Near detector flux analysis

Rosen Matev
Roumen Tsenov (presenter)
Yordan Karadzhov

St. Kliment Ohridski University of Sofia

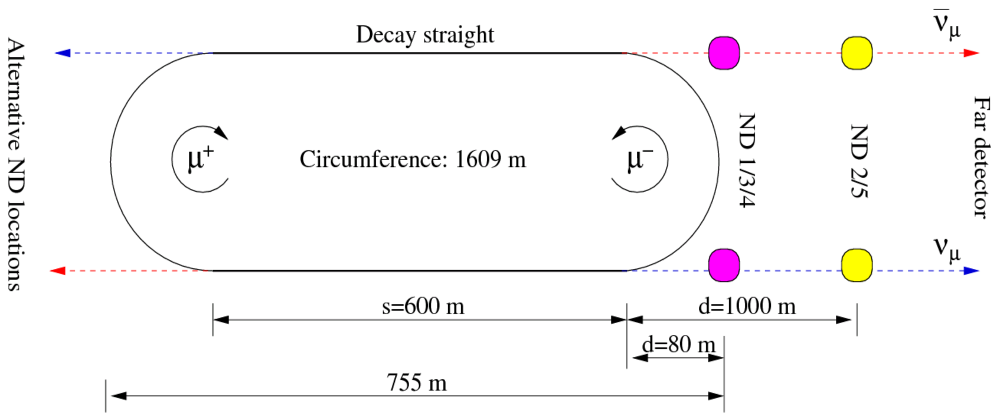
Neutrino Factory Near Detector(s)

E_μ = 25 GeV ±80 MeV

Straight section length = 600 m

Muon angular spread 0.5 mrad

1×10^{20} muon decays/per charge/per year



Neutrino Factory Near Detector aims:

- Measurement of neutrino flux with ~1% precision and extrapolation to the Far Detector;
- Measurement of charm production(main background to oscillation signal);
- Cross-section measurements: DIS, QEL, RES scattering;
- Search for Non Standard Interactions (NSI).

Can we achieve this by using the quasielastic scattering off electrons?

Measurement of the neutrino flux with a Near detector

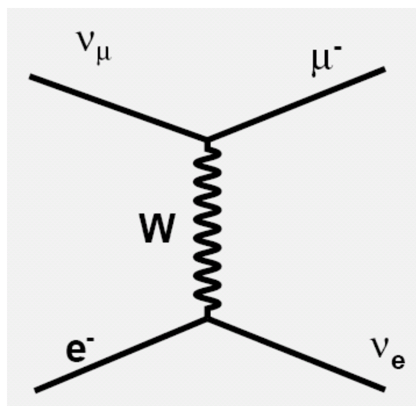
Quasi-elastic scattering off electrons can be used to measure the flux, because its absolute cross-section can be calculated theoretically with enough confidence. The two processes of interest for neutrinos from μ^- decays are:

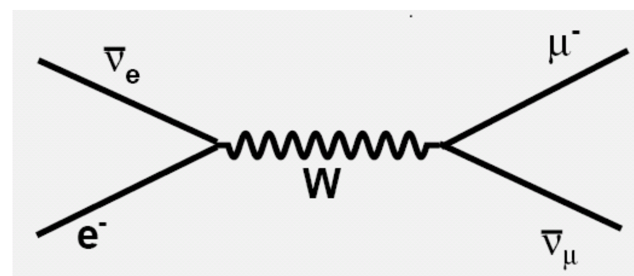
$$\nu_\mu + e^- \rightarrow \nu_e + \mu^- \qquad\qquad \bar{\nu}_e + e^- \rightarrow \bar{\nu}_\mu + \mu^-$$

$$\sigma = \frac{G_F^2}{\pi}\frac{\left(s - m_\mu^2\right)^2}{s} = 4 \times 10^{-41}\, cm^2$$

for 15 GeV ν_μ .

It is ~10^{-3} of $\sigma_{total}(\nu N)$





$$\sigma = \frac{2G_F^2}{\pi}\frac{\left(s - m_\mu^2\right)^2 (E_e E_\mu + \frac{1}{3} E_{\nu 1} E_{\nu 2})}{s^2}$$

