Jet substructure for Snowmass 2021

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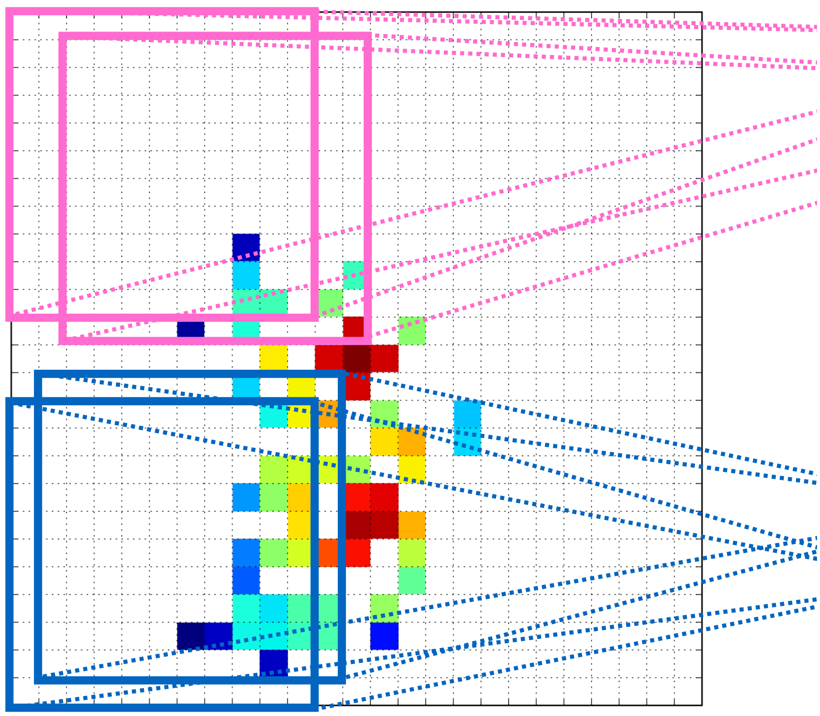

BERKELEY LAB

EF05 Snowmass meeting

September 20, 2020

Jets and Jet Substructure at Future Colliders

Letter of Interest for Snowmass 2021

The BOOST community[1]

Jet substructure (JSS) has emerged as a powerful framework for studying the Standard Model (SM) and provides a key set of tools for probing nature at the highest energy scales accessible by terrestrial experiments [1-6]. While not an experimental or theoretical consideration of the design of original LHC experiments, JSS is now being widely used ***to extend the sensitivity of searches*** for new particles, to ***enhance the precision of measurements*** of highly-Lorentz-boosted SM particles, as well as ***to probe the fundamental and emergent properties*** of the strong force in new ways. Along the way, the JSS community has been a catalyst for new detector concepts, new analysis tools (e.g., deep learning), new theory techniques, and more. Jet substructure has been transformative for the physics program of the LHC[2] and it can play a central role in the physics case for future colliders.

The goal of this document is to describe new physics that could be done with JSS at future colliders[3] and what experimental and theoretical considerations are required to empower this physics program. The focus will be on qualitatively new capabilities and most strongly aligns with the ***Precision QCD*** [EF05] *and* ***BSM Physics*** [EF08, EF09, EF10] topical groups of the ***Energy Frontier***, but will have strong connections to other efforts in QCD and strong interactions (Hadronic Structure [EF06], Heavy Ions [EF07], 3rd generation quarks [EF03]) as well as in EW Physics. Furthermore, JSS tools are intimately connected with efforts in the Theory Frontier (e.g. EFT, Collider phenomenology), the Instrumentation Frontier (e.g. Solid State Detectors, Trigger, Calorimetry), Computational Frontier (e.g. Algorithms, Theory, Machine Learning, User Analysis, Quantum Computing), and Community Engagement.

