A Search for Lepton Flavor Violation in Upsilon Decays with CLEO-3 at CESR

$$\Upsilon \to \mu\,\tau, \quad \tau \to \nu_\tau \bar{\nu}_e e$$

Vladimir Savinov

University of Pittsburgh

http://www.phyast.pitt.edu/~savinov

Standard Model's Accidental Symmetries
Conservation of lepton and baryon numbers

$$\Upsilon(\mathbf{nS}) \to \tau^- \mu^+$$

$$\tau^- \to \mathbf{e}^-\gamma \quad \tau^- \to \mathbf{e}^+\mathbf{e}^-\mathbf{e}^- \quad \tau^- \to \mu^+\mu^-\mathbf{e}^-$$

$$\tau^- \to \mu^-\gamma \quad \tau^- \to \mu^+\mu^-\mu^- \quad \tau^- \to \mathbf{e}^+\mu^-\mu^-$$

neutrinoless double beta decay

proton decay

Breaking of global symmetries

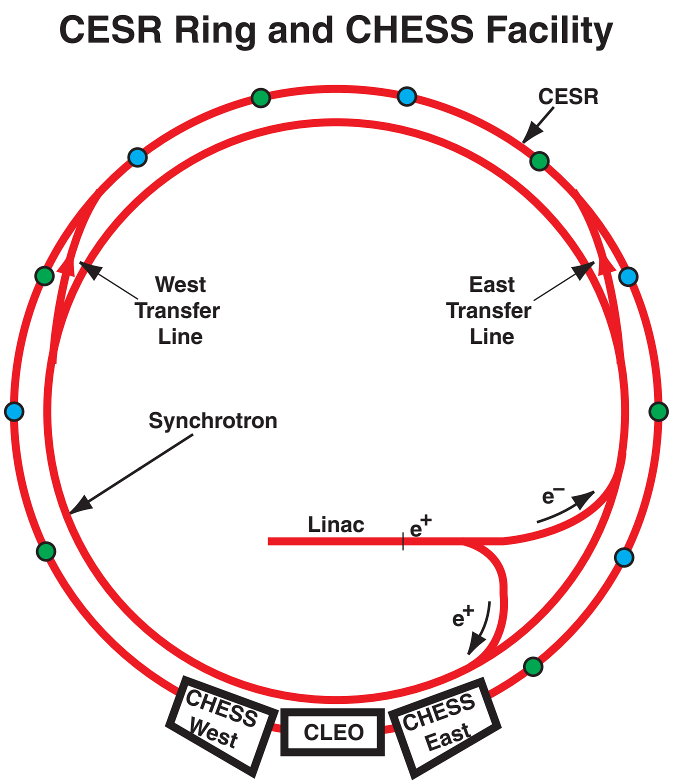
Neutrino oscillations and see-saw mechanism

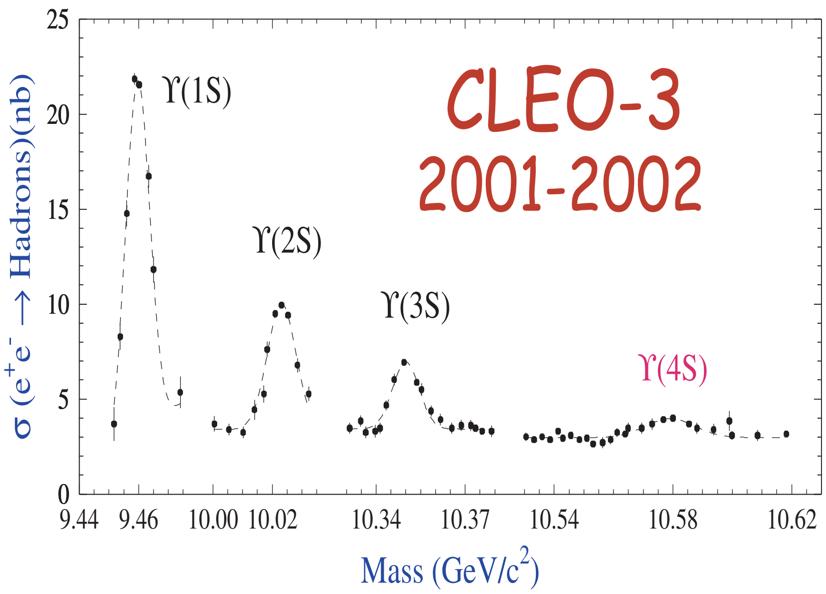
LFV and new higher-order gauge symmetries

