Tracking/Timing L2

US HFCC Strategy Meeting
Stony Brook Nov 8-9, 2025

US Areas of Interest in Tracking and Timing

- Solid State Tracking: MAPS for vertexing and for tracking, integration and test
- Timing: TOF wrapper layer using LGAD or other fast timing technology
- Gas: Straw tracker
- Gas: Open volume drift chamber (DCH)
- PID using dE/dx or dN/dx
  - Basic studies of performance and comparisons
  - Design of appropriate FE electronics
  - Interface with TOF?
- Mechanics: low mass support structure for vertex and global support, timing layers, CF components for drift chambers, including CF wires
- General considerations of how to design systems for low systematic uncertainties (at the Z pole)
  - Acceptance and efficiency monitoring
  - Calibration and survey
  - Flavor tagging

Areas of Existing US Expertise and Synergy

- Considerable technical overlap with EIC (EPIC) detector
  - A number of people in the US HF community are already also engaged with EIC and growing
  - Early tests and proof of concept, fabrication processes
  - EIC mechanics overlap with multiple US HF/EIC institutions for both tracking and TOF
- Leading institutions on the development of the Si-LGAD technology and electronics, and also in the design and fabrication of the new timing layers for LHC. New efforts on SiC-LGADs and alternatives
- Strong IC design teams at national laboratories and universities with growing involvement in MAPS developments
- ATLAS and CMS silicon trackers fabrication and integration
- Strong multi-institutional teams already on straw tubes and gas tracking going back to ATLAS tracker and muon system
- Leading institutions on low mass support and cooling with many contributions to the LHC (and earlier) experiments and the heavy ion collider program

Specific Areas for Solid State Tracking

- MAPS R&D at SLAC: For FY25, propose to advance the design, simulation and integration of critical MAPS components for next-generation detectors. Key deliverables include high-performance low-power TDC enabling sub-ns timing resolution, thorough trade-off studies addressing power, timing resolution and calibration, and innovative research into wafer stacking and scaled CMOS processes (below 65 nm) to achieve breakthrough improvements in vertex detector granularity. The team will also conduct detailed characterization of the SLAC-designed NAPA-p2 prototype.
- MAPS R&D at FNAL: FY25 program will drive progress toward the next prototype submission. Specific objectives include TCAD simulations for sensor optimization and development of crucial IC elements for wafer-scale MAPS designs, such as shunt LDO components for stitched wafer-scale sensors and advanced serializers capable of 1.2 GB/sec transmission speeds. Additional innovations under development include TDC timing performance improvements and chip-to-chip transmission solutions for the outer vertex detector.
- MAPS R&D at BNL, Brandeis, Brown, Caltech, MIT, Oregon, Stony Brook: support for MAPS through physics studies to optimize design requirements.

Specific Areas for Timing

- There is substantial ongoing work which is supported through generic R&D and/or the LHC upgrades efforts
- BNL: Strip and Pixel LGAD sensor R&D, LGAD in MAPS
- FNAL, SLAC: Strip and Pixel LGAD sensor and readout electronics R&D, LGAD in MAPS and 3D-integrated LGADs
- UCSC: Strip and Pixel LGAD sensor R&D
- LBNL: working on SiC-LGAD, ongoing support already in place

Solid State Testing and Characterization Activities

- Collaborative efforts are the key in the development of Silicon systems (for Vertex, Tracker or Silicon wrapper)
  - Numerous institutions with strong history in testing/characterization, construction and integration have expressed interest to participate
    - BNL, Brandeis, Brown, Caltech, FNAL, MIT, Oregon, SLAC, Stony Brook
- Deliverables:
  - Simulation of Beam-Induced Backgrounds to define requirements for tracking systems and MDI
  - Perform detailed testing and characterization studies of the prototypes

