

At the end of

**NUINT 2024 –  
14th INTERNATIONAL  
WORKSHOP ON NEUTRINO-  
NUCLEUS INTERACTIONS**

Natalie Jachowicz on behalf of the INC and the **NuSTEC** Board

What happens if you lock up a bunch of neutrino physicists for one week

in here ?



# A lot of interesting talks

## $\nu - Q^2$ kinematic region

- Because of the absence of any sharp cut on the kinematical variables defining the separation of the  $\nu$  and DIS regions, in literature, there is large variation in the consideration of the values of  $W$  and  $Q^2$  at the onset of the DIS region.

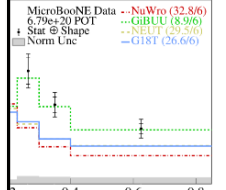
## Energy reconstruction

- Energy reconstruction method is function of selection and detector technology
- NOvA, DUNE and SBN have sampling calorimeters and often events with multiple tracks
  - CC-inclusive selection
  - Energy estimator which sums up energy deposits

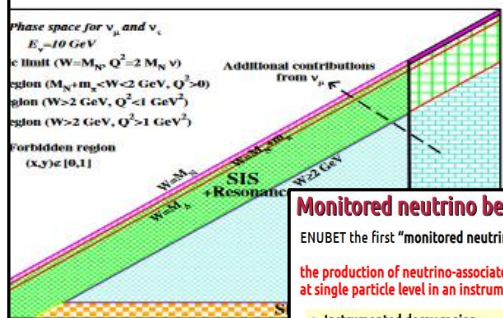
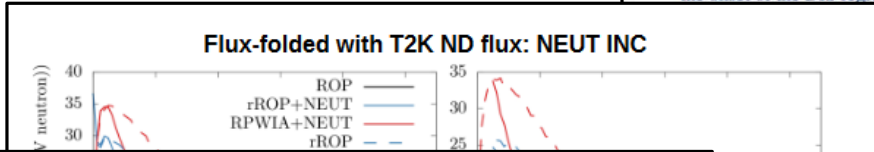
## SI

Dark matter structure currently

$\rho_{DM} < 180^{\circ}$



DATA

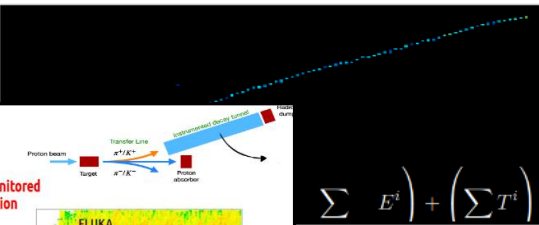


## Monitored neutrino beams

ENUBET the first "monitored neutrino beam":  
 the production of neutrino-associated leptons is monitored at single particle level in an instrumented decay region

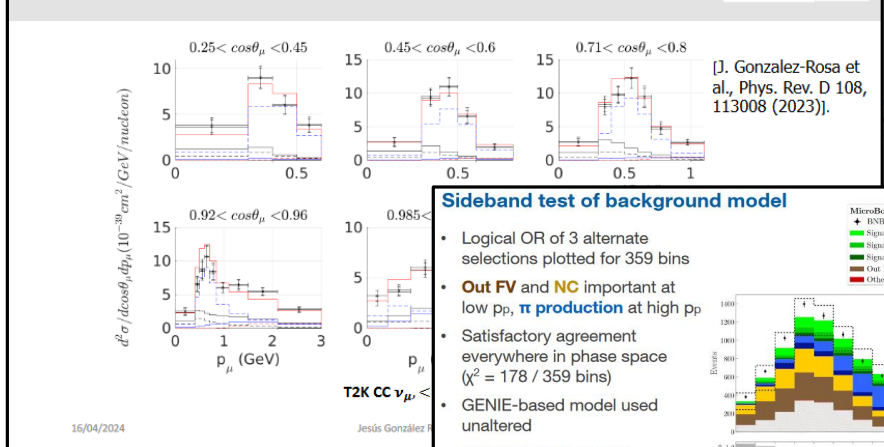
- Instrumented decay region
  - $K^+ \rightarrow e^+ \nu_e \pi^0 \rightarrow (\text{large angle}) e^+$
  - $K^+ \rightarrow \mu^+ \nu_\mu \pi^0 \rightarrow \mu^+ \nu_\mu \rightarrow (\text{large angle}) \mu^+$
  - $\nu_e$  and  $\nu_\mu$  flux prediction from  $e/\mu$  rates

Needs a collimated momentum-selected hadron beam  $\rightarrow$  only the decay products hit the tagger  $\rightarrow$  manageable rates and irradiation in the detectors  
 Needs a "short", 40 m, decay region:  $\sim$  all  $\nu_e$  from  $K$ , only  $\sim 1\%$   $\nu_\mu$  from  $\mu$  (large flight length)  
 NB: it requires a specialized beam, not a "pluggable" technology for existing super-beams (unfortunately)



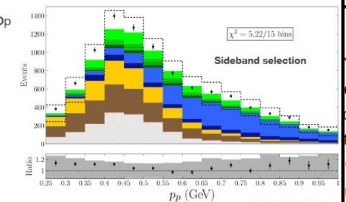
$$\sum E^i + \left( \sum T^i \right)$$

## Results: T2K



## Sideband test of background model

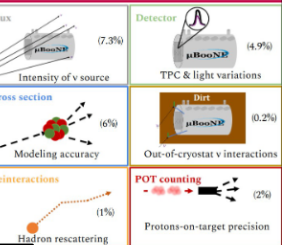
- Logical OR of 3 alternate selections plotted for 359 bins
- Out FV and NC important at low  $p_\mu$ ,  $\pi$  production at high  $p_\mu$
- Satisfactory agreement everywhere in phase space ( $\chi^2 = 178 / 359$  bins)
- GENIE-based model used unaltered
- Full sideband results in supplement and data release



effects for  $\nu_\tau$  - A DIS process has as theoretical efforts are required

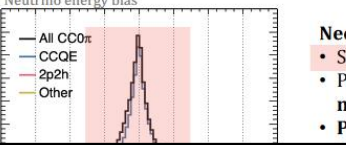
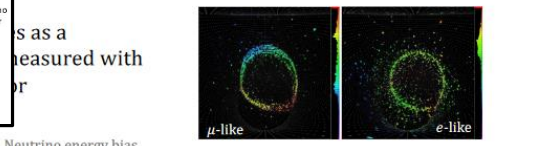
## we make the n

events with:  
 on-like track  
 on-like track  
 else  
 uncertainties on predicted



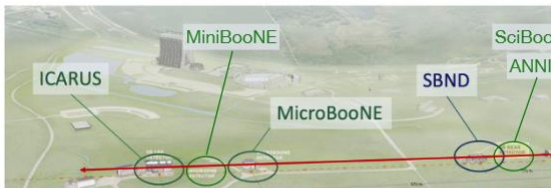
Infer neutrino energy using lepton information under 2-body reaction assumption

## oscillations with T2K



- Need to control: (1st order)
- Shape of Fermi motion
  - Proportion of QE vs non-QE processes
  - Physics beyond PWIA

## Booster Neutrino Beam



## Nuclear Wave Functions

Variational wave function for nucleus in J state

$$|\psi\rangle = S \prod_{i,j} \left[ 1 + U_{ij} + \sum_{k,l,i,j} U_{ijkl} \right] \left[ \prod_{i,j} f_i(r_{ij}) \right] \Phi(JMTT_3)$$

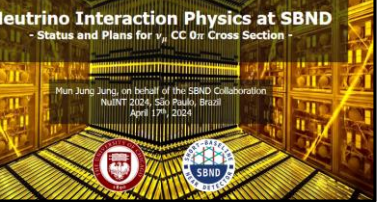
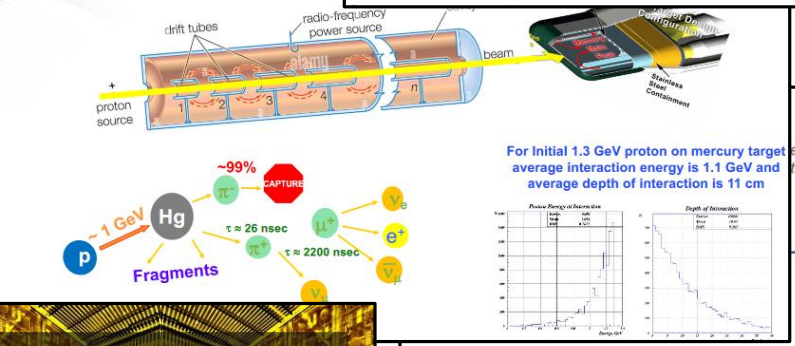
Two-body spin- and isospin-dependent correlations

$$U_{ij} = \sum_p f^p(r_{ij}) O_{ij}^p$$

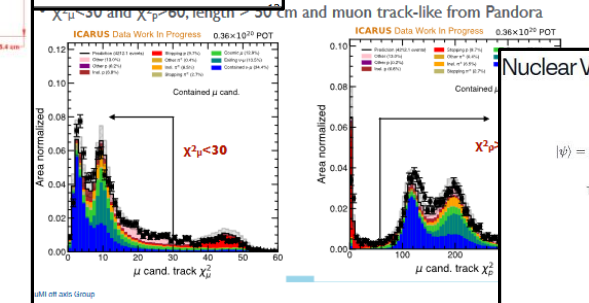
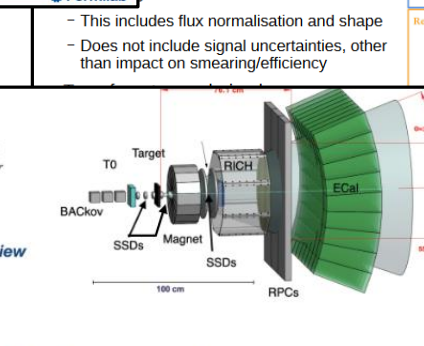
$$O_{ij}^p = [1, \sigma_i \cdot \sigma_j, S_{ij}] \otimes [1, \tau_i \cdot \tau_j]$$

$$U_{ijkl} = c U_{ijkl}(\vec{r}_{ij}, \vec{r}_{jk}, \vec{r}_{ki})$$

The trial wave function can be improved by eliminating spurious contaminations via  $\delta$  propagation in imaginary time (GFMC).



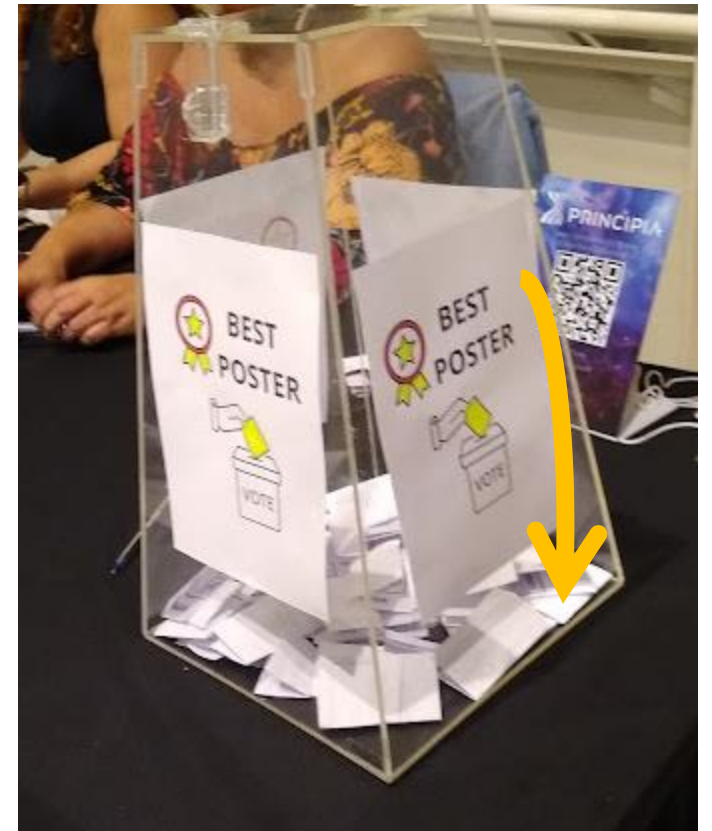
- Focus on low-momentum beam: pbeam < 15 GeV/c, but will also make measurements with beam from 20-120 GeV/c. Ultimate design: 350 mrad acceptance
- Collection of small detectors to track particles with high precision before and after a target, perform particle identification, and measure calorimetric energy.



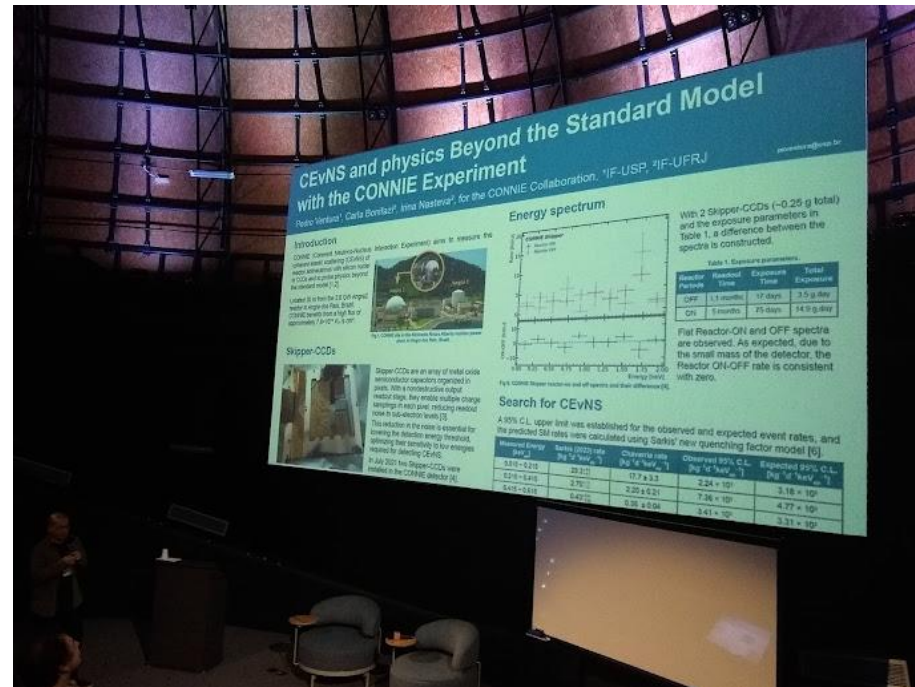
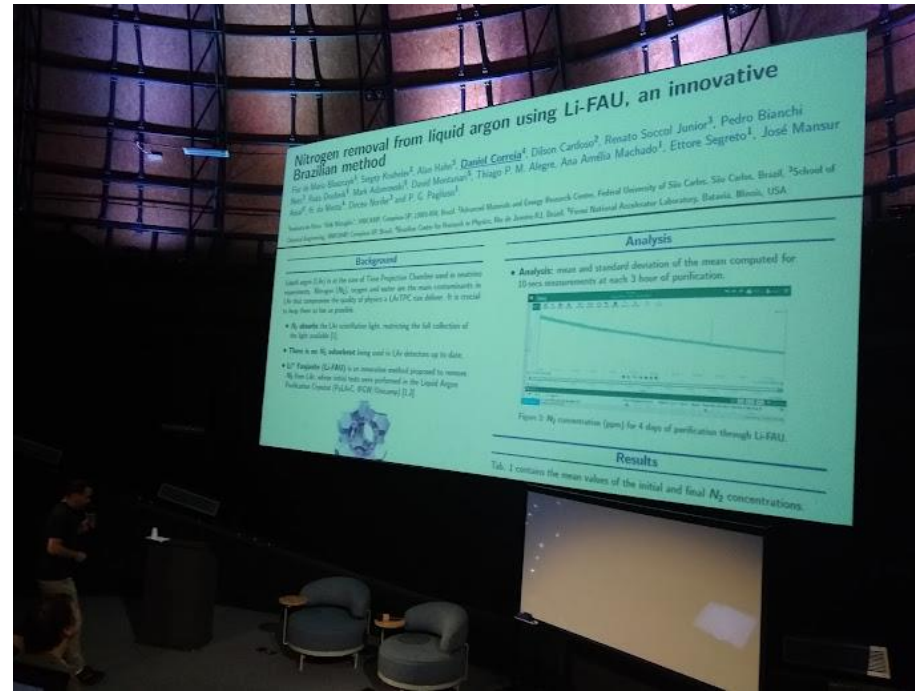
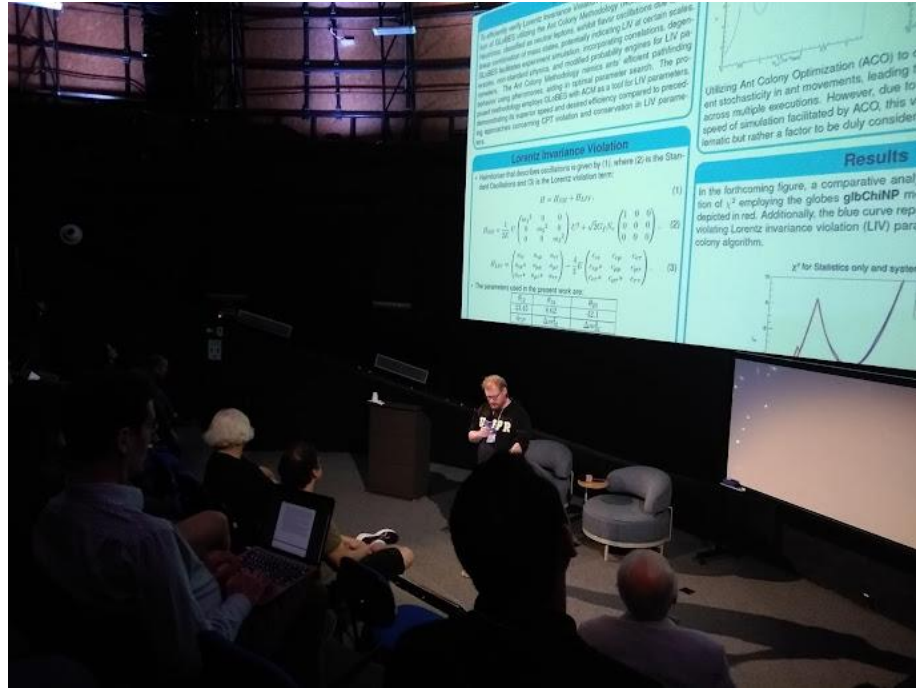
Vivid discussions ...



and a lot of best posters !



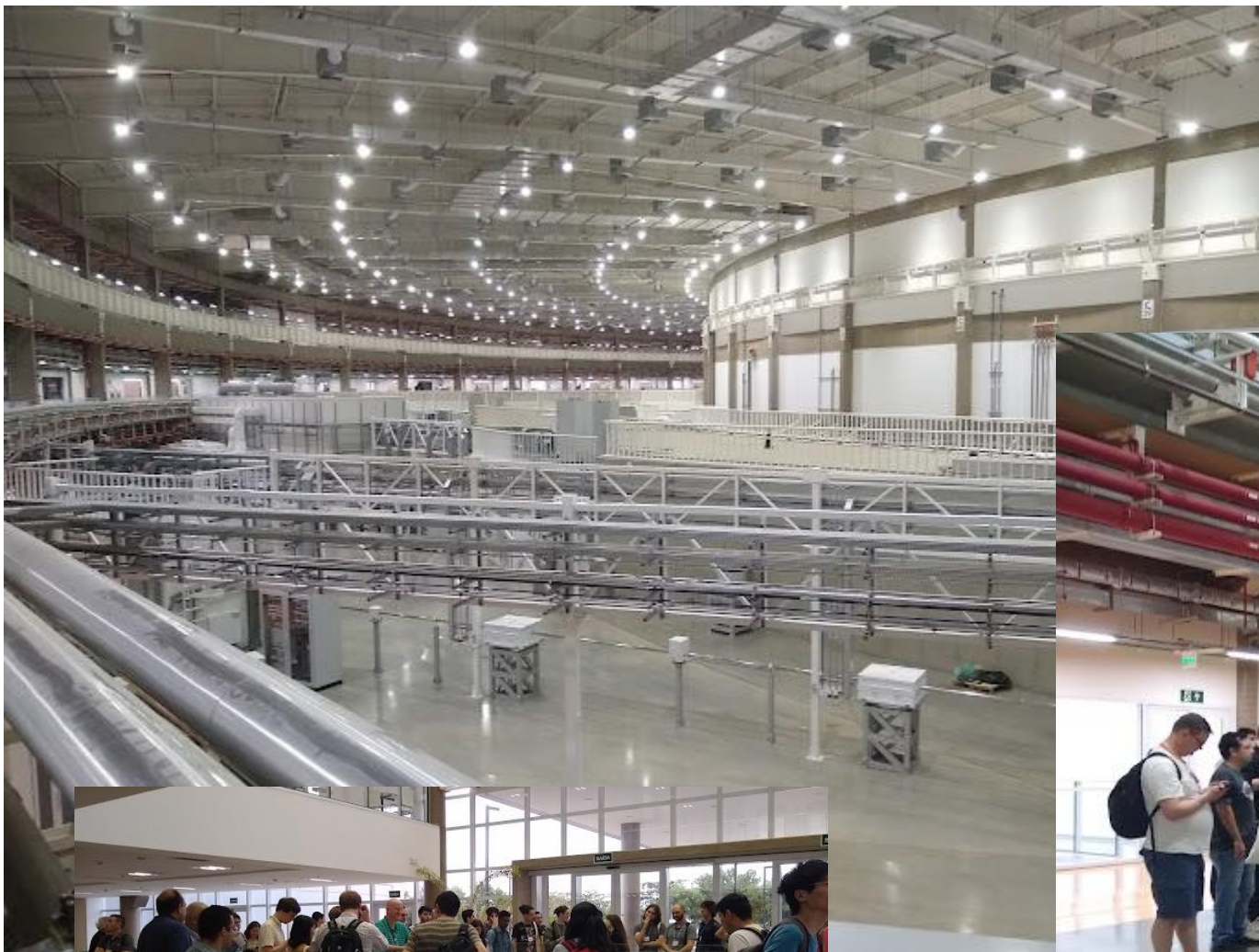
# Three very best posters !



A very interesting excursion



Brazilian Synchrotron  
Light Laboratory



And more very important things ...



Thanks to (a non-exhaustive list) :

**LOCAL ORGANIZING COMMITTEE**

Anibal Bezerra (UNIFAL)

Ana Amélia Machado (UNICAMP)

Franciole Marinho (ITA)

Hélio da Motta (CBPF) - cochair

Irina Nasteva (UFRJ)

Humberto Neto (ICTP-SAIFR)

Laura Paulucci (UFABC)

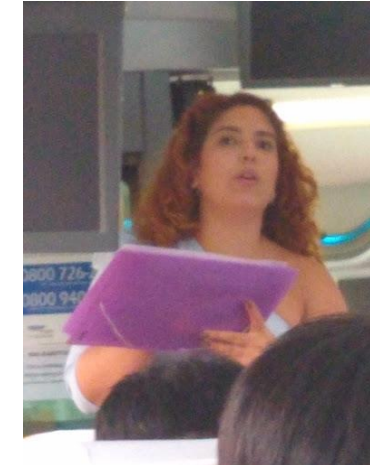
Orlando Peres (UNICAMP) - cochair

Elisa Pomari (ICTP-SAIFR)

Norma Reggiani (Instituto Príncipia)

Gustavo Valdivieso (UNIFAL)

.. especially our chairs Helio and Orlando



and secretaries Thaissa and Sonia

..for an excellent organization !





# Thanks to (a non-exhaustive list) : **WORKING GROUP CONVENERS**

## **Session 1: Neutrino flux predictions and measurements**

Katsuya Yonehara (Fermilab)

Laura Fields (Notre Dame University)

Megan Friend (KEK)

## **Session 2: Neutrino Interaction generators**

Yoshinari Hayato (ICRR, The University of Tokyo)

Julia Tena-Vidal (Tel Aviv University)

Pedro Machado (Fermilab)

## **Session 3: QE + 2p2h / 0-pi production**

Stephen Dolan (CERN)

Joanna Sobczyk (Johannes Gutenberg University)

Saori Pastore (Washington University in Saint Louis)

Richard Gran (University of Minnesota Duluth)

## **Session 4: Pion Production/SIS/DIS**

Minoo Kabirmezhad (Imperial College London)

Mohammad Sajjad Athar (Aligarh Muslim University)

Laura Munteanu (CERN)

Kirk Bays (Minnesota)

## **Session 5: Low-energy neutrino scattering**

Bryce Littlejohn (Illinois Institute of Technology)

Maria Cristina Volpe (APC/CNRS)

Claudia Nones (CEA/IRFU)

Raimund Strauss (TUM)

## **Session 6: Charged lepton and pion scattering**

Adi Ashkenazi (Tel Aviv University)

Camilo Martani (Virginia Tech)

Artur Ankowski (Wroclaw)

## **Session 7: Impact of scattering uncertainties on measurements**

Callum Wilkinson (Lawrence Berkeley National Laboratory)

Linda Cremonesi (Queen Mary University of London)

Luke Pickering (STFC UKRI)



Thanks to : (a non-exhaustive list) : all participants !



# NuInt : a very incomplete and very biased timeline



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NuInt05, Okayama, Japan  
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NuInt17, Toronto, Canada  
NuInt18, L'Aquila, Italy  
NuInt22, Seoul, Korea  
NuInt24, Sao Paulo, Brazil

Neutrino and anti-neutrino cross-sections and CP phase measurement #14  
Y. Obayashi (KEK, Tsukuba) (2002)  
Published in: *Nucl.Phys.B Proc.Suppl.* 112 (2002) 18-23 • Contribution to: NuInt 01, 18-23  
DOI cite claim reference search 1 citation

Modeling deep inelastic cross-sections in the few GeV region #7  
A. Bodek (Rochester U.), U.K. Yang (Chicago U., EFI) (Mar, 2002)  
Published in: *Nucl.Phys.B Proc.Suppl.* 112 (2002) 70-76 • Contribution to: NuInt 01, 70-76 • e-Print: [hep-ex/0203009](#) [hep-ex]  
pdf DOI cite claim reference search 150 citations

A Study of nuclear effects in nu interactions with the NOMAD detector #9  
NOMAD Collaboration • M. Veltri (Urbino U. and INFN, Florence) for the collaboration. (Feb, 2002)  
Published in: *Nucl.Phys.B Proc.Suppl.* 112 (2002) 124-131 • Contribution to: NuInt 01, 124-131 • e-Print: [hep-ex/0202038](#) [hep-ex]  
pdf DOI cite claim reference search 7 citations

Precise determination of the oscillation parameters: Need to understand low energy neutrino interactions #12  
A. Para (Fermilab) (2002)  
Published in: *Nucl.Phys.B Proc.Suppl.* 112 (2002) 9-14 • Contribution to: NuInt 01, 9-14  
DOI cite claim reference search 2 citations

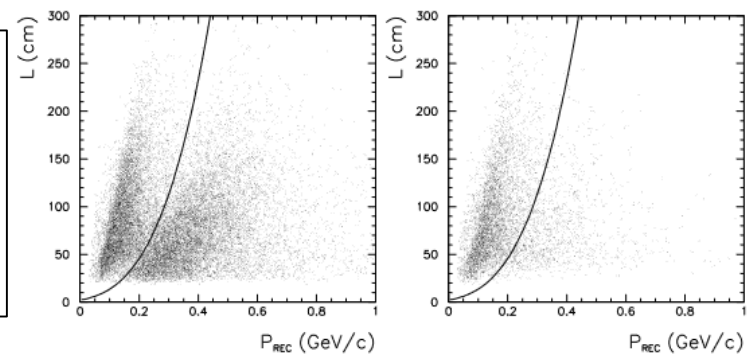


Figure 1. Distributions of length vs. momentum for positive (left) and negative (right) backward going tracks selected as described in the text. The line indicates the position of the cut.

A-saurus



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MINERνA

## MINERνA: a dedicated neutrino scattering experiment at NuMI

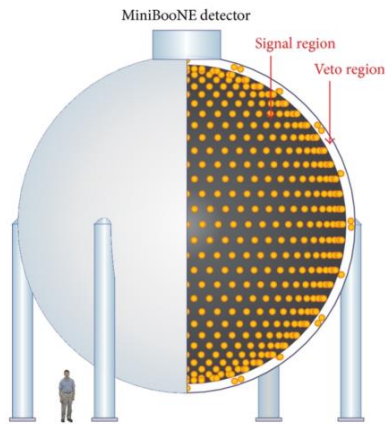
K. S. McFarland<sup>a</sup>, *on behalf of the MINERνA collaboration*

<sup>a</sup>University of Rochester, Rochester, NY 14627 USA

MINERνA is a dedicated neutrino cross-section experiment planned for the near detector hall of the NuMI neutrino beam at Fermilab. I summarize the detector design and physics capabilities of the experiment.

MINERνA is a dedicated neutrino cross-section experiment planned for the NuMI beamline at

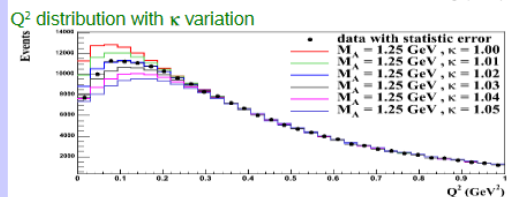
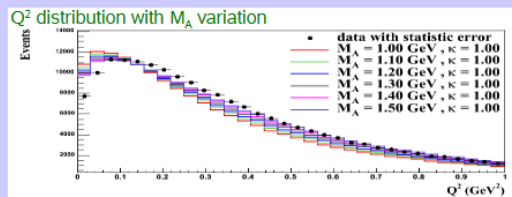




### 3. CCQE data-MC comparison

$M_A$  and  $\kappa$  are simultaneously fit to the data

2% change of  $\kappa$  is sufficient to take account the data deficit at low  $Q^2$  region



### Conclusions / More discussion

Some very good neutrino data sets available now and upcoming

Experiments must start to provide proper cross sections  
 differential cross sections  
 take advantage of statistics to bin in angle, pmu

Continue (accelerate) incorporation of known nuclear physics as well as uncertain nuclear physics effects into understanding neutrino data and systematics

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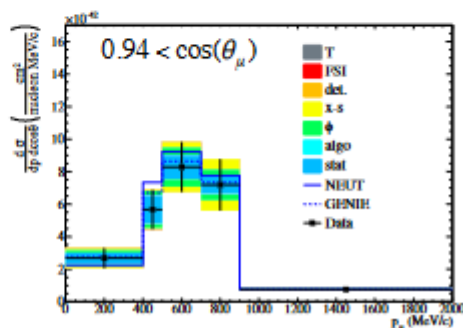
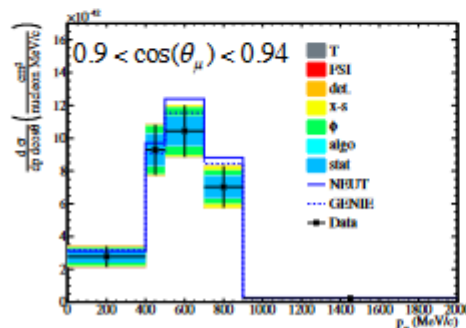
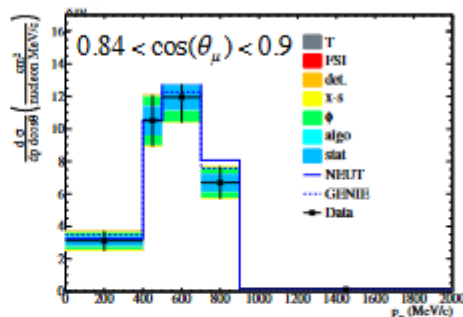
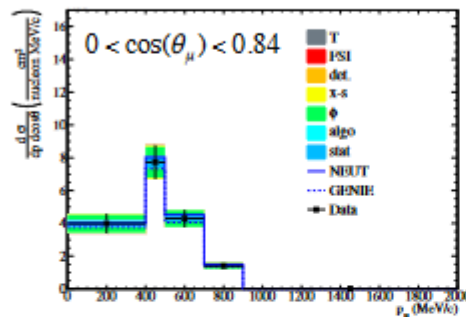
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## Differential Cross Section



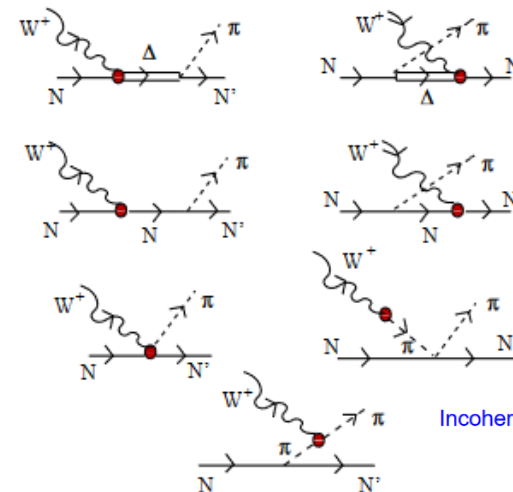
T: Target, FSI: Final State Interaction det.: detector, x-s: cross-section, algo: unfolding algorithm



Oct-2012

A.Weber, NuInt2012

15



Incoherent one-pion production in neutrino-nucleus scattering

E.Hernández<sup>1</sup>, J. Nieves<sup>2</sup>, M.J. Vicente Vacas<sup>3</sup>

## Eta Production

Charged current ν(anti-ν) induced eta production

$$\nu_e(k) + N(p) \rightarrow e^-(k') + N'(p') + \eta(p_\eta)$$

$$\bar{\nu}_e(k) + N(p) \rightarrow e^+(k') + N'(p') + \eta(p_\eta)$$

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Considerable time for discussion is being planned into these sessions.

We invite you to attend NuInt12 to continue the study of these important interactions.



**The call for abstracts is open**

You can submit an abstract for reviewing.

[Submit new abstract](#)



**Registration**

You are registered for this event.

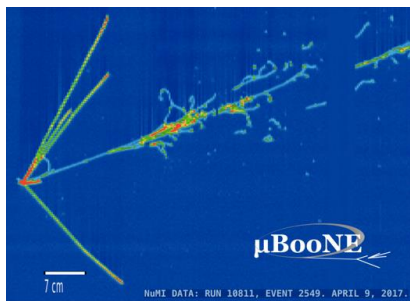
[See details >](#)



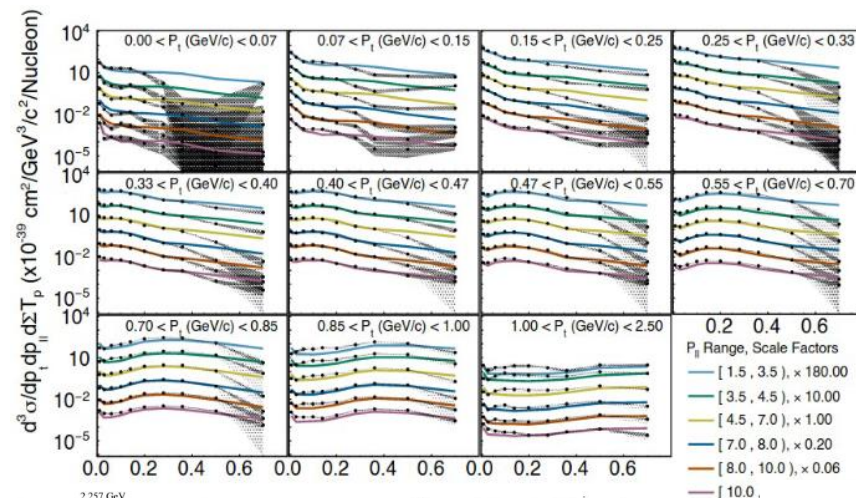
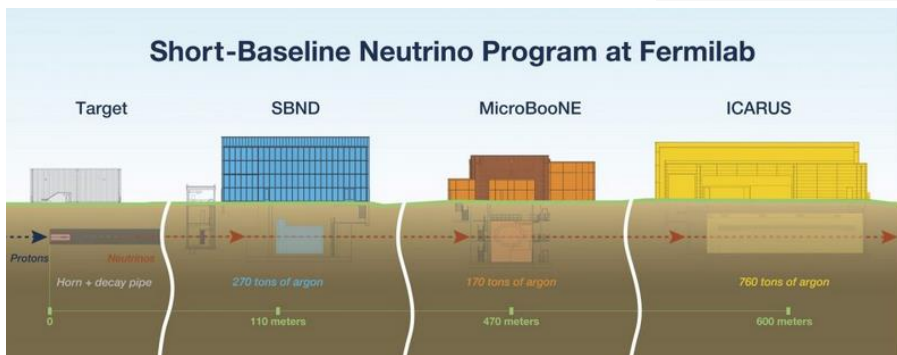
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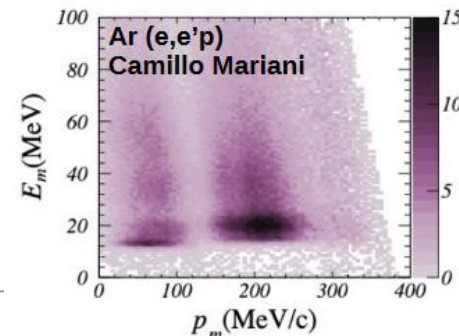
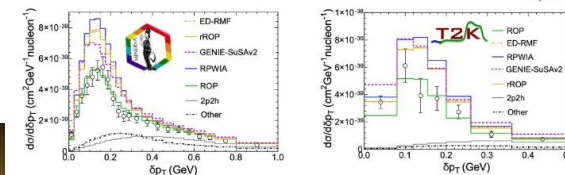
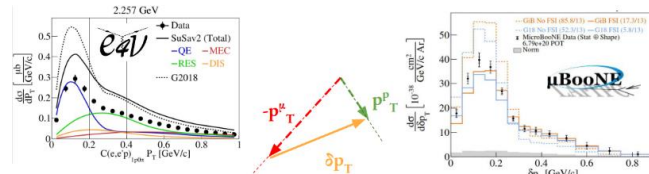
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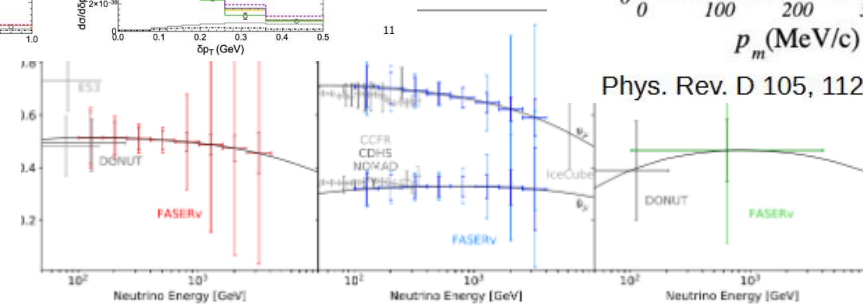
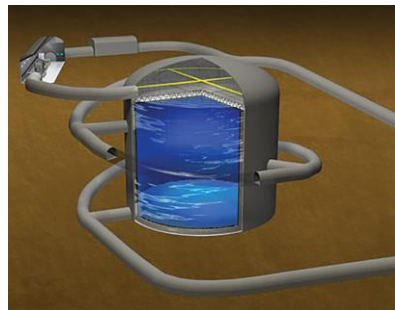
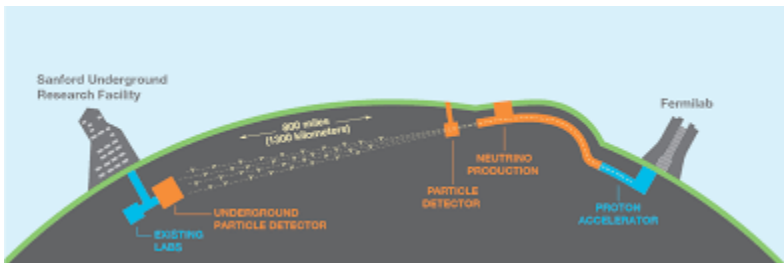
Fast Forward ...



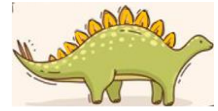
MINERvA



Phys. Rev. D 105, 112002, (2022)

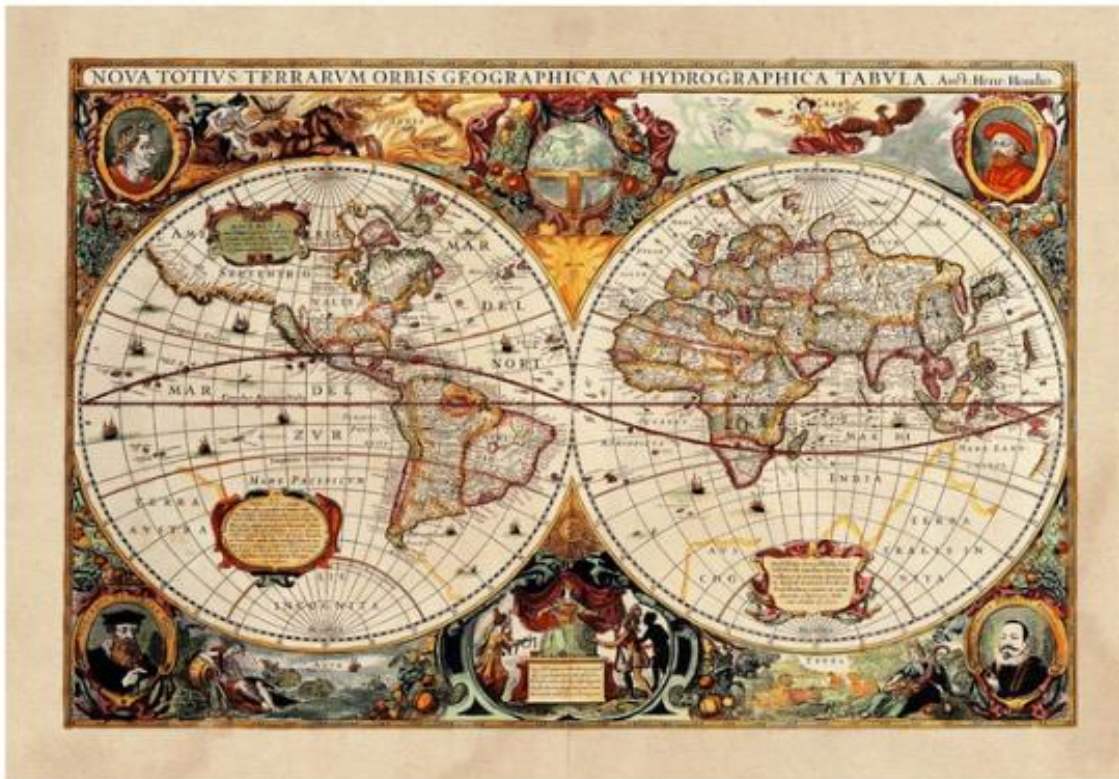


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- ★ All in all, the present knowledge of neutrino interactions appears to be still comparable to the knowledge of the geography of North America around 1650

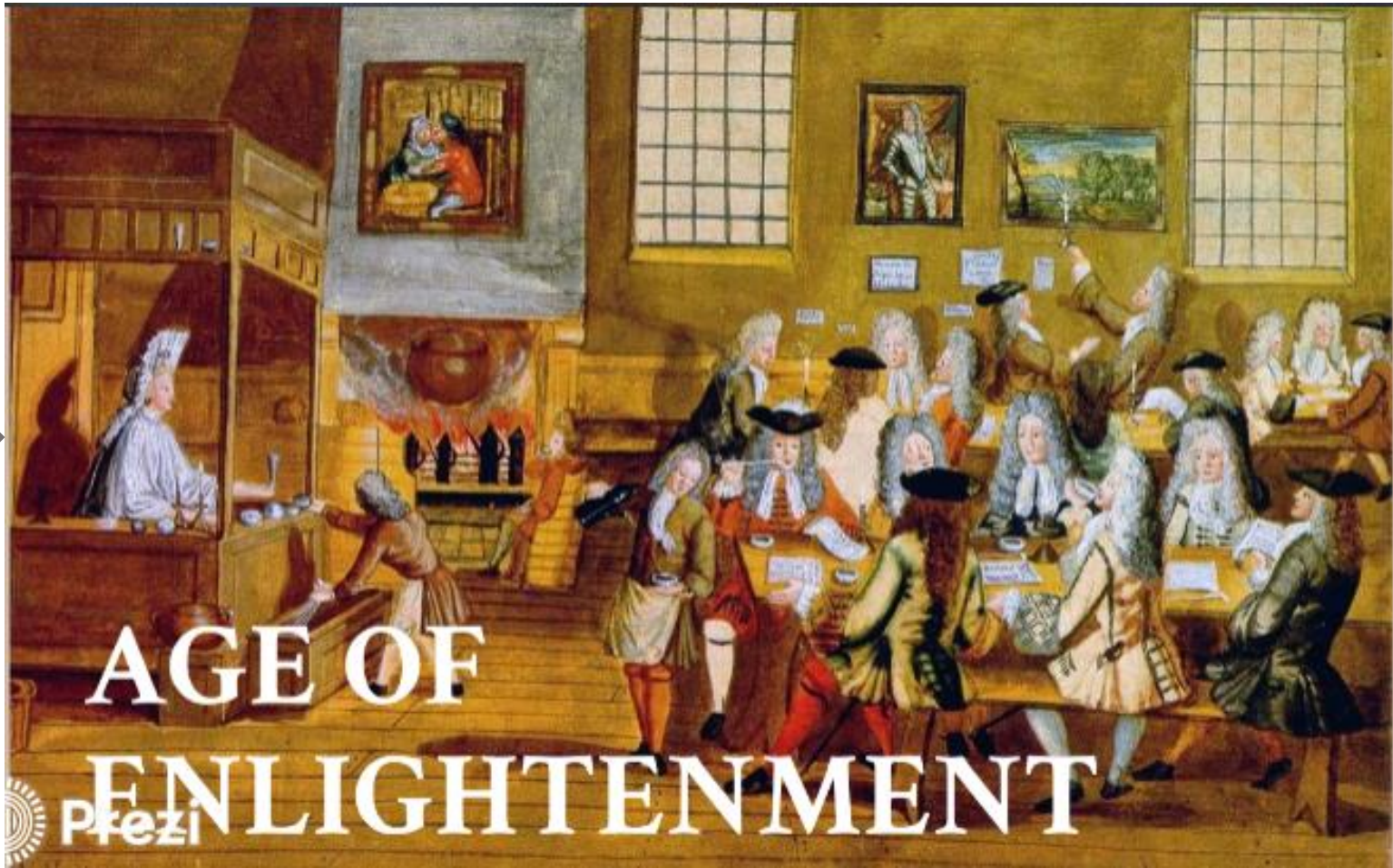
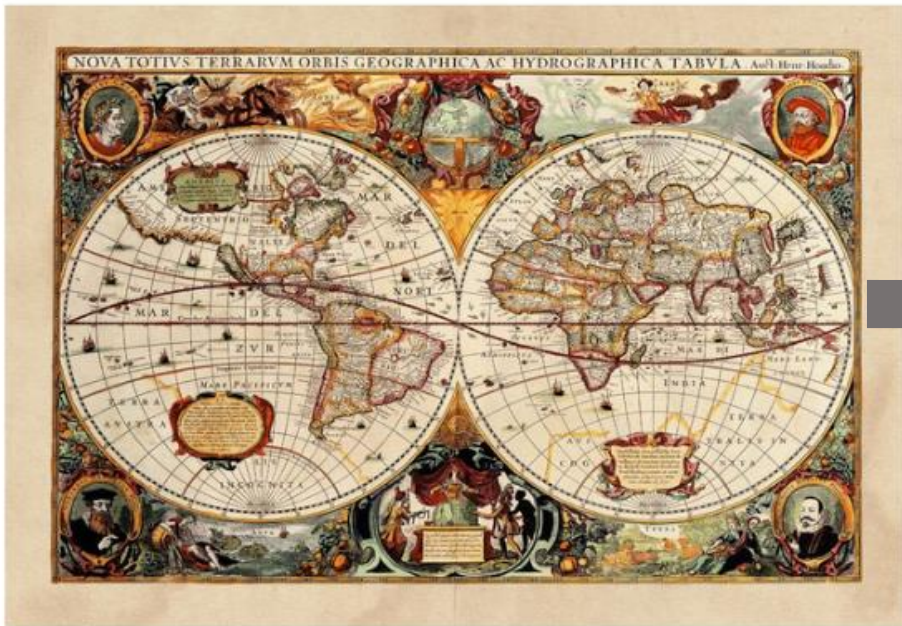


Omar Benhar @ NuInt22

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That calls for ...



NuInt 2025

Mainz, Germany

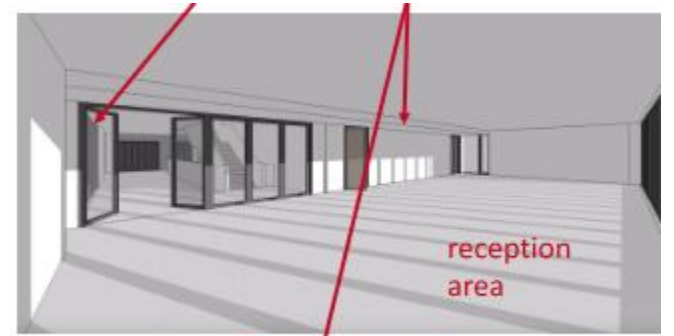
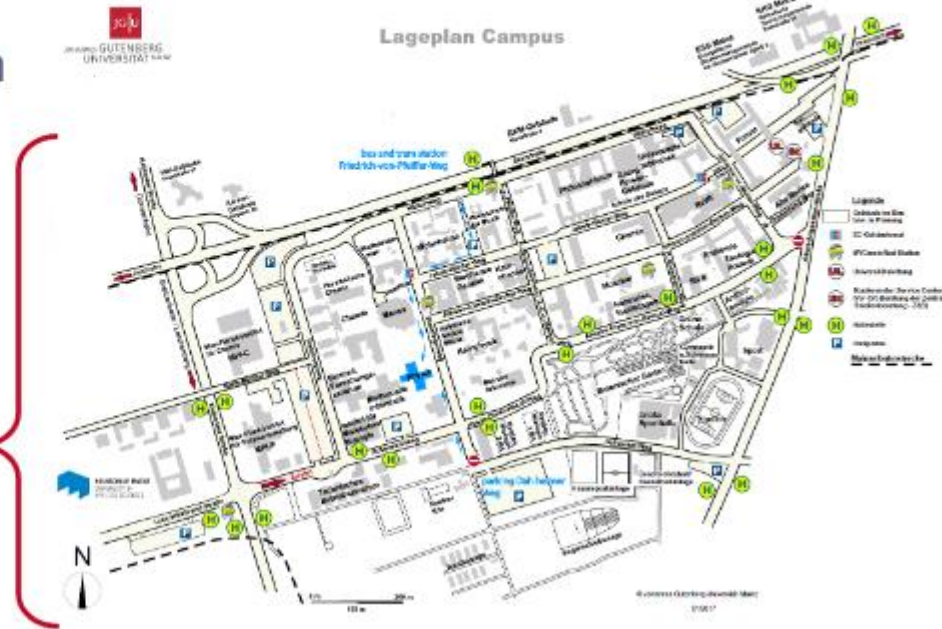
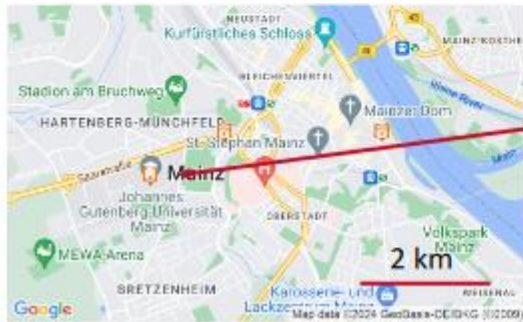


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UNIVERSITÄT MAINZ

JG|U

## THE JGU CAMPUS

- Venue is located on JGU Campus.
- 10 min public transport from city centre (hotels) or 40 min walk
- We will provide public transport passes for participants.



➤ Early fall 2025 – before the semester starts (end of October)

## THE TEAM



Sonja



Luca



Lukas\*



Joachim



Asia



Alfons

Sonja Bacca, Luca Doria, Lukas Koch, Joachim Kopp, Asia Sobczyk,  
Alfons Weber (Chair)

## EXCURSIONS

- Many options are possible
  - Wine tasting in old monastery with/without dinner
  - Boat trip on river Rhine (can be combined with the above)
  - Visit of KATRIN experiment in Karlsruhe (tbc)
- Tours of local facilities
  - TRIGA nuclear reactor
  - MESA/MAMI accelerators
- Gutenberg Museum & Roman Ship Museum
  - Local transport ticket allows free entry to most museums







& hope to see you in Mainz at NuInt2025 !