Higgs, SUSY, Dark Matter and possible LFV

Lepton number violation and baryogenesis

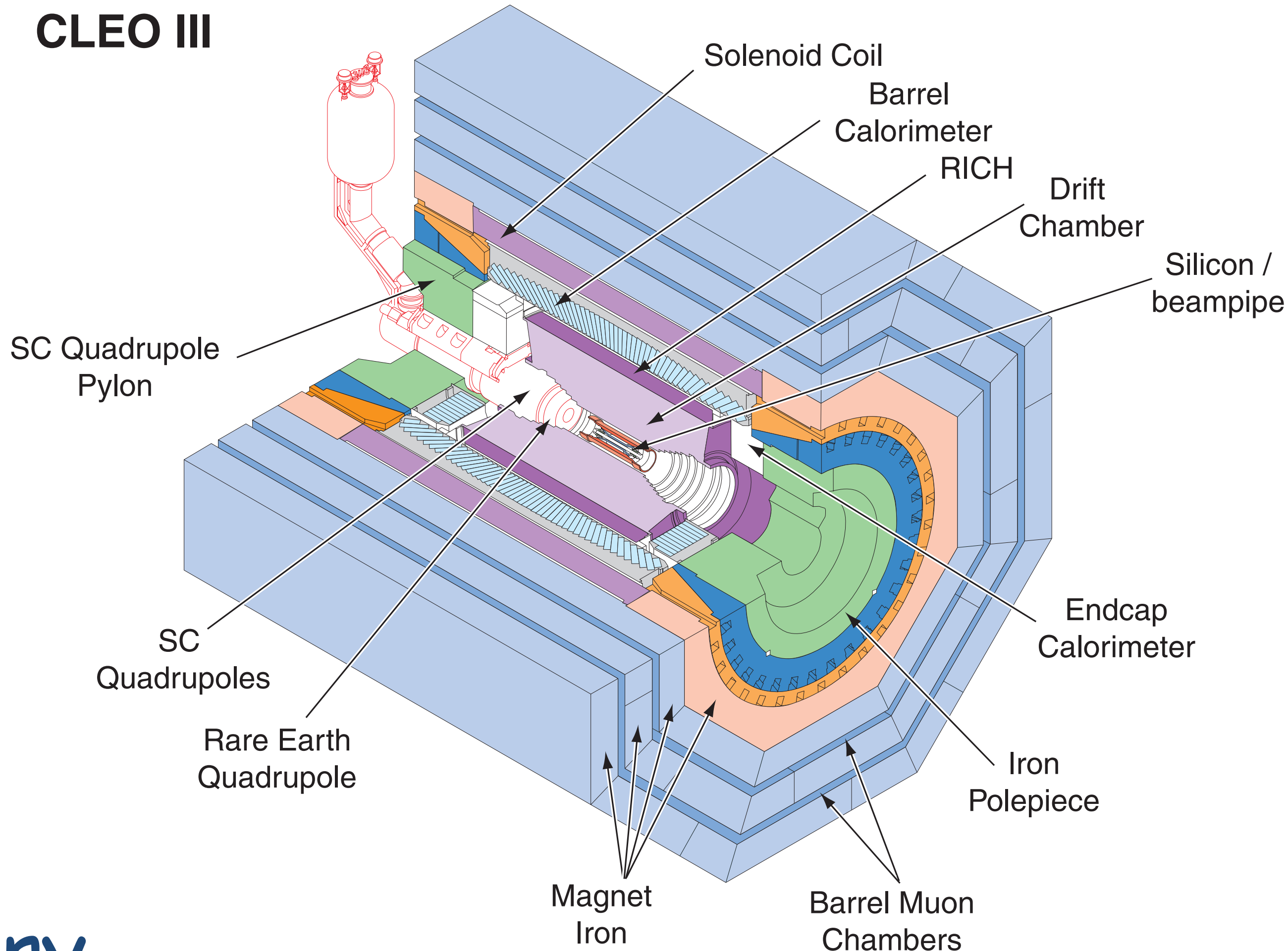
The Experiment





The Detector, Data Sample and CLEOns

CLEO III



CsI EM calorimetry,
muon identification, dE/dx
$\delta p/p$(@5GeV) ~0.8% tracking

21 million Υ(1S)
5.4 million Υ(2S)
5.0 million Υ(3S)

Accidental Symmetries of the SM and LFV

Lepton number, lepton flavor numbers and baryon numbers are conserved at low energies, however, the absence of LFV terms in the SM Lagrangian is accidental, not by design!

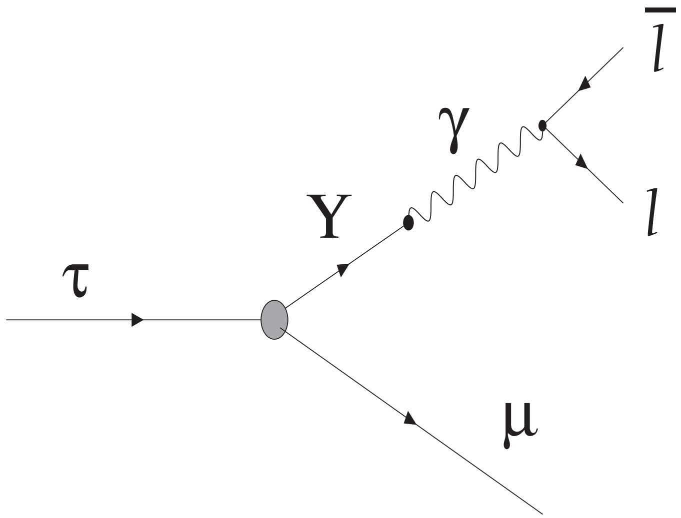
These quantum numbers are violated non-perturbatively - this is necessary for baryogenesis (via leptogenesis).

Lepton flavor is violated at very high energies - neutrino oscillations are living proof - so what do we search for in our analysis? What kind of New Physics? Any model?

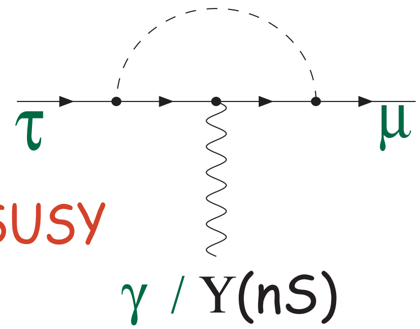
We search for LFV processes that would occur at "intermediate" energies, i.e. between 1 TeV and below GUT scale... LFV at such energies is possible, e.g. in SUSY with broken R-parity...

Not favored by LSP interpretation of Dark Matter... :)

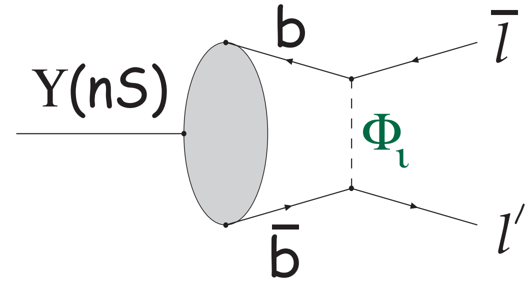
LFV Decays of τ lepton and Upsilon Mesons



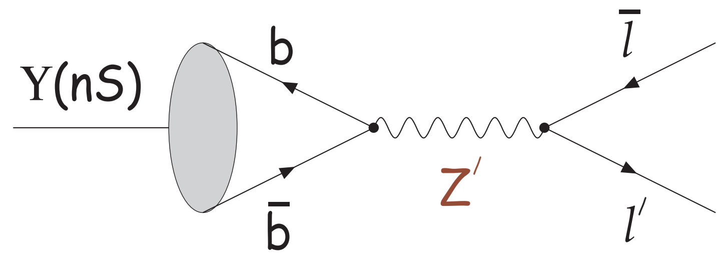
Unitarity arguments



SUSY



Leptoquarks



Additional vector bosons and CP-odd Higgs(es)

If we assume $B(\tau \to \mu\mu\mu) < 10^{-7}$ then

$B(\Upsilon(nS) \to \mu\tau) < 10^{-3}$ S. Nussinov, R.D. Peccei and X.M. Zhang, *Phys. Rev.* **D63** (2000), 016003

model-independent: $< 3\times10^{-5}$ GUT LQ or Z'/TC2 $< 1.3\times10^{-8}$

SUSY $< 2.2\times10^{-9}$ W.J. Huo, C.X. Yue and T.F. Feng, *Phys. Rev.* **D67** (2003), 114001

Analysis Algorithm and Selection Criteria

Exactly two charged tracks

Only one muon candidate (muon ID)

Only one electron candidate (E/|p|, dE/dx)

$$\mathcal{L} = e^{-(N_1+N_2+..+N_M)} \prod_{i=1}^{N_{\rm ev.}} \sum_{j=1}^{N_M} N_j \mathcal{P}_j(\{x_i\},\{s_j\})$$

