Heavy Flavour Physics with the ALICE Muon Spectrometer at the LHC

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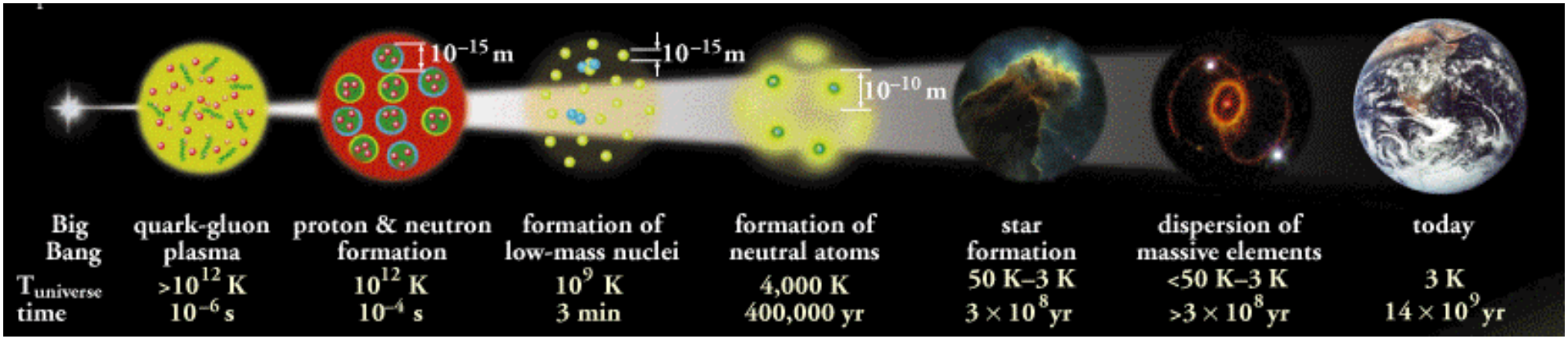
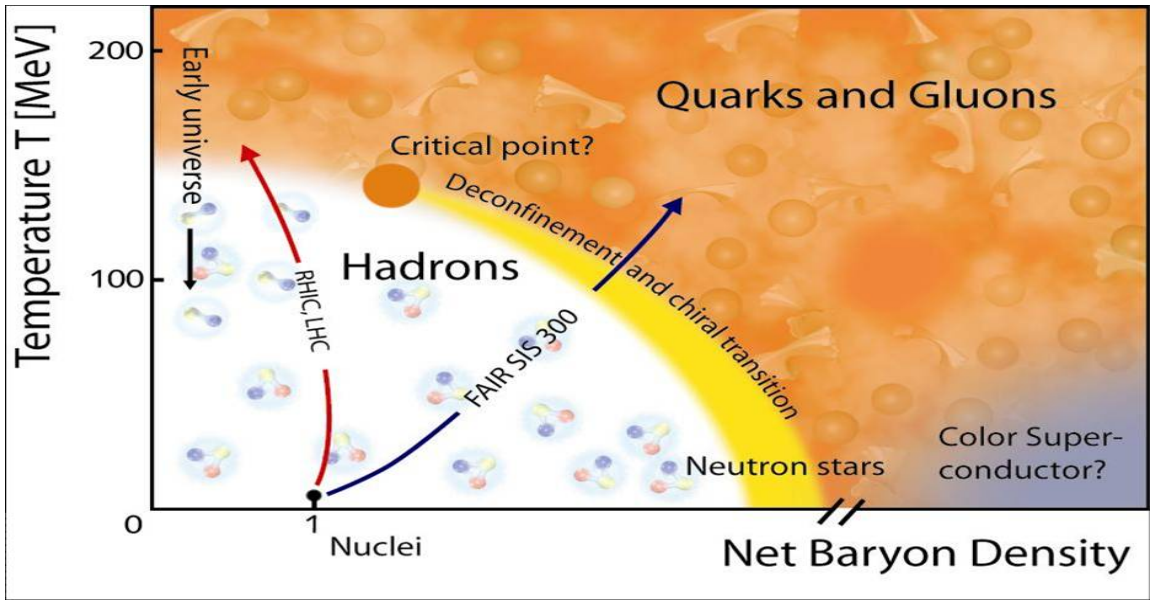
1. Heavy Flavour & Lepton Physics with ALICE at the LHC
2. Heavy Flavour Measurement via (di)muons in pp Collisions
3. Analysis Code Development for Heavy Flavour Measurement via (di)muons
4. Analysis of First pp Data at 900 GeV in the MUON spectrometer
5. Summary of My Activities
6. Conclusions

Study of the Quark Gluon Plasma at LHC Energies





- free quarks & gluons exist $\simeq 10^{-6}$ s after the Big Bang;
- in normal world, they are confined in the hadrons;
- study of the Quark Gluon Plasma (QGP) should help to reveal the origin of the Universe and the strong interaction properties;
- heavy ion collisions is the only way to study QGP properties in laboratory.

- the LHC, with $\sqrt{s_{\rm NN}} = 5.5$ TeV (nearly 30 times larger than that reached at RHIC), will open a new era for studying the properties of strongly interacting matter under extreme thermodynamical conditions!

