Measurements and Model Validations of Inclusive ν_μCC Events with the Wire-Cell Reconstruction at MicroBooNE

Wenqiang Gu
BNL
on behalf of the MicroBooNE

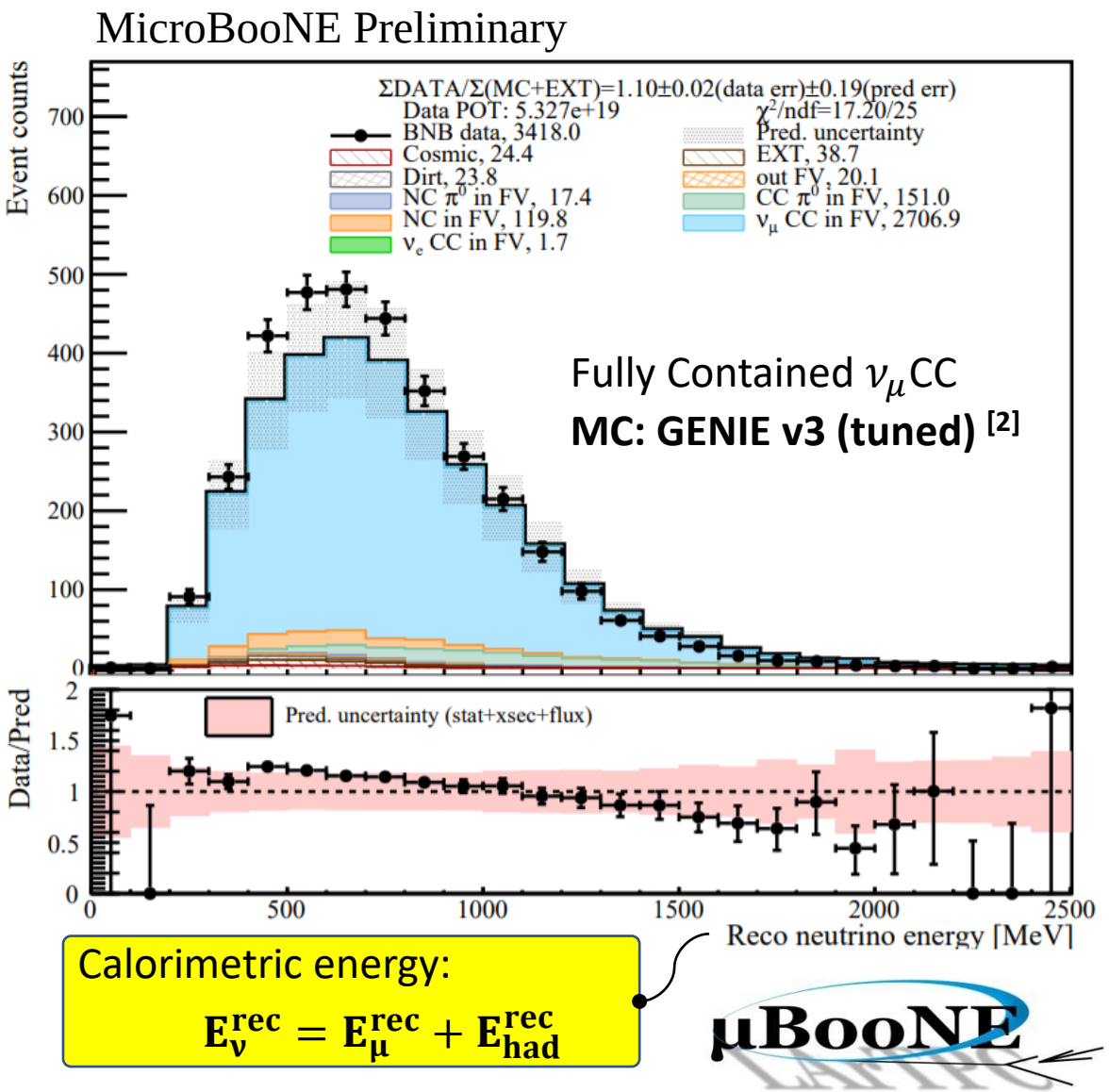
BROOKHAVEN NATIONAL LABORATORY

μBooNE

Event Selection of Inclusive Charged-Current ν_μ Interactions

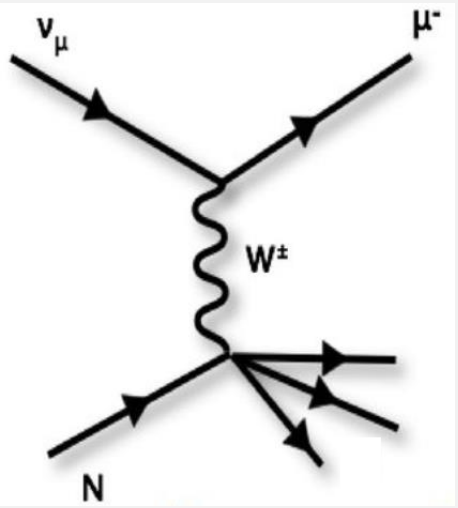
	Efficiency	Purity	Cosmic-μ rejection
Trigger	1	5e-5	1
Generic-ν detection	80%	65%	7e-6
ν_μCC **(Fully & Partially Contained)**	**64%**	**93%**	7e-7

- Achieved excellent cosmic-μ rejection
  - Wire-Cell[1] reconstruction: arXiv:2101.05076
  - Generic-ν detection: arXiv:2012.07928, arXiv:2011.01375
- The **high-statistics** event selection allows for high-precision multi-dimensional cross-section measurements
  - MICROBOONE-NOTE-1095-PUB



Validation of Neutrino Energy Modeling: $\mathbf{E_\nu}$ to $\mathbf{E_\nu^{rec}}$

- **Neutrino energy modeling is crucial to neutrino oscillation measurements**
