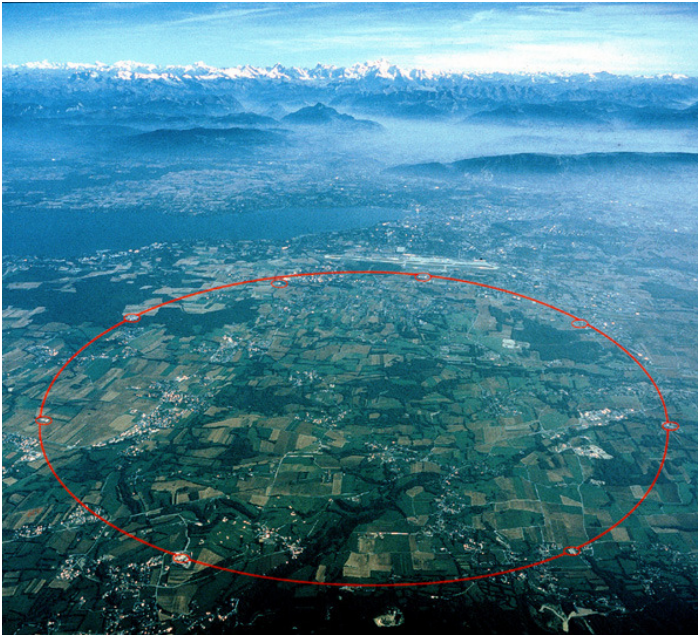
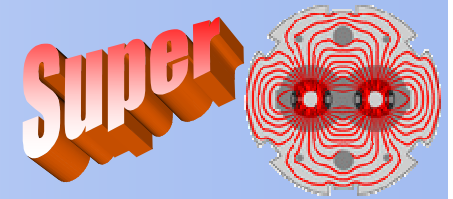


CMS and the SLHC Upgrade

Daniela Bortoletto
Purdue University
October 16, 2007



The LHC



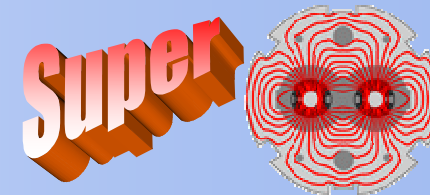
Energy: 14 TeV = 7 x Tevatron
Length: 27 km = 4 x Tevatron
Magnetic Field: 8.3 T = 2 x Tevatron
Beam Energy: 350 MJ = 250 x Tevatron
Bunch Collisions: 40 MHz = 20 x Tevatron
Instantaneous Luminosity = 60 x Tevatron
of Collisions in an event = 10 x Tevatron
Data Rate: 1 Terabyte / sec = 50 x Tevatron
of Detector Channels: 100 M = 100 x Tevatron
of Scientists (~2500/expt) = 3 x Tevatron

- 7 TeV on 7 TeV proton-proton collider, 27km ring
- 1232 superconducting 8.4T dipole magnets @ T=1.9°K
 - ~8K total magnets & components





CMS



SUPERCONDUCTING COIL

CALORIMETERS

ECAL Scintillating $PbWO_4$ Crystals

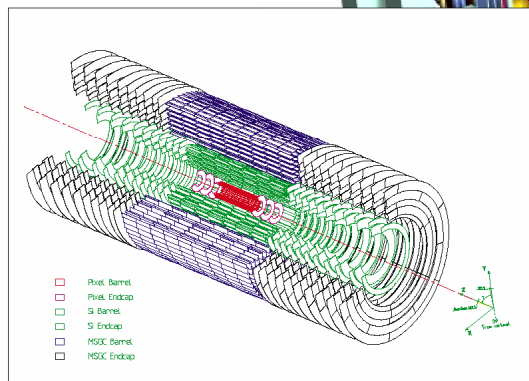
HCAL Plastic scintillator

copper sandwich

IRON YOKE

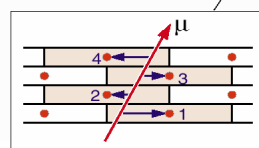
Total weight : 12,500 t
 Overall diameter : 15 m
 Overall length : 21.6 m
 Magnetic field : 4 Tesla

TRACKERS

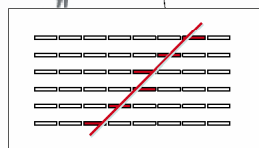


Silicon Microstrips
 Pixels

MUON BARREL

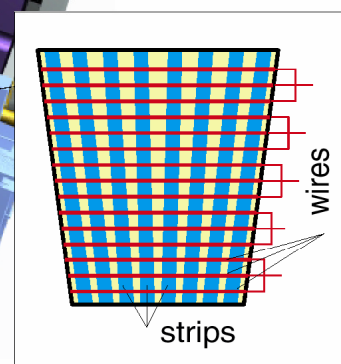


Drift Tube
 Chambers (**DT**)



Resistive Plate
 Chambers (**RPC**)

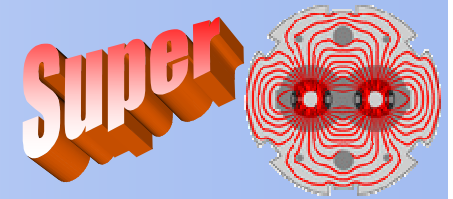
MUON ENDCAPS



Cathode Strip Chambers (**CSC**)
 Resistive Plate Chambers (**RPC**)

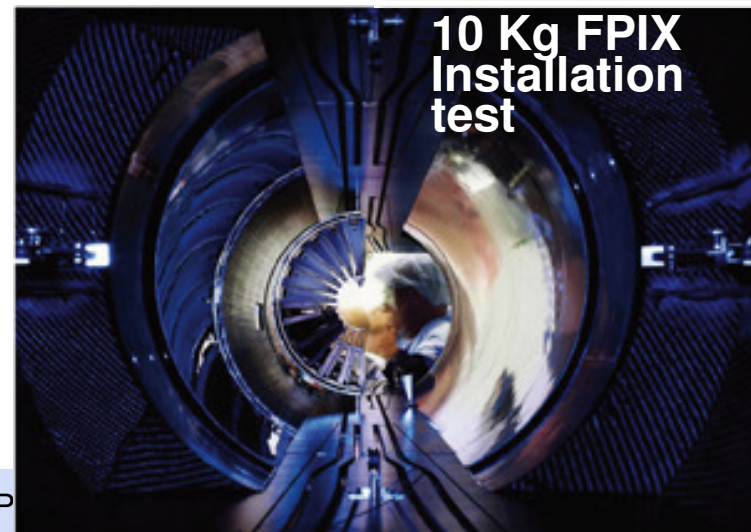
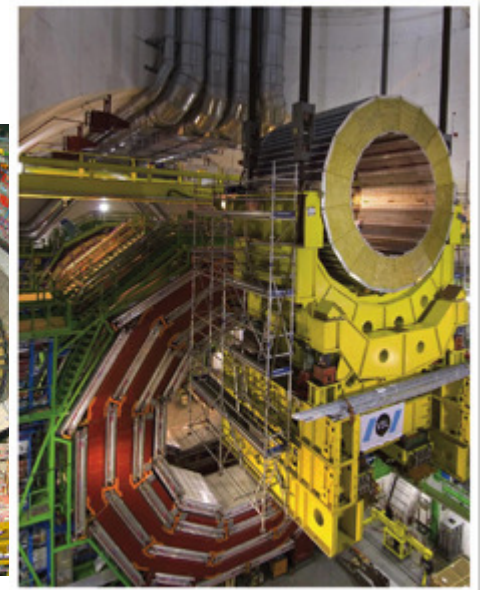


US contributions to CMS



- Large US Investment in the LHC: \$531 M for ATLAS, CMS and the accelerator.
- \$165 M for the CMS detector:
 - Magnet (complete system \$23M))
 - Hadron calorimeter (Complete system- \$44 M)
 - Endcap Muon System (Complete system - \$41 M)
 - Forward Pixels (Complete system- \$12 M)
 - Tracker Outer Barrel: Assembly and installation of 100 m² of silicon strips (\$9 M)
 - Electromagnetic Calorimeter (\$14 M)
 - Trigger and DAQ (\$15 M)
- Computing Facilities: Tier1 computing center at Fermilab and the 7 Tier 2 centers
- LHC Physics Center and remote Operations Center at Fermilab

- 13,000 tons, 20-foot-diameter, nearly 43-foot-long superconducting solenoid

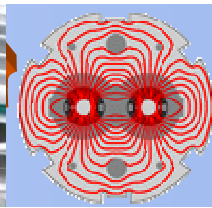
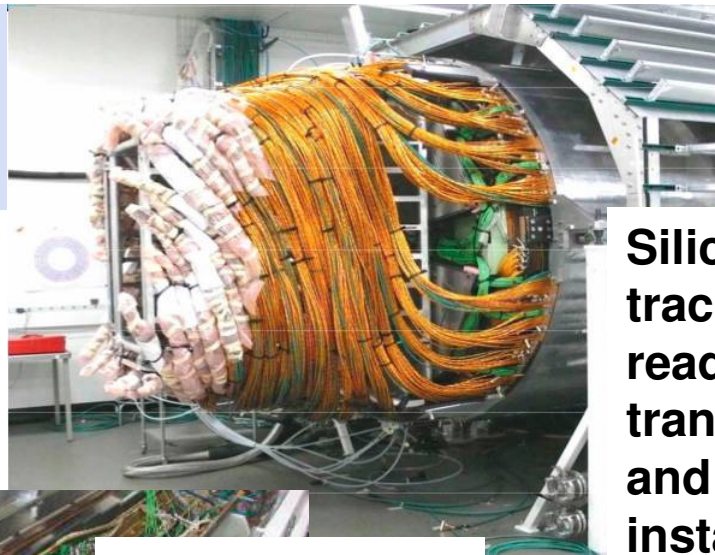


10 Kg FPIX
Installation
test



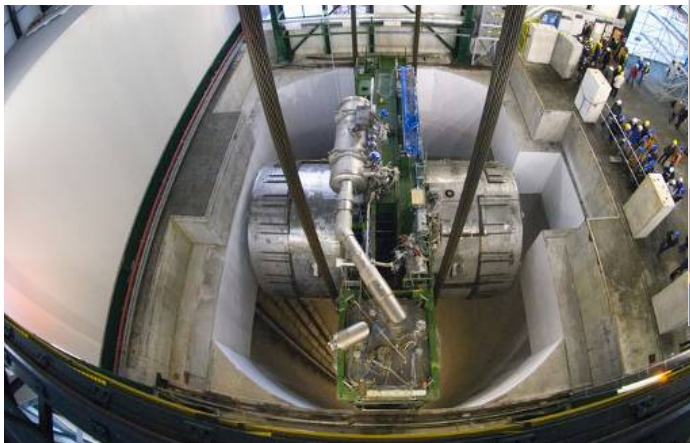
Status of CMS

- The detectors preassembled into complete structures and the lowered in the CMS cavern



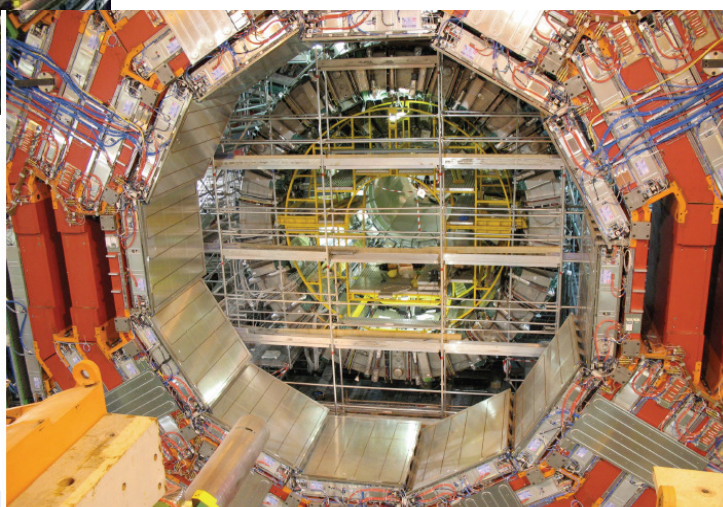
Silicon tracker ready for transport and installation

YB0: central wheel and magnet (2000 tons) Feb. 28, 2007



Pixel detector will be ready in January 2008

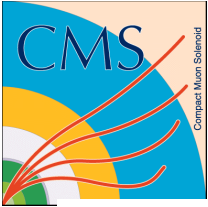
- CMS on track to achieve the target of CMS closed (including 1 EM Endcap and pixel detectors) with field on in April 2008



