Search for the Flavor-Changing Neutral Current Decay $D^0 \rightarrow \mu^+\mu^-$ in 920 GeV Proton-Nucleus Collisions

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Introduction

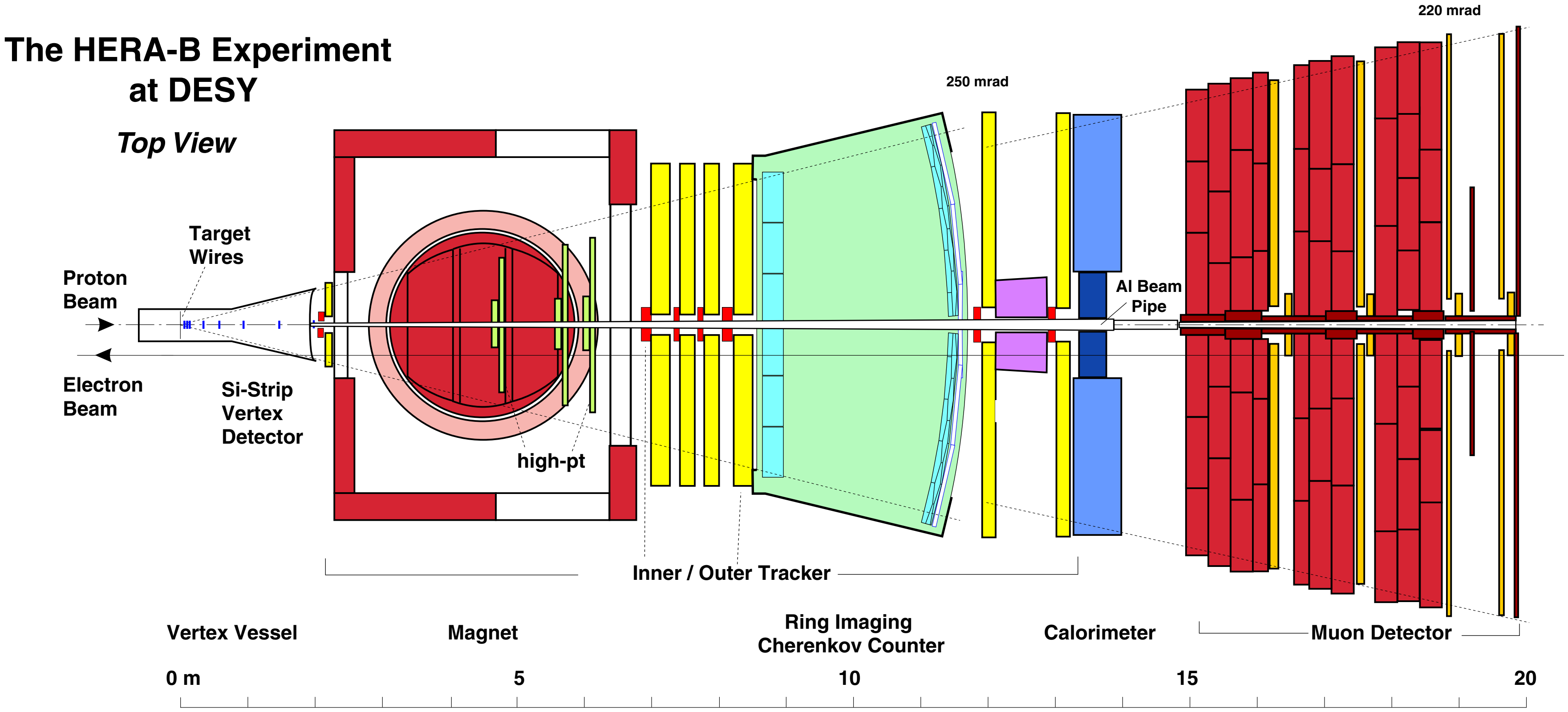
Standard Model	10^{-13} – 10^{-19}
MSSM with R-parity violation	3.5×10^{-6}

Prediction is close to the limit existing in the literature

4.1×10^{-6} at 90% CL	BEATRICE	PDG
2.5×10^{-6} at 90% CL	CDF	PR D68 (2003) 091101

Further searches for $D^0 \to \mu^+\mu^-$ decay are desirable

The HERA-B Detector



The HERA-B fixed-target spectrometer operates at the 920 GeV proton beam of the HERA storage ring at DESY and features a vertex detector and extensive tracking and particle identification systems (RICH, MUON, ECAL)

