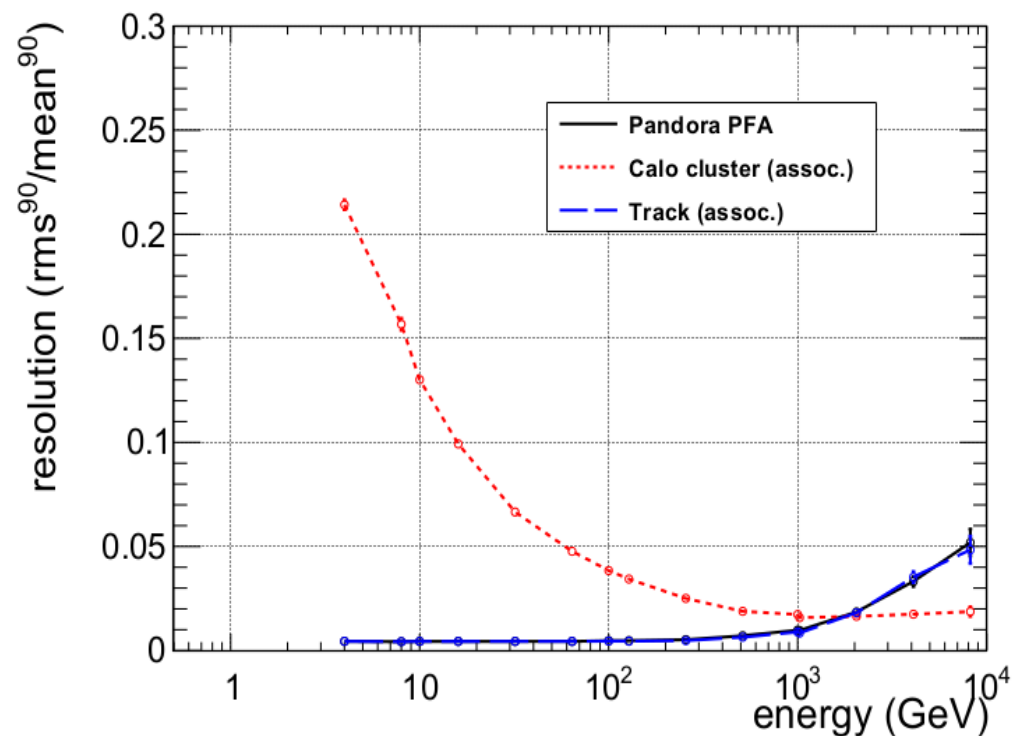
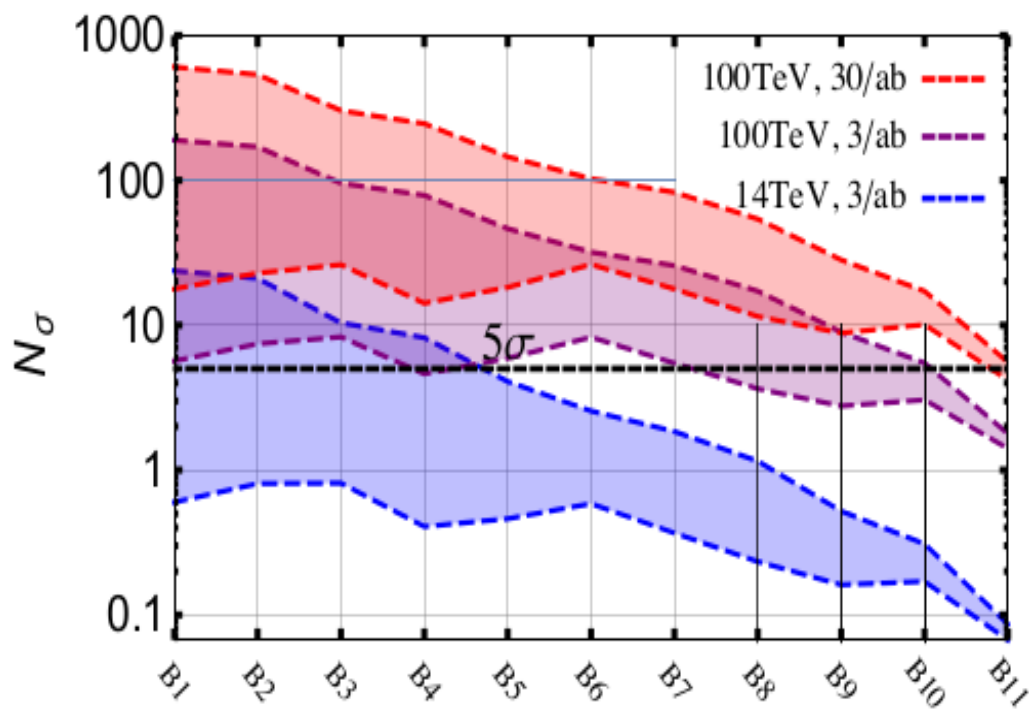