Specific Requests for Support: Solid State and Timing

Effort	Detector systems	Institutions	Requested Support
Development of MAPS sensors	Vertex, Outer Tracker, Si Wrapper, Calorimeters	Caltech, BNL, Brown, FNAL, SLAC, UOregon	\$300k (SLAC) \$300k (FNAL)
Development of LGAD	Si Wrapper	BNL, FNAL, SLAC UCSC	UCSC (0.5FTE PD) BNL (0.5 FTE PD)
Testing and Characterization	Vertex, Outer Tracker, Si Wrapper, Calorimeters	Caltech, Brandeis, Brown, FNAL, SLAC, Stony Brook, MIT	FNAL (0.5 FTE PD) SLAC (0.5 FTE PD) MIT (0.25 FTE grad +0.25 FTE research sci.) BROWN (0.25 FTE grad)
Simulation efforts	Overall Detector Optimization	Brown, FNAL, MIT, SLAC	SLAC (0.25 FTE grad) BROWN (0.25 FTE grad) MIT (0.25 FTE grad +0.25 FTE research sci.)
Tracker readout with the smart on-chip data processing	Tracker simulations, AI/ML training, and circuit design	ANL	ANL (50-100k)

General Aspects for Gaseous Tracking

- Michigan, BNL, Duke, UT Austin, Tufts, UMass, Harvard, MSU, UCI, SLAC
- Challenges
  - **DCH:** ~350k wires, wire assembly, mechanical structure (10 tons of total load on each end plate), O(100μm) single hit resolution, dN/dX
  - **Straw:** thin-wall straw production, wire assembly, mechanical support of 4-5 m straws, O(100μm) single hit resolution, dN/dX
  - **TPC**: ion backflow, occupancy/hit density, number of readout channels, dE/dX resolution
- Develop reliable simulations
- Electric field design with FEM techniques
- Garfield and Garfield++ microscopic analysis
- Monte Carlo techniques for reconstruction and digitization
- Wire R&D from different manufacturers
- Build a prototype chamber
- Study performance and establish dN/dX in CR and test beam campaigns
- Study electronics and readout architecture

Specific Areas for Straw Tubes

- Detector geometry and layout optimization studies using GEANT: occupancy, straw length, radius, stereo angles, resolution etc
- Straw assembly: end plugs, end plates, assembly procedure, wire material, wire tension, gas leakage etc
- Mechanical support: end plate, straw holding, precision etc
- Gas mixture studies: Garfield simulation, primary and secondary clusters etc
- Prototype chamber: build a prototype chamber with ~25 straws
- dN/dx: new front end electronics to provide enough gain to detect single electron peaks and record the whole waveform for dE/dX and dN/dX studies
- Cosmic ray and test beam studies using the prototype chamber

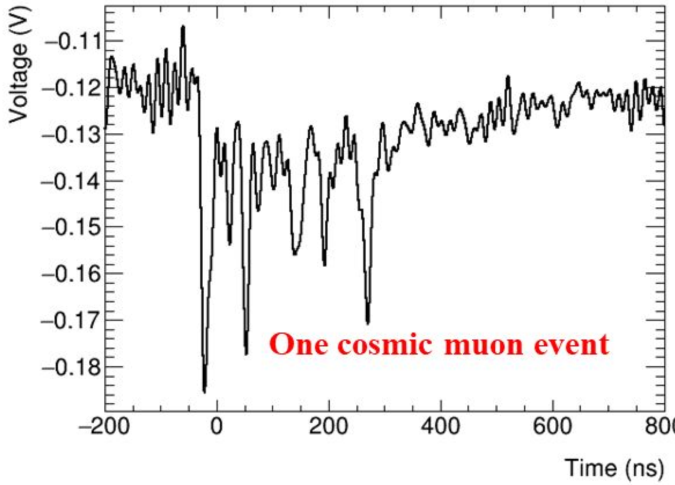
Specific Areas for Drift Chamber (some common to Straw)