Muon momentum normalized to beam energy: $x = \frac{E_\mu}{E_{\rm beam}}$

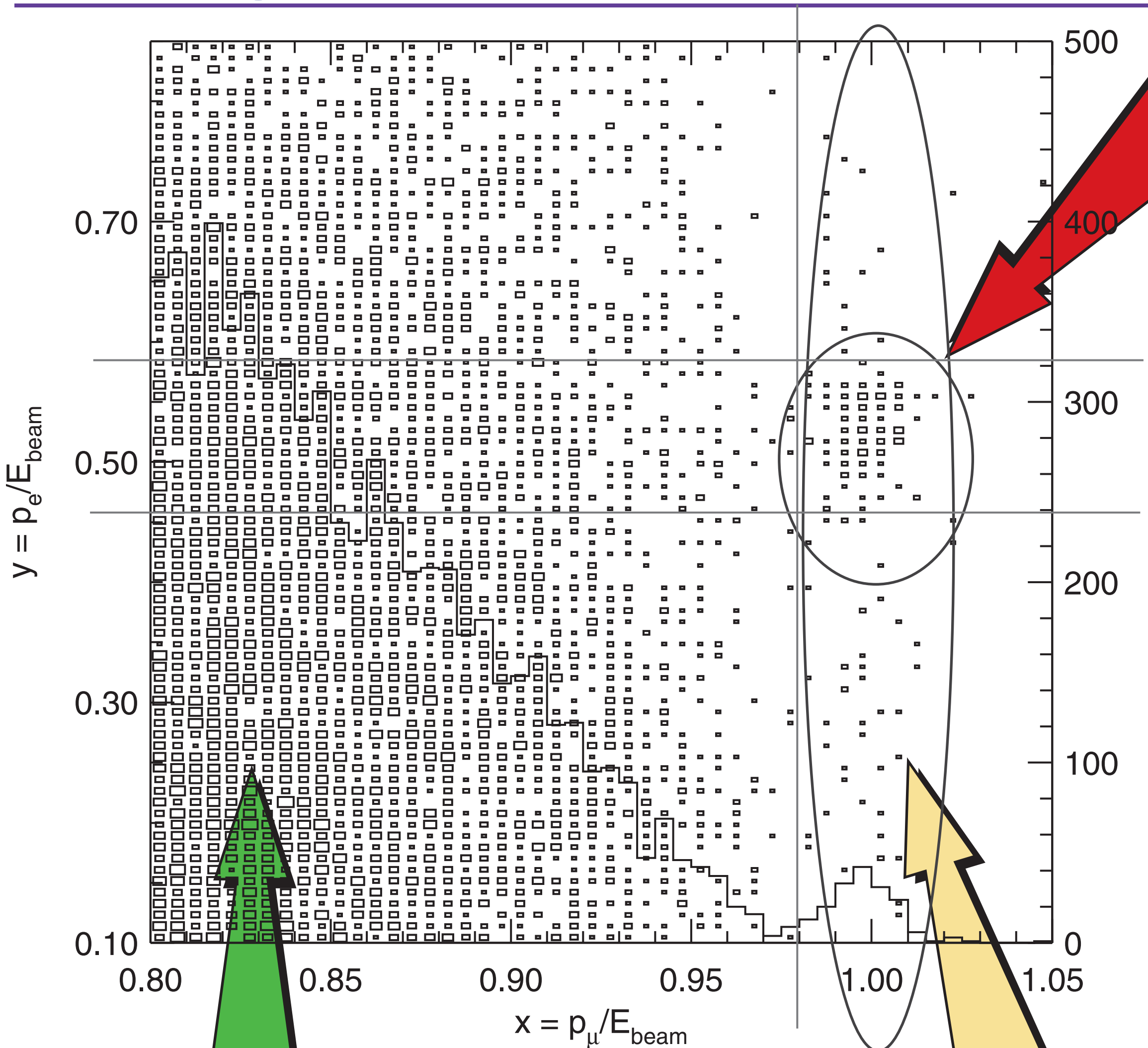
Electron momentum normalized to beam energy: $y = \frac{E_e}{E_{\rm beam}}$

dEdx measurement for electron candidate

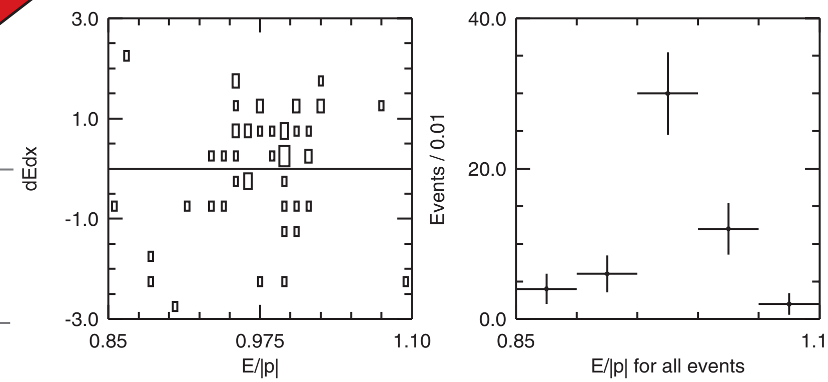
$E/|p|$ for electron candidate

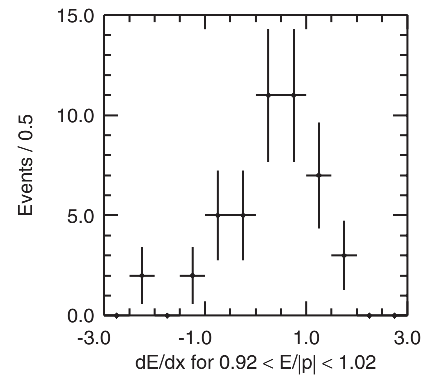
Using Υ(4S) data for efficiency calibration

Backgrounds arise from tau and muon pairs



Muon pairs with hard bremsstrahlung





$x > 0.98$ & ($y < 0.45$ || $y > 0.59$)

on-Υ(4S) data

Tau pairs (irreducible)

