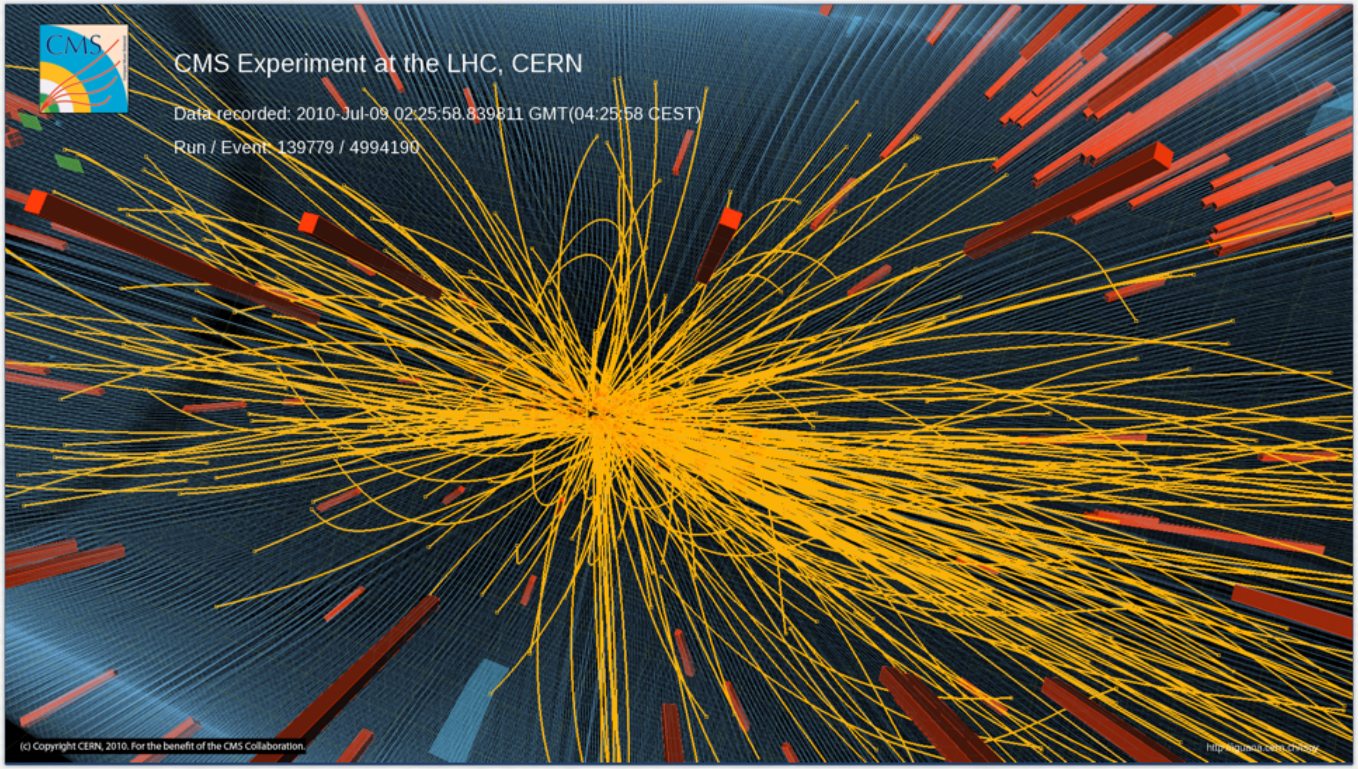
CMS Status & Upgrades

Fermilab



Richard Cavanaugh
LHC Physics Center Co-Coordinator

Fermilab Physics Advisory Committee Meeting
Fermilab, 4-5 November, 2010

CMS @ FNAL

- Fermilab
  - ~41 Senior Scientists
  - 14 Research Associates
  - ~120 Fermilab Staff on CMS ; more than 50% working full time
- US CMS Operations Program draws on resources from all organizations at the Lab:
  - CMS Center: overall coordination of Fermilab's contribution to CMS
    - Post-doc research associates, Wilson Fellows
  - Computing Division: CPU & Storage facilities, data access, software development & support, data operations support
    - scientists, computer professionals, programmers, engineers, technicians, managers
  - Particle Physics Division: detector R&D, design, construction ops
    - scientists mechanical & electronics engineering, technicians, managers, office space, secretariat, admin support
- Facilities provided to CMS and US CMS
  - Tier-1 and analysis computing facilities
  - SiDet and other detector facilities, test-beam
  - Remote Operations Center
  - LHC Physics Center (LPC) at Fermilab

Operations Efforts

- Large Fermilab commitments to operations
  - HCAL, Tracking, End-cap muons, Data Acquisition, Trigger, Run/Technical Coordination, Computing Facilities, Data Operations, etc
- Large Role for Fermilab staff in CMS Leadership
  - 6 members in the CMS Management Board
    - Level-1 positions within CMS:
      - Chair CMS Collaboration Board: Dan Green
      - Deputy Upgrade Coordinator: Joel Butler
      - Computing Coordinator: Ian Fisk, Deputy Patty McBride
      - Offline Coordinator Deputy: Liz Sexton Kennedy
      - HCAL Project Leader: Jeff Spalding
  - Plus 9 Level-2 “Convener” positions in Computing, Offline, Physics

Leadership in Physics

- Fermilab has the single largest institutional group of senior and junior scientists outside of CERN
  - Strongly involved in CMS physics, both broad and focused
  - Senior scientist working with RA(s)
- Large role in Physics Leadership
  - Physics Group Conveners
    - QCD Physics Analysis Group: V. O'del (to be replaced by K. Koussouris)
    - Jets/Missing ET Physics Object Group: R. Harris
    - Tracking Physics Object Group: K. Burkett
    - HCAL Detector Performance Group: F. Chlebana
  - Physics Sub-group Conveners:
    - Electro-weak Vector Boson Task Force: J. Berryhill
    - SUSY All-Hadronic: D. Elvira

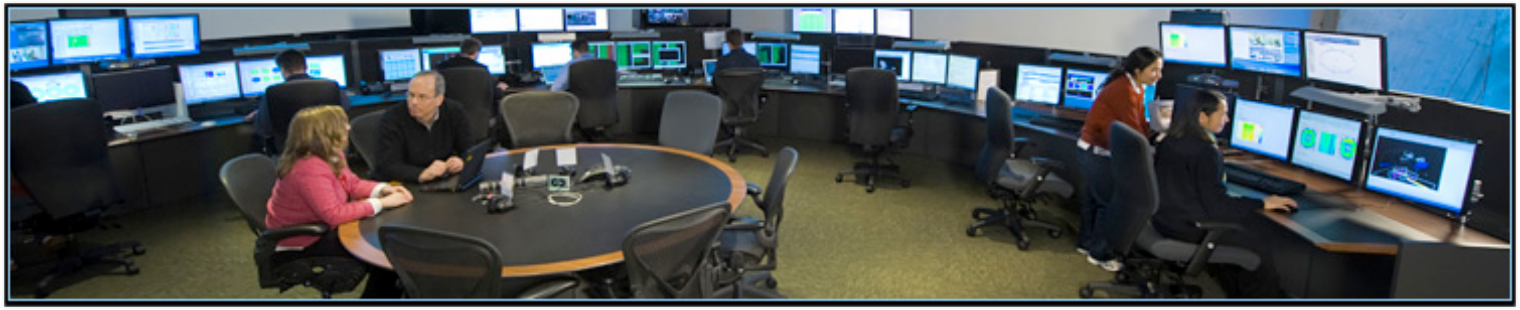
LHC Physics Center

- **Effective remote collaboration is an LHC Challenge**
  - **Particularly difficult to be plugged into day-to-day CMS activities**
- **The LPC provides an "Outpost" of CMS in the US**
  - **physical space, access to experts, critical mass, intellectual community, access to computing**
- **The LPC serves CMS; The LPC is ~~embraced~~ promoted by CMS!**
  - **engages more of the collaboration**
  - **lowers the barrier to participation**
  - **provides direct & transparent connection to CMS Physics Org.**
  - **functions as a center of excellence for CMS in targeted areas**

LHC Physics Center

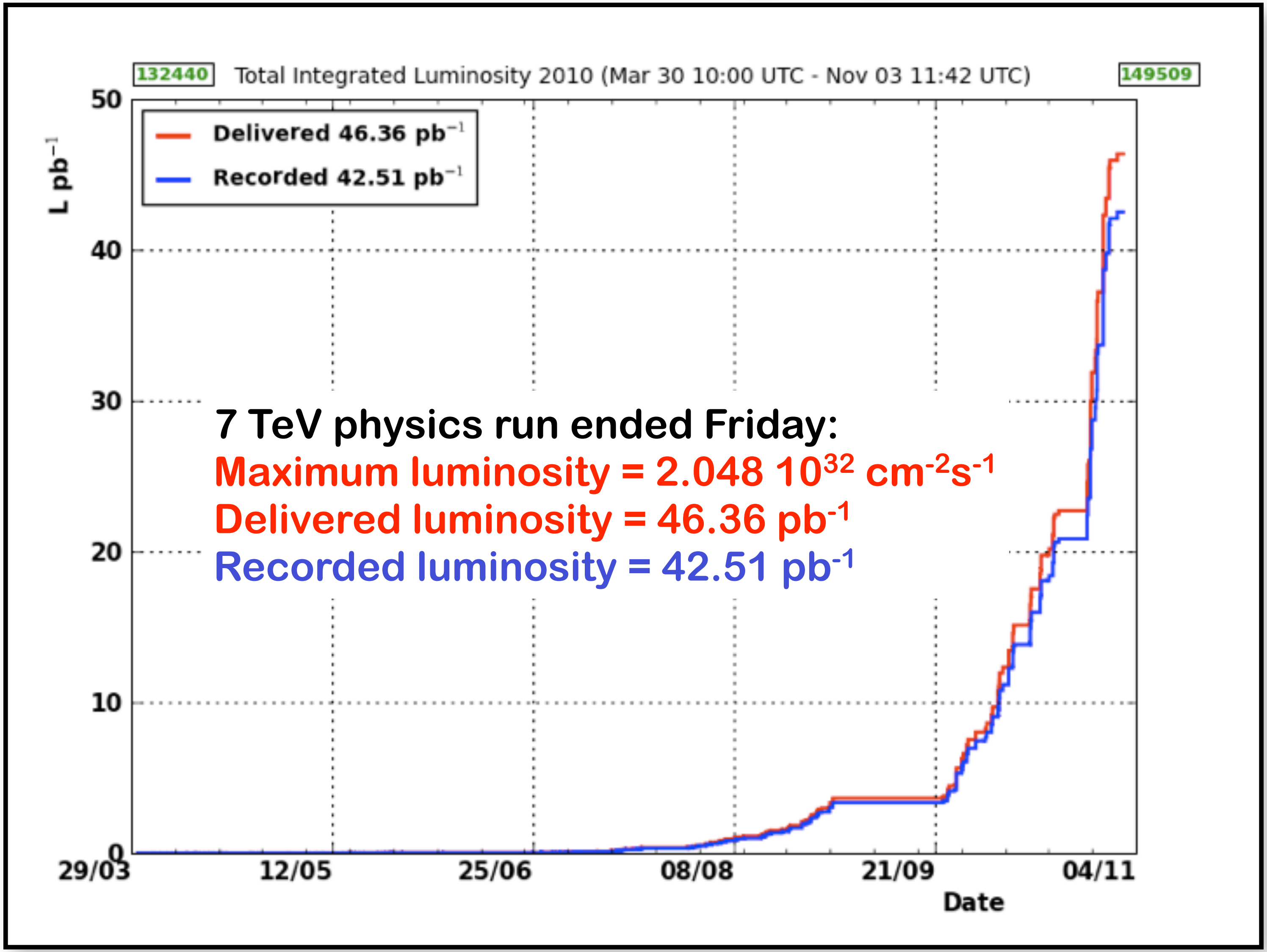
- **LPC Fellows Program: Building a Discovery Program**
  - International Competition; Prestigious recognized award
  - Strengthen an already strong LPC physics program
    - transition from SM Benchmark activities to Searches
    - build activities which deliver targeted Papers in SUSY, Higgs, Exotica
  - Solicitation announced late Summer: Deadline 18 October.
    - Received 25 (very strong, highly recognized) applicants, including from Europe!
    - Currently in the early stages of the selection process
- **EJTerm: Feeder School for CMS & the LPC**
  - Builds human resource capital; educate students to work with FNAL Scientists and LPC Fellows; engages more of the collaboration!

