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Answers to Questions for CMS

The Fermilab CMS Group
DOE Institutional Review
February 12, 2015

Question 1

- We have heard reports on many topics but do not have a firm grasp of the level of effort by Fermilab personnel and how central is the Fermilab role. Please indicate level of effort by Fermilab personnel (approximate FTE count) in each of the major areas of engagement. What is the total effort on each project, or alternatively what fraction does the Fermilab effort represent in each area?

Question 1

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- Examples for fractions that Fermilab effort represents across US CMS

- ★ Phase 1 Upgrade Project

Table 1

U.S. CMS Phase 1 Upgrade FTE in FY15				
Role	PM	HCAL	FPIX	L1T
FNAL Technical	3.9	1.7	5.3	0
Institute Technical	1	6	4.3	9.7
FNAL Contributed	0	2.1	5.1	0
Institute Contributed	0.5	5.7	7	12.3
Undergrad	0	0.7	5.1	2.1
Grand Total	5.4	16.2	26.8	24.1

Total Fermilab effort in Areas

	Tota
Research	11.6
Trigger (incl. Upgrades)	6
HCAL + Cal R&D	7.1
Tracker (incl. Upgrades)	13.4
DAQ	1.1
S&C	31.4
Detector Support	5.5
Outreach, PR	1.2
CMS Coordinators (including Physics)	7.1
Management and Admin Support	13.4

Q1 continued

- **Stage-1 Level-1 Trigger::**
 - ★ FNAL total 2.25 FTE of 8.25 US Total = 27%
 - ★ NB: all CMS total is = 10.25 FTE, FNAL is 22%
 - ★ (run through the Operations program in close collaboration with the Phase 1 effort)
- **DAQ:**
 - ★ FNAL effort is DAQ is me 1.1 FTE, which represents about 25% of the US effort and about 1/3rd of the total CMS DAQ effort (the other 2/3 is CERN), so in total FNAL is about 8% of the total CMS effort on DAQ.
- **Fractions of USCMS authorship for the main areas:**
 - ★ DAQ: 1/12 (8.3%)
 - ★ HCAL: 14/135 (10.4%)
 - ★ Trigger: (3+2)/(16+60) (6.6%)
 - ★ Tracker: 17/129 (13.2%)

Q1 continued

- **Software and Computing efforts at Fermilab**

- To give an estimate of the Fermilab fraction on S&C, we only show the Operations Program supported effort of about 28 FTE at Fermilab. In addition, Fermilab is also providing 3.4 FTE of scientist and other contributed effort in this area, which is harder to normalize as the equivalent effort at other institutions is not tracked and unknown.

- ★ **Tier-1:**

- Fermilab provides 40% of CMS-wide Tier-1 resources. The ~13 FTE of Fermilab facilities effort (which includes LPC-CAF and part of the experiment services like data transfer support etc) is estimated to be around 15-20% of total Tier-1 effort in CMS.

- ★ **Tier-2:**

- Fermilab has no effort, 0 of 14 FTE = 0%

- ★ **Computing Operations:**

- Fermilab has 2.1 of 8.0 FTE = 26%

- ★ **Computing Infrastructure and Services:**

- Fermilab has 5.5 of 9.8 FTE = 56 %

- ★ **Software and Support:**

- Fermilab has 5.2 of 8.6 FTE = 60%

- ★ **S&C Technologies & R&D:**

- Fermilab has 0.3 of 4.1 FTE = 7%

- ★ **S&C Coordination:**

- Fermilab has 1.3 of 2.8 FTE = 46%

Question 2

How has the Fermilab effort changed over the last five years? For example, how have activities evolved given that the CMSSW development was completed a number of years ago

