Scintillator module design concept

Andy Furmanski

Preliminary Design Review

7th February 2025

Calibrations/LED – monitor system, repair replace, etc

Introduction

- I will outline the conceptual design of the active detector modules
- Julianna will describe the mechanical details of the design
- I will summarise our prototyping plans
- Mayly will describe our construction plans

Scintillator detectors

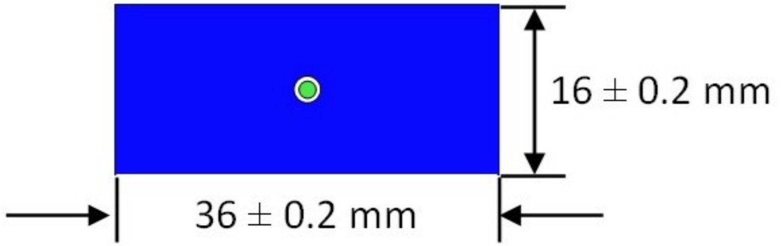
- Interleaved with steel
  - See earlier talks for the details
  - Gaps are 50mm – not much space!
- Core requirements:
  - Measure muon trajectories to sufficient precision to
    - Determine charge from bend in B-field
    - Measure range for energy estimate
    - Measure position/direction to match to ND-LAr
  - Cost-effective
- Plan is to use extruded scintillator bars from Fermilab's extrusion facility

Scintillator bar dimensions

- Bend in B-field leads to ~8cm total sagitta
  - Need to distinguish +8cm from -8cm
- Matching to LAr limited to ~5cm by multiple scattering
- Fast timing (few-ns) will separate RF buckets, and we'll see <1 muon per RF bucket
  - Therefore few-cm resolution is sufficient
- Light yield needs to provide "digital" response at minimum, 90% single-plane efficiency
  - This needs to still be true after 10 years
- Additional requirement is to fill the minimum active area (~7m x 3m)

Scintillator bar dimensions

- 3.6cm wide bars provide sufficient spatial resolution
- Dimensions fill space neatly, when split into 32-bar modules
  - 96 horizontal bars (3x32) would be 3.45m tall
  - 192 vertical bars (6x32) would be 6.9m wide
- This bar width leads to ~19,000 channels over the detector
- Bars are 1.6cm thick
  - Largely driven by mechanical design of modules



WLS fiber and readout

- 1.4mm fiber inserted into extruded hole
  - No glue used
  - Similar to T2K FGD construction
- All fibers read out on one end
- No “active” reflection added at other end
  - If prototypes suggest this is needed, it can be added

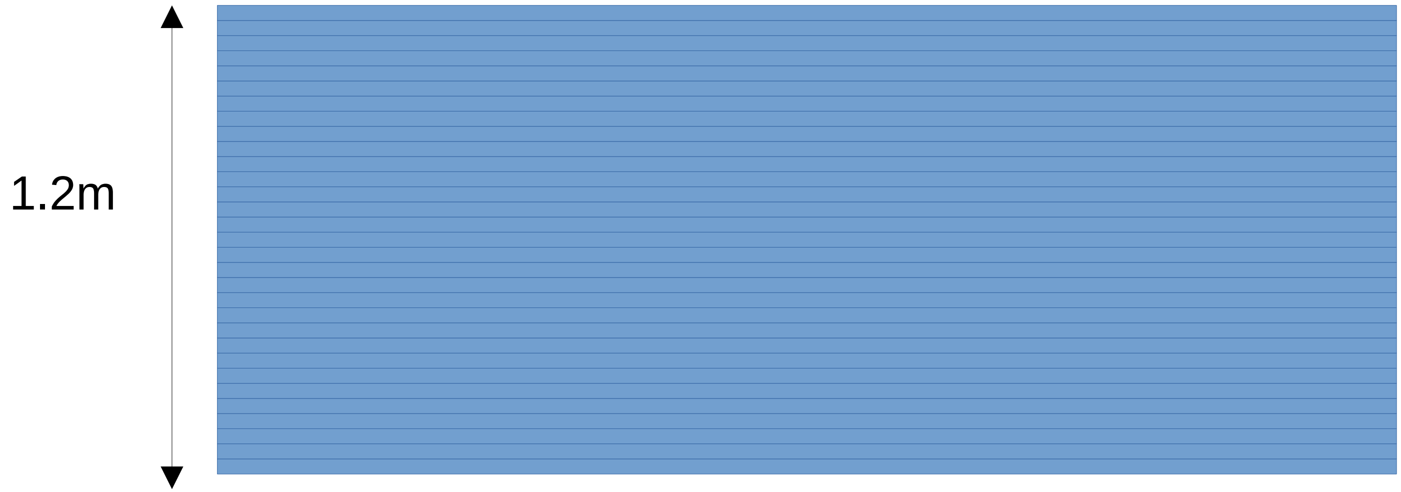
Evaluated alternatives. Using Kurary Y11 etc…
Well-known timing characteristics

Light yield

- Muons (MIPs) will deposit approx. 2.5 MeV per bar
  - Assuming perpendicular – path length can be longer
- Mu2e CRV tested TMS-like counters recently
- Same scintillator, similar dimensions
  - 10mm x 40mm (vs 16mm x 36mm)
  - Same 1.4mm fiber
- Test stand observed 38.8 PE per MIP
- Implication for TMS, with thicker scintillator → 45+ PE per MIP
  - Assuming up to 5% decline per year from aging, still over 20PE per MIP after 10 years

“Modules”

- 32 bars make a module (~1.2m wide)
  - Each module has a mass of ~60kg
- Module design allows trivial adjustments to length
  - Planning 3.15m and 3.65m - see later



