CMS Upgrade and US/Fermilab Roles

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- **Outline**
  - The physics reach
  - Machine upgrade scenarios
  - The CMS detector upgrade plans
  - The role of FNAL
  - Examples of R&D
  - Conclusions

The Physics of the TeV scale

- New particle physics era where experimental data has to direct theoretical
- New physics expected in TeV energy range
  - Many frameworks for physics beyond the standard model
  - Each containing a large set of models
  - Ex. SUSY spectrum could be complex

- <u>Large data </u>set are expected to be needed to solve the LHC inverse problem: Reconstruct the Lagrangian of new physics
- Initial LHC data should point to the physics emerging at the TEV scale and to the detector capabilities necessary to study it
- More luminosity will:

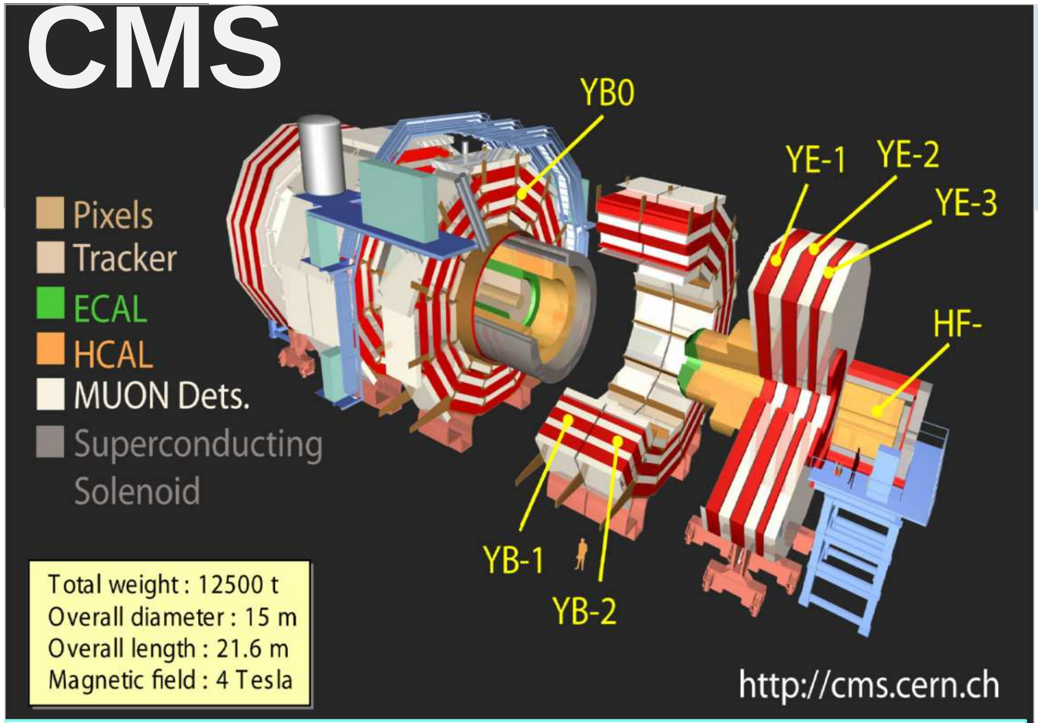
  1)Improve the accuracy of SM parameters

  2)Improve measurement of new phenomena observed at the LHC

  3)Extend the sensitivity to rare processes

  4)Extend the discovery reach in the high-mass region

CMS



- **Tracking is based on all-silicon components**
  - **A silicon pixel detector with 66 million pixels, 4 - 11 cm**
  - **A silicon microstrip detector with 11 million strips, out to 1.2m**
  - **Excellent primary and secondary vertex reconstruction**
  - **High segmentation yields low occupancy**

- **Large solenoid (d=6m, l=13 m) 4 Tesla field**
- **Tracking and calorimetry inside the solenoid**
  - **Avoid to degrade in energy resolution**
- **Strong B field**
  - **Coils up soft charged particles**
  - **Excellent momentum resolution**
- **A lead tungstate crystal calorimeter (~80K crystals) for photon and electron reconstruction**
  - **Excellent energy resolution**
- **Brass/scintillator Hadronic calorimeter**
- **Tracking chambers in the return iron track and identify muons**
  - **Very compact system**

We believe that maintaining the expected performance at 10^{34} will be essential for the physics reach of the upgraded LHC

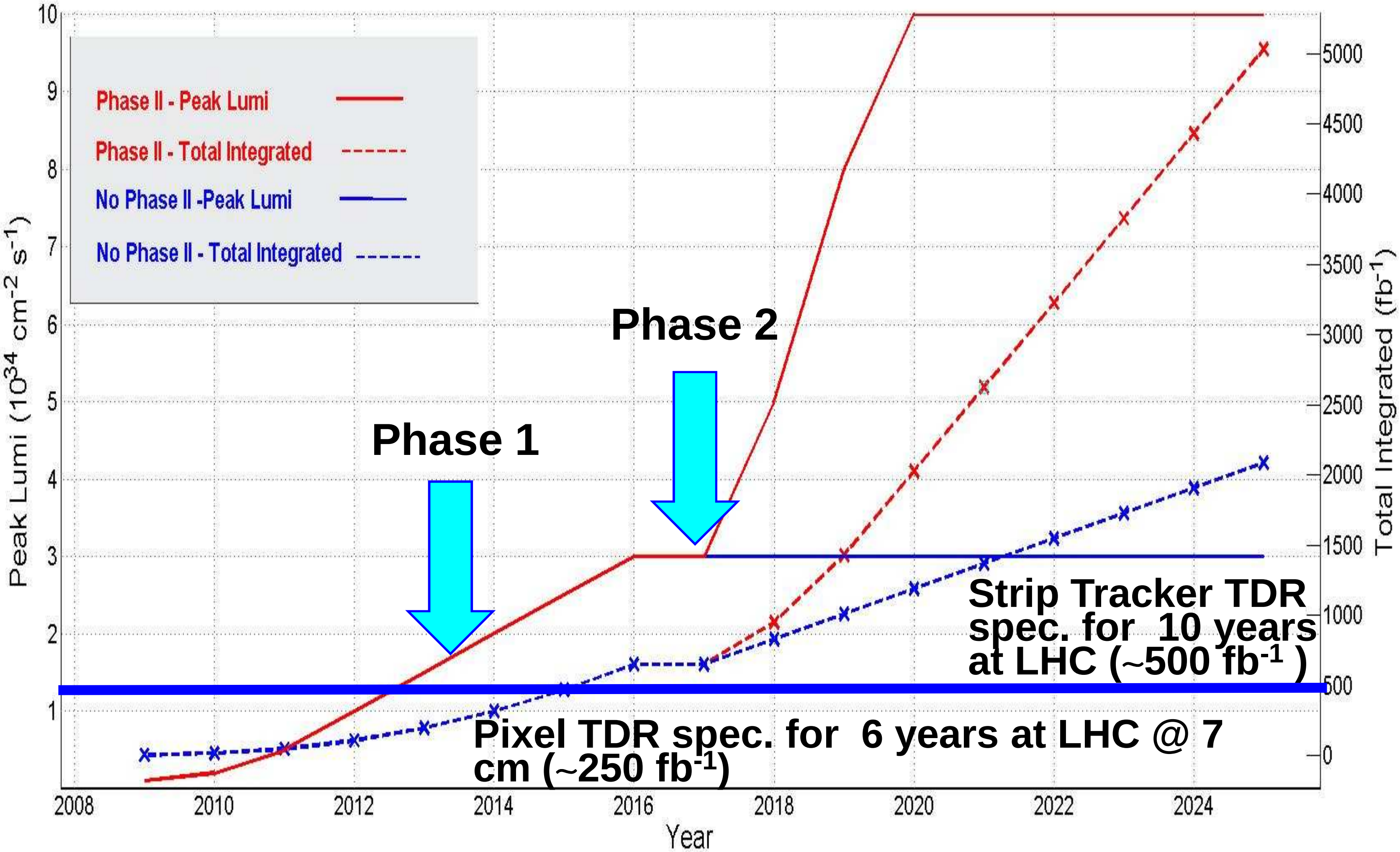
Upgrade scenarios

- **In January 2008 CERN presented a detailed plan for the machine upgrade**
  - **PHASE 1 to start in 2013 with L= 2-4 × 10^{34} cm^{-2} s^{-1}**
  - **PHASE 2 to be decided in 2011 with L=8 × 10^{34} cm^{-2} s^{-1} and to start in 2016 (More recently Luminosity leveling at L=5 × 10^{34} cm^{-2} s^{-1} has been discussed)**

Phase 1 well defined

1. **The interfaces between LHC and experiments remain unchanged at ± 19 m.**
2. **Beam crossing remains 25 ns**
3. **Reliable operation of the LHC at double the operating luminosity**
   - **Linac4 now under construction (potential to double the intensity/ pulse)**
   - **Improve collimation**
   - **IR upgrade to enable focusing of the beams to β*=0.25 m in IP1 and IP5 .**

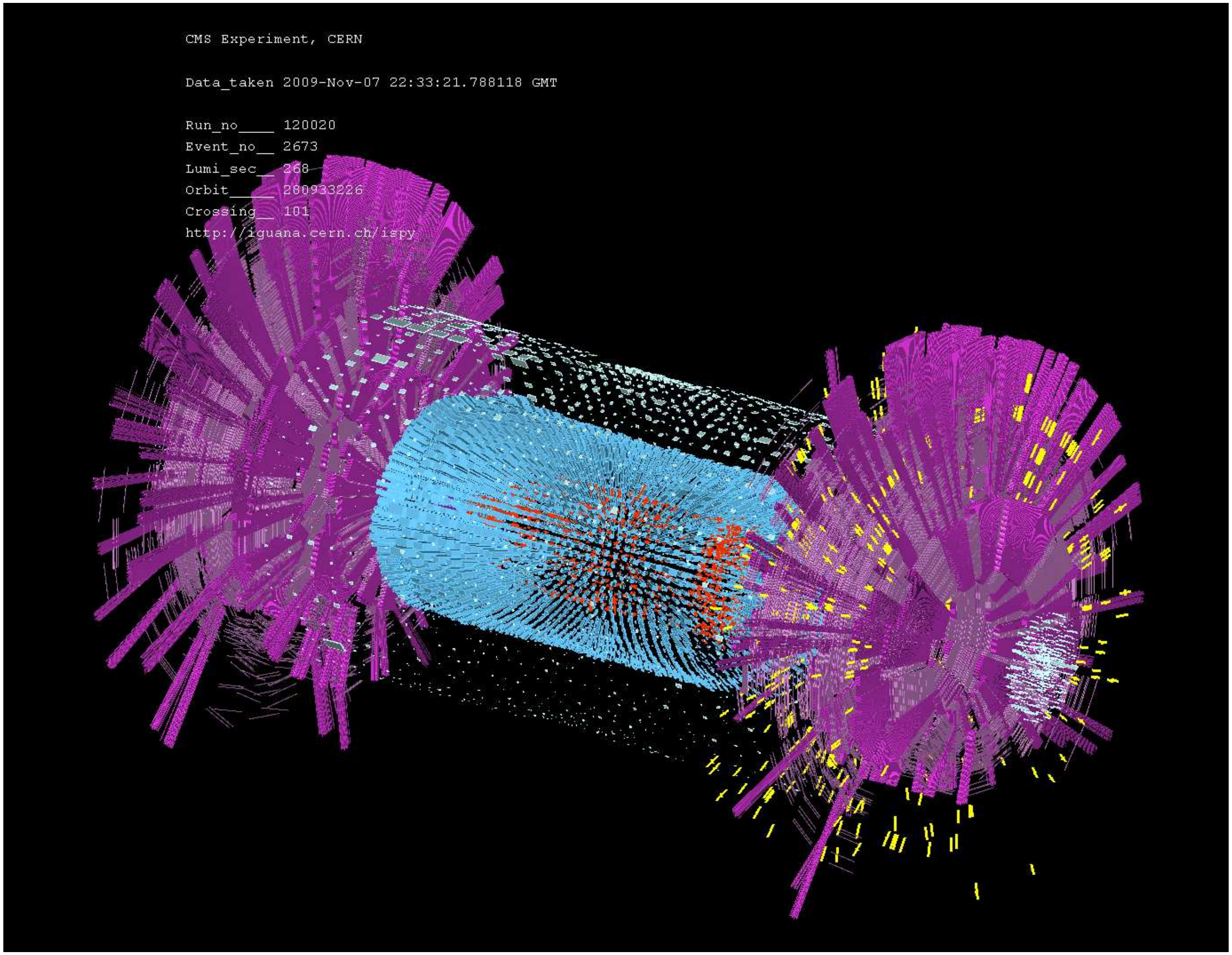
LHC Upgrade scenarios



LHC Upgrade scenarios

- A lot of uncertainty in schedule for the machine
- With the news over the summer of the splices needing to be repaired the priority will be to reach the 14 TeV design energy. This might now happen near the timescales of the “Phase I” upgrade
- We need to revisit the timescales for Phase I and Phase II once the machine really starts running.
- Data will allow us :
  - Begin to understand and to test our ability to simulate various backgrounds and hard to calculate effects
  - Learn as much as possible about the detector performance and the trigger
  - Begin to track the performance of each detector as a function of radiation exposure
  - Our developing understanding of the physics will help us define the schedule and justify the upgrade project itself
- We might have more time to do R&D and to work toward more ambitious solutions to the challenges of Phase 1

Beam Splashes in CMS



CMS Upgrade

- Develop a flexible plan to maintain the CMS detector physics performance expected for $L=10^{34}$ cm^{-2} s^{-1} at higher luminosities
- Issues to be addressed
  - Radiation damage
  - High occupancy affecting reconstruction or triggering
  - High occupancy that leads to buffer overflows and to problems with link bandwidth
  - Pileup creating dead time or affecting trigger
- CMS is accessible, has been designed to be opened, and therefore "easy" to upgrade

Upgrade Scope

System	Phase 1	Phase 2
Pixel	New Pixel Detector (1 or 2 iterations?)	
Tracker	FEDs?	New Tracking System (incl Pixel)
HCAL	Electronics + PD replacement	HF/HE?
ECAL	TP (Off Detector Electronics) ?	EE?
Muons	ME4/2, ME1/1 ,RPC endcap, Minicrate spares, CSC Electronics	Electronics replacement
Trigger	HCAL/RCT/GCT to μTCA	Complete replacement

Some of these fall *in between*

Even without Phase II once we reach the luminosities expected in Phase I we will need to replace the detectors which suffer significant degradation

J. Nash

Phase 1 upgrade cost

Sub-Detector	Estimated Cost in FY09 $	Estimated U.S. Share in FY09 $
Pixel System	18.46 M (*)	7.21 M
CSC Muon System	8.98 M	8.18 M
RPC Muon System(*)	9.60 M	0.00 M
DT mini crates (*)	1.00 M	0.00 M
HCAL	10.45 M	7.32 M
Trigger	13.20 M	5.40 M
DAQ	8.10 M	2.70 M
Total	**69.79M**	**30.81M**
Total with contingency	**95.43 M**	**41.33M**

US CMS R&D

- **R&D effort is growing**

	FY08	FY09	FY10
HCAL	285,000	488,000	884,830
ECAL	50,000	49,000	177,497
EMU	15,000	260,000	348,645
STRIP	183,000	234,816	389,800
PIXEL	670000	837,072	1,193,715
TRIGGER		269,268	472,585
DAQ		40,000	70,000
SIMULATION	100,000	95,000	60,000
DATA LINKS		226,844	182,772
TRAVEL mid-year corrections	50,000	**187,500**	
TOTAL	**1,353,000**	**2,687,000**	**3,779,844**

- **Interest exceeds the funding that the project can dedicate to R&D (which is growing toward 10% of M&O)**
  - **Focus on Phase 1 needs**
    - **Phase 1: 80-85 %**
    - **Phase 2: 15-20%**
- **US CMS groups (and Fermilab) are very active in upgrade R&D**

Year	CMS upgrade proposals	US CMS	FNAL
2006	1	1	1
2007	13	9	5
2008	7	5	4
2009	7	6	4

US CMS R&D

FY10	Total ($)	Universities and CERN team account ($)	FNAL ($)
Labor	2,757,900	1,517,900	1,240,000
Engineers and computer professionals (FTE)	15.3	11.3	4
Tech (FTE)	7.5	4	3.5
M&S	1,021,944	601,944	420,000

R&D proposals

- **FNAL Physicists are involved in 11 of the 28 proposals for Upgrade R&D that have earned CMS approval**
  - **Letter of Interest for Research and Development for CMS Tracker in the LHC Era – Spiegel (with Rochester)**
  - **Study of Suitability of Magnetic Czochralski Silicon for the SLHC Strip Tracker – Spiegel (with Rochester and Brown)**
  - **3D Detectors for Inner Pixel Layers – Kwan, Cihangir, Tan (with Purdue)**
  - **Proposal for US CMS Pixel Mechanics R&D –Kwan, J.C. Yun, J. Howell, C.M. Lei (with Purdue)**
  - **R&D for thin Single-Sided Sensors with HPK – Kwan (with Purdue)**
  - **Development of Pixel and Microstrip Sensors on Radiation Tolerant Substrates for the Tracker Upgrade at the SLHC – Cihangir, Kwan, Joshi, Uplegger (with Purdue)**
  - **Power Distribution System Studies for the CMS Tracker – Kwan, Joshi, Prosser, Rivera, Turqueti (with Iowa and Mississippi)**
  - **USCMS Detector Upgrades for Phase 1 of the LHC Luminosity Upgrade – USCMS upgrade team**
  - **Proposal for a Quartz Plate Calorimeter as an Upgrade to the CMS Hadronic Endcap Calorimeter – Freeman, Whitmore (with Iowa, Fairfield, Fermilab, Maryland, Mississippi, Trieste)**
  - **Proposals for the Hadron Forward Calorimeter HF Upgrade Phase 1 – Freeman, Whitmore, Los, Zimmermann, Hoff (with Iowa, Fairfield, Fermilab, Maryland, Mississippi, Trieste)**
  - **Proposal for Phase 2 Tracker and Trigger Planes based on Vertically Integrated Electronics - Cooper, Demarteau, Deptuch, Hoff, Johnson, Lipton, Miao, Spiegel, Tkaczyk, Trimpl, Yarema, Zimmerman (with Boston, Brown, CERN, Cornell, Davis, FNAL, Riverside, Rochester, Santa Barbara, Texas A&M, Vanderbilt)**

