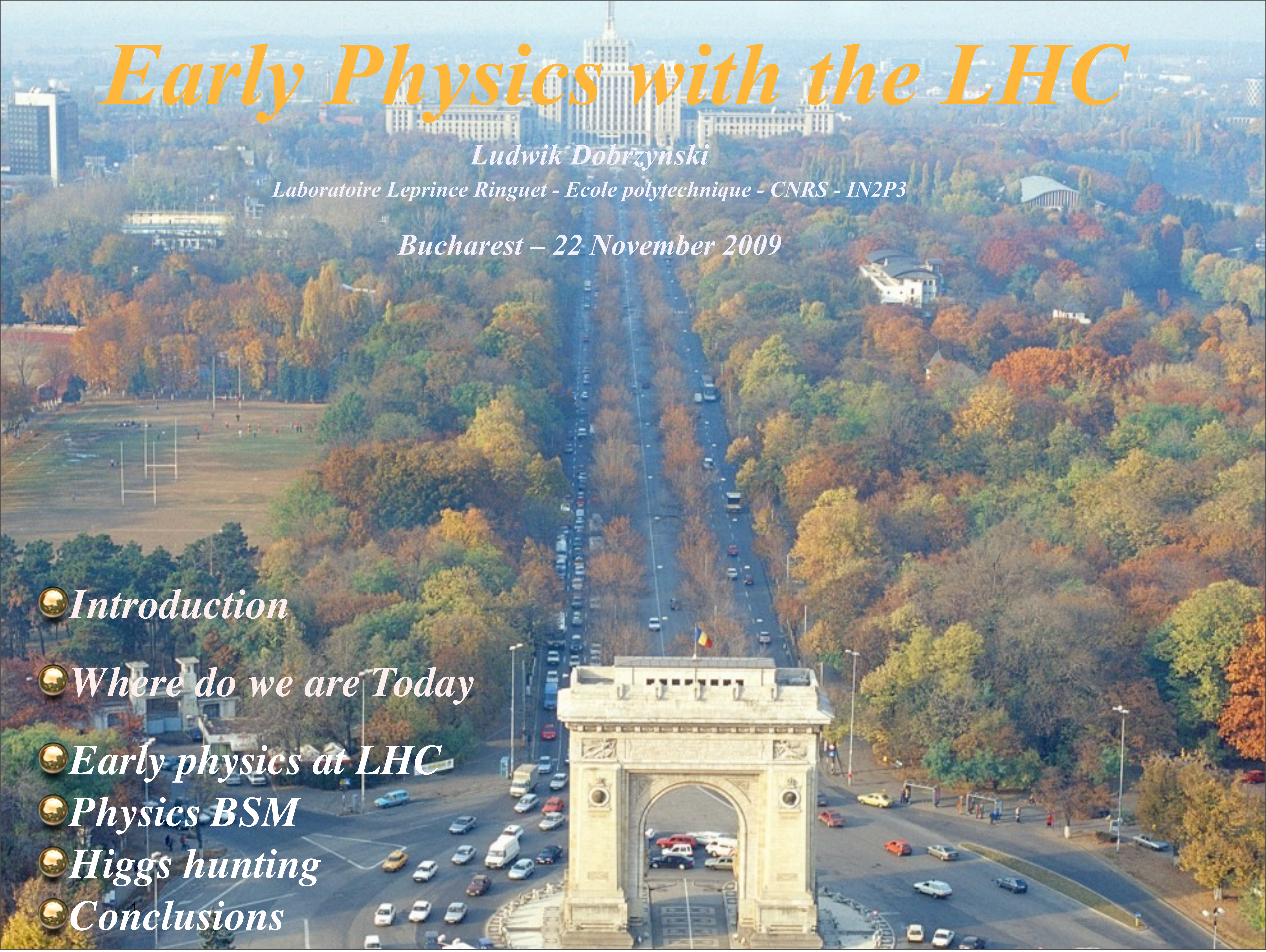
Early Physics with the LHC

Ludwik Dobrzynski

Laboratoire Leprince Ringuet - Ecole polytechnique - CNRS - IN2P3

Bucharest – 22 November 2009



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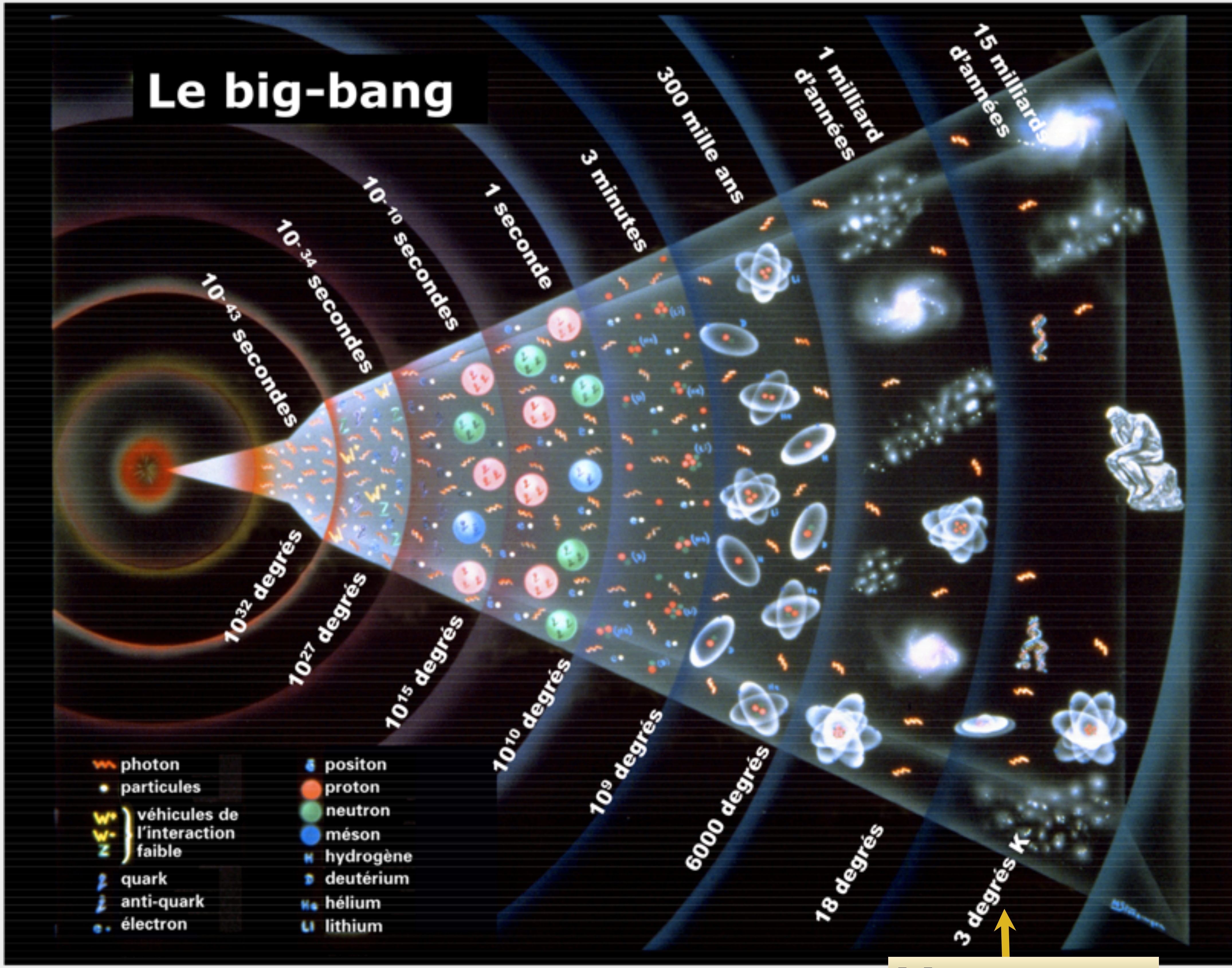
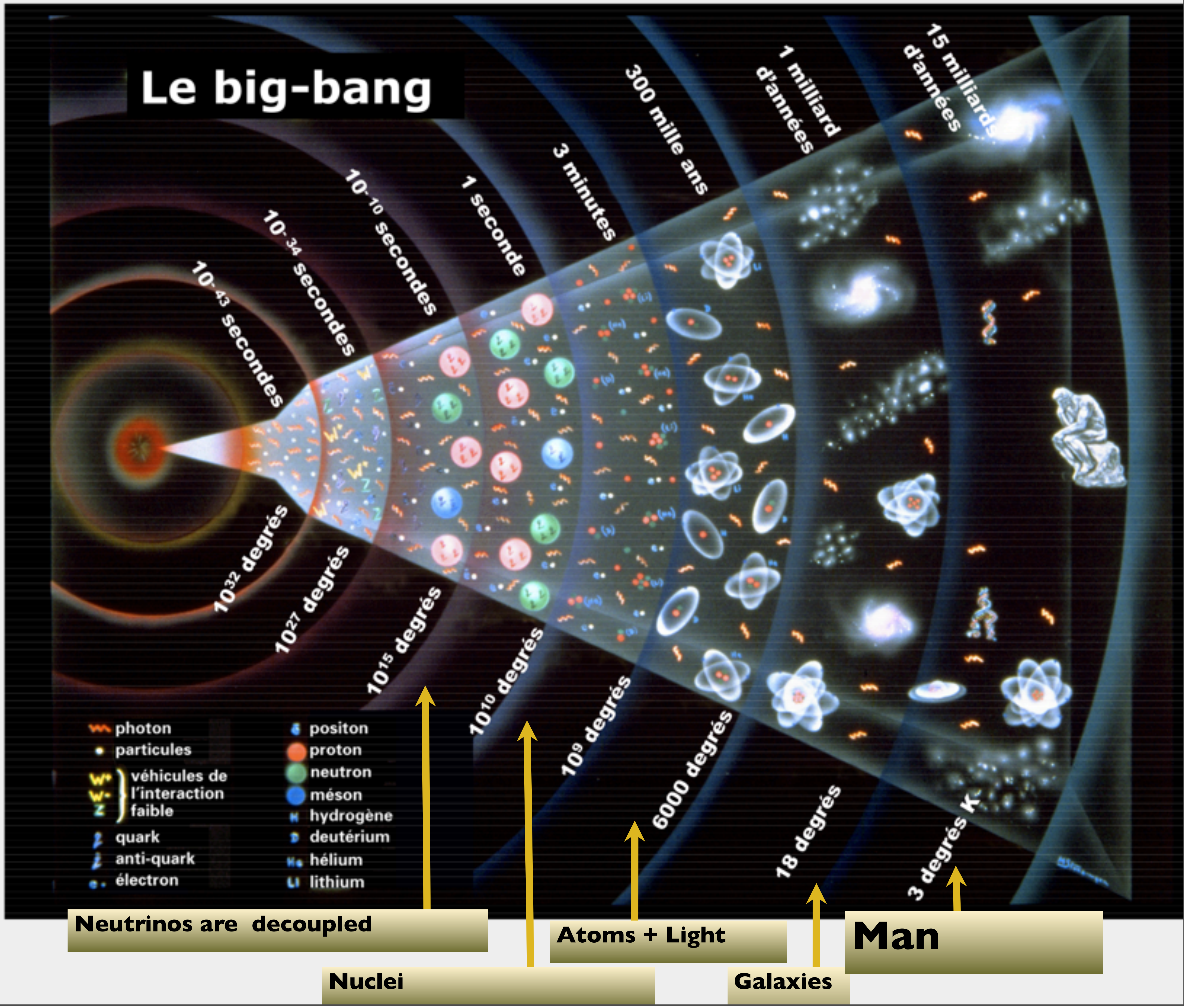
- *Introduction*
- *Where do we are Today*
- *Early physics at LHC*
- *Physics BSM*
- *Higgs hunting*
- *Conclusions*

Unveiling the Universe



Man

Unveiling the Universe



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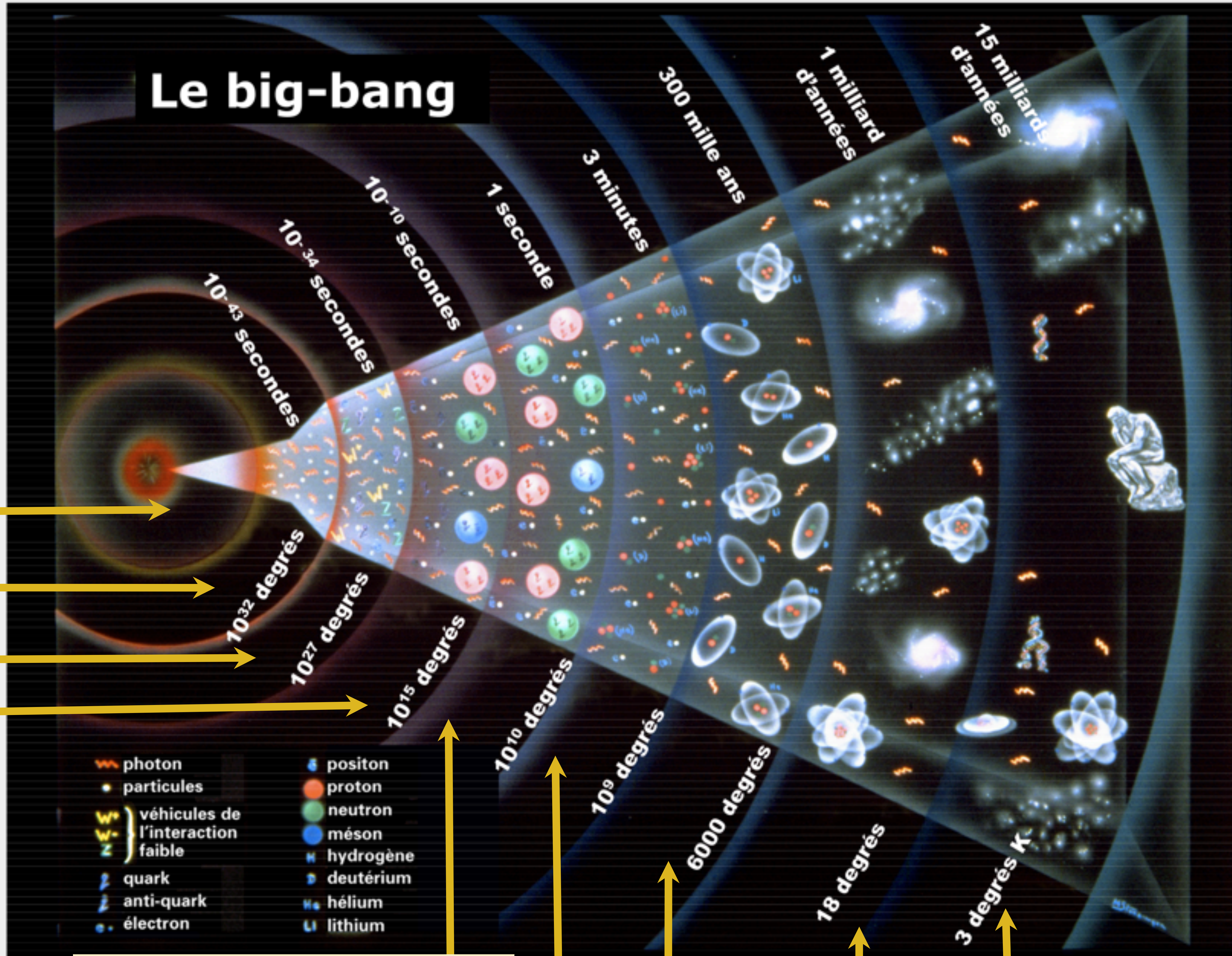
Unveiling the Universe



Quantum Gravity Era
(10^{19} GeV - 10^{-34} m)

Grand Unified Era
(10^{16} GeV - 10^{-32} m)

Electroweek Era
(100 GeV - 10^{-18} m)

proton - neutron
(1 GeV - 10^{-16} m)

Neutrinos are decoupled

Nuclei

Atoms + Light

Galaxies

Man

Open Cosmological Questions

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  - **~ 15,000,000,000 years**

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LHC

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Dark Matter in the Universe

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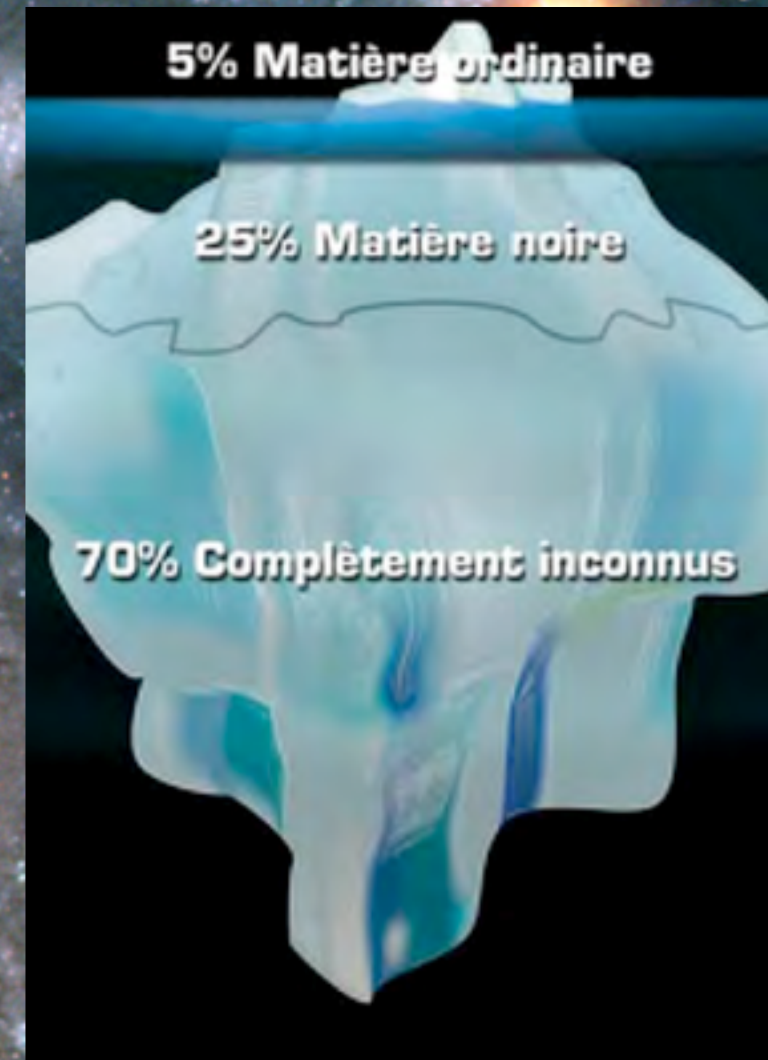
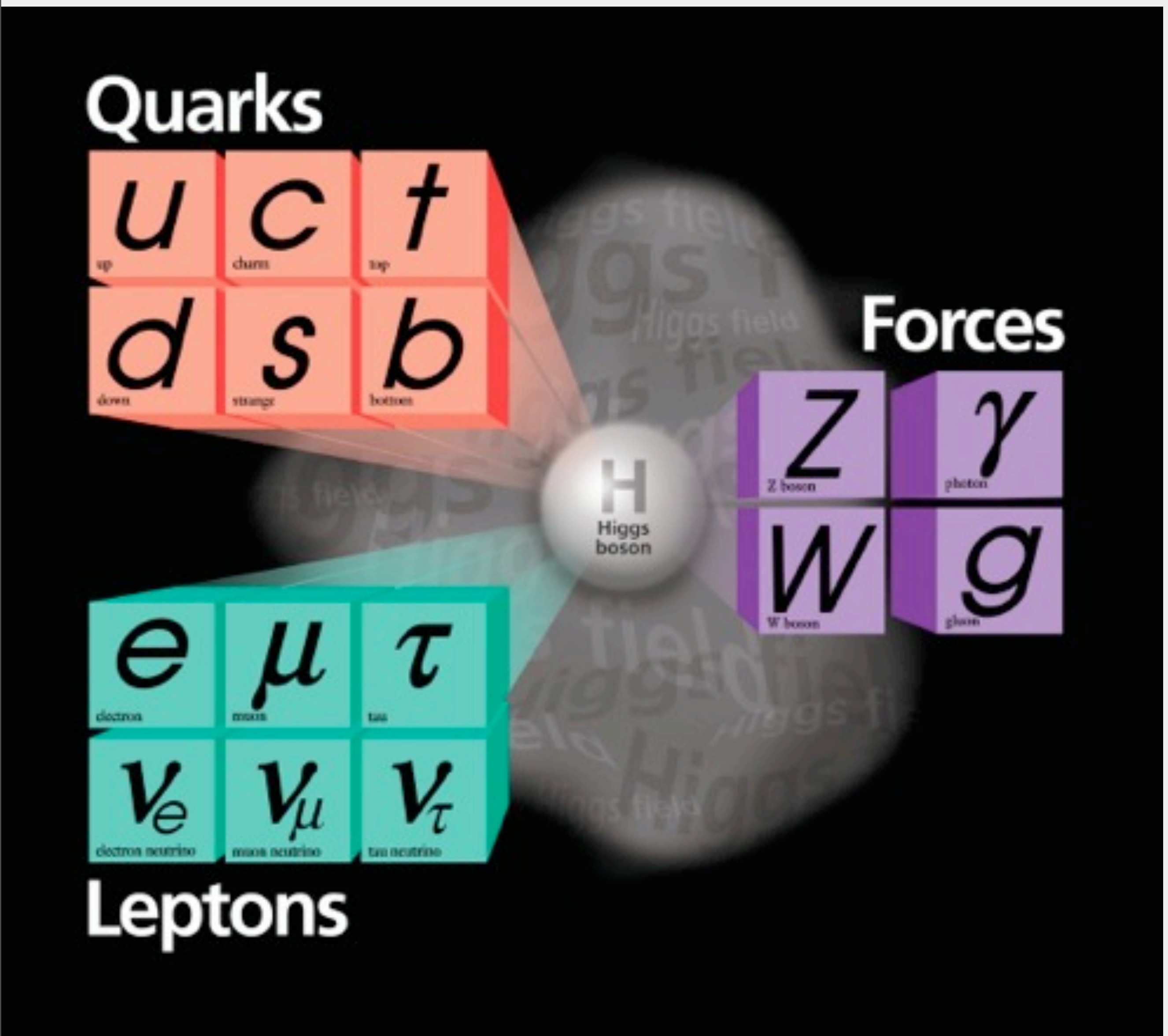


Dark Energy?
Remnant of some elementary scalar field analagous to the Higgs field?

Our present world : the Standard Model



- **Matter**
  - is made out of fermions
- **Forces**
  - are mediated by bosons
- **Higgs boson**
  - breaks the electroweak symmetry and gives mass to fermions and weak gauge bosons

Amazingly successful in describing precisely data from all collider experiments

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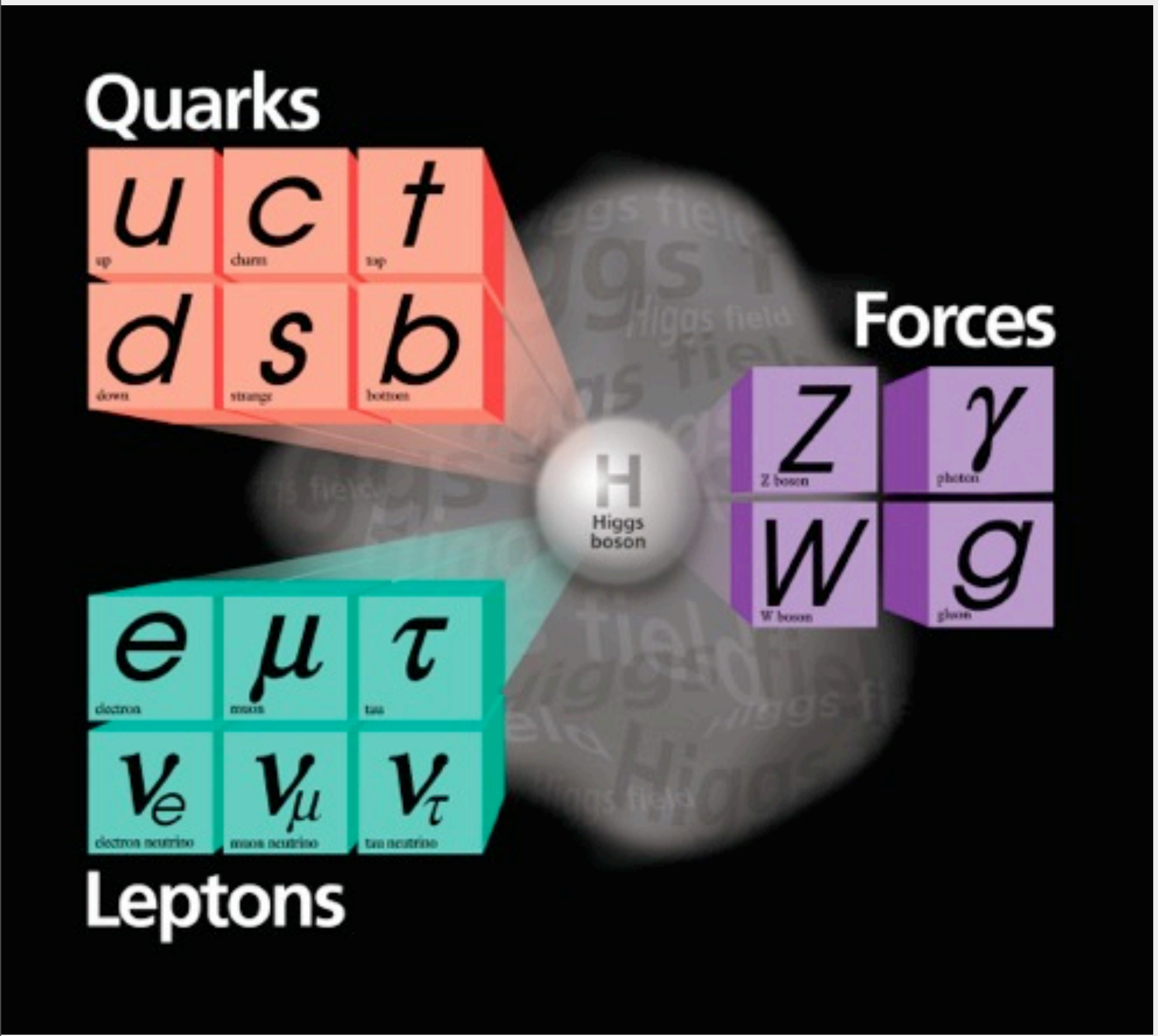

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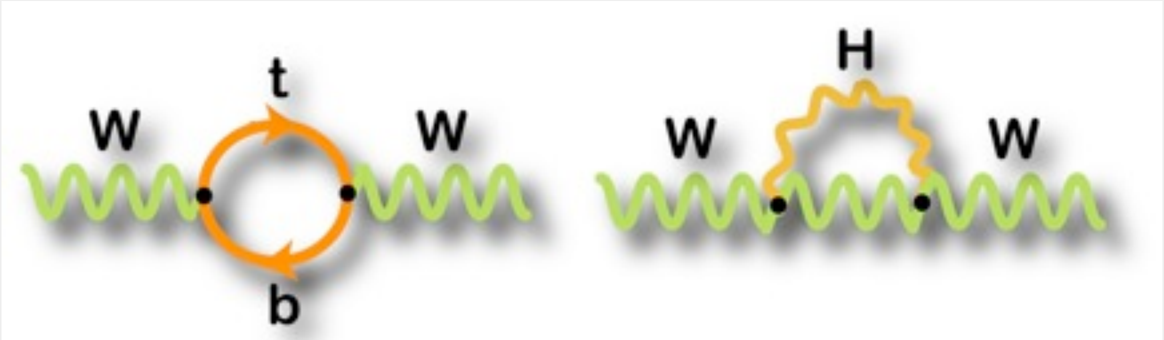
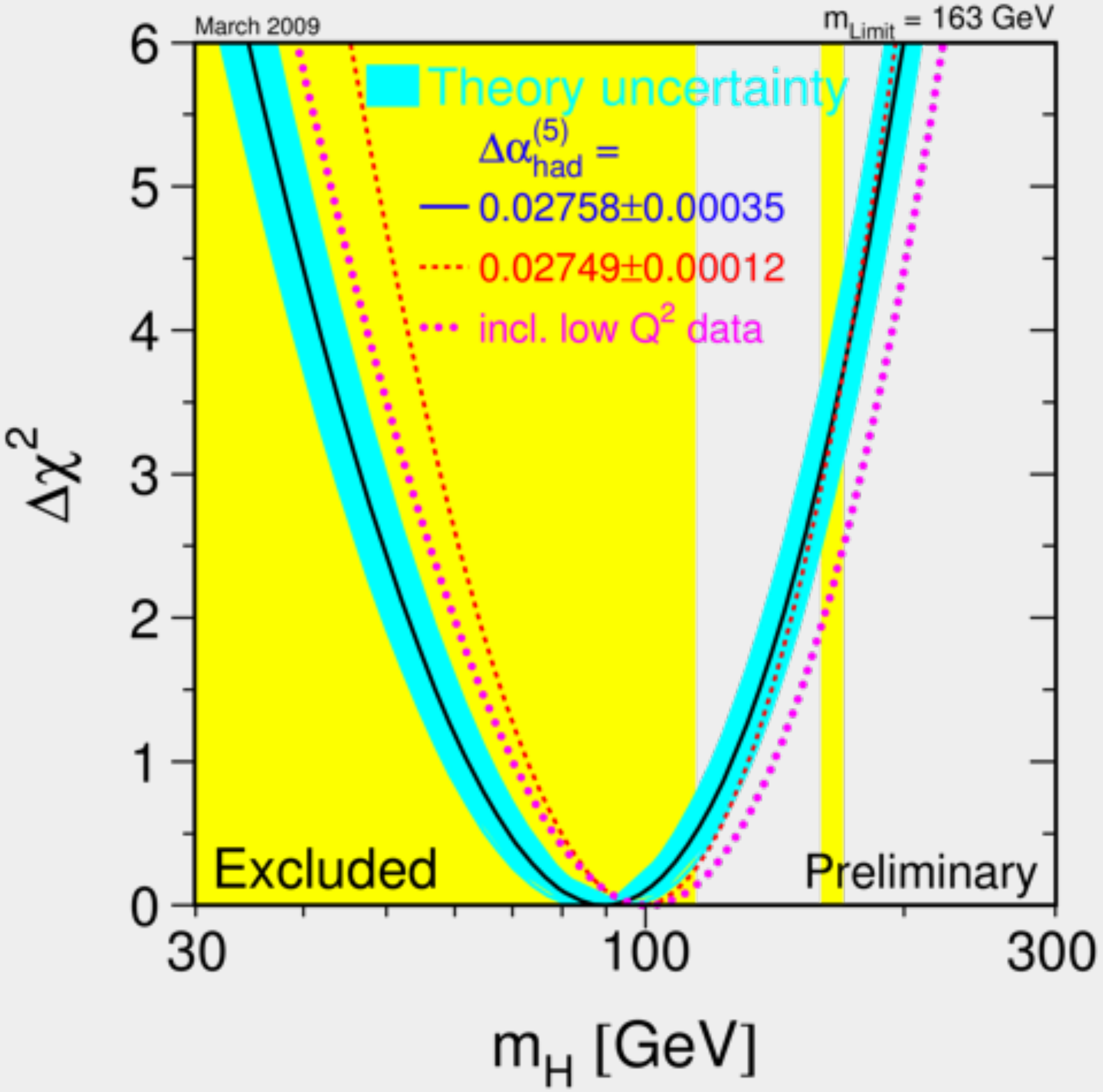
LEP, SLC and the Tevatron: established that we really understand the physics at energies up to √s ~ 100 GeV

And any new particles have masses above 200-300 GeV – and in some cases TeV.

Problem I: Where is the Higgs boson?

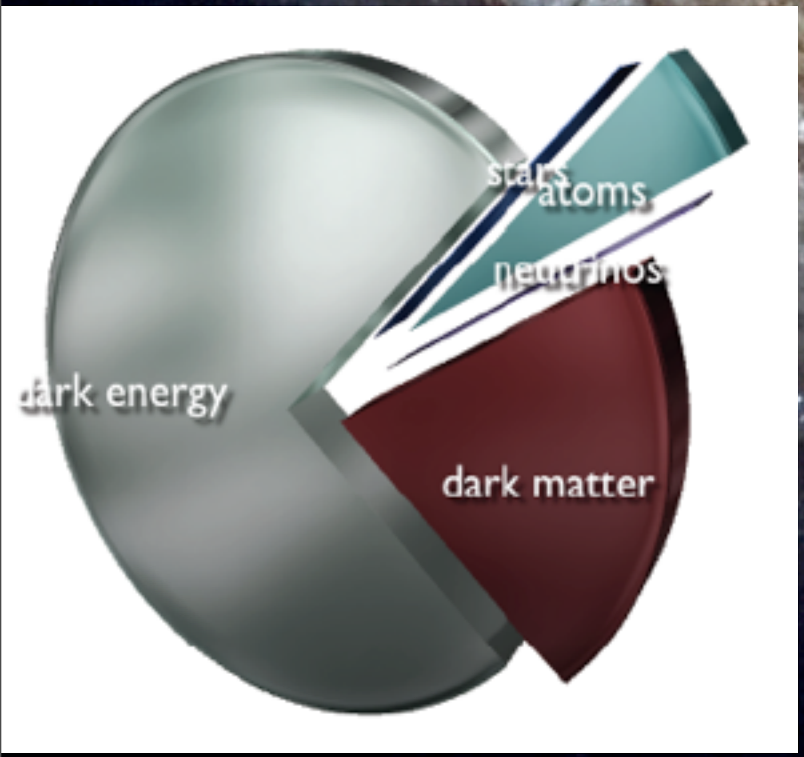
- Precision measurements of
  - M_W =80.399 ± 0.023 GeV/c²
  - M_{top}=173.1 ± 1.2 GeV/c²
  - Precision measurements on Z pole
- Prediction of higgs boson mass within SM due to loop corrections
  - Most likely value: 90^{+36}_{-27} GeV
- Direct limit (LEP): m_h>114.4 GeV





- **m_H<163 GeV @95%CL**

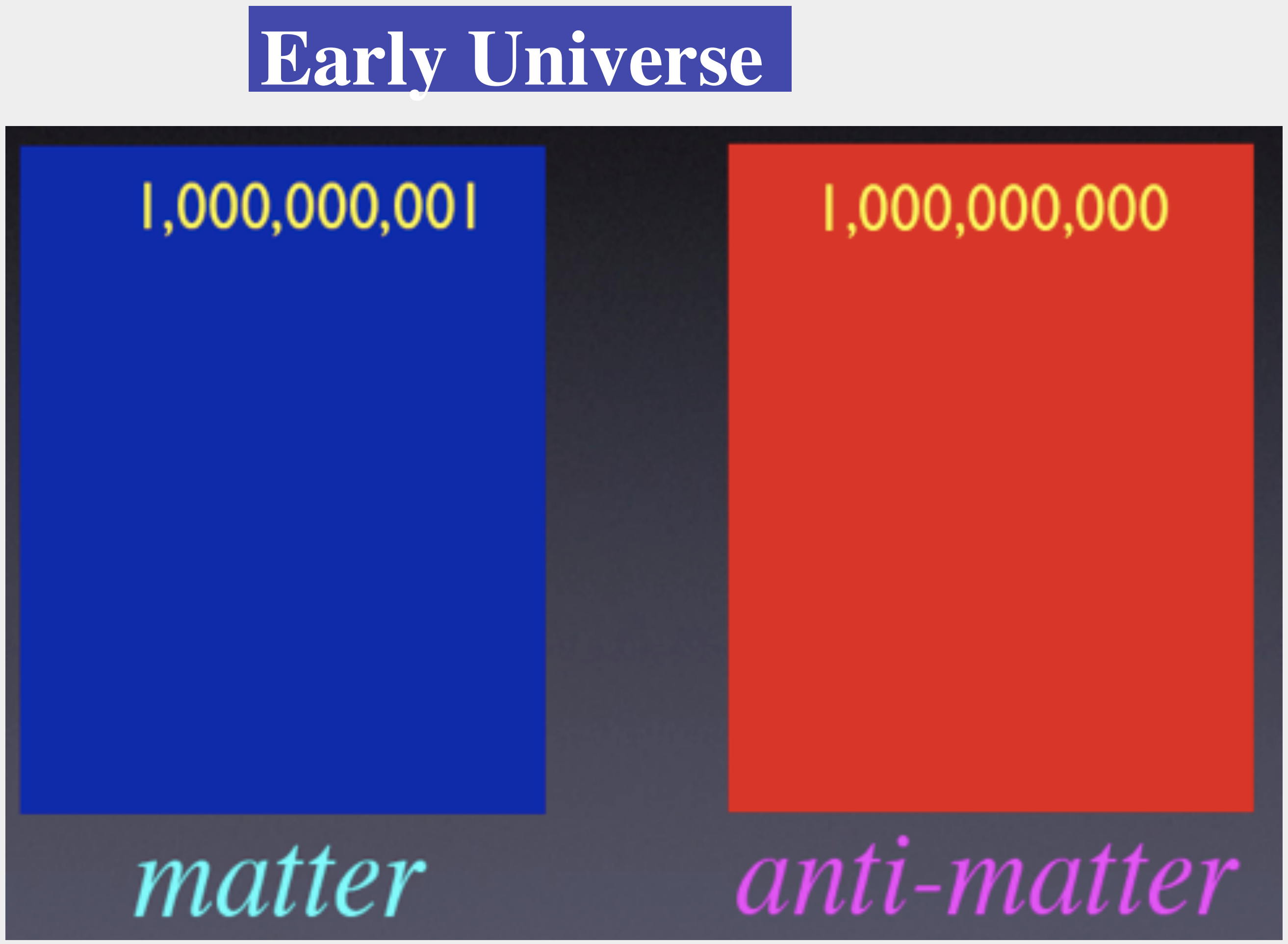
Problem II: What is the Dark Matter?

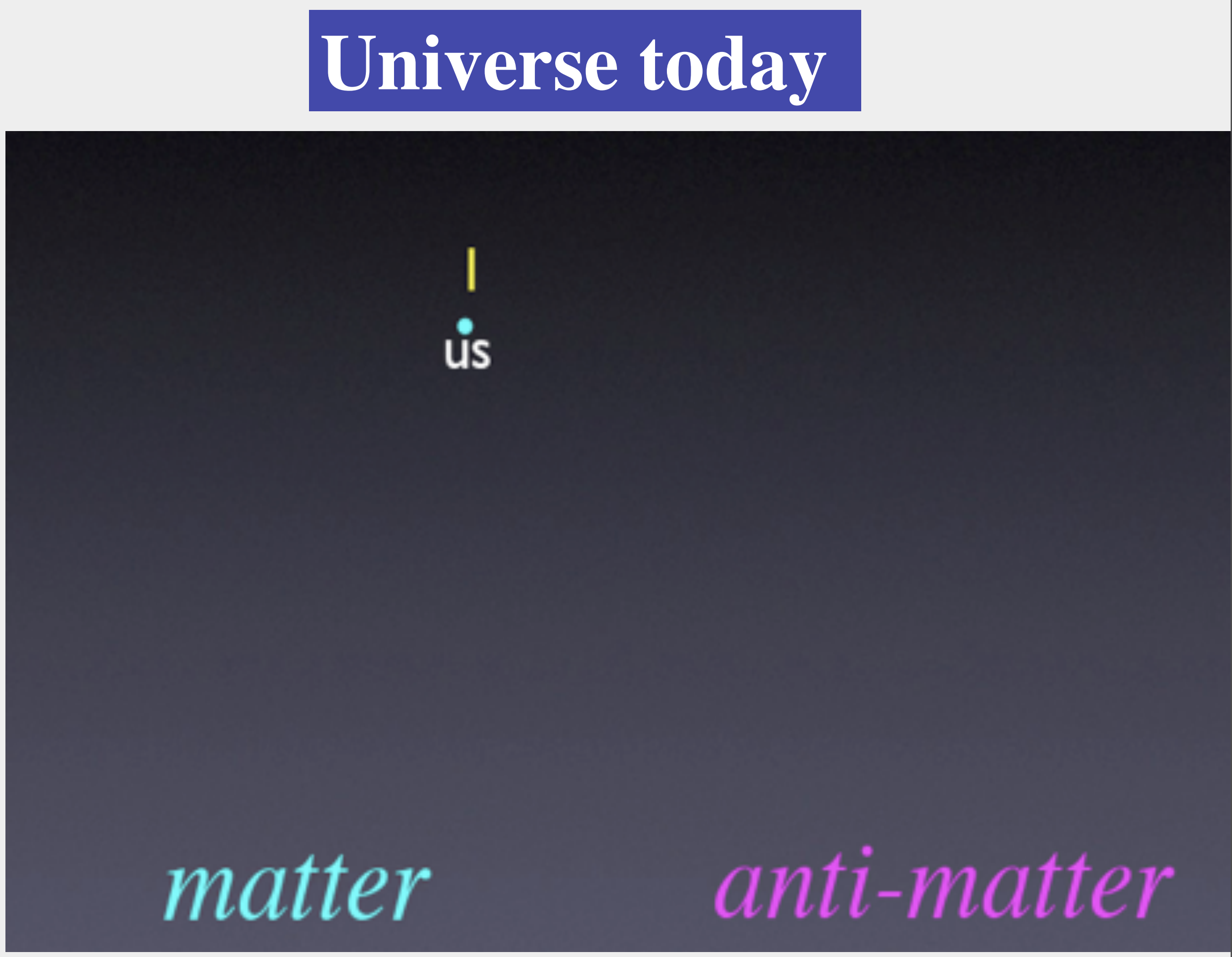


Standard Model only accounts for 20% of the matter of the Universe

$$\frac{\text{matter}}{\text{all atoms}} = 5.70^{+0.39}_{-0.61}$$

Problem III: Where did all the Antimatter go?



