Solid State Tracking
Emerging ideas from BRN studies

Marina Artuso, Syracuse University

Carl Haber, LBL

Solid State: R. Brenner (University of Uppsala), V.Fadeyev (University of California, Santa Cruz), T.Heim (Lawrence Berkeley National Lab), S.C. Hsu (University of Washington), K. Krizka (Lawrence Berkeley National Laboratory), J. Metcalfe (Argonne National Laboratory), S. Seidel (University of New Mexico), D.Stuart (University of California, Santa Barbara), C. da Via (Uniersity of Mancester, SBU)

Introductory remarks

- General goal shared by BRN study and Snowmass:"accelerated development of cost-effective instrumentation with greatly improved sensitivity and performance" to facilitate ambitious physics program being currently laid out.
- To frame goals, decide to set Grand Challenges (or unifying principles):
  - Advance HEP detectors to new regimes of sensitivity
  - Using integration to enable scalability for HEP sensors
  - Build next-generation HEP detectors with **novel materials** and **advanced techniques**
  - Mastering **extreme environments** and **data rates** in HEP experiments
- Start with physics motivation (P5 science drivers) & match them with instrumentation R&D directions

Input drivers

1. **Higgs and the Energy Frontier**
2. Neutrino physics
3. Dark matter
4. Cosmic acceleration: Dark energy and inflation
5. **Explore the Unknown**

Higgs (e+e-)	σ_{p_T}/p_T=0.2% ,GeV $\frac{\sigma_{p_T}}{p_T^2} = 2\times10^{-5}/GeV$ central tracks p_T>100 GeV Impact parameter resolution $\sigma_{r\phi} = \left(5 \oplus 15\left(p\left[GeV \sin^{3/2}(\vartheta)\right]\right)^{-1}\right)$µm Per track timing resolution 10 ps
Higgs (pp)	σ_{p_T}/p_T=0.5% central tracks p_T <100 GeV+ above Per track timing resolution of 5ps Radiation tolerance to 300 MGy and $8\times10^{17} n_{eq}/cm^2$
New physics through flavor interactions	Medium term: timing 10-30 ps/hit in Si VTX detector 1—30 ps/track PID/calorimeter Medium term: Radiation tolerance $5\times10^{16} n_{eq}/cm^2$ Long term: Radiation tolerance $1\times10^{18} n_{eq}/cm^2$
CLFV	Low mass tracking with 20 ps/track timing resolution

Historical context

- Introduction of Si microstrip detectors in the early '80 was **transformative** (made possible studies of *b* and *c* at fixed target experiments, then at LEP, Tevatron & LHC cornerstone of the physics)
- Radiation hard hybrid pixel detectors **transformative** (granularity, radiation hardness, electronics integration)
- Developments in services and mechanics/cooling are **transformative** (e.g. CO_2 evaporative cooling) and they are become increasingly important

Priority research direction I – ps timing

Develop high spatial resolution pixel detectors with precise per-pixel time resolution to resolve individual interactions in high-collision-density environments

Thrust 1: Lepton colliders, requiring timing on the order of 10 ps; pixel pitch on the order of 10 microns

Thrust 2: Hadron colliders, requiring timing resolution down to 1 ps to achieve HL-LHC-like pileup, in a high radiation environment (up to fluences in the order of $10^{18} n_{eq}/cm^2$) [this thrust includes forward detector at pp machine]

Research directions

- Currently two sensor technologies being pursued:
  - LGADs – issue: loss of gain at fluence >$2\times10^{15}\ n_{eq}/cm^2$
  - 3D sensors – rad hard excellent: 80% charge collection efficiency at $3\times10^{16}\ n_{eq}/cm^2$ [150V bias], 20 ps time resolution TIMESPOT collaboration – issue VLSI capable of delivering this performance
- Future plans need to optimize not only sensor, but integrate sensor/readout electronics and surrounding services [**cooling, data transfer, power]**
- Monolithic pixel system incorporating timing may be a good starting point, but integration issues are still non-trivial

Priority reseach direction II: New materials

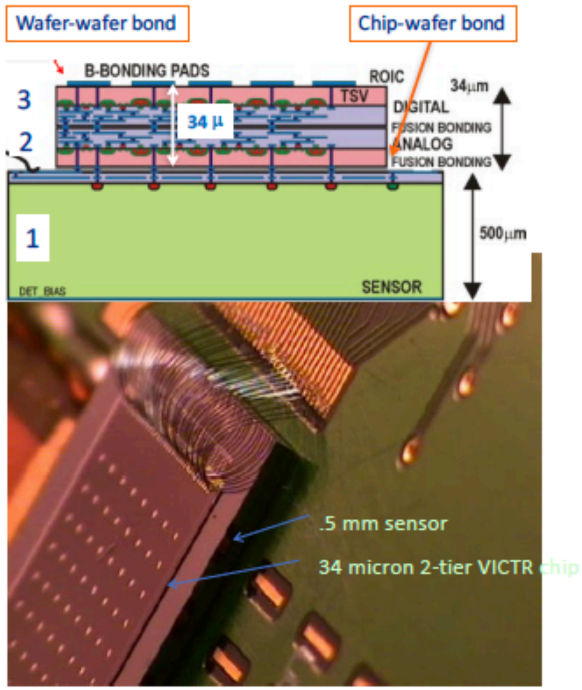
Adapt new materials for sensor (and electronics) development, and fabrication/integration techniques