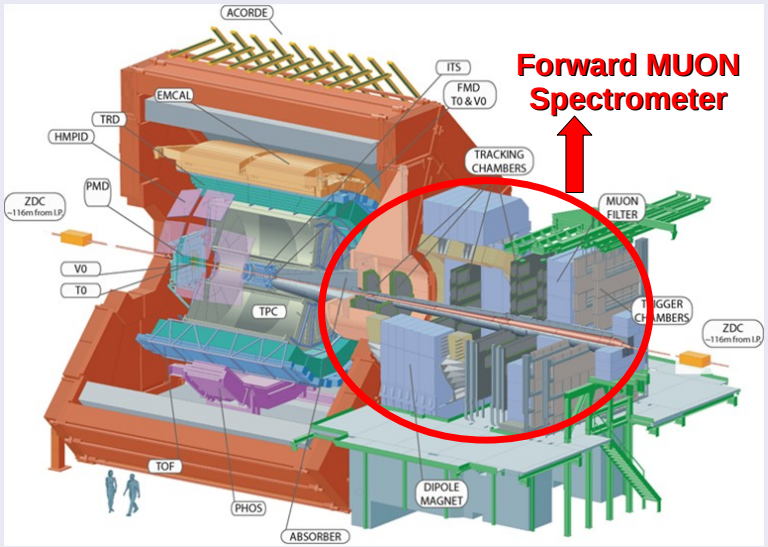
Heavy Ion Physics Program with ALICE at the LHC

- The LHC provides the biggest step in energy in the history of heavy ion collisions;
- ALICE is the only experiment focussed on heavy ion collisions at LHC;

center col.	$\sqrt{s_{\rm NN}}$ [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	17	500	1	1.1	3	$\leq$2	$\sim$10	$\sim 10^3$
RHIC	200	850	0.2	1.9	5	2$\sim$4	20$\sim$30	$\sim 10^4$
LHC	5500	2000$\sim$4000	0.1	3$\sim$4.2	15$\sim$60	$\geq$10	30$\sim$40	10^5

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;

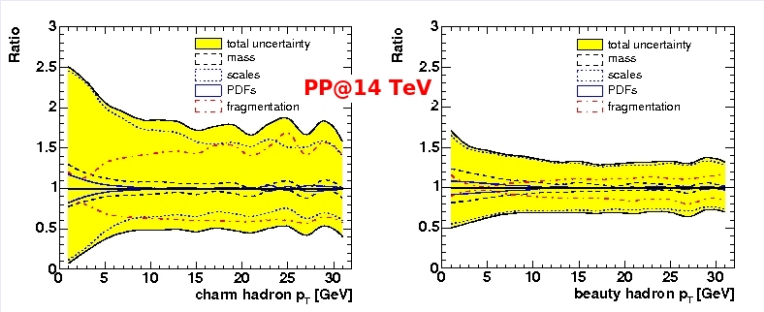


- degree of freedom vs. T – hadron ratios & spectra, direct photons, dilepton continuum;
- energy loss of partons in QGP – jet quenching, high p_t spectra, open charm & bottom;

Heavy quarks & leptons provide a rich physics program at the LHC

Heavy Flavour (HF) Physics

HF in pp collisions



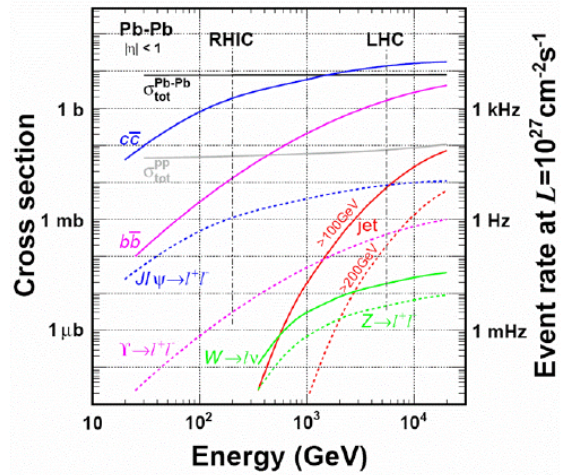
1. baseline of AA & pA collisions;
2. important test of pQCD predictions: large uncertainties.

HF in pA collisions

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

HF are the 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:
   - $R_{AA}(p_t,\eta) = \frac{1}{<N_{coll}>} \times \frac{d^2N_{AA}/dp_t d\eta}{d^2N_{pp}/dp_t d\eta}$, medium induced gluon radiation,
   - $\frac{R^D_{AA}(p_t)}{R^h_{AA}(p_t)}$, color charge effect of parton energy loss,
   - $\frac{R^B_{AA}(p_t)}{R^D_{AA}(p_t)}$, mass dependence of parton energy loss in high p_t region;
3. $Q\bar{Q}$ bound state formation is sensitive to the temperature of the crossing medium: suppression vs. recombination.



Large HF production rate @ LHC!