This contribution has emerged from within the BOOST community. BOOST is a joint theory-experiment workshop that has been held annually since 2009. The 2020 iteration of the workshop included a discussion about future colliders and we have taken this opportunity to organize an effort to contribute to Snowmass 2021 with the goal of

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[1] See the last page for the complete list. Contact: bpnachman@lbl.gov.
[2] See reviews cited above. Concrete experimental examples include [7-12]. These papers are meant to be representative, but do not reflect the breadth and depth of studies conducted by ATLAS, CMS, and ALICE.
[3] Beyond the LHC, such as a Higgs factory or a high-energy proton-proton/electron-positron collider, and including the EIC.

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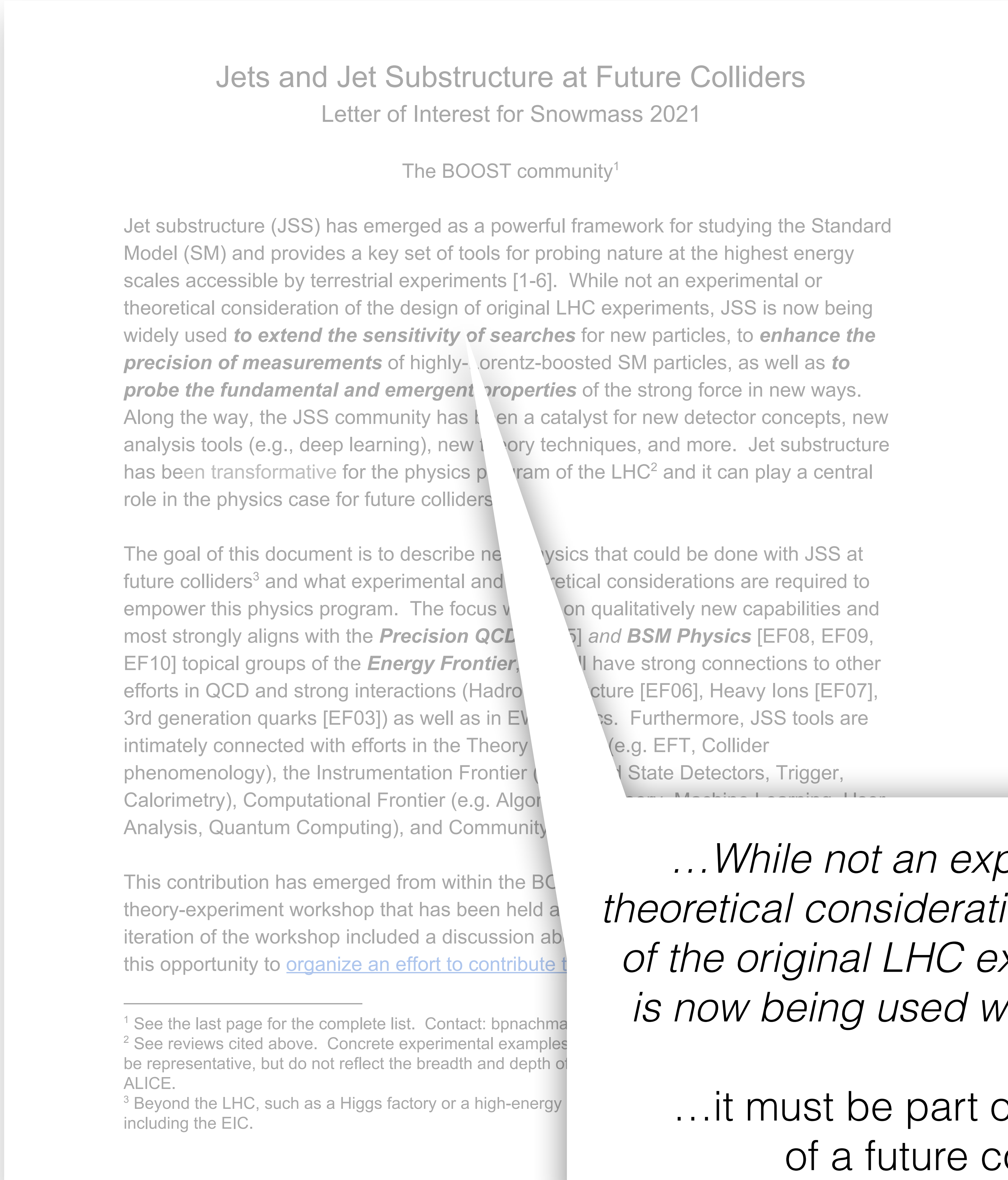

