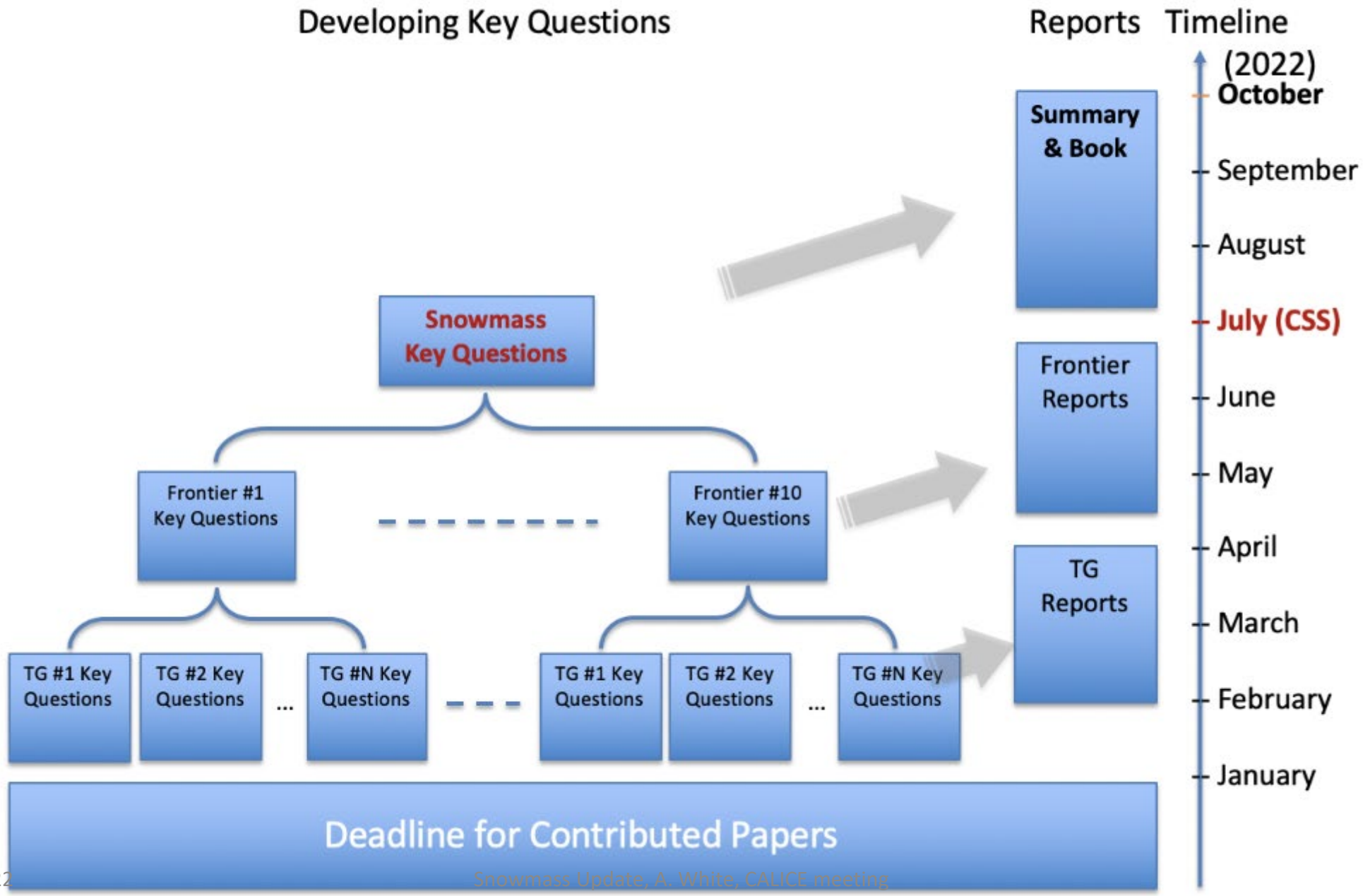
Snowmass 2021/2
Update and plans
for Instrumentation Frontier/Calorimetry

Andy White
University of Texas at Arlington

CALICE Collaboration Meeting, April 2022

Snowmass Timeline & Process (Preliminary)



Snowmass 2021
Update and plans
for Instrumentation Frontier/Calorimetry

- Instrumentation Frontier/Calorimetry specific items

  Organization, topics, experiments, facilities

  LOIs received – breakdown, categorization

- White papers -> Topical Group Summary

- Overall Snowmass schedule

- Snowmass Community Summer Study

Snowmass 2021/2
for Instrumentation Frontier/Calorimetry

INSTRUMENTATION FRONTIER

Topical groups

- IF1: Quantum Sensors
- IF2: Photon Detectors
- IF3: Solid State Detectors and Tracking
- IF4: Trigger and DAQ
- IF5: Micro Pattern Gas Detectors (MPGDs)
- IF6: Calorimetry
- IF7: Electronics/ASICs
- IF8: Noble Elements
- IF9: Cross Cutting and Systems Integration
- IF10: Radio Detection

Conveners

Name	Institution	email
Phil Barbeau	Duke University	psbarbeau[at]phy.duke.edu
Petra Merkel	Fermi National Accelerator Laboratory	petra[at]fnal.gov
Jinlong Zhang	Argonne National Laboratory	zhangjl[at]anl.gov

Liaisons

Other Frontier	Liaisons
Energy Frontier	Maksym Titov (CEA SACLAY), Caterina Vernieri (SLAC)
Neutrino Physics Frontier	Mayly Sanchez (ISU), NF10
Rare Processes and Precision	Marina Artuso (Syracuse)
Cosmic Frontier	Kent Irwin (SLAC), Hugh Lippincott (UCSB)
Accelerator Frontier	Andy White (UTA)
Computational Frontier	Darin Acosta (Florida)
Underground Facilities	Eric Dahl (Northwestern), Maurice Garcia-Sciveres (LBNL)
Community Engagement	Farah Fahim (FNAL)

Snowmass 2021/2
Instrumentation Frontier
IF06 - Calorimetry - Conveners

Andy White (UTA), Minfang Yeh (BNL), Rachel Yohay (Florida State)

Snowmass 2021/2
Instrumentation Frontier - Calorimetry

- Calorimetry Requirements from Physics
- Experiments/Facilities using Calorimetry
- Technology Tools and Calorimetry Development Areas
- Performance studies
- Calorimeter R&D