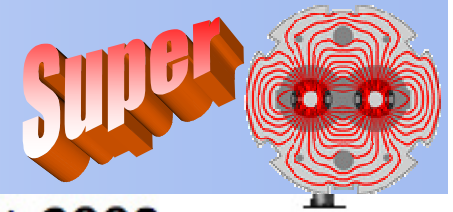
Status experimental cavern



The campaign to cable

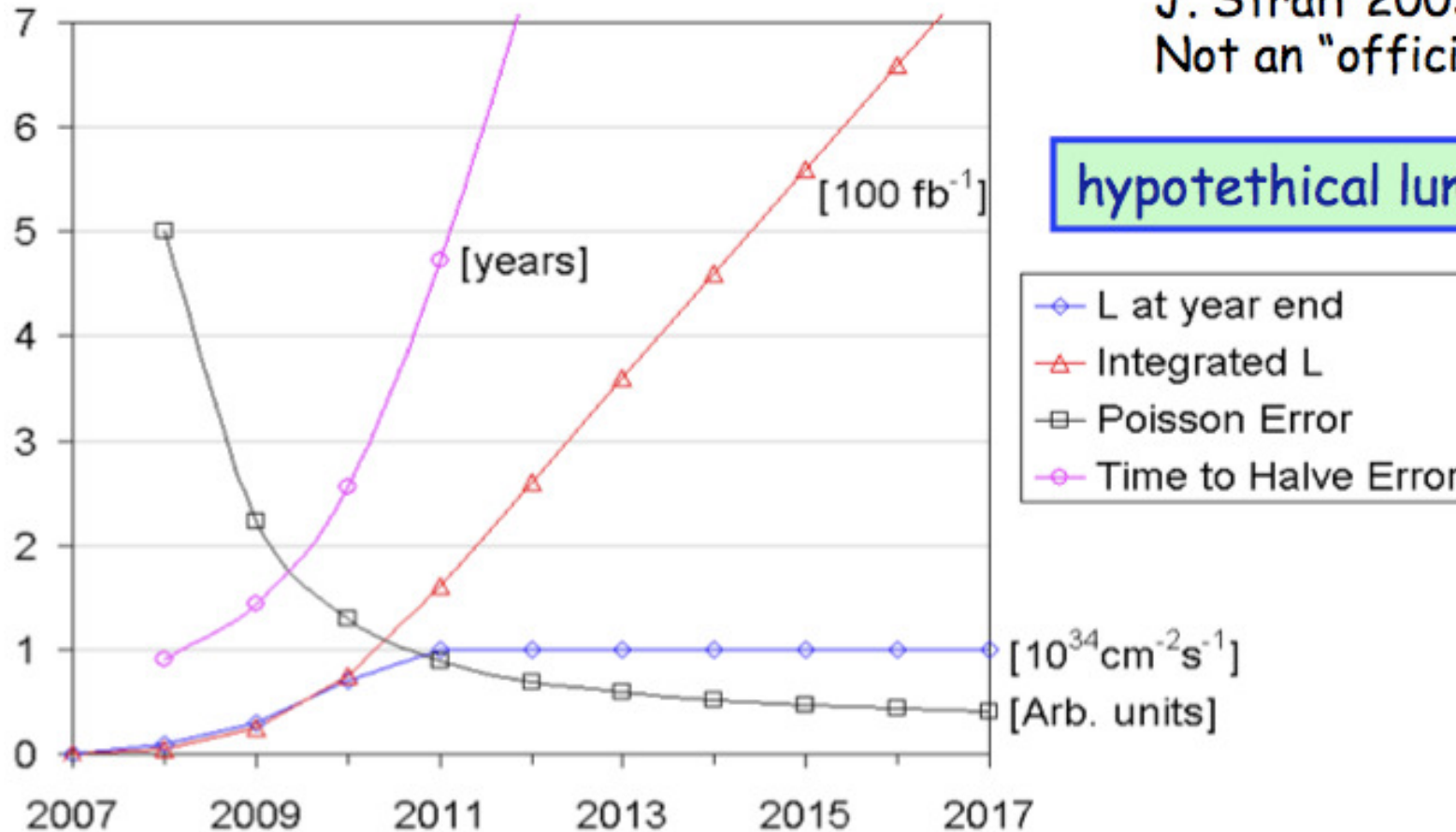


Evolution of the LHC



J. Strait 2003:
Not an "official" LHC plot

hypothetical lumi scenario



- IR quadrupole lifetime ~ 8 years owing to high radiation doses
- Halving time of the statistical error ≥ 5 y already after 4-5 y of operation
- Luminosity upgrade to be planned by the middle of next decade

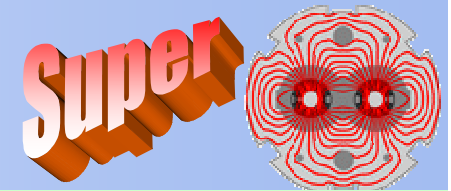


Favorite Upgrade scenario

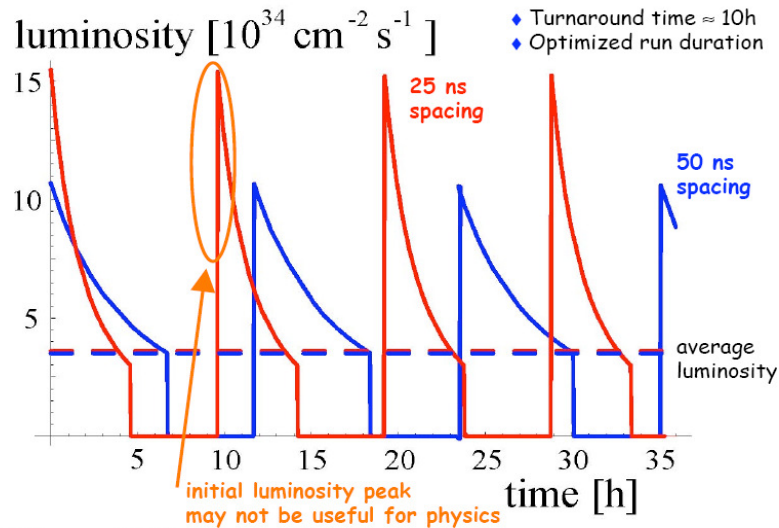
- Avoid problems with beam heating
- Peak luminosity $\sim 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

parameter	symbol	25 ns, small β^*	50 ns, long
transverse emittance	ϵ [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β^* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwiński parameter	$\phi = \theta_c \sigma_z / (2 \sigma_x^*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{\text{turnaround}} = 10 \text{ h}$)	L_{eff} [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	2.4	2.5
	$T_{\text{run,opt}}$ [h]	6.6	9.5
effective luminosity ($T_{\text{turnaround}} = 5 \text{ h}$)	L_{eff} [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	3.6	3.5
	$T_{\text{run,opt}}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_1 [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

Luminosity Lifetime



IP1& 5 luminosity evolution for 25-ns & 50-ns spacing



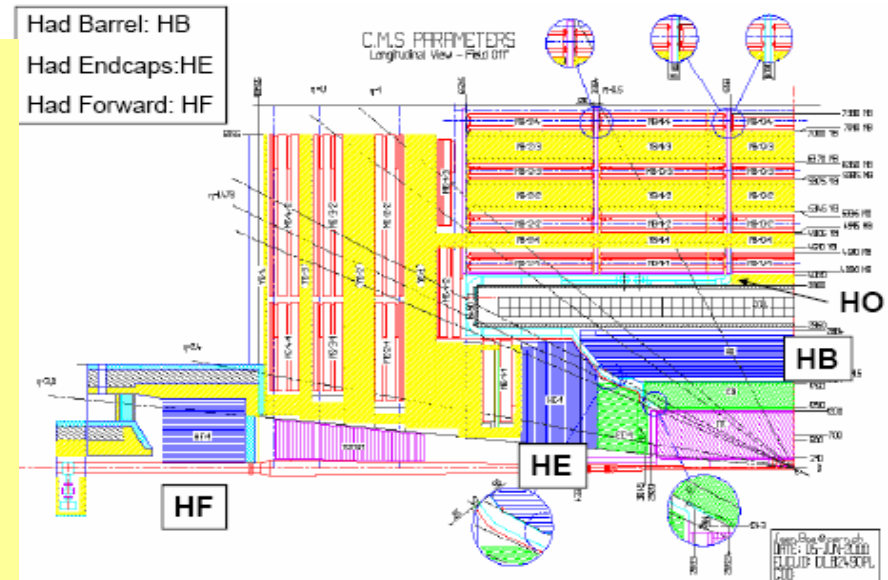
W. Scandale/F. Zimmermann, 19.03.2007

• 25ns scenario:

- Small β^* required (squeeze from ~ 50 to below $\sim 10\text{cm}$ in CMS)
- Requires magnet integration inside the detectors
- Luminosity lifetime $\sim 2\text{hours}$ but larger peak
- Merits: No increase in beam current beyond design and event/crossing ~ 290

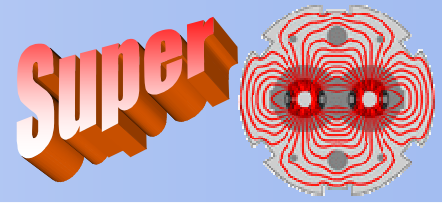
• 50ns scenario:

- Decrease collision rate to 20MHz
 - Space charge effect minimized
 - Events/crossing $\sim 400!$ ☹
- Increase from current from 1.15 to 4.9×10^{11} p/bunch!
- Increase crossing angle to 381mrad
 - Bunch length increases from 7.6cm to 11.8cm
 - Luminosity lifetime 4.5hours





The SLHC Physics case



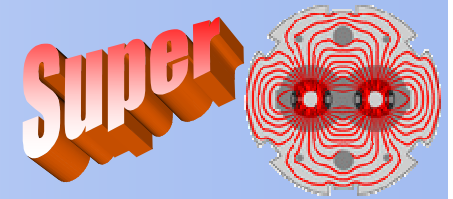
- **New physics expected in TeV energy range**
 - **Higgs, SUSY, extra dimensions, ...?**
- **Initial LHC data should indicate what physics is present at this energy scale and what kind of detector capabilities can best study it**
- **SLHC will:**
 - 1) **Improve the accuracy of SM parameters**
 - 2) **Improve measurement of new phenomena observed at the LHC**
 - 3) **Extension of the sensitivity to rare processes**
 - 4) **Extension of discovery reach in the high-mass region**
- **In making the physics case:**
 - **Assume that the detector performance can be at least maintained and perhaps even improved to exploit the physics**
 - **Assume that the LHC (SLHC) will yield $100 \text{ fb}^{-1}/\text{year}$ ($1000^{-1} \text{ fb}/\text{year}$)**

Eur. Phys. J. C 39, 2005

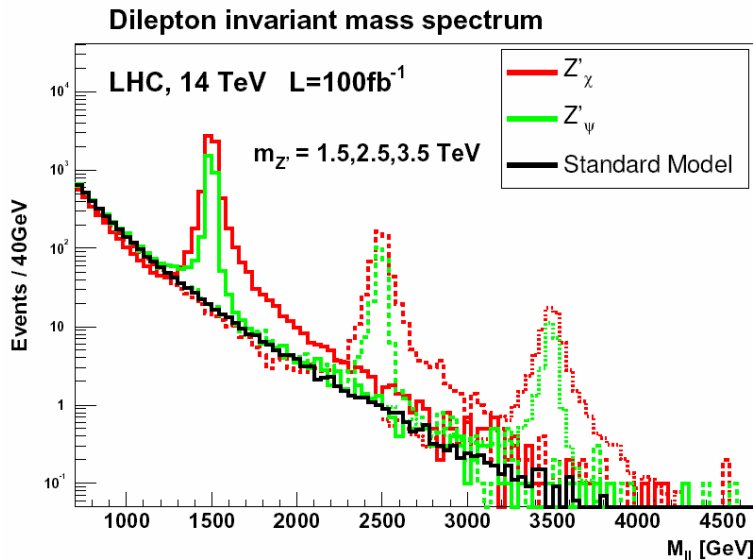
**Physics Potential and Experimental challenges of the LHC
Luminosity upgrade**



High Mass Sensitivity



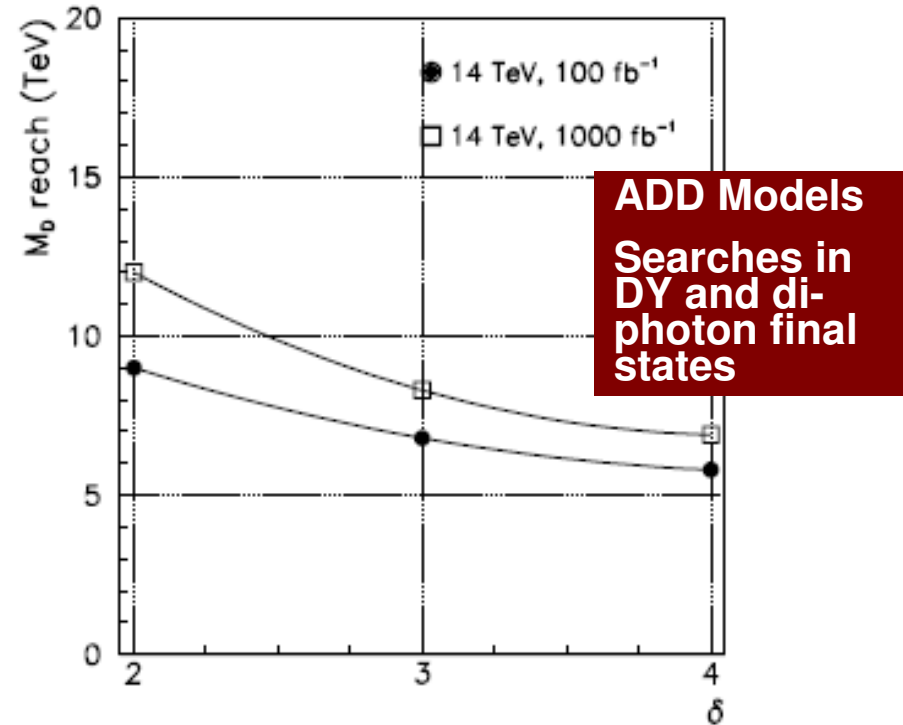
- New gauge bosons**



LHC/600 fb^{-1}	5.3 TeV
SLHC/6000 fb^{-1}	6.5 TeV

- SLHC Can also help in differentiating models if Z' found at LHC**

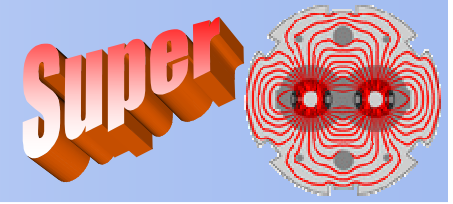
- Extra Dimensions**



The reach in the gravity scale M_D for $\delta = 3$ increases from $\sim 8\text{TeV}$ (100 fb^{-1} at LHC) to 11.7TeV (1000 fb^{-1} at SLHC).



