Detectors for Super-Beams and Neutrino Factories

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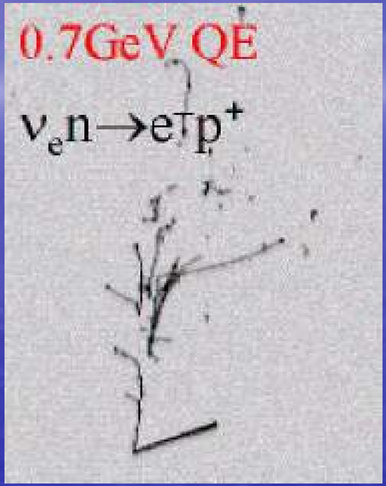
NUFACT ’03
10 June 2003

Acknowledgements

- This summary is greatly informed by:
  - The recent FNAL study on neutrino detectors for super-beams (M. Goodman and D. Harris, chairs)
  - J-PARC ν studies
  - BNL oscillation LOI
  - Recent *Annual Review* on Oscillation Physics at Neutrino Factories (J.J. Gomez-Cadenas, D. Harris)
- Thank you!

Organizational Preamble…

- This is the first of two talks reviewing detectors
  - André Rubbia will cover liquid Argon



- The rationale, courtesy of Hugh Montgomery:

  "Should we hold off for liquid Argon, or should we proceed with the *miserable technologies* we have in hand?"

Miserable Technologies for Super-Beams and Neutrino Factories

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The Catalog of Misery ☹

- Large черенков (Čerenkov) detectors
- Low Z Sampling Calorimeters
- Magnetized Fe Sampling Calorimeters
- And their "issues"…
  - efficiencies and backgrounds
  - construction and funding realities

for superbeams,
$\nu_\mu \rightarrow \nu_e$,
accept ν_e CC.
Reject π^0

for neutrino factories,
$\nu_e \rightarrow \nu_\mu$ (gold), ν_τ (silver)
accept "wrong-sign" CC.

The Ground Rules

- After the present generation of superbeams (NUMI, CNGS), order of magnitude increases in flux appear difficult
  - corollary: also difficult to increase the number of facilities by an order of magnitude
- To reach sensitivity to CP violation in oscillations, we must improve detectors
  - size ↑, signal efficiency ↑, backgrounds ↓
  - or add new capabilities, e.g., electron charge (André)

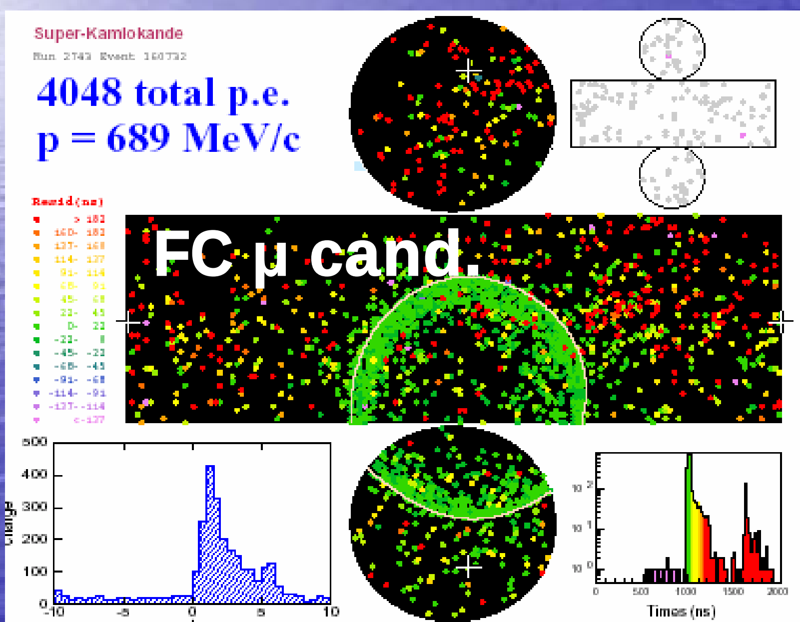
Teragram[§]-Class Water Čerenkov

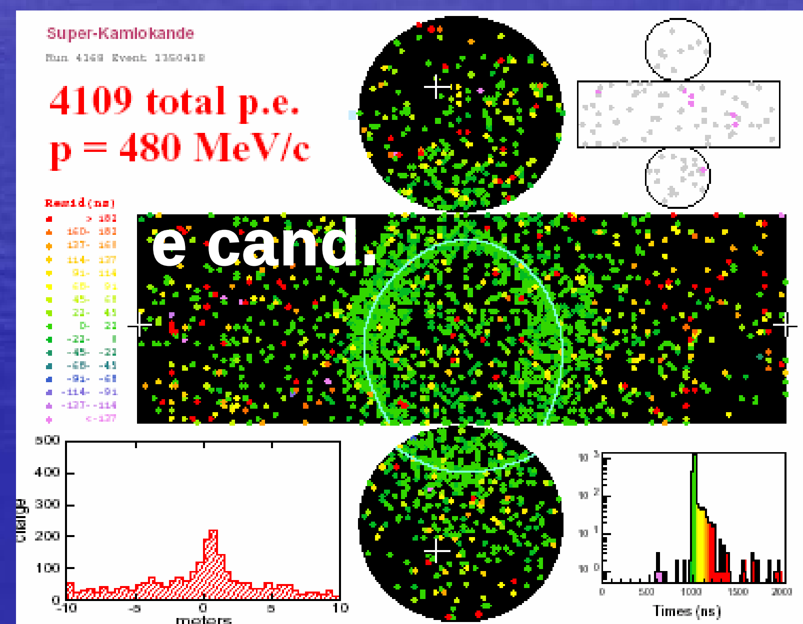
- Perceived widely as a "straightforward" extension of existing engineering
- No shortage of proposals, e.g., Hyper-K, UNO
- No shortage of sites, e.g., DUSEL, Frejus, Kamioka, etc.
- Physics case is "broad"
  - proton decay, neutrino astrophysics

[§] *Labeling this a "Megaton" detector would be an enormous public relations mistake. We need to expunge this unfortunate jargon ASAP before someone overhears us…*

Teragram H_2O Č : Signatures I

- Elegant proof of e/μ separation from Super-Kamiokande atmospheric neutrino results
  - Sub-GeV single-ring dominated: "Sharpness!"