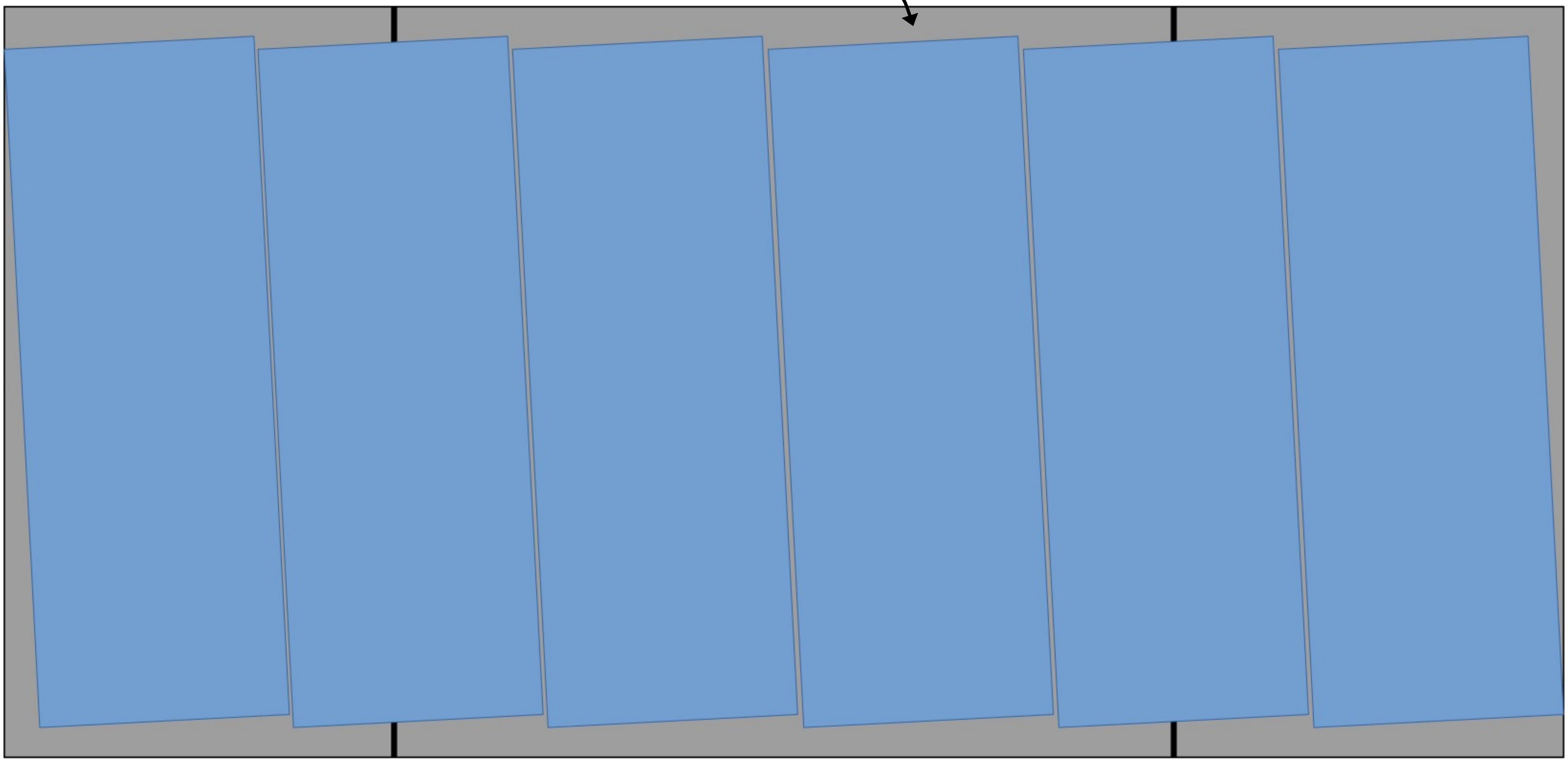
Module orientation

- Modules tilted pm 3 degrees from vertical (U and V)
- Each *module* is tilted, not each bar
  - i.e. modules are rectangles, and we get small empty triangles
- Periodic counters placed horizontally to improve vertical resolution
  - Referred to as Y counters (they measure Y)
  - Expect ~10% of counters to be horizontal

