Summary and plans for 2021 Snowmass meeting

Meenakshi Narain (Brown U)

CPM Session #26: “Energy Frontier Discovery Machines”

October 7, 2020

On behalf of

AF Conveners: Vladimir Shiltsev, Tor Raubenheimer and Steve Gourlay

EF Conveners: Meenakshi Narain, Laura Reina, Alessandro Tricoli

TF Conveners: Nathaniel Craig, Csaba Csaki, Aida El-Khadra

My task is to

Summarize how the

Accelerator Frontier, Energy Frontier, and Theory Frontier groups

plan to proceed between now and summer 2021 Snowmass workshop with respect to topics discussed at the meeting.

Plans of the Accelerator Frontier

AF Conveners: Vladimir Shiltsev, Tor Raubenheimer and Steve Gourlay

AF-EF Liaisons: Dmitri Denisov, Meenakshi Narain

AF-TF Liaison: LianTao Wang

Three primary AF Working Groups overlapping with EF

- AF3 (EW/Higgs Factories): Marc Ross (SLAC), Qing Qin (IHEP, Beijing), and Georg Hoffstaetter (Cornell)
  - Covers range up to 1 TeV Focus on performance and cost mitigation and alternative schemes

- AF4 (Multi-TeV) : Alexander Valishev (Fermilab), Mark Palmer (BNL), and Nadia Pastrone (INFN/Torino)
  - 1 – 100 TeV and beyond Potential machine routes, R&D requirements and parameters required to reach community's physics goals
  -
- AF6 (Advanced Colliders): Cameron Geddes (LBNL), Mark Hogan (SLAC), Pietro Musumeci (UCLA), and Ralph Assmann (DESY)
  - new accelerator technologies to revolutionize cost and capability of future accelerators

EF and AF are Intricately Linked

- EF science goals currently envision two types of future colliders (in arbitrary order)
  - Higgs (and other known elementary particles) factory
  - Next high energy frontier machine
- Discoveries at the Energy Frontier are intricately linked to the progress in accelerators.
- To do physics studies of options, and to make a physics case, machine parameters and estimates of luminosity and backgrounds are needed for the proposed options.
- An important aspect is community participation
  - While we can help find resources, the drive/enthusiasm to perform the study needs to come from a group interested in promoting a specific option
  - Input from AF groups for the studies is critical
    It will be an iterative process between AF and EF groups to identify most valuable options

Integration of EF and AF effort has begun

- Two joint meetings have been held (June 24 and July 1) Each proponent provided a table with parameters, technical readiness/feasibility, cost, timeframe for start of construction, for various collider options
- More than a dozen options were presented, and they will form a baseline for studies pursued by the Energy Frontier groups
- Options divided into two categories:
  - More mature (CDR/TDR level)
    - CLIC, HE-LHC, SppC, FCC-hh
  - And not quite mainstream
    - Plasma, Beam and Structure WF, Muon (3 – 14 TeV)

Options in the range of
3 - 100 TeV CoM

Key Question for AF: 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?”

- To answer that question, AF has created an Implementation Task Force (ITF)
  - The ITF is charged with developing metrics and processes to facilitate such a comparison between projects.
- Task Force members: Thomas Roser (chair), Philippe LeBrun, James Strait, Katsanobu Oide, John Seeman, Reinhard Brinkman, and the AF Co-coveners
- Next Steps
  - Assimilate input from LoI’s, CPM
  - Continue joint workshops
  - Focused working groups to fill gaps

Plans of the Energy Frontier

EF Conveners: Meenakshi Narain, Laura Reina, Alessandro Tricoli

AF-EF Liaisons: Dmitri Denisov, Meenakshi Narain

Energy Frontier Perspective

- Within the EF, there is wide interest in defining the "discovery machine(s)" for the future
- Directions being pursued:
  - Hadron-hadron colliders
    - Proposals for pp at 100 TeV (FCC-hh, SppC)
    - Some studies at 27 TeV and 33 TeV exist
  - lepton colliders
    - Studies for muon colliders >=10 TeV,
      - international collaboration being formed
  - Gamma-gamma collider
    - 30 TeV? Discussed in session #186???