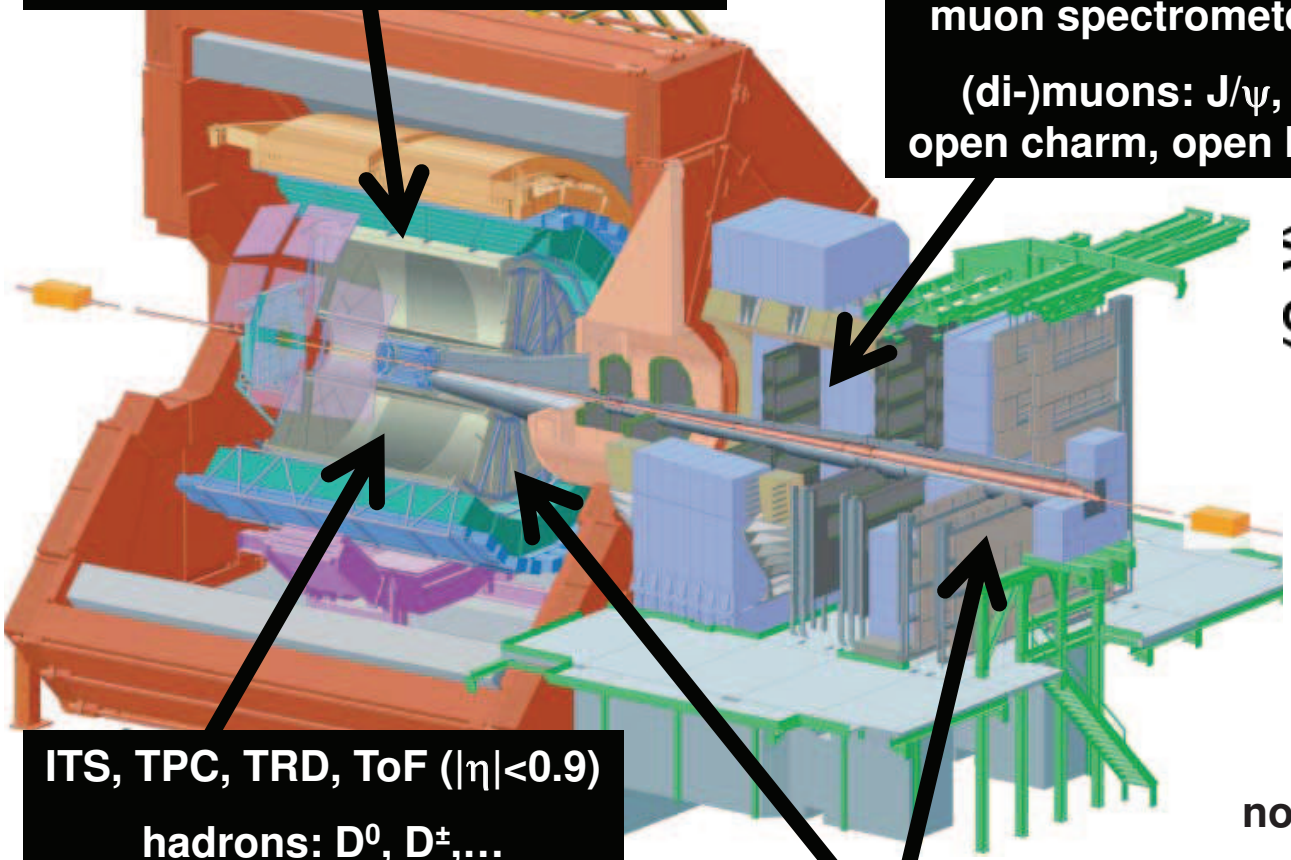
Heavy Flavours with ALICE

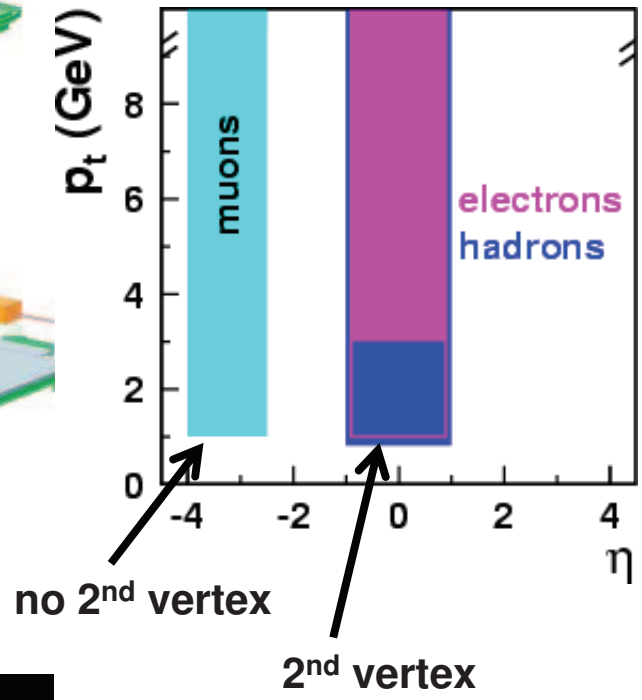
ITS, TPC, TRD, ToF ($|\eta|<0.9$)

(di-)electrons: J/ψ, ψ', Υ, Υ',Υ'', open charm, open bottom, $W^{\pm}$, Z^0

muon spectrometer ($-2.5<\eta<-4$)

(di-)muons: J/ψ, ψ', Υ, Υ',Υ'', open charm, open bottom, $W^{\pm}$, Z^0





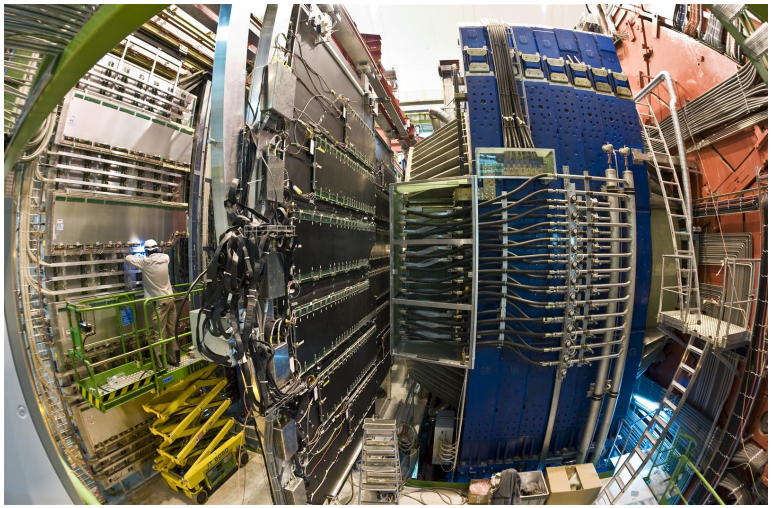
ITS, TPC, TRD, ToF ($|\eta|<0.9$)

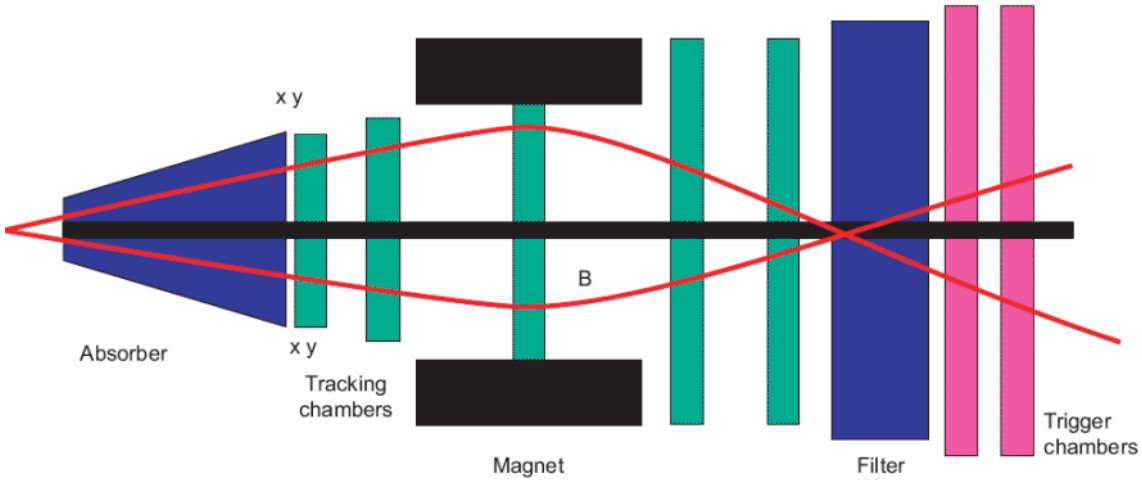
hadrons: D^0, $D^{\pm}$,...

electron-muon coincidences: open charm & bottom

Open charm & open bottom in the (di)muon channel is my PhD subject.