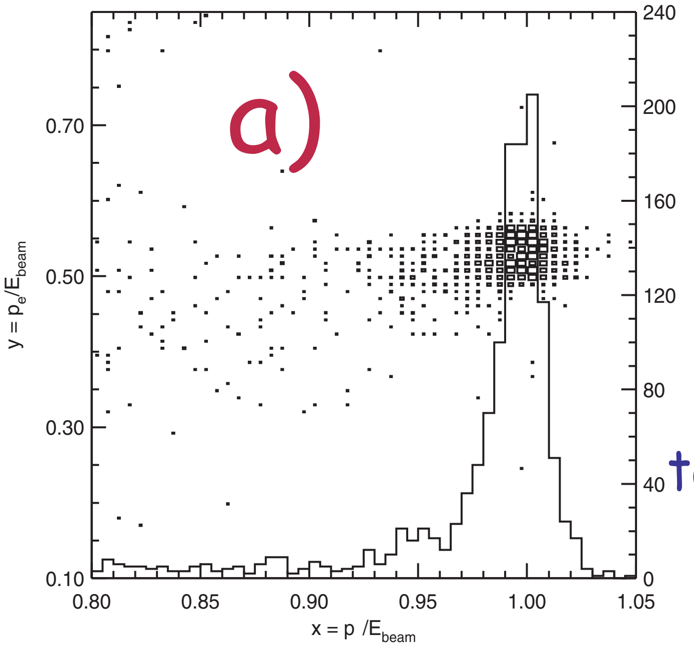
Muon pairs with decay to e in flight

$\beta c\tau$ = 33km -> the fraction of μ decaying at R < 1m = 3 x E-5

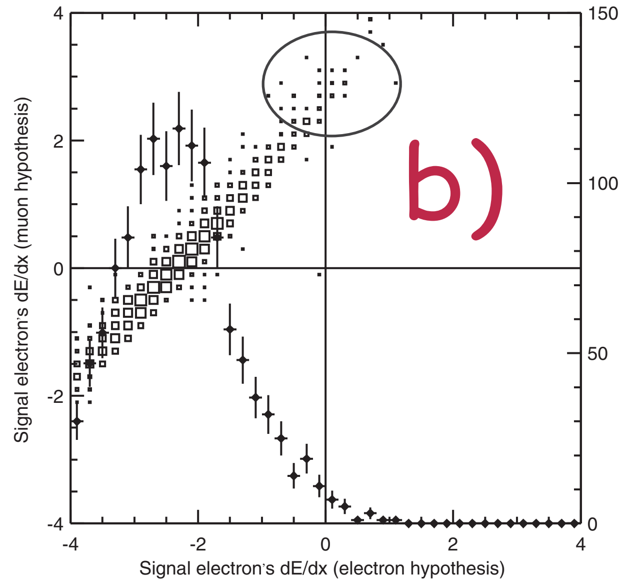
on-Υ(4S): 380 decays!

Muons with Hard Bremsstrahlung + Matching

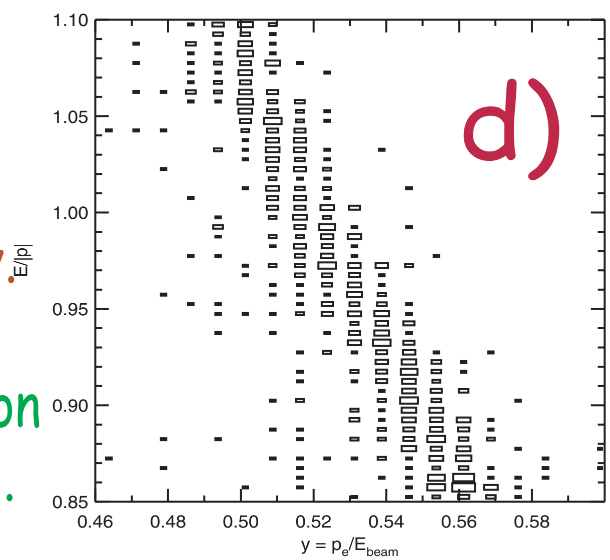
y vs x for on-Υ(4S) data when "electron" is a poorly reconstructed muon

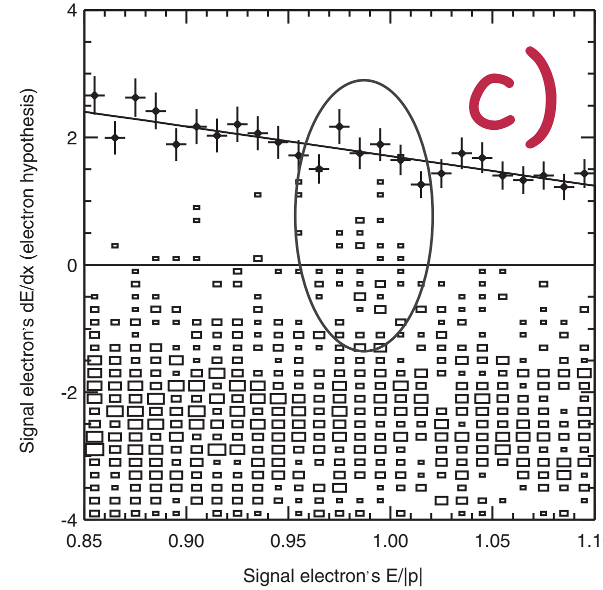


Significant correlations are present between E/|p| and y. This is now incorporated in our 4D fits. dE/dx correlation with y is insignificantly small.

