MINERνA: Past, Present, and Future

Rob Fine

on behalf of the MINERνA Collaboration

13 June 2019

MINERνA has completed data-taking

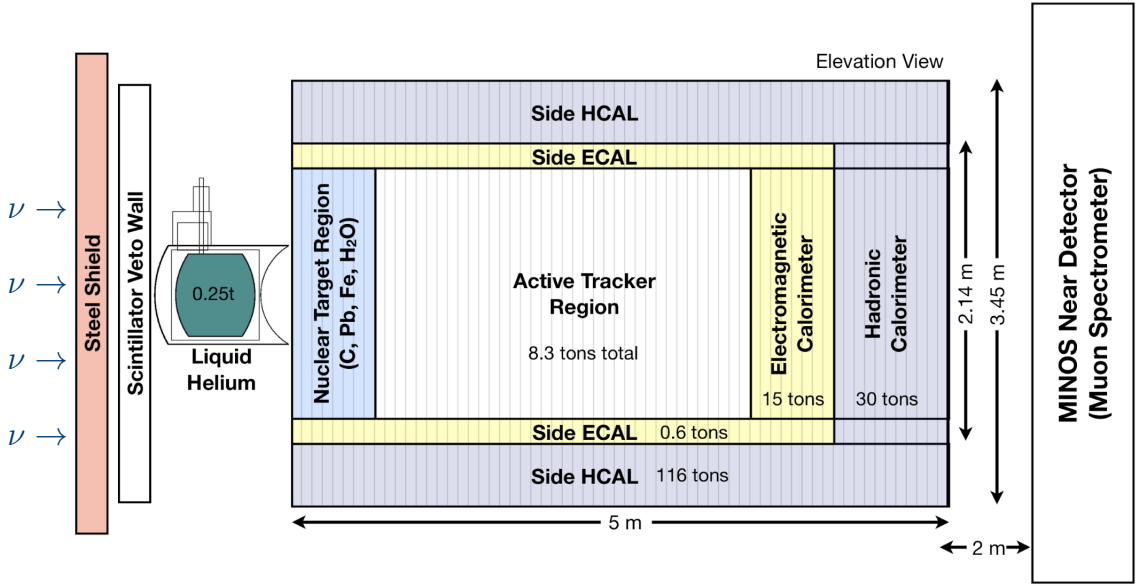
Muon g-2
Last Data Recorded: 26 Feb 2019 07:03:15

Your community, your science. It's about everyone that makes it happen

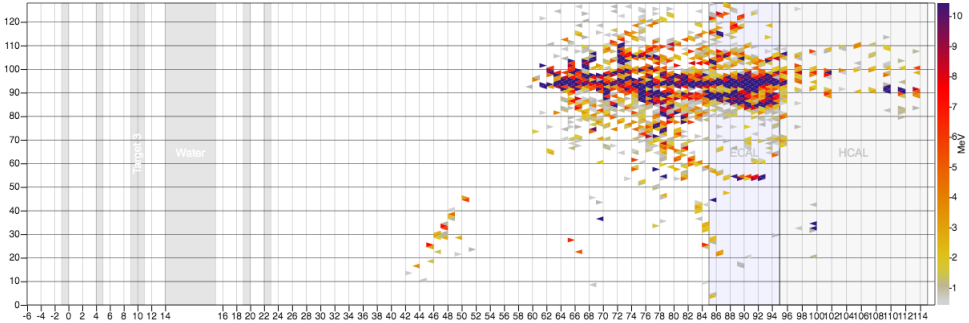
Thank you to everyone who has made MINERνA happen!

Jim Hylen • Sam Childress • Gordon Koizumi • Keith Anderson • Ken Bourkland • Kris Anderson • Lee Hammond • Mike Andrews • Jim Kilmer
Bob DeMaat • Chris France • John Voirin • John Cornele • Tom Olszanowski • Mark Shoun • Andy Lathrop • Kourosh Taheri • Sabina Aponte
Scott Doer • Eileen Hahn • Irina Picschalikova • Galina Teredhkina • Tim Griffin • Chris Richardson • Jeannie Wilson • Wanda Newby • Bill Brown
Dmitri Sidorov • Lyuda Rykalina • Jennifer Gimmell • Anna Pla • Karen Kephart • Virgil Bocean • Jaimie Grado • Joe Morgan • Mike Diesburg
Hugh Montgomery • Ed Temple • Dean Hoffer • Lee Lueking • Peter Wilson • Mike Lindgren • Crae Tate • TJ Sarlina • Cindy Joe • Ken Domann
Ellie Arroyo • Jenny Teng • Suzanne Saxer • Dale Knapp • Rick Ford • Rob Bushek • Amber Larson • Heng Bao • Kevin Retzke • Dan Ruggiero
Janina Gieltana • Victor Martinez Chivas • Joe Collins • Walt Jaskierny • Steve Hahn • Joe Boyd • Bonnie King • Bill Badgett • Paul Rubinov
Christian Gingu • Geoff Savage • Phil Schlabach • Martin Murphy • Mandy Rominsky • Aria Soha • Michael Backfish • Dan Johnson • Pam Lee
Cons Gattuso • Patti Hedrick • Mary Simmons • Mary Robbins • Dwane Newhart • Cindy Kane • Dee Hahn • Julie Saviano • Susan Braddy-Suhr
Art Kreymer • Marc Mengel • Ken Herner • Michael Kirby • Tanya Levshina • Margherita Vittone Wiersma • Olga Vlasova • Svetlana Lebedeva
Donatella Torretta • Mitchell Renfer • Margaret Votava • Anna Mazzacane • Vito Di Benedetto • Jeny Teheran • Robert Illingworth • Andrew Norman
and many others...