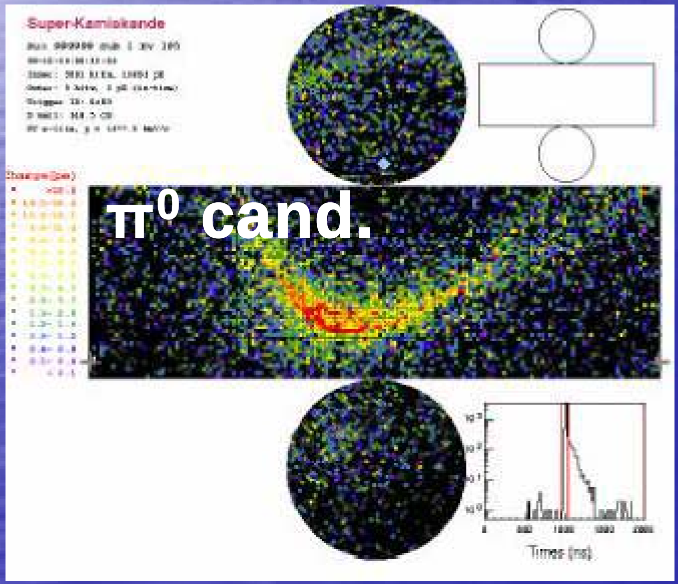


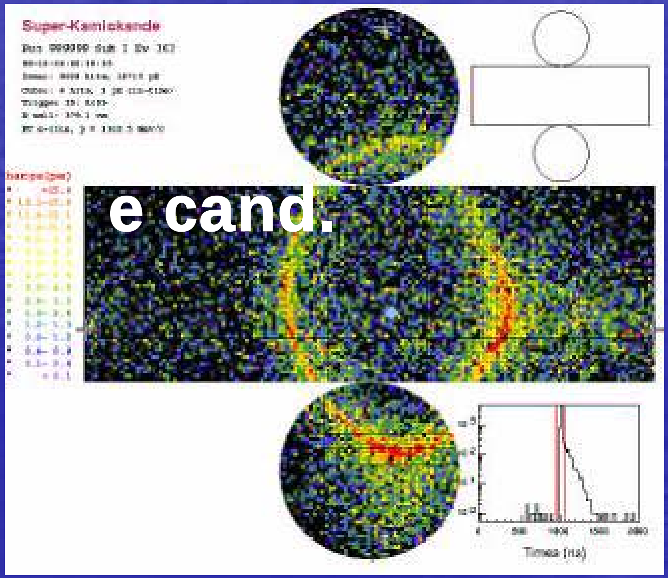


Figures courtesy M. Messier

Teragram H_2O Č : Signatures II (cont'd)

- e/π^0 separation is a more subtle business
  - Multi-ring topologies more difficult
  - At high energies, $\pi^0 \rightarrow \gamma\gamma$ more "closed"

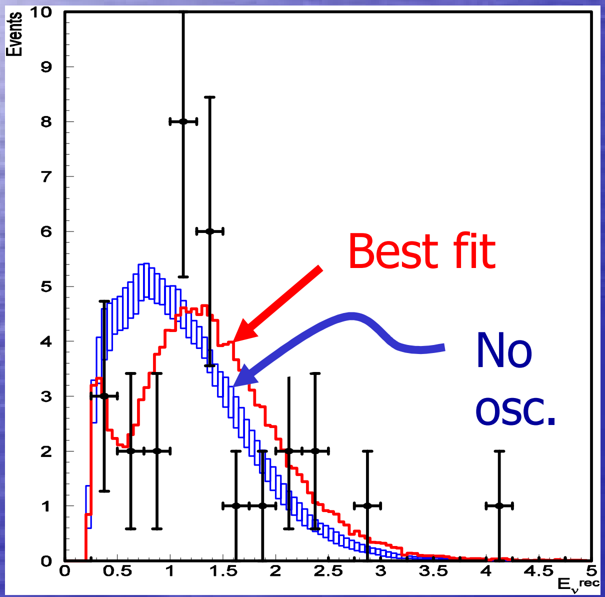




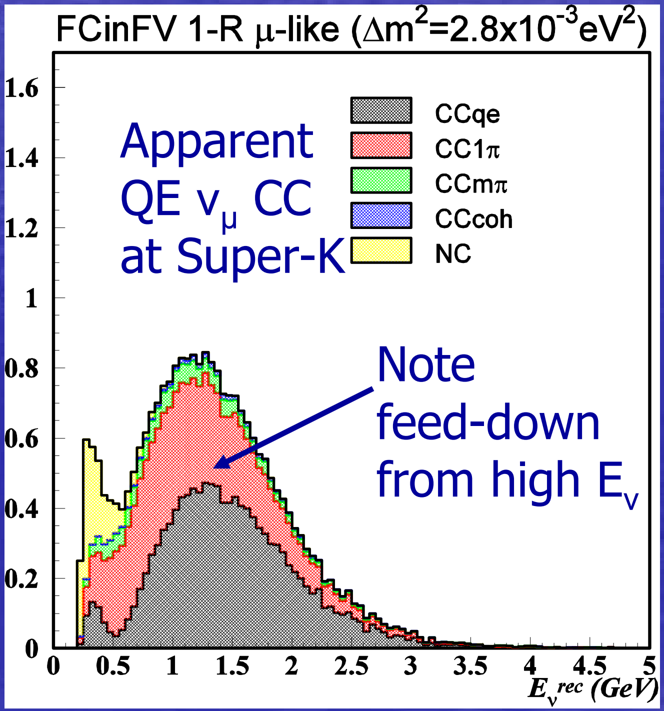
Figures courtesy M. Messier

Teragram H_2O Č : Signatures II (cont'd)

- Also, many processes contribute to single-ring
  - Example: K2K (broadband) beam at Super-K
  - At E_ν~3 GeV, FC 1-ring μ candidates are *1/3 QE, 1/3 single π, 1/3 "DIS"*



Figures courtesy T. Kajita



Teragram H_2O Č : Signatures II (cont'd)

- Can avoid problems by sticking to low energy, quasi-elastic regime (and paying a rate price!)

Flux *(not rate)* on and off-axis

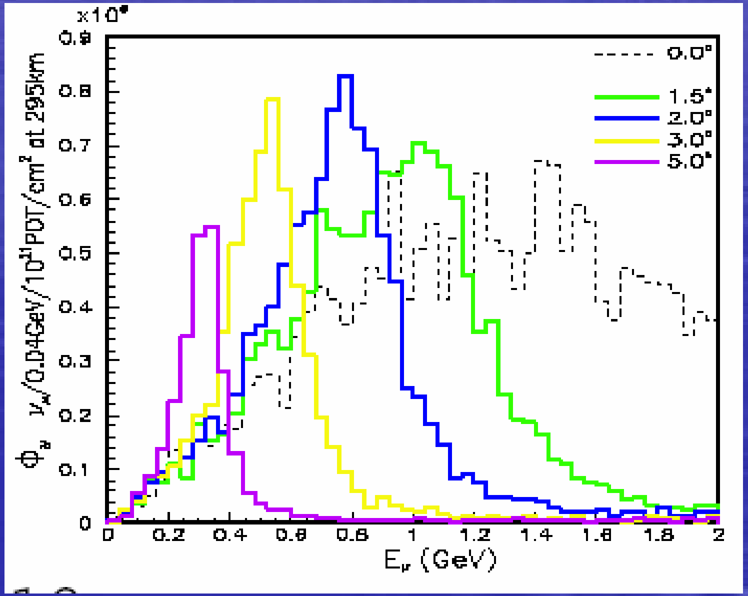
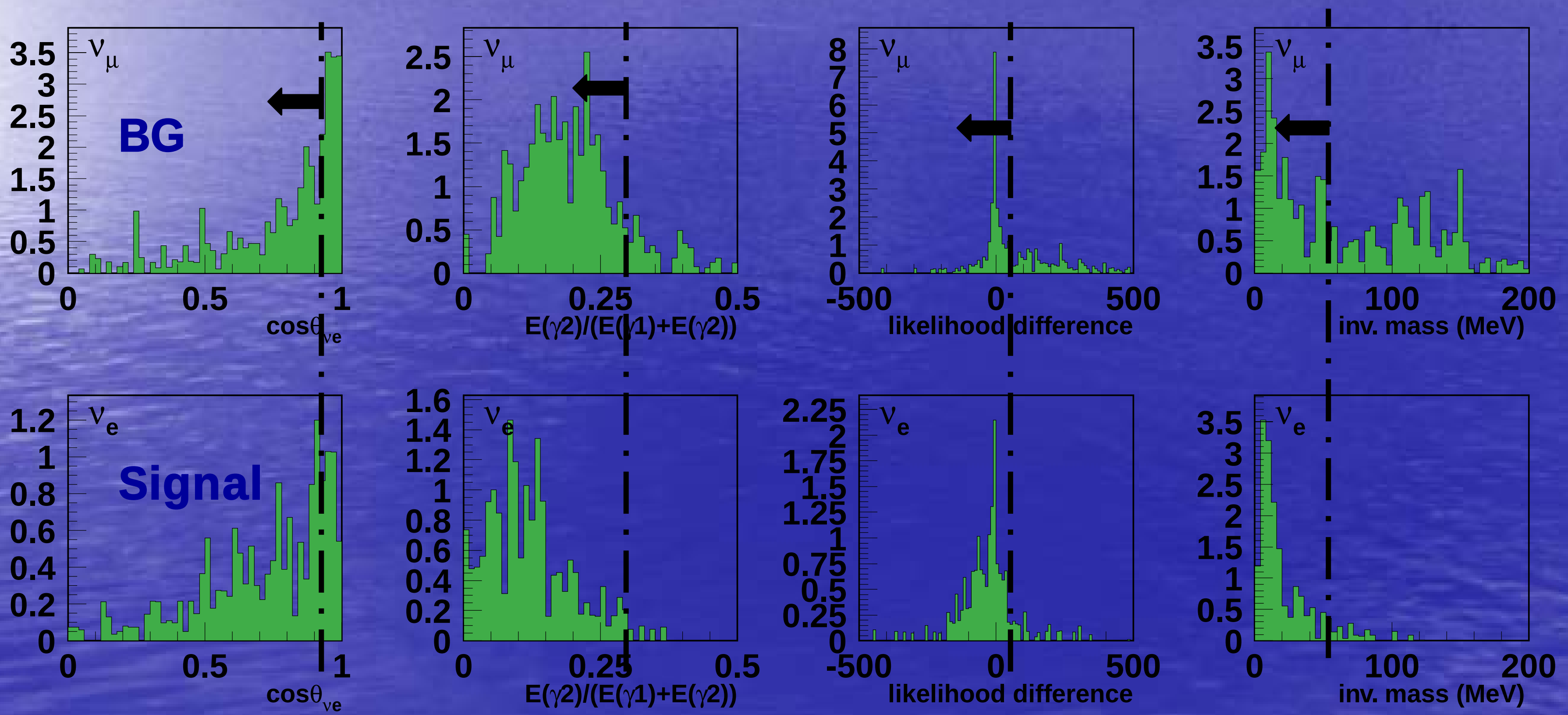