Modules arranged in planes

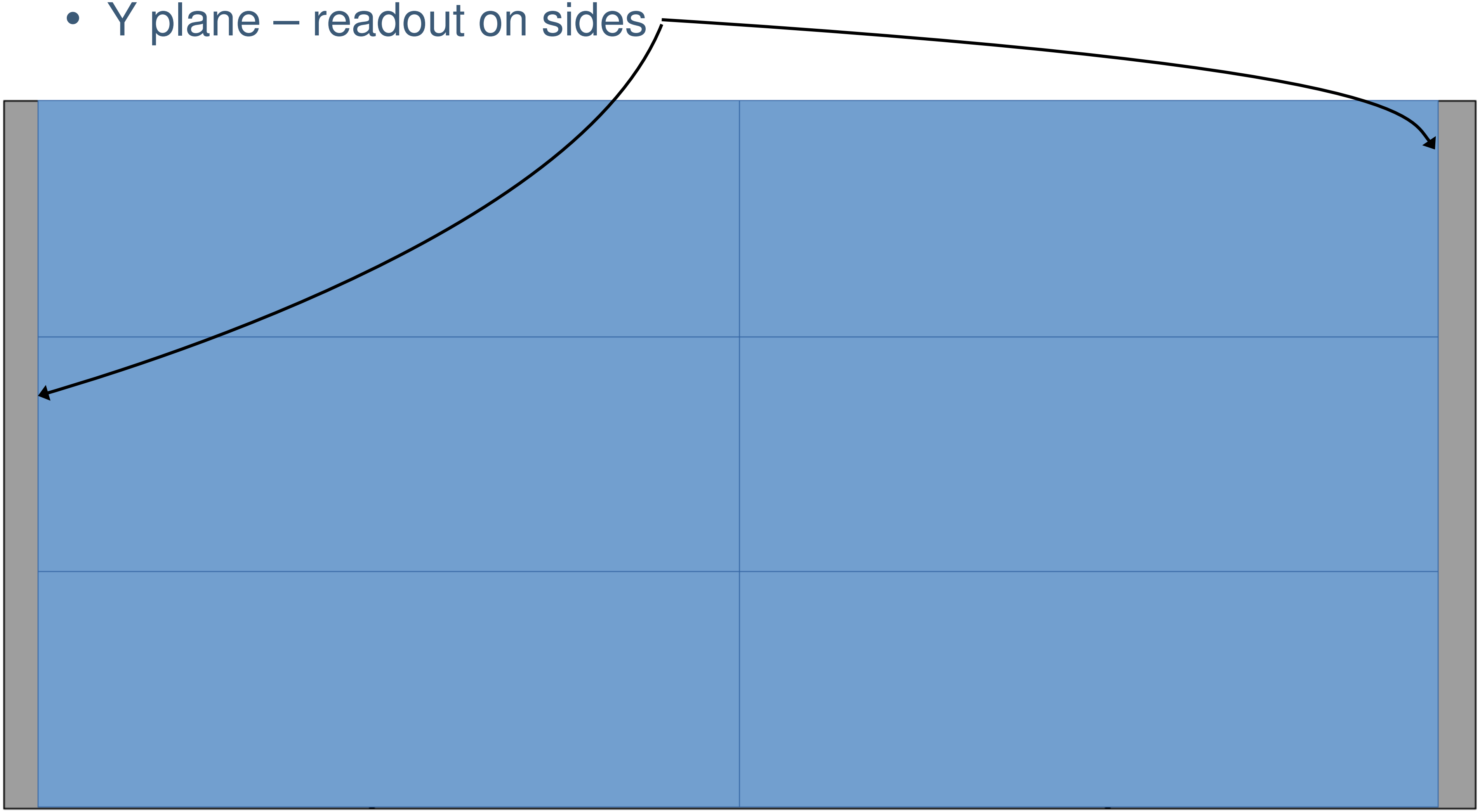
- U/V plane – readout on top

Clarify centering, Y coverage includes all U/V coverage



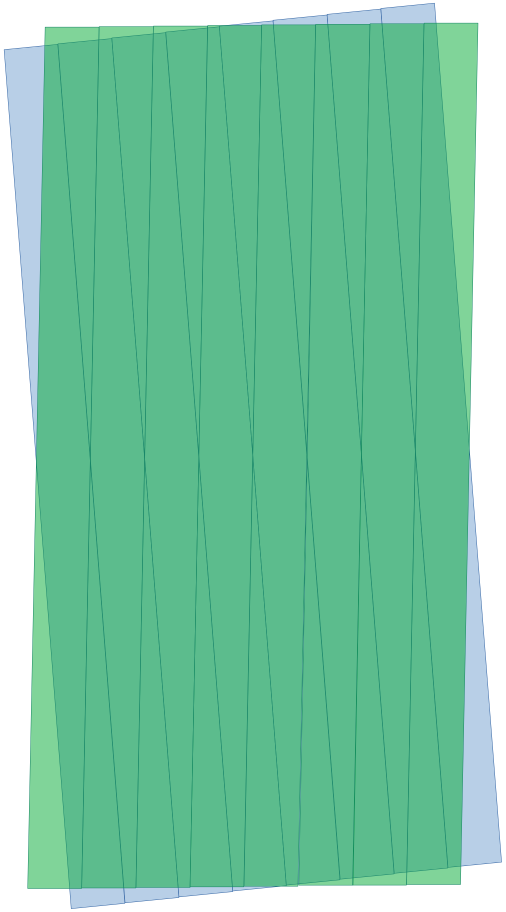
Modules arranged in planes

- Y plane – readout on sides



Why Y?

- Stereo tilt provides ~30cm vertical position resolution
- But ~2cm horizontal resolution
  - This is to maximise bending plane resolution
- Knock-on effect on range measurement due to uncertain direction
- Add horizontal counters periodically!



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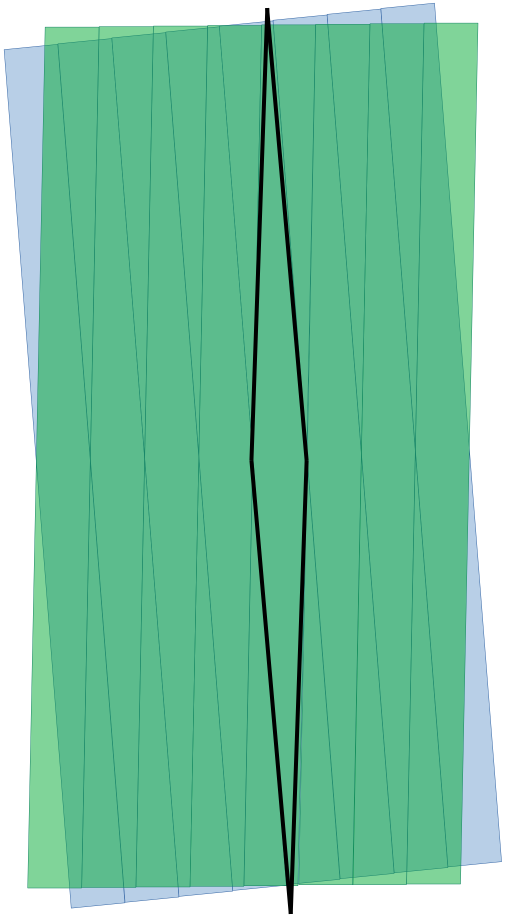

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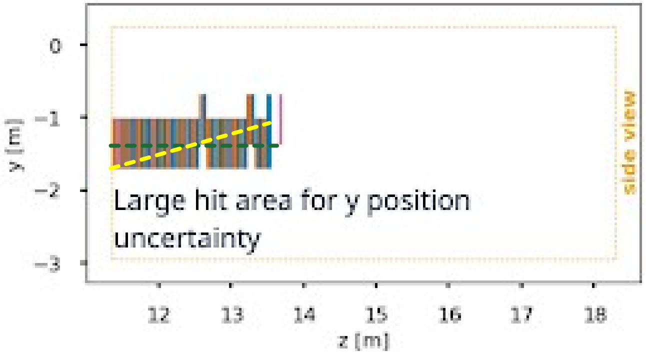
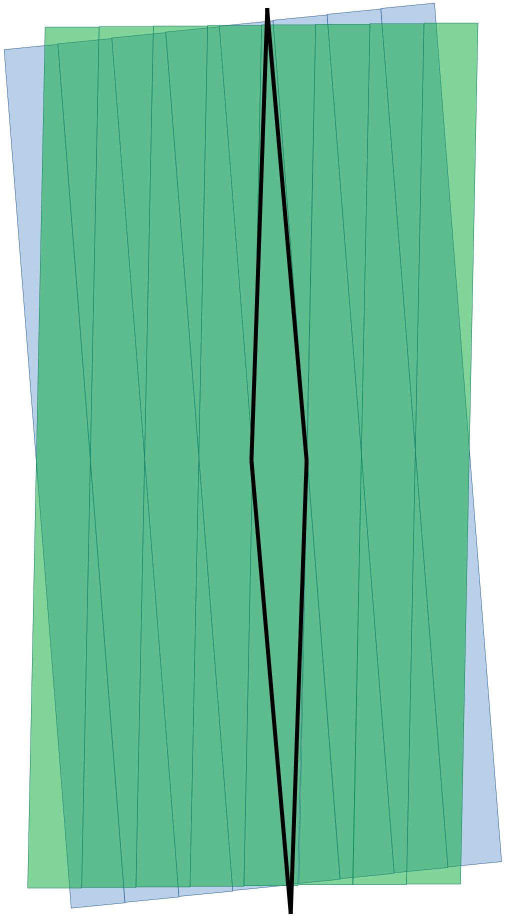
Example – green and yellow paths are 3% different in length





