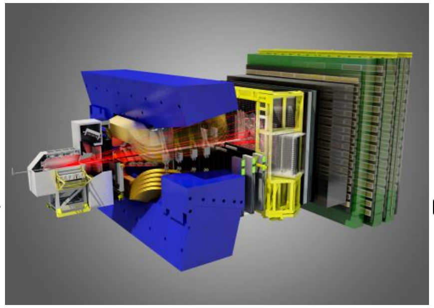
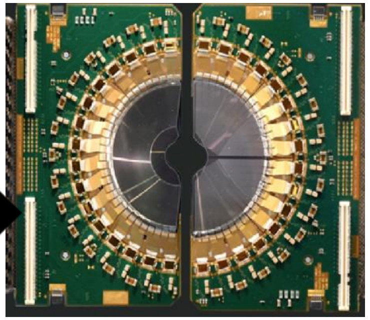
Monte Carlo Event Generators are designed to bridge the gap.
They are more like “Virtual Collider” => Direct Comparison with data

The Data Flow Chart

pp collision



Interaction with detector

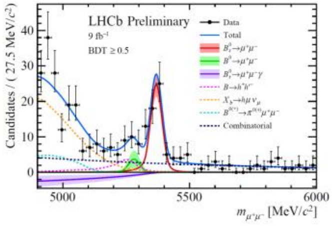


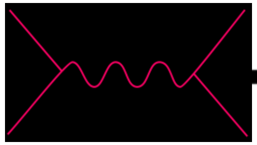
Readout of detector electronics

Event selection

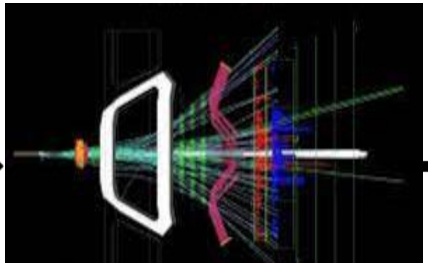
Data reconstruction

Physics analysis

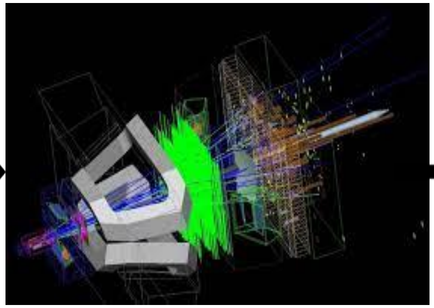




Physics modelling



Event generation

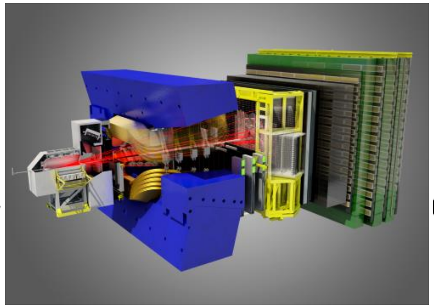


Detector simulation

Simulation of detector electronics

The DATA Flow Chart

pp collision



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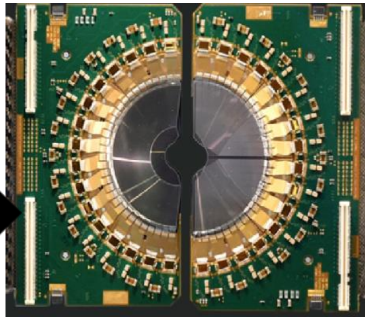

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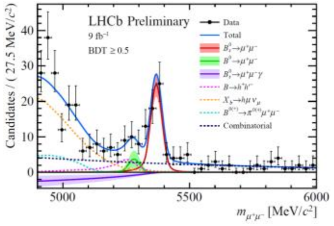

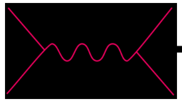

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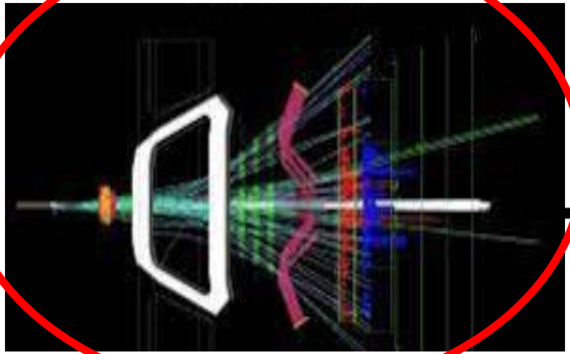
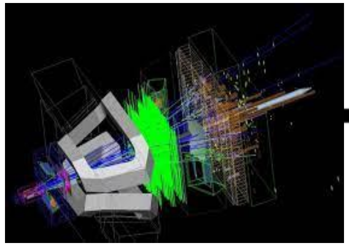


Event Generation



Detector simulation

Simulation of detector electronics

Monte Carlo Generator marketplace

- Pythia 6
- Pythia 8
- HERWIG+
- Herwig++
- Sherpa
- Others: Cascade, PHOJET…

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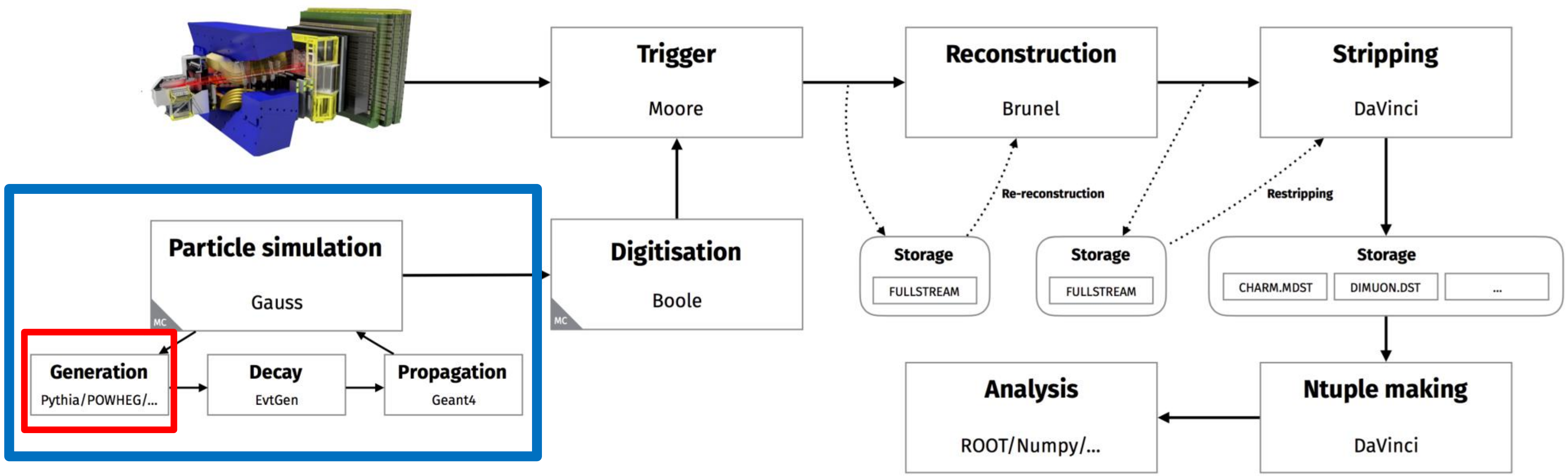
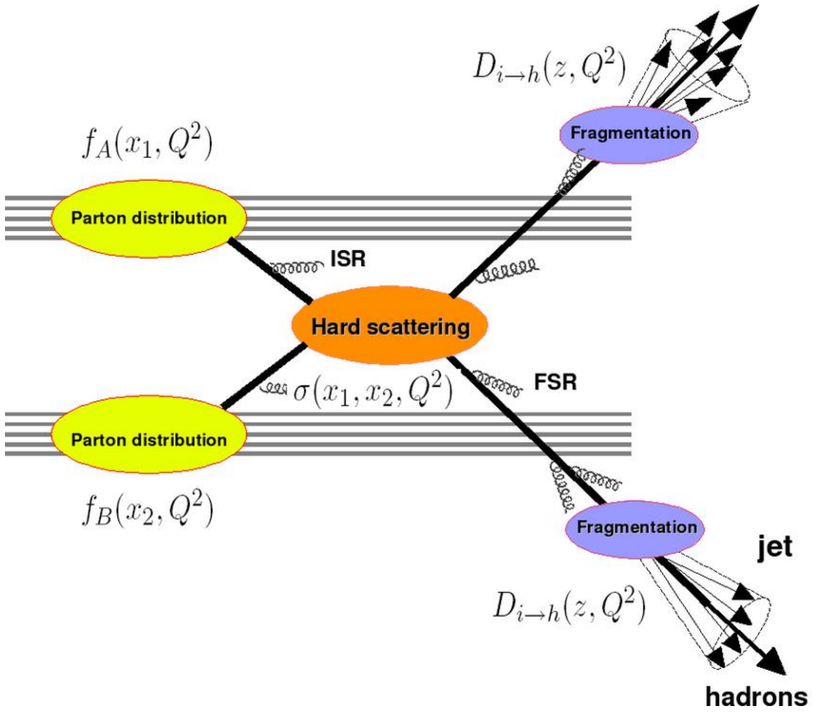
Particle Simulation at LHCb

There are different applications taking care of different physics
Gauss is the application for simulation at LHCb
It consists of two independent phases:
- Generation of primary events
- Tracking of particles produced in experimental setup (detector)



Quantum Chromodynamics (QCD)

- QCD has been quite successful in describing hard interactions.
- However high energy pp collisions are dominated by soft partonic collisions.
- Different phenomenological models are implemented in several Monte Carlo (MC) event generators such as PYTHIA, PHOJET and HERWIG to simulate these interactions.
- These MC event generators have free parameters which need to be tuned to improve the agreement with the data.



