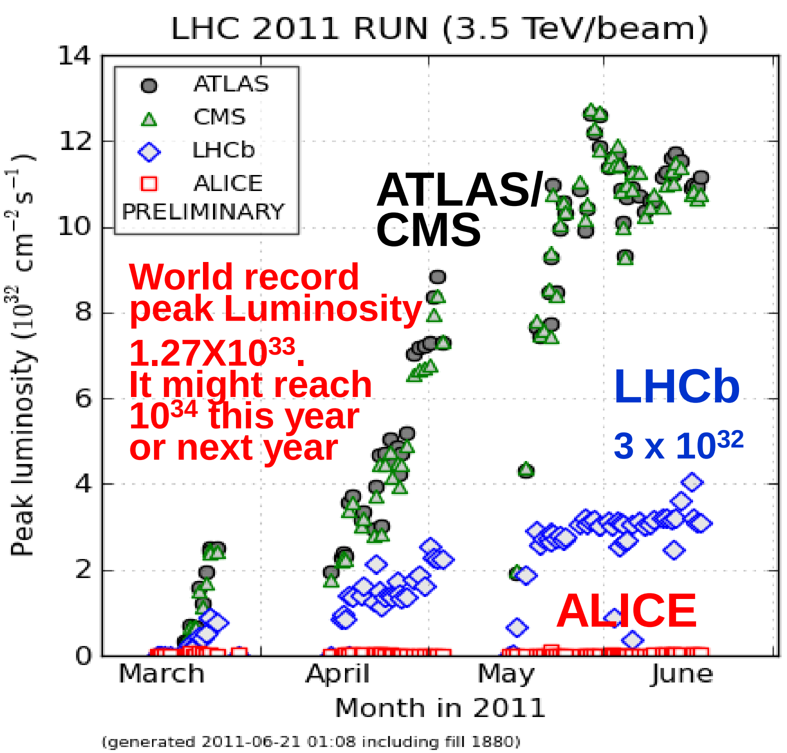
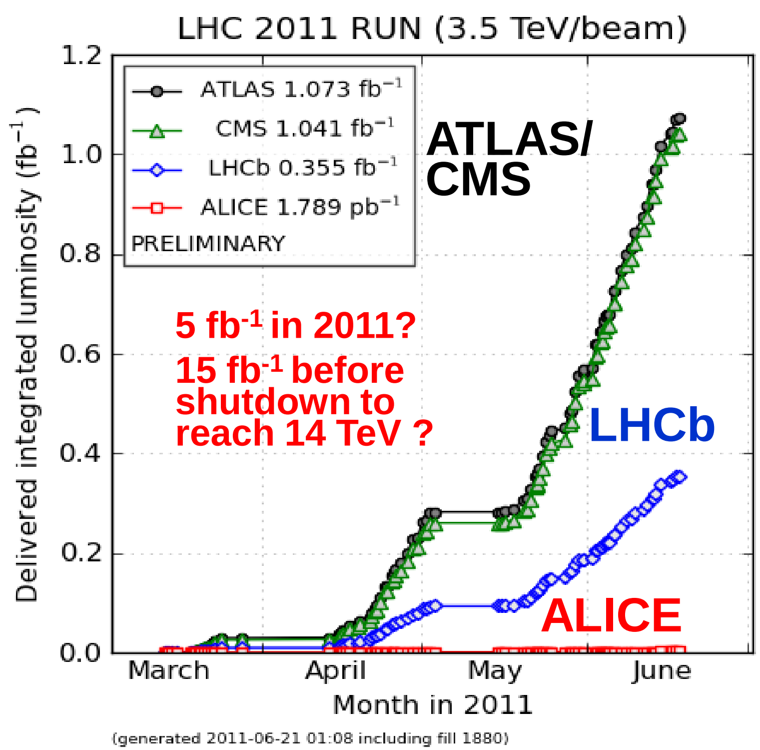
The upgrade of the LHC detectors

- **Outline**
  - **LHC Performance**
  - **The CERN luminosity plan**
  - **Physics with the luminosity upgraded LHC**
  - **Overview of the LHC detectors upgrade plans**
  - **The US role**
  - **Conclusions**

Spectacular machine performance

- **Great 2010:**
  - **pp achievements: 368 colliding bunches, 150 ns spacing, peak luminosity 2 $\times 10^{32}$ cm^{-2} s^{-1}, integrated luminosity 46 pb^{-1} /experiment**
  - **Pb-Pb: ~9.5mb^{-1} /experiment delivered.**
- **Exceptional 2011: 1092 bunches (it could reach 1404), 50 ns spacing**
- **All experiments doing well. For example, average fraction of operational channels per CMS sub-system >99%. Overall data taking efficiency ~92%.**



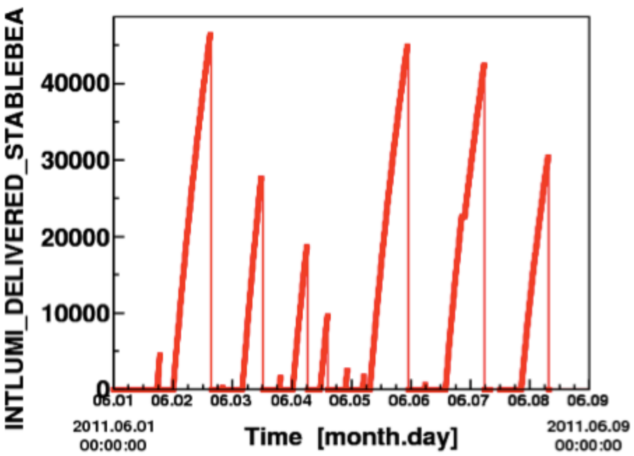


LHC performance

- Issues dealt with in 1st half of 2011: electron cloud (improved with scrubbing), Luminosity leveling for LHCb, and operation with bunch trains.
- Potential issues in 2nd half of 2011: Unidentified Falling Objects (leading to sudden fast local losses and beam dumps) and Single Event Upsets

	2011 so far	Nominal
Energy [TeV]	3.5	7
β^* [m]	1.5	0.55
Emittance [μm]	2.5	3.75
Transverse beam size at IP [μm]	40	16.7
Bunch population	1.2×10^{11} p	1.15×10^{11} p
Number of bunches	1092/IP	2808
Stored energy [MJ]	100	360
Peak luminosity [$cm^{-2}s^{-1}$]	1.6×10^{33}	1×10^{34}

Good week delivered 200pb^{-1}



LHC upgrade timeline

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity — Long shutdown 1

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity — Long shutdown 2

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling — Long shutdown 3

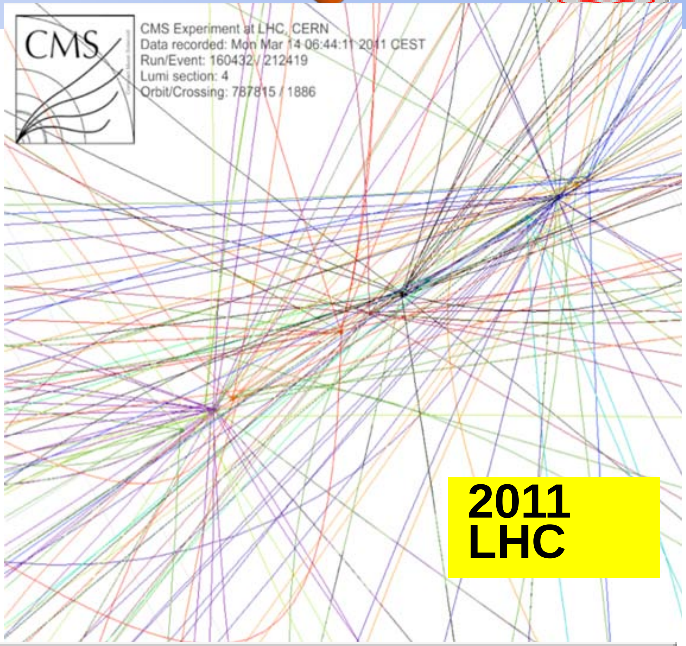
Run 4: Collect data until > 3000 fb^{-1}

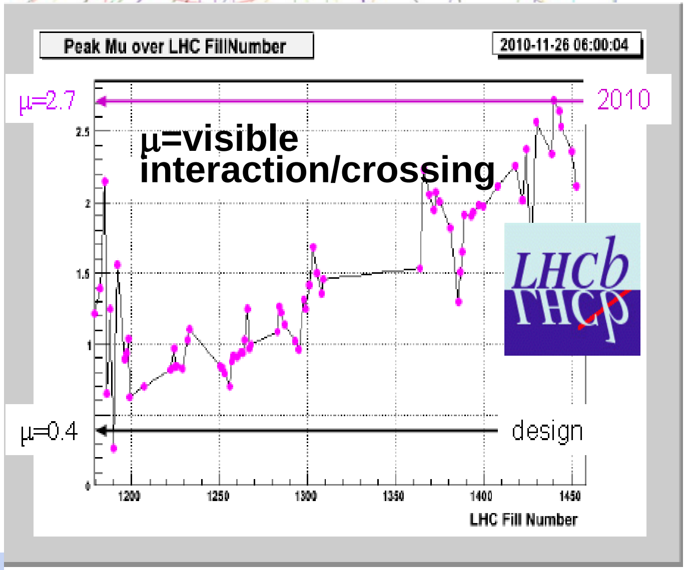
2030 — e^+e^- collider, High energy LHC, ... ?

S. Bertolucci PLHC 2011

Detector Upgrade issues

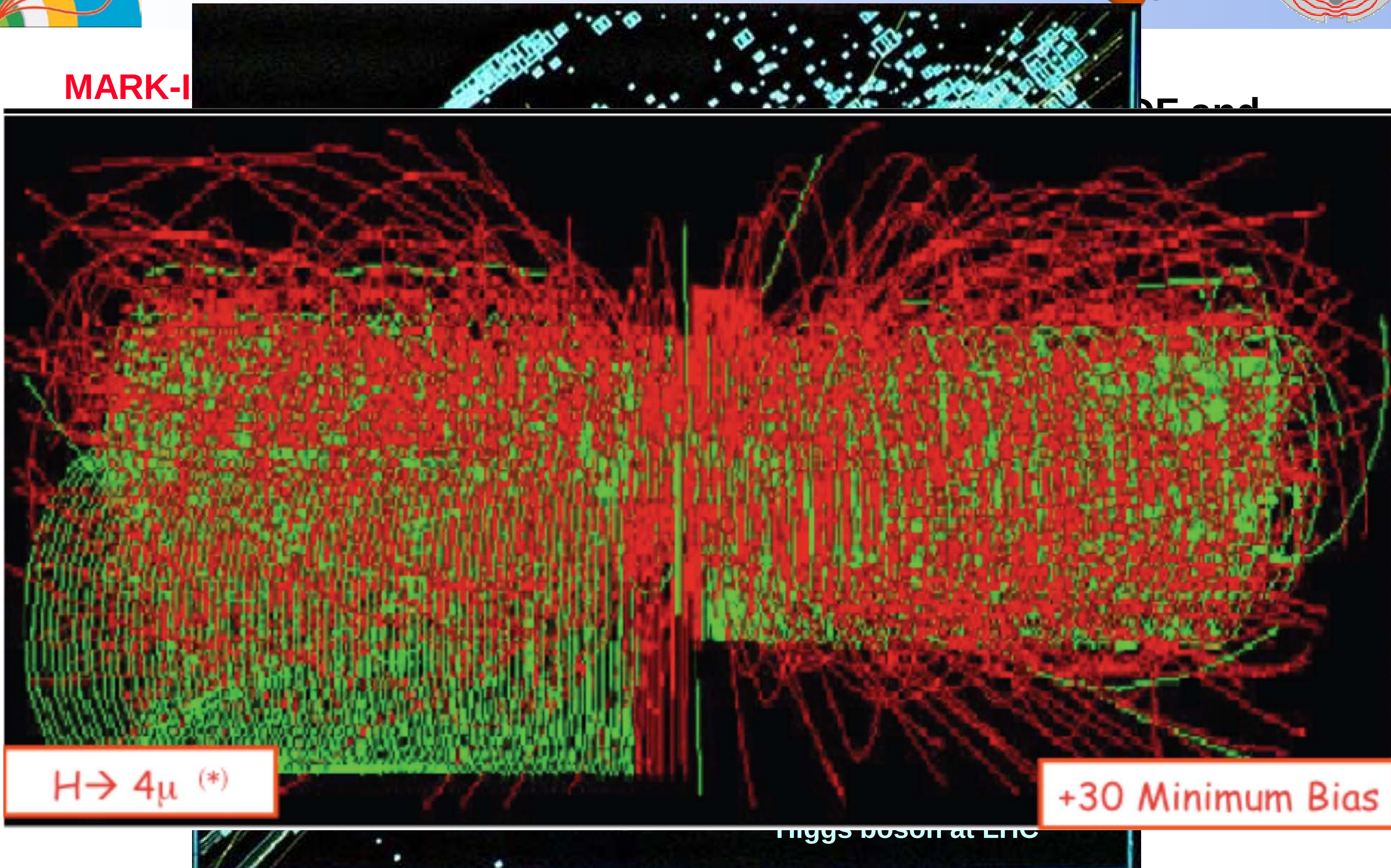
- Increase number of interactions/crossing leads to:
  - Trigger performance degradation & rate limitation
  - Increase occupancy & more complex event reconstruction
  - Data losses due to latencies & limited buffering
  - Increase in radiation damage worsening the response of detectors in the innermost layers and in forward regions close to the beam
  - Decreases discrimination of electrons from jets
  - Material budget becomes critical to reduce occupancy and maintain momentum resolution
- All collaborations plan to upgrade their detectors to maintain/improve the physics performance
  - Most data will be collected with peak luminosity beyond the one for which detectors were designed (10^{34} for ATLAS/CMS and $2x10^{32}$ for LHCb)
  - Take advantage of technology improvements and achieve better performance
  - Limit deterioration of performance due to detector's aging



