White Papers for IF03

Snowmass Topical Group on Solid State Detectors and Tracking

Anthony Affolder, Artur Apresyan, Steven Worm

November 19, 2021

IF03 Update

- **IF03 Topical Group Meetings**
  - Thursday 13:00 Central: https://indico.fnal.gov/category/1183/
  - Emphasis on White Paper planning and completion
- **Kickoff (Restart) Meeting Nov 11**
  - Discussed overall timeline and expectations, also plans for Instrumentation Summaries
  - Important dates (WP, TG, F submissions) and upcoming meetings (IF-Snowmass/CPAD, CSS)
  - Opportunity to hear of recent progress and to ensure full-community is captured by the White Papers and Topical Group Summary
  - Finalised contacts for each White Paper, addressed a few open questions on LOIs
  - Short (~10 minute) presentations related to each White Paper, discussed status & draft structure
- **Actions:**
  - Post draft White Papers, LoIs, contacts to the twiki: https://snowmass21.org/instrumentation/tracking
  - Follow up White Paper contacts, Plan meetings approximately monthly: Dec, Jan, Feb…

IF03 White Papers (part 1)

(1) Physics motivations for requirements of tracking detectors (Requirements)

- **Muon collider tracker requirements**: IF9_IF3-EF9_EF0-AF4_AF1-143 S. Jindariani (FNAL)
- **Strange Quark as probe for new physics in Higgs Sector**: EF1_EF2-IF3_IF0_Valentina_Maria_Martina_Cairo-047 V.M.M. Cairo (SLAC)
- **Searching for $B_s \to \Phi\nu\nu$ and other $b \to s\nu\nu$ processes at CEPC**: EF3_EF0-RF1_RF0-IF3_IF6-077 M. Ruan (IHEP China)
- **Exploring precision electroweak physics measurement potential of e+e- colliders**: EF4_EF0-AF3_AF0-IF3_IF5_GrahamWilson-119 G. Wilson (KU)
- **Jets and jet substructure at future colliders:** EF5_EF7-TF7_TF0-IF6_IF3-CompF3_CompF0_Ben_Nachman-035 B. Nachman (LBNL)
- **Letter of interest from the US LHCb Group:** RF-EF-OF-CompF-011 M. Artuso (Syracuse)
- **Solid State & Tracking in BRN**: M. Artuso (Syracuse) IF03 Presentation
- **Silicon detectors R&D and physics drivers for future machines:** Caterina Vernieri IF03 Presentation
- **Parameters for future trackers:** Simone Griso (LBNL) IF03 Presentation
- **EF perspective** (Maxim Titov) and **RF perspective** (Marina Artuso (Syracuse)): CPM 130

- Will be organized by EF and RF liaisons to IF (Maxim, Caterina, Marina)
- Designed to give requirements/motivation for the rest of the White Papers

IF03 White Papers (part 2)

(2) 4D trackers, precision time + position; OR precision position + moderately good time (Timing)

- **Use of extremely thin 'LGAD' ultra-fast silicon detectors for fast timing and tracking in high radiation sections at future colliders:** IF3_IF0_University_of_California_Santa_Cruz-018 S. Mazza (UCSC)
- **Precision timing detectors for future colliders:** IF3_IF7_Karri_DiPetrillo-142: K. DiPetrillo
- **4-dimensional trackers**: IF3_IF7-131 A. Schwartzman (SLAC)

(3) Monolithic integrated silicon detectors, CMOS (MAPs)

- **Silicon Pixel Detectors in Space:** IF3_IF2_Jessica_Metcalfe-154 J. Metcalfe (ANL)
- **Large area CMOS monolithic active pixel sensors for future colliders:** IF3_IF7_Martin_Breidenbach-113 M. Breitenbach (SLAC)
- **Monolithic active pixel sensors for high performance tracking**: IF7_IF3_Leo_Greiner-160 L. Greiner (LBNL)

(4) Integration and Packaging (Integration)

