CERN Japan Fellow
Second Report
Dec. 2018 - Nov. 2019

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Quick recap

- Fellowship: September 2018 - August 2020
- Second postdoctoral job
  - Ph.D. Carnegie Mellon University, 2015 → CMS experiment
  - First postdoc at MIT, 2015-2018 → CMS experiment
- Had planned to join ATLAS as a CERN fellow, but decided to continue on CMS to maximize output
- Interests
  - Exploration of exotic properties of the Higgs boson
  - Physics analyses with photons in the final state
  - Software and computing technologies for HEP

Projects

- Planned at the start of the year
  - Measurement of the differential production cross section of the Higgs boson in the WW decay channel
  - Search for an exotic decay of the Higgs boson into a photon and a dark photon
  - CMS Phase-II endcap calorimeter (HGCal) trigger development
  - Study of deep learning application to complex calorimetry
- New involvements
  - Measurement of electroweak-exclusive single photon production ($qq\gamma$) cross section
  - Subconvenership at the SUSY Photons group

H→WW differential cross section

- Indirect probe of non-SM Higgs couplings
  - Was an uncovered topic with straightforward prospect
  - Good opportunity to absorb know-how in SM Higgs analyses
- Original plan: have a preliminary result for Moriond (March) with 2016 + 2017 data, publication with full Run 2 data in summer
- Problem in background estimation method found in February
  - Method revision required 4 months of work
  - Meanwhile, decided to include 2018 data already for preliminary result
- Presented at Higgs Couplings 2019 (September)
- Now working on the paper manuscript
  - Expected to be the first full Run 2 Higgs paper from CMS