Technical Overview

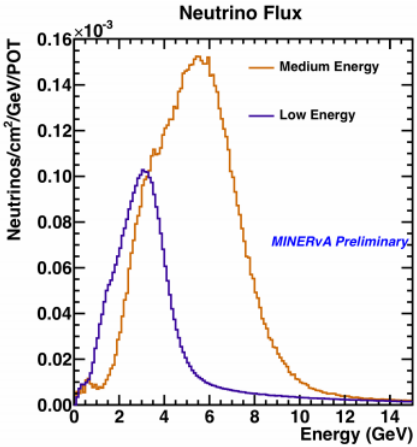


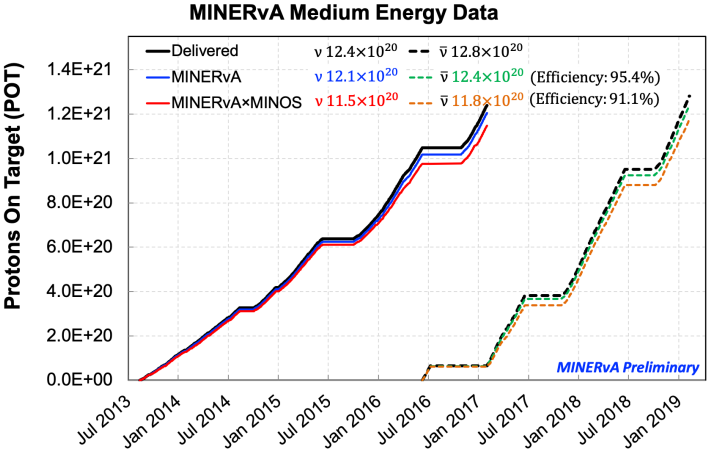
Thank you MINOS(+) Collaboration!



Last DIS Candidate Event (26 February 2019)

- LE ν POT: 4.0e20
- LE $\bar{\nu}$ POT: 1.7e20
- ME ν POT: 12.1e20
- ME $\bar{\nu}$ POT: 12.4e20

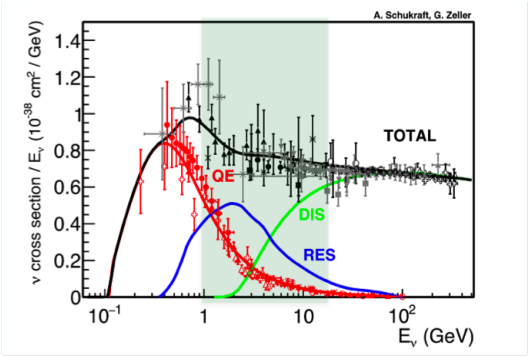


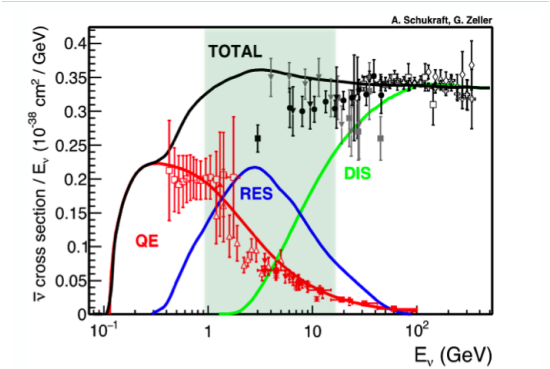


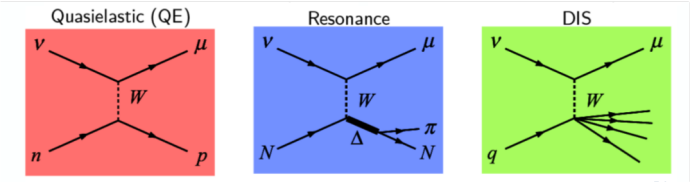
Thank you to the Fermilab Accelerator and Computing Divisions!

MINERνA Strives to Understand Nuclear Effects

Interaction Channels

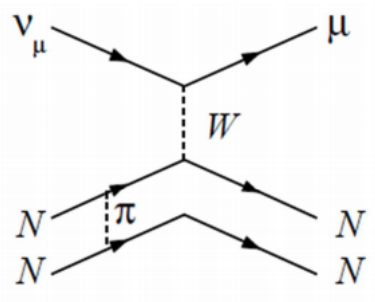


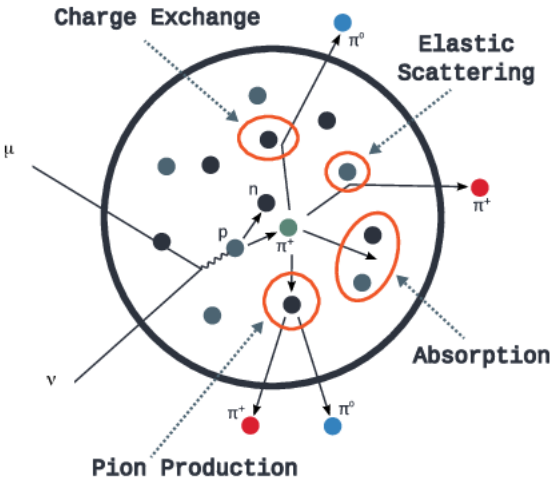




Plots courtesy of A. Schukraft, G. Zeller

Nuclear Effects





- MINERνA helps improve the models in our generators

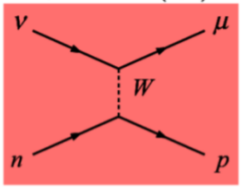
Illustration courtesy of T. Golan

MINERνA Strives to Understand Nuclear Effects Using the Low Energy Data Set

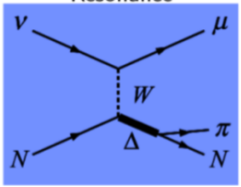
26 (+5)

Minerva LE Publications

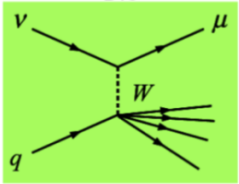
Quasielastic (QE)

