A Precise Measurement of Charm Dimuon Production in Neutrino Interactions from the NOMAD Experiment

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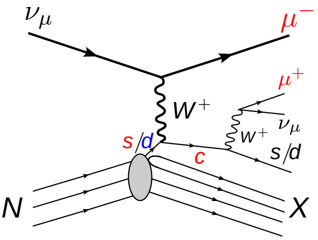
Outline

Outline

Neutrino Induced Charm Dimuon Production



Charm Dimuon Cross-Section

$$\frac{d^2\sigma_{\mu\mu}}{dxdydz} = \frac{d^2\sigma_c}{dxdy} D_c(z) B_\mu; \qquad z = \frac{P_L(h_c)}{P_L^{\max}}$$

$$B_\mu = \sum_h f_h Br(h \to \mu^+ X); \; h = D^0, D^+, D_s^+, \Lambda_c^+;$$

$D_c(z)$ average charm fragmentation function

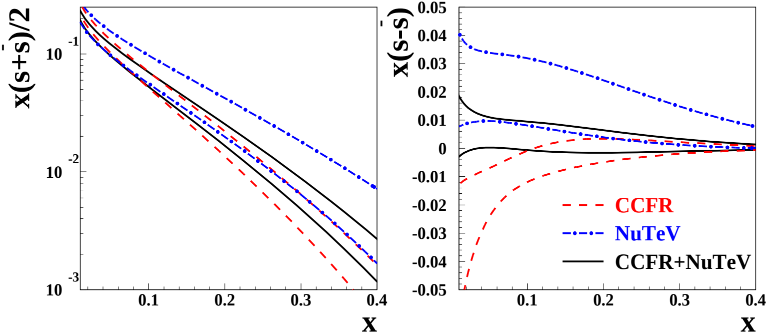
Structure Functions for Charm Production

$$F_{2,c}(x,Q) = 2\xi \left[|V_{cs}|^2 s(\xi,\mu) + |V_{cd}|^2 \frac{u(\xi,\mu) + d(\xi,\mu)}{2} \right]$$

$$\xi = x\left(1 + m_c^2/Q^2\right), \; \mu = \sqrt{Q^2 + m_c^2}$$

Simple LO approximations are given for illustration purpose

Direct Probe of Strange Sea



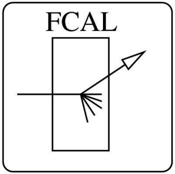
Global PDF fit with NuTeV and CCFR dimuon data

$$\kappa_s = \frac{\int_0^1 x\left[s(x,Q^2)+\bar{s}(x,Q^2)\right]dx}{\int_0^1 x\left[\bar{u}(x,Q^2)+\bar{d}(x,Q^2)\right]dx} = 0.62 \pm 0.04(exp.) \pm 0.03(QCD)$$

$$S^- = \int_0^1 x\left[s(x)-\bar{s}(x)\right]dx = 0.0013 \pm 0.0009(exp.) \pm 0.0002(QCD)$$

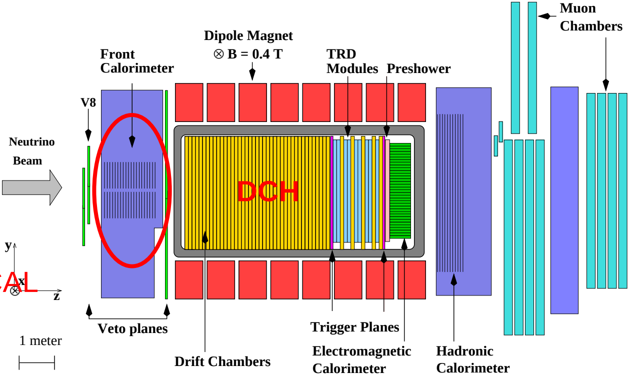
S. Alekhin, S. Kulagin, R.P., Phys. Lett. B 675 (2009) 433

