Snowmass 2013 &
Accelerator Capabilities for HEP

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For Study Group Conveners

HEP Frontier ~~facilities~~ capabilities

- Assess existing & proposed capabilities of two distinct classes of experimental capabilities for high energy physics *broadly understood*
  - Those provided by accelerator-based facilities (Barletta)
  - Those provided by underground detector facilities distinct (Gilchriese)

- Accelerator Capabilities areas:
  - Proton Colliders – Conveners: M. Battaglia, M. Klute, S. Prestemon, L.Rossi
  - Energy Frontier Lepton Colliders: M. Klute, M. Battaglia, M. Palmer, K. Yokoya
  - Intensity Frontier (IF) Protons: J. Galambos, M. Bai, S. Nagaitsev
  - IF Electrons & Photons: G. Varner, J. Flanagan, J. Byrd
  - Accelerator Technology: G. Hoffstaetter, , W. Gai, M. Hogan, V. Shiltsev

What are long term “big questions” regarding accelerator-based HEP capabilities

- *How would one build a 100 TeV scale hadron collider?*
- *How would one build a lepton collider at >1 TeV?*
- *How would one generate 10 MW of proton beam power?*
- *Can multi-MW targets survive? If so, for how long?*
- *Can plasma-based accelerators achieve energies & luminosities relevant to HEP?*
- *Can accelerators be made 10x cheaper per GeV? Per MW?*

These are issues for the long term future

Questions to address:

- ❖How high a luminosity is possible for the LHC?
  - ✧ What are strategies for increasing integrated luminosity without compromising experiments or detector survival?
- ❖How high an energy is possible in the LHC tunnel?
- ❖The energy frontier beyond LHC
  - ✧ What are the impediments to a 100 TeV cm collider?
- ❖What is the accelerator R&D roadmap?

Priority: Full exploitation of LHC

- => Strong LHC Accelerator Research Program continuing to U.S.-LHC high luminosity construction project
- Continue a focused integrated laboratory program (LARP-like) emphasizing engineering readiness of technologies suitable for High Energy-LHC
  - Next generation high field Nb_3Sn magnets (~15 Tesla)
  - Beam control technology
- This is most critical technology *development* toward higher energy hadron colliders in the near to mid-term
- Reach of an LHC energy upgrade is very limited
  - No engineering materials beyond Nb_3Sn
  - Difficult synchrotron radiation management

Focused engineering development is no substitute for innovative R&D

Proton colliders beyond LHC

- ❖ US multi-lab study of VLHC is still valid (circa 2001);
  - ✧ Snowmass has stimulated renewed interest/effort in US
    - o 2013 Snowmass white paper
- ❖ We recommend participating in international study for colliders in a large tunnel (CERN-led)
- ❖ Study will inform directions for expanded U.S. technology reach & guide long term roadmap
  - ✧ Beam dynamics, magnets, vacuum systems, machine protection, …

Extensive interest expressed in this possibility

Hadron colliders:
Long term innovative R&D

- New engineering conductors (e.g., small filament HTS)
- Advanced magnets – greater temperature margin, stress management techniques, magnet protection, novel structural materials
- Beam dynamics
  - Effects of marginal synchrotron radiation damping
  - Beam physics of the injection chain
  - Control of beam halo
  - Noise & ground motion effects
- Machine protection & beam abort dumps (multi-GJ beams)
- Interaction Region design & technology options

Strong technology overlap with muon / intensity machines

Energy-frontier lepton & photon colliders
Questions to address (on the Wiki)

- ❖ Can ILC & CLIC designs be improved using new technologies?
  - ✧ Can they be constructed in stages? what is a staging plan?
  - ✧ What would be the parameters of a Higgs factory as a first stage?
- ❖ Higgs factories
  - ✧ Could a Higgs factory be constructed in the LHC tunnel?
  - ✧ What would be parameters of a photon collider Higgs factory
  - ✧ Could one build a $\mu^+\mu^-$ collider as a Higgs factory?
- ❖ Could one design a multi-TeV $\mu^+\mu^-$ collider?
- ❖ What is the accelerator R&D roadmap?

Excitement & boundary conditions driven by Higgs discovery

We welcome the initiative for ILC in Japan

- U.S. accelerator community is capable to contribute
  - Supported by the physics case as part of a balanced program
- ILC design is technically ready to go
  - TDR incorporates leadership U.S. contributions to machine physics & technology
    - SRF, high power targetry (e+ source), beam delivery, damping rings, beam dynamics
- Important that there is an upgrade path of ILC to higher energy & luminosity (> 500 GeV, > 10^{34} cm^{-2}s^{-1})

