



A Study of Quark Energy Loss at the Fermilab E906/SeaQuest Experiment

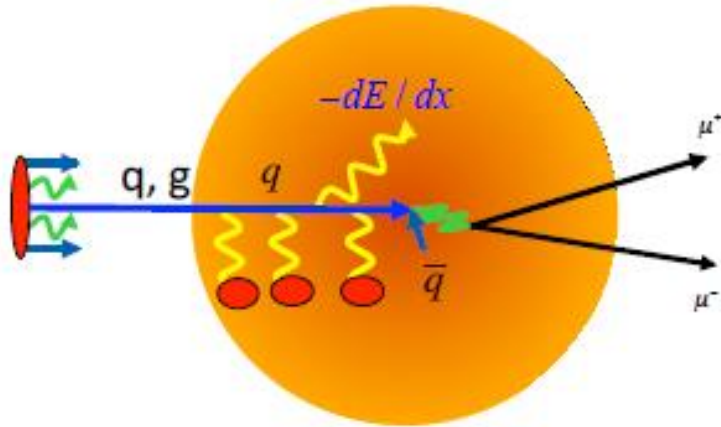
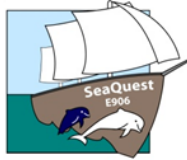
Po-Ju Lin

University of Colorado

25th DIS, Birmingham UK

April 04, 2017

Quark Energy Loss

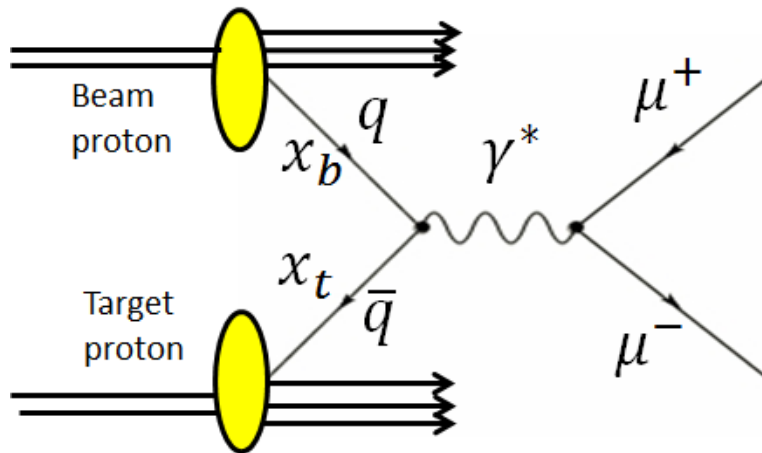
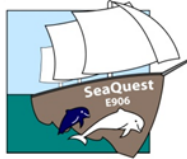


- Quark moves through nuclear matter and loses energy via different processes.
- Fundamental process within QCD, directly connected to nuclear property.

- Measurement in cold nuclear matter provides baseline for elucidating data of heavy-ion collisions.
- Help to investigate nuclear dependence of J/ψ , Ψ' production
- **Can be ideally investigated with the Drell-Yan Process.**



The Drell-Yan Process



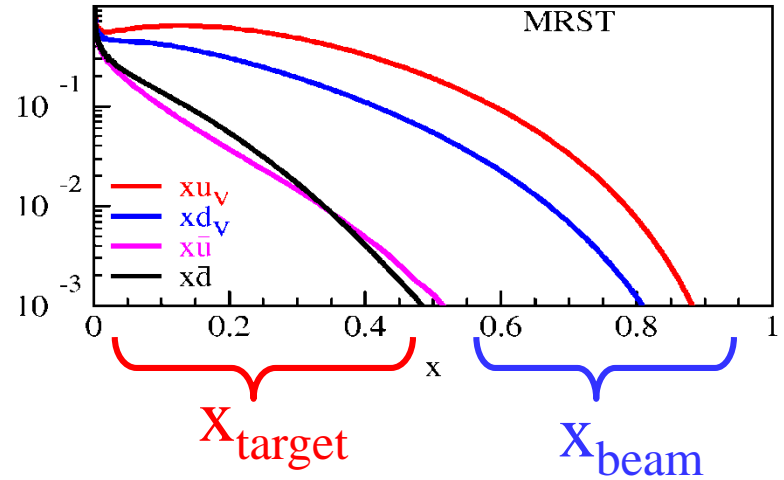
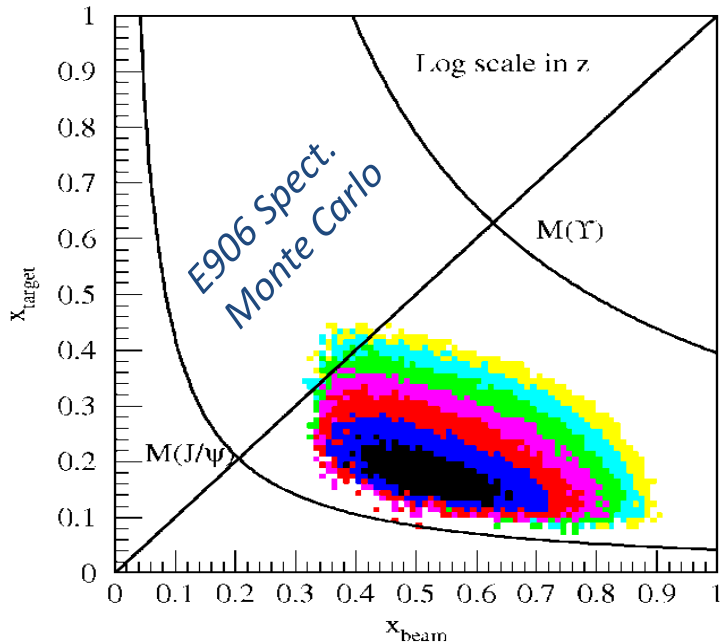
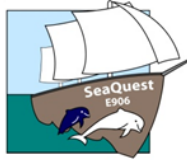
Massive Di-lepton pairs from Hadron-Hadron Collisions firstly proposed by S. D. Drell and T. M. Yan at 1970