Summary of US Physics and Detector Studies and Plans

Ashutosh Kotwal
Duke University / Fermilab



Outline of Activities

- Increase the engagement from the US HEP Community for physics case studies and detector concept studies for a 100 TeV pp collider
- Workshops
- Biweekly Seminar Series
- Publication of physics sensitivity studies
- GEANT simulation of detector concepts (see talk by S. Chekanov)
- Minimum time integration calorimetry (see talk by D. Denisov)
- Tracking detectors for muon systems

Workshops

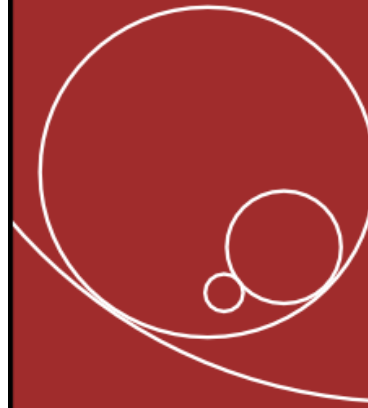
- Snowmass 2013 triggered the discussion of a 100 TeV – scale pp collider following the HL-LHC
- Workshop on Physics at a 100 TeV collider (April 23-25, 2014) at SLAC
 - <http://www.slac.stanford.edu/th/100TeV.html>
- Next steps in the Energy Frontier – Hadron Colliders, Workshop at LPC@FNAL (August 25-28, 2014)
 - <https://indico.fnal.gov/conferenceOtherViews.py?view=standard&confId=7864>

Workshops

- Probing the Electroweak Phase Transition with the Next Generation pp Collider (September 17-19, 2015) at University of Massachusetts, Amherst
 - <https://www.physics.umass.edu/acfi/seminars-and-workshops/probing-the-electroweak-phase-transition-with-a-next-generation-pp-collider>
- Dark Matter at a Future Hadron Collider (December 4-6, 2015) at Fermilab
 - <https://indico.cern.ch/event/445743/>
- New Accelerators for the 21st Century (May 31 – June 10, 2015) at KITP Santa Barbara
 - <https://www.kitp.ucsb.edu/activities/accelerators-m16>

Workshop on Physics at a 100 TeV Collider

April 23-25, 2014, SLAC



Workshop Topics
PDFs and Generators
Detector Challenges
SM at 100 TeV
Physics Reach
BSM Spectroscopy

Organizing Committee
Timothy Cohen (SLAC)
Mike Hance (LBNL)
Jay Wacker (SLAC)
Michael Peskin (SLAC)
Nima Arkani-Hamed (IAS)

www.slac.stanford.edu/th/100TeV.html

Next steps in the Energy Frontier - Hadron Colliders, Workshop at LPC@FNAL

chaired by Sanjay Padhi (University of California, San Diego), Richard Cavanaugh (Fermilab and University of Illinois Chicago), Meenakshi Narain (Brown University), Boaz Klima (Fermilab)

from Monday, August 25, 2014 at **08:00** to Thursday, August 28, 2014 at **18:00** (US/Central)
at **FNAL (WH One West)**

Hosted by LHC Physics Center (LPC) at FNAL



AMHERST CENTER FOR FUNDAMENTAL INTERACTIONS

Physics at the interface: Energy, Intensity, and Cosmic frontiers

University of Massachusetts Amherst

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Probing the Electroweak Phase Transition with a Next Generation PP Collider

Co-organizers:

Andrey Katz (U. Geneva & CERN)

Ashutosh Kotwal (FNAL & Duke U.)

