EMPHATIC detector development

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for the EMPHATIC collaboration

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Outline

- EMPHATIC?
- Physics motivation
- Neutrino flux prediction
- Detector development
- Outlook

Experiment to Measure Proton Hadron Production in A Testbeam In Chicagoland Collaboration

EMPHATIC

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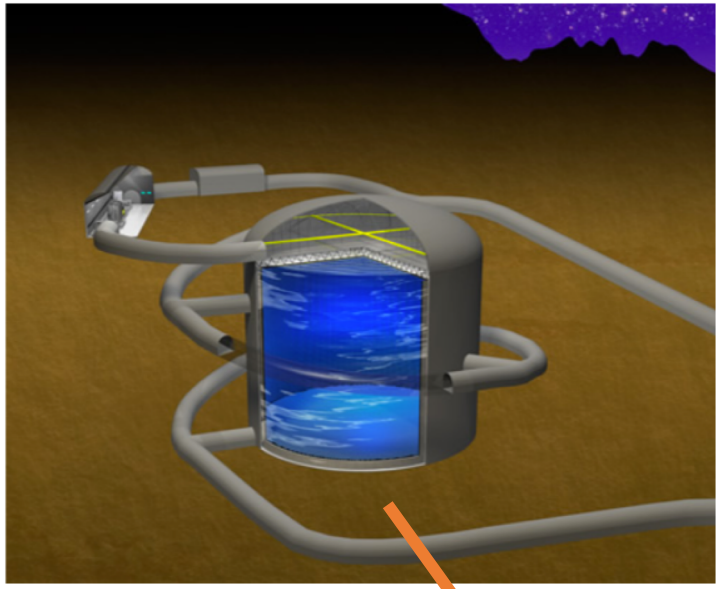
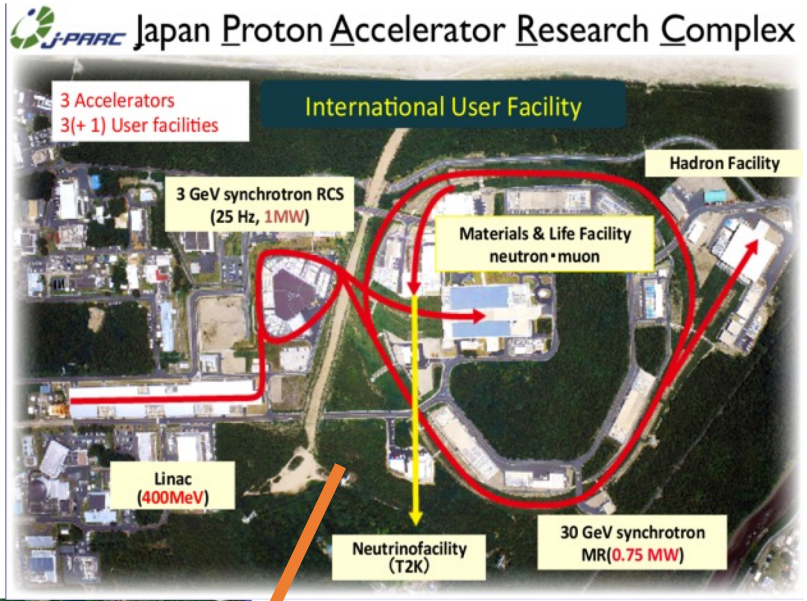
大阪大学 OSAKA UNIVERSITY

