Physics with the CMS forward CASTOR calorimeter

For the CMS Collaboration

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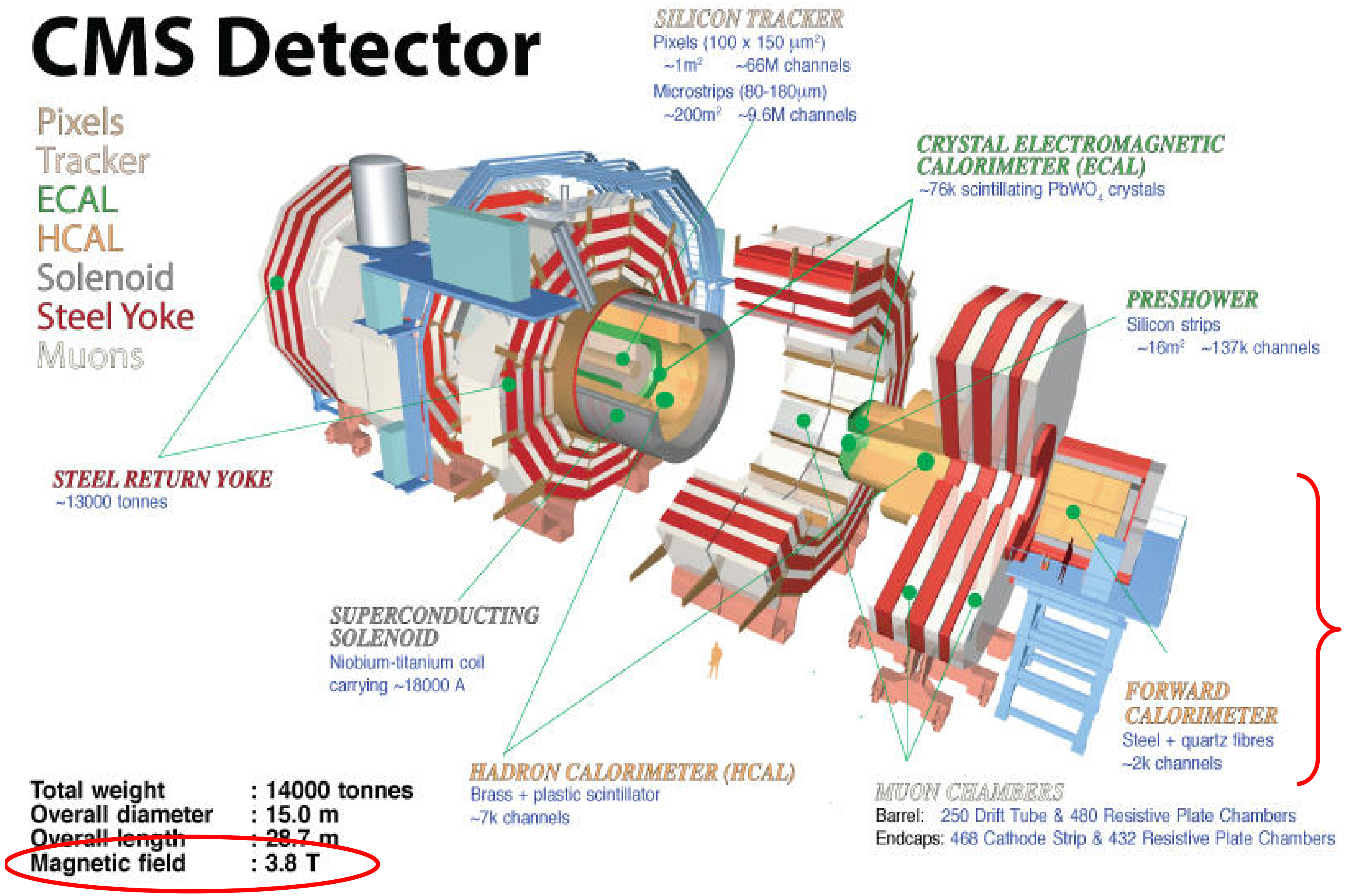
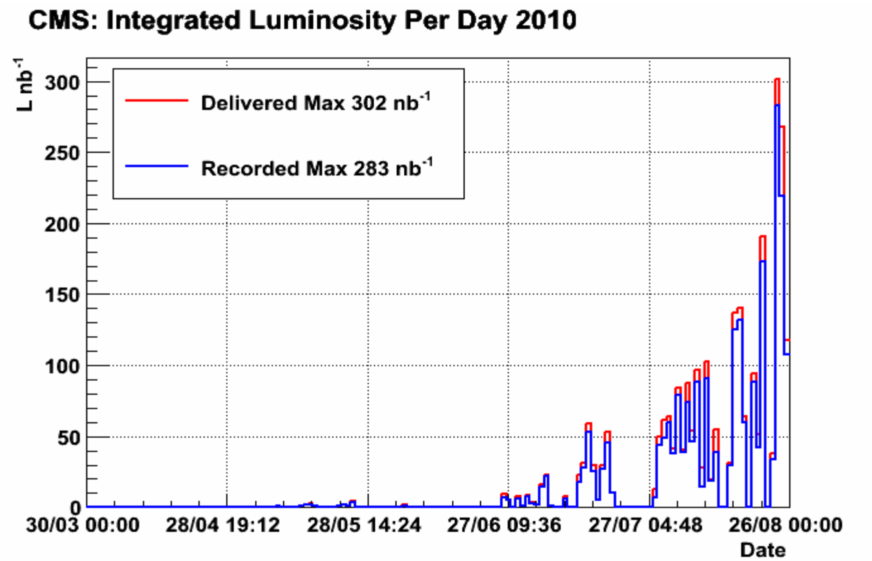
HELMHOLTZ | ASSOCIATION

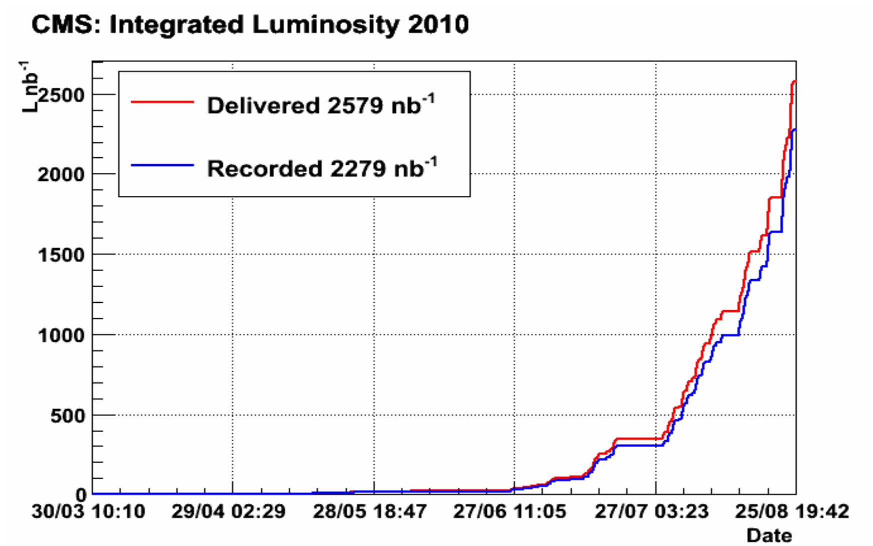
Detector overview



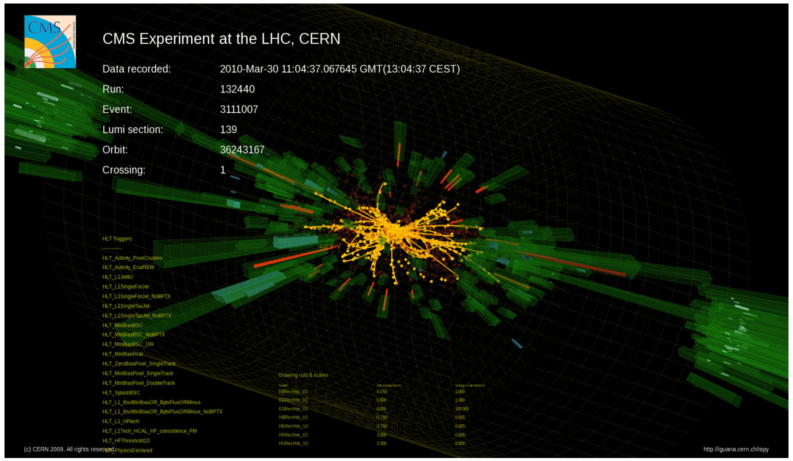
HF platfom with Hadronic Forward and CASTOR calorimeters

Figures of merit



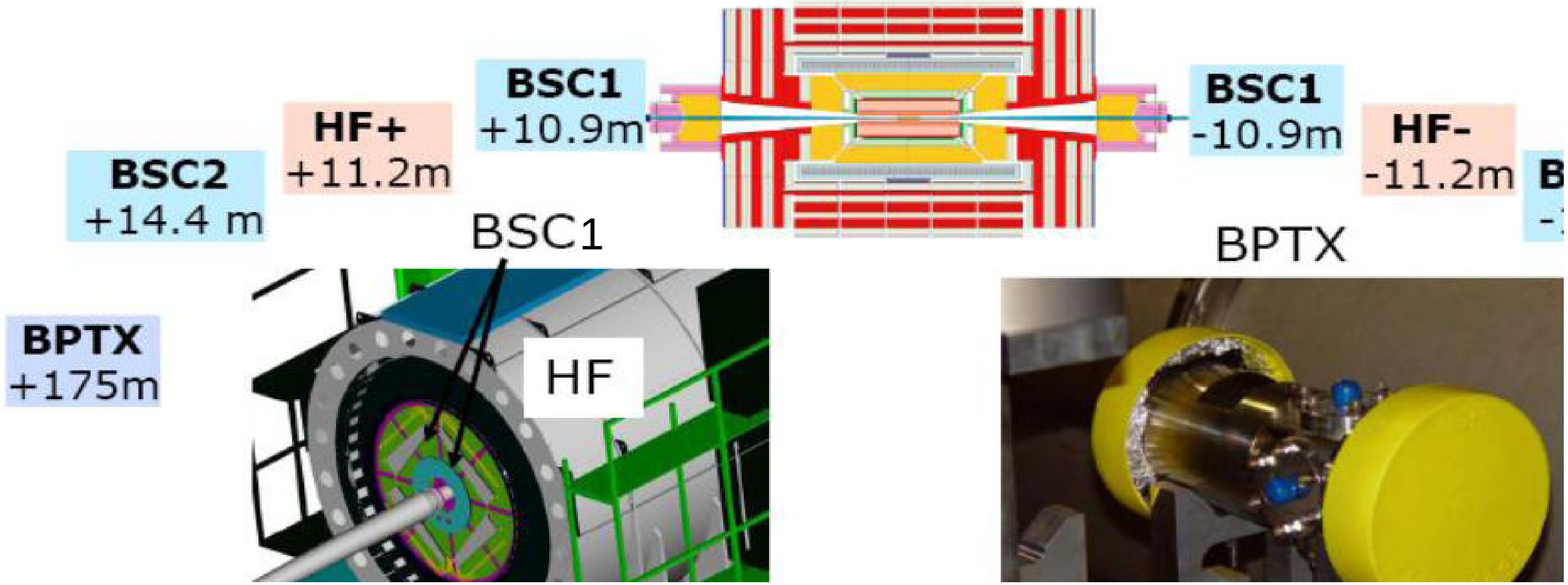


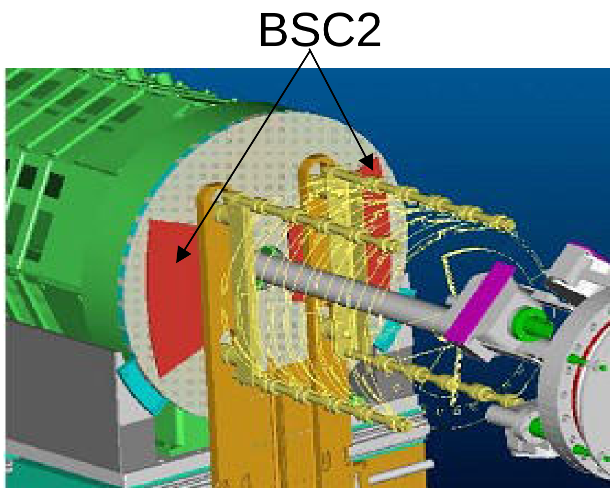
- Now running with 35 bunches colliding at CMS (out of 50 circulating)
- Long fills are now routine → ~ 1 pb^{-1} can be delivered with just a couple of fills → bunch trains commissioning



DESY

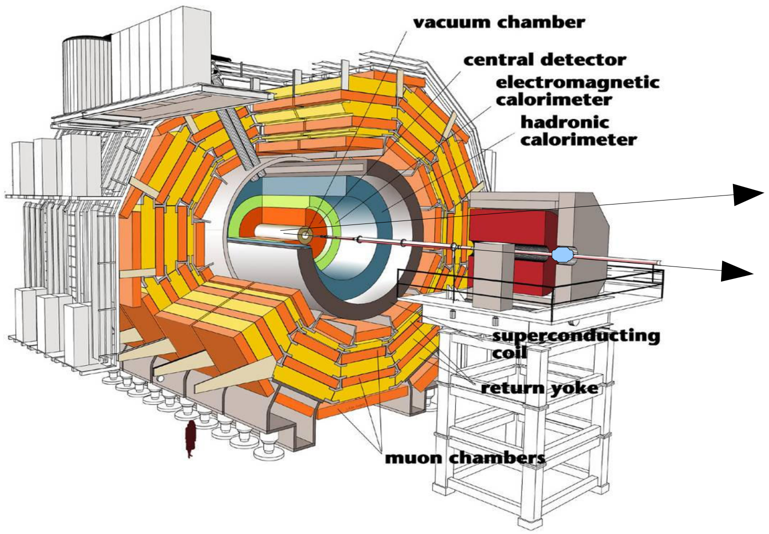
Trigger System

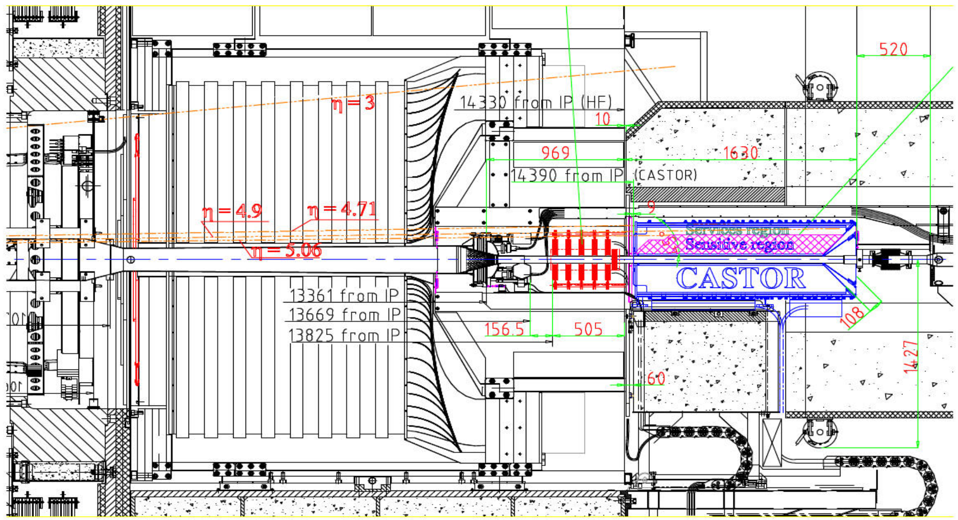




- Beam scintillation counter: info on hits and coincidence signals
- Beam Pick-up Timing for eXperiments: precise info on structure and timing of LHC beams
- BSC + BPTX → minimum bias (beam halo/gas/splash, high multiplicity) triggering / monitoring for pp and HI