Experiments/Facilities using Calorimetry

Colliders

- LHC (ATLAS, CMS, ALICE, LHCb)/HL-LHC, FCChh,…
- Lepton Colliders – ILC (SiD, ILD), CLIC, CEPC, FCCee, …
- CALICE
- EIC

Neutrino experiments

- DUNE
- neutrinoless double-beta decay (CUORE, nEXO)
- MINOS, SuperNEMO, NovA

Low Energy Experiments

- Mu2e, EDM, rare decays

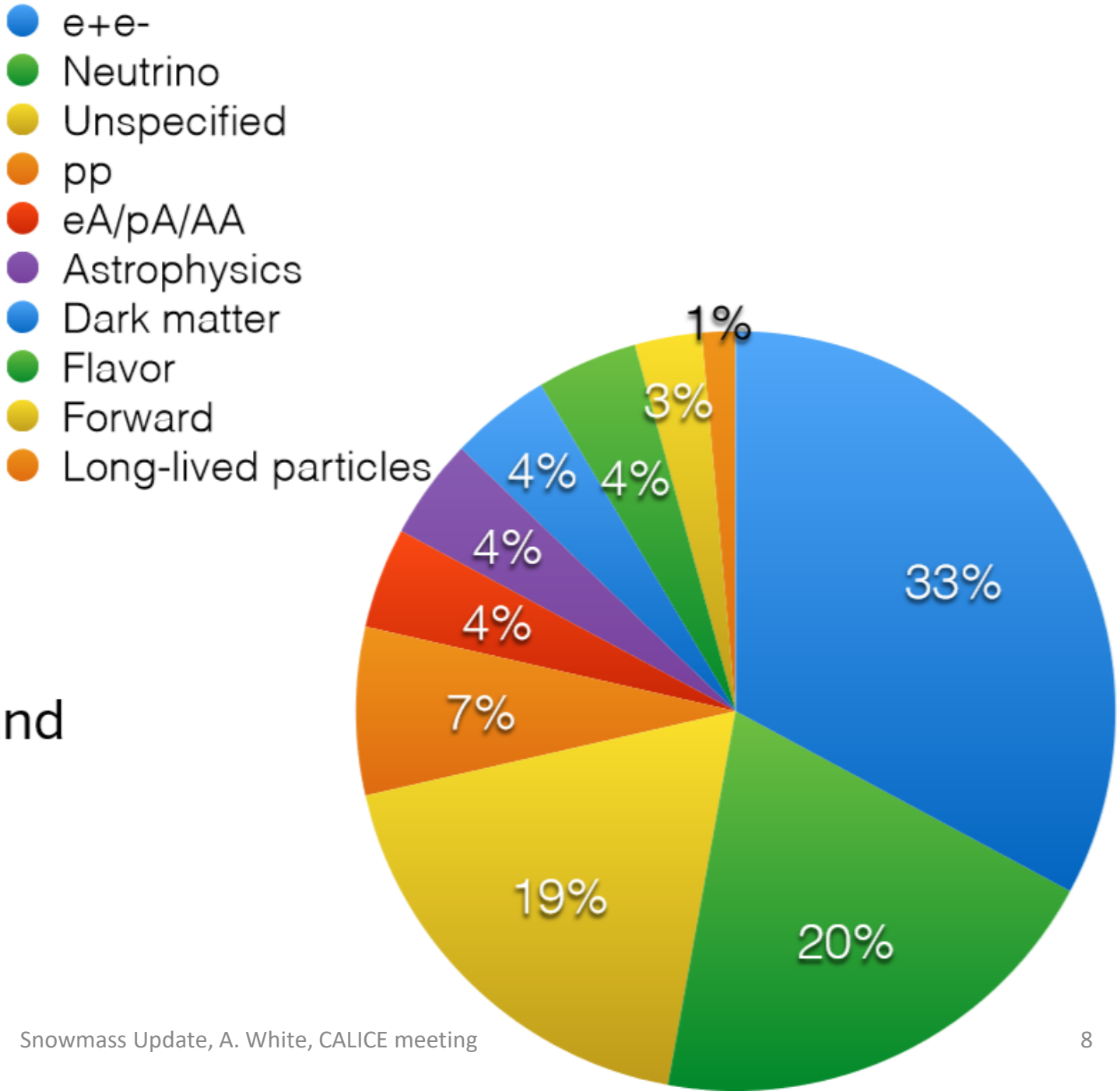
Dark Matter Search Experiments

- veto (e.g. LZ)
- future G3 concept

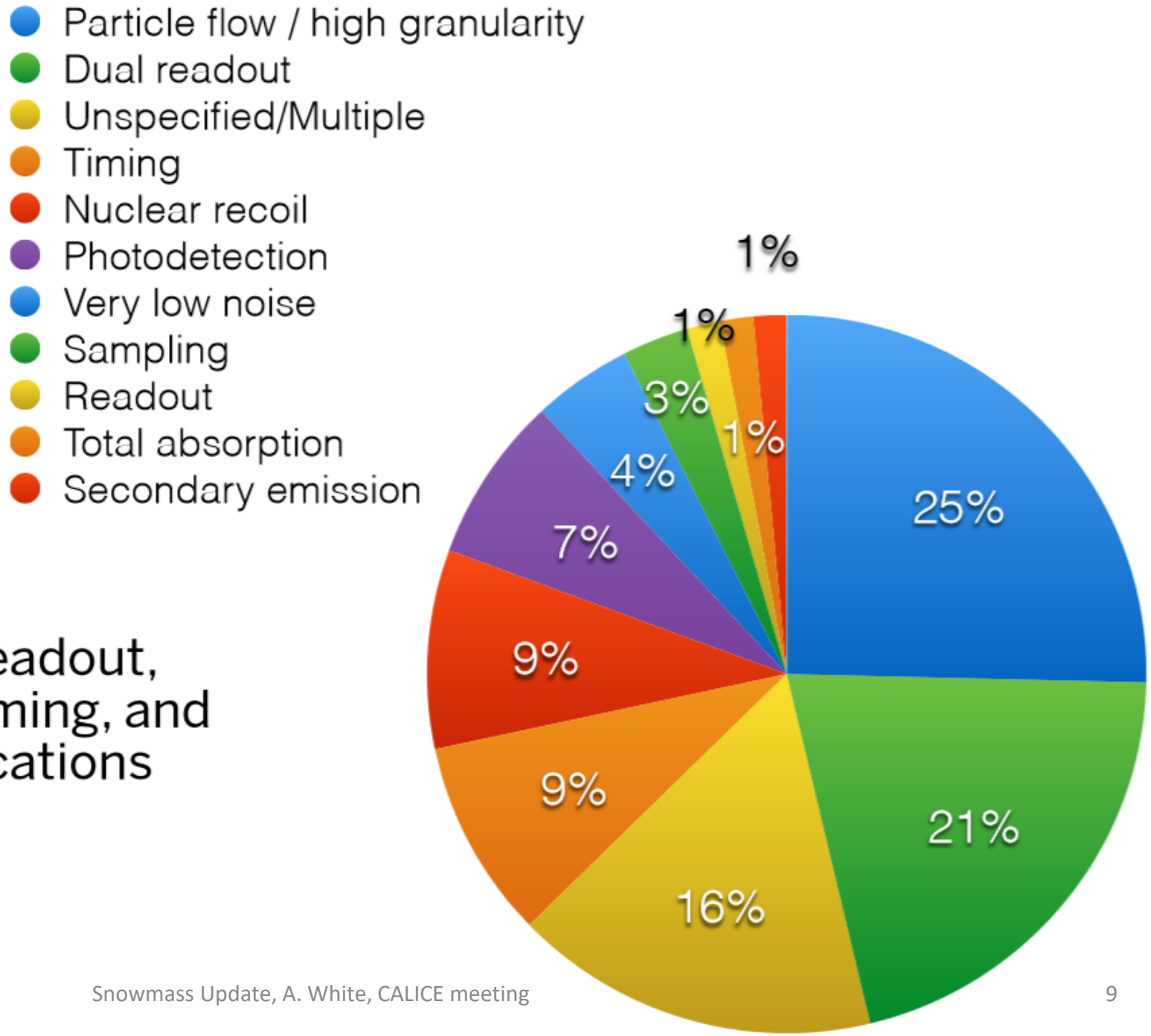
Experiments in Space

- AMS

65 LOIs Submitted



- e^+e^-, generalized R&D, and neutrino applications dominate



- Particle flow, dual readout, generalized R&D, timing, and nuclear recoil applications dominate

Organize LOIs into groups for White Paper planning

Particle Flow						
Title	Contact	File	e	Experiment	Material	Physics
e+e-						
Belle II detector upgrades	sevahsen@hawaii.edu	IF2_IF7_IF3_IF4_IF5_IF6-056.pdf	Multiple	Belle II	Plastic scintillator	e, gamma ID
Detector optimisation and detector technology R&D for the CLIC detector and for the CLD detector of FCC-ee	mbenoit@bnl.gov	IF3_IF6_Mathieu_Benoit-188.pdf	PF	CLIC, CLD	Si, scintillator	e+e-
SiD	A.White	IF3_IF6-EF1_EF4_Andy_White,_Marcel_Stanitzki-027.pdf	PF	SiD/ILC	Si, scintillator	e+e-
Advanced GEM detectors for future collider experiments	A.Colaleo (Bari)	IF5_IF6-EF4_EF0_COLALEO-068.pdf	Sampling	FCC, muon collider	GEM	e+e-, mu+mu-, hh
Development of highly granular scintillator strip electromagnetic calorimeter	wataru@icepp.s.u-tokyo.ac.jp	IF6_IF0_CALICE-058.pdf	PF	CALICE	Scintillator	e+e-
CALICE R&D for a highly granular silicon tungsten electromagnetic calorimeter, SiW-ECAL	Vincent.Boudry@llr.in2p3.f	IF6_IF0_CALICE-077.pdf	PF	CALICE	Si	e+e-
CALICE R&D for compact readout systems for highly granular calorimeters	katja.krueger@desy.de	IF6_IF0_CALICE-082.pdf	PF	CALICE	Asic	e+e-
Digital hadron calorimetry	yasar-onel@uiowa.edu	IF6_IF0_Yasar_Onel-048.pdf	PF	ILC/CLIC/FCC	RPC	e+e-
High-granularity crystal calorimetry	S.Eno	IF6_IF0_Yong_Liu-064.pdf	PF	ILC/CLIC/FCC	Crystals	e+e-
CALICE R&D for compact readout systems for highly granular calorimeters	katja.krueger@desy.de	IF6_IF0-026.pdf	Readout			e+e-
Particle flow calorimeters for the CEPC	liujianb@ustc.ac.cn	IF6_IF0-176.pdf	PF	CEPC	Si, scintillator	e+e-
Fast optical photon transport at GEANT4 with dual-readout calorimeter at future e+e- colliders	hdyoo@yonsei.ac.kr	IF6_IF0-CompF2_CompF0_Hwidong_Yoo-060.pdf	DRO	CEPC, FCCee	Optical fibers	e+e-
Tau reconstruction and identification using machine learning technique with dual-readout calorimeter at future e+e- colliders	hdyoo@yonsei.ac.kr	IF6_IF0-EF1_EF0_Hwidong_Yoo-063.pdf	GEANT, DRO	CEPC, FCCee	Optical fibers	e+e-
pp						
The High Granularity Calorimeter upgrade to the Compact Muon Solenoid detector	ryohay@fsu.edu	IF6_IF0-165.pdf	PF	CMS	Si, scintillator	pp
Advanced optical instrumentation for ultra-compact, radiation hard EM calorimetry applications	rruchti@nd.edu	IF6_IF4-EF1_EF4-102.pdf	Sampling, photodetection	FCChh	Scintillator	pp
Forward region of future colliders, high intensity and low earth orbit cosmic frontiers	irfield.edu	IF6_IF9_David_R_Winn-036.pdf	Photodetection	any	PMT, dynodes	