  - Search for $\boldsymbol{\nu_e}$ low-energy excess at BNB @ *H. Wei, Feb 23rd*
- Key challenge: understanding $\boldsymbol{\nu}$**-Ar** cross section as a function of energy
  - **NuPRISM**: use a series of off-axis measurements to constrain cross-section modeling
- **A new idea based on the calorimetric energy reconstruction: validation of $\mathbf{E_{had}^{rec}}$ after applying constraints of the muon kinematics distribution**
  - Common systematics (e.g., flux) are cancelled, providing a more stringent validation of cross-section modeling



$\mathbf{E_\mu^{rec}} \Rightarrow \boldsymbol{X}$

$\mathbf{E_{had}^{rec}} \Rightarrow \boldsymbol{Y}$

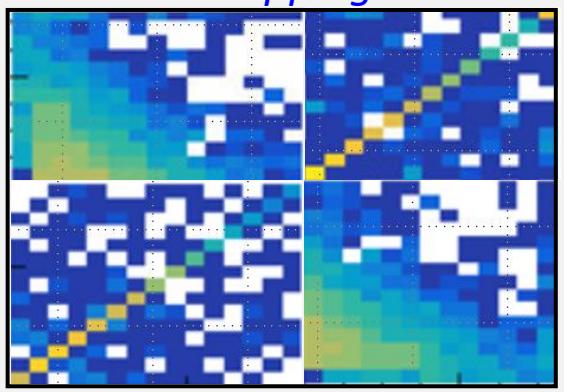
Conditional Covariance [3]

$$\boldsymbol{\mu}_{X,Y} = \begin{pmatrix} \boldsymbol{\mu}_X \\ \boldsymbol{\mu}_Y \end{pmatrix}, \qquad \boldsymbol{\Sigma}_{X,Y} = \begin{pmatrix} \boldsymbol{\Sigma}_{XX} & \boldsymbol{\Sigma}_{XY} \\ \boldsymbol{\Sigma}_{YX} & \boldsymbol{\Sigma}_{YY} \end{pmatrix}$$

