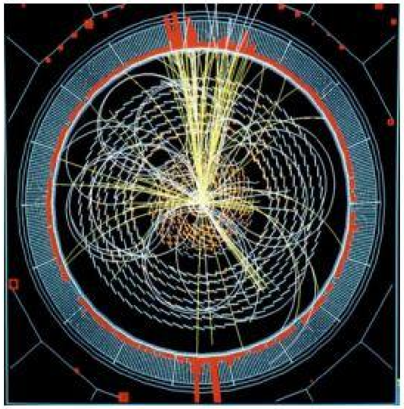
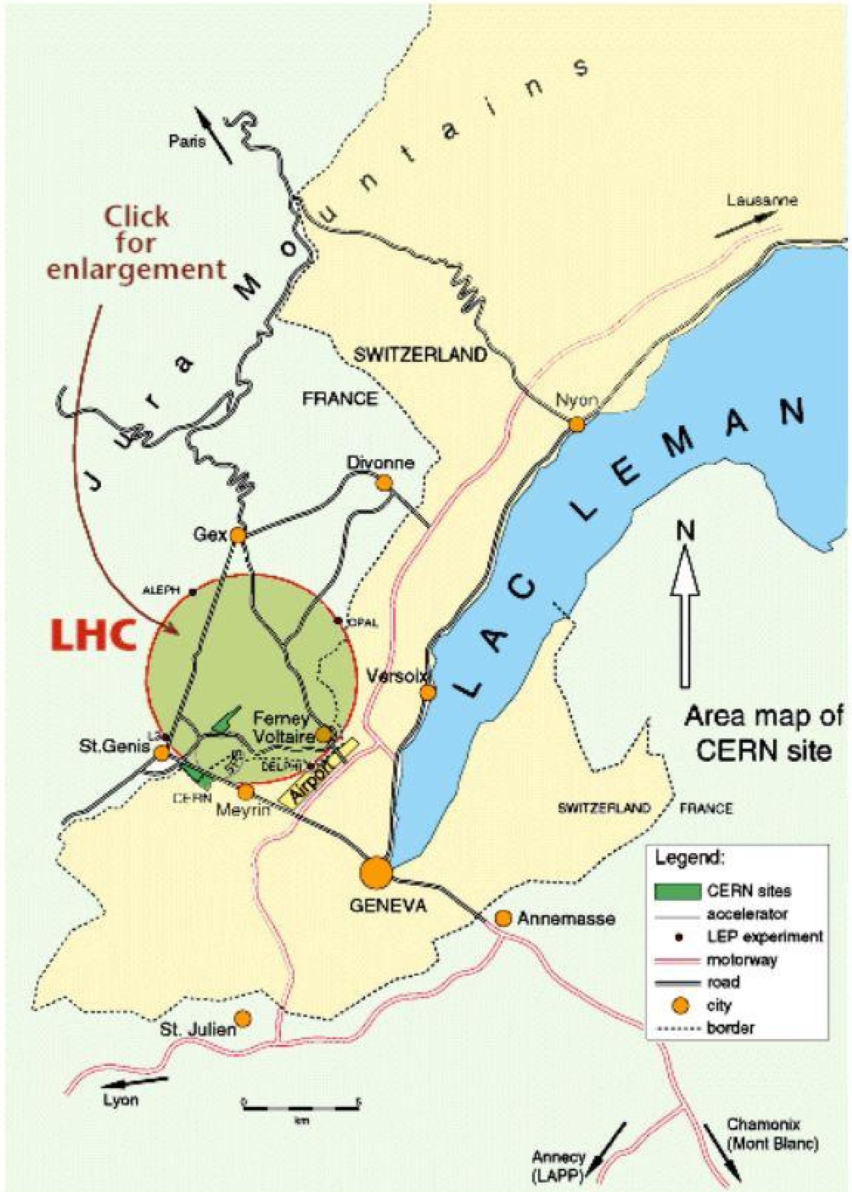


New England Particle Physics
Student Retreat V
Cape Cod, Aug. 18, 2006

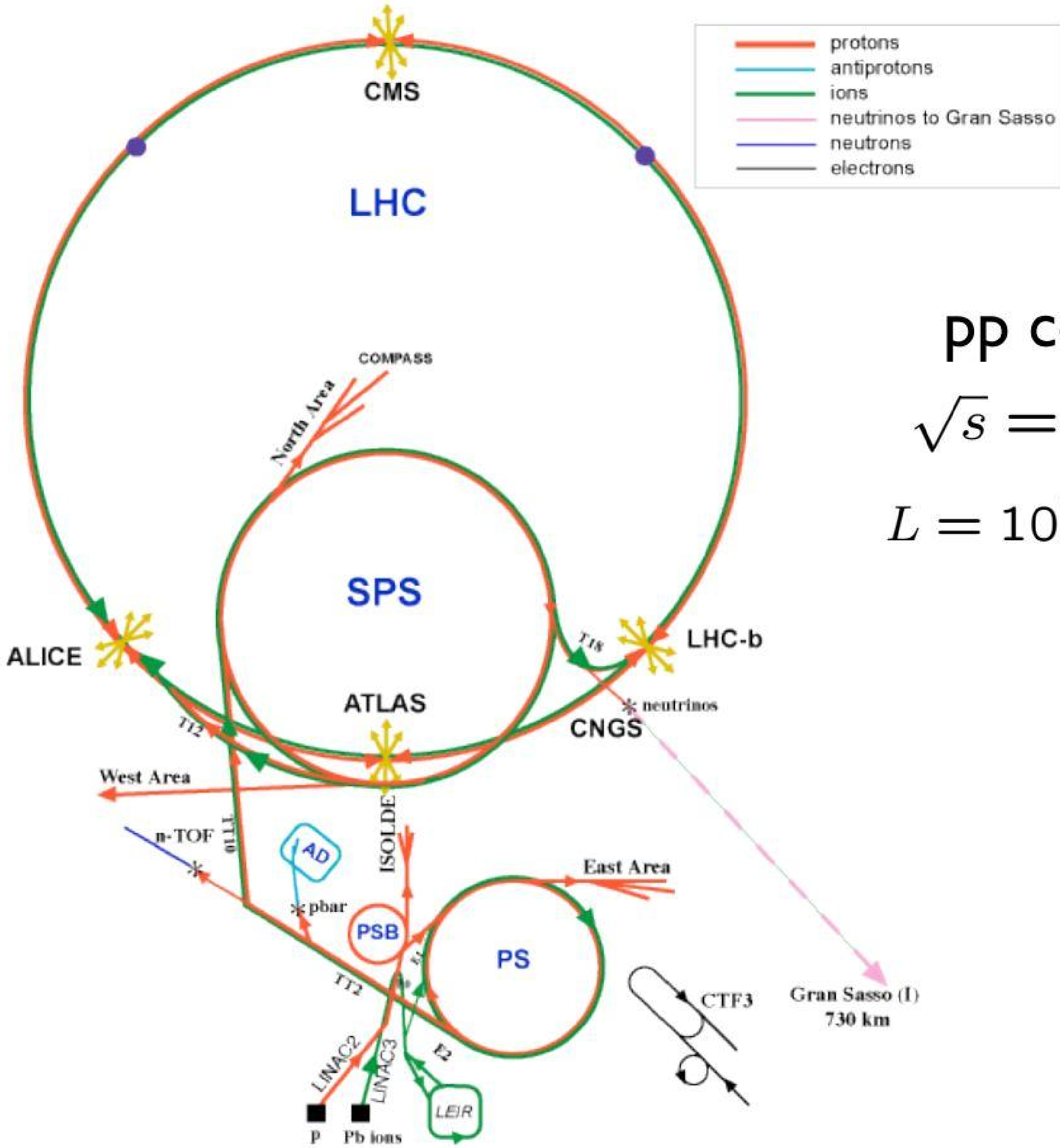
Physics at the LHC

Jim Rohlf
Boston University

LHC Geographical Situation



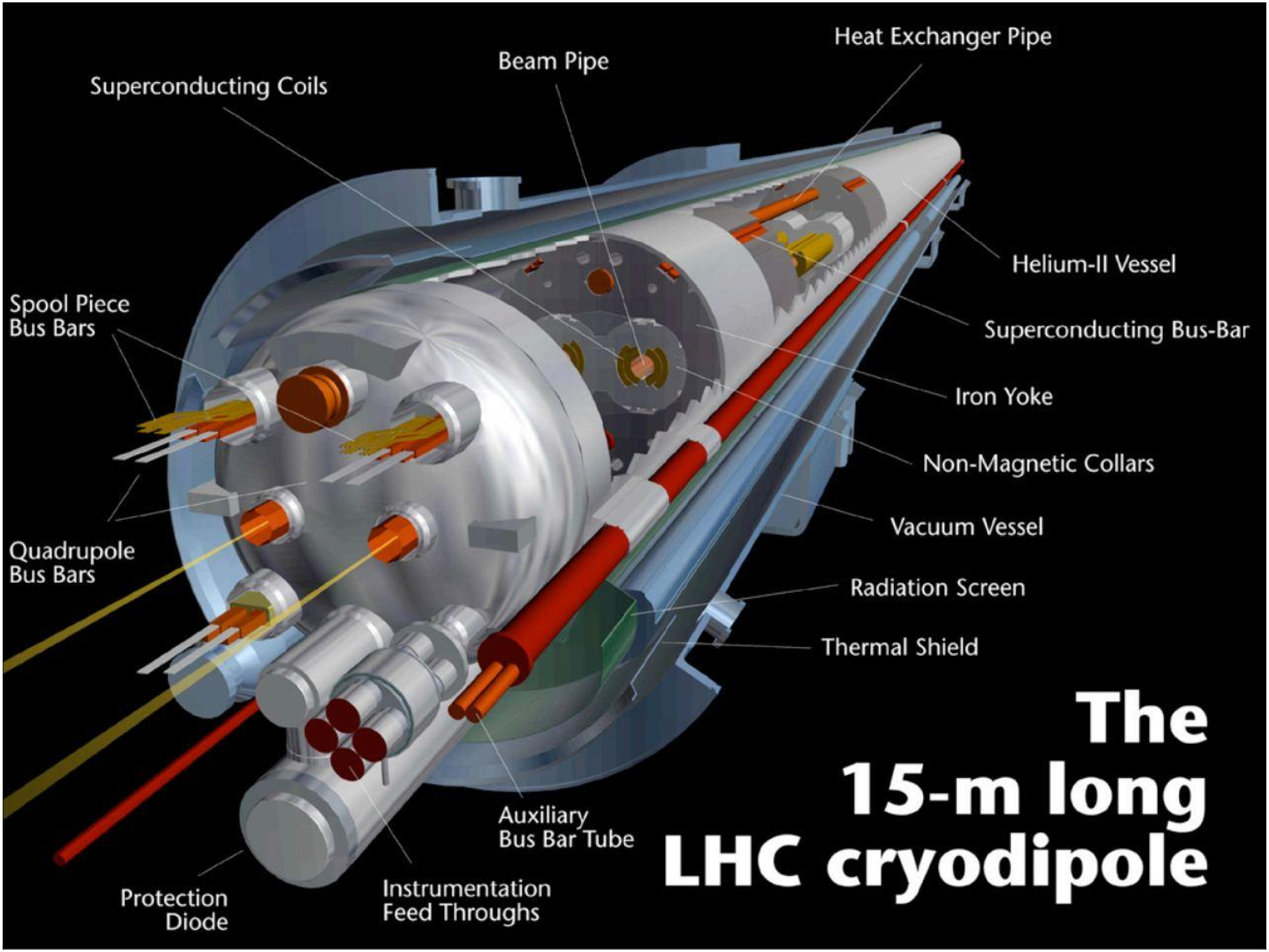

P2: LHCb
P1: ATLAS
P5: CMS
P8: ALICE
f=11.245 kHz
T=88.924 μs

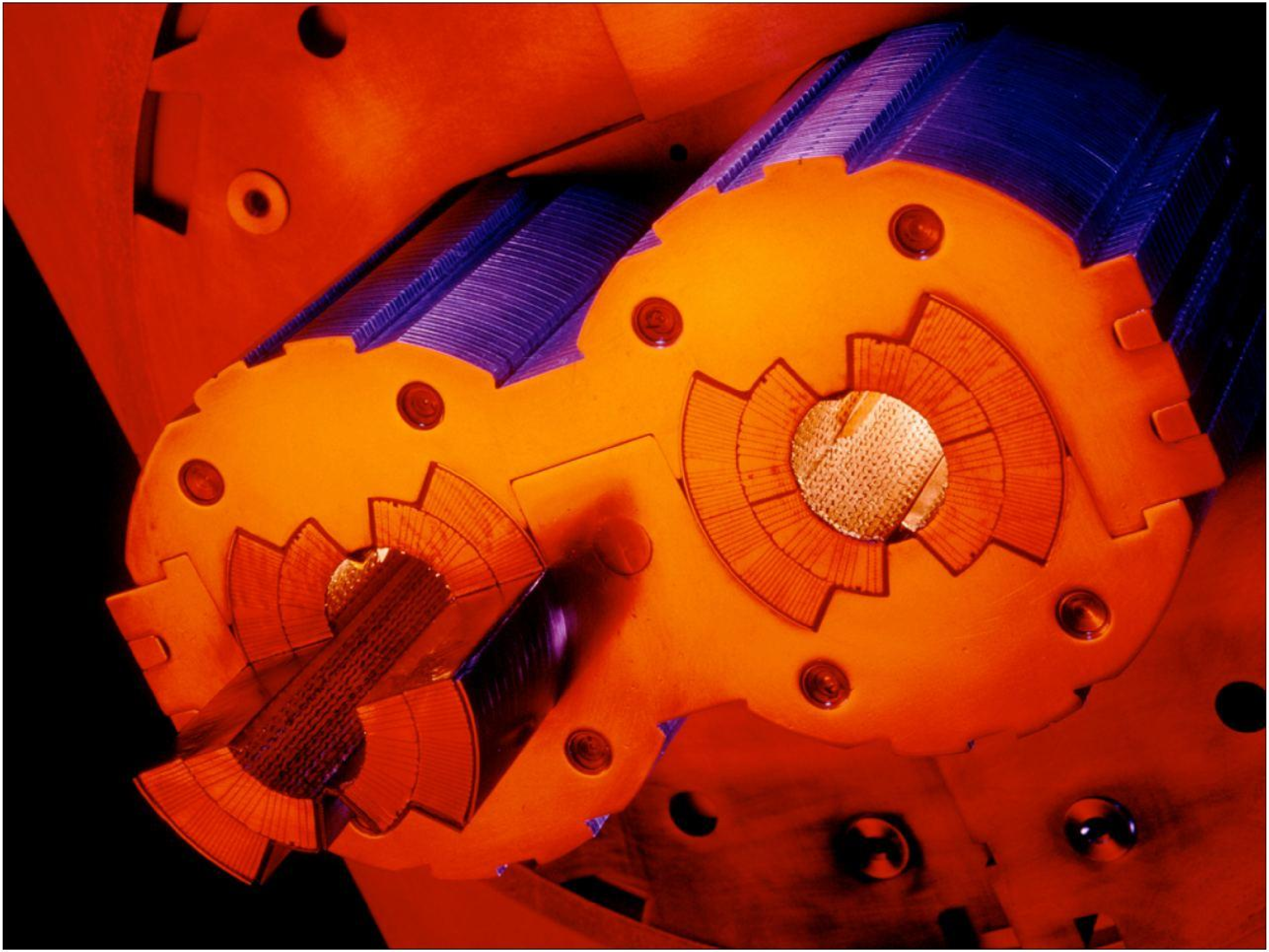


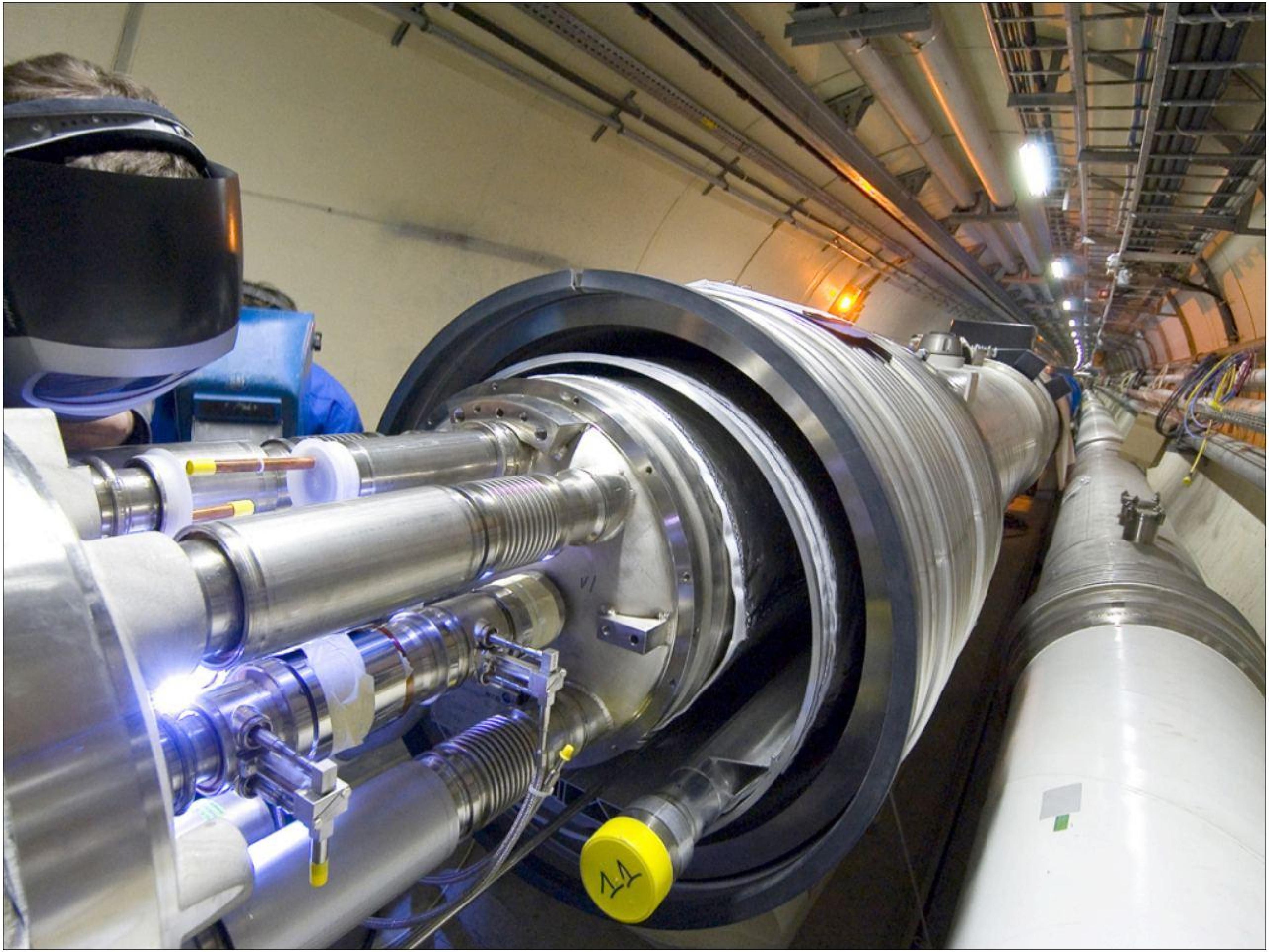
pp collisions:

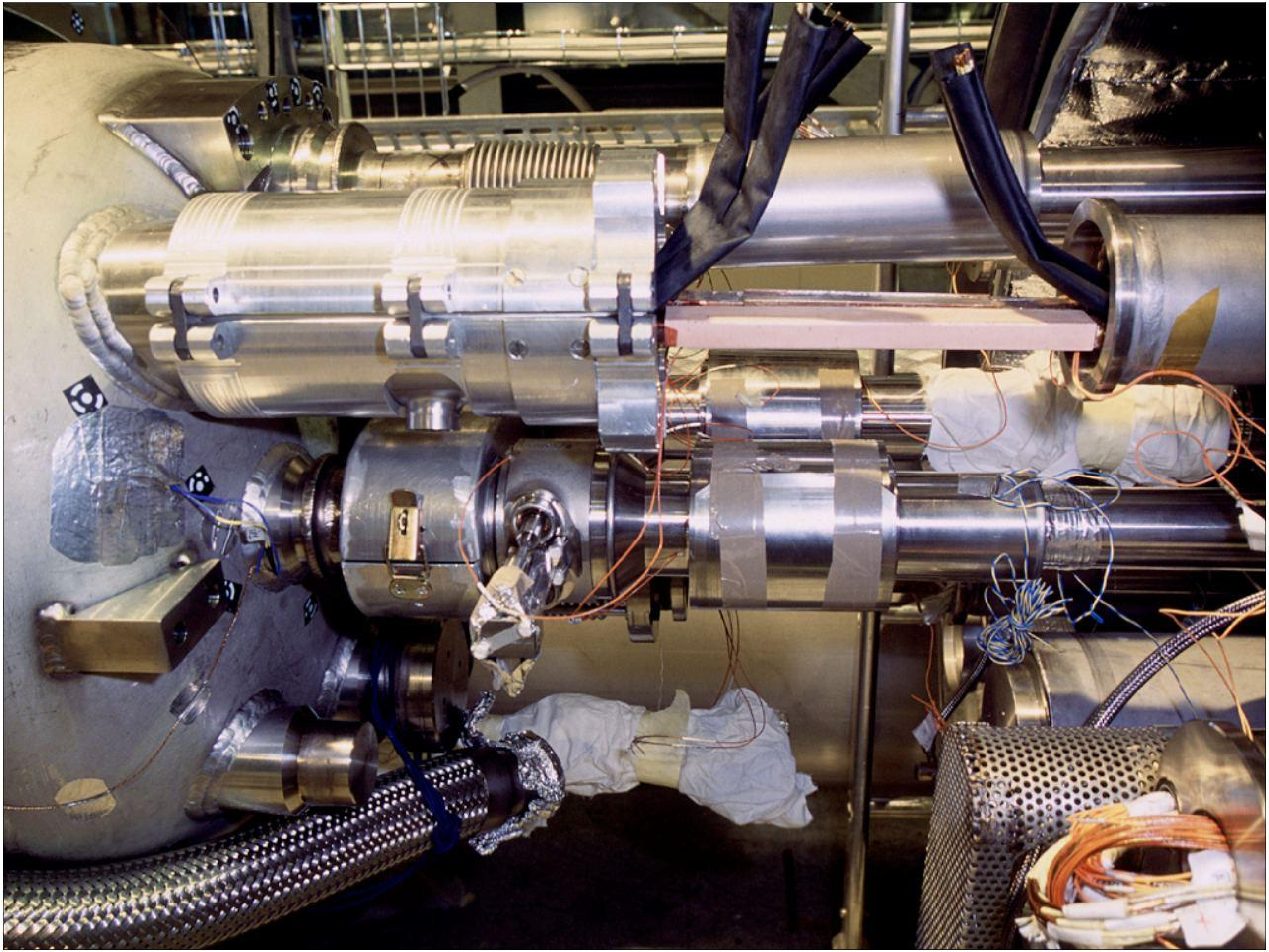
$$\sqrt{s} = 14\ \text{TeV}$$

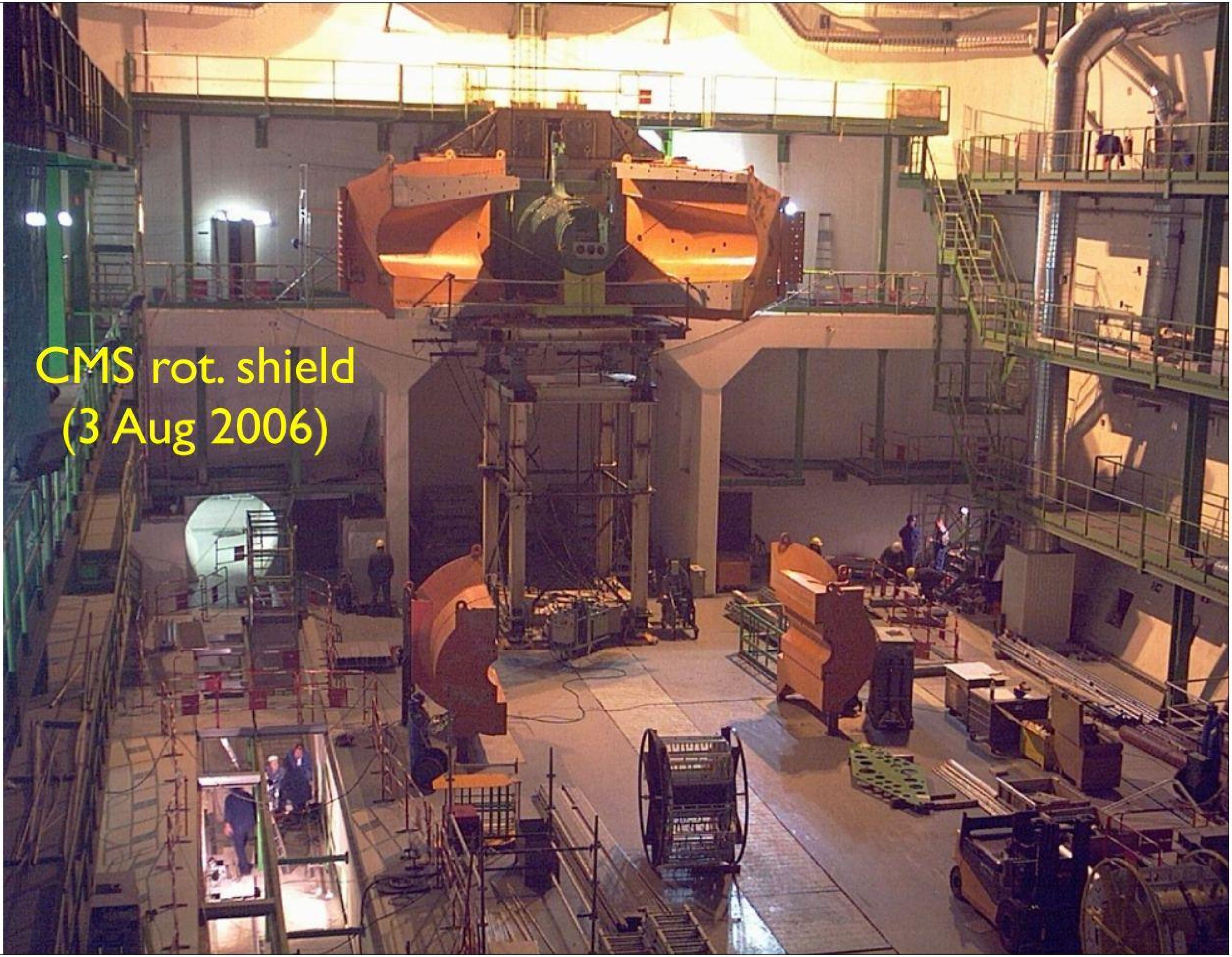
$$L = 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$$

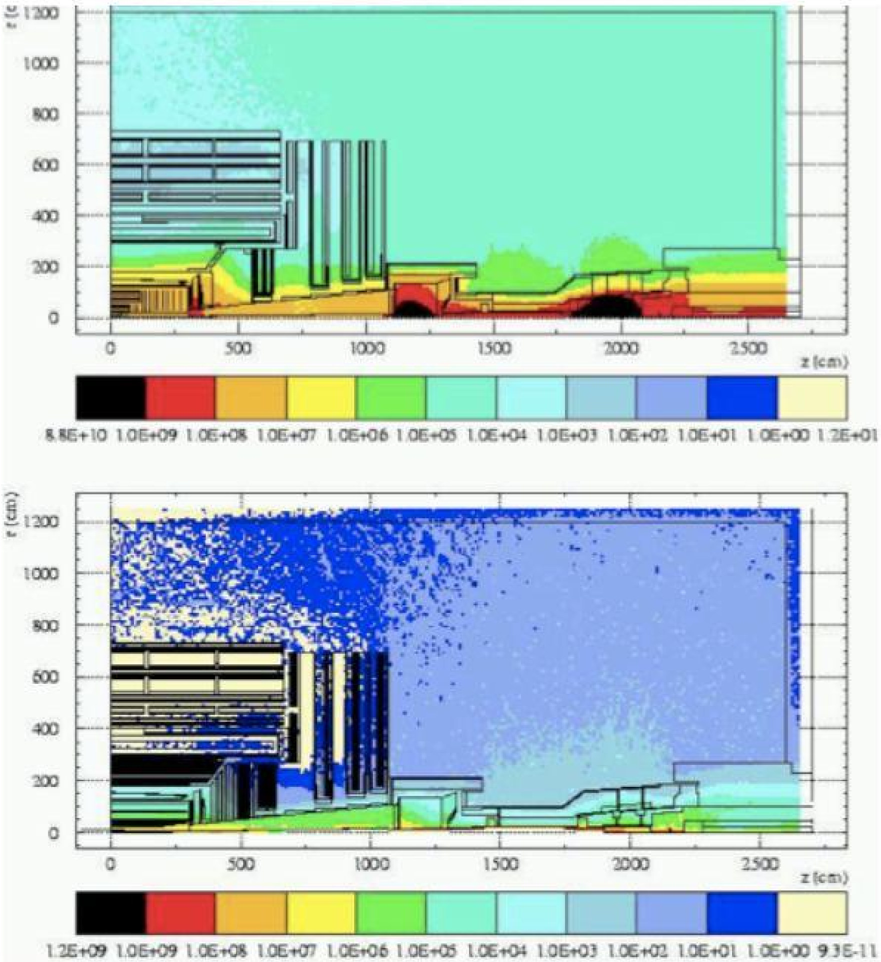

Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs





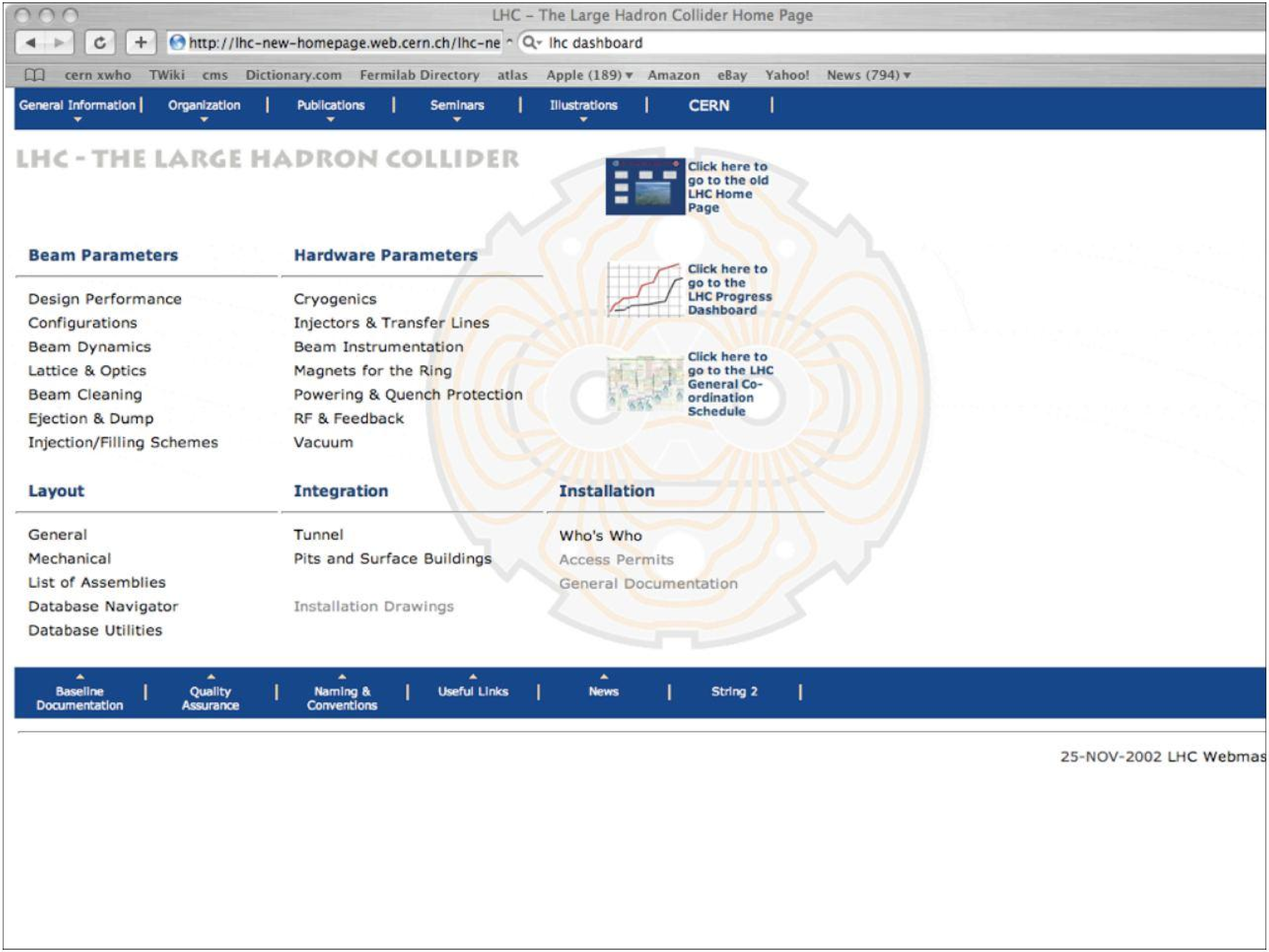



CMS rot. shield
(3 Aug 2006)



neutron flux

dose (Gy=J/kg absorbed)
2500 fb^{-1}



LHC – The Large Hadron Collider Home Page

http://lhc-new-homepage.web.cern.ch/lhc-ne | lhc dashboard

cern xwho | TWiki | cms | Dictionary.com | Fermilab Directory | atlas | Apple (189) | Amazon | eBay | Yahoo! | News (794)

General Information | Organization | Publications | Seminars | Illustrations | CERN

LHC - THE LARGE HADRON COLLIDER

Click here to go to the old LHC Home Page

Click here to go to the LHC Progress Dashboard

Click here to go to the LHC General Co-ordination Schedule

Beam Parameters

Design Performance
Configurations
Beam Dynamics
Lattice & Optics
Beam Cleaning
Ejection & Dump
Injection/Filling Schemes

Hardware Parameters

Cryogenics
Injectors & Transfer Lines
Beam Instrumentation
Magnets for the Ring
Powering & Quench Protection
RF & Feedback
Vacuum

Layout

General
Mechanical
List of Assemblies
Database Navigator
Database Utilities

Integration

Tunnel
Pits and Surface Buildings

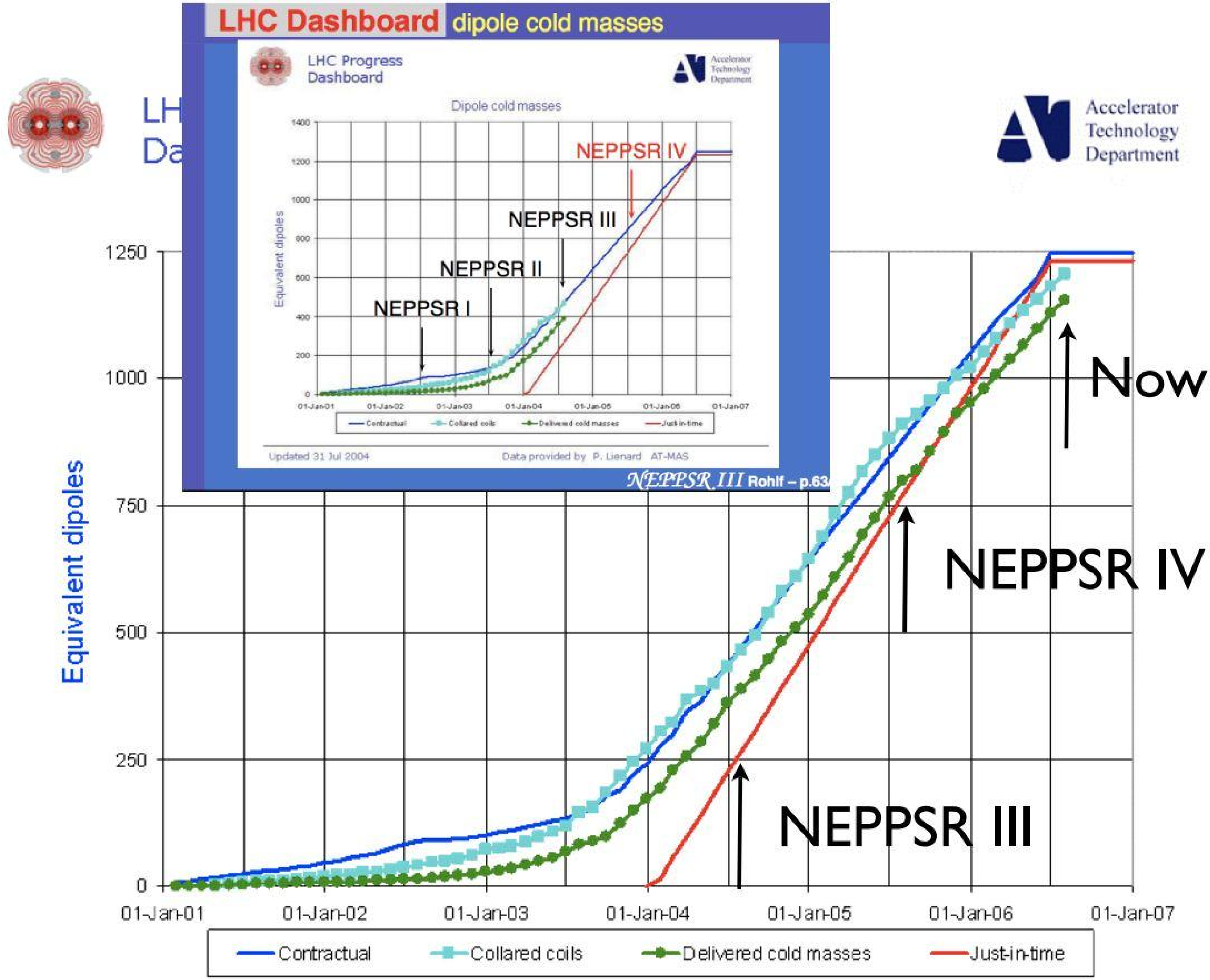
Installation Drawings

Installation

Who's Who
Access Permits
General Documentation

Baseline Documentation | Quality Assurance | Naming & Conventions | Useful Links | News | String 2

25-NOV-2002 LHC Webmas

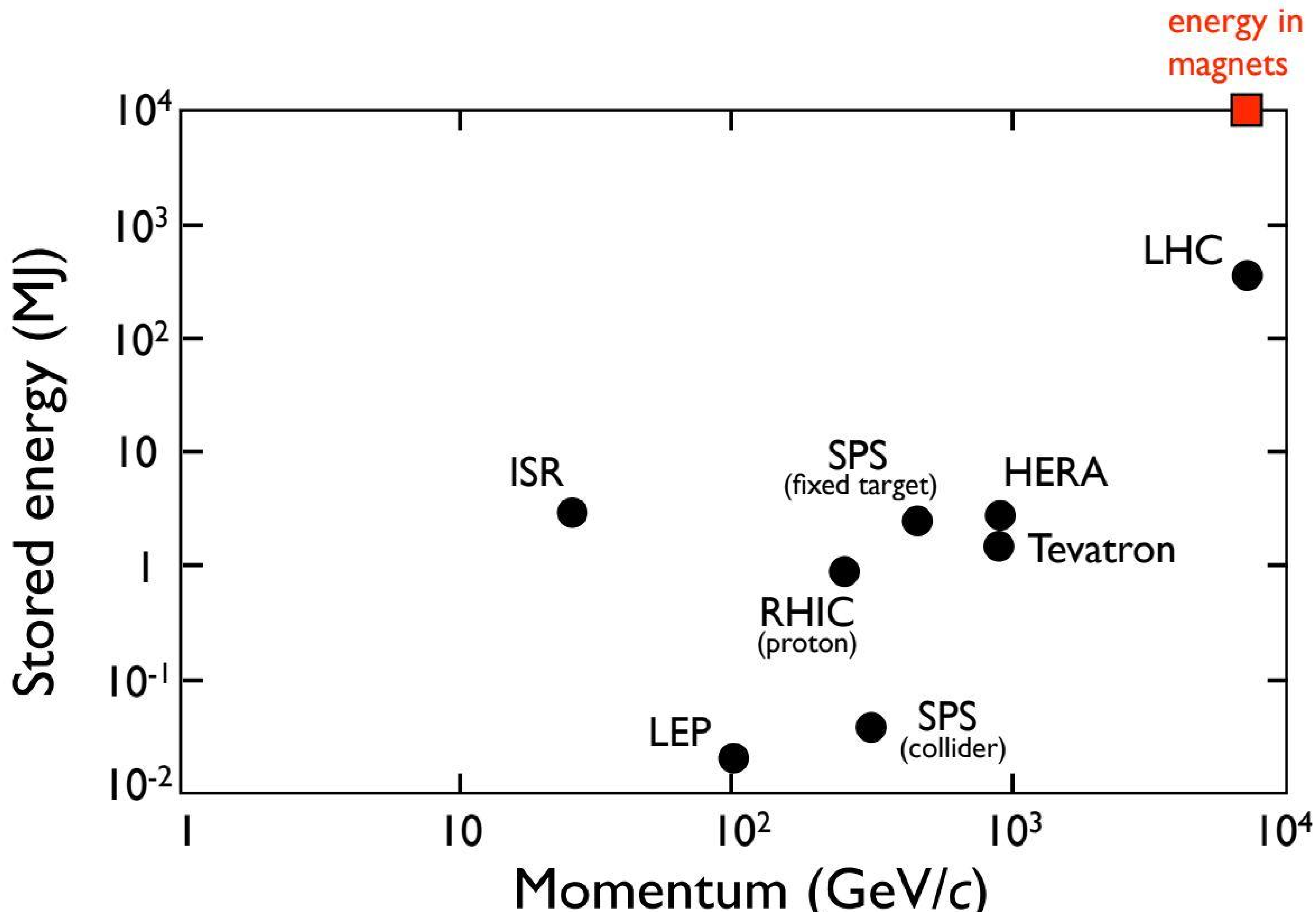

LHC Dashboard dipole cold masses
LHC Progress Dashboard
Accelerator Technology Department
Dipole cold masses
NEPPSR IV
NEPPSR III
NEPPSR II
NEPPSR I
Equivalent dipoles
Contractual
Collared coils
Delivered cold masses
Just-in-time
Updated 31 Jul 2004
Data provided by P. Lienard AT-MAS
NEPPSR III Rohlf – p.63
Accelerator Technology Department
1250
1000
750
500
250
0
01-Jan-01
01-Jan-02
01-Jan-03
01-Jan-04
01-Jan-05
01-Jan-06
01-Jan-07
Now
NEPPSR IV
NEPPSR III
Contractual
Collared coils
Delivered cold masses
Just-in-time

Superconducting RF

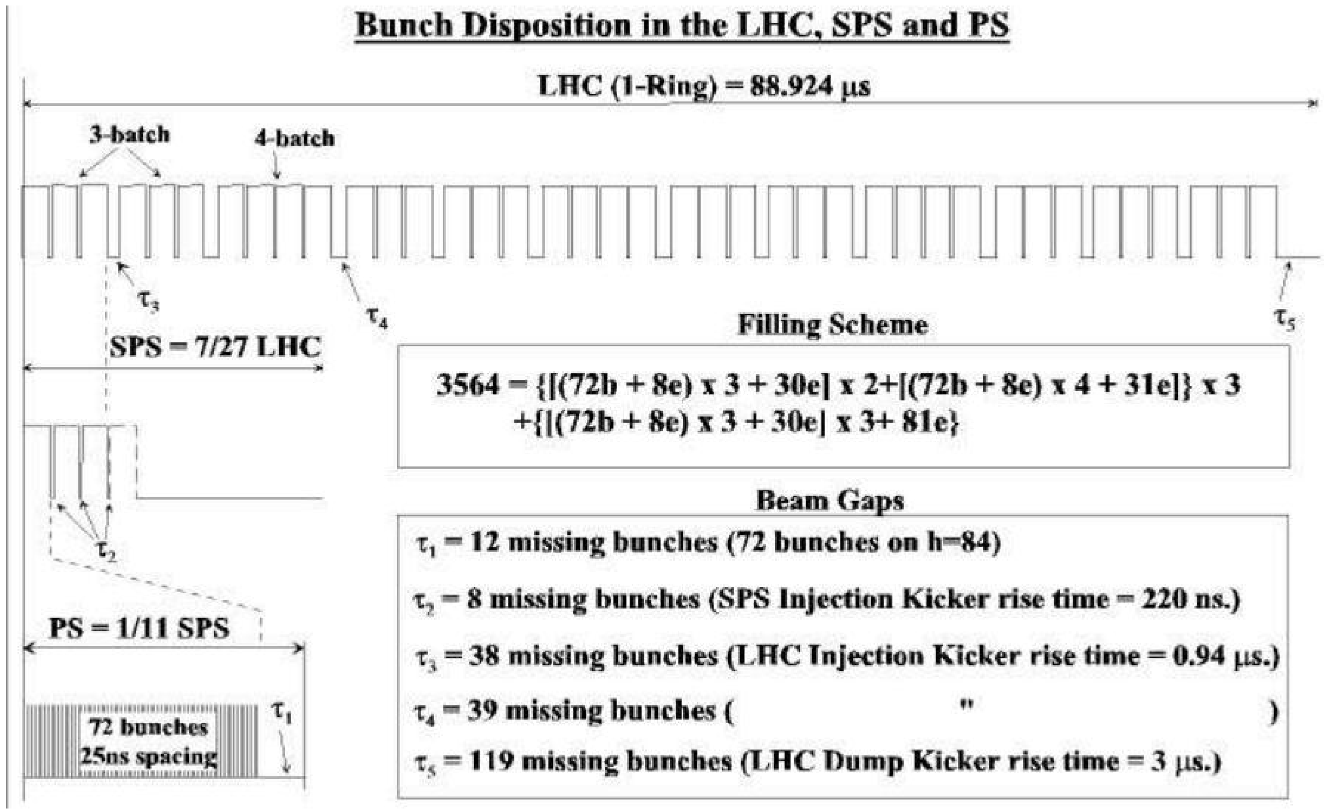
klystron (1937): vacuum tube for microwave amplication