Figure courtesy
A. Konaka

Teragram H_2O Č : Signatures II (cont'd)

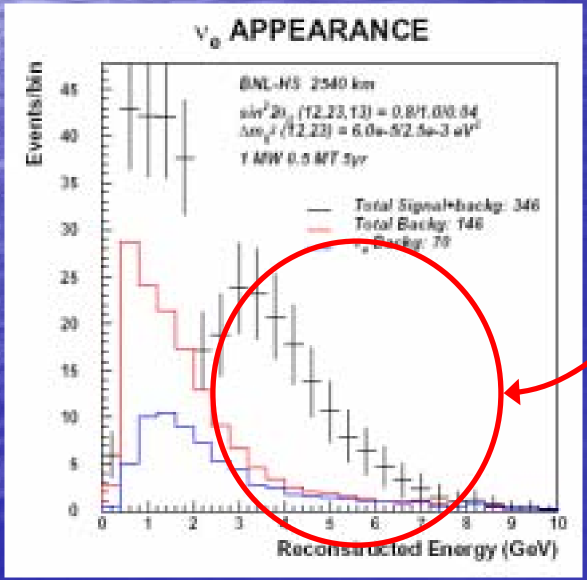
- e/π^0 separation demonstrated (in low E_ν OA beam)
  - but it will be a complicated multi-variate business

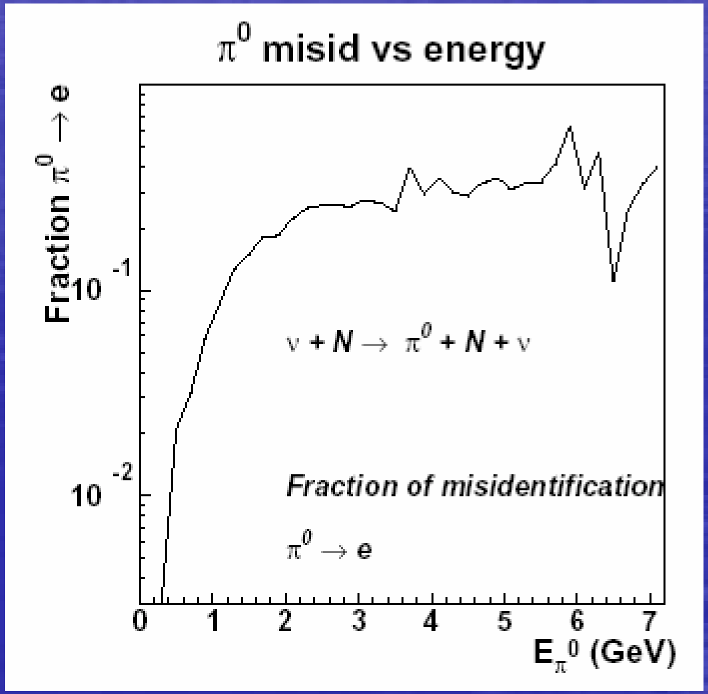


Figures courtesy T. Kajita

Teragram H_2O Č : Signatures II (cont'd)

- *Editorial comment*: e/π^0 separation is much tougher at high energies
  - BNL proposal (in my view) needs more to demonstrate feasibility of this rejection
  - Background control relies on rarity of single pions at high $E_{\pi 0}$
  - Note that single-ring events in this region are mostly inelastic!





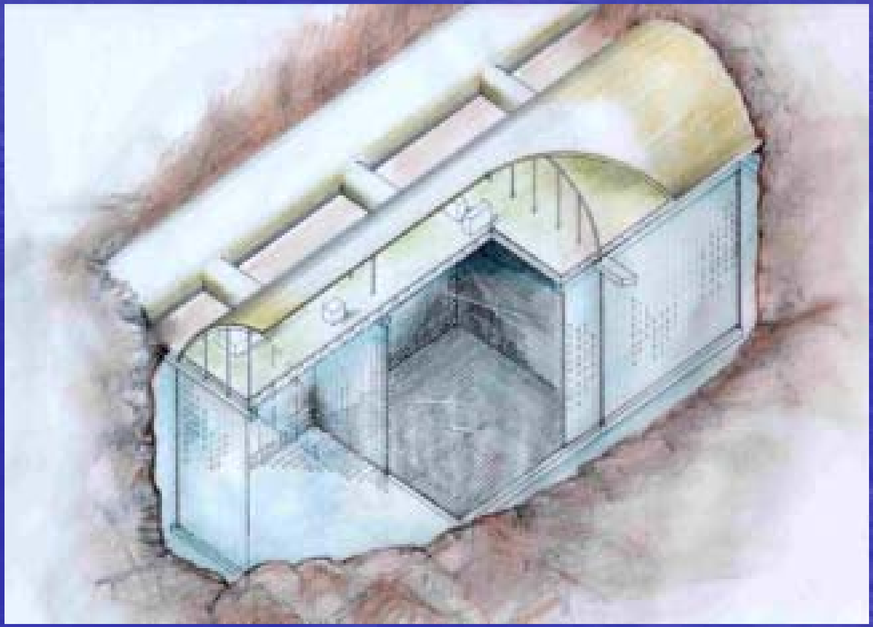
Single π^0 background vs $E_{\pi 0}$ (M. Diwan)

Teragram H_2O Č : Technology

- Contained detector with instrumented wall has been extensively studied at engineering level
- "Open" technology (CNGT) historically risky
- Photosensors
  - figure of merit at low E: (coverage)×(quantum eff.)
  - is this figure of merit identical for use of H_2O Č as a neutrino target?