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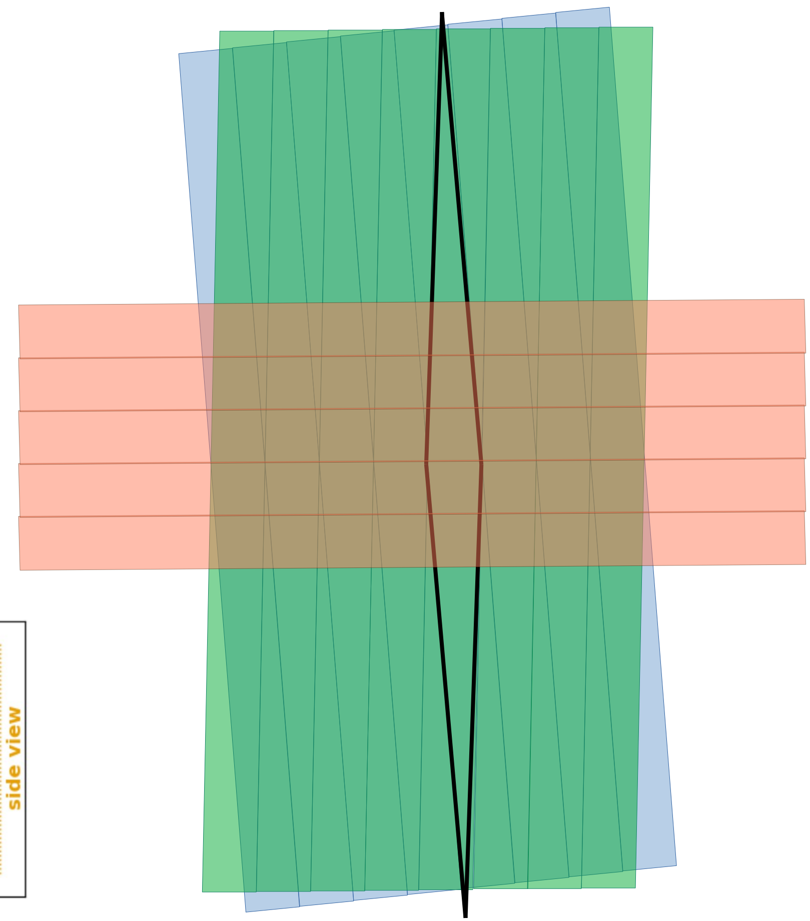
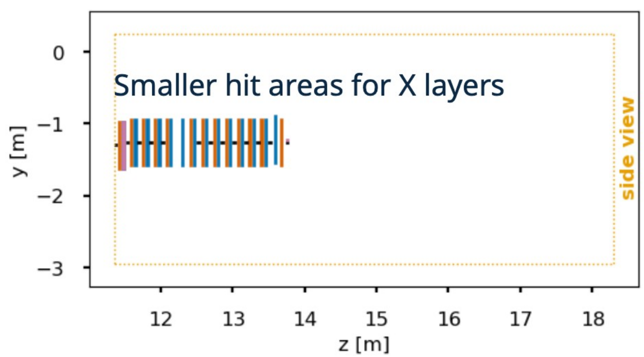


Now only a very narrow range of paths



Some technical requirements

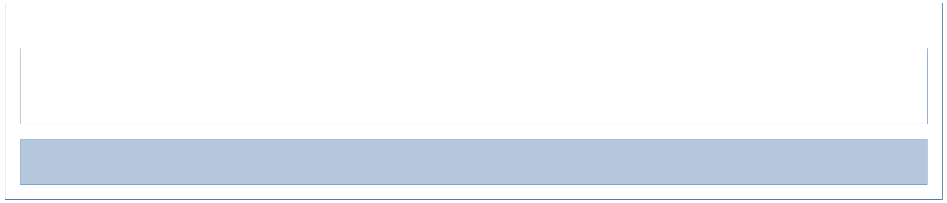
- One plane (view) of scintillator per inter-steel gap
- To meet efficiency and resolution requirements, single-plane muon efficiency must be >90%
- This can be a combination of:
  - Dead material
  - Dead/noisy electronics channels
  - Low efficiency (light yield)
- Goals are:
  - Light yield sufficient for ~100% efficiency
  - Dead channels < 5% (assumed requirement is 3%)
  - **Dead material <5% (over the active area)**

Module concept

- As far as possible, rely on:
  - Well-understood previously used design concepts
  - Off-the shelf, or mass-producible components
  - Re-use of equipment
- MINOS design for light-tight structural case
- NOvA-inspired injectable glue joints
- NOvA (and mu2e) automated flycutters for fiber ends
- Previous reviews urged us to consider ways to keep electronics accessible
  - Everything electronic is now separate from the mechanical modules

Light case

- Nesting aluminium half-boxes
- Edges crimped together



End view

Light case

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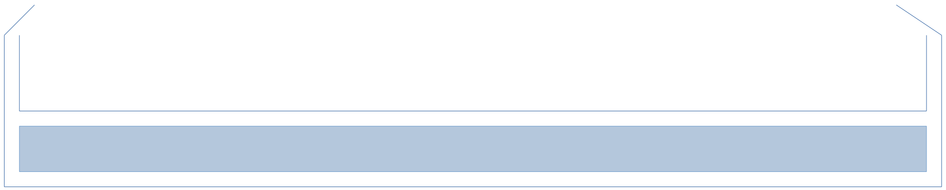
- Edges crimped together



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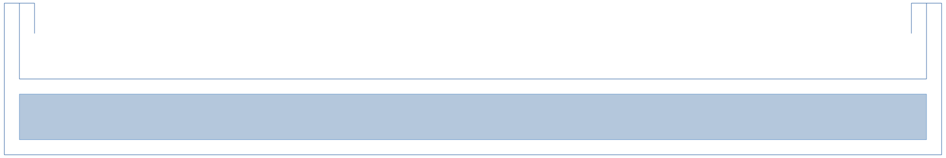

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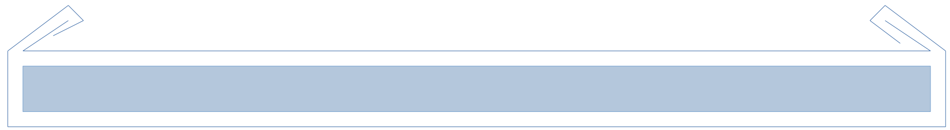

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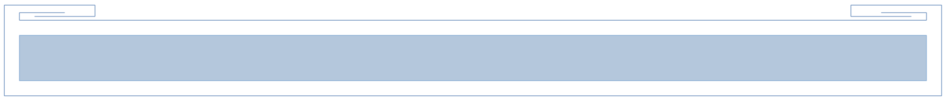