Method

Branching ratio computation relies on normalizing the number of events in the D^0 signal region to the number of reconstructed $J/\psi \to \mu^+\mu^-$ events

$$Br(D^0 \to \mu^+\mu^-) = \frac{N_{cl}}{N_{J/\psi}} \frac{\alpha_{J/\psi}}{\alpha_{D^0}\epsilon_{D^0}} \frac{\sigma^{pA}_{J/\psi}}{\sigma^{pA}_{D^0}} Br(J/\psi \to \mu^+\mu^-)$$

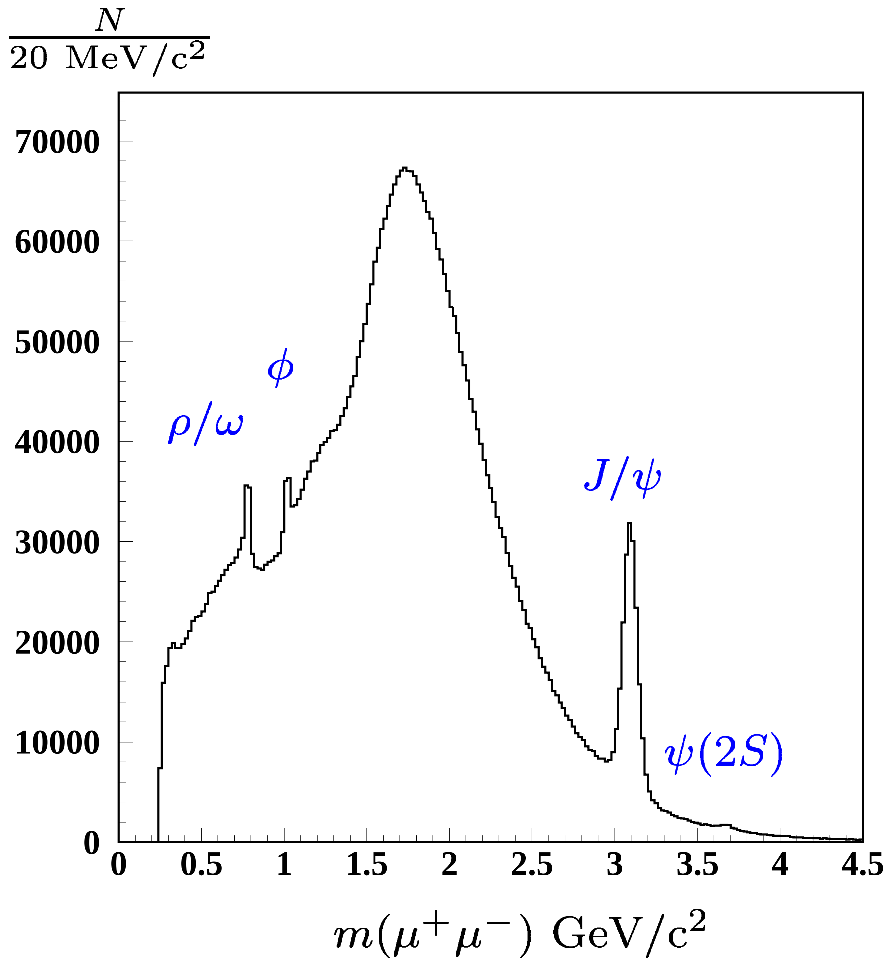
- N_{cl} - number of observed D^0 events;
- $N_{J/\psi}$ - number of observed $J/\psi \to \mu^+\mu^-$ events;
- $\alpha_{D^0(J/\psi)}$ - efficiency for observing $D^0 \to \mu^+\mu^-(J/\psi \to \mu^+\mu^-)$ after applying all cuts (including trigger cuts) except for those applied only to extract the D^0 signal;
- ϵ_{D^0} - reduction factor for $D^0 \to \mu^+\mu^-$ due to cuts applied only to extract the D^0 signal;
- $\sigma^{pA}_{D^0(J/\psi)}$ - production cross-section per target nucleus for $D^0(J/\psi)$;
- $Br(J/\psi \to \mu^+\mu^-)$ - branching ratio of $J/\psi \to \mu^+\mu^-$

