Applications for "*Large*" Solid Scintillator Detectors in Neutrino and Particle Astrophysics

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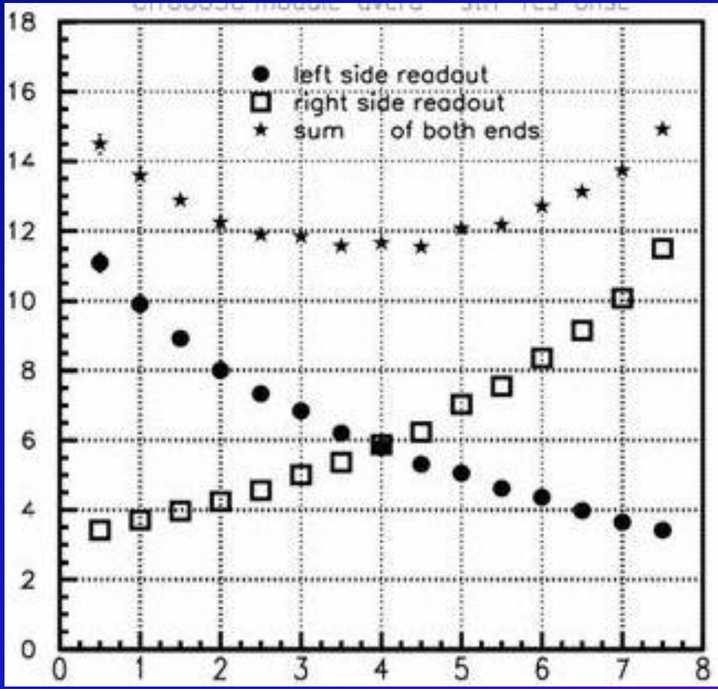
Athens, Greece

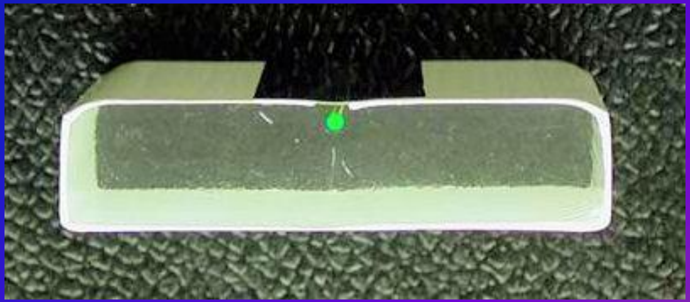
Large Underground Solid Scintillator Detectors (SSD)

- Neutrino Physics
  - Accelerator
  - Atmospheric
  - Cosmic (Super Nova)
- Nucleon Decay
  - *Define Large*
- Dark Matter Experiments

SSD: Neutrino Physics Applications

- MINOS Set the Stage
  - Roughly 0.5 kT of extruded scintillator
  - Magnetic Field → Magnetized Iron
- Can we go much Larger?
  - Magnetized Iron Neutrino Detector (MIND) is the baseline detector for the Neutrino Factory Study (IDS-NF)
    - 100kT Fid Mass   10 kT of Scintillator
      - Ken Long's talk and IDS-NF Poster A08
      - Roumen Tsenov Poster A02
  - Totally Active Scintillator Detector (TASD) is the baseline detector for the Low-Energy Neutrino Factory)
    - 20 kT+ Fid Mass
      - Tracy Li's Poster A12
- Talk is Cheap
  - Can costs be controlled?





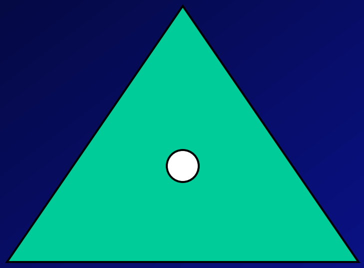
Extruded Scintillator

- The extruded scintillator R&D Program started at Fermilab about 15 years ago
- In-house facility now producing high-quality, low cost ($5-10kg) scintillator
  - Automated, continuous process
- So far, Scintillator has been provided for
  - D0*
  - MINOS*
  - Minerva
  - K2K/SciBoone
  - TJNLAB – Hall B
  - T2K/INGRID
  - Double-Chooz
  - Amiga
  - Pierre Auger
  - Mayan Pyramid μ-Tomography Study

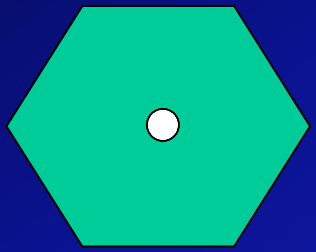
*At Outside Vendor

Scalable
20+kT possible
With Industry

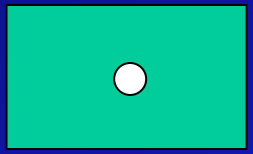
Possible shapes of the extrusion process



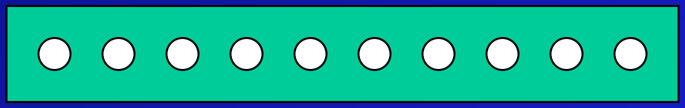
MINERVA, D0 approach, gives very good coordinate resolution, die is in our disposal(base 3.3 cm, height 1.7cm)



Calorimeter applications, die is not available.



K2K solution, the die is available(2cm*1cm)



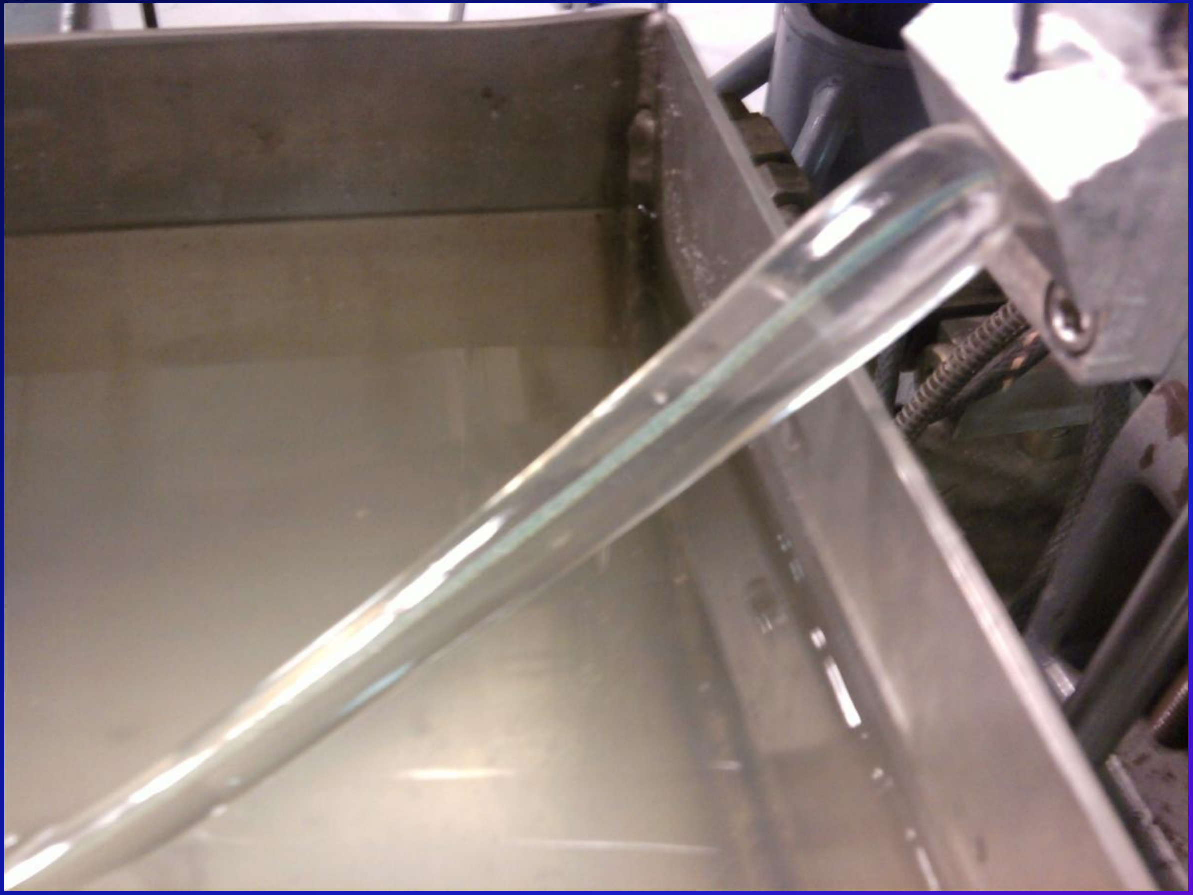
Imagination is limited by the fiber cost, the die is in our disposal(10cm*0.5cm)