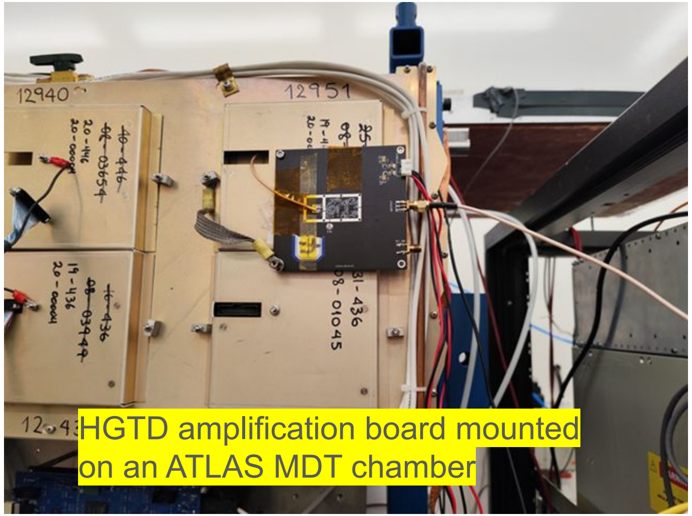
- Develop reliable simulation
  - Electric field design with FEM techniques
  - Garfield and Garfield++ microscopic analysis
- Monte Carlo techniques for reconstruction and digitization
- Wire R&D from different manufacturers
- Study performance and establish dN/dX in test beam campaigns
- Study electronics and readout architecture

PID using dE/dx and dN/dx

- dE/dX resolution: $\sigma = 0.4\, n^{-0.46}\, (tp)^{-0.32} \rightarrow$ ~4.5%
- dN/dX resolution: $\sigma = N_{clusters}^{-0.5} \rightarrow$ ~2.3%

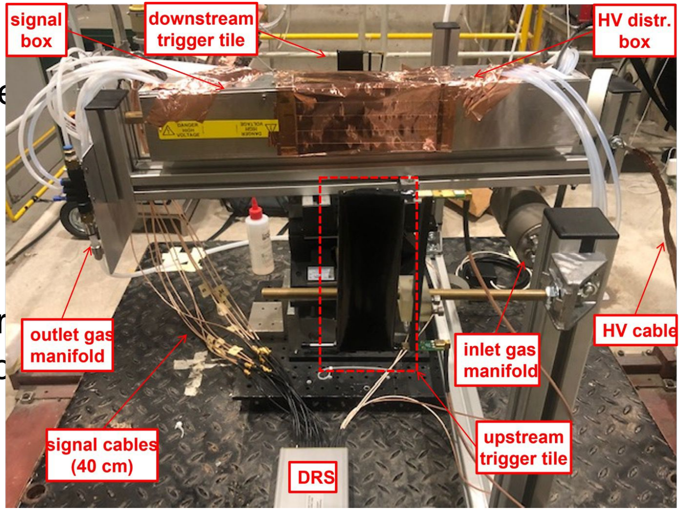
- Need to detect single electron peaks and perform clustering → signal amplification, waveform recording, and peak-finding and clustering algorithms
  - modify the ATLAS HGTD amplification board to amplify raw signals
  - use CAEN waveform digitizers to read out multiple channels
  - algorithms will be developed offline and implemented inside FPGAs later
- Perform cosmic ray studies in the lab and test beam studies at Fermilab (scheduled for summer 2025) and CERN