Remote Operations Center



- The ROC pioneered CMS remote operations
  - There are now several remote Centres in CMS
  - Major impact from Fermilab physicists on the shift operations
- Remote Shifts get full service credit with CMS
  - Offline DQM, Computing, Data Operations,
    Sub-detector (HCAL, Tracker, Trigger)
- Opportunity taken by many US collaborators
  - Large number of US university participate
- The ROC is a great service to the US community.

Collected Luminosity by CMS



Autumn Physics Harvest!

Fermilab

1. Search for Dijet Resonances in the Dijet Ma... Distribution in pp Collisions at sqrt(s)=7 TeV
2. Search for New Physics with the Di... Ratio
3. Dijet Azimuthal Decorrelations ... butions in pp Collisions at sqrt(s) = 7 ...
4. Single-Particle Response i...
5. Measurement of the Inclusive ... Collisions at 7 TeV
6. Jet Performance in pp Collisio... 7...
7. Commissioning of the Particle-Flow re... Bias and Jet Events from pp Collision...
8. Missing Transverse Energy Performance ... Events from Proton-Proton Collis...

1. Measurement of th... sections at sqrt(s...
2. Particle-flow commi... muon ... Psi and W events at ...

1. Selection of Top-Like Events in the Di... n-plus-Jets Channels in Early 7 TeV Data

1. Cluster pro... le angular correlat... sqrts = 0.9, 2.36 and 7TeV
2. T... tex Results in First 7 TeV
3. ... acking Efficiency
... acker Material
... avy Stable Charged ... in pp ... t √s = 7 TeV

... f CMS ...

... -Driven Background

... nd identification at sqrt(s) =

1. Measurement of the Inclusive Upsilon production cross section in pp co... ons at sqrt(s)=7$~TeV
2. J/Psi promp... ompt cross sections in pp collisio... 7 TeV

Jets

Tracking

W/Z

Photons

Top

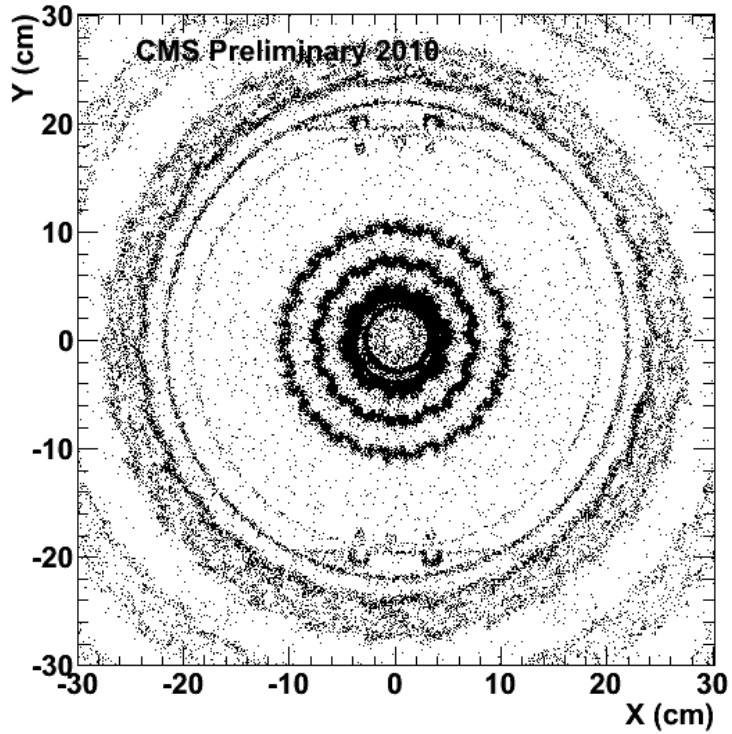
Onia

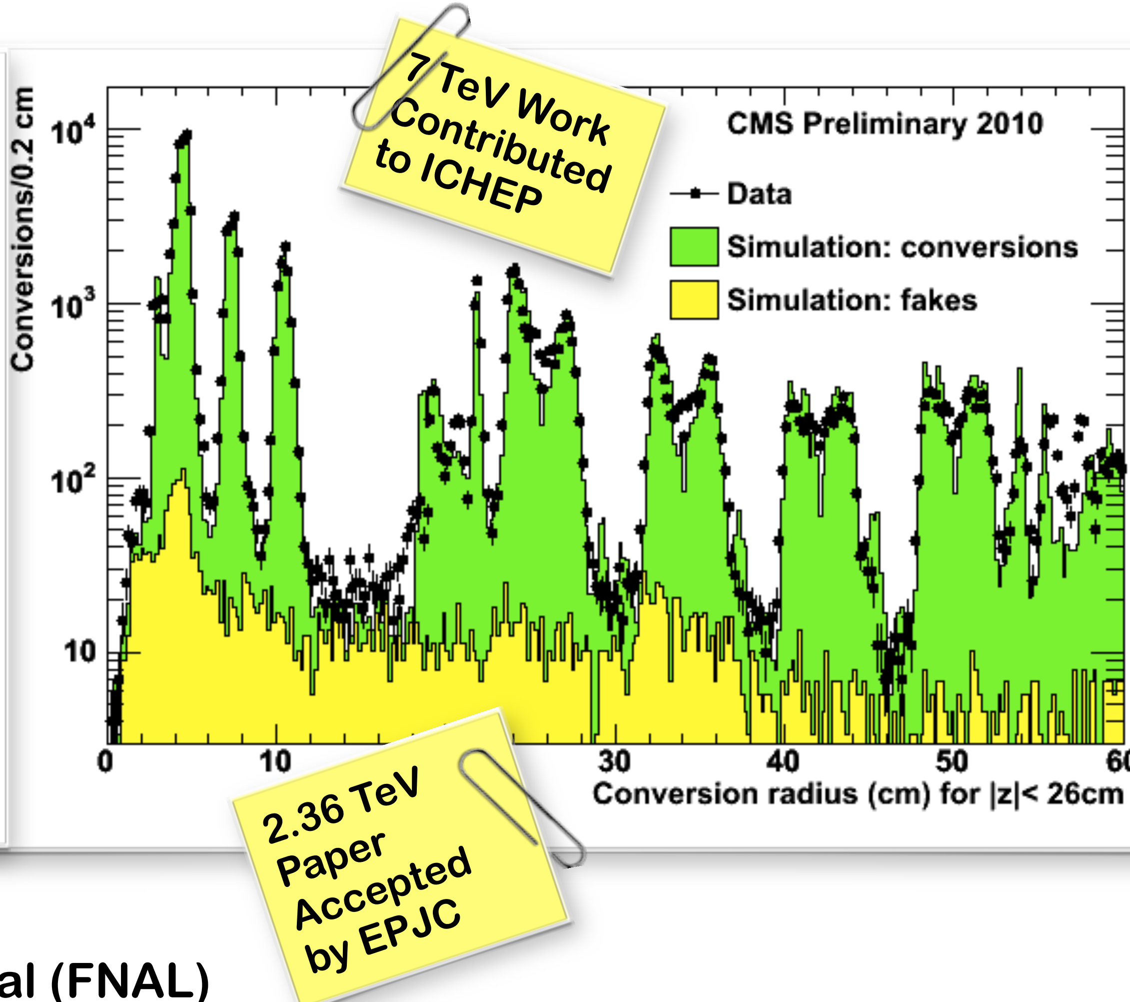
18 out of the 36 CMS contributions to ICHEP, had strong FNAL association.

21 out of the 36 CMS contributions to ICHEP, had strong LPC association.

4 out of the first 10 CMS Journal Publications (0.9, 2.36, 7 TeV), led by FNAL.

Tracking performance



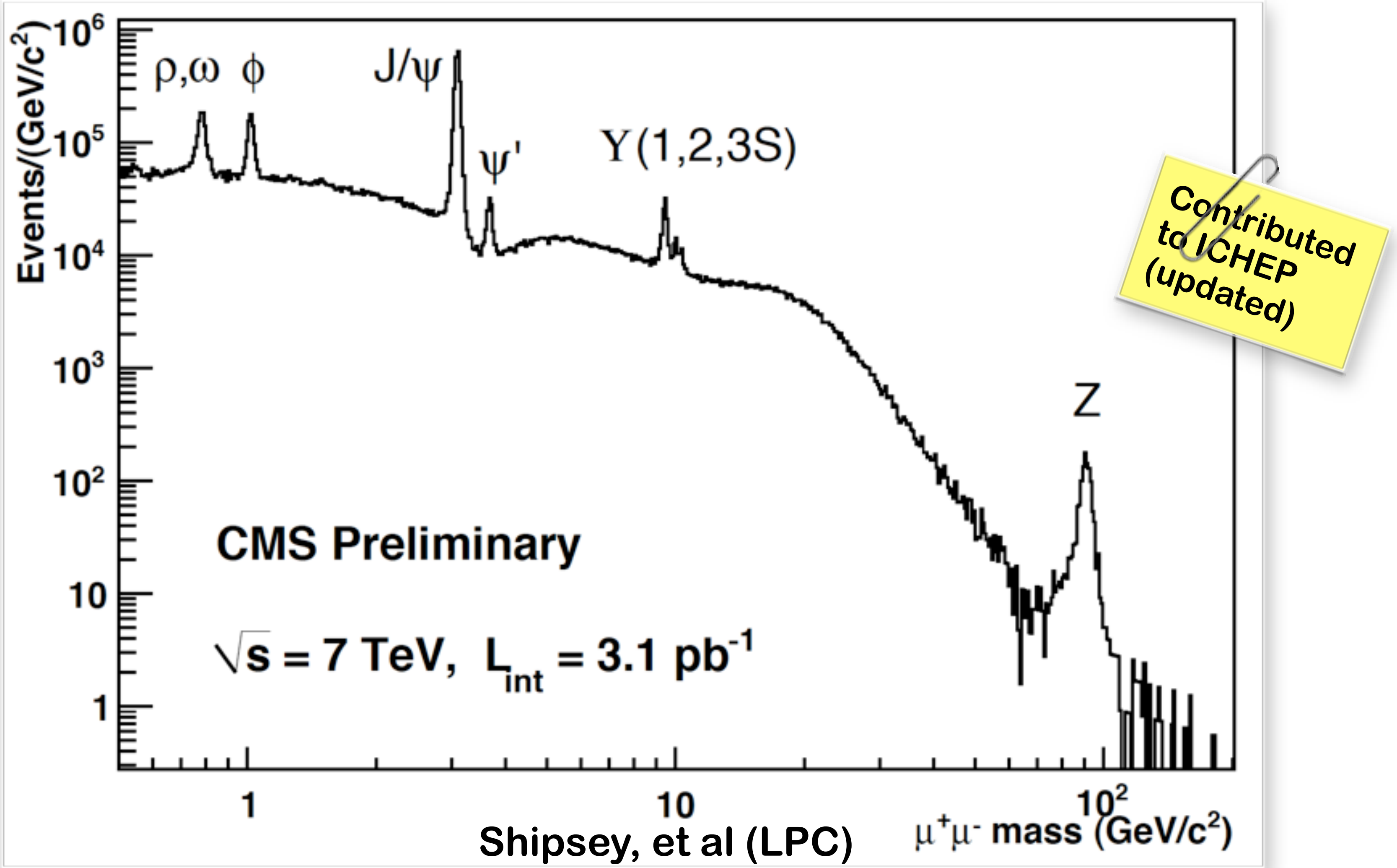


Kevin Burkett, et al (FNAL)

