Signals and background in the muon spectrometer

- Physics topic to be studied with the muon spectrometer
- Dimuon sources
- Evaluation of the combinatorial background
- Level background in pp, peripheral and central Pb-Pb collisions
- Quality of background subtraction
- Summary

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Terzo Convegno Nazionale sulla Fisica di Alice
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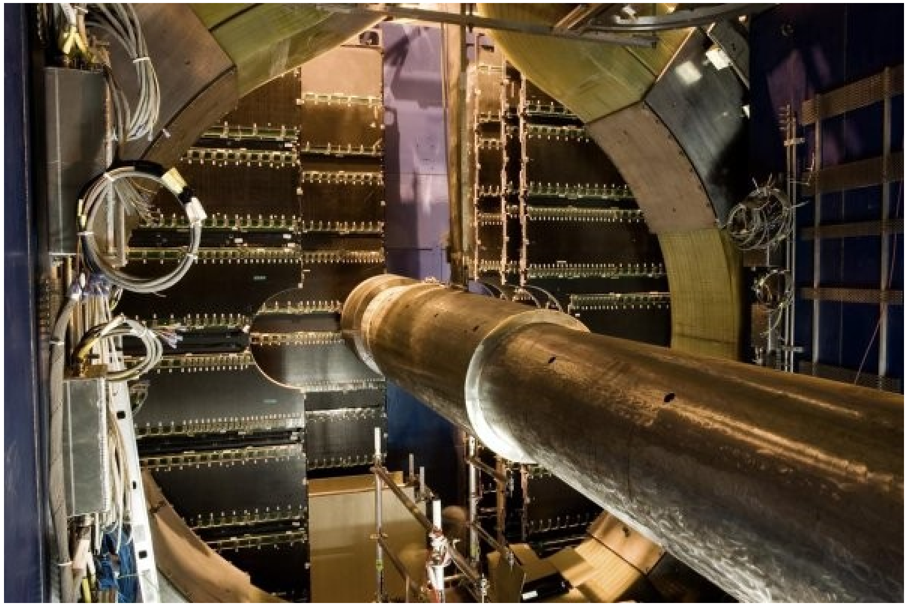


Physics topics that can be studied with the muon spectrometer

only a selection

pp collisions:

- Detailed study of quarkonia production (colour octet model, colour evaporation model,...): p_T, polarisation, relative yields of the 1S, 2S, ... states
- Accessing the low Bjorken-x region ("gluon saturation")
- Measuring the open beauty production cross-section

p-A collisions:

- Nuclear modifications of PDFs
- Establish reference baseline for heavy-ion studies

A-A collisions:

- Quarkonia suppression (or enhancement?) pattern versus centrality
  for the first time: extend studies to the Υ
- Quarkonia polarisation should be different in A-A than in pp

Sources of the dimuon mass spectrum and their expected yields

Correlated pairs come from

- resonance decays
- by pairing simultaneous semileptonic decays of DDbar and BBar

  $D \to \mu X$ and Dbar$\to \mu X$ "open charm"

  $B \to \mu X$ and Bbar$\to \mu X$, etc "open beauty"
- by pairing simultaneous semileptonic decays of correlated

  π / $K \to \mu \nu_\mu$

Uncorrelated pairs ("combinatorial background") come from randomly pairing muons from any of those sources

After one nominal year of data taking [$L(pp) = 3 \cdot 10^{30}\ cm^{-2}s^{-1} \times 10^7 s$ and $L(Pb\text{-}Pb) = 5 \cdot 10^{26}\ cm^{-2}s^{-1} \times 10^6 s$] we should have sufficient statistics:

particle	pp $[10^3]$	Pb-Pb @ $\sqrt{s} = 5.5$ TeV $0 < b < 3$ $[10^3]$	$3 < b < 6$ $[10^3]$	$6 < b < 9$ $[10^3]$	$9 < b < 12$ $[10^3]$	$b > 12$ $[10^3]$
J/ψ	4670	130	230	200	95	21.7
ψ'	122	3.7	6.5	5.5	2.6	0.59
Υ	44.7	1.3	2.4	2.0	0.93	0.20
Υ'	11.4	0.35	0.62	0.52	0.24	0.054
Υ''	6.9	0.20	0.35	0.30	0.14	0.030

How can we estimate the combinatorial background?

- Imply the Event Mixing Technique:

Muons, satisfying certain selection criteria, are put into pools and then picked randomly (provided they come from different events) to form an uncorrelated pair

- Requirement: the kinematical distributions of the muons put into the pool must be the same as the background muons (i.e. apply the same single muon cuts as done for physics analysis; do *not* apply cuts on dimuon level prior to the mixing $\rightarrow$ introduces correlations)

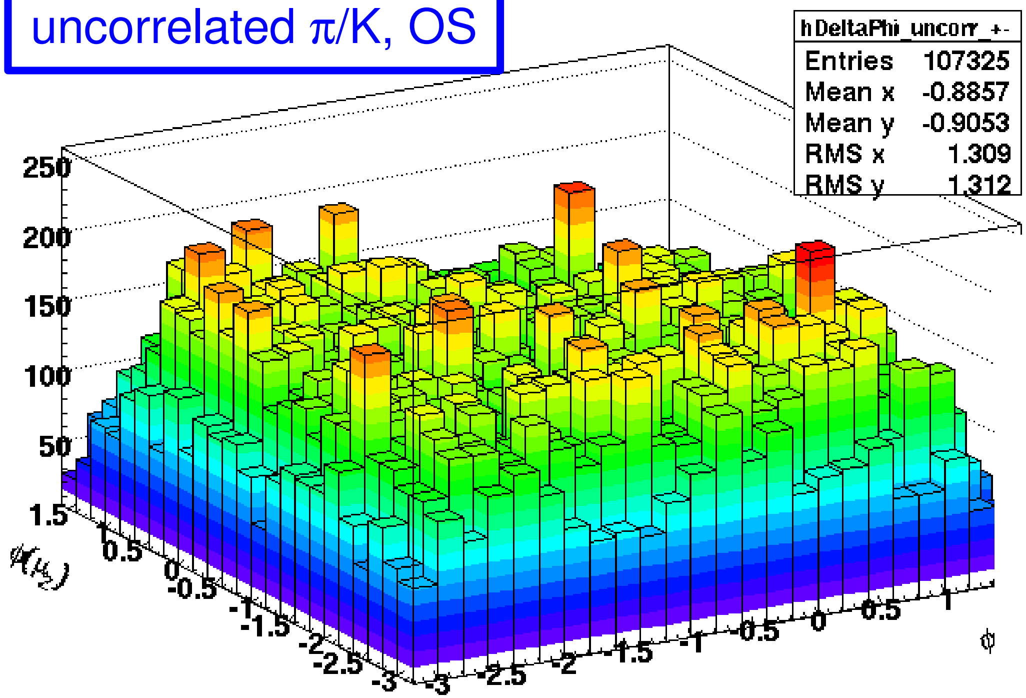
- Complication at LHC energies: no "control" BG sample as at lower energies (LS dimuons contain signal)

- Details: perform the mixing in various bins, reflecting the experimental situation
  - muons from different z-vertex positions have different acceptance
  - muon multiplicity depends on centrality
  - elliptic flow determines specific geometry of collision
  - ...

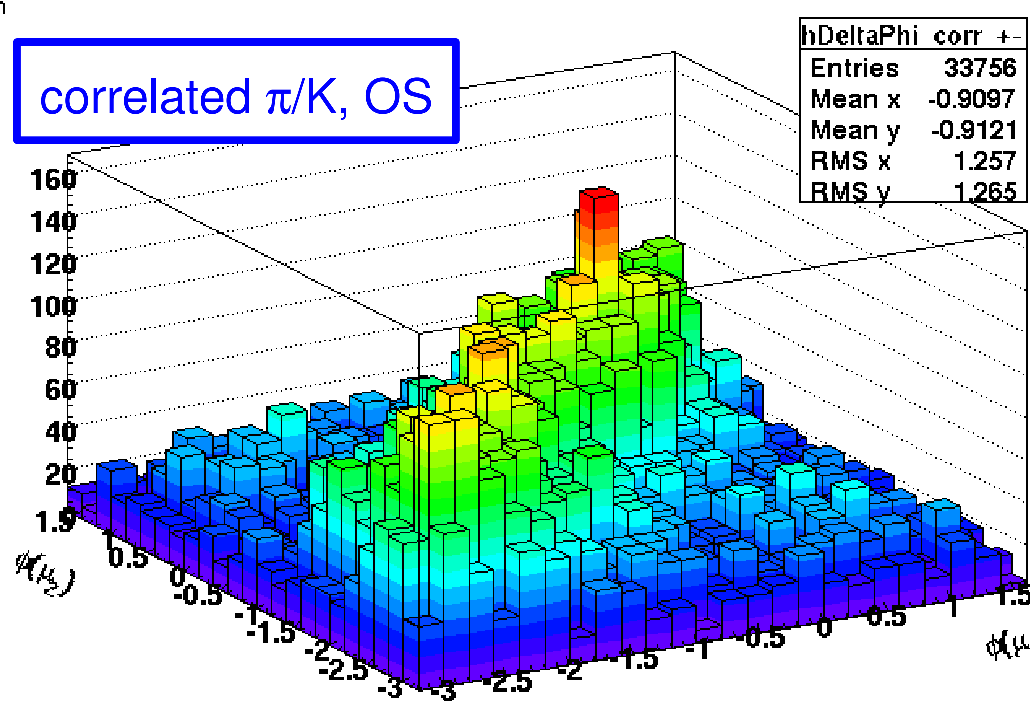
Dimuons from correlated π/K decays

- At high energies many hadrons fragment from one common string:
  "Jet-like" production of soft particles ⇒ These particles will be correlated
- The dimuon mass, $M^2 = 4m_\mu^2 + 2p_{T,1}\, p_{T,2} (\cosh(\Delta\eta) - \cos(\Delta\phi))$
  depends on the p_T value of the two muons and on the opening angle $\Delta\phi$.