Moving Forward: Next step in R&D

- Potential Process Modifications
  - Run multiple threads (For Very-Large-Scale Applications)
    - Maximizes throughput of machine [Note: Nova is running 450kg/hr]
    - Minimizes linear speed of extrusion part exiting die
      - Stability/Cooling issues
  - Co-extrude Kuraray fiber with the scintillator profile
    - Reduce handling of WLS
- Fiber Co-extrusion
  - Prototyped with outside vendor some 8 years ago
  - Post-clad Kuraray fiber
    - Polyethylene
    - Kynar
    - Teflon
  - No degradation of fiber seen (but thin (100-300 μm) coatings
    - WLS fiber did see large heat excursion, however

Fiber-Scintillator Co-Extrusion

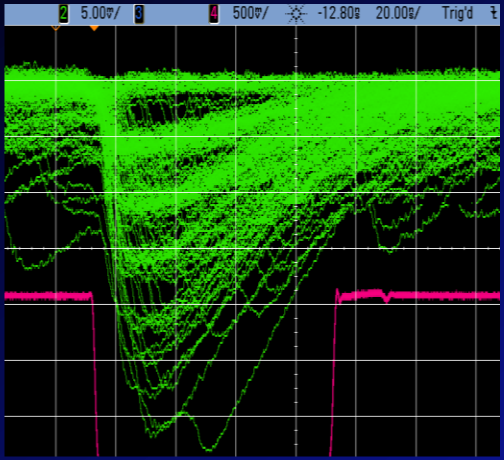
- Work has started again

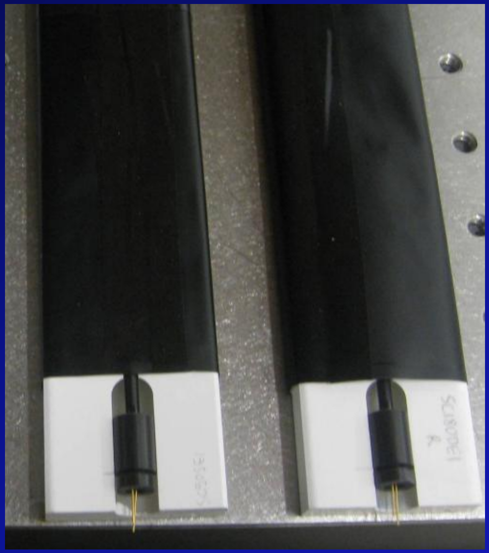


Next Step

- If you can produce the scintillator (at acceptable cost), co-extrude with the WLS to reduce handling cost (& improve performance somewhat)
- Still need cost-effective photodetector
- Enter Stage Left
  - Silicon PM (SiPM) aka MPPC, aka MRST

Silicon Photomultiplier

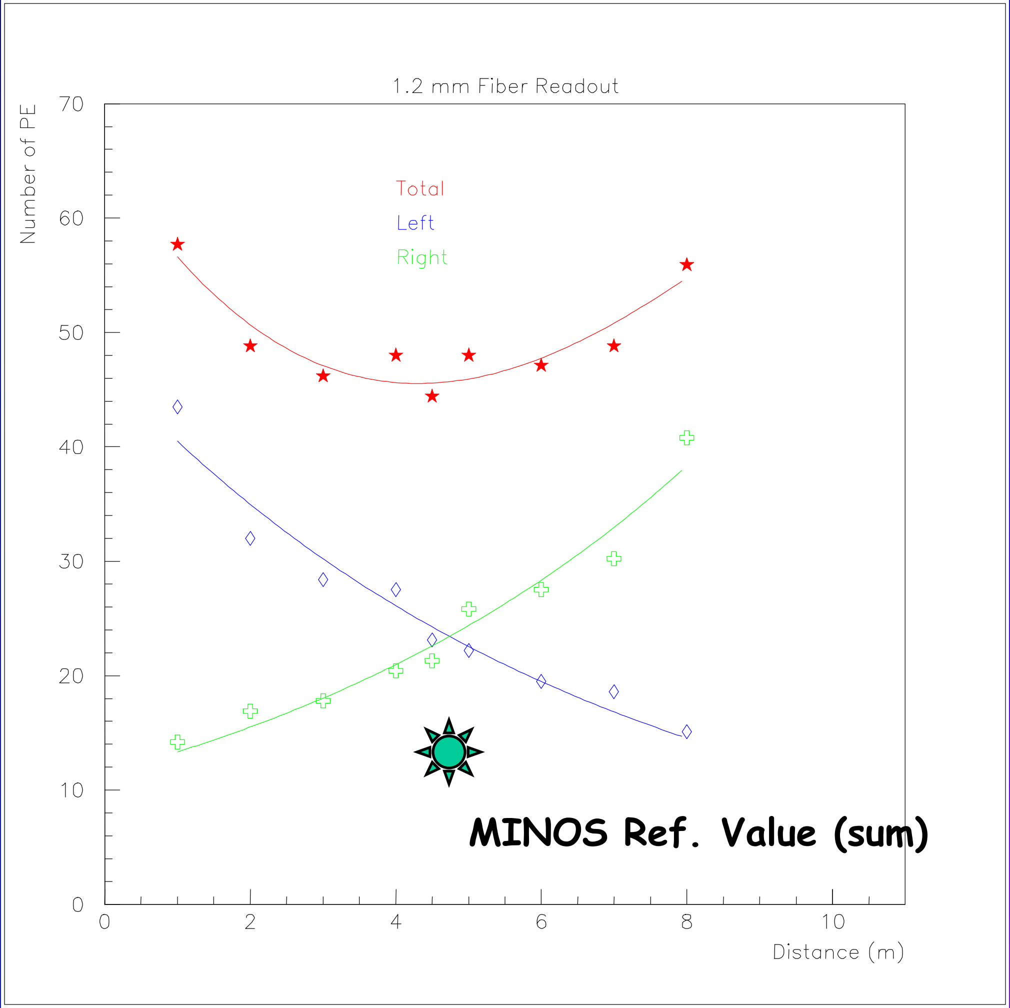




- SiPM status:
  - Extensive use in T2K
  - Being considered for many experiments (Minerva, μ2e, ILC Detector R&D)
- High performance
  - X4 QE over MAPMTs used in MINOS
  - Large gain, very robust devices
- Extensive Industry R&D involvement
  - US, Europe, Japan
  - Also University and National Lab R&D
- The mythical \$1/ch may be possible
  - Advanced processing techniques can likely lead to \$1/mm^2 for detector (unpackaged)
    - Issue will become packaging

Extrapolating Light Yield

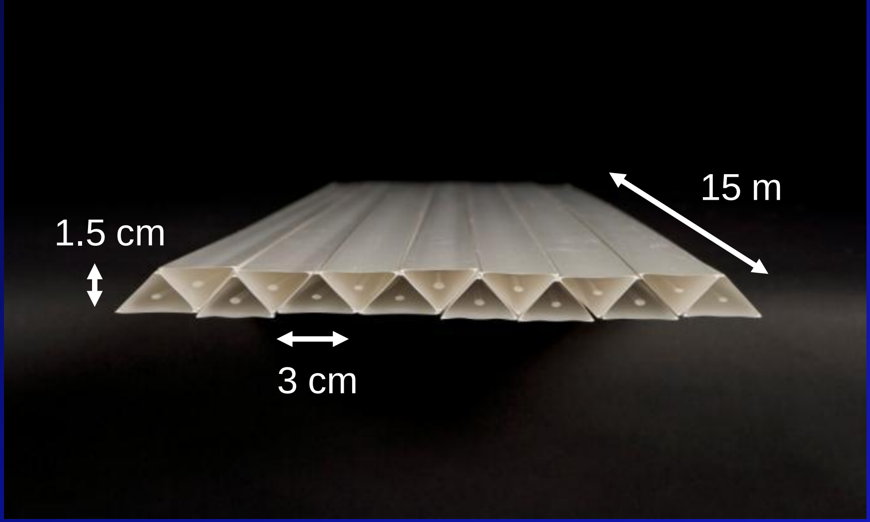
- Data taken with Visible Light Photons (VLPCs), QE ≈ 90%
- SiPM should do almost as well (optimized coupling, QE (# μpixels)
- The increase in detected PE potentially will allow for the use of smaller WLS fiber (large cost savings cost ∝ d^2
  - LY ∝ $(D_1/D_2)^{1.2-1.5}$