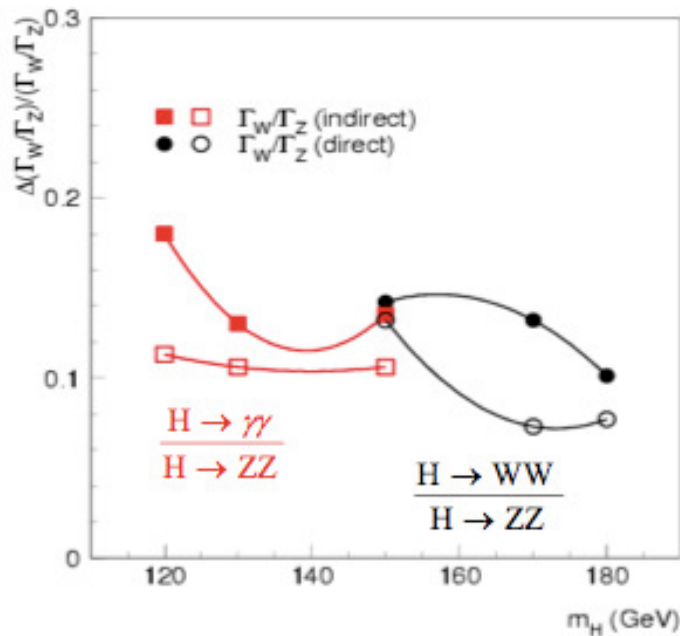
Higgs Decays



SLHC 3000 fb⁻¹

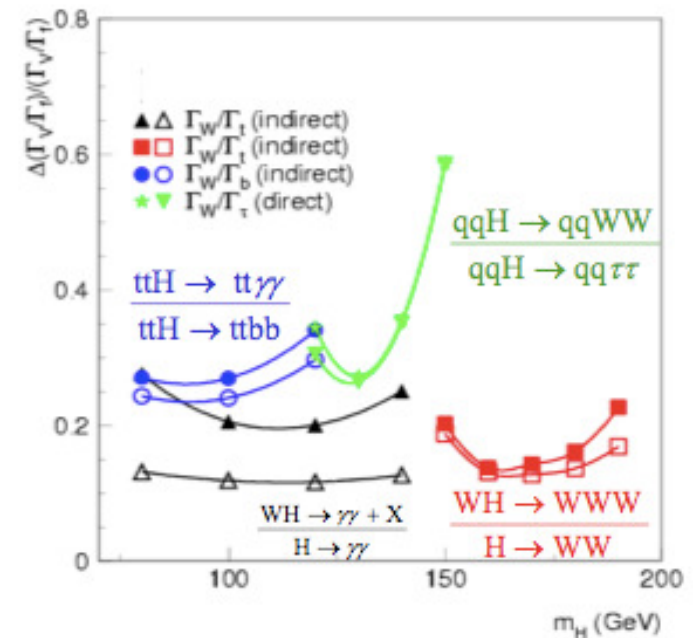
- $H \rightarrow \mu\mu$ has a BR of 10^{-4} in the SM and it is marginal at the LHC ($\sim 3\sigma$)
- Improvements in the measurements of Higgs couplings

m_H (GeV)	S/\sqrt{B}	$\frac{\delta\sigma \times \text{BR}(H \rightarrow \mu\mu)}{\sigma \times \text{BR}}$
120 GeV	7.9	0.13
130 GeV	7.1	0.14
140 GeV	5.1	0.20
150 GeV	2.8	0.36



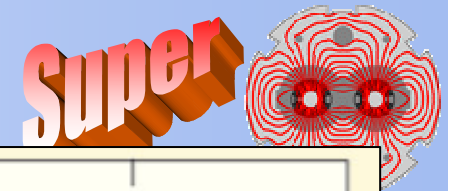
Closed symbols:
LHC 600 fb⁻¹

Open symbols:
SLHC 6000 fb⁻¹

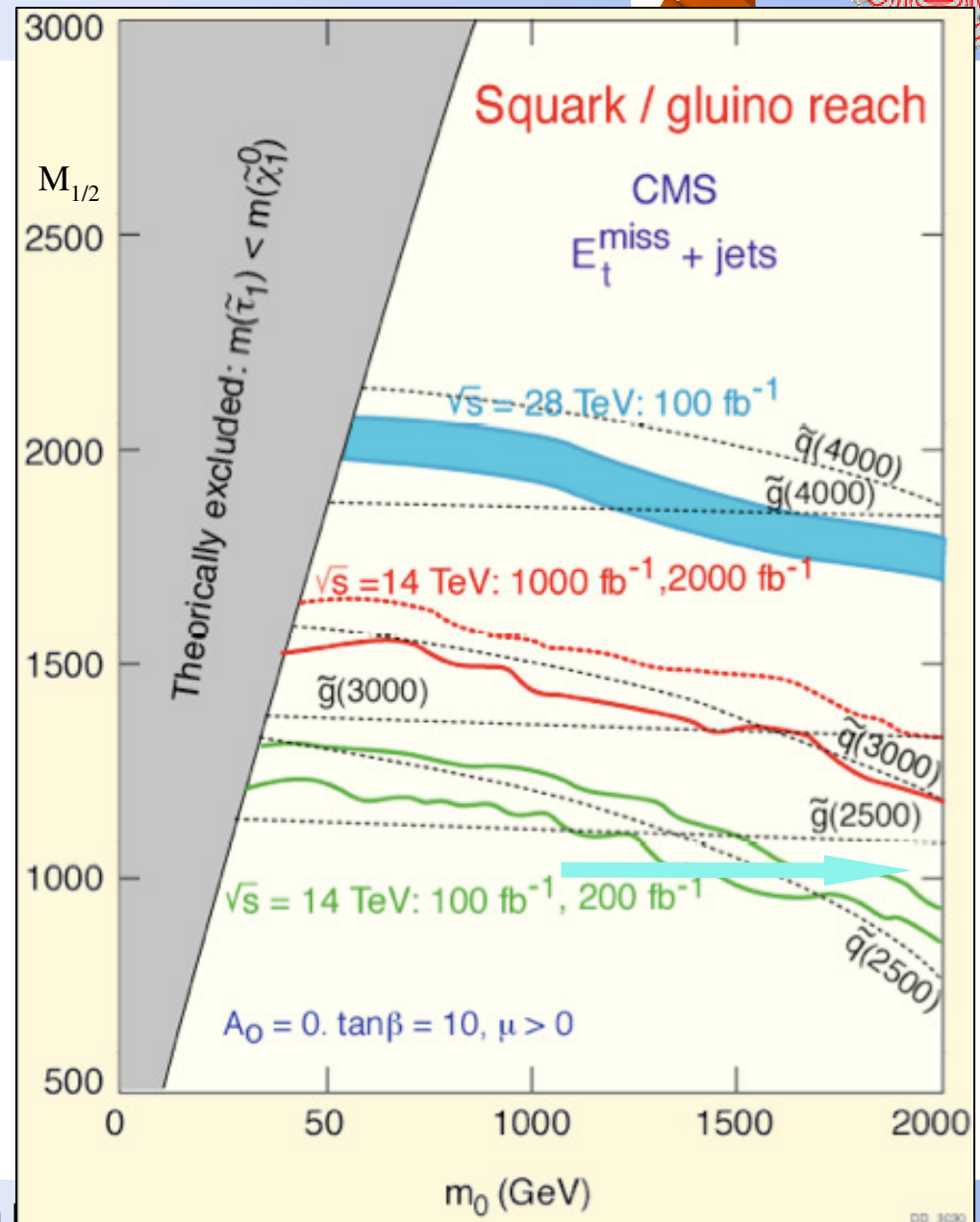




SUSY reach

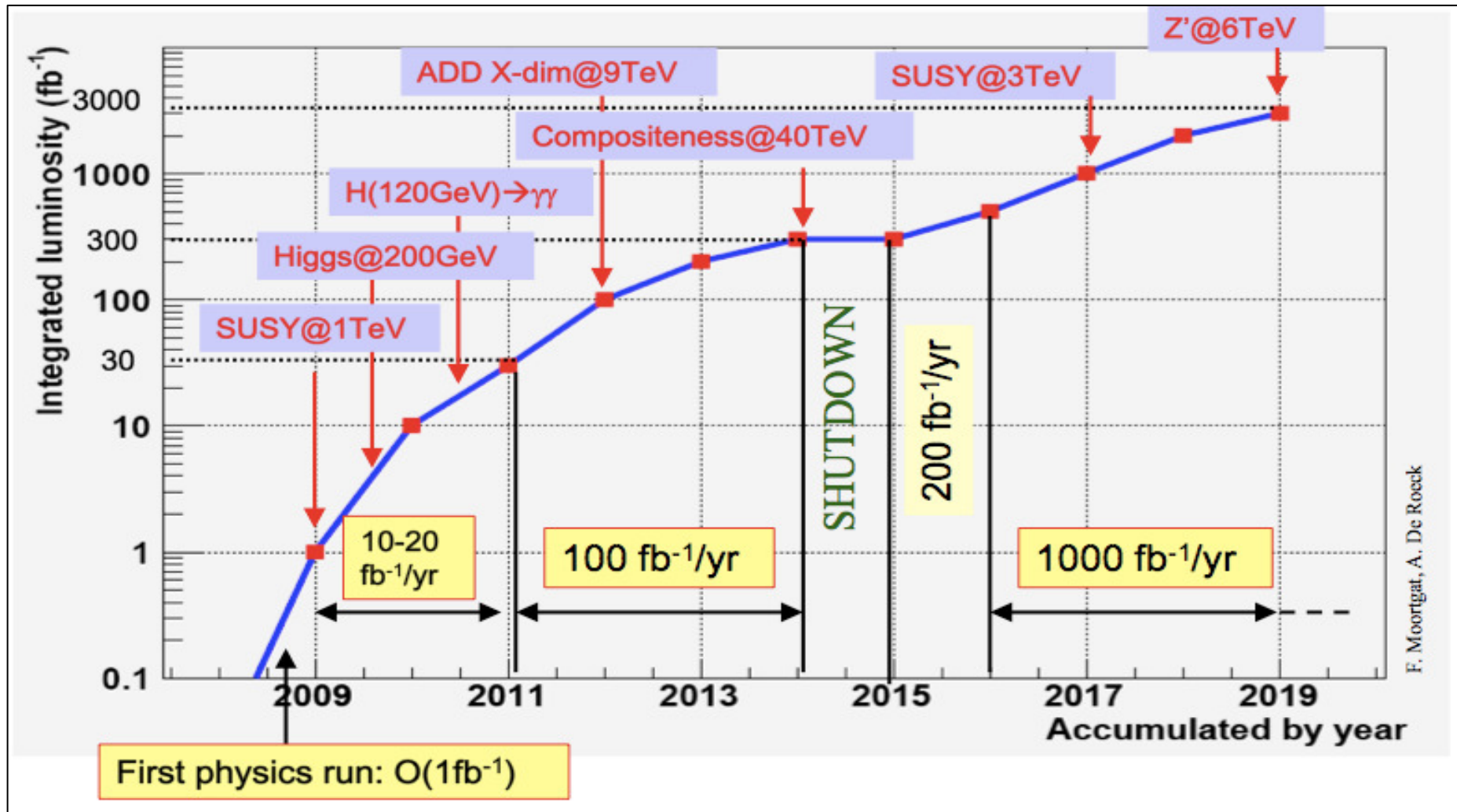
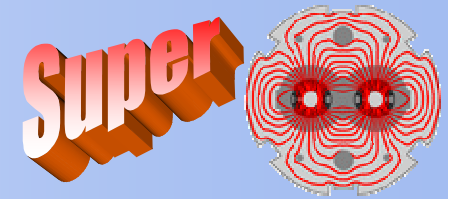


- LHC reaches squarks, gluinos ~ 2.5 TeV
- Does not cover all dark matter region
- SLHC could reach squarks, gluinos ~ 3.0 TeV



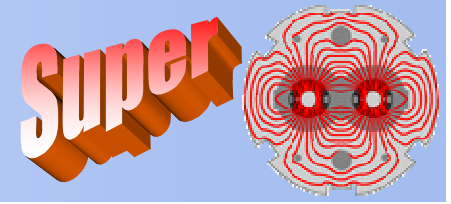


The SLHC physics case





European Strategy

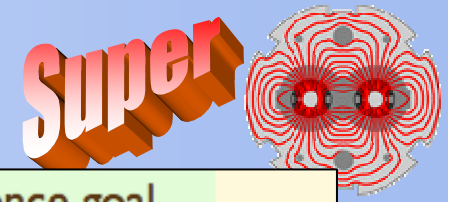


- **Highest priority is to fully exploit the potential of the LHC: nominal performance and possible luminosity upgrade (SLHC) ~ 2015**
- **R&D on CLIC, high-field magnets, high-intensity neutrino facility**
- **Participation in ILC R&D, decide ~ 2010**
- **Prepare for neutrino facility decision ~ 2012**
- **Non-accelerator physics**
- **Flavor and precision low-energy physics**
- **Interface with nuclear physics, fixed-target experiments**

