Detectors for e^+/e^- Identification in FGT

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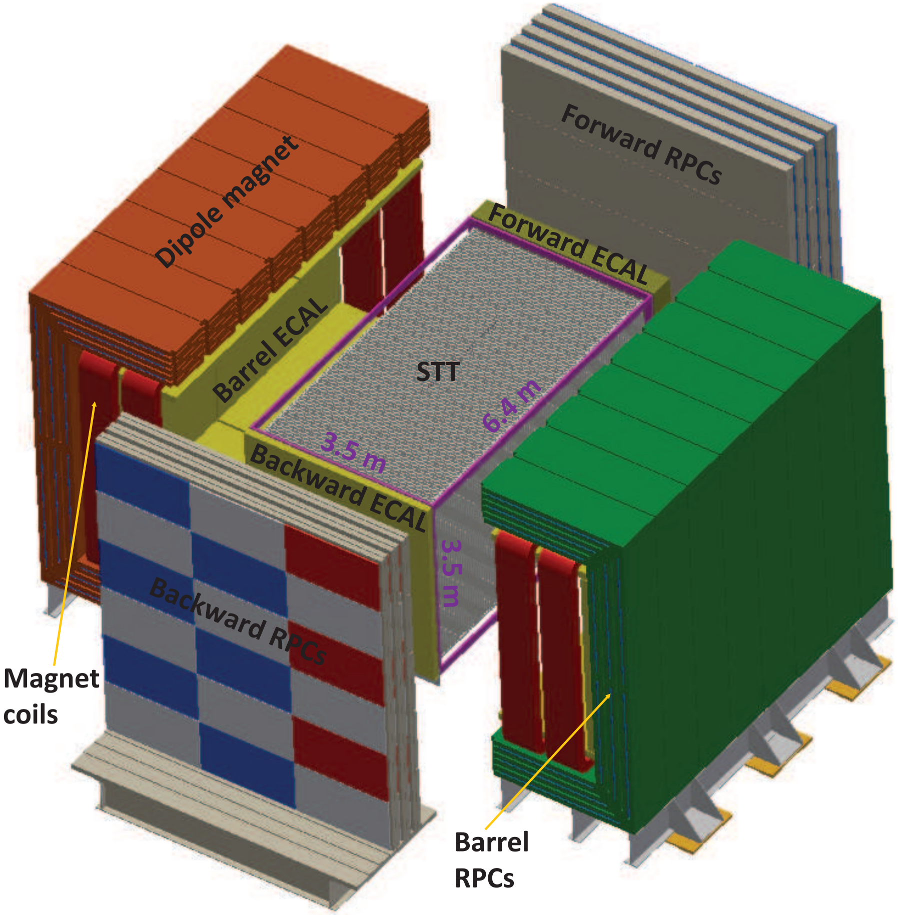
THE DUNE FGT CONCEPT

- ✦ *Evolution from the NOMAD experiment*
- ✦ *High resolution spectrometer*

  $B = 0.4$ *T*
- ✦ *Low density "transparent" tracking*

  $\rho \sim 0.1 g/cm^3 \qquad X_0 \sim 5m$
- ✦ *Combined particle ID & tracking*
  for precise reconstruction of 4-momenta
  - *Transition Radiation* $\Longrightarrow e^-/e^+$ *ID*, γ
  - $dE/dx \Longrightarrow$ *Proton ID*, $\pi^{+/-}$, $K^{+/-}$
- ✦ *Tunable thin target(s) spread over entire tracking volume* $\Longrightarrow$ *target mass* $\sim$ *7t*
- ✦ *4*π *ECAL in dipole* B *field*
- ✦ *4*π μ*-Detector (RPC)* $\Longrightarrow \mu^+/\mu^-$



"ELECTRONIC BUBBLE CHAMBER" WITH $\mathcal{O}(10^8)$ EVENTS

DETECTION OF e^-/e^+ IN FGT

- ✦ *Key feature reconstruction of e^-/e^+ as single CHARGED TRACKS, as opposed to compact electromagnetic showers:*
  - *Require low density (< 0.1 g/cm^3) tracking with thickness $\sim 1X_0$ and track sampling $\mathcal{O}(10^{-3})$;*
  - *Require magnetic field to separate e^+ from e^- and reconstruct γ converted in tracking volume*
    $\Longrightarrow$ *With B=0.4 T e^-/e^+ tracks can be reconstructed down to $\sim$ 80 MeV*
  - *Provide accurate 4-momentum measurement of e^-/e^+ (measure both $\vec{p}$ and E)*

- ✦ *Continuous e^-/e^+ identification fully integrated into tracking volume:*
  - *Transition Radiation (TR) only produced by e^-/e^+ with $\gamma > 1000$;*
  - *Ionization dE/dx provides additional e/π separation in the DUNE energy range;*

  $\Longrightarrow$ *Measurement of energy deposition in active straws sensitive to both*

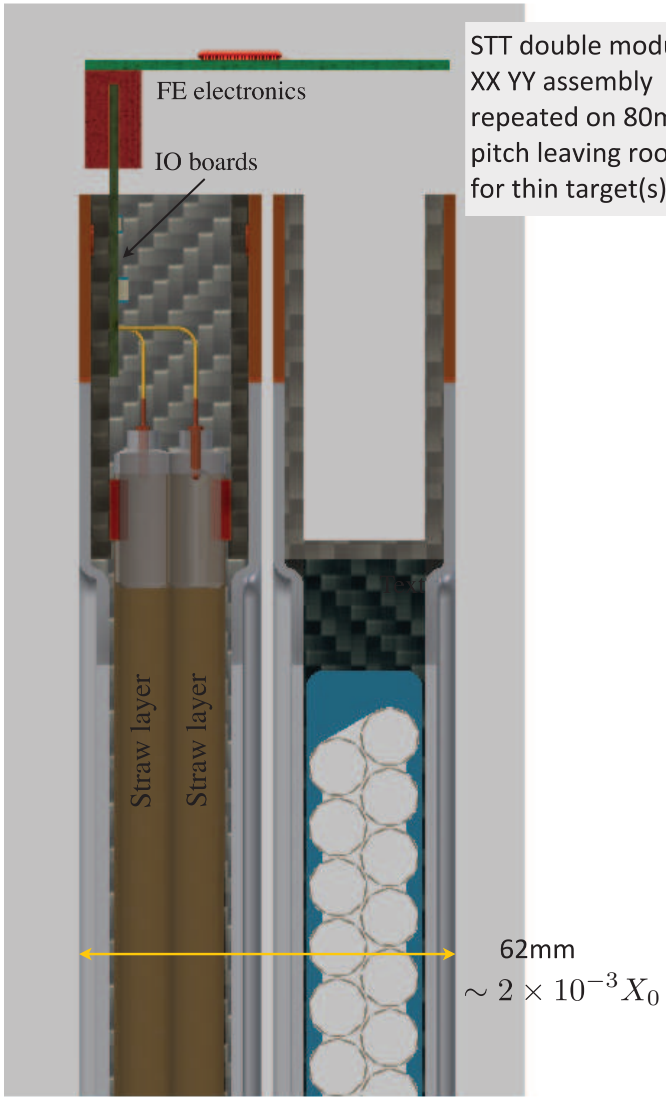
- ✦ *Matching of extrapolated e^-/e^+ tracks with ECAL electromagnetic showers (clusters):*
  - *Energy deposition in ECAL powerful e/π rejection;*
  - *Transverse and longitudinal profile of electromagnetic showers (clusters) in ECAL provides additional e/π rejection;*
  - *Reconstruction of Bremsstrahlung γ's emitted by e^-/e^+ in the bending plane from ECAL and STT (conversions).*