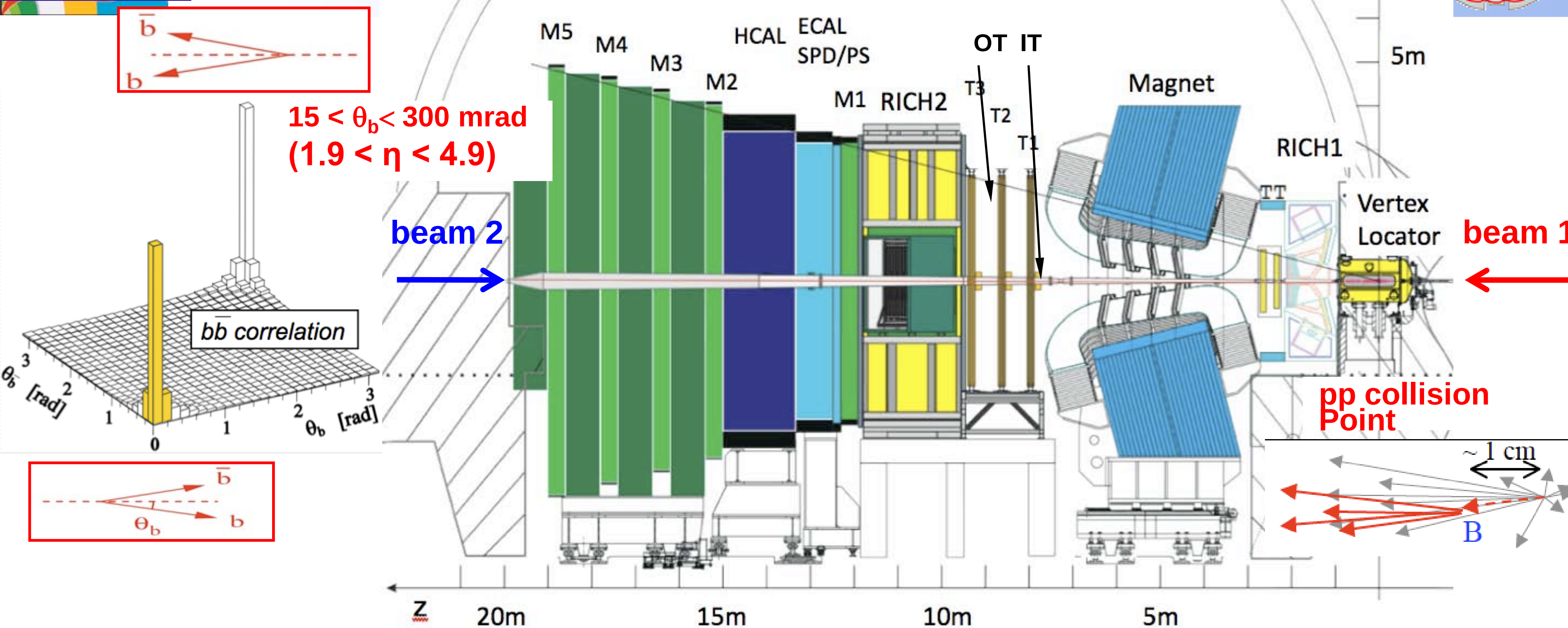


Increasing challenge

MARK-I



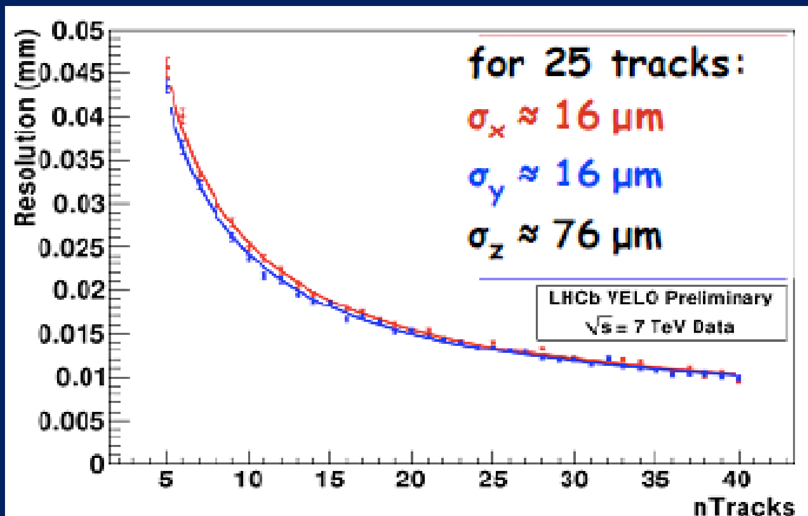
Current LHCb

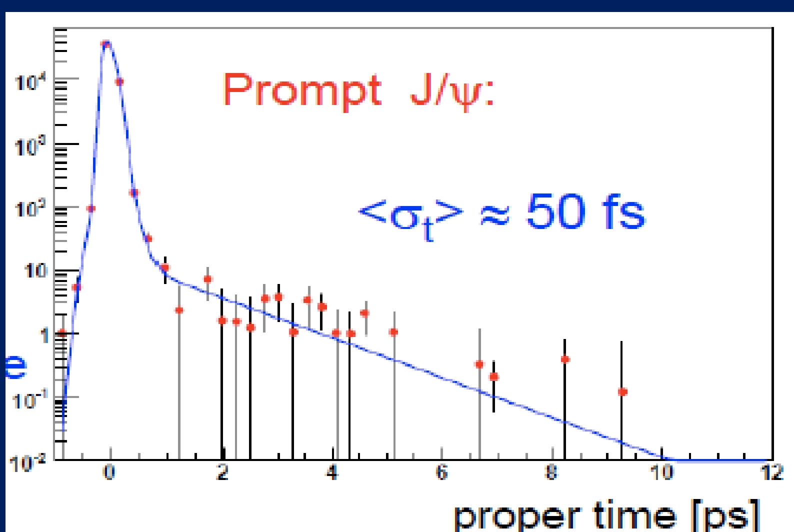


- **Current LHCb physics goals:**
  - **Indirect search for new physics via CP asymmetries and rare decays**
  - **Focus on flavor physics with b and c decays**
- **Forward spectrometer designed to exploit huge $\sigma_{b\bar{b}}$ @ LHC**
  - **10^{12} *bb* pairs produced per 2 years of data taking @ $\mathcal{L} = 2\times10^{32}$ cm^{-2}s^{-1}**
  - **Access to all b-hadrons: B_d, B_u, B_s, b-baryons and B_c**
  - **Big experimental challenge: $\sigma_{b\bar{b}}$< 1% σ_{inel} total, Bs of interest BR < 10^{-5}**
- **Current LHCb : Collect ~5 fb^{-1} before 2nd LHC shutdown 2017**

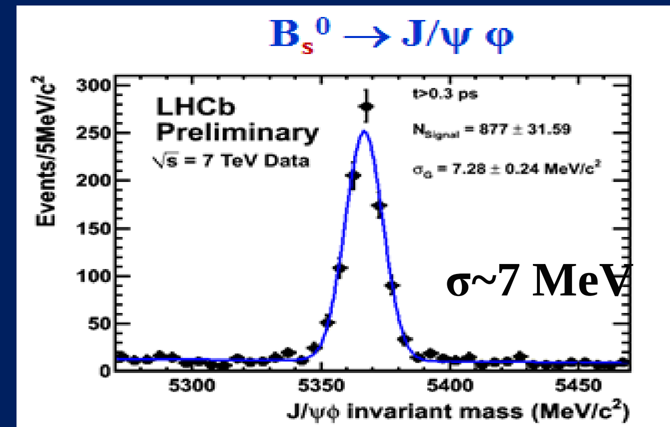
LHCb Detector performance

Vertex resolution on primary vertex



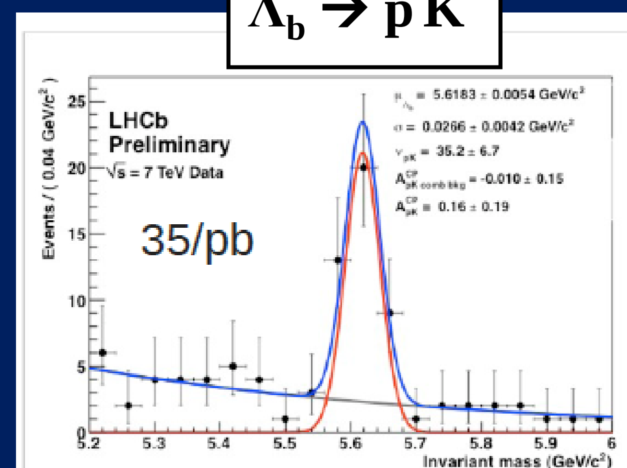


Mass resolution



Particle ID

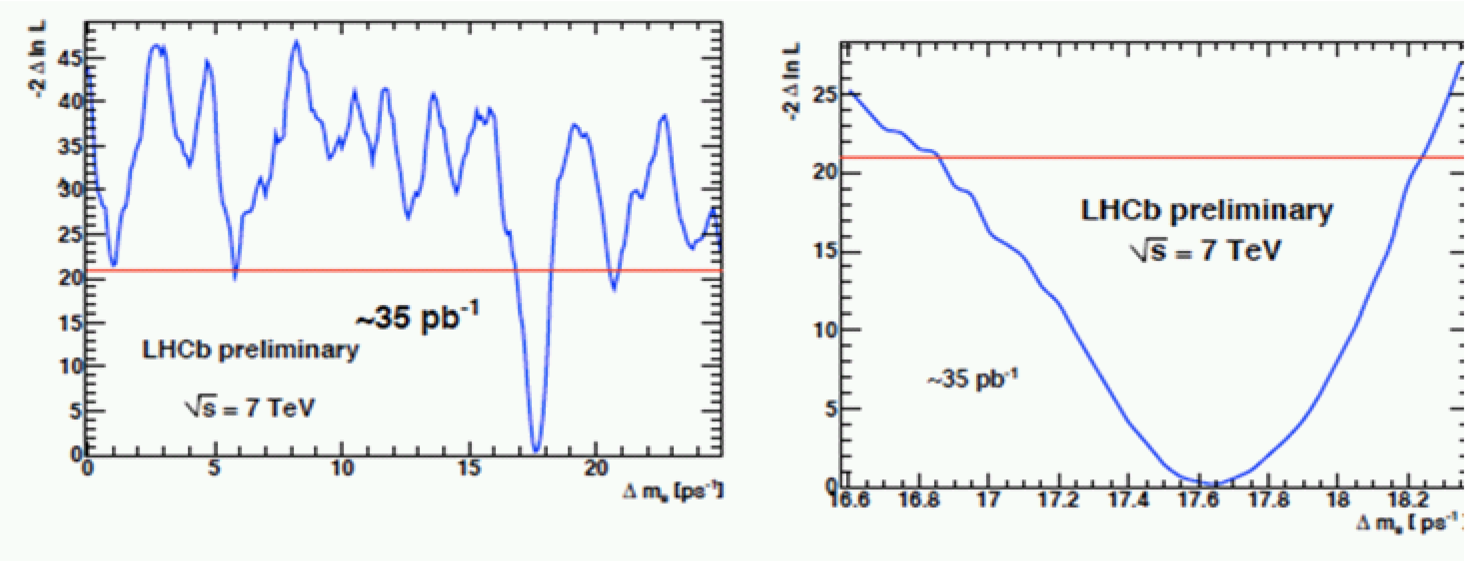
$\Lambda_b \to p\,K$



LHCb physics prospects

- Excellent
  - Per event proper time uncertainties $\langle\sigma_t\rangle$ =36-44 fs
  - Per event mistag rate ε_{eff} = 3.8$\pm$2.1%

Provide measurement of the B_s oscillation frequency with 35 pb^{-1}

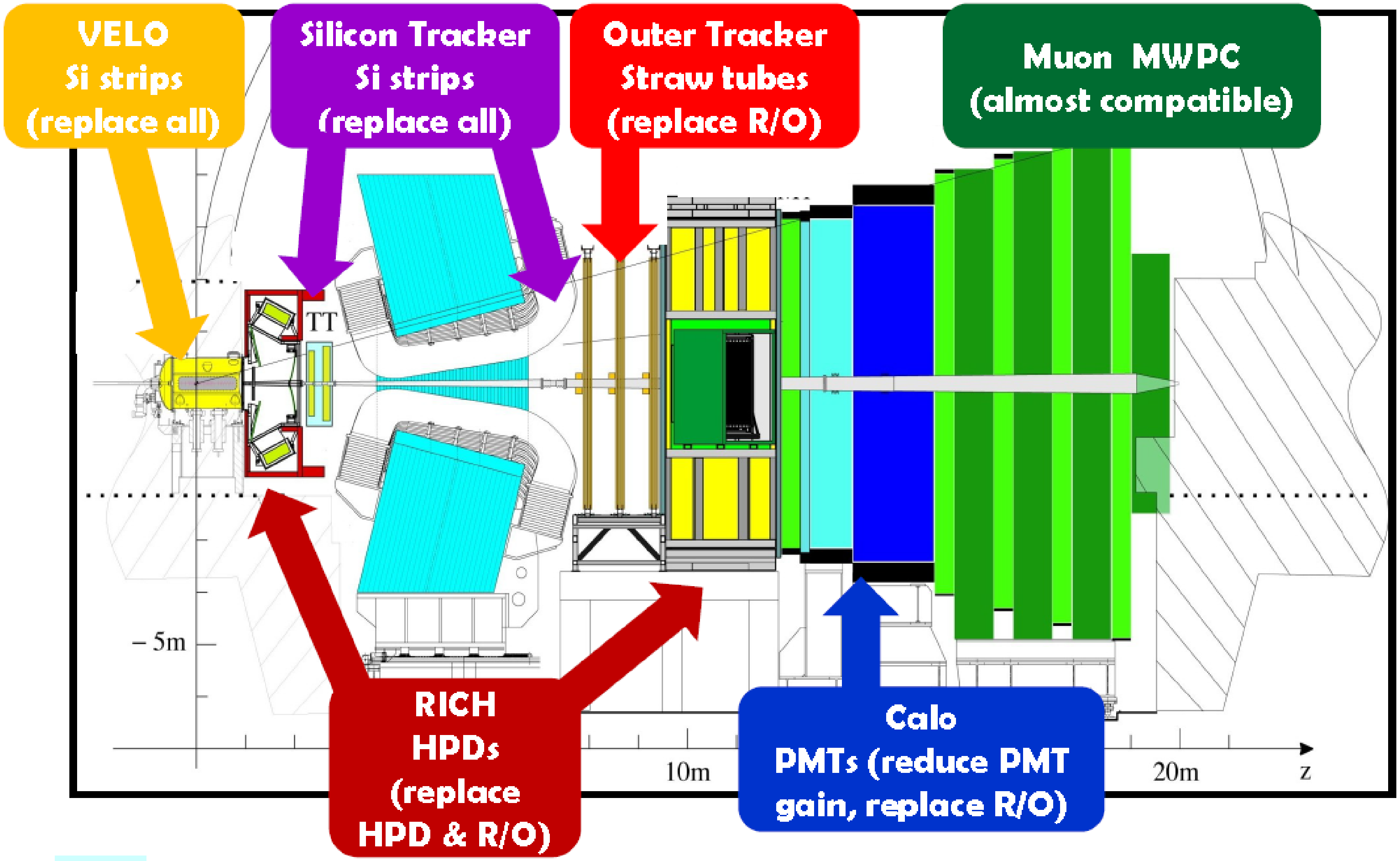


The line at 20.94 indicates the likelihood value evaluated in the limit of infinite mixing frequency

- LHCb Δm_s=17.63$\pm 0.11(stat) \pm 0.04(sys) ps^{-1}$ (4.6 σ stat. significance)
- CDF Δm_s=17.77$\pm 0.10(stat) \pm 0.07(sys) ps^{-1}$ (with 1 fb^{-1})

LHCb upgrade Strategy

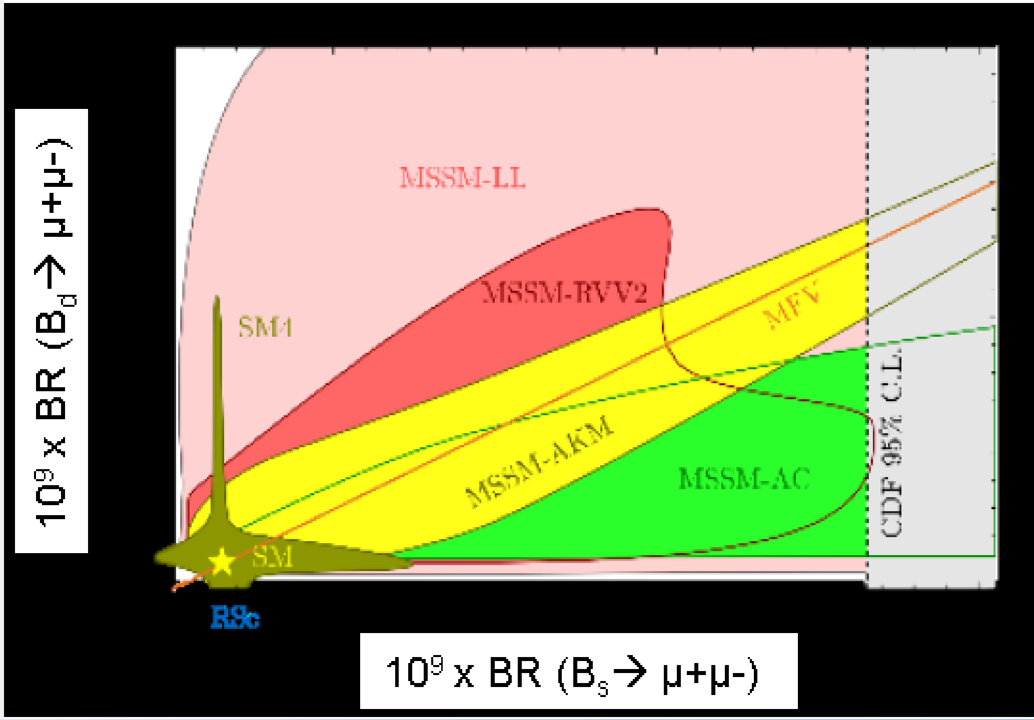
- **Flexible software trigger with 40 MHz input rate and 20 kHz output rate**
  - **upgrade electronics & DAQ architecture**
- **Rebuild detectors limited to the current 1MHz input, 2 KHz out electronics**
- **Remove some detectors due to increased occupancies at higher luminosity**



LHCb upgrade goals

- Run at L ~ 10^{33} cm^{-2} s^{-1} ,collect ~5/fb per year, ~50/fb in 10 years
- Big gain in signal efficiency (factor 7 for hadronic modes)
- LOI submitted to LHCC in March [CERN-LHCC-2011-001]
  - Physics case well received!
    - Quark Flavor Physics: rare decays, CP violation in B_s, measurement of angle γ
    - Lepton physics: Searches for Majorana ν, Lepton Flavor Violating τ-decay
    - Electroweak physics
    - Exotic searches: long lived neutral particles in hidden valley scenarios
- LHCC has recommended LHCb to proceed to the TDR

- Example LHCb upgraded performance:
  - SM BR($B_s \to \mu^+\mu^-$) can be measured to 8% precision @ 50 fb^{-1}
  - Strong constraints for NP models
  - Measure ratio BR($B_d \to \mu^+\mu^-$) over BR($B_s \to \mu^+\mu^-$) to ~35% level (SM uncertainty ~5%)