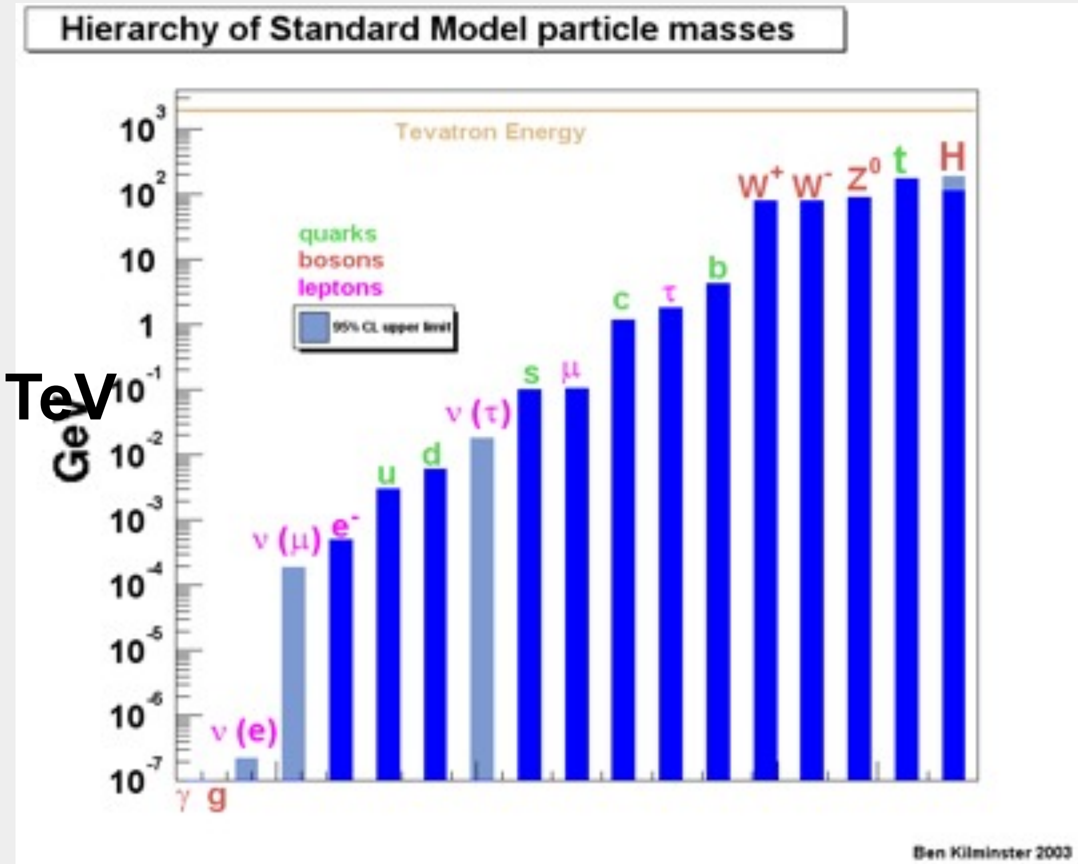


- **Not explained by Standard Model**

(Some) More Problems …

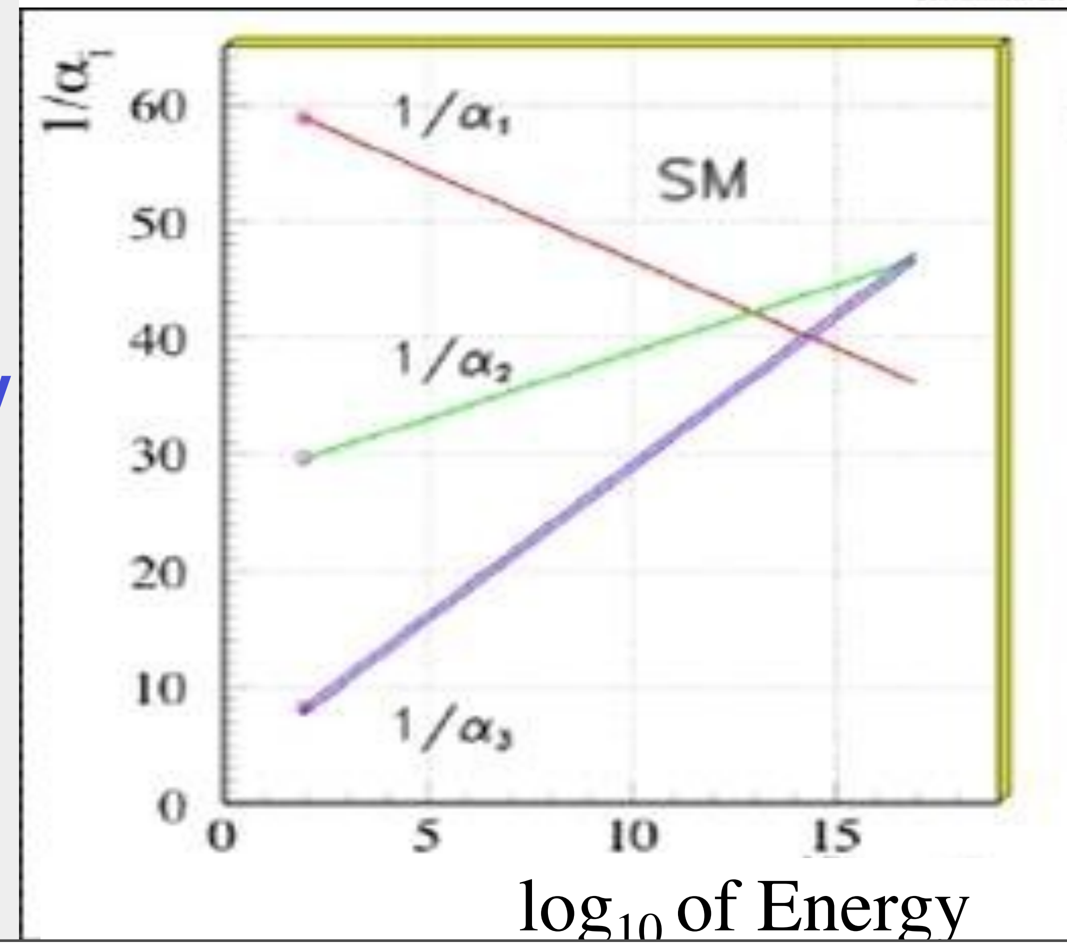
Hierarchy Problem

- **Why is gravity so weak?**
  - Free parameter $m^2_H{}^{tree}$ needs to be “finetuned” to cancel huge corrections
- Can be solved by presence of **new particles at M ~1 TeV**
  - Already really bad for M~10 TeV



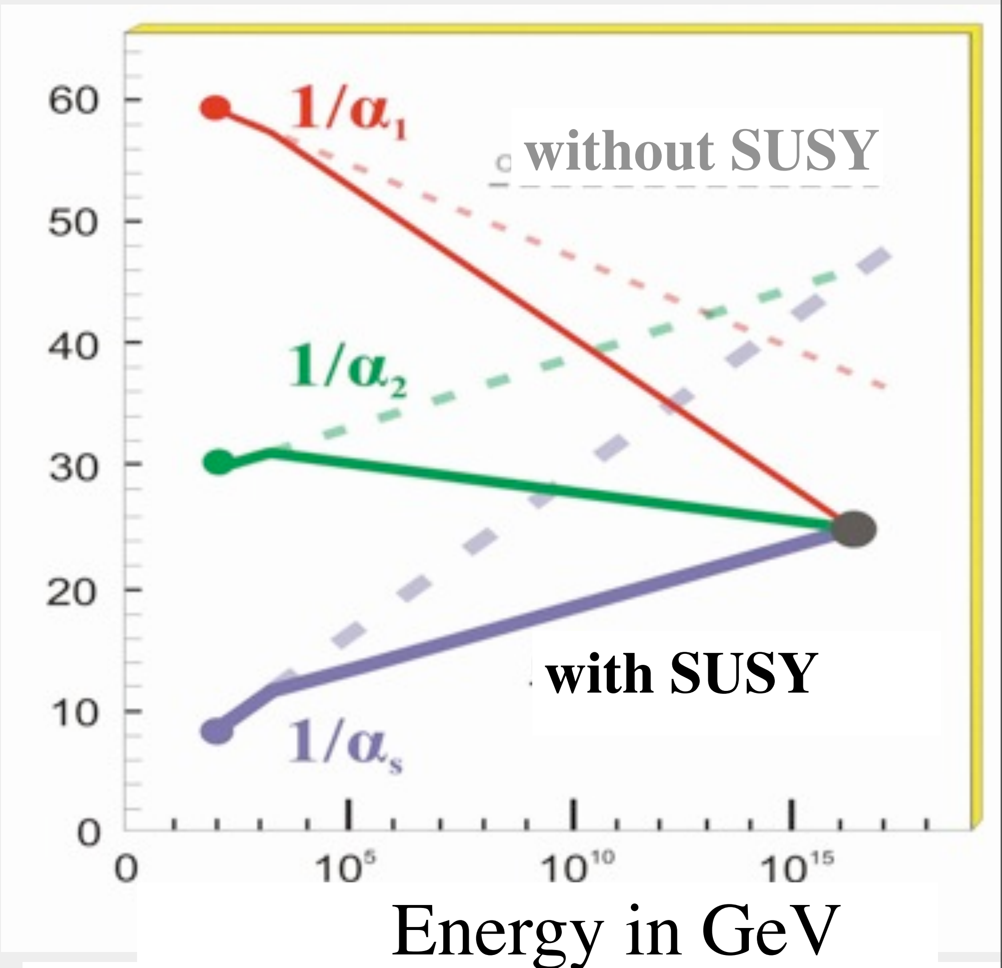
- **Matter:**
  - SM cannot explain **number of fermion generations**
  - or their **large mass hierarchy**
    - m_{top}/m_{up}~100,000
- **Gauge forces:**
  - electroweak and strong **interactions do not unify** in SM
  - SM has no concept of **gravity**
- **What is Dark Energy?**

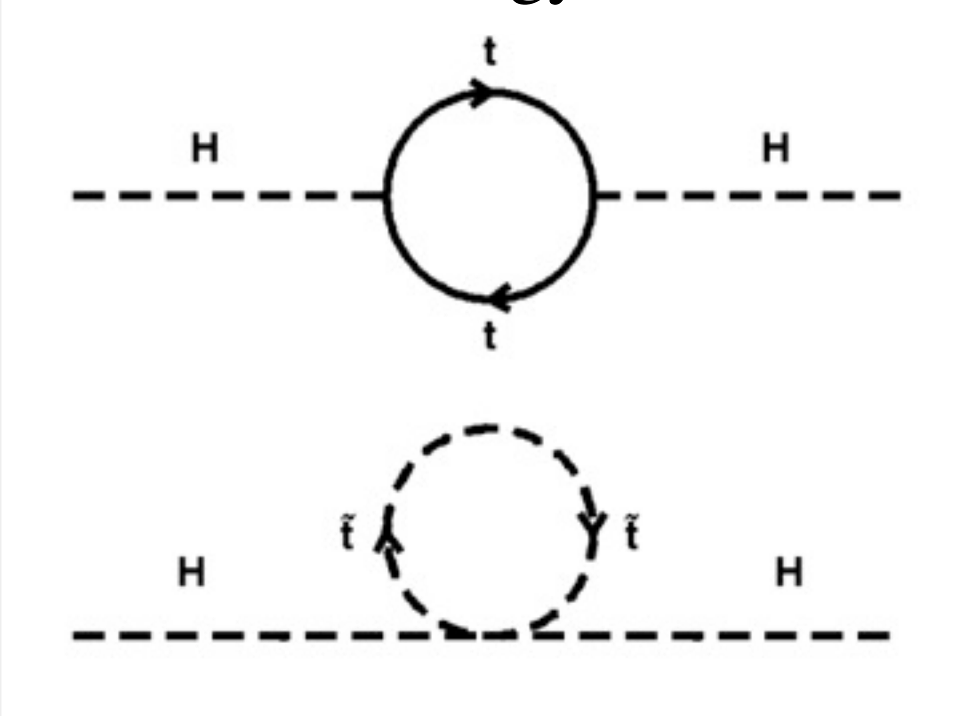
“Supersymmetry” (SUSY) can solve some of these problems



SUSY can solve some problems

- Supersymmetry (SUSY)
  - Each SM particle gets a partner differing in spin by 1/2
- Unifications of forces possible
  - SUSY changes running of couplings
- Dark matter candidate exists:
  - The lightest neutral partner of the gauge bosons
- No (or little) fine-tuning required
  - Radiative corrections to Higgs acquire SUSY corrections
    - Cancellation of fermion and sfermion loops



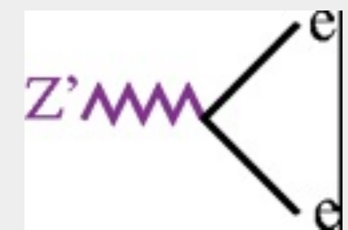


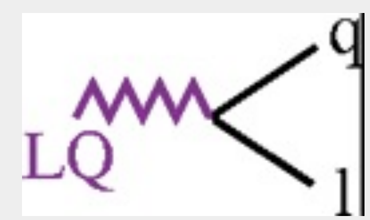
Mass of supersymmetric particles must not be high (~TeV)

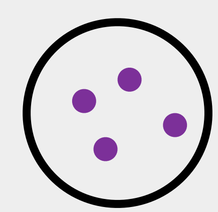
Beyond Supersymmetry

- **Strong theoretical prejudices for SUSY being true**
  - But so far there is a lack of SUSY observation….

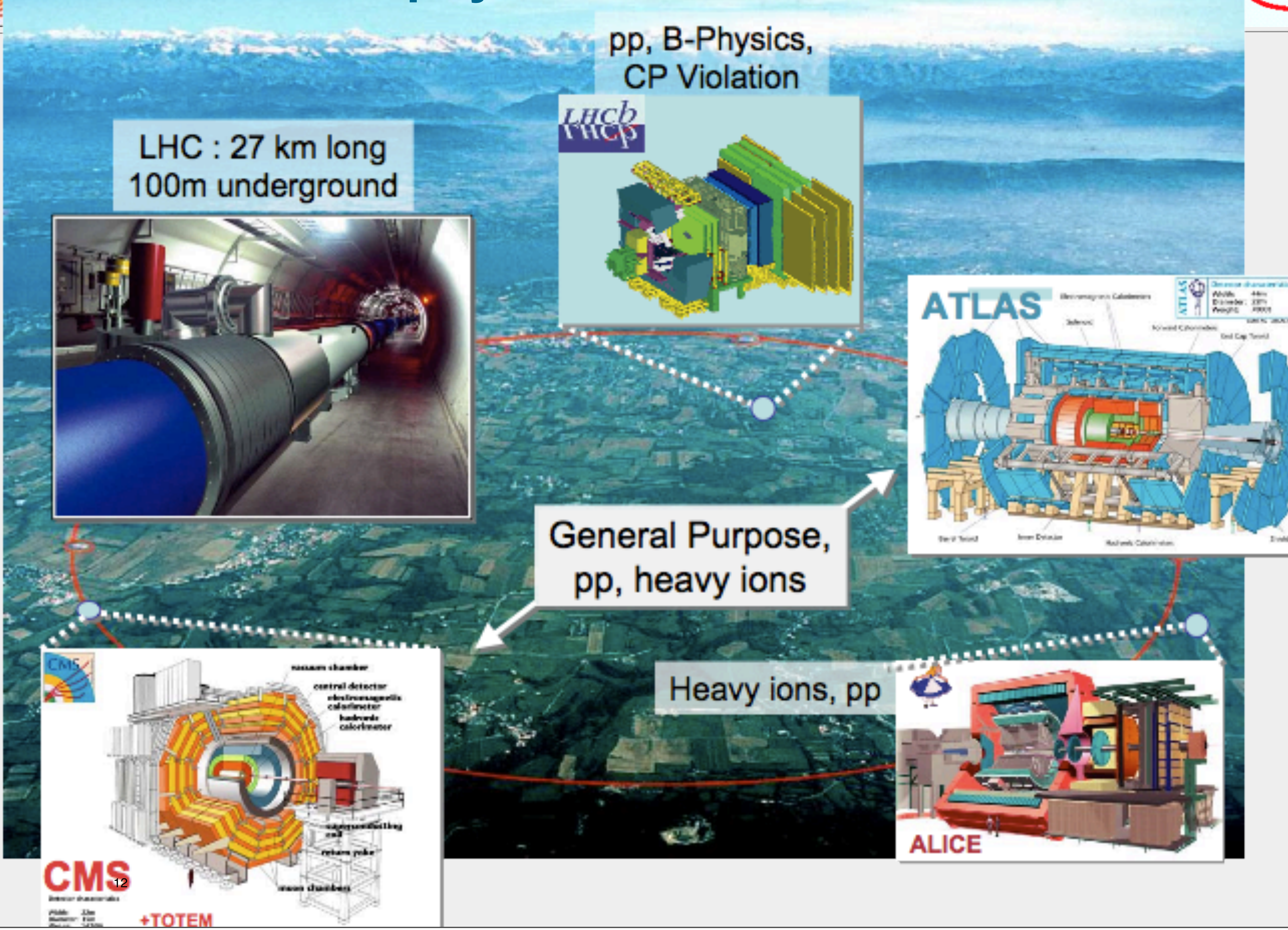
- **Need to keep an open eye for e.g.:**
  - **Extra spatial dimensions:**
    - Addresses hierarchy problem: make gravity strong at TeV scale
  - **Extra gauge groups: Z’, W’**
    - Occur naturally in GUT scale theories
  - **Leptoquarks:**
    - Would combine naturally the quark and lepton sector
  - **New/excited fermions**
    - More generations? Compositeness?
  - **Preons:**
    - atom⇒nucleus ⇒ proton/neutron ⇒ quarks ⇒ preons?
  - … ????: something nobody has thought of yet



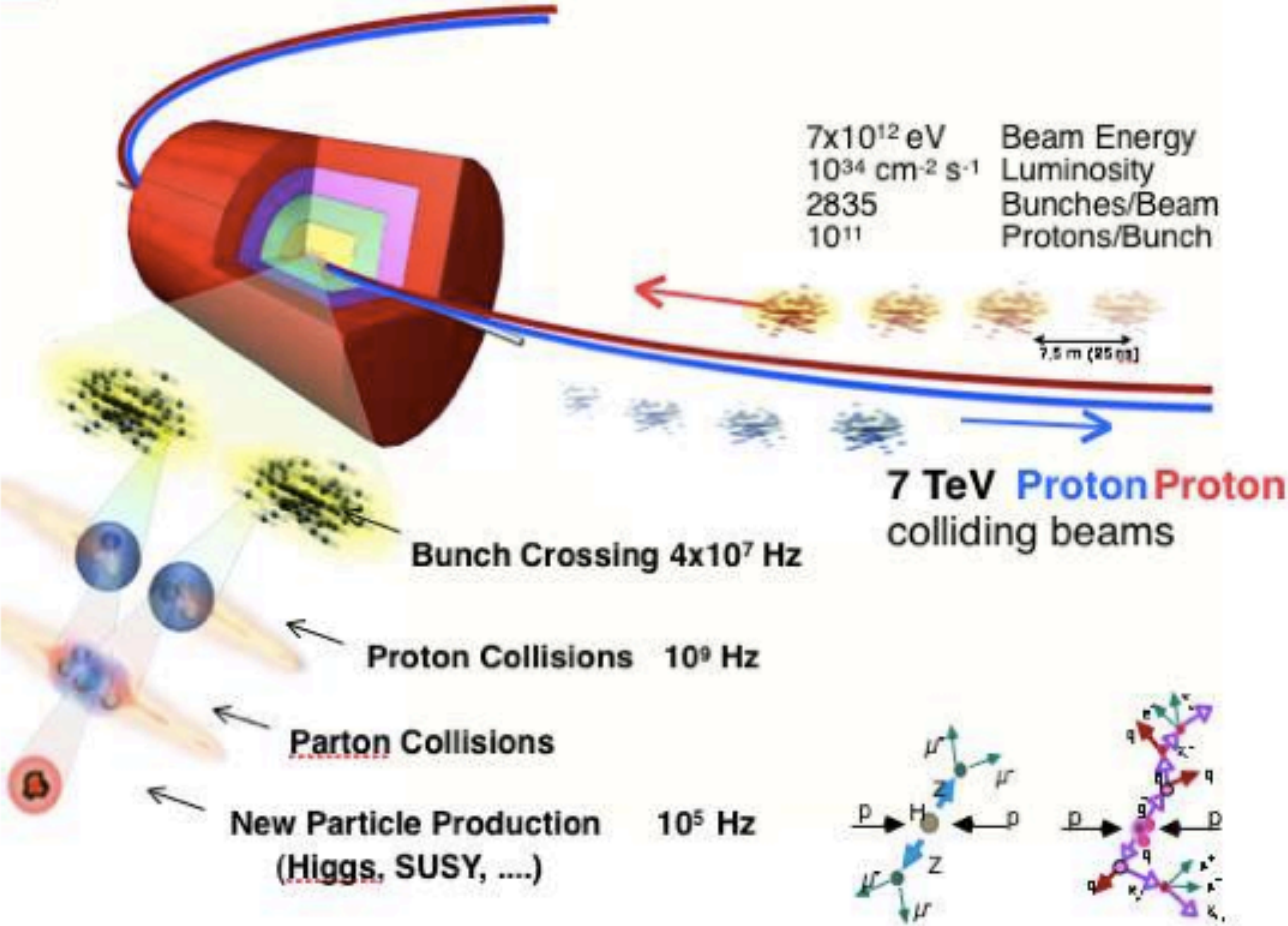




Towards physics at CERN with LHC



Some constants for the LHC



1 Higgs for 10 000 000 000 000 collisions

Some of the physicists' jargon

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  - Units: barns (10^{-28} cm^2)
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- **Number of events** (N)
  - Number of (expected) events (N) after a certain time of running

$$N = \sigma \cdot \mathcal{L}$$

Signal vs background(s)

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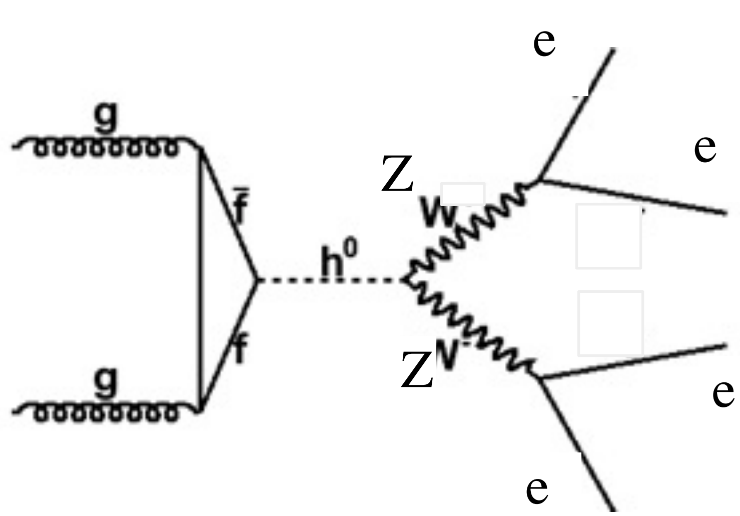

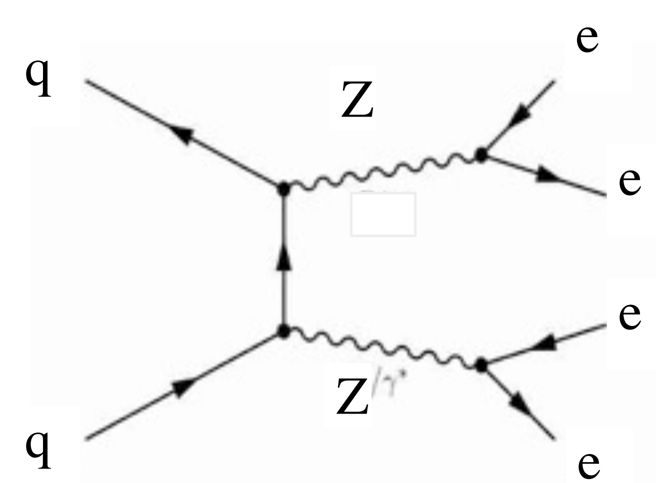

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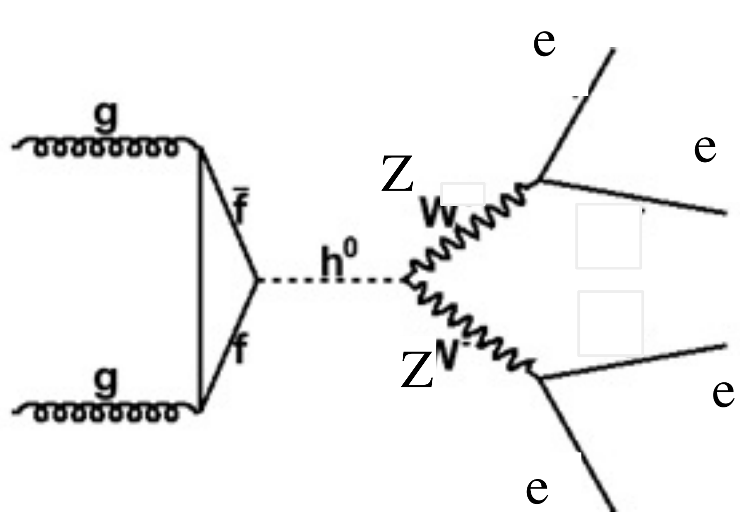

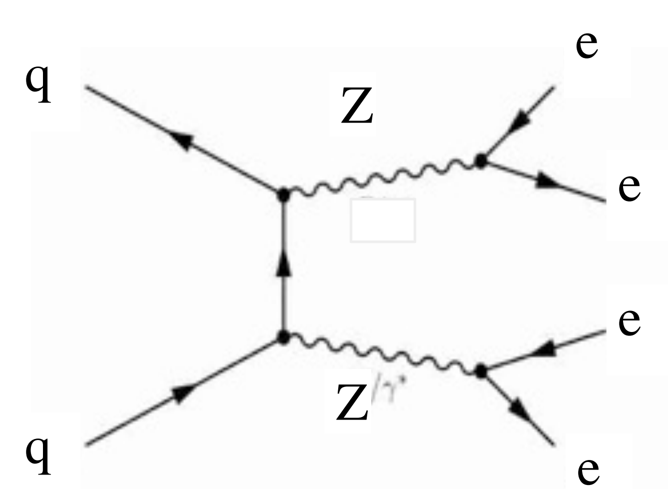

Signal: $pp \rightarrow H \rightarrow ZZ \rightarrow 4e$

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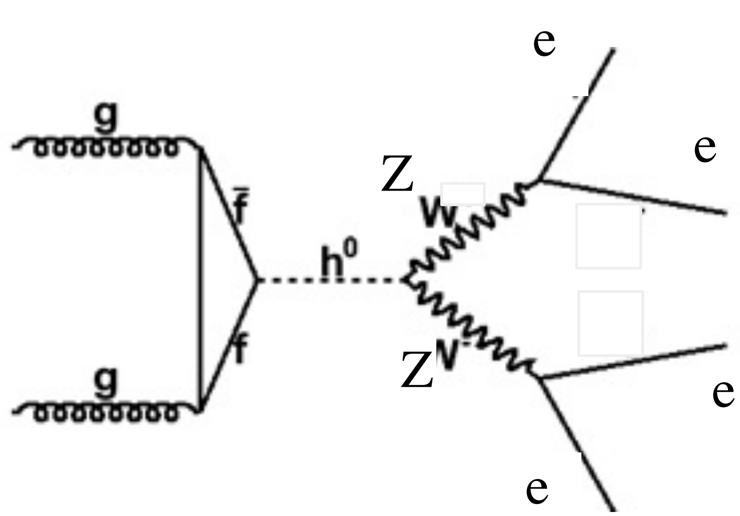

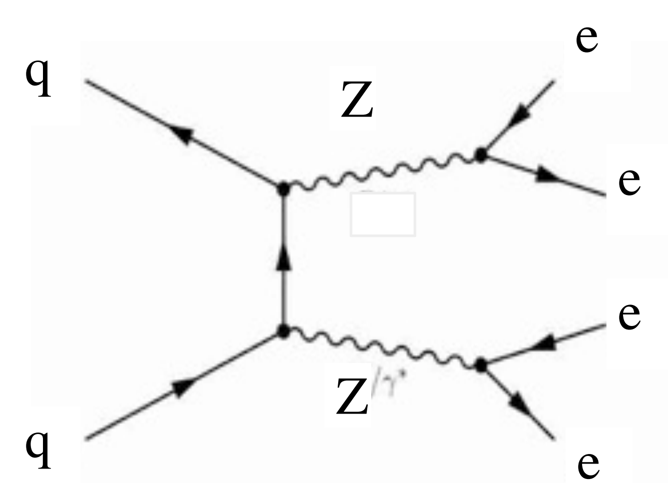

Signal: pp→H→ZZ→4e

'Dangerous' background: pp→ZZ→4e

Measurements vs predictions

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Predictions/Simulation

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Output: final state particles

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Tools: Detectors (CMS, ATLAS,...)

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Predictions/Simulation	Measurements
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Output: final state particles	*Output:* final state particles
↓	↓
Detector simulation	**Data acquisition**
Tools: **MC** simulators (GEANT)	*Tools:* Detectors (CMS, ATLAS,...)
Output: simulated detector response	*Output:* detector response
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Event reconstruction

Tools: Detectors' software packages (custom made; **MC** used in algorithms)

Output: reconstructed physical objects (electrons, muons, jets ...)

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↓

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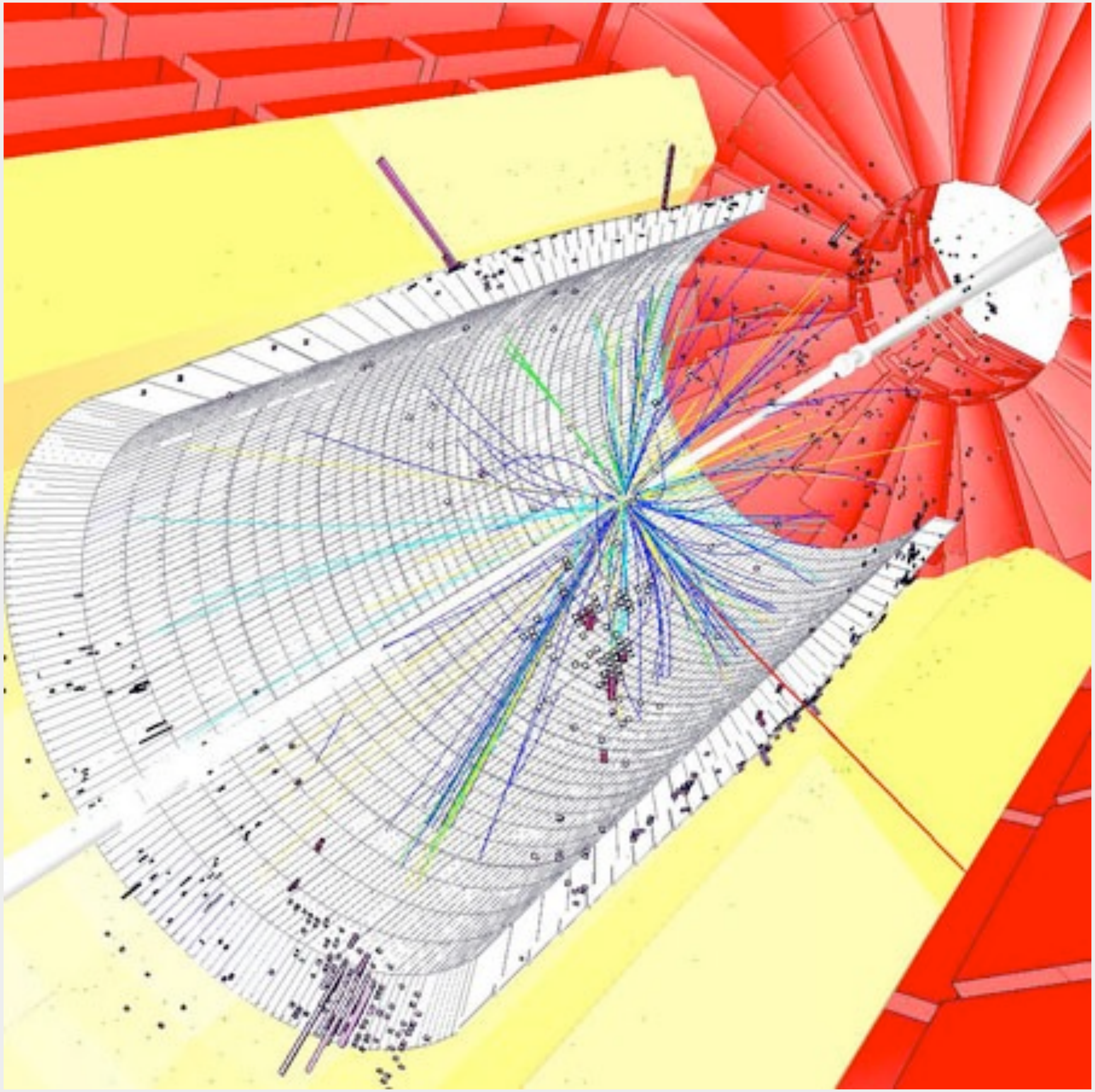
↓

Data analysis

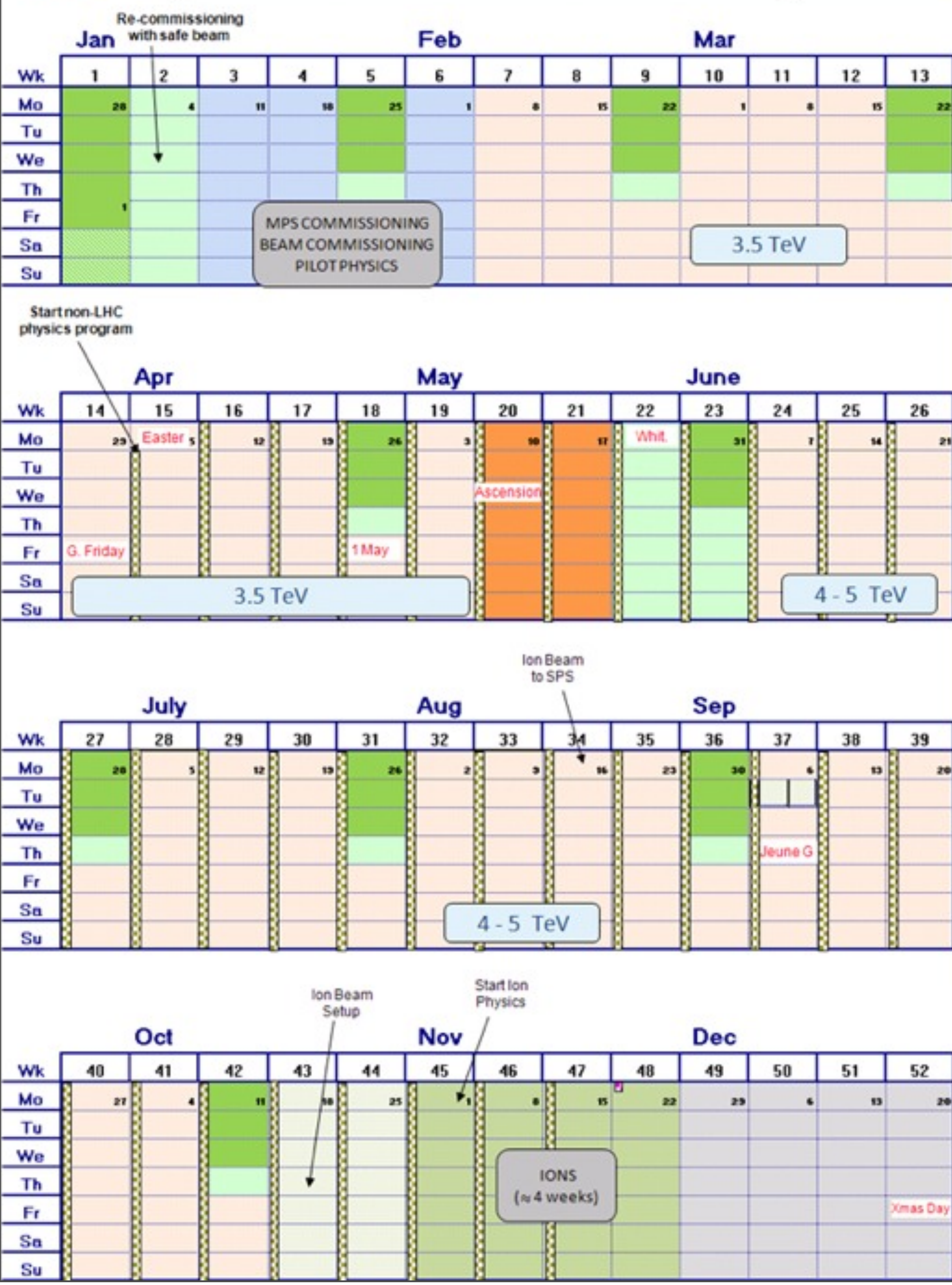
Tools: Statistics (ROOT, ...; **MC** used in algorithms; f.g. **Toy MC**)

Output: new knowledge (parameter/interval estimates, hypothesis tests, article, talks ...)