THE STRAW TUBE TRACKER

- *Main parameters of the STT design:*
  - *Straw inner diameter* 9.530 ± 0.005 *mm;*
  - *Straw walls* $70 \pm 5 \mu m$ *Kapton 160XC370/100HN* ($\rho = 1.42$, $X_0 = 28.6 cm$, *each straw* $< 5 \times 10^{-4} X_0$ *);*
  - *Wire W gold plated 20*μm *diameter;*
  - *Wire tension around 50g;*
  - *Operate with 70%/30% Xe/CO*$_2$ *gas mixture.*
  - *Straws are arranged in double layers of 336 straws glued together (epoxy glue) inserted in C-fiber composite frames;*
  - *Double module assembly (XX+YY) with FE electronics (each XX+YY tracking module* $\sim 2 \times 10^{-3} X_0$*);*
  - *Readout at both ends of straws (IO & FE boards on all sides of each XX+YY STT module);*
  - *160 modules arranged into 80 double modules over* ~ 6.4 *m (total 107,520 straws).*

  $\Longrightarrow$ *Total tracking length* $\sim 0.3 X_0$

- *Add dedicated (anti)neutrino thin target(s) to each STT double module keeping the average STT density* ~ 0.1 *g/cm*^{3} *for required target mass.*



STT double module XX YY assembly repeated on 80mm pitch leaving room for thin target(s)

RADIATOR TARGETS

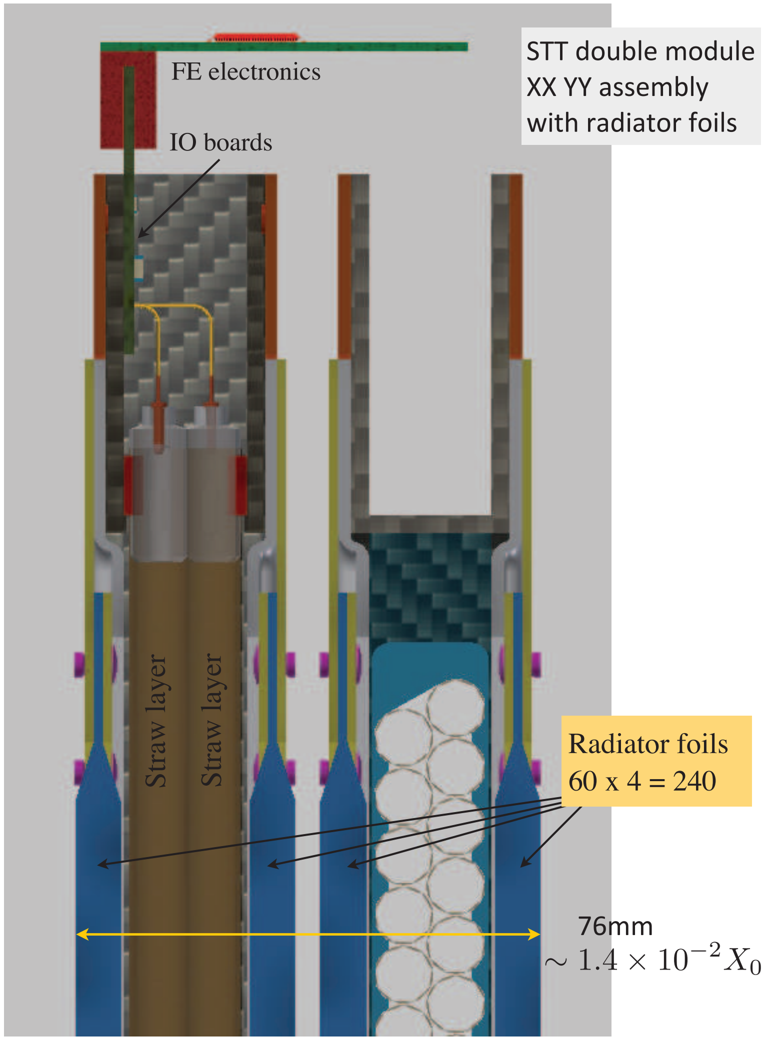
- ✦ *Design and physics performance (Transition Radiation) of radiator targets optimized (docdb # 9766)*

  $\Longrightarrow$ *Mechanical engineering model available*

- ✦ *Radiator targets integrated at both sides of each STT (double layer) module to minimize overall thickness (foils could be removed if needed):*
  - *Embossed polypropylene foils*, *25 μm thick, 125 μm gaps;*
  - *Total number of radiator foils 240 per XXYY module*, *arranged into 4 radiators composed of 60 foils each;*
  - *Total radiator mass in each XXYY module: 69.1 kg,* $1.25 \times 10^{-2} X_0$.

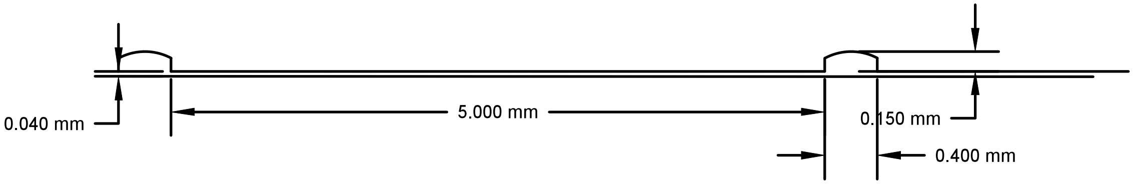
  $\Longrightarrow$ *The radiator represents 82.6% of the total mass of each STT module*

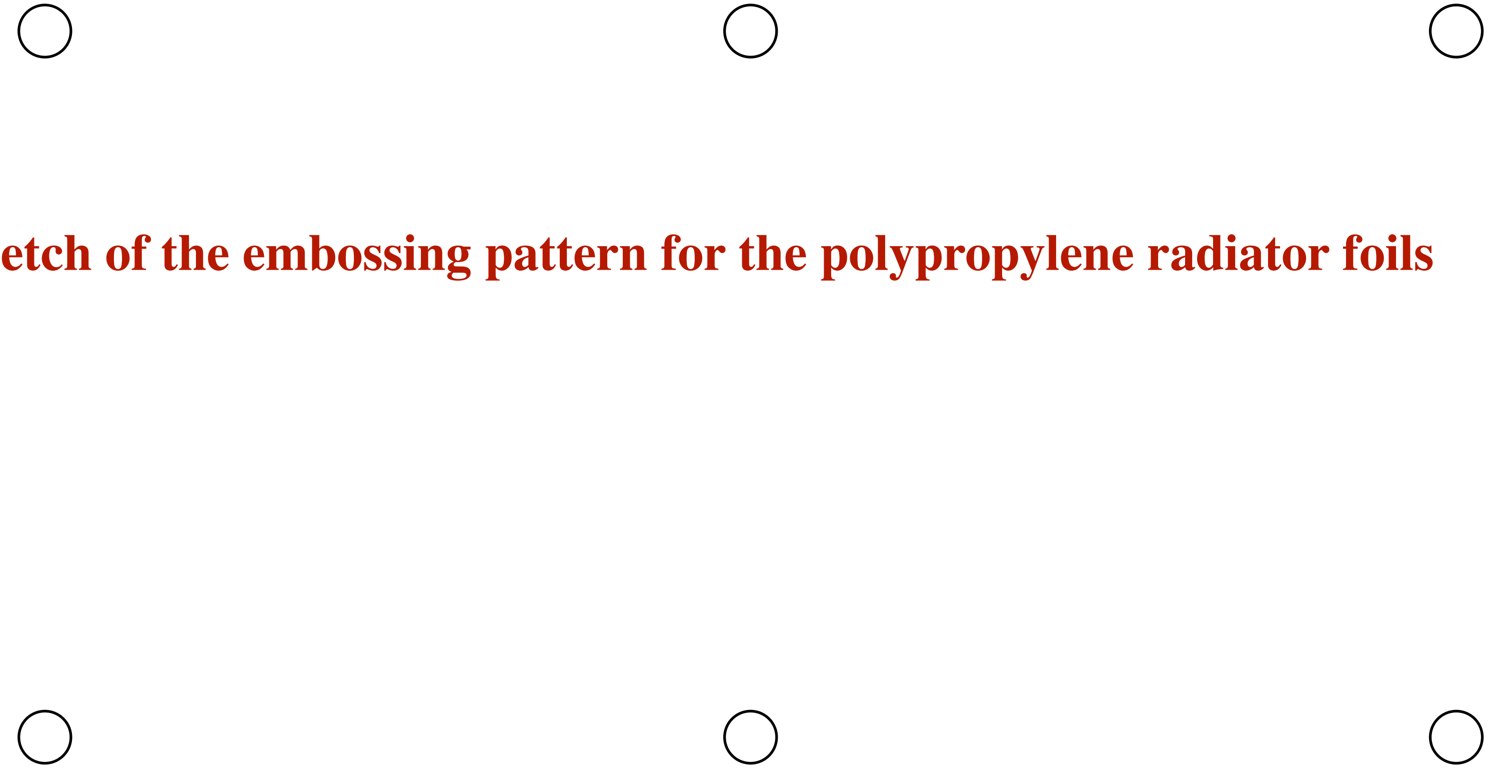
  $\Longrightarrow$ *Tunable for desired statistics & p resolution*