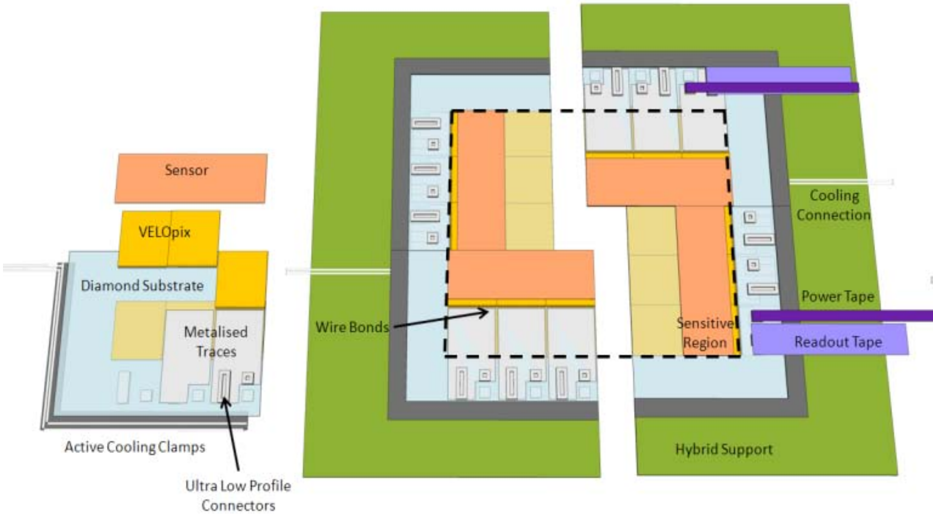
VELO UPGRADE

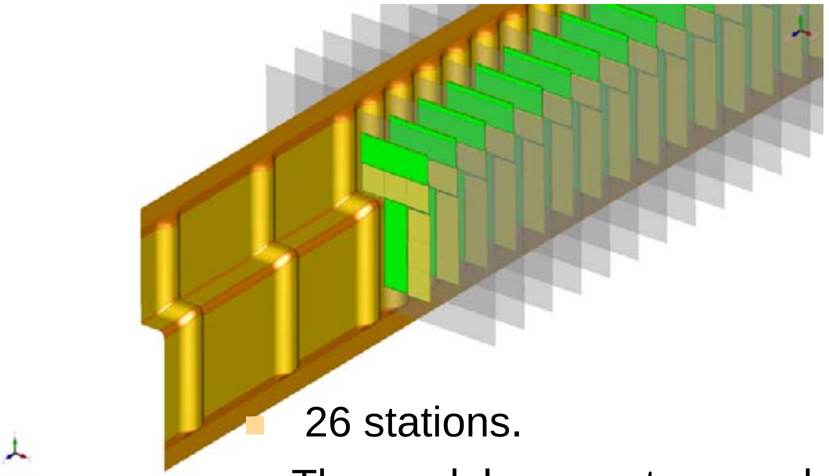
- **Challenges:**
  - Data rates up to 200MHz cm^{-2}
  - Closest pixel is at 7.5 mm from the beam $\Rightarrow$ maximum dose = $5X10^{15}$ 1 MeV $n_{eq}cm^{-2}$
  - Low material budget
- Two options:
  - **pixel detector**: based on Timepix chip with 55 µm x 55 µm pixel size advantageous for pattern recognition
  - **strip detector**: proven technology with reduced strip pitch and increased number of strips

R&D program :

- module structure (X_0)
- sensor options: Planar Si, Diamond, 3D
- CO_2 cooling
- Electronics
- RF-foil of vacuum box

A 'station' is made of 8 sensor tiles.





- 26 stations.
- The modules are staggered to create overlap regions.

PID Upgrade

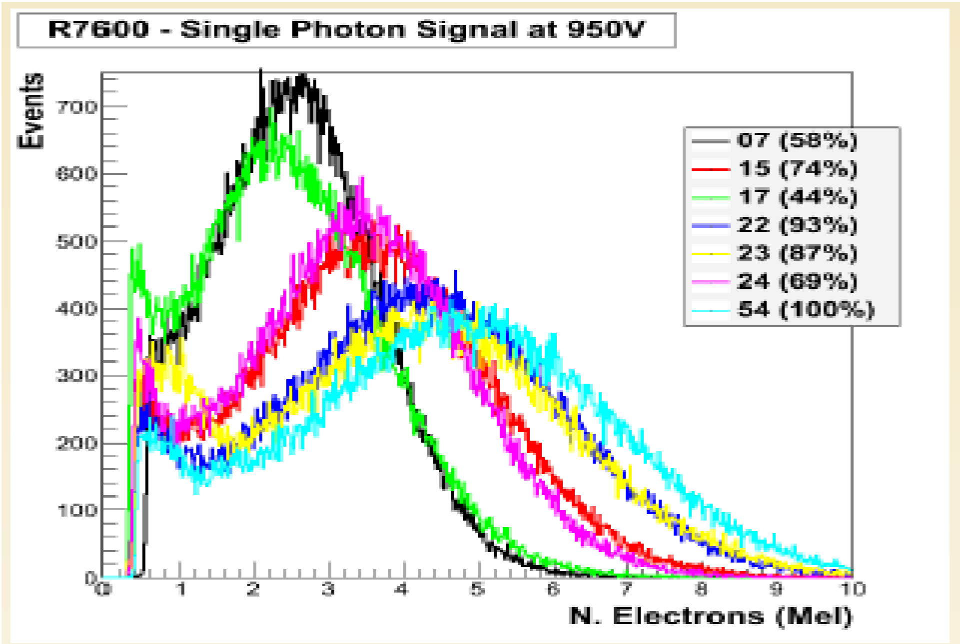
- **RICH-1 and RICH-2 detectors remain:**
  - **Baseline option: replace pixel HPDs by MaPMTs & readout out by 40 MHz ASIC**
  - **alternative: new HPD with external readout**

MaPMT (baseline) option

Prototyping using MAROC3:

- Gain compensation
- Binary output

Digital functions in ACTEL flash FPGA



R7600 MaPMT characterization:

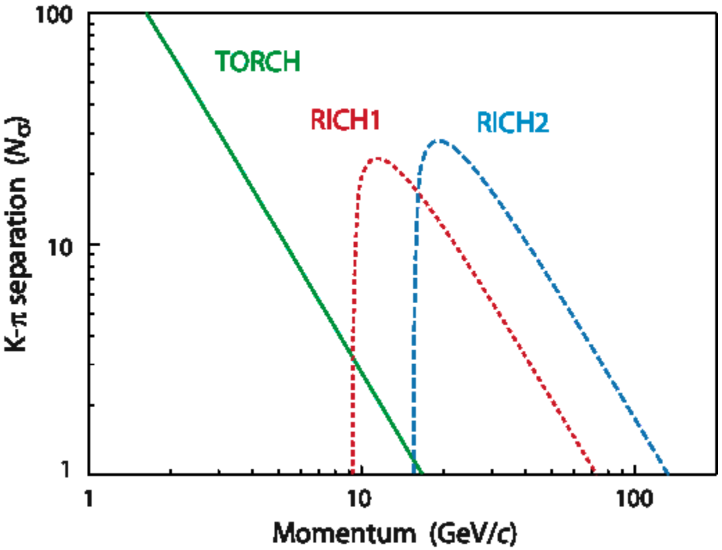
- **Channel to channel gain variation (correction in FE)**
- **Excellent cross-talk (below 1%)**
- **~10% gain reduction in 50 gauss B_L-field (25 gauss max B_L-field in LHCb)**

PID upgrade: TORCH

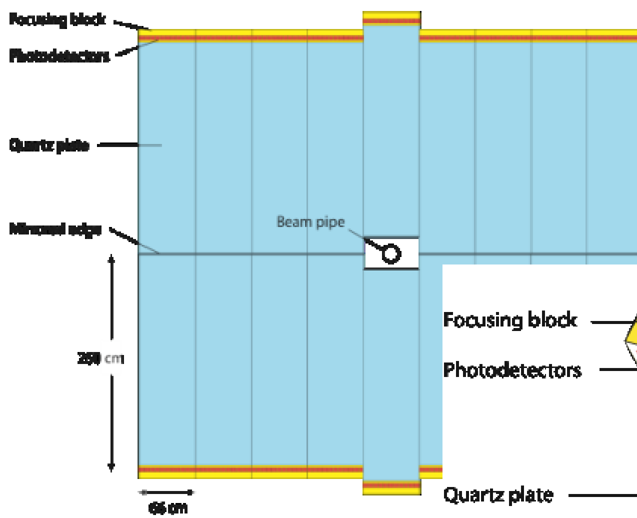
Replace Aerogel with Time-of-Flight detector “TORCH” (TORCH=Time Of internally Reflected Cherenkov light) for low momentum particle identification

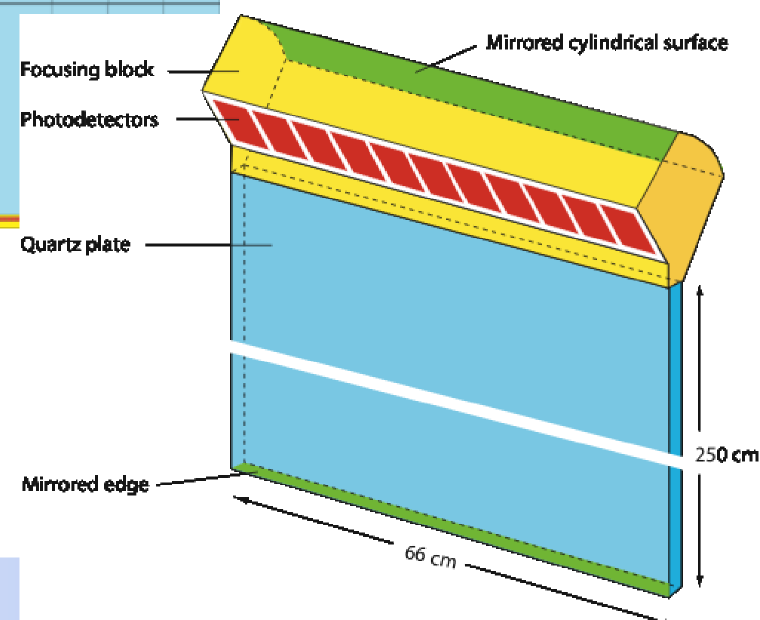
- 1 cm thick quartz plate combining technology of time-of-flight and DIRC (Detection of Internally Reflected Cherenkov (Light))
- measure ToF of tracks with 10-15 ps (~70 ps per photon).

K-π separation vs p in upgrade:



TORCH detector:

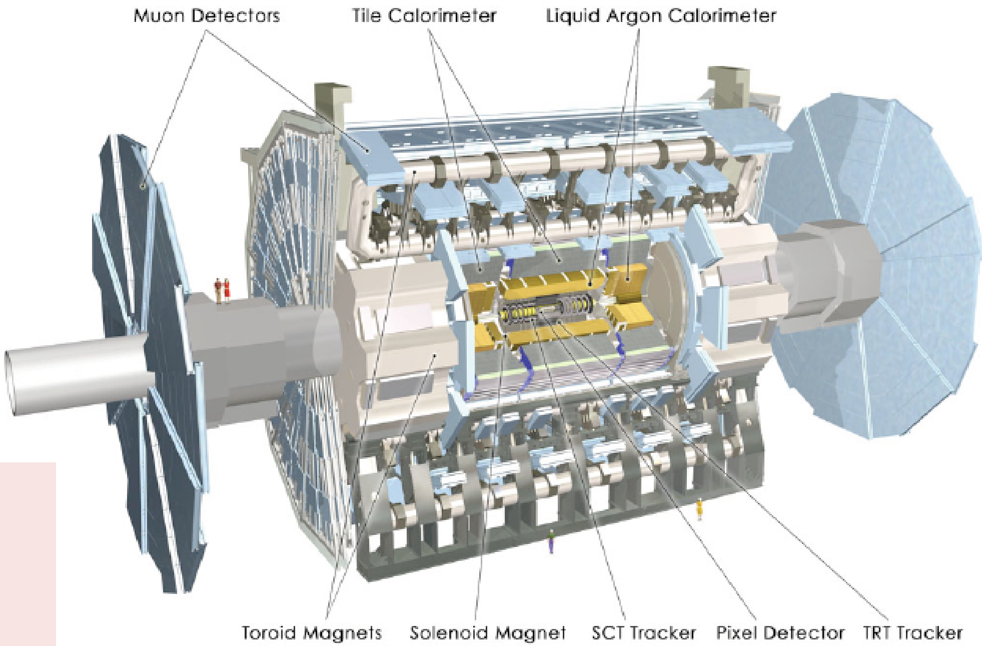




Could be installed later than 2018!

ATLAS

Inner Detector: |η|<2.5
- Si Pixels: **50μm x400 μm**
- Si Strips: 80 μm
- Transition Rad. Tracker
- Solenoid: B=2 T

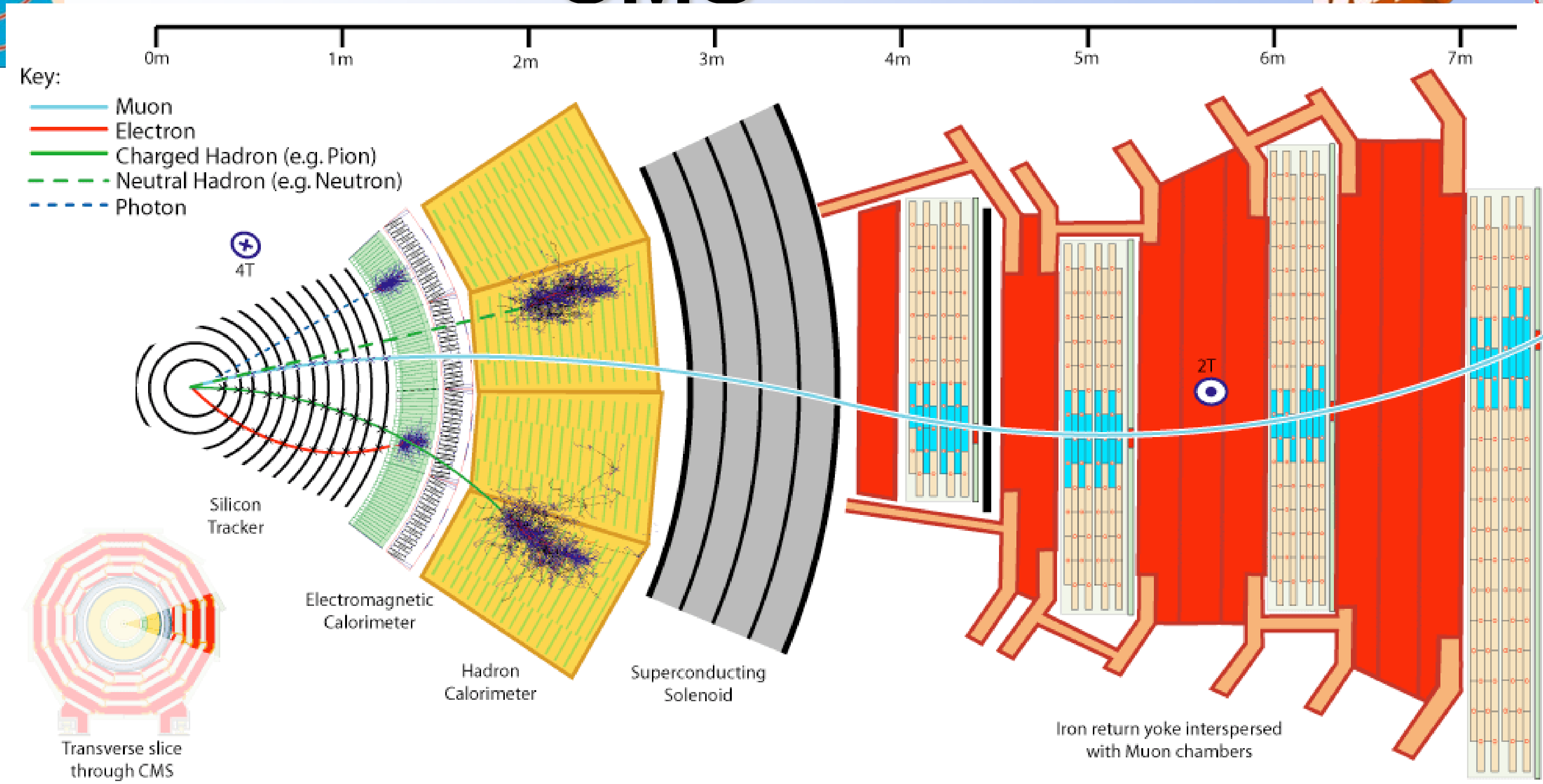


Calorimeters: |η|<4.9
- Lead/LAr : Electromagnetic
- Cu/LAr : Hadronic Endcap
- Tile (steel/plastic scintillator): Hadronic Barrel

Muon System: |η|<2.5
- Trigger chambers (RPC and TGC)
- Precision chambers (MDT and CSC)
- Air-core toroid magnet ($\int$BdL=1-7.5 Tm)