Klystron tube-- first important use

- A klystron tube is used by Dan Aykroyd's character in the 1988 comedy film, *My Stepmother Is an Alien*. In this case, the equipment overloads after coming in contact with the metal buttons of a jacket, causing a reaction that sends a powerful signal to a distant world. That signal gains the attention of aliens who come to Earth to investigate. Later, the original malfunction is intentionally reproduced and an alien creature is destroyed by contact with the electrified tube.



energy in
magnets
LHC
ISR
SPS
(fixed target)
HERA
Tevatron
RHIC
(proton)
LEP
SPS
(collider)
Stored energy (MJ)
Momentum (GeV/c)



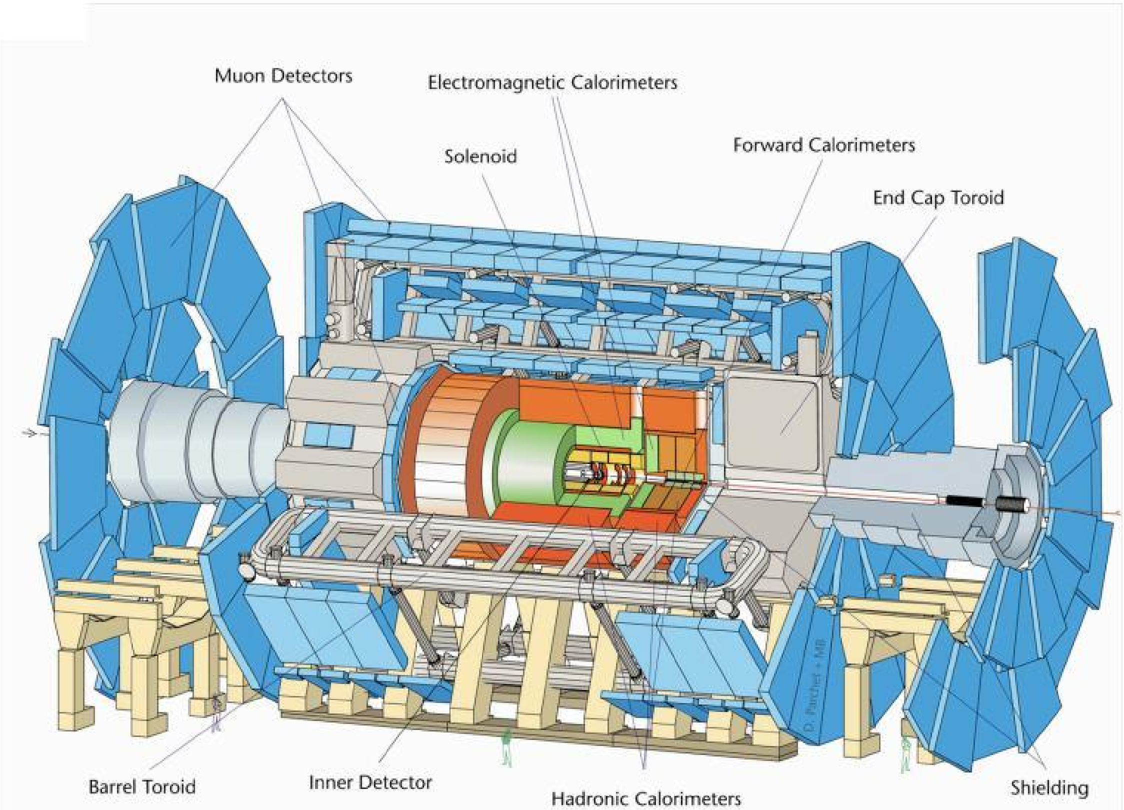
$$84 \times 11 \times 27/7 = 3564$$

3564 RF buckets, but only 2208 have protons, in a well defined pattern, necessary for synchronization

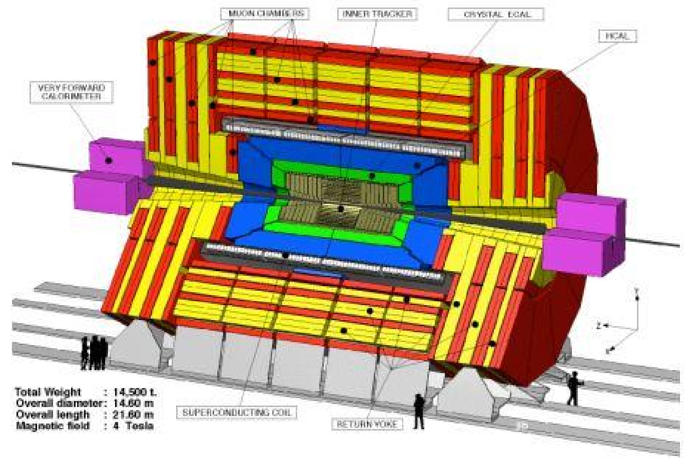
$$88924 \text{ ns} / 3565 = 24.95 \text{ ns}$$

$$1 / 24.95 \text{ ns} = 40.079 \text{ MHz}$$

Detectors: Overview



- muon detectors
- tracking in B field
- EM calorimetry
- hadron calorimetry



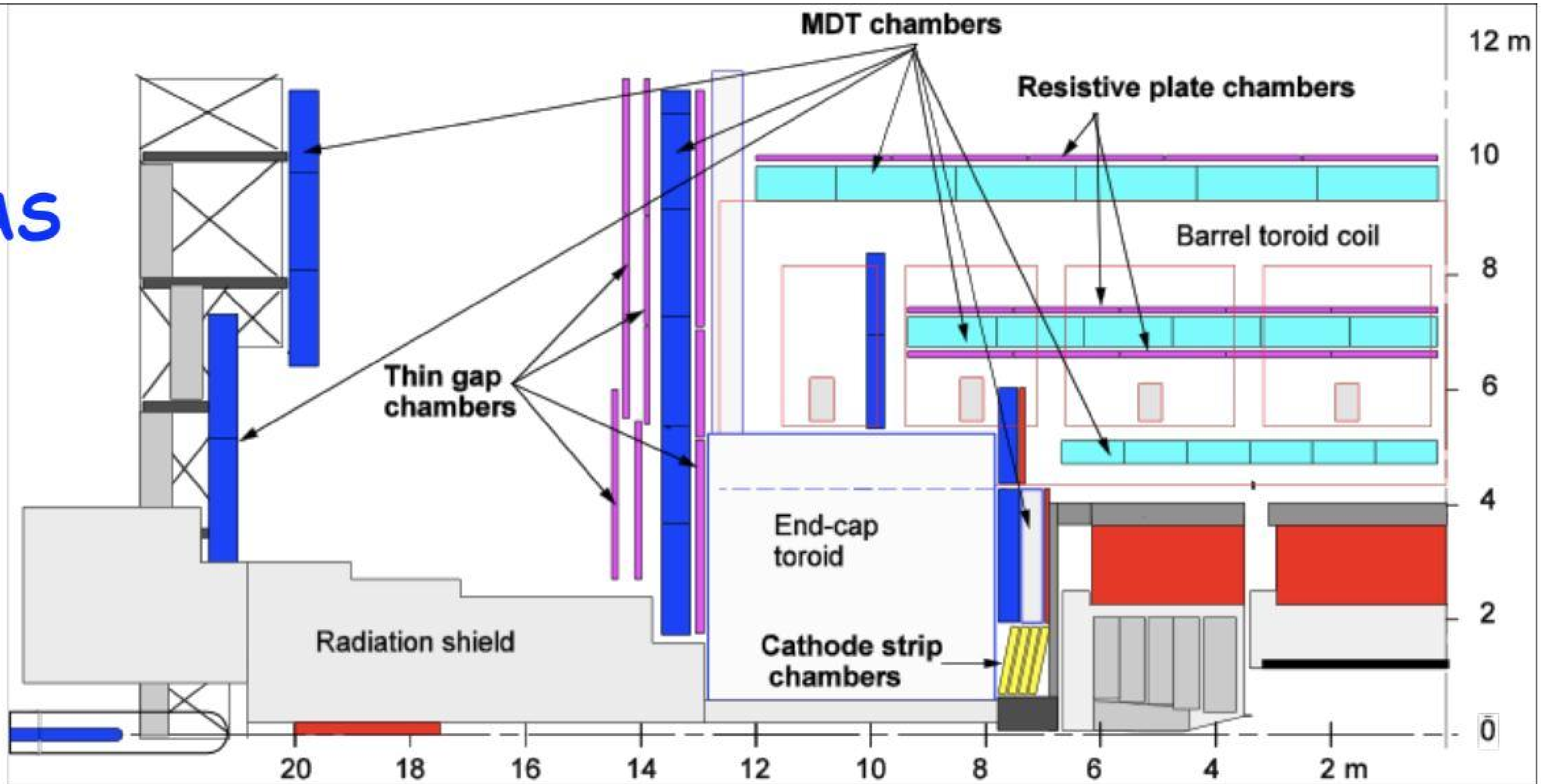
A Toroidal Large hadron collider AparatuS (ATLAS)
7 kTons 0.5 T toroid,
2 T solenoid, $(25\ \mathrm{m})^2 \times 46$ m
magnet=40% of $$,
good stand-alone muon res.

Compact Muon Solenoid (CMS) 14 kTons
4 T solenoid,
$(15\ \mathrm{m})^2 \times 22$ m
magnet=25% of $$,
high res.tracker & ECAL

Detector Technology

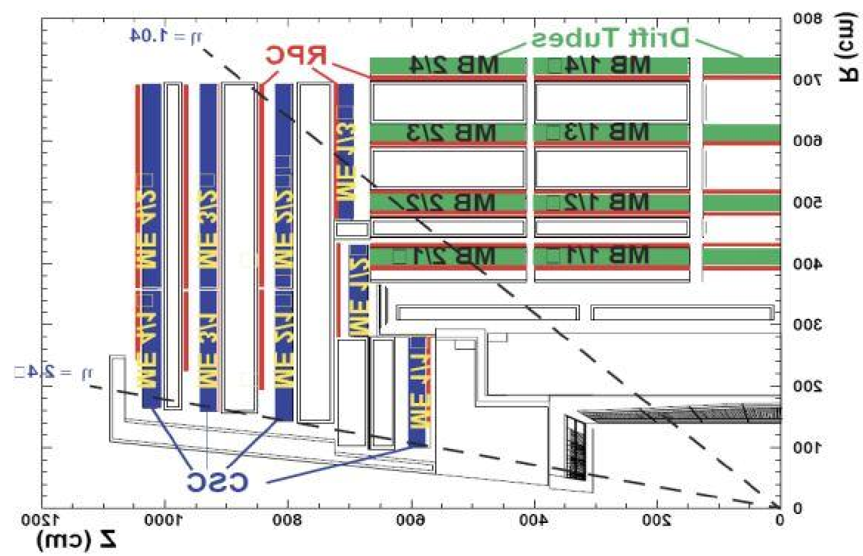
		ATLAS	CMS
Tracking	inner	pixels	pixels
	barrel	silicon strips/ straw tubes	silicon strips
	endcap	silicon strips/ straw tubes	silicon strips
ECAL	barrel	liquid argon / Pb	crystals ($PbWO_4$)
	endcap	liquid argon / Pb	crystals ($PbWO_4$)
HCAL	barrel	scintillator / Fe	scintillator / brass
	endcap	liquid argon / Cu	scintillator / brass
	forward	liquid argon / Cu-W	quartz / Fe
Muon	barrel	drift tubes	drift chambers
		+resistive plate (trigger)	+resistive plate (trigger)
	end cap	drift tubes, cathode strip	cathode strip
		+ thin gap (trigger)	+ resistive plate (trigger)

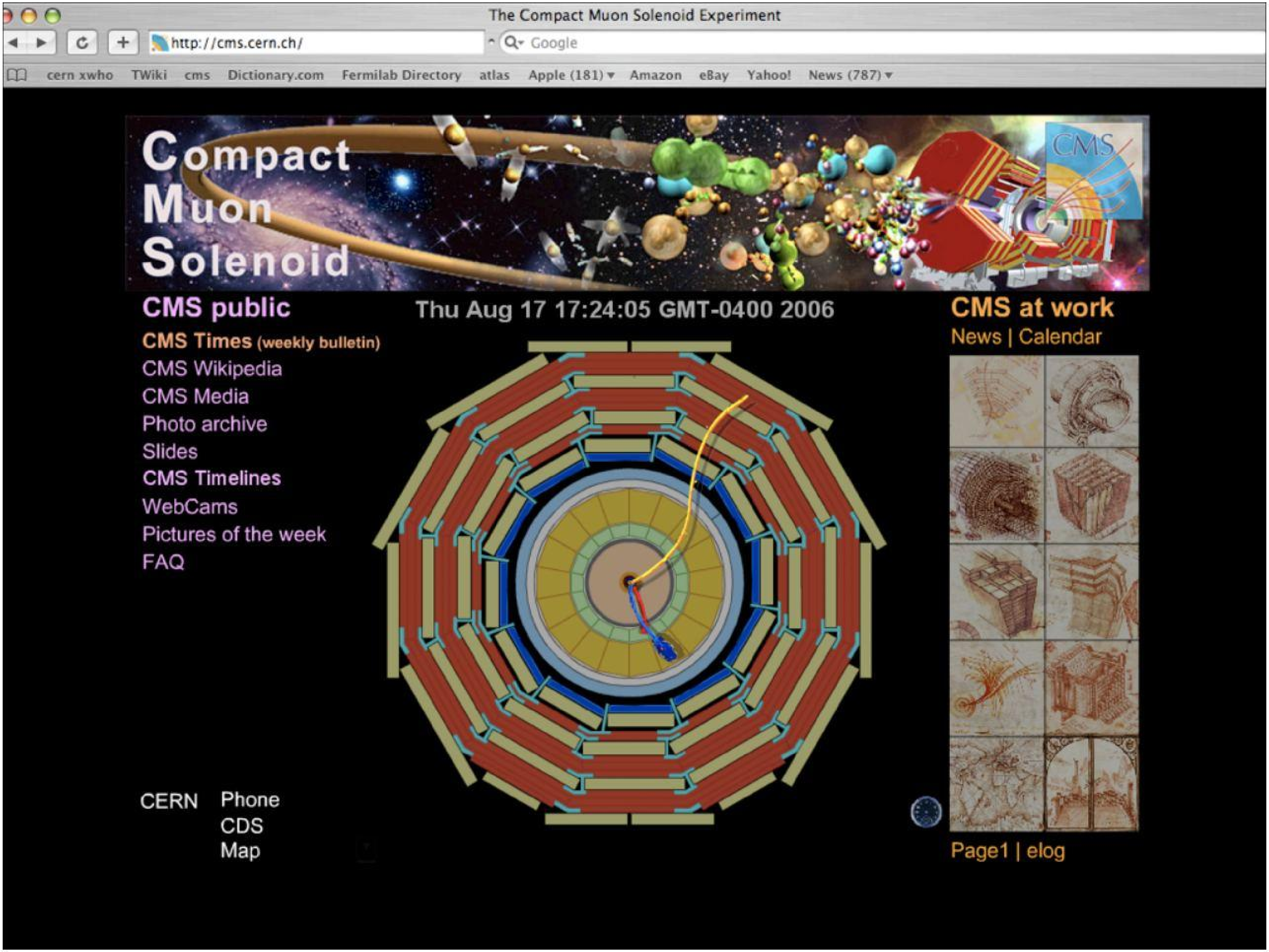
ATLAS



Detector Size Octant Comparison

CMS




The Compact Muon Solenoid Experiment
http://cms.cern.ch/
Google
cern xwho TWiki cms Dictionary.com Fermilab Directory atlas Apple (181) Amazon eBay Yahoo! News (787)
Compact Muon Solenoid
CMS
CMS public
CMS Times (weekly bulletin)
CMS Wikipedia
CMS Media
Photo archive
Slides
CMS Timelines
WebCams
Pictures of the week
FAQ
Thu Aug 17 17:24:05 GMT-0400 2006
CMS at work
News | Calendar
CERN Phone
CDS
Map
Page1 | elog

Atlas Collaboration

http://atlas.web.cern.ch/Atlas/index.html

atlas cern page 1

cern xwho TWiki cms Dictionary.com Fermilab Directory atlas Apple (181) Amazon eBay Yahoo! News (787)

The ATLAS Experiment

CERN | Public | ATLAS Cavern Webcam

Agendas & Minutes | Forthcoming Meetings | Conferences | ATLAS Overview Week, Stockholm

ATLAS Directory 2005
LHC Members

Phones

Search

Services
EDH | CET | CDS | EDMS | CDD | CATIA | Rack | PPT | Simba | HyperNews | TWiki

- ATLAS Secretariat
- Job Vacancies
- ATLAS eNews
- Documentation
- Access & Visits to Point 1
- Safety at Point 1
- CERN, ATLAS Registration
- Visa Requirements for Visitors
- Video Conferencing
- LINKS

Today's meetings Calendar Tomorrow

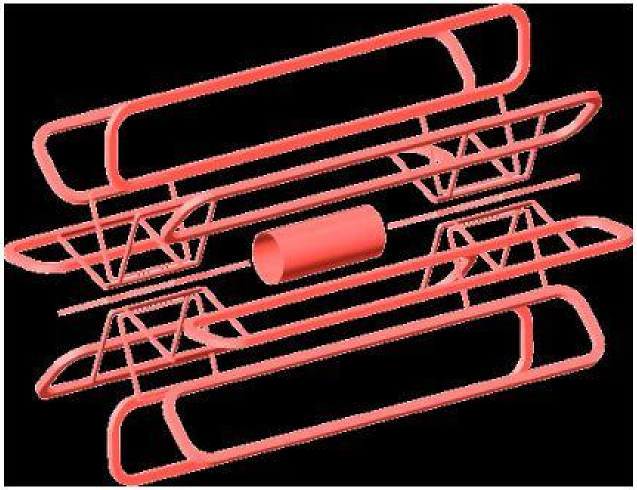
Thursday August 17, 2006
08:30 / ATLAS Meetings / National and institute meetings / United States / US ATLAS Tier2 Meetings / US ATLAS Tier2 Workshop/
10:30 / ATLAS Meetings / Trigger & Data Acquisition & DCS / General ATLAS TDAQ meetings and workshops / pre-series meeting/
15:00 / ATLAS Meetings / Trigger & Data Acquisition & DCS / DAQ/HLT-Infrastructure / Monitoring Working Group/
15:00 / ATLAS Meetings / Liquid Argon Calorimeter / Combined Beam Tests / CBT-Barrel / LARG-H8 analysis meeting/40-4-C01
16:00 / ATLAS Meetings / Tile Calorimeter / commissioning / TileCal Commissioning/40-RC-10
17:00 / ATLAS Meetings / Liquid Argon Calorimeter / Commissioning Phase 3 / BA/EC P3C Meetings / End-cap Phase 3 Commissioning / Endcap commissioning analysis meeting/

ATLAS Organisation
| Management | Executive Board | Collaboration Board | Institutions | Publications Committee | Speakers Committee
| Operation Model working documents |

Coordination	Systems	Working Groups
Installation & Commissioning TMB, Commissioning, Installation, Counting Room, ECR, Electronics, Cooling & Gas, Cabling, Action List **Computing** Sitemap, Beginner's Workbook, Wiki, Bug Report **Physics** Working Groups, Software, Validation	Inner Detector, Magnets, LArg Calorimeter, Tile Calorimeter, Muon Spectrometer, Trigger/DAQ/DCS, Shieldings&Radiation	Magnetic Field, Luminosity & Forward Physics, High Luminosity Upgrades, Education/Outreach

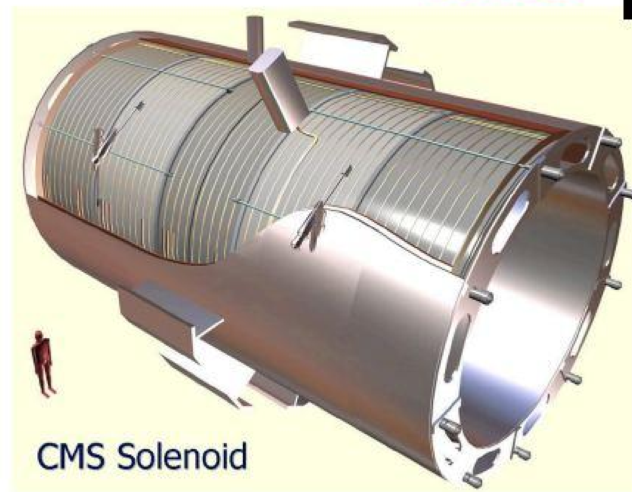
Magnet

ATLAS

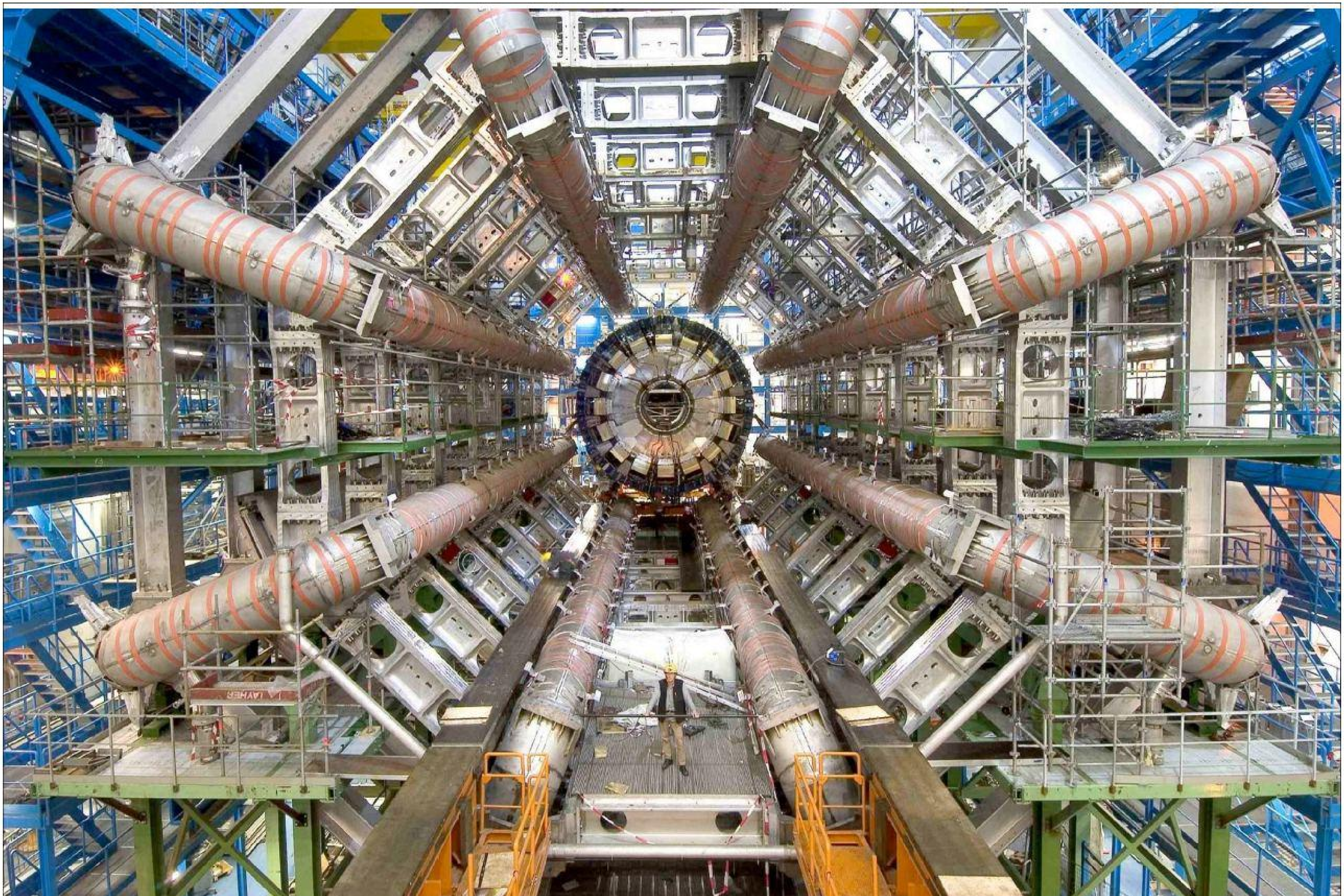


barrel toroid	length	25 m
	outer diameter	20.1 m
	peak field	4 T
	current	20.5 kA
endcap toroids	length	5 m
	outer diameter	10.7 m
	peak field	4 T
	current	20.5 kA
solenoid	length	5.3 m
	radius	1.2 m
	field	2 T
	current	7.6 kA
	stored energy (total)	1.6 GJ
	superconductor length	78 km

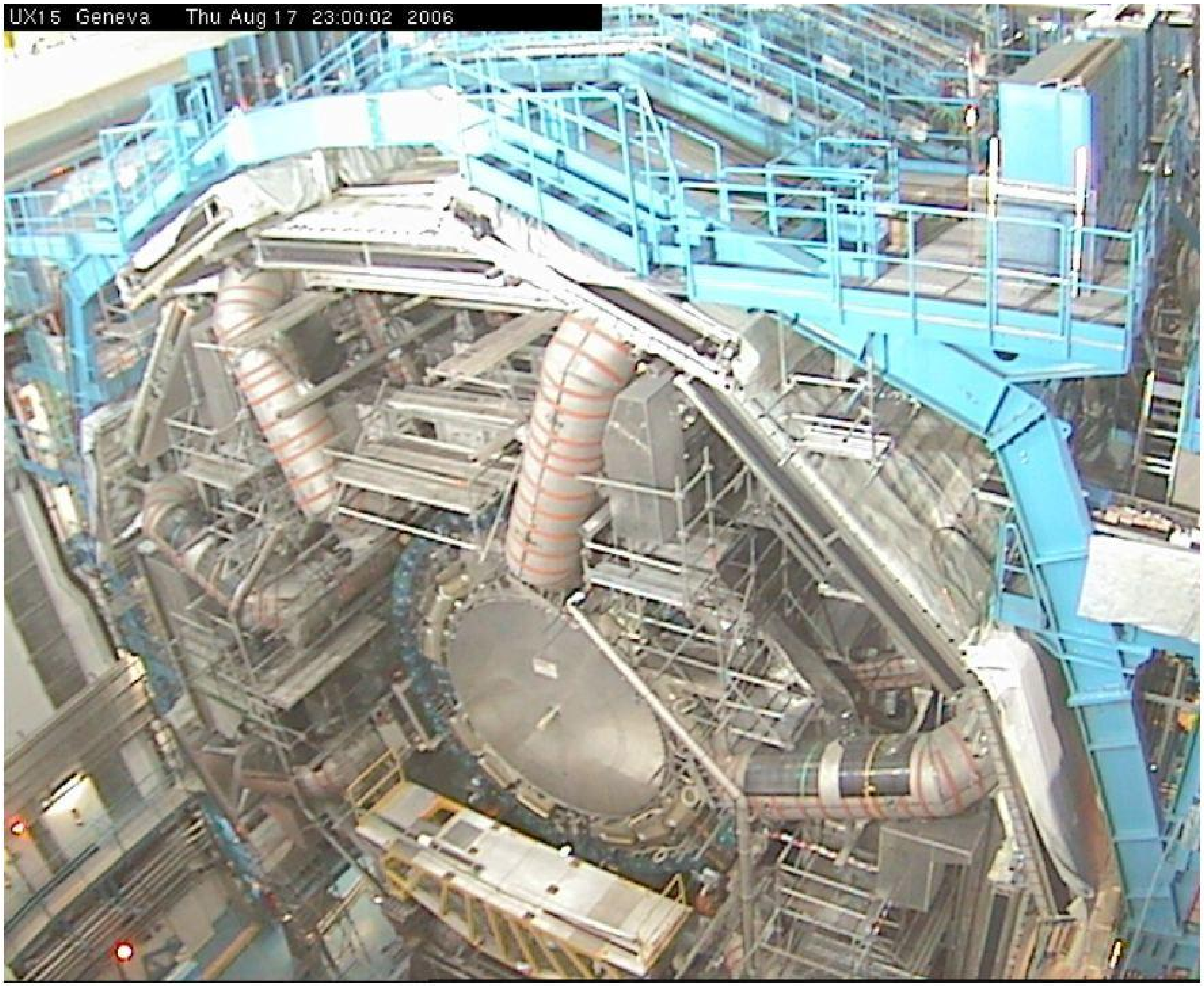
CMS



length	13 m
diameter	5.9 m
coil turns (4 layers)	2112
superconductor length	43 km
current	20 kA
field	4 T
length	13 m
inductance	12.6 H
stored energy	2.5 GJ



Multiple webcams for real-time viewing



CMS Magnet History

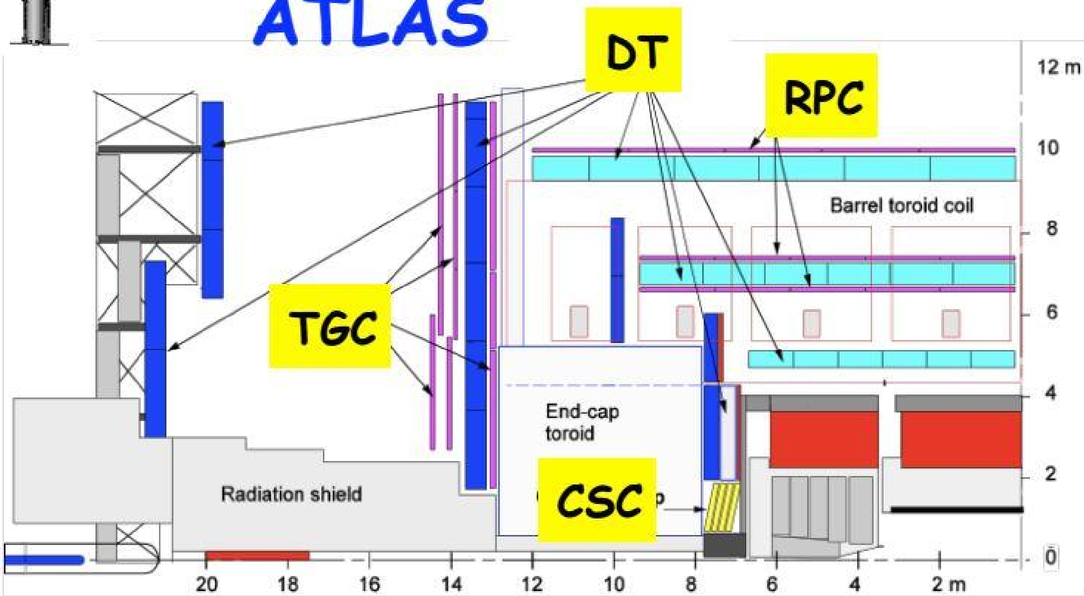
http://cmsdaq.cern.ch/cmsmon/cmsdb/servlet/GenericQuery?DB=omds&SCHEMA=DCS_ENVIRONMENT&TABLE=CMSFWMAGNET2DCS&SELECT_CHANGE_DATE=on&ORDER_CHANGE_DATE=1&SELECT_MAGNET_CURRENT=on&SUBMIT=SubmitQuery

	17554.000
2006.08.17 13:25:21	
	17548.000
2006.08.17 13:25:28	
	17554.000
2006.08.17 14:03:44	
	17548.000
2006.08.17 14:03:54	
	17430.000
2006.08.17 14:28:03	
	17340.000
2006.08.17 14:28:03	
	null
2006.08.17 14:28:06	
	null
2006.08.17 14:28:11	
	17038.000
2006.08.17 14:28:11	
	16988.000
2006.08.17 14:28:1	

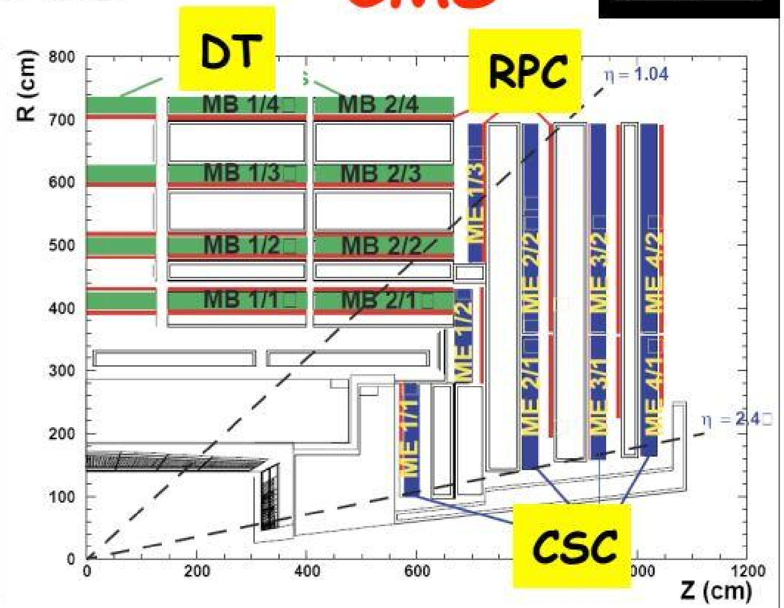
17.5 kA, 3.6 T

Muons

ATLAS



CMS



Res. at 100 GeV

$$\frac{\Delta p_T}{p_T} = 0.2 - 1\%$$

"stand alone"

DT = drift tube
RPC = resistive plate chamber
CSC = cathode strip chamber
TGC = thin gap chamber

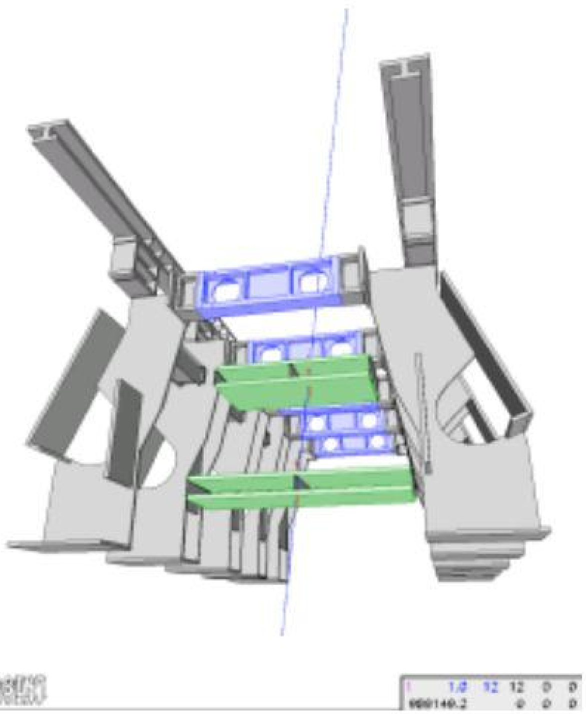
Res. at 100 GeV

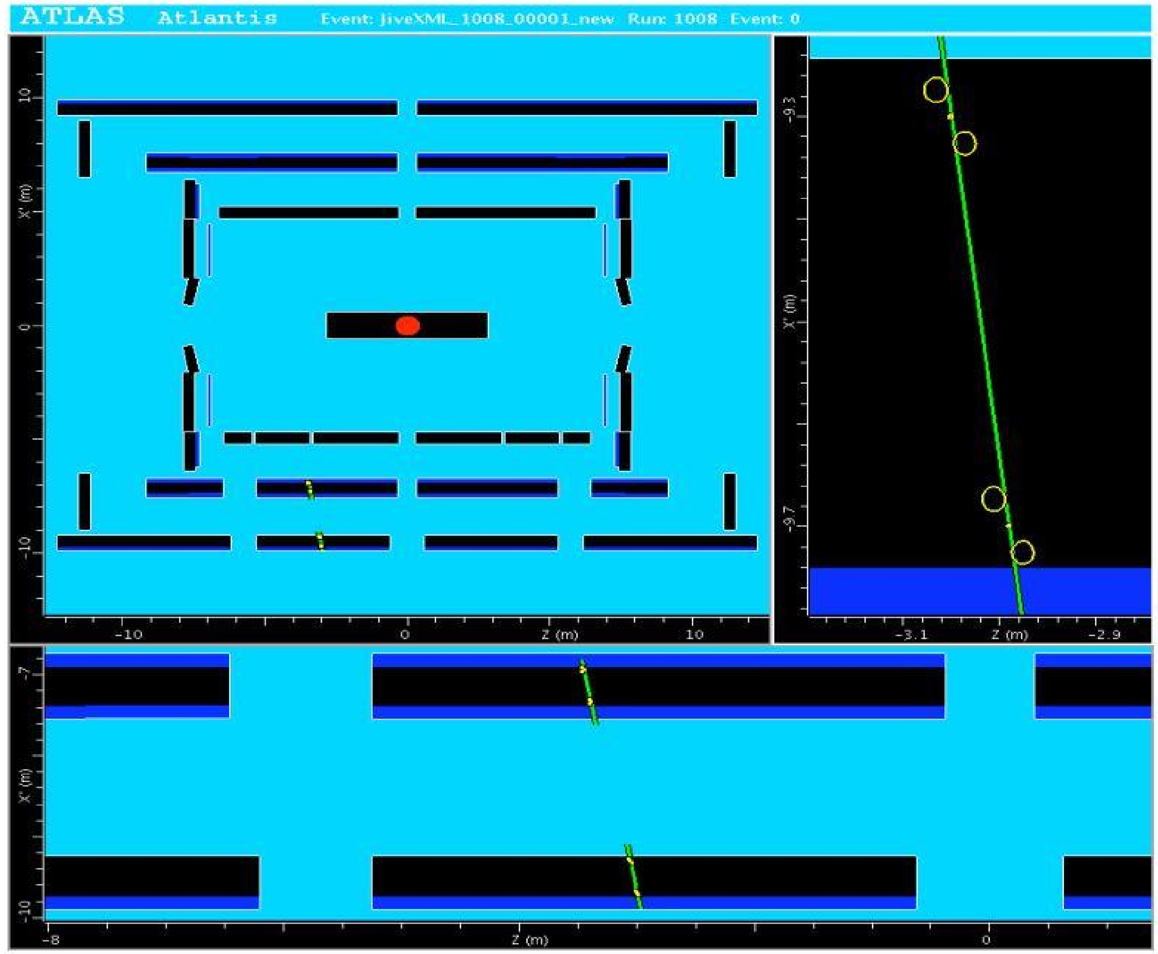
$$\frac{\Delta p_T}{p_T} = 0.6 - 1.7\%$$

(2-4% "stand alone")

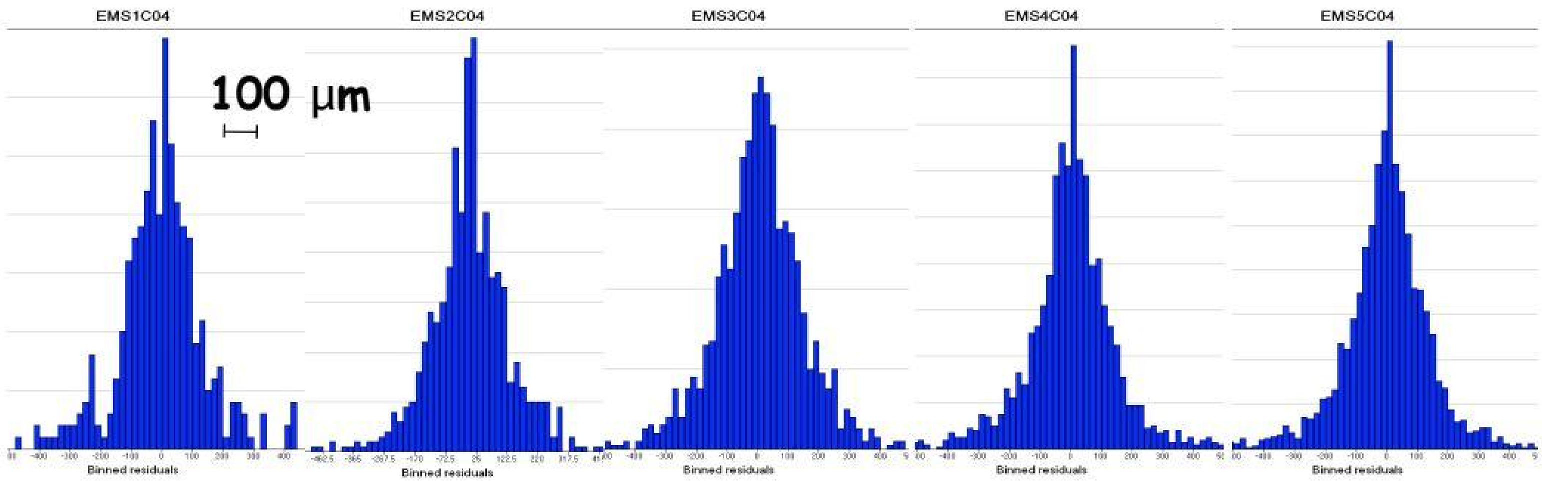
	rapidity	*stations*	*trigger*
ATLAS barrel	$\eta < 1.0$	3, 50 μm	3 RPC
endcap	$1 < \lvert\eta\rvert < 2.7$	3, 60 μm	3 TGC
CMS barrel	$\eta < 1.3$	4, 100 μm	4 DT+6 RPC
endcap	$1 < \lvert\eta\rvert < 2.4$	4, 100 μm	4 RPC