IF06: Calorimetry

- C.-H. Yeh, S. V. Chekanov, A. V. Kotwal, J. Proudfoot, S. Sen, N. V. Tran, S.-S. Yu, "Studies of granularity of a hadronic calorimeter for tens-of-TeV jets at a 100 TeV pp collider", arXiv:1901.11146 [physics.ins-det] (pdf). (also under EF09)
- S. V. Chekanov, A. V. Kotwal, C.-H. Yeh, and S.-S. Yu, "Physics potential of timing layers in future collider detectors", arXiv:2005.05221 [physics.ins-det] (pdf). (also under EF09)
- I. Pezzotti, Harvey Newman, J. Freeman, J. Hirschauer, et al. "Dual-Readout Calorimetry for Future Experiments Probing Fundamental Physics", arXiv:2203.04312 [physics.ins-det] (pdf).
- Minfang Yeh, Ren-Yuan Zhu. "Materials for Future Calorimeters", arXiv:2203.07154 [physics.ins-det] (pdf).
- S. V. Chekanov, F.Simon, V. Boudry, W. Chung, P. W. Gorham, M. Nguyen, et al. "Precision timing for collider-experiment-based calorimetry", arXiv:2203.07286 [physics.ins-det] (pdf).
- Chen Hu, Liyuan Zhang, Ren-Yuan Zhu. "Inorganic Scintillators for Future HEP Experiments", arXiv:2203.06731 [physics.ins-det] (pdf).
- Chen Hu, Liyuan Zhang, Ren-Yuan Zhu. "Ultrafast Inorganic Crystals with Mass Production Capability for Future High-Rate Experiments", arXiv:2203.06788 [physics.ins-det] (pdf). (also under EF01, RF05)
- David R Winn. "Novel Low Workfunction Semiconductors for Calorimetry and Detection: High Energy, Dark Matter and Neutrino Phenomena", arXiv:2203.09939 [physics.ins-det] (pdf).
- David R Winn, Yasar Onel. "Photomultipliers as High Rate Radiation-Resistant In-Situ Sensors in Future Experiments", arXiv:2203.09941 [physics.ins-det] (pdf).
- T. Anderson, T. Barbera, D. Blend, N. Chigurupati, B. Cox, P. Debbins, et al. "RADiCAL: Precision-timing, Ultracompact, Radiation-hard Electromagnetic Calorimetry", arXiv:2203.12806 [physics.ins-det] (pdf). (also under EF04)
- Randal Ruchti, Katja Kruger. "Particle Flow Calorimetry", arXiv:2203.15138 [physics.ins-det] (pdf). (also under EF0)
- Sergey Pereverzev, Gianpaolo Carosi, Viacheslav Li. "Superconducting Nanowire Single-Photon Detectors and effect of accumulation and unsteady releases of excess energy in materials", arXiv:2204.01919 [quant-ph] (pdf). (also under NF0, CF0)

Instrumentation Frontier
IF06 – Calorimetry – White Papers

- **Collider**

1. **Particle Flow Calorimetry for Future Colliders**
   - Katja Kruger (DESY), Randi Ruchti (Notre Dame)
   - Submitted: https://arxiv.org/abs/2203.15138

2. **Dual Readout Calorimetry for Future Colliders**
   - Sarah Eno (Maryland), Franco Bedeschi (INFIN-Pisa),Nural Akchurin (Texas Tech)
   - Submitted: https://arxiv.org/abs/2203.04312

3. **Precision Timing for Collider Experiment based Calorimetry**
   - Frank Simon (MPP Munich), Sergei Chekanov (ANL)
   - Submitted: https://arxiv.org/abs/2203.07286

Instrumentation Frontier
IF06 – Calorimetry – White Papers – cont.

- **Neutrino**

4. Calorimeter Techniques and Materials for Neutrino Experiments

- Milind Diwan (BNL), Jae Yu (UTA)
- Overlap with other frontiers
  - **Neutrino Frontier** Neutrinos from Natural Sources (NF04), Applications (NF07), Neutrino Detectors (NF10)
    Instrumentation Frontier Calorimetry (IF6), Cross Cutting and Systems Integration (IF9)
    Underground Facilities Underground Facilities for Neutrinos (UF01)
- A two-page summary with references to above frontiers; no WP submission

- **Dark Matter**

5. New Calorimeter Techniques and Materials for Dark Matter Detection

- David Winn (Fairfield), Rick Gaitskell (Brown)
- Four WP created – will use one closest to DM/Calorimetry – waiting for arXiv link…

- **Materials**

6. Materials for Future Calorimeters

- Ren-Yuan Zhu (Caltech), Minfang Yeh (BNL)
- Submitted: https://arxiv.org/abs/2203.07154

Instrumentation Frontier
IF06 – Calorimetry – White Papers – Summary

Just started!

6.1 Precise timing for Calorimetry

The primary purpose of electromagnetic and hadronic calorimetry is the measurement of the energy of charged and neutral particles and overall event energy. However, they are also important systems for overall event reconstruction, particle identification and triggering. The physics goals and the experimental conditions at future colliders require technical advances in calorimeter technology to fully exploit the physics potential of these facilities. For future e+e colliders, so-called Higgs Factories, the overall precision of event reconstruction is the main focus, while future hadron colliders at energies and luminosities significantly beyond the HL-LHC impose new challenges in terms of the experimental environment.

Precision timing can add an important extra dimension to calorimeter systems. The prospect of achieving timing resolution at the 10 ps level, the few ps level and even sub-ps level allows the possibility of a number of new aspects of calorimeter technology implementation and event reconstruction. Event reconstruction can benefit from the calorimeter timing capacities at several hierarchical levels: timing in cells, in highly granular calorimeters, helps shower reconstruction and energy corrections, timing of individual showers improves particle identification and objects reconstruction, and object timing allows event pile-up mitigation and characterization.

Particle identification via time-of-flight systems with a resolution at the 10 ps level allows pions to be resolved up to about 3 GeV, K-mesons to about 10 GeV, and neutrons and hyperons to several tens of GeV. While this may be useful for proposed e+e- colliders detectors, future very high energy hadron colliders will require resolution at the picosecond level. Precision timing resolution can either be obtained by dedicated timing layers integrated in the electromagnetic calorimeter achieving the required resolution for minimum-ionizing particles, or by a corresponding resolution for hadronic showers provided by the overall calorimeter system. Calorimeters with tens-of-picosecond timing can also lead to significant benefits for reconstruction of heavy long-lived particles which can have distinct signatures.

Particle flow algorithms, using association of tracking and calorimetric information, can also benefit from the addition of precise timing information. Since hadronic showers show a complex time structure, with late components connected to neutron-induced processes, timing on the cell level can have benefits for the spatial reconstruction of hadronic showers. A time resolution on the order of a few 100 ps to 1 ns results in a sharper definition of the core part of the shower, and thus potentially in a better separation of different particles in the calorimeter, and improved track-cluster assignment in PFA. Full space-time evolution of showers could be achieved with 10ps or better timing resolution. Multi-dimensional information from highly

Snowmass 2021/2
Instrumentation Frontier – Calorimetry
Schedule

- 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.