**TOWARDS THE EUROPEAN STRATEGY
FOR PARTICLE PHYSICS:
THE BRIEFING BOOK
Hep-ex/06091216**

**CERN-PH-TH/2006-175
September 2006
Physics Opportunities with Future
Proton Accelerators at CERN**

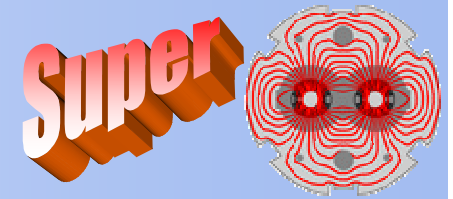
Performance



The performance at 10^{34} should be taken as a minimal reference goal

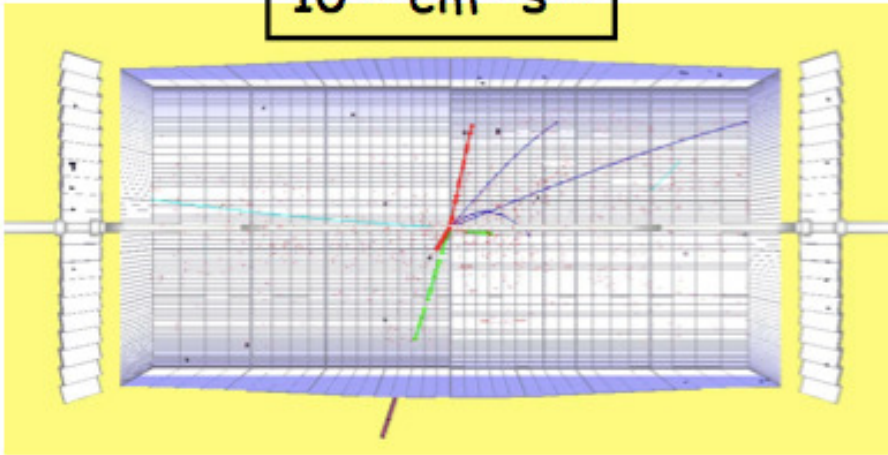
Object	Physics benchmark	Performance benchmark	Detector issue
b jets & tau	Higgs identification, BR measurements	Tagging efficiency vs purity (statistics and bg suppression)	Tracking Pileup
b jets	Higgs mass determination, bg suppression	Mass resolution in the ~ 1-few x 100 GeV region	Pileup
fwd jets	Vector boson fusion: - measure H couplings - if no H, search strong WW phenomena	- jet tagging efficiency/fake rate vs jet E_T - jet E_T resolution	Final focus magnets: - acceptance - bg - resolution Pileup
cen jets	Jet vetoes for vector boson fusion Mass spectroscopy	fake rate mass resolution	Pileup Pileup
electrons	W/Z ID, SUSY decays, etc W'/Z' properties	ID efficiency vs fake rate	Pileup
muons	W/Z ID, SUSY and H decays, W'/Z' properties, etc.	Forward acceptance, fake rate	albedo forward efficiency final focus geometry

Pile-up and Luminosity

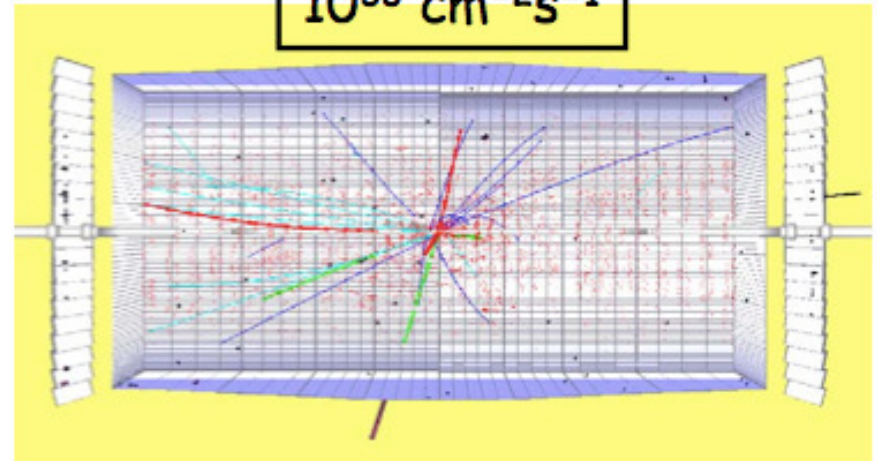


$H \rightarrow ZZ \rightarrow \mu\mu ee$ event with $M_H = 300$ GeV for different luminosities

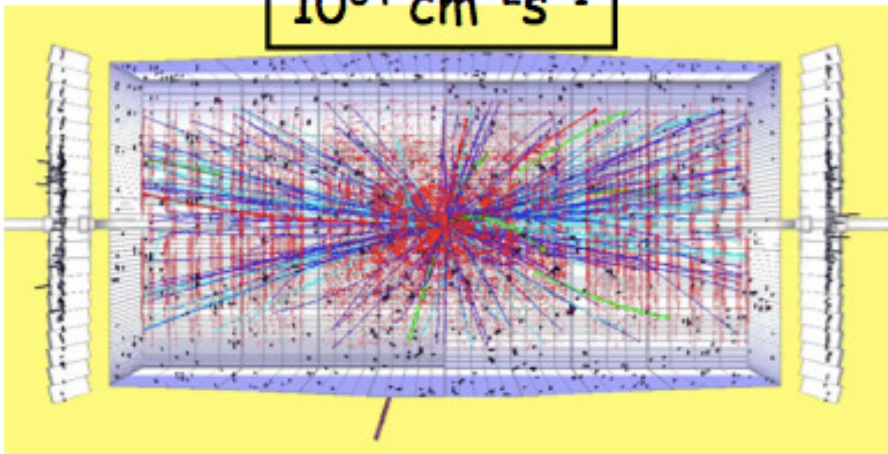
$10^{32} \text{ cm}^{-2}\text{s}^{-1}$



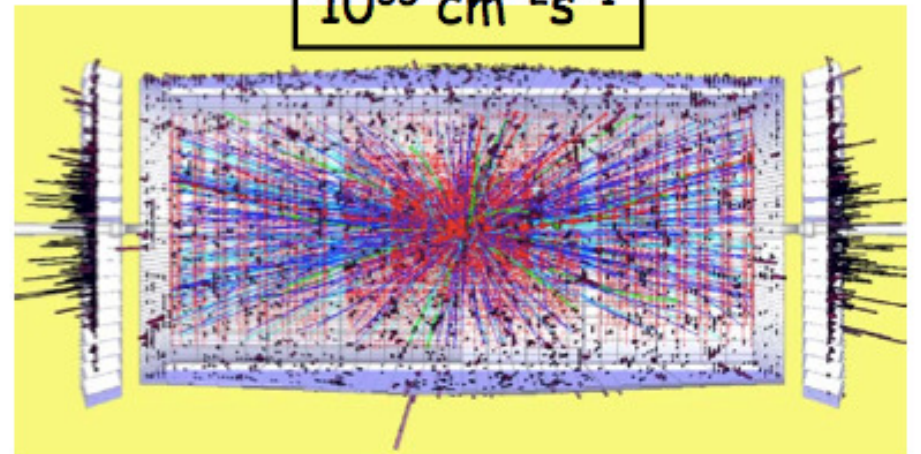
$10^{33} \text{ cm}^{-2}\text{s}^{-1}$



$10^{34} \text{ cm}^{-2}\text{s}^{-1}$

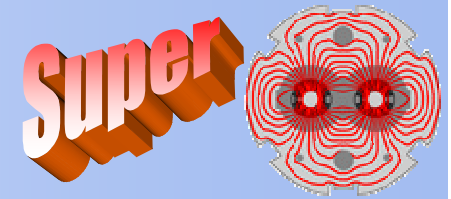


$10^{35} \text{ cm}^{-2}\text{s}^{-1}$





CMS Upgrade Plan



•Eol submitted to LHCC March 2007

Key issues for the upgrade

• Tracker

- Higher Granularity → More channels → more power required
- Power and material budget

• Trigger upgrade:

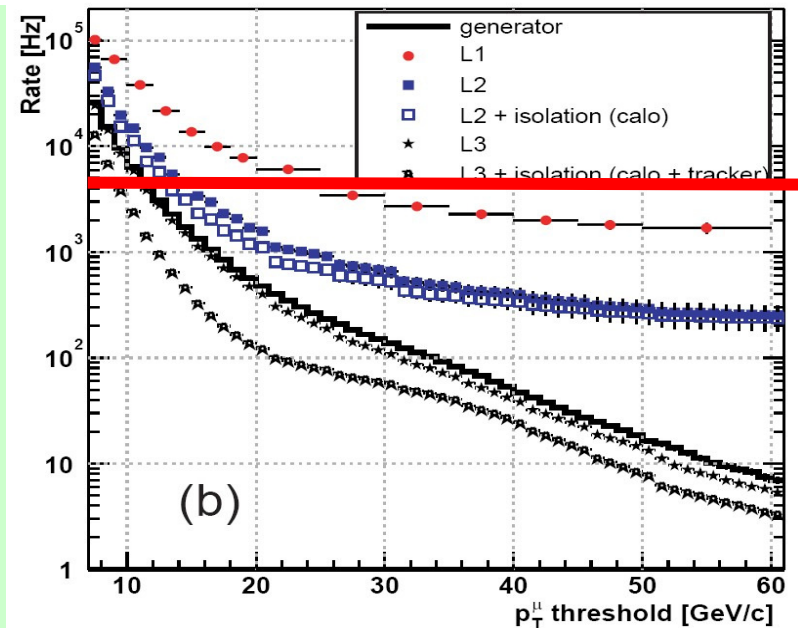
- Tracking in the Level 1
- Foresee smaller upgrades to the calorimetry and muon system

• Plan LOI in 2008 and TDR in 2011-2012

• 5 years R&D with intermediate proof of principle

- Possibly replacement for existing layers
- Additional tracker layers to prototype and test tracking trigger

• Full upgrade 8-10 years from LHC Startup

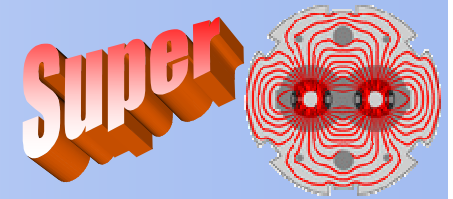


Not enough rejection power using muon and calorimeter triggers to handle the higher luminosity conditions at SLHC

R&D need to start now



CMS Plans

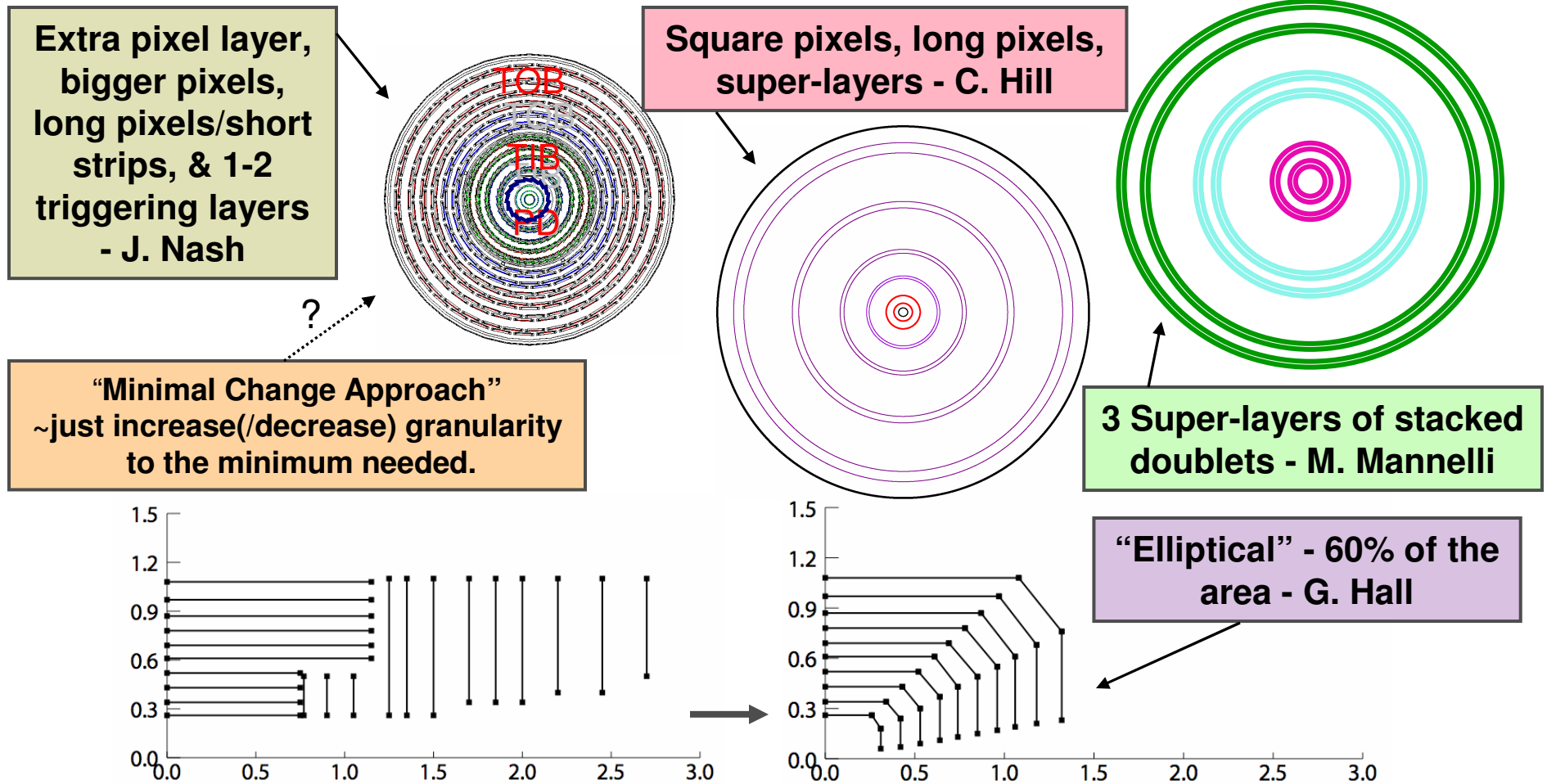


- **Replacement of the tracking system**
 - Finer granularity to control occupancy
 - Improve radiation hardness
 - L1 track trigger information
- **TRIGGER/DAQ**
 - Doubling the Level 1 trigger latency from 3.2 μsec to 6.4 μsec
 - Adding a new tracking triggers at L1
 - Cross component correlation of trigger primitives.
 - Enhance DAQ to accommodate the 10X increase in data transfer
- **Less extensive modifications of muon system, and calorimetry**
 - Possible addition of a part of the EMU 4th layer.
 - Readout electronics may be modified for increase the trigger latency
 - Muon and calorimeter triggers improvement