CASTOR placement in CMS and physics goals

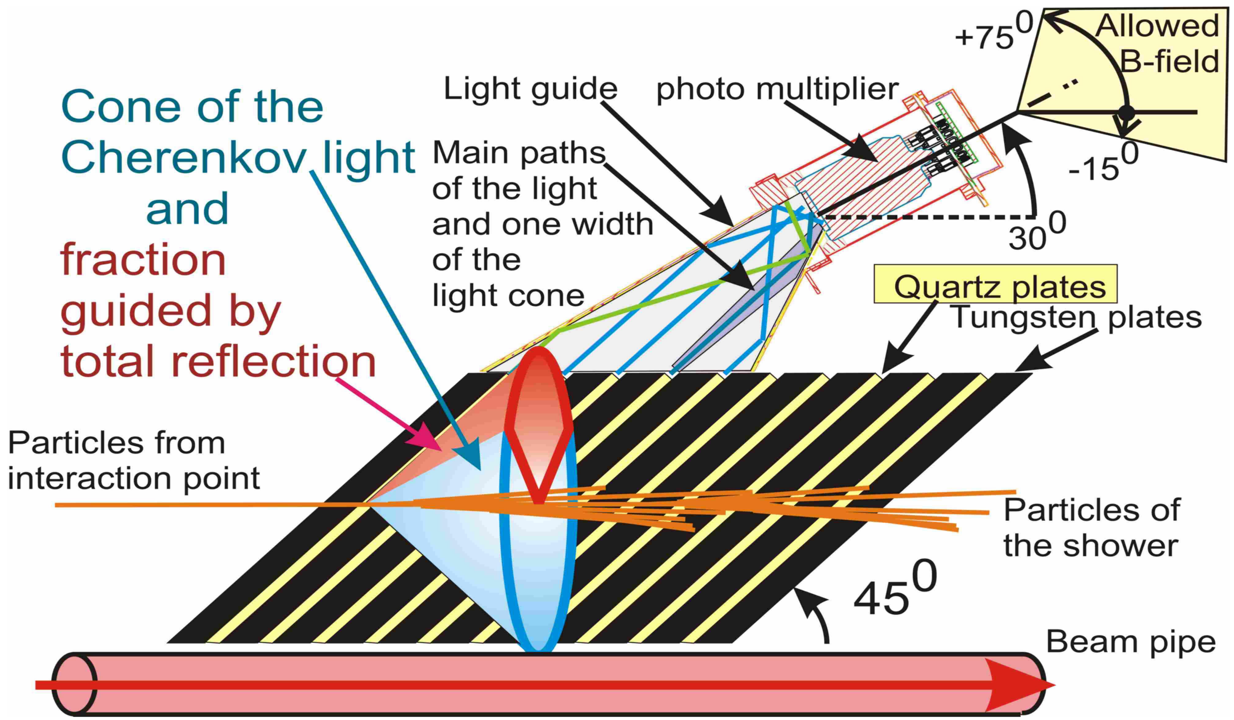




- **>** Forward calorimeter (-6.6 < η < -5.2), behind hadronic forward calorimeter (HF) and TOTEM/T2 tracking station, for low-x parton dynamics, minimum bias event structure, diffraction, cosmic ray related physics in low-luminosity (≤10^{33} $cm^{-2}s^{-1}$) proton-proton and heavy-ion collisions

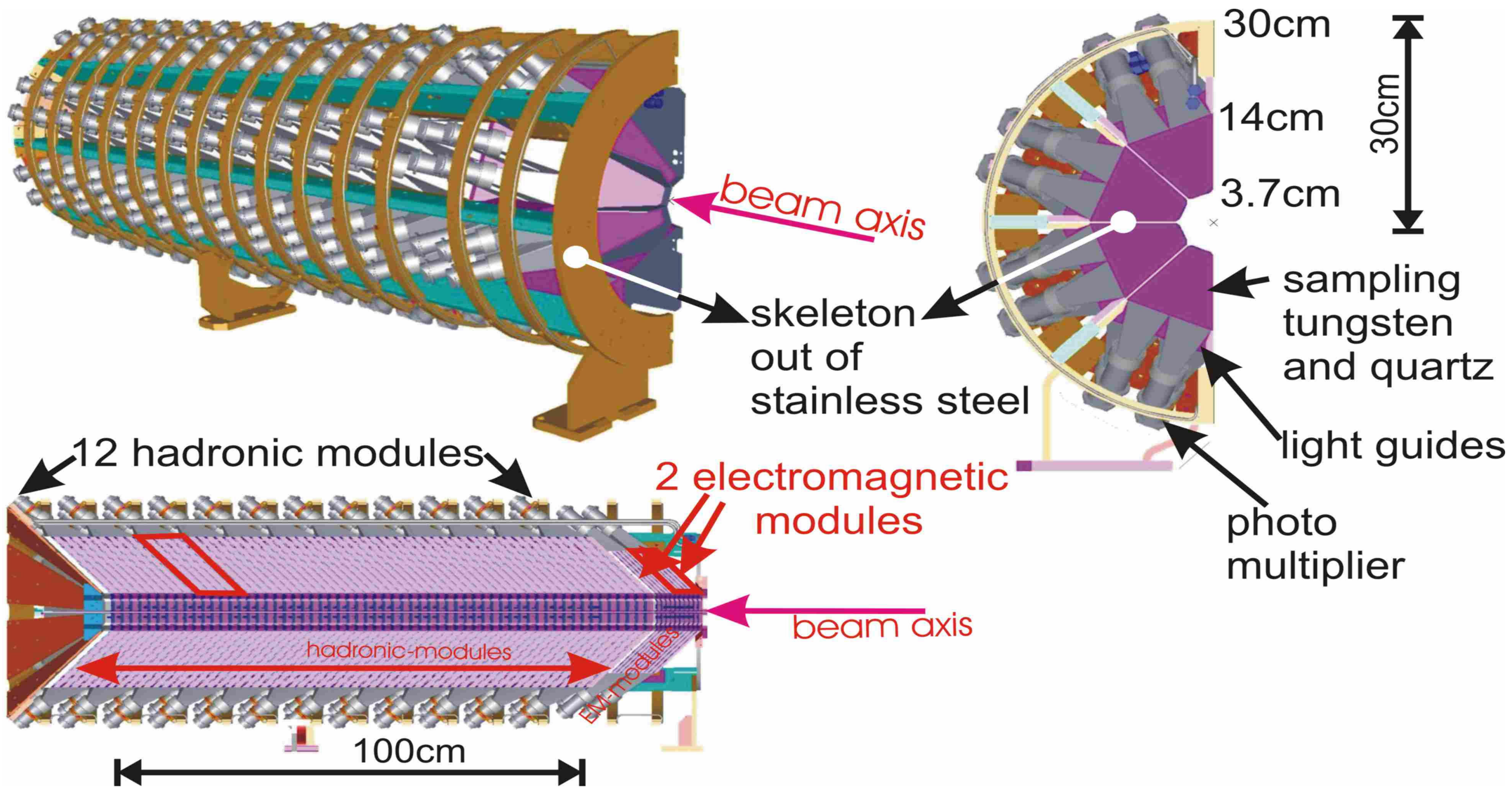
- **>** Design challenges: restricted space available, high radiation level (≤ 20 kGy in 2009/10), operation in magnetic field (≤ 0.16 T), pileup

Calorimeter design



- Cherenkov quartz-tungsten sampling calorimeter for CMS@LHC with quartz plates as active medium and tungsten as absorber → compact, radiation hard and fast

Calorimeter design (cont'd)



- 16 azimuthal sectors (semi-octants/towers) mechanically organised in two half calorimeters; EM part (2 modules) + HAD part (12 modules); EM = 0.7λ = 20X0; HAD = 12 ∗ 0.7 = 9.24λ ; overall depth = 10λ

Project overview

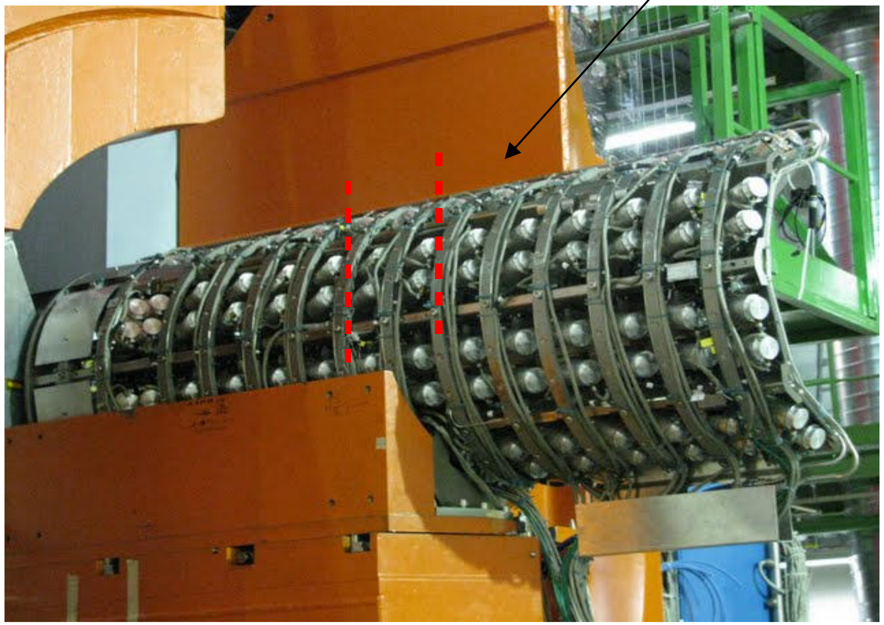
> Collaboration: Belgium (Antwerp), Brazil (UERJ), CERN, DESY, Greece (Athens), Russia (JINR, INR, ITEP, MSU), Turkey (Adana, Cukurova), USA (Northeastern)

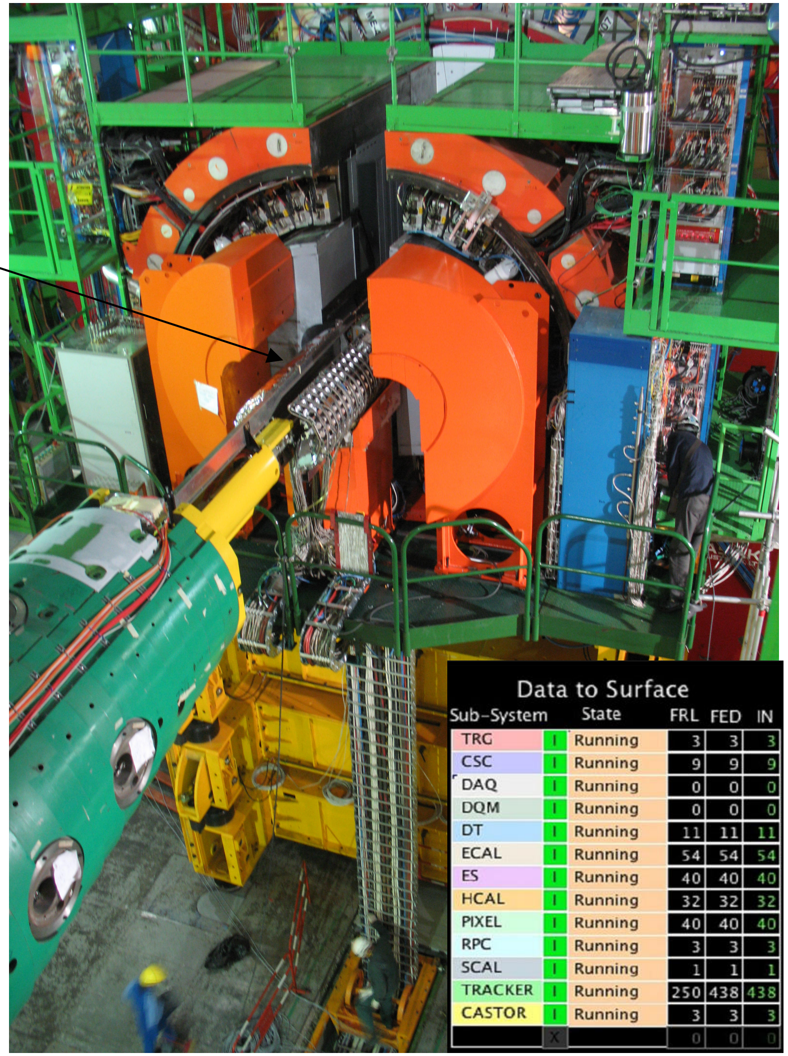
> Milestones:

- 2003: CASTOR project aims to become part of CMS
- Feb 2007: review of all projects in the CMS forward region
- May 2007: review of CASTOR project → approved as CMS component
- Aug 2007: test beam at CERN
- Oct 2007: completion of Engineering Design Review (EDR)
- Jan 2008: successful follow-up EDR for integration/installation → start production
- Jun 2008: test beam at CERN
- Aug 2008: one half calorimeter (with one octant equipped) installed in CMS → strong stray magnetic field in forward region → Oct 2008 calorimeter de-installed
- Jan 2009: Engineering Change Review for modification of forward region
- May 2009: test beam at CERN
- June 2009: CASTOR installation in experimental cavern of CMS

Calorimeter in CMS cavern: up and running!