- ★ While the overall effort envelope stayed relatively constant over the past 5 years (after the initial surge of construction) it is now increasing again for the Phase 1 Upgrade Project which is expected to create a multi-year bump in the overall effort profile.
- ★ Detector Operations is a large part of the effort which is roughly constant during the run, but has gone down during the past 2 years of the long shutdown LS1. During the shutdown detector improvement work dominated, roughly making up for operations keeping the sum at an overall constant effort.
- ★ The software and computing effort also stayed at an almost constant level ($\pm 5\%$) over the five years, at about 32 FTE.
- ★ The number of authors and the envelope of effort spent on research also stayed roughly constant.
- ★ These overall constant effort envelopes are to be expected for a operations program and a mature research program of intense physics exploitation of the large CMS data set. However, within these envelopes individual activities and projects went through a series of life cycles. These are often driven by technology changes or the increasing scale of complexity and data sizes in particular in S&C.

Question 2 continued

- ★ The CMS framework efforts (CMSSW) are an excellent example to illustrate that. A first version of the framework was built in 2006-2009 and then went into a maintenance phase with functionality and scalability upgrades at a support level of about 2 FTE. With the advent of multi-core CPU architectures the framework group embarked on the multi-threaded framework upgrade which was a major undertaking with several FTE years of effort, that now is in integration and deployment, followed by the upcoming maintenance and scalability upgrade period.
- ★ Other components go through similar life cycles, like in data management and bookkeeping where the 2nd re-engineering was finished about a year ago, or the DAQ system which went to its 2nd version during LS1 to exchange antiquated networking technology and provided more throughput and capacity for increase pileup and trigger rates for run2.
- ★ Other changes have to do with generational transitions replacing senior people many of which are retired by people mostly from the Tevatron, a few targeted hires to prepare refresh the group technical expertise e.g. in the silicon pixel area, and the first wave of postdocs leaving and being replaced about 2-3 years ago.

Question 3

- As the second largest group in CMS, what are the unique strength and responsibilities of the Fermilab CMS group that are critical to the CMS experiment? What are Fermilab plans to retain its expertise and leadership in CMS? (targeted hires?)
- SiDet
 - past expertise from CDF, D0, CMS trackers
 - Extensive use for Phase 1 FPIX
 - Module production capacity key for Phase 2
- Calorimetry
 - Past success with QIE, expertise in calorimeter ops
 - Scintillator R&D, extrusion facility
- Trigger
 - Development of 3D ASICs for tracking trigger
- Computing
 - Tier-1 site support, and same team supports analysis facilities
 - Expertise in computing infrastructure
 - Framework expertise
- Project Management

Question 3 continued

- Targeted Hires
 - Upgrade project manager
 - SiDet
 - Guest scientist as part of Phase 2 simulation team
 - Considering further hires to support detector operations at CERN and for analysis
- Hire the absolute best postdocs we can and look for a match within the group, as opposed to targeting a specific detector need

Question 4

- How many of the LPC head count are Fermilab personnel? How many Run-1 papers were led by them? We also like to know the count of LPC people by rank (senior, post-doc, grad student)
- LPC Headcount
 - Universities: Residents and Frequent Visitors - 89 physicists and 52 graduate students
 - Fermilab employees – 48 physicists
 - Total – 189 (137+52)
- Tough to distinguish postdocs vs. faculty in CMS database, but assume roughly 80% postdocs

Question 4: Fermilab / CMS Run 1 Papers

- Fermilab group Scientists and Postdocs were leading authors on **74 physics papers** in run 1
 - 25 Standard Model (primarily Electroweak)
 - 15 SUSY
 - 14 Exotica
 - 13 Higgs
 - 3 Physics Object Performance
 - 2 Top
 - 1 BPH
 - 1 HIN

Question 6

- We heard in every report how well Fermilab is doing in CMS. What are your 2-3 major issues?
- We are now entering a challenging period where we must balance a successful launch of Run 2 (both in operations and in physics), complete the Phase 1 upgrades, and launch the Phase 2 project
- For USCMS and Fermilab to succeed in the upgrades, we must maintain the needed technical expertise and facilities, shifting or growing to match the needed skills