Simulation

Near detector flux simulation

flux driver

GENIE

http://www.genie-mc.org

arXiv:0905.2517

ROOT file

GEANT4

ROOT file

(Simple) digitization

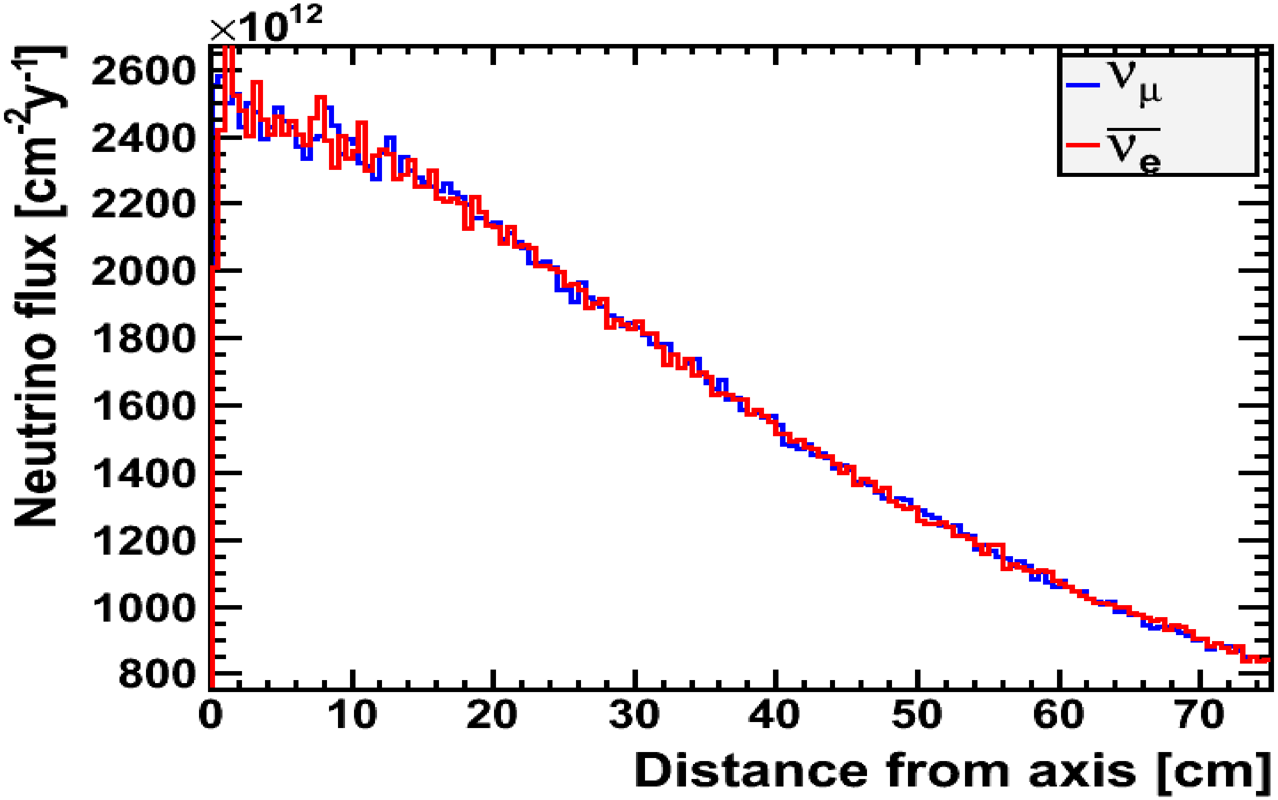
Reconstruction

Processes included in GENIE

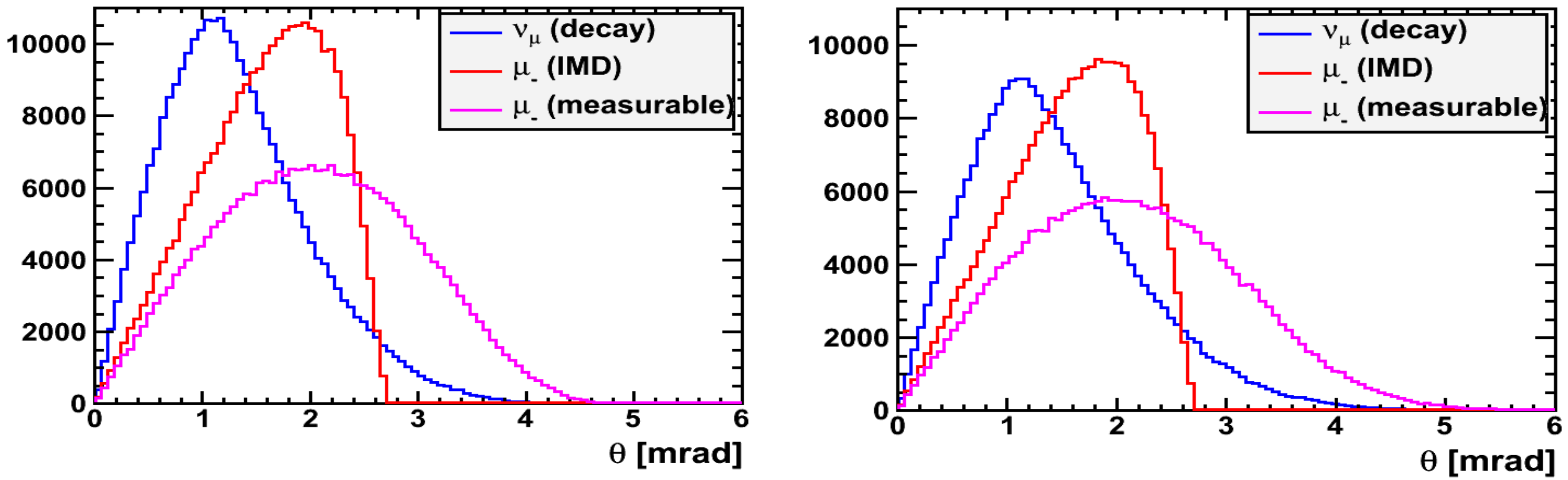
- Quasi-elastic scattering $\nu_\mu + n \rightarrow \mu^- + p$
- Elastic NC scattering
- Baryon resonance production in CC and NC
- Coherent neutrino-nucleus scattering $\nu_\mu + A \rightarrow \nu_\mu + \pi^0 + A$ $\nu_\mu + A \rightarrow \nu_\mu + \pi^0 + A$
- Non-resonant inelastic scattering (DIS)
- Quasi-elastic charm production
- Deep-inelastic charm production
- Neutrino-electron elastic scattering and inverse muon decay $\nu_\mu + e^- \rightarrow \nu_e + \mu^-$

