Rencontres QGP-France 2009

Low-mass Dimuons in the ALICE Experiment

Liang Sun

IPNL / CCNU

Outline

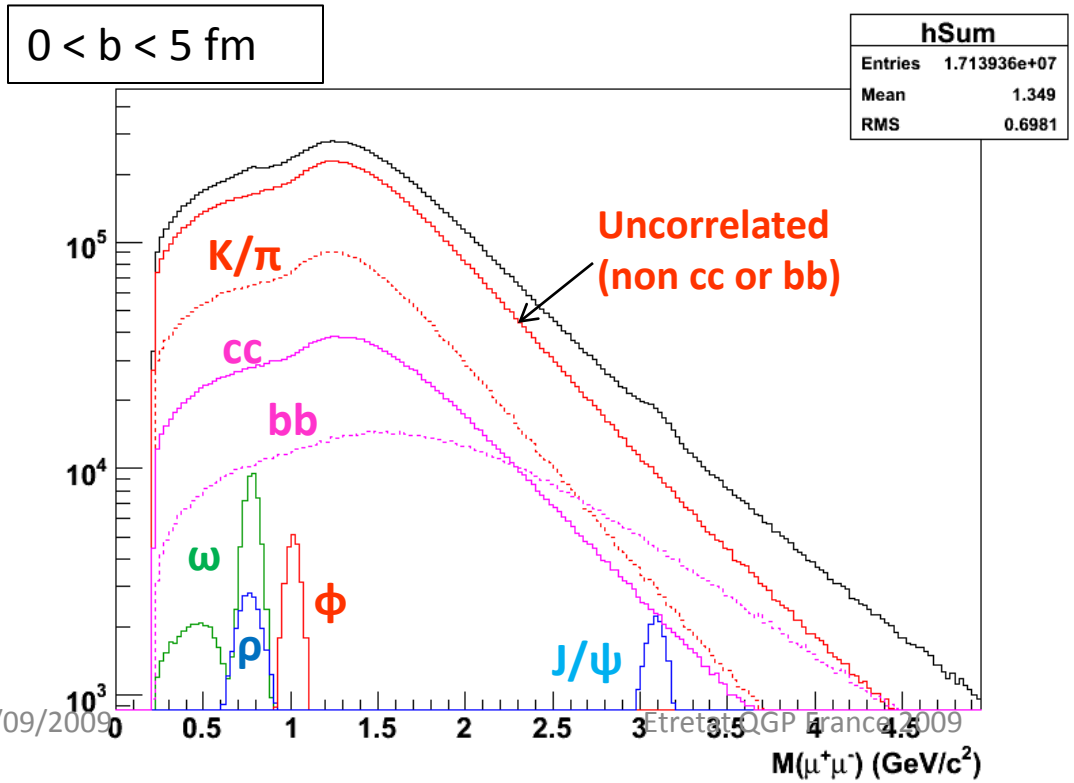
- Motivation
- Background subtraction
- Fit Model
- Summary

Motivation

- The $\mu^+\mu^-$ pair production in heavy-ion collision is very important for the search of the phase transition between the normal quark matter and the QGP phase
- In the dimuon low mass region ($m_{\mu\mu} < 1$ GeV/c^2), light vector mesons ρ, ω and ϕ mediate thermal dilepton production
- The low mass dimuon production is a rare process
  - The cross sections for ρ, ω and ϕ mesons are not small
    - But their branching ratios to dimuons are rather rare ~$O(10^{-6})$
  - In the Pb-Pb collision, background level is two orders of magnitude higher than signals
  - Sophisticated background suppression techniques are of vital importance for this type of study

Backgrounds in Pb-Pb Collisions

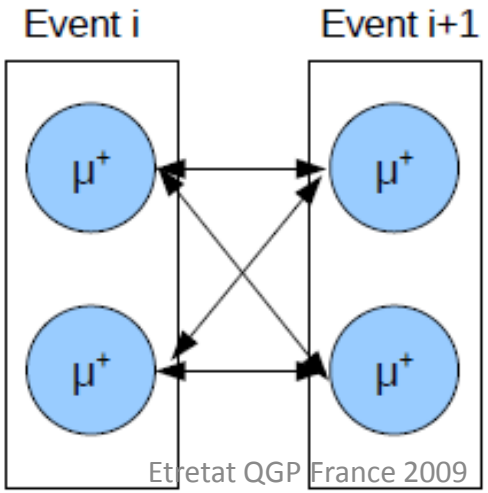
- 10 Million Pb-Pb collisions at $\sqrt{s}$ = 5.5 TeV are simulated and reconstructed for the background studies



- Cut for single muon P_t at P_t > 0.5 GeV/c^2
- The charm and beauty events are all uncorrelated at the generator level
- In the low mass region, the majority of muons come from K/π decays
- The normalizations of low mass resonances are obtained from fast simulations

Event-mixing Technique

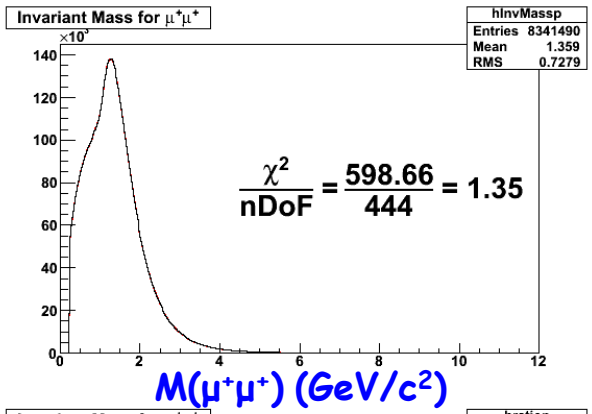
- To mimic the (uncorrelated) combinatorial background for subtraction, we combine two muons from different events as a **mixed** muon pair
- We can look at the like-sign cases first
  - If the mixed (++) and (--) dimuons reproduce the corresponding invariant mass shapes of the simulated like-sign dimuons, the event-mixing technique should also work in the opposite-sign case