Sub-Detector	Estimated Cost
Inner Tracker	30 MChf
Outer Tracker	90 MChf
Level-1 Trigger	20 MChf
DAQ	10 MChf
Muons and Calorimeters	10 MChf
Infrastructure	15 MChf
Total	175 MChf

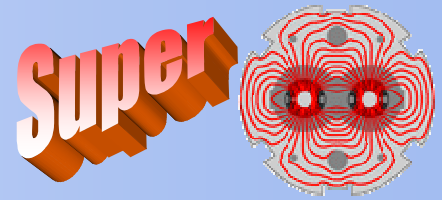
The M&S cost of the upgrade (not including R&D)

- No single straw-man tracking system or tracking trigger strategy/design**





PRIORITY

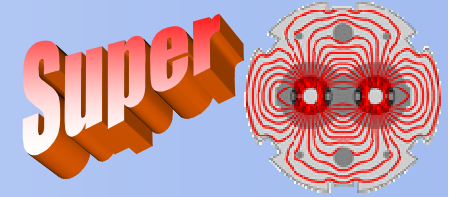


• Develop straw-man design

- Developing tool for “Standard” simulations and benchmarks
 - **Basic Tracking performance**
 - Based e.g. on tracking related validation packages, e.g. tracker, vertexing, b-tagging packages (maximize code reuse, but fit to our needs)
 - **Trigger Performance (incl. tracking info/trigger)**
 - Performance of L1 triggers using tracking information for SLHC luminosities
 - **Physics Performance**
 - Few physics analyses will be used to evaluate performance with higher occupancies, and higher rates
 - Measure performance for physics objects in the context of specific physics channels and backgrounds, etc.
- **GOALS:**
 - **Location of first layer**
 - **How many layers**
 - **Improve layout to reduce material**
- **Common effort on simulations with significant US input**
- **Many US groups involved: FNAL, BROWN, COLORADO, MARYLAND, PURDUE, UCR, UCSB, UCD, PUERTORICO**

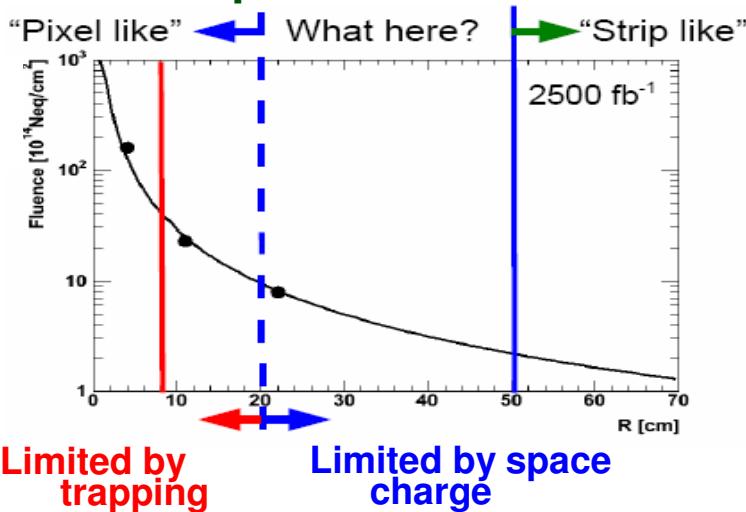


Tracker Upgrade R&D



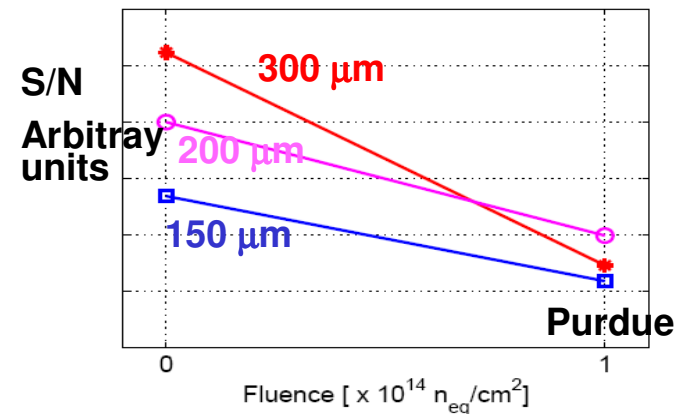
• Ultra rad-hard sensors

- $R < 10$ cm: performance is limited by trapping
 - Technology used for current pixel detect (n-on-n) could be sufficient for 8cm
- Technology for innermost layer at 4 cm is problematic



• Thin sensors:

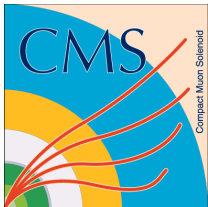
- For fluences $> 10^{15}$ p/cm² sensors contribute significantly to power dissipation
 - Thinner sensors → less volume → less current
- Submission of thin silicon strip sensors with Hamamatsu (UCSB, CERN, PERUGIA)



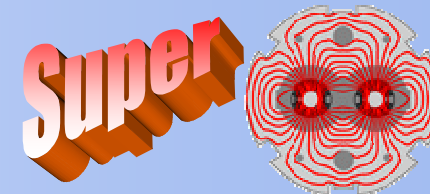
• Support R&D on 3D detectors (FNAL, PURDUE). Prototype sensors with RD50 available by the end of the year.

Goals:

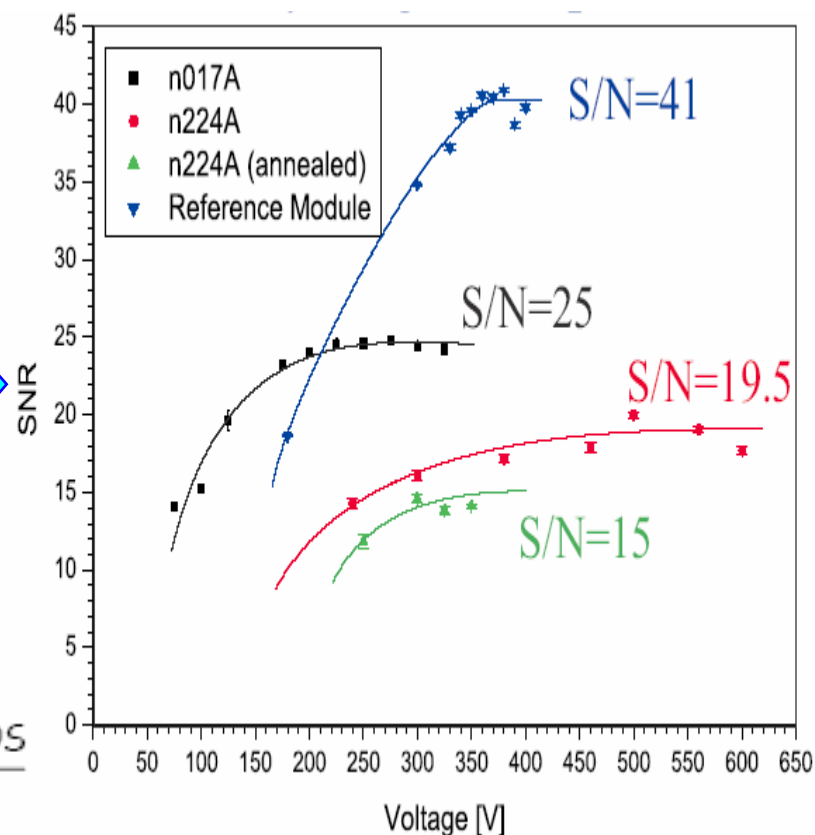
- Can thin sensors be made reliably ?
- Capacitance of very thin sensors
- Keep Hamamatsu involved with CMS



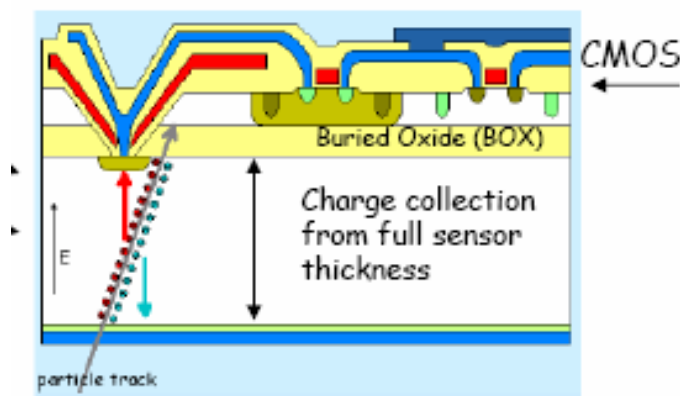
Tracker Upgrade R&D



- **Sensors on materials with higher radiation tolerance such MCz (FNAL, PURDUE, UCSB, Rochester, PIRE institutions).**
 - **Planning submission with Hamamatsu or Sintef**
- **Beam Test (FNAL, Rochester, Finland, Karlsruhe) set-up**
 - **Support expertise to allow prompt evaluation of sensor R&D**
- **More advanced R&D possible (could overlap with ILC goals but SLHC will need a robust system that can be produced much earlier)**



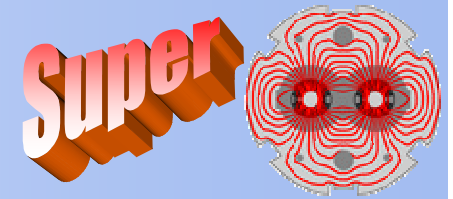
3D or SOI detectors



SOI Pixel Cross Section⁷

- **Neutron irradiation for 10^{14} , 5×10^{14} & 10^{15} n/cm² at Louvain nuclear reactor**
- **Proton irradiation same doses at Karlsruhe using 8 MeV proton beam**

Tracker Upgrade R&D



- Large area low cost interconnections (FNAL, PURDUE, PSI, US institutions supported by PIRE)
 - Investigate of interconnection techniques such as IBM injection-molded solder

- Low mass components and cooling methods (UCSB, PURDUE, FNAL)
 - Prototype structures aimed at material minimization. Solid model and FEA studies

UCSB: potential stave for long pixels



- Serial powering (FNAL, BUFFALO, MISSISSIPI, IOWA)

- Power consumed by n modules = P_{cable}
 - Independent power $P_{cable} = nI^2R$
 - Serial Power $P_{cable} = I^2R$
- Serial power leads to significant savings in power dissipation
- Critical R&D for SLHC

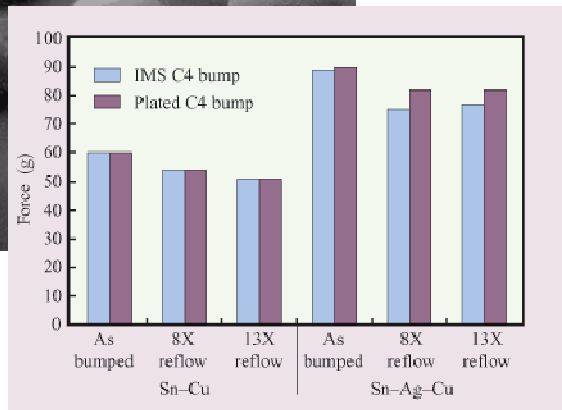
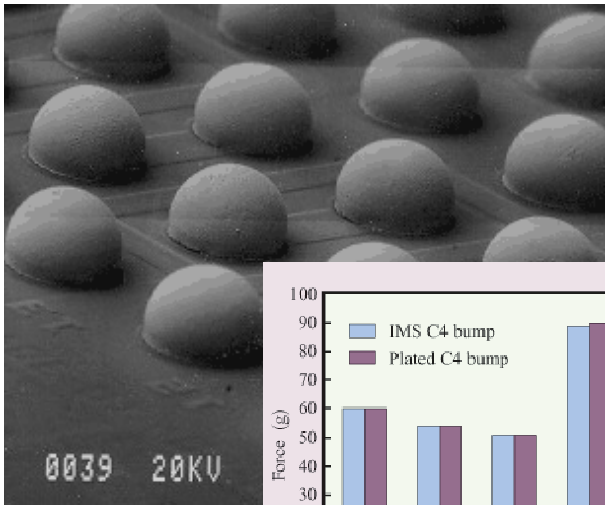
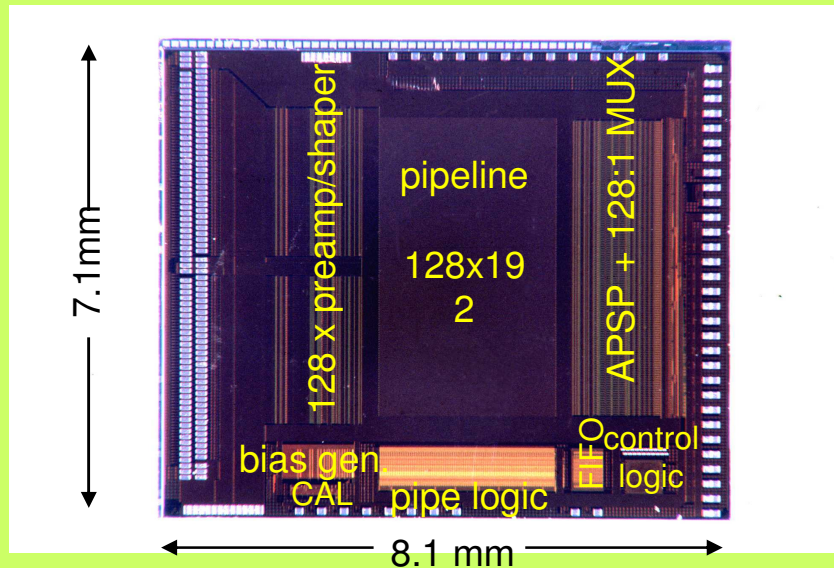


Figure 12

C4 shear strength comparison: IMS-transferred vs. plated bumps.