C. Andreopoulos et al., *The GENIE Neutrino Monte Carlo Generator*, **arXiv:0905.2517**

Neutrino flux through the detector per $1x10^{20}$ μ^- decays

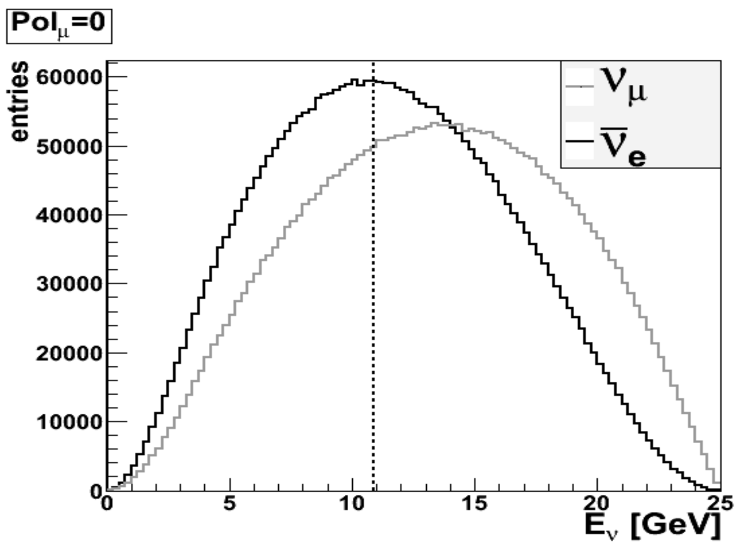


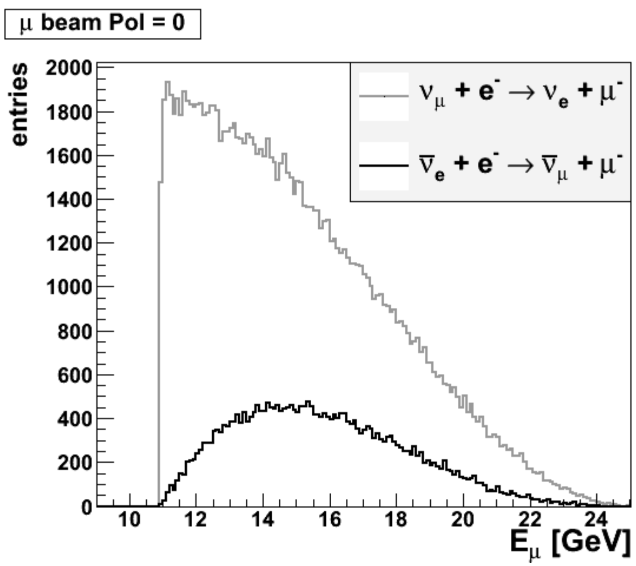
Intrinsic and observable angles

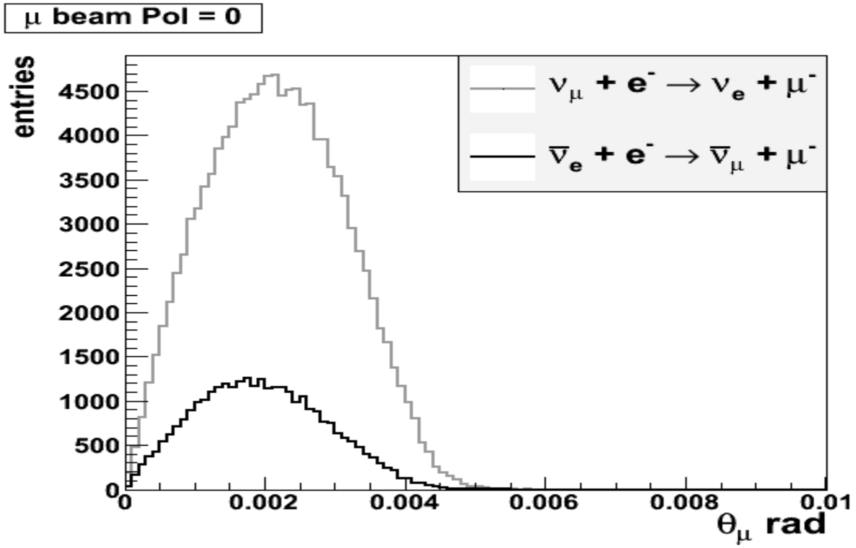


- Left – zero divergence of muon beam
- Right – muon beam with Gaussian spread on θ (1 mrad)
- Number of events differ, but there is only slight change in distribution

ν_μ flux & IMD muons







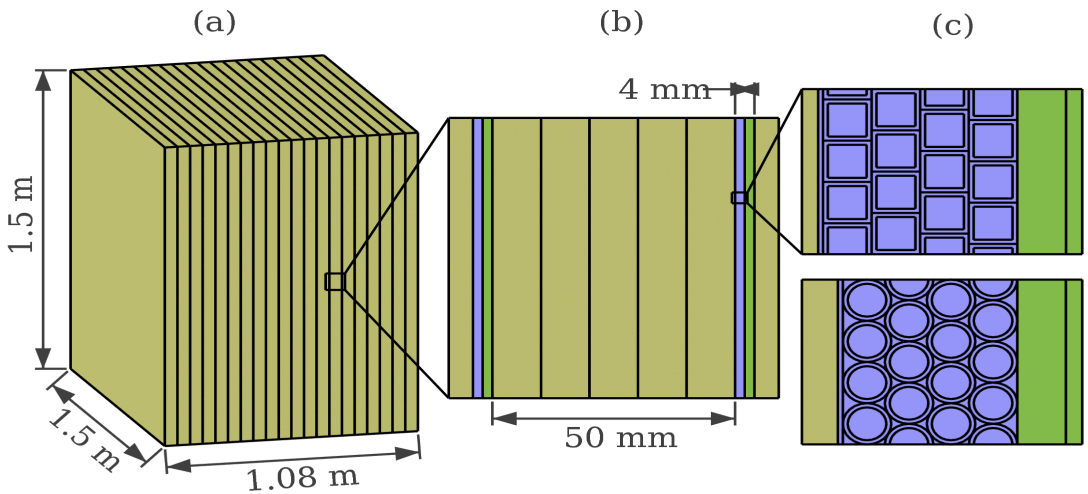
Discriminating variables

- muon scattering angle θ_μ;
- $E_\mu \theta_\mu^2 =\sim (1-y), \quad y -$ inelasticity;
- muon p_T^2

Detector requirements:

- To provide sufficient interaction rates. This requires a **solid detector;**
- To be able to reconstruct the polar angle of the scattered muon with 0.5 mrad precision or better. This requires a **low Z tracker;**
- To be able to measure the hadron recoil energy down to values of several MeV. This requires a **precise calorimeter**.

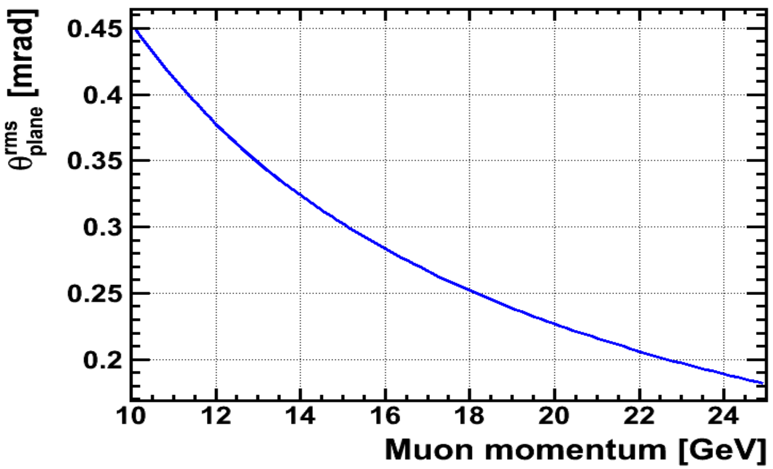
Detector design

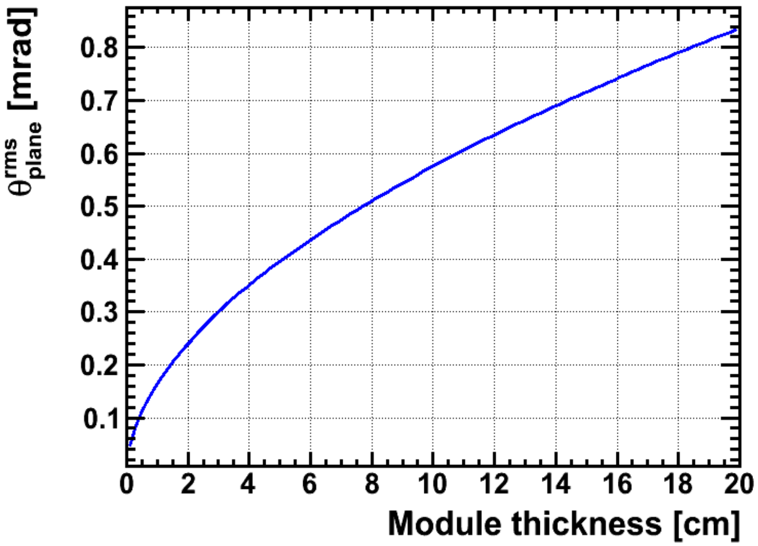


- Polystyrene (1.06 g/cm3)
- Approx. 2.5 t
- 20 modules
- A module: absorber & tracker station

- A tracker station – horizontal and vertical layers, each has 4 fiber planes shifted in respect to each other
- Scintillating fibers – 0.5 mm width (round or square)
- 24000 fibers per station
- Absorber is 5 cm thick, divided into 5 slabs to allow for more precise measurement of recoil energy near the event vertex
- We want to be able to measure deposited energy in a slab down to values of several MeV

Tracking capabilities





- Rad. length X_0 = 41.31 cm
- RMS(θ_{plane}) = 0.2 – 0.4 mrad
- Each module is 5.4 cm thick
- Ultimately, with perfect space alignment of fibers, a position resolution of 50 μm per station is achievable.