The ALICE muon Spectrometer

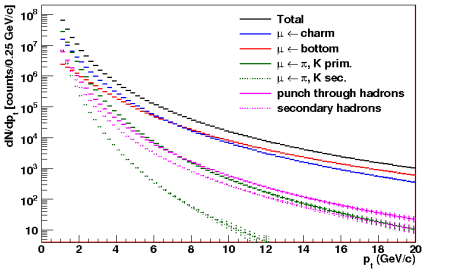


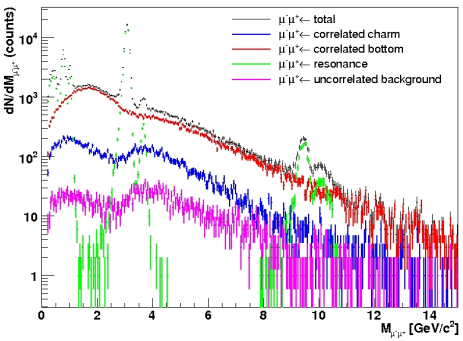


1. **Front Absorber:** reduces hadron yield & decreases decay μ yield by limiting the free path of primary K/π.
2. **Magnet Dipole:** 3 Tm integrated field perpendicular to the beam axis.
3. **Tracking System:**
   - multi-wire CPC with 1.1 M readout channels,
   - position resolution $\lesssim 100$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

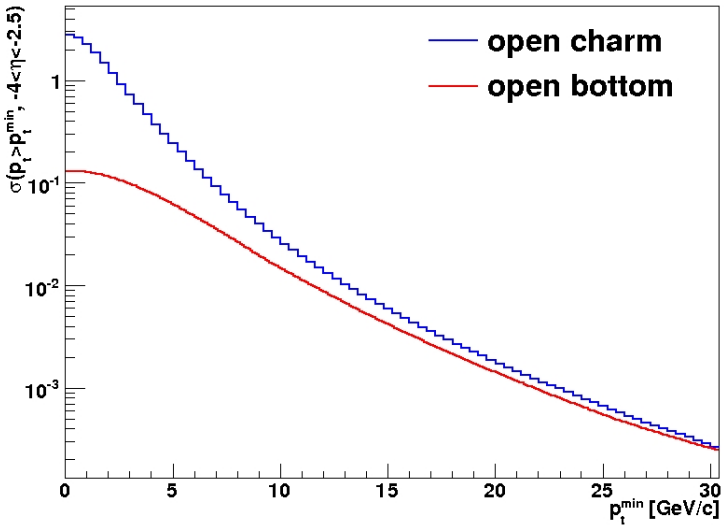
Measurement of the B (D)-hadron cross sections via (di)muons: method

pp @ 14 TeV





$\Rightarrow$



1. Background subtraction;
2. extract $N_{\mu^{\pm}/\mu^{-}\mu^{+}\leftarrow B/D}$ from "data";
3. correct for integrated luminosity, detection efficiency & acceptance;
4. correct for decay kine. (F_{MC} calculation);
5. get differential integrated B & D hadron cross sections.

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

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

Method widely used and well documented

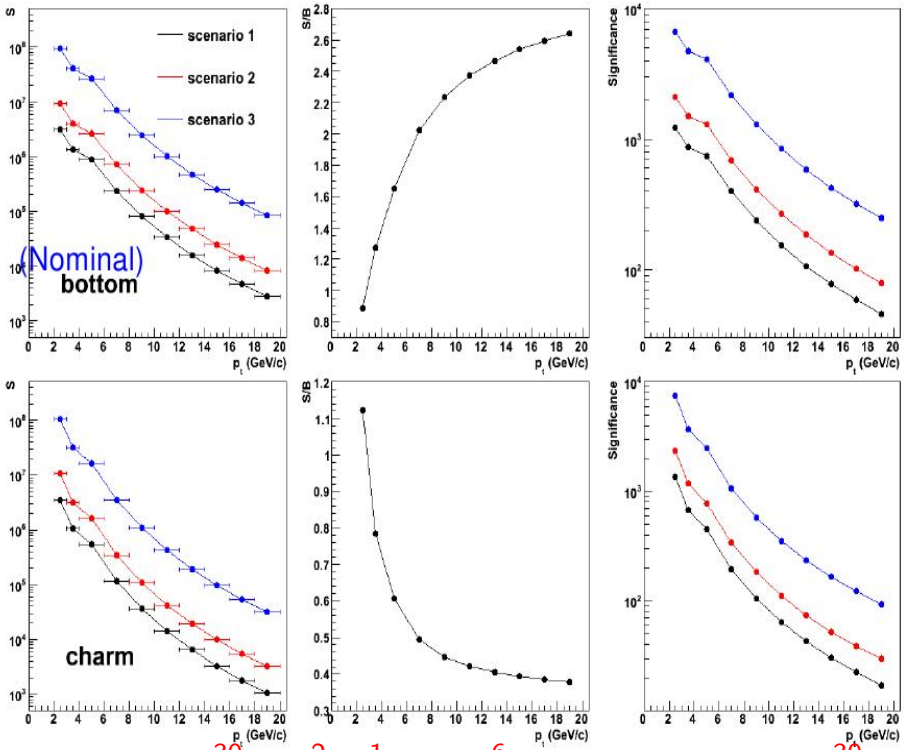
- **UA1:** $p\bar{p}$ colissions @ $\sqrt{s}=0.63$ TeV, single muons and dimuons, C. Albajar *et al.*, PLB 213 (1988) 405.
- **CDF:** $p\bar{p}$ colissions @ $\sqrt{s}=1.8$ TeV, single electrons, F. Abe *et al.*, PRL 71 (1993) 4.
- **D0:** $p\bar{p}$ colissions @ $\sqrt{s}=1.8$ TeV, single muons and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

