

CERN – A Gateway to Science and Technology



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CMS detector performance
New 13 TeV results
and
some of its Upgrade perspectives

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New 13 TeV results
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Ludwik Dobrzynski

Laboratoire Leprince Ringuet - Ecole polytechnique - CNRS - IN2P3

Split - 14 September 2015

CERN – The European Organization for Nuclear Research



The Mission of CERN



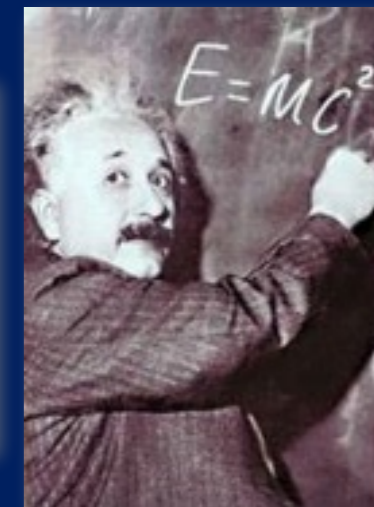


The Mission of CERN



- **Push forward** the frontiers of knowledge

E.g. the secrets of the Big Bang ...what was the matter like within the first moments of the Universe's existence?



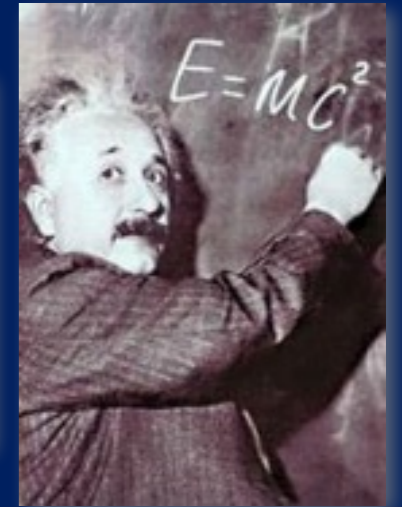


The Mission of CERN



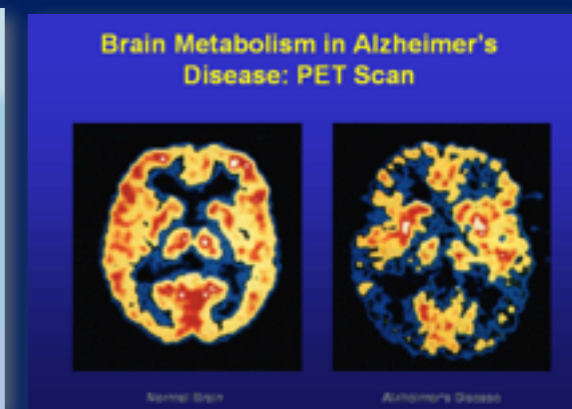
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- **Develop** new technologies for accelerators and detectors

Information technology - the Web and the GRID
Medicine - diagnosis and therapy



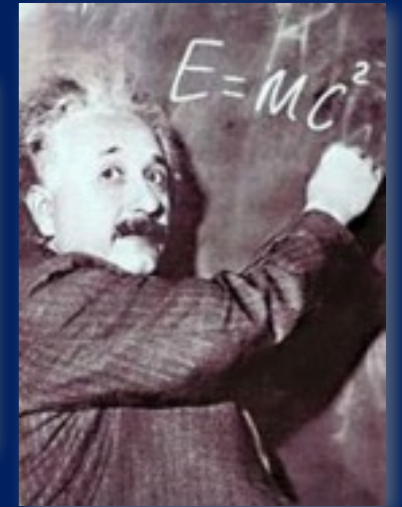


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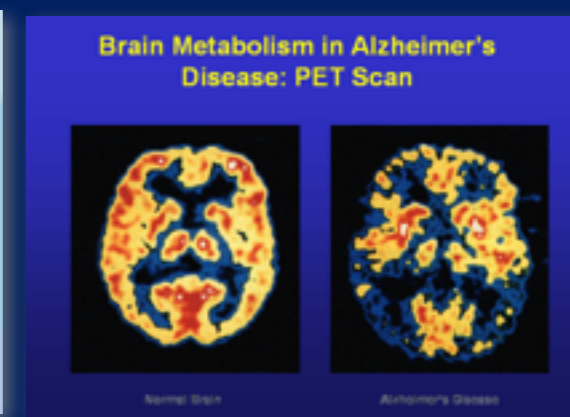
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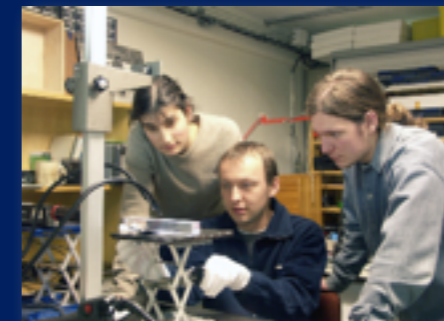


- **Develop** new technologies for accelerators and detectors

Information technology - the Web and the GRID
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- **Train** scientists and engineers of tomorrow



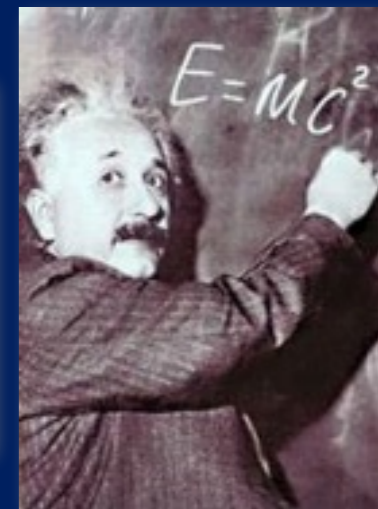


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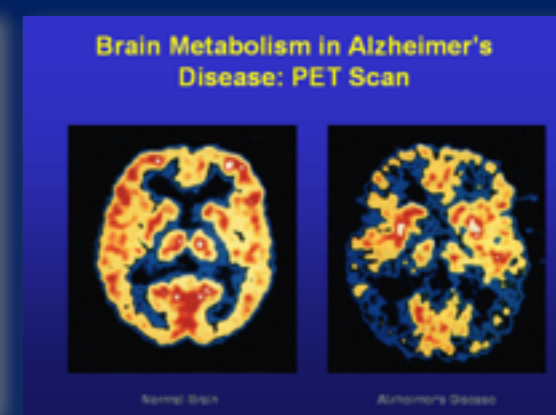
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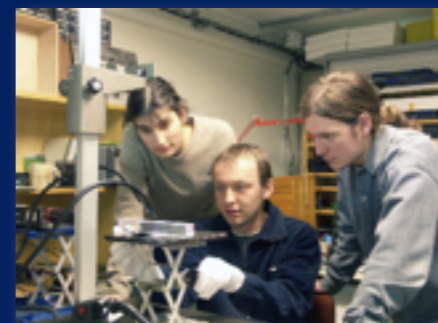


- ❑ **Develop** new technologies for accelerators and detectors

Information technology - the Web and the GRID
Medicine - diagnosis and therapy



- ❑ **Train** scientists and engineers of tomorrow



- ❑ **Unite** people from different countries and cultures



CERN was founded 1954: 12 European States

“Science for Peace”

Today: 21 Member States

Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

Candidate for Accession: Romania

Associate Member in Pre-Stage to Membership: Serbia

Applicant States for Membership or Associate Membership: Brazil, Croatia, Cyprus, Pakistan, Russia, Slovenia, Turkey, Ukraine

Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO



CERN was founded 1954: 12 European States

“Science for Peace”

Today: 21 Member States

~ 2300 staff

~ 1600 other paid personnel

~ 10500 scientific users

Budget (2014) ~1000 MCHF

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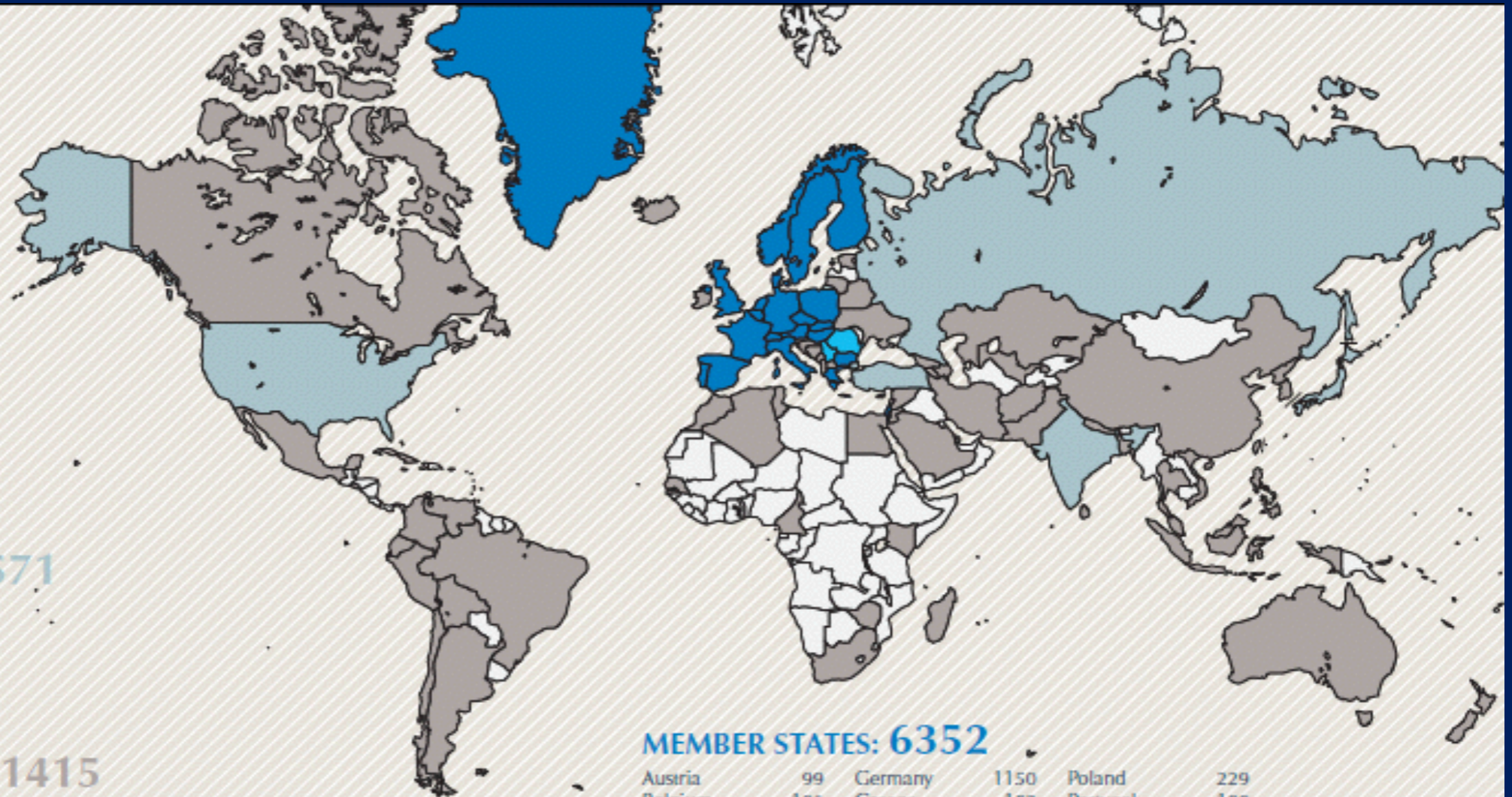
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CERN – building bridges across continents



OBSERVERS: 2571

India	220
Japan	244
Russia	982
Turkey	146
USA	979

OTHER STATES: 1415

Afghanistan	1	Colombia	30	Korea, D.P.R.	1
Albania	2	Croatia	35	Korea Rep.	117
Algeria	8	Cuba	7	Kuwait	1
Argentina	11	Cyprus	16	Lebanon	12
Armenia	25	Ecuador	3	Lithuania	19
Australia	25	Egypt	19	Luxembourg	4
Azerbaijan	8	El Salvador	1	Madagascar	4
Bangladesh	4	Estonia	16	Malaysia	15
Belarus	47	Georgia	36	Mauritius	1
Bolivia	3	Gibraltar	1	Mexico	64
Bosnia & Herzeg.	1	Hong Kong	1	Montenegro	3
Brazil	108	Iceland	4	Morocco	12
Cameroon	1	Indonesia	1	Nepal	5
Canada	134	Iran	28	New Zealand	7
Cape Verde	1	Ireland	22	Pakistan	41
Chile	12	Jordan	2	Palestine (O.T.)	4
China	280	Kazakhstan	1	Peru	8
China (Taipei)	45	Kenya	1	Philippines	1

MEMBER STATES: 6352

Austria	99	Germany	1150	Poland	229
Belgium	106	Greece	152	Portugal	109
Bulgaria	75	Hungary	68	Slovakia	88
Czech Republic	202	Israel	51	Spain	337
Denmark	53	Italy	1686	Sweden	75
Finland	87	Netherlands	153	Switzerland	180
France	751	Norway	61	United Kingdom	640

CANDIDATE for accession

Romania	118
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ASSOCIATE MEMBERS in the pre-stage to membership

Serbia	41
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Distribution of All CERN Users by Nationality on 14 January 2014

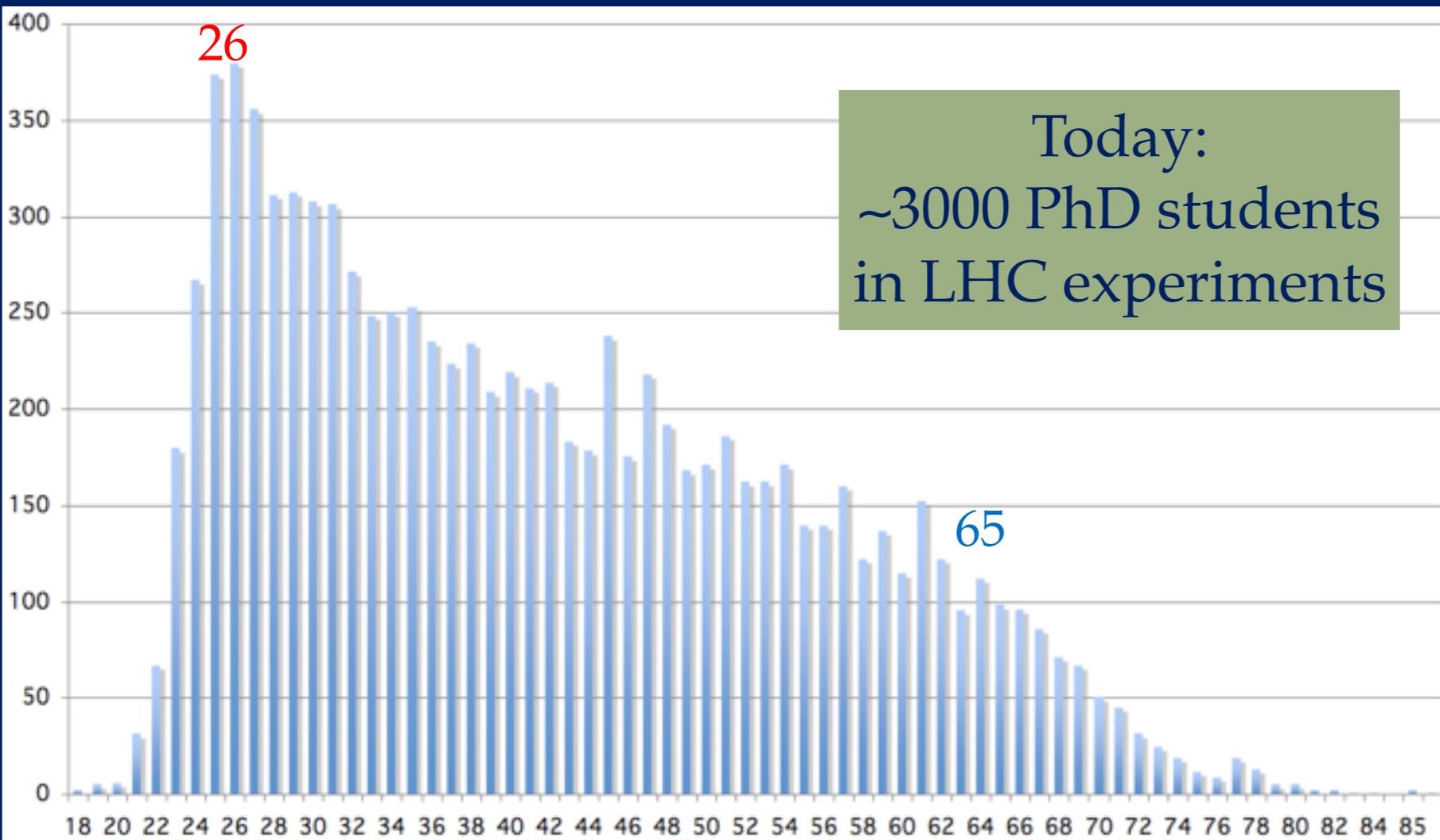


Age Distribution of Scientists

- and where they go afterwards



Survey in March 2009



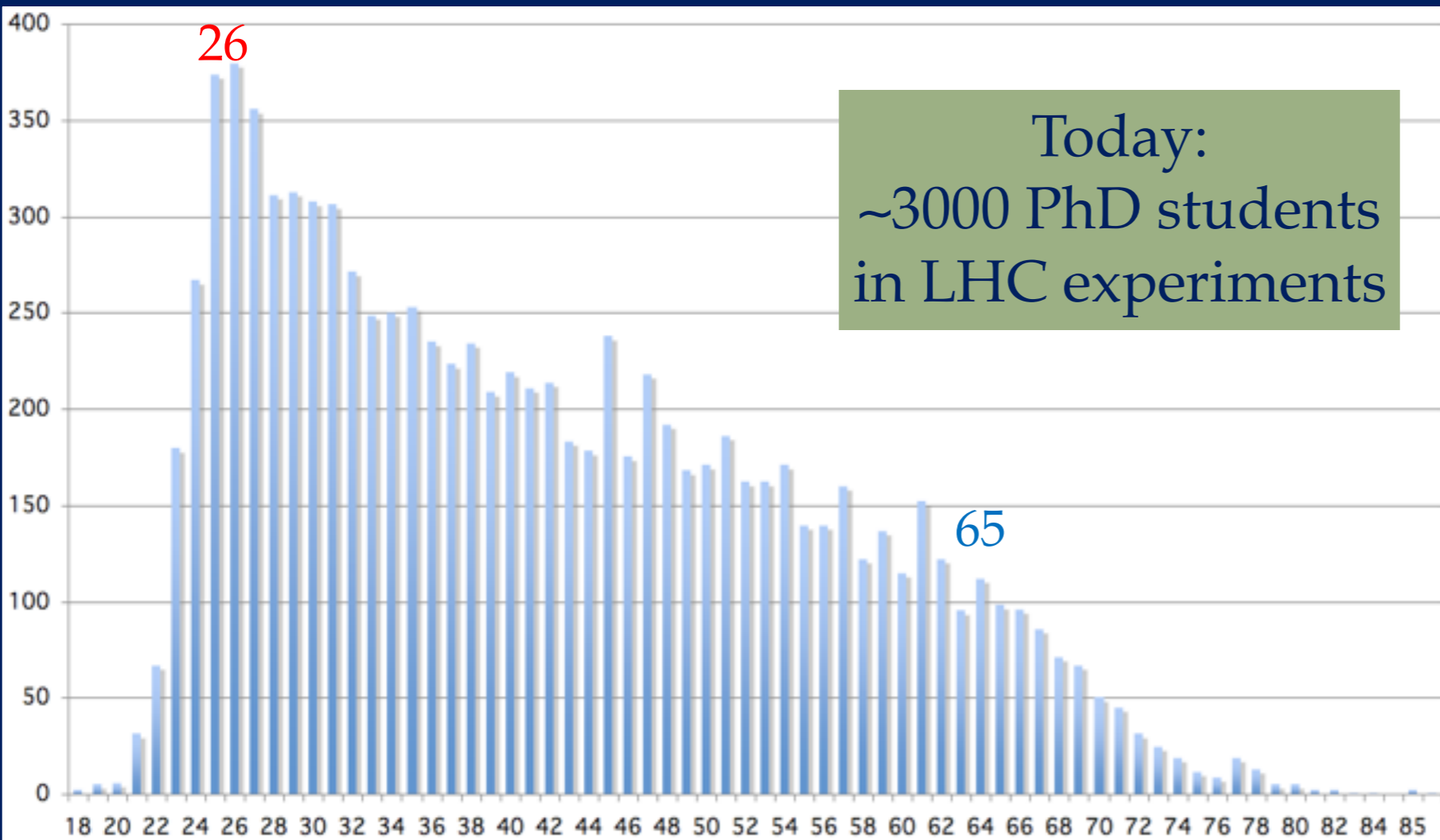


Age Distribution of Scientists

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They do not all stay: where do they go?

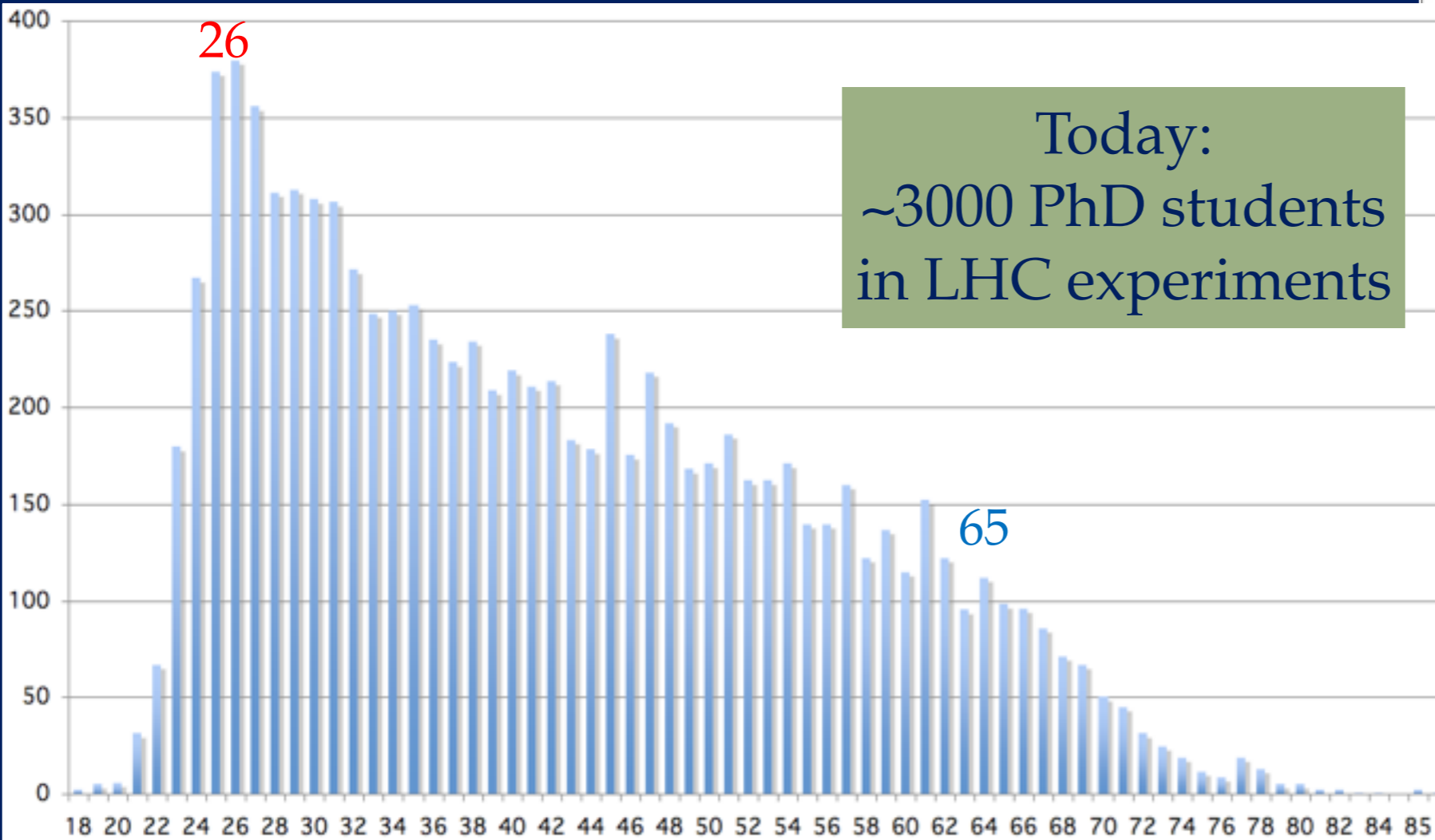
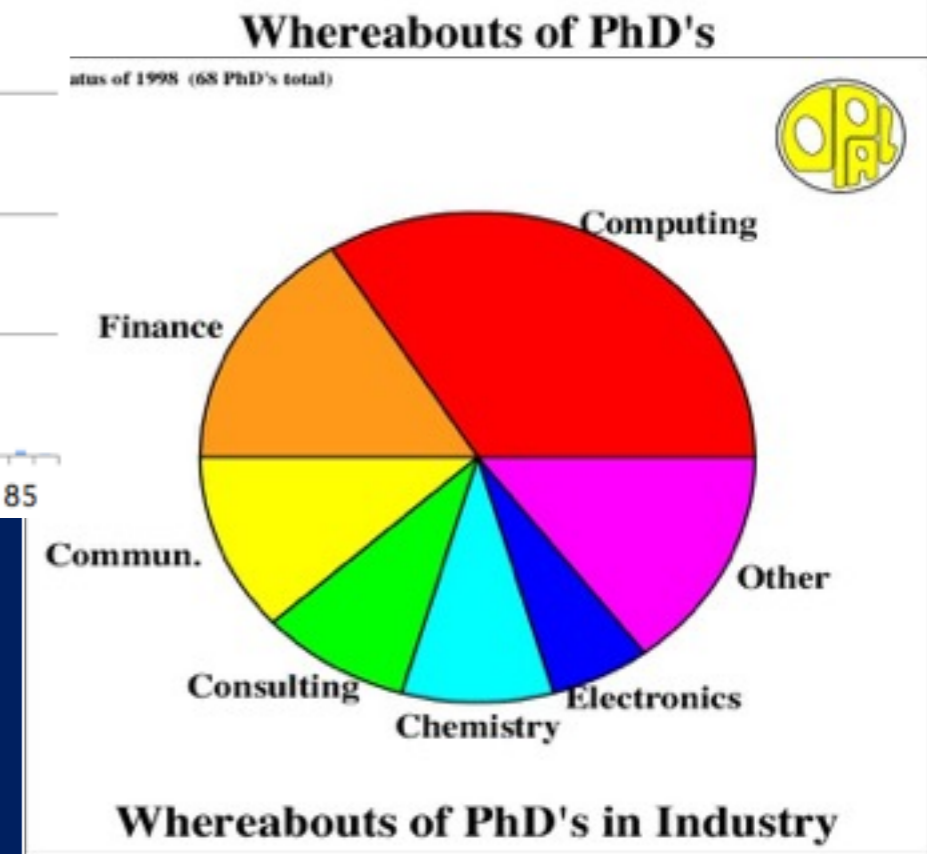
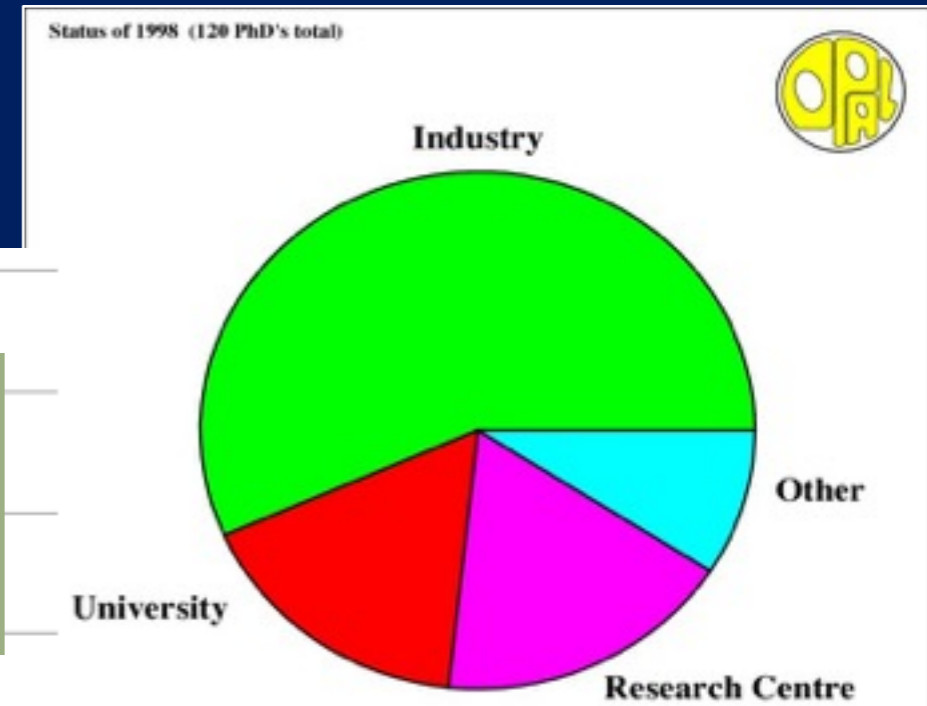


Age Distribution of Scientists

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They do not all stay: where do they go?

