US-Japan proposal

- Precision neutrino oscillation studies
- Potential US-Japan proposal

Akira Konaka (TRIUMF)

Precision era in ν oscillation physics

- Statistics
  - Solar/reactor neutrinos: already in precision era!
  - Long baseline neutrino CP violation studies
    - T2K-II: ~400 events (σ~5%)
    - HyperK: ~3000 events (σ~2%)
  - Atmospheric neutrino studies
    - SK: ~10,000 sub-GeV events (σ~1%) for CP
    - SK: ~30 multi-GeV matter oscillated events (σ~20%)
      an order of magnitude statistics for HK and PINGU
- Systematics is the key for future experiments
  - Let me use ε'/ε as a guide for the discussion

Double ratio (Asymmetry)

- Cancellation of systematic uncertainties:

$$Re(\epsilon'/\epsilon) \sim \frac{1}{3} \times \frac{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-) - \Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-) + \Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)}$$

  – Beam normalization: K_L or K_S
  – Decay modes: $\pi^+\pi^-$ or $\pi^0\pi^0$

- Double ratio for neutrino CP measurement

$$\frac{\Phi_{far}(\nu_e)/\Phi_{near}(\nu_\mu) - \Phi_{far}(\bar{\nu}_e)/\Phi_{near}(\bar{\nu}_\mu)}{\Phi_{far}(\nu_e)/\Phi_{near}(\nu_\mu) + \Phi_{far}(\bar{\nu}_e)/\Phi_{near}(\bar{\nu}_\mu)} \simeq \frac{-16 J_{CP} \sin\Delta_{21} + 16 c_{13}^2 s_{13}^2 s_{23}^2 a/\Delta m_{31}^2}{8 c_{13}^2 s_{13}^2 s_{23}^2}$$

$$\simeq -0.28 \sin\delta_{CP} + (0.07, 0.17, 0.3)\ [T2K, NO\nu A, DUNE]$$

at osc. max

  – Beam normalization: $\Phi_{far}\sigma_{far}/\Phi_{near}\sigma_{near}$
  – Particle types: ν or ν-bar

How well does cancellation work?

- Normalization: $\Phi_{far}\sigma_{far}/\Phi_{near}\sigma_{near}$
  - Near-Far flux shape difference:
    - Wider solid angle at near from line neutrino source: could be suppressed by an intermediate detector
    - Oscillation effect on the far flux: large difference for the wide band beam
  - Cross section: ν_μ (near) and ν_e (far)
    - ν_μ/ν_e cross section difference: a few % uncertainty? radiative correction, 2nd class current, nuclear effect?
    - Significant uncertainty in the background: several %? e.g. high energy tail (near), beam ν_e (far)
  - Flux and cross section need to be constrained separately for a systematics uncertainty of a few % level

How well does cancellation work?

- Particle types: ν or ν–bar
  - Flux is similar for ν and ν-bar
    - similar π^+ and π^- flux at the production target
    - oscillation is the same except for CP viol. & matter effect
  - Cross sections and backgrounds are very different!
    - $d\sigma/dE_\nu$ and $d\sigma/d\theta_\nu$ are different for ν and ν-bar
    - Large wrong sign background for ν-bar
    - CC1π backgrounds are different for ν and ν-bar
    - free proton contribution w/o nuclear effect for ν-bar
  - Flux & cross section need to be studied separately
  - Handle on backgrounds and ν/ν-bar separation

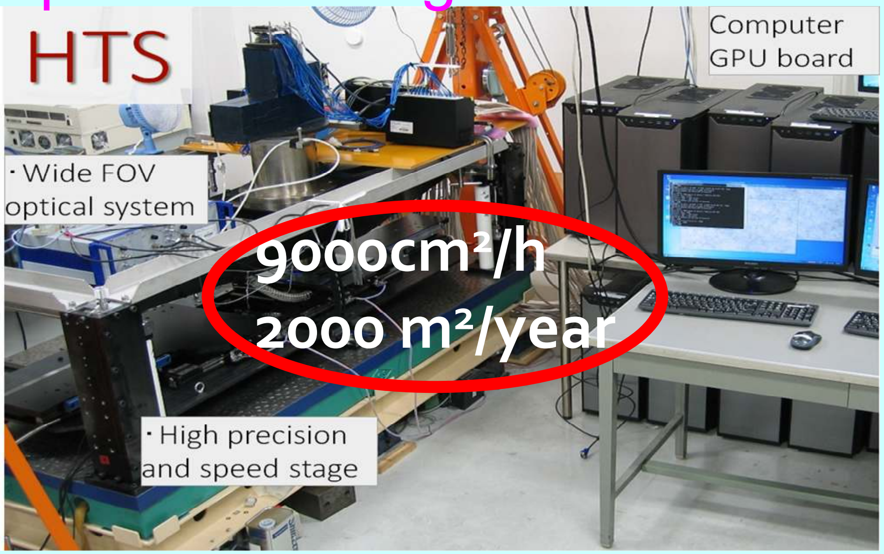
Key components for systematics

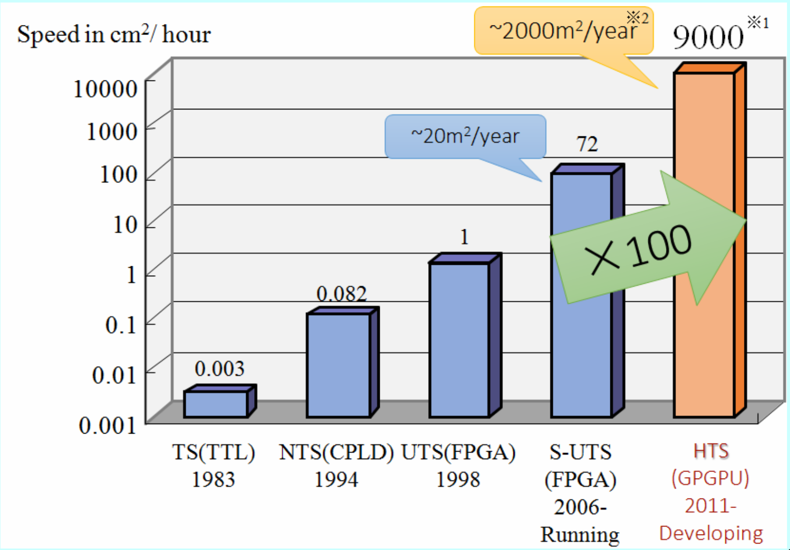
- Systematics that do not cancel remains:
  - several of them at a few% level each:
    Important to study them to achieve a few % systematics
- Flux systematics:
  - Hadron production "Emulsion experiment"
- Cross section systematics
  - Cross section study with flux control "NuPRISM"
- Background identification
  - Gd : wrong sign backgrounds
  - WbLS : wrong sign and CC1π backgrounds
  - mPMT, LAPPD : multi-prong backgrounds
  - Can be tested with controlled flux "NuPRISM"