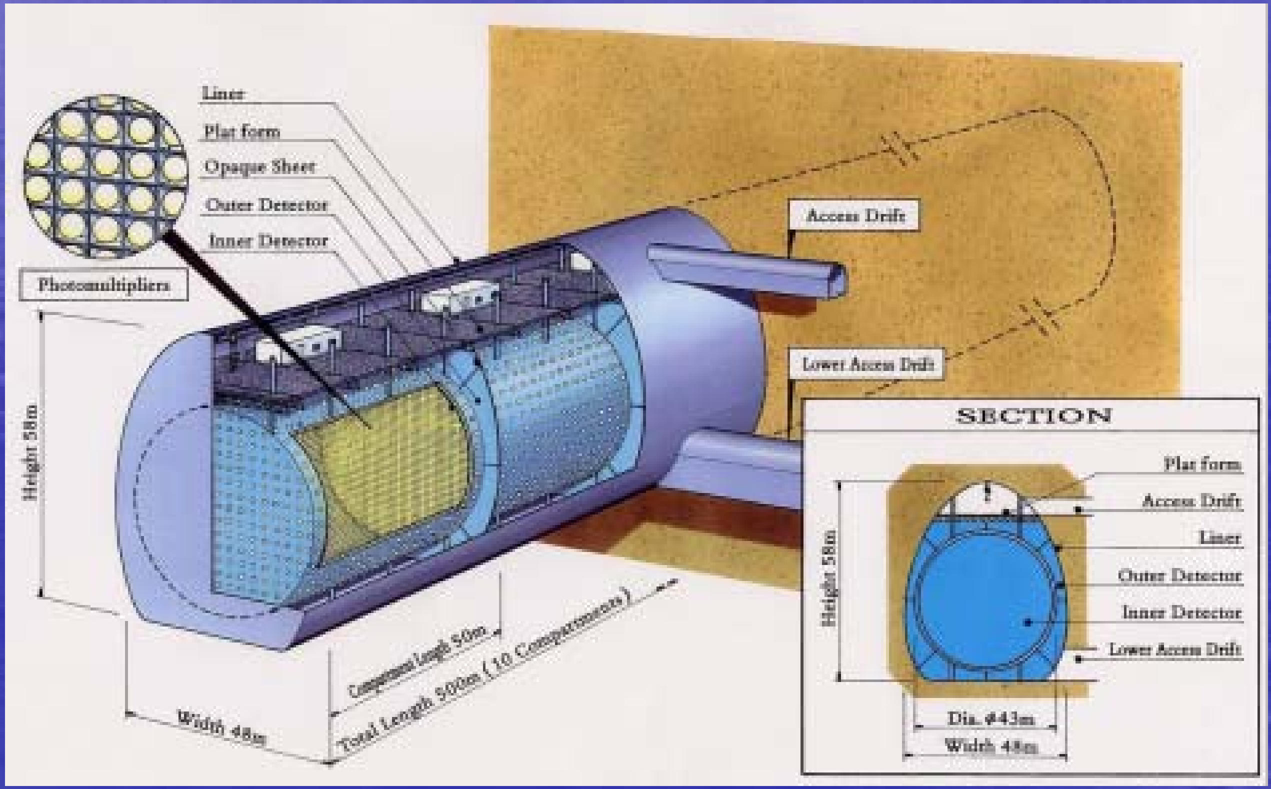
Teragram H_2O Č : Technology (cont'd)

- Some UNO details:
  - depth reduced by "sideways" topology
  - two photocathode density zones to lower sensor costs
    - middle zone is high density for nucleon decay and solar ν
    - edge zones lower density: suitable for atmospheric and beam ν



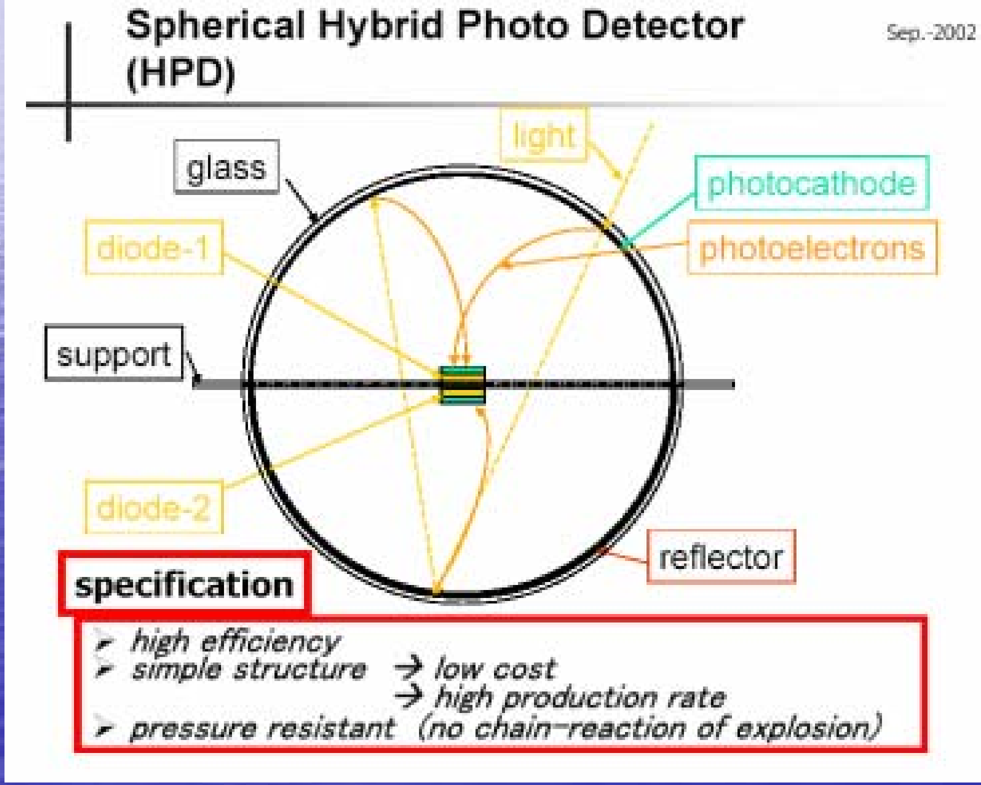
Teragram H_2O Č : Technology (cont'd)

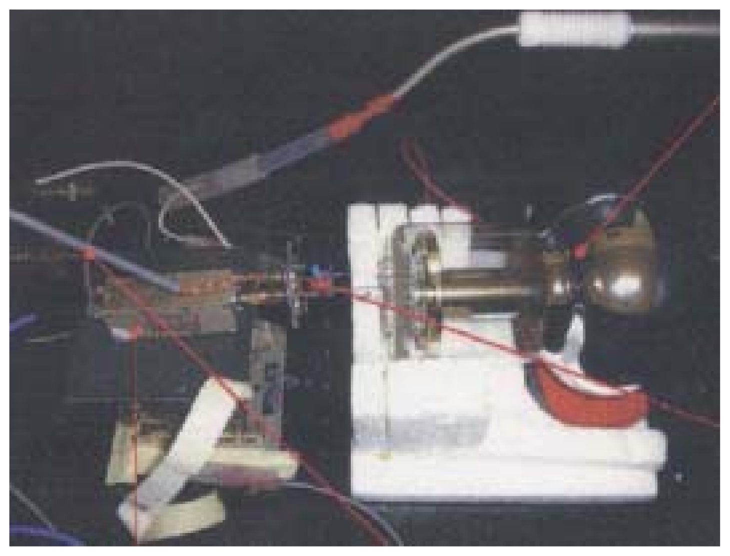
- Some Hyper-K details:
  - sideways cylinder limits depth, simplifies geometry with beam
  - copious segmentation (10 modules)



Teragram H_2O Č : Technology (cont'd)

- Photosensor R&D: can one drive down cost?

