The LHC Experiments

Taller de Altas Energias

Benasque – 18 Septiembre 2013

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Preamble

- Physics is measurements. Th use mathematics, Ex –in HEP- use accelerators and detectors

- Investing in accelerator and detector development, and maintaining a healthy training of the new generations are fundamental requisites for the viability of our field

- The advance in science is linked to **precision** measurements:

"New directions in science are launched by new tools much more often than by new concepts.

The effect of concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained"

Freeman Dyson

… where are we today?

Content

1 The challenge of the LHC experiments

2 General purpose ATLAS and CMS detectors

3 A word on specialized detectors: ALICE and LHCb

4 The future: technology R&D themes

How LHC started?

1984 For the community it all started in a way with the 1st CERN – ECFA Workshop Lausanne on the feasibility of a hadron collider in the future LEP tunnel

1987 La Thuile LHC Workshop

1989 ECFA Study Week in Barcelona for LHC instrumentation

1990 ECFA Large Hadron Collider Workshop in Aachen

1991 December CERN Council: ʻLHC is the right machine for advance of the subject and the future of CERN ʻ(thanks to the great push byDG C Rubbia)

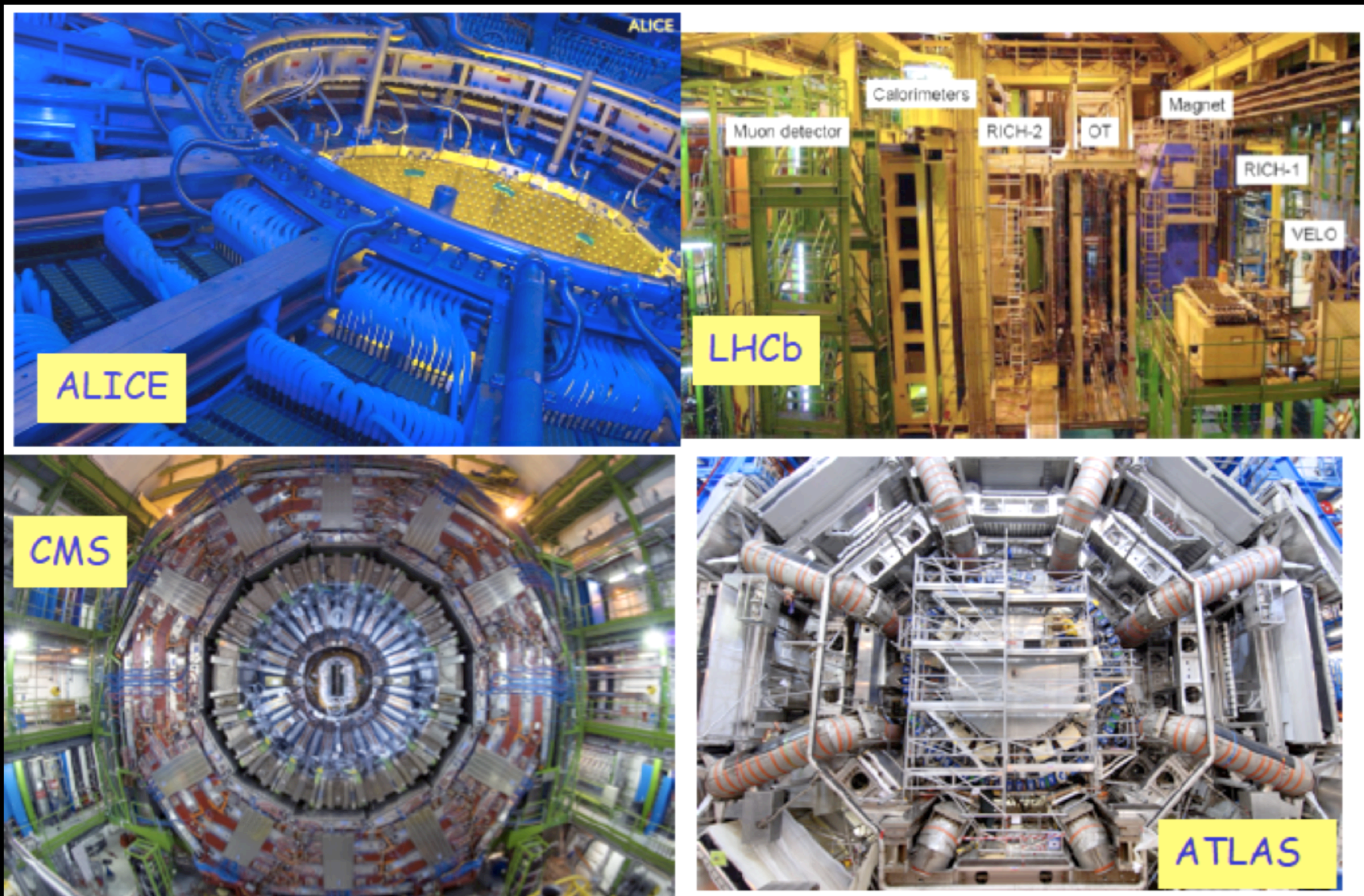
1993 December proposal of LHC with commissioning in 2002

16 December 1994 Council: (Two-stage) construction of LHC was approved

15 December 1994: ATLAS and CMS Technical Proposal were submitted

(from P. Jenni- More reference at the end)

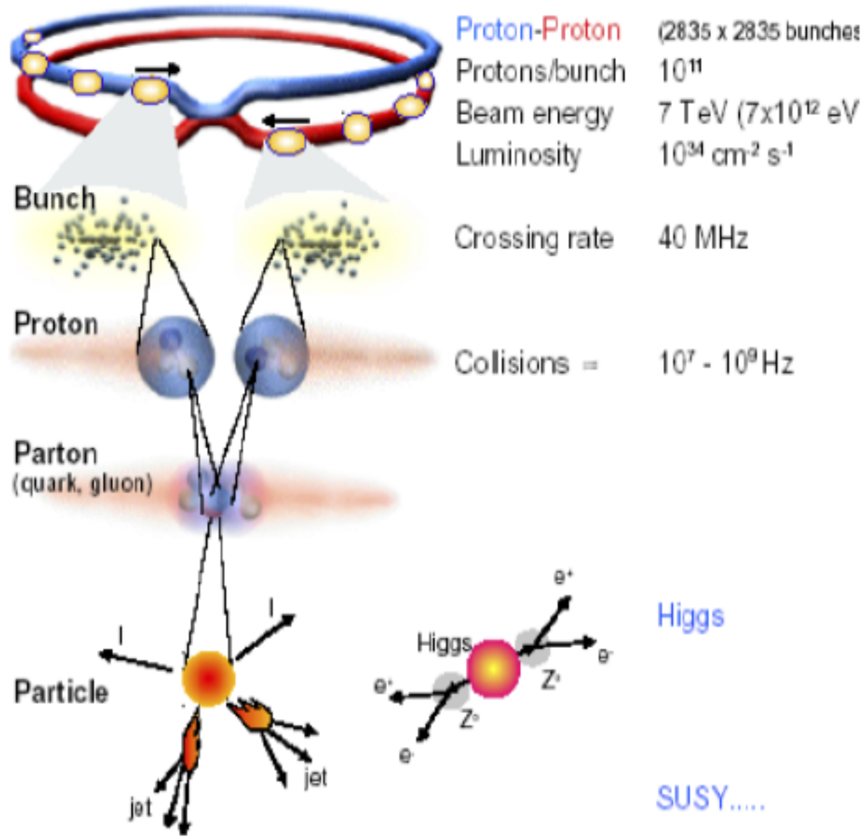
… 20 years later …



Construction of LHC Experiments Some Observations

- LHC Experiments were the first truly global construction projects in our field (ATLAS/CMS each with 150 institutions from 40 countries with >40 funding agencies)
- The time needed was long ~20 years, required stability of resources - including human resources, funding, raw material costs..- in the changing technological/economic conditions
- Early decision were needed in many fronts that could not benefit from the rapid change of some technological products
- Very challenging design and construction – many phases: R&D of different technologies, prototyping mostly with industry, worldwide distributed construction, assembly & installation at CERN
- .. With many surprises all along the process

(J. Virde. ES2012)



Conditions and requirements

LHC Environment

Main design operation parameters of the LHC

Beam energy	7	TeV
Instantaneous luminosity L	10^{34}	$cm^{-2}s^{-1}$
Integrated luminosity/year	~ 100	fb^{-1}
Dipole field	8.4	T
Dipole current	11700	A
Circulating current/beam	0.53	A
Number of bunches	2808	
Bunch spacing	25	ns
Protons per bunch	10^{11}	
R.m.s. beam radius at IP1/5	16	μm
R.m.s. bunch length	7.5	cm
Stored beam energy	360	MJ
Crossing angle	300	μrad
Number of events per crossing	20	
Luminosity lifetime	10	hours

Very high radiation levels

Precise timing, High event rates

High pile-up, high multiplicity and event size

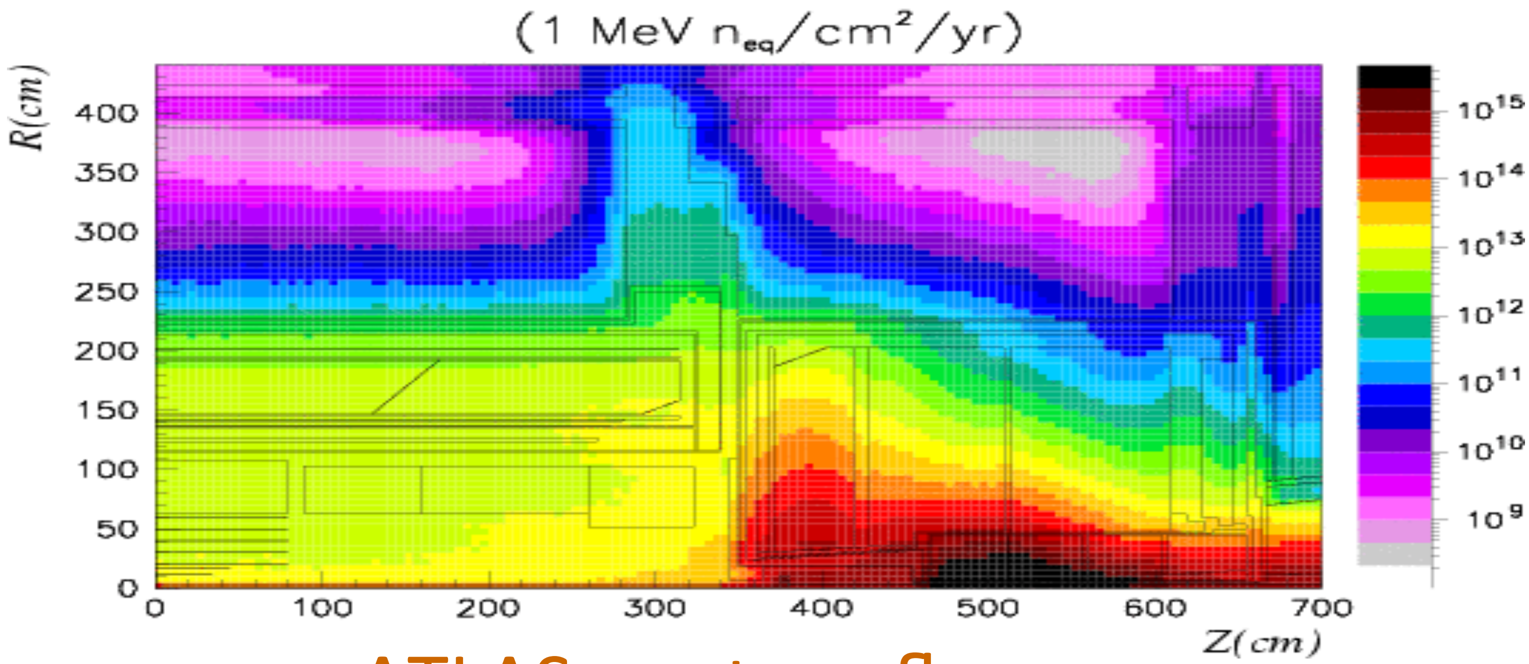
Keep these items in mind !

Severe Experimental Constraints

2808 bunches, each containing 100 billion protons, crossing 40 million times per second in the centre of each detector

1 billion proton-proton interactions per second in ATLAS and CMS (few orders of magnitudes less in ALICE and LHCb)

High Radiation Levels ⇨ radiation hard (tolerant) detectors and electronics

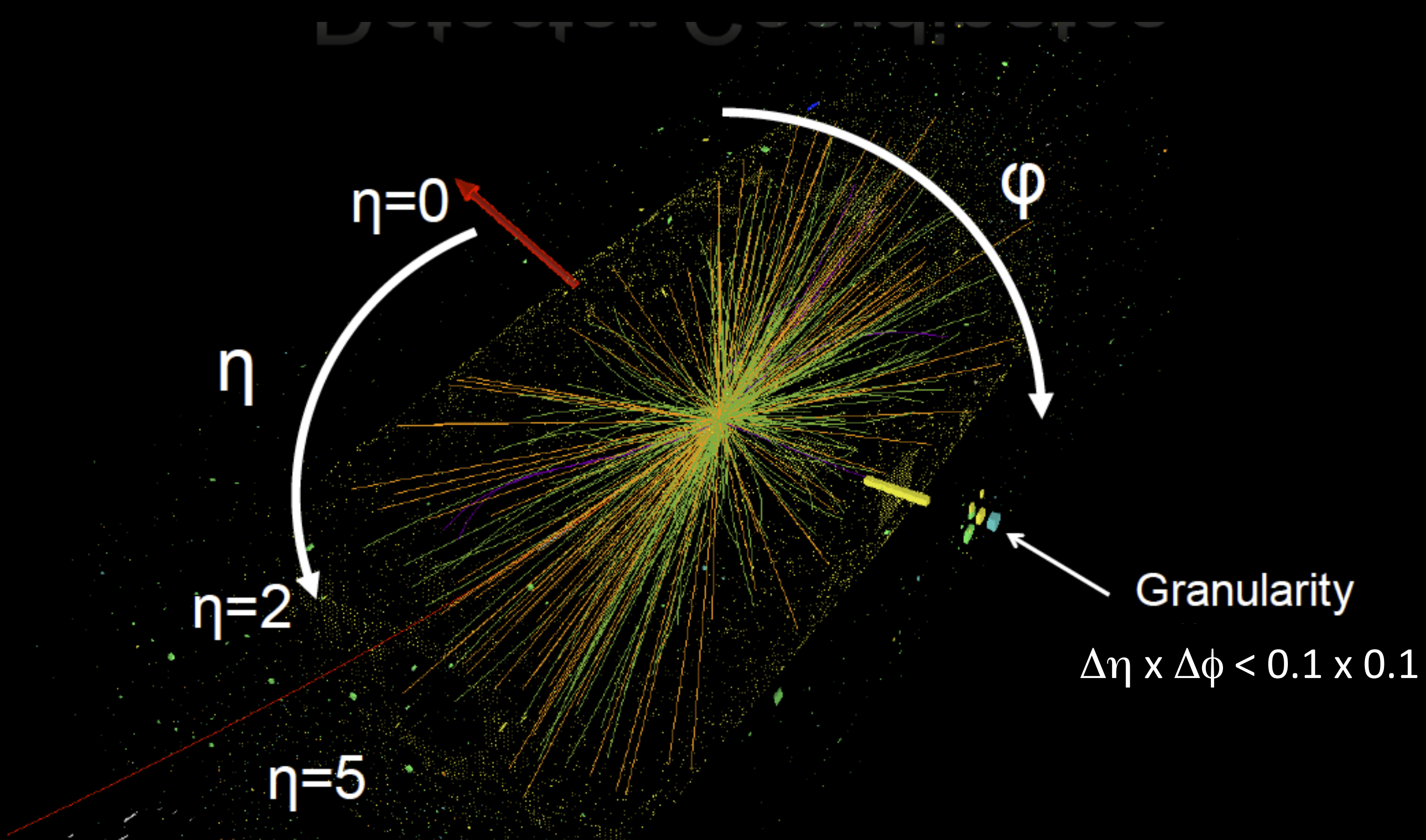


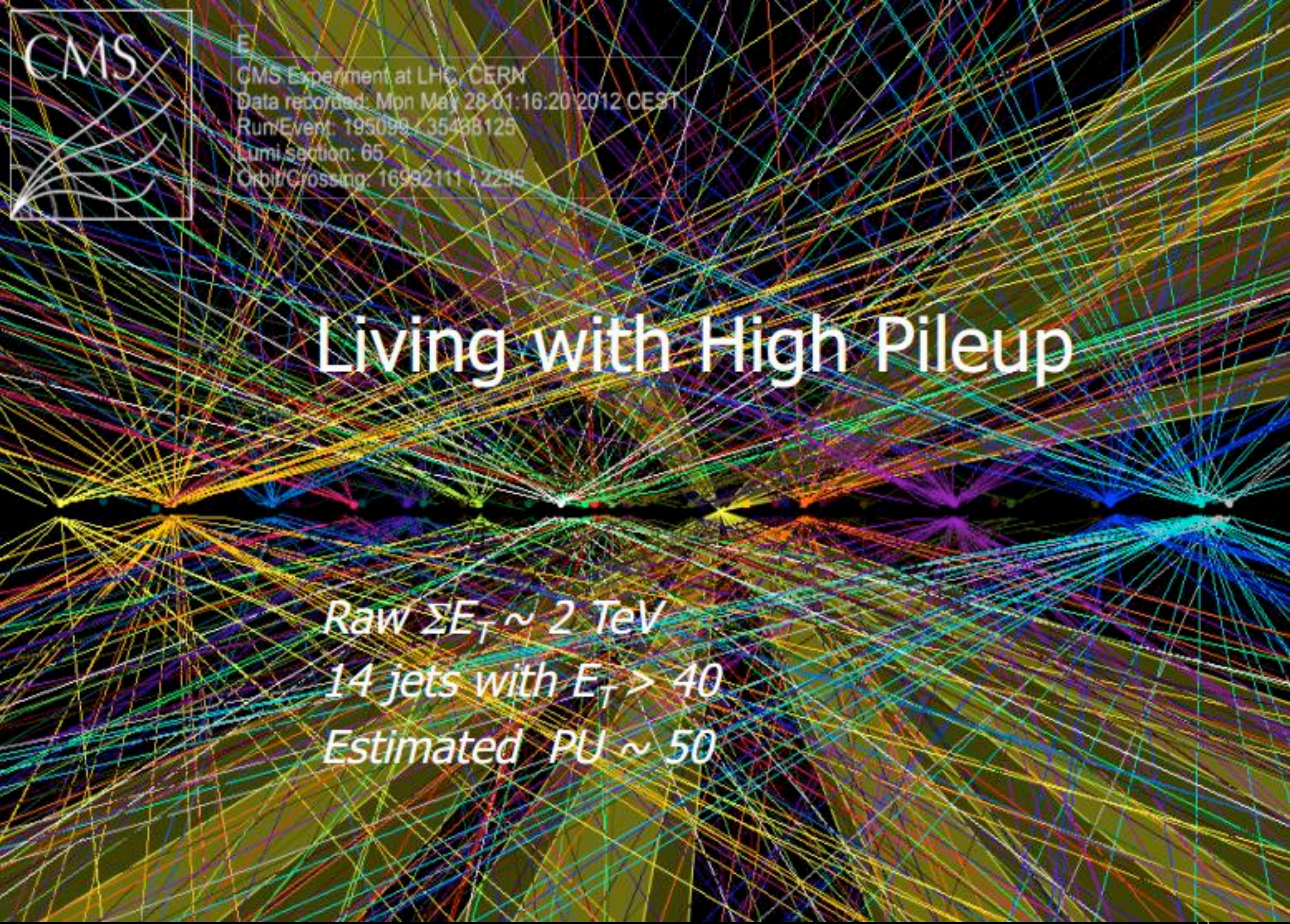
ATLAS neutron fluences

High rate of collisions per second and high pile-up

Large Particle Fluxes, ~ thousands of particles stream into the detector every 25 ns

⇨ **Highly granular detectors, large number of channels (~ 100 M channels in ATLAS and CMS) ~ 1 MB/25ns i.e. 40 TB generated per second**