New readout system

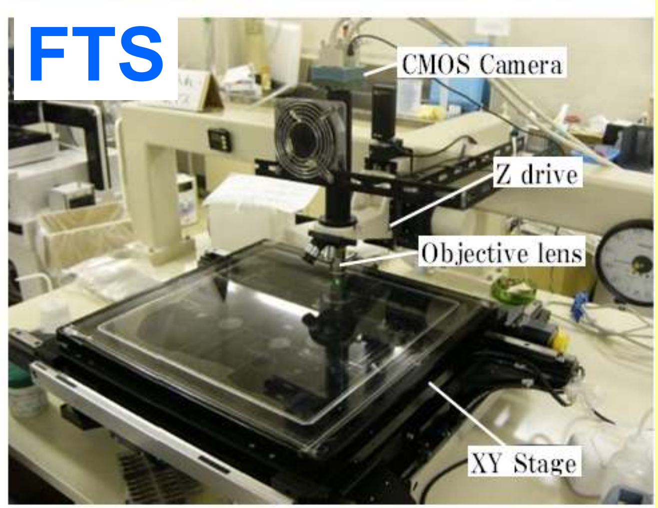
T.Fukuda

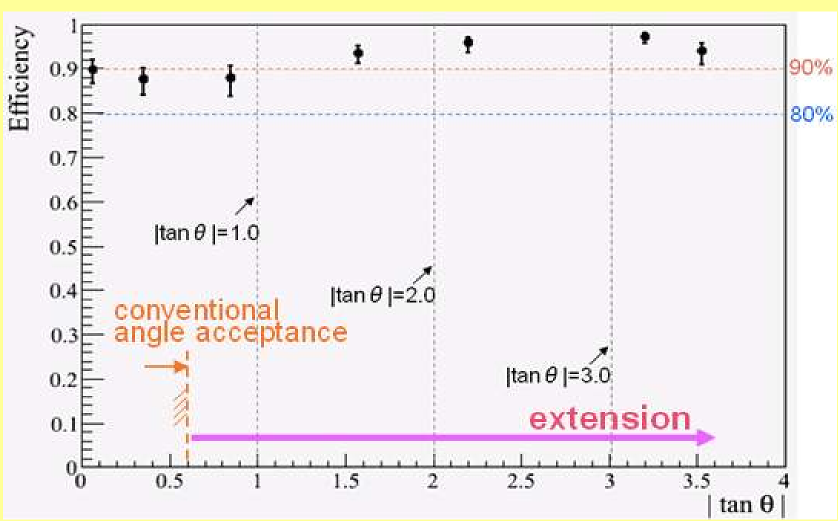
High speed scanning

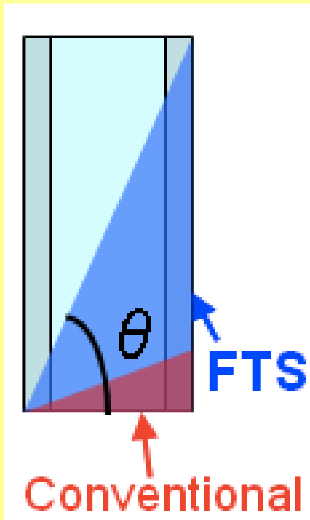




Large angle scanning

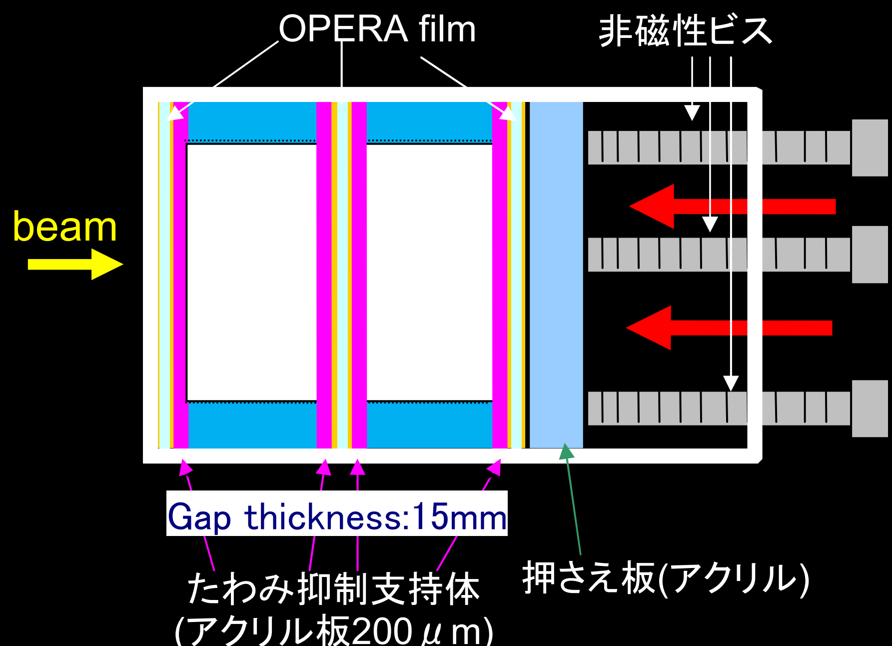


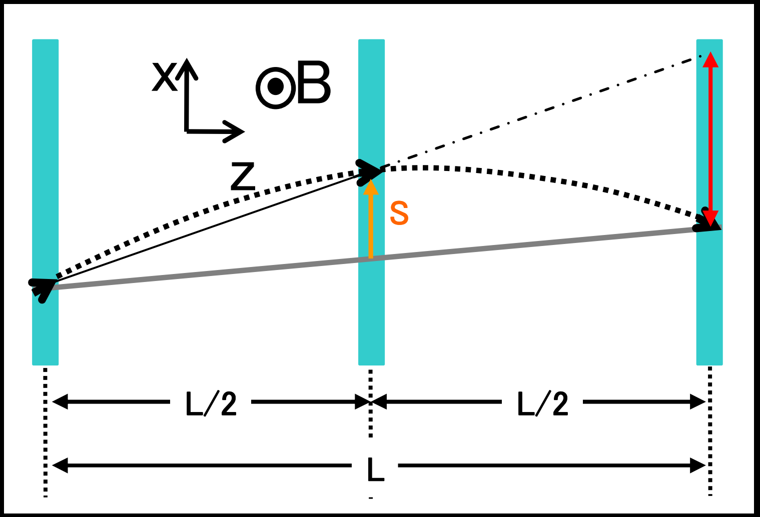




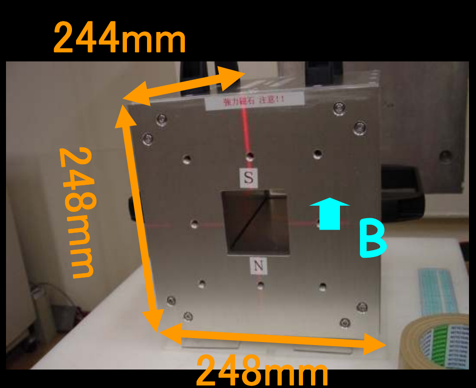