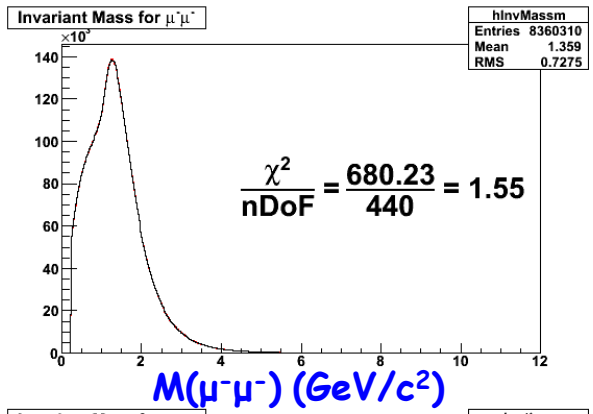


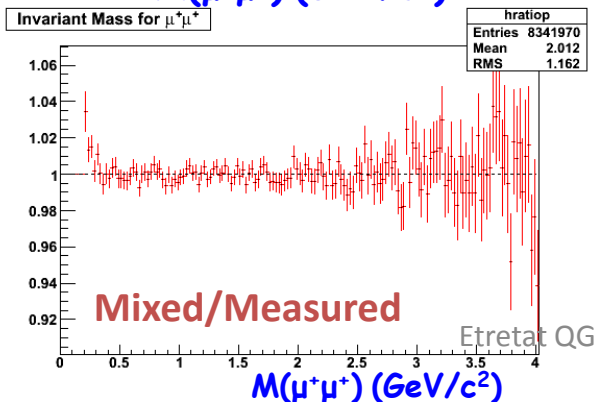
Event mixing for like sign muons

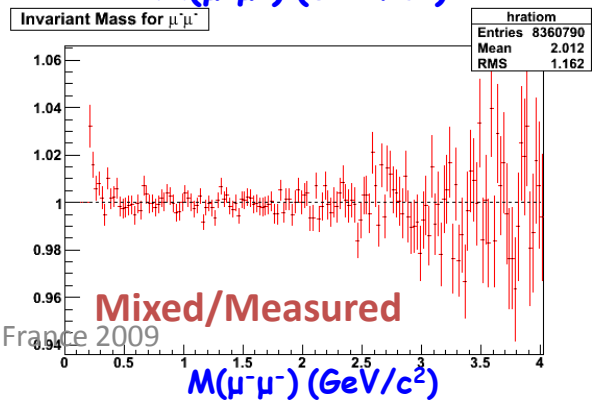
Like-sign Dimuons

- Comparison between measured & mixed dimuons
  - Agreement in the low mass region well within 1%



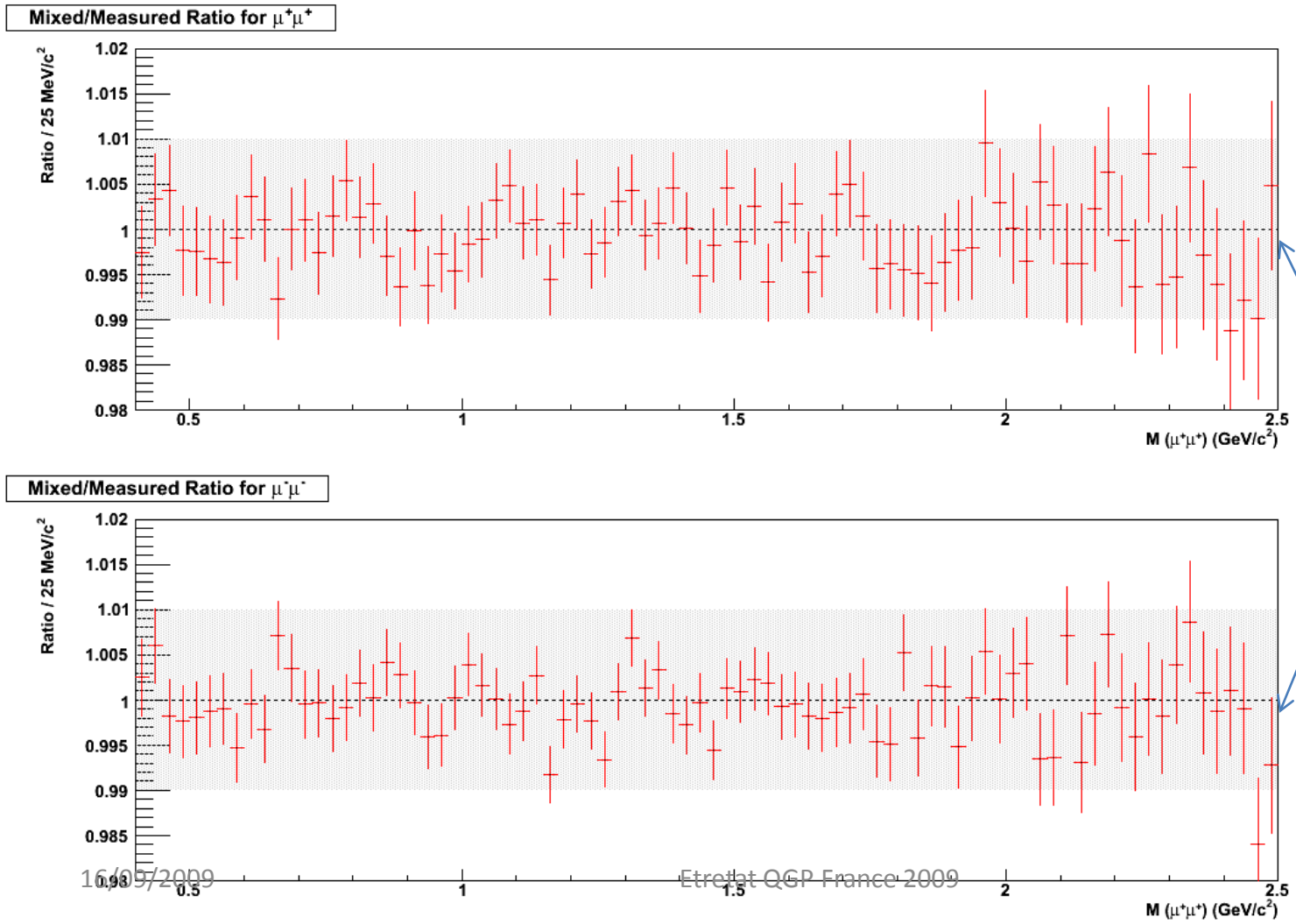






Agreement within 1% is essential for reliable observations of ρ, ω and φ with S/B ~ 0.01