$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9x_b x_t} \frac{1}{s} \sum_q e_q^2 [\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)]$$

- $q_t(x_t), \bar{q}_t(x_t)$: target quark, anti-quark PDF
- $q_b(x_b), \bar{q}_b(x_b)$: beam quark, anti-quark PDF



The Drell-Yan Process



$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9x_b x_t} \frac{1}{s} \sum_q e_q^2 [\bar{q}_t(x_t)q_b(x_b) + \cancel{q_t(x_t)\bar{q}_b(x_b)}]$$

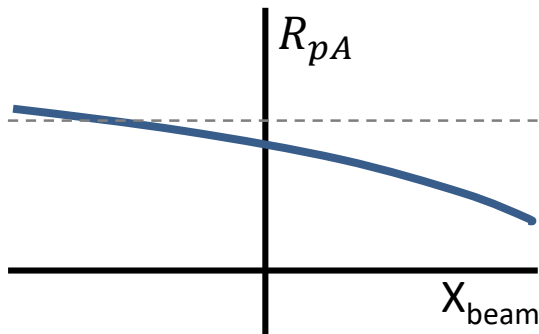
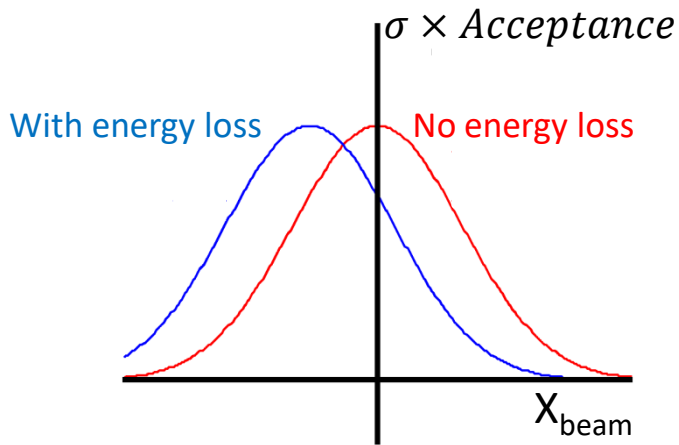
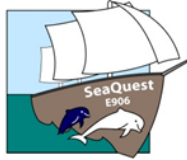
$\bar{q}_t(x_t)$: target sea quark at low/intermediate x
 $q_b(x_b)$: beam valence quark at high x

Small in fix target exp. with very forward acceptance

- Energy loss of the incoming quark can be studied with negligible final state interaction.



Quark Energy Loss in DY process



- Apparent kinematic values (x_{beam} or x_F) would be shifted
- Various Models:

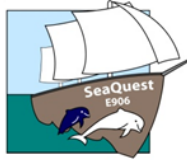
- Galvin and Milana: $\Delta x_{\text{beam}} = -\kappa_1 x_{\text{beam}} A^{1/3}$
- Brodsky and Hoyer: $\Delta x_{\text{beam}} \approx -\frac{\kappa_2}{S} A^{1/3}$
- Baier *et al.*: $\Delta x_{\text{beam}} \approx -\frac{\kappa_3}{S} A^{2/3}$

- Expect suppression of the per-nucleon cross section ratio to be significant at high x_{beam}

$$R_{pA} = \left(\frac{1}{A_A} \sigma(p + A) \right) / \left(\frac{1}{A_C} \sigma(p + C) \right)$$