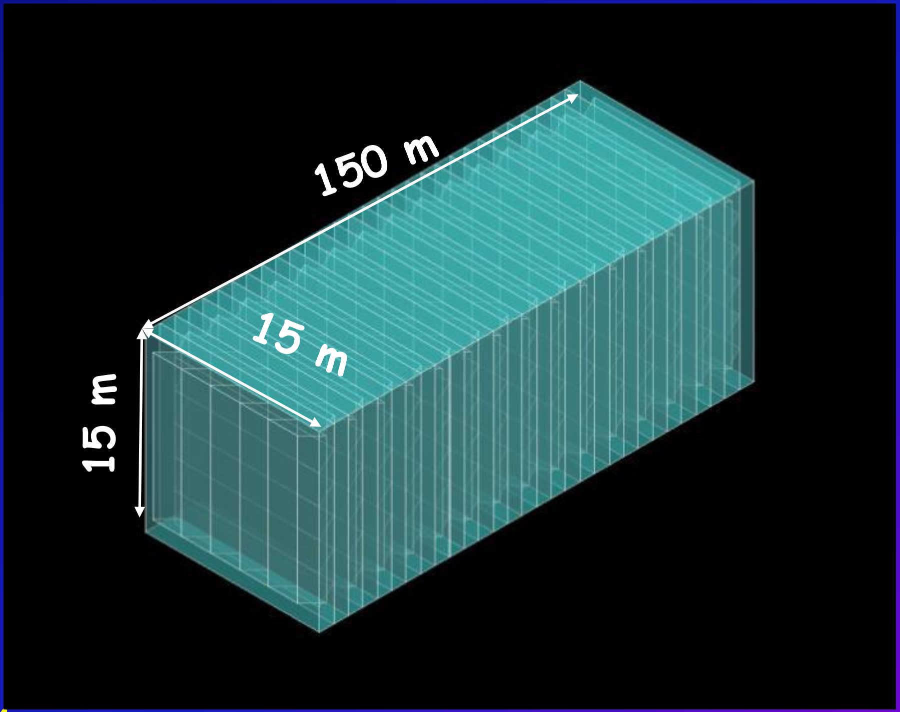


Application: Fine-Resolution Totally Active Segmented Detector

Simulation of a Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts with Geant4

- 35 kT (total mass)
- 10,000 Modules (X and Y plane)
- Each plane contains 1000 cells
- Total: 10M channels