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Implementation Task Force Status

Thomas Roser for the Implementation Task Force

AF topical Group meeting

April 13, 2022

@BrookhavenLab

AF Implementation Task Force

- Key question for Snowmass'22 Accelerator Frontier to address: "…What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facility?"
- The Accelerator Implementation Task Force is charged with developing metrics and processes to facilitate the evaluation of proposals and allow a fair comparison between between them, including the expected costs, using the same accounting rules, schedule, and R&D status.
- Liaison with Energy Frontier: Dimitri Denisov, Meenakshi Narain
- Liaison with Theory Frontier: LianTao Wang

Steve Gourlay (LBNL)

Philippe Lebrun (CERN)

Thomas Roser (BNL, Chair)

Tor Raubenhelmer (SLAC)

Katsunobu Olde (KEK)

Jim Stralt (FNAL)

Sarah Cousineau (ORNL)

Marlene Turner (LBNL)

Spencer Gessner (SLAC)

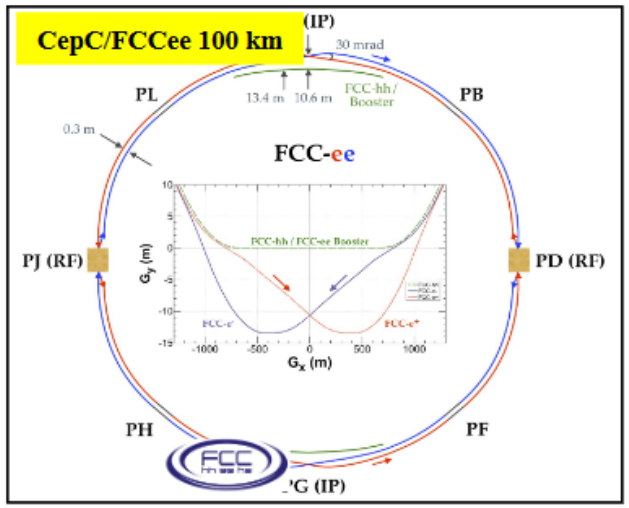
Vladimir Shiltsev (FNAL)

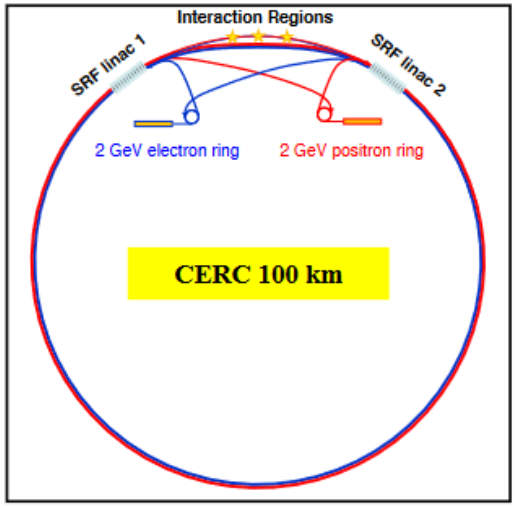
Reinhard Brinkmann (DESY)

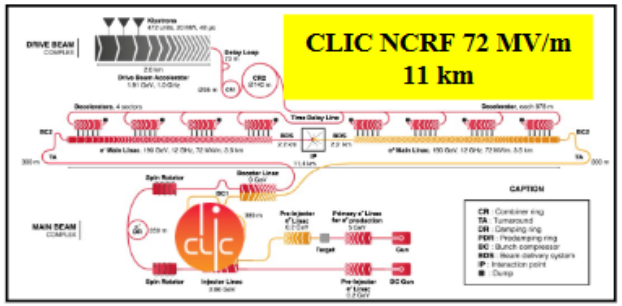
John Seeman (SLAC)

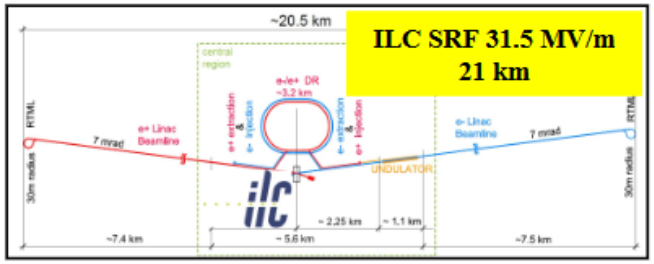
Higgs factory concepts (10)

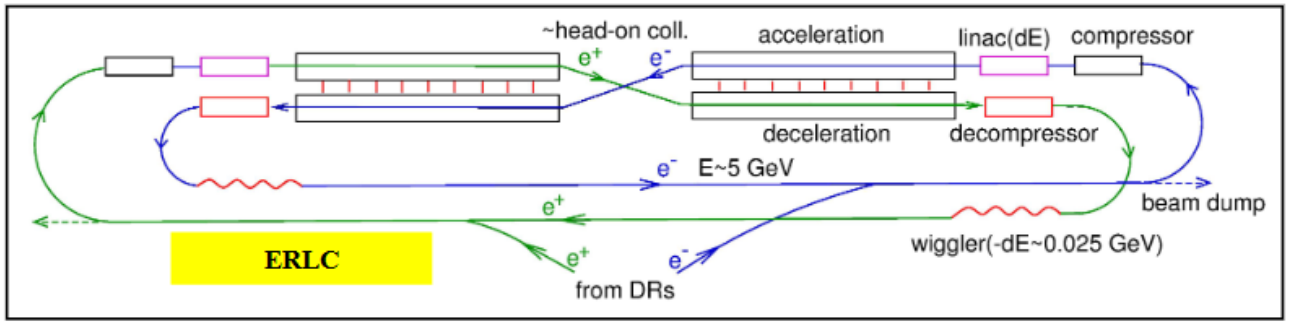
Name	Nominal COM energy and peak luminosity per IP at nominal energy
FCC-ee	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 8.5 $\times 10^{34}$
CEPC	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 8.3 $\times 10^{34}$
ILC (Higgs factory)	e+e-, $\sqrt{s}$ = 0.25 TeV, L= 2.7 $\times 10^{34}$
CCC (Cryo Cooled Collider)	e+e-, $\sqrt{s}$ = 0.25 TeV, L= 1.3 $\times 10^{34}$
CLIC (Higgs factory)	e+e-, $\sqrt{s}$ = 0.38 TeV, L= 1.5 $\times 10^{34}$
CERC (ERL ee collider)	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 78 $\times 10^{34}$
ReLiC (Linear ERL Collider)	e+e-, $\sqrt{s}$ = 0.24 TeV, L= 165 $\times 10^{34}$
ERLC (ERL Linear Collider)	e+e-, $\sqrt{s}$ = 0.25 TeV, L= 90 $\times 10^{34}$
XCC FEL-based $\gamma\gamma$ collider	ee ($\gamma\gamma$),$\sqrt{s}$ = 0.125 TeV, L= 0.1 $\times 10^{34}$
MC (Higgs factory)	$\mu\mu$, $\sqrt{s}$ = 0.13 TeV, L= 0.01 $\times 10^{34}$

