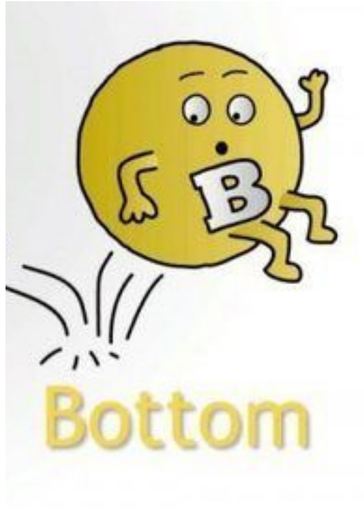
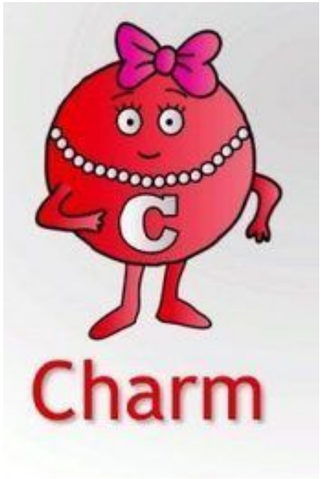
Heavy-flavour hadron production as a function of charged-particle multiplicity measured by ALICE





ZimÁnyi school 2021

(6 -10 December)

Joyful Elma Mdhluli

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

National Research Foundation

iThemba LABS
Laboratory for Accelerator Based Sciences

Overview

1. Introduction
2. Physics motivation
3. Measurements in ALICE
4. Results
5. Summary

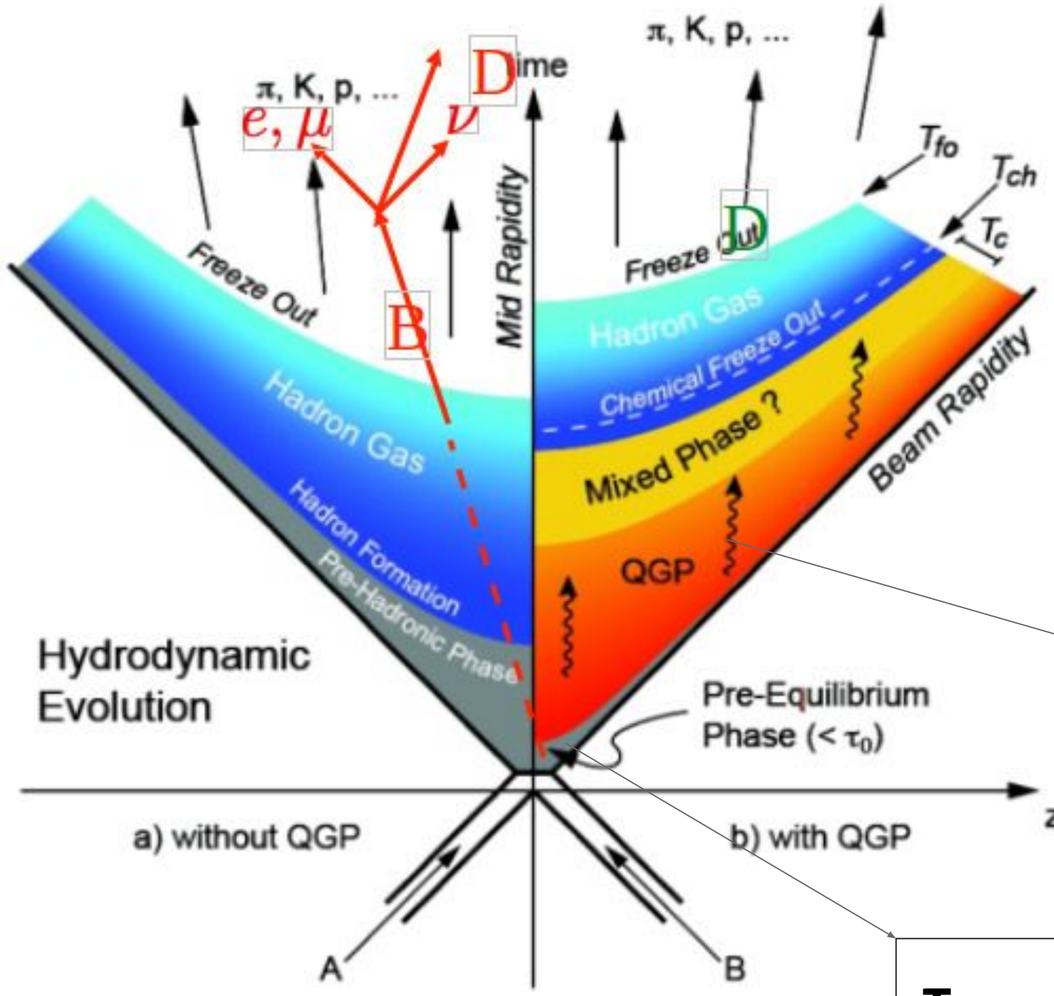
Heavy-Flavour (HF) Probes

Time evolution of pp collisions on the left vs A-A collisions on the right

Small systems (pp & p-A)
- Test pQCD theory
- Reference for AA collision

Nucleus-nucleus (AA)
- Study QGP

fm/c = 3x10^{-24} second (s)