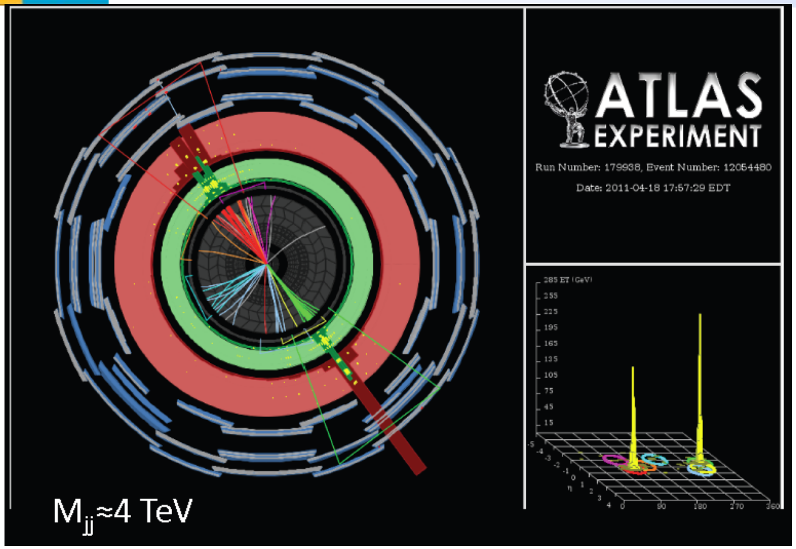
- **Several forward detectors**
  - LUCID, MBTS,ZDC
  - Luminosity measurement and forward physics

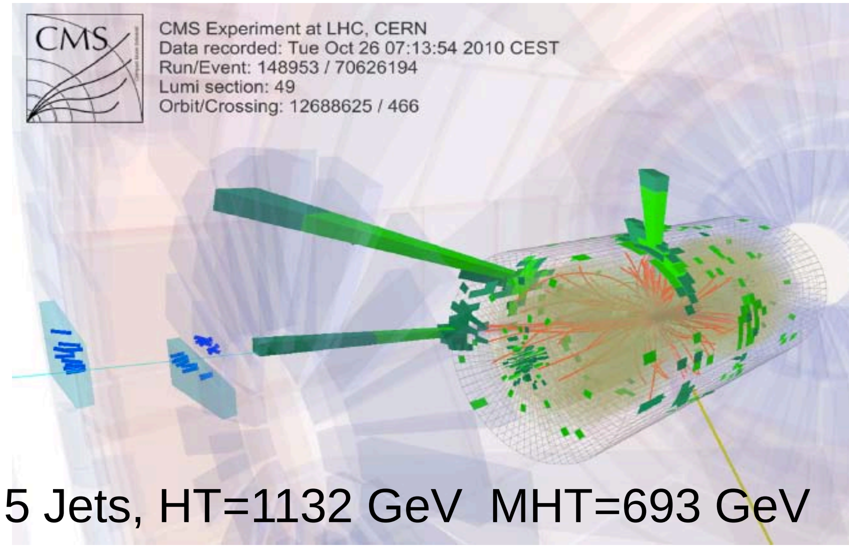
CMS

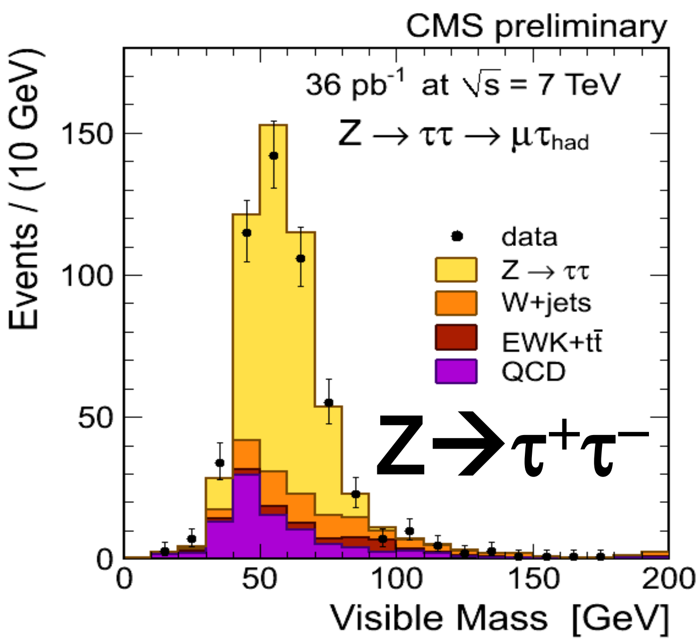


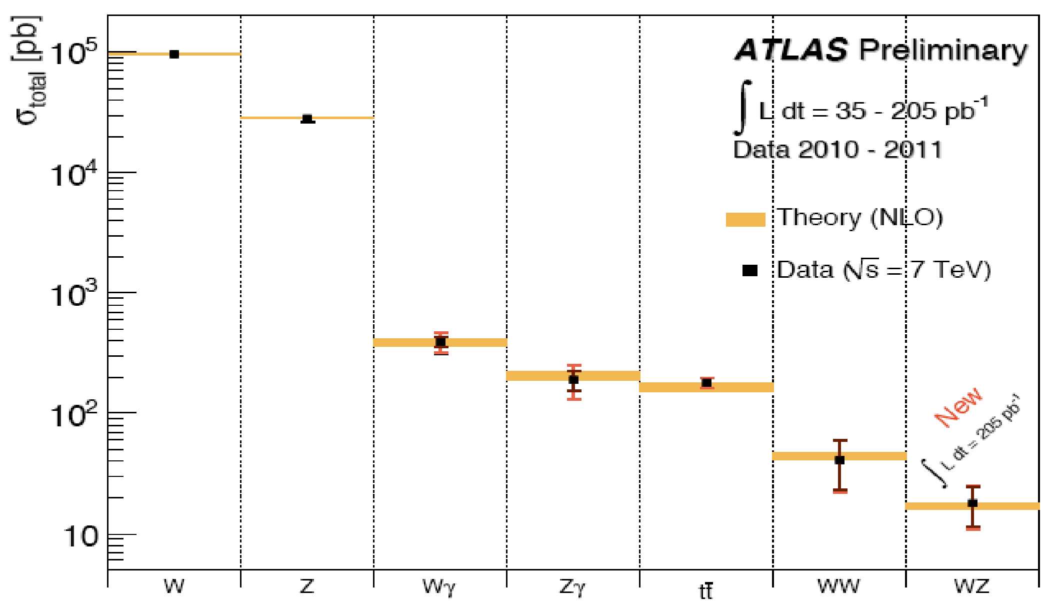
- **Excellent momentum and secondary vertex resolution provided by 200 m^2 all silicon tracker in 3.8 T B field**
- **High resolution PbWO4 crystal EM calorimeters (~ 0.5% @ E_T ~ 50 GeV) measures energy and position of electrons and photons**
- **Brass scintillator sampling hadronic calorimeters for jet energy measurements $\sigma(E)/E=100\%/\sqrt{E}+0.05$**
- **Muon spectrometer (+ tracker) identifies and measures muon momentum (dp/p<1% @ 100GeV and <10%@1 TeV)**
- **Neutrinos inferred through measurement of missing transverse energy**

ATLAS/CMS performance



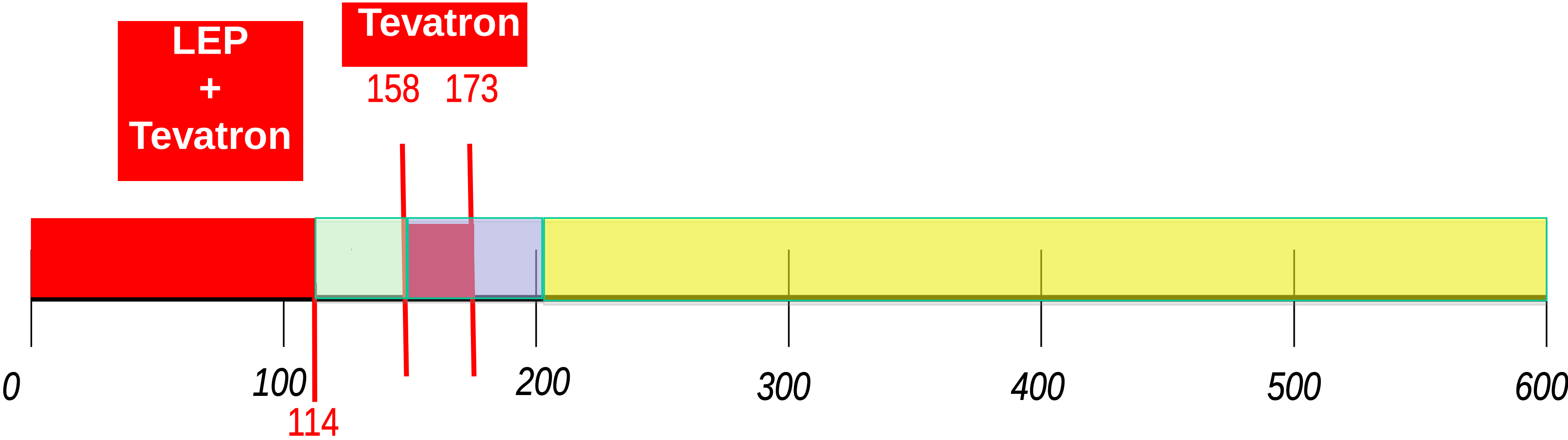






LHC Higgs Searches

95% CL Excluded Mass range



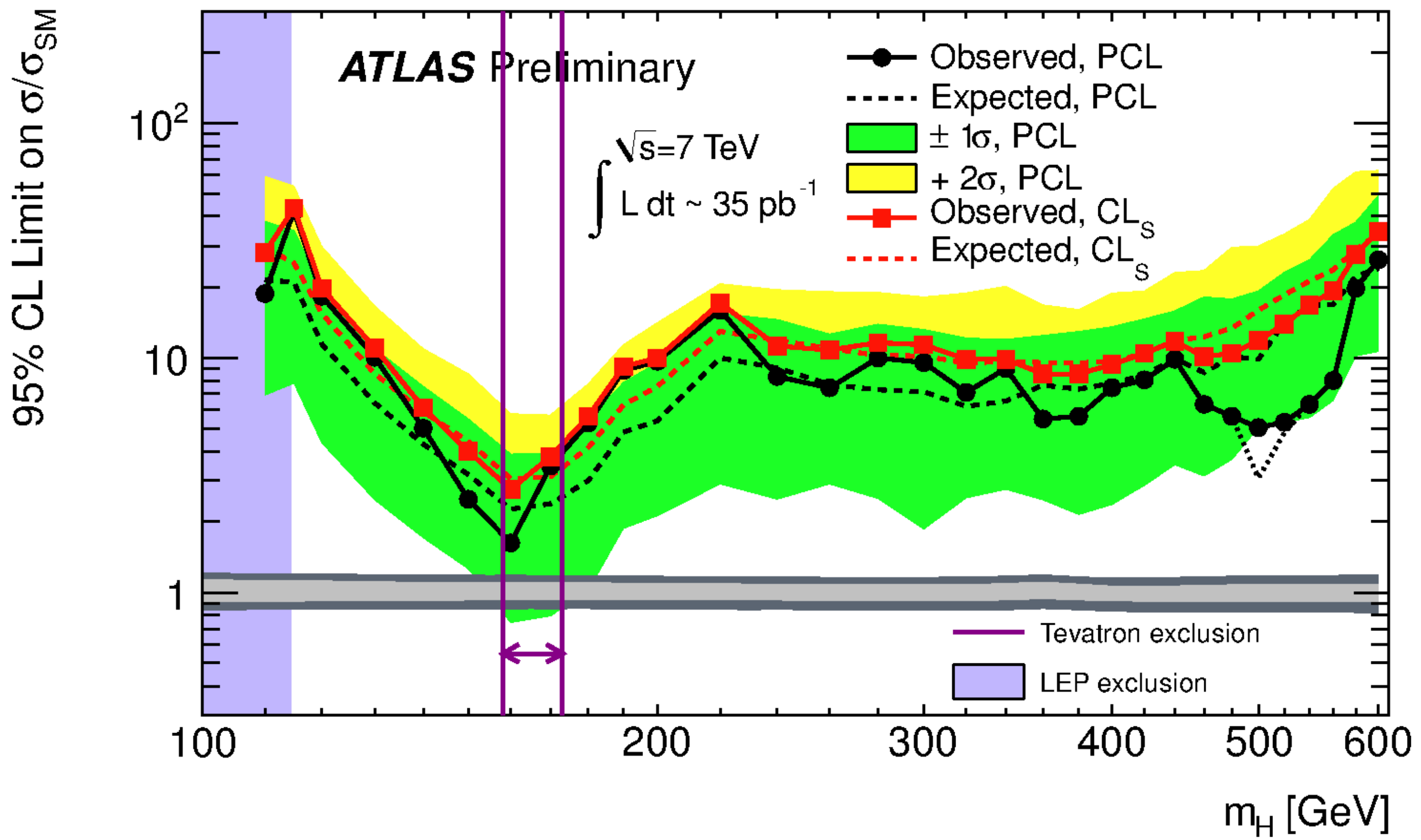
Low Mass
($M_H \approx$ 120 GeV)
$H \rightarrow \gamma\gamma$
$H \rightarrow WW$
$qqH \rightarrow \tau\tau$
$V + H \rightarrow bb$
$qqH \rightarrow bb$
$V + H \rightarrow WW$

Mid Mass
($M_H \approx$ 160 GeV)
$H \rightarrow WW$
$H \rightarrow ZZ$

High Mass
($M_H \approx$ 400 GeV)
$H \rightarrow ZZ$
$H \rightarrow WW$

Higgs Search Status

- **ATLAS/CMS are exploiting ALL decay channels accessible**
- **ATLAS/CMS are preparing to combine their results**
- **Updated results will be presented at EPS and Lepton Photon**



CMS/ATLAS Higgs Summary prospects

Higgs Boson, if it exists between masses of (114 - 600 GeV) will either be discovered or ruled out in

≈ next two years

→ Decided to run in 2011 and 2012

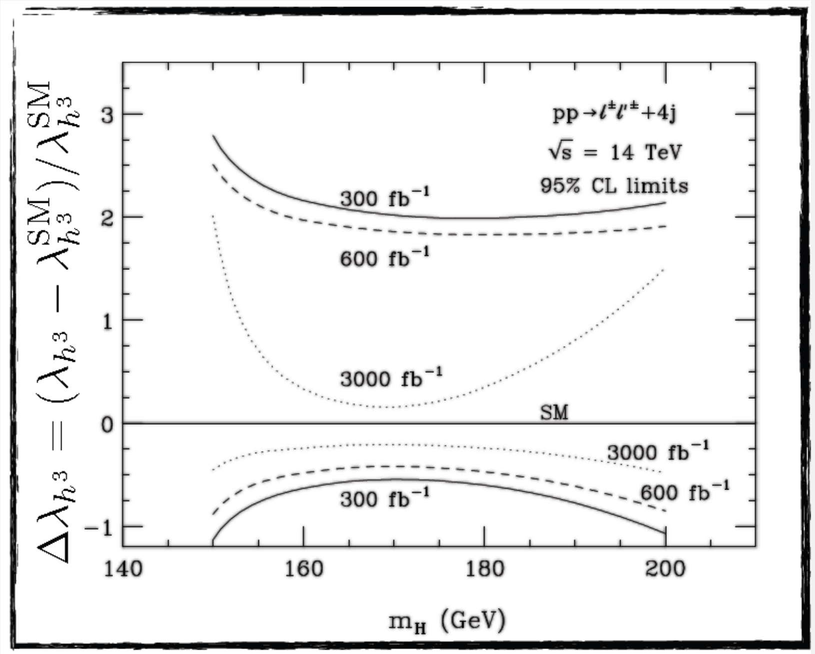
SM Higgs Search Prospects (Mass in GeV)			
ATLAS + CMS ≈ 2 x CMS	95% CL exclusion	3 σ sensitivity	5 σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535

Upgrade Physics Goals

More luminosity allows to move from exploration to precision studies

- Higgs physics
  - Higgs anomalous couplings to SM fermions and bosons
  - Higgs self-couplings
  - Rare Higgs decays; multi-Higgs (MSSM or not)
  - Dynamics of EW symmetry breaking
- Electroweak physics
  - anomalous gauge boson self-couplings
  - top quark flavor violating decays
- Supersymmetry
  - extend the mass gluino/squarks reach to 3 TeV.
- Extra dimensions, New forces

Example: Higgs self-coupling sensitivity



Luminosity upgraded LHC:

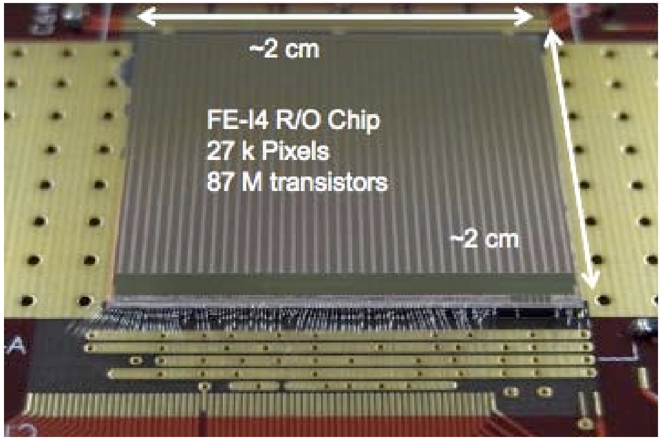
With 300 fb^{-1} λ_{h3}=0 can be excluded at 95% CL

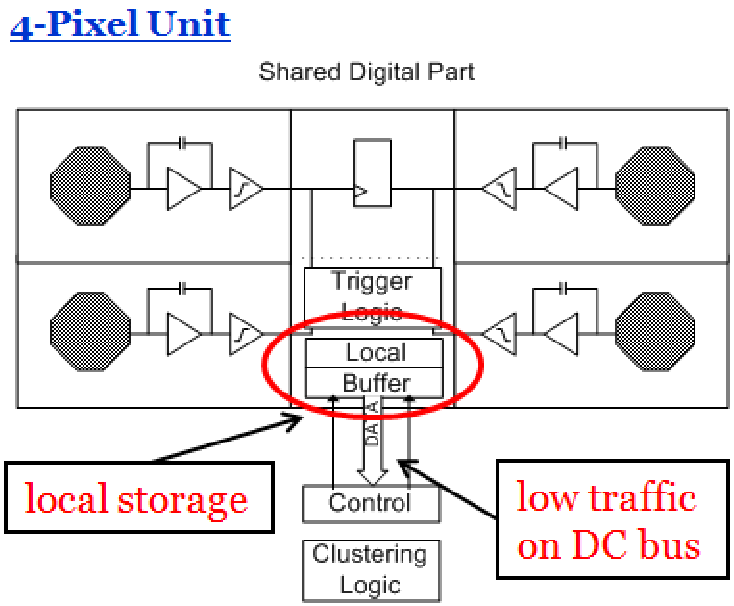
With 3000 fb^{-1} λ_{h3} can be determined to 20÷30%

Upgrade Work for ATLAS

- The US part of the ATLAS Upgrade effort has been supported by the US Operations Program for over 5 years.
  - FE-I4 New pixel frontend chip
    - Allows significant improvements in performance and cost reduction.
    - Key element of the pixel upgrade
  - New types of pixel and strip detectors for tracking applications.
  - New calorimeter electronics systems:
    - New frontend, ADC, and high speed data transmission chips.
    - Small feature size CMOS, SiGe bipolar, and Silicon-on-Sapphire technology.
  - New data collection and transmission components as well as use of the ATCA platform for higher bandwidth data collection.