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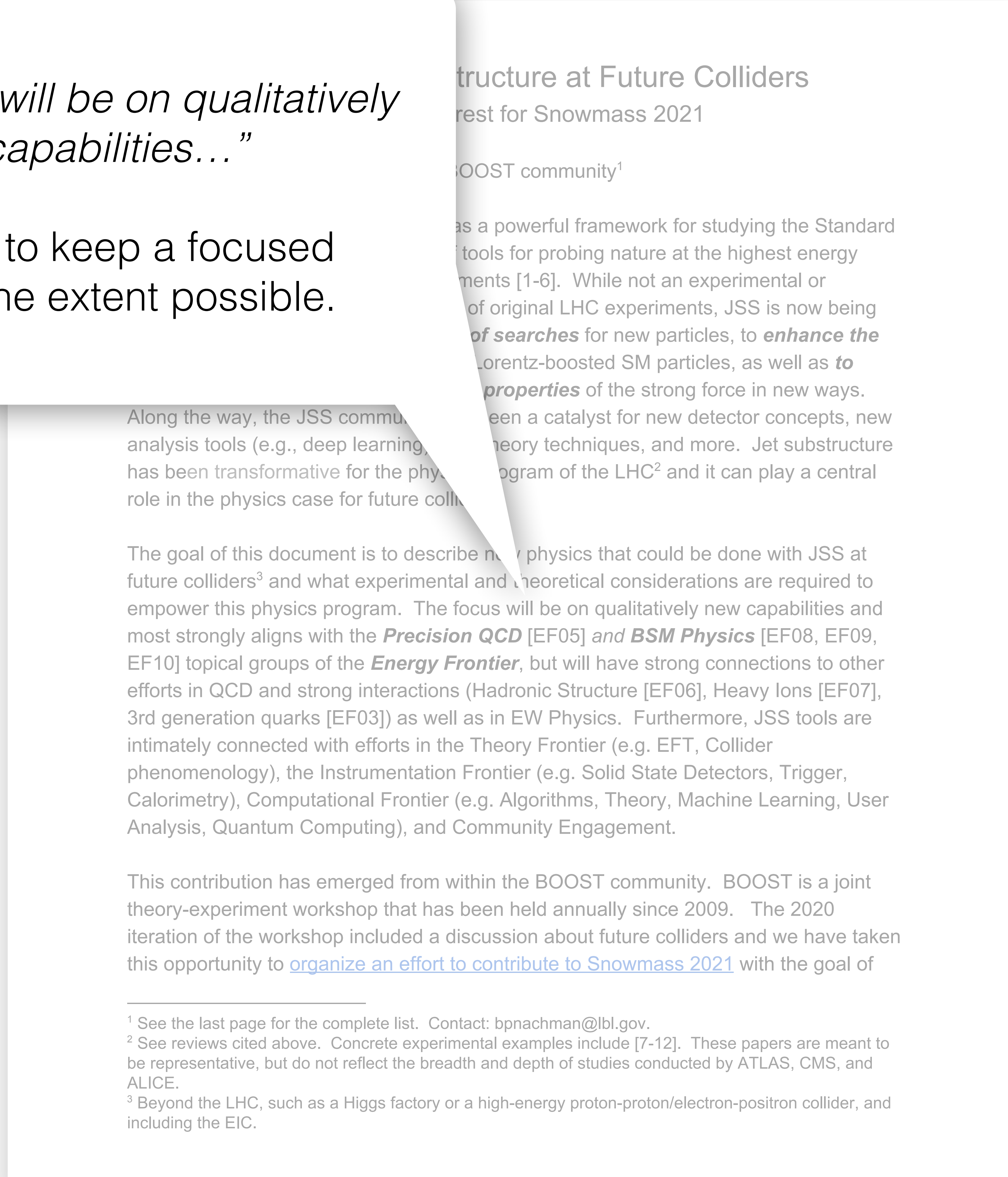