uncorrelated π/K, OS

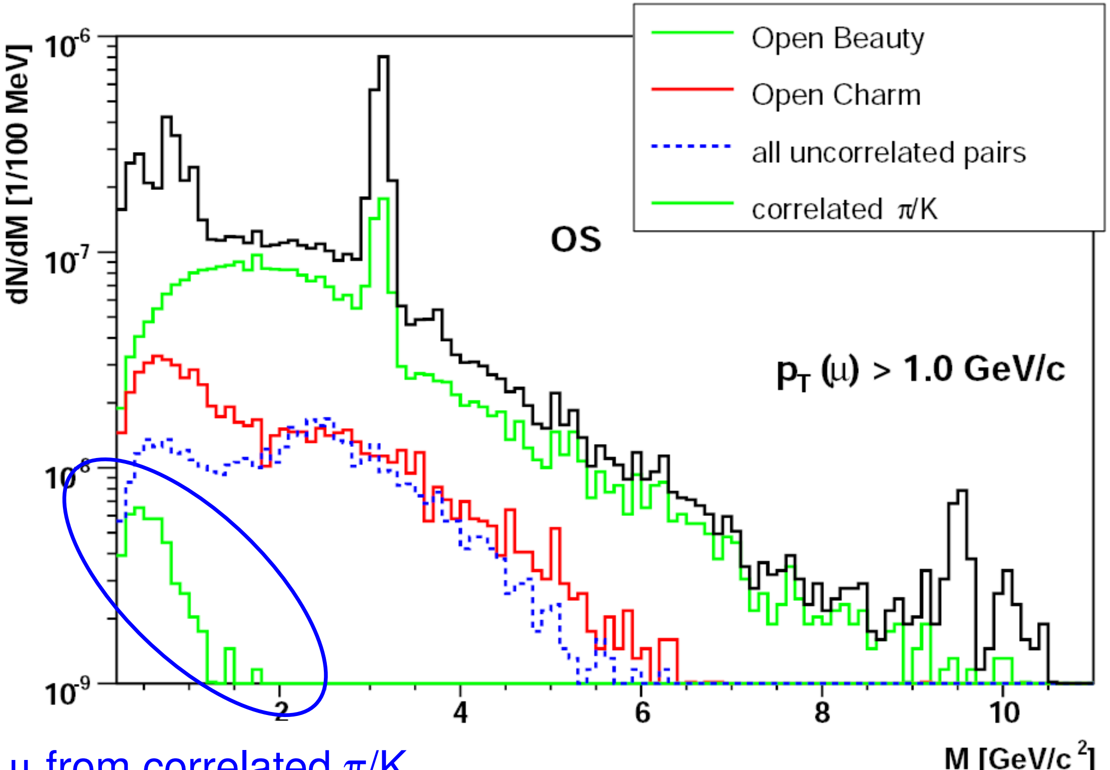


correlated π/K, OS



plots performed without a cut on the single muon's p_T

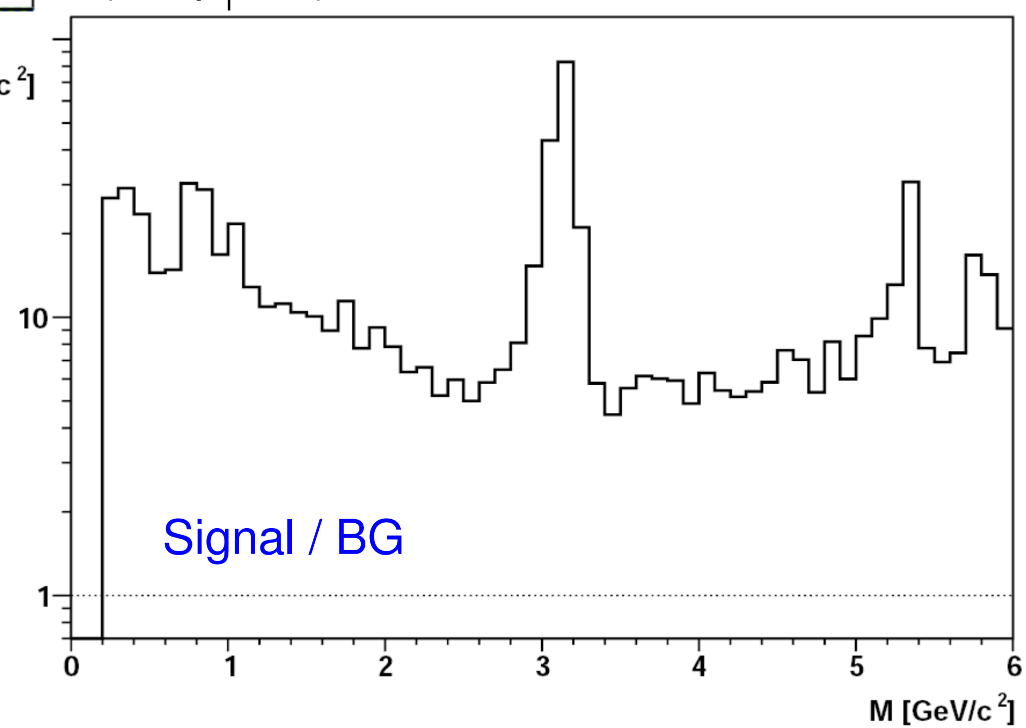
OS Dimuon Mass and p_T Spectrum for pp @ $\sqrt{s}$=14 TeV



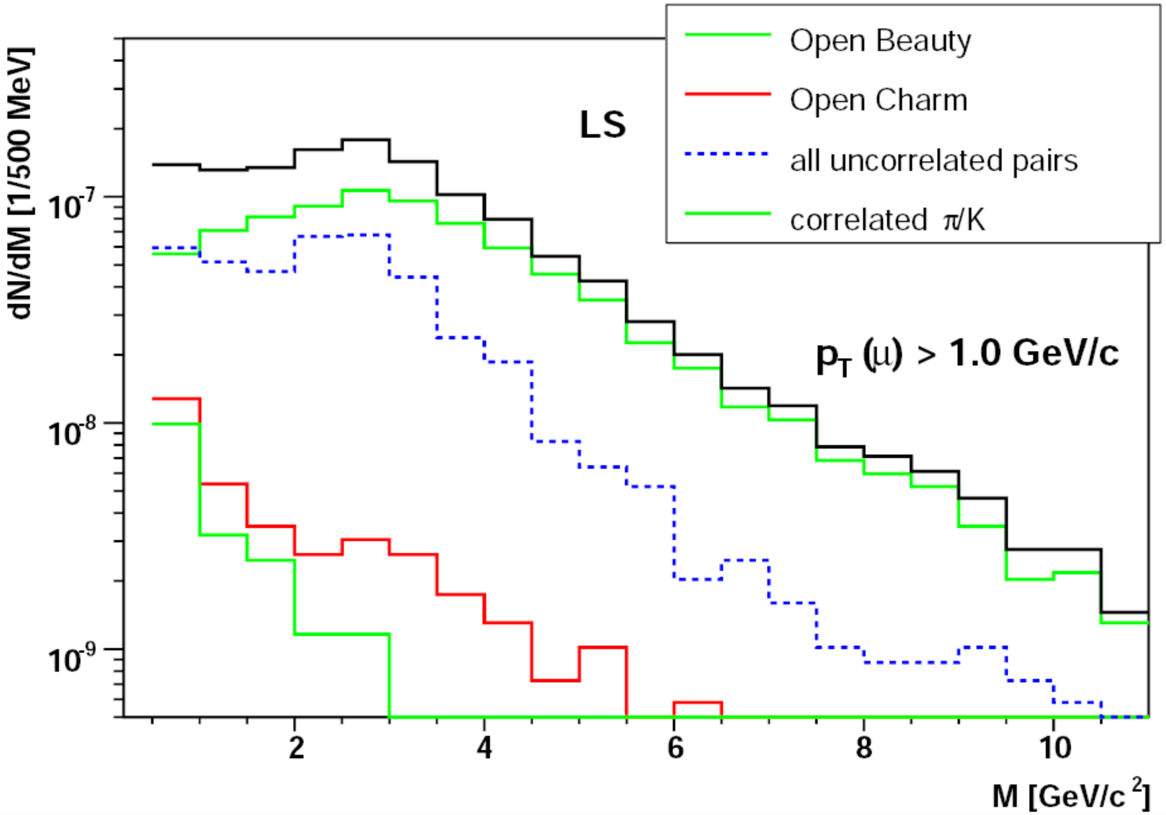
μ from correlated π/K

- Continuum dominated by "open beauty"; feed-down into J/ψ noticeable (to be taken into account in its suppression studies)
- Open charm suppressed w.r.t. open beauty, due to kinematics
- Contribution from correlated π/K small
- Good acceptance for light vector and pseudo-scalar mesons (η, ρ/ω, ϕ) (but p_T cut)

- In pp collisions we are overwhelmed by signal in the opposite sign sample
- The background is not an issue



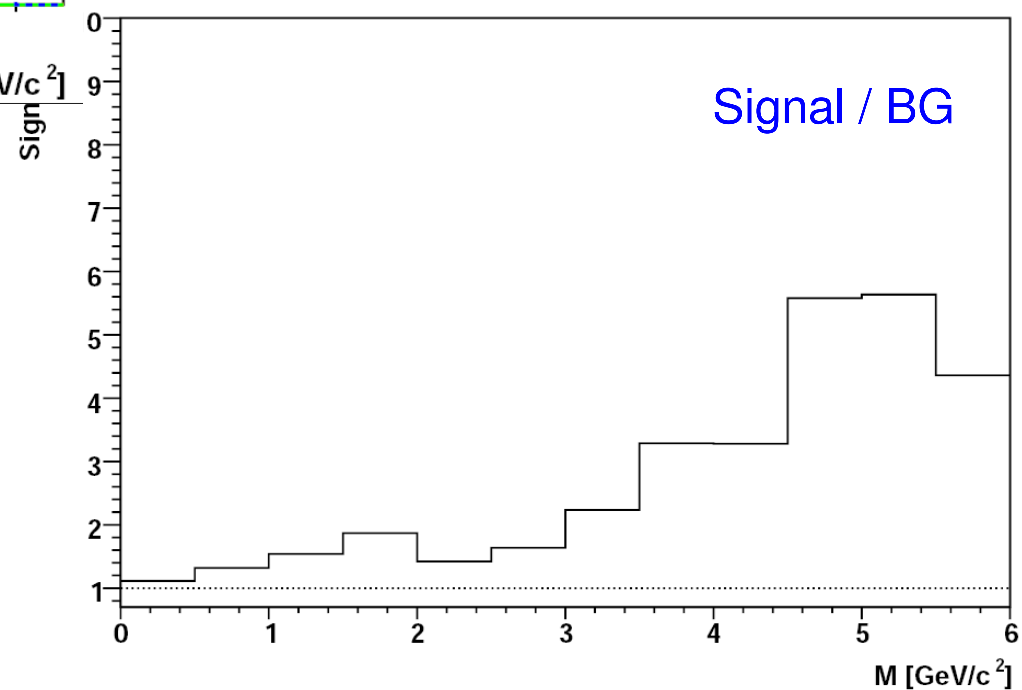
LS Dimuon Mass and p_T Spectrum for pp @ $\sqrt{s}$=14 TeV