Measurements from E866/NuSea



Energy Loss vs. shadowing

- Correction must be made for shadowing effect

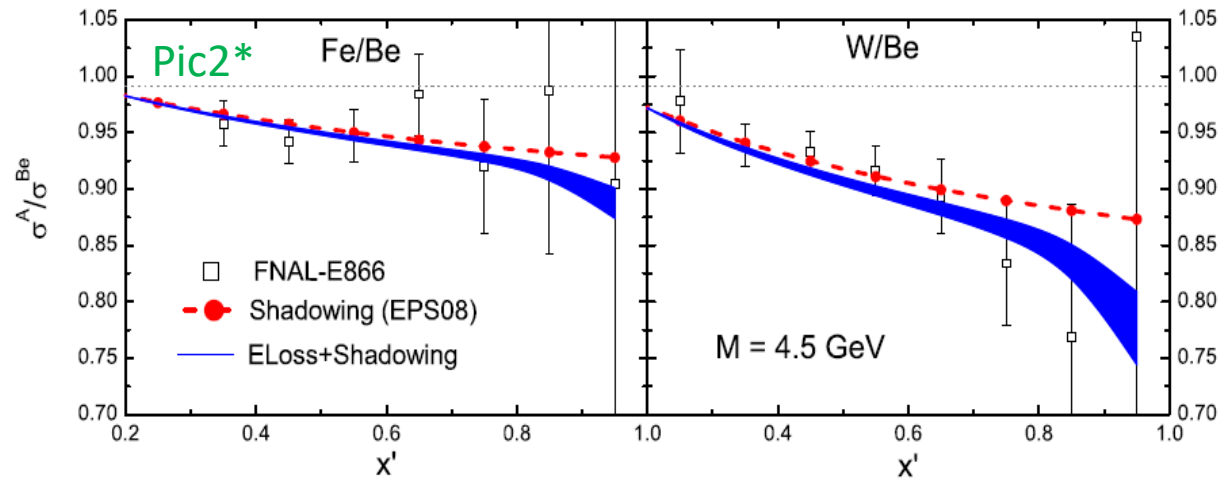
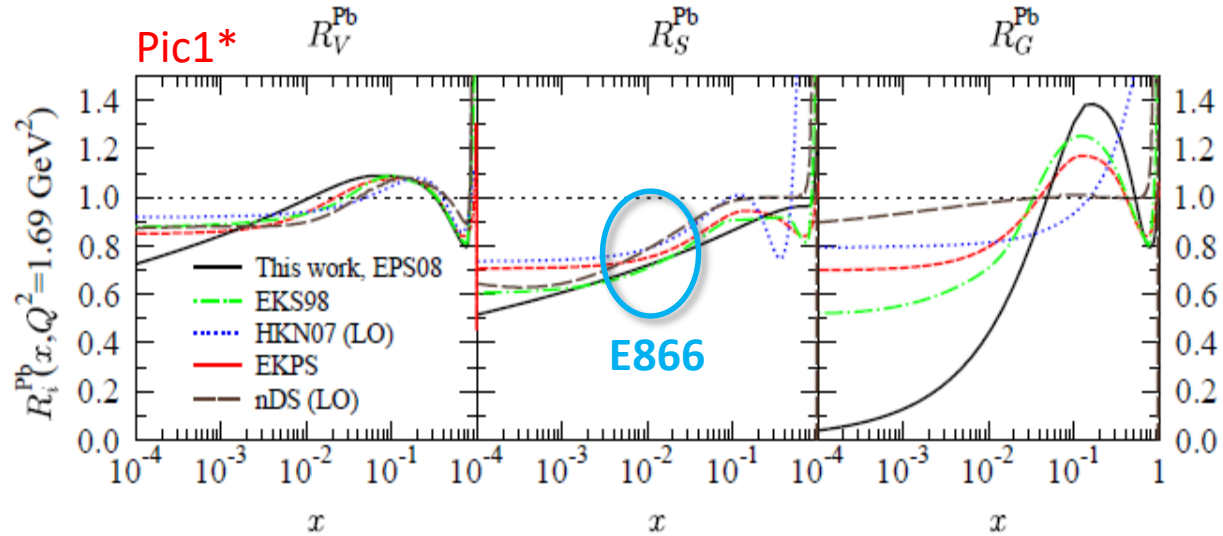
Garvey & Peng PRL 90 (2003)

- No partonic energy loss, all effect from shadowing

Vasiliev et al., PRL 83 (1999)

- Significant parton energy loss, ~ 1.2 GeV/fm if all from energy loss

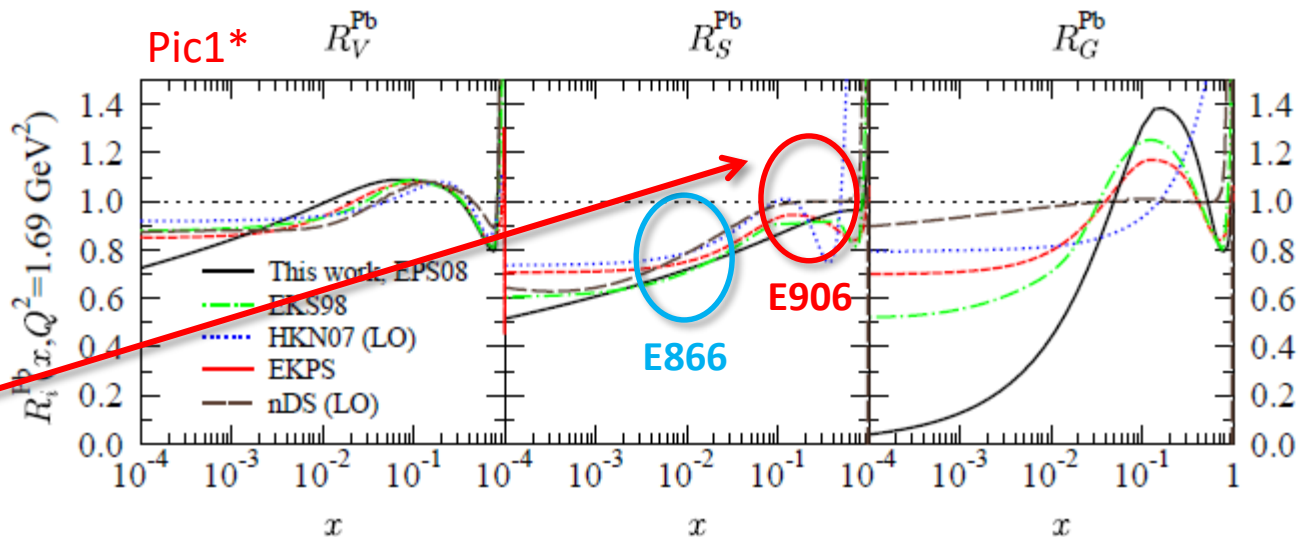
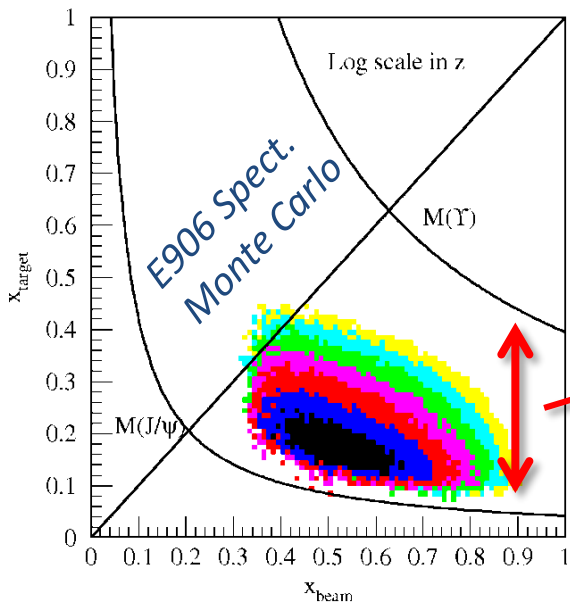
Johnson et al., PRC 65 025203 (2002)