Like-sign Dimuons

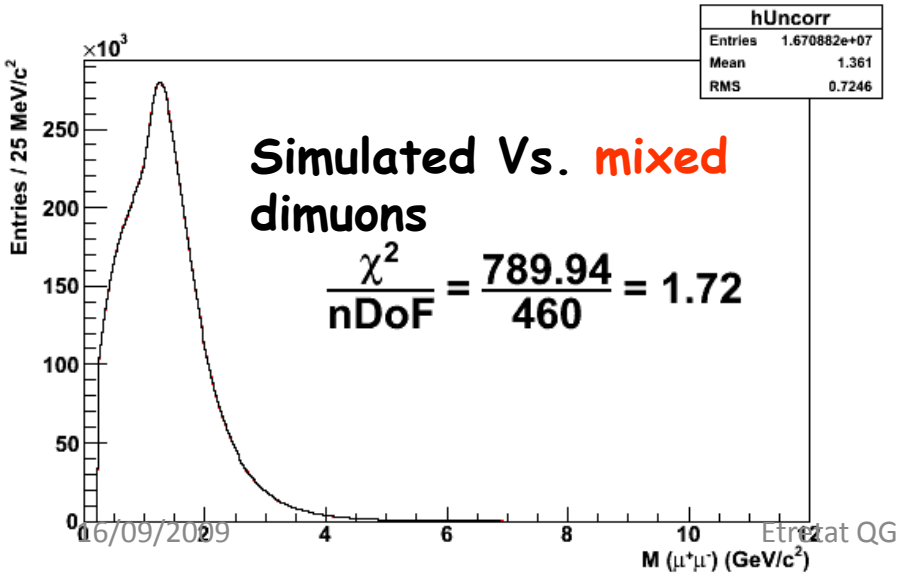


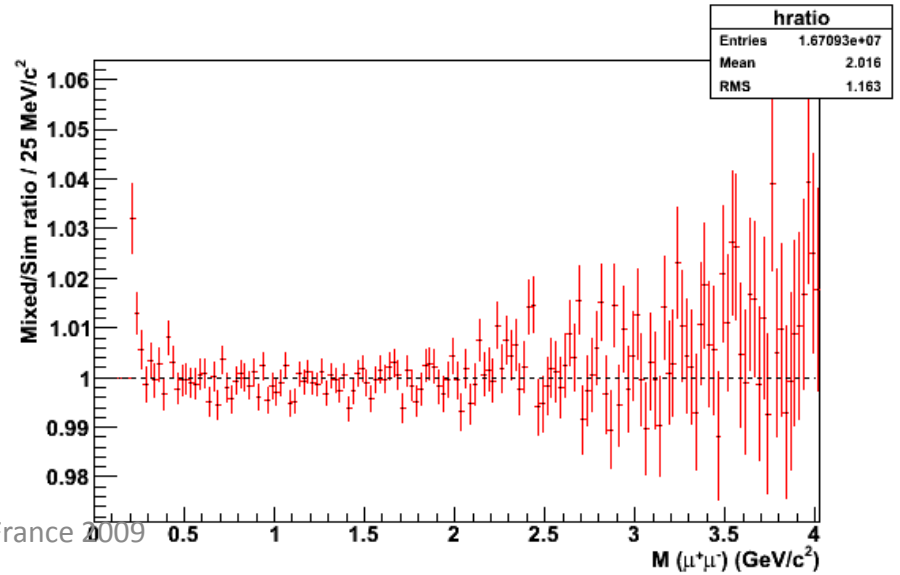
± 1% band

Most of bins within one σ from unity

Opposite-sign Dimuons

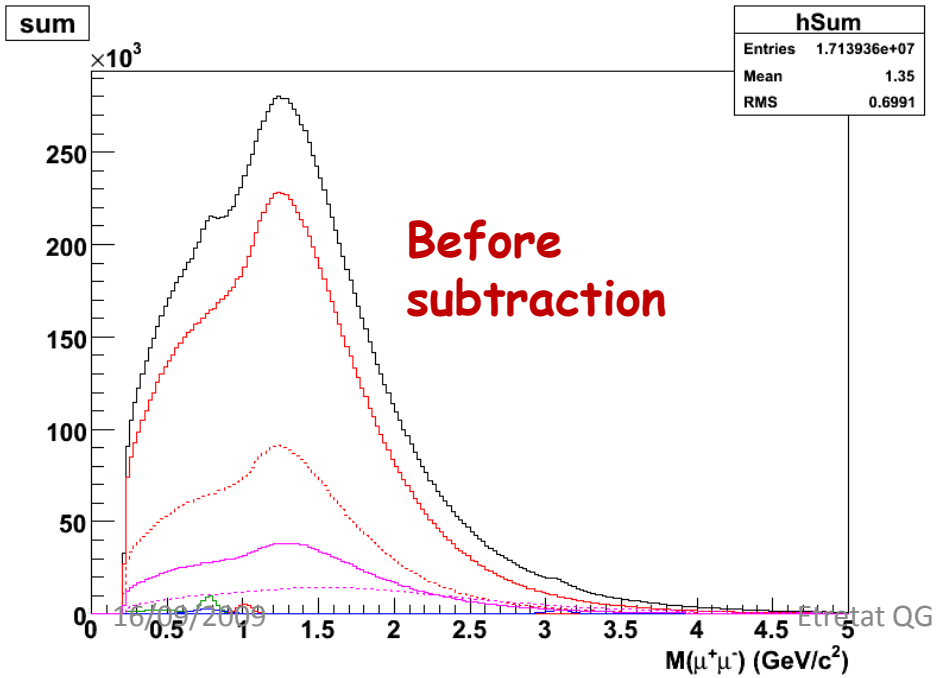
- For the $\mu^+\mu^-$ pairs, the mixed dimuons are compared to the uncorrelated simulated dimuons
  - Good agreement is also observed