Assumptions for digitization and reconstruction

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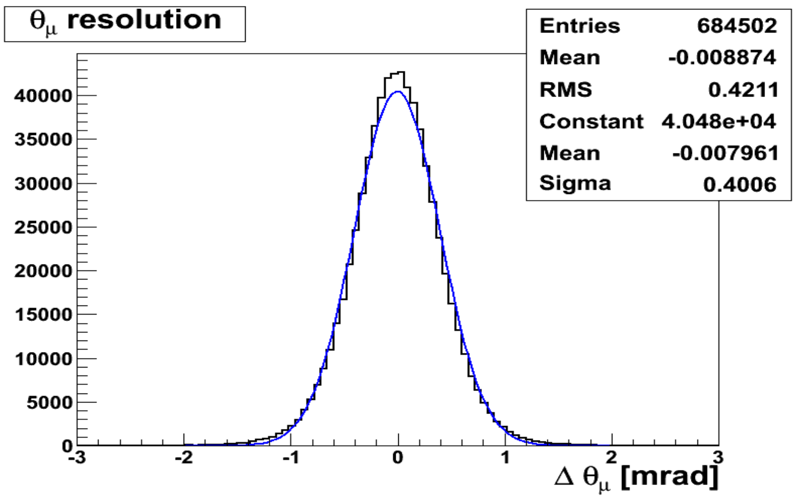
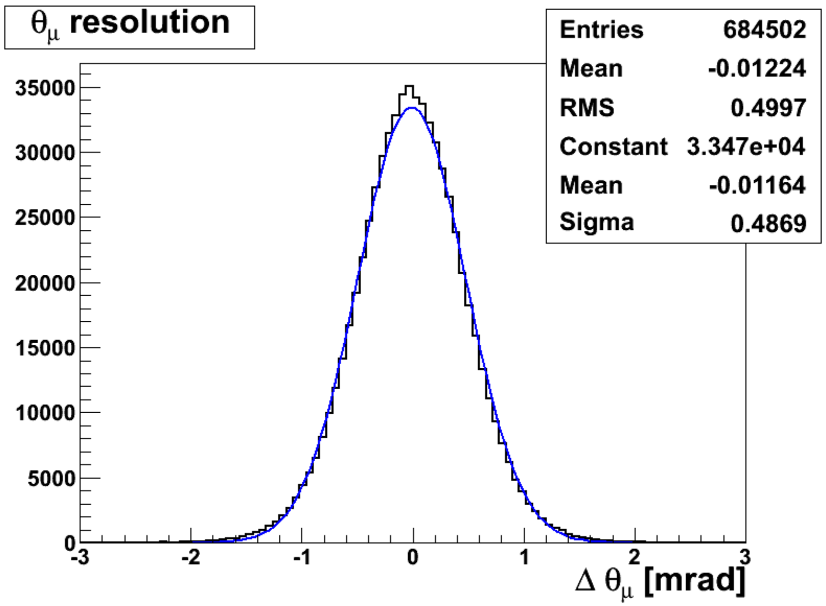
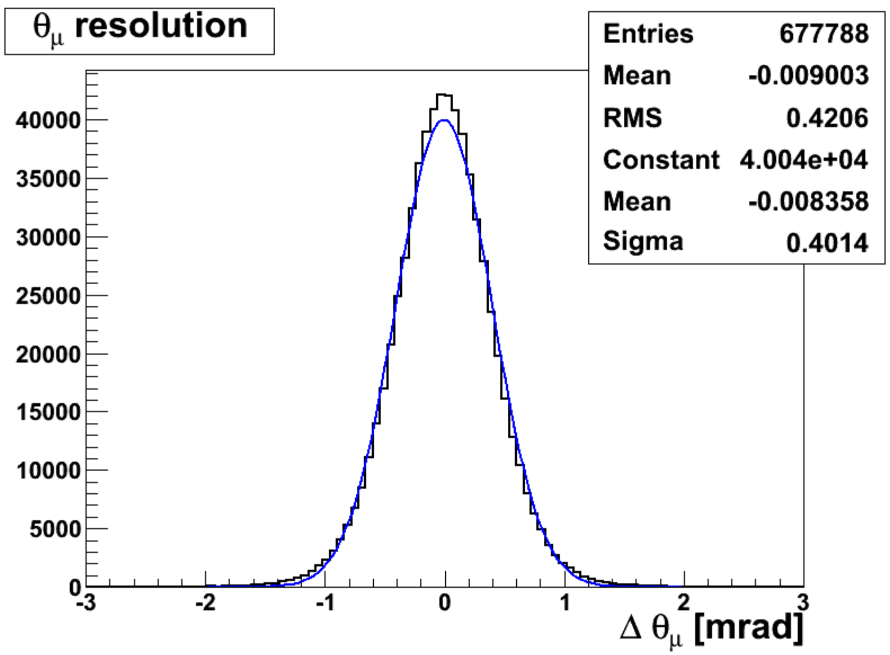
- Digitization
  - Fiber signal is proportional to energy deposition corrected for attenuation and smeared with a Gaussian with $\sigma/E = 25\%$
  - Slab signal is proportional to total energy deposition, smeared with $\sigma/E = 5\%$
- Muon momentum can be measured with an error of 1% (not crucial for the moment)
- Can determine event vertex slab with high certainty