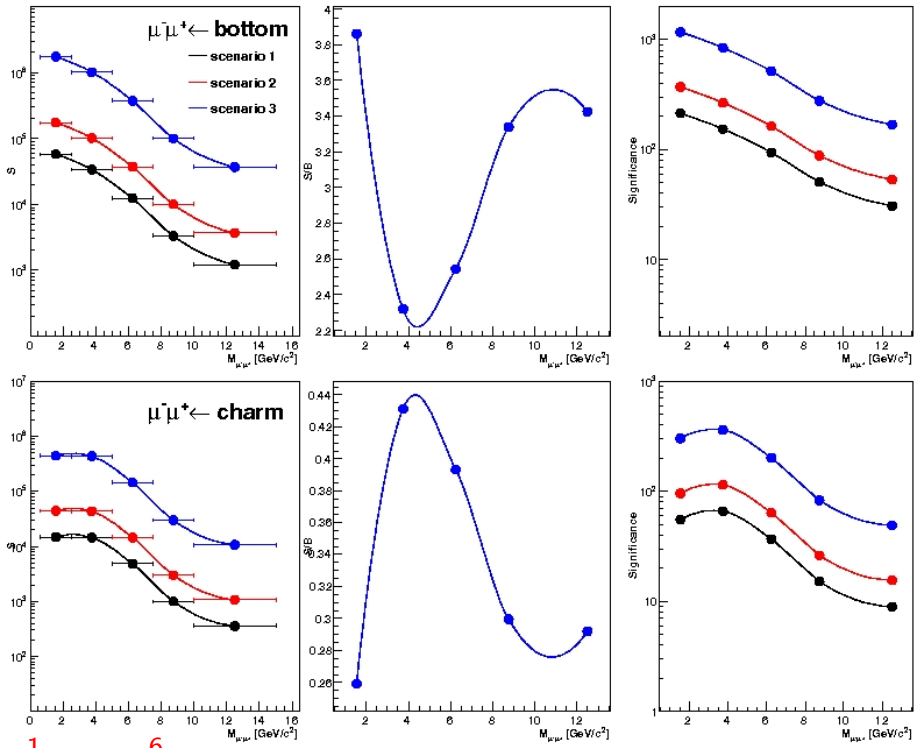
Extraction of the (di)muon yield from bottom and charm decay

After background subtraction, $N^{\mu^{\pm}/\mu^{-}\mu^{+}\leftarrow B/D}(\Phi^{\mu^{\pm}/\mu^{-}\mu^{+}})$ is extracted via a combined fit of $p_t(M_{\mu^{-}\mu^{+}})$ spectrum of $\mu^{\pm}/\mu^{-}\mu^{+}$ from heavy flavours.

