The US CMS Program 2008-2018

Presentation to P5

March 6, 2008

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US CMS Program Manager

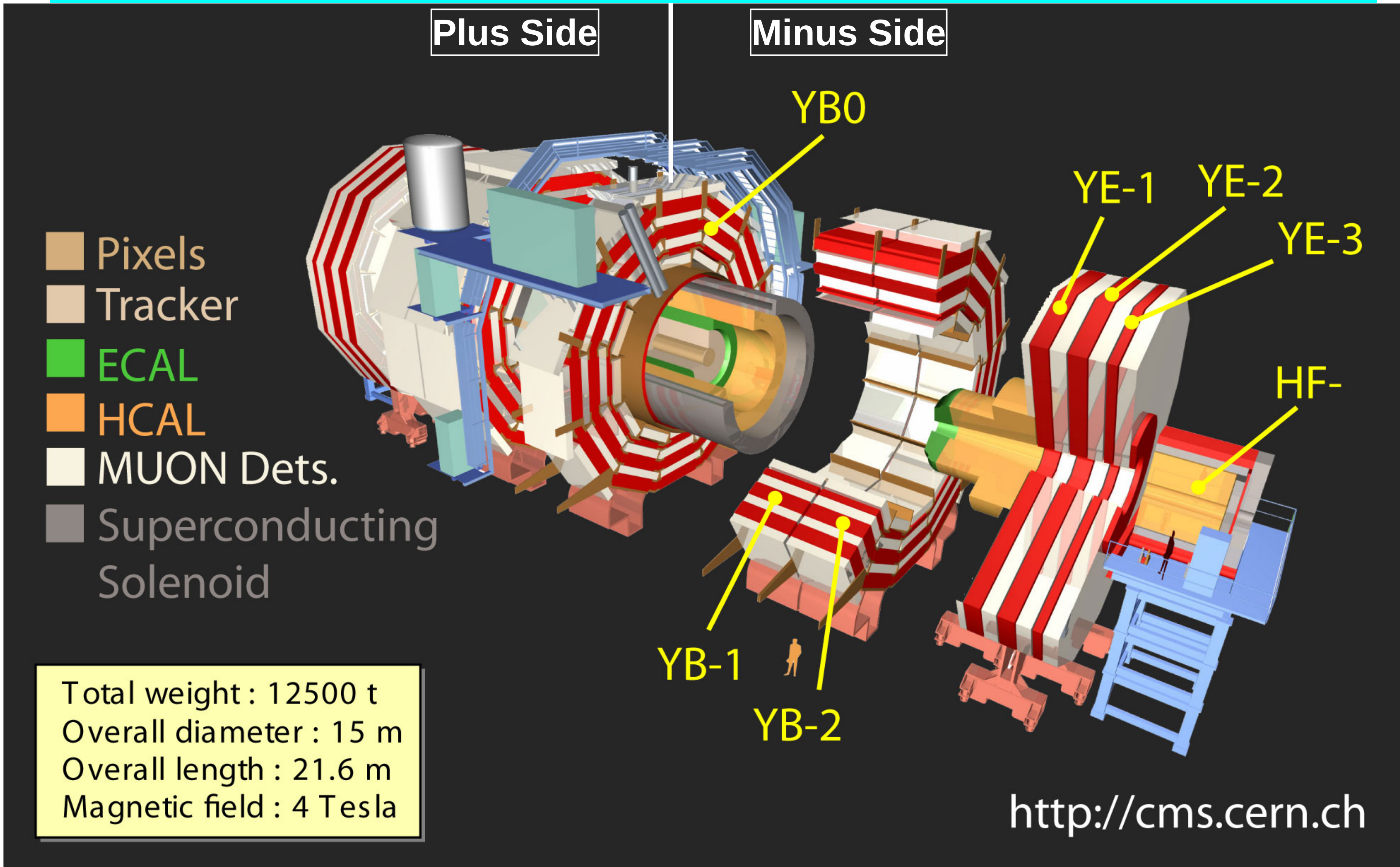
Outline

1. The CMS detector -1
2. The CMS detector CMS - 2
3. US CMS demographics
4. US CMS contributions to the detector construction
5. The Operations (a.k.a Research) Program – 1
6. The Operations Program – 2
7. US Leadership positions in CMS
8. Upgrade Plan from CERN
9. Upgrade drivers: performance vs luminosity
10. Upgrade status – Phase 1
11. Snapshot of Phase 1 Project file
12. Upgrade status – Phase 2
13. Upgrade Budgets
14. Total budget (Operations and Upgrade)
15. Vulnerabilities, Risks, and Opportunities
16. Summary

Final Act of Heavy Lowering
January 22, 2008

You have already heard a talk on the exciting physics expected at the LHC.

