Single pion production

Theoretical dependences and experimental limitations

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Introduction

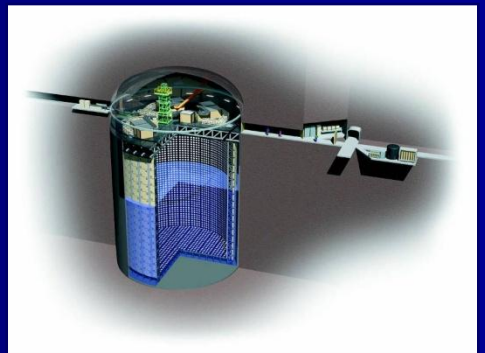
- We are looking for uncertainties in $\nu\ \mathrm{N} \rightarrow \nu\ \pi^0\ \mathrm{N}$
- Uncertainties
  - Various theoretical models predict different pion production rate
- Processes we will look at:
  - CC piplus
  - CC pizero
  - NC pizero

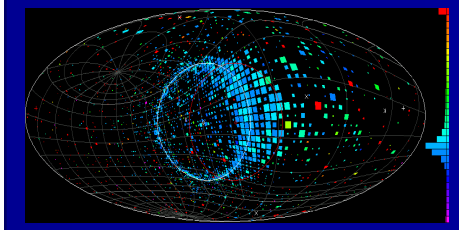
$$\nu N \rightarrow \mu^- \pi^+ N$$
$$\nu n \rightarrow \mu^- \pi^0 p$$
$$\nu N \rightarrow \nu \pi^0 N$$

- Are the uncertainties similar?

For that we will use two generators

- New experiments, high precision
- We need to predict backgrounds very precisely
- Pions (pizeros in particular) are one of main sources of background in water cerenkov detectors





Generators

Nuance 3.006

- Generator: **Nuance 3.006** (by Dave Casper from UCI)
- Tested with K2K data
- FSI (final state interactions) implemented
  - They can be turned off (for comparison purposes)
- Resonance model: Rein-Sehgal (multiple resonances)

NuWro

- Generator: NuWro (by Jan Sobczyk, Czarek Juszczak, Jarek Nowak et al. – Wrocław Neutrino Group)
- We can easily change form factors in NuWro for comparison purposes
- No FSI (at the time of the analysis this was not yet available in NuWro)
- Resonance model: single delta resonance (good approximation in ~1GeV energy range)

Nuance is used here as a reference

Nuance

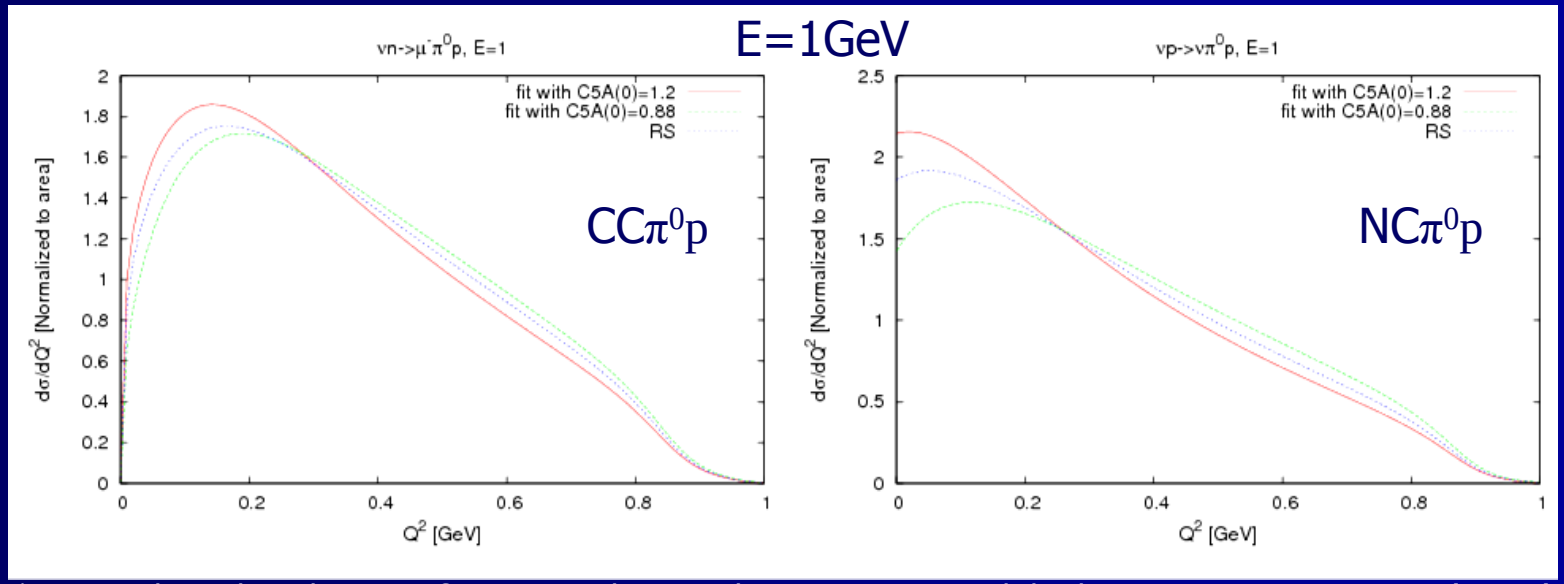
K2K*: R=σ(NC π^0)/σ(CCtotal)=0.064±0.001*(stat)*±0.007*(sys)*