THE NOMAD DETECTOR



μ recon in DCH

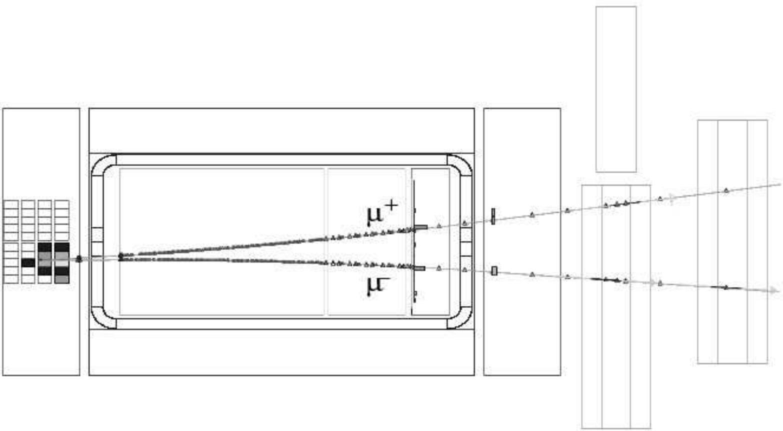
Hadr. recon in FCAL



- Total of $\sim 13 \times 10^6$ ν_μ Charged Current (CC) interactions on Iron in the Front Calorimeter (FCAL), which is Fe/Scintillator sampling with mass $\sim$ 30t
- Excellent muon reconstruction in DCH: $\varepsilon \gtrsim 95\%$, $\Delta p/p \simeq 3.5\%$
- FCAL resolution for hadronic showers: $\Delta E/E \simeq 104\%/\sqrt{E[\mathrm{GeV}]}$

NIM A 404 (1998) 96-128

A Dimuon Event in the NOMAD FCAL

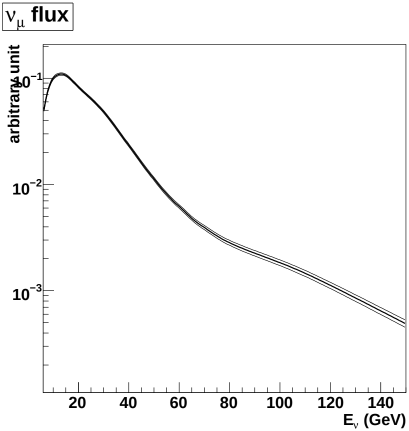


FCAL Statistics $\times$10 main DCH target (Carbon, 2.7t)

The Neutrino Beam

- Distance from ν source 620m
- Wide Band Beam (WBB): broad energy spectra $\langle E_{\nu_\mu} \rangle \simeq$ 27 GeV in FCAL
- Detailed beam simulations and direct flux measurements $\Longrightarrow$ flux uncertainties 2-10 %

