Measurement of Heavy Flavour Production via Single Muons with ALICE

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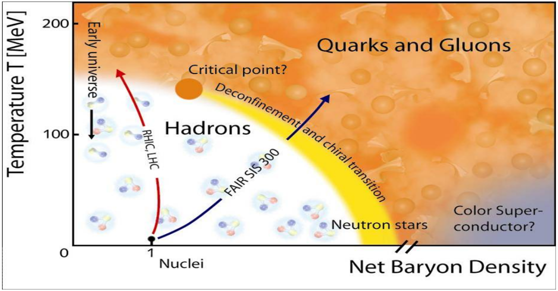
Study of the Quark Gluon Plasma at LHC Energies



- Study of the Quark Gluon Plasma (QGP) should help understanding the properties of the hadronic matter under extreme conditions of temperature and density.
- heavy ion collisions are the only way to study the QGP properties in laboratory.

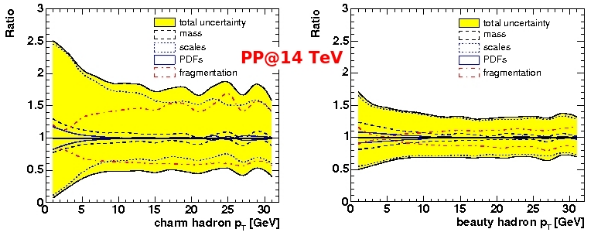
- Super Proton Synchroton (SPS), CERN (1986∼2003), Pb-Pb collisions+other system;
- Relativistic Heavy Ion Collider (RHIC), BNL (2000∼20*xx*), Au-Au collisions+other system;
- Large Hadron Collider (LHC), CERN (2010∼20*xx*), Pb-Pb collisions+other system.

center coll.	$\sqrt{s_{NN}}$ [GeV]	$\frac{dN}{dy}\|_{y=0}$	τ^0_{QCD} [fm/c]	T_{QGP}/T_c	ϵ [GeV/fm^3]	τ_{QGP} [fm/c]	τ_f [fm/c]	V_f [fm^3]
SPS	6.3∼17.3	500	1	1.1	3	≤ 2	∼10	$\sim 10^3$
RHIC	62∼200	850	0.2	1.9	5	2∼4	20∼30	$\sim 10^4$
LHC	2760∼ · · ·	1600∼2000(?)	0.1	3∼4.2	15∼60	≥ 10	30∼40	10^5

The LHC, with $\sqrt{s_{NN}} = 2.76$ TeV (nearly 14 times larger than that reached at RHIC), opened a new era for studying the properties of strongly interacting matter under extreme thermodynamical conditions!

Motivations: Open Charm & Bottom in pp Collisions

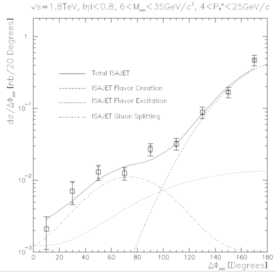
Test NLO pQCD Calculations



HvQMNR prediction: *hep-ph*/0601164

- Large theoretical uncertainties on cross section predictions;
- similar uncertainties expected at 7 TeV (M. Cacciari).

Unravel NLO Processes



D. L. Vititoe, PhD, D0 *exp*. (1996)

References for Normalization

- $\sigma^{D/B}$ in pA and AA collisions;
- $\sigma^{J/\Psi,\ \Upsilon}$ in pp, pA and AA, production, absorption, suppression or recombination?
  obtain the information on the thermodynamical state of QCD medium: E_c, T_c.
- ratio of $N^{J/\Psi \leftarrow B}/N^{\mathrm{direct}J/\Psi}(10 \sim 20\%?$ in $4\pi)$.

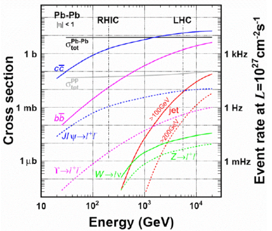
Motivations: Open Charm & Bottom in *pA* & *AA* Collisions

HF in *pA* Collisions

- initial state radiations;
- shadowing & anti-shadowing;
- k_t broadening of partons;
- color glass condensate (CGC).