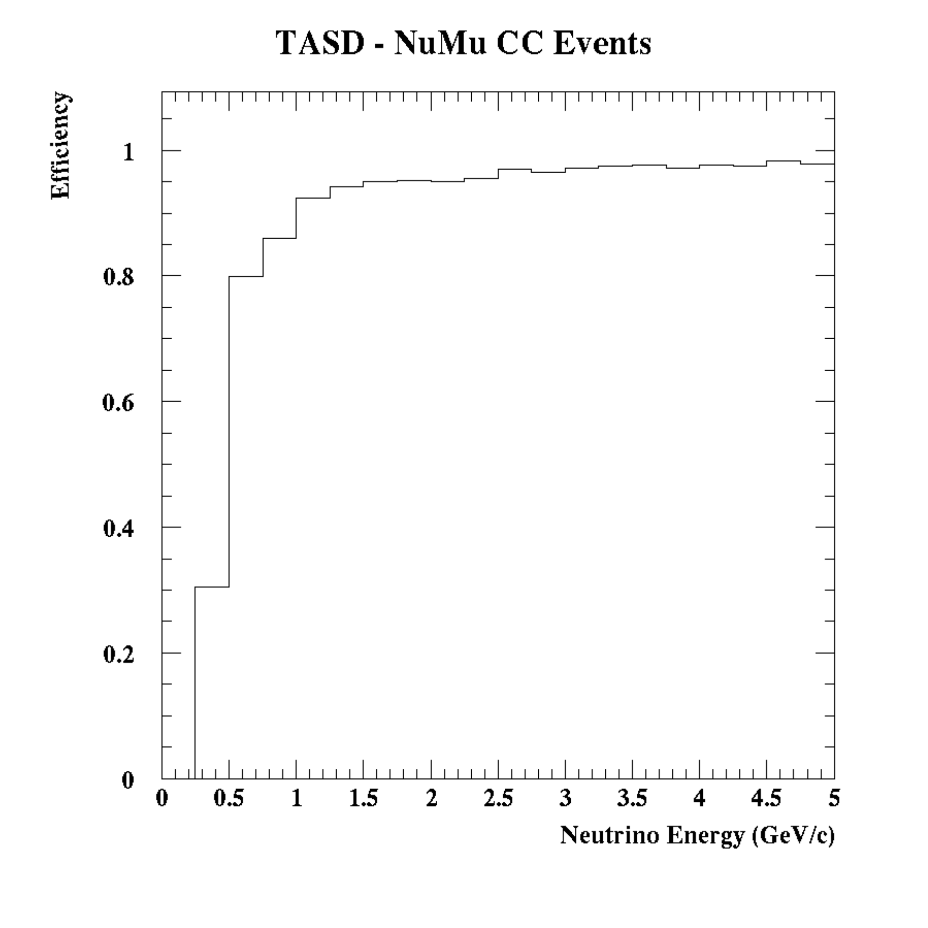


- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

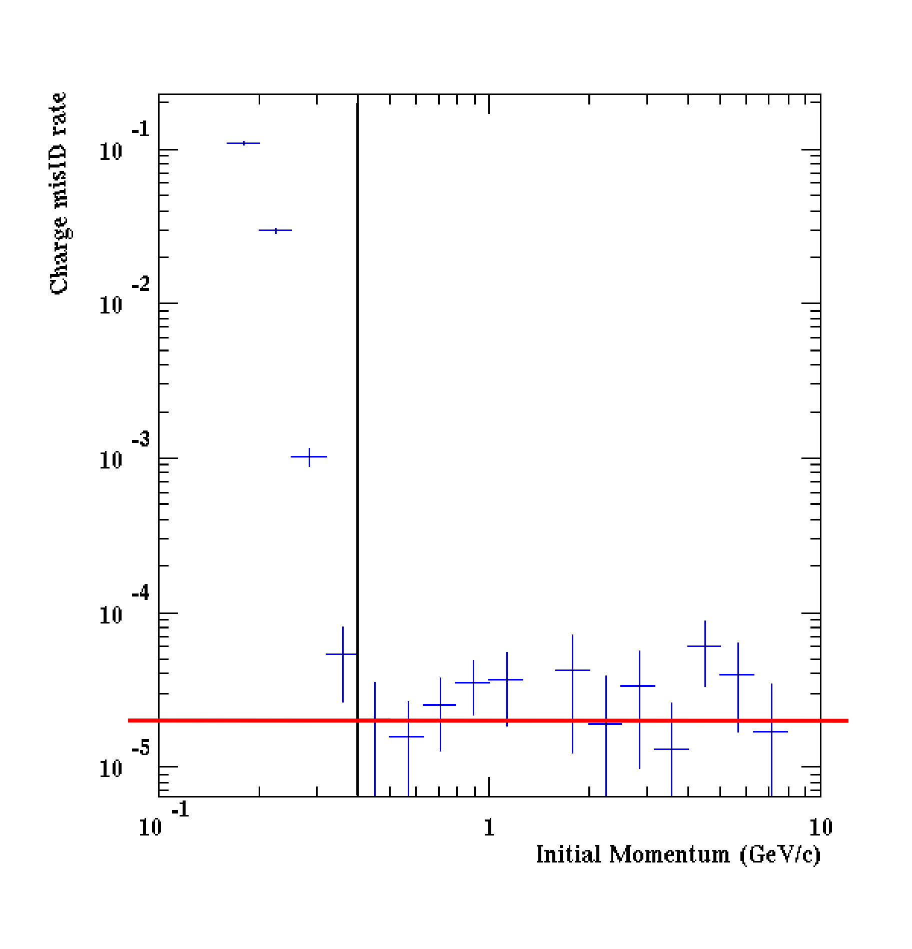
B = 0.5T

TASD Performance

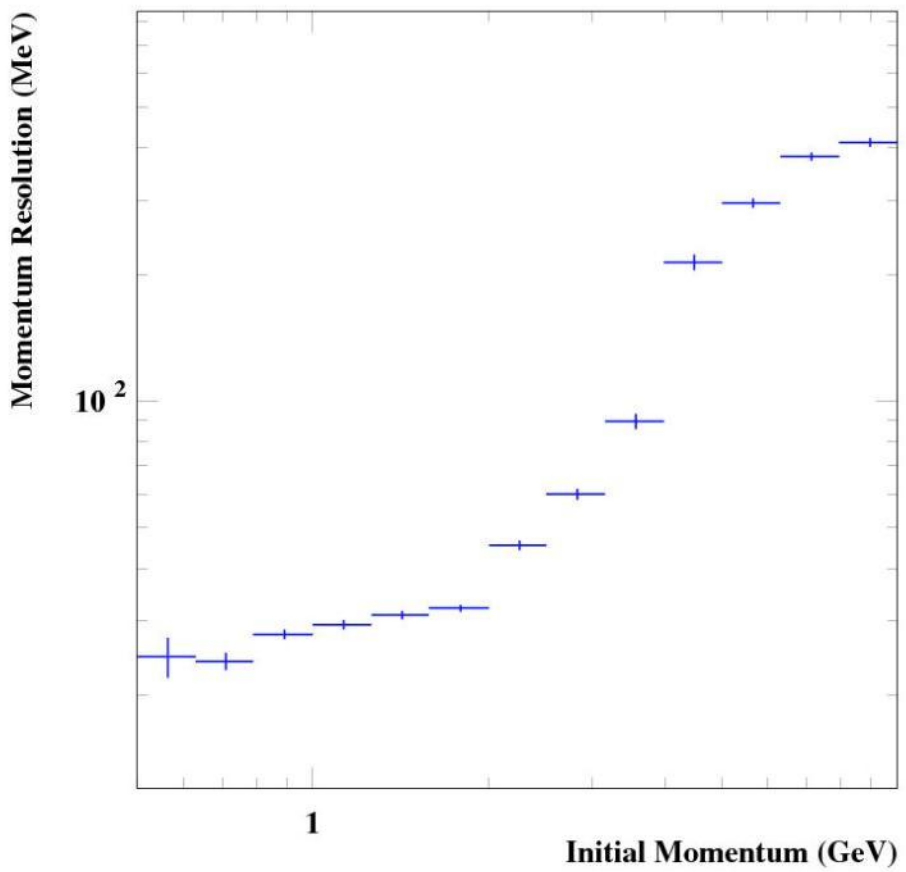
ν Event Reconstruction Efficiency



Muon charge mis-ID rate

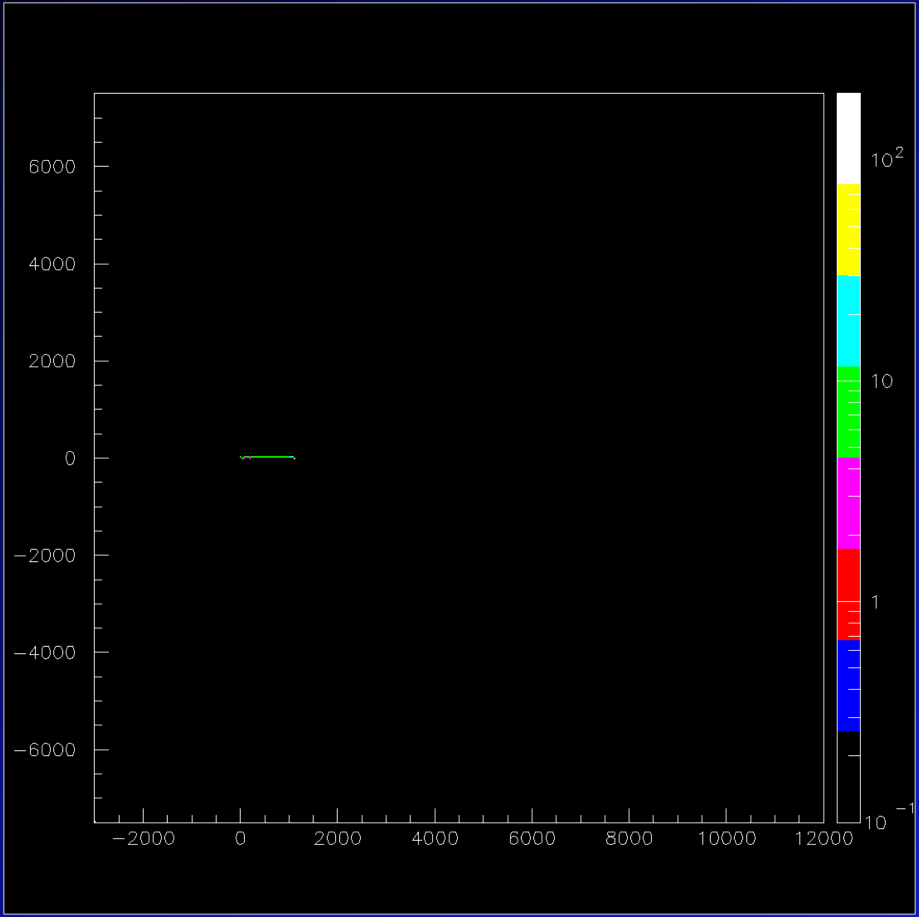


TASD Performance II

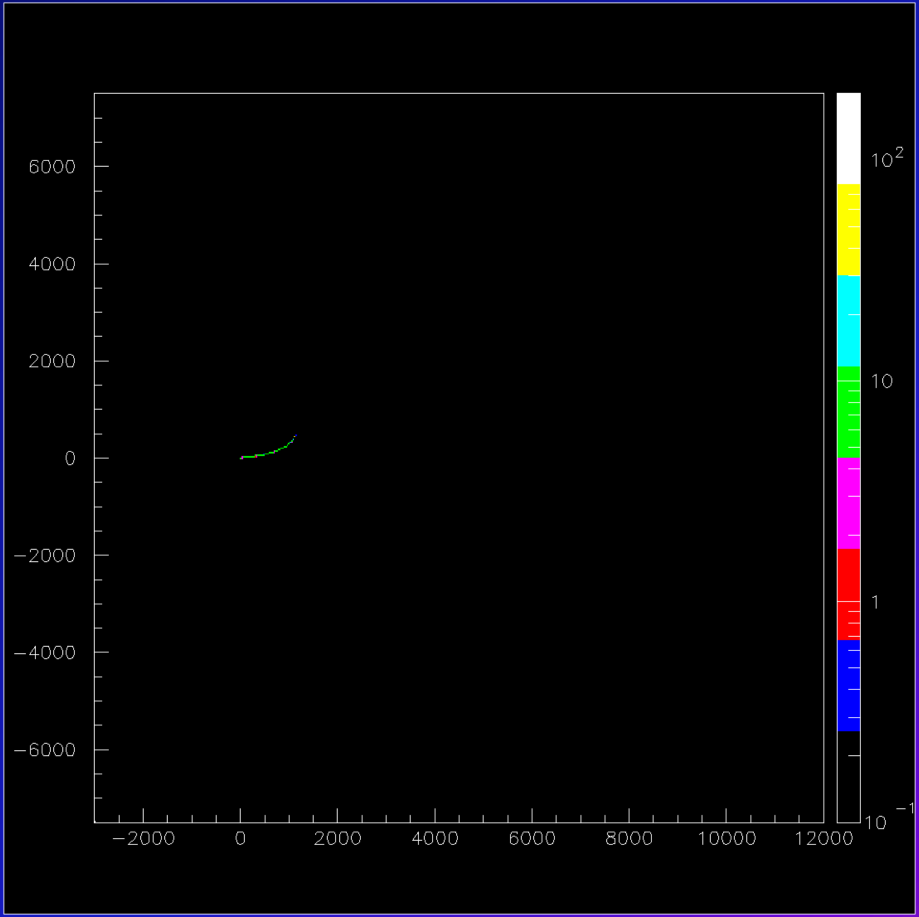


- **Momentum resolution excellent**
  - Neutrino Event energy reconstruction from tracking
  - EM component from hit counting possibly
- **Simplifies electronics**
  - No calibration needed
  - Hit efficiency is only consideration
- **Expect**
  - $\sigma(E_{evt}) \approx$ 5-10% @ 2GeV
    - Based on extrapolations from Nova simulations