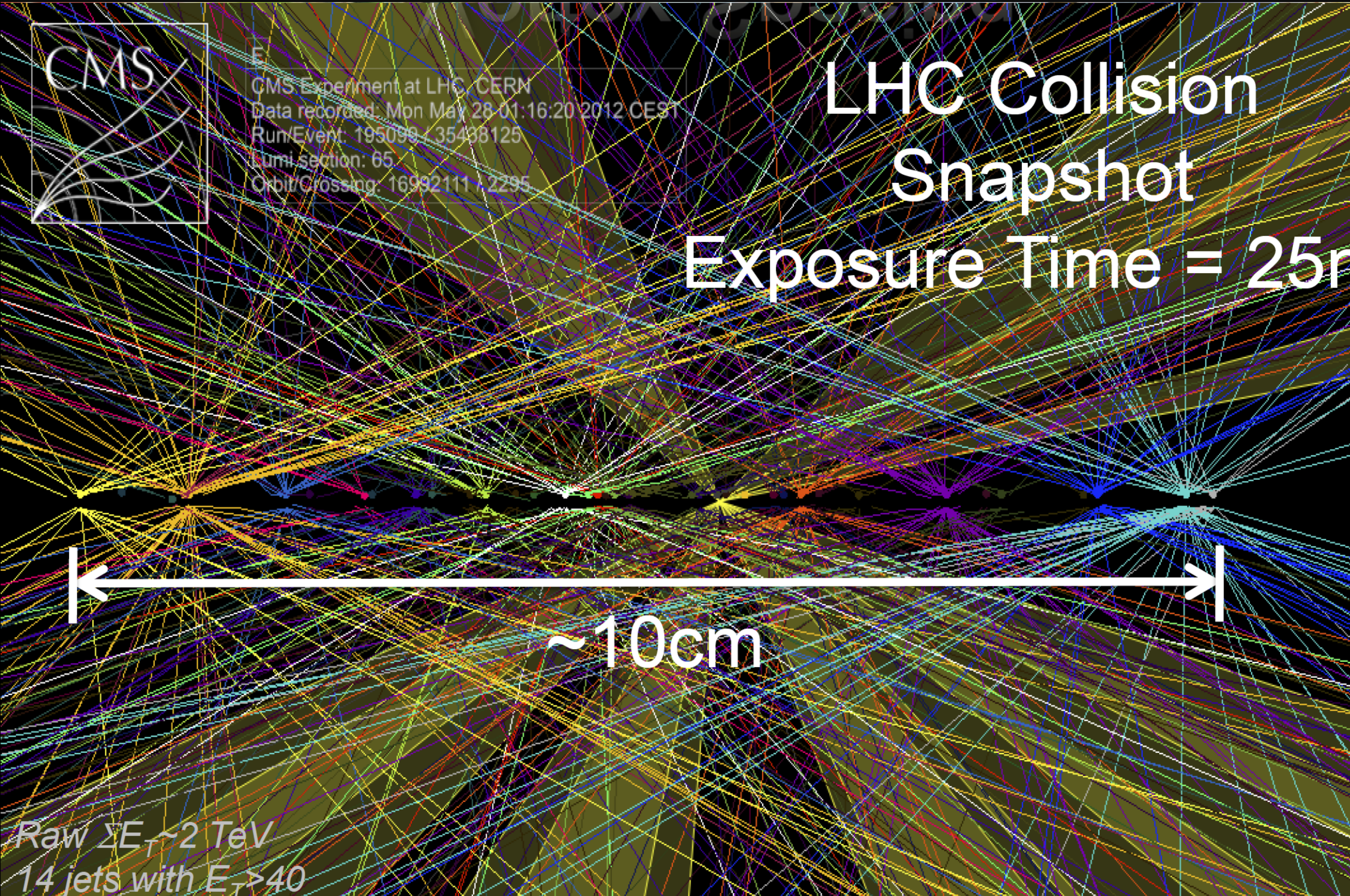
Living with High Pileup

Raw $\Sigma E_T \sim 2$ TeV

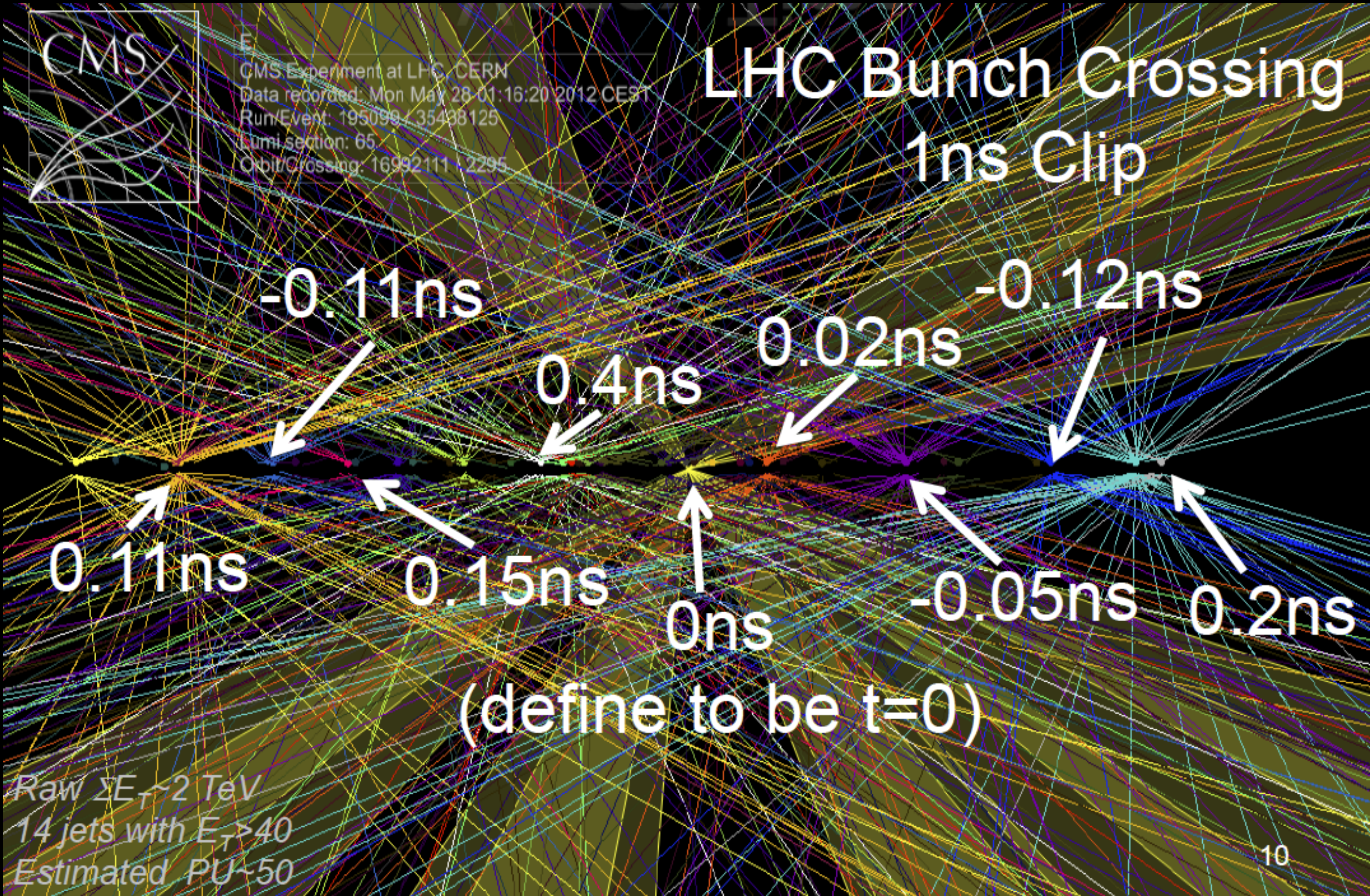
14 jets with $E_T > 40$

Estimated PU ~ 50

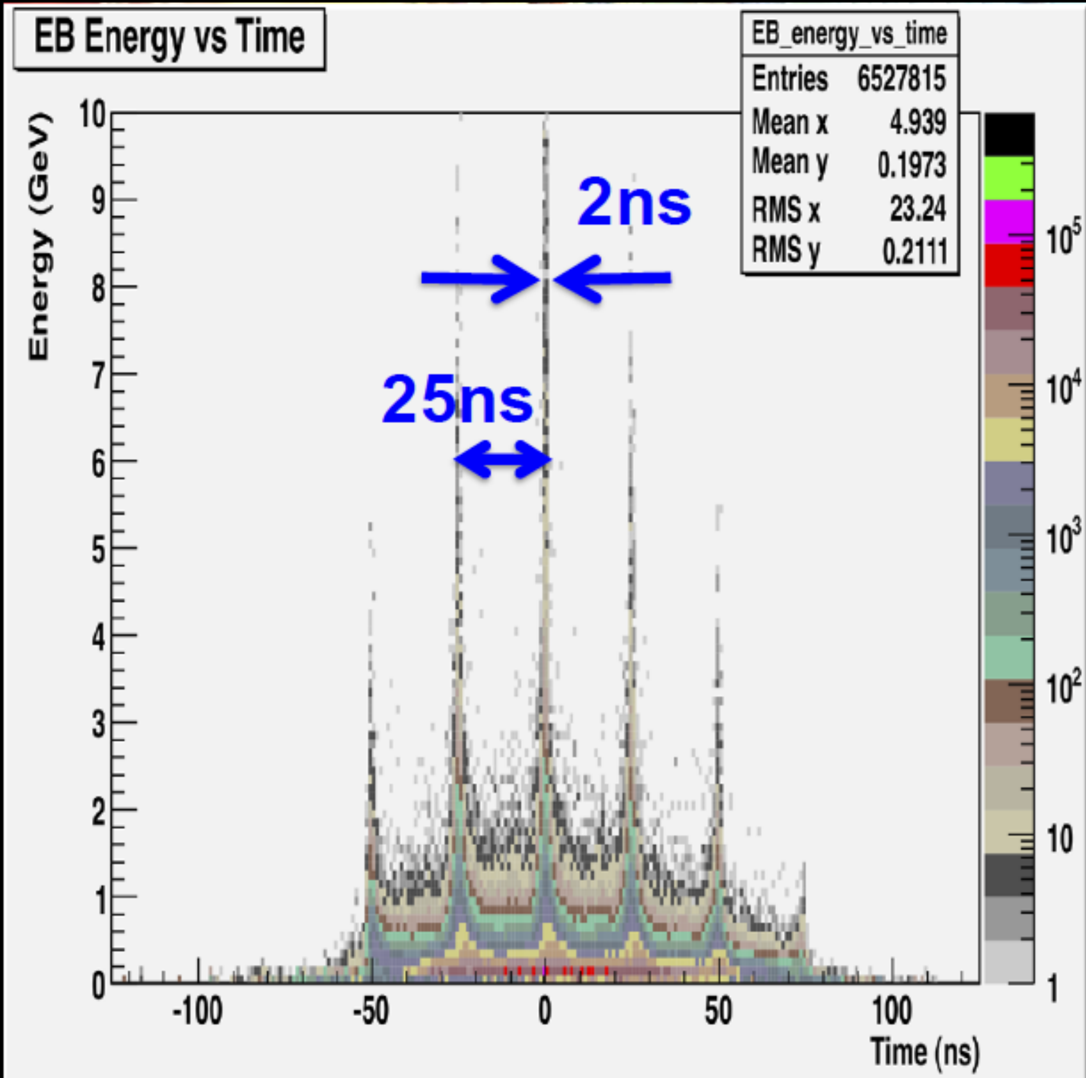
Vertex Spacing



In-time Pile-up



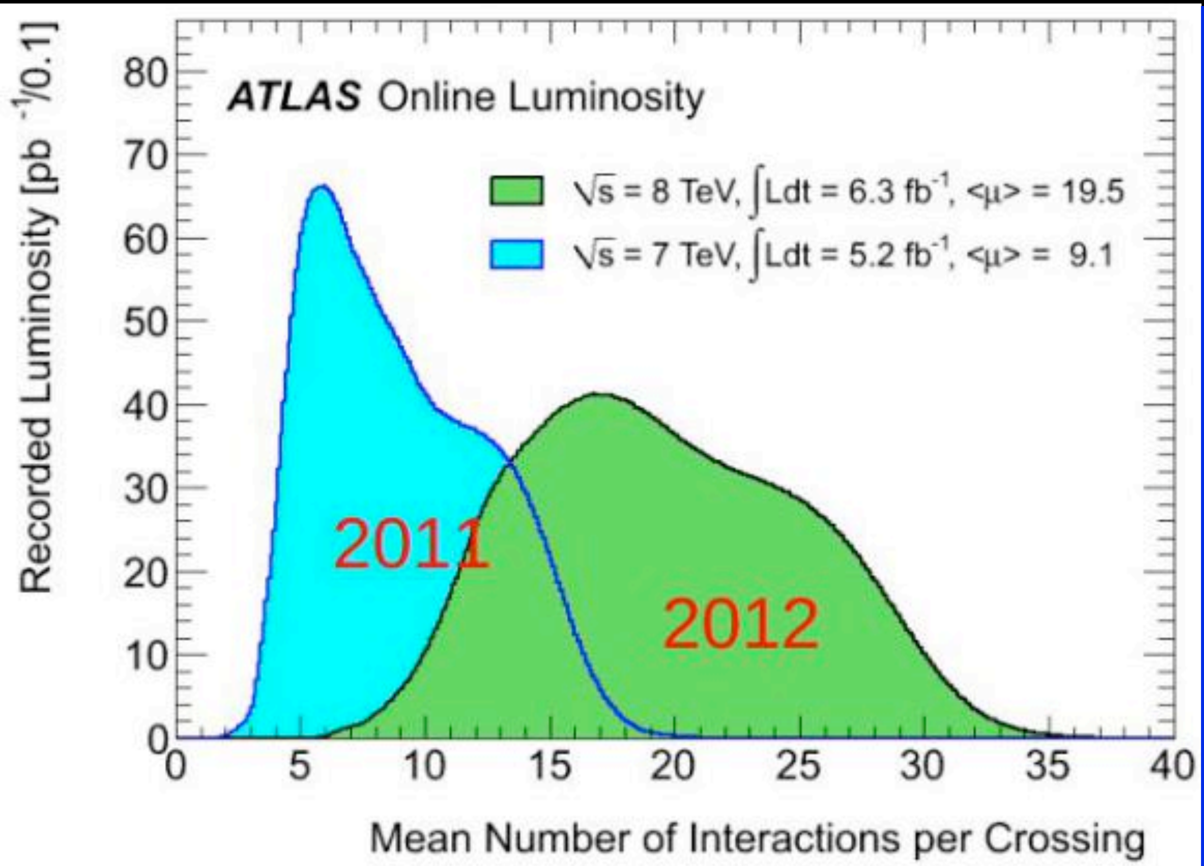
Out-of-time Pile-up



Some subdetectors, typically those than make precision energy measurements, have signal pulses that last ~100-150ns (or 600ns).

High pile-up will swamp the low energy pulses making it difficult to determine the correct bunch crossing assignment from the pulse shape alone.

Pile up distribution



Distributions are broad and change as the proton intensity of the beams drops

A given data set has a corresponding distribution of instantaneous luminosities that needs to be matched by the simulation

Therefore

LHC detectors must have fast response, and as good as possible timing resolution

Otherwise will integrate over many bunch crossings → large "pile-up"

→ integrate over 1-2 bunch crossings → pile-up of 25-50 min-bias

→ very challenging readout electronics

LHC detectors must be highly granular

Minimize probability that pile-up particles be in the same detector element as interesting object (e.g. γ from H → $\gamma\gamma$ decays)

→ large number of electronic channels

→ high cost

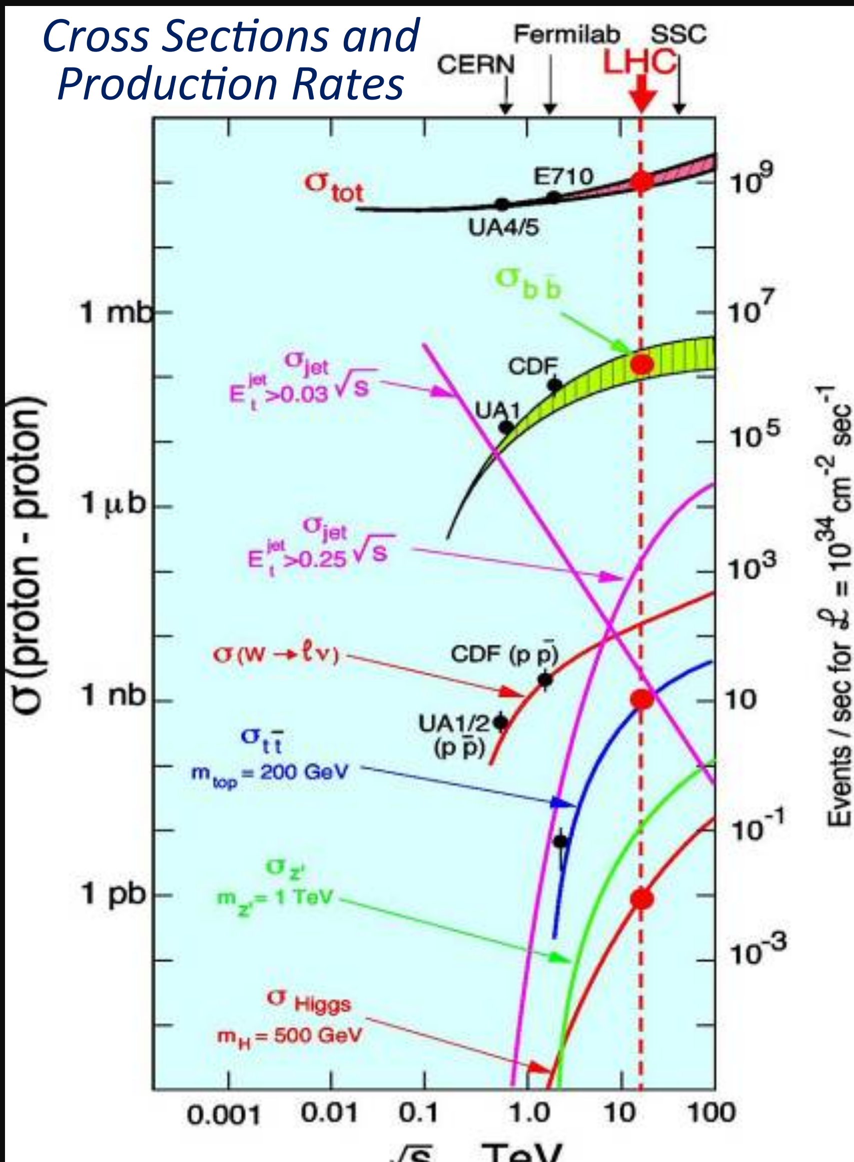
LHC detectors (and electronics) must be radiation resistant

Detectors must survive ~ 20 years under high flux of particles from pp collisions → high radiation environment e.g. in forward calorimeters:

- up to 10^{17} n/cm^2 in 10 years of LHC operation

- up to 10^7 Gy (1 Gy = unit of absorbed energy = 1 Joule/Kg)

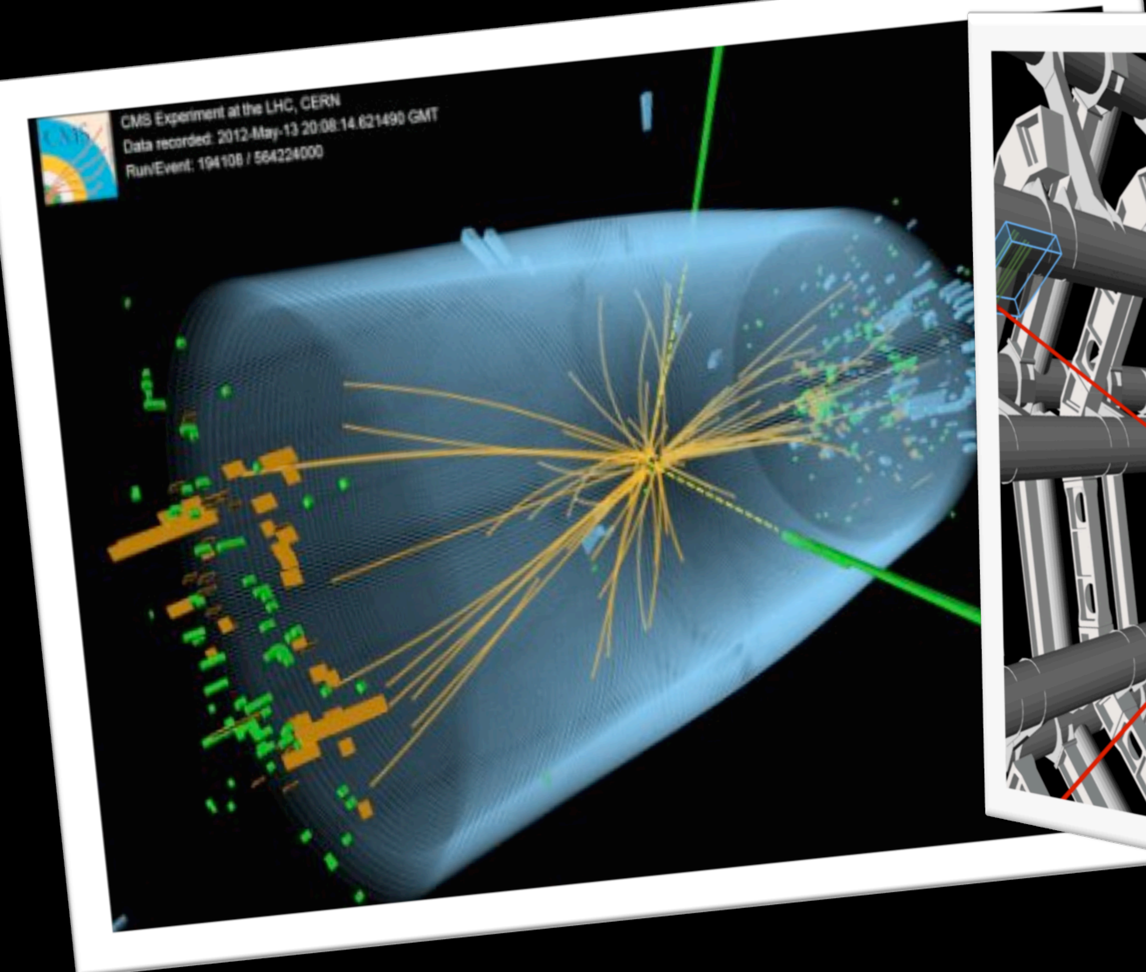
Requirements from Physics
The road map for discoveries

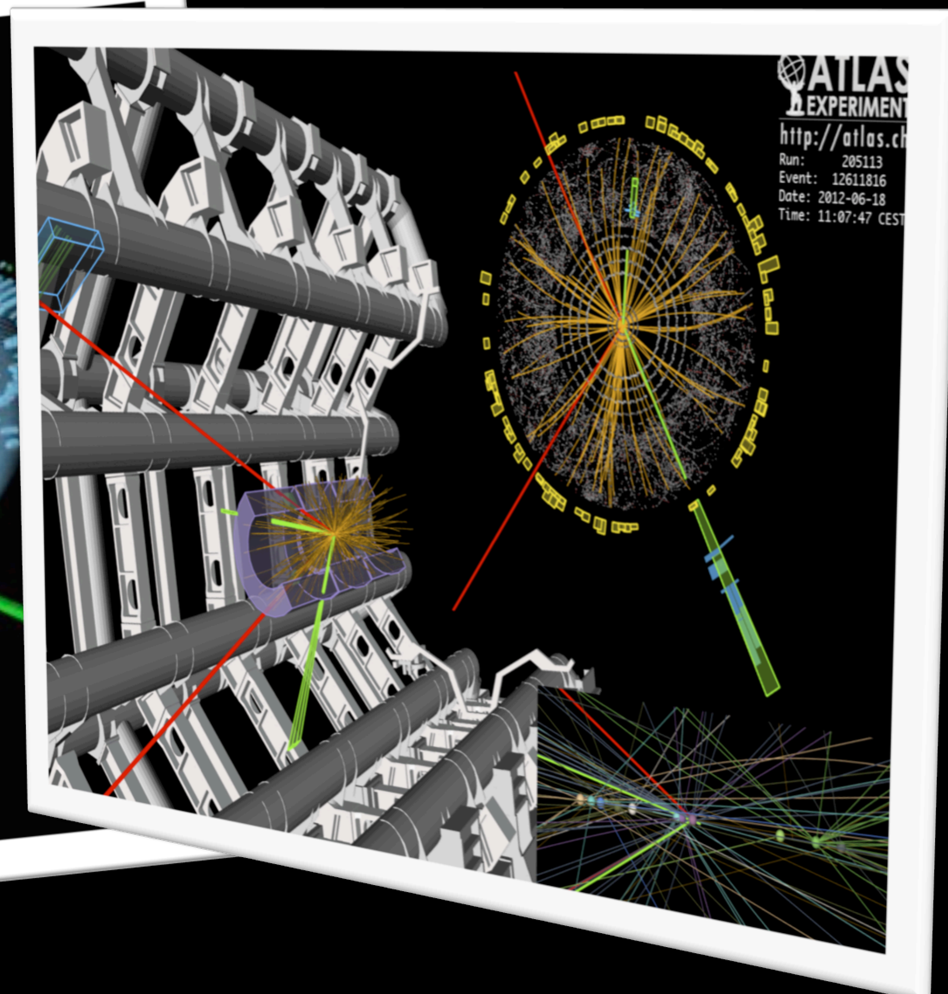


- Orders of magnitude of event rates for various physics processes
- Small x-sections need highest possible Luminosity
- Event rates:
  - Inelastic: 10^9/s
  - W-> lν (e or μ): 150/s
  - tt pairs: 8/s
  - Higgs (150 GeV): 0.2 /s
  - Gluino, Squarks (1TeV): 0.03 /s

⇒ Selection power ~ $10^{14\text{-}15}$ for Higgs discovery

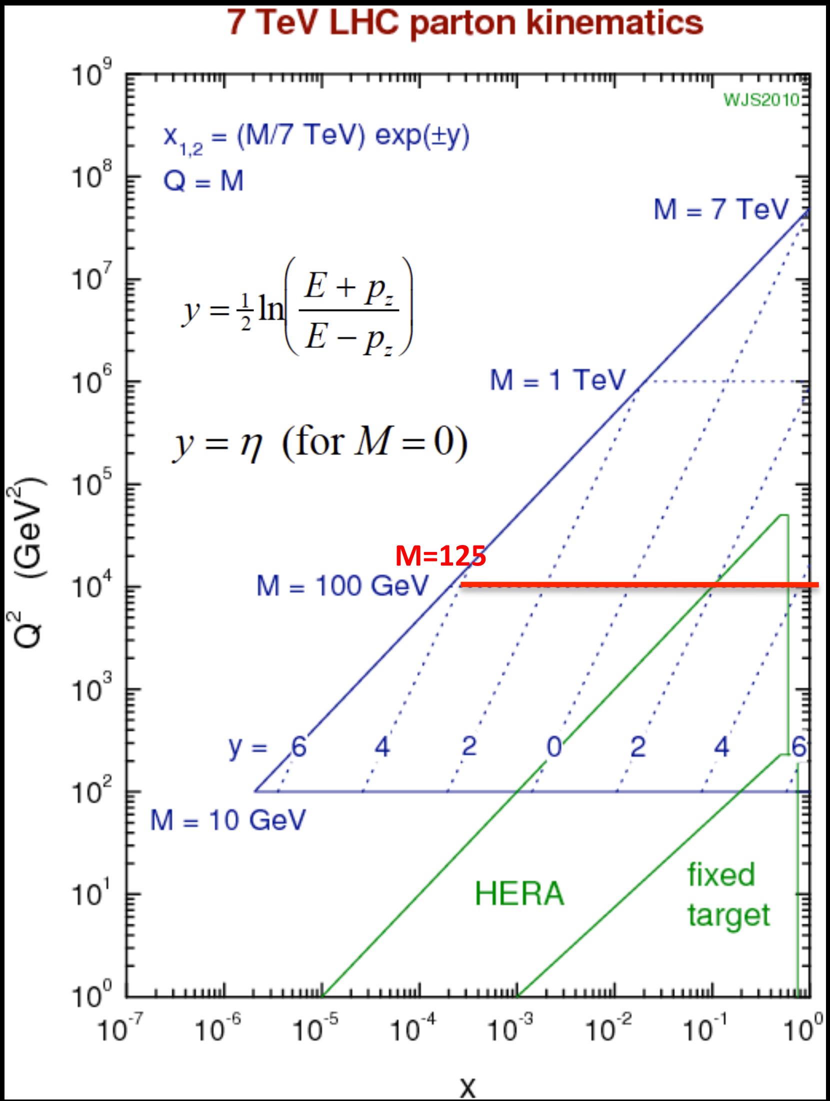
⇒ Optimization criteria??