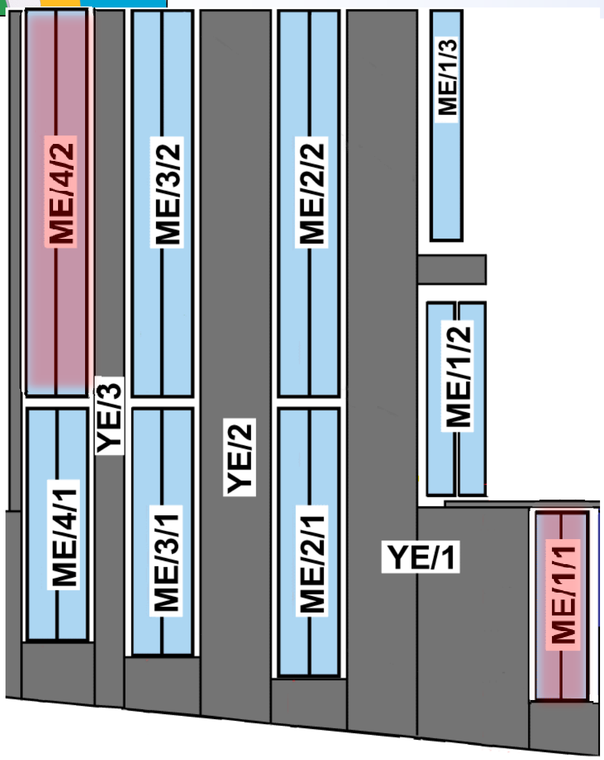
- **14 FNAL Physicists involved in the upgrade**
- **H. Cheung of FNAL is the co-leader of the simulation effort ,which is key for optimizing the design for the upgrade**
- **Vivian O'Dell is key to the DAQ upgrade**

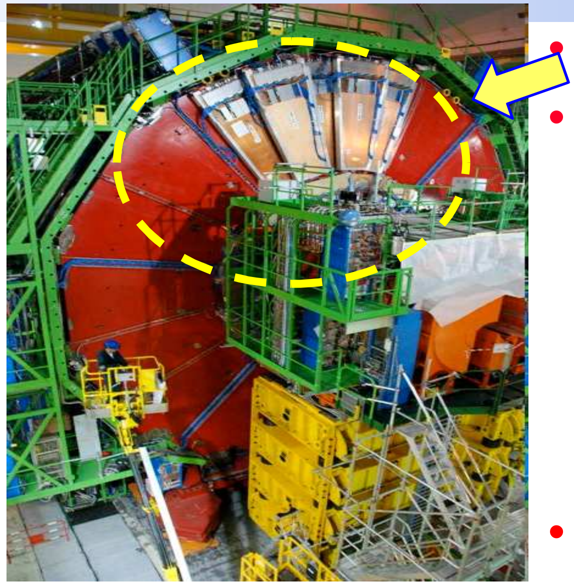
Fermilab's Role in R&D and Future Construction

- **FNAL physicists are playing a strong role in formulating the SLHC R&D program and in executing it**
  - **The engagement of FNAL engineers and technicians is increasing**
  - **We expect Phase 1 R&D to continue until 2012/2013 and for Phase 2 somewhat longer**
- **FNAL effort should complement and the strengthen the University role:**
  - **Important projects where the lab infrastructure is unique should be completed on a fixed cost basis as is requested for University groups**
  - **University groups support some engineering for CMS out of the "base funding". Similarly Fermilab Physicists should bring some engineering resources. It should not be expected that all engineering costs should be supported by the project (otherwise FNAL will not be competitive)**
- **FNAL effort is well-aligned with the US-CMS and CMS International upgrade goals**
- **US-CMS has just completed a new document for the DOE and NSF and we hope that we will begin down the approval path to funding in 2011**
- **We expect FNAL physicists, engineers and technicians to play a significant role in the Upgrade Construction once its funding is approved**
- **Specific responsibilities will have to be negotiated within CMS and US-CMS**

Upgrade R&D and the beginning of Upgrade Construction will be an Important part of the US program over the next 3 years

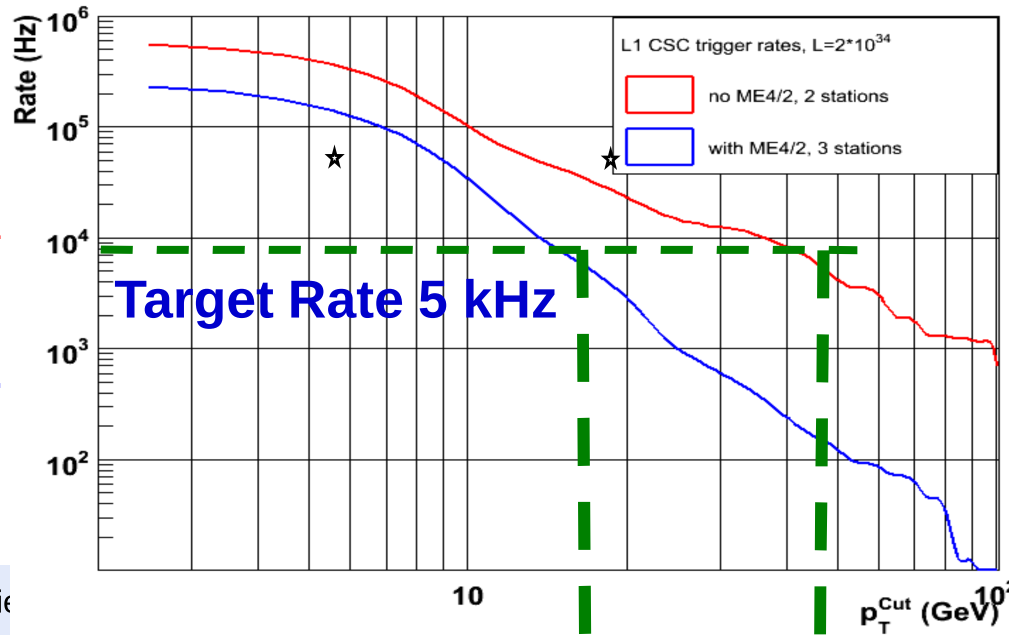
EMU upgrade





- ME4/2 is "Shovel-ready"
- Arranging for chamber factory at CERN
  - Experienced Russian teams will do the work at CERN (cheaper)
  - CERN will also offer some support
- Tooling to be shipped to CERN in few months

- Triggering with & without the ME4/2 upgrade at 2X10^{34} cm^{-2} s^{-1}:
  - The high-luminosity Level 1 trigger threshold has to be increased from 18 → 48 GeV/c



FNAL contribution

- Found new vendor capable to make 5ft x 12ft FR-4 skins (old vendor discontinued a production of these skins)
- Restored a factory tooling for CSC prototype production
- Procured chamber parts, constructed and tested a new ME4/2 chamber prototype using a factory tooling and new FR-4 panels

- Panel Production at FNAL (Lab.8)
- FNAL has unique capability to machine large chambers

Axxiom machine

Vacuum lifting system

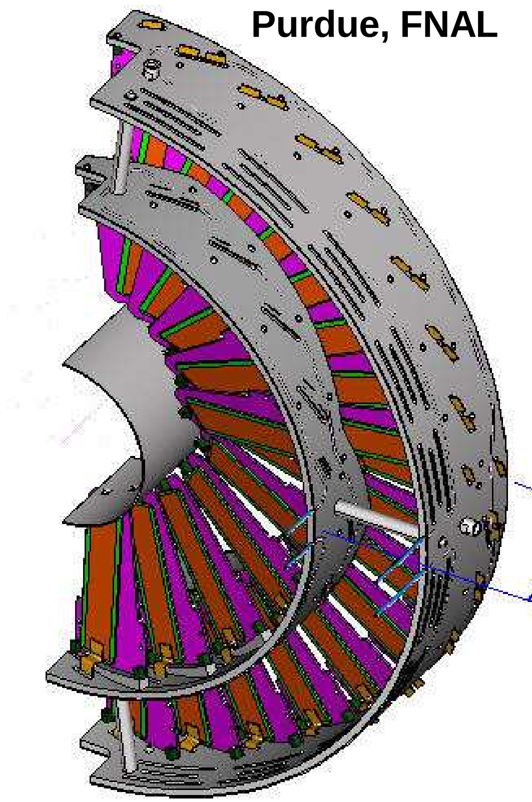
Gerber machine

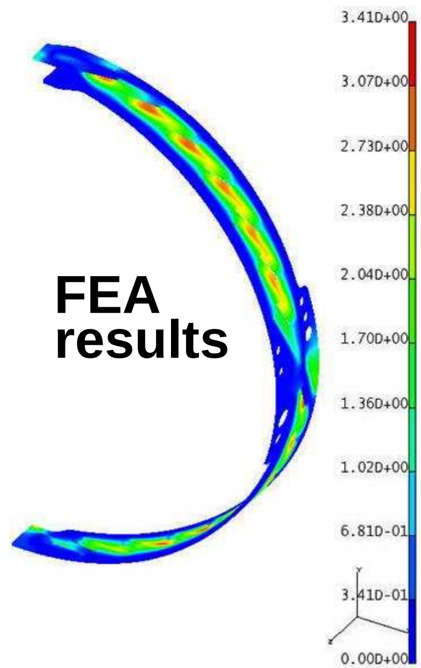
Pixel Upgrade

- Plan formed in 2008 under the as assumption that new pixel detector would be needed by 2013
  - BPIX: 3 layers to 4 layers
  - FPIX: 2x2 disks to 2x3 disks
- Many constraints: use existing cables, fibers, cooling pipes
- Baseline plan:
  - Same n-on-n sensors which are more rad hard than the specs set in the TDR
  - Small modifications to ROC and electronics to decrease dead-time in the inner layer at 2×10^{34} $cm^{-2}s^{-1}$
- Goals
  - Reduce material to improve position resolution
    - CO_2 cooling & light-weight mechanics
    - Move material budget out of the tracking region
  - Pixel tracking and vertexing significantly improved and more robust by increasing number of hits from 3 to 4 up to η of 2.5

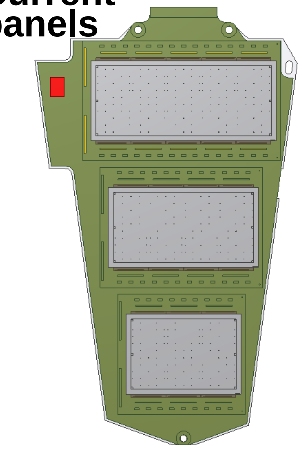
Mechanical and cooling progress

Purdue, FNAL

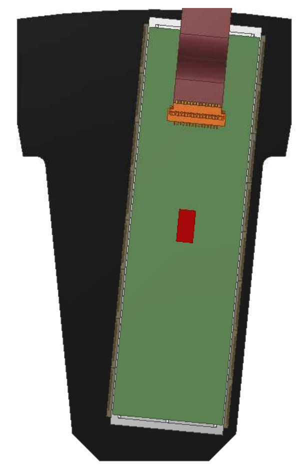




Current panels



Phase1 panels

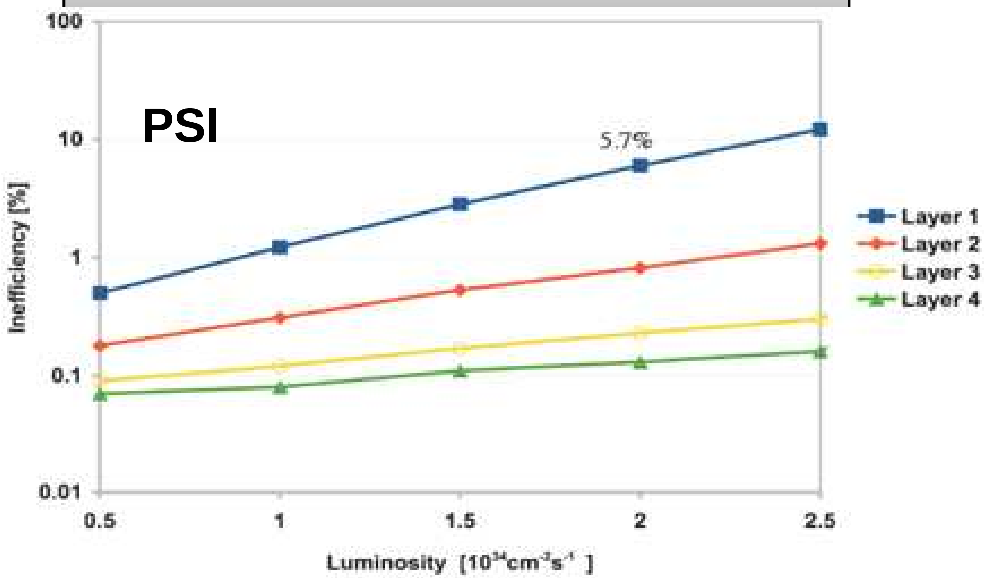


- Reduce # of module types and interfaces. One type of module (with 2x8= 16 ROCS) instead of 7 module types as in current FPIX detector.

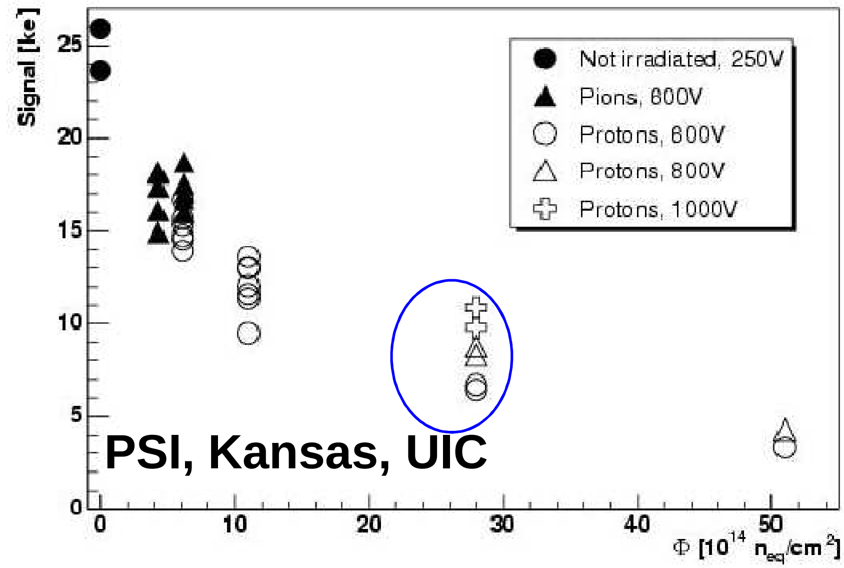
- CO_2 cooling
  - A full-scale prototype cooling system will be built at CERN.
  - Fermilab plans to build a smaller prototype system for cooling (up to) 3 half-disks in a service half-cylinder
  - It will also allow studies of flow balancing

Issues

New ROC



Sensors

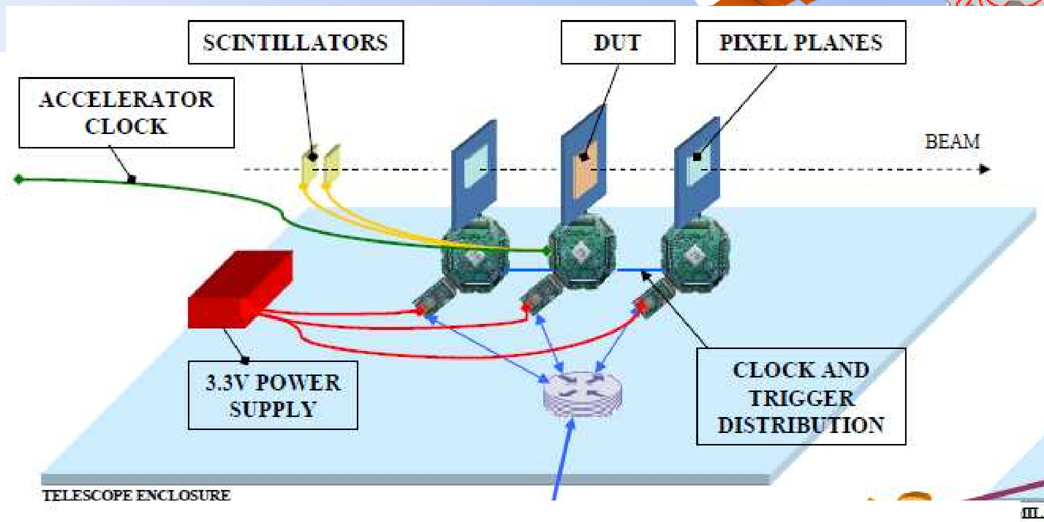


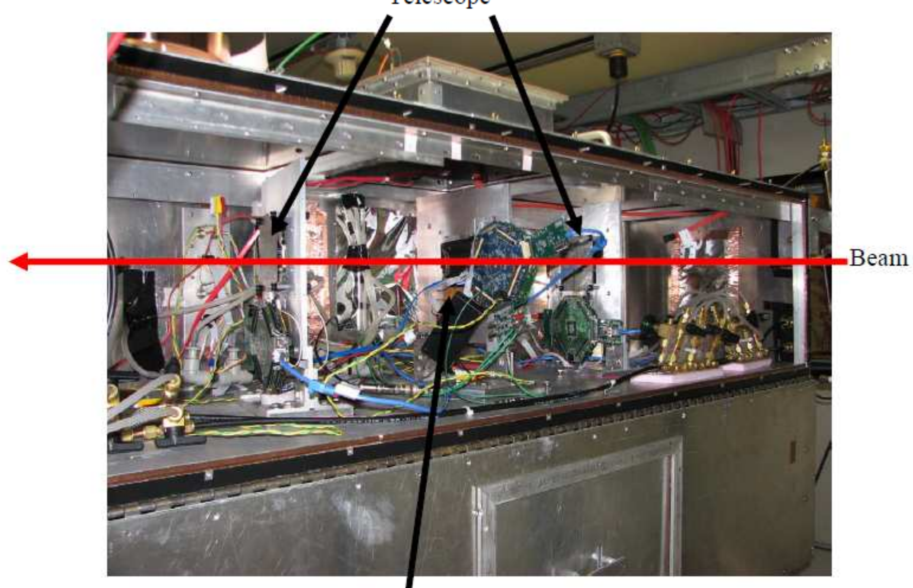
- Simulation has no safety factor
- May be optimistic due to quality of simulation. It should be repeated after we have some real data at 14 TeV
- Limit of the technology (250 nm) and architecture

- Charge collected at 2.8 X10^{15} cm^2 is only around 8,000 e^-
- The current threshold is about 3,000 e^-
- Loss of charge sharing will lead to decrease position resolution

FNAL Pixel Team

- **Sensor:** S. Kwan, S. Cihangir, P. Tan
- **Test beam: Marcos, Alan, Ryan Rivera, L. Uplegger, A. Todri, JC Yun, S. Kwan, U. Joshi, F. Yumiceva**
- **Mechanics :** Cm lei, J. Howell, + one designer and one tech, Simon, JC Yun
- **Cooling:** R. Schmitt, T. Tope + a contract engineer, 1 tech, one draftsman
- **Readout:** Sergey Los
- **Opto readout:** A. Prosser, J. Chramowicz, S. Kwan
- **Power distribution:** A. Todri, M. Turqueti, S. Kwan (also L. Perera)