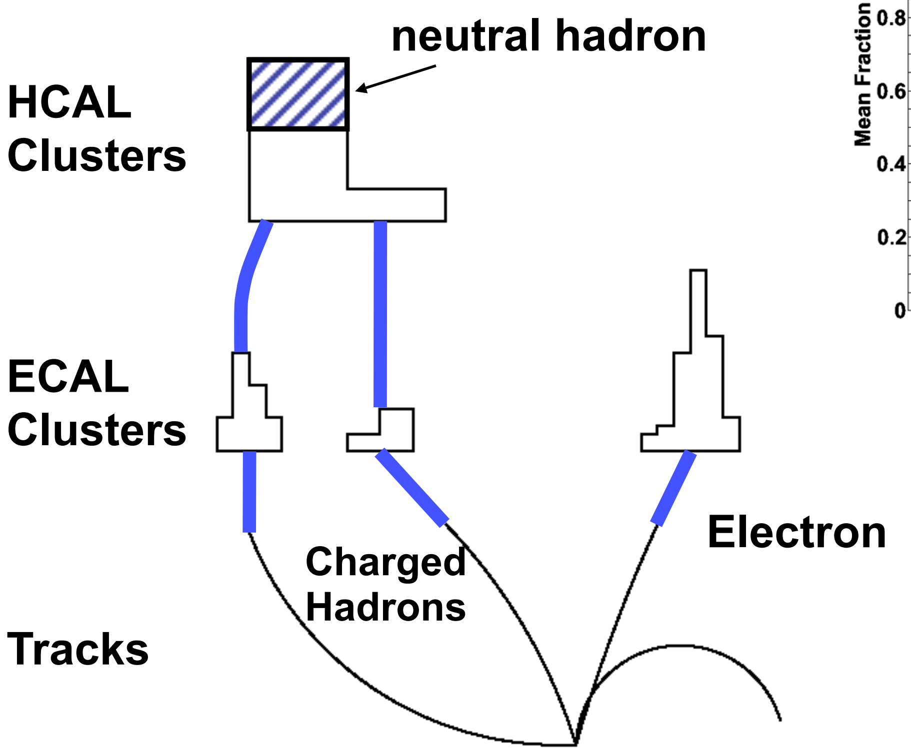
Dimuons in CMS

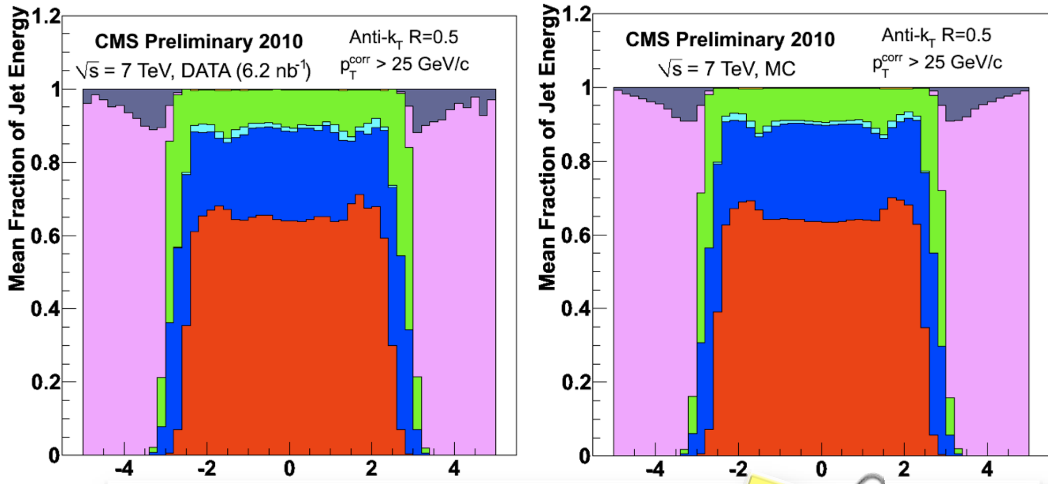
Fermilab

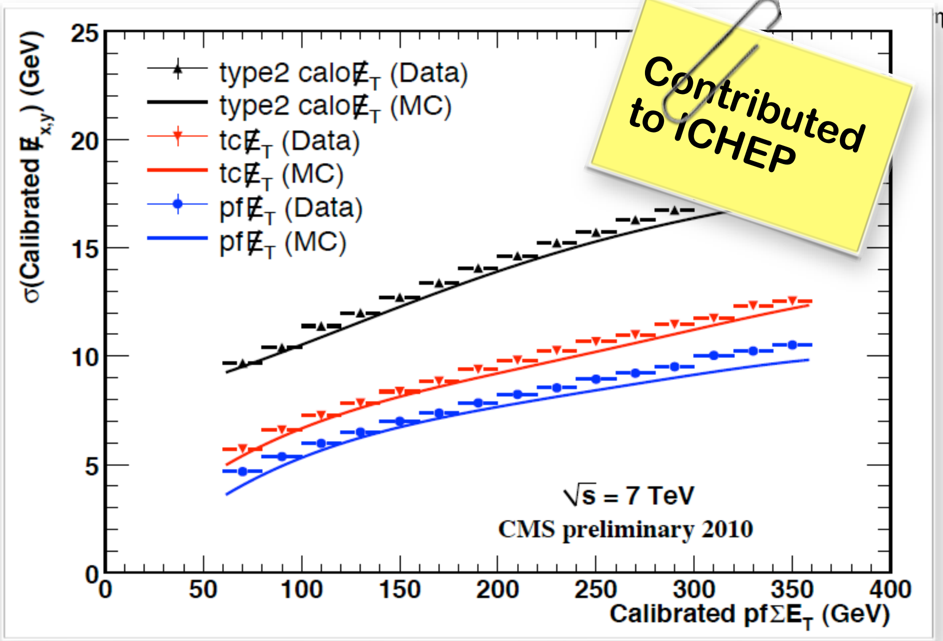
Vector Boson resonances over 2 orders of magnitude, from ρ to Z0



Shipsey, et al (LPC)