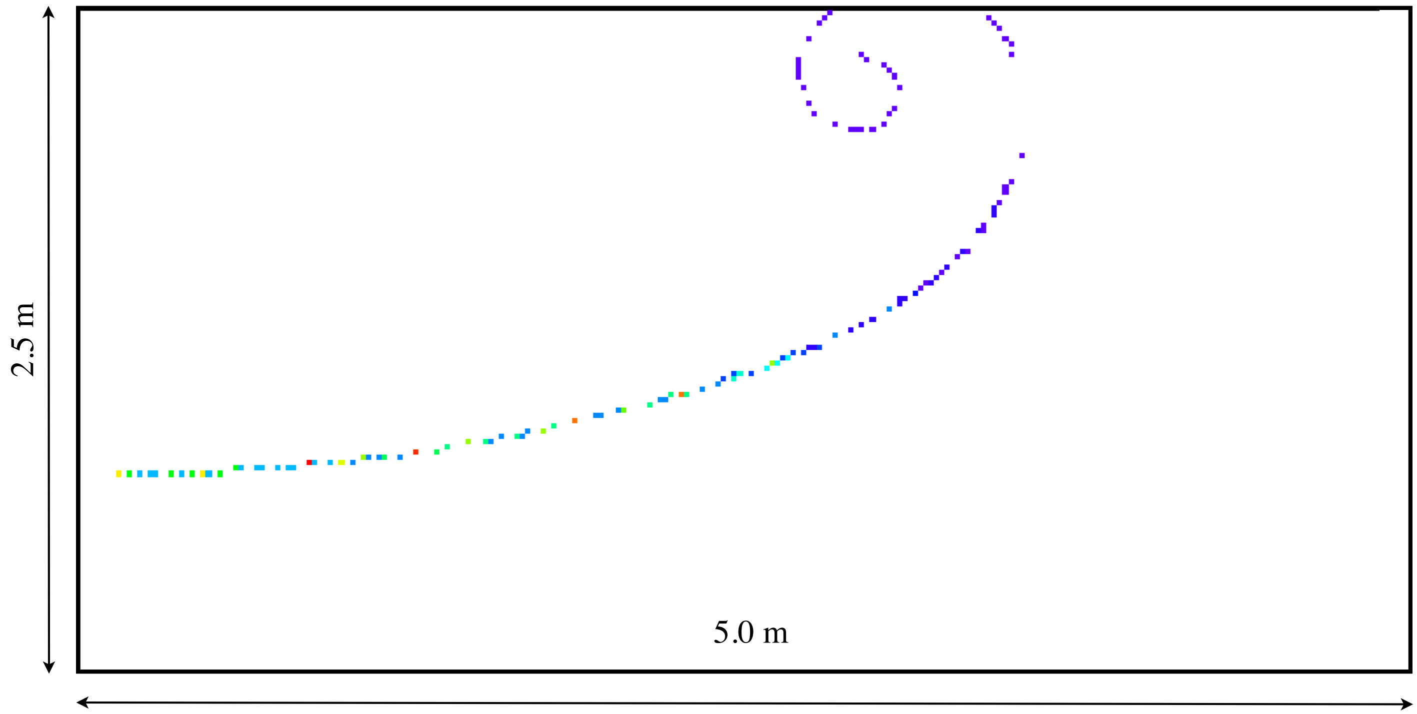
STT double module
XX YY assembly
with radiator foils

Sketch of the embossing pattern for the polypropylene radiator foils





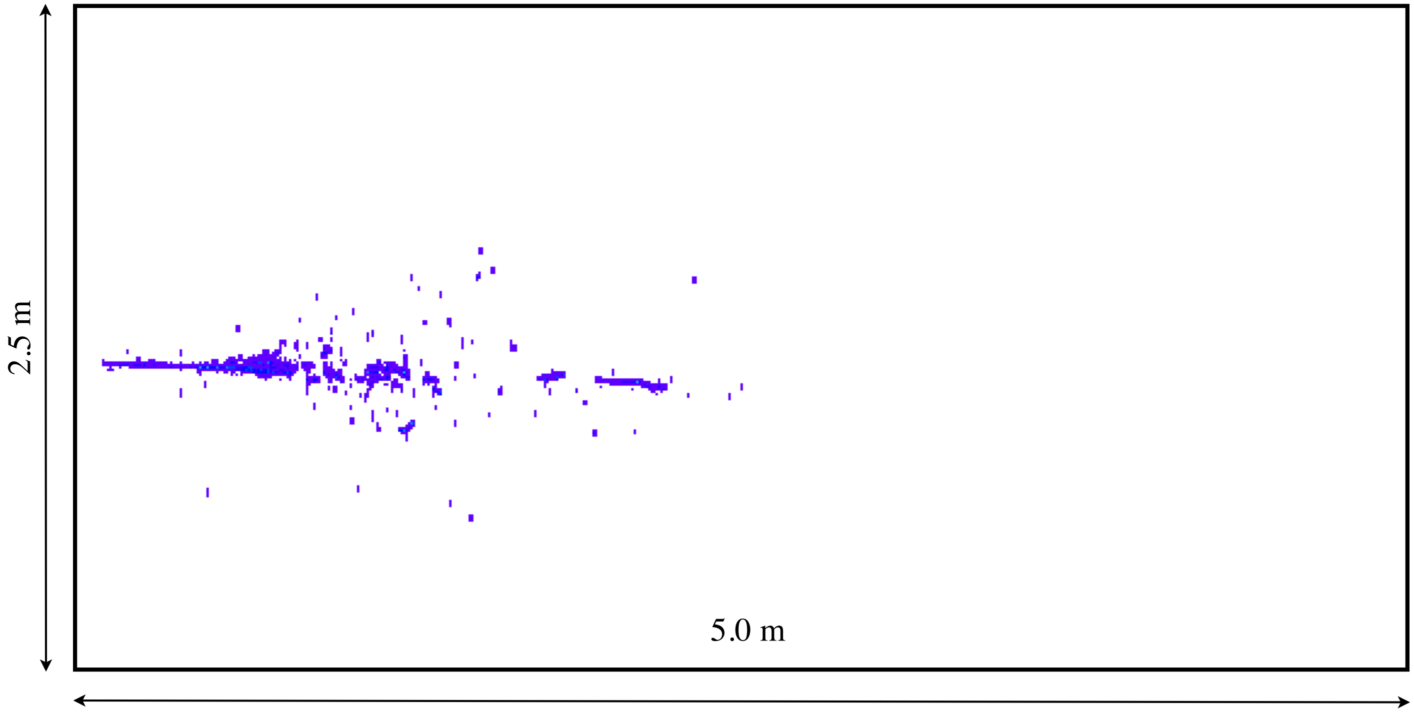
FGT G4 simulation: 1 GeV e^+



$$\rho = 0.1\ g/cm^3,\ X_0 = 500cm,\ \textit{track sampling 1.9cm/500cm} = \textit{0.38\%}$$