Tomography of QCD Medium in AA Collisions:

1. HF produced at the beginning of interaction: $\tau \sim 1/m_{Q\bar{Q}} \lesssim 0.1$ fm/c;
2. open heavy flavour quenching in QCD medium:
   - $R_{AA}(p_t, \eta) = \frac{1}{<N_{\rm coll}>} \times \frac{d^2 N_{AA}/dp_t d\eta}{d^2 N_{pp}/dp_t d\eta}$, medium induced gluon radiation,
   - $\frac{R^D_{AA}(p_t)}{R^h_{AA}(p_t)}$, color charge effect of parton energy loss,
   - $\frac{R^B_{AA}(p_t)}{R^h_{AA}(p_t)}$, mass dependence of parton energy loss in high p_t region;
   - $\frac{R^B_{AA}(p_t)}{R^D_{AA}(p_t)}$, isolate mass dependence.



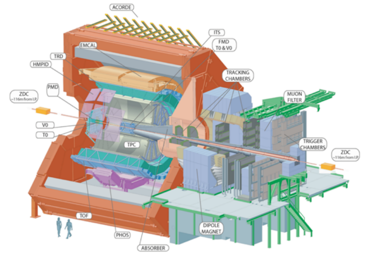
Large HF production rate @ LHC!

Heavy Ion Physics Program with ALICE at the LHC

- There are 6 experiments at LHC: ATLAS, CMS, LHCb, LHCf, TOTEM & ALICE;
- ALICE (A Large Ion Collider Experiment) is dedicated to heavy ion collisions at the LHC.

Main Physics Topics at ALICE

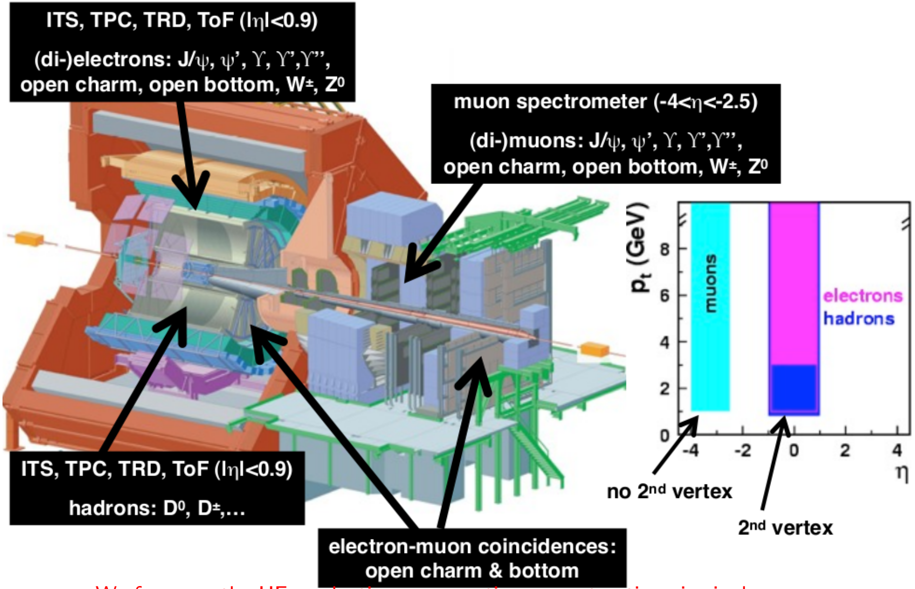
- global characteristics of events – mult & η dist;
- collective effects – elliptic flow;
- fluctuations & critical behaviour – E-by-E particle composition and spectra;
- geometry of the emitting source – HBT, zero degree energy flow;
- chiral symmetry restoration – neutral to charged ratios, resonance decays;
- deconfinement – charmonium and bottomonium;



- degree of freedom vs. T – hadron ratios & spectra, direct photons, dilepton continuum;
- energy loss of partons in QGP – jet quenching, high p_t spectra, open charm & bottom;

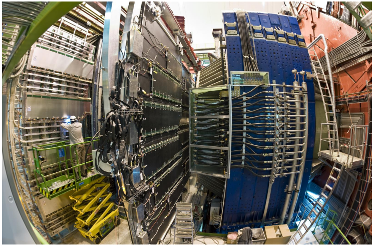
Heavy quarks provide a rich physics program at the LHC!