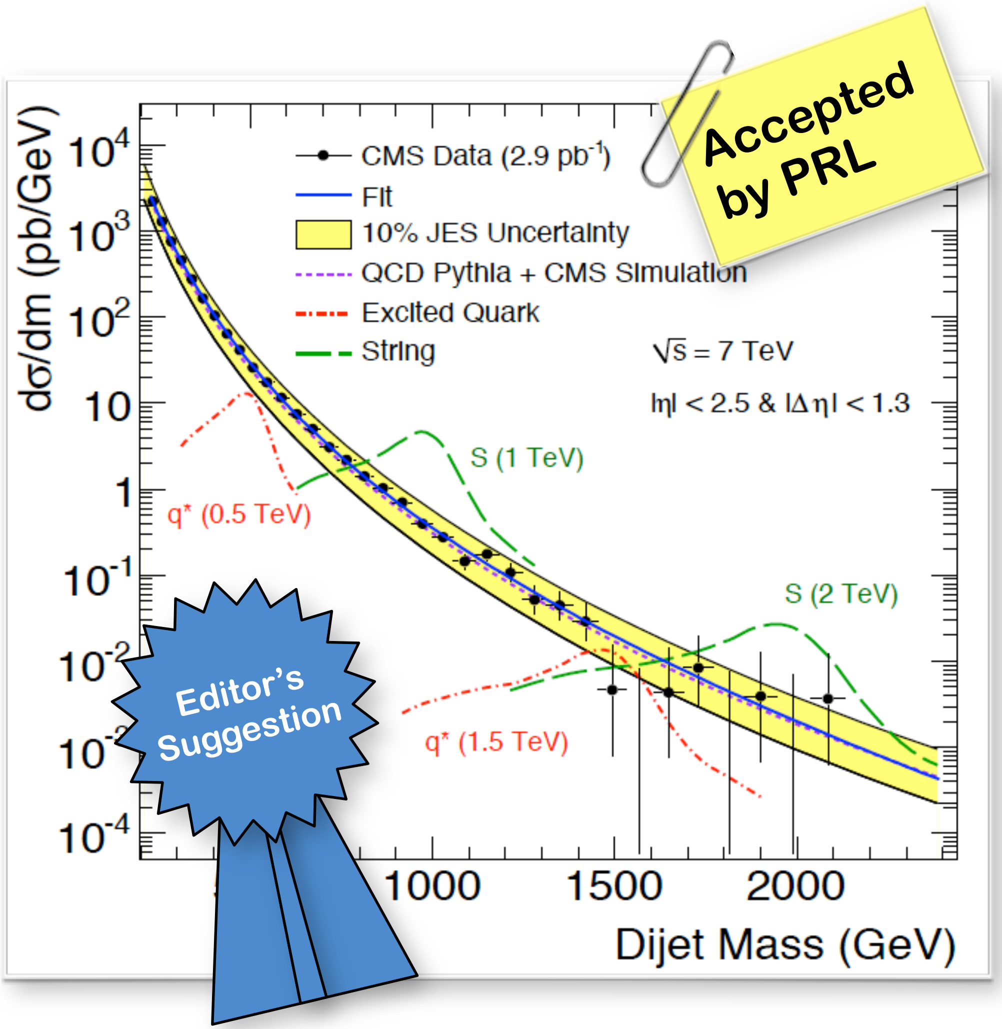


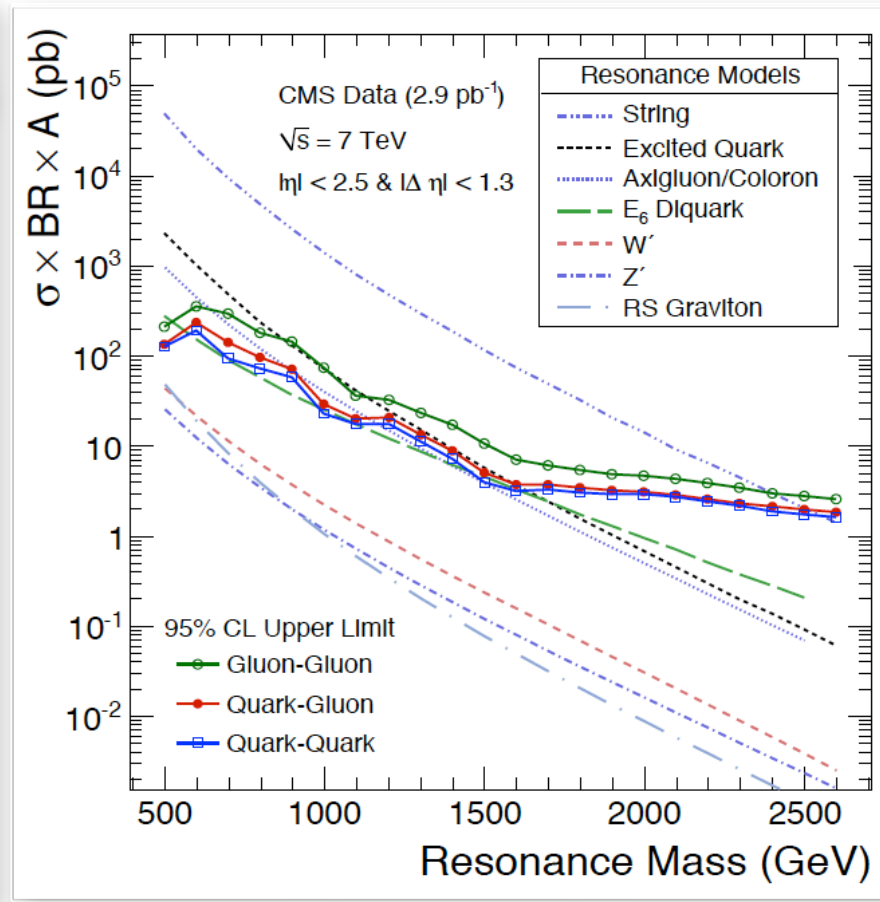




Cavanaugh, et al (FNAL)

Search for Dijet Resonances



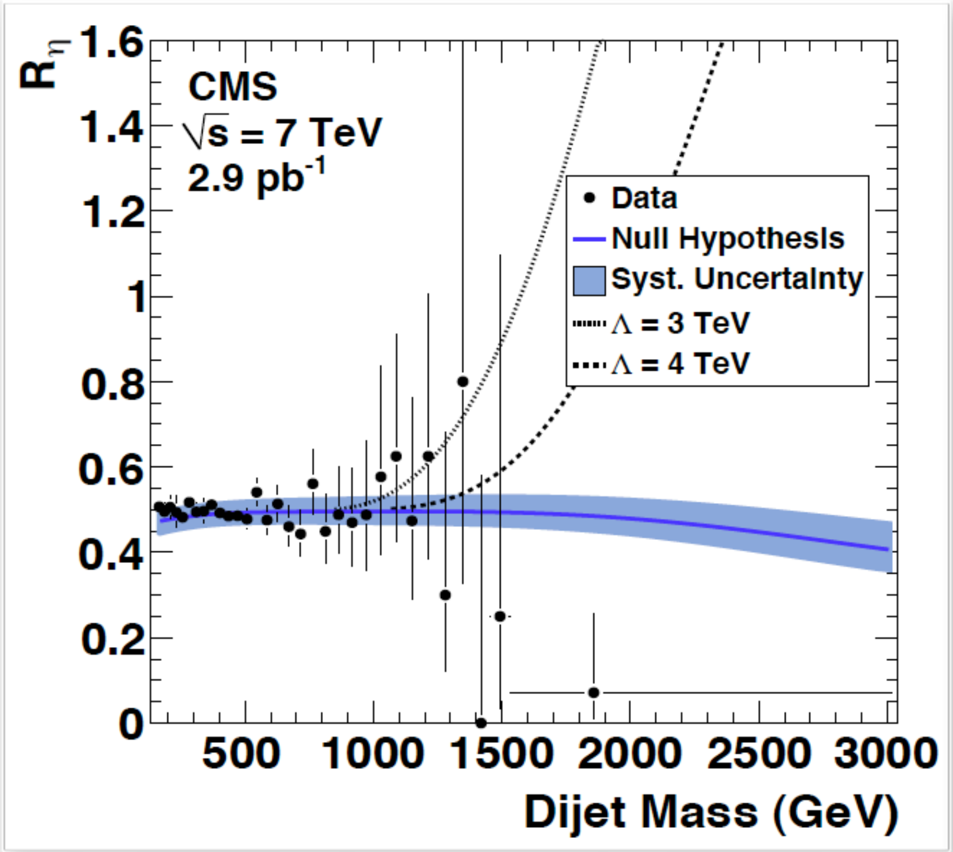


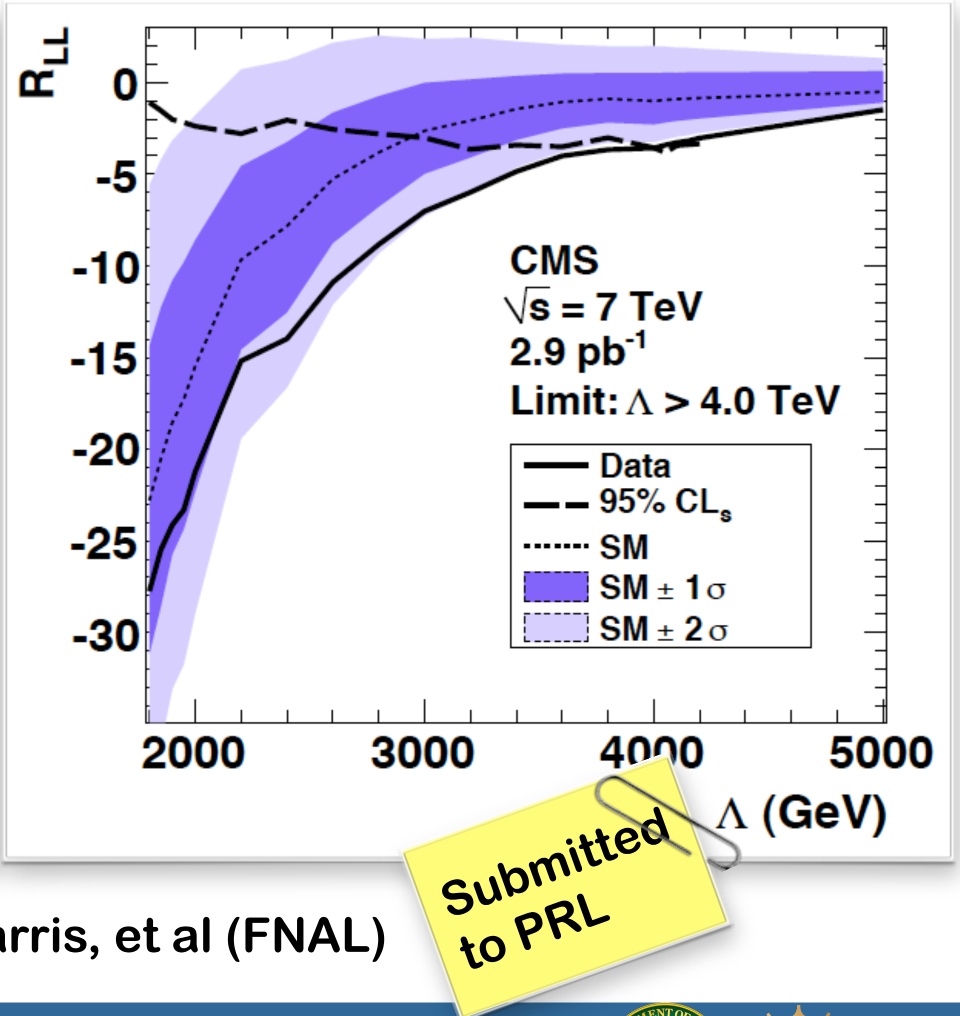
Rob Harris, et al (FNAL)

Search for Contact Interactions

Dijet Centrality Ratio

$$R_{LL} = \ln \mathcal{L}_{\Lambda} - \ln \mathcal{L}_{\mathrm{QCD}}$$

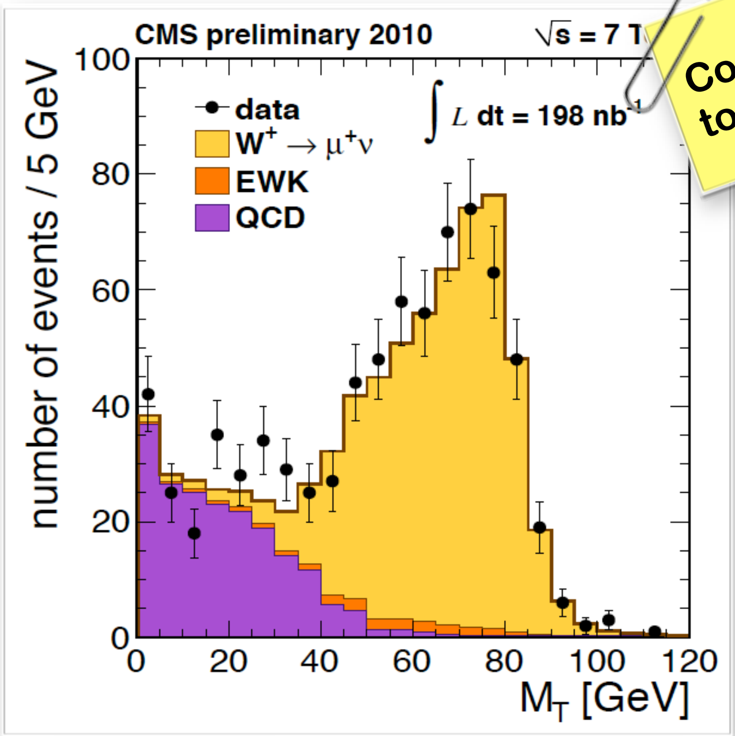




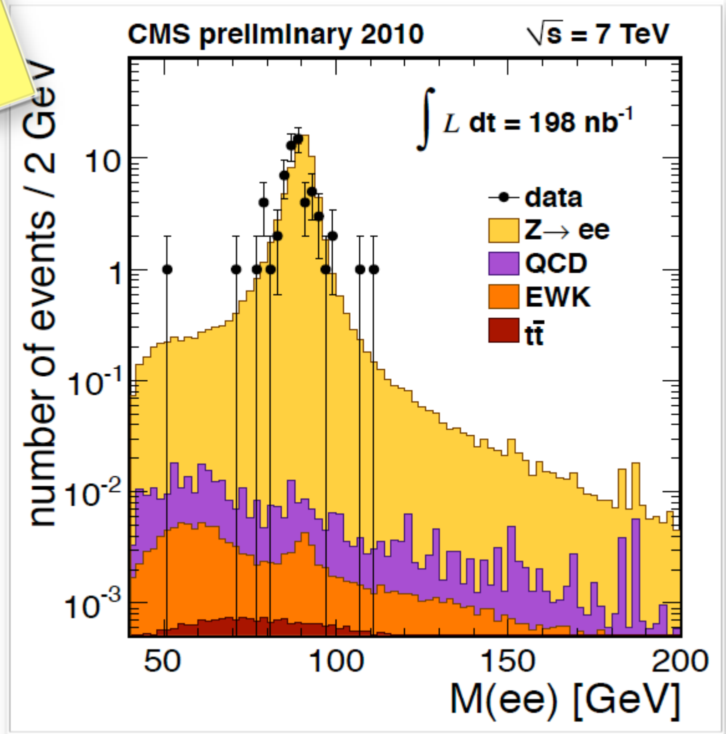
$$R_\eta = \frac{N_{jj}(|\eta| < 0.7)}{N_{jj}(0.7 < |\eta| < 1.3)}$$