Simulation example



LHC 2010 – very draft

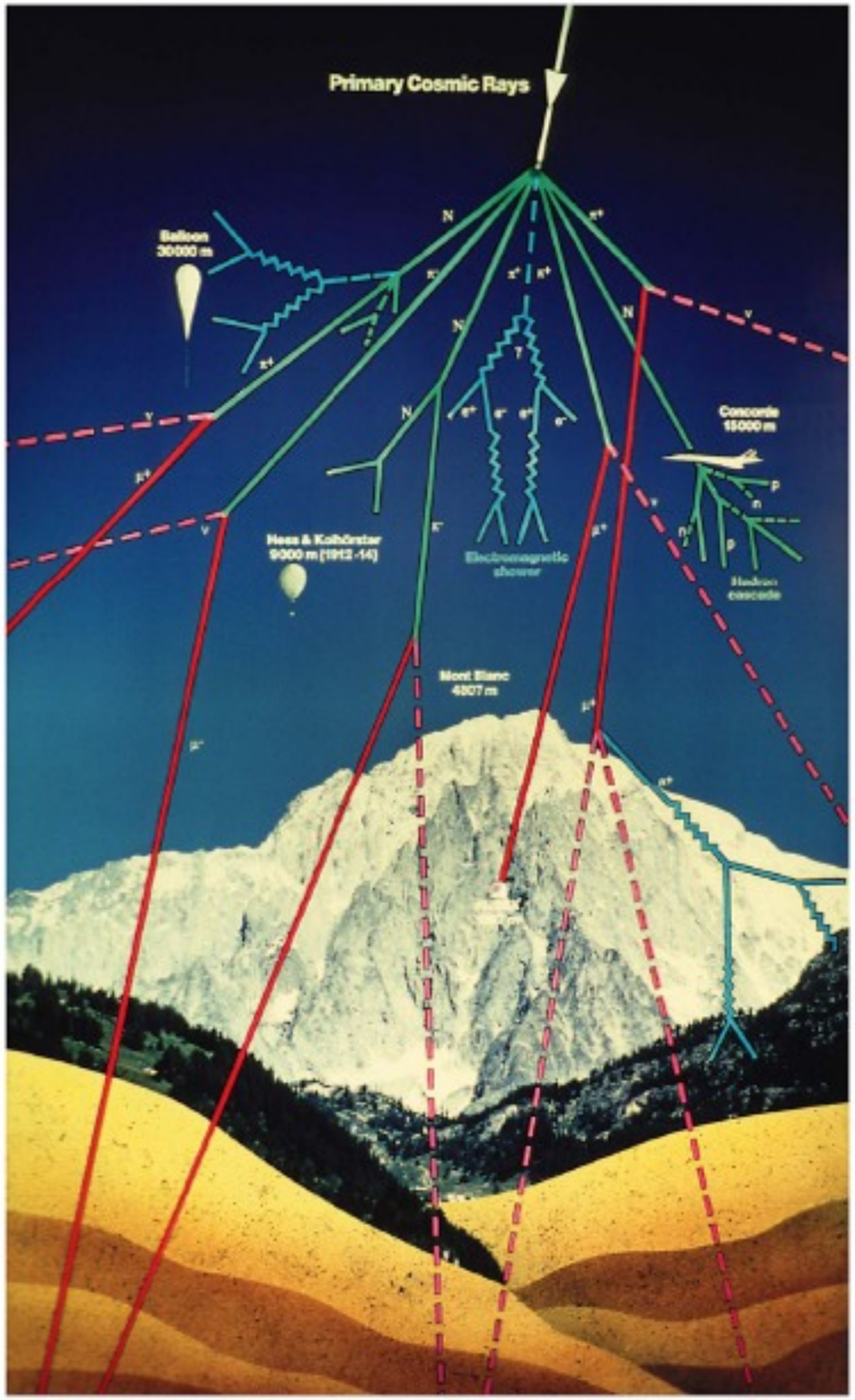


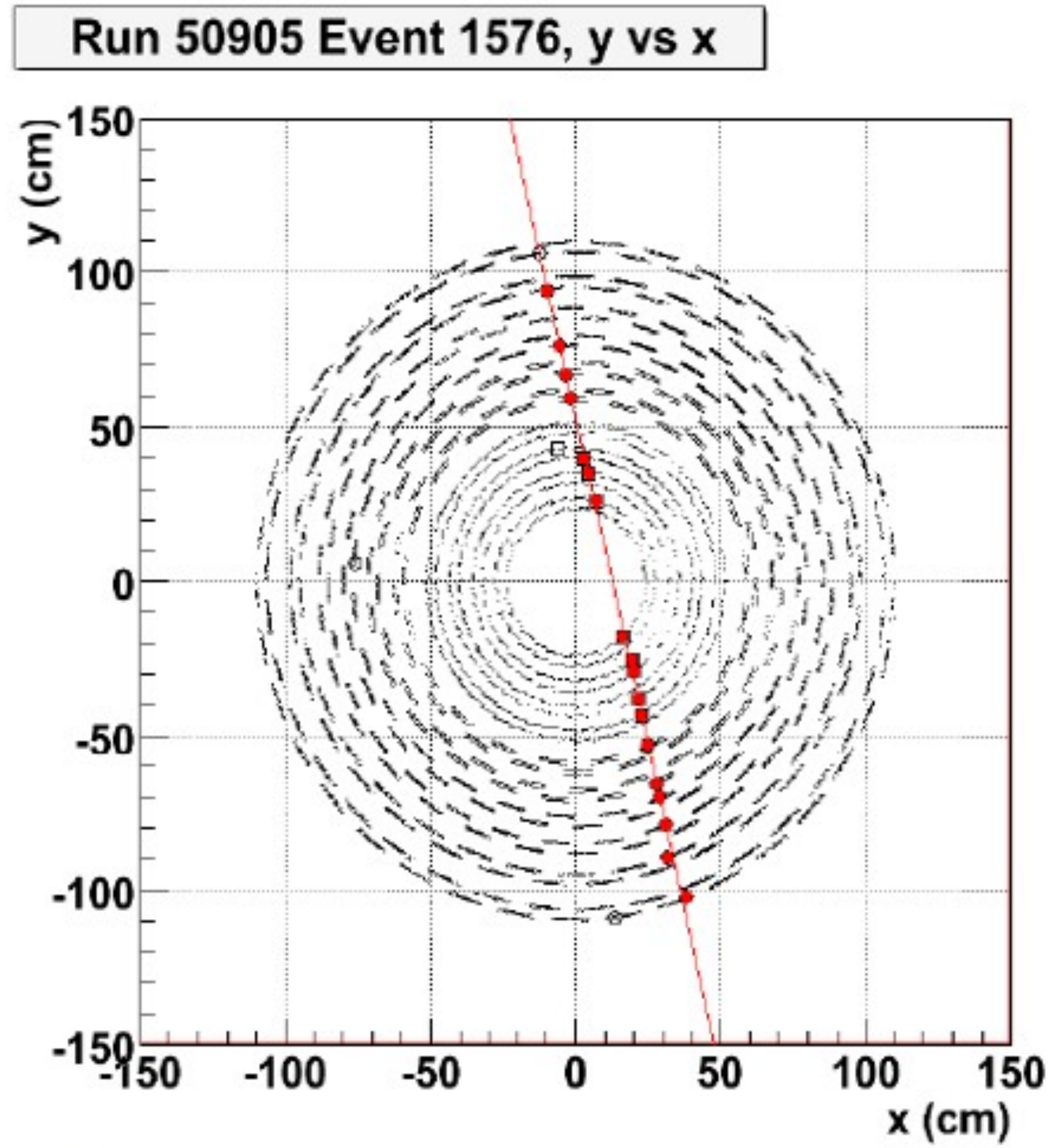
- **2009**:
  - 1 month commissioning
- **2010**:
  - 1 month pilot & commissioning
  - 3 month 3.5 TeV
  - 1 month step-up
  - 5 month 4 - 5 TeV
  - 1 month ions

Plugging in the numbers – 3.5 TeV

Month	OP scenario	Max number bunch	Protons per bunch	Min beta*	Peak Lumi	Integrated	% nominal	events/X
1	Beam commissioning							
2	Pilot physics combined with commissioning	43	3×10^{10}	4	8.6×10^{29}	~200 nb^{-1}		
3		43	5×10^{10}	4	2.4×10^{30}	~1 pb^{-1}		
4		156	5×10^{10}	2	1.7×10^{31}	~9 pb^{-1}	2.5	
5a	No crossing angle	156	7×10^{10}	2	3.4×10^{31}	~18 pb^{-1}	3.4	
5b	No crossing angle – pushing bunch intensity	156	1×10^{11}	2	6.9×10^{31}	~36 pb^{-1}	4.8	1.6
6	partial 50 ns – nominal crossing angle	144	7×10^{10}	2-3	3.1×10^{31}	~16 pb^{-1}	3.1	0.8
7		288	7×10^{10}	2-3	8.6×10^{31}	~32 pb^{-1}	6.2	
8		432	7×10^{10}	2-3	9.2×10^{31}	~48 pb^{-1}	9.4	
9		432	9×10^{10}	2-3	1.5×10^{32}	~80 pb^{-1}	12	
10		432	9×10^{10}	2-3	1.5×10^{32}	~80 pb^{-1}	12	
11		432	9×10^{10}	2-3	1.5×10^{32}	~80 pb^{-1}	12	

Preparing for data – Cosmic rays





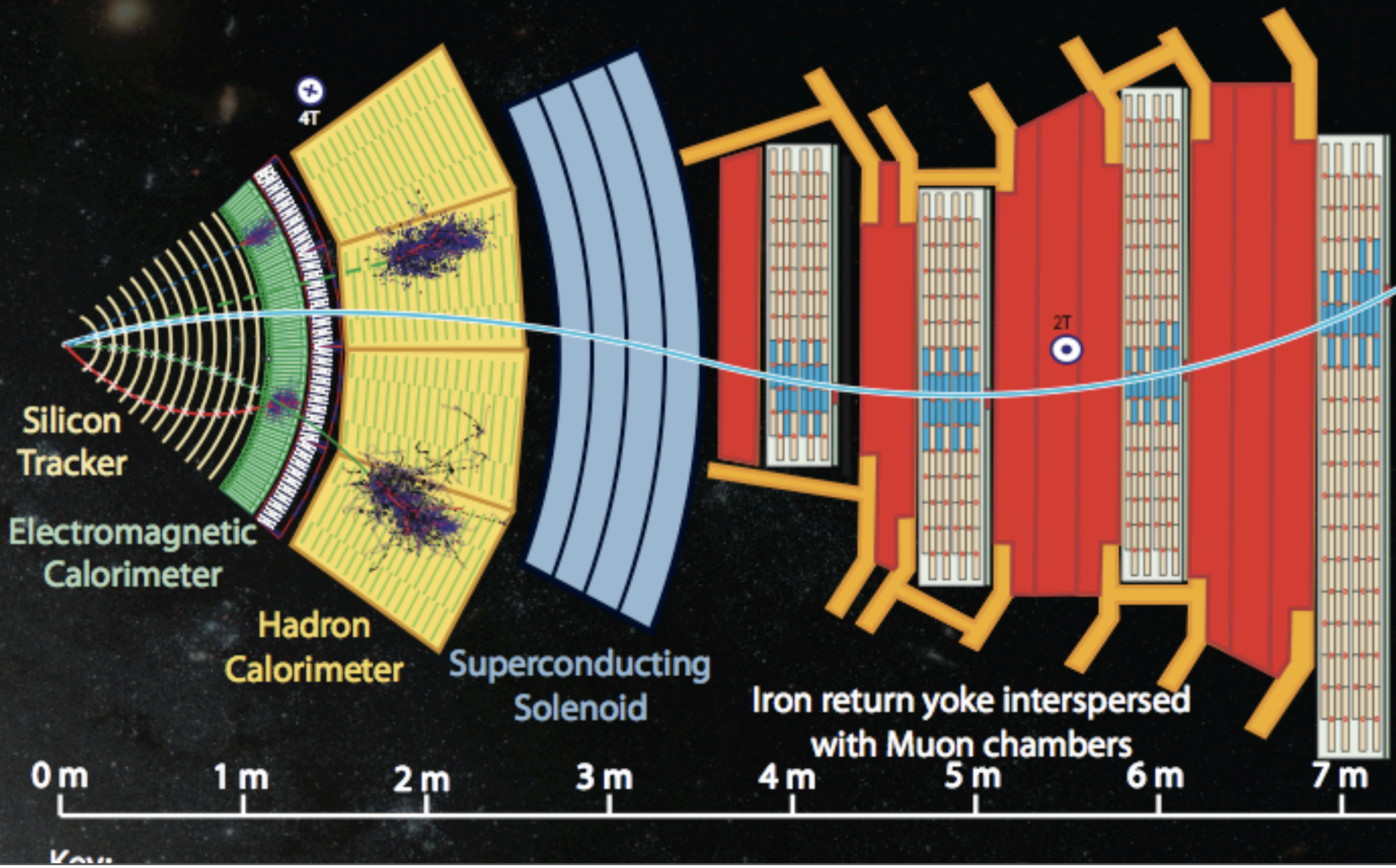
Tens of millions of cosmic ray muon “events’ recorded by experiments

T. Virdee, Split08

Transverse slice through CMS detector

Pattern Recognition

New particles discovered in CMS will be typically unstable and rapidly transform into a cascade of lighter, more stable and better understood particles. Particles travelling through CMS leave behind characteristic patterns, or 'signatures', in the different layers, allowing them to be identified. The presence (or not) of any new particles can then be inferred.



Detector commissioning

Understanding the detectors is still a MAJOR task.

- ➡**LHC eagerly awaited by a large community, theorists…**
- ➡**Pressure for early results**
- ➡**Strong internal competition**

➡ ***But must not compromise quality!***

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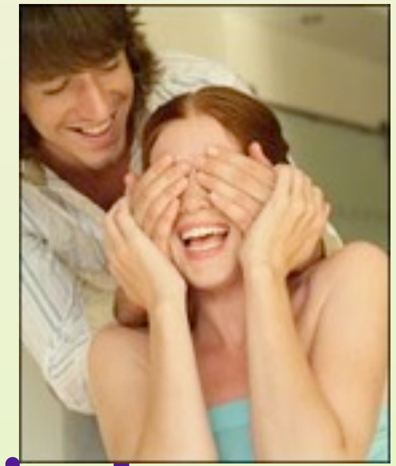

Blind analyses: desirable, practical?

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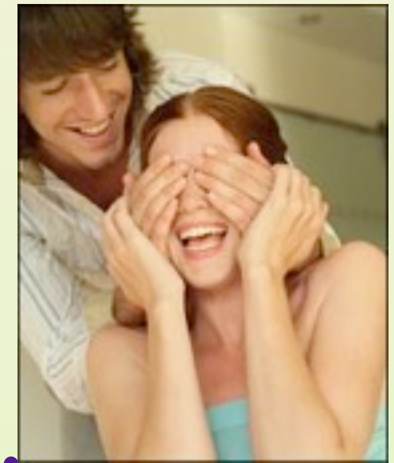


Blind analyses: desirable, practical?

Look at 10^7 bins, see three 5σ peaks even if no new physics!

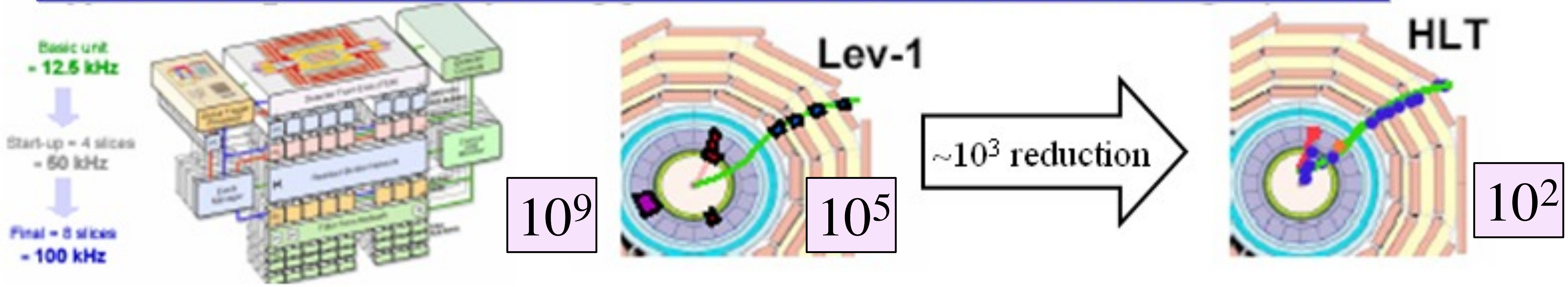
pp at 7/10/14 TeV is, for both ATLAS and CMS, a new territory.
We need to find the north, make a map, firm ground under our feet.

Often remarked: LHC can make discoveries with one month of data.

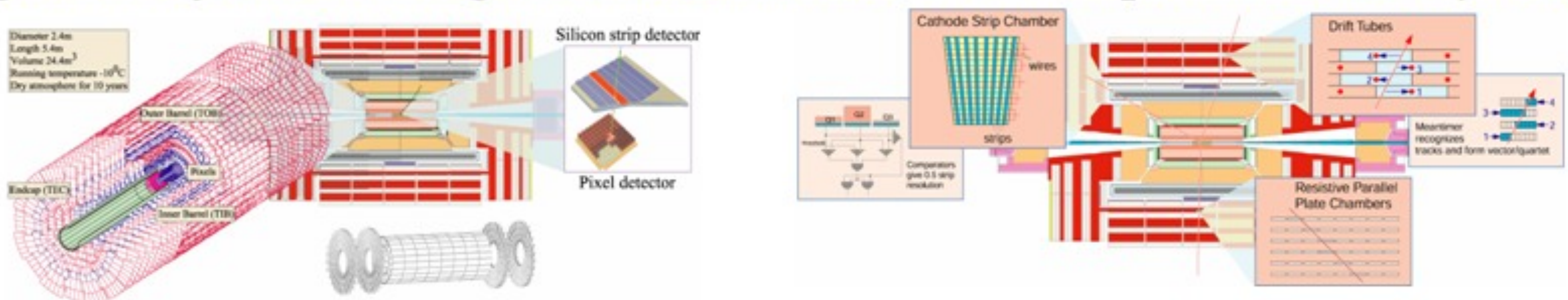
May be correct. But not the first month of data...

Major Commissioning Challenges

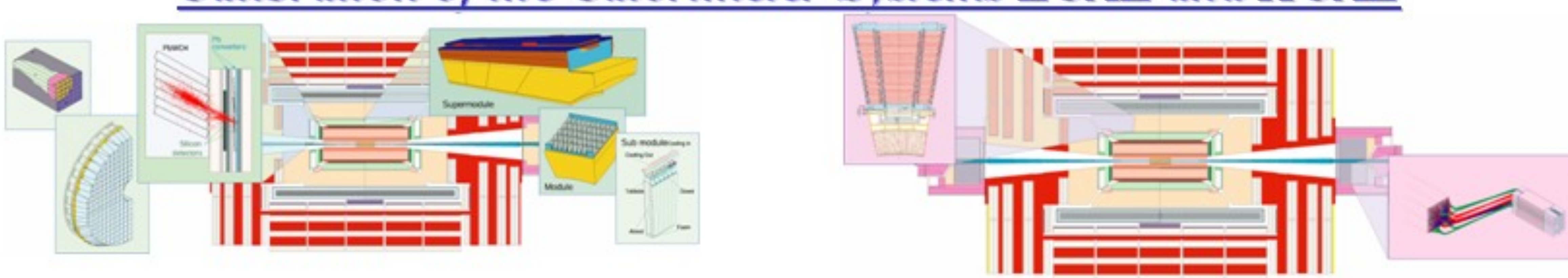
Efficient operation of Trigger (Level1/HLT) and DAQ System



Alignment of the tracking devices Tracker(PIXEL,Strip) and Muon System

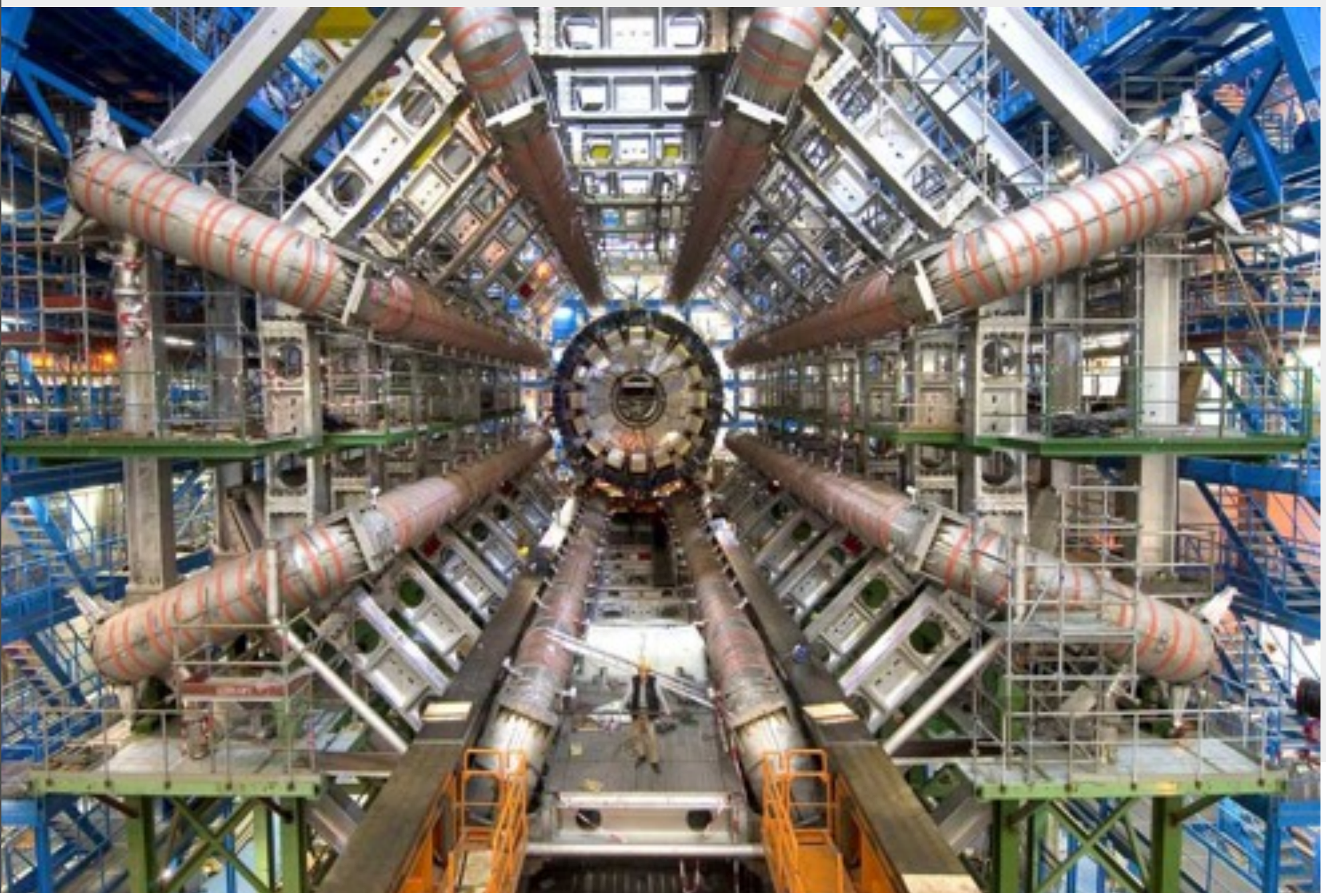


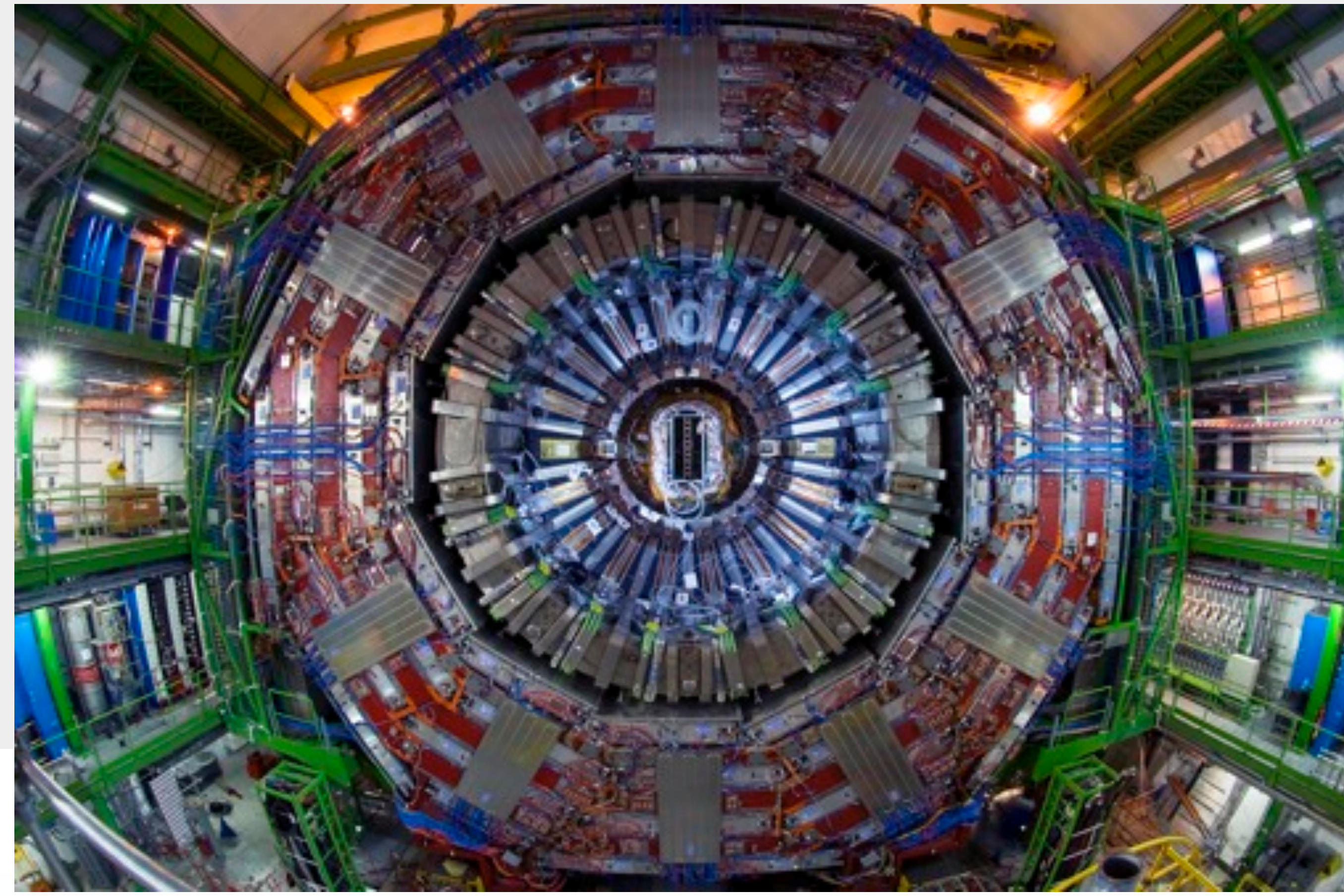
Calibration of the Calorimeter Systems ECAL and HCAL



form the base for the "commissioning of physics tools" like b tagging, electrons/photons, muon, jets, missing E_T ...

The ATLAS/CMS detectors at LHC





Tracker: $\|\eta\| < 2.5$	Tracker: $\|\eta\| < 2.5$
SI pixels, SI strips, straw-tubes	SI pixels, SI strips
$\sigma/p_T \approx 0.05\%\ p_T \oplus 1\%$	$\sigma/p_T \approx 0.015\%\ p_T \oplus 0.5\%$
Muon spectrometer: $\|\eta\| < 2.7$	Muon spectrometer: $\|\eta\| < 2.6$
Drift tubes (barrel), CSC (endcap), RPCs	Drift tubes (barrel), CSC (endcap), RPCs
$\sigma/p_T \approx 10\%$ (1 TeV muons)	**σ/p_T = 4.5-7 % (1 TeV μ), if comb. with TK**
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Lead/LAr	Lead tungstate (PbWO4) crystals
$\sigma/E \approx 10\% / \sqrt{E} \oplus 0.7\%$	**$\sigma/E = 2.8\%/\sqrt{E} \oplus 0.3\%$ (barrel)**

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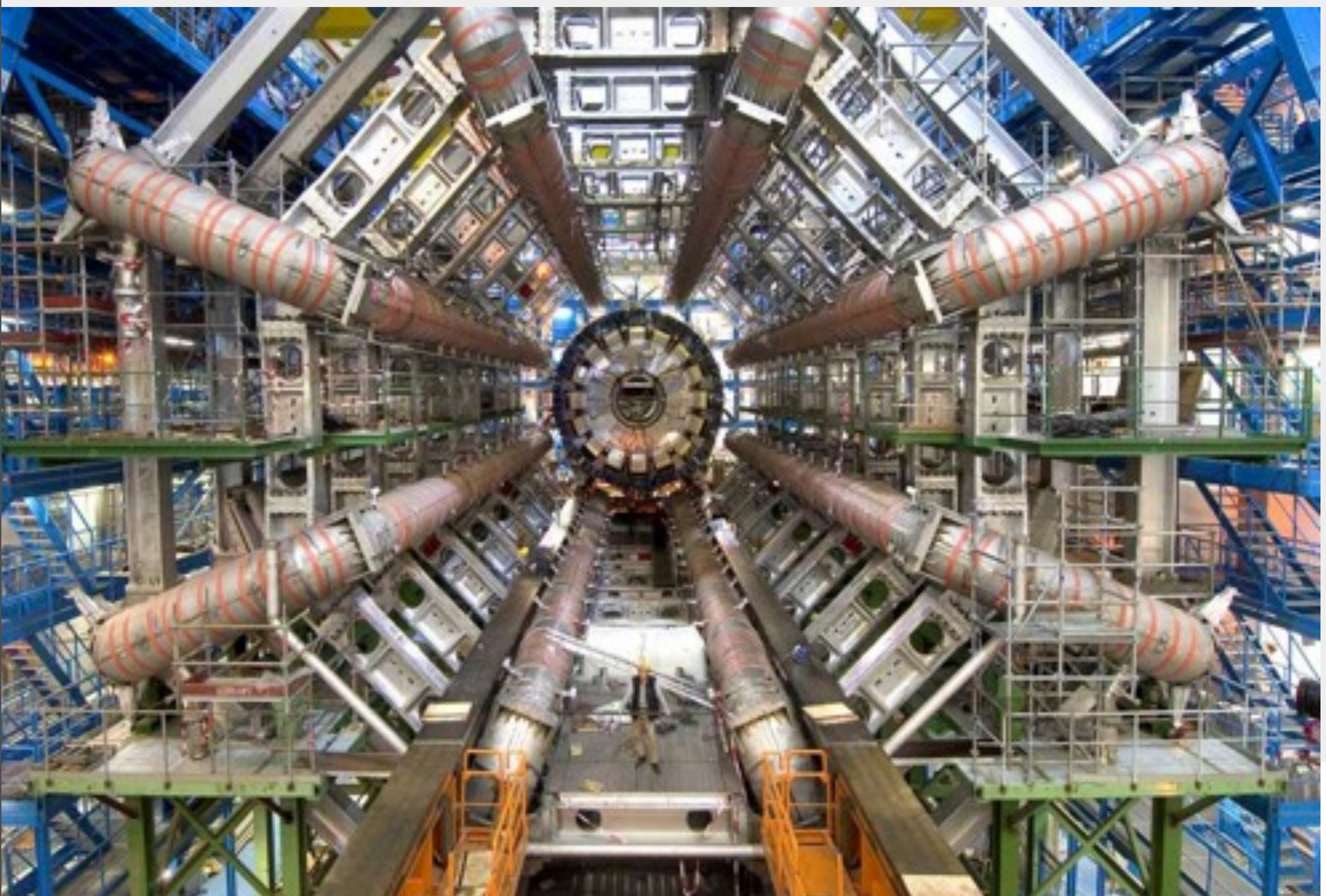	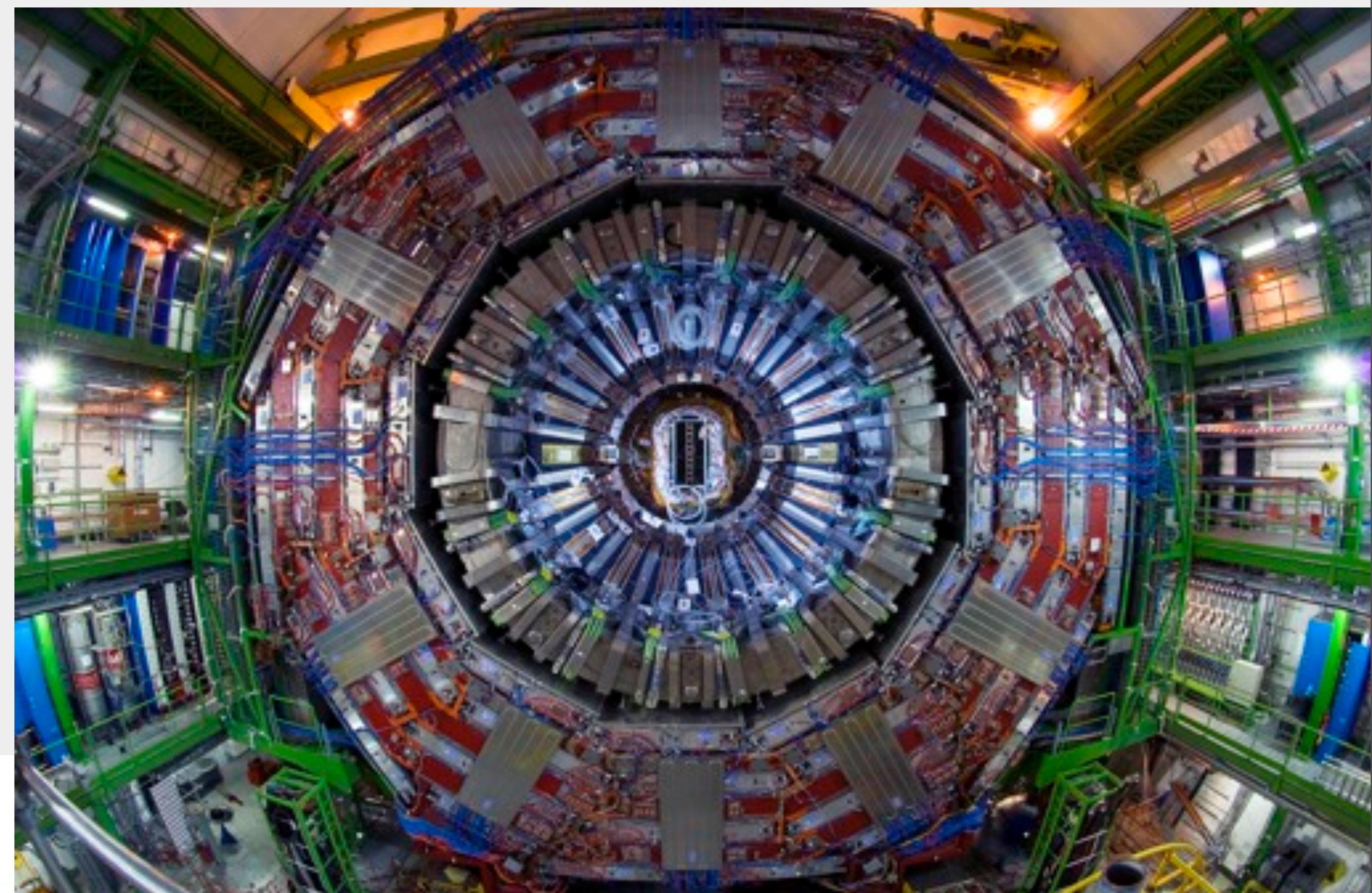
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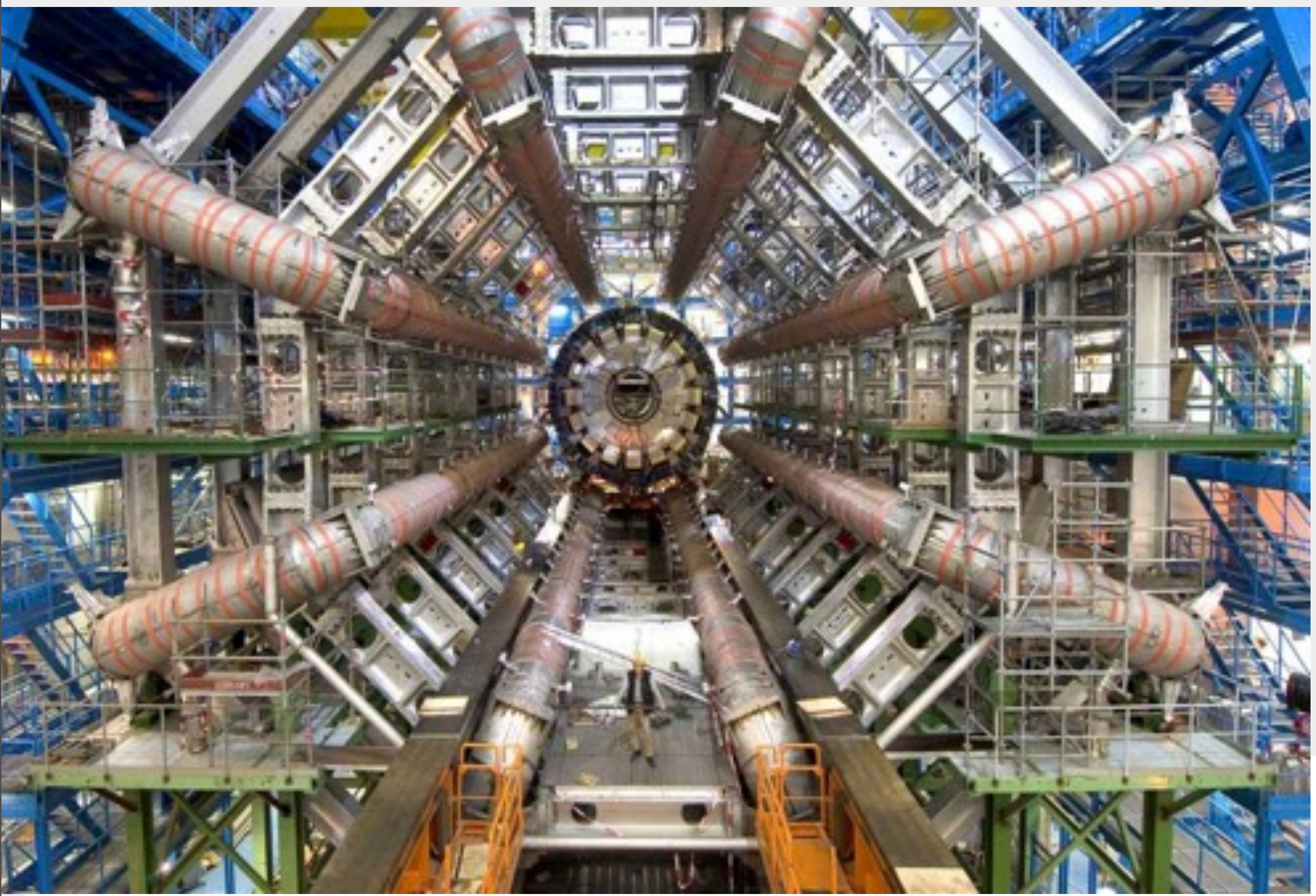

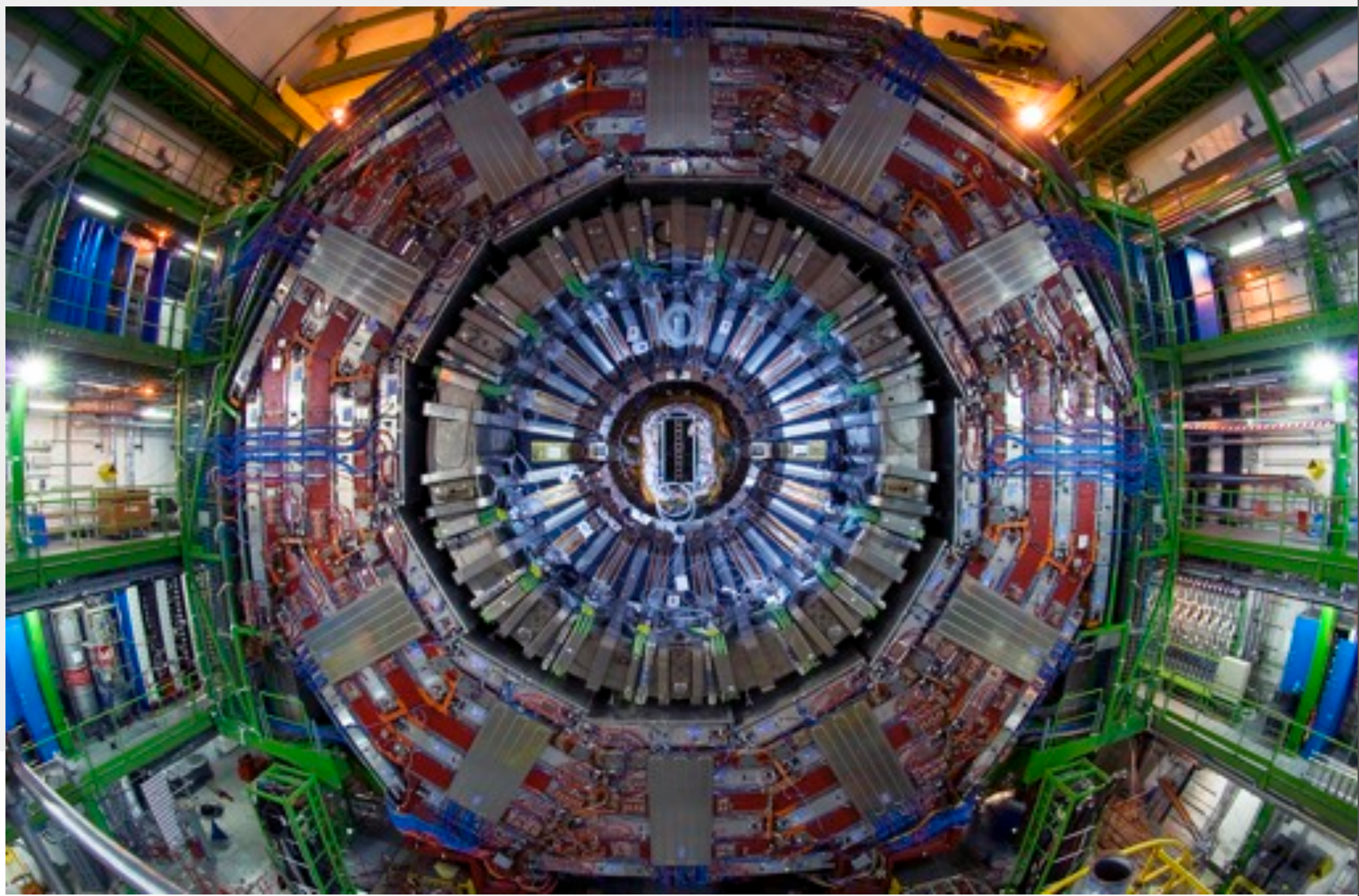

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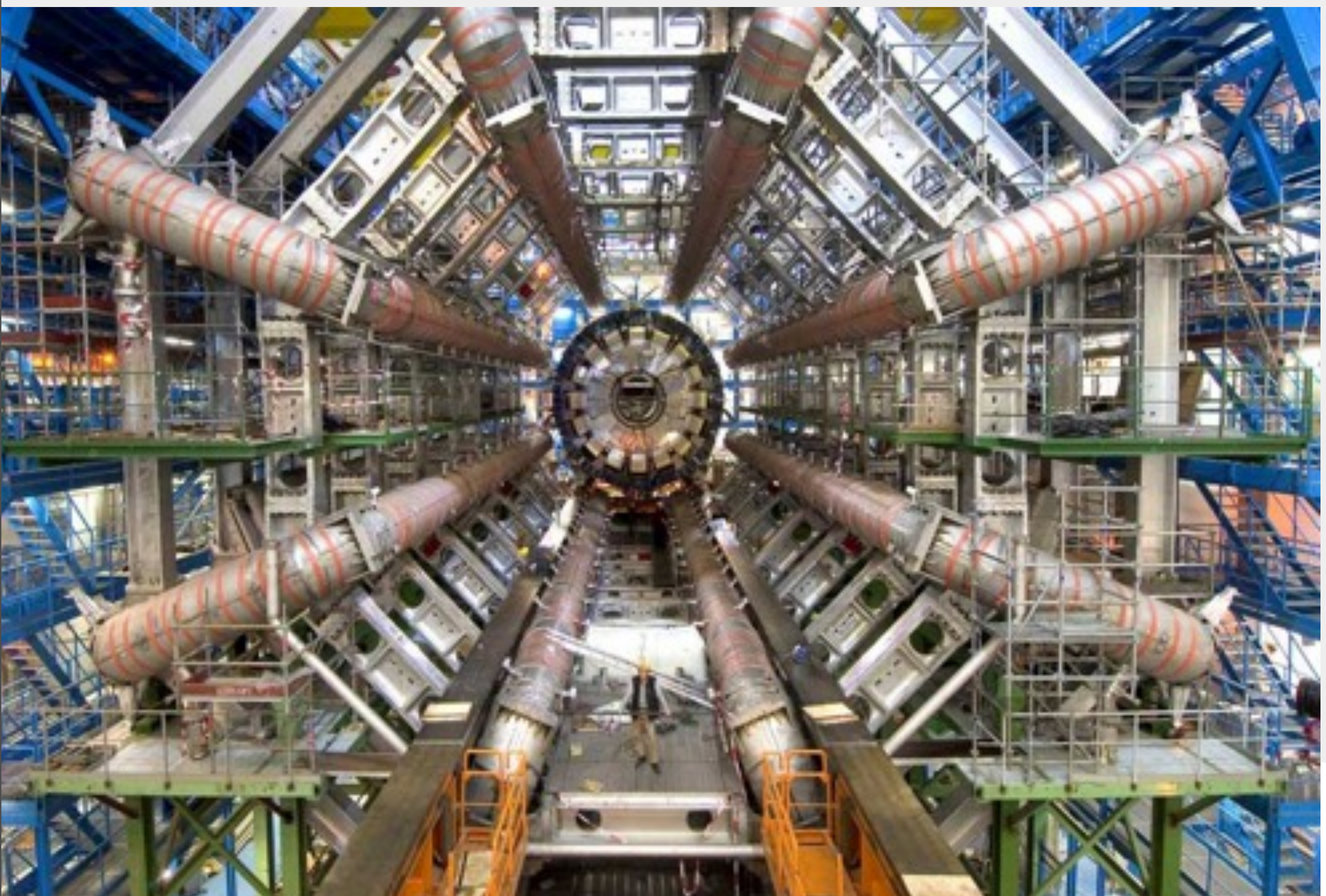