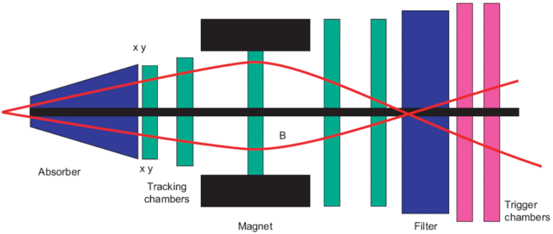
Heavy Flavours with ALICE



We focus on the HF production cross section reconstruction via single muons.

The ALICE muon Spectrometer

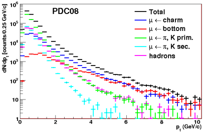


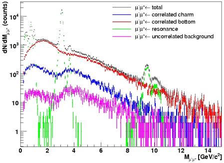


1. **Front Absorber:** reduces hadron yield & decreases decay μ yield by limiting the free path of primary K/π.
2. **Magnet Dipole:** 3 Tm integrated field perpendicular to the beam axis.
3. **Tracking System:**
   - multi-wire CPC with 1.1 M readout channels,
   - position resolution $\lesssim$ 100 μm $\Rightarrow \sigma_M \sim$ 100 MeV/c^2 @ 10 GeV/c^2(separation of Υ states).
4. **Trigger System:**
   - RPC with 21000 readout channels;
   - time resolution $<$ 2 ns, decision in $<$ 800 ns, L0 dimuon trigger$<$ 1 kHz in PbPb collisions;
   - two programmable trigger p_t cuts among,
     $p_t \sim$ 0.5 GeV/c (min) $p_t \sim$ 1 GeV/c (J/Ψ) $p_t \sim$ 2 GeV/c (Υ).
5. **MUON Filter:** stop hadrons and low p_t muon track.
6. **Data taking rate:** $<$ 1 kHz (DAQ bandwidth & tracking chamber readout).

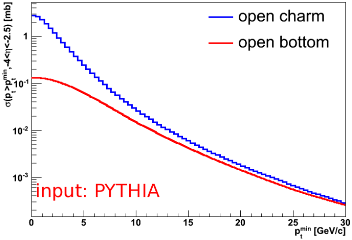
Strategy of Measurement $\sigma^{B/D}$ in pp via (di)muons

pp @ 14 TeV simulation





$\Rightarrow$



1. Background subtraction;
2. extract $N_{pp}^{\mu^{\pm}/\mu^{-}\mu^{+}\leftarrow HF}$;
3. correct for integrated luminosity, detection efficiency & acceptance;
4. obtain $\sigma_{pp}^{\mu\leftarrow HF}$;
5. disentagling charm & bottom components;
6. correct for decay kine.;
7. get differential inclusive B & D hadron cross sections.

$$\sigma^{B/D}(p_t > p_t^{min}, -4 < \eta < -2.5) = \frac{N_{\mu^{\pm}/\mu^{-}\mu^{+}\leftarrow B/D}(\Phi^{\mu^{\pm}/\mu^{-}\mu^{+}})}{\int Ldt} \times \frac{1}{\epsilon} \times \left[\frac{\sigma^{B/D}(p_t > p_t^{min})}{\sigma^{B/D}(\Phi^{\mu^{\pm}/\mu^{-}\mu^{+}})}\right]_{MC}$$