The CMS Detector



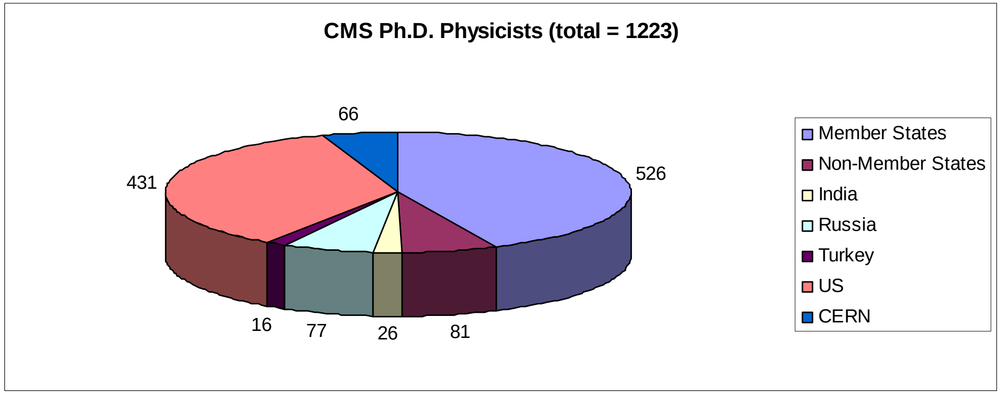
CMS Design Features

- Optimized for high transverse momentum DISCOVERY physics
- Very large solenoid – 6m diameter x 13 m long – with strong 4 Tesla field
  - Tracking and calorimetry inside the solenoid
    - Particle energies are measured before they pass through the solenoid coil and cryostat which would degrade their resolution
  - Strong field
    - coils up soft charged particles
    - results in excellent momentum resolution
- Tracking chambers in the return iron track and identify muons
  - This makes the system very compact
  - The weight is dominated by all the steel and is 12,500 Tonnes
- A lead tungstate crystal calorimeter (~80K crystals) for photon and electron reconstruction
- Tracking is based on all-silicon components
  - A silicon pixel detector with 66 million pixels, out to ~ 11 cm
  - A silicon microstrip detector with 11 million strips, out to 1.2 m
  - Gives CMS excellent charged particle tracking and primary and secondary vertex reconstruction up to $10^{34} cm^{-2} s^{-1}$ and beyond
    - High segmentation results in very low occupancy
    - Silicon detectors are radiation hard

US CMS Demographics

- **US CMS consists of 48 institutions**
- **It has 431 out of the 1223 Ph.D. physicists in CMS (35%)**
  - **Of these, 18 are supported by US DOE/NSF NP**
- **There are currently 196 graduate students in US CMS**

Source	Number
DOE HEP	329
NSF HEP	84
DOE NP	16
NSF NP	2
Total US	431
Total CMS	1223
US HEP Fraction	33.6%
US Fraction	35.1%



Collaboration expectations for US contributions are based on this fraction!

US Contributions to CMS Detector Construction

- Hadron calorimeter – leading role
- Endcap Muons – leading role
- Forward Pixels – leading role
- Silicon Strip Tracker – leading role in construction of "Tracker Outer Barrel" and a leader in integration and installation of the full Tracker
- Trigger – leading role, full responsibility for Regional Calorimeter and Endcap Muon Triggers
- Electromagnetic Calorimeter – sensors (avalanche photodiodes), electronics and optical links, and laser calibration systems
- Data Acquisition -- partnership with CERN. US did work on Myrinet switches, Readout/Event builder and Data to Surface subsystem.

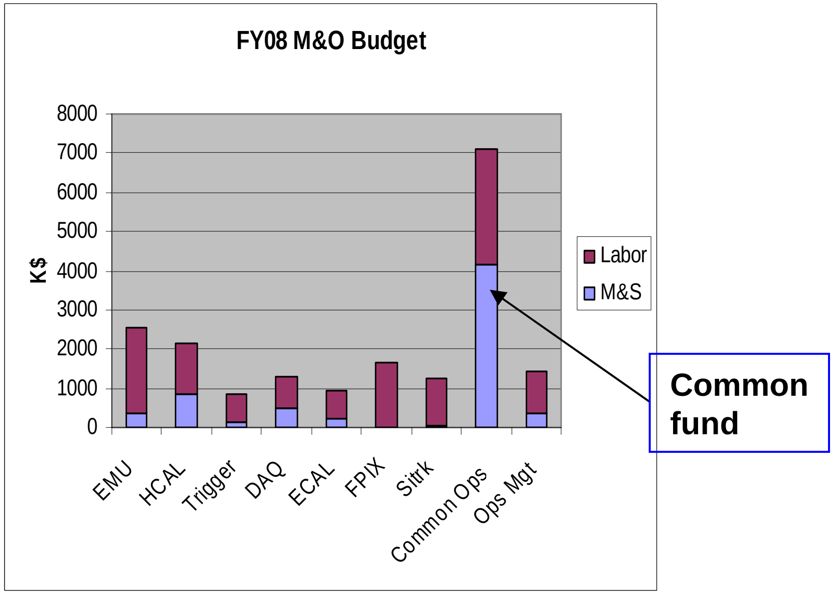
Total Cost of US Construction Project: $167M

Operations Program - I

A ~$37M/year program supporting the maintenance, operations, software and computing activities of >600 US Ph. D physicists and graduate students on CMS

- **Maintains the detector components the US built including M&S and support for engineers, technicians and programmers**
  - who developed mechanics and electronics and programmed the devices (e.g. FPGAs)
  - who assist in maintenance during beam down periods
- **Supports operations including**
  - running of shifts, by providing travel and COLA
  - developing and maintaining online and data quality monitoring software, and local reconstruction software
  - remote operations at FNAL (ROC)
- **Support Program offices**
  - At FNAL
  - At UCLA (NSF)
  - At CERN
- **Carry out R&D for future detector upgrades**
  - But not the construction of the upgrades

We will need ~150-200 people at CERN for operations and to participate in physics. 75% will still be in the US.