  NIM A 515 (2003) 800-828

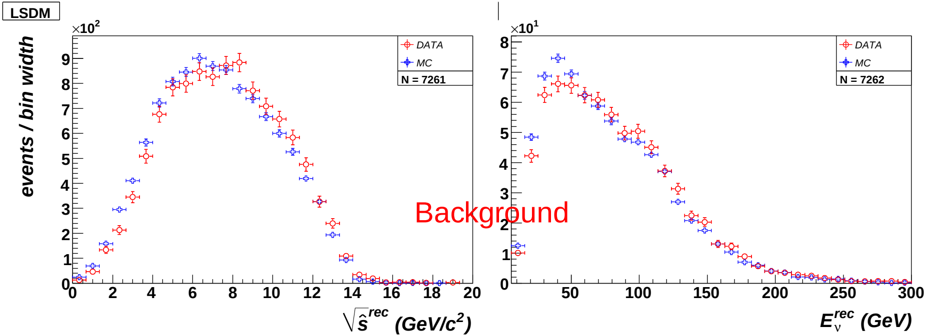


OUTLINE

BACKGROUND SUBTRACTION

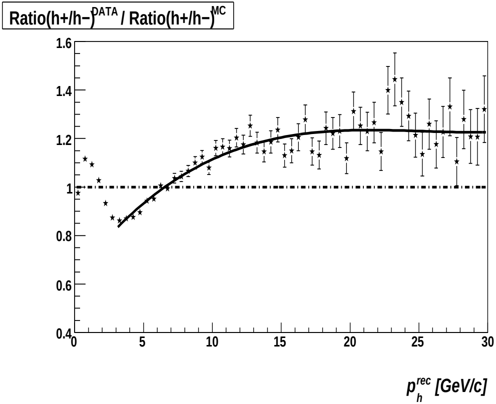
Background subtraction based upon the LIKE SIGN $\mu^-\mu^-$ FCAL data:

$$N^{\text{DATA}}_{\mu\mu_c} = N^{\text{DATA}}_{\mu\mu^+} - \boxed{N^{\text{DATA}}_{\mu\mu^-}} \times \left(N^{\text{MC bkg}}_{\mu\mu^+} / N^{\text{MC}}_{\mu\mu^-}\right)$$



All backgrounds produced by π^+, K^+-mesons decaying into $\mu^+\nu_\mu$.

Background Measurements



- Background scale $N^{MC}_{\mu\mu^+}/N^{MC}_{\mu\mu^-}$ sensitive to fragmentation
- Measure the ratio of h^+/h^- from DCH data in NOMAD
- Re-weight all parent h^+ hadrons in the MC

$\Longrightarrow$ Final ratio $N_{\mu\mu^+}/N_{\mu\mu^-}$ obtained using NOMAD DCH data is 0.71

$\Longrightarrow$ Constraint from DCH data crucial to lower E_μ cut to 3 GeV

MEASUREMENT OF $\mathcal{R}_{\mu\mu}$

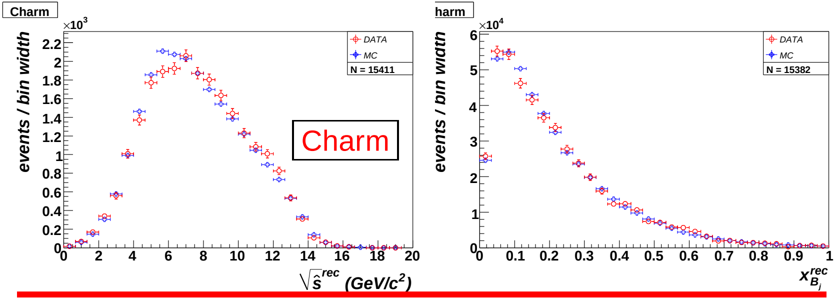
Measure **RATIO** of cross-sections to reduce systematics:

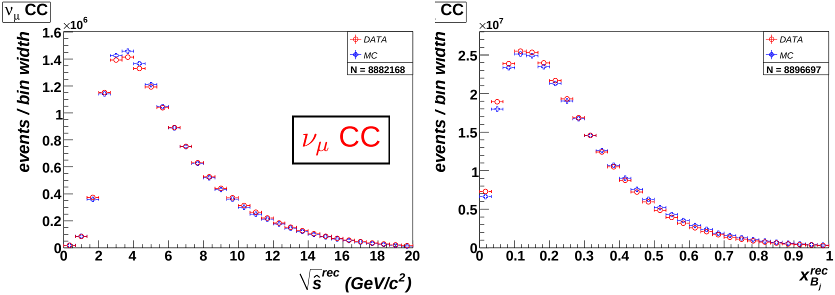
$$\mathcal{R}_{\mu\mu} \equiv \sigma_{\mu\mu c}/\sigma_{cc} \simeq N_{\mu\mu c}/N_{cc}(x); \quad x = E_\nu, x_{B_j}, \sqrt{\hat{s}}$$