Knowledge and Technology Transfer



CERN: Particle Physics and Innovation

- **Interfacing** between fundamental science and key technological developments





CERN: Particle Physics and Innovation

- **Interfacing** between fundamental science and key technological developments



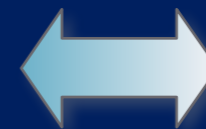
- **CERN Technologies and Innovation**



Accelerating particle beams



Detecting particles



Large-scale computing (Grid)



CERN Technologies and Innovation

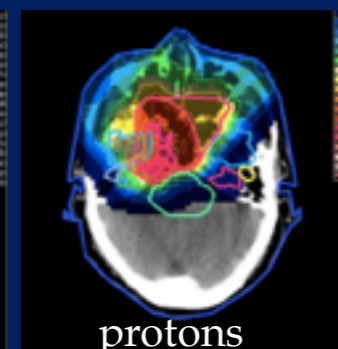
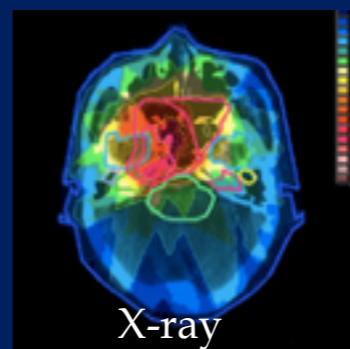
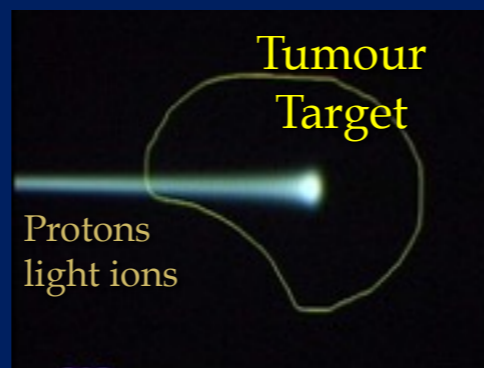
Example – Medical Applications



Combining Physics, ICT, Biology and Medicine to fight cancer



←→ Hadron Therapy



Accelerating particle beams

~30'000 accelerators worldwide
~17'000 used for medicine

>70'000 patients treated worldwide (30 facilities)
>21'000 patients treated in Europe (9 facilities)

Leadership in Ion
Beam Therapy now in
Europe and Japan



CERN Technologies and Innovation

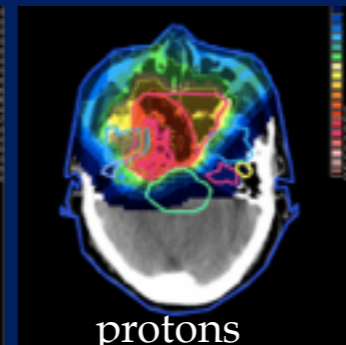
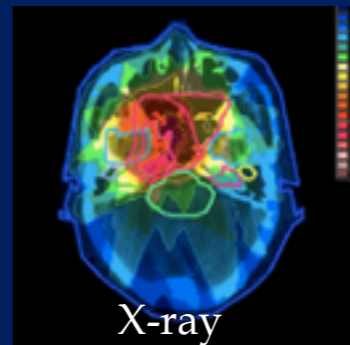
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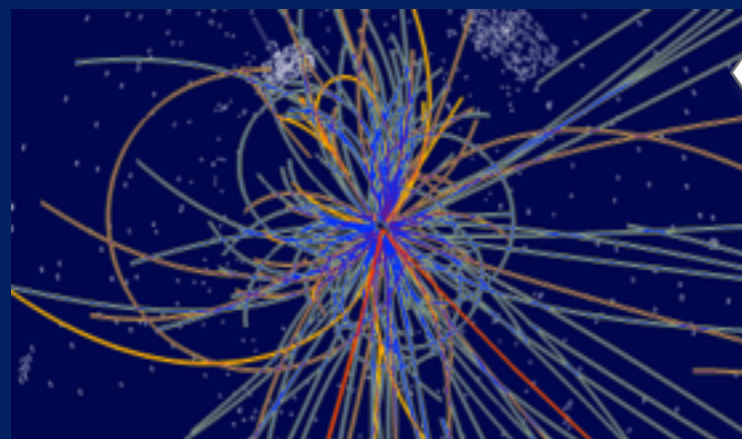
Hadron Therapy



Leadership in Ion Beam Therapy now in Europe and Japan

Accelerating particle beams
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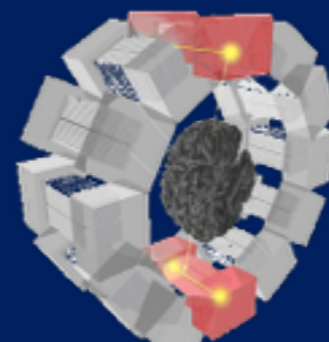
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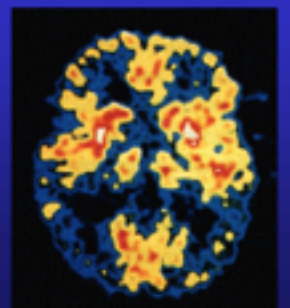
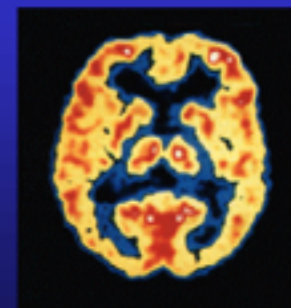
Imaging

PET Scanner

Clinical trial in Portugal for new breast imaging system (ClearPEM)



Brain Metabolism in Alzheimer's Disease: PET Scan



Detecting particles

Normal Brain

Alzheimer's Disease



Breaking the Wall of Communication 25 years ago: the Web was born





Breaking the Wall of Communication 25 years ago: the Web was born



Tim Berners-Lee



Breaking the Wall of Communication 25 years ago: the Web was born



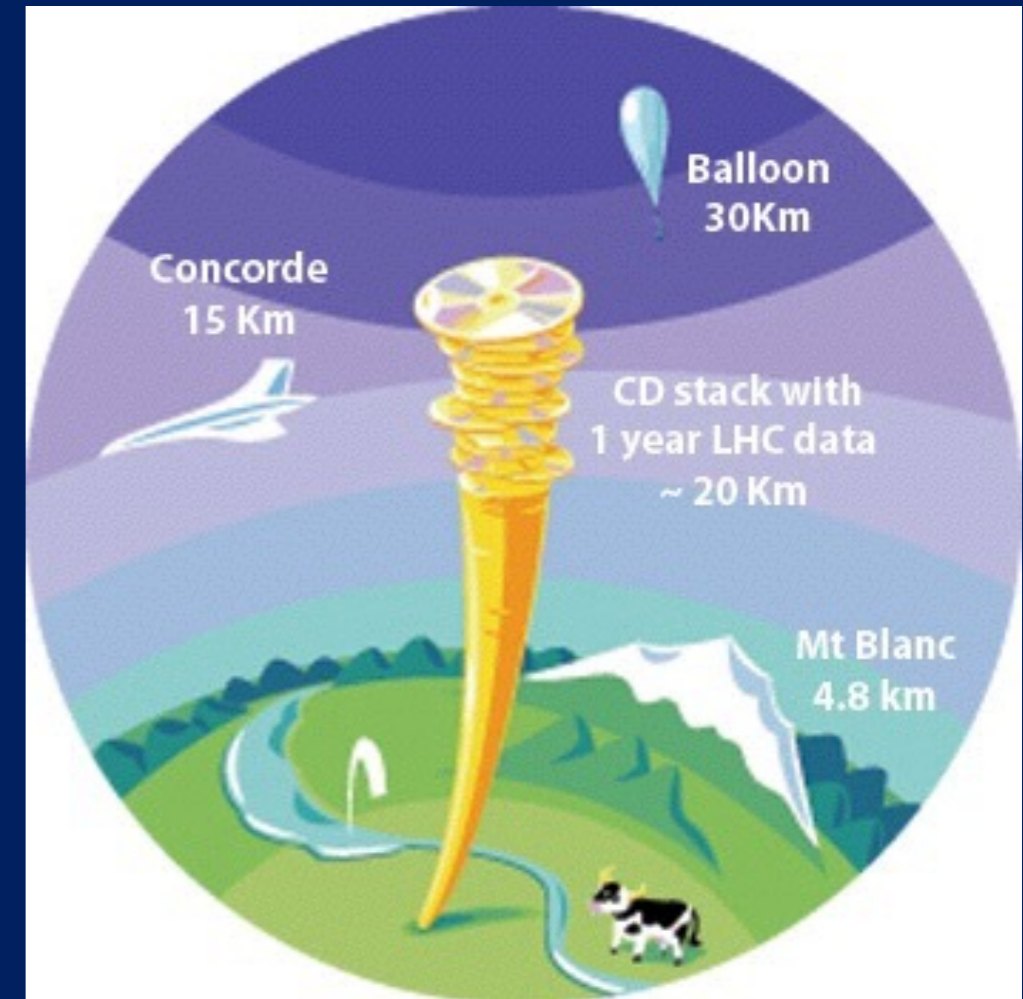
Tim Berners-Lee

... and today ?

The LHC Data Challenge



- ▣ Experiments were anticipated to produce about **25 Million Gigabytes** of data each year (~30 million CDs!).
- ▣ LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors**.
- ▣ => Requires many cooperating computer centres, as CERN can only provide ~20% of the capacity.



 **GRID Computing**

The Worldwide LHC Computing Grid



The Worldwide LHC Computing Grid

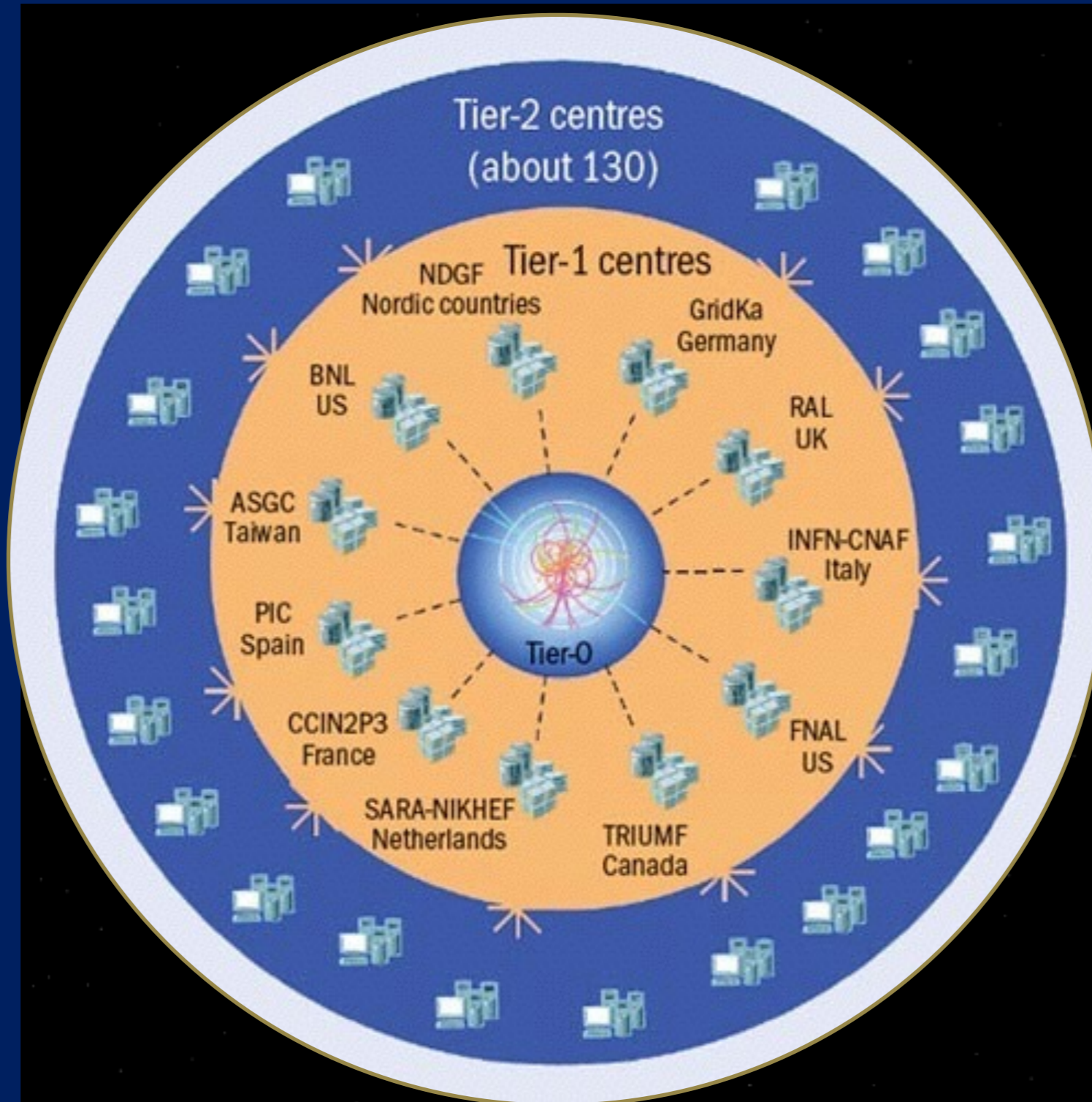


WLCG:

An International collaboration to distribute and analyse LHC data

Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists

The Worldwide LHC Computing Grid



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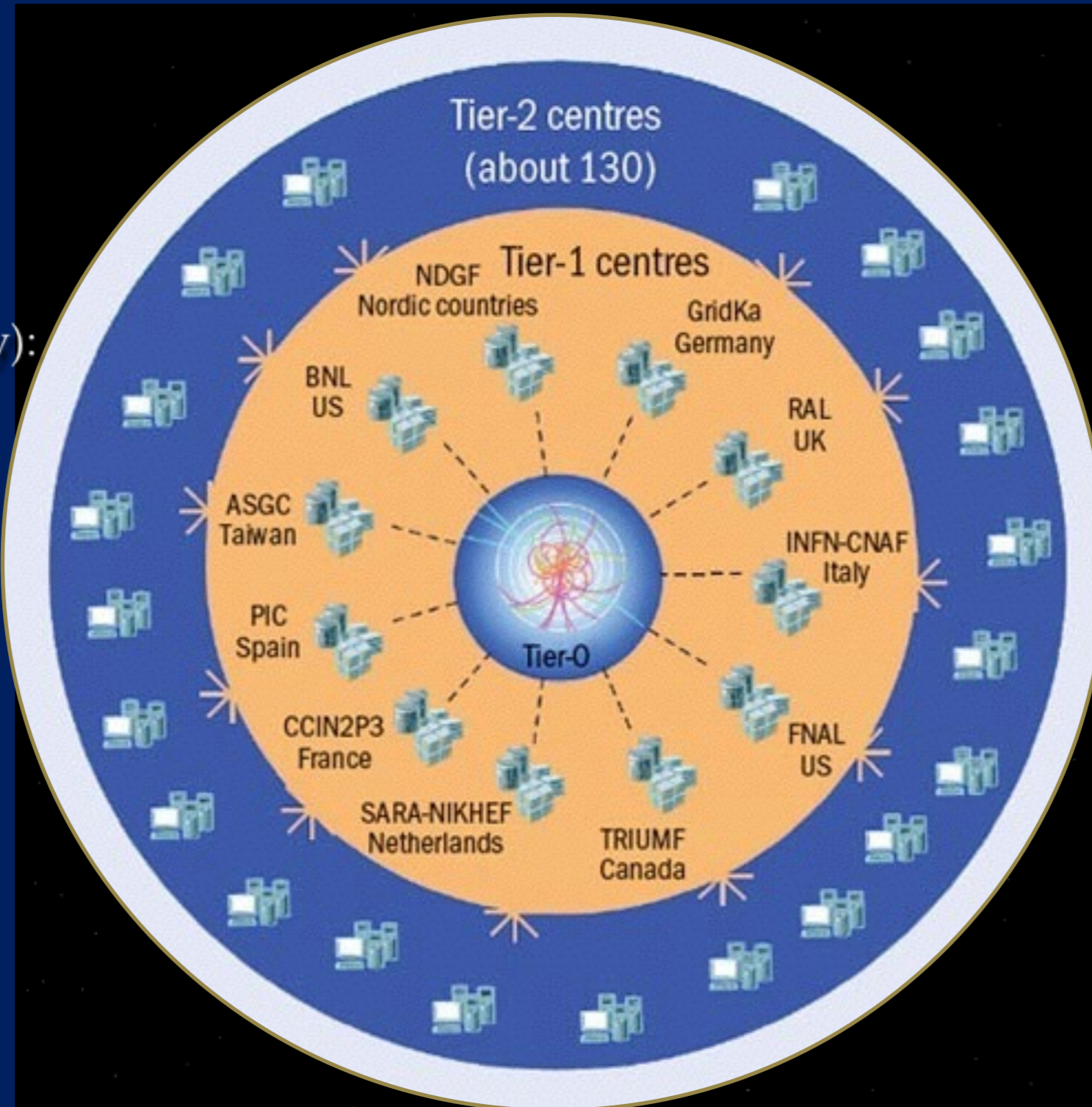
The Worldwide LHC Computing Grid



Tier-0
(CERN and Hungary):
data recording,
reconstruction and
distribution

Tier-1: permanent
storage, re-
processing,
analysis

Tier-2: Simulation,
end-user analysis



nearly 160 sites,
35 countries

~250'000 cores

173 PB of storage

> 2 million jobs/day

10 Gb links

WLCG:

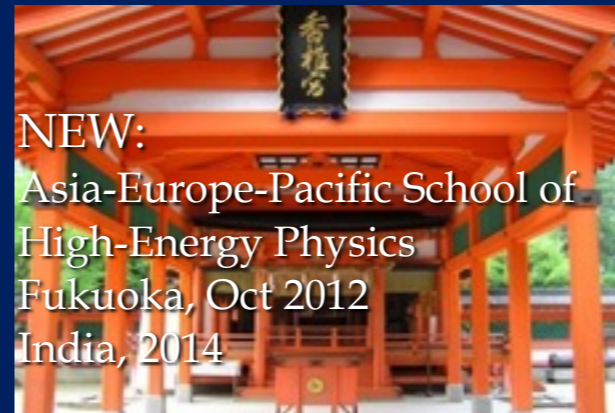
An International collaboration to distribute and analyse LHC data

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CERN Education Activities



Scientists at CERN
Academic Training Programme



NEW:
Asia-Europe-Pacific School of
High-Energy Physics
Fukuoka, Oct 2012
India, 2014



Latin American School
Natal, Brazil, 2011
Arequipa, Peru, 2013

Young Researchers

CERN School of High Energy Physics
CERN School of Computing
CERN Accelerator School



CERN School of Physics
Hungary, June 2013



Physics Students
Summer Students
Programme

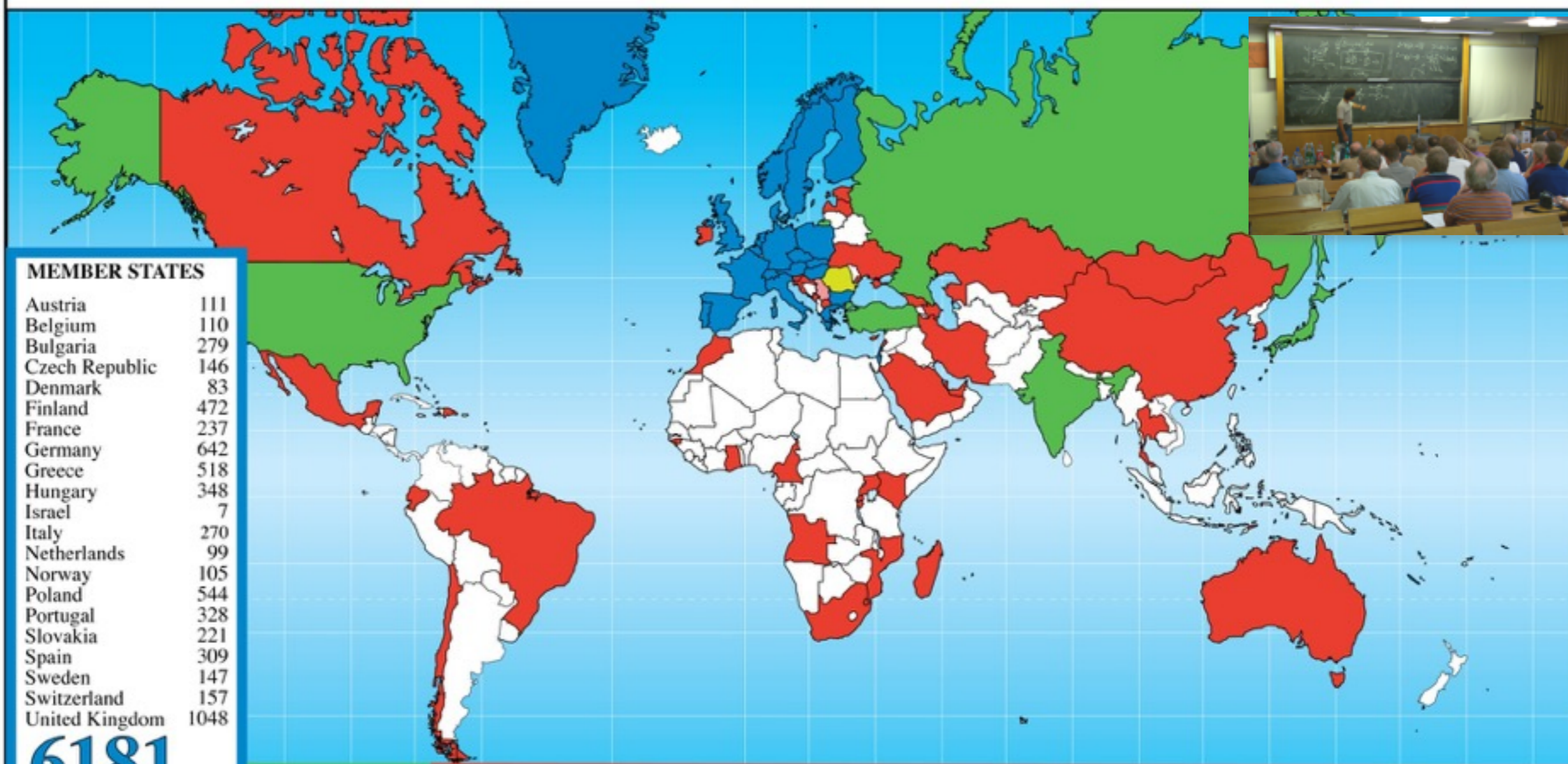


CERN Teacher Schools
International and National
Programmes

CERN Teacher Programme



Teacher Programme Participants 1998 - 2013 (Total: 7067)



MEMBER STATES

Austria	111
Belgium	110
Bulgaria	279
Czech Republic	146
Denmark	83
Finland	472
France	237
Germany	642
Greece	518
Hungary	348
Israel	7
Italy	270
Netherlands	99
Norway	105
Poland	544
Portugal	328
Slovakia	221
Spain	309
Sweden	147
Switzerland	157
United Kingdom	1048

6181

CANDIDATE FOR ACCESSION

Romania	12
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ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Serbia	14
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OBSERVER STATES

India	2
Japan	5
Russia	193
Turkey	3
USA	65

268

OTHERS

Angola	4	China	1	Ireland	5	Morocco	2	Swaziland	1
Australia	5	Croatia	1	Kazakhstan	3	Mozambique	17	Thailand	7
Azerbaijan	1	Cyprus	8	Kenya	4	Qatar	1	T.F.Y.R.O.M.	11
Brazil	114	Dominican Rep.	21	Latvia	1	Rwanda	17	Timor-Leste	7
Burundi	1	Ecuador	2	Lebanon	1	Sao Tome	4	Uganda	3
Cameroon	3	Estonia	46	Madagascar	2	Saudi Arabia	1	Ukraine	77
Canada	3	Georgia	74	Malta	36	Singapore	2	U.A.E.	1
Cape Verde	3	Ghana	6	Mexico	6	Slovenia	21		
Chile	3	Guinea Bissau	1	Mongolia	1	South Africa	6		
		Iran	1	Montenegro	13	South Korea	44		

592

Summer Students 2014



Summer Students 2014



Discovery Science

Scientific Challenge: to understand the very first moments of our Universe after the Big Bang

Big Bang

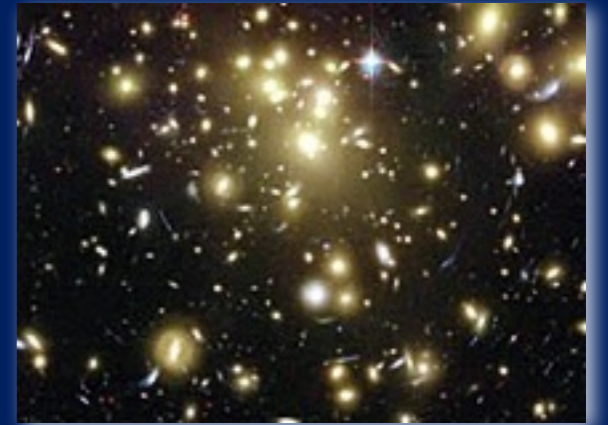
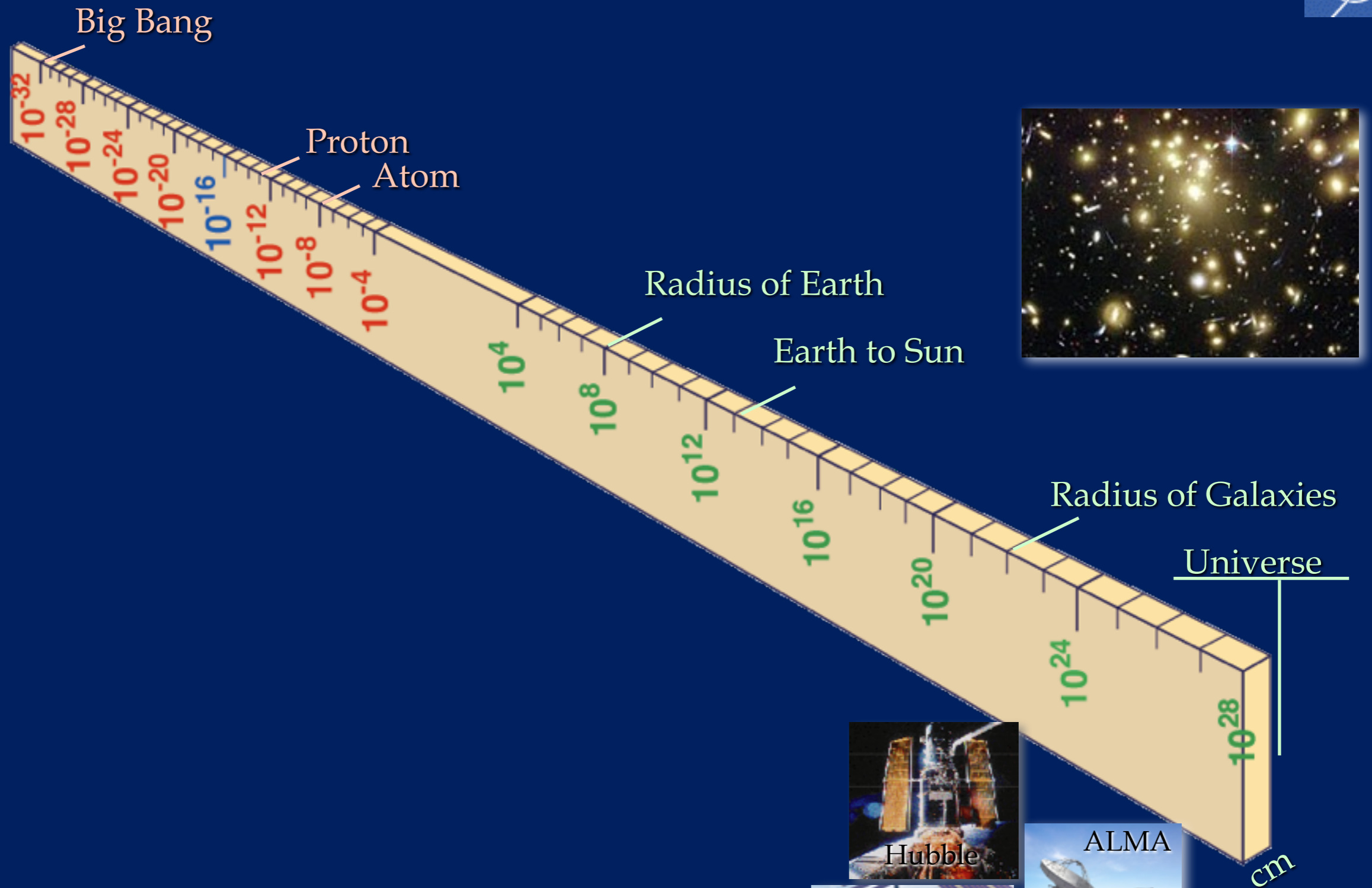