- Design polished in beam tests of several prototypes
- CASTOR installed on collar table of HF platform (-Z side) in June 2009
- Fully functional and integrated into CMS operations



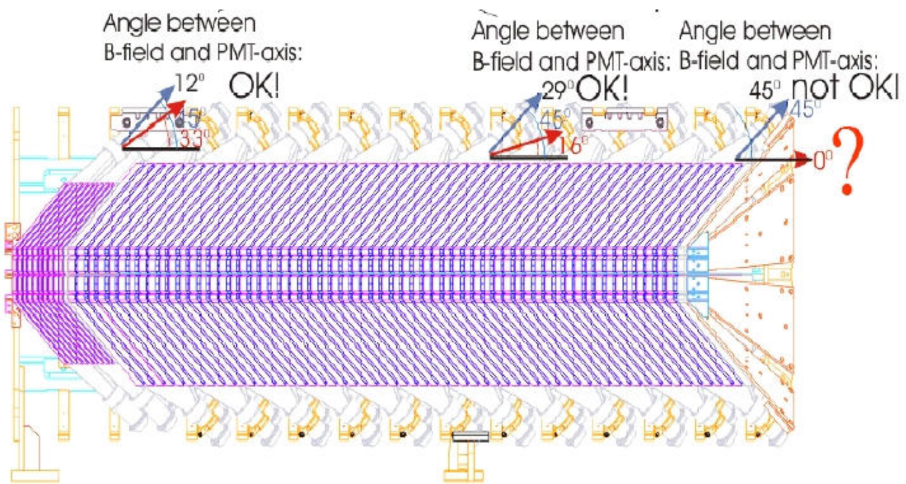


Data to Surface

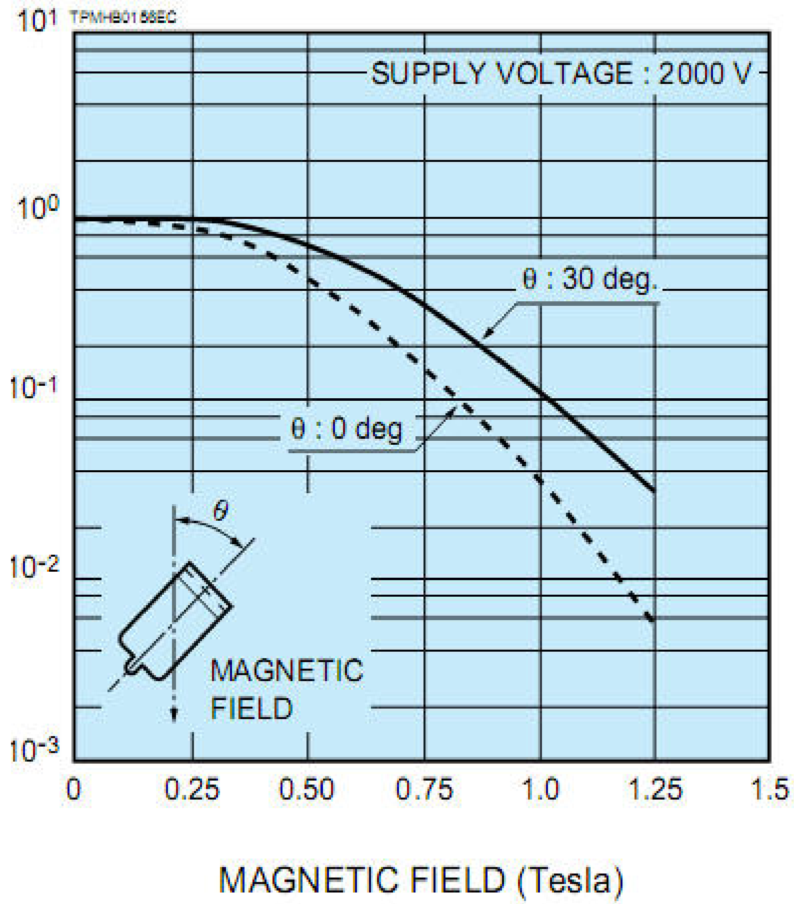
Sub-System		State	FRL	FED	IN
TRG	I	Running	3	3	3
CSC	I	Running	9	9	9
DAQ	I	Running	0	0	0
DQM	I	Running	0	0	0
DT	I	Running	11	11	11
ECAL	I	Running	54	54	54
ES	I	Running	40	40	40
HCAL	I	Running	32	32	32
PIXEL	I	Running	40	40	40
RPC	I	Running	3	3	3
SCAL	I	Running	1	1	1
TRACKER	I	Running	250	438	438
CASTOR	I	Running	3	3	3
	X		0	0	0

CMS magnetic field

- Parts of CASTOR located in beam pipe shield gaps => high stray magnetic field, field vector direction varies => try to recover:
  - H1 SpaCal fine-mesh PMT's (tolerate < 0.5 T, should survive radiation corresponding to 800 pb^{-1})
  - Redesign of air-core light guides to account for field direction
  - Close shield gaps



R5505 Typical Gain in Magnetic Fields



Hamamatsu data-sheet

CMS magnetic field

CMS preliminary

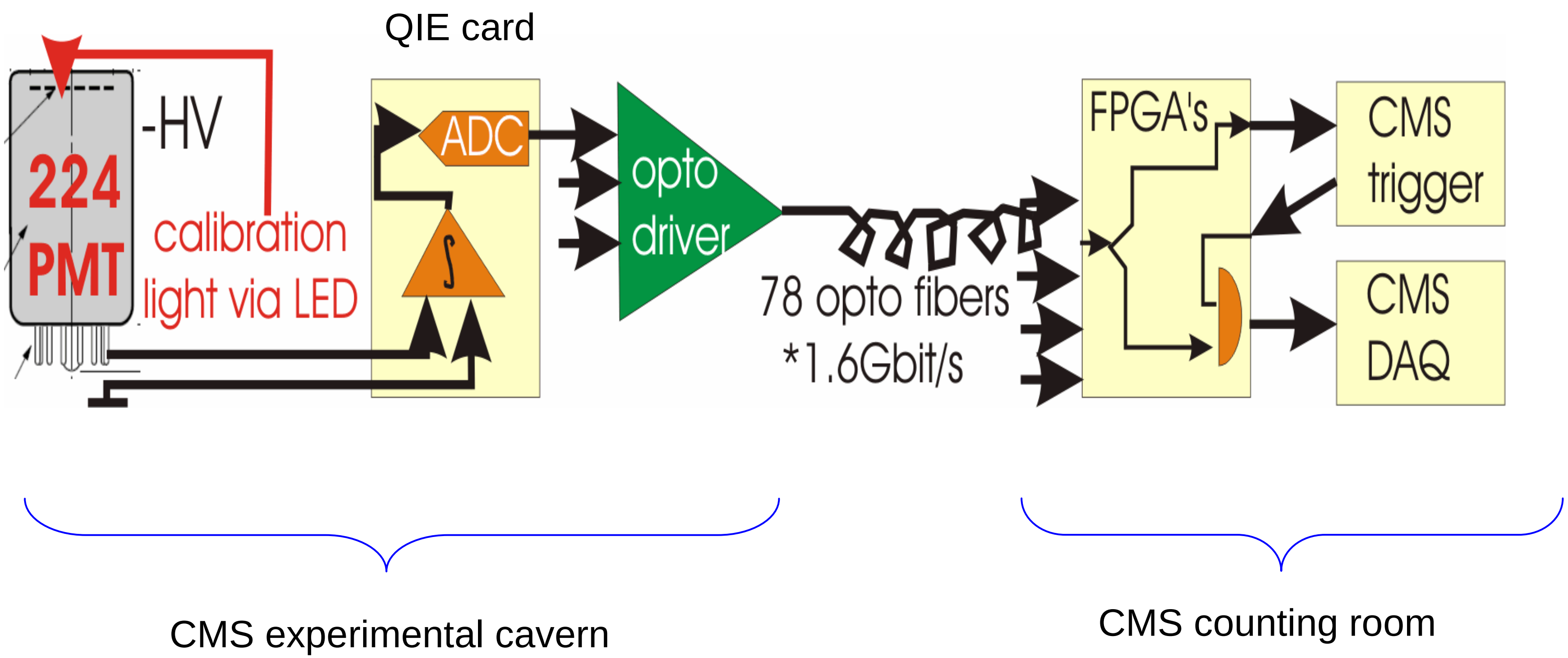
φ \ Z	1	2	3	4	5	6	7	8	9	10	11	12	13	14
16	0.96	1.03	1.06	1.10	1.44	0.71	0.03		0.79	0.92	1.00	1.09	1.12	1.06
15	1.06	1.00	1.0	1.11	1.32	1.44	0.02		0.89	1.01	0.98	1.03	1.09	1.10
14	0.93	1.02	1.07	1.06	1.35	0.60	0.04		0.82	0.94	1.13	1.12	1.21	1.3
13	1.01	1.05	1.05	1.15	1.48	0.21	0.03			0.87	1.03	1.13		1.21
12	0.99	1.10	1.12	1.10	1.10	0.17	0.00	0.00	0.67	0.86	1.07	1.05	1.16	1.21
11	0.99	1.00	1.10	1.14	1.31	0.28	0.01	0.02	0.81	0.99	1.06	1.01	1.08	1.10
10	1.10	1.06	0.99	1.06	1.08	0.34	0.01	0.69	0.98	0.98	1.01	0.95	0.99	1.19
9	0.99	1.00	1.03	1.09	1.01	0.33	0.02	0.76	0.83	0.95	0.95	0.98	1.03	0.96
8	1.03	0.85	0.94	1.00	0.91	1.14	0.02	0.77	0.78	0.88	0.95	0.93	1.03	0.95
7	1.01	0.90	1.00	1.01	1.03	0.20	0.01	0.60	0.84	0.78	0.88		0.90	0.95
6		1.14	0.95	0.90	1.23	0.32	0.02	0.02	0.75	0.76	0.89	0.76	0.80	0.94
5		1.00	0.95	0.95	1.2	0.49	0.07	0.01	0.04		0.82	0.68	1.06	1.03
4	0.93	1.01	0.94	1.01	0.90	0.58	0.03	0.00	0.02	0.78	0.85	0.94	0.96	1.06
3	0.98	1.00	0.97	0.94	1.08	0.60	0.03	0.03	0.42	0.78	0.93	0.96	1.08	0.89
2	0.94	0.88	0.98	0.96	1.02	1.48	0.07	0.25	0.79	0.85	0.83	0.96	0.99	1.00
1	1.11	0.95	1.01	1.11	1.06	1.91	0.04	0.72	0.83	0.96	0.92	0.98	0.99	1.06

Minimum bias data: Run 133874 (Nominal B-field) / Run 133239 (No B-field)

- Ratio of average channel response in minimum bias dataset with B = 3.8 T and B = 0 T
- Operation of modules from 6 (3.5λ) to 9 (5.6λ) hampered; some channels can be recovered

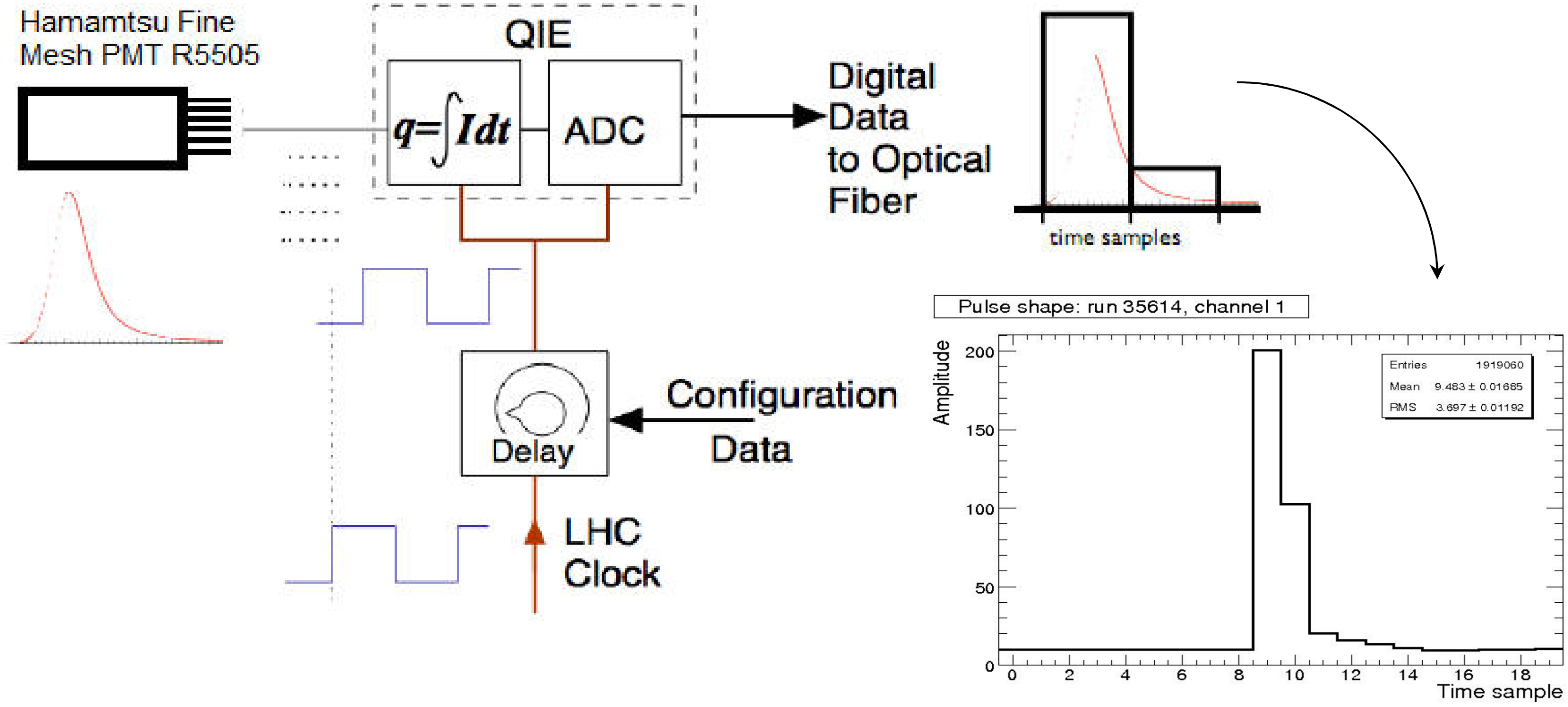
Readout chain

- High occupancy, signal separation for every LHC bunch crossing, wide dynamic range needed (from mip for calibration to beam energies): Conditions are similar to HF calorimeter hence design of CMS hadronic calorimeter readout electronics is used



Front-end electronics

- Front-end electronics based on charge integrating and encoding card providing almost constant relative precision over range of 10000

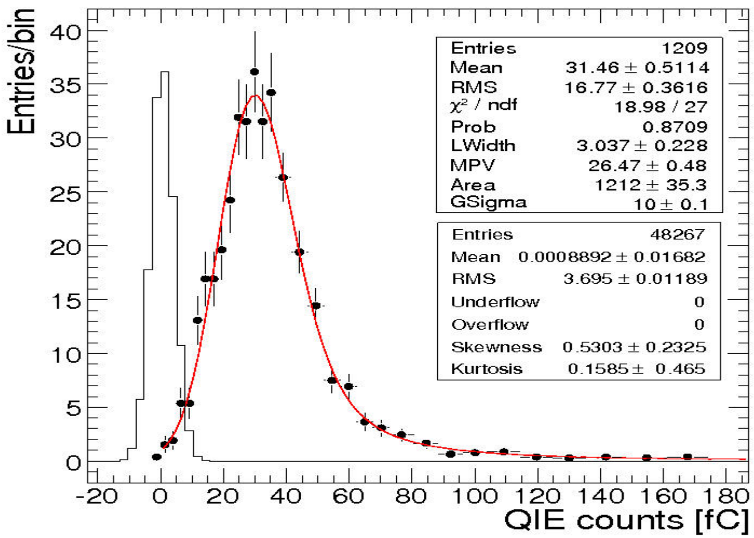


Results from beam tests

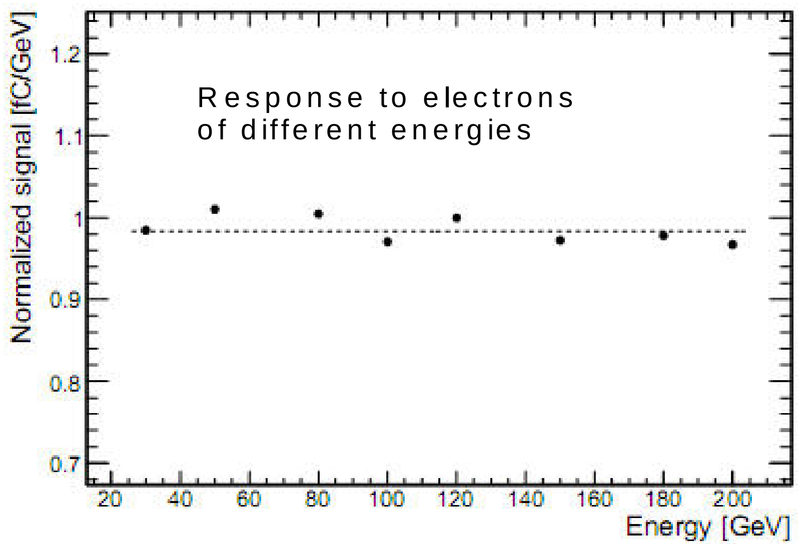
> Test beam 2007 results [EPJC 67 (2010) 601]: full-length prototype tested with muons, electons, pions in wide energy range