Question 7

- Given that CMS computing needs will increase due to more data and to support new analyses and code development, what is Fermilab's plan to meet these needs?
- Fermilab experts will continue to evolve and enhance the CMS data management, workflow management and submission infrastructure solutions to increase efficiency and flexibility of the resource utilization. These improved capabilities will allow to increase the scalability of the Fermilab CMS facility beyond traditional hardware increases and will allow CMS to further optimize the effectiveness of the planned facility investments. Fermilab's flexible and state-of-the-art computing rooms and networking setup allows for very cost-efficient resource increases. Enough tape robot capacity is available to allow CMS to store CMS data and MC needing only media costs for years to come. Therefore the effectiveness of the planned extension of the CMS facility at FNAL of \$3.4M for FY15 will be very high and will meet the needs of CMS computing.

Question 9

- What is FNAL policy regarding postdoc/student mentoring onsite?
- The CMS group at Fermilab has developed a process for mentoring Fermilab/CMS RAs and guidelines for supervisors/mentors.
 - Each new CMS RA has a month to discuss with the group, choose a supervisor (and mentor) and develop a research plan.
 - These research activities are managed by the RA's supervisor with periodic review by our RA mentoring committee and CMS group management.
- CMS RA Mentoring Process activities/events
 - RA Research Plan
 - a brief research plan, written by the RA, the supervisor and optional mentor, and then extensively reviewed and approved by a mentoring committee reporting to Fermilab CMS management
 - RA Reports at monthly "Pizza meetings"
 - RAs share their ongoing research strategy annually with the CMS group at Fermilab via informal and friendly pizza meetings.
 - RA Performance reviews following the lab process
 - Supervisor Presentations (training the mentors)
 - Supervisors present the status and research strategy of their RA annually to the mentoring committee
 - Career Development Activities
 - RA Practice Talks
 - Award Nominations (inform supervisors/mentors of opportunities.)
 - Job Application Package Review