NASA
WMAP
Telescope

13.8 Billion Years (Planck Telescope)

10^{28} cm

Today

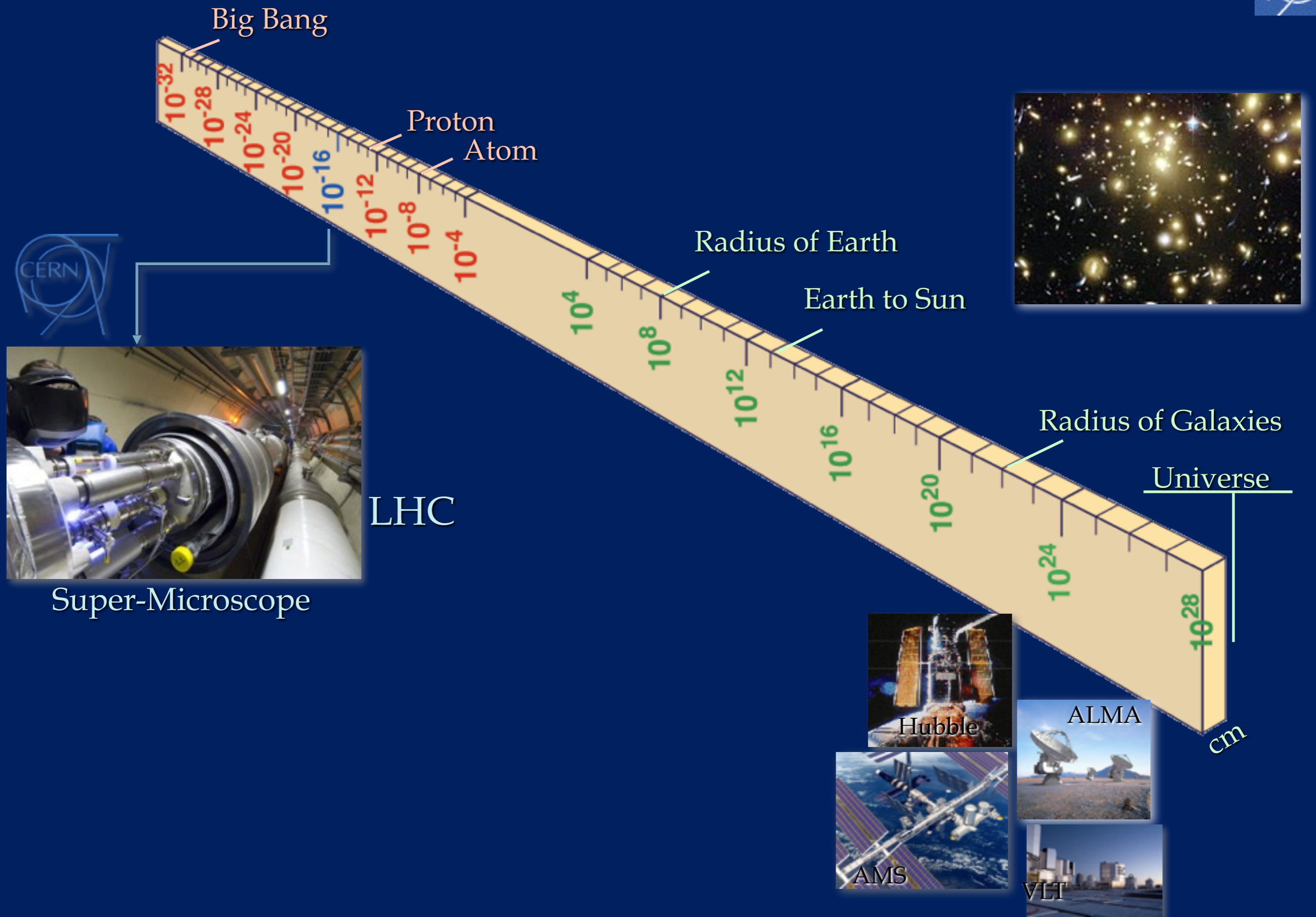


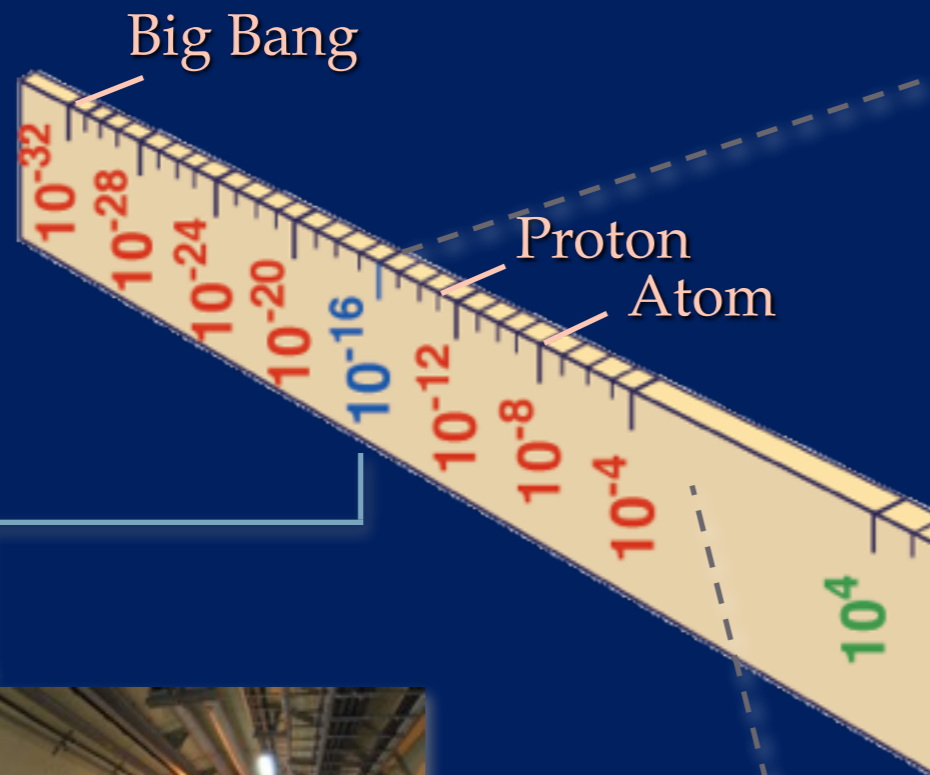
AMS

VLT

Hubble

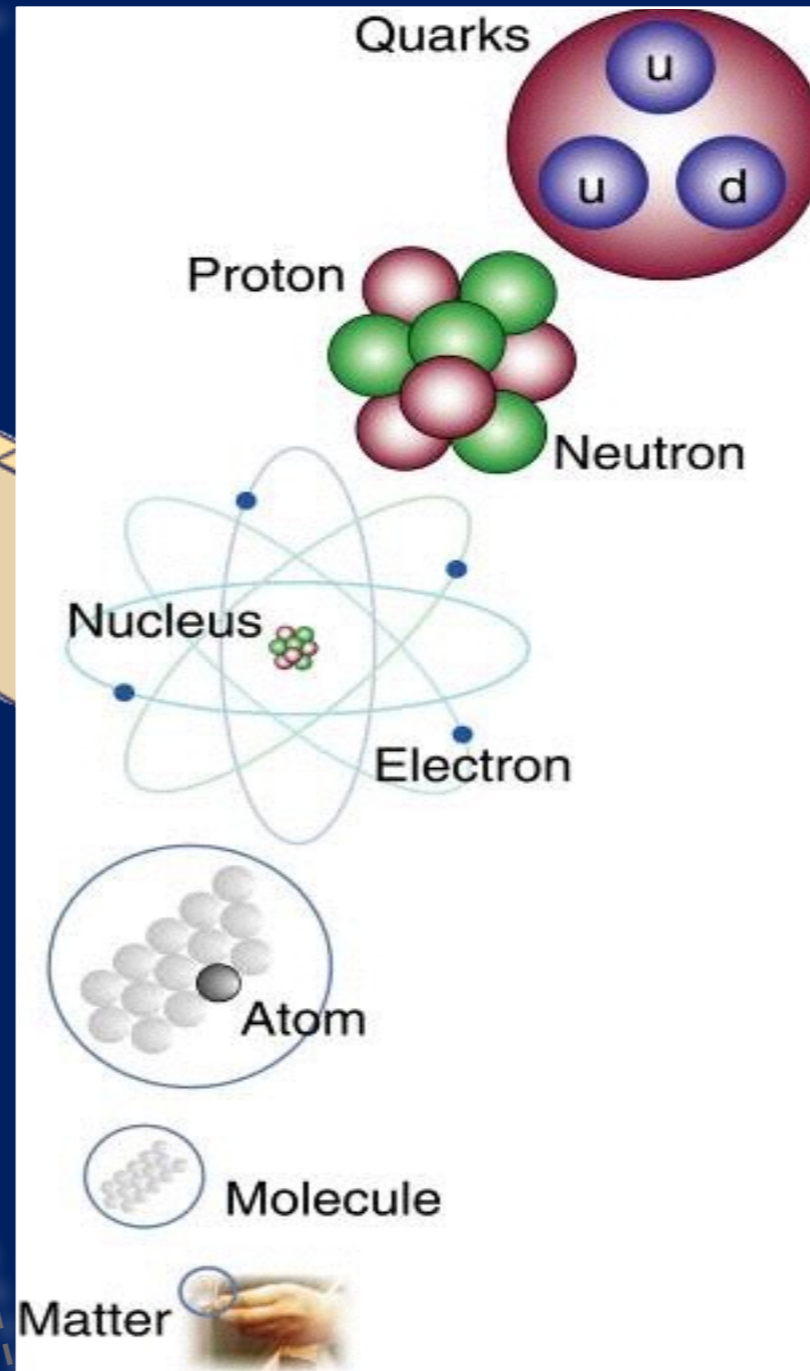
ALMA



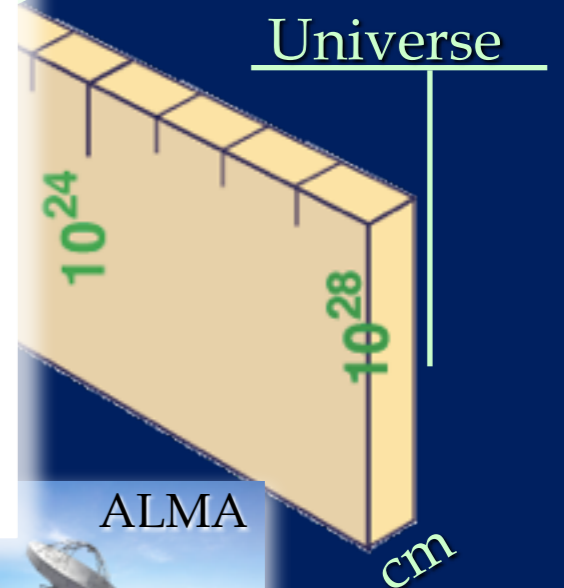


LHC

Super-Microscope



Radius of Galaxies



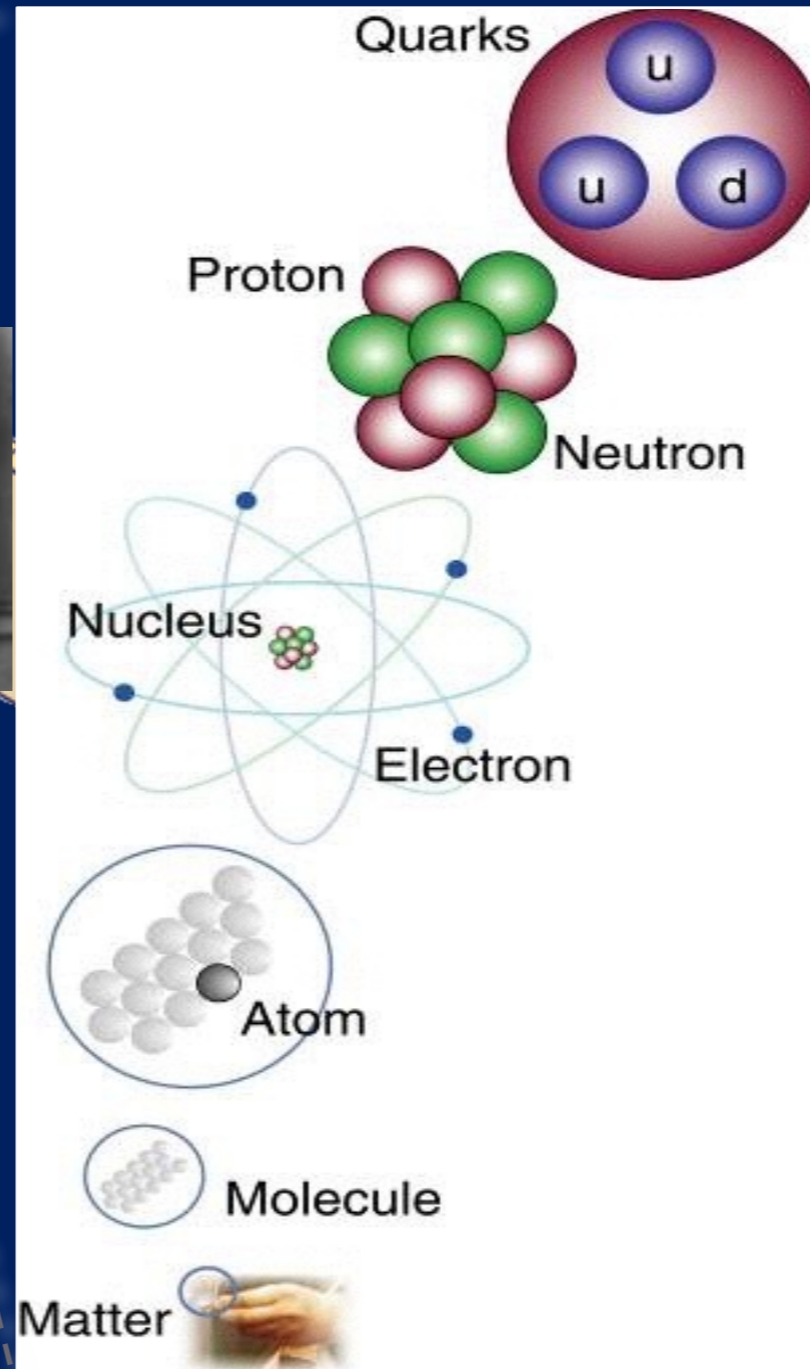
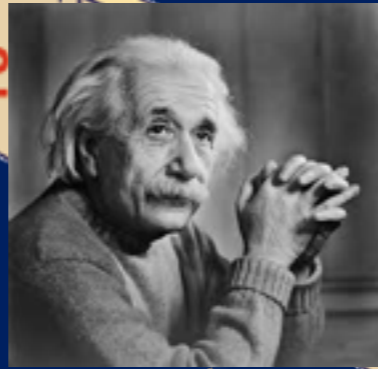
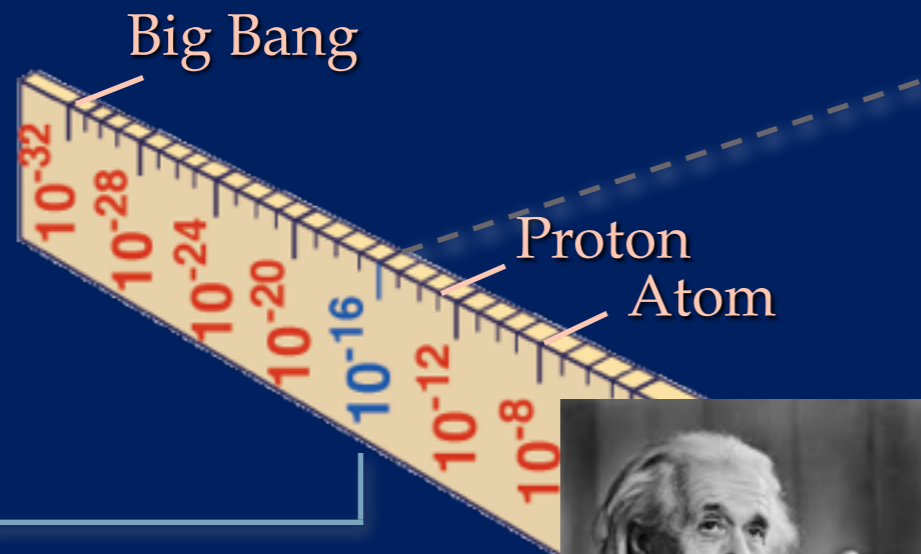
AMS



ALMA



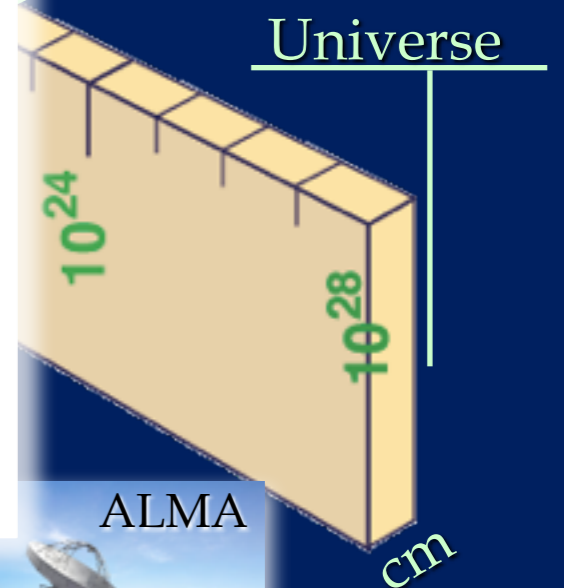
VLT



LHC

Super-Microscope

Radius of Galaxies



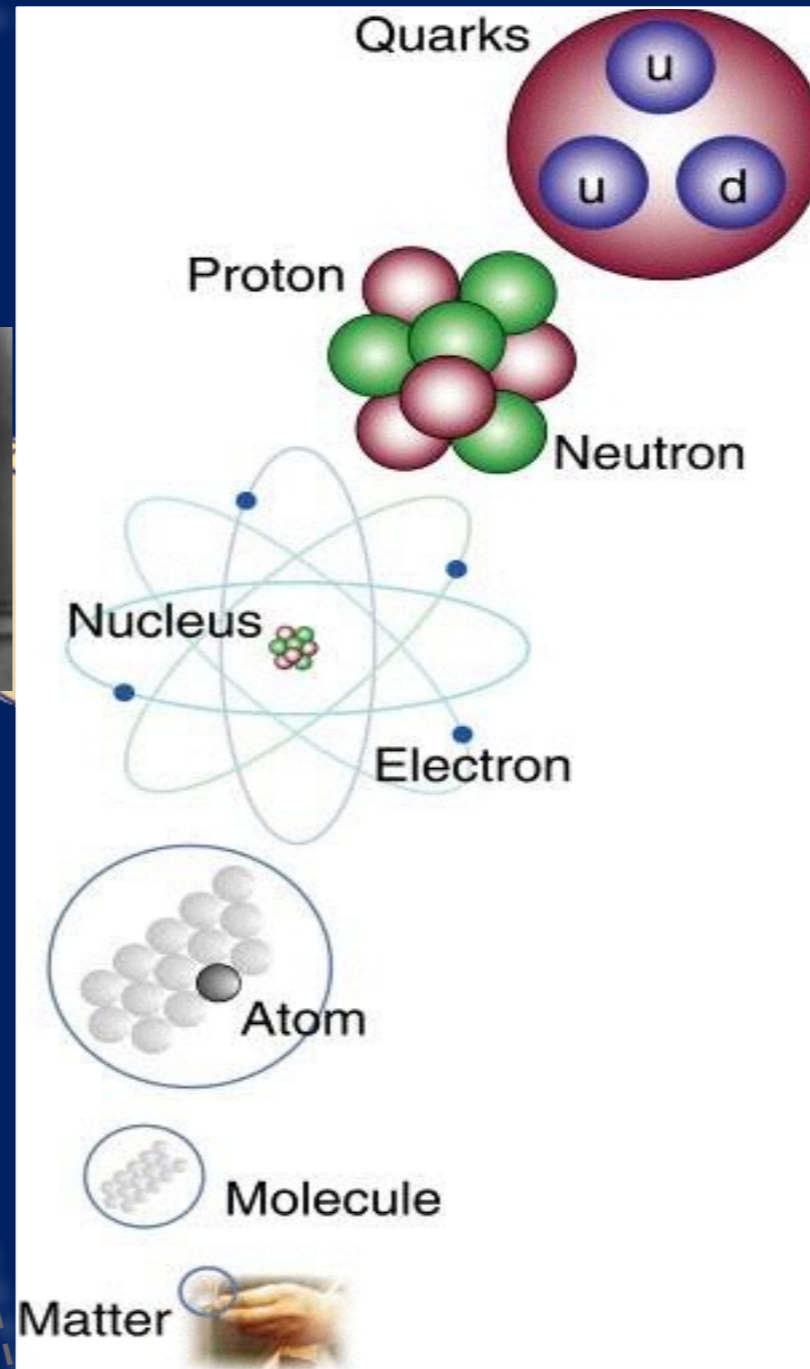
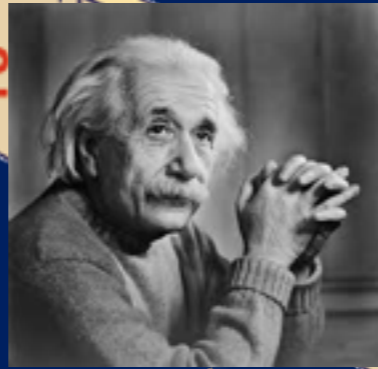
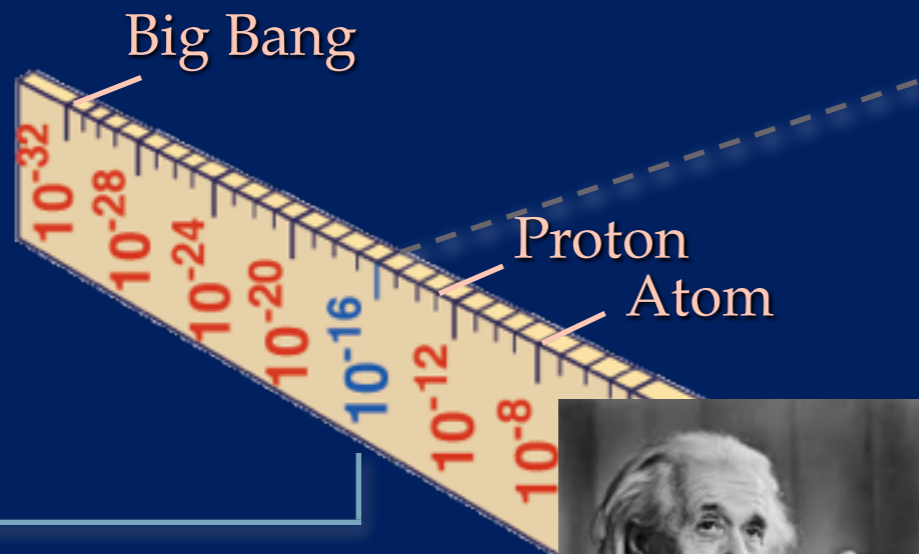
AMS



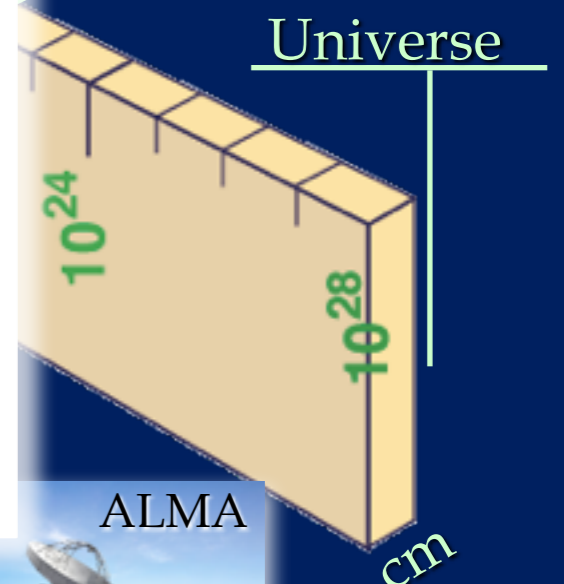
ALMA



VLT



Radius of Galaxies



LHC

Super-Microscope



Study physics laws of first moments after Big Bang
 increasing Symbiosis between Particle Physics,
 Astrophysics and Cosmology



AMS



ALMA

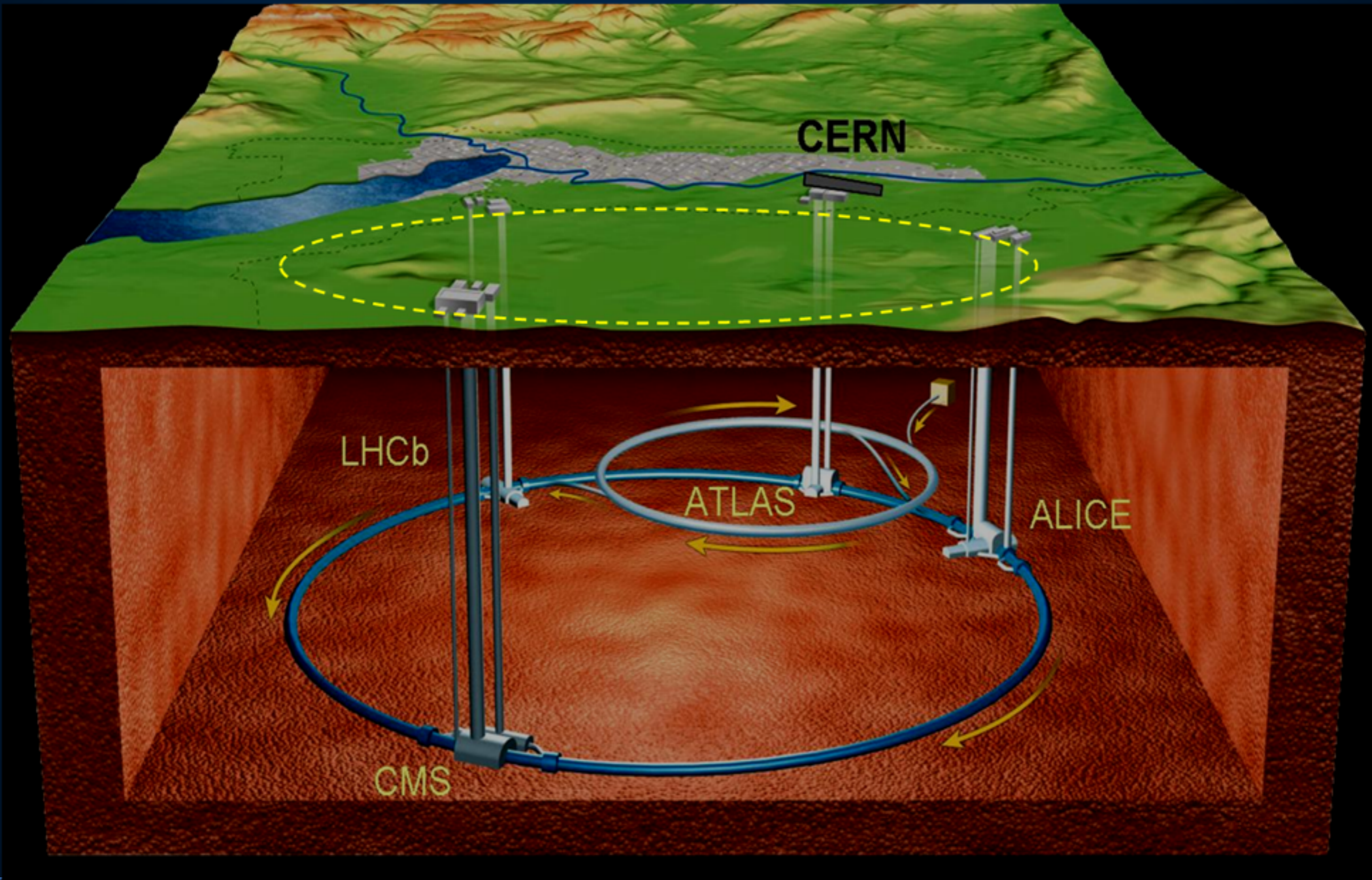


VLT

The Large Hadron Collider

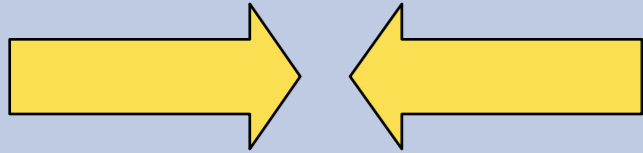


LHC – Large Hadron Collider

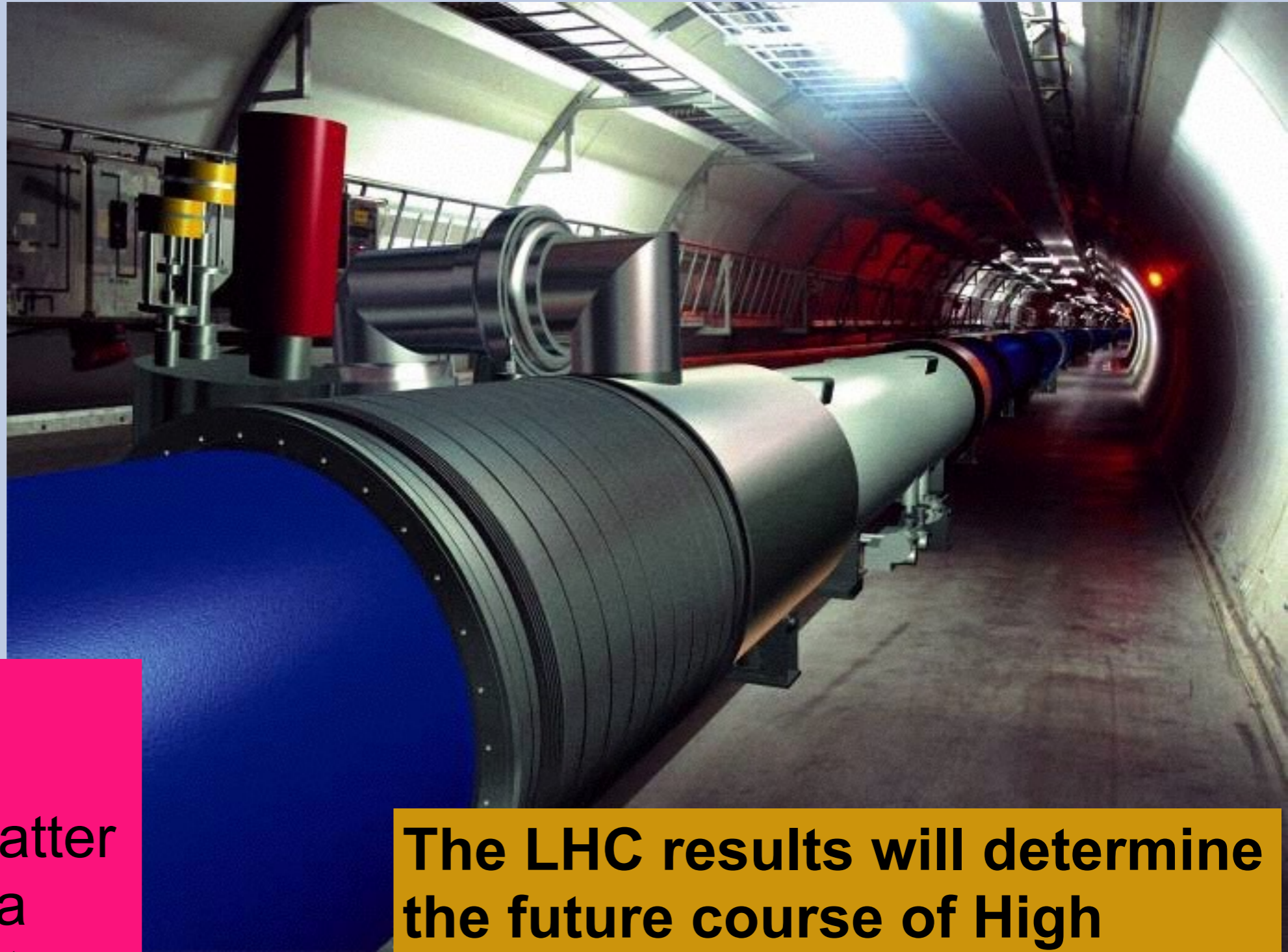


LHC - Large Hadron Collider

7 TeV + 7 TeV



Luminosity =
 $10^{34} \text{cm}^{-2} \text{sec}^{-1}$



Primary targets:

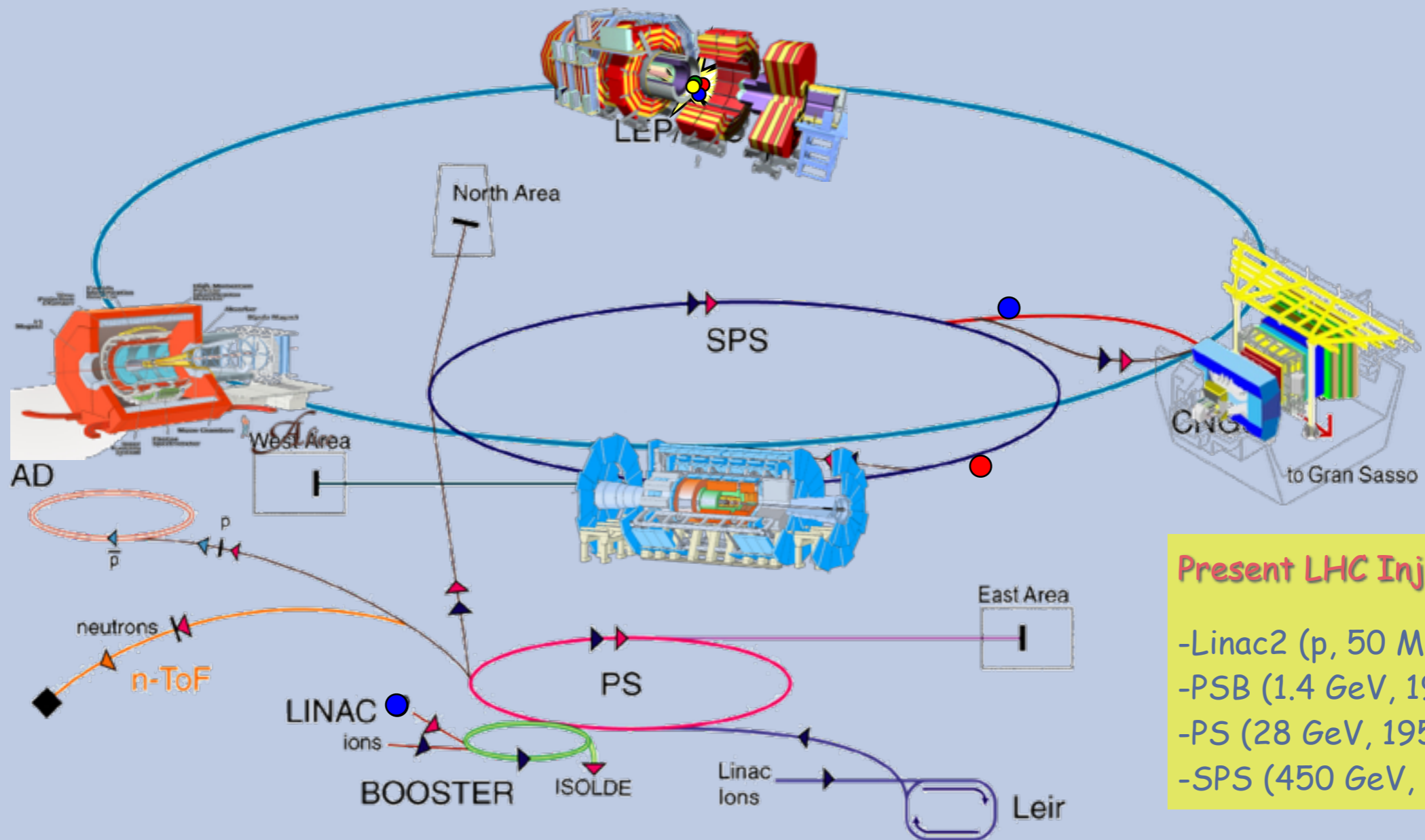
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

The LHC results will determine the future course of High Energy Physics

The large Hadron Collider

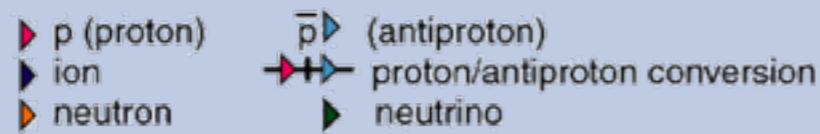
Collision of proton beams...

...observed in giant detectors



Present LHC Injectors

- Linac2 (p, 50 MeV, 1978)
- PSB (1.4 GeV, 1972)
- PS (28 GeV, 1959)
- SPS (450 GeV, 1976)



AD Antiproton Decelerator
 PS Proton Synchrotron
 SPS Super Proton Synchrotron

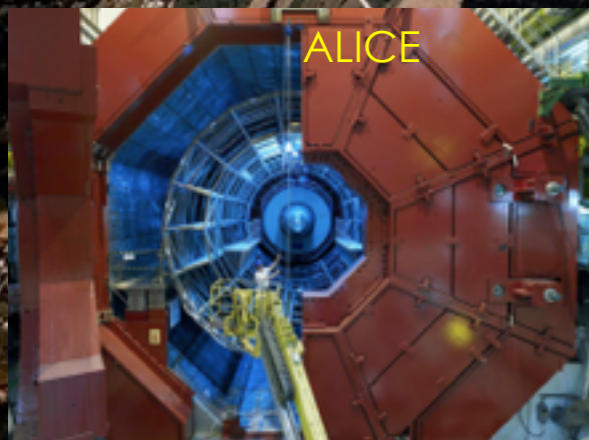
LHC Large Hadron Collider
 n-ToF Neutron Time of Flight
 CNGS Cern Neutrinos Gran Sasso

Enter a New Era in Fundamental Science

Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.