- Test for π^0 production – K2K experiment
- Measurement on water (significant role of FSI – we don't have any measurements on deuterium)
- Nuance with FSI: R=0.065 (in agreement with the experiment, also with Neut result quoted in the article)

**Measurement of single π^0 production in neutral current neutrino interactions with water by a 1.3 GeV wide band muon neutrino beam*, K2K Collab., Physics Letters B 619 (2005) 255–262

Form factor parametrizations

- Large uncertainties in cross sections can be expected to come from differences in form factors
- We can study them thanks to **NuWro** capabilities of form factor modification
- 3 parametrizations taken into account:
  1. Graczyk Sobczyk c5a(0)=1.2*
  2. Graczyk Sobczyk c5a(0)=0.9*
  3. Paschos Lalakulich BNL fit**



* Graczyk, Sobczyk *Form factors in the quark resonance model,* Phys.Rev. D77, 053001 (2008)
** Paschos, Lalakulich Phys.Rev. D71, 074003 (2005)
Lattice calculations favor c5a(0)=0.9: Alexandrou et al., Phys.Rev.Lett. 98, 052003 (2007)

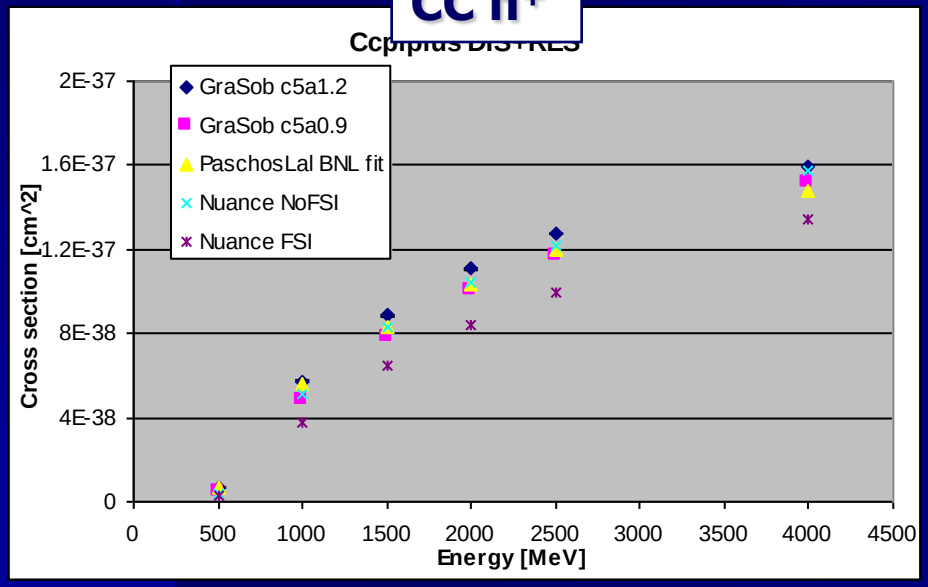
MC samples

- Neutrino interactions generated on **water**, ca 500000 evts
- Samples:
  - 5 files for energies 0.5-2.5GeV and 4GeV (for cross-section estimation)
  - K2K near station energy profile (for comparison with K2K measurement)
- Nuwro: noFSI, Nuance – with and w/o FSI
- No detector effects here
- We take into account RES and DIS events