Tao Liu (Hong Kong U. Science & Technology)

Michelangelo Mangano (CERN)

Michael Ramsey-Musolf (U. Mass. Amherst)

Shufang Su (U. Arizona)

Dark Matter at a future hadron collider

4-6 December 2015
FERMILAB

Mangano, Michelangelo
Kotwal, Ashutosh
Ramsey-Musolf, Michael
Su, Shufang
Schwaller, Pedro Klaus
Liu, Tao
Cavanaugh, Rick
Katz, Andrey

Upcoming Workshops



Kavli Institute for
Theoretical Physics
University of California, Santa Barbara

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[FOR VISITORS](#) ▾

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New Accelerators for the 21st Century

Coordinators: Nima Arkani-Hamed, Nathaniel Craig, David Gross, Joe Incandela, Michelangelo Mangano, and Liantao Wang

Further theme workshops on specialized topics being considered:

- Naturalness (e.g., top partners)
- BSM Higgs (Conventional channels, exotic decays...)
- Exotics/Rare processes (Lepton number & flavor violation, CPV, hidden sector...)
- New resonances (Z' , KK...)
- Standard Model Topics (Jets, PDFs,)

Physics Case Investigations

- Strategy:

- Should be useful contributions to FCC-hh physics report
- Physics case studies should be published in refereed journals (to incentivize young people to participate)

- Resources:

- Full analysis chain available for MADGRAPH + PYTHIA showering → Ntuples → repository → C++ analysis code
- Simple detector performance assumptions (ATLAS/CMS)
- Argonne HEP analysis cluster for CPU and Ntuple storage
- Quick ramp-up for anyone to pursue any model and channel of interest
- recruiting experimentalists with analysis experience
 - “how to convert ATLAS / CMS analysis into future collider study”
 - Additional paper and visibility with 10% more work !
- Plan to include DELPHES detector cards from FCC benchmark detector