New pixel readout chip of higher performance





Status of Planning for Phase 1 Upgrade

- **Definition of Phase 1: Detector improvements and additions that will be installed by the end of the first shutdown in 14 TeV running.** Includes some projects that are now planned to go in prior to any 14 TeV running, during the next long LHC shutdown.
- **ATLAS has appointed a sub-committee that will guide the production of an LOI, due by the end of the summer, for the Phase 1 Upgrade projects.** There are a number of high priority projects being planned, however, ATLAS still need to sharpen the physics case as well as better evaluate time schedules and available support levels for some of the projects. The next slides go over those that are far along. There are also two additional projects that are under discussion and development, which may end up part of Phase 1. These two, which have had significant support from the U.S. Upgrade R&D program, are:
  1) **Construction and installation of a replacement of the entire (3 layer) pixel detector. This is based on new technology that offers significantly better performance with much less mass in the detector.**
  2) **A possible phased plan for upgrading the calorimeter electronics. Would allow much more information from the calorimeter for triggering.**

ATLAS Phase 1 Upgrade Projects

- **IBL (Insertable B Layer)** an extra inner pixel layer at a radius of about 3 cm located entirely within the present detector. Participation in construction by 11 universities, LBNL, and SLAC. Improves rejection of light-quark jets by about a factor 2 for 60% b-jet efficiency. Significantly improves b-jet tagging performance at luminosities beyond design. Goal is to **insert this prior to any 14 TeV running**. (Phase 0)
- **FTK (FastTracKer)** a new tracking trigger that finds nearly all sufficiently stiff-tracks based on stored patterns, does a track parameter fit, and presents information to be used in the second level trigger. Major participation by Chicago, Illinois, Argonne, NIU and a subcontract to FNAL for engineering. Would vastly improve participation of charged particle tracking in the second level trigger and free up processing time in the second level trigger for dealing with the calorimeter and muon information.
- **A new inner wheel** of the forward muon coverage. Goal is to improve the forward muon trigger by reducing fakes. Participation in R&D on micromegas (candidate for chamber technology), readout electronics, alignment, and new Readout Drivers. US Institutions involved are BNL, Arizona, Brandeis, and SLAC.
- For **the Phase 1 L1Calo trigger** upgrade the plan is to add topological trigger algorithms, which allow using the correlation of jet directions in the Level 1 trigger. MSU and Argonne project. Goal is to have this **ready prior to 14 TeV running**. (Phase 0)

Enhanced Vertex Detection: IBL

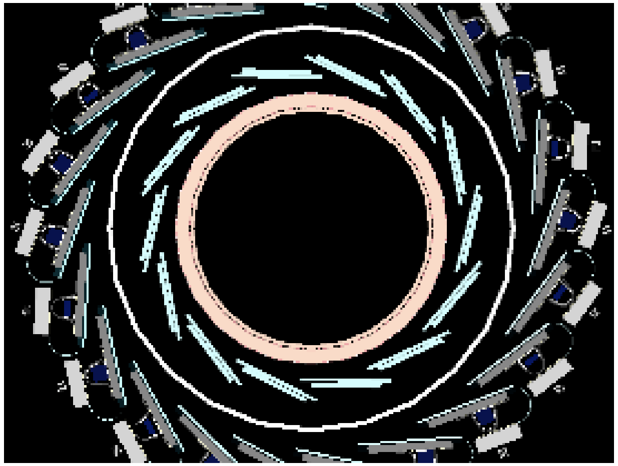
- Originally planned for Phase 1 now installation foreseen in 2013/2014
- IBL improves physics performance of the present Pixel Detector:
  - 3 pixel layers → 4 pixel layers
  - Decreases R/O inefficiencies at LHC ultimate luminosity and above (i.e. 3×10^{34} $cm^{-2}s^{-1}$).
  - Increase radiation hardness to 5×10^{15} 1MeV neutrons/cm^2

Current Detector

Final detector choice, based on beam and radiation tests expected in about 1 month: to allow construction on a tight time-table.

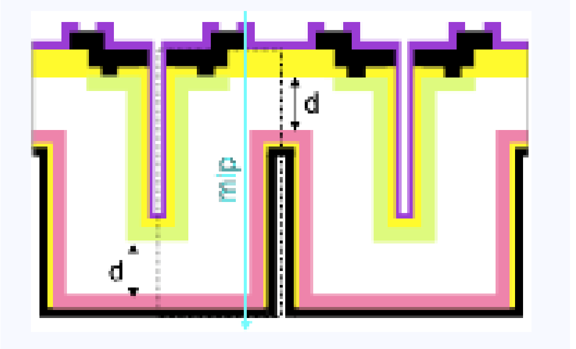
Choice between:

- Planar silicon sensor
- 3d silicon sensor
- Diamond sensor → postponed for future upgrade



IBL inside existing B-Layer.

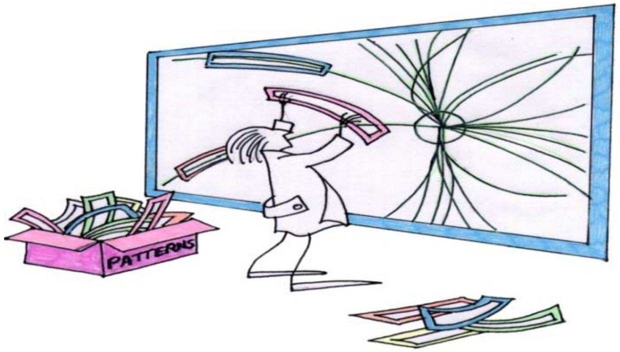
- New cooling system
- New beam pipe (steel → Al : reducing background in the muon detector),
- Repairs, improving reliability, …

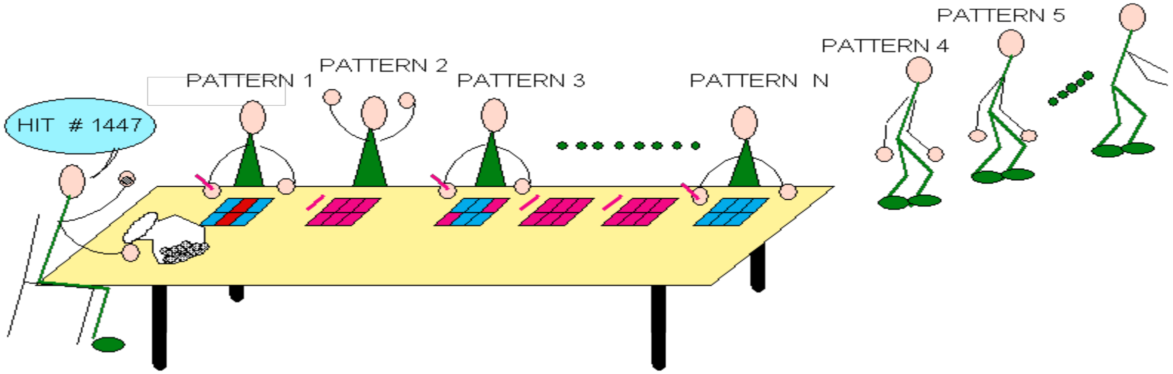


Double sided 3D sensor

FTK: Very Fast Execution of Two Time-Consuming Stages in Tracking.

- **Pattern recognition – find track candidates with enough Si hits.**



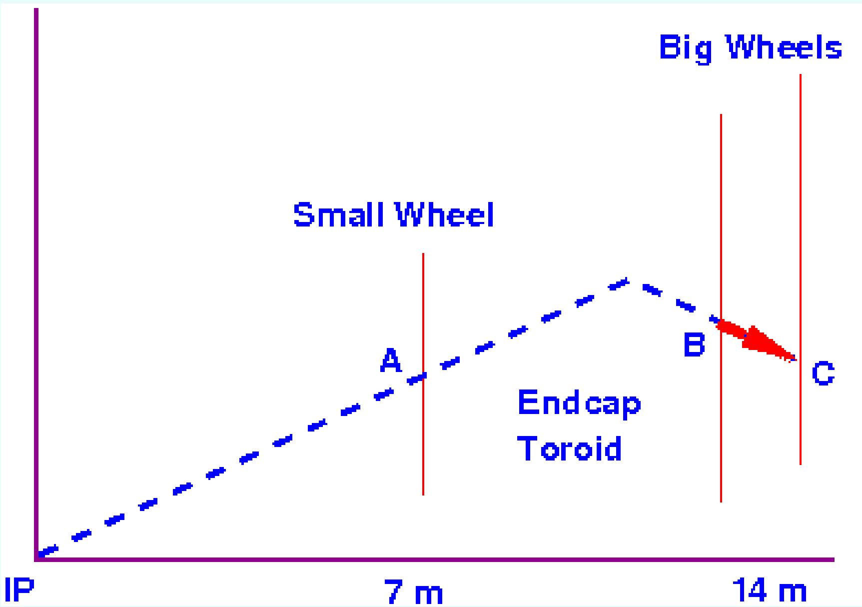


  - **10^9 prestored patterns used in FTK, simultaneously see each silicon hit leaving the detector at full speed.**
- **Track fitting – precise helix parameter & χ^2 determination.**
  - **Equations linear in the 14 local hit coordinates give near offline resolution, using pre-stored constants *a* & *b*. VERY fast in FPGA.**

$$p_i = \sum_{j=1}^{14} a_{ij} x_j + b_i$$

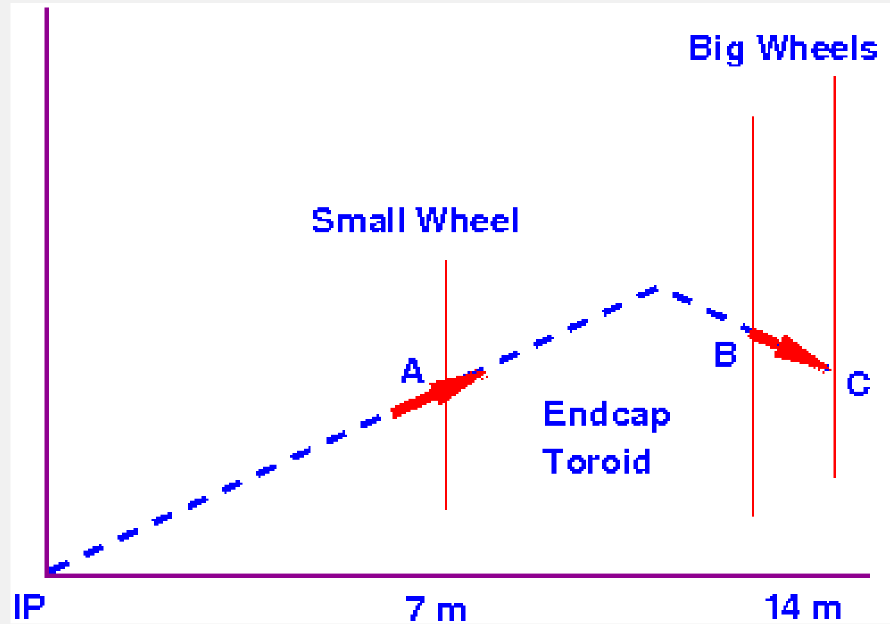
A U.S., Italian, Japanese collaboration with work in progress.

Improving the Forward Muon System



Current Endcap Trigger

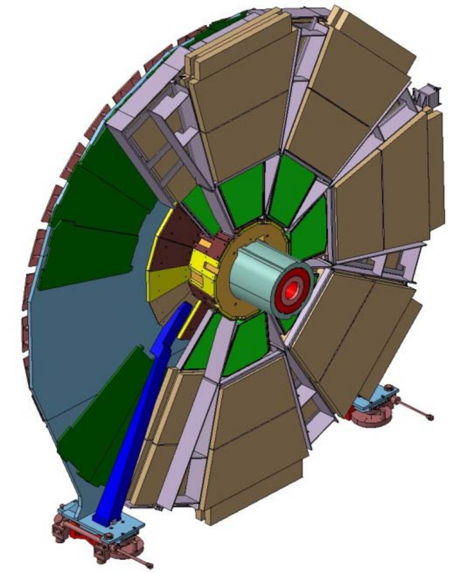
- Only a vector **BC** at the Big Wheels is measured
- Momentum defined by assumption that track originated at IP
- Random background tracks can easily fake this



Proposed Trigger – Phase 1 Upgrade

- Provide vector **A** at Small Wheel
- Powerful constraint for real tracks
- With pointing resolution of ~1 mrad it will also improve p_T resolution
- Currently 96% of High p_T triggers have no track associated with them in small wheel

New small wheel : candidate technologies



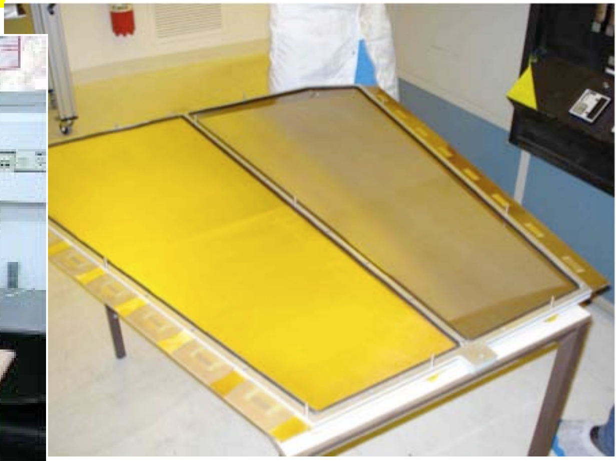
Small tube

15 mm tube : much shorter drift time. works at x7 rate

Fine strip Thin Gap Chambers

- **Fine strip analog readout.**
- **Position resolution 60 μm**
- **Used for precision tracking and L1 trigger.**

Large Micromegas



- **Success of resistive anode ensuring stability at high rate.**
- **Used for precision tracking and L1 trigger.**

CMS Requirements for the upgrades in 2010-2020

LS= Long Shutdown
TS= Technical stop

- The CMS Upgrade plan is documented in the **Technical Proposal** submitted to the LHCC in November 2010

CMS U1TDR
2010/11/15

2010/11/15
Head Id: 16688
Archive Id: 0:21642M
Archive Date: 2010/08/31
Archive Tag: trunk

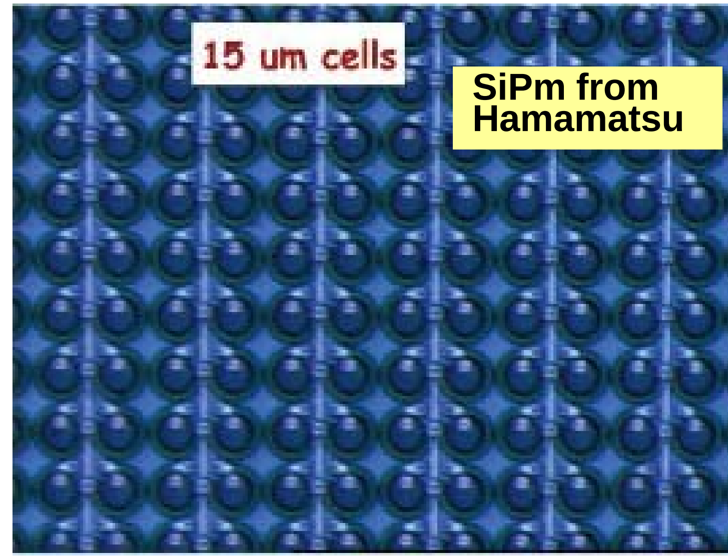
TECHNICAL PROPOSAL FOR THE UPGRADE OF THE CMS DETECTOR THROUGH 2020

System	2010-2020	
Pixel	**New Pixel Detector**	**LS2 or TS ~2017**
Tracker	FEDs?	
HCAL	**Electronics + PD replacement**	**HO - LS1** **HB/HE - LS2 or TS ~ 2017**
ECAL	TP (Off Detector Electronics) ?	
Muons	**ME4/2, ME1/1** ,RPC endcap, Minicrate spares, some CSC Electronics	**LS1**
Trigger	**HCAL/RCT/GCT to μTCA**	**LS2 or TS~ 2017**

LHCC has recommended CMS to proceed to the TDR

CMS phase 1 deliverables

- The US part of the CMS Upgrade effort has been supported by the US Operations Program for about 4 years.
  - Tracking systems
    - Ultra low mass mechanics
    - Development of CO_2 cooling
  - New calorimeter electronics systems:
    - Radiation Hard SiPm
    - New QIE with increased dynamic range/resolution and TDC output
    - Digital data transmitted using new CERN GBT serial data link
  - Development of the microTCA platform for higher bandwidth data collection.