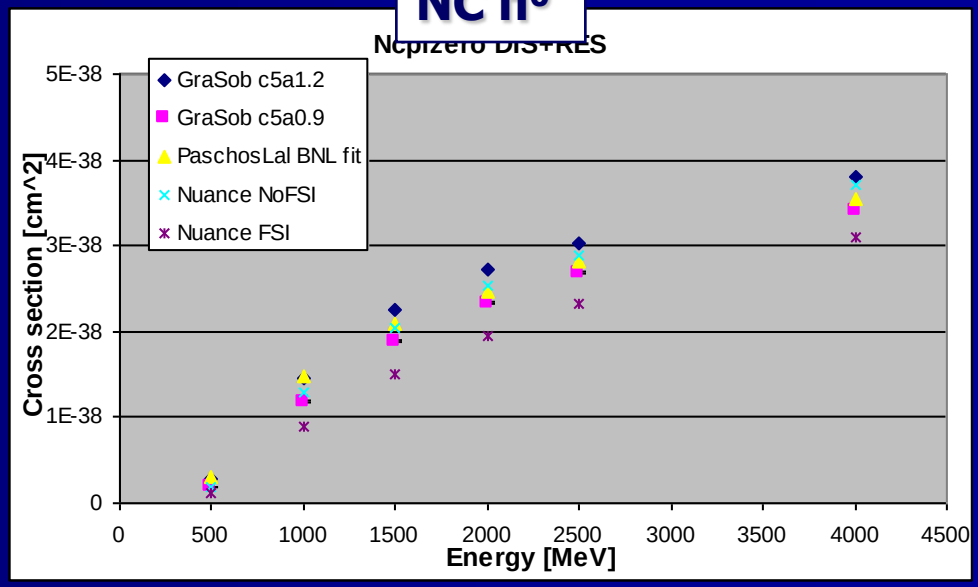
Single pion production xsec (on water)

- Cross sections calculated by **Nuance** are shown here for reference
  - Nuance uses Rein-Sehgal with M_A=1.1
  - one curve with FSI turned off (no nuclear reinteractions) that can be directly compared with NuWro curves, and one with FSI that reflects the reality.