Rob Harris, et al (FNAL)

Inclusive W/Z Cross-section



Contributed to ICHEP

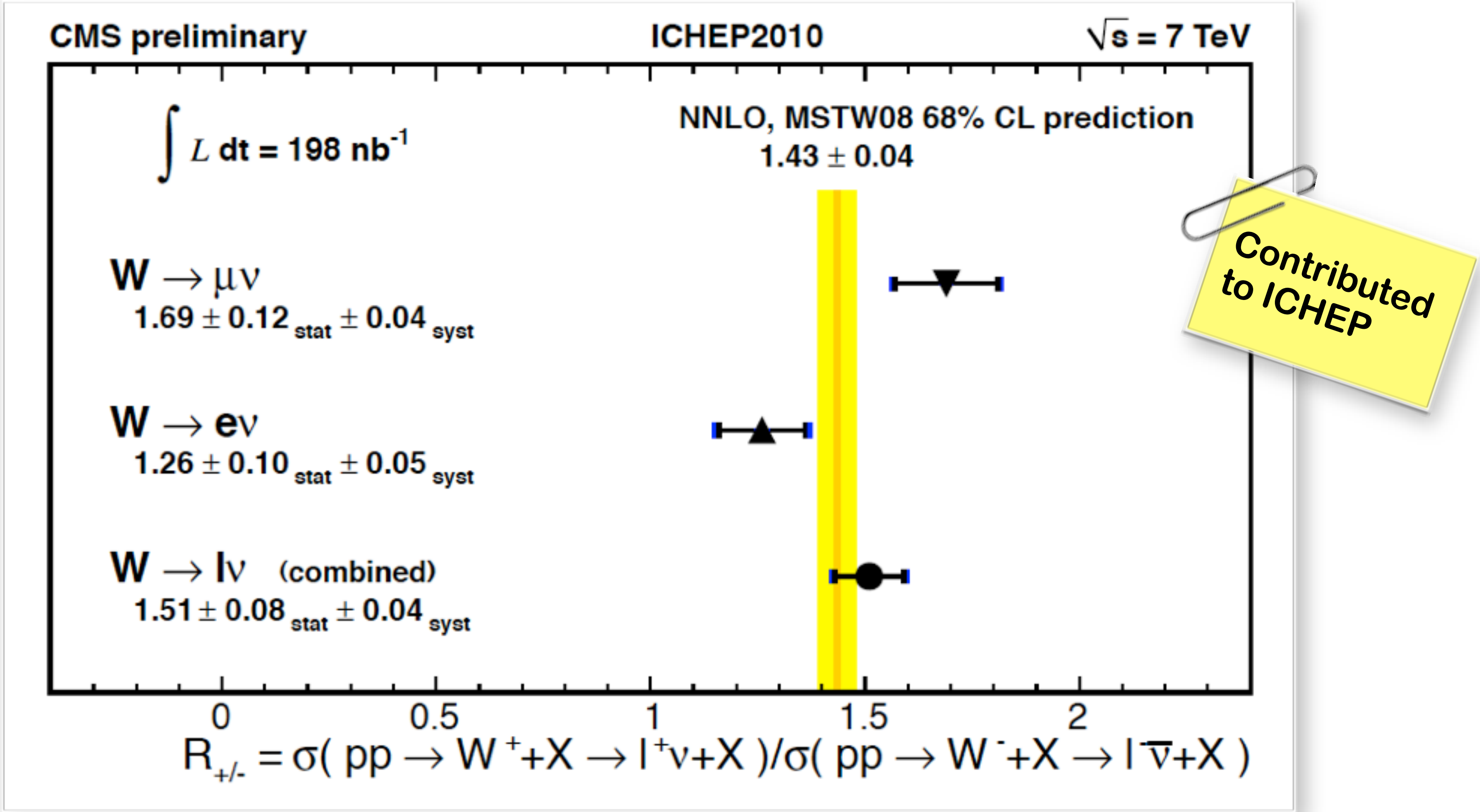


$$\sigma(\mathbf{pp} \to \mathbf{W} + \mathbf{X} \to \mathbf{l}\nu + \mathbf{X}) = \mathbf{9.22} \pm \mathbf{0.24}(\mathrm{stat}) \pm \mathbf{0.47}(\mathrm{syst}) \pm \mathbf{1.01}(\mathrm{lumi})\ \mathrm{nb}$$

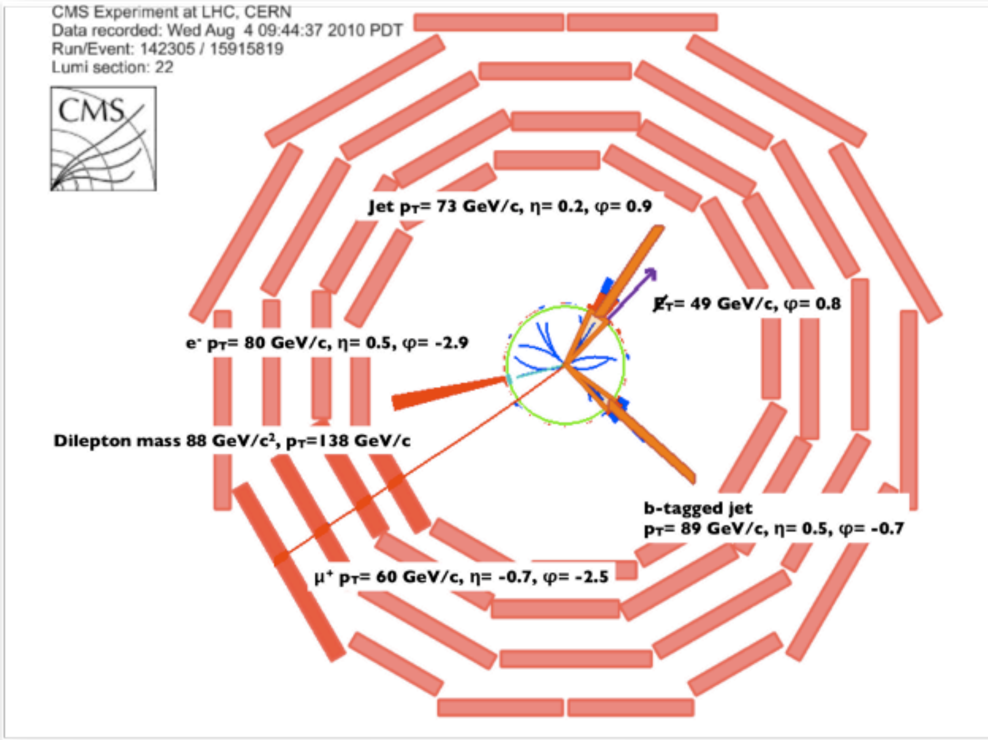
$$\sigma(\mathbf{pp} \to \mathbf{Z}(\gamma^*) + \mathbf{X} \to \mathbf{ll} + \mathbf{X}) = \mathbf{0.882}^{+\mathbf{0.077}}_{-\mathbf{0.073}}(\mathrm{stat})^{+\mathbf{0.042}}_{-\mathbf{0.036}}(\mathrm{syst}) \pm \mathbf{0.097}(\mathrm{lumi})\ \mathrm{nb}$$

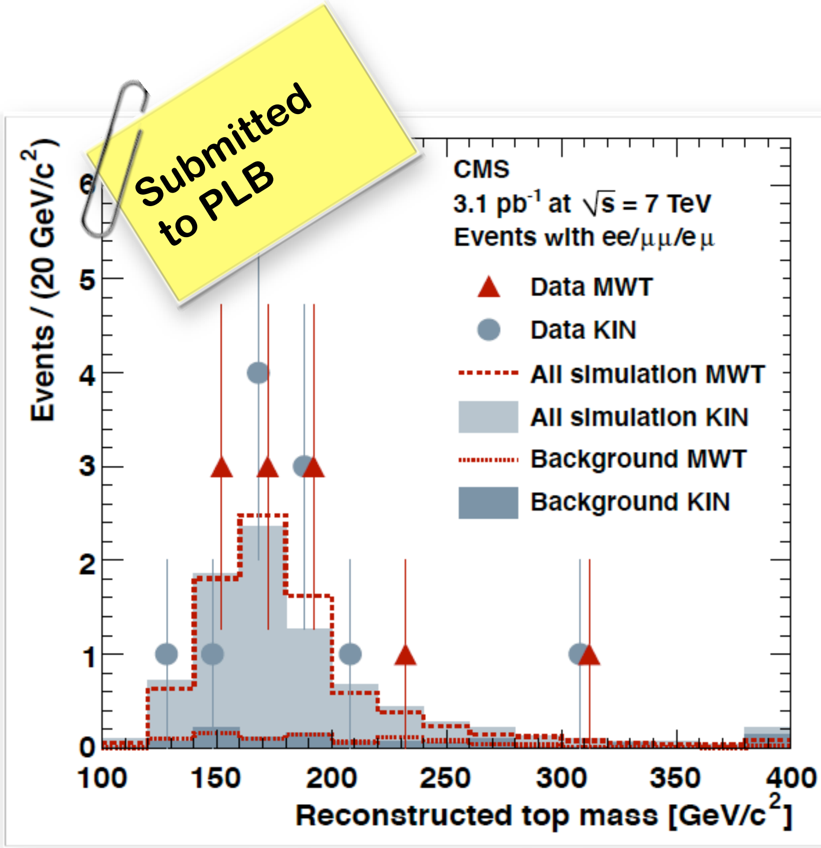
Jeff Berryhill, et al (FNAL)

W Asymmetry



Ping Tan, et al (FNAL)





$$\sigma(\mathbf{pp} \rightarrow \mathbf{t\bar{t}}) = \mathbf{194} \pm \mathbf{72}(\mathrm{stat}) \pm \mathbf{24}(\mathrm{syst}) \pm \mathbf{21}(\mathrm{lumi})\ \mathrm{pb}$$