Data Analysis

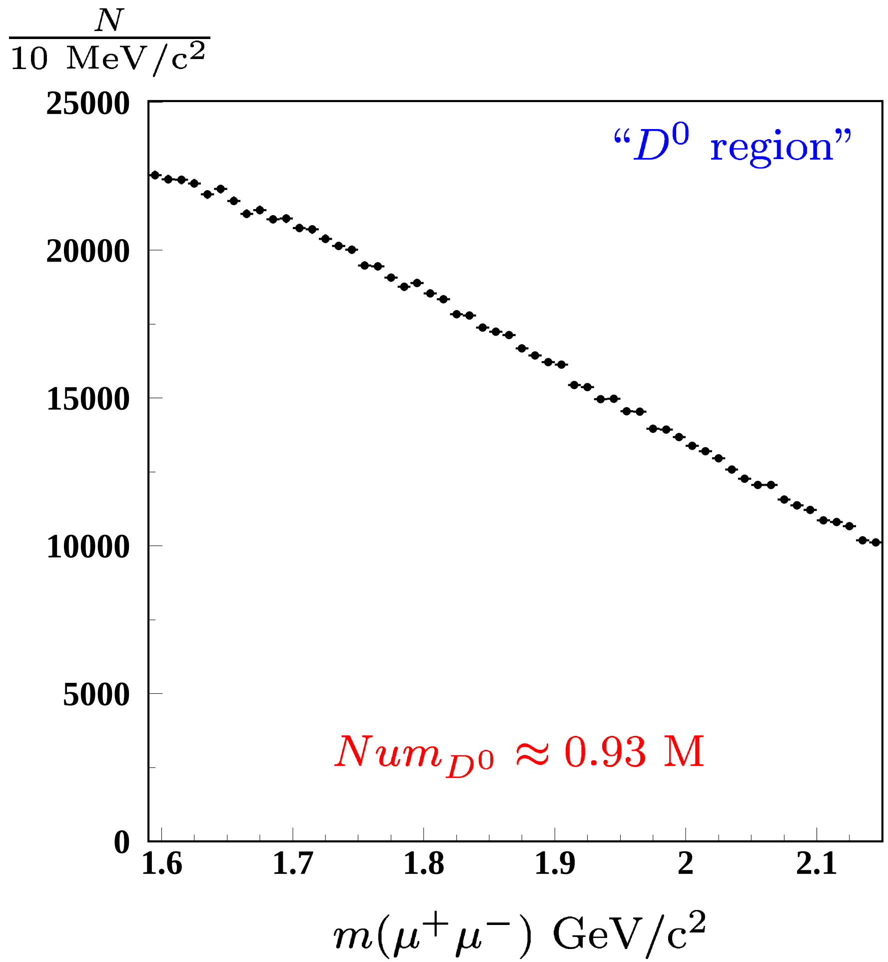
$$N_{J/\psi} = 147710 \pm 520$$
$$\sigma_{J/\psi} = 44 \text{ MeV/c}^2$$
$$\sigma_{D^0} = 25 \text{ MeV/c}^2$$