CC π⁺



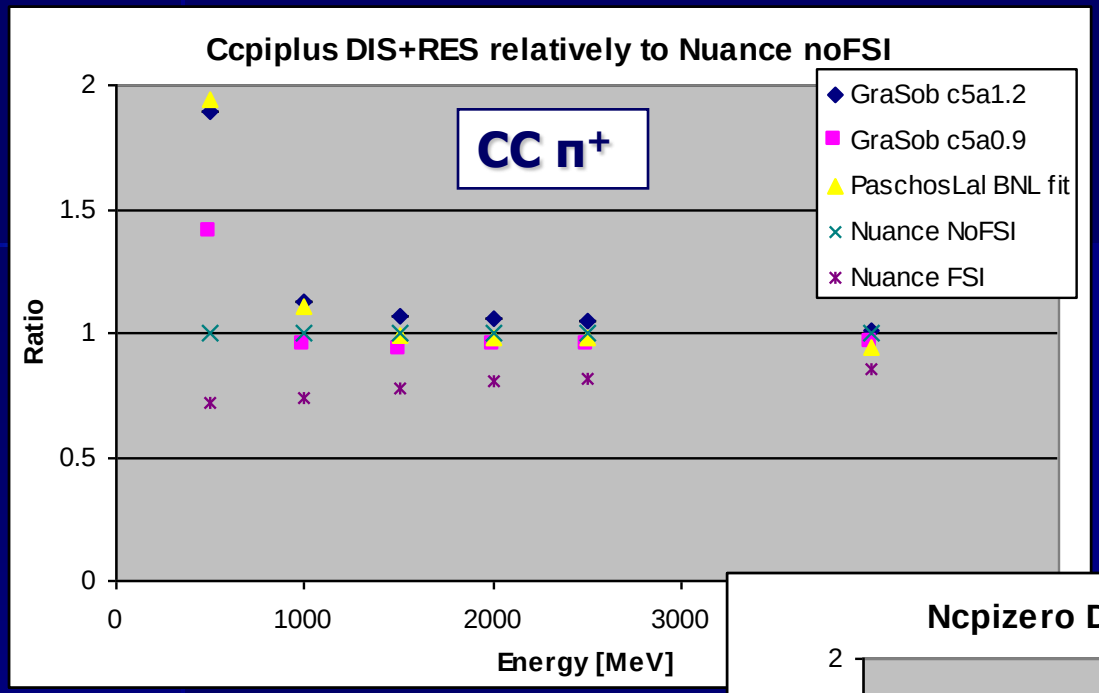
NC π⁰

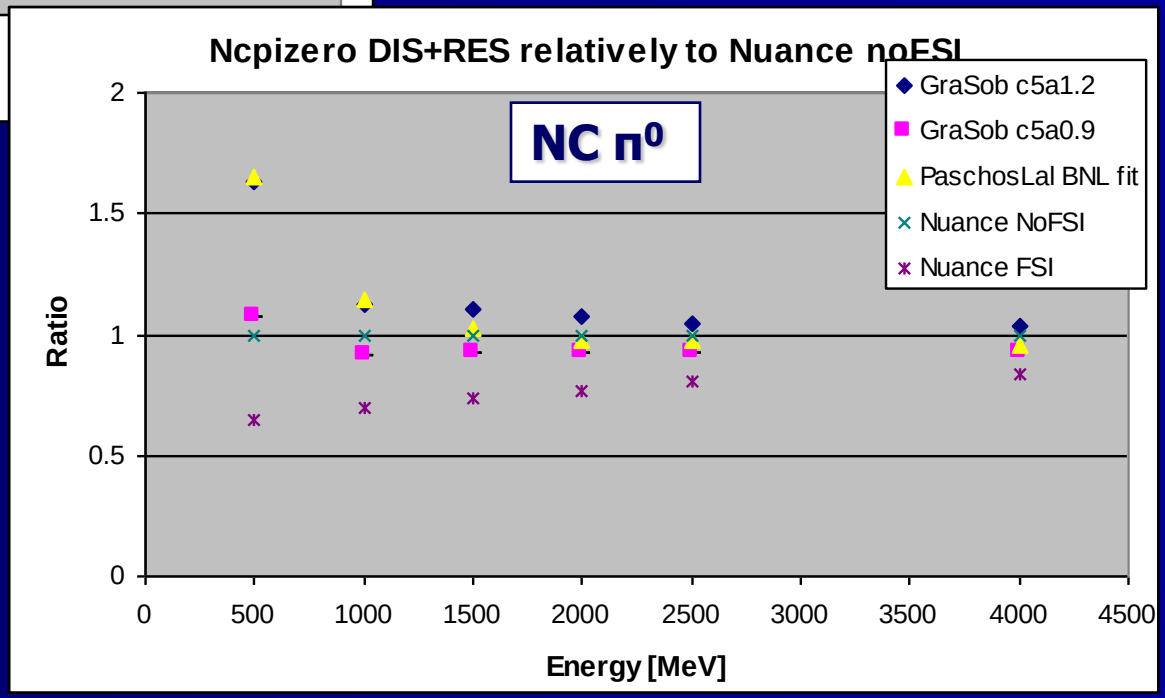


Higher energies count!

All values relatively to Nuance noFSI

Single pion production xsec (on water), relatively



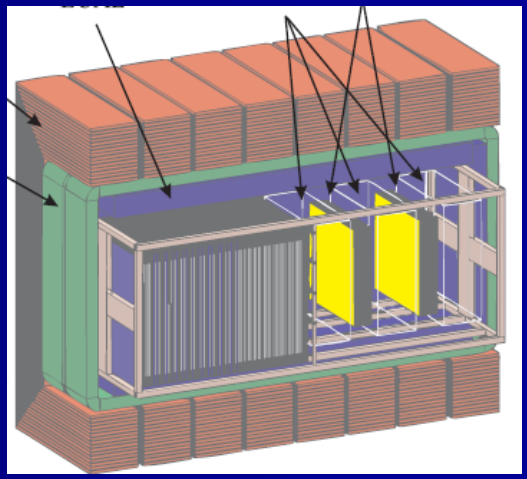


Significant differences in NC π^0 channel (up to 20%), larger than for CC piplus/pizero

Pi production in real detectors

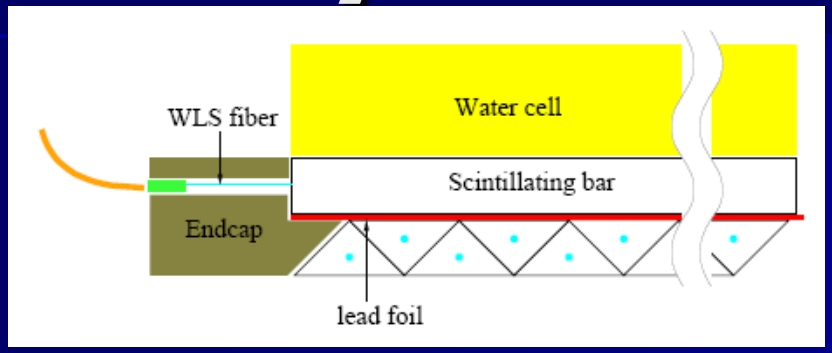
- Model problems
- What can we learn from experimental measurements?
- Let's look at CC π production to learn something about NC π^0