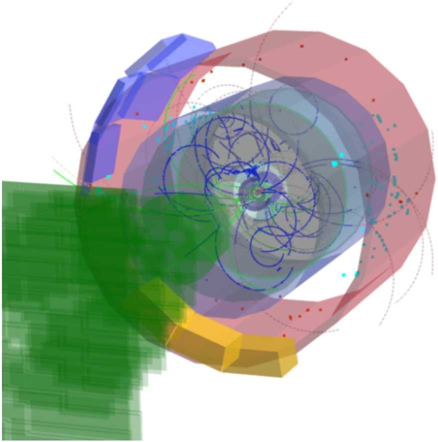
*$\Phi^{\mu^{\pm}/\mu^{-}\mu^{+}}$ denotes a special kinematic phase space of $\mu^{\pm}/\mu^{-}\mu^{+}$.

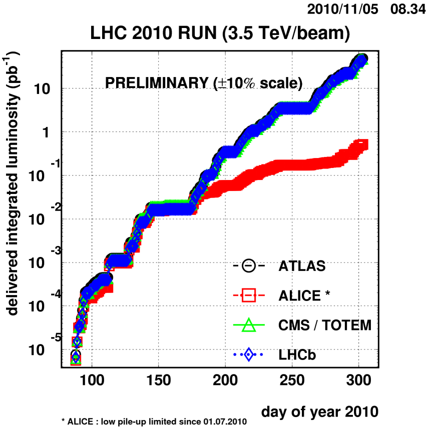
Method widely used and well documented

- **UA1:** $p\bar{p}$ colissions @ $\sqrt{s} = 0.63$ TeV, single muons and dimuons, C. Albajar *et. al.*, PLB 213 (1988) 405.
- **CDF:** $p\bar{p}$ colissions @ $\sqrt{s} = 1.8$ TeV, single electrons, F. Abe *et. al.*, PRL 71 (1993) 4.
- **D0:** $p\bar{p}$ colissions @ $\sqrt{s} = 1.8$ TeV, single muons and dimuons, B. Abbott *et. al.*, PLB 487 (2000) 264-272.

Note: disentangling charm and bottom components has never been achieved with such a method in the past.

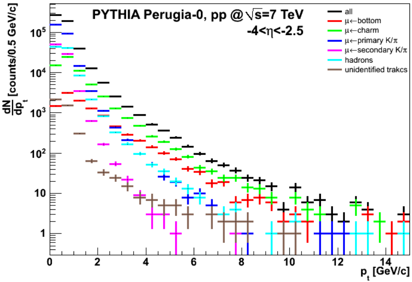
Run Condition in *pp* data @ LHC 2010

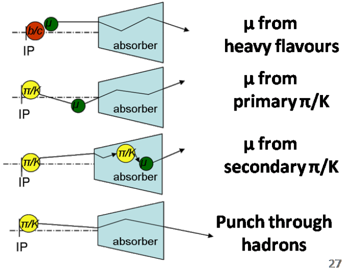




$\sim 1.2 \times 10^9$ min-bias triggered events and $\sim 1.3 \times 10^8$ MUON triggered events in 2010 data taking of *pp* collisions @ $\sqrt{s} = 7$ TeV.

Strategy of $\mu^{\pm} \leftarrow$HF Extraction in *pp* data @ 7 TeV





Road Map

1. Event and track selection;
2. background subtraction;
3. correction for the acceptance and reconstruction efficiency;
4. obtain muon p_t spectrum from HF, $dN^{\mu \leftarrow HF}/dp_t|_{-4<\eta<-2.5}$;
5. convert muon p_t spectrum to muon differential cross section, $d\sigma^{\mu \leftarrow HF}/dp_t|_{-4<\eta<-2.5}$.