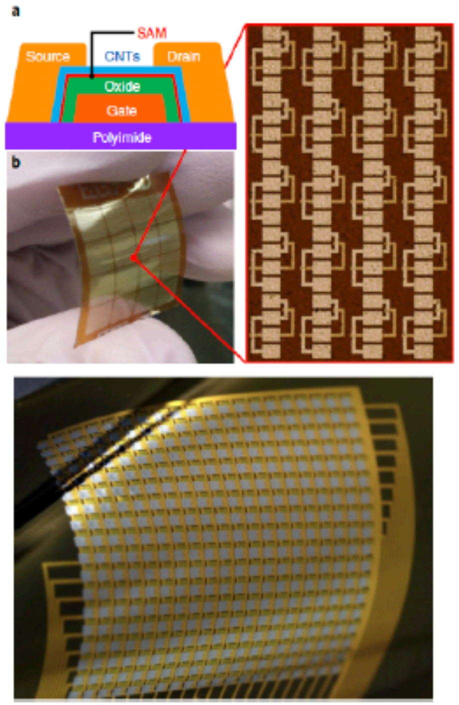
Look for alternative materials to silicon, especially for extreme radiation environments

Develop electronics in conjunction with novel sensors, 3d integration

Research directions

- Alternatives to silicon for sensors (diamond, large-bandgap semiconductor,thin fim material)
- Readout technologies matched to new sensor, integration of nanotechnology
- 3d vertical integration of multi-tier processing electronics and sensor.
- Overall material budget optimization





Priority research direction III: Scalable/irreducible mass tracking

Realize scalable, irreducible mass trackers

Develop highly integrated, monolithic active sensors
Scaling of low-mass detector system
Adapt technologies to special applications

Research directions

- Ultimate goal realize a full-scale mass minimized tracker:
  - Detector thinning (e.g. Alice)
  - Efficient services
  - New ideas coming from other fields

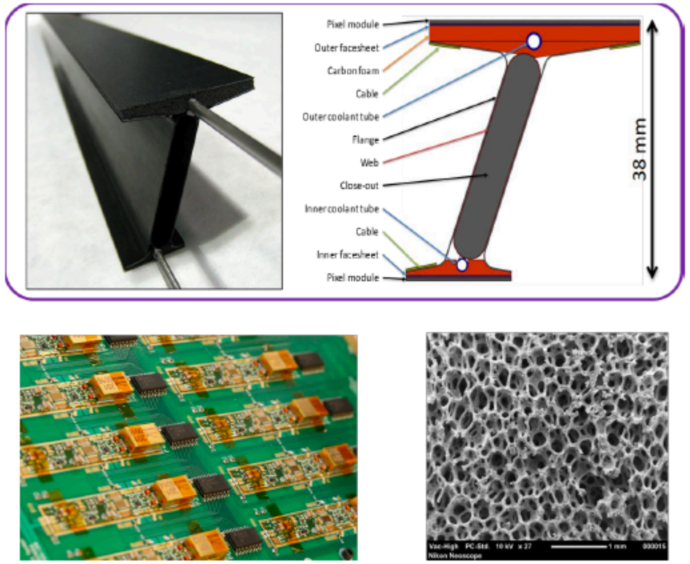


Figure 47: Top: Low mass I-beam structure designed to support two layers of pixel detectors in a cylindrical barrel geometry. Faces are made of high modulus, high conductivity carbon fiber, high thermal conductivity carbon foam fills the interior along with embedded cooling pipes carrying high pressure CO2. Entire composite is bonded using a co-curing process. Bottom Right: Thermally conductive carbon foam developed in part through the DOE SBIR program with HEP. This foam, which is machinable, has a thermal conductivity of 30-40 W/m-C at 10% the density of solid carbon. It can be used as a low mass thermal conductor and heat spreader within composite tracker support structures. Bottom Left: Low mass power regulation and control hybrid being developed for a large collider tracker. Hybrid includes DCDC conversion, HV multiplexing and filter, and monitoring and control ASICs. To produce and test thousands of hybrids, circuits are assembled, tested, and burned-in on large panels.

Connection with other fields

- Astroparticle, medical, homeland security, engineering, and art

Cern news Sept. 21, 2020

Left: Graphic combining energy spectra measured by RToo scanner (© InsightART, 2019); Right: RToo scanning the painting Madonna and Child (© Jiří Lauterkranc, 2019). (Image: CERN)

Many interesting synergies to be exploited

Infrastructure needed

	Higgs and Energy Frontier	Neutrinos	Dark Matter	Cosmic Acceleration	Unknown
Irradiation, ionizing and non-ionizing	✓	✓			✓
Test Beams	✓	✓			✓
Test Stands at Ultra-low Temperature			✓	✓	✓
Calibration Facilities	✓	✓	✓	✓	✓
Low Background Materials and Assay		✓	✓		✓
Ultra-light Composites	✓				✓
Novel CCD Development			✓	✓	
Superconducting Detector and Device Foundry			✓	✓	
Microelectronics Engineerin and Foundry Access	✓	✓	✓	✓	✓
Simulation Framework	✓	✓	✓	✓	✓

Table 23: Facility and capability needs for the five Science Drivers.