- High resolution scintillator detectors are popular for measuring cross-sections in near stations of long baseline experiments
  - K2K – SciBar, SciFi
  - T2K – P0D, FGD
- We'll estimate what can be seen in T2K detectors



Estimate of slow particle visibility

POD



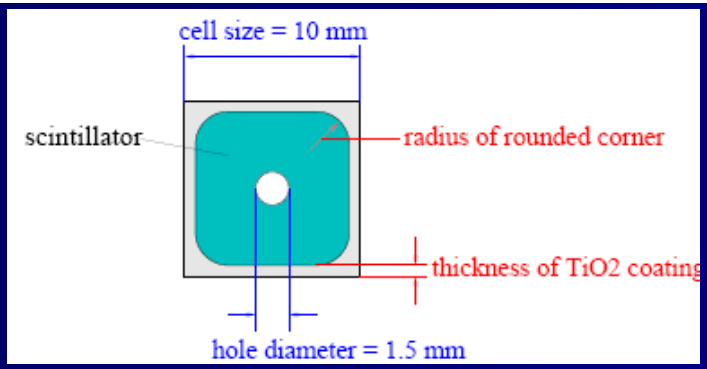
3cm

1.7cm

1.7cm

-> One layer 6.5cm

Water
FGD



Water layer in FGD: 2.5cm

Scintillator: 1cm each (x or y) layer

-> One layer 4.5cm

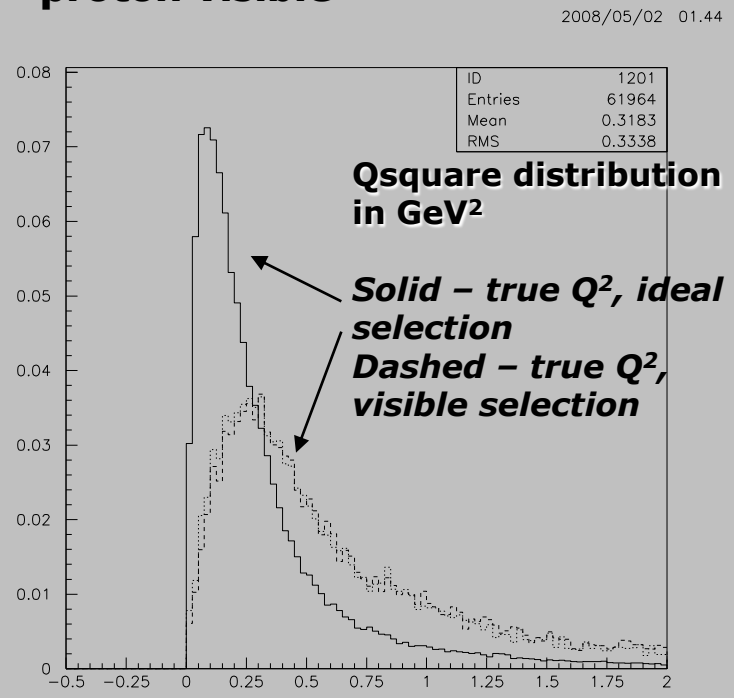
- Assumption: two active x-y layers to see the particle
- This amounts to ~10.5cm for POD and 6.5cm for water FGD

Track length	Proton momentum cut	Piplus momentum cut
6cm	400MeV/c	110MeV/c
10cm	450MeV/c	120MeV/c
14cm	500MeV/c	130MeV/c
18cm	550MeV/c	140MeV/c

Q^2 distributions for piplus production

- **Nuance water sample**
- **Visibility assumptions for selection and Q^2 reconstruction (for ND280 detector)**
  - **Protons** and **pions** – 6cm cut (400MeV/c, 110MeV/c)
  - **Muons, electrons** always visible
  - π^0 always visible
- **Event selection**
  - For simplicity we restrict ourselves to RES and DIS events only
  - In reality we would have ~2% of QE events in our sample