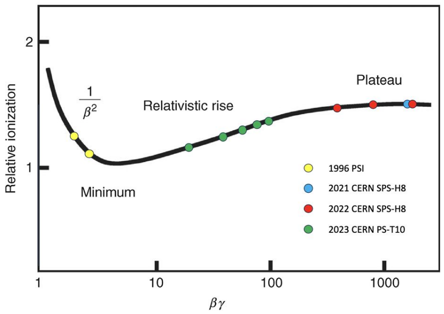


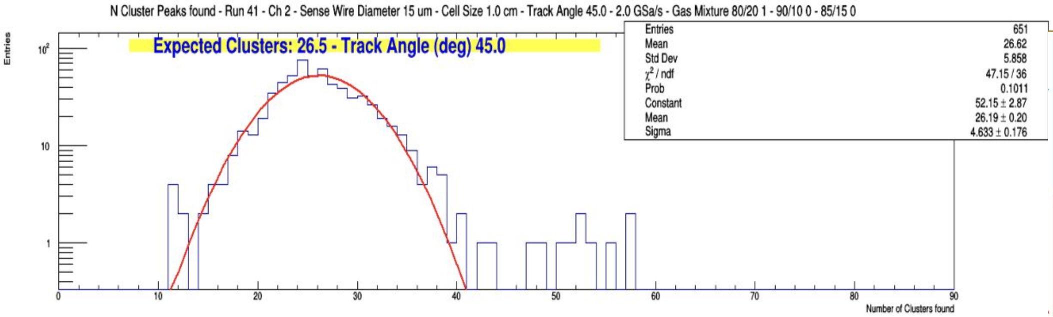


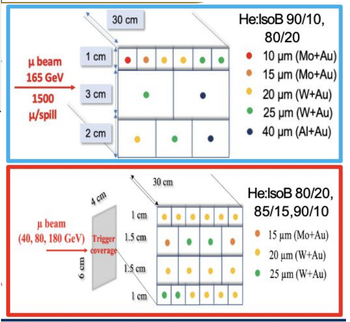
Promise of PID using dE/dx and dN/dx (DCH) based on Studies ongoing in Europe

- Several **test beams** to experimentally assess and optimize the pe counting/timing techniques covering big range of $\beta\gamma$ range
- **Several algorithms under testing**
  - Derivative Algorithm (DERIV)
  - Running Template Algorithm (RTA)
  - Long short-term memory (LSTM) (Recurrent Neural Networ Dynamic Graph Convolutional neural networks (DGCNN) to primary cluster





