#cpm_topic_131

Physics requirements for HEP detectors at colliders

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Starting point : BRN

DOE Basic Research Needs Study on Instrumentation is in the process of releasing its conclusions on:

- Survey the present state of the HEP technology landscape.
- Identify key capabilities & performance requirements.
- Identify technologies to provide or enhance such capabilities.
- Articulate PRDs to push well beyond the current state of the art, potentially leading to transformative technological advances with broad-ranging applicability.
- Flesh out required R&D efforts with deliverables with notional timelines & key technical milestones.
- Elucidate the technical infrastructure required to support these efforts.
- Formulate a small set of instrumentation Grand Challenges that could result in game-changing experimental capabilities.

Note this is a 10-years view: Snowmass has a much long-term target (20 years-vision)

EF drivers in BRN

The transformative physics goals include 4 inspiring & distinct directions:

- Higgs properties @ sub-%
- Higgs self-coupling @ 5%
- Higgs connection to DM
- New multi-TeV particles

Technical requirements mostly from existing detector proposals.

- muon collider is not on the map

Science	Measurement	Technical Requirement (TR)	PRD
Higgs properties with sub-percent precision Higgs self-coupling with 5% precision	TR 1.1: Tracking for e^+e^-	TR 1.1.1: p_T resolution: $\sigma_{p_T}/p_T = 0.2\%$ for central tracks with $p_T < 100$ GeV, $\sigma_{p_T}/p_T^2 = 2 \times 10^{-5}$/GeV for central tracks with $p_T > 100$ GeV TR 1.1.2: Impact parameter resolution: $\sigma_{r\phi} = 5 \bigoplus 15\ (p\ [\text{GeV}]\ \sin^{\frac{3}{2}}\theta)^{-1}\ \mu\text{m}$ TR 1.1.3: Granularity : $25 \times 50\ \mu\text{m}^2$ pixels TR 1.1.4: 5 μm single hit resolution TR 1.1.5: Per track timing resolution of 10 ps	18, 19, 20, 23
Higgs connection to dark matter	TR 1.2: Tracking for 100 TeV pp	Generally same as e^+e- (TR 1.1) except TR 1.2.1: Radiation tolerant to 300 MGy and 8×10^{17} n_{eq}/cm^2 TR 1.2.2: $\sigma_{p_T}/p_T = 0.5\%$ for tracks with $p_T < 100$ GeV TR 1.2.3: Per track timing resolution of 5 ps rejection and particle identification	16, 17, 18, 19, 20, 23, 26
New particles and phenomena at multi-TeV scale	TR 1.3: Calorimetry for e^+e^-	TR 1.3.1: Jet resolution: 4% particle flow jet energy resolution TR 1.3.2: High granularity: EM cells of 0.5×0.5 cm^2, hadronic cells of 1×1 cm^2 TR 1.3.3: EM resolution : $\sigma_E/E = 10\%/\sqrt{E} \bigoplus 1\%$ TR 1.3.4: Per shower timing resolution of 10 ps	1, 3, 7, 10, 11, 23
	TR 1.4: Calorimetry for 100 TeV pp	Generally same as e^+e- (TR 1.3) except TR 1.4.1: Radiation tolerant to 4 (5000) MGy and 3×10^{16} (5×10^{18}) n_{eq}/cm^2 in endcap (forward) electromagnetic calorimeter TR 1.4.2: Per shower timing resolution of 5 ps	1, 2, 3, 7, 9, 10, 11, 16, 17, 23, 26
	TR 1.5: Trigger and readout	TR 1.5.1: Logic and transmitters with radiation tolerance to 300 MGy and 8×10^{17} n_{eq}/cm^2 TR 1.5.2: Total throughput of 1 exabyte per second at 100 TeV pp collider	16, 17, 21, 26

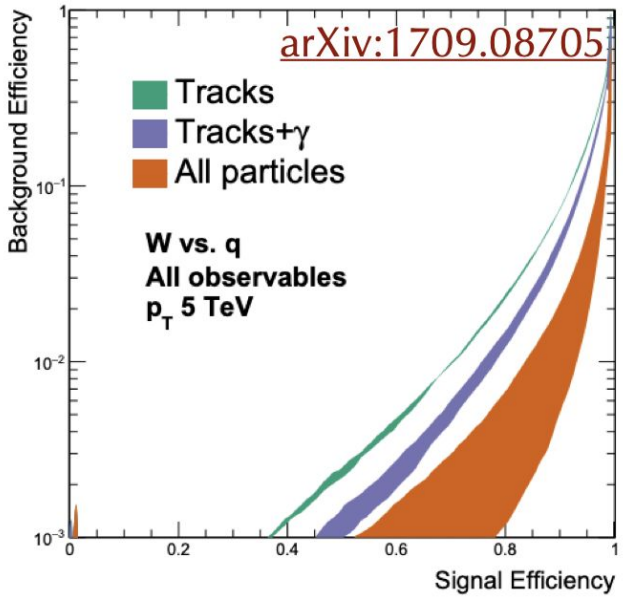
Beyond BRN

In the BRN physics drivers are very Higgs-centered, beyond Higgs:

- LLP searches could be an important benchmark for timing/trigger
  - Study of min radius for (few layers of) tracking detectors at future colliders
  - “Acceptance” for non-prompt charged particles at future detectors
- Boosted/Substructure object reconstruction is an important driver to guide detector design at future multi-TeV machines
  - pixel hit merging as one of the limiting factors
  - Also any improvement in tracking will directly impact jet reconstruction and calibration, pflow

More on this in today’s discussions

Just one example:



EF drivers: b/c/strange-tagging

- A class of BSM models predicts that the origin of the 1st and 2nd generation fermion masses is an additional source of EWSB, predicts large deviations from the SM values
  - Higgs to ss as well as cs at future colliders is the next milestone to probe the nature of Yukawa couplings
- Strange quarks mostly hadronize to prompt kaons which carry a large fraction of the jet momentum
  - The most powerful high momenta K± tags with dedicated particle identification detectors may be an exclusive territory of e+ e- colliders
  - The leading V0 s (K0 s and Lambda) have a distinctive 2-prong vertices topology
- The use of precise timing information would become very relevant for flavor tagging and providing an additional handle for separation between light quarks.
  - intermediate momentum K± ID from fast timing can become a significant contributor for b and c decays (s tag K± could be too high momentum for timing)
  - Detector design have a role too in capturing the high momenta V0 s that can decay deep into the tracker
    - Investigate optimal configurations for 4D tracking at future e+e- machines

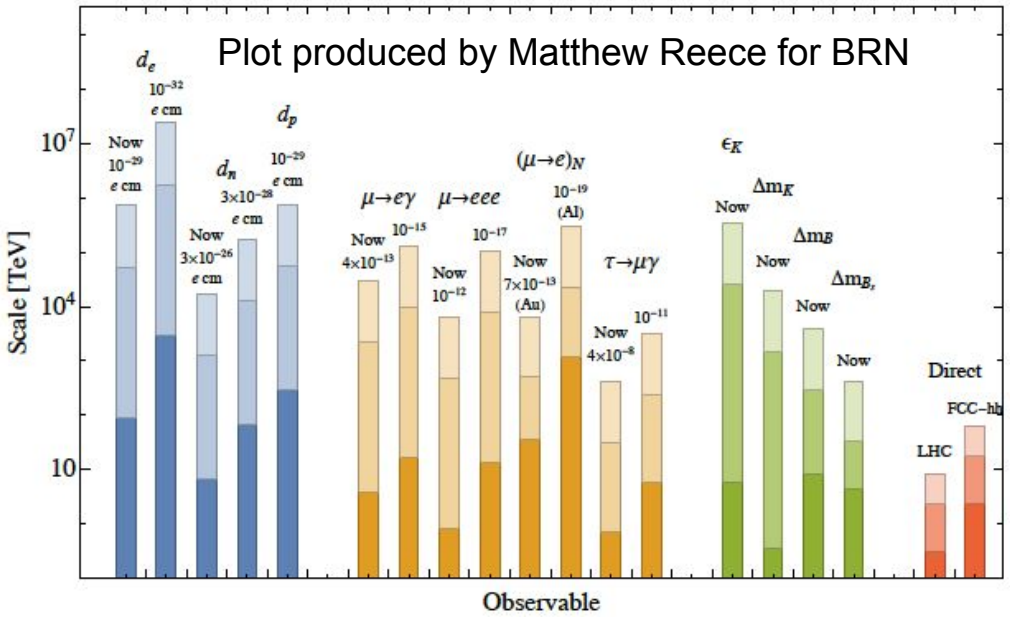
HEP detector in the forward direction

Science driver (P5, BRN):

Search for the unknown :

- charged lepton flavor violation
- EDM

But also: general purpose detector in the forward direction [electroweak physics, dark sector, long lived particles (see panel today), Higgs to charm coupling...