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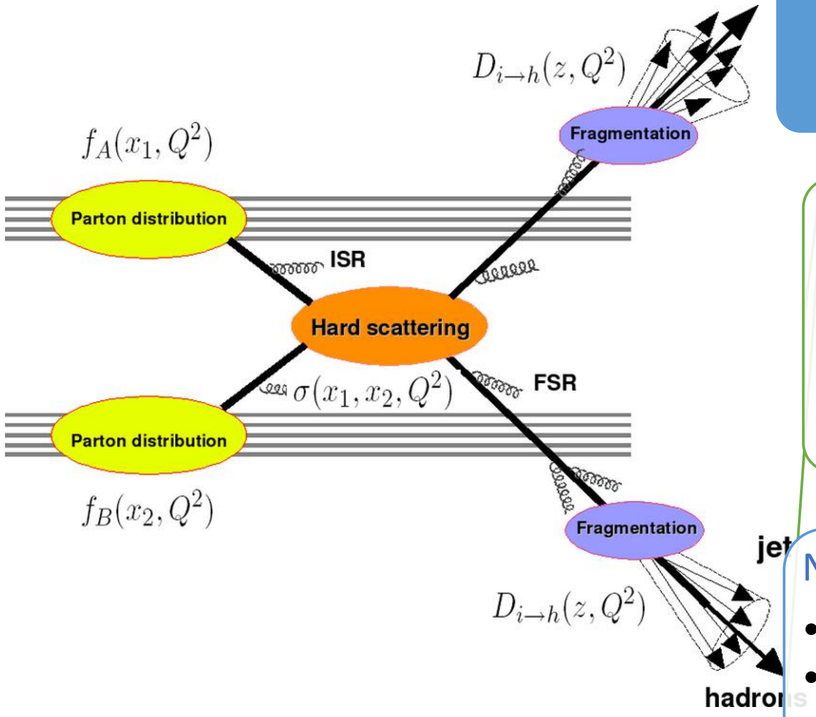


QCD

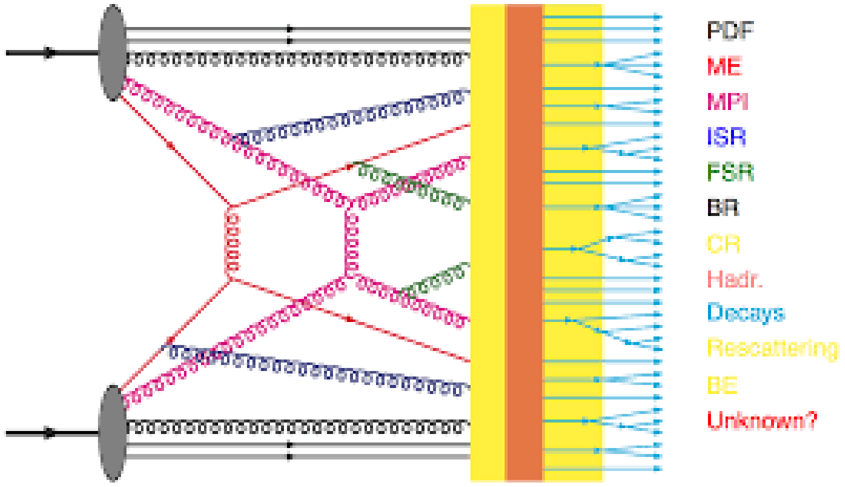
Perturbative (Hard)

- High energy
- Probe shorter distance
- Asymptotic freedom

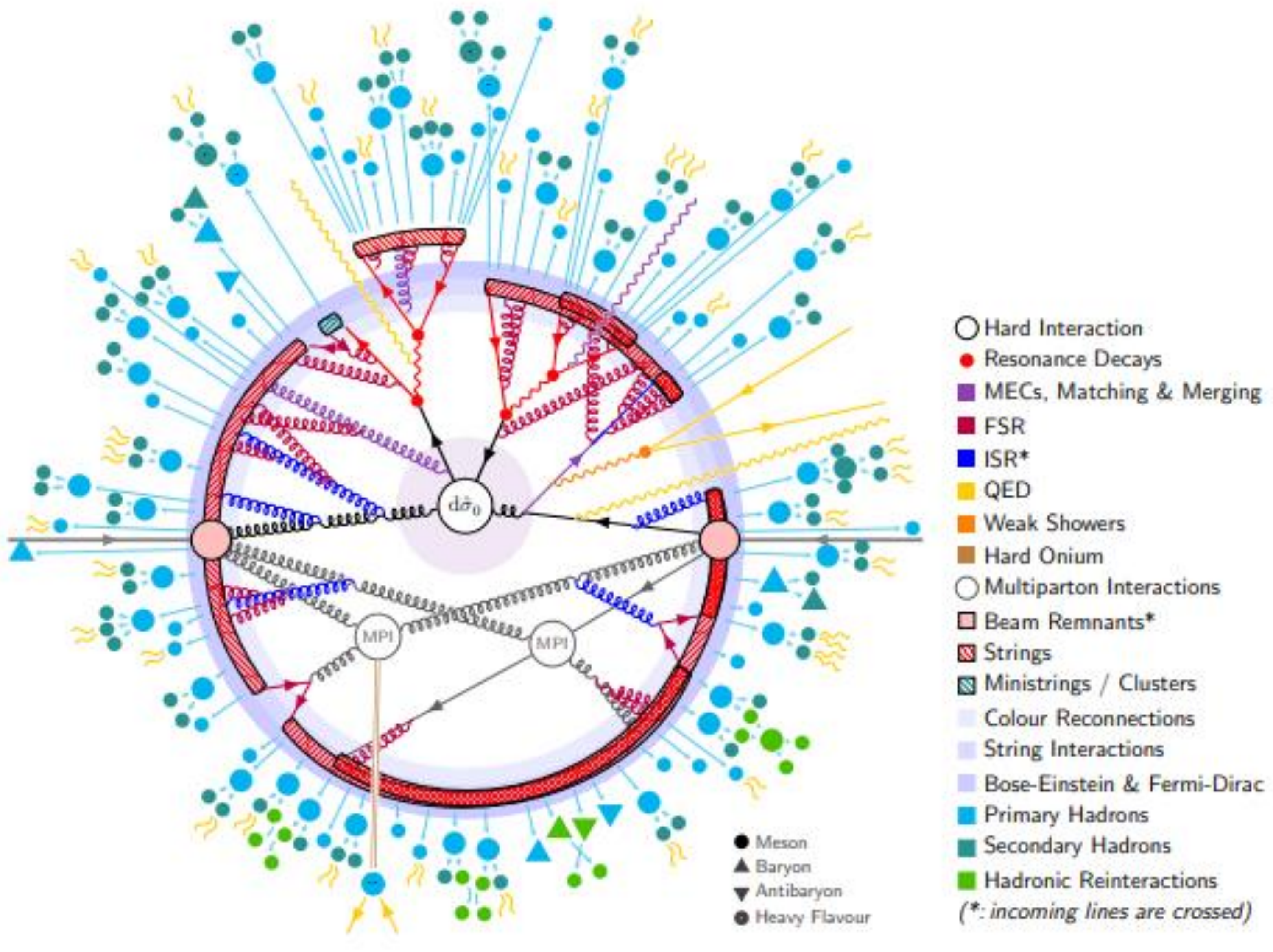
Non -Perturbative (Soft)

- Low energy
- Probed at longer distances
- Confinement
- Phenomenological models (with many free parameters)

- In particle physics, the outcome of a collision between two incoming particles, or of the isolated decay of a particle, is called an "event"
- The main goal of PYTHIA is to simulate particle production in high-energy collisions
- In LHCb, Pythia is one of the main generator used for modeling the pp collision
- The generator keeps evolving and currently used version is Pythia8.3



Modelling of an event in Pythia



arXiv:2203.11601v1 [hep-ph]

Physics processes in Pythia

- Hard Processes
  - -- Hard QCD
  - -- Electroweak
  - -- Higgs
  - -- SUSY
  - -- New Gauge Bosons
  - -- Leptoquark
  - -- Compositeness
  - -- Hidden Valleys
  - -- Extra Dimensions
  - -- Dark Matter
- Phase Space Cuts
- Second Hard Process
- Total Cross Sections
- Soft QCD Processes
- Low-energy QCD Processes
- Multiparton Interactions
- Diffraction

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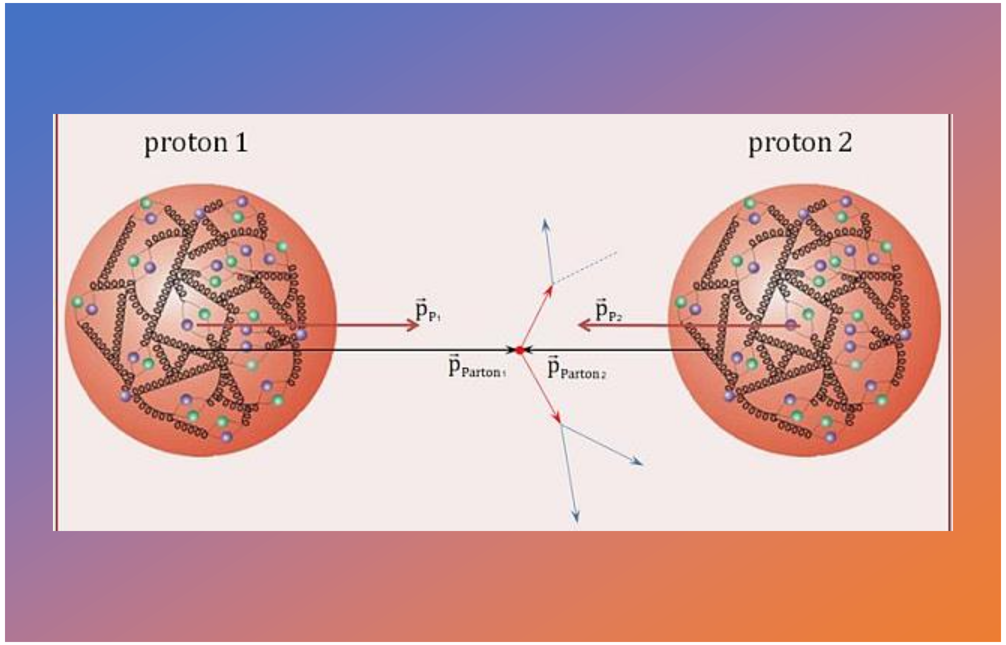