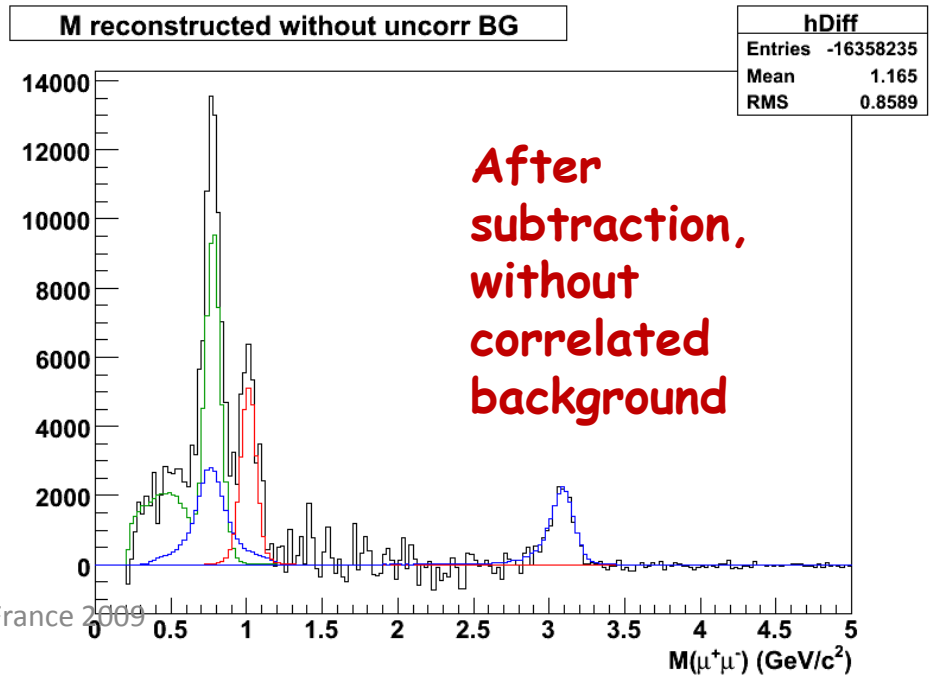




Background Subtraction

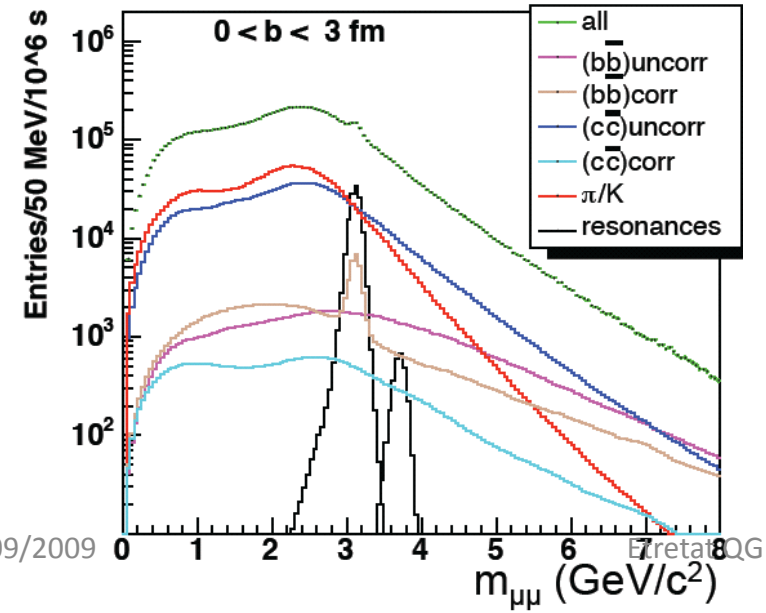
- The simulated cc and bb background events are all uncorrelated and can thus be completely removed using the event-mixing technique
- The normalization for the total uncorrelated background is taken as 2 $R\sqrt{(N_{++}*N_{--})}$, where $R = A_{+-}/\sqrt{A_{++}A_{--}}$
  - The simulated uncorrelated events N_{+-} is very close to $2\sqrt{(N_{++}*N_{--})}$, which indicates R ~ 1





Background Subtraction

- Though absent in the simulation, the correlated charm and beauty backgrounds are expected to be small even compared to the corresponding uncorrelated backgrounds
- After background subtraction, the residual correlated background will be comparable to the low mass resonances, and a final S/B ratio ~ 1 is desirable
- A fit model is required to extract the signals

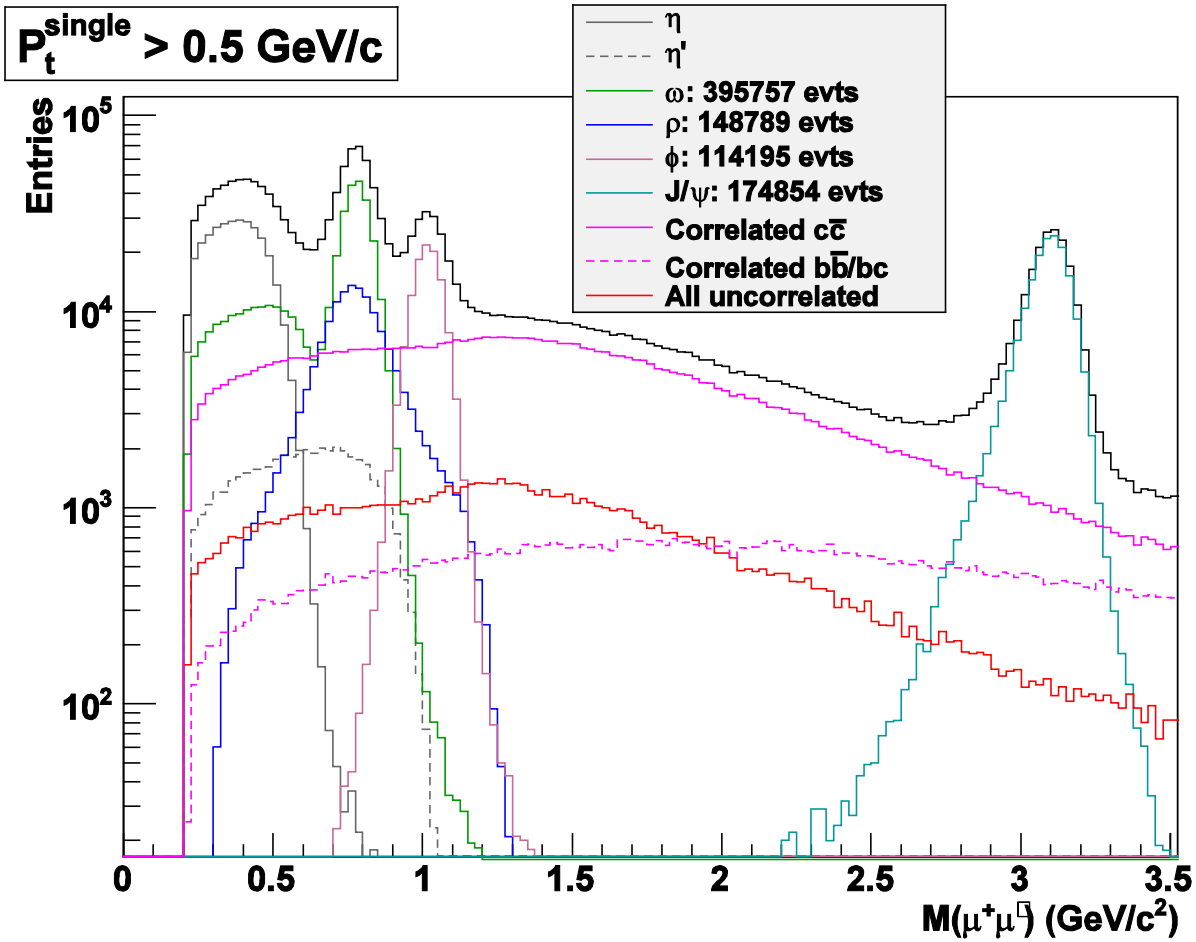


Backgrounds and charmonium resonances from fast simulations, from Javier Castilllo's talk in Rencontres QGP-France 2008

Dimuons in the pp collisions

- In the first year of LHC, events of pp collisions at $\sqrt{s}$ = 10 TeV will be collected.
- Simulated pp events are available at PDC09
  - 2976200 events processed for muon analysis
    - Take 50% of events for the parameterization of signal & background shapes, the rest for testing the complete fit model by faking as real data
  - Corresponding to ~5 days at nominal luminosity
  - AliRoot, root & geant 3 versions: v4-17-Rev-04, v5-24-00,& v1-11
  - Without polarization, correlated background events simulated