We are experienced & ready to do it

Higgs factory: Alternate approaches

- Circular e+e- in very large tunnel (50 – 100 km)
  - Substantial extrapolation albeit from large experience base
    - LEP/LHC tunnel not preferred for physics & programmatic reasons
  - Energy reach & luminosity are very strongly coupled – details!
    - Very large luminosity at Z peak: falls rapidly as $\sqrt{s}$ increases
    - Tight linkage to 100 TeV proton collider opportunity
- Muon collider: Feasibility study is underway (see next slide)
  - Could provide options from Higgs to multi-TeV
- Gamma-gamma collider
  - Basis is US leadership in "industrial strength," high energy lasers
  - Can be ILC option or stand-alone facility
  - Laser technology overlap with laser wakefield accelerators

Caveat emptor: It is difficult to compare mature,
detailed engineering designs with parameter studies

Recommendations: Increase research effort toward a compact, muli-TeV lepton collider

- ❖ Vigorous, integrated R&D program toward demonstrating feasibility of a muon collider (Muon Accelerator Program)
  - ✧ Current support insufficient for timely progress
  - ✧ Closely connected with intensity frontier & intense neutrino sources
- ❖ Stay involved in high gradient, warm linac approach (CLIC)
  - ✧ Practical energy reach: wakefield control, accelerating gradient
  - ✧ Industrialization path to be developed
- ❖ Continue R&D in wakefield accelerators (plasmas & dielectric)
  - ✧ Fruitful physics programs with high intellectual content
  - ✧ Feasibility issues: Positron acceleration, multi-stage acceleration, control of beam quality, plasma instabilities at 10's of kHz rep rate
  - ✧ All variants require an integrated proof-of-principle test

Motivations: Lower cost, smaller footprint, higher energy

High intensity proton sources:
Neutrinos, muons, rare processes

Questions to address:

1. What secondary beams are needed for IF experiments?
2. What proton beams are needed to generate these?
    - ✧ > 1 MW , flexible timing structure
3. Can these be made by existing machines?
4. What new facilities are needed to deliver 1) ?
5. What accelerator / target R&D is needed to realize 4?

General comments & approach

- ❖ IF is more diverse in experiments than energy frontier
- ❖ We surveyed anticipated particle physics requirements for secondary beams, i.e. neutrino, kaon, muon, neutron, etc.?
  - ✧ 19 secondary beam requests filled out by experiment advocates
- ❖ We derived primary proton beam characteristics
- ❖ Common characteristics of required beams
  - ✧ High average power (> 1 MW)
  - ✧ Flexible time structure
- ❖ We compared these with existing proton beam characteristics
  - ✧ 20 existing proton beam-lines + 14 planned upgrades

The comparison leads to our primary finding

Overarching conclusion

Next generation of intensity frontier experiments will require proton beam intensities & timing structures beyond the capabilities of any existing accelerators

Project X: a world leading facility for Intensity Frontier research

- Based on a modern multi-MW SCRF proton linac
  - Flexible "on-demand" beam structure
- Could serve multiple experiments over broad energy range
  - 0.25 – 120 GeV
- Platform for future muon facilities (νFactory/muon collider)
- Complete, integrated concept Reference Design Report
  - arXiv:1306.5022
- R&D program underway to mitigate risks in Reference Design
  - Undertaken by 12 U.S. & 4 Indian laboratories and universities

Could initiate construction in the second half of this decade

Exciting possibilities for capabilities of narrower experimental scope

- DAEδALUS: Decay At Rest anti-neutrinos – experiments based on short baseline oscillations
  - Three Multi-MW H_2^+ cyclotrons & target stations located ~2-20km from experiment large hydrogenous detector
  - First stage: IsoDAR – compact cyclotron 15 m from Kamland
  - International collaboration with strong industry connection
- nuSTORM: Neutrinos from STORed Muons
  - Supports sterile neutrino & neutrino cross-section experimental program as well as muon accelerator R&D
  - Muon storage ring sends well-characterized beams to near & far detectors at 50 m & 1900 m
  - First step towards long baseline neutrino factory capability

Common IF issues of accelerator R&D

- High quality, high current injection systems
  - Low emittance, high current ion sources
  - Effective beam chopping
  - Space charge control
- SCRF acceleration (Project X, muons)
- Multi-MW cyclotrons DAEδALUS
- Radiation resistant magnets
- Very high efficiency extraction
- &

Understanding & controlling beam loss

Efficient collimation

Beam dynamics simulations of halo generation

Large-dynamic-range instrumentation

High power targets are a hard problem
that limits facility performance

- ❖ Displacements & gas production are the main underlying damage mechanisms
  - ✧ Particulars depend on primary beam characteristics, material, …
  - ✧ Can not simply scale from nuclear power experience
- ❖ Targets are difficult to simulate
  - ✧ Radiation effects need validating (inhomogeneous, time-varying)
  - ✧ Thermo-mechanical models complex
  - ✧ Ill defined failure criteria (classical limits may be too conservative)
- ❖ Need controlled, instrumented in-beam tests
- ❖ Need a source before you can test materials
  - ✧ Takes a long time to build up data (accelerated testing)

Requires a structured R&D program for accelerator-based science

(International RADIATE collaboration has formed)

High Intensity Electron & Photon Beams
Questions to address

- ❖ What additional accelerator capabilities at heavy flavor factories are required to realize the full range of physics opportunities?
- ❖ What new or existing accelerator-based facilities provide opportunities for dark sector / axion searches ?
- ❖ What are new physics opportunities using high power electron and photon physics?
- ❖ What accelerator and laser R&D is required to realize the physics opportunities in these areas?