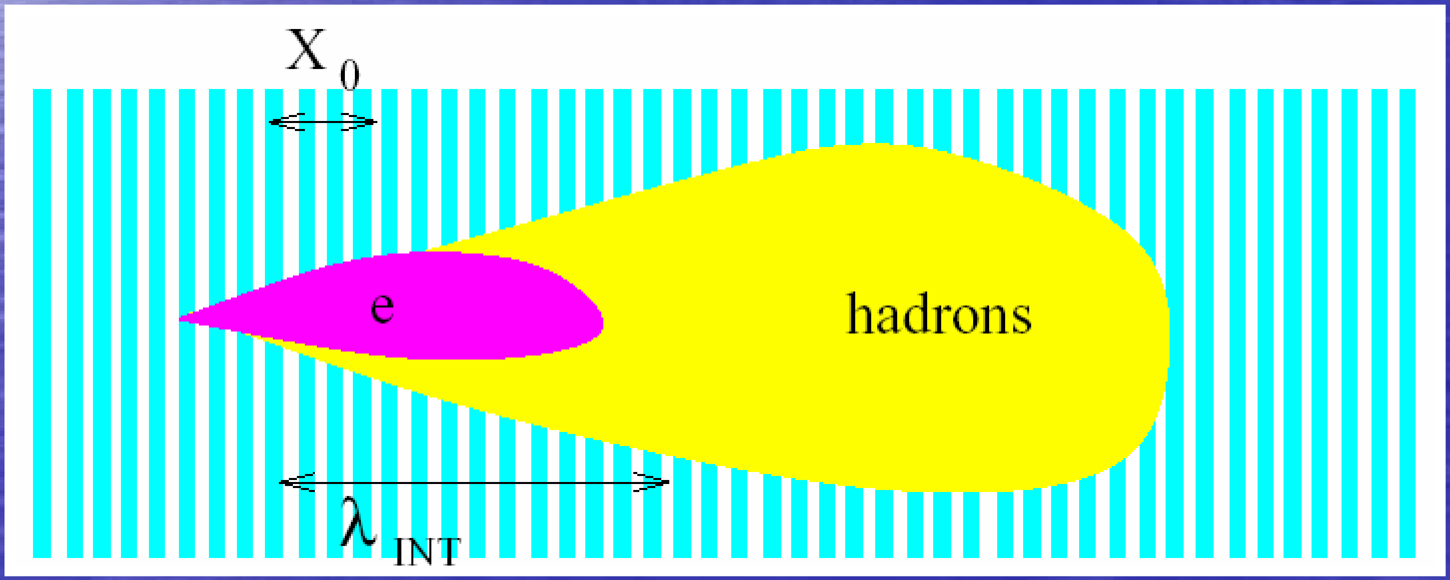




5 inch HPD prototype
(Shiozawa, NP02)

Low-Z Sampling Calorimetry

- The concept in a nutshell:
  - Low Z absorber in a calorimeter ⇒ X_0 increases for fixed mass
    - improved resolution for electromagnetic showers
      - key for π^0/e separation



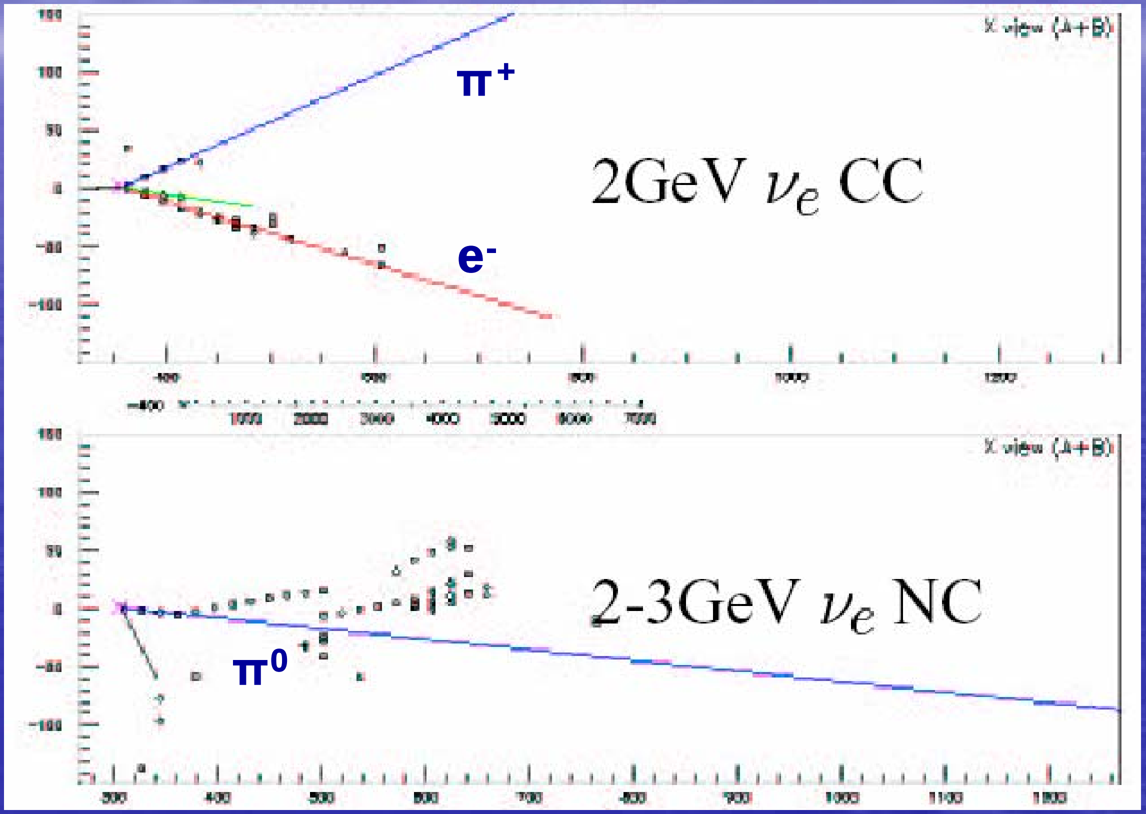
Low-Z Sampling Calorimetry (cont'd)

- Issues: coping with increased size per unit mass
  - Construction/building issues
  - Structural issues of absorber
  - Increased number of ionization sensors
- All lead to a new generation of requirements of industrial capability for detector construction

Low-Z: Signatures (cont'd)

In theory…

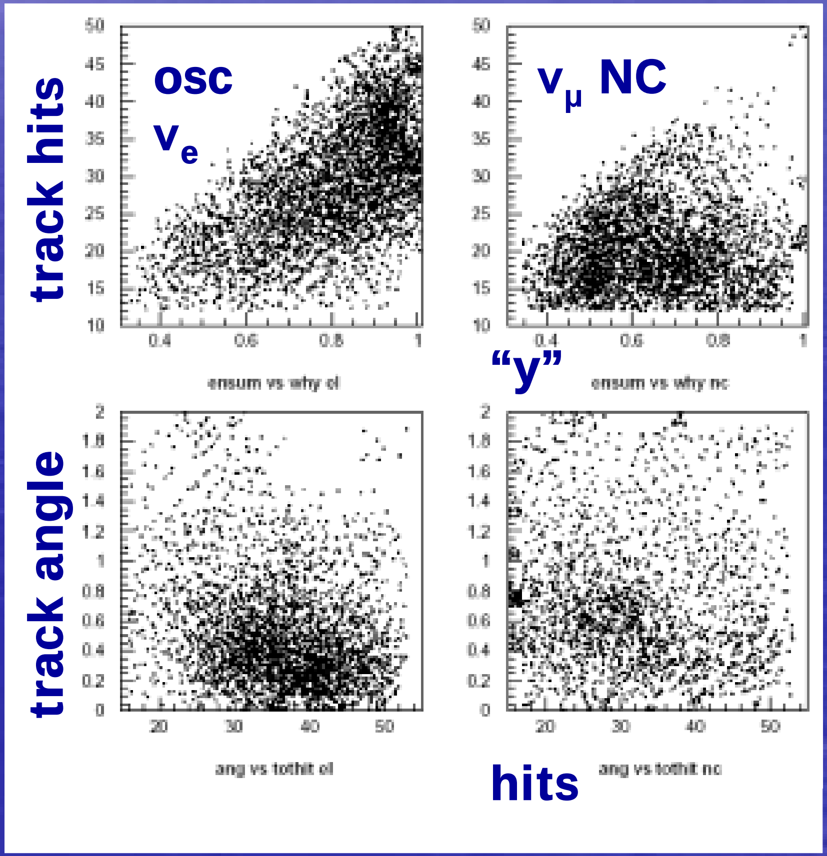
- With long X_0, two photons should rarely be degenerate
- Other final state particles well separated



figures courtesy A. Para

Low-Z: Signatures (cont'd)