• Redesign APV 25 CHIP



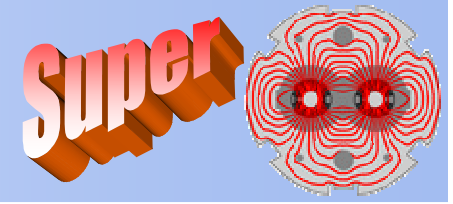
- Power is the issue: 130 nm technology helps
 - Simulation by IC shows preamp/shaper power consumption reduction: 1.025 mW (APV25) → 0.192 mW (130 nm)
- Sparsification on chip required for SLHC. FNAL experience with SVX3/SVX4 chip could play an important role.

• Pixel ASIC Development

- Current pixel ROC architecture
 - Efficiency drops soon after LHC luminosity
 - Loss dominated by buffer sizes
- Limitations can be improved by going from 250nm to 130nm technology
- Architecture can be pushed further:
 - column drain per column instead of double column
 - extra readout buffer stage or more intelligent buffer to avoid dead time during readout
- An architecture based on the present pixel ROC cannot be modified to run at SLHC luminosity at a radius < 8 cm
- R&D needed to improve SEU protection

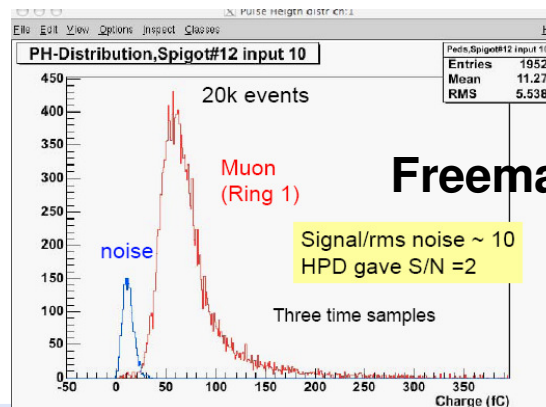
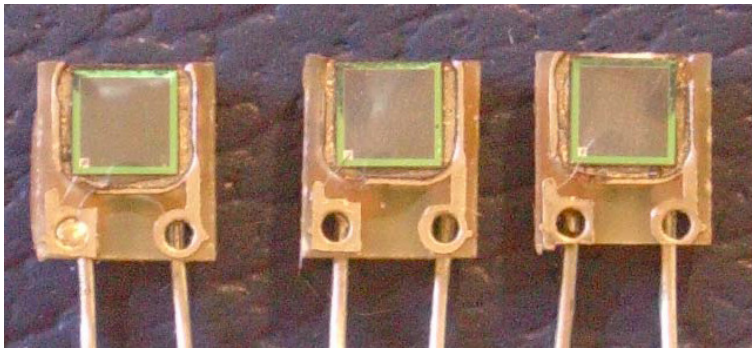


Calorimeters



• Hadron Calorimeter

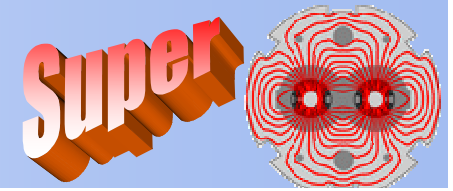
- Plastic scintillator tiles and wavelength shifting fiber is radiation hard up to 2.5 MRad while at SLHC we expect 25MRad in **HE**.
 - R&D new scintillators and waveshifters in liquids, paints, and solids, and Cerenkov radiation emitting materials for example Quartz (ND, Iowa)
- Support R&D in SiPM (Fermilab, Iowa, ND, Princeton, BU)
 - Procure SiPM from the several vendors
 - Characterize: gain, electrical characteristics, recovery time, wavelength response, operational stability, environmental stability
 - Test magnetic field sensitivity at Princeton
 - Test radiation exposure testing at the IU Cyclotron



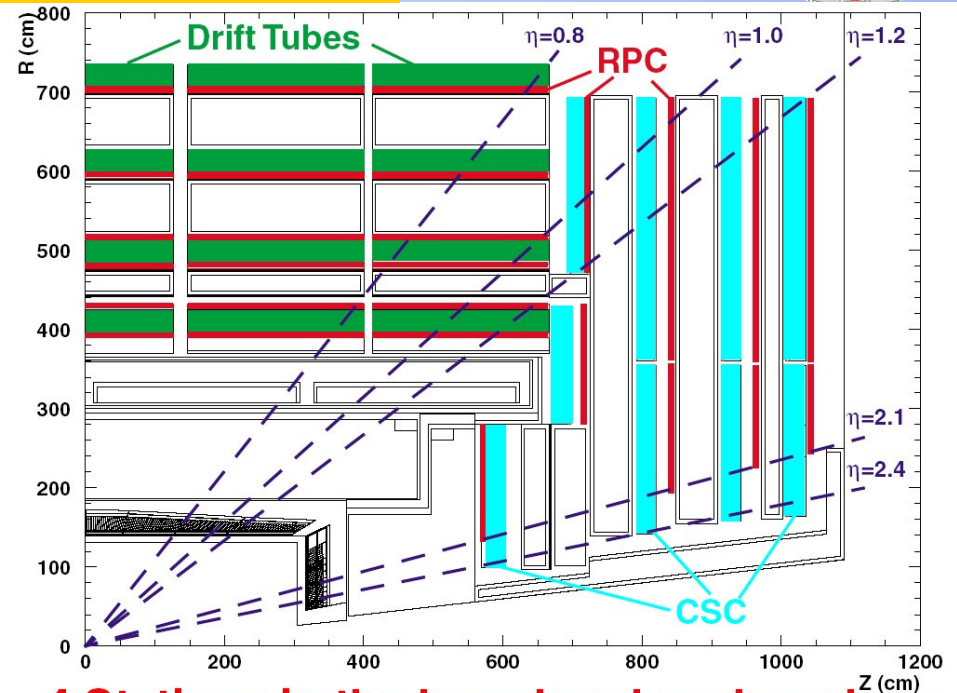
Freeman, USCMS meeting



Drift Tubes(DT) /Resistive Plate Chambers(RPC) in Barrel Cathode Strip Chambers(CSC)/RPC in Forward



- Looks fairly robust at SLHC
- Concerns for RPC at $\eta > 1.6$
 - Tested at Neutron fluence $\sim 10^{12} \text{cm}^{-2}$ (> 10 years of LHC operation)
 - Expected strip rate in LHC is 100 kHz/strip for $\eta > 1.6$
 - Maximum Front-End sustainable rate $\sim 10 \text{MHz}$ \rightarrow can be used in SLHC
 - High rate \rightarrow decrease the charge in the detector $\sim 1 \text{pC}$ \rightarrow few tens of fC
- CSC: Re-scope ME4/2 (4th disk at $\eta < 1.8$)
 - Improve P_T resolution in L1 CSC Track-Finder
 - Redundancy with 4 disks \Rightarrow efficiency
 - Identify and remove Local Charged Track segments spoiled by showering TeV muons

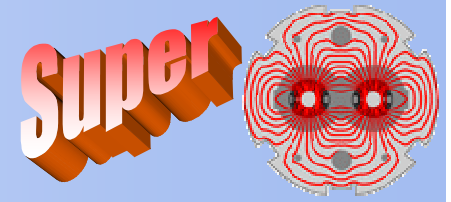


4 Stations in the barrel and each endcap

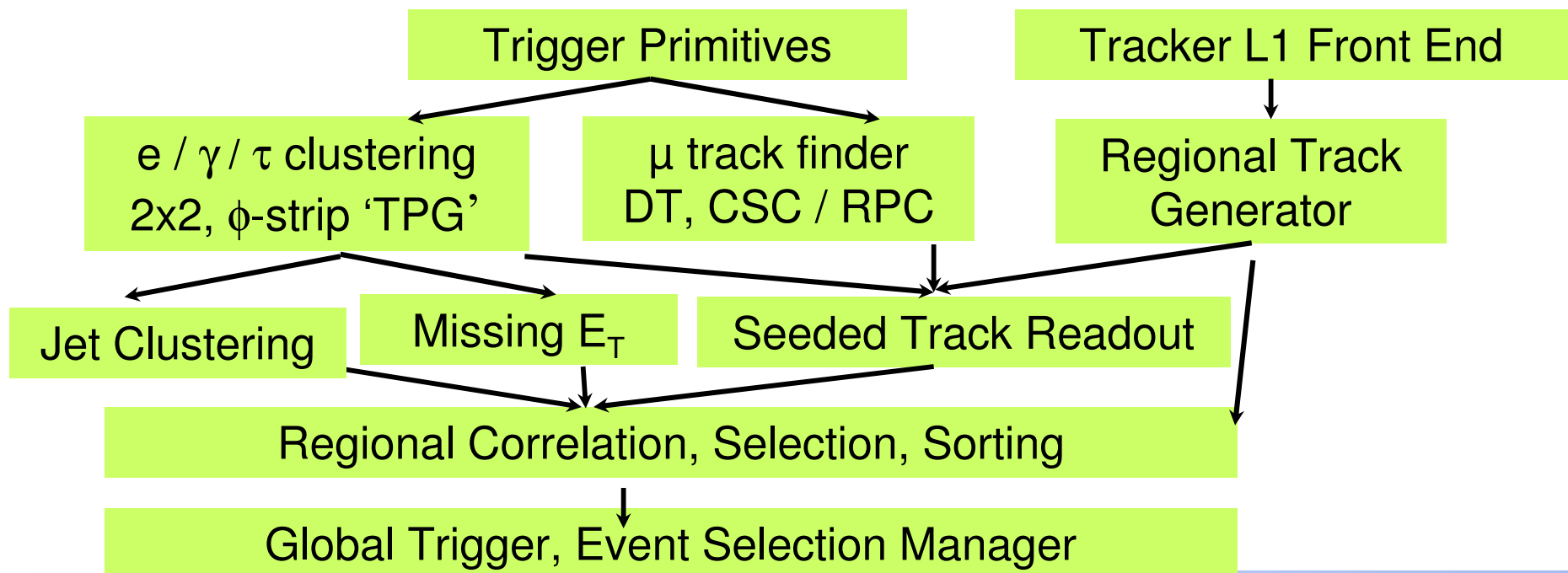
- Initial coverage of RPC is staged to $\eta < 1.6$ and 3 disks
- Initial trigger coverage of CSC 1st station is staged to $\eta < 2.1$
- Fourth CSC disk staged for $\eta < 1.8$



Trigger R&D

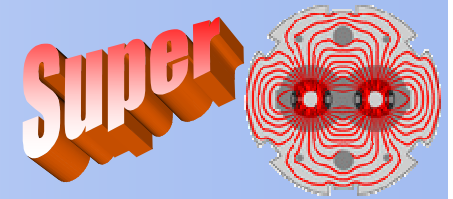


- 50 ns beam crossing is the SLHC baseline
- 25 ns (current baseline) is a backup
- Buffer sizes may need to be enlarged for more interactions distributed in half the number of crossings and larger event size.
- Increase the Level 1 latency to 6.4 μ sec
- Leave present L1+ HLT structure intact (except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





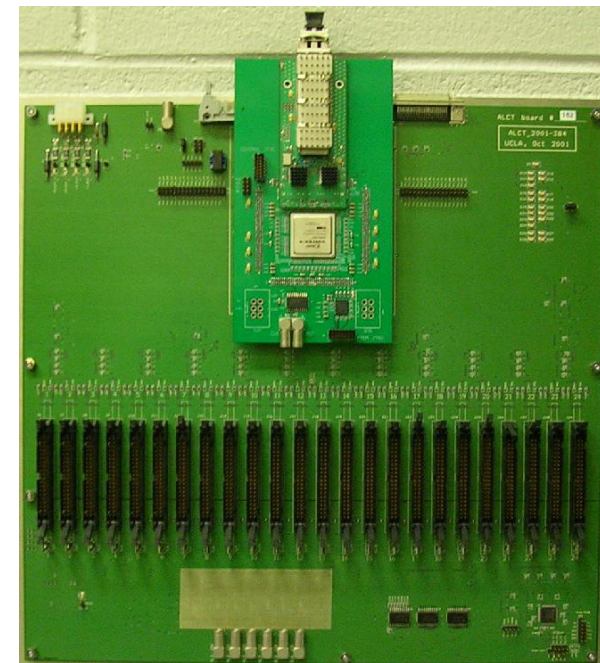
Muon Trigger R&D



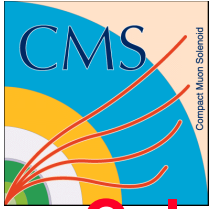
- Interest in CSC Trigger R&D :
 - Simulation of high occupancy SLHC muon trigger algorithms, silicon detector and muon detector track-finding processor studies
 - The Clock and Control Board will need upgrading because of Timing Trigger Control (TTC) changes
 - Redesign Muon Port Card (MPC) to increase 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

(Florida, Rice, UCLA)

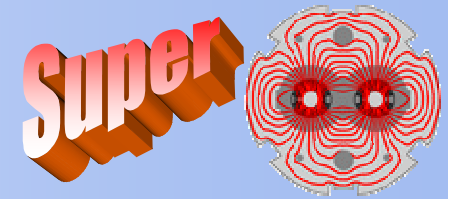
- **Some ongoing activities**
- **ALCT with new mezzanine (U.Florida)**



- **Xilinx Virtex-5 Mezzanine card (Rice)**



Calorimeter Trigger R&D



• Calorimeter Trigger (Wisconsin)