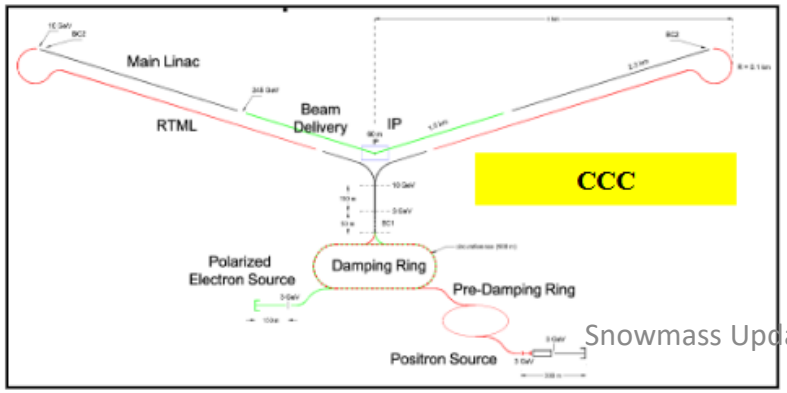


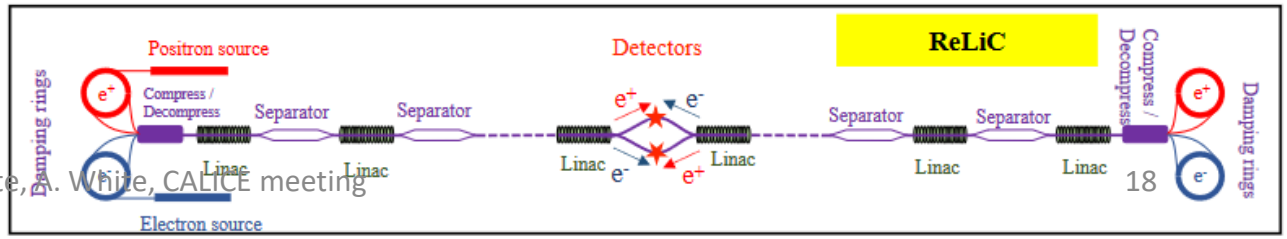












Proposed Higgs factory comparison table

Proposal Name	Nominal COM energy (Range) [TeV]	Luminosity per IP at nominal COM energy [10^{34} cm^{-2} s^{-1}]	Years of pre-project R&D required	Years until first physics	Construction cost range, including explicit labor [2021 MUS$]	Estimated operating electric power consumption [MW]
FCC-ee (1,2)	0.24 (0.09 - 0.37)	8.5 (28.9)				
CEPC (1,2)	0.24 (0.09 - 0.24)	8.3 (16.6)				
ILC (Higgs factory) (3)	0.25 (0.09 - 3)	2.7				
CCC (Cryo Cooled Collider) (3)	0.25 (0.25 - 0.55)	1.3				
CLIC (Higgs factory) (3)	0.38 (0.09 - 3)	1.5				
CERC (ERL ee collider) (3)	0.24 (0.09 - 0.6)	78				
ReLiC (Linear ERL Collider) (1,3)	0.24 (0.09 - 3)	165 (330)				
ERLC (ERL Linear Collider) (3)	0.25 (0.25 – 0.5)	90				
XCC FEL-based γγ Collider	0.125 (0.125 - 0.14)	0.1				
MC (Higgs factory) (3)	0.13	0.01				

Higgs factory summary plot

From European Strategy Study 2021:

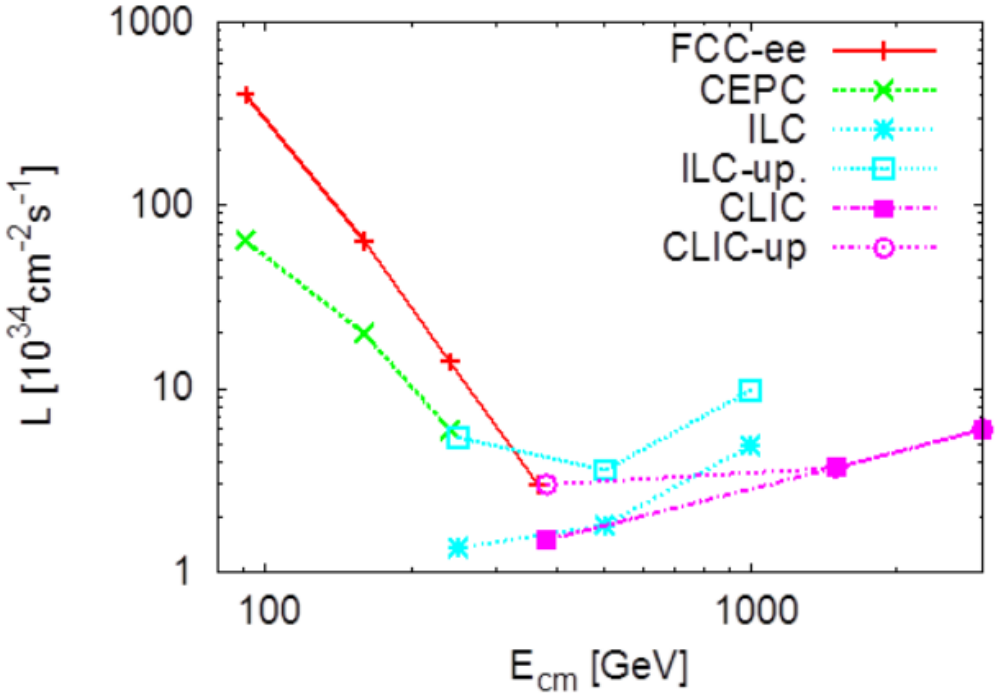
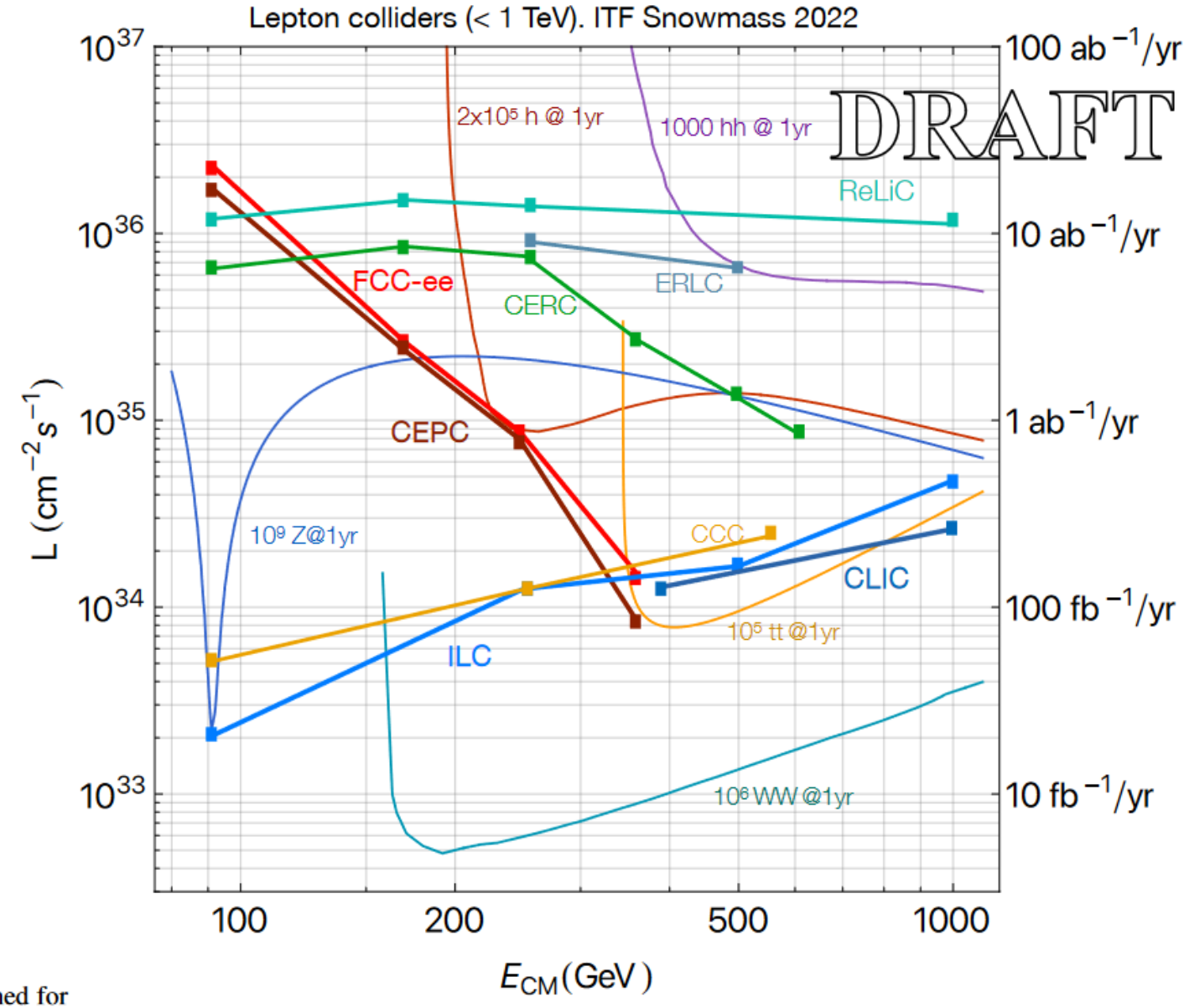