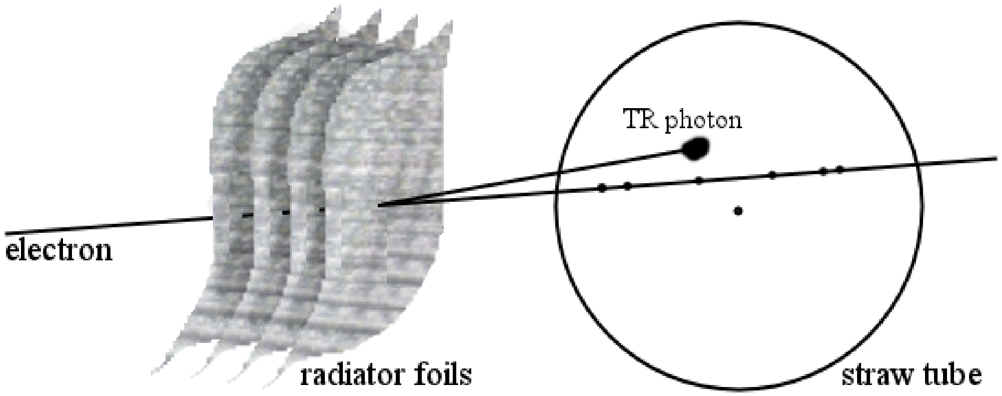
$$\textit{track sampling} \perp \textit{0.95cm/500cm} = \textit{0.19\%}$$

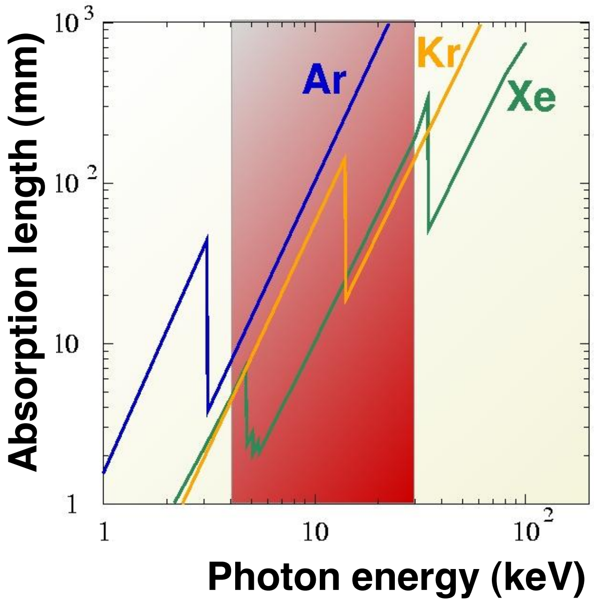
FD G4 simulation: 1 GeV e^+



$$\rho = 1.4\ g/cm^3,\ X_0 = 14cm,\ \mathit{track\ sampling\ 4.667mm/140mm = 3.33\%}$$

TR photons emitted within a cone $1/\gamma < 1$ mrad from the track direction





Xe gas has an absorption length 10 times smaller than Ar and $\ll$ straw diameter
Use a proven gas mixture with 70% Xe and 30% CO_2 for TR detection

Need closed gas system to minimize Xe leakage (Xe is expensive)
and avoid Xe content in gas volume outside straws (flush with CO_2)

TRANSITION RADIATION

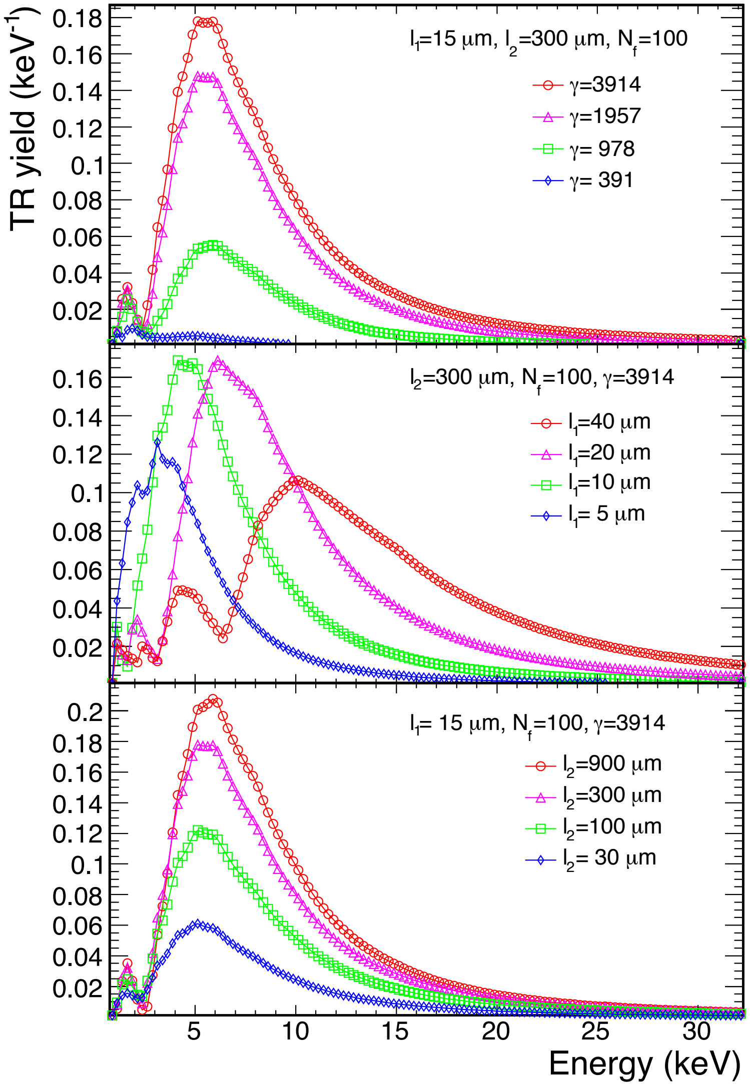
- *Simulation of Transition Radiation (TR) based on formalism by Garibian (1972), Cherry (1975)*
  $\Longrightarrow$ *Narrow energy range* $\sim$ *few keV*

- *Radiator design optimized for TR performance:*
  - *TR build-up over many interfaces;*
  - *Self-absorption of lower part of energy spectrum;*
  - *Need compact radiarors to keep large tracking sampling.*