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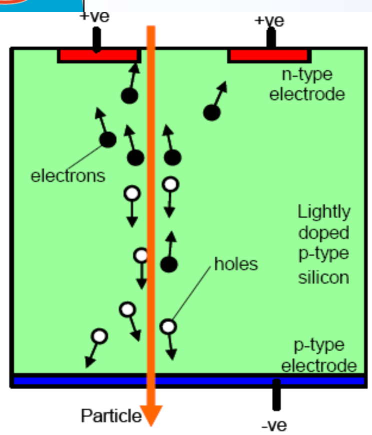
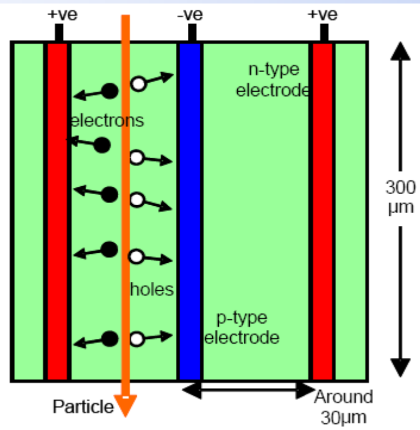
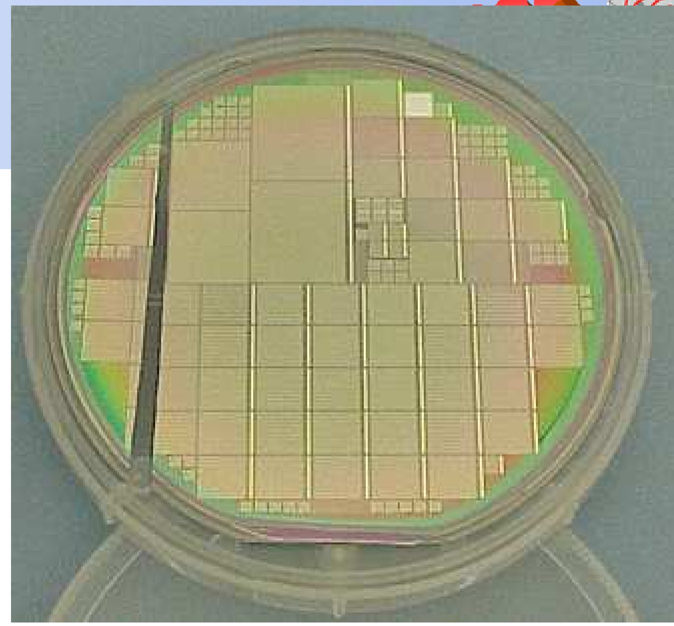
More R&D

Planar

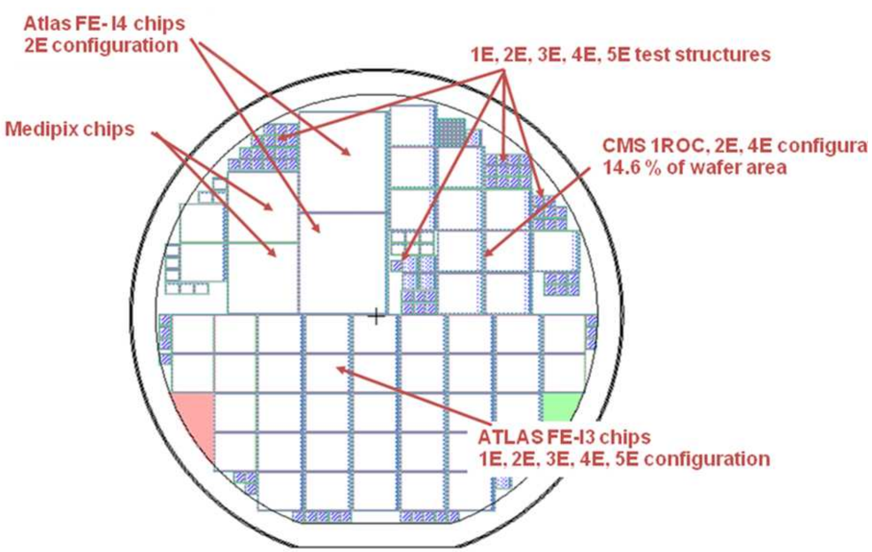


3D

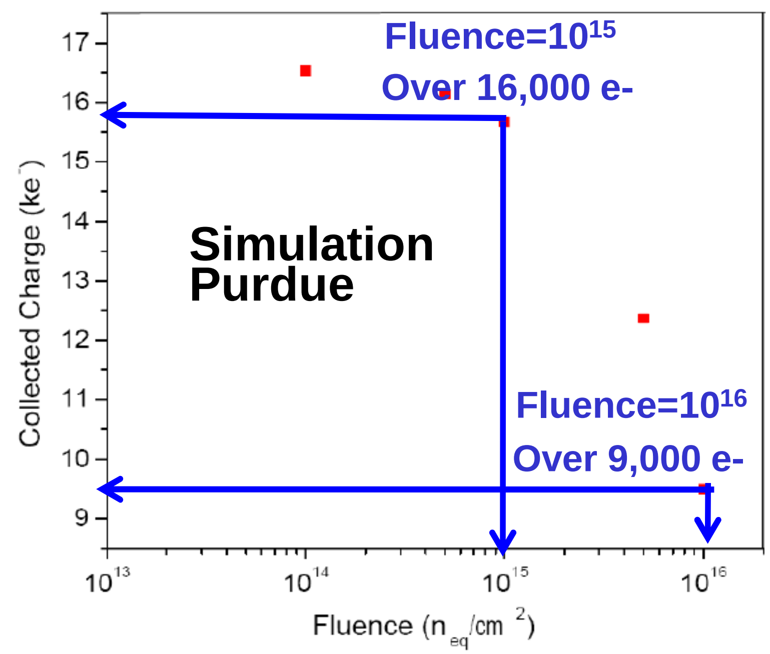




3D-C

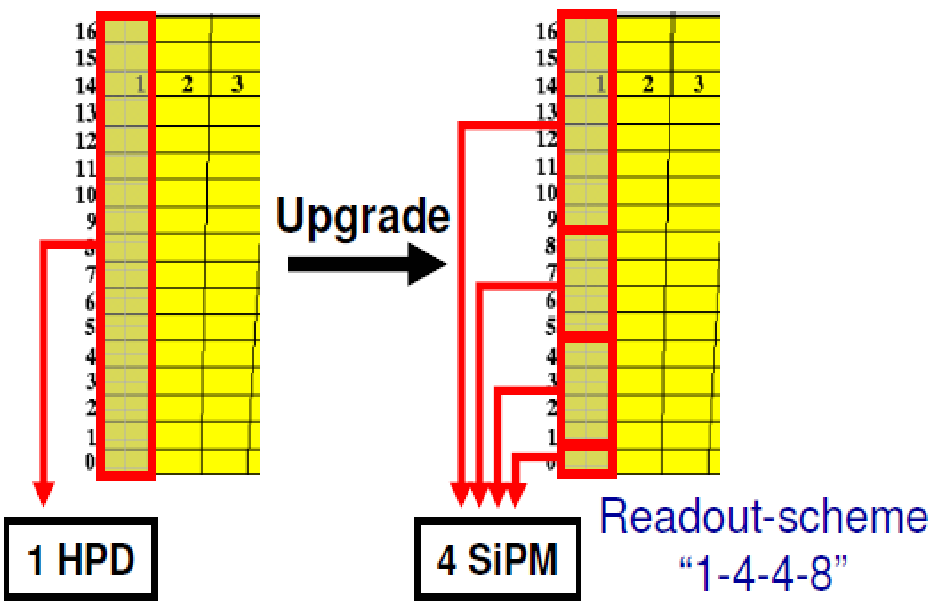


Charge Collection Efficiency:



HCAL R&D

- **Radiation levels in phase 1 for HE**
  - **Will kill some inner layers.**
  - **Current HCAL has analog summing over all tower depths**
  - **Longitudinal segmentation will allow recover via reweighting**
    - **Improve linearity and energy resolution**

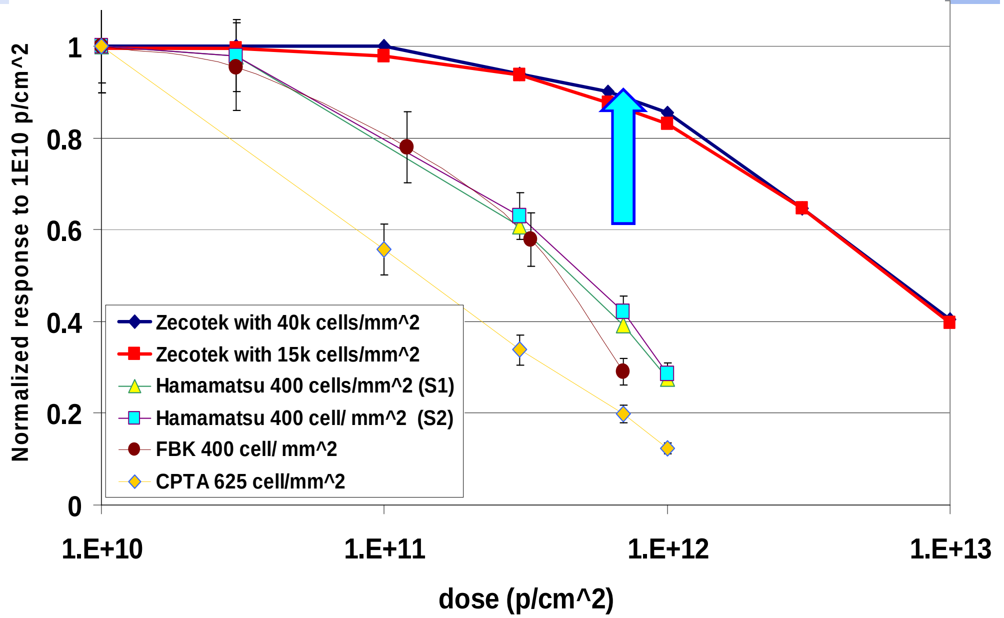


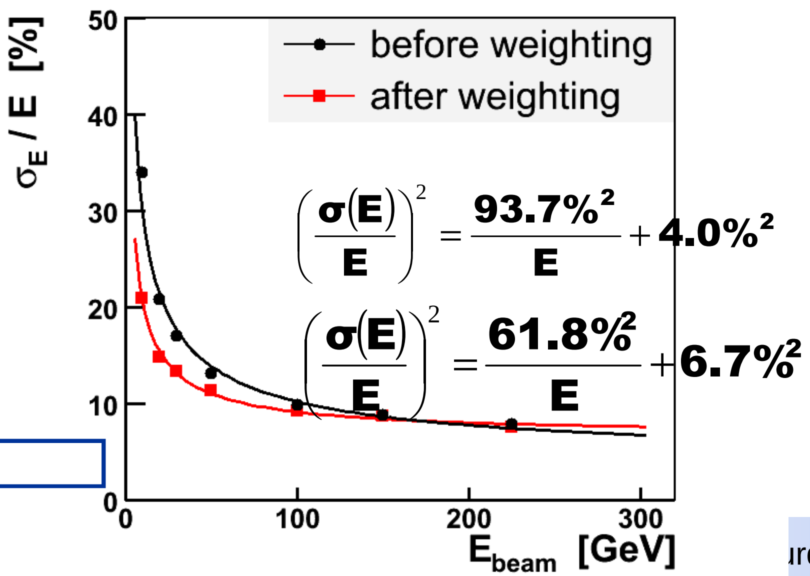
- **Front-end**
  - **SiPMs and new ROC (QIE)**
    - **To accommodate increased data bandwidth necessary for longitudinal segmentation (and TDC-like measurements)**
    - **Keep as much of the current infrastructure as possible**
- **Back-end**
  - **Complete redesign, abandoning VME in favor of uTCA**
    - **Accommodate increased FE bandwidth requirement**
    - **Increased flexibility for L1A triggering, Selective Readout**
- **FE/BE communication**
  - **Transition from wires to fiber**
  - **Increased bandwidth**
  - **Increased redundancy**

HCAL

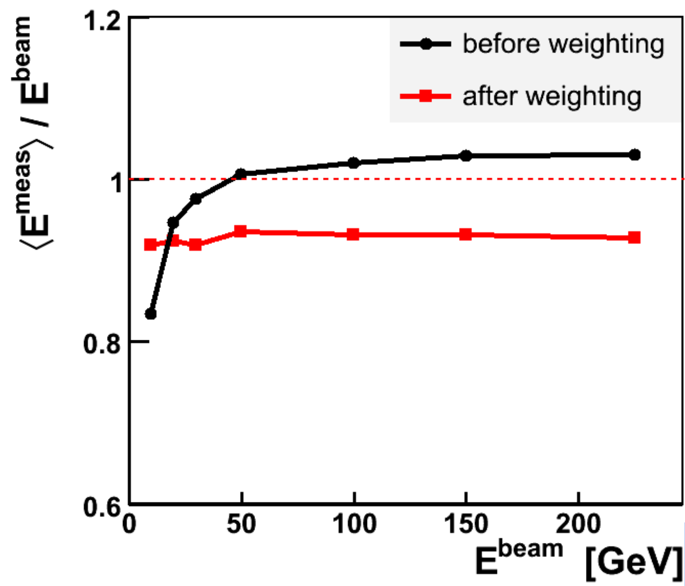
- **Tests on SiPM**
  - **Thermal stability to 0.1-0.2 ^{0}C**
  - **Radiation hardness**
    - **Expected dose 1E12 and 3Krad ionizing (+ safety factor)**
  - **Dynamic range (pixels)**
  - **Adjust recovery time (specify to vendor)**
- **Segmentation preliminary results**

