Testing Lepton Flavor Conservation Law(LFCL) in J/ψ Decay

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- **Introduction**
  - **Motivation**

    Important to test LFCL

    1. In the Standard Model,Total and Individual Lepton Numbers are conserved.
    2. In many extensions of the SM,such as SUSY, GUT, Left-Right Symmetric Models,lepton numbers are violated.
    3. Super-Kamiokande[1] indicates $m_\nu \neq 0$,then LF symmetrie are broken
    4. In Lab,we have performed different kind of Experiments to test LFCL at BES, such as the measurement of $\tau \to e\gamma$, $\mu\gamma$, $e\pi^0$, $\mu\pi^0$ with D_s data.

– **Theoretical Consideration**

1. We have had very large samples($2.38 \mathrm{x} 10^7$) of J/ψ in the world(BESII),and we will accumulate about $5 \mathrm{x} 10^7$ J/ψ Data in two years, so we trust we can obtain more accurate conclusion about LFCL in the J/ψ Decay:
   J/$\psi \to e\mu$
2. Experimental Measurement on Br(J/$\psi \to e\mu$) is interesting(No data exists in Particle Data Book).
3. Theoretical Consideration
   There are some theoretical paper to study LFCL decays.[2][3][4][5][6][7][8] According to the paper,

depend on momtenum linearly:

Br(J/$\psi \to e\mu) < 10^{-6}$

depend on momtenum quadratically:

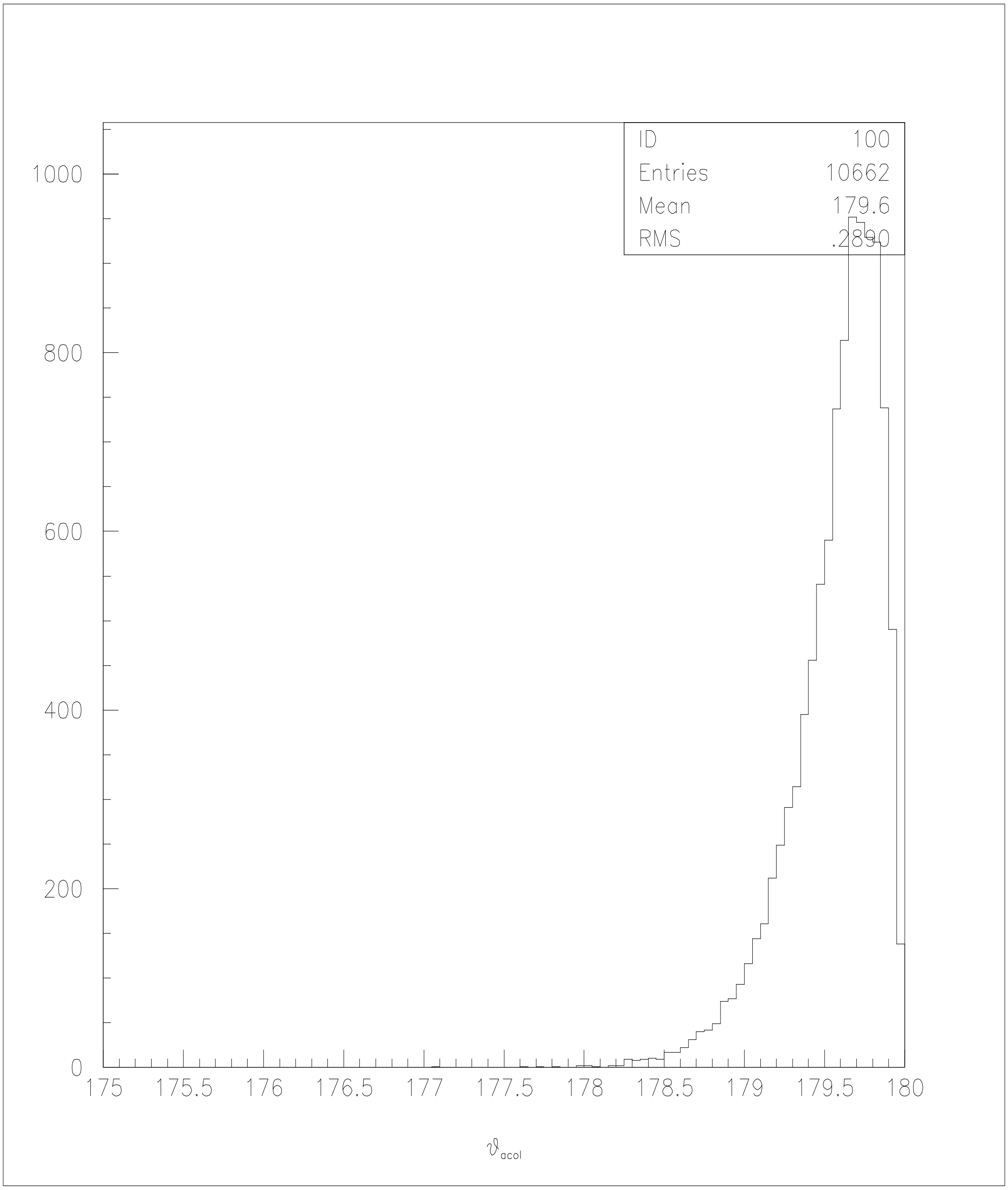
Br(J/$\psi \to e\mu) < 10^{-9}$

- **Events Selection of J/$\psi \to e\mu$**

  Global selection: $N_{chrg} = 2$, $\Sigma Q = 0$, $N_{neu} = 0$, M_fit=2 or -19.