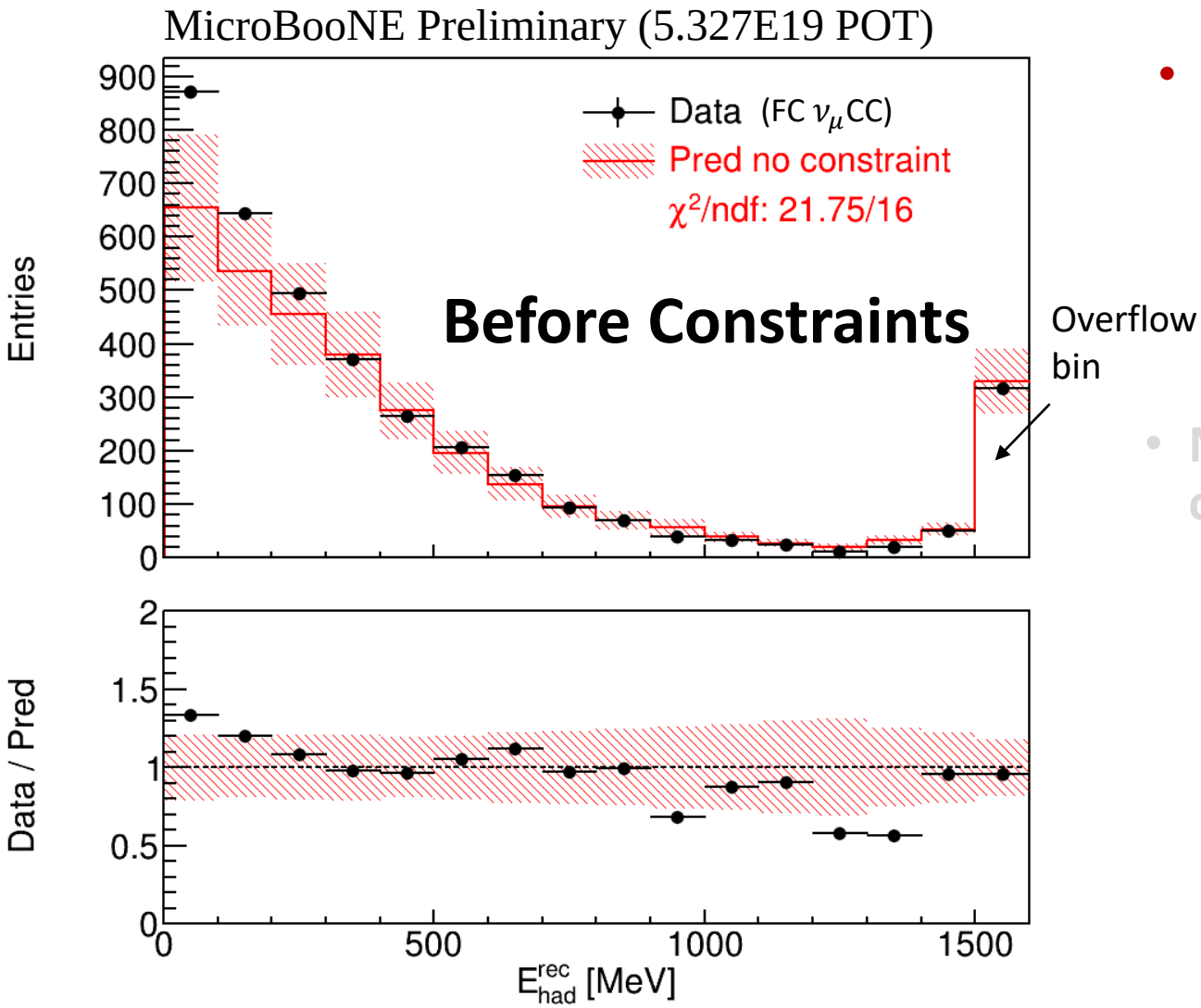
$$\mu_{Y|X} = \mu_Y + \Sigma_{YX}\Sigma_{XX}^{-1}(X - \mu_X)$$

$$\boldsymbol{\Sigma_{Y|X} = \Sigma_{YY} - \Sigma_{YX}\Sigma_{XX}^{-1}\Sigma_{XY}}$$ (reduce uncer.)