Physics Case Studies

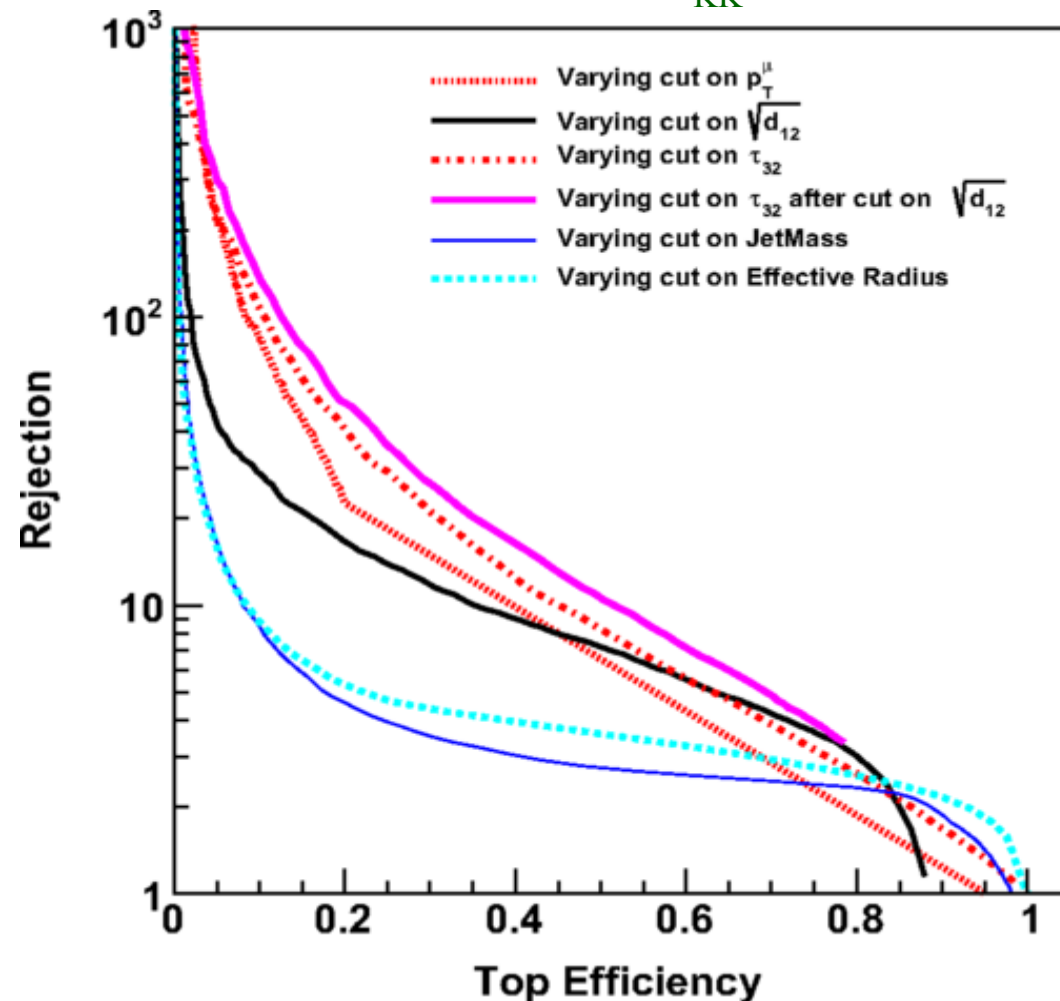
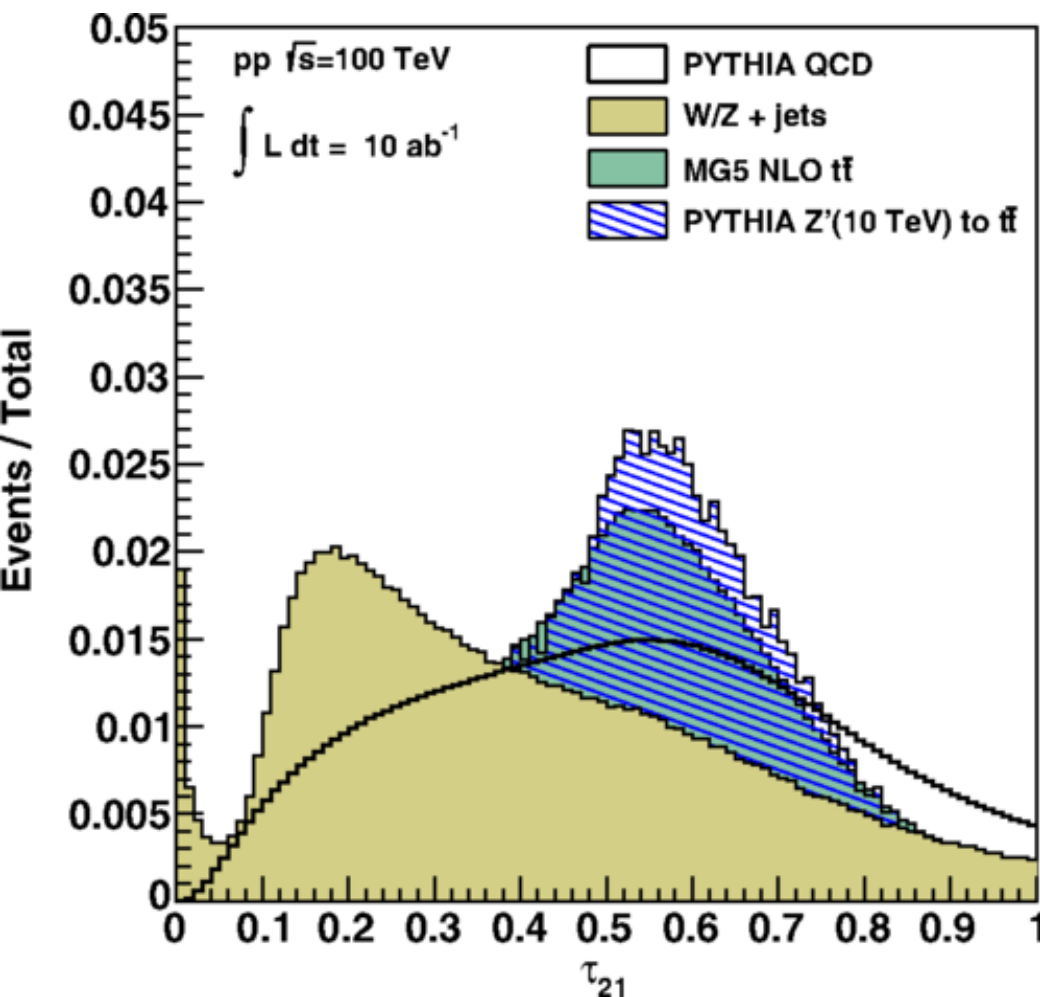
- Forming collaborations between theorists and experimentalists to publish studies of interesting channels
 - Electroweakino dark matter (Ismail Ahmed, AVK) – in preparation
 - 1st order phase transition via additional scalar (P. Winslow, J. M. No, M. Ramsey-Musolf, AVK) – in preparation
 - $T\bar{t}$ resonances and highly boosted tops with substructure (S. Chekanov, J. Love, J. Proudfoot, AVK) – PRD published
 - Vector boson scattering (AVK, S. Chekanov, M. Low) – PRD published
 - more papers in nascent stages
- Biweekly Seminar + Brainstorming Session Thursday 1 PM CST via ReadyTalk/Indico on topic relevant for FCC-hh
 - Announcement on Fermilab Today / Labwide Calendar & future collider mailing list
 - VLHCPHYSICS@fnal.gov (or email me at kotwal@fnal.gov)
 - FCC announcements also forwarded to this mailing list