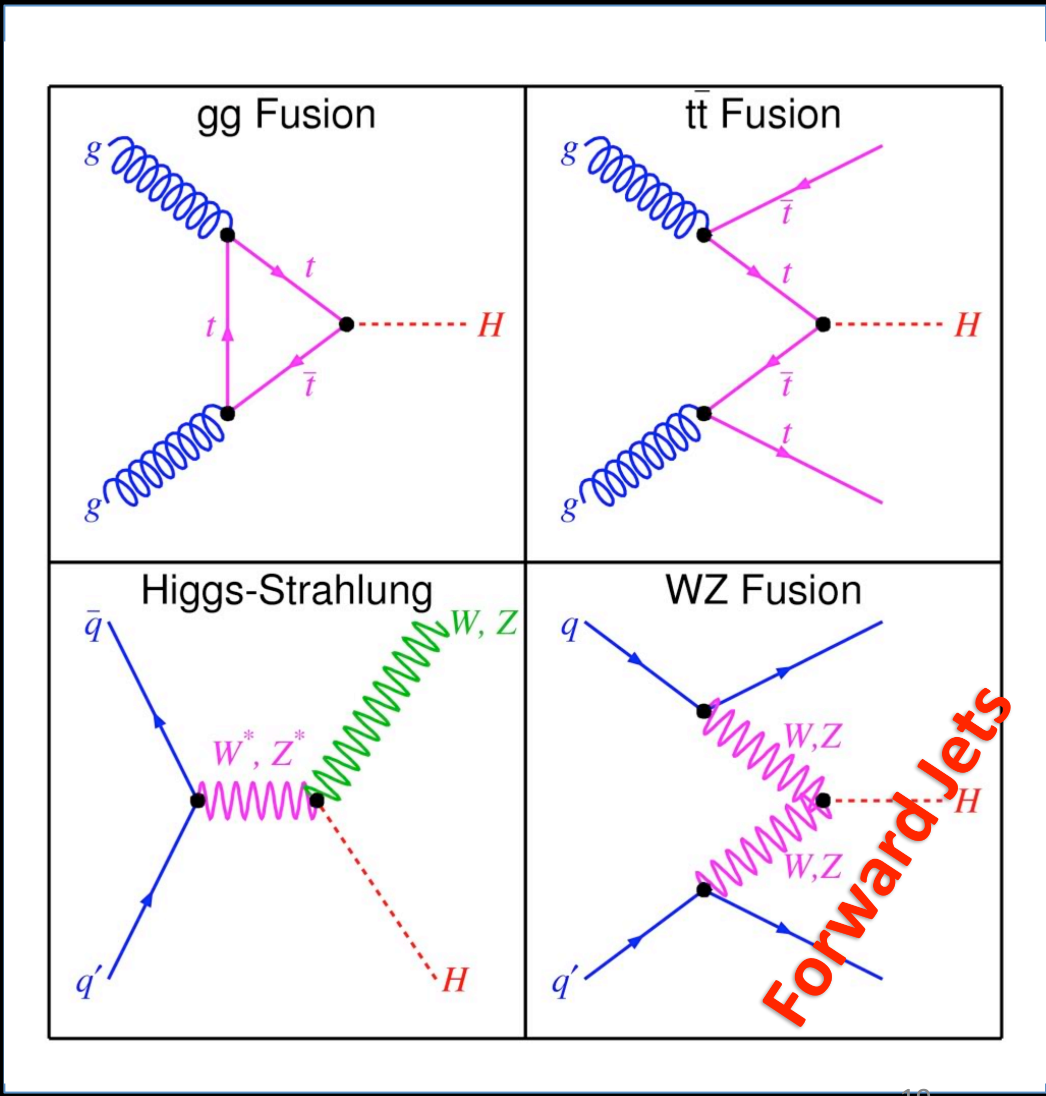


This has not been just good luck … ATLAS and CMS were optimized for Higgs discovery in the whole range of Higgs masses (but not only!)

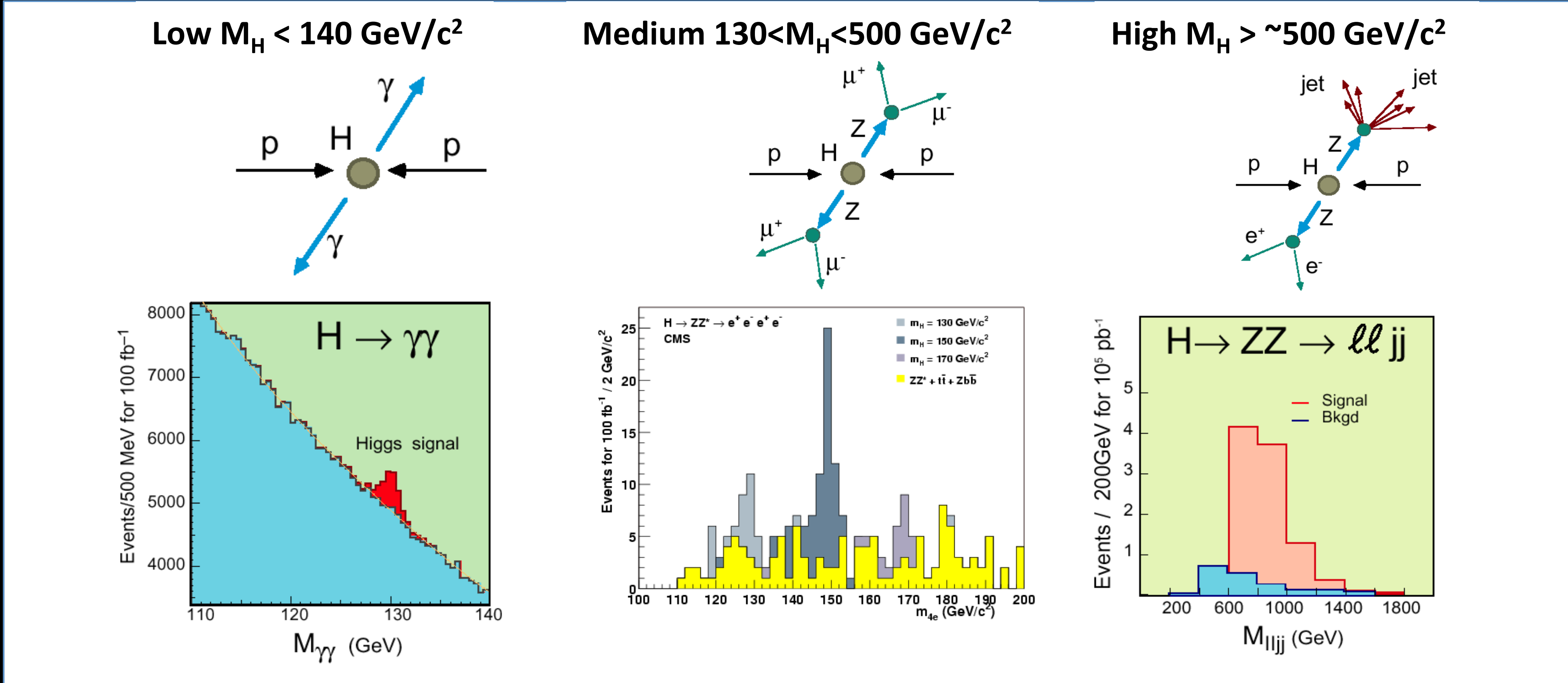
4π Coverage



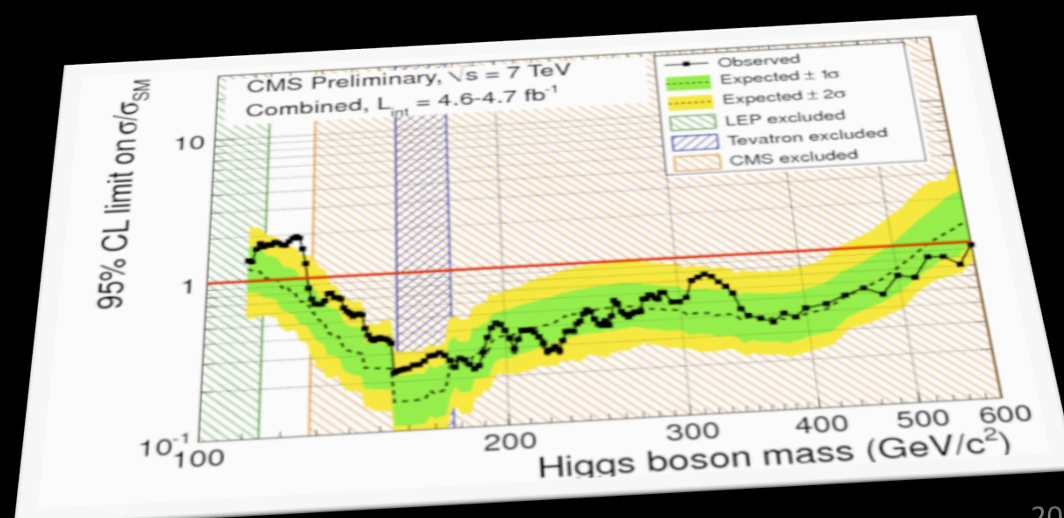
7 TeV LHC parton kinematics
WJS2010
$x_{1,2}$ = (M/7 TeV) exp(±y)
Q = M
$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$
$y = \eta$ (for $M = 0$)
M = 7 TeV
M = 1 TeV
M=125
M = 100 GeV
M = 10 GeV
y = 6 4 2 0 2 4 6
HERA
fixed target
Q^2 (GeV^2)
x



gg Fusion
$t\bar{t}$ Fusion
Higgs-Strahlung
WZ Fusion
W^*, Z^*
W, Z
W,Z
H
Forward Jets



From the old simulations … to reality



Therefore

LHC detectors must detect with high precision particles in a wide range of momenta and angle

- Tracking and vertexing (τ and b reconstruction)
- Electromagnetic calorimeter (H->$\gamma\gamma$, H->4e)
- Muon spectrometer (H->4μ)
- Missing Transverse Energy and di-jet mass resolution (H->tt, taus,Supersymmetry)

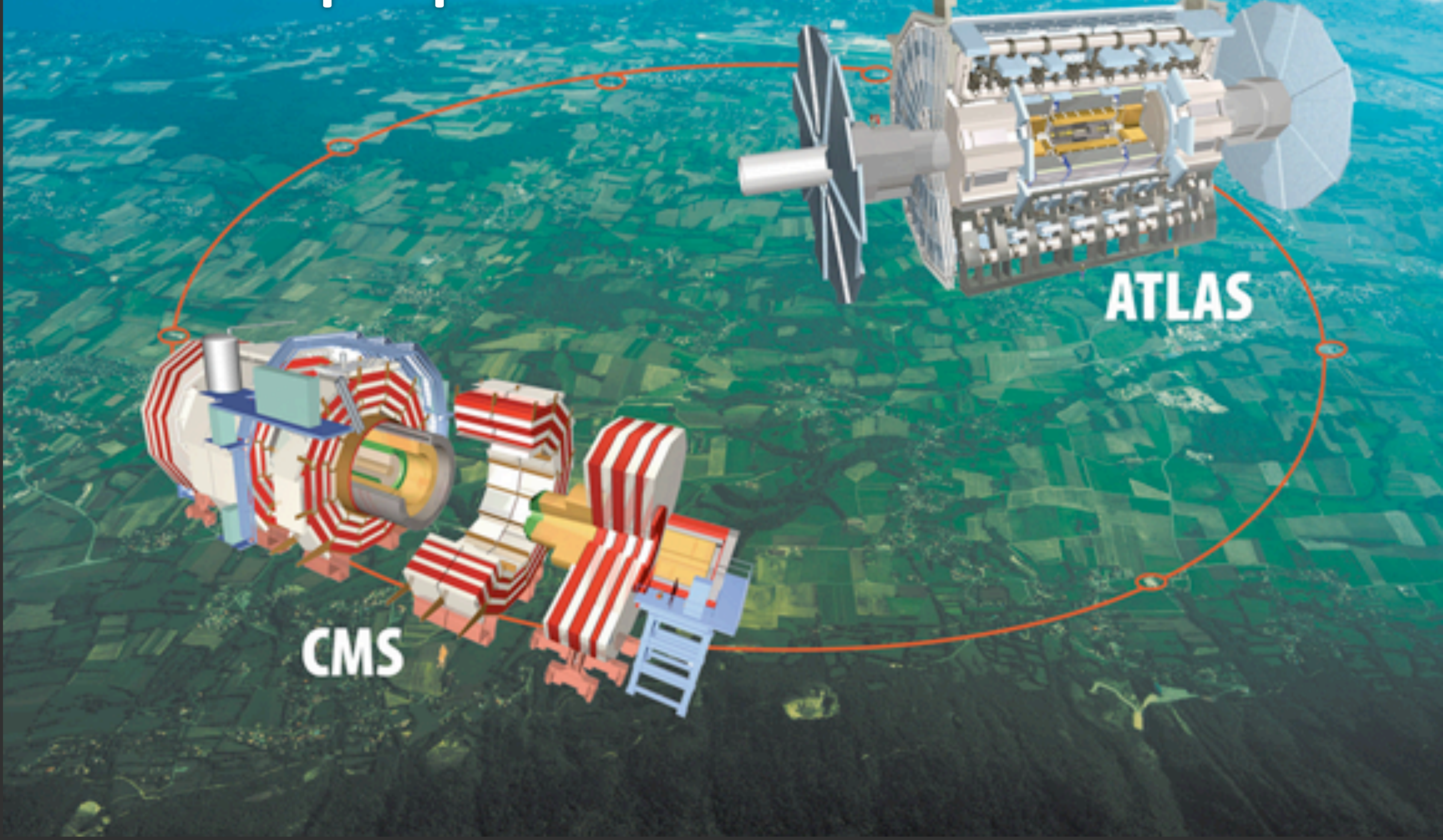
LHC detectors must identify very rare events, mostly in real time

- Robust lepton identification in the presence of a huge QCD background
- Achieve online rejection above ~ 10^7
- Store large data volumes to tape/disk

LHC detectors must "please"

- Detectors must be cost affordable for the funding agencies
- Large collaborations must be attractive to young physicists

General purpose 4π detectors



ATLAS & CMS

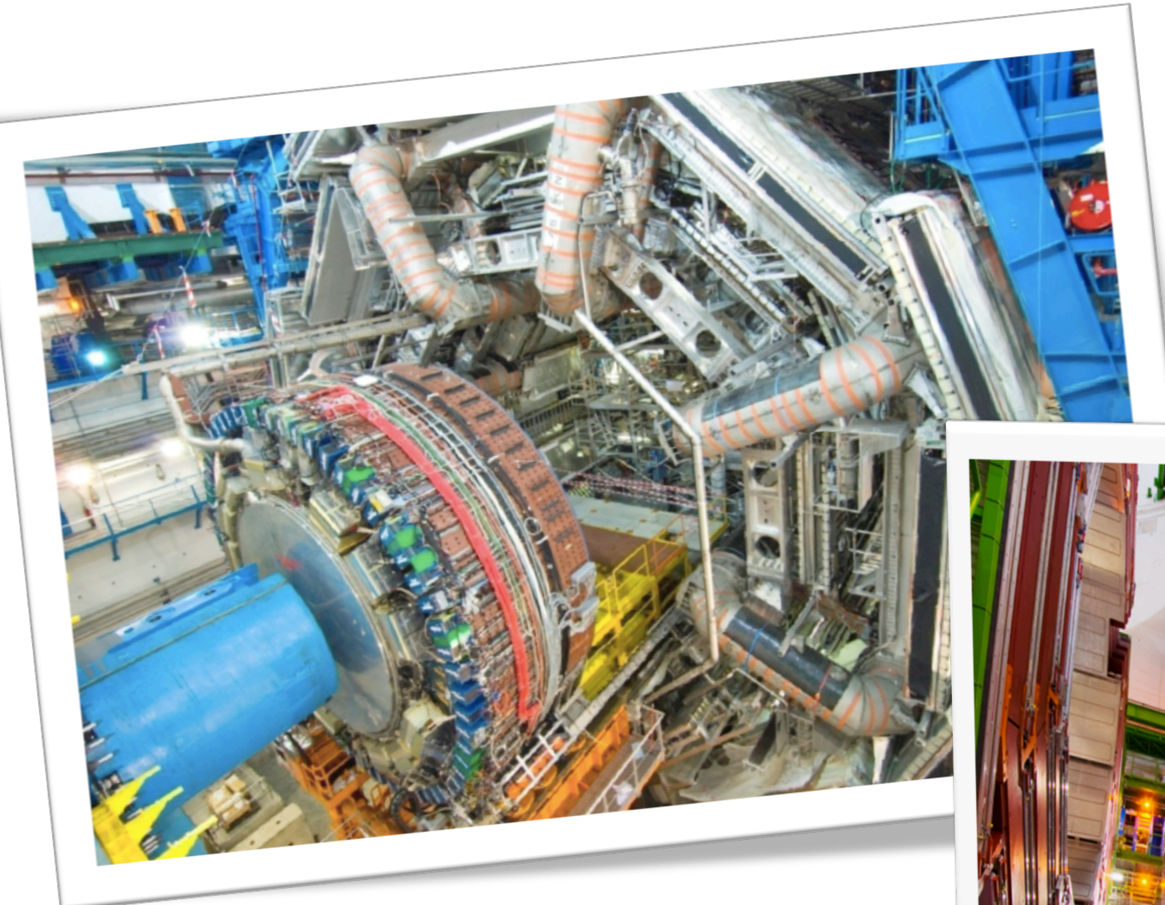
The big numbers

- Volume of ATLAS 20 000 m^3
- Weight of CMS 12 500 tons
- 66 to 80 million pixel readout channels near the vertex
- 200 m^2 of active Silicon of the CMS tracker
- 175 000 readout channels of the ATLAS LAr EM calorimeter
- 10 000 m^2 are of muon chambers
- Very selective Trigger/DAQ systems
- Large scale offline software and worldwide GRID computing

The size of ATLAS & CMS is directly related to energies of particles produced: need to absorb energy of 1 TeV electrons (30 X_0 or 18 cm of Pb), of 1 TeV pions (11 λ or 2 m Fe) and to measure momenta of 1 TeV muons outside calorimeters (BL^2)

Detector specifications

	ATLAS	CMS
MAGNET	4 magnets: 4T, 2T Air toroids + Solenoid Calorimeters outside field	1 magnet: 4T Solenoid Calorimeters inside field
TRACKER $\vert\eta\vert<2.5$	Si pixels + strips + TRT $\sigma/p_t \sim 4\times10^{-4} \oplus 0.015$	Si pixels + strips $\sigma/p_t \sim 1.5\times10^{-4} \oplus 0.005$
EM CALO $\vert\eta\vert<5$	Pb-Liquid Argon w/ long. segmentation $\sigma/E \sim 10\%/\sqrt{E}$	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$
HAD CALO $\vert\eta\vert<5$	Fe-scint + Cu-LA (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu+scint (5.8 λ + catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON $\vert\eta\vert<2.6$	Precision+Trigger Air→ $\sigma/p_t \sim 7\%$ @ 1 TeV w/ tracker (~10% standalone)	Precision+Trigger Fe→ $\sigma/p_t \sim 5\%$ @ 1 TeV w/ Tracker (~10-30% standalone)



Magnet Systems

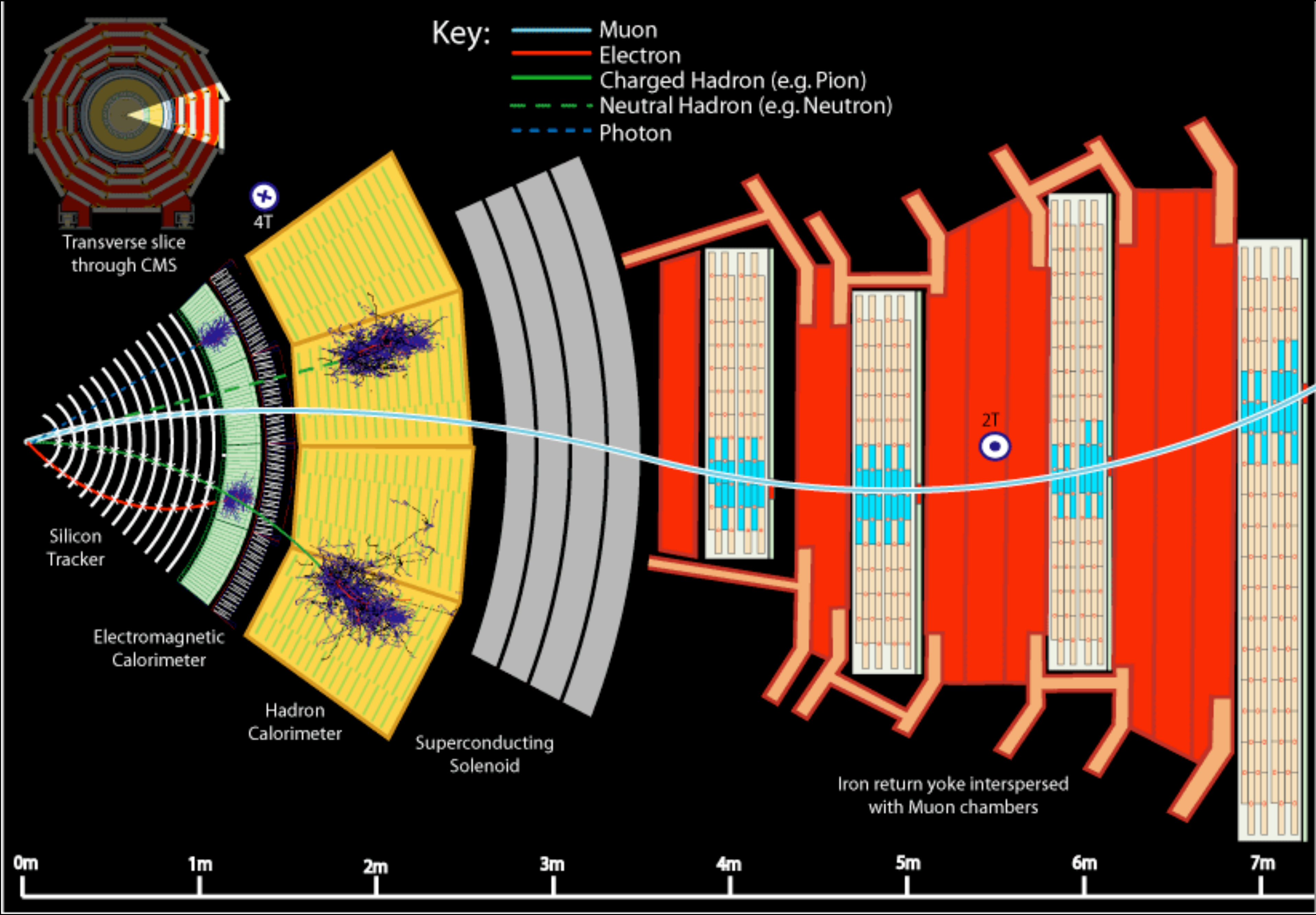
The choice of the magnet system shaped the experiments in a major way. The magnet is required to measure momenta and directions of charged particles near vertex and also to at the outer muon detectors