Normalize response versus fluence



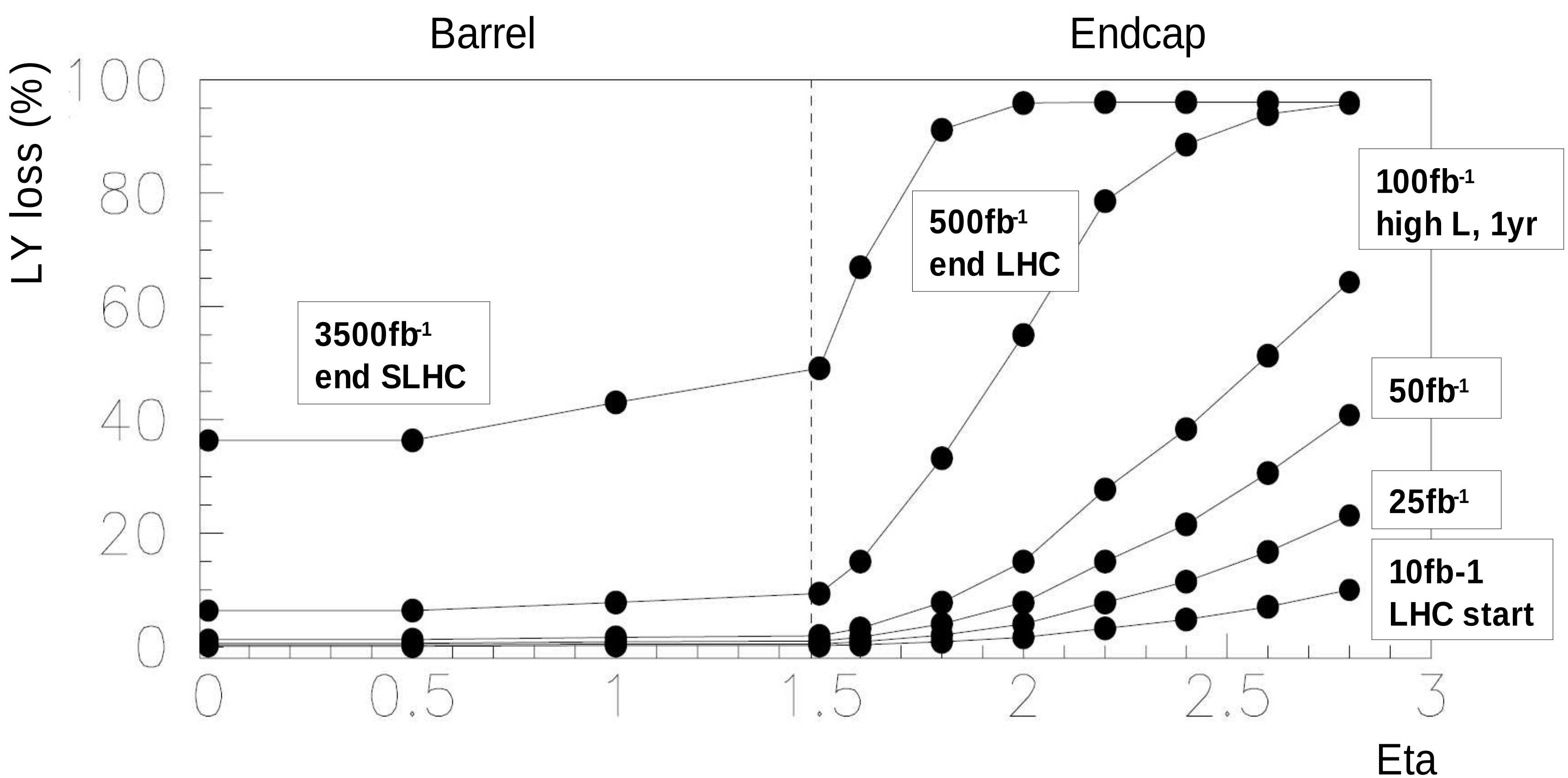


Gcalor



More problems could emerge

- **Light loss in ECAL**



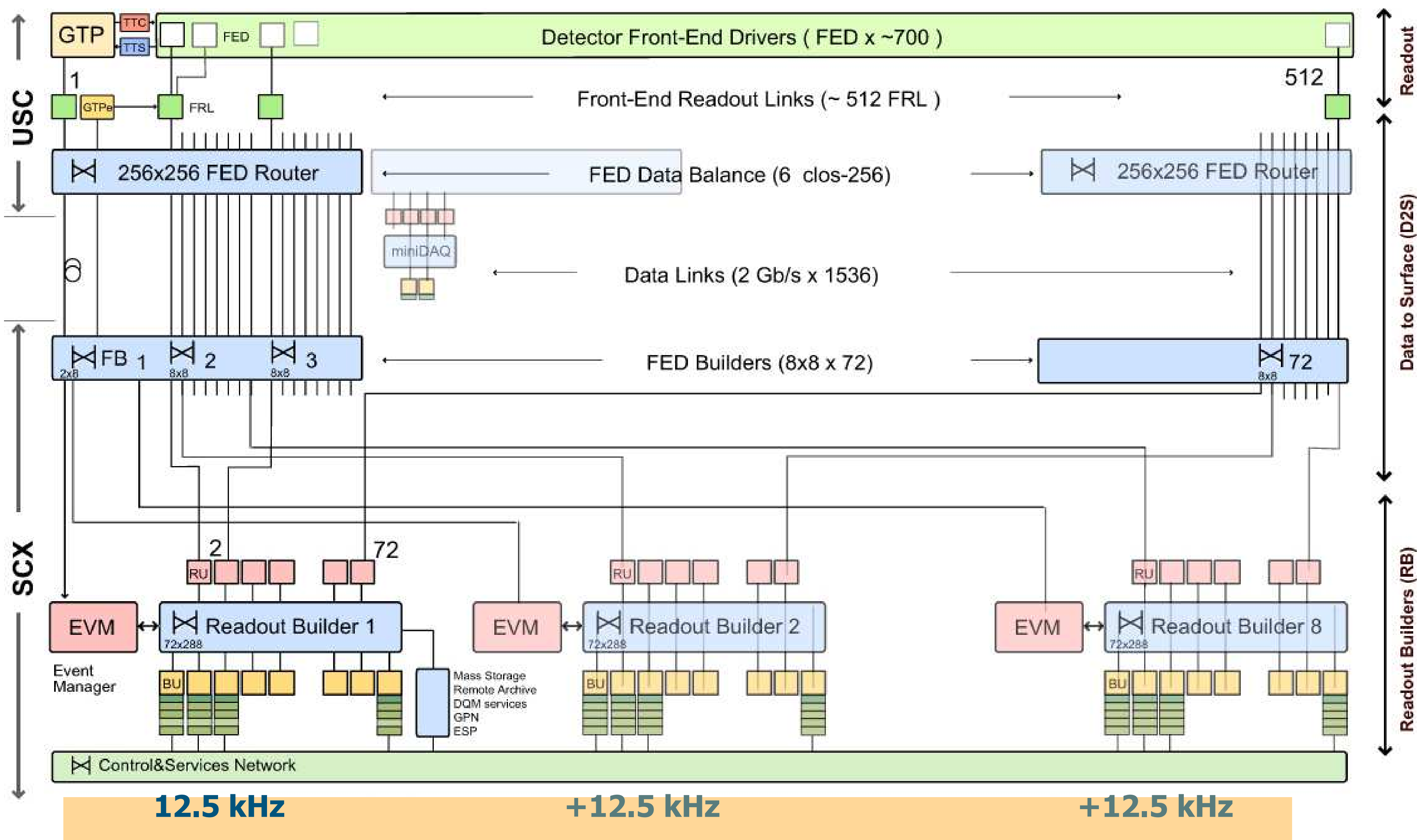
Conclusions

- **The SLHC physics program requires detector upgrades able to maintain the performances expected at the standard 10^{34} cm^{-2} s^{-1} luminosity.**
- **The SLHC detector upgrades are very challenging and require significant detector R&D, especially for the inner tracking systems**
- **FNAL can provide unique infrastructures/expertise to achieve the upgrade goals**

- **The program at the LHC and SLHC will dominate the exploration of the energy frontier for a long time…. We need success!!!!**

Hopefully we will send many postcards about the discoveries from the Tera-energy scale

CMS DAQ Design



Current CMS DAQ

- DAQ well designed for 100 kHz L1 rate, 2KB fragment size, 500 inputs
  - Total data volume supported through to HLT is 100 GB/s (1 MB*100kHz)
    - Some safety factor included in design (~ 50%)
  - Current HLT CPU budget ~ 50ms/event
  - Data writing at ~ 2GB/s
    - Hardware upload to 2.5 GB/s
      - (upload to T0 currently capped at~300 MB/s)
- Upgrades necessary for:
  - Larger data volumes (occupancy/granularity dependent)
    - Will learn from 09/10 running
  - Larger HLT budget (upgrading CPU power)
  - Writing more data
  - Maintainability/robustness

DAQ Bottlenecks to higher data volumes

1. **Getting data off the detector**
   - **Slink/FRL (Data to Surface)**
     - ~ 500 links between detector and 1st stage EVB
     - Most expensive part of upgrade (~$10k/link)
2. **Building data**
   - **Builder networks (Event Building)**
     - Networks currently GbE – will start testing 10 GbE networking soon
3. **Writing data**
   - **HLT filtering**
     - Done on commodity PCs: continuously evaluating performance
   - **Storage Manager**
     - Dedicated FC raid arrays + PC "data loggers"
   - **Getting data to offline**
     - Dedicated 2 10 Gb optical uplinks to T0

1st CMS data running will serve as DAQ upgrade design testbed!

(Current) DAQ people

Role	Total International CMS	US contribution (subset of column 1)	Fermilab contribution (subset of column 1)
D2S	4	1	
EVB	4	3	1
Storage Manager	4	4	2
Software architecture/monitoring /Integration/test stands/infrast.	12	1	
Total	**24**	**8**	3

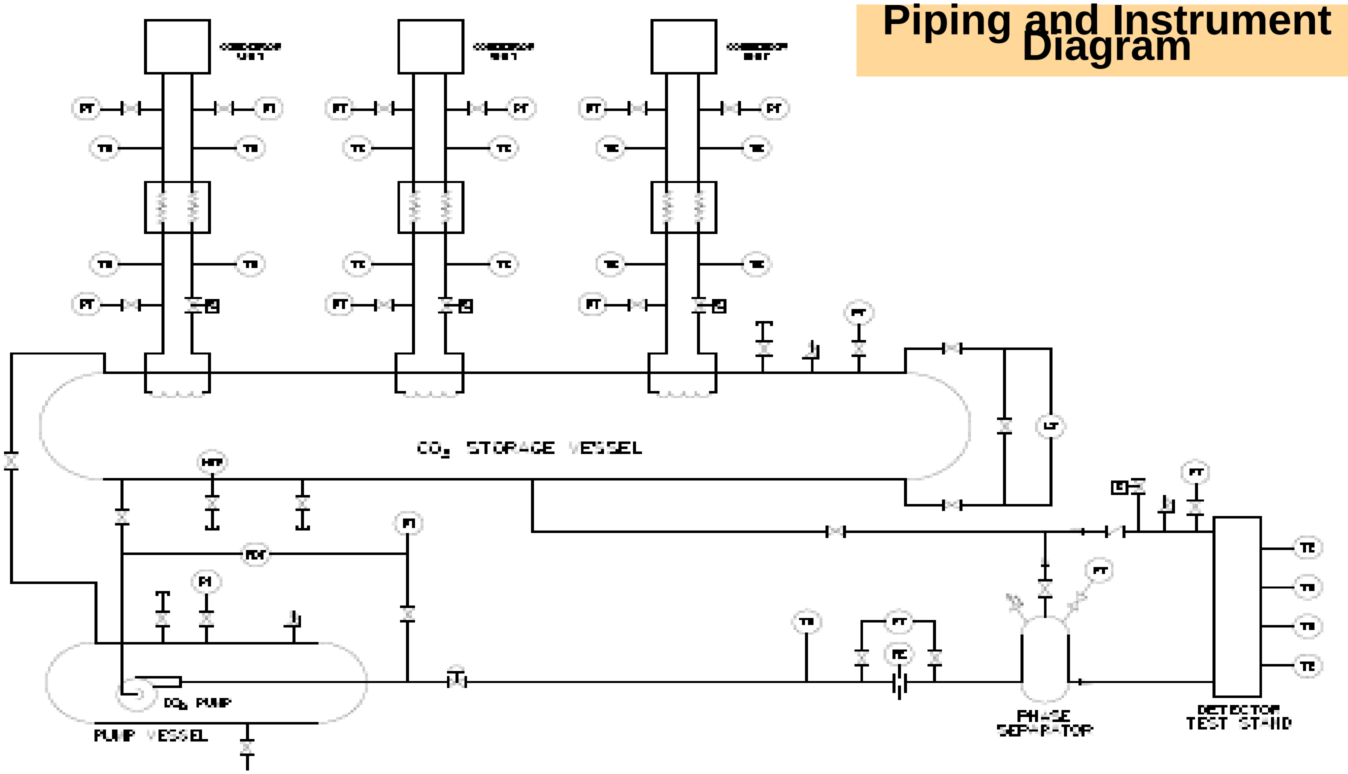
- **Current levels of DAQ staffing**
    - **Same people will roll off M&O and onto upgrade**
- **US involved in all areas requiring upgrades**
    - **Will begin R&D on EVB networking in FY10**
- **US also heavily involved in current DAQ operations**
    - **With an eye towards upgrade designs in the coming year(s)**

FNAL workshop

- FNAL provides a focus for the US community upgrade activities
- Two general upgrade workshops every year, one at FNAL in the Fall and one at CERN in the spring
- Latest CMS upgrade workshop at FNAL in October 2009
  - ~175 people attended
  - about 40 from Europe (including SP designate, Guido Tonelli)
  - Progress on both Phase 1 and Phase 2
- Flexibility is a very important aspect of the planning
  - Detector performance issues or even physics considerations may make it desirable to accelerate some upgrades.
  - Lower than expected luminosity may mean that detectors that will eventually suffer radiation damage will last somewhat longer and make it reasonable to delay the installation of their replacements.
  - The development of certain physics results may argue for an upgrade to be deferred until the discovery is pinned down with the existing configuration.
  - The lower than expected development of luminosity might argue in favor of installing something that would improve the efficiency of CMS or add a new capability that was not part of the original design.

CO2 Cooling

Piping and Instrument Diagram



- **A full-scale prototype CO2 cooling system will be built at CERN.**
- **Fermilab proposal is to build a prototype CO2 system for cooling (up to) 3 half-disks in a service half-cylinder that could be expanded for the full-scale pixel system (see diagram above)**
- **Flow balancing options could be studied at Fermilab. Parallel flow balancing has not appeared on the agenda of other CO2 cooling test sites.**

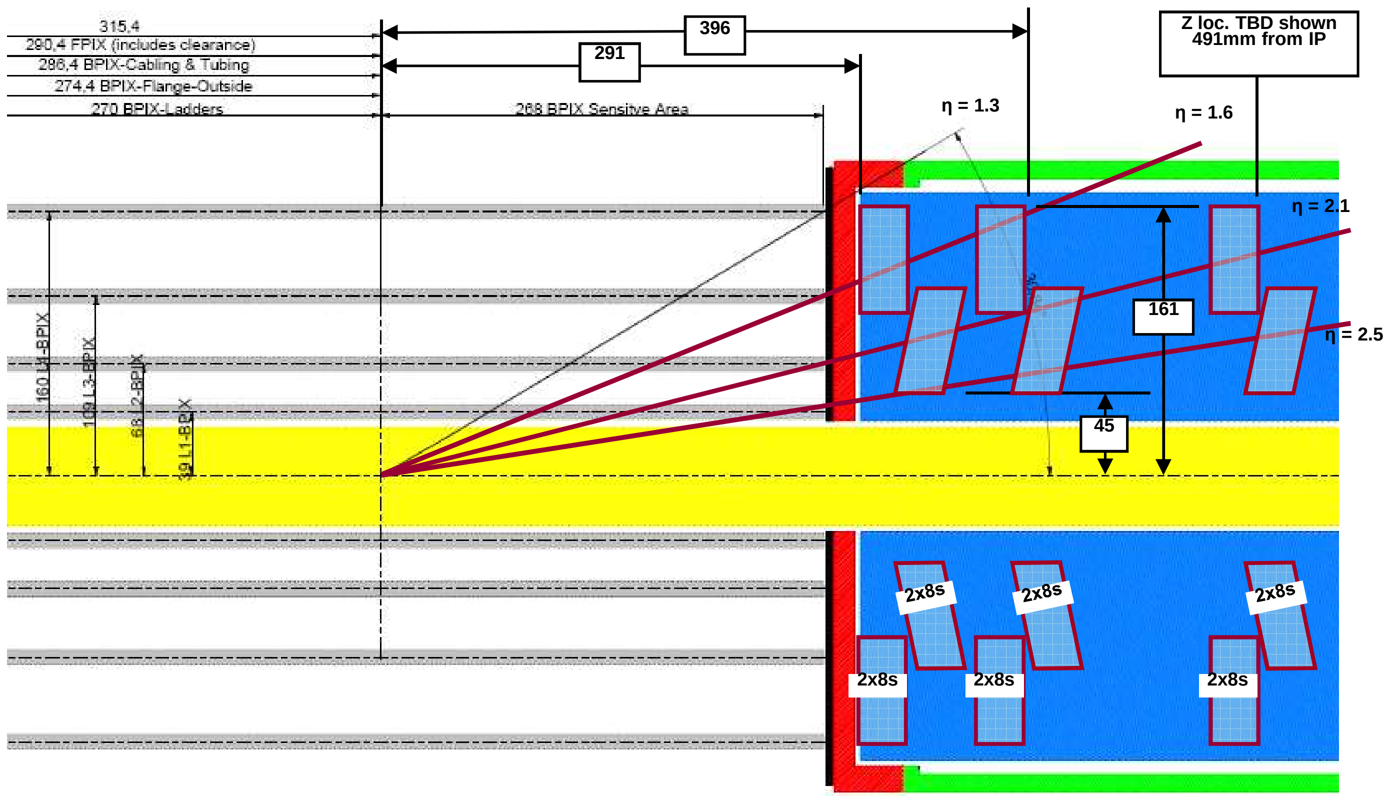
Phase 1 pixel upgrade

- **Reduce material budget by at least a factor of 3 in the barrel region and 2 in the forward region**
  - **Current modules used high density kapton signal cables**
  - **Substitute with μ-twisted pairs 2x125μm of enameled Copper Cladded Aluminum (CCA) wires**

1) **Freedom in bending cables in all directions**
2) **Omit endflange print → no soldering, simpler mechanics endflange, no PCB, no strong mechanics supports of PCB for plugging forces**
3) **Can move pxAOH-motherboard & pxDOH-motherboad with PLL, Delay25 etc further back (~50cm) to high η - range and remove material budget from sensitive tracking region**

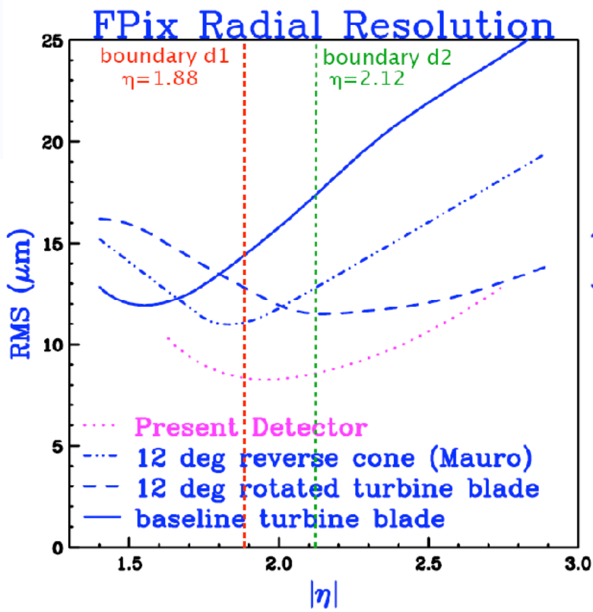
- **Use Bi-phase CO_2 cooling instead of C_6F_{14}**
- **CO_2 allows <u>serialized pipes</u> without pressure drop problems ⇒ reduces resident cooling liquid by large factor.**

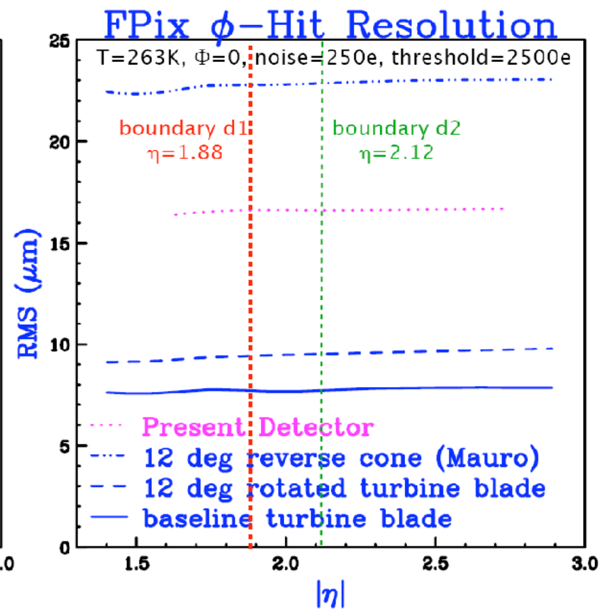
FPIX layout



With separate inner and outer blade assemblies, it's possible to optimize the layout of each to obtain excellent resolution in both the azimuthal and radial direction throughout the FPix acceptance angle.

An inverted cone array combined with the 20 deg Rotated Vanes for the inner blade assemblies results in better radial resolution at large eta (see diagram above).





Proposed FPix geometries were studied by Morris Swartz (JHU) using the detailed Pixelav simulation currently used to generate reconstruction templates. Five geometries were studied: the current design, the Rotated Vane, 20° a nd 30° 'Fresnel Lens' (with castellated modules) layouts, and a 12° inverted cone array of R otated Vanes.

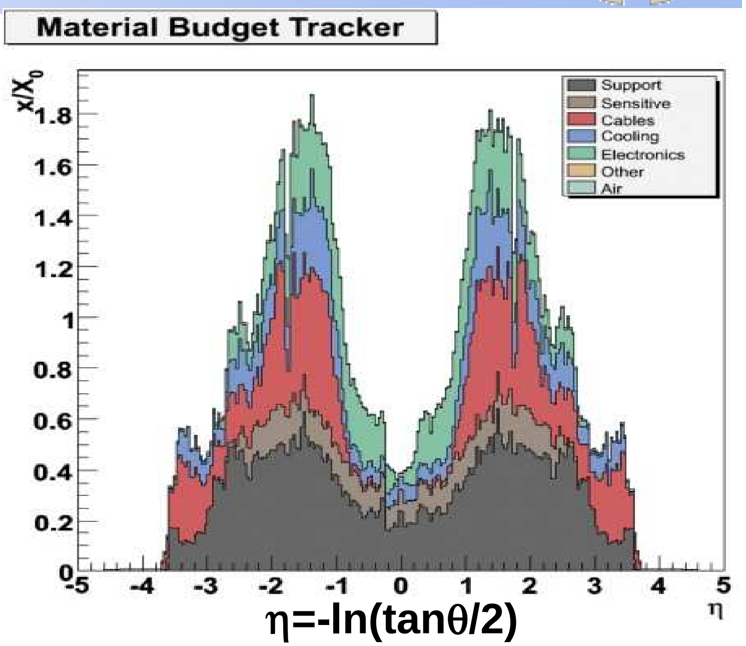
The Rotated Vane design (labeled 'baseline turbine blade' in the above plots) has excellent azimuthal (phi) resolution (better by x2 compared to the current FPix detector); however, the radial resolution is worse for high eta.