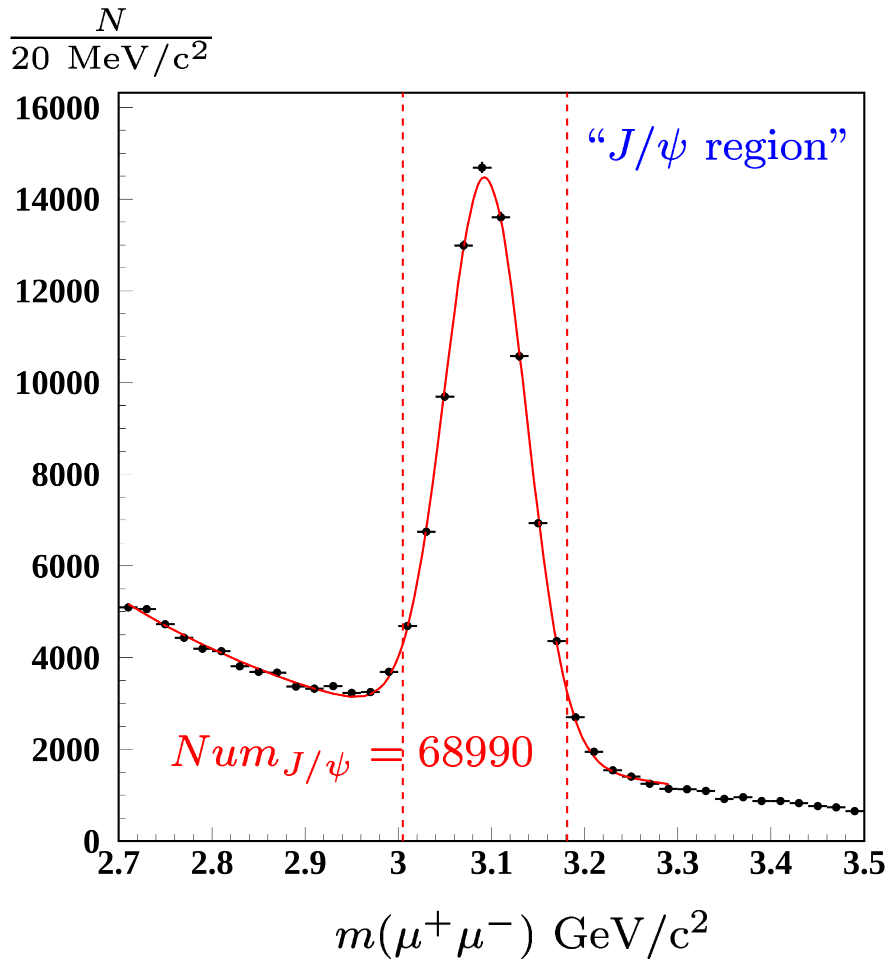
"D^0 region" - 1.59 - 2.15 GeV/c^2

"J/ψ region" - 2.7 - 4.0 GeV/c^2



Data Analysis





one reconstructed primary vertex per active target wire

$L^{prob}_{muon} > 0.01, \chi^2_{tr}/d.o.f < 20, Prob(\chi^2_{prim}) > 0.01, Prob(\chi^2_{sec}) > 0.2, N^{tr}_{prim} < 50$

Common cuts

Common cuts applied both for "D^0 region" and "J/ψ region"

χ^2_{track}/dof	to suppress π/K decays in flight
L^{prob}_{muon}	to reduce fake di-muon events
track-multiplicity cut	to suppress multi-event pile-up
transverse momentum	majority of pions and kaons produced in pA interactions have small p_T