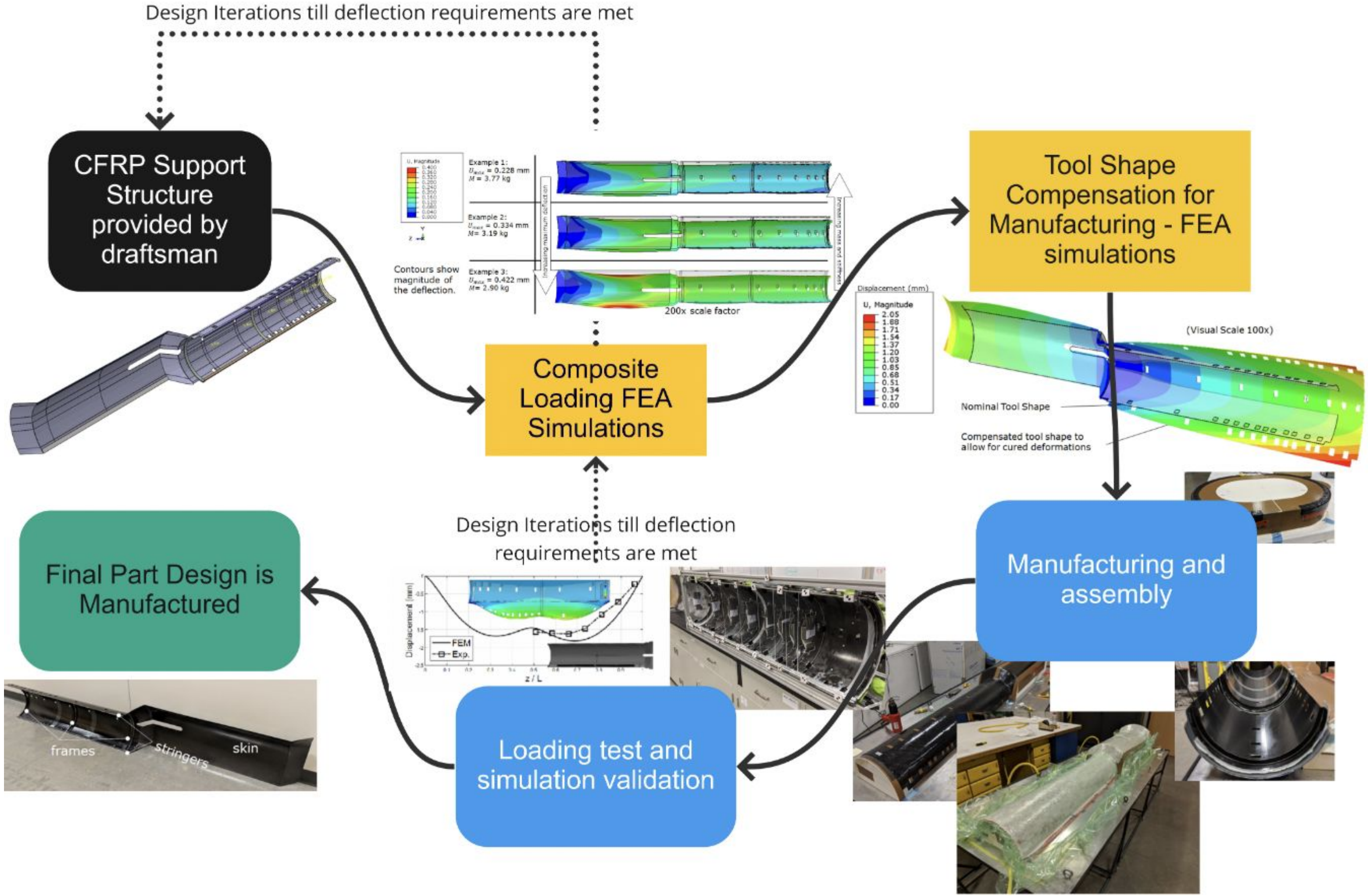




University of Michigan	Building a prototype chamber with 25 straws, new electronics and dN/dX studies using cosmic ray and test beams at Fermilab (summer 2025) and CERN	60K	$25k for building a prototype chamber, $10k for frontend electronics/waveform readout, $5k for test beam, $20k for student support
Duke University	Bundling straws for strength, string a few straws and check operations	6.5K	$3.3k for material/machining, $3.2k for undergraduate student
Tufts University	Cosmic ray and test beam studies, straw tracker optimization	47K	0.5 FTE (graduate student)
UT Austin	Detector and layout optimizations (DELPHES simulation, stereo angle, w/ and w/o silicon wrapper, dN/dX)	30K	1 semester (graduate student)
BNL	Simulation (analytic + e-field), monte carlo reconstruction for TB, validate dN/dX during TB with small prototypes Wire R&D from different manufacturers	30K	Support student for simulation studies
SLAC	Momentum resolution studies, DCH cell geometry optimization	0K	
U of Kansas + others	TPC feasibility studies	0K	