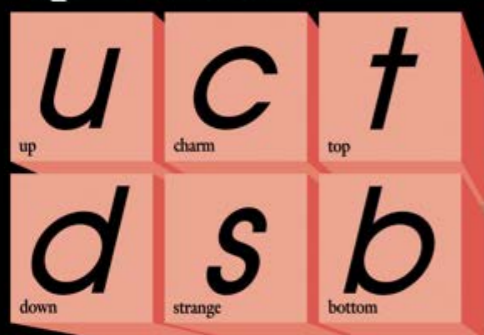
Exploration of a new energy frontier
Proton-proton collisions at E_{CM} up to 14 TeV



The discovery of the **Higgs particle** – the most important result from LHC (currently)

4.07.2012

Quarks



Forces

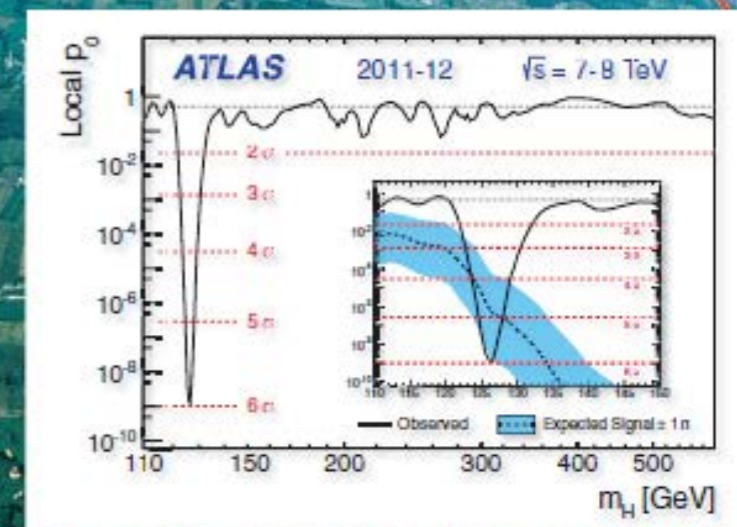
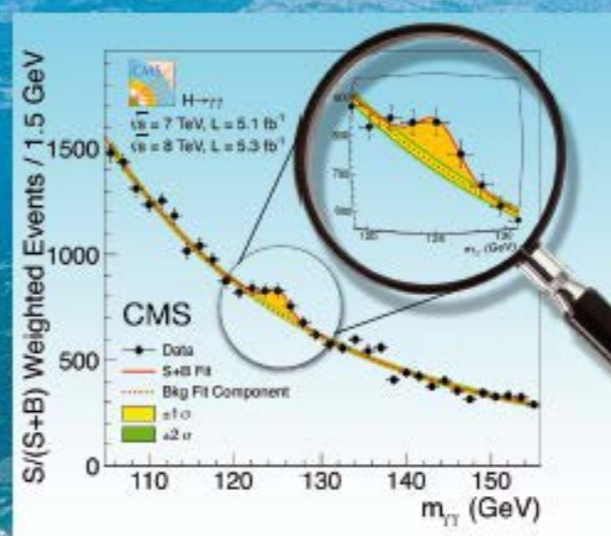


Leptons



Published:
Physics Letters B 716,
17 Sep 2012

First observations of a new particle in the search for the Standard Model Higgs boson at the LHC



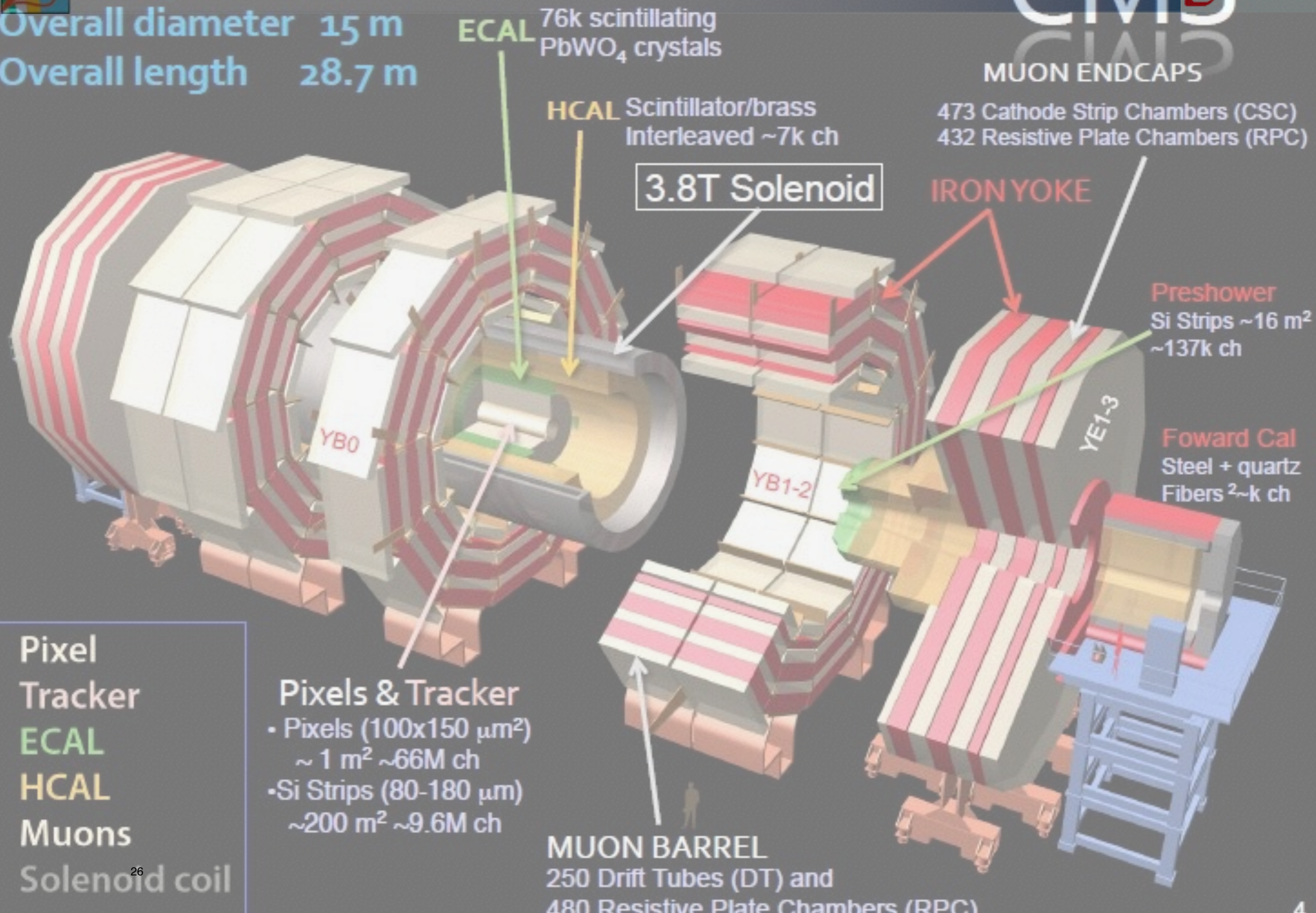




CMS



Total weight 14000 t
 Overall diameter 15 m
 Overall length 28.7 m



3.8T Solenoid

MUON ENDCAPS

473 Cathode Strip Chambers (CSC)
 432 Resistive Plate Chambers (RPC)

IRON YOKE

Preshower
 Si Strips ~16 m²
 ~137k ch

Foward Cal
 Steel + quartz
 Fibers ~k ch

YB0

YB1-2

YE1-3

Pixel
 Tracker
 ECAL
 HCAL
 Muons
 Solenoid coil

Pixels & Tracker
 • Pixels (100x150 μm²)
 ~ 1 m² ~66M ch
 • Si Strips (80-180 μm)
 ~200 m² ~9.6M ch

MUON BARREL
 250 Drift Tubes (DT) and
 480 Resistive Plate Chambers (RPC)



Total weight 14000 t
 Overall diameter 15 m
 Overall length 28.7 m

ECAL 76k scintillating PbWO₄ crystals

HCAL Scintillator/brass Interleaved ~7k ch

MUON ENDCAPS

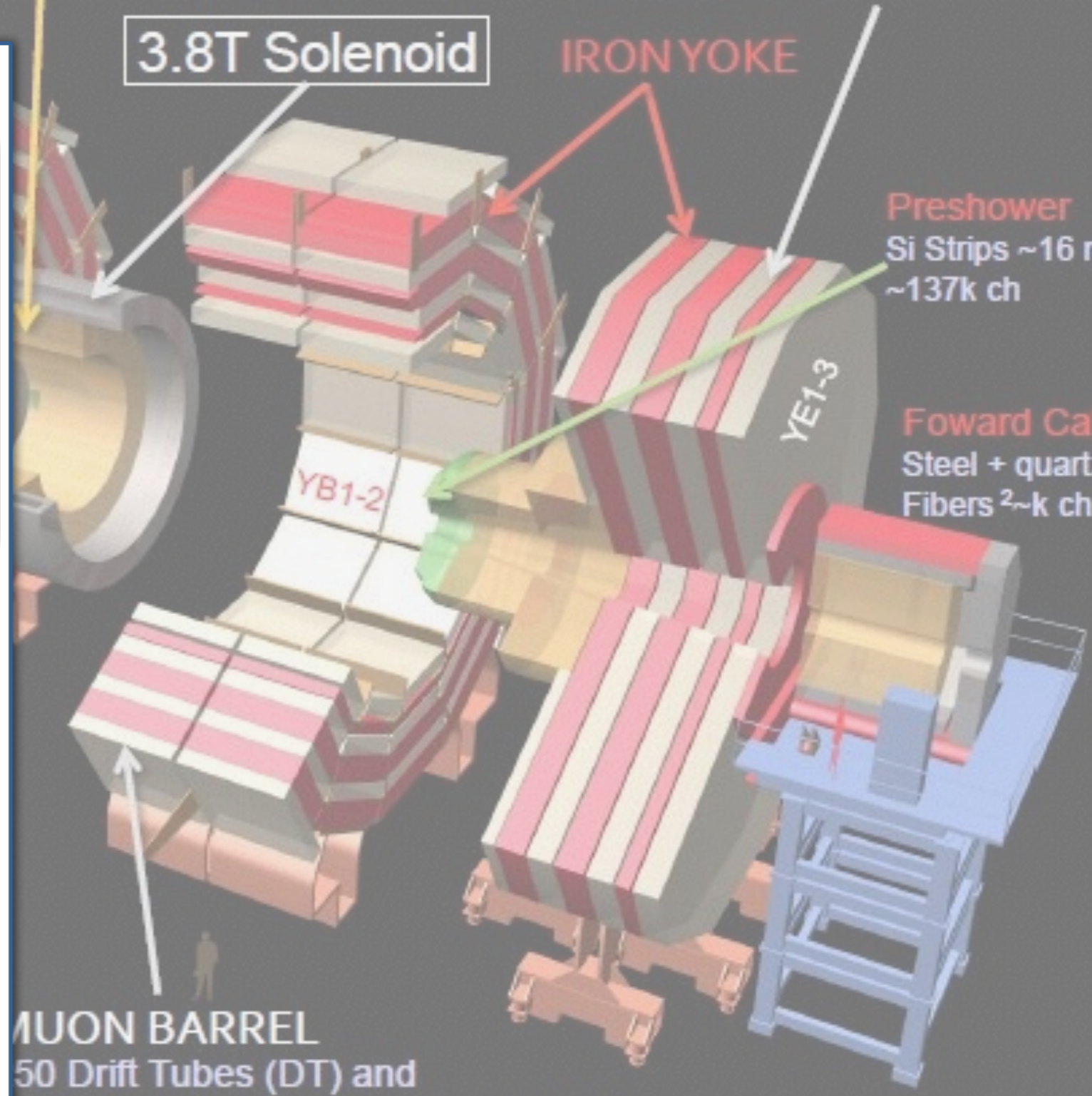
473 Cathode Strip Chambers (CSC)
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3.8T Solenoid

IRON YOKE

Preshower
 Si Strips ~16 m²
 ~137k ch

Foward Cal
 Steel + quartz
 Fibers ~k ch



The design goals of CMS:

1. A very good and redundant muon system
2. The best possible ECAL consistent with 1)
3. A high quality central tracking to achieve 1) and 2)
4. A financially affordable detector

-3.8T solenoid 13m long, 6m diameter
 - high eta HCAL coverage

-Silicon based inner tracking system supplementing all types of reconstr.

Powerful reconstruction of:

μ , e/ γ , τ -jets, jets, MET
 (+tracks, vertices)

MUON BARREL
 50 Drift Tubes (DT) and
 480 Resistive Plate Chambers (RPC)



Total weight 14000 t
 Overall diameter 15 m
 Overall length 28.7 m

CMS

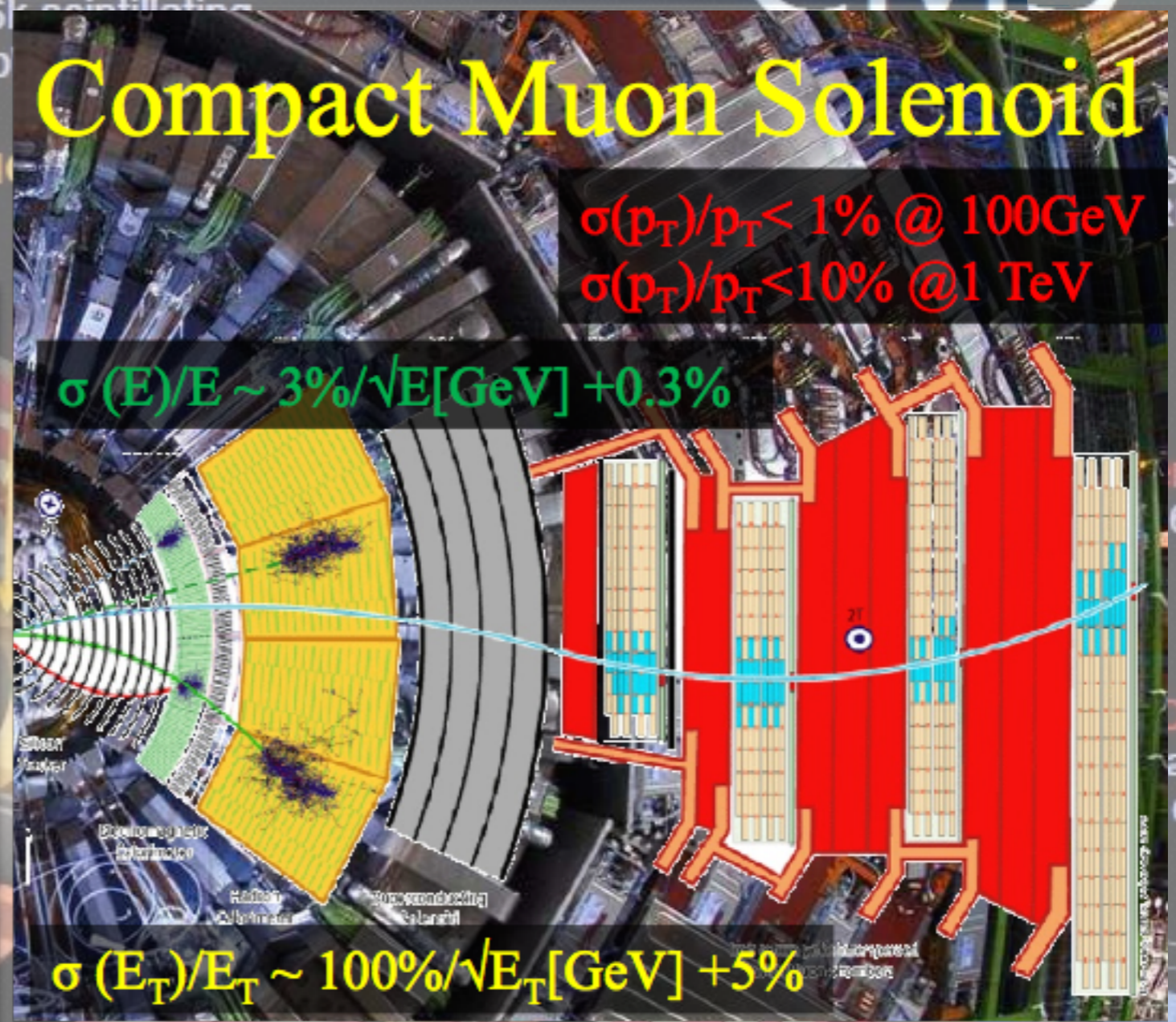
CMS

Compact Muon Solenoid

$\sigma(p_T)/p_T < 1\% @ 100\text{GeV}$
 $\sigma(p_T)/p_T < 10\% @ 1\text{TeV}$

$\sigma(E)/E \sim 3\%/\sqrt{E[\text{GeV}]} + 0.3\%$

$\sigma(E_T)/E_T \sim 100\%/\sqrt{E_T[\text{GeV}]} + 5\%$



- The design goals of CMS:**
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MUON BARREL
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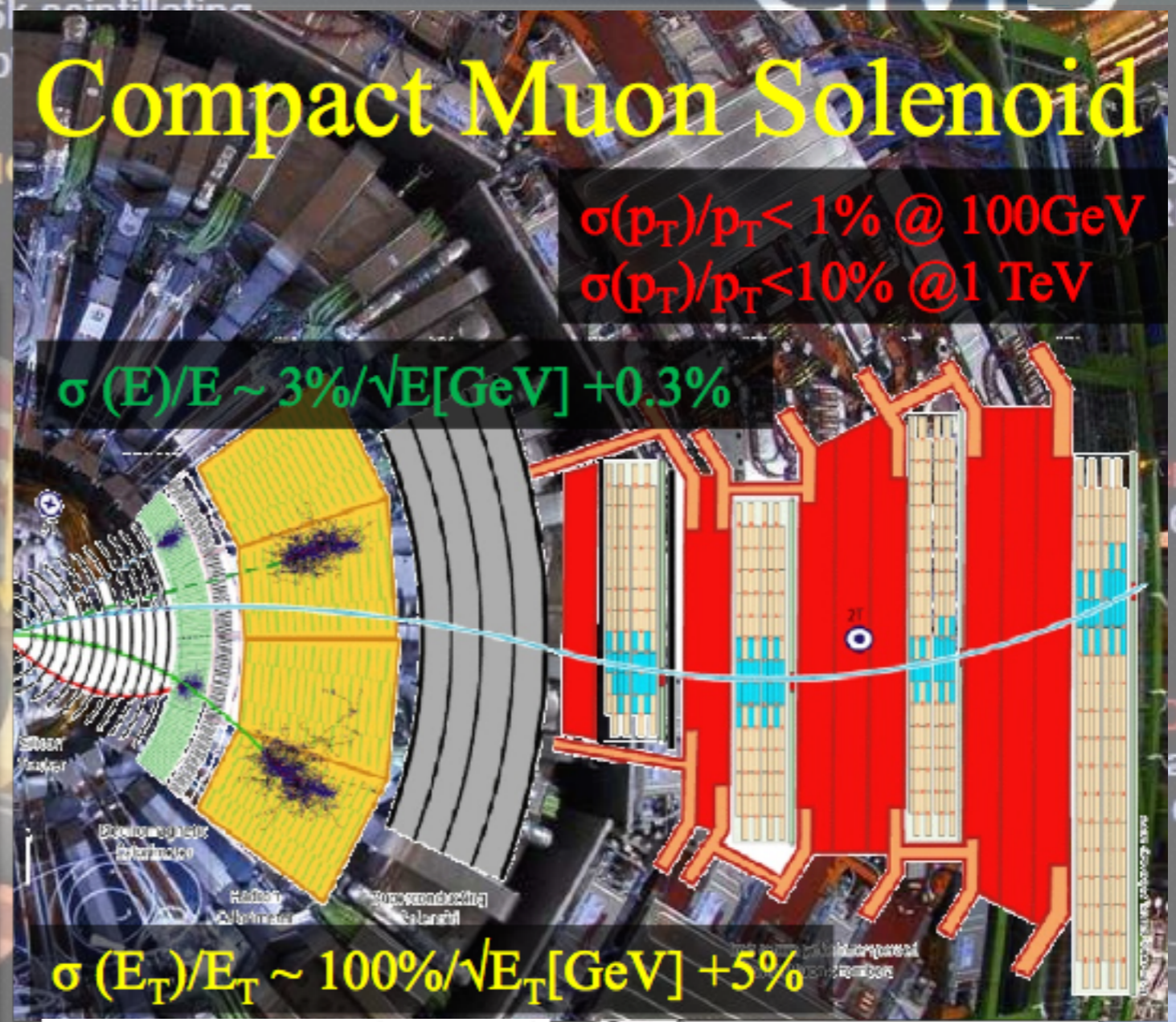
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 $\sigma(p_T)/p_T < 10\% @ 1\text{TeV}$

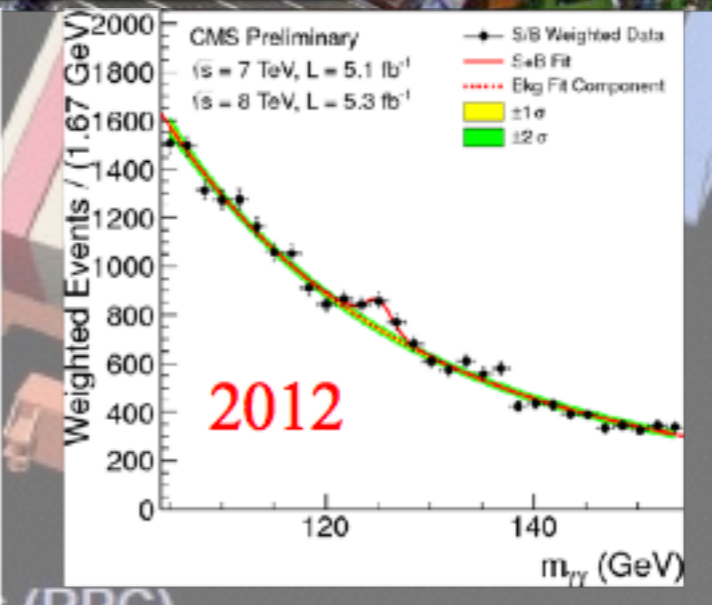
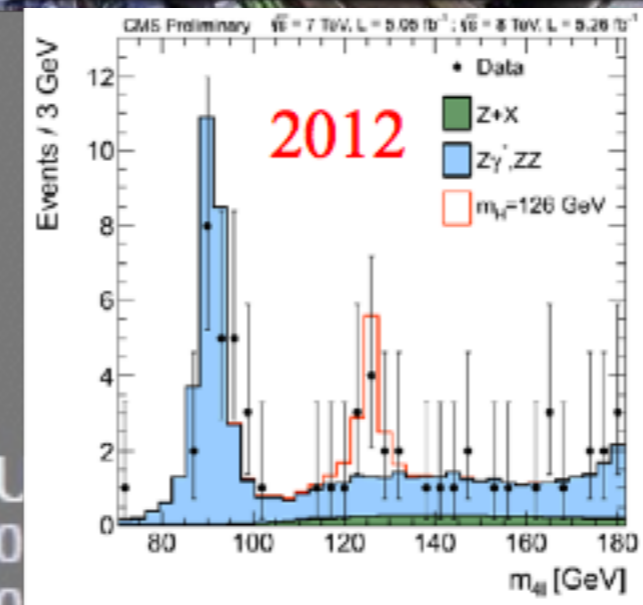
$\sigma(E)/E \sim 3\%/\sqrt{E[\text{GeV}]} + 0.3\%$

$\sigma(E_T)/E_T \sim 100\%/\sqrt{E_T[\text{GeV}]} + 5\%$

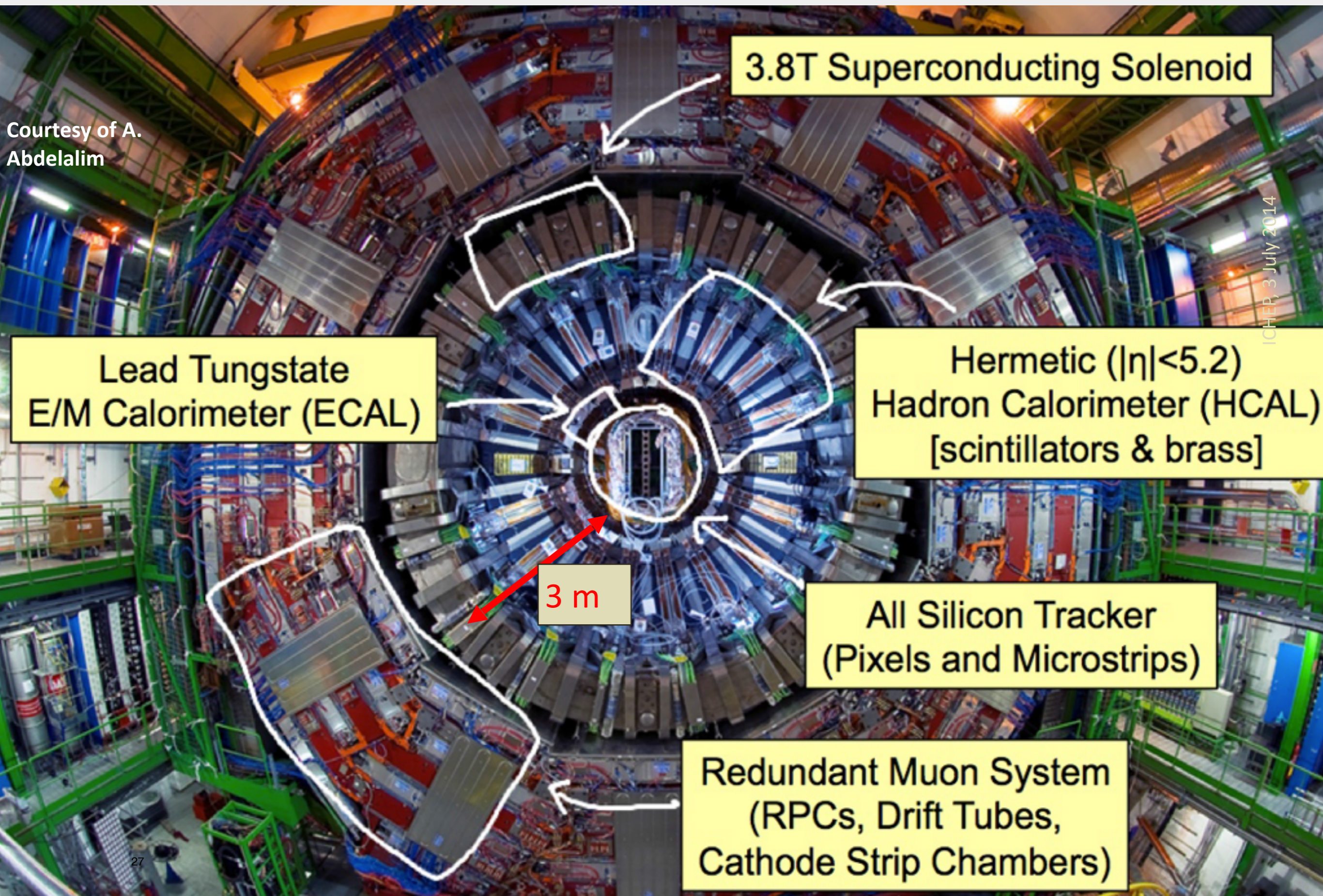


- The design goals of CMS:**
1. A very good and redundant muon system
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-3.8T solenoid 13m long, 6m diameter
 - high eta HCAL coverage
 -Silicon based inner tracking system
 supplementing all types of reconstr.
Powerful reconstruction of:
 μ , e/γ , τ -jets, jets, MET
 (+tracks, vertices)



Courtesy of A. Abdelalim



3.8T Superconducting Solenoid

Lead Tungstate E/M Calorimeter (ECAL)

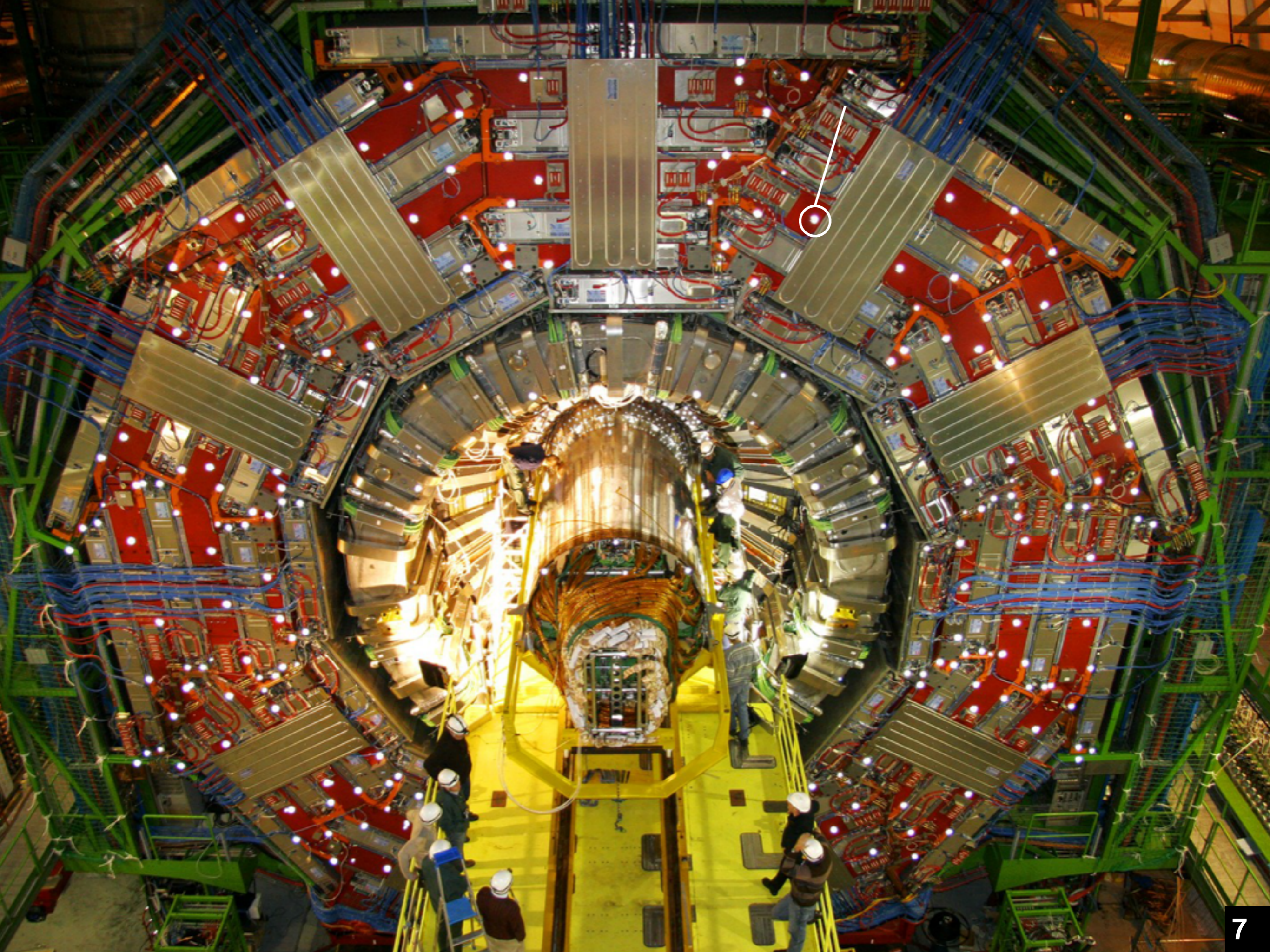
Hermetic ($|\eta| < 5.2$) Hadron Calorimeter (HCAL) [scintillators & brass]

All Silicon Tracker (Pixels and Microstrips)

Redundant Muon System (RPCs, Drift Tubes, Cathode Strip Chambers)

3 m

ICHEP, 3 July 2014



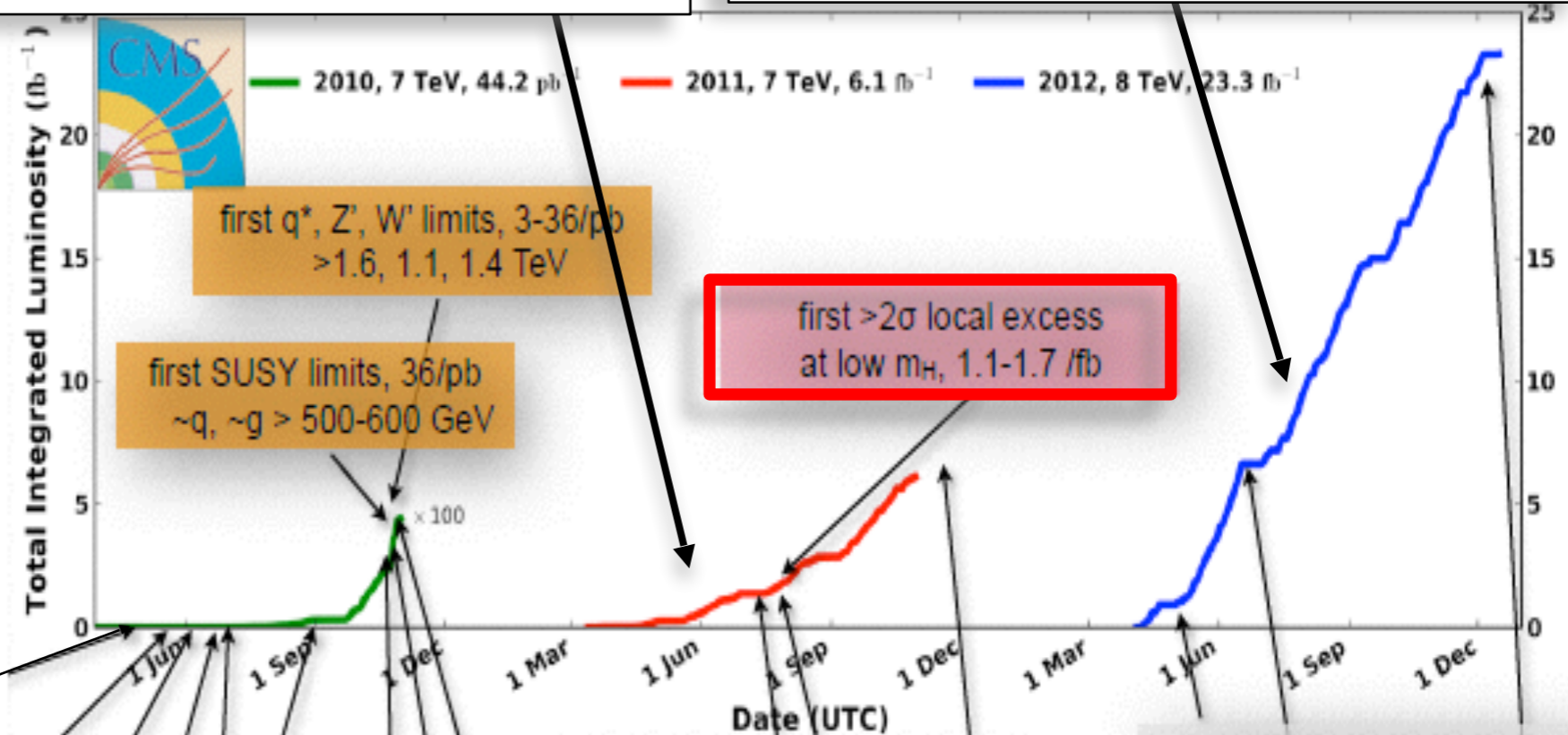


Plenty of barrel muons in online display!

100 Khz barrel muons (all pt)

2009 running:

- Hard to see anything apart from min bias in the displays.
- Serious analysis to find muons in the barrel.



What a run!

first MinBias / UE studies, particle multiplicities

first incl. b x-section, 8/nb δ ~ 15 %

first incl. jet x-section, PF jets 60/nb δ ~ 20-30%

first incl. W/Z x-sections, 200/nb δ ~ 4-6%, +11% lumi

first incl. J/ψ x-section, 100/nb δ ~ 20%

first top xsec, 3/pb δ ~ 40%

first single top xsec, t-chan., 36/pb δ ~ 36%

first m_{top}, 36/pb Δ ~ 6.5 GeV

first WW xsec, 36/pb δ ~ 40% first limit on HWW

first ZZ xsec, 1.1 /fb δ ~ 40%

going more differential, e.g. Z/W + j,b,c

first significant limit on B_s → μμ, BR < 1.9 × 10⁻⁸

first particle discovered by CMS: Ξ_b

BSM searches continue, limits pushed

a new boson is announced, 5 /fb

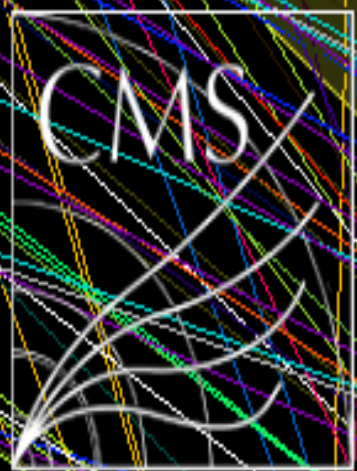


first spin parity analysis of the boson, 17 /fb

δ .. relative uncert

Δ .. absolute uncert.

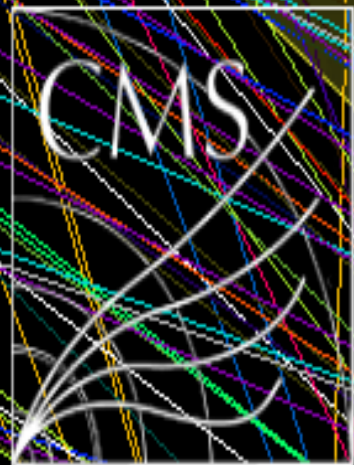
G. Dissertori



E
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

2012 Data at 8 TeV. Event with:
Raw $\Sigma ET \sim 2$ TeV
14 jets with $ET > 40$ GeV
Estimated pile up ~ 50

ICHEP, 3 July 2014

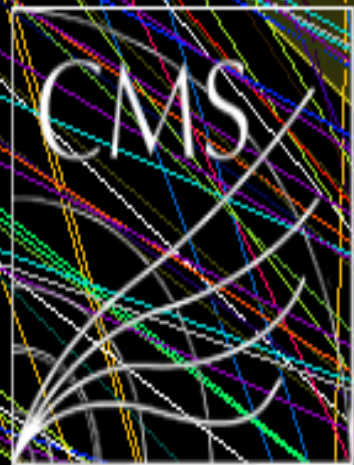


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This starts being a not so
easy enviroment...