  1. For charges tracks
     - $\theta_{acol} > 175^0$ (see Fig.1)
     - The momentum of charged tracks were required :
       $1.45 < p < 1.65 GeV$ (see Fig.2)
     - To identify e and μ

     (a) To identify e and μ/π
       E/p > 0.7 (e) (see Fig.3)
       E/p < 0.3 (μ or π)
       The following is information of E/p from samples of e and μ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175
175.5
176
176.5
177
177.5
178
178.5
179
179.5
180
ϑ_{acol}

Figure 1:

(b) To identify μ using information of μ counter with general criteria:

P_{xy}	μ_{hit}
$P_{xy} < 0.75$GeV	$\mu_{hit} >0$
$0.75 < P_{xy} < 0.95$GeV	$\mu_{hit} \geq 2$
$P_{xy} > 0.95$GeV	$\mu_{hit}=3$

2. To reject events with isolated photon. The criteria to select isolated photons are as follows:
   $E_{sc} \geq 50MeV$
   $\theta_{\gamma c} > 15^0$
   $\alpha < 18^0$ (α is the angle between the hiting direction and devoleping direction at BSC)
3. Requirement of invariant mass of e and μ:
   $2.95 < M_{e\mu} < 3.25$ GeV (see Fig.4)

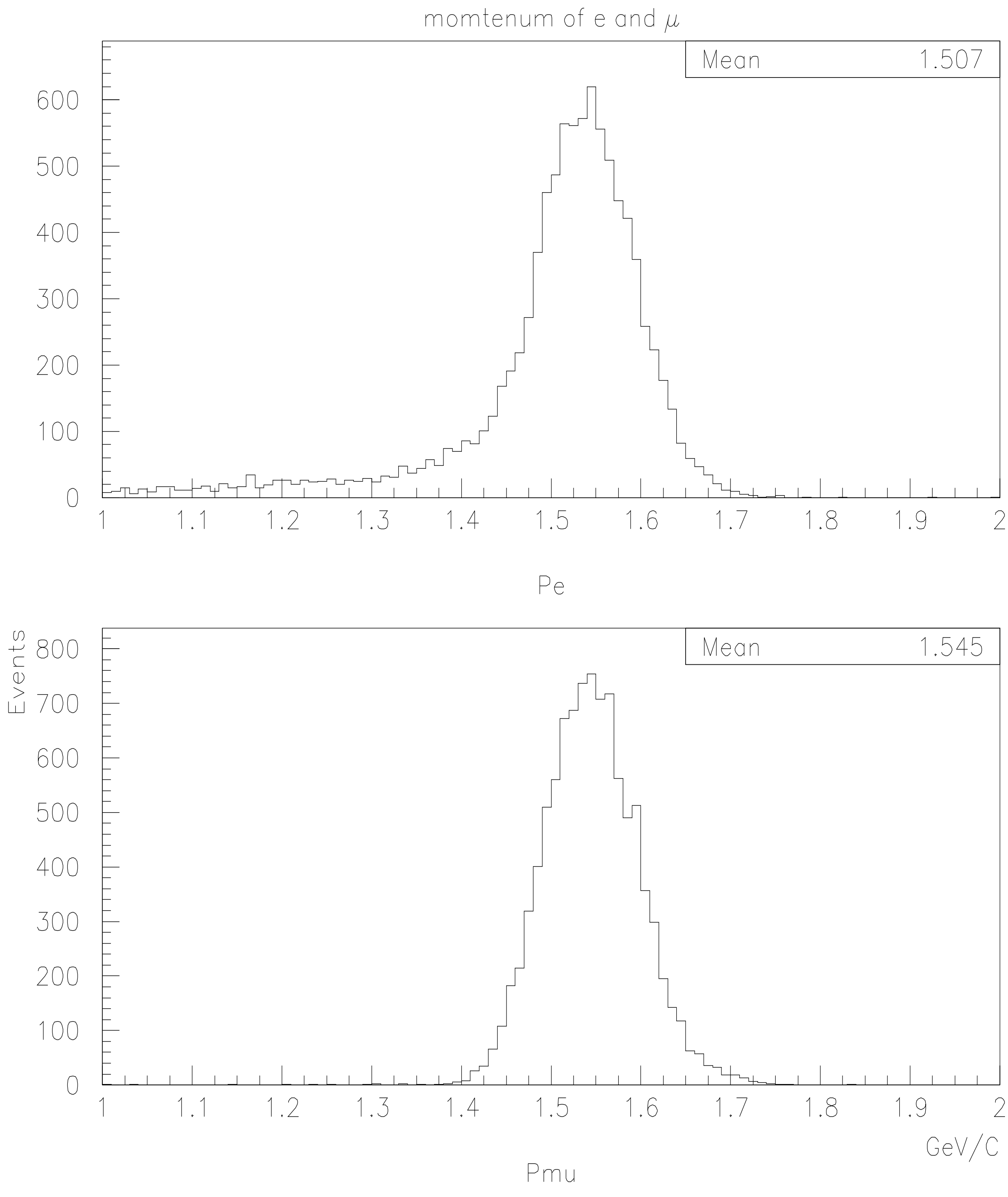
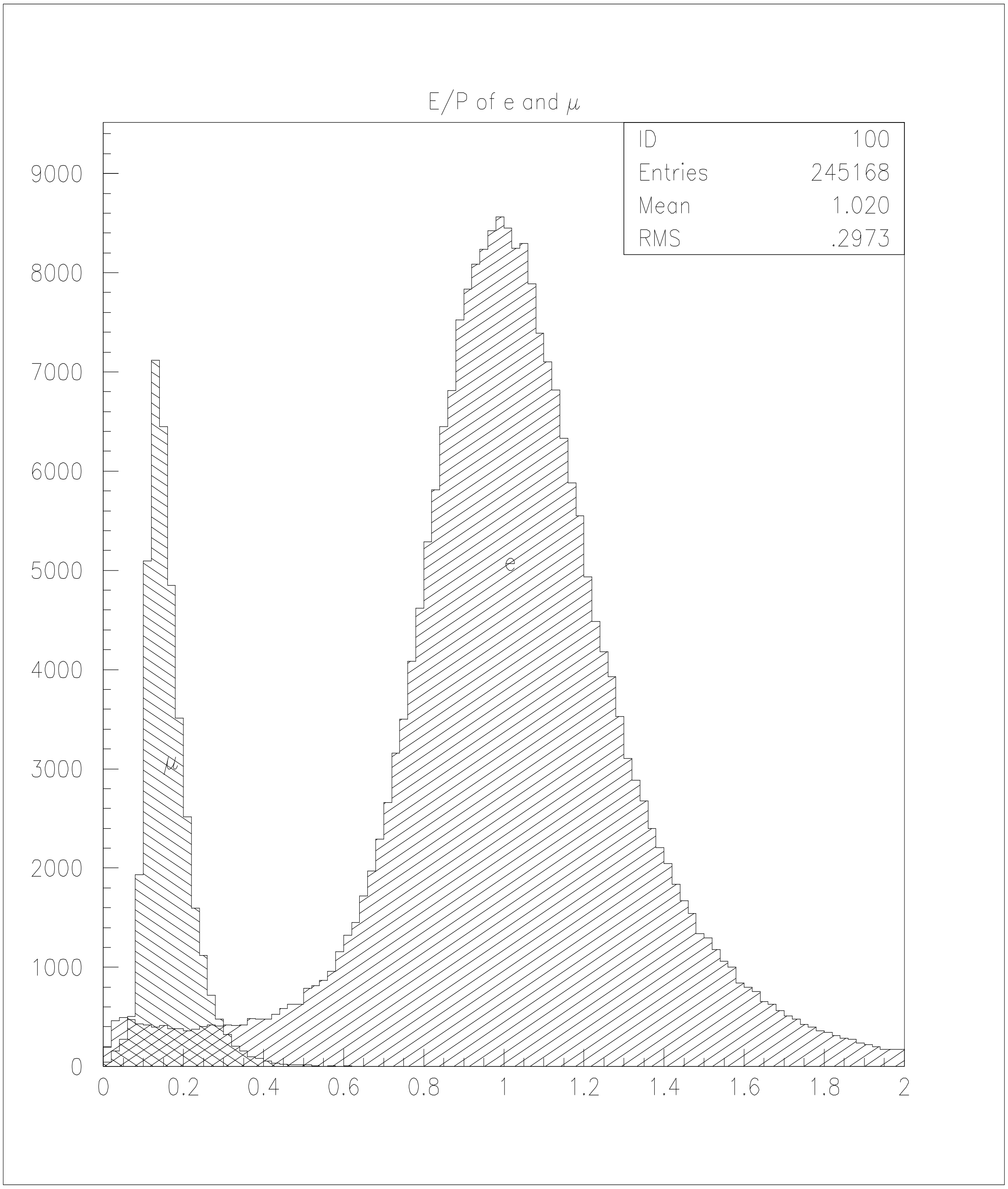

momtenum of e and μ
Mean 1.507
600
500
400
300
200
100
0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Pe
Events
Mean 1.545
800
700
600
500
400
300
200
100
0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
GeV/C
Pmu

Figure 2:


E/P of e and μ
ID 100
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Mean 1.020
RMS .2973
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
μ
e
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

Figure 3:

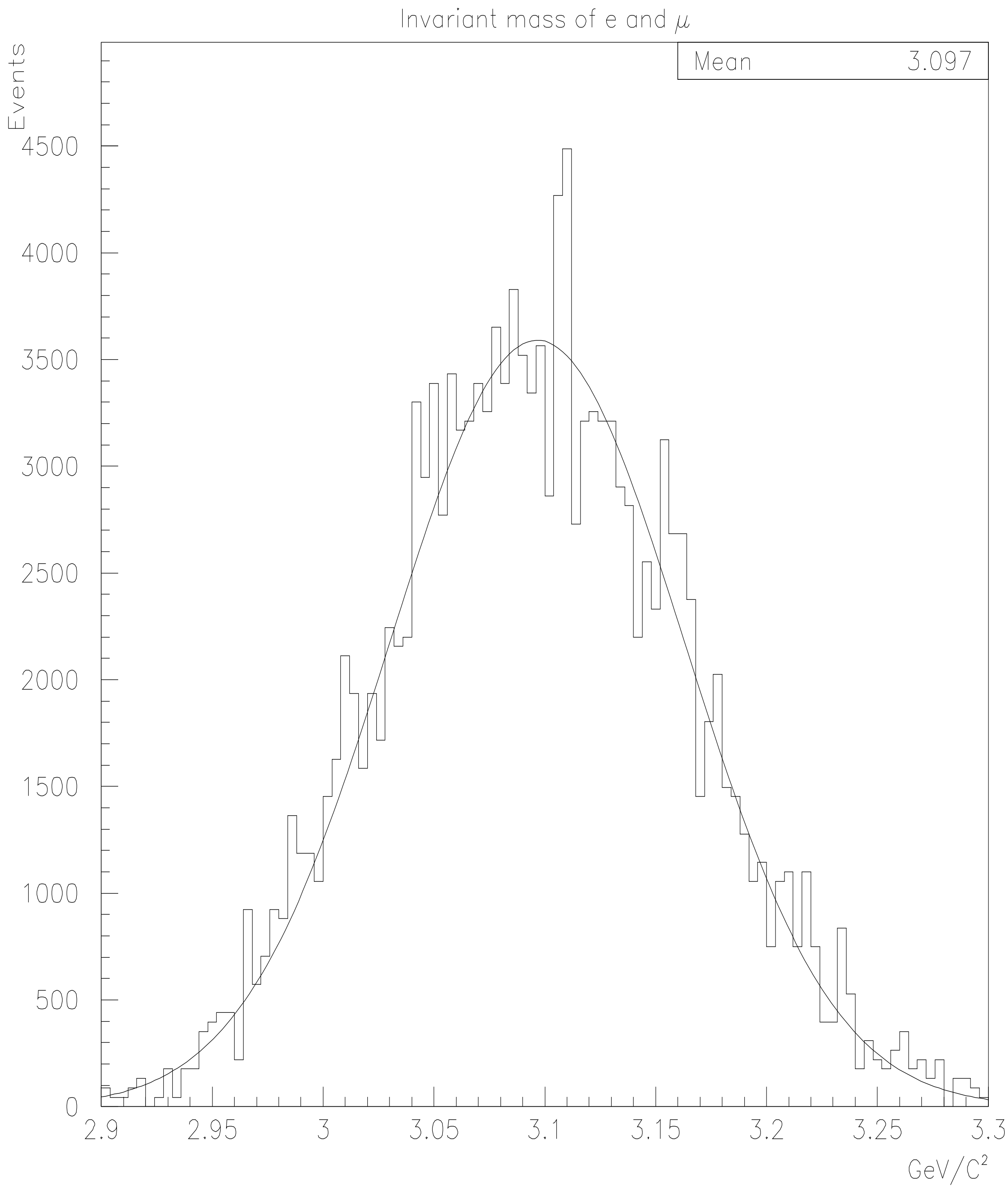
Invariant mass of e and μ
Mean 3.097
Events
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2.9
2.95
3
3.05
3.1
3.15
3.2
3.25
3.3
GeV/C^2

Figure 4:

The list of main cuts

Cuts	Test data
$N_{chrg} = 2$	34224384
vertical cuts and M_fit=2 or -19	13946593
ΣQ$_i$=0	12986383
μ counter,MDC,BSC have information	5158863
$1.65 > P > 1.45GeV/c$	2209329
$\|cos\theta\| < 0.8$	2101843
$sacol > 175$	846308
$onlyoneofE/P > 0.7$	44018
$theohterE/P < 0.3$	2356
$N_{iso} = 0$	1910
$N_{mulayer>0}$=1	71
P_{xy}cuts(toμ)	7
$3.25 > M_{e\mu} > 2.95$GeV	6

- After Criteria above ,six $J/\psi \to e\mu$ candidates are found.

No.	number of run	number of record
1	14132	18963
2	14353	5075
3	14676	16877
4	14984	15080
5	15121	2800
6	16628	23738

- Real Data Sample selection.

  Since MC couldn't simulate the information of BSC and μ counter well, it is necessary to select real data sample of e,μ and π/K to study the sub-detectors performance.

  The e and μ samples were selected from back-to-back events.The samples of π/K were selected from four-prong events.

  The following are the cuts to select the samples of e ,μ and π/K:

  1. e sample selection: $1.45GeV/c < P_{1,2} < 1.65GeV/c$, the one charged track with higher momentum must be satisfied :

     $\mu_{hit} = 0$

E/P > 0.7

Then another charged track is e sample . 757820 ee events were selected from total BESII J/ψ data.

By using same selection above to select e samples,713100 events were selected from e samples.

Then $\epsilon_{e\to e}$=713100/757820=94.1%.