中央研究院 ACADEMIA SINICA

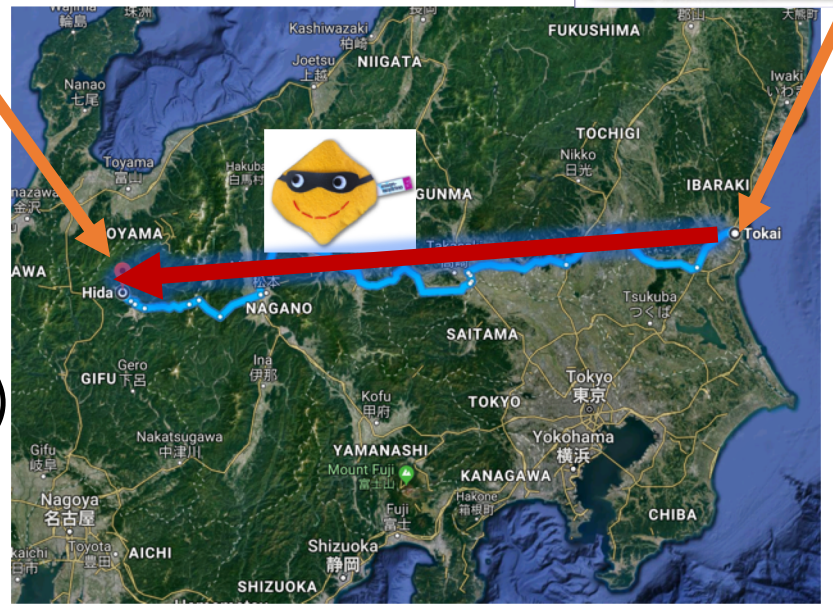
KOBE UNIVERSITY

Motivation: next generation long-baseline search for CP violation in neutrinos will be systematics limited





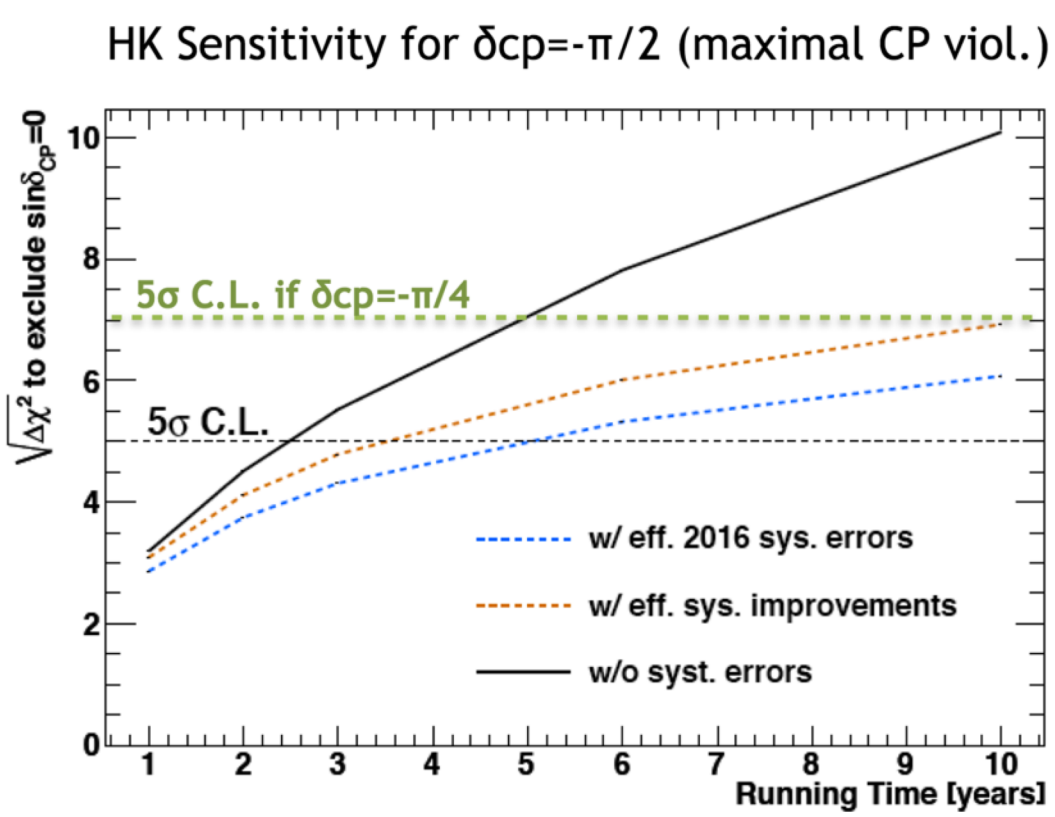
260 kton Water Cherenkov Detector
H = 60 m
ϕ = 74 m
40,000 50 cm PMTs
(40% photo-coverage)
High QE box and line