- Require leading μ^- and $Q^2 \geq 1$ GeV^2
  $\Longrightarrow$ Total of 20570 OSDM in data with 25% background
- Re-weight MC with full modeling for acceptance corrections:
  – NNLO structure functions (NLO for charm FFS) + High Twists;
  AKP, Phys. Lett. B 675 (2009) 433; AIP Conf.Proc. 967 (2007) 215-224
  – Nuclear corrections for Iron; S. Kulagin and R.P., Phys.Rev.D76 (2007) 094023
  – Electroweak corrections. A. Arbuzov, D. Bardin and L. Kalinovskaya, JHEP 78 (2005) 506
- After unfolding $\mathcal{R}_{\mu\mu}$ for detector smearing and acceptance fit charm prameters in the model
  $\Longrightarrow$ Iterate until convergence

DISTRIBUTIONS OF KINEMATIC VARIABLES

$\mathcal{R}_{\mu\mu} \equiv$





Relevance of the NOMAD Measurement

Exp.	Publ.	Stat. ($N_{\mu\mu}$)	E_ν (GeV)
		νN	
CDHS	1982	9922	30 – 250 (20)
CHARM II	1999	3100	35 – 300 (24)
NuTeV	2001	5102	20 – 400 (157.8)
CCFR	2001	5030	30 – 600 (150)
CHORUS	2008	8910	15 – 240 (27)
NOMAD	2010	**15400**	**6** – 300 (27)
		$\bar{\nu} N$	
CDHS	1982	2123	30 – 250
CHARM II	1999	700	35 – 300
NuTeV	2001	1458	20 – 400
CCFR	2001	1060	30 – 600
CHORUS	2008	430	15 – 240

- NOMAD has the largest sample of ν-induced charm dimuons
- The neutrino energies closest to the charm production thresold

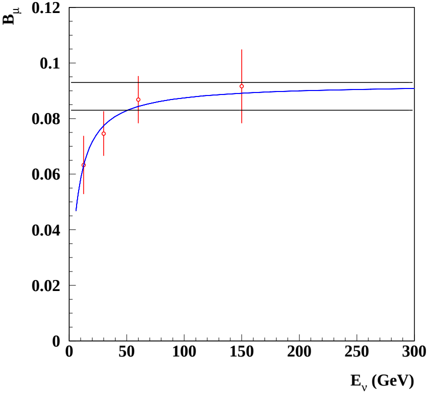
SEMILEPTONIC BRANCHING RATIO B_μ

- Only measurement of $f_h(E_\nu)$ by E531 emulsion experiment
  arXiv:hep-ex/9708014

- Combine with PDG values of $B_l(h \to \mu^+ X)$ from CLEO-c

- Fit the resulting data points:

$$B_\mu(E_\nu) = \frac{0.0950}{1 + 6.898/E_\nu}$$



S. Alekhin, S. Kulagin, R.P., Phys. Lett. B 675 (2009) 433

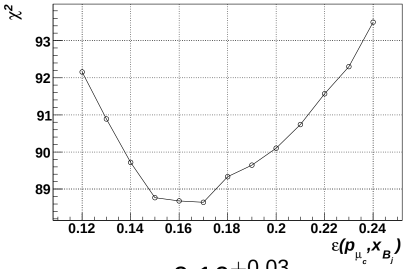
Simultaneous fit with NOMAD dimuon data reduces $\delta(B_\mu)$ by a factor 2

CHARM FRAGMENTATION

Collins-Spiller fragmentation:

$$D_c(z,\epsilon) \sim \left[\frac{1-z}{z} - \epsilon\frac{2-z}{1-z}\right](1+z)^2\left[1-\frac{1}{z}-\frac{\epsilon}{1-z}\right]^{-2}$$