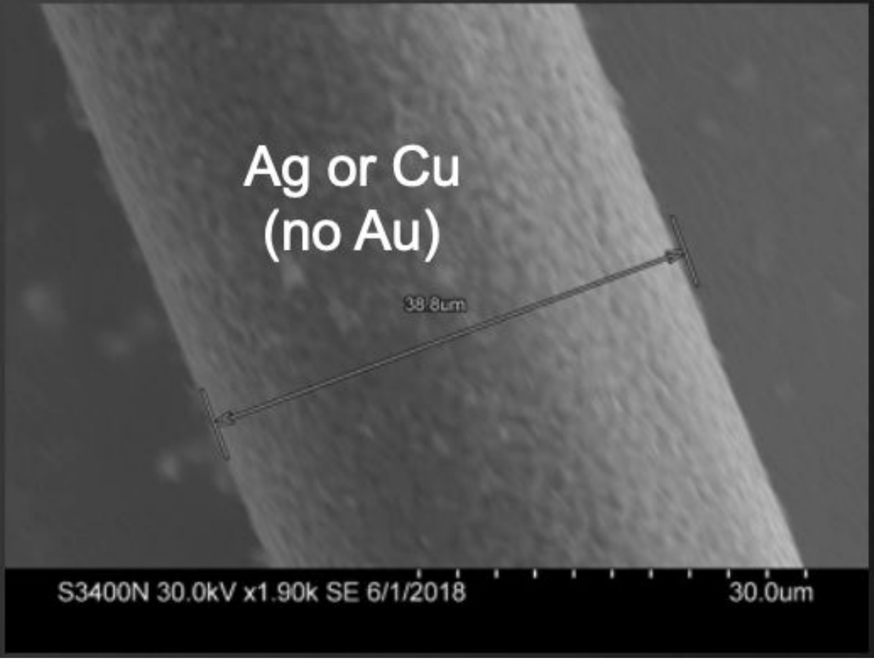
Areas for Low Mass Supports

- ❖ Institutes: Purdue, Hawaii, Yale, FNAL, Cornell, Florida, ANL, LBNL
- ❖ CF components for gas tracking - wires, support
- ❖ CF components for the calorimeter
- ❖ Support structures for silicon tracking
- ❖ Highly integrated development and fabrication cycle: CAD→FEA→tooling design→manufacturing→validation→(FEA loop back)
- ❖ Integration of support and services/cooling in fabrication
- ❖ Multi-functional structures
- ❖ Strong support and contacts with industry in the USA - SBIR/STTR,
- ❖ Expertise and training of engineers, techs, students


Design Iterations till deflection requirements are met
CFRP Support Structure provided by draftsman
Contours show magnitude of the deflection.
Example 1:
Example 2:
Example 3:
200x scale factor
Composite Loading FEA Simulations
Tool Shape Compensation for Manufacturing - FEA simulations
Displacement (mm)
U, Magnitude
(Visual Scale 100x)
Nominal Tool Shape
Compensated tool shape to allow for cured deformations
Manufacturing and assembly
Design Iterations till deflection requirements are met
FEM
Exp.
z / L
Loading test and simulation validation
Final Part Design is Manufactured
frames
stringers
skin

High-power impulse magnetron sputtering (HiPIMS)

physical vapor deposition of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm^2 in short pulses of tens of μs at low duty cycle <10%)



Low Mass Supports Funding Requests

Interest in CF based gaseous detector:

- Purdue (Jung)
- Hawaii (Vahsen) and Yale (Prakhar)

Interest in composite mechanics:

- Cornell (radiation hard interface materials)
- Florida Institute of Technology (thermal interface materials)
- Purdue (advanced composite structures, integrated detector support systems, simulations)
- LBNL, Fermilab, ANL (multiple people)

Institute	$	Remarks
ANL	0k	Novel TIMs, high thermal conductivity
Cornell	10k	Radiation hard interface materials, UG support
Florida	5k	Thermal interface material, UG support, material characterization as “service”
FNAL	30k	Low mass supports + vertex detector, 0.25 FTE junior person / tech
Hawaii	5k	Experience / synergies w Belle II upgrade, readout
LBNL	0k	Vertex detector
Purdue	55k	30k$ S&E, 25k$ 0.2 FTE technician. Existing Blue Sky on CF wire chamber and integrated composites, the ask here is for 45k$ in equipment - see remark. Material characterization as “service”.
Yale	5k	Wire chamber / readout
Total	110k$	

→ Unique leadership opportunity, no CF coating facility (world’s only is Russian: non-accessible)

→ **Establish Facility in US**:

- Re-commission sputtering/coating available via Purdue Nuclear value of > 50k$
- Discussion with INFN Bari, potential for ~50k$ contribution if adequate funding from US side - unique opportunity!