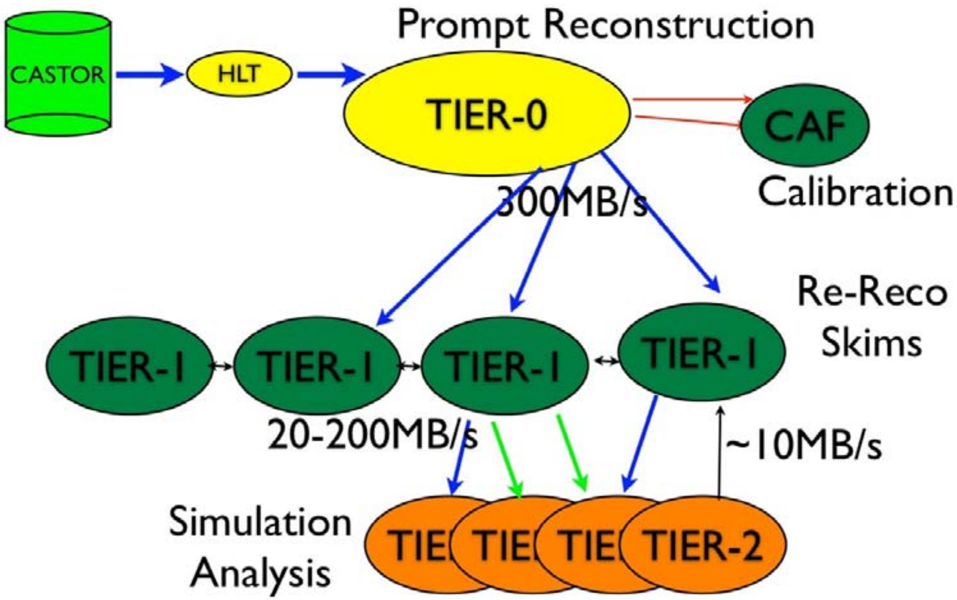


Example: FY'08 Endcap Muon $2.25M total

(468 chambers, 60 VME crates)

$1.7M Labor (support of engineers, technicians, and programmers mostly at universities)
$225K Travel (engineer/technician travel and COLA to do M&O tasks)
$300K M&S
25 people full time at CERN
R&D (small for EMU)

Operations Program - II



	FY07	FY08	FY09
Total Labor Costs	9,385	10,374	10,746
Facility Costs	5,050	7,297	6,846
management	290	1,105	898
Total (w.o. MR)	14,525	18,876	18,490

- **FNAL is a dedicated Tier-1 Facility for CMS**
  - **Meeting the obligations of the U.S. to CMS Production Computing**
  - **The only Tier-1 center for CMS in the Americas**
- **FNAL is the largest Tier-1 center in CMS**

Seven US Tier 2 centers:

- **Production computing**
- **Data analysis efforts**
- **Provided by NSF//DOE/university funds**

Site	CPU (kSI2K)	Disk (TB)	WAN (Gb/s)
Caltech	586	60	10
Florida	519	104	10
MIT	1155	250	10
Nebraska	650	145	10
Purdue	743	184	10
UCSD	932	188	10
Wisconsin	1350	220	10

LPC-CAF at FNAL also helps in final physics analysis

US Role: e.g. CMS Physics Organization (January 2008)

US collaborators in red

Physics Coordinator: P.Sphicas
Deputies: J.Incandela, R.Tenchini

- **e/γ**: C.Seez, P.Vanlaer
- **Jets/MissET**: G.Dissertori, D.Elvira
- **ParticleFlow/τ**: R.Cavanaugh, P.Janot
- **Muons**: N.Amapane, M.Mulders
- **b-tagging**: T.Speer, T.Boccali
- **MC generators**: P.Bartalini, R.Chierici
- **Forward Physics**: M.Grothe
- **Heavy Ions**: D.D'Enterria, O.Kodolova
- **Super LHC**: D.Denegri
- **QCD**: K.Rabbertz, N.Varelas
- **EWK**: J.Alcaraz, S.Dasu
- **Top**: C.Campagnari, J.D'Hondt
- **B physics**: U.Langenegger, J.Olsen
- **Higgs**: C.Mariotti, Y.Sirois
- **SUSY**: O.Buchmuller, L.Pape
- **Exotica**: A.De Roeck, S.Eno

Deputy Spokesperson: Robert Cousins (UCLA)
Chair-elect of Collaboration Board: Daniel Green (FNAL)
Trigger Coordinator: Wesley Smith (Wisconsin)
Deputy Offline Computing Head: Patricia McBride (FNAL)
Deputy Commissioning and Run Coordinator: Darin Acosta (U of Florida)

Upgrade Definition and Drivers

•Phase 1: CERN has committed to this.

- **Time scale: ~2013**
- **Luminosity goal: $2x10^{34}$ or more**
- **LHC modifications inside +/-19m zone: no**
- **Shutdown for installation: 3 months, perhaps 6 months**

•Phase 2: CERN will evaluate after initial LHC results are in and understood around 2010-2011

- **Time scale: 2016-2017**
- **Luminosity goal: $1x10^{35}$ or more**
- **LHC modifications inside +/- 19 m zone are possible**
- **Shutdown for installation unclear but could be long (18 months)**
- **This could be an adiabatic campaign**

It is MANDATORY that the Phase 1 Upgrade

- contribute to the physics by maintaining or improving detector performance at the higher luminosity
- Fit within the available construction and installation time
- Fit within the available funding (TBD)

It is also HIGHLY DESIRABLE that

- each part of the Phase 1 Upgrade should be a significant step on the ROADMAP for the Phase 2 Upgrade

The CMS Management Board has taken note of the two phase approach and has endorsed it as way to upgrade CMS consistent with the CERN schedule. CMS has an Upgrade Organization with strong US participation.

Luminosity/Performance Matrix

Components degrade because of:

1. **Radiation damage (rad)**
2. **High occupancy that confuses pattern recognition (occ)**
3. **High occupancy that overflows buffers, link bandwidths etc (occ)**

Trigger degrades because it fails to achieve adequate rejection while maintaining efficiency

Component	1.00E+34	2.00E+34	1.00E+35	
Pixel	OK	Rad, Occ	Rad, Occ	
Tracker	OK	OK	Rad, Occ	
EB	OK	OK	OK	
EE	OK	OK	Rad @ high eta	
HB	OK	OK	Rad @ high eta	
HE	OK	Rad @ high eta	Rad @ high eta	
HF	OK	OK	Rad, Occ	
HO	HPD in 4T	HPD in 4T	HPD in 4T	
DT	OK	OK	Occ	
CSC	OK	Occ	Occ	
RPC	OK	Occ	Rad & Occ @ high eta	
Trig	OK	Occ	Occ	