Dimuon Mass Distribution for pp@10TeV

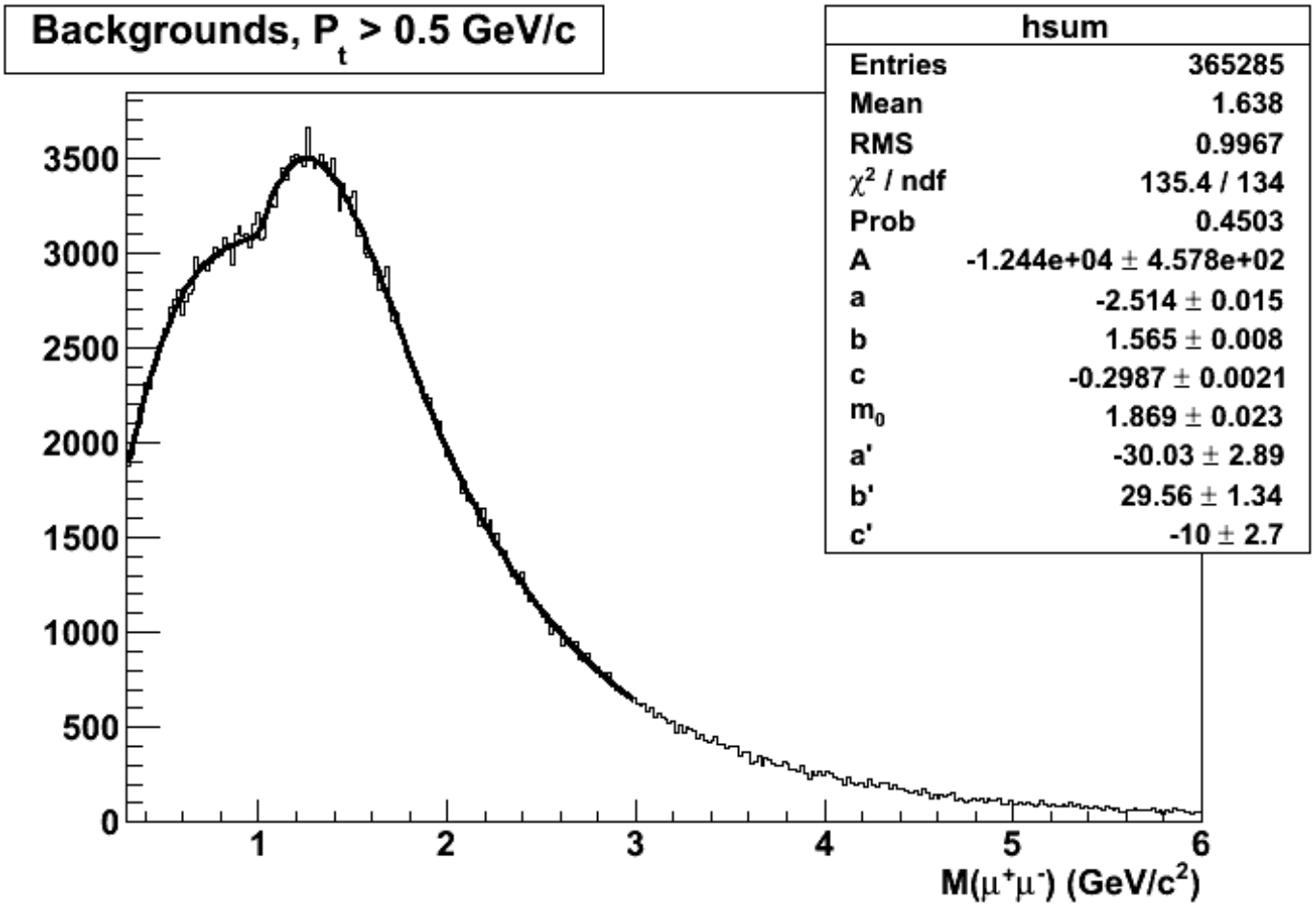


- Large Signal/Background ratio in the low mass region
- Correlated ccbar as the dominating background source

Background Fit

- The background distribution of $M(\mu^+\mu^-)$ is fit using two 3rd order polynomial shapes for $M(\mu^+\mu^-)$ below and above 1 GeV/c^2 with an exponential tail on its high side:
  - The fit function has 7 free parameters:
    - $$f(m)=\begin{cases} A'\cdot\left(1+\boldsymbol{a'}\cdot m+\boldsymbol{b'}\cdot m^2+\boldsymbol{c'}\cdot m^3\right) & m<1 \\ \boldsymbol{A}\cdot\left(1+\boldsymbol{a}\cdot m+\boldsymbol{b}\cdot m^2+\boldsymbol{c}\cdot m^3\right) & 1\le m<\boldsymbol{m_0} \\ A''\exp\left(-c\cdot m\right) & m\ge m_0 \end{cases}$$
  - c is carefully chosen so that the function will be kept smooth at the transition point m_0

Background Fit



Fit to all background events with both muons not from the same origin

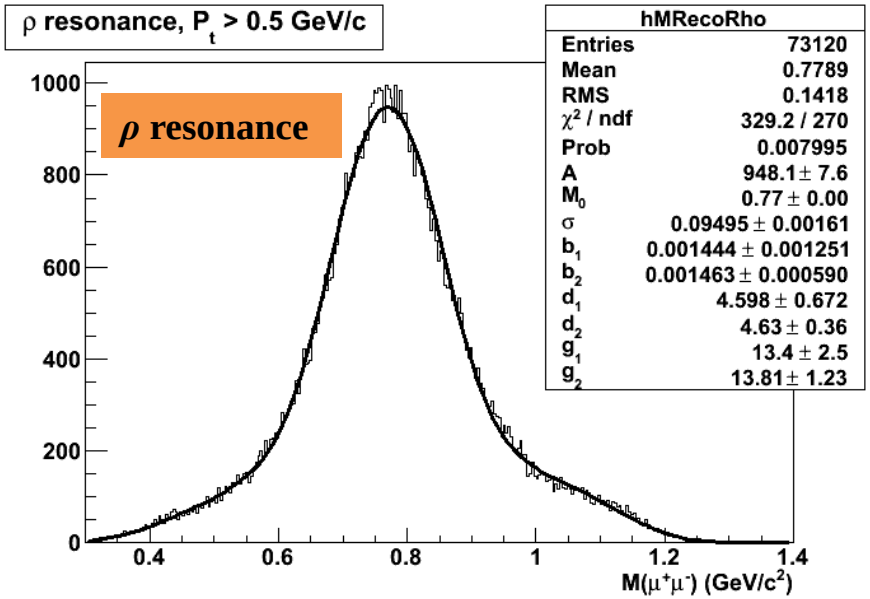
Resonance Fits

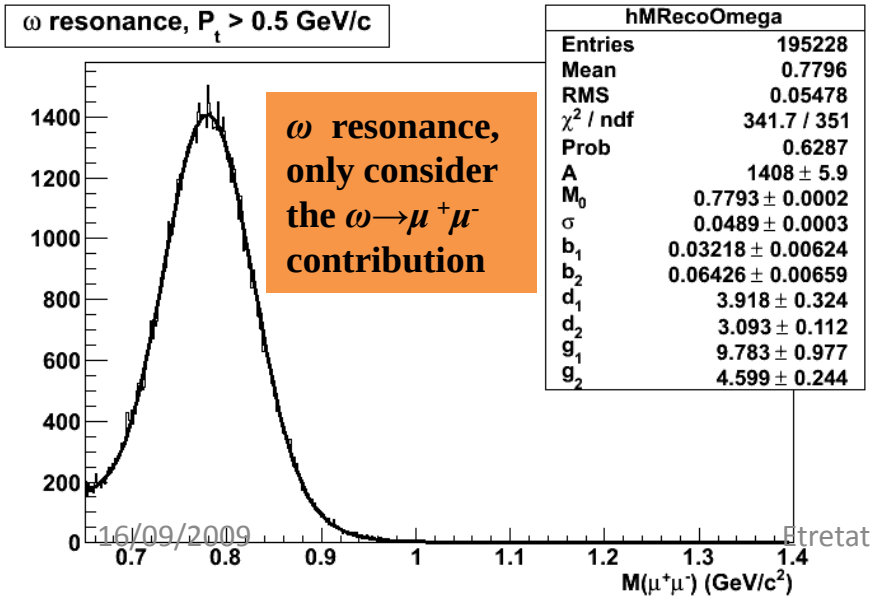
- The fitting shape is based on the Gaussian PDF $A\exp(-t^2/2)$, where $t = (M\text{-}M_0)/\sigma_{res}$ with σ_{res} as a function of M:
  - $$\sigma_{res}(M) = \begin{cases} \sigma + b_1 (M_0 - M)^{d_1 - g_1\sqrt{M_0 - M}} & for\ M < M_0 \\ \sigma + b_2 (M - M_0)^{d_2 - g_2\sqrt{M - M_0}} & for\ M \geq M_0 \end{cases}$$