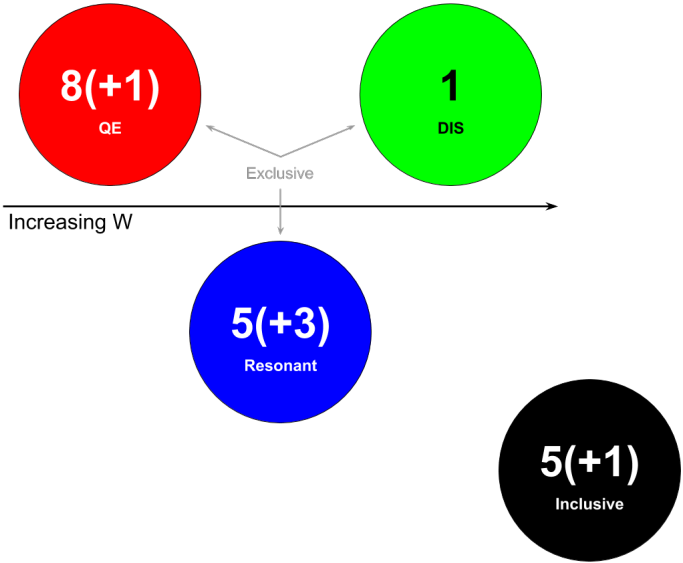


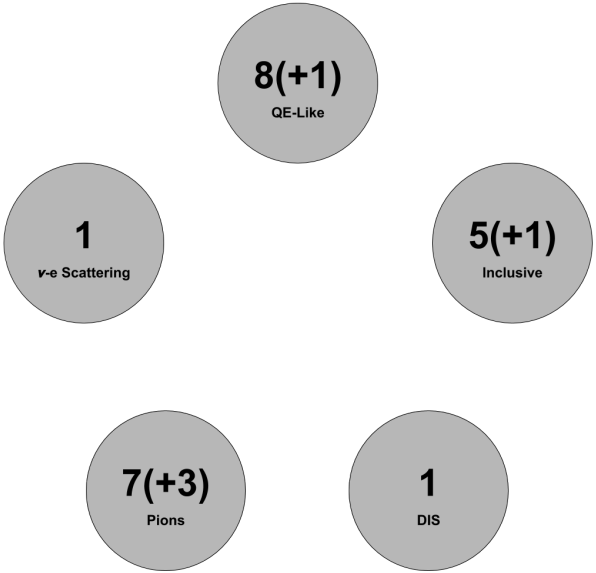
Resonance

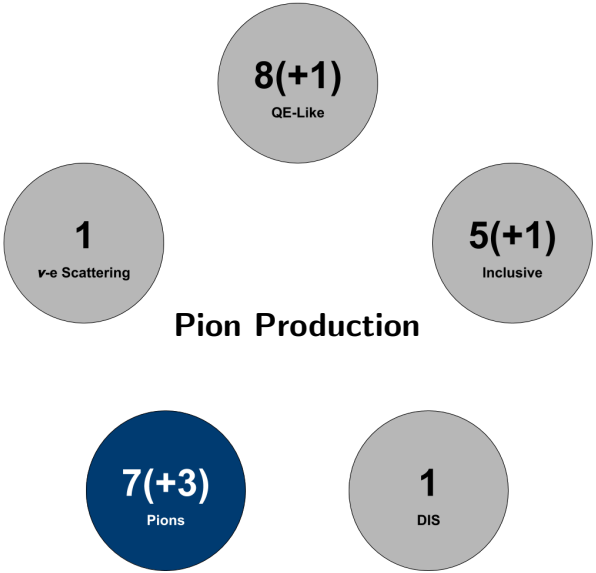


DIS

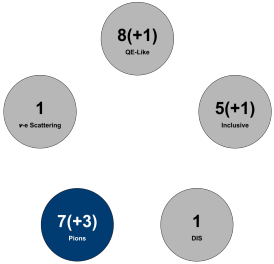


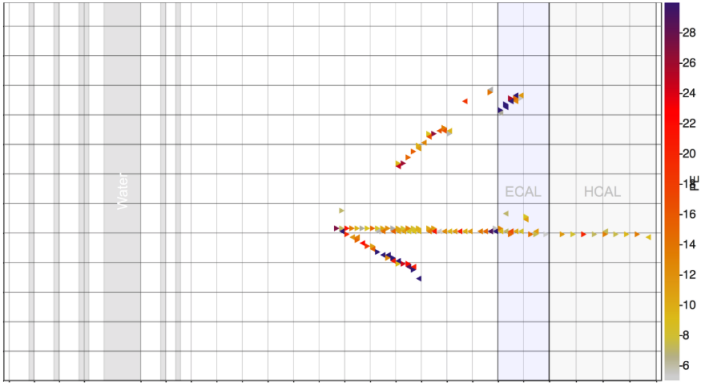



8(+1)
QE-Like
5(+1)
Inclusive
1
DIS
7(+3)
Pions
1
ν-e Scattering

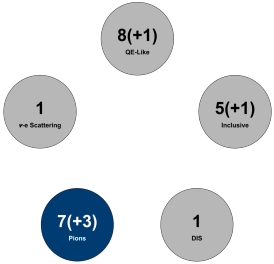

8(+1)
QE-Like
1
ν-e Scattering
5(+1)
Inclusive
Pion Production
7(+3)
Pions
1
DIS

Single π Production

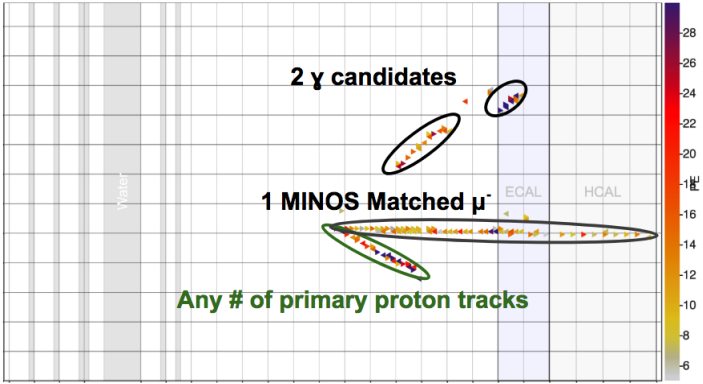




$$\nu_\mu + CH \rightarrow \mu^- + 1\pi^0 + X(\text{nucleons})$$

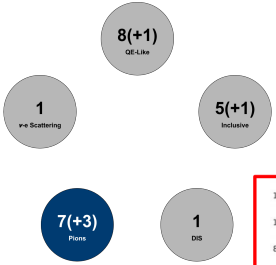


Single π Production



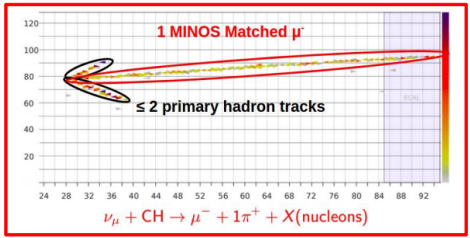
$$\nu_\mu + CH \rightarrow \mu^- + 1\pi^0 + X(\text{nucleons})$$