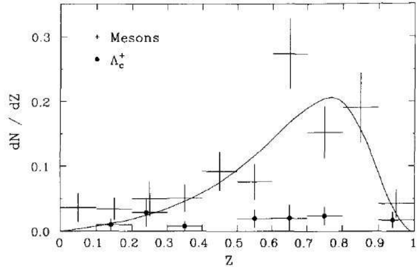
Fit of NOMAD dimuon DATA



$$\epsilon = 0.16^{+0.03}_{-0.02}$$

Fit of E531 emulsion data

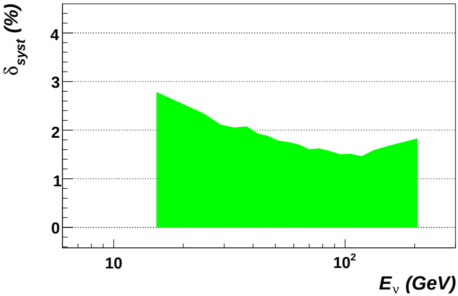
Phys. Lett. B206 (1988) 380



$$\epsilon = 0.163$$

Systematic Uncertainties

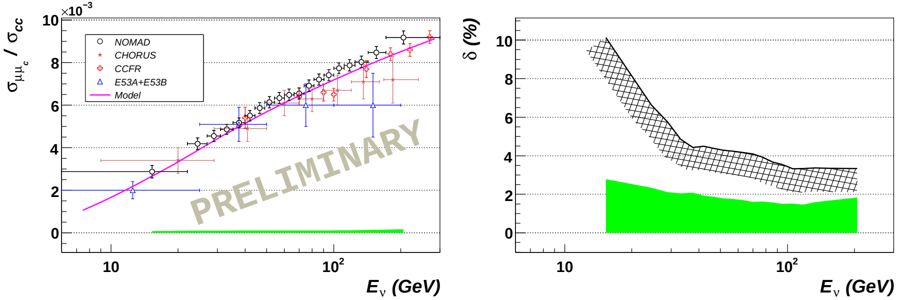
- <u>Included 17 different sources:</u>
  – variation of cuts;
  – muon & hadron energy scales
  – beam flux;
  – model systematics.
- Use the large inclusive ν_μ CC sample to constrain systematics
- Dominant systematics:
  I. charm fragmentation;
  II. background scale;
  III. mass of charm quark.



$\Longrightarrow$ Total systematics $\sim$ 2%

Results for the Measurement of $\mathcal{R}_{\mu\mu}(E_\nu)$

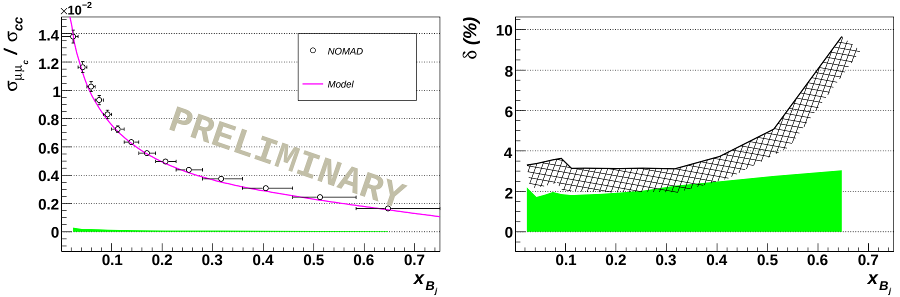
Model calculation based upon NuTeV/CCFR fit only ($Q^2 \geq 1$ GeV^2)
Statistical (black) and systematic uncertainties (green)



$$\int N_{\mu\mu}(E_\nu)dE_\nu / \int N_{cc}(E_\nu)dE_\nu = 5.20 \cdot 10^{-3}$$

Results for the Measurement of $\mathcal{R}_{\mu\mu}(x_{\mathrm{Bj}})$

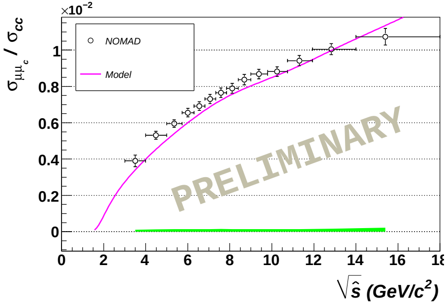
Model calculation based upon NuTeV/CCFR fit only ($Q^2 \geq 1$ GeV^2)
Statistical (black) and systematic uncertainties (green)