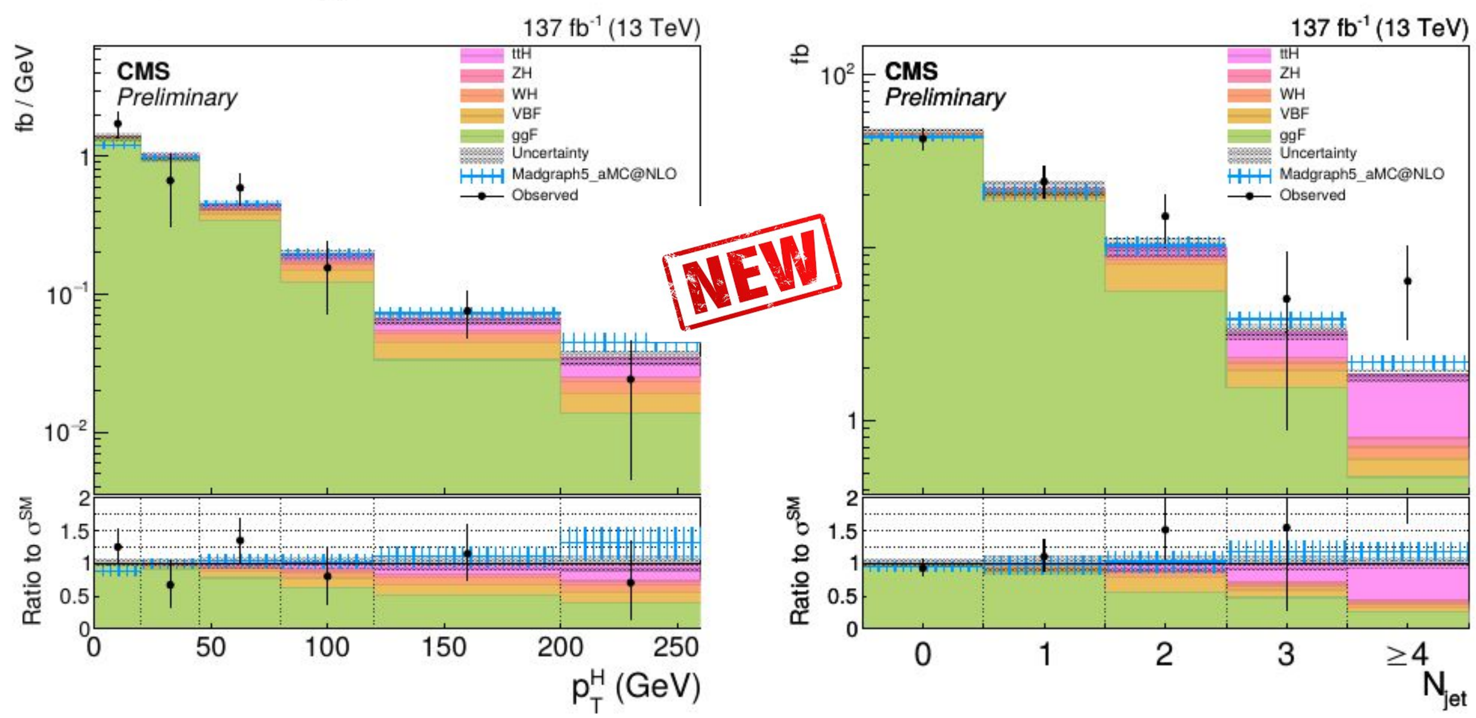
H→WW differential cross section

Full run 2 H ⟶ WW Differential analysis

Fiducial and differential cross sections with 137/fb in H ⟶ WW

$$\mu^{\text{fid}} = 1.03^{+0.12}_{-0.11} \; \left(^{+0.05}_{-0.05}\,(\text{stat.})\; ^{+0.08}_{-0.07}\,(\text{theo.})\; ^{+0.03}_{-0.03}\,(\text{lumi.})\; ^{+0.07}_{-0.07}\,(\text{exp.})\right)$$

$$\sigma^{\text{fid}} = 85.0^{+9.9}_{-9.3}\,\text{fb}.$$



Uncertainties of the same order as di-photon analyses in #jets and similar in high ptH.

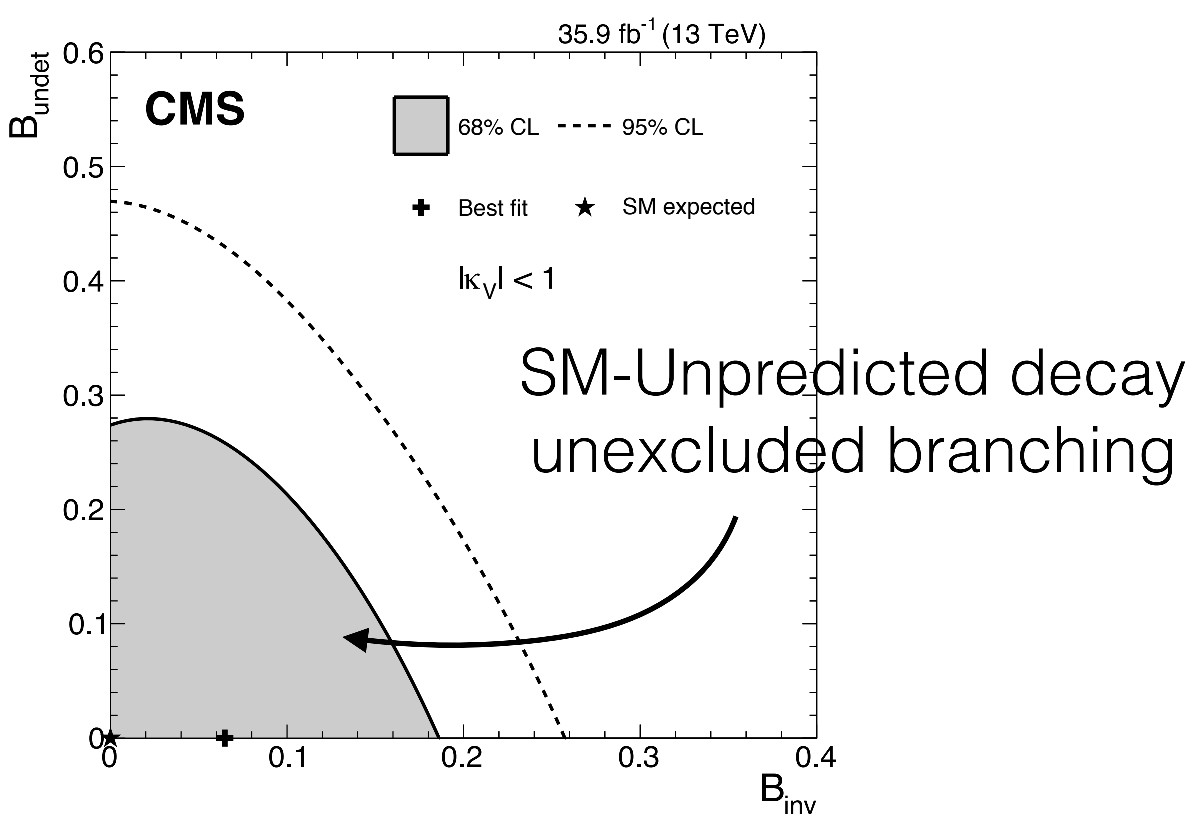
Unfolding with Tichonov regularization embedded as a constraint in the likelihood function