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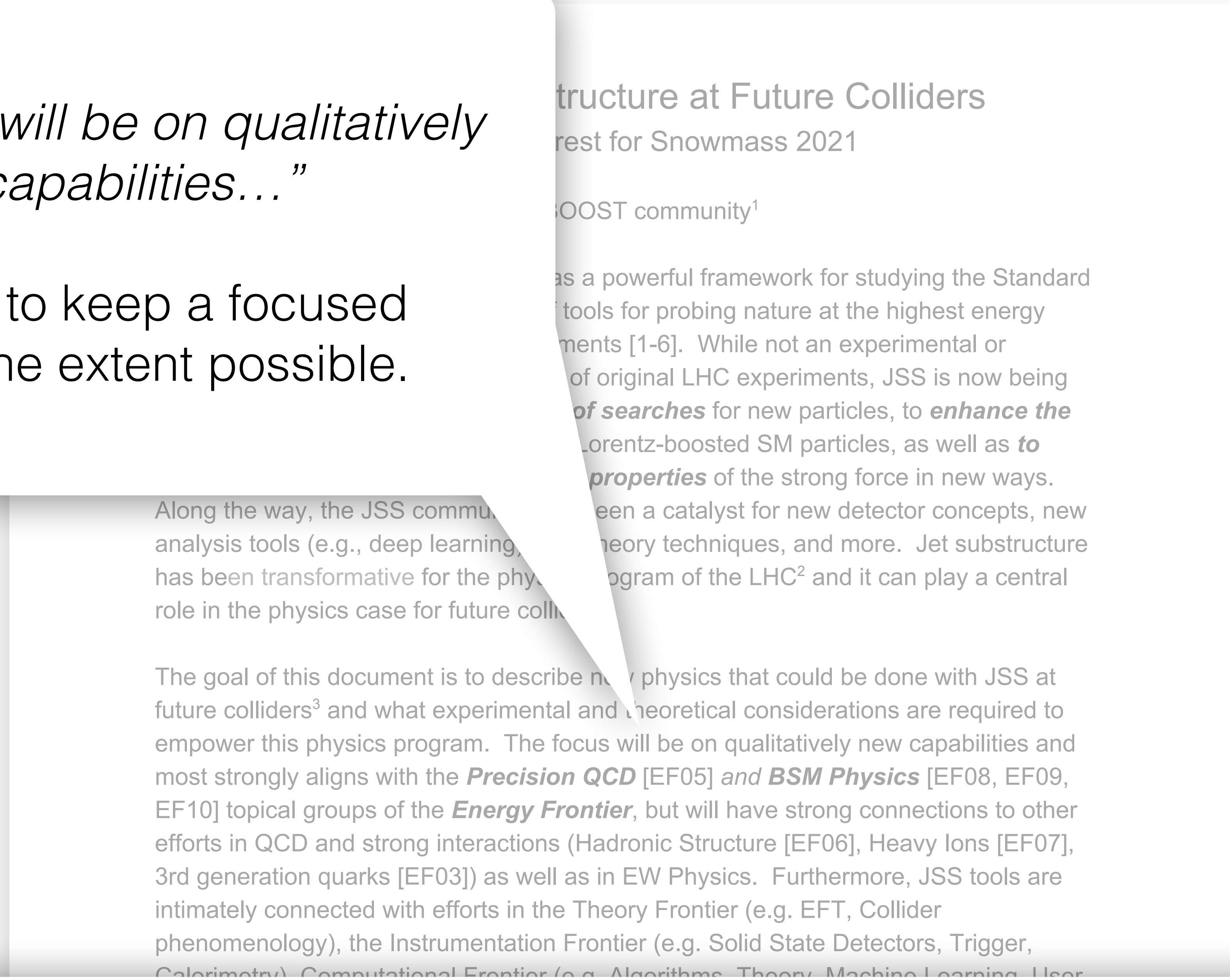
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Our ultimate goals are to influence the decision on the choice of the next energy frontier machine, influence the decision of the detectors (and other expensive resources like trigger/computing) at said machine and the EIC, and to make a case for funding research / training programs in jet substructure (P5 driver?).

delivering a white paper to be completed on the timescale of BOOST 2021 (in time for the community workshop at the University of Washington).