Upgrade J-PARC neutrino beam to 1.3 MW beam power

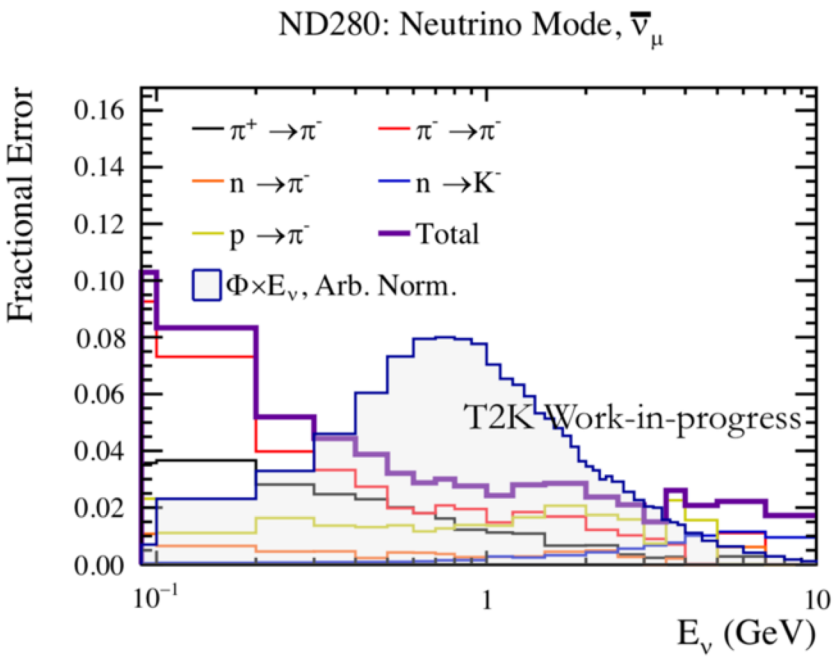
New/upgraded near detectors

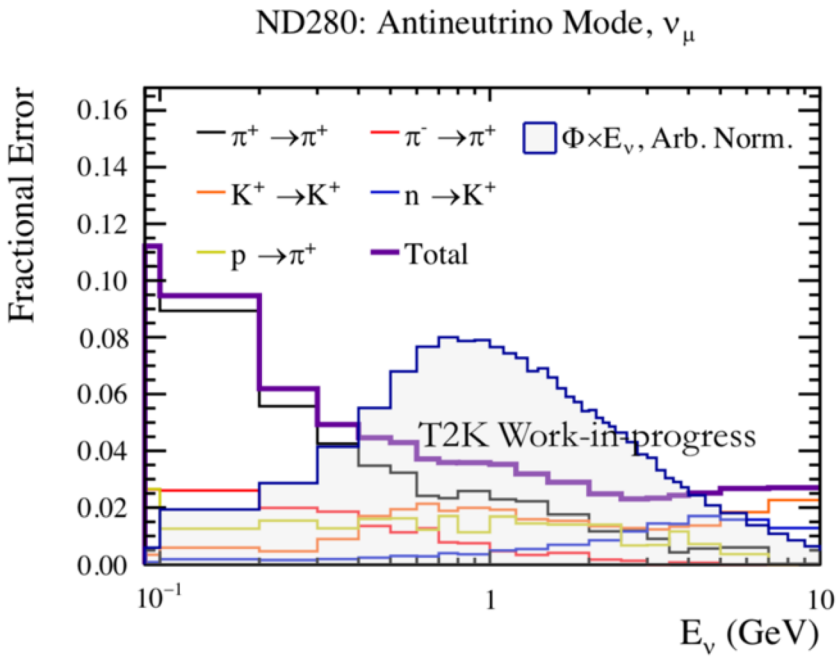
Systematic Uncertainties in HK Era



- Reaching 5σ C.L. for maximal CP will require improved systematic uncertainty estimates
- Will require improved understanding of:
  - Hadron-production distributions
  - ν cross-section
  - Detection efficiencies

Neutrino beam flux uncertainties



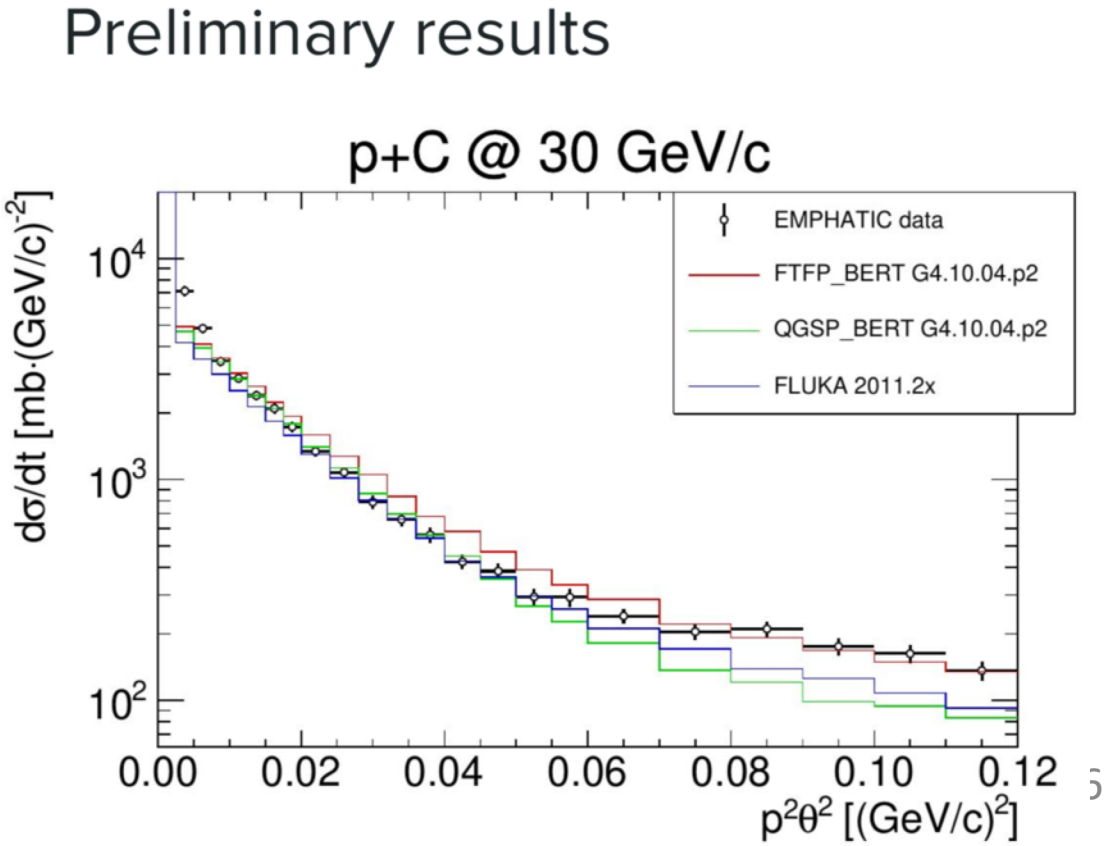


- Large contribution from hadron production uncertainty
- Also from pion and kaon re-scattering in target and in magnetic focusing horns