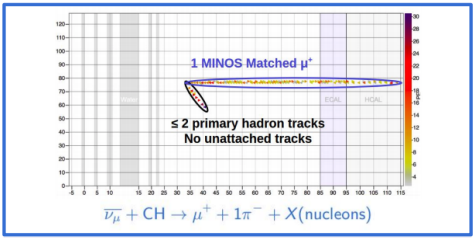
Single π Production



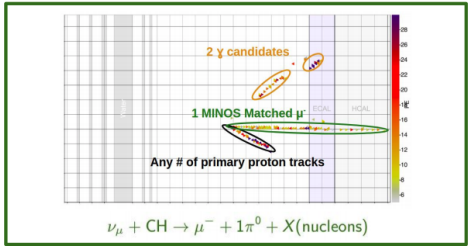
ν $\bar{\nu}$

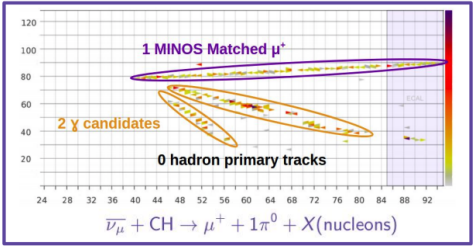
$\pi^{\pm}$

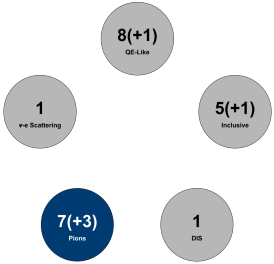




π^0





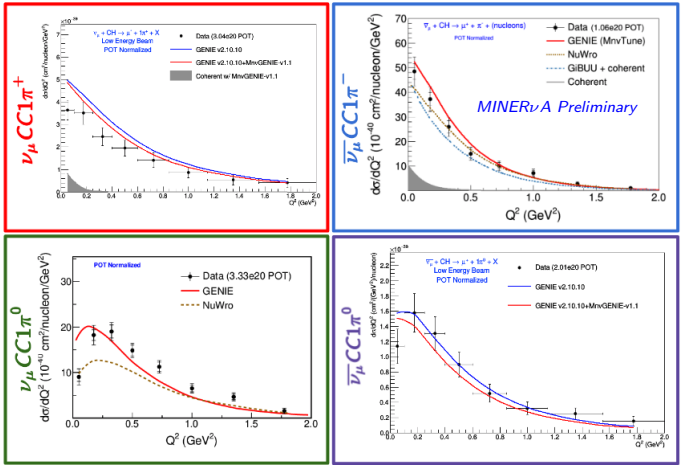


Single π Production

ν $\bar{\nu}$

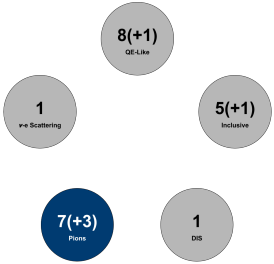
$\pi^{\pm}$

π^{0}

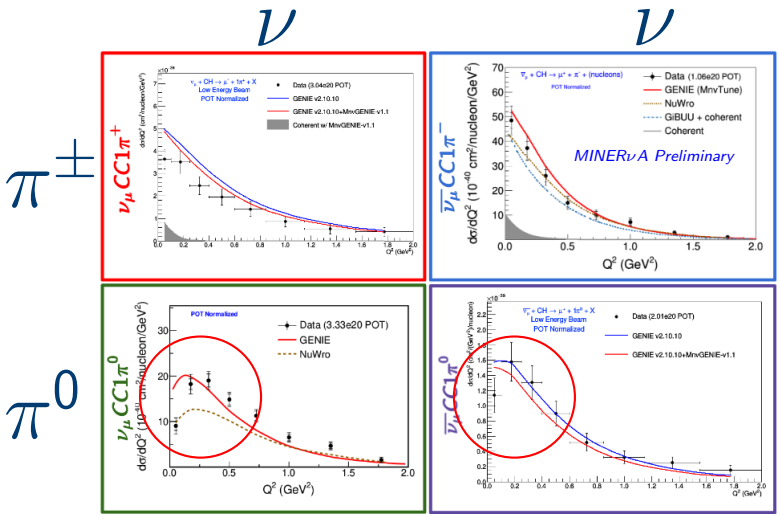


- $Q^2 = 2E_\nu(E_\mu - p_\mu cos(\theta_{\mu\nu})) - m_\mu^2$

$\nu\pi^+, \bar{\nu}\pi^0$: *Phys. Rev. D* 94, 052005 (2016), $\nu\pi^0$: *Phys. Rev. D* 96, 072003 (2017)

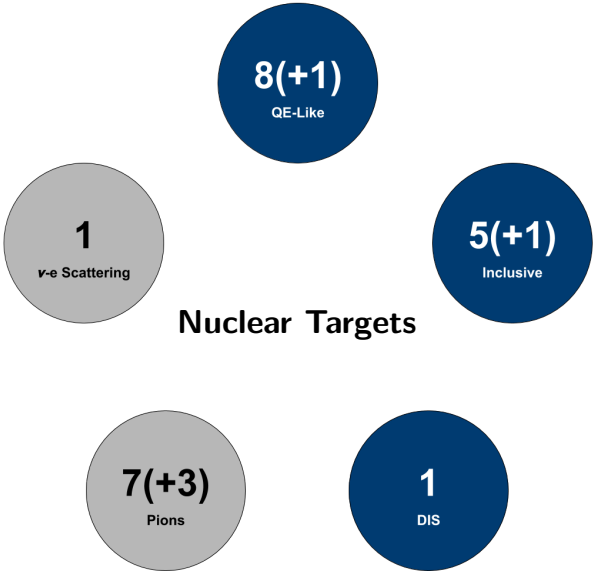


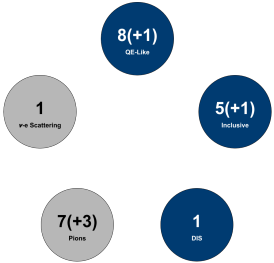
Single π Production



- $Q^2 = 2E_\nu(E_\mu - p_\mu cos(\theta_{\mu\nu})) - m_\mu^2$

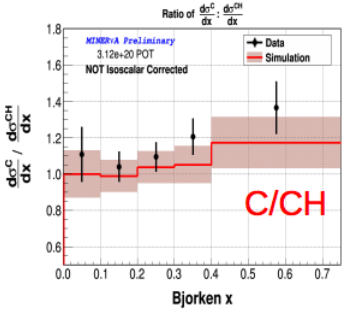
$\nu\pi^+$, $\bar{\nu}\pi^0$: *Phys. Rev. D* 94, 052005 (2016), $\nu\pi^0$: *Phys. Rev. D* 96, 072003 (2017)