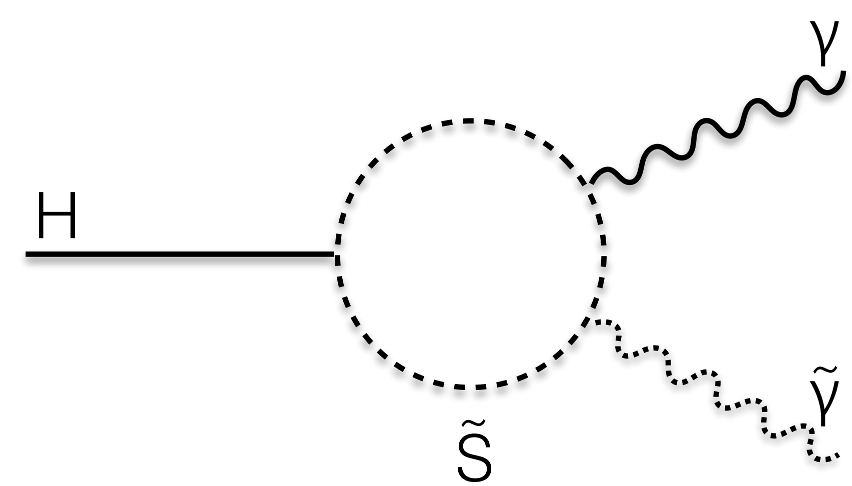
Overall fiducial measurement competitive with di-photon (with larger theoretical uncertainties)

- Presented by P. Lenzi (INFN Firenze)

Search for H→$\gamma\gamma_D$

- "Higgs cannot be the end of the story"
- New physics naturally couples to Higgs ("portal")
    - Non-SM coupling induces non-SM decays of h(125)
- H→$\gamma\gamma_D$ predicted by an interesting model with a dark sector and a dynamic origin of Yukawa couplings [1]
- Started a search program while at MIT, continuing