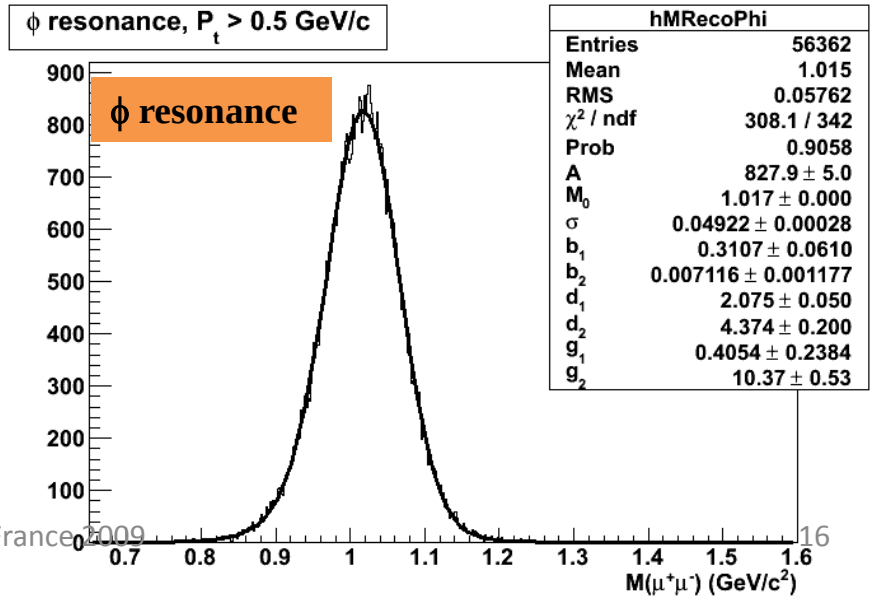
9 free parameters

R. Shahoyan, Thesis, Universidade Tecnica de Lisboa (2001)

Resonance Fits







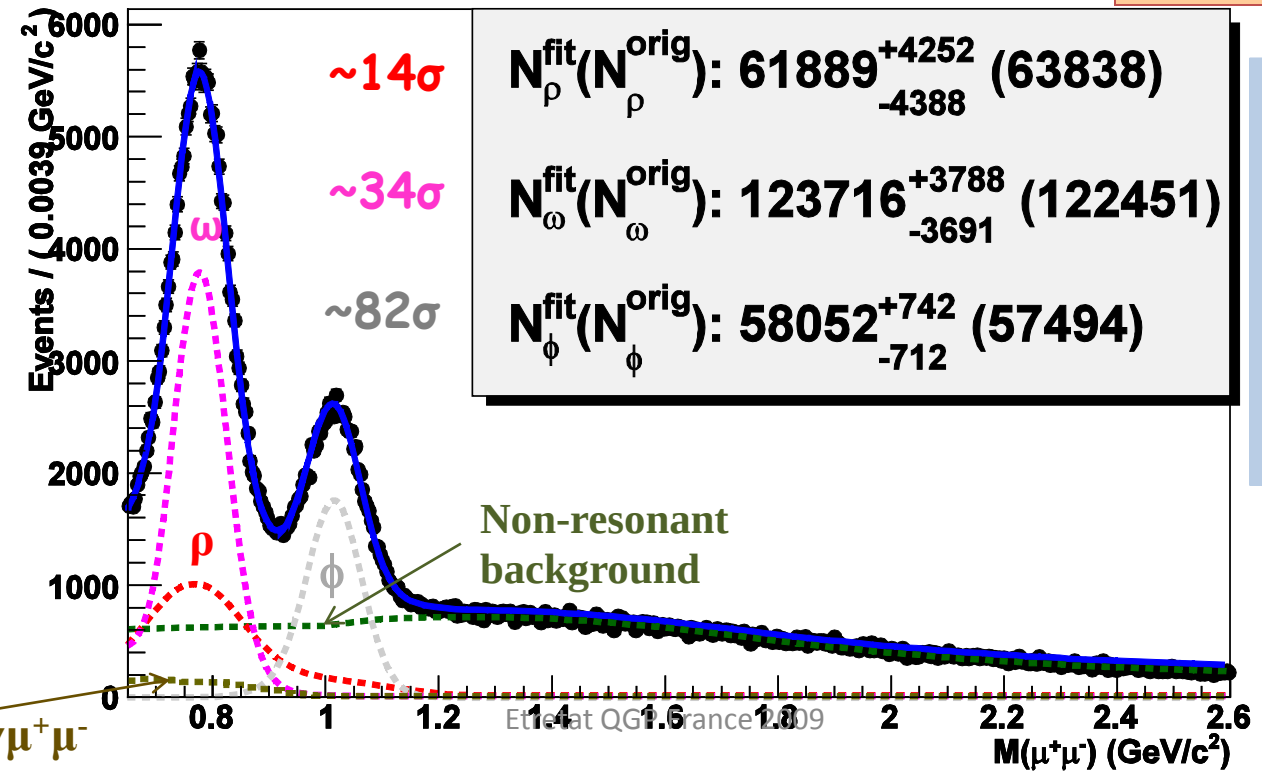
Fit to Simulated Events

- All the simulated pp events are fitted with most of resonance and background shape parameters fixed to previous individual fits
  - The only free parameters: Normalizations for ρ, ω, ϕ signals and background, Gaussian mean $M_{0\omega}$ & width σ_ω of ω meson
  - The Gaussian means & widths of ρ, ϕ are constrained as:

$$M^{fit}_{0\rho,\phi} = M^{MC}_{0\rho,\phi} + \left(M^{fit}_{0\varpi} - M^{MC}_{0\varpi}\right)$$

$$\sigma^{fit}_{0\rho,\phi} = \sigma^{MC}_{0\rho,\phi}\frac{\sigma^{fit}_{0\varpi}}{\sigma^{MC}_{0\varpi}}$$