- Simulation of high occupancy SLHC calorimeter trigger algorithms
- Combined tracking trigger + calorimeter trigger processor studies
- Develop automated timing testing & distribution system
- Test new commercial PCI-X backplane technology
- Study more complex higher-resolution algorithms in new FPGAs
- Evaluate short distance high bandwidth links, cables,

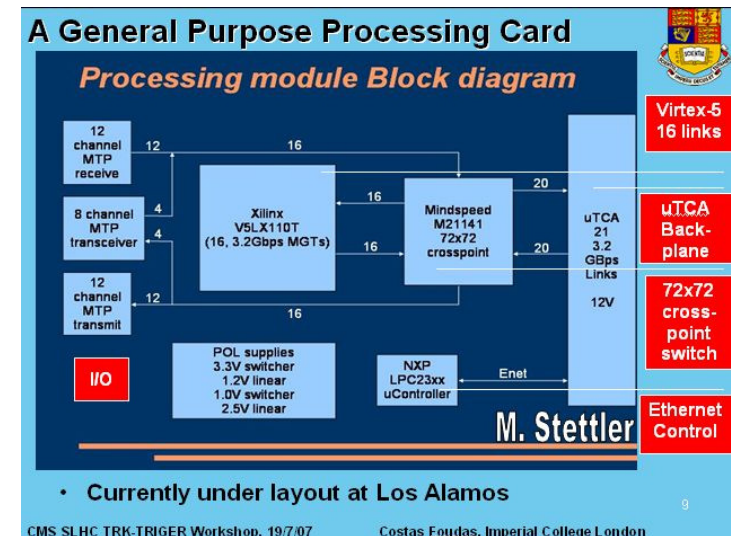
• Telecommunication Computing Architecture Processing Card and Backplane (Imperial, Los Alamos, Maryland, Wisconsin, Princeton, Minnesota)

- Electronics must re-orient “channel” to “Physics $\eta\phi$ ” for trigger decision
- Telecommunications industry reorients signals all the time using TCA

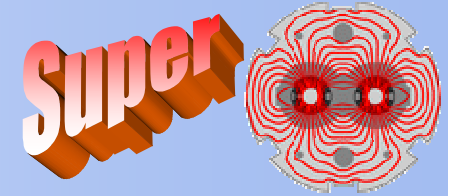
- Similar to VME but has high speed (>5Gbps) differential backplane

• Develop common processing card

- Parallel optical links for fiber optic inputs
- Modern FPGAs for logic, memory, and serialization/deserialization
- TCA backplane for data transmission
- Reduces number of cards in trigger system
- More powerful!!!

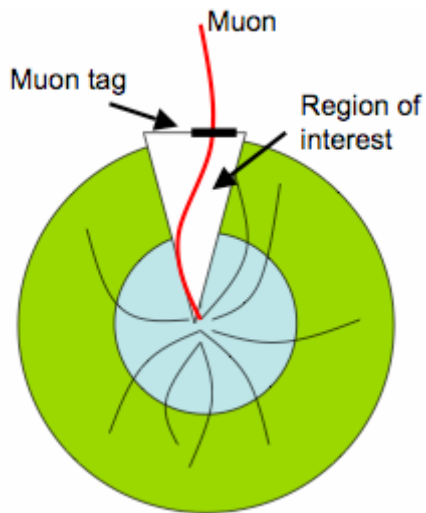


Tracking/trigger R&D

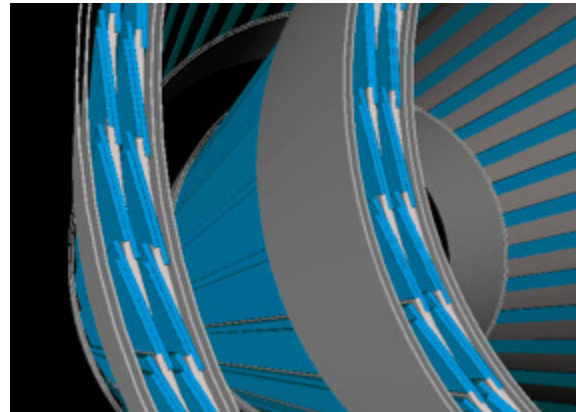


- **Data reduction on the detector or selective readout is essential**
- **Ideas are emerging and R&D needed to evaluate feasibility**

MUON TRACK FAST TAG



Stacked layer tracking trigger

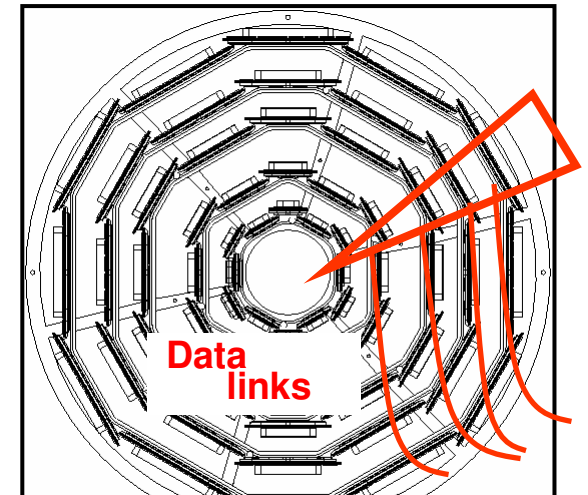


Close space minimize combinatorics

Separation between stacks allow calculation of P_t

Could be implemented on detector

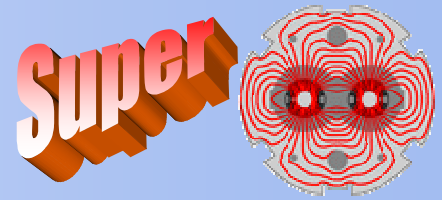
Use Associative memories ala CDF



1 AM for each enough-small $\Delta\phi$ Patterns
 Hits: **position+time stamp**
 All patterns inside a single chip
 N chips for **N overlapping events identified by the time stamp**



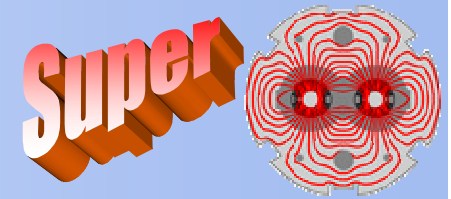
Opto electronics R&D



- **Common CERN/CMS/ATLAS R&D**
- **LHC Link builders have teamed up to pool efforts for SLHC in the SLHC Optical Link Working Group**
- **Effort divided in three main areas:**
 - **WGa: Lessons Learned**
 - **WGb: Radiation & Reliability testing**
 - **WGC: Evaluation criteria and Reference Optical Link**
- **Total Dose/Fluence**
 - **Currently-used Edge Emitters transmitters expect 5mA threshold shift at LHC, this will scale directly with SLHC luminosity**
 - **compensated by the Laser Driver adjustable bias**
 - **VCSELs show lower threshold shifts along with lower initial threshold currents by factors of 3-5, but this requires verification and investigation of system issues**
- **SEU**
 - **Important for Control links, current system able to mitigate using a sufficiently high input optical power**
- **US groups involved (FNAL, Minnesota)**
 - **Test 5 GHz Gb Optical Link from CERN and VCSELs lasers from Oxford**
 - **Experience working at these frequencies**
 - **Perform the radiation tests that were done for 1 GHz version**



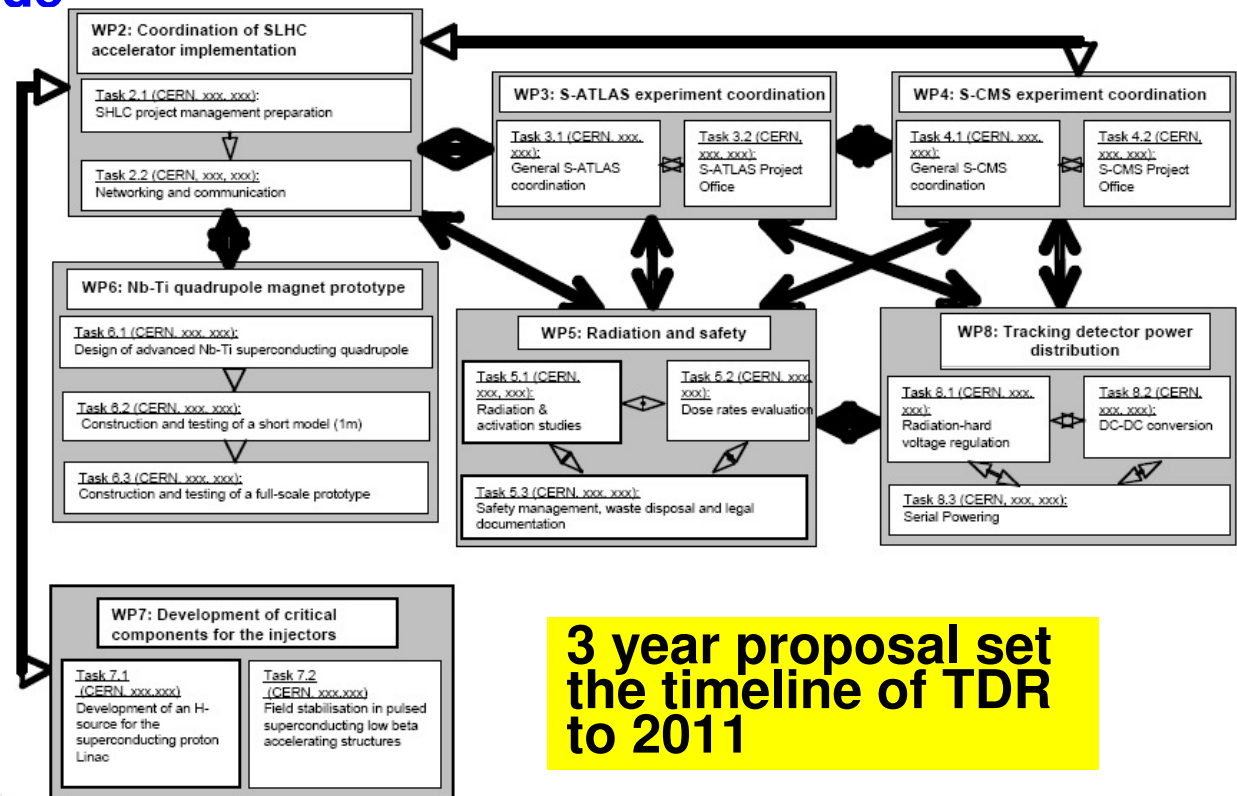
CERN preparation



- The proposal “Preparatory Phase of the LHC Upgrade” for FP7 SLHC-PP has been accepted by the EU
 - Overall Coordinator : Lyn Evans
 - Funds projects for machine, power distribution, radiation and safety. It also provides support for the management structure for the CMS and ATLAS upgrade

- CMS will receive around 500 KEuro in funds to help with project management of the CMS upgrade project

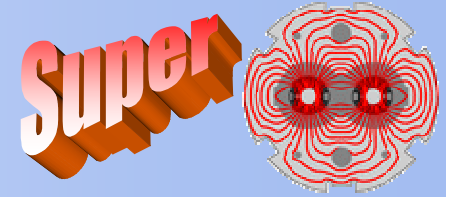
- Set up the Technical Coordination Unit and the Management structures
- Goals - LOI/TDR preparation - Cost books



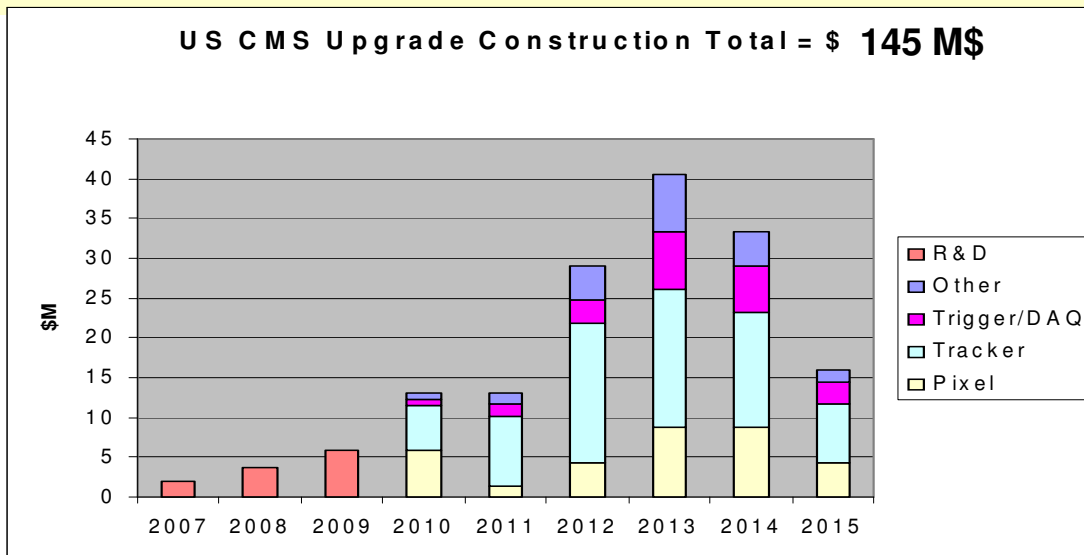
3 year proposal set the timeline of TDR to 2011



USCMS Upgrade Budget Profile



- **The M&S cost of the upgrade (not including R&D) is estimated to be 175 MCHF**
 - 80% of the cost and effort is in tracker and trigger
- **US CMS is ~ 33% of the collaboration. Expected to cover that fraction of upgrades and the upgrade R&D.**
 - US has a leadership position in the SLHC upgrade
 - Effort and resources are needed to retain it