Muons: 0.3 to 3 GeV

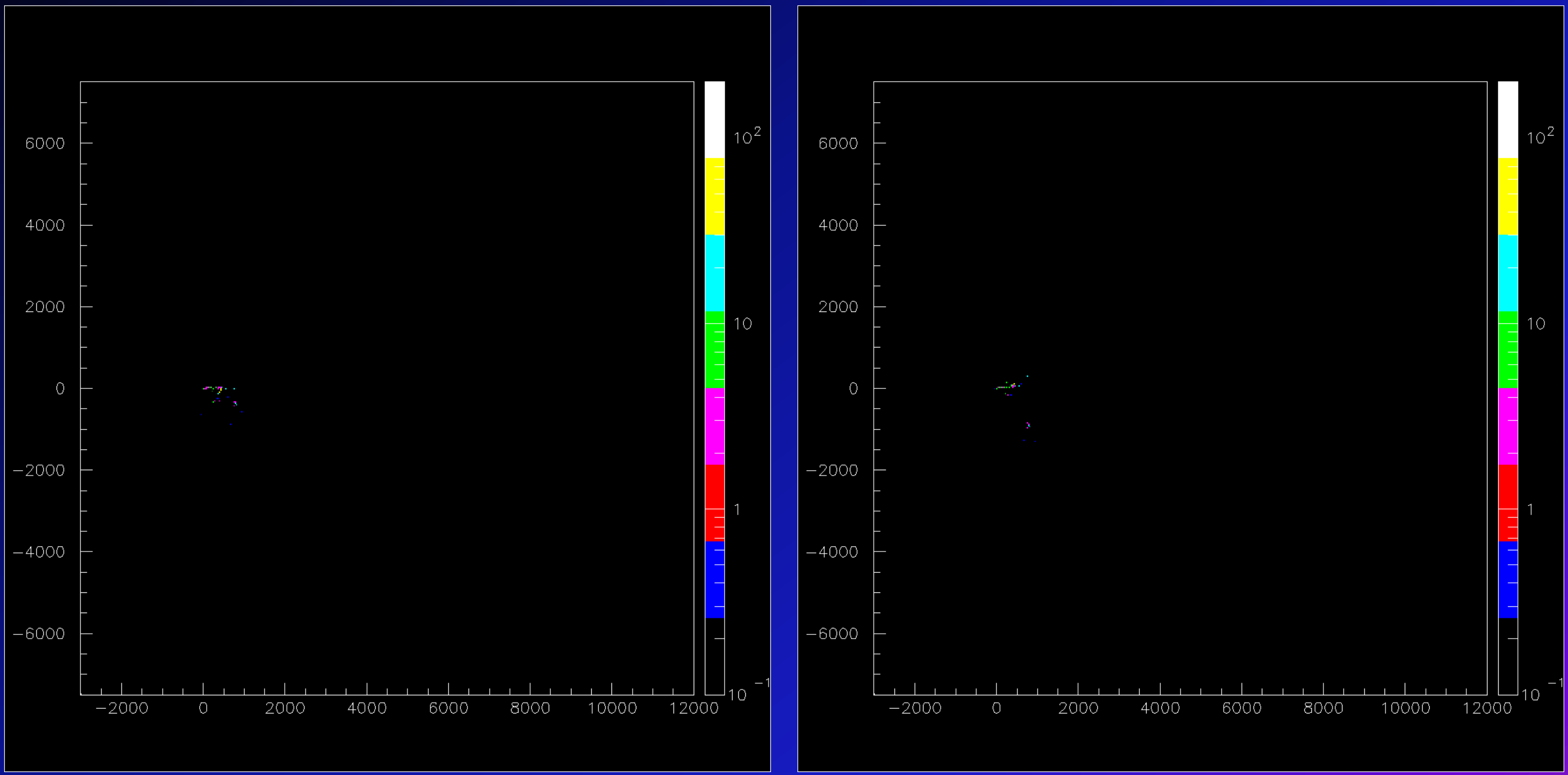


Non-Bend Plane

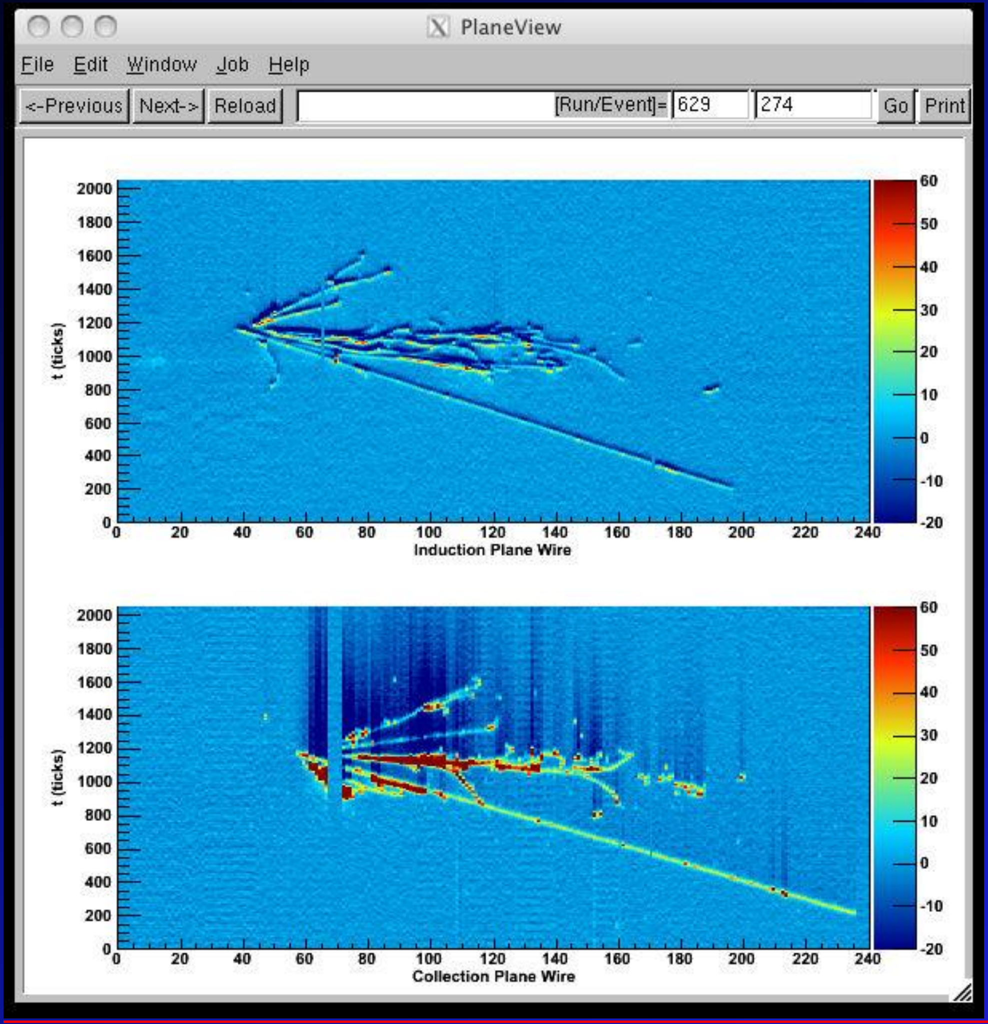


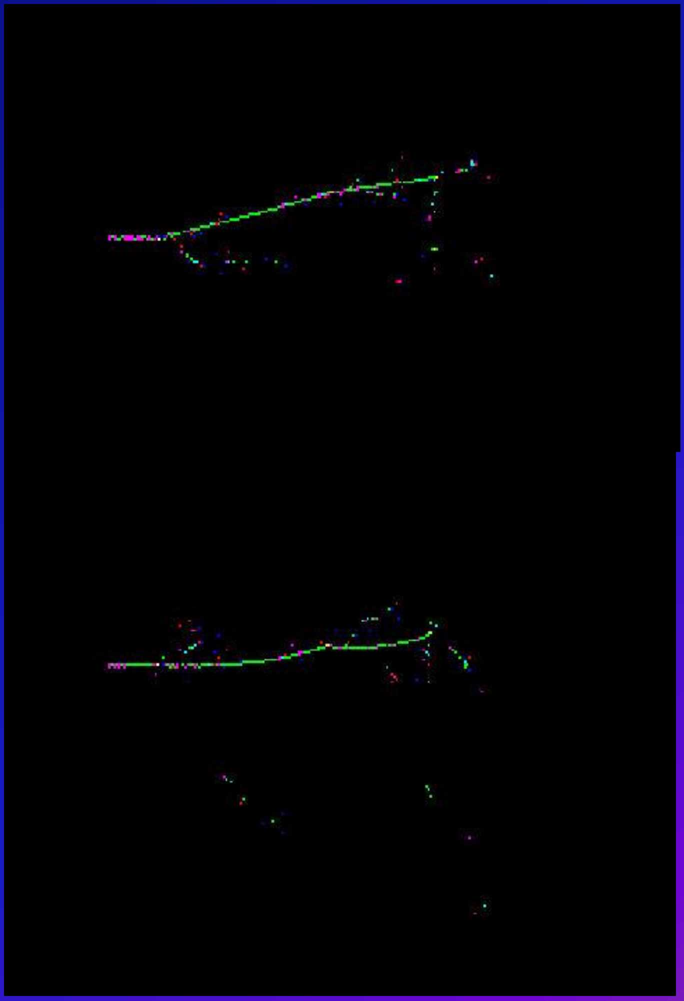
Bend Plane

Pions


6000
4000
2000
0
−2000
−4000
−6000
−2000
0
2000
4000
6000
8000
10000
12000
10^2
10
1
10^{-1}

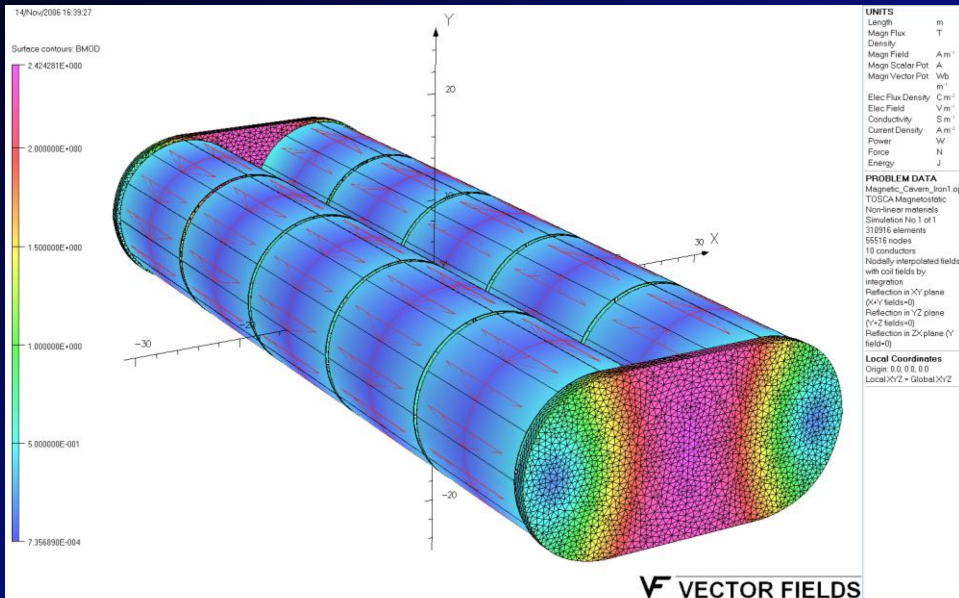
Information Density: Imaging Detectors: LAr & TASD