- Preliminary efficiency and backgrounds…
  - with realistic detector, see $\varepsilon \sim 10^{-3}$, few$\times 10^{-4}$ for NC, CC, respectively
  - maintain ~40% efficiency for signal
- For $P(\nu_\mu \rightarrow \nu_e)$, see high $(S/\sqrt{B}) \sim 40$
  - $\delta m^2 = 2.4\times 10^{-3}$, $\sin^2\theta_{13} = 0.1$, 200kTon-yr, 4×10^{20} POT/yr NUMI



figures courtesy L. Camilleri

Low-Z: Technologies

- First things first… can we afford absorber?
  - visions of walnut shells, cracked corn, “all liquid”…
- Real question: can we afford *structural* absorber
  - one idea: Particle board (wood scrap + glue)
    - very strong against compression along board
    - laminations of sheets provide sound 3D structures
  - 50 kTon of particle board is two weeks of production at one northern Minnesota plant; cost is ~15 MUSD cut & delivered

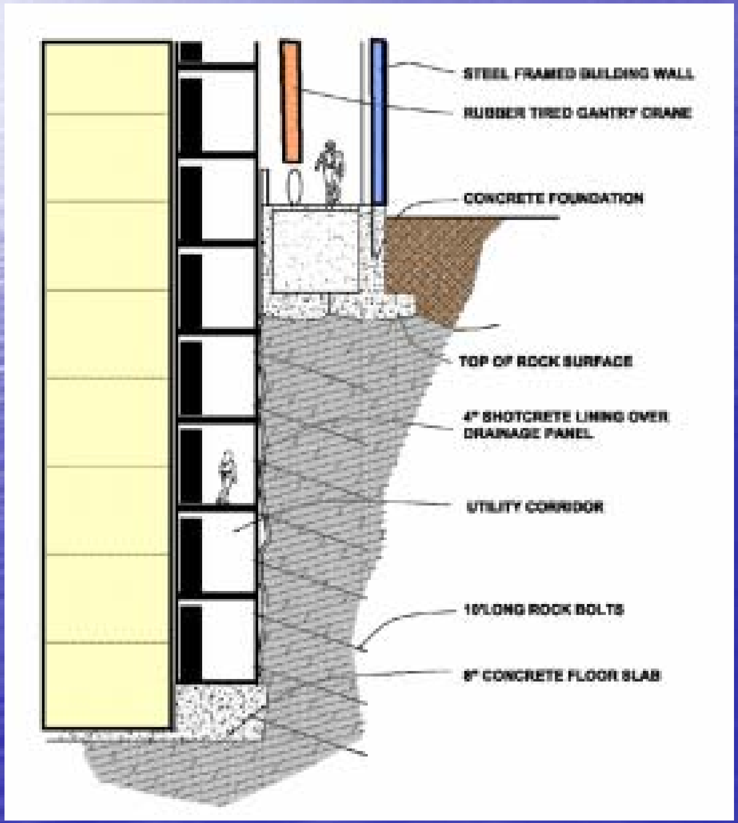
Low-Z: Technologies (cont'd)

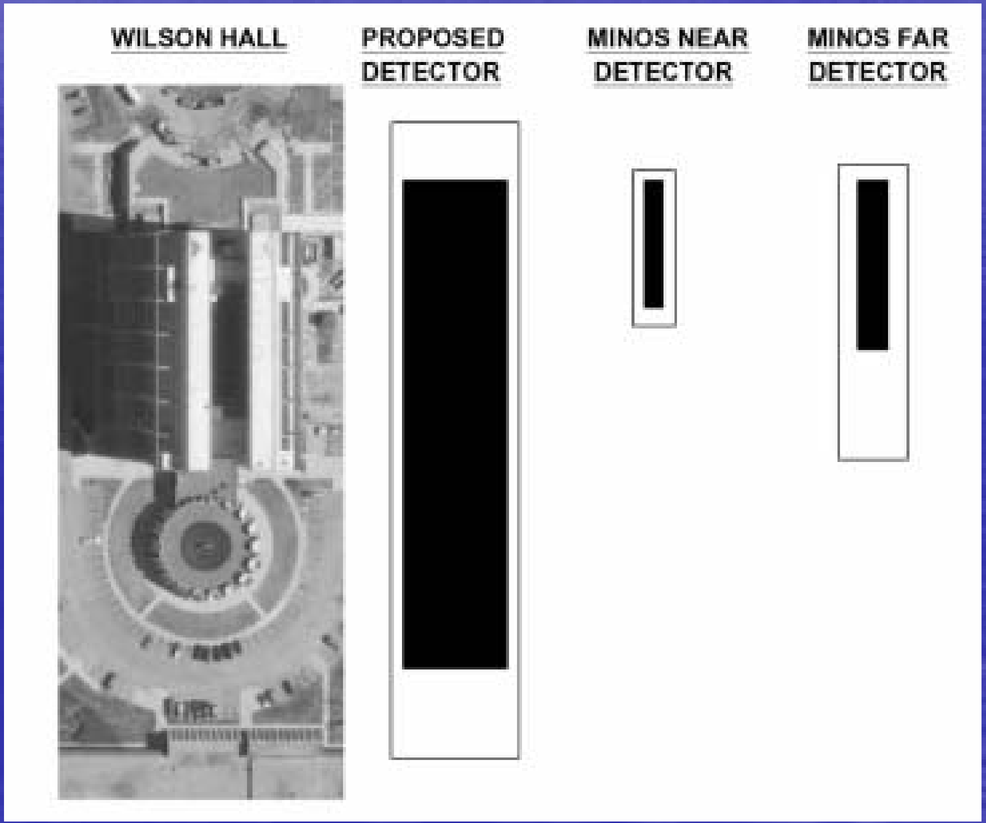
- "Containerization" and modular construction
  - shipping containers (J. Cooper) appear to be a cost-effective way to house modules

Low-Z: Technologies (cont'd)

- Containing the container...