Reduced efficiency

severe degradation

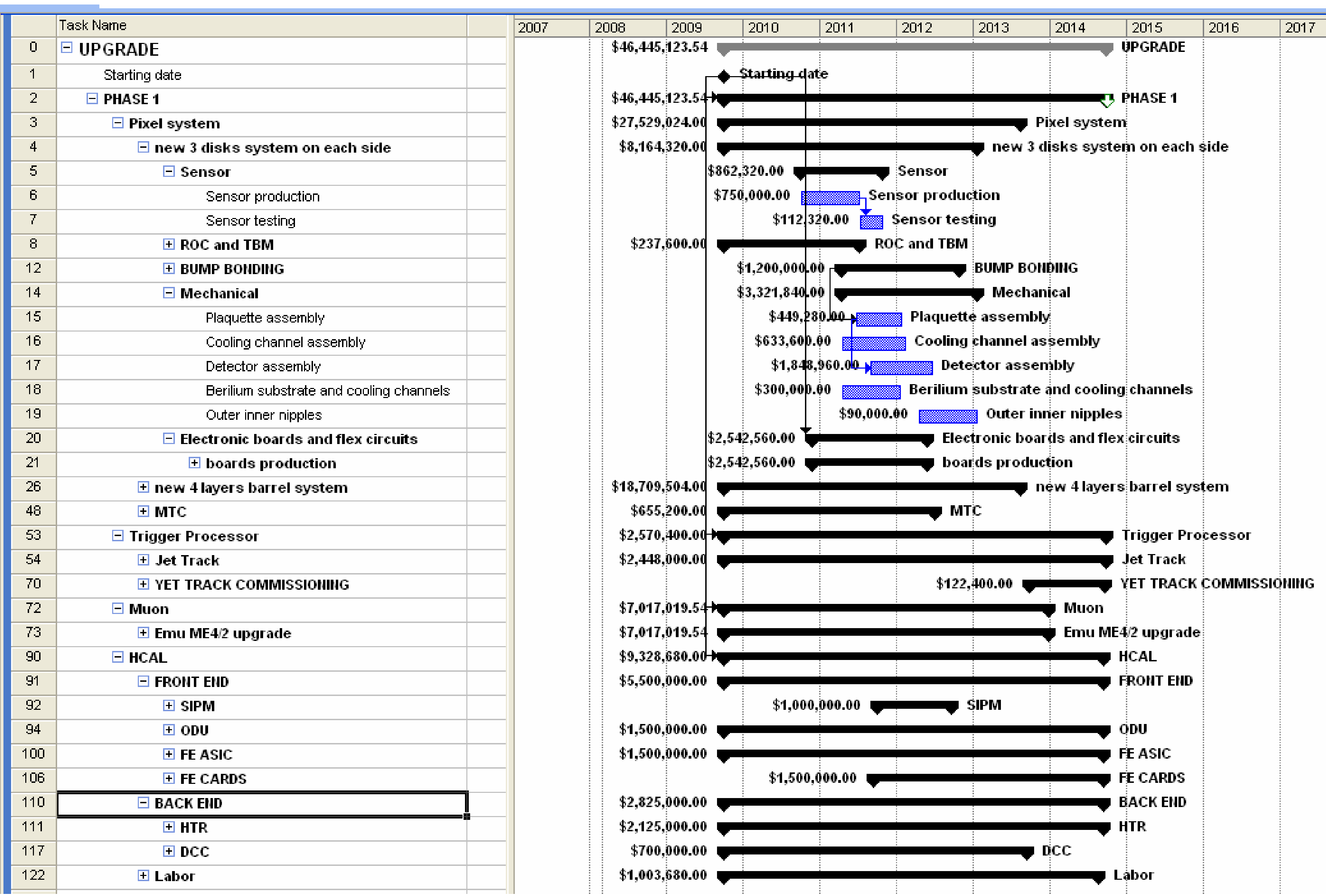
Most detectors work even at 2x 10^{34}.

Component	1.00E+34	2.00E+34	1.00E+35
Pixel Tracker	OK	Replace/add to barrel, disk	Full Upgrade / Replace
Silicon Strip Tracker	OK	OK	Full Upgrade / Replace
Barrel ECAL	OK	OK	OK
Endcap ECAL	OK	OK	OK ex. High eta replace
Barrel HCAL	OK	Upgrade readout X2	No further action
Endcap HCAL	OK	Upgrade readout X2	No further action
Forward HCAL	OK	OK	Full Upgrade / Replace
Outer HCAL	Upgrade readout	no further action	no further action
Muon Drift Tube (barrel)	OK	OK	Upgrade Electroncs
Muon Cathode Strip (endcap)	OK	More Planes in Endcap	& Upgrade Electroncs
Muon Resistive Pad Chambers(both)	OK	More Planes in Endcap	& Upgrade Electroncs
Trigger	OK	OK w/minor enhancements	Full upgrade/track trigge

Phase 1 Upgrade

- Pixel system replacement with
  - 4 barrel layers (3 now)
  - 3 forward disks (2 now)
  - MTC (Module Trigger Chip) for pixel-based trigger at Level 1
- Trigger processor
  - implement a jet-track correlation trigger using pixel information
- Muon
  - Endcap Muon ME4/2 upgrade to add redundancy
  - Endcap Muon ME1/1 electronics upgrade with new CSC Front End Board (CFEB) to add this layer to the trigger for added redundancy
- HCAL
  - Electronics Front End modification
    - Convert to Silicon Photomultipliers (SiPMs) from Hybrid Photodiodes (HPDs)
    - Implement longitudinal segmentation
  - Backend Electronics modification
- Development of a TDR including R&D for the full Tracker upgrade that is required for Phase 2 by end of 2011 (funded through current R&D part of Operations Program)