Muon polar angle reconstruction

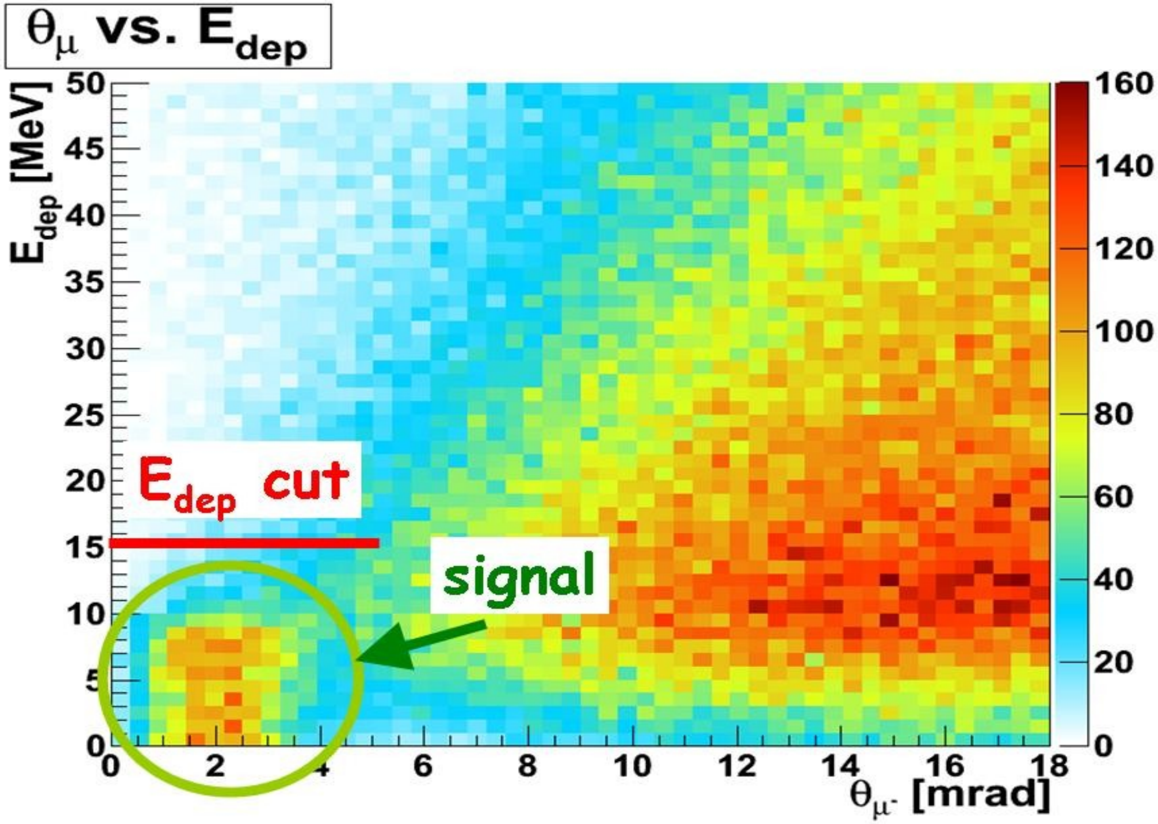


- One configuration with 0.5 mm round fibers (top) and two configurations with 0.5 mm square fibers (bottom)
- Resolution ~ 0.5 mrad in all setups



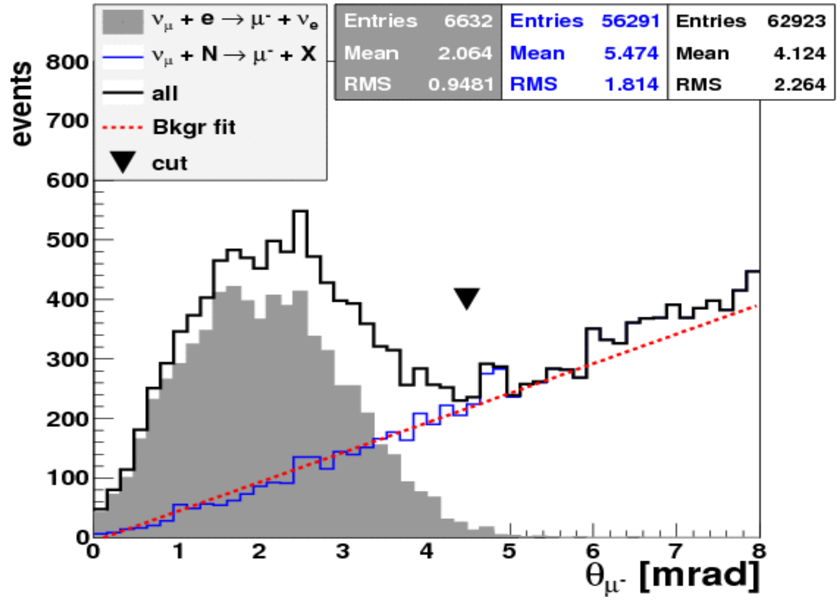


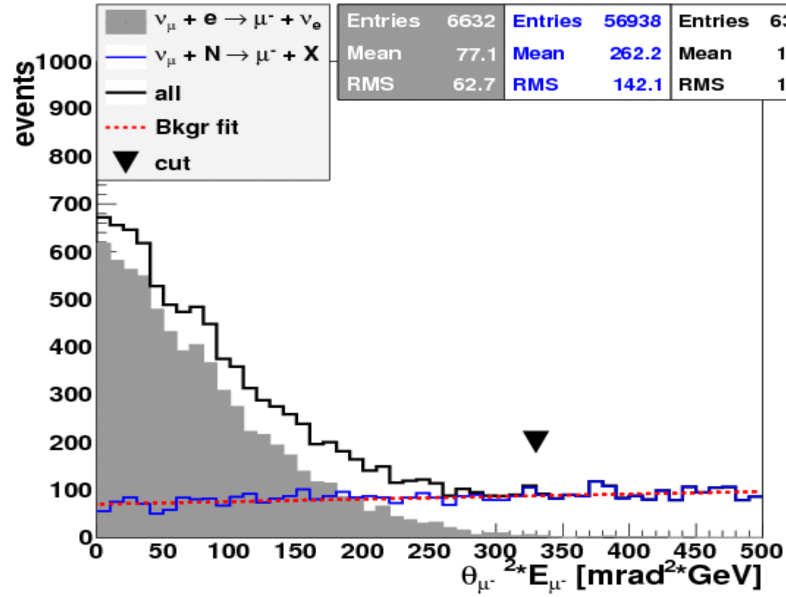
Event selection



Energy deposition in the first illuminated absorber (5 cm thick) vs. reconstructed muon angle

Signal extraction





cut on	all events below the cut	bkgr events below the cut	bkgr events from the fit	simulated leptonic events	leptonic events from the fit
θ_μ	9450	2860	2865 ± 57	6632	6585 ± 57
$E_\mu \cdot \theta_\mu^2$	9284	2666	2596 ± 74	6632	6688 ± 74

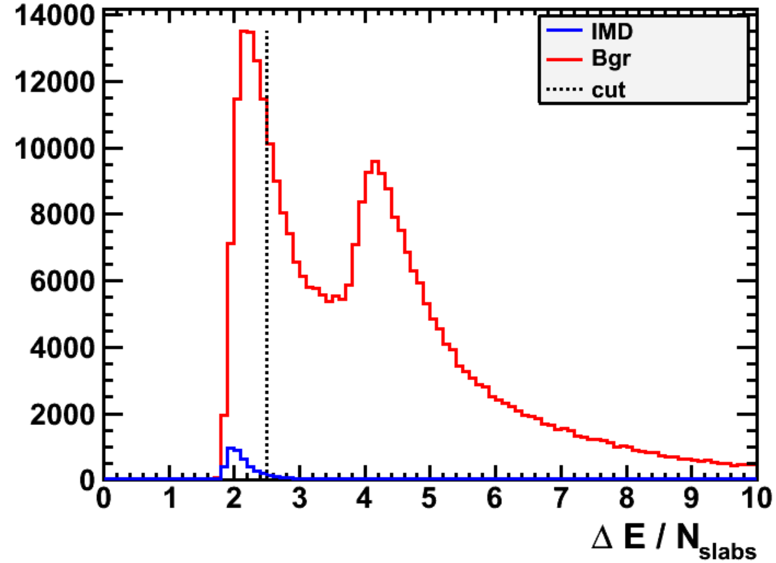
(for 0.25×10^{20} μ^- decays)