ICHEP, 3 July 2014

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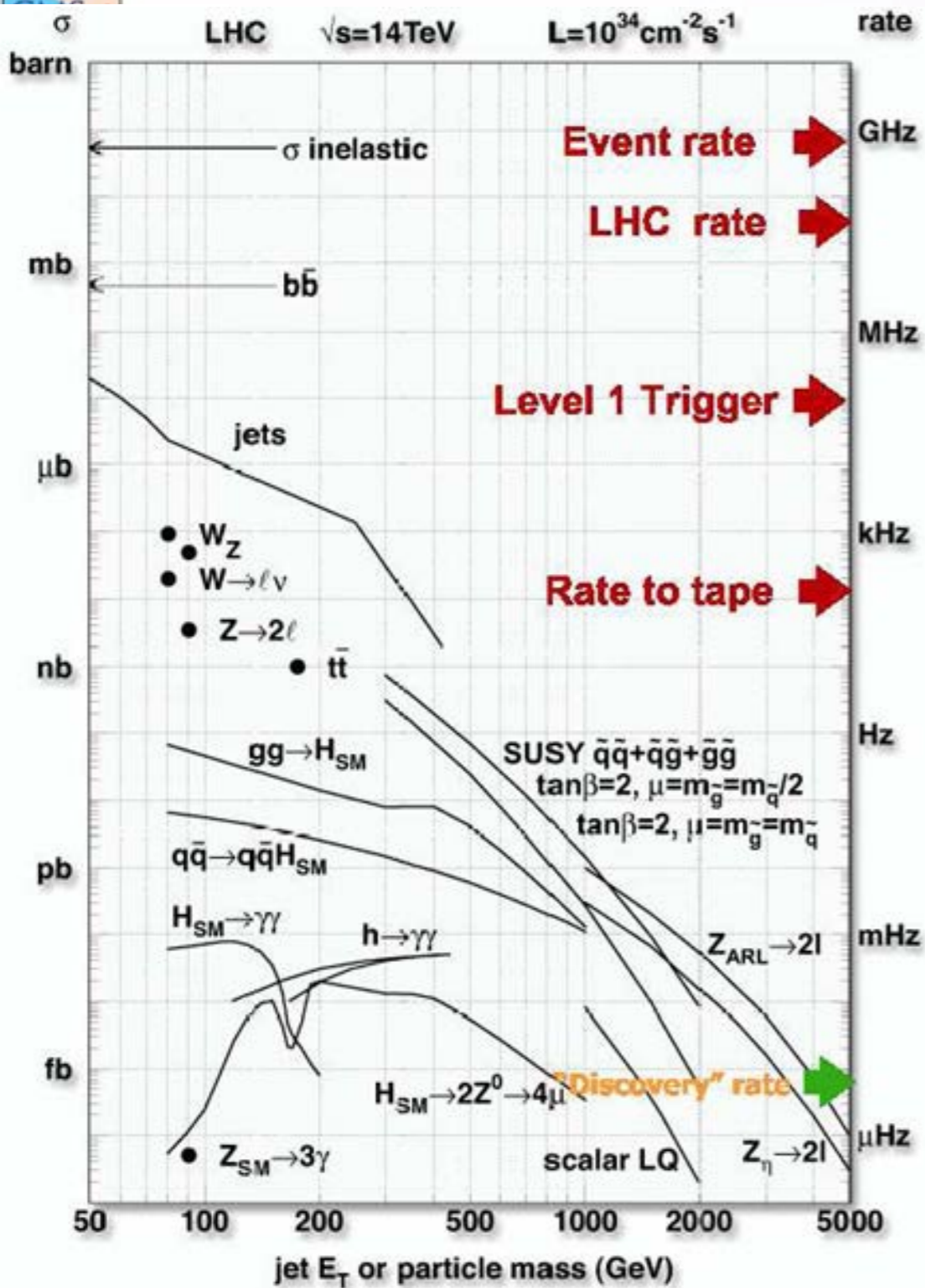
This starts being a not so
easy environment...
Conditions in Run1 could be
similar to these.

ICHEP, 3 July 2014

2012 Data at 8 TeV. Event with:
Raw $\Sigma ET \sim 2$ TeV
14 jets with $ET > 40$ GeV
Estimated pile up ~ 50



CMS: Event processing



Level-1: dedicated hardware, data available with reduced granularity, no tracker data

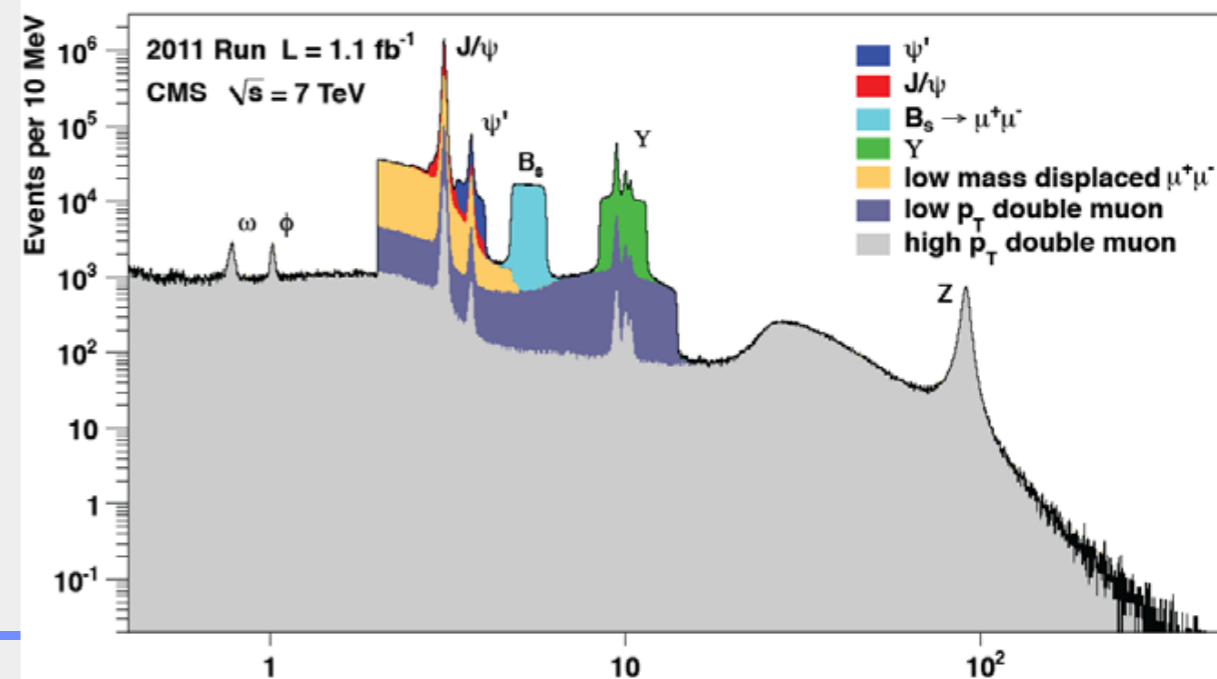
HLT: computer farm, ~13kCPU, all data, algorithm paths seeded by L1, with reconstruction similar to offline (up to 450 paths: physics obj. and complex alg.)

CMS trigger reduce # of p-p interactions from: $2 \cdot 10^7$ Hz (input) through ≤ 100 kHz down to: ~300-500 Hz “core data” – main Physics program (+ ~300-600 Hz “parked” for later analysis + 1kHz “scouting”)

More than 12 billion of data events in 2010-2012

object	L1 threshold (GeV)
Single μ	16
($ \eta < 2.1$)	12
Single e/γ	20
Single Isolated e/γ	18
Single jet	128
Double μ	10, 0
Double e/γ	13, 7
Double jet	56
Double τ_{jet}	44
$e/\gamma \oplus \mu$	12, 3.5
	7, 12
H_T	150
E_T^{miss}	40
E_T^{tot}	300

Reconstruction: Standalone detector based reconstruction but also **Particle Flow** (attempts to reconstruct individually each particle in the event, prior to the jet clustering, based on information from relevant sub-detectors. → better reconstruction of the jets, E_T , MET, tau)



Reconstructed events

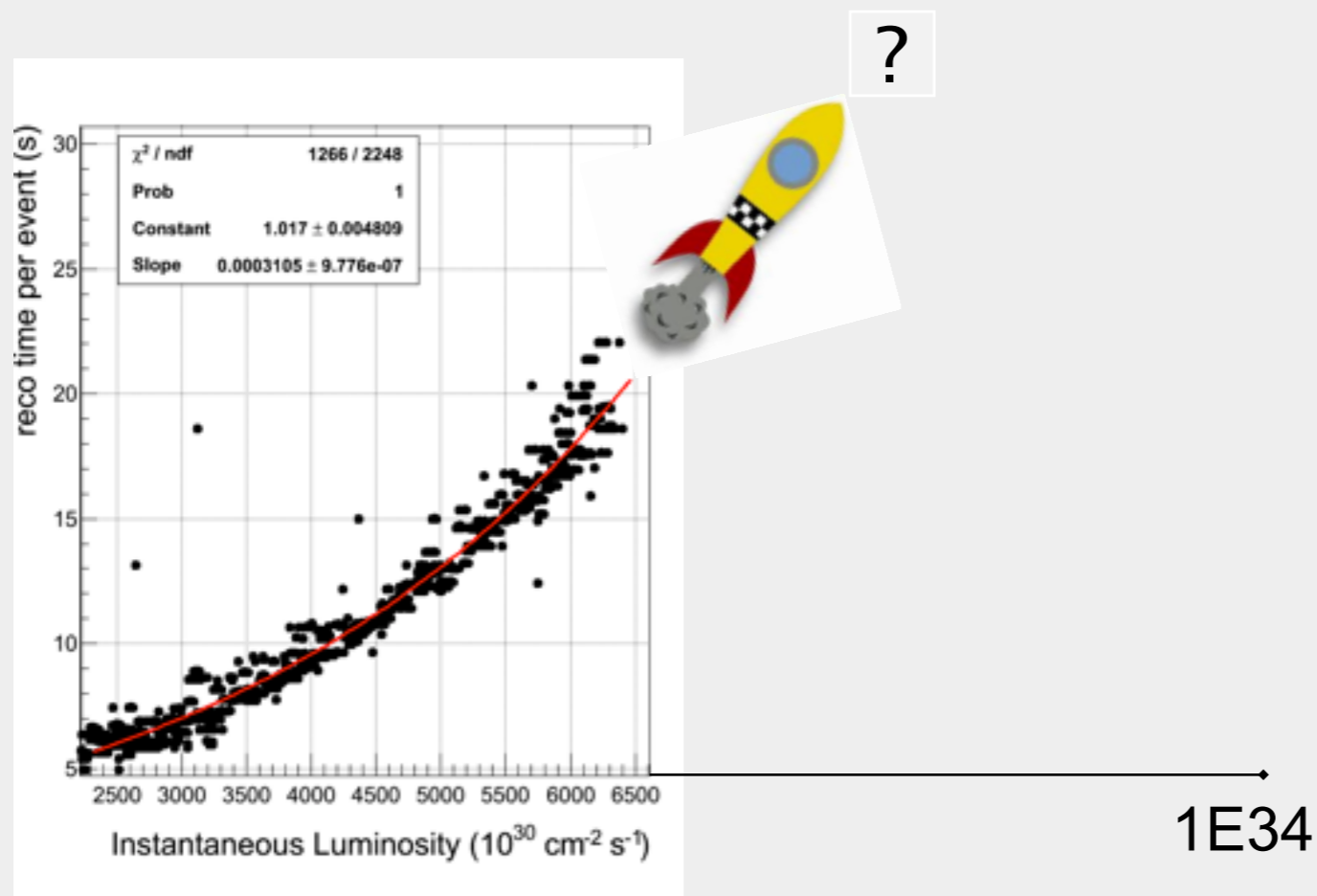
20 billion simulated events
12 billion data events

Data volume

More than 25PB moved to Tier-1s
70PB moved to Tier-2s

- Improvements in the reconstruction code to cope with pile up
- Reconstruction time per event reduced by maintaining the physics performance.

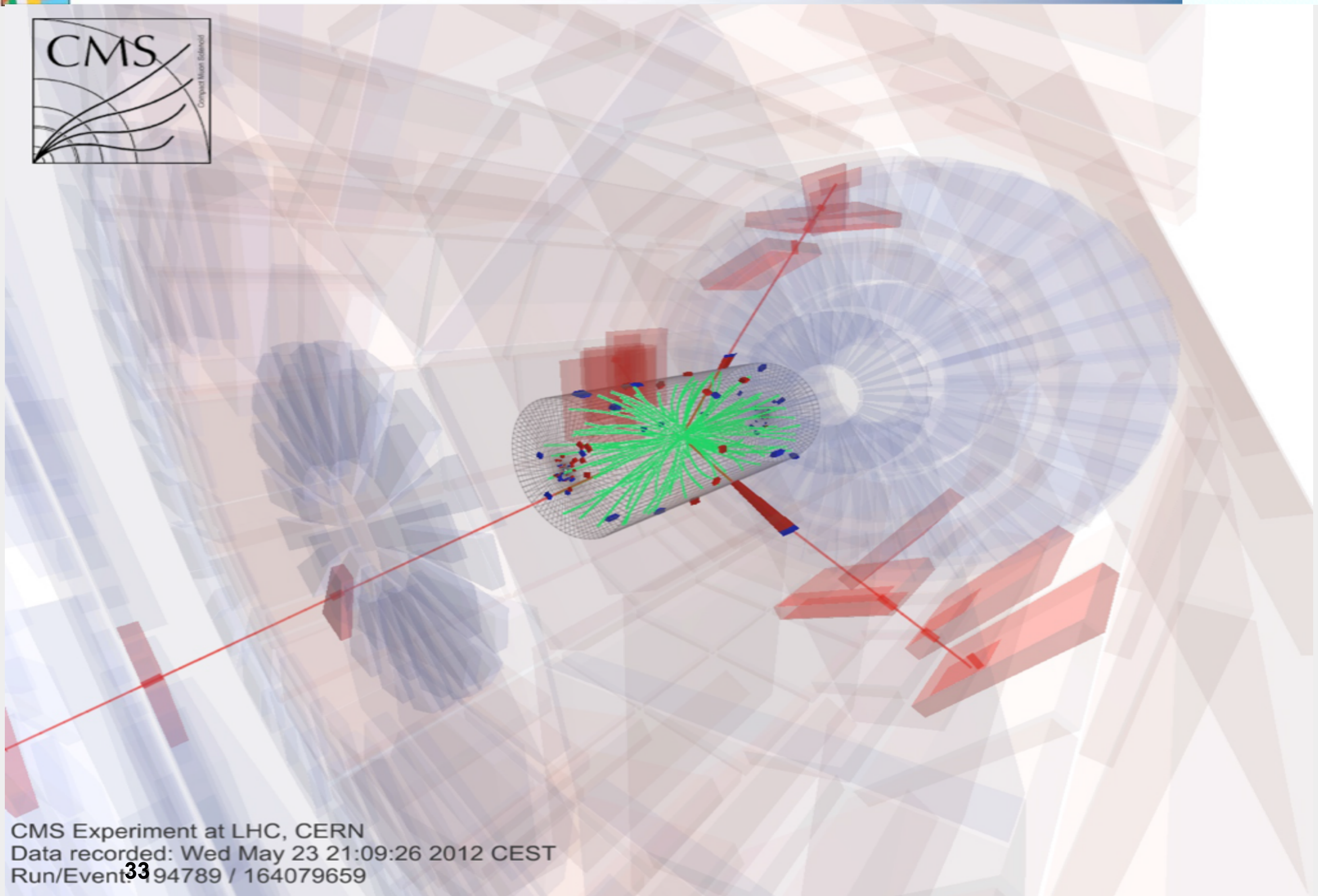
• Non-linear with PU → explodes



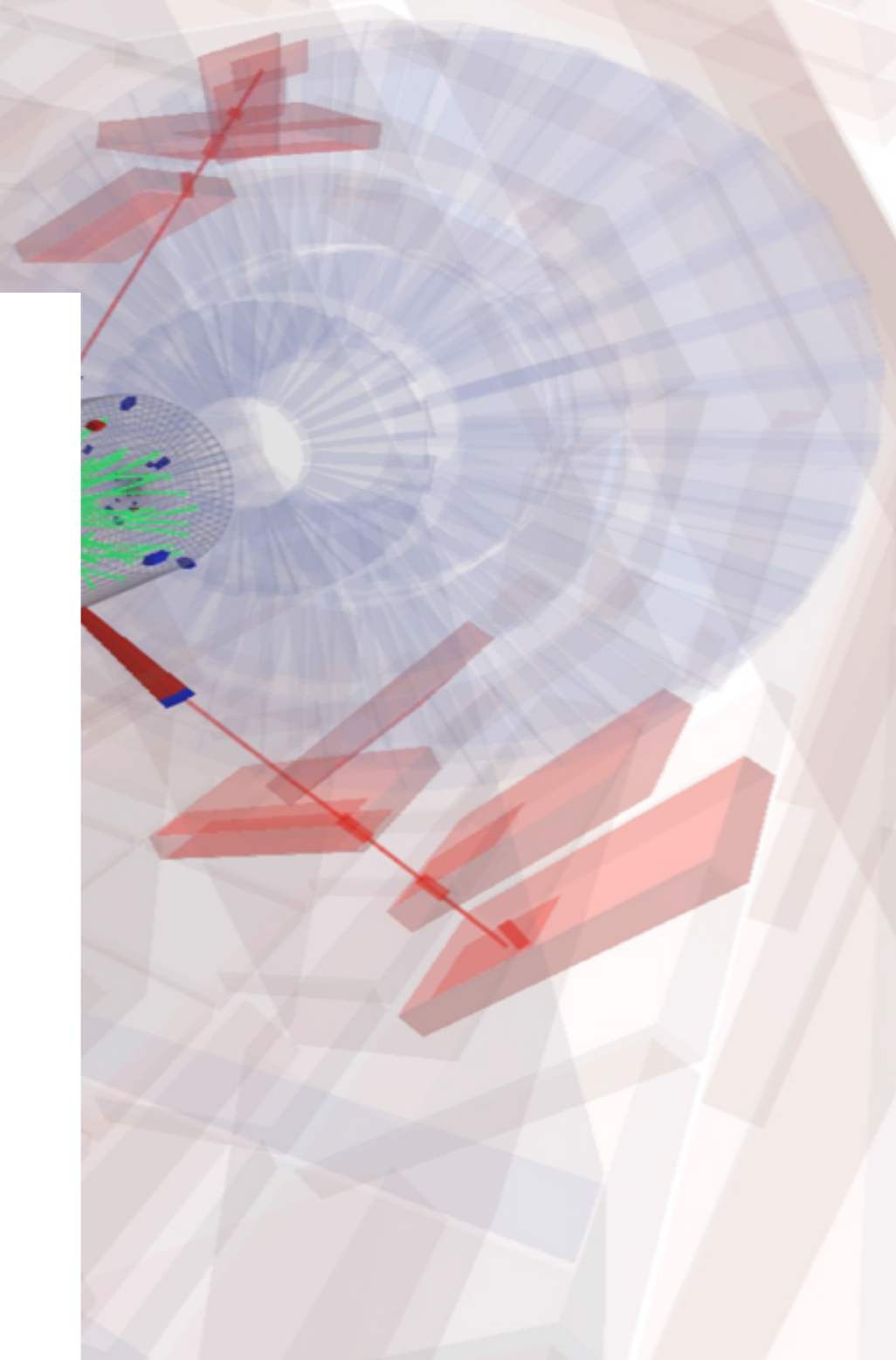
Quite a challenge:
All things equal,
2015 computing
needs increase x10



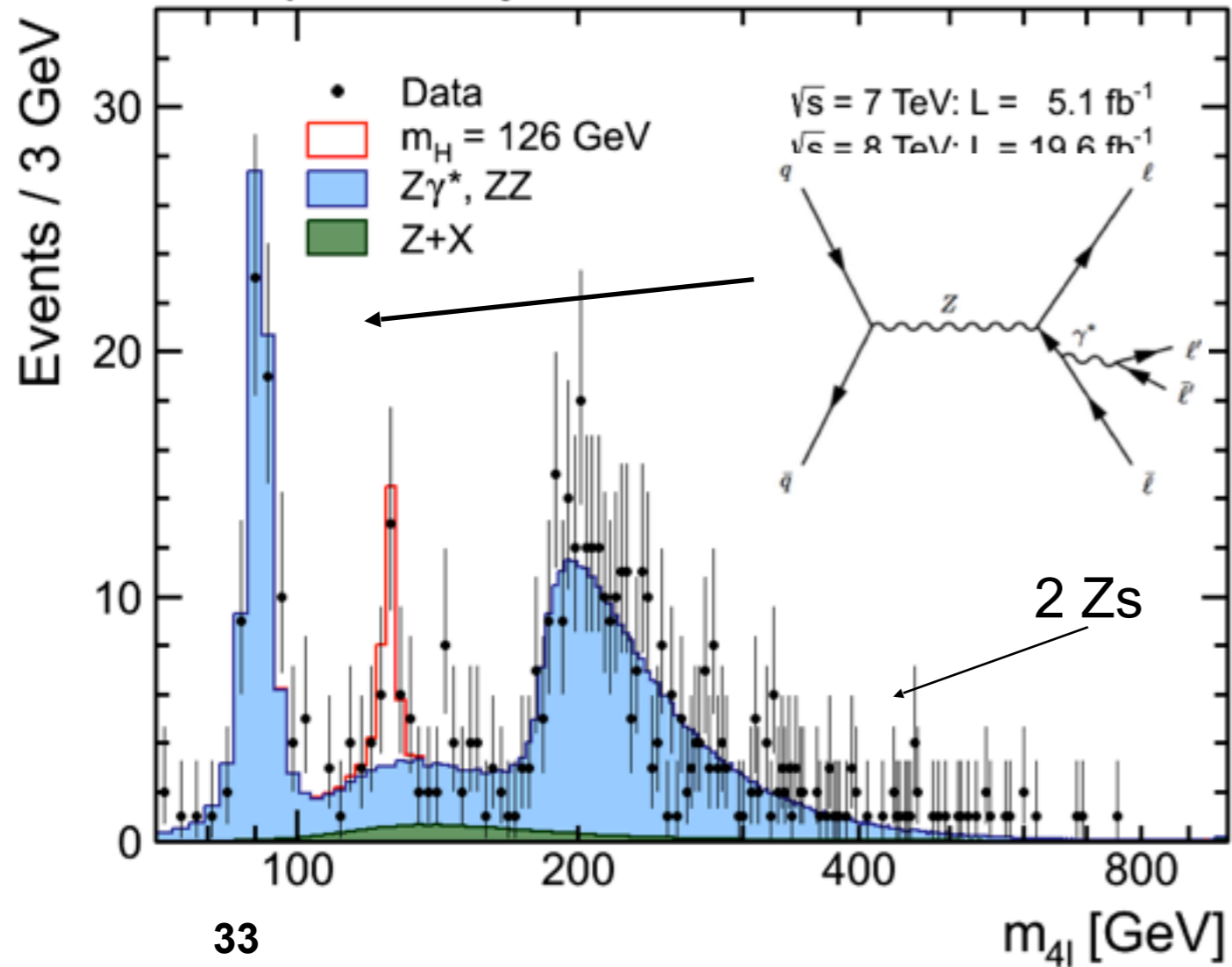
CMS in action: $H \rightarrow 4$ lepton

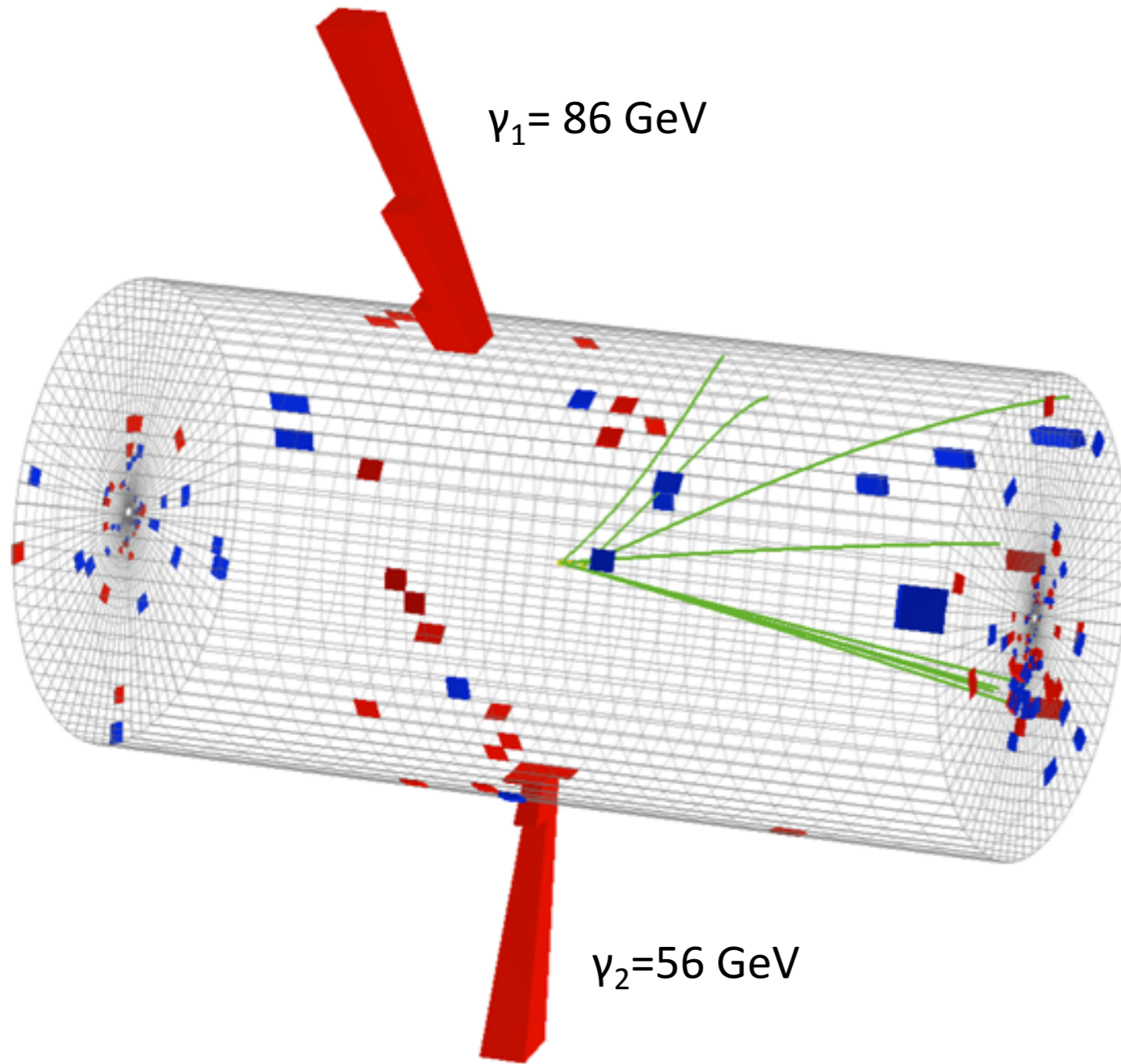


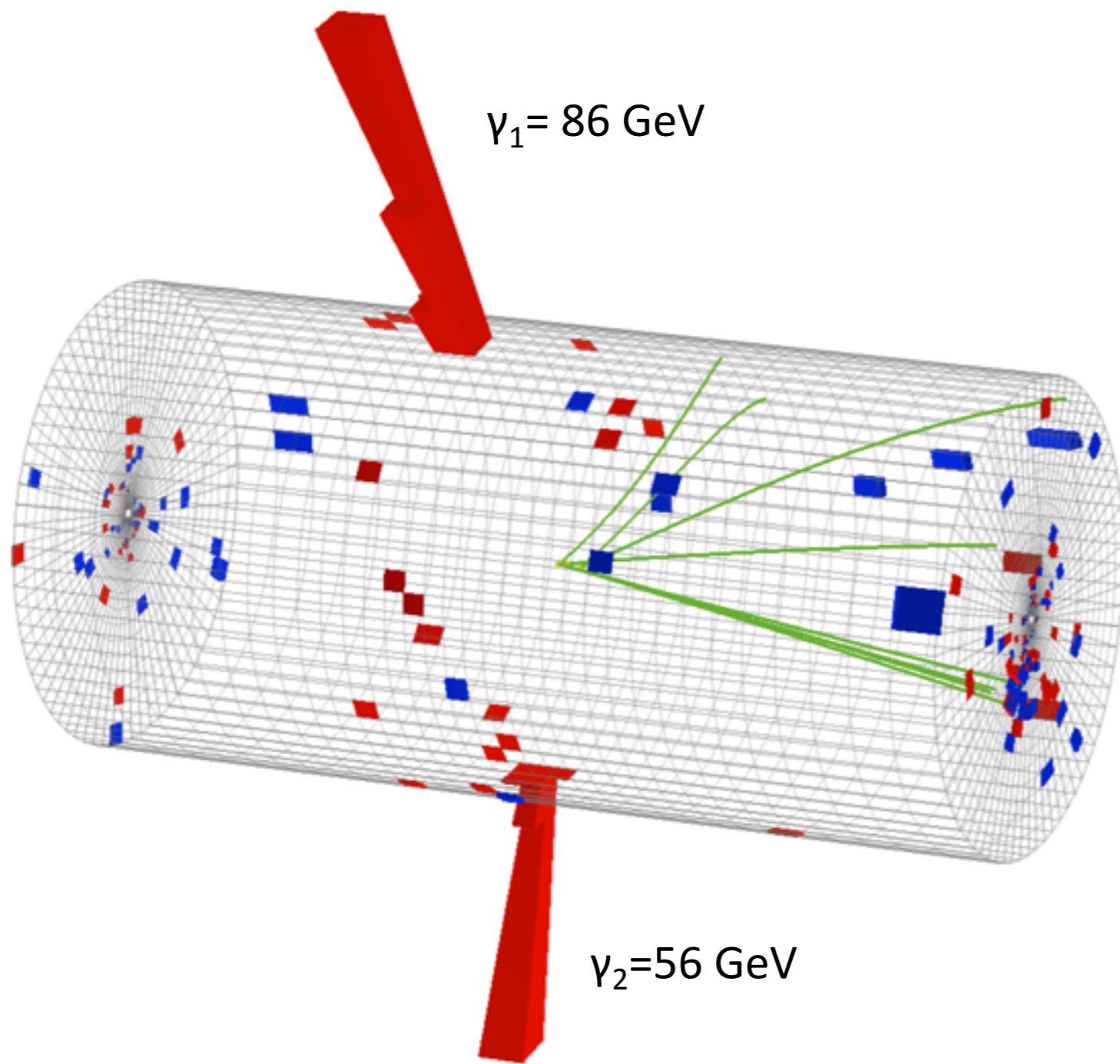
CMS Experiment at LHC, CERN
Data recorded: Wed May 23 21:09:26 2012 CEST
Run/Event: 194789 / 164079659