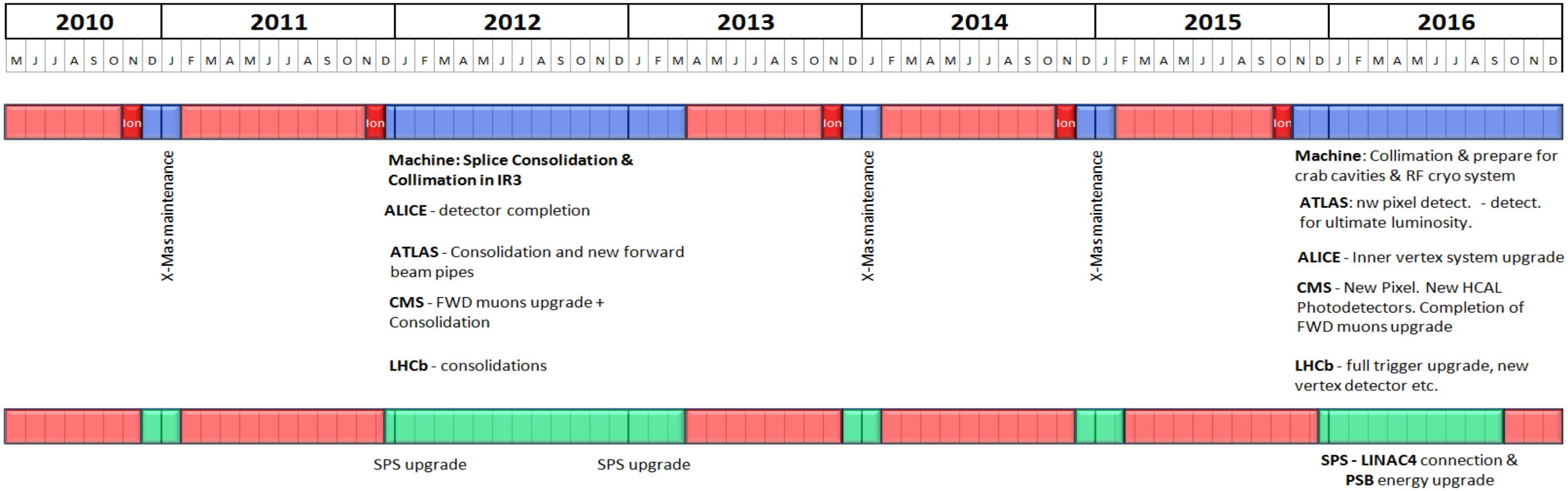
Francisco Yumiceva, et al (FNAL)

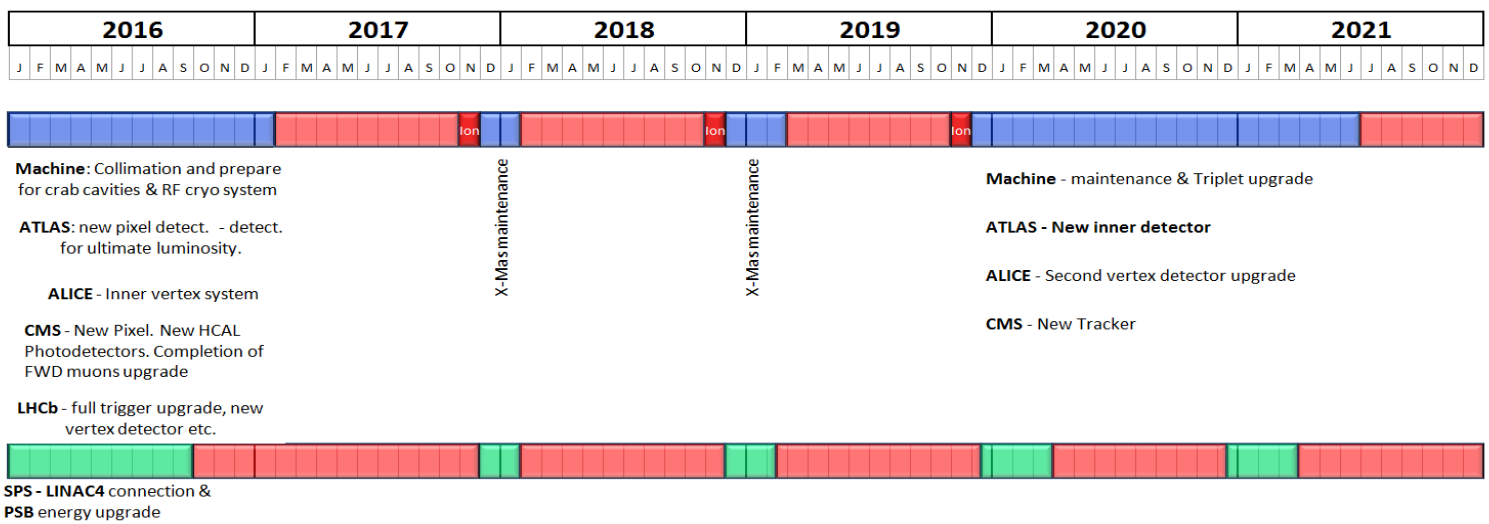
CERN Upgrade Plan

- **CERN "10 year Technical Plan" and Longer Range planning revealed at ICHEP 2010 on July 26**
  - "Phase 1 of Operations" through 2020 final luminosity is $2.18 \times 10^{34} cm^{-2} s^{-1}$
  - "Phase 2 of Operations" after 2020 with major upgrade of detectors to handle 300 fb^{-1}/year
- **Main consequences for upgrade:**
  - Two shutdowns currently scheduled for 2012 and 2016 dominate the schedule to prepare for Phase 1 operation
    - 2012 shutdown will bring the LHC to ~ design energy
    - Through 2020 the projected integrated luminosity~ 350 fb^{-1}.
    - 50% of the total is recorded with instantaneous luminosity > $1 \times 10^{34} cm^{-2} s^{-1}$
    - At end phase 1 operation, the luminosity/year is ~ 115 fb^{-1} so doubling time is 3 years

The 10 year technical Plan

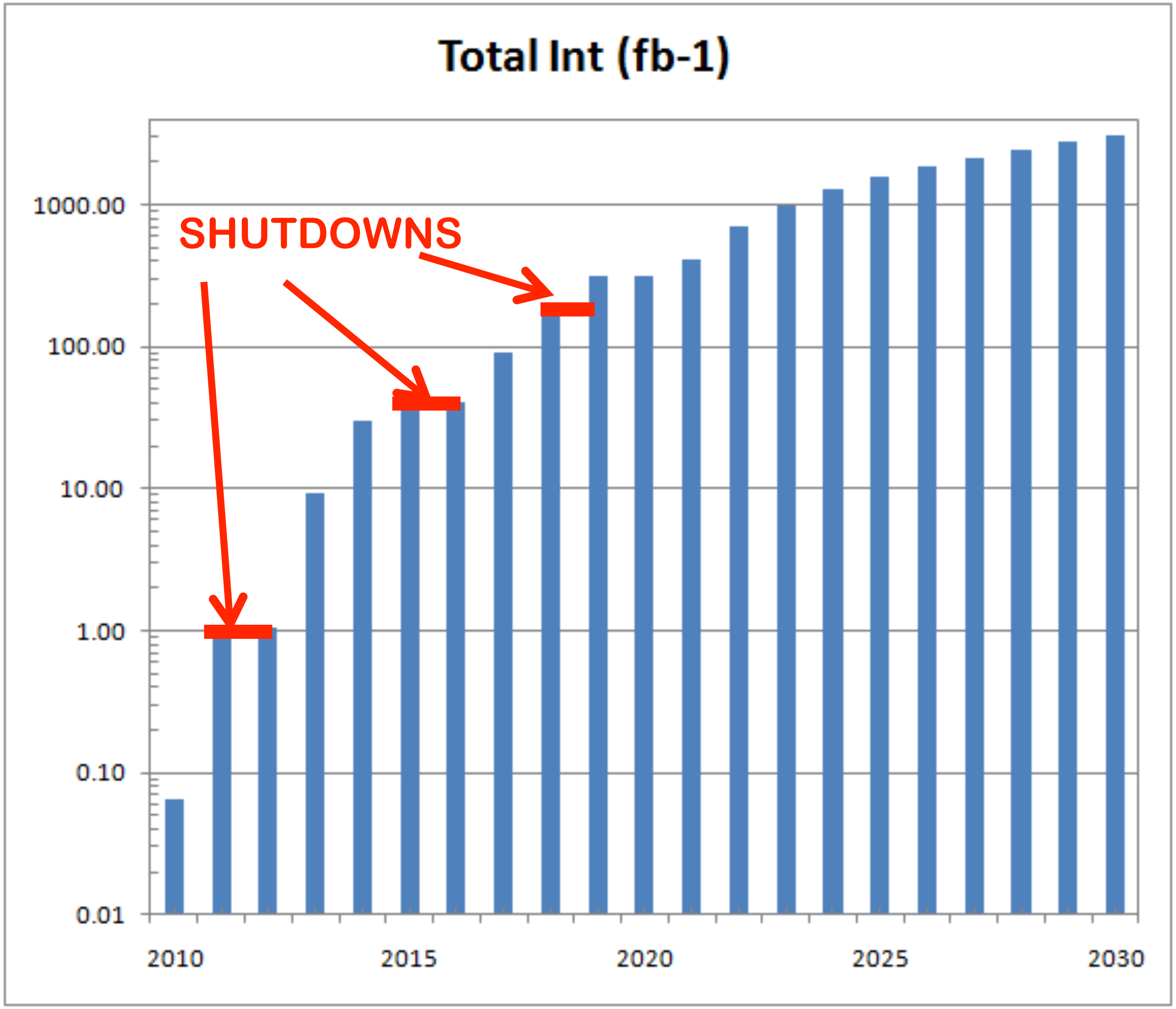
Fermilab





Preliminary Long Term Predictions

Fermilab



Requirements for Phase I detectors?

- They should be able to operate with a peak luminosity of up to 2 x 10^{34}
- They should be able to cope with an integrated luminosity of up to around 700/fb (quadrupoles radiation hardness limit)
  - Looking at potential increase in luminosity, this would only happen if Phase 1 goals were achieved but it was decided to extend the running (physics reasons, delays in readiness of upgrades of machine and/or experiments) for a few years
  - Question of whether they should be required to work at 50ns at highest luminosity
- They should offer increased physics performance to maximize the value of the luminosity we will get
- They should improve the robustness, maintenance ability, and up time of the detector

Planning for the Two Phase I shutdowns

- **Work plan for 2012 Shutdown well studied**
  - Timescale 2012 and extending into beginning of 2013 –with reasonable accuracy
  - Splices to permit operation close to 14 TeV
  - Collimator upgrade
- **Second Shutdown at the end of 2015 through 2016**
  - Final collimators for full luminosity
  - Bringing Linac4 online

- **EMU:** DCFEB in ME1/1 (now in EMU not in Upgrade R&D), re-certify construction of the ME4/2 chambers to be ready to start production
- **HCAL:** SiPM choice, QIE10 developments, new back end electronics
- **Pixel:** CO2 cooling and new mechanics to reduce material budget
- **Trigger improvements:** upgrade the Local Charged Tracks (LCT)and the muon port card for the CSC trigger, upgrade the Regional and the Global Calorimeter Trigger (RCT and the GCT)

Schedule and US R&D effort

Fermilab

Detector	2012 Shutdown	Technical Stop	2016 Shutdown	Comment
CSC and RPC endcap 1	X			
CSC and RPC endcap 2		X		
CSC and RPC endcap 2			X	If necessary
ME1/1 electronics			X	
DT mods			X	Some work may be done 2012 (fibres to USC)
HO	X			
HF	X			Additional electronics work later
CASTOR	X			
PLT	X			
HE/HB			X	Need to develop SiPM
PIXELS			X	
TRIGGER			X	
DAQ			X	
BSC and other			X	Some work done before

Summary

- Fermilab has crucial and leading roles in CMS, participating in nearly all aspects of the experiment
  - Operate and upgrade detectors, software, and computing systems
  - Provide first-class facilities for US physicists to participate in CMS
    - computing facilities, Remote Operations Center, LHC Physics Center
- Fermilab CMS group has a broad & productive research program
  - starting from detector commissioning and calibration
  - establishing the physics objects and signatures
  - re-measuring the standard model
  - toward the exciting discoveries expected beyond the standard model
- The CMS program will produce exciting and fundamental contributions to science over the coming 20 years, and Fermilab will play a huge part in it