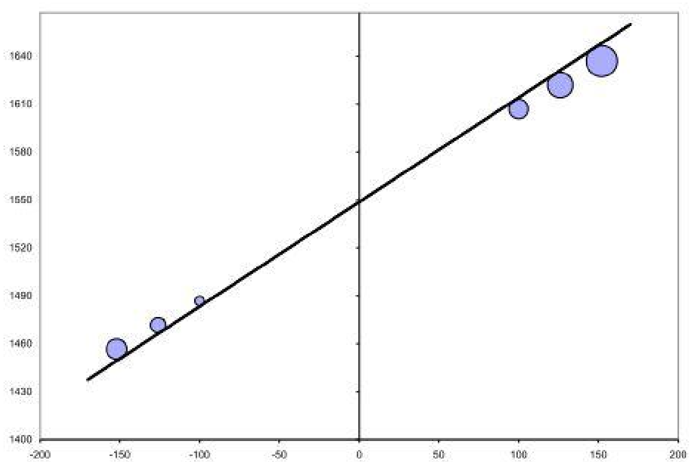
Cosmic Rays in ATLAS

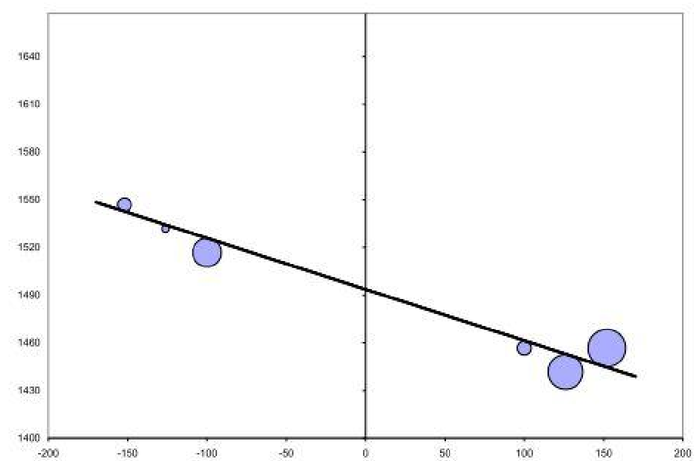




ATLAS Endcap Cosmic Ray Residuals for Small Wheel Sector C04



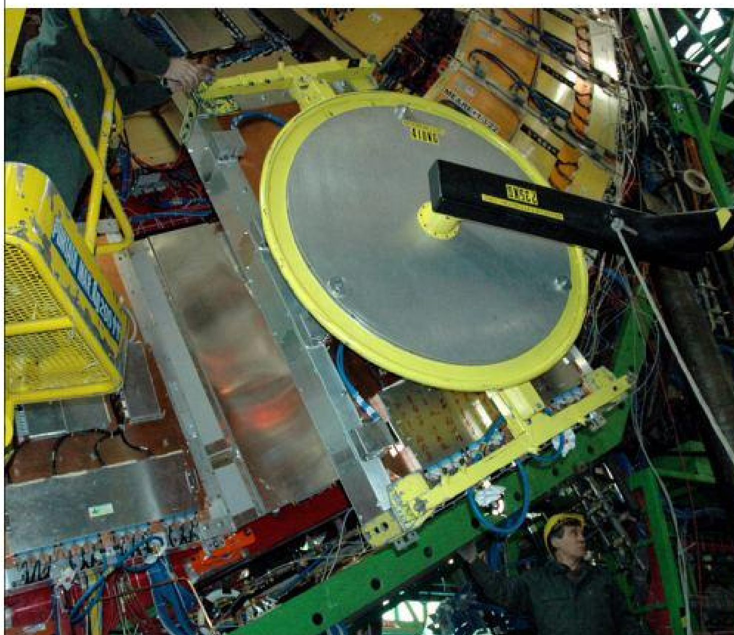


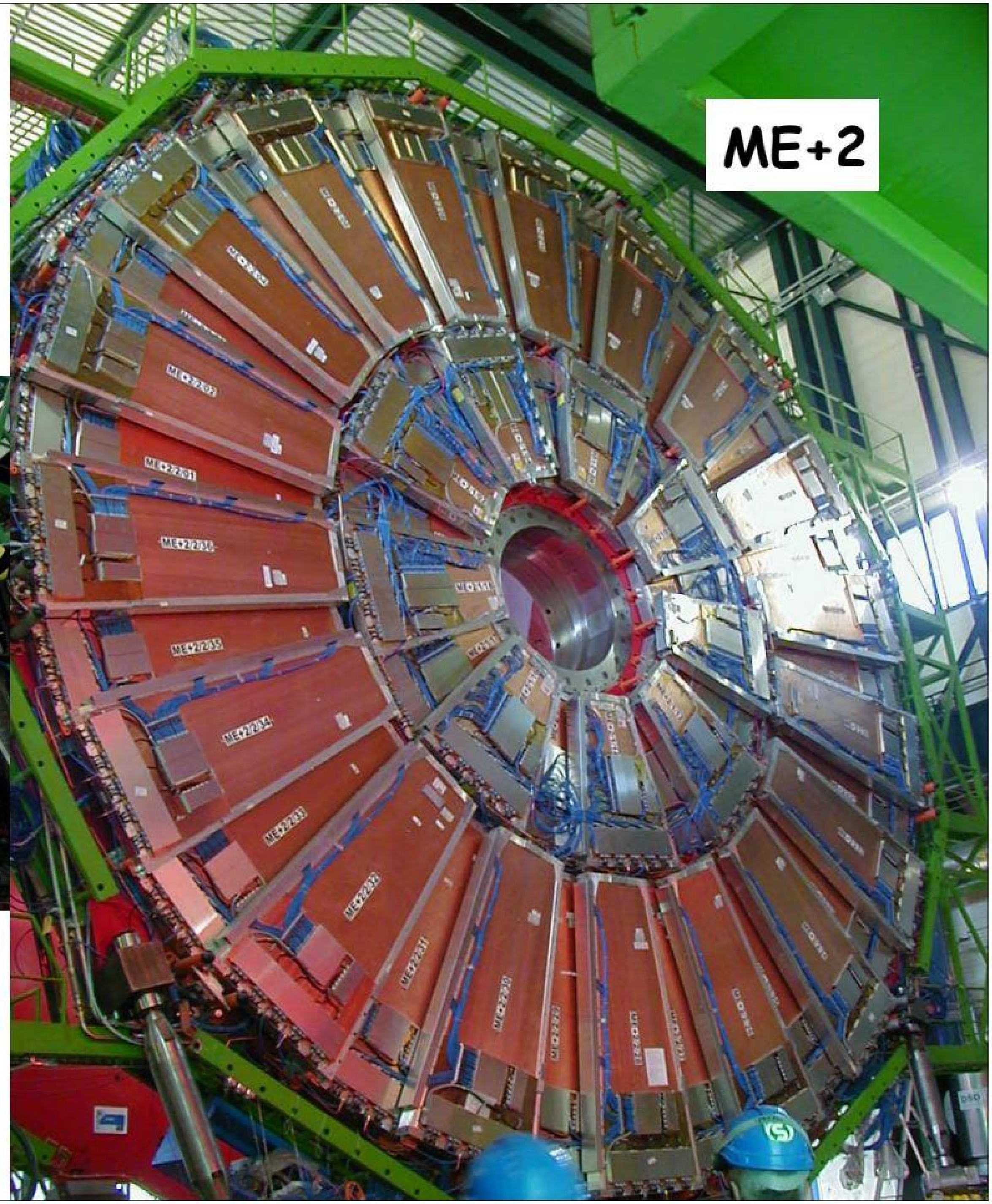


CMS

Muon Endcap

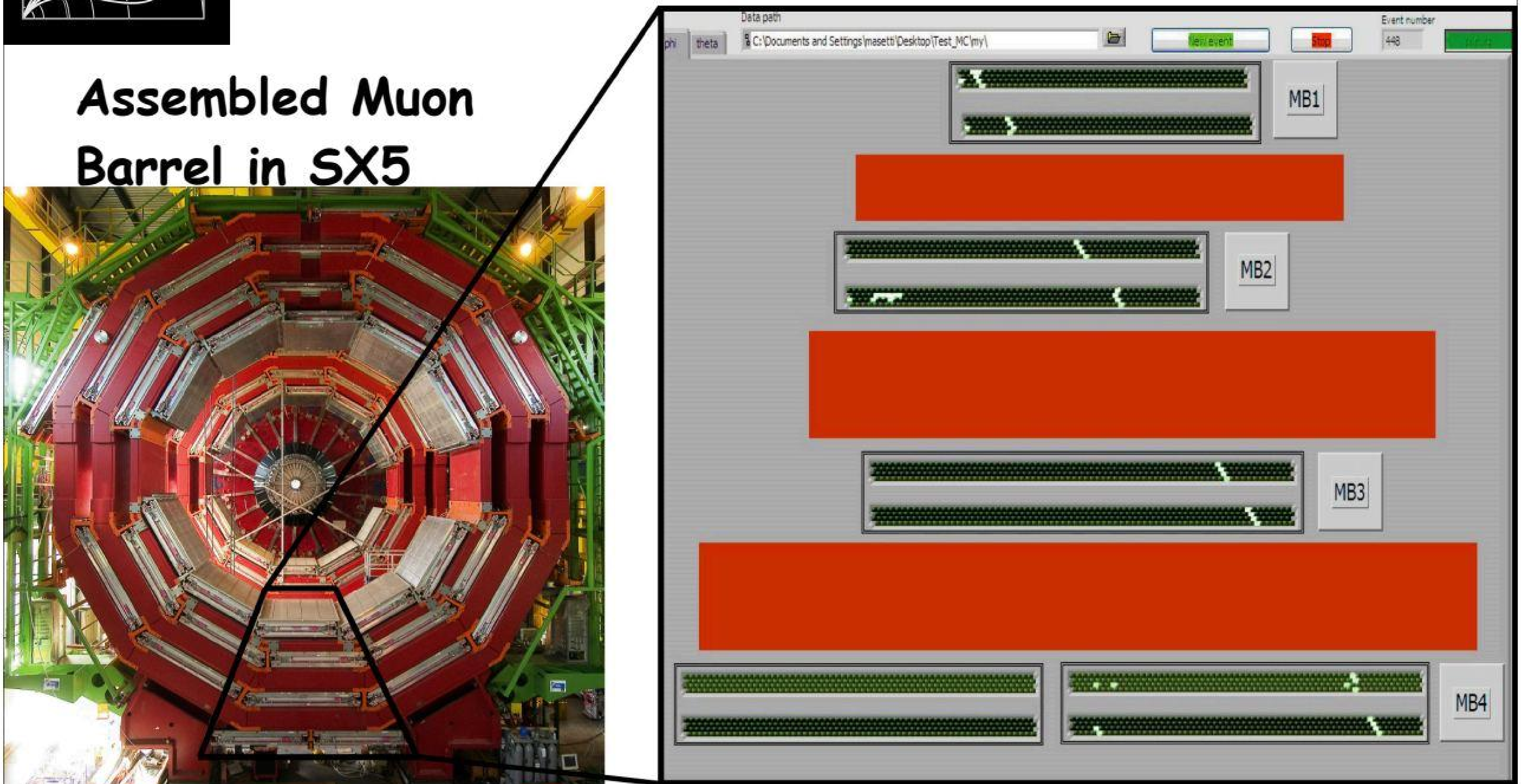
cathode-strip chambers



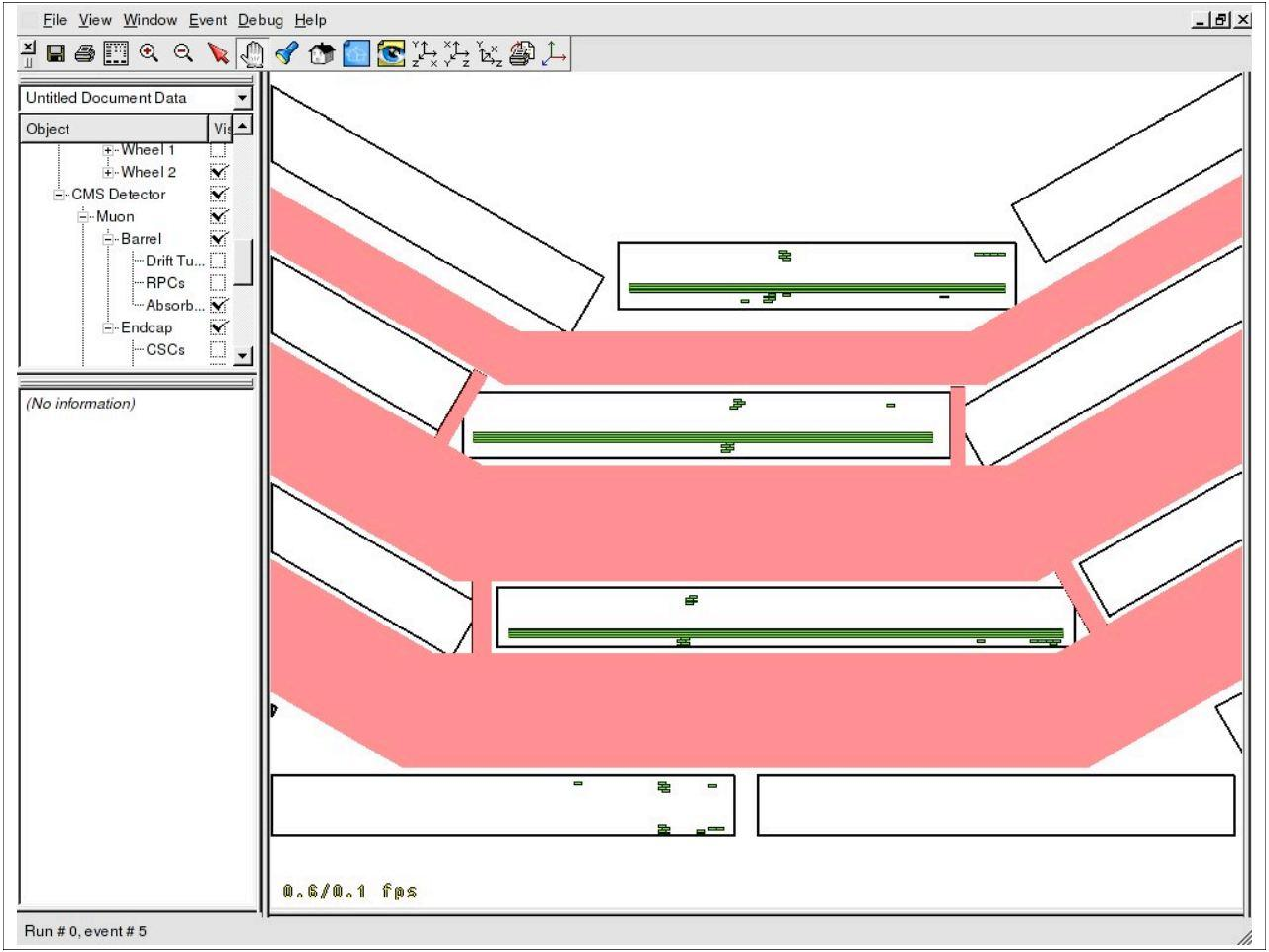


Cosmic Rays in CMS

Assembled Muon Barrel in SX5

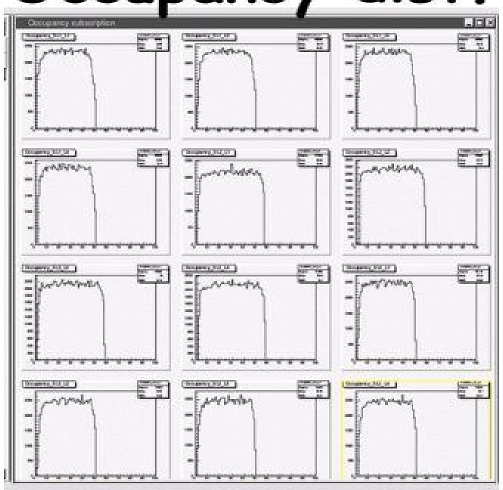


(Dec. 15, 2005) Dan Green: "Wow - we may have an experiment..."


File View Window Event Debug Help
Untitled Document Data
Object
Vis
Wheel 1
Wheel 2
CMS Detector
Muon
Barrel
Drift Tu...
RPCs
Absorb...
Endcap
CSCs
(No information)
0.6/0.1 fps
Run # 0, event # 5

CMS DT Commisioning with Cosmic Rays

Occupancy dist.



Sector commissioning

autotriggering

Sector test

Read with local DAQ

Sector test-regional

Triggering with TTC

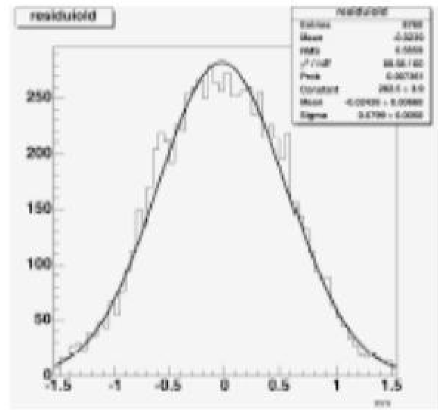
3-Sector test

Cosmic trigger 3 sectors

FED intgration

Autotriggering has random time distribution

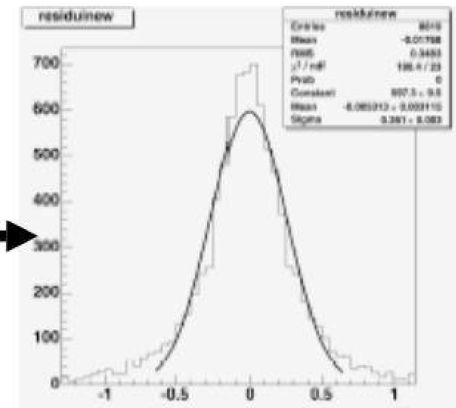
No time corr.



layer	mean [μm]	sigma [μm]
1	-8±15	518±7
2	-12±7	546±6
3	-14±7	552±5
4	14±7	537±6
5	-14±6	547±5
6	28±7	559±6
7	-22±7	556±5
8	15±6	526±5

$\sigma_{media_{old}} =$ 543+- 2 ım
mu

Drift time corr.

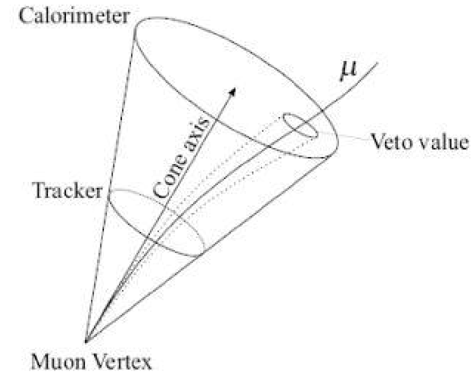


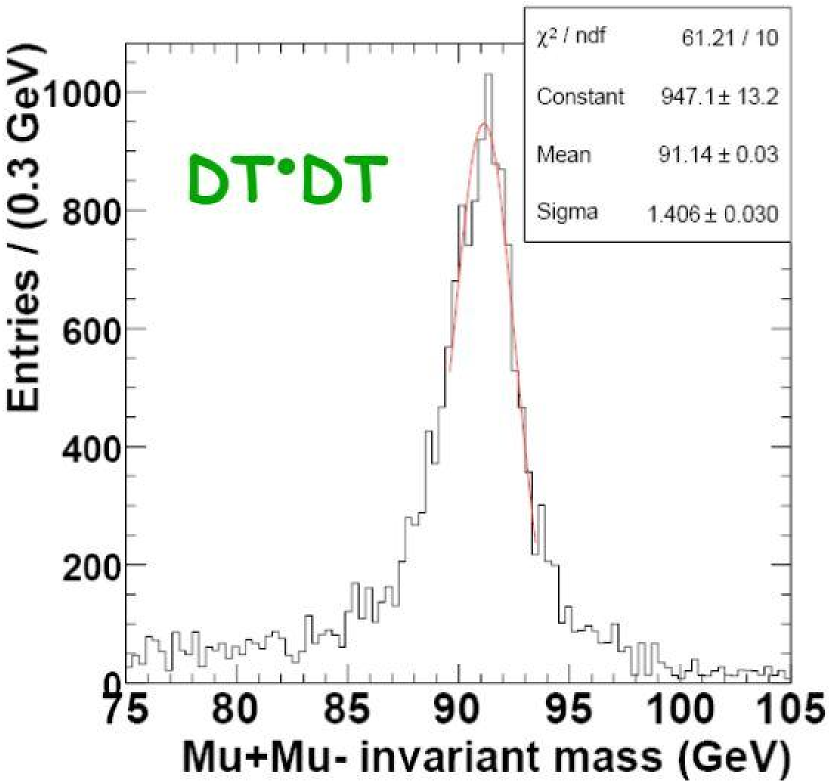
layer	mean [μm]	sigma [μm]
1	-2±3	221±3
2	-16±3	220±3
3	7±3	227±3
4	9±3	239±3
5	-9±3	247±3
6	25±3	235±3
7	-18±3	222±3
8	3±3	244±3

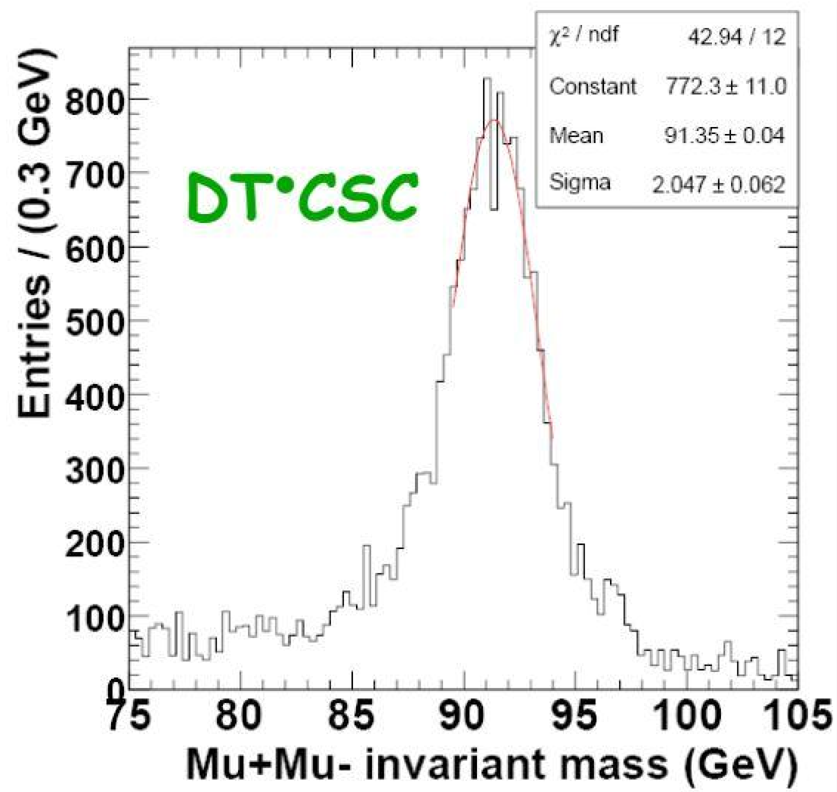
$\sigma_{media_{new}} =$ 232+-2 ım
mu

CMS $\mu^+\mu^-$ mass resolution: 1 day at 2×10^{33} cm^{-2}s^{-1}

2 isolated muons with
$p_T > 20$ GeV/c, 10 GeV/c







CERN/LHCC 2006-001, CMS TDR 8.1, 02 Feb. 2006

Calorimetry

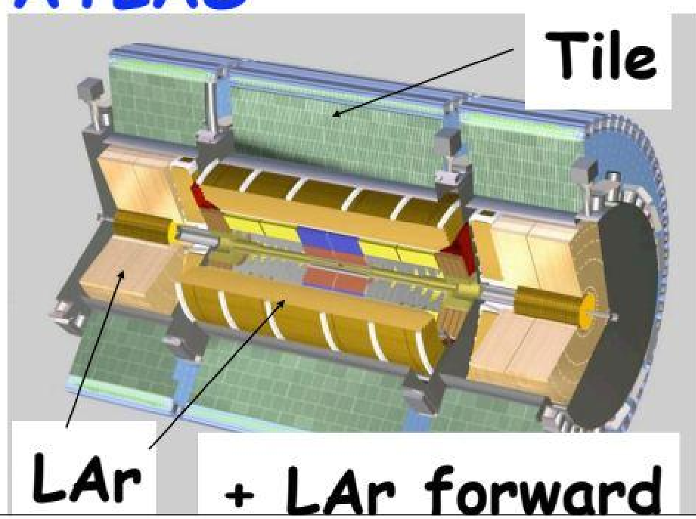
ECAL

	res. @ 50 GeV	material in front	thickness	$\Delta\eta \times \Delta\phi$
ATLAS	1.3%	2-4 χ_0	21-36 χ_0	front 0.003×0.1 middle 0.025×0.025 back 0.05×0.025
CMS	0.8%	0.4-1.3 χ_0	25-27 χ_0	0.0174×0.0174

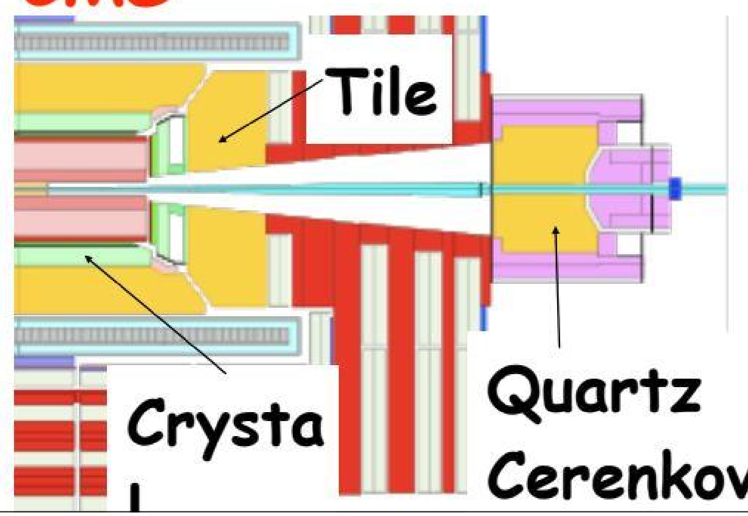
HCAL

	coverage	res. @ 100 GeV	thickness	$\Delta\eta \times \Delta\phi$
ATLAS barrel	$\lvert\eta\rvert < 1.0$	8%	8-10 λ	front 0.1×0.1
extended barrel	$0.8 < \lvert\eta\rvert < 1.7$			back 0.2×0.1
endcap	$1.5 < \lvert\eta\rvert < 3.2$			$0.1\text{-}0.2 \times 0.1$
forward	$3.1 < \lvert\eta\rvert < 4.9$			0.2×0.2
CMS barrel	$\lvert\eta\rvert < 1.4$	10%	11-15 λ	0.087×0.087
endcap	$1.4 < \lvert\eta\rvert < 3.0$			$0.087 \times 0.087\text{-}0.17$
forward	$3.0 < \lvert\eta\rvert < 5.0$	20%		0.17×0.17

ATLAS



CMS

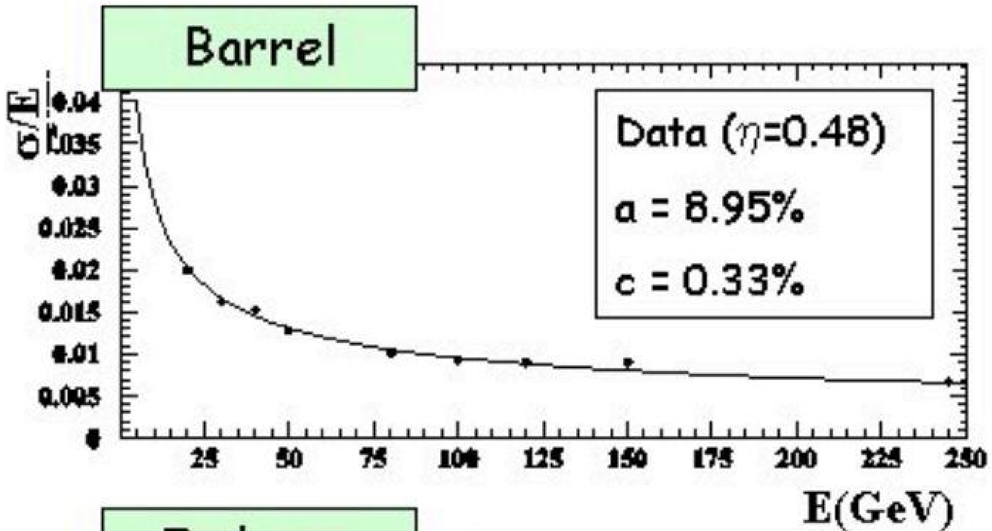


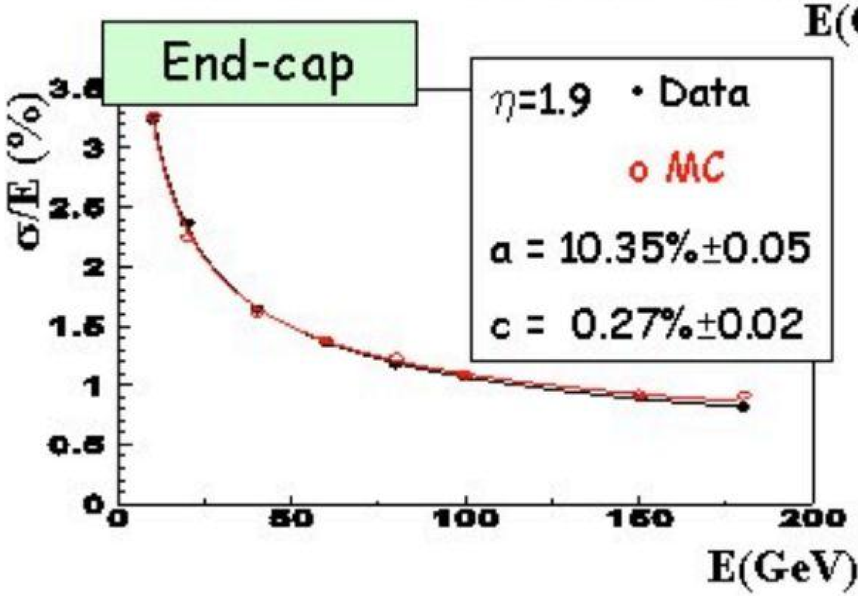
ATLAS ECAL (LAr) Barrel

LAr barrel EM calorimeter module at one of the assembly labs

LAr barrel EM calorimeter after insertion into the cryostat

EM beam test results: Energy resolution





$$\sigma_E/E = a/\sqrt{E} \oplus c \oplus n/E$$

For every tested points:

Barrel	End-cap
a < 10%	a < 12.5%
c < 0.4%	c < 0.5%

- Within specifications
- Good agreement with MC

Impact on Higgs mass resolution

Simulations, m_H=130 GeV

✓ $H \rightarrow \gamma\gamma$

Resolution: 1% (low lum)

1.2% (high lum)

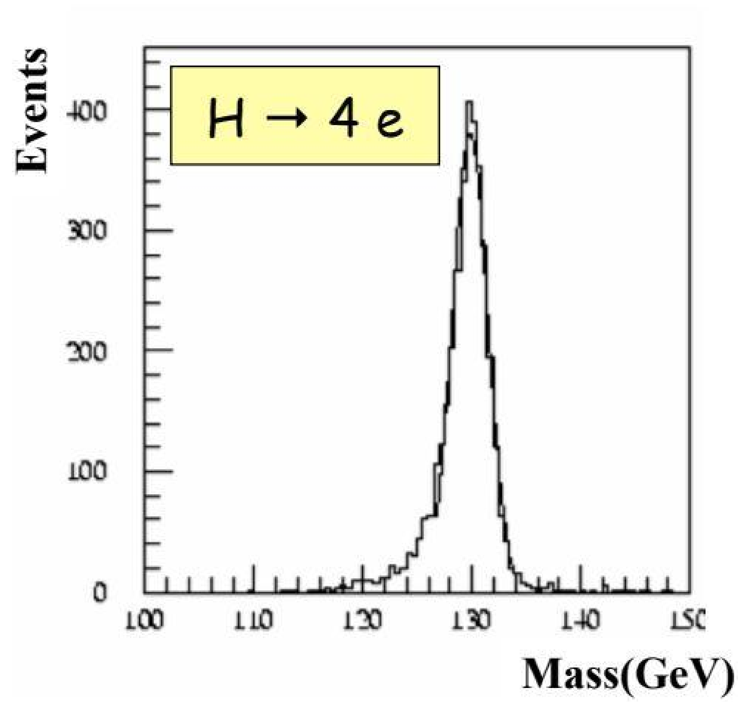
Acceptance: 80% within ±1.4 σ

✓ $H \rightarrow 4e$

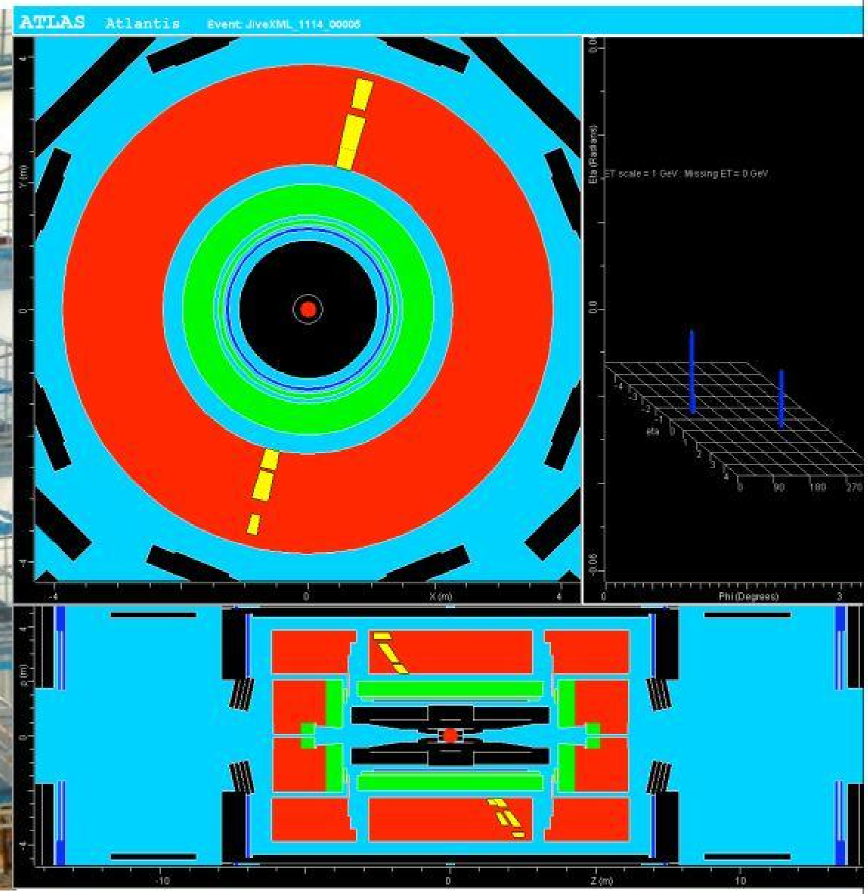
Resolution: 1.2% (low lum)

1.4% (high lum)

Acceptance: 84% within ±2 σ



ATLAS HCAL (Tile) + ECAL (LAr) Barrel

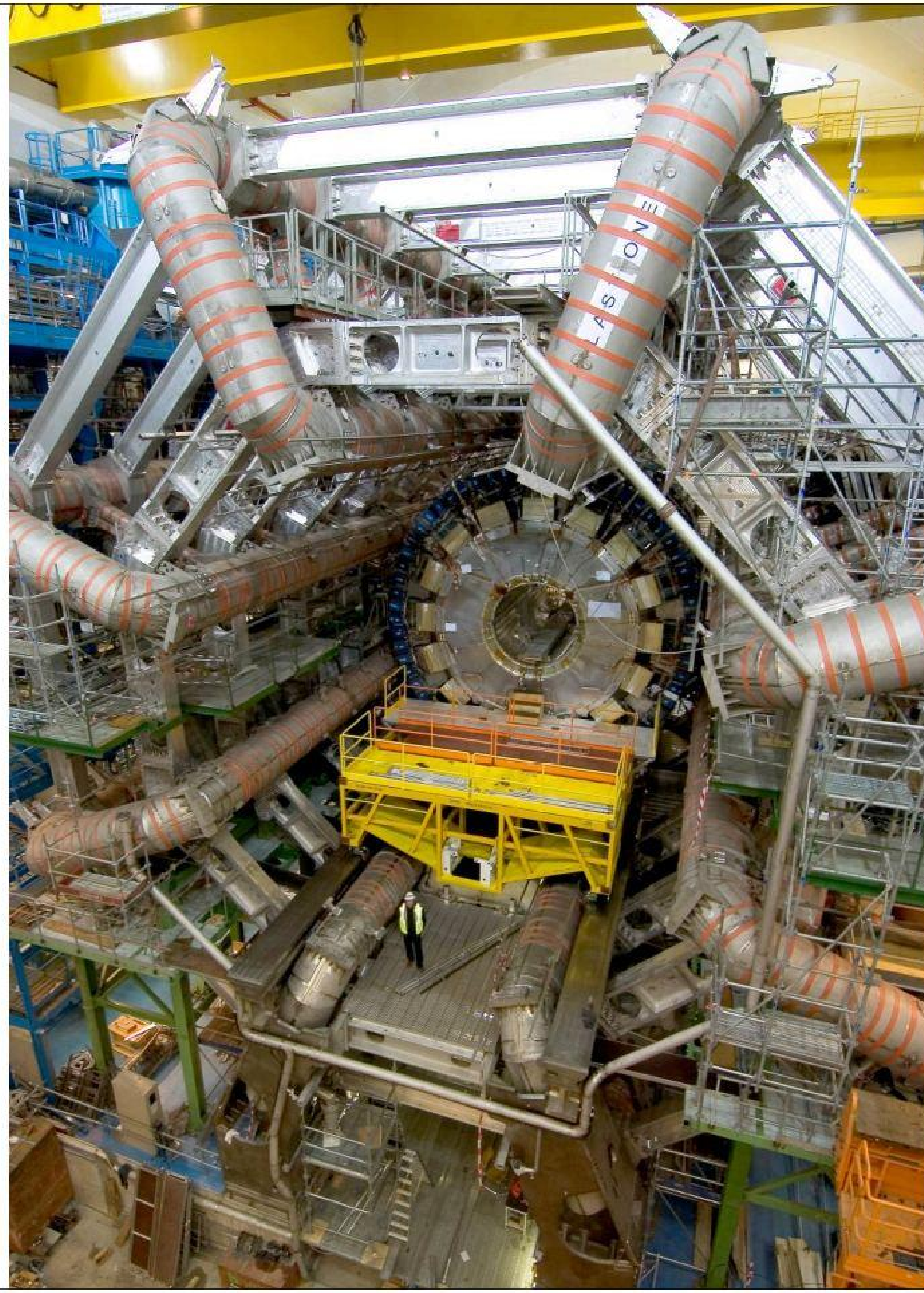


Cosmic ray in the tiles

ATLAS ECAL+HCAL Barrel

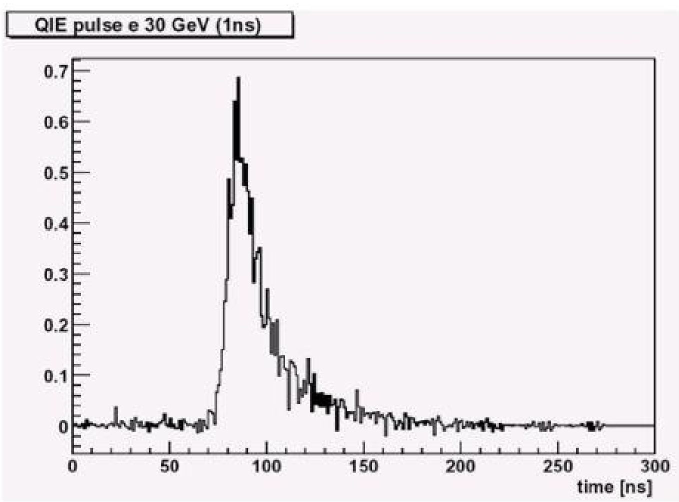
ATLAS

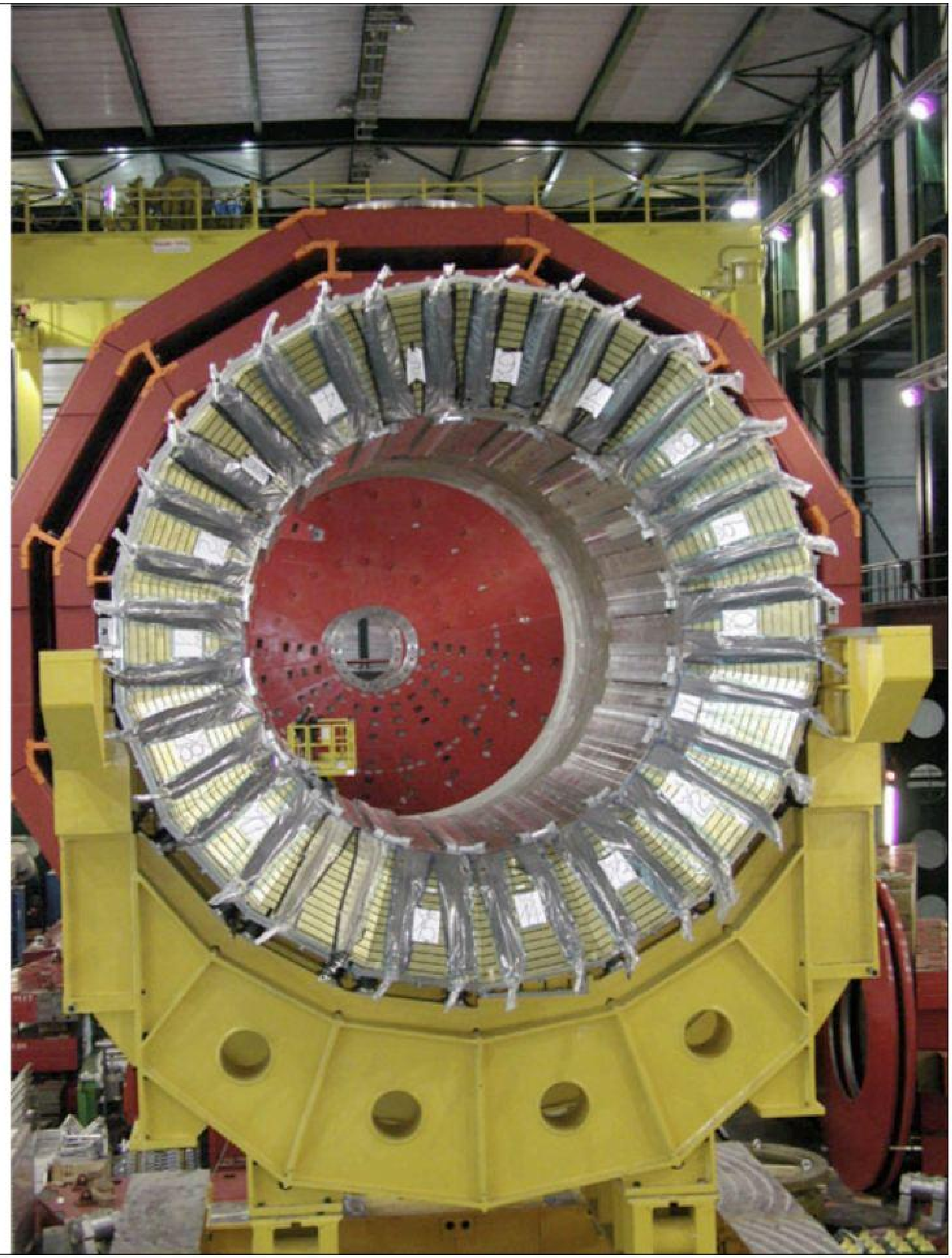
another view



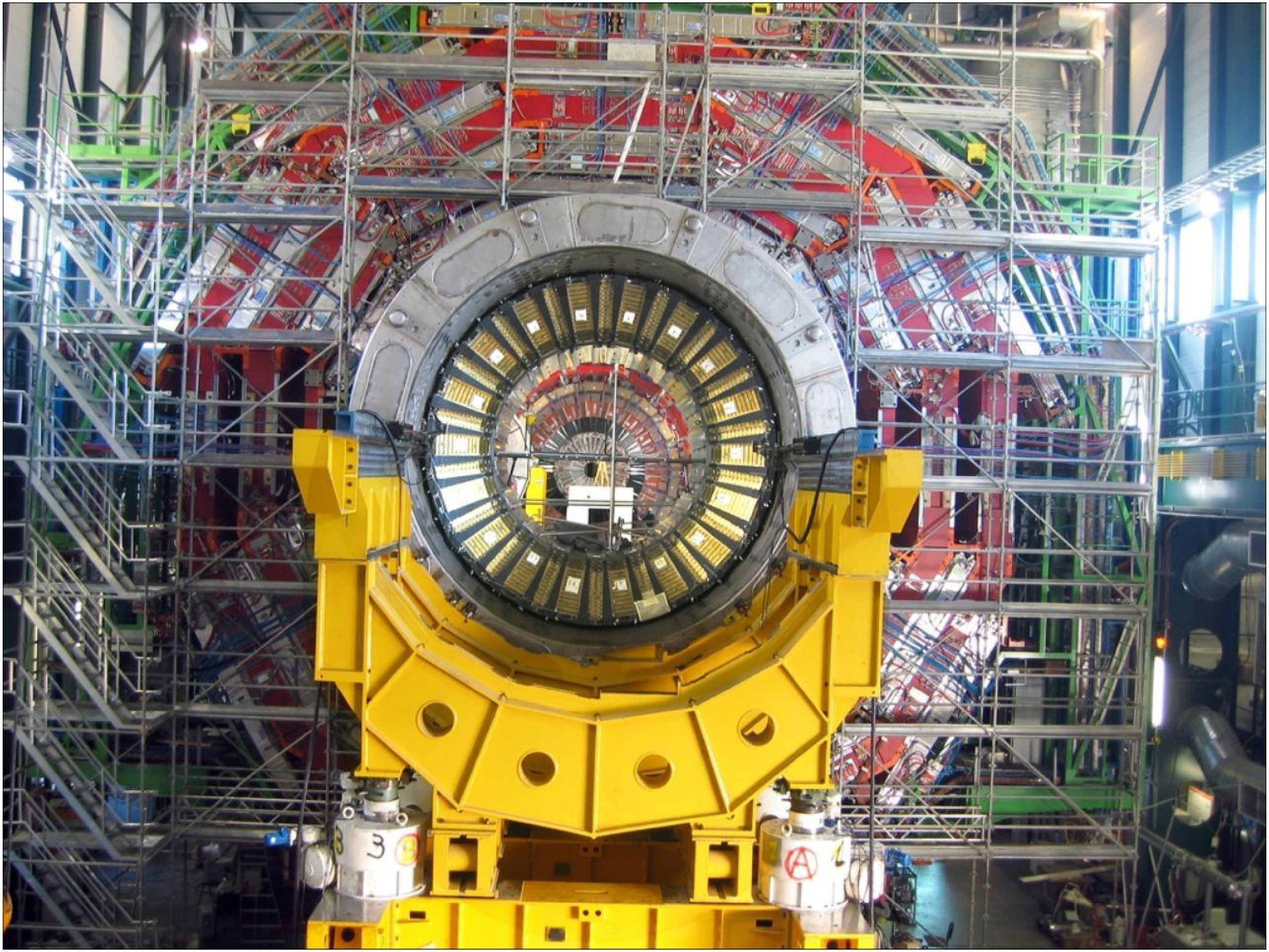
CMS
HCAL Barrel

All components of HCAL have been extensively tested in test beam and surface hall SX5



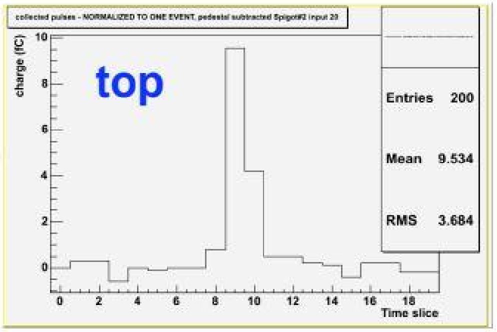


CMS
HCAL Endcap

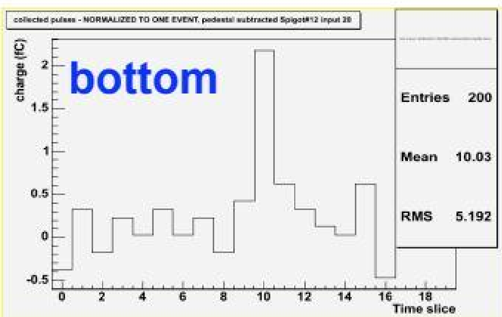


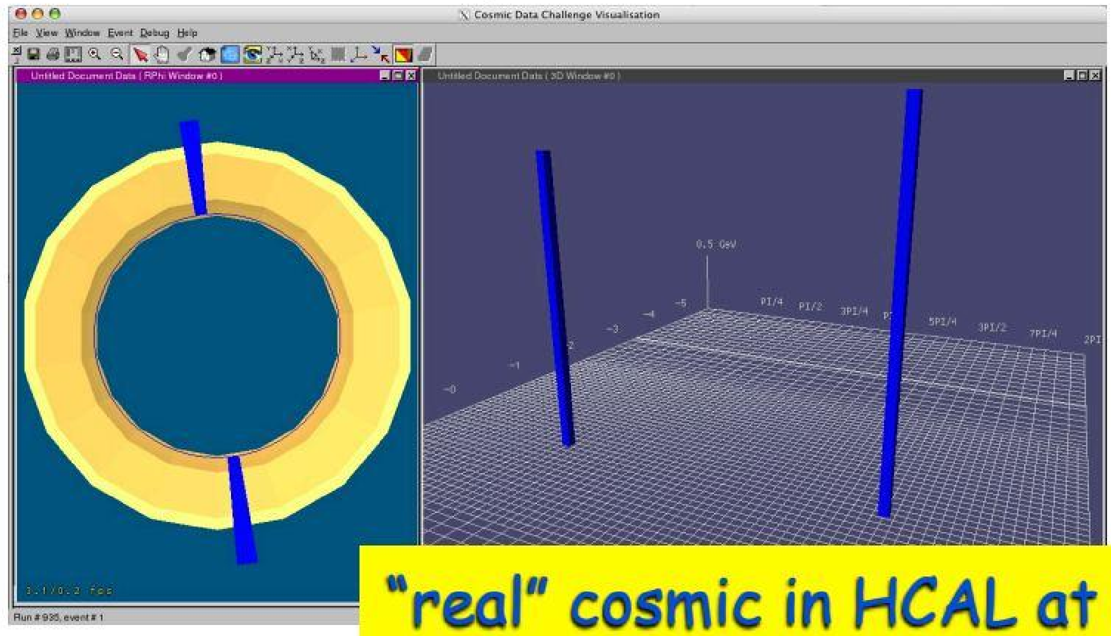
CMS HCAL: Cosmic Rays at SX5

Q (fC)



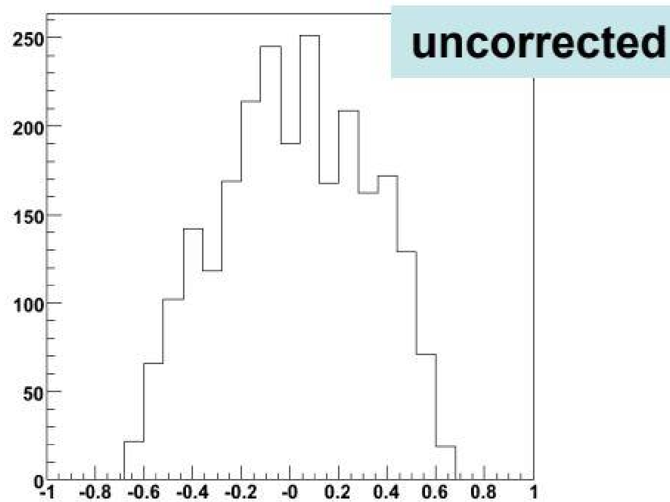
Time (25 ns)





"real" cosmic in HCAL at SX5

$$\frac{dN}{d\cos\theta}$$



$\cos\theta$

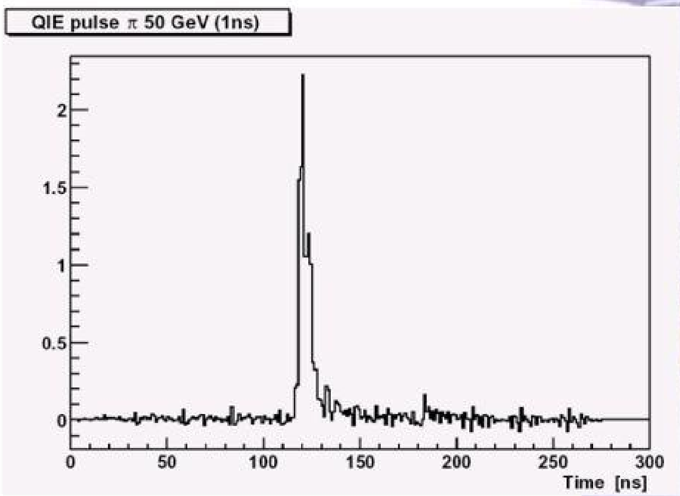
Note:

1) time shift of ½ bin due to transit time of cosmic ray.