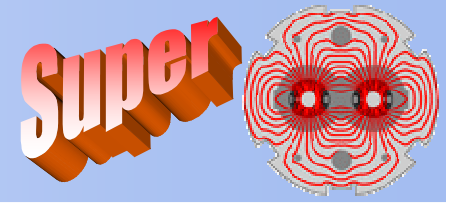


- **Total US CMS Upgrade construction = \$ 145 M**
- **R&D is \$11 M\$**

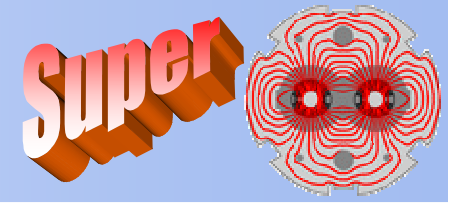
- **Expect heavy involvement in pixel, tracker, track trigger, and trigger upgrades.**
- **Contributions must be worked out with our funding agencies**
- **Assume prototype layers in 2011, full replacement by SLHC Startup probably in 2016**



Conclusions



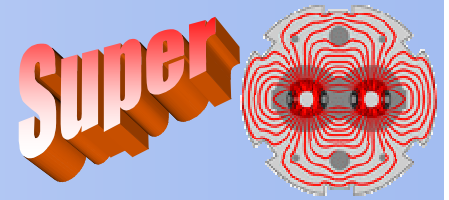
- **The SLHC provides excellent physics reach at moderate extra cost relative to the overall initial LHC investment,**
- **It extends the lifetime of the LHC complex, completing its physics potential, and bridging the time gap with future activities.**
- **The feasibility of the SLHC physics program requires detector upgrades able to maintain the performances expected at the standard $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ luminosity.**
- **The detector upgrades will require significant detector R&D, especially for the inner tracking systems, which has to start now**
- **A vigorous R&D activity for the SLHC will entail general and significant progresses in the area of particle detector developments, and therefore will ultimately have impacts on future machines**
- **LHC/SLHC machine development and commissioning provides a unique learning opportunity for accelerator scientists in several areas of research at the DOE science.**



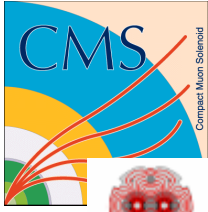
Backup



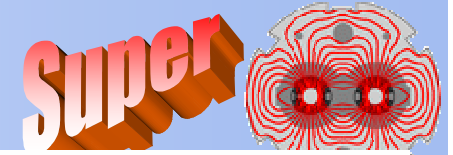
US Strategy P5



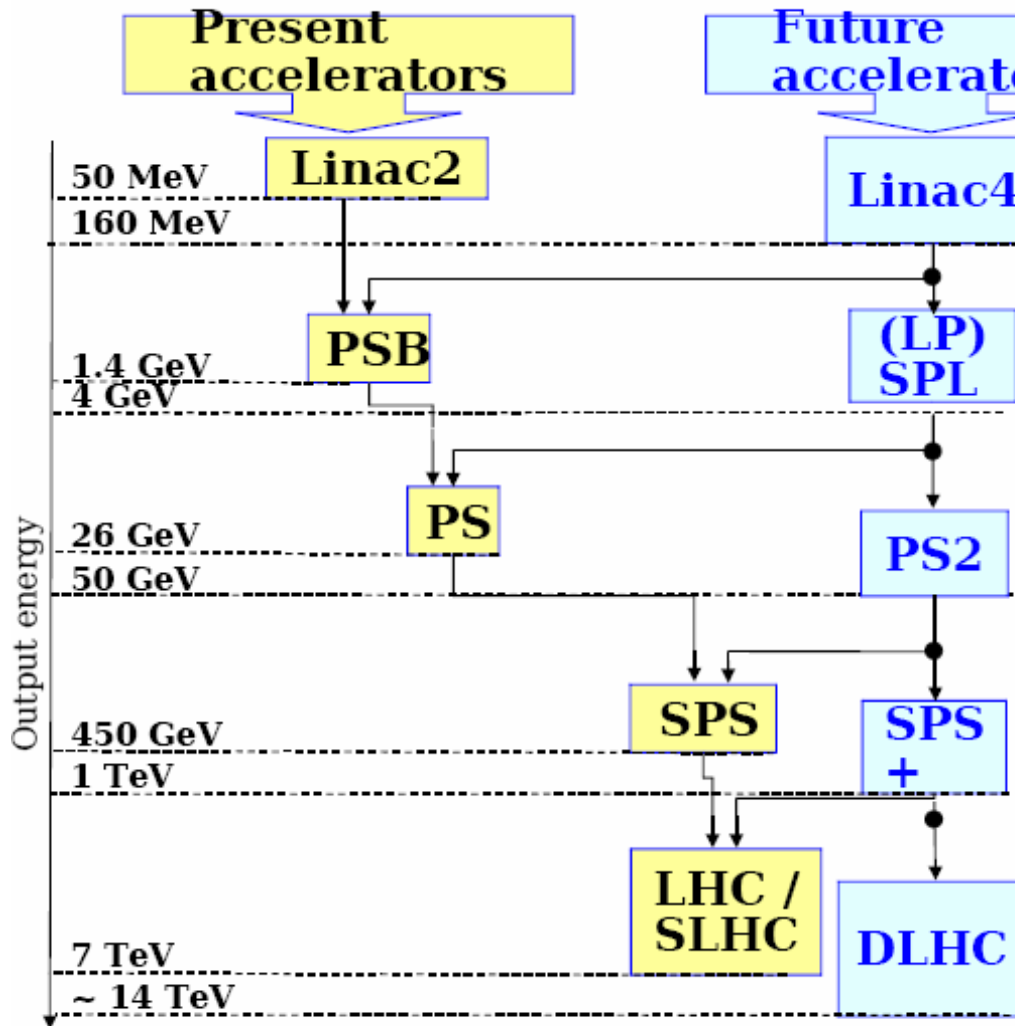
- **The highest priority group involves the investigations at the energy frontier. These are the full range of activities for the LHC program and the R&D for the ILC.**
- **The second group includes the near-term program in dark matter and dark energy, as well as measurement of the third neutrino-mixing angle. This grouping includes the three small experiments: DES, the 25 kg CDMS experiment, and the Daya Bay reactor experiment. Also in this group is the support for the LSST and SNAP, to bring these to the “Preliminary Design Review Stage” in the case of the NSF and “CD2 Stage” in the case of the DOE over a two to three year time frame. We recommend that the DOE work with NASA to ensure that a dark energy space mission can be carried out and that the three potential approaches to the mission have been properly evaluated. The final item in this group is the R&D funding for DUSEL, along with support by the NSF and the DOE for R&D for both a large dark matter and neutrino-less double beta decay experiment.**
- **The next item is the construction of the NOvA experiment at Fermilab along with a program of modest machine improvements.**



LHC upgrade options



Themes 1 (2012) & 3 (2016)



"DONE" DEAL Linac4

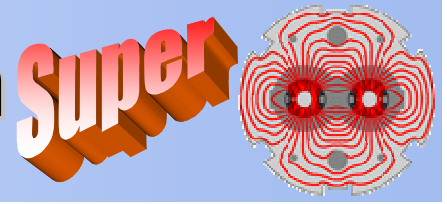
THEME 1
NEAR TERM FOCUS ~2012
(LP)SPL (Low Power)
 Superconducting Proton
 Linac (4-5 GeV)
PS2 High Energy PS
 (~ 5 to 50 GeV - 0.3 Hz)

THEME 3
LUMI UPGRADE ~2016
SLHC "Superlumi" LHC
 (up to $10^{35} \text{ cm}^{-2}\text{s}^{-1}$)

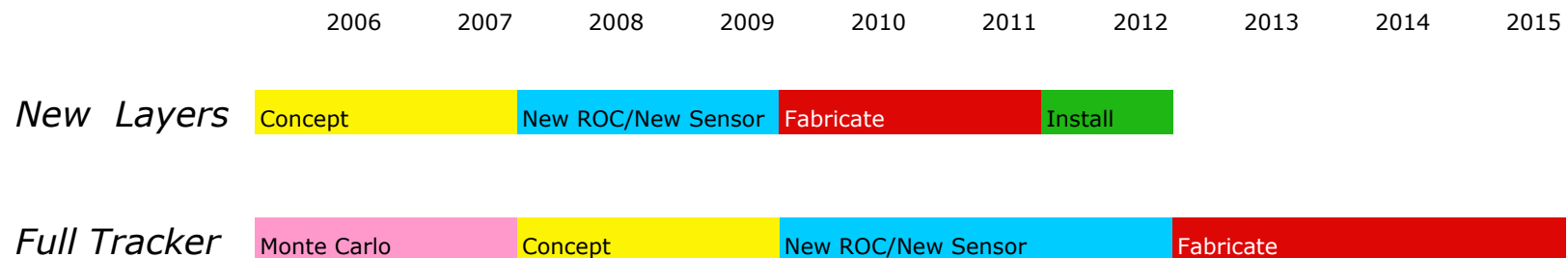
LONG TERM FANTASY
SPS+ Superconducting SPS
DLHC "Double energy" LHC



CMS Tracker Upgrade Plan

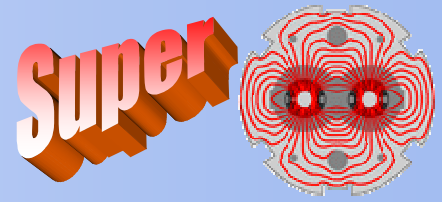


- **Within 5 years of LHC start**
 - **New layers within volume of the Pixel tracker incorporating tracking information for Level 1 Trigger**
 - Room within the current envelope for additional layers
 - Possibly replacement for existing layers (first barrel layer)
 - Prototype for full tracking trigger
 - **Elements of new Level 1 trigger**
 - Utilize new tracking information and correlation between systems
- **Upgrade tracker system by SLHC (8-10 years from LHC Startup)**
 - Full upgrade to trigger system





CMS Commissioning

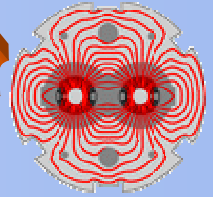


- **CMS is still a construction site, with major components still being installed and cabled.**
- **Very difficult to commission sensitive electronics and detectors while the basic services are still being installed and commissioned**
 - **Need final LV power, cooling, cabling**
 - **Must arrange that sensitive pieces of equipment are left undisturbed**
 - **Must deal with cavern noise due to arc welding, for example**
- **Temporary arrangements (wall power) have been needed in some places to achieve what we have so far**
 - **Limits to ~5% front-end electronics powered in-situ**
- **Central services like DAQ and Trigger are not quite in their final form, and are still being commissioned**
 - **Limits how much Tracker DAQ electronics can participate in global commissioning**
- **Preparation of Software, Computing & Physics Analysis on track**

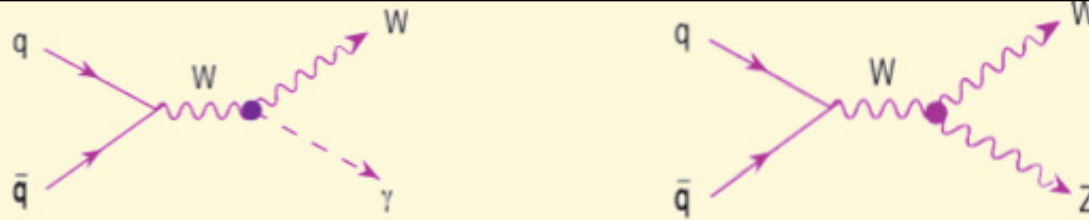


Multiple W/Z Boson Couplings

Super

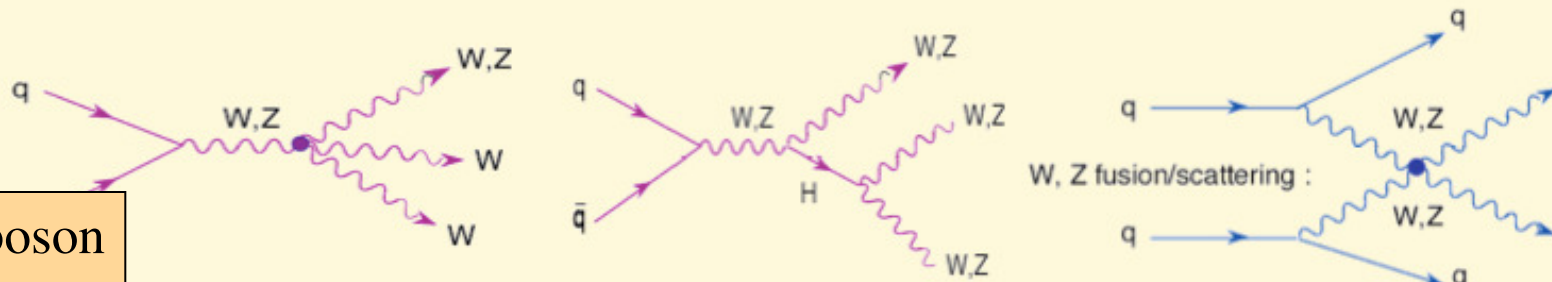


Accuracies for triple couplings



Coupling	14 TeV 100 fb ⁻¹	14 TeV 1000 fb ⁻¹	28 TeV 100 fb ⁻¹	28 TeV 1000 fb ⁻¹	LC 500 fb ⁻¹ , 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g_1^Z	0.0038	0.0024	0.0023	0.0007	0.0050

Multi-boson final states



(LO rates, CTEQ5M, $k \sim 1.5$ expected for these final states)

Process	WWW	WWZ	ZZW	ZZZ	WWWW	WWWZ
$N(m_H = 120 \text{ GeV})$	2600	1100	36	7	5	0.8
$N(m_H = 200 \text{ GeV})$	7100	2000	130	33	20	1.6