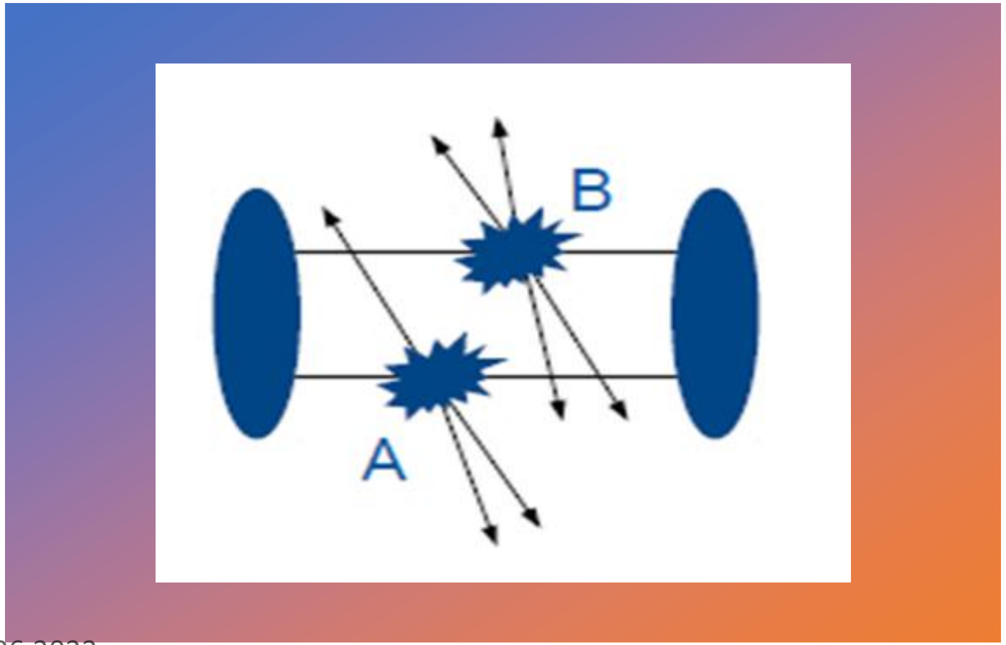

Multiparton Interactions (MPIs)

- When two hadrons collide, there is a possibility for several parton pairs to collide — multiparton interactions (MPIs).
- Processes with exactly two parton pairs, double parton scattering (DPS), was proposed in the early days of QCD, but then viewed as a rare perturbative process

Pythia Parameters for Multiparton Interactions

- **Cross-section regularization**
  - MultipartonInteractions:pT0parametrization
  - MultipartonInteractions:pT0Ref
  - MultipartonInteractions:ecmPow
  - MultipartonInteractions:enhanceScreening
  - MultipartonInteractions:pTmin
- **Cross-section parameters**
  - MultipartonInteractions:alphaSvalue
  - MultipartonInteractions:alphaSorder
- **Impact-parameter dependence**
  - MultipartonInteractions:bProfile
  - MultipartonInteractions:coreRadius
  - MultipartonInteractions:bSelScale
- **Rescattering parameters**
  - MultipartonInteractions:allowRescatter
  - MultipartonInteractions:allowDoubleRescatter
- **PDF Selection**
  - PDF:pSet

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Multiparton Interactions: p_{T0}^{ref}

- The Perturbative QCD scattering diverges at low momentum transfers:

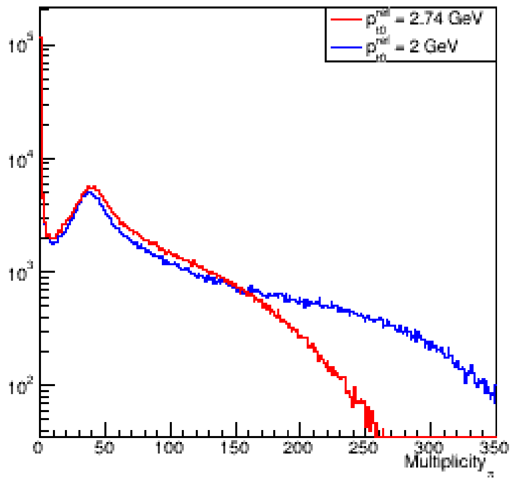
$$d\sigma_{2\to 2} \propto \alpha_s^2(p_T^2)\frac{dp_T^2}{p_T^4}$$

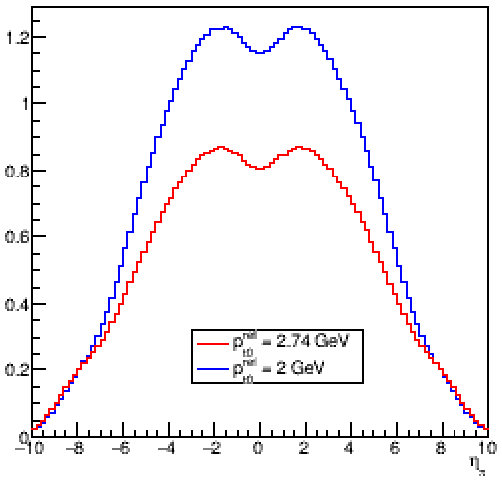
- The momentum transfer cutoff for MPIs is given by:

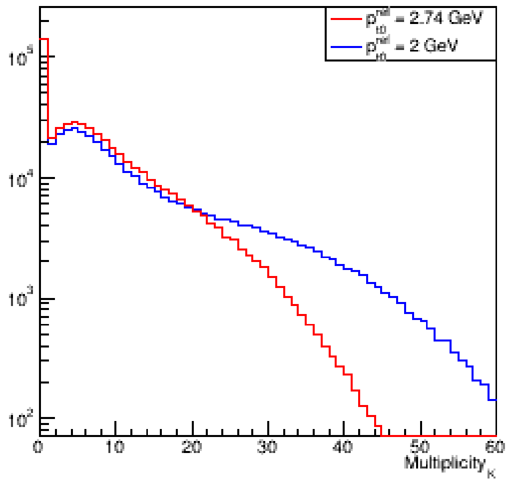
$$p_{T0} = p_{T0}^{ref}\left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{\epsilon}$$

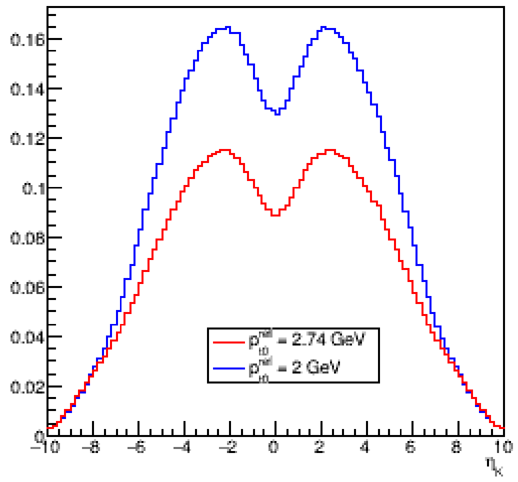
  - p_{T0}^{ref} $\rightarrow$ is p_{T0} at the reference parameter $\sqrt{s_0}$
  - ϵ $\rightarrow$ *is the parmeter governing the energy rescaling pace*

Impact on Multiplicity of Individual particles by tuning p_{T0}^{ref}

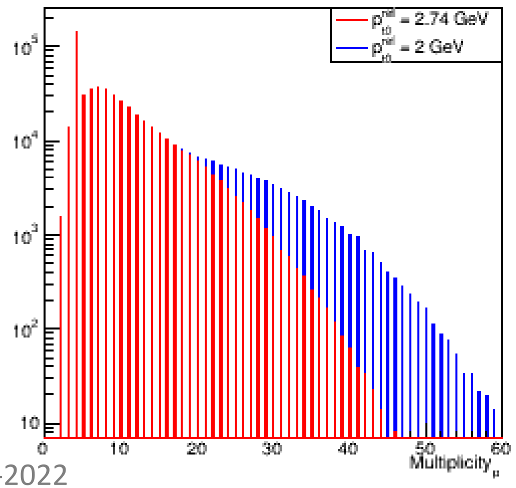


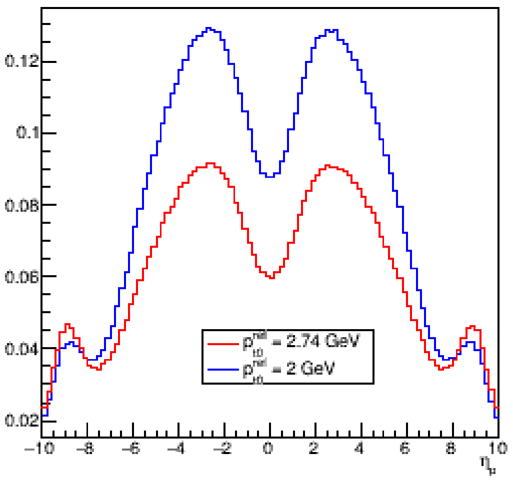




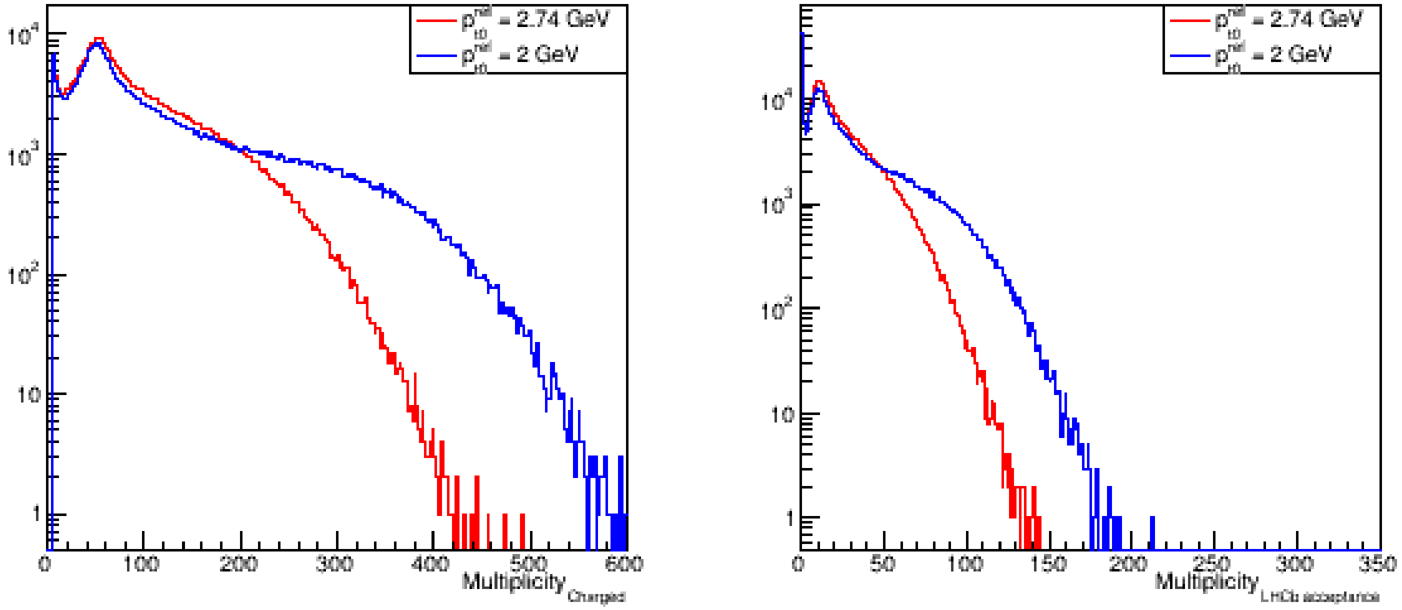


The p_{T0}^{ref} is set to 2 GeV and then to 2.742289 GeV
By reducing the value, the number of particles have increased.