2) Energy loss.

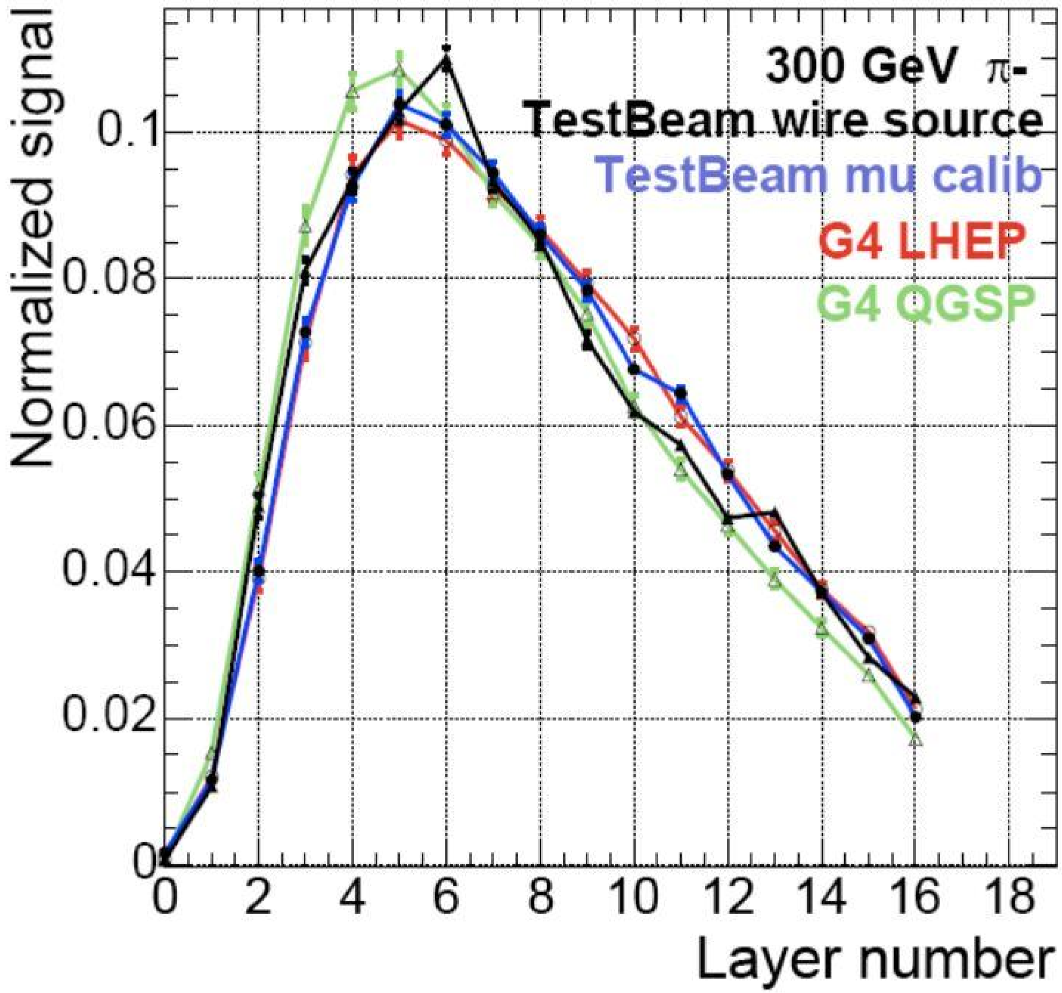
Real-time data access:
http://cmsmoe3.cern.ch:40000

CMS HCAL Forward



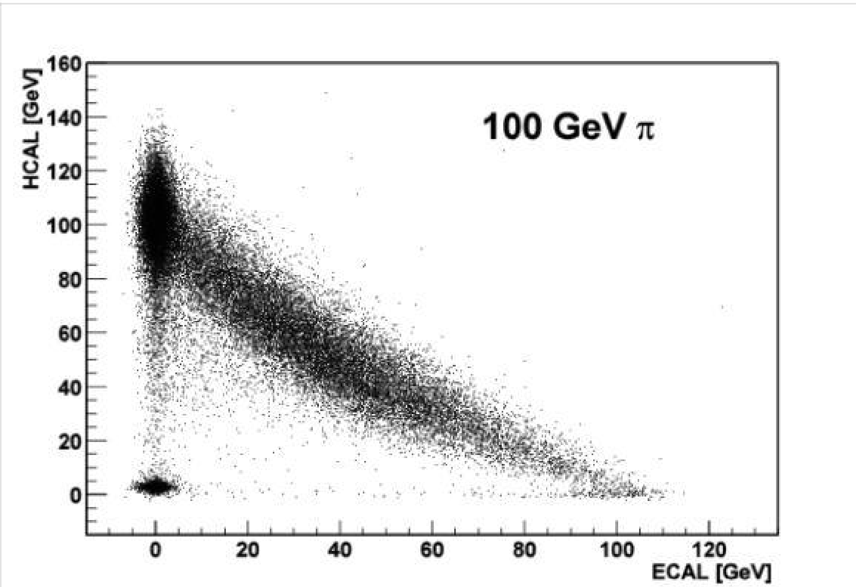
First subdetector to be lowered into pit

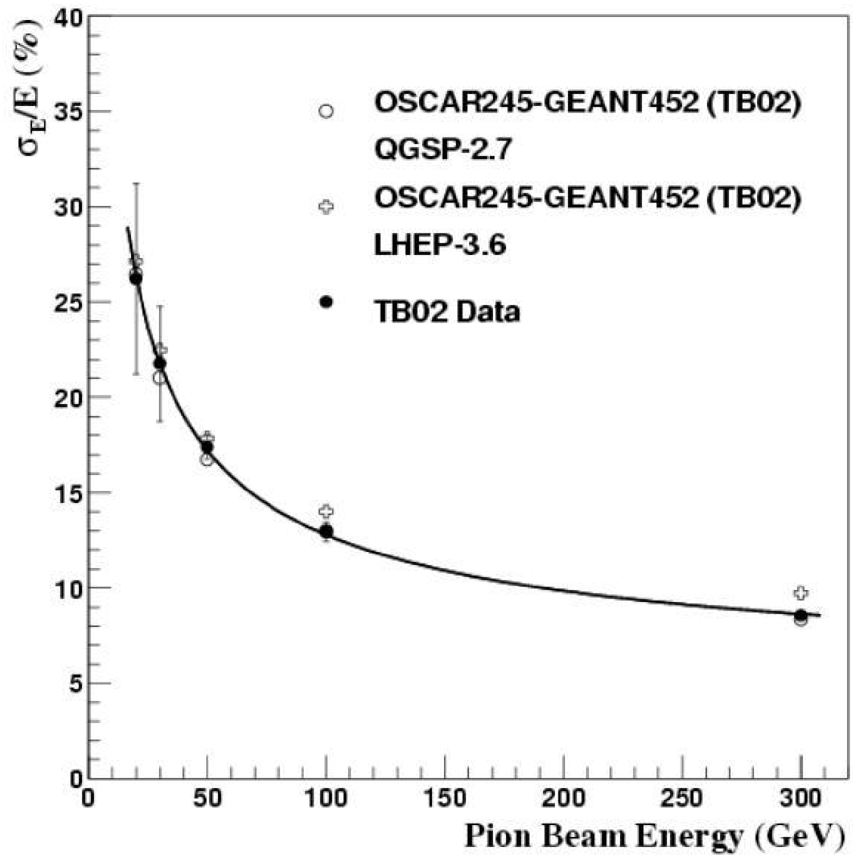
CMS HCAL longitudinal shower profile



CERN/LHCC 2006-001, CMS TDR 8.1, 02 Feb. 2006

CMS ECAL+HCAL Energy Resolution

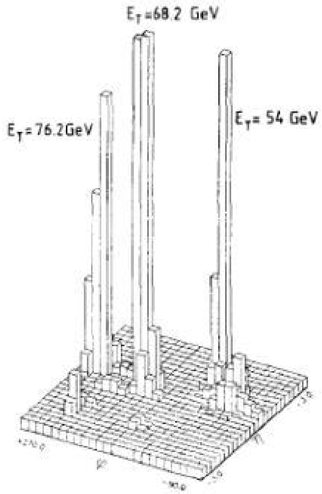




Jets at the LHC

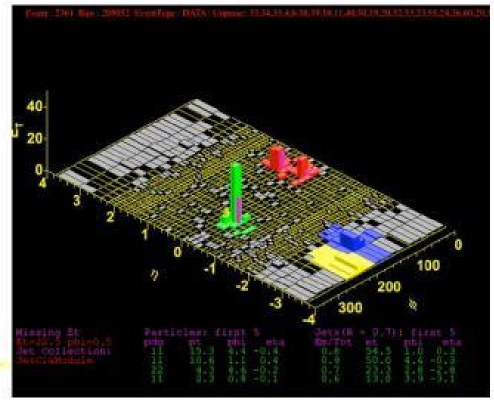
CERN $\bar{p}p$

$\sqrt{s} = 0.540$ TeV



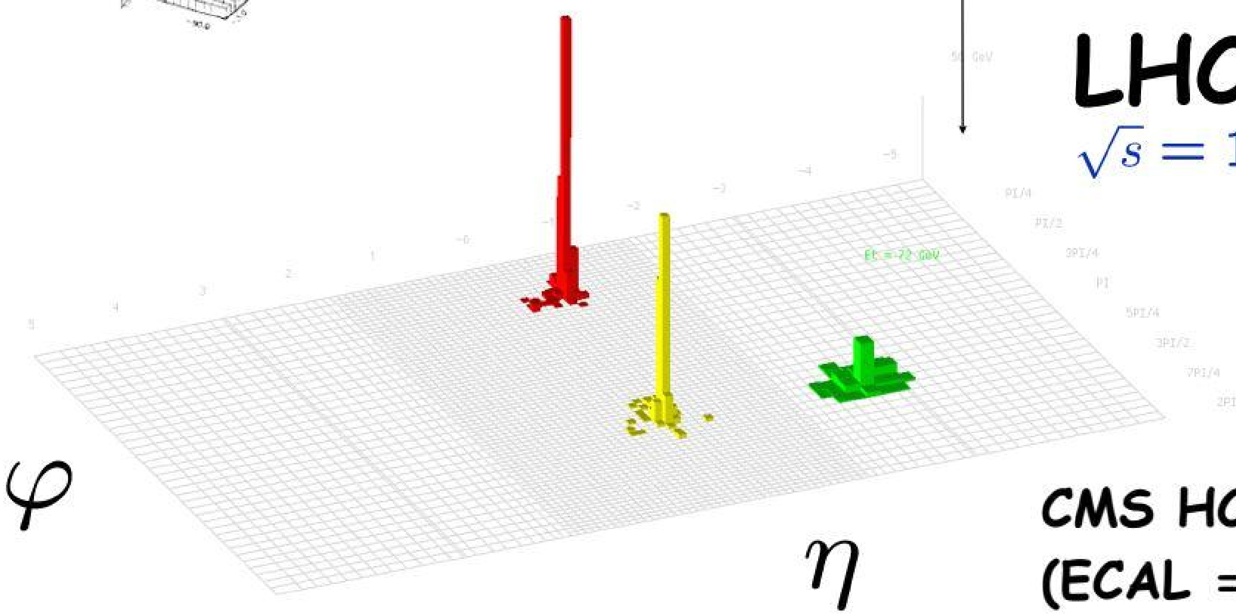
Tevatron $\bar{p}p$

$\sqrt{s} = 2$ TeV



LHC pp

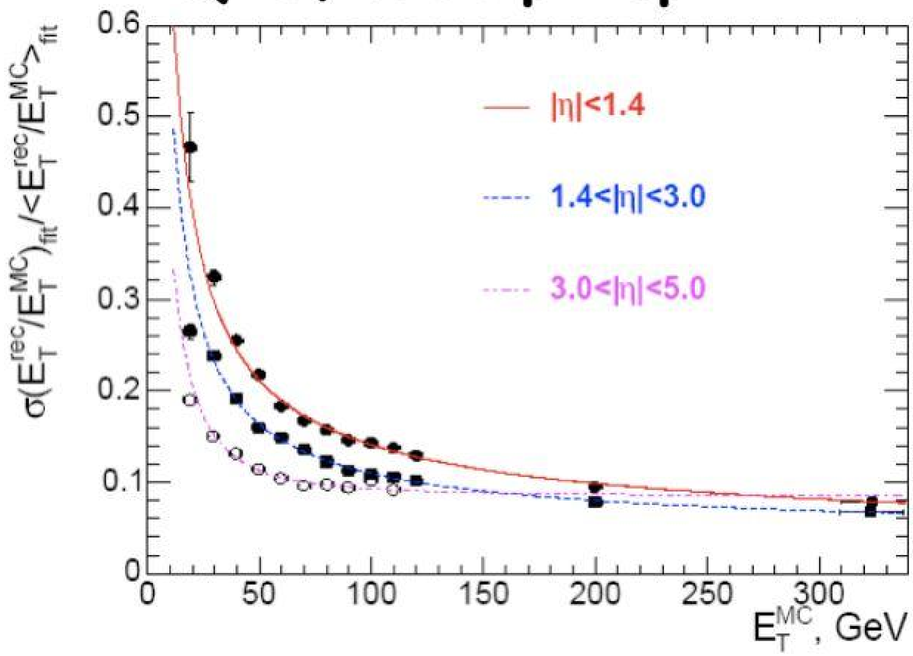
$\sqrt{s} = 14$ TeV



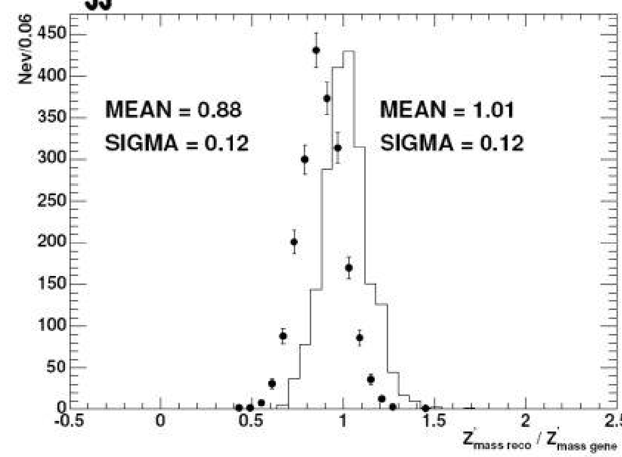
CMS HCAL towers
(ECAL = x5 granularity)

Jet resolution

QCD, with pileup $\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

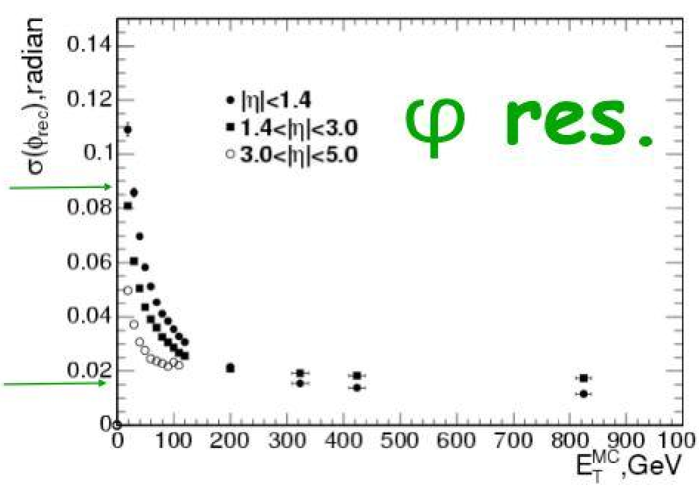


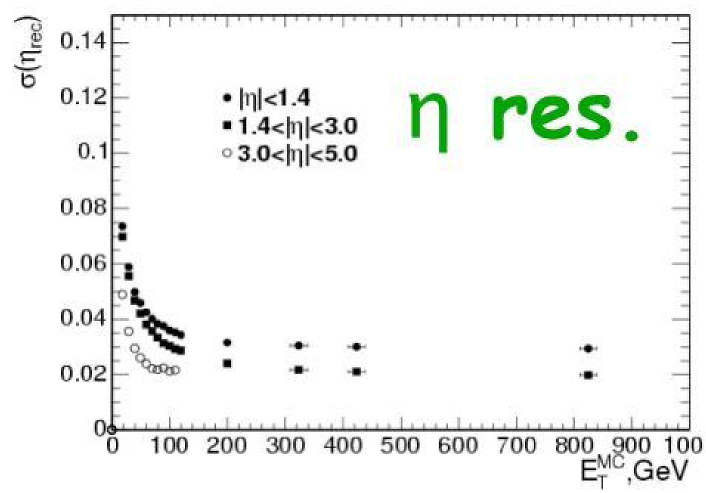
m_{jj} res. at 120 GeV/c^2



HCAL tile

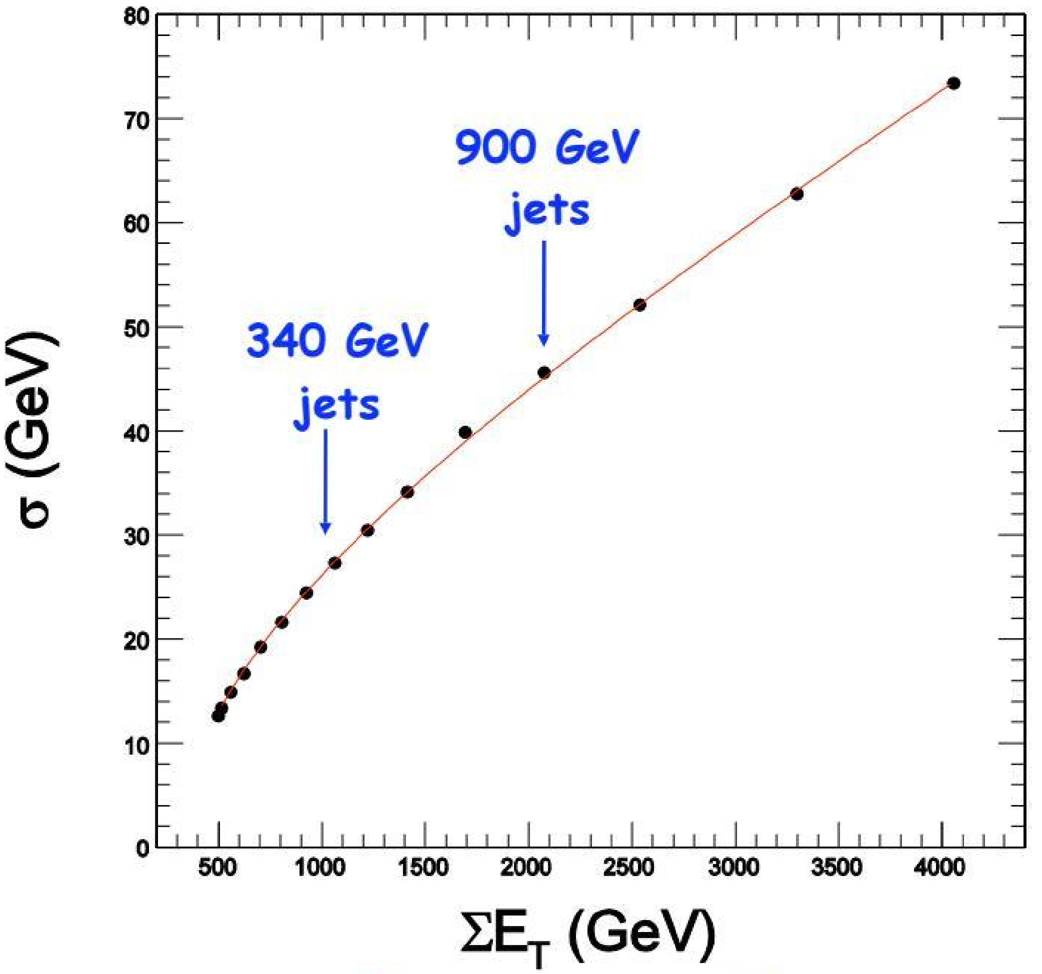
crystal





E_T^{miss} resolution

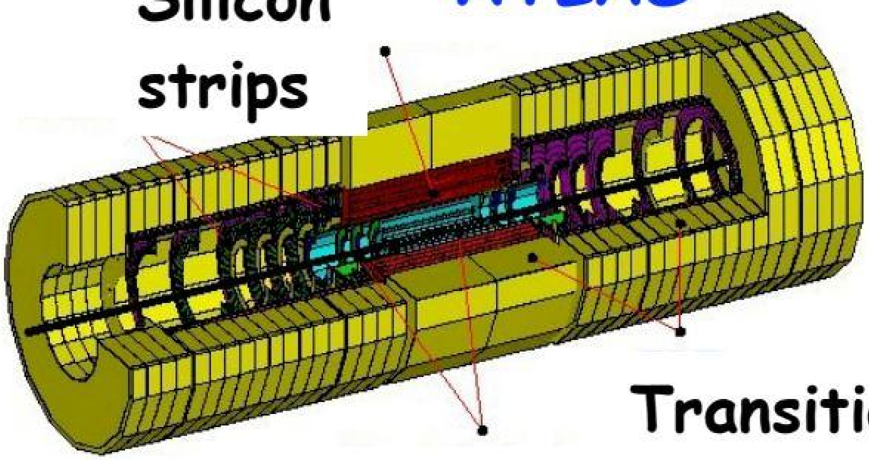
QCD, with pileup $\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

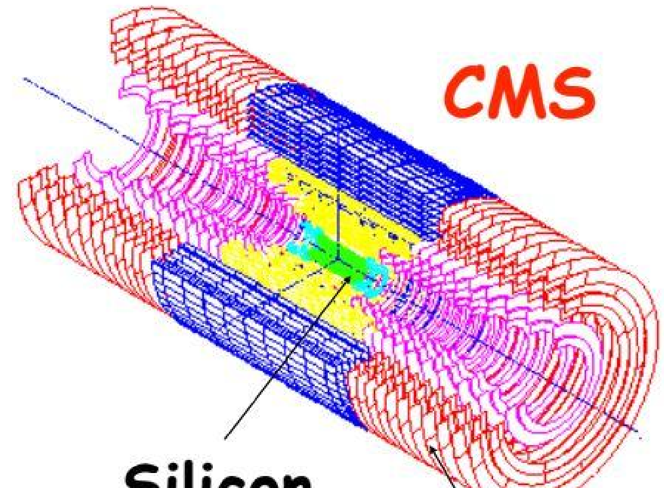


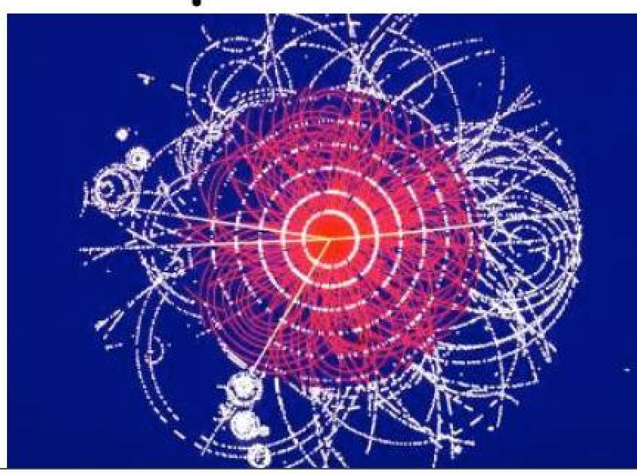
Fit: $$\sigma = [(3.8\ \mathrm{GeV})^2 + (0.97\ \mathrm{GeV}^{1/2}\sqrt{\Sigma E_T - 350\ \mathrm{GeV}})^2 + [0.012(\Sigma E_T - 350\ \mathrm{GeV})]^2]^{1/2}$$

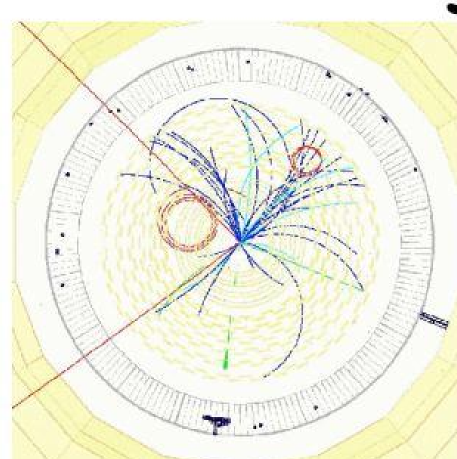
Tracking

	Si pixels	*Si strips*	*TR straws*
ATLAS	80M ch, 2 m^2	6M ch, 60 m^2	420k ch.
CMS	66M ch, 1 m^2	10M ch, 220 m^2	









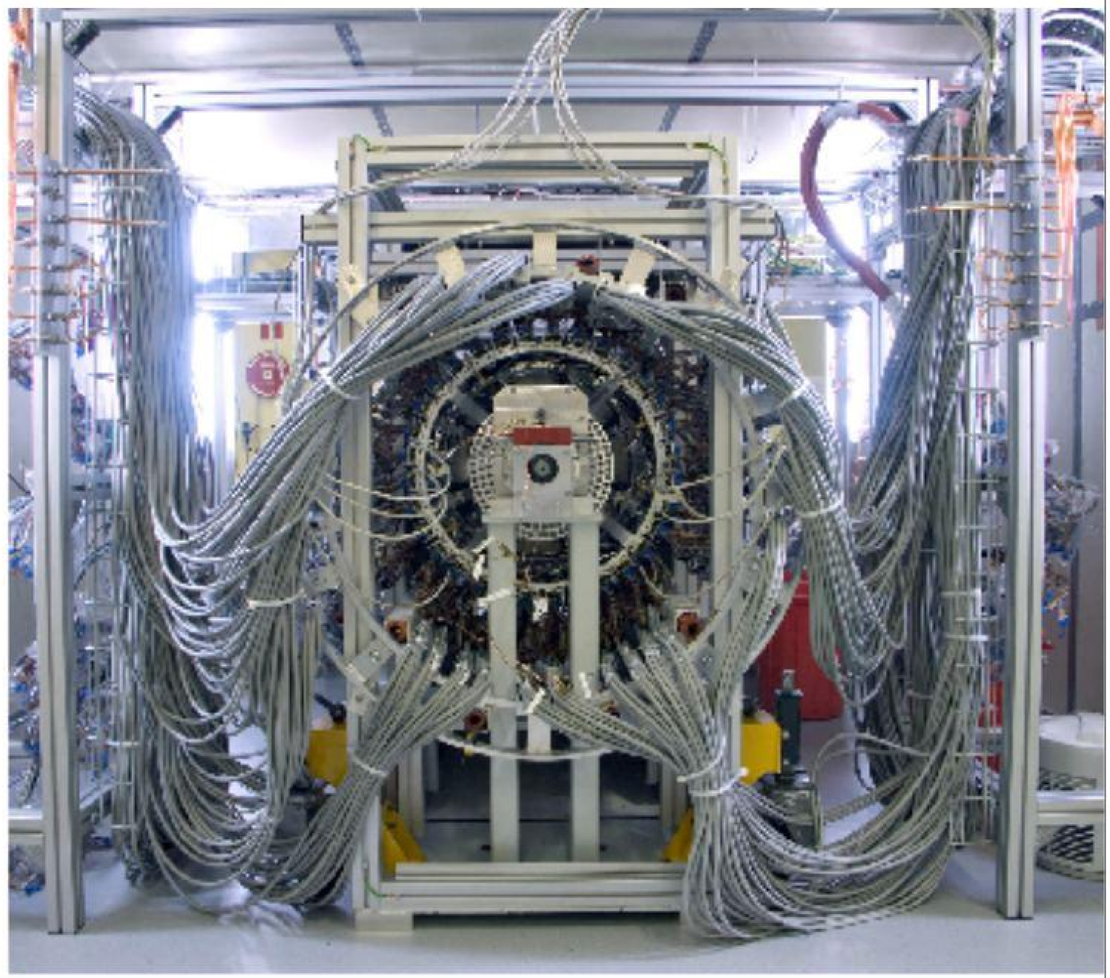
ATLAS Silicon Tracker (SCT) Barrel

All four cylinders are complete and at CERN.
The SCT is being integrated with the TRT.

SCT acceptance tests
(each barrel fully tested)

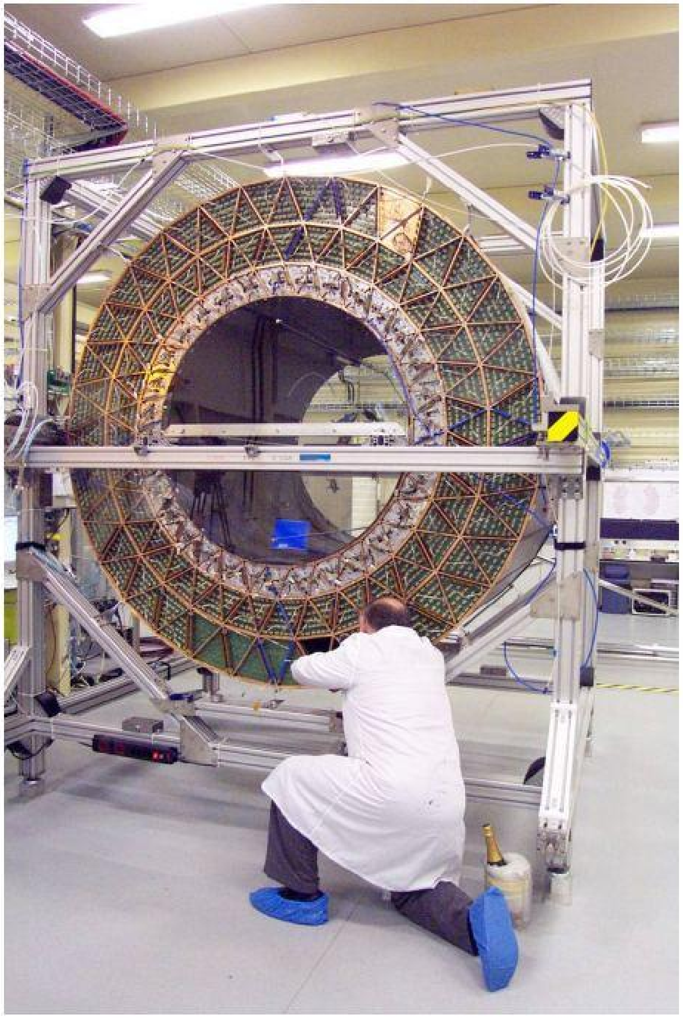
Barrel	Total Channels	Total Defects
3	589824	1483
4	737280	841
5	884736	1818
6	1032192	5720
Total	**3244032**	**9862**

99.7% of ch. fully functional



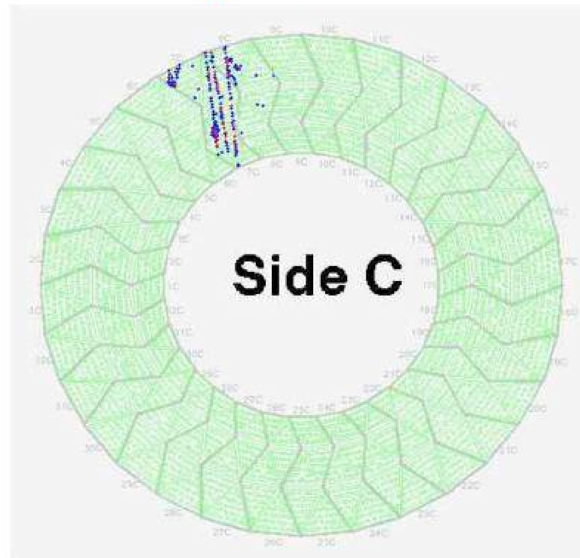
Commissioning at the surface

ATLAS Transition Radiation Tracker (TRT)

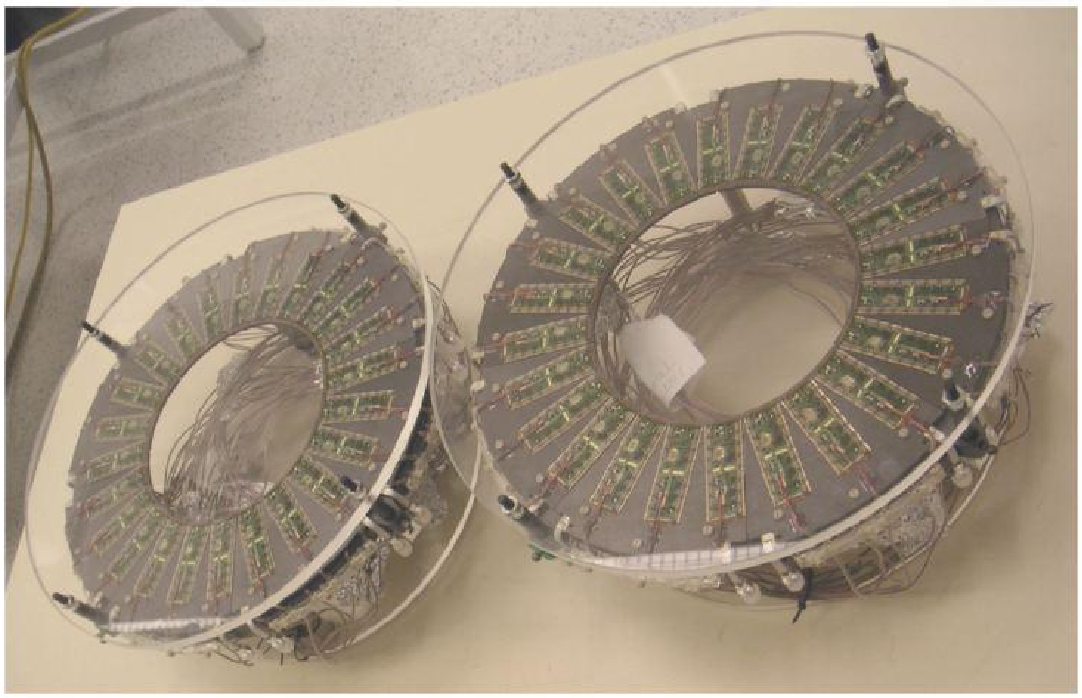


Barrel TRT during insertion of the last modules

Cosmic rays on the surface

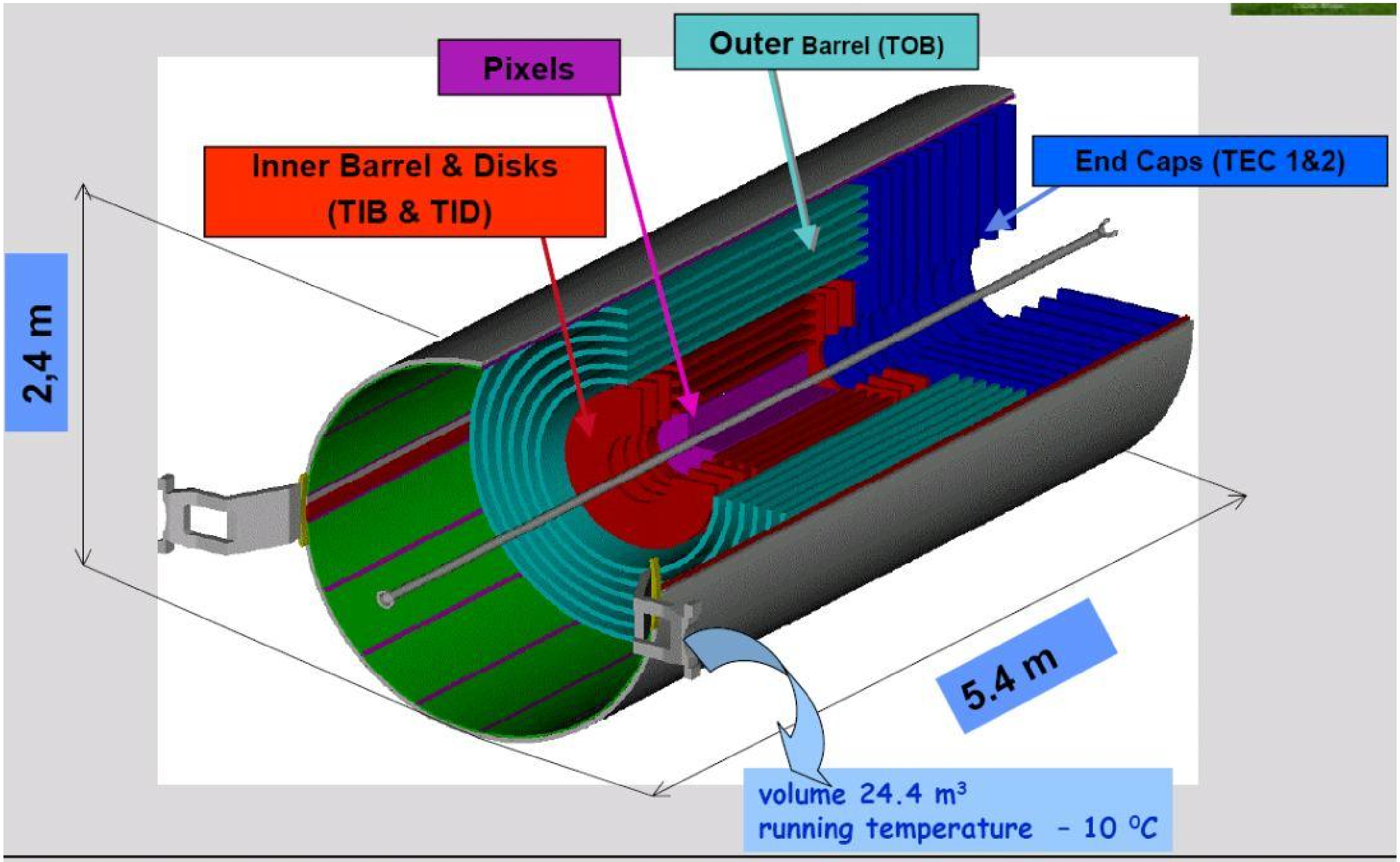


ATLAS Pixels



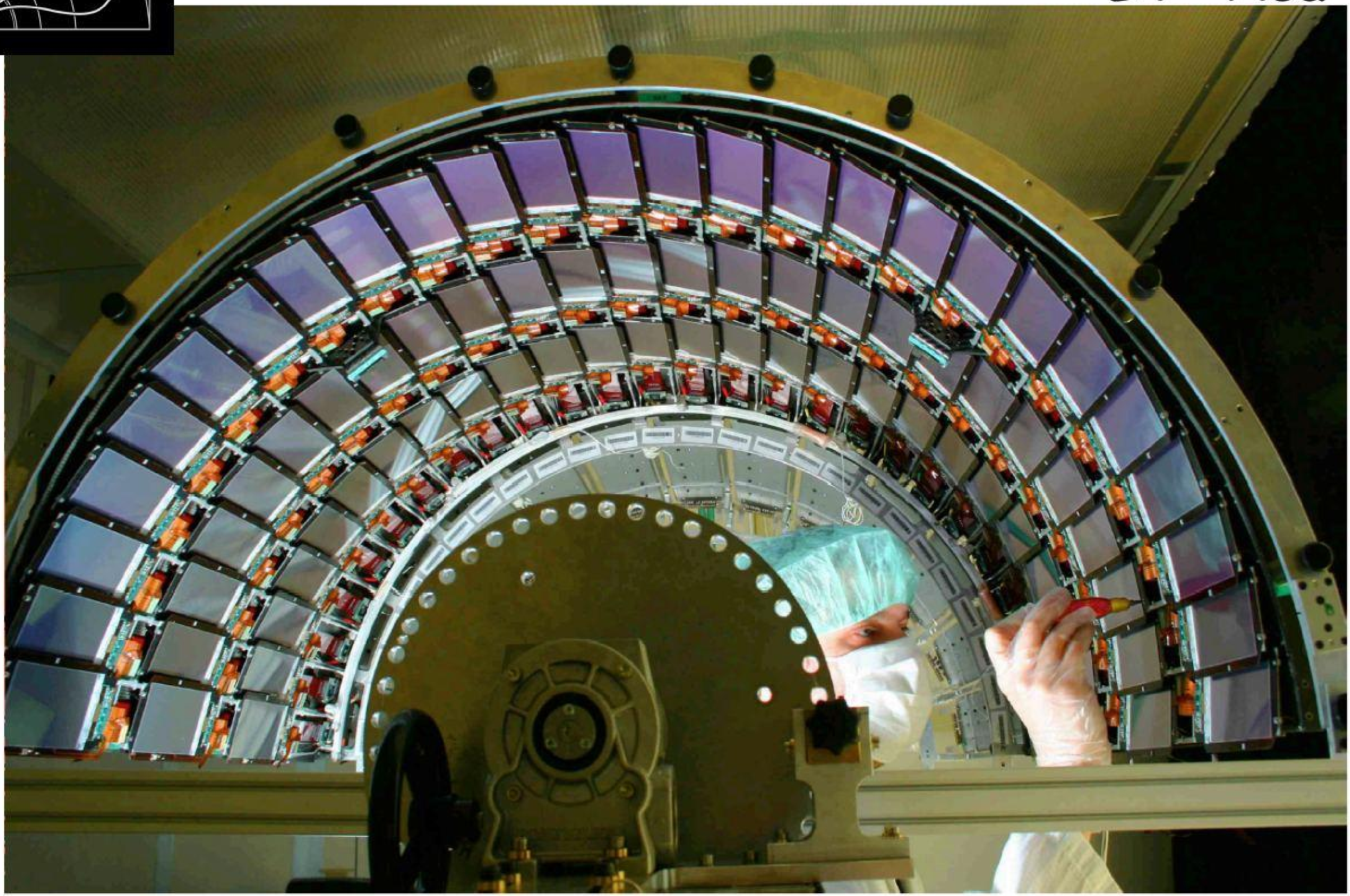
Two completed Pixel disks,
each with 2.2 M channels