The Fresnel Lens layouts perform worse compared to the current detector geometry.

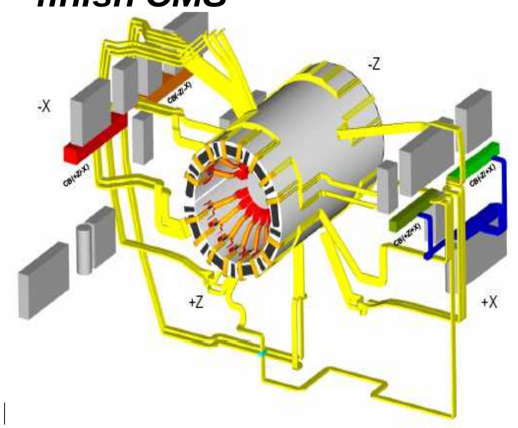
Tilting the blades in the Inner Assemblies into inverted cones (labeled '12 deg rotated turbine blade' above) improves the high-eta radial resolution and only slightly worsens the high-eta azimuthal resolution. The radial resolution curves break along the vertical dotted lines at the eta between the Outer and Inner Blade Assemblies.

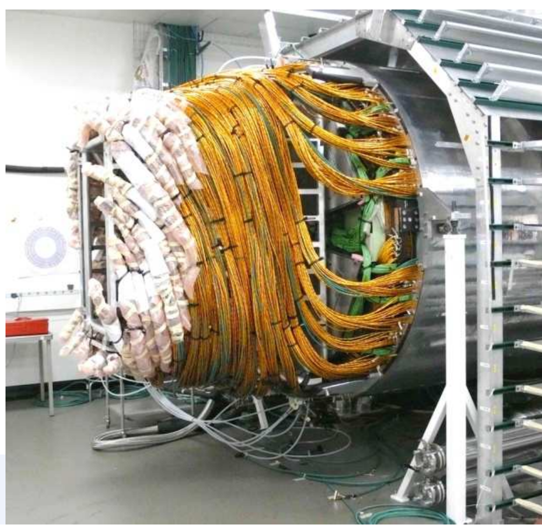
Phase II: Tracker replacement

- We need a tracker **with equal or better performance** ⇨ **More channels**
- To do so, solve several <u>very</u> difficult problems
  - deliver power (probably greater currents)
  - develop sensors to tolerate radiation fluences ~10x larger than LHC
  - construct readout systems to contribute to the L1 trigger using tracker data
  - reduce material in the tracker



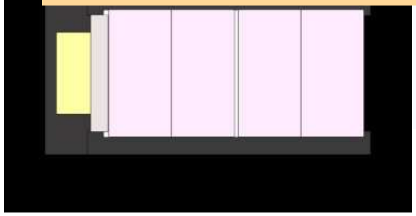
Installation of services one of the most difficult jobs to finish CMS



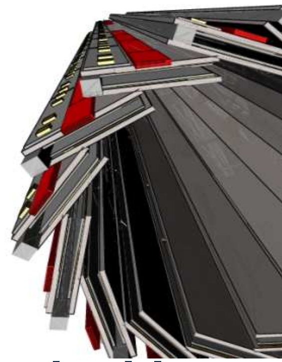


•Tracker R&D focus

- **Performance**
- **Detector layout**
- **Sensor material optimization at various radii**
- **Readout systems for inner and outer radii**
- **Triggering**
- **Manufacture and material budget**



Phase II layout



Strawman A :

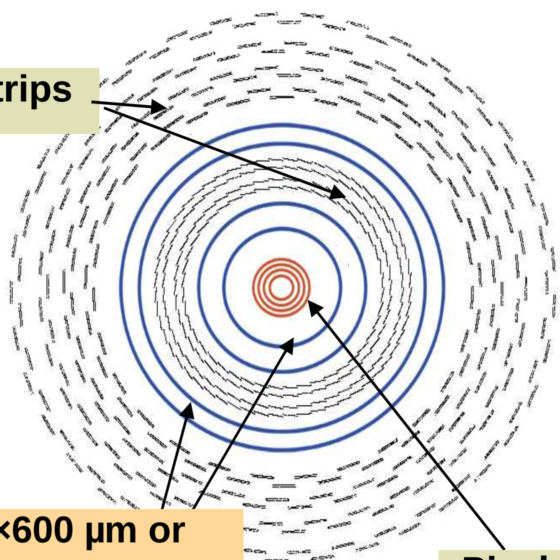
Similar to current tracking system

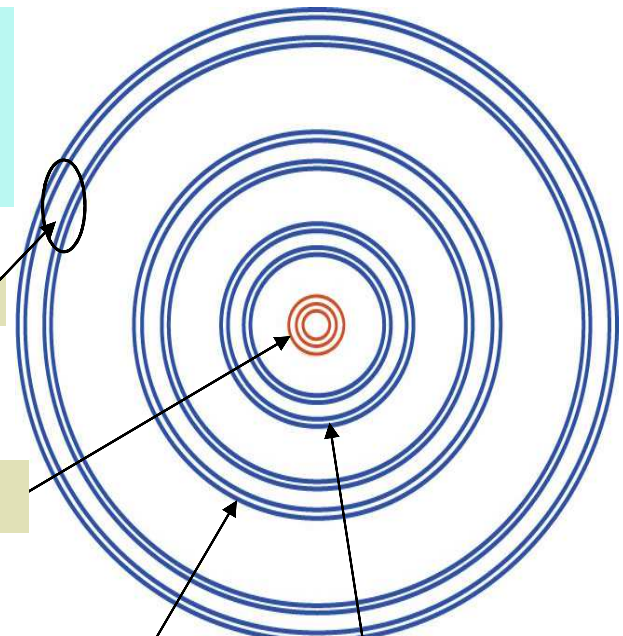
4 Inner pixel layers, 2 strixel + 2 short strip layers (TIB), 2-strixel + 4 short strip layers (TOB); strixel layers can be doublets

Strawman B :

Different from current tracking system

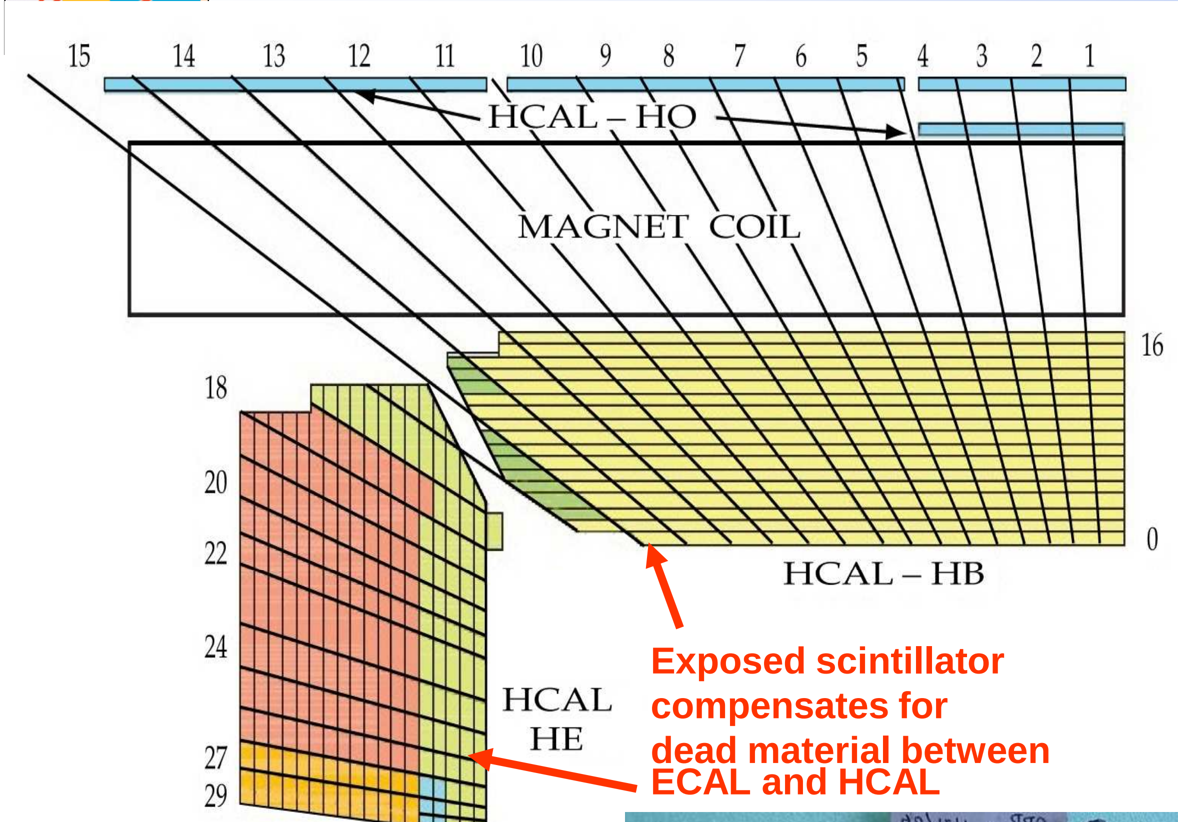
Super-layers, each with two doublet layers (integrated tracking/ triggering layers); 3 inner Pixel layers; can use inner doublet for track seeding

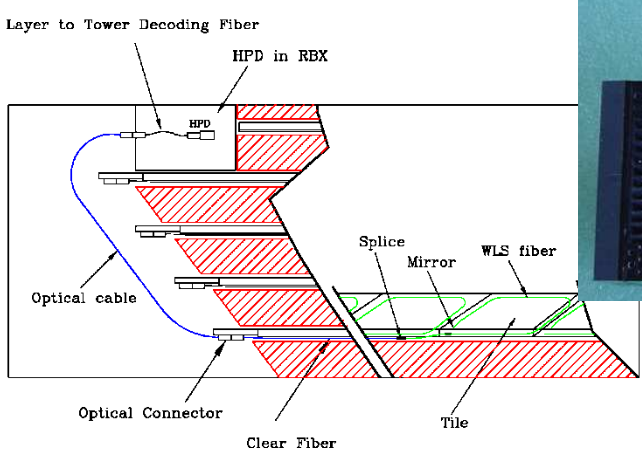


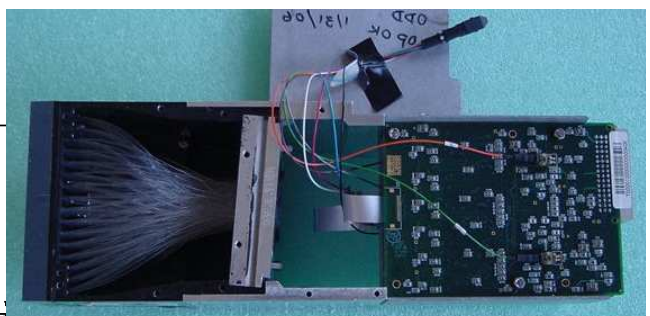


(Layers simplified as rings for illustration!)

Phase 1 HCAL upgrade

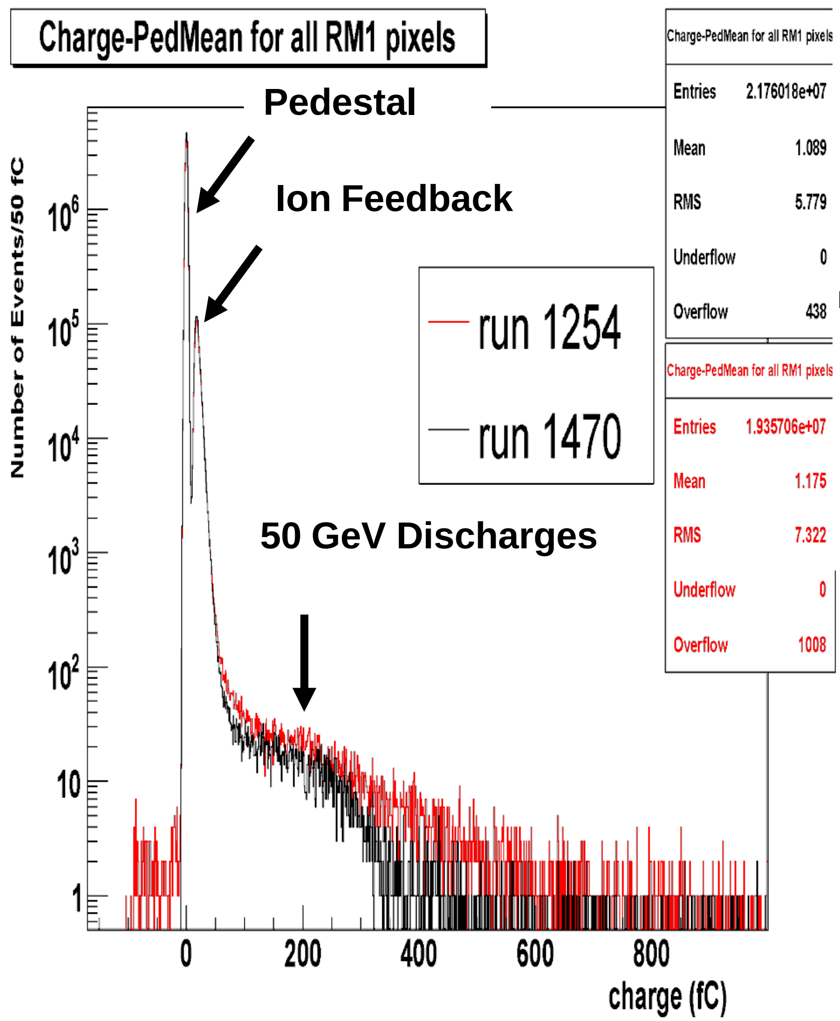




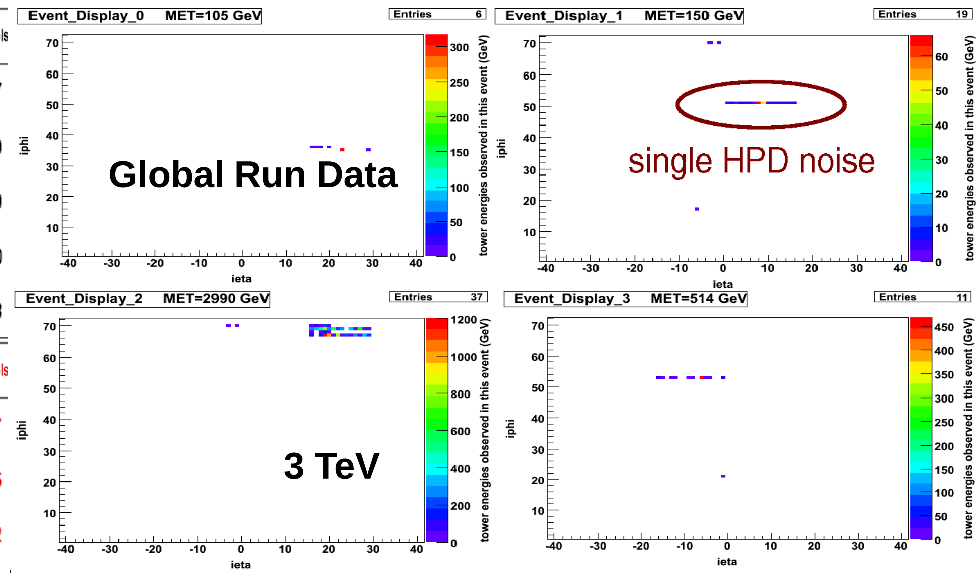


- Change Hybrid Photo Detectors (HPD) to SiPm
- This will allow longitudinal segmentation
  - Radiation damage in the forward region $2.5<\eta<3$ of the HE, reduces the light from the inner layers.
  - The effect can be corrected by applying different weighting
  - Longitudinal segmentation in HB and HE and add shaping (HB/HE) and timing circuitry (HB/HE/HF) to reduce out-of-time pileup.

Phase I HCAL upgrade



First four events with MET > 100 GeV



Asynchronous HPD Discharging can be identified in low occupancy events

Advantages of SiPm over HPD:

x2 Higher Quantum Efficiency (~34%)

x1000 Higher Gain (~10^6)

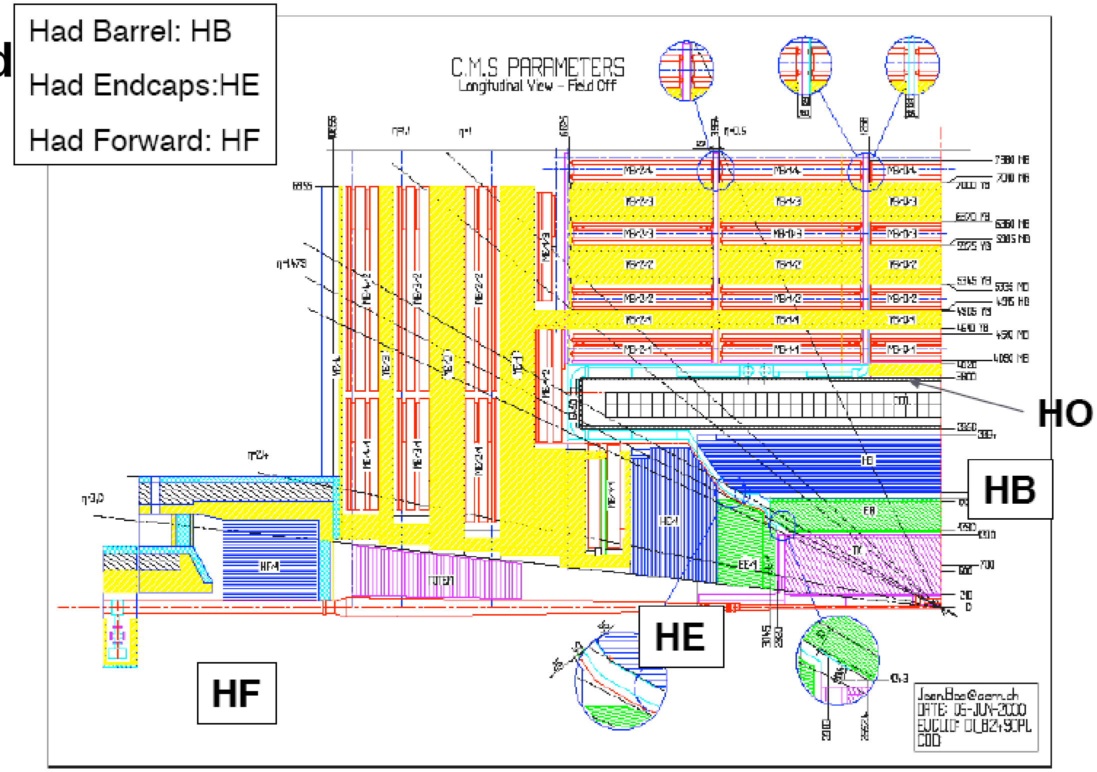
x4 Higher Channel Density

No Ion Feedback, No Discharging

Phase II HCAL upgrade

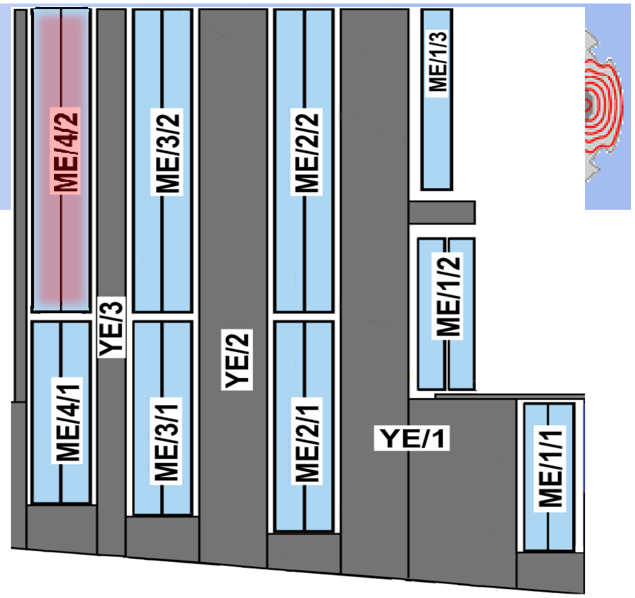
- **HCAL**
  - **HE: Plastic scintillator tiles and wavelength shifting fiber is radiation hard up to 2.5 MRad while at SLHC we expect 25MRad in HE.**
  - **HF: Tower 1 loses 60% of light during LHC, down to 4% of original after SLHC. Tower 2 down to 23% light after SLHC.**
  - **HF: May be blocked by potential changes to the interaction region**
    - **Direct impact on WW scattering**