This Letter of Interest aims to outline the multiple avenues of research that the authors believe will be important in the context of Snowmass 2021. As introduced above, we believe that numerous topics of relevance for the Snowmass process should be discussed and evaluated with explicit considerations of the impacts for and benefits from JSS theory, phenomenology, and experimental tools (both hardware and software). These topics include, but are not limited to:

1. Theoretical innovation to enable new approaches, including advances in fixed order, resummation, and non-perturbative corrections
    a. (Beyond the) Standard model parameters (α_s (including running), m_{top}, EFTs, Higgs self coupling, etc.)
    b. Unique tests of fundamental physics, including unique probes of high energy / collective behavior of the strong force
    c. General-purpose Monte Carlo generator development and tuning
2. Experimental innovation to enable new approaches
    a. Detector optimization (e.g. calorimeter granularity [13,14])
    b. Low-level calibration and systematic uncertainties
    c. Reconstruction algorithms (online (trigger), clustering algorithms, etc.)
3. Enhancing sensitivity
    a. Uncovered scenarios (long lived particles, complex dark sectors)
    b. New observables (including track-based observables)
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    Among other things, this will be a test bed for new and creative ideas in theory and analysis.

It is also critical to examine what experimental and theoretical studies we should do still at the LHC that will inform work at future colliders. Furthermore, we will consider how lessons learned at the LHC can be adapted to future, potentially non-hadron, colliders.

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J. Dolen, Purdue University Northwest
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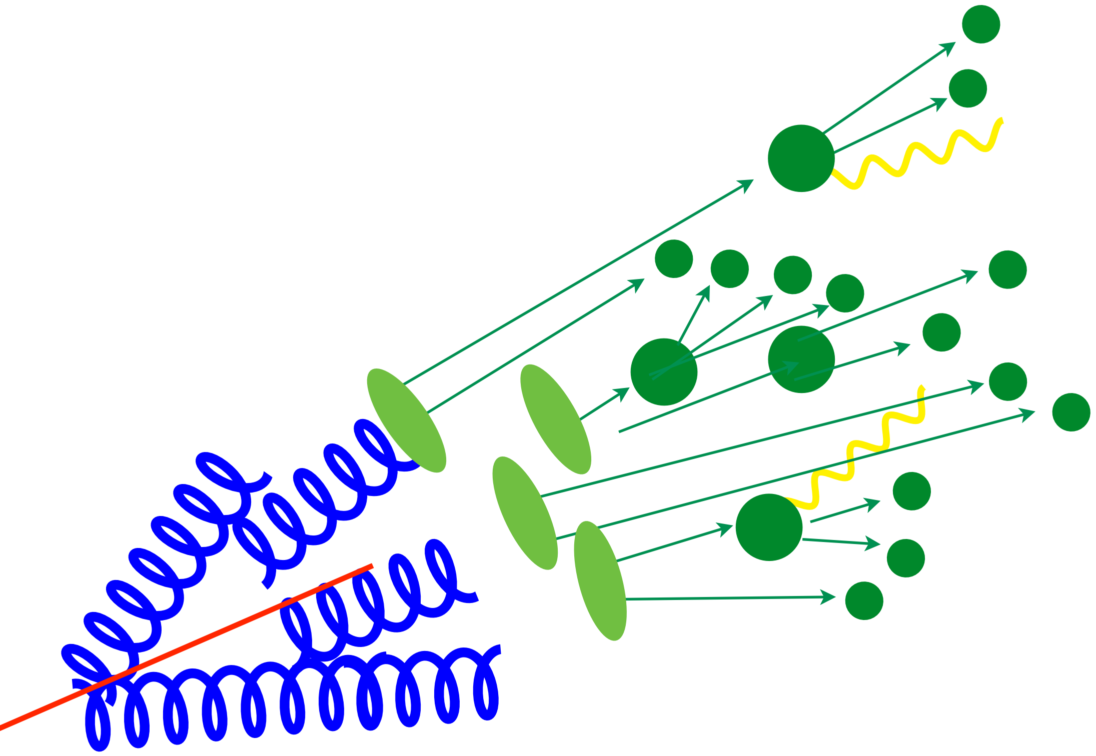