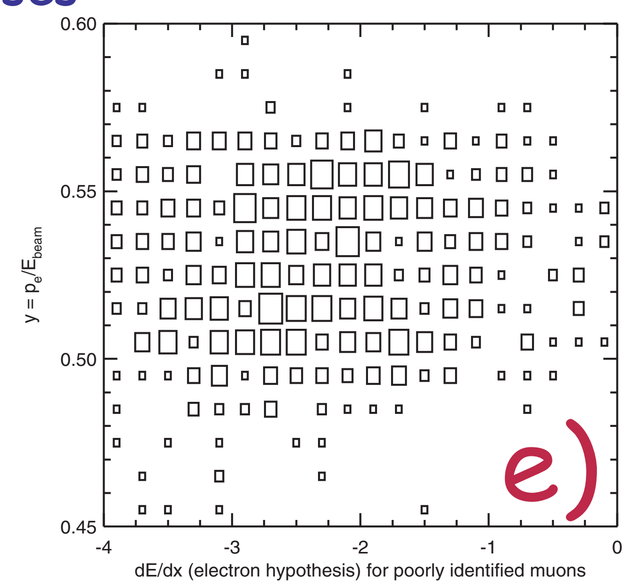


dE/dx interpreted according to muon vs electron hypotheses

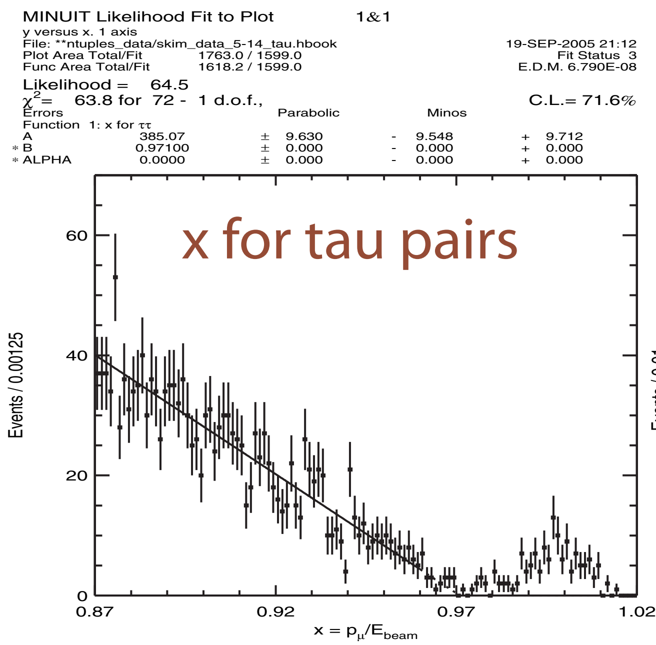


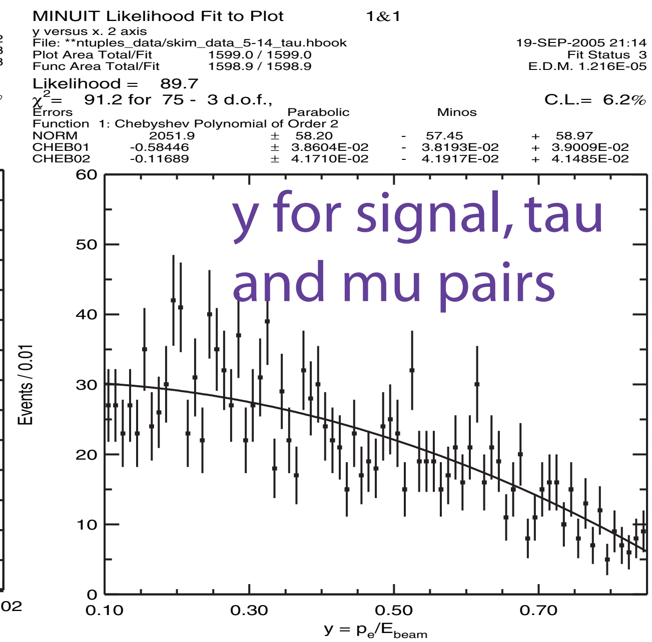


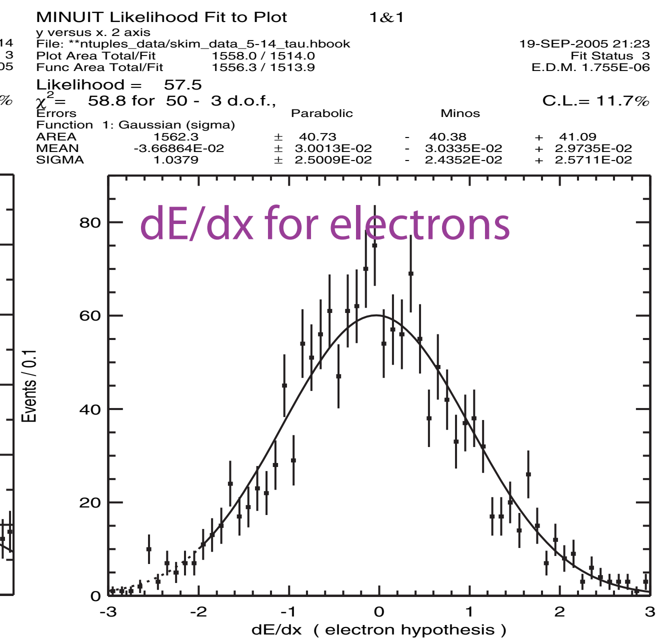
dE/dx vs E/|p|

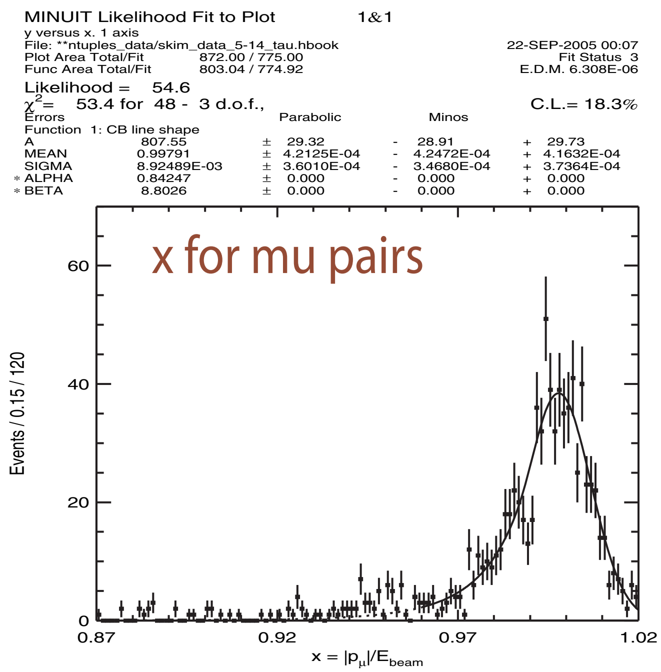


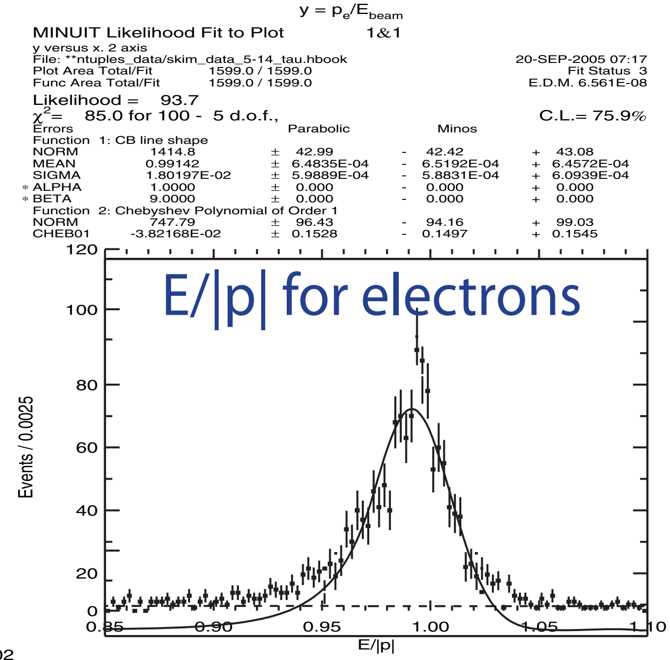