Impact on the Multiplicity of Charged Hadrons in and out of LHCb Acceptance



p_{T0}^{ref} is like a barrier between perturbative and non-perturbative particles.

So, if we change the value of p_{T0}^{ref} we are allowing more hard interactions which would mean more particles.

Pythia Parameters for Multiparton Interactions

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  - **MultipartonInteractions:enhanceScreening**
- Cross-section parameters
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- Impact-parameter dependence
  - **MultipartonInteractions:bProfile**
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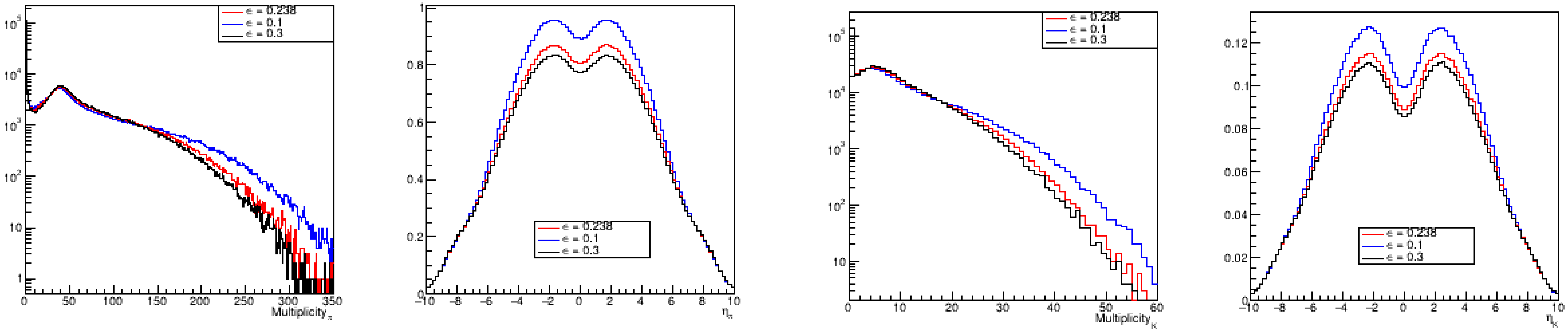
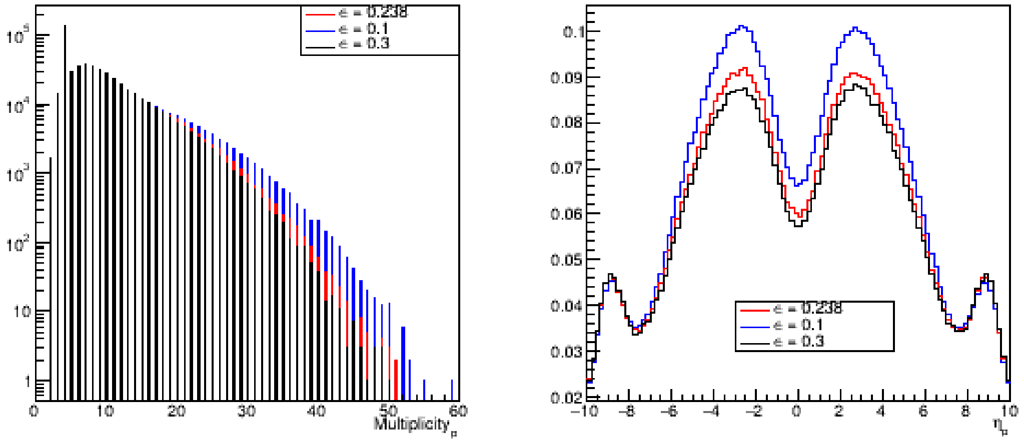
Impact on Multiplicity of Individual particles by tuning ϵ



Again, the ϵ which is the energy rescaling pace has an impact on the multiplicity:

$$p_{T0} = p_{T0}^{ref}\left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{\epsilon}$$

By decreasing this value, we have more multiplicity then by **increasing,** the red is in the LHCb settings.



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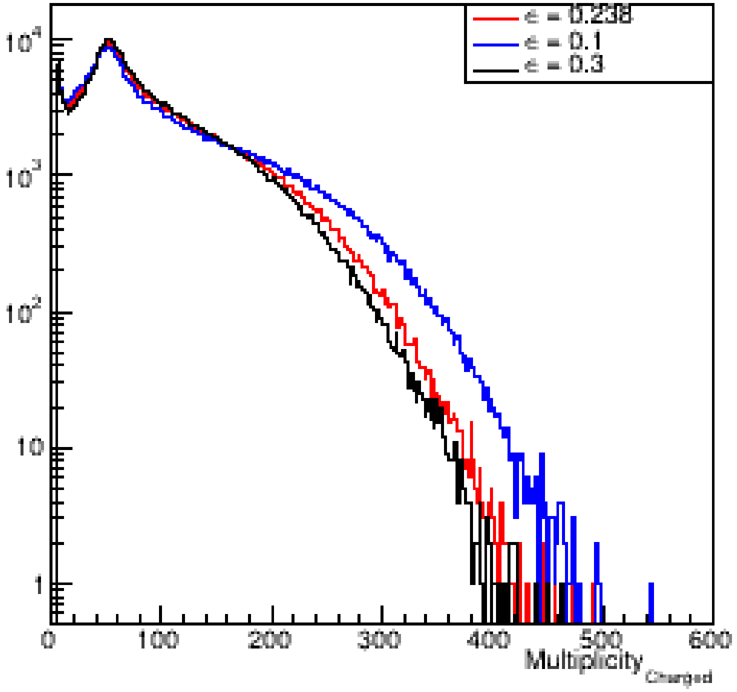

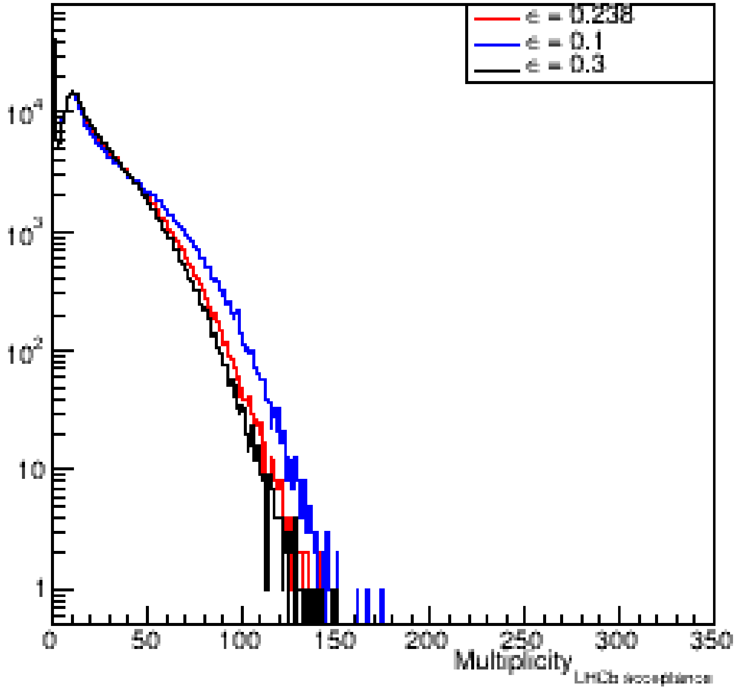

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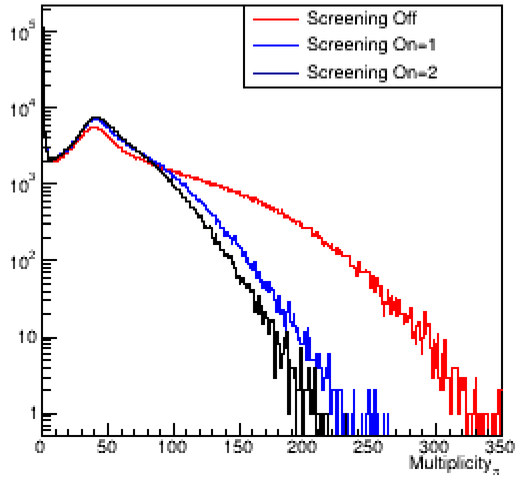
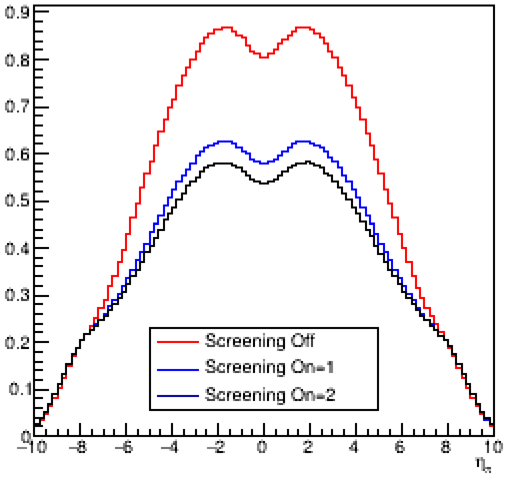
Multiparton Interactions: enhance Screening

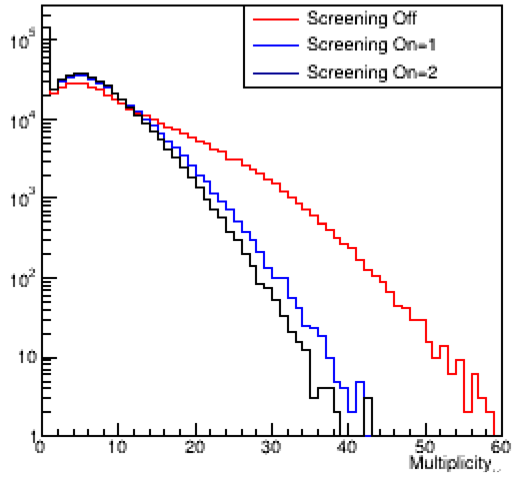
- This idea was introduced from the modelling of initial states using dipoles (Mueller dipole formalism).
- In this picture the initial state dipoles are evolved forward in rapidity before the collision of incoming states.
- And the size of the screening is determined by the dipole size ‘r’ which is related to the interaction cross-section as a p_T cut-off; $p_{T0} \sim 1/r$
- This implies that a smaller dipole imply larger effective cut-off and an enhanced amount of screening.
- To model this in Pythia, we do have this parameter which could be given various values.