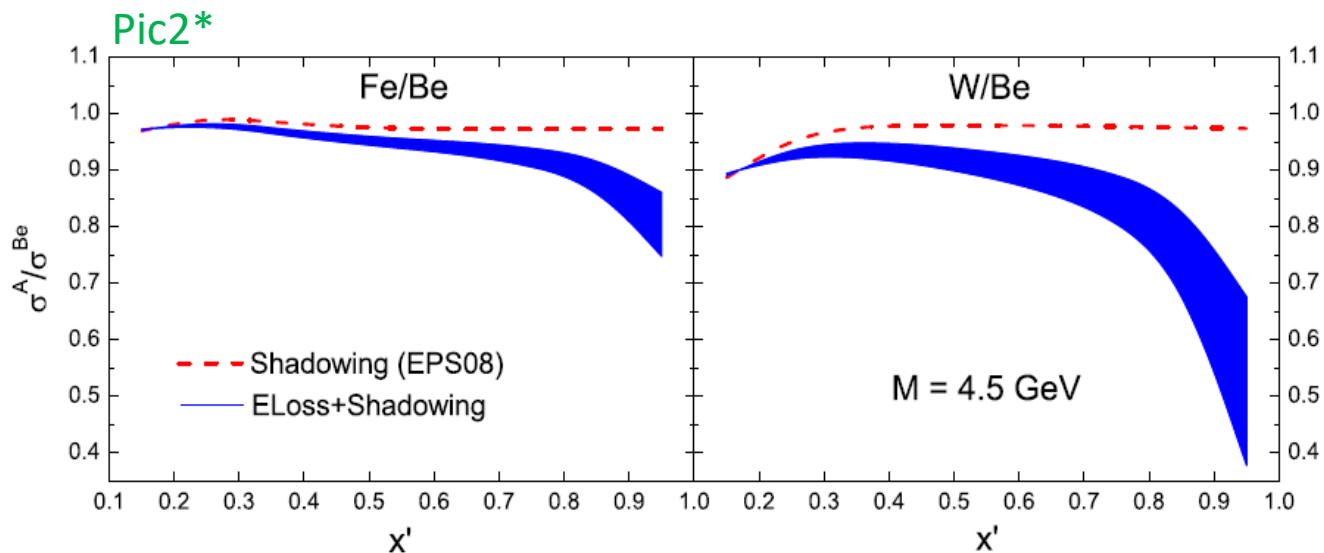
➤ E866 energy loss measurement obscured by the competing shadowing effect



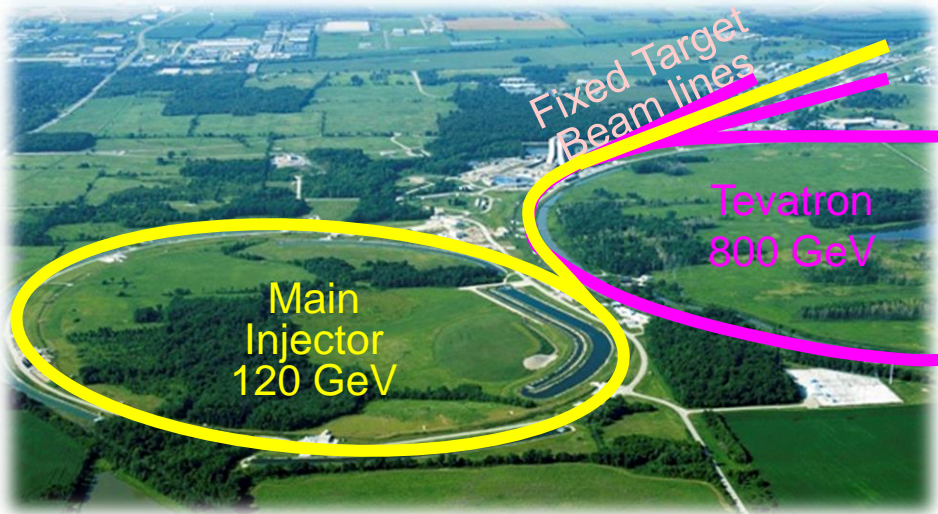
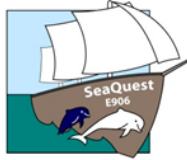
E906 Acceptance