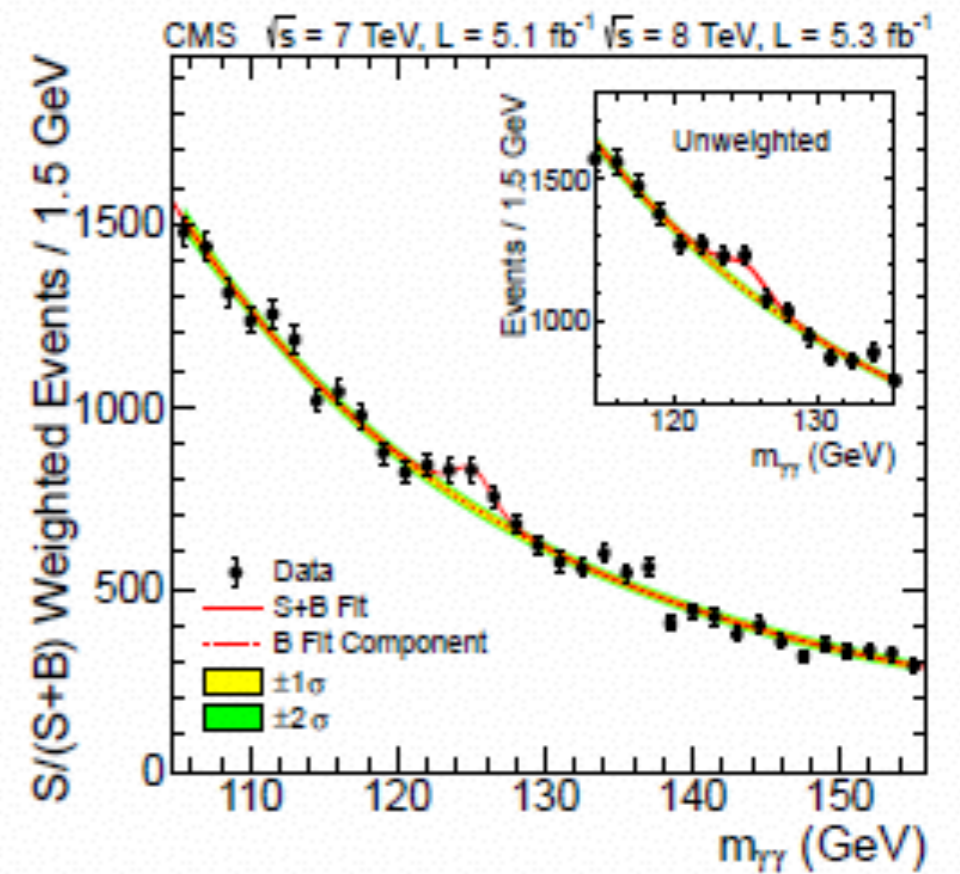
CMS preliminary







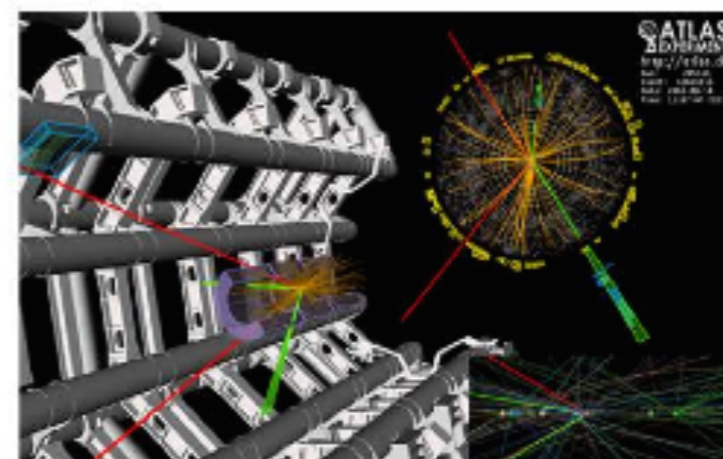
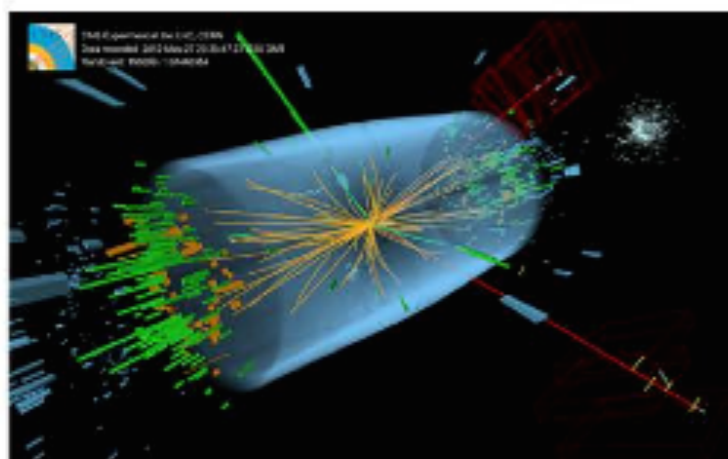
CMS Collaboration,
Phys. Lett. B716 (2012) 30-61



The Nobel Prize in Physics 2013

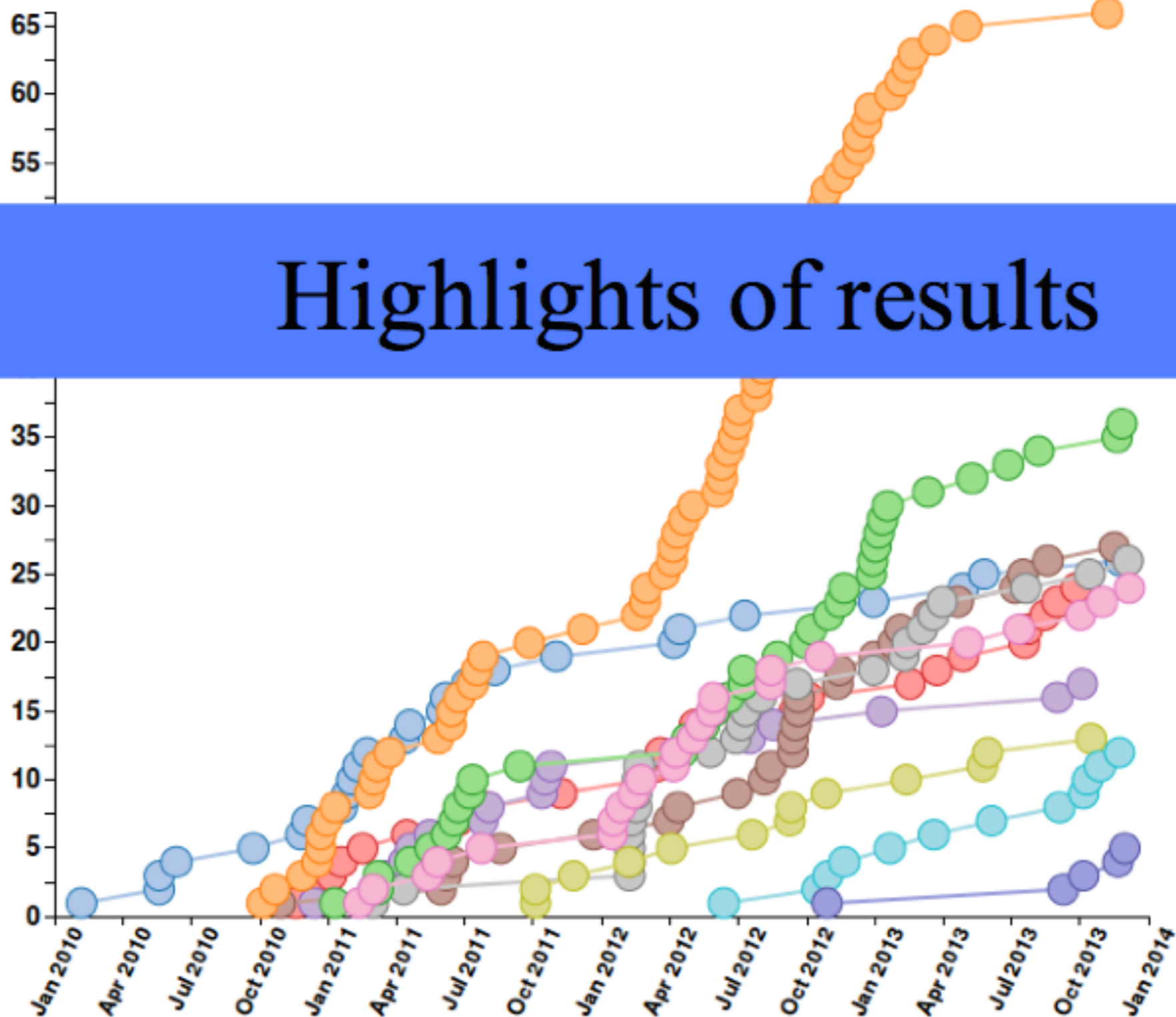


The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider



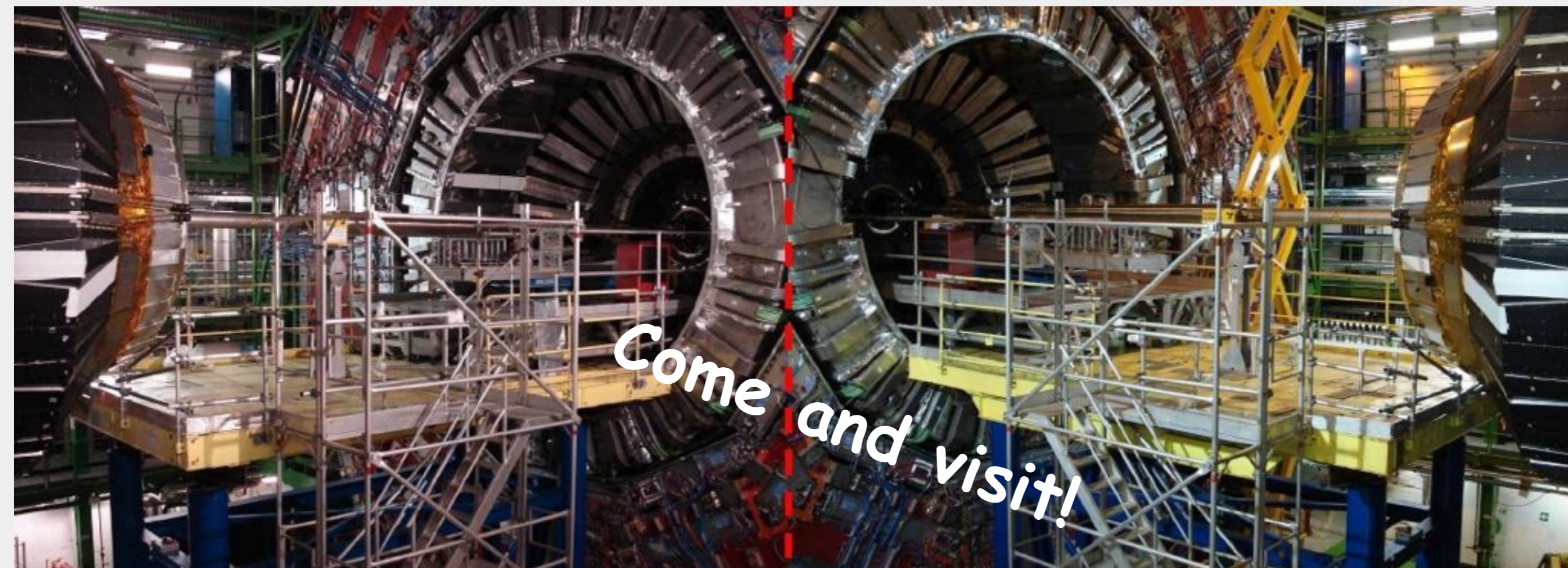
275 papers published (1 Jan 2014)

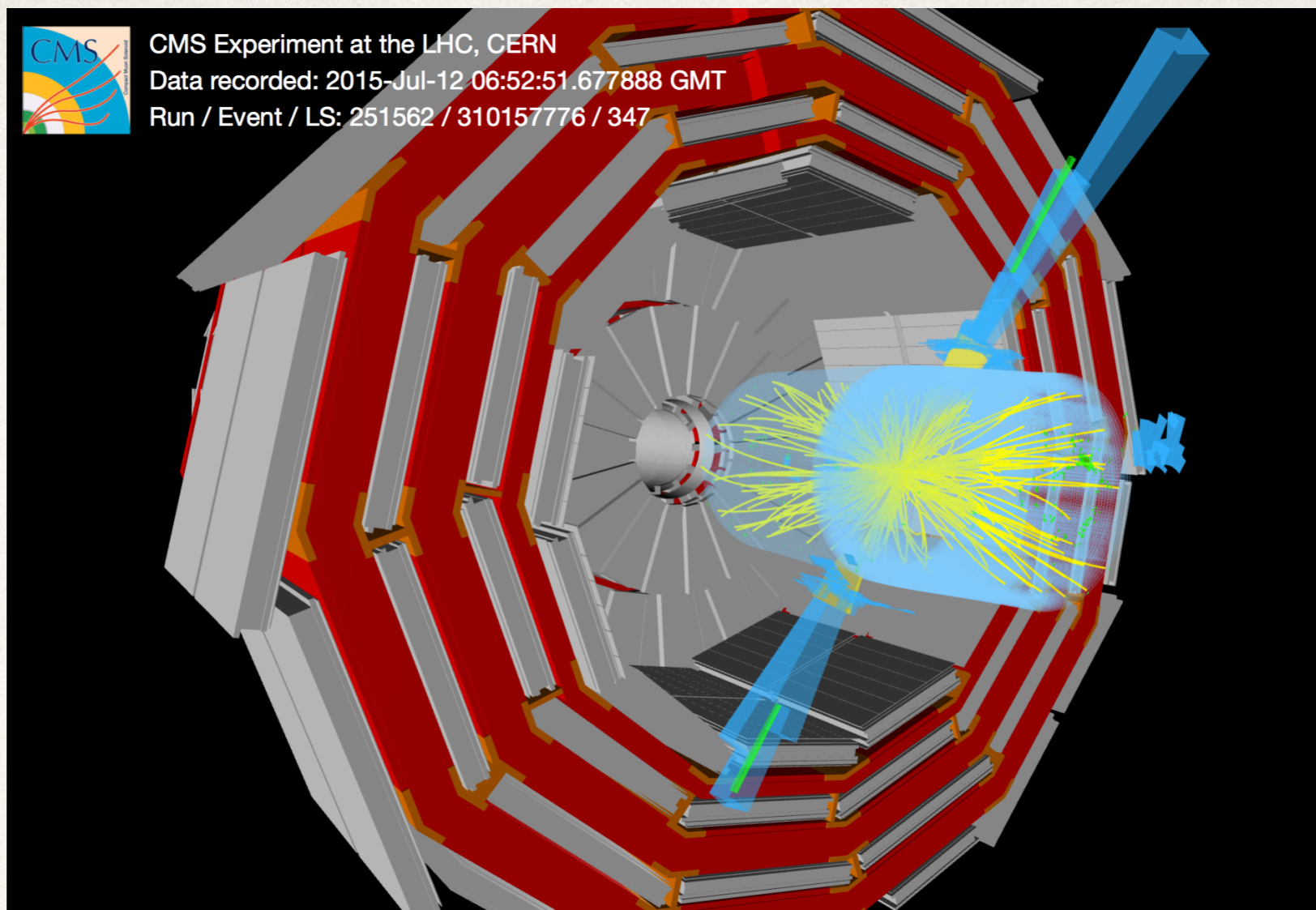
Highlights of results



- Excellent performance of CMS detector during Run I
 - Tracking, vertexing
 - Lepton identification
 - Jet and MET reconstruction
 - Triggering capabilities
- And final physics performance!

2013-2014 : Detector open for maintenance and upgrade

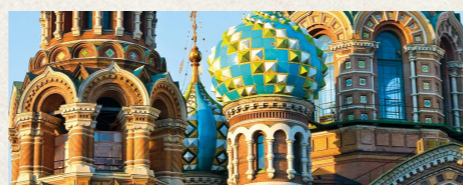




CMS: First look at 13 TeV data

Paolo SPAGNOLO on behalf of the CMS Collaboration

August 31 2015



LHCP 2015 - St Petersburg

CMS detector for Run2

Improvements during
Long Shut Down LS1

Tracker / Pixel:
Cold Operation

Tracker:

~1 m² Pixels (66M channels)

~200 m² Si microstrips (9.6M channels)

Iron Yoke

4th muon station

4 stations of
muon detectors

new Beam Pipe

new Luminosity
telescopes

3.8 T Solenoid

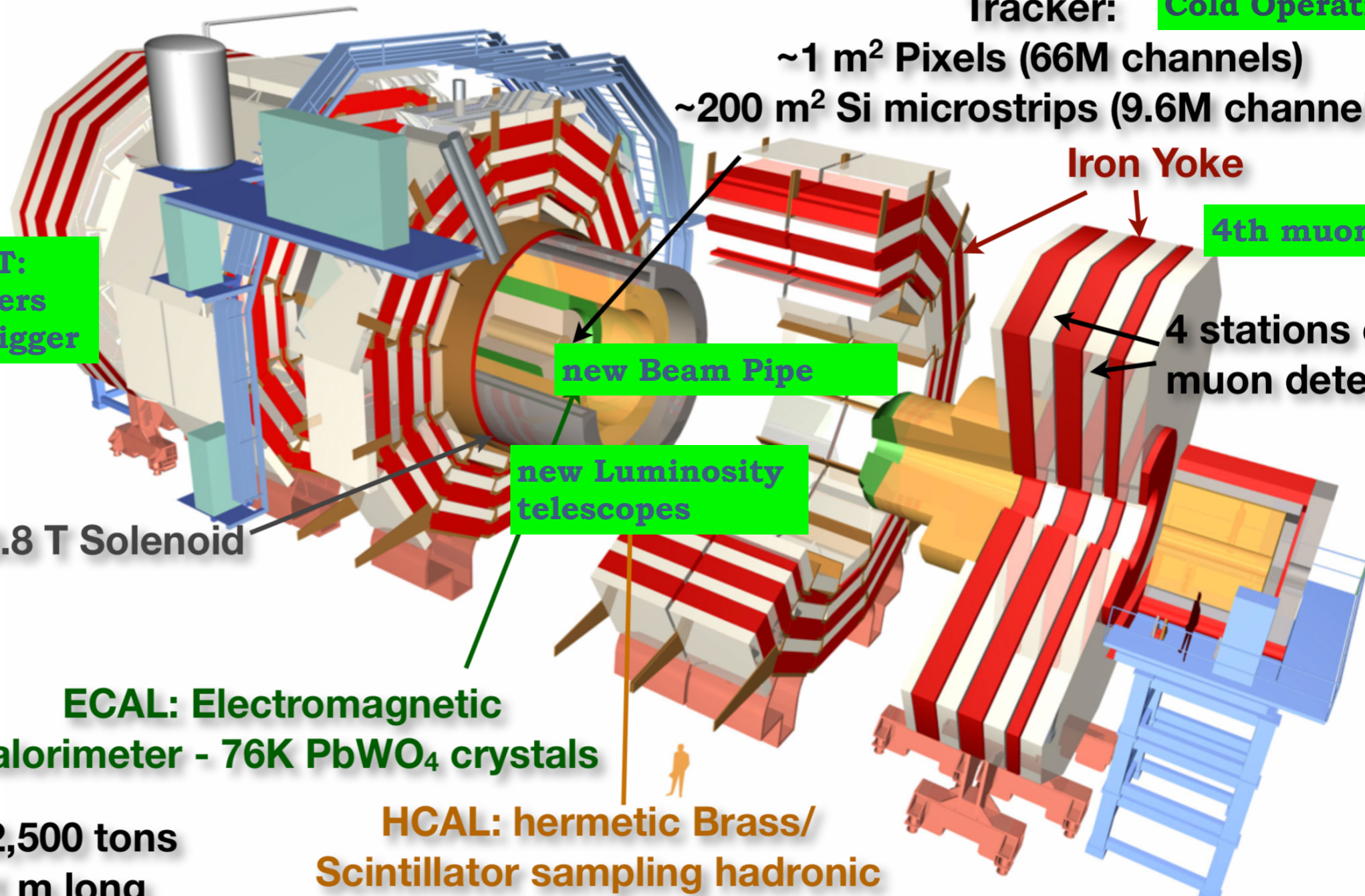
ECAL: Electromagnetic
calorimeter - 76K PbWO₄ crystals

12,500 tons
21 m long
15 m diameter

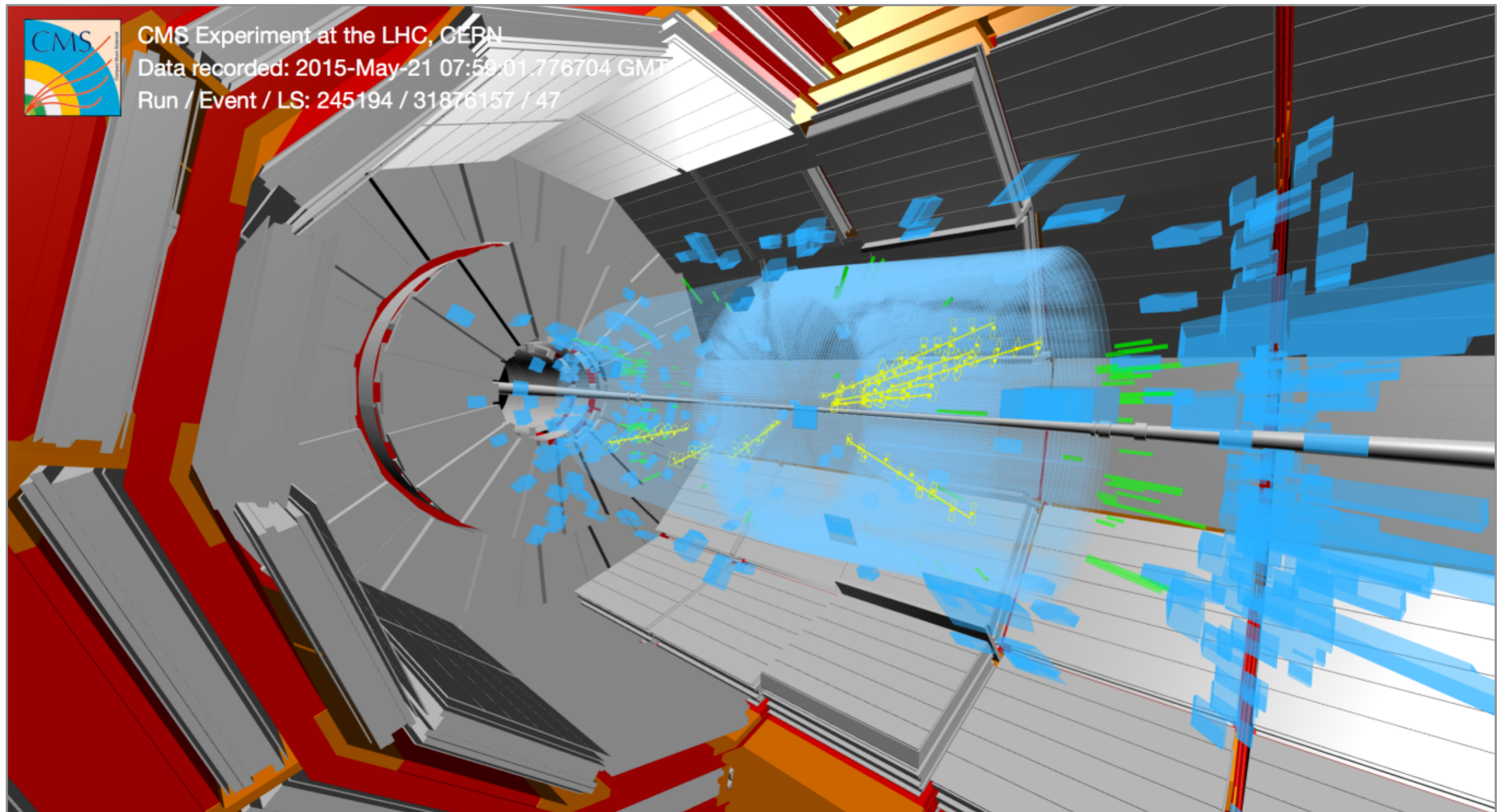
HCAL: hermetic Brass/
Scintillator sampling hadronic
calorimeter

HCAL new photosensors

DAQ and HLT:
New computers
Improved Trigger



First Physics collision @ 13 TeV



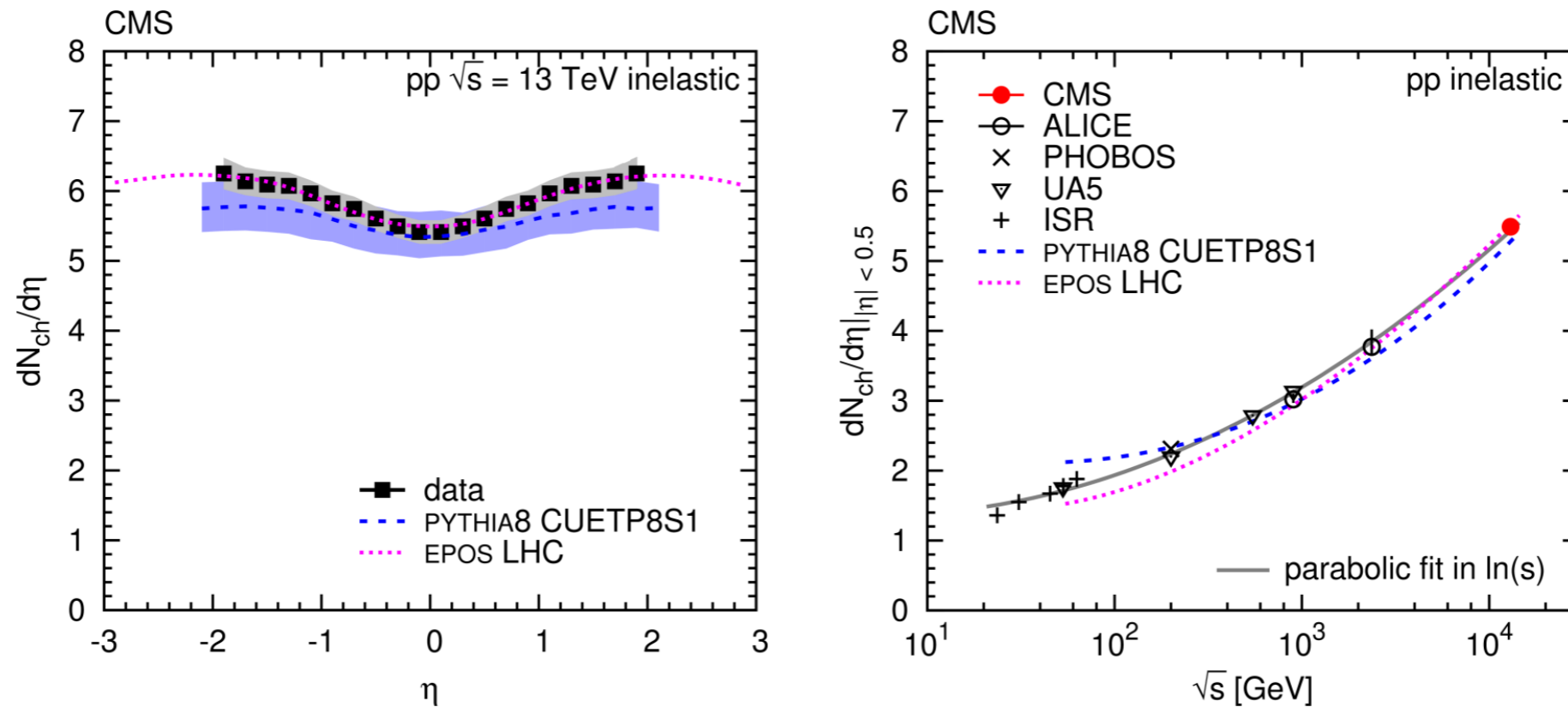
First CMS publication @ 13 TeV

First paper from LHC @13 TeV

First paper, submitted to PLB few weeks after the first collision <http://arxiv.org/abs/1507.05915>

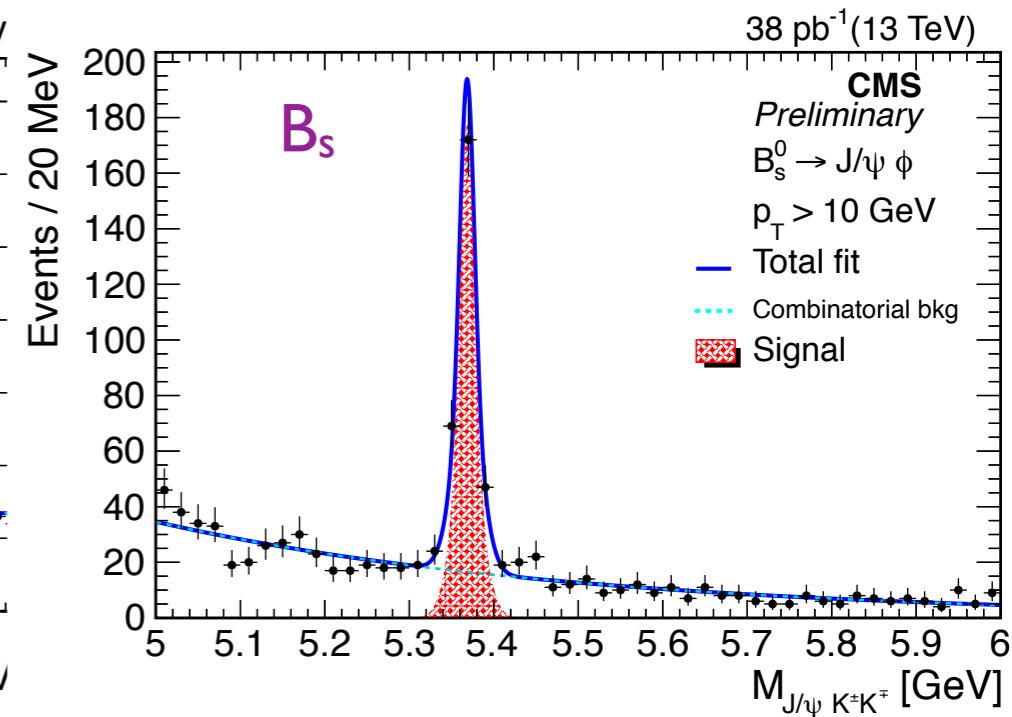
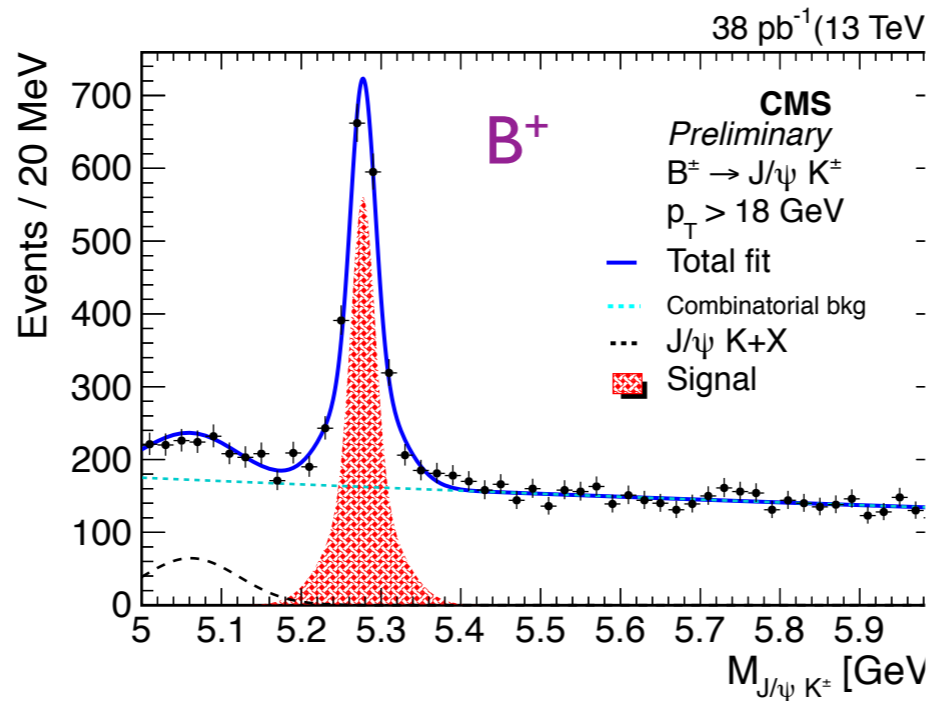
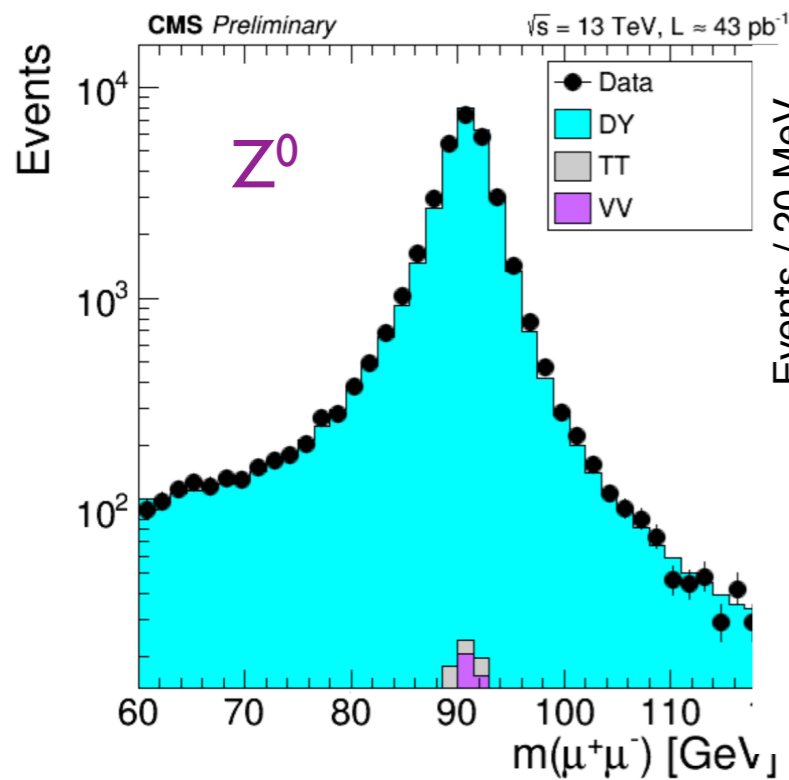
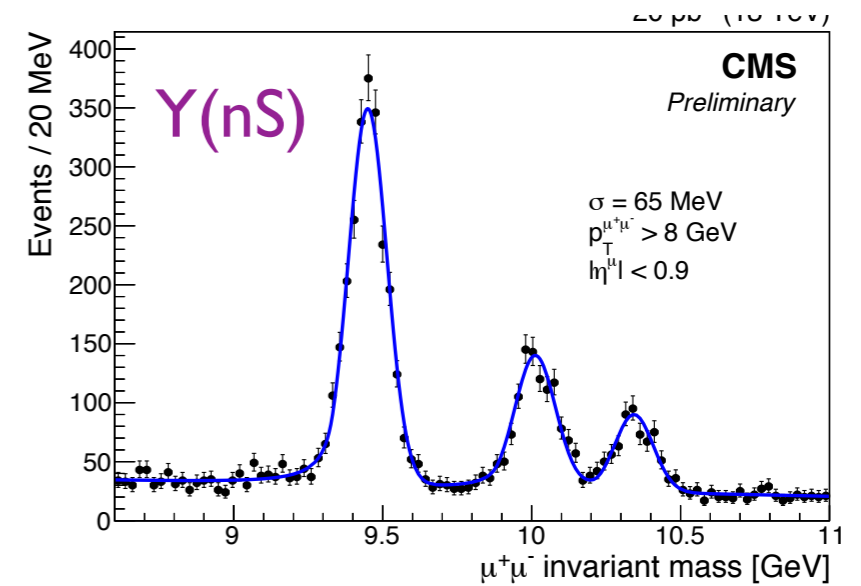
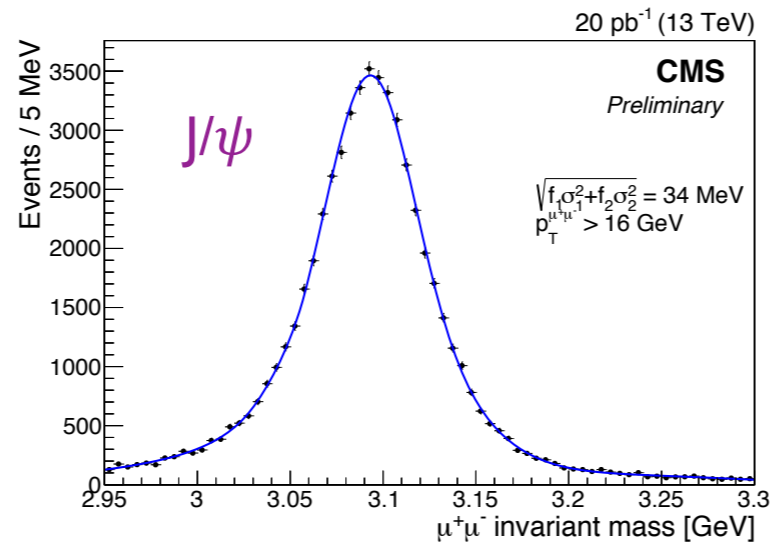
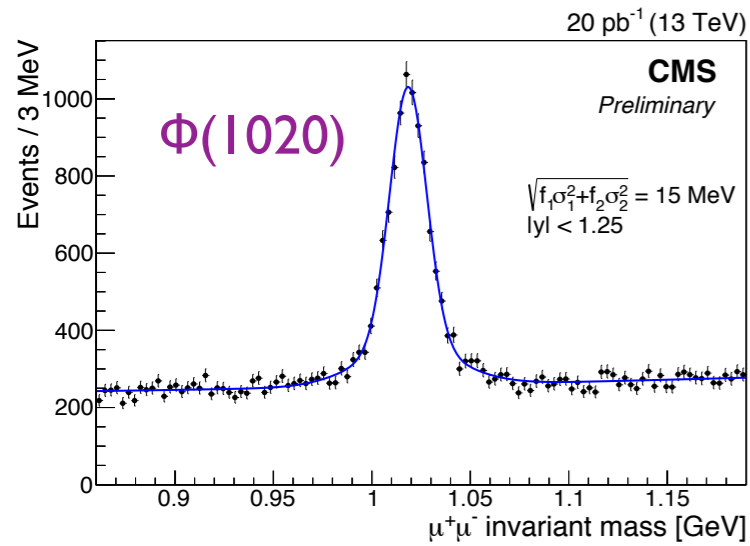
Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s} = 13$ TeV

$$dN_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01 \text{ (stat)} \pm 0.17 \text{ (syst)}$$