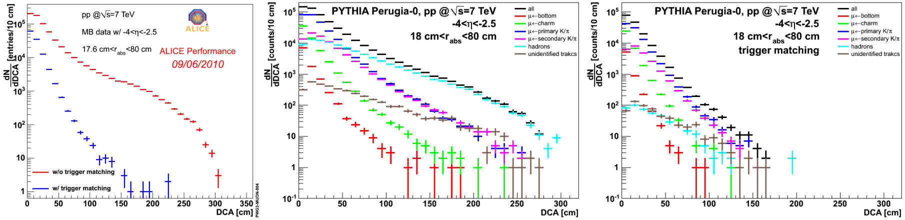
Event and Track Selection for Data in pp @ 7 TeV

Event Selection

- Select INEL events with minimum-bias trigger or MUON trigger.

Track Selection

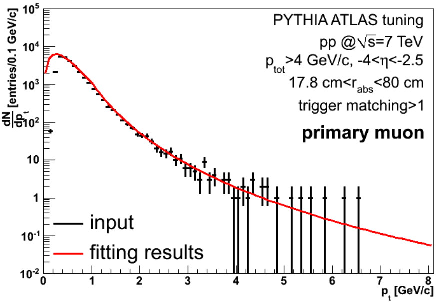
- from reconstructed vertex, improve the precision of track kinematics;
- $-4 < \eta < -2.5$, select tracks in ALICE/MUON acceptance;
- $171^\circ < \theta_{abs} < 178^\circ$, cut off radius at the end of front absorber, avoid multi-scattering effect from different materials;
- matching with MUON trigger, remove punch-through hadrons.

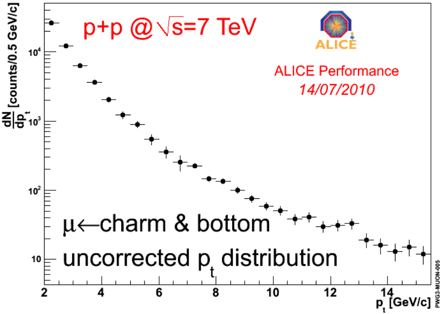


- MUON trigger system very effective to reject the hadronic component;
- after event and track selection, the main background is $\mu \leftarrow$primary K/π (in $p_t > 2$ GeV/c).

$\mu \leftarrow$Primary K/π Subtraction: Using Simulated Shapes

- Assume the shape of the p_t distribution of $\mu \leftarrow$primary K/π is described by models;
- get the p_t shape of primary muons from MC predictions;
- get the ratio $R^{MC}(\eta) = \frac{N_\mu^{\mathrm{primary}}}{N_\mu^{\mathrm{total}}}|_{low\ p_t}$ in different η regions;
- normalize the MC shape to the data according to the value of $R^{MC}(\eta)$ in each η region;
- subtract the normalized primary muons from data.





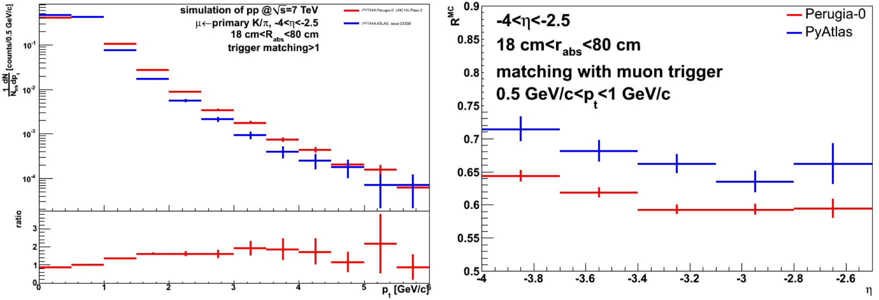
We focus on the region in $p_t > 2$ GeV/c, the contribution of secondary muons can be neglected.