> Muon signal vs pedestal: noise under control, important for calibration

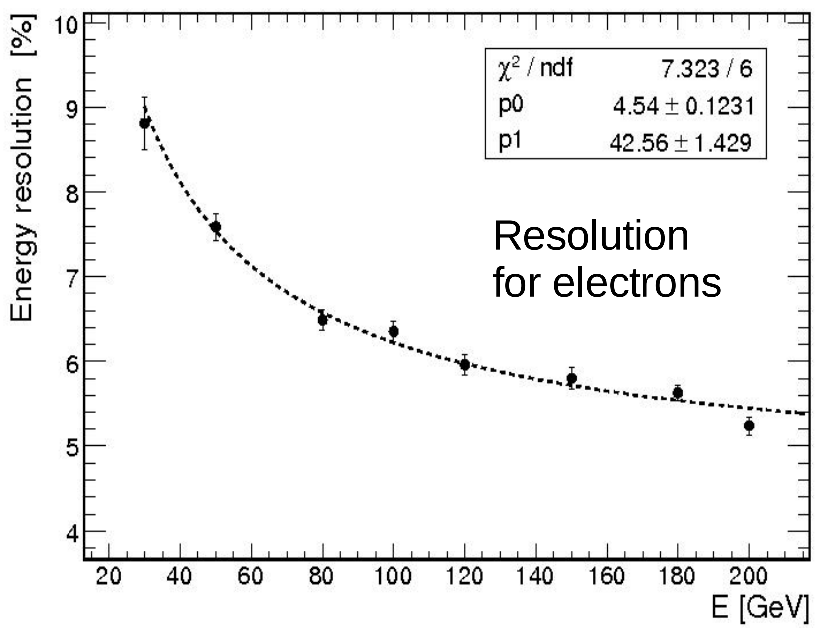
> Reasonable linearity and resolution for harsh conditions of CMS forward region

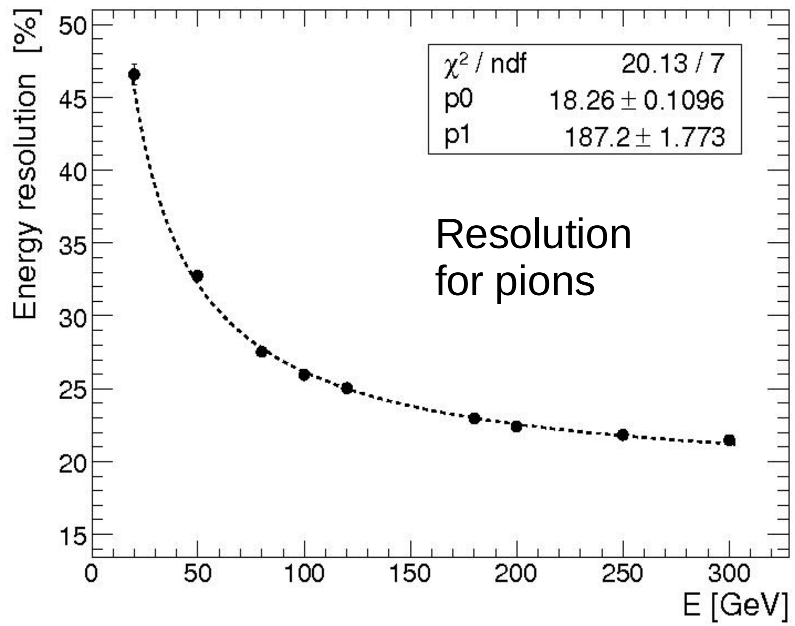


Response to 150 GeV muon beam in one EM channel



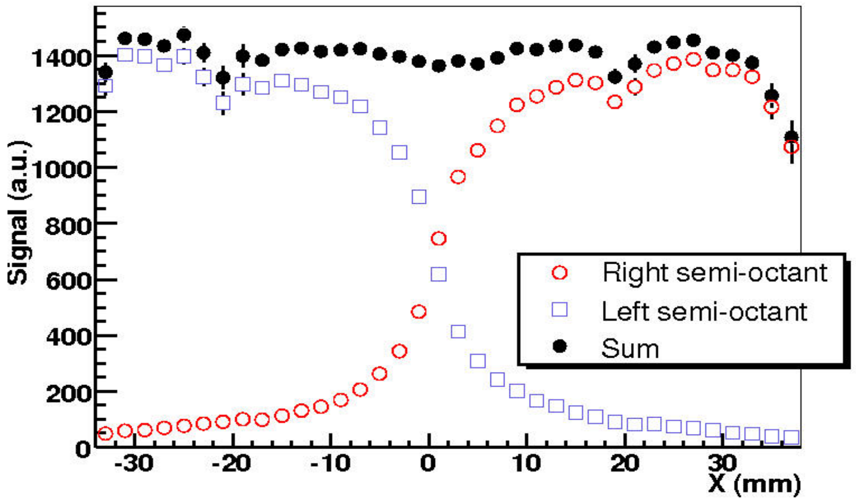
Results from beam tests

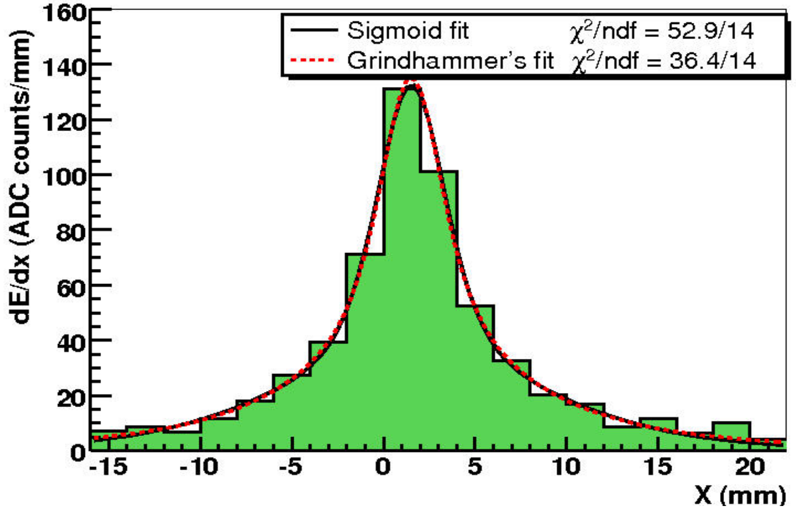


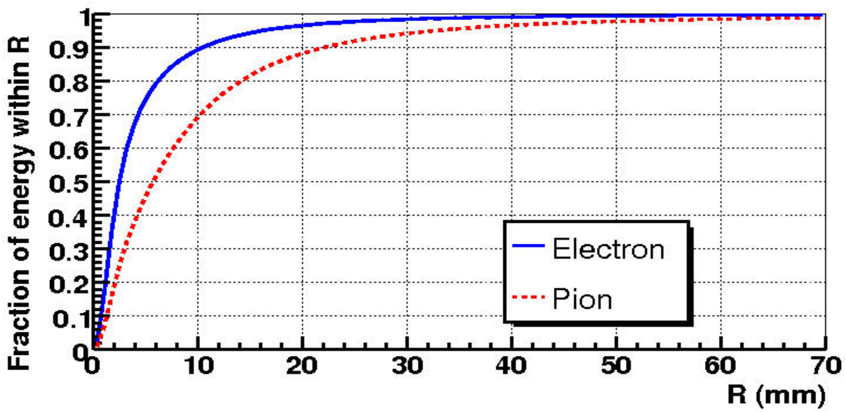


- Test beam 2007 results [EPJC 67 (2010) 601]
- Results shown with beam spot cut

Results from beam tests





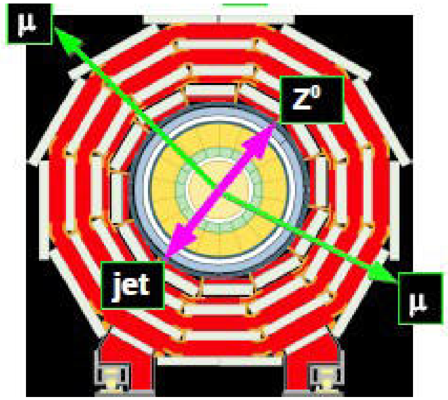


Test beam 2007 [EPJC 67 (2010) 601]

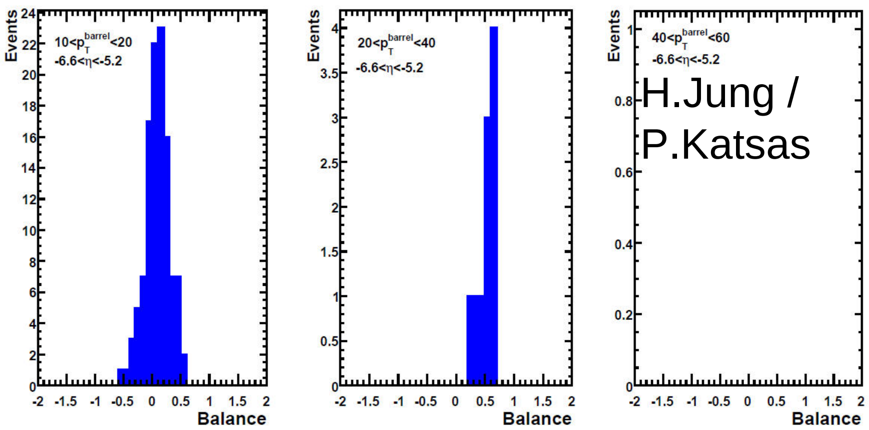
- Horizontal position scan with 80 GeV pion beam: FWHM of differential x-profile ~6 mm indicating compact shower dimensions (shower core calorimeter)

Calorimeter calibration

- Test beam results not directly applicable due to magnetic field influence
- Intercalibration (ensuring that fixed energy deposit gives the same response in all channels) in situ with muons:
  - Zero bias / minimum events with signal patterns consistent with muons (low efficiency without CASTOR dedicated trigger)
  - Special runs during injection / ramp to collect beam halo muons using BSC2-based trigger (BSC2 overlaps with CASTOR sensitive volume but still efficiency is low due to limited acceptance and beam gas)
  - Beam splashes (limited statistics and no magnetic field)
- Absolute calibration:
  - Electromagnetic energy scale: Z → ee (following strategy used by HF; significant integrated lumi needed)
  - Jet energy scale: di-jet events; jet + gamma; Z + jets
  - Aiming at first at 10-20% precision driven by need of energy flow & underlying event / low-x QCD studies



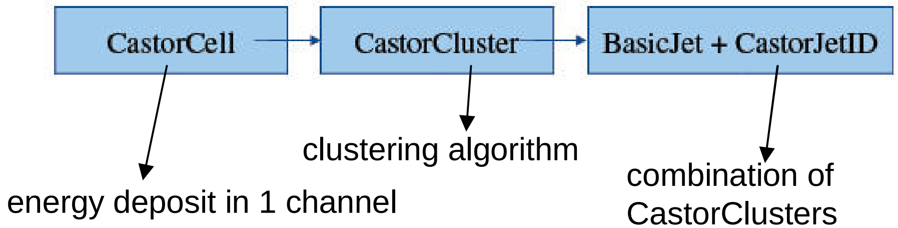
pt > 10 GeV; back-to-back; no jet #3



(pt_probe – pt_barrel) / pt_barrel

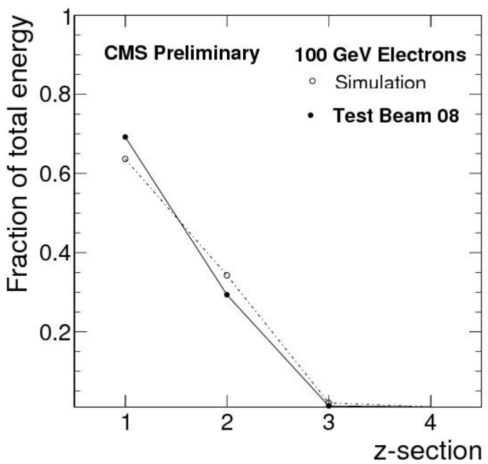
Reconstruction and simulation

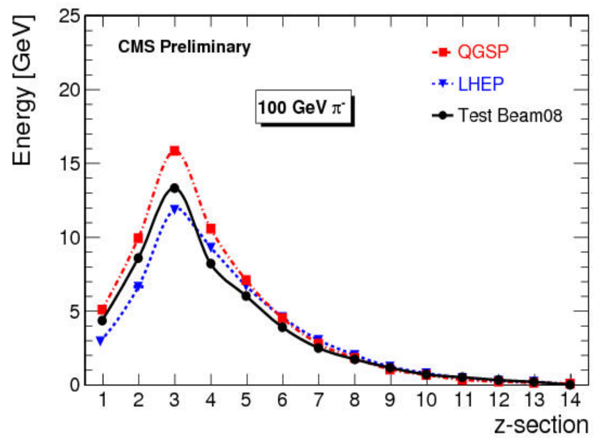
- All needed software has been implemented in CMS global software framework (CMSSW):
  - Reconstruction = from RAW data written to “tape” to high level objects like jets (given conditions)
  - Full simulation and shower library: still need some fine tuning/validation, especially the latter so that CASTOR could be included in standard CMS Monte Carlo samples

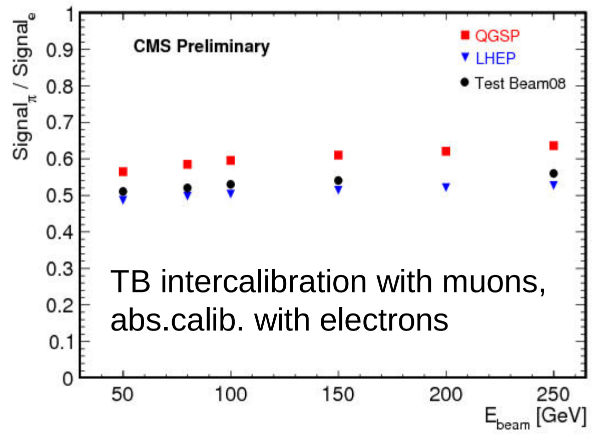


combination of CastorClusters using a jet algorithm (fixed η)