Common cuts

blind analysis technique

$N_{J/\psi}/\sqrt{B_{D^0}}$

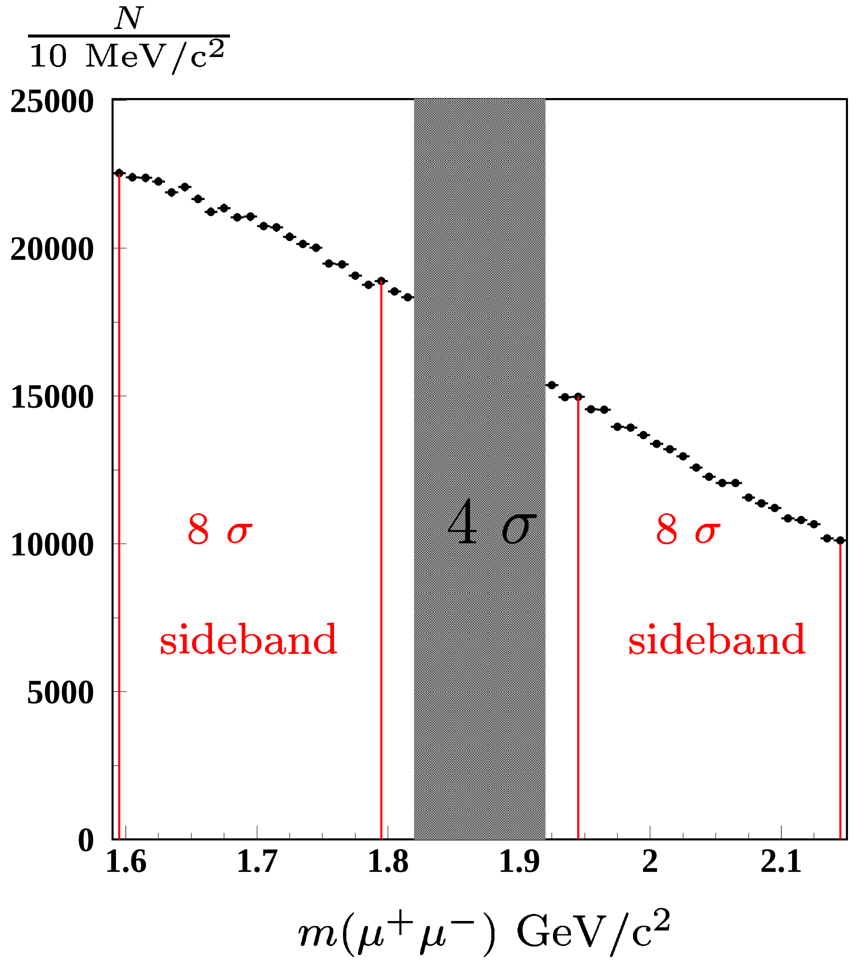
$N_{J/\psi}$ - number of J/ψ candidates

B_{D^0} - expected background

D^0 region (1.82-1.92 GeV/c^2)

sidebands:

- 1.595-1.795 GeV/c^2
- 1.945-2.145 GeV/c^2



After all common cuts have been applied

- 238036 events in the "D^0 region"
- 46050 events in the J/ψ peak

Lifetime cuts

Cuts applied only for the "D^0 region"

- impact parameter of the di-muon to the primary vertex
  the distance between the primary vertex and the point of intersection of the di-muon pseudo-particle flight direction with the xy plane at the z position of the primary vertex
- separation between primary and secondary vertices
  $(z_{sec} - z_{pr})/\sqrt{\sigma^2_{z_{sec}} + \sigma^2_{z_{pr}}}$, z_{pr} and z_{sec} are the z-coordinate along beam direction of primary and secondary vertices and $\sigma_{z_{sec}}$, $\sigma_{z_{pr}}$ are their errors
- proper decay length
  $mc \cdot L/p$, m is the invariant mass, L is the decay length in the laboratory frame and p is the reconstructed momentum of di-muon pseudo-particle

Lifetime cuts

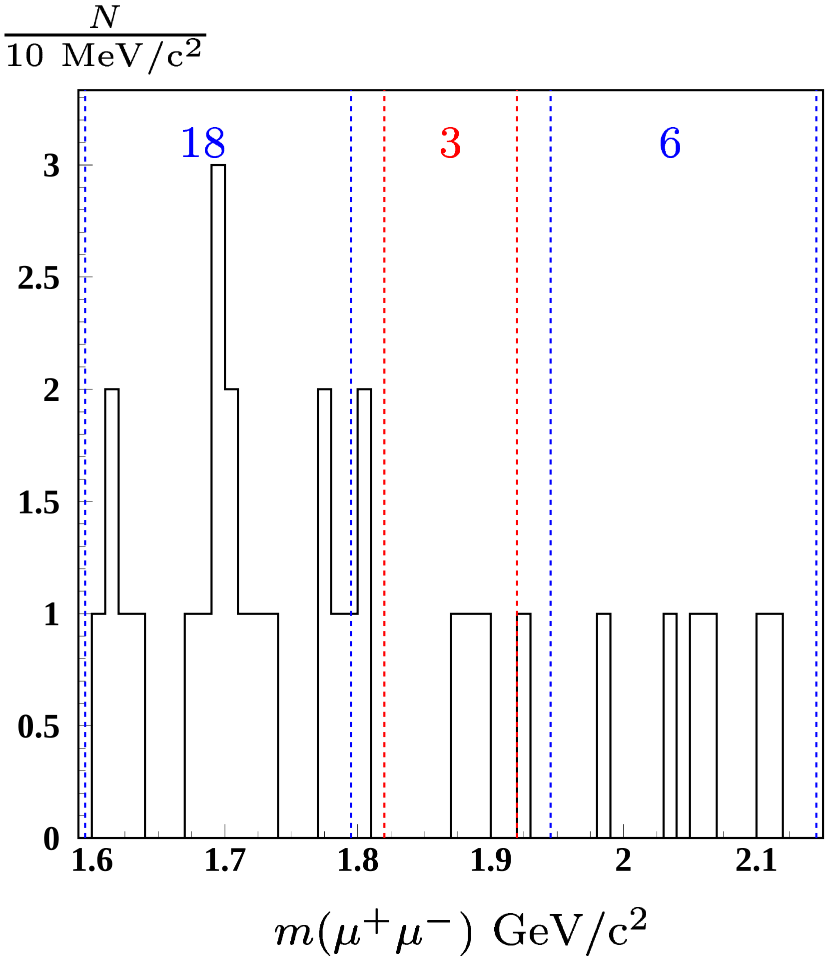
Three-dimensional optimization: $N^{MC}/Sensitivity$