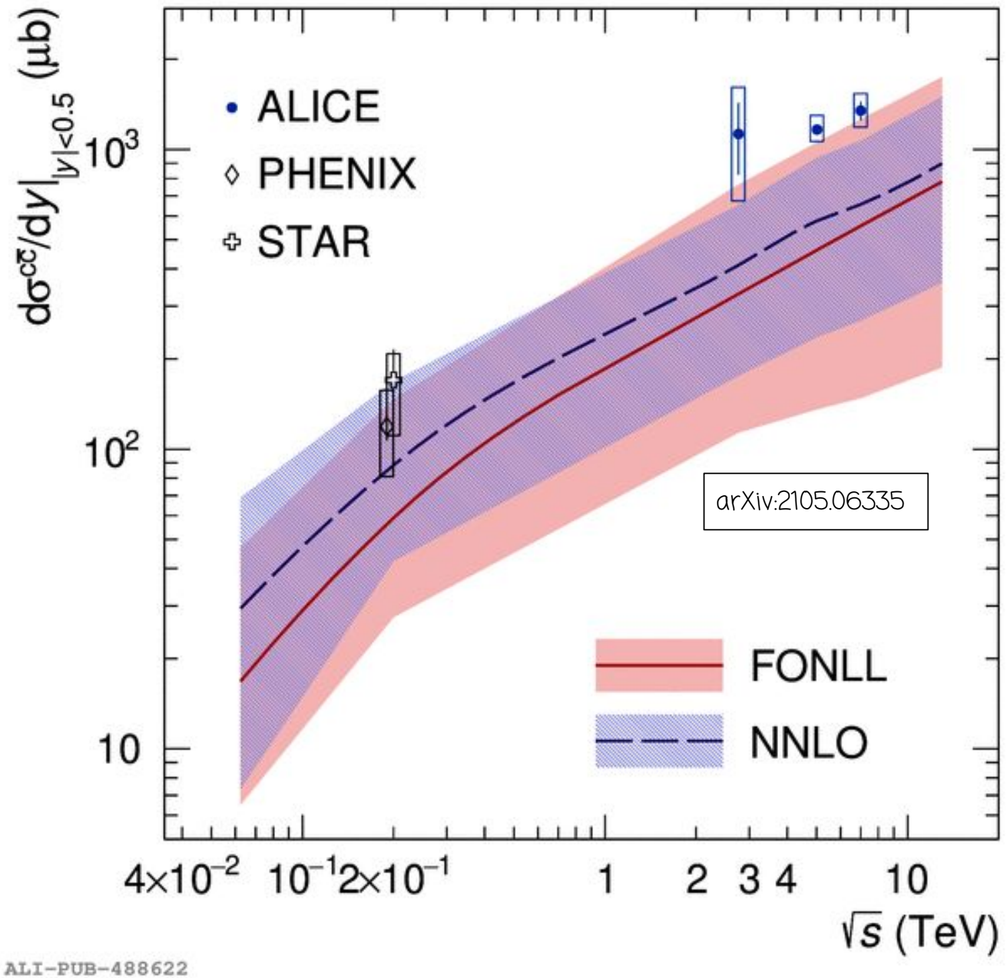
τ_{QGP} ~ 1 fm/c

$\tau_{c,b}$ ~ 0.6 fm/c

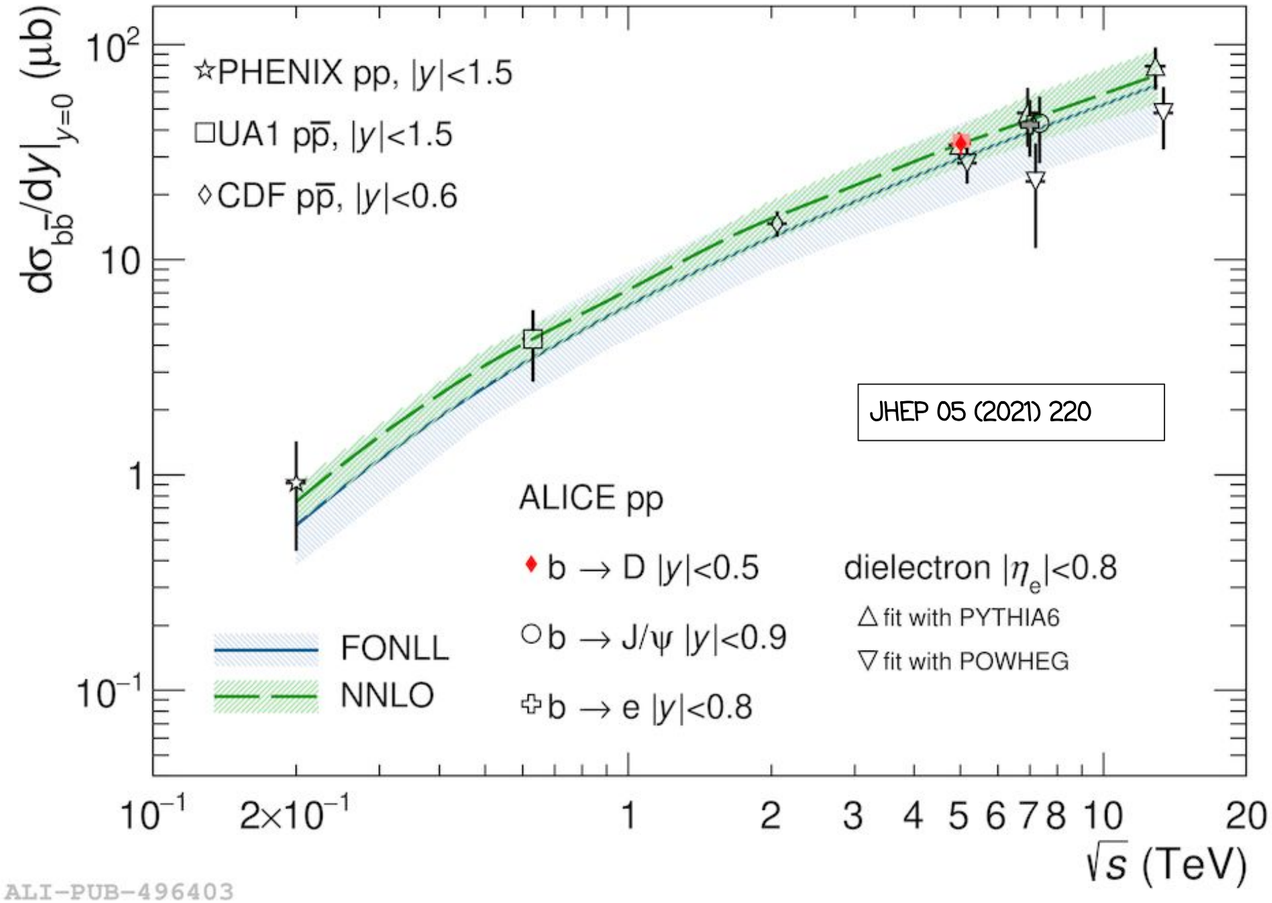
DOI: 10.22661/AAPPSBL.2019.29.4.16

HF in pp collisions

- Heavy quarks (charm and beauty) are produced in partonic scattering processes with large Q^2
- The production cross section can be determined using perturbative QCD (pQCD) calculations.



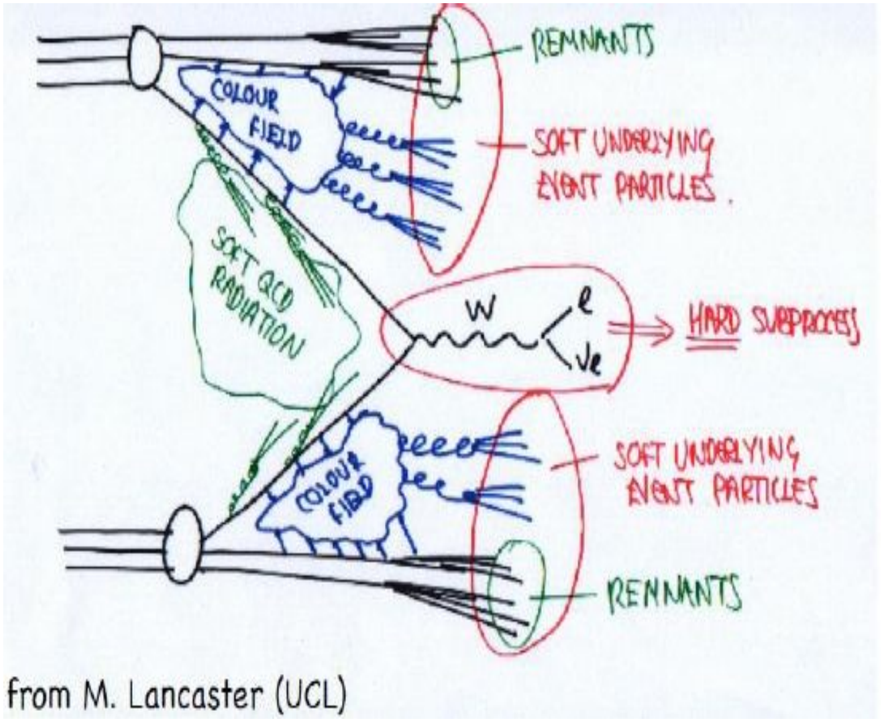
ALI-PUB-488622



ALI-PUB-496403

HF production vs charged-particle multiplicity

- Two component approach:
  1. <u>Initial hard scattering process</u>
     - Relevant for heavy-flavour (HF) quark production
  2. <u>Underlying event (UE):</u>
     - Semi-hard Multiple Parton Interactions (MPI)
     - Soft hadronic processes



from M. Lancaster (UCL)

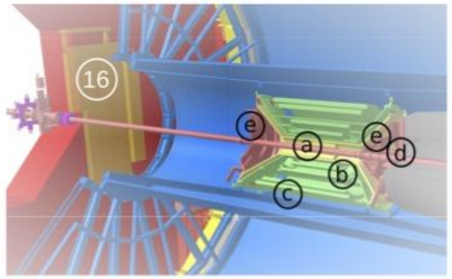
- Multiplicity-dependent measurements allow for study of interplay between soft and hard particle production mechanisms.
- Intriguing observation: multiplicity-dependent studies in small colliding systems show remarkable similarities with AA collisions - *Nature Physics* volume 13, pages 535–539 (2017)

https://indico.cern.ch/event/615153/contributions/2721637/attachments/1535786/2405810/HighPtEraAtLHCandRHIC.pdf

The ALICE Detector

10 000 t , 26 m long, 16 m high, and 16 m wide.

ITS ($|\eta| < 0.9$) - localizing the primary vertex and reconstructing the secondary vertices from the decays of hyperons and D and B meson



a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

TOF - provides charged-particle PID

TPC - tracking of charged particles and particle identification

T0 ($-3.28 < \eta < -2.97$ and $4.61 < \eta < 4.92$) - luminosity

V0 ($-3.8 < \eta < -1.7$ and $2.8 < \eta < 5.1$) - Trigger, luminosity and centrality