The only signals for LS dimuons are:

- open beauty
- open charm
- correlated π/K

Open beauty clearly dominates in the whole mass region



- Even for the LS, the signal to BG ratio is larger than 1 → should make feasible a study of (LS) open beauty cross-section

Event mixing in pp collisions

- Muon multiplicity in pp collisions is low → use muons from single muon triggered events only to fill the “mixing pools”
- Normalisation based on the single muon probability

The probability to obtain one and only one muon satisfying the selection criteria:

$$P_{1\mu} = \frac{N_{1\mu}}{N_{MB}}$$

$N_{1\mu}$: number of events where one and only one muon is present

N_{MB}: number of minimum bias (Pythia) events

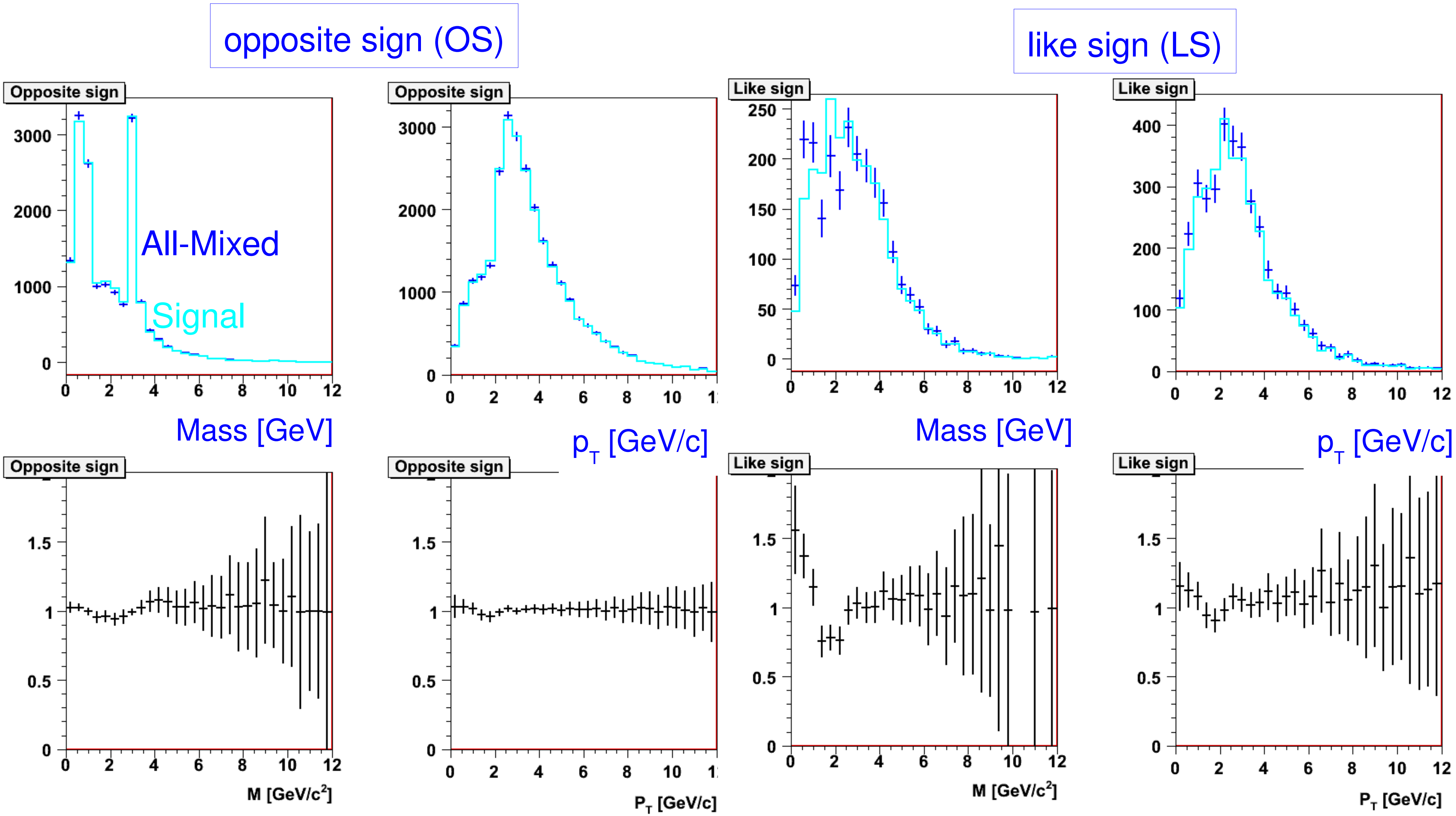
The probability to have two uncorrelated muons, forming a background pair is then:

$$P_{2\mu} = \left(\frac{N_{1\mu}}{N_{MB}} \right)^2$$

The expected number of background pairs is then:

$$N_{BG} = P_{2\mu} N_{MB} = \frac{N_{1\mu}^2}{N_{MB}}$$

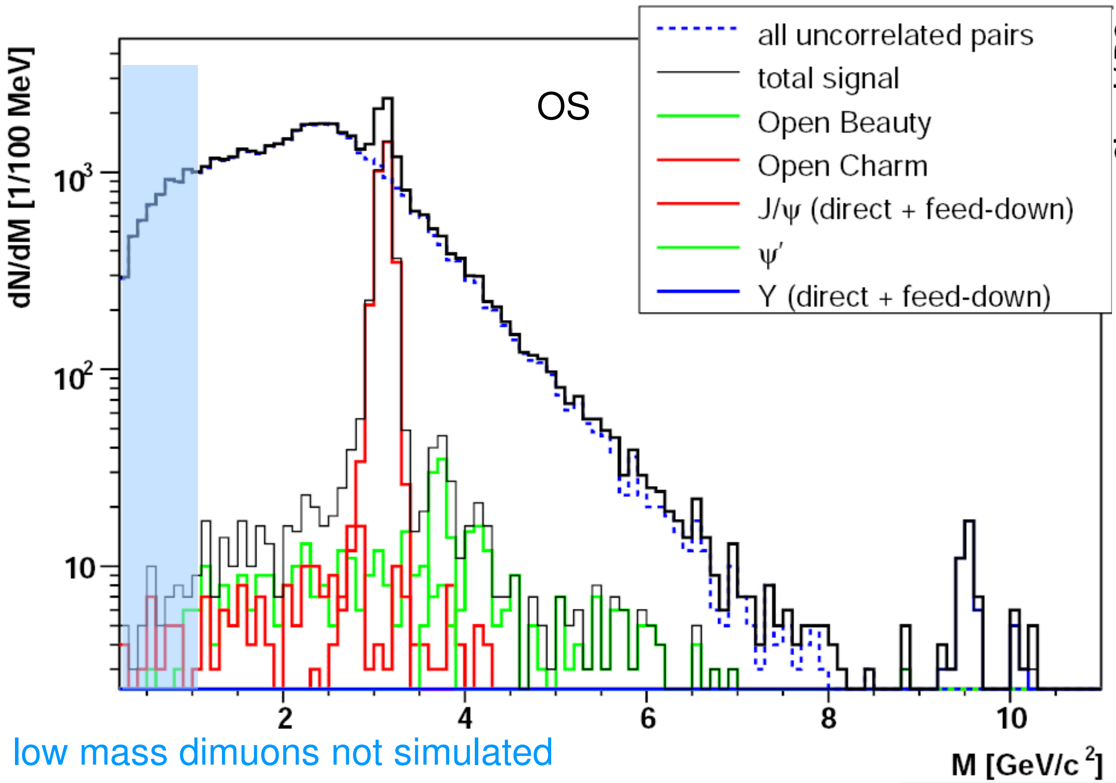
Can we reproduce the signal after background subtraction?



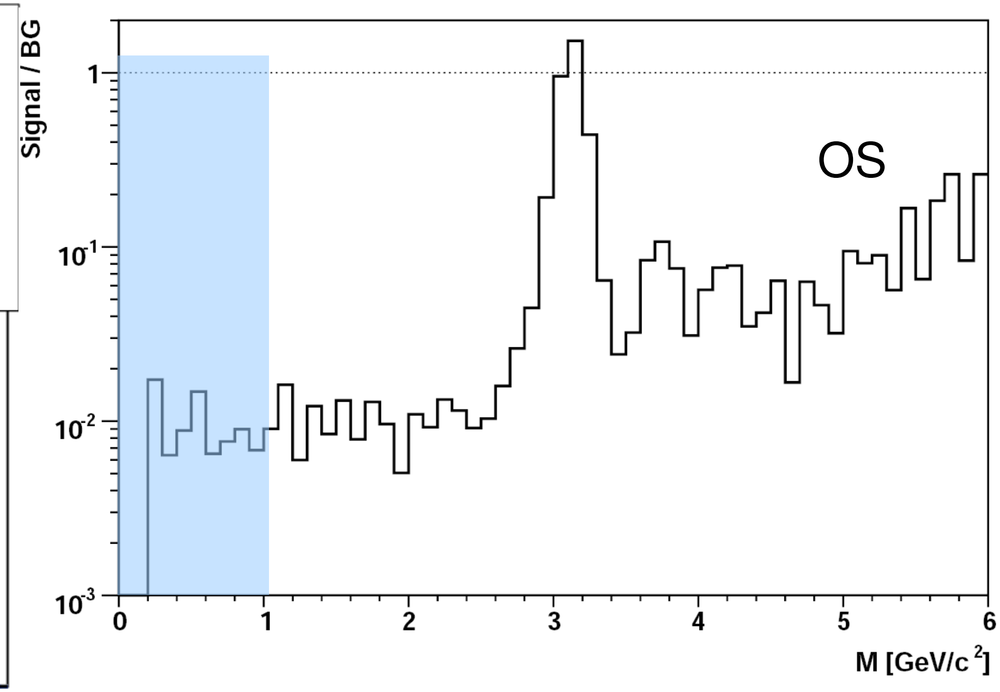
OS: the background subtracted spectra agree quite well with the expected signal

LS: the control sample still contains unaccounted correlated pairs → to be corrected