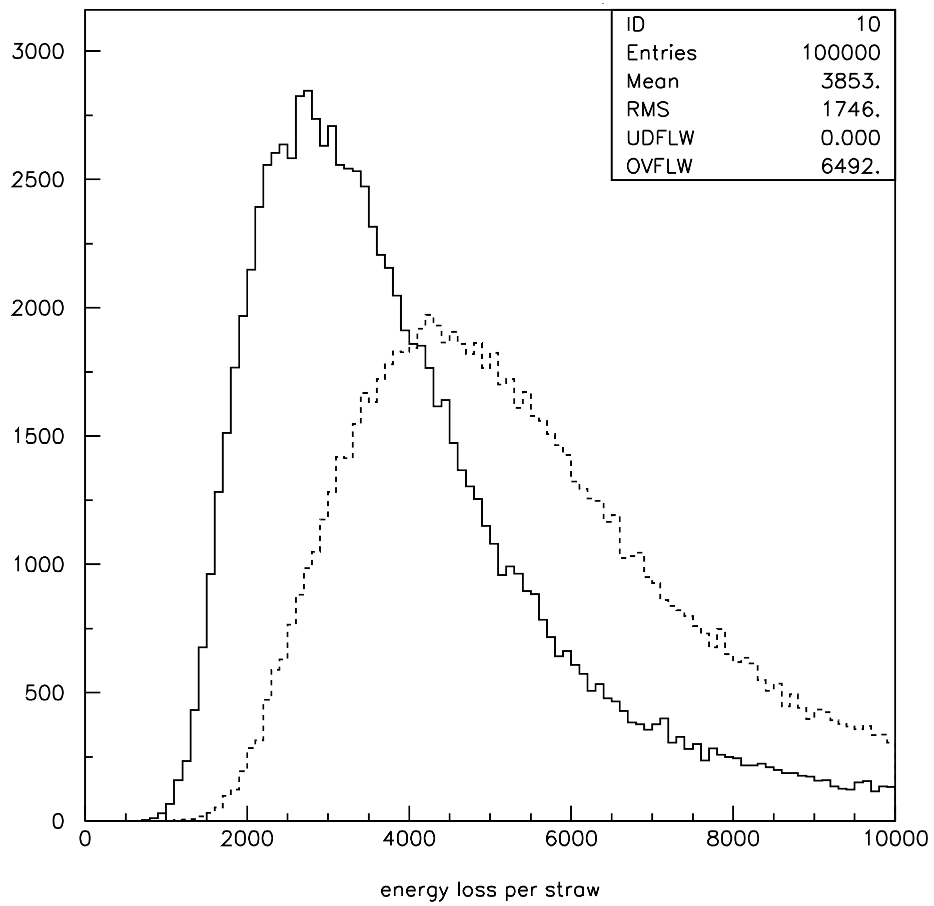
  $\Longrightarrow$ *Select 25* μm *foils, 125* μm *spacing*

- *On average* $\sim$*1 TR photon with* $E > 5$ *keV detected in a single STT module from a 1 GeV e*

- *dE/dx in straws are of the same order as TR at energies of few GeV: a 5 GeV e(*π*) has a probability* $\sim 41\%(18\%)$ *of depositing* $E > 6$ *keV*



Ionization dE/dx, E=5 GeV



COMPARISON WITH NOMAD

- *Continuous TR+dE/dx detection over entire STT volume, NOMAD only limited forward coverage*
  $\Longrightarrow$ *Improved acceptance and e^+/e^- ID*

- *NOMAD TRD configuration:*
  - *9 radiators made of 315 $(C_3H_6)_n$ foils each;*
  - *foils 15 μm thick, with 250 μm air gaps;*
  - *16 mm diameter straws without tracking capability.*

  $\Longrightarrow$ *Total 2,835 foils over $\sim$ 154 cm length*

- *Need $\sim$ 12 double STT modules (4 straw layers each) to match the total foils of the NOMAD TRD*
  $\Longrightarrow$ *More compact design with length $\sim$ 92 cm*

- *Opposite effects in STT:*
  - *Smaller air gaps and thicker foils reduce TR production with respect to NOMAD;*
  - *Larger Xe volume more uniformly distributed within radiator foils increases TR detection efficiency.*

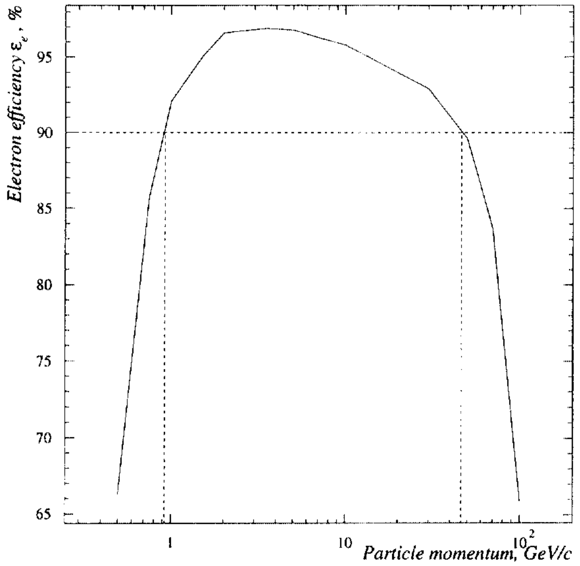
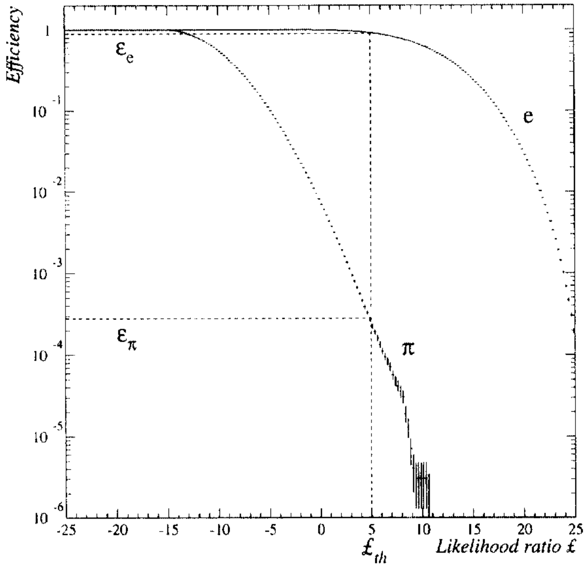


Fig. 8. Monte Carlo predicted electron efficiency ε_e corresponding to $\varepsilon_\pi = 10^{-3}$ as a function of the momentum of the particle



THE ELECTROMAGNETIC CALORIMETER

✦ Glo-Sci-51,23 *measure absolute and relative ν_μ, ν_e and $\bar{\nu}_\mu, \bar{\nu}_e$ spectra separately.*

Glo-Sci-24 *measure rates, kinematic distributions and topologies of bkgnd processes*

$\Longrightarrow$ *reconstruction of $e^+/e^-, \gamma$ with accuracy comparable to μ^+/μ^- and FD*

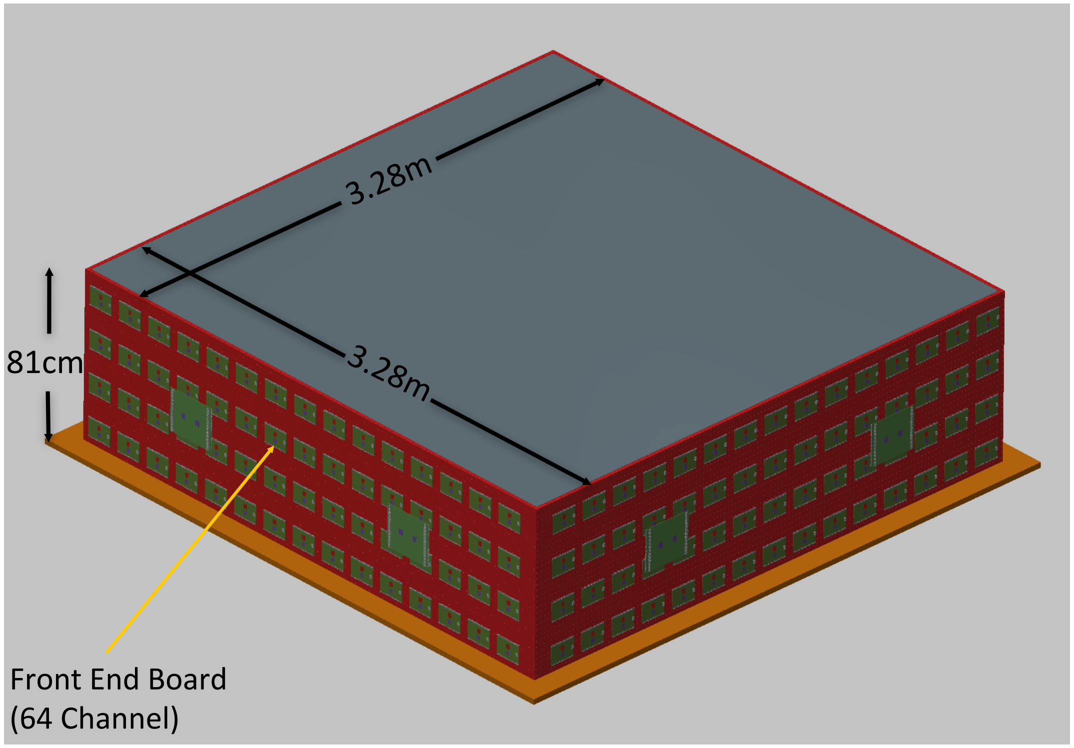
$\Longrightarrow$ *containment of $> 90\%$ of shower energy* NDC-L2-29,37