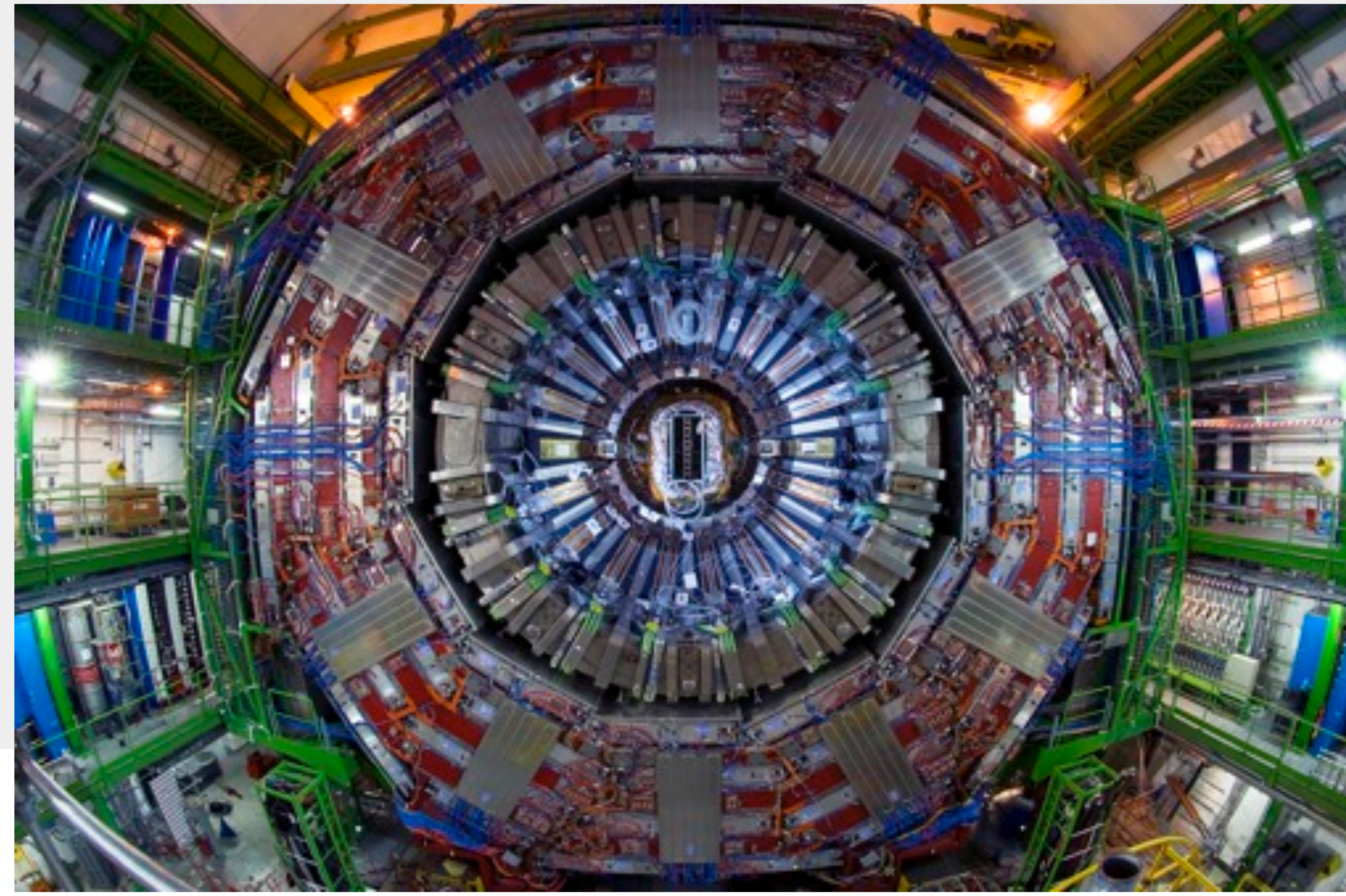

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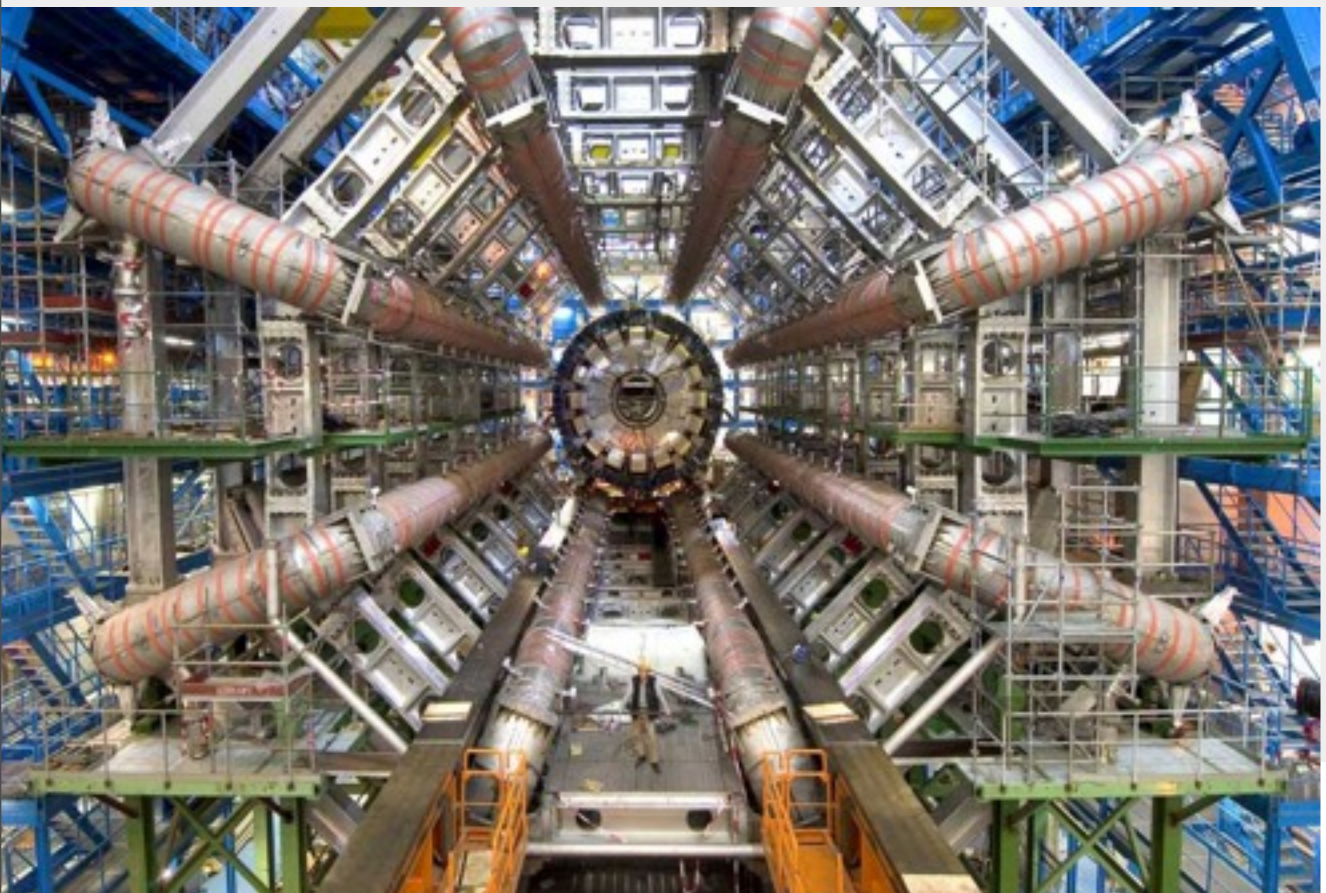

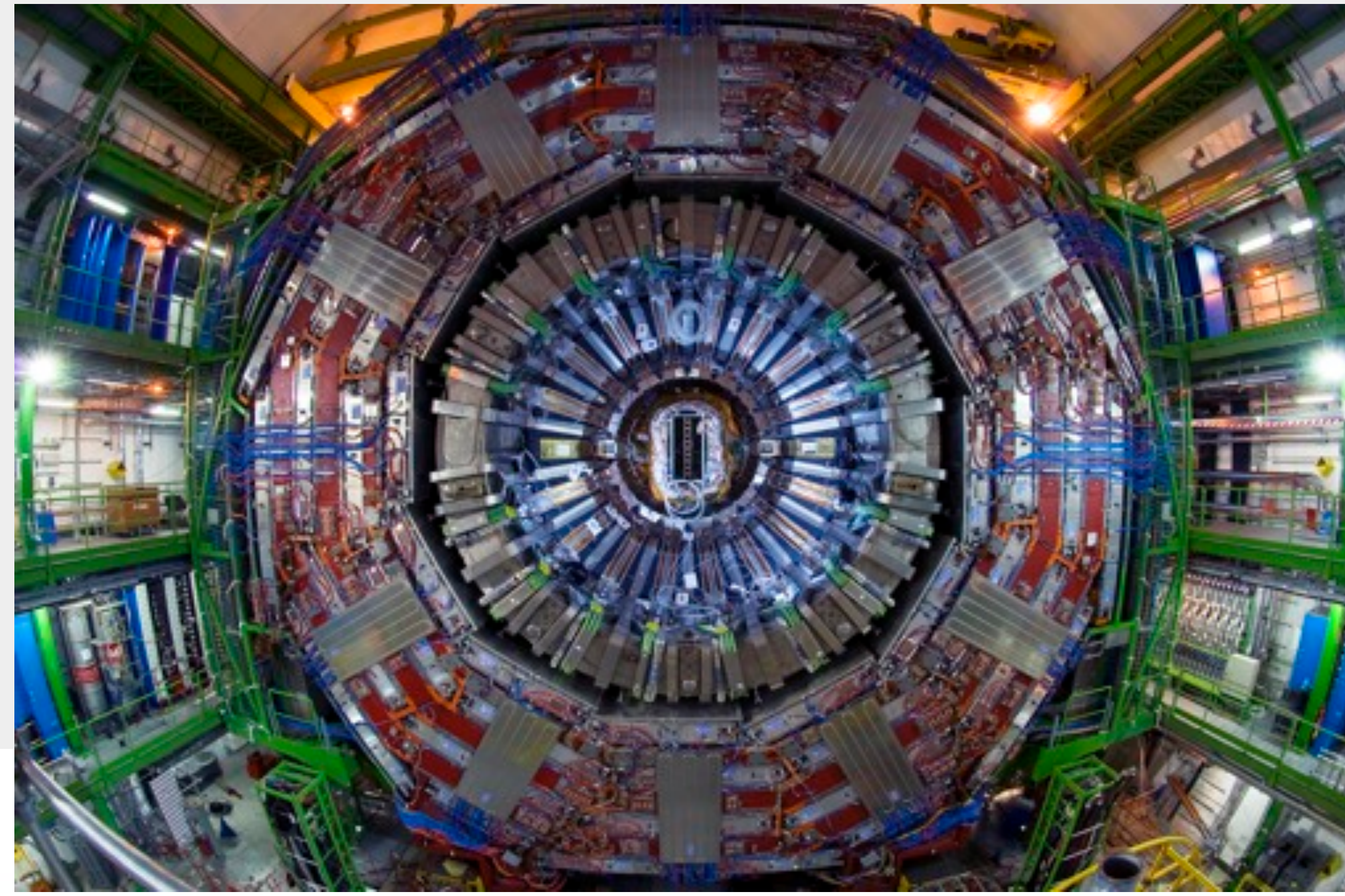

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Early physics program

Detector commisioning

- Much already done using cosmics/test beam

Early beam

- First collisions at injection energy, then at 7 TeV
- Detector synhronization and alignement, minimum bias events, early calibration

Early beam – collisions, up to 10 – 20 pb^{-1} @ 7 TeV

- Trigger commisioning, start "physics commisioning" – rediscover SM
- Measure physics objects: f.g. jet and lepton rates; observe W, Z, top
- And look at possible extraordinary signatures (discoveries ☺)

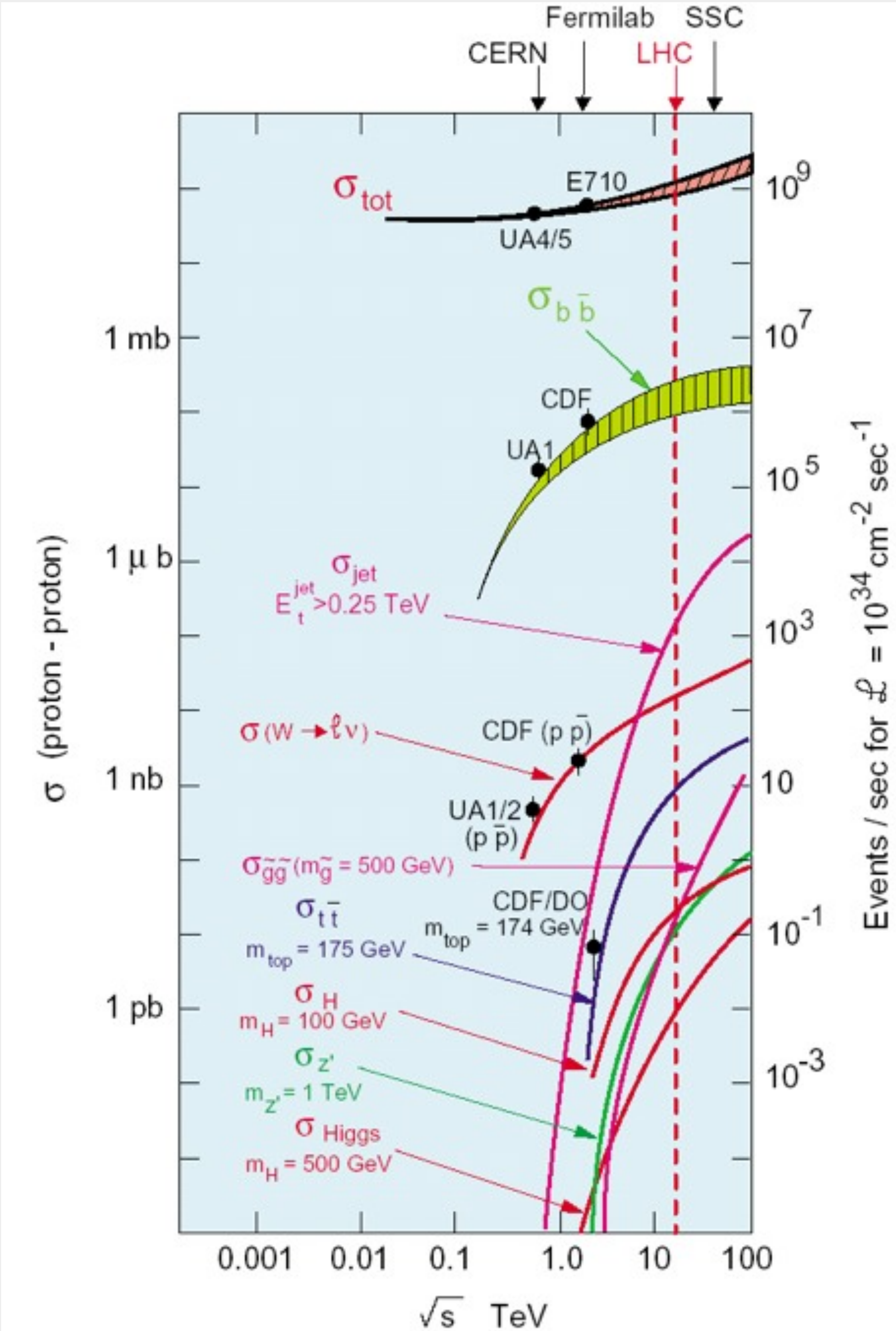
Up to 100 pb^{-1} @ 7 TeV: mesure SM, start searches

- Approx per pb-1: 3000 W→lν, 300 Z→ll, 5 tt→μ+X
- Improve understanding of physics objects
- Measure/understand backgrounds for SUSY and Higgs searches
- Early look for excess from Z' and SUSY resonances

Collisions at higher energies

- Explore large part of SUSY and ~ few TeV resonances
- ~ 1000 pb-1 enter Higgs boson discovery era

Cross section and Events rate (√s=14 TeV)



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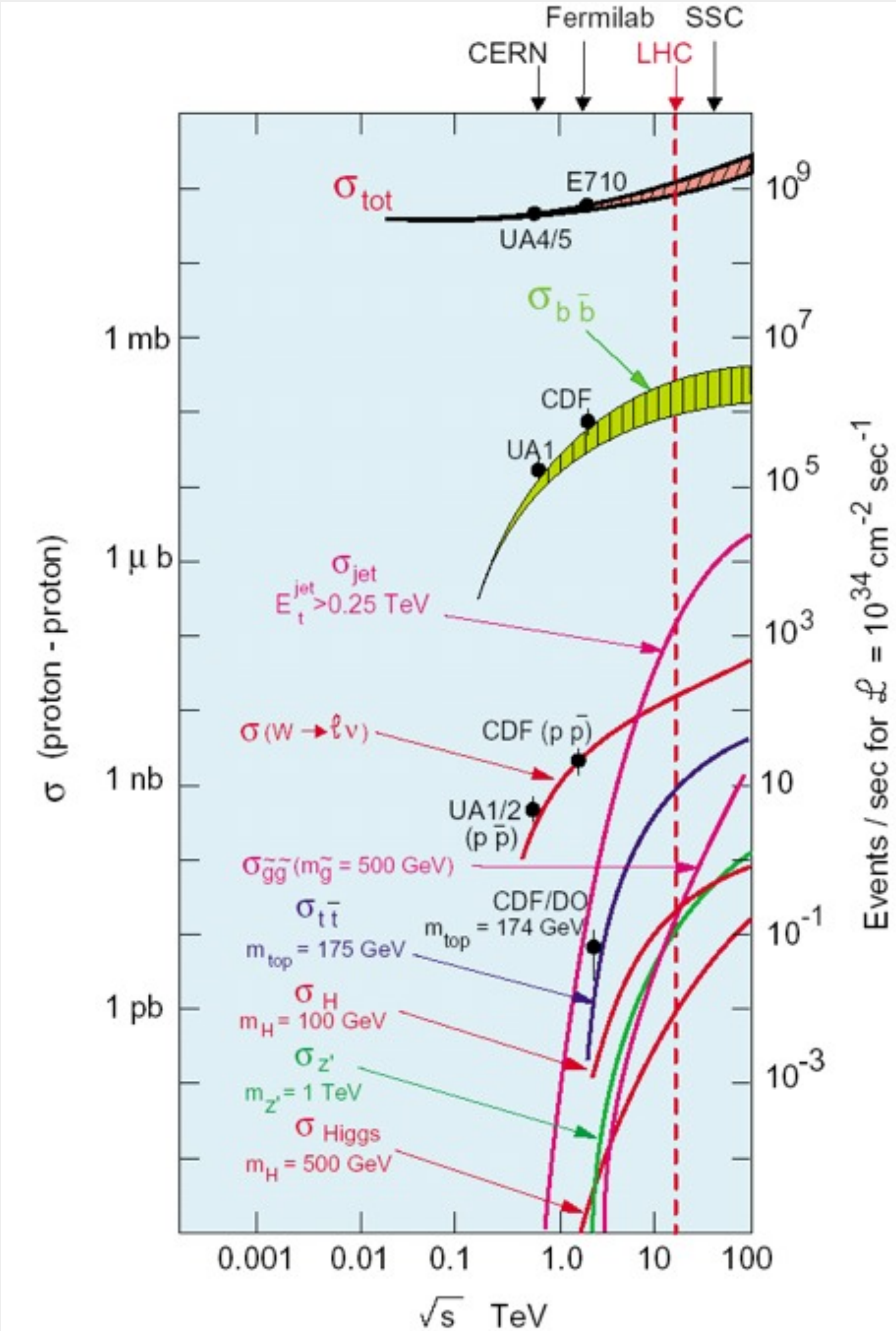

At Luminosity (10^{32} cm^{-2} s^{-1})

SM Higgs (115 GeV/c^2)	→ 0.001 Hz
t t production:	→ 0.1 Hz
W→ ℓ ν:	→ 1 Hz
bb production:	→ 10^4 Hz
Inelastic:	→ 10^7 Hz

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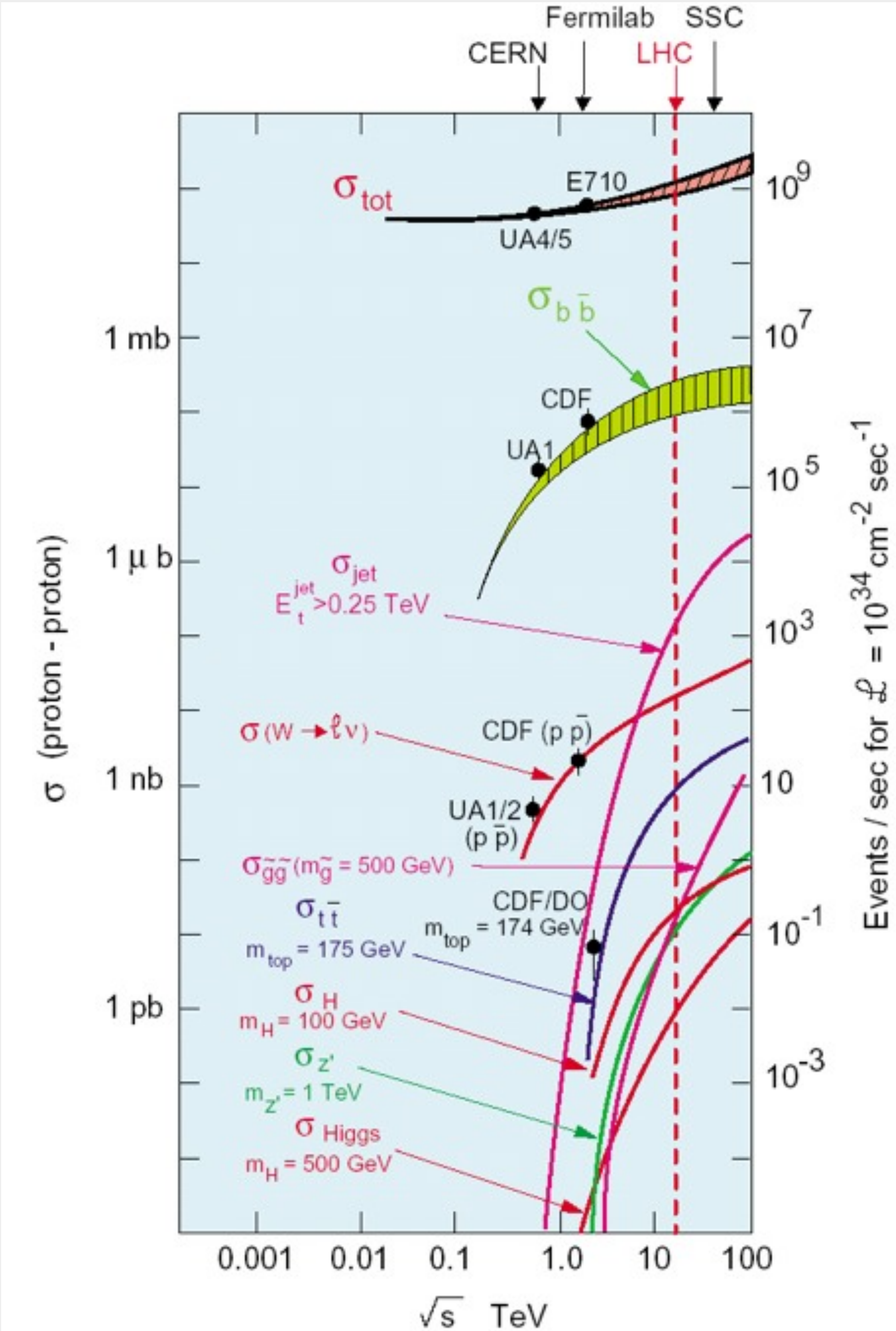

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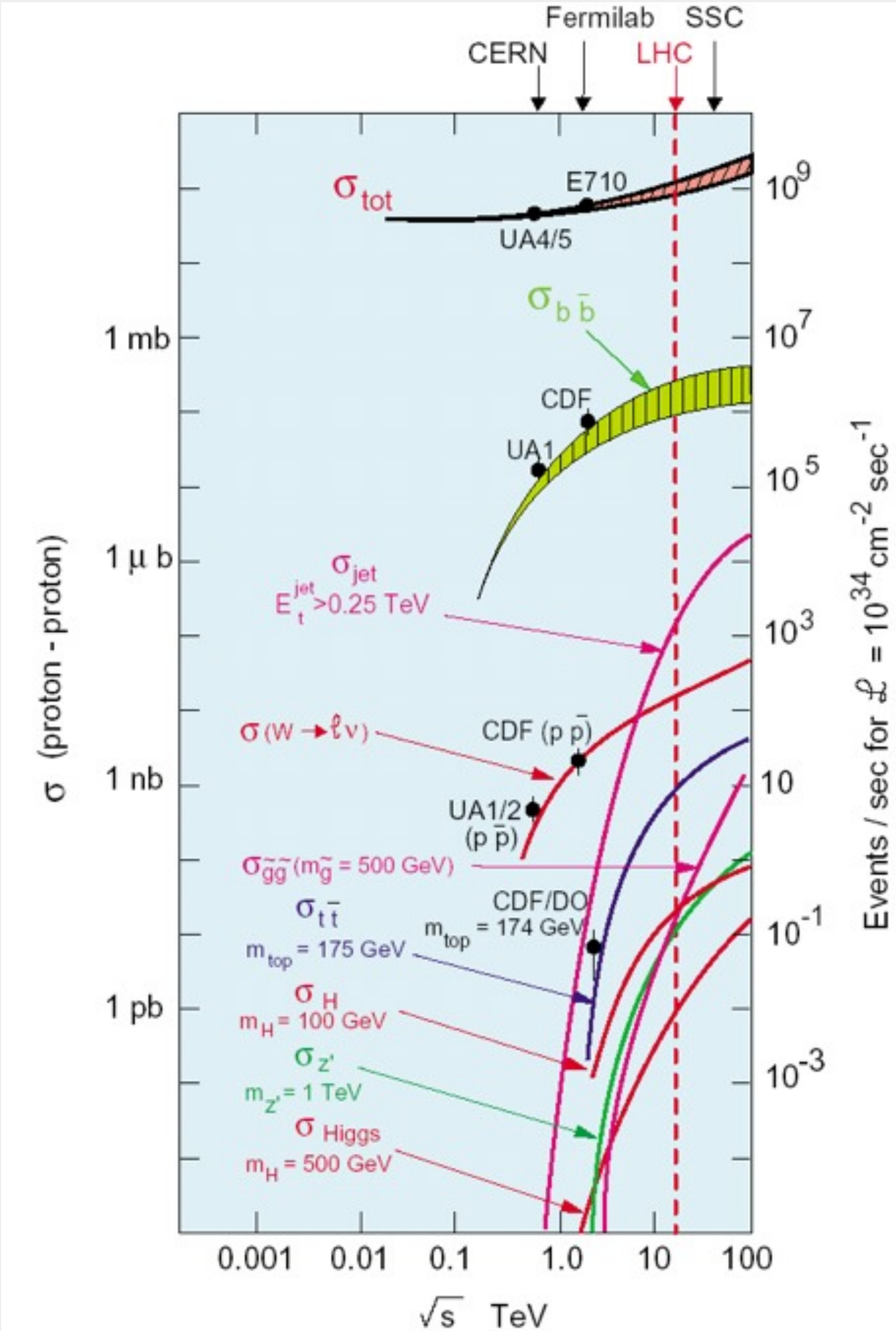

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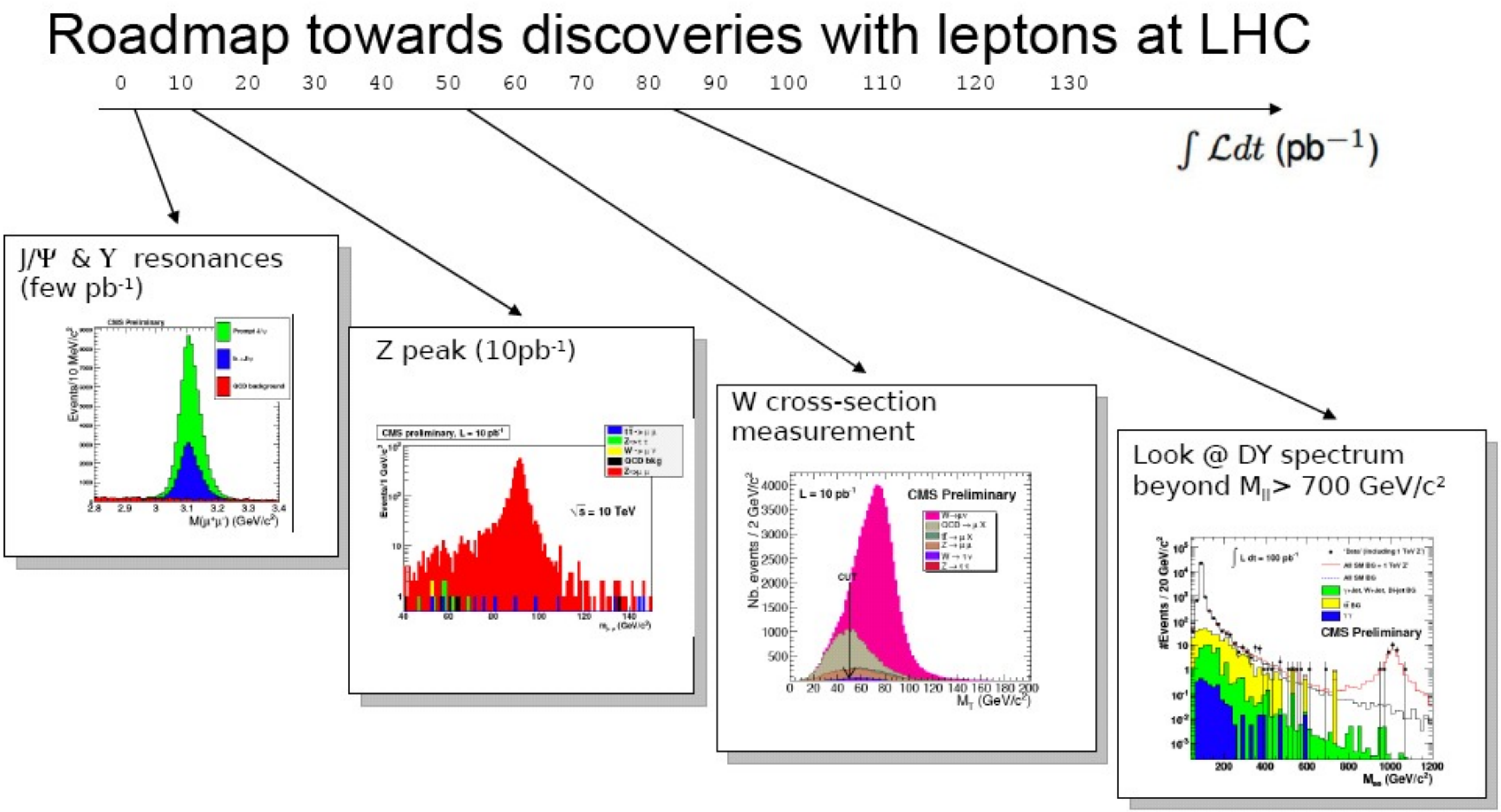
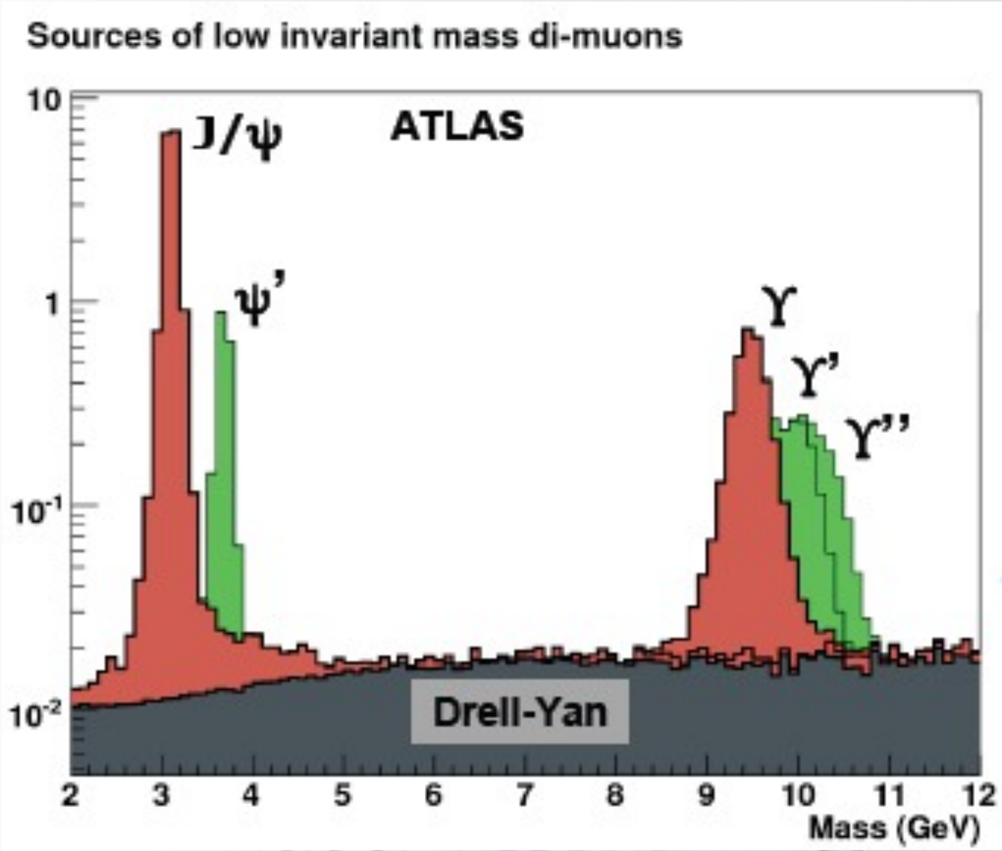
Process	$\mathcal{L}$=10pb^{-1}	$\mathcal{L}$=1 fb^{-1}
Minimum bias	10^{12}	~10^{14}
Inclusive jets – p_T>200GeV	10^6	~10^8
W → eν	10^5	~10^7
Z → e^+e^-	10^4	~10^6
Dibosons	10	10^5
ttbar		10^6
tt →μ+X	10^3	10^5

~ 1 Day ~ end 2010 ?

The roadmap for discoveries

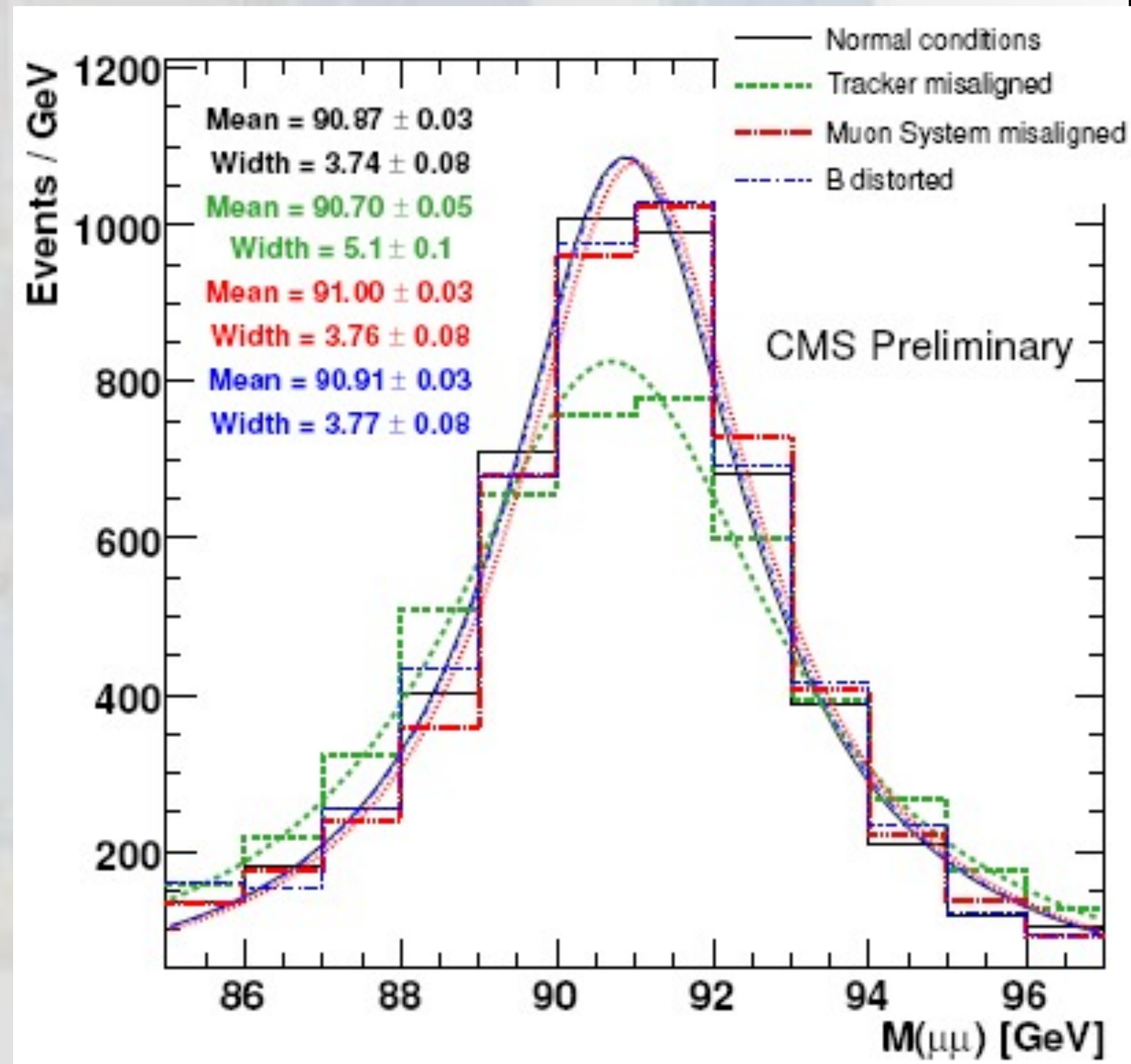


Main Calibration Samples



These will be the first peaks in data

Events in 100pb^{-1}:
J/ψ→μμ ~1600k (+~10% ψ')
ϒ→μμ ~300k (+~40% ϒ′/ϒ″)
Z→μμ ~60k

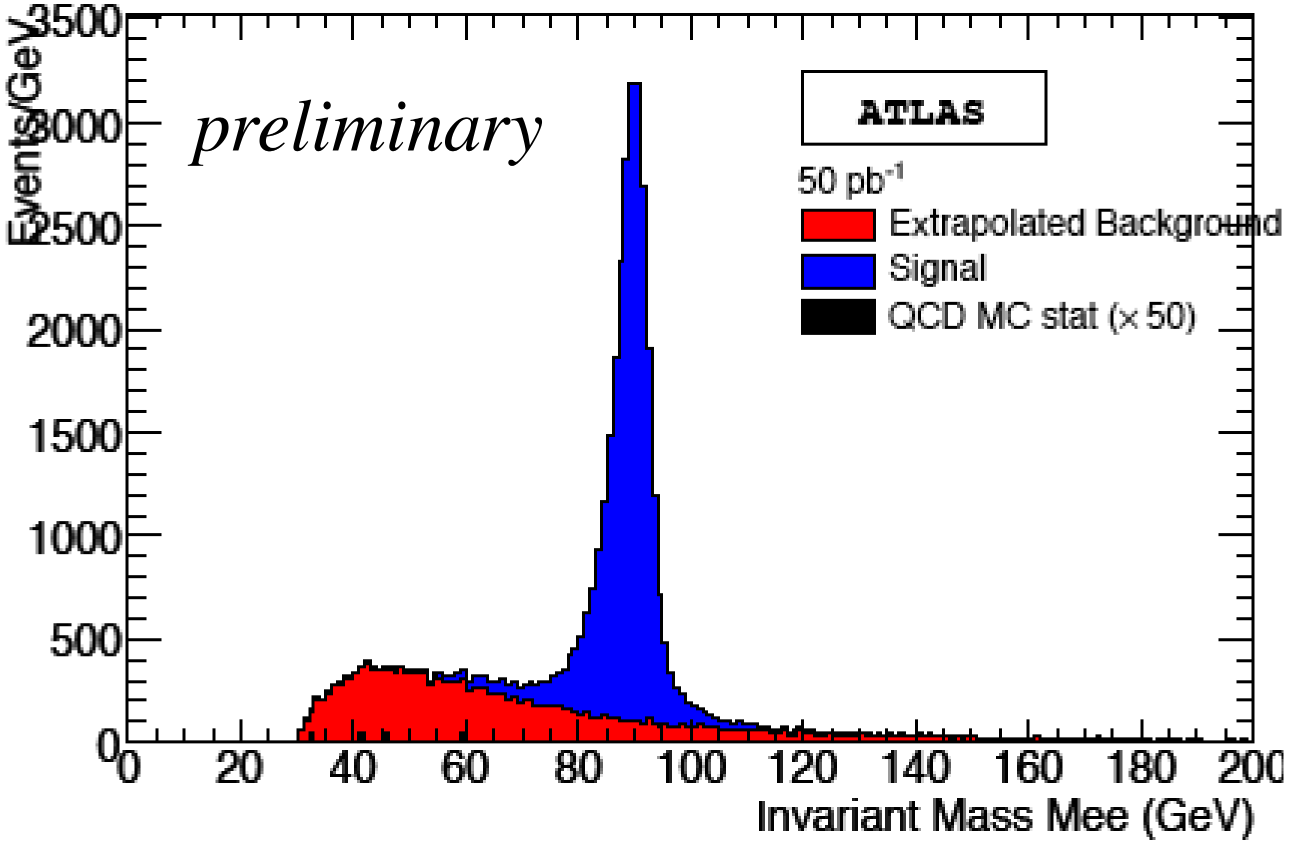


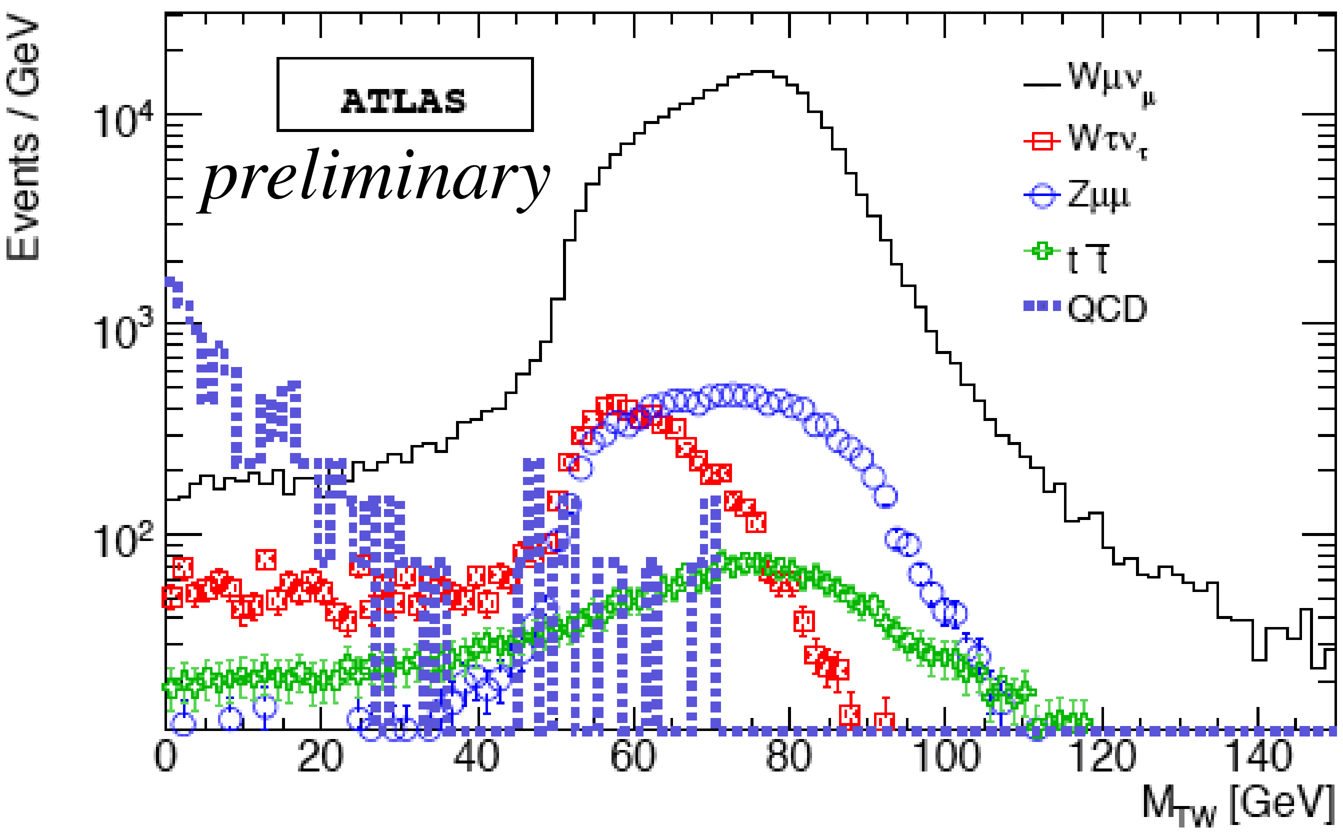
Dilepton resonances (mostly Z) sensitive to:

- Tracker-spectrometer misalignment
- Uncertainties on Magnetic field
- Detector momentum scale
- Width is sensitive to muon momentum resolution

J/ψ and Z Cross-checks between samples

LHC signals of W's and Z's with 50 pb^{-1}

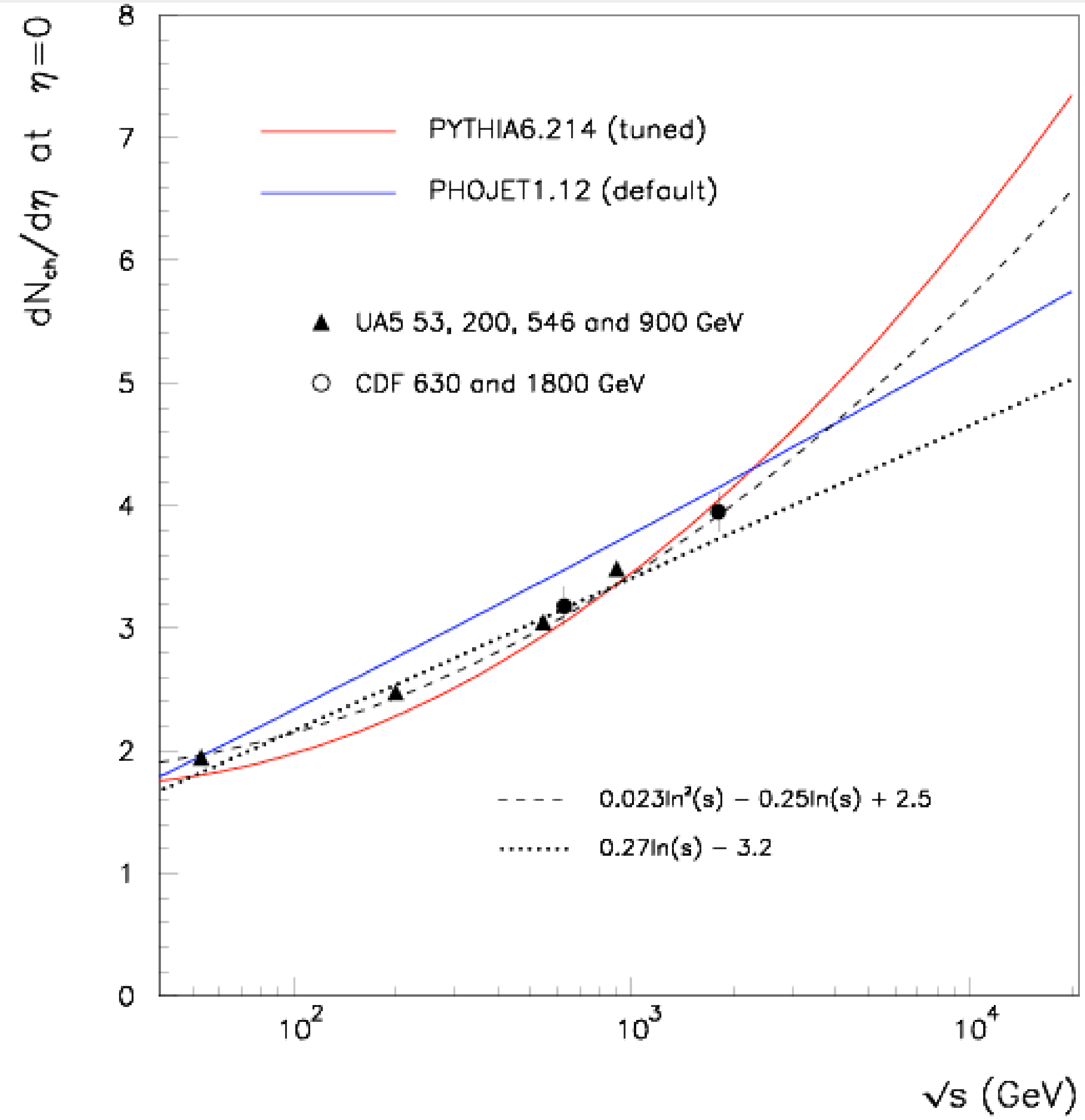


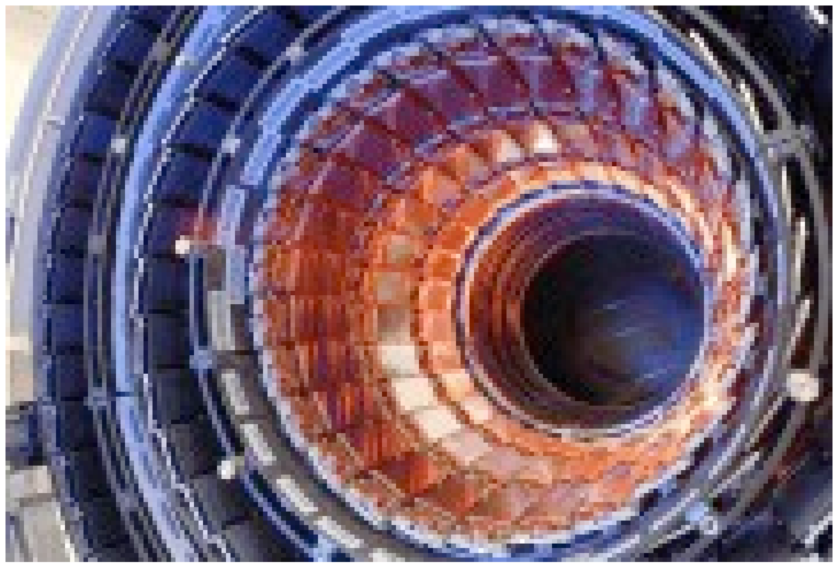


- 50 pb^{-1} yield clean signals of W's and Z's
- Experimental precision
  - ~5% for 50 pb^{-1} $\oplus$ ~10% (luminosity)
  - ~2.5% for 1 fb^{-1} $\oplus$ ~10% (luminosity)

Measure $dN_{ch}/d\eta$, dN_{ch}/dp_T

- In theory, we know:
  - W, Z cross sections at ~3%,
  - ttbar cross section at ~10%,
  - but minimum bias charge multiplicity only at ~50%
- Candidate for very early measurement
  - few 10^4 events enough to get $dN_{ch}/d\eta$, dN_{ch}/dp_T
    - ~15 minutes of good data !
  - Caveat: need to understand
    - Beam backgrounds,
    - Pile-up
    - Tracking efficiency !!!
- Initial tracker alignment is good enough as long as it is accounted for in the tracking algorithm.





Current models predict for
14 TeV: 90 – 130 mb

Aim of TOTEM: ~ 1%

First year : ~5%

Luminosity independent method:

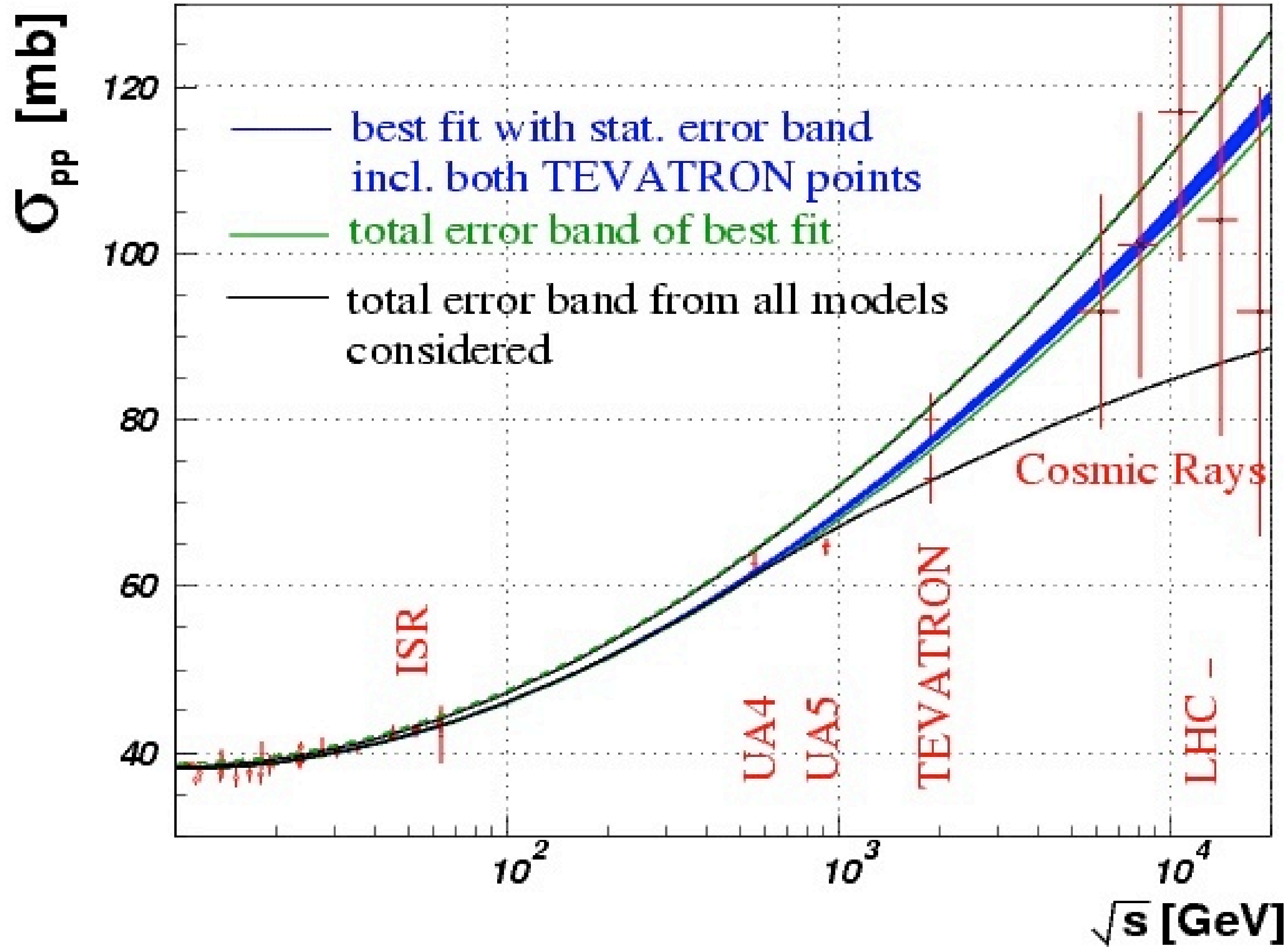
Optical Theorem $$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

⇩

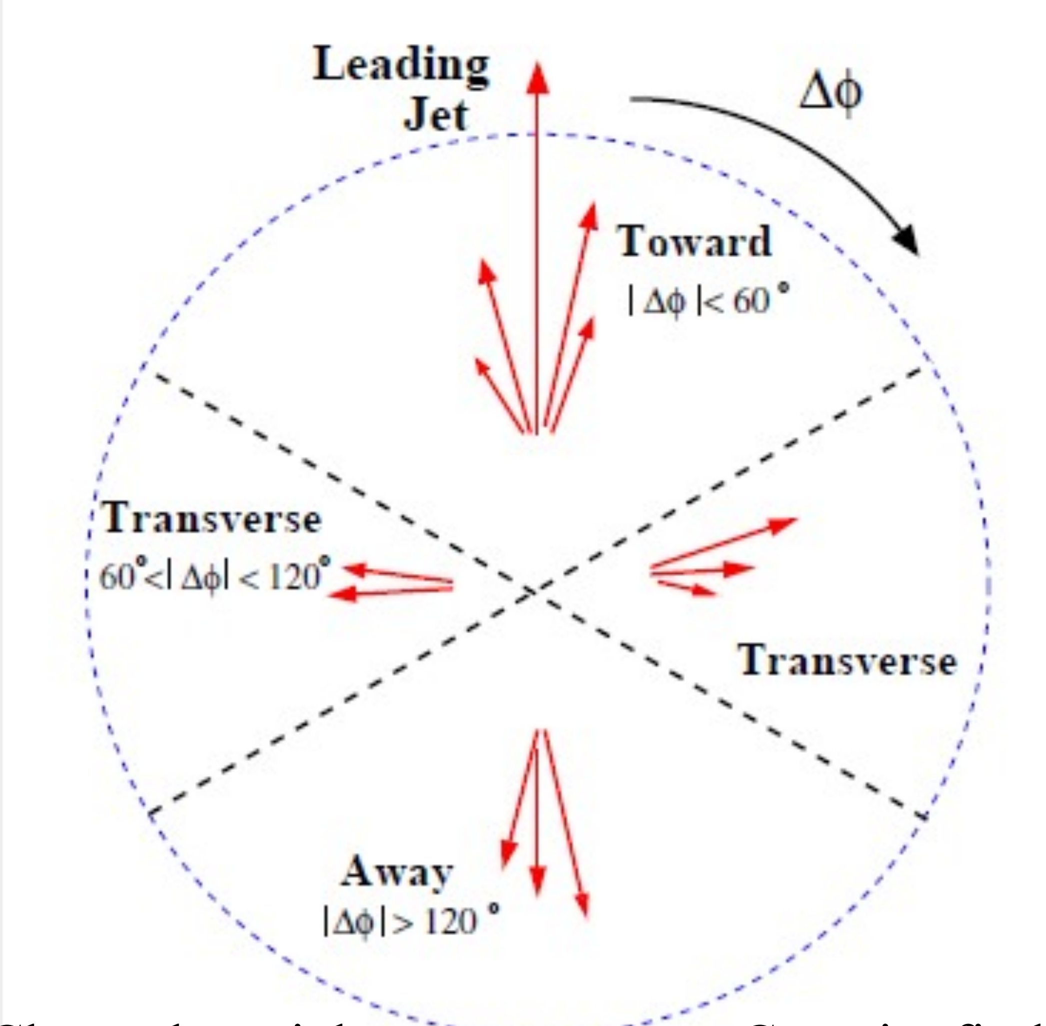
$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN/dt)|_{t=0}}{N_{el} + N_{inel}}$$

COMPETE Collaboration:

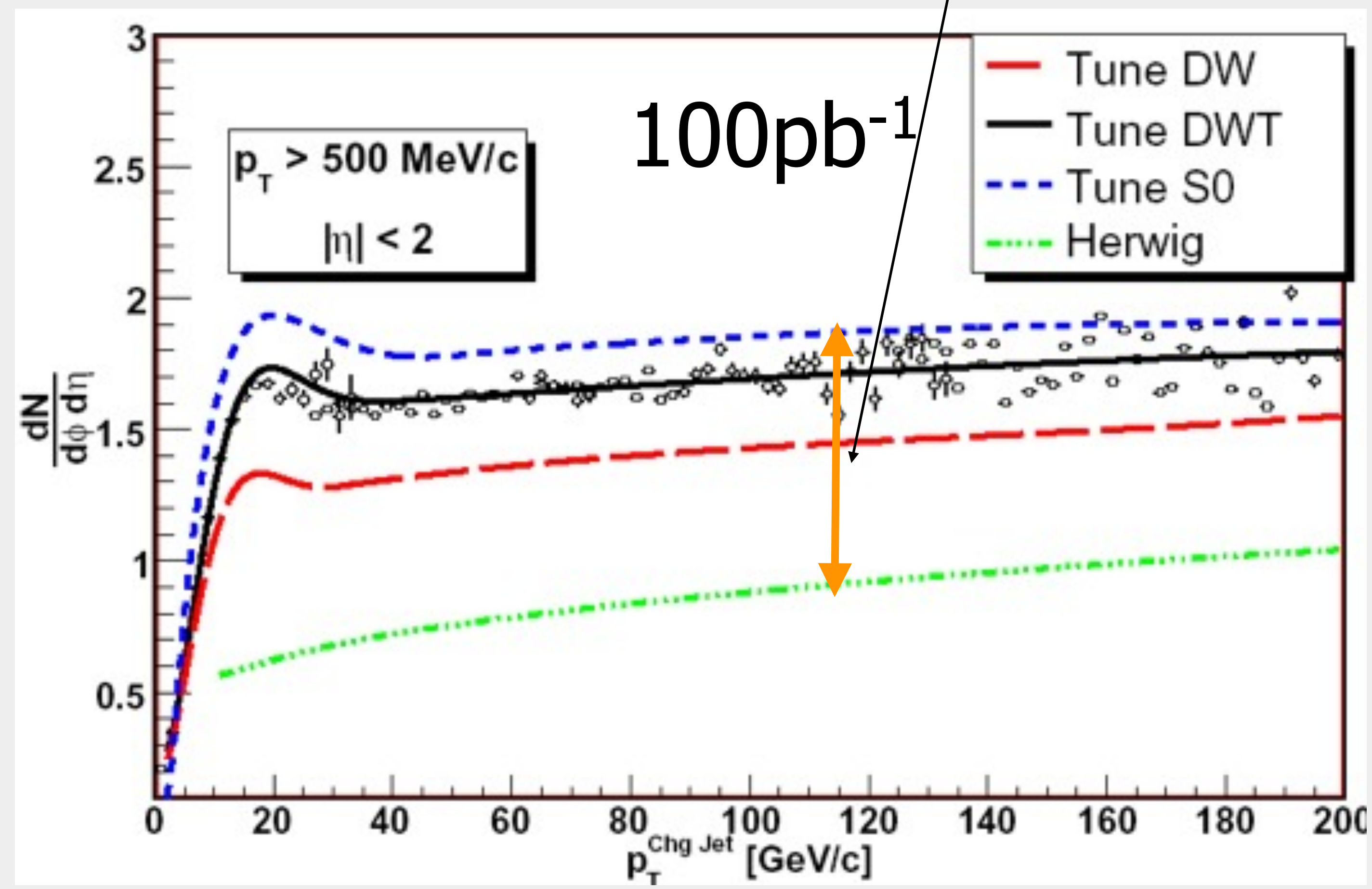


Underlying Event in pp collisions at $\sqrt{s}$ = 14 TeV

Underlying Event particles come from region transverse to the leading jet.
(The underlying event is defined as everything in the collision except the hard process .)



Large difference depending on the models



Charged particles:
p_t>0.5 GeV and |η|<1

Cone jet finder:

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$$

ATL-PHYS-PUB-2005-007

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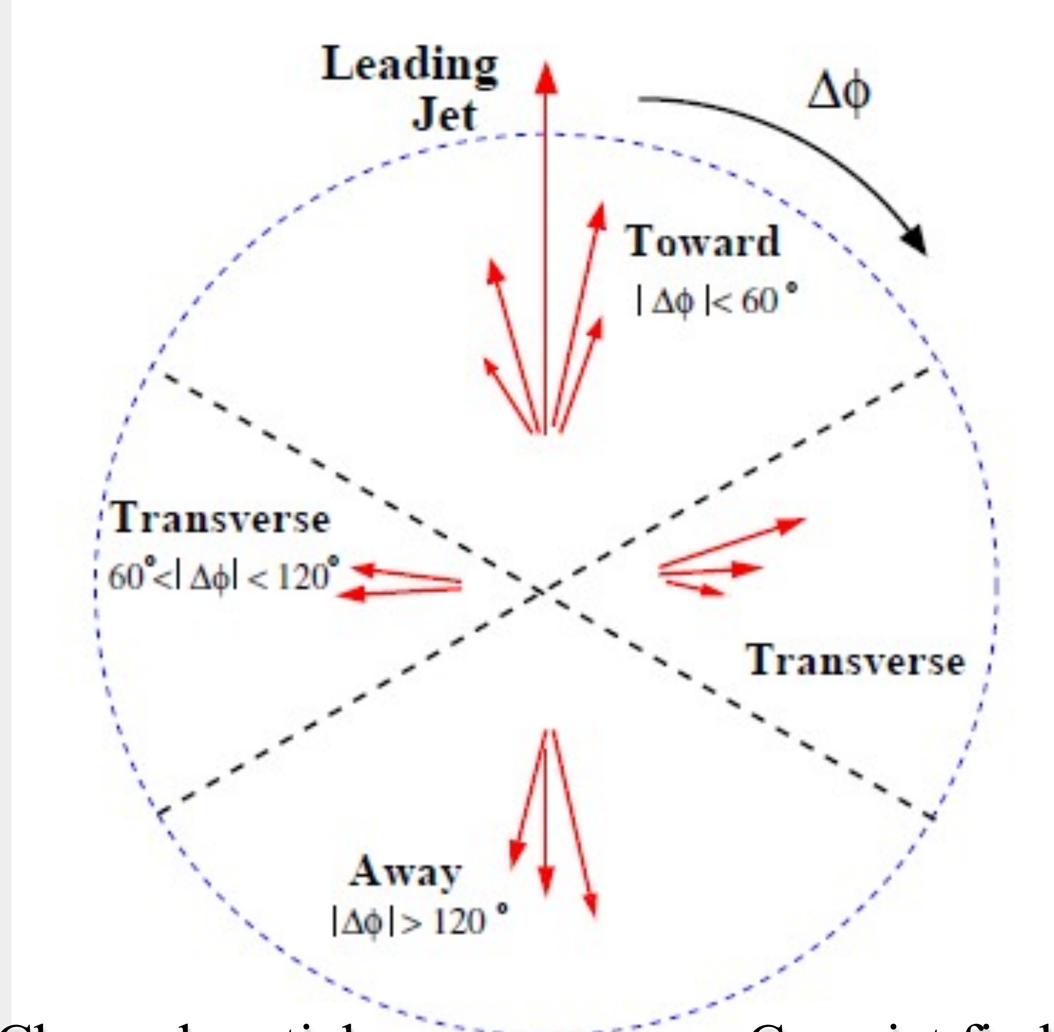

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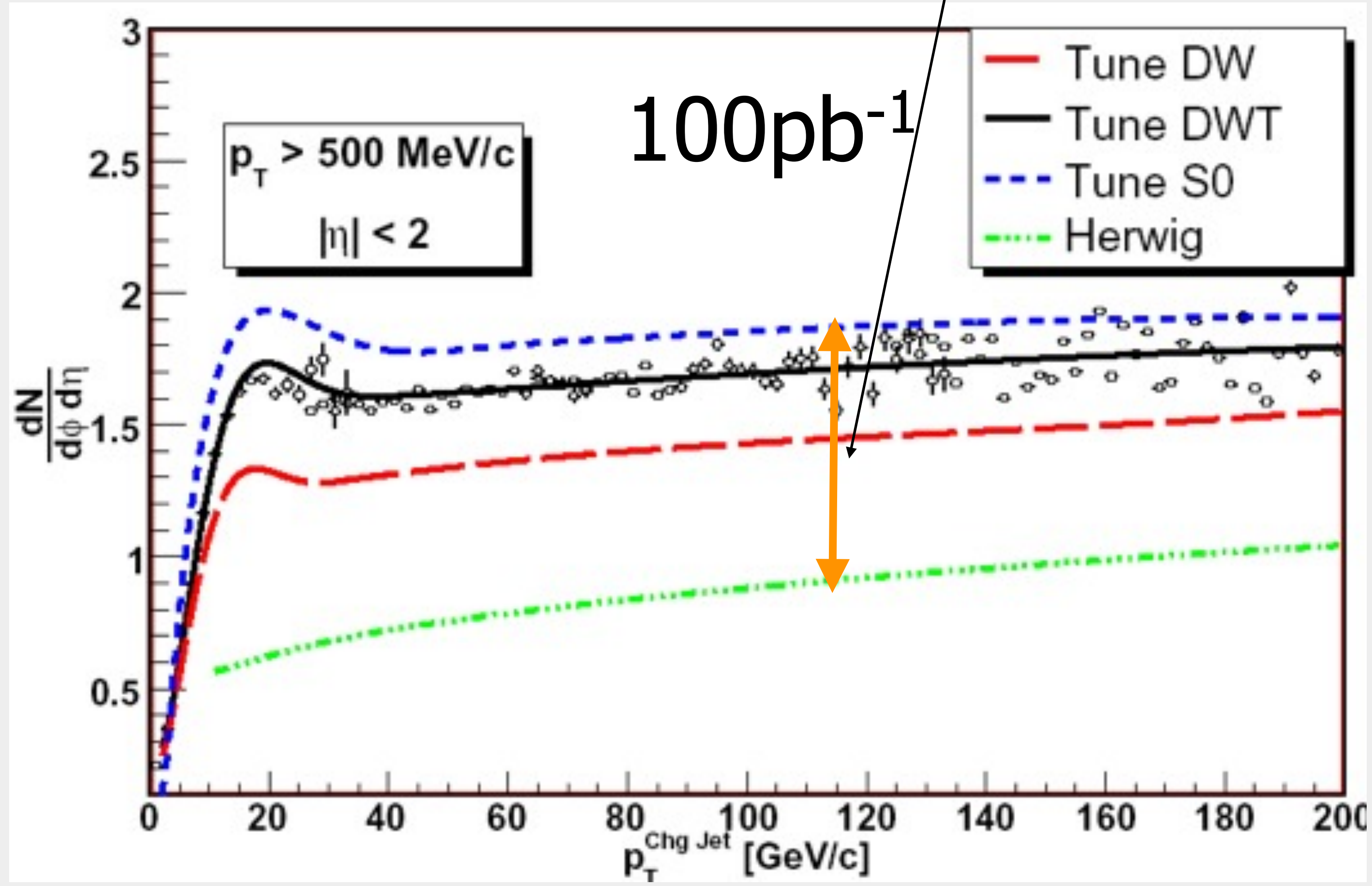

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ATL-PHYS-PUB-2005-007

Extrapolation Uncertainties of UE:
➡Multiple interactions
➡ Radiation
➡ Fragmentation

Pile up and underlying events affect :
- ➡ isolation of leptons and jets,
- ➡ jet energy reconstruction ("pedestal")
- ➡ jet veto
- ➡ ....

Jet measurement

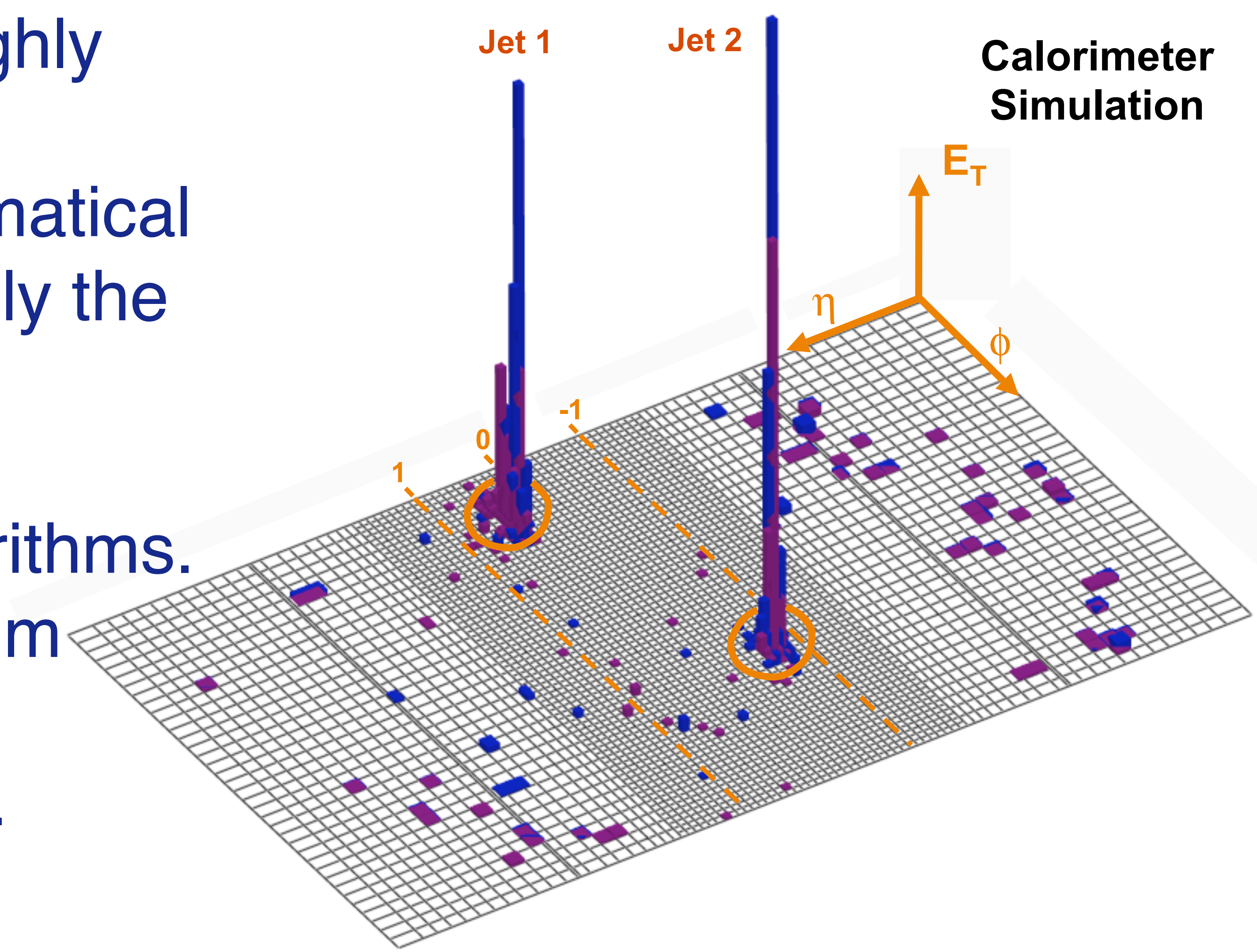
✦ Jets are the experimental signature of quarks and gluons, observed as highly collimated sprays of particles.

✦ A jet algorithm is a set of mathematical rules that reconstruct unambiguously the properties of a jet.

- Fixed cone algorithms.
- Successive recombination algorithms.

✦ Different inputs to the jet algorithm lead to different types of jets:

- Calorimeter energy depositions.
- Tracks.
- Particle or energy flow objects.
- Simulated particles.



Possible early discovery: anomalies in high E_T QCD jets, di-jet masses

- **1 fb^{-1} : jets up to 3-3.5 TeV, di-jet masses up to 6 TeV: <u>new territory!</u>**
- **Sensitive to substructure, contact interactions, high mass resonances**

CMS

10^8

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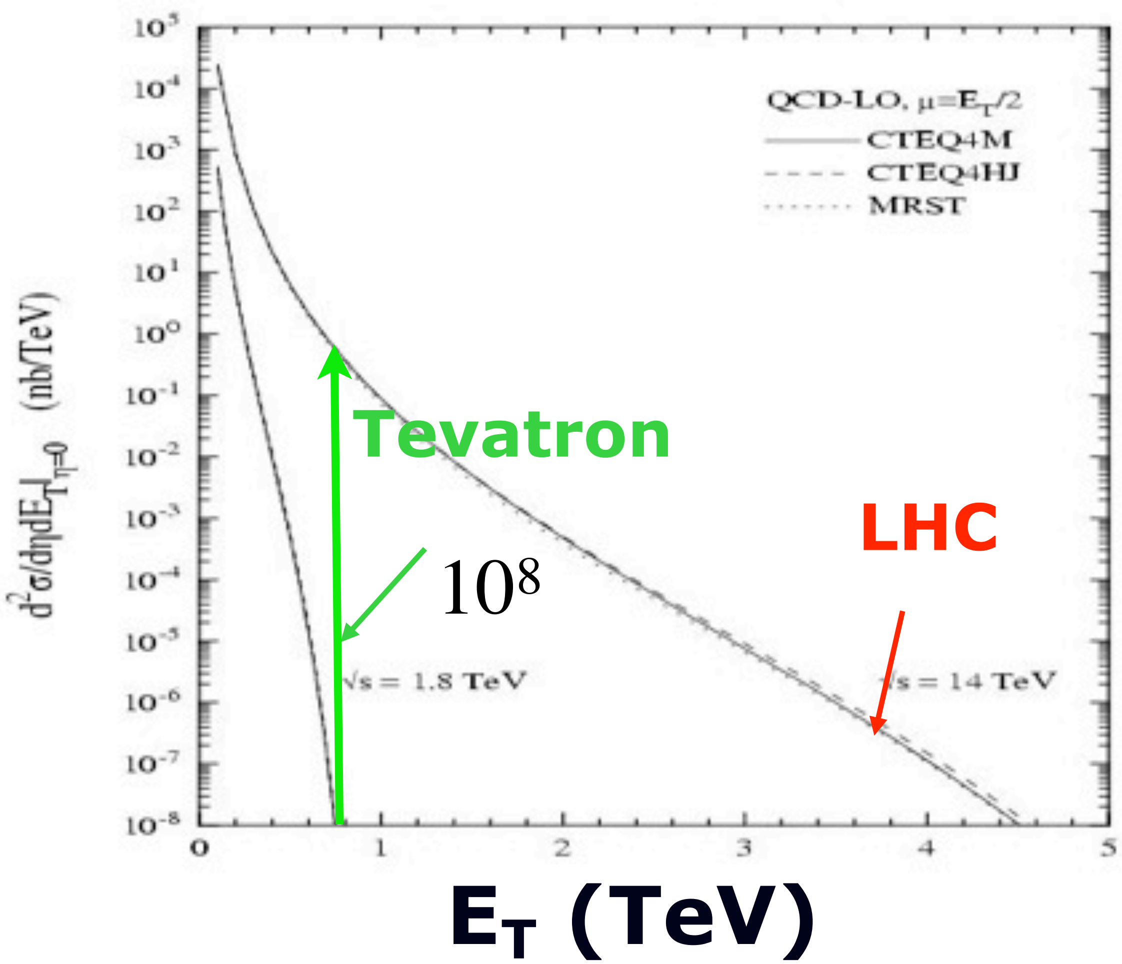
Jet cross section



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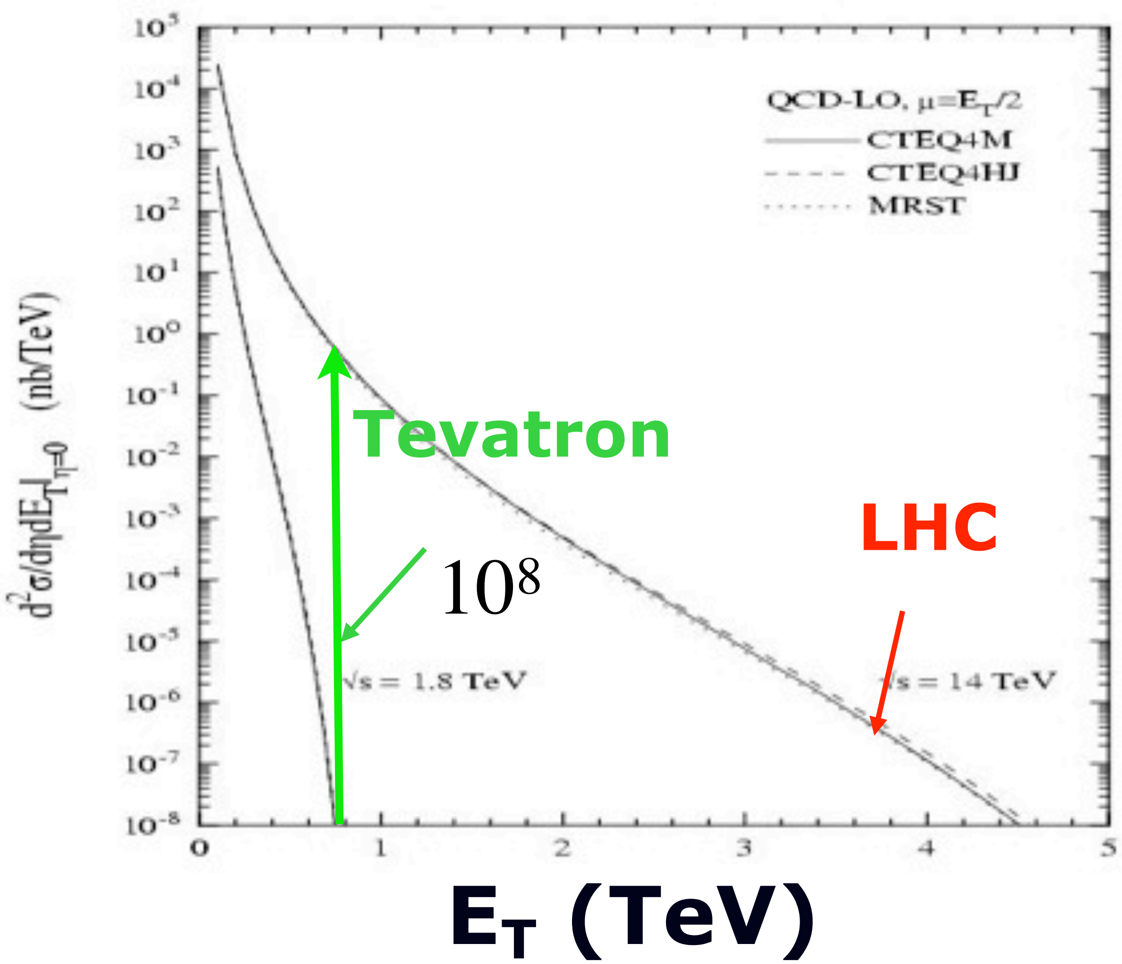