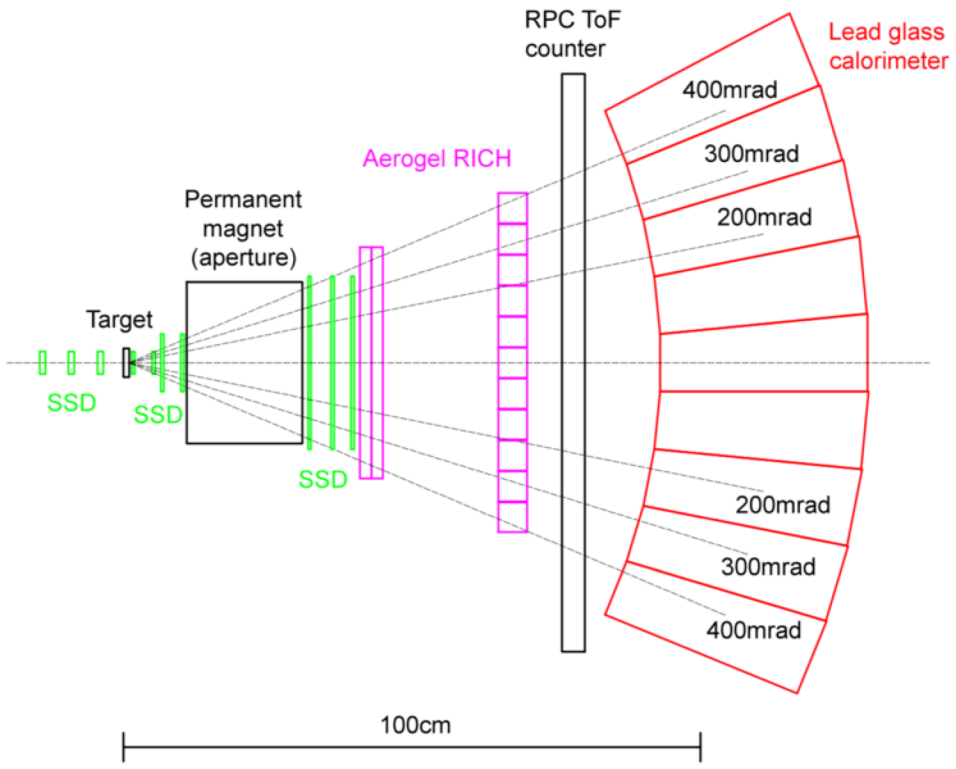
EMPHATIC experiment

- Reduce neutrino flux prediction uncertainties in long-baseline neutrino oscillation
- Compact spectrometer to measure hadron production uncertainties
- Reduce flux uncertainties by factor of two
- Detector development : this poster!

- Fall 2018 results coming soon:
  - Session R2-10 Thu 13:40 Matej Pavin “Measurements of proton-cabon differential cross-sections at 20, 30 and 120 GeV/v in EMPHATIC experiment”