Most PDFs were measured from Y(4S) data

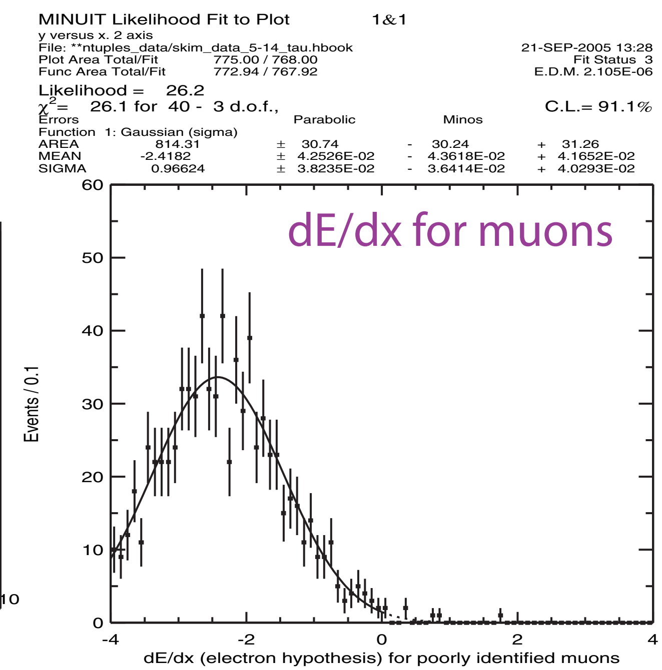




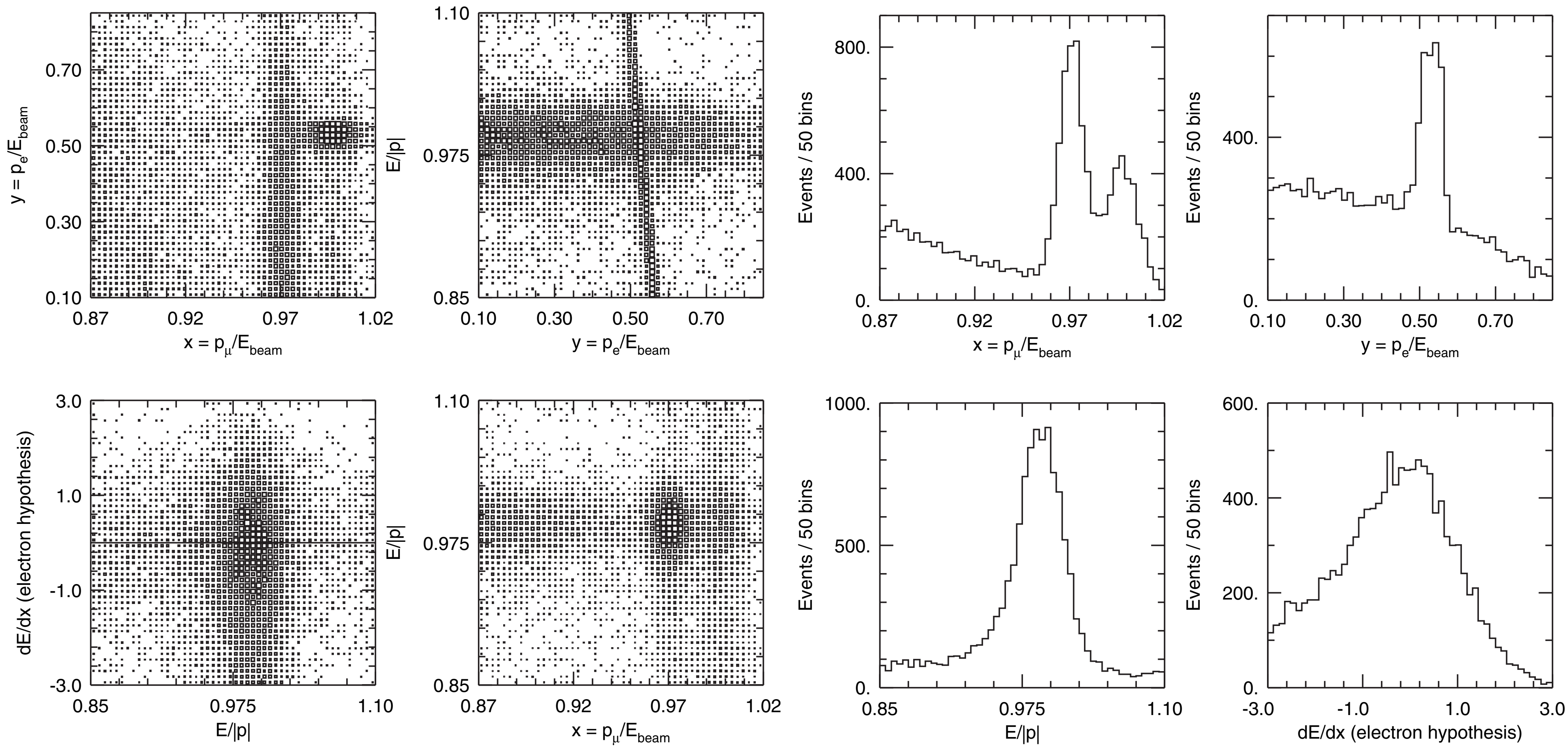








An Example of Toy MC Fit with All Components

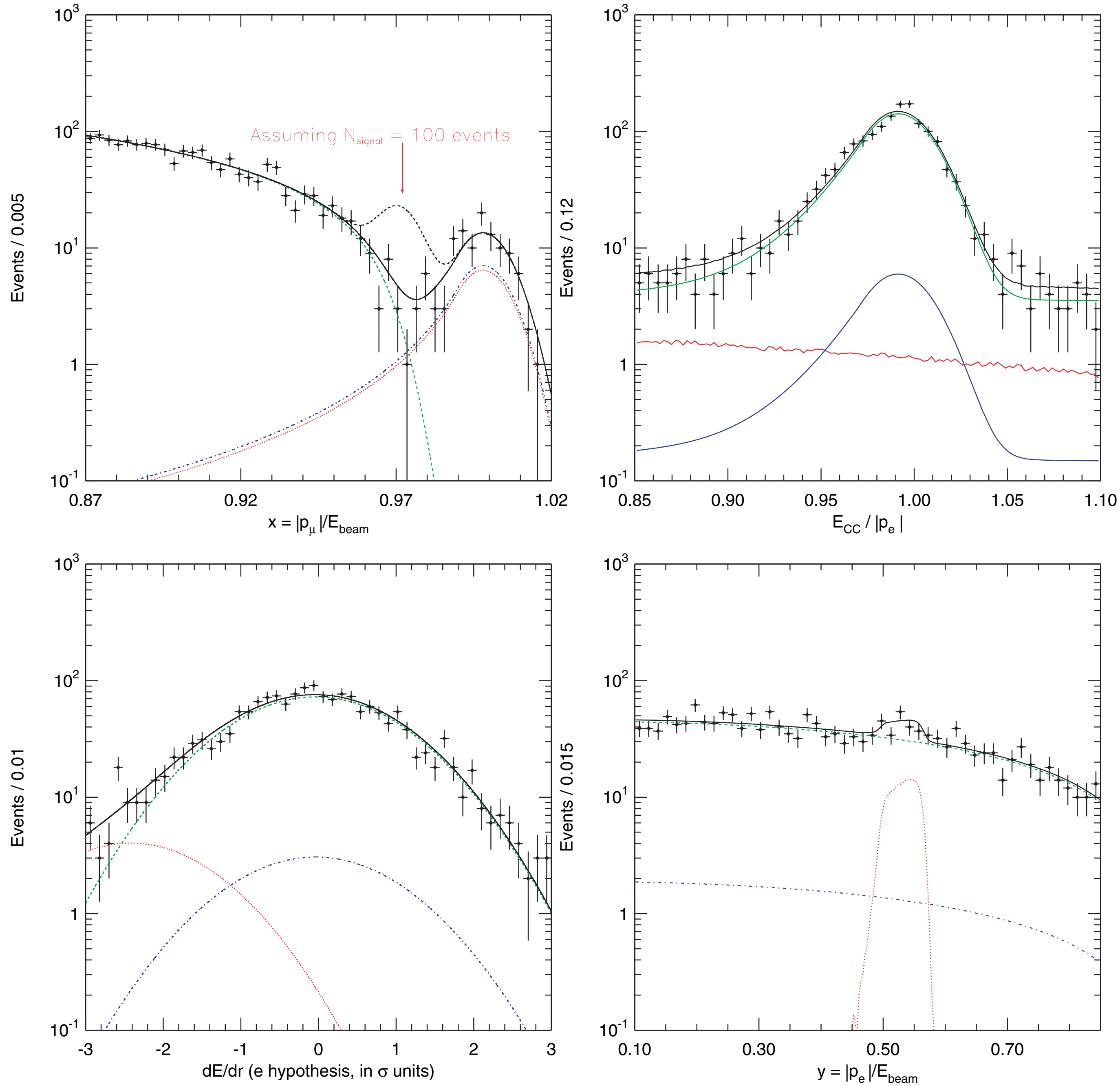


Toy MC Events Generated (all merged together for the 4D fit with four components) and Obtained from the Fit:

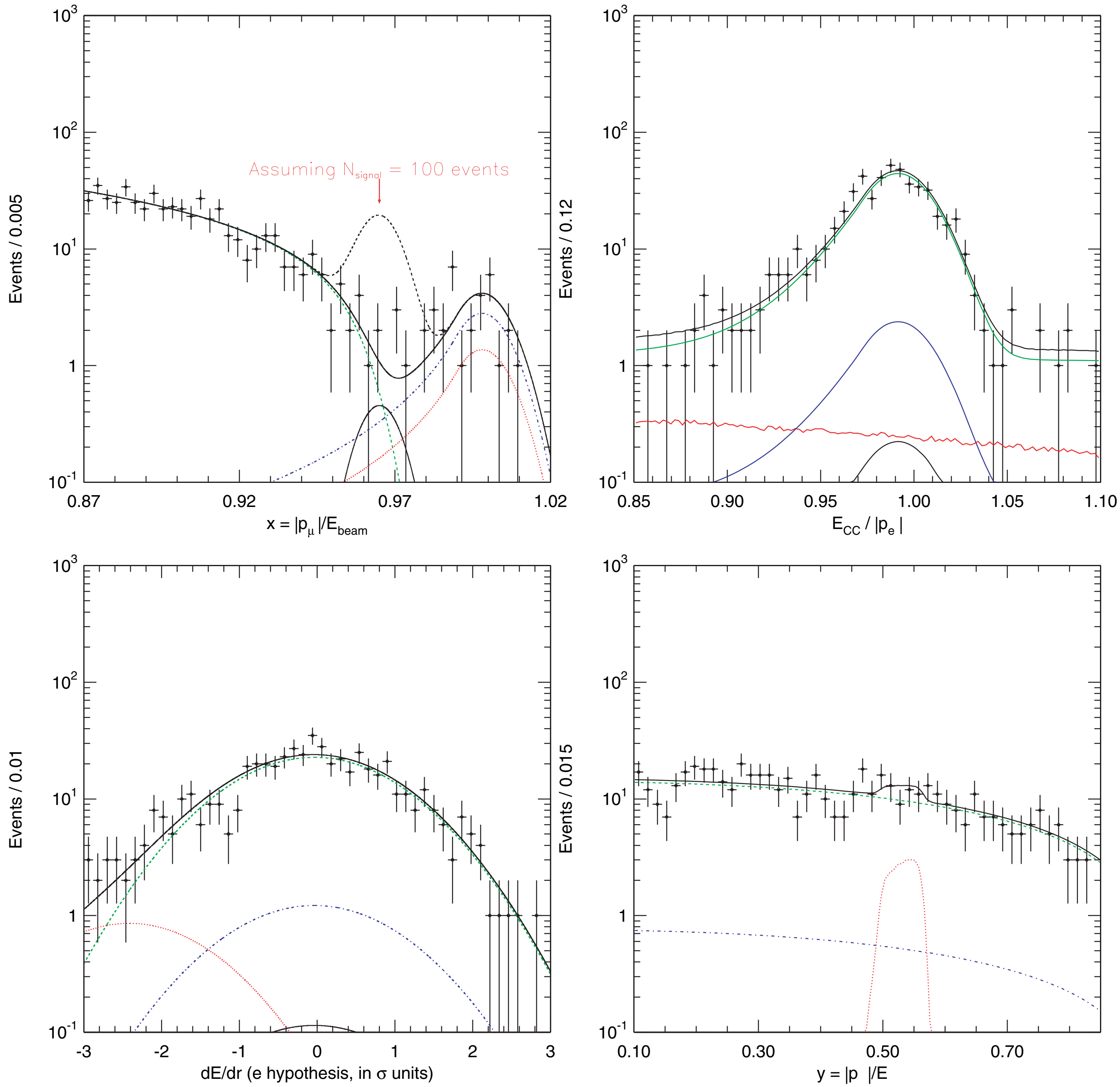
Fits to merged toy MC samples consistently predict meaningful distributions of estimators

$\tau\tau$	4000	3965 +- 65
$\mu\mu(\gamma)$ with hard radiation	2000	2015 +- 48
$\mu\mu(\gamma)$ with decay to e	2000	2008 +- 50
LFV signal	4000	4012 +- 67

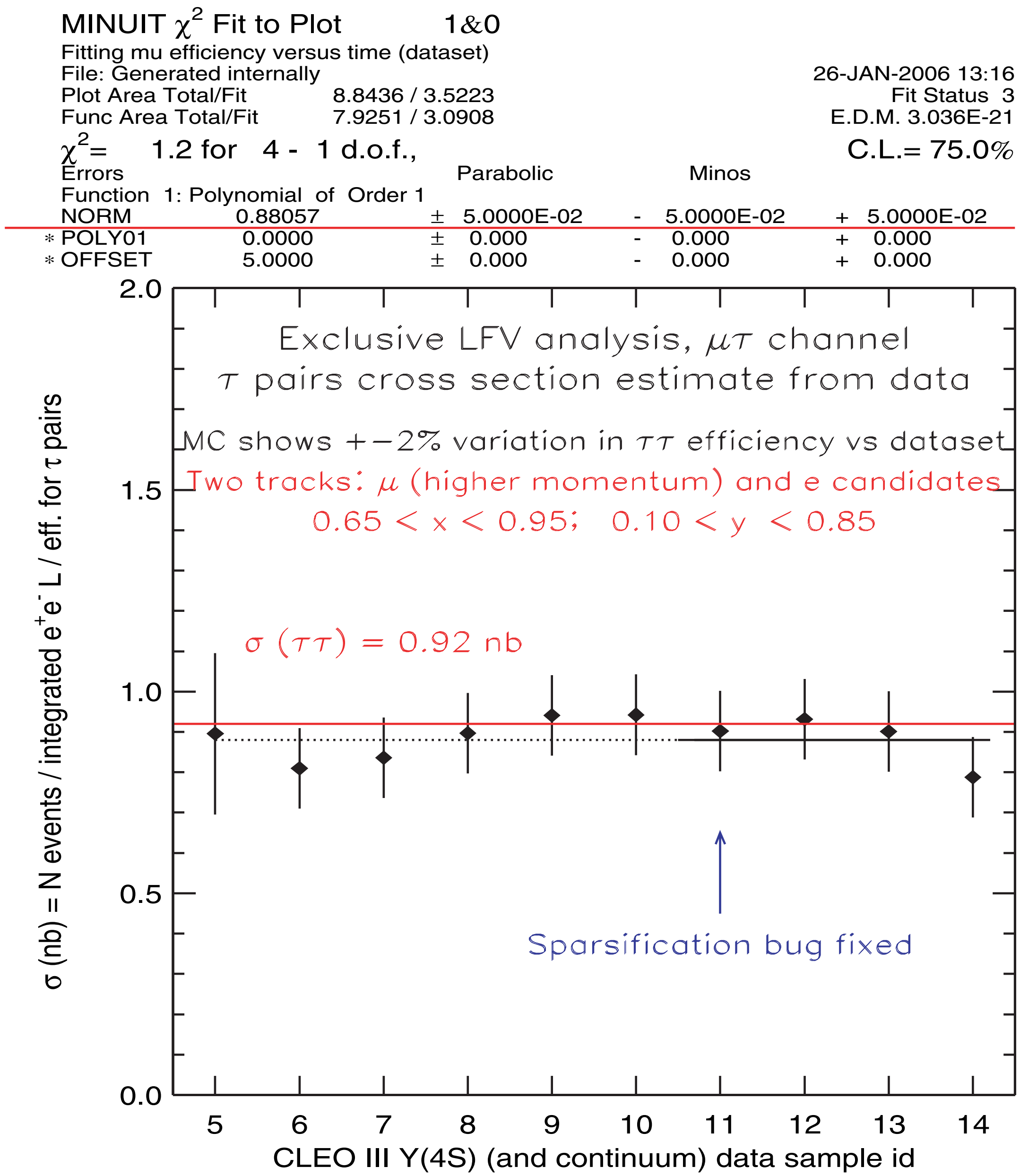
4D Four-Components Fits to Calibration Data