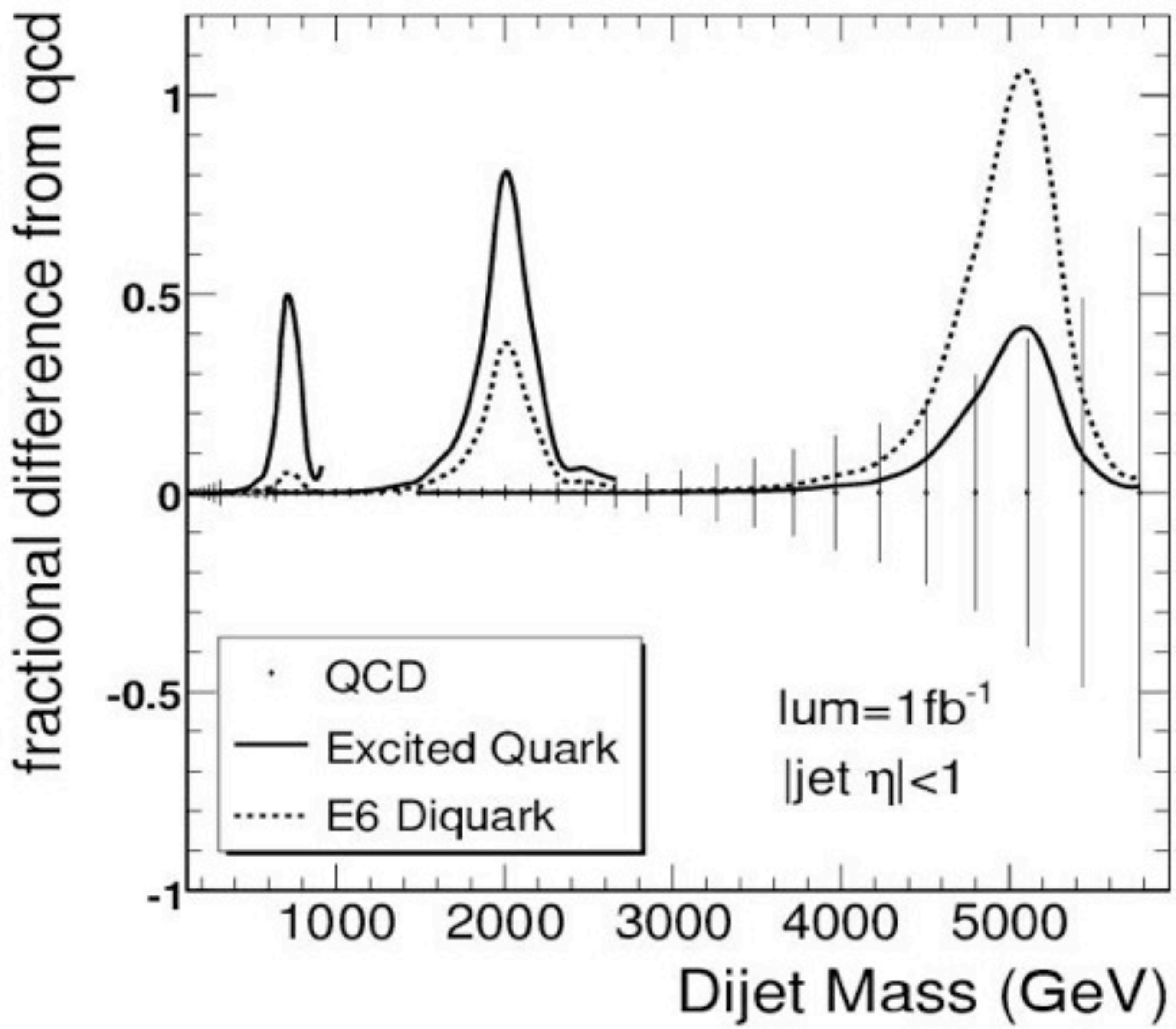

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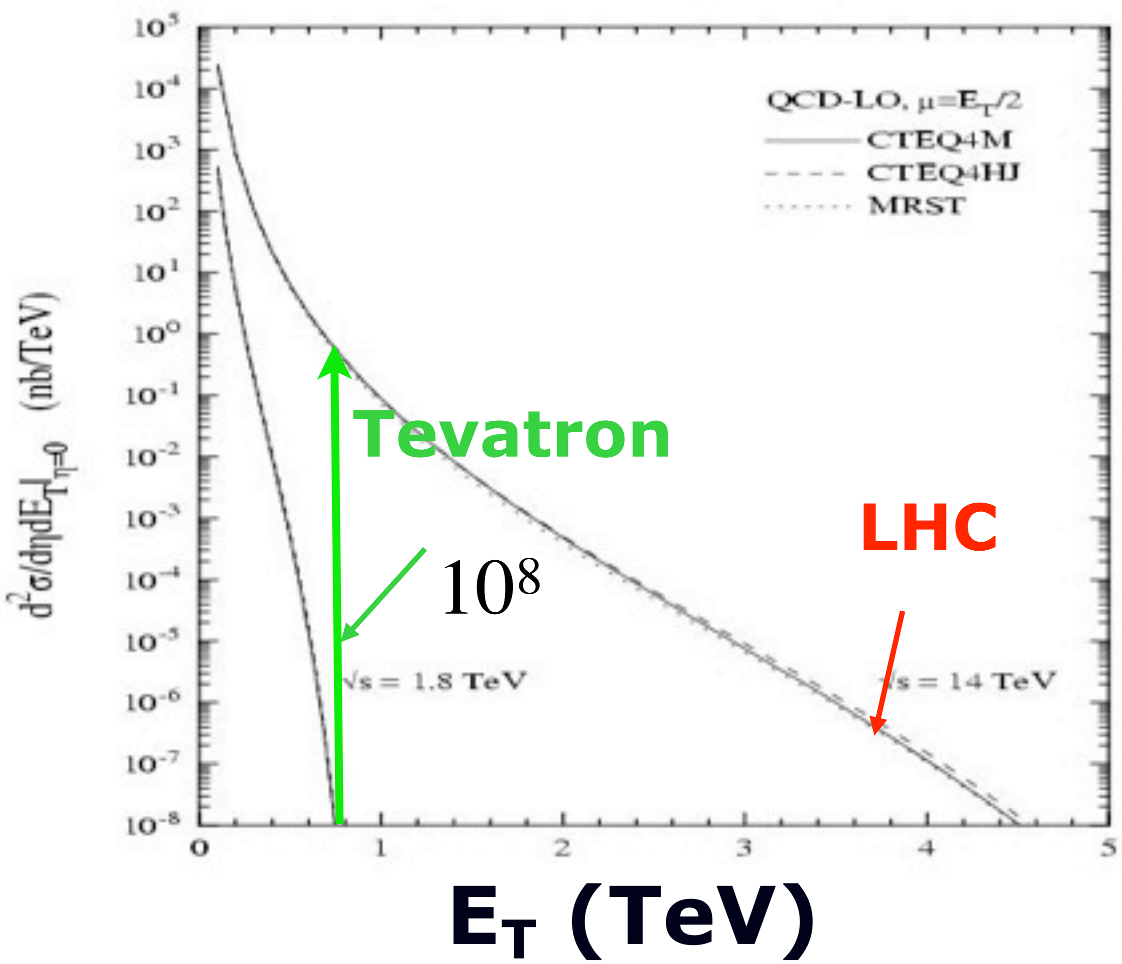
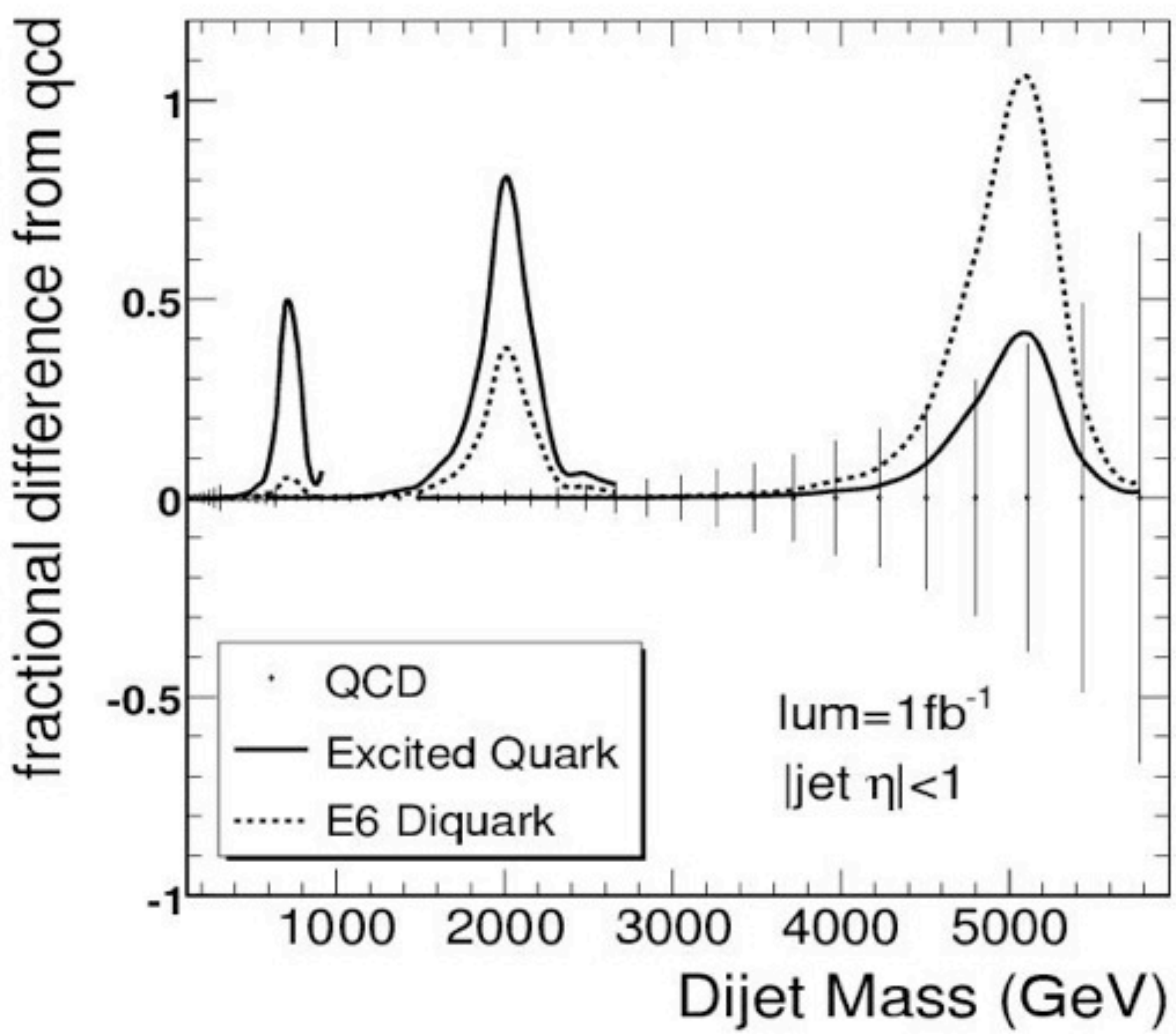
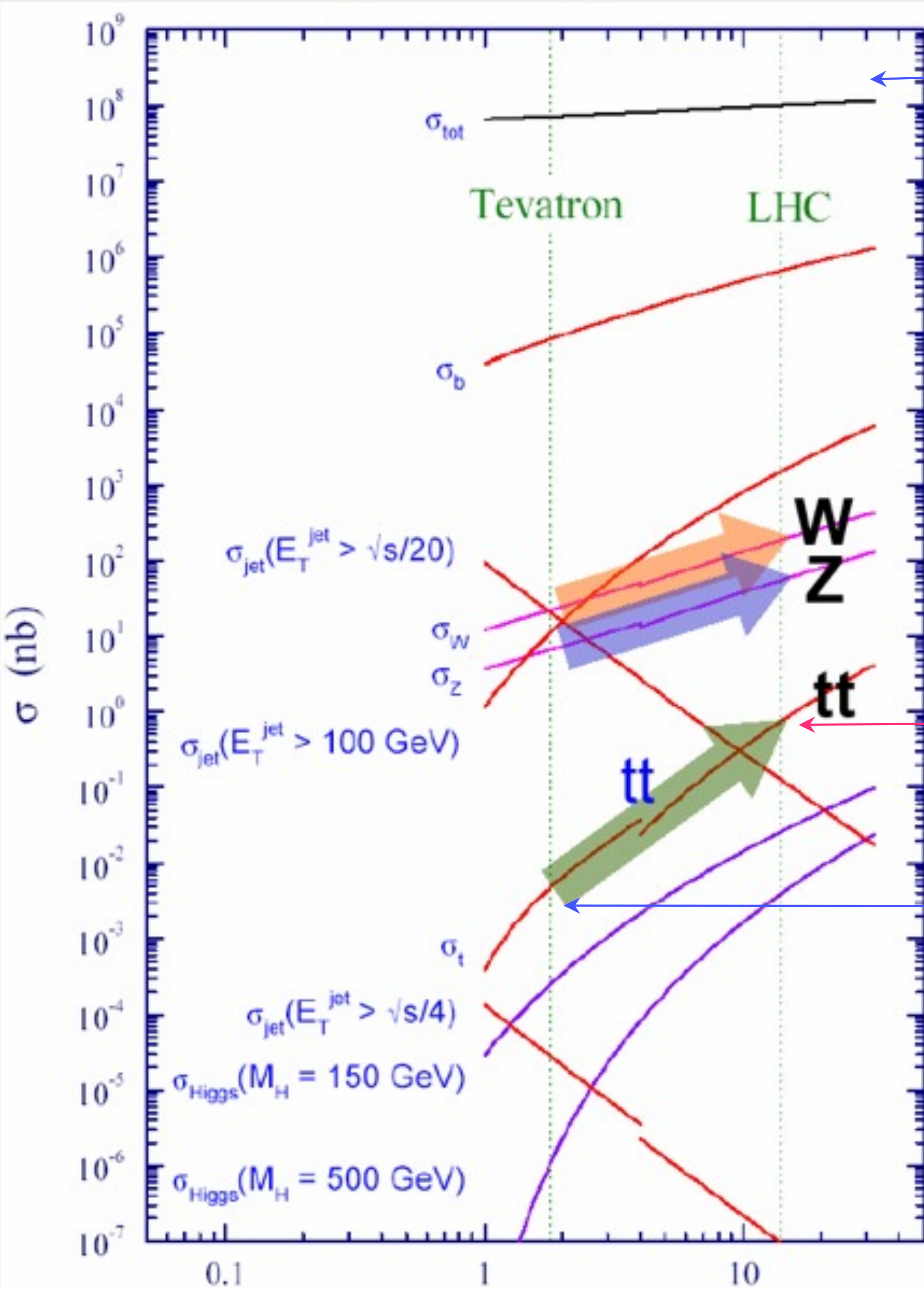




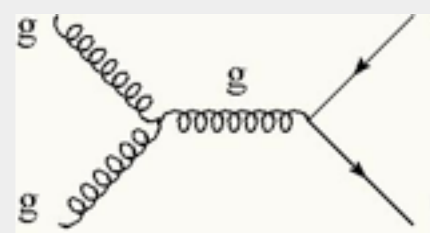
Challenges

- Jet energy scale,
- Parton density function (PDF)
- underlying event, trigger,
- scale variation, hadronization

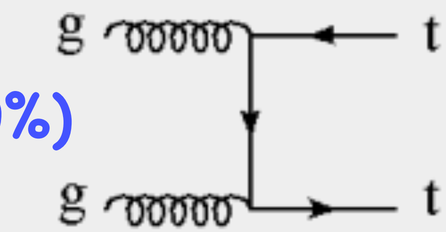
LHC is a $t\bar{t}$ factory



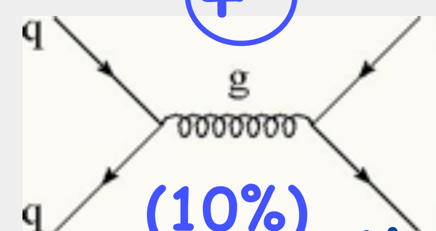
Total production cross section



(90%)



+



(10%)

$t\bar{t}$ production cross section at LHC:

~833 pb

$\bar{t}t$ production cross-section

at Tevatron:

6.7 pb

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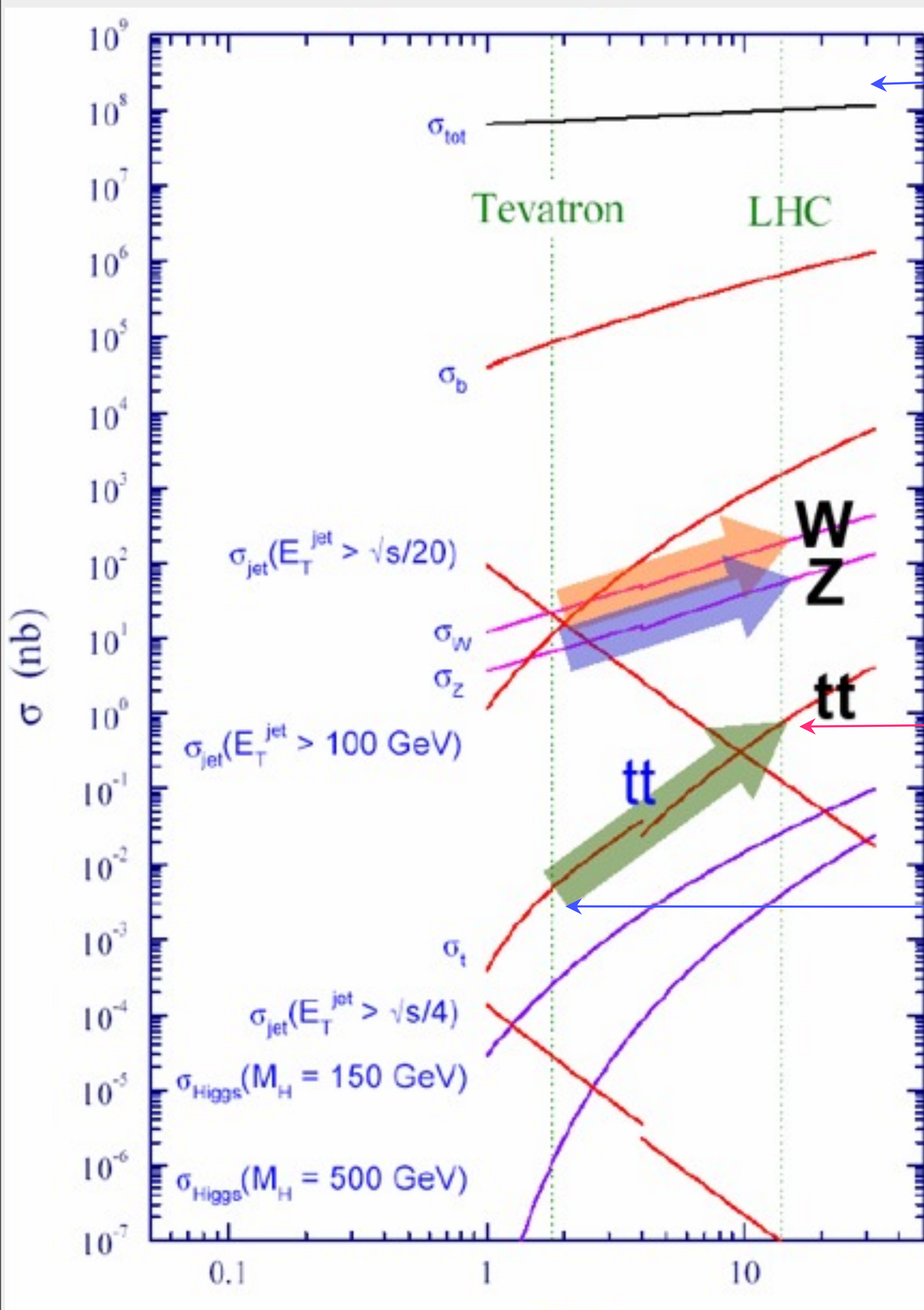

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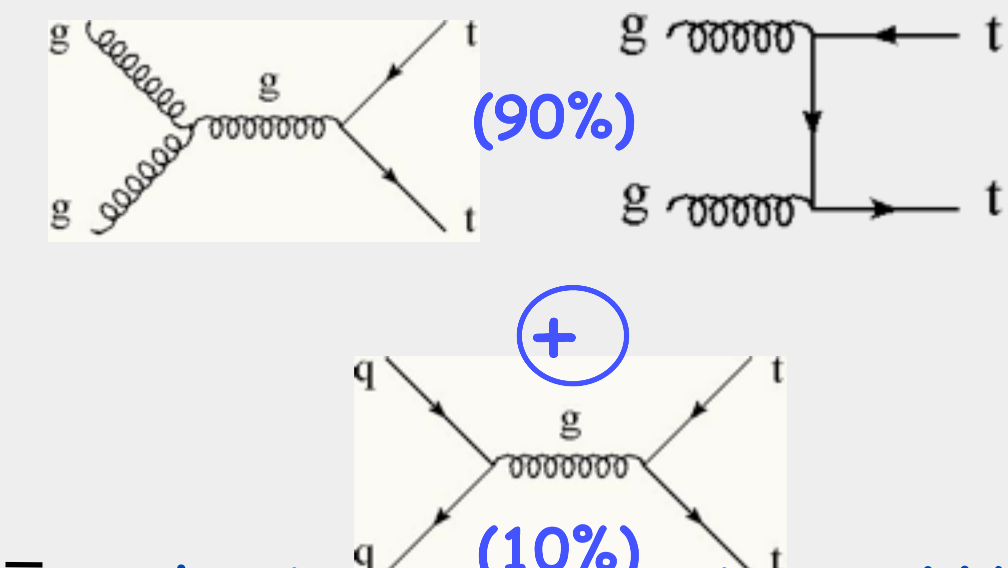

(90%)

+

(10%)

$t\bar{t}$ production cross section at LHC:
~833 pb

$\bar{t}t$ production cross-section
at Tevatron:
6.7 pb

2 tt events per second !
> 8 millions tt events expected per year

TOP at the LHC is important

- ATLAS and CMS goals in TOP sector are identical : a good knowledge of detectors
  - So the road to full detector commissioning pass through the TOP physics
  - So first ..

- Top rediscovery : *Commissioning in 2009*

- ***Light and bJet => Jet Energy Scale***
- ***Overall jet calibration***
- ***b Tag efficiency***

- Precise measurements in the top sector : *EW probing in 2010 and over*

  - ***Precise top parameters measurements***
  - ***Constraints in the SM and beyond***

- New physics search... *As soon as detectors are well understood.*

  - ***both in the production and decay sectors : ttbar-> X, X->ttbar, ttbarX***
  - ***Large coupling with the Higgs***
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We could get top signal with ~ 10 - 100 pb^{-1}

- **$\sigma(tt)$ to ~13% and M_{top} to 1% with $1fb^{-1}$**

Focus on semileptonic channel :

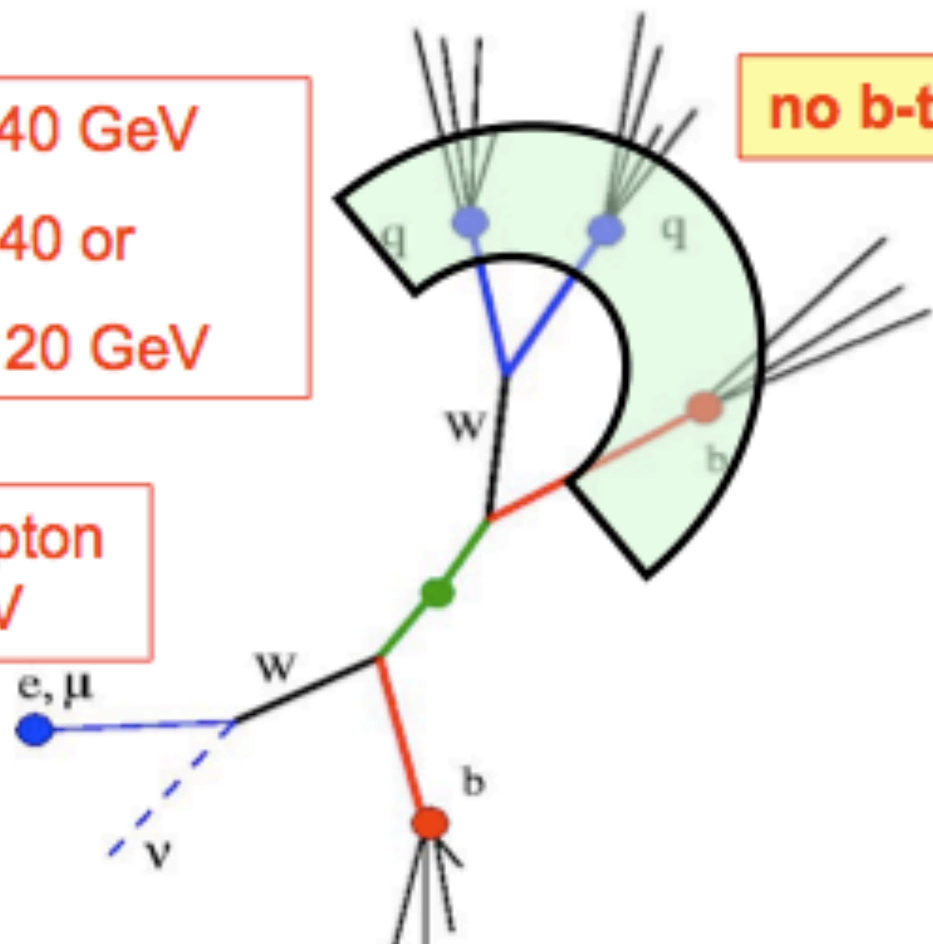
BR ($t\bar{t} \to WbW\bar{b} \to (l\nu b)(\bar{b}jj)$) ~30 %
Easy to trigger thanks to isolated lepton (e or μ)
Clean topology : t and $\bar{t}$ central and back-to-back

Typical event selection:

3 jets p_T >40 GeV
4th jet p_T >40 or 20 GeV

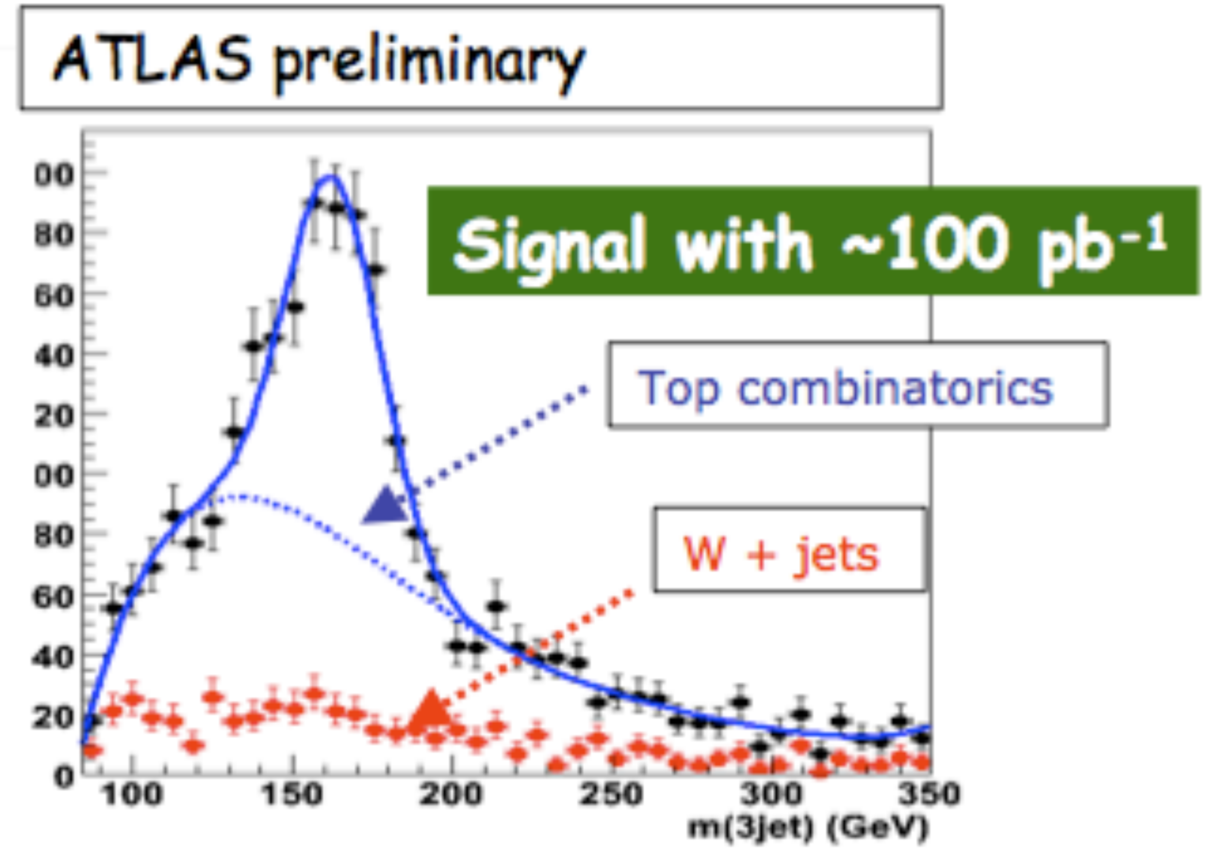
Isolated lepton p_T>20 GeV

no b-tag !



E_T^{miss} > 20 GeV

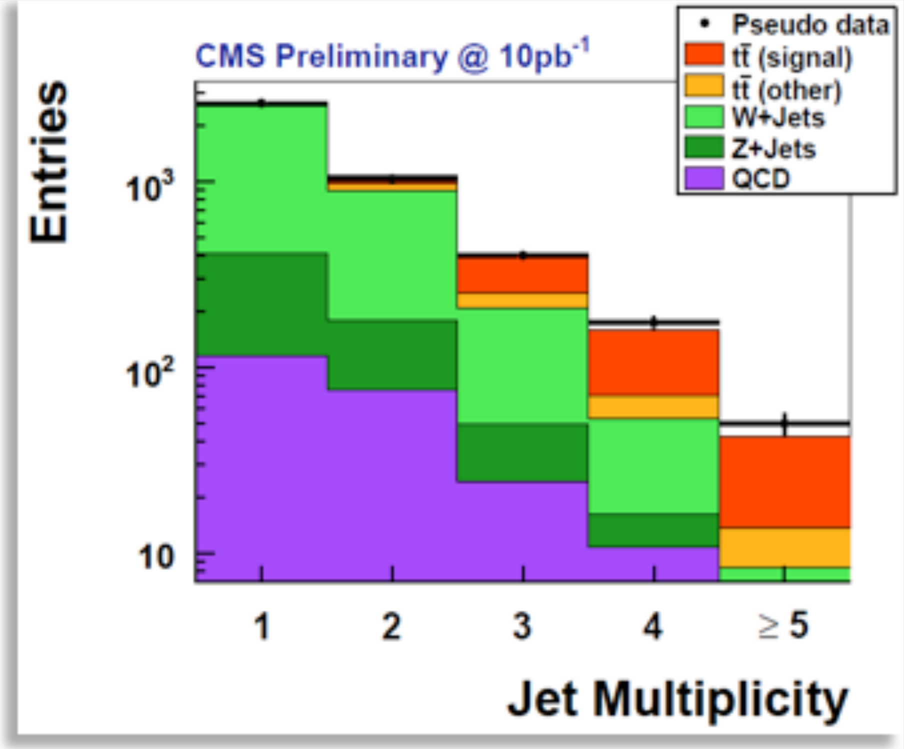
Compute invariant mass of 3 jets with highest Σp_T :



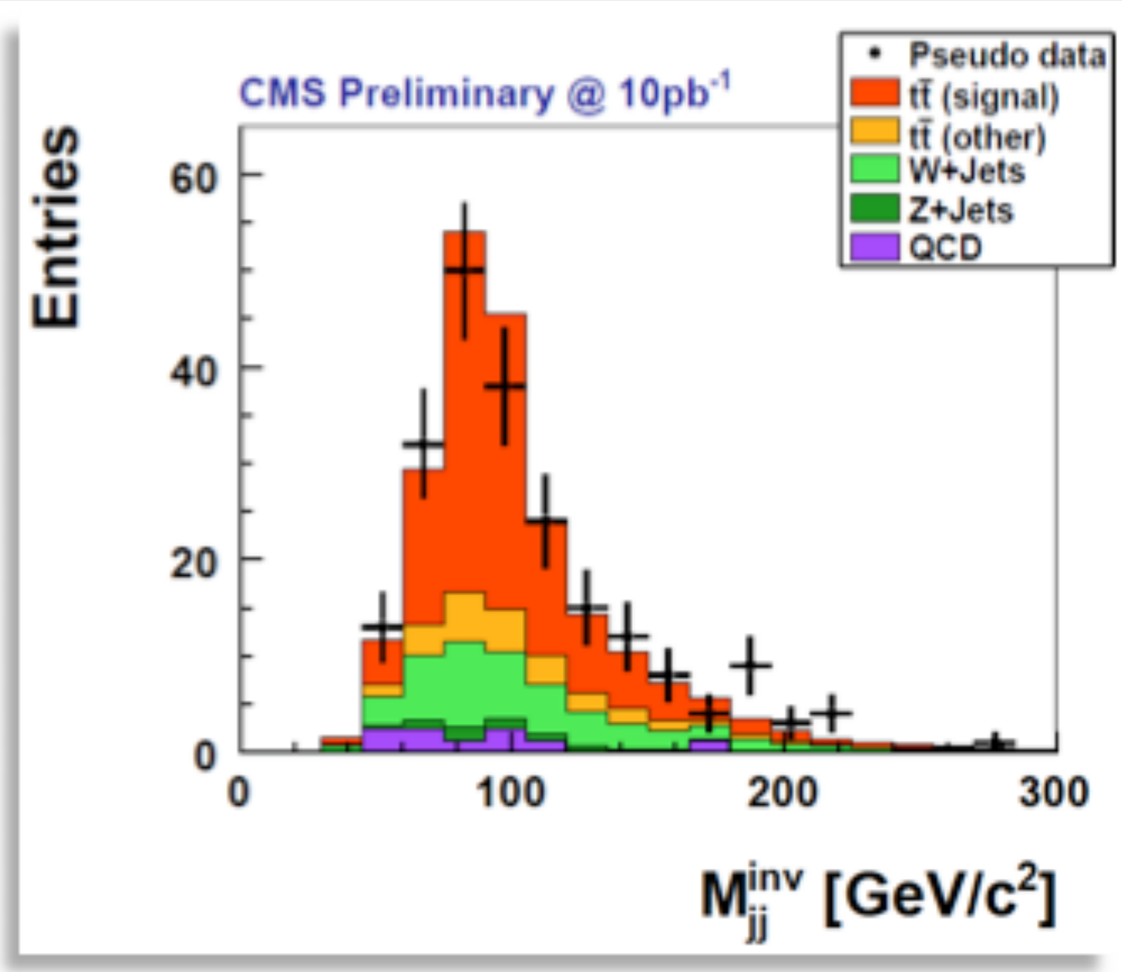
If 2 b-jets requested :
BKG <2% : mainly W/Z+jets, WW, WZ, ZZ
Efficiency 1-2%

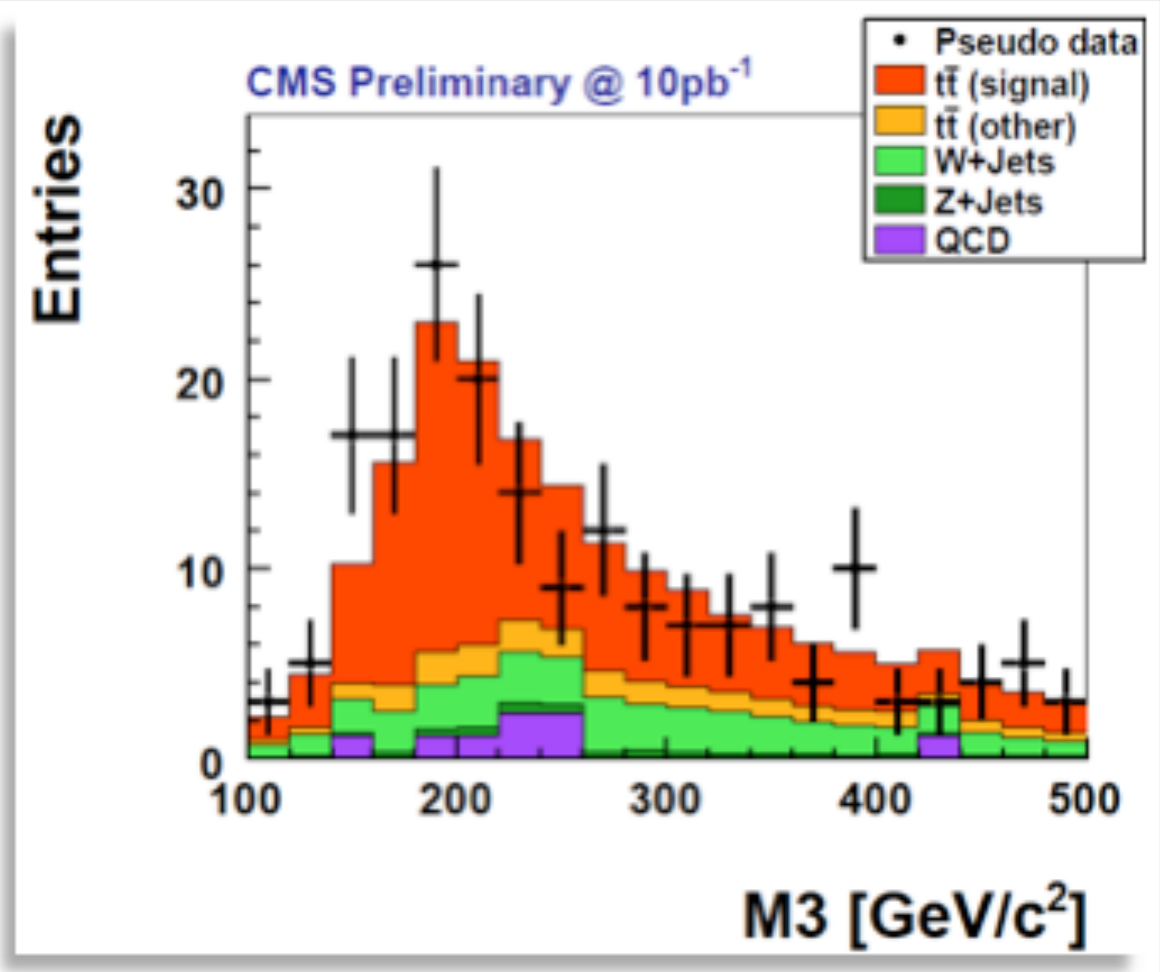
Top Quark pair production (10 pb^{-1})

- CMS muon channel selection:
  - 1muon p_T>30 GeV, |eta|<2.1 (loose)
  - Isolation E(calo,iso)<1GeV and dR(mu-jet)>0.3
  - at least 4 jets; |eta|<2.4, E_T>65,40,40,40 GeV
  - no b-tagging



For 10pb^{-1} : 128/90 signal/background





Brief motivation for beyond SM searches

- However successful the Standard Model (SM) has been so far (it well describes all current experimental data), it is at the same time plagued by instabilities (divergent loop corrections at high energy).
- So different ideas have been proposed to cure these limits, so called “beyond the SM” models :

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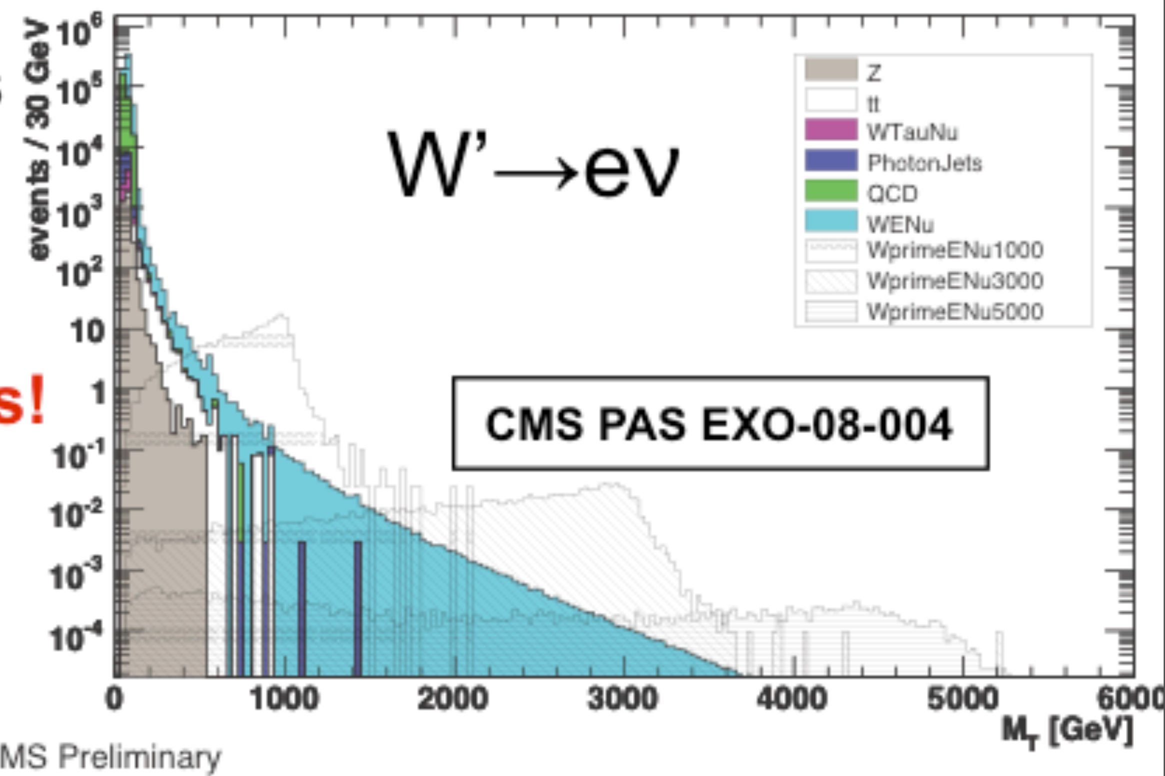
Extra dimensions

Has the SM interactions confined to four dimensions and gravity occupying the extra dimensions

di-object signature search

Search for final states with just two physic objects like leptons, jets, E_T^{miss}, predicted by various models



definition of signature allows generic searches!

- **di-lepton**
  models: GUT, extra dimensions,...