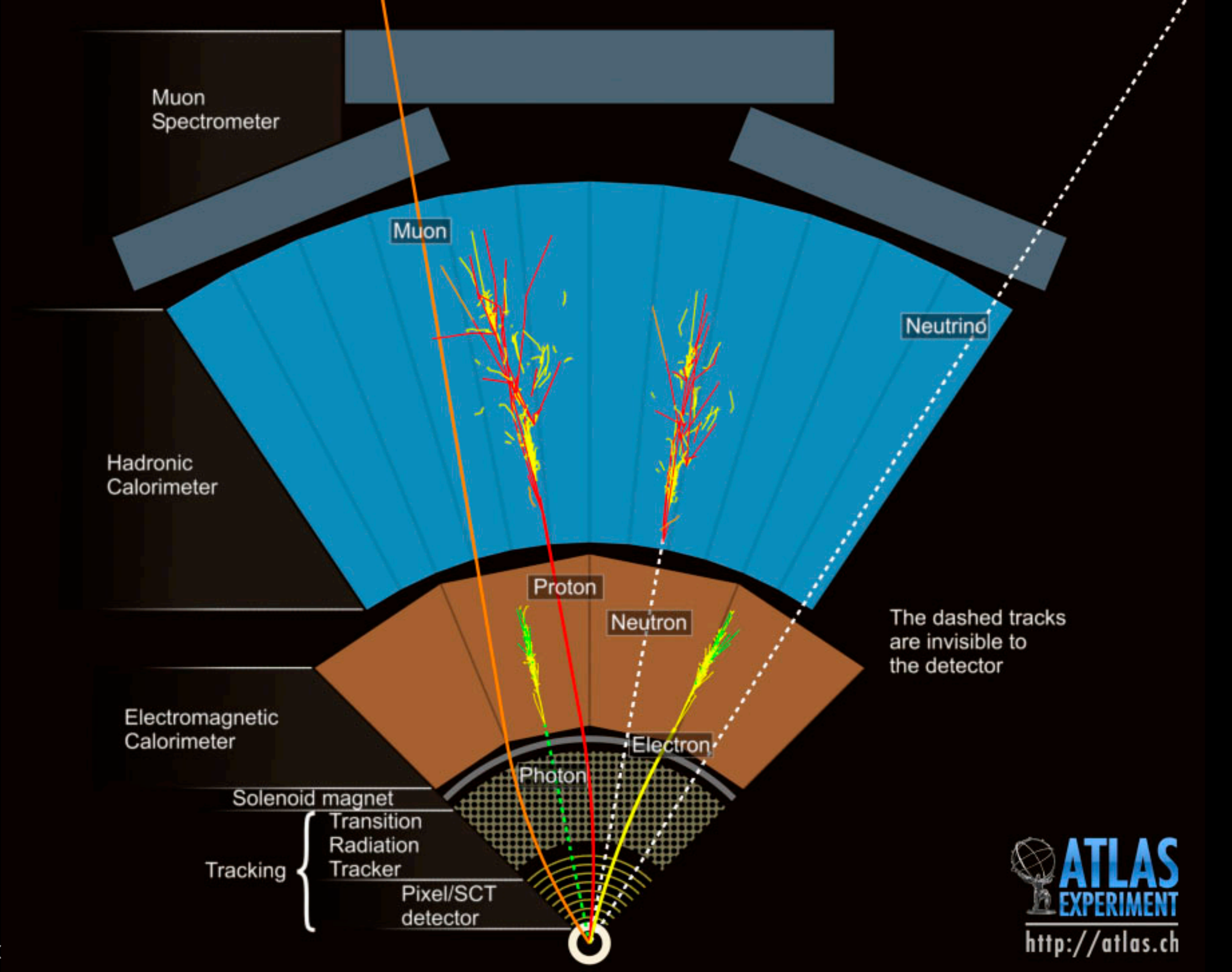
ATLAS choice: separate magnet systems ("small" 2 T solenoid for tracker and huge toroids with large BL^2 for muon spectrometer)

- **Pros**: large acceptance in polar angle for muons and excellent muon momentum resolution outside, without using inner tracker
- **Cons**: very expensive and large-scale toroid magnet system with complicated field configuration

CMS choice: one large 4 T solenoid with instrumented return yoke

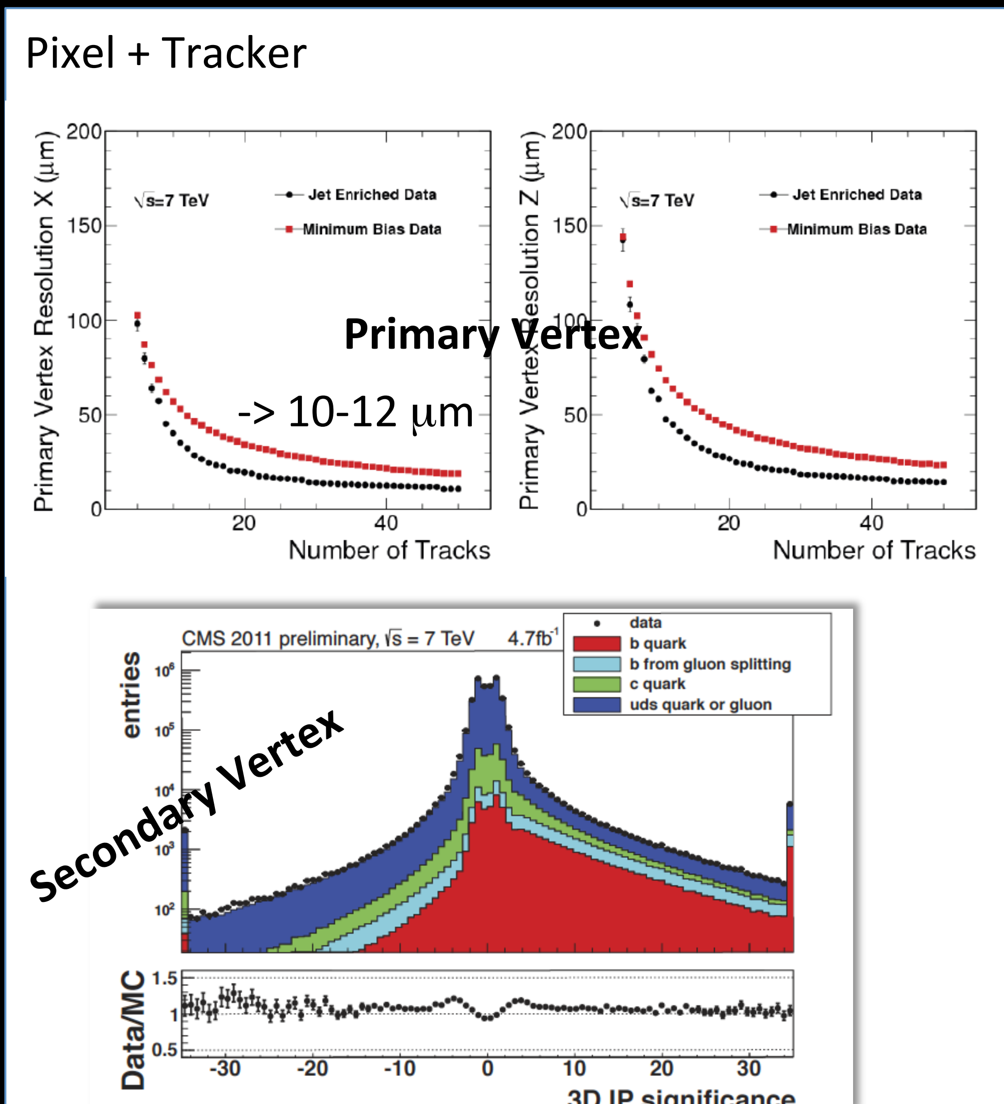
- **Pros**: excellent momentum resolution using inner tracker and more compact experiment with well defined field configuration
- **Cons**: limited bending power for endcap and limited space for calorimeter inside coil

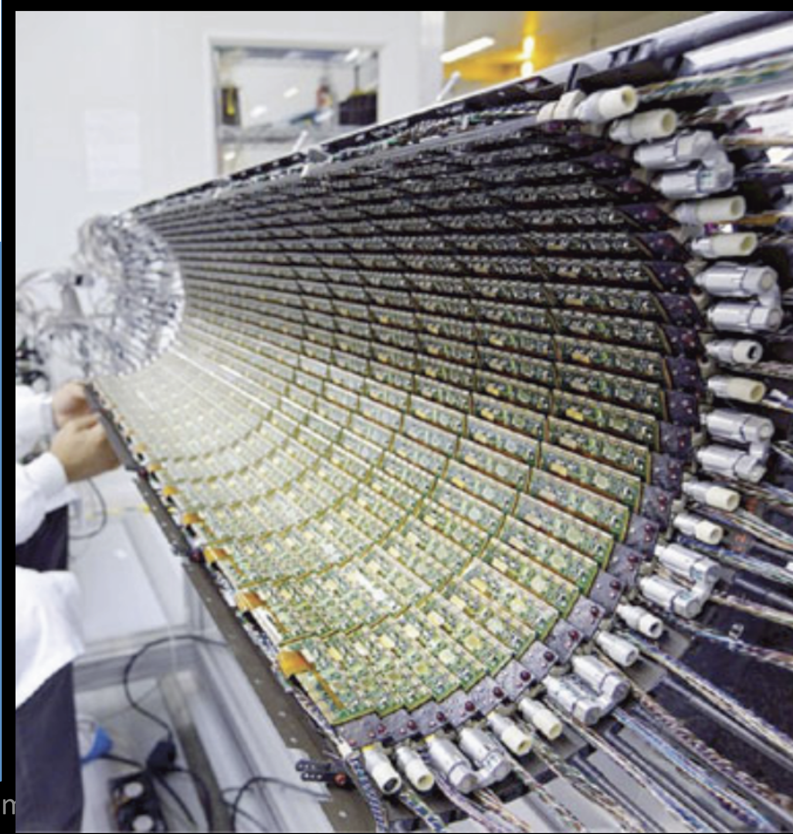

Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
Transverse slice through CMS
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0m
1m
2m
3m
4m
5m
6m
7m


Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks are invisible to the detector
ATLAS EXPERIMENT
http://atlas.ch

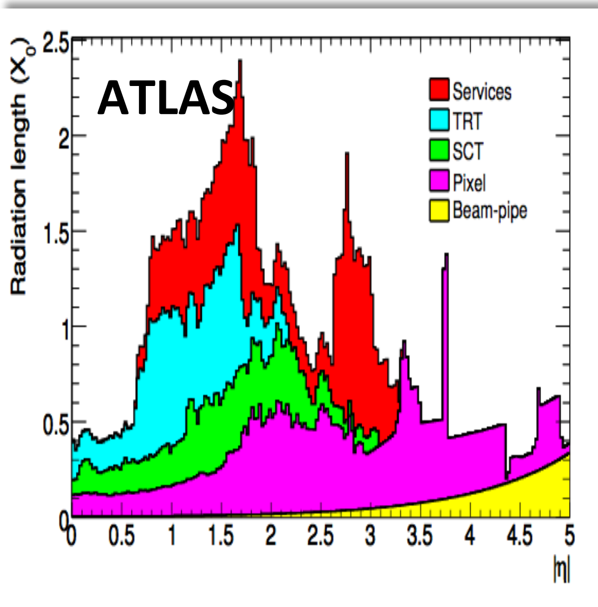
Pixel detectors

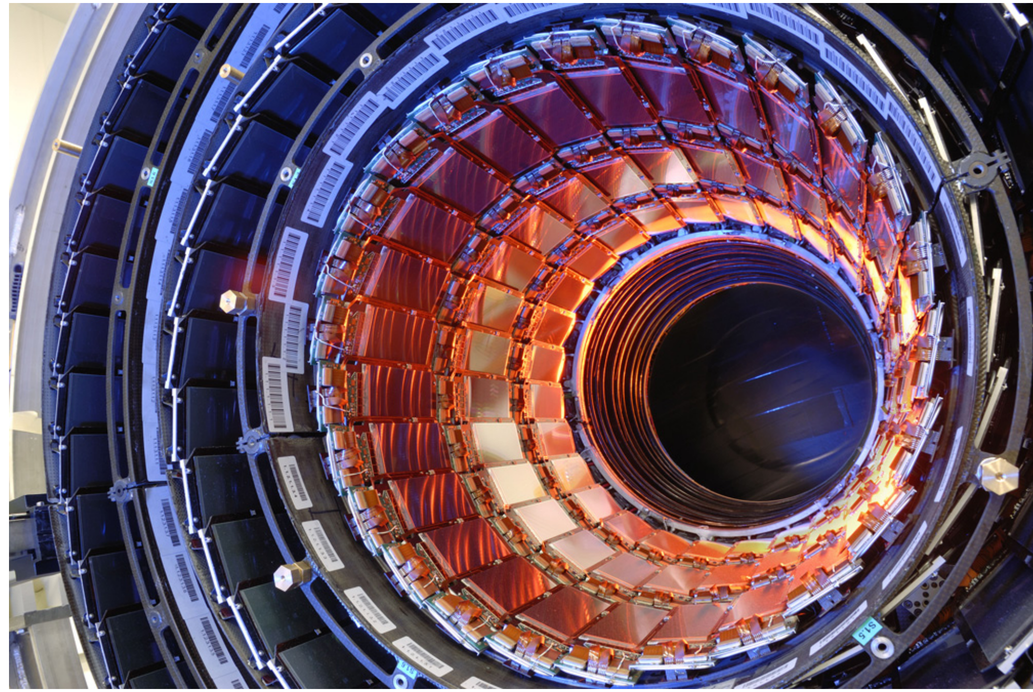
- The most critical detector for a high pile-up environment
- It provides unambiguous spatial coordinates close to the beam pipe (IP)
- It covers ~ 2 m^2 with pixels ~50 x 300μm^2 in 3 barrel shells (5-12 cm radii typically) and 3 forward disks at each end



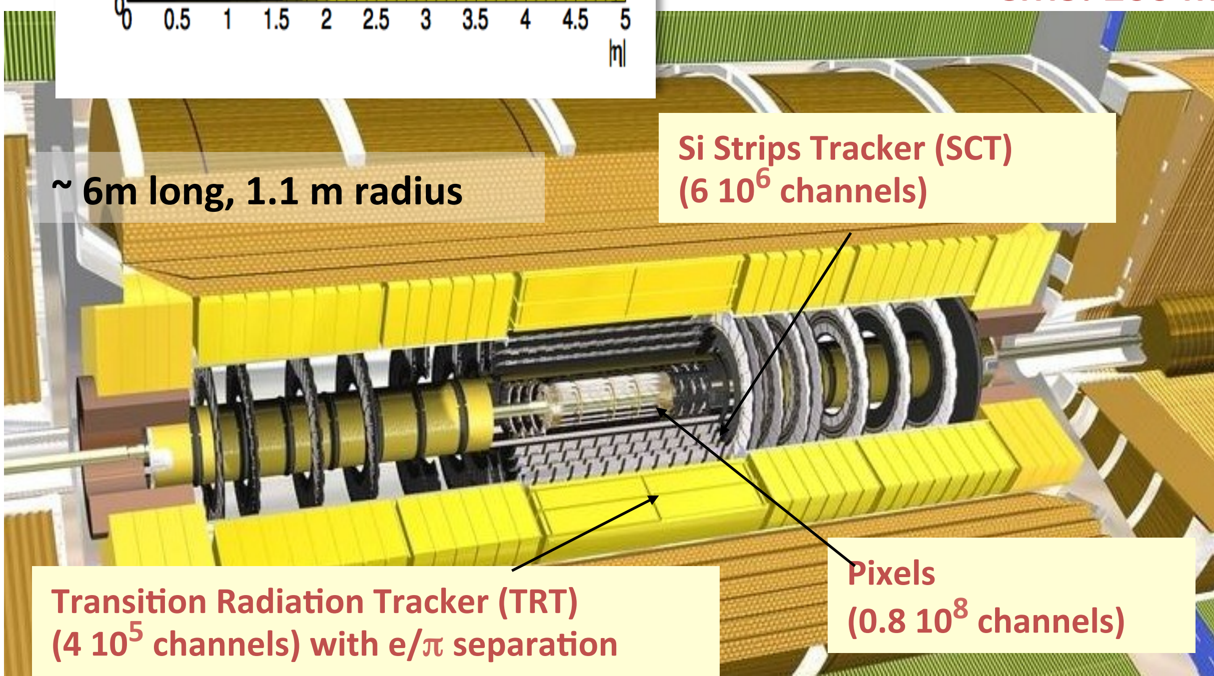


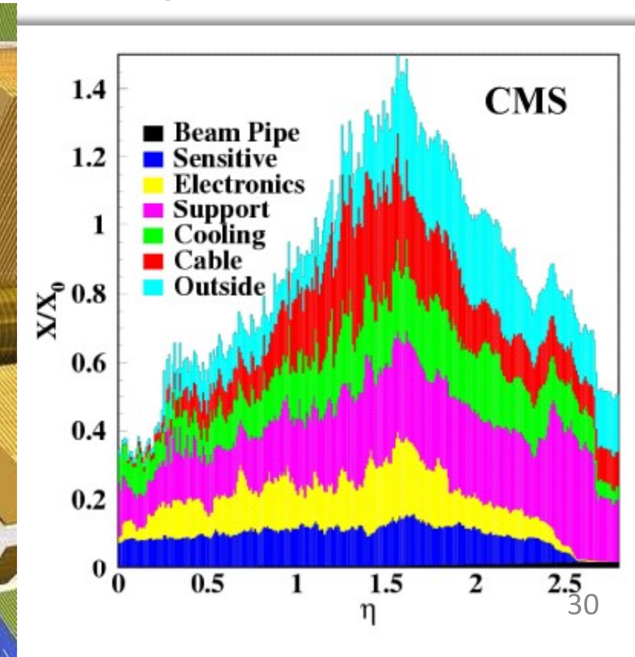
Tracker systems





CMS: 200 m^2 Si, 8 layers, 9.6 million channels





Electrons and Photons

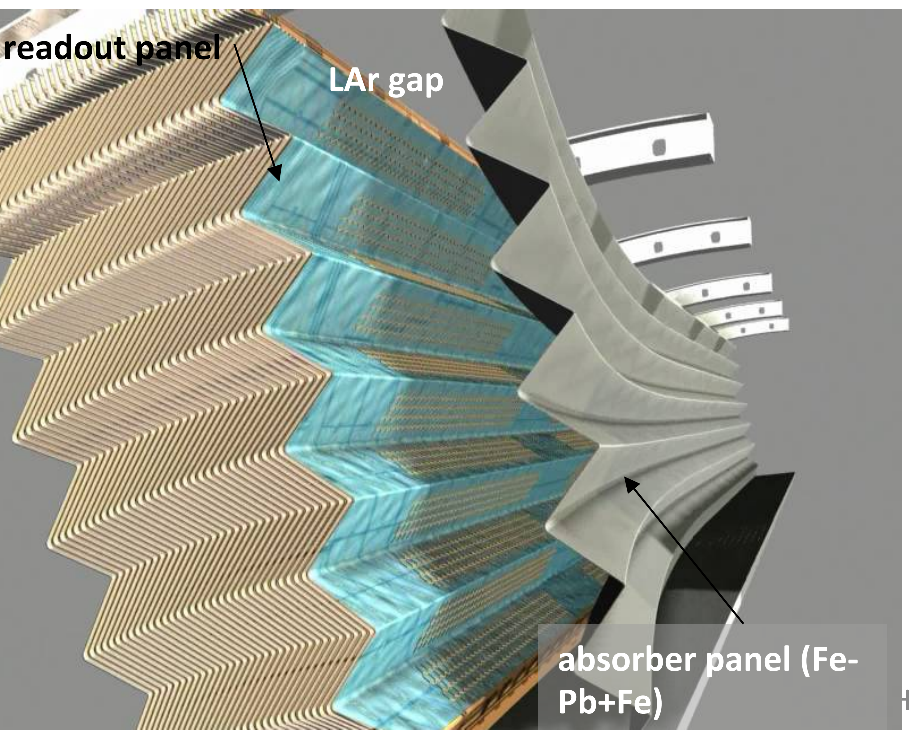
- Among the physics objects, leptons (electrons and muons) are key signatures in many processes and crucial to select interesting events
  - Electrons are easy to measure precisely in EM calorimeters but hard to identify
  - Muons are easy to identify but difficult to measure precisely at high energies

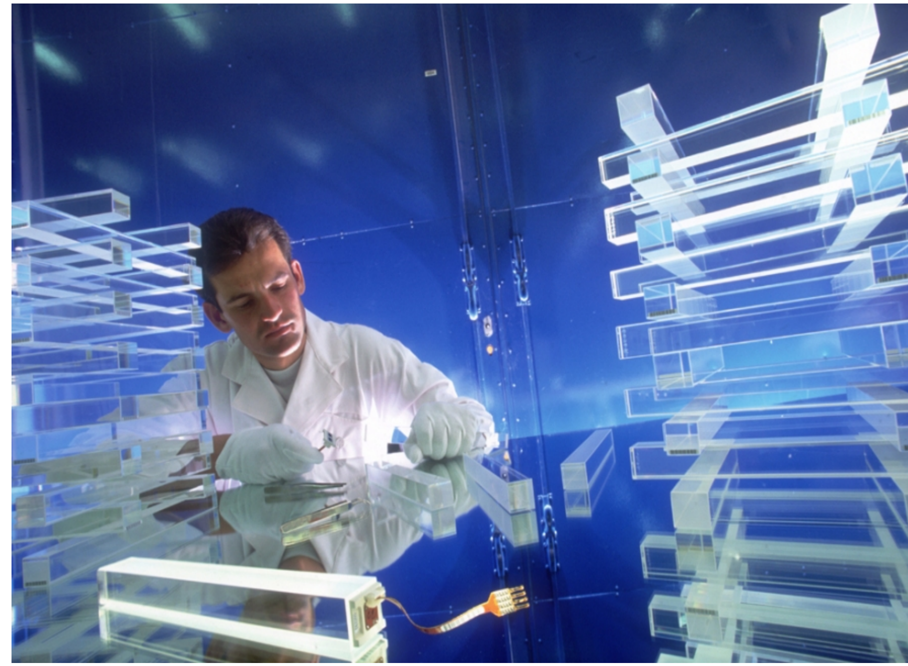
- ATLAS and CMS selected very different technologies for the EM calorimeters to obtain a precise measurement of electrons and photons
  - ATLAS uses LAr sampling calorimeter with good energy resolution and excellent lateral and longitudinal segmentation (important for γ reconstruction)
  - CMS uses PbWO4 scintillating crystals with excellent energy resolution (important for narrow resonances, like low mass Higgs), it also has a an excellent lateral segmentation but not longitudinal segmentation