Additional accelerator capabilities are desired for heavy flavor factories

- Super B-Factory (SuperKEKB):
  - U.S. labs & universities have made important contributions to design
    - Participation in commissioning & machine studies desirable
  - Luminosity upgrades (refine physics case)
  - Polarized beams (refine physics case)
    - Technical feasibility
- Tau-charm Factory beyond BEPC-II
  - What kind of facility would be interesting? (refine physics case)
    - What luminosity is needed? Is polarization necessary?

Factory machines require BOTH high intensity & low emittance beams.

Many areas of overlap with LC damping ring & light source R&D efforts

History of fruitful international collaborations/cooperation

Accelerator-based FEL facilities provide HEP opportunities

- "Flashlight through a wall" experiments using high-intensity photon beams in strong magnetic fields
  - JLab/MIT: Dark Light axion search
    - 1 ab^{-1} in one month of running
- Search parameters are unconstrained
  - Use existing facilities
- keV level searches could use X-ray FELs
- More speculative idea (non-FEL)
  - Generating low emittance muon beams from intense positron beams

e^+e^- IF accelerator improvement exploits strong synergy with light sources

- Beam stability & control
  - Examples: Electron cloud & fast ion instabilities
- Coherent Synchrotron Radiation issues with short bunches
- High-rate injection
  - High top-up rate to compensate for low lifetimes
  - Timing jitter, and attendant energy jitter
- Low-emittance beam issues
- Beam instrumentation

Opportunity for fruitful collaboration across a broad accelerator community

Accelerator technology test beds

Charge:

- ❖ Identify broad range of test capabilities existing or needed
  - ✧ Category 1: Provides testing beam physics / accelerator components to manage technical risks in planned projects
  - ✧ Category 2: Integrates proof-of-practicality tests
  - ✧ Category 3: Provides tests of physics feasibility of concepts / components
- ❖ 35 existing facilities were identified
  - ✧ Beam / no-beam
  - ✧ US & overseas

Hadron colliders:
LHC-Lumi & Energy upgrades, VLHC

Technical challenges	Capabilities (existing / planned)
• High performance SC wire	Critical industry couplings
• High Field SC magnets	LBNL, FNAL, BNL, CERN
• SR & photon-stops	Existing e-rings
• Collimation	LHC, RHIC, Main Inj.
• Injectors – SCRF	PXIE (FNAL), SNS(limited)
• Injectors – Space charge	Booster, AGS, PS, ASTA
• Beam cooling (optical, coherent)	ASTA (FNAL), RHIC cool

Injector studies need new, dedicated facilities

Lepton colliders:
ILC and beyond

Risk reduction areas	Capabilities (existing / planned)
• ILC: SRF-system no beam	JLab, Cornell, Industry
/with beam	/ DESY, KEK, ASTA,
• ILC: FF, Damping rings, e+ production	KEK, Cornell, LLNL

Practicality / feasibility tests	Capabilities (existing / planned)
• CLIC NCRF two-beam	CERN
• Muon Colliders – technical components	MuCool-TA (FNAL)
– 4D / 6D ionization cooling	MICE @ RAL / nuSTORM
• Wakefield accelerators	
– acceleration demo / staging	SLAC, LBNL, ANL/ upgrades
– luminosity / beam control	Needs integrated testbed

Energy reach beyond ILC will need new test capabilities

Intensity frontier accelerators :
Includes Project X, DAEdALUS, Neutrino Factory

Challenges	Facilities (existing / planned)
• Pr X – H^- source & chopping	PXIE, SNS
– CW SC RF low-beta	PXIE, Atlas (ANL)
– pulsed SC RF, space charge	ASTA (FNAL)
• DAEdALUS – H_2^+ source	LNS Catania
– Multi-MW cyclotrons	PSI, RIKEN, ORNL, Best
• Neutrino factory	see Muon Collider
• Instabilities, collimation, extraction	FNAL, RHIC
• Dedicated high power targetry	Critical need

A new generation of IF machines needs new test facilities

Flavor factories & Electron-ion colliders

Challenges	Facilities (existing / planned)
• Beam Instabilities, IR optics	Existing rings
• IP designs, collimation	BNL, CERN
• Non standard Beam-beam	Needed
• Intense polarized. e- source	JLab, BNL, Cornell
• CW SRF (ß=1)	CERN, Cornell, JLab, BNL, KEK
• Heavy ion sources	MSU, LBNL

Good test facility basis for technical design of HEP machine

We are ready to move forward with the highest priority accelerators for high energy physics

The long term future of HEP facilities will need dedicated test capabilities in the near term

Thank you