Emulsion spectrometer

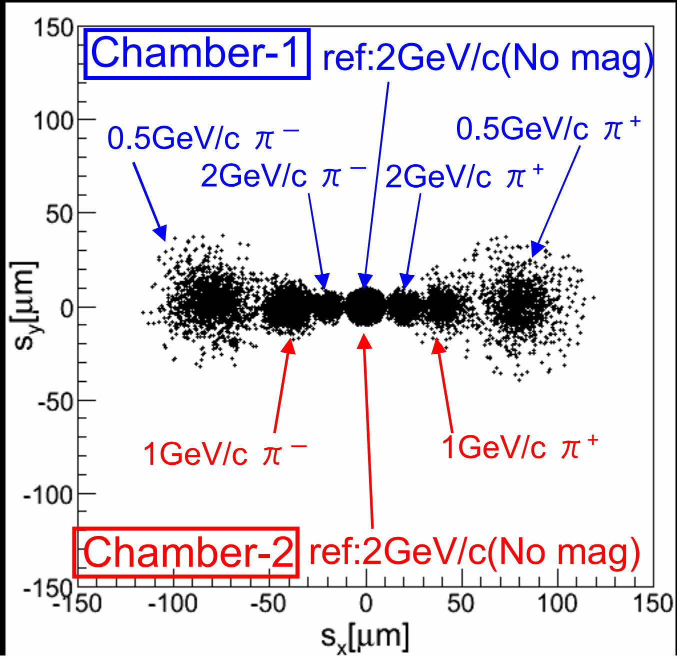
T.Fukuda





Test beam : 15mm gap, B = 1T



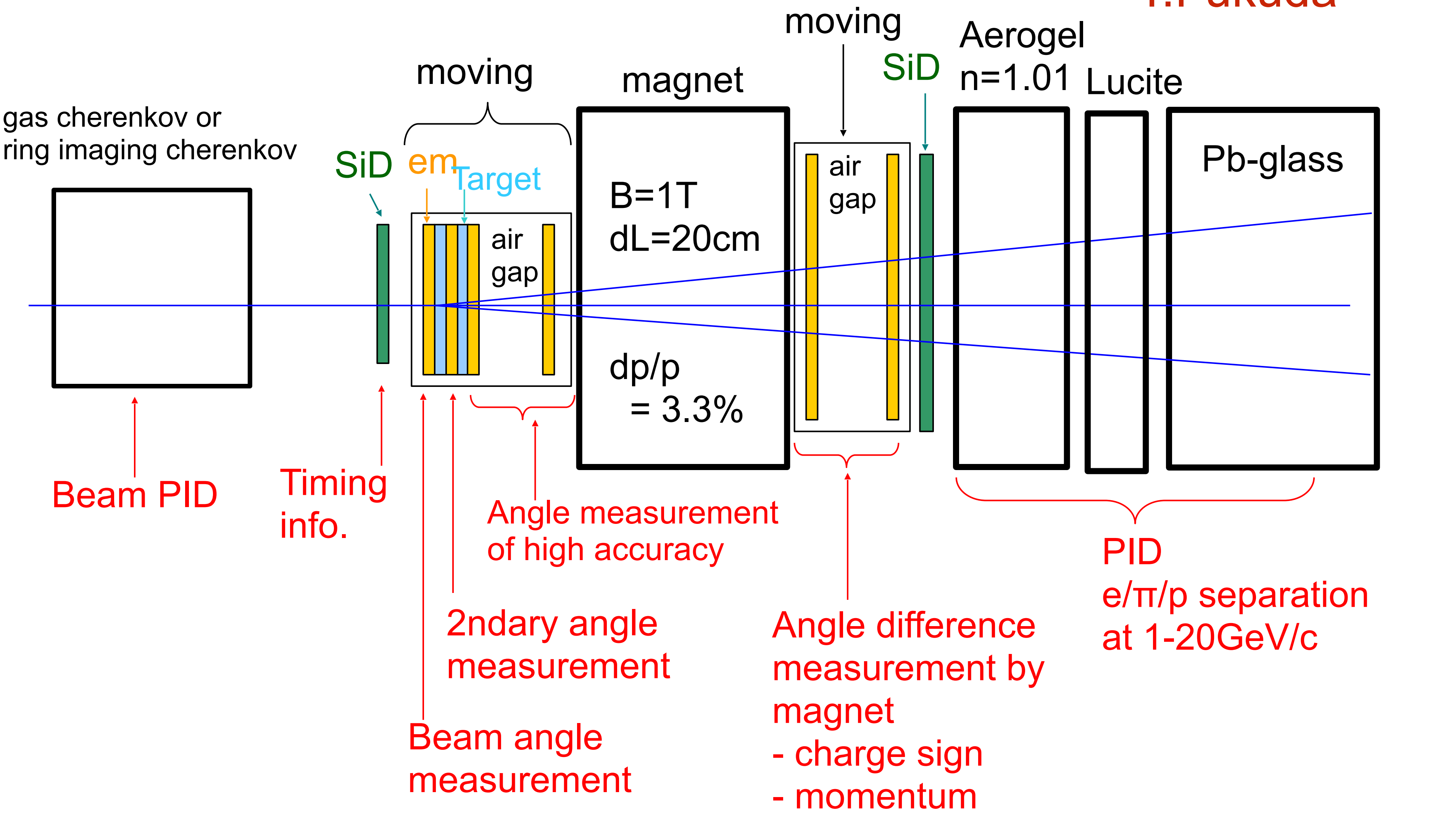


C. Fukushima et al., Nucl. Instr. and Meth. A 592 (2008) 56

An emulsion spectrometer concept

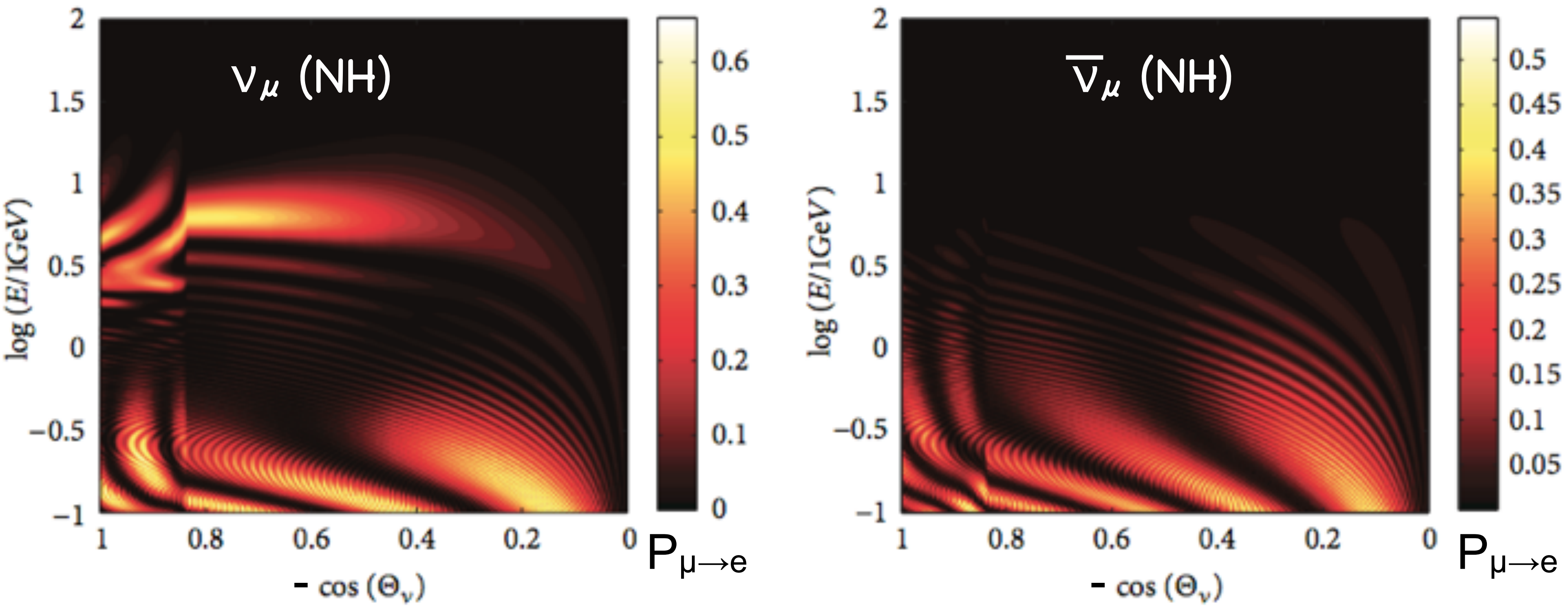
Excellent vertexing at the target
Compact (~1m) and low cost

