IF06: Calorimetry
High Luminosity Physics Drivers and Technology Priorities

Rachel Yohay
Florida State University
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Future physics drivers

- Physics goals of future accelerators
  - Understand the nature of electroweak symmetry breaking
  - Investigate the flavor sector and its role in the matter-antimatter asymmetry
  - Hunt for dark matter candidates
  - Explore new physics that solves the hierarchy problem
- Future accelerators will operate at <u>higher energies and luminosities</u> than today, and with similarly <u>long run times</u>

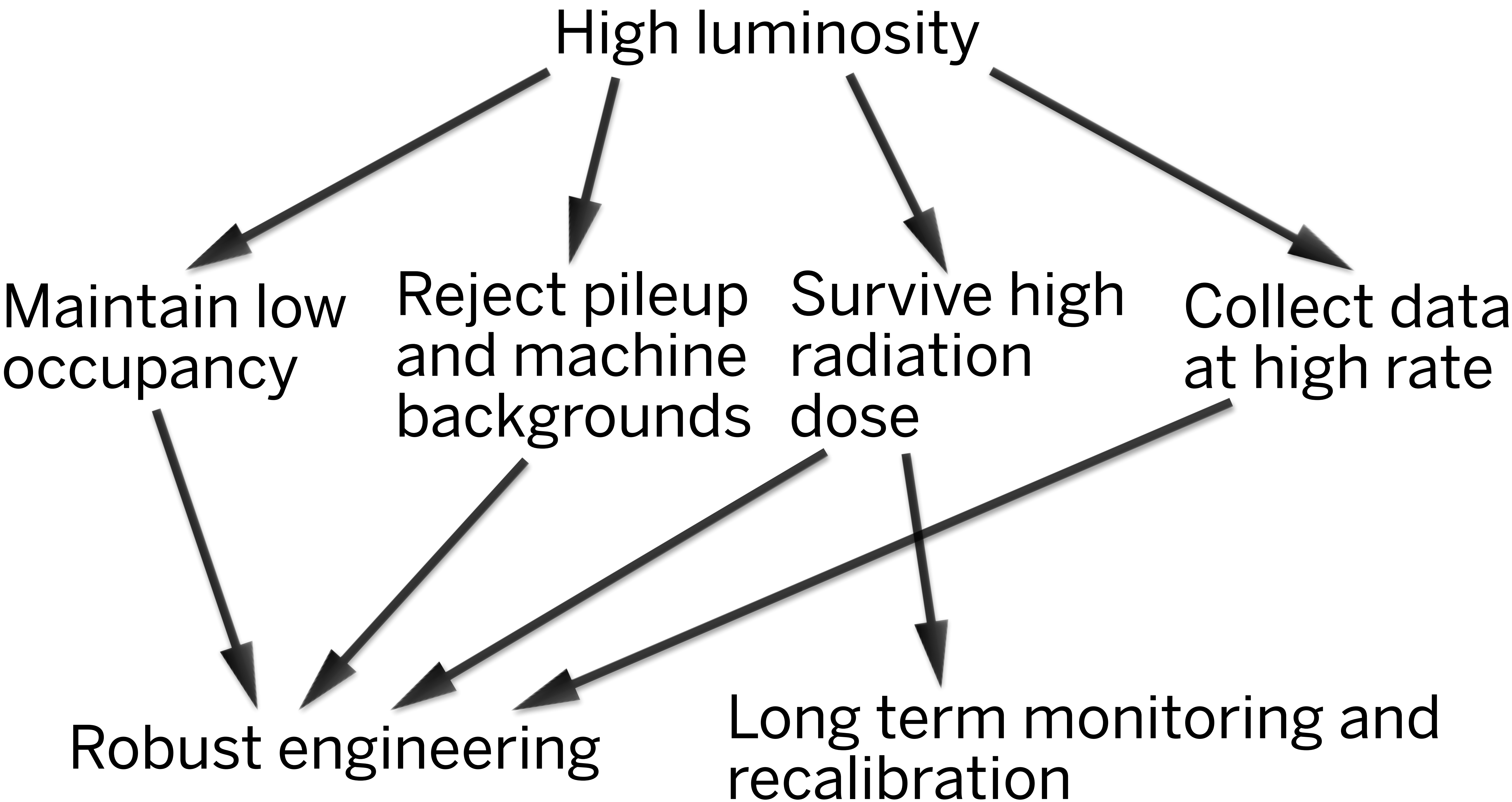
Physics Briefing Book

Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] $[e^-/e^+]$	N_{Det}	$\mathscr{L}_{\text{inst}}$/Det. $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathscr{L}$ $[\text{ab}^{-1}]$	Time [years]	Ref.
HL-LHC	pp	14 TeV	–	2	5	6.0	12	[23]
HE-LHC	pp	27 TeV	–	2	16	15.0	20	[23]
FCC-hh	pp	100 TeV	–	2	30	30.0	25	[636]
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[636]
		$2M_W$	0/0	2	25	10	1-2	
		240 GeV	0/0	2	7	5	3	
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5	
		(1y SD before $2m_{top}$ run)					(+1)	
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[341]
		350 GeV	±80/±30	1	1.6	0.2	1	[345]
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5	
		(1y SD after 250 GeV run)					(+1)	
CEPC	ee	M_Z	0/0	2	17/32	16	2	[508]
		$2M_W$	0/0	2	10	2.6	1	
		240 GeV	0/0	2	3	5.6	7	
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[637]
		1.5 TeV	±80/0	1	3.7	2.5	7	
		3.0 TeV	±80/0	1	6.0	5.0	8	
		(2y SDs between energy stages)					(+4)	
LHeC	ep	1.3 TeV	–	1	0.8	1.0	15	[635]
HE-LHeC	ep	1.8 TeV	–	1	1.5	2.0	20	[636]
FCC-eh	ep	3.5 TeV	–	1	1.5	2.0	25	[636]

Basic Research Needs for Dark Matter Small Projects New Initiatives

	Requirements		
Detection Approach and Concept Name	**Beam energy**	**Detector**	**Sensitivity Limitation**
Low-energy proton beam dump (e.g., COHERENT@SNS)	1 GeV p 3×10^{23} POT	1 tonne LAr/NaI @ 25m	Yield, Systematics
Low-energy proton beam dump (e.g., CCM@Lujan)	800 MeV 1.4×10^{22} POT	10 tonne liquid argon detector @15 to 40 m	Yield, Systematics
Mid-energy proton beam dump (e.g., SBN@BNB)	8 GeV 6×10^{20} POT	New dedicated beam dump, 112 tonne LAr-TPC @ 110 m	Yield
Electron beam dump (e.g., BDX @ CEBAF)	2-11 GeV 10^{22} EOT	1 m^3 scale CsI(Tl) EM calorimeter	Yield
Missing momentum @ CW electron beam (e.g., LDMX)	8 GeV 10^{16} EOT	10% X_0 target, kinematics on recoil electron energy less than 0.25 * E_{beam}	Rate