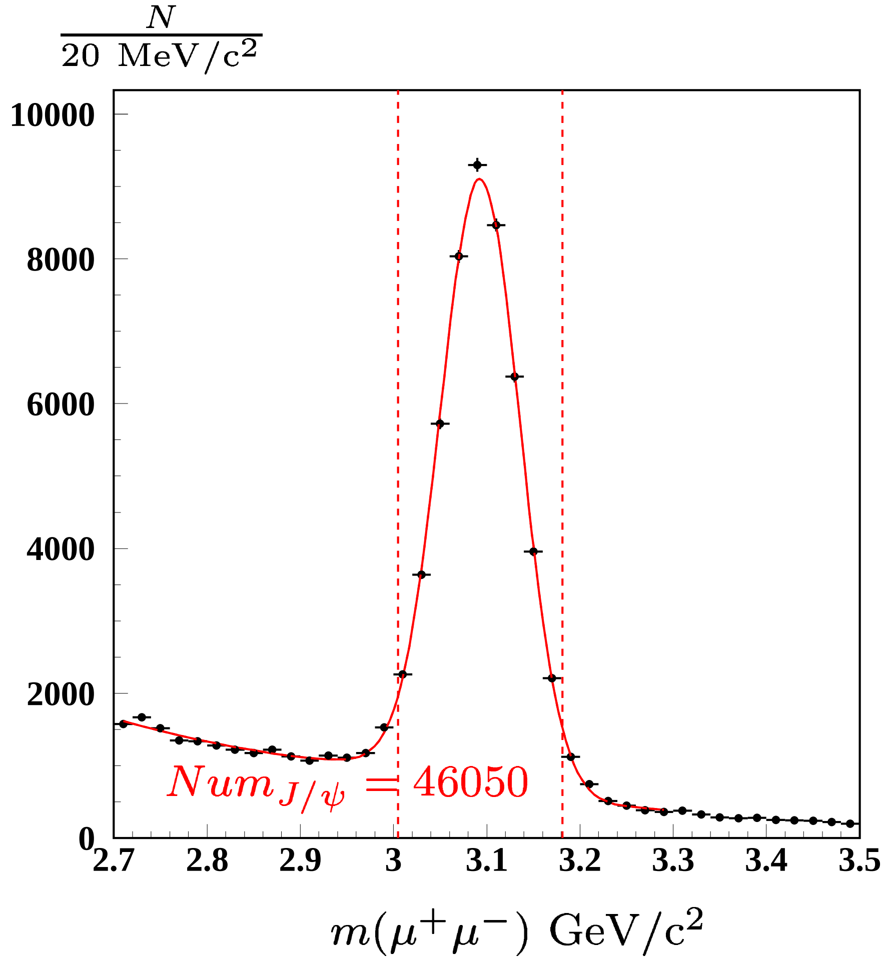
N^{MC} - number of reconstructed D^0 Monte Carlo events
$Sensitivity$ - the average upper limit obtained with the expected background estimated from the D^0 sidebands and no true signal

- 110 μm for the impact parameter cut
- 7.0 for the separation between primary and secondary vertices
- 0.25 mm for the minimum proper decay length

Preliminary result

Mass distributions after applying all cuts





Preliminary result

Linear interpolation of the numbers of events in the sidebands

$$N_{background}^{expected} = \frac{18+6}{4} \pm \frac{\sqrt{18+6}}{4} \pm 0.12 = 6.00 \pm 1.23(stat) \pm 0.12(sys)$$

Since the background level is extracted from the data, systematic uncertainty on the background estimation is related to the background parametrization and the fit technique used