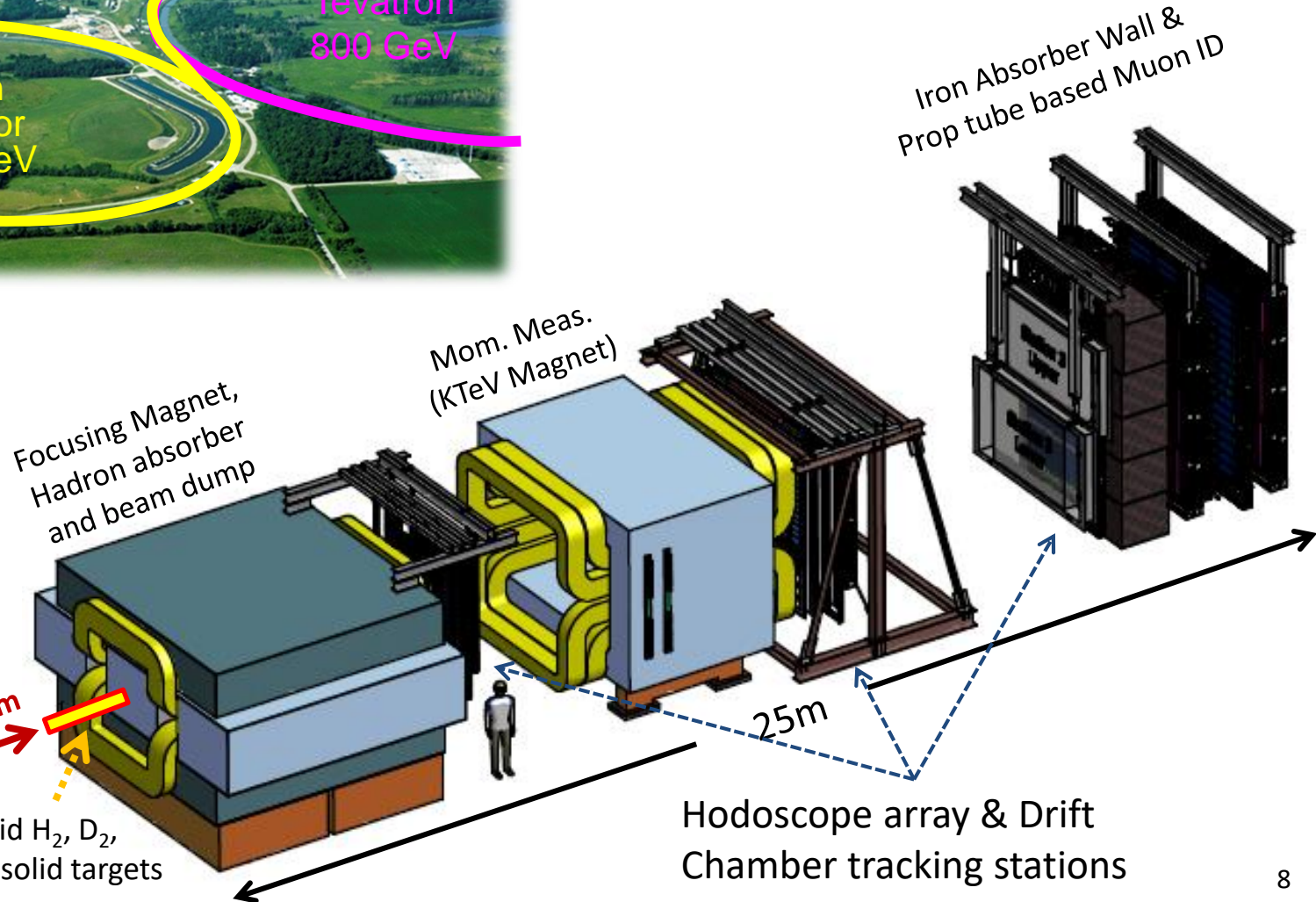
- Minimal shadowing with $x_{\text{Target}} > 0.1$
- Energy loss effect amplified



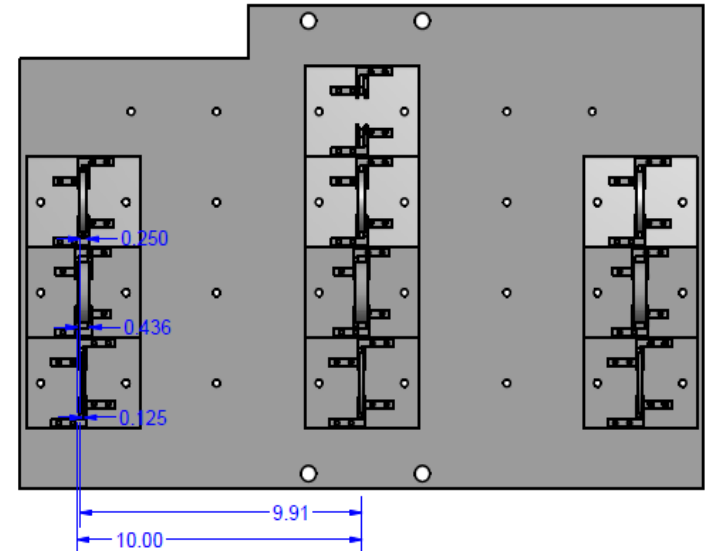
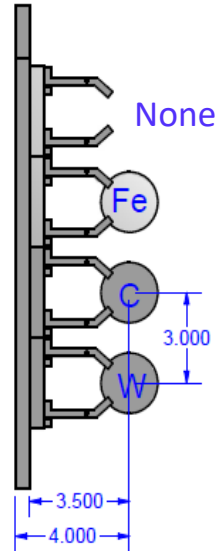
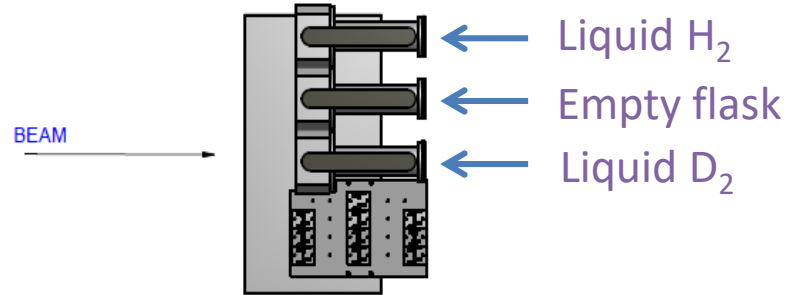
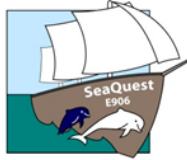
E906/SeaQuest at Fermilab



