Hunting for Terascale physics at the LHC

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2 December 2010

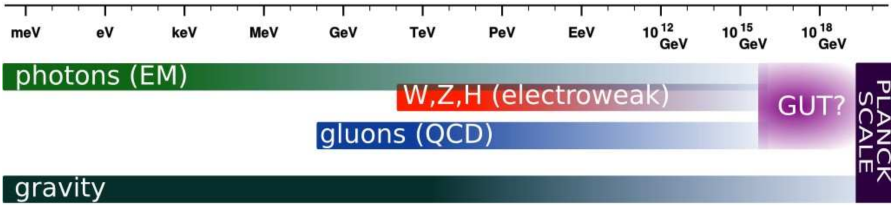
The LHC has been colliding protons for about a year now

The world's largest fundamental physics endeavour

Involving $\mathcal{O}(10\,000)$ scientists and engineers
From about 60 countries across the world
At a cost of several billion US dollars

What brought us here?
At what stage is the LHC today?
And what are the prospects and challenges for the years ahead?

The scales at play



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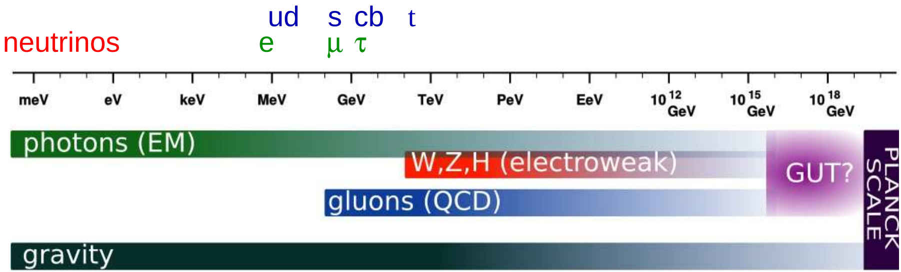

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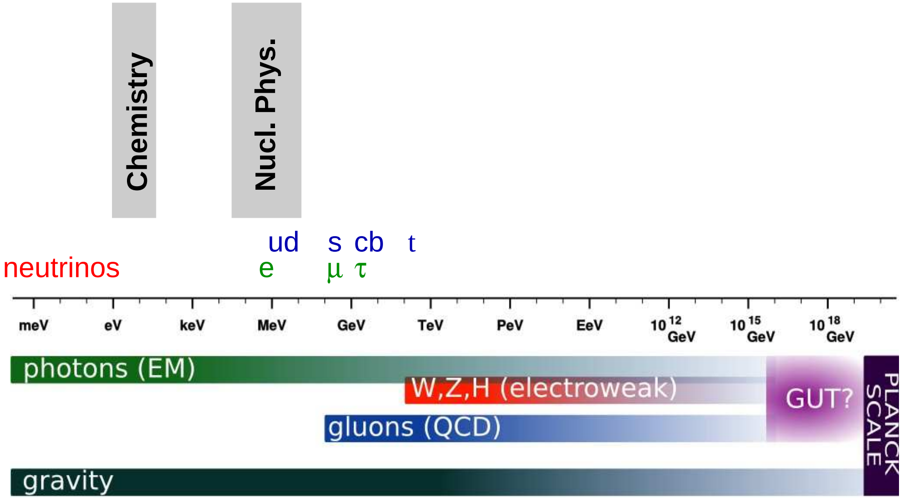

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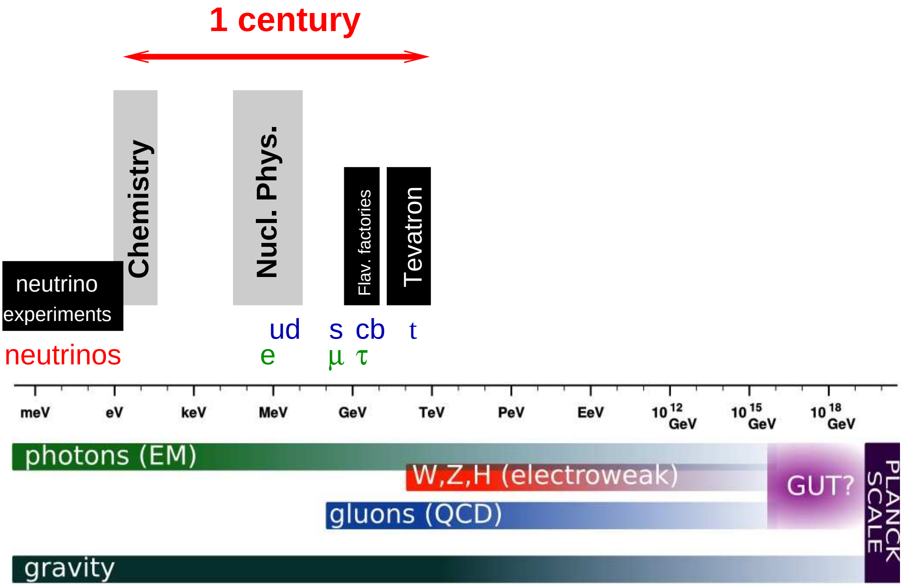

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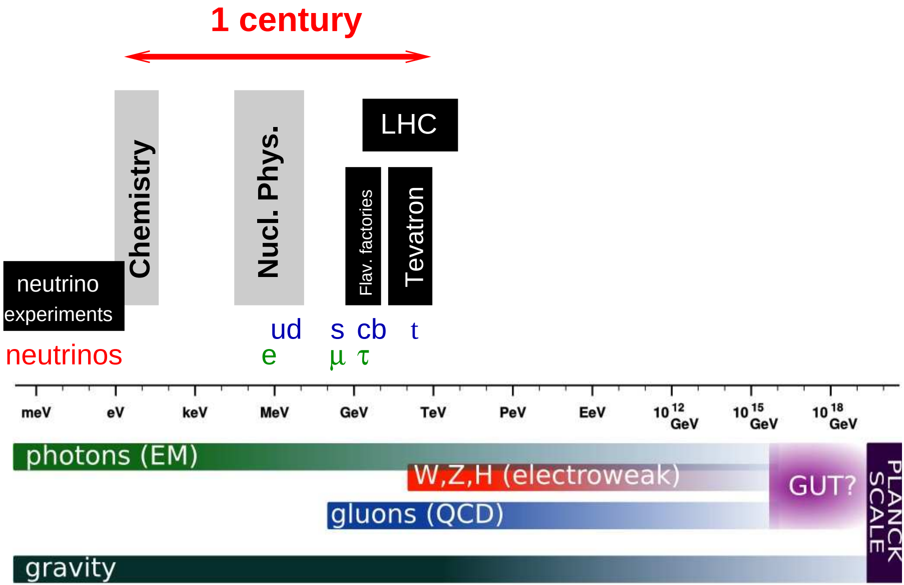

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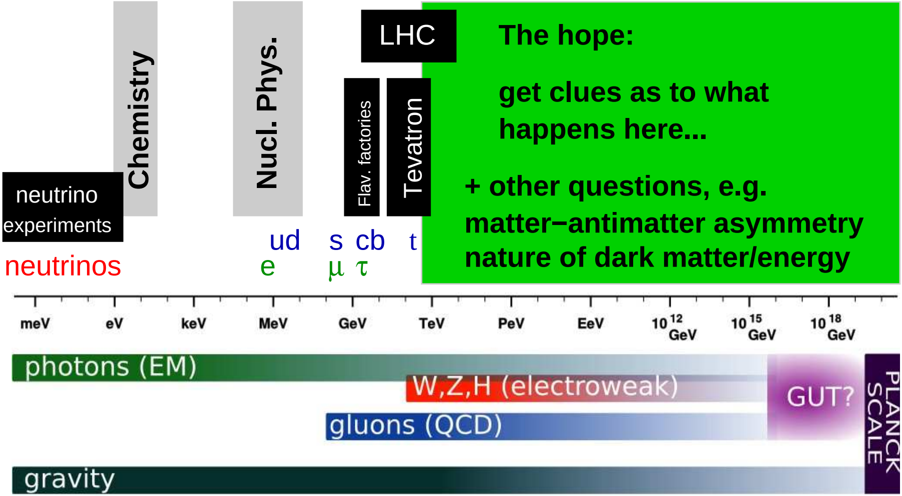

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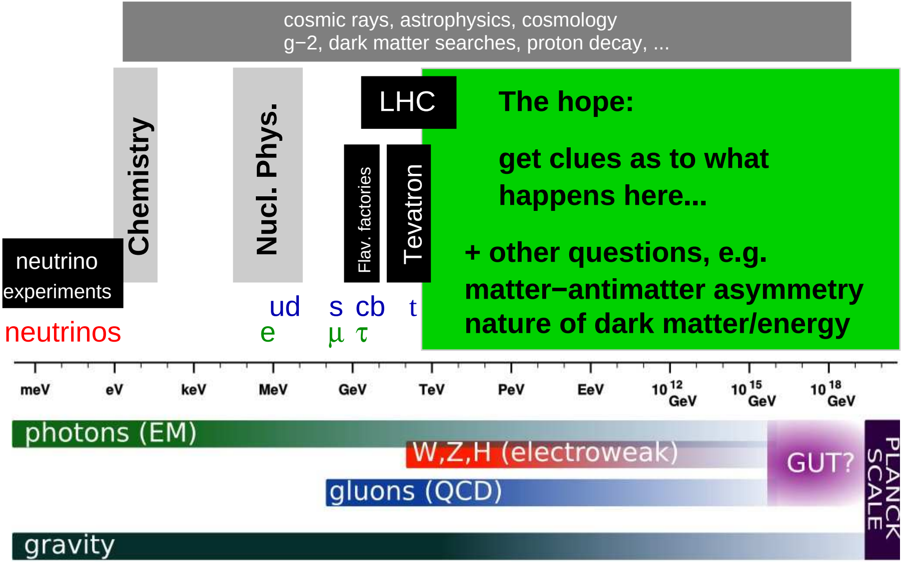

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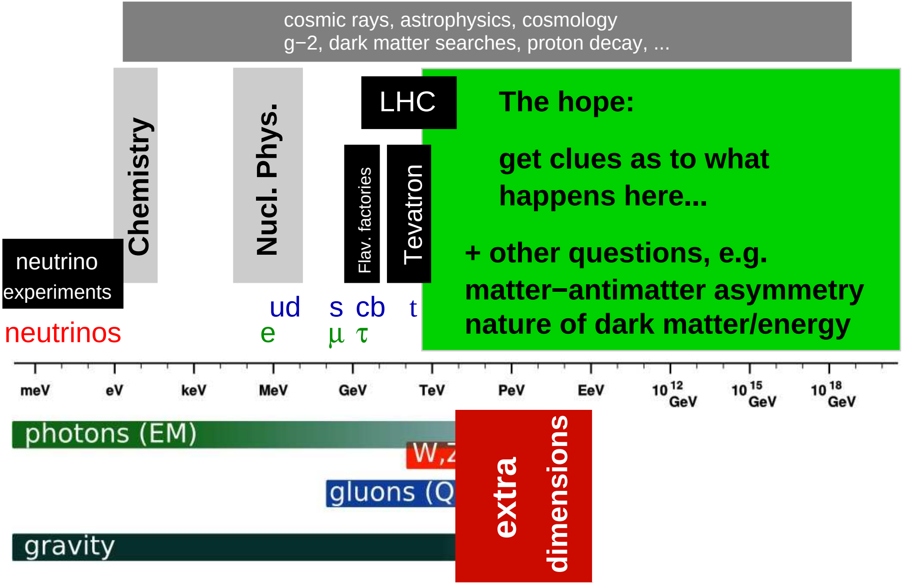

Energy–frontier colliders of the past 25 years

Collider	Lab	Date	Collided		C.o.M. Energy
Tevatron	Fermilab/USA	1987 –	$p\bar{p}$	@	1960 GeV
SLC	SLAC/USA	1989 – 1998	e^+e^-	@	100 GeV
LEP	CERN/Europe	1989 – 2000	e^+e^-	@	209 GeV
HERA	DESY/Germany	1992 – 2007	$e^\pm p$	@	330 GeV

Protons are made of quarks, anti-quarks and gluons. It's the individual quarks and gluons that collide. Only a fraction of the proton's energy is actually available in a single *quark/gluon* collision.

The challenges in reaching high energies

Circular e^+e^- collider. Basic issue is synchrotron radiation

$$\text{Energy loss per orbit} \sim \frac{E^4}{m^4 R}$$

At LEP the numbers are $\mathcal{O}(10\%)$ of the electron's energy per orbit.

Circular pp collider

Proton mass 2000 times larger, so synchrotron radiation not a problem.
The limitation is magnetic field needed to bend the protons round

$$B \sim \frac{E}{R}$$

Tevatron: $R \sim 1\,\text{km}$, $E_{c.o.m} \sim 2$ TeV $\implies$ $B = 4$ TeV.

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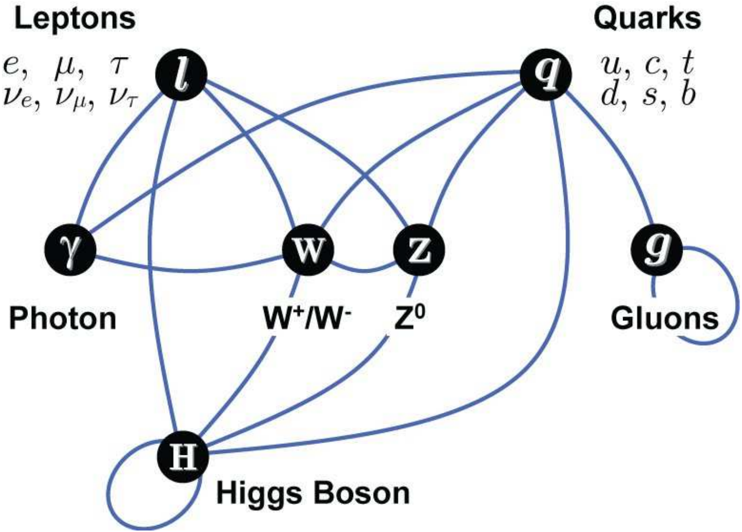
So what energy do you need?

The Standard Model



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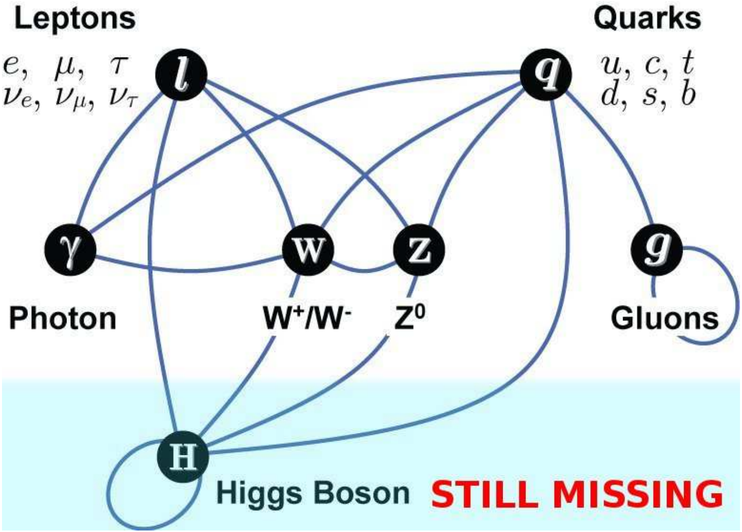

Higgs/ABEHGHK'tH in an (oversimplified) slide

Among the terms in the Standard Model Lagrangian:

$$g_{\mathrm{W}}^2 \;\; \phi^2 \;\; Z_\mu Z^\mu$$

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Z-boson fields

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Among the terms in the Standard Model Lagrangian:

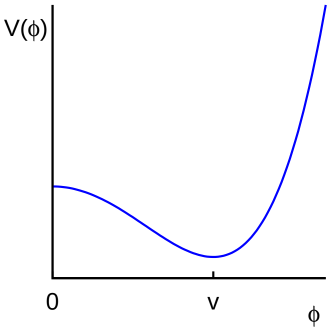
$$g_W^2 \ \phi^2 \ Z_\mu Z^\mu$$

gauge coupling → g_W^2; scalar field → ϕ^2; Z-boson fields → $Z_\mu Z^\mu$

Potential for scalar field is

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4$$

Universe lives at minimum of potential, $\phi \simeq v$. Rewrite ϕ in terms of perturbations H around minimum



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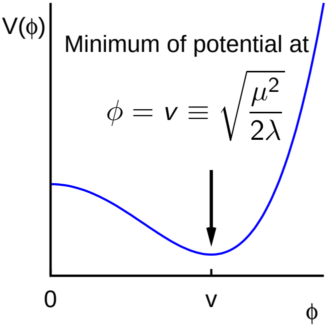

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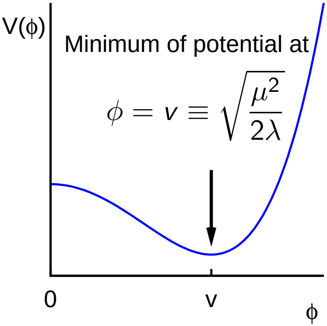

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$$\phi \equiv v + H \;\rightarrow\; \phi^2 = v^2 + 2vH + H^2$$

H is the **Higgs-boson** field

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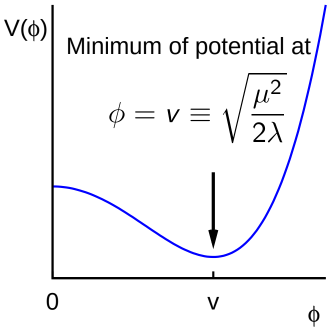

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H is the **Higgs-boson** field

$$g_w^2\phi^2 Z_\mu Z^\mu \rightarrow \underbrace{g_w^2 v^2}_{\text{Z mass}} Z_\mu Z^\mu + \underbrace{2g_w^2 v}_{\text{HZZ coupling}} H Z_\mu Z^\mu$$

Mechanism generates particle masses

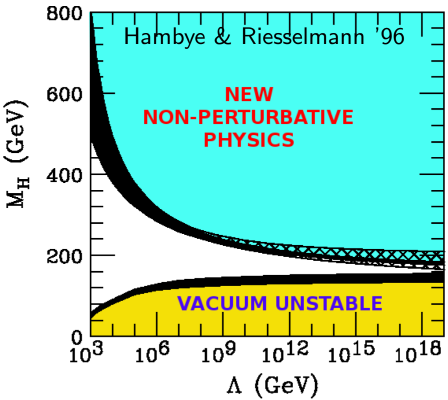
And a "Higgs" boson

Higgs Mass ↔ no-lose proposition

The standard model does not predict the Higgs Mass

But strong arguments to say

- either it lies between 70 GeV and 800 GeV
- or there is new physics at $\mathcal{O}$ (1 TeV)



So ideally build a collider that can discover Higgs-boson up to 800 GeV and perform WW scattering up to $\simeq$ 1 TeV

Tevatron could have discovered Higgs at $m_H = 160$ GeV (it's not there!)

So you want a collider at least 6 times more energetic

LHC concept got serious in first half of 80's

From the CERN Courier in **1984:**

The installation of a hadron collider in the [27km] LEP tunnel, using superconducting magnets, has always been foreseen by ECFA and CERN as the natural long term extension of the CERN facilities beyond LEP. [...]

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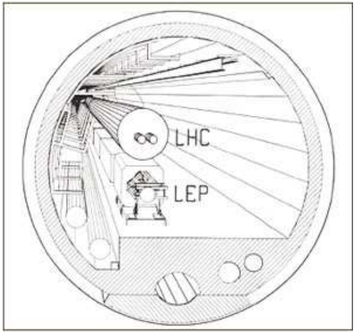

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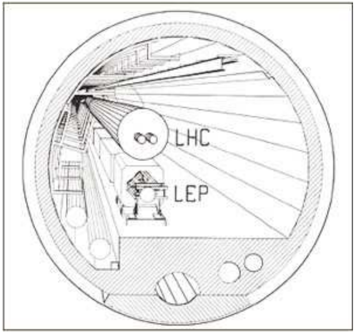

$$E \propto BR$$

ring radius $R \sim 4\times$Tevatron
superconduction magnets: $B = 8$ T
($2\times$ Tevatron)

Tevatron $\sim$ 2 TeV $\longrightarrow$ LHC $\sim$ 16 TeV

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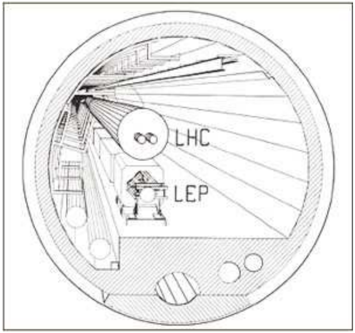

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Tevatron ∼ 2 TeV ⟶ LHC ∼ 14 TeV

Energy's not enough

To produce an object of mass M, the fundamental colliding objects — quarks and gluons — need to come within a distance $\sim 1/M$.