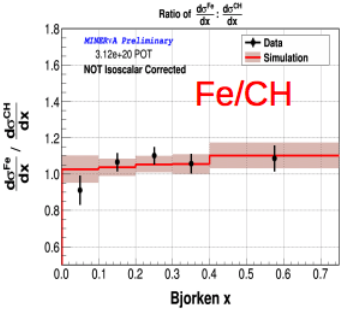

8(+1)
QE-Like
1
ν-e Scattering
5(+1)
Inclusive
Nuclear Targets
7(+3)
Pions
1
DIS

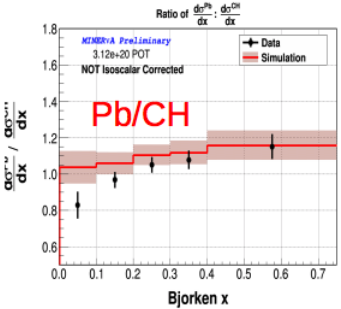


Analysis in the Nuclear Targets

- Inclusive, DIS, and QE cross sections measured on C, Fe, and Pb
- 'Bjorken x' is the fraction of the proton momentum carried by the struck quark

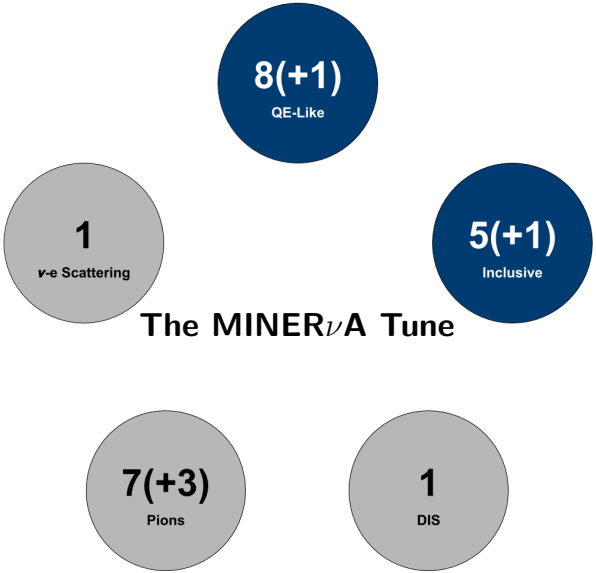


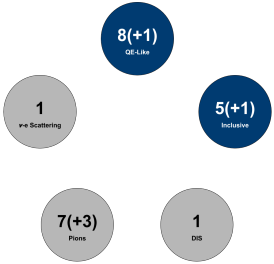




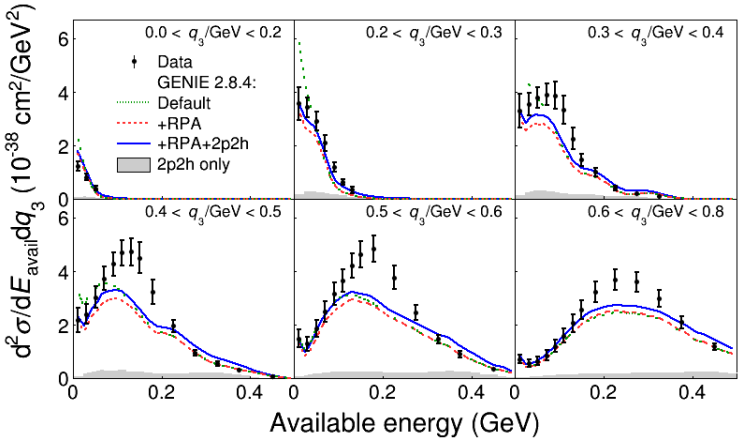
DIS ratios

Phys. Rev. D 93, 071101 (2016)


8(+1)
QE-Like
1
ν-e Scattering
5(+1)
Inclusive
The MINERνA Tune
7(+3)
Pions
1
DIS



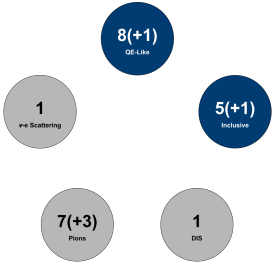
The MINERνA Tune



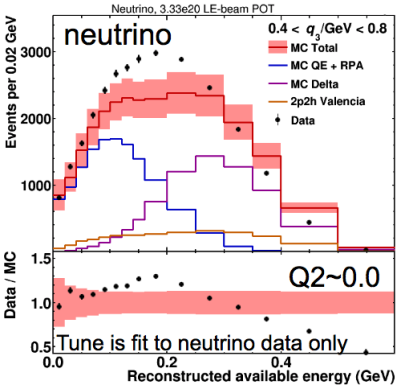
- Our data prefer even more strength than we initially thought

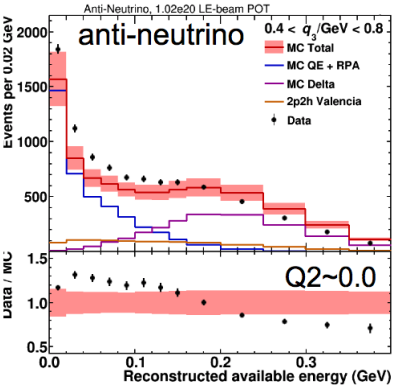
Phys. Rev. Lett. 116, 071802 (2016)