ValueMap with jet properties specific to CASTOR jets





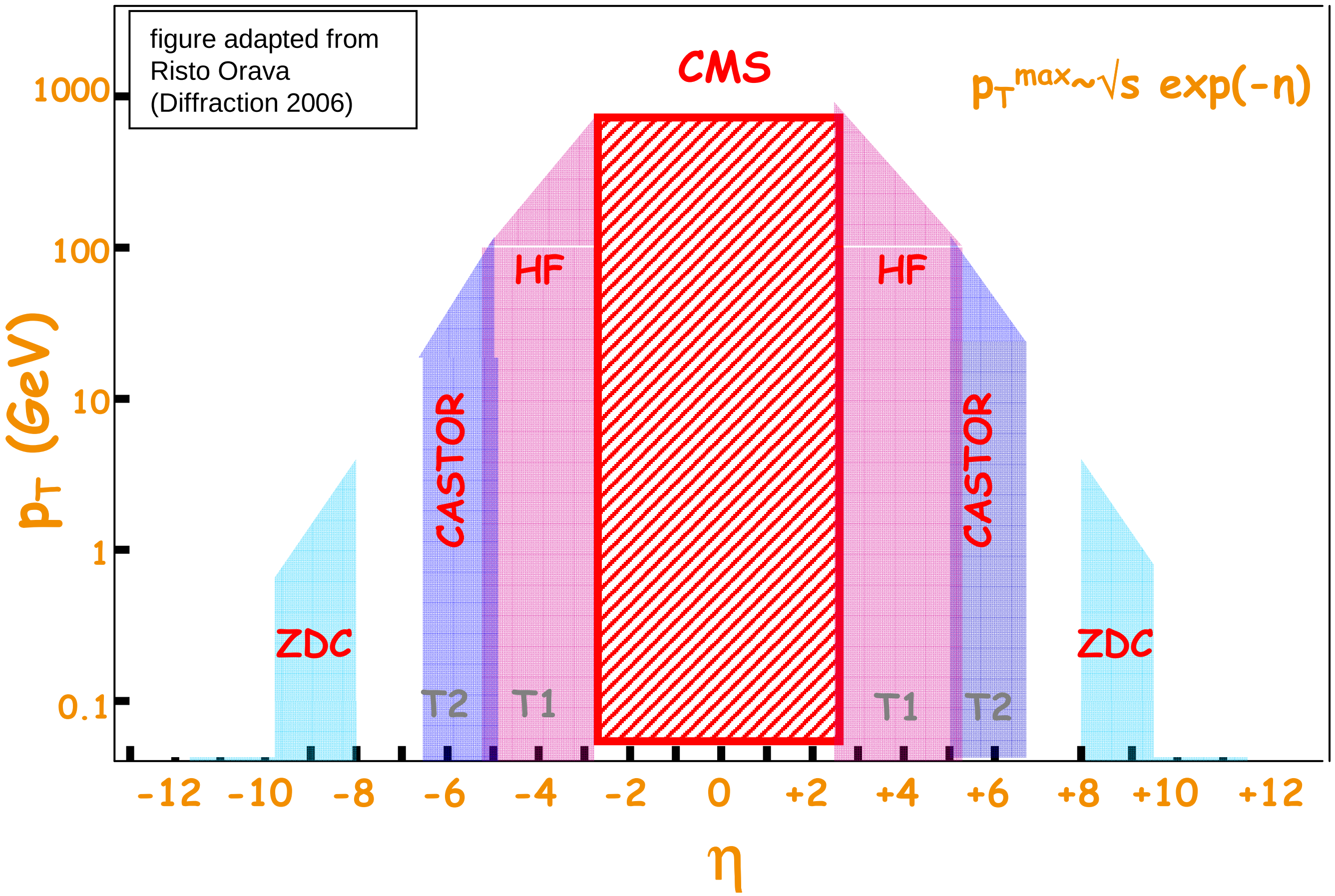


CASTOR calorimeter trigger

- HCAL-based technical trigger architecture (to be implemented soon)
- All at calorimeter sector level:
  - Muon trigger (calibration)
  - E^{tot} above thresholds
  - Rapidity gap
- Basic trigger strategy
  - Use existing (central detector) triggers at low lumi
  - Add CASTOR conditions at high lumi to avoid prescale factors
  - Inclusive forward jets, forward jets plus central jets, diffractive jets/W

Coverage in pseudorapidity and pt

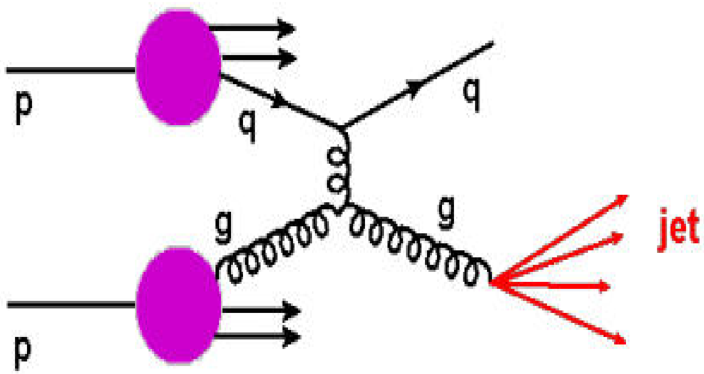
[A. Panagiotou]

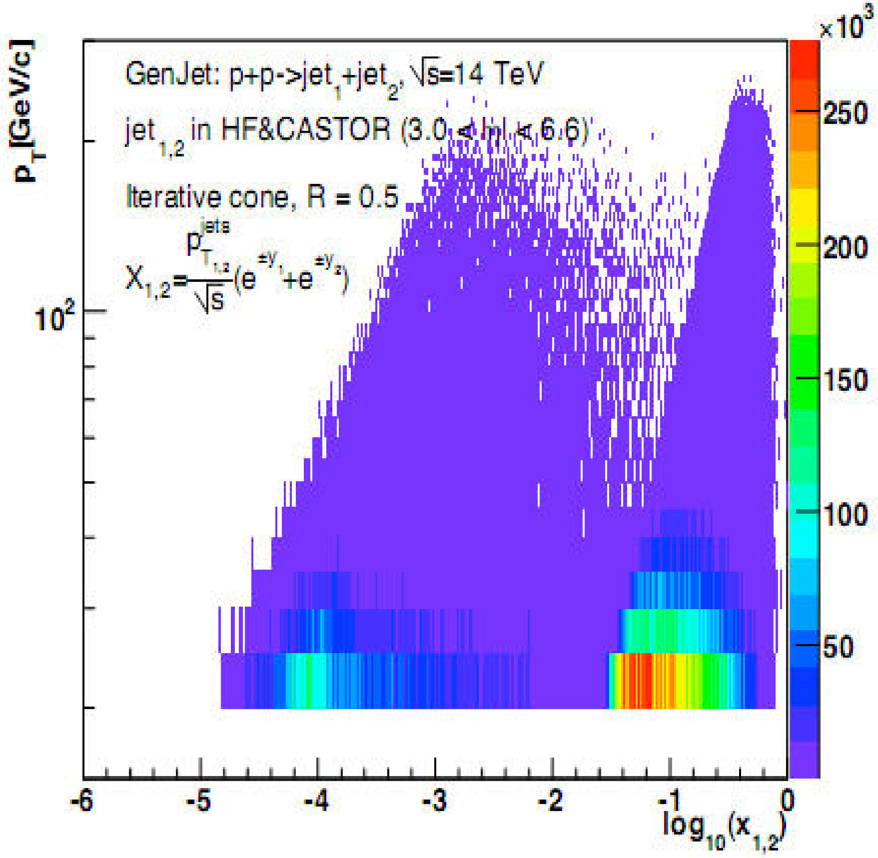


> CASTOR, ZDC calorimeters + TOTEM detectors → unparalleled forward coverage

Forward jets

- Forward jets allow to probe Bjorken-x as low as 10^{-5}: region sensitive to non-linear QCD effects of parton recombination and saturation
- Cannot beat HERA insight into gluon PDFs, can do better looking at correlations



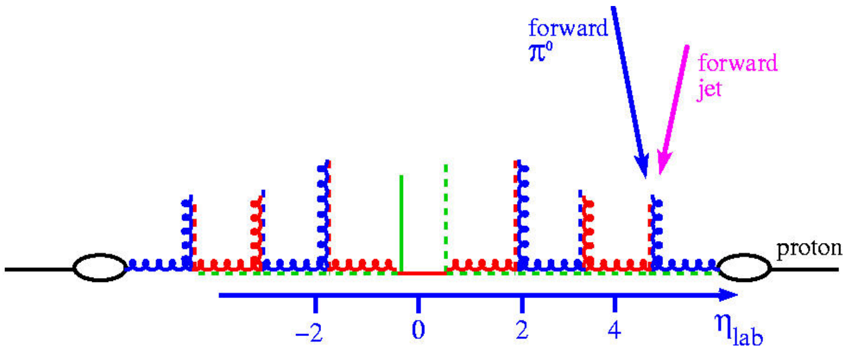


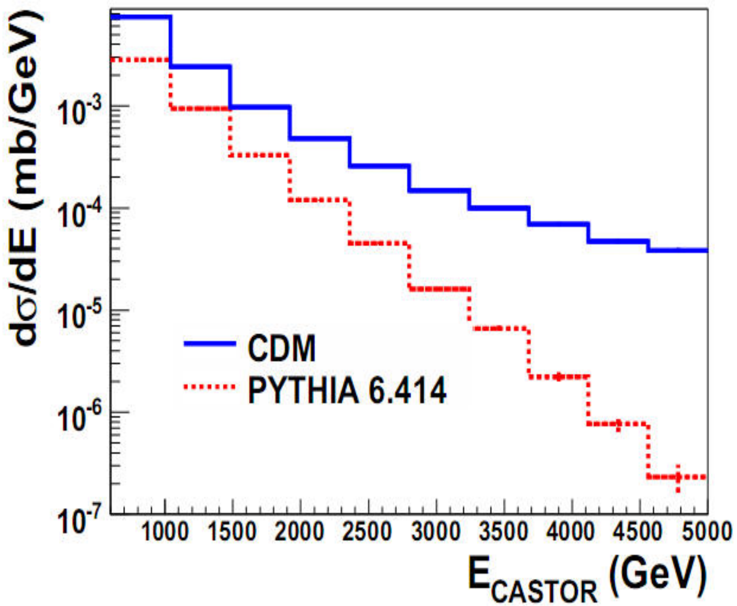
[CMS PAS FWD-08-001 / FWD-10-003]

[CMS and TOTEM Collaborations, CERN/LHCC 2006-039/G-124]

Central jets + forward jets

- Centrally produced dijets plus a forward jet in CASTOR: ability to distinguish between DGLAP- and BFKL-like QCD parton dynamics



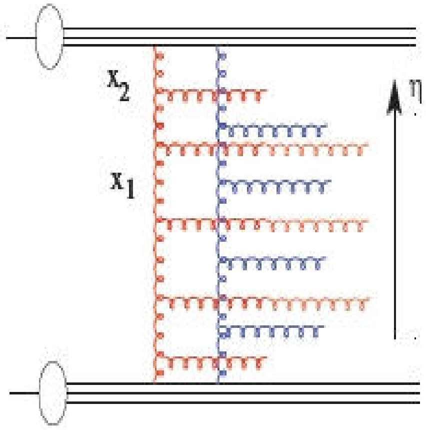


Feasible with < 1 pb^{-1}

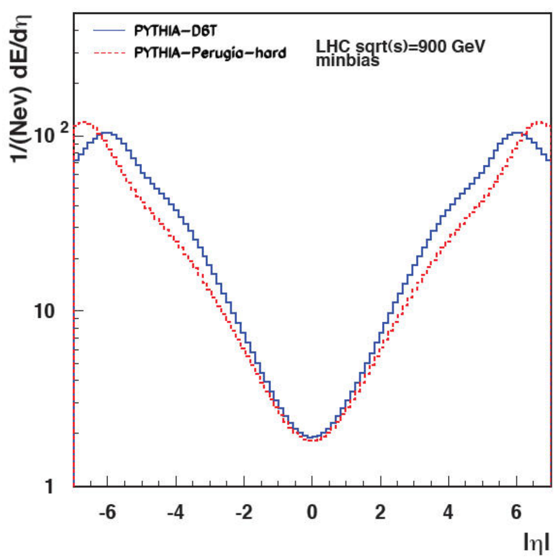
[A. Knutsson in Proceedings of HERA-LHC workshop DESY-PROC-2009-002]

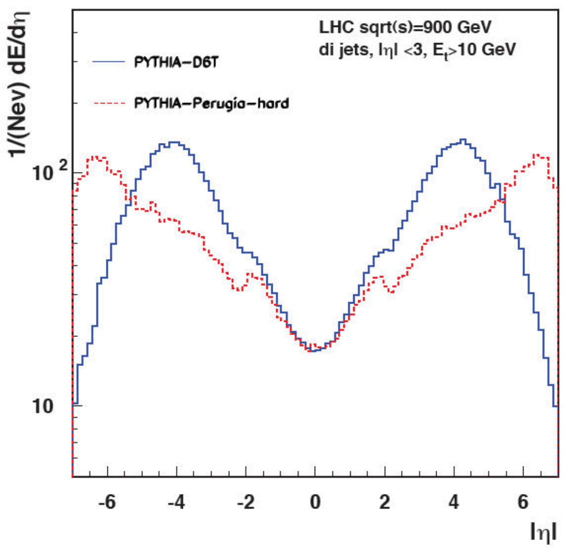
Energy flow measurement

- Energy flow in forward region:
  - directly sensitive to the amount of parton radiation and to multiparton interaction
  - complementary measurement compared to those performed using the central region alone
  - input to determination of parameters for multiparton interaction models