Granularity Requirements for Boosted Top Quarks

Sensitivity to new high-mass states decaying to $t\bar{t}$ at a 100 TeV collider

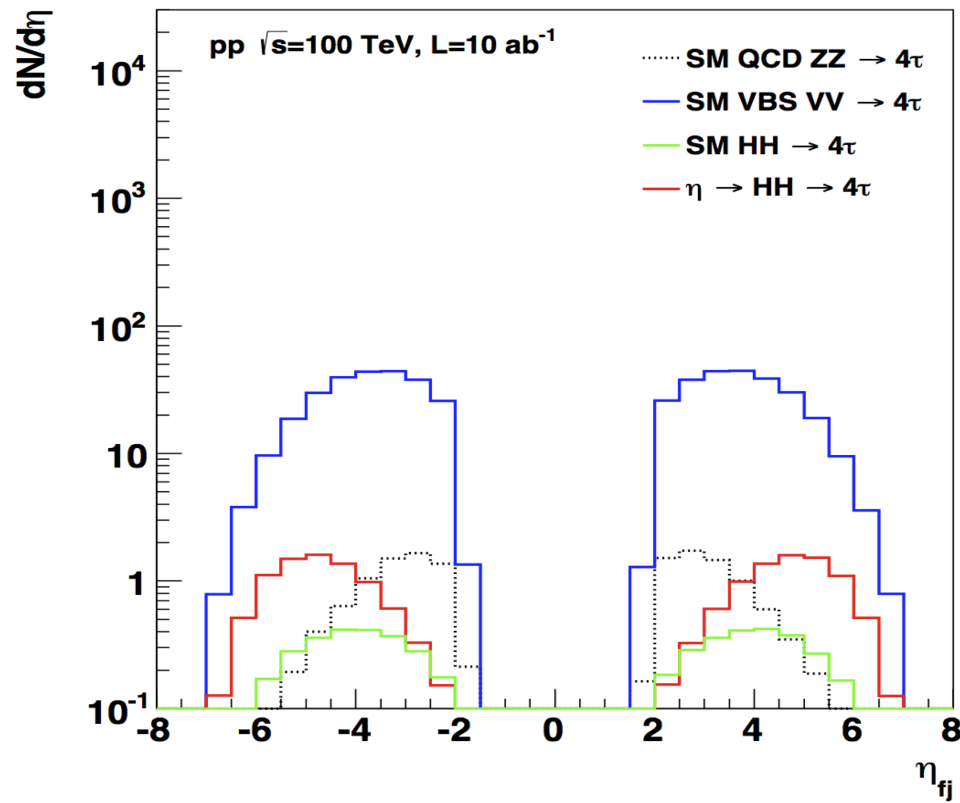
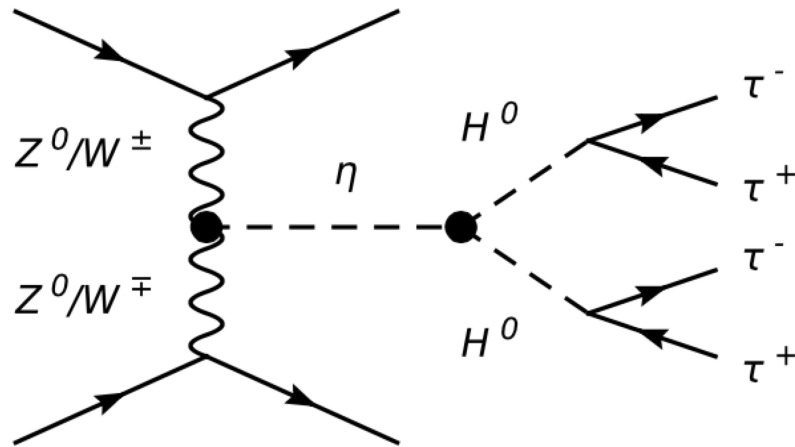
B. Auerbach, S. Chekanov, J. Love, J. Proudfoot, and A. V. Kotwal
Phys. Rev. D **91**, 034014 – Published 17 February 2015