Originally from T.Fukuda



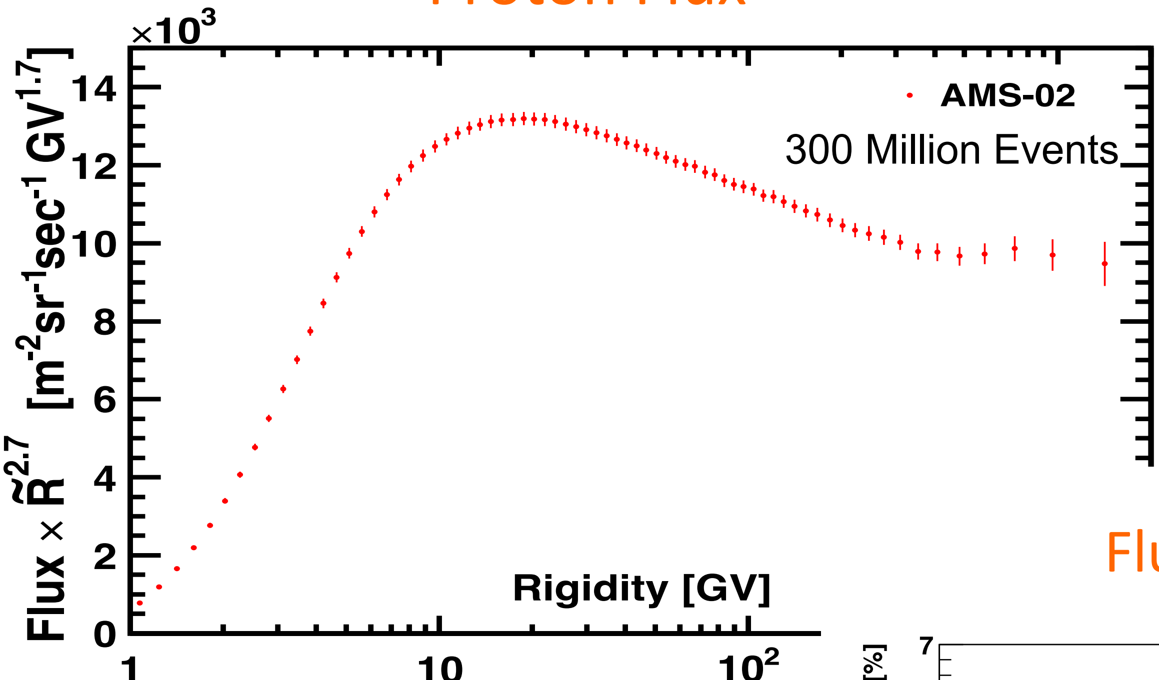
Precision atmospheric $\nu_\mu \to \nu_e$

- $\nu_\mu \to \nu_e$ at several GeV: matter resonance
  - Mass hierarchy determination
- Δ_{12} oscillation in the sub-GeV region:
  - large θ_{12} effect, matter effect, and CP violation
- ν cross section and hadron production are also the key



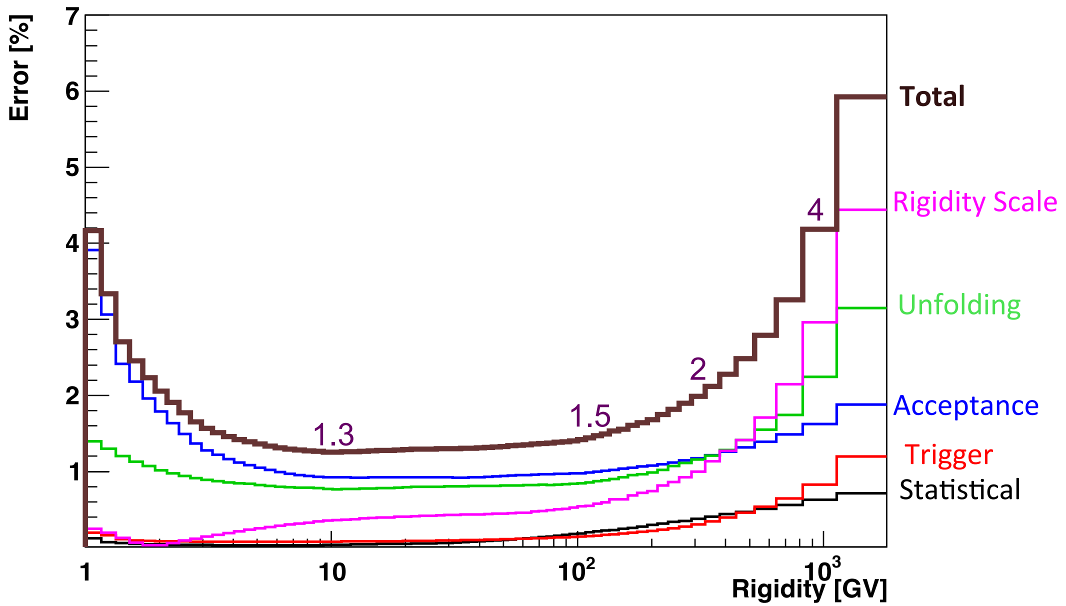
Primary Cosmic Ray Flux (AMS)