$\mu \leftarrow$Primary K/π Subtraction: Systematic Error Estimation

- The systematic error on primary muon subtraction includes the systematic error from R^{MC} and that from p_t shape of primary muons;
- the systematic error from R^{MC} depends on the different MC models and different transport codes (Geant3, Geant4 and Fluka $\cdots$).

$$\sigma(primary\ \mu\ sub) = \sigma(R^{MC}) \oplus \sigma(shape\ p_t^{MC}), \sigma(R^{MC}) = \sigma(model) \oplus \sigma(transport\ code)$$

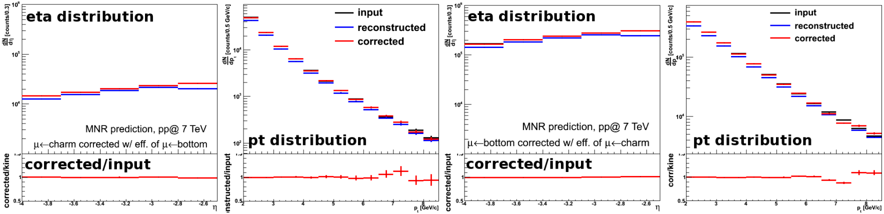
Pythia Perugia-0 tuning, Pythia ATLAS-CSC tuning



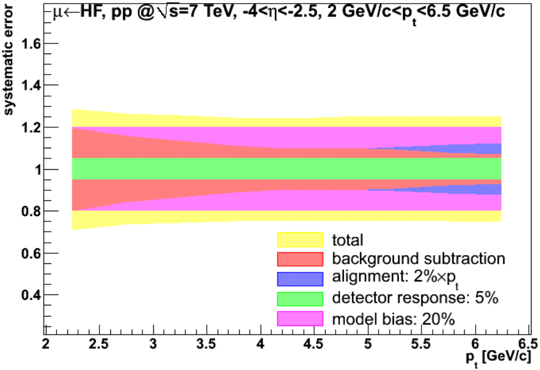
- The systematic uncertainty from different transport codes is estimated by adjusting the yield of the secondary muons within $\pm 100\%$.

Detection and acceptance Efficiency Correction

- 2D (η & p_t) correction is applied;
- correction matrices (eff_{corr}) are built by $\mu \leftarrow$charm & $\mu \leftarrow$bottom via MNR predictions;
- systematic error is estimated by comparing the corrected result from $eff_{corr}^{\mu\leftarrow\mathrm{charm}}$ and that from $eff_{corr}^{\mu\leftarrow\mathrm{bottom}}$.

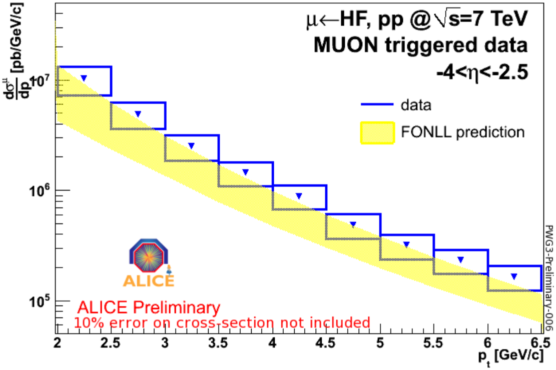


- the correction efficiency is not sensitive to the p_t shapes of muons in $p_t > 2$ GeV/c;
- the differences between the corrected results via $eff_{corr}^{\mu\leftarrow\mathrm{charm}}$ and that via $eff_{corr}^{\mu\leftarrow\mathrm{bottom}}$ in data $< 1\%$;
- the systematic error from efficiency correction can be neglected.



- background subtraction: from 20% to 7% with p_t;
- alignment: $2\% \times p_t$;
- detector response: 5%;
- model bias: 20%;
- min-bias cross section: 10% (not included);
- total: from 29% ($p_t = 2$ GeV/c) to 24.4% ($p_t = 6.5$ GeV/c).