Data Extrapolation for single muons



Data Extrapolation for $\mu^{-}\mu^{+}$

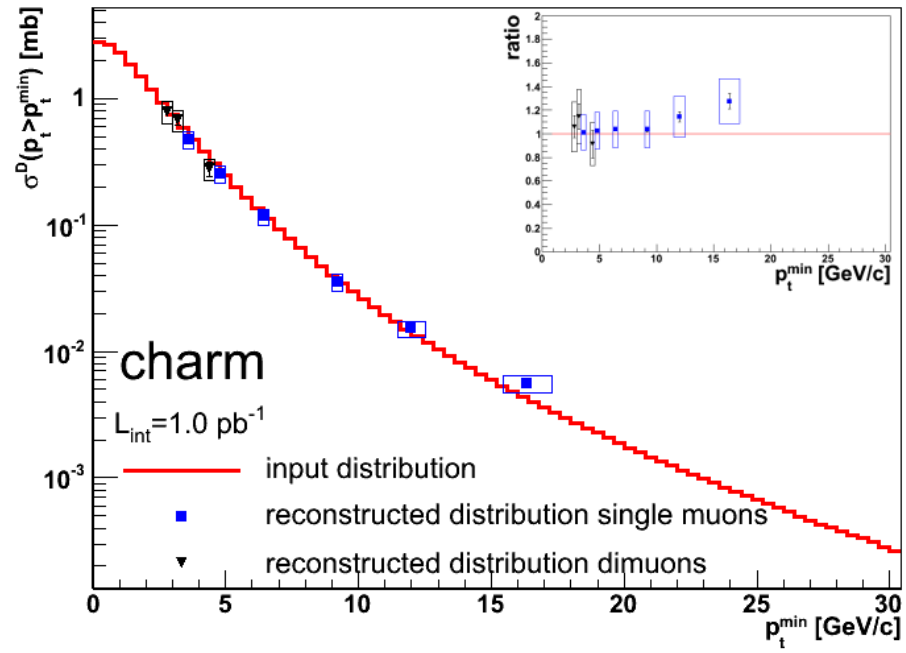


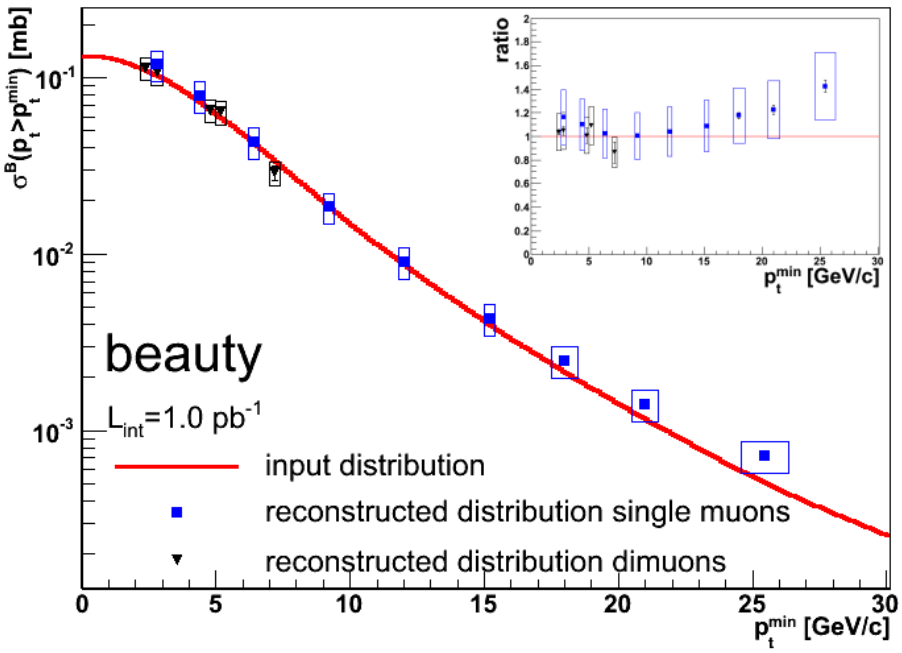
scenario 1: $L = 10^{30}\text{cm}^{-2}\text{s}^{-1}$, $t = 10^{6}\text{s}$; scenario 2: $L = 3 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$, $t = 10^{6}\text{s}$;

scenario 3: $L = 3 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$, $t = 10^{7}\text{s}$.

Large yield and large significance are expected even with data taking scenario one

Reconstructed $\sigma^{B/D}$ in Simulation pp @ 14 TeV via (di)muons



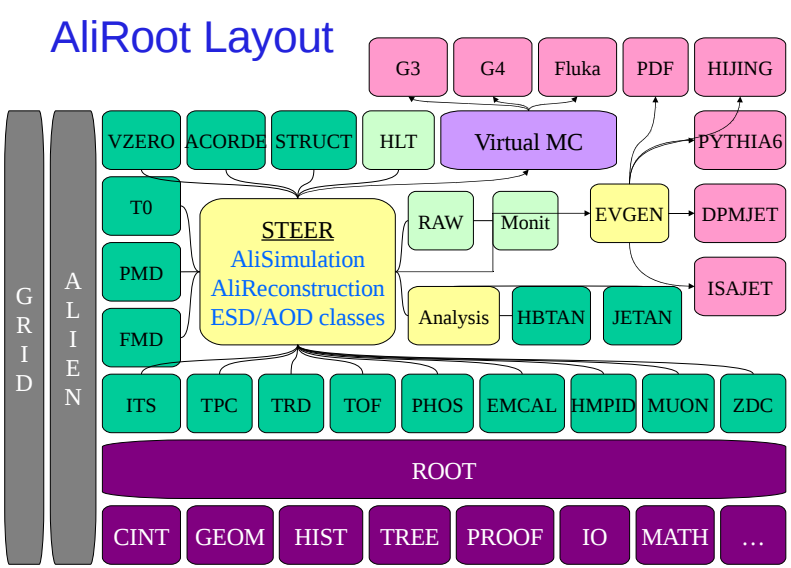


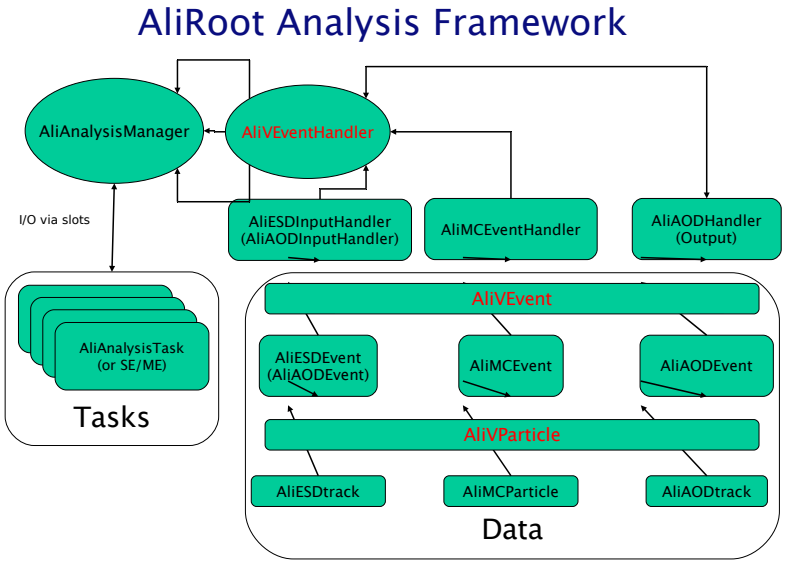
1. input distributions are well reconstructed;
2. nice agreement between single muon and dimuon channels;
3. statistical errors are negligible even in the so-called scenario one, systematic errors are 20% for B and 15% for D in the single muon channel and, 15% for B and 20% for D in the dimuon channel;
4. 82% (17%) of σ^B (σ^D) is reconstructed via single muons and, 84% (33%) of σ^B (σ^D) is reconstructed via dimuons;
5. our measurements allow to cover the p_t range from 2 GeV/c to 25 GeV/c (3 GeV/c to 15 GeV/c) for bottom (charm) component;
6. analysis procedure will be applied to pp data at 7 TeV.

Note: this analysis is strongly model dependent.

Analysis Code Development for σ^{HF} Reconstruction via (di)muons

- AliRoot is the software platform of data simulation, reconstruction and offline/online analysis for ALICE;
- analysis classes for $\sigma^{HF} \leftarrow \mu^{\pm}/\mu^{-}\mu^{+}$ reconstruction in AliRoot analysis framework have been developed.