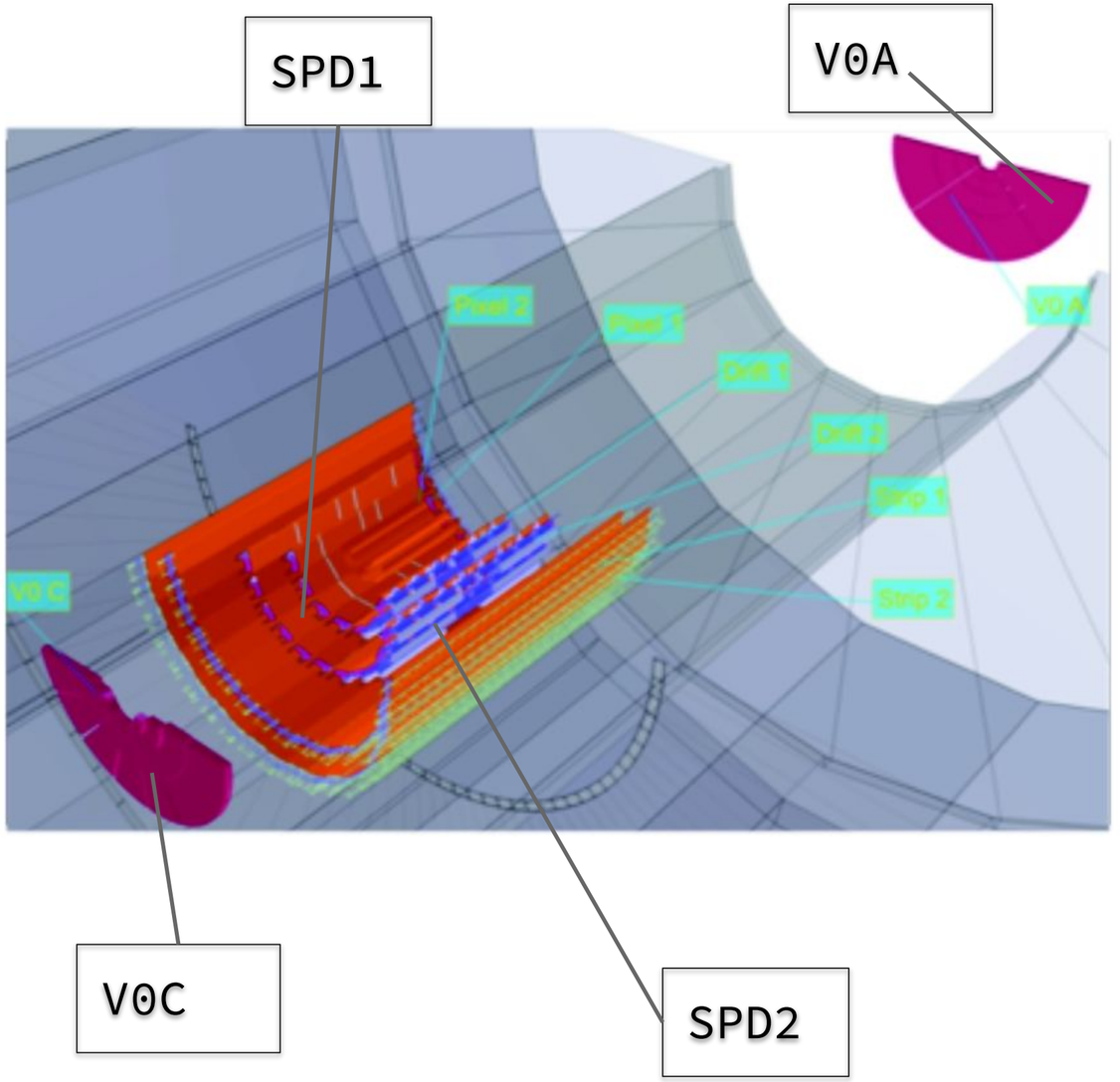
Muon Spectrometer($-4 < \eta < -2.5$)

Multiplicity Selection

Multiplicity estimators used to define event classes:

- Midrapidity : number of reconstructed tracklets in the two innermost layers of the ITS (SPD - detectors)

- Forward-rapidity : percentiles of the total V0 amplitude distribution, obtained by summing the signals of V0A and V0C detectors

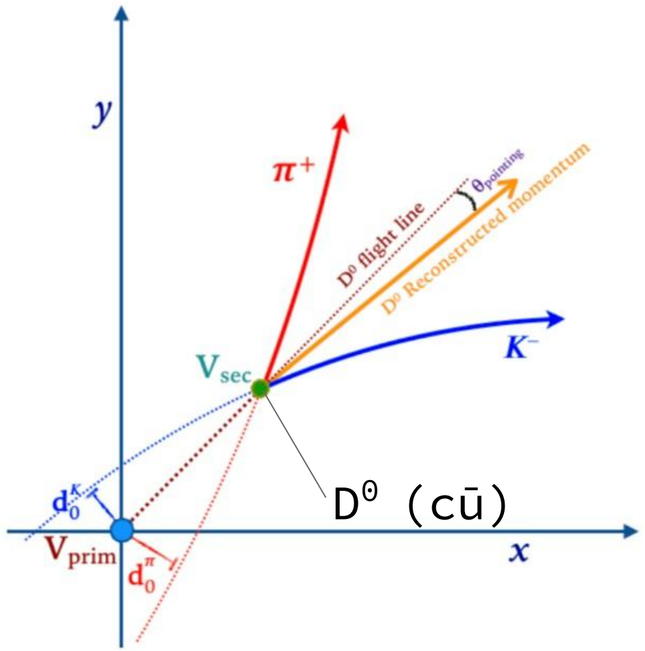


HF measurement in ALICE

- Hadronic Decay Channel

Open heavy flavour - $D^0(c\bar{u})$, $D^+(c\bar{d})$ and $D^*(c\bar{s})$

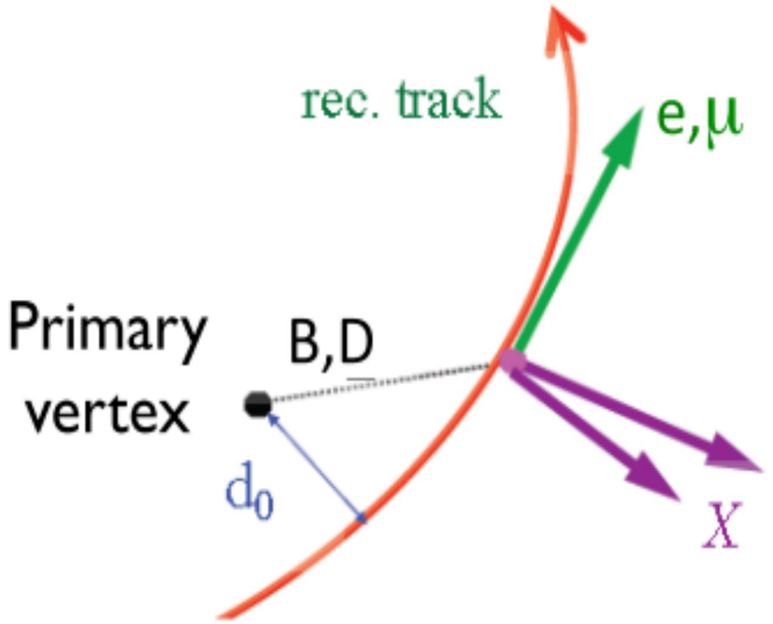
$D^0 \to \pi^- K^+$	$BR \approx 3.93\ \%$
$D^+ \to K^- \pi^+ \pi^+$	$BR \approx 9.46\ \%$
$D^{*+} \to D^0(\to K^- \pi^+)\pi^+$	$BR \approx 2.66\ \%$
$D_s^+ \to \Phi(\to K^- K^+)\pi^+$	$BR \approx 2.27\%$