EM Calorimeters

LAr sampling calorimeter with ‘accordion’ geometry

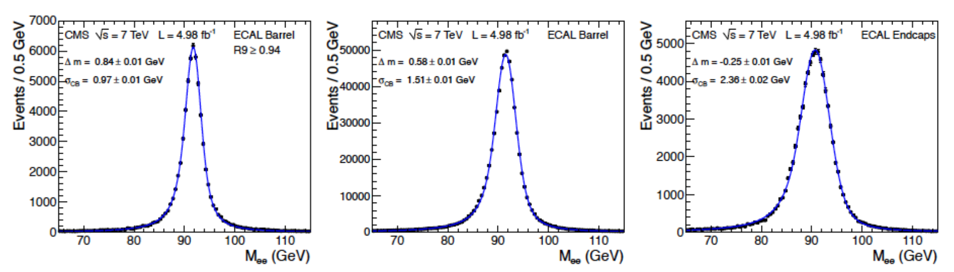
Radiation hard; allows longitudinal segmentation; good energy and angular resolution





PbWO4 crystal calorimeter

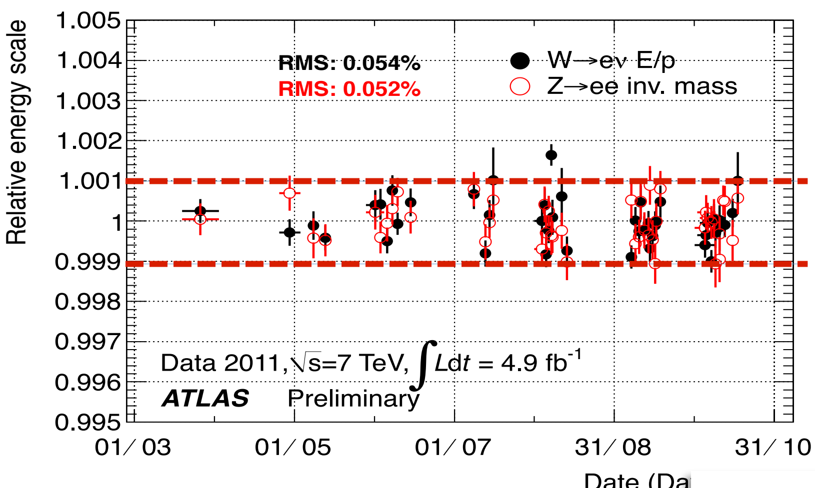
Radiation tolerant; excellent energy and angular resolution

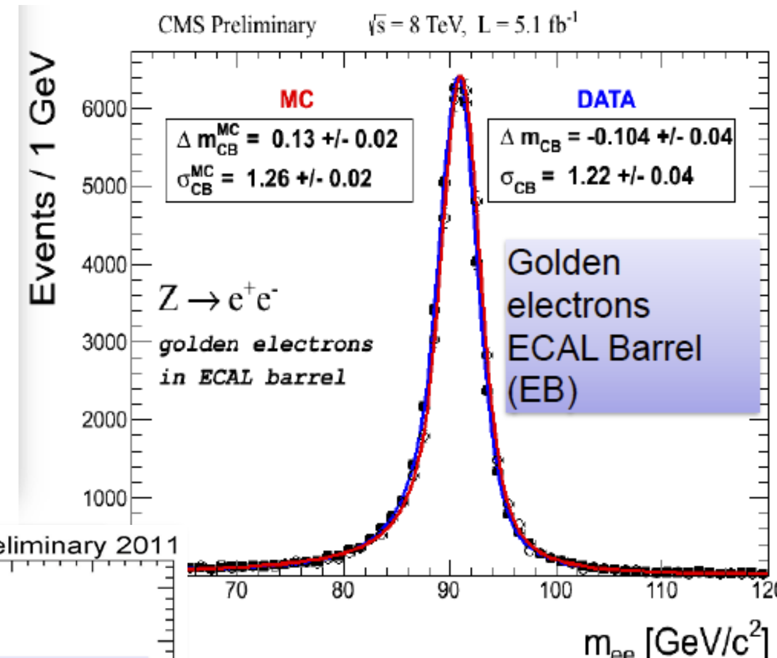


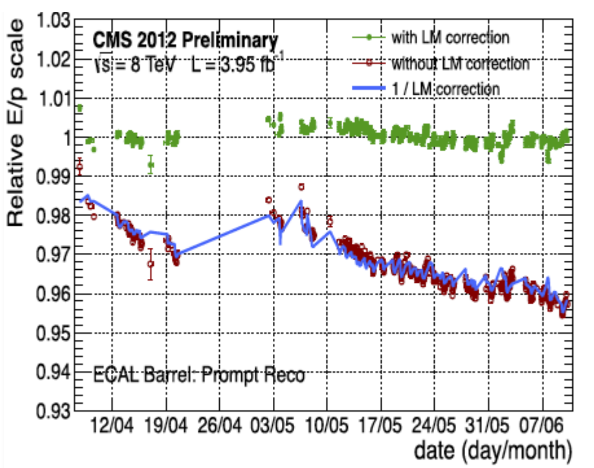
Energy scale and resolution

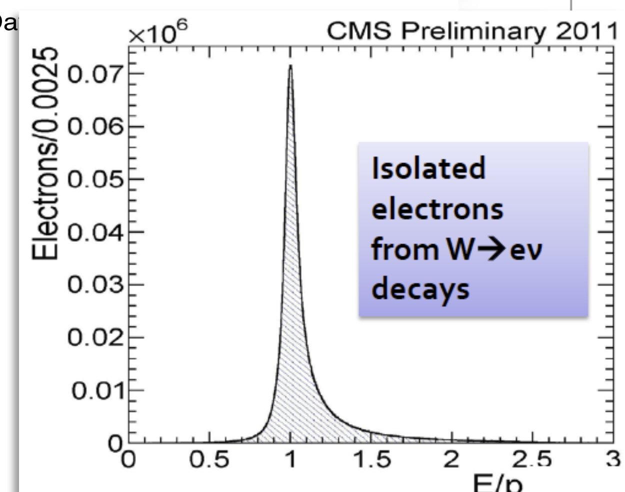
Determined at the Z peak using all the electron categories, aiming for 0.2% of better

Electron scale is then transported to photons using MC (small systematics from material effects)



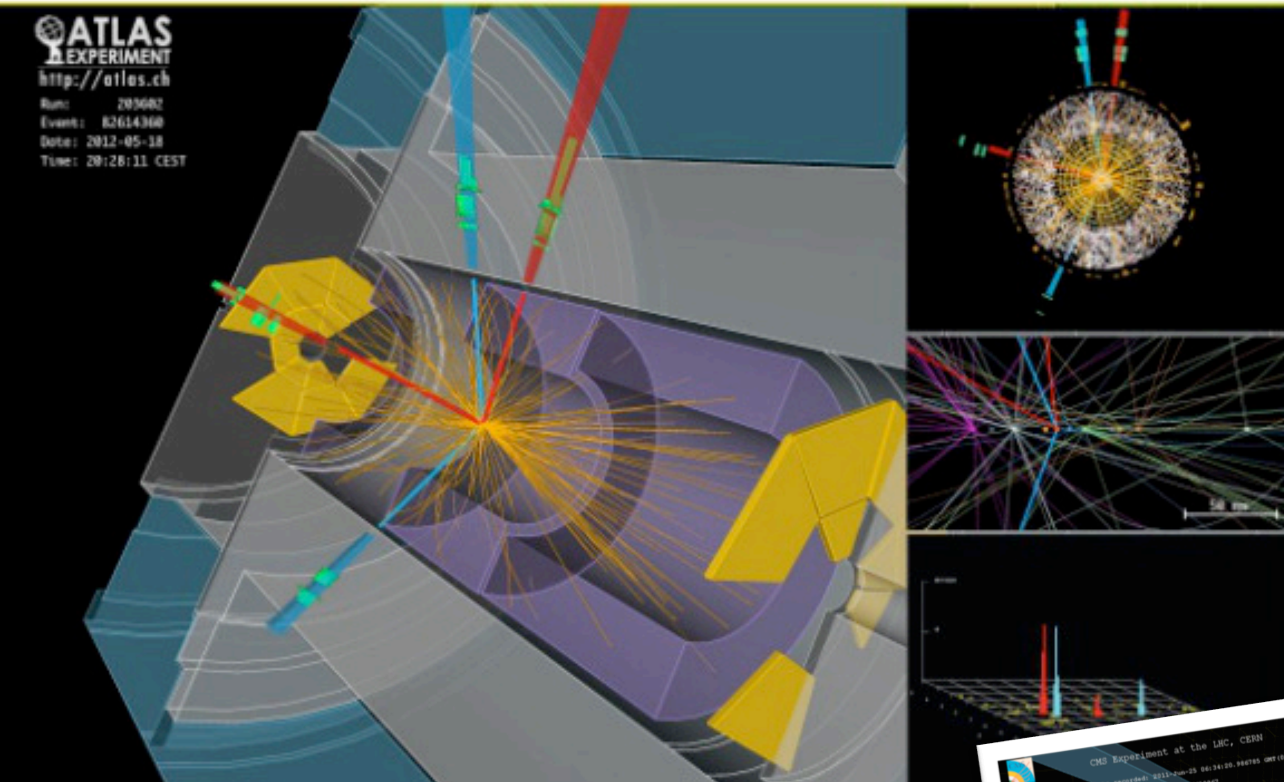


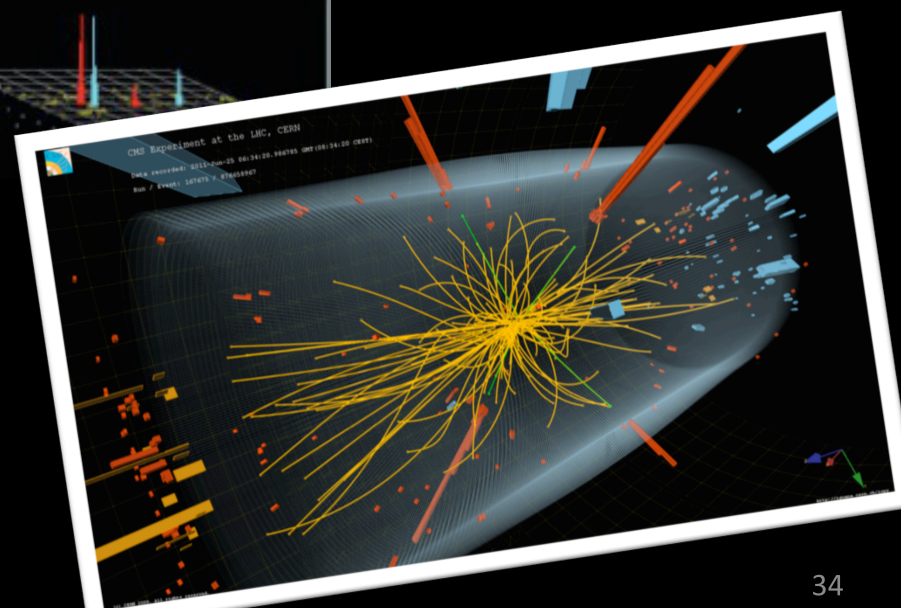




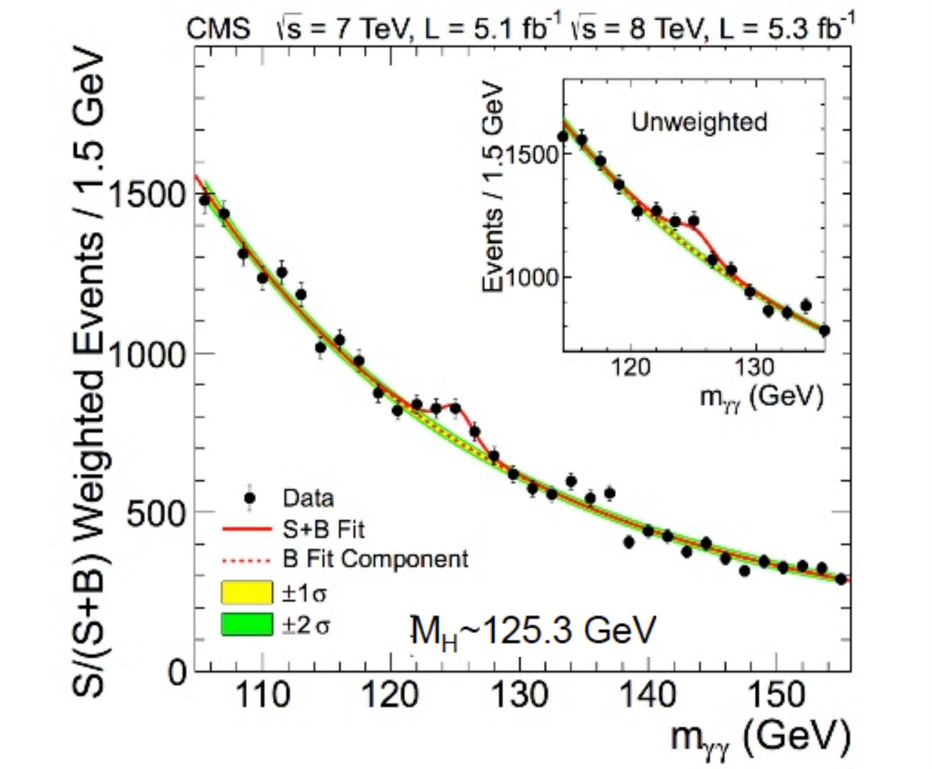
4e candidate with m_{4e}= 124.6 GeV

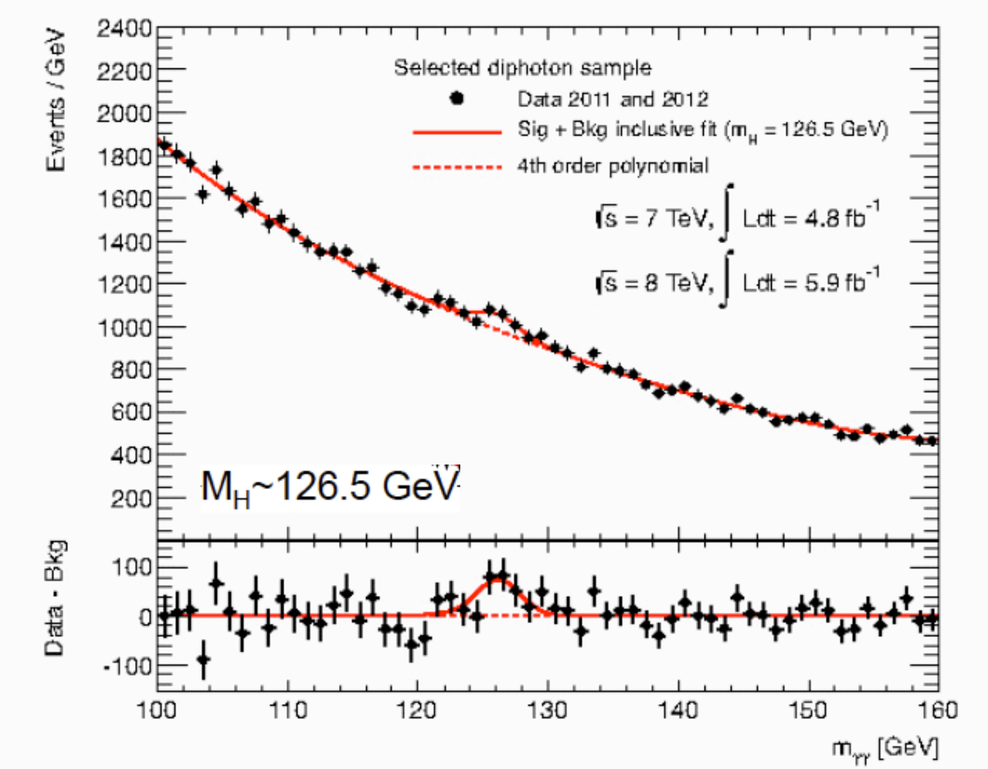
p_T (electrons)= 24.9, 53.9, 61.9, 17.8 GeV m_{12}= 70.6 GeV, m_{34}= 44.7 GeV
12 reconstructed vertices





Di-Photon Invariant Mass





Main systematic uncertainties (ATLAS)

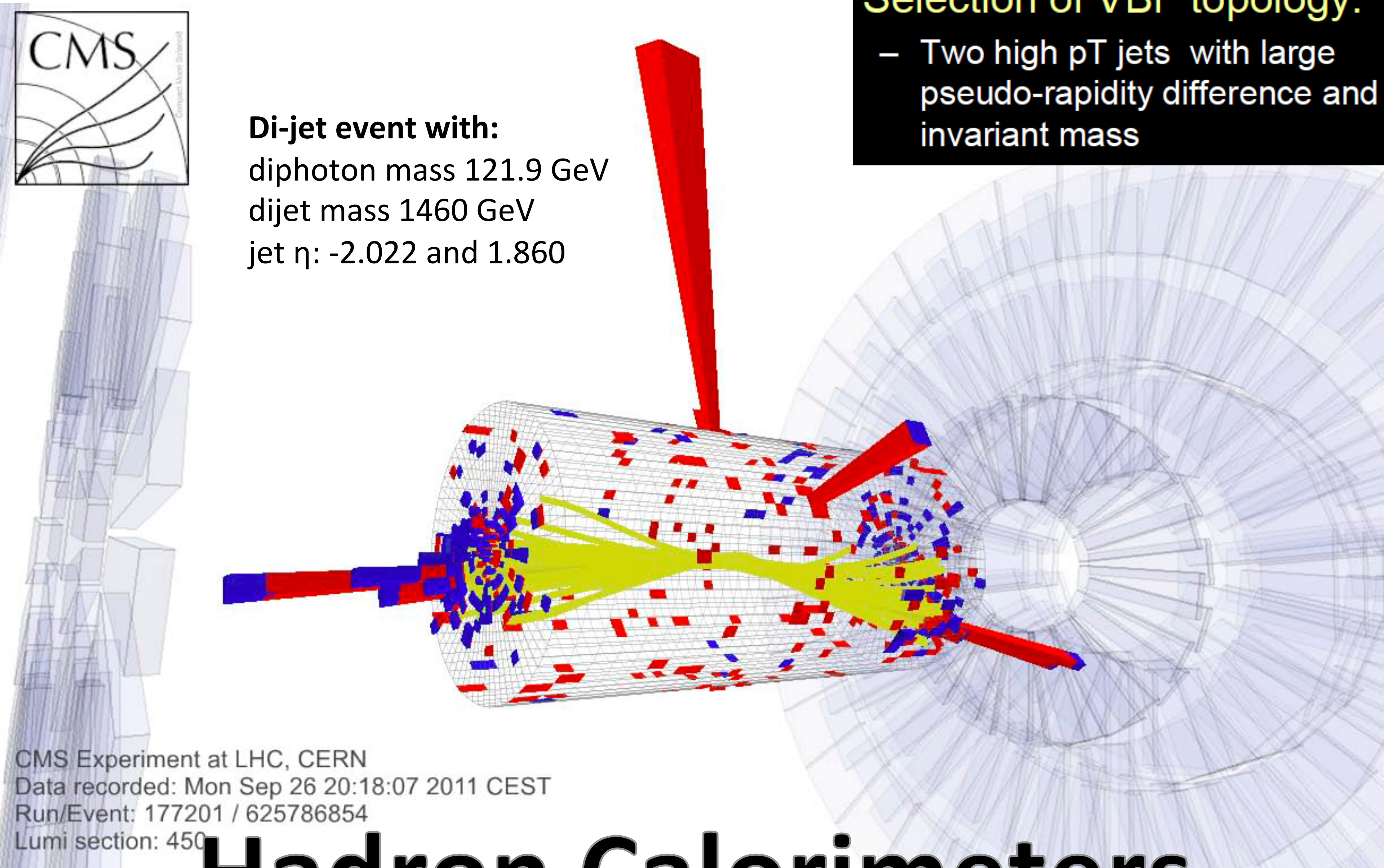
Signal yield	
Theory	~ 20%
Photon efficiency	~ 10%
Background model	~ 10%
Categories migration	
Higgs p_T modeling	up to ~ 10%
Conv/unconv γ	up to ~ 6%
Jet E-scale	up to 20% (2j/VBF)
Underlying event	up to 30% (2j/VBF)
H→ γγ mass resolution	~ 14%
Photon E-scale	~ 0.6%

Hadron Calorimeters

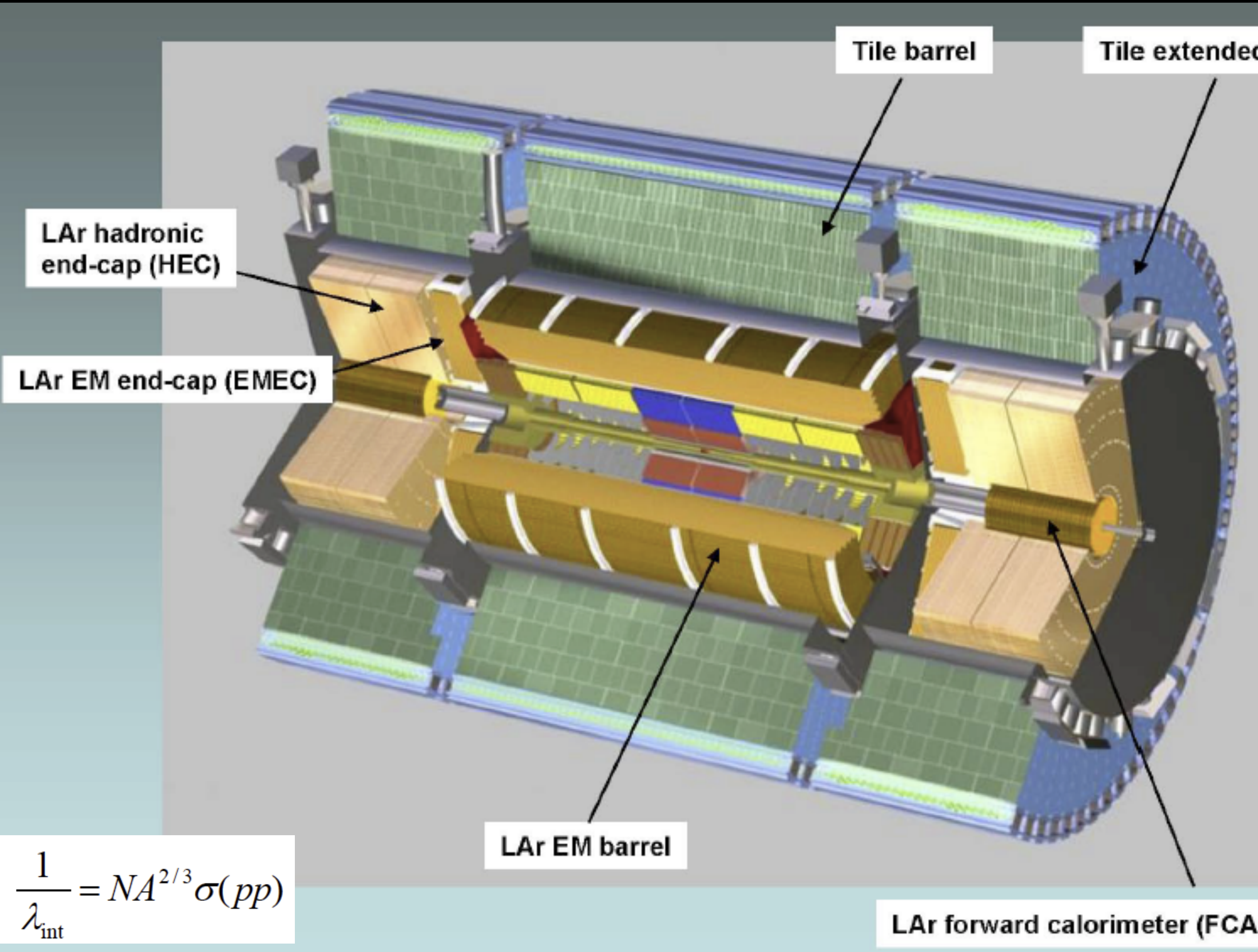
Selection of VBF topology:

– Two high pT jets with large pseudo-rapidity difference and invariant mass

Di-jet event with:
diphoton mass 121.9 GeV
dijet mass 1460 GeV
jet η: -2.022 and 1.860



Hadron Calorimeters



$$\frac{1}{\lambda_{\text{int}}} = NA^{2/3}\sigma(pp)$$

Important for trigger, jets , missing ET, lepton/ photon isolation etc.