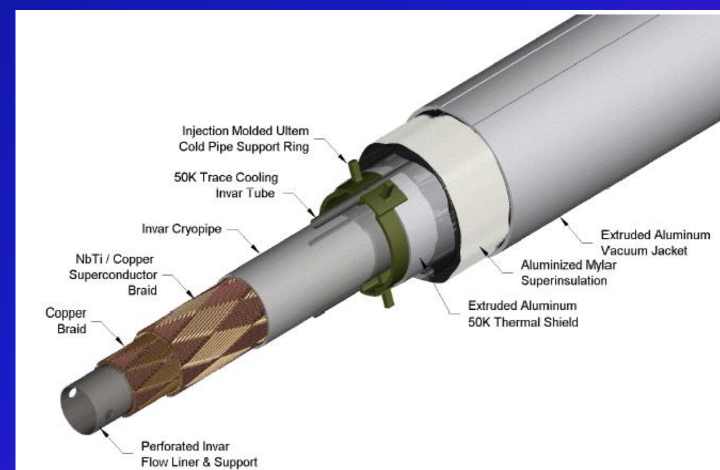


Magnetic Field?

Magnetic Cavern based on Superconducting Transmission Line



- STL based design (VLHC)
- Design features
  - 10 solenoids
  - Solenoid length 15 m
  - Inner diameter 15 m
  - B_{nom}~0.5 T



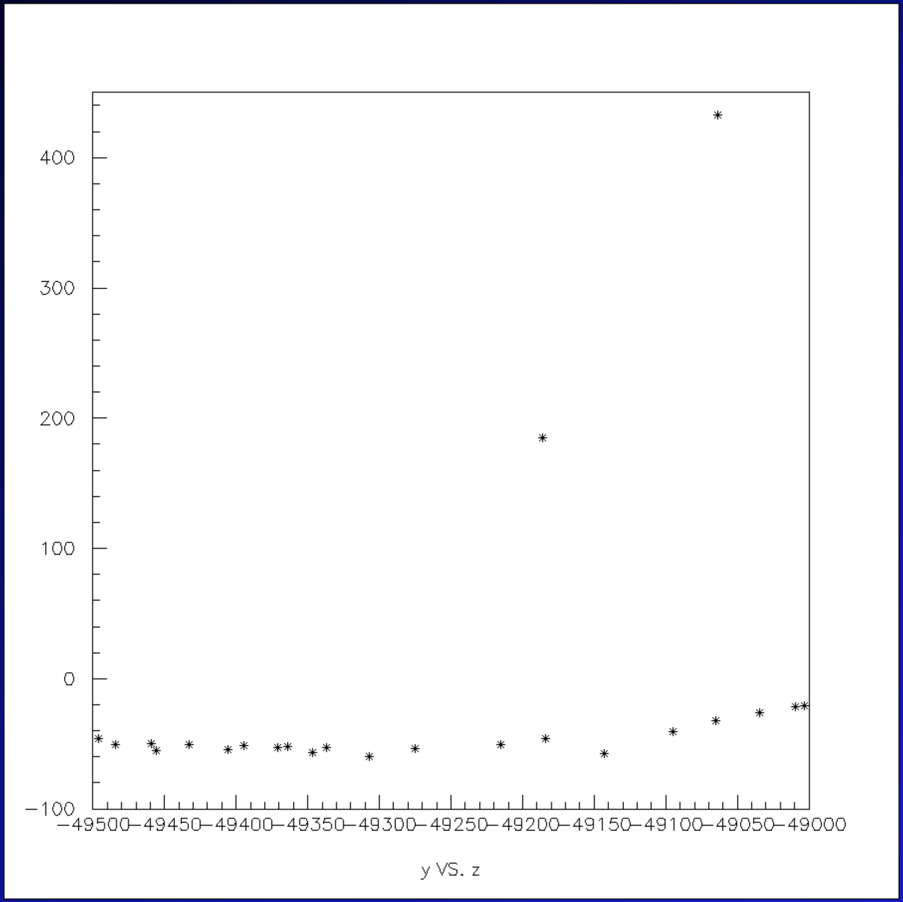
•Base on work for VLHC (2000)