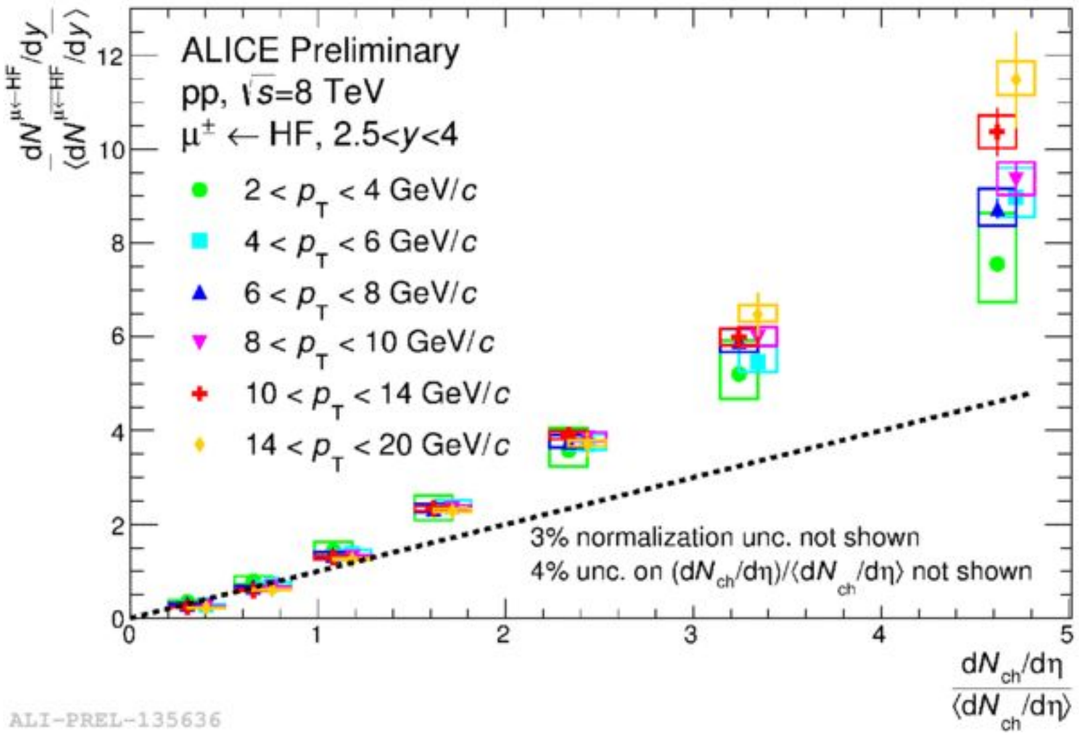
- Semi-leptonic Decay Channel

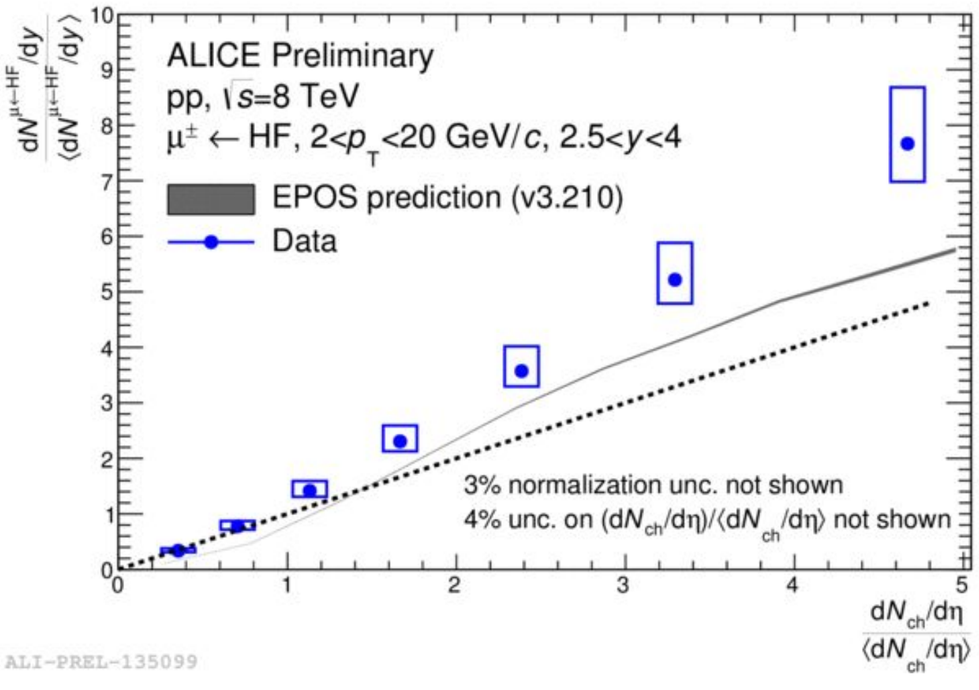
Charm -> lepton + X BR~10%
Beauty -> lepton + X BR~10%
Beauty -> charm -> lepton + X BR~9%

Quarkonia -J/ψ -> mu^+mu^-



HF muon production vs charged-particle multiplicity

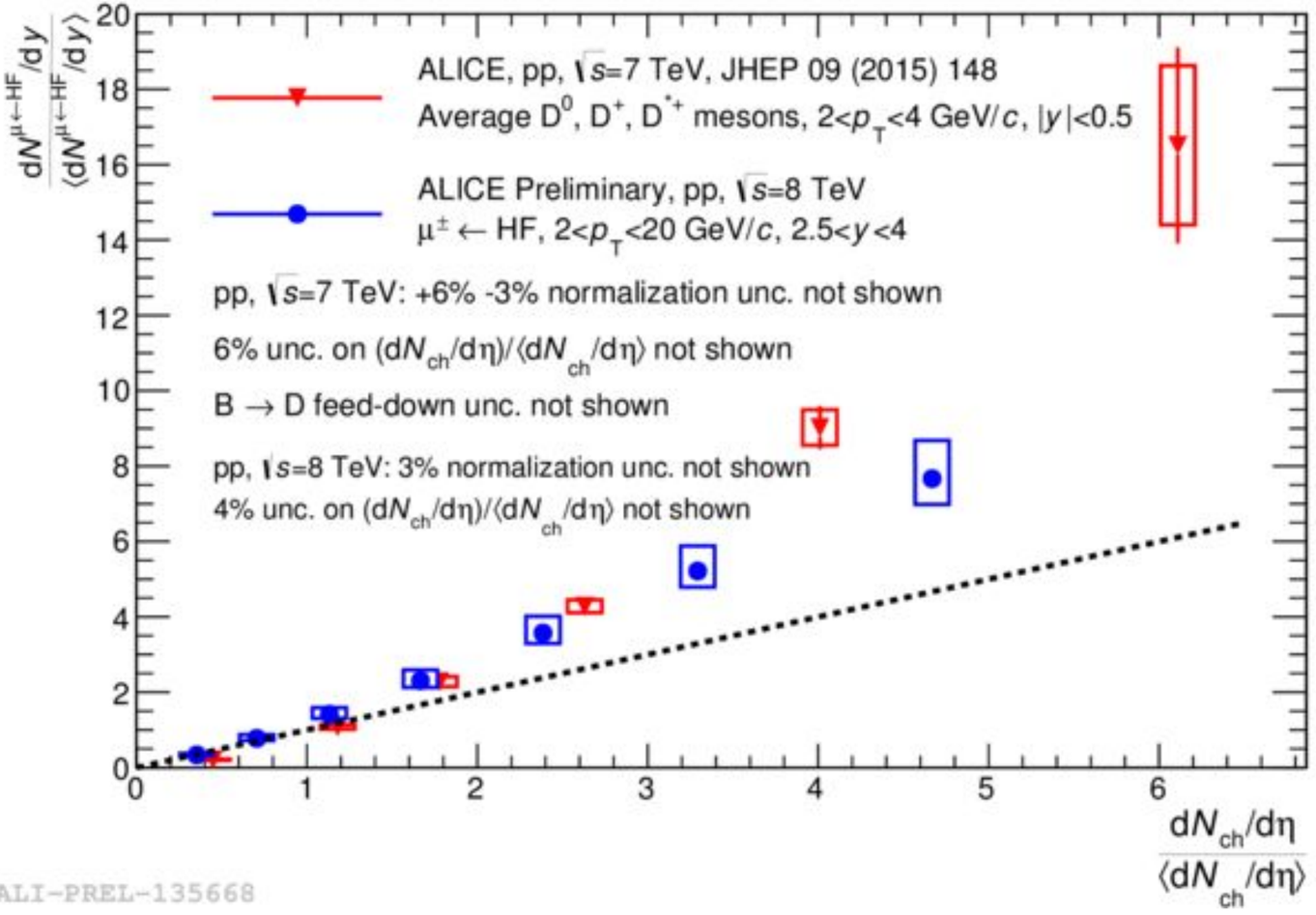




- HF vs multiplicity at √s = 8 TeV at forward rapidity (Run 1 Data).
- EPOS - is a parton model with many binary parton-parton interactions with each one creating a parton ladder.

Takes into account: 1) Initial state and; 2) includes hydrodynamic evolution (Phys. Rev. C 89, 064903 (2014).

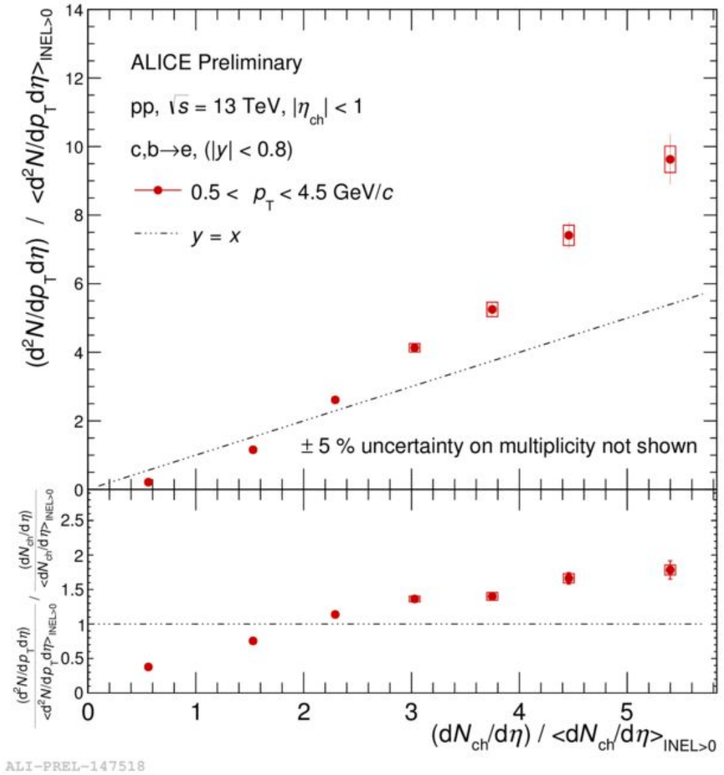
Rapidity dependence of HF production vs charged-particle multiplicity