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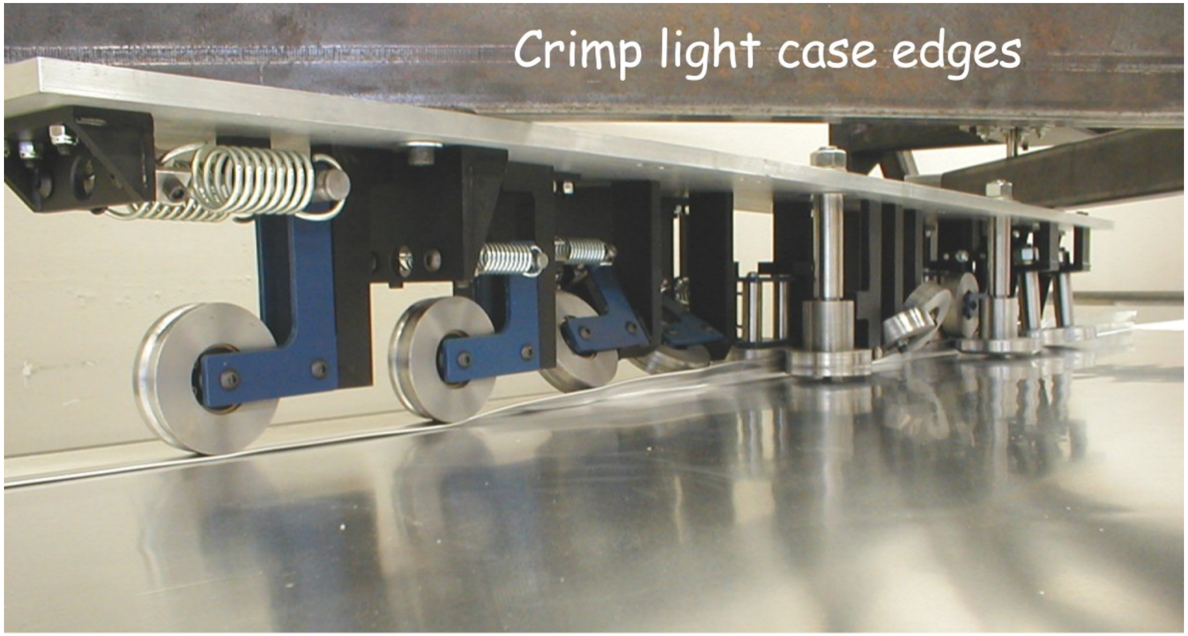
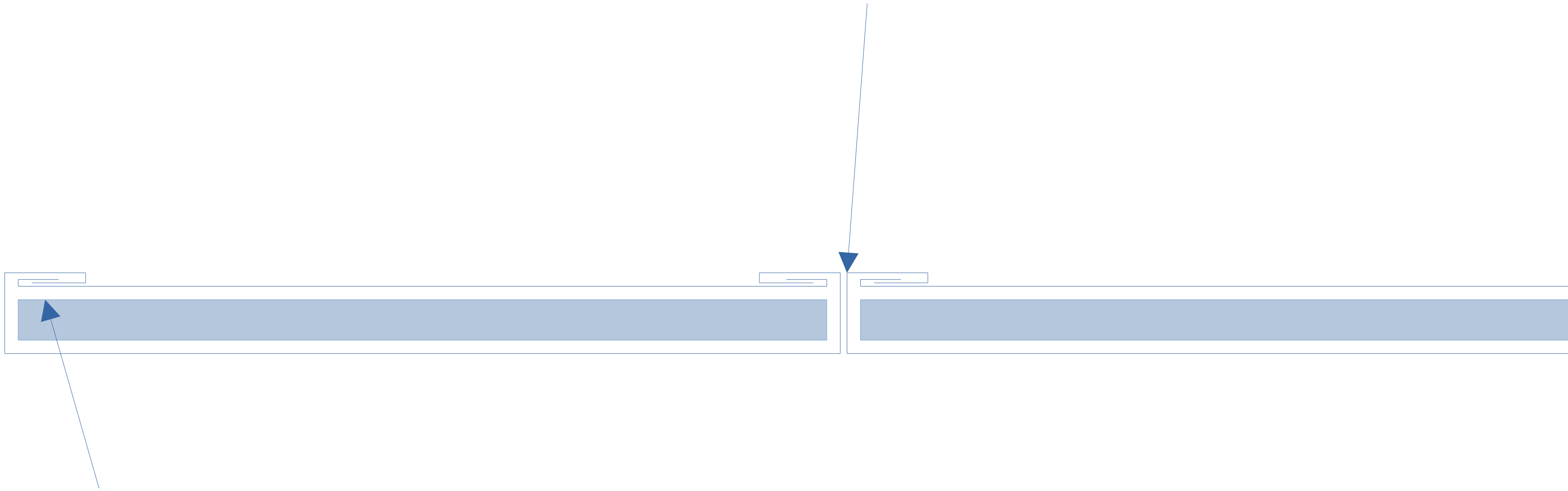


Crimping machine runs along the length, whatever that length may be

Light case

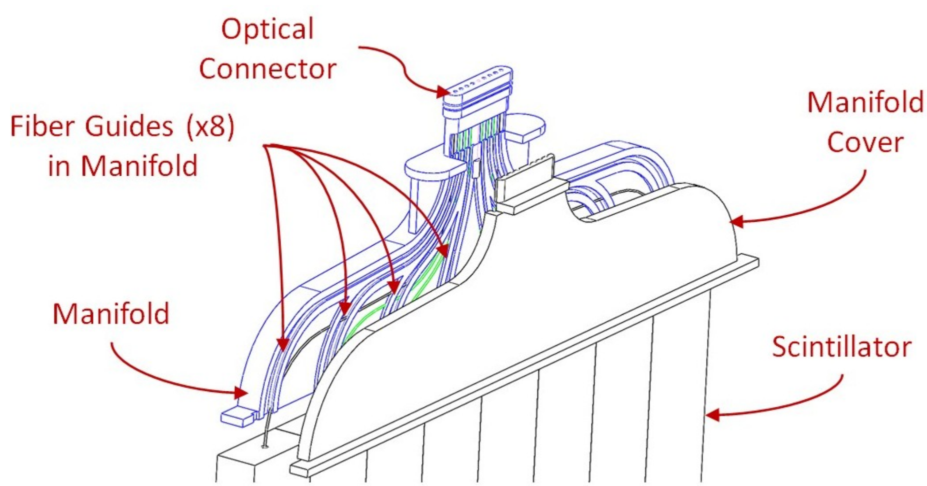
- Nesting aluminium half-boxes
- Edges crimped together
- Dead material between modules is 2x0.5mm aluminium



Sharp metal edges hidden!