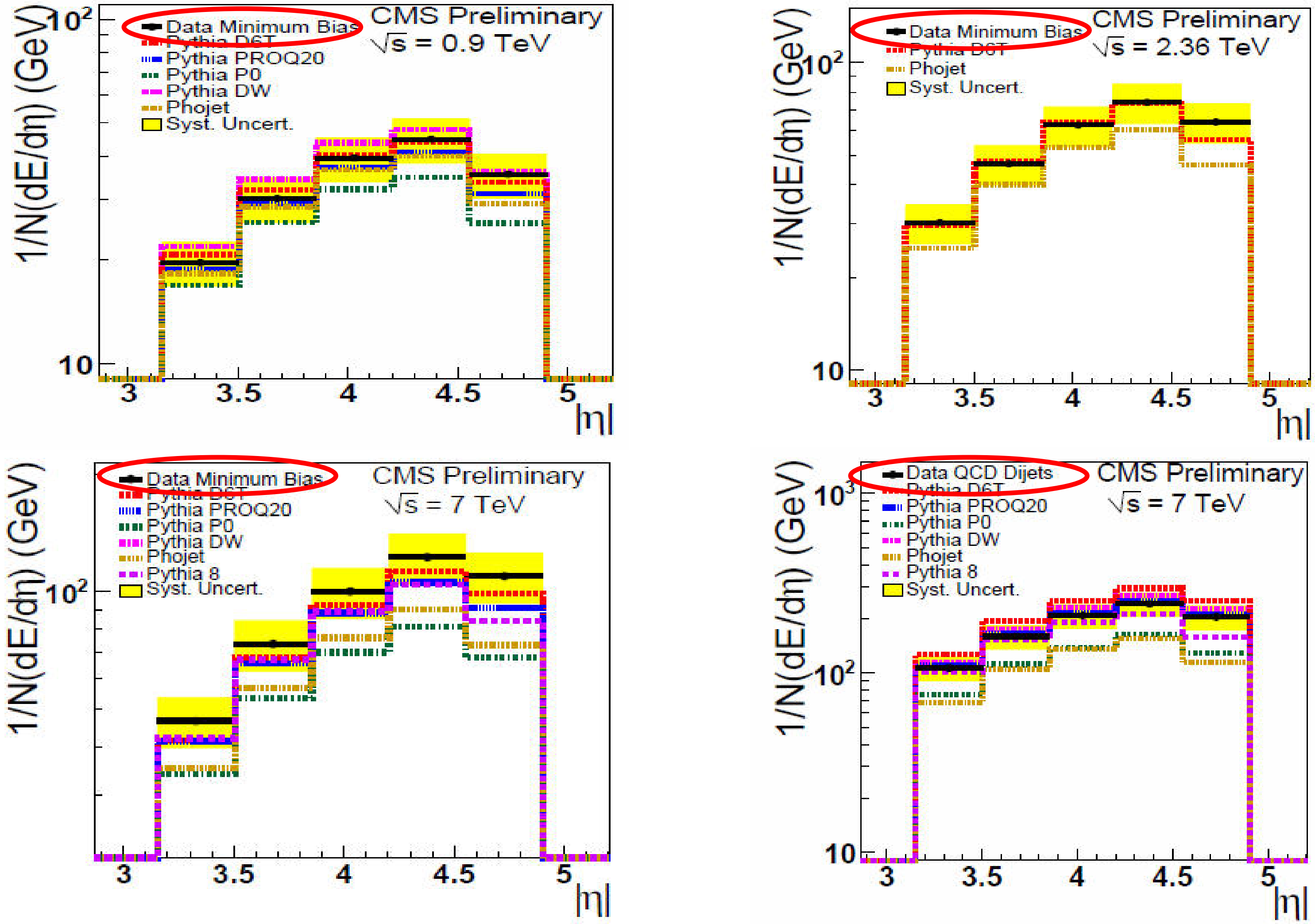


[CMS PAS FWD-10-002]



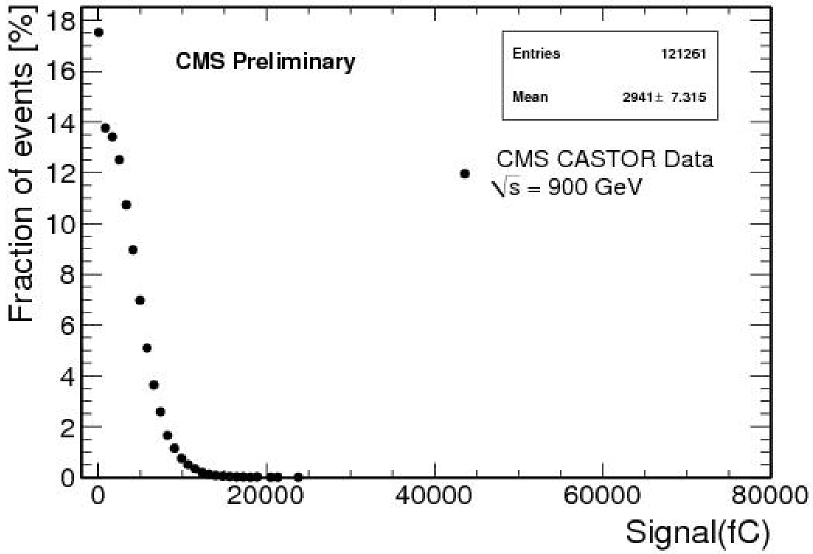


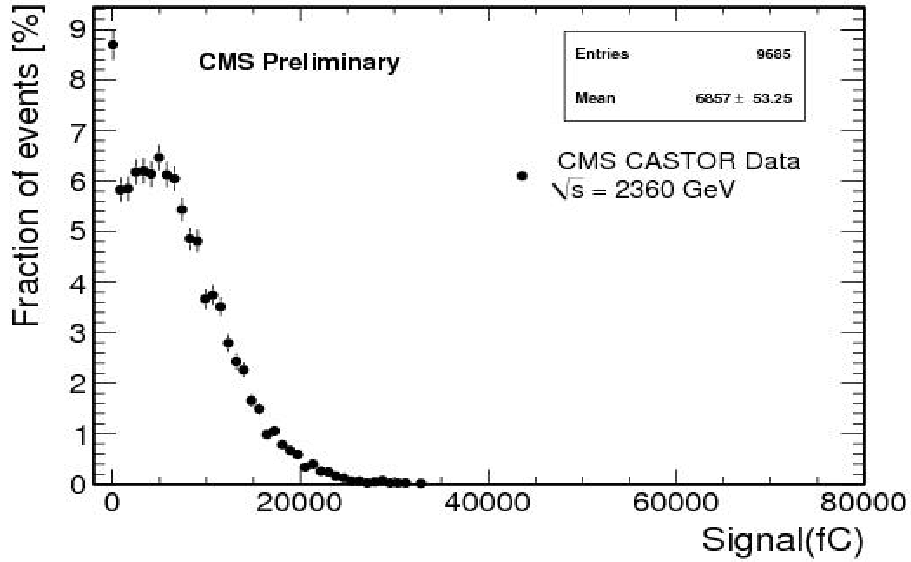
Energy flow measurement

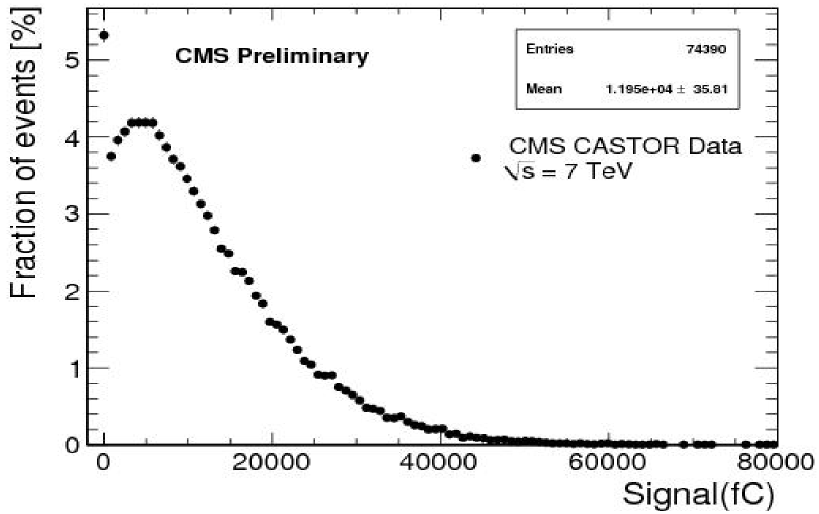


> Energy flow growing with c.m.e.; no tune is perfect; CASTOR results, extending rapidity coverage, pre-approved

Energy flow measurement



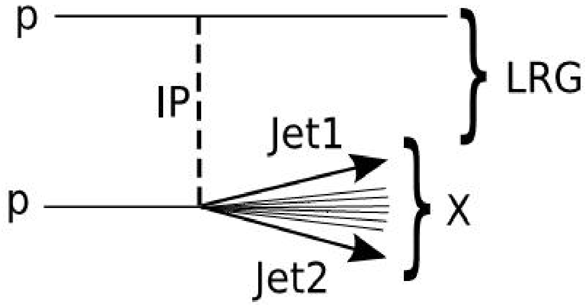


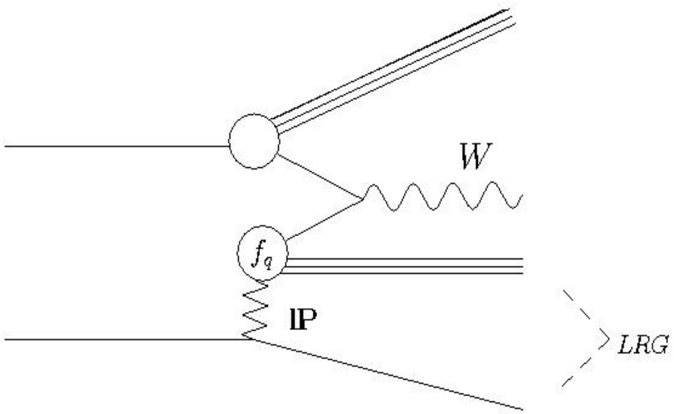


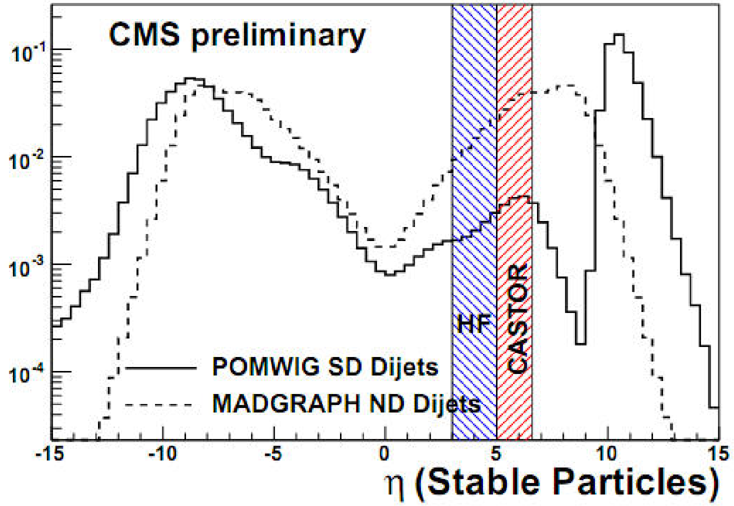
- Amplitude/charge as measured in first 5 calorimeter modules (2.8λ; no intercalibration)
- Energy flow is growing with centre of mass energy
- Sensitivity to events with rapidity gap

CASTOR as veto for diffraction

- Forward activity veto detector for diffraction: analysis strategies based on selection of large rapidity gaps



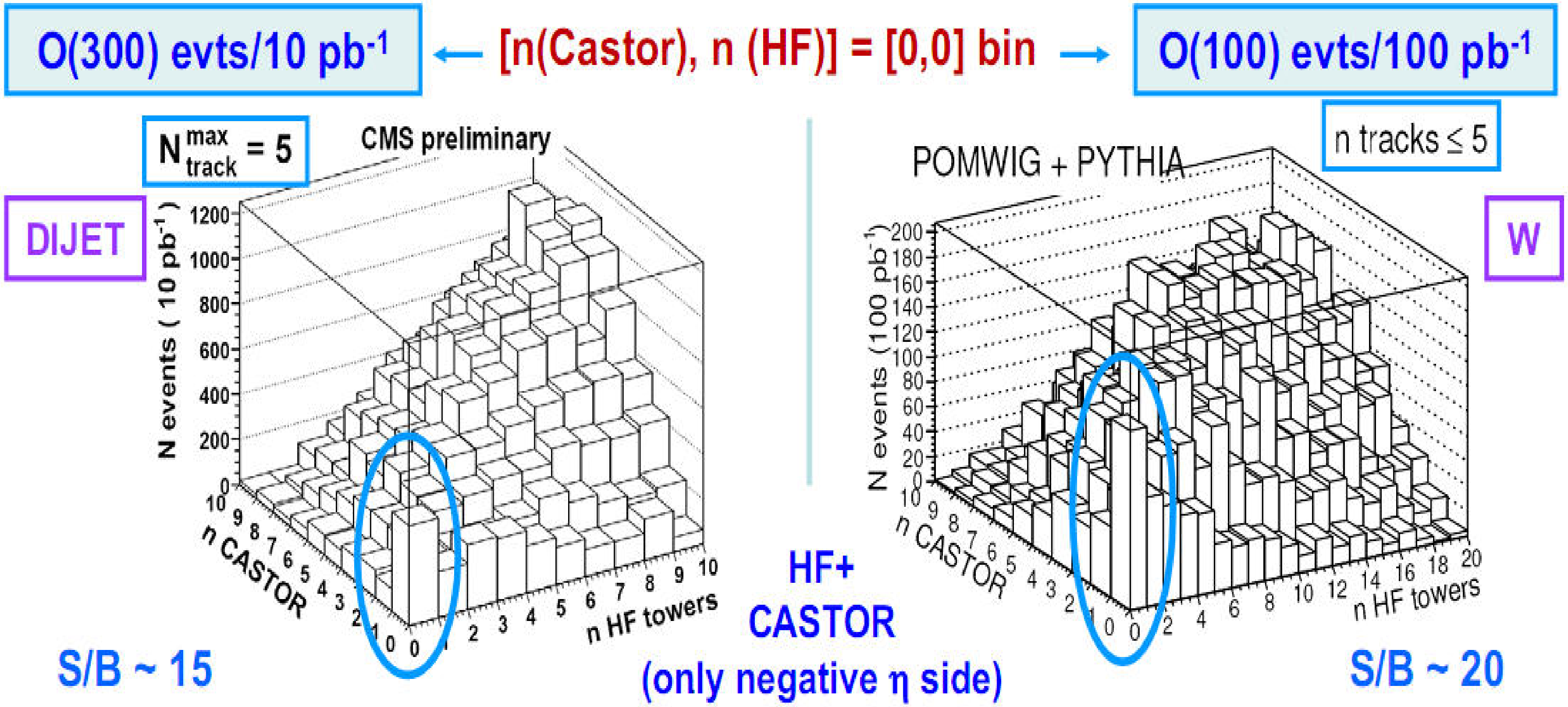




Wider η coverage suppresses non-diffractive events where gap is due to fluctuations

CASTOR as diffractive veto

Maria Margherita Obertino



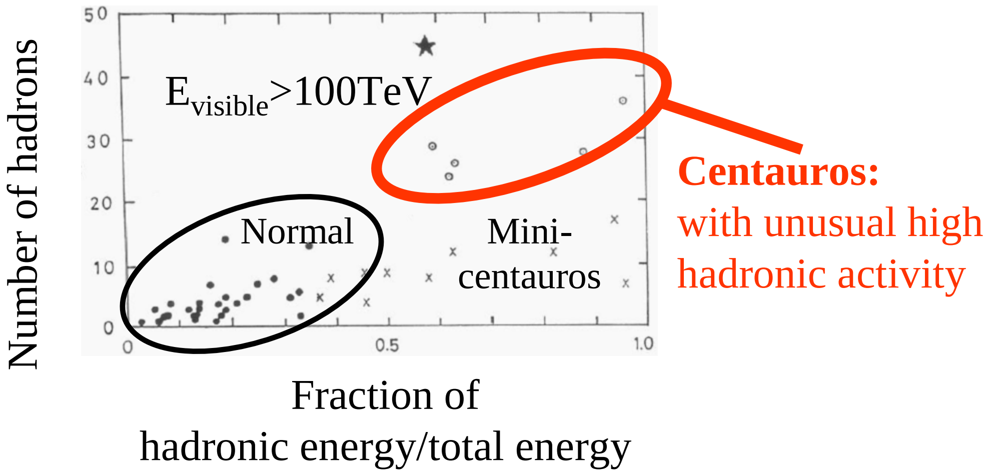
[CMS PAS FWD-08-002]

[CMS PAS DIF-07-002]