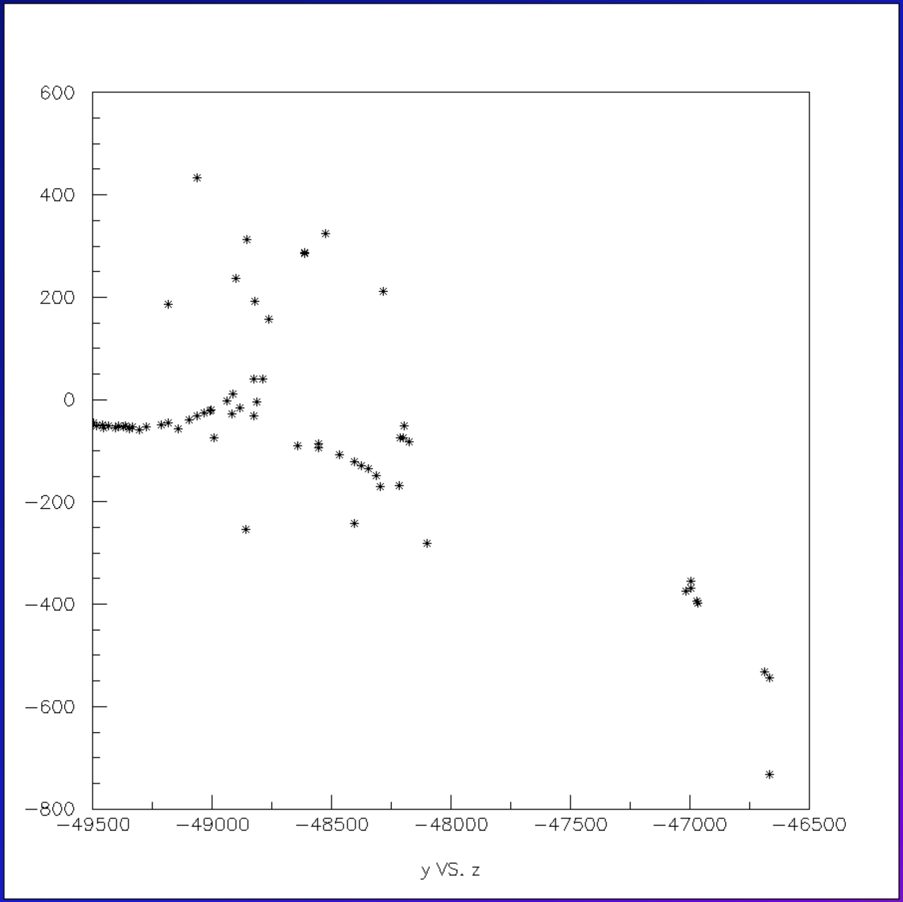
•and has been fully prototyped

•and tested

Also applicable for LAr

Sample Events

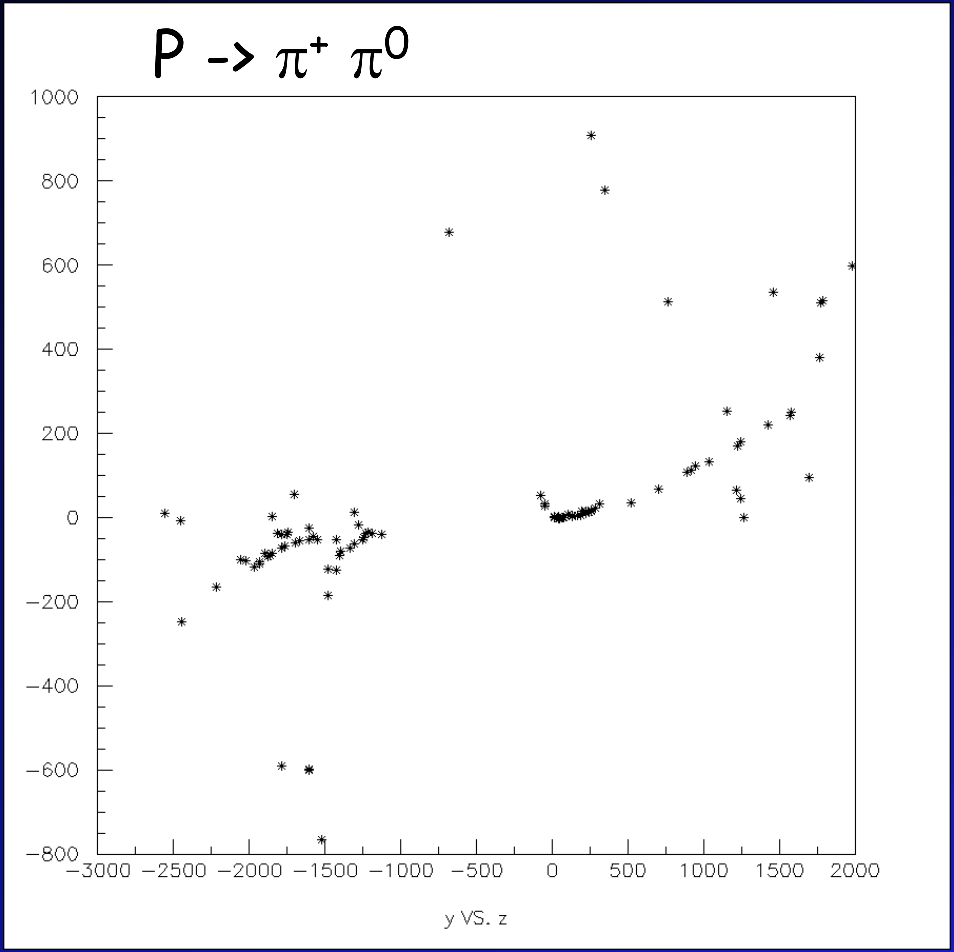


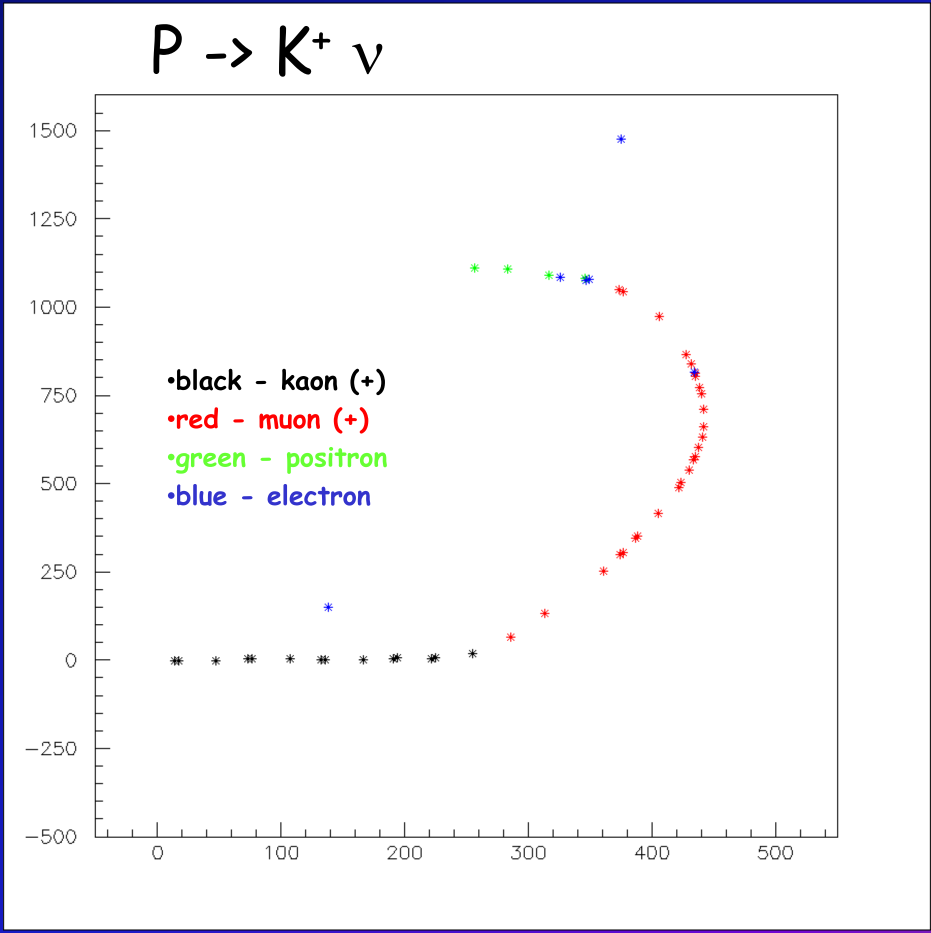


Another possibility for TASD?