- **High density 3D integration of LGAD sensors through wafer-to-wafer bonding**: IF3_IF5_Simone_Mazza-175 S. Mazza (UCSC)
- **3D Integration of Sensors and Electronics**: IF3_IF0_Ronald_Lipton-080 R. Lipton (FNAL)
- **2.5/3D integration:** Robert Patti (NHanced Semiconductor INC) IF03 presentation

IF03 White Papers (part 3)

(5) Mechanics, lightweight materials, cooling (Mechanics)

- **Light-weight and highly thermally conductive support structures for future tracking detectors**: IF3_IF0_Jung-118: A. Jung (Purdue)
- **Mechanics supports for future tracking detector:** Eric Anderssen (LBNL) IF03 presentation
- **Future cooling:** Yadira Padilla upcoming IF03 meeting No longer involved ANYONE THAT COULD PROVIDE INPUTS HERE?

(6) Novel Sensors for Particle Trackers (Novel)

- **Beyond CMOS sensors, submicron pixels for the vertex detector**: IF3_IF0_N._Fourches-107: N.T. Fourches (CEA-Saclay)
- **Thin Film Detectors:** IF3_IF9_Jessica_Metcalfe-161: Jessica Metcalfe (ANL)
- **3D Diamond Detectors:** IF3_IF0_H_Kagan-130: H. Kagan (OSU)
- **Silicon Sensors in 3D Technology:** IF3_IF0_Seidel-198: S. Seidel (New Mexico)

(7) Non-silicon trackers: (Non-silicon)

- **Gamma-ray Scintillator Fiber Tracker:** IF3_IF2_Mazziotta-100: M. Nicola Mazziotta (INFN Bari)
- **Mu2e-II Tracker:** IF0_IF0-RF0_RF0_Daniel_Ambrose-094: D. Ambrose (Minnesota)
- **Identification of TeV hadrons:** Transition Radiation Detectors: IF0_IF0-043: M. Albrow (FNAL)
- **Exploration of charge particle tracking using InAs quantum dots in GaAs semiconductor matrix:** IF3_IF0_Pavel_Murat_129: M. Hedges (Purdue)

(8) Simulation Tools for Silicon Detector Developments (Simulation)

- **Simulation tools and radiation damage** Ben Nachman (LBNL) IF 03 presentation
- **Simulation tools and radiation damage** Timo Peltola (Texas Tech) IF03 presentation

Status and preparations for the contributed papers

Thursday Nov 11, 2021, 1:00 PM → 4:00 PM US/Central

Description Zoom Link

1:00 PM → 1:10 PM **Intro** 10m

Speakers: Artur Apresyan (Fermilab) , Steven Worm, Tony Affolder (UCSC- SCIPP)

IF03 Meeting Intro ...

1:10 PM → 1:20 PM **4D trackers and precision timing** 10m

Speaker: Ryan Heller (Fermilab)

heller_4D_trackers_I...

1:20 PM → 1:30 PM **Integration and Packaging** 10m

Speaker: Simone Mazza (UC Santa Cruz)

IF03 3D integration ...

1:30 PM → 1:40 PM **Exotic Solid-state Materials** 10m

Speakers: Sally Seidel, Sally Seidel (University of New Mexico) , Sally Seidel (University of New Mexico)

detectors.pdf snowmass-talk-11n...

1:40 PM → 1:50 PM **Mechanics, lightweight materials, cooling** 10m

Speakers: Andreas Jung (Fermilab) , Eric ANDERSSEN (LBNL)

1:50 PM → 2:00 PM **Simulation tools** 10m

Speaker: Benjamin Nachman (LBNL)

SiSimulation_snow...