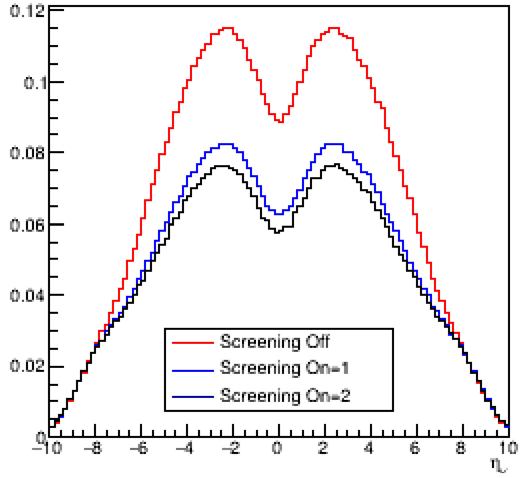
AGH

Impact on Multiplicity of Individual particles by tuning the Screening parameter

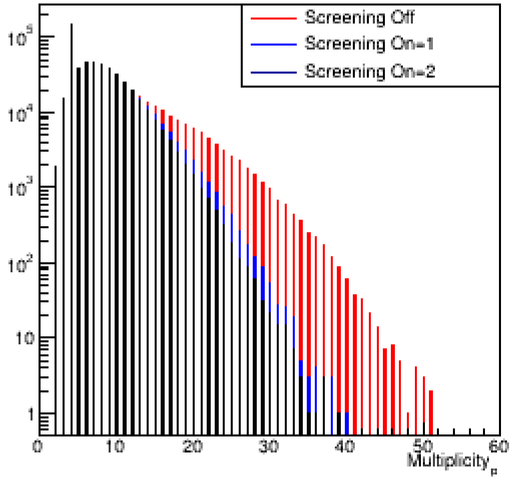


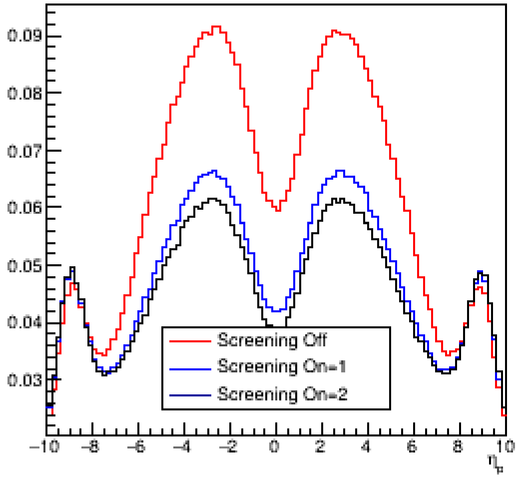






- 0 would mean no activity dependent screening (LHCb),
- 1 would mean p_{T0} scale is increased as a function of the number of MPI's,
- 2 would mean the influence of both MPI and ISR on screening.





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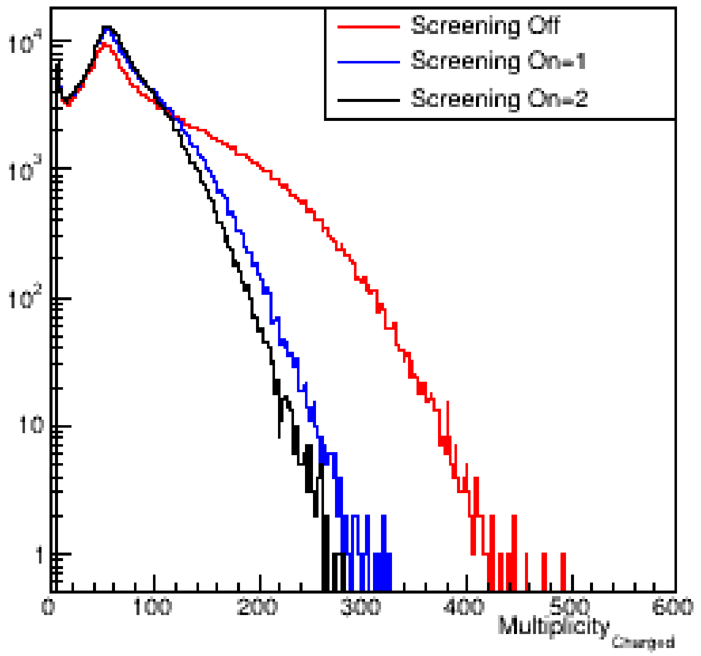

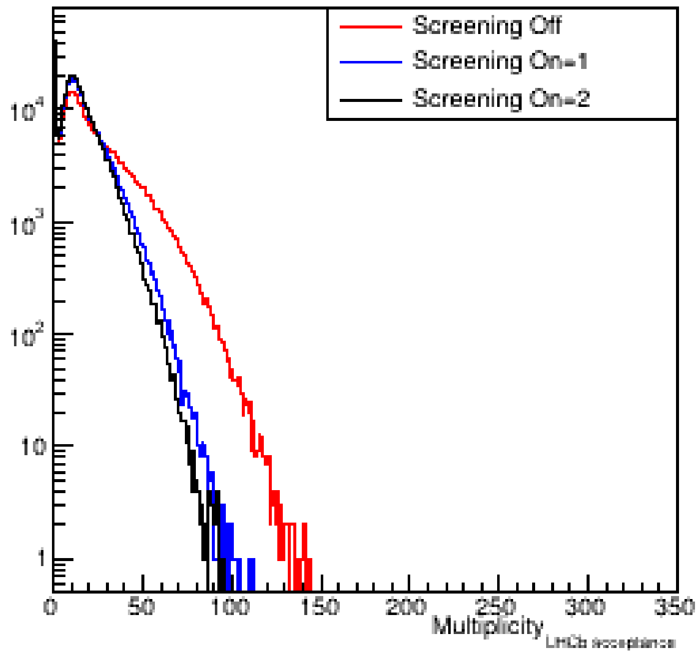

The screening parameter does play an important role in the multiplicity of the particles.

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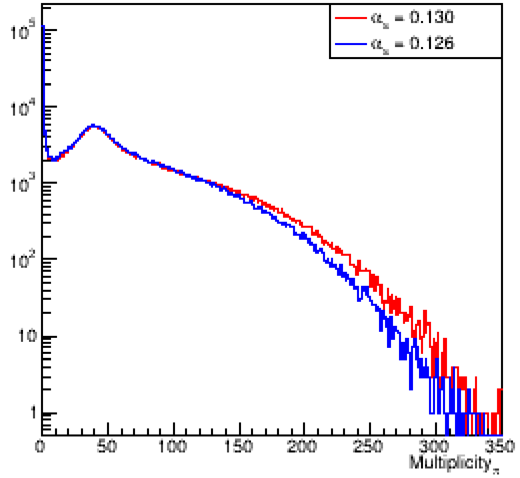
Multiparton Interactions: α_s

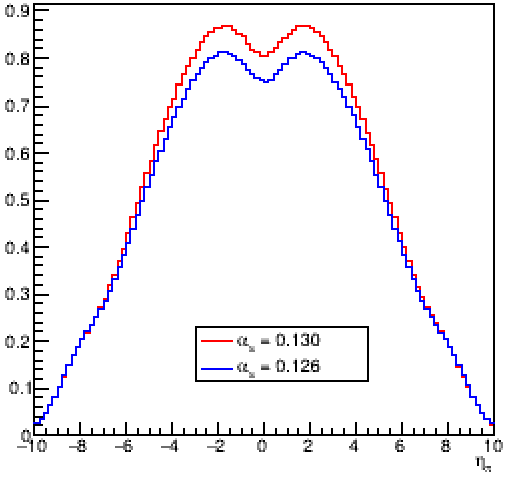
- The starting point for parton based MPI models is the observation that the α_s factor in perturbative QCD diverge at low- momentum transfers:

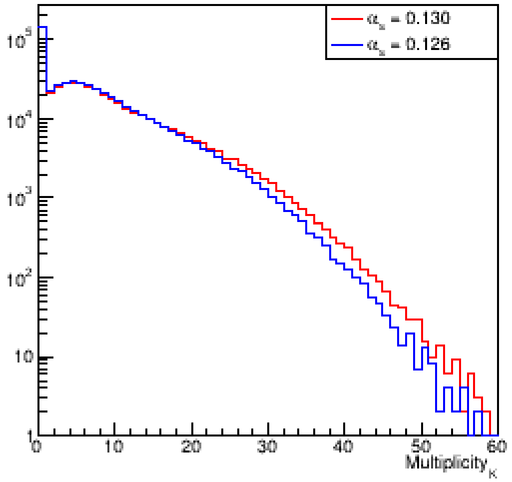
$$d\sigma_{2\to 2} \propto \frac{g_S^4}{16\,\pi^2}\frac{dt}{t^2} \sim \alpha_s^2(p_T^2)\frac{dp_T^2}{p_T^4}$$

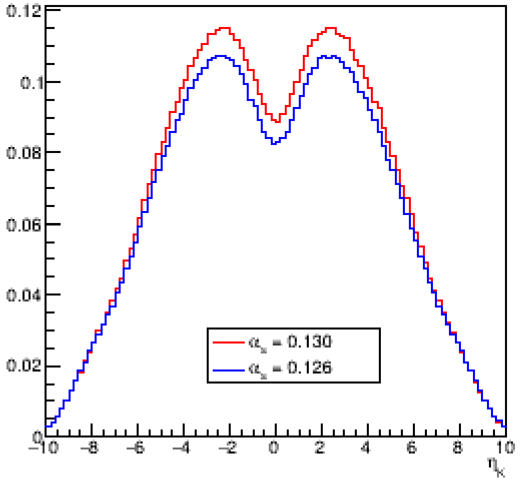
Therefore, we expect some sort of opposite behavior as to what was observed in p_{T0}^{ref} .