2. μ sample selection: $1.45 GeV/c < P_{1,2} < 1.65 GeV/c$, the one charged track with higher momentum must be satisfied :

   μ_{hit} must pass P_{xy} cuts

   E/P < 0.3

   Then another charged track is μ sample .149260 $\mu\mu$ events were selected from total BESII J/ψ data.

   By using same selection above to select μ samples,68353 events were selected from μ samples.

   Then $\epsilon_{\mu\to\mu}$=68353/149260=45.8%.

   E/p distributions from samples of e,μ are shown in Fig.3.

3. Since π/K can't be selected purly from two-prong events,the sample was selected from four-prong events.

Select π/K:the highest momentum of charged tracks must be more than 1.0GeV/c and its mass(from TOF) be less than 0.6GeV/c^2 to exclude Proton.

Proton mass distribution is shown in Fig.5.

160422 π/K events were selected from total BESII J/ψ data.

- Efficiency determination.

  By Generating 10000 $J/\psi \to e\mu$ MC events(phase space generator),the selecting acceptance has been obtained:ϵ_Ω=58.5%(except BSC and μ counter).Consider the two sub-detectors particle identifying efficiency from e and μ samples:

  $\epsilon_{e\to e}$=94.1%

  $\epsilon_{\mu\to\mu}$=45.8%

  So the selecting efficiency is $\epsilon_{J/\psi\to e\mu}$=$\epsilon_\Omega \times \epsilon_{e\to e} \times \epsilon_{\mu\to\mu}$ =25.2%.

- **Background analysis**

  Because MC can't simulate the information of BSC and μ counter well,we used e and μ samples to estimate backgound events.

  – Estimate the background rates from $J/\psi \to e^+e^-, \mu^+\mu^-, \pi^+\pi^- and K^+K^-$:

  1. We obtain the acceptances of $J/\psi \to e\mu$ selection except cuts of using μ counter and BSC information by using MC:
     J/$\psi \to ee(\epsilon_{ee-MC})$: 25.5%
     J/$\psi \to \mu\mu(\epsilon_{\mu\mu-MC})$: 59.9%
     J/$\psi \to \pi\pi(\epsilon_{\pi\pi-MC})$: 68.8%
     J/$\psi \to KK(\epsilon_{KK-MC})$: 27.9%
  2. We obtain the particle identifying rate by using μ counter and BSC information from the real data samples:
     (a) Background from J/$\psi \to ee$ .If e sample can pass the following cuts, the ee samples can be misidentified as eμ:
     E/P < 0.3 Pass the P_{xy} cut.
     10 events pass the above cuts.
     Then $\epsilon_{e\to\mu}$=10/757820=1.31x10^{-5}
     (b) Background from J/$\psi \to \mu\mu$ .If μ sample can pass the following cuts,the $\mu\mu$ samples can be misidentified as eμ:
     E/P > 0.7 μ_{hit} =0
     $1.45 GeV/c < P <$ 1.65GeV/c
     3 events pass the above cuts.
     Then $\epsilon_{\mu\to e}$=3/149260=2.00x10^{-5}

(c) Background from J/$\psi \to \pi\pi, KK$ .If π or K sample can pass the following cuts,the π or K samples can be misidentified as eμ:
π or K misidentified as e: E/P > 0.7 and μ_{hit} =0.
9555 events found in π/K samples.
Then $\epsilon_{hadron\to e}$=9555/160422=5.96%
π or K misidentified as μ: E/P < 0.3,pass the P_{xy} cuts.
2061 events found in π/K samples.
Then $\epsilon_{hadron\to\mu}$=2061/160422=1.28%

– At last,we get the total background rate by timing two rate above.
J/$\psi \to ee$:
$\epsilon_{ee} = \epsilon_{e\to e} \times \epsilon_{e\to\mu} \times \epsilon_{ee-MC}$=3.14x10^{-6}.
J/$\psi \to \mu\mu$:
$\epsilon_{\mu\mu} = \epsilon_{\mu\to\mu} \times \epsilon_{\mu\to e} \times \epsilon_{\mu\mu-MC}$=5.49x10^{-6}.
J/$\psi \to \pi\pi$:
$\epsilon_{\pi\pi} = \epsilon_{hadron\to e}\times\epsilon_{hadron\to\mu}\times\epsilon_{\pi\pi-MC}$=5.25x10^{-4}.
J/$\psi \to KK$:
$\epsilon_{KK} = \epsilon_{hadron\to e}\times\epsilon_{hadron\to\mu}\times\epsilon_{KK-MC}$=2.13x10^{-4}.
2.38x10^7 J/ψ data were analysed,according to the branching ratio (J/$\psi \to ee$,J/$\psi \to \mu\mu$,J/$\psi \to \pi\pi$,J/$\psi \to KK$ in PDG 2000),there are about 4.43 J/$\psi \to ee$,7.68 J/$\psi \to \mu\mu$,1.84 J/$\psi \to \pi\pi$,1.20 J/$\psi \to KK$ events may be misidentified as J/$\psi \to e\mu$ events.Total number of background events is 15.15.