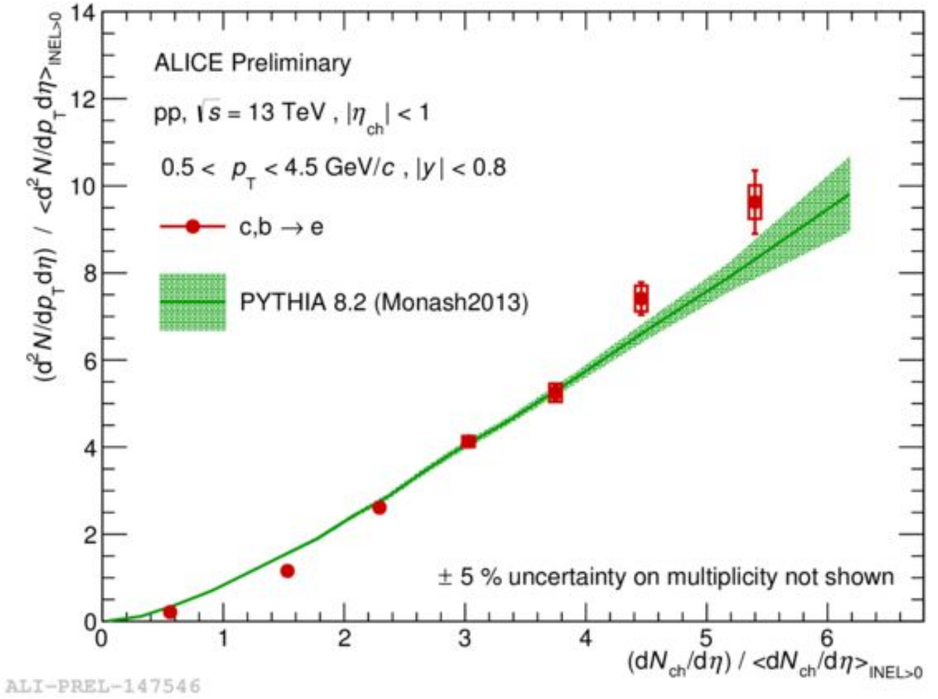


- Comparison of open charm measurements at mi-rapidity (JHEP 09 (2015) 148) and inclusive HF measurements at forward rapidity.
- The dashed line is y=x.
- Both HF decay muons reconstructed at forward rapidity and D-meson reconstructed at mid-rapidity show faster than linear increase vs multiplicity. With a larger enhancement at mid-rapidity.
- Steepness more pronounced at high multiplicity.

ALI-PREL-135668

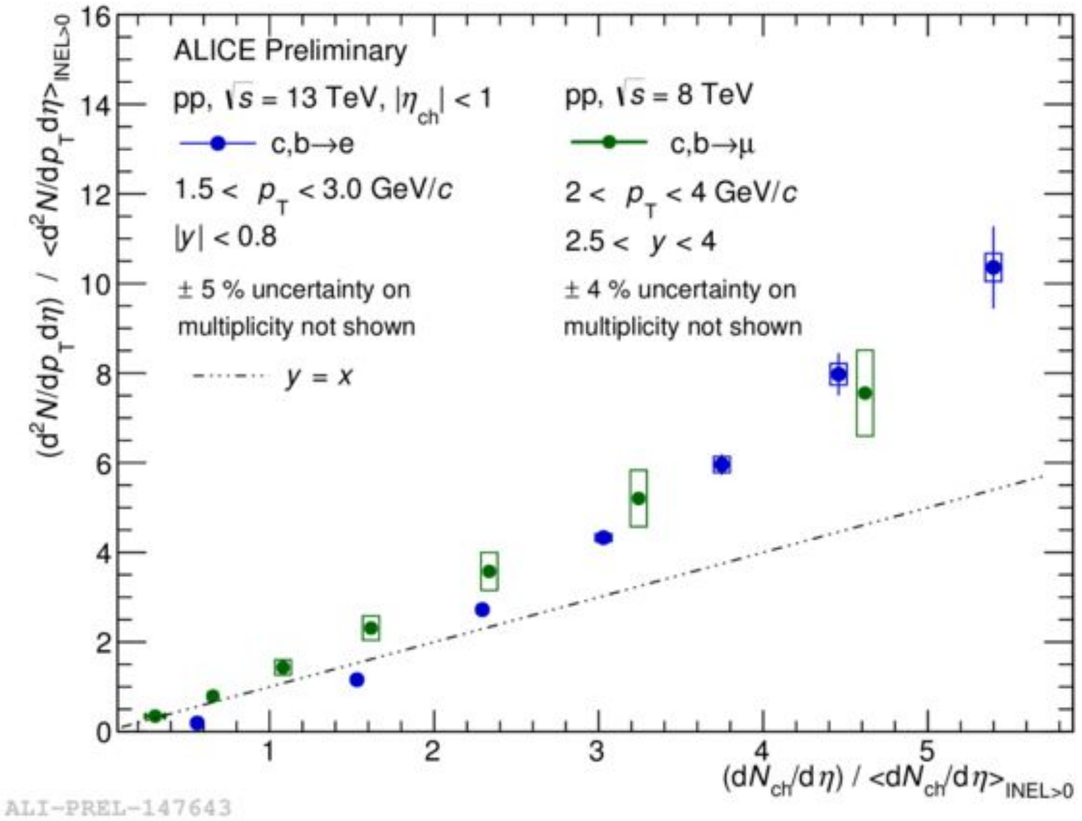
HF electron decay production vs charged-particle multiplicity





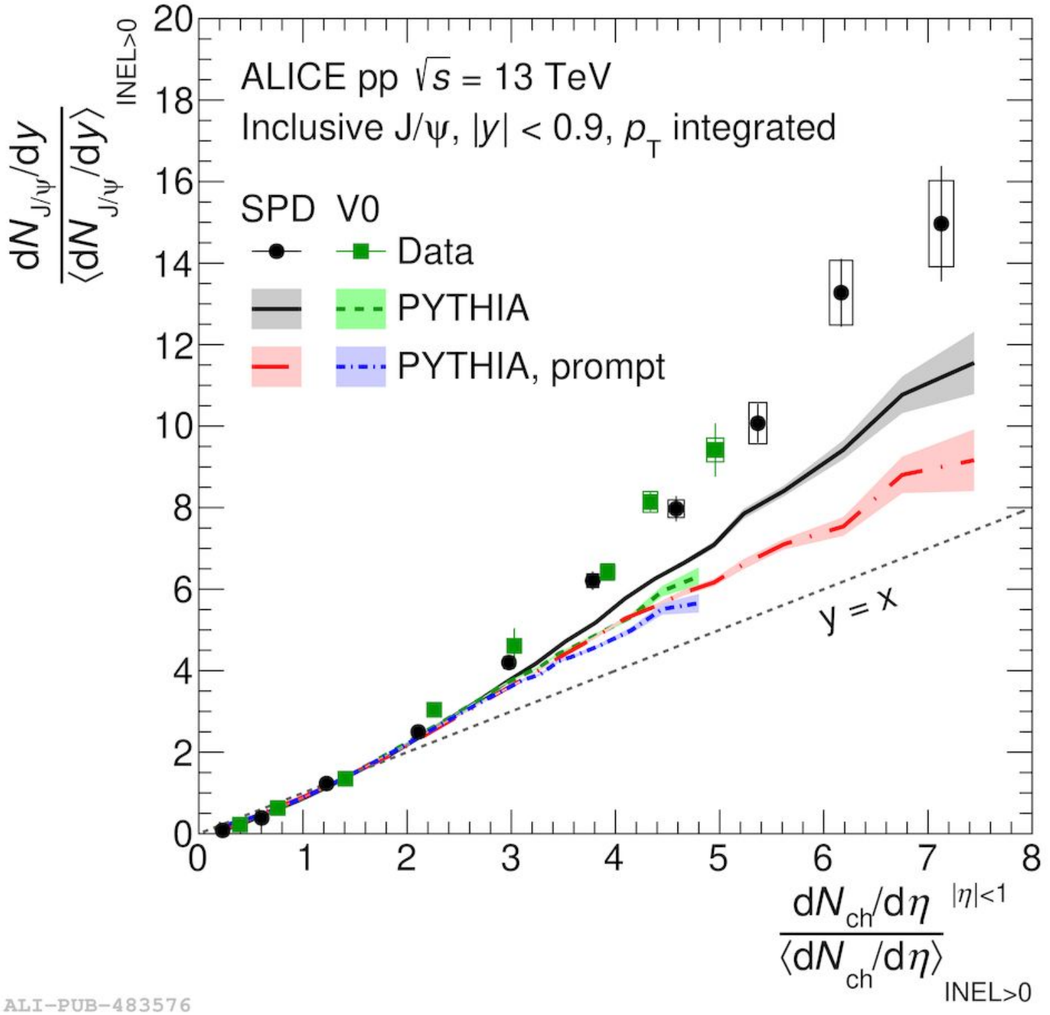
- HF electron decay production vs multiplicity at √s = 13 TeV at mid-rapidity
- Fair agreement between the theoretical model and data
- PYTHIA 8.2 (Monash 2013) - generate events in high energy collisions between elementary particle physics that comprise of a set of physics models for the evolution of few-body hard-scattering processes to a complex multi-particle final state (arXiv:1404.5630).