CMS HCALs

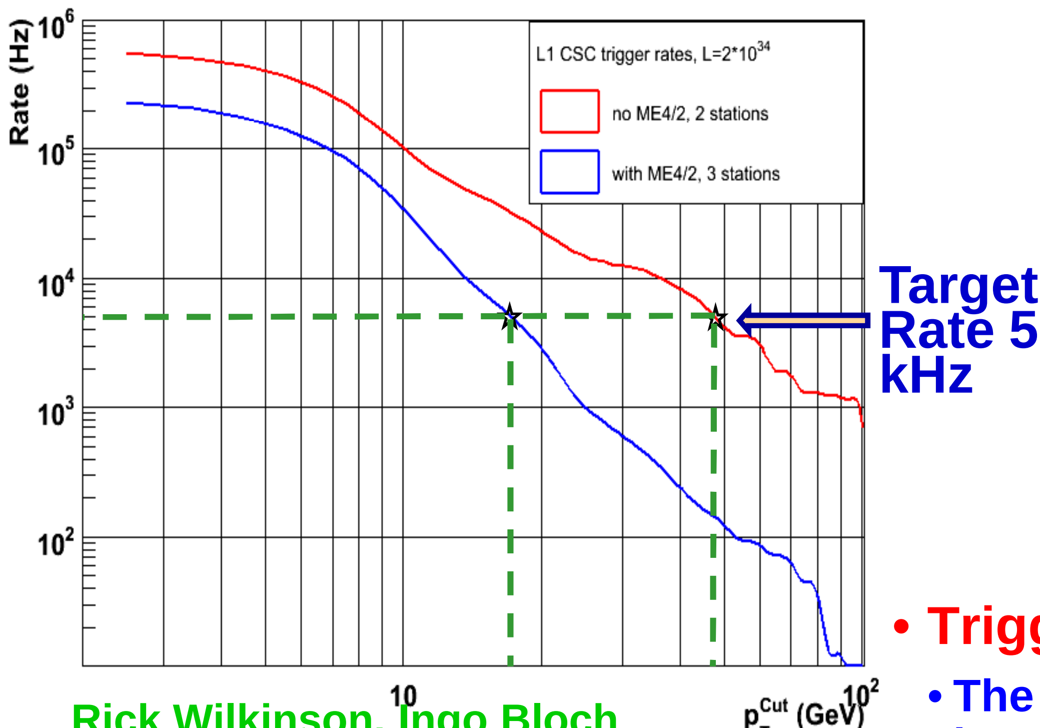


- **ECAL**
  - **Barrel Crystal calorimeter electronics designed to operate in SLHC conditions**
  - **Vacuum Photo Triodes in Endcap and Endcap crystals may darken at SLHC**
    - **Very difficult to replace**

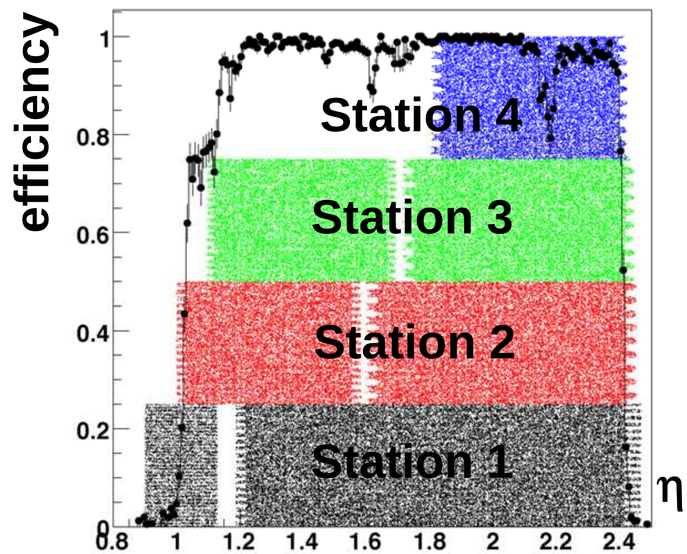
Phase 1 muon



- **Build ME4/2 chambers (72) for high-luminosity triggering in 1.1<|η|<1.8**
- **Replace ME1/1 cathode cards with Flash ADC version (DCFEB), restore trigger to 2.1<|η|<2.4 and handle high rate.**



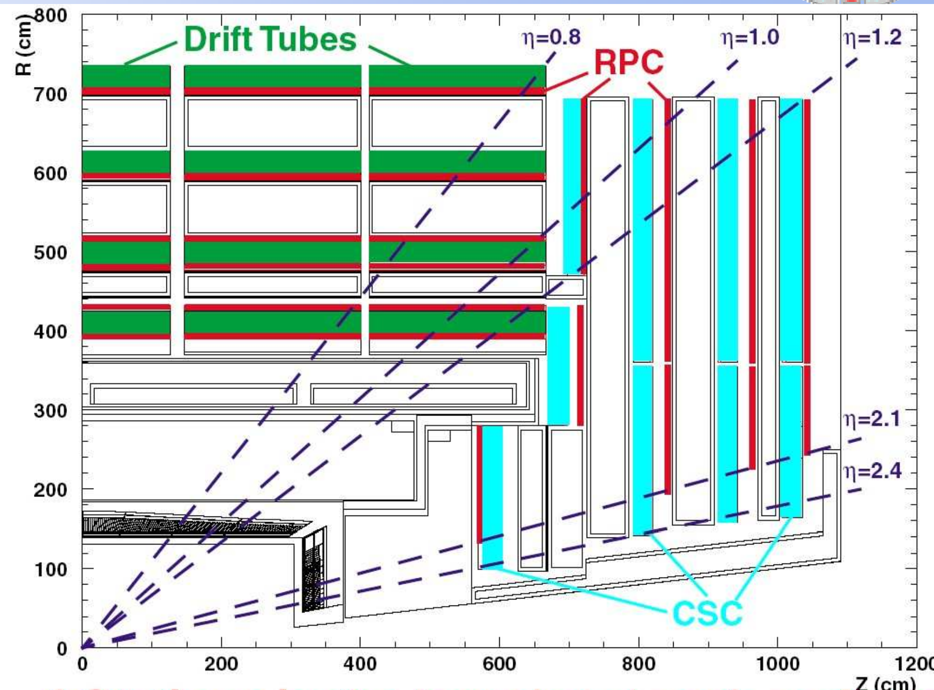
Rick Wilkinson, Ingo Bloch



- **Trigger on 3/4 vs. 2/3 stations:**
  - **The high-luminosity L1 trigger threshold is reduced from 48 →18 GeV/c**

Phase II Muon

- **Barrel fairly robust even in Phase II**
- **Concerns for RPC at $\eta>1.6$**
  - **Tested at neutron fluence ~ $10^{12}cm^{-2}$ (> 10 years of LHC operation)**
  - **High rate $\rightarrow$ decrease the charge in the detector**
    - **Possible technologies for $\eta>1.6$:**
      - **Evolution of RPC (thinner gap)**
      - **Thin gap chambers (ATLAS)**
      - **Gas Electron Multiplier (LHCb)**



4 Stations in the barrel and each endcap

- **The Clock and Control Board will need upgrading because of Timing Trigger Control (TTC) changes**
- **Redesign Muon Port Card (MPC) to increase throughput**
- **Upgrade of the trigger primitive generator cards (ALCT) for increased occupancy & asynchronous operation**
- **Upgrade CSC Track finder to achieve finer granularity in η, ϕ (L1 Track Trigger)**
- **Tests of high-bandwidth digital optical links operating at 10Gbps or greater, testing asynchronous data transmission and trigger logic**

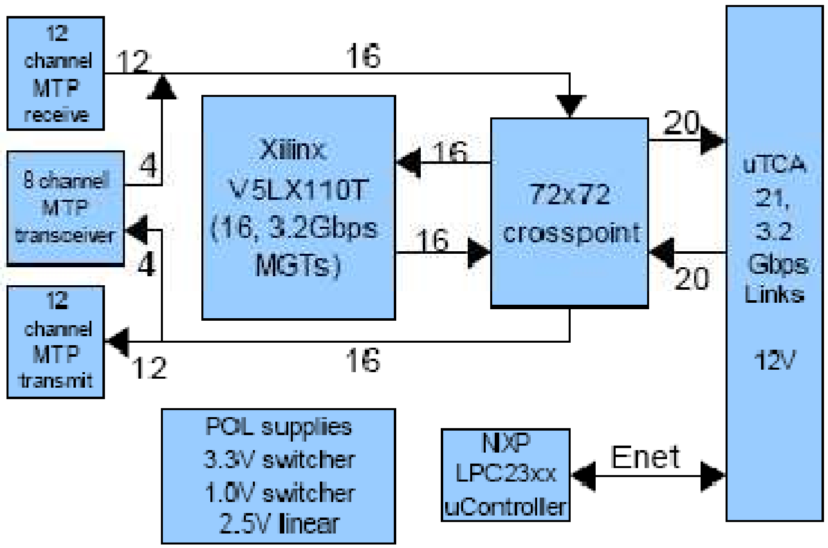
Might be needed already in Phase I

Phase 1Trigger upgrade

- CMS trigger is designed to deliver the physics up to $L=10^{34}$.
  - The Level-1 trigger is a fairly complex processor with ~ 10^2 different components.
  - Uses data from the calorimeters and muon systems to derive the L1-Accept decision with a latency of 128 Bx (144 Bx at the moment).
  - The input rate is 40 MHz and the max. output rate is 100 KHz.
- Phase 1 upgrade
  - Need to investigate what is to be done to cope with $L=2\text{-}4\times10^{34}$ using almost the same detector but more clever electronics.
- Trigger related changes already foreseen for this phase.
  - HCAL Electronics upgrade.
  - Global Calorimeter Trigger (GCT) is moving to the uTCA (Telecom Computing Architecture) $\rightarrow$ Large increase in algo. capability
  - GCT-to-Global Trigger (GT) links become industry standard asynchronous optical links which will also increase the bandwidth.
  - Already in 2009 CMS plans to adopt industry standard with compatible optical interfaces for GCT and GT .
  - In 2010 we should be able to upgrade GCT into uTCA system.

Proto. Generic Trigger System

Concept for Main Processing Card

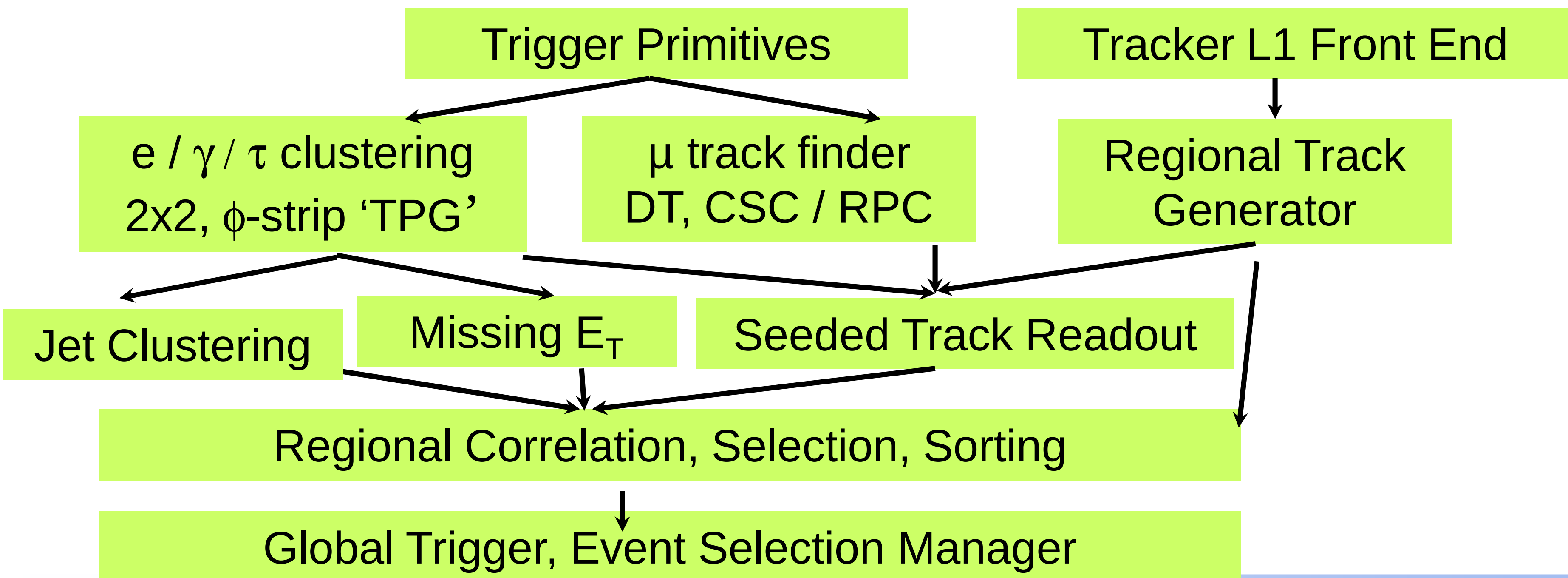


uTCA Crate and Backplane

- **The Main Processing Card (MPC):**
  - **Receives and transmits data via front panel optical links.**
  - **On board 72x72 Cross-Point Switch allows for dynamical routing of the data either to a V5 FPGA or directly to the uTCA backplane.**
  - **The MPC can exchange data with other MPCs either via the backplane or via the front panel optical links.**
- **The Custom uTCA backplane:**
  - **Instrumented with 2 more Cross-Point Switches for extra algorithm flexibility.**
  - **Allows dynamical or static routing of the data to different MPCs.**

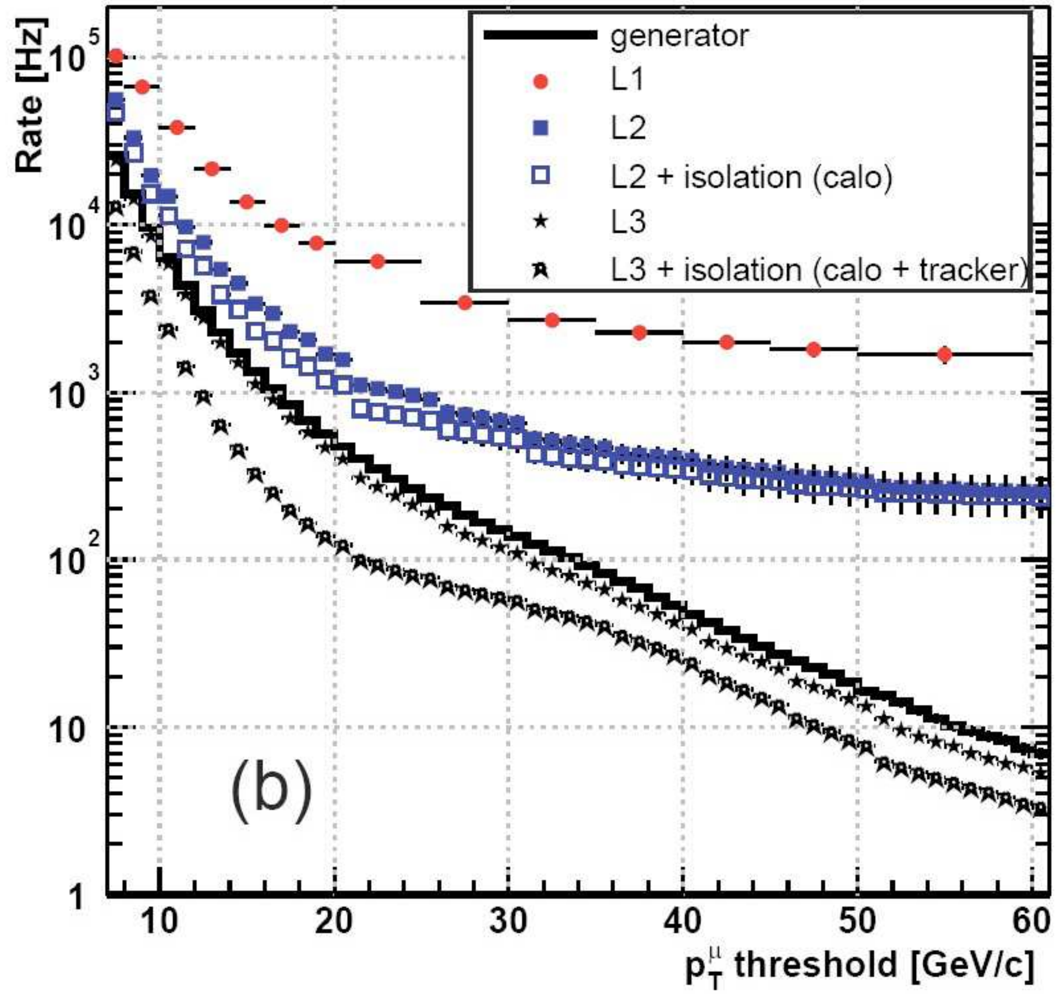
Phase II Trigger upgrade

- 50 ns beam crossing is the SLHC baseline
- 25 ns (current baseline) is a backup
  - Buffer sizes may need to be enlarged for more interactions distributed in half the number of crossings and larger event size.
  - Increase the Level 1 latency to 6.4 μsec
  - Leave present L1+ HLT structure intact (except latency)
  - Combine Level-1 Trigger data between tracking, calorimeter & muon at Regional Level at finer granularity