- **Results**

From discussing above,we can get the upper limit of Br(J/$\psi \to e\mu$):

$Br < \lambda(N_{OB}, N_{BG})/[N_T \epsilon_{J/\psi \to e\mu}]$[9]

λ is the average value for a possion distribution such that there is a 90% probability.N_{OB} is the number of events observed.N_{BG} is the number of background events.Here λ=1.47 when N_{OB}=6 and N_{BG}=15.N_T is the total number of J/ψ. ϵ is the efficiency.So we can obtain:

$$Br < 2.45\text{x}10^{-7}$$

Discussion

- About the Br. upper limit calculation

  Because the possible background mixing from e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^- channels may be overestimated due to the duplicated counts, so the number of backgrounds(15.15) may be a bit more than the reality. Here we take the backgrounds number as 9, then calculate the Br. upper limit to be $\mathbf{5.04 \times 10^{-7}}$.

- About particle identify

  To identify e ,μ and other particles,we use E/P and information of μ counter.About the information of DE/DX(see Fig6,7),although it can't identify e and μ effectively as E/P cut,but it can check the condidates selected.

- About rib of BSC

  If one particle hits the rib,its E/P will decrease and the probability of hiting μ counter will decrease too.So this effect will help reject background events.

- There are several other theoretical models[10] that predicted the branching ratios for the lepton flavor violation decays, some values are listed in the following table. From the table we can see that the decay channels of $\mu\tau$ are accessible to experiments, such as on BES.

Boson	Mode	Predicted BR(ESM)	Predicted BR(DSM)	PDG
J/ψ	$\mu\tau$	1.1×10^{-8}	6.3×10^{-6}	
	$e\tau$	small	1.7×10^{-7}	
	$e\mu$	small	1.1×10^{-10}	
Z_0	$\mu\tau$	7.2×10^{-10}	1.0×10^{-7}	1.2×10^{-5}
	$e\tau$	small	8.8×10^{-9}	9.8×10^{-6}
	$e\mu$	small	3.5×10^{-11}	1.7×10^{-6}

Reference

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[6] "Probing Lepton Flavor Violation in Decays of Charmonium and bottonium System" (unpublished), Z.K.Silagadze, hep-ph/9907328

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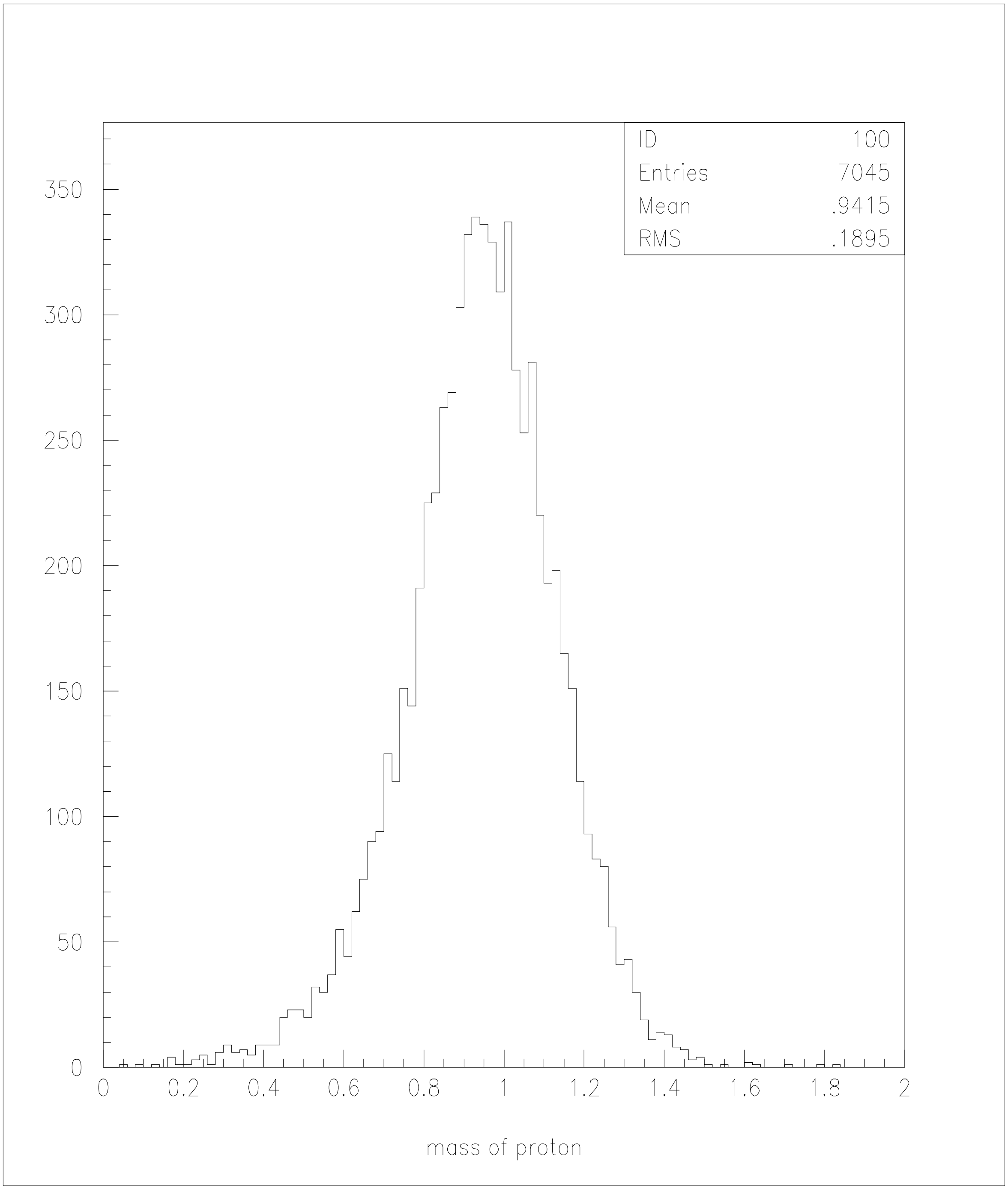
[9] G.J.Feldman and R.D.Cousins, Phys. Rev. D, 1998, 57:3873