- **di-jets: contact interactions** ⇒ large rate at high pT
  q*, Z' ⇒ heavy mass resonances

- **di-photons:** Important cross-check to **rule out spin-1 hypothesis**
  (i.e. **RS graviton** instead of a Z')

- **lepton+ E_T^{miss} :** signature of new **heavy W-like bosons** (LR model)

- **jet+ E_T^{miss}: signature: 1 high p_T central jet + E_T^{miss} ~back to back**
  mono-jet final states proposed by extra dimension models ADD

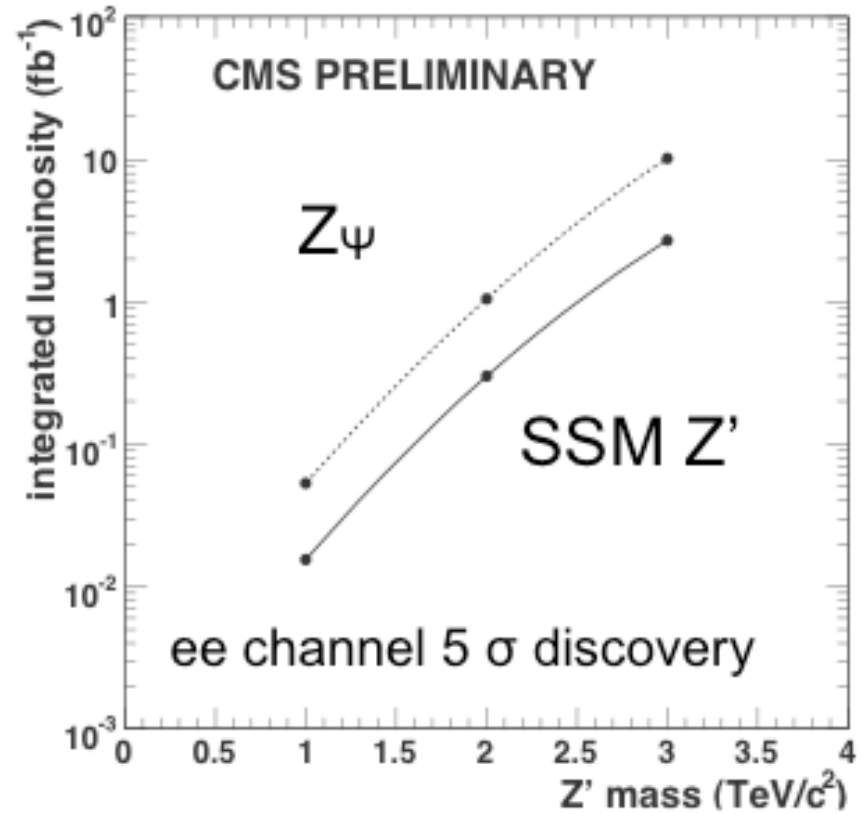
Di-lepton resonance (Z')

SSM Z' (carbon copy of Z)
Z_ψ: arises in E_6 and SO(10) GUT theories

Z' → ee/μμ: (CMS , ATLAS) CMS PAS EXO-08-004

- very clean signature
- various methods developed to evaluate: efficiencies, background, uncertainties

search strategies are in good shape



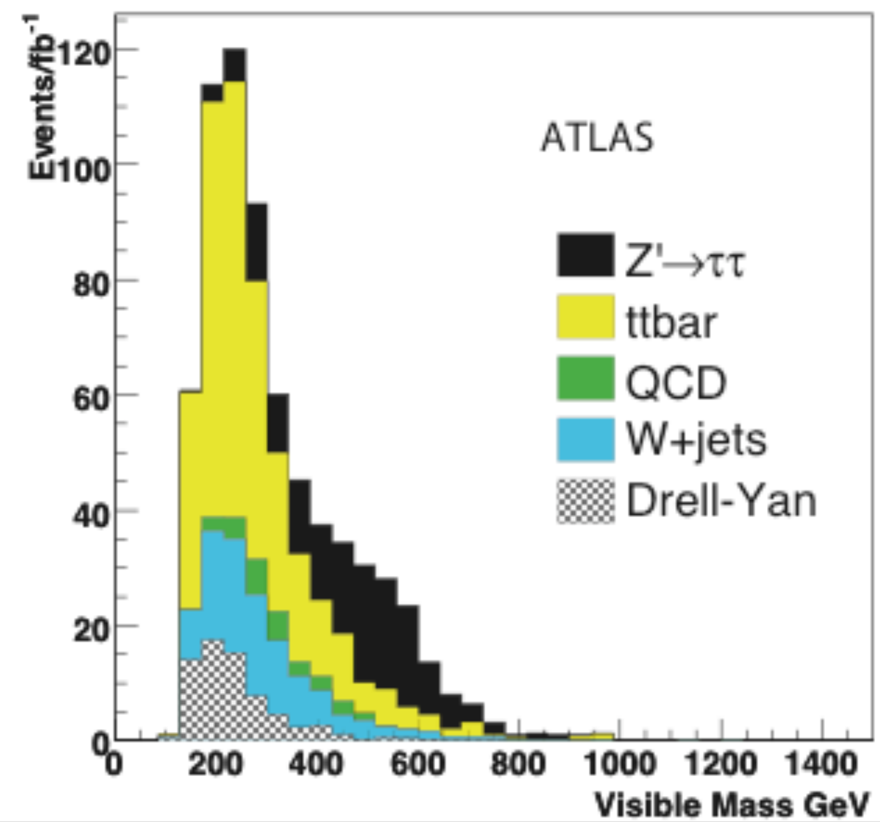
Z' → ττ: (ATLAS): ATLAS: CERN-Open-2008-020

- studied: hadron-lepton final state for m(Z')=600 GeV
- event selection: hadronic tau + charged l + E_T^{miss}
- **direct mass reconstruction not possible**
- use m_{vis} instead

$$m_{vis} = \sqrt{\vec{p}_l + \vec{p}_h + \vec{E}_T^{miss}}$$

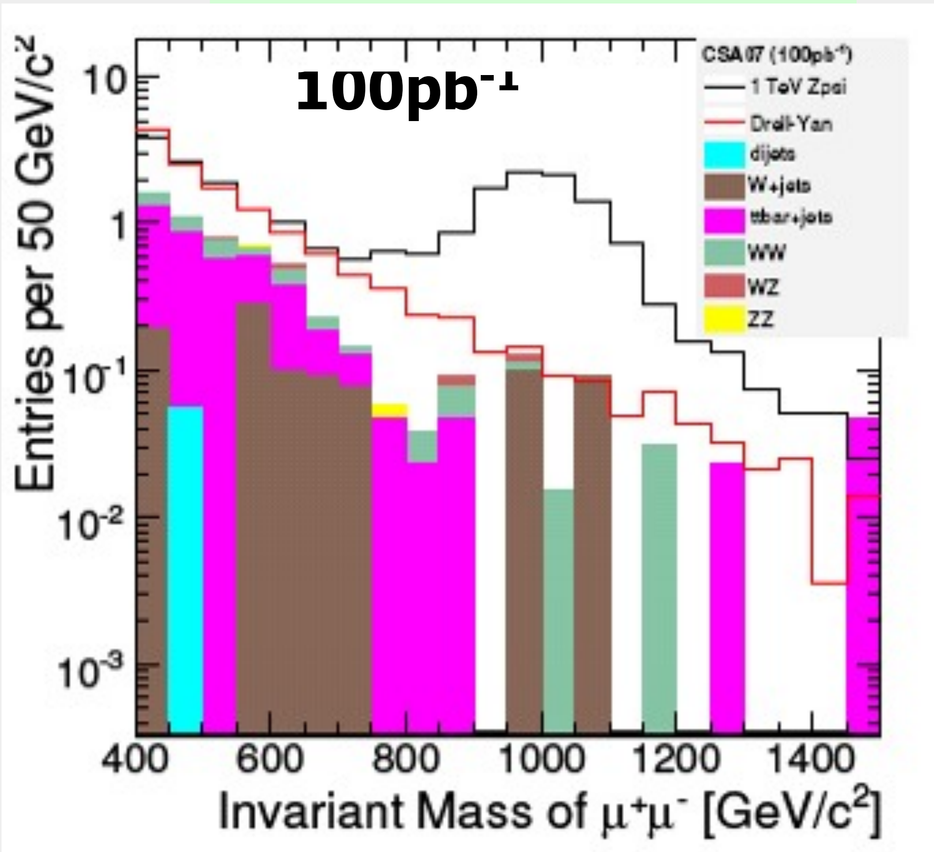
significance : $\frac{S}{\sqrt{B + \delta B^2}}$ = 3.4 at 1 fb^{-1}

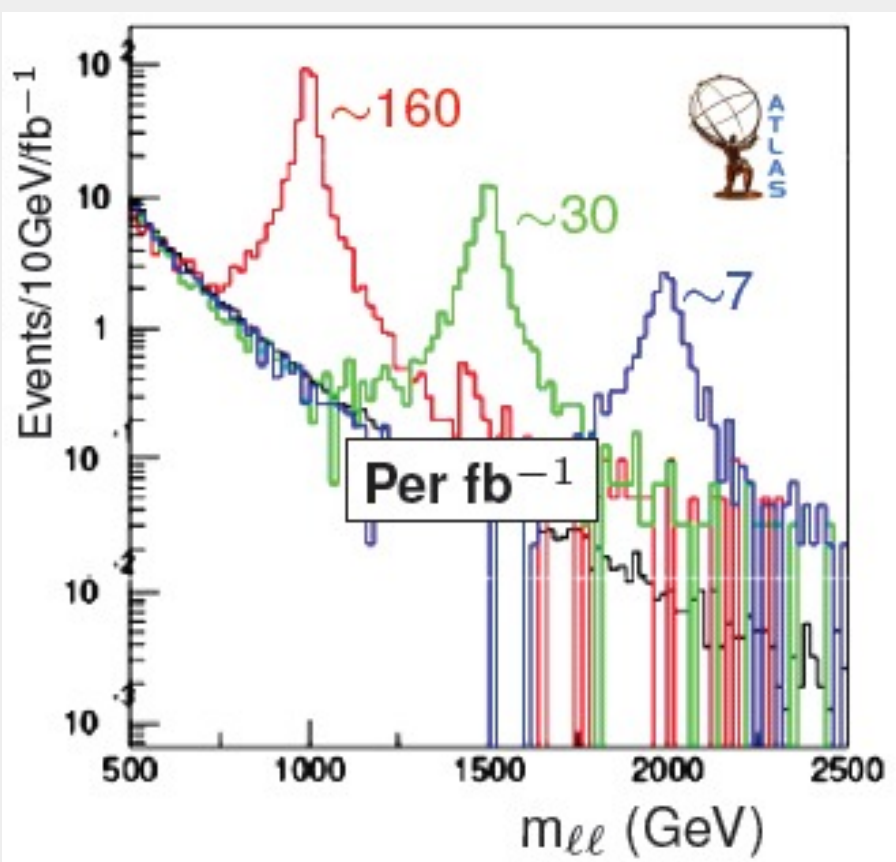
δB: background uncertainties

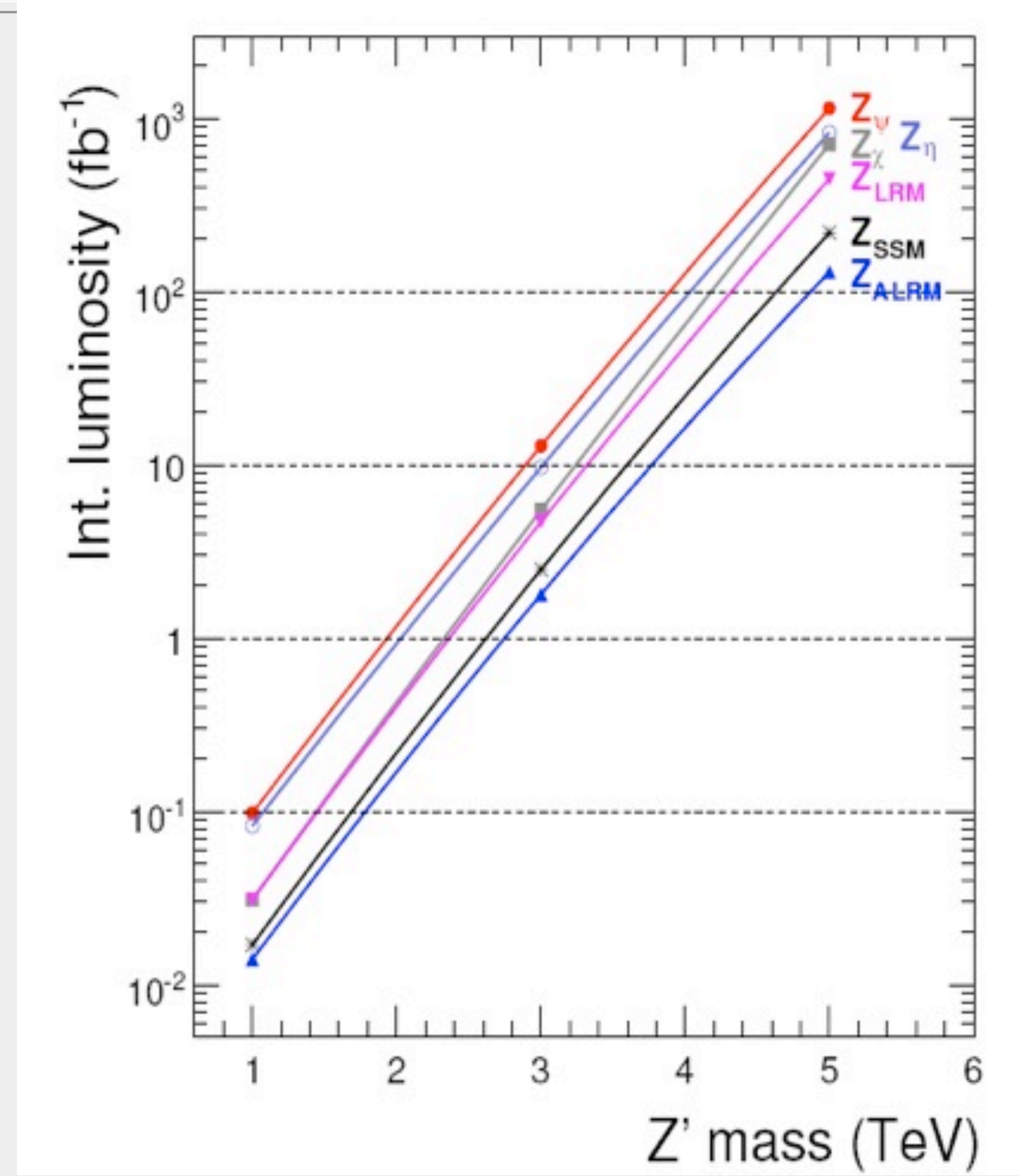


Extra Dimensions: Z'

Z' → μμ production







Mass (TeV)	$\int \mathcal{L}dt$ for discovery
1	~70 pb^{-1}
1.5	~300 pb^{-1}
2	~1.5 fb^{-1}

High lumi 100 fb^{-1}: extend range to 3.5-4.5 TeV

More exotic searches

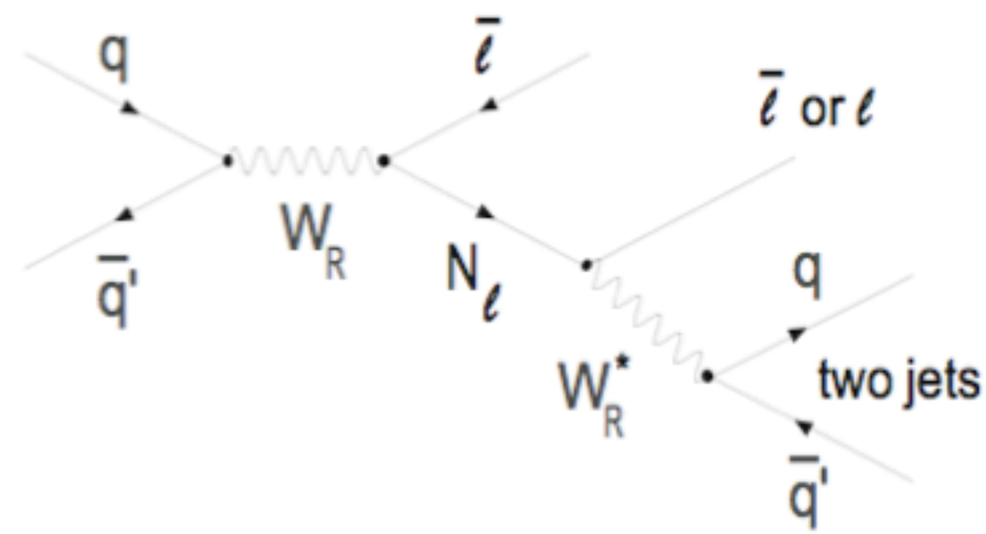
3-object searches:

2 leptons + jets: W_R, lepto-quarks (LQ)

studied decay modes: LQ → e\μ q

W_R → e\μ N

N: heavy majorana neutrino



something even more spectacular:

Vector boson resonances (high luminosity search):

signature: - 2 high rapidity high pT "tag" jets
- no jets between the two "tag" jets

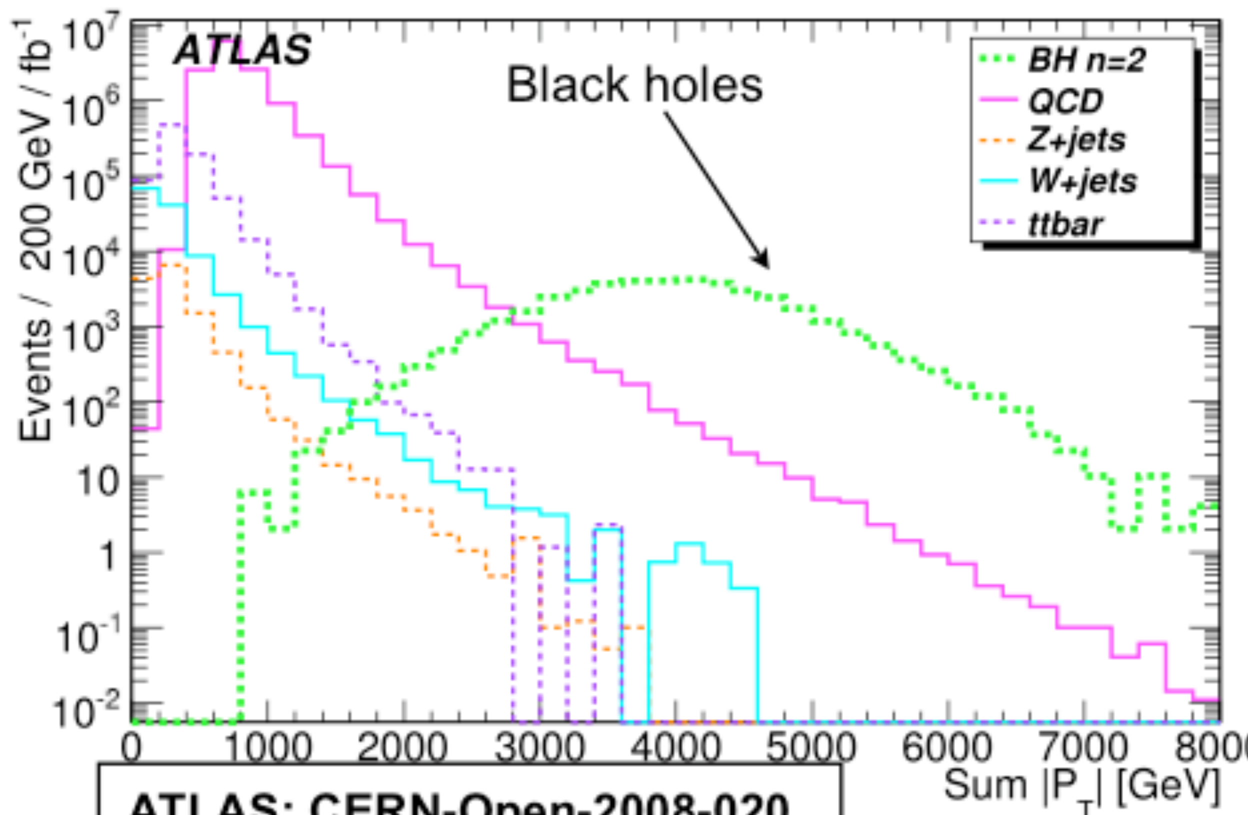
b'b'->WWWWbb: a fourth generation quark

signature: lots of leptons(1-4) +2 b-jets

Black holes: decay via Hawking radiation

signature: large number of decay products

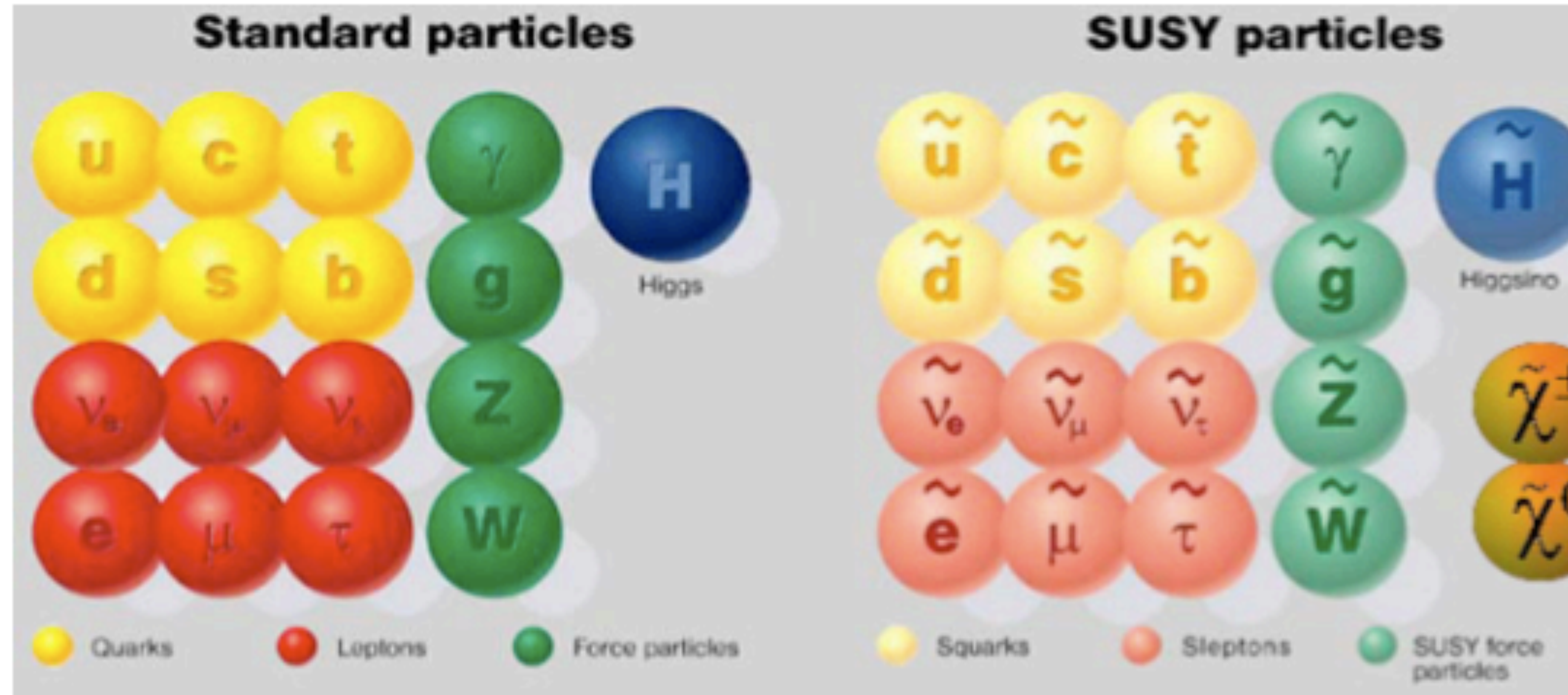
⇒ large transverse momentum sum



ATLAS: CERN-Open-2008-020

Supersymmetry

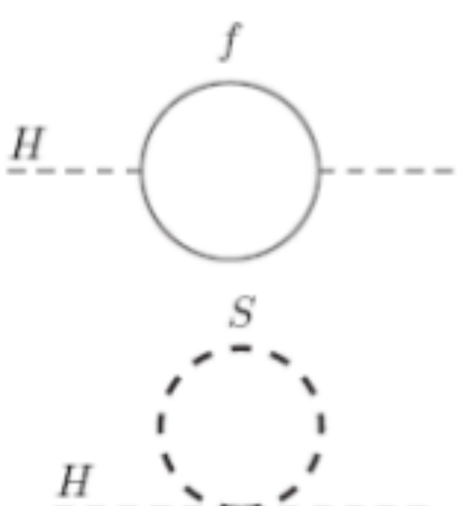
Proposes a new symmetry
Fermions ↔ Bosons



R-parity can be conserved or not!

$R_p = -1^{B+L+2s}$

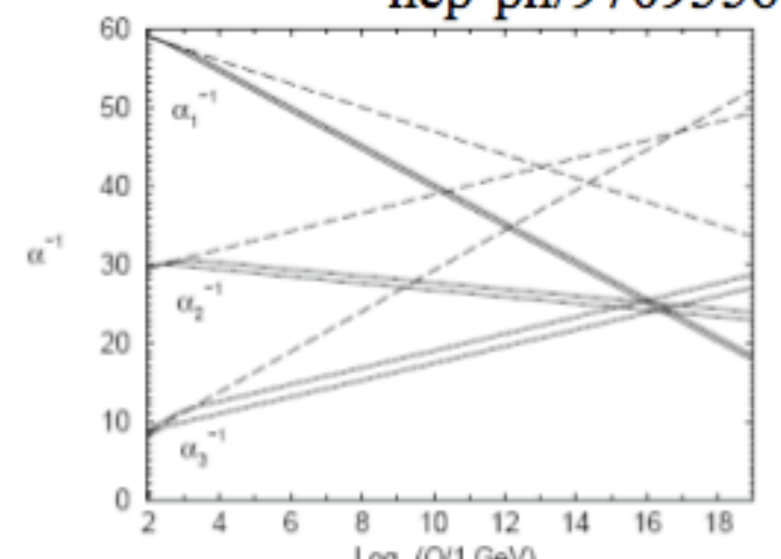
Solves the hierarchy problem



Possibly a dark matter candidate, if R_p conserved

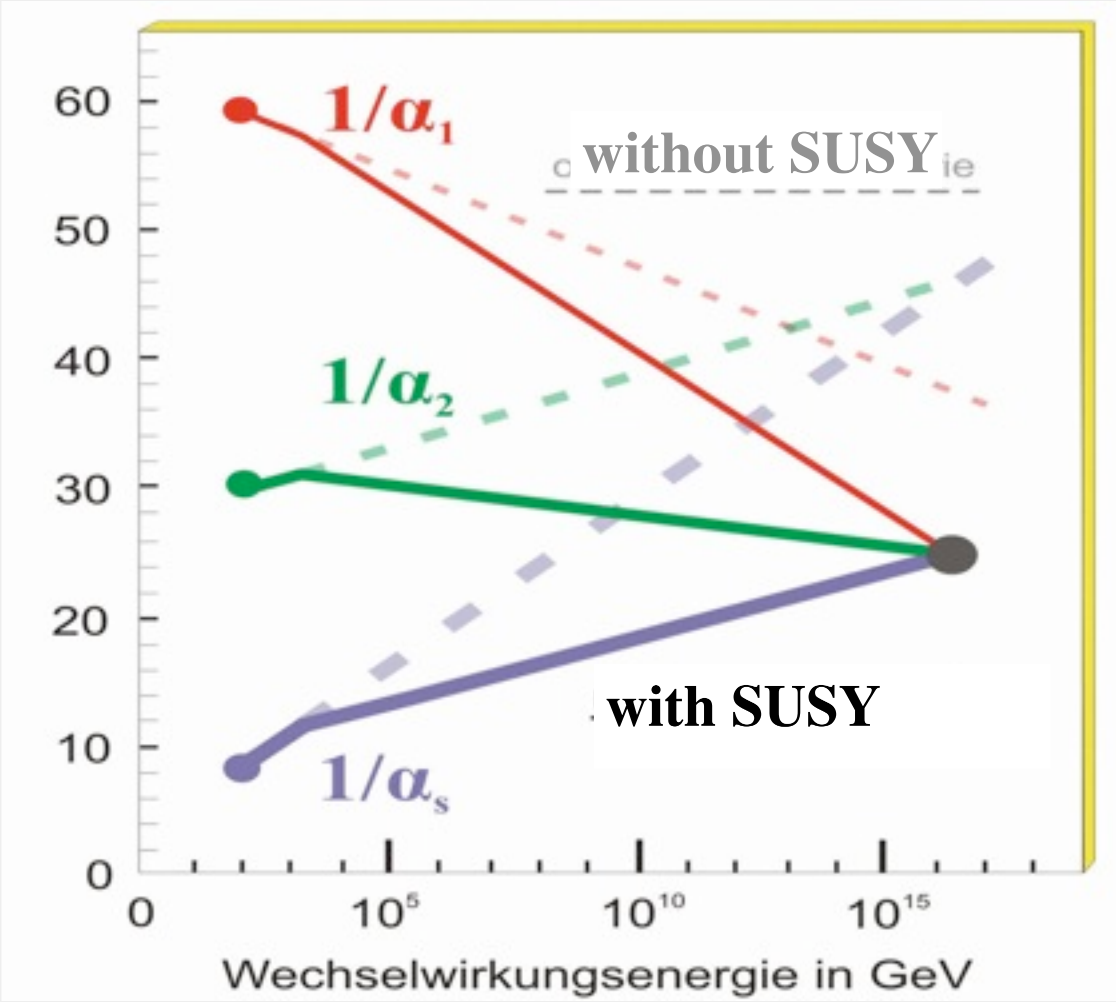
Unifies gauge couplings

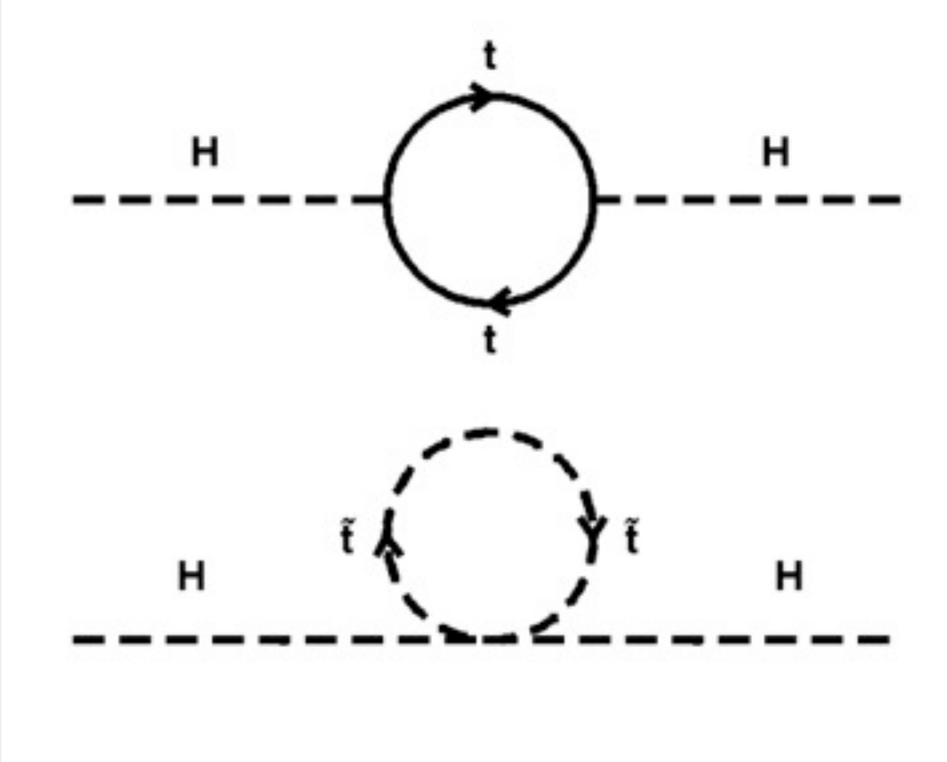
hep-ph/9709356



What's Nice about SUSY?

- Introduces symmetry between bosons and fermions
- Unifications of forces possible
  - SUSY changes runnning of couplings
- Dark matter candidate exists:
  - The lightest neutral gaugino
  - Consistent with cosmology data
- No fine-tuning required
  - Radiative corrections to Higgs acquire SUSY corrections
    - Cancellation of fermion and sfermion loops
- Also consistent with precision measurements of M_W and M_{top}
  - But may change relationship between M_W, M_{top} and M_H





SUSY signatures in CMS

Event topologies of SUSY:

- multiple jets, often energetic
- + possibly some lepton,
- + missing E_T
- multileptons + missing ET
- **Large missing energy**

- **2 LSPs**
- **Many neutrinos**

- **In a word**

Spectacular!

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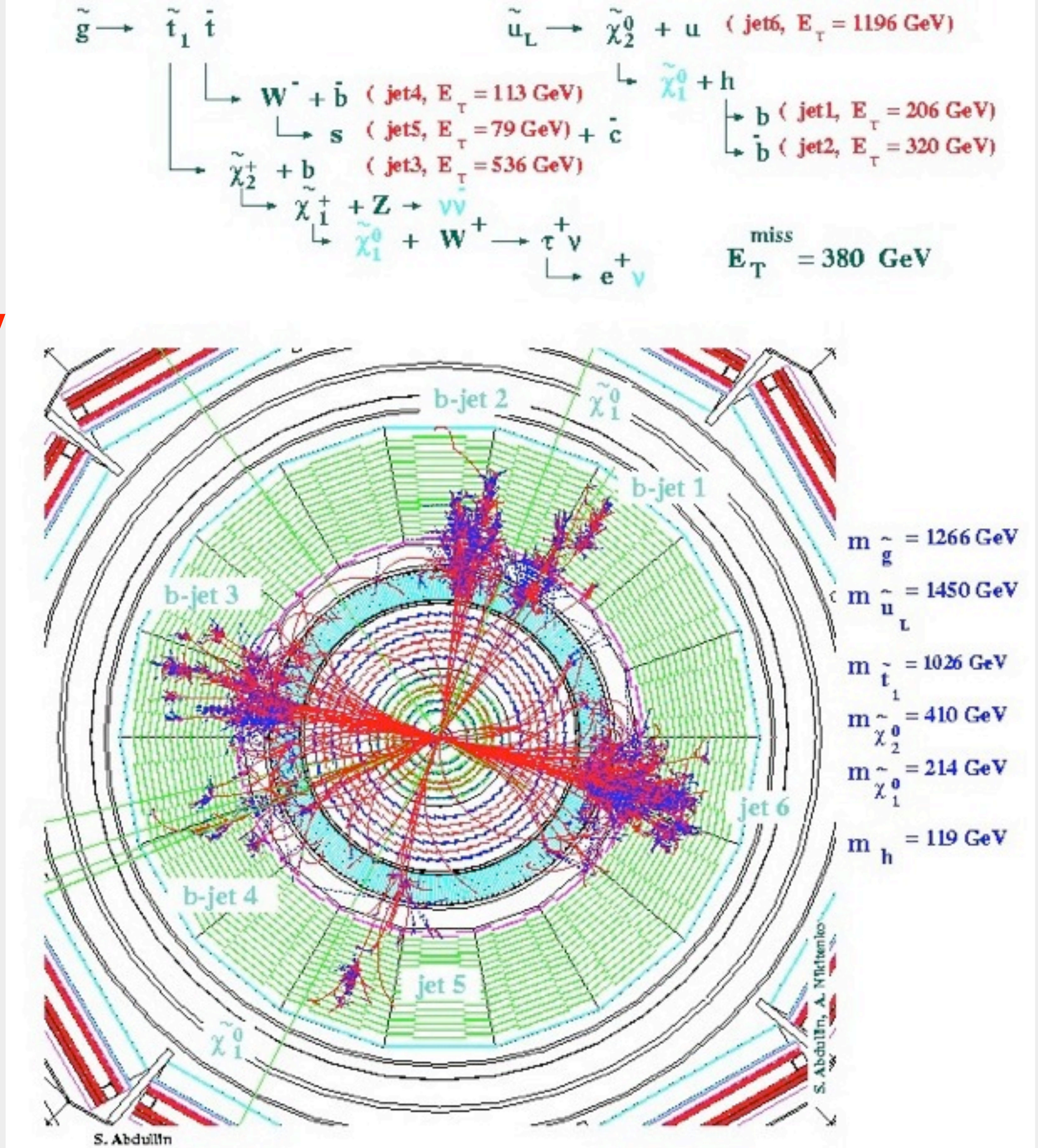
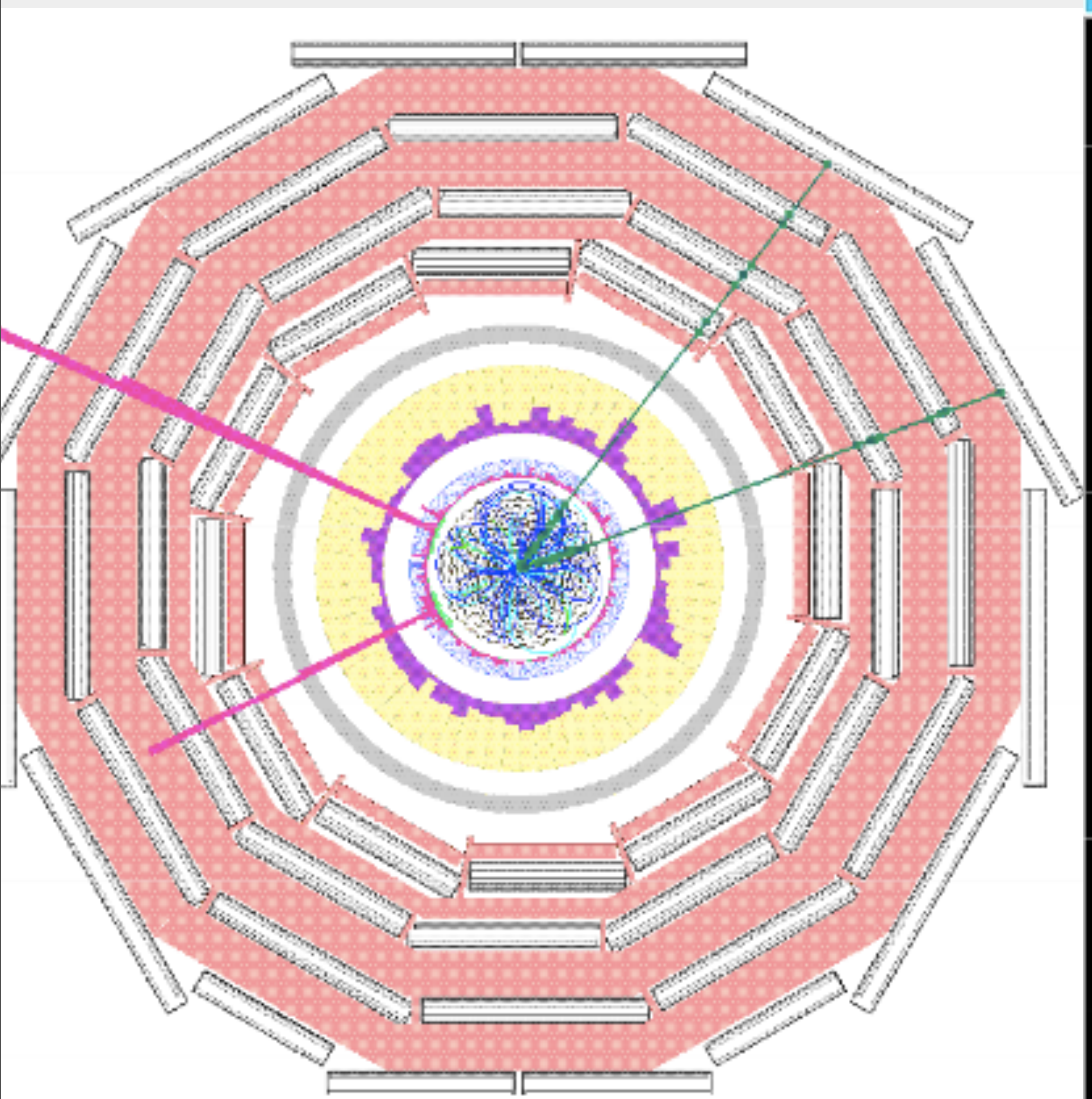


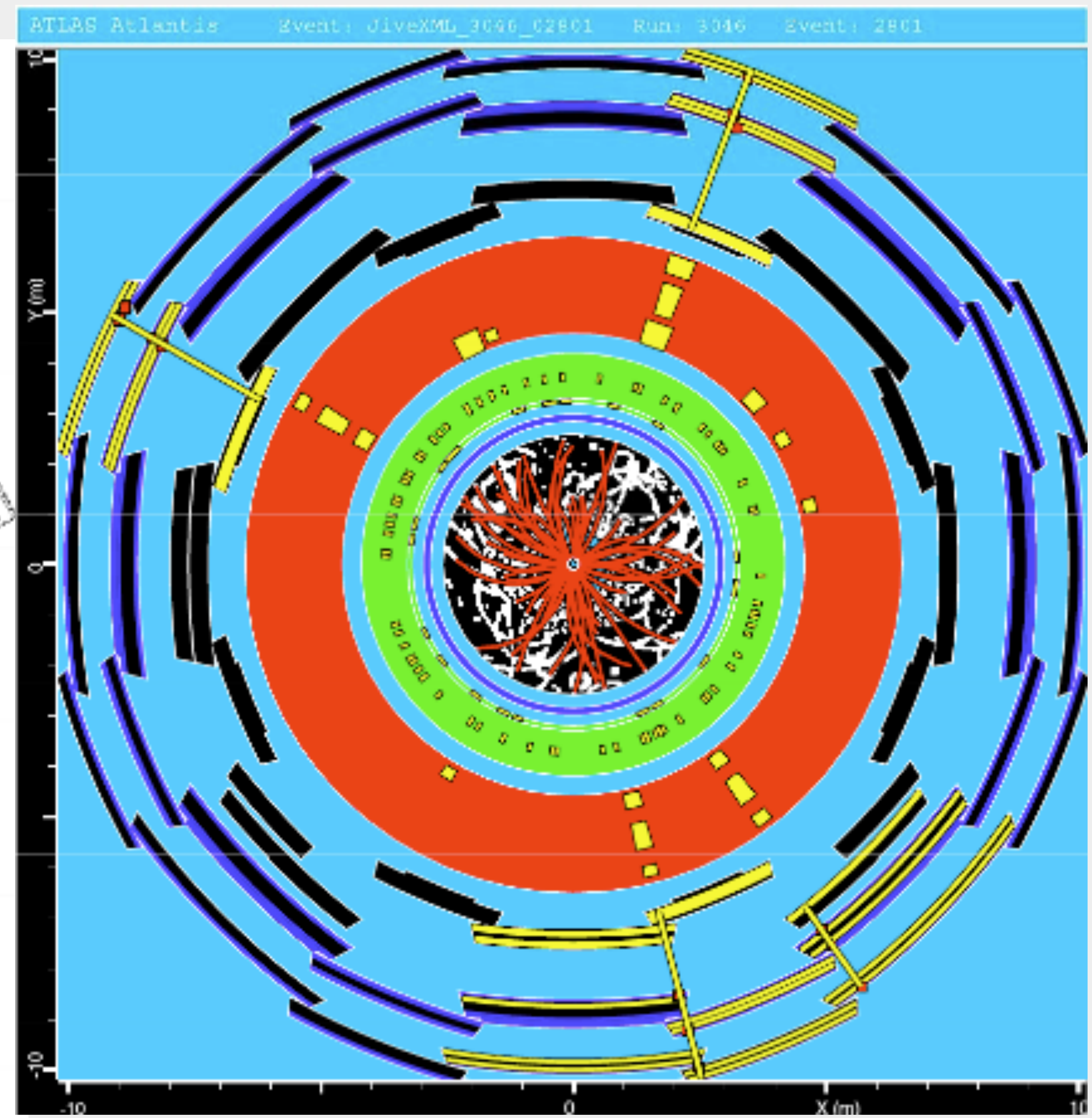
Higgs hunting

CMS



$H \to ZZ \to ee\mu\mu$

Atlas



$H \to ZZ \to 4\mu$

Origine of mass: the Higgs mechanism

- **In the basic theory => Particles are massless**
  - **One suppose that there exist in the Univers a specific Field**
  - **All particles interacting with that field are getting their mass. It's value is related to the strength of the interaction.**
  - **The quantum of that Field is the Higgs boson**
  - **The observation of the Higgs boson will establish the existence of the Field and so the origin of the particles mass.**
  - *Higgs mechanism has been proposed by Brout, Englert, Guralnik, Hagen, Higgs, Kibble (1964)*