AliAnalysisTaskSEMuonsHF : analysis task class;

AliMuonsHFHeader : collects information at event level, creates & fills the output histograms;

AliMuonInfoStoreRD : $\mu^{\pm}$ candidate analysis class with data;

AliDimuInfoStoreRD : $\mu^{-}\mu^{+}$ candidate analysis class with data;

AliMuonInfoStoreMC : $\mu^{\pm}$ candidate analysis class with simulation;

AliDimuInfoStoreMC : $\mu^{-}\mu^{+}$ candidate analysis class with simulation;

Analysis Code Development for σ^{HF} Reconstruction via (di)muons

```
AliAnalysisTaskSEMuonsHF* AddTaskMuonsHF(...)
{
  Int_t mode=0;          // set running mode
  Bool_t isMC=kFALSE;    // flag for using MC
  Bool_t isTree=kFALSE;  // switch of tree output
  ... ...
  char *trigger = "+CINT1B-ABCE-NOPF-ALL"; // trigger classes
  Double_t cutsEvsH[3] ={    0.5,  // low limit of Ncontrs
                            10.0,  // up limit of |vz|
                             3.0}; // up limit of vt
  Double_t cutsMuon[10]={    4.0,  // Pmin  [GeV/c]
                          9999.0,  // Pmax  [GeV/c]
                             1.5,  // PtMin [GeV/c]
                          9999.0,  // PtMax [GeV/c]
                            -4.0,  // EtaMin
                            -2.5,  // EtaMax
                             0.0,  // DCAmin [cm]
                             9.3,  // DCAmax [cm]
                             0.5,  // trigger matching low
                             3.5}; // trigger matching high
  Double_t *cutsDimu   = cutsMuon; // single muon cuts for dimuon
  AliMuonsHFHeader::SetTriggerClasses(trigger);
  AliMuonsHFHeader::SetVertexCuts(cutsEvsH);
  AliMuonInfoStoreRD::SetSelectionCuts(cutsMuon);
  AliDimuInfoStoreRD::SetSelectionCuts(cutsDimu);
  AliAnalysisTaskSEMuonsHF *taskMuonsHF =
    new AliAnalysisTaskSEMuonsHF("MuonsHF Analysis Task");
  taskMuonsHF->SetAnaMode(mode);
  taskMuonsHF->SetIsUseMC(isMC);
  taskMuonsHF->SetIsOutputTree(isTree);
  mgr->AddTask(taskMuonsHF);
  ... ...
  return taskMuonsHF;
}
```

Three modes of running:

- mode 0, analyze both $\mu^{\pm}$ & dimuon;
- mode 1, analyze only single muon;
- mode 2, analyze only dimuon.

Two kinds of outputs:

- histograms (default);
- tree (if switched on).

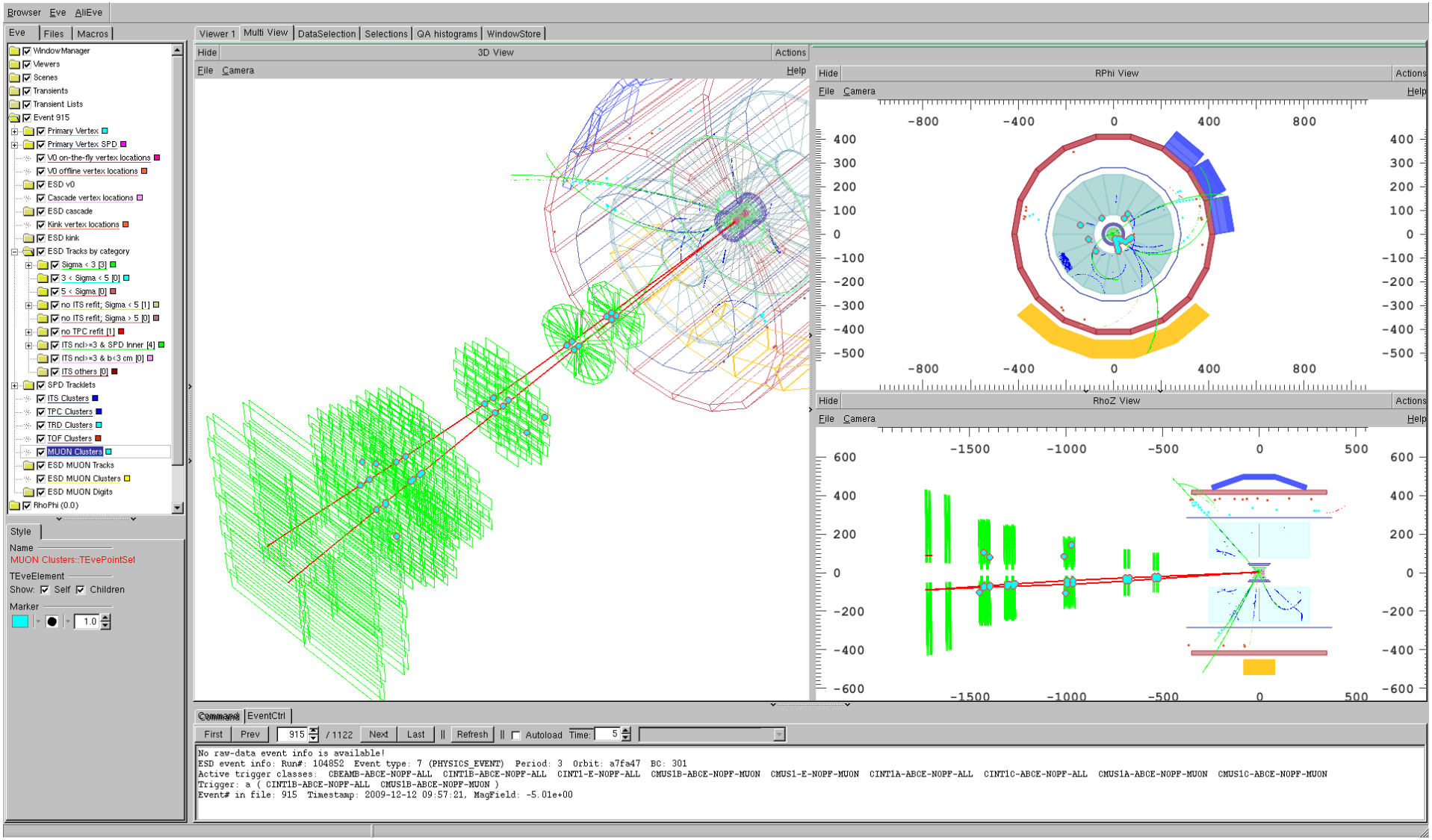
One flag for MC information:

- w/o MC, for real data analysis;
- w/ MC, for simulation analysis.