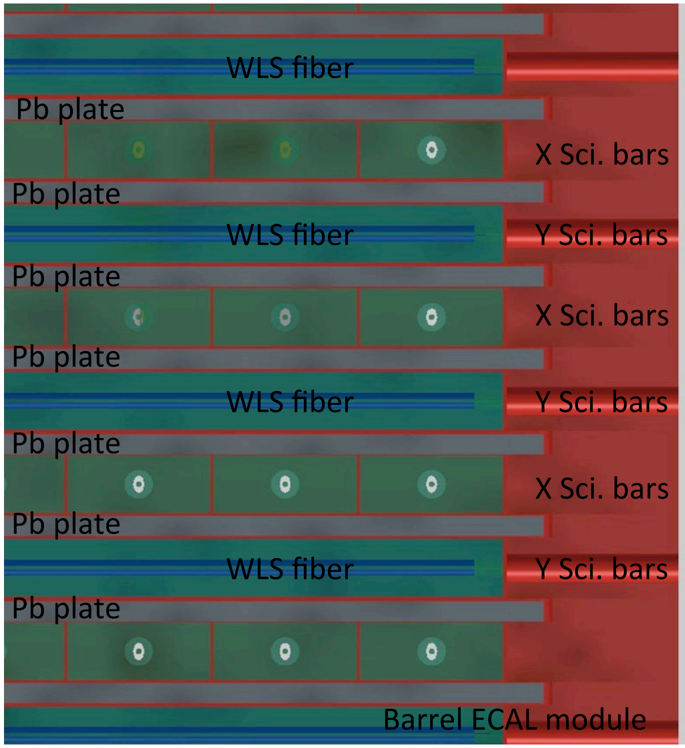
$\Longrightarrow$ *energy resolution $< 6\%/\sqrt{E}$* NDC-L2-38

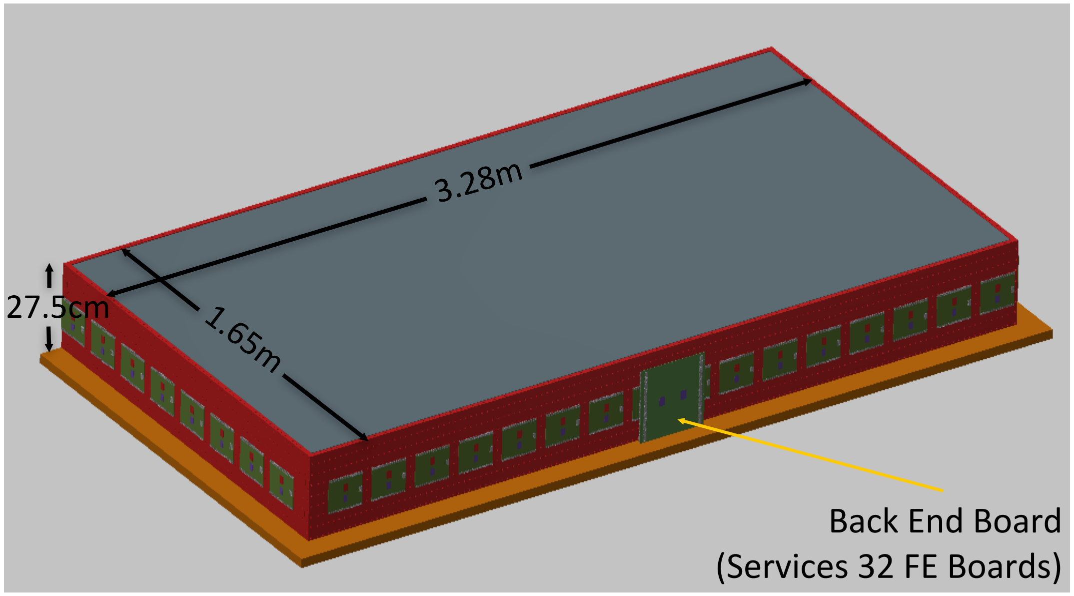
✦ *Based upon the design of the T2K ND-280 ECAL (to be further optimized)*

✦ *Sampling electromagnetic calorimeter with Pb absorbers and alternating horizontal and vertical (XYXYXY....) $3.2m \times 2.5cm \times 1cm$ scintillator bars readout at both ends by ~ 1 mm diameter extruded WLS fibers and SiPM*

- *Forward ECAL: 60 layers with 1.75 mm Pb plates* $\Longrightarrow 20X_0$
- *Barrel ECAL: 18 layers with 3.5 mm Pb plates* $\Longrightarrow 10X_0$
- *Backward ECAL: 18 layers with 3.5 mm Pb plates* $\Longrightarrow 10X_0$