- If only CASTOR multiplicity used signal would be further enhanced

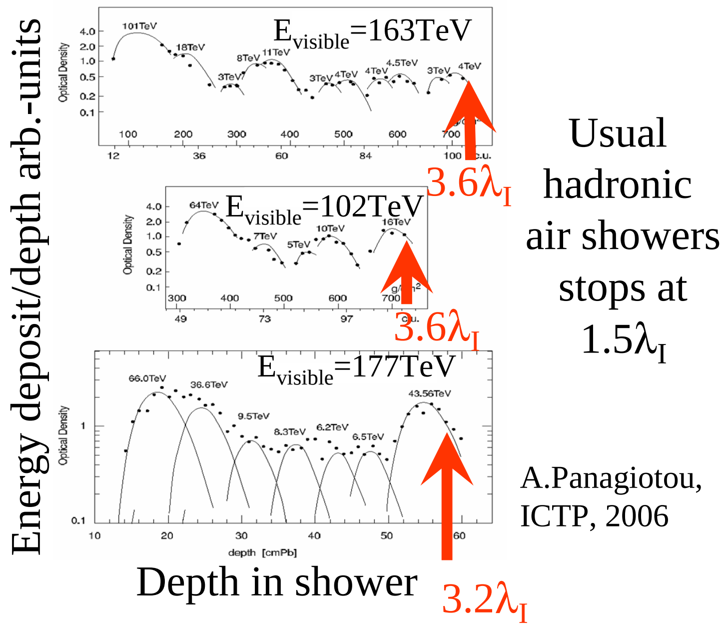
Heavy Ion physics

- Interplay with low-x physics: saturation effects / Color Glass Condensate
- Centrality measurement: along with ZDC improve determination of collision impact parameter
- Exotic objects with unusual longitudinal shower profile properties observed by cosmic ray experiments: stranglets / centauros → ideas involving quark-gluon plasma / dark matter candidates (CASTOR stands for **C**entauro **A**nd **ST**range **O**bject **R**esearch)



- CASTOR with its fine longitudinal segmentation is in a perfect position: in ultra-relativistic ion-ion collisions at LHC η –coverage corresponds to a baryon-rich region

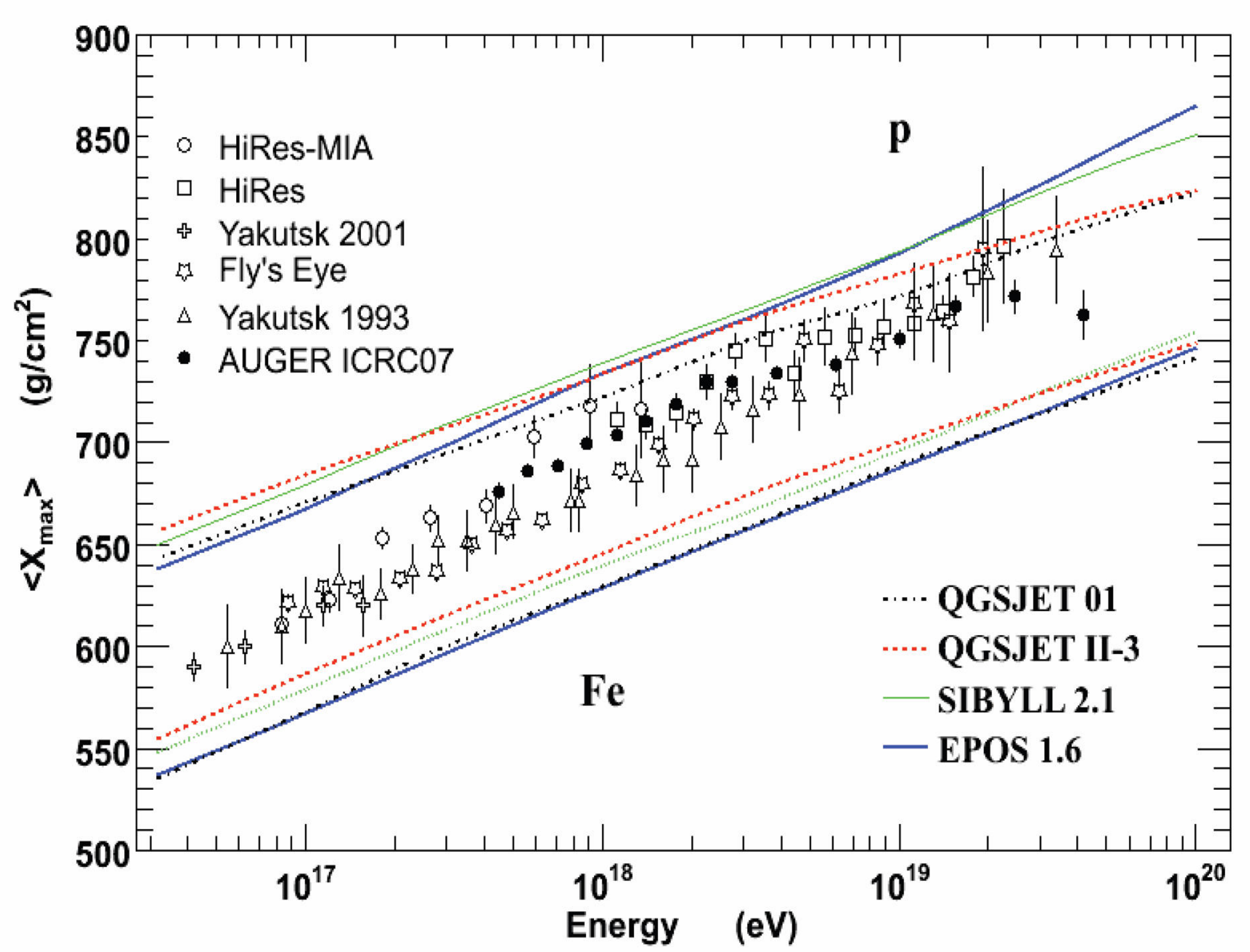
Stranglets with high energy deposited deep in the shower



A.Panagiotou, ICTP, 2006

Cosmic ray physics

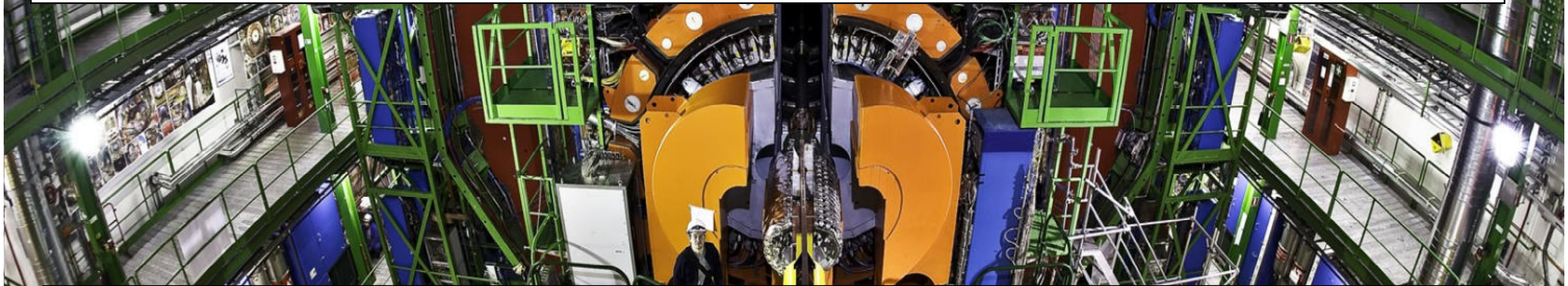
Shower maximum of extensive air showers



- High energy cosmic rays
- So far only indirect measurements (EAS) at $E^{lab} > 10^{15}$ eV
- Treatment severely dependent on simulations
- In particular, conclusions on chemical composition of most interesting Ultra High Energy Cosmic Rays
- Large uncertainty of hadronic interactions modeling
- Most important for shower development simulation is projectile (pion, proton, nuclei) fragmentation region
- Accelerator data are scarce
- Castor looks at that region → is very valuable for validation of shower simulation codes

Summary and outlook

- Cherenkov forward CASTOR calorimeter has been designed, studied in beam tests, installed, commissioned and fully integrated into CMS
- CASTOR calorimeter in CMS enhances physics potential substantially: largest rapidity coverage in a collider experiment; broad range of topics such as tuning of Monte Carlo generators, investigation of fundamental properties of QCD, astrophysics studies, potential discovery of exotica
- Detector took data at centre-of-mass energies 900, 2360 and 7000 GeV; extension of forward energy flow analysis, sensitive to underlying event modeling, is in progress



Inspiration

28 June 2010 Last updated at 00:49 GMT

LHC smashes beam collision record

By Katia Moskvitch
Science reporter, BBC News, Cern in Geneva

The CMS experiment will search for signs of new physics in collisions at the LHC

Scientists working on the Large Hadron Collider (LHC) say they have moved a step closer to their aim of unlocking the mysteries of the Universe.

The world's highest-energy particle accelerator has produced a record-

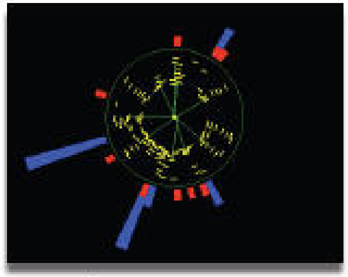
BACKUP

LHC/CMS Timeline

[Taylan Yetkin CALOR2010]

Sep 2008 — CMS sees first beam events in the from of splashes.

Jul 2009 — Repairs in LHC magnets finished



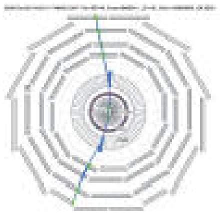
Dec 2009 — CMS sees collisions from 0.9 TeV, 2.36 TeV protons.

$\int L dt$

Apr 2010 — CMS records more than 1 nb^{-1} of data

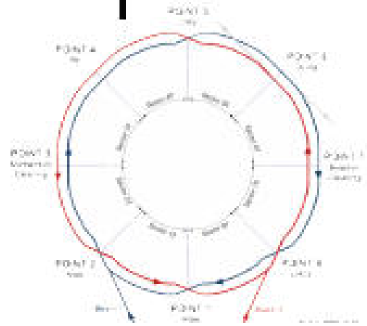
2008 ——————————————— **2010**

Oct 2008 — CMS collects events from cosmic muons with 3.8 T field.



Sep 2008 — Electrical failure in superconducting magnets of LHC causes large amount of Helium leak. Released pressure wrench many magnets from their support.

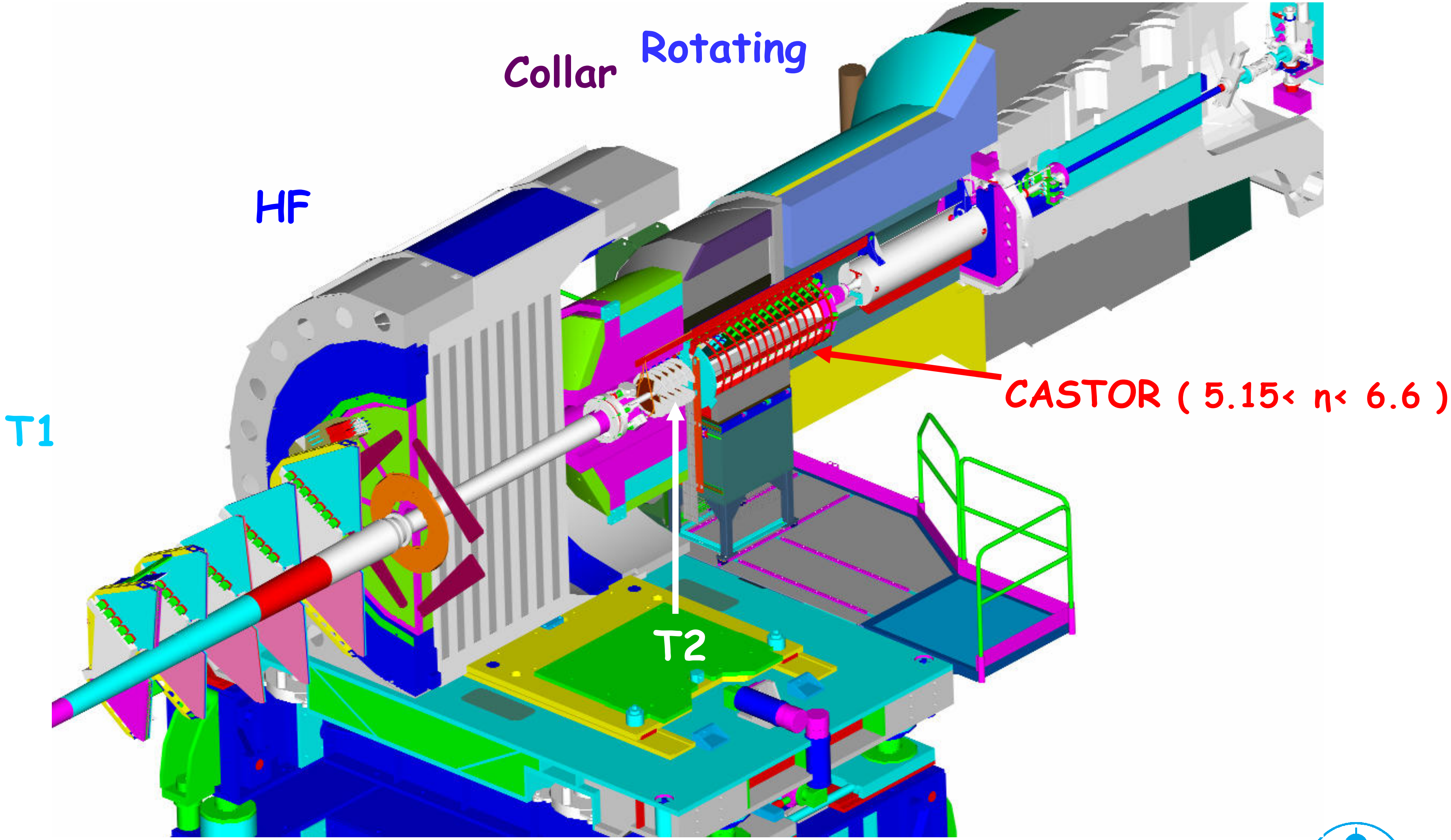
Nov 2009 — CMS sees two circulating beams.