Fiber manifolds

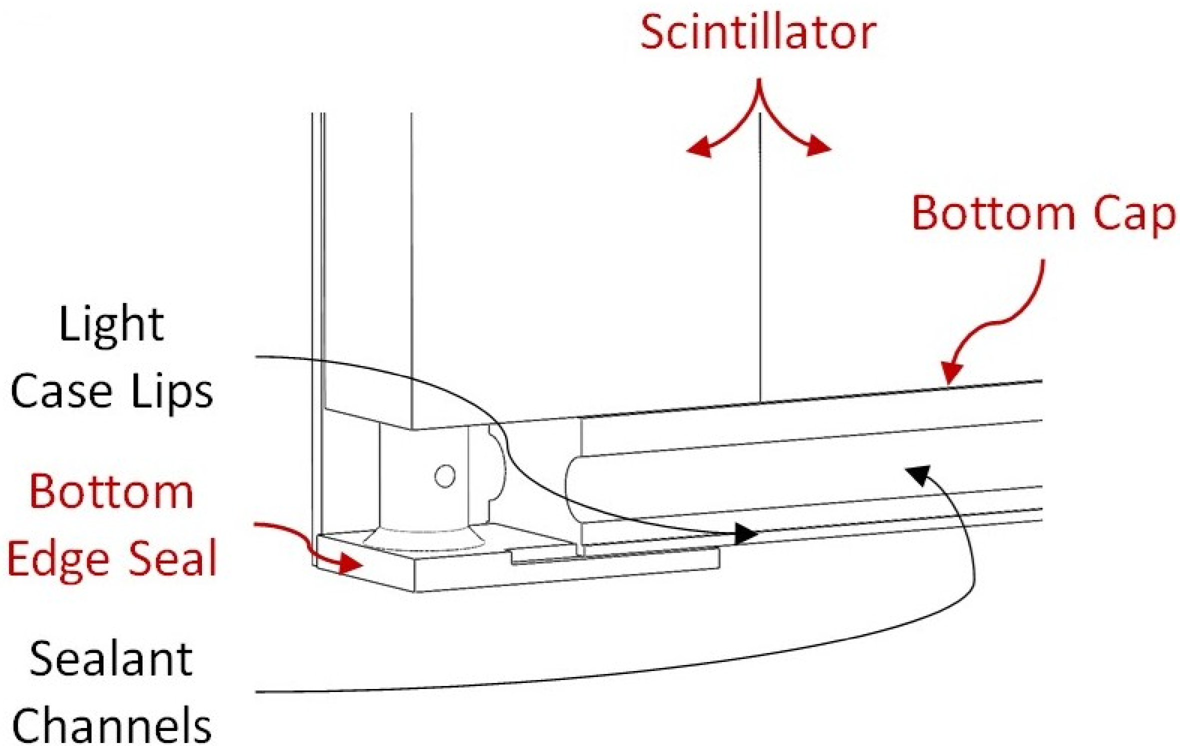
- Fibers grouped into sets of eight
  - Cables will have 10 conductors – 8xSiPM, 1xLED, 1xRTD
- Four manifolds per module
- Reduce number of connectors by factor of 8
- Size dictated by minimum bend radius