2:00 PM → 2:10 PM **Non-silicon trackers** 10m

2:10 PM → 2:20 PM **[Postponed] Monolithic integrated silicon detectors, CMOS (MAPs)** 10m

Speakers: Caterina Vernieri (Fermi National Accelerator Laboratory) , Caterina Vernieri (SLAC)

Snowmass 2021

IF03: Solid State Detectors and Tracking Status and Plans

Artur Apresyan, Steve Worm, Tony Affolder

November 9, 2021

Fermilab DESY. UC SANTA CRUZ

Snowmass Important Dates

- White Paper submission to arXiv: no later than March 15, 2022. Late submissions and updates are likely not to be incorporated in the working group reports, but will be included in the Snowmass on-line archive documents.
- Preliminary reports by the Topical Groups due: no later than May 31, 2022.
- Preliminary reports by the Frontiers due: no later than June 30, 2022.
- Snowmass Community Summer Study (CSS): July, 2022 at UW-Seattle.
- All final reports by TGs and Frontiers due: no later than September 30, 2022.
- Snowmass Book and the on-line archive documents due: October 31, 2022.

White Paper Content, Templates, Topic Summaries

- The white papers should address the challenges that are being tackled, at least briefly summarize the physics motivation, show some recent results of R&D and lay out a roadmap for near- to middle-term R&D.
  - Our white papers with 3-4 LOI will be suggested length of 10-15 pages (with ~1 page executive summary)
    - We have asked the Intensity Frontier for a template for the White Papers
      - On https://snowmass21.org/submissions/start, there is a Snowmass 2021 LaTex template.
  - The executive summaries will be used to build up our Topical Group Summary
- Our Topical Group Summary should try to give a bit of a global and more general overview of the whole area of silicon trackers, in addition to the more specific summaries of each white paper.
  - Suggested length of 5-10 pages (with 1-2 page executive summary for IF report)

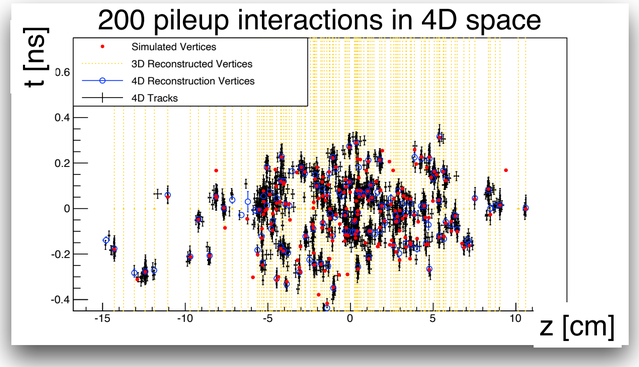
4D Tracking (Heller)

4D trackers and precision timing

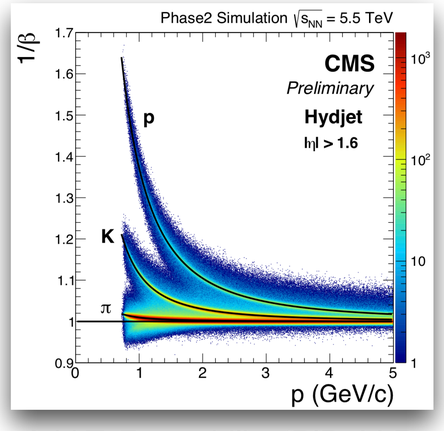
Valentina Cairo, Ryan Heller, Simone Mazza, Ariel Schwartzman
IF03 Solid State Detectors
November 11th, 2021

Motivation for 4D tracking

- ATLAS & CMS constructing timing layers for HL-LHC
  - 30-50 ps resolution, but coarse spatial resolution: “Zeroth” example of 4D tracker



Simplify complex environment
(Reject PU tracks)



Add ToF capability (PID, LLPs..)

Fermilab

4D trackers and precision timing

- White paper covering 4D trackers and precision timing
  - LOIs #25, #37, #39

- Proposed structure
  - Motivation for 4D tracking & requirements for future collider experiments
    - FCC, ILC, EIC, muon collider
    - Resolutions approaching 5-10 microns & 5-10 ps in most extreme cases
    - Layout considerations
  - Sensor technologies, current status, key challenges, and R&D roadmap
    - Advanced LGADs (AC-LGADs, TI-LGADs, DJ, DG..) achieve excellent spatial resolution already
    - Concentrate R&D effort on radiation hardness and sub 20 ps resolution (ultra thin sensors?)
  - Electronics: challenges of density & power consumption, roadmap for future.