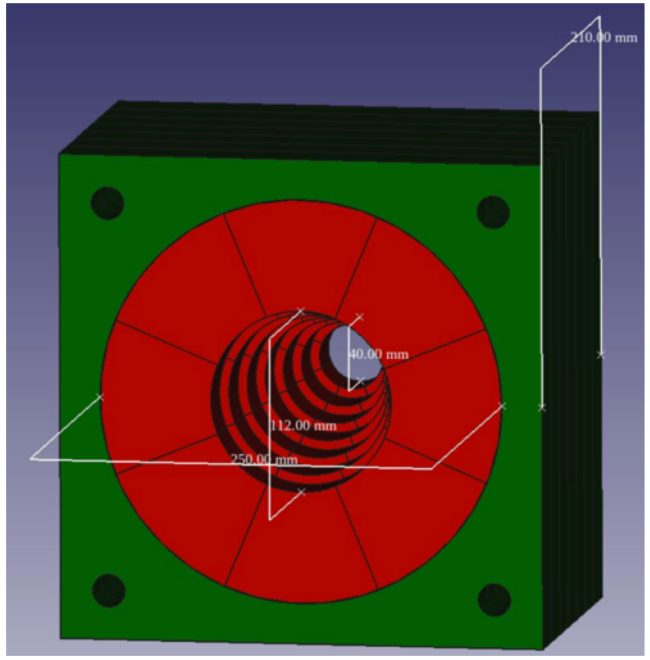


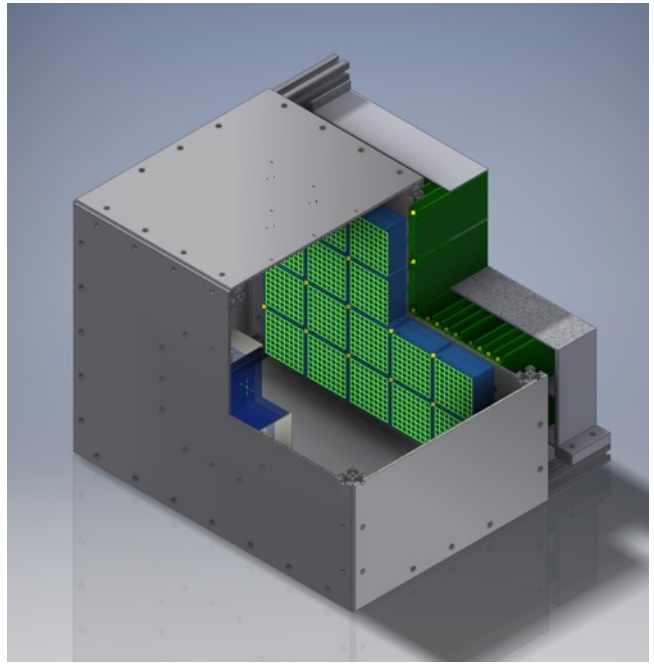
EMPHATIC Spectrometer



- Poster will discuss
  - design of permanent magnet
  - Design of aerogel RICH

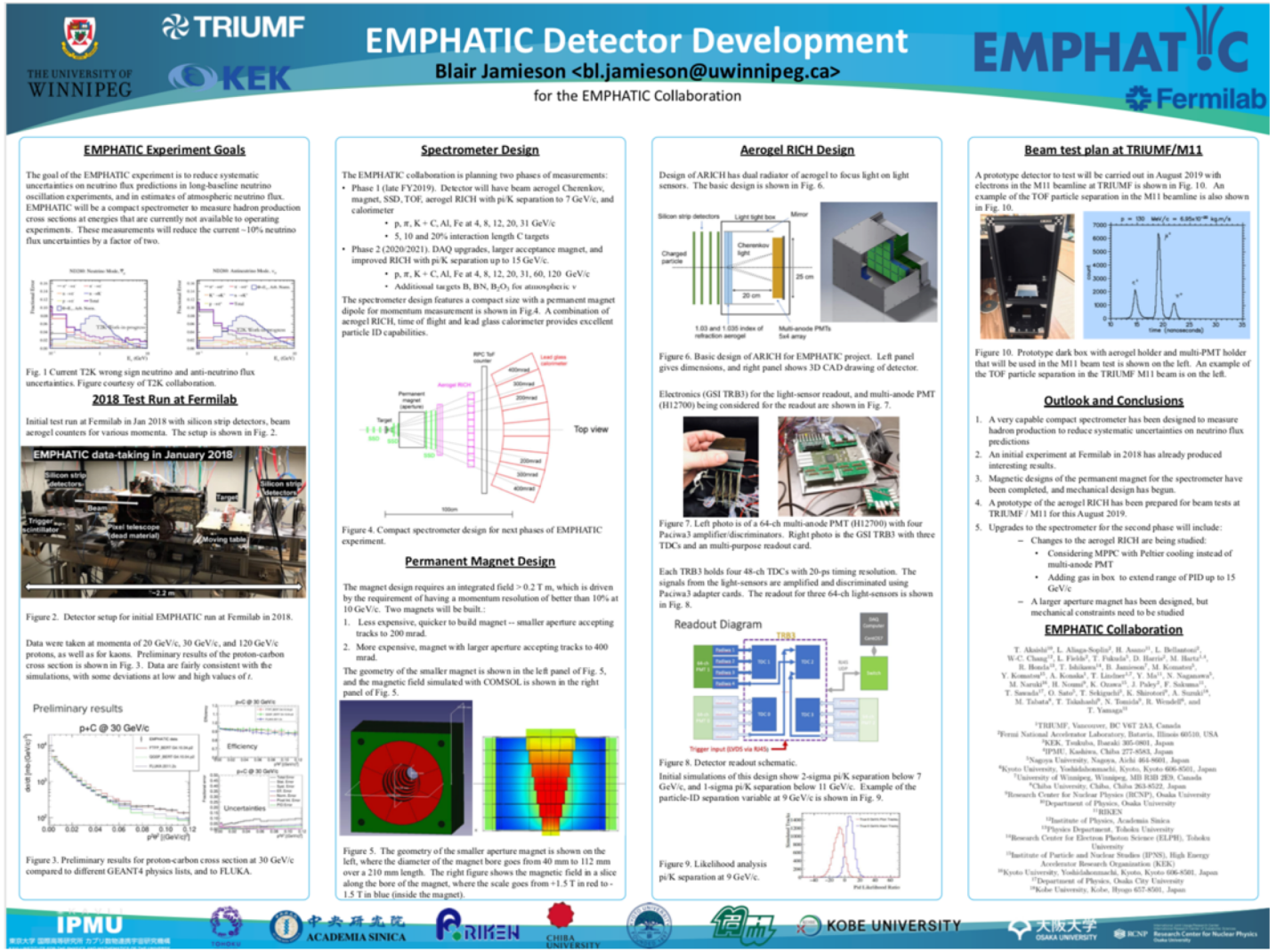
Top view





Thanks for your attention!

- Questions? Come see poster number 62 this evening.



EMPHATIC Detector Development

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EMPHATIC Experiment Goals

The goal of the EMPHATIC experiment is to reduce systematic uncertainties on neutrino flux predictions in long-baseline neutrino oscillation experiments, and in estimates of atmospheric neutrino flux. EMPHATIC will be a compact spectrometer to measure hadron production cross sections at energies that are currently not available to operating experiments. These measurements will reduce the current ~10% neutrino flux uncertainties by a factor of two.

Fig. 1 Current T2K wrong sign neutrino and anti-neutrino flux uncertainties. Figure courtesy of T2K collaboration.

2018 Test Run at Fermilab

Initial test run at Fermilab in Jan 2018 with silicon strip detectors, beam aerogel counters for various momenta. The setup is shown in Fig. 2.

Figure 2. Detector setup for initial EMPHATIC run at Fermilab in 2018.

Data were taken at momenta of 20 GeV/c, 30 GeV/c, and 120 GeV/c protons, as well as for kaons. Preliminary results of the proton-carbon cross section is shown in Fig. 3. Data are fairly consistent with the simulations, with some deviations at low and high values of t'.

Figure 3. Preliminary results for proton-carbon cross section at 30 GeV/c compared to different GEANT4 physics lists, and to FLUKA.