with $\mathcal{L}_{\text{int}} = 3.49\ \text{nb}^{-1}$



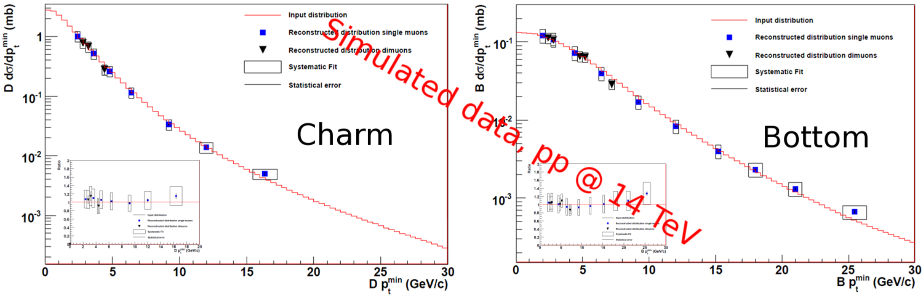
Recent Updates:

- analysis of the whole 2010 statistics w/ new detector aligment;
- using the updated σ_{pp}^{MB} ($\sim$ 12% lower);
- get differential $\sigma^{\mu \leftarrow HF}$ in given p_t & η regions;
- measured the $\sigma^{\mu \leftarrow HF}/dp_t$ up to 15 GeV/c in different η regions;
- improve the estimation of the systematics errors;
- new results are expected to be shown at QM2011 conference.

The pQCD (FONLL) calculation reproduces well the shape and is in agreement with data within errors.

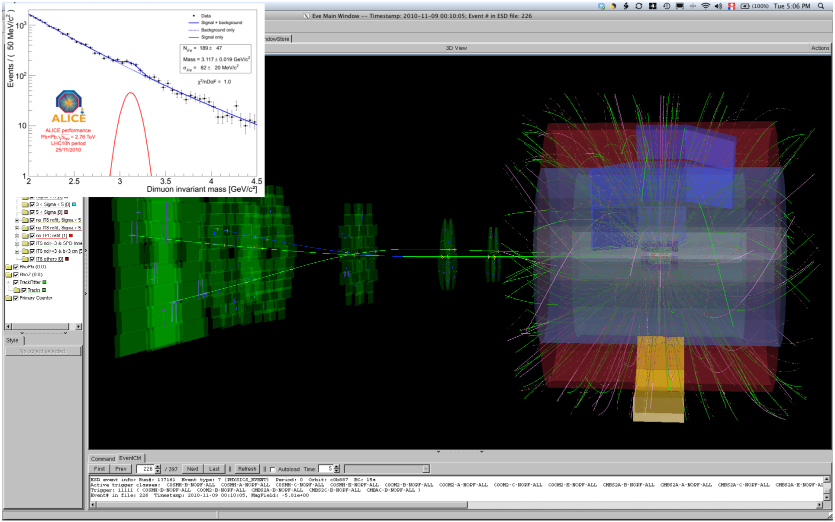
Outlook: $\sigma^{B/D}$ in *pp* @ 14 TeV via (di)muons

- disentangle open charm & bottom components, $d\sigma^{\mu\leftarrow D/B}/dp_t|_{-4<\eta<-2.5}$;
- from muon cross sections to open charm & bottom hadron cross sections, $d\sigma^{D/B}/dp_t|_{-4<\eta<-2.5}$.



- input distributions are well reconstructed;
- nice agreement between single muon and dimuon channels;
- systematic errors are 20% for B and D in the single muon channel and, 15% for B and 20% for D in the dimuon channel;
- 92% (33%) of σ^B (σ^D) is reconstructed via single muons and, 84% (34%) of σ^B (σ^D) is reconstructed via dimuons;
- this analysis procedure is currently applied to *pp* data at 7 TeV.

PbPb data @ $\sqrt{s_{NN}} = 2.76$ TeV



Muon R_{CP} and R_{AA} in PbPb collisions at 2.76 TeV: work in progress.

Summary of My Activities (2010∼now)

Co-PhD Student of FCPPL:

- between: Institute of Particle Physics, Huazhong Normal University, Wuhan, China
  Laboratoire de Physique Corpusculaire, Université Blaise Pascal et IN2P3/CNRS, Clermont-Fd, France;
- Supervisors: Daicui Zhou (China), Philippe Crochet & Nicole Bastid (France);
- work within the ALICE-MUON Collaboration;
- scholarship is supported partially by a grant from the France-China embassy.