Correlated statistical uncertainty with bootstrapping method



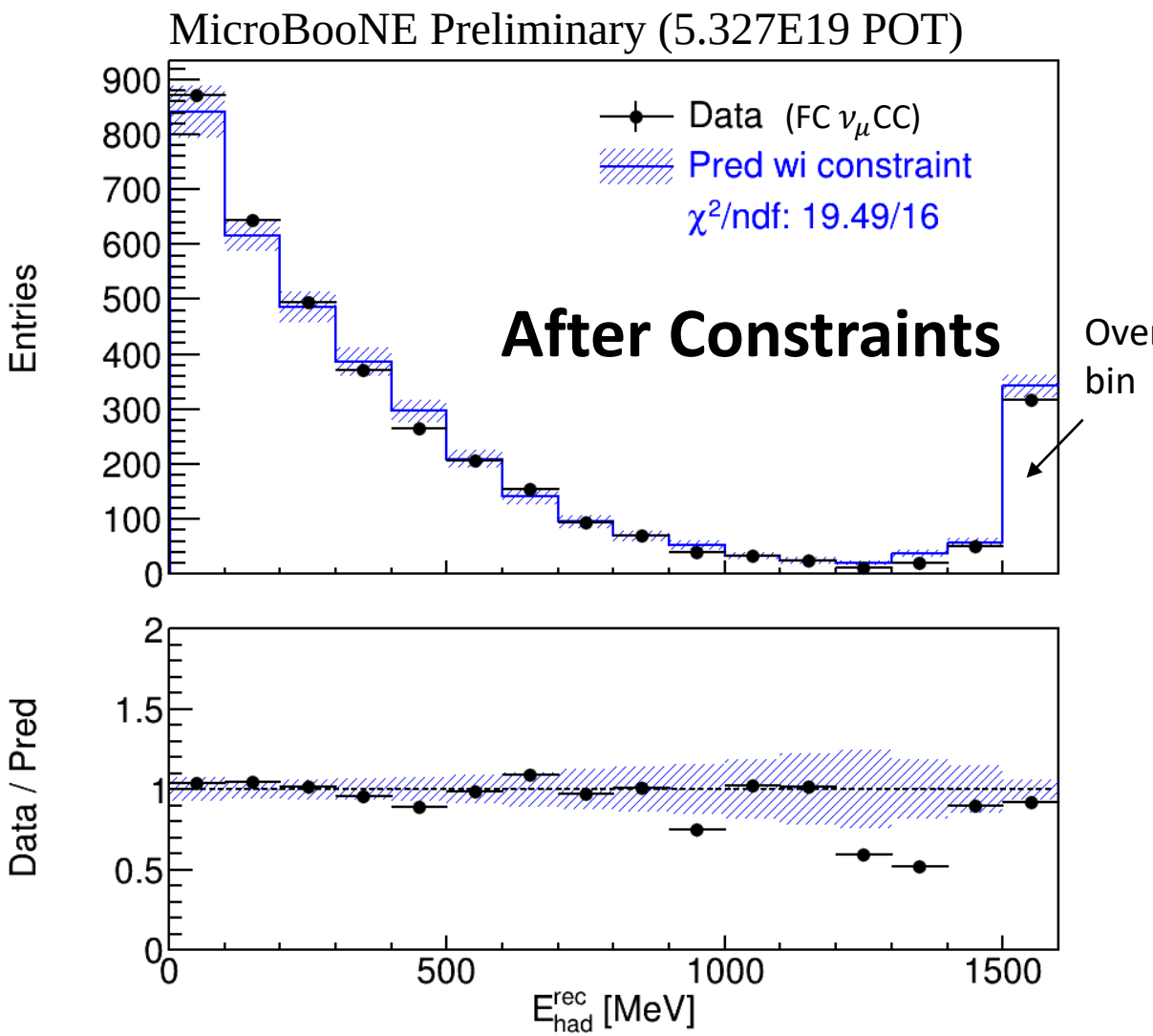
Model Constraint with Conditional Covariance



- **Excess observed at low hadronic energy**
  - Mis-modeling of missing energy in the hadron final states?