Cross sections (σ), i.e. likelihood of an interesting interaction, scale as follows

$$\sigma \;\sim\; \text{coupling constants} \times \frac{1}{M^2}$$

Probing masses $\sim$ 7 times higher than at Tevatron

$\rightarrow$ cross sections 49 times smaller

To fully exploit higher energies, LHC needs about 50 times more pp collisions, "luminosity", than Tevatron.

Tevatron: 10^{15} $p\bar{p}$ collisions $\rightarrow$ LHC: $5 \cdot 10^{16}$ pp collisions

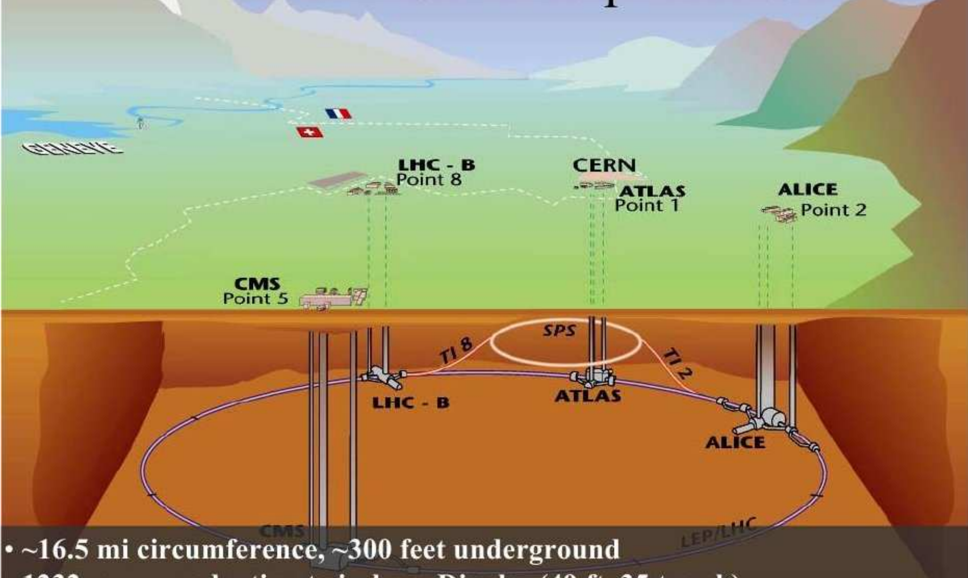
An over-simplification; but the numbers $\sim$ final design

Summary:
relative to Tevatron, LHC should provide

7 times more energy

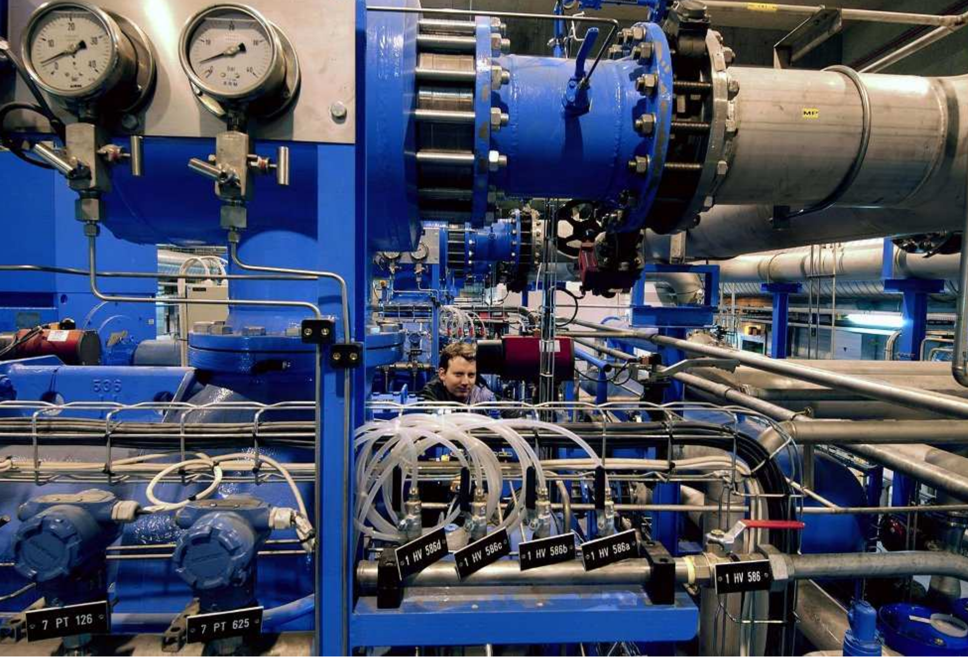
50 times more collisions

The LHC and its Experiments



- ~16.5 mi circumference, ~300 feet underground
- 1232 superconducting twin-bore Dipoles (49 ft, 35 t each)
- Dipole Field Strength 8.4 T (13 kA current), Operating Temperature 1.9K
- Beam intensity 0.5 A (2.2 10^{-6} loss causes quench), 362 MJ stored energy

Interconnection between two “dipoles” (bending magnets) in the LHC tunnel.



Cyrogenics plant: 96 000 kg of Helium circulate through the machine at 1.9K

The detectors:

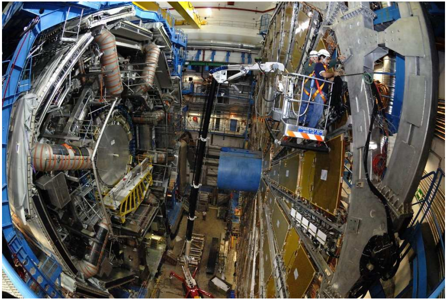
To accumulate 5×10^{16} collisions over a few years, they have to be able to handle a pp collision rate of 10^9 Hz

[25 collisions every 25 ns]

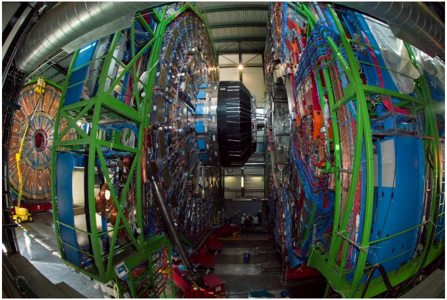
Typically, about 100 000 000 channels to read out.

[must be examined 40 000 000 times/s,
interesting events written to tape 200-400 times/s]

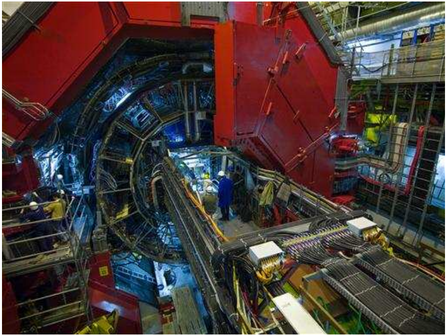
ATLAS: general purpose



CMS: general purpose



ALICE: heavy-ion physics

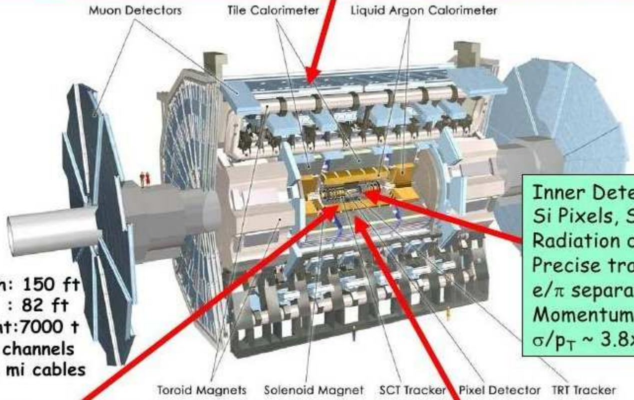


LHCb: B-physics

+ TOTEM, LHCf

ATLAS

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to $E_{\mu} \sim 1$ TeV



3-level **trigger** reducing the rate from 40 MHz to ~200 Hz

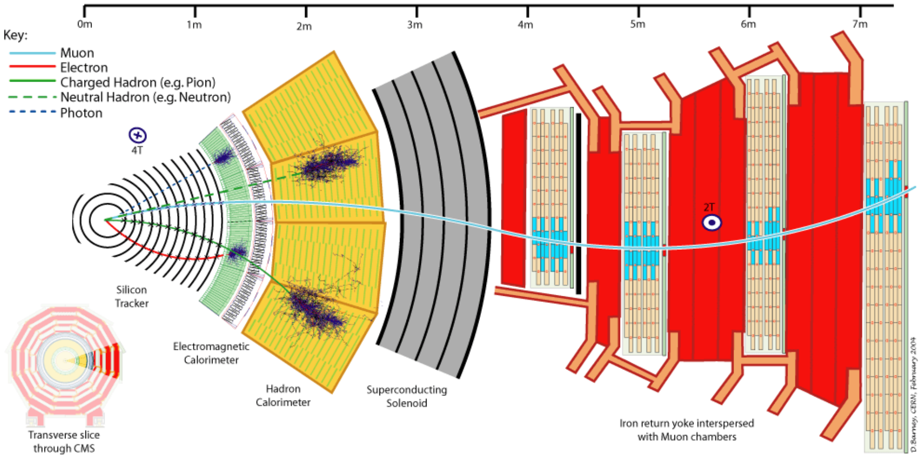
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

Length: 150 ft
Ø : 82 ft
Weight: 7000 t
~10^8 channels
~2000 mi cables

EM calorimeter: Pb-LAr Accordion
e/γ trigger, ID and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

A slice of CMS



LHC has now been operating for a year

1995: LHC approved
2000: LEP closed

2008/09: LHC beams circulated
2008/09: severe "incident"

poor electrical connection, arc, catastrophic Helium release, much damage

Followed by reviews, the fixes that could be made in $\sim$ 1 year

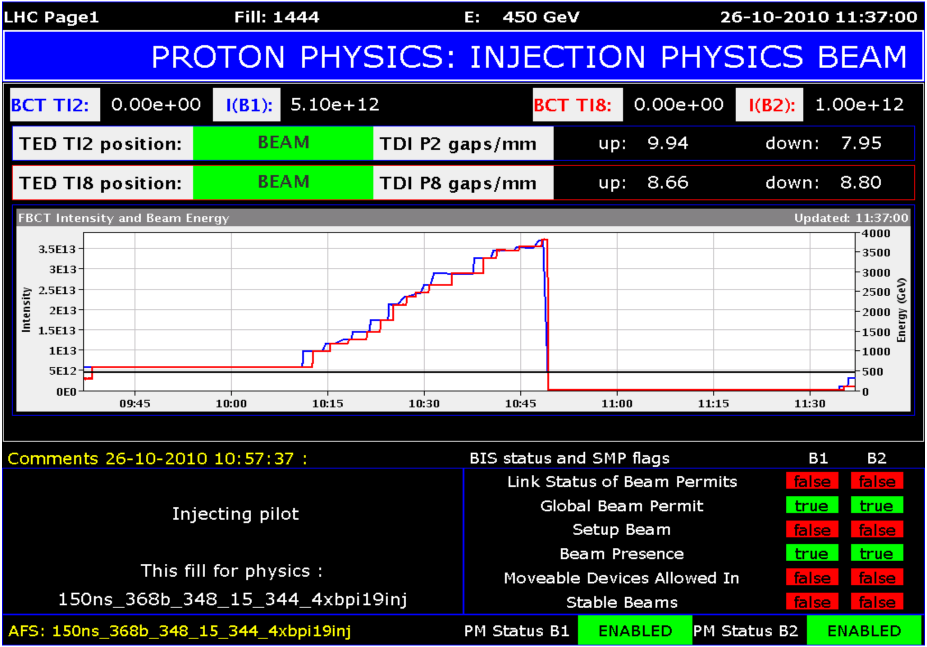
2009/11: LHC starts up again, 900 GeV pp collisions
2009/12: 2360 GeV pp collisions
2010/03: 7000 GeV pp collisions

"reduced-energy" target for safe operation

2010/11: 2760 GeV PbPb collisions

http://bit.ly/1WGndS

LHC operation



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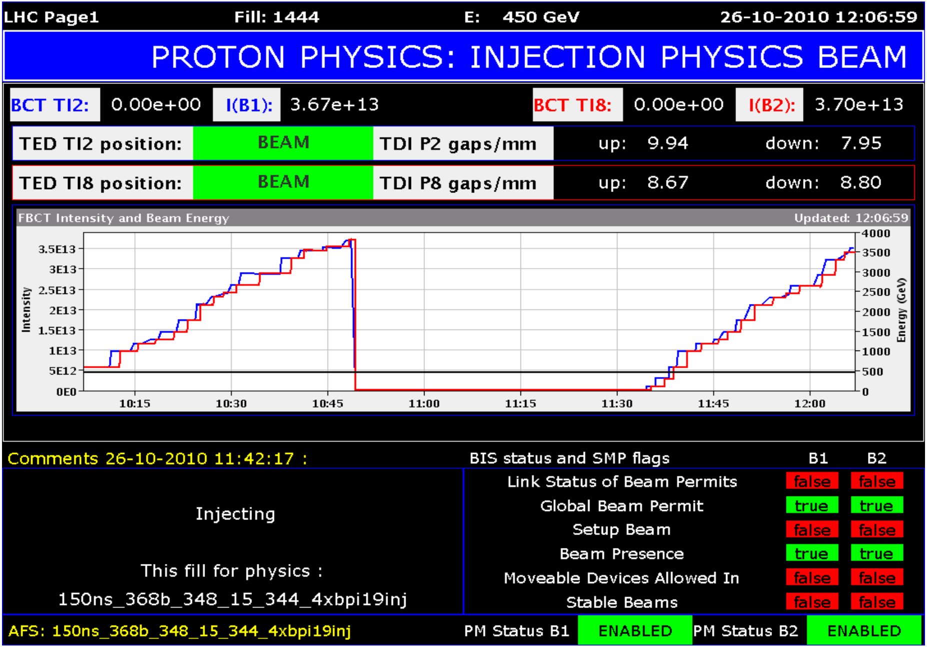

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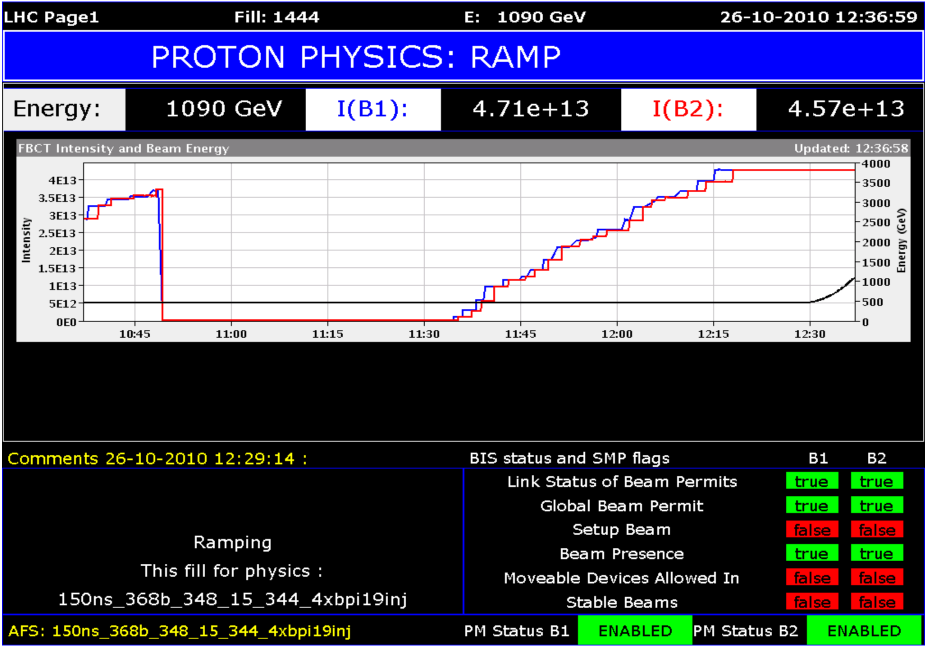

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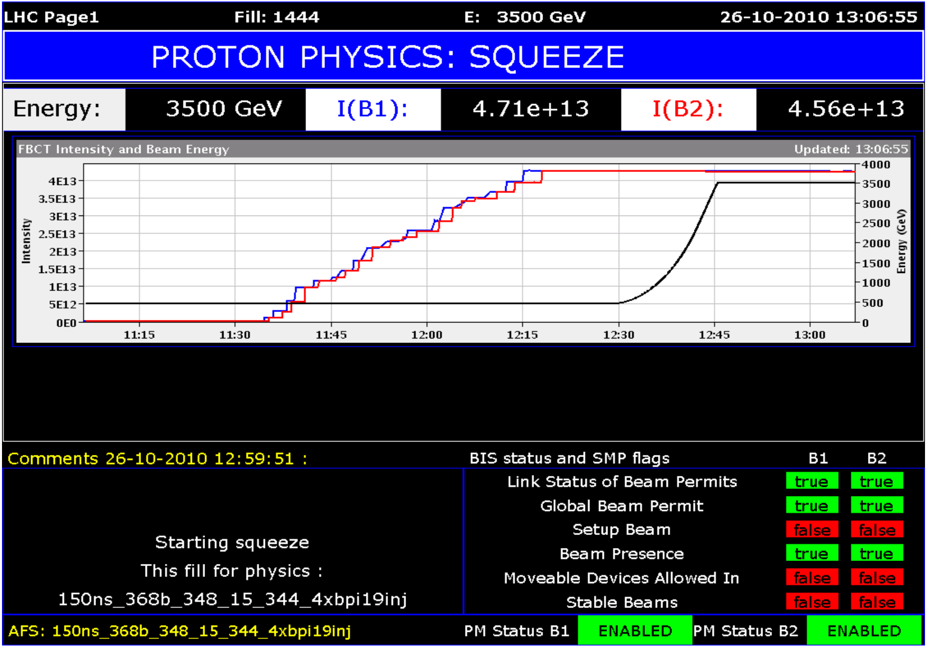

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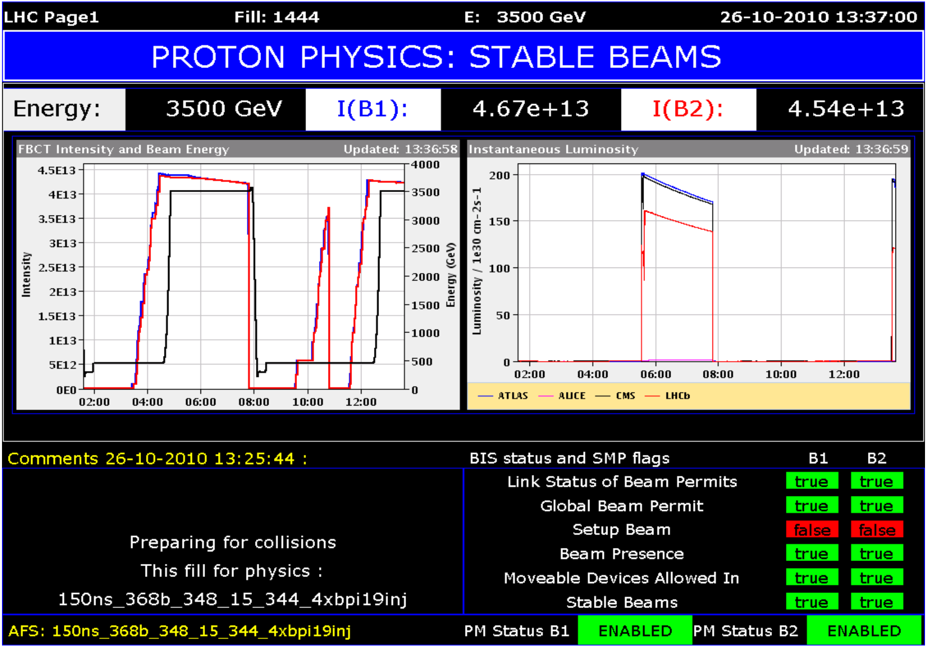