ATLAS has a compact and robust hadron calorimeter, with a reasonable resolution

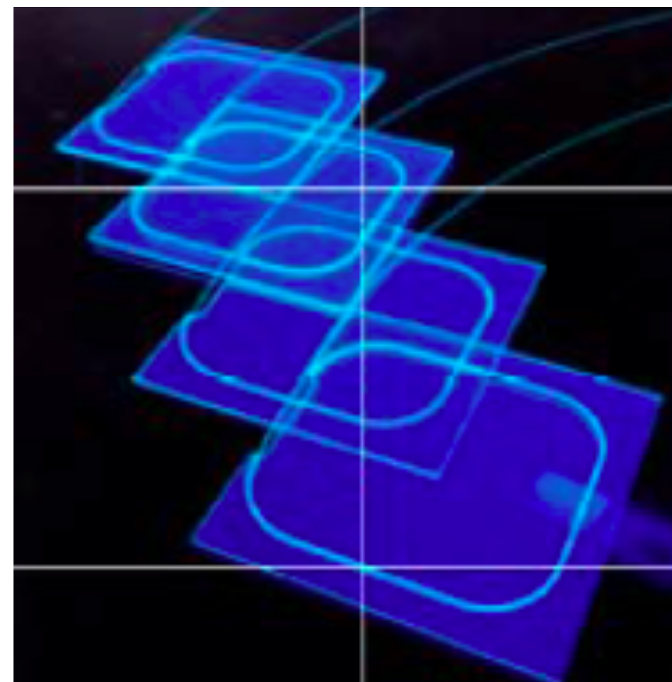
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
pion (10 λ)

Barrel/Endcap:
11 l Fe +Scintillator
Forwad: Tubular
28 X0 LAr-Cu
2x3.7 l Lar-W hadronic

CMS HCAL

Cu absorber + scintillators

2 x 18 wedges (barrel)
+ 2 x 18 wedges (endcap)
≈ 1500 T absorber



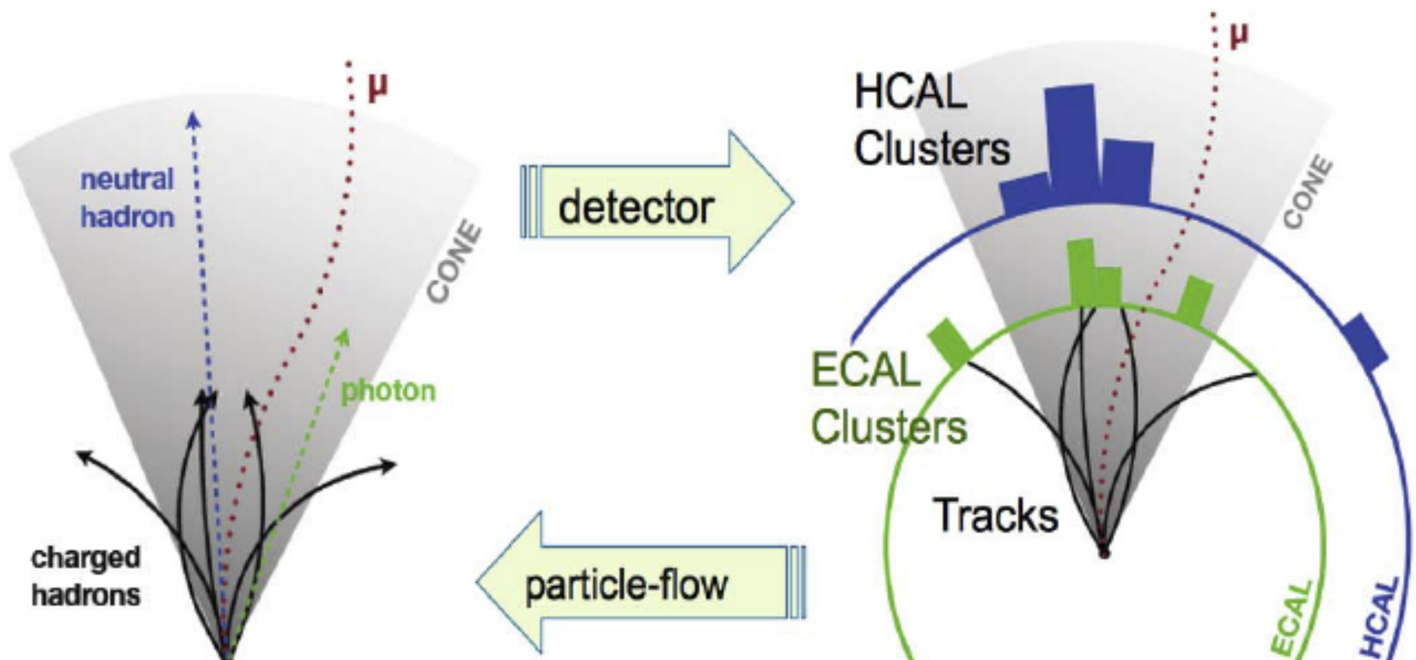
Scintillators fill slots and are read out via fibres by HPDs

Test beam resolution for single hadrons

$$\frac{\sigma_E}{E} = \frac{65\%}{\sqrt{E}} \oplus 5\%$$

In CMS the hadron calorimeter has modest performance. To compensate, CMS developed a Particle Flow reconstruction profiting the strong tracker and highly granular ECAL to identify charged hadrons, HCAL measurements are used for neutral hadrons

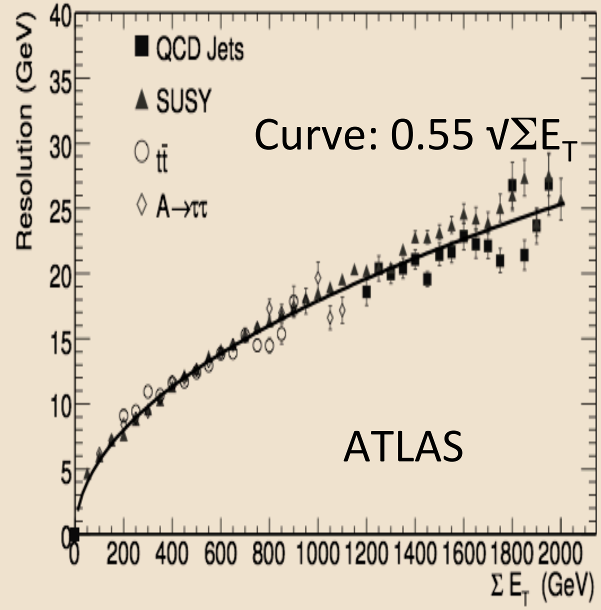
Particle Flow in CMS (Global Event Description)

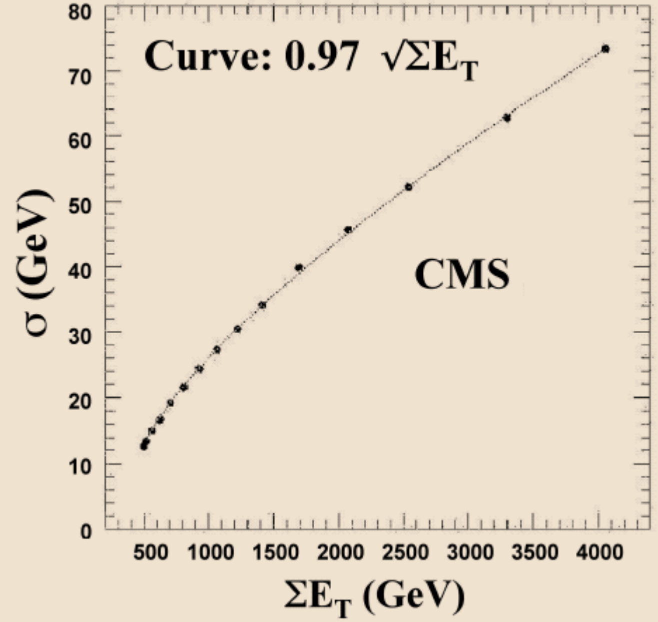


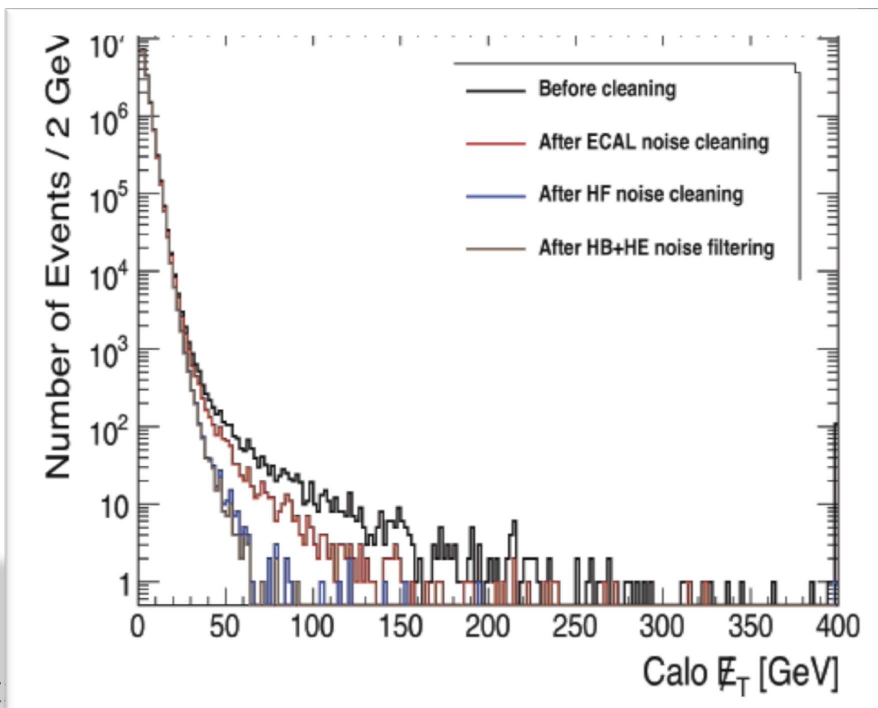
Old Simulations

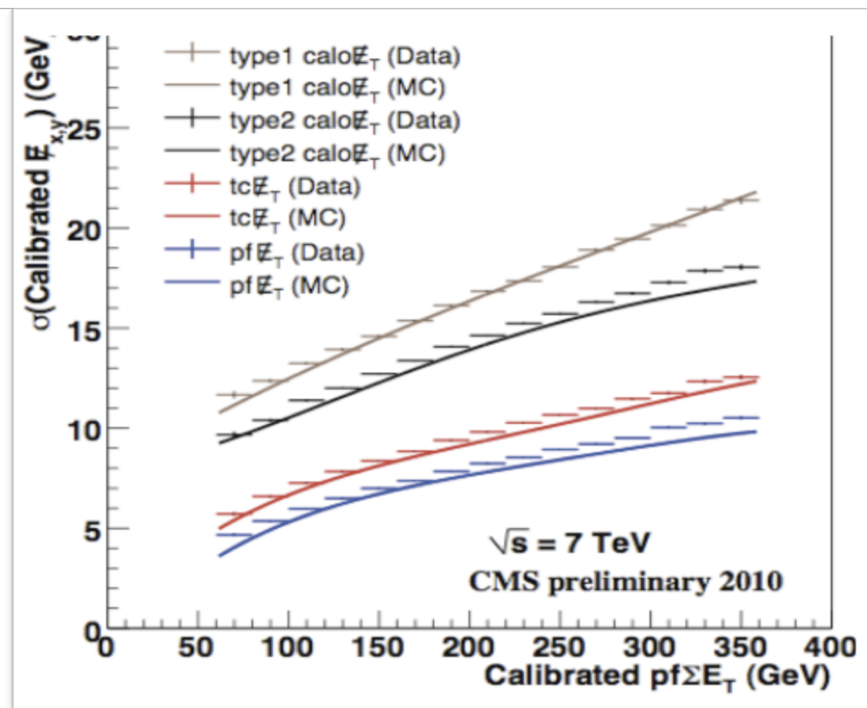
From the intrinsic calorimeter response

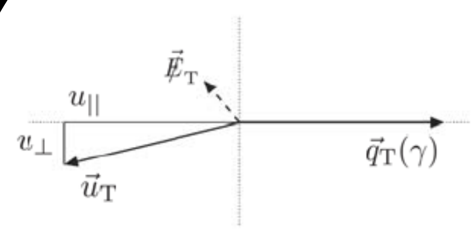
$\not{E}_T$





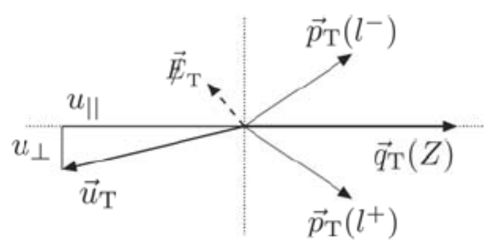






CMS PAS JME-12-002

(just un example)



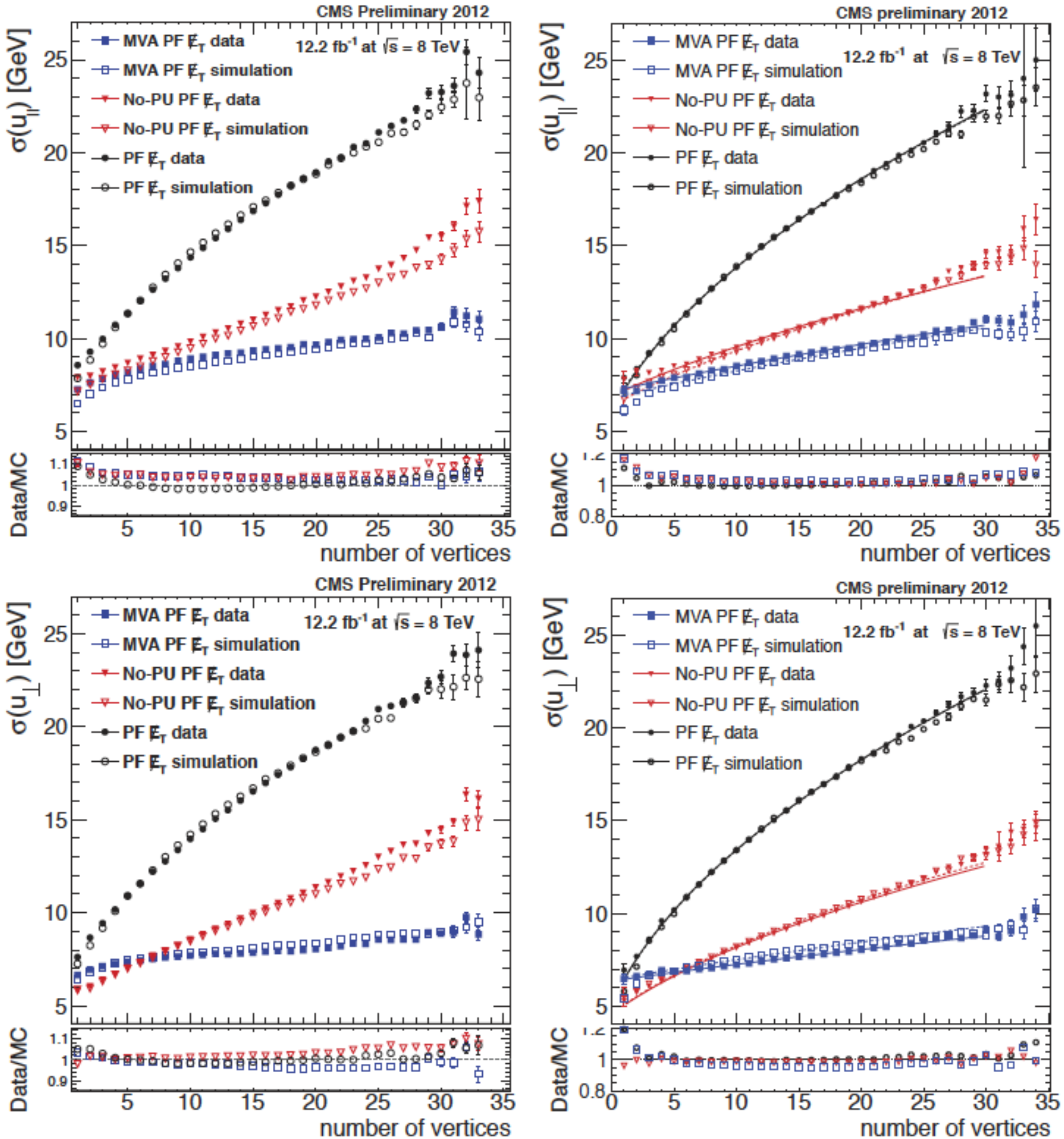
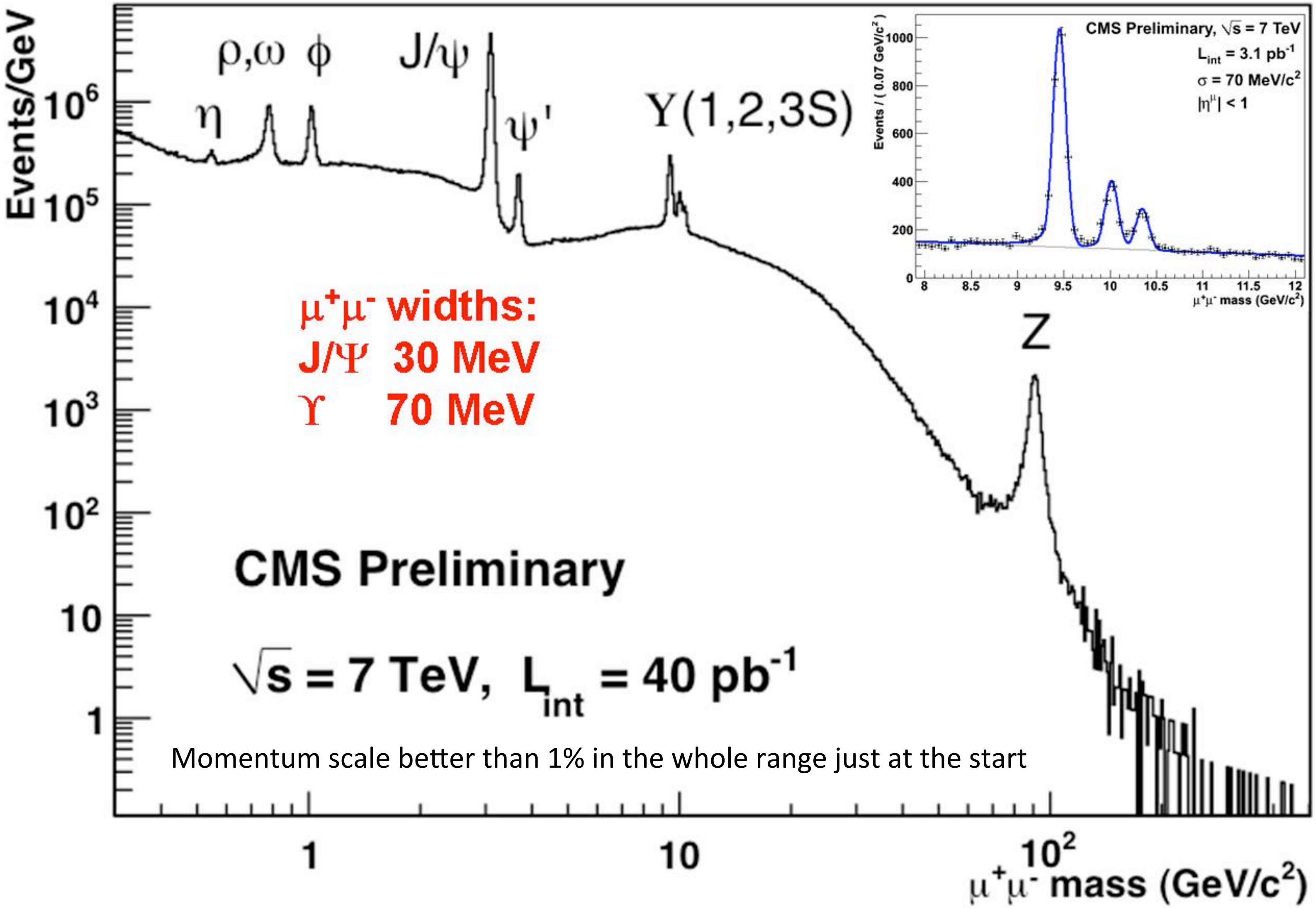


Figure 19: Parallel (top) and perpendicular (bottom) resolution as a function of the number of reconstructed vertices for PF $\vec{\not E}_T$, No-PU PF $\vec{\not E}_T$, and MVA PF $\vec{\not E}_T$ in $Z \to \mu^+\mu^-$ (left) and $Z \to e^+e^-$ (right) events.