CMS Silicon Tracker

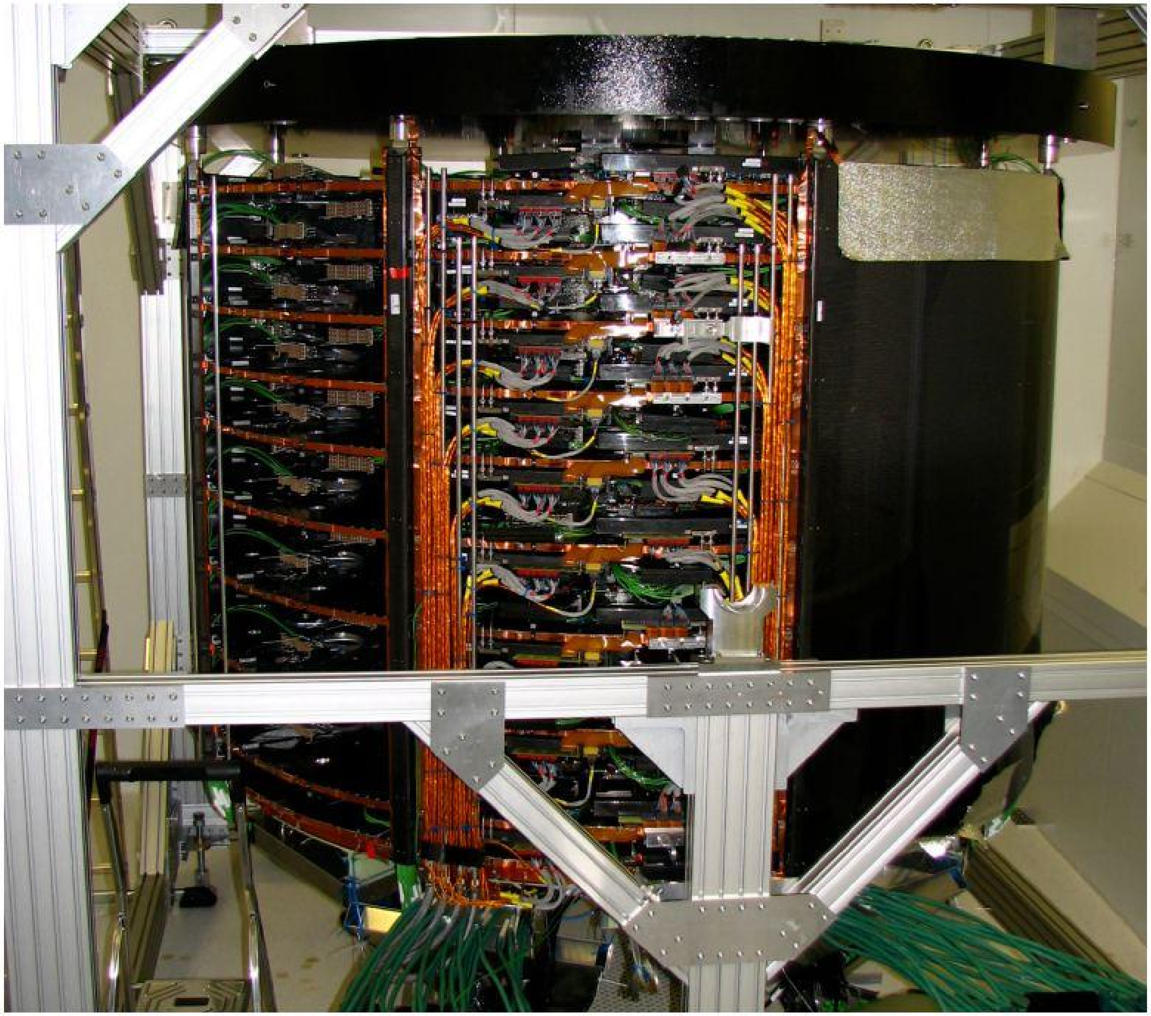


CMS Si Tracker Barrel

L4+ Pisa



CMS Si Tracker Endcap (TEC+)

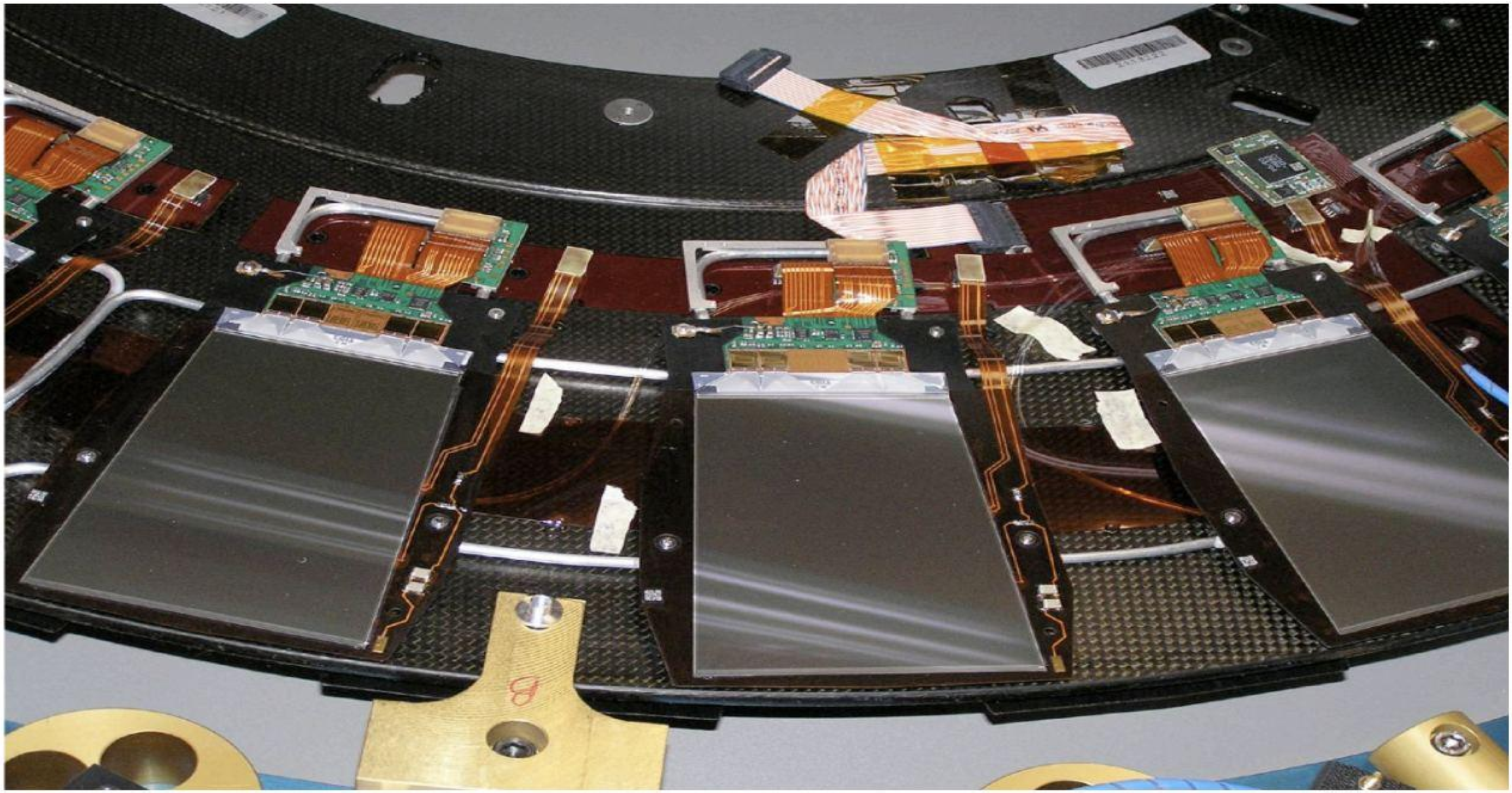


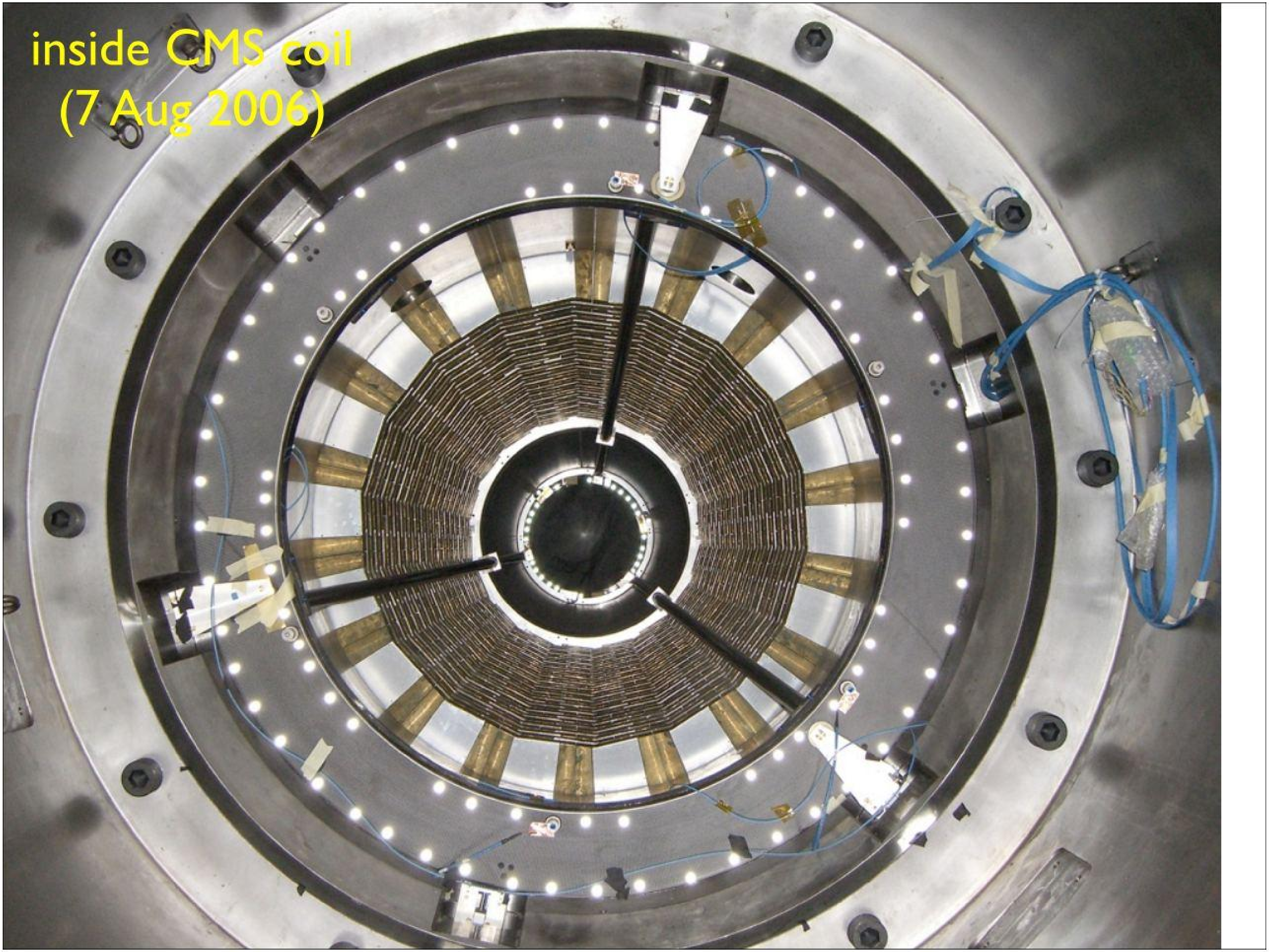
Aachen, Jan. 2006

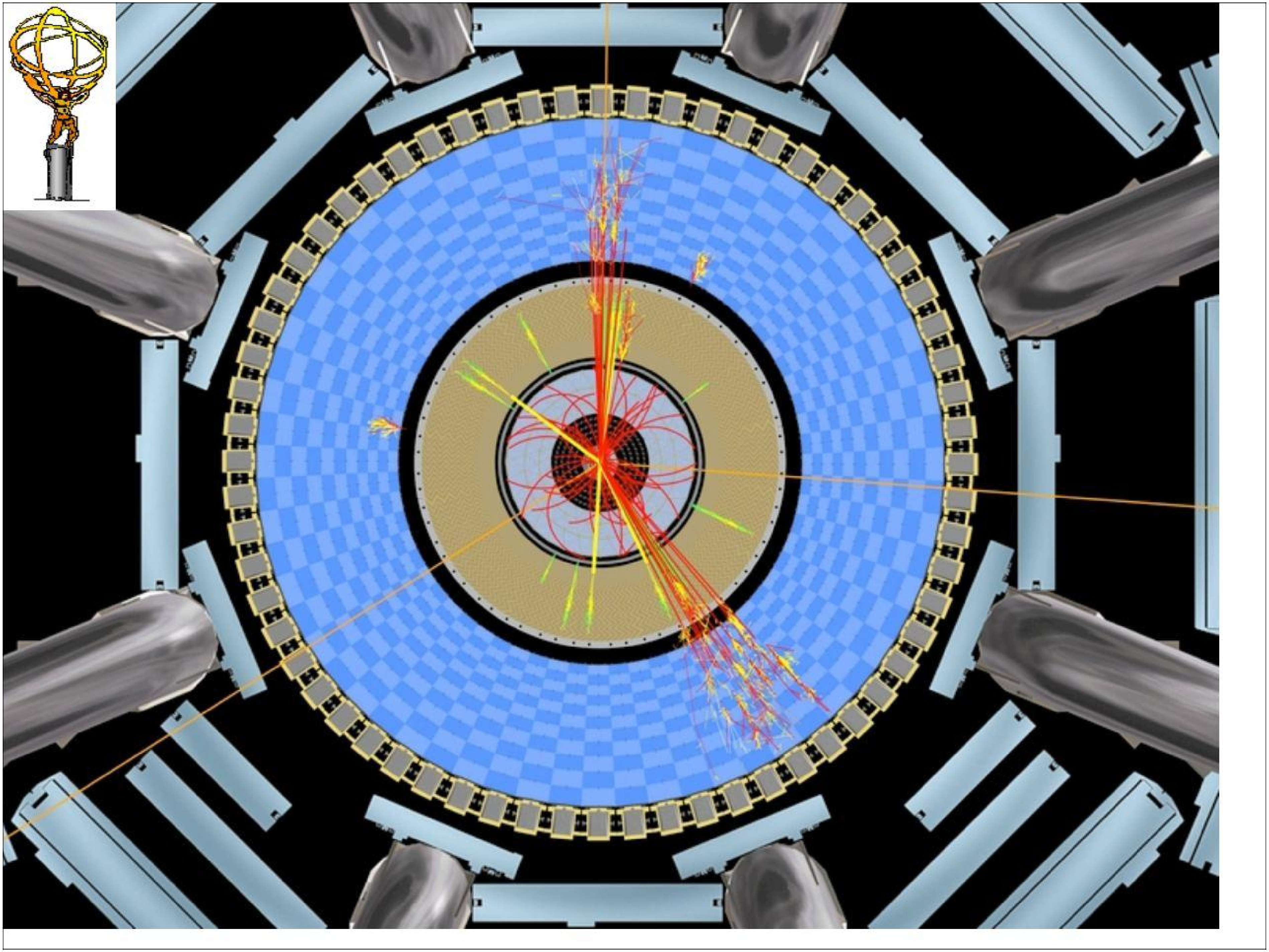
Being read out and debugged

CMS Si Tracker Inner Disk

integration at Torino

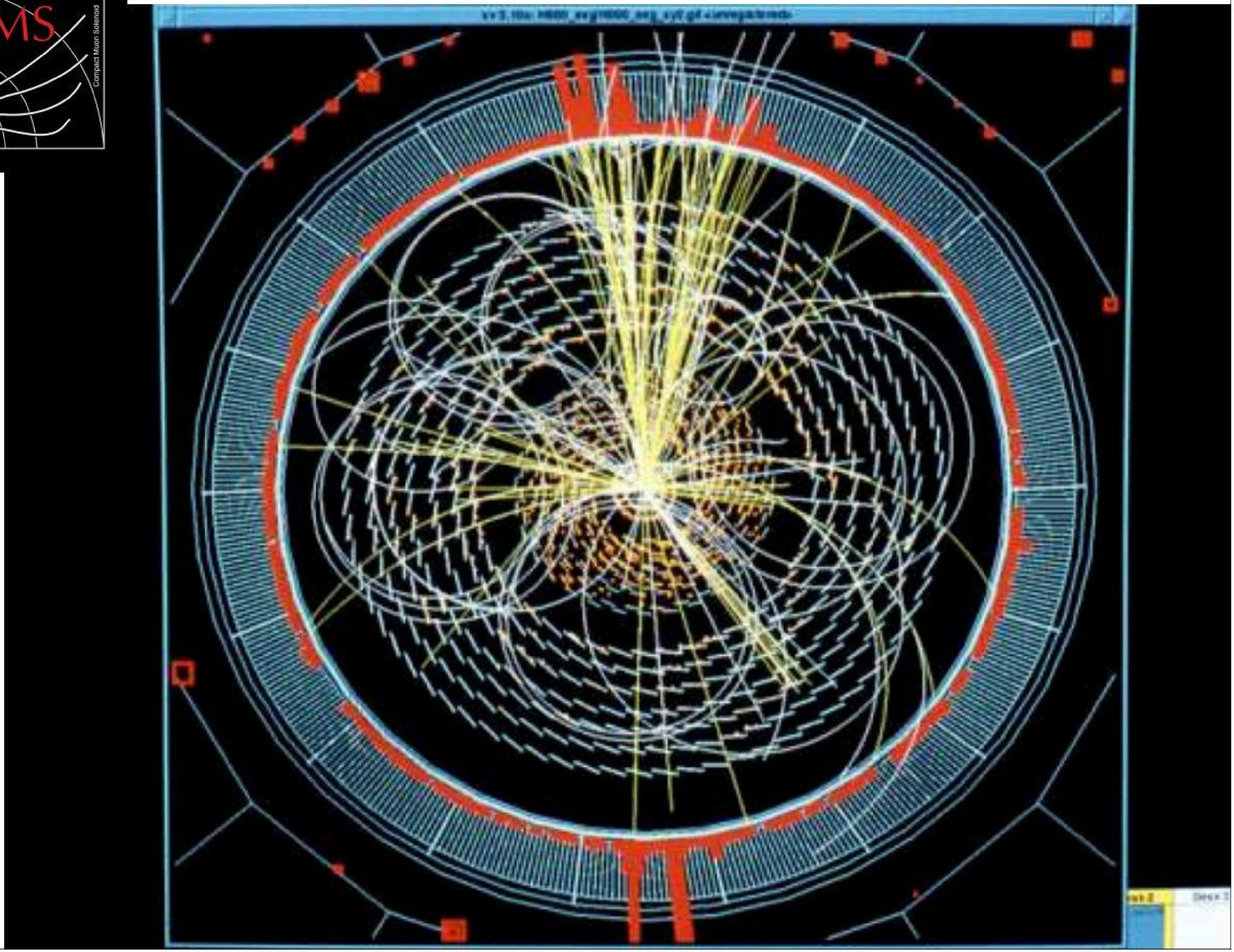



inside CMS coil
(7 Aug 2006)

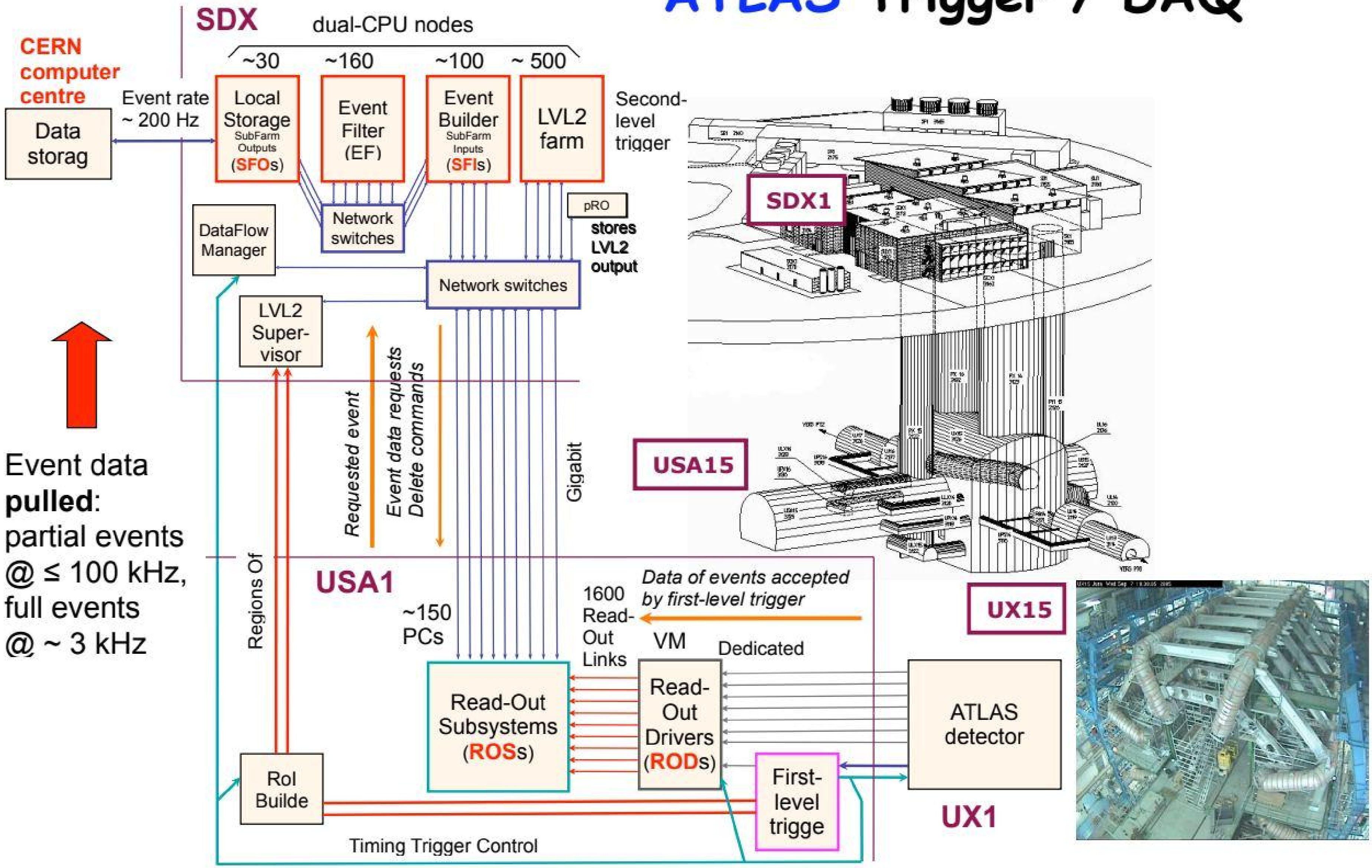


CMS

Compact Muon Solenoid

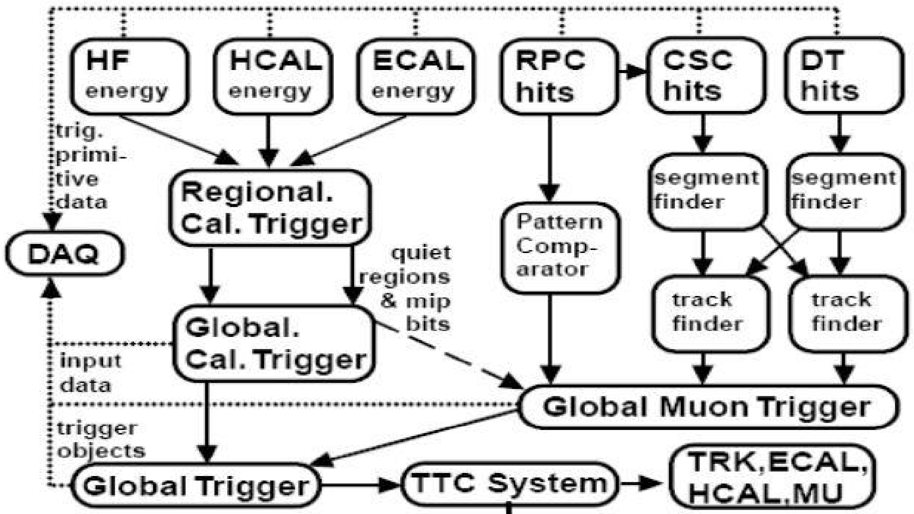


ATLAS Trigger / DAQ



Event data **pushed** @ ≤ 100 kHz,
1600 fragments of ~ 1 kByte each

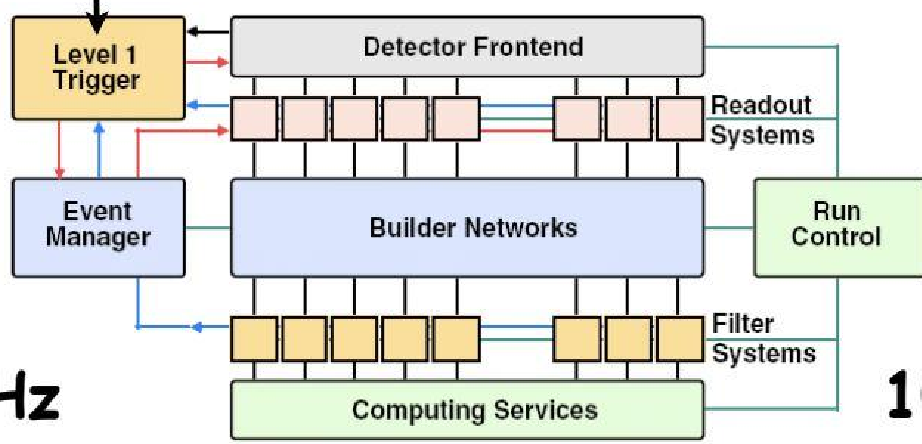
CMS Trigger / DAQ



40 MHz

10^5 Hz

100-200 Hz



100 Tbyte/s

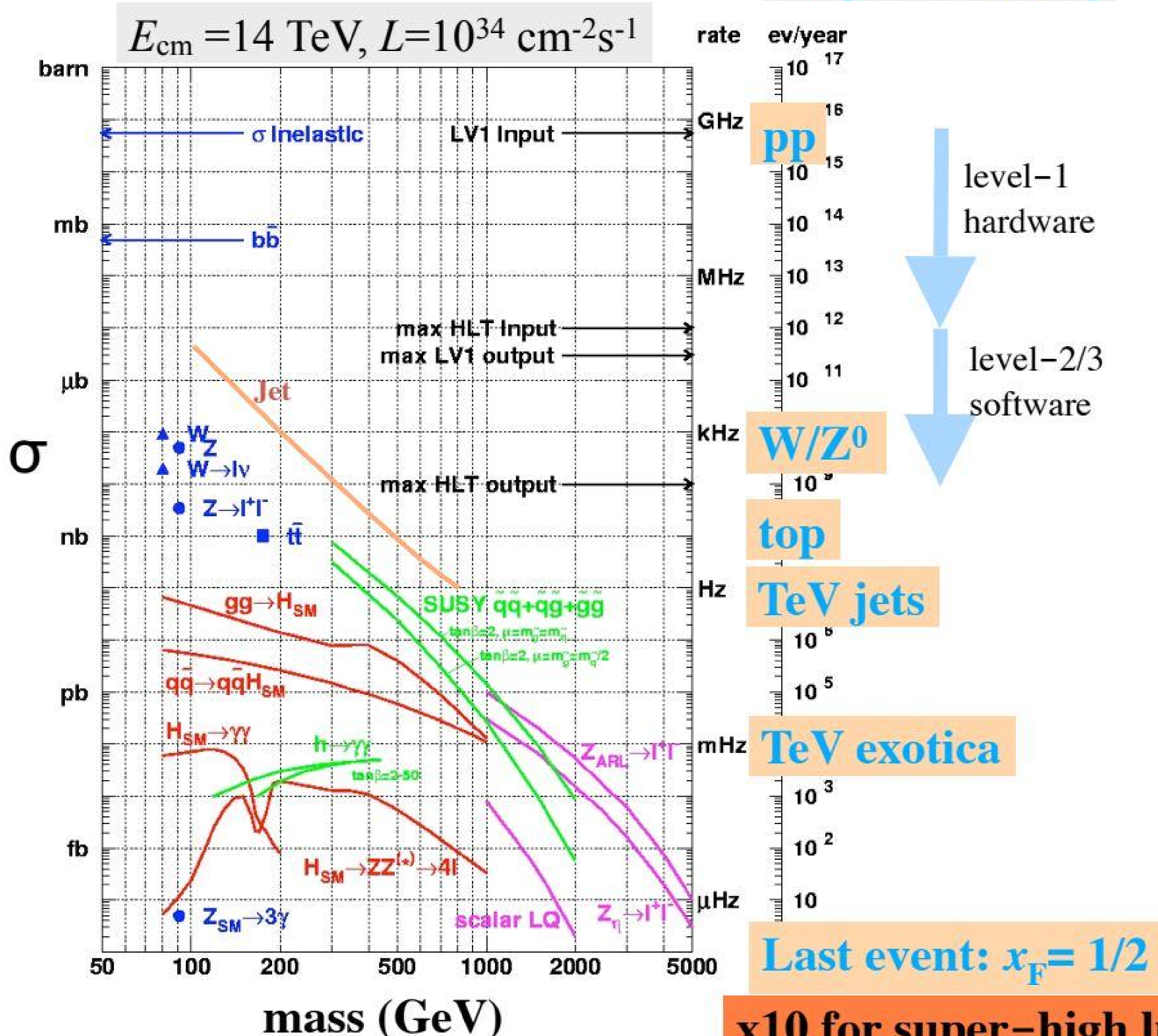
100 Gbyte/s

100-200 MByte/

Level-1 Maximum trigger rate	100 kHz	No. Readout Units	≈512
System efficiency	98%	No. Builder Units	≈512
Event Flow Control	≈10^6 Mssg/s	No. Filter Unit	≈n x 512
Builder network (512x512 port)	≥500-1000 Gb/s	No. (C&D) Network ports	≈10000
Event filter computing power	≈5 10^6 MIPS	No. programmable units	≈10000

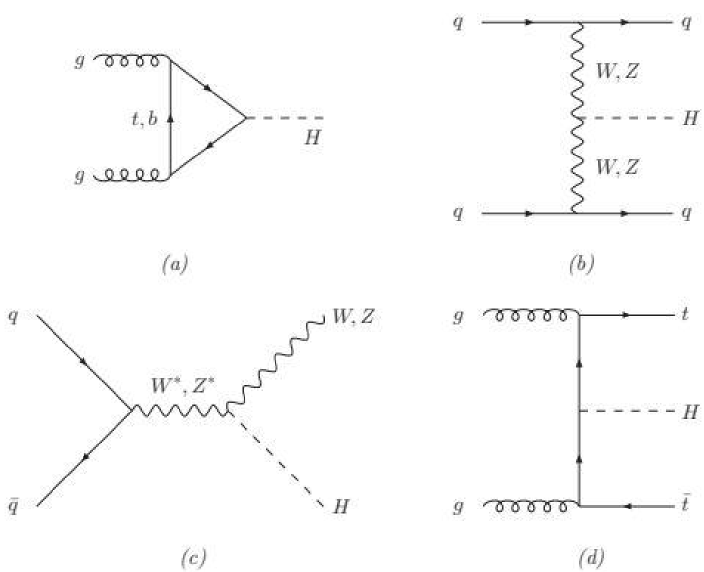
LHC Rates

design luminosity

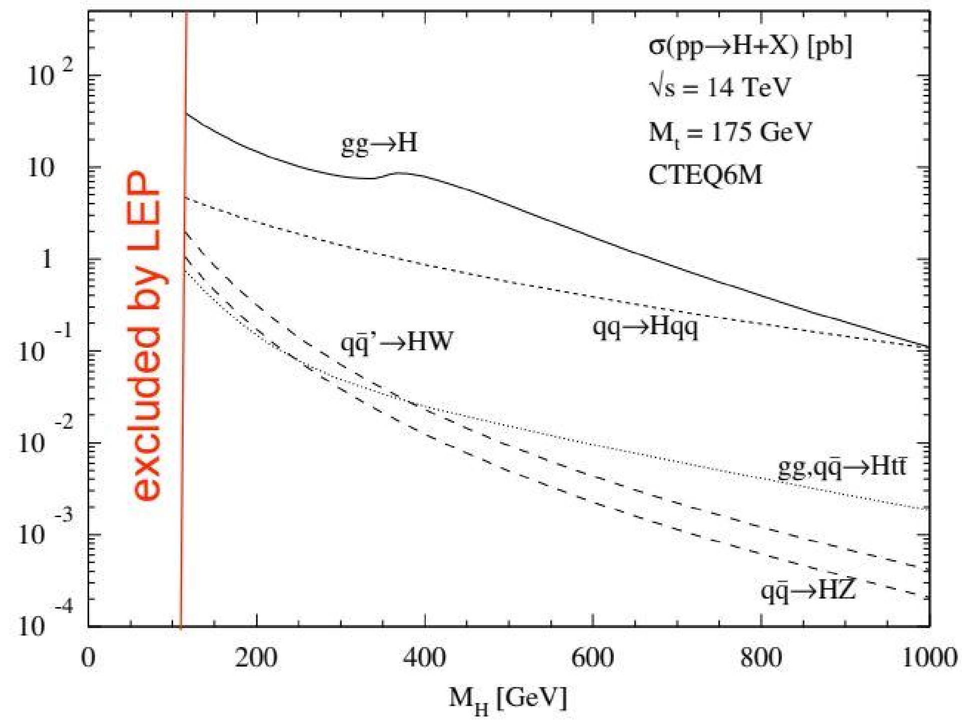


x10 for super−high lum.

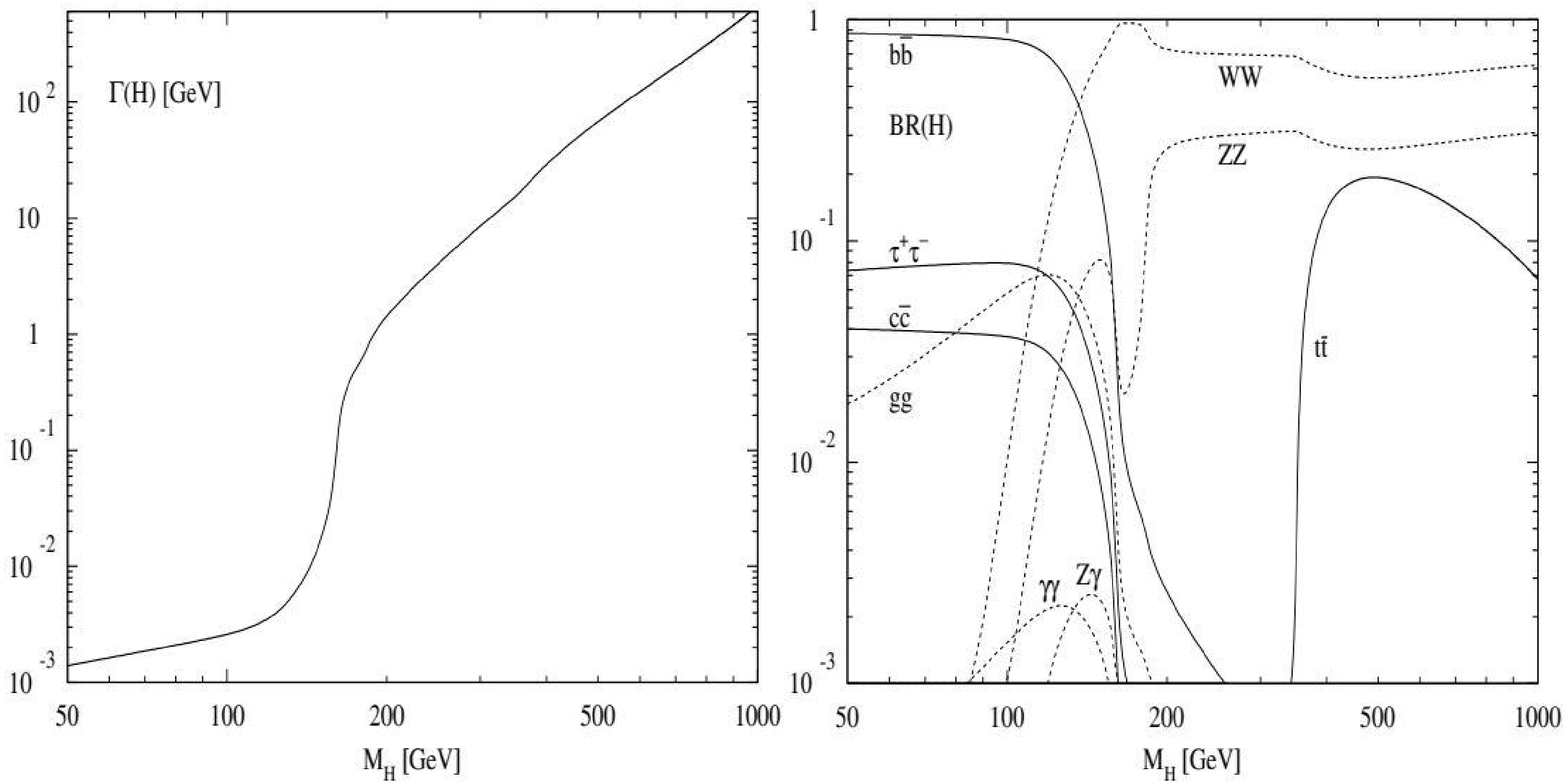
Higgs Boson



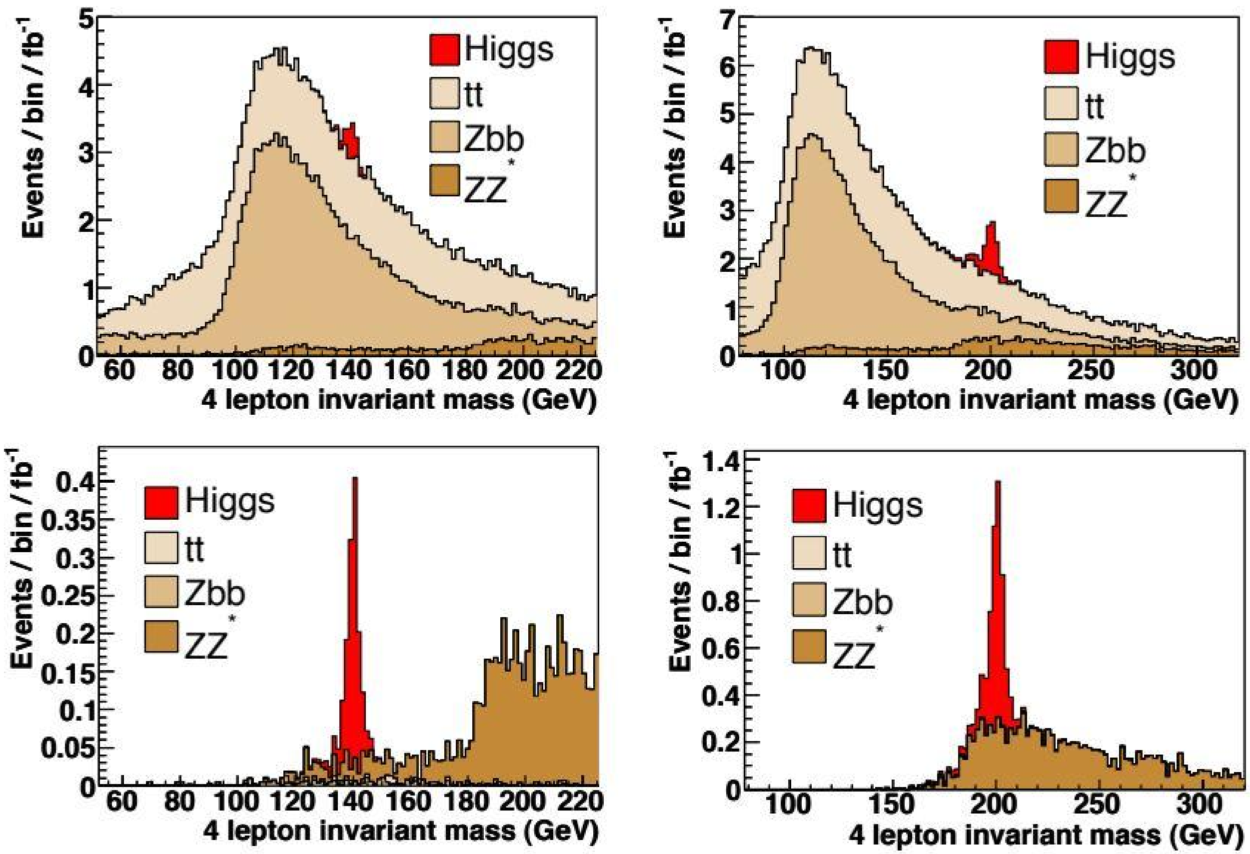
(a)
(b)
(c)
(d)



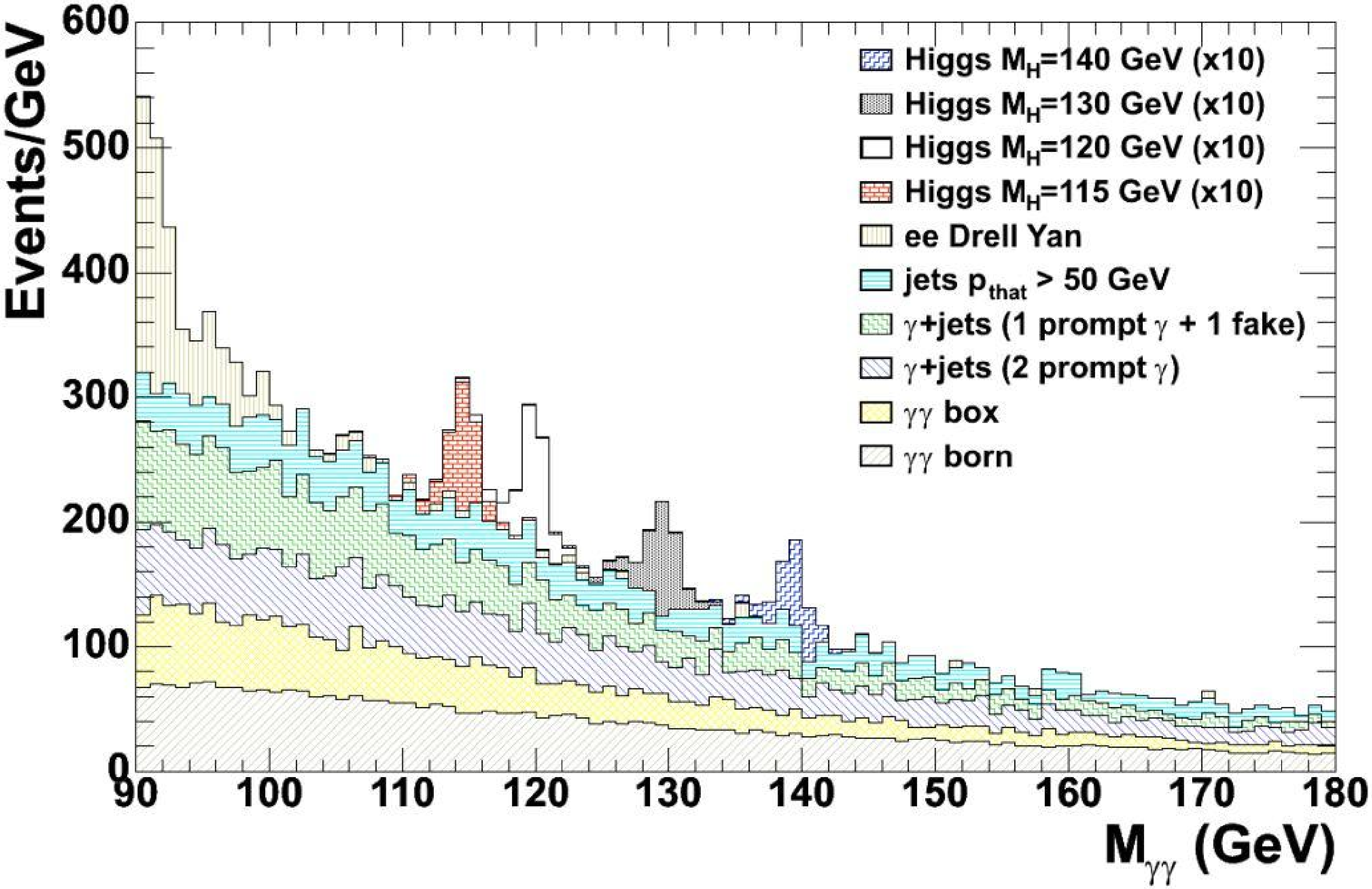
σ(pp→H+X) [pb]
√s = 14 TeV
M$_t$ = 175 GeV
CTEQ6M
gg→H
qq→Hqq
qq̄'→HW
gg,qq̄→Htt̄
qq̄→HZ
excluded by LEP
M$_H$ [GeV]