3D Integration (Mazza)

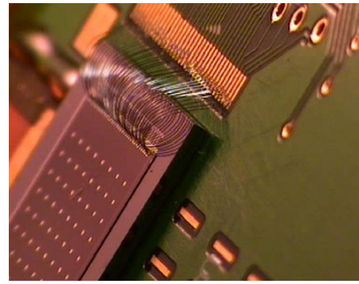
IF03 3D integration

S. Mazza (UCSC), R. Lipton (FNAL),
R. Patty (NHanced)

R. Lipton: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF0_Ronald_Lipton-080.pdf
S. Mazza: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF5_Simone_Mazza-175.pdf
R. Patti: https://indico.fnal.gov/event/45749/contributions/198237/attachments/135412/167907/NHanced_Snowmass_10012020.pdf

Status

- 3D integration still lacks a large scale research application
  - But recent efforts produced or will produce working prototypes of 3D integrated modules
- Pursued by FNAL since some time
  - E.g. “3D integration of sensors and electronics” https://doi.org/10.22323/1.309.0025
  - Comparison of performance of 3D integrated sensor vs bump bonded
- UCSC (new in the game) working with cactus material to test 3D integration and substrate engineering of LGADs
  - Funded through SBIR, expected results early next year



White paper structure

Proposed title: **Integration and packaging**

- Introduction to technology
  - Review of companies available with respective capabilities
- Advantages in respect to current available packaging
- Foreseen applications for 3D integration
  - Possible use in oncoming experiments (EIC, X-rays ...)
- Preliminary results (FNAL past results, possible UCSC near future results)
- Path for future development
- Conclusions

Novel Sensors (Seidel+Fourches)

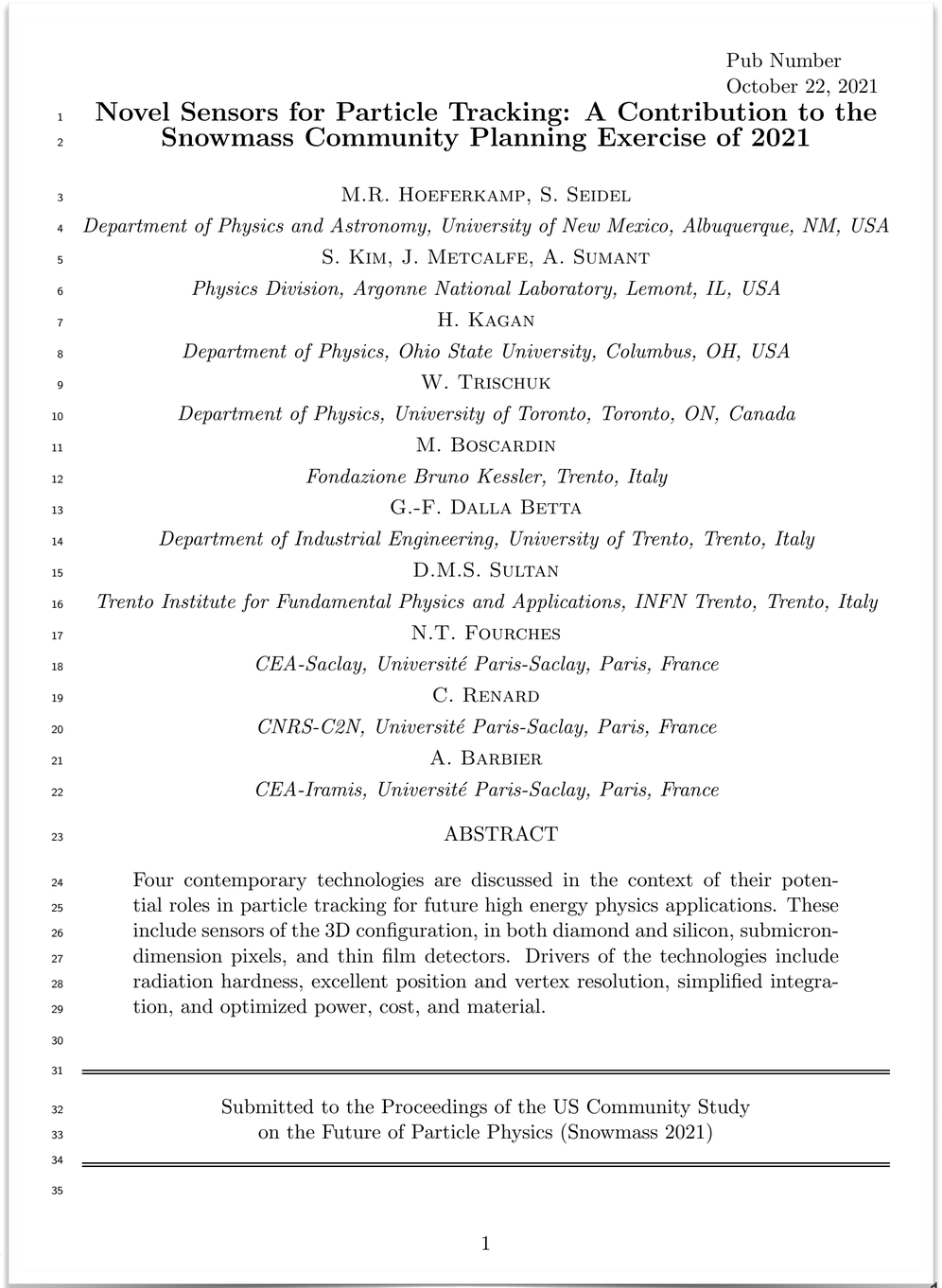
A complete first draft has been written. At present this paper absorbs the full text of the following LoI's:

#156: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF0_H_Kagan-130.pdf
#158: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF0_N._Fourches-107.pdf
#162: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF0_Seidel-198.pdf
#165: https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF2_Jessica_Metcalfe-154.pdf

Structure of the paper:

9 pages long

Page 1 – Author list and abstract
Page 2 – I. Introduction, II. Silicon Sensors in 3D Technology (Boscardin, Dalla Betta, Hoeferkamp, Seidel, Sultan)
Page 3 – III. 3D Diamond Detectors (Kagan, Trischuk)
Page 4 – IV. Beyond CMOS: Submicron Pixels for Vertexing (Fourches, Renard, Barbier)
Page 5 – V. Thin Film Detectors (Kim, Metcalfe, Sumant)
Page 6 – Thin Film, continued
Page 7 – VI. Conclusion, References
Pages 8-9 – References, continued



Pub Number
October 22, 2021

Novel Sensors for Particle Tracking: A Contribution to the Snowmass Community Planning Exercise of 2021

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ABSTRACT

Four contemporary technologies are discussed in the context of their potential roles in particle tracking for future high energy physics applications. These include sensors of the 3D configuration, in both diamond and silicon, submicron-dimension pixels, and thin film detectors. Drivers of the technologies include radiation hardness, excellent position and vertex resolution, simplified integration, and optimized power, cost, and material.