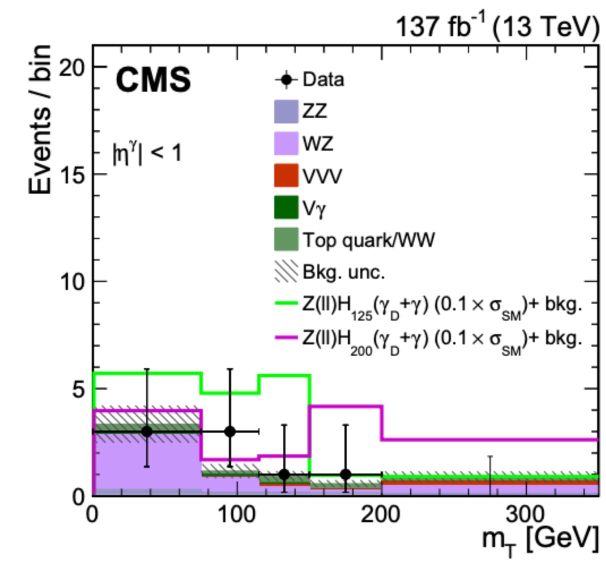


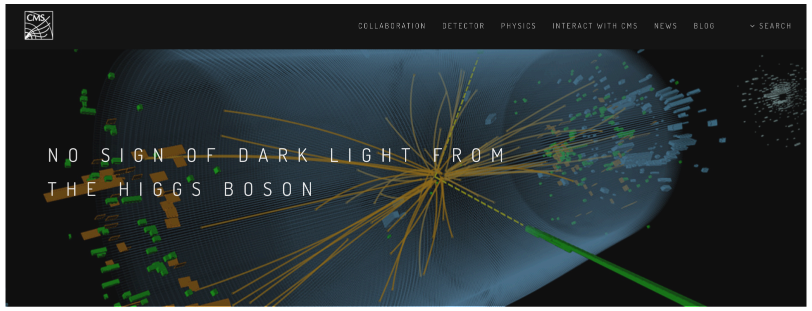


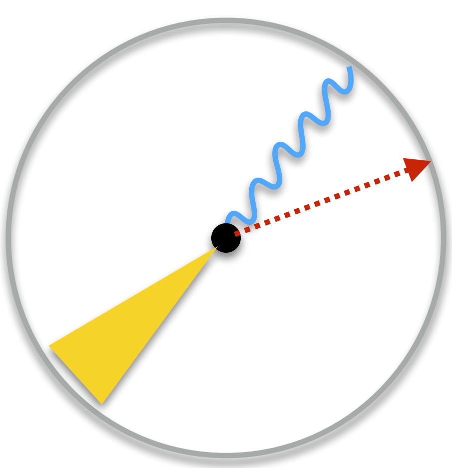
[1] Gabrielli et al.1405.5196

Search for H→γγ$_D$

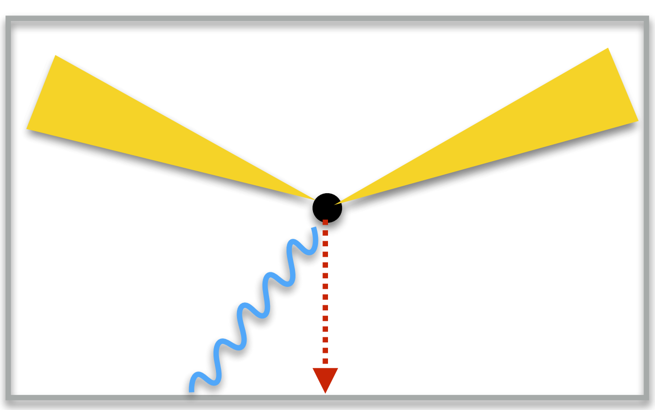
- Search in three Higgs production modes: ggH, qqH, ZH
- ZH search completed in May by MIT colleagues
  - YI was in supporting role
  - Featured by the collaboration as one of the first full Run-2 data analyses
- Now working on the qqH channel