Impact on Multiplicity of Individual particles by tuning α_s

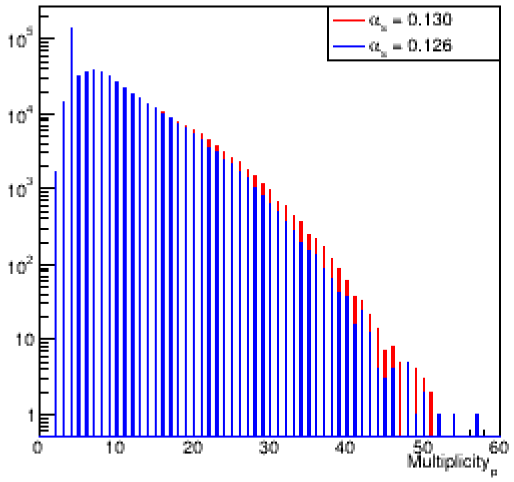


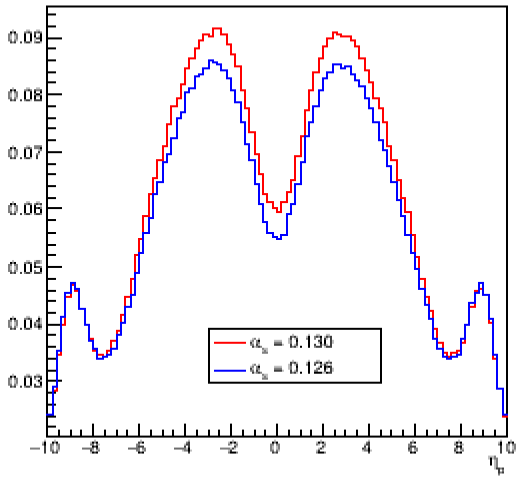




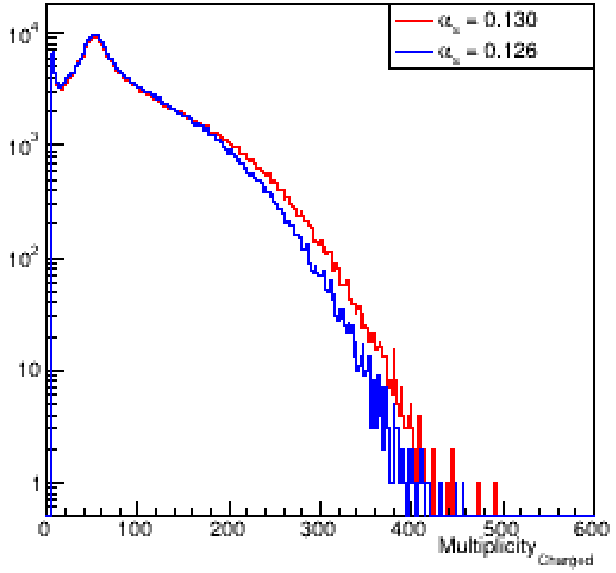


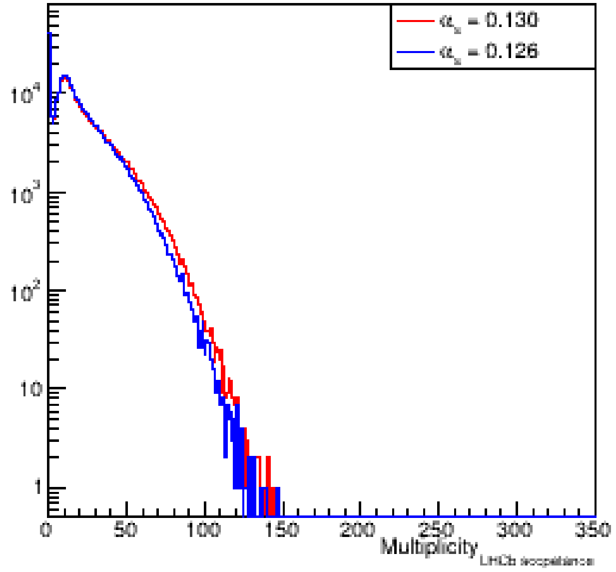
- The comparison is made for two different values of α_s, at 0.130 (LHCb) and 0.126.
- Decreasing the value of α_s , decreases the multiplicity of particles.





Impact on the Multiplicity of Charged Hadrons in and out of LHCb Acceptance



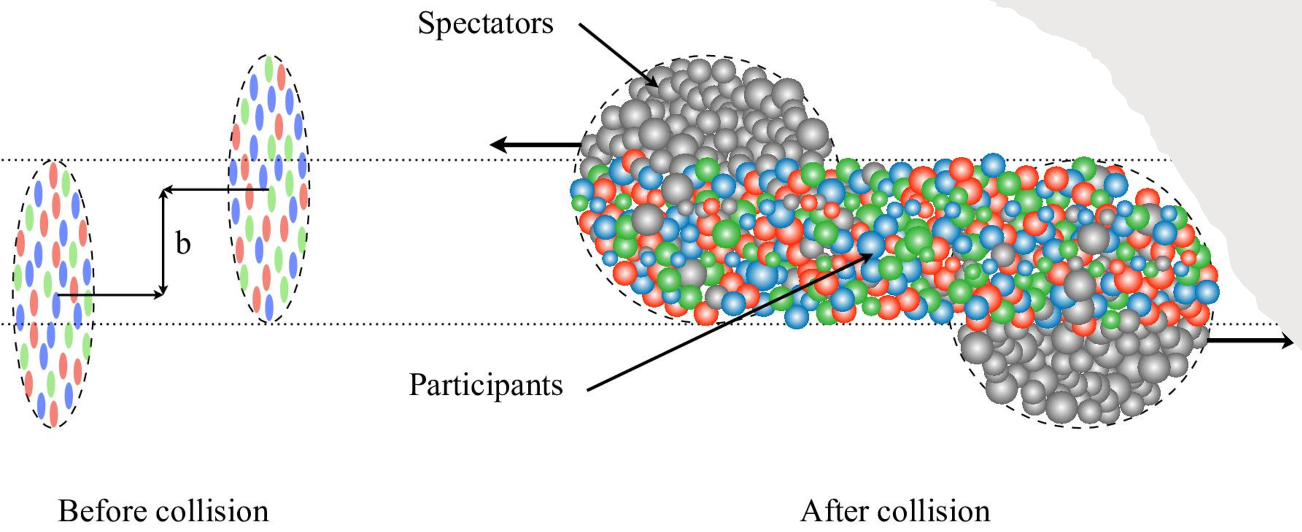


As expected, the multiplicity decreases if we decrease the value of α_s.

Pythia Parameters for Multiparton Interactions

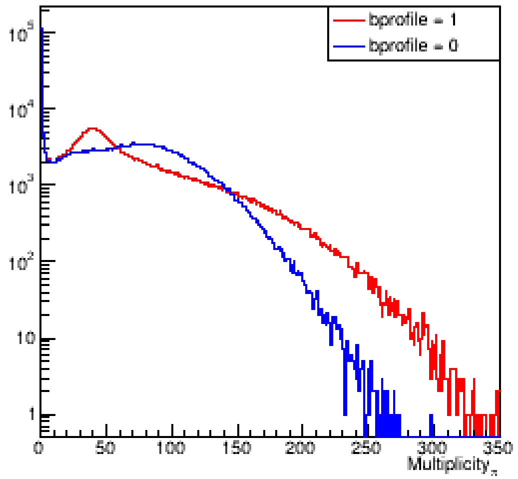
- Cross-section regularization
  - **MultipartonInteractions:pT0Ref**
  - **MultipartonInteractions:ecmPow**
  - **MultipartonInteractions:enhanceScreening**
- Cross-section parameters
  - **MultipartonInteractions:alphaSvalue**
- Impact-parameter dependence
  - **MultipartonInteractions:bProfile**
- PDF Selection
  - **PDF:pSet**

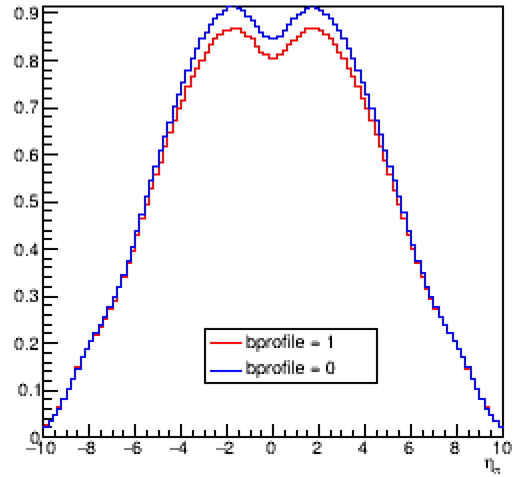
Multiparton Interactions : b Profile

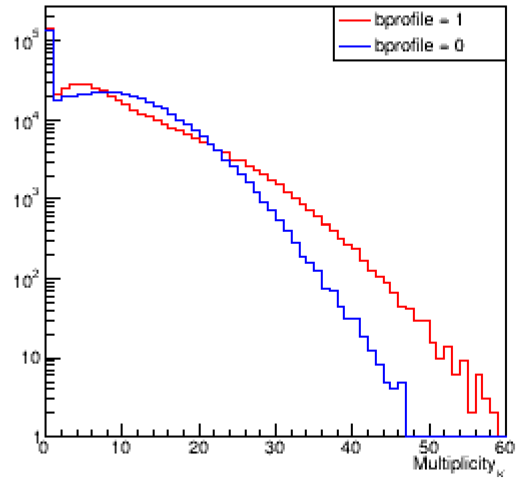


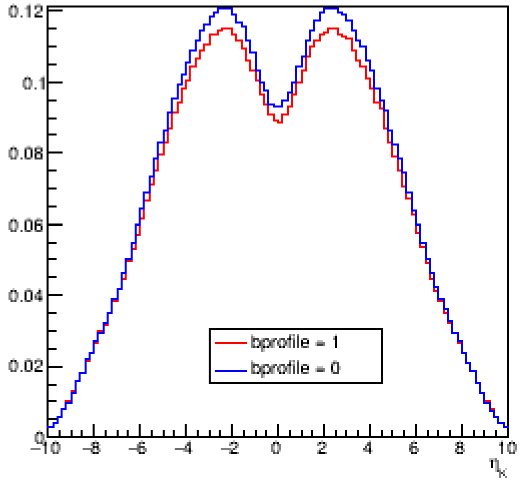
- The choice of impact-parameter dependence is regulated by several parameters.
- Choice of impact parameter profile for the incoming hadron beams.
    - option 0 : no impact parameter dependence at all.
    - option 1 : a simple Gaussian matter distribution; no free parameters.