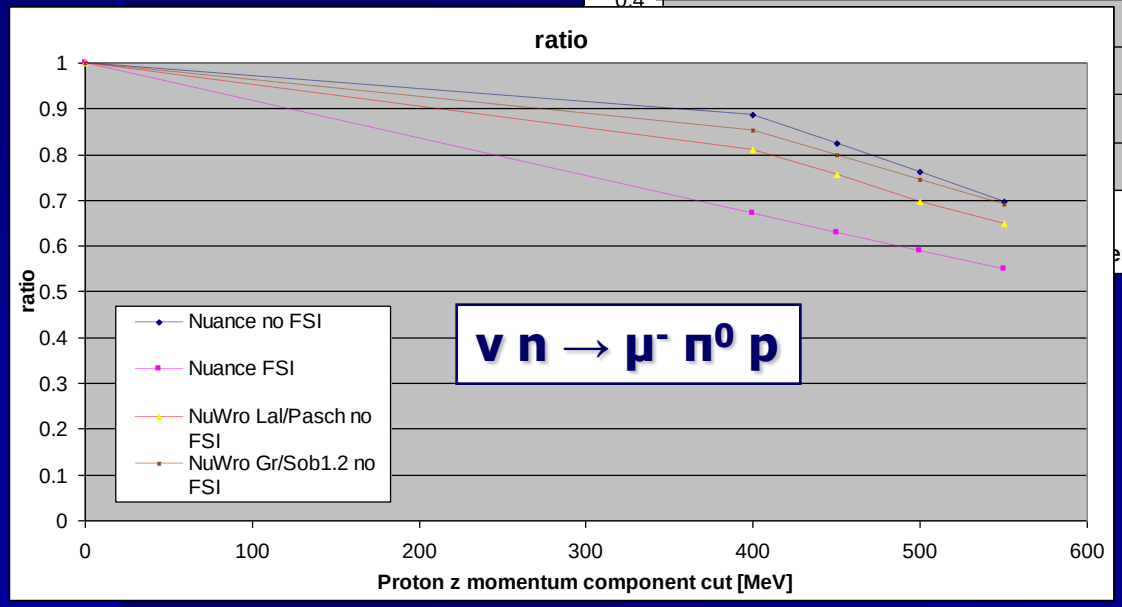
- **Targeting at** $\nu\, p \rightarrow \mu^-\, \pi^+\, p$ **(via** Δ^{++}**)**
- **Visible selection: 1** μ**, 1** π^+ **, 1 proton visible**