- **No more excess at low hadronic energy after constraints with E_μ^{rec}, $\cos\theta_\mu^{rec}$**
  - Significant reduction in overall systematic uncertainties (20% → 5%)
  - No sign of mis-modeling of the **hadron missing energy**

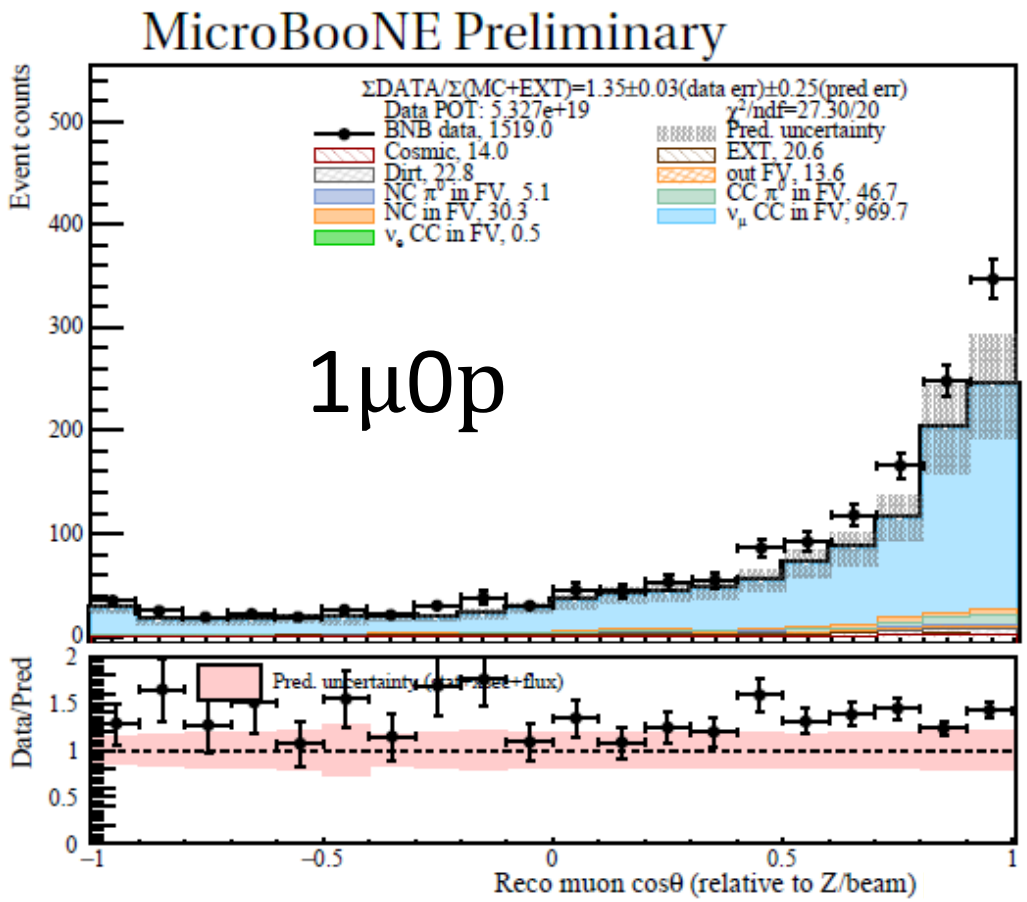
Model Constraint with Conditional Covariance