These upgrades can be installed in a 3-6 month shutdown



Snapshot of the project file

Phase 2 Upgrade Concept

- For Phase 2, we follow the existing upgrade EOI
  http://cmsdoc.cern.ch/cms/archives/07/LHCC/slhc-eoi-final.pdf
  - Full replacement of Tracker (inner and outer), including layers used to generate L1 track primitives
  - Upgrade of the trigger including
    - longer Level 1 latency (3.2 μs→6.4 μs)
    - incorporation of tracking triggers at Level 1
    - Correlation of tracking trigger primitives with muon and calorimeter primitives at the regional level and with finer granularity than currently employed
    - Replacement of front-end and readout electronics for Calorimeters and Muon detectors to cope with higher occupancy where required
  - Replacement of HF (Forward Hadron Calorimeter)
  - Upgrade of DAQ and High Level Trigger (HLT) to handle the larger data volumes
- Construction and Installation
  - We have established the ability to construct a major tracking device in under 4 years
    - Current Silicon Strip Tracker built in 3 years
    - Current Pixel detector built in 2.5 years
  - Installation in CMS can be very quick
    - Current Silicon Strip detector was installed and will be connected to cooling and cabling (power, control, signal) in 4 months
      - We also need time to extract the existing detector
    - Pixel detector is planned to take two weeks to install and cable
  - A shutdown of 6 months to 1 year would be desirable around 2016-2017 to install the Phase 2 upgrade

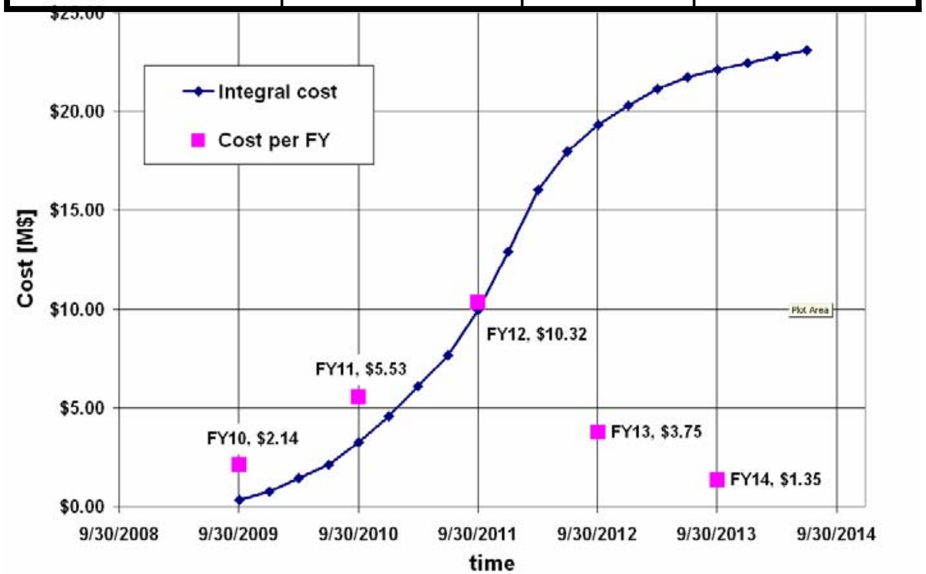
Upgrade Budgets

Derived from US WBS based on current detector. US share is 35%

Extrapolated from current detector, adjusted for US costing and to $FY'08, w.o. contingency. US share is 35%

•Phase 1

Detector	Base Estimate M$ FY '05	Escalation M$ FY'08	Contingency 30% M$ FY'08
Pixel	27.5	30.1	39.1
Muon	7.0	7.7	10.0
Trigger	2.6	2.8	3.7
HCAL	9.3	10.2	13.3
Total	46.4	50.8	66.0
Total USCMS	16.3	17.8	23.1



•Phase 2

Detector	Escalation M$ FY'08	Contingency 30% M$ FY'08
Inner Tracker	60	78
Outer Tracker	180	234
Trigger	40	52
DAQ	20	26
Calorimeters	20	26
Infrastructure	30	39
Total	350	455
Total US	122	160

Total Budget: 2008-2018

US CMS Research Program and Upgrade Project Needs (estimated to 10%) (AY=At Yea

The Research Program includes Software and Computing Facilities, Maintenance and Operations and Upgrade R&D.

Fiscal Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$	AY K$
Current DOE Guidance (constant level of effort after FY12) (4% inflation)	27,300	28,000	29,500	30,200	31,600	32,864	34,179	35,546	36,968	38,446	39,984
Current NSF Guidance (assumed flat-flat) note 1	10,000	10,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
Total Current Guidance	37,300	38,000	38,500	39,200	40,600	41,864	43,179	44,546	45,968	47,446	48,984
Constant Level of Effort after 2011(4.0% inflation)	37,300	38,000	38,500	39,200	40,600	41,864	43,179	44,546	45,968	47,446	48,984
Additional Computing needs for Pre phase 1(incl DISUN-it replacement)			3,000	3,000	3,000	3,000			0	0	0
Commissioning of Phase 1 upgrade					1,000	2,000	1,000				
Software and Computing for Phase 1 Upgrade							2,000	2,000	2,000	2,000	2,000
Commissioning of Phase 2									3,000	4,000	3,000
Additional Computing for Phase 2									2,000	5,000	2,000
Total Research Program Request to P5 (AY K$)	37,300	38,000	41,500	42,200	44,600	46,864	46,179	46,546	52,968	58,446	55,984
Total Research Program Request to P5 ('08 K$)	**37,300**	**36,538**	**38,369**	**37,516**	**38,124**	**38,519**	**36,496**	**35,371**	**38,703**	**41,064**	**37,821**
The Upgrade Program includes Phase 1 (Luminosity 2-3x10^{34} cm^{-2}s^{-1}) and Phase 2 (Luminosity 1x10^{35} cm^{-2}s^{-1}) (estimated to 30%) ('08K$)											
Upgrade Construction for Phase 1 (FY08)			1,646	4,254	7,938	2,885	1,038				
Upgrade Construction/*10 luminosity(FY08$)					10,000	25,000	32,000	30,000	18,000	5,000	2,000
Upgrade Totals(FY08$)			1,646	4,254	17,938	27,885	33,038	30,000	18,000	5,000	2,000
Grand Totals(FY08 K$)	**37,300**	**36,538**	**40,015**	**41,769**	**56,063**	**66,403**	**69,534**	**65,371**	**56,703**	**46,064**	**39,821**
										515,761	555,582
	Mar 6 version based on bottoms up estimate for Phase 1										