Dimuon Mass Spectrum for Pb-Pb @ √s=5.5 TeV: peripheral bin

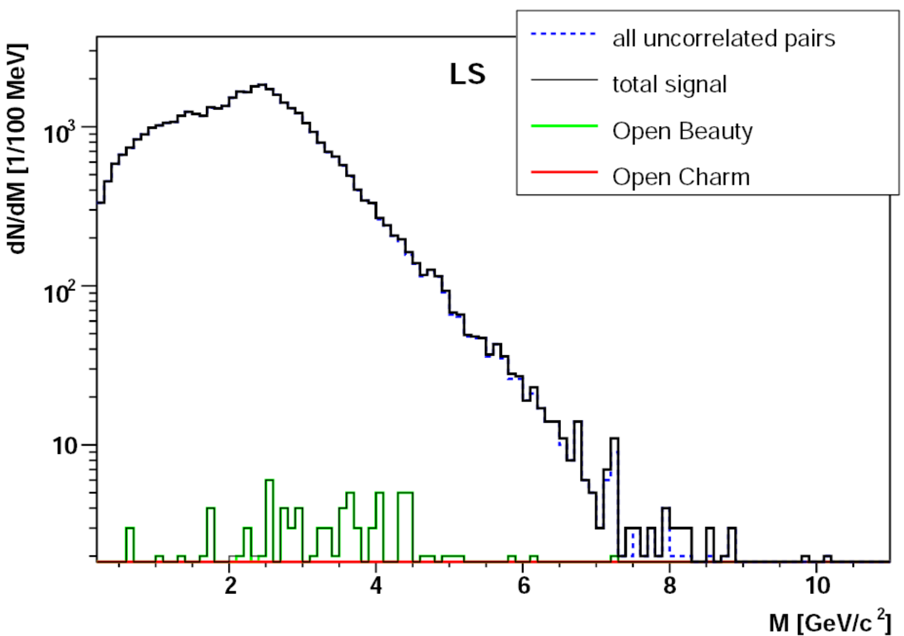


low mass dimuons not simulated



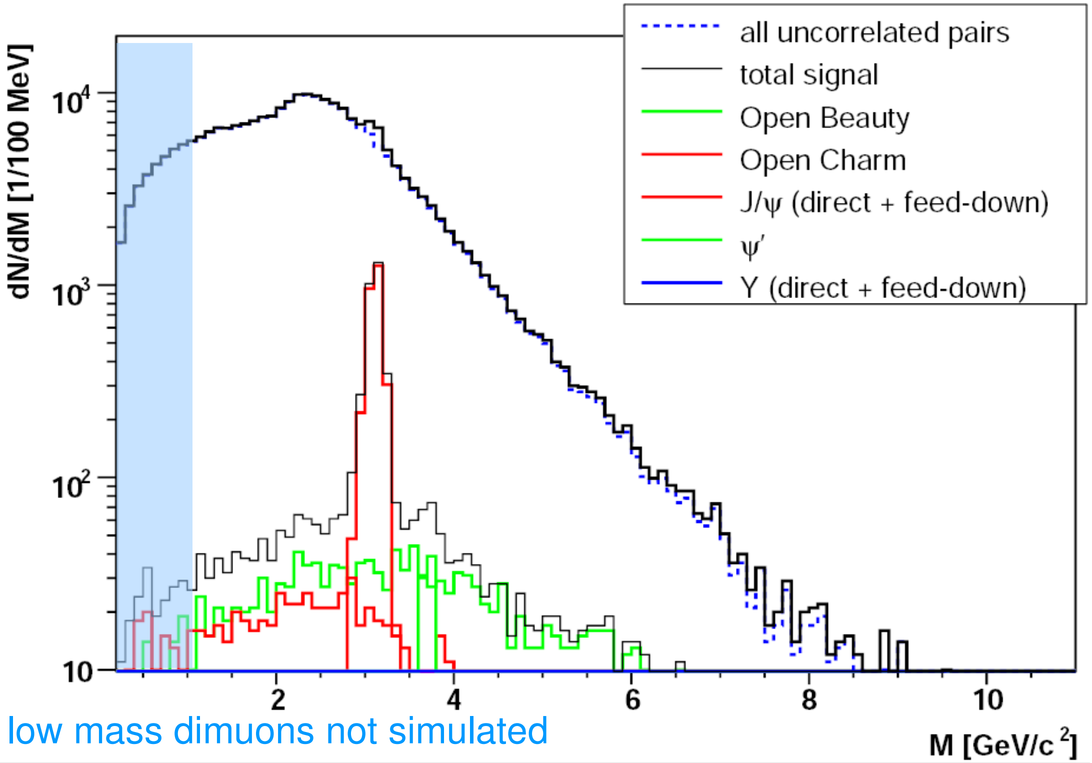
9 < b < 12 fm, ⟨b⟩ = 11.53 fm

⟨Npart⟩ = 71, ⟨Ncoll⟩ = 189

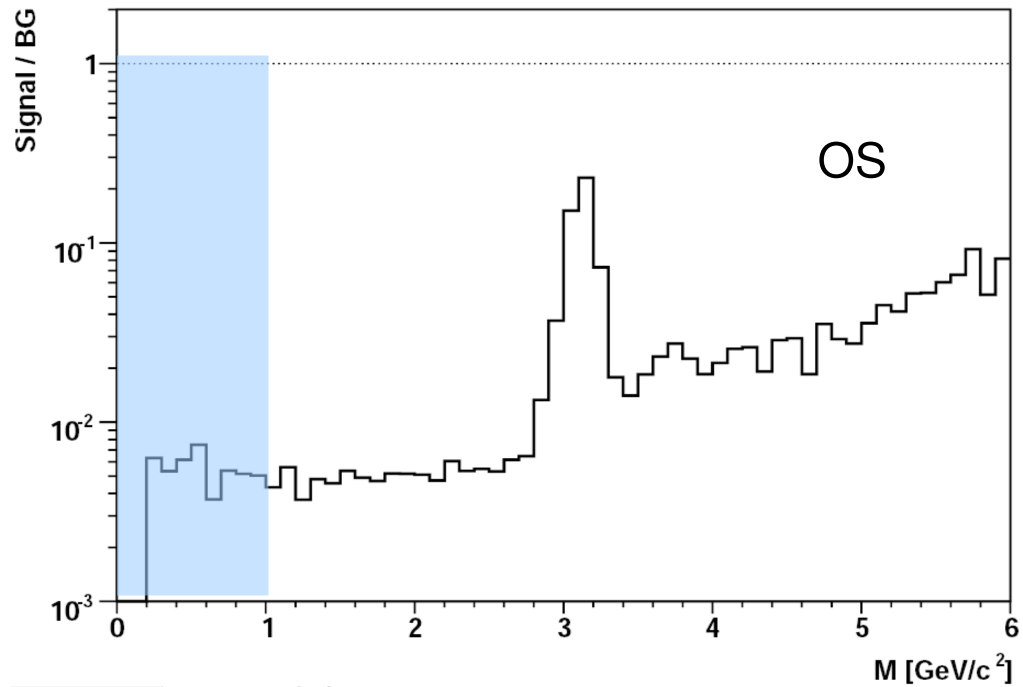


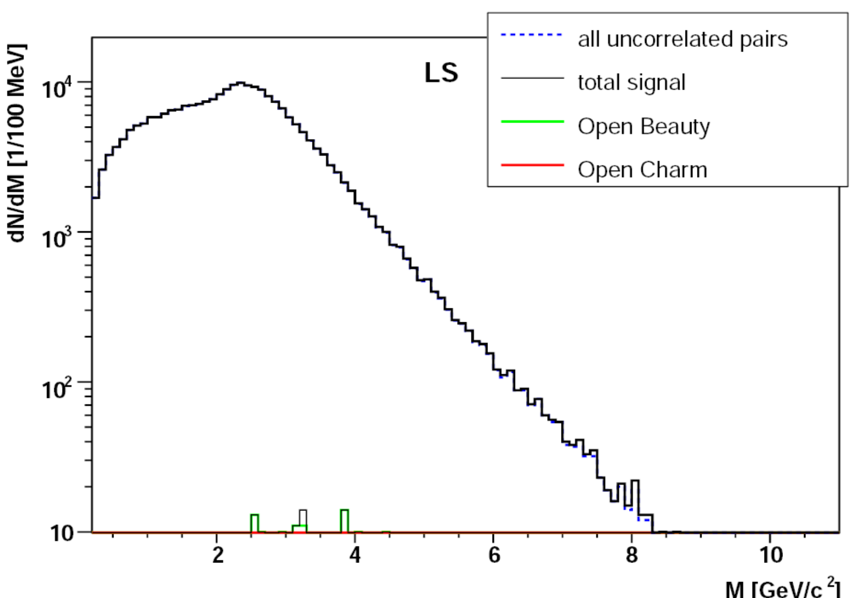
- Under the assumption of very "conservative" particle multiplicities (i.e. Nch = 8000 in most central collisions), we see a large combinatorial background already in peripheral collisions...
- Signal in LS practically not present