- several cuts are set for event & track selection,
- added in ALICE official analysis train,
- ready for analysis of HF with pp @ 7 TeV!

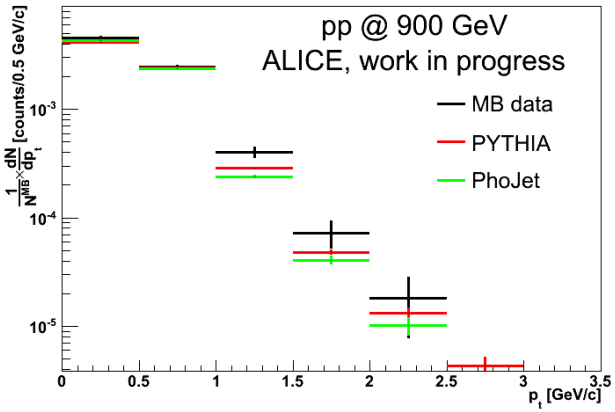
Muon Event in the ALICE muon spectrometer with pp Data at 900 GeV

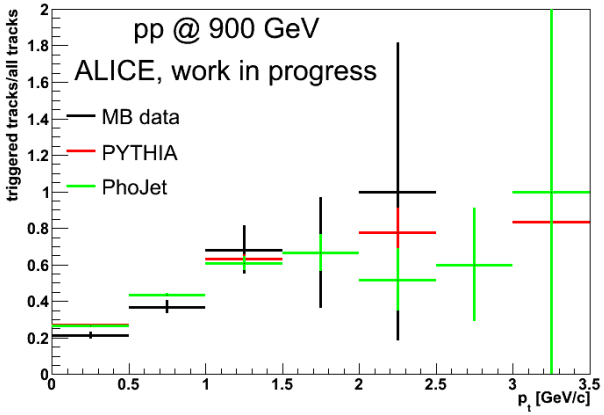
First dimuon event in pp @ 900 GeV collisions, December 2009

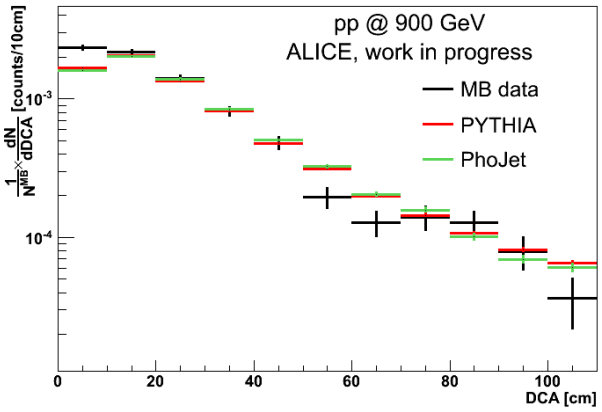


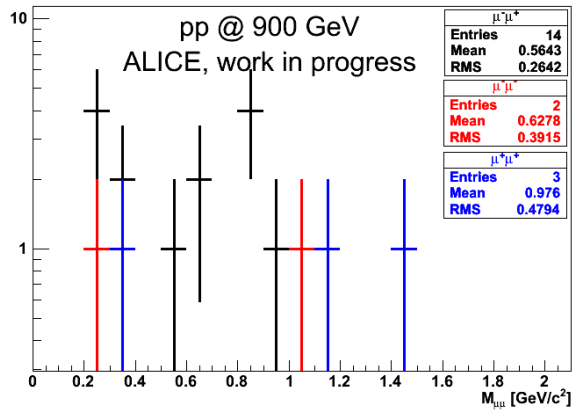
minimum bias events: 161639, reconstructed tracks in MUON spectrometer: 1234 (with $-4<\eta<-2.5$).

Analysis of First pp Data at 900 GeV in the ALICE muon spectrometer









- main trends of data well reproduced by simulations;
- we are ready for the data analysis of both muons and dimuons;
- getting now prepared for the analysis of the 7 TeV data currently collected.

Summary of My Activities Up to 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.

Activities list:

1. Performance of the MUON spectrometer for the heavy flavour measurement:
   - publications,
     - ALICE note: ALICE-INT-2010-004,
     - another ALICE note is in preparation,
     - proceedings of the 5th International Conference on Quark and Nuclear Physics, to be published;
   - presentations:
     - talk at ALICE-PWG3 meeting, Dec/09/2008,
     - **talk at the 5th International Conference on Quark and Nuclear Physics, Sep/21∼Sep/26, 2009, Beijing.**
2. Analysis code development for the heavy flavour measurement:
   - presentations:
     - two talks at ALICE-PWG3-MUON meeting: Nov/12/2009 and Dec/15/2009.
3. Analysis of first ALICE data with pp collisions at 900 GeV:
   - publications:
     - ALICE note, in preparation;
   - presentations:
     - three talks at ALICE-PWG3-MUON meeting, Feb/08/2010, Mar/01/2010 and Mar/15/2010,
     - talk at ALICE-PWG3 meeting, Feb/16/2010,
4. Shift for the trigger system of ALICE-MUON spectrometer, Mar/26/2010∼Mar/31/2010.

Conclusions

- heavy flavours are promising probes for the study the QGP properties;
- large production rate of heavy flavours is expected at LHC energies;
- performance study of the MUON spectrometer shows that the production cross section of B & D hadrons is reconstructed very well via (di)muons;
- the code of σ^{HF} reconstruction via (di)muons is developed;
- preliminary results with first ALICE pp data at 900 GeV are shown and main trends in the data are reproduced by simulations;
- we are ready for analysis the ALICE pp data at 7 TeV.

Thanks!