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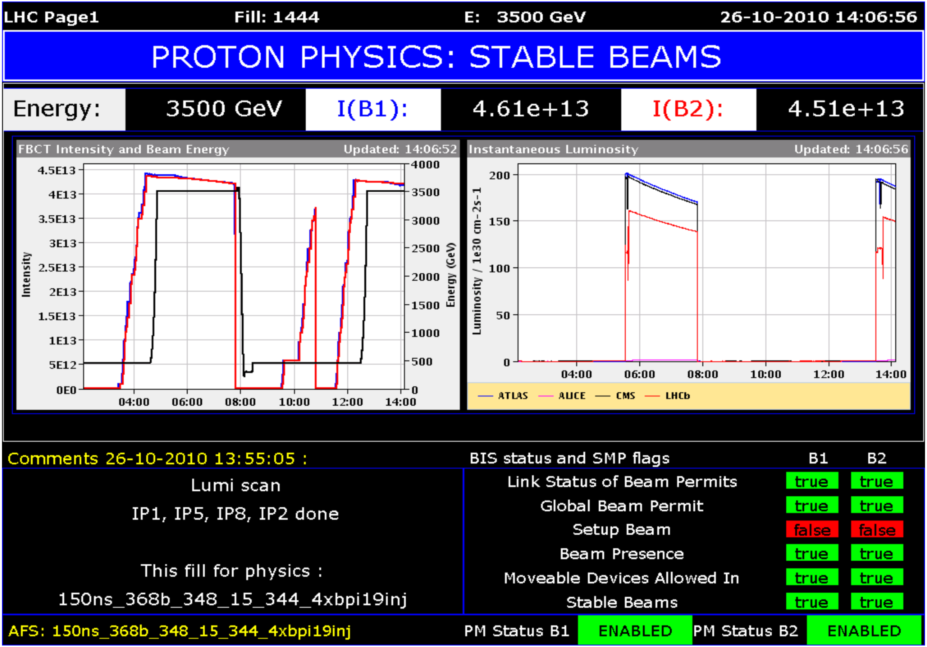

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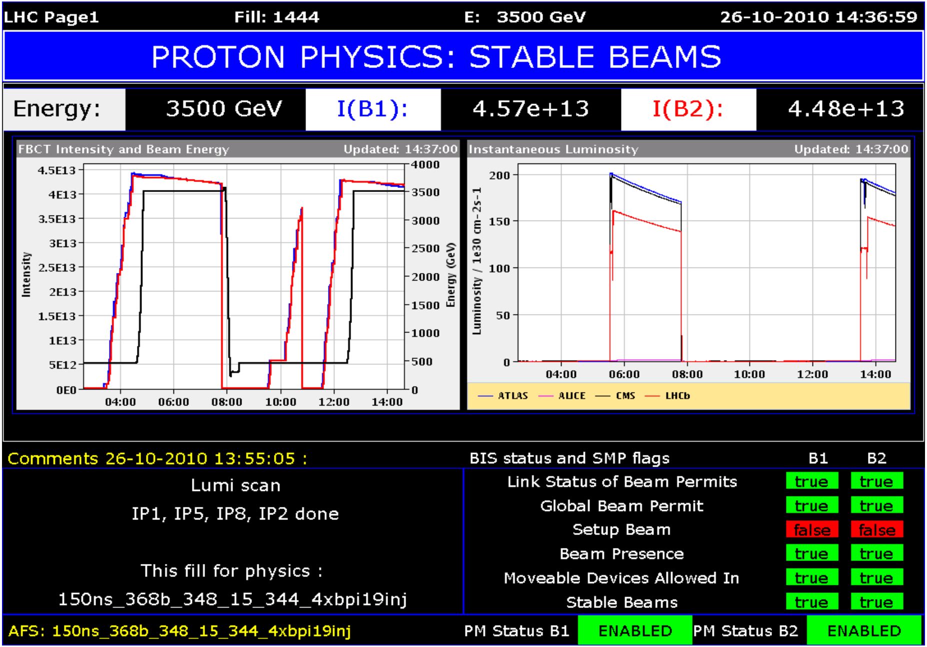

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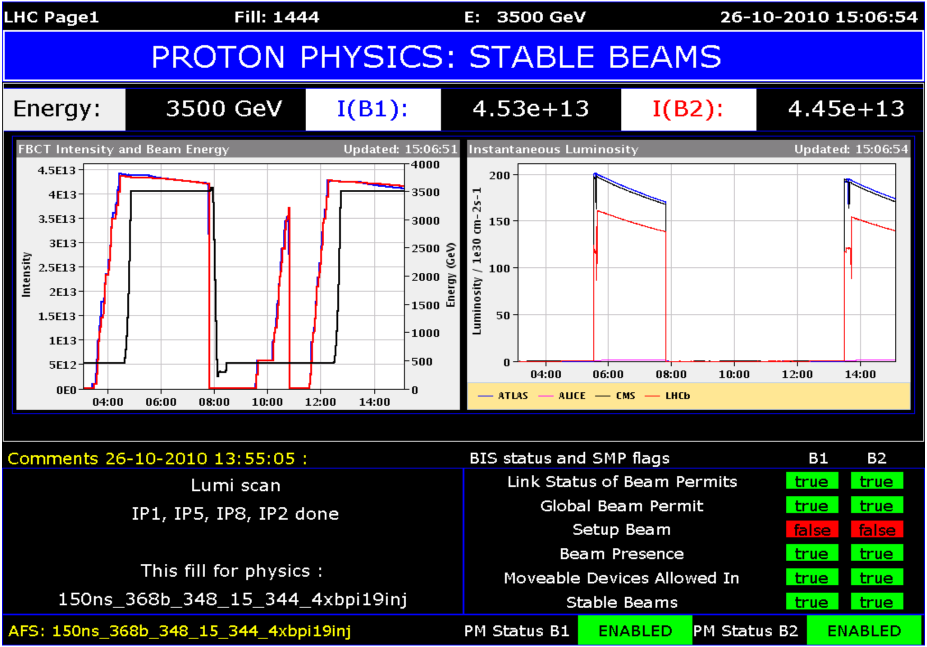

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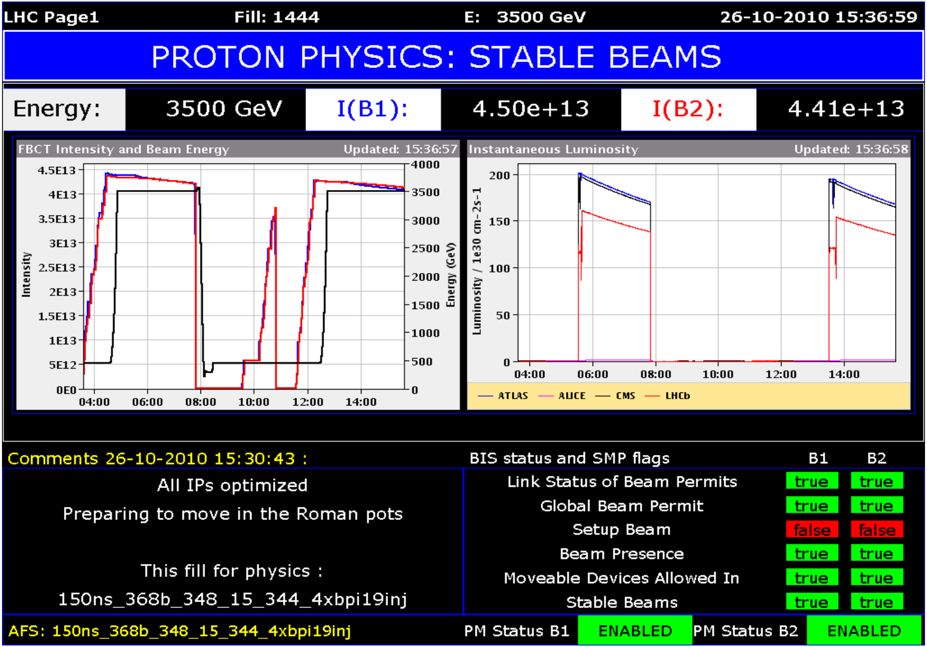

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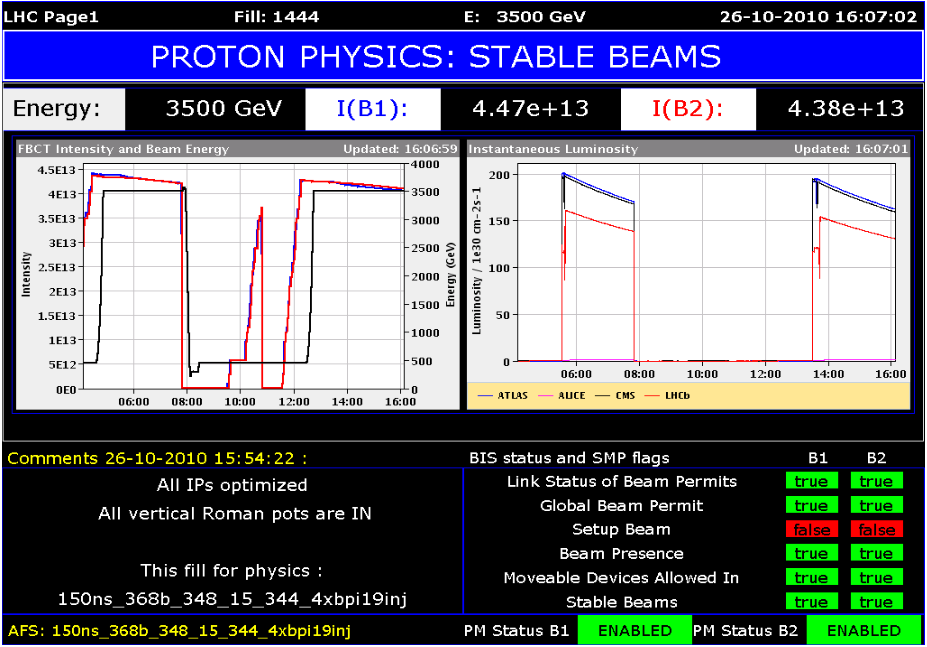

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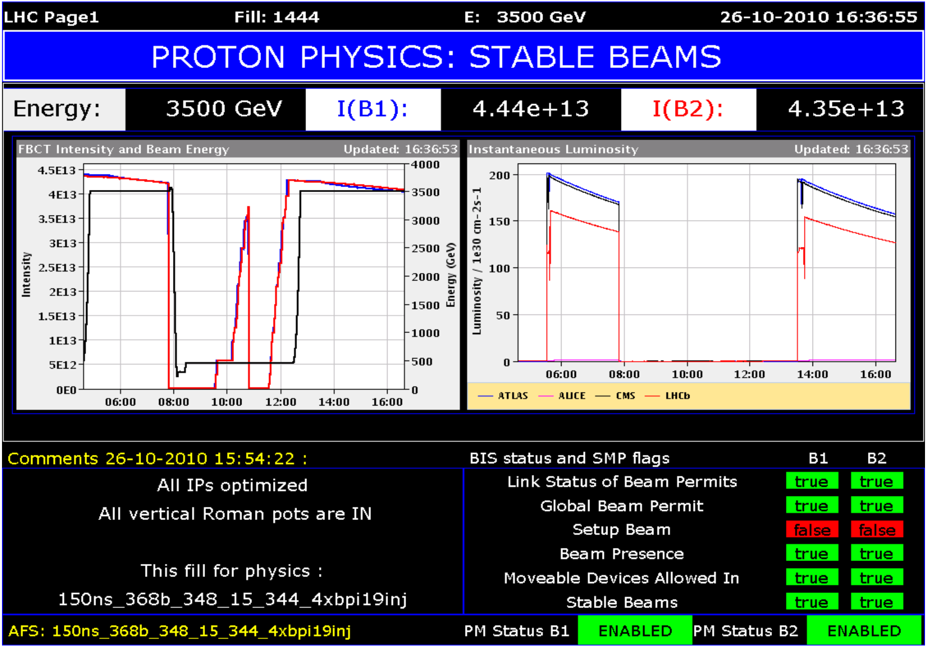

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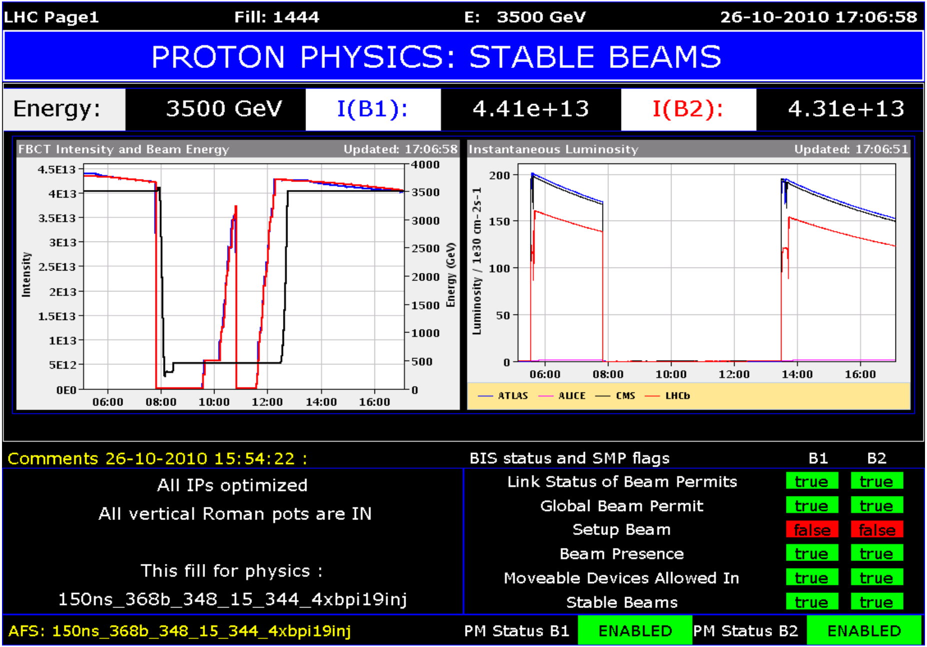

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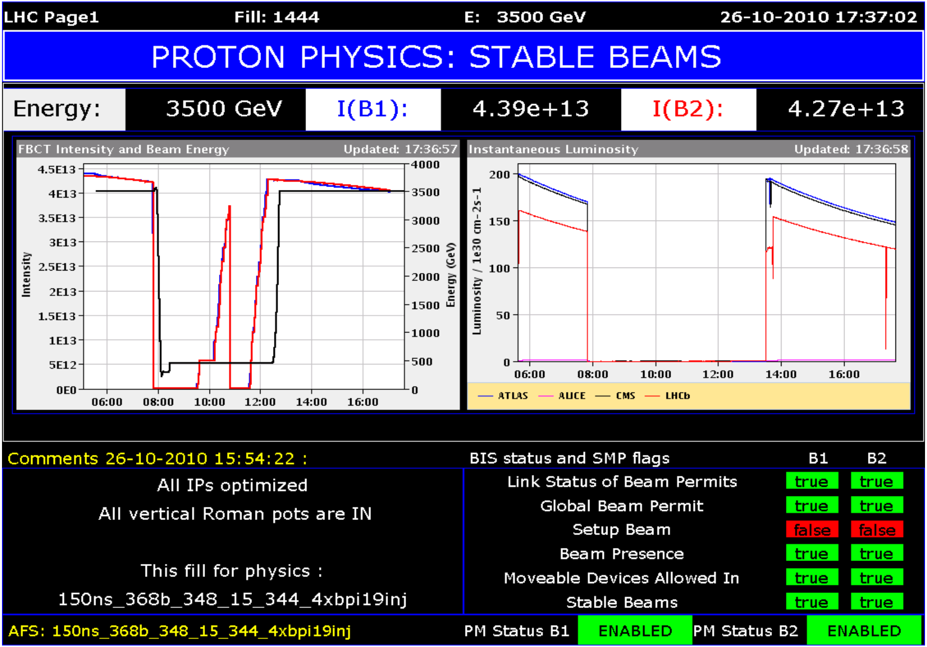

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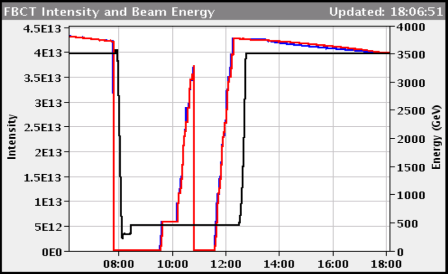
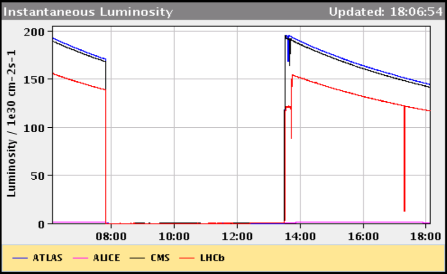
LHC operation

LHC Page1	Fill: 1444	E: 3500 GeV	26-10-2010 18:06:55

PROTON PHYSICS: STABLE BEAMS

Energy:	3500 GeV	I(B1):	4.36e+13	I(B2):	4.24e+13





Comments 26-10-2010 18:05:26 :

Dump foreseen at around 21h00
Then physics fill with 400+ bunches
Before: dump interlock test at injection
Info: no beam from injector tomorrow
8h00 to 13h00

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

AFS: 150ns_368b_348_15_344_4xbpi19inj

PM Status B1	ENABLED	PM Status B2	ENABLED

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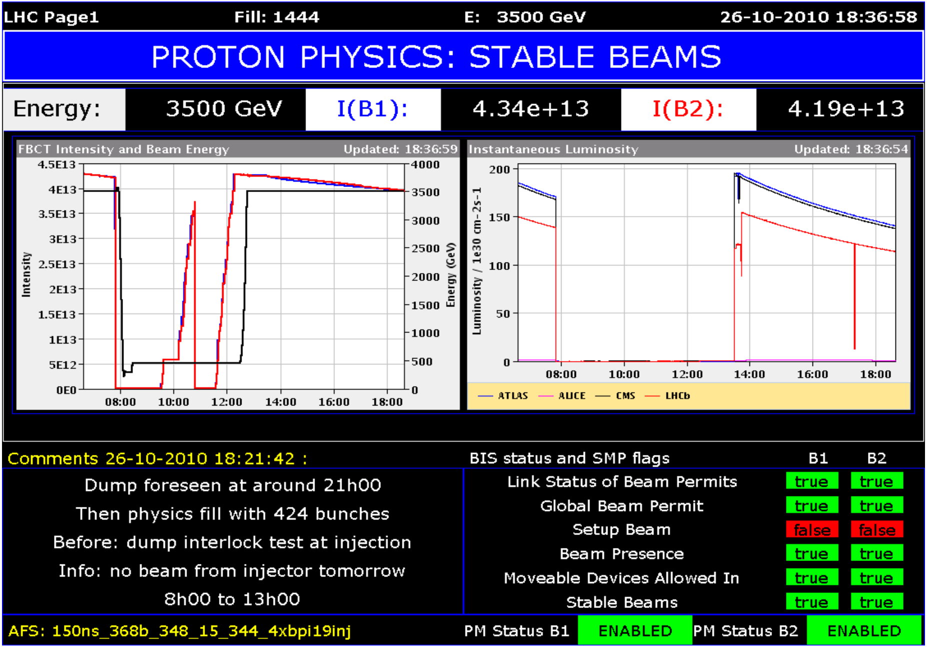

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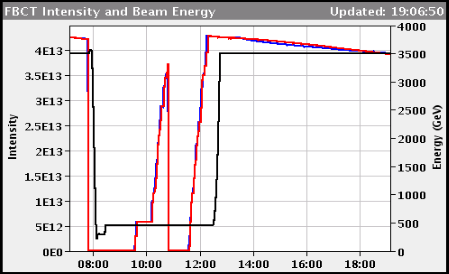
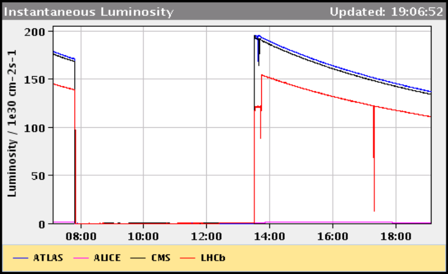
LHC operation