Dimuon Mass Spectrum for Pb-Pb @ √s=5.5 TeV: central bin



low mass dimuons not simulated



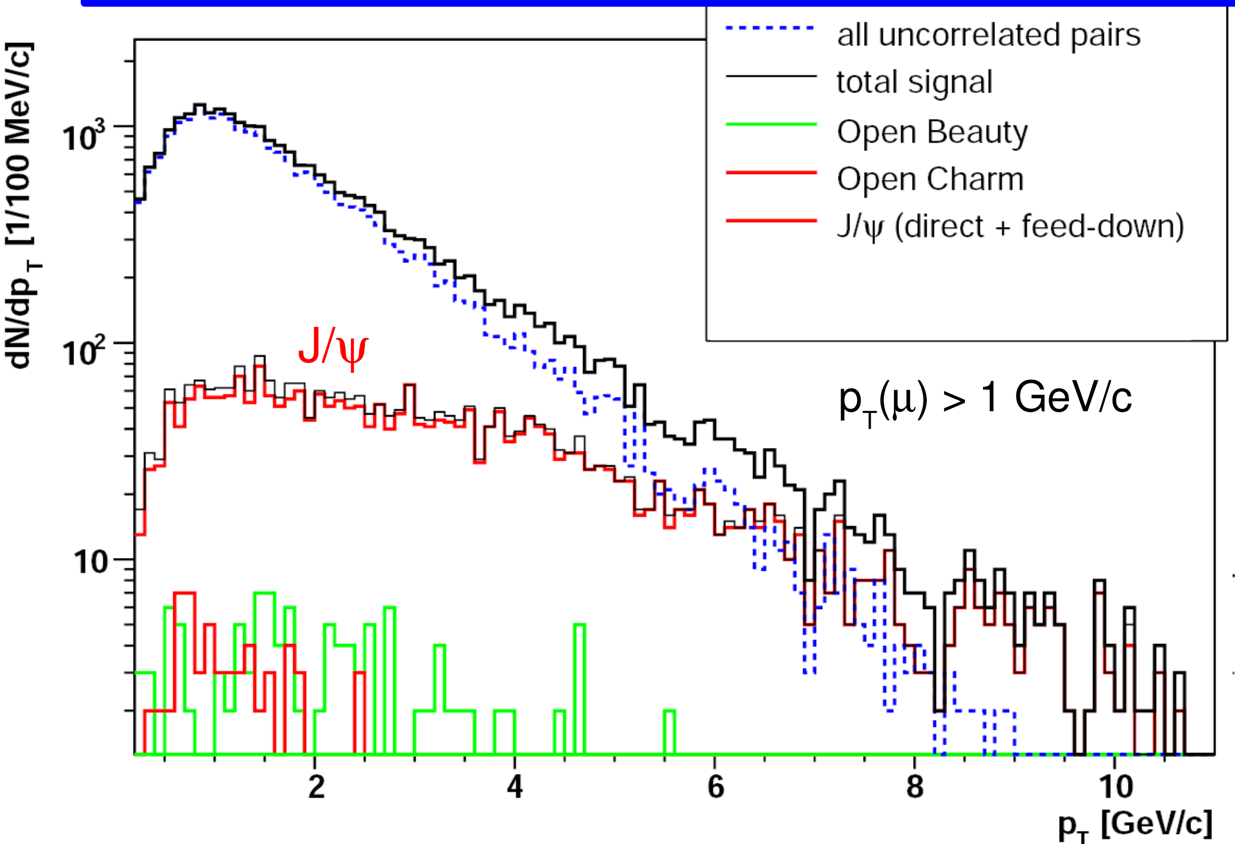


$0 < b < 3$ fm, $\langle b \rangle = 2.64$ fm

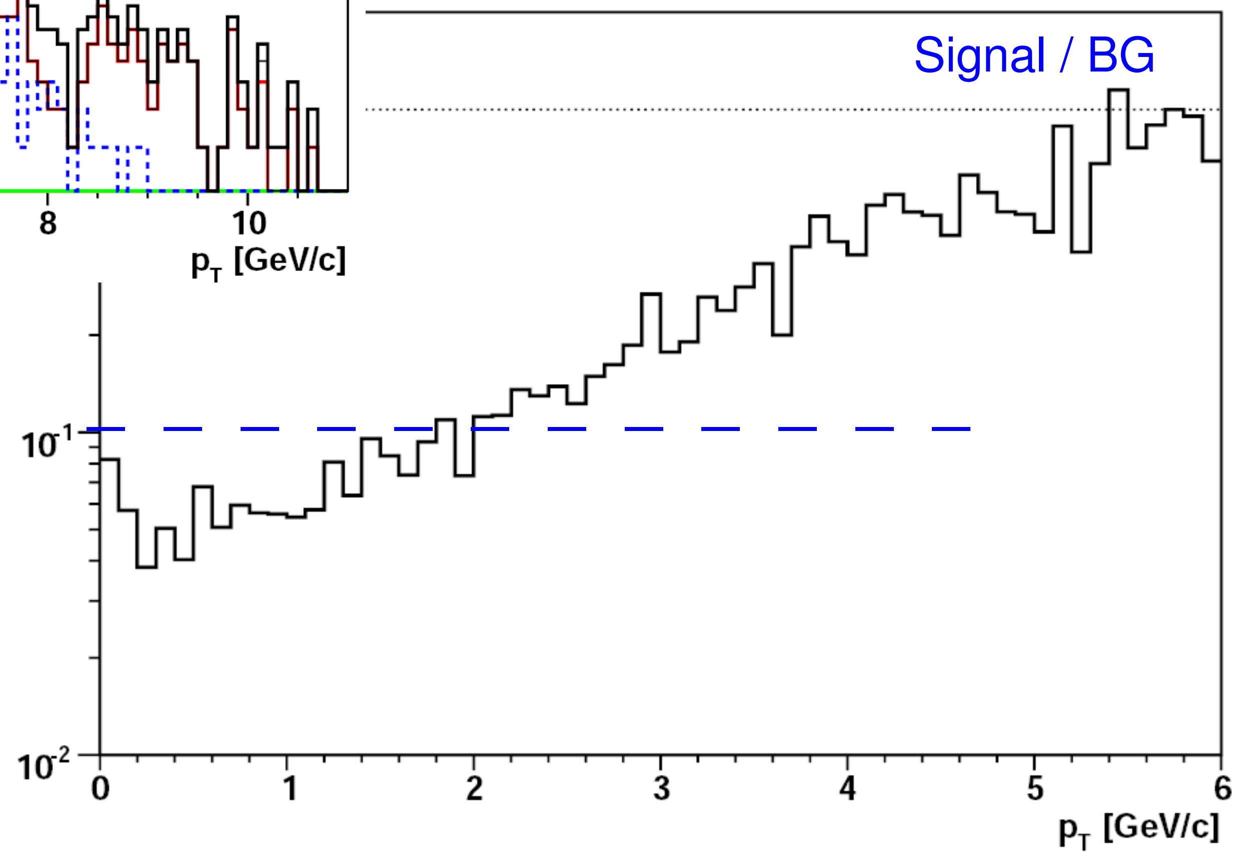
$\langle Npart \rangle = 381$, $\langle Ncoll \rangle = 1981$

- The signal-to-background ratio is 1 / 100 for masses below masses of the J/ψ and rises only slowly with increasing mass...
- Under such conditions a study of the continuum physics will be very much affected by a correct evaluation of the background

The J/ψ mass region in central (b < 3 fm) Pb-Pb collisions



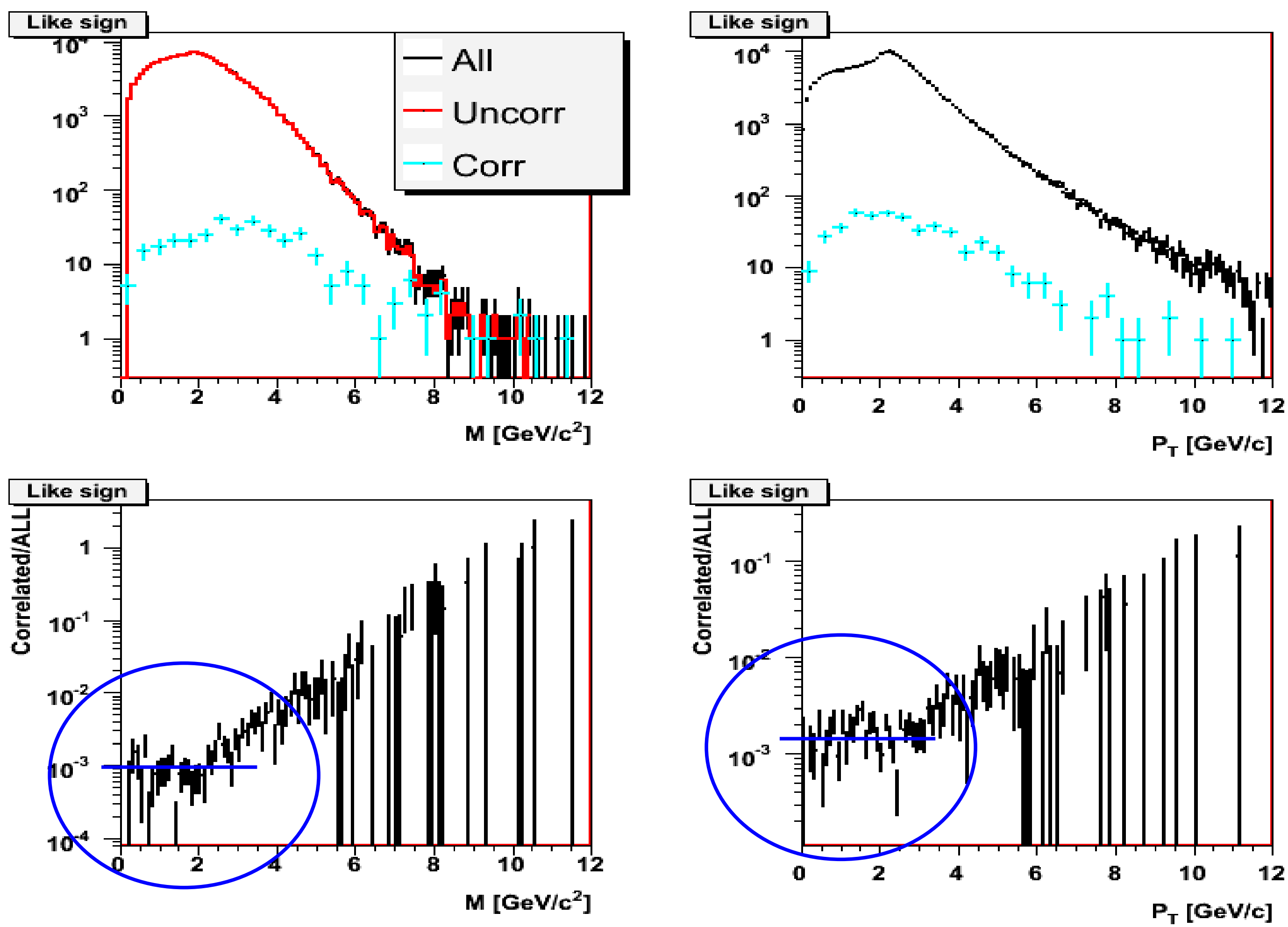
p_T distribution for $2.9 < M < 3.3$ GeV



With the current assumption on particle multiplicities, in central collisions, the signal to background ratio for J/ψ is above 0.1 for $p_T > 2$ GeV/c:

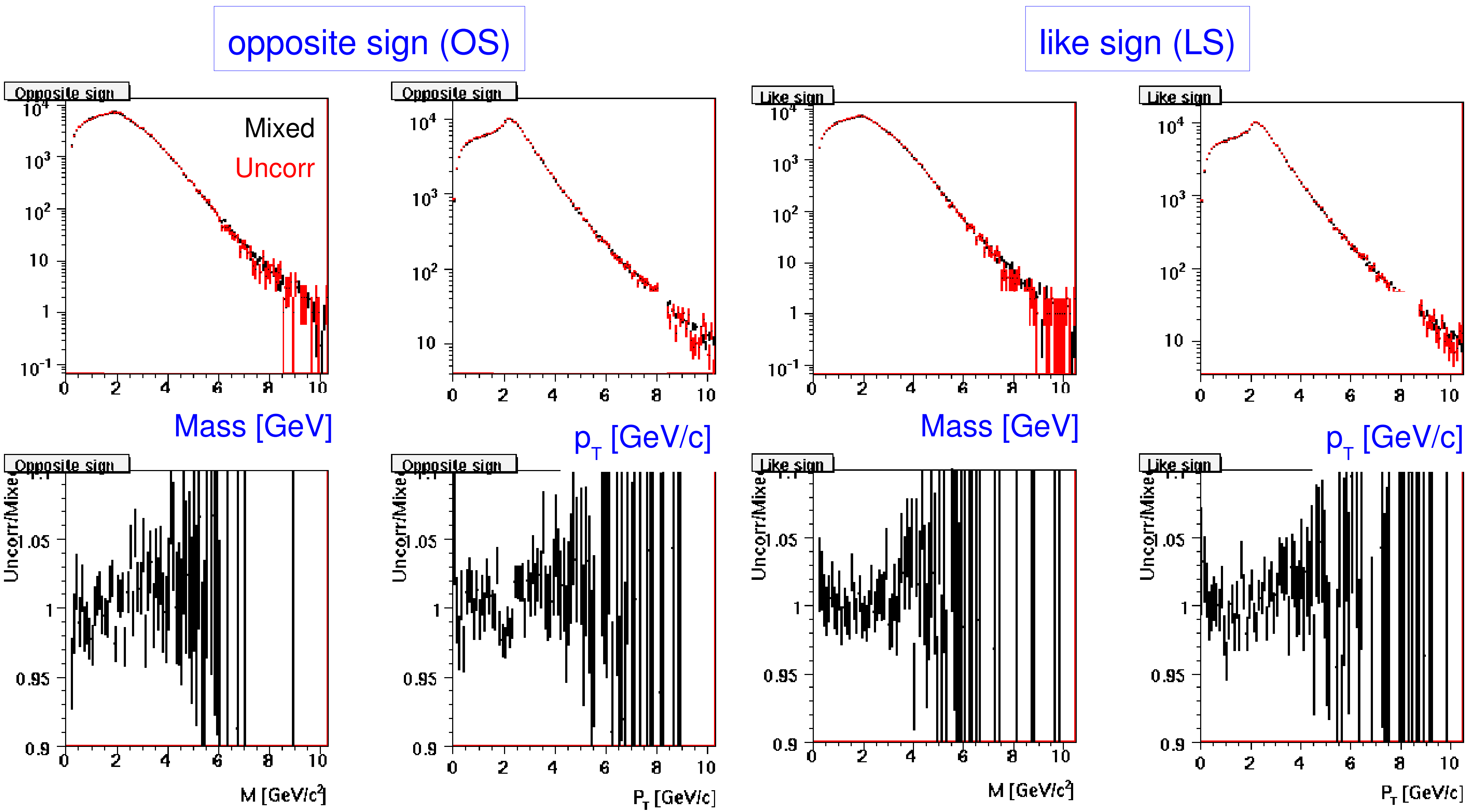
Event mixing in Pb-Pb collisions

- In Pb-Pb collisions we are dominated by combinatorial background; the pools are filled from muons in dimuon triggered events
- The normalisation of the mixed background sample can be done by looking at low mass, low p_T like sign pairs:



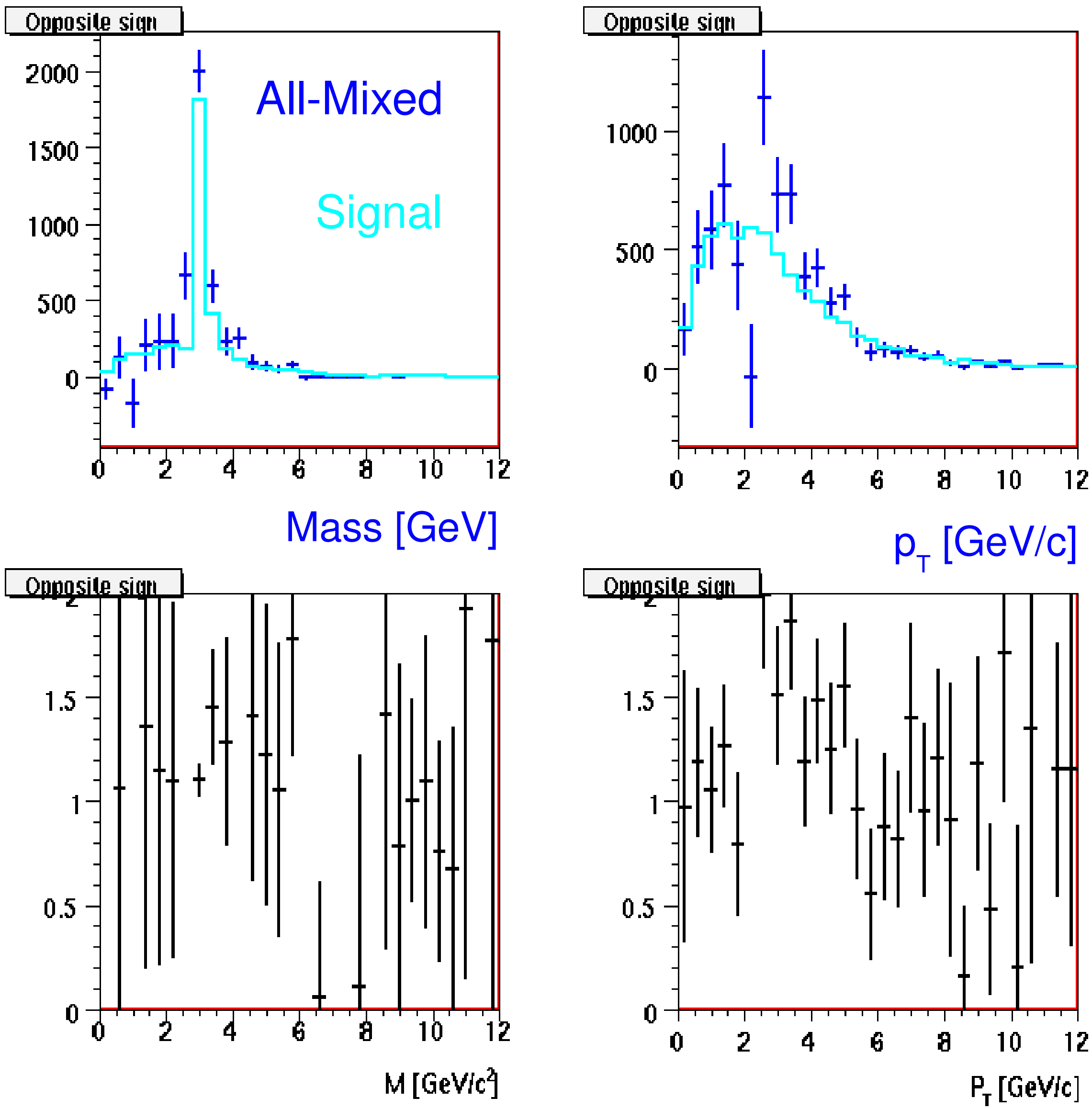
For masses below J/ψ and p_T below ~ 3 GeV/c the signal to background ratio in the LS is ~ 1 permill.

Quality of event mixing: most central Pb-Pb collisions



- Within the statistics generated we can reasonably well reproduce the expected background (shown on the example of the most central Pb-Pb collisions, $p_T(\mu) > 1$ GeV/c)

Can we reproduce the signal after background subtraction?



The background subtracted spectra agree with the expected signal.

Summary

- With the dimuon spectrometer we should be able to perform an accurate, high statistics measurement of the quarkonia (J/ψ, ψ', Y, Y', Y'') for which we have acceptance down to $p_T = 0$
- The cross-section measurement of open beauty should be easily feasible in pp collisions – including the fraction that is seen in the LS sample; in heavy-ion collisions its accuracy depends on the level of real background and the accuracy with which the background can be subtracted
- The event mixing technique will be used to subtract the combinatorial background; it has been applied to pp, as well as to heavy-ion collisions and the present results look quite promising
- Detailed study should be extended when applying various selection cuts, suitable for the individual physics data analyses
- In order for the background subtraction to work in pp collisions, we need to know the number of minimum bias events and we need to collect data with single muon triggers

Muon pair event topologies for open beauty

- The two muons can come from a different B hadron, e.g.:

  $B^{*-} \to B^{+} X \to D^{*0}$barX $\to D^{0}$barX $\to \mu^{-}X$

  B_s^{*0}bar $\to B_s^{0}X \to \mu^{-}X$

  } LS pairs

  or:

  B^{*0}bar $\to B^{0}$barX $\to \mu^{-}X$

  $B^{*+} \to B^{+}X \to \mu^{+}X$

  (and similar for open charm)

  } OS pairs

- Both muons come from the same B hadron, e.g.:

  $B^{*-} \to B^{-}X \to D^{0}\mu^{-}X$

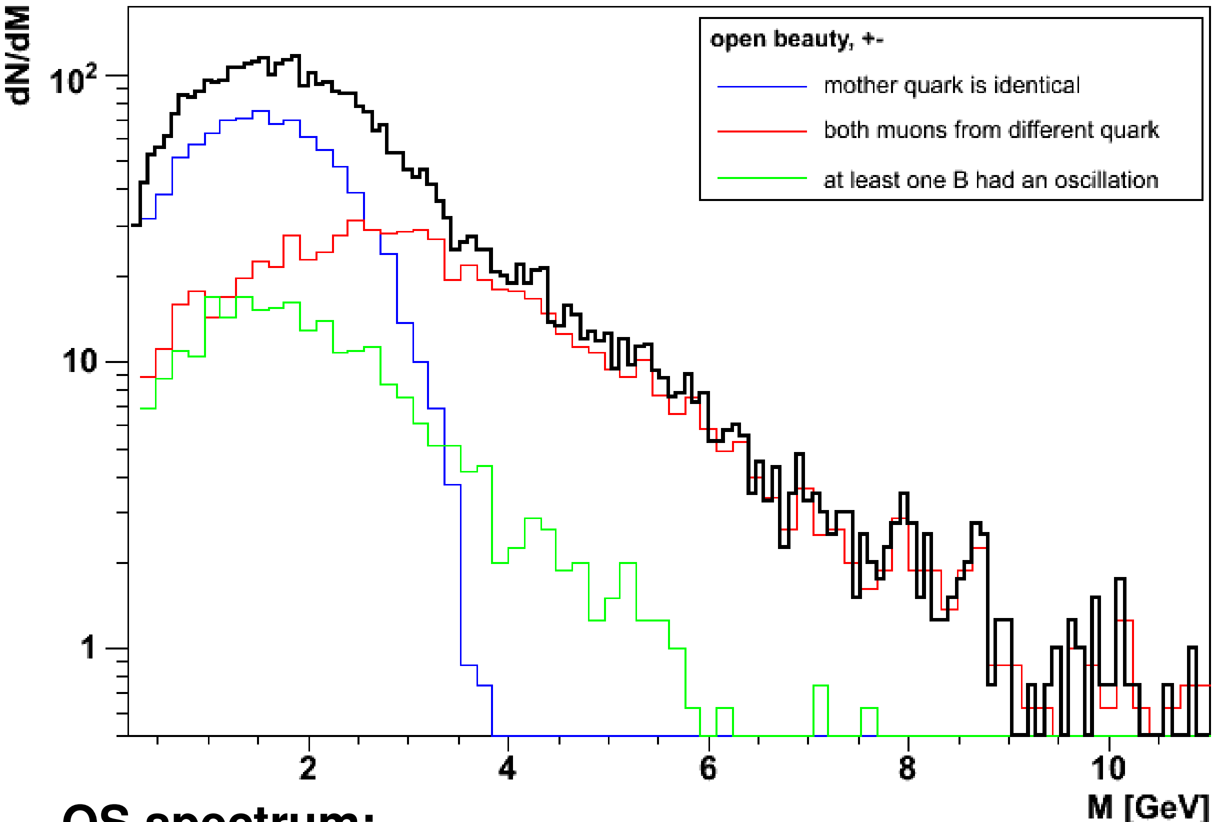
  with $D^{0} \to \mu^{+}X$

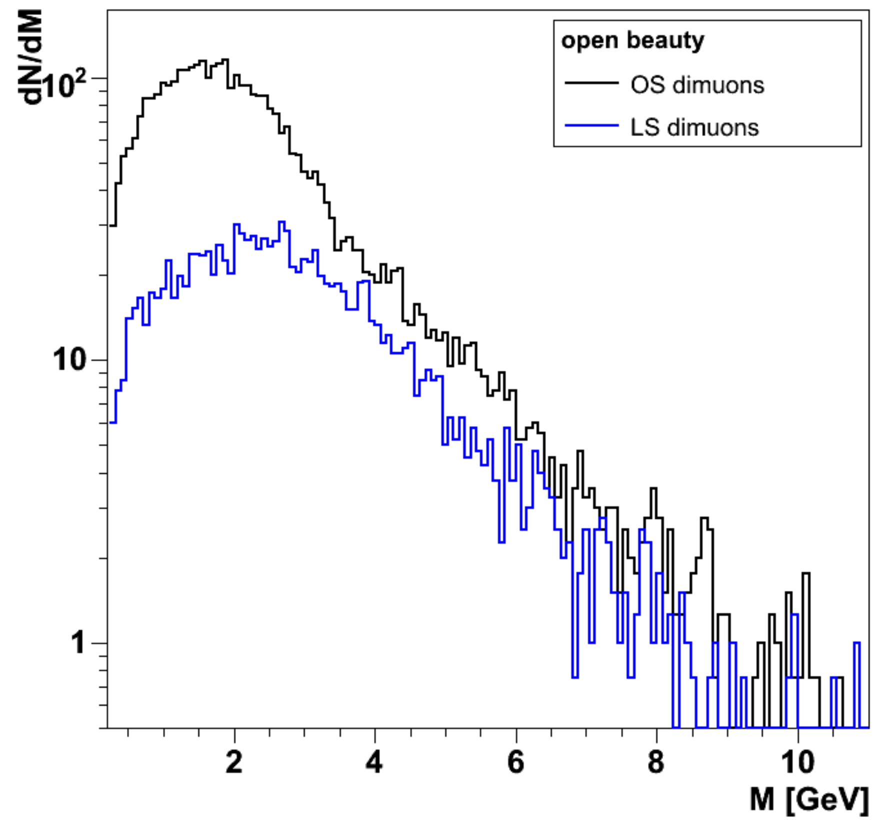
  } OS pairs

- BBbar oscillation in the neutral B meson sector lead to muon pairs of all sign combinations

  $B_d^0 \overline{B_d^0}$ and $B_s^0 \overline{B_s^0}$

Open beauty mass spectra





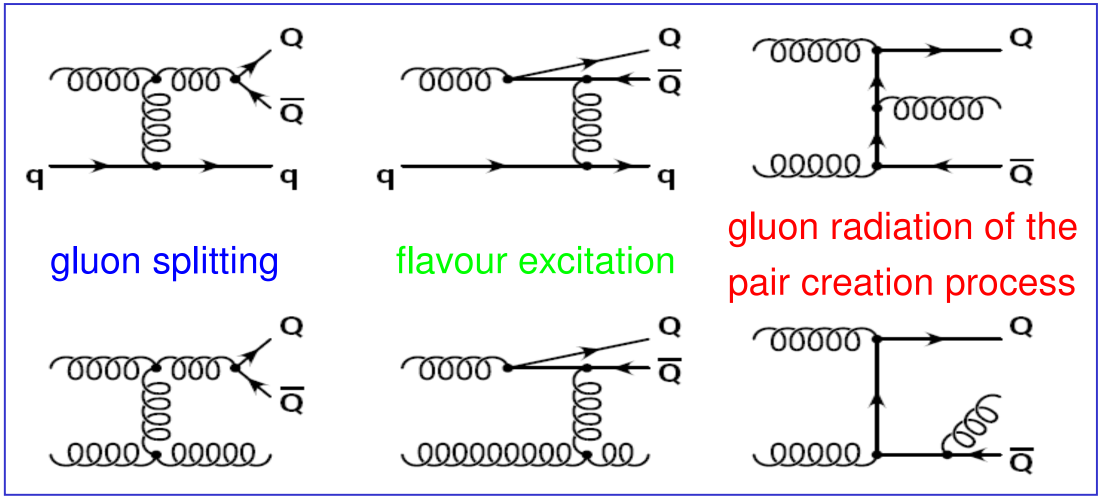
OS spectrum:

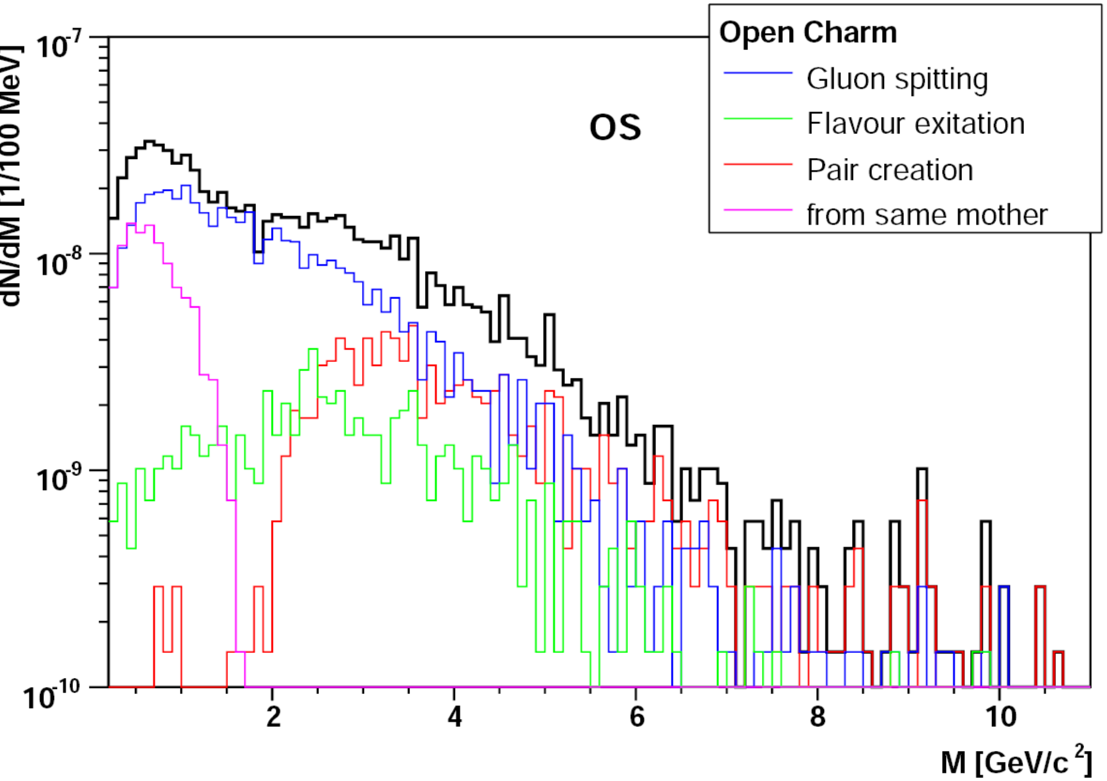
- Low mass beauty mass spectrum dominated by chain decays of a single B hadrons
- Contribution from BBbar decays (muons come from different B hadrons) dominant for M > 3 GeV/c and extends up to the Y mass
- BBbar oscillations amount roughly to 10% of the total open beauty signal

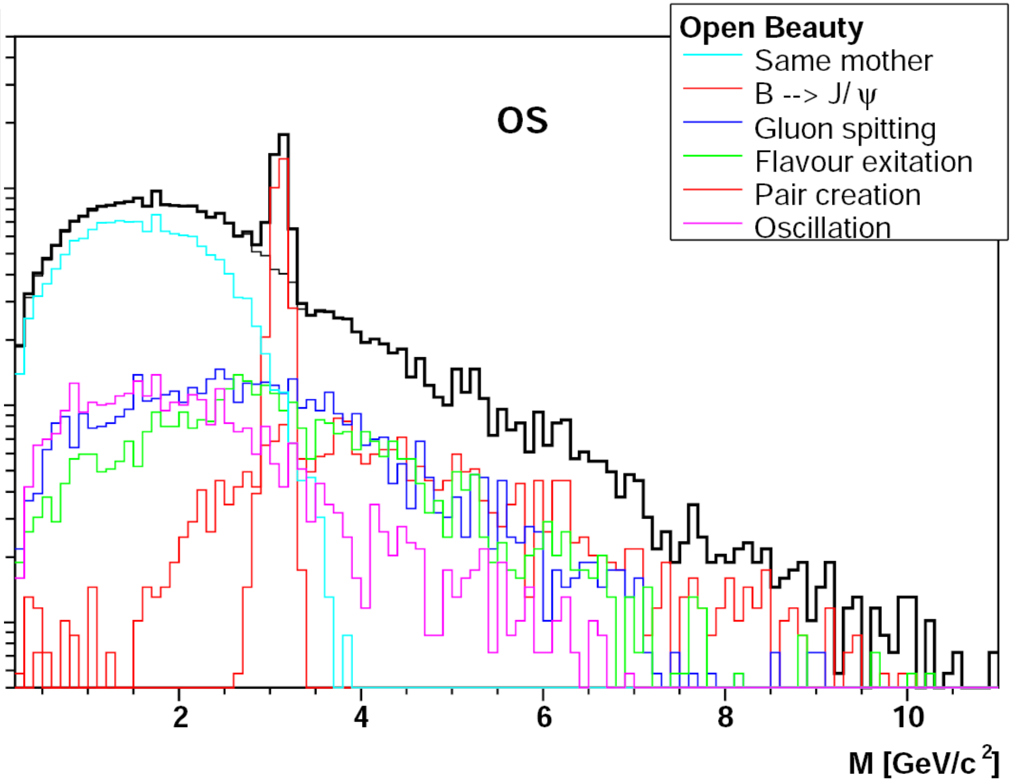
OS vs LS dimuons:

- LS dimuons (practically) cannot be formed from decays of the same B meson
  $\rightarrow$ this contribution is missing
- For M > M(J/ψ): contributions in LS of the same order as in OS

Individual contributions of open beauty

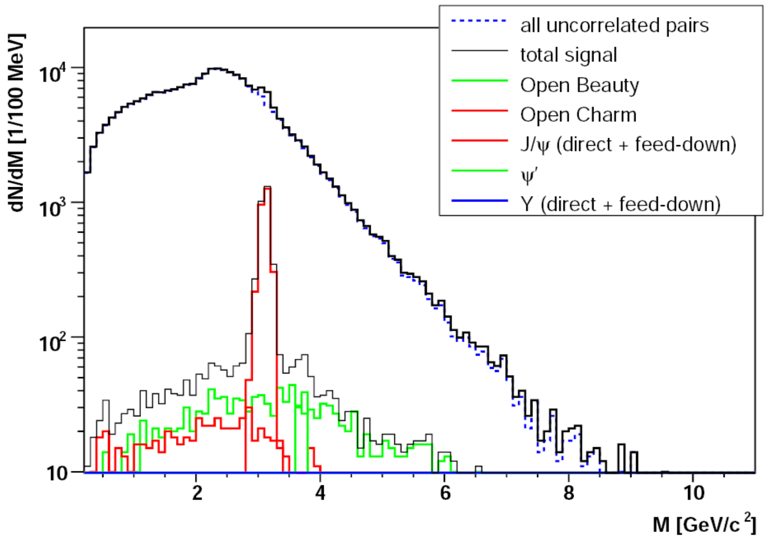




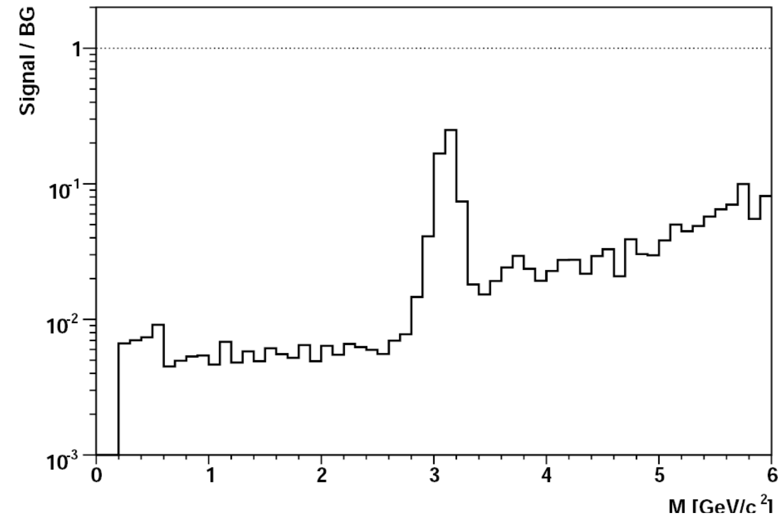


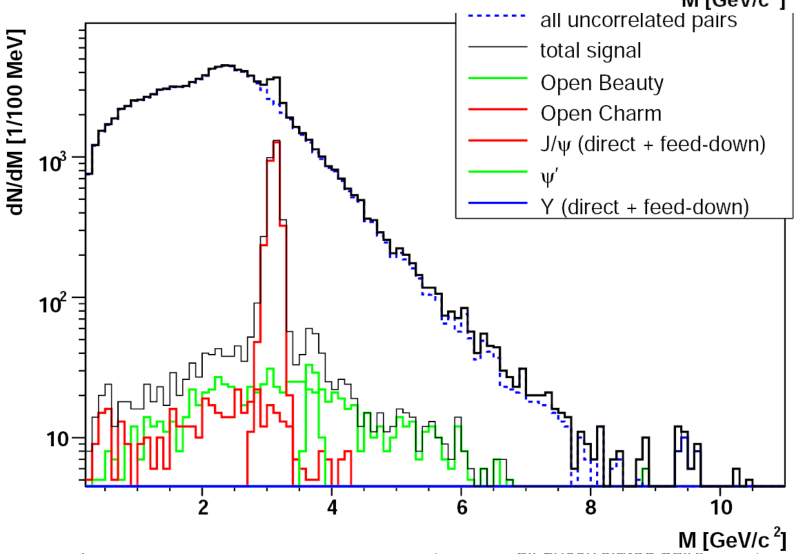
Cross-sections and branching ratios for collisions at $\sqrt{s}$=5.5 TeV

	σ [μb]	shadowing	BR [%]	σ·Sh·BR [nb]
DDbar	6.64	0.65	(8.5)^2	31.2
BBbar	0.21	0.84	(10.95)^2	2.1
J/ψ	31.0	0.60	5.88	1.1
ψ'	4.680	0.60	1.03	28.9
Y	0.501	0.76	2.48	9.4
Y'	0.246	0.76	1.31	2.4
Y''	0.1	0.76	1.81	1.4
π	18000	---	99.99	18·10^6
K	240	---	63.51	152.4

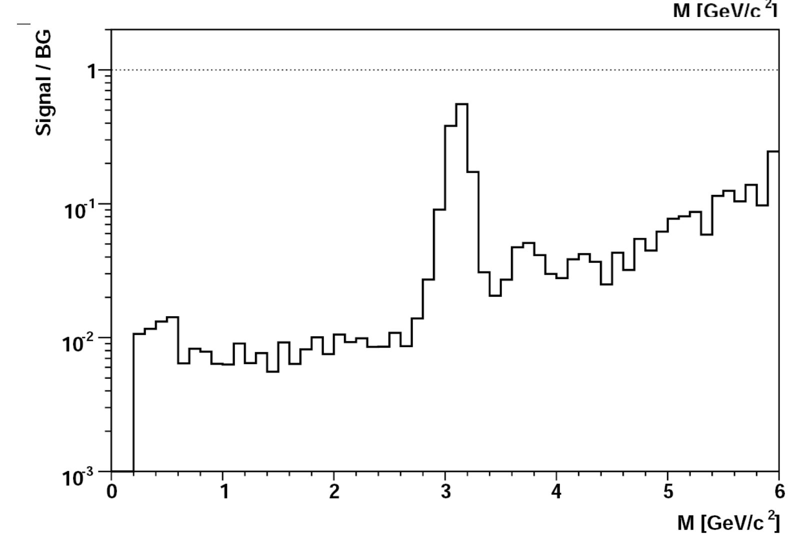

all uncorrelated pairs
total signal
Open Beauty
Open Charm
J/ψ (direct + feed-down)
ψ′
Υ (direct + feed-down)
dN/dM [1/100 MeV]
M [GeV/c ²]

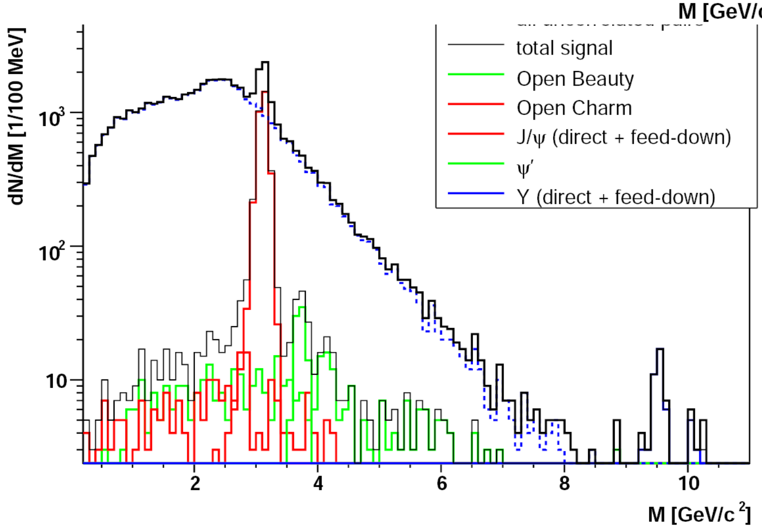
c1


Signal / BG
M [GeV/c ²]

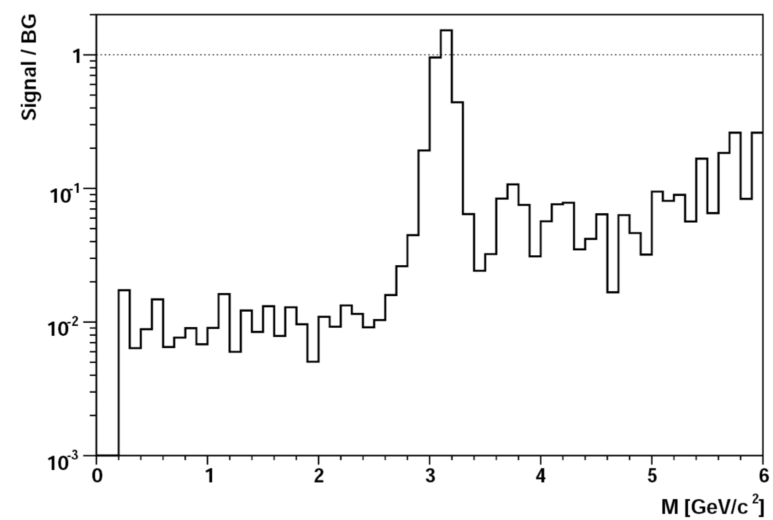

all uncorrelated pairs
total signal
Open Beauty
Open Charm
J/ψ (direct + feed-down)
ψ′
Υ (direct + feed-down)
dN/dM [1/100 MeV]
M [GeV/c ²]

c3


Signal / BG
M [GeV/c ²]


total signal
Open Beauty
Open Charm
J/ψ (direct + feed-down)
ψ′
Υ (direct + feed-down)
dN/dM [1/100 MeV]
M [GeV/c ²]

c4


Signal / BG
M [GeV/c ²]