Spectrometer Design

The EMPHATIC collaboration is planning two phases of measurements:

- Phase 1 (late FY2019). Detector will have beam aerogel Cherenkov, magnet, SSD, TOF, aerogel RICH with pi/K separation to 7 GeV/c, and calorimeter
  - p, π, K + C, Al, Fe at 4, 8, 12, 20, 31 GeV/c
  - 5, 10 and 20% interaction length C targets
- Phase 2 (2020/2021). DAQ upgrades, larger acceptance magnet, and improved RICH with pi/K separation up to 15 GeV/c.
  - p, π, K + C, Al, Fe at 4, 8, 12, 20, 31, 60, 120 GeV/c
  - Additional targets B, BN, B_2O_3 for atmospheric ν

The spectrometer design features a compact size with a permanent magnet dipole for momentum measurement is shown in Fig.4. A combination of aerogel RICH, time of flight and lead glass calorimeter provides excellent particle ID capabilities.

Figure 4. Compact spectrometer design for next phases of EMPHATIC experiment.

Permanent Magnet Design

The magnet design requires an integrated field > 0.2 T m, which is driven by the requirement of having a momentum resolution of better than 10% at 10 GeV/c. Two magnets will be built.:

1. Less expensive, quicker to build magnet -- smaller aperture accepting tracks to 200 mrad.
2. More expensive, magnet with larger aperture accepting tracks to 400 mrad.

The geometry of the smaller magnet is shown in the left panel of Fig. 5, and the magnetic field simulated with COMSOL is shown in the right panel of Fig. 5.

Figure 5. The geometry of the smaller aperture magnet is shown on the left, where the diameter of the magnet bore goes from 40 mm to 112 mm over a 210 mm length. The right figure shows the magnetic field in a slice along the bore of the magnet, where the scale goes from +1.5 T in red to -1.5 T in blue (inside the magnet).

Aerogel RICH Design

Design of ARICH has dual radiator of aerogel to focus light on light sensors. The basic design is shown in Fig. 6.

Figure 6. Basic design of ARICH for EMPHATIC project. Left panel gives dimensions, and right panel shows 3D CAD drawing of detector.

Electronics (GSI TRB3) for the light-sensor readout, and multi-anode PMT (H12700) being considered for the readout are shown in Fig. 7.

Figure 7. Left photo is of a 64-ch multi-anode PMT (H12700) with four Paciwa3 amplifier/discriminators. Right photo is the GSI TRB3 with three TDCs and an multi-purpose readout card.

Each TRB3 holds four 48-ch TDCs with 20-ps timing resolution. The signals from the light-sensors are amplified and discriminated using Paciwa3 adapter cards. The readout for three 64-ch light-sensors is shown in Fig. 8.

Figure 8. Detector readout schematic.

Initial simulations of this design show 2-sigma pi/K separation below 7 GeV/c, and 1-sigma pi/K separation below 11 GeV/c. Example of the particle-ID separation variable at 9 GeV/c is shown in Fig. 9.

Figure 9. Likelihood analysis pi/K separation at 9 GeV/c.

Beam test plan at TRIUMF/M11

A prototype detector to test will be carried out in August 2019 with electrons in the M11 beamline at TRIUMF is shown in Fig. 10. An example of the TOF particle separation in the M11 beamline is also shown in Fig. 10.

Figure 10. Prototype dark box with aerogel holder and multi-PMT holder that will be used in the M11 beam test is shown on the left. An example of the TOF particle separation in the TRIUMF M11 beam is on the left.

Outlook and Conclusions

1. A very capable compact spectrometer has been designed to measure hadron production to reduce systematic uncertainties on neutrino flux predictions
2. An initial experiment at Fermilab in 2018 has already produced interesting results.
3. Magnetic designs of the permanent magnet for the spectrometer have been completed, and mechanical design has begun.
4. A prototype of the aerogel RICH has been prepared for beam tests at TRIUMF / M11 for this August 2019.
5. Upgrades to the spectrometer for the second phase will include:
   - Changes to the aerogel RICH are being studied:
     - Considering MPPC with Peltier cooling instead of multi-anode PMT
     - Adding gas in box to extend range of PID up to 15 GeV/c
   - A larger aperture magnet has been designed, but mechanical constraints need to be studied

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