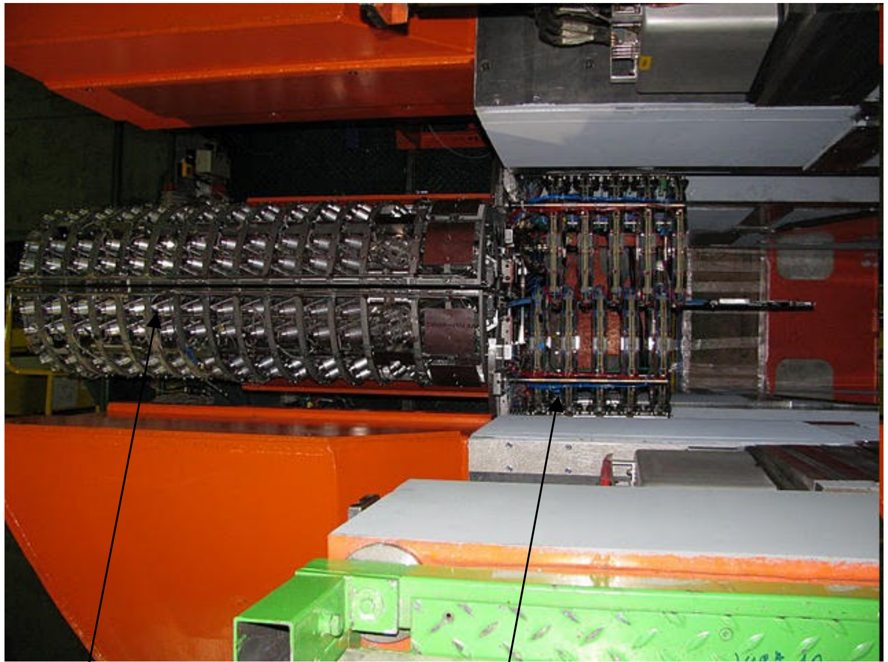
Mar 2010 — Another world record by LHC: 7 TeV collisions

DESY

Calorimeter integration in 3D



Calorimeter installed in CMS experimental cavern



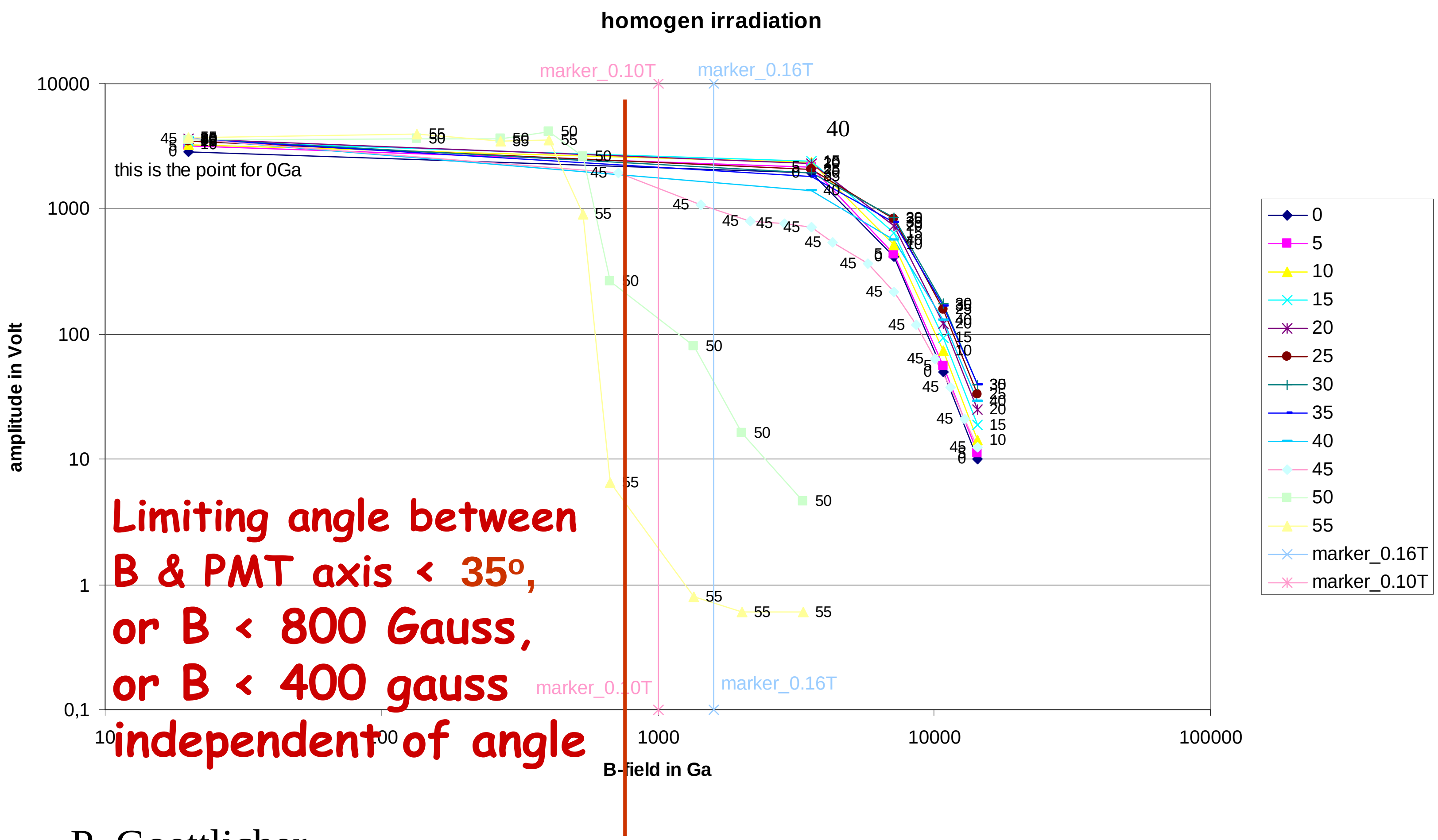
TOTEM / T2

CASTOR

Interface of collar / rotating shielding

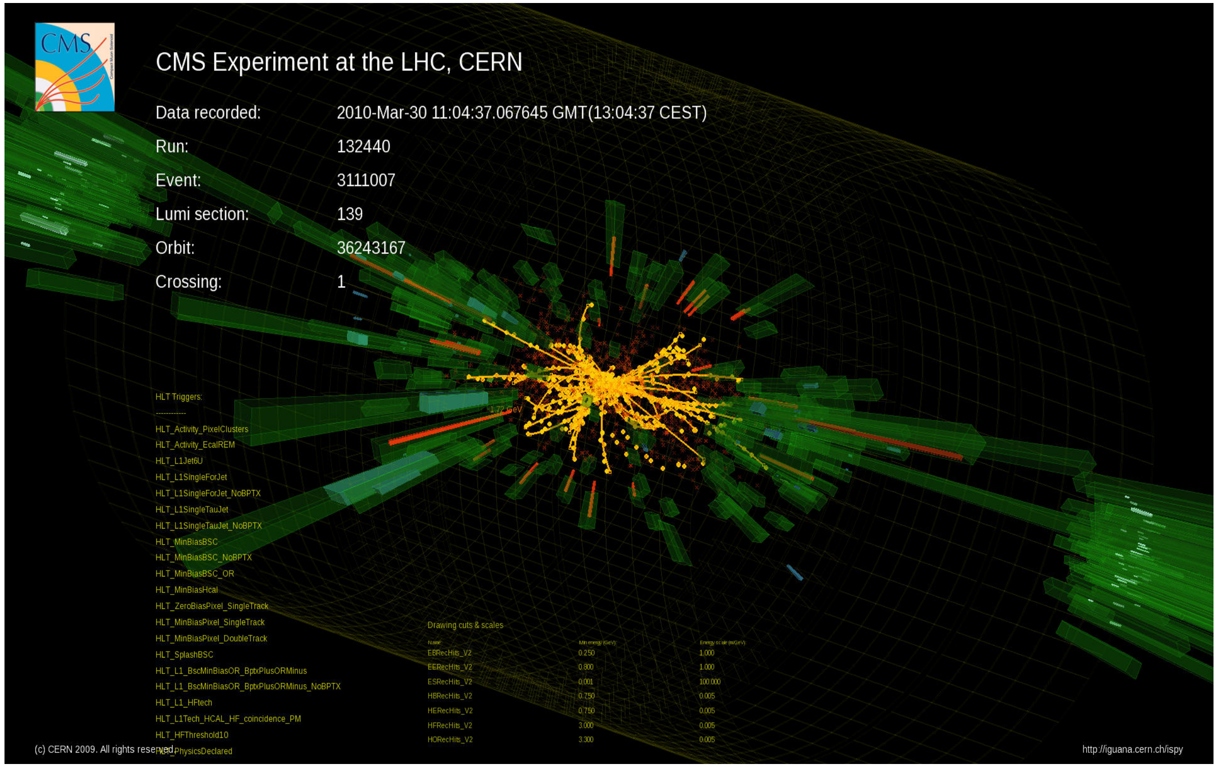
Fine mesh PMT response vs B & angle

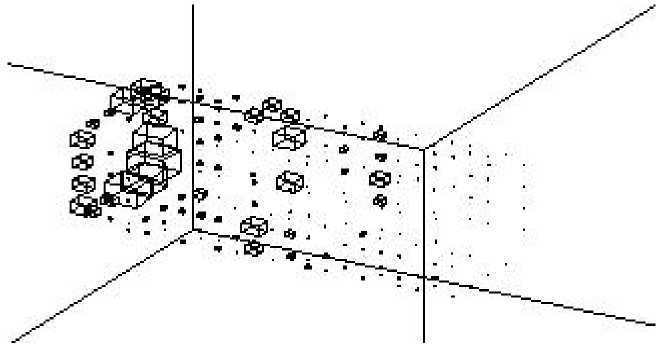
LED illumination, measured with SPACAL R5505 PMT at DESY



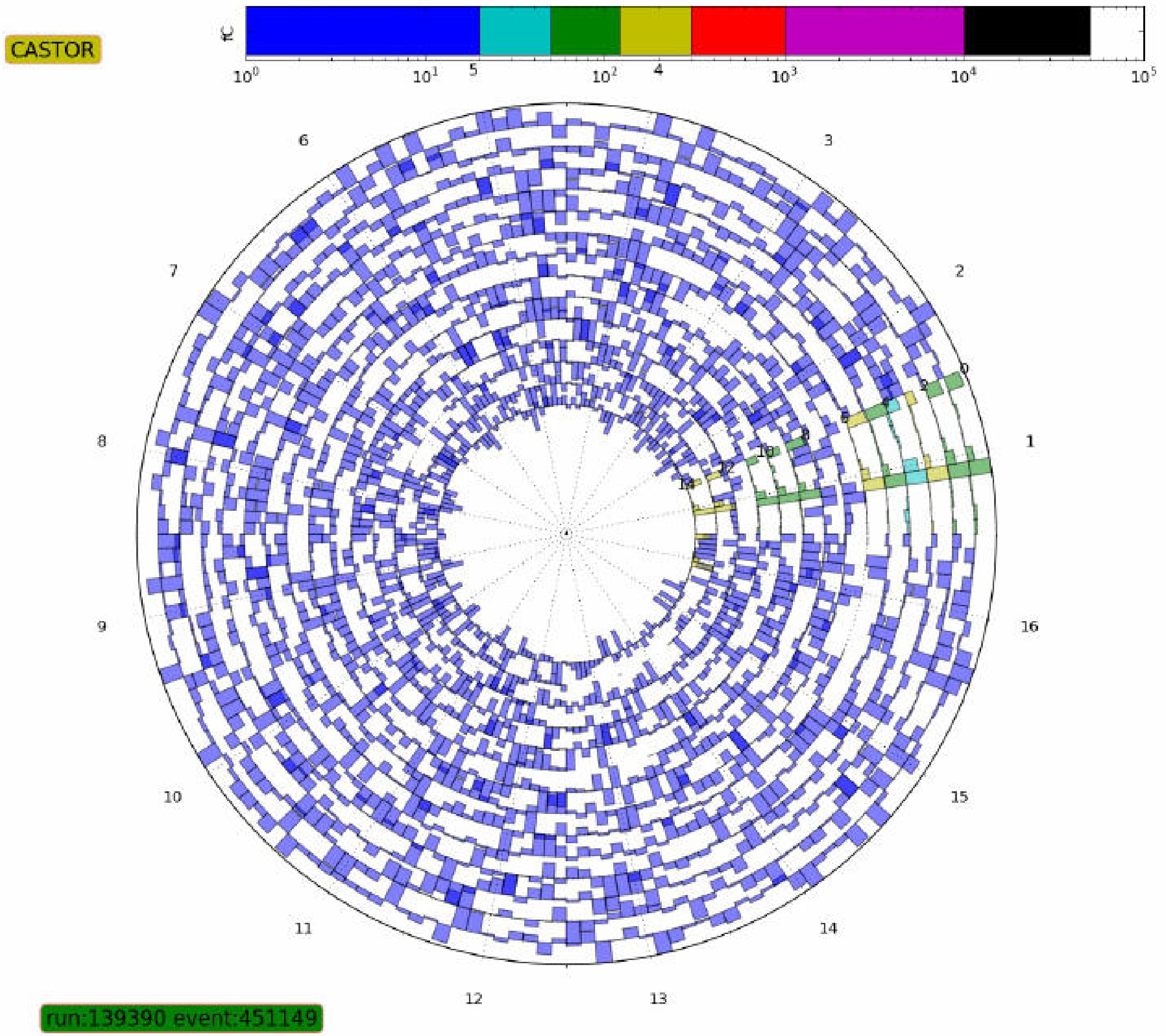
P. Goettlicher

First collisions at 7 TeV c.m.e.



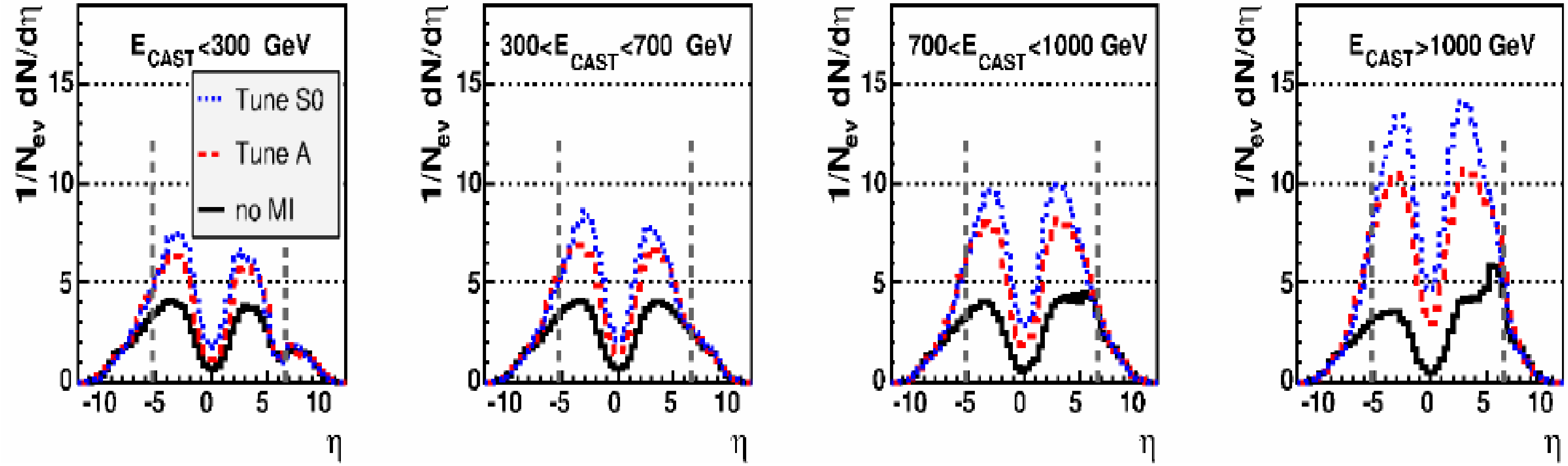


CASTOR calibration runs during injection / ramping: beam halo



Physics: forward-central multiplicity correlations

- Forward - central multiplicity correlations: better constraints on underlying event contributions
- Clear long-range correlation observed in case of Multi-Parton-Interactions



[Z. Rurikova, A. Bunyatyan in Proceedings of HERA-LHC workshop DESY-PROC-2009-002]