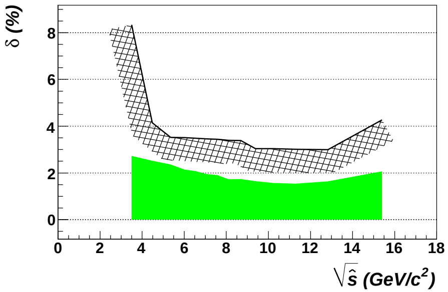


$$\int N_{\mu\mu}(x_{B_j})dx_{B_j} / \int N_{cc}(x_{B_j})dx_{B_j} = 5.26 \cdot 10^{-3}$$

RESULTS FOR THE MEASUREMENT OF $\mathcal{R}_{\mu\mu}(\sqrt{\hat{s}})$

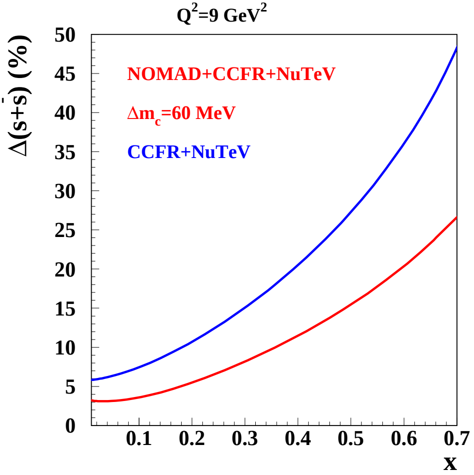
Model calculation based upon NuTeV/CCFR fit only ($Q^2 \geq 1$ GeV^2)
Statistical (black) and systematic uncertainties (green)





$$\int N_{\mu\mu}(\sqrt{\hat{s}})d\sqrt{\hat{s}} / \int N_{cc}(\sqrt{\hat{s}})d\sqrt{\hat{s}} = 5.22 \cdot 10^{-3}$$

Sensitivity to Strange Sea



- Add NOMAD $\sigma_{\mu\mu}/\sigma_{CC}$ data to the global PDF fit with NuTeV and CCFR dimuon data

  Collaboration with S. Alekhin; AKP, PLB 675 (2009) 433

- Consistency of central values
- Reduction of $s(x)$ uncertainty by a factor 2 down to $\delta \sim 3\%$

$$\kappa_s = 0.60 \pm 0.02$$

- Reduction of Δm_c from 110 MeV to 60 MeV

Outline

SUMMARY AND OUTLOOK

- The NOMAD measurement provides the largest charm dimuon data sample available with $E_\nu \geq 6$ GeV: 15400 events
- Background directly extracted from NOMAD data:
  — Like sign dimuon data in FCAL;
  — Ratio of *pi*, *K* production in DCH
- Study of the charm fragmentation ($\epsilon = 0.16^{+0.03}_{-0.02}$) and of the inclusive semileptonic branching ratio $B_\mu(E_\nu)$
- Most precise measurement of the ratio of dimuon to inclusive CC cross-sections $\sigma_{\mu\mu}/\sigma_{\rm CC}$:
  — Statistical uncertainty 3.0 – 6.0%
  — Total systematic uncertainty $\sim$ 2%
- The addition of NOMAD dimuon data to the global PDF fits improves the accuracy of the strange sea distribution and of the charm quark mass by a factor 2