Upgrade of Honda atmospheric neutrino flux calculation with implementing recent hadron interaction measurements

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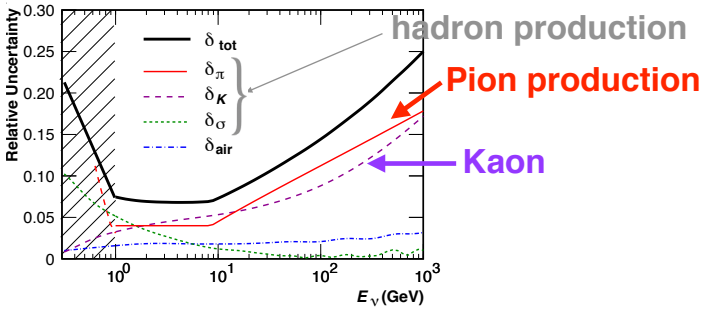
HONDA flux calculation (ATMNC)

ATMospheric **M**uon **N**eutrino **C**alculation code

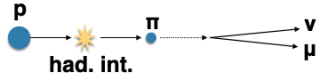
- Developed by M. Honda [1]
- Simulate **air shower**
  - →calculate **atm. ν flux** at a given detector pos.
  - provide full and 3D simulation
  - High speed calculation by *inclusive code*
- Have been used for atm. ν analysis in **Super-Kamiokande**

→ For high precision measurements in the next generation detectors (e.g. Hyper-Kamiokande), **need to reduce uncertainty of ATMNC**

Uncertainty of ATMNC [2]



- dominant uncertainty : **hadronic** process



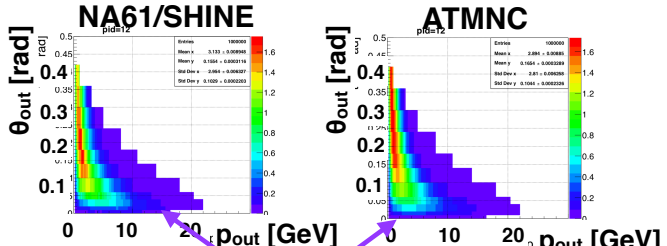
- evaluate & correct using **atm. μ data** [2]
- Low-E μ doesn't reach to ground → >10% uncertainty in E_ν < 1 GeV region
- Kaon also contributes to ν production → uncertainty in E_ν > O(10) GeV region

☞ **incorporate hadron measurements by beam experiments to compensate for μ data**

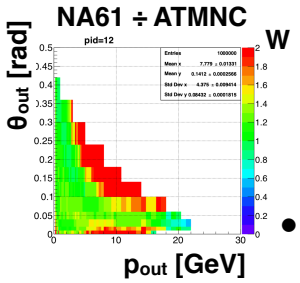
incorporate hadron measurement into ATMNC

- Hadron production measurements
  - Several measurements are conducted/planned
    - mainly for long-baseline ν experiments *NA61/SHINE, BNL-E910, HARP, …*
  - →provide **dσ/dp$_{out}$dθ$_{out}$** of h_{in} + A → h_{out} + X

e.g.) $\frac{1}{\sigma_{prod}}\frac{d\sigma}{dp_{out}d\theta_{out}}$ in p + A → π⁺ + X



- Want to correct *this* difference



apply ***weight*** for each hadron vertex

$$W = \frac{\left(\frac{dn}{dp_{out}d\theta_{out}}\right)_{Data}}{\left(\frac{dn}{dp_{out}d\theta_{out}}\right)_{ATMNC}}$$

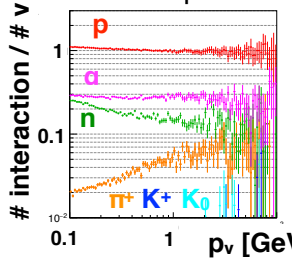
- table of *W* should be prepared for each h_{in}, h_{out}

* This weighting method was used in T2K [3].
→ can discuss correlation of systematic uncertainty between SK-T2K

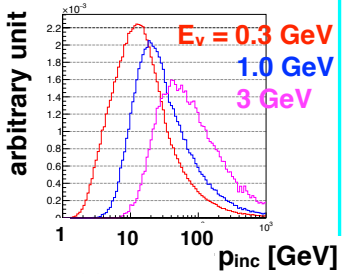
preparing weight tables *(still working…)*

which kind on particle involves in ν production?

type of incident hadron (h_{in}) causing hadron interaction related to ν produciton



momentum of incident proton



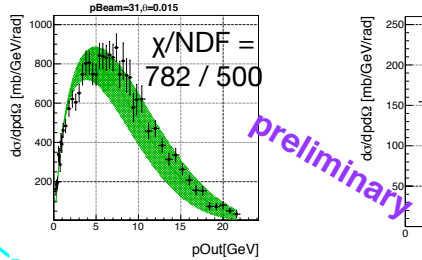
→ had. int. is dominantly caused by **p, n**

available recent data of p+A

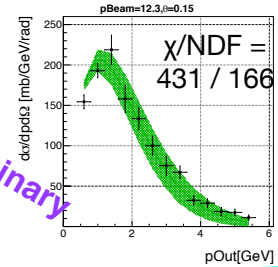
	target	P_{beam} [GeV]	h_{out}	ref.
HARP	Be,C, Al, Pb	3,5,8,12	π⁺,π⁻	[4]
NA61/SHINE	C	31	p,π⁺⁻,K⁺⁻	[5]
BNL E910	Be	6.4,12.3,17.5	π⁺,π⁻	[6]

- trying to parameterize these data
  - to interpolate/extrapolate to different P_{beam}.
  - to compensate rough binning and limited p_{out} and θ_{out} measurement range.
  - searching for good parameterization …

BMPT parameterization NA61 and HARP C data



Sanford-Wang fit NA61 and HARP C data



preliminary

[1] M. Honda et.al., PRD 92, 023004 (2015) and ref.s therein
[2] M. Honda et.al., PRD 75, 043006 (2007)
[3] T2K collaboration, PRD 87, 012001 (2013)
[4] HARP collaboration, PRC 80, 035208 (2009)
[5] NA61/SHINE, Eur. Phy. J. C76 (2016)
[6] E910, PRC 77 015209 (2008)