The MINERνA Tune



$\nu / \bar{\nu}$

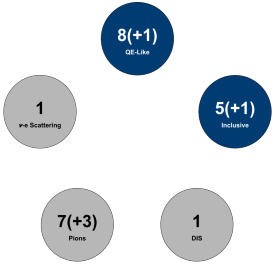




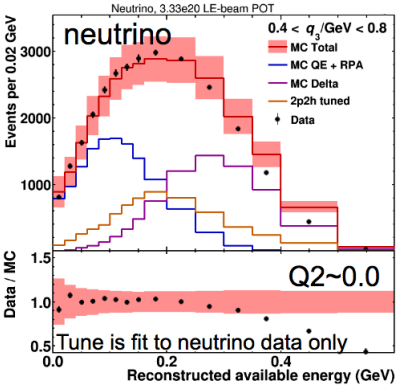
- We perform an empirical fit to scale up the 2p2h contribution
- The fit is performed using neutrino data, then applied in anti-neutrino analyses

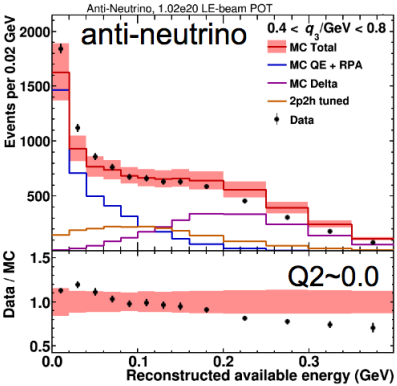
Phys. Rev. Lett. 120, 221805 (2018)

The MINERνA Tune



$\nu / \bar{\nu}$

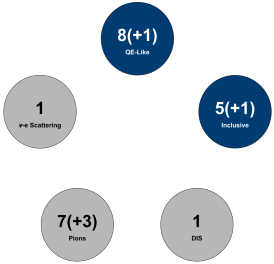




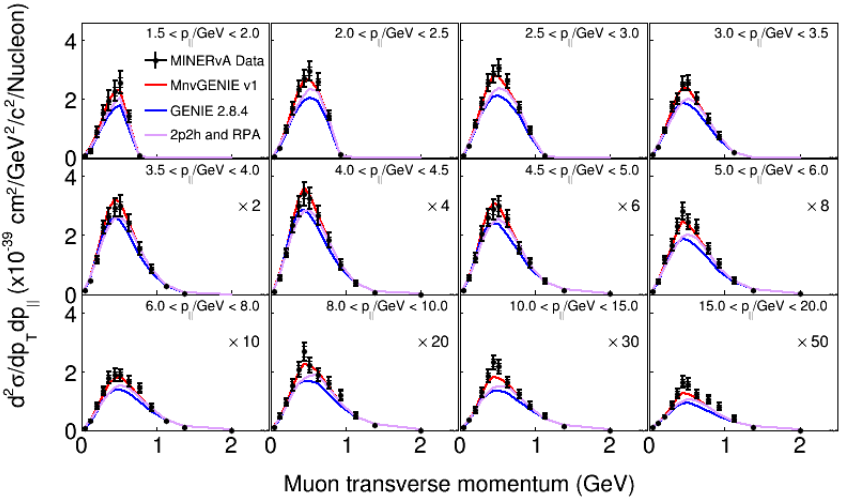
- We perform an empirical fit to scale up the 2p2h contribution
- The fit is performed using neutrino data, then applied in antineutrino analyses

Phys. Rev. Lett. 120, 221805 (2018)

The MINERνA Tune

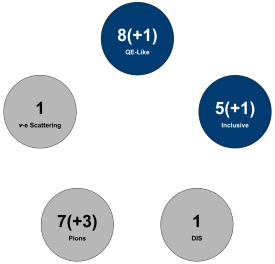


ν



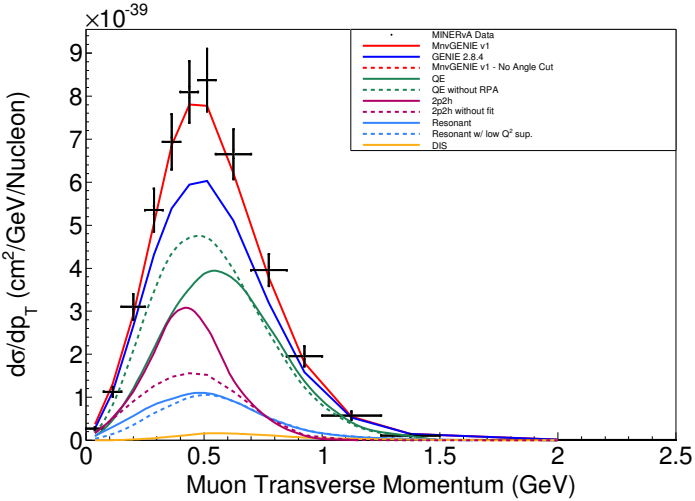
- The tune improves agreement between data and MC in exclusive ν channels

Phys. Rev. D 99, 012004 (2019)



ν

The MINERνA Tune



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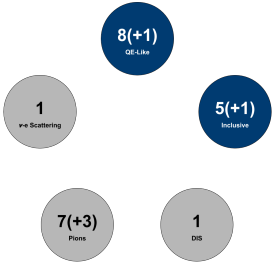
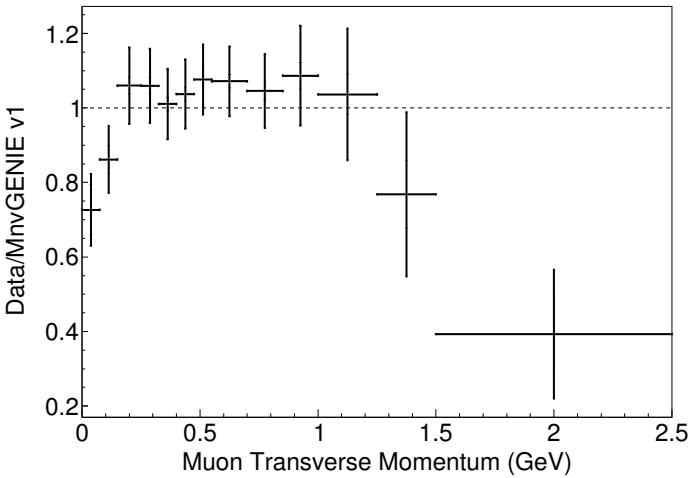
Phys. Rev. D 99, 012004 (2019)