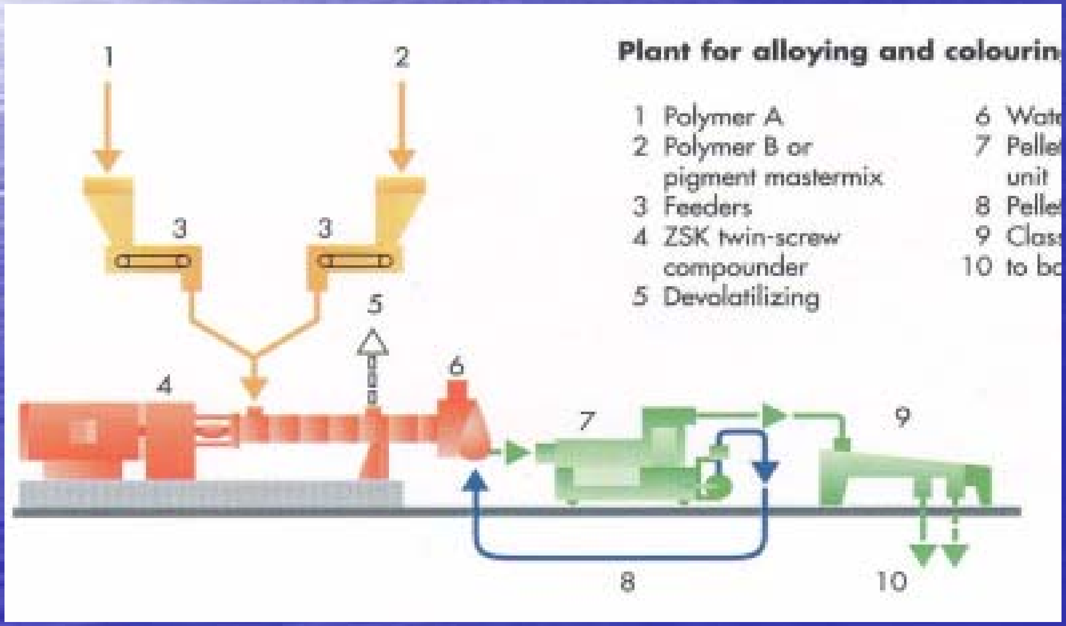
figures courtesy J. Cooper





Low-Z: Technologies (cont'd)

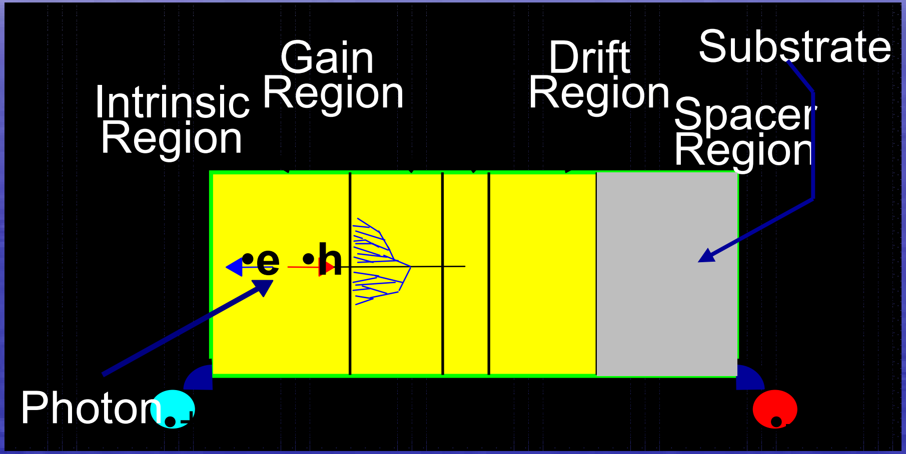
- Ionization sensors: scintillator+WLS fiber
  - extrapolation from successful MINOS experience
  - new construction facility at FNAL Lab 5: continuous inline extrusion process



figures courtesy A. Bross

Low-Z: Technologies (cont'd)

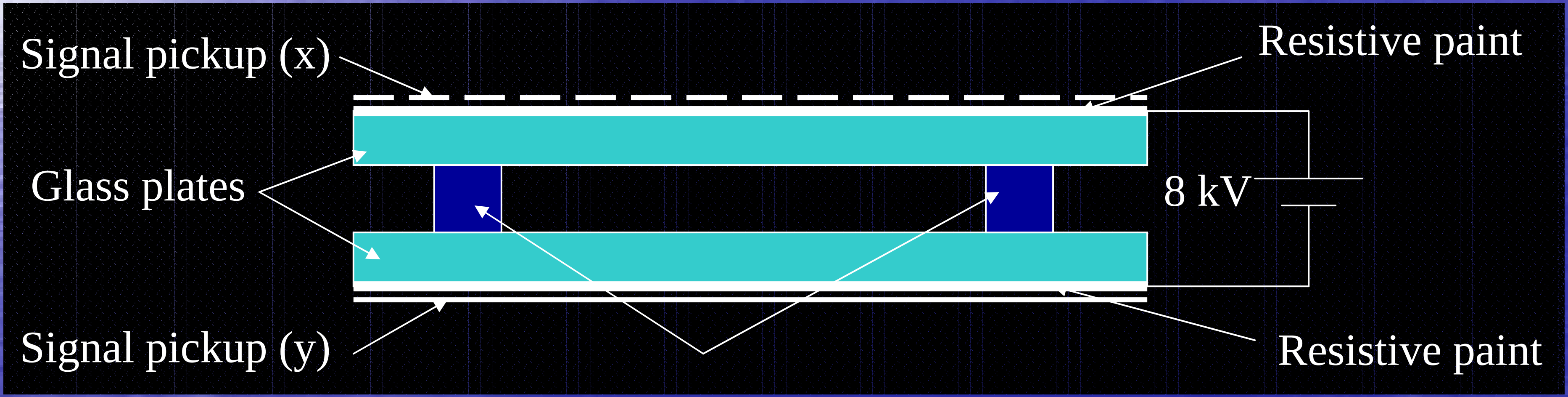
- New and old photosensors:
  - new: VLPCs
    - very high QE
    - success at D0
    - R&D going on now to lower costs. Enough?
  - old: IITs, APDs potentially significant cost savings!
    - IITs: noise? timing?
    - APDs: noise (cooling)
    - being revisited in design studies for NUMI



figures courtesy A. Bross, J. Nelson, R. Rusack

Low-Z: Technologies (cont'd)

- Ionization sensors: RPCs
  - inspired by recent use at B-factories
  - reliability problems at BaBar apparently understood
  - gas system, readout under active study for NUMI