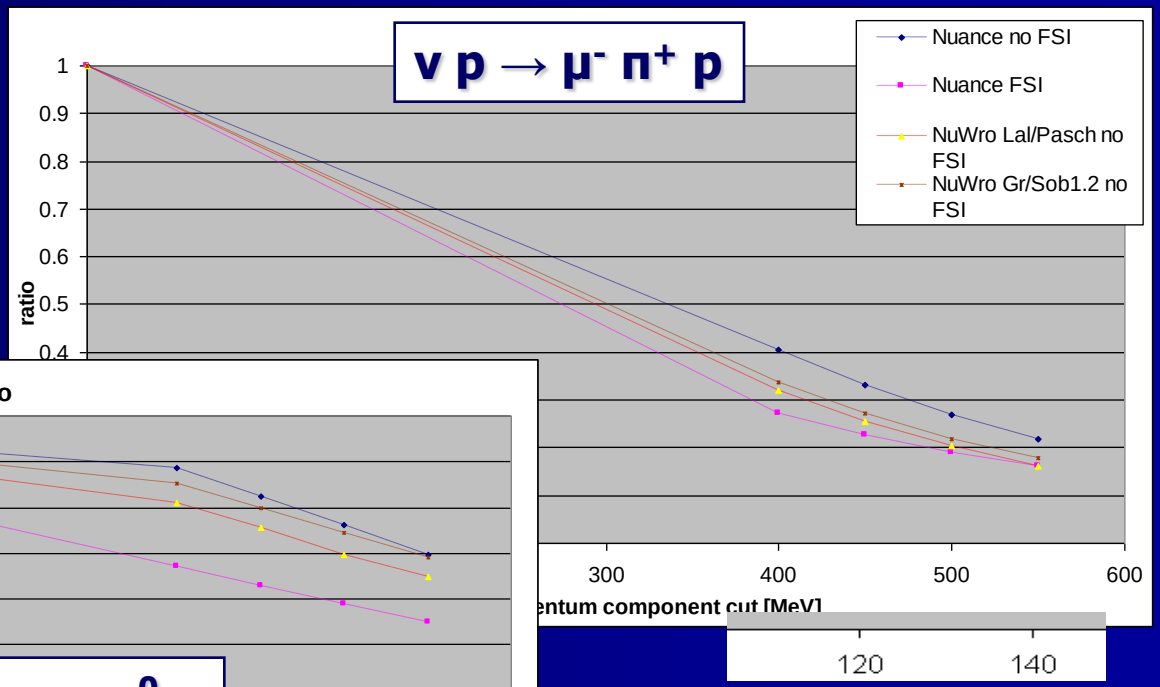


Visibility cut for 6cm of track length (corresponds to 400MeV/c for protons, 110MeV/c for pions) All curves presented on this slide are normalized (to enable shape comparison)

Track visibility study

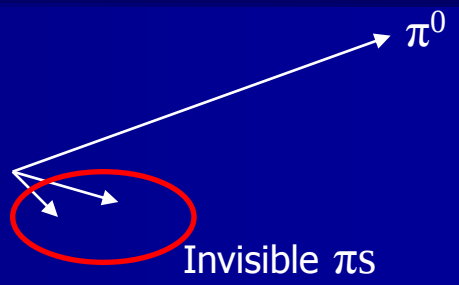
Fraction of measured interactions as a function of track length cut





Multipion background estimation

- When we see a single π^0 it doesn't have to be a single pion event; it can also be **a multipion event** ($\pi^0+n\pi^{+/-}$), with other (charged) pions being sub-threshold in water Čerenkov detector like SK
- Let's estimate **how much we miss** by taking into account only single pion events
- In other words – how many multipion events may look like a single pizero in SK?

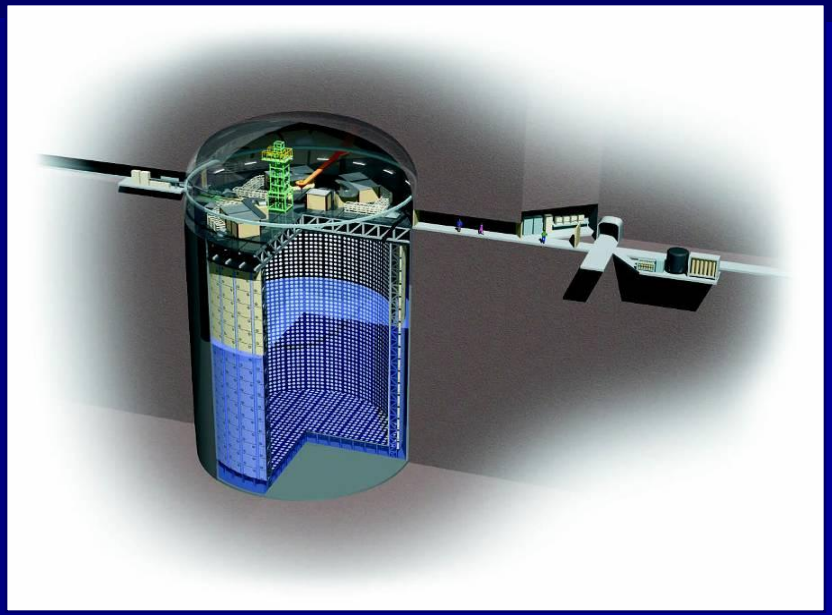


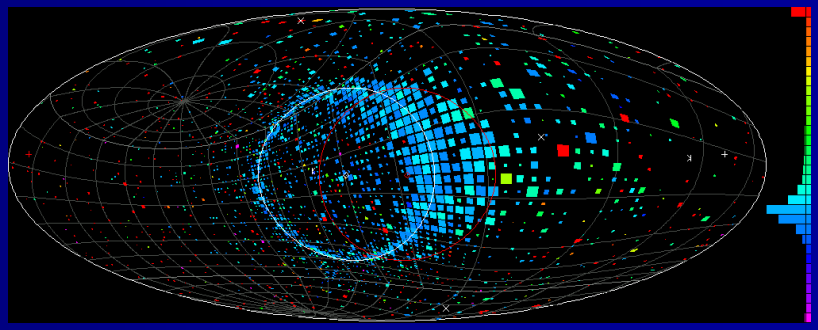
	Nuance Monte Carlo (water, 50,000evts)
NC1pizero total	**26377**
NC1pizero **0 pichrgd**	20841 (79%)
NC1pizero **1 pichrgd**	3218 (12%)
NC1pizero **2 pichrgd**	1723 (7%)