The MINERνA Tune



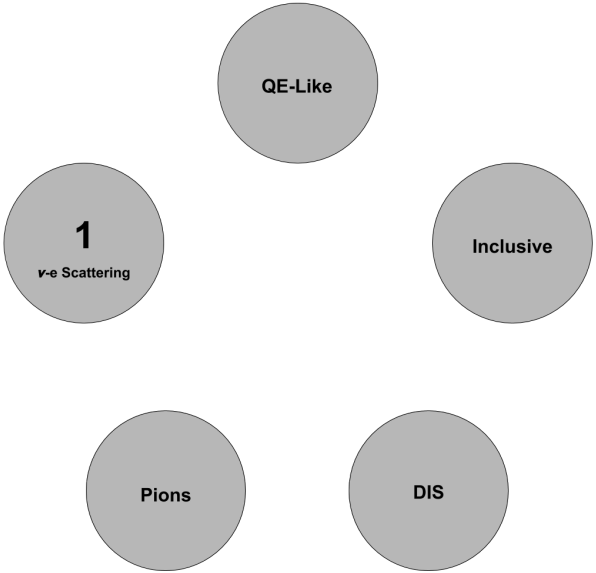
- But there is still work to be done!

Phys. Rev. D 99, 012004 (2019)

MINERνA Strives to Understand Nuclear Effects Using the Medium Energy Data Set

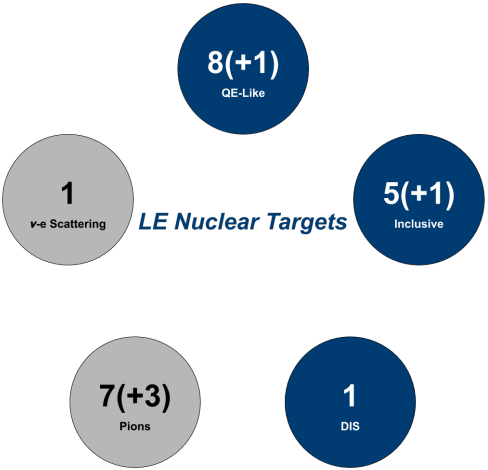
1 (+??)

Minerva ME Results

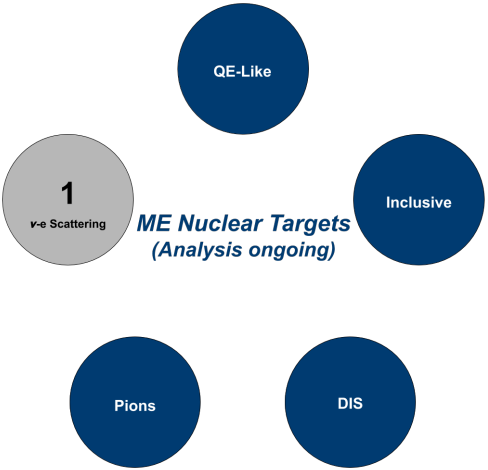

QE-Like
1
ν-e Scattering
Inclusive
Pions
DIS

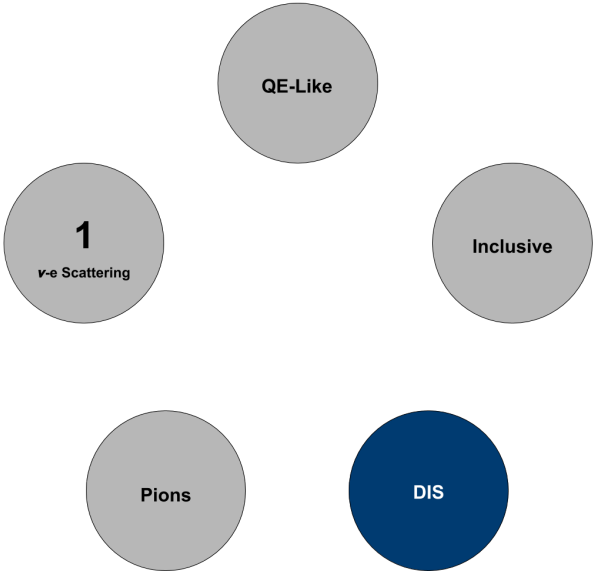
QE-Like
1
ν-e Scattering
Analysis
Ongoing
Inclusive
Pions
DIS

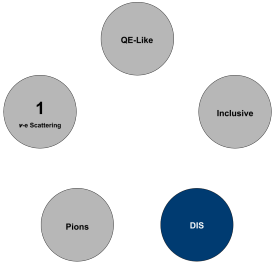
8(+1)
QE-Like
1
ν-e Scattering
LE Antineutrino
5(+1)
Inclusive
7(+3)
Pions
1
DIS


8(+1)
QE-Like
1
ν-e Scattering
LE Nuclear Targets
5(+1)
Inclusive
7(+3)
Pions
1
DIS

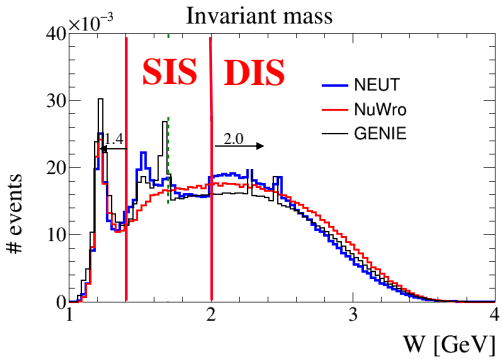
QE-Like
1
ν-e Scattering
ME Antineutrino
(Analysis ongoing)
Inclusive
Pions
DIS


QE-Like
1
ν-e Scattering
ME Nuclear Targets
(Analysis ongoing)
Inclusive
Pions
DIS