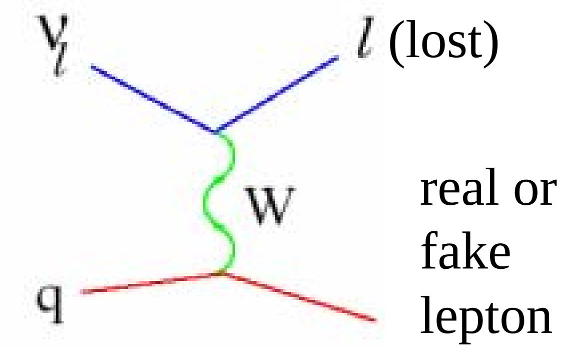


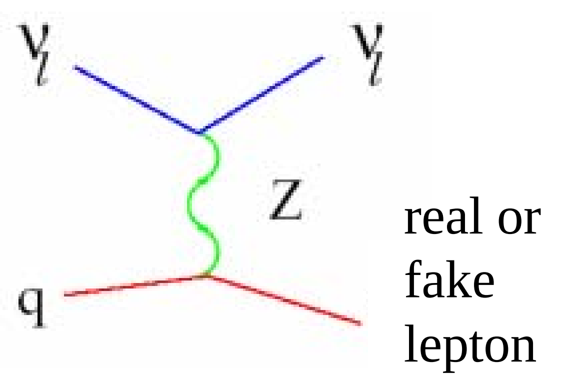
Magnetized Sampling Calorimeters

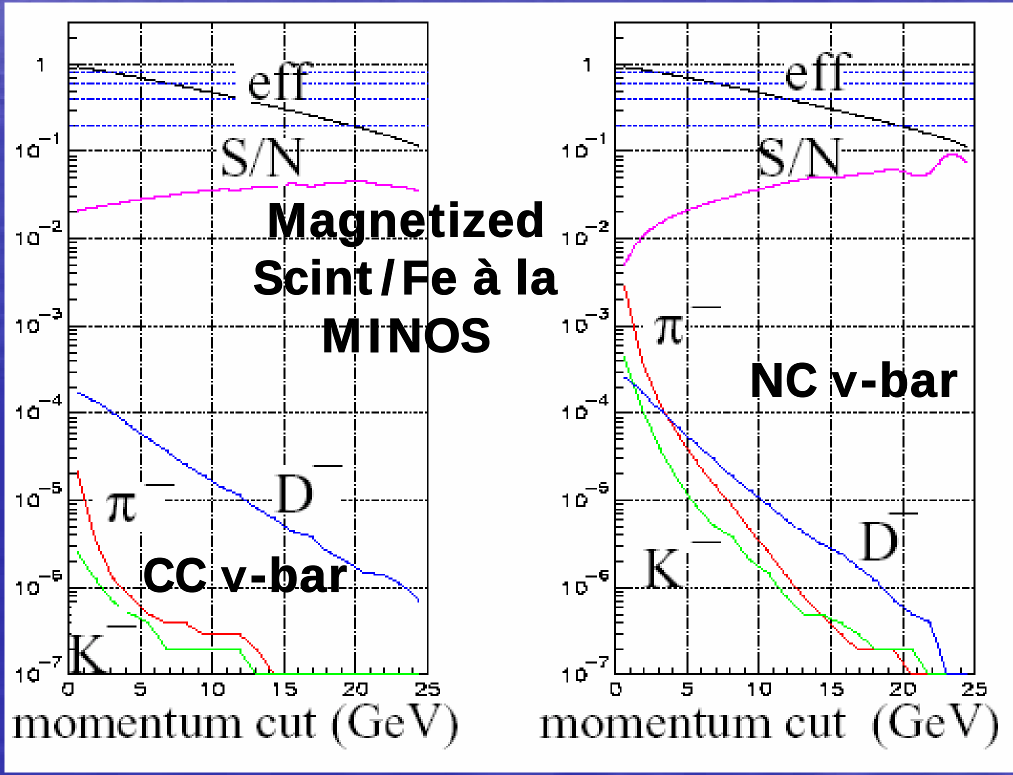
- Successful construction of MINOS has bolstered the case that this is an "easy" technology
  - could clearly build a longer MINOS
- Precious ("golden", "silver") channels at a neutrino factory requires identifying muon charge in DIS events
- Questions:
  - intrinsic background level
  - τ identification? ("silver")
  - can low cost teragram detector compensate for available flux at "affordable" neutrino factory?

Magnetized Calor.: Signatures

- $\nu_e \rightarrow \nu_\mu, \nu_\tau$ in presence of $\bar{\nu}_\mu, \bar{\nu}_\tau$ (or charge conjugate)
- Wrong-charge background for "golden" channel?



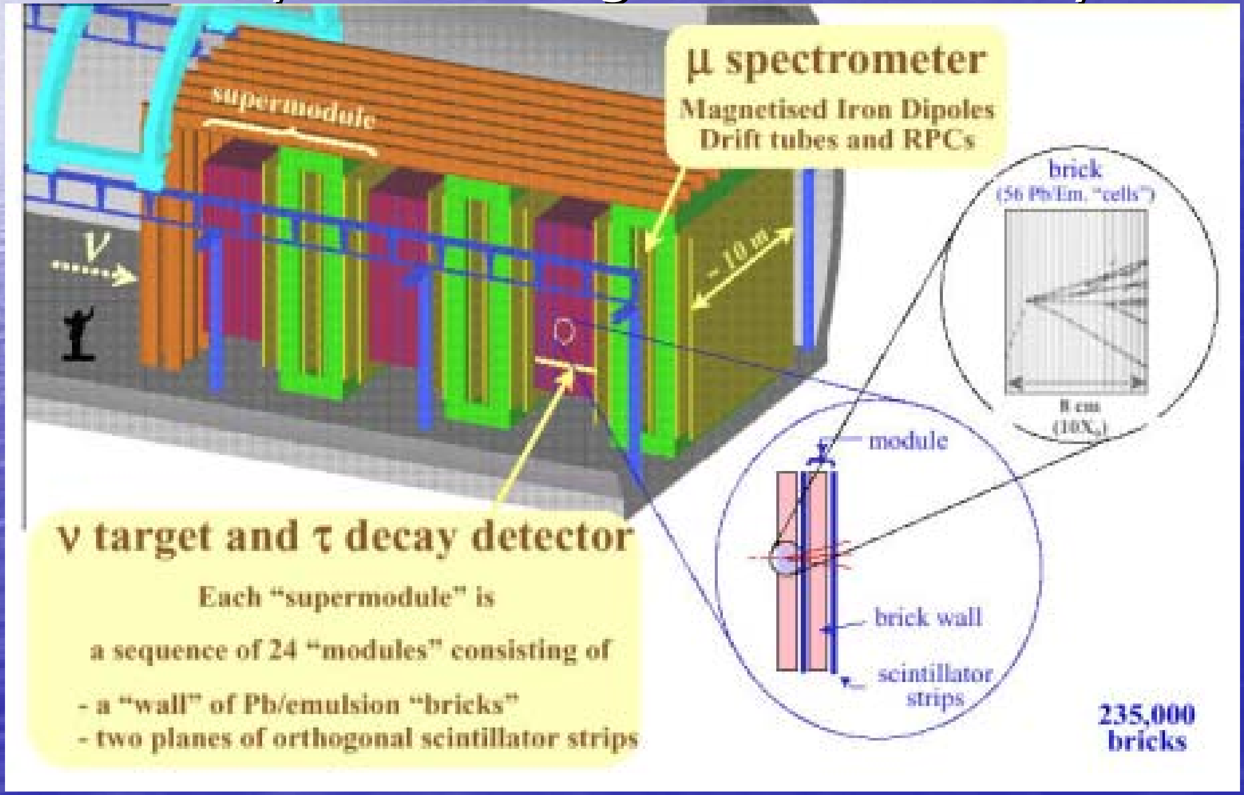


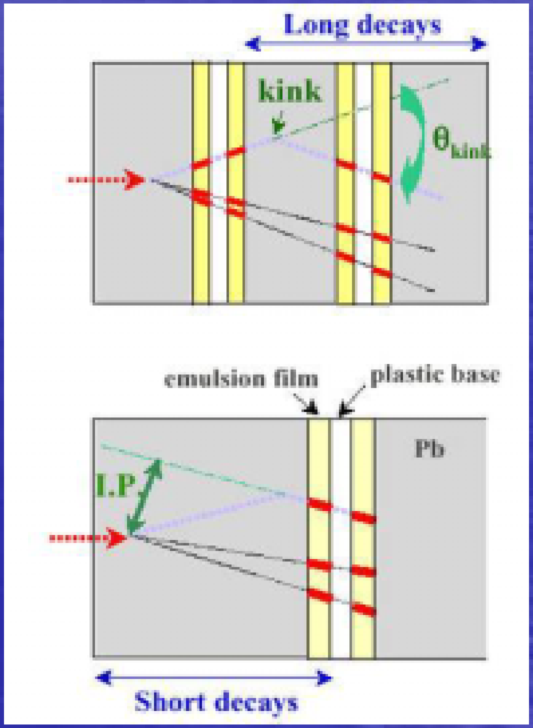


Cervera et al

Magnetized Calor.: Technology

- τ appearance ("silver"): OPERA technique
  - topological tau tag to separate from μ+DIS
  - fully tested long before ν factory beam is available…





Conclusions

- "Teragram-class" detectors will be needed to access CP violation in oscillations
- Superbeams:
  - H_2O Č "in the bag" but difficult at higher energies
    - *I look forward to the BNL proponents proving me wrong!*
  - Low-Z calorimeter work (driven by NUMI OA proposal) looks promising
- Neutrino factories:
  - extensions of MINOS (golden), OPERA (silver)
- *Or should we wait for "less miserable technology"? (André)*