Discovery Machine benchmark parameters

- These are some scenarios where physics studies have begun at various level of maturities.

Snowmass 2021 Energy Frontier Collider Study Scenarios

Collider	Type	$\sqrt{s}$	P [%] e^-/e^+	L_{int} ab^{-1}
FCC-hh	pp	100 TeV		30
LHeC	ep	1.3 TeV		1
FCC-eh	ep	3.5 TeV		2
muon-collider (higgs)	$\mu\mu$	125 GeV		0.02
High energy muon-collider	$\mu\mu$	3 TeV		1
		10 TeV		10
		14 TeV		20
		30 TeV		90

Note for muon-collider: It is important to note that the plan is not to run subsequently at the various c.o.m etc. These are reference points to explore and assess the physics potential and technology. The luminosity can be varied to determine how best to exploit the physics potential.

Plans until CSS [July 2021]

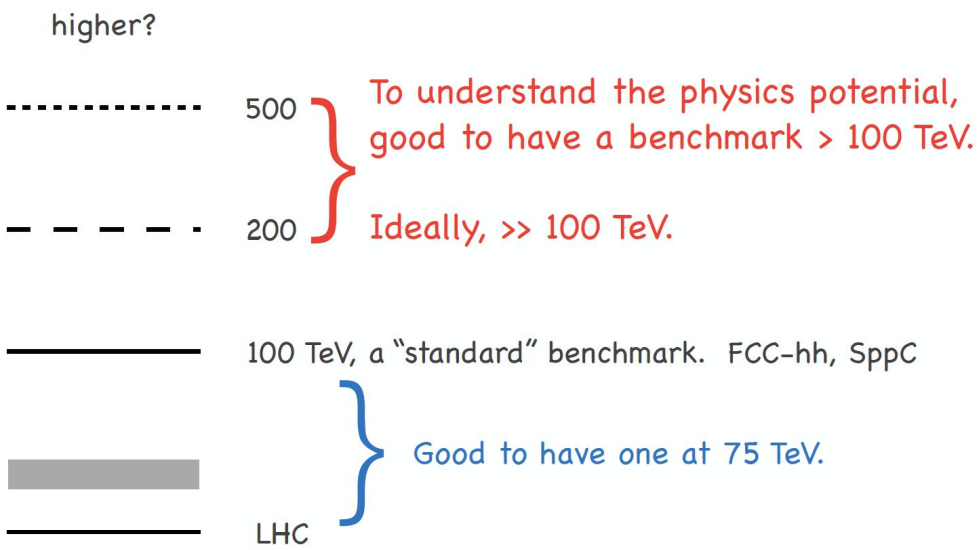
- There is a large interest in EF community in understanding what “Energy and luminosity” would be best suited for a discovery machine
  - pp >> 100 TeV
  - High energy muon collider > 30 TeV
  - Very high energy e+e- collider
- LianTao and Patrick gave a nice summary of physics motivations
  - These studies will be the basis for forging our future directions and the dialogue with the AF colleagues on the technology challenges and R&D and similarly with IF.
- Much more work is planned!!!

Plans until CSS [July 2021]

- Other options to explore:
  - Addition of other CoM options for very high energy pp collider? Currently studies use 100 TeV, shall we add an intermediate $\sqrt{s}$ e.g. ~75 TeV documenting sensitivity loss
    - 100 TeV with 16T magnets would have long timeline and high cost, while 75 TeV with 12T magnets is feasible but still very expensive.
  - Given the number of LOIs submitted, there large interest in muon colliders with $\sqrt{s}$ 30 and 100 TeV "dream" machines – big, very expensive and low(er) lumi! [and physics studies have started.]
  - Gamma-gamma with $\sqrt{s}$ 30 TeV is a proposed option from AF side [electron beams are used for photons scattering].
    - Is there a physics interest or a collaboration who is willing to do these studies?