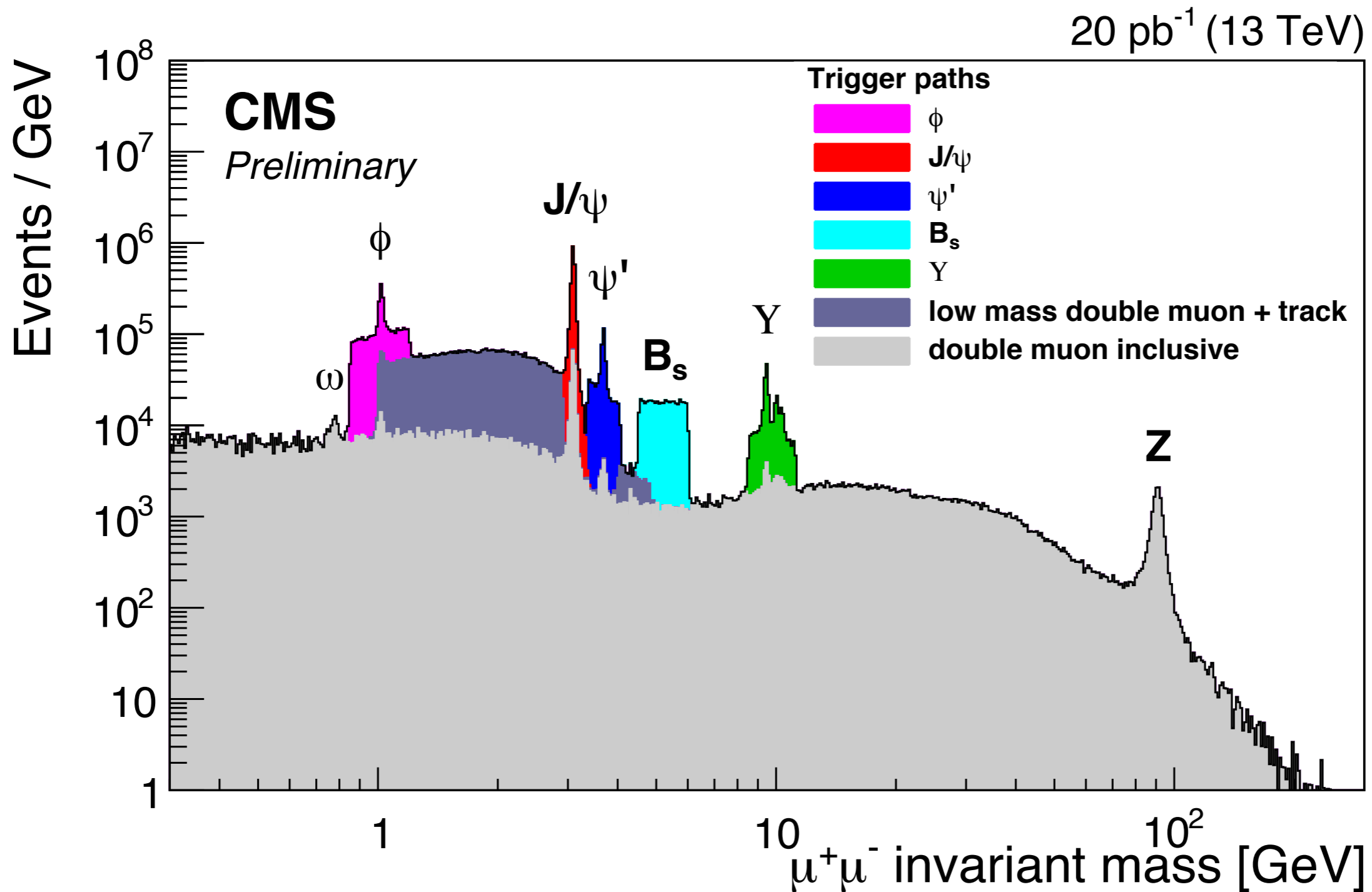


- measured in CMS in a special early run @13 TeV taken on June 7th (~1h30') with $B = 0$ T
- $dN/d\eta$ vs \sqrt{s} gives an handle on the relative weight of soft and hard scattering contribution
- both EPOS (better) and PYTHIA8 compatible with data

Di-muon spectroscopy: standard candles resonances and first B mesons



Di-muon spectroscopy: standard candles



Top pair cross-section measurement

inclusive $\sigma_{tt}(13\text{TeV}) = 772 \pm 60 \text{ (sta)} \pm 62 \text{ (sys)} \pm 93 \text{ (lum)} \text{ pb}$

CMS PAS TOP-15-003

Integrated lumi = 42 pb⁻¹

- all validated data from 50 ns run

Selection

- At least 2 good (OS) leptons (1e and 1μ)
- $pt(\text{lept}) > 20 \text{ GeV}$ and $|\eta| < 2.4$
- If more than 2 good leptons, the two with highest pt are retained
- Di-lepton invariant mass $> 20 \text{ GeV}$
- At least 2 jets (anti-kT R = 0.4)
- $pt(\text{jets}) > 30 \text{ GeV}$ and $|\eta| < 2.4$

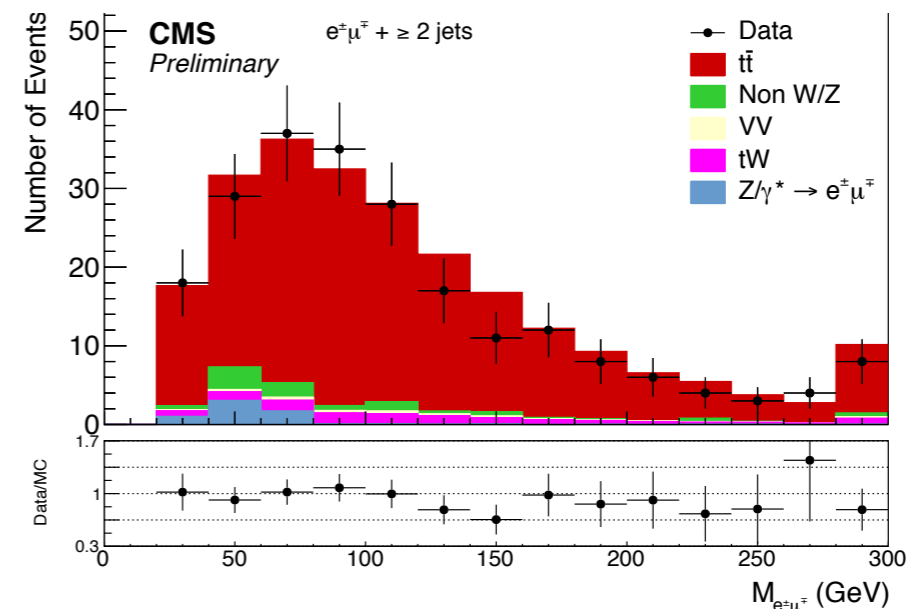
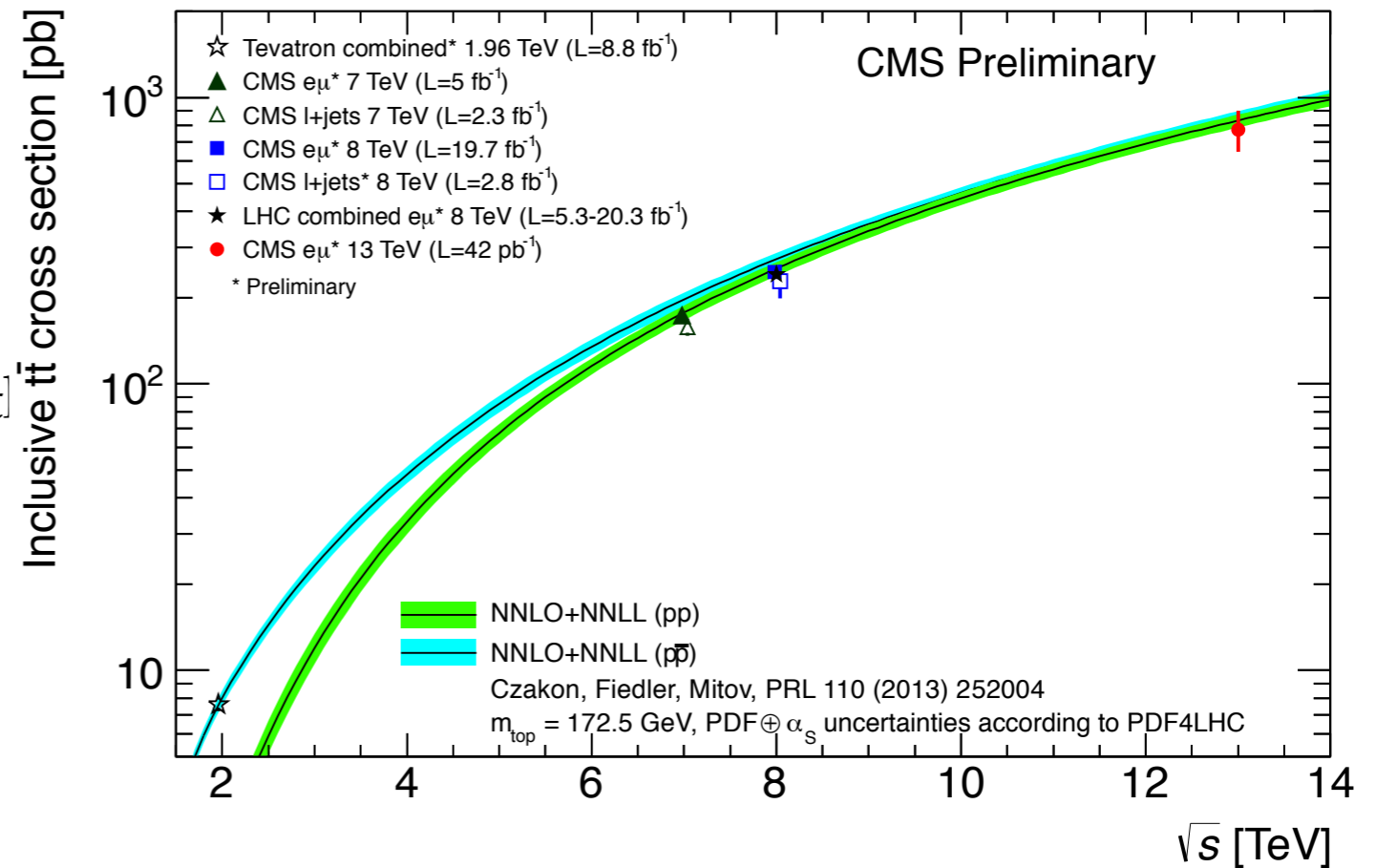
From Run1 data **NEW RESULTS**
(CMS TOP 13-004)

$$\sigma_{t\bar{t}} = 174.5 \pm 2.1 \text{ (stat)}^{+4.5}_{-4.0} \text{ (syst)} \pm 3.8 \text{ (lumi)} \text{ pb at } \sqrt{s} = 7 \text{ TeV}$$

$$\sigma_{t\bar{t}} = 245.6 \pm 1.3 \text{ (stat)}^{+6.6}_{-5.5} \text{ (syst)} \pm 6.5 \text{ (lumi)} \text{ pb at } \sqrt{s} = 8 \text{ TeV}$$

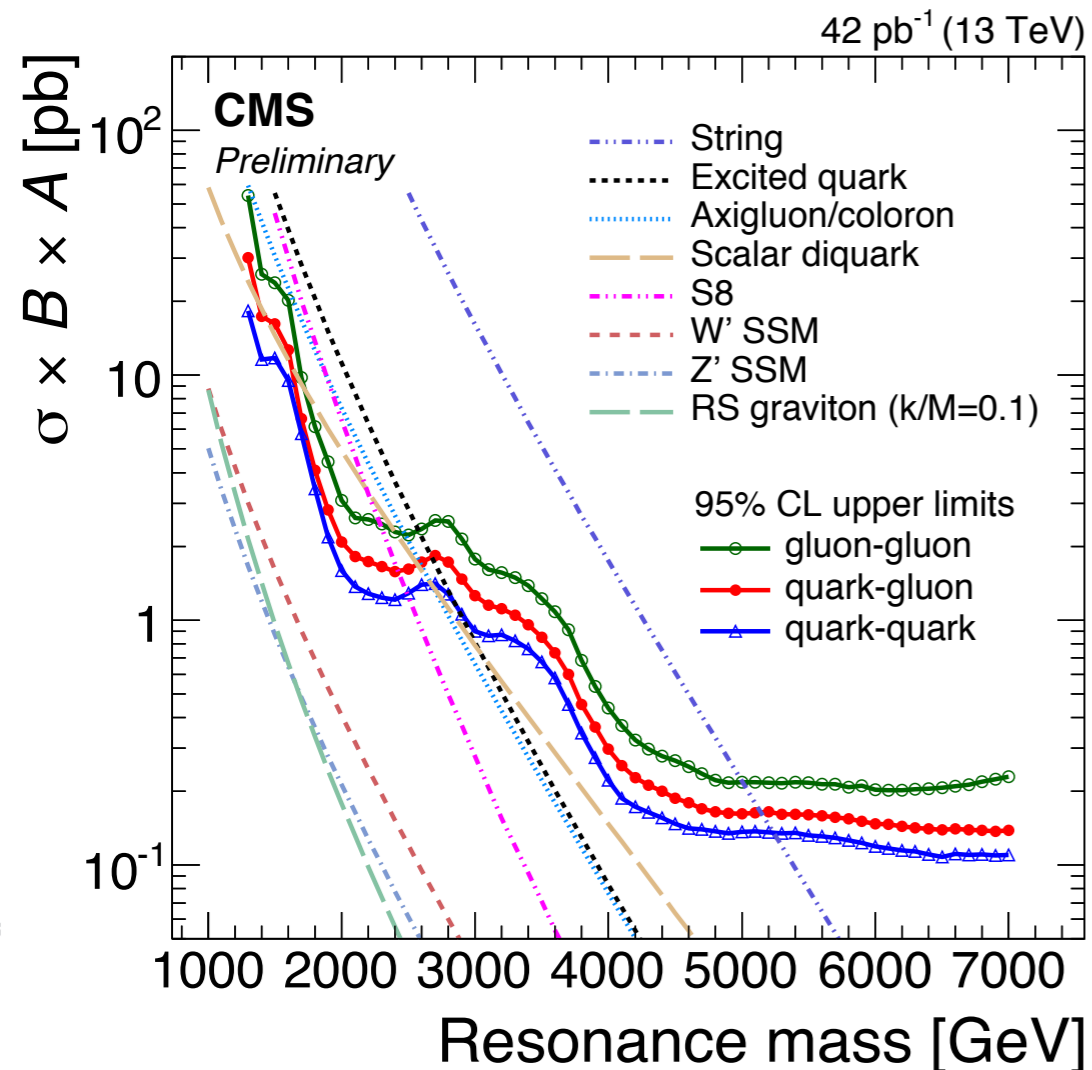


Allow to extract the pole mass from NNPDF30 PDF to be $m_{t,\text{pole}} = 173.6^{+1.7}_{-1.8} \text{ GeV}$



Di-jet resonance search

CMS PAS EXO-15-001



Confirms Run2 is already more sensitive than Run1 for $M > 5$ TeV

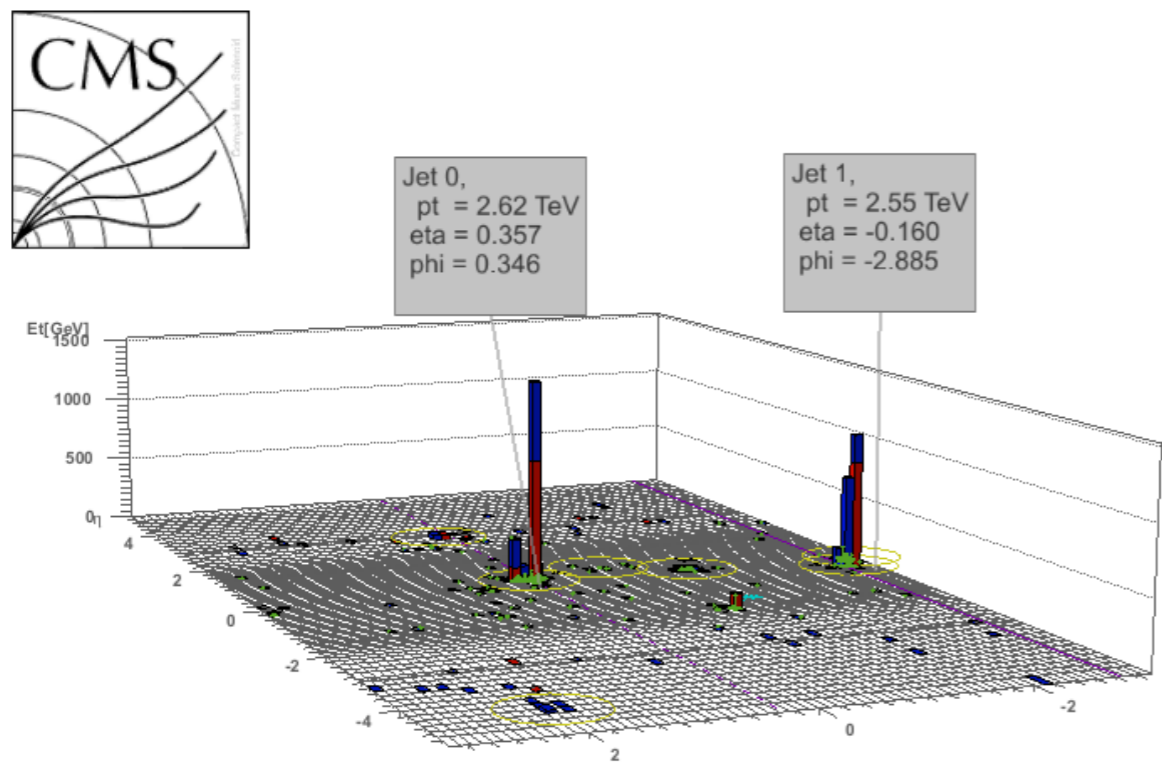
- Observed limits at 95% CL on cross section of qq , qg , gg resonances
- Get worse when there are gluons in the final state because radiation increases and resolution degrades
- Extend to 7 TeV in di-jet mass for the first time
- plateaus at high mass due to absence of events

Model	Mass Limits (TeV)			
	Run 1 (20 fb ⁻¹)		Run 2 (42 pb ⁻¹)	
	Observed	Expected	Observed	Expected
String Resonance (S)	5.0	4.9	5.1	5.2
Excited Quark (q*)	3.5	3.7	2.7	2.9
Axigluon (A) / Coloron (C)	3.7	3.9	2.7	2.9
Scalar Diquark (D)	4.7	4.7	2.7	3.3
Color Octet Scalar (S8)	2.7	2.6	2.3	2.0

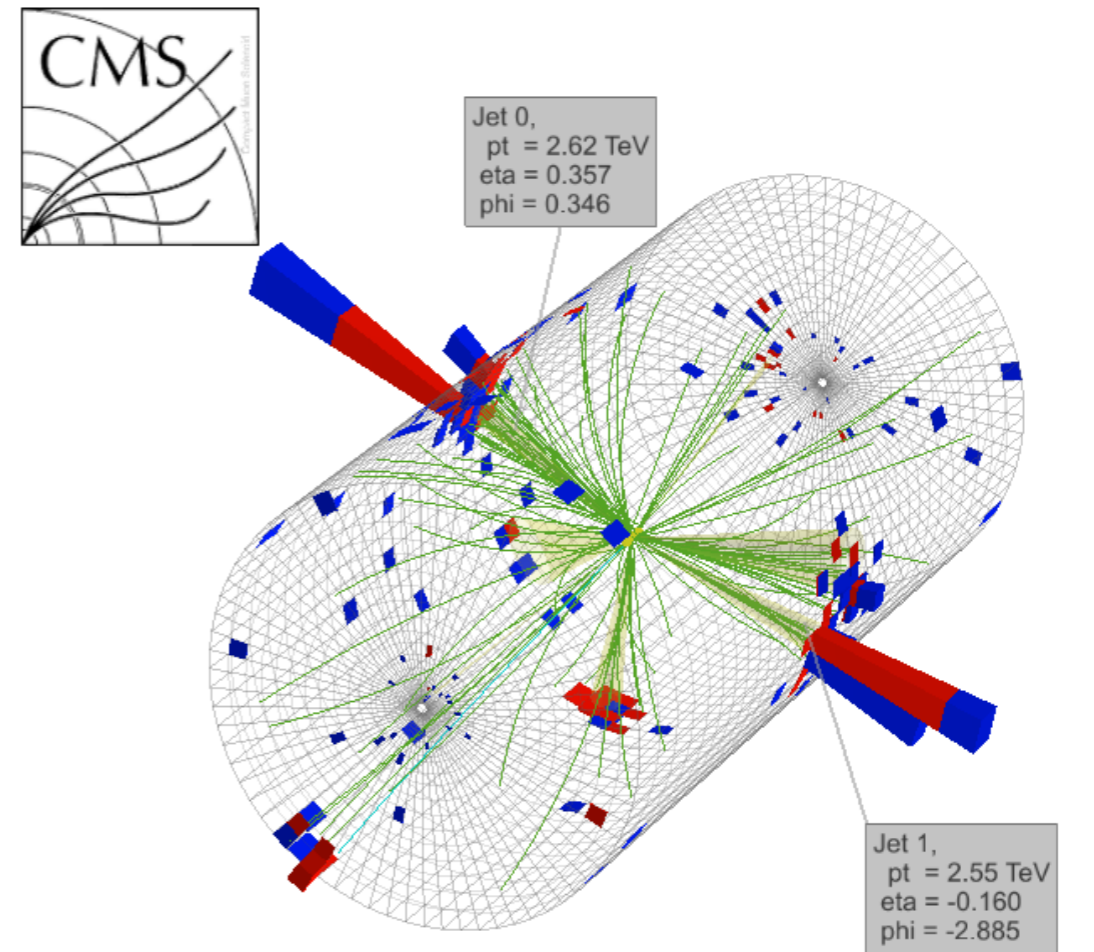
Di-jet resonance search

CMS PAS EXO-15-001

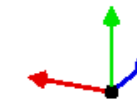
Highest Mass di-jet event $M = 5.4$ TeV



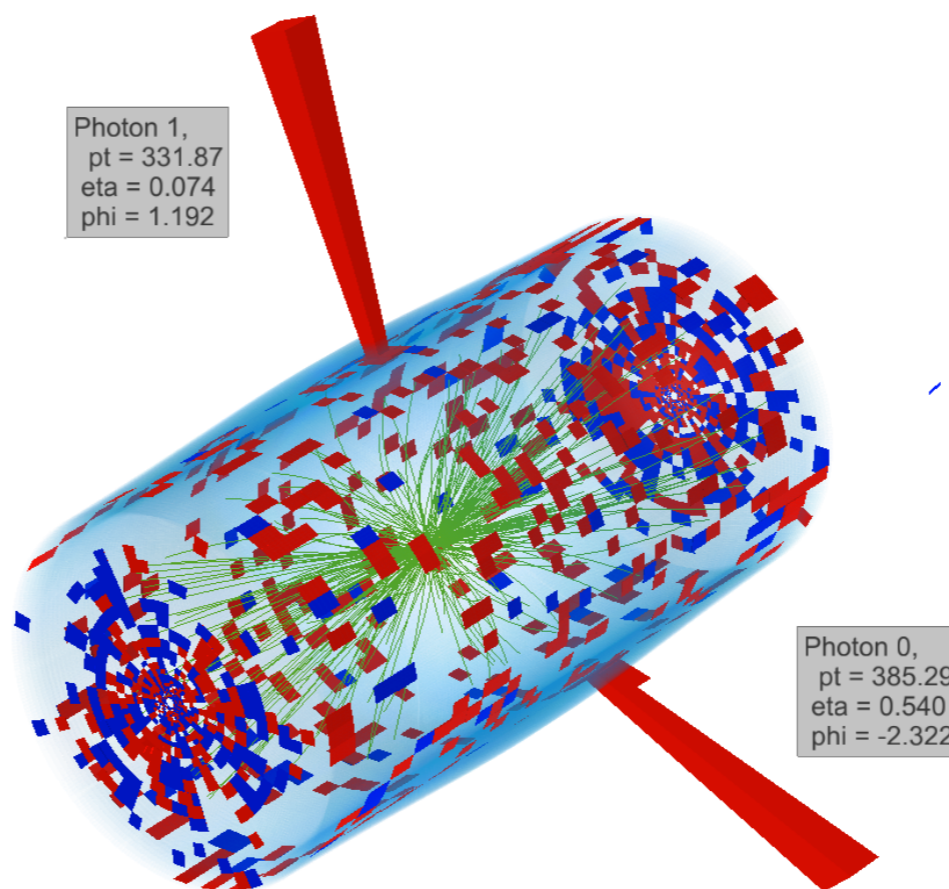
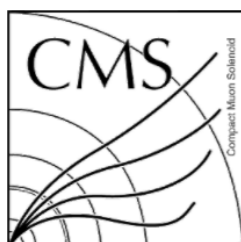
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 01:52:51 2015 CDT
Run/Event: 251562 / 310157776
Lumi section: 347
Dijet Mass : 5.4 TeV



CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 01:52:51 2015 CDT
Run/Event: 251562 / 310157776
Lumi section: 347
Dijet Mass : 5.4 TeV



Event display of the highest mass di-photon candidate ($M = 730$ GeV)

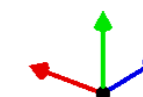


Photon 1,
pt = 331.87
eta = 0.074
phi = 1.192

Photon 0,
pt = 385.29
eta = 0.540
phi = -2.322

$m^{\gamma\gamma} = 730$ GeV
 $p_T^{\gamma\gamma} = 50$ GeV
 $E_T^{\text{miss}} = 20$ GeV
 $N_{\text{vtx}} = 28$

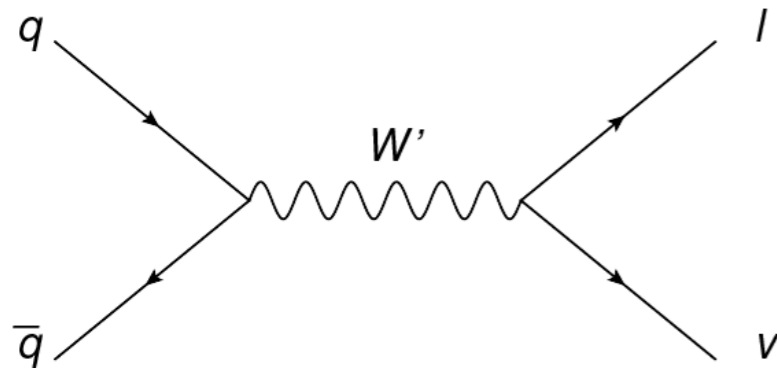
CMS Experiment at LHC, CERN
Data recorded: Thu Jul 16 04:37:00 2015 CEST
Run/Event: 251883 / 108749975
Lumi section: 171
Orbit/Crossing: 44591162 / 323



Photon selection

$p_T > 100$ GeV and $|\eta| < 2.5$ with at least one candidate in the ECAL Barrel with $|\eta| < 1.4442$
isolated photons with shape in ECAL compatible with prompt photon

Muon + MET resonance Search



Muon selection

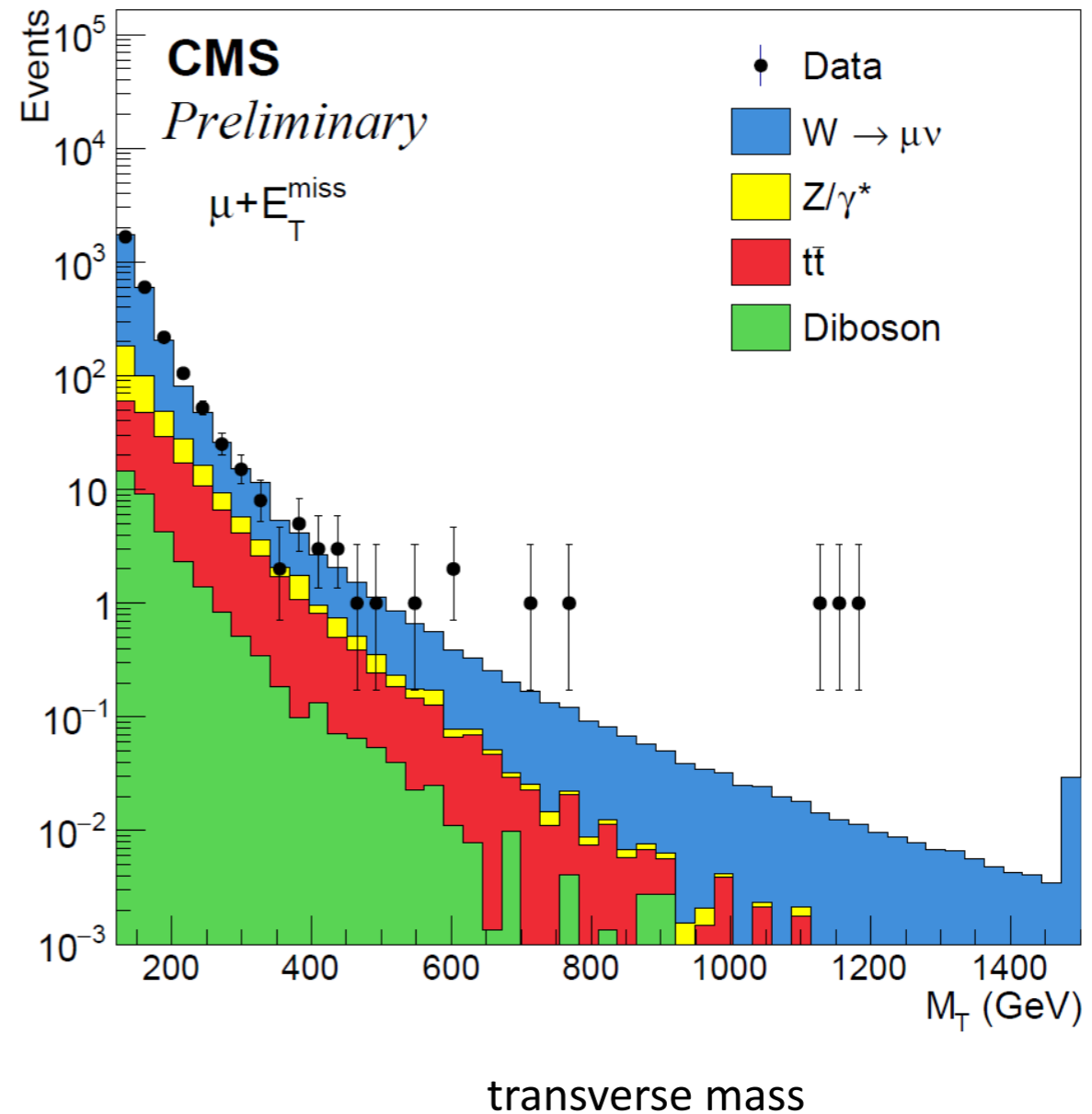
Good-quality isolated high- p_T muon with $p_T > 55$ GeV and $|\eta| < 2.4$