LHC Page1 | **Fill: 1444** | **E: 3500 GeV** | **26-10-2010 19:06:52**

PROTON PHYSICS: STABLE BEAMS

Energy:	3500 GeV	I(B1):	4.31e+13	I(B2):	4.16e+13





Comments 26-10-2010 18:21:42 :

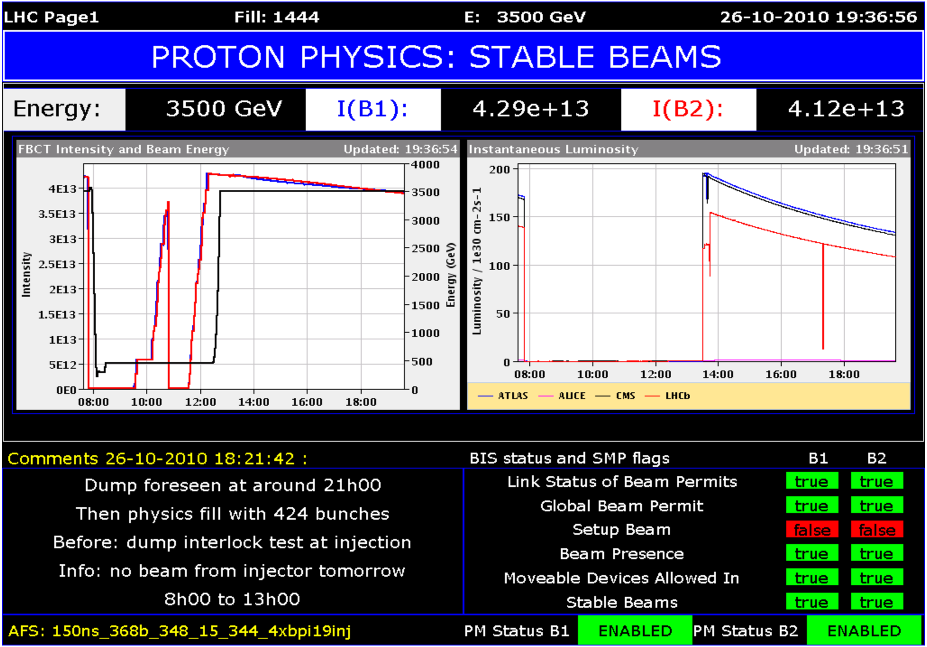
Dump foreseen at around 21h00
Then physics fill with 424 bunches
Before: dump interlock test at injection
Info: no beam from injector tomorrow
8h00 to 13h00

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

AFS: 150ns_368b_348_15_344_4xbpi19inj | PM Status B1 ENABLED | PM Status B2 ENABLED

http://bit.ly/1WGndS

LHC operation



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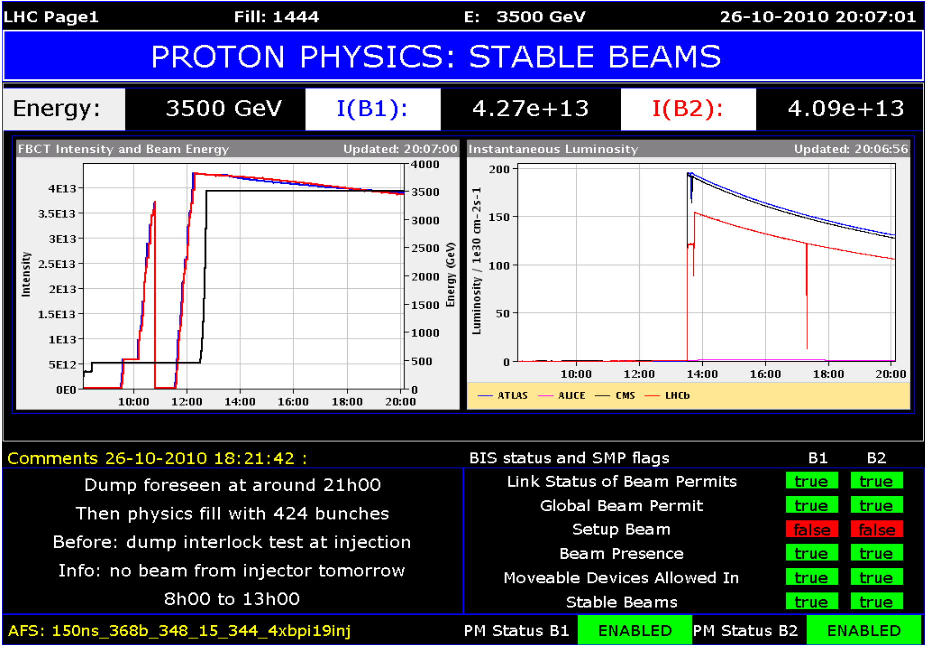

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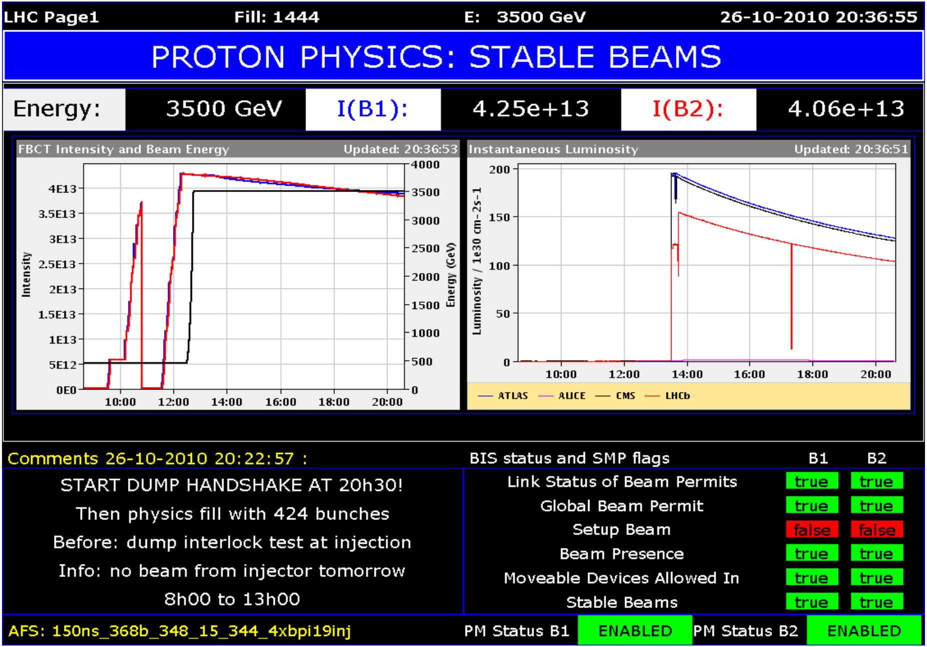

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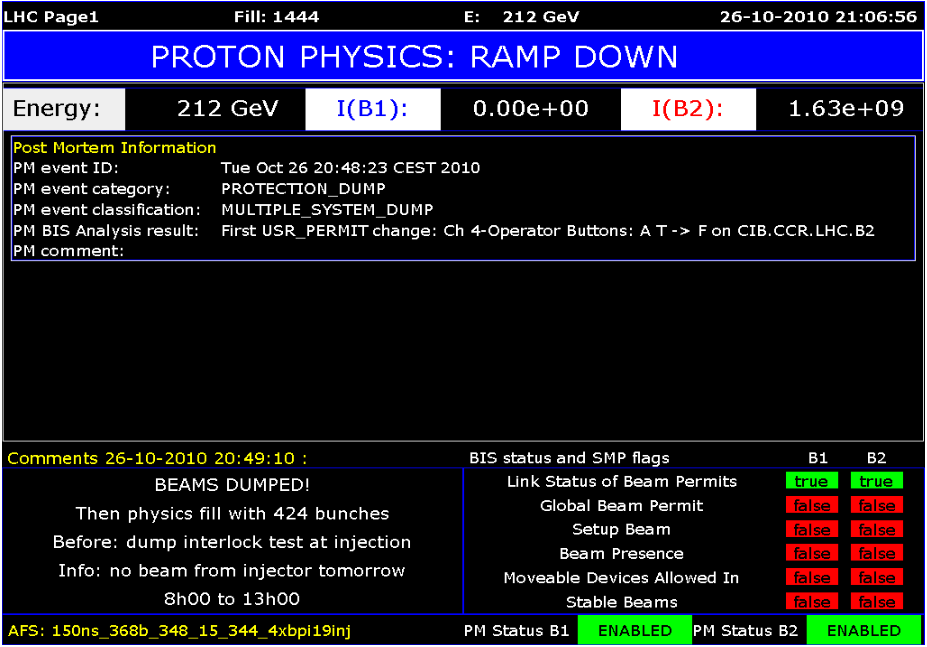
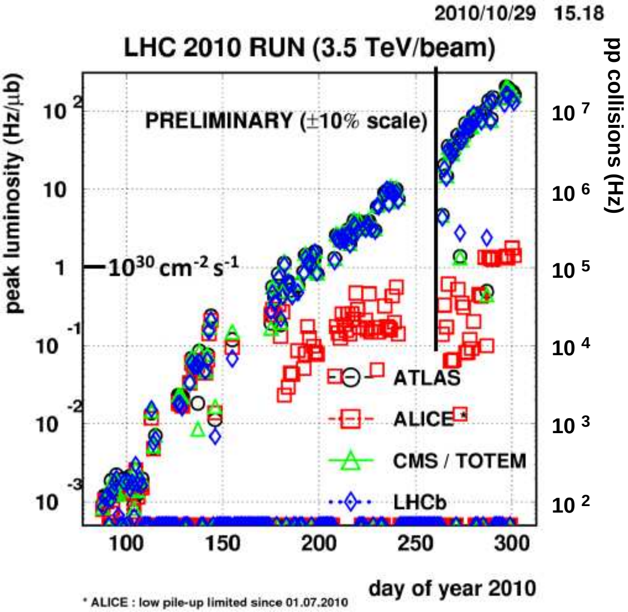


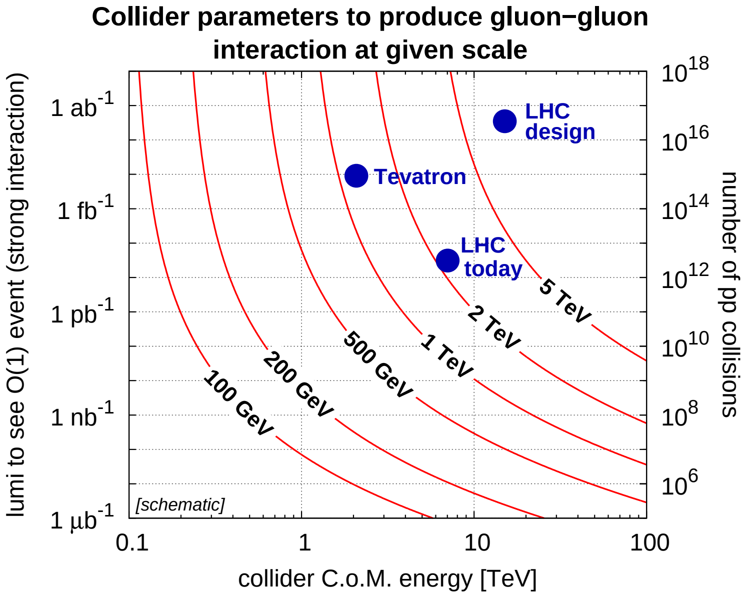
collision rate since start of 7 TeV operations



At close of *pp* running for 2010, LHC had delivered

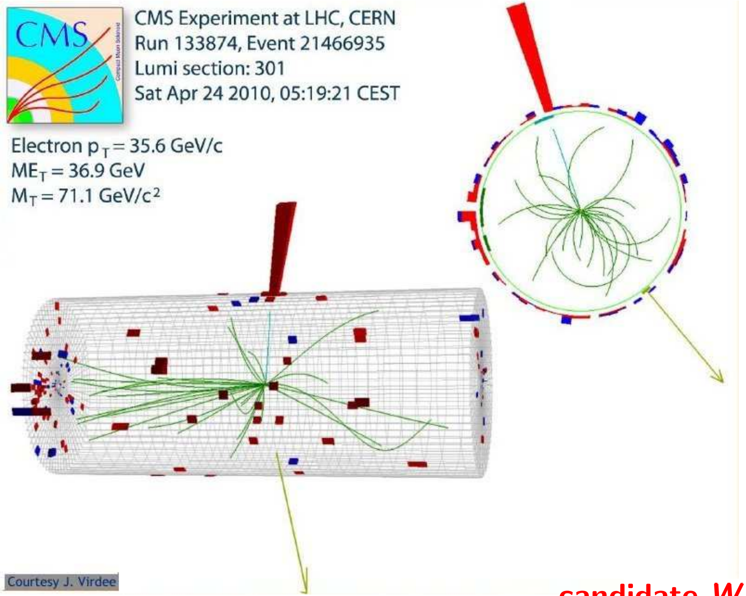
$\sim 40\text{pb}^{-1}/\text{expt}$

$\sim 4 \cdot 10^{12}$ *pp* collisions


Collider parameters to produce gluon−gluon interaction at given scale
lumi to see O(1) event (strong interaction)
1 ab-1
1 fb-1
1 pb-1
1 nb-1
1 μb-1
number of pp collisions
10^18
10^16
10^14
10^12
10^10
10^8
10^6
0.1
1
10
100
collider C.o.M. energy [TeV]
LHC design
Tevatron
LHC today
5 TeV
2 TeV
1 TeV
500 GeV
200 GeV
100 GeV
[schematic]

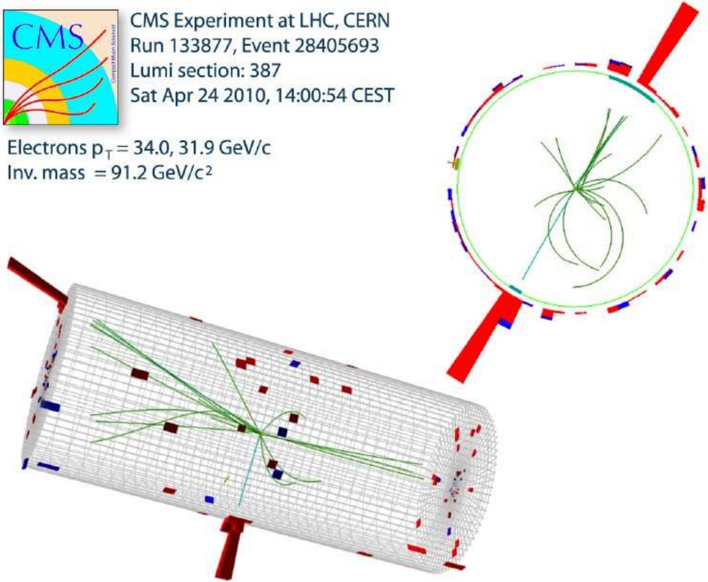
What have the experiments seen?

Rediscovering the standard model



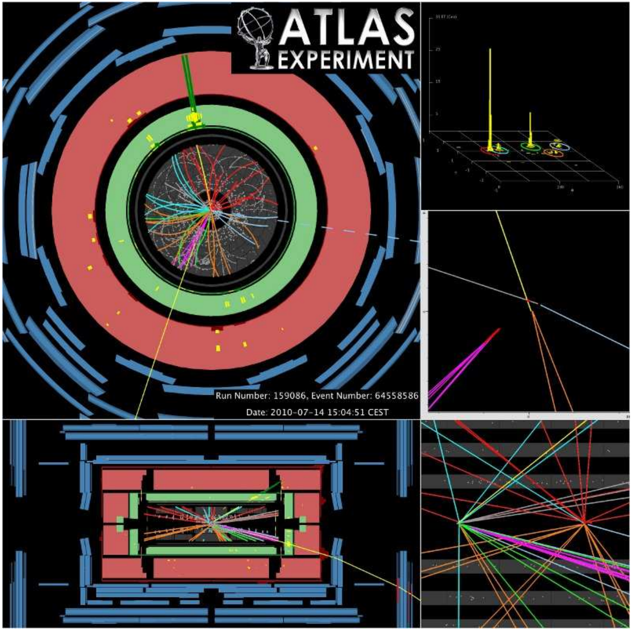
candidate $W \to e\nu$ event

Rediscovering the standard model



candidate $Z \to e^+e^-$ event

Rediscovering the standard model



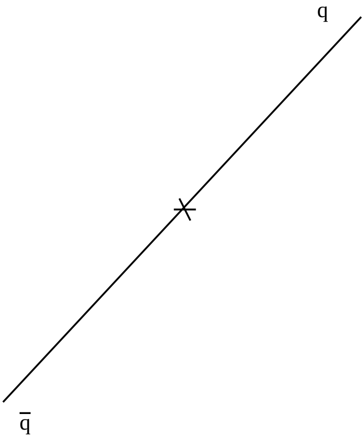
candidate
$t\bar{t} \to b\bar{b}q\bar{q}e\nu$
(with pileup)

Quarks, gluons and the LHC

LHC collides quarks and gluons, and many of the new things that have been postulated decay to quarks or gluons

Experiments inevitably have to deal with quarks and gluons

Quarks & gluons? They quite don't exist



Start off with quark and anti-quark, $q\bar{q}$

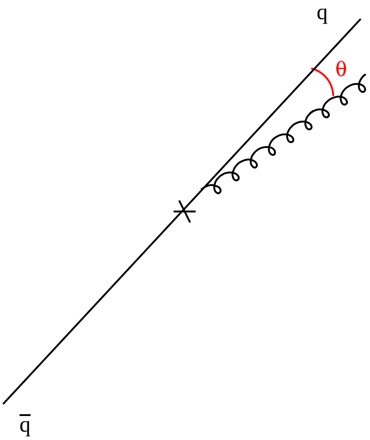
Quarks & gluons? They quite don't exist

In perturbative quantum chromodynamics (QCD), probability that a quark or gluon emits a gluon:

$$\sim \frac{dE}{E}\frac{d\theta}{\theta}$$

Diverges for small gluon energies E

Diverges for small angles θ



A quark never survives unchanged

it always emits a gluon (usually low-energy, at small angles)

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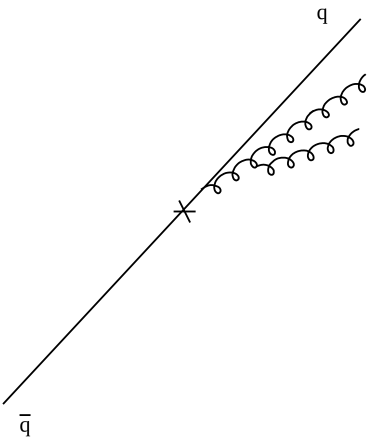

Each gluon radiates a further gluon

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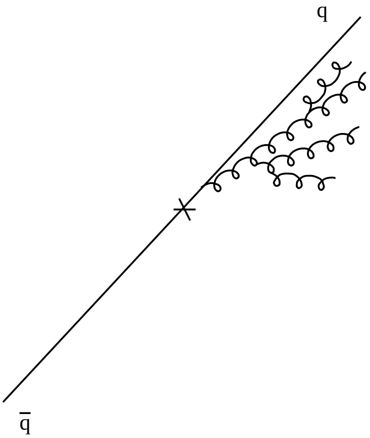

And so forth

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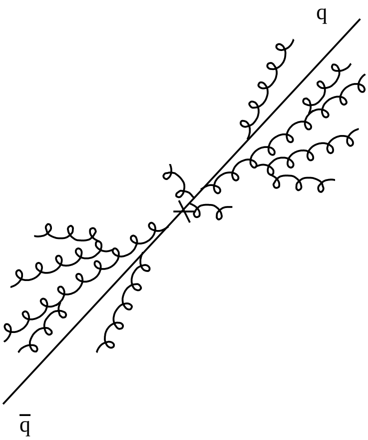
Diverges for small angles θ