High energy pp colliders

Conclusion: benchmark for physics studies



LianTao Wang,
Previous talk at this session
"Physics potential of high energy pp (ep) colliders

What is a reasonable upper limit?

An example

Hind Al Ali[1], Nima Arkani-Hamed[2], Ian Banta[1], Sean Benevedes[1], Tianji Cai[1], Junyi Cheng[1], Timothy Cohen[3], Nathaniel Craig[1], JiJi Fan[4], Isabel Garcia Garcia[5], Samuel Homiller[6], Seth Koren[7], Giacomo Koszegi[1], Zhen Liu[8], Qianshu Lu[6], Kunfeng Lyu[9], Amara McCune[1], Patrick Meade[10], Isobel Ojalvo[11], Umut Oktem[1], Matthew Reece[6], Raman Sundrum[8], Dave Sutherland[12], Timothy Trott[1], Chris Tully[11], Ken Van Tilburg[5], Lian-Tao Wang[7], and Menghang Wang[1]

- Illustrate:
  - Muon collider as an all-in-one machine - can achieve both precision and energy!
  - Muon collider as an electroweak boson collider
- Attempt to quantify the integrated luminosity required at a given com Energy to discover or constrain a given point in parameter space.

For the purposes of forecasting two luminosity scalings are used -- “optimistic" scaling assumes integrated luminosity growing with “s” and, a more “conservative” scaling which follows the optimistic scaling up to c.o.m. E of 10 TeV, after which it remains at at 10 ab-1 for all subsequent energies.

$\sqrt{s}$ [TeV]	1	3	6	10	14	30	50	100
$\mathcal{L}_{\rm int}^{\rm opt}$ [ab^{-1}]	0.2	1	4	10	20	90	250	1000
$\mathcal{L}_{\rm int}^{\rm con}$ [ab^{-1}]	0.2	1	4	10	10	10	10	10

EF-TF collaboration!

An example

Hind Al Ali[1], Nima Arkani-Hamed[2], Ian Banta[1], Sean Benevedes[1], Tianji Cai[1], Junyi Cheng[1], Timothy Cohen[3], Nathaniel Craig[1], JiJi Fan[4], Isabel Garcia Garcia[5], Samuel Homiller[6], Seth Koren[7], Giacomo Koszegi[1], Zhen Liu[8], Qianshu Lu[6], Kunfeng Lyu[9], Amara McCune[1], Patrick Meade[10], Isobel Ojalvo[11], Umut Oktem[1], Matthew Reece[6], Raman Sundrum[8], Dave Sutherland[12], Timothy Trott[1], Chris Tully[11], Ken Van Tilburg[5], Lian-Tao Wang[7], and Menghang Wang[1]

EF-TF collaboration!

What's the takeaway from this talk?
That ***potentially*** there is...

P. Meade,
Previous talk at this session
"Physics potential of lepton and
gg colliders with energies above 3 TeV"

Plans of the Theory Frontier

TF Conveners: Nathaniel Craig, Csaba Csaki, Aida El-Khadra

AF-TF Liaison: LianTao Wang

Theory Frontier

- Collect theory input through contributed papers along three lines:
  - *Assessment of physics potential and development of collider analyses strategies (TF07)*
  - *Implications of physics potential for BSM theories (TF08)*
  - *Theory desiderata for maximizing physics potential (TF06)*
- Dedicate a session to EF discovery machines at the March Theory Frontier meeting @ KITP.
- Coordinate with theory activities for proposed facilities being undertaken by international partners (Europe/Japan/China).
- Hold a joint AF-EF-TF workshop on energy frontier discovery machines, date & details TBD.