HF electron decay production vs charged-particle multiplicity



- Comparison of measurements at midrapidity (HF electron decay) and forward rapidity (HF muon decay).
- Faster than linear trend observed
- For HF decay electrons different trend is observed, especially at low multiplicity as compared to HF decay muons

Inclusive J/ψ production vs charged-particle multiplicity



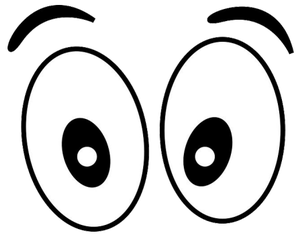
- Inclusive J/ψ production vs multiplicity at midrapidity at 13 TeV (Phys. Lett. B 810 (2020) 135758)
- Faster than linear increase of J/ψ yield with charged-particle multiplicity.
- PYTHIA8 is used to compare with data (Eur.Phys.J.C 79 (2019), 36).

ALI-PUB-483576

Summary

- Results of measurements in pp collisions at $\sqrt{s}$ = 7, 8 and 13 TeV have been shown.
- A faster than linear increase is observed in J/ψ production, HF muon and electron decay production vs multiplicity.
- A faster increase is observed in midrapidity than forward rapidity -> possible "auto-correlation" effects due to the overlapping between pseudo-rapidity regions of HF measurements and multiplicity estimator
- Theoretical models including HF-production in MPI describe qualitatively the observed trends

Outlook



- HF muon production vs multiplicity at pp collisions in $\sqrt{s}$ = 5 and 13 TeV (Run 2 Data).
- The new Muon Forward Tracker (MFT) detector will contribute to distinguish between c and b decay muons.
- High Luminosity (HL-LHC) during Run 3 will introduce more physics opportunities:
  - Charmonia at low-p_T, probe of deconfinement
  - Particle production in high-multiplicity events

ACKNOWLEDGEMENTS

- The organizers of the school

science & innovation

Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

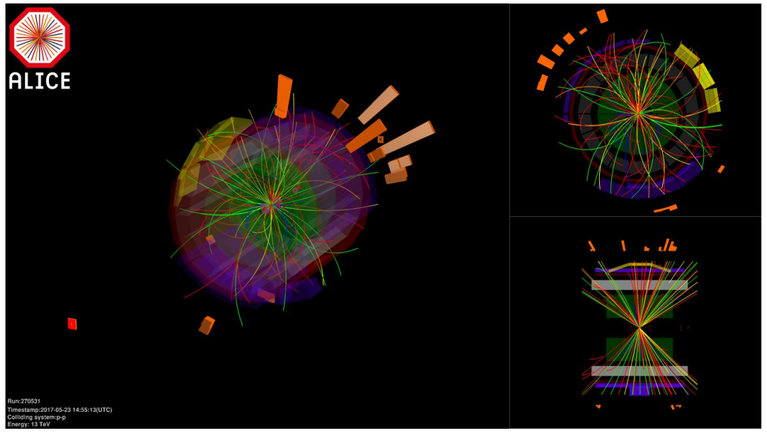
National Research Foundation

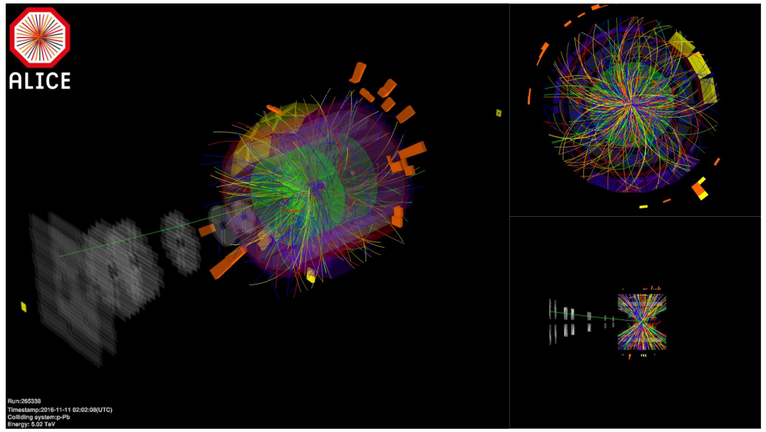
iThemba LABS
Laboratory for Accelerator Based Sciences

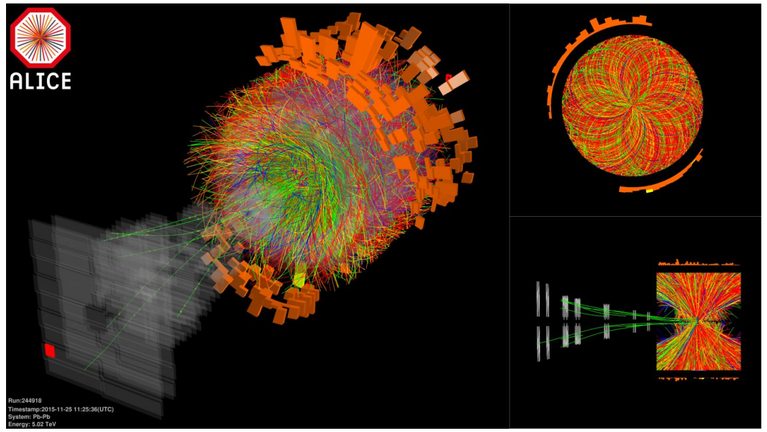
THANK YOU

Back up slides

Colliding systems at the LHC







pp collisions:

- Test pQCD theories
- Reference for p-Pb and Pb-Pb collision

p-Pb collisions:

- To assess the role of Cold Nuclear Matter (CNM) effects

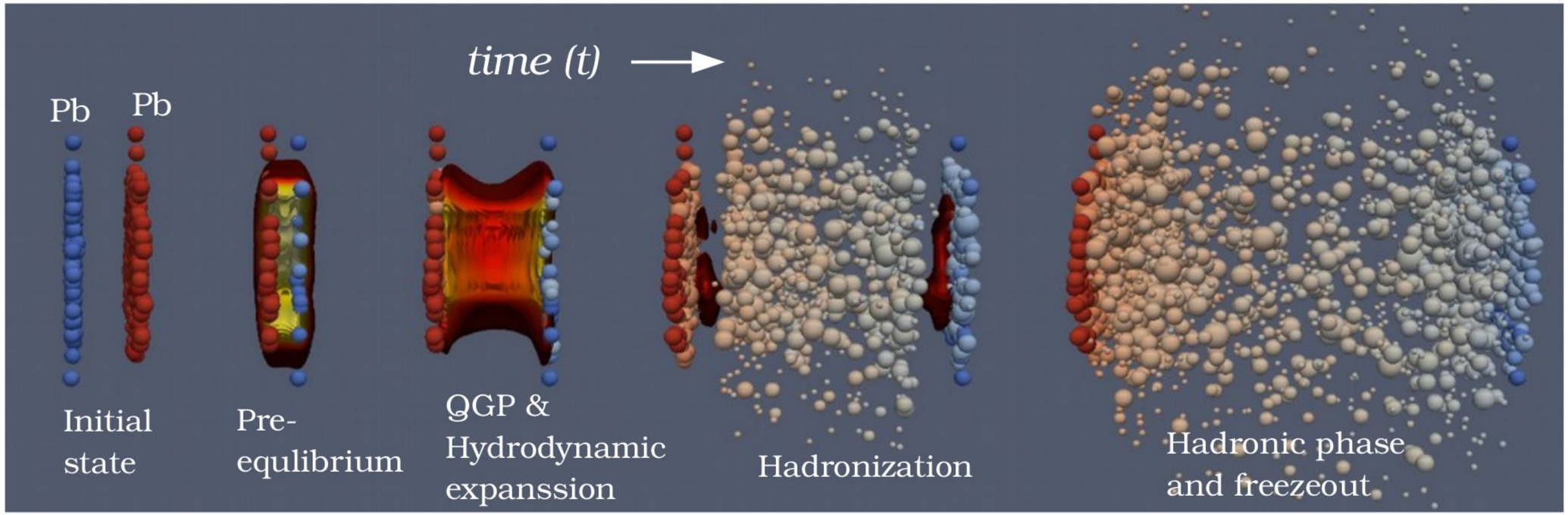
Pb-Pb collisions:

- Study the QGP and its properties

https://cds.cern.ch/record/226582 https://home.cern/news/news/accelerators/lhc-report-proton-lead-physics-begins- https://cds.cern.ch/record/210829

Heavy-Ion collisions at LHC

Time evolution of Heavy ion collisions



Deconfined quarks and gluons

High density and temp. leads to formation of QGP

Hadron formation through Fragmentation

Chemical freeze-out and Kinetic freeze-out

HF in pp collisions

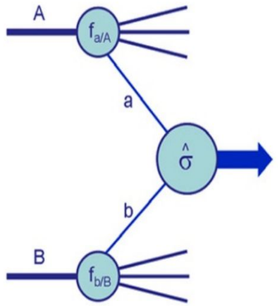
- Heavy quarks (charm and beauty) are produced in partonic scattering processes with large Q^2
- The production cross section can be determined using perturbative QCD (pQCD) calculations.

$$d\sigma^{hard}_{AB\to C} = \sum_{a,b} f_{a|A(x_a,Q^2)} \otimes f_{b|B(x_b,Q^2)} \otimes d\sigma^{hard}_{ab\to C}(x_a, x_b, q^2) \otimes D_{c\to C}(z, Q^2)$$

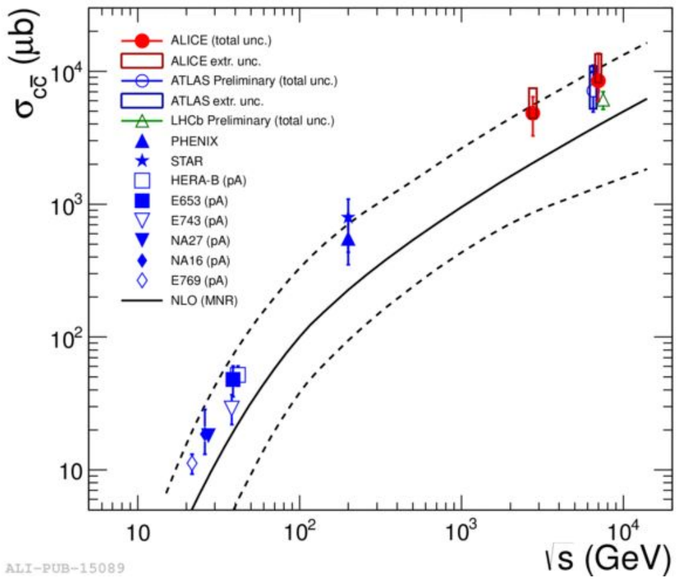
Parton Distribution Function (PDF)

Parton Hard scattering cross-section

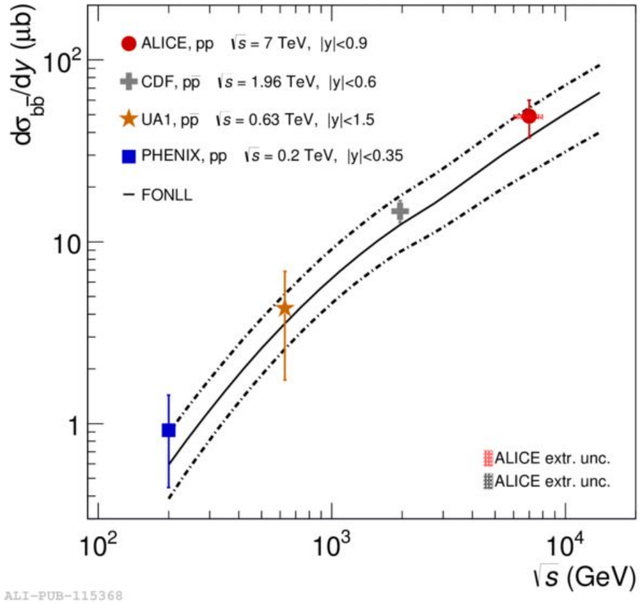
Fragmentation function



J M Campbell *et al* 2006 *Rep. Prog. Phys.* 70 89



arXiv:1205.4007



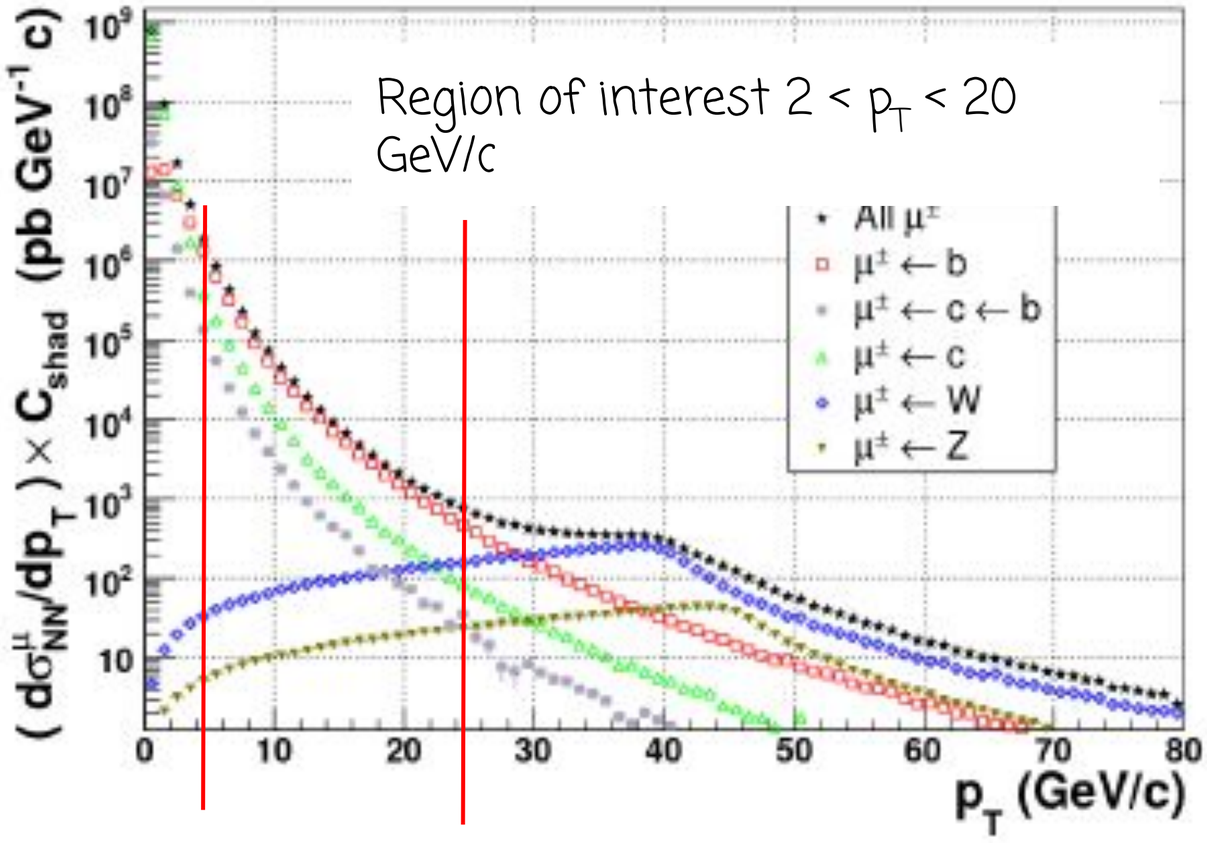
https://doi.org/10.1016/j.physletb.2013.01.069