Γ(H) [GeV]
10 2
10
1
10 -1
10 -2
10 -3
50
100
200
500
1000
M_H [GeV]
1
bb̄
BR(H)
WW
ZZ
10 -1
τ+τ−
cc̄
gg
tt̄
10 -2
γγ
Zγ
10 -3
50
100
200
500
1000
M_H [GeV]

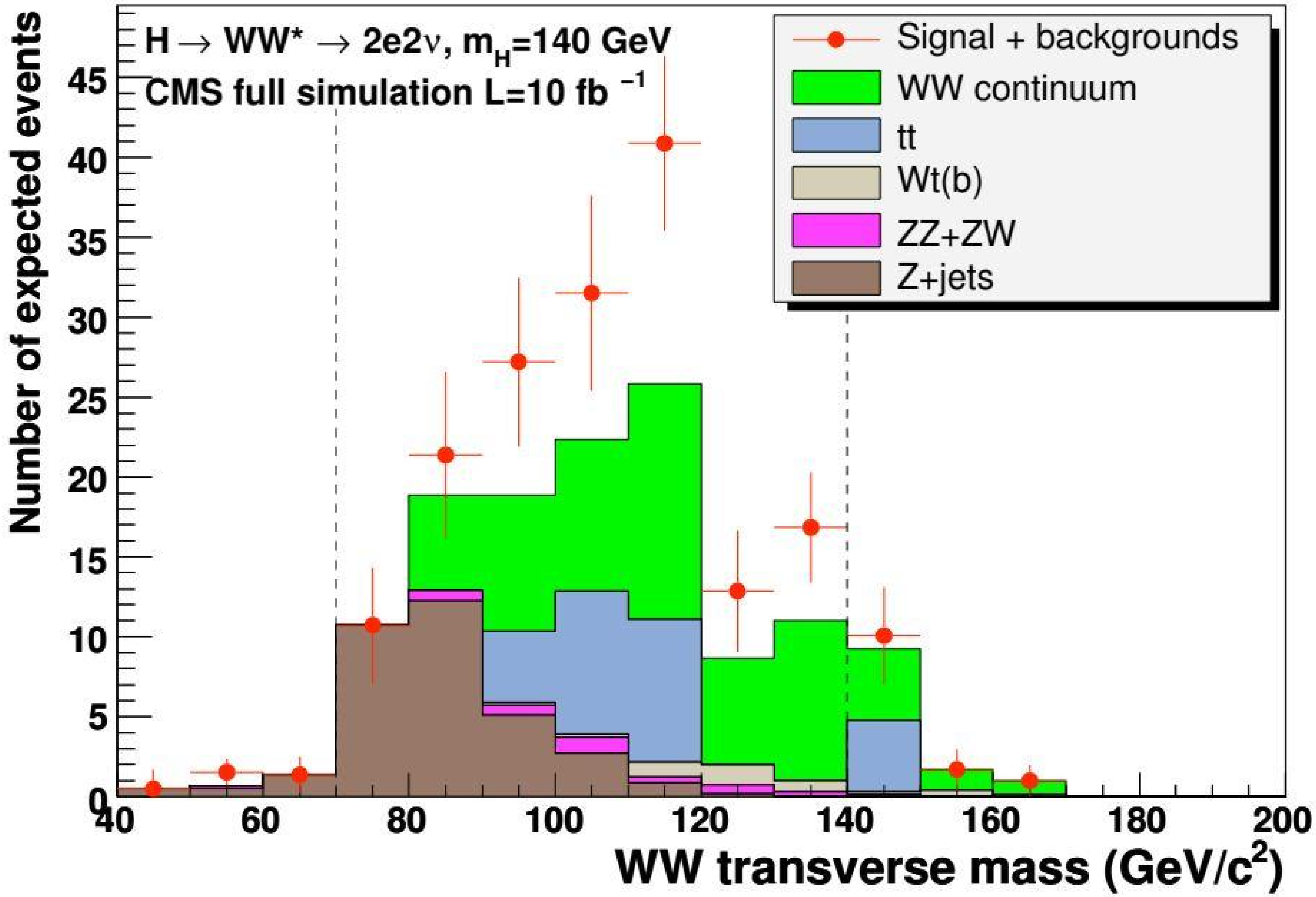
$H \to Z^0 Z^0 \to 4$ leptons

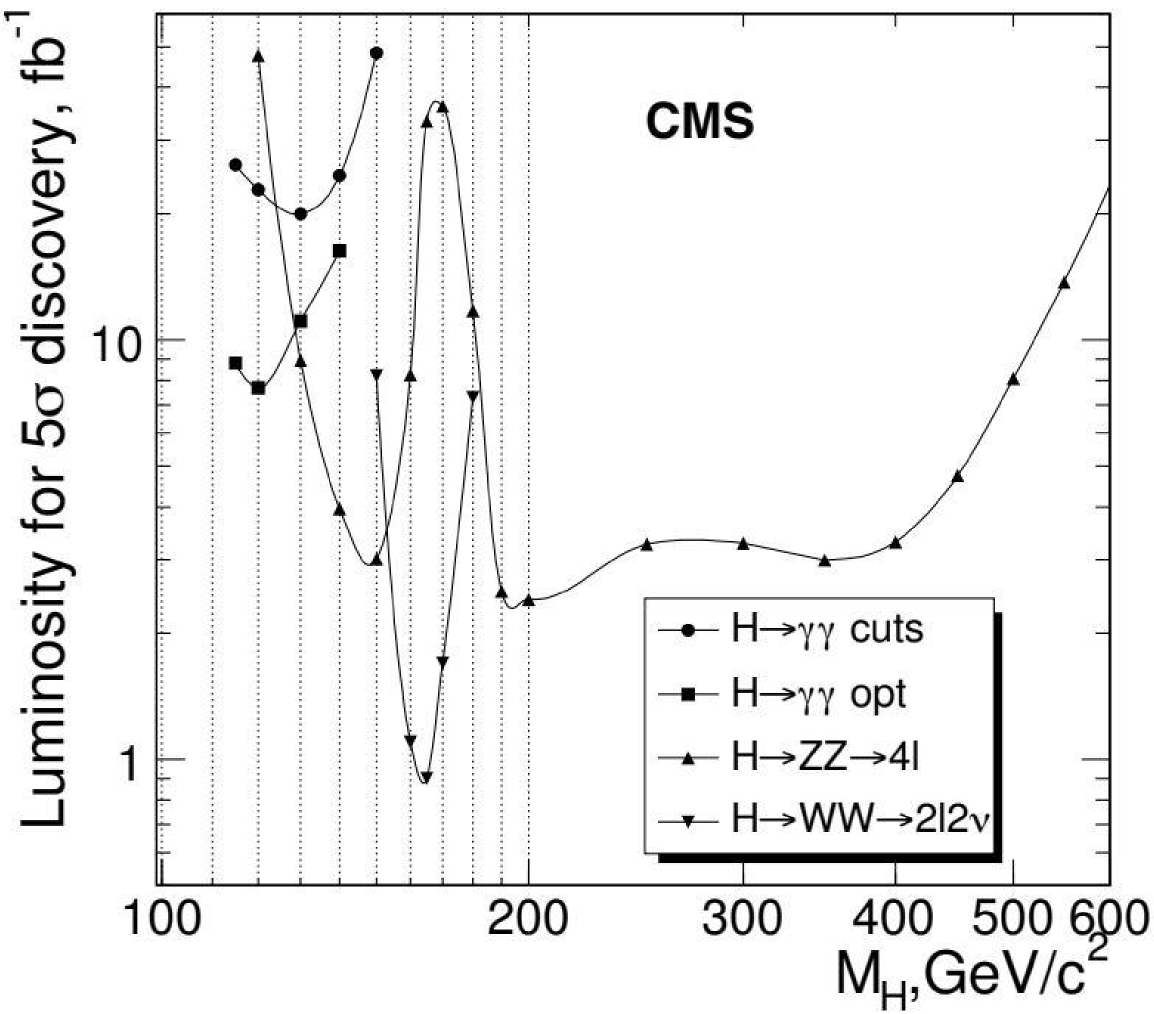


$H \rightarrow \gamma\gamma$



$H \rightarrow WW \rightarrow e^{+}\nu\ e^{-}\bar{\nu}$



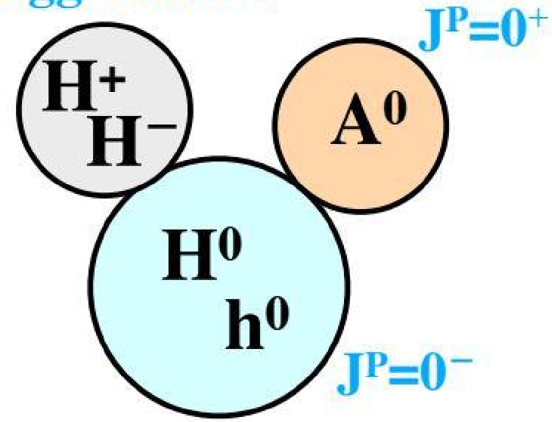


CMS
Luminosity for 5σ discovery, fb^-1
10
1
100
200
300
400
500
600
M_H,GeV/c^2
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν

MSSM Higgs

Minimal Supersymmetric Standard Model

... a 3−ring circus of Higgs bosons



Two parameters:

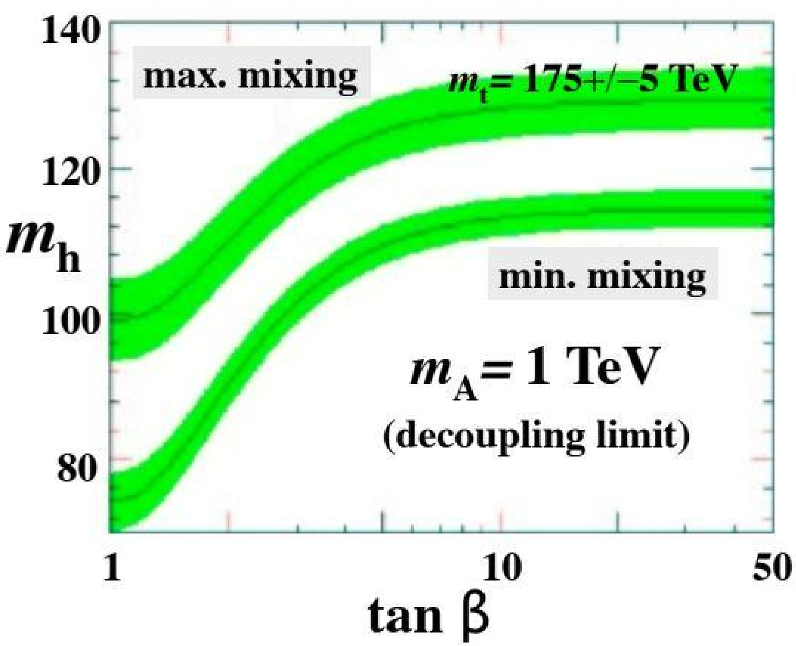
$\tan\beta = \frac{v_u}{v_d}$ (where $v_u = \sqrt{2}\langle\Phi_u^0\rangle, v_d = \sqrt{2}\langle\Phi_d^0\rangle$) and m_{A^0}

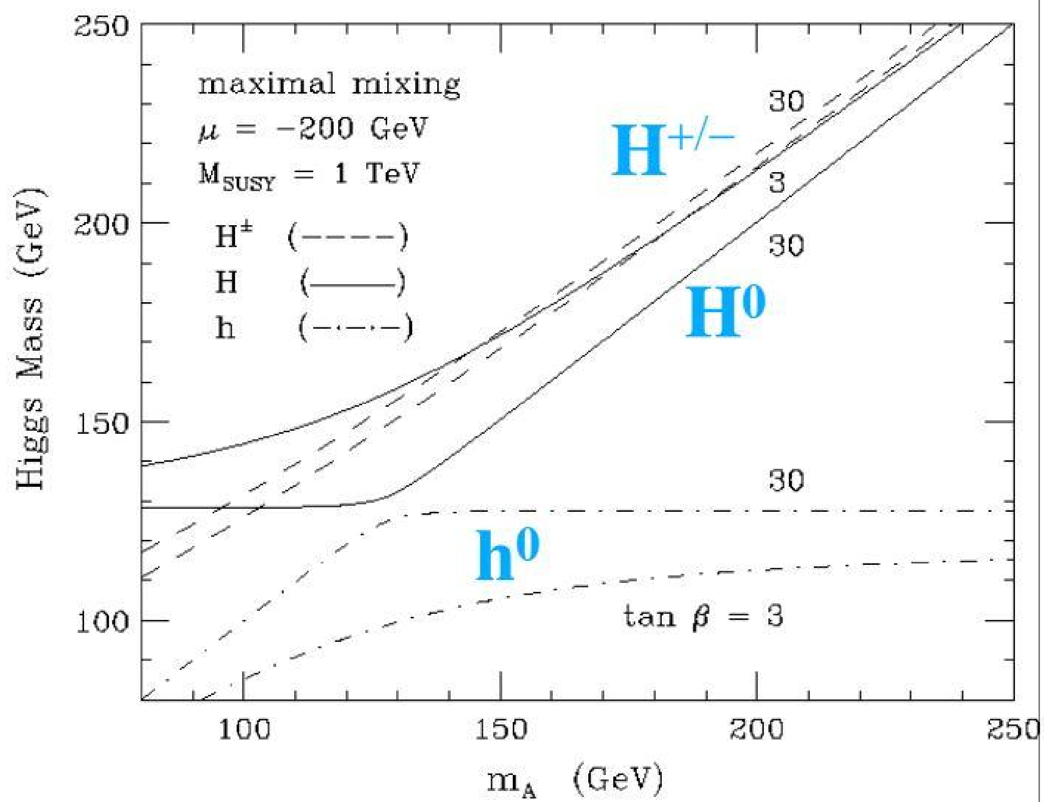
LEP limits are substantial!

Stay alive with maximal top−squark mixing

h^0 behaves like *SM*−Higgs and is light

Low−mass *SM* channels are important





Rates and Backgrounds

qqH

$l^{\pm}\nu jj$

signal

$120 < \mathrm{m_H} < 250\mathrm{GeV/c^2}$

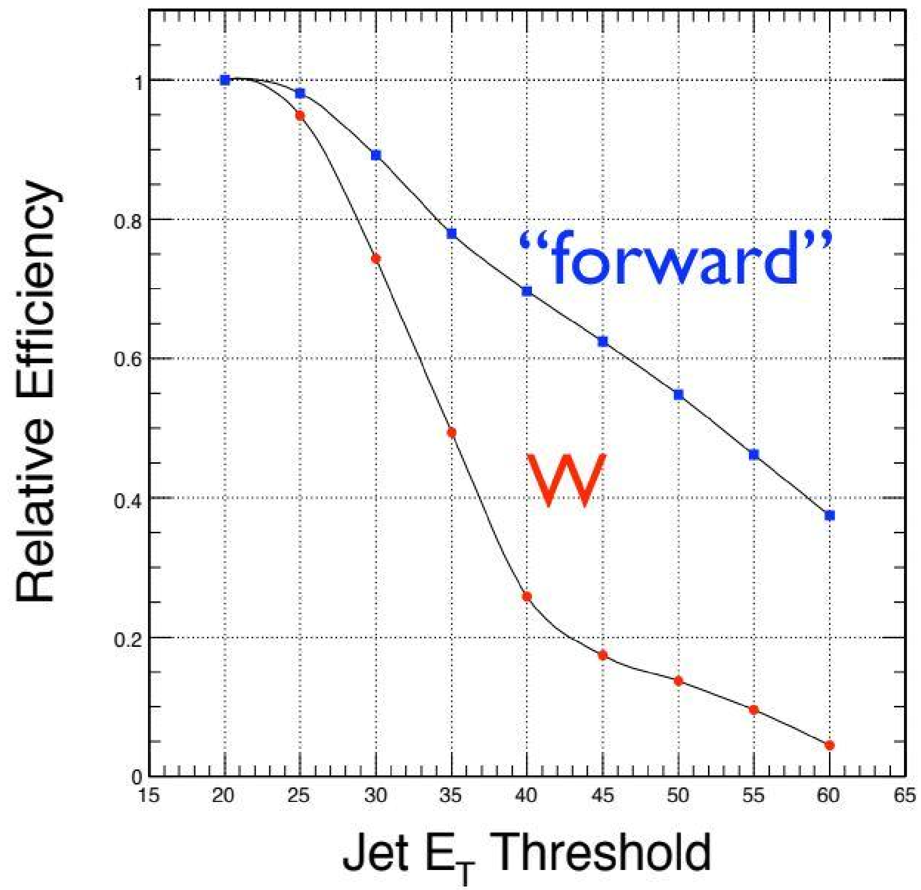
$\mathrm{m_H}$	BR ($\mathrm{H \to WW^{(*)}}$)	$\sigma(\ell\nu\mathrm{jj})$ (pb)	Events in 60 $\mathrm{fb^{-1}}$	Generated
120	0.122	0.1789	10734	465.8 %
130	0.279	0.3623	21738	230.0 %
140	0.480	0.5520	33120	150.9 %
150	0.685	0.7037	42222	118.4 %
160	0.918	0.8530	51180	97.70 %
170	0.967	0.8489	50934	98.17 %
180	0.929	0.7639	45834	109.1 %
190	0.778	0.5995	35970	139.0 %
200	0.735	0.5287	31704	157.7 %
210	0.727	0.4895	29370	170.2 %
220	0.719	0.4539	27234	183.6 %
250	0.700	0.3701	22206	225.2 %

backgrounds

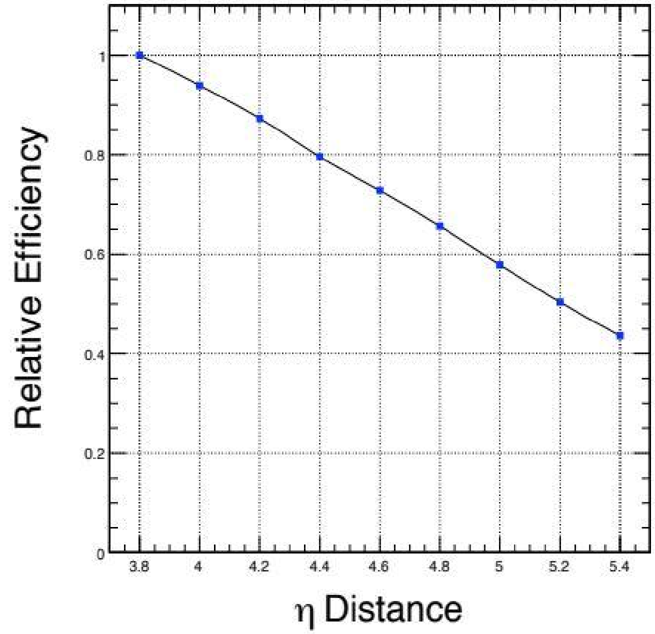
Channels	σ (pb)	Events in 60 $\mathrm{fb^{-1}}$	Generated
$\mathrm{t\,\bar{t}}$ + jets	840	50.4 million	6.9 %
W + $\mathrm{t\,\bar{b}\,(\bar{t}b)}$	100	6.0 million	57.6 %
WW + jets (QCD)	73.1	4.39 million	3.95 %
WW + 2jets (EW)	1.26	75600	113.0 %
WZ + jets	27.2	1.63 million	15%
ZZ + jets	10.7	0.642 million	68.1 %
W + 4 jets	677.4 $(e/\mu/\tau+\nu)$	40.7 million	1.95 %
W + 3 jets	1689.7 $(e/\mu/\tau+\nu)$	101.3 million	1.04 %
Z + 4 jets	44.6 $(ee/\mu\mu)$	2.68 million	11.2 %
Z + 3 jets	112.1 $(ee/\mu\mu)$	6.73 million	8.91 %

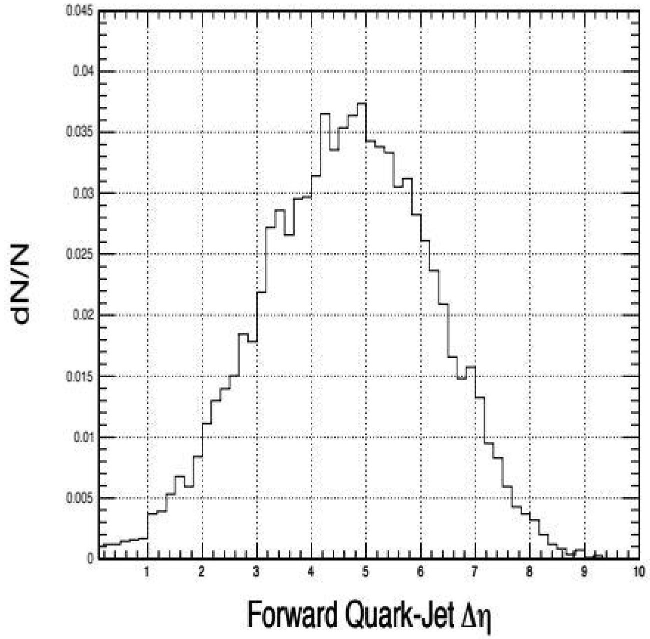
AN 2006/47 H. Pi et al.

Low E_T Jets are Important

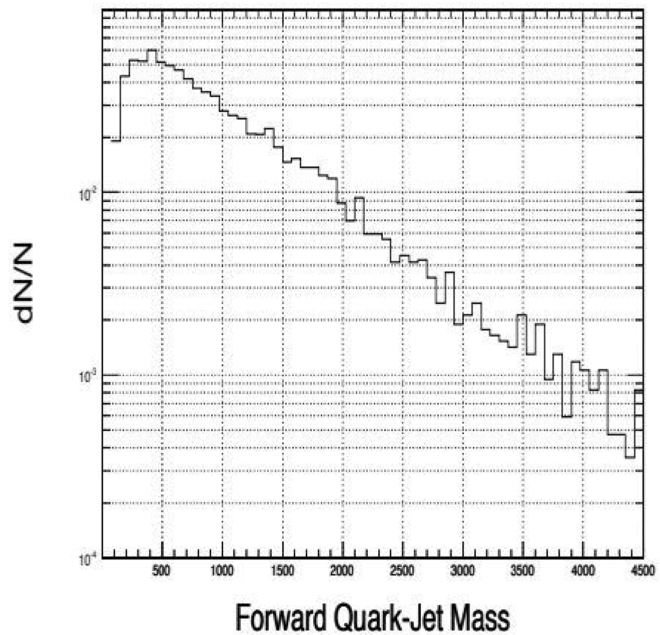


Forward Jet Properties





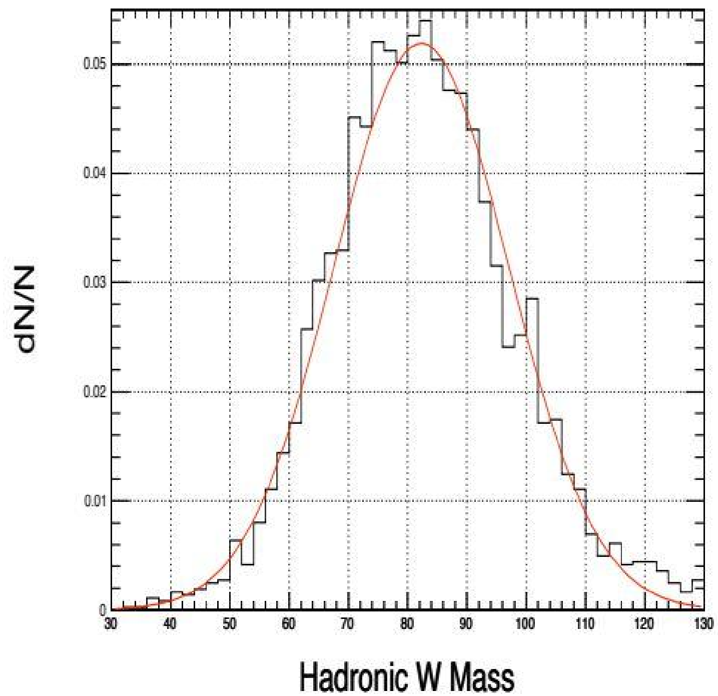
(a)

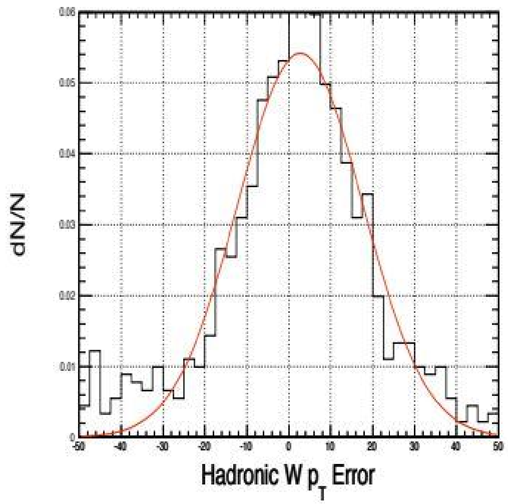


(b)

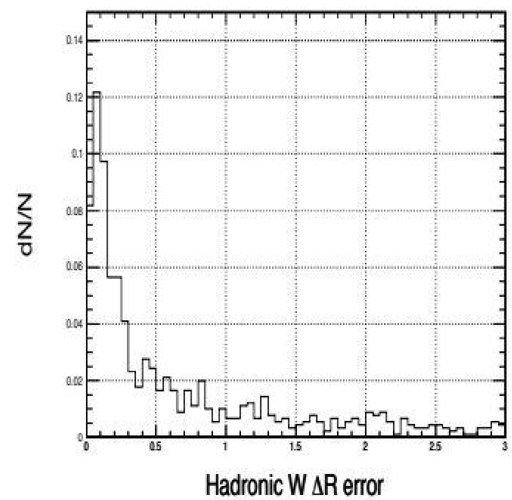
Jets from W

σ = 15 GeV





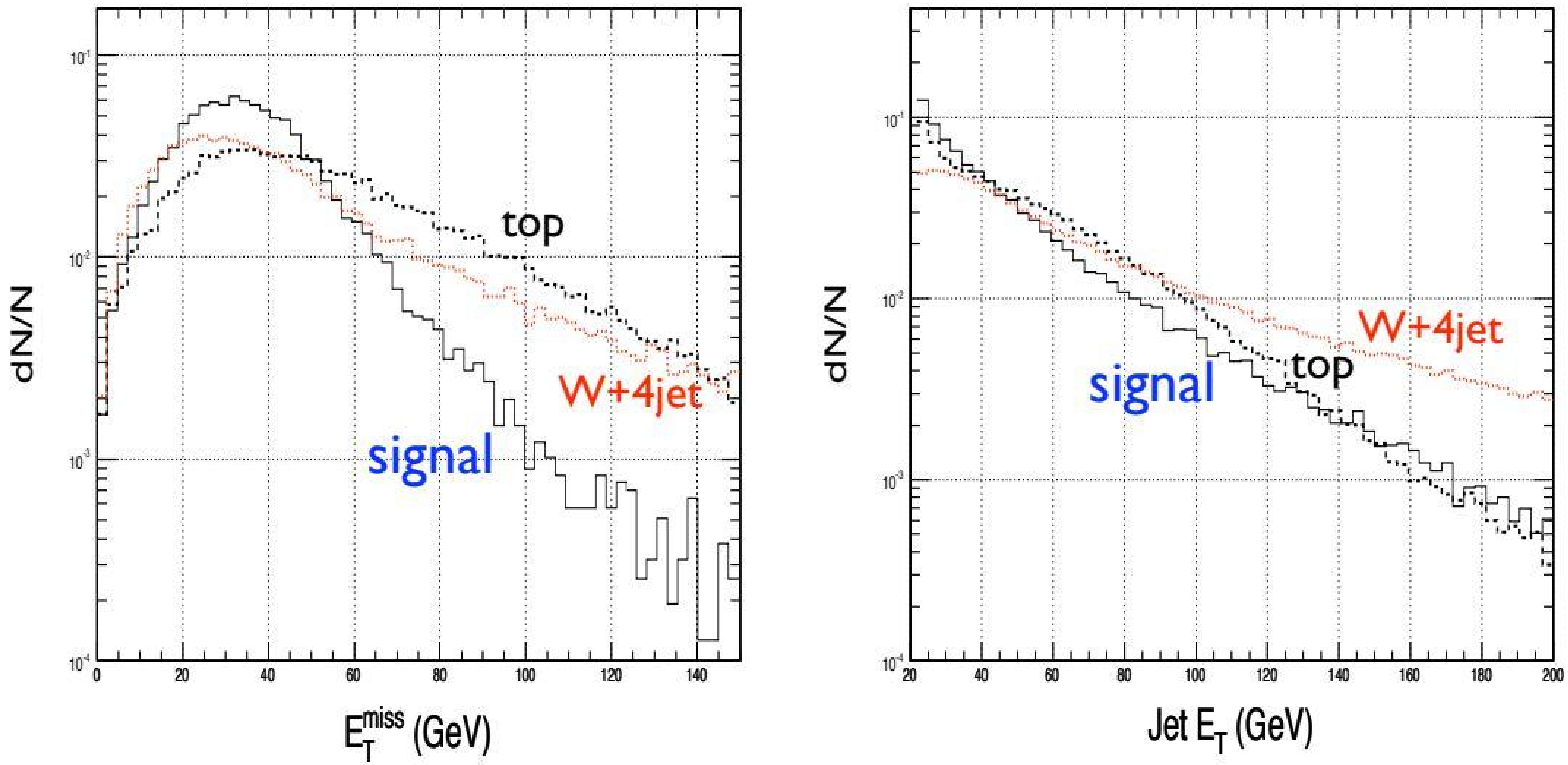
(a)



(b)

Cone Size	$< \mathrm{m_W} >$ GeV/c^2	Detector $\sigma(\mathrm{m_W})$ GeV/c^2	Scaled $\sigma_\mathrm{s}(\mathrm{m_W})$GeV/$\mathrm{c}^2$
0.4	55.1	11.52	16.8
0.6	82.3	14.75	14.4
0.8	90.27	17.25	15.4

MET and Jet Distributions



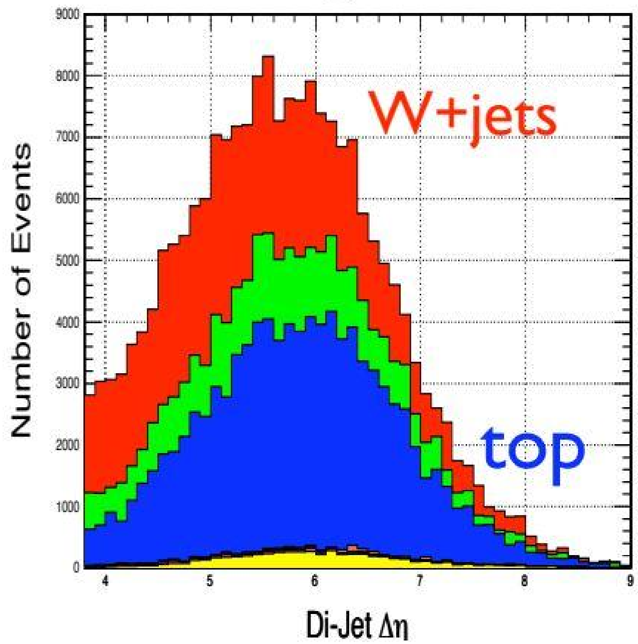
(a) (b)

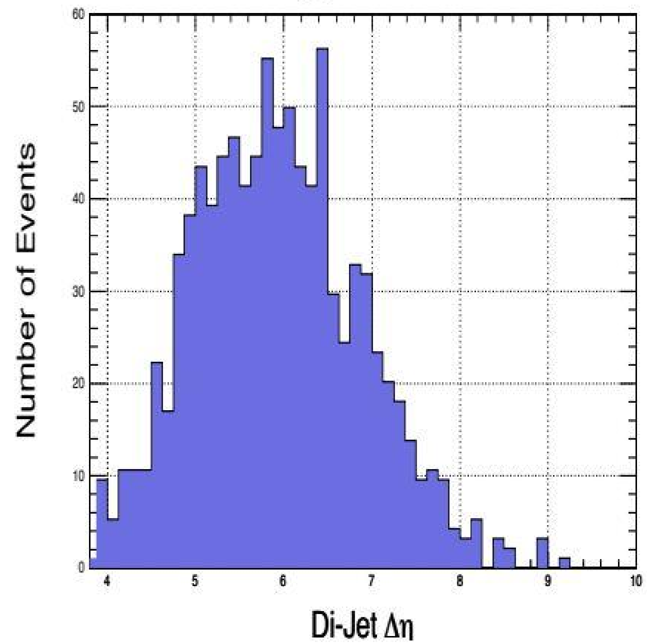
Selection Cuts (I)

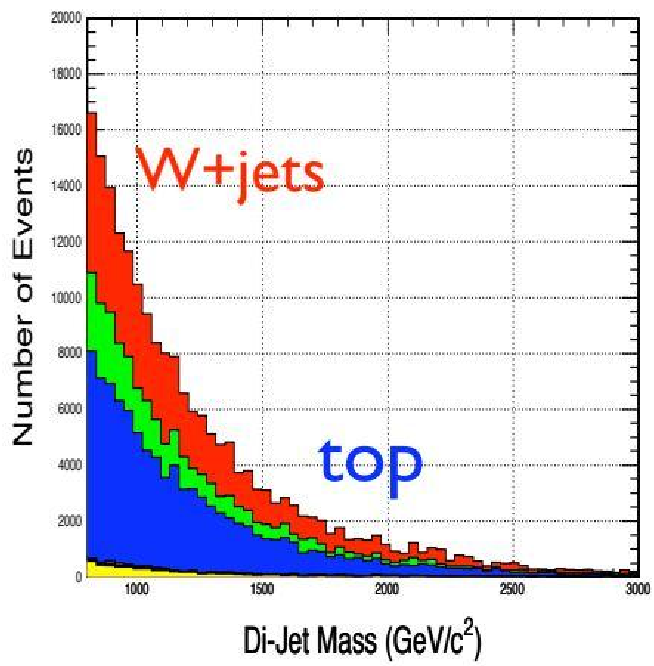
Selection	Configuration
Lepton selection (L-S)	Electron: $E_T^{Hcal}/E_T^{Ecal} < 0.05$ $0.9 < E/p < 1.8$ $\lvert E_T^{0.2} - E_T^{e}\rvert < 5.0$ GeV $\lvert (E_T^{0.2} - E_T^{e})/E_T^{e}\rvert < 0.3$ $E_T^{0.2-0.4}/E_T^{e}\rvert < 0.3$ Muon : $\lvert E_T^{0.2} - p_T^{\mu}\rvert < 9.0$ GeV $\lvert (E_T^{0.2} - p_T^{e})/p_T^{\mu}\rvert < 0.3$ $E_T^{0.4}/E_T^{\mu}\rvert < 0.3$ $30 < p_T < 120$ GeV/c $\Delta R_{\ell - j} > 0.5$
Event selection (E-S)	$N_{jet} > 4$ jets with $E_T > 25$ GeV $E_T^{miss} > 30$ GeV
Forward jet tagging (FJT)	$E_T > 30$ GeV $\eta_1 \cdot \eta_2 < 0$ $\lvert \eta_1 - \eta_2 \rvert > 3.8$ $m_{qq} > 800\ GeV/c^2$
Hadronic W reco (H-W)	$\Delta w_M < 25\ GeV/c^2$ ($m_H \geq 160\ GeV/c^2$) $30 < m_{jj} < 90\ GeV/c^2$ ($m_H < 160\ GeV/c^2$) select di-jet with least Δw_M for multiple ones
Leptonic W reco (L-W)	select leptonic W candidates of smaller ΔR with hadronic W

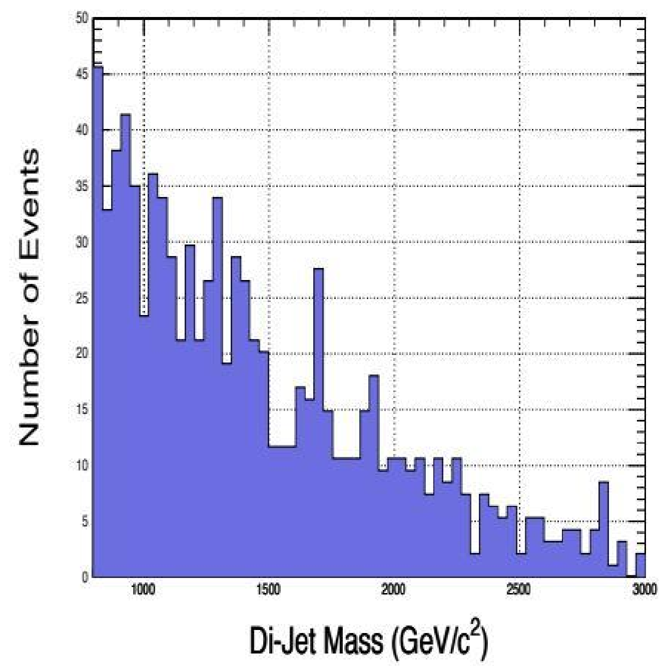
Backgrounds

Signal





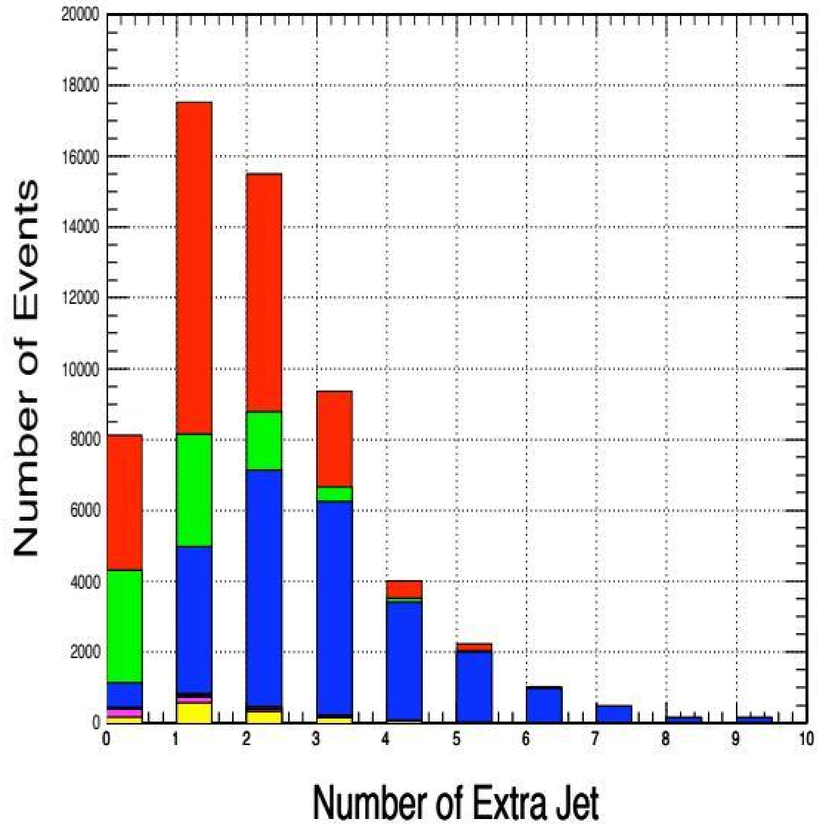


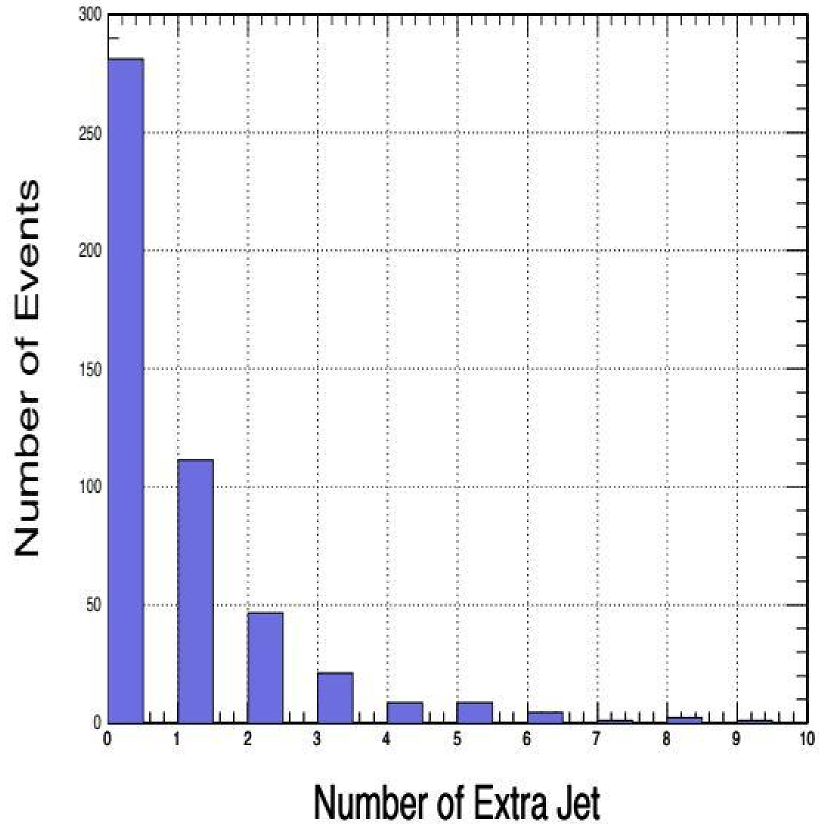


Selection Cuts (II)

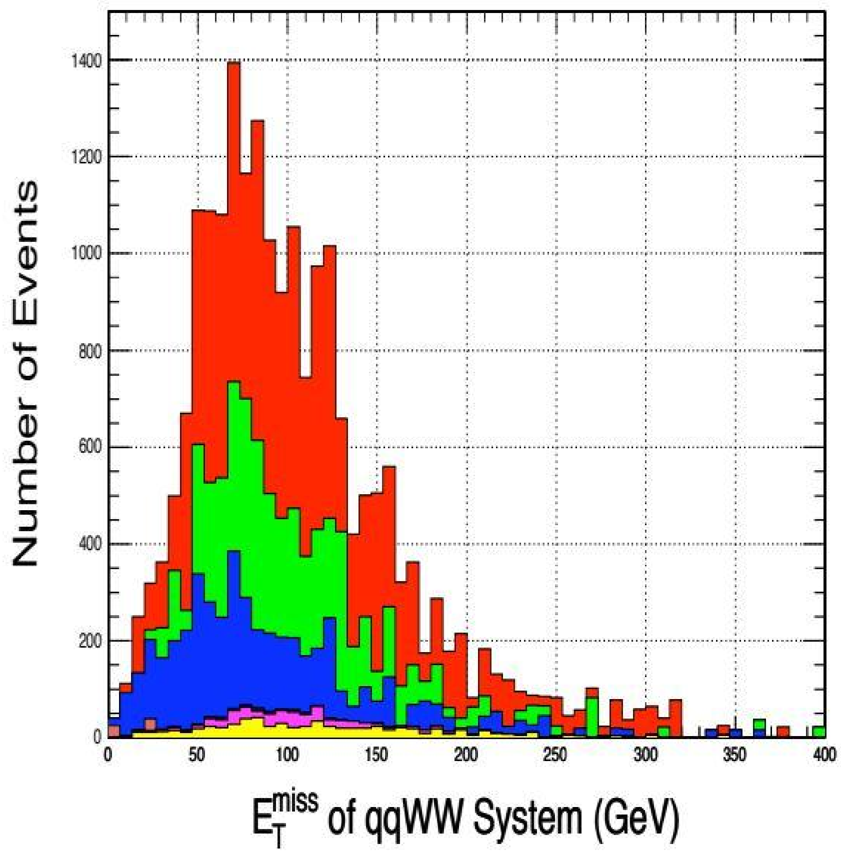
Selection	Loose Extra Jet Veto	Extra Jet Veto
Step-1 (L-S)	$\mathrm{E_T^{FH}} > 45(40)$ GeV $\mathrm{E_T^{FL}} > 35(30)$ GeV $\Delta\eta > 4.2$ $\mathrm{m_{qq}} > 1200\ \mathrm{GeV/c^2}$	$\mathrm{E_T^{FH}} > 45(40)$ GeV $\mathrm{E_T^{FL}} > 35(30)$ GeV $\Delta\eta > 4.2$ $\mathrm{m_{qq}} > 1000\ \mathrm{GeV/c^2}$
Step-2 (E-S)	$\mathrm{E_T^{CH}} > 30$ GeV $\mathrm{E_T^{FL}} > 25$ GeV $30 < \mathrm{W_M} < 90\ \mathrm{GeV/c^2}$ $\mathrm{N_{extra}} < 2$	$\mathrm{E_T^{CH}} > 30$ GeV $\mathrm{E_T^{FL}} > 25$ GeV $30 < \mathrm{W_M} < 90\ \mathrm{GeV/c^2}$ $\mathrm{N_{extra}} < 1$
Step-3 (FJT)	$\mathrm{E_T^{miss}}$(qqWW)$<$ 40 GeV ΔR(lepton-W)$<$ 1.6 ΔR(Di-W)$<$ 1.0	$\mathrm{E_T^{miss}}$(qqWW)$<$ 40 GeV ΔR(lepton-W)$<$ 2.0 ΔR(Di-W)$<$ 1.0