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

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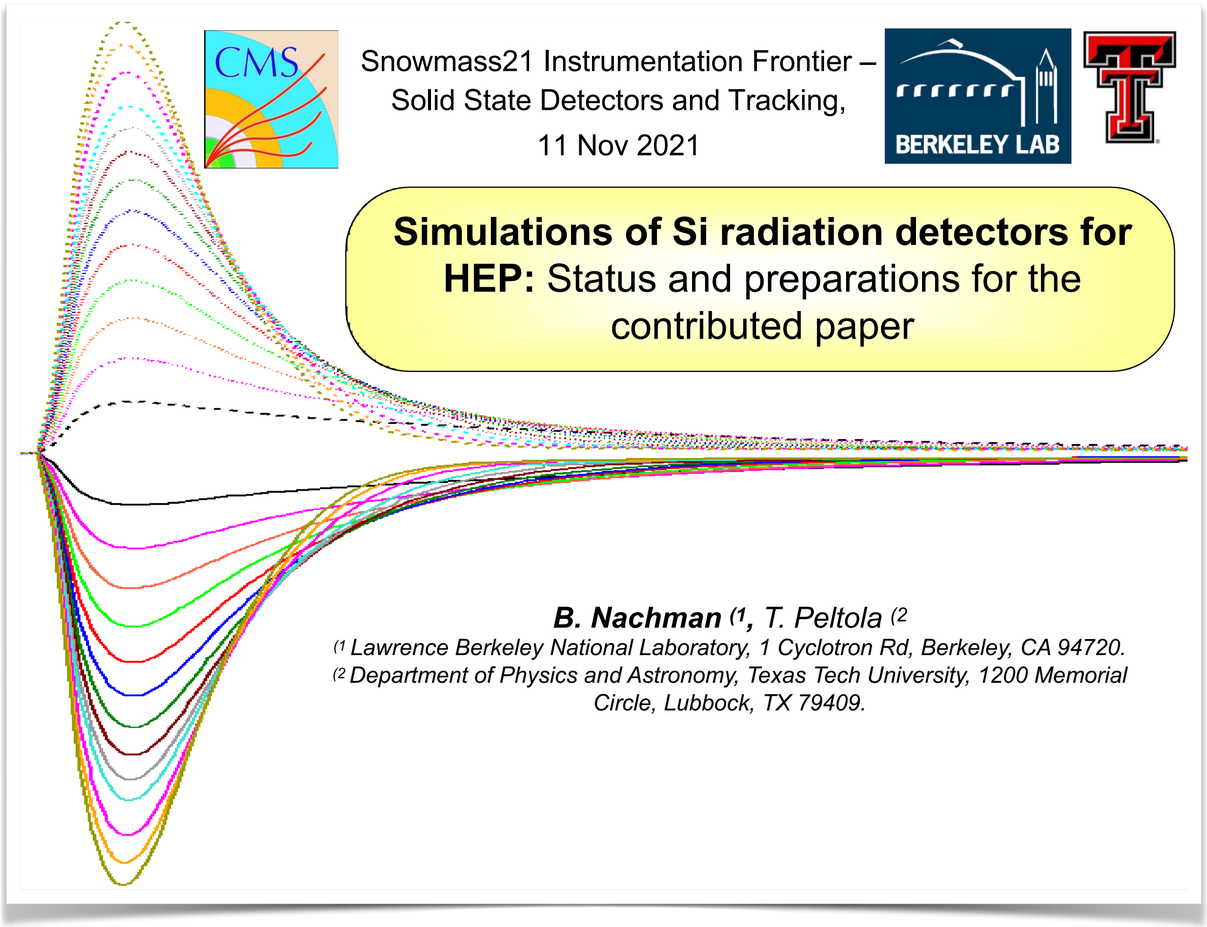
Simulation Tools (Nachman)



Proposed report outline

Part I: Existing Tools

- Models for single quantities
  - Annealing (e.g. Hamburg Models)
  - Straggling (e.g. Bichsel Model)
- TCAD simulations for detector properties
  - Many multitrap models for radiation damage
  - Lighter-weight alternatives: TRACS and Weightfield2
- Testbeam
  - Pixelav
  - Allpix^2
- Full detector systems
  - ATLAS approach (modified digitization)
  - CMS approach (efficiency corrections)
  - LHCb approach (tuned charge transport)

Proposed report outline

Part II: Challenges and Needs

- Unified radiation damage (TCAD) and annealing model
- Prescription for uncertainties in TCAD models
- Measurements of damage factors (many of the inputs in the RD50 database are based on simulation or less)
- Update to basic silicon properties? https://cds.cern.ch/record/2629889
- How to deal with proprietary software and device properties?
- Feedback between full detector systems and per-sensor models
- Extreme fluences of future colliders

Thank you

Contact

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Snowmass Timelines