Sensitivity up to 13 TeV (Z') and 20 TeV (g_{KK})



Vector Boson Scattering

(AVK, Chekanov, Low)
(PRD 91 (2015) 114018)



Forward Jet Coverage for Longitudinal VBS

$$V_L V_L \rightarrow \eta \rightarrow HH$$

M. Low, S. Chekanov, AVK

TABLE II. 5σ discovery mass reach for the $\eta \rightarrow HH \rightarrow 4\tau$ resonance, at a pp collider with $\sqrt{s} = 100$ TeV and $\mathcal{L} = 10 \text{ ab}^{-1}$, for various cuts values on minimum p_T of the forward jets. The fractional width of the η resonance is set to $\Gamma/M = 20\%$.

p_T^{\min} (GeV)	30	50	70	90	110
m_η (TeV)	3.53	2.90	2.35	1.92	1.56

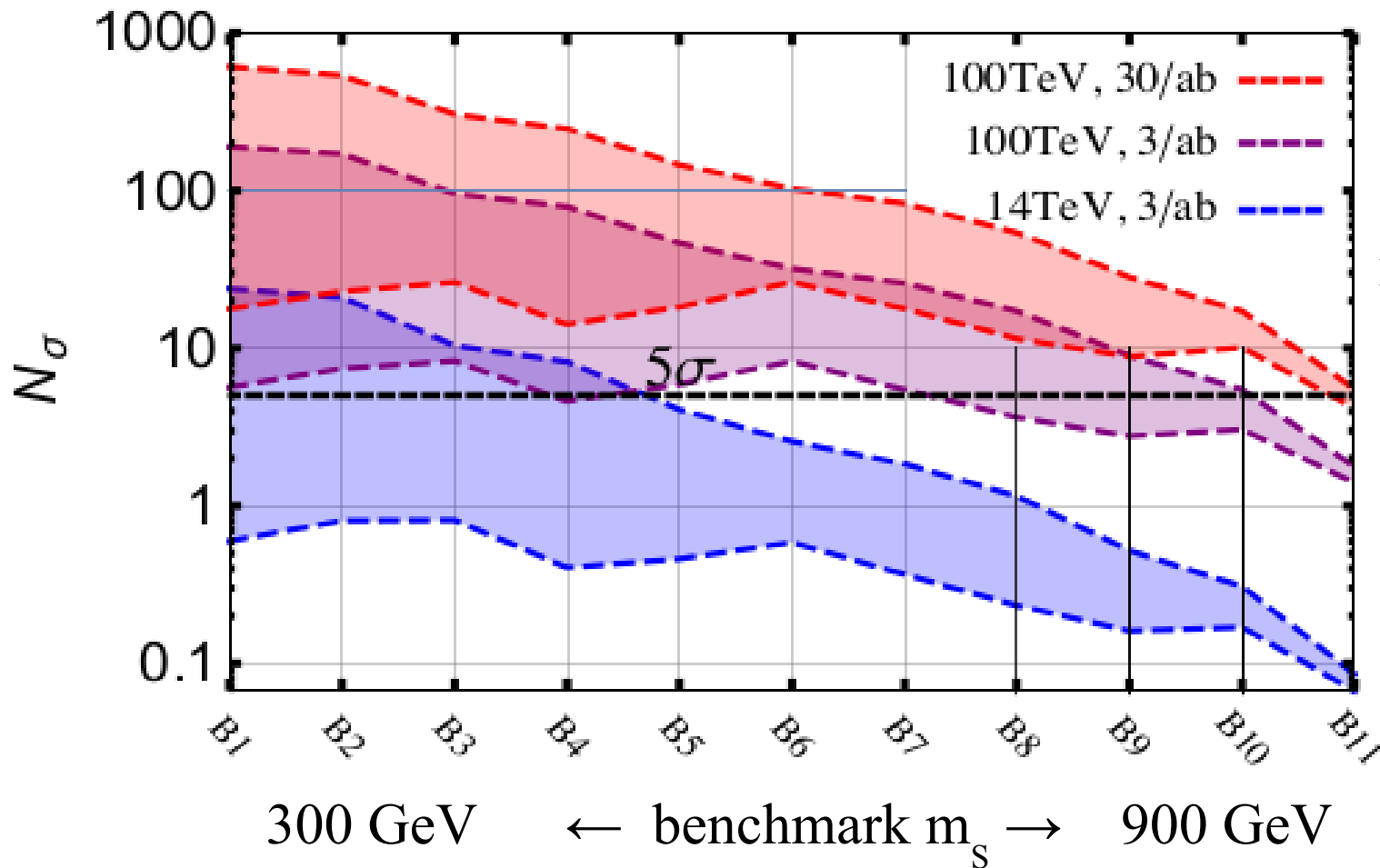
TABLE III. 5σ discovery mass reach for the $\eta \rightarrow HH \rightarrow 4\tau$ resonance, at a pp collider with $\sqrt{s} = 100$ TeV and $\mathcal{L} = 10 \text{ ab}^{-1}$, for various cuts values on the maximum rapidity (y) of the forward jets. The fractional width of the η resonance is set to $\Gamma/M = 20\%$.