The Operations Program could use about 15% more than this for
- **travel and COLA needs (estimated at $1M)**
- **computing needs for Tier3s at universities and additional Tier2s ($1-2M)**
- **additional R&D in preparation for upgrades ($1-2M)**
- **need for more management reserve to handle unforeseen problems ($2M)**

Vulnerabilities, Risks, and Opportunities

- We are very vulnerable to
  - declining value of the $ relative to the Swiss Franc and Euro, which have hit us badly in the last year
  - Possible leveling off of CPU or disks price/performance that will require more money to keep up with increasing luminosity
- We need continuing and improved support for the university and lab groups that provide the key personnel that propel the physics analysis and operations
- We do not yet have enough experience to understand
  - The true maintenance requirements
  - The actual resources needed for operations in light of
    - Continuous increases in luminosity in early years
    - Need to manage radiation damage in later years
    - Experience with aging of detector components, electronics, and infrastructure
  - The actual patterns and requirements for physics analysis (as opposed to production) computing
  - How much ongoing software development is required and for how long
    - Experience of BABAR, CDF, and D0 indicate it will be needed well into the operations period
- The opportunity is to provide our researchers, experienced from many years of data analysis, with a dataset and analysis capability that will reveal the secrets of the Terascale

Summary

- The US has made a large investment in CMS and the LHC through the Construction Project and the Operations Program
- US CMS and US ATLAS are the biggest programs in US HEP, involving ~50% of all HEP researchers because the community believes that this is where the next great physics discoveries will come from.
  - US physicists are poised to play a major role in the physics analysis and in the understanding of TeV scale physics that will lead to new insights into nature
- US CMS and US ATLAS, with their large datasets will be the main source of new Ph.Ds to continue this field into the future.
- The Upgrades permit operations at higher luminosity and provide a chance to IMPROVE the experiments in light of the results of the first few years of LHC operation.
  - They will also train another generation of students and postdocs in advanced detector techniques

We urge the Panel to endorse US CMS, US ATLAS, the LHC machine program and the upgrades under all four funding scenarios for at least the proposed levels and to consider a modest increase of ~15% to the Operations Program and funds to strengthen the associated university groups. Additional funding under the more expansive budget scenarios would secure a long term leadership role for the US.

Backup Slides

Annotated Budget Table

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
US CMS Research Program and Upgrade Project Needs (estimated to 10%) (AY=At Yea											
The Research Program includes Software and Computing Facilities, Maintenance and Operations and Upgrade R&D.											
Fiscal Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
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										515,761	555,582
Mar 6 version based on bottoms up estimate for Phase 1											

Note 1 The current NSF Cooperative Agreement ends in 2011 and we are unsure of what the future NSF funding will be but assume it is the same. DISUN-IT funidng ends in 2010. We have not assumed renewal.

Note 2 We just had a DOE/NSF Review on Feb. 4-7, We identified computing shortfalls as our main immediate problem. We did not quantify them at that time as we do here.

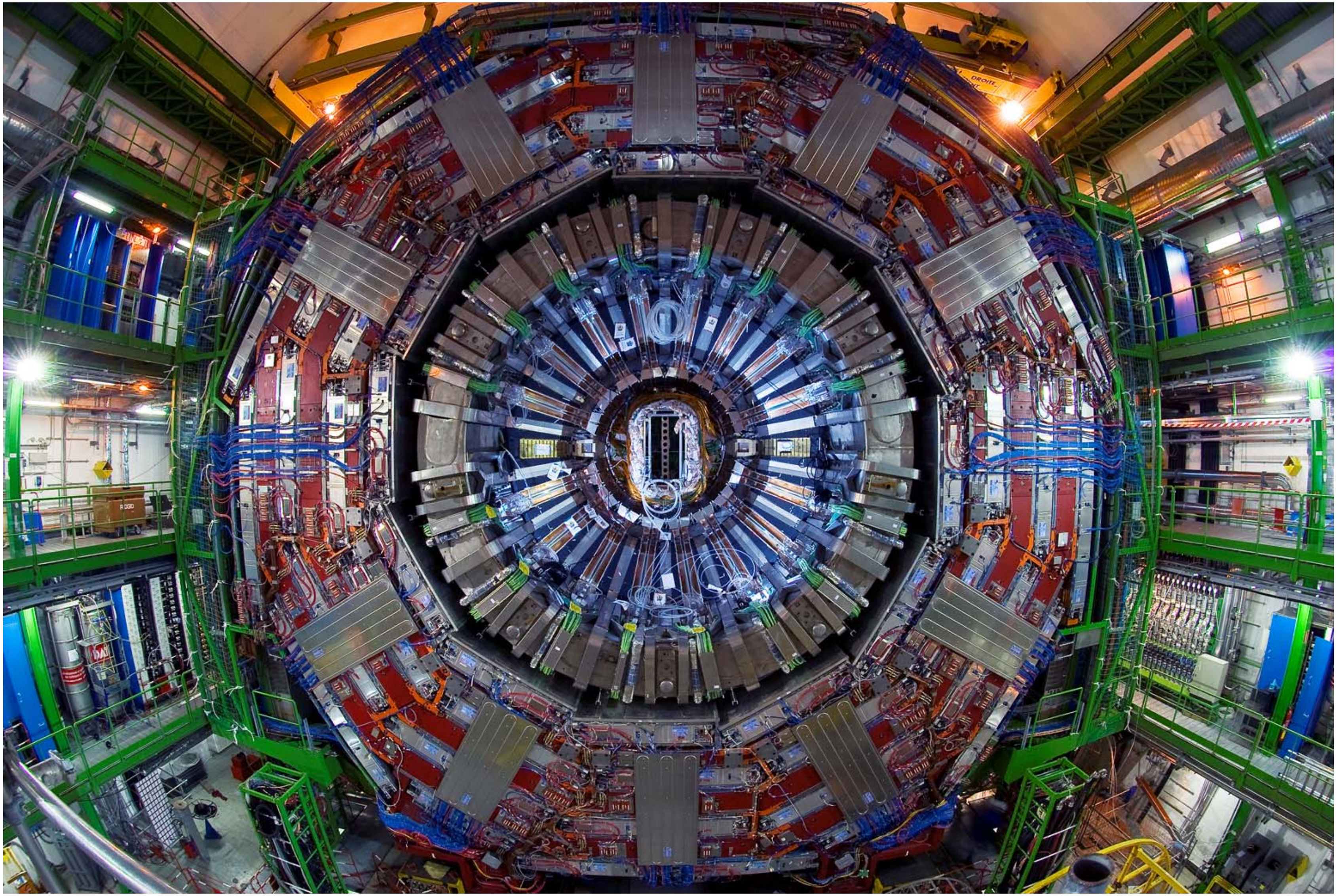
Note 3 We plan for extra needs for the research program to support the Upgrade Construction work: Pre-operations and Commissioning of the Upgrade Detector Elements, rebuilding the Software Framework, and an increase in CPU and Disk for the larger and more complicated events.