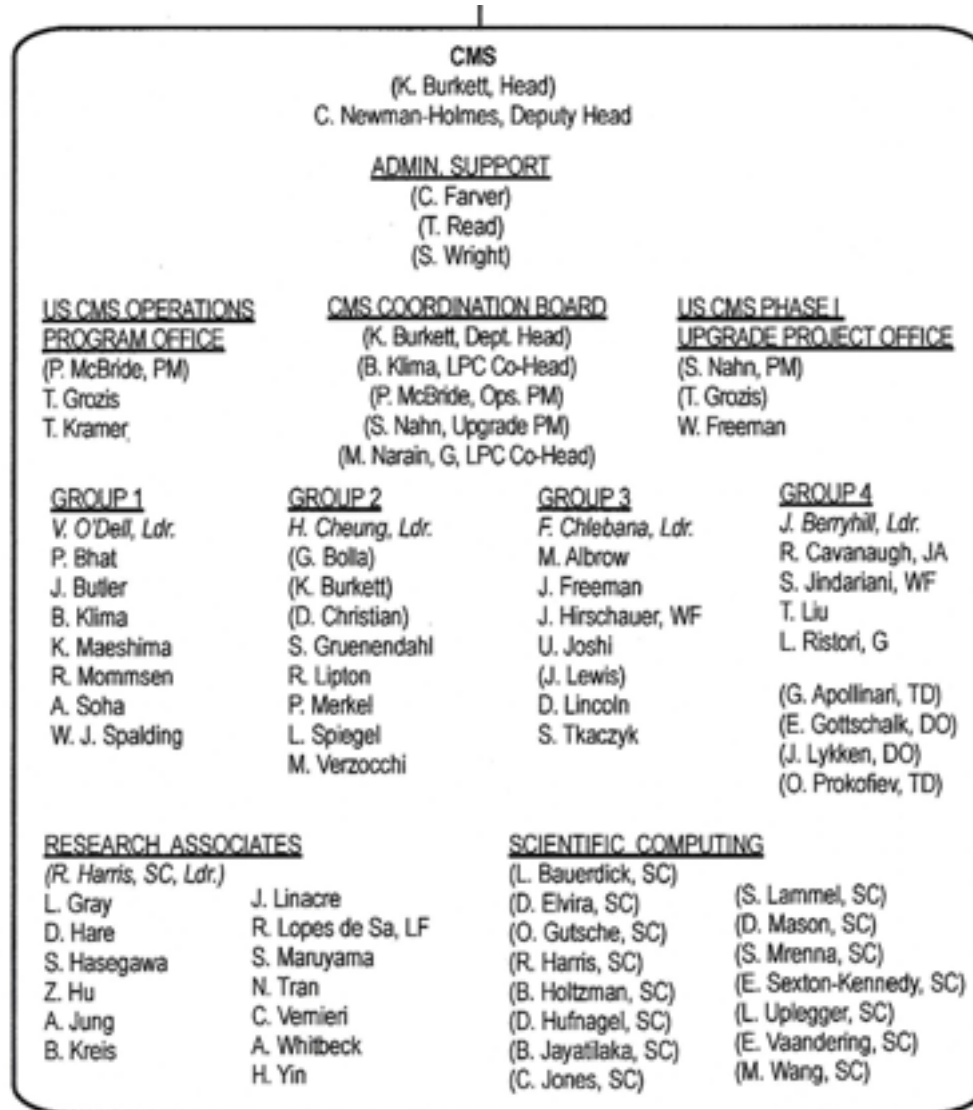
Question 9 continued

- The RA mentoring committee has the following tasks:
 - Provide guidance to supervisors and mentors: see “Guidelines for CMS-FNAL RA Supervisors and Mentors”.
 - Review the research plan of the RA and advise management, supervisor, mentor and RA.
 - Receive annual presentations from supervisors and mentors about the past and future research program of the RA. Advise the supervisors and management on the RAs research program
 - Review requests to extend RA appointment.
 - Review requests to extend RA stays at CERN and advise management.
 - Keep lists of conferences and awards and notify supervisors.
 - Assist the supervisor, mentor, management and the RA in reviewing and refining the job application package of the RA.

Current Positions of Past FNAL Postdocs

<i>Jake Anderson</i>	<i>Data Scientist, Pearson Education Software</i>
<i>Ingo Bloch</i>	<i>DESY Staff</i>
<i>Vasundhara Chetluru</i>	<i>Data Scientist, Jump Trading</i>
<i>Yanyan Gao</i>	<i>Postdoc, U. of Edinburgh</i>
<i>Oliver Gutsche</i>	<i>Scientist, SCD, Fermilab</i>
<i>Jim Hirschauer</i>	<i>Wilson Fellow, PPD, Fermilab</i>
<i>Benjamin Hooberman</i>	<i>Asst. Professor, UIUC</i>
<i>Ketino Kaadze</i>	<i>Asst. Professor, Kansas State</i>
<i>Konstantinos Kousouris</i>	<i>CERN Staff</i>
<i>Verena Martinez Outschoorn</i>	<i>Asst. Professor, UIUC</i>
<i>Dave Mason</i>	<i>Applications Physicist, SCD, Fermilab</i>
<i>Kalanand Mishra</i>	<i>Data Scientist, Vectra Networks</i>
<i>Carsten Noeding</i>	<i>System & Flight Safety Engineer, Northrop Grumman</i>
<i>Seema Sharma</i>	<i>Asst. Professor, IISER Pune India</i>
<i>Ping Tan</i>	<i>Postdoc, University of Iowa</i>
<i>Lorenzo Uplegger</i>	<i>Applications Physicist, SCD, Fermilab</i>
<i>Fan Yang</i>	<i>Trader, Quantitative Analyst, White Bay PT LLC, NY</i>
<i>Francisco Yumiceva</i>	<i>Asst. Professor, Florida Institute of Technology</i>