y^{\max}	8	7	6	5	4
m_η (TeV)	2.9	2.9	2.81	2.42	1.75

Inducing First-Order Electroweak Phase Transition

$$V(H, S) = -\mu^2 (H^\dagger H) + \lambda (H^\dagger H)^2 + \frac{a_1}{2} (H^\dagger H) S + \frac{a_2}{2} (H^\dagger H) S^2 + \frac{b_2}{2} S^2 + \frac{b_3}{3} S^3 + \frac{b_4}{4} S^4$$

$S \rightarrow HH \rightarrow \gamma\gamma bb$ and 4τ



(P. Winslow, J.M. No, M.J. Ramsey-Musolf, AVK)

GEANT Simulations

- Strategy:
 - Focus on high-granularity calorimeters
 - Resolve highly-boosted vector and Higgs bosons, top quarks, τ -leptons
 - 5 TeV resonance \rightarrow HH \rightarrow 4 τ produces 1 TeV τ^2 lepton
 - photons within τ -jet are separated by ~ 3 mm
 - τ -leptons from Higgs separated by ~ 10 cm
 - 20 TeV resonance \rightarrow $t\bar{t}$, top decay products separated by ~ 3 cm

Geant4 simulation of a high-granular calorimeter for TeV-scale boosted particle

S. Chekanov
HEP/ANL

FCC Week. April 11-15, 2016
Rome, Italy

With contributions from:

A.Kotwal (Fermilab/Duke), L.Gray (Fermilab), J.Strube (PNNL), N.Tran (Fermilab), S. Yu (NCU), S.Sen (Duke), J.Repond (ANL), J.McCormick (SLAC), J.Proudfoot (ANL), A.M.Henriques Correia (CERN), C.Solans (CERN), C.Helsens (CERN)