All events, P_t > 0.5 GeV/c

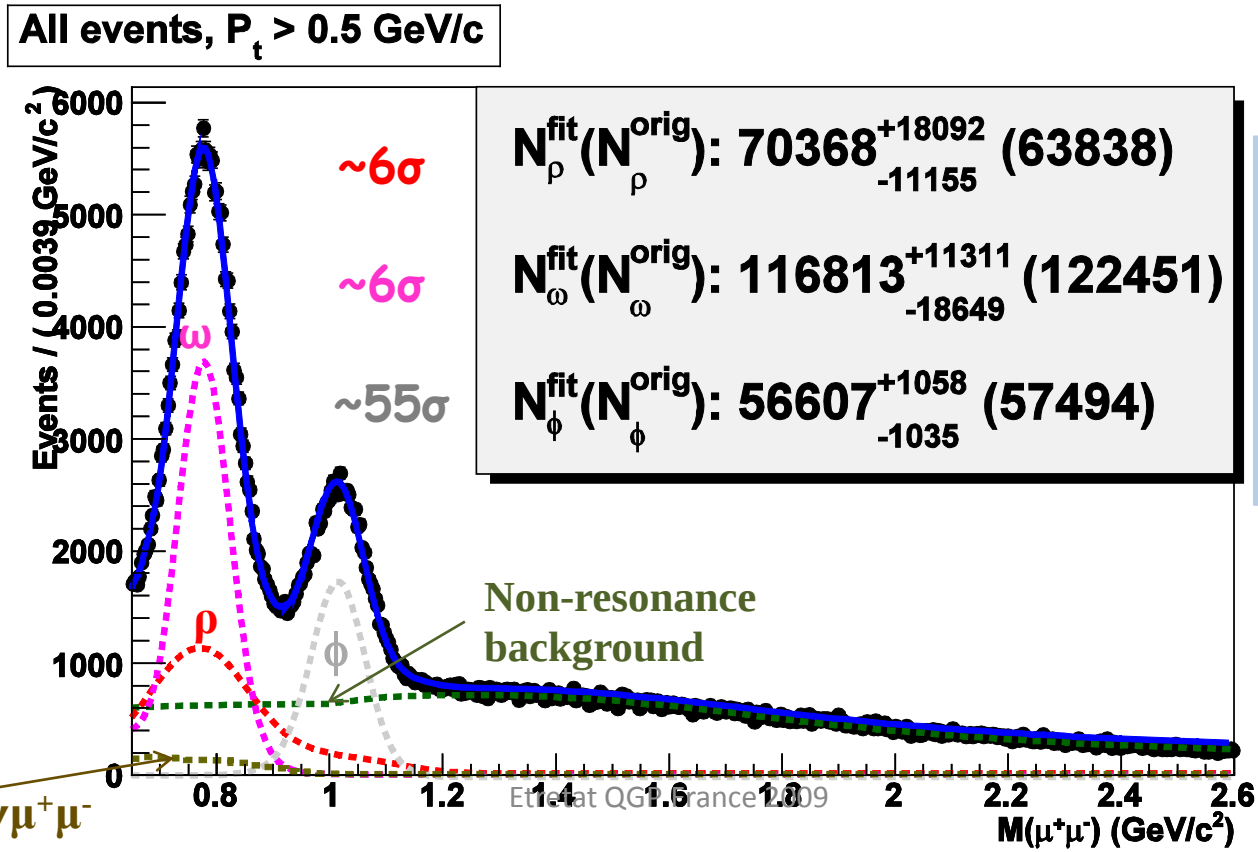


The decay $\eta' \to \gamma\mu^+\mu^-$ as the only sizable peaking background source after requiring $M(\mu^+\mu^-) > 0.65$ GeV/c²

The fitted signal yields are in reasonable agreement with the true values

Fit with Floating Mean & Width Values

- Redo the fit with more free parameters:
  - All Gaussian means & widths are floating in the fit



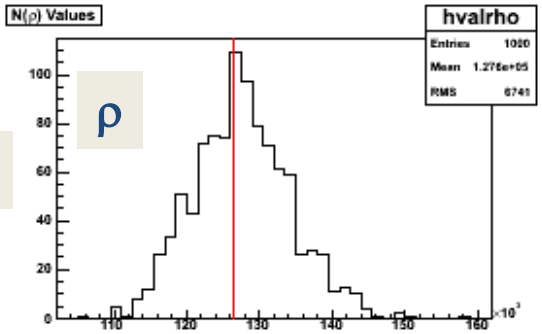
The decay $\eta' \to \gamma\mu^+\mu^-$ as the only sizable peaking background source after requiring $M(\mu^+\mu^-) > 0.65$ GeV/c²

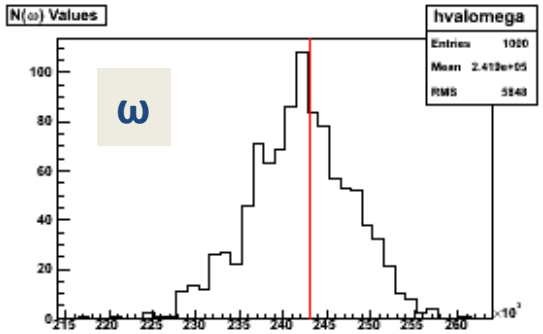
Deteriorated signal significances, can be used as a check of systematics

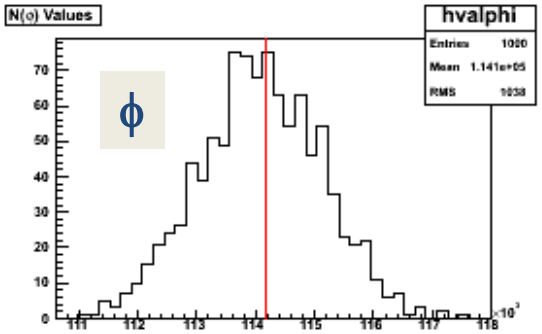
Check of Fit Quality

- The entire fit model is checked by fitting to 1000 generated toy datasets

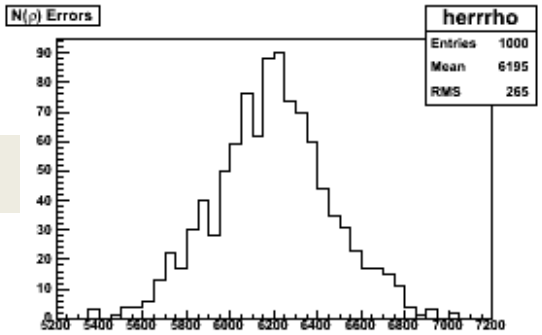
N

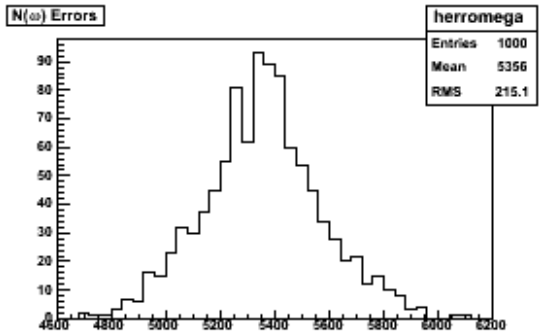


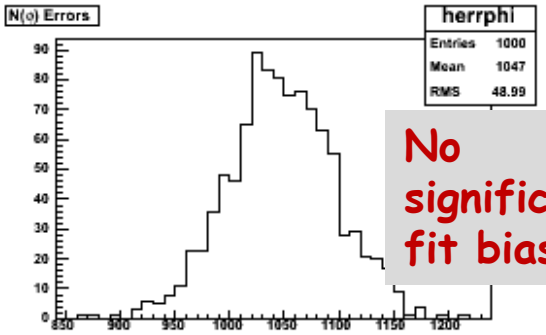




ε(N)