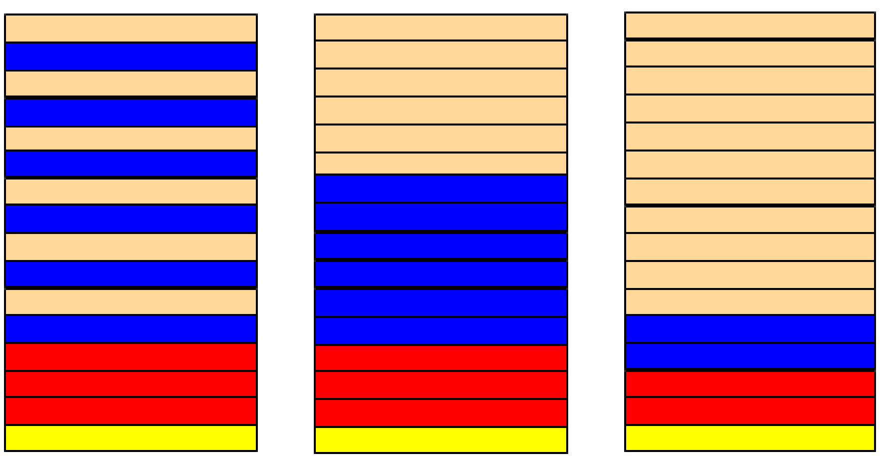


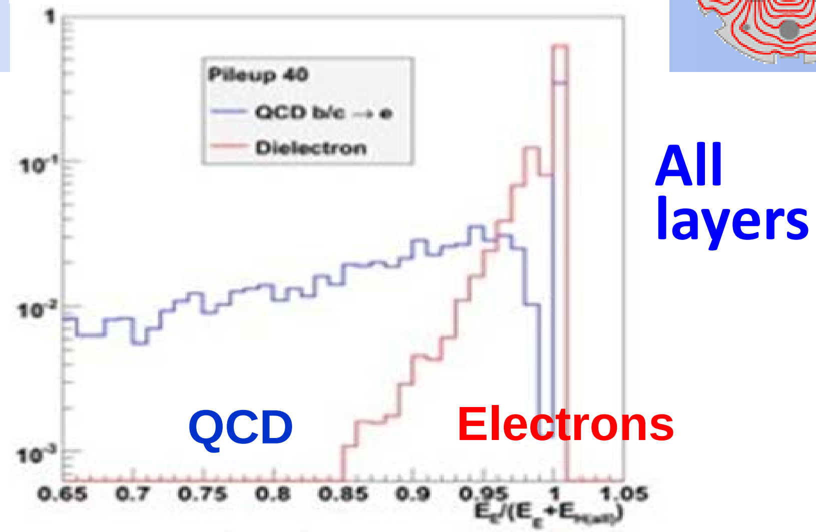
MicroTCA card

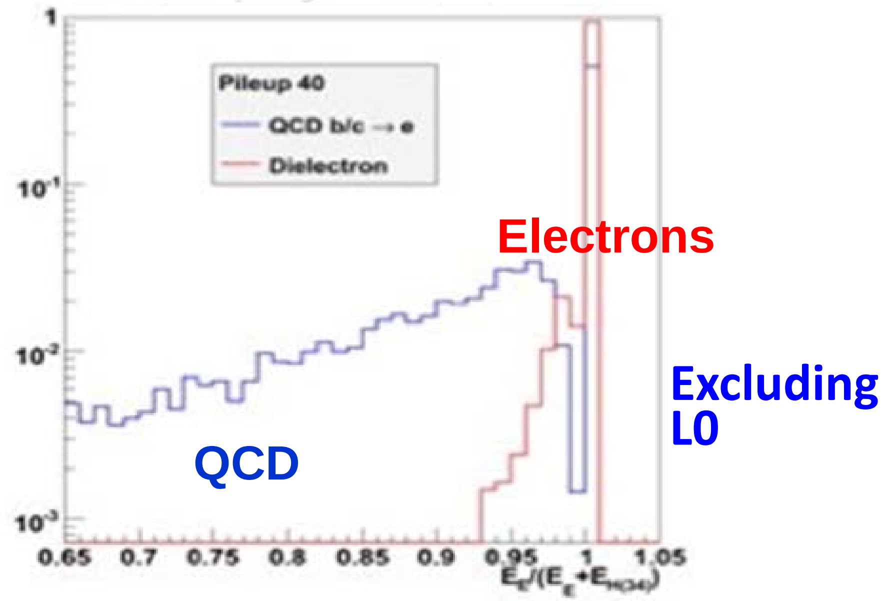
HCAL upgrade

40 pileup events = 1E34 and 50 ns spacing

- **Replace HPD with higher performance SiPM in HB/HE**
- **Compact size of SiPMs allows depth segmentation in HB/HE**
  - **Redundancy for non-BX signals &channel failure**
  - **Reweighting of inner layer to:**
    - **Mitigate rad damage**
    - **Improve electron isolation**



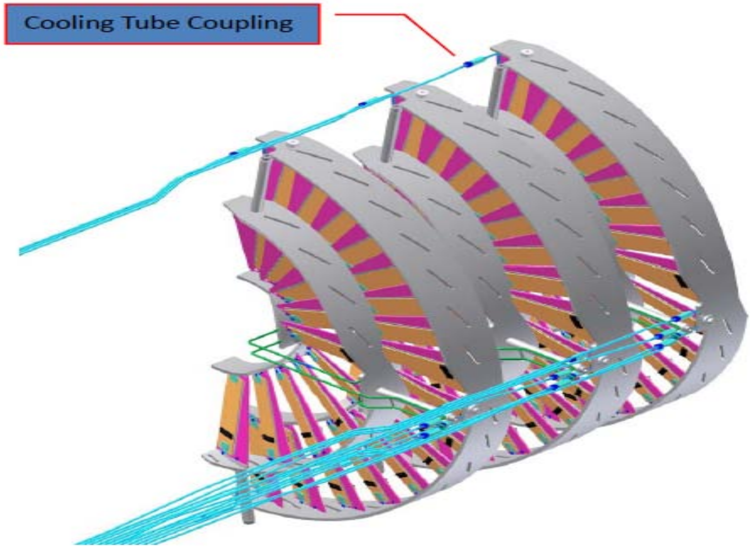


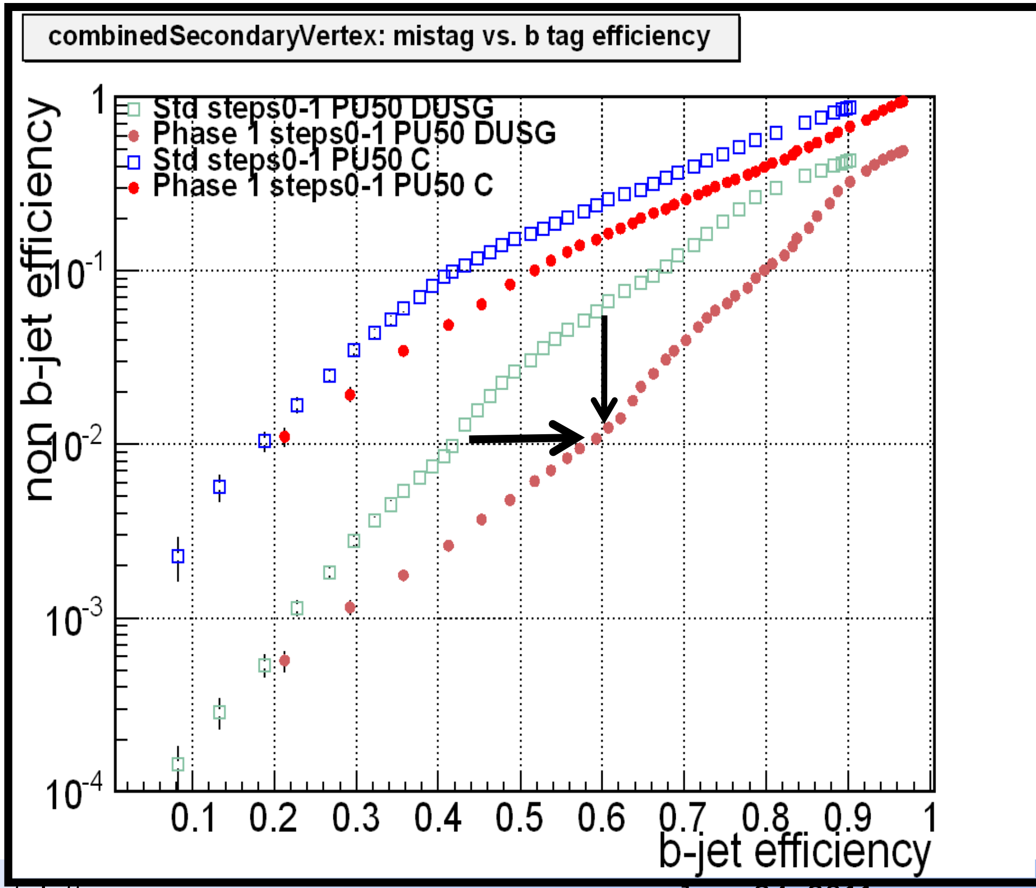


- **Isolation of electrons and photons $E_{ECAL}/(E_{ECAL}+E_{HCAL})$ is impacted by pileup in Layer-0.**

Ultra-low mass Pixel detector

- **A 4 barrel layers and 3 endcap disks at each end**
- **Readout-chip with expanded buffers, embedded digitization, and high speed data link**
- **CO_2 two-phase cooling and displaced optical transceivers**

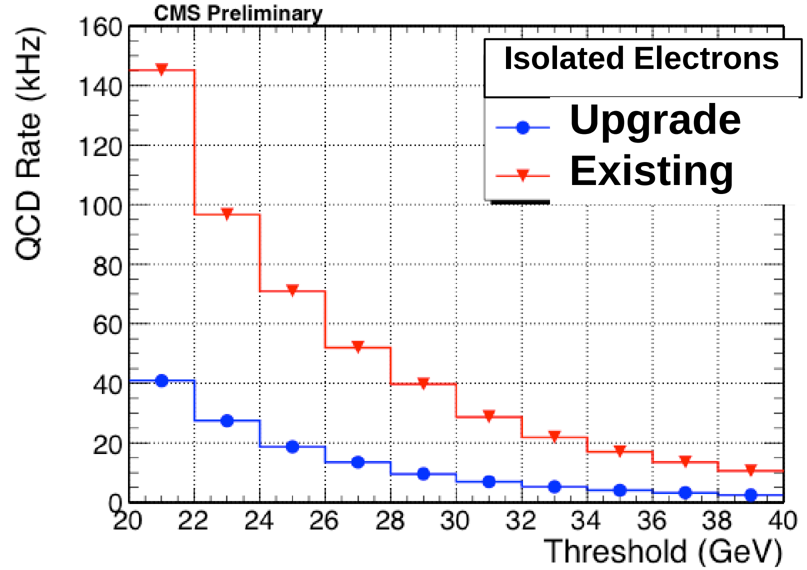


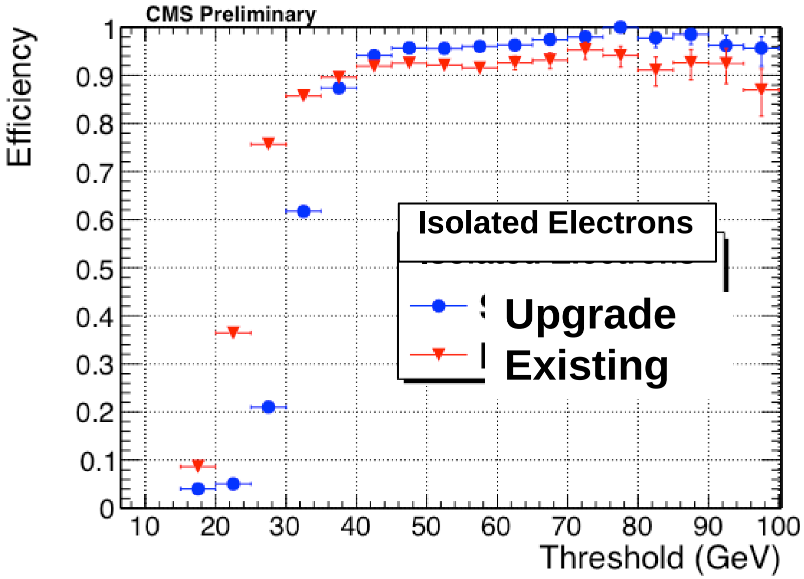


Material reduction by a factor of 2-3 leads to a b-tagging increases from 42% to 60% for 10^{-2} fake rate.

CMS Trigger Upgrade

- Constraints
  - Output rate at 100 kHz
  - Input rate increases x 2 over LHC design (10^{34}) and number of interactions in a crossing (Pileup) goes up by x4 at 50 ns
  - Present L1 algorithms inadequate above 10^{34}
    - Pileup degrades object isolation
- Strategy for Phase 1 Calorimeter
  - Use full granularity of calorimeter trigger information
  - **Phase in microTCA architecture** for higher bandwidth data collection
  - **Rely on powerful modern FPGAs** with huge processing & I/O capability to implement more sophisticated algorithms
- Achieve factor of 2 reduction in rate as shown with initial L1 Trigger studies.