Muons

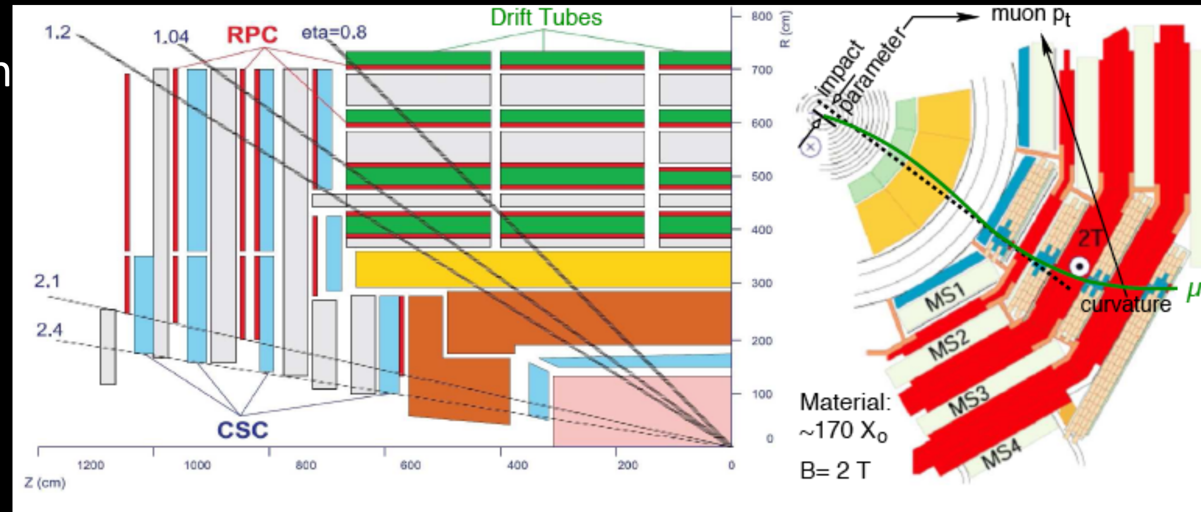
(Central Tracker + Muon system)



Momentum scale better than 1% in the whole range just at the start

Robust technologies for precision chambers (DT and CSC)

Trigger: is redundant in CMS (precision chambers + RPCs). ATLAS uses dedicated TGC and RPCs



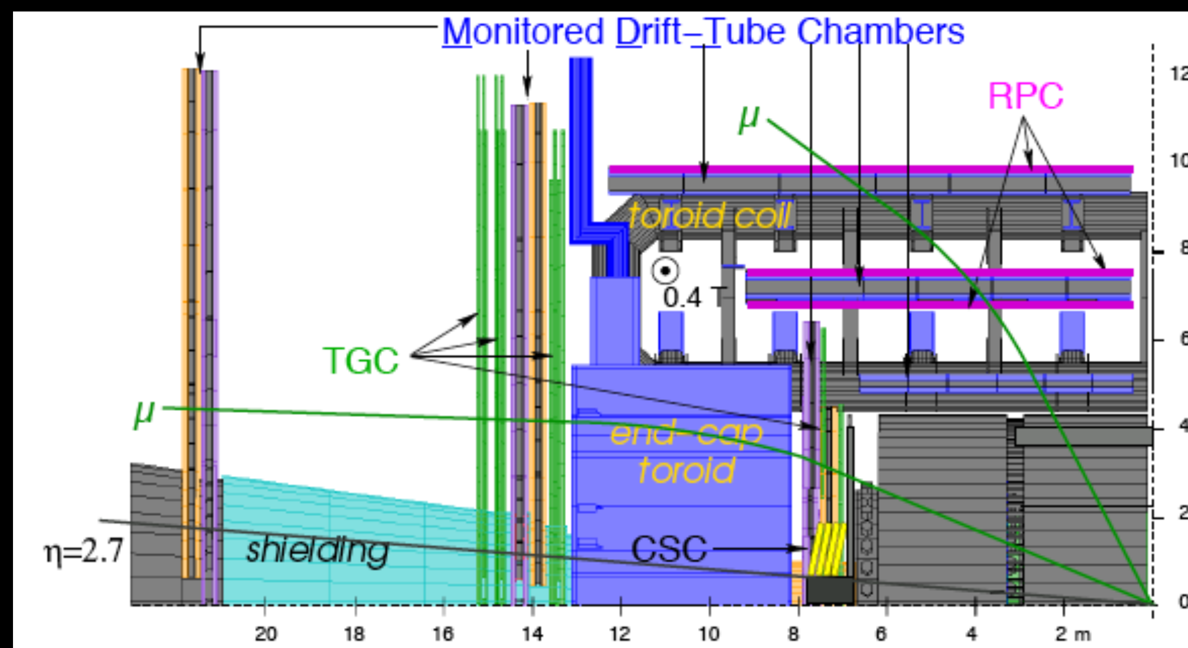
Muon Spectrometers

Large η coverage with good resolution up to TeV muons

In CMS: The overall resolution in the forward regions degrades where solenoid bending power becomes insufficient

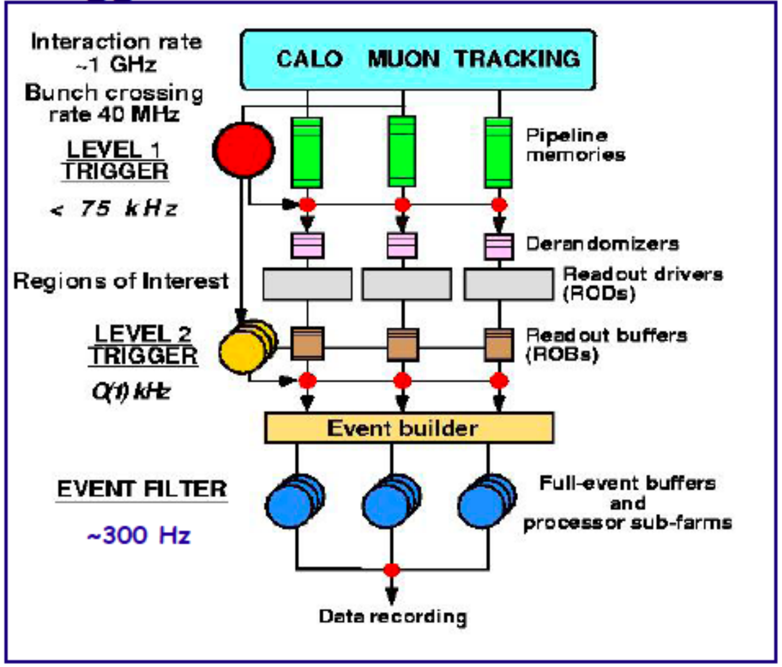
In ATLAS: Complicated geometry and field configuration (large fluctuations in acceptance and performance over full potential

η x ϕ coverage



Trigger & Data Flow

Trigger and Data Flow Architecture



Overall recording rate: ~ 300 Hz

Level-1:

- Implemented in hardware,
- Muon + Calo based, coarse granularity
- e, μ, π, τ, jet candidate selection

Level-2:

- Implemented in software
- Seeded by level-1 ROIs, full granularity
- Inner Detector – Calo track matching

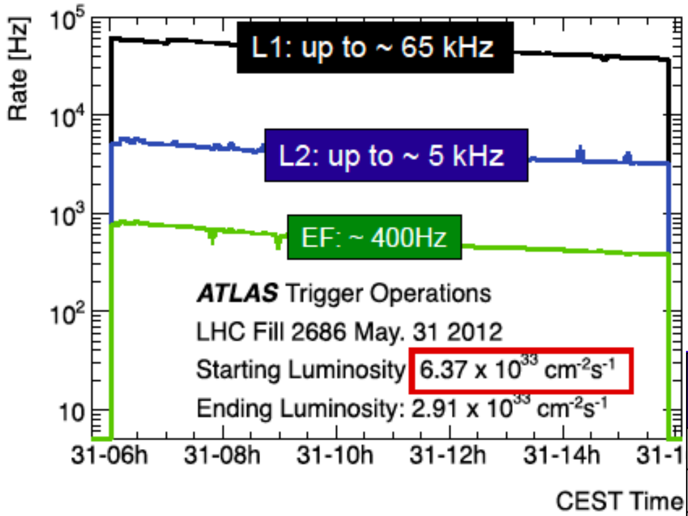
Event Filter:

- Implemented in software
- Offline-like algorithms for physics signatures
- Refine LV2 decision
- Full event building

High Level Trigger = **HLT**

- Optimization of selections (e.g. object isolation) to maintain low un-prescaled thresholds (e.g. for inclusive leptons) in spite of projected x2 higher L and pile-up than in 2011
- Pile-up robust algorithms developed (~flat performance vs pile-up, minimize CPU usage, ...)

→ Results from 2012 operation show trigger is coping very well (in terms of rates, efficiencies, robustness, ..) with harsh conditions while meeting physics requirements

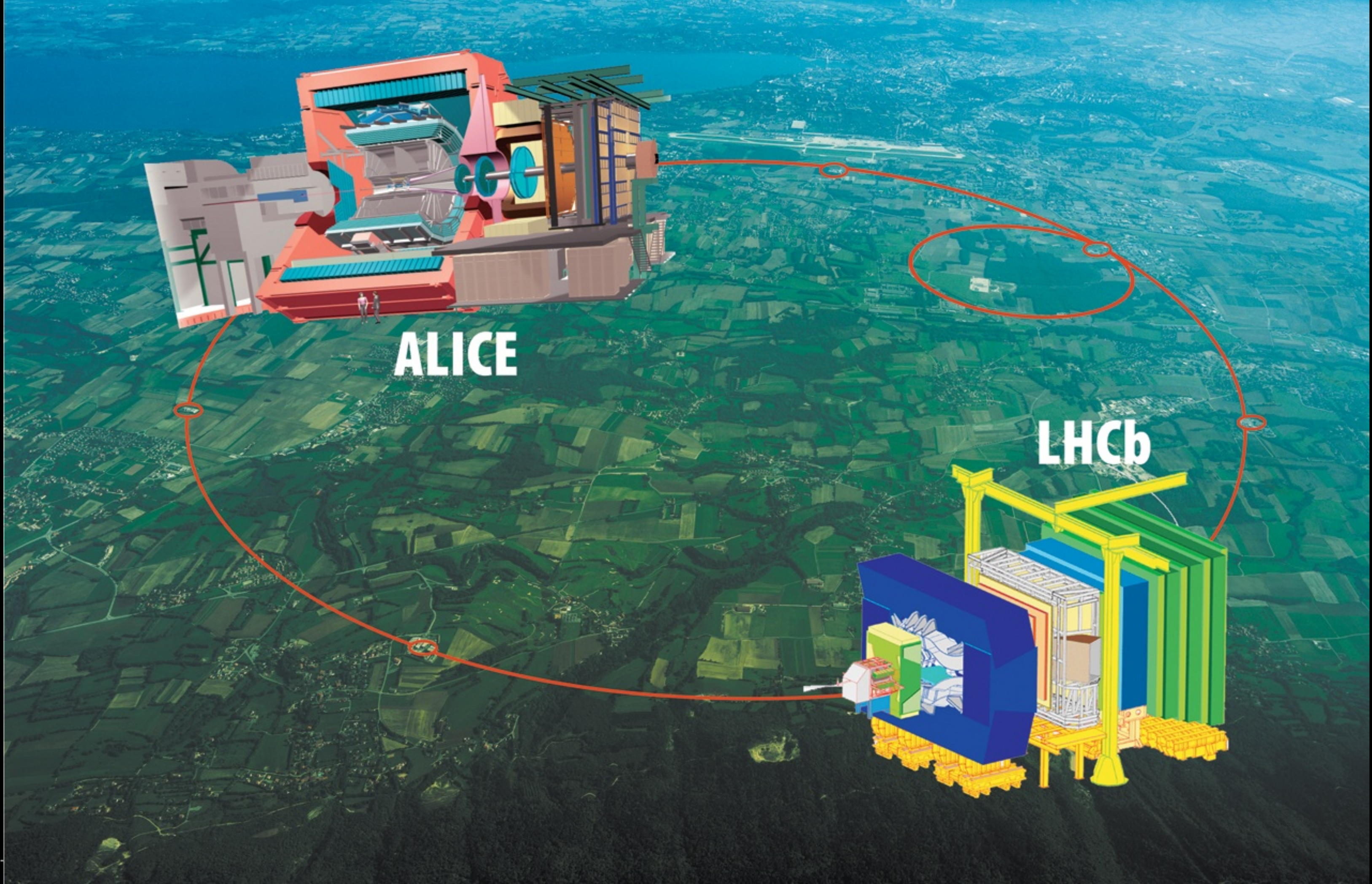


~ 500 items in trigger menu !

High-Level Trigger @ 6e33

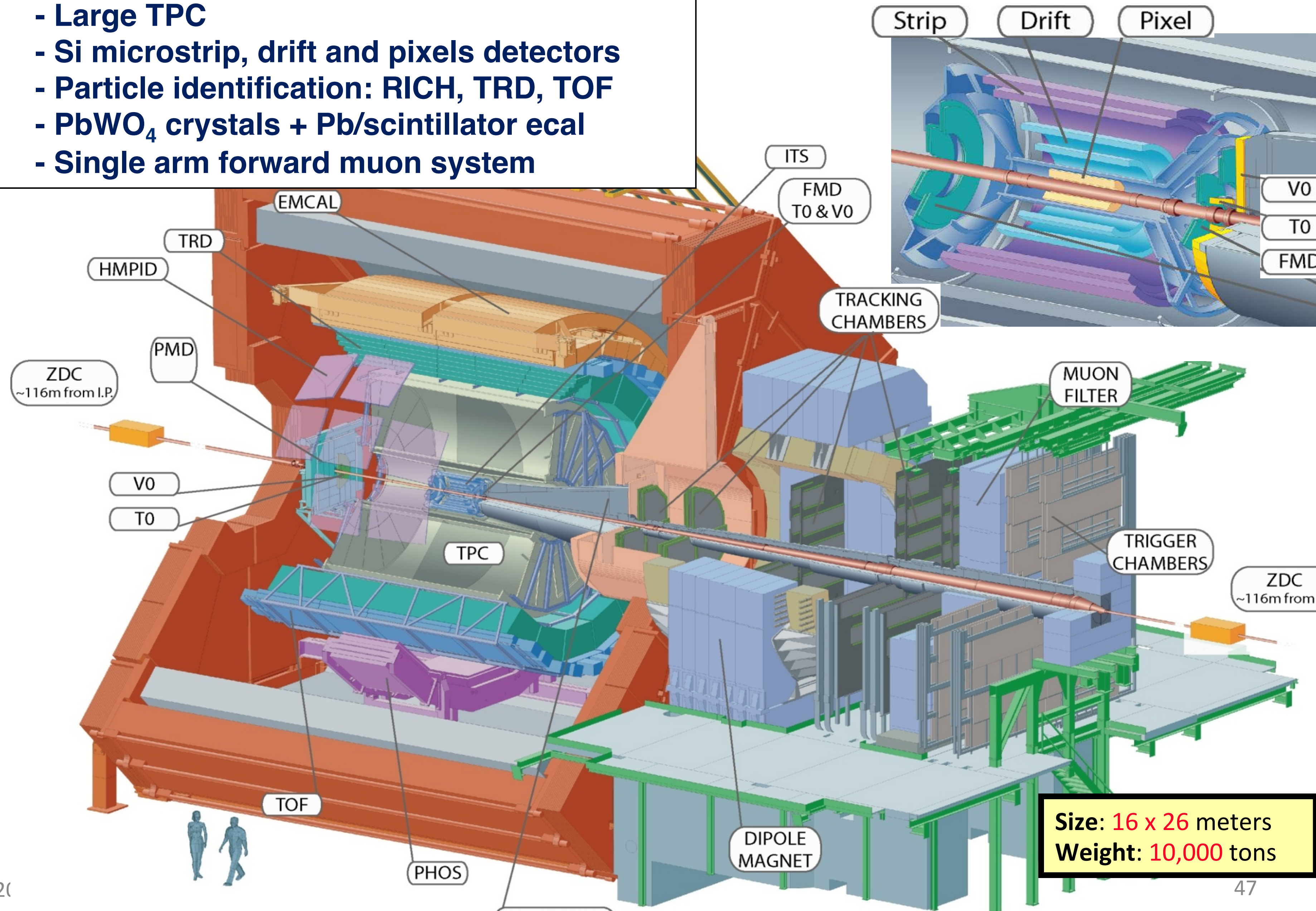
(Unprescaled) Object	Trigger Threshold (GeV)	Rate (Hz)	Physics
Single Muon	40	21	Searches
Single Isolated muon	24	43	Standard Model
Double muon	(17, 8) [13, 8 for parked data]	20 [30]	Standard Model / Higgs
Single Electron	80	8	Searches
Single Isolated Electron	27	59	Standard Model
Double Electron	(17, 8)	8	Standard Model / Higgs
Single Photon	150	5	Searches
Double Photon	(36, 22)	7	Higgs
Muon + Ele x-trigger	(17, 8), (5, 5, 8), (8, 8, 8)	3	Standard Model / Higgs
Single PFJet	320	9	Standard Model
QuadJet	80 [50 for parked data]	8[100]	Standard Model /Searches
Six Jet	(6 x 45), (4 x 60, 2 x 20)	3	Searches
MET	120	4	Searches
HT	750	6	Searches

Specialized detectors



ALICE: study of quark-gluon plasma

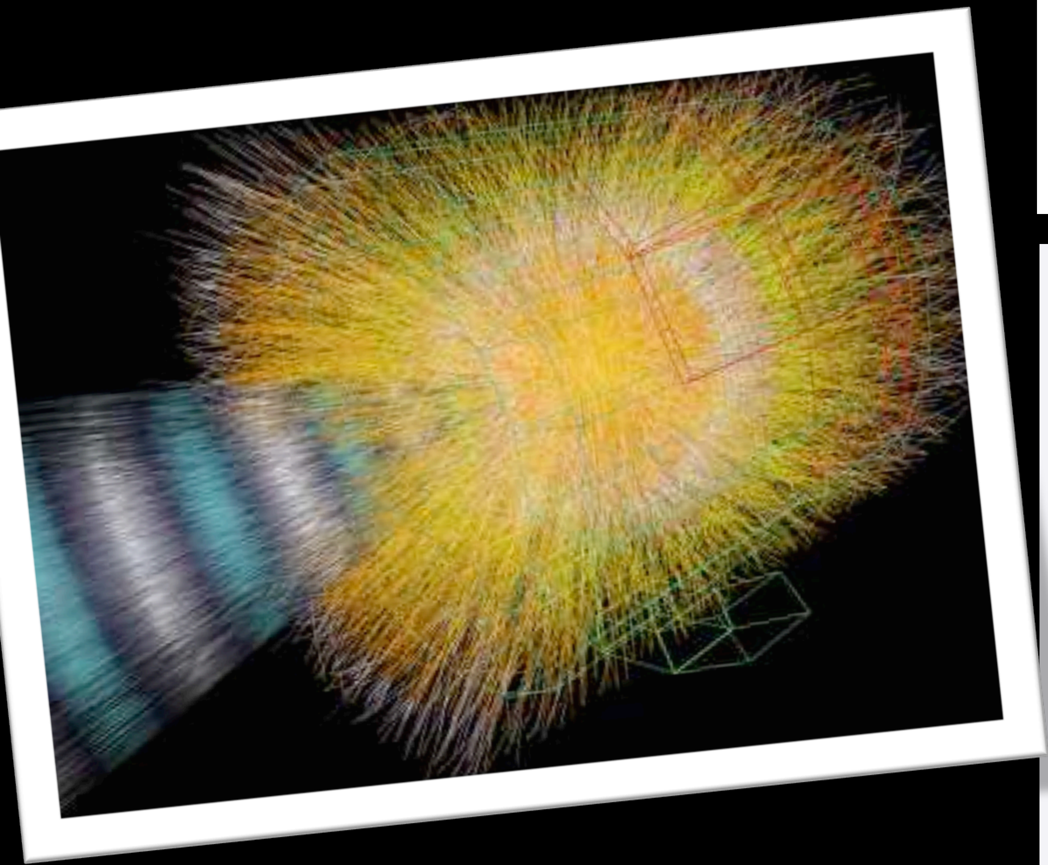
- L3 solenoid
- Large TPC
- Si microstrip, drift and pixels detectors
- Particle identification: RICH, TRD, TOF
- $PbWO_4$ crystals + Pb/scintillator ecal
- Single arm forward muon system

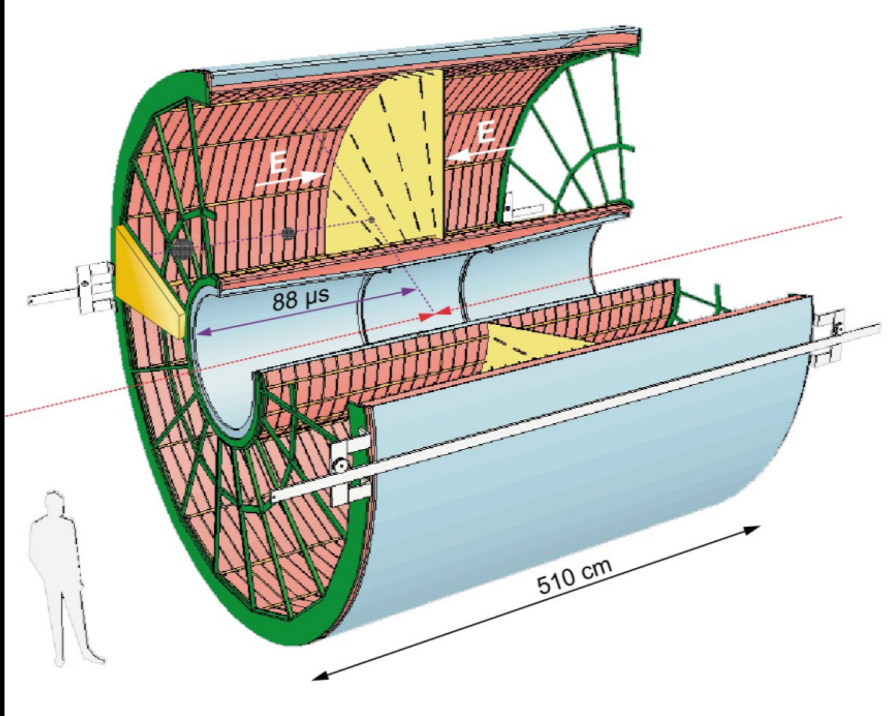


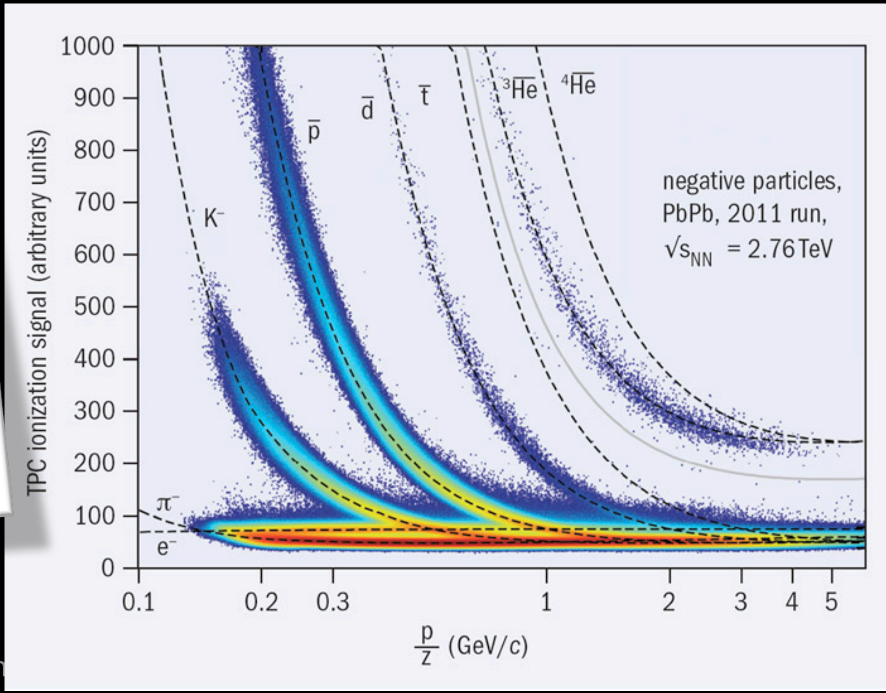
Size: 16 x 26 meters
Weight: 10,000 tons