[10] J. Feng, MIT-CTP-3066, hep-ph/0101122



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50
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150
200
250
300
350
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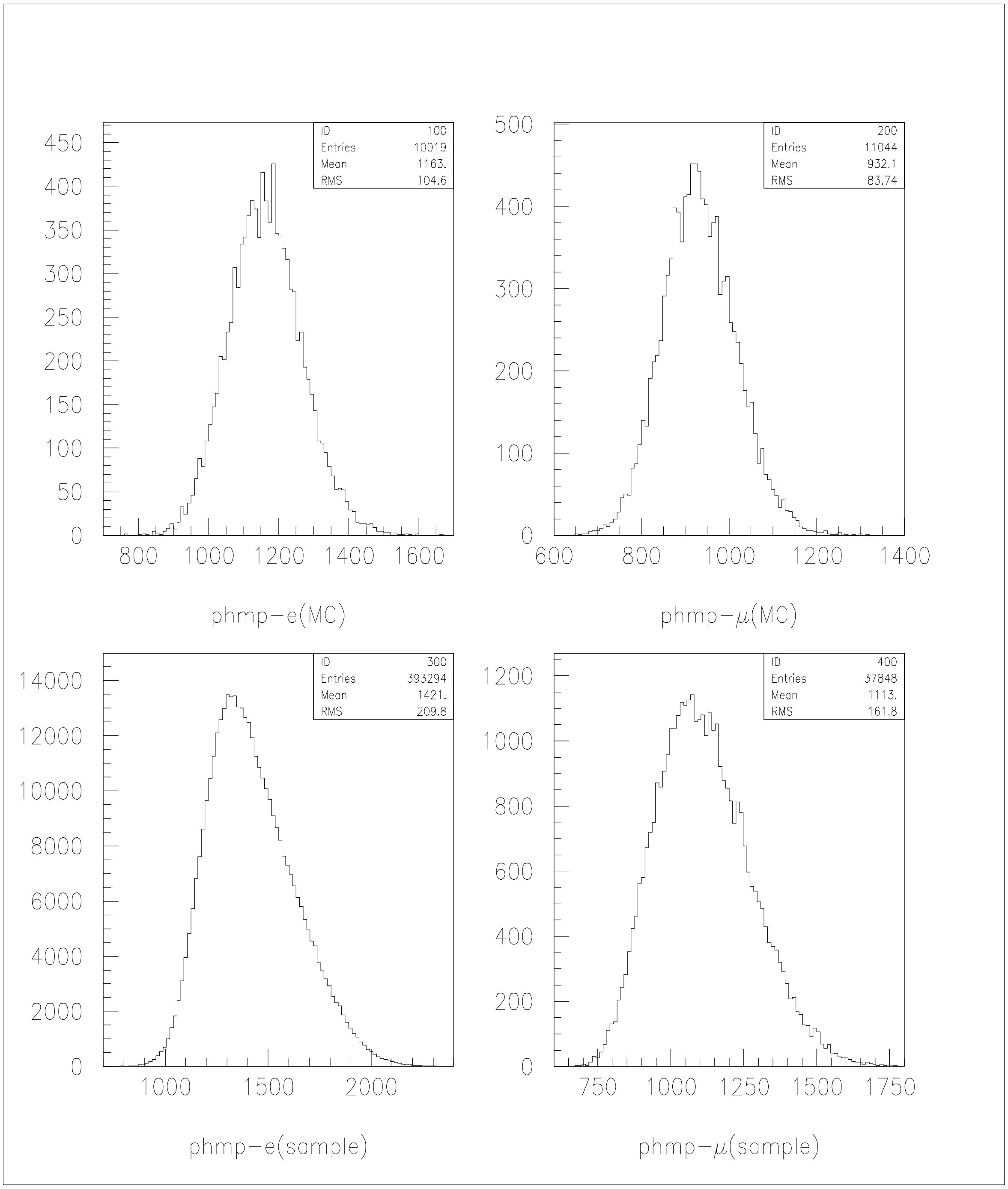
mass of proton