CMS Department Organization



Fermilab / CMS Run 1 Papers

- Fermilab group Scientists and Postdocs were leading authors on **74 physics papers** in run 1
 - 25 Standard Model (primarily Electroweak)
 - 15 SUSY
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 - 3 Physics Object Performance
 - 2 Top
 - 1 BPH
 - 1 HIN
- Following is a list of the actual papers by Fermilab lead author
 - Very **rough** assignment (sometimes 1st postdoc), and an attempt to list Fermilab co-authors, who sometimes were actually the lead.

Run 1 Papers by Lead Author

• Jacob Anderson (4) with K. Mishra, F. Yang, J. Berryhill

1. **HIN** Serguei Chatrchyan et al. [CMS Collaboration], “Indications of suppression of excited Y states in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *Phys. Rev. Lett.* 107, 052302 (2011) [arXiv:1105.4894 [nucl-ex]].
2. **SMP** S. Chatrchyan *et al.* (CMS Collaboration), “Measurement of the sum of WW and WZ production with W+dijet events in pp collisions at TeV”, *Eur. Phys. J. C73*, 2283 (2013) [arXiv:1210.7544 [hep-ex]].
3. **SMP** S. Chatrchyan *et al.* (CMS Collaboration), “Study of the dijet invariant mass distribution in W plus jets events produced in pp collisions at TeV”, *Phys. Rev. Lett.* 109, 251801 (2012) [arXiv:1208.3477 [hep-ex]].
4. **HIG** S. Chatrchyan *et al.* (CMS Collaboration), “Search for a standard-model-like Higgs boson with a mass of up to 1 TeV at the LHC”, *Eur. Phys. J. C73*, 2469 (2013).

• Jeff Berryhill (5) with K. Mishra and others

1. **SMP** Measurement of the inclusive W and Z production cross sections in pp collisions at 7 TeV with the CMS experiment , S. Chatrchyan et al. (CMS Collaboration), *JHEP* 10 (2011) 132.
2. **SMP** Measurements of inclusive W and Z cross sections in pp collisions at 7 TeV, S. Chatrchyan et al. (CMS Collaboration), *JHEP* 01 (2011) 080.
3. **EXO** Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays in pp collisions at 8 TeV S. Chatrchyan et al. (CMS Collaboration), *JHEP* 08 (2014) 173 (2013).
4. **SMP** A search for and production and constraints on anomalous quartic gauge couplings in pp collisions at 8 TeV S. Chatrchyan et al. (CMS Collaboration), *Phys. Rev. D90* (2014) 032008.
5. **EXO** Search for a boson decaying to a bottom quark and a top quark in pp collisions at = 7 TeV, S. Chatrchyan et al. (CMS Collaboration), *Phys. Lett. B718* (2013) 1229

Run 1 Papers by Lead Author (cont.)

- **Kevin Burkett (1) with Sergo Jindariani**

1. **POG** Description and performance of track and primary vertex reconstruction with the CMS tracker", JINST 9 (2014) 10, P10009.

- **Joel Butler (1)**

1. **BPH** Bs-->mumu joint paper fwith LCHB, submitted to Nature.

- **Vasu Chetluru (3) with Vivian O'Dell**

1. **SMP** Measurement of the triple-differential cross section for photon + jets production in proton-proton collisions at $\sqrt{s} = 7$ TeV, JHEP 1406 (2014) 009
2. **SMP** Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV, Phys. Rev. D 84, 052011 (2011)
3. **SMP** Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV, Phys.Rev.Lett.106:082001,2011

Run 1 Papers by Lead Author (cont.)