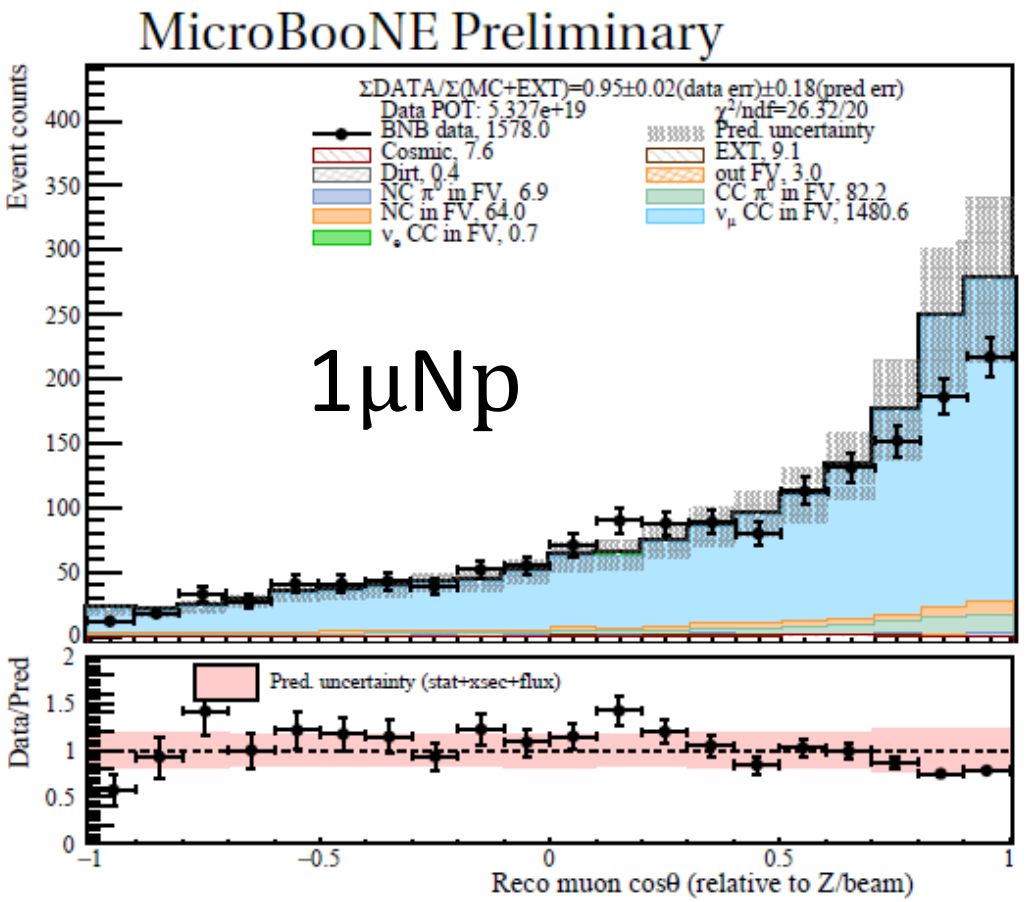
- **Excess observed at low hadronic energy**
  - Mis-modeling of missing energy in the hadron final states?

- **No more excess at low hadronic energy after constraints with E_μ^{rec}, $\cos\theta_\mu^{rec}$**
  - Significant reduction in overall systematic uncertainties (20% → 5%)
  - No sign of mis-modeling of the **hadron missing energy**

Model Comparison in High Dimension



Overall excess



Deficit at muon forward angle

- High-statistics ν_μCC allows for multi-dimensional cross-section measurements

Summary

- A high-performance inclusive ν_μCC selection (**93% purity, 64% efficiency**) has been achieved using Wire-Cell reconstruction at MicroBooNE

- New technique with conditional covariance matrix allows for more stringent validations of the **cross-section modeling** and **neutrino energy reconstruction** for (oscillation and cross section) measurements
  - Examination of hadronic energy distribution after constraining muon kinematics explains the observed low-hadronic-energy excess

- High-statistics ν_μ CC event selection (**≈225k expected for 1.2E21 POT**) for multi-dimensional differential cross-section measurements
  - Stay tuned for the nominal flux-averaged cross section (Wiener-SVD unfolding arXiv:1705.03568)

References

[1]: Wire-Cell Software Package for LArTPC: https://lar.bnl.gov/wire-cell/

[2]: Neutrino Interaction Model and Uncertainties for MicroBooNE Analyses. MICROBOONE-NOTE-1074-PUB

[3]: Eaton, Morris L. (1983). Multivariate Statistics: a Vector Space Approach. John Wiley and Sons. pp. 116–117. ISBN 0-471-02776-6