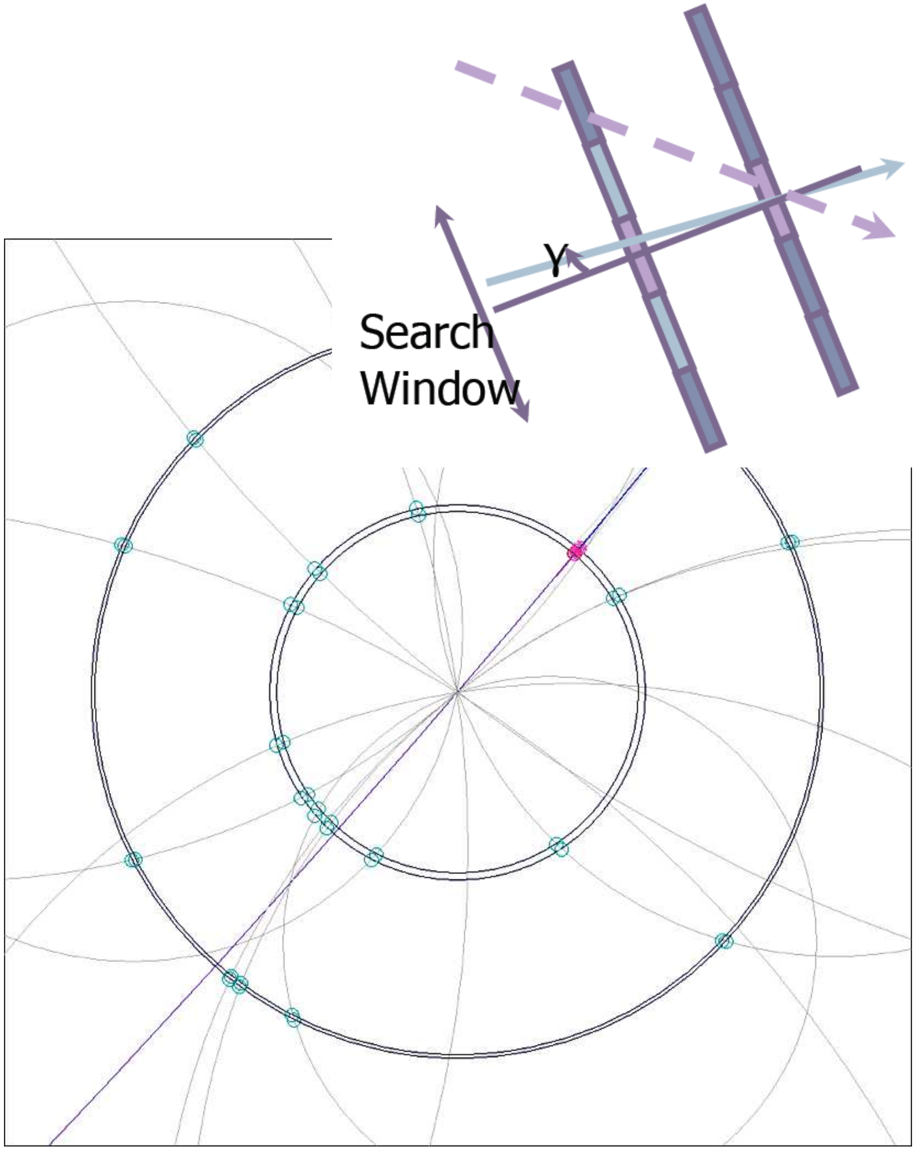
Phase II LEVEL 1 Trigger

- **Trigger**
  - **Adding tracking information at Level 1 give the ability to adjust P_T thresholds**
  - **Might be important for:**
    - **Single muon trigger**
    - **Single electron trigger rate**
      - ***Isolation criteria are insufficient to reduce rate at $L = 10^{35}\ cm^{-2}s^{-1}$***



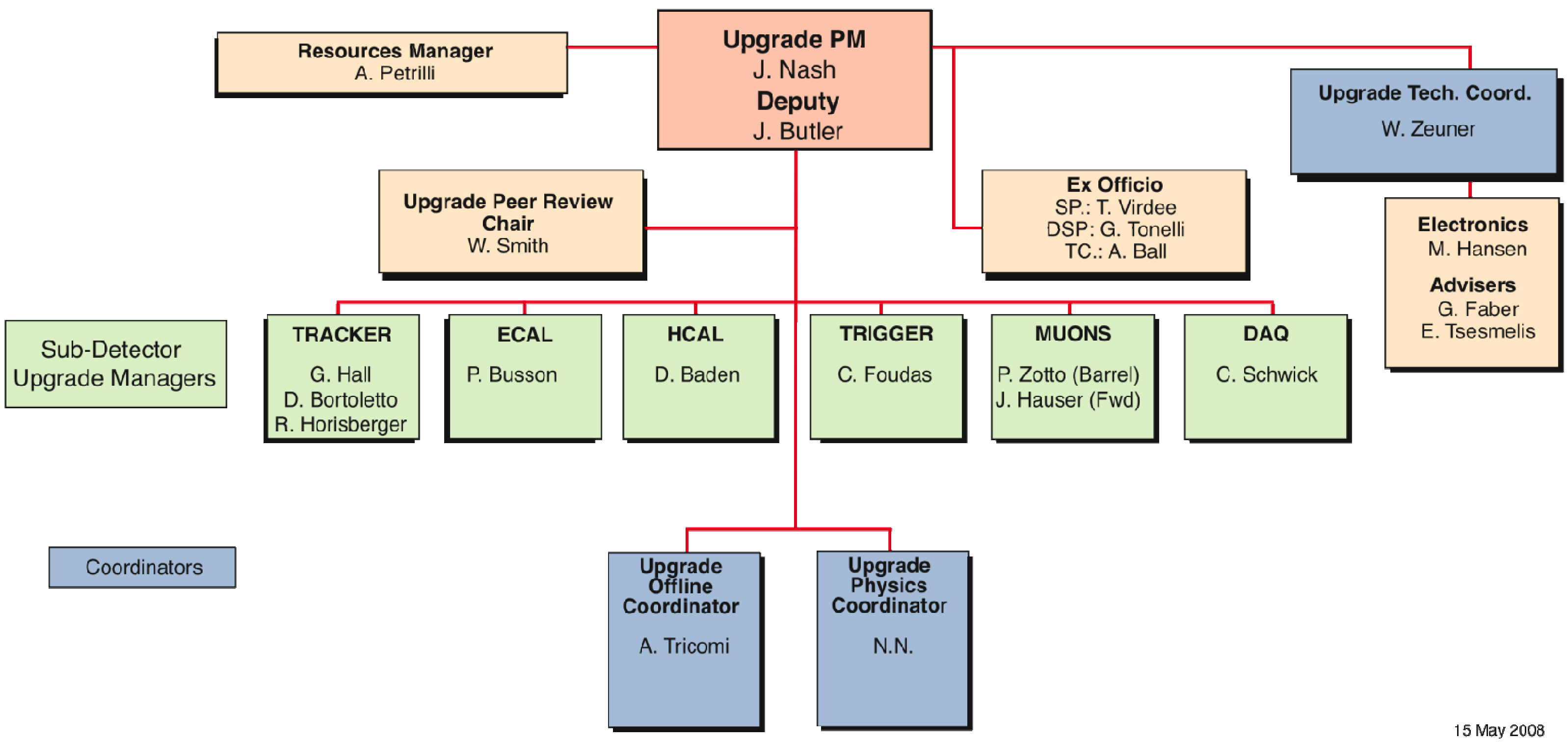
Phase II Trigger concepts

- **Tracking could have a critical impact on L1 trigger**
  - **Number of hits in tracking devices on each trigger is enormous**
  - **Impossible to get all the data out in order to form a trigger inside**
- **Investigating:**
  - **"Stacked" layers which can measure locally the p_T of track segments**
    - **Two layers about 1mm apart that could "communicate"**
  - **Cluster width may also be a handle**
- **Extensive R&D needed**



CMS Upgrade Management

CMS Upgrade Project

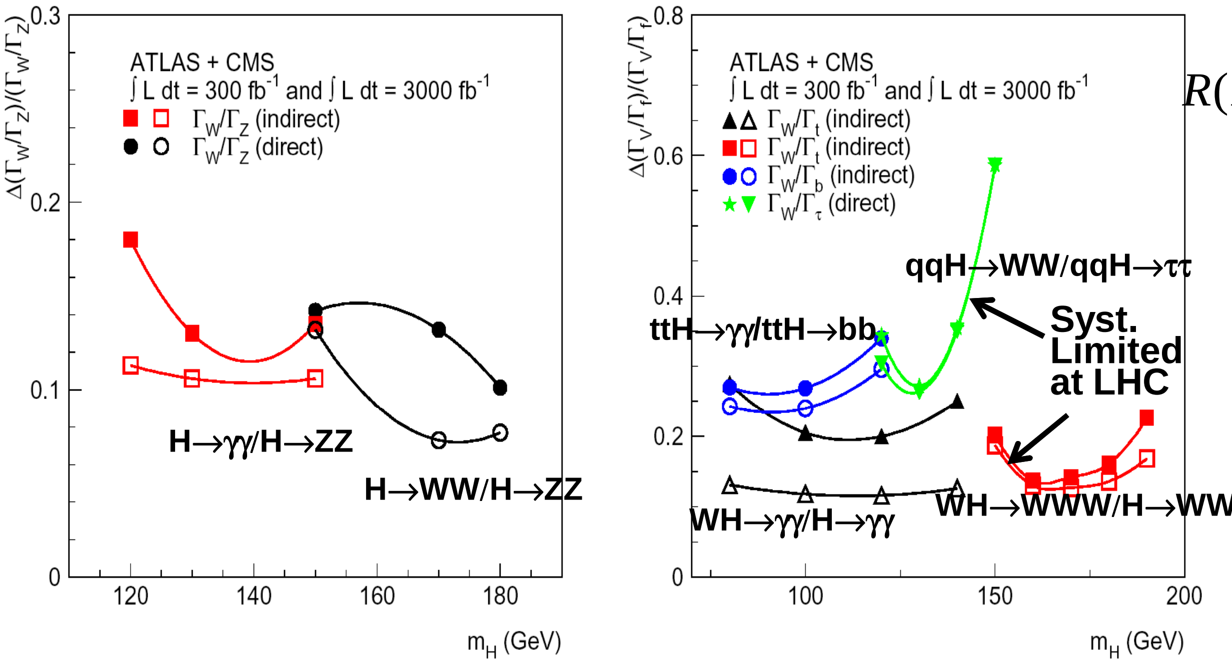


Higgs Decays

- **Rare decays:**
  - **H →Zγ BR of 10^{-3} in the SM**
  - **H→μμ BR of 10^{-4} in the SM**

	300 fb^{-1}	3000 fb^{-1} (per experiment)
H→Zγ	3.5 σ	11 σ
H→μμ	<3.5 σ	7 σ

SLHC, 3000 fb^{-1} per experiment



- **Higgs couplings**

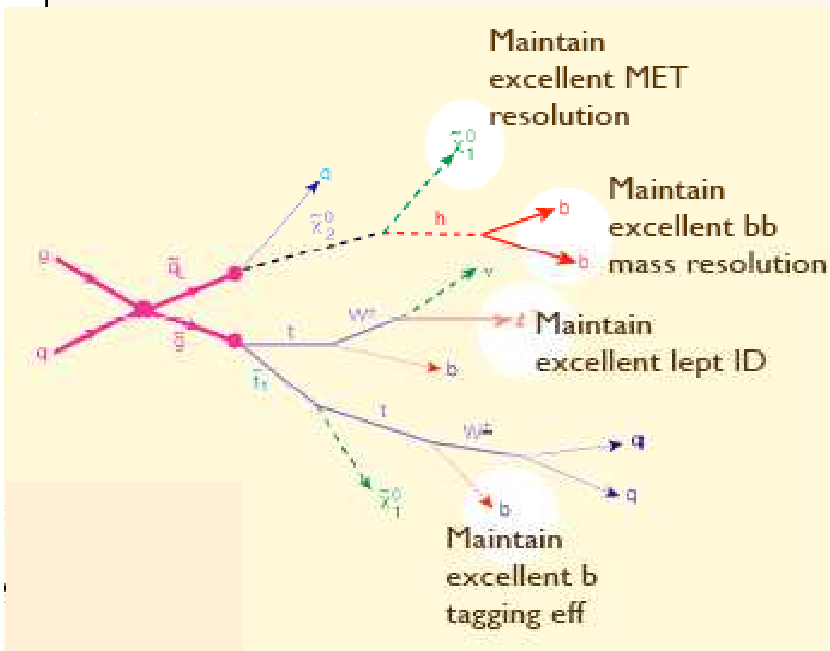
$$R(H \to ff) = \int Ldt \cdot \sigma(pp \to H) \cdot \frac{\Gamma_f}{\Gamma}$$

- **Combining different production mechanisms and decay modes get ratios of Higgs couplings to bosons and fermions**
- **Statistics limited at LHC**

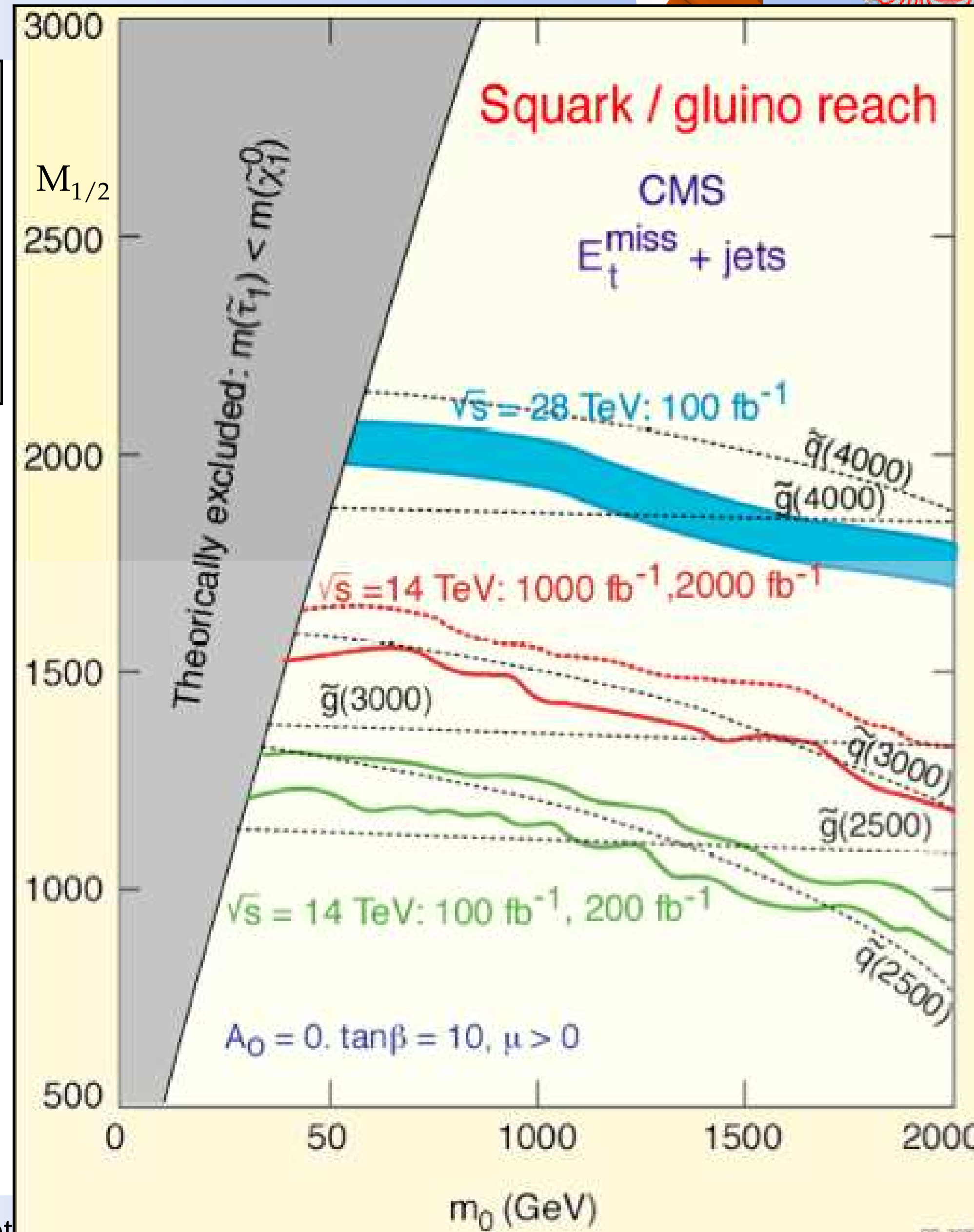
At phase 2 SLHC (~1000 fb^{-1} per year) the ratios of Higgs couplings should be measurable with a ~ 10% precision