No momentum cuts

Visibility criteria

- With other rings in the vicinity, the realistic energy threshold for charged pions is assumed to be **50MeV over the Cerenkov threshold** (we need a distinguishable ring)
- Pi zero is assumed to be always visible by its decay into two gammas

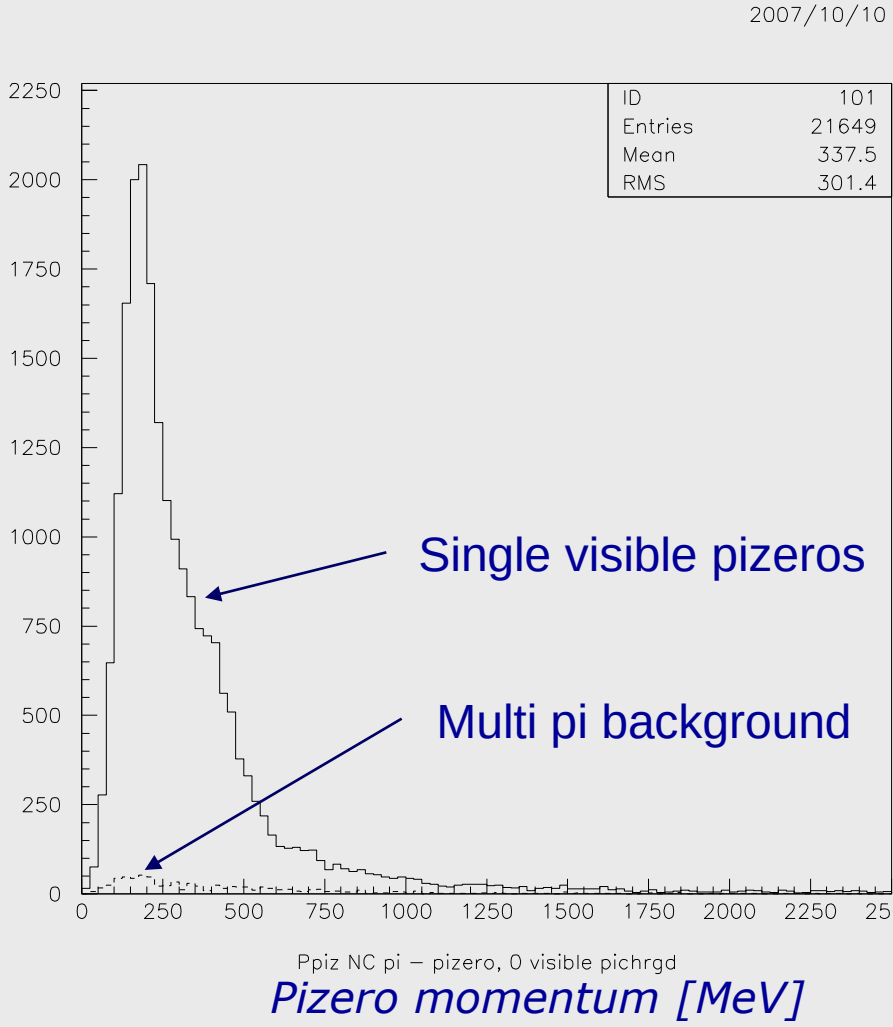




Result

	All events visible as single pizero	Events that fake single pizero (being in fact a multipi)
Nuance sample with visibility cuts	**21649 (100%)**	**808(3.7%)**

- The contribution is small enough that modelling uncertainties are not relevant
- But in the phase of precise measurements even 4% may be significant



Conclusions

- Significant cross section uncertainties in NC π^0 channel (up to ±10%) due to different form factors
  - ->precise measurements neccessary
- Experimental challenges - not all tracks visible
  - ->difficult to measure in low Q^2 region
- Further improvements in theory and new experimental results are neccessary

Backup

New K2K Result: CC π^0

- inclusive CC π^0/QE cross section ratio (paper in preparation)

$$\sigma_{CC\,\pi^0}/\sigma_{QE} = 0.306 \pm 0.023(\text{stat}) \,{}^{+\,0.023}_{-\,0.021}(\text{syst})$$

(10% measurement)

- rare glimpse at multi-π prod
  (not well-measured σ historically)
- ~40% higher than MC prediction
- already telling us something about the inadequacies of our multi-π predictions
  (larger effect for higher E exps)