4D Four-Components Fits to Υ(1S) Data



Uncertainties in Selection Criteria



Preliminary Results

Resonance	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Signal in data (events, 90% CL)	10.0	10.7	8.5
Overall efficiency (%, central value)	8.9	8.9	8.9
Systematics in efficiency (%, σ)	8.5	8.5	8.5
Overall efficiency (%, -1σ)	8.1	8.1	8.1
Statistics (number of Υ's)	21 ± 1	5.4 ± 0.2	5.0 ± 0.3
$\mathcal{B}(\Upsilon \to \mu\tau)$ (90% CL UL, $\times 10^{-6}$)	5.9	24	21
With Υ statistics included	6.2	25	22

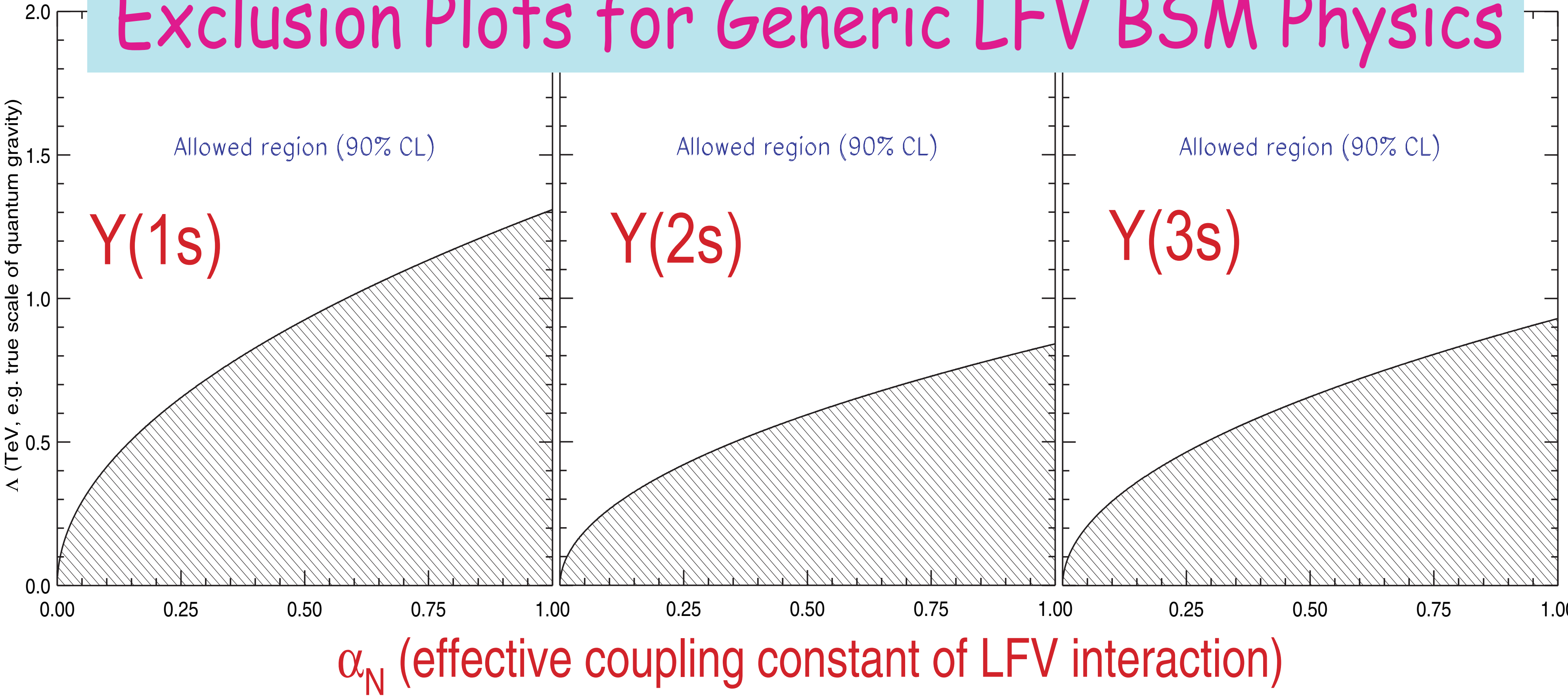
Resonance	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Resonance mass (GeV/c^2)	9.46	10.02	10.36
$\Gamma(\Upsilon \to \mu\mu)$ (keV, central value)	1.336	0.616	0.425
$\Gamma(\Upsilon)$ (keV, central value)	53.0	43.0	26.3
$\mathcal{B}(\Upsilon \to \mu\mu)$ ($\times 10^{-3}$)	25.2	14.3	16.2
$\mathcal{B}(\Upsilon \to \mu\tau)$ (90% CL UL, $\times 10^{-6}$)	5.9	24	21
$\mathcal{B}(\Upsilon \to \mu\tau)/\mathcal{B}(\Upsilon \to \mu\mu)$	0.00023	0.0017	0.0013
Λ from Equation 2 assuming $\alpha_N = 1.0$ (90% CL *lower* limit, TeV)	1.3	0.84	0.93

The End: No LFV discovered in decays of Upsilon Mesons

$$\frac{\Gamma(\Upsilon \to \mu^{\pm}\tau^{\mp})}{\Gamma(\Upsilon \to \mu^{+}\mu^{-})} = \frac{1}{2e_b^2}\left(\frac{\alpha_N}{\alpha}\right)^2\left(\frac{M_{\Upsilon}}{\Lambda}\right)^4$$

Leading-order estimate from Z.Silagadze (*Phys. Scripta* 64 (2001), 128):

Exclusion Plots for Generic LFV BSM Physics



SUSY LSP still qualifies as a candidate for Dark Matter :)