Backups

Preliminary Luminosity Predictions

Year	TeV	OEF	β*	Nb	Ib	Itot	MJ	Peak luminosity	Pile up	pb-1/day	Physics Days	Integrated (fb-1/year)	Total Int (fb-1)
2010	3.50	0.20	2.00	796	8.0E+10	6.4E+13	36.0	1.886E+32	1.2643	3.3	20.0	0.1	0.07
2011	3.50	0.25	2.00	796	8.0E+10	6.4E+13	36.0	1.886E+32	1.2643	4.1	240.0	0.98	1.04
2012												0.0	1.0
2013	6.50	0.20	0.55	796	1.15E+11	9.2E+13	96.1	2.632E+33	17.6429	45.5	180.0	8.2	9.2
2014	7.00	0.20	0.55	1404	1.15E+11	1.6E+14	182.5	5.000E+33	19.0000	86.4	240.0	20.7	30.0
2015	7.00	0.20	0.55	2808	1.15E+11	3.2E+14	365.0	1.000E+34	19.0000	172.8	210.0	36.3	66.3
2016											0.0	0.0	66.3
2017	7.00	0.25	0.55	2808	1.15E+11	3.2E+14	365.0	1.000E+34	19.0000	216.0	240.0	51.8	118.1
2018	7.00	0.28	0.55	2808	1.50E+11	4.2E+14	476.1	1.701E+34	32.3251	411.6	240.0	98.8	216.9
2019	7.00	0.30	0.55	2808	1.70E+11	4.8E+14	539.6	2.185E+34	41.5198	566.4	210.0	118.9	335.8
2020											0.0	0.0	335.8
2021	7.00	0.20	0.30	2808	1.70E+11	4.8E+14	539.6	4.006E+34	76.1197	692.3	150.0	103.8	439.7
2022	7.00	0.27	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1257.3	220.0	276.6	716.3
2023	7.00	0.27	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1257.3	220.0	276.6	992.9
2024	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1290.0
2025	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1587.1
2026	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	1884.2
2027	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2181.3
2028	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2478.4
2029	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	2775.5
2030	7.00	0.29	0.25	2808	1.80E+11	5.1E+14	571.3	5.390E+34	102.4060	1350.5	220.0	297.1	3072.6

Muon CSC Upgrade

Fermilab

- By 2015 the luminosity will reach 10^{34} $cm^{-2}s^{-1}$. The in-time pileup will present challenges for the Muon System to trigger on P_T of the muons
- Cathode Strip Chambers (CSCs) upgrade is driven by considerations of the impact of peak instantaneous luminosity on the muon trigger.
  - Addition of a fourth layer of chambers (ME4/2) to reduce the accidental trigger rate and to preserve a low P_T threshold for the Level 1 MuonTrigger at high instantaneous luminosity;
  - Upgrade of the layer 1 (ME1/1) electronics with a new CSC "Digital" Front End Board (DCFEB) so every strip can be read out separately (they are now ganged into groups of three). This will allow ME1/1 to contribute effectively to the muon trigger at high instantaneous luminosity so CMS can retain four plane coverage from $2.1 < |\eta| < 2.5$
  - Deployment of new muon trigger primitive electronics to deliver the additional muon track segments, produced at high luminosity, and by the additional planes, to the upgraded CSC Trigger Track-Finder.

HCAL HB and HE Upgrade

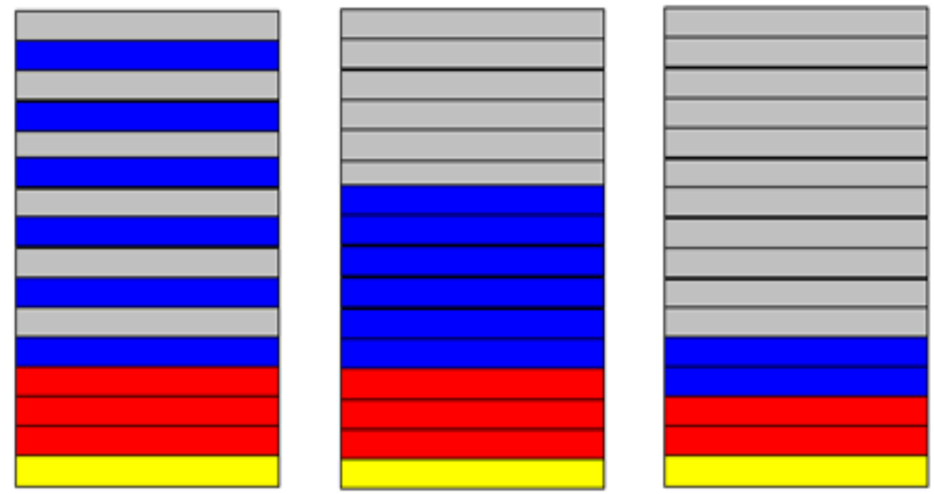
- This upgrade is directed at handling instantaneous luminosity, integrated luminosity, overall robustness and efficiency and providing opportunities to make improvements to the trigger at all luminosities.
- Calorimeters inside the CMS Solenoid (HB/HE)
  - Replacement of the HPDs with an improved photo-detector, the Silicon Photomultiplier (SiPM). SiPMs have better quantum efficiency, higher gain, and better immunity to magnetic fields than HPDs. Since SiPMs operate at relatively low voltages, they do not produce large pulses from high voltage breakdown that mimic energetic showers like HPDs do. These features of the SiPMs together with their compact size compared to HPDs enable several major changes to the HCAL.
  - Implementation of depth segmentation, which has advantages in coping with higher luminosities and compensating for radiation damage to the scintillators. This is made possible by the use of SiPMs;
  - Use of timing to clean up backgrounds, made possible by the extra gain and better signal-to-noise of the SiPMs
  - New backend electronics designed to provide enhanced information to the upgraded Regional Calorimeter Trigger (RCT).

Improved HCAL capabilities

Fermilab

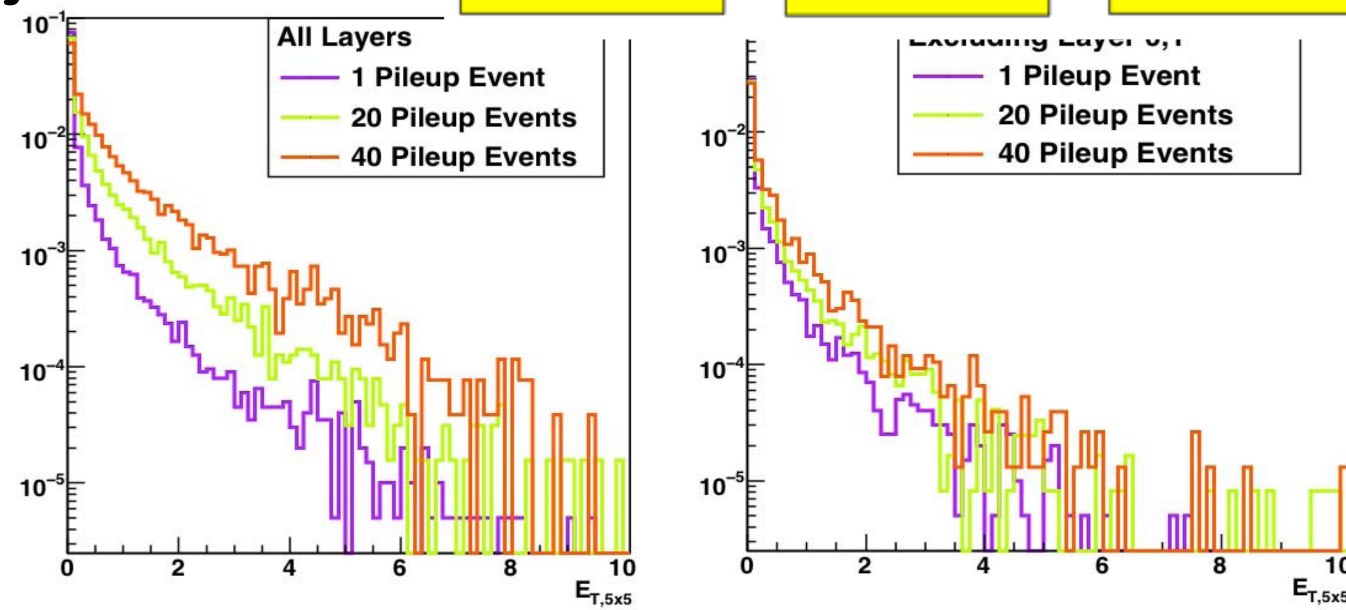
- **Separate Layer-0 Readout**
- **Layer 0 is different from the others, no absorber in front, x 2.4 thickness and 20% brighter scintillator**
- **Catches shower tails from low energy pions from pileup, layer 0 was originally designed to be readout separately**

Examples of longitudinal segmentation into 4 channels



PILE-UP Mitigation

new trigger primitives that remove layer-0 from tower E_T when Layer 0/all layers >0.9