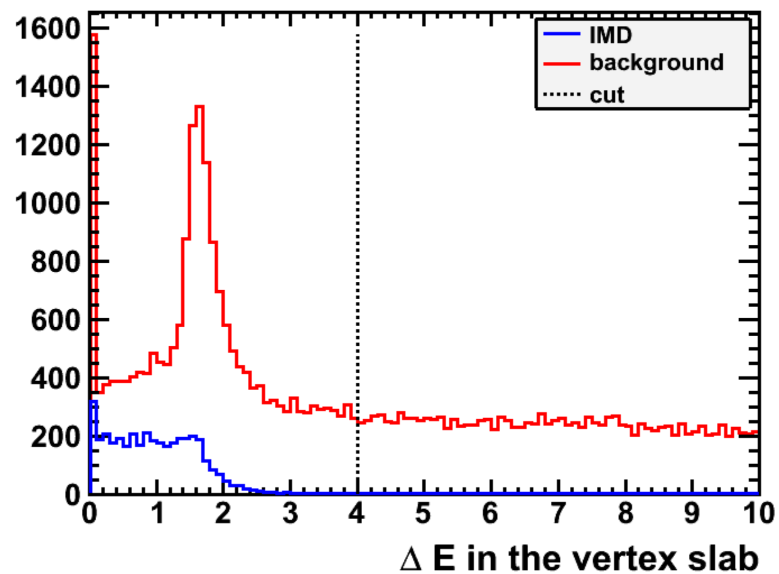
Latest development
(not included in the IDR draft)

Background rejection

Elaborated cuts :

- < 1 MeV (or no) total backward energy deposition
- < 2.5 MeV energy eposition averaged over lluminated slabs
- < 4 MeV energy deposition in event vertex slab





Background subtraction exploiting anti-ν_μ interactions

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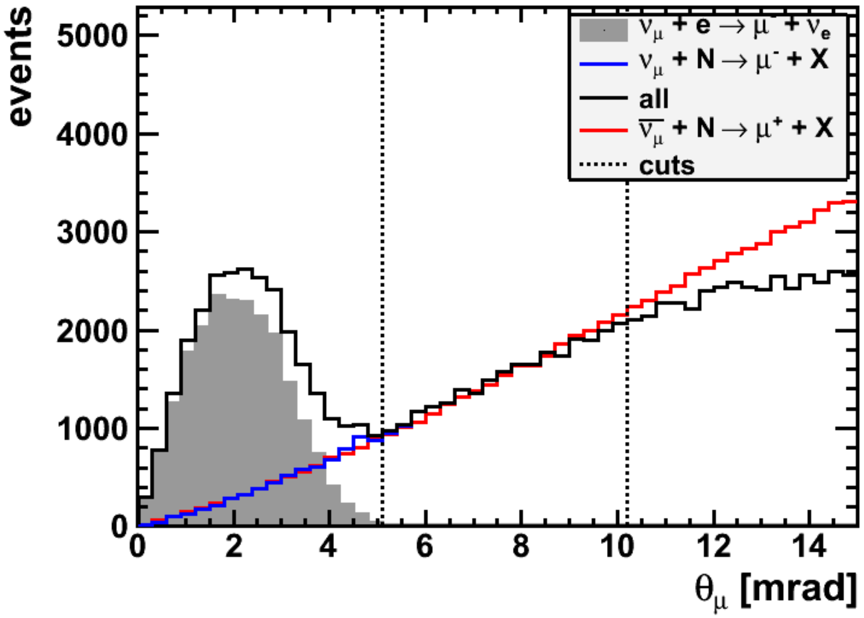
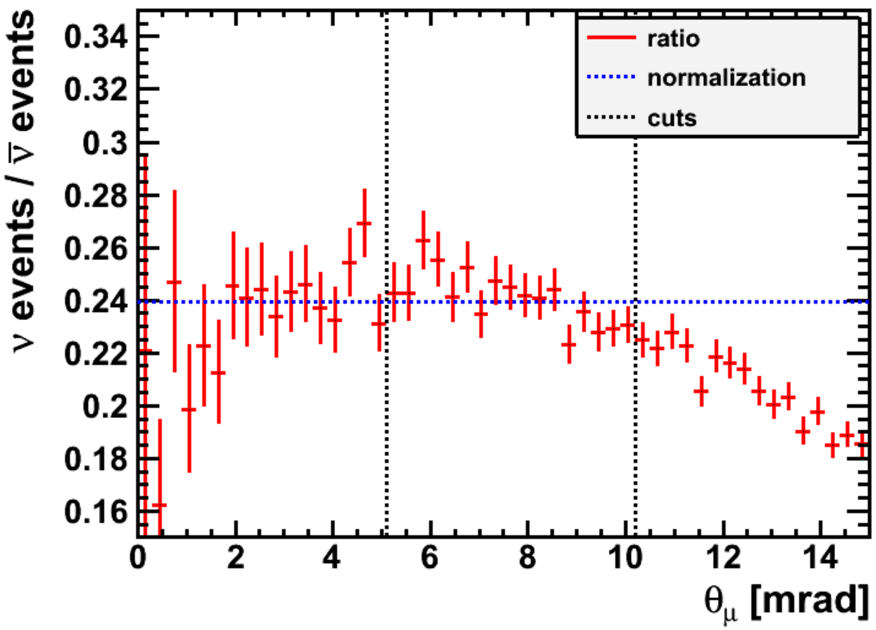
- No IMD peak in anti-ν_μ interactions
- Normalize μ^+ distribution to μ^- one (currently, on what appears to be a linear region)
- Subtract
- Systematic errors under investigation...