Proton Flux



AMS: April 2015

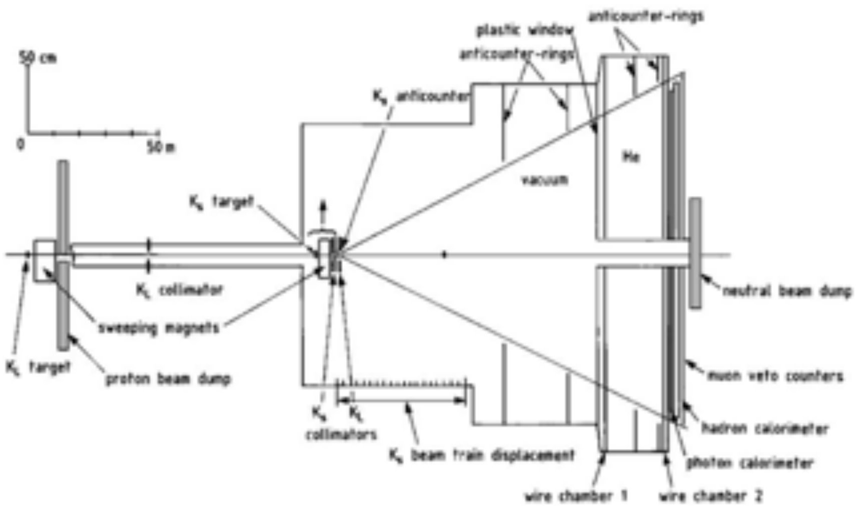
Flux Errors Breakdown

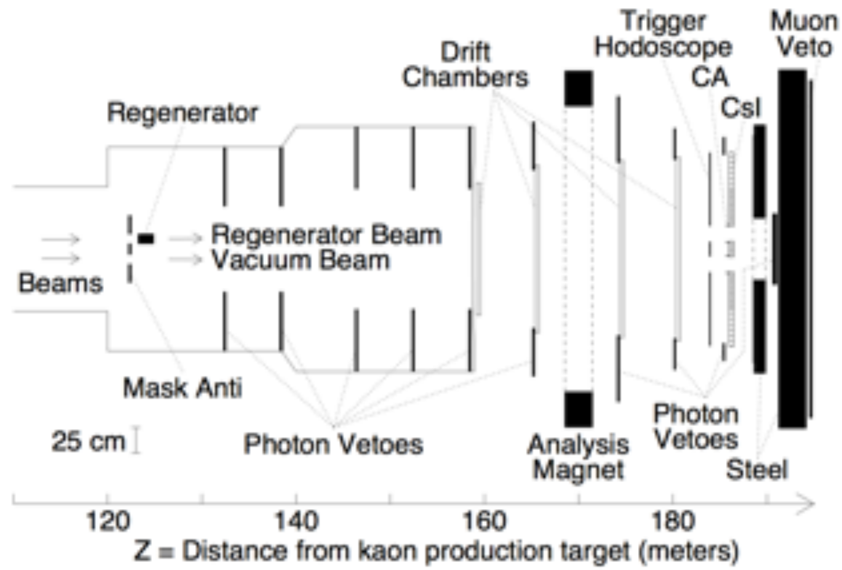


- Primary cosmic ray flux is now measured at 1-2% level.
- Open the door for very precise atm.ν studies with **precise hadron production**