QE-Like
1
ν-e Scattering
Inclusive
Pions
DIS

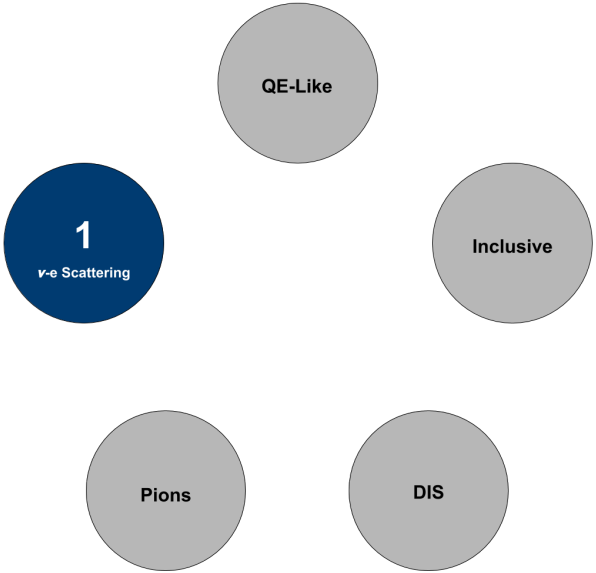


Higher-W Inelastic Scattering



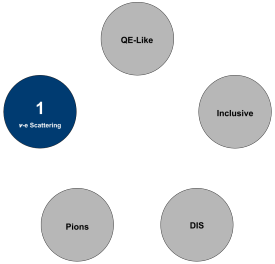
- ME provides access to higher-W ($W > m_\Delta$) scattering regime, enabling:
  - Measurement of inclusive, DIS cross section ratios
  - Measurement of 1π and $N\pi$ production in SIS region (in nuclear targets)
  - Study of duality and non-perturbative QCD effects in SIS/DIS transition region

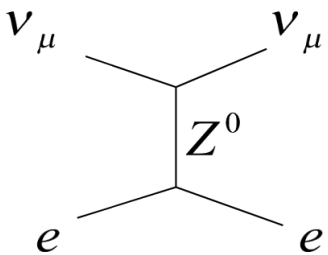
Plot courtesy of C. Bronner

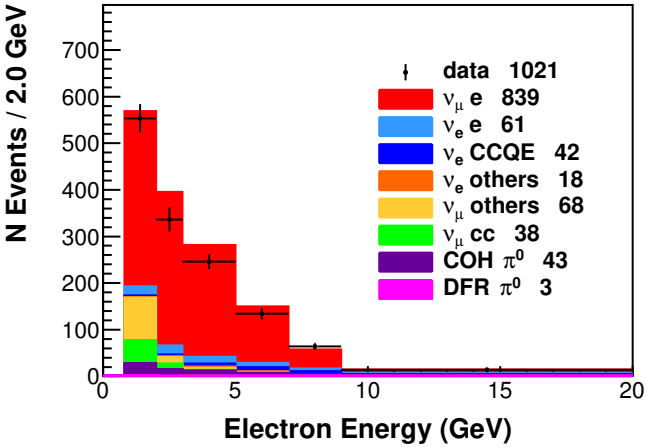

QE-Like
1
ν-e Scattering
Inclusive
Pions
DIS

$\nu - e$ Scattering

Brand New!

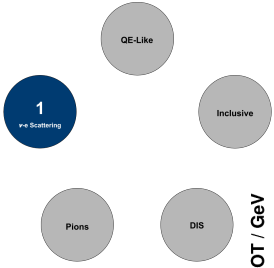






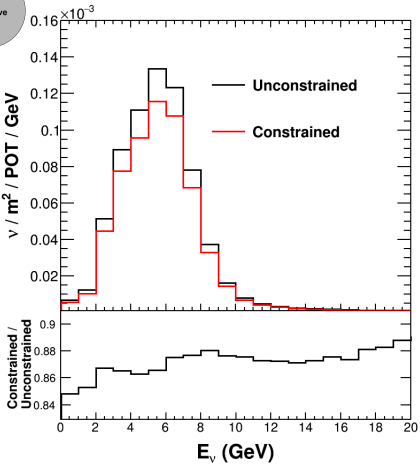
- Standard candle process; cross section calculable to high precision
- >800(!) events after background subtraction

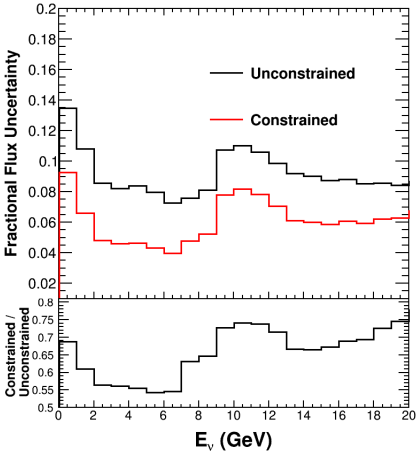
arXiv:1906.00111



$\nu - e$ Scattering

Brand New!



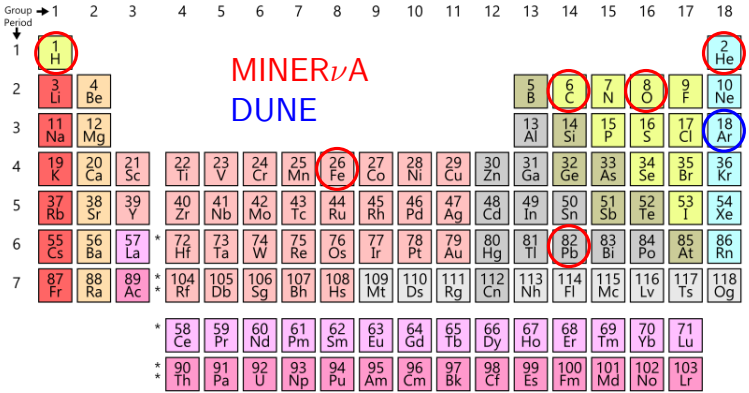


- Normalization uncertainty on NuMI ν_μ flux integrated between 2 and 20 GeV reduced from 7.5% to 3.9%

arXiv:1906.00111

MINERνA Data Preservation

MINERνA in the DUNE Era



- We are undertaking a data preservation effort to ensure that our data remains available into the DUNE era
- The goal is to enable future analysis of MINERνA data broadly within the neutrino community

Illustration courtesy of Wikipedia

MINERνA has completed data-taking, but we're not done!

We'll continue to improve our understanding of neutrino interactions

Look forward to many results from us in the future

THANK YOU