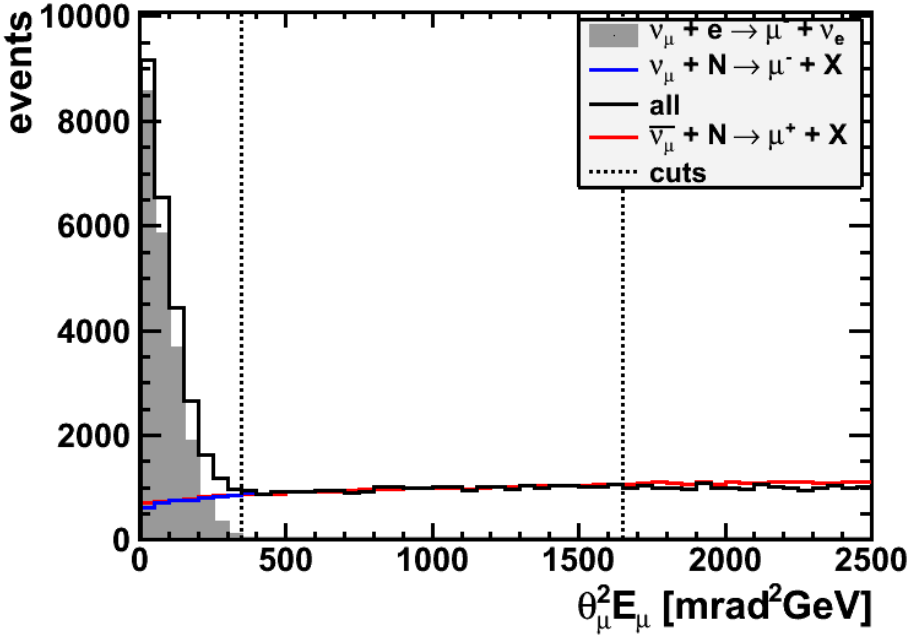
Discriminating on θ_μ

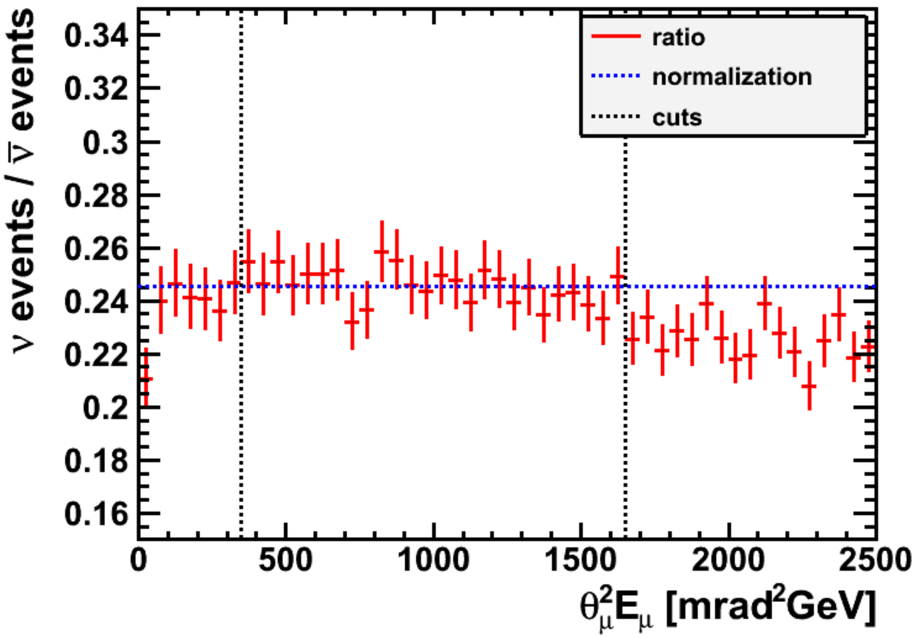




Efficiency	Purity	All	Background	Signal/Eff	MC IMDs
84%	75%	28329 +/- 168 (0.6%)	7055 +/- 20 (0.3%)	25323 +/- 202 (0.8%)	25276

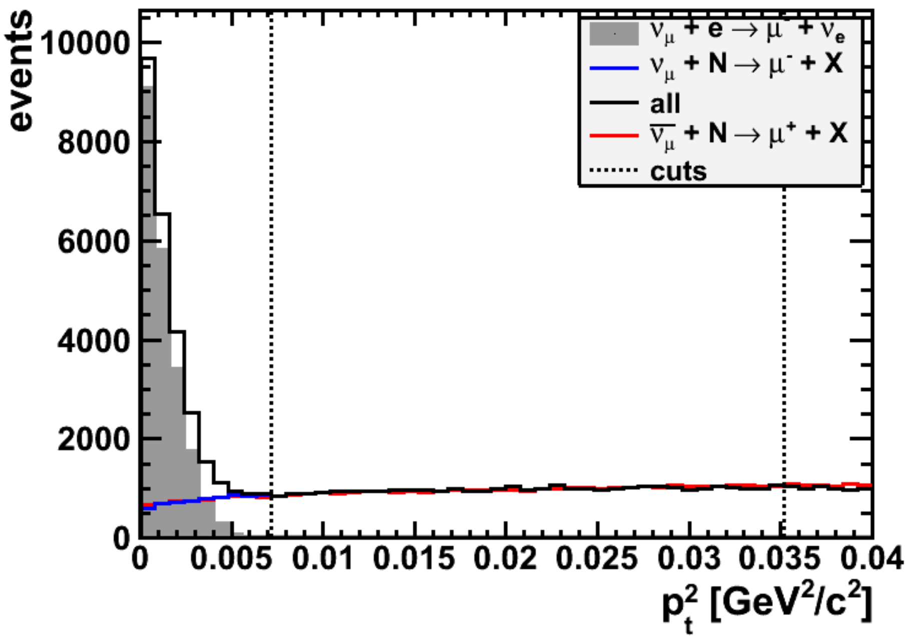
Discriminating on $\theta_\mu^2 * E_\mu$ variable

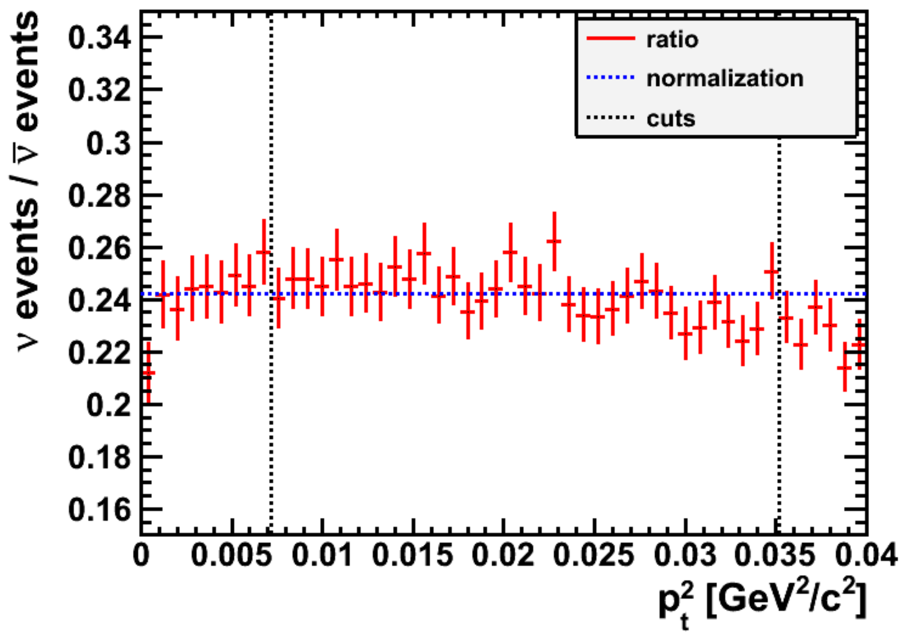




Efficiency	Purity	All	Background	Signal/Eff	MC IMDs
84%	80%	26564 +/- 163 (0.6%)	5513 +/- 18 (0.3%)	25073 +/- 195 (0.8%)	25276