Contribution from $D^0 \rightarrow K^+\pi^- / \pi^+\pi^-$ decays in which both decay products are identified as muons is estimated from Monte Carlo

$$N_{D^0 \rightarrow K^+\pi^-, D^0 \rightarrow \pi^+\pi^-}^{``D^0 region``} < 1.8$$

Linear hypothesis for background shape is not significantly compromised

Preliminary result

From values of $22^{+9}_{-7} \pm 5$ (E653) and $38 \pm 3 \pm 13$ (E743)

$$\sigma^{pN}_{D^0} = 28.1 \pm 8.2 \ \mu b/nucleon \quad \text{(for whole } x_F \text{ range, 800 GeV)}$$

$$\sigma^{pN}_{D^0} = 30.2 \pm 8.8 \ \mu b/nucleon \quad \text{(for whole } x_F \text{ range, 920 GeV)}$$

Prompt J/ψ production cross section per nucleon

$$\sigma^{pN}_{J/\psi} = 357 \pm 8 \pm 27 \ nb/nucleon \ \text{(920 GeV)}$$

Preliminary result

$$Br(D^0 \to \mu^+\mu^-) < \frac{N_{cl}}{\sum_i \left(N^i_{J/\psi} A_i^{\alpha_{D^0} - \alpha_{J/\psi}} \right)} \frac{a_{J/\psi}}{a_{D^0}\epsilon_{D^0}} \frac{\sigma^{pN}_{J/\psi}}{\sigma^{pN}_{D^0}} Br(J/\psi \to \mu^+\mu^-)$$

parameter	value	%
$a_{J/\psi}$	$(1.23 \pm 0.03 \pm 0.06) \cdot 10^{-2}$	5.5
$\sigma_{J/\psi}$	$357 \pm 8 \pm 27$	7.9
$\mathrm{Br}(J/\psi \to \mu^+\mu^-)$	$(5.88 \pm 0.10) \cdot 10^{-2}$	1.7
$a_{D^0}\epsilon_{D^0}$	$(2.38 \pm 0.17 \pm 0.24) \cdot 10^{-4}$	12.4
σ_{D^0}	30.2 ± 8.8	29.1
$N^{carbon}_{J/\psi}$	31010 ± 200	0.7
$N^{tungsten}_{J/\psi}$	12660 ± 140	1.1
$N^{titanium}_{J/\psi}$	2430 ± 60	2.5
$\alpha_{D^0} - \alpha_{J/\psi}$	0.065 ± 0.036	12.3
trigger		7.2
MUON PID		3.4
RICH PID		1.7
total systematic error	from all contributing terms	36.3

Prelimenary result

To incorporate systematic uncertainties and background fluctuation into the upper limit, we adopt the method of Cousins and Highland as implemented by Hill.

Systematic uncertainty, $\sigma_{F^{sens}}$	36.3 %
Number of signal events, n_0	3
Expected background rate, b	6.0 ± 1.24
Upper limit at 90 % C.L., N_{cl}	2.14
Upper limit for $Br(D^0 \to \mu^+\mu^-)$ at 90 % C.L.	
without systematic errors	1.4×10^{-6}
Upper limit for $Br(D^0 \to \mu^+\mu^-)$ at 90 % C.L.	
with systematic errors included	2.0×10^{-6}

Using the background estimate, our 90% C.L. sensitivity is 3.5×10^{-6}

R.D.Cousins, NIM A 320 (1992) 331

G.J.Feldman, R.D.Cousins, PR D 57 (1998) 3873

J.Conrad *et al.* PR D 67 (2003) 012002

G.C.Hill, PR D 67 (2003) 118101

Conclusion

Using the values of D^0 and J/ψ production cross-sections published in the literature we have set a preliminary upper limit

$$Br(D^0 \to \mu^+\mu^-) \; < \; 2.0 \times 10^{-6} \quad (90\ \%\ C.\ L.)$$

Our limit for $D^0 \to \mu^+\mu^-$ decay is the best to date

In the case of strong R-parity violation in the MSSM the $D^0 \to \mu^+\mu^-$ branching ratio is at the level of 3.5×10^{-6}

Burdman et al PR D 66 (2002) 014009

The result constrains the product of R-parity violating couplings