Meanwhile the same happens on other side of event

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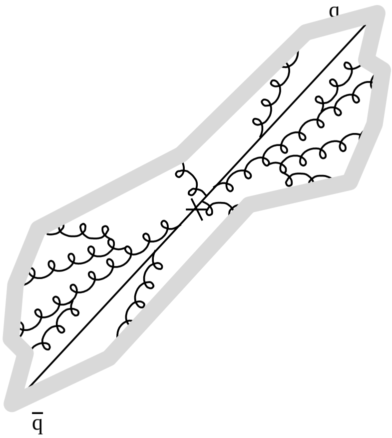
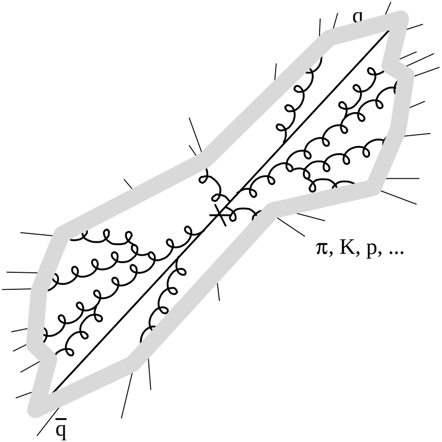


And then a non-perturbative transition occurs

Quarks & gluons? They quite don't exist



Giving a pattern of hadrons that "remembers" the gluon branching

Hadrons mostly produced at small angle wrt $q\bar{q}$ directions or with low energy

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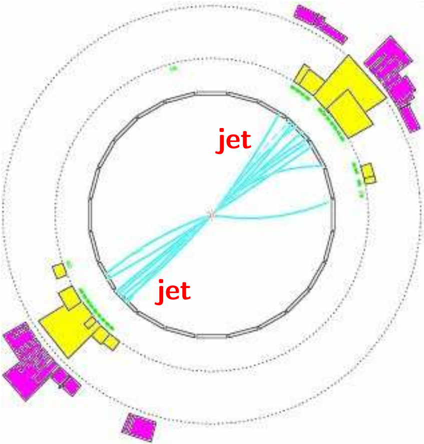

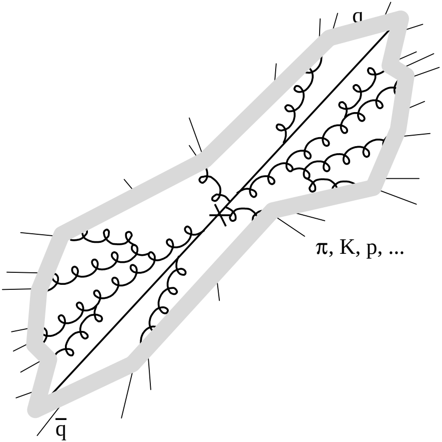

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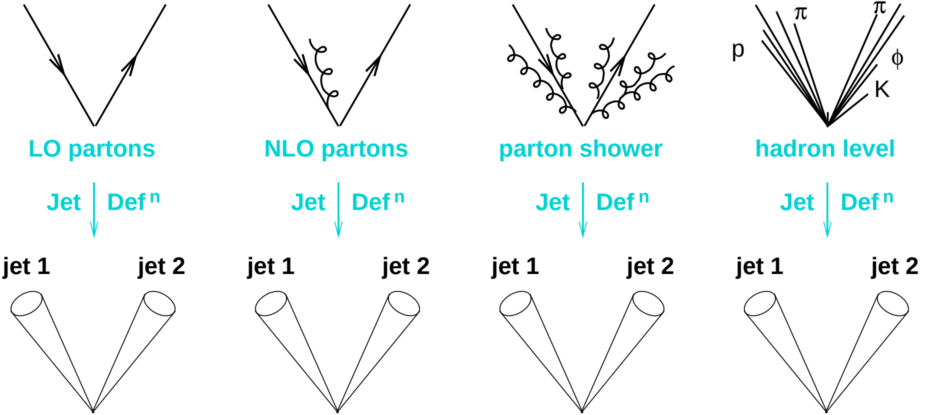
Jets made systematic: jet definitions



LHC events may be discussed in terms of quarks, quarks+gluon, or hadrons

A **jet definition** provides common representation of different "levels" of event complexity.

A \$100 000 000, 20-year old problem

A significant community of QCD theorists has spent the past ten years making accurate calculations of signals and backgrounds at the LHC (with remarkable advances in field theory on the way)

$\mathcal{O}(100)$ people $\times$ 10 years $\simeq$ \$100 000 000

Problem 1: the jet definitions used by LHC experiments were not compatible with these calculations — they "leaked" infinities:

$$\sigma = c_1 \alpha_s + c_2 \alpha_s^2 + \infty \alpha_s^3 + \cdots$$

α_s is perturbative expansion parameter (strong coupling)

Problem 2: the jet definitions advocated by theorists since 1990's had been mostly shunned by proton-collider experiments

a) bad response to experimental noise

b) severe computational issues (1 minute/event $\times 10^{10}$ recorded events)

Solving the jets problem

Discovered a link between QCD jet-finding and problems of 2D computational geometry

Cacciari & GPS '05

Many techniques could be carried over from comp. geom field

Developed a theory of the interplay between jet-finding, QCD radiation and experimental noise

Cacciari, GPS & Soyez '08

A crucial element was linearity of response

Proposed a new jet-definition based on what we'd learnt

anti-k_t

Cacciari, GPS & Soyez '08

How anti-k_t works:

- Define pairwise i–j distances

$$d_{ij} = \min\left(\frac{1}{p_{ti}^2}, \frac{1}{p_{tj}^2}\right) \Delta R_{ij}^2$$

- Define single-particle distances

$$d_{iB} = \frac{1}{p_{ti}^2}$$

  - If smallest is d_{ij} merge i and j
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A non-intuitive successor to k_t alg of Catani et al. '91

You can cluster anything

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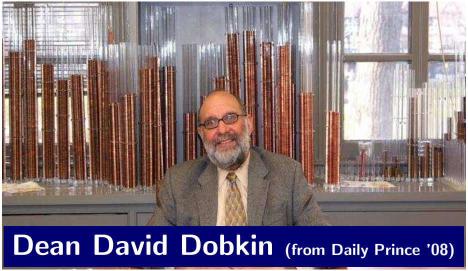

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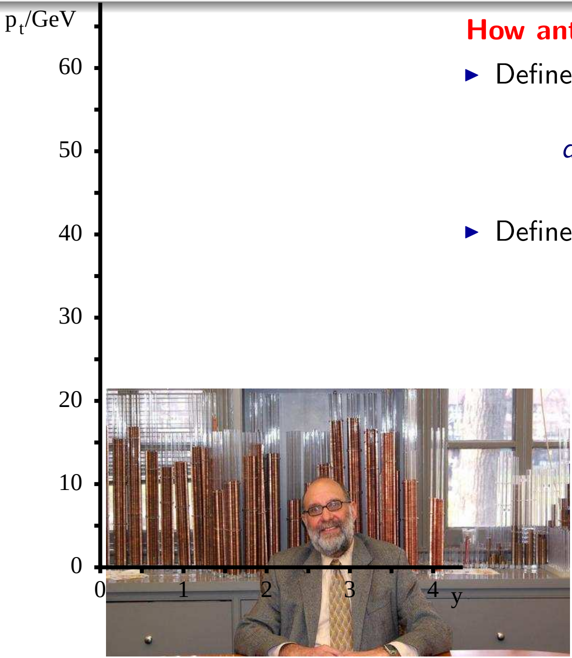

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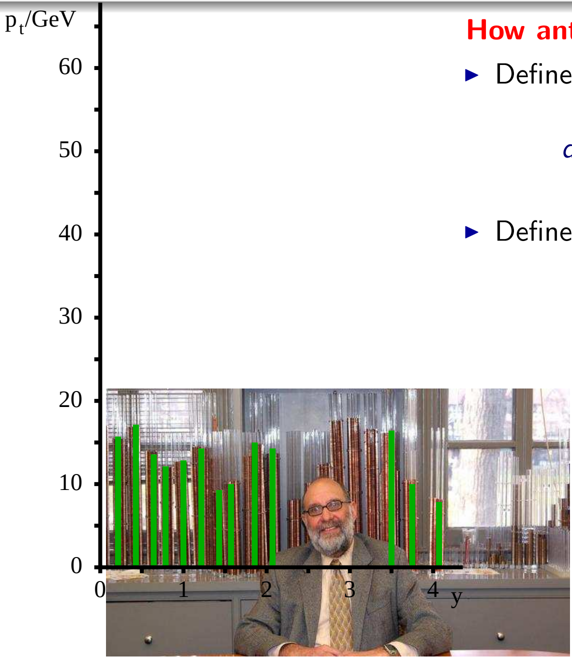

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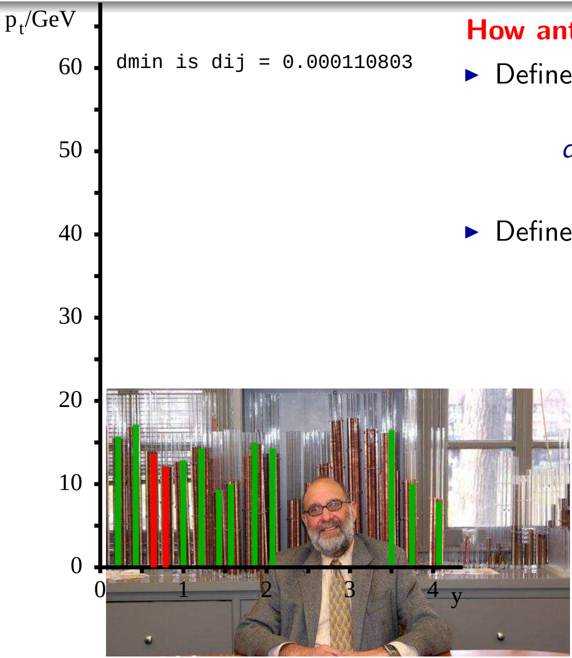

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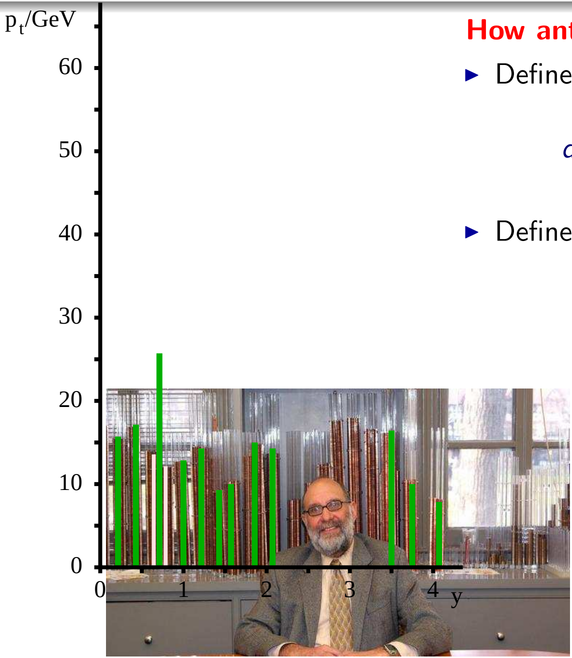

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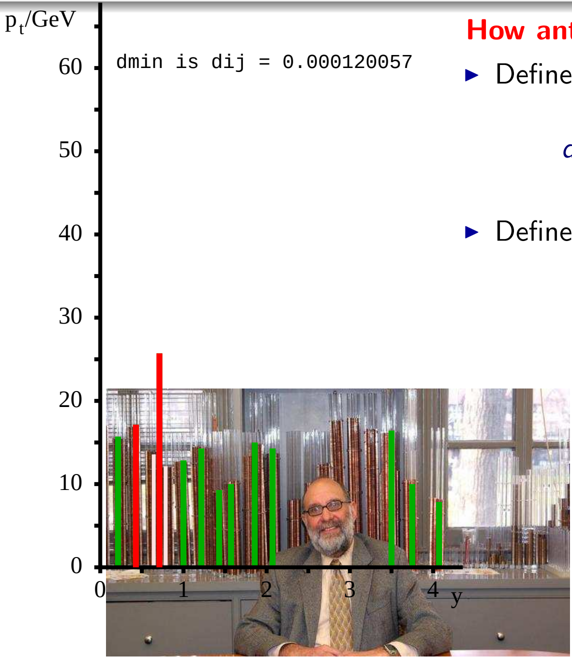

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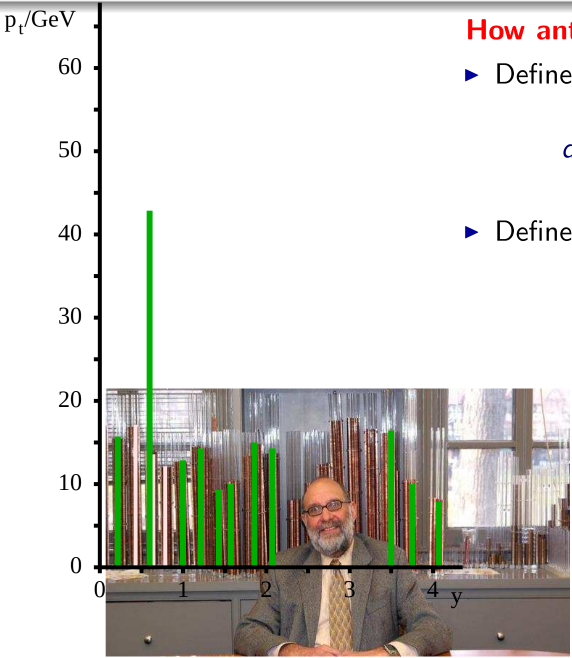

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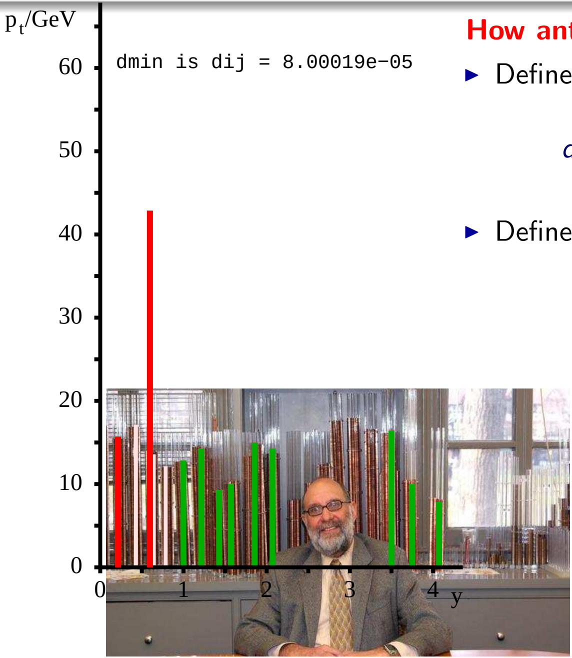

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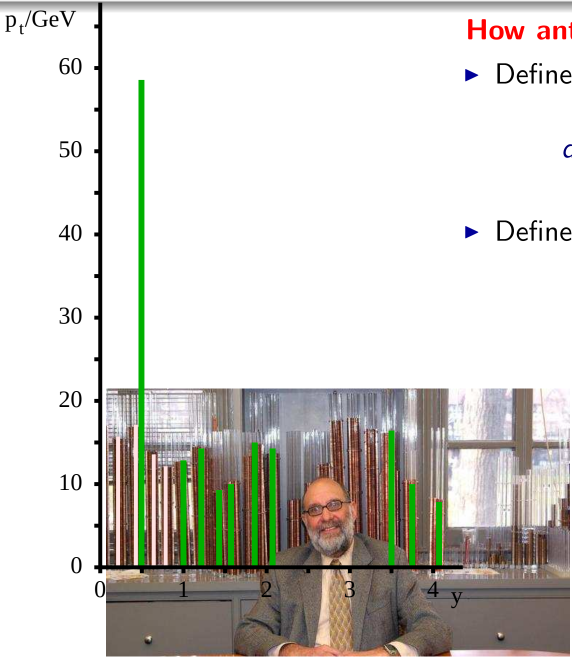

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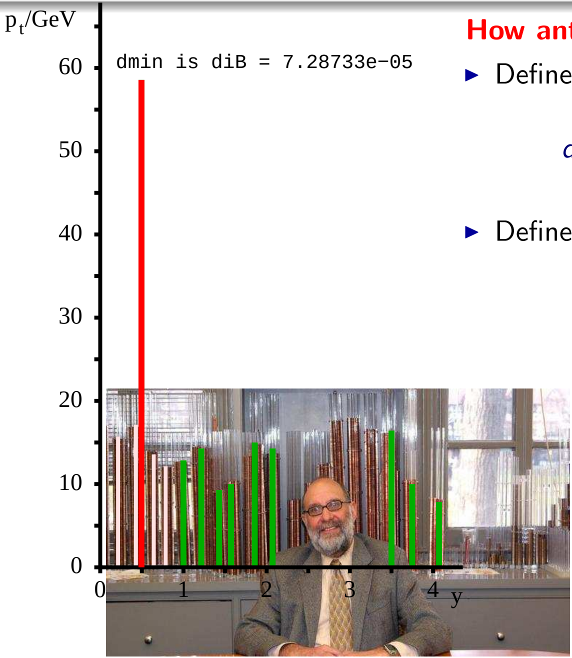

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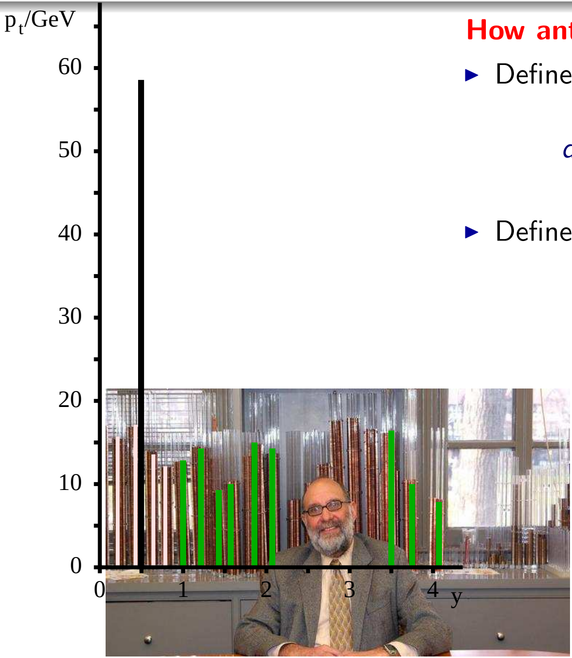

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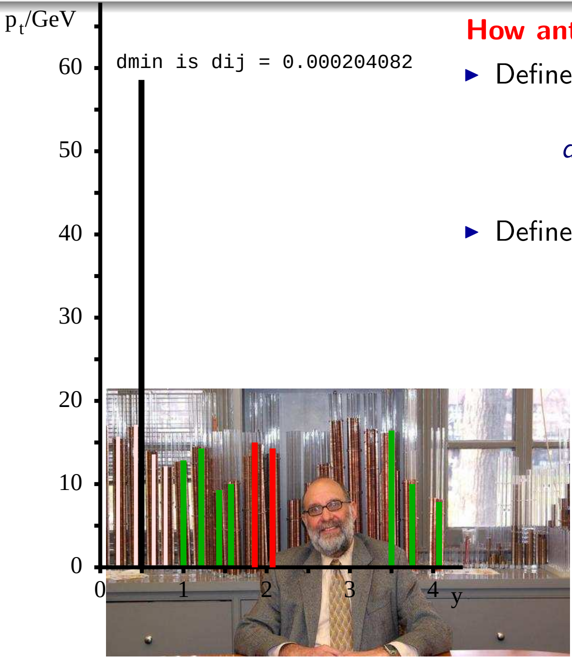

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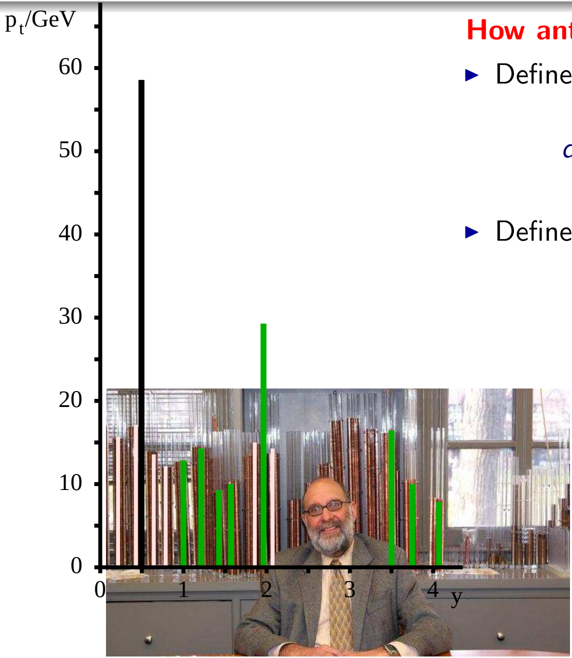