Event selection

- Single high- p_T muon accompanied by a large missing transverse energy (E_T^{miss}).
- Events containing additional muons with $p_T > 25$ GeV are vetoed
- Kinematic selection:
 $0.4 < p_T(\mu) / E_T^{\text{miss}} < 1.5$
 $\Delta\Phi(\mu, E_T^{\text{miss}}) > 2.5$

Early Alignment used in data

42 pb^{-1} (13 TeV)

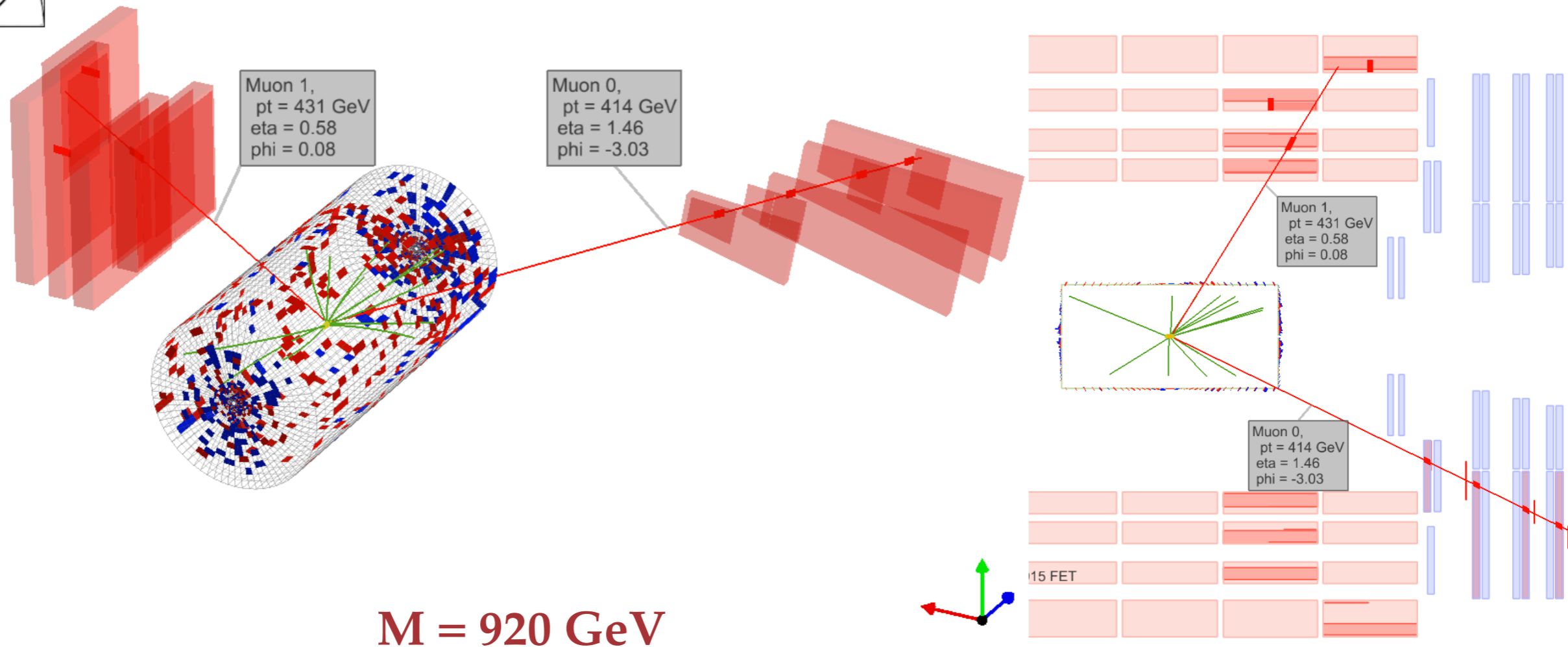


last bin includes overflow

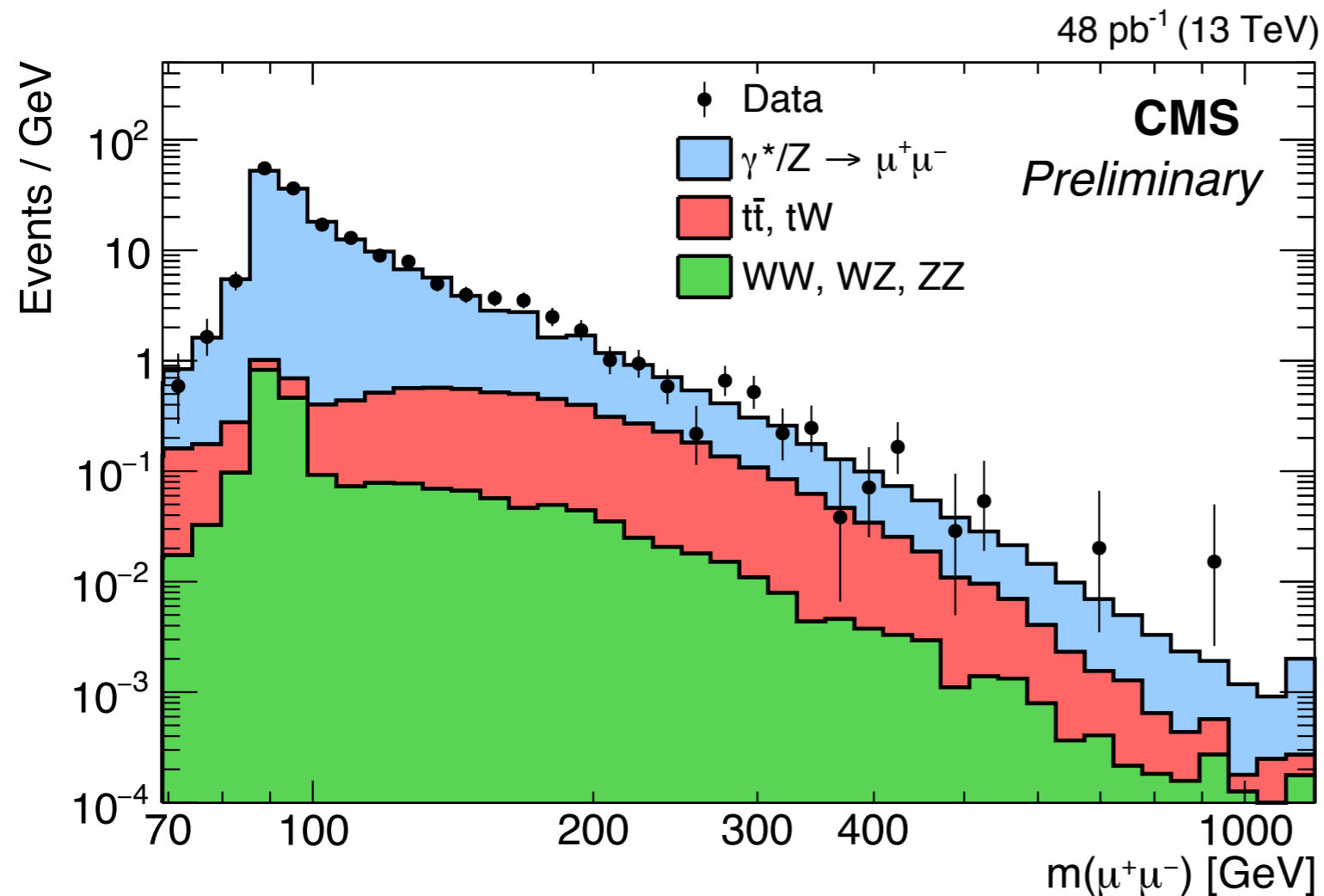
Di-muon resonance search



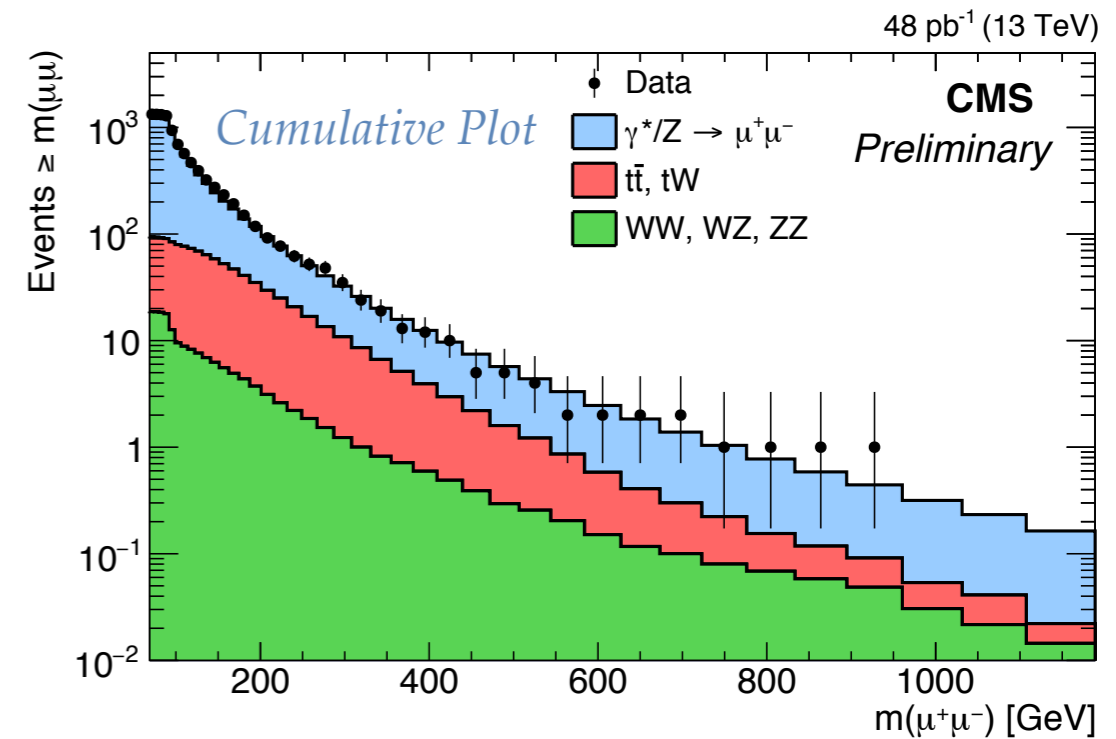
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 10:18:52 2015 FET
Run/Event: 251562 / 367325039
Lumi section: 414



Di-muon resonance search



last bin includes overflow



Highest mass event = 920 GeV

Early alignment of Muon system
and Tracker used in data

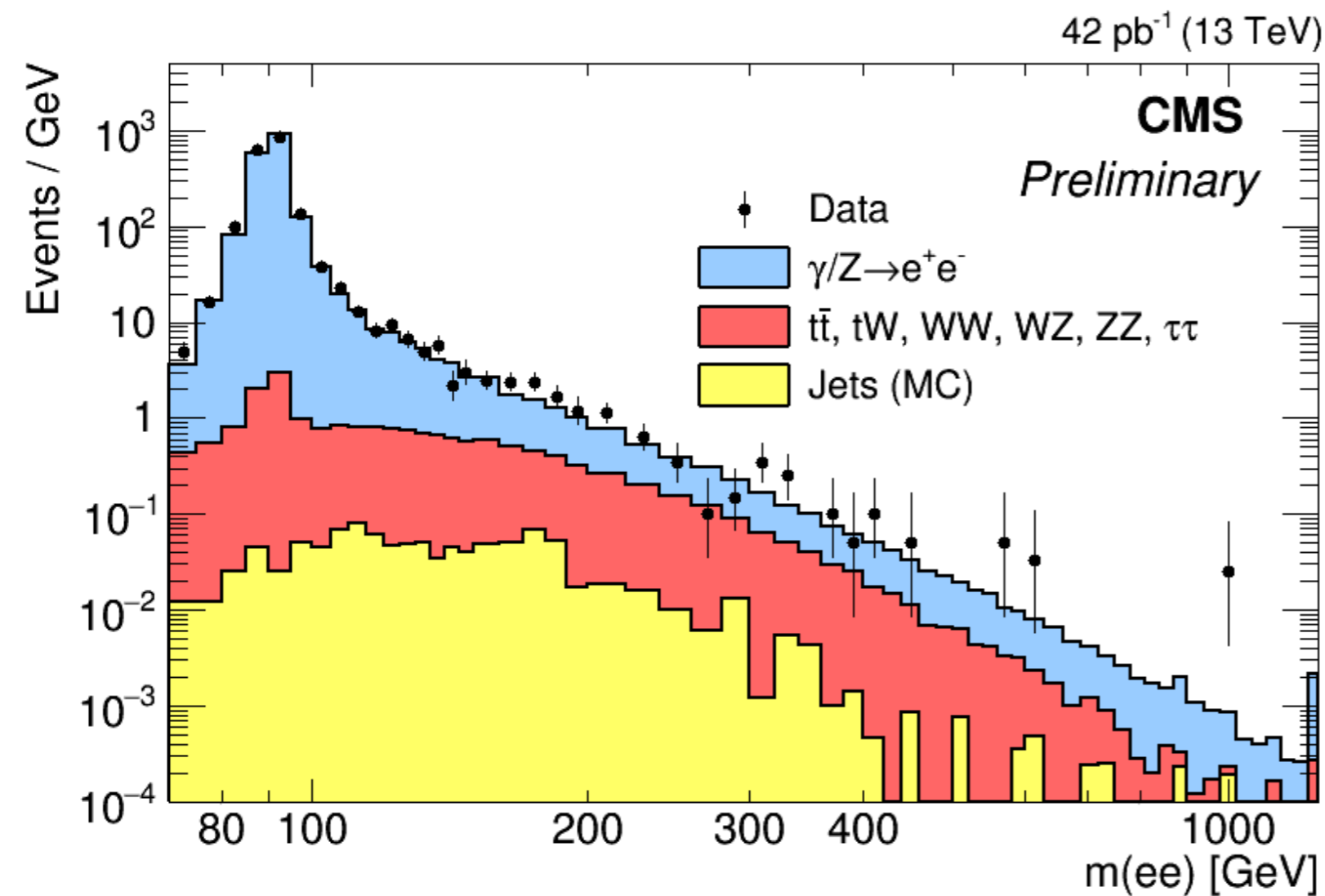
contribution from di-jets
negligible and not shown

2 isolated muons muons are required to satisfy:

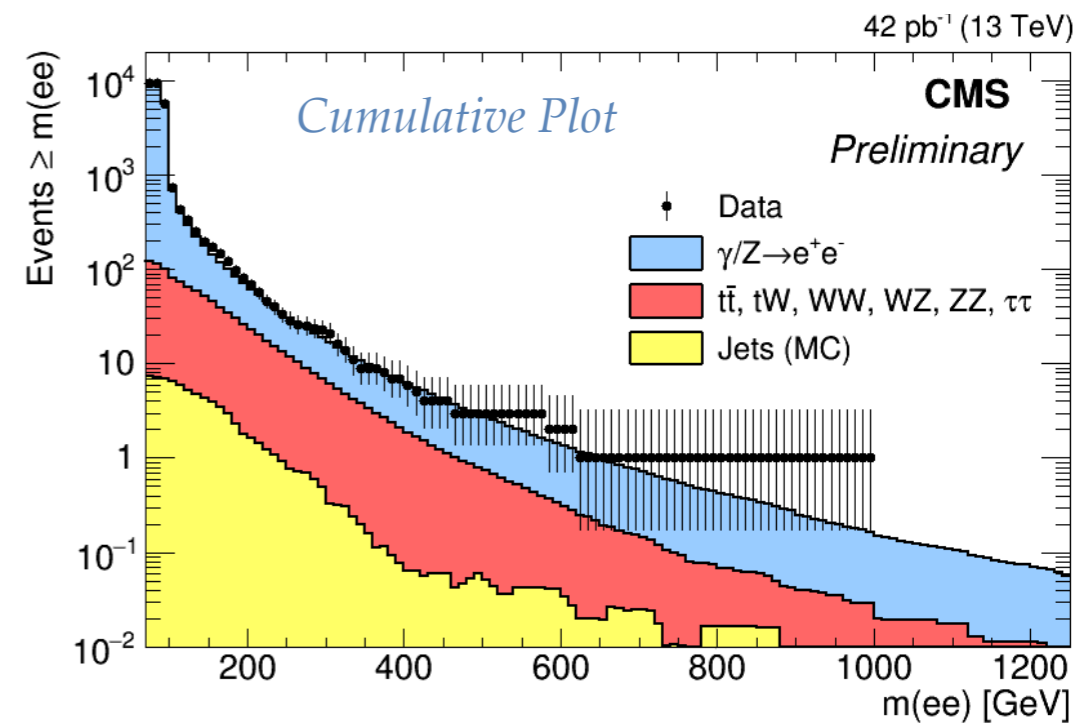
$$p_T > 48 \text{ GeV and } |\eta| < 2.4$$

MC samples: aMC@NLO for Drell-Yan, POWHEG for $t\bar{t}$ and dibosons

Di-electron resonance search



last bin includes overflow



Highest mass event ~ 1 TeV

Run1 Limit for SSM Z' < 2.9 TeV

Run1 sensitivity will be reached
 after about 2 fb⁻¹

2 electrons in ECAL with $E_T > 35$ GeV and at least one electron in the ECAL barrel

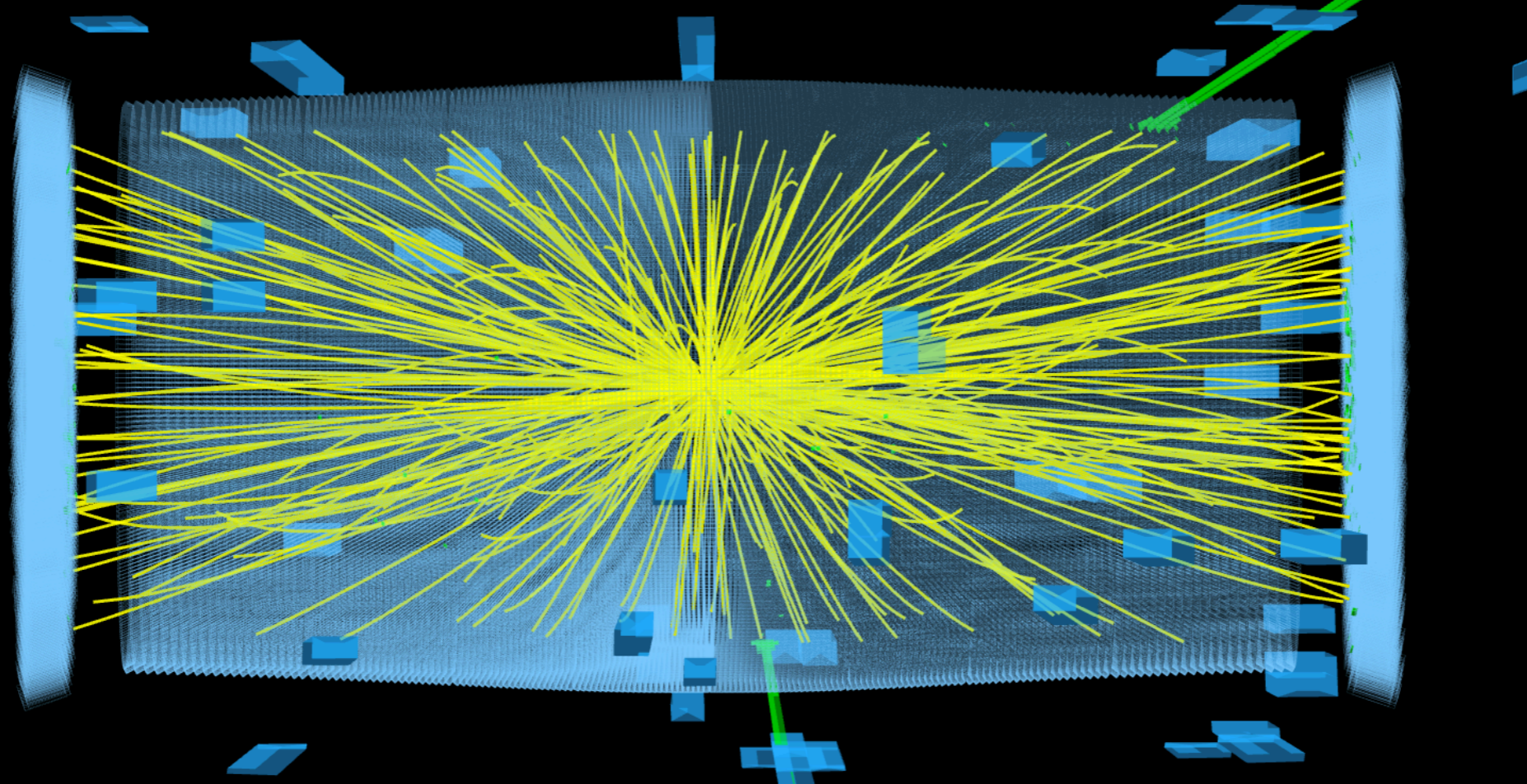
($|\eta| < 1.4442$ or $1.566 < |\eta| < 2.5$ with one electron within $|\eta| < 1.4442$)



CMS Experiment at the LHC, CERN

Data recorded: 2015-Aug-22 02:13:48.861952 GMT

Run / Event / LS: 254833 / 1268846022 / 846



M = 2.9 TeV !!!

Di-electron resonance search

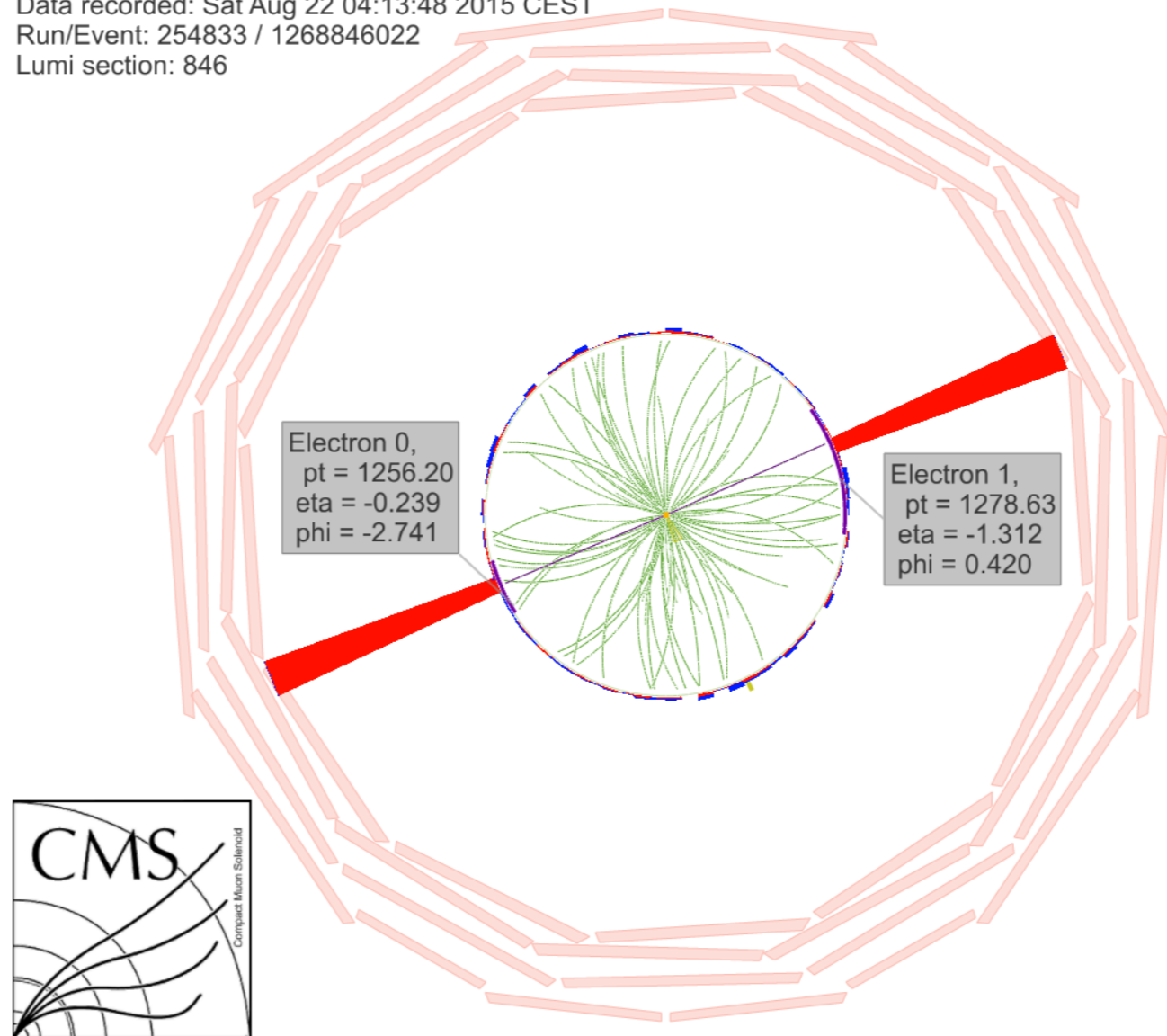
In the additional 25 pb⁻¹ data @13 TeV and 50 ns processed last Wednesday:

An event with a di-electron mass of 2.9 TeV has been observed

The event consists in two perfectly balanced electrons and no other significant activity

CMS Experiment at LHC, CERN
Data recorded: Sat Aug 22 04:13:48 2015 CEST
Run/Event: 254833 / 1268846022
Lumi section: 846

M = 2.9 TeV !!!



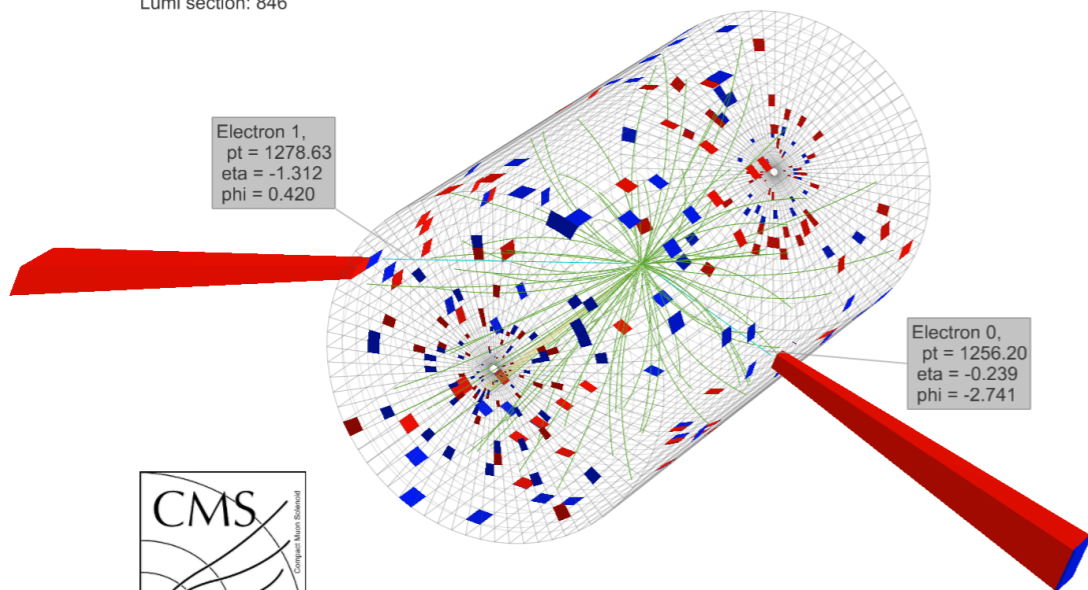
Di-electron resonance search

M = 2.9 TeV !!!

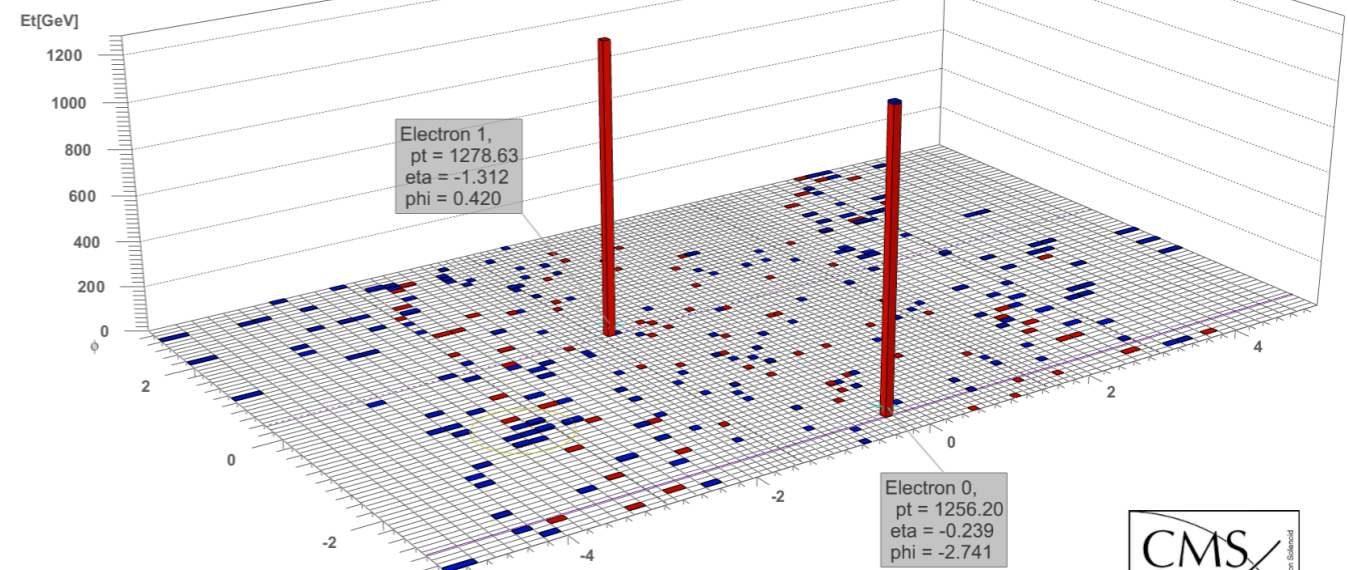
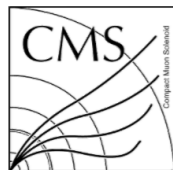
CMS Experiment at LHC, CERN
Data recorded: Sat Aug 22 04:13:48 2015 CEST
Run/Event: 254833 / 1268846022
Lumi section: 846



Electron 1,
pt = 1278.63
eta = -1.312
phi = 0.420



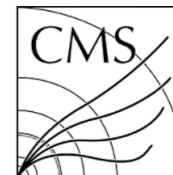
Electron 0,
pt = 1256.20
eta = -0.239
phi = -2.741



Electron 1,
pt = 1278.63
eta = -1.312
phi = 0.420

Electron 0,
pt = 1256.20
eta = -0.239
phi = -2.741

CMS Experiment at LHC, CERN
Data recorded: Sat Aug 22 04:13:48 2015 CEST
Run/Event: 254833 / 1268846022
Lumi section: 846



- Successful operation in 2010 - 2012 runs at \sqrt{s} - 7 and 8 TeV
- A major discovery : **Higgs boson**
- **Large number of analysis and publications** from many CMS physics groups
- The 13 TeV campaign is expected to be highly fruitful.

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Physics: exciting times

CMS EX0 2015-001

$d\sigma/dm_{jj}$ [pb / GeV]

Dijet Mass [GeV]

42 pb⁻¹ (13 TeV)

CMS Preliminary

- data
- background fit to data
- QCD MC
- q* (4.5 TeV)

$|\eta| < 2.5, |\Delta\eta| < 1.3$
 $M_{jj} > 1.1$ TeV
 Wide Jets

(Data-Fit)/ σ

ATLAS-CONF-2015-042

ATLAS Preliminary

$\sqrt{s}=13$ TeV, 80 pb⁻¹

- Data
- Background fit
- BumpHunter interval
- BlackMax, m = 4.0 TeV
- BlackMax, m = 5.0 TeV

p -value = 0.79
 Fit Range: 1.1 - 5.3 TeV
 $|y^*| < 0.6$

Signif.

m_{jj} [TeV]

An event with a di-electron mass of 2.9 TeV has been observed

The event consists in two perfectly balanced electrons and no other significant activity

CMS Experiment at LHC, CERN
 Data recorded: Sat Aug 22 04:13:48 2015 CEST
 Run/Event: 24833 / 126846022
 Lumi section: 846

M = 2.9 TeV !!!

CMS

Conclusion (2)

- CMS is (~continuously) improving and upgrading to take advantage of the increasing LHC energy and luminosity
 - The LS1 projects are nearly complete
 - Upgrades to tracking and trigger will happen during Run 2
 - Further upgrades during LS2 to improve calorimeter granularity, trigger
 - R&D is underway for upgrades for HL-LHC

The CMS upgrade program aims to fully exploit the LHC physics potential