- Large neutrino detectors are often considered for nucleon decay experiments as well.
- Could the TASD be used for such searches?
  - How Large is Large Enough?
    - Dare we say 100 kT? (Danny Lehman would certainly have something to say about it)
- Nothing serious done so far, but a couple of quick simulations seem to indicate that this might be worth further consideration.

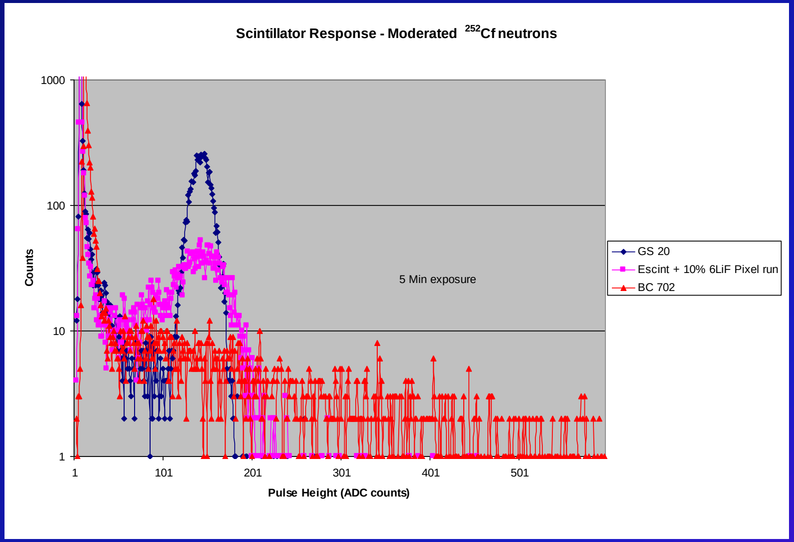
Proton Decay Event Sim in TASD

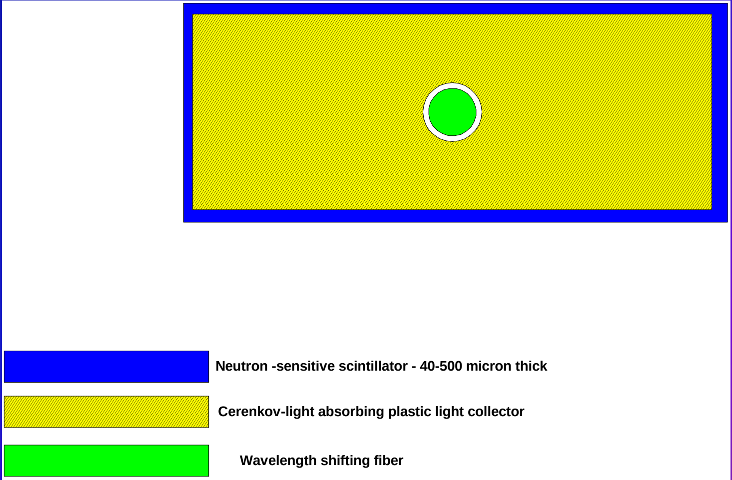




Extensions to Plastic Scintillator

- Neutron Detector via doping
  - Gd
  - B
  - Li^6 ($n + {}^6Li \rightarrow {}^4He + {}^3H + 4.79$ MeV)
- Not likely applicable to Very Large detectors (10s of kT), but might be useful in special applications benefiting from n detection capabilities
  - SuperNova neutrinos
    - OMNIS
  - Reactor
    - $\bar{\nu}_e + p \rightarrow e^+ + n$ (P. Dijkstra's Poster A03)



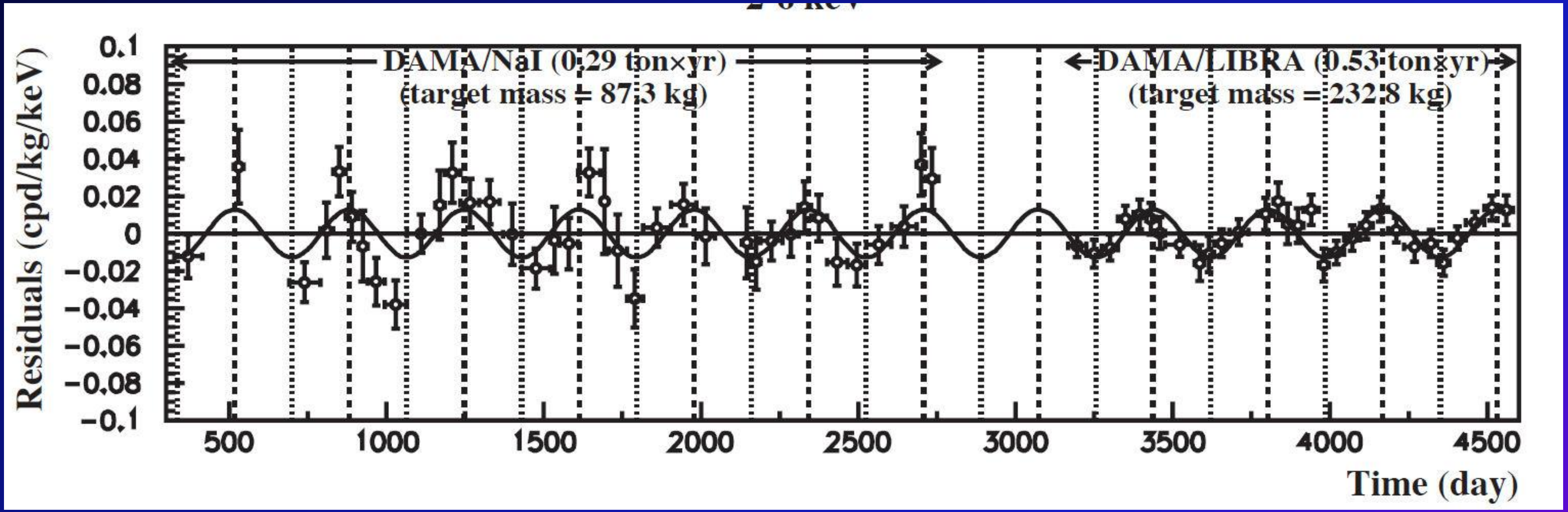


Outlook

- The performance of TASD looks to be very impressive
- Costing is understood for the scintillator
  - New developments in photodetection (SiPM) could lower readout costs significantly
  - Multi-kT seems feasible at this time
- Its power as a Nucleon decay experiment would need to be looked at in much more detail
  - It may also be a powerful detector for Atmospheric neutrino detection, neutrinos from relic SN, etc.
- Event topologies in TASD and LAr (to the extent looked at so far) have complementary properties

Inorganic Scintillators

- Motivation for R&D on new Inorganic Scintillators?
- Dark Matter: DAMA/LIBRA (NaI)



- I am not an expert in this field, so to be polite I will say that this result has not been confirmed by either solid-state semiconductor detector or noble liquid detector experiments.
  - Other experiment using non-NaI inorganic scintillator?

New Inorganic Scintillators

- Proposed development of high brightness, cost-effective inorganic scintillator for hermetic hadron calorimetry applications [cost-effective ⇒ Large (kT scale) feasible]
  - Pb_2F
  - LSO
- Requirements
  - High brightness
  - High density (stopping power)
  - Scintillation – Cerenkov discrimination (Dual Readout)
    - Scintillator transparent to Cerenkov light
      - May yield interesting approaches to background rejection in DMS
- HEP applications do not require the low background count rate
  - Will depend on the final scintillator formation and the ability to purify atomic constituents

Conclusions

- Solid Scintillator (plastic) has many potential applications
  - Large-Scale (many kT) applications are looking more affordable
    - Producing massive quantities of plastic scintillator straightforward. But, the ultimate Cost is the CONCERN
  - R&D needed to address cost issues is relatively modest
    - SiPM development and packaging
    - High-rate extrusion capability (X5)
    - WLS Fiber (??) Need industry involvement/interest
  - Clear Opportunities in certain applications
    - Near detectors for conventional ν beams
    - Doping for neutron detection
- Proposals to develop new Inorganic Scintillators for HEP may have application in DMS as complementary experiment to noble liquid experiments
  - This work is just starting

Detectors: Decisions, Decisions

- Whether Very Large Solid Scintillator Detectors will play a role in future ν experiments is an open question.
- Many unknowns, Many uncertainties

θ_{13}

Surprises, Surprises

Consult the Oracle

Thank You

Σας ευχαριστούμε