Muon missing momentum @ muon beam (e.g., M^3)	15-25 GeV 10^{13} μOT	50 X_0 target, kinematics on recoil muon energy less than 0.6 * E_{beam}	Rate
Proton spectrometer (e.g., at the MI @ Fermilab)	120 GeV $10^{18}-10^{20}$ POT	Spectrometer, vertex resolution, EMCal	Yield

From drivers to requirements



From drivers to requirements

Physics goals

Excellent electromagnetic, hadronic, and missing energy resolution over a wide energy range

CEPC goals

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Cutting edge materials and methods

Technological priorities

- All have seen significant R&D for HL-LHC and ILC
- Calorimetric methods show promise for the next generation of e^+e^- or hh colliders and high intensity fixed target experiments…
- …but require significant R&D to meet physics performance and radiation tolerance specs

Technological priorities

- Particle flow calorimetry
  - Fine lateral and longitudinal segmentation
  - Good timing resolution
  - Close integration with charged particle tracking detectors
- Dual-readout calorimetry
  - FE SiPM readout with low crosstalk
  - Optical fibers with high Čerenkov light yield

Technological priorities

- Radiation tolerance
  - Radiation hard materials, including FE ASICs and power converters
  - Mitigation with temperature control
  - Damage tracking and recalibration over time
- Data volume
  - Significant FE preprocessing
  - High bandwidth, small footprint cables

Technological priorities

- Engineering
  - Production at scale
  - Low-power FE components
  - Efficient and scalable cooling systems
  - Redundancy

Key active media and FE technologies

- Silicon sensors
  - Advantages: high granularity at scale, radiation tolerance
  - R&D: cost, extreme radiation-hard engineering, engineering for specific properties (e.g. rise time, collected charge, drift time, etc.)
- Crystals
  - Advantages: absorber + scintillator, compact
  - R&D: radiation tolerance, engineering for specific properties (e.g. high light yield, fast scintillation, etc.), production at scale, calibration
- Plastic scintillator
  - Advantages: cost, machining
  - R&D: radiation tolerance, optical properties (e.g. light yield, scintillation vs. transmission wavelengths)

Key active media and FE technologies

- Optical fibers (scintillating and Čerenkov)
- FE SiPM readout
  - Advantages: size, scalability, sensitivity
  - R&D: dynamic range, integration with transparent materials