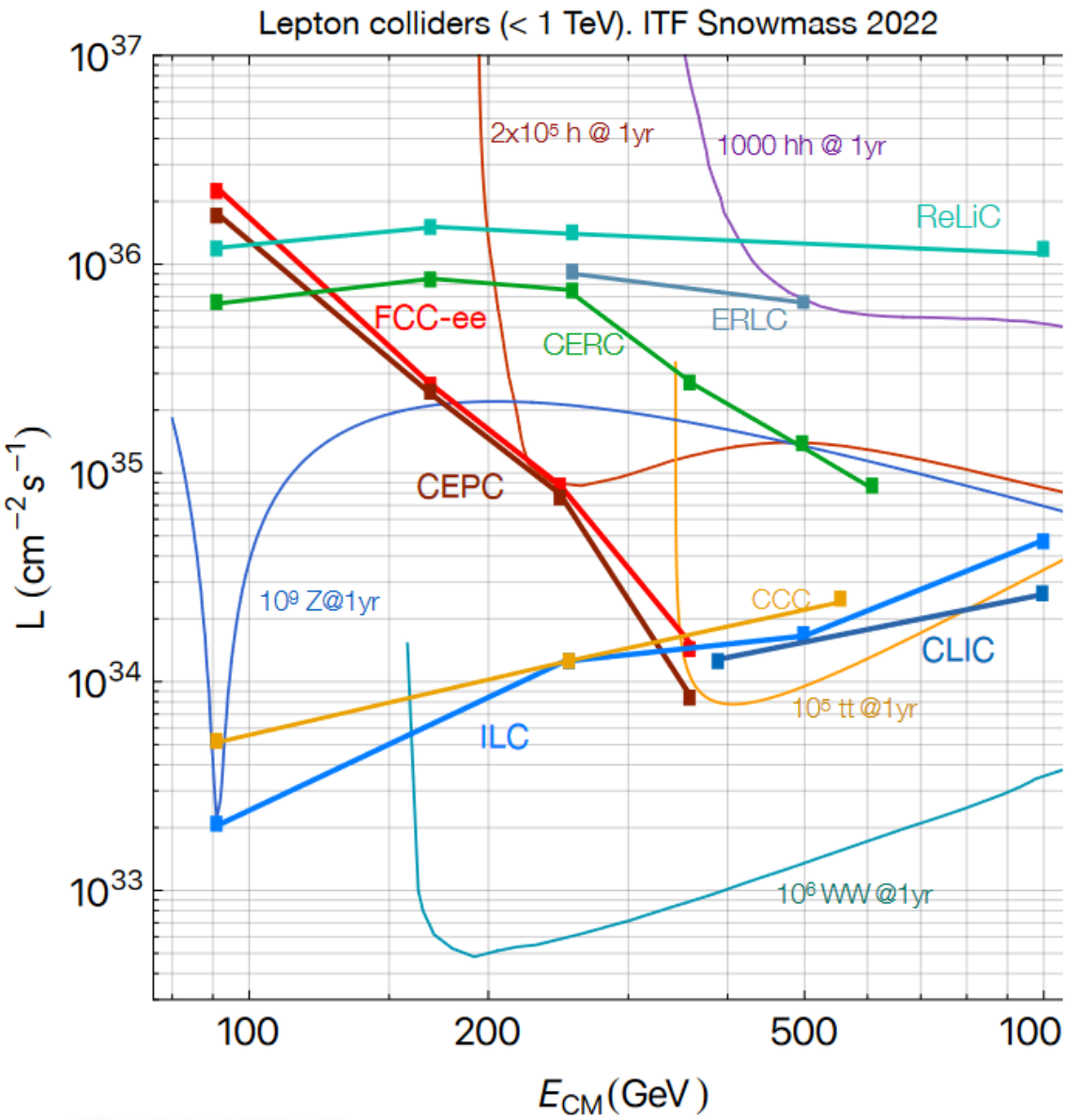
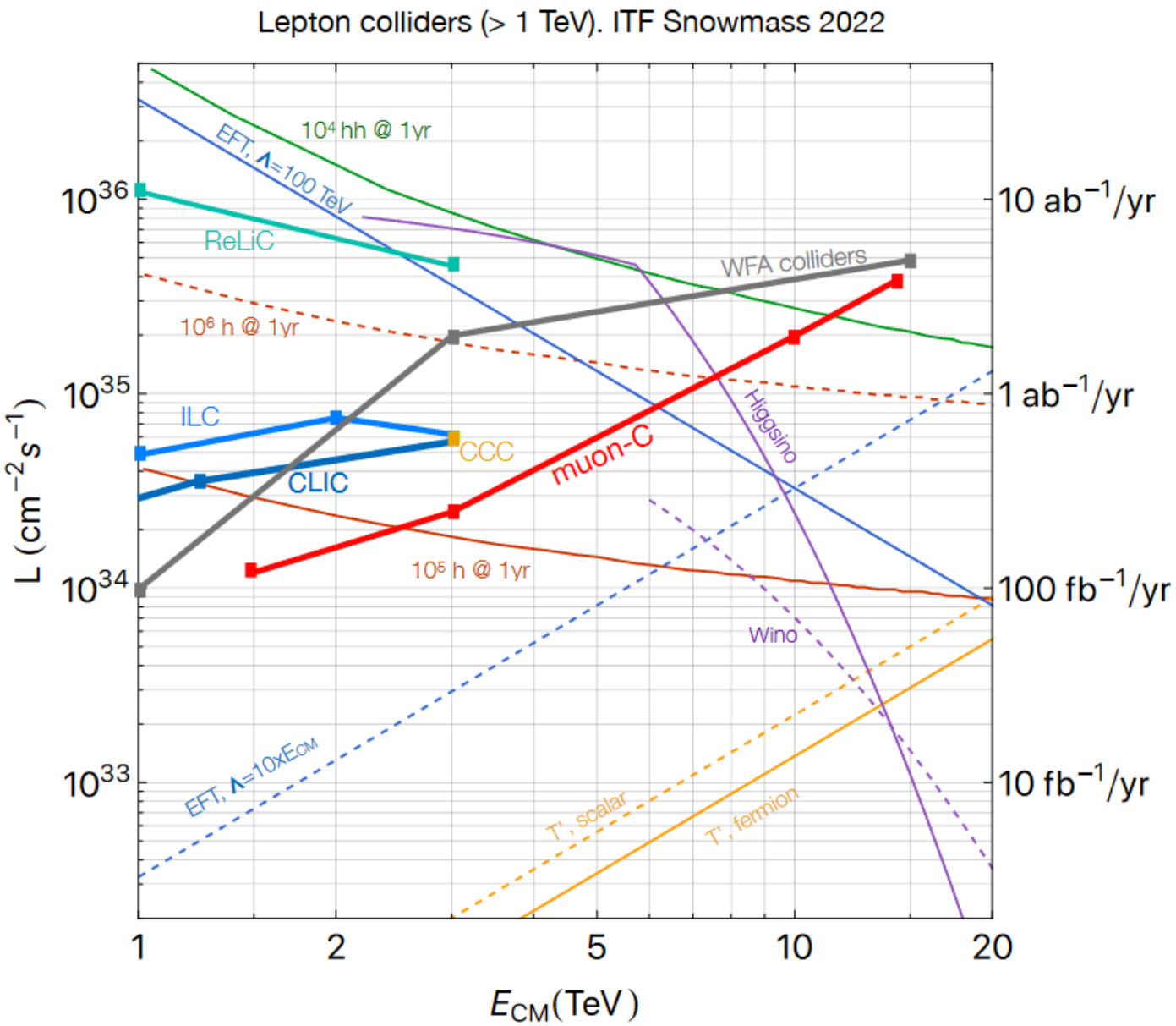