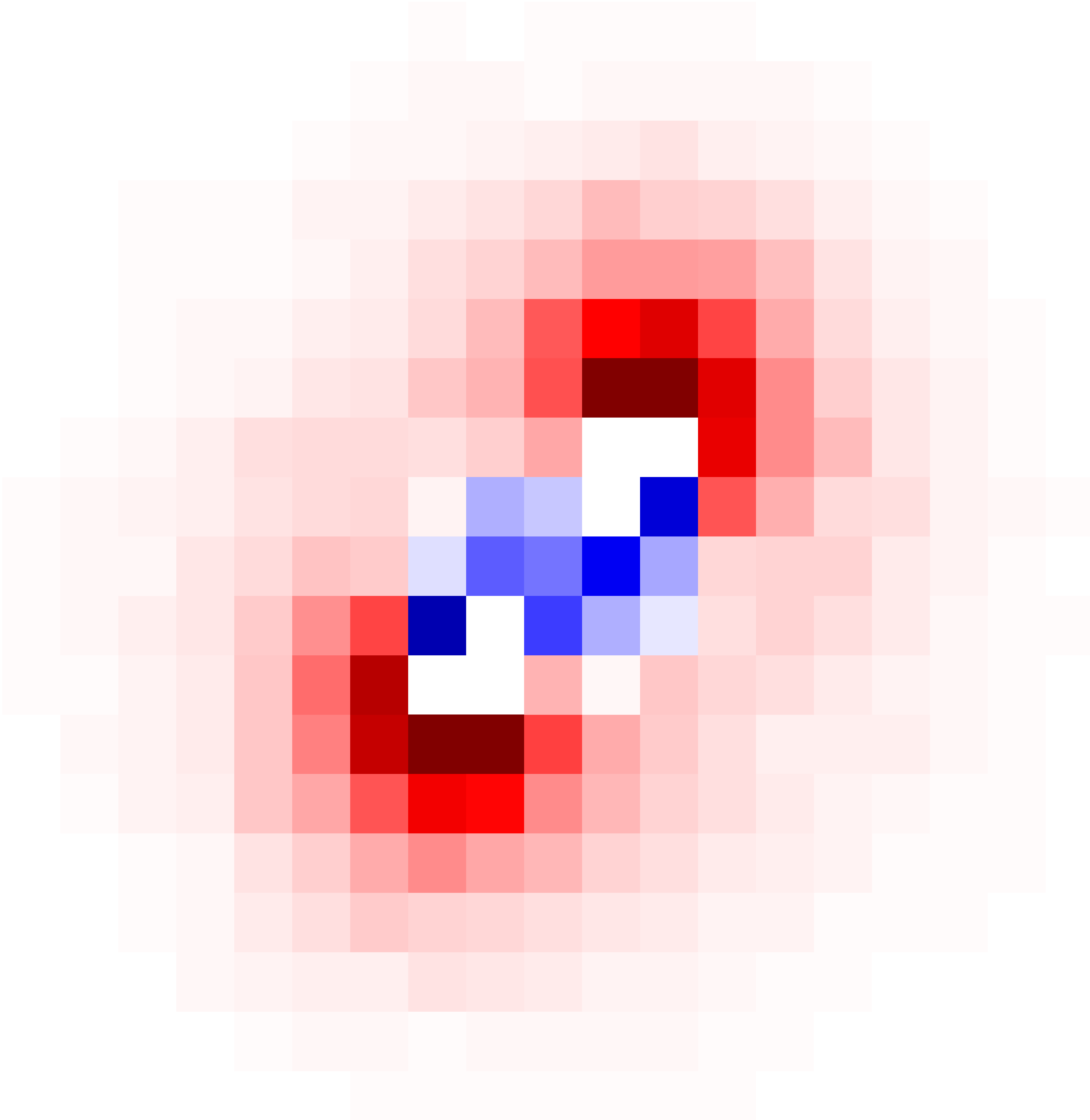

Fin.