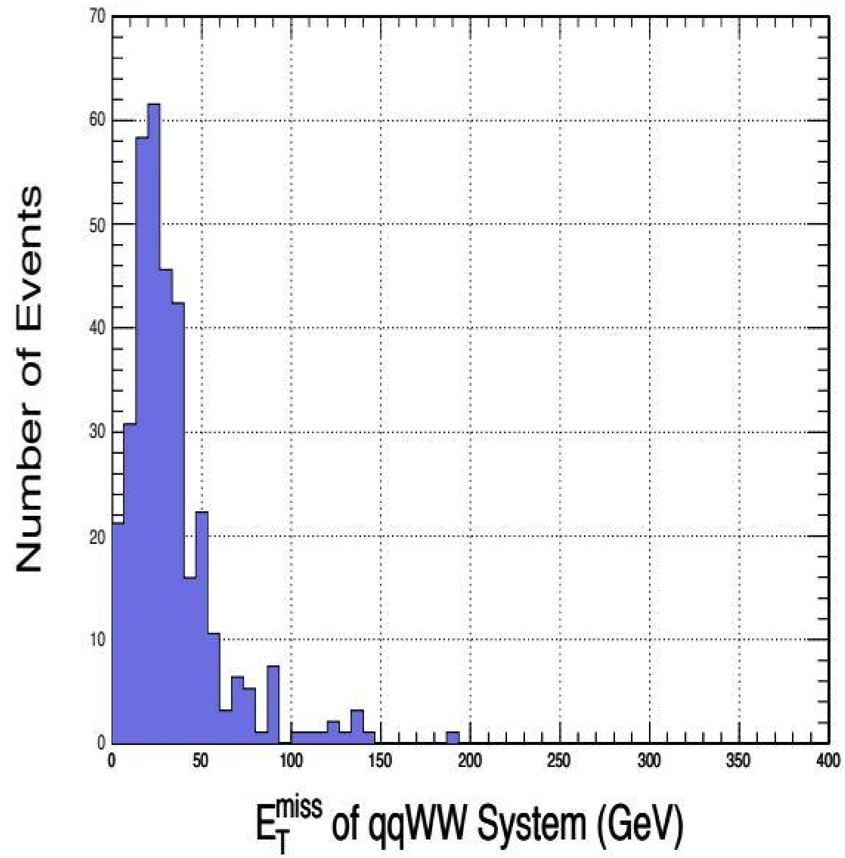
Additional Jets



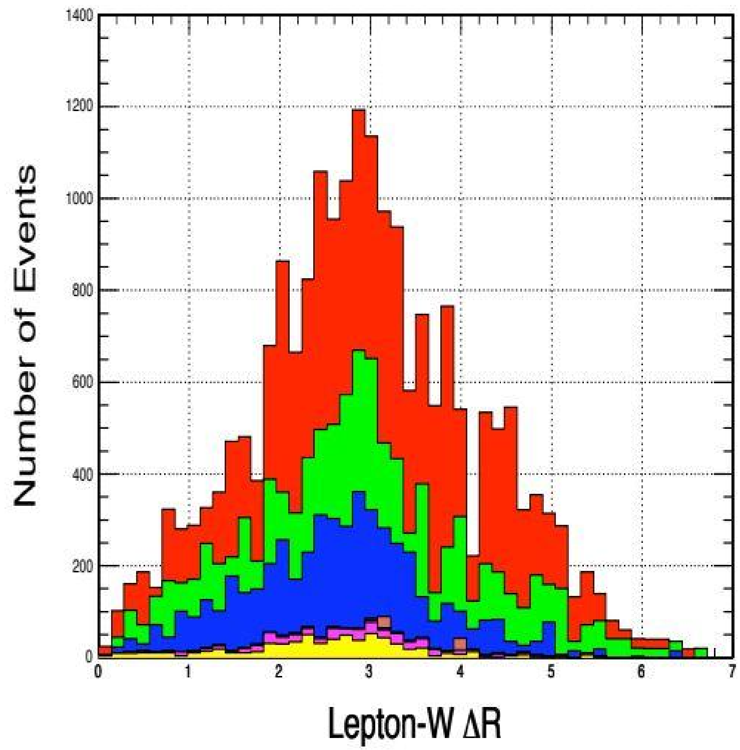


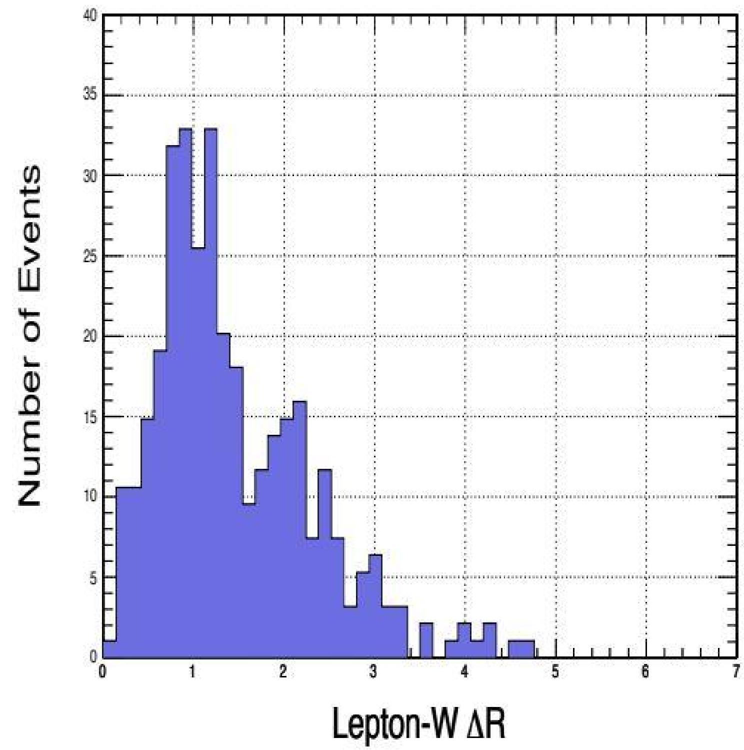
qqH E_T Balance



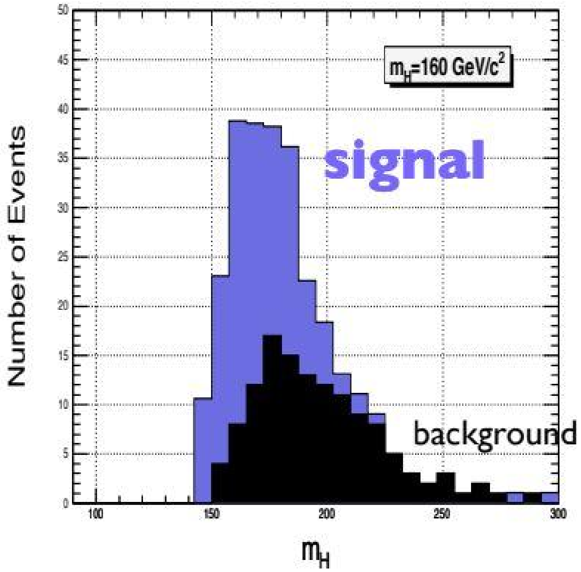


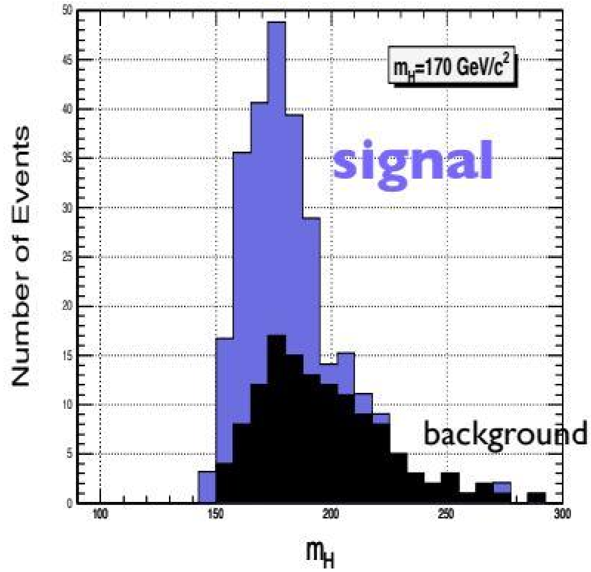
WW Separation

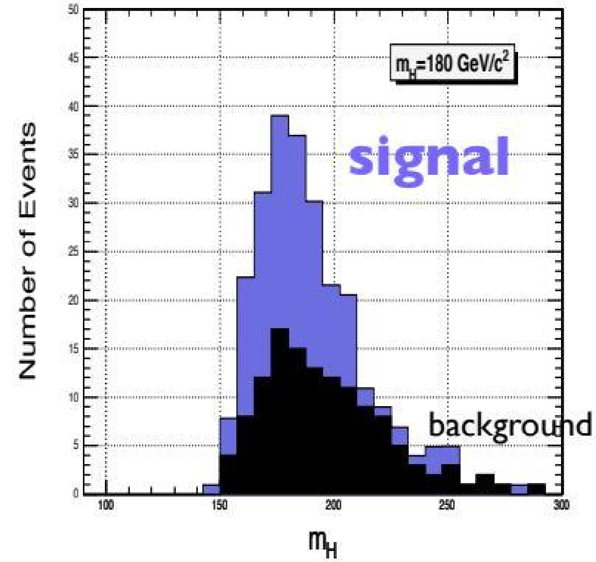


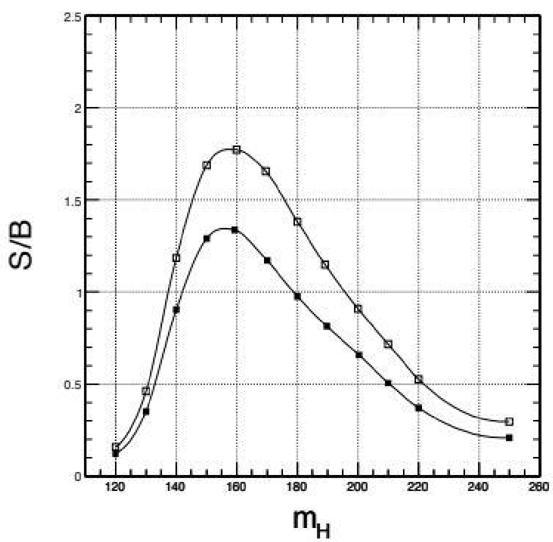


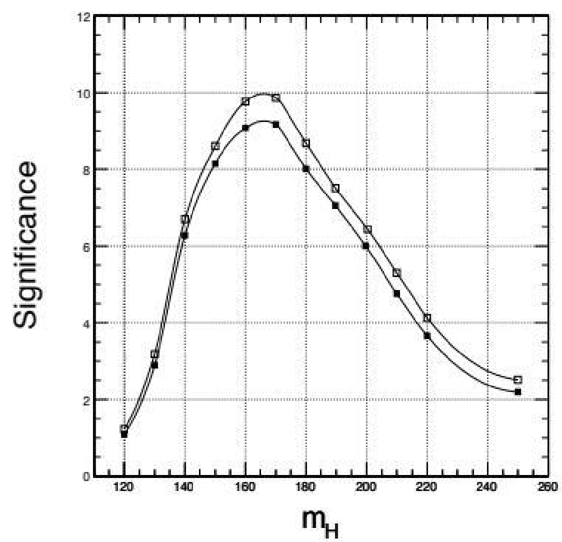
Final Mass Plots



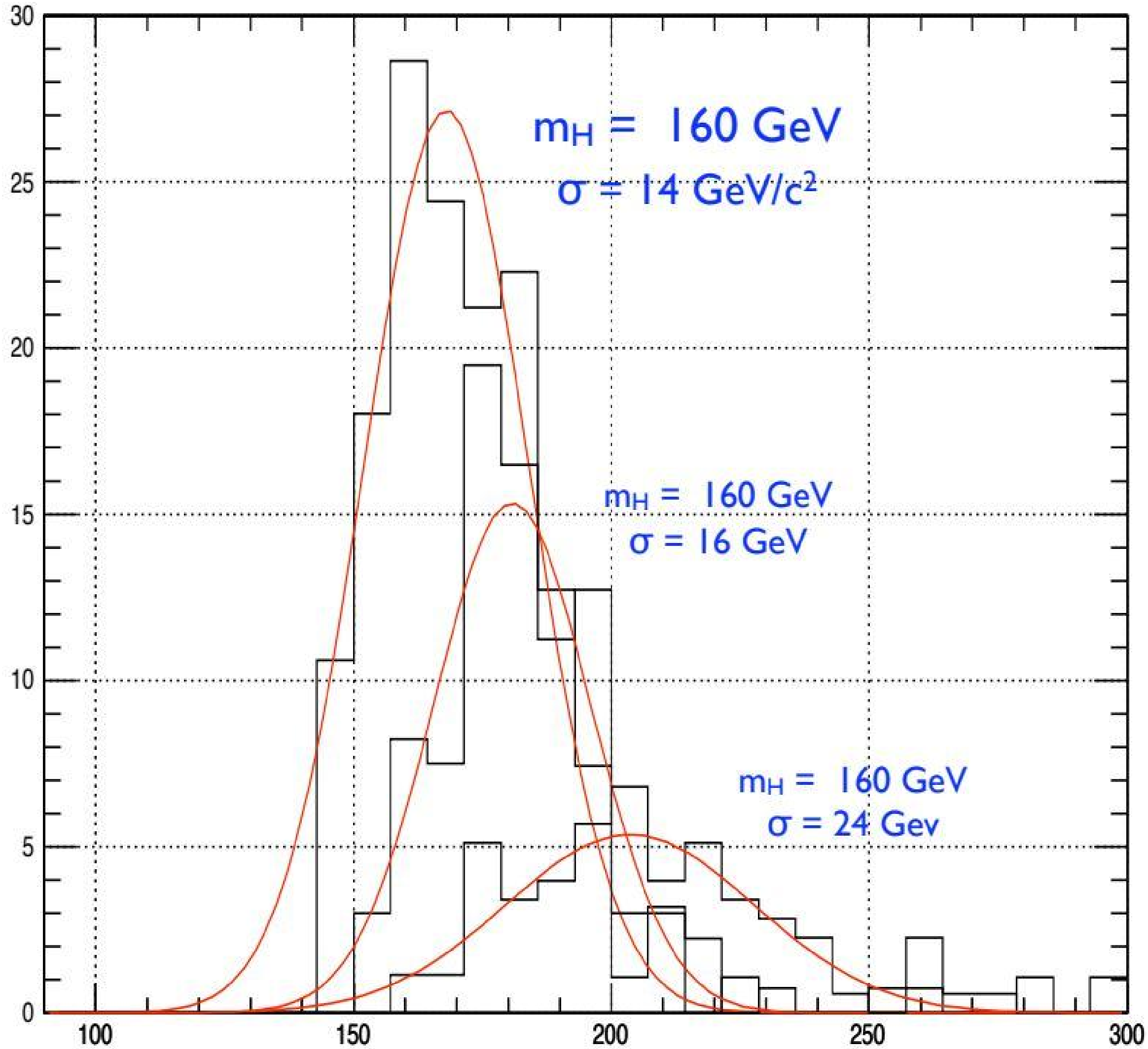






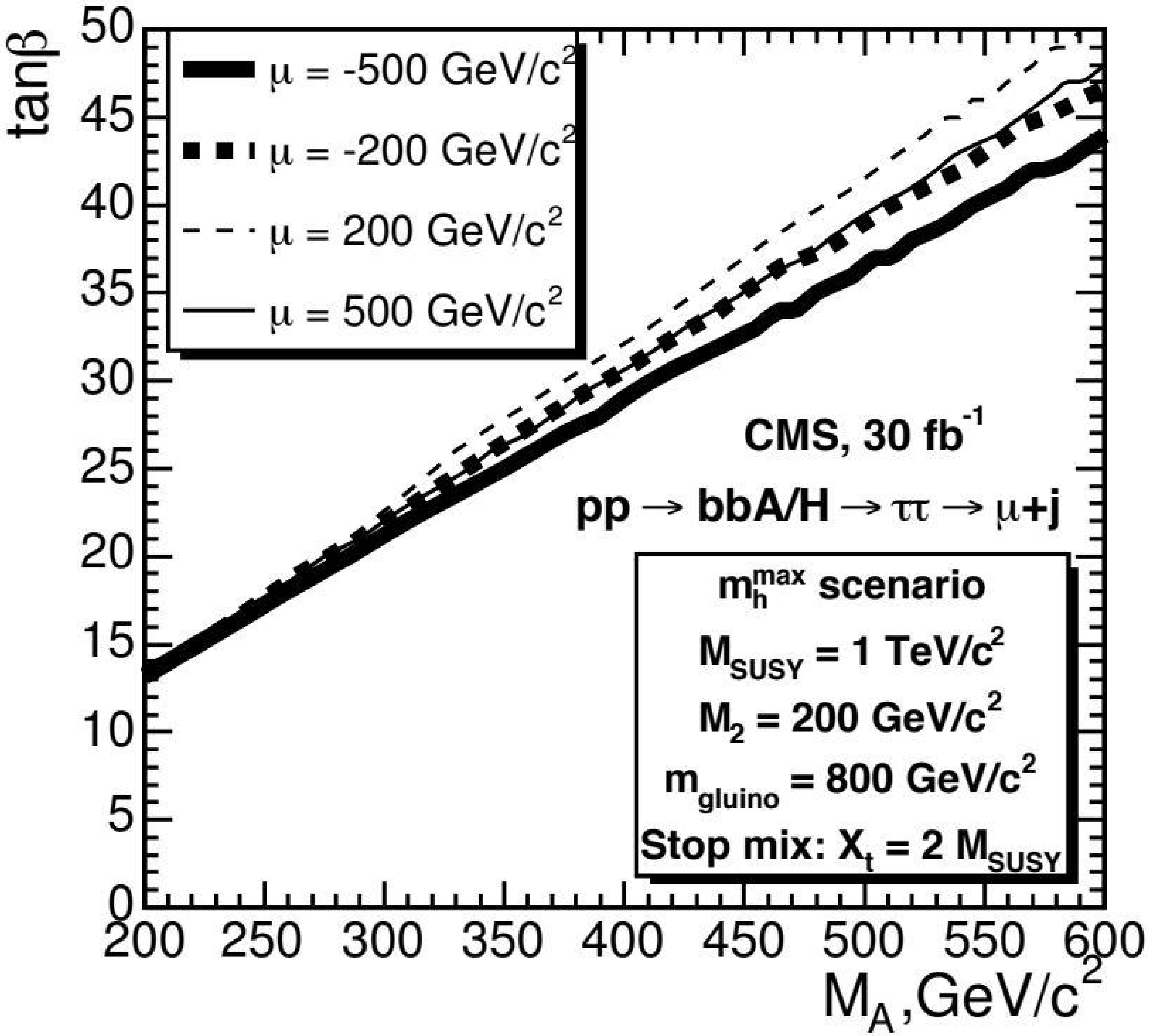


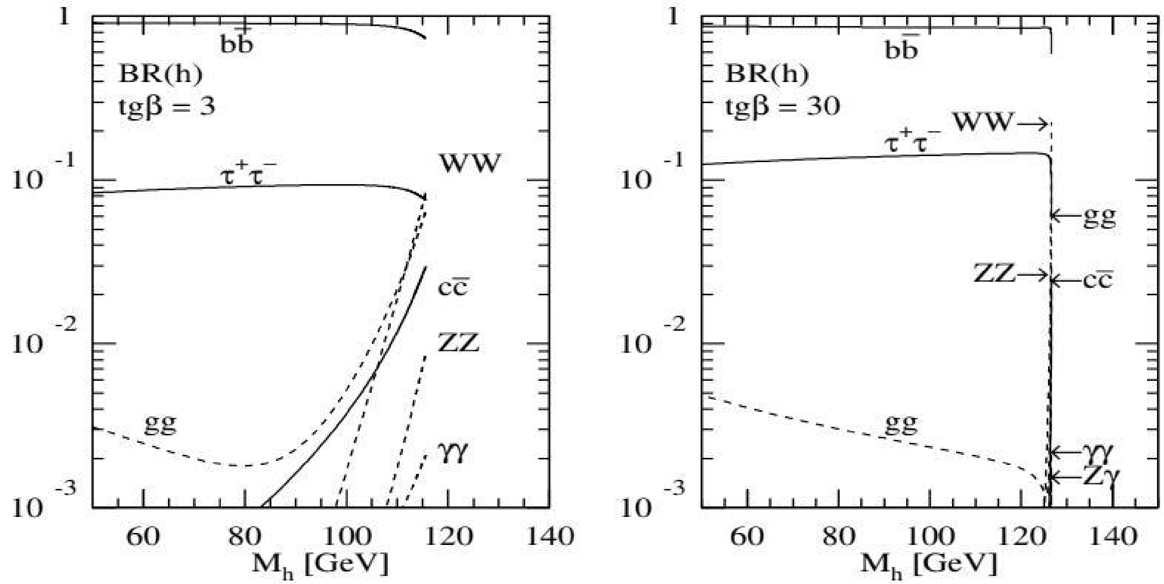
Mass Resolution



m_H

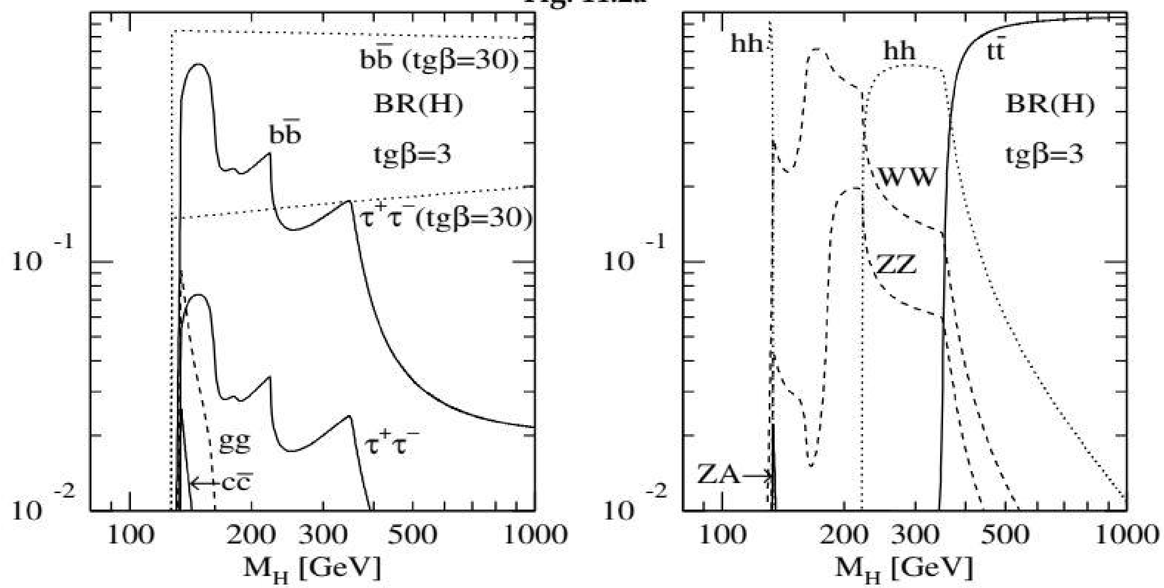
Example: MSSM Higgs reach





BR(h)
tgβ = 3
bb̄
τ⁺τ⁻
WW
cc̄
ZZ
gg
γγ
1
10 -1
10 -2
10 -3
60 80 100 120 140
M_h [GeV]
BR(h)
tgβ = 30
bb̄
τ⁺τ⁻
WW→
←gg
ZZ→
←cc̄
gg
←γγ
←Zγ

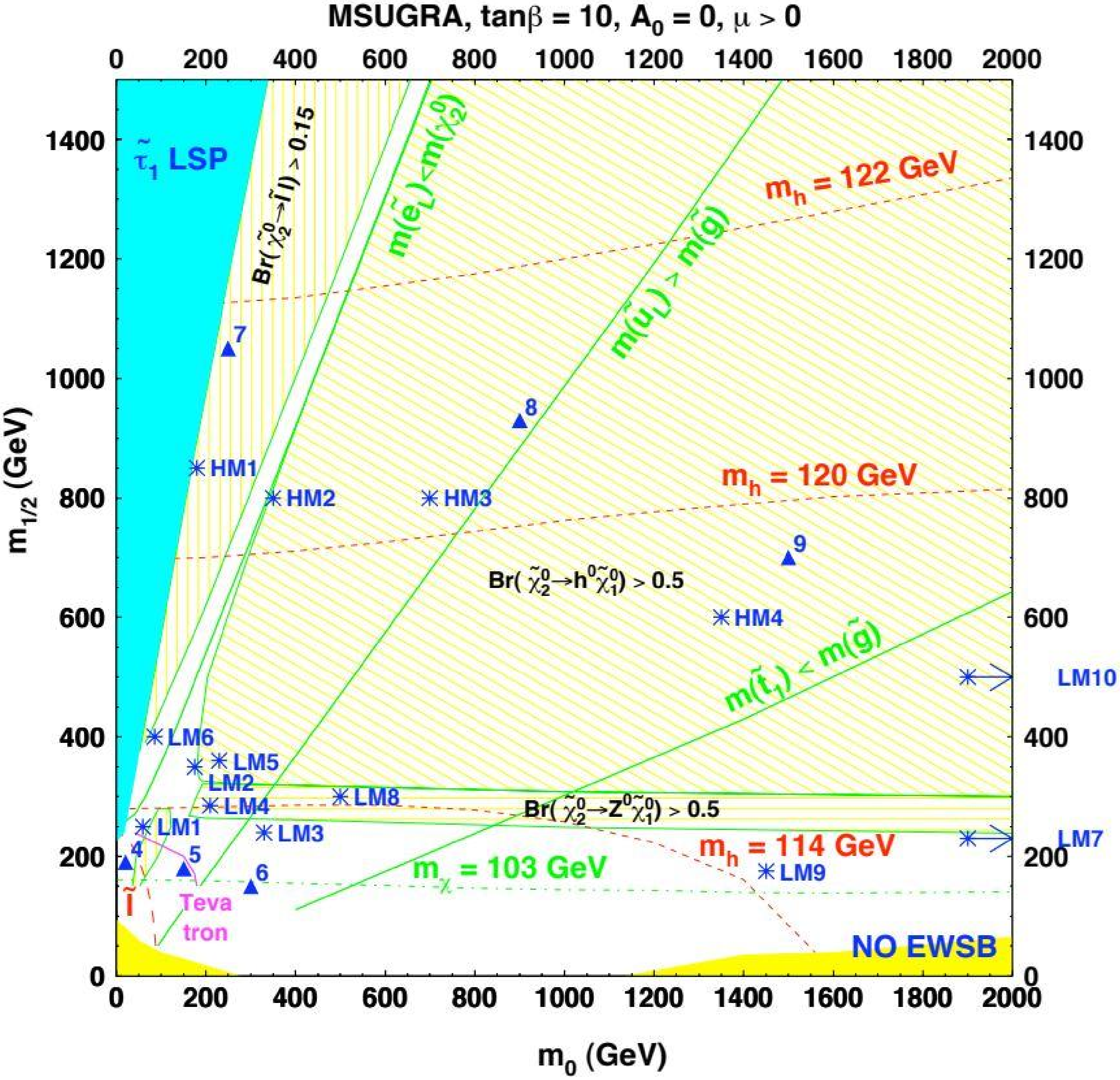
Fig. 11.2a



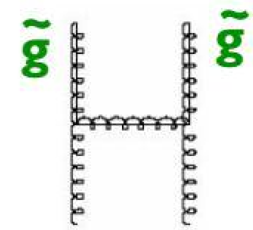
bb̄ (tgβ=30)
BR(H)
bb̄
tgβ=3
τ⁺τ⁻(tgβ=30)
gg
←cc̄
τ⁺τ⁻
10 -1
10 -2
100 200 300 500 1000
M_H [GeV]
hh
hh
tt̄
BR(H)
tgβ=3
WW
ZZ
ZA→

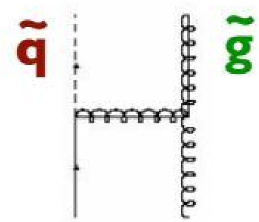
CMS SUSY-BSM:

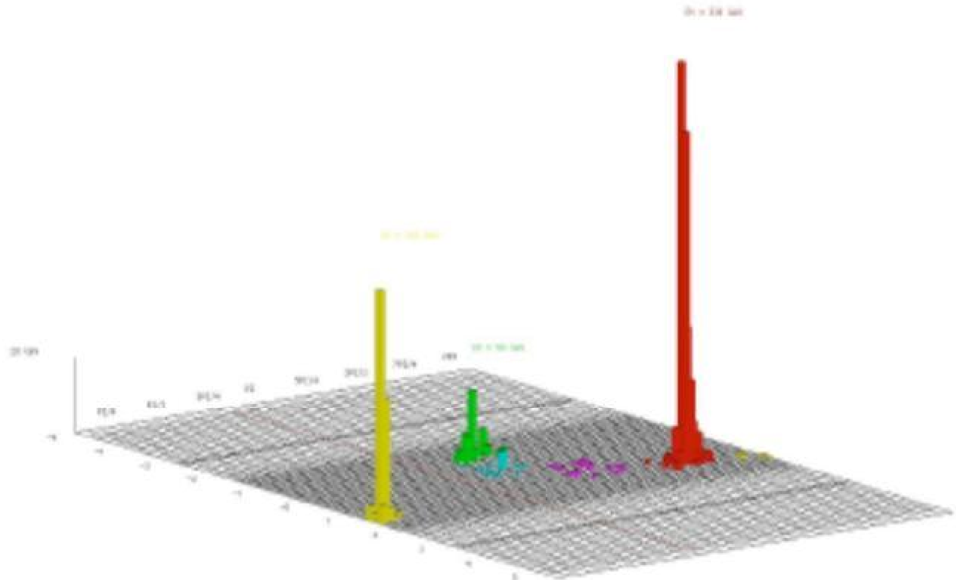
http://cmsdoc.cern.ch/cms/PRS/susybsm/

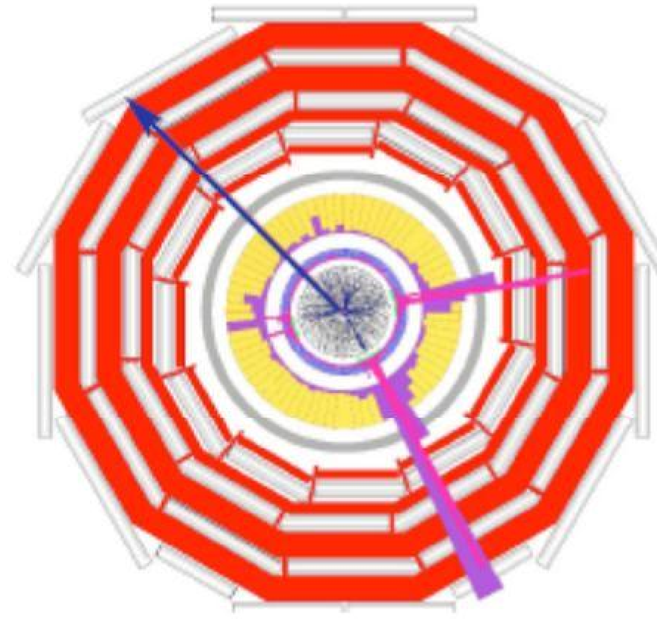


Typical diagrams









LM1

m_{gluino} = 611 GeV/c^2

m_{squark} = 411-559 GeV/c^2

LSP $m_{neutralino}$ = 95 GeV/c^2

```
*********************************************
*                                           *
* ISAJET     V7.69   21-AUG-2003 11:39:06 *
*                                           *
*********************************************


Minimal supergravity (mSUGRA) model:

M_0,  M_(1/2),  A_0,  tan(beta),  sgn(mu),  M_t =
   60.000   250.000    0.000    10.000     1.0   175.000

ISASUGRA unification:
M_GUT      = 0.228E+17   g_GUT          =0.715     alpha_GUT =0.041
FT_GUT     = 0.508       FB_GUT         = 0.049    FL_GUT = 0.069

1/alpha_em =  127.81     sin**2(thetaw) =0.2308    a_s^DRB   =  0.119
M_1        =   99.32     M_2            =  192.14  M_3       =  579.05
mu(Q)      =  335.53     B(Q)           =   44.17  Q         =  459.22
M_H1^2     = 0.274E+05   M_H2^2         =-0.114E+06 TANBQ    =    9.749

ISAJET masses (with signs):
M(GL)  =   611.32
M(UL)  =   558.61   M(UR)  =   541.95   M(DL)  =   564.69   M(DR) =   541.61
M(B1)  =   514.05   M(B2)  =   534.87   M(T1)  =   410.94   M(T2) =   575.84
M(SN)  =   168.45   M(EL)  =   188.57   M(ER)  =   118.88
M(NTAU)=   167.86   M(TAU1)=   110.58   M(TAU2)=   191.65
M(Z1)  =   -94.92   M(Z2)  =  -179.60   M(Z3)  =   341.26   M(Z4) =  -361.73
M(W1)  =  -179.54   M(W2)  =  -360.89
M(HL)  =   112.98   M(HH)  =   375.78   M(HA)  =   373.01   M(H+) =   383.83

theta_t=   1.0014   theta_b=   0.4202   theta_l=   1.3274   alpha_h=   0.1123

NEUTRALINO MASSES (SIGNED) =   -94.923  -179.596   341.261  -361.727
EIGENVECTOR 1        =   0.05745  -0.15189  -0.05775   0.98503
EIGENVECTOR 2        =   0.17110  -0.28767  -0.93597  -0.10921
EIGENVECTOR 3        =  -0.71050  -0.69518   0.09083  -0.06043
EIGENVECTOR 4        =   0.68015  -0.64101   0.33522  -0.11886

CHARGINO MASSES (SIGNED)  =  -179.542  -360.891
GAMMAL, GAMMAR             =   2.02360   1.83292
```

MET • 3 Jet

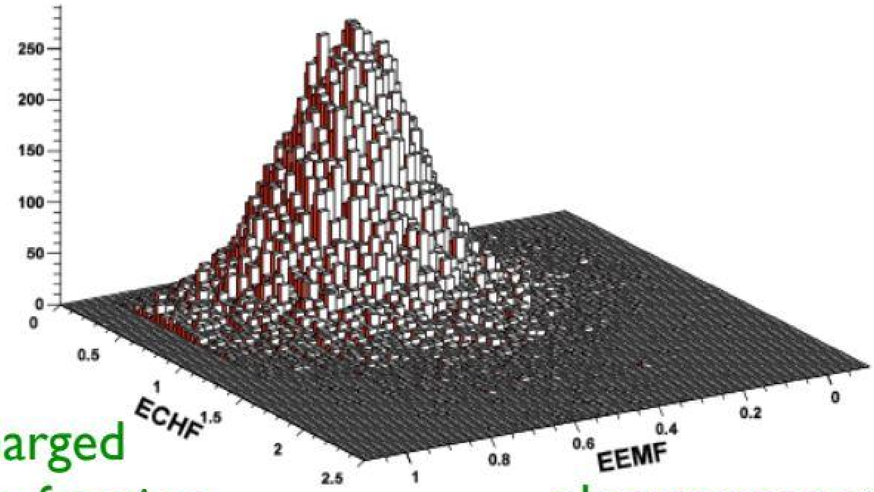
AN 2006/xx T. Yetkin et al. (to be released Apr. 10)

SUSY signal

Backgrounds

Sample	X-Sec(fb)	Gen.($\times 10^3$)	Used ($\times 10^3$)
LM1	4.90×10^4	495	451
$t\bar{t}$	4.92×10^5	3488	1205
single t	2.59×10^5	99	99
QCD($120 < \hat{p}_T < 170$)	4.99×10^8	300	289
QCD ($170 < \hat{p}_T < 230$)	1.01×10^8	370	348
QCD ($230 < \hat{p}_T < 300$)	2.38×10^7	394	374
QCD ($300 < \hat{p}_T < 380$)	6.39×10^6	296	239
QCD ($380 < \hat{p}_T < 470$)	1.90×10^6	199	185
QCD ($470 < \hat{p}_T < 600$)	6.90×10^5	198	167
Z + jets ($75 < \hat{p}_T < 125$)	1.25×10^5	149	147
Z + jets ($125 < \hat{p}_T < 200$)	2.70×10^4	99	93
Z + jets ($200 < \hat{p}_T < 350$)	5.43×10^3	50	48
Z + jets ($350 < \hat{p}_T < 550$)	6.44×10^2	36	34
W + jets ($75 < \hat{p}_T < 125$)	9.45×10^5	285	282
W + jets ($125 < \hat{p}_T < 200$)	2.15×10^5	181	164
W + jets ($200 < \hat{p}_T < 350$)	4.38×10^4	97	88
W + jets ($350 < \hat{p}_T < 550$)	4.28×10^3	79	77
WW + jets (inclusive)	1.88×10^5	495	457
ZZ + jets (inclusive)	1.11×10^4	491	479
ZW + jets (inclusive)	2.69×10^4	280	266
Z + jets (invisible)	1.25×10^4	100	86

Cleaning up the events



charged energy fraction

electromagnetic energy fraction

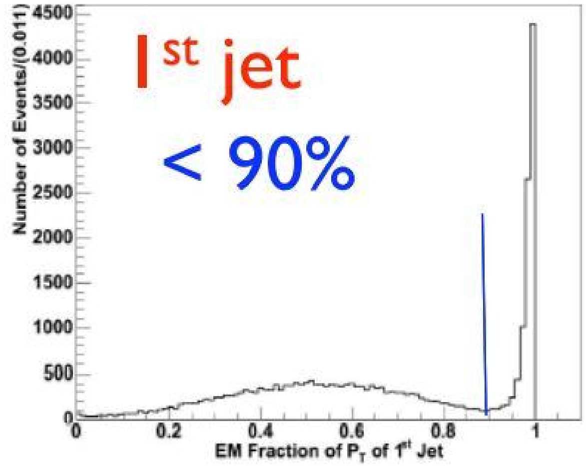
preemptive strike against:

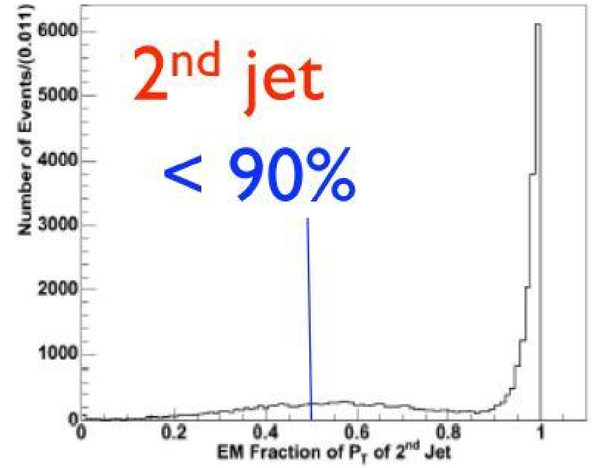
- Beam Halo Particles
- Data Acquisition problems
- Detector problems (dead channels, cracks etc.)
- Cosmic Rays
- Everything that goes wrong

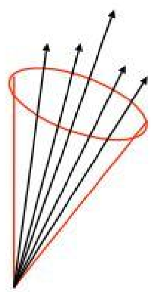
Pre-Selection: Clean-up Requirements.
at least one jet with $\lvert\eta_d\rvert < 1.7$ and $N_{trk} \geq 4$
$\mathrm{ECHF} \geq 0.175$
$\mathrm{EEMF} \geq 0.1$

Lepton Veto

EM Fraction







$$P_{isol} = \frac{\sum_{i \neq \text{Lead Trk}}^{N^{\text{Trks}}} P_T^{i\text{Trk}}}{P_T^{i\text{Lead Trk}}}$$

> 10%

Leading track isolation

	Base. Req.	EMF(1)&&EMF(2)	$\text{Iso}^{lead\ trk} = 0$	Both
Sample	(N_{events})	(%)	(%)	(%)
$W(\to e\nu)+ \geq 2$ jets	28090	86.04	39.25	89.32
$W(\to \mu\nu)+ \geq 2$ jets	8038	10.69	53.42	58.17
$W(\to \tau\nu)+ \geq 2$ jets	19324	23.08	20.27	39.28
$Z(\to ee)+ \geq 2$ jets	19855	94.57	57.29	97.11
$Z(\to \mu\mu)+ \geq 2$ jets	5474	15.16	75.44	79.06
$Z(\to \tau\tau)+ \geq 2$ jets	16742	26.32	28.71	48.27

Rejecting QCD

Angle between E_T^{miss} and 2nd jet

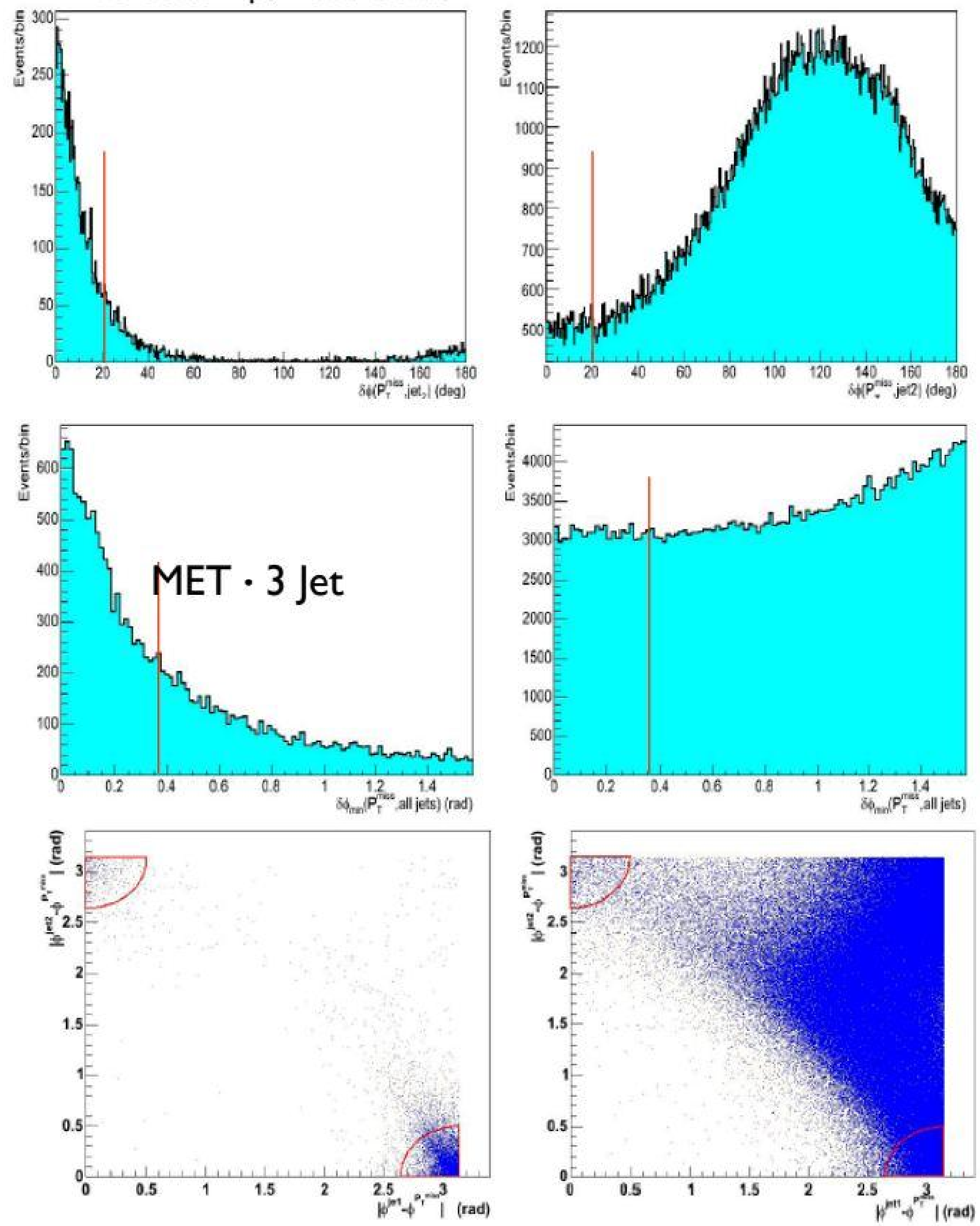
Angle between E_T^{miss} and closest jet