Explain why this is needed

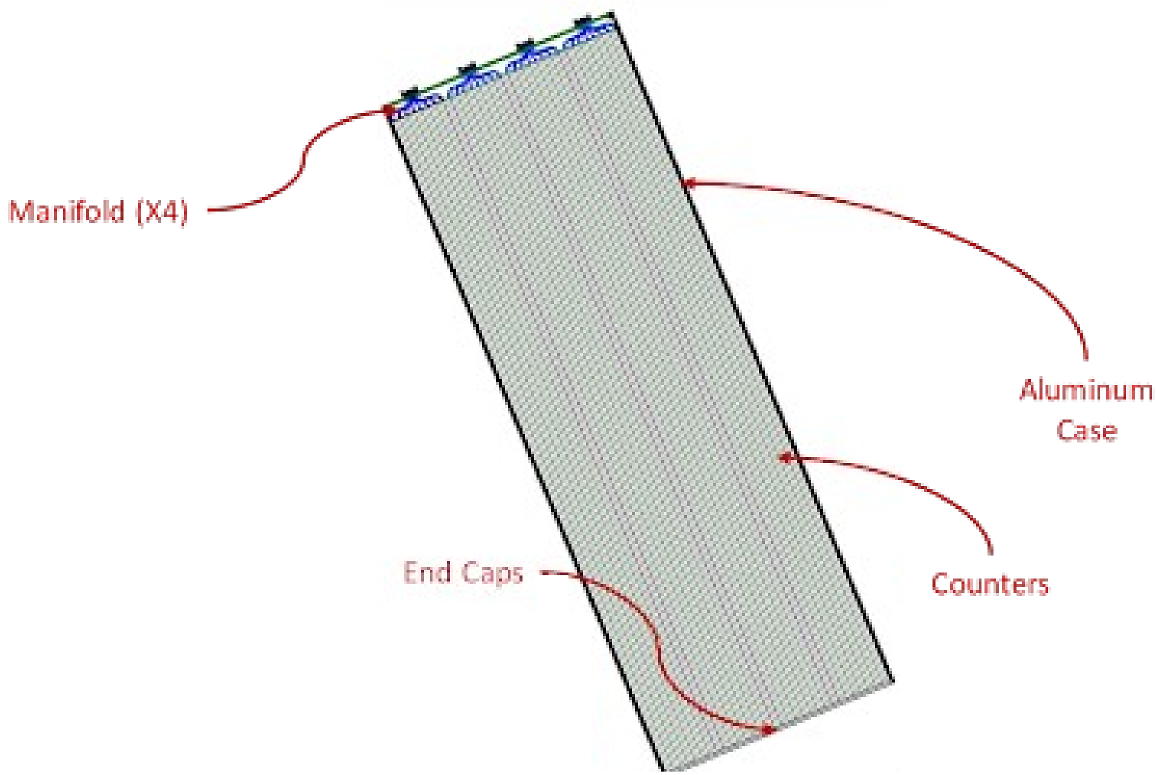
End caps

- Injectable glue joints allow a simple extrusion to form a light-tight seal



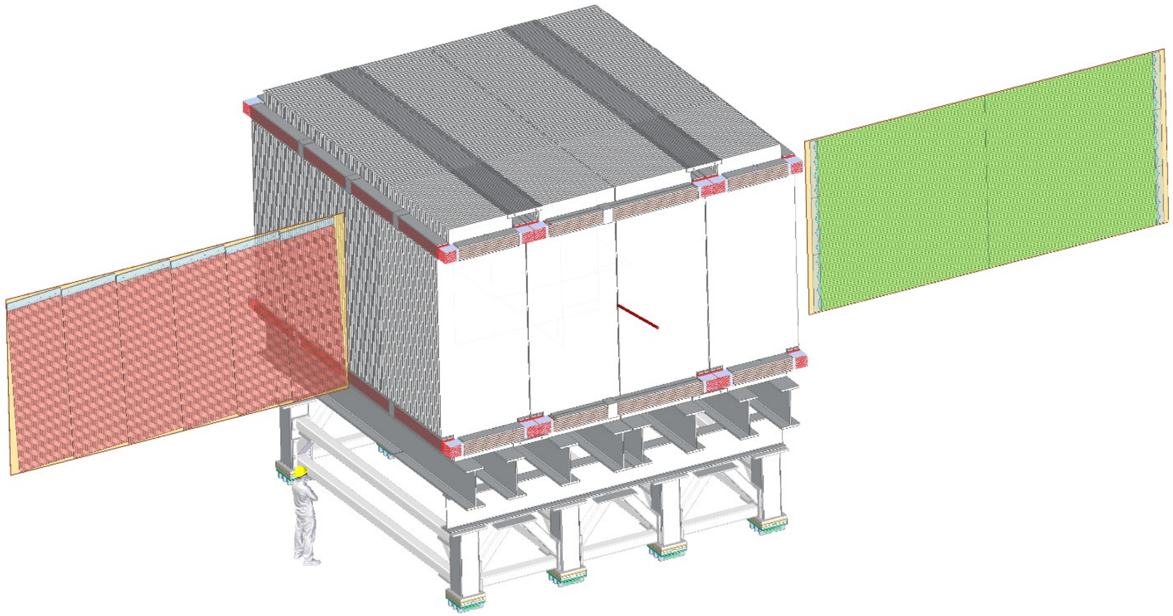
Whole module

- A whole module will therefore look like this



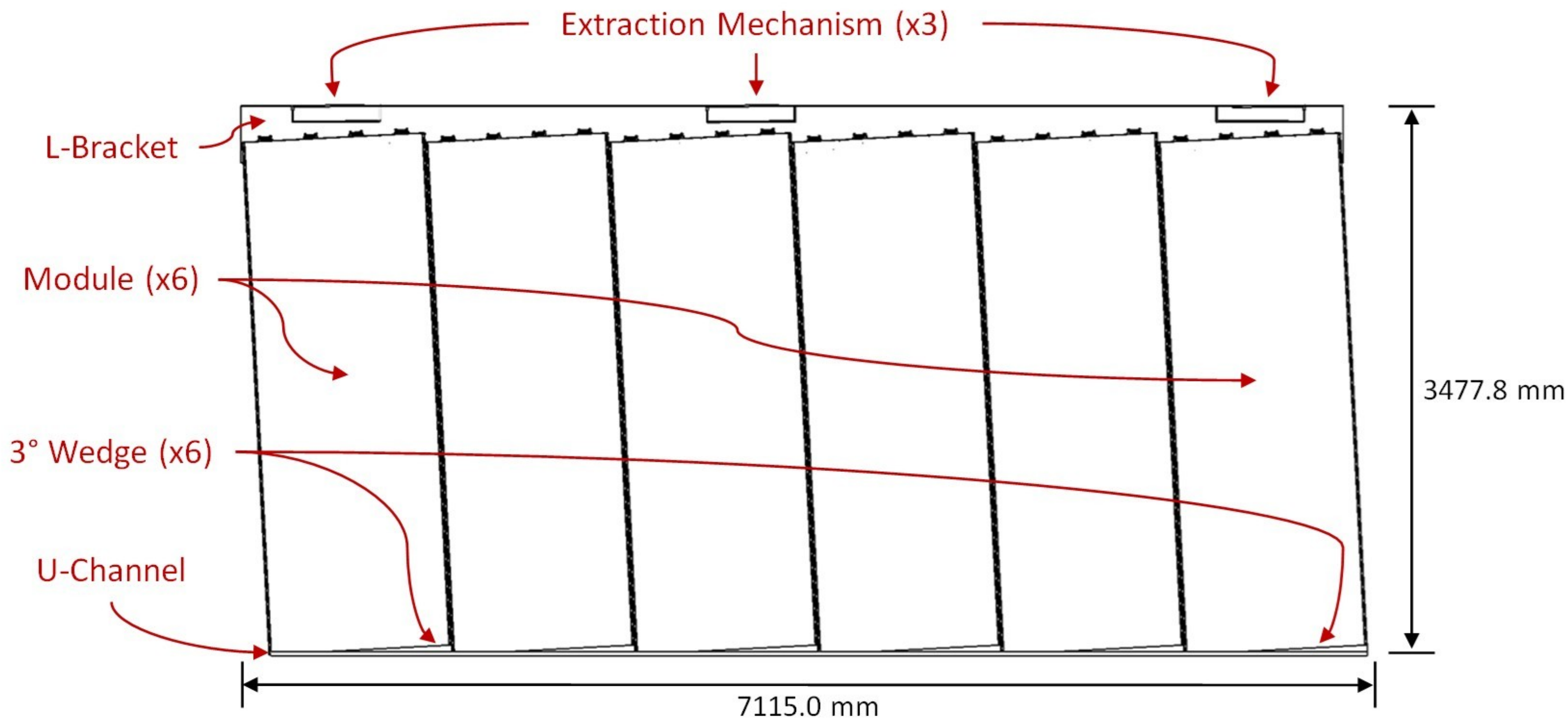
Cassette concept

- Magnet will be built and tested before installation of active detectors
- Each full plane will be constructed as a “cassette” to be inserted later
- Separates steel installation and detector construction timelines
- Allows removal of a cassette for repair/replacement in principle