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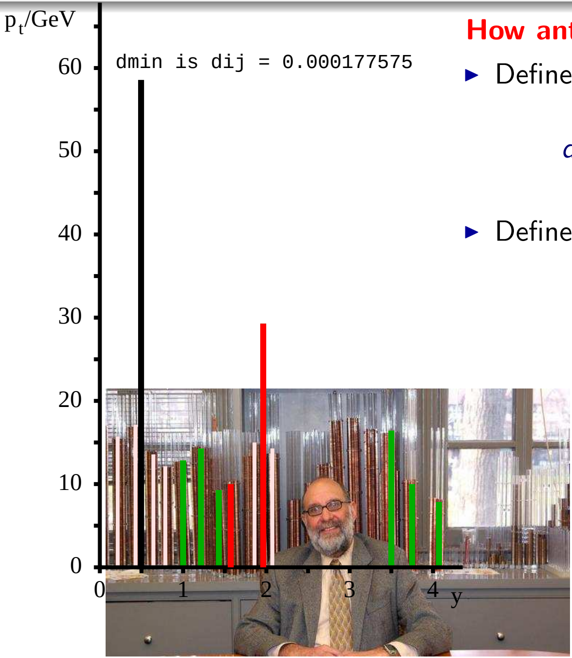

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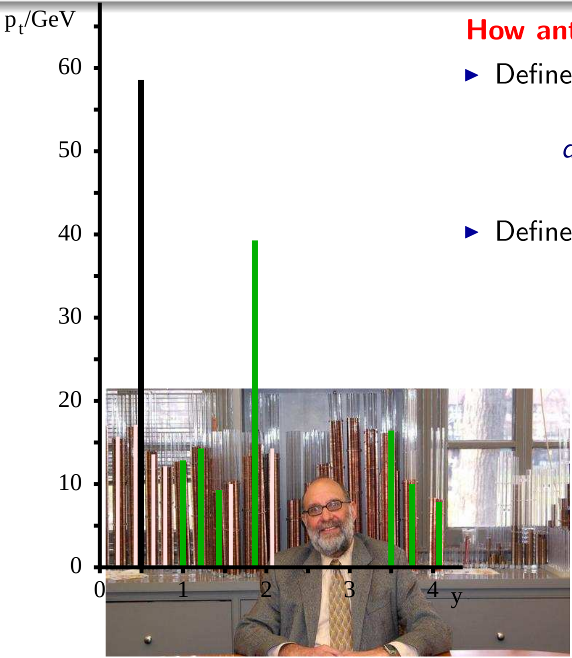

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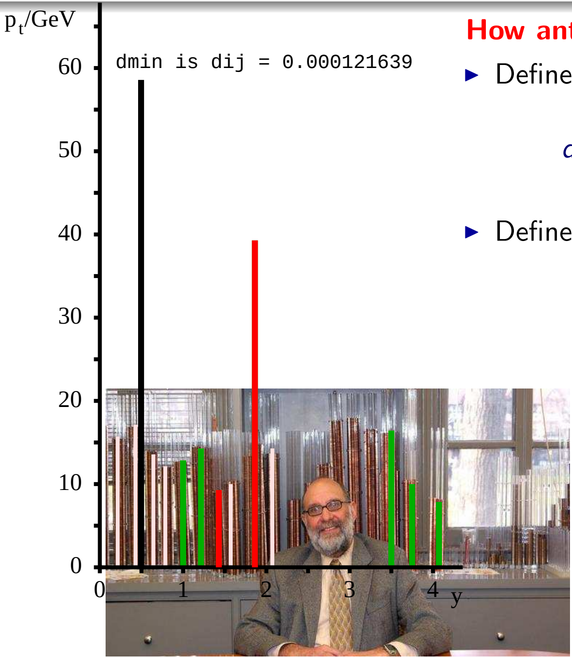

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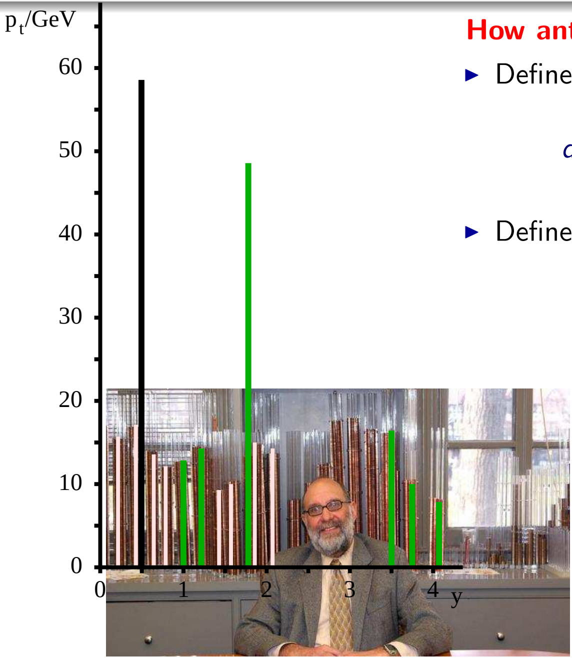

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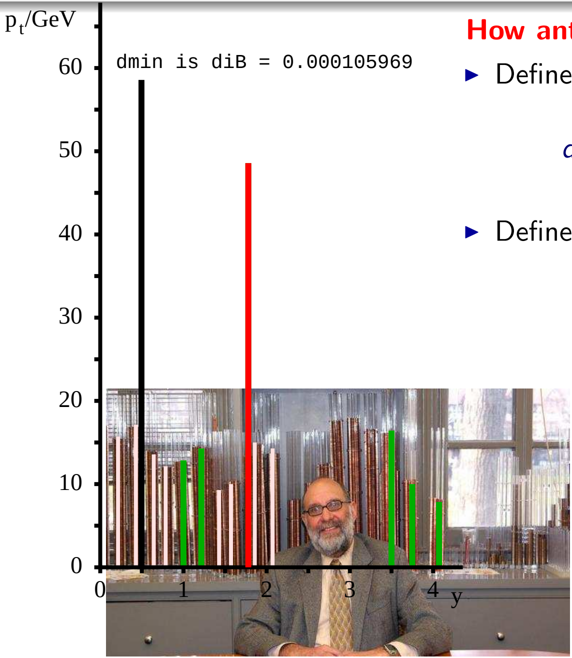
A non-intuitive successor to k_t alg of Catani et al. '91

You can cluster anything



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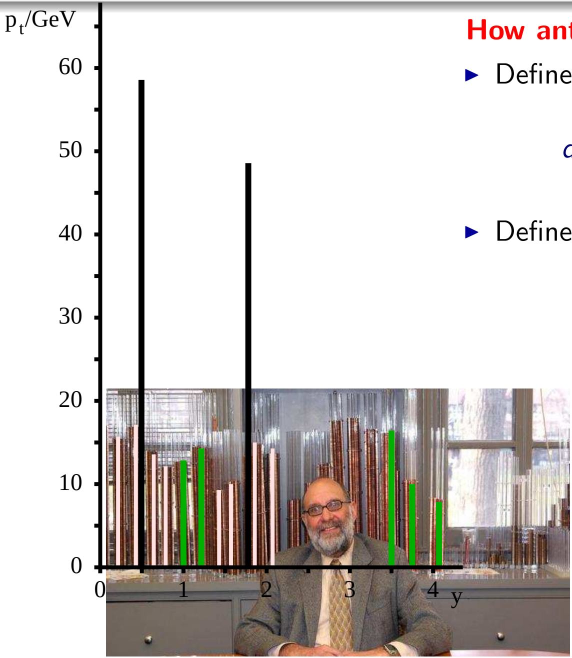

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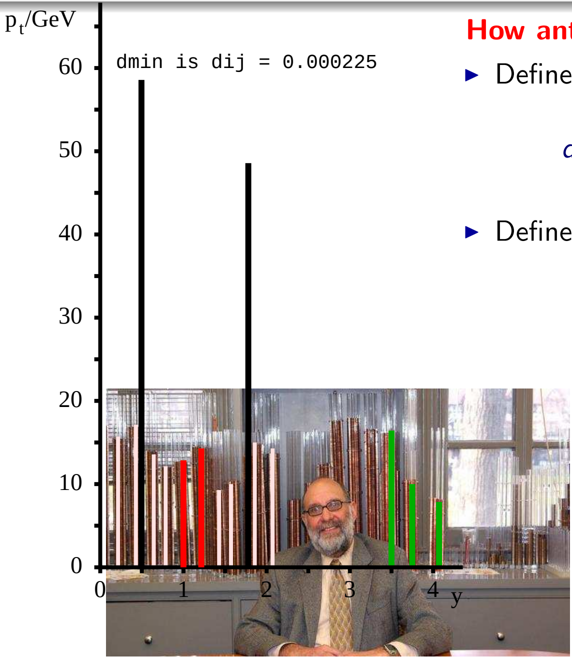

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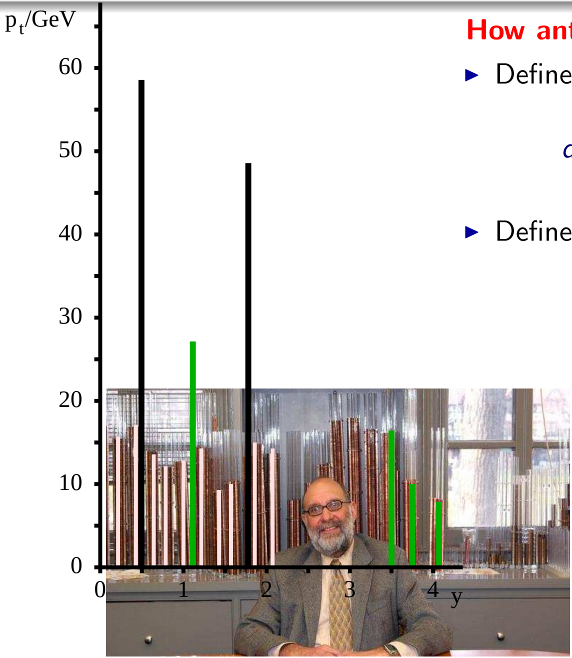

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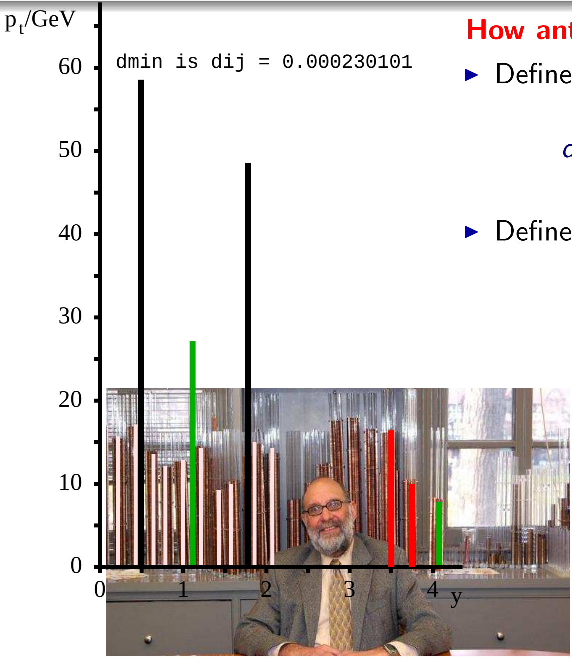

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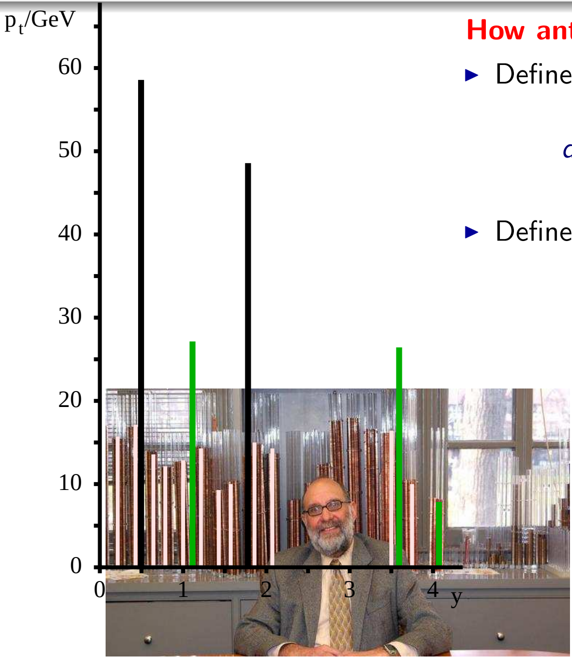

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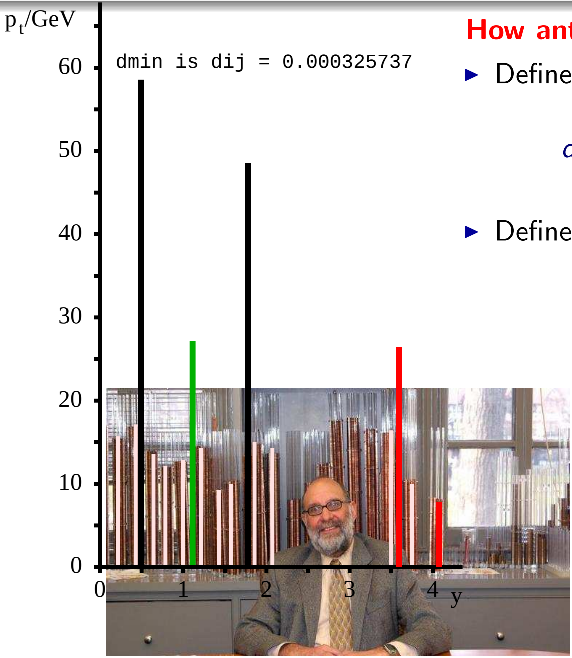

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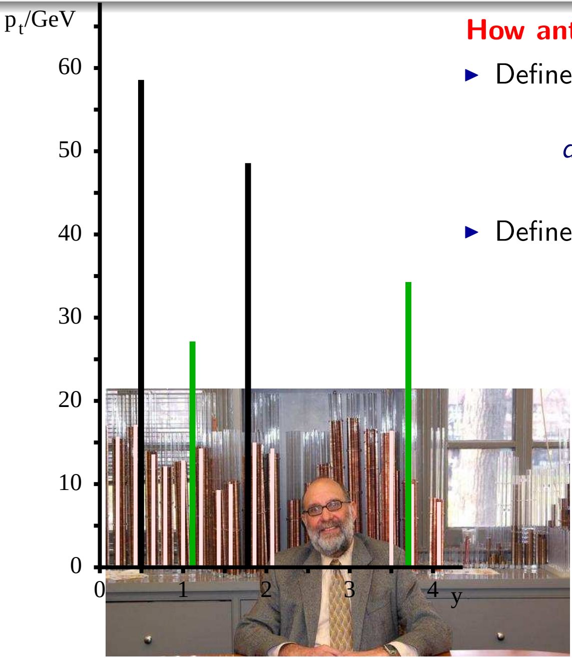

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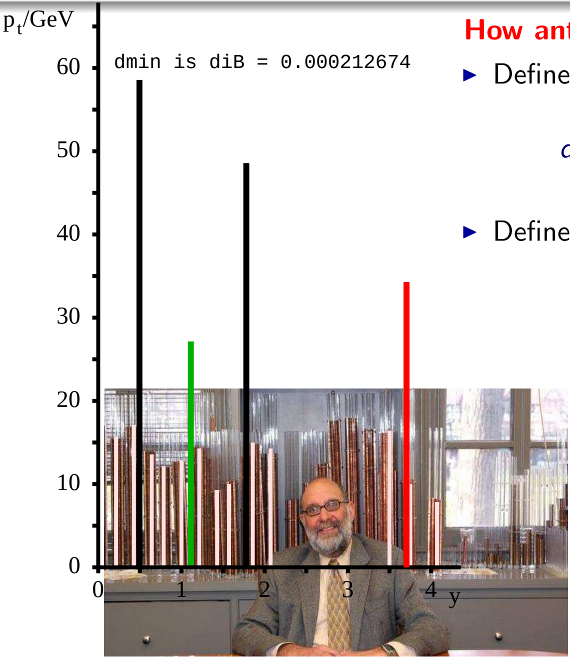

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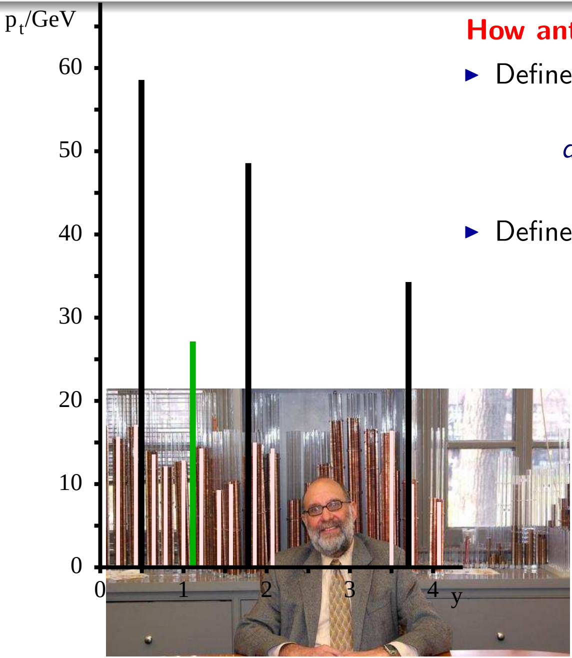

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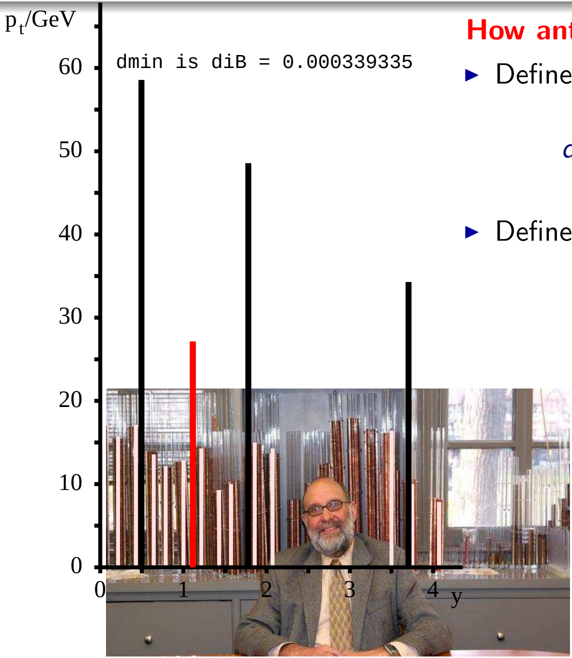

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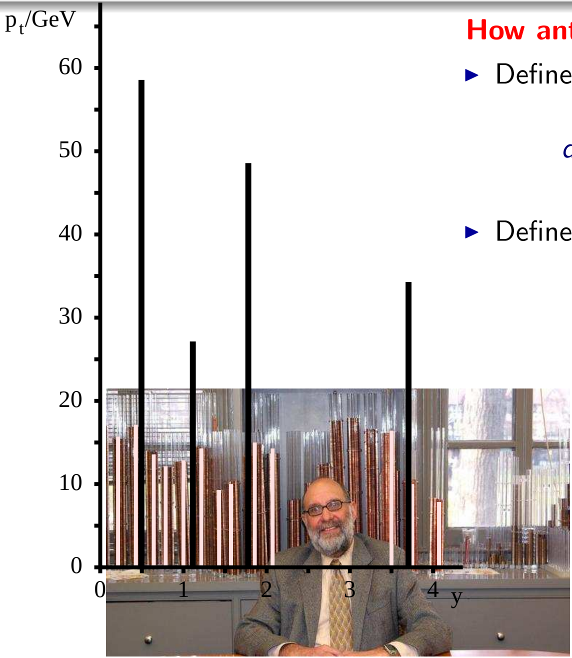

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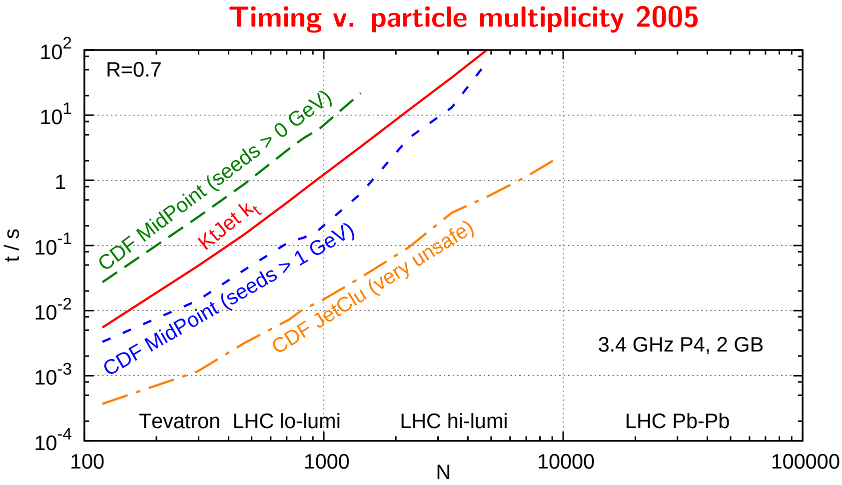
How does anti-k_t fare?