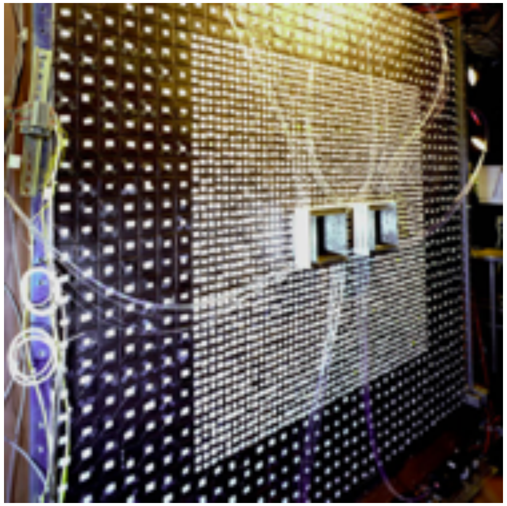
Innovations in ε′/ε

- Dual beam

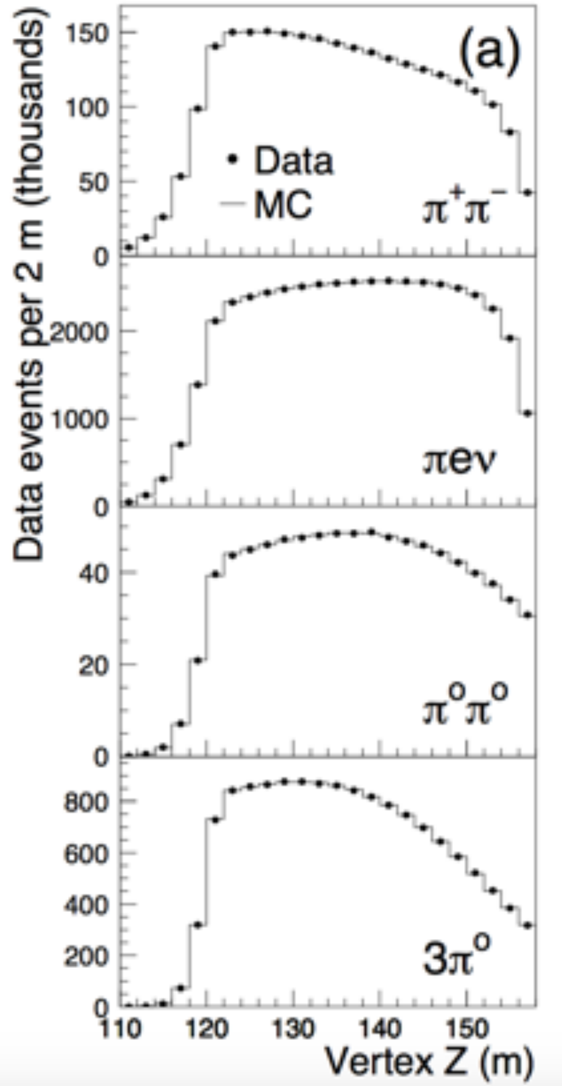


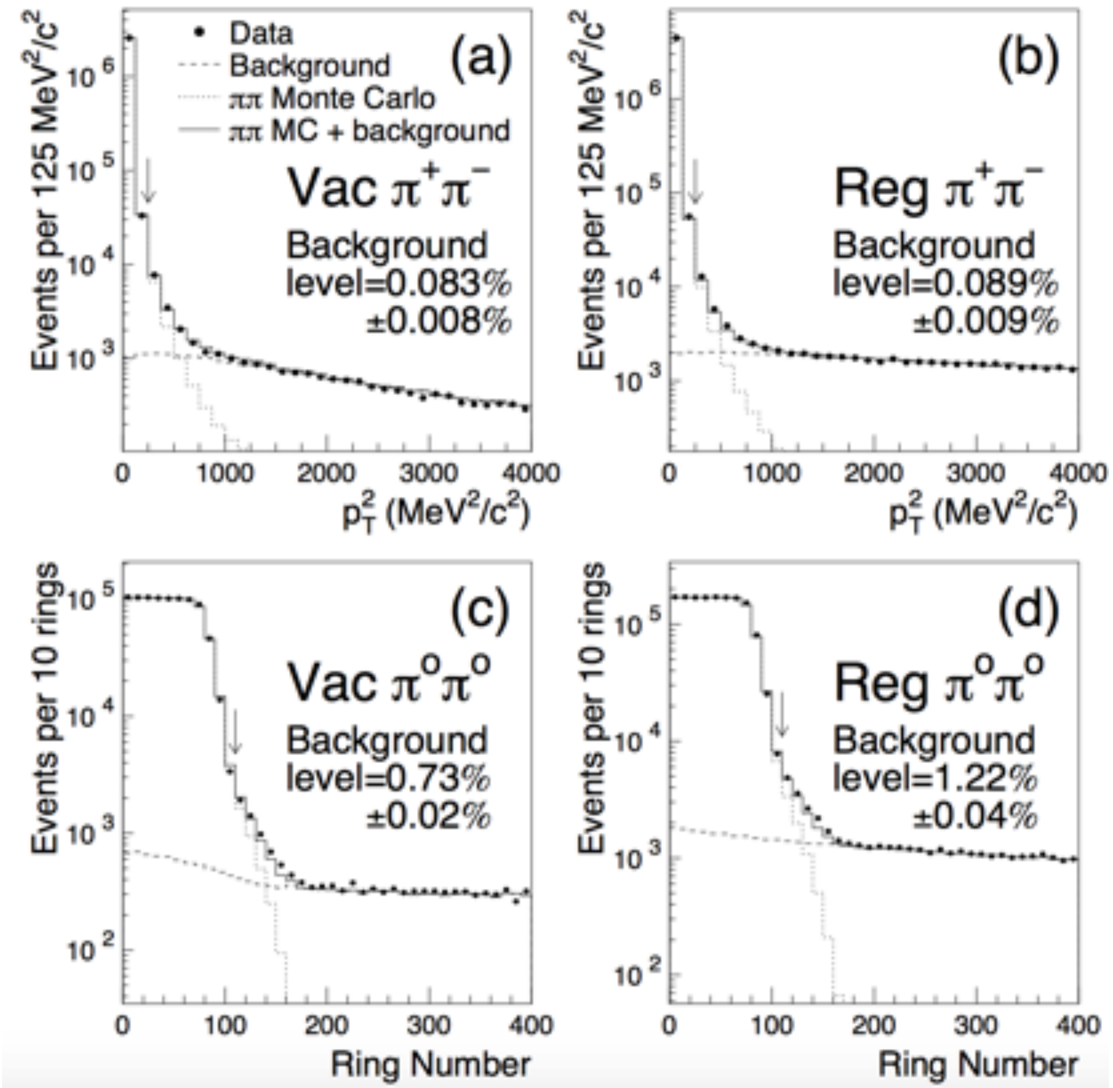


- Precision calorimetry
  - fine grained and excellent resolution
    - Pure CsI (KTeV)
    - Liq. Kr (NA48)



Innovation: Data / Monte Carlo comparison





Innovations for neutrino oscillations

- Large detector technology
  - Liquid Ar detector
  - Water Cherenkov detector
    - Photosensor innovation: large PMT, mPMT, LAPPD
    - Background identification: Gd, WbLS
- Simulations/event reconstructions
  - WCSim, FiTQun, RATPAC, ...
  - NEUT, GENIE, ...
- Untangling neutrino flux and cross section
  - "NuPRISM", "Emulsion hadron production", ...

Communities

- Vibrant K physics community lead by ε'/ε
  - Critical studies on the challenging systematics
    - Competition between NA48(CERN) and KTeV(Fermilab)
  - Rare K-decay community going together
- Neutrino oscillation community is expanding
  - from T2K vs. MINOS/NOvA to DUNE vs. HyperK
    - critical studies on the challenging systematics to come
  - Cosmic/atmospheric ν community going together
- Water Cherenkov community
  - Innovations: Photosensors, Gd, WbLS, software
  - Platforms: NuPRISM, Hadron production

US-Japan special funding request