- **Daniel Elvira (2)**

1. **SUS** Search for New Physics with Jets and Missing Transverse Momentum in pp collisions at 7 TeV (CMS Collaboration), J. High Energy Phys. 08 (2011) 155.
2. **SUS** Search for Supersymmetry in pp Collisions at 7 TeV in Events with Two Photons and Missing Transverse Energy, (CMS Collaboration) PRL 106 (2011) 211802.

- **Yanyan Gao (6) with K. Burkett and S. Jindariani**

1. **HIG** Search for the standard model Higgs boson in the H to ZZ to $2l2\nu$ channel in pp collisions at $\sqrt{s} = 7$ TeV, published in J. High Energy Physics. 03(2012) 040.
2. **HIG** Search for the standard model Higgs boson decaying to a W pair in the fully leptonic final state in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B 710(2012) 91-113.
3. **HIG** Study of the mass and spin-parity of the Higgs boson candidate via its decays to Z boson pairs”, arXiv:1212.6639
4. **HIG** Observation of a new boson at a mass of 125 GeV with the CMS experiments”, Phys. Lett. B716, 30-61
5. **HIG** A New boson with a mass of 125 GeV observed with the CMS experiments at the Large Hadron Collider”, Science 388, 6114(2012) 1569-1575
6. **HIG** On the spin and parity of a single produced resonance at the LHC”, Phys. Rev. D86, 095031(2012)

- **Lindsey Gray (1) with J. Berryhill**

1. **HIG** search for a light standard model Higgs decaying to a photon and a Z boson, Phys. Lett. B 726 (2013) 587
2. **POG** Performance of electron reconstruction and selection with the CMS detector at $\sqrt{s}=8\text{TeV}$, submitted to JINST.

Run 1 Papers by Lead Author (cont.)

- **Daryl Hare (1) with R. Cavanaugh and D. Elvira**

1. **SUS** 3rd generation squark searches in all hadronic final state (CMS Collaboration, in CWR now,

- **Robert Harris (7) with K. Kousouris and D. Elvira**

1. **EXO** 3 pb⁻¹ @ 7 TeV: *Search for Dijet Resonances in 7 TeV pp Collisions at CMS*, Phys.Rev.Lett.105 (2010) 211801
2. **EXO** 1 fb⁻¹ @ 7 TeV: *Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS*, Phys.Lett. B704 (2011) 123-142
3. **EXO** 5 fb⁻¹ @ 7 TeV: *Search for narrow resonances and quantum black holes in inclusive and b-tagged dijet mass spectra from pp collisions at sqrt(s) = 7 TeV*, JHEP 01 (2013) 013,
4. **EXO** 4 fb⁻¹ @ 8 TeV: *Search for narrow resonances using the dijet mass spectrum in pp collisions at sqrt(s) = 8 TeV*, Phys. Rev. D 87 (2013) 114015
5. **EXO** 20 fb⁻¹ @ 8 TeV: *Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at sqrt(s)=8 TeV*, iv:1501.04198 , Accepted by PRD.
6. **EXO** Search for pair-produced dijet resonances in four-jet final states in *pp* collisions at $s\sqrt{=7}$ TeV, Phys. Rev. Lett. 110, 141802 (2013).
7. **POG** Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS , JINST 6 (2011) P11002.

- **Jim Hirschauer (3) with R. Harris and D. Elvira**

1. **SUS** Search for stealth supersymmetry in events with jets, either photons or leptons, and low missing transverse momentum in pp collisions at 8 TeV, CMS Collaboration, submitted to PLB (2014); arXiv:1411.7255.
2. **SUS** Search for supersymmetry in events with photons and low missing transverse energy in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys. Lett. B 719 42 (2012); arXiv:1210.2052.
3. **EXO** Search for quark compositeness with the dijet centrality ratio in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys. Rev. Lett. 105, 262001 (2010); arXiv:1010.4439.

Run 1 Papers by Lead Author (cont.)