Phase 2 ATLAS and CMS upgrades

- The goal of phase 2 is to achieve 3000/fb integrating ~300/fb-yr
  - Requires new tracking detectors since the current trackers designed for 500-700 fb^{-1}
  - Tracking information might be needed at the first trigger level to maintain the necessary trigger threshold for physics
  - Replacement/Upgrade of Endcap calorimeters might be necessary
- Substantial R/D required for the detectors to be able to operate at these higher luminosities and to provide trigger information
  - Longer term R&D items with the potential for significant impact have formed the basis of proposals submitted by US-ATLAS and US-CMS to the generic R&D program announced by DOE in January 2011.
  - Critical Phase 2 R&D has been included as an appendix to the CMS upgrade Technical Proposal
- Massive/ Difficult projects
  - The construction of large trackers (~ 200 m^2) for ATLAS and CMS will require at least 5 years once the R&D is finalized and therefore R&D must be supported now

New Phase 2 trackers

- ATLAS/ CMS New trackers for phase-2
  - All silicon strip + pixel (like the current CMS tracker) with higher granularity to keep occupancy low
  - Improved material budget
- New technologies:
  - New electronics for lower power consumption
  - New cooling and support structure for reducing materials
- R&D is ongoing in all areas
  - Readout chips
  - Module integration
  - Cooling/ Powering
  - Layout and physics performance
  - Triggering

Evaporative CO_2 cooling
- large latent heat
- good heat transfer
- allowing smaller cooling pipes (material budget)

New powering schemes;
- DC-DC convertors
- Serial powering

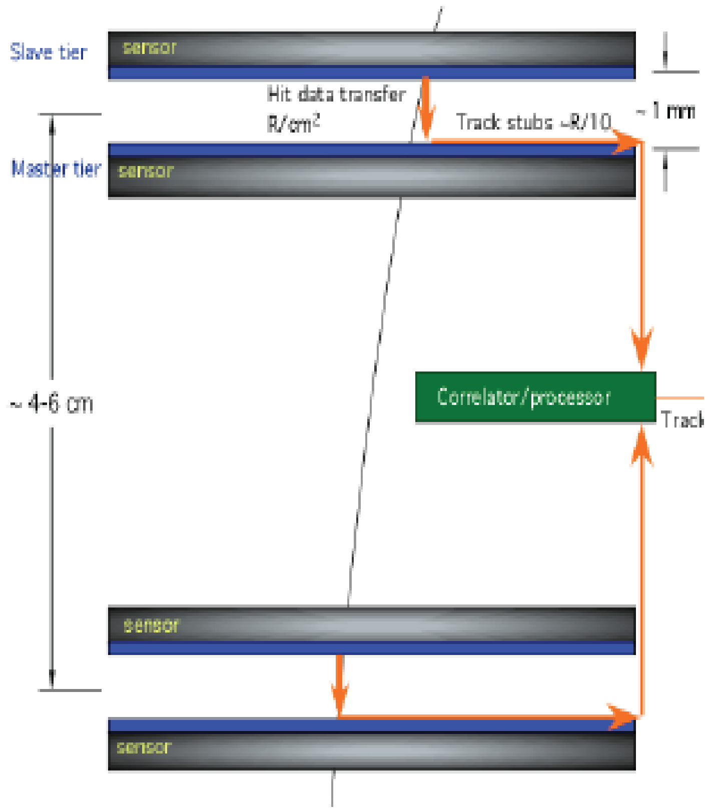
being successfully tested

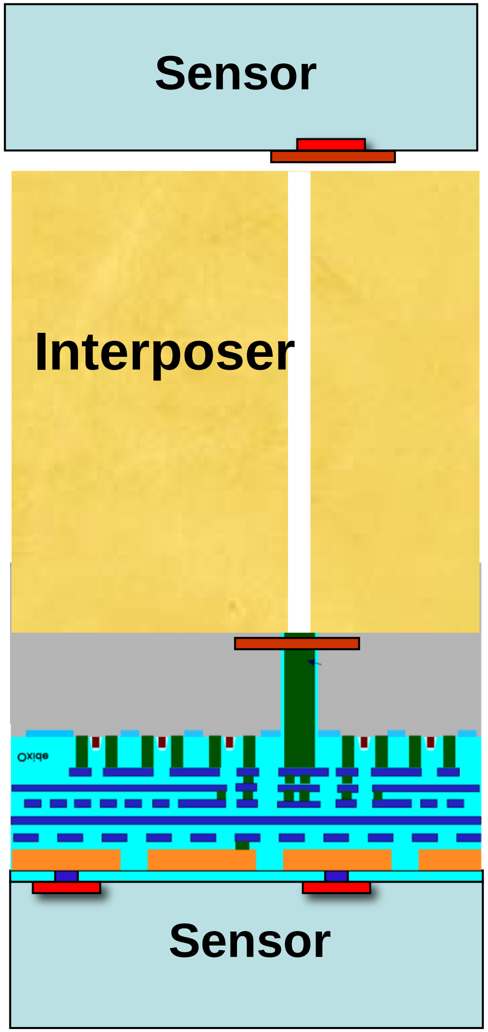
Novel Module integration concepts
- Vertically integrated sensors and readout chips
- Stave and other mechanical module design
- High-speed fault-tolerant integrated circuits
- Low mass bump bonded interposer
- Large area arrays

CMS Track trigger development

Vertically integrated sensors and readout chips

- Stack of two detectors separated ≈1mm in r
- Correlate hit information from both sensors on the detector
- Reject hits that do not have a match in the other detector, consistent with p_T>threshold
- Move selected hits to off-detector processor





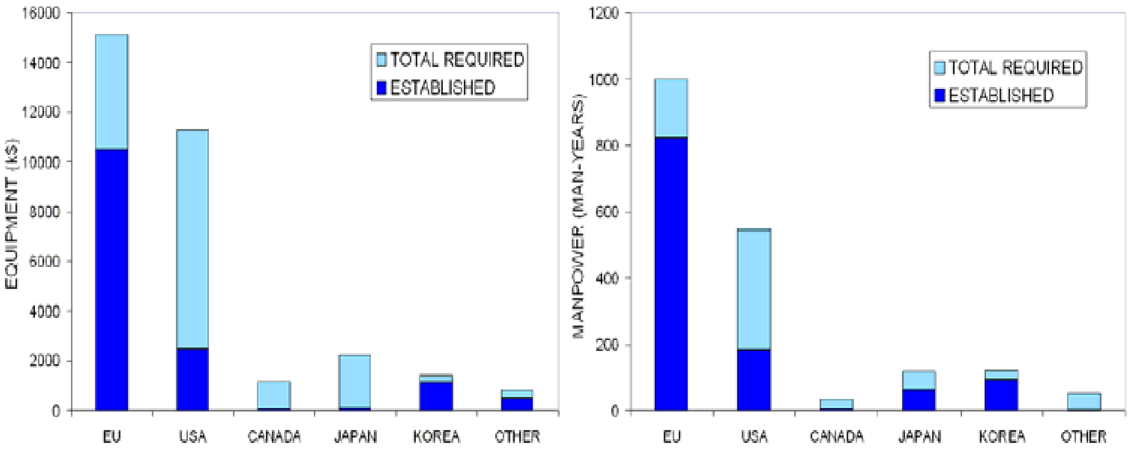
- **techniques being developed by industry**
- **collaborate with industrial partners**

R&D funding in the US

- The generic R&D program announced by DOE in January 2011 could play a critical role in enabling the participation of US laboratories and universities in the truly innovative R&D required for the LHC phase 2 detectors
- Even if the funding outlook in the US is challenging the LHC and its upgrades will dominate the exploration of the energy frontier for this and the next decade and therefore US participation is critical
- The lack of funding in FY11 for this new DOE program and the uncertainties for FY12 endanger our progress, create uncertainties with our international partners, and further weaken detector R&D in the US which is historically poorly funded

ILC Detector Research and Development

Status Report and Urgent Requirements for Funding (2006)



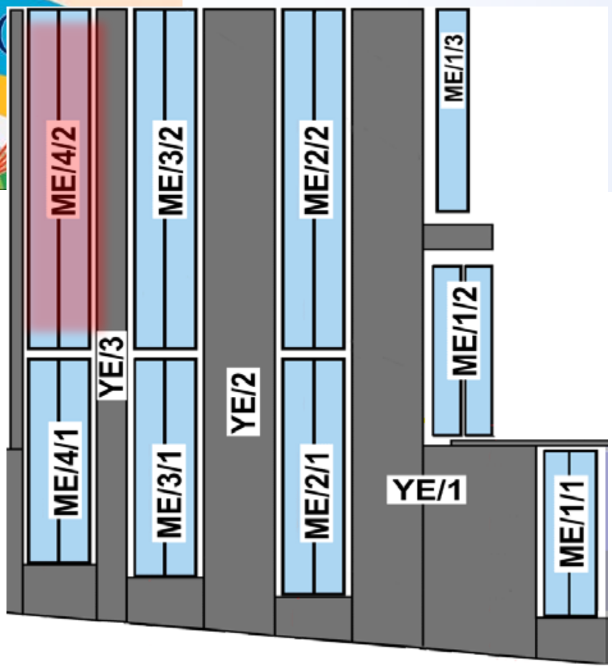
	USA	EU
GDP in T$	14.58	16.41

Summary

- **LHC and its experiments are performing extremely well**
  - We are ready for discoveries!!
- **Phase 1 Upgrade plans are well developed**
  - Upgrade plans were presented at the LHCC and were very positively received
  - CMS and LHCb are now working on TDRs.
  - ATLAS has already developed TDR for parts of the Phase 1 upgrade and it now preparing a Phase 1 LOI
- **Phase 1 installation timeline**
  - ATLAS upgrades will be installed during the first LHC and the second LHC shutdown
  - CMS expects to install upgrades/improvements in the first and the second LHC shutdown or in technical stops before the second shutdown
  - The LHCb upgrade is scheduled for the second LHC shutdown
  - **A clear funding plan for the US to participate in the construction of the Phase 1 upgrades must be developed ASAP**
- **R&D for Phase 2 is in a critical stage and requires funding continuity.** The role of the generic R&D program in the Phase 2 R&D should be clarified.

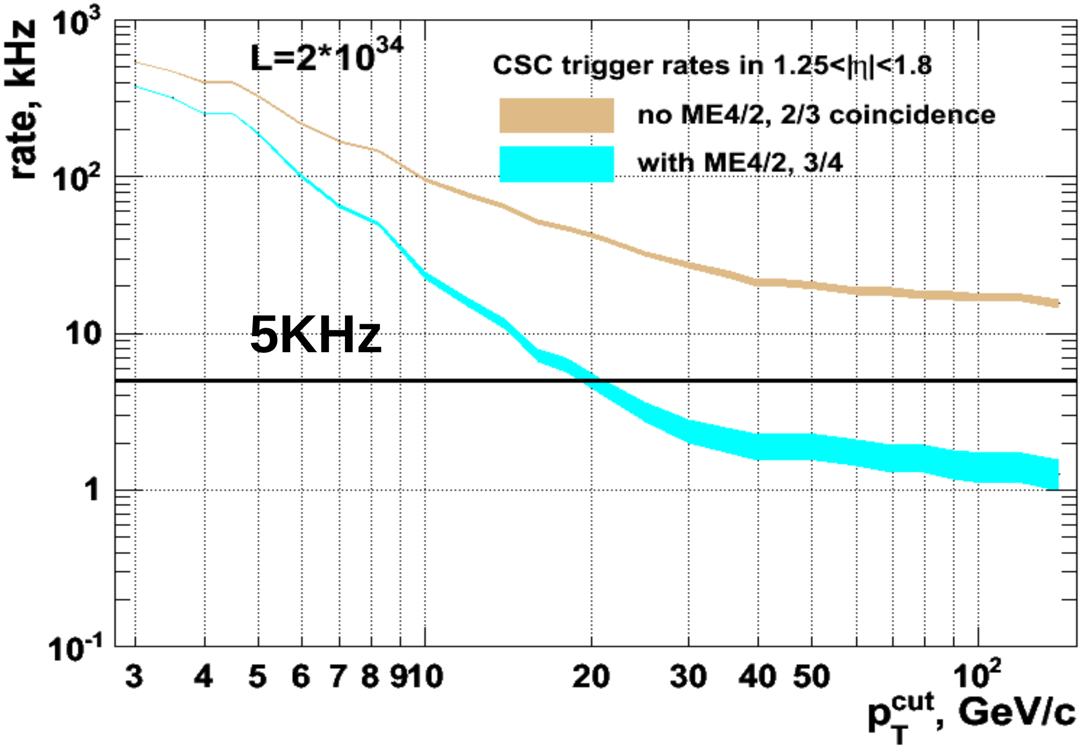
•BACKUP

CMS CSC Muon Upgrade



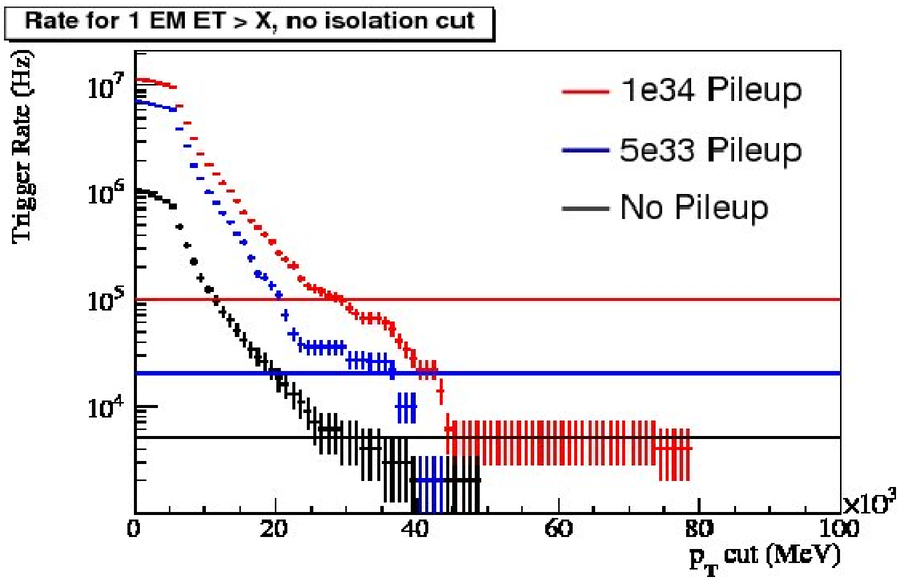
- **Present System:** **473 Cathode Strip Chambers covering both endcaps**
- **Proposed Upgrade: Complete the 4th station**
- **Muon Trigger robustness in 1.2<|η|<1.8**

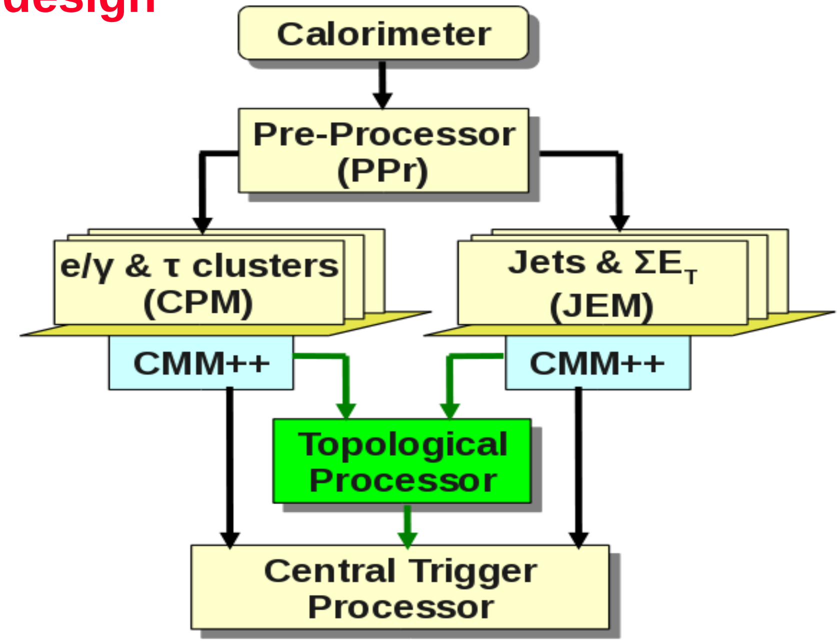
5 chambers already installed



L1Calo Upgrade: Ready Early Like IBL

- **L1Calo compromised as lumi exceeds design**





$L = 10^{34}$	2-jet: $E_T > 35$ GeV	+ $\Delta\Phi < 2.5$
Rate	35 kHz	9 kHz

- **Topological Triggers include more information about jets for multi-jet events (column to the right), helps reduce rates and allows keeping additional data.**

– **Existing Trigger (yellow)**

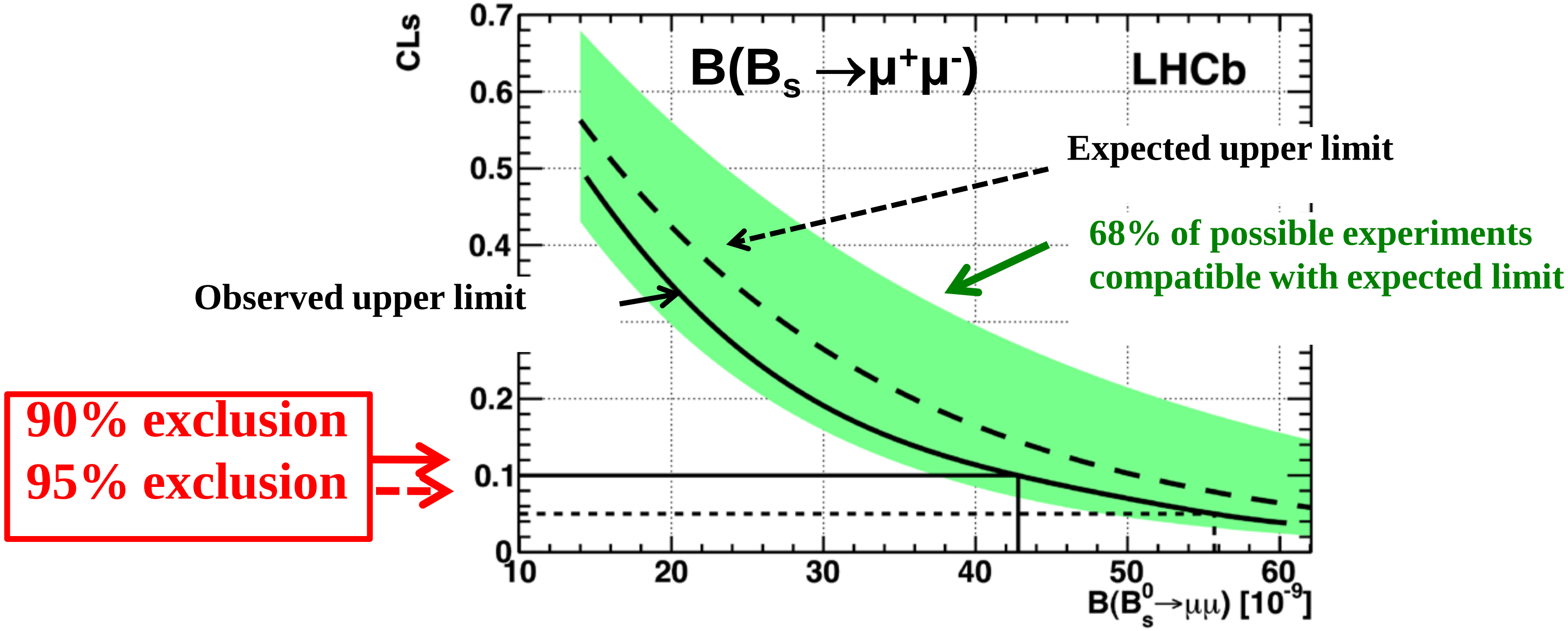
– **40 → 160 MHz bus speed to be implemented, new firmware (gold)**

– **CMM → CMM++ (blue)**

– **Topological Processor (green)**

U.S role. – CMM++ modules in this international project.