Forward detectors in the BRN

Science	Timescale	Technical Requirement (TR)	PRD
Search for new physics though rare flavor interactions	medium term	TR 5.1: Timing resolution at the level of $10-30$ ps per hit in the silicon-pixel vertex detectors and $10-30$ ps per track for both PID detectors (RICH, TORCH) and electromagnetic calorimeters	2, 10, 18
	medium term	TR 5.2: Development of radiation-hard, fast and cost-effective photosensors for TORCH and RICH detectors and tracking systems with optical readout	9, 11
	medium term	TR 5.3: Development of the next generation ASICS to extract the large data rate (and possibly pre-process it) out of inner pixel layer detectors in a very challenging radiation environment	16, 17
	medium term	TR 5.4: Radiation-hard silicon pixel detectors (fluences of 5×10^{16} n_{eq}/cm^2)	18, 20
Tests of the CKM quark mixing matrix description	medium term	TR 5.5: Cost-effective electromagnetic calorimeter with granularity of typically 2×2 cm^2, resolution of $\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}} \oplus 1\%$ and timing resolution of a few tens of ps; total radiation dose of ~ 200 Mrad	1
	medium term	TR 5.6: Real-time processing of large amount of data (400-500 Tb/sec) and development of radiation-hard, high-rate optical links, with tight constraints of low-power consumption and low mass	16, 17, 21, 22
	long term	TR 5.7: Fast-timing resolution at the level of 1 ps per track for $\pi/K/p$ separation up to 50 GeV	3, 10
	long term	TR 5.8: Further ASICS development to extract and pre-process on detector the large data rate of inner layers detectors in an extreme radiation environment	16, 17
Studies of Lepton Flavor Universality	long term	TR 5.9: Radiation-hard, ultra-fast silicon pixel detectors (fluences of 10^{18} n_{eq}/cm^2)	18, 19, 20
	long term	TR 5.10: Very high granularity calorimeters preserving an energy resolution of $\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}}$	1, 2, 7, 9
	long term	TR 5.11: Real-time processing of large amount of data (1Exabytes/sec) and development of radiation-hard, high-rate optical links, with tight constraints of low-power consumption and low mass	16, 17, 21, 22, 23

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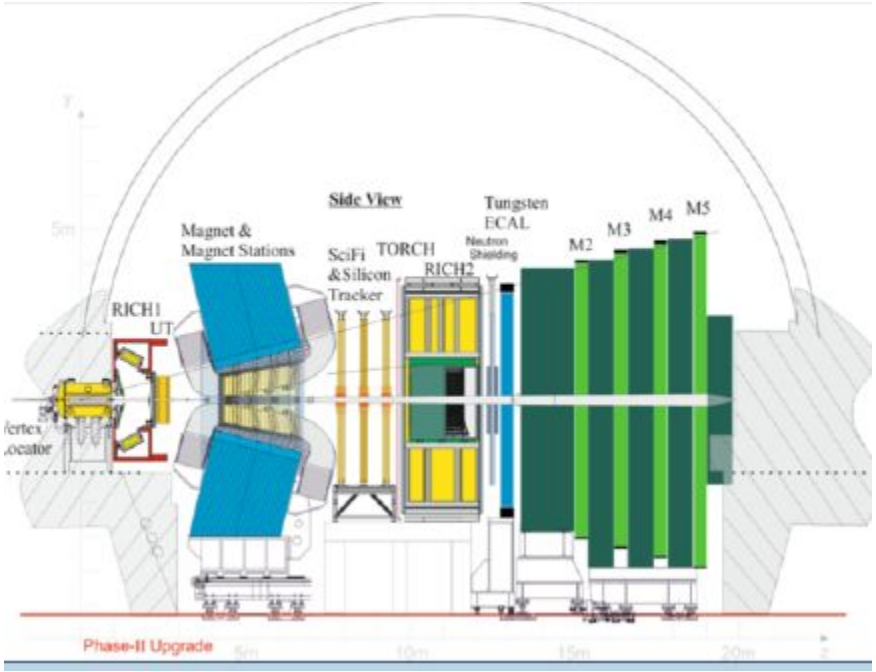
Importance of hadron identification

Community effort on the next generation of ASICs

Key experimental features of EF forward detector

- **Software trigger**, maximum flexibility to pursue the “interesting physics”
- **High data rates/fast processing**
- Add 4th dimension (time) to allow for fast processing, vertex resolution
- New EM calorimeter with at least some components providing 5D information
- Optimization of granularity/time resolution requirements
- Rad-hardness for detector components close to the beam



Open questions

How we can design better detectors to improve on:

- ***jet resolution and jet substructure observables by better combining tracking-calorimetry-timing?*** **today!**
- ***LLP searches***
- Testing Higgs flavor: c/s-tagging, tau-tagging
- Forward detector capabilities