GEANT Simulation of Silicon/Tungsten EM Calorimeter

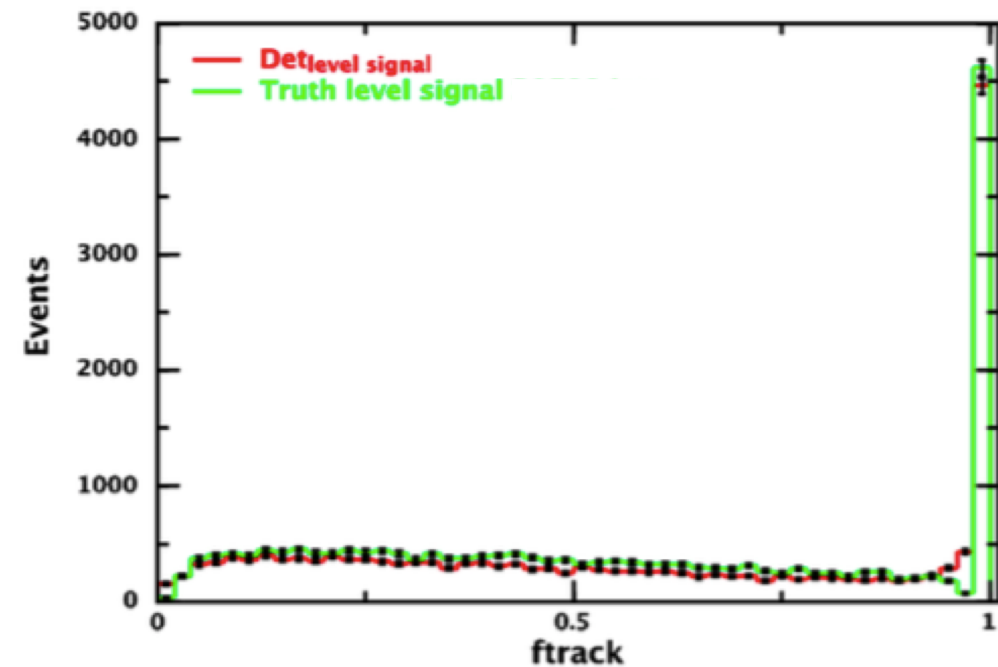
500 GeV hadronic τ -lepton decays with 4mm x 4mm silicon pads

Background simulation in progress, will investigate larger pad sizes and higher p_T

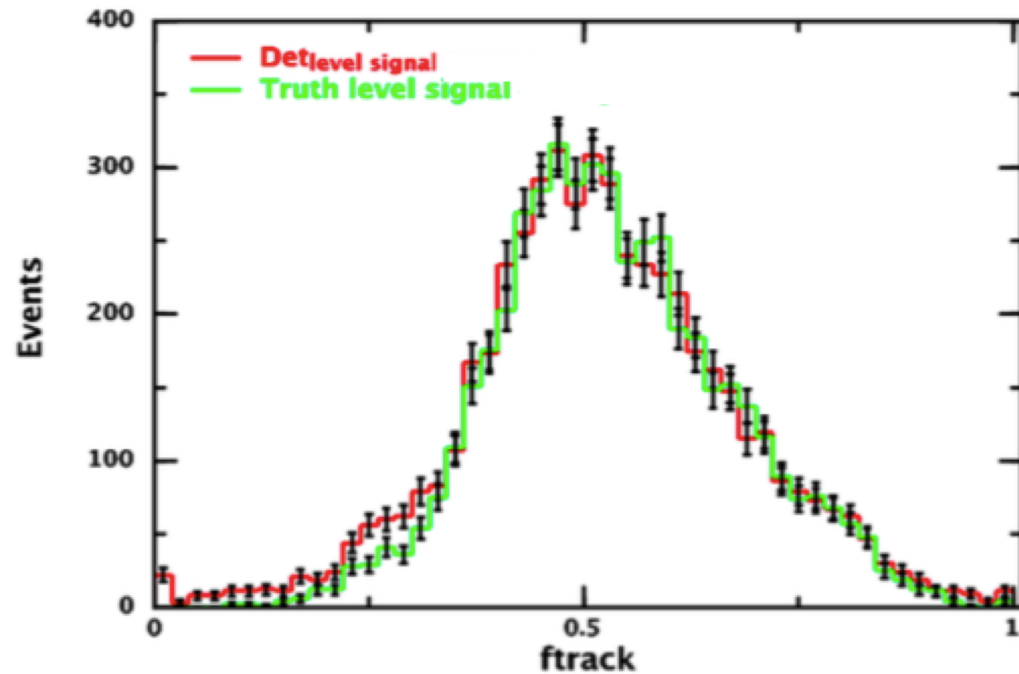
f_{track} (leading track momentum fraction)

$= (\text{pT of highest pT track in core region } (\Delta R < \text{core})) / (\text{Total } E_T \text{ deposited in } \Delta R < \text{core})$

core = 0.1



1 prong



3 prong

Summary

- Started a number of activities in US to contribute to FCC-hh
 - Sensitivity studies of physics channels
 - Investigation of detector concepts
 - Workshops and seminar series to increase awareness and intellectual involvement
- Creating opportunities for more colleagues from US to participate
 - eg. opportunities for undergraduate research at universities
- New ideas welcome