Impact on Multiplicity of Individual particles by tuning the bProfile



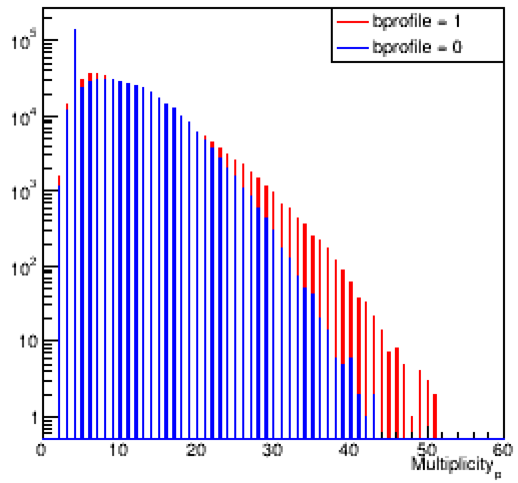


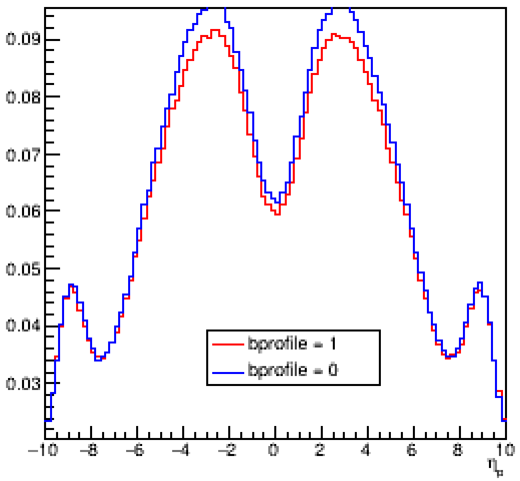




These are the distributions for two different settings of bprofile:

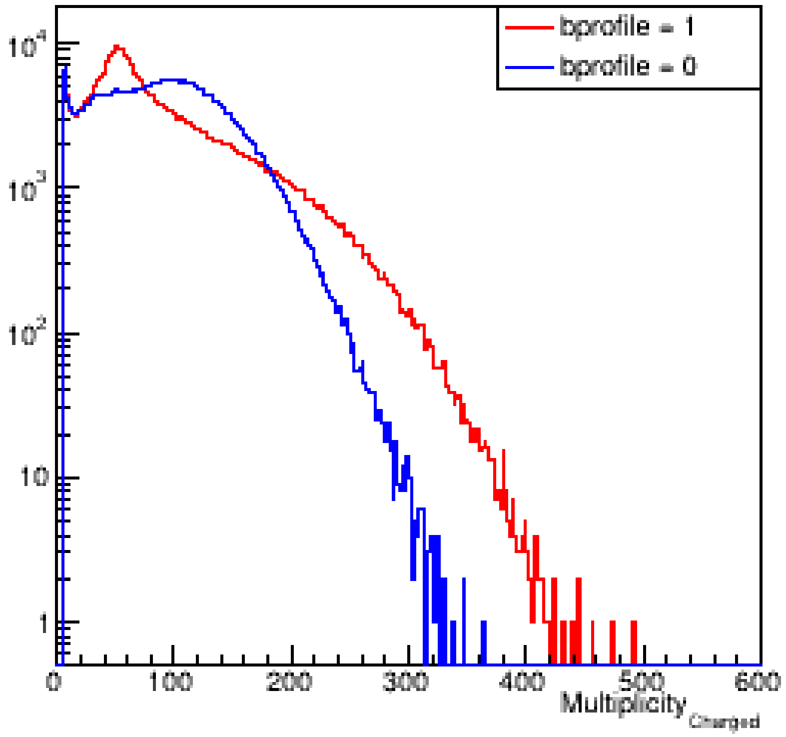
- The first is 0 which shows no impact parameter dependence
- And 1 (LHCb settings), a simple Gaussian matter distribution.

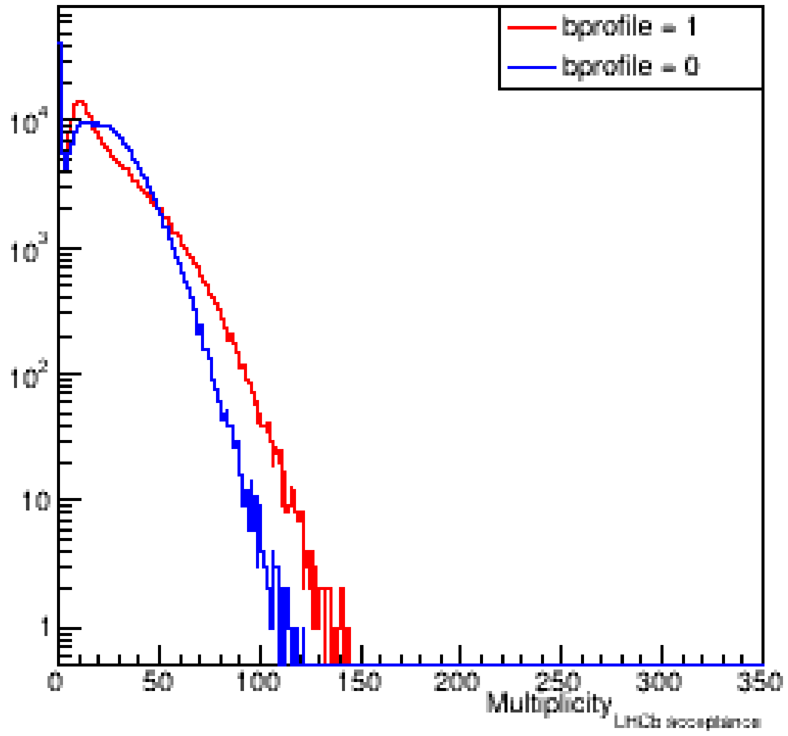




Impact on the Multiplicity of Charged Hadrons in and out of LHCb Acceptance

bProfile is another parameter that does have an impact on the multiplicity of particles which is evident from the distributions.





Pythia Parameters for Multiparton Interactions

- Cross-section regularization
  - **MultipartonInteractions:pT0Ref**
  - **MultipartonInteractions:ecmPow**
  - **MultipartonInteractions:enhanceScreening**
- Cross-section parameters
  - **MultipartonInteractions:alphaSvalue**
- Impact-parameter dependence
  - **MultipartonInteractions:bProfile**
- PDF Selection
  - **PDF:pSet**

PDF: pSets

$$d\sigma^{h_1 h_2 \to cd} = \int_0^1 dx_1 \int_0^1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, Q^2) f_{b/h_2}(x_2, Q^2)\, d\sigma^{ab \to cd}(Q^2)$$

$f_{a/h_i}(x_i)$: Parton Distribution Function (PDF) (Probability of finding a parton of type a with momentum fraction x_i in hadron h_i)

- ❑ Not calculable in perturbation theory
- ❑ Needs data to be determined
- ❑ $Q^2 \sim$ 4-momentum transfer at scale of partons

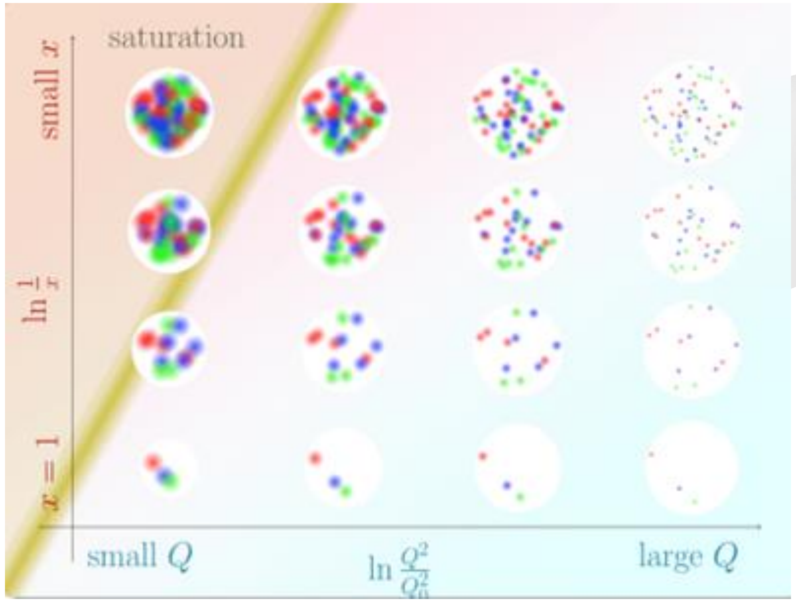
$\sigma^{ab \to cd}$: parton level hard scattering cross-section