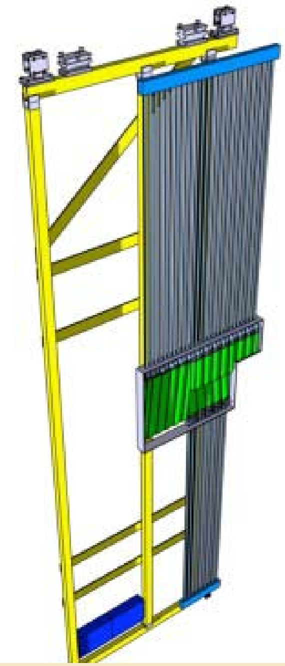
LHCb prospects

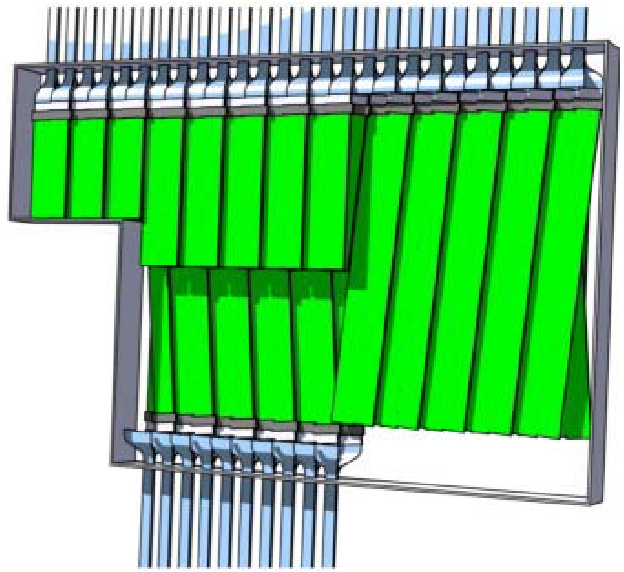


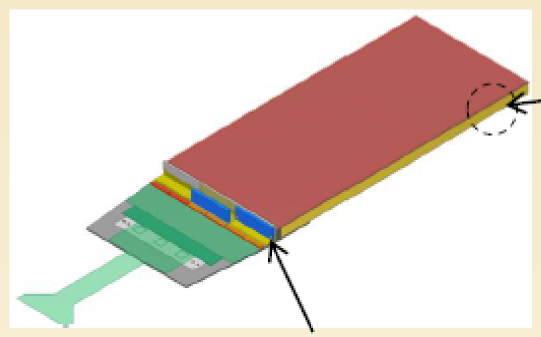
	B($B_s \to \mu^+\mu^-$)	@ 90% CL	@ 95% CL
LHCb	Today, 37 pb^{-1}	< 43 $\times 10^{-9}$	< 56 $\times 10^{-9}$
D0	World best, 6.1 fb^{-1} PLB 693 539 (2010)	< 42 $\times 10^{-9}$	< 51 $\times 10^{-9}$
CDF	Preliminary, 3.7 fb^{-1} Note 9892	< 36 $\times 10^{-9}$	< 43 $\times 10^{-9}$

Main Tracker upgrade: OT, IT, TT

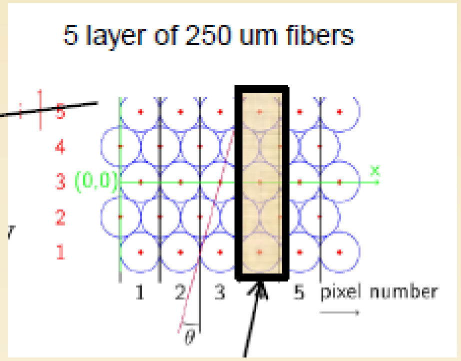
- IT and TT detectors must be replaced: (1 MHz electronics integrated)
- Two options:
  - Silicon strips (current technology, but R/O outside acceptance?)
  - 250 µm Scintillating Fiber Tracker (new technology)
- R&D started:
  - 250µm scint. fibres (8 layers)
  - fibres coupled to SiPM
  - SiPM radiation tolerance?
  - ASIC investigation started







SiPM array

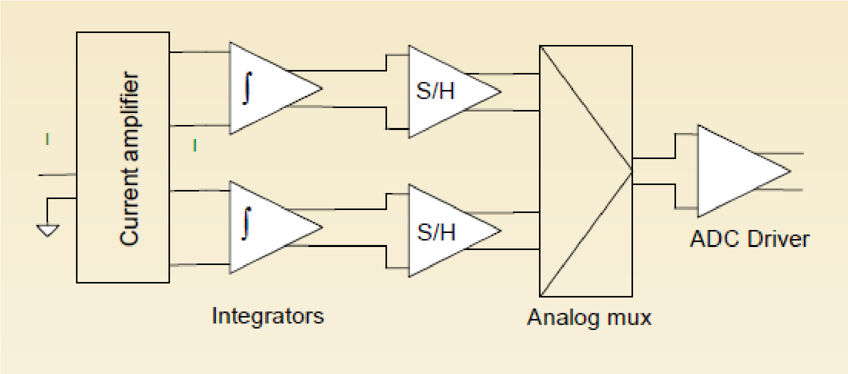


SiPM cell coverage

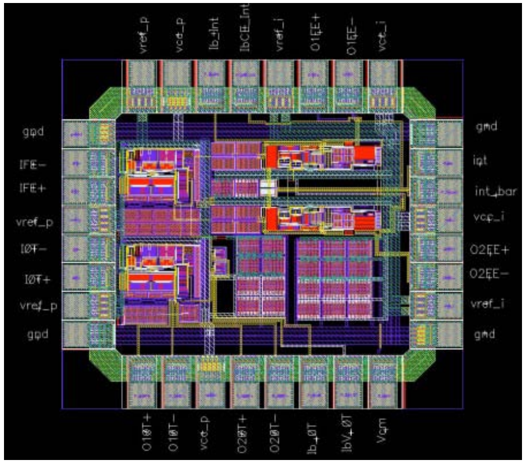
Calorimeters upgrade

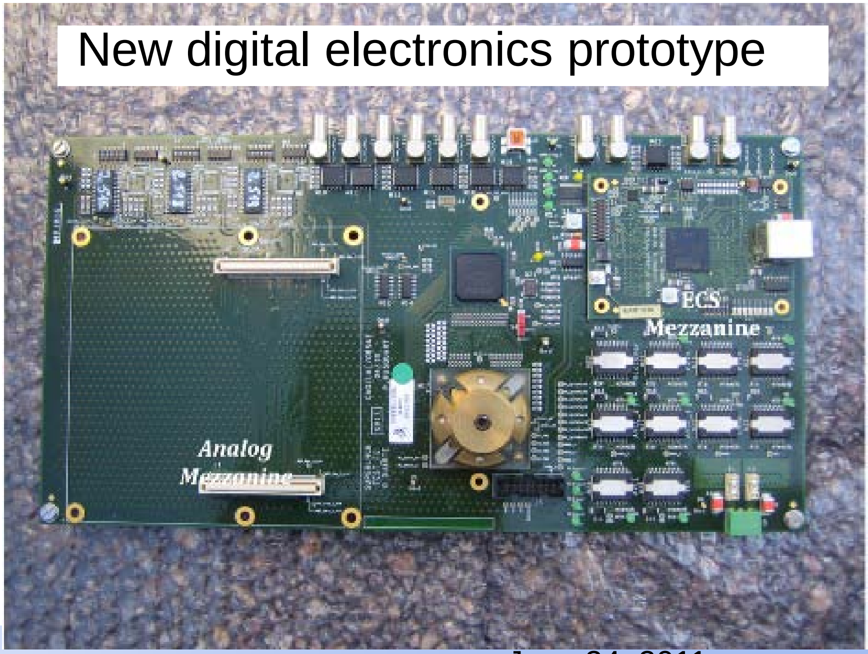
- ECAL and HCAL are maintained
  - keep all modules & photomultipliers
  - reduce PM gain in upgrade
  - PS and SPD might be removed
  - e/γ separation provided by tracker
  - Front End electronics modified for lower yield and to allow 40 MHz readout
- PMT gain reduction:
  - reduce electronics noise
  - active termination in ASIC

Interleaved integrators



ASIC prototype

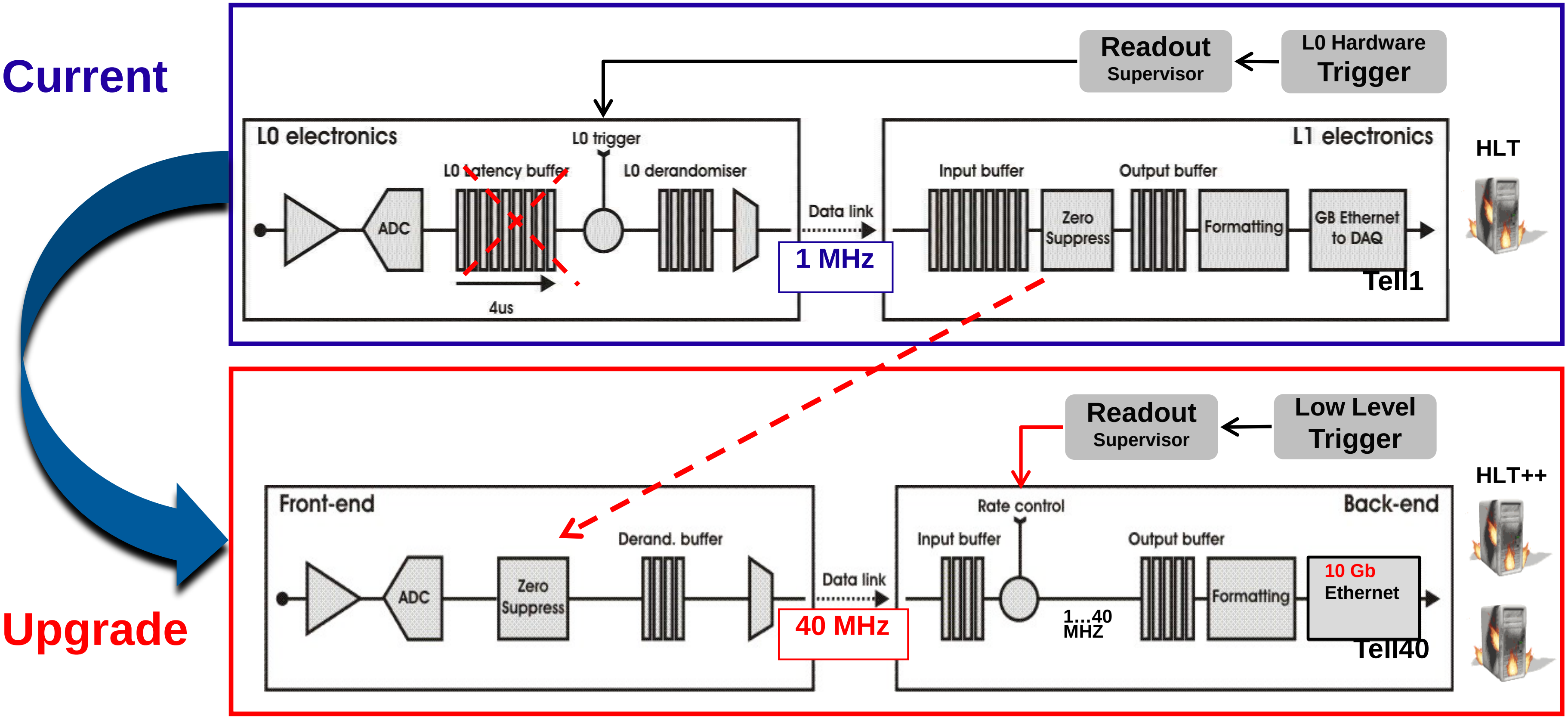




Common DAQ architecture

Current

Upgrade

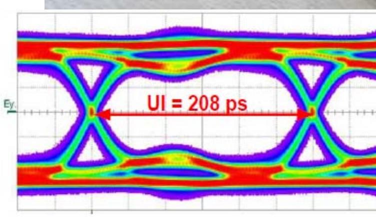


- Front-end electronics should:
  - ➢ Transmit collision data @ 40 MHz
  - ➢ Zero-suppress to minimize data bandwidth
- The L0 hardware trigger is re-used to reduce the event rate to match the installed router and CPU farm capacity (staging). Initially run at 5~10 MHz

Common developments

TELL40: Common Back-End readout module:

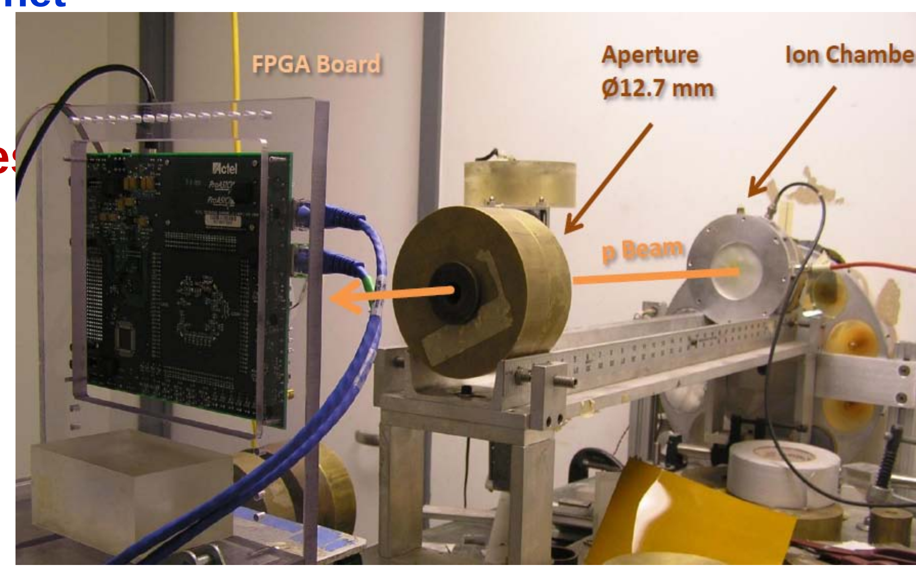
- Modular mezzanine-based approach (diff tasks)
- Processing in FPGAs
- Format: Advanced-TCA motherboard
- Tests of high-speed links on proto-board: 12-way Optical I/Os (12 x > 4.8 Gb/s), GBT compatible
- 24 channels/mezzanine ➔ up to 96/BE module
- Transmission to the DAQ using 10 Gb Ethernet



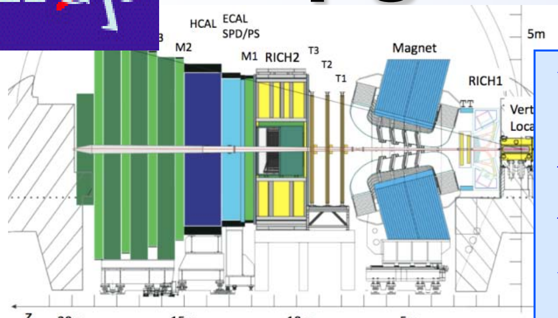
Eye-diagram from one channel @ 4.8 Gbit/s

ACTEL Flash FPGA for front-end modules

- Advantages over ASICs: re-programmable,
  faster development time.
- Can they survive the radiation?
- Irradiation program started on A3PE1500
  - Preliminary results up to 30 krad ok.



Upgrade LHCb Trigger



- ✓ flexible software trigger with up to 40 MHz input rate and 20 kHz output rate
- ✓ trigger has all the event information
- ✓ runs in a stageable Event Filter Farm
- ✓ run at 5 times LHCb luminosity (→ $L = 10^{33}\ cm^{-2}s^{-1}$)
- ➢ **Big gain in signal efficiency with up to factor 7 for hadronic modes**

40 MHz

Calorimeters
Muon

Low Level Trigger

p_T of h, μ, e/γ

LLT custom electronics

1 - 40 MHz

HLT

tracking and vertexing
p_T and impact parameter cuts
inclusive/exclusive selections

CPU
Event Filter Farm

20 kHz

Signal efficiencies

LLT-rate (MHz)	1	5	10
$B_s \to \phi\phi$	0.12	0.51	0.82
$B^0 \to K^*\mu\mu$	0.36	0.89	0.97
$B_s \to \phi\gamma$	0.39	0.92	1.00

EFF size*	5×2011	10×2011
LLT-rate (MHz)	5.1	10.5
HLT1-rate (kHz)	270	570
HLT2-rate (kHz)	16	26
Total signal efficiency		
$B_s \to \phi\phi$	0.29	0.50
$B^0 \to K^*\mu\mu$	0.75	0.85
$B_s \to \phi\gamma$	0.43	0.53

* Size of the Event Filter Farm available for the 2011 run