Higgs mass: theoretical constraints

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- Problem: Higgs mass is free parameter

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  - Unitarity (no probabilities > 1)

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- Triviality
(Higgs self coupling remains finite)

Higgs mass: theoretical constraints

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$$M_H^2 = 2\lambda v^2 \quad \ldots\ldots \quad v = 246\ \text{GeV}$$

- Theoretical constraints
- Unitarity (no probabilities > 1)

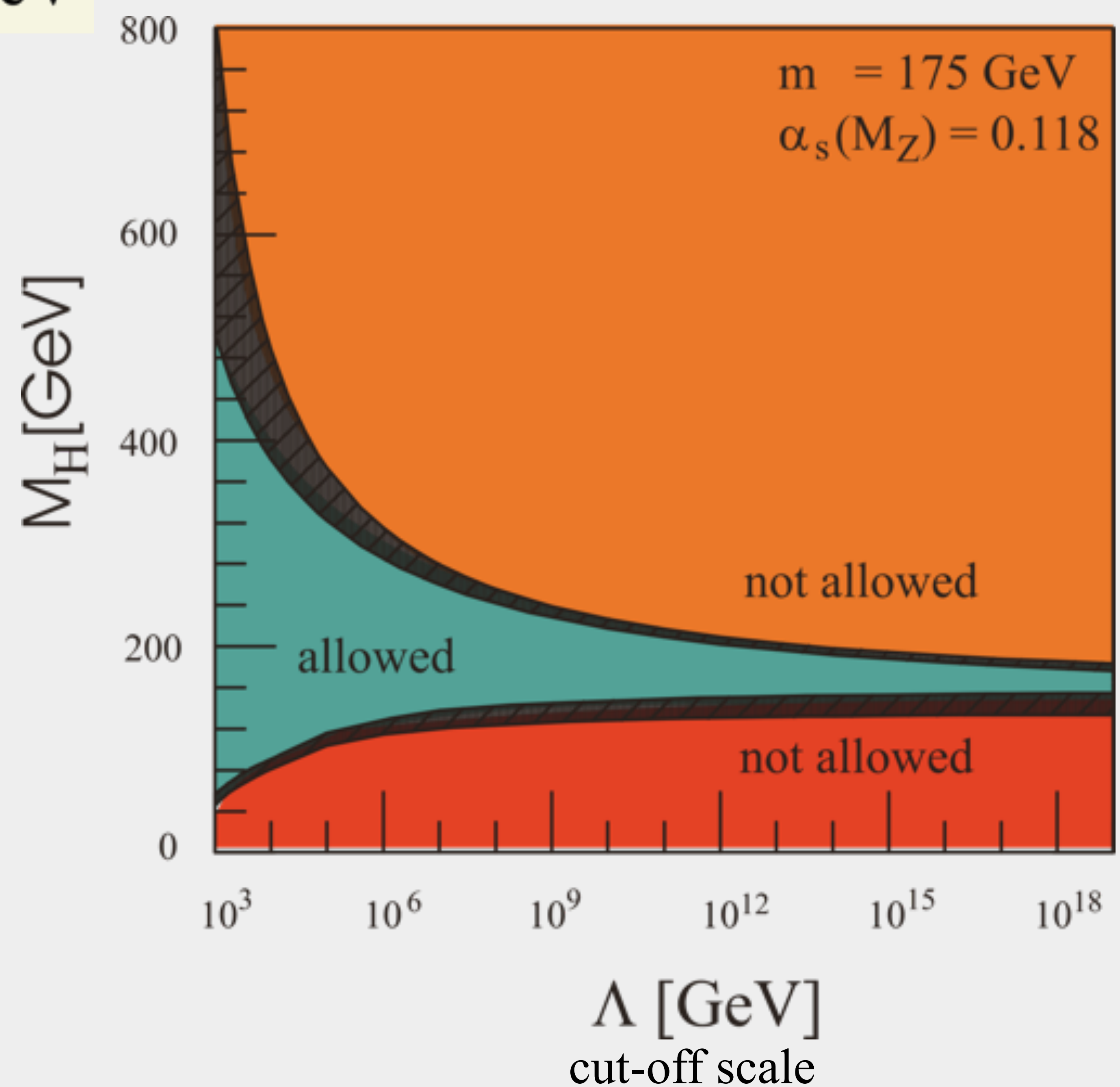
$$M_H < 700 - 800\ \text{GeV}$$

- Triviality
(Higgs self coupling remains finite)

$$M_H^2 < \frac{4\pi v^2}{3\ln(\Lambda/v)}$$

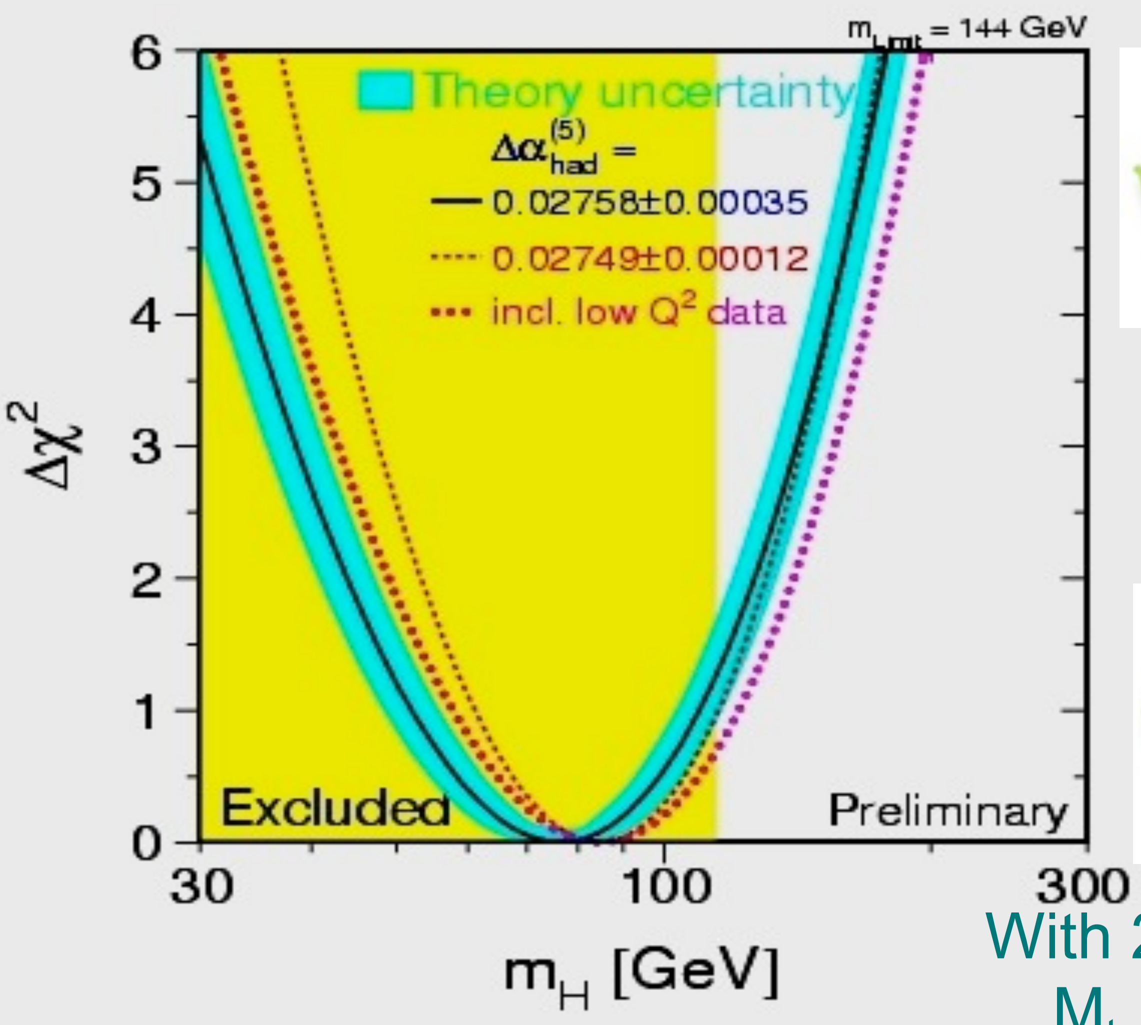
- Stability (of vacuum)

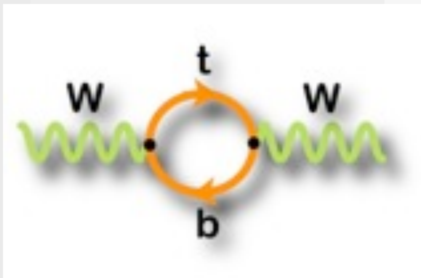
$$M_H^2 > \frac{4m_Z^4}{\pi^2 v^2}\ln(\Lambda/v)$$

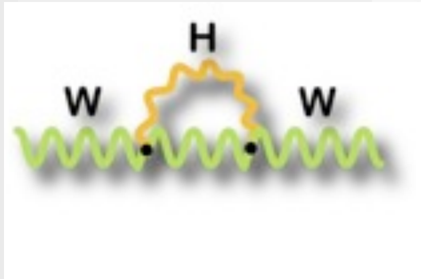


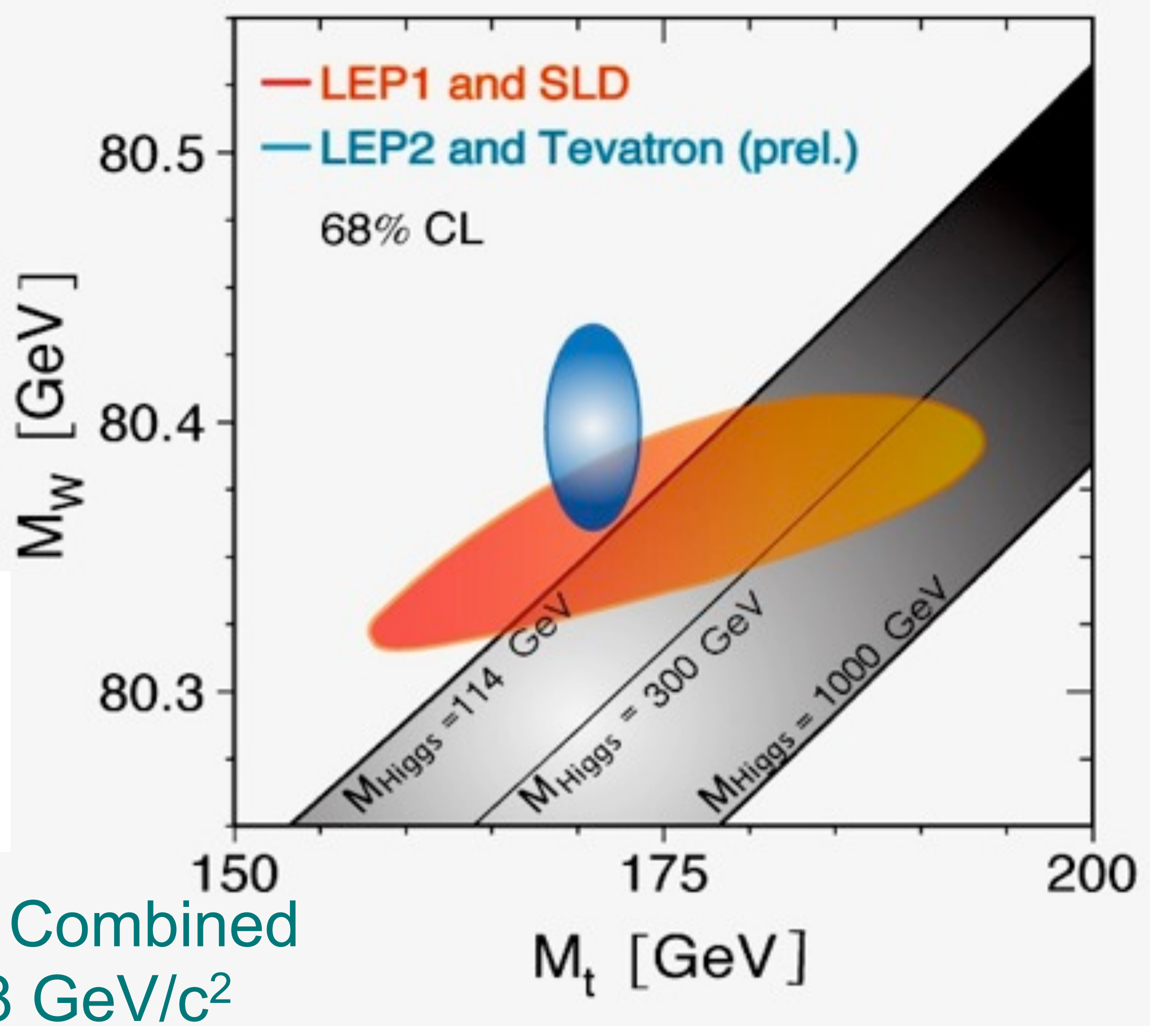
Low Mass Preferred !

- Direct search @ LEP excludes $M_H<114.4$ GeV @ 95% C.L.
- SM global fit gives the first indication on where to look !







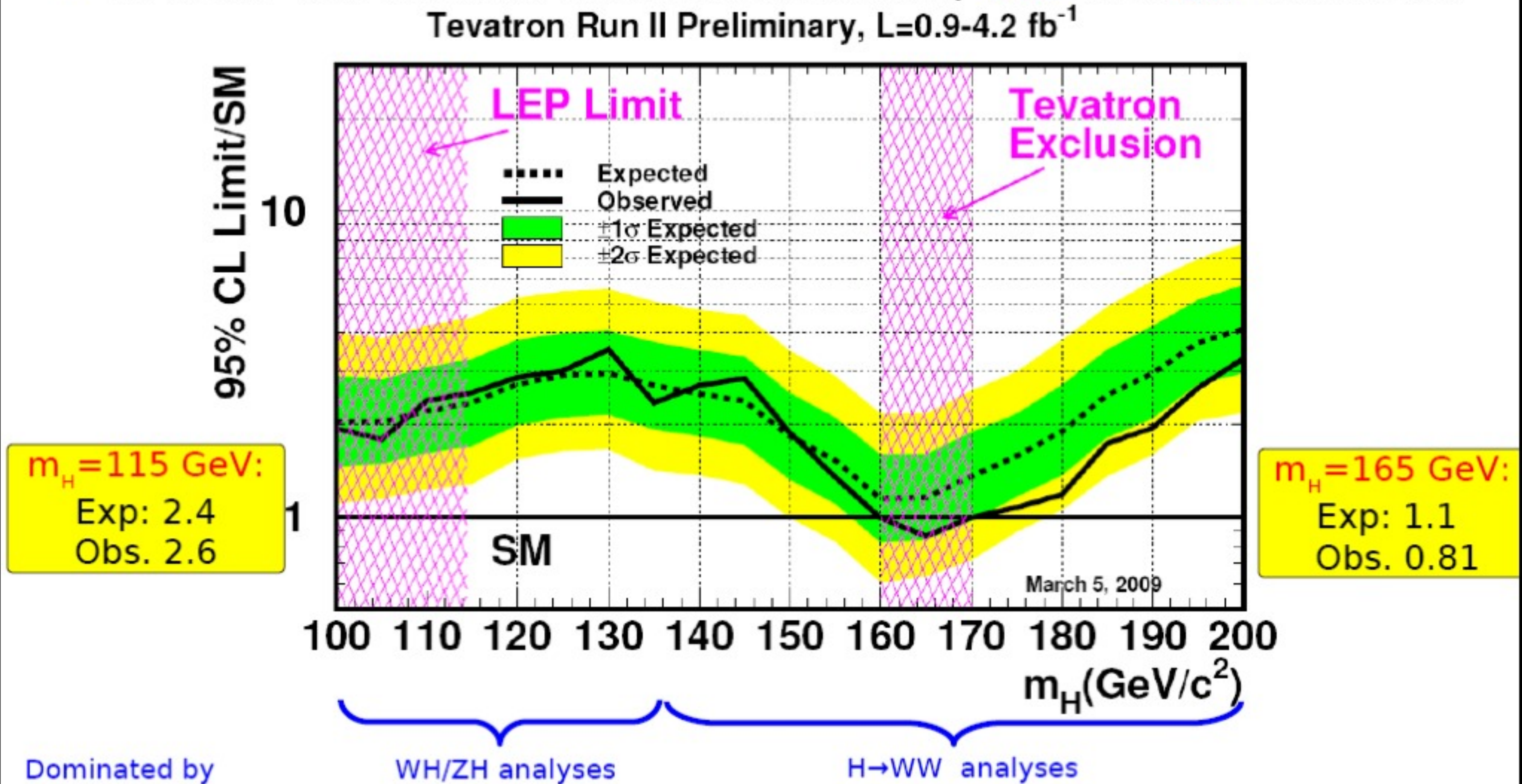


With 2007 Tevatron Combined
M_{top} = 170.9 ± 1.8 GeV/c²

- The most probable value from SM global fit : $76\,^{+33}_{-24}$ GeV
  Upper bound (95% C.L) : <144 GeV (182 GeV if LEP limit included)

Recent results from Tevatron

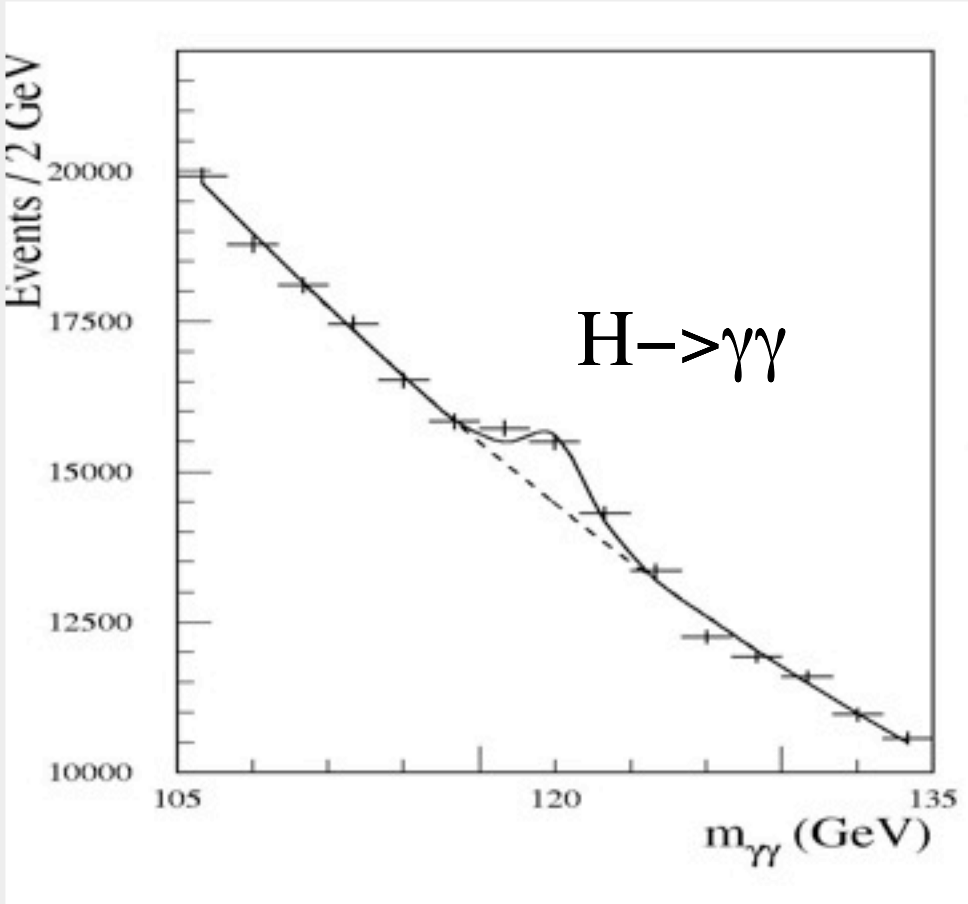
- In order two achieve maximal sensitivity CDF and DØ combined



- Excluding significant region, rapidly adding more Data

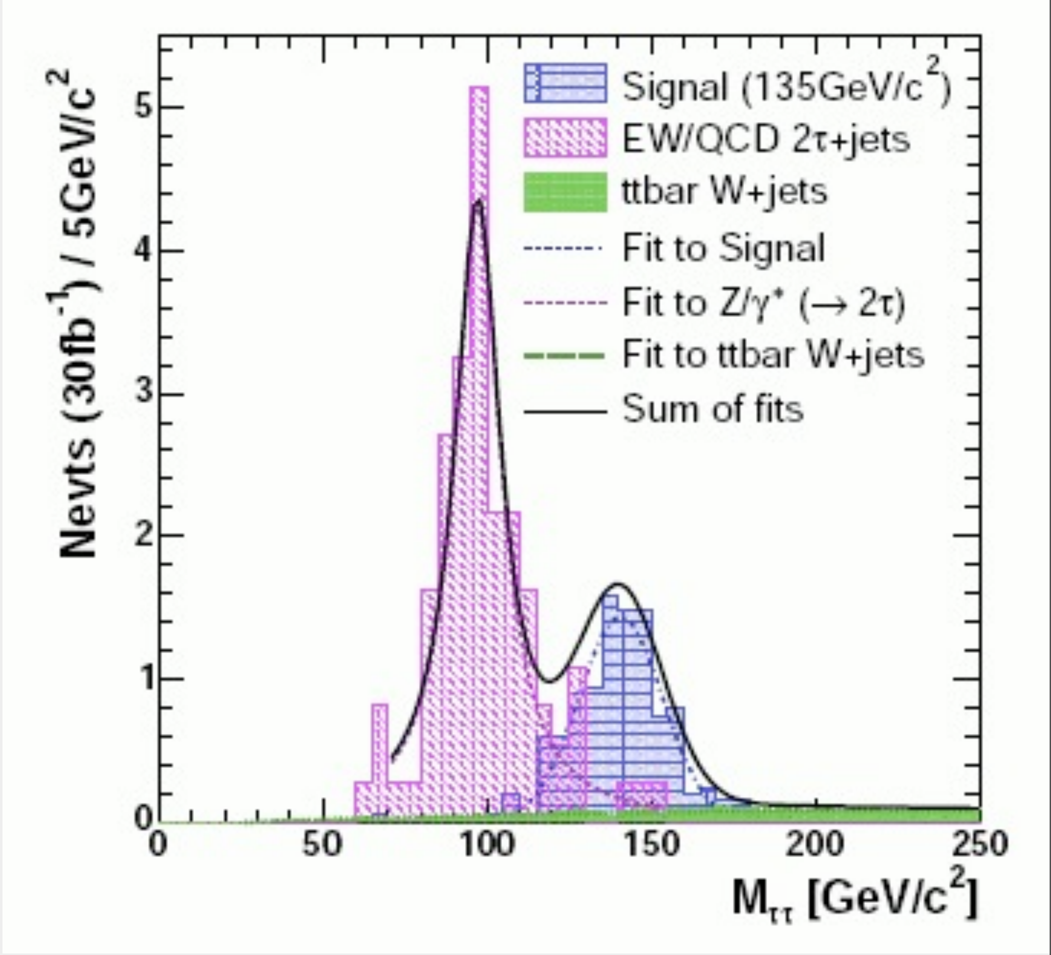
Low Mass Higgs Signals at LHC

ATLAS, 100 fb^{-1}



VBF H–>ττ

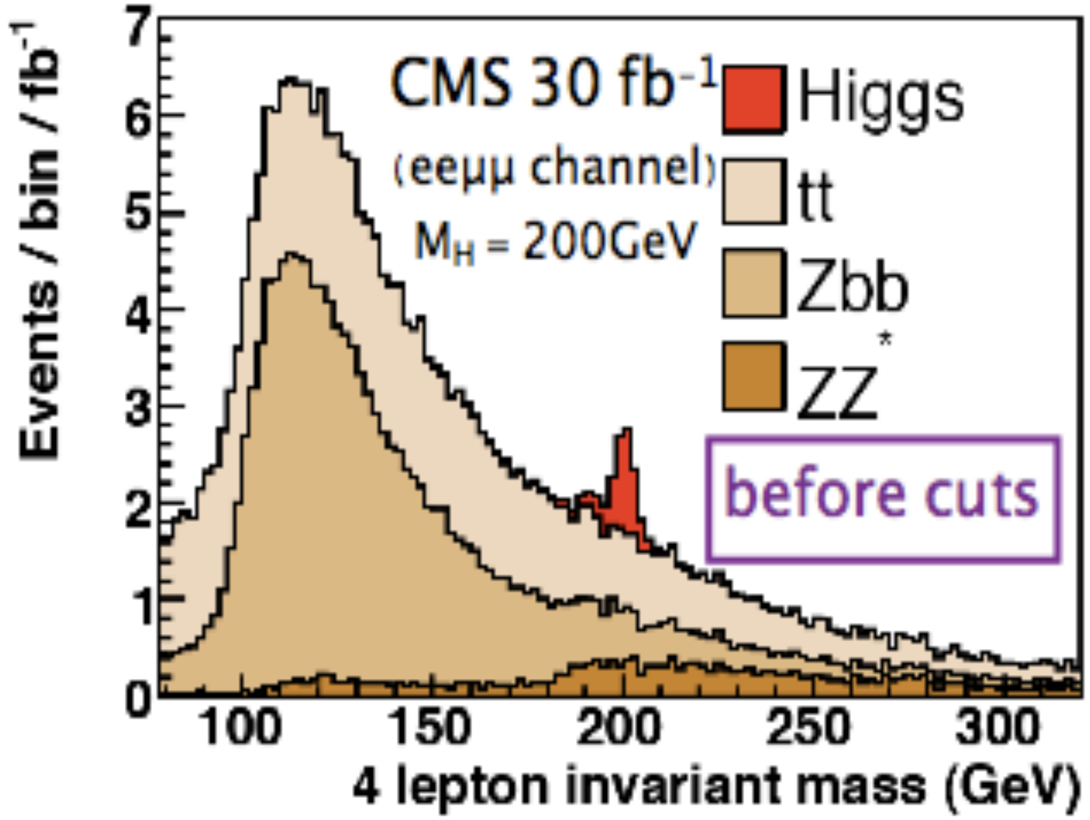
CMS, 30 fb^{-1}

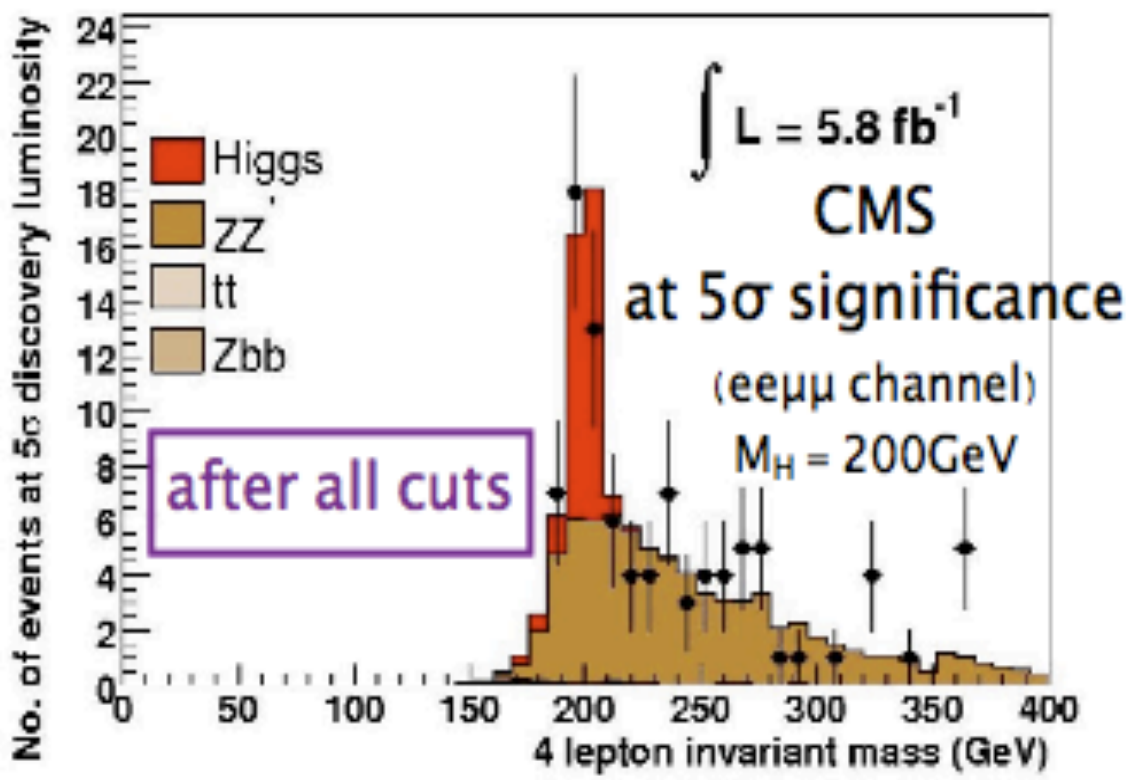


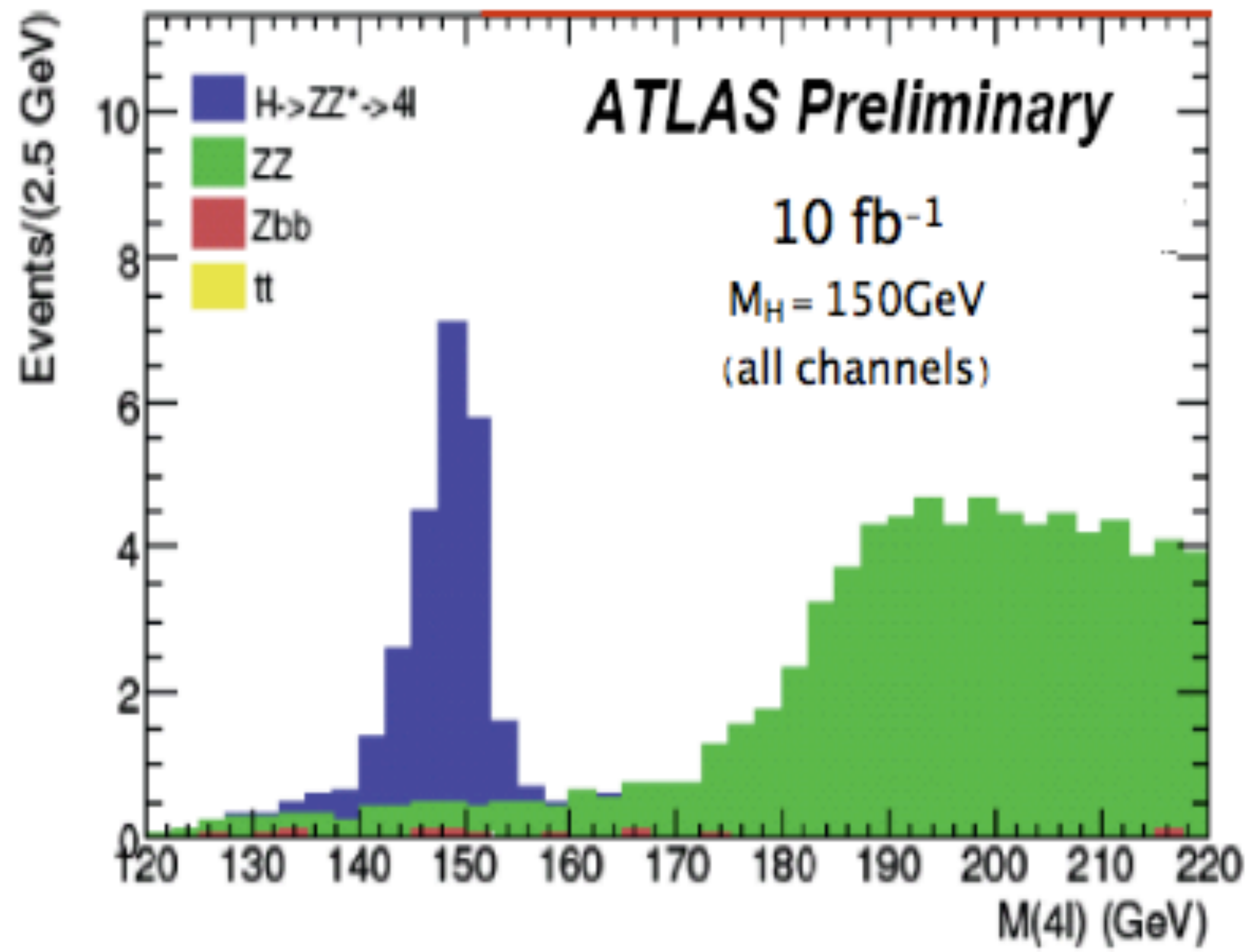
- Main observation channels:
- H–>γγ
- qqH–>qqττ
- ttH–>ttbb
- Total S/√B=4.2
- m_H=115 GeV/c^2

	H–>γγ	ttH–>ttbb	qqH–>qq ττ
S (115)	150	15	10
B	3900	45	10
S/√B	2.4	2.2	2.7

H → ZZ → 4 leptons



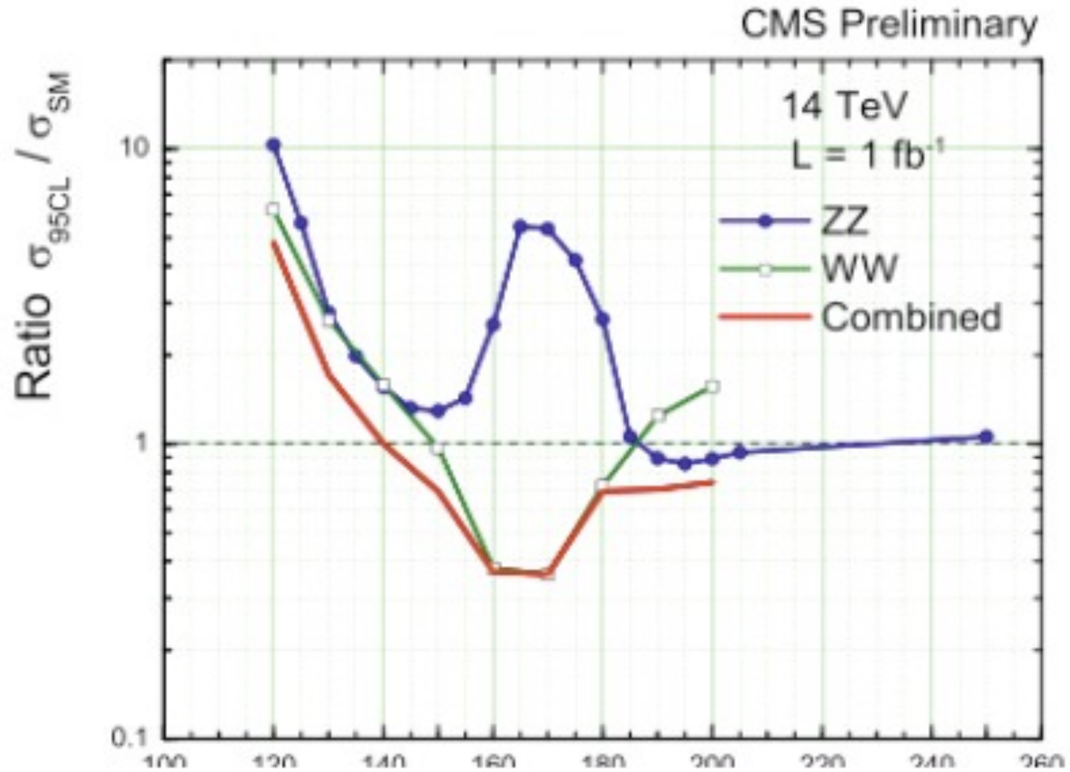




Background negligible
after all selections
except for ZZ

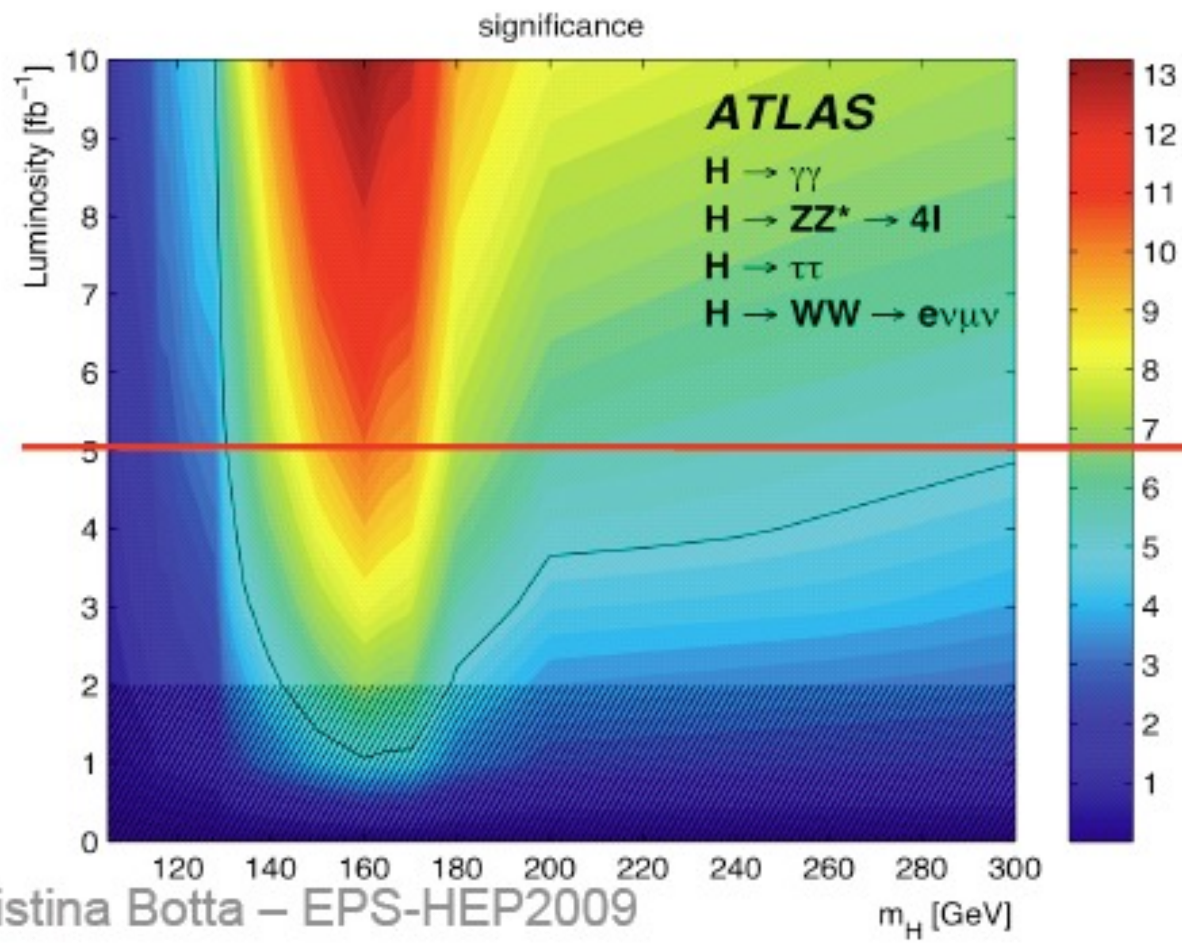
53

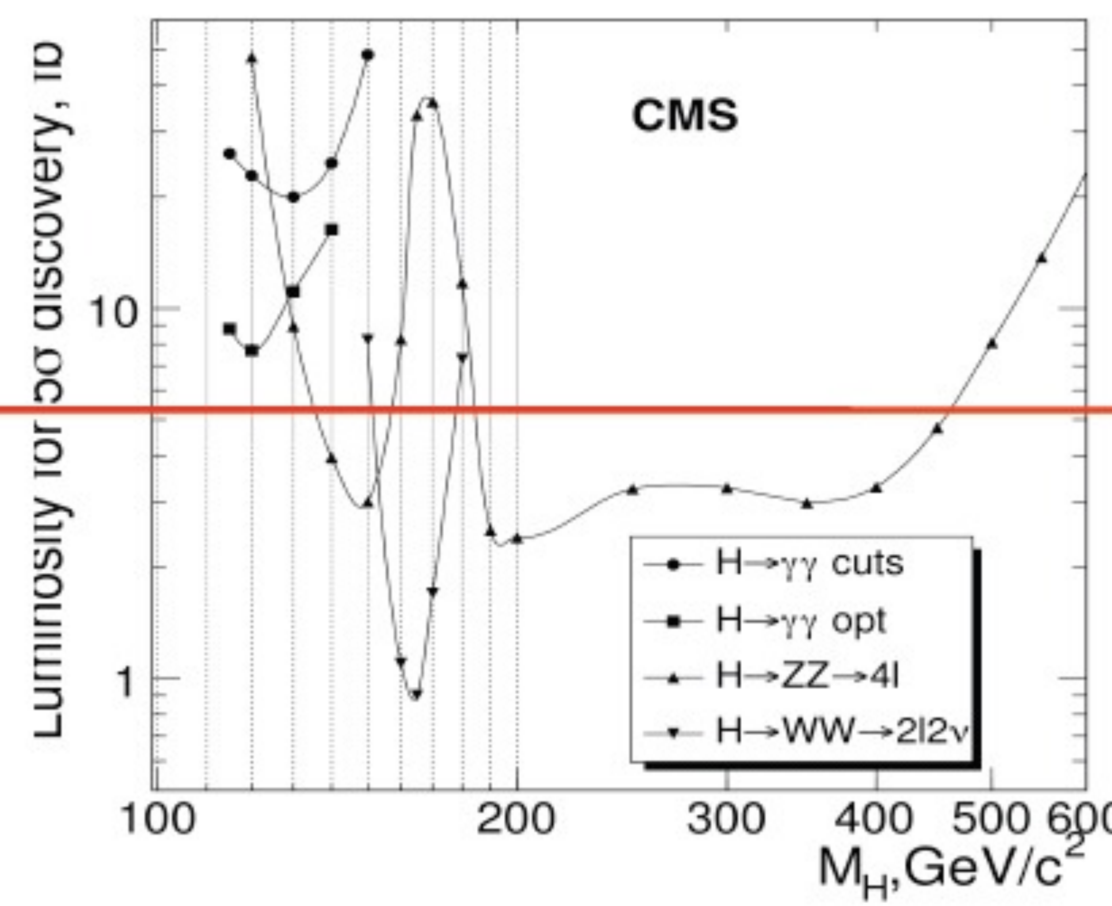
Combining channels