Aimed at dimuon production in Drell-Yan and charmonium decay



E906 Targets

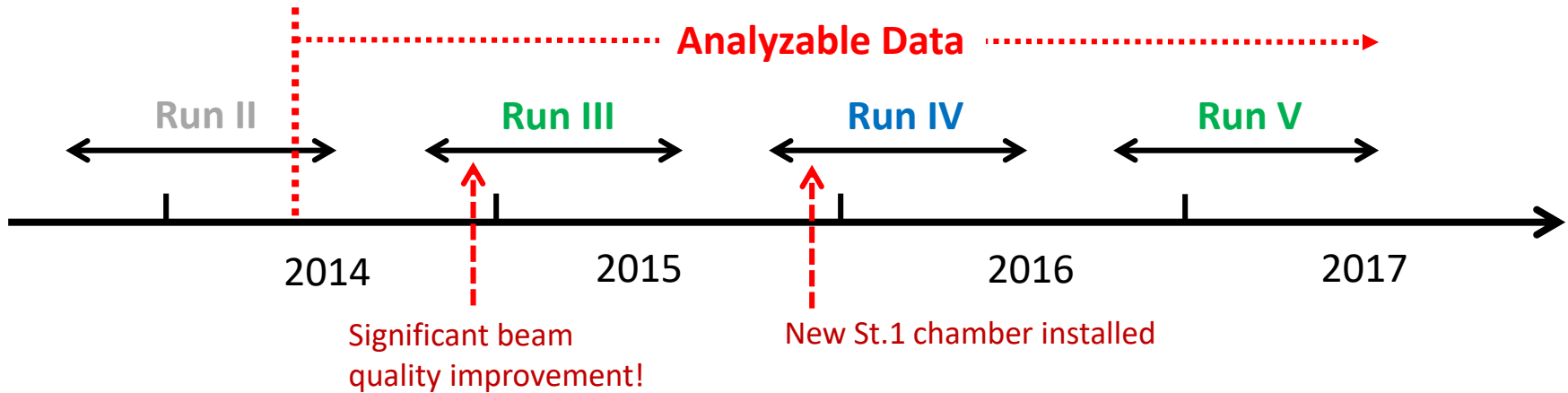
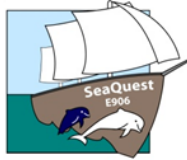


LH₂ MT LD₂ None Fe C W

<i>Spills</i>	LH ₂	MT	LD ₂	None	Fe	C	W
<i>Cycle</i>	10	2	5	2	1	2	1



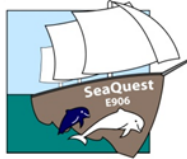
E906 Timeline



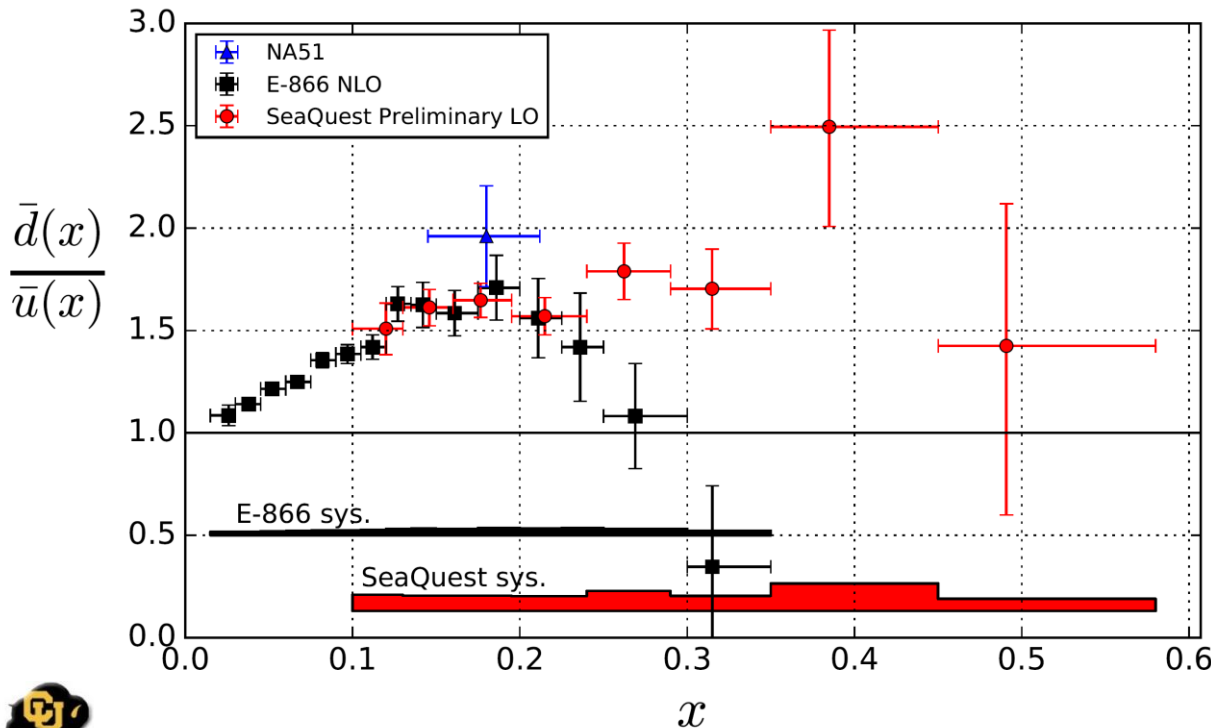
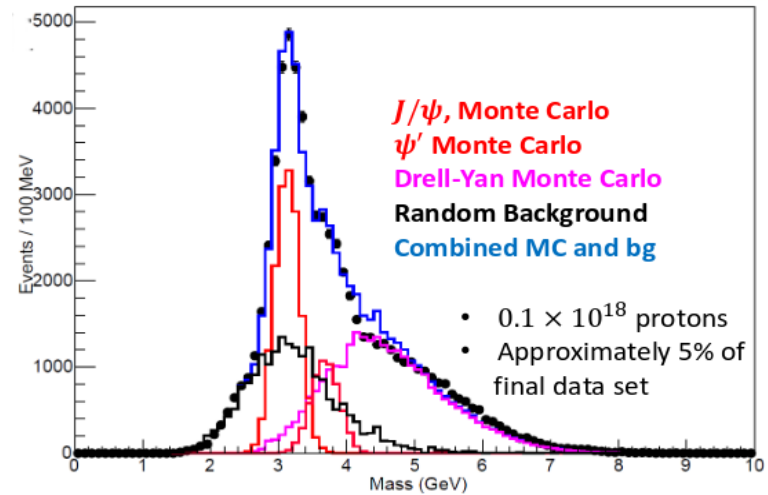
- Analyzable data starting from mid-June, 2014
- Significant beam quality improvement in mid-December, 2014
- New St.1 chamber installed in November, 2015.
 - Acceptance increased at higher X_{Target} and mass.
- Data taking will continue until this Summer.