• Ben Hooberman (5) with V. Martinez and J. Linacre

1. **SUS** Search for Physics Beyond the Standard Model in Opposite-sign Dilepton Events at $\sqrt{s} = 7$ TeV", JHEP 6 (2011) 26
2. **SUS** Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states in pp collisions at $\sqrt{s} = 8$ TeV, JHEP 11 (2012) 147.
3. **SUS** Search for physics beyond-the-standard model in events with a Z boson, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B716 (2012) 260-284
4. **SUS** Search for new physics in events with opposite-sign leptons, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B718 (2013) 815-840
5. **SUS** Search for top-squark pair production in the single-lepton final state in pp collisions at $\sqrt{s} = 8$ TeV", Eur. Phys. J C73 (2013) 2677

• Sergo Jindariani (5) with Y. Gao and K. Burkett

1. **HIG** Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV", accepted by PRD.
2. **HIG** Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states", JHEP 1401 (2014) 096.
3. **SMP** Measurement of W+W- and ZZ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV", Phys. Lett. B721 (2013) 190-211.
4. **HIG** Search for the standard model Higgs boson decaying into W+W- in fully leptonic state in pp collisions at $\sqrt{s} = 7$ TeV", Phys. Lett. B710, 91-113(2012)
5. **HIG** Measurement of WW production and search for the higgs boson in pp collisions at $\sqrt{s} = 7$ GeV", Phys. Lett. B 699 (2011) 25-47, preprint at arXiv:1102.5429

Run 1 Papers by Lead Author (cont.)

- **Keti Kaadze (2) with Kevin Pedro**

1. **EXO** Search for third generation leptoquarks and top squarks, Physics Letters B 739, 229 (2014)
2. **EXO** Search for neutral MSSM Higgs bosons decaying to a pair of tau leptons in pp collisions, JHEP10(2014)160

- **Jacob Linacre (3) with Oliver Gutsche**

1. **TOP** Measurements of t t-bar spin correlations and top-quark polarization using dilepton final states in pp collisions at $\sqrt{s} = 7$ TeV” Phys. Rev. Lett. 112 (2014) 182001
2. **TOP** “Measurements of the t t-bar charge asymmetry using the dilepton decay channel in pp collisions at $\sqrt{s} = 7$ TeV” JHEP 04 (2014) 191
3. **EXO** Search for heavy, top-like quark pair production in the dilepton final state in pp collisions at $\sqrt{s} = 7$ TeV,” Phys.Lett. B716 (2012) 103–121

- **Verena Martinez Outschoorn (1) with B. Hooberman**

1. **SUS** Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states in pp collisions at $\sqrt{s} = 8$ TeV”, Eur. Phys. J. C74 (2014) 9, 3036

- **Dave Mason (1) with Daniel Elvira**

1. **SUS** Search for new physics in events with photons, jets, and missing transverse energy in pp collisions at 7 TeV (CMS Collaboration), J. High Energy Phys. 03 (2013) 111.

- **Steve Mrenna (1)**

1. **SUS** Interpretation of Searches for Supersymmetry, Phys. Rev. D 88, 052017 (2013)

Run 1 Papers by Lead Author (cont.)

- **Rafael Lopes De Sa (2) with Sergo Jindariani**

1. **SMP** Study of Vector Boson Scattering and Search for New Physics in Events with Two Same-Sign Leptons and Two Jets, PhysRevLett.114.051801.
2. **SMP** Measurement of the $W+W^-$ cross section in pp collisions at $\sqrt{s} = 8$ TeV and limits on anomalous gauge couplings”, in CWR

- **Niki Saoulidou (1)**

1. **SMP** Measurement of the differential dijet production cross section in proton-proton collisions at $\sqrt{s}=7$ TeV, Phys. Lett. B 700 (2011) 187–206

- **Seema Sharma (2) with Daniel Elvira**

1. **SUS** Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at 8 TeV (CMS Collaboration), J. High Energy Phys. 06 (2014) 055.
2. **SUS** Search for New Physics with Jets and Missing Transverse Momentum final state in pp collisions at $\sqrt{s} = 7$ TeV”, PRL 109, 171803 (2012)

- **Lenny Spiegel (1)**

1. **EXO** Search for contact interactions in $\mu + \mu^-$ events in pp collisions at $\sqrt{s} = 7$ TeV , Phys. Rev. D 87, 032001 – Published 1 February 2013

Run 1 Papers by Lead Author (cont.)