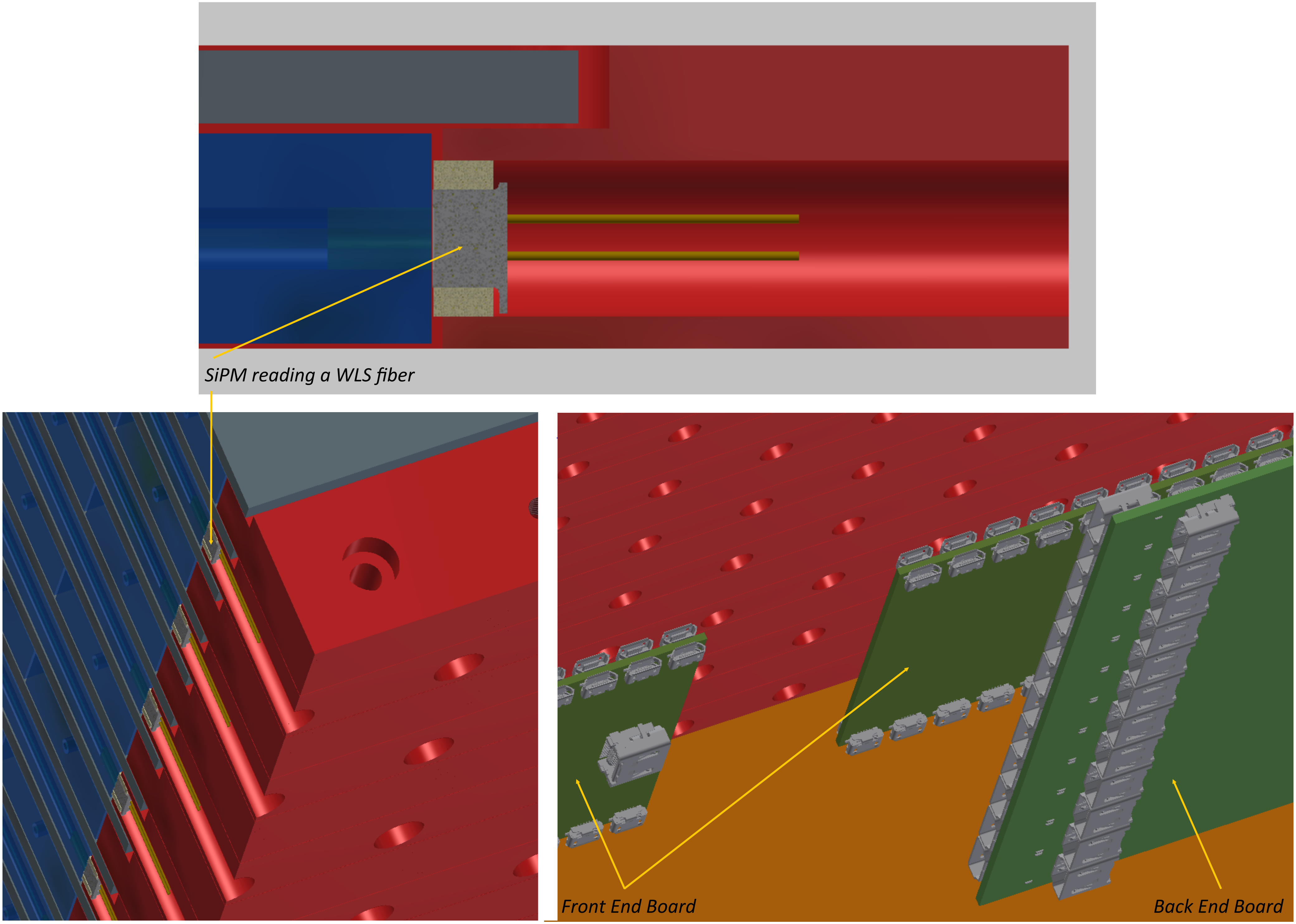






Forward ECAL
mass 21.7 tons

Barrel ECAL Module
(16 Barrel, 2 Backward ECAL)
mass 4.9 tons


SiPM reading a WLS fiber
Front End Board
Back End Board

Backup slides

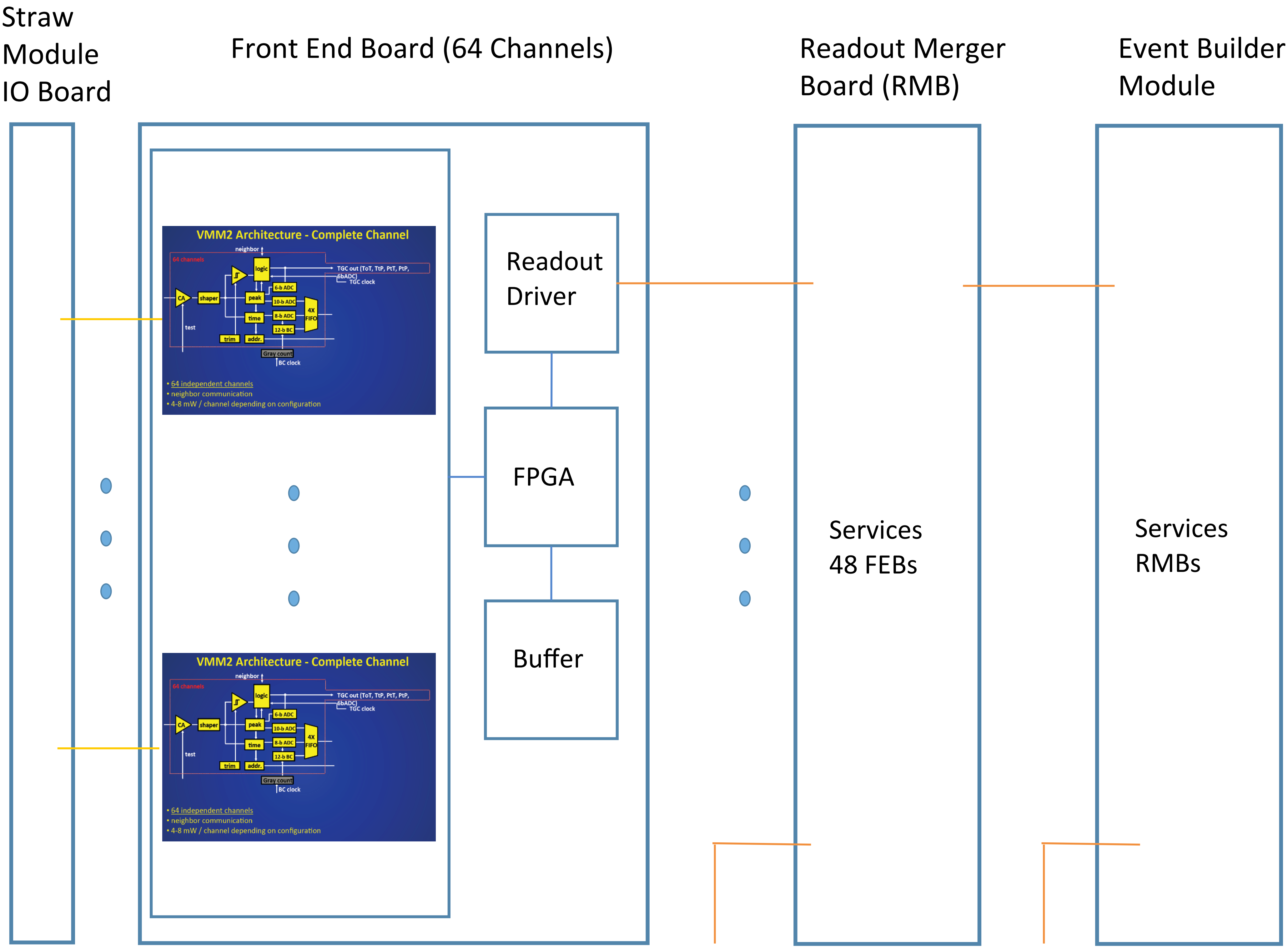
Simulation of a 10 STT MODULES

Geometry variant (# foils, thickness)	**Electrons E=1.5 GeV**			**Electrons E=5.0 GeV**		
	> 5.0 *keV*	> 5.5 *keV*	> 6.0 *keV*	> 5.0 *keV*	> 5.5 *keV*	> 6.0 *keV*
$N = 75, d = 40\mu m$	5.20	5.01	4.82	7.44	7.23	7.00
$N = 150, d = 40\mu m$	6.08	5.92	5.74	7.21	7.04	6.85
$N = 120, d = 25\mu m$	8.30	8.08	7.77	9.47	9.21	8.85
$N = 150, d = 25\mu m$	8.44	8.22	7.91	9.40	9.15	8.80
$N = 120, d = 15\mu m$	7.83	7.33	6.76	8.46	7.93	7.32
$N = 120, d = 20\mu m$	8.54	8.17	7.71	9.46	9.05	8.54
$N = 130, d = 20\mu m$	8.65	8.29	7.82	9.52	9.12	8.61
$N = 130, d = 25\mu m$	8.39	8.16	7.85	9.48	9.22	8.87
$N = 150, d = 20\mu m$	8.77	8.41	7.96	9.54	9.16	8.67

Total longitudinal length of 10 STT modules (double layers) 40 cm

STT READOUT

- ✦ *Double readout at both ends of straws: 215,040 channels in STT*
- ✦ *Each of the 80 STT XXYY assemblies equipped with:*
  - *44 I/O Boards (11 per side) with 64 channels each;*
  - *44 Front End Boards (FEB) with 64 channels each (11 per side).*
    Consider VMM2 chip (ASICS) developed for ATLAS upgrades, with fast ADC and TDC;
  - *Number of straw ends readout:*
    21 groups of 32 straws per double layer (XX or YY) $\times$ 2 ends $\times$ 2 modules $=$ 2,688
- ✦ *Back End electronics:*
  - *80 receiver modules - Readout Merger Board (RMB) - (one per XXYY assembly) mounted in racks;*
  - *5 crates (MicroBooNE), each holding 16 receiver modules, 1 controller, 1 XMIT, 1 trigger module;*
- ✦ *High Voltage: 160 channels, one for each XX (or YY) double layer module*
- ✦ *Low Voltage: one per RMB (80 total) servicing each 48 FEB $+$ 80 distribution boards.*