Lepton isolation

- **Preliminary results on trigger improvements when excluding Layer 0**

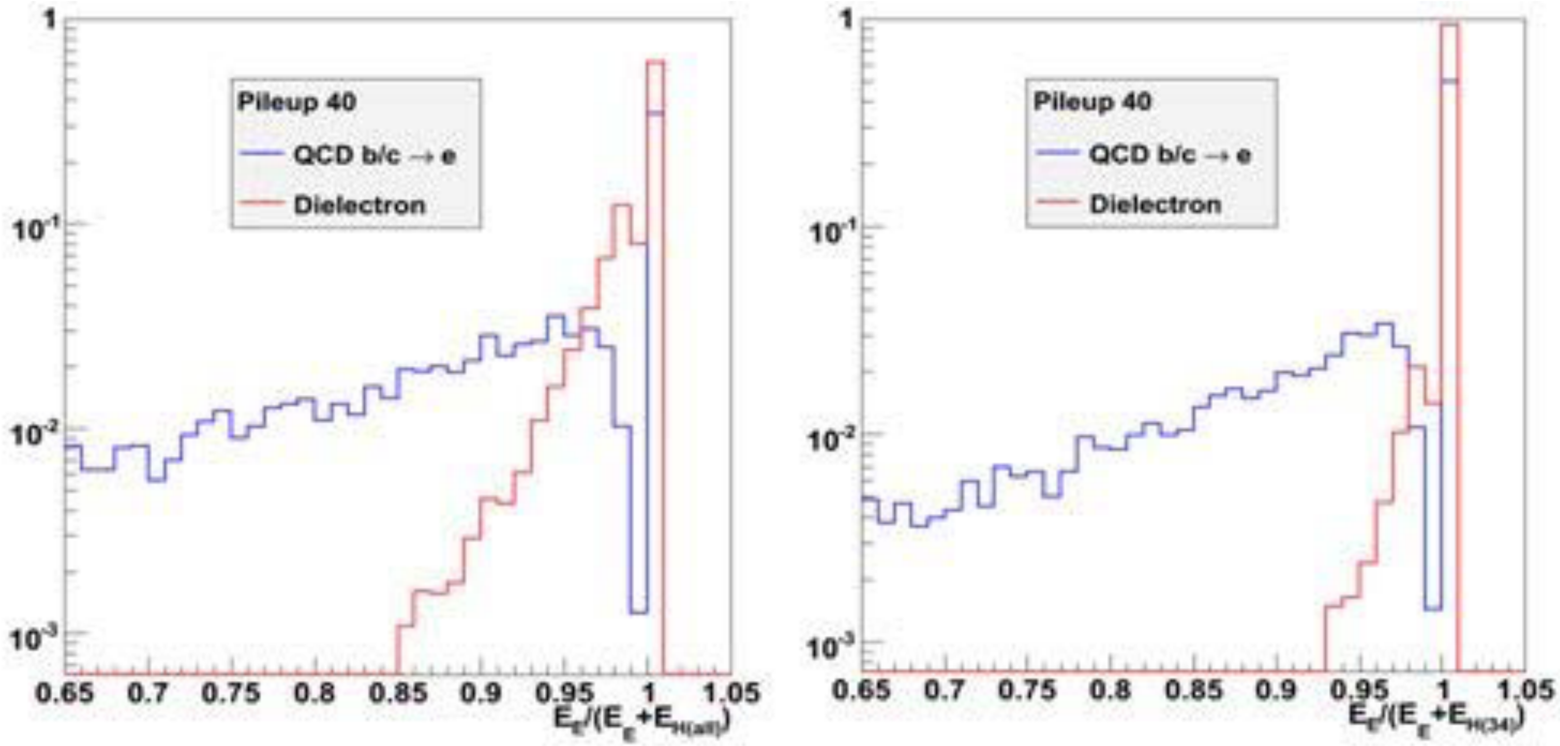
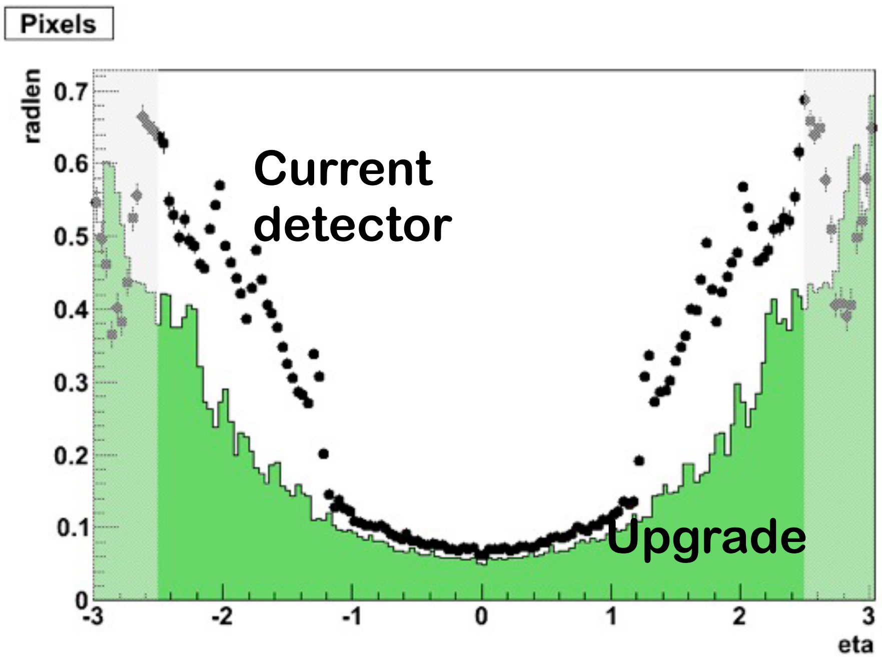


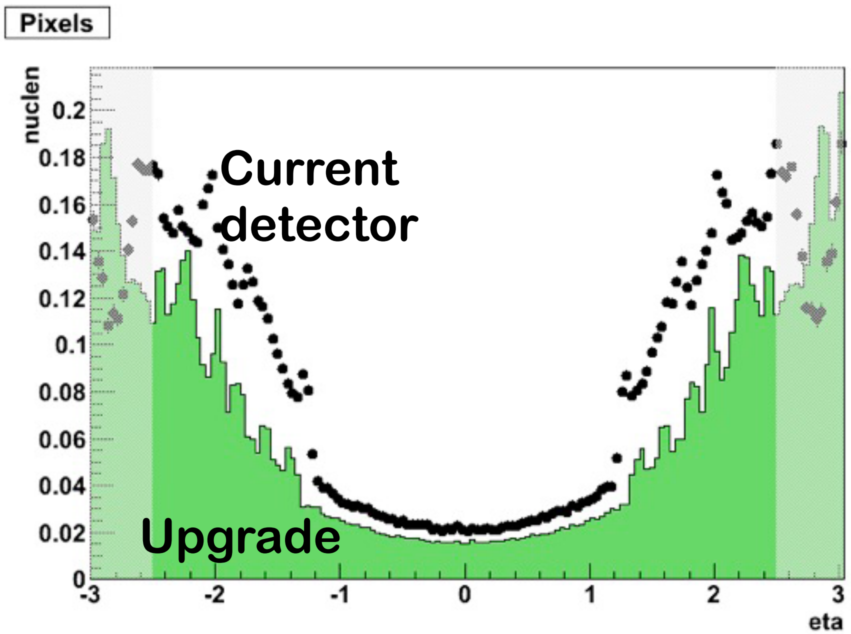
Figure 4.18: Pileup at 2×10^{34} can reduce the capability to trigger on isolated leptons. The left side of the figure shows the impact of using all HCAL layers in the determination of isolation; the right hand side shows how this improves when the first layer of the HCAL is not used.

Pixel Upgrade

- The goal of the Phase 1 pixel upgrade is to provide a detector that can maintain a high tracking efficiency at a luminosity of $2\times10^{34}\ cm^{-2}s^{-1}$, with much less material, and will provide 4 hits over pseudorapidities up to 2.5. The main features of the upgraded detector are:
  - Replacement of the current 3 layer barrel , 2 disk endcap system with a 4 layer barrel, 3 disk endcap system for four hit coverage.
  - Ultra-lightweight support with CO2 cooling and displacement of the electronic boards and connections out of the tracking volume for material reduction.
  - Development of a new readout chip with reduced data loss at higher collision rates expected in Phase 1.
  - Development of high bandwidth readout electronics and links as well as DC-DC power converters, which allow reuse of the existing fibers and cables.
  - The extra layers with reduced mass, reduced innermost radius and increased lever arm significantly improve performance over the present system against all relevant criteria, such as tracking, vertexing and b-jet identification.

Material budget

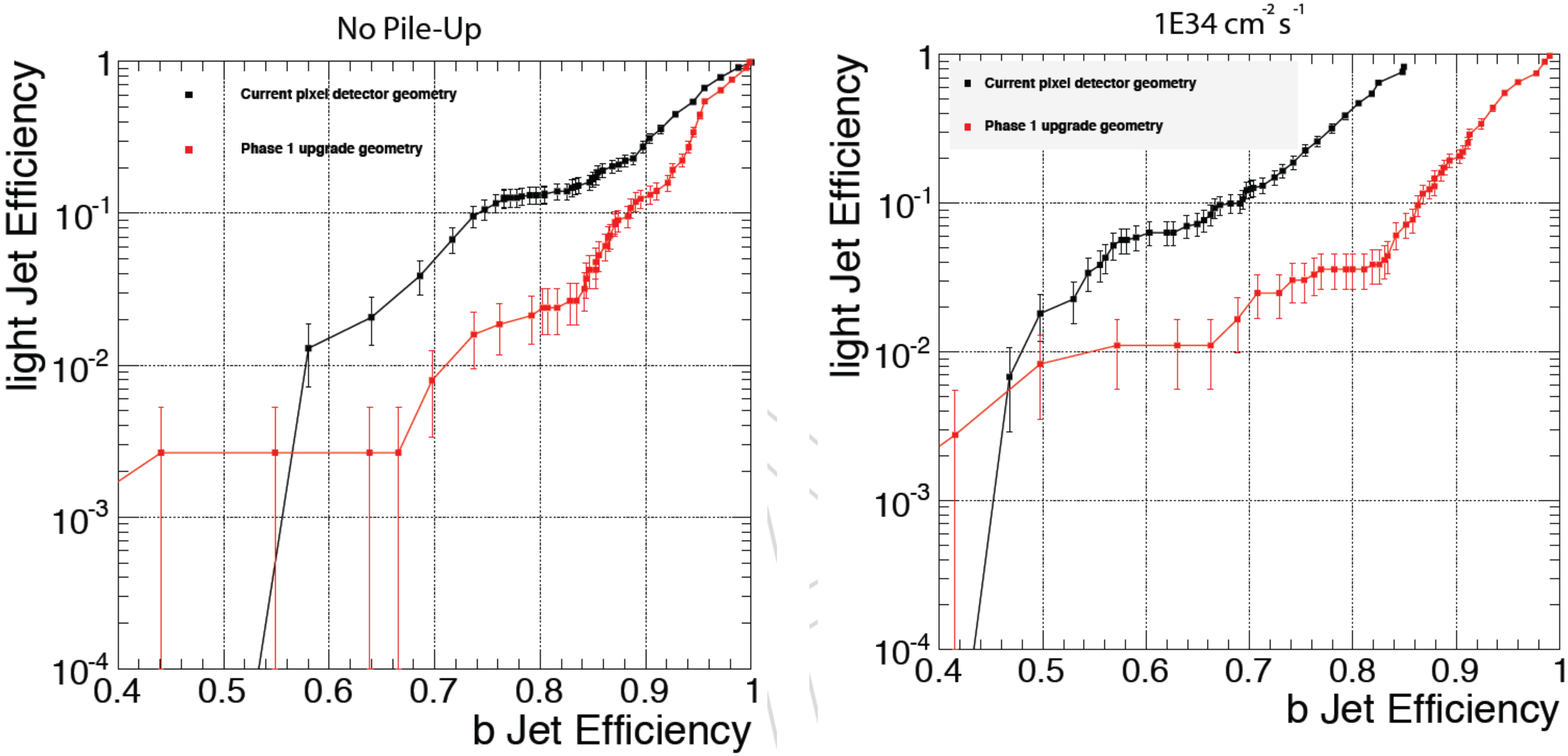




- Radiation length
- Nuclear interaction length

Reductions in the amount of passive material will have a large impact on charged particle tracking efficiency as well as electron and photon identification and resolution. For example, for a photon at $|\eta| = 1.5$, the probability that it would convert into an electron-positron pair inside the pixel volume is 22%with the current detector, but would be 11%with the proposed upgraded detector. Implications for $H \rightarrow \gamma\gamma$.

B-tagging



- **The upgraded detector would reduce the light quark background of the Combined Secondary Vertex Tag by more than a factor of 6 for a b-efficiency of 60% or conversely, it would increase the b-efficiency by 50% at the fixed light quark efficiency of 5×10−2.**

Trigger system

- The trigger system will migrate to a new technology which is more maintainable and more flexible with respect to data interconnection than the current VME system. The candidate is μ-TCA, which has become important in many commercial areas, including telecommunications and other applications requiring high speed and bandwidth, and has been used in the current version of the Global Calorimeter Trigger. The trigger upgrade includes:
  - Rebuilding the Regional Calorimeter Trigger (RCT) using advanced technologies, such as μ-TCA to take advantage of the full granularity of the data available from the calorimeter front end and to implement more sophisticated clustering and isolation algorithms. This will permit the trigger to handle higher rates and more complex events;
  - Rebuilding the CSC Trigger Track-Finder to accommodate the additional information from ME4/2 and ME1/1, to use more input segments and to combine a greater variety of tracks to enhance performance amidst greater occupancy and backgrounds;