Note 4 We will present on March 6 the details of a two phase upgrade that is consistent with CERN's statement of their plans. Start dates are based on time required to get DOE approval
.

Note 5 These parts of the upgrade will be needed if CERN decides to go for the full factor of 10 increase in luminosity in ~2011. .

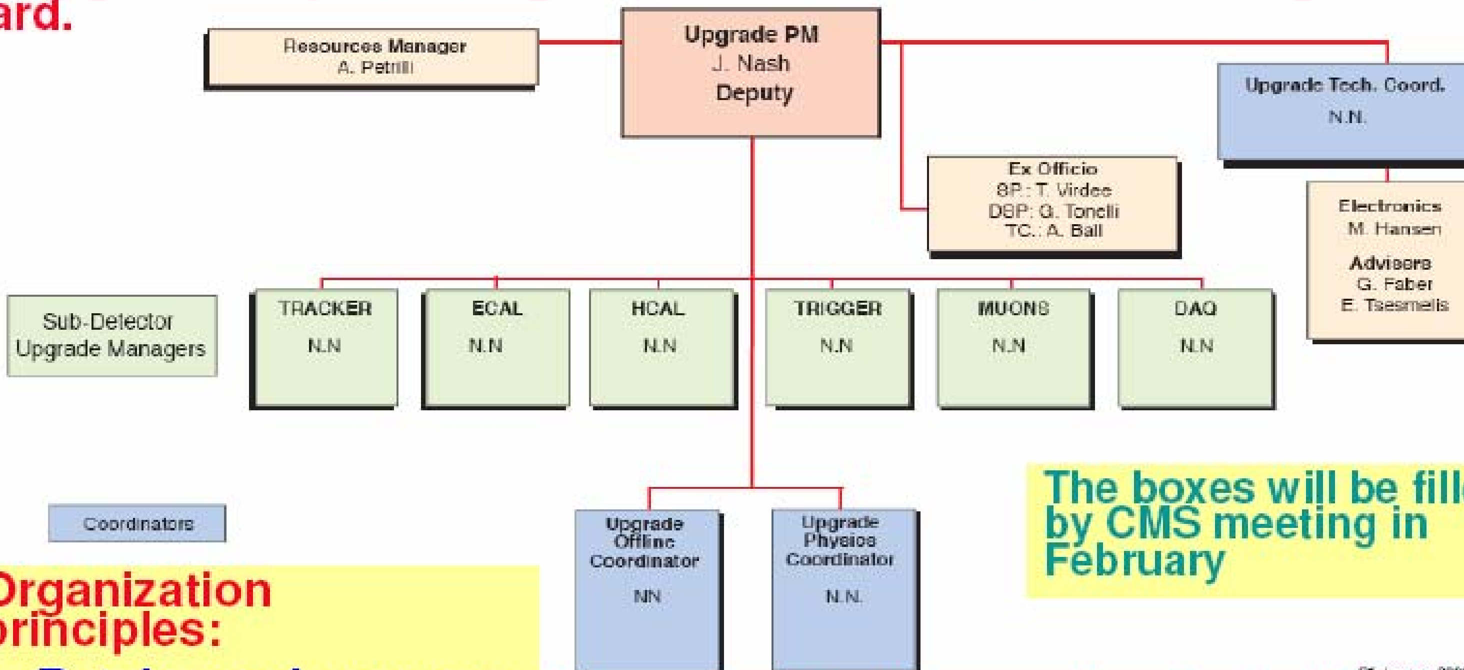
Note 6 The upgrade numbers are, as requested, without contingency. Some parts have similarities to work already done. We regard 30% as an adequate contingency.

CMS with the Tracker Installed



CMS Upgrade Project Structure

The Upgrade Project Manager is a member of the CMS Management Board.