1. publications (with direct contribution),
   - ALICE note: ALICE-INT-2010-004,
   - ALICE note: ALICE-INT-2011-XXX,
   - Chinese Phys., **C34** (9):1538, 2010,
   - proceeding for Bormio Winter Workshop, to be published;
   - measurement of $\sigma^{\mu \leftarrow HF}$ in pp collisions @ $\sqrt{s} = 7$ TeV, in preparation;
2. presentations:
   - ALICE Physics Week, Paris, France, May 17-21, 2010,
   - Rencontres QGP-France 2010, Etretat, France, September 20-23, 2010,
   - First ReteQuartonii Workshop, Nantes, France, October 25-28, 2010,
   - XLIX International Winter Meeting on Nuclear Physics, Bormio, Italy, January 24-28, 2011,
   - LHCC Students' Poster Session, CERN, March 23, 2011,
   - oral talk at Quark Matter 2011, approved by ALICE (abstract to be submitted to QM2011);
   - several talks in ALICE-PWG3 & ALICE-MUON meetings;
3. Paper Committe Member in ALICE:
   - "Heavy flavour production in the single muon channel in proton proton collisions at $\sqrt{s} = 7$ TeV, measured with the ALICE detector",
   - "Heavy flavour production in the single muon channel in PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV, measured with the ALICE detector";
4. Shifts for the trigger of the ALICE-MUON spectrometer.

Conclusion & Outlook

Conclusion

- The differential production cross section as a function of p_t of muons from HF has been measured in 2 GeV/c$< p_t <$ 6.5 GeV/c, $-4 < \eta < -2.5$;
- results are consistent with the FONLL predictions within errors.

Outlook

- Use other methods to subtract primary muons for cross check;
- separation of D and B meson decay muon cross sections;
- calculate R_{CP} & R_{AA} in PbPb collisions @ 2.76 TeV;
- single muon flow analysis in forward region.

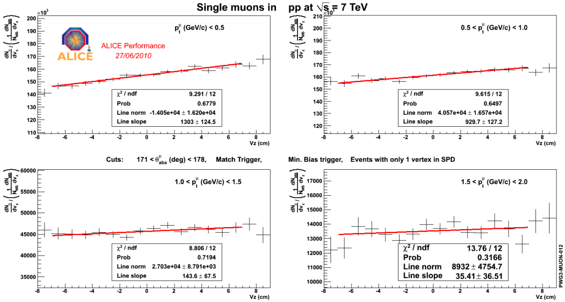
Thanks!

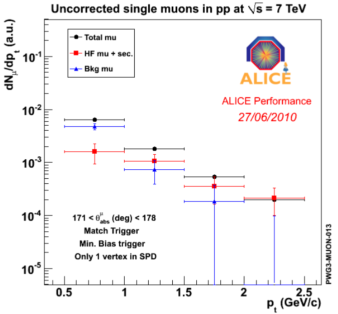
Backup

Outlook: $\mu \leftarrow$Primary K/π Subtraction: Vertex Unfolding Fitting

$$\frac{d^2 N_\mu}{dp_t dv_z} = \frac{d^2 N_\mu^{c/b}}{dp_t dv_z} + \frac{d^2 N_\mu^{primary\ K/\pi}}{dp_t dv_z} + \frac{d^2 N_\mu^{secondary\ K/\pi}}{dp_t dv_z} (neglected)$$

$$\frac{1}{\rho(v_z)} \frac{d^2 N_\mu}{dp_t dv_z} \sim \frac{d^2 N_\mu^{c/b}}{dp_t dv_z} + (L + v_z) \times \left(\frac{1}{L + \langle v_z \rangle} \frac{d^2 N_\mu^{primary\ K/\pi}}{dp_t dv_z}\right)$$





- Method has been already successfully tested on simulations;
- expected linear increase of muon yield w/ the vertex position evidenced with data;
- high statistics is needed.
- the method is not used in the results shown in the following.