Correlation of angle between E_T^{miss} and 1st jet, E_T^{miss} and 2nd jet

QCD

470 Gev/c < p_T < 600 GeV/c

LM1



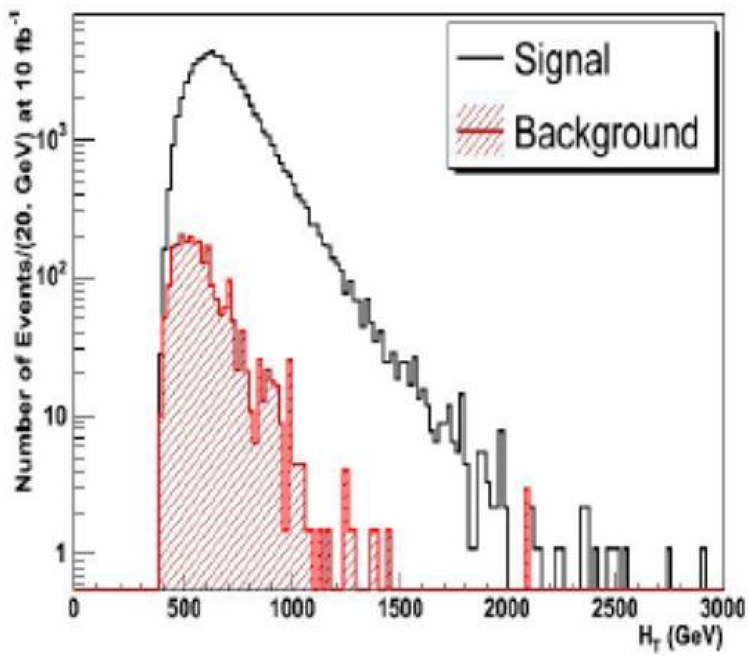
Events per 10 fb^{-1}

Cut/Sample	Signal	$t\bar{t}$	single t	$Z(\rightarrow \nu\bar{\nu})$+ jets	W/Z, $WW/ZZ/ZW$+ jets
All	489998	8.30e+06	259301	125302	1.584e+07
L1 Trig. Par	450027	3.36e+06	75818	125139	9.102e+06
HLT Offline $P_T^{miss} > 200$ GeV	264990	46955	508	67310	136118
Num. P.V.C >0	264088	46769	502.886	66776	134835
Num. Jets ≥ 3	190297	30128	165	4801	15864
$\lvert\eta_d(1^{st} jet)\rvert \geq 1.7$	167665	25148	115	3692	10774
EEMF ≥ 0.175	167471	25141	115	3680	10728
ECHF ≥ 0.1	164071	24012	113	3583	10065
$\delta\phi_{min} > 20^0$	130054	16207	73	3138	6504
$\delta\phi(P_T^{miss}, 2^{nd} jet) > 20^0$	128952	15677	65	3114	6295
2D $\delta\phi$ $R1 > 0.5$	126829	14479	58	3048	5965
2D $\delta\phi$ $R2 > 0.5$	126795	14444	55	3048	5965.09
$Iso^{lead\ trk} = 0$	112106	7666	37	2914	3554
$EMF(j1).or.EMF(j2) \geq 0.9$	108128	7198	34	2794	3141
$P_{T,1} > 180$ GeV, $P_{T,2} > 110$ GeV	68075	1267	8	590	541
Final Eff.(%)	13.89	0.015	0.03	0.47	0.003

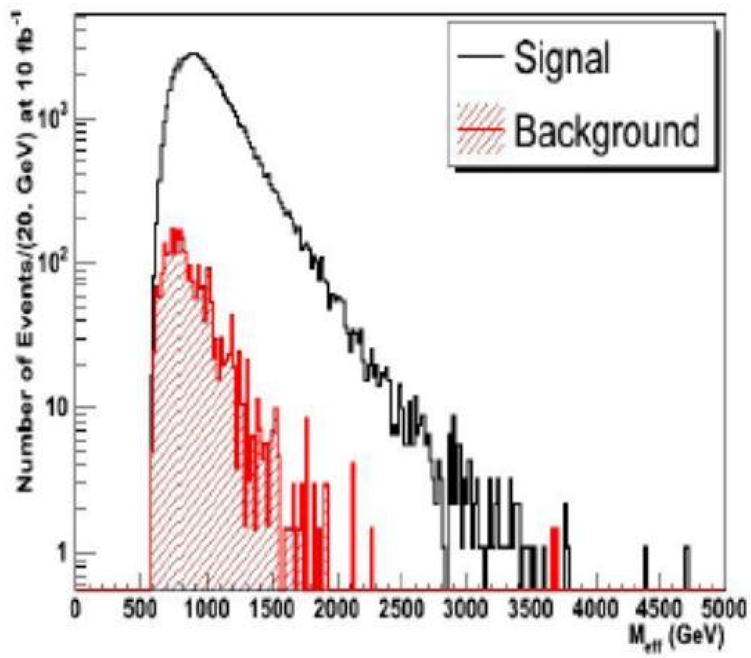
S/B = 30 so can (in principle) see signal in 1 pb^{-1}

$$H_T = P_{T,2} + P_{T,3} + P_{T,4} + P_T^{miss}$$

$$M_{eff} = P_{T,1} + P_{T,2} + P_{T,3} + P_{T,4} + P_T^{miss}$$

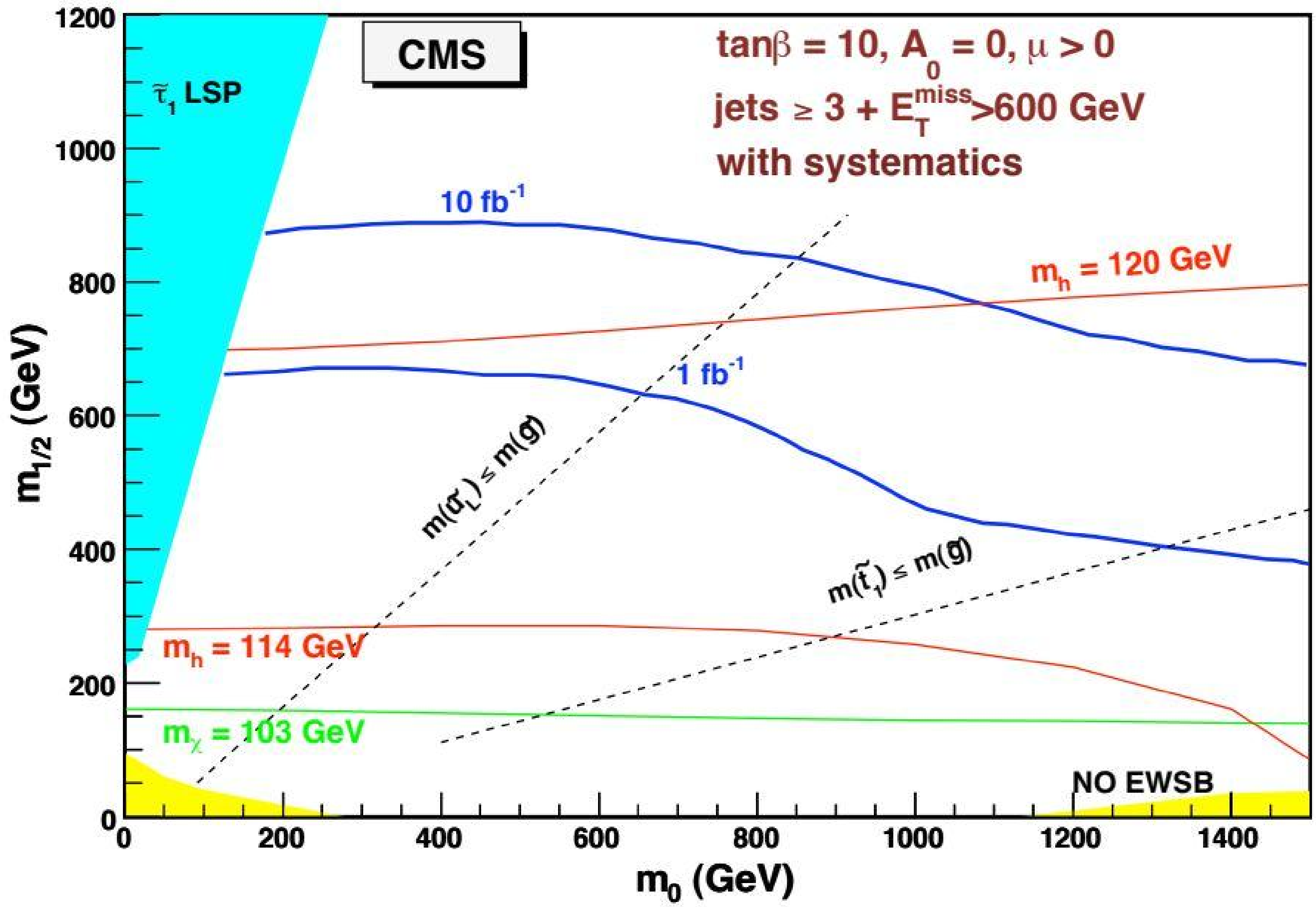


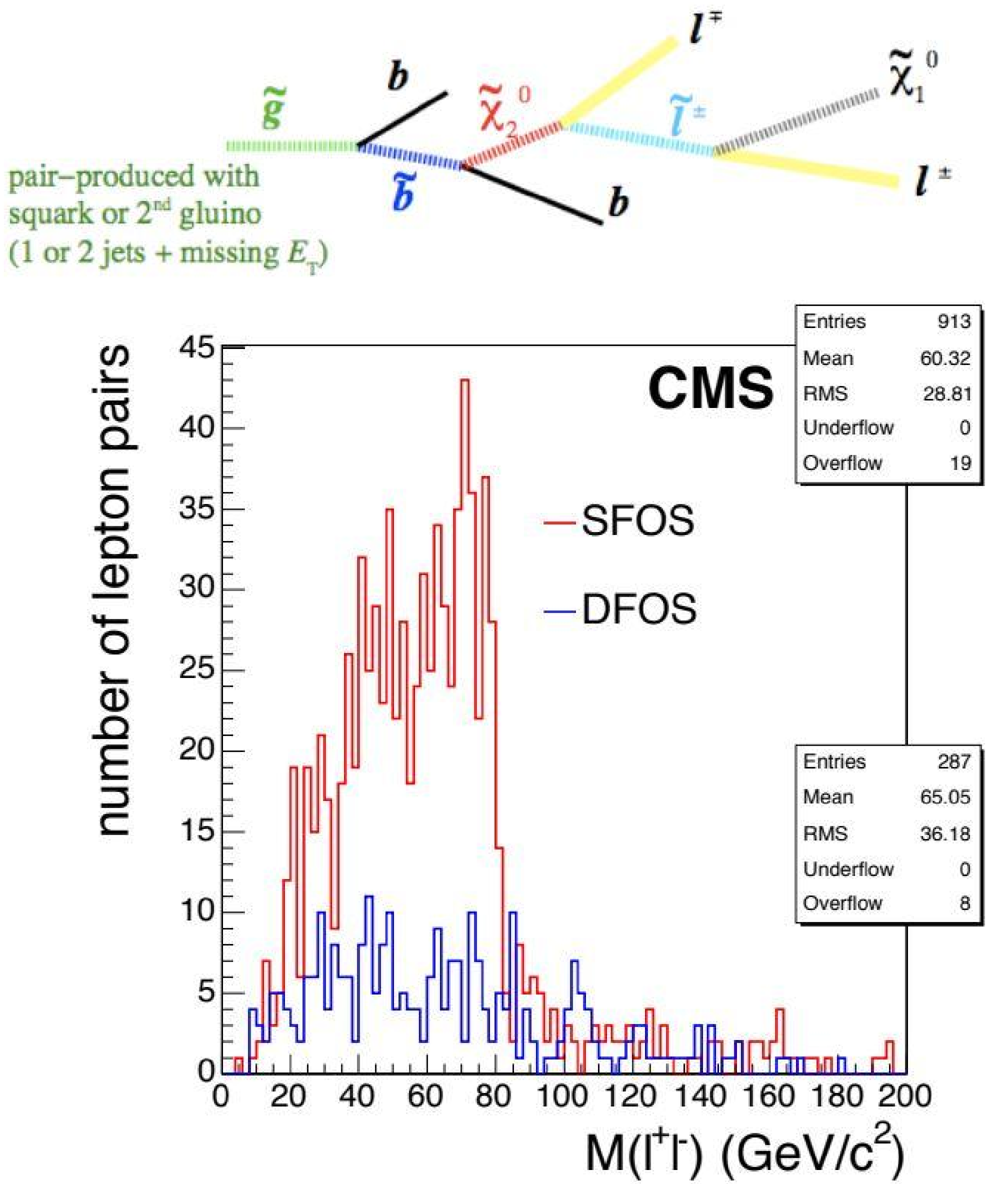
H_T



M_{eff}

Example: SUSY reach




b
b
pair–produced with
squark or 2nd gluino
(1 or 2 jets + missing E_T)
Entries 913
Mean 60.32
RMS 28.81
Underflow 0
Overflow 19
CMS
SFOS
DFOS
Entries 287
Mean 65.05
RMS 36.18
Underflow 0
Overflow 8
number of lepton pairs
M(l+l-) (GeV/c2)

Jet Cross Section

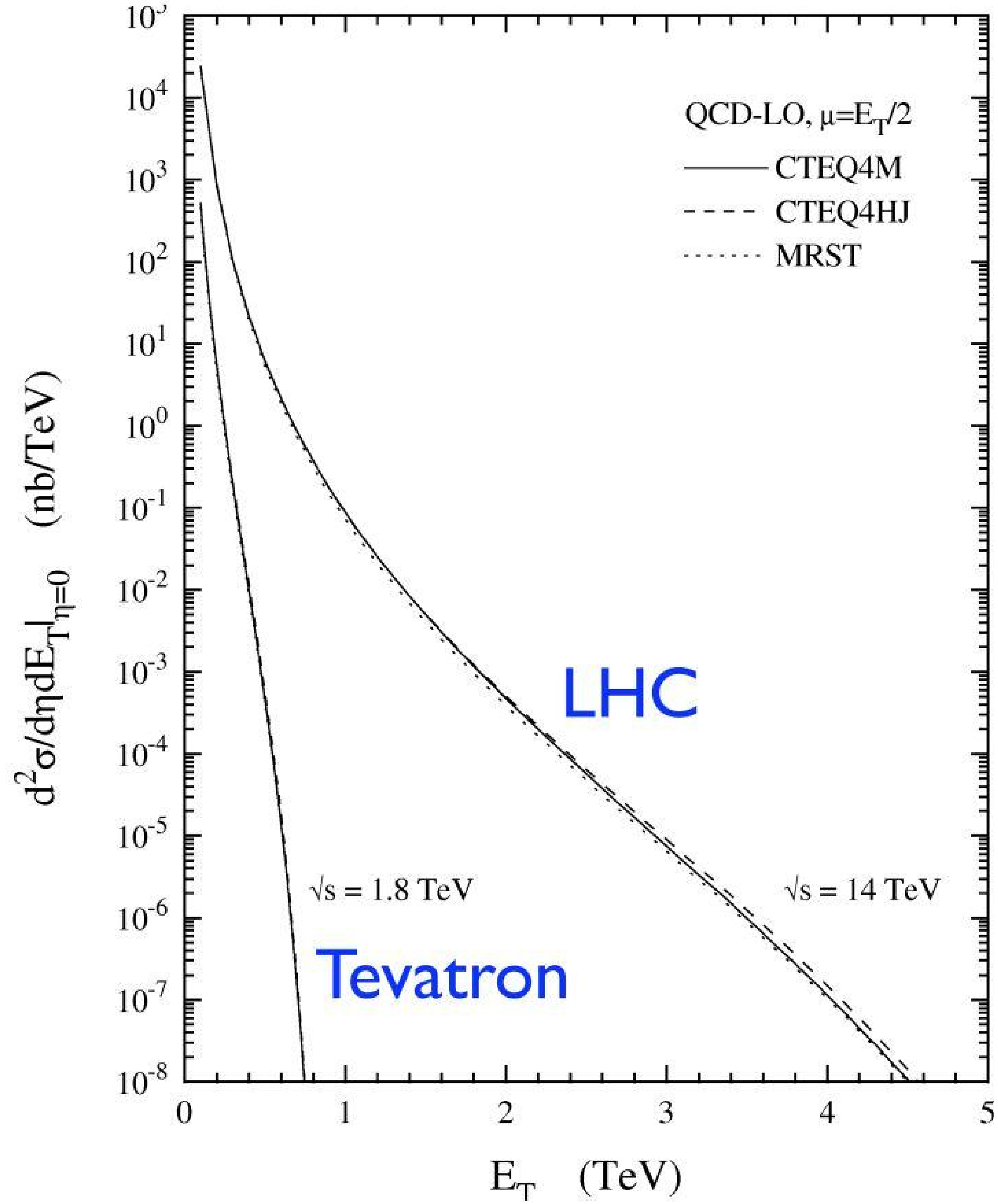
$\mathcal{L} = 2 \times 10^{24}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
φ calibration

$\mathcal{L} = 2 \times 10^{25}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
σ measurement

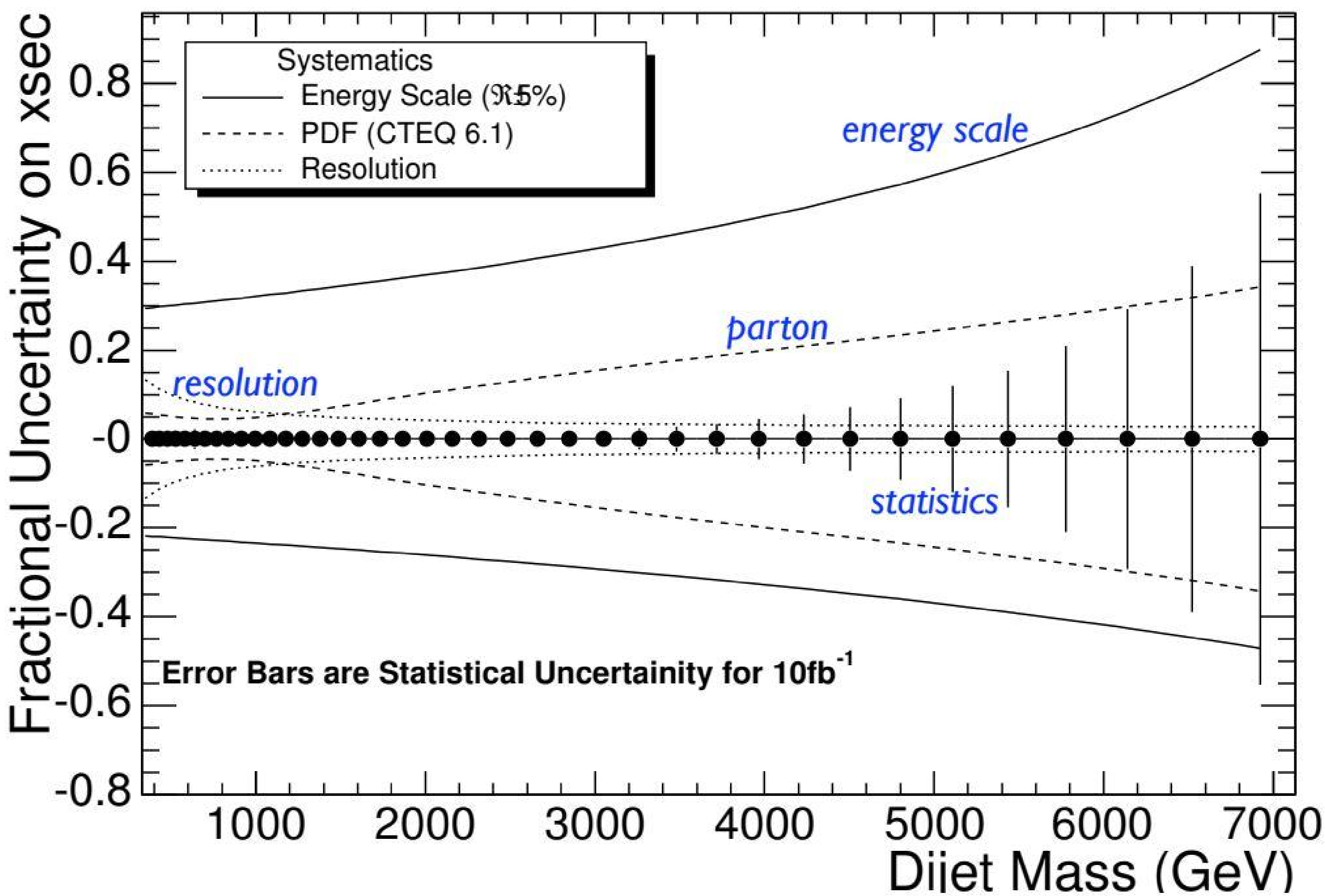
$\mathcal{L} = 2 \times 10^{26}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
η calib., MET studies

$\mathcal{L} = 2 \times 10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
m_{jj} > 2 TeV

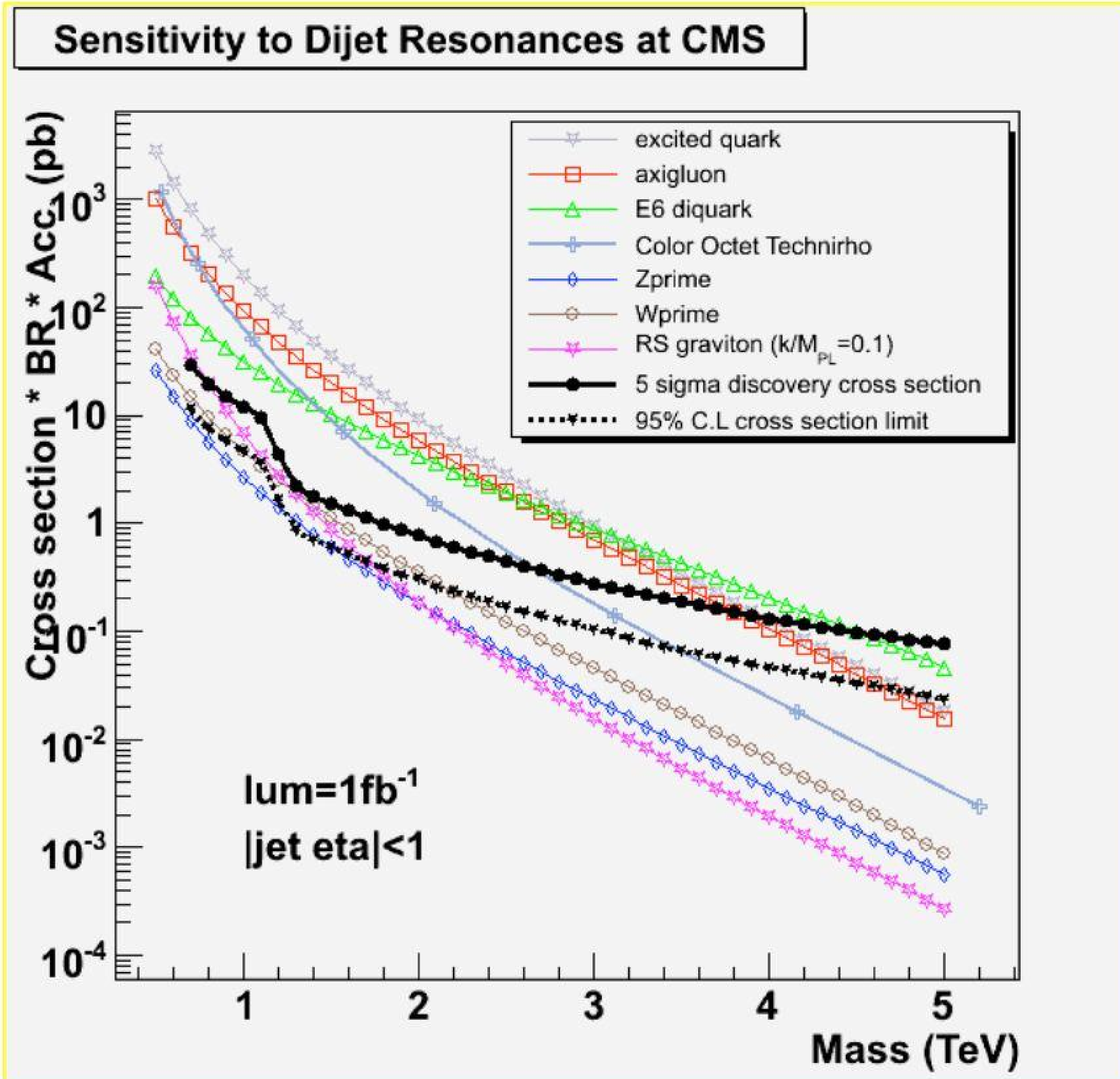
Design luminosity
$\mathcal{L} = 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
top at 10 Hz,
W at 1 kHz



Expected error on dijet cross section*

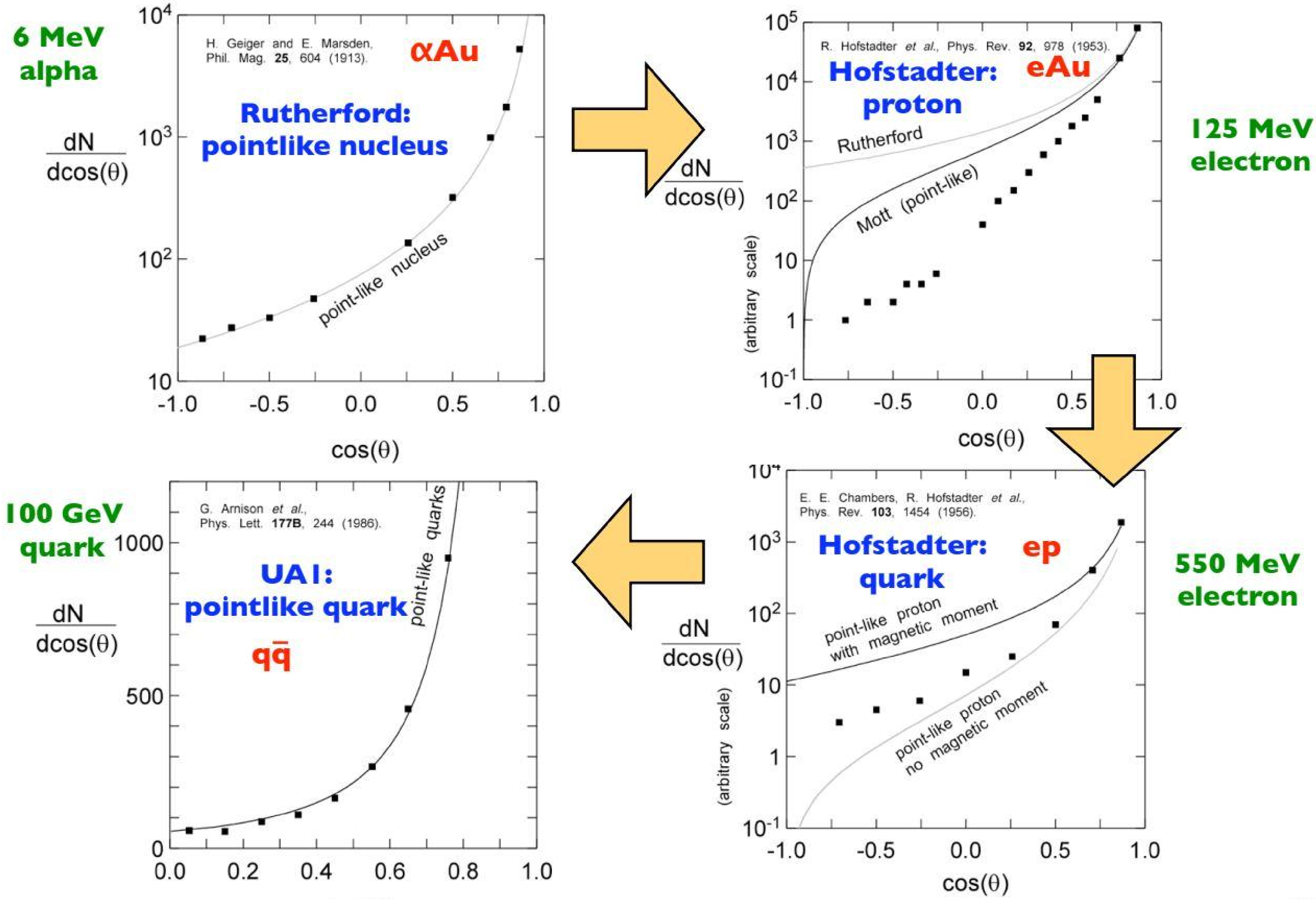


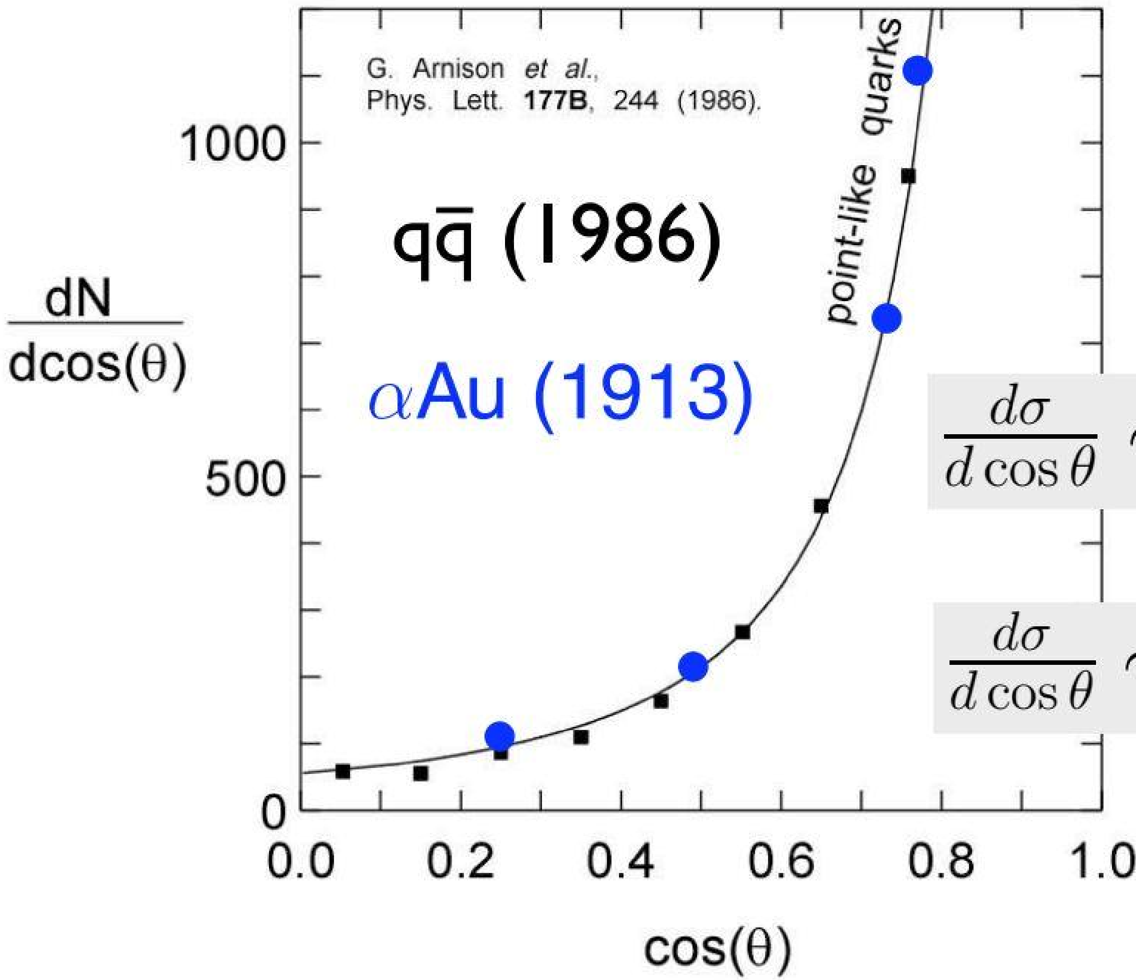
*Does not include luminosity error.


Sensitivity to Dijet Resonances at CMS
Cross section * BR * Acc. (pb)
Mass (TeV)
excited quark
axigluon
E6 diquark
Color Octet Technirho
Zprime
Wprime
RS graviton (k/M_PL=0.1)
5 sigma discovery cross section
95% C.L cross section limit
lum=1fb-1
|jet eta|<1

History of compositeness

J. Rohlf: Modern Physics from α to Z^0





Electromagnetism

$$\frac{d\sigma}{d\cos\theta} \sim \alpha^2 \left(\frac{\hbar c}{E_\mathrm{k}}\right)^2 \frac{1}{(1-\cos\theta)^2}$$

QCD

$$\frac{d\sigma}{d\cos\theta} \sim \alpha_s^2 \left(\frac{\hbar c}{E_\mathrm{CM}}\right)^2 \frac{1}{(1-\cos\theta)^2}$$

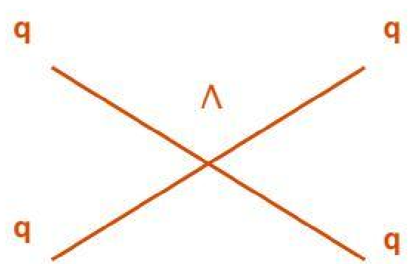
$$\frac{d\hat{\sigma}(q_i q_i \to q_i q_i)}{d\cos\theta^*} =$$

$$\frac{\pi}{2\hat{s}}\left\{\underbrace{\frac{4}{9}\alpha_S^2\left[\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{s}^2}{\hat{u}^2}-\frac{2}{3}\frac{\hat{s}^2}{\hat{t}\hat{u}}\right]}_{\text{QCD}}+\underbrace{\frac{8}{9}\alpha_S\frac{A}{\Lambda^2}\left[\frac{\hat{s}^2}{\hat{t}}+\frac{\hat{s}^2}{\hat{u}}\right]+\frac{8}{3}\frac{\hat{s}^2}{\Lambda^4}}_{\text{New Physics}}\right\}$$

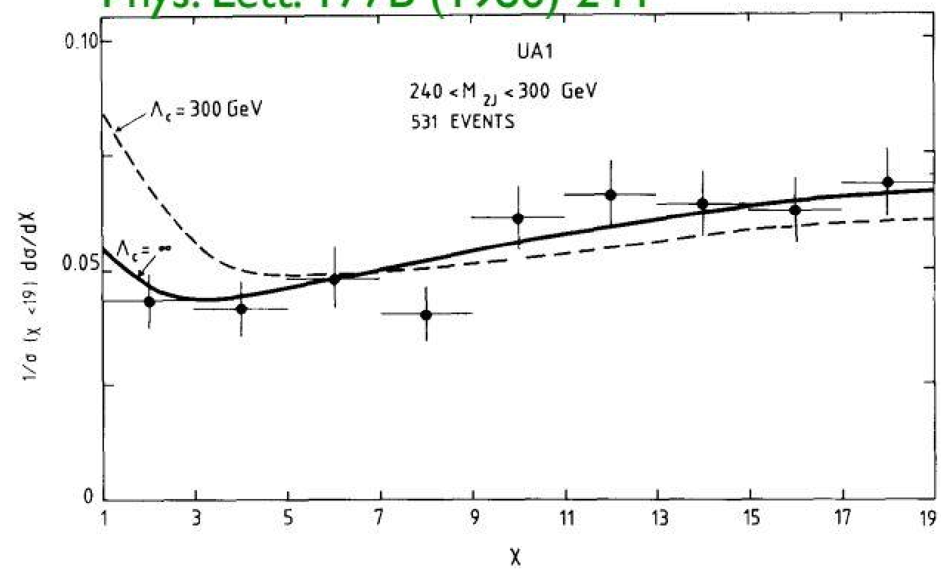
can be positive or negative

$$\hat{t} = \hat{s}(1-\cos\theta^*)/2$$

$$\hat{u} = \hat{s}(1+\cos\theta^*)/2$$

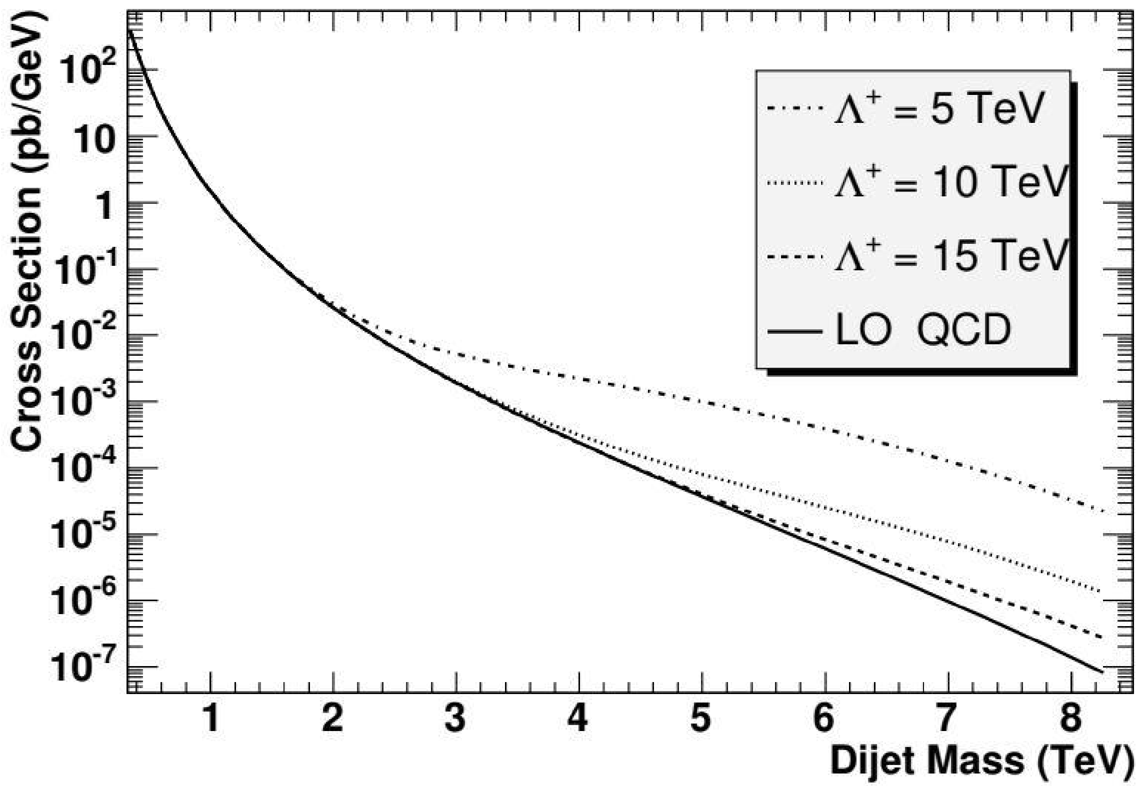


Phys. Lett. 177B (1986) 244



$$\frac{1+\cos\theta^*}{1-\cos\theta^*}$$

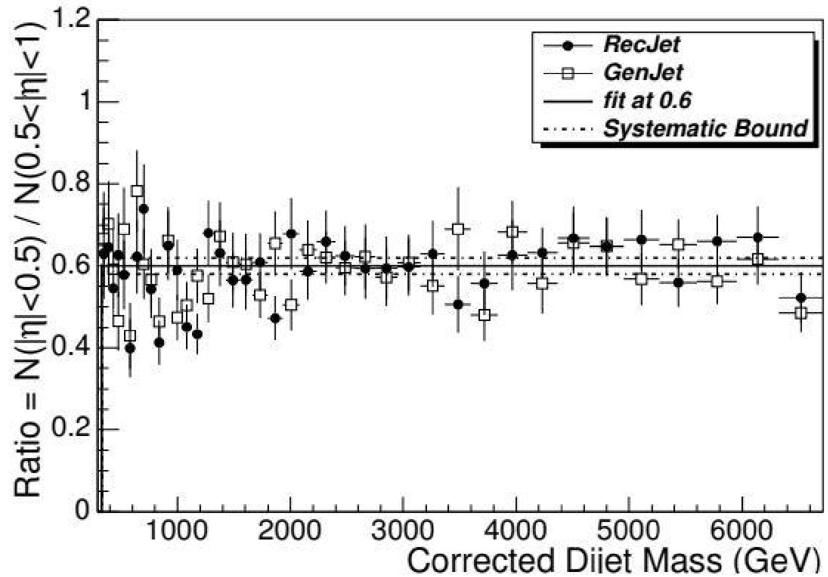
Dijet Cross Section

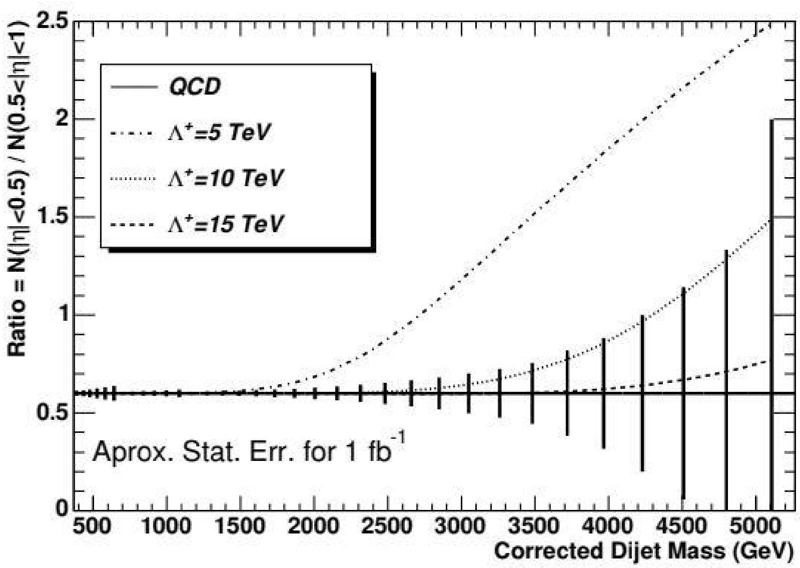


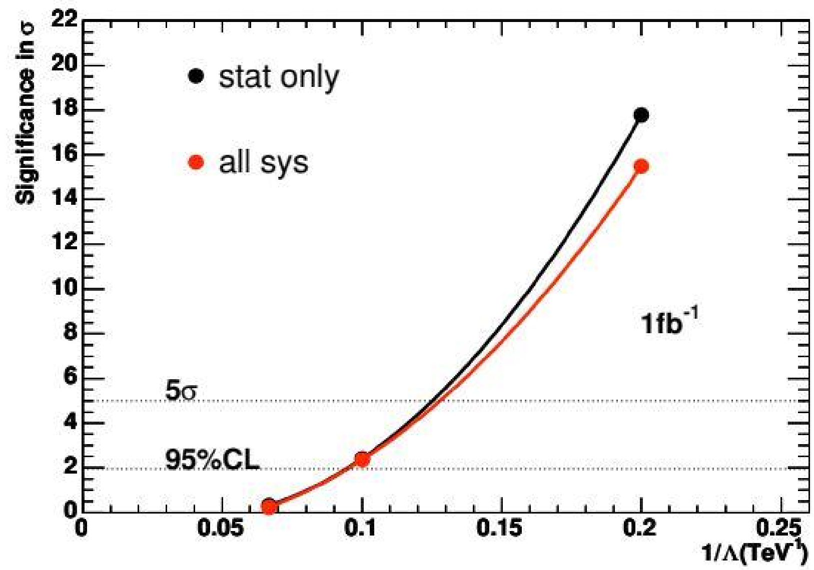
Deviations from QCD

Dijet Ratio

N(|η|<0.5) / N(0.5<|η|<1)







	95% CL Excluded Scale			5σ Discovered Scale		
	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}
Λ^+(TeV)	<6.4	<10.6	<15.1	<4.7	<8.0	<12.2

Then

M. Veltman (SLAC Accelerator Summer School, 1982) quoted by Leon Lederman:

"The outstanding problems in today's theory of particles are such that none of the projections beyond the standard model can be considered with any confidence. What we need is experimental guidance: exposure to the no-mans land of lepton-lepton or quark-quark collisions up to the mass range of 1 TeV and beyond."

Now

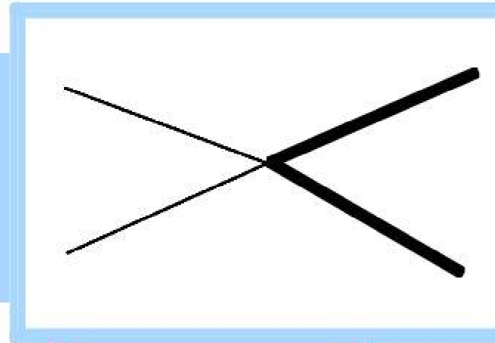
From: "M.J.G. Veltman"
To: James Rohlf

Dear Jim;
Well, you know as well as I do that essentially nothing has changed. Supersymmetry and strings have not come closer to reality. The Higgs is more elusive than ever. I am happy to see that I saw that correctly in 1982.
Best wishes,
Tini

Summary

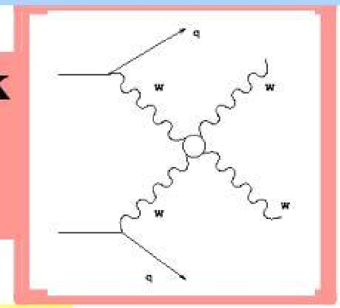
Big Picture:

FIRST look at the TeV mass scale to find a clue to the hierarchy problem...
(*What lies between the weak scale and the Planck mass?*)



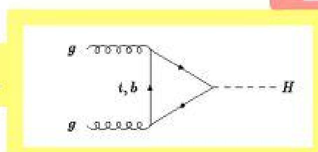
Medium Picture:

EXPLORE the mechanism for electroweak symmetry breaking...
(*How do W/Z interact at high energies?*)



Small Picture:

NAIL down the elusive Higgs...



LHC physics will be exciting!

LHC physics is even coming soon!