Fig. 10.2: Luminosity versus c.m. energy for e^+e^- Higgs Factories. Two IPs are assumed for the circular colliders FCC-ee and CEPC.



- Plot lumi vs. energy as reported by proponents
- Plan to plot lumi/IP (lumi for one IP) and only one version
- What physics measures should be plotted?


Lepton colliders (< 1 TeV). ITF Snowmass 2022
L (cm^{-2}s^{-1})
E_{CM}(GeV)
2x10^5 h @ 1yr
1000 hh @ 1yr
ReLiC
FCC-ee
CERC
ERLC
CEPC
10^9 Z@1yr
CCC
CLIC
10^5 tt @1yr
ILC
10^6 WW @1yr


Lepton colliders (> 1 TeV). ITF Snowmass 2022
L (cm^{-2}s^{-1})
E_{CM}(TeV)
10 ab^{-1}/yr
1 ab^{-1}/yr
100 fb^{-1}/yr
10 fb^{-1}/yr
10^4 hh @ 1yr
EFT, Λ=100 TeV
ReLiC
WFA colliders
10^6 h @ 1yr
ILC
CCC
muon-C
Higgsino
CLIC
10^5 h @ 1yr
Wino
EFT, Λ=10xE$_{CM}$
T', scalar
T', fermion

Snowmass 2021/2
for Instrumentation Frontier/Calorimetry

Snowmass Community Summer Study

First Bulletin

http://seattlesnowmass2021.net/