- ❑ Calculable in perturbative QCD

PDF	x range	Q^2 range [GeV^2]	α_S	$\alpha_S(M_Z)$
GRV94L	$10^{-5}-1$	$0.40-10^6$	LO	0.128
CTEQ5L	$10^{-6}-1$	$1.00-10^8$	LO	0.127
MRST LO*	$10^{-6}-1$	$1.00-10^9$	NLO	0.12032
MRST LO**	$10^{-6}-1$	$1.00-10^9$	NLO	0.11517
MSTW LO	$10^{-6}-1$	$1.00-10^9$	LO	0.13939
MSTW NLO	$10^{-6}-1$	$1.00-10^9$	NLO	0.12018
CTEQ6L	$10^{-6}-1$	$1.69-10^8$	NLO	0.1180
CTEQ6L1	$10^{-6}-1$	$1.69-10^8$	LO	0.1298
CTEQ66 (NLO)	$10^{-8}-1$	$1.69-10^{10}$	NLO	0.1180
CT09MC1	$10^{-8}-1$	$1.69-10^{10}$	LO	0.1300
CT09MC2	$10^{-8}-1$	$1.69-10^{10}$	NLO	0.1180
CT09MCS	$10^{-8}-1$	$1.69-10^{10}$	NLO	0.1180

arXiv:1007.0897 [hep-ph]

PDF- Set Description



CT09-MCS/1

- SetDesc: "CT09 MC PDF with 2-loop alphas and no momentum sum rule violation.“
- QMax: 34496.9
- AlphaS_Qs
- AlphaS_Vals

CT09-MC1

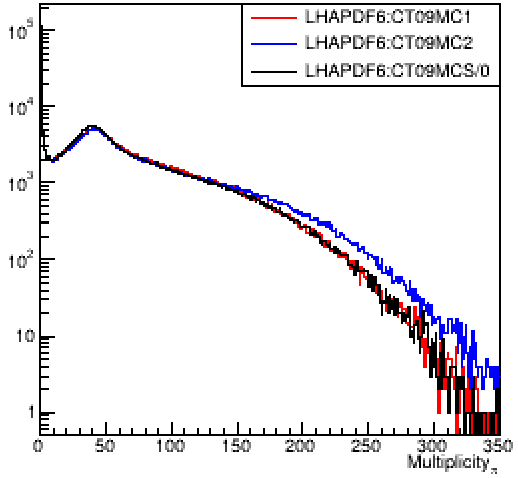
- SetDesc: "CT09 MC PDF with 1-loop alphas and momentum sum rule violation.“
- QMax: 37328.5
- AlphaS_Qs
- AlphaS_Vals

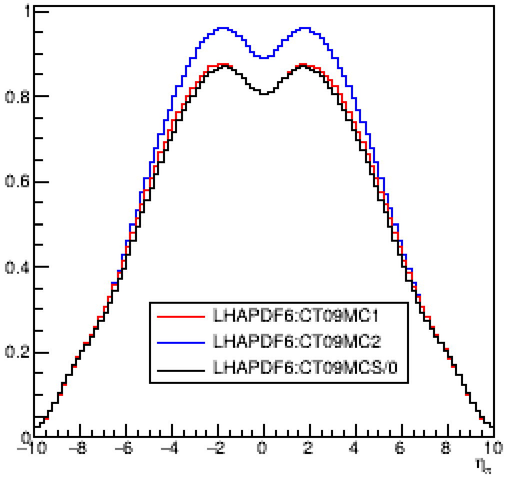
CT09-MC2

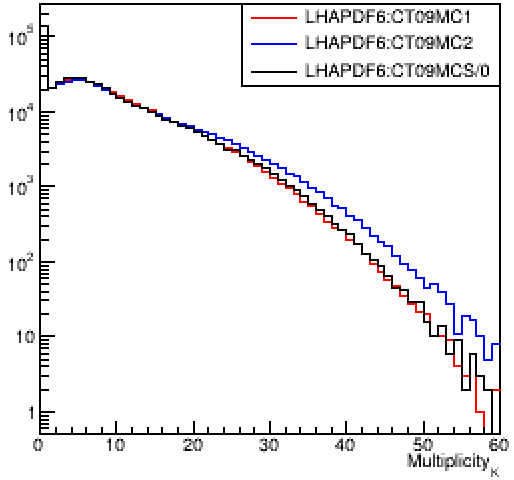
- SetDesc: "CT09 MC PDF with 2-loop alphas and momentum sum rule violation.“
- QMax: 34328.6
- AlphaS_Qs
- AlphaS_Vals

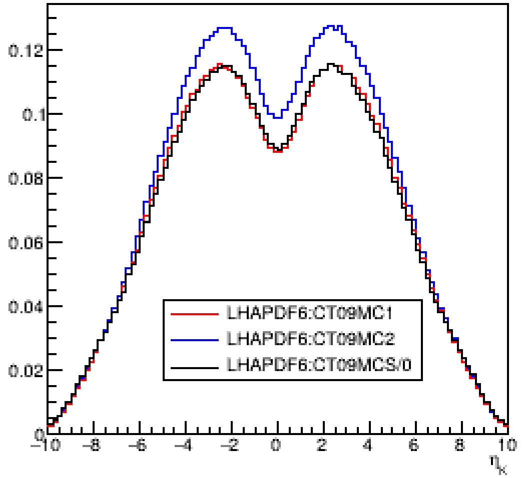
https://lhapdf.hepforge.org/pdfsets

Impact on Multiplicity of Individual particles by tuning the PDFs

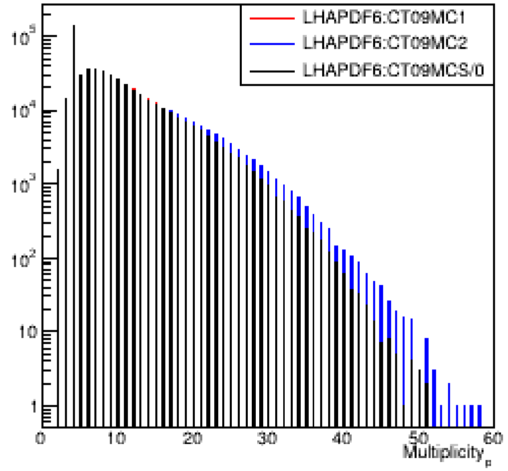


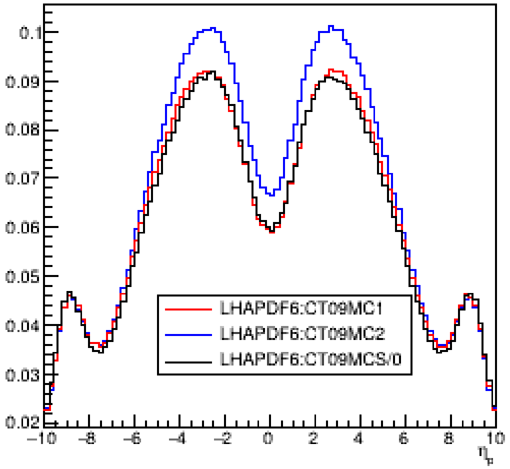




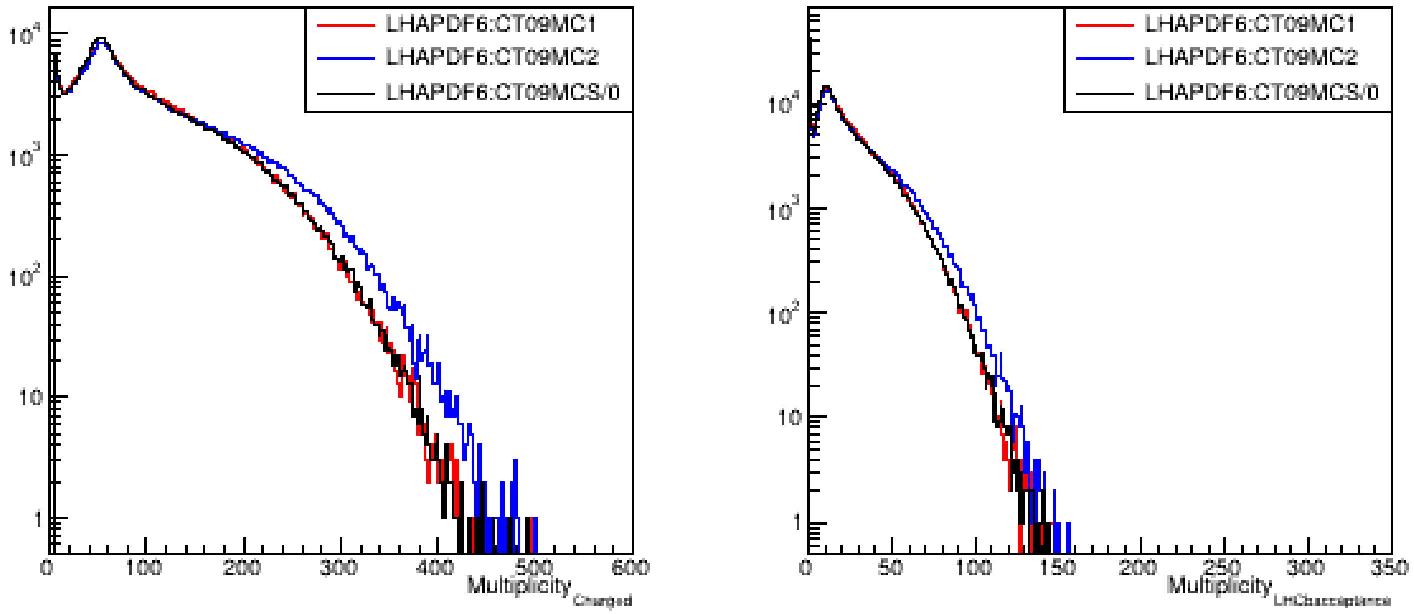


The PDF:pSet is chosen for three different settings.
The CT09MC1 behaves very similar to CT09MC1, however, there is an impact on the multiplicity if we change these settings to CT09MC2.





Impact on the Multiplicity of Charged Hadrons in and out of LHCb Acceptance



The impact on the multiplicity of particles is very visible if we change the PDF:pSet to a different settings, mainly because these parameters are x and α_s dependent. And this impact is visible in the distributions.

Summary and Conclusion

- Monte Carlo Event Generators are used to generate high-energy-physics events and mimic the data.
- Pythia is a MC event generator of hadron-hadron collision based on perturbative QCD
- Pythia depends upon several parameters which could be tuned to better match the data.
- Different parameters were tested and their impact on multiplicity is shown.
- This would help us to check the multiplicity distributions produced from the real data and tune the model for Run 3 accordingly.

Future Work

There is not only Pythia model there are other models like DPMJET which would be used further in this studies.

Further, comparison of data and different models would help us to figure out which model best describes the data.

Thank You!