E906 Data & Results

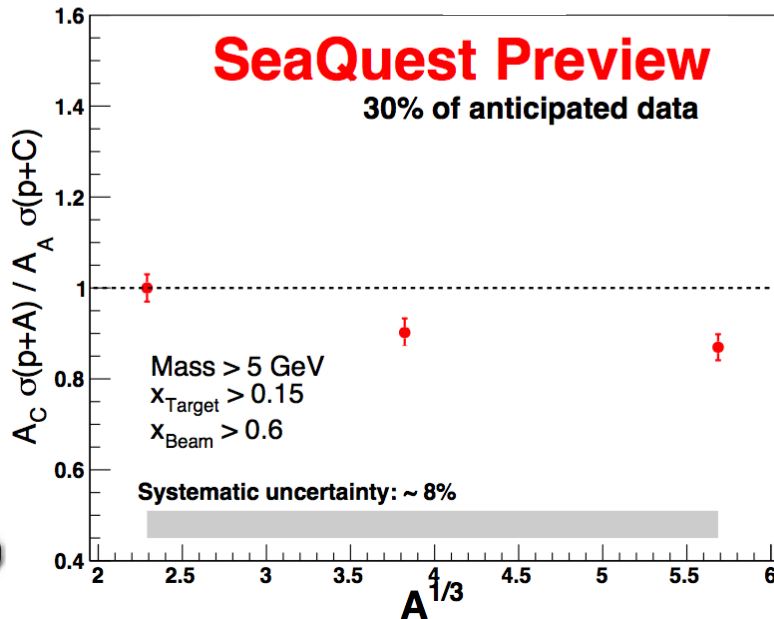
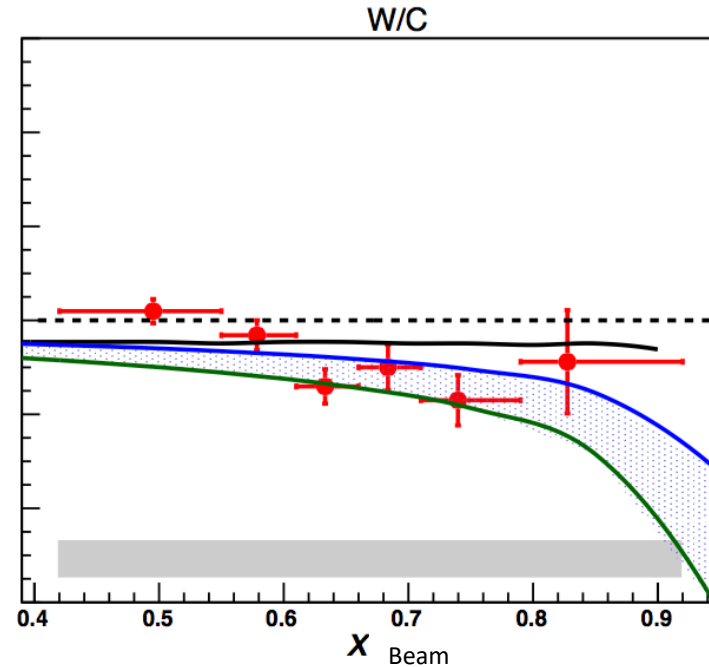
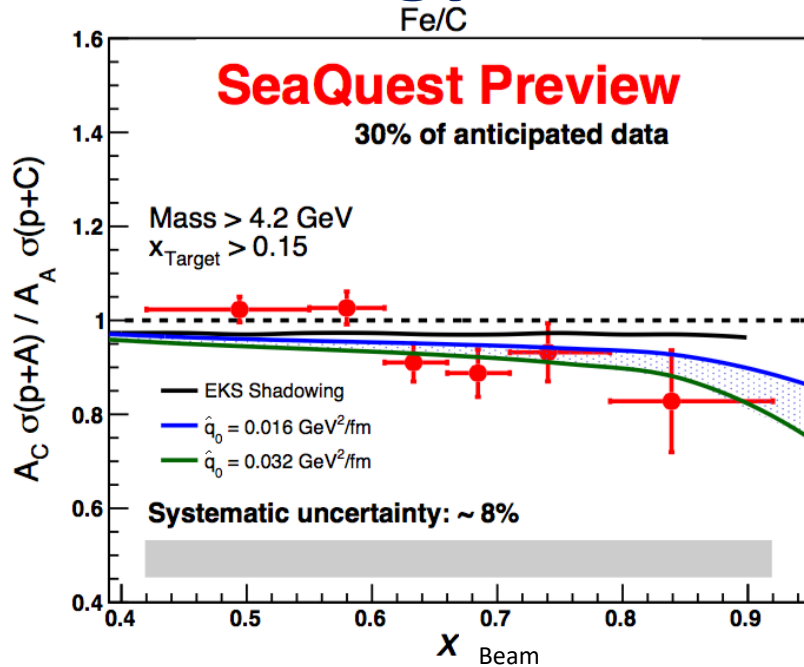
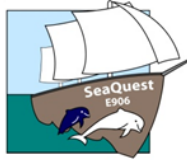