• Slawek Tkaczyk (12) with EWK team

1. **SMP** Study of vector boson scattering and search for new physics in events with two same-sign leptons and two jets CMS Collaboration (Vardan Khachatryan (Yerevan Phys. Inst.) et al.). Oct 23, 2014. 27 pp. Published in Phys.Rev.Lett. 114 (2015) 051801
2. **HIG** Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Apr 4, 2014. 35 pp. Published in Eur.Phys.J. C74 (2014) 2980
3. **SMP** Measurement of inclusive W and Z boson production cross sections in pp collisions at $s\sqrt{= 8}$ TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Feb 4, 2014. 17 pp. Published in Phys.Rev.Lett. 112 (2014) 191802
4. **SMP** Measurement of the muon charge asymmetry in inclusive $pp \rightarrow W+X$ production at $s\sqrt{= 7}$ TeV and an improved determination of light parton distribution functions CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Dec 21, 2013. 33 pp. Published in Phys.Rev. D90 (2014) 3, 032004
5. **SMP** Measurement of the $W+W-$ Cross section in pp Collisions at $s\sqrt{=7}$ TeV and Limits on Anomalous $WW\gamma$ and WWZ couplings CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jun 5, 2013. Published in Eur.Phys.J. C73 (2013) 10, 2610
6. **SMP** Forward-backward asymmetry of Drell-Yan lepton pairs in pp collisions at $s\sqrt{=7}$ TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jul 2012. 29 pp. Published in Phys.Lett. B718 (2013) 752-772
7. **SMP** Measurement of the electron charge asymmetry in inclusive W production in pp collisions at $s\sqrt{=7}$ TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jun 2012. 27 pp. Published in Phys.Rev.Lett. 109 (2012) 111806
8. **SMP** Measurement of the Rapidity and Transverse Momentum Distributions of Z Bosons in pp Collisions at $s\sqrt{=7}$ TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Oct 2011. 21 pp. Published in Phys.Rev. D85 (2012) 032002

Run 1 Papers by Lead Author (cont.)

10. **SMP** Measurement of the weak mixing angle with the Drell-Yan process in proton-proton collisions at the LHC CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Oct 2011. 41 pp. Published in Phys.Rev. D84 (2011) 112002
11. **SMP** Measurement of the lepton charge asymmetry in inclusive W production in pp collisions at $\sqrt{s}=7$ TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Mar 2011. 28 pp. Published in JHEP 1104 (2011) 050
12. **SMP** The WLWL Scattering at the LHC: Improving the Selection Criteria K. Doroba (Warsaw U.), J. Kalinowski (Warsaw U. & Hamburg U.), J. Kuczumarski, S. Pokorski, J. Rosiek (Warsaw U.), M. Szleper (Warsaw, Inst. Nucl. Studies), S. Tkaczyk (Fermilab). Jan 2012. 25 pp. Published in Phys.Rev. D86 (2012) 036011

• Nhan Tran (3)

1. **SMP** Studies of jet mass in dijet and W/Z + jet events", JHEP 1305 (2013) 090.
2. **SMP** Identification techniques for highly boosted W bosons that decay into hadrons", JHEP 1412 (2014) 017
3. **EXO** Search for massive resonances decaying into pairs of boosted bosons in semileptonic final states at $\sqrt{s} = 8$ TeV", arXiv:1405.3447 (2014)