The boxes will be filled by CMS meeting in February

- **Organization principles:**
  - **Retain maximum use of knowledge gained in the building of the CMS detectors**
  - **Not interfere with the operation of CMS.**

- **Resources for the upgrade project will initially be in the sub-detector budgets**
- **Steering Group duties will be split**
  - **Project review board**
    - **Peer review of proposals for upgrades**
  - **Upgrade Management Board**

From Talk by Jordan Nash, CMS Upgrade Project Leader

- **At CMS Management Board Feb. 22, 2008**

SLHC Project Phase I

- In January, the CERN DG announced the first phase of LHC Upgrades
  - Concentrates on a change to the insertion to allow $2*10^{34}$ luminosity
  - Compare with previous “Ultimate” LHC luminosity achieved by increasing the bunch current
- Several different motivations for this first phase
  - Removes limiting aperture for the machine
  - Technology for this well understood
- Second phase of upgrade also now being exposed
  - Concentrates on upgrade of injector chain

CERN DG Talk 16/1/2008

Upgrade of the LHC insertions: "Phase I"

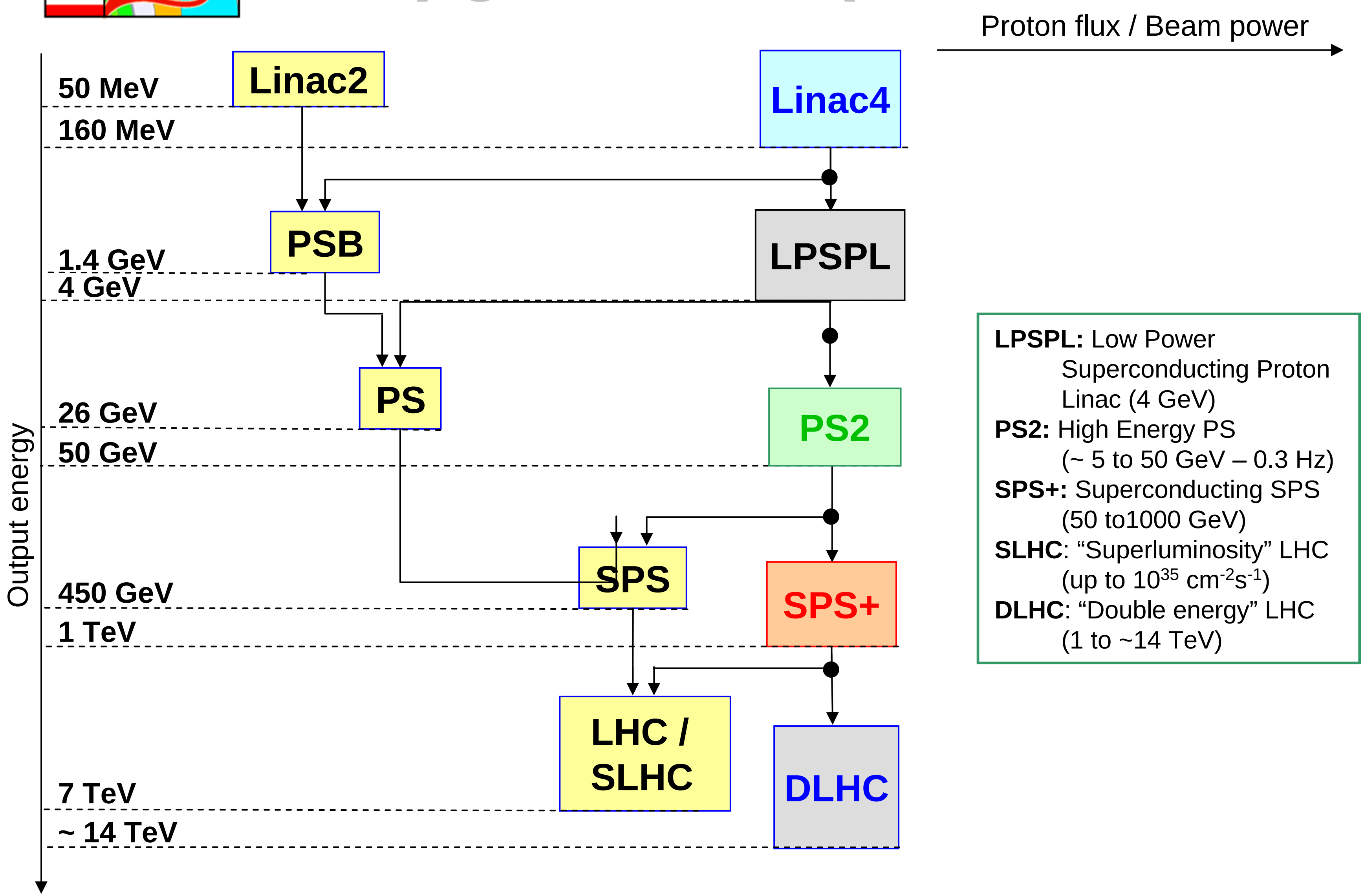
Goal of "Phase I" upgrade:

Enable focusing of the beams to $\beta^*=0.25$ m in IP1 and IP5, and reliable operation of the LHC at 2 10^{34} $cm^{-2}s^{-1}$ on the horizon of the physics run in 2013.

Scope of "Phase I" upgrade:

1. Upgrade of ATLAS and CMS experimental insertions. The interfaces between the LHC and the experiments remain unchanged at $\pm$ 19 m.
2. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole cables (Nb-Ti) cooled at 1.9 K.
3. Upgrade the D1 separation dipole, TAS and other beam-line equipment so as to be compatible with the inner triplet aperture.
4. The cooling capacity of the cryogenic system and other main infrastructure elements remain unchanged.
5. Modifications of other insertion magnets (e.g. D2-Q4) and introduction of other equipment in the insertions to the extent of available resources.

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)

EU Projects SLHCPP/DevDet

- Kickoff meeting for SLHCPP will be early April
  - SLHC "Preparatory Phase"
    - FP7 Money to set up management of the Machine project and the ATLAS/CMS Upgrade projects
    - Also includes some money for specific R/D projects
  - April 8,9 at CERN
  - Open presentation on the morning of 9 April
    - DG invited to give the plan (TBC)
- DevDet is currently being prepared for Detector R/D infrastructures
  - 11 work packages being put together
    - Software, Radiation Facilities, Test Beam facilities
  - Coordination through experiment and national contacts
  - Needs to be submitted by 29 Feb
  - CMS involvement in many of the work packages