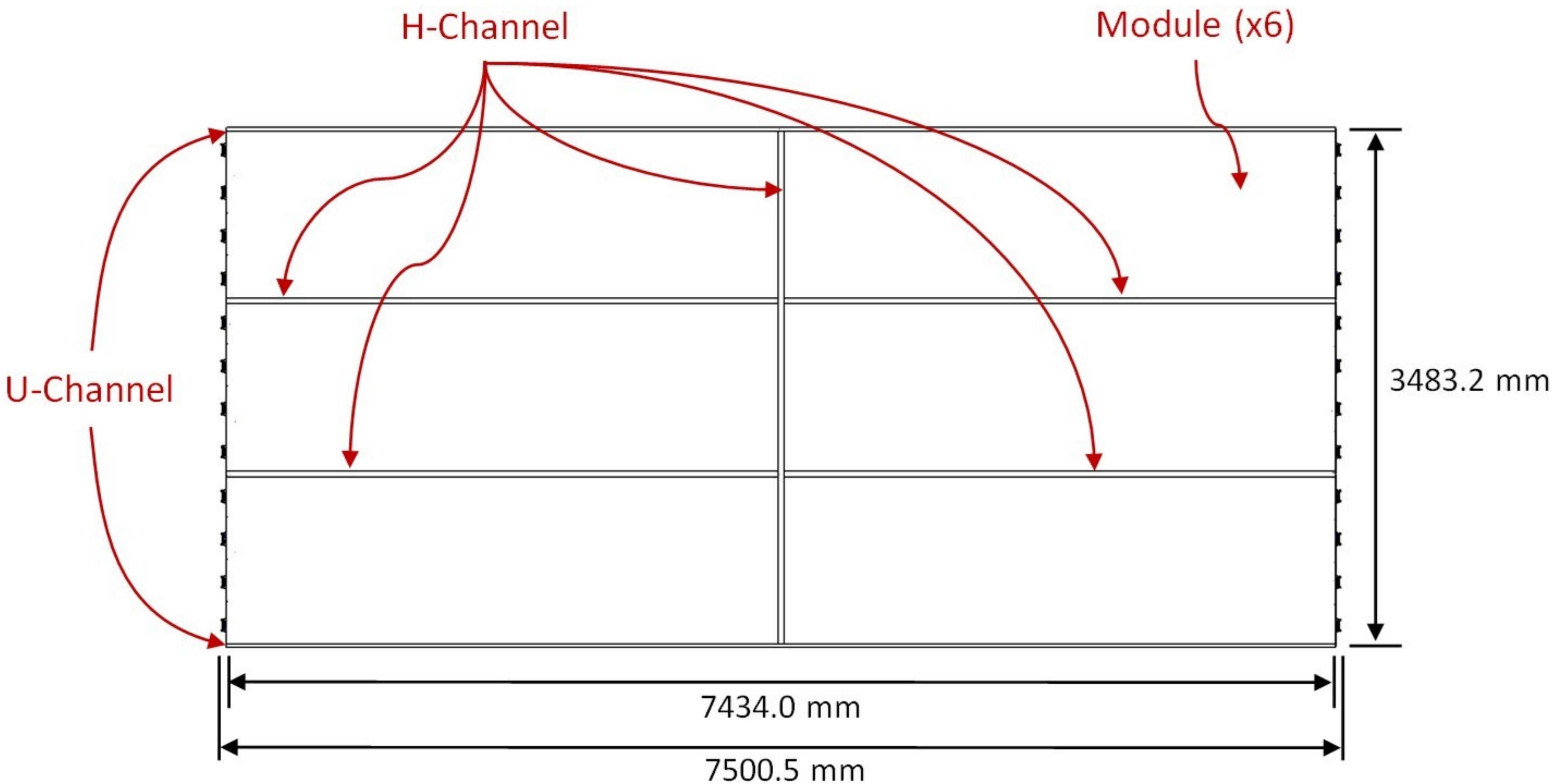
Cassette outline

- Cassette is not a distinct object, which contains modules
- Modules are joined together to form a cassette
- This keeps the thickness minimised



Y cassette

- Horizontal counters assembled into a cassettee

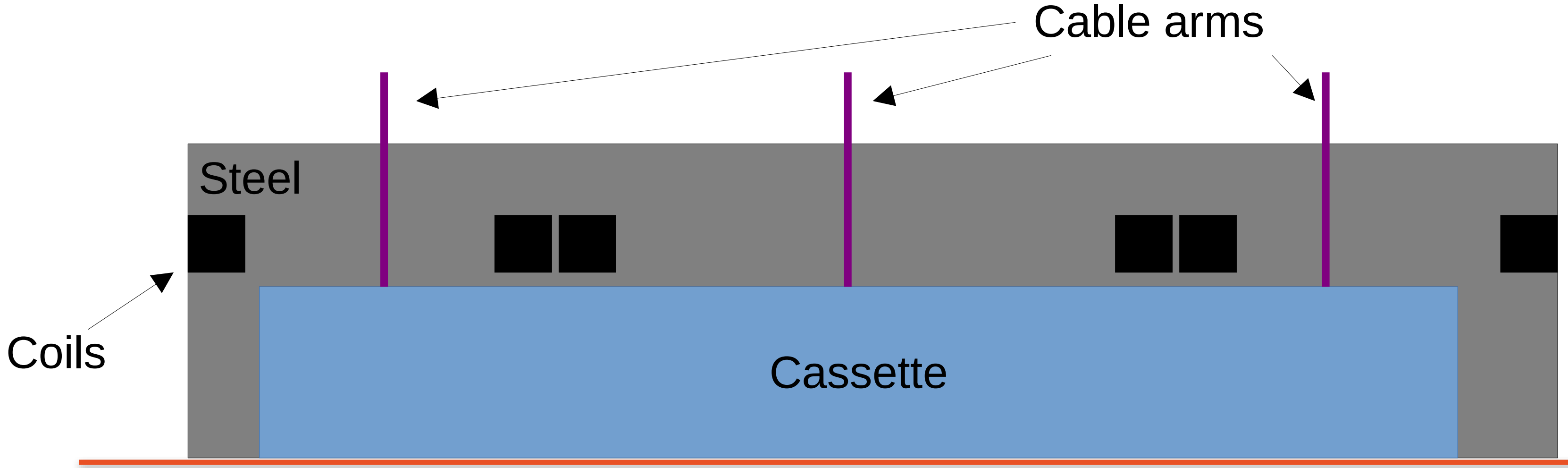


Cassette installation

- Cassette will slide on a rail
  - Rail is supported below coils
- Low-friction surface provided by “ultra high molecular weight polyethylene” (UHMW-PE)
  - Available as adhesive-backed tape
- Cassette will be pulled, not pushed
- Angled pull allows reduced friction
  - Optimal angle TBD

Cable routing

- To keep cables short, electronics are directly above the magnet
- Coils will be installed before cassettes
- Cables need to be extracted after insertion
- Space is 5cm wide, and ~1m deep
  - A human arm isn't going to suffice
- Retractable arms built in to top of cassette allow a simple hook to lift pre-bundled cables



Potential performance improvements

- Conservative inter-steel gaps (50mm gaps, only 16mm of scintillator)
- More layers would increase reach (higher momentum, or better resolution)
  - Determine if cassette thickness can be reduced
  - Determine flatness of cassettes and steel
- Some easy fine-tuning possible:
  - Number and location of Y counters
  - Exact U/V stereo angle

Construction plans

- Two sites identified for module construction
  - University of Minnesota
  - Florida State University
- Expect to produce all modules (~600) in under 24 months
- Cassette construction will be done at Fermilab
  - Specifics depend on installation schedule
- See Mayly’s talk later for details

Responses to charge

- Design updates from CDR design
  - Electronics/modules repairable/replaceable
  - Magnet and detector timelines decoupled
  - Module light-sealing and mechanical structure fully designed
  - Y modules now considered in addition to U and V
- See later talks for mechanical details, prototyping, and electronics plans