DOE BRN Study
Solid State Tracking

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Charge

- Requested by DOE to develop a report on “transformative” technologies aimed at a future physics facility on the 15-25 year time scale
- Our group interprets this to be a future hadron or lepton collider, beyond the HL-LHC, at the energy frontier
- Agency would like to see a limited number of high priority directions
- We have drafted a document based upon limited community input and therefore seek a wider engagement
- Please consider the following as a first pass and offer us constructive suggestions
- Leadership recruited two conveners, we recruited additional conveners and then a group of topic experts

Conveners

- Marina Artuso, Syracuse, LHCb, CLEO, RD42, RD50, BTeV
- Carl Haber, LBNL, ATLAS, CDF
- Petra Merkel, FNAL, CMS, CDF
- Alessandro Tricoli, BNL, ATLAS, OPAL, RD50

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Topics and Experts

- Fast Timing: Dave Stuart (UCSB) , A. Tricoli (BNL)
- Pixel Front Ends: T.Heim (RD53)
- Sensors: Vitaliy Fadeyev (UCSC)
- MAPS: Vitaliy Fadeyev, Jessica Metcalfe (ANL)
- 3D: Cinzia da Via (Manchester, SBU)
- Data Transmission: Richard Brenner (Uppsala)
- Radiation Damage: Sally Seidel (UNM), Karol Krizka (LBNL)
- Low Mass Mechanics: Shih-Chieh Hsu (UW)
- Facilities and Infrastructure

Transformative Technologies

- Informed by past experience
- In 50 years solid state detectors have advanced from ~1 channel benchtop spectroscopic systems to 10^8 channel, 200 m^2, >10 year deployments
- Transformative
  - Silicon strip detector
  - FE ASIC
  - Hybrid pixel detector
  - Precision Carbon Fiber/CO2 cooling
- Incremental: radiation hard electronics, sensors

Hadron Collider View

generation	year	luminosity	ΔT	chan/area	dose	readout
1 CDF SVX	1990	10^{29}	3.5 μs	50K/ 0.68 m^2	25 Krad	3 μm CMOS
2 CDF SVX*	1995	10^{30}	3.5 μs	50K	100 Krad	1.2 μm RHCMOS
3 Run 2	2000	10^{32}	128 ns	600K / 5 m^2	1 Mrad, 10^{13}/cm^2	0.8 μm RHCMOS
4 LHC	2009	10^{34}	25 ns	5 x10^6 / 68 m^2 10^8 pixels	10 Mrad 10^{15}	0.25 μm CMOS RH Bi-CMOS
5 HL-LHC	2025	5 x 10^{34}	25 ns	10^8 / 200 m^2 10^9 pixels	100 Mrad 10^{16}	65 – 130 nm CMOS SiGe, Commercial
6 HE-LHC/FCC	>2035	3 x 10^{35}	25 ns (10 ps)	5 x 10^8 / 400 m^2 5 x 10^9 pixels	1-10 Grad 10^{18}	Unknown features Monolithic CMOS?

Future Facilities Requirements

- Most developments require a systems approach – sensors, electronics, DAQ, mechanics, cooling
- HE LHC or FCC-hh
  - Granularity, speed, radiation resistance, background rejection
  - $L = 3 \times 10^{35}\ cm^{-2}s^{-1}$
  - $10^{18}\ n_{eq}\ cm^{-2}$
- ILC or FCC-ee
  - Low mass
  - Small pixels
  - Mechanical precision
- Scale: use of commercial fabrication attractive
- Capabilities to test components in real conditions
- Engineering and technical infrastructure and support

Priority Research Directions

- This is not an ordered list
- PRD1: High resolution pixel detectors with per pixel fast timing
- PRD2: New materials and processes for sensors and associated components
- PRD3: A high intensity irradiation facility for the US community
- PRD4: Large scale “irreducible mass” tracking systems

PRD1:High Resolution Pixel Detectors with Per Pixel Fast Timing

- Background and pile-up rejection for multiple interactions at a hadron collider
- Emerging fast timing efforts at HL-LHC with ~1 mm^2 pads using Low Gain Avalanche Detectors
- Can this be scaled to ~50 um^2 pixels? A big step
  - Interpixel dead regions, efficiency
  - Acceptable power levels
  - Radiation resistance
  - System implementations: timing, services, cooling

PRD2: New Materials and Processes from Sensors and Components

- Silicon has been the work horse and has shown radiation resistance up to current requirements
  - Special processing, biasing, low temperature
- Are there game changing materials?
  - Example: radiation hard at room temperature?
  - Thin and low mass
  - Increased density for smaller pixels
- Significant R&D over 25 years
  - Diamond, 3D, Ge, Large band gap materials
  - But no large industrial base…yet
- Emerging commercial markets
  - Power electronics -> high temperature, radiation hard
  - Thin films /flexible components, nano, organics -> low mass

PRD3: A High Intensity Irradiation Facility for the US Community

- Radiation effects: dose, rate, SEE
- We lack a central, reliable facility for these measurements
- How can we reach the integrated doses of a future hadron collider?
- Propose a dedicated US based proton facility with appropriate support and infrastructure, long term and consistent operation
- Could a study group be convened to make recommendations to the FA’s?

PRD4: Large Scale "Irreducible Mass" Tracking Systems

- For future electron colliders minimal mass, small pixels are required. Also of benefit in hadron machine.
- An "irreducible" system means it approaches just the mass of the active sensor material
- Aspects of this have been under study for >10 years
  - Thin sensors, gas cooling, pulsed power…
- New aspects include maturing MAPS devices from commercial processes – potential cost and fabrication time advantages
- Systems deployed for heavy ion collisions
  - ALICE ITS: 10 m^2 of thinned MAPS, 24K chips
- This may actually now be driven by a series of incremental developments
- But heavy reliance on commercial processes so community must remain engaged as processes evolve

Other Considerations

- New or transformative technologies are usually introduced with a staged approach
- Need opportunities to scale up through several generations of experiments
- Infrastructure and engineering
  - Examples: Silicon facilities, EE and ME teams, composite fabrication facilities, test beams
  - Much of this exists today and has been built up over the past 25 years
  - Must be sustained and modernized
  - Like an accelerator…these are “national” facilities serving our broad ***collaborations***

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