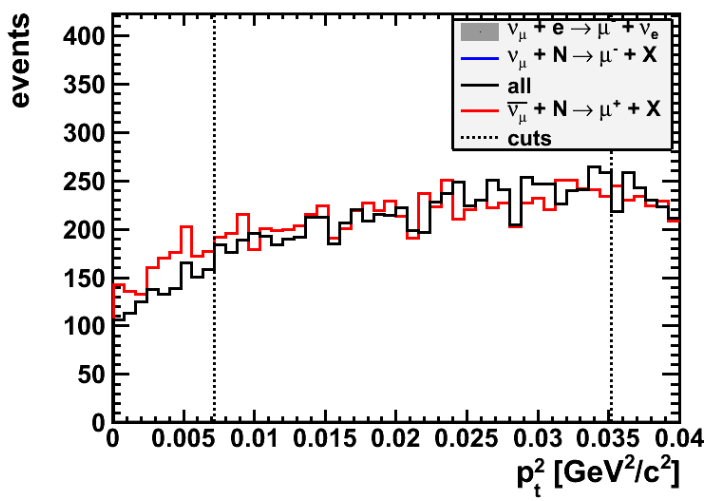
Discriminating on p_t^2

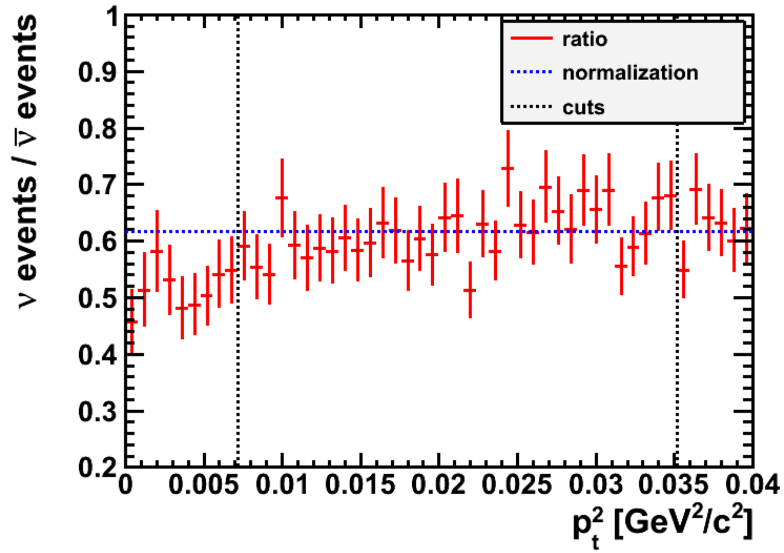


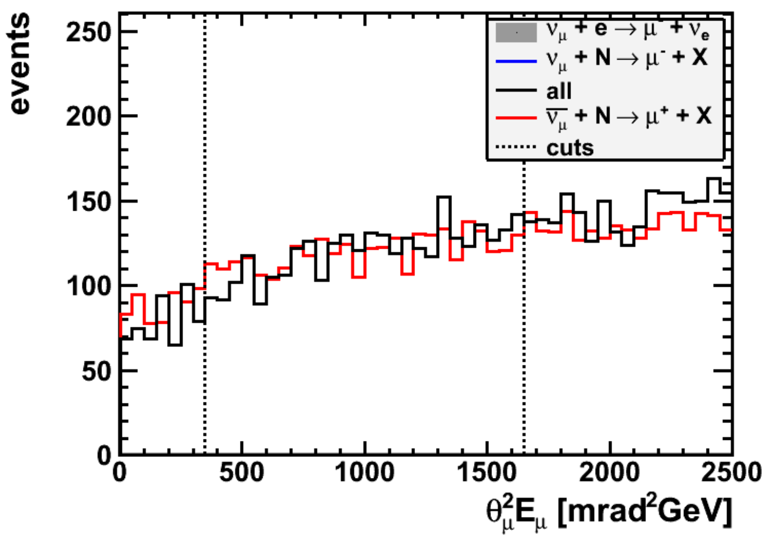


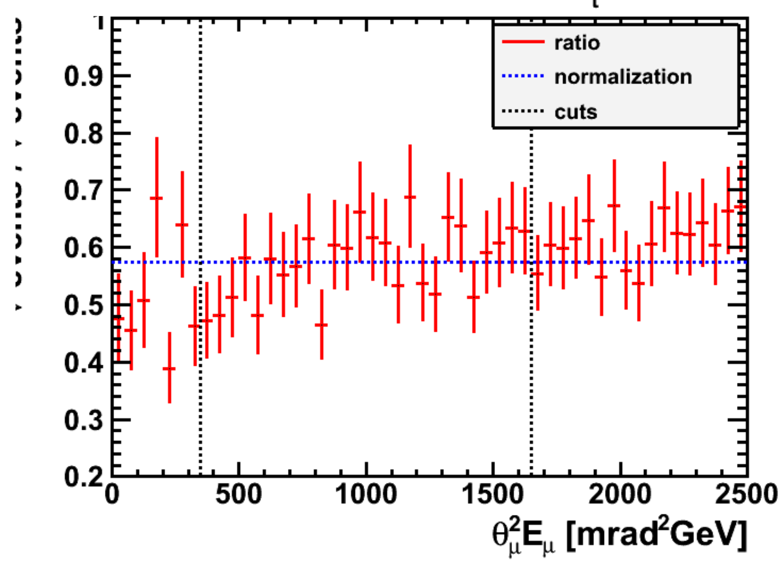
Efficiency	Purity	All	Background	Signal/Eff	MC IMDs
84%	75%	28276 +/- 168 (0.6%)	7004 +/- 20 (0.3%)	25282 +/- 201 (0.8%)	25276

μ^+/μ^- ratio below the treshold…









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In lieu of conclusions

- μ^+/μ^- ratio method needs further analysis and we want to go below threshold;
- comparison GENIE/data for small Q^2 ;
- more realistic digitization (different photodetector options);
- *ν-e* elastic scattering (can we see a signal?) – reconstruction issues.