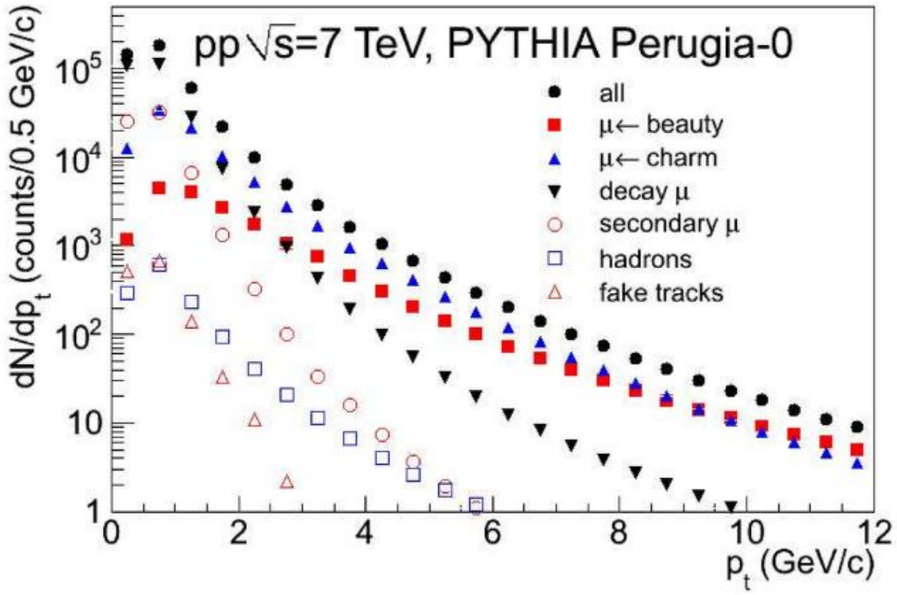
- NLO (next-to-leading order) - model for calculating the single inclusive heavy quark production cross section.
- FONLL (Fixed Order + Next-to-Lead Log) - allows one to calculate predictions for one-particle inclusive distributions of a heavy quark (charm and beauty)

https://www-conf.kek.jp/past/DIS06/transparencies/WG5/hfl-cacciari.pdf

Inclusive Single muon cross section

[Phys. Lett. B 708 (2012) 265]



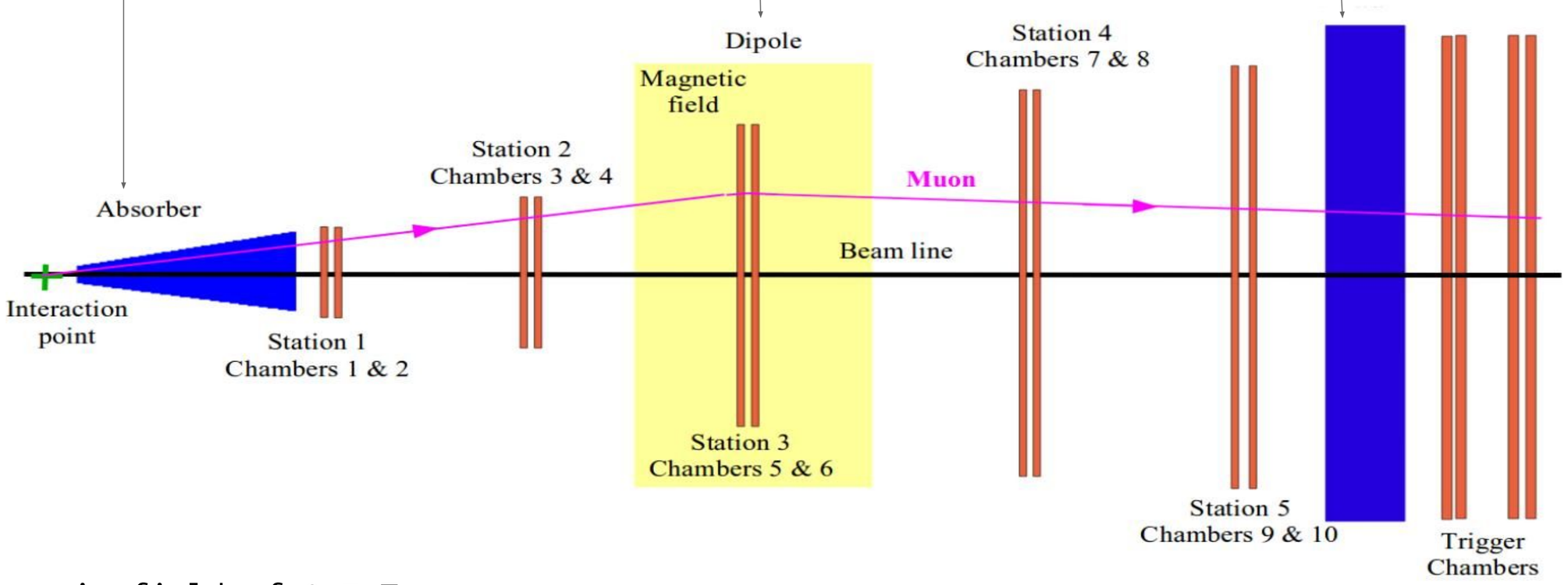


Muon Spectrometer

To minimize background from light hadrons

To determine charge and momentum

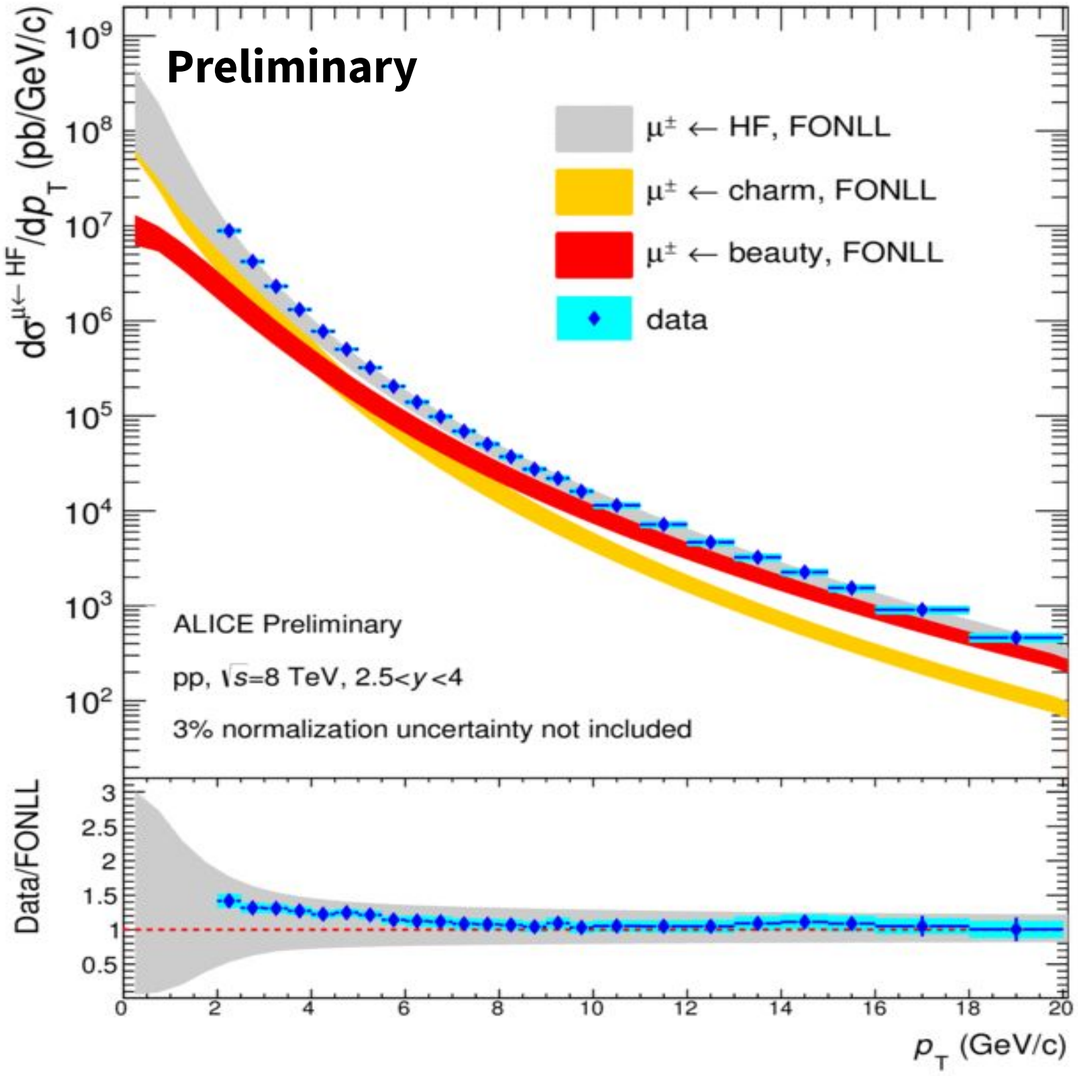
It reduces the background on the trigger stations by absorbing pions and low momentum muons



- Magnetic field of 0.7 T
- Resolution ~100 MeV/c^2
- p > 4 GeV/c.
- MSL: single muon low p_T (≥ 0.5 GeV/c)
- MSH: single muon high p_T (≥ 4.2 GeV/c)

To trigger muons of interest

Heavy-flavour measurements in pp collisions



- The production cross section of HF decay electrons and muons (c,b→**μ**) in pp collisions at √s= 8 TeV, compared to the FONLL pQCD model calculations
- Data reproduced by theoretical calculations within uncertainty.
- Muons from charm decays dominate the low p_T region while those from beauty dominate the high p_T region