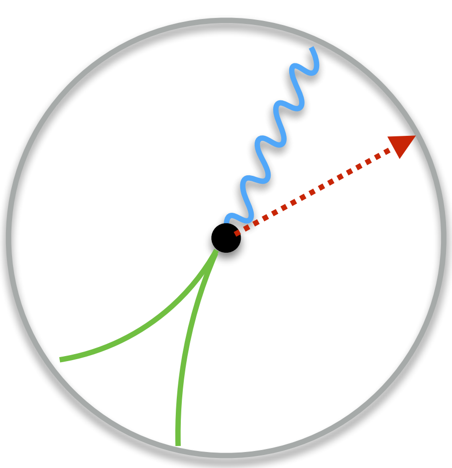




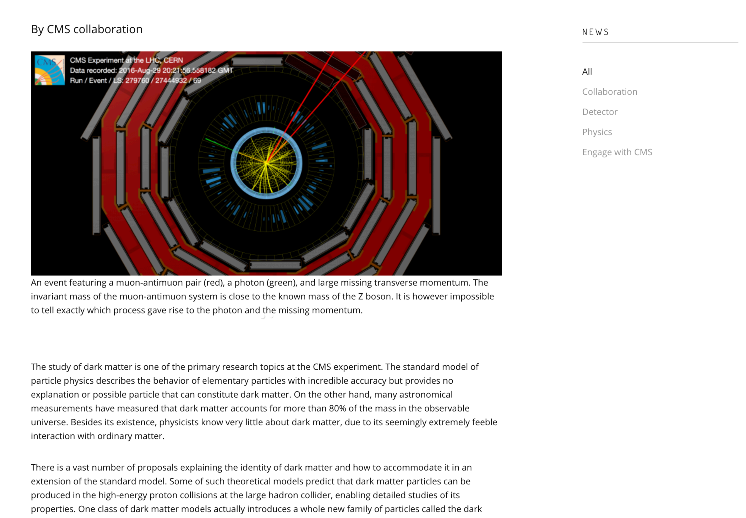
ggH



qqH



ZH



By CMS collaboration

NEWS

All

Collaboration

Detector

Physics

Engage with CMS

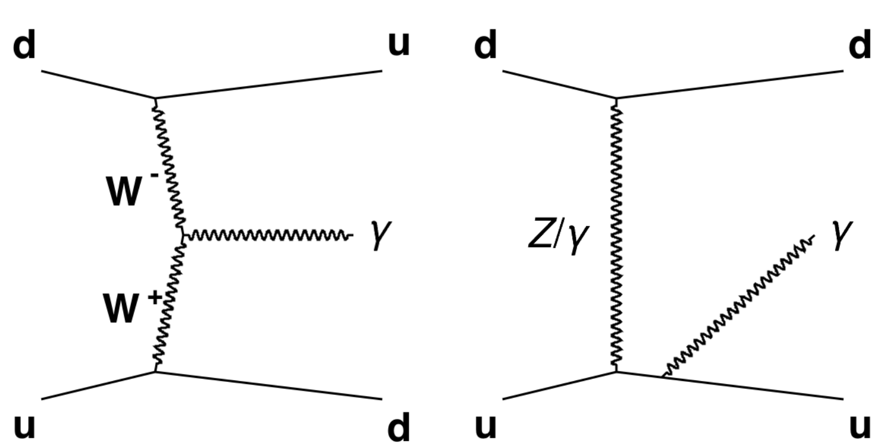
An event featuring a muon-antimuon pair (red), a photon (green), and large missing transverse momentum. The invariant mass of the muon-antimuon system is close to the known mass of the Z boson. It is however impossible to tell exactly which process gave rise to the photon and the missing momentum.

The study of dark matter is one of the primary research topics at the CMS experiment. The standard model of particle physics describes the behavior of elementary particles with incredible accuracy but provides no explanation or possible particle that can constitute dark matter. On the other hand, many astronomical measurements have measured that dark matter accounts for more than 80% of the mass in the observable universe. Besides its existence, physicists know very little about dark matter, due to its seemingly extremely feeble interaction with ordinary matter.

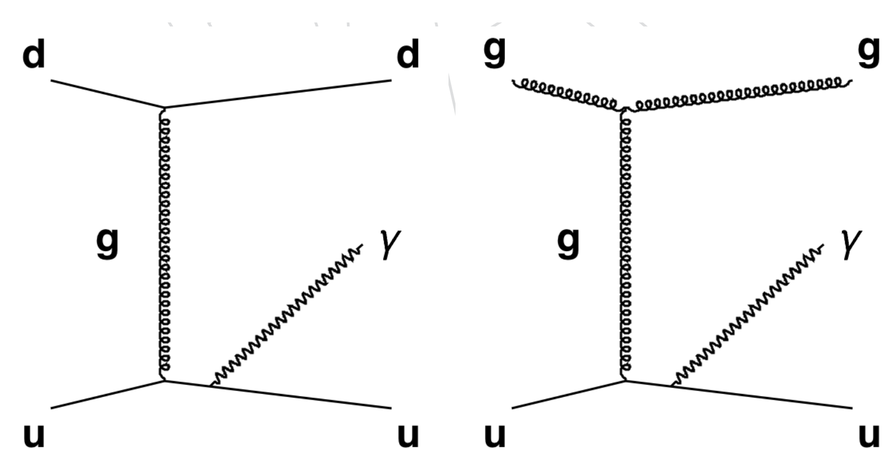
There is a vast number of proposals explaining the identity of dark matter and how to accommodate it in an extension of the standard model. Some of such theoretical models predict that dark matter particles can be produced in the high-energy proton collisions at the large hadron collider, enabling detailed studies of its properties. One class of dark matter models actually introduces a whole new family of particles called the dark

SMP EWK gamma

- Joined members of the CERN CMS group (CMG) in the project to measure the cross section of electroweak-exclusive single photon production
- Final state similar to qqH→$\gamma\gamma_D$
  - Similar challenges, similar solutions
- In particular: largest obstacle = modeling QCD background
  - Need higher-order simulation
  - CMS-standard NLO calculation ("FxFx merging") not applicable
  - Introducing new method ("UNLOPS") from literature