- For meetings to prepare for the full US-Japan proposal next February.
- With discussion with Japanese neutrino leaders, a request was submitted.
  - Avoiding overlap of personnel with on-going US-Japan program on neutrino technology
- $10k of travel for Japanese members was awarded to attend this meeting

日米科学技術協力事業(高エネルギー物理学分野)特別枠申請書(検討会等開催支援)

氏名	小中　哲　Akira Konaka	職	特任教授	
所属	大阪大学核物理センター			
分野名	素粒子実験　ニュートリノ			
検討会等の詳細				
検討会等の内容	（議論する内容、将来計画との関連性、結論の見通し等） T2Kおよび将来計画であるHyperKの感度の向上のため新しいプロジェクトを立ち上げる為の準備検討を行う。 今年７月のJ-PARC PACに、１−４度のビームオフアクシス角を水チェレンコフ検出器で広く覆うことによりニュートリノ相互作用をモデルによらず測定し、長基線ニュートリノ振動実験や大気ニュートリノ観測実験でのCP非保存パラメータへの感度を向上させる実験nuPRISMが提案される。本検討会はnuPRISM計画をより具体化し日米の協力体制を組織する事を目的として、本年１０月２８−３１日にStonybrookで行われるNNN国際会議のサテライト会議として計画する。この検討会の結論をもとに日米共同研究課題を立案し、翌年度日米事業の本課題としての提案をまとめる事を目指す。 本特別枠では日本の派遣メンバーの旅費を申請する。米国側はnuPRISM spokespersonのMichael Wilkingがホストとなりまた BNLのグループやNNN参加者も参加する予定である。			
開催場所	The State University of New York at Stony Brook			
開催期間	平成２７年１０月２６日　〜　平成２７年１０月２７日			
必要経費				
物件費	件名	単価	員数	計
	合計			円
派遣旅費	氏名	所属・職	日数	旅費見込額
	久世 正弘	東京工業大学　准教授	7	250,000
	石塚 正基	東京工業大学　助教	7	250,000
	住吉　孝行	首都大学東京　教授	7	250,000
	角野　秀一	首都大学東京　准教授	7	250,000
	合計			円
招聘旅費	氏名	所属・職	日数	旅費見込額
	Michael Wilking	Stonybrook Assist. Prof.		
	Kendall Mahn	Michigan State Assist. Prof.		
	合計			円
所要総額				1,000,000円