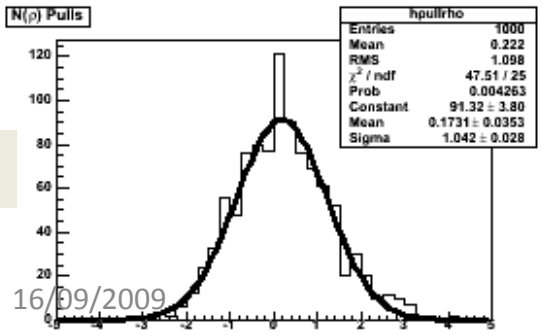


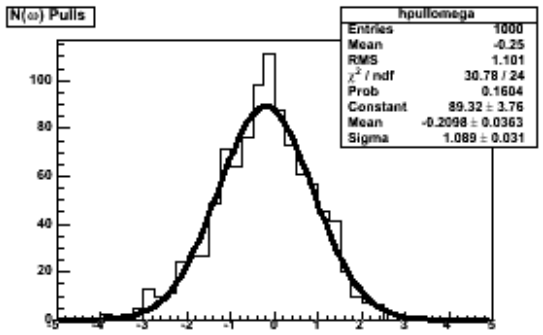


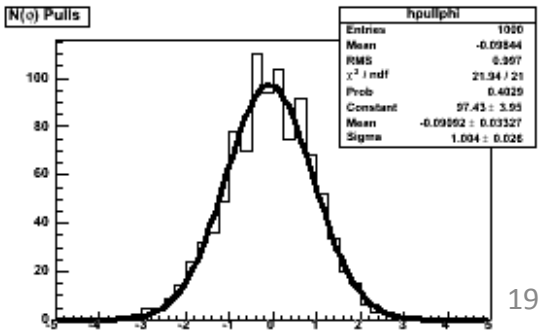


No significant fit biases

Pull







Summary

- In the Pb-Pb collisions:
  - The combinatorial background is well modeled with the event-mixing technique
  - After the background subtraction, the S/B ratio for low mass resonances will be greatly improved
- The fit model is fully set up based on the simulated events of pp collisions @ 10 TeV
  - This will be very useful for the real data in the first year of LHC

Backup Slides

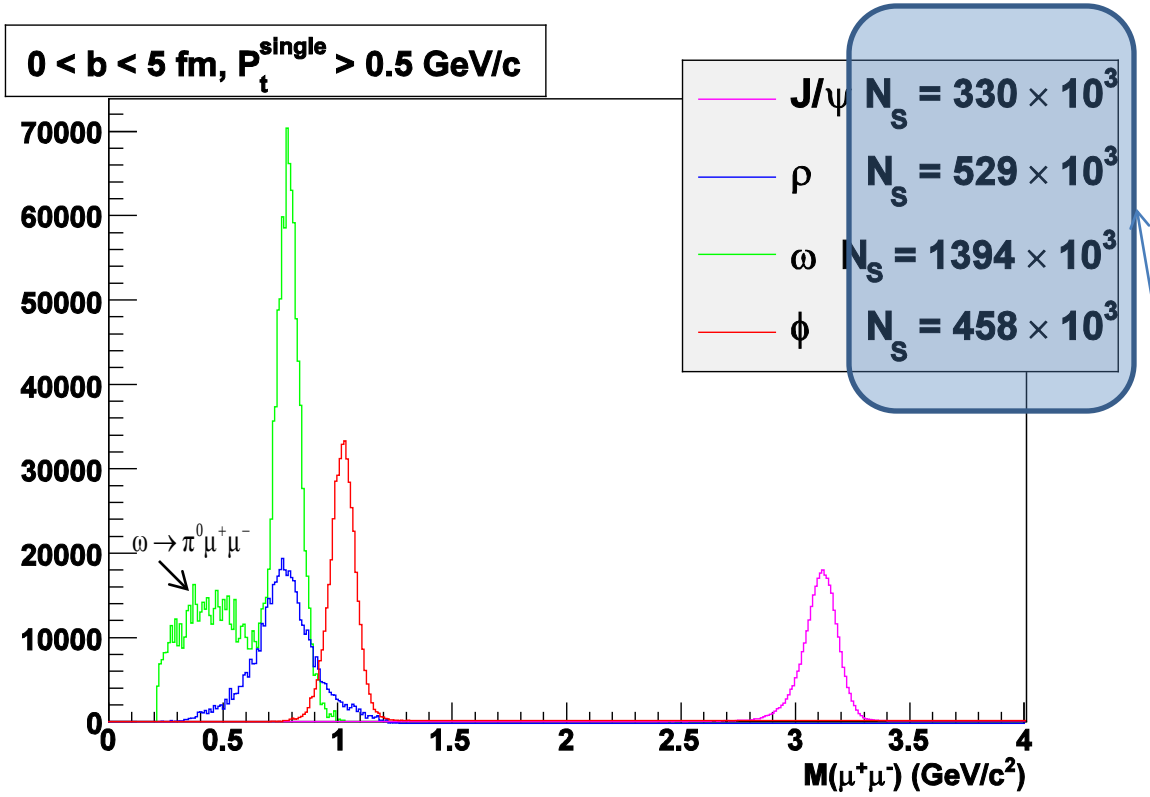
MC Simulation

- Software environment:
  - AliRoot: v4-15-Release
  - Root: v5-21-01-alice, Geant3: v1-9
- Muon generator: AliGenMUONCocktail
  -

```
AliGenMUONCocktail *gener = new AliGenMUONCocktail();
gener->SetYRange(-4.,-2.4);
gener->SetPhiRange(0., 360.);
gener->SetMuonMultiplicity(2);
gener->SetMuonThetaCut(171.,178.);
gener->SetMuonPtCut(0.5); // Require single muons with Pt above 0.5 GeV/c
gener->SetOrigin(0., 0., 0.);
gener->SetSigma(0., 0., 5.);
gener->SetImpactParameterRange(0., 5.); // 10% most centra PbPb collisions
gener->SetVertexSmear(kPerEvent);
gener->Init();
```

Fast Simulation

- The ratios of low mass resonances with respect to J/ψ are determined via fast simulation



Expected resonance signal yields after 10^6s data-taking time @ ALICE

Expected Signal & Bkg Yields

$p_T^{single} > 0.5$ GeV/c					
Meson	b range (fm)	S[$\times 10^3$]	B[$\times 10^3$]	S/B	Significance
ρ	0 - 3	255	16703	0.02	62
	3 - 6	457	20700	0.02	99
	6 - 9	381	9672	0.04	120
	9 - 12	184	2136	0.09	121
	12 - 16	41	167	0.25	92
ω	0 - 3	503	8485	0.06	168
	3 - 6	884	10841	0.08	258
	6 - 9	755	5178	0.15	310
	9 - 12	364	1092	0.33	302
	12 - 16	82	89	0.92	199
ϕ	0 - 3	210	10668	0.02	64
	3 - 6	371	13081	0.03	101
	6 - 9	323	6125	0.05	127
	9 - 12	153	1385	0.11	124
	12 - 16	34	112	0.31	91