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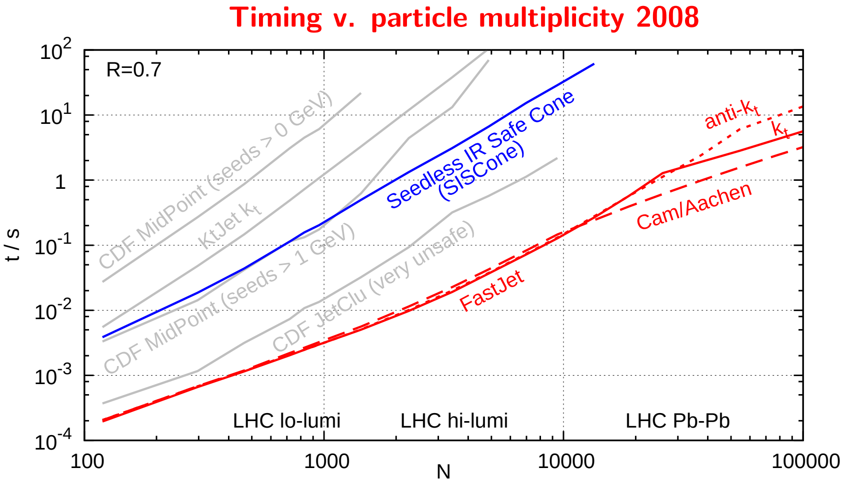
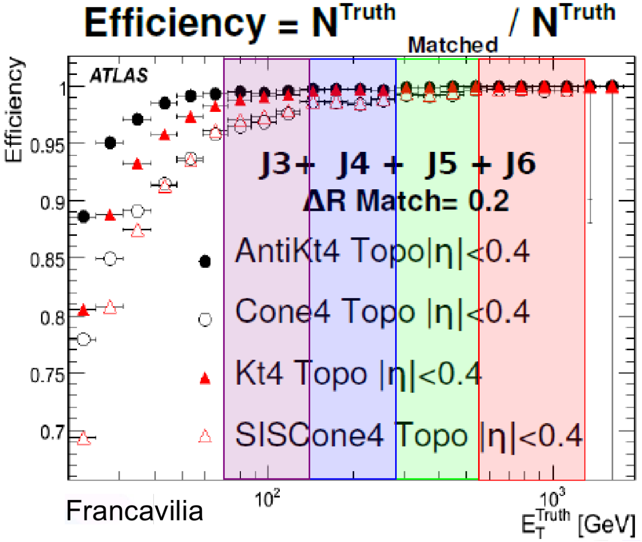


in critical region of $N \sim 2000 - 4000$

1000 times faster than previous attempts with similar jet algorithms

How does anti-k_t fare?

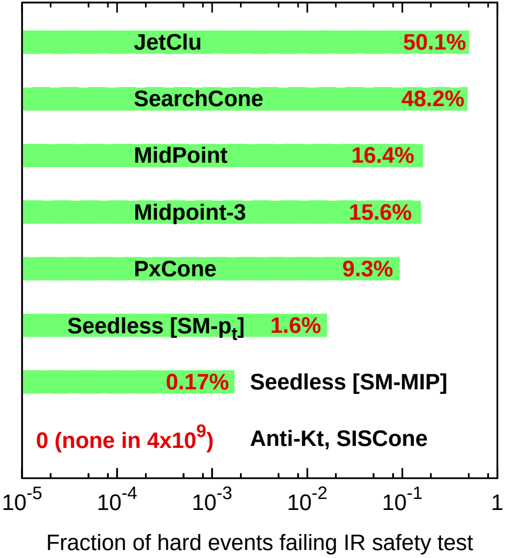
Experimental sensitivity to noise



As good as, or better than all previous experimentally-favoured algorithms

How does anti-k_t fare?

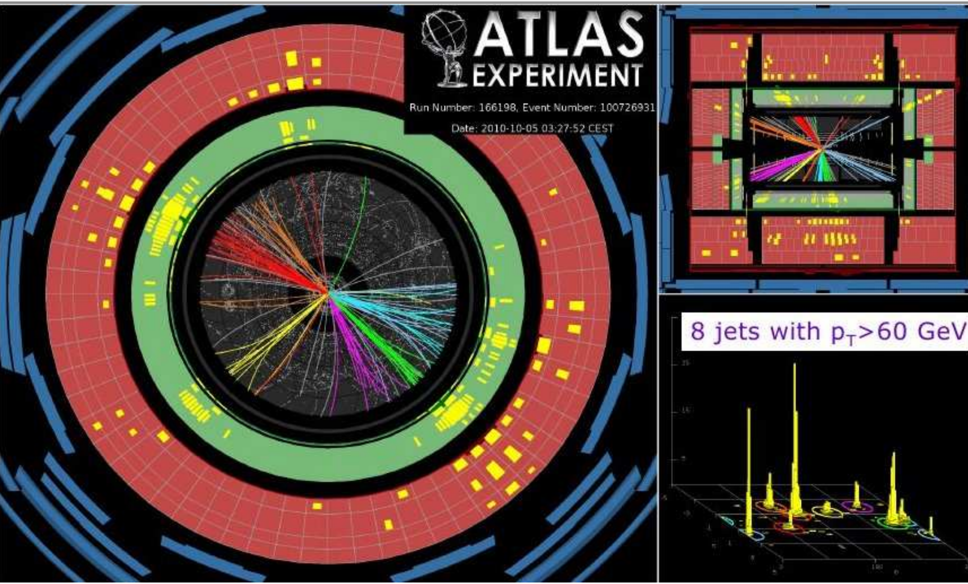
Coefficient of "infinity"



Safe for perturbative QCD predictions:

No "leakage" of infinities to higher orders

ATLAS & CMS use anti-k_t for all their jet-finding



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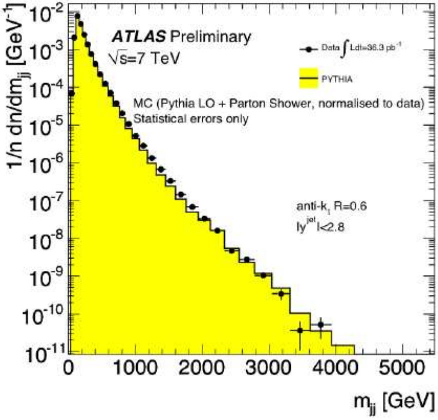
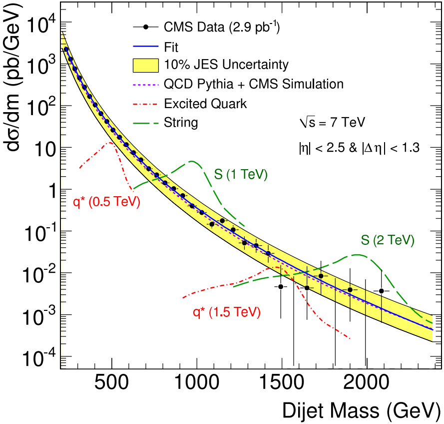


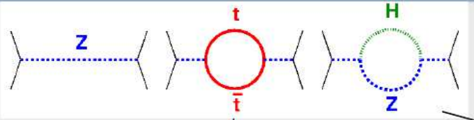


Among the few LHC searches so far, jets have probed the highest scales, ~ 2 TeV, about twice as high as Tevatron.

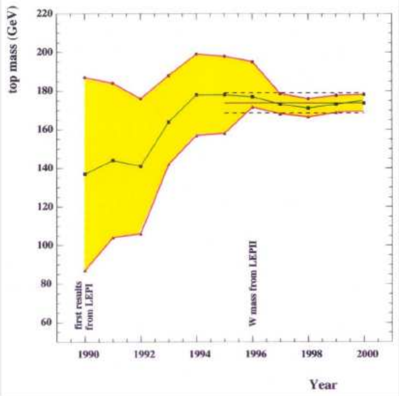
The quest for the Higgs

Using jets better, in order to make discoveries possible

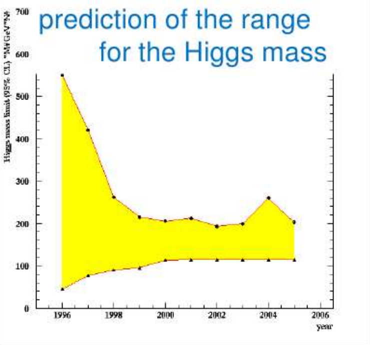
Test of the SM at the Level of Quantum Fluctuations



indirect determination of the top mass



prediction of the range for the Higgs mass

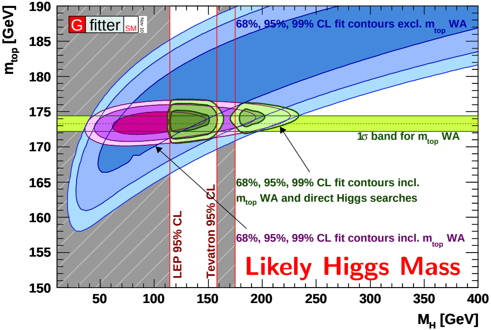


possible due to

- precision measurements
- known higher order electroweak corrections

$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$

Higgs mass and Higgs decays?



There's some likelihood that the Higgs boson will be "light", $M_H \sim 120$ GeV

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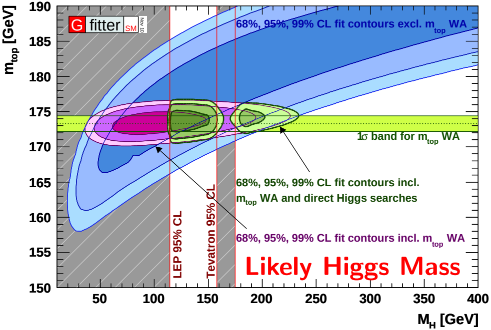
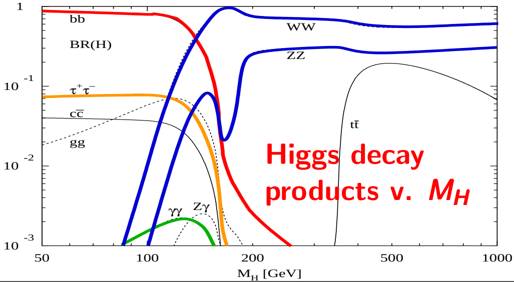




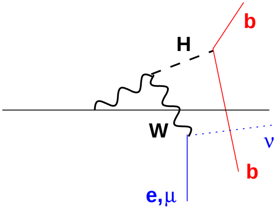
There's some likelihood that the Higgs boson will be "light", $M_H \sim 120$ GeV

If it is, crucial test of whether it **is** the Higgs, will come from measuring several different decays

Remember: Higgs couplings intimately related to origin of particle masses

$H \to b\bar{b}$ (main light-Higgs decay) v. hard to see

Best hope is $pp \to W^{\pm}H$, $W^{\pm} \to \ell^{\pm}\nu$, $H \to b\bar{b}$.



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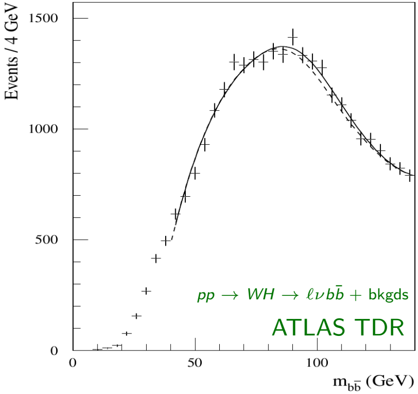
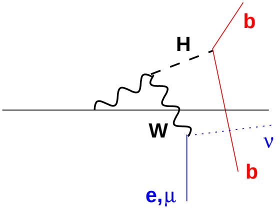


Conclusion (ATLAS TDR):

"The extraction of a signal from $H \to b\bar{b}$ decays in the WH channel will be very difficult at the LHC, even under the most optimistic assumptions [...]"

Low efficiency, huge backgrounds, e.g. $t\bar{t}$



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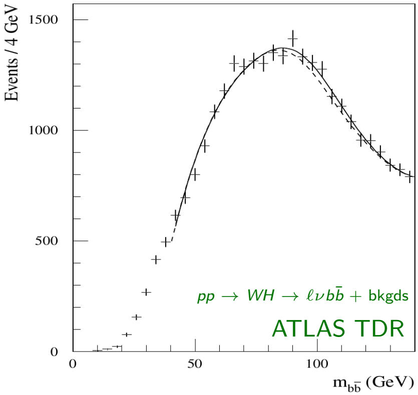

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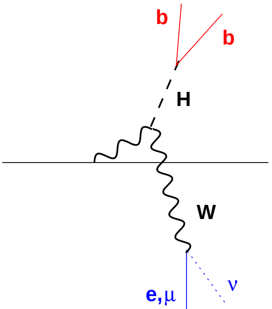

Try a long shot?

- Go to high p_t ($p_{tH}, p_{tW} > 200$ GeV)
- Lose 95% of signal, but more efficient?
- Maybe kill $t\bar{t}$ & gain clarity?

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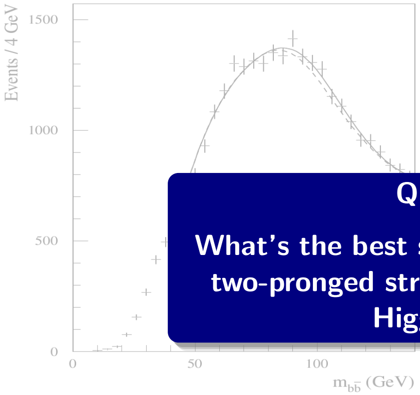

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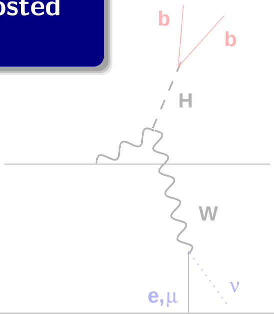
Question:

What's the best strategy to identify the two-pronged structure of the boosted Higgs decay?



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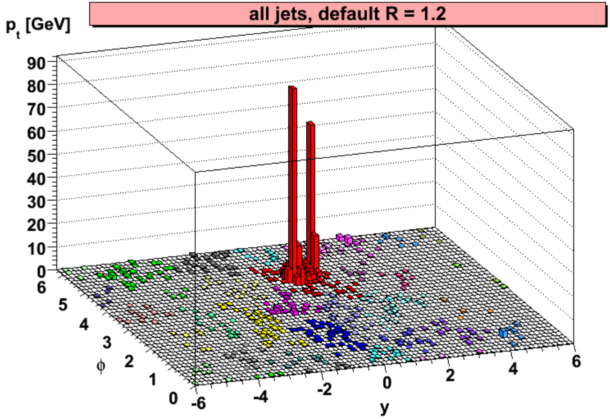
$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



Zbb BACKGROUND

Cluster event, C/A, R=1.2

Butterworth, Davison, Rubin & GPS '08

arbitrary norm.

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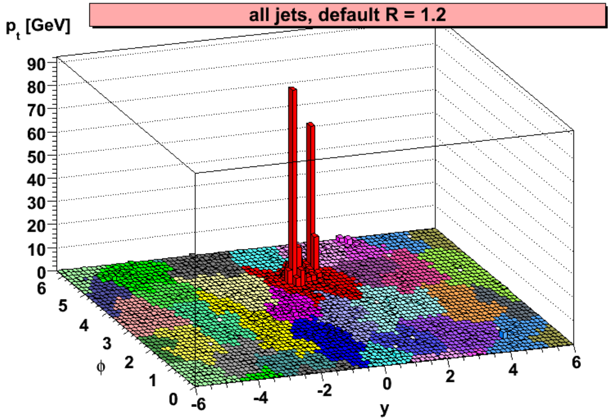

Zbb BACKGROUND

Fill it in, → show jets more clearly

Butterworth, Davison, Rubin & GPS '08

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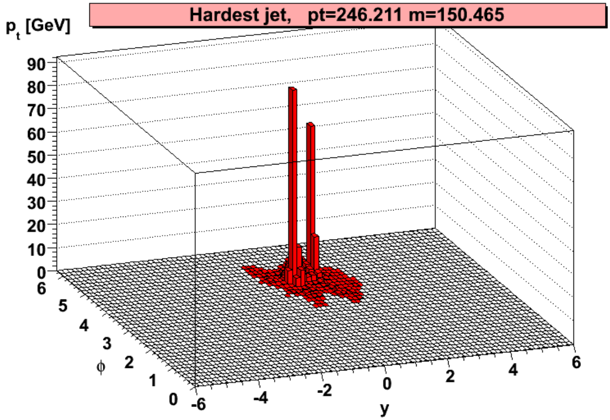
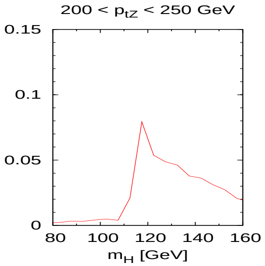


Consider hardest jet, $m = 150$ GeV

Butterworth, Davison, Rubin & GPS '08

SIGNAL



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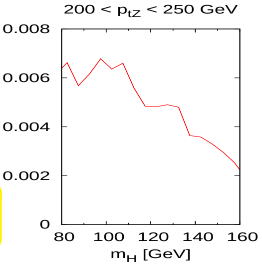

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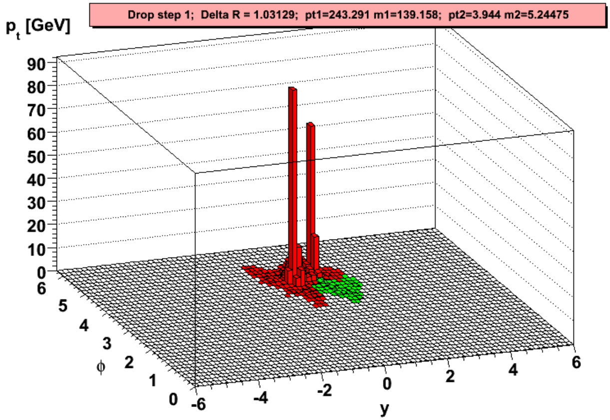

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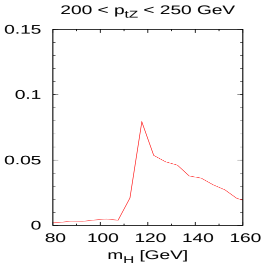

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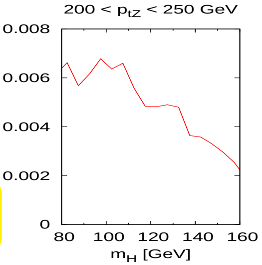

split: $m = 150$ GeV, $\frac{\max(m_1, m2)}{m} = 0.92 \to$ repeat

Butterworth, Davison, Rubin & GPS '08

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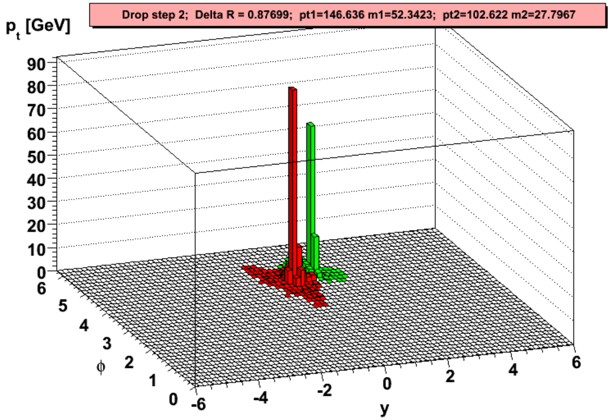