SUSY reach

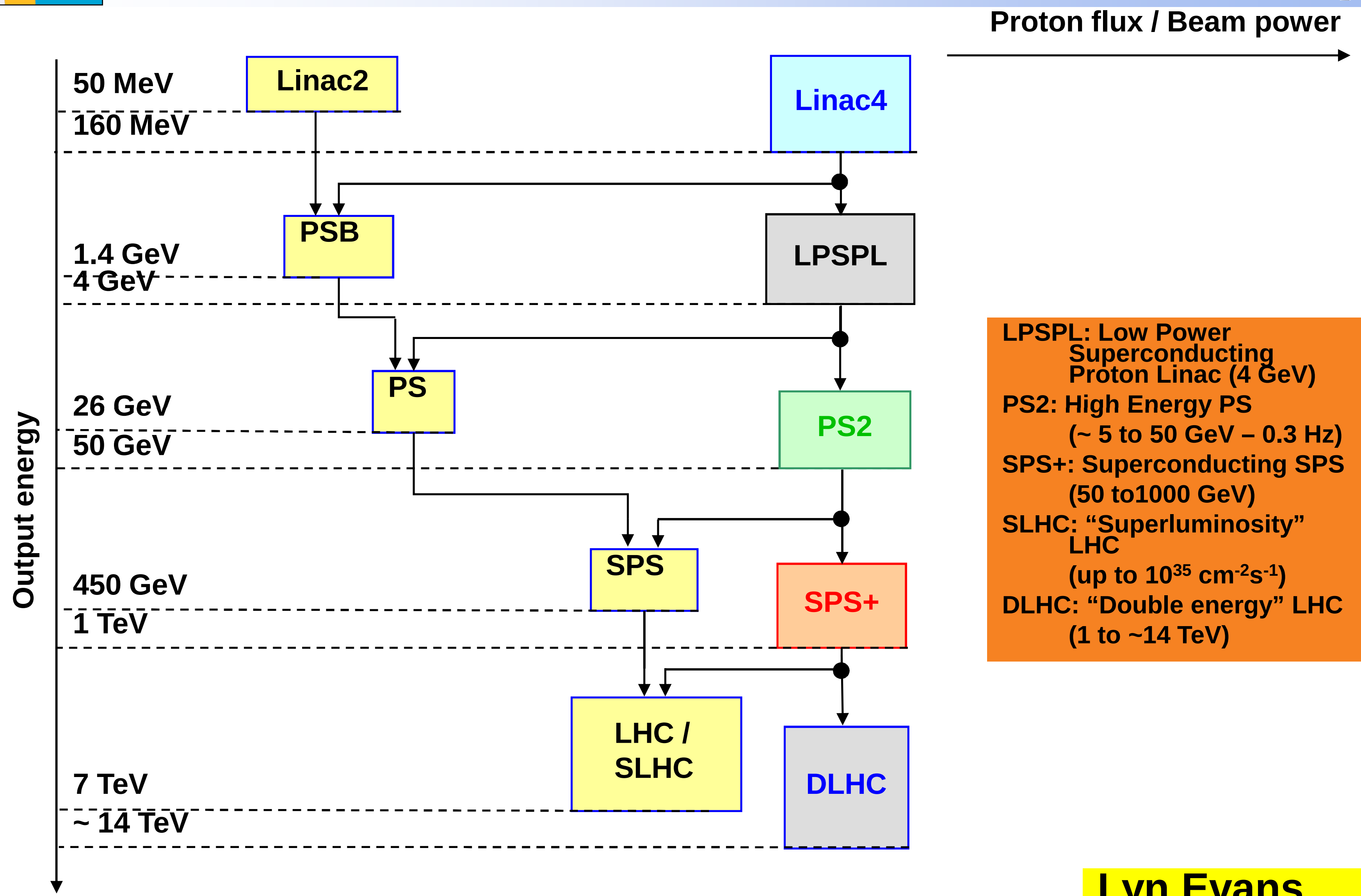
- **LHC reaches squarks, gluinos ~ 2.5 TeV**
- **SLHC Phase II could reach squarks, gluinos ~ 3.0 TeV**



- **Increased statistics (SLHC/I and II) yields increased sparticle spectrum reconstruction**
- **Requires excellent b-tagging**



Upgrade components



LPSPL: Low Power Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Lyn Evans

Phase 1 pixel upgrade

For Luminosity: 1×10^{34} cm^{-2}sec^{-1}

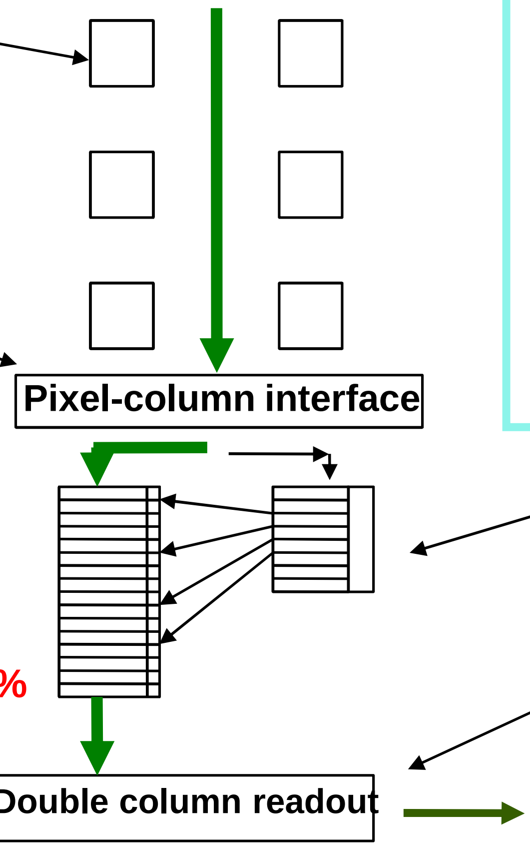
Radii = 11 cm / 7 cm / 4 cm layer

Total data loss @ L1A =100kHz

- 0.8%
- 1.2%
- 3.8%

Pixel busy:
0.04% / 0.08% / 0.21%
pixel insensitive until hit transferred to data buffer (column drain mechanism)

Double column busy:
0.004% / 0.02% / 0.25%
Column drain transfers hits from pixel to data buffer. Maximum 3 pending column drains requests accepted



Timestamp Buffer full:
0 / 0.001% / 0.17%

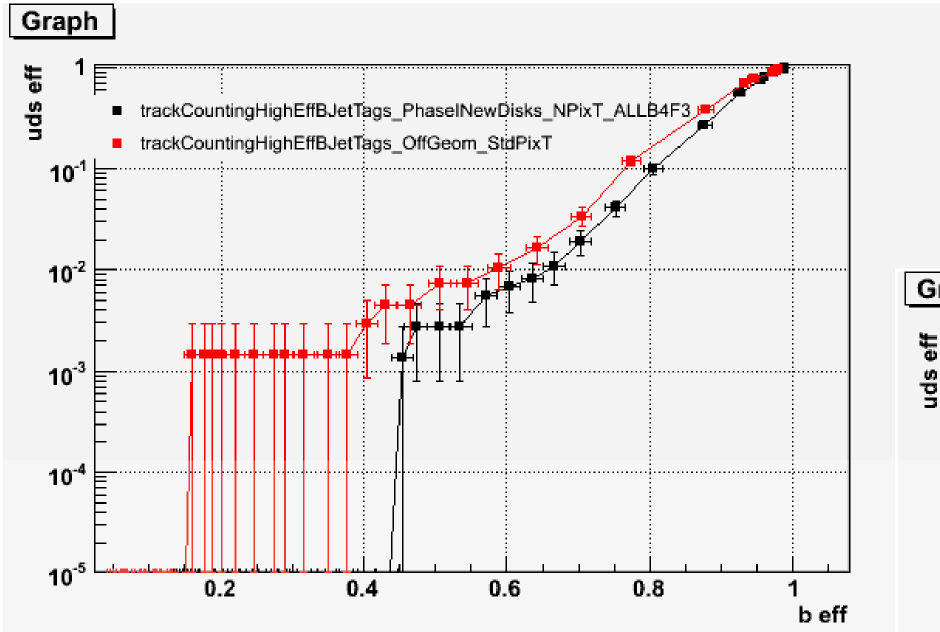
Data Buffer full:
0.07% / 0.08% / 0.17%

Readout and double column reset:
0.7% / 1% / 3.0%
for 100kHz L1 trigger rate

SLHC rate data losses dominated by finite buffer sizes !

→ chip size !
periphery bigger

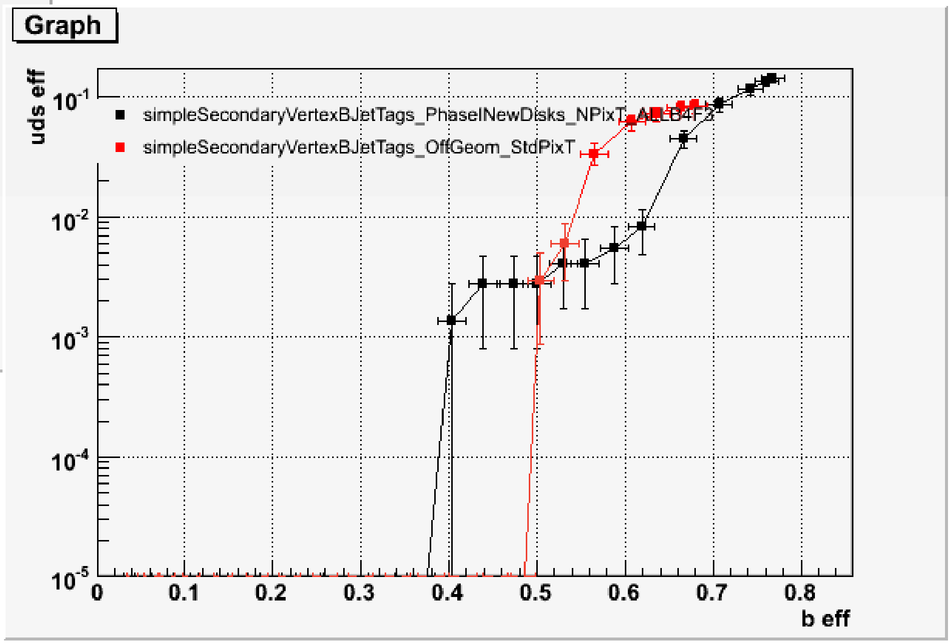
Improved layout



e_{uds}= 1% e_b= 58% to 68%

Using ttbar sample

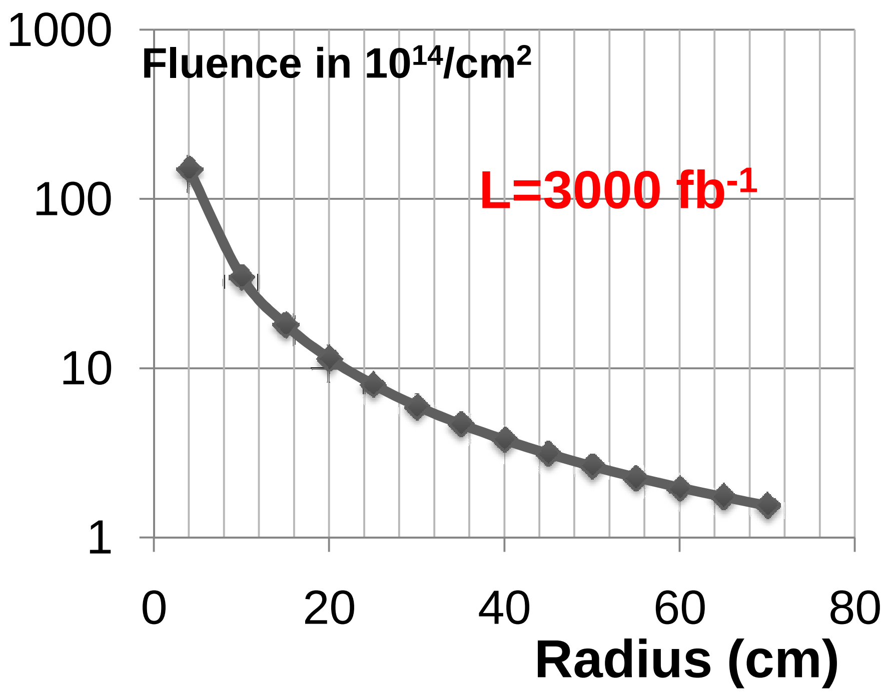
A. Tricomi

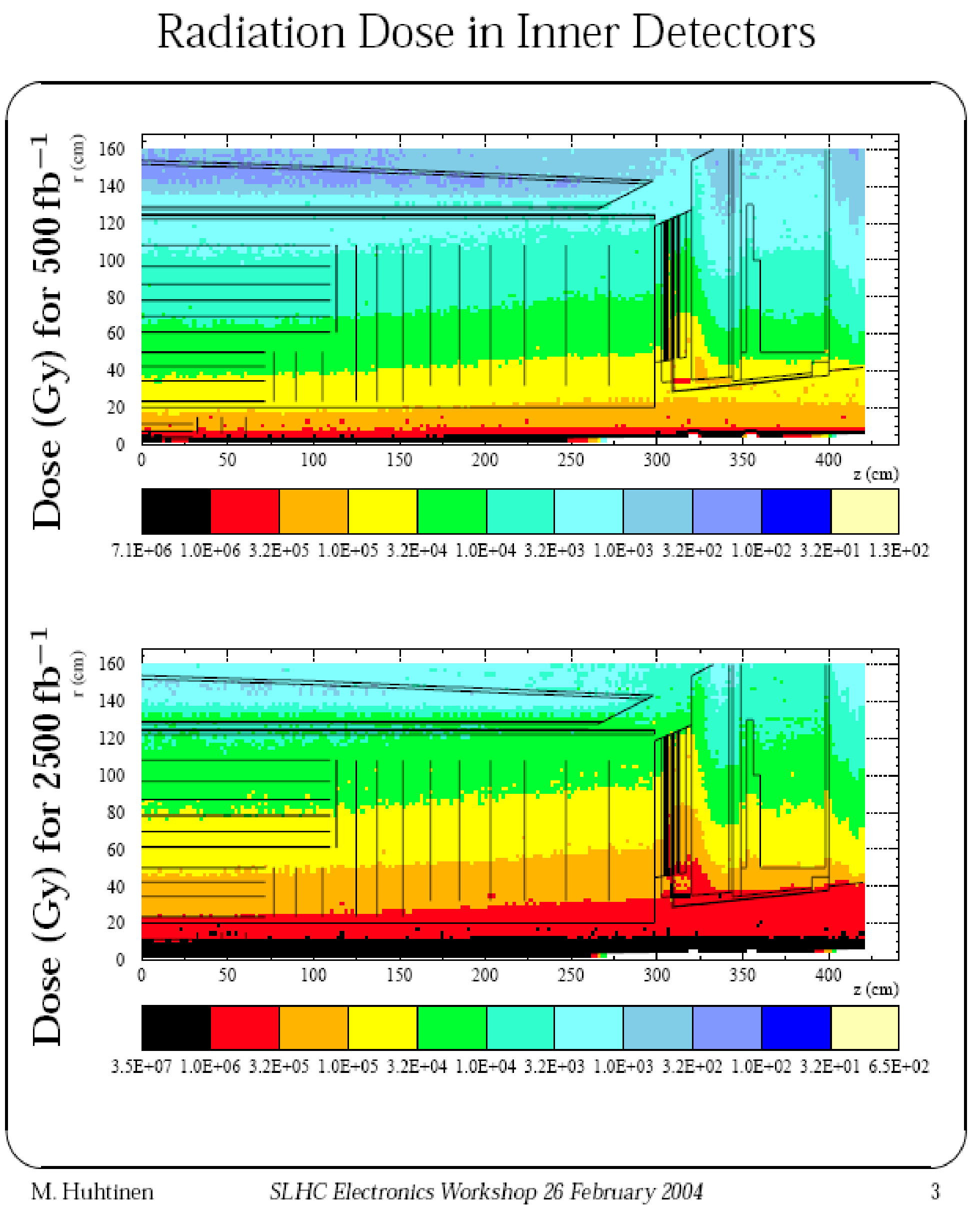


e_{uds}= 1% e_b= 54% to 64%

Standard Geometry
Phase I

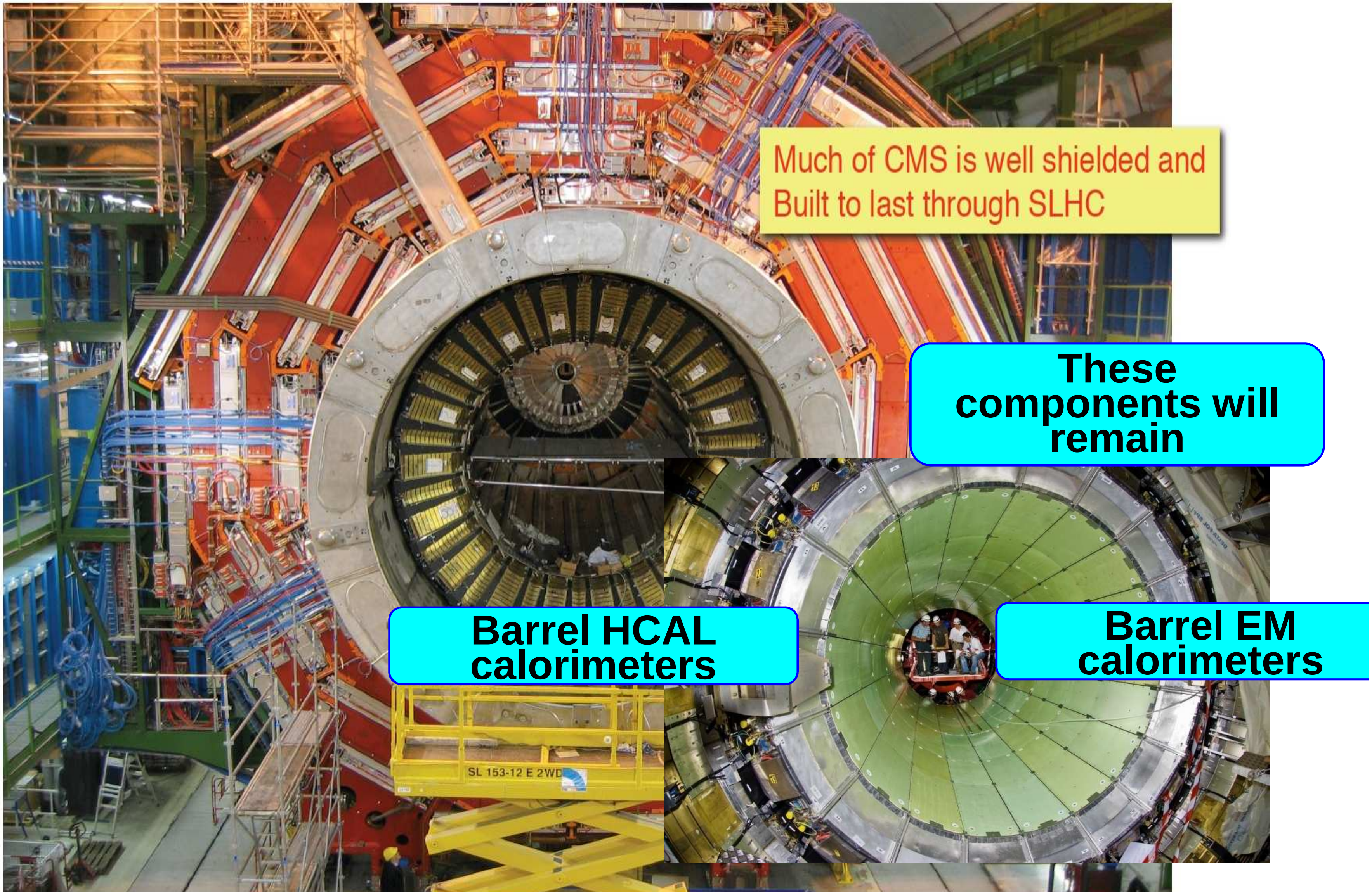
Phase II Radiation Damage





- **Develop sensors that can function at $10^{16}/cm^2$**

CMS



Much of CMS is well shielded and
Built to last through SLHC
These components will remain
Barrel HCAL calorimeters
Barrel EM calorimeters
SL 153-12 E 2WD