Figure 5: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RMS 83.74
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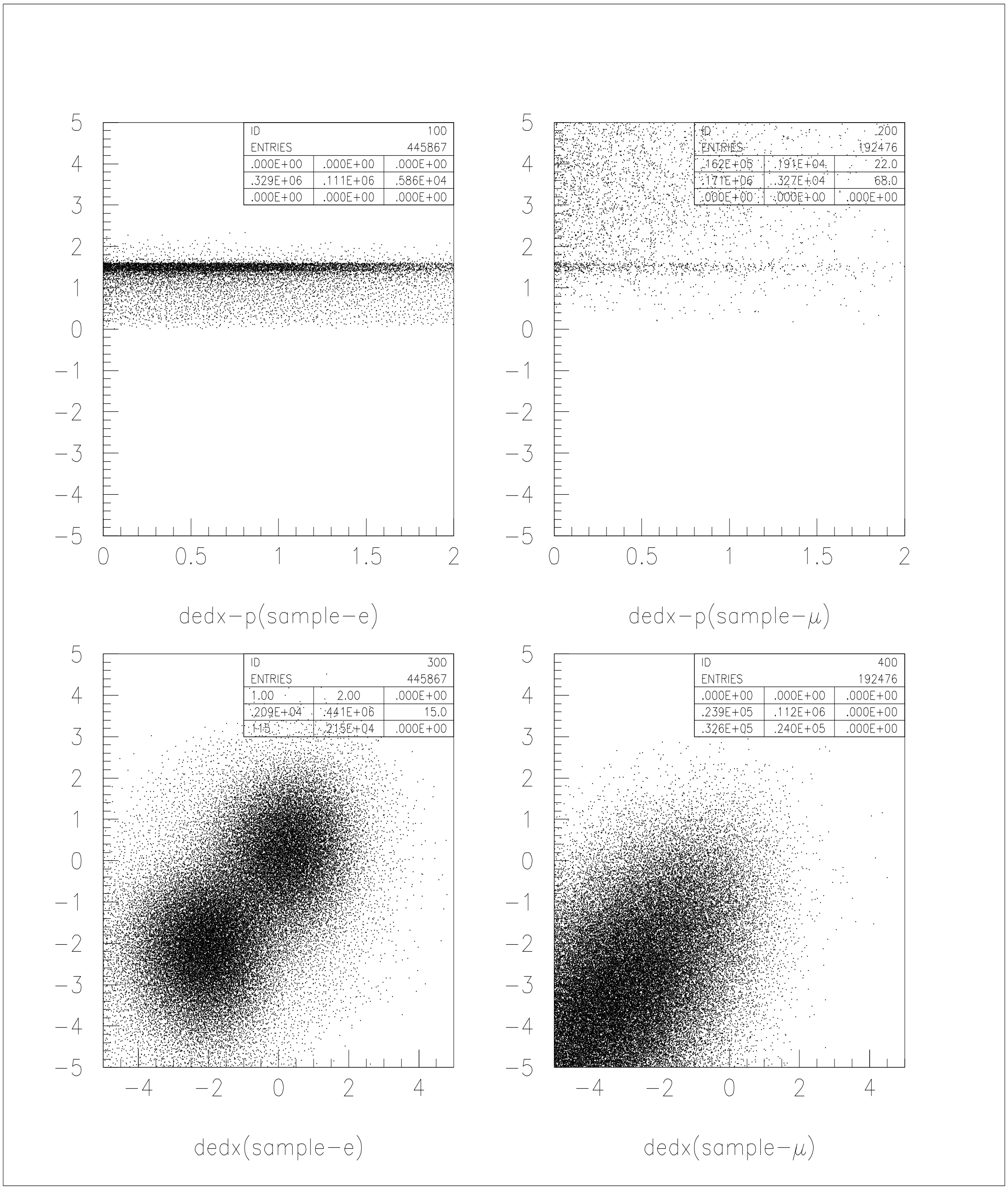
ID 300
Entries 393294
Mean 1421.
RMS 209.8
phmp−e(sample)
ID 400
Entries 37848
Mean 1113.
RMS 161.8
phmp−μ(sample)

Figure 6: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.239E+05 .112E+06 .000E+00
.326E+05 .240E+05 .000E+00
dedx(sample−μ)

Figure 7:

The information of event(RUN:14132,IREC:18963)

	μ	e
P	1.525GeV/c	1.525GeV/c
sacol	177.5	
E/P	0.1925	0.91
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.017GeV	

The information of event(RUN:14353,IREC:5075)

	μ	e
P	1.525GeV/c	1.525GeV/c
sacol	177.5	
E/P	0.089	0.87
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.017GeV	

The information of event(RUN:14676,IREC:16877)

	μ	e
P	1.525GeV/c	1.575GeV/c
sacol	177.5	
E/P	0.1775	0.71
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.117GeV	

The information of event(RUN:14984,IREC:15080)

	μ	e
P	1.575GeV/c	1.575GeV/c
sacol	177.5	
E/P	0.2025	1.025
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.117GeV	

The information of event(RUN:15121,IREC:2800)

	μ	e
P	1.525GeV/c	1.575GeV/c
sacol	177.5	
E/P	0.0345	0.99
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.117GeV	

The information of event(RUN:16628,IREC:23738)

	μ	e
P	1.575GeV/c	1.525GeV/c
sacol	177.5	
E/P	0.1325	0.73
n	1	1
μ_{hit}	3	0
$M_{e\mu}$	3.117GeV	