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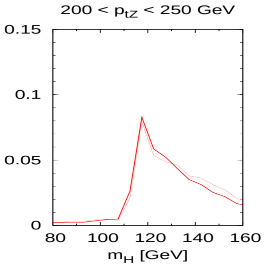

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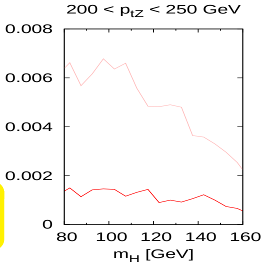

split: $m = 139$ GeV, $\frac{\max(m_1, m2)}{m} = 0.37 \to$ mass drop

Butterworth, Davison, Rubin & GPS '08

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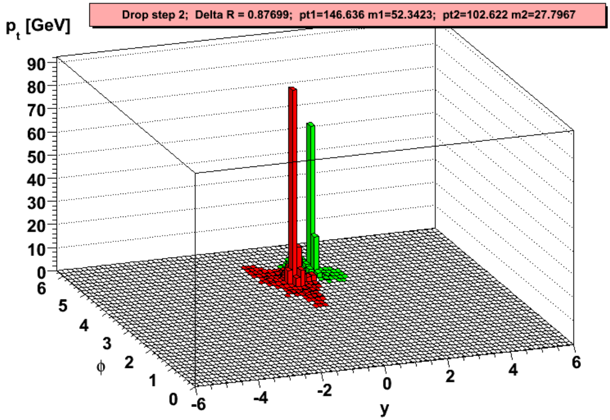

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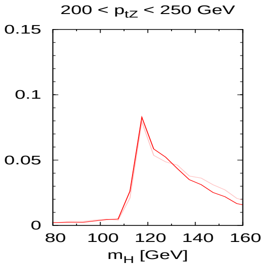
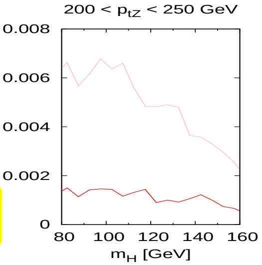


Zbb BACKGROUND



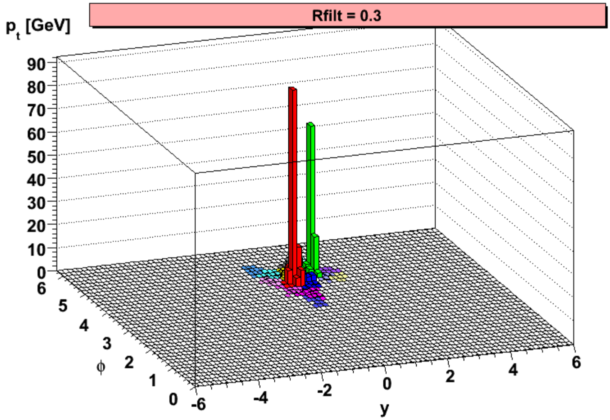
check: $y_{12} \simeq \frac{p_{t2}}{p_{t1}} \simeq 0.7 \to$ OK + 2 b-tags (anti-QCD)

Butterworth, Davison, Rubin & GPS '08

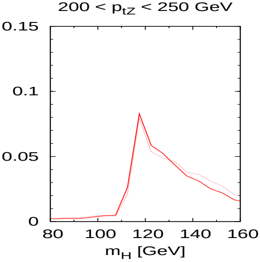
arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

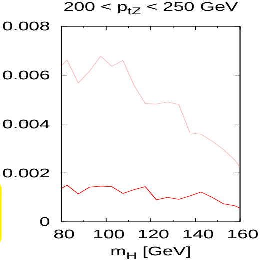
Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



Zbb BACKGROUND



$R_{filt} = 0.3$

Butterworth, Davison, Rubin & GPS '08

arbitrary norm.

$pp \to ZH \to \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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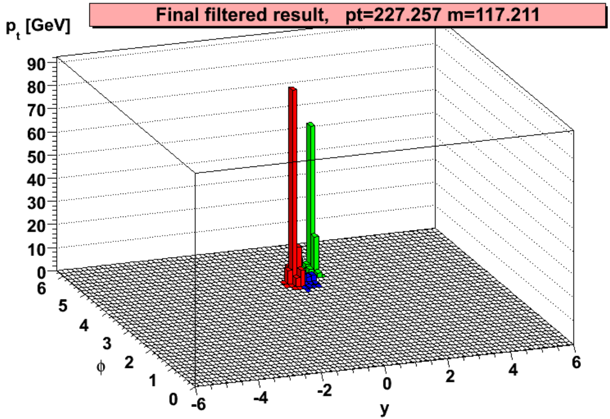
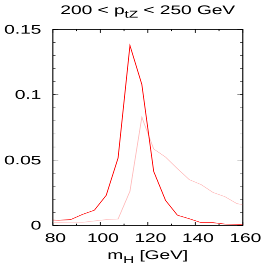
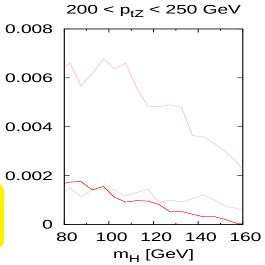


SIGNAL



Zbb BACKGROUND



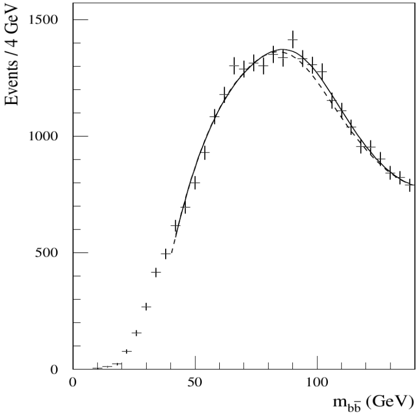
$R_{filt} = 0.3$: take 3 hardest, **m = 117 GeV**

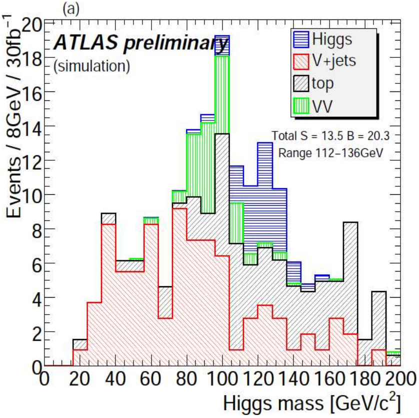
Butterworth, Davison, Rubin & GPS '08

arbitrary norm.

How well-designed jet-finding helps you

Search for main decay of light Higgs boson, W/Z+H, H → $b\bar{b}$
(The only way of seeing this decay — other than the next slide)

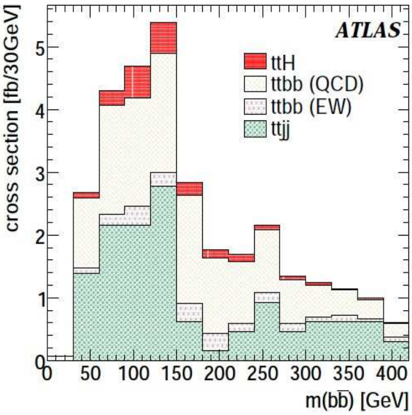


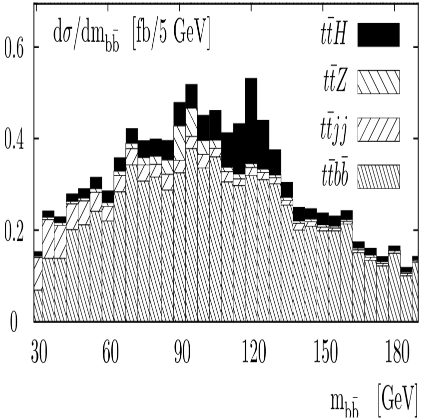


using the method from Butterworth, Davison, Rubin & GPS '08
Princeton CMS group working on improving this yet further

How well-designed jet-finding helps you

Recovering the ttH, $H \to b\bar{b}$ Higgs channel



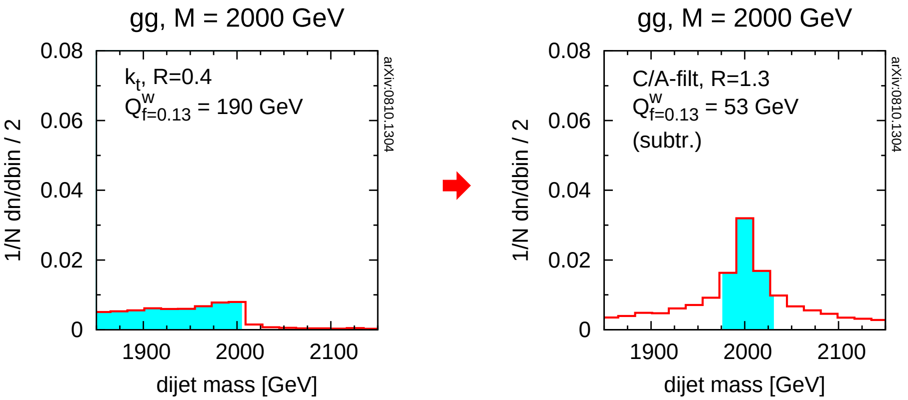


Plehn, GPS & Spannowsky '09

Boosted top tagging in Princeton: Thaler & Wang '08

How well-designed jet-finding helps you

Dijet mass reconstruction for new heavy resonance $X \to gg$

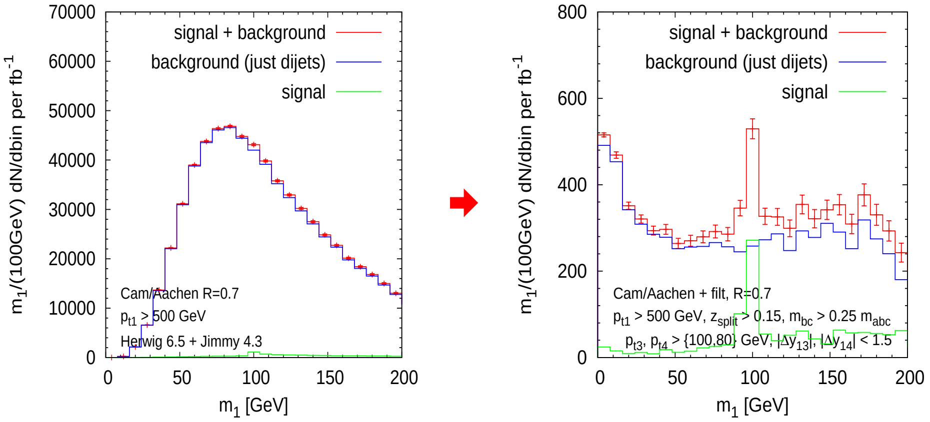


Cacciari, Rojo, GPS & Soyez '08

Also Princeton contributions: Krohn, Thaler & Wang '09

How well-designed jet-finding helps you

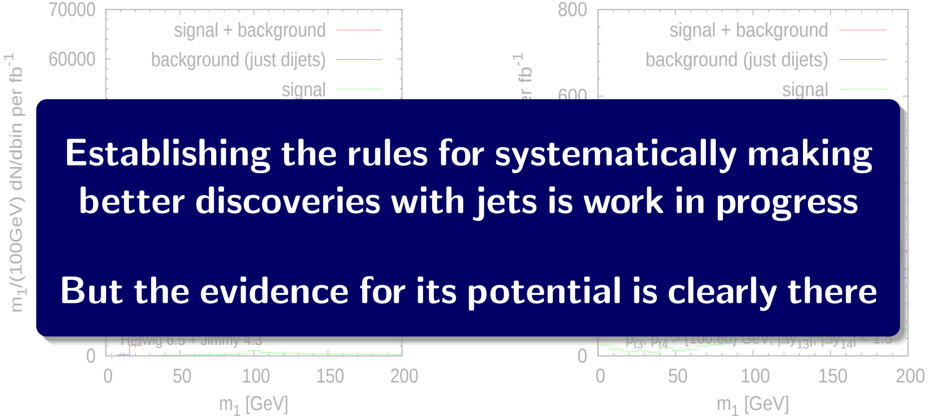
Supersymmetry with R-parity violating decays $\tilde{\chi}_1^0 \to$ qqq
One of its most difficult incarnations



Butterworth, Ellis, Raklev & GPS ’09

How well-designed jet-finding helps you

Supersymmetry with R-parity violating decays $\tilde{\chi}^0_1 \to qqq$
One of its most difficult incarnations



Establishing the rules for systematically making better discoveries with jets is work in progress

But the evidence for its potential is clearly there

Butterworth, Ellis, Raklev & GPS '09

How well-designed jet-finding helps you

PRINCETON CENTER FOR THEORETICAL SCIENCE

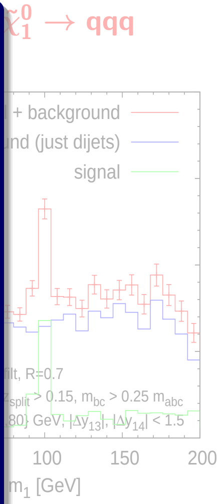
Boost 2011

The Boost 2011 conference will be held in May (5/23/11 - 5/27/11) at Princeton University, hosted by the Princeton Center for Theoretical Science. As with prior conferences in the Boost series, the weeklong event will focus on bringing together theorists and experimentalists for in-depth discussions of jets, jet substructure, and jets in more exotic contexts (e.g. lepton jets).

This workshop is open to the public. Early registration is encouraged.

Previous Boost conferences: SLAC, U.W., Oxford

m$_1$/(100GeV) dN/dbin per fb^{-1}



Raklev & GPS '09

Outlook for LHC

2011

Between 40 and 200 times more data $2 - 8\ \text{fb}^{-1}$

Maybe increasing energy from 7 TeV to 8 TeV

2012

Shutdown to complete modifications needed for safe operation at design energy

2013-

Running at $13 - 14$ TeV

Accumulating several $100\ \text{fb}^{-1}$ by 2016

Higgs visible by 2014?

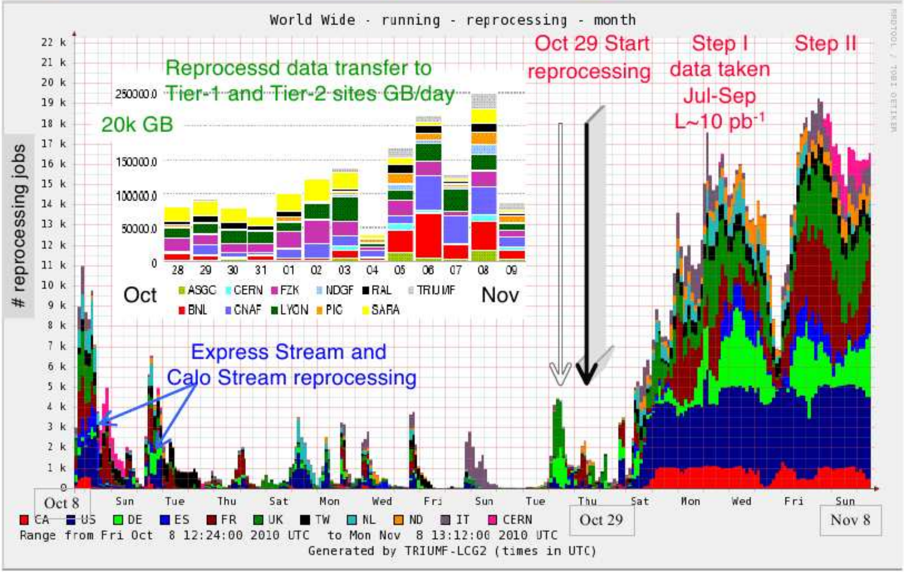
Beyond

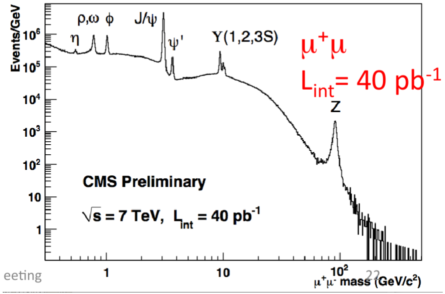
LHC luminosity upgrades: factor 5-10

Linear collider (to study whatever is discovered at LHC), or even higher-energy LHC

EXTRAS

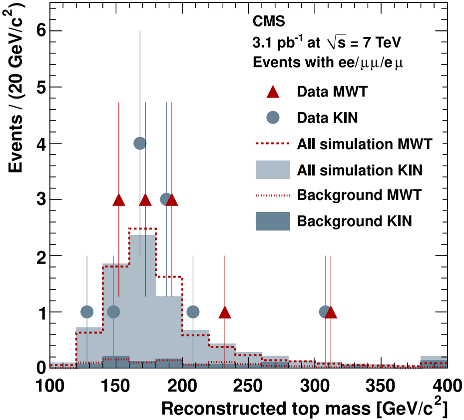
Autumn 2010 Reprocessing





Events/GeV
ρ,ω
φ
J/ψ
η
ψ'
Υ(1,2,3S)
μ+μ
L_int= 40 pb-1
Z
CMS Preliminary
√s = 7 TeV, L_int = 40 pb-1
μ+μ- mass (GeV/c2)

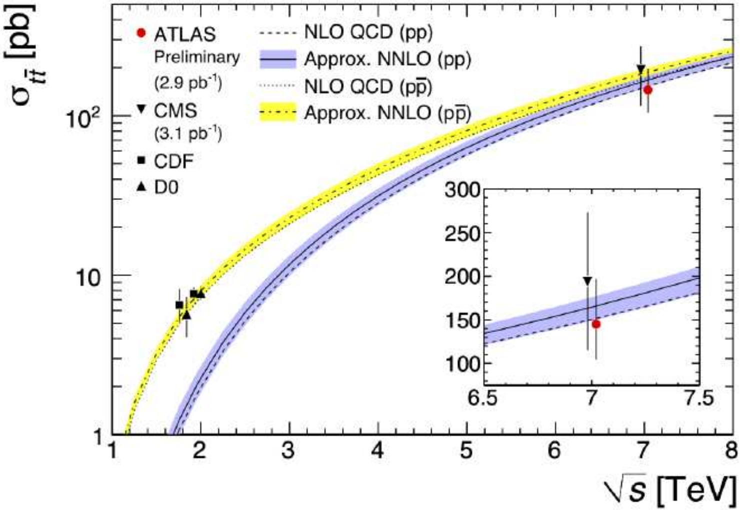
Reconstructed top mass distribution



Top production cross section

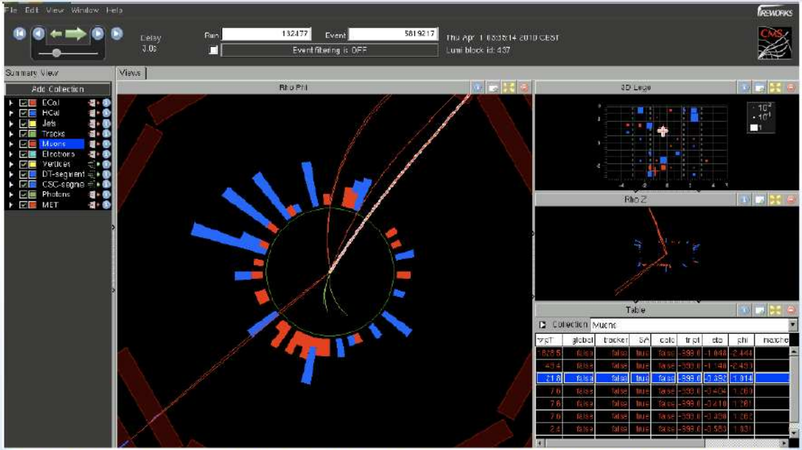
Combining all channels, $\sigma_{t\bar{t}} = 145 \pm 31^{+42}_{-27}$ pb

Significance of ~4.8σ w.r.t. background only hypothesis.



And not so standard events

Weird events: multi-muon (CMS)



- 7 standalone muons. Maybe a 1.8 TeV muon – out of time cosmic in coincidence with minimum bias events. Reported to the Muon POG – under investigation.

CMS exotica hotline

Weird events: monster tracker

- Events with 4000+ tracks, in BOTH Pixel and Strip detectors
- Detailed investigation (Andrea Rizzi) showed that they come from satellite bunch collisions during the fills of April 24-25 weekend
- Highly asymmetric track distribution (Ellie Twedt)