EWK exclusive γjj



"QCD" γjj

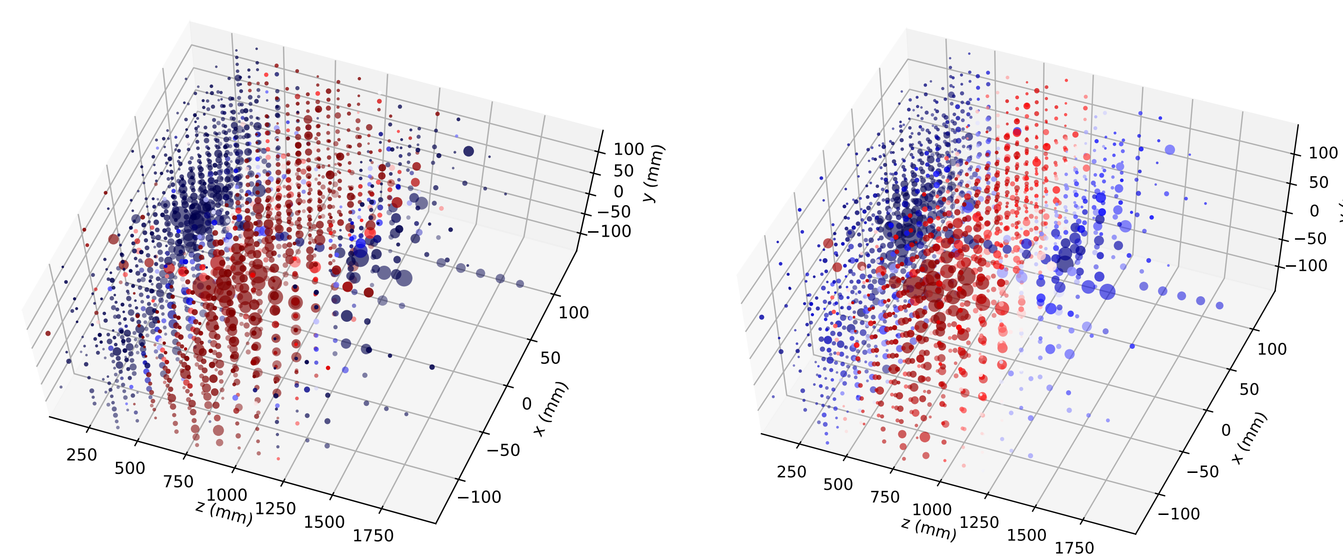
SUSY photons subconvenership

- CMS supersymmetry search group organized by final state signatures: hadronic, leptons, photons, etc.
  → Facilitate analysis knowledge sharing
- Previous photon subgroup coordinator ("subconvener") got a job outside CMS → YI recruited as replacement
  - Have experience with Ph.D. thesis work:
    SUSY with photon + lepton
- Coordinating and advising 4 analyses
- Also launching a new analysis project for first year of Run 3

Deep learning for HGCal reconstruction

- Joint effort by subsets of CMG & FNAL CMS groups
- Focus on graph neural network (GNN) architecture
  - Most well-known DL architecture = convolutional (CNN)
  - CNN only works on regular grid (e.g. images)
  - GNN allows pattern recognition over irregular geometry
- Paper on prototype model published in February [1]
- Real-life application to HGCal under development
- Will present at NeurIPS '19

Clustering by GNN



Truth   Reconstruction

[1] Qasim et al. 1902.07987

HGCal trigger development

- Lower activity level than planned; prioritized physics analysis
- Also explored GNN application in this context
- Problem: running high-level machine learning inference at level-1 trigger → FPGA implementation of neural networks
- HLS4ML [1] framework allows translating neural network architectures specified in python into FPGA firmware
- GNN not supported yet, helping expand

hls4ml

[1] Duarte et al. 1804.06913

Prospects for the next year

- Winter & spring: complete $H \rightarrow \gamma\gamma_D$ and EWK γjj analyses
- Continue with more Higgs exotics analyses
- Publish $H \rightarrow WW$ differential measurement paper in spring
  - Another paper planned for later in the year with more observables and interpretations
- SUSY photons subconvenership through end of August
- HGCal trigger
  - Continue the current GNN investigation
  - Also perform more "grounded" studies: algorithm tuning, calibration, etc.

Summary

- Work load distribution and timespan of projects somewhat diverged from original plan
  - HWW took longer with higher level of required commitment
  - Additional analysis involvements and responsibilities
- Nevertheless, first year has been fruitful
  - Most importantly, acquired many new skills
- Would like to have more physics output in the second year