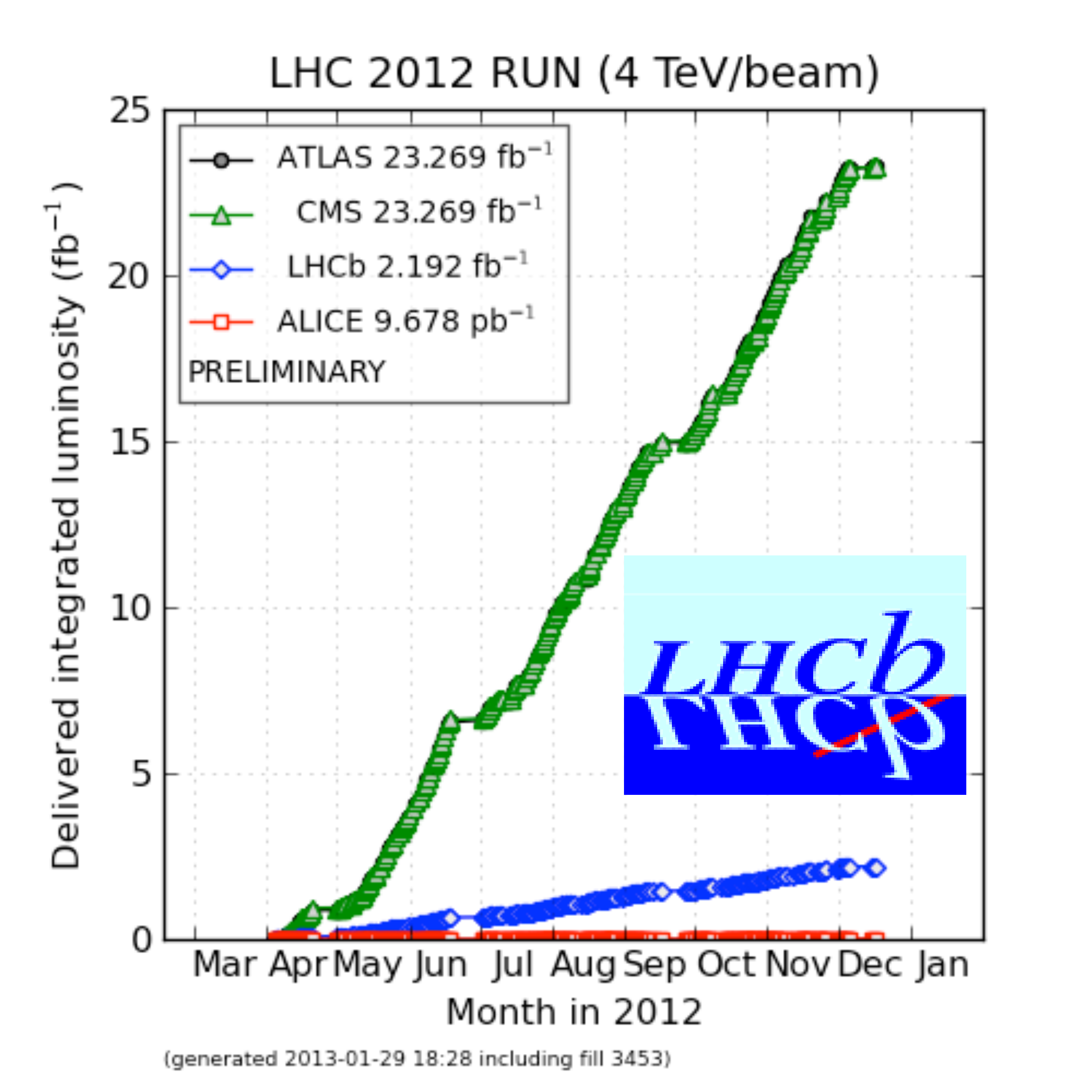
Largest TPC

Length 5m; Diameter 5m; Volume 88m^3 ;Detector area 32m^2; and ~570 000 channels



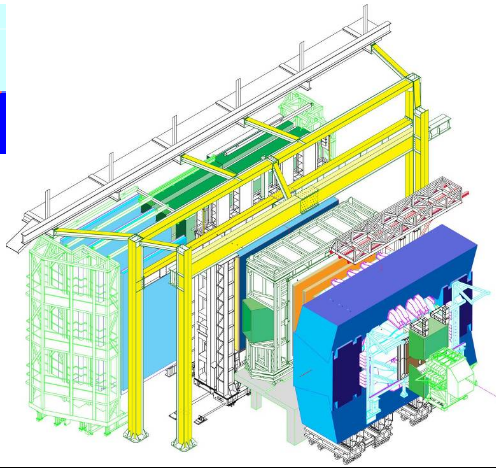


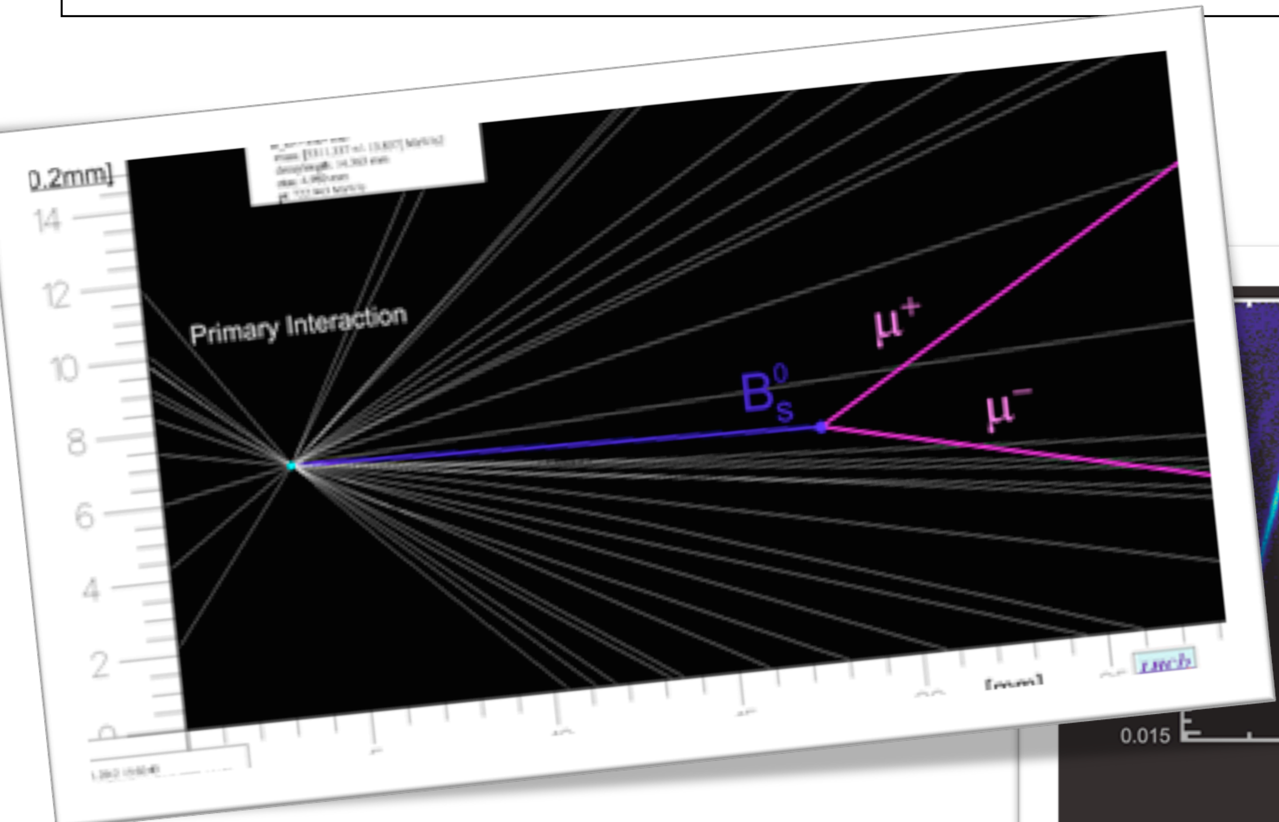


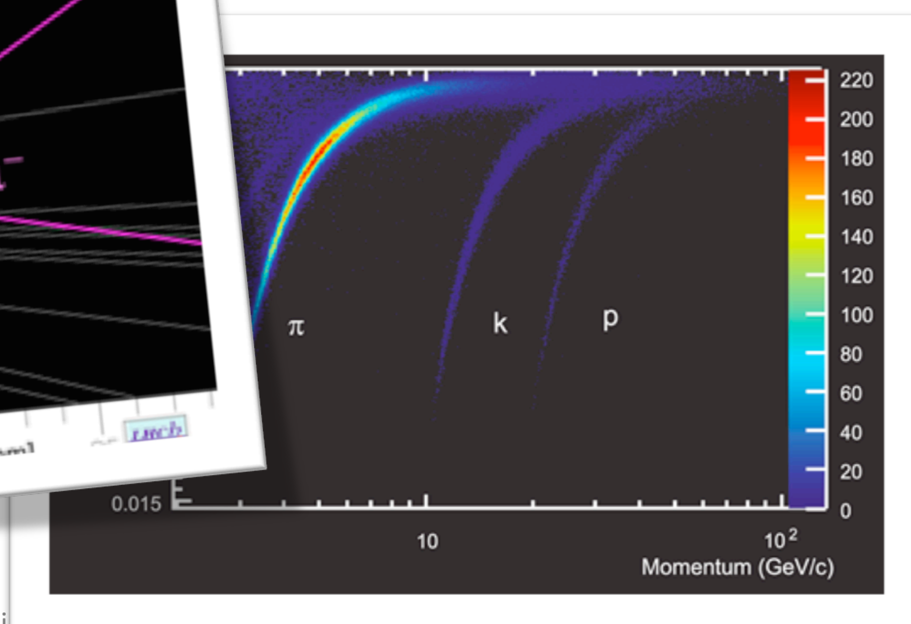

LHC 2012 RUN (4 TeV/beam)
ATLAS 23.269 fb^{-1}
CMS 23.269 fb^{-1}
LHCb 2.192 fb^{-1}
ALICE 9.678 pb^{-1}
PRELIMINARY
Delivered integrated luminosity (fb^{-1})
0
5
10
15
20
25
Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Month in 2012
LHCb
(generated 2013-01-29 18:28 including fill 3453)

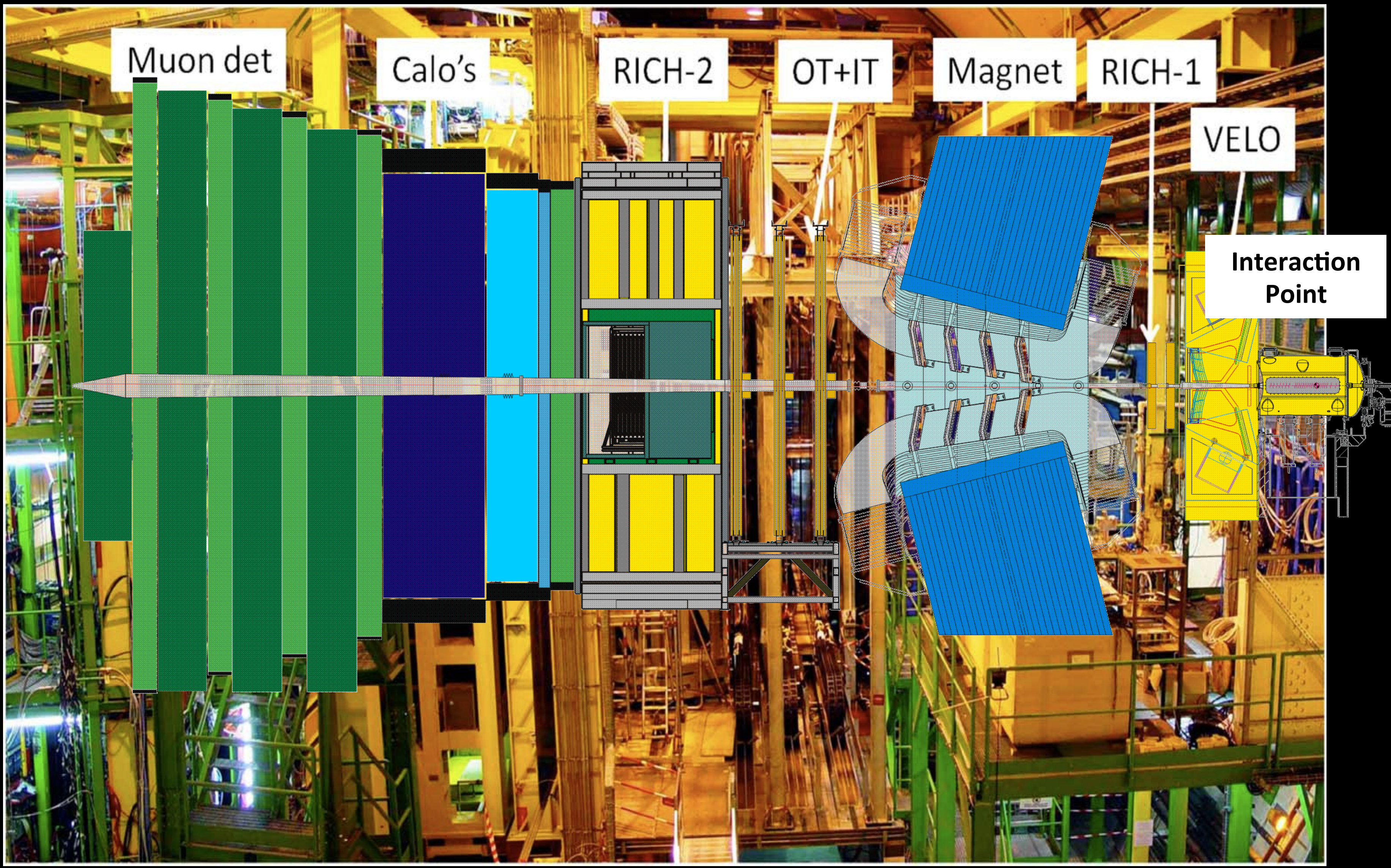
LHCb: Study of B decays and CP Violation

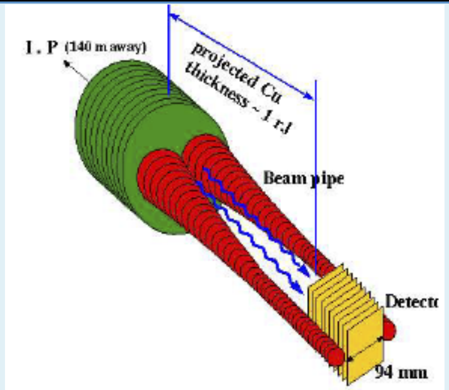
- Dipole magnet (4 T.m)
- Particle Identification (2 RICH)
- 21 layer of Si microstrip vertex locator (VELO)
- Tracking: Silicon + long straw tubes
- Shashlik (Pb/scint) em calorimeter
- HCAL (Fe/scint),
- MWPC muon system





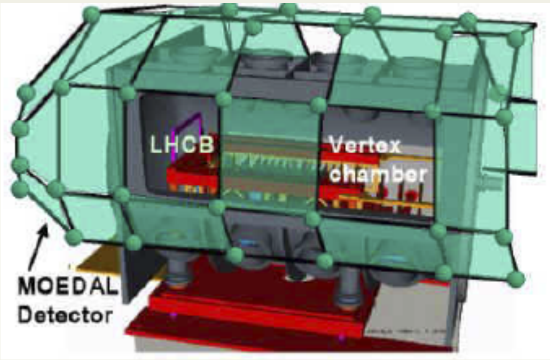


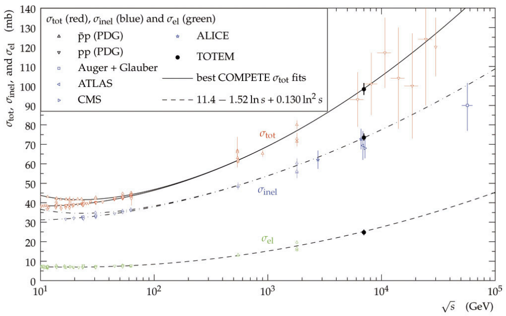

Muon det
Calo's
RICH-2
OT+IT
Magnet
RICH-1
VELO
Interaction Point



LHCf: measurement of photons and neutral pions. EM calorimeter in the very forward region of LHC, at 140 m from IP1 (ATLAS)

Moedal: Monopole and Exotics Detector at the LHC. Looking for Direct Monopole production





TOTEM: Measuring the total, elastic and diffractive cross sections.

A series of tracking detectors integrated in CMS and Roman Pots far from the IP

Up to now

- LHC detectors are performing extremely well; they provide precision physics under very harsh environment
- A sustained (and huge) effort is required during operation in the areas of trigger, detector alignment, calibration, reconstruction, etc. to cope with the always changing conditions
- Towards the future, we need to aggressively optimize for pile-up in order to remain a discovery facility (HL-LHC)

Road Map of Expected Hadron Collider Performances

End 2010	**Tevatron**	**2 TeV**	**7 fb^{-1} (analysed)**
	LHC	**7 TeV**	**45 pb^{-1}**
End 2011	**Tevatron**	**2 TeV**	**10 fb^{-1}**
	LHC	**7 TeV**	**5 fb^{-1}**
End 2012	**LHC**	**8 TeV**	**20 fb^{-1}**
End 2015	**LHC**	**14 TeV**	**30 fb^{-1}**
End 2017	**LHC**	**14 TeV**	**100 fb^{-1}**
Early 2020s	**LHC**	**14 TeV**	**300 fb^{-1}**
2030	**HL-LHC**	**14 TeV**	**3000 fb^{-1}**

(These are round numbers and estimates …)

THE FUTURE: TECHNOLOGY R&D

	2012	HL-LHC
Beam energy	4 TeV	7 TeV
Luminosity	$7.7 \times 10^{33}/cm^2/s$	$5 \times 10^{34}/cm^2/s$
Integrated luminosity	24/fb	3000/fb
Interactions/crossing	~20	~140
Bunch spacing	50 ns	25 ns
Radiation dose (r~5cm)	3×10^4 Gy	5×10^6 Gy

Machine parameters

	ILC	CLIC	TLEP
$\sqrt{s}$ (GeV)	(91/) 250-1000	350 -3000	91-350
Min Bunch spacing (ns)	366	0.5	
Bunches/Train	2625	312	4400
Collision Rate (Hz)	5	50	
Luminosity (10^{34})	4.9	5.9	56
Number of pairs/BX	$\sim 4 \times 10^5$	$\sim 7 \times 10^8$	?
$\gamma\gamma \rightarrow$ hadrons/BX	4.1	3.6	?

R&D Themes

Leitmotivs: granularity, energy, time and space resolution, speed, higher trigger and data readout rates, rad hardness, purity, low material budget, robustness, integration, large scale apparatus

Pixelated Sensors: how to build affordable, large area arrays of pixelated detectors.?

- Low mass, pixelated radiation hard detectors will be needed for all next generation detectors/facilities
- New silicon technologies include CMOS MAPS, SOI, and 3D.
- Micro-pattern gas detectors (MPGDs) for charged particle tracking and muon detection are also studied as an alternative to pixelated silicon vertex and tracking detectors.

Trends in calorimetry

Two major developments in the field: the dual readout approach (Cherenkov and scintillator light) and imaging calorimetry motivated by the Particle Flow event reconstruction approach.

- Fluctuations in the electromagnetic component of hadronic showers are corrected for by making a separate measurement of that component using the Cherenkov radiation produced by electromagnetic showers
- Extend that tracking into the calorimeter and follow the showers as they develop

Advance in data transmission, ASICS and electronics

- Increasing needs to process high densities of analog information, digitize it, and transmit it to processors or storage. Studies of high-speed links, FPGAs, etc. and ATCA (Advance Telecommunication Computing Architecture) based systems
- HEP applications require unique levels of radiation hardness or operation at cryogenics temperatures

Mechanics and Power: integrated issues of precision support structures, cooling, and electrical and thermal services

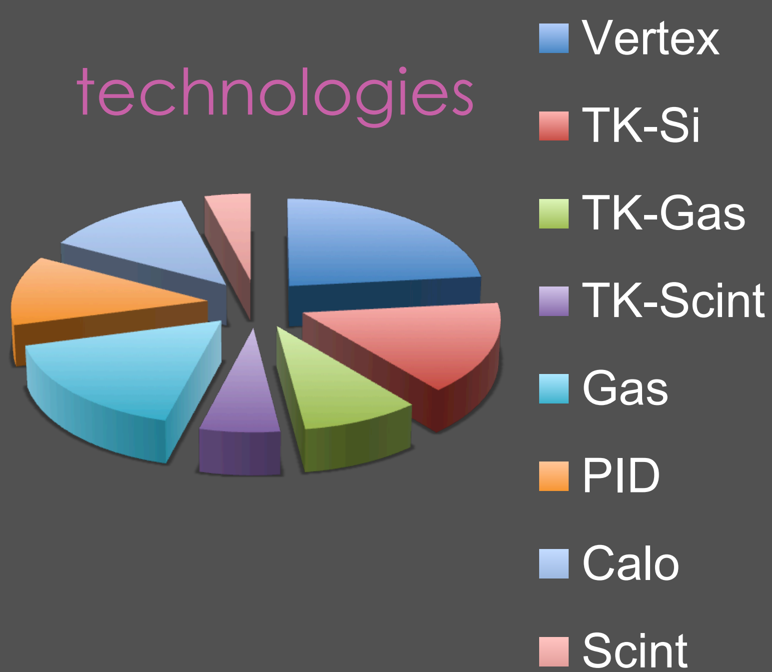
- A coordinated effort to develop new temperature tolerant materials, active materials, and implement the standardization of their quality assurance is key to frontier science and has spin-off potential
- Low mass materials include carbon fiber, carbon derivatives such graphene, beryllium, titanium and titanium alloys, ceramics, advanced compounds such as silicon carbide and diamonds, conducting polymers, and thermally conductive foams ⇒ Emerging technologies

European survey on detectors R&D

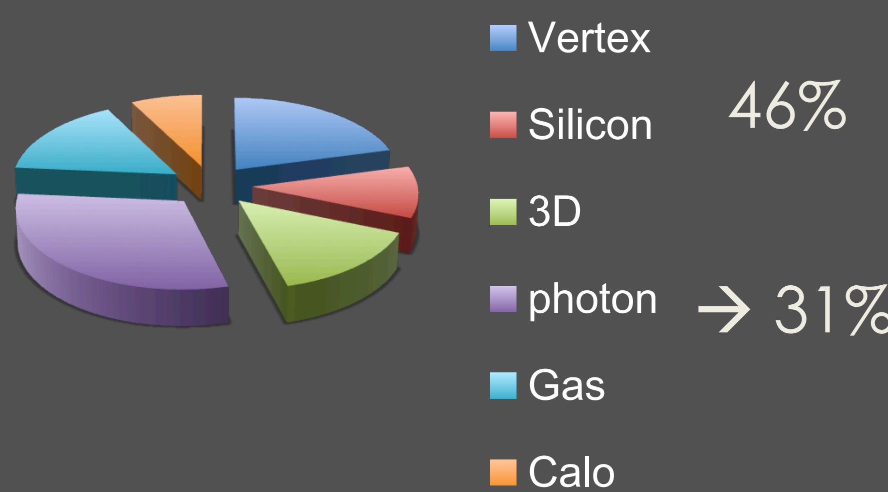
ICFA Inst. Panel and ECFA

preliminary results that reflect the work of ~1700 hardware oriented people: 85% in experiments and 40% also within consortia

technologies



electronics



www.surveymonkey.com/s/Detectors_RD →

Some references

- LHC: Accelerator and Experiments
  http://jinst.sissa.it/LHC/

- Lectures, talks, etc..
  Previous TAE lectures (P. Jenni, A. de Roeck, etc..)
  SSI (2006, 2012- C. Tully) http://www-conf.slac.stanford.edu/ssi/2012/
  Discrete 2008 (D. Froidevaux) http://ific.uv.es/discrete08/
  CERN Summer Student Lectures
  http://cds.cern.ch/collection/Summer%20Student%20Lectures?ln=en
  Excellence in Detectors and Instrumentation Technologies
  http://detectors-school.web.cern.ch/detectors-school/

- Future R&D
  European strategy:
  http://council.web.cern.ch/council/en/EuropeanStrategy/ESParticlePhysics.html
  Snowmass: http://www.hep.umn.edu/css2013/

And “millions” of talks, videos, etc.. available in the web