- Mass Spectrum well described by Monte Carlo
- Good mass resolution, better than expected.
 - $\sigma_M(J/\psi) \sim 180 \text{ MeV}$
 - $J/\Psi, \Psi'$ separation



- Disagreement with E866 result at high x_{Target}
- Difference in $\langle Q^2 \rangle$ not expected to cause significant difference
- Studies of corrections underway
- More high x_{Target} data coming with new D1

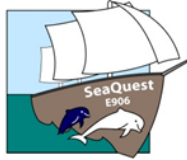
Quark Energy Loss at E906



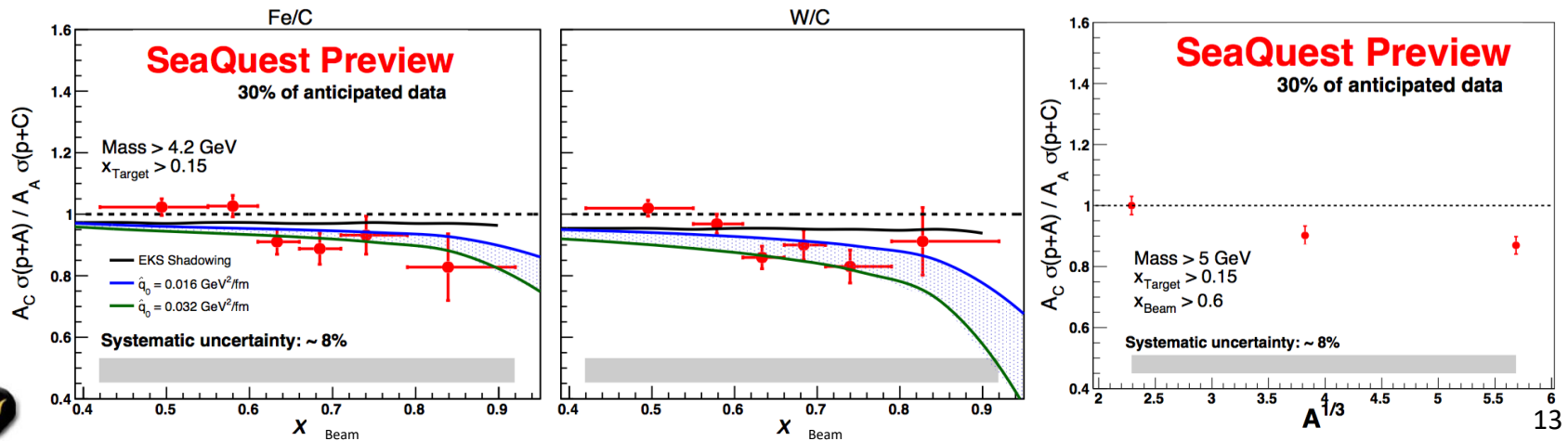
- Negative slope observed both in p+Fe and p+W results
- L-dependence of E-Loss:
 - $dE \propto A^{1/3}$ (or $\propto L$)
 - $dE \propto A^{2/3}$ (or $\propto L^2$)
- Working on minimizing systematic uncertainty



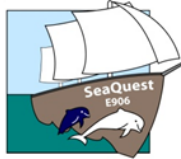
Summary



- Quark energy loss can be ideally measured in E906
- Current result shows trend of suppression in R_{pA} at high x_{Beam}
- Other E906 measurements:
 - Sea quark distribution
 - EMC effect
 - Angular distribution of dimuons
 - J/Ψ production, and more...
- Expecting results with higher statistics soon!



Thank you



Abilene Christian University

Ryan Castillo, Michael Daugherity, Donald Isenhower, Noah Kitts, Lacey Medlock, Noah Shutty, Rusty Towell, Shon Watson, Ziao Jai Xi

Academia Sinica

Wen-Chen Chang, Ting-Hua Chang, Shiu Shiuan-Hao

Argonne National Laboratory

John Arrington, [Don Geesaman*](#), Kawtar Hafidi, Roy Holt, Harold Jackson, David Potterveld, [Paul E. Reimer*](#), Brian Tice

University of Colorado

Ed Kinney, Joseph Katich, Po-Ju Lin

Fermi National Accelerator Laboratory

Chuck Brown, Dave Christian, Su-Yin Wang, Jin-Yuan Wu

University of Illinois

Bryan Dannowitz, Markus Diefenthaler, Bryan Kerns, Hao Li, Naomi C.R Makins, Dhyaanesh Mullagur R. Evan McClellan, Jen-Chieh Peng, Shivangi Prasad, Mae Hwee Teo, Mariusz Witek, Yangqiu Yin

KEK

Shin'ya Sawada

Los Alamos National Laboratory

Gerry Garvey, Xiaodong Jiang, Andreas Klein, David Kleinjan, Mike Leitch, Kun Liu, Ming Liu, Pat McGaughey, Joel Moss

Mississippi State University

Lamiaa El Fassi

University of Maryland

Betsy Beise, Yen-Chu Chen, Kazutaka Nakahara

University of Michigan

Christine Aidala, McKenzie Barber, Catherine Culkin, Vera Loggins, Wolfgang Lorenzon, Bryan Ramson, Richard Raymond, Josh Rubin, Matt Wood

National Kaohsiung Normal University

Rurngsheng Guo, Su-Yin Wang

RIKEN

Yoshinori Fukao, Yuji Goto, Atsushi Taketani, Manabu Togawa

Rutgers, The State University of New Jersey

Ron Gilman, Ron Ransome, Arun Tadepalli

Tokyo Tech

Shou Miyaska, Kei Nagai, Kenichi Nakano, Shigeki Obata, Florian Sanftl, Toshi-Aki Shibata

Yamagata University

Yuya Kudo, Yoshiyuki Miyachi, Shumpei Nara

[*Co-Spokespersons](#)