Straw Module IO Board

Front End Board (64 Channels)

Readout Merger Board (RMB)

Event Builder Module

VMM2 Architecture - Complete Channel

- 64 independent channels
- neighbor communication
- 4-8 mW / channel depending on configuration

VMM2 Architecture - Complete Channel

- 64 independent channels
- neighbor communication
- 4-8 mW / channel depending on configuration

Readout Driver

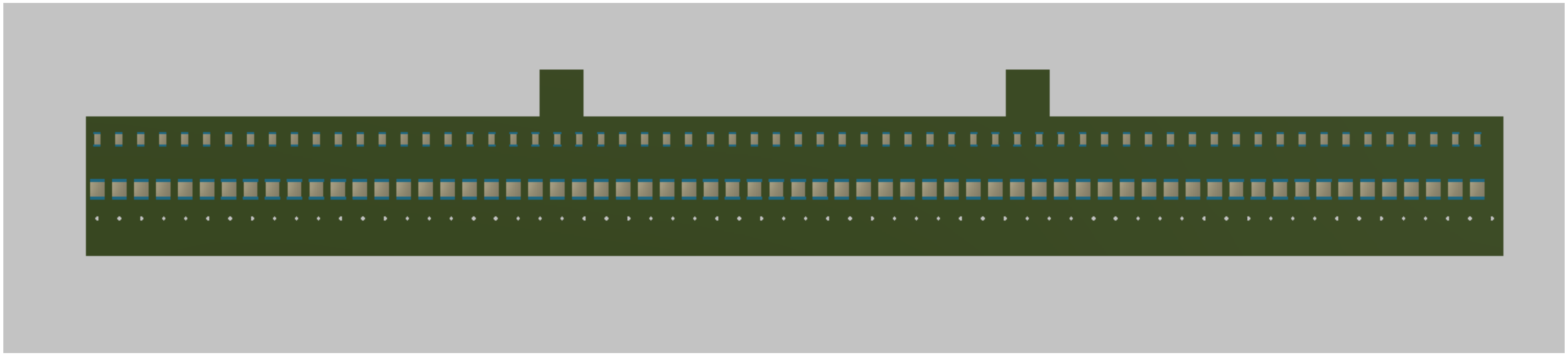
FPGA

Buffer

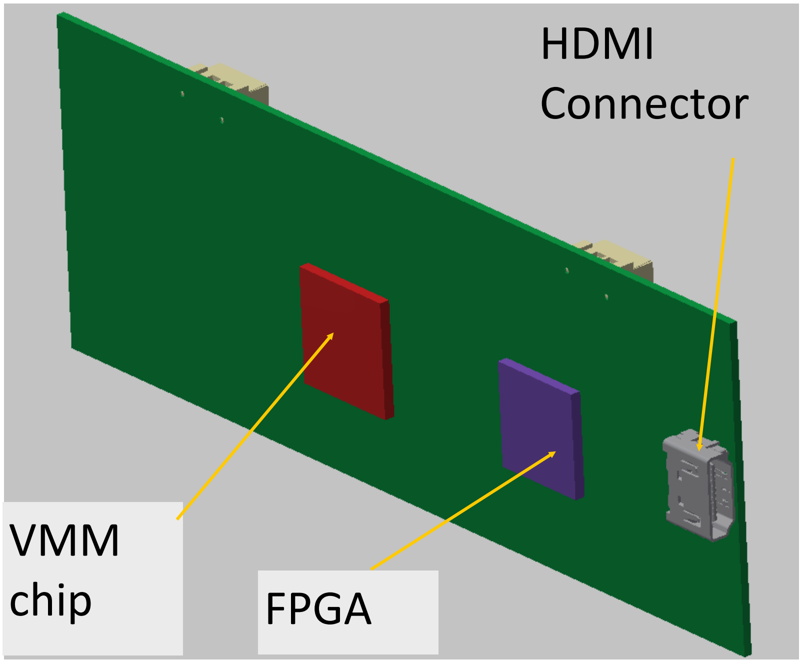
Services 48 FEBs

Services RMBs

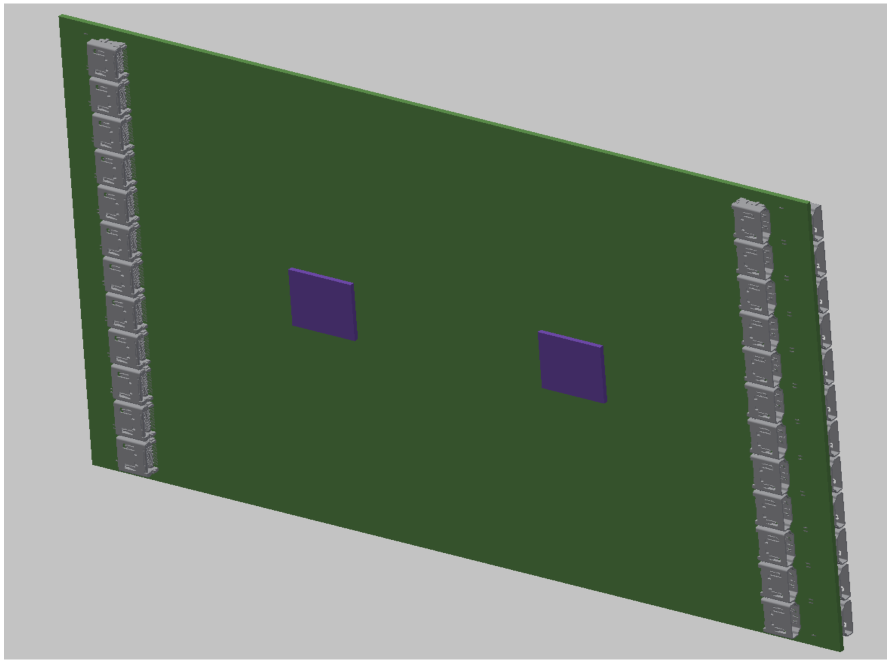
Straw Tube Chamber IO Board (304mm x 30mm): 3,520 total



Front End Board (175mm x 60mm): 3,520 total



Back End Board (200mm x 300mm): 80 total



STT GAS SYSTEM

- *The active gas is Xe(70%)/CO_2(30%) mixture for the STT modules with radiators and Ar(70%)/CO_2(30%) for the STT modules with nuclear targets.*

- *Total active gas volume 26.7 m^3 and should be flushed with approximately one volume change/hour;*

- *Gas distribution is a closed recirculation system to minimize Xe losses;*

- *Exit gas from the straws is recovered, cleaned and recirculated;*

- *Gas tightness of straws ~ 1 mbar/min/bar to minimize Xe losses (standard ATLAS acceptance criteria);*

- *To protect straws from moisture CO_2 is flushed around the straws throughtout the outer envelope of the STT (53.4 m^3);*

- *Forced flaw of $\sim$ 100 m^3/hour.*

TRIGGER AND EVENT RATES

- *The maximum drift time for a Xe/CO_2 gas mixture is 125 ns for a distance of 5mm (lower for Ar), as measured in testbeam.*

- *The STT can resolve individual beam pulses (resolution $\sim$ ns)*

- *Expect a rate of 1.5 events/spill ($\sim$ 10 μs) for events originated within STT volume.*

- *Possible a self-triggering scheme in which hits are stored in pipelines (can use FE ADC to operate in digital domain) waiting a later decision*

  $\Longrightarrow$ *Avoid trigger based upon geometrical acceptance (problem in NOMAD).*

- *Depending upon the background rate, it should be possible to read and timestamp everything within one spill and to take a decision later in the cycle.*

- *In addition, calorimetric trigger (complementary)*