Constraints on US-Japan grant

- Current US-Japan fund (PI: M.Yokoyama)
  - Covering wide range of R&D for long baseline neutrino
  - Expected to spawn off specific proposals:
    This new US-Japan proposal would fit as a specific project
- Budget
  - Budget can cover travel for Japanese members, equipments and engineering costs
  - Scale: $200-300k/year? (Based on the current funding)
    - considered to be a seed fund for future large funding from other sources
  - Award in May and the fund has to be spent by March
    - request to be submitted every year

Potential scope

- Experiments for precision ν oscillations :
  - NuPRISM for flux independent cross section study
    - Cross section systematics for water Cherenkov for T2K/HyperK, atmospheric/cosmic ν projects
    - Test bed for Photosensor, Gd, WbLS technologies:
      - monochromatic ν beam, atmospheric ν flux responses
      - possibly 2nd phase of ANNIE, development for THEIA?
  - Emulsion spectrometer for hadron production
    - Precise hadron cross section studies at 2-100GeV: Important for all the atm. ν and LBL ν flux studies
    - Experiment to be done at Fermilab and/or CERN
    - JSPS grant request is being submitted by emulsion, atmospheric ν, cross section, beam experts

Timeline

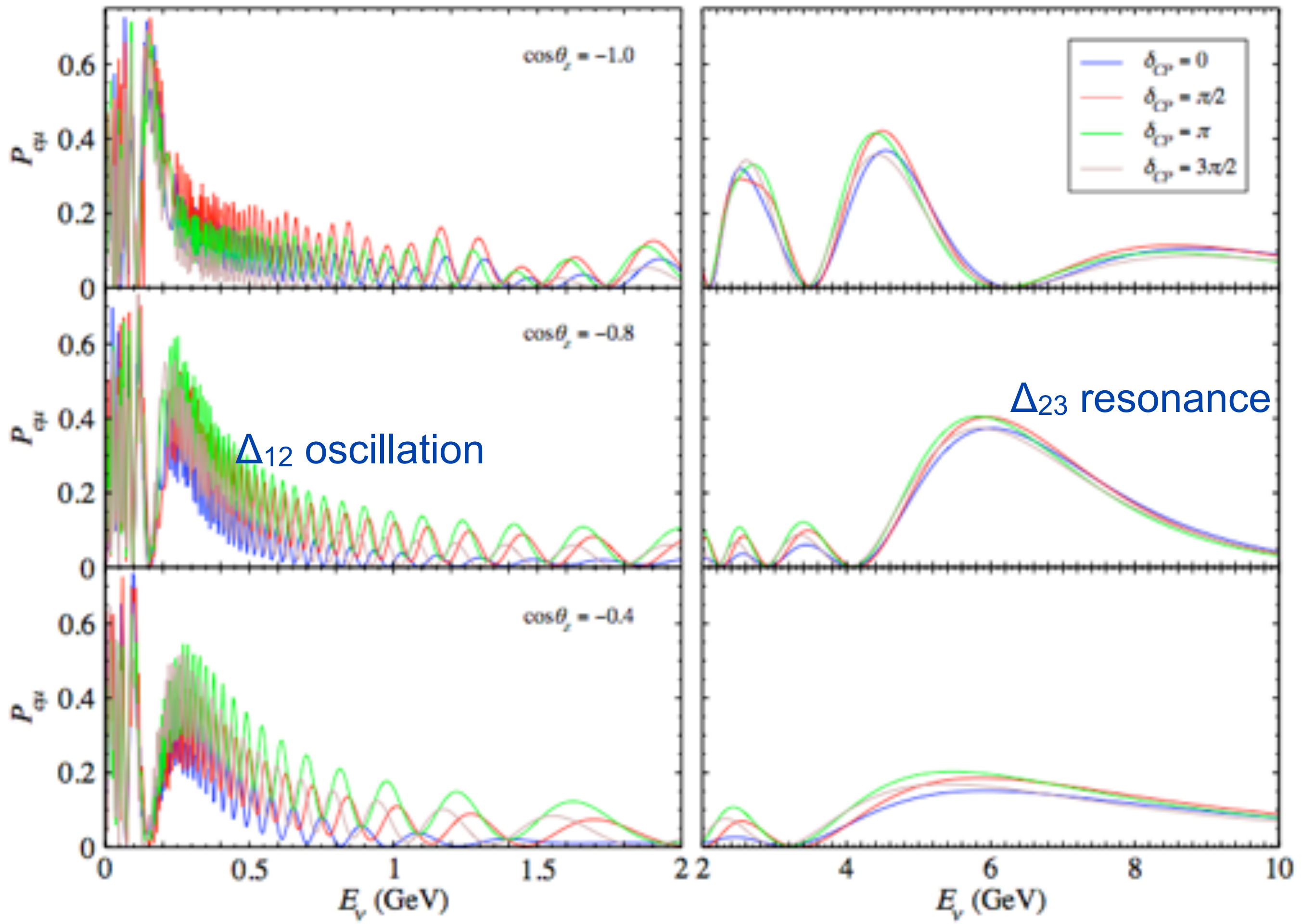
- 2015
  - Oct.27: this workshop
- 2016
  - Early January: call for US-Japan proposal
  - January 13-15: J-PARC PAC
  - February: Deadline for US-Japan proposal
  - March: Japanese committee
  - May: US-Japan committee and fund release
  - ???: Fermilab/CERN PAC's for hadron production

Summary

- Neutrino oscillation enters precision era:
  - Critical study of systematic uncertainty needed: we can learn from the past success (ε'/ε)
- Key components for systematic uncertainties
  - Flux: precision hadron production studies
  - Neutrino cross section: independent of flux
  - Background ID: wrong sign, multi-ring
- US-Japan program to develop a platform?
  - NuPRISM for flux independent cross section study and test the new technologies (photosensor, Gd, WbLS)
  - Hadron production study with emulsion spectrometer

Backup

arXiv:1406.1407 (Smirnov et.al.)



CP violation effect is large! $P_{\mu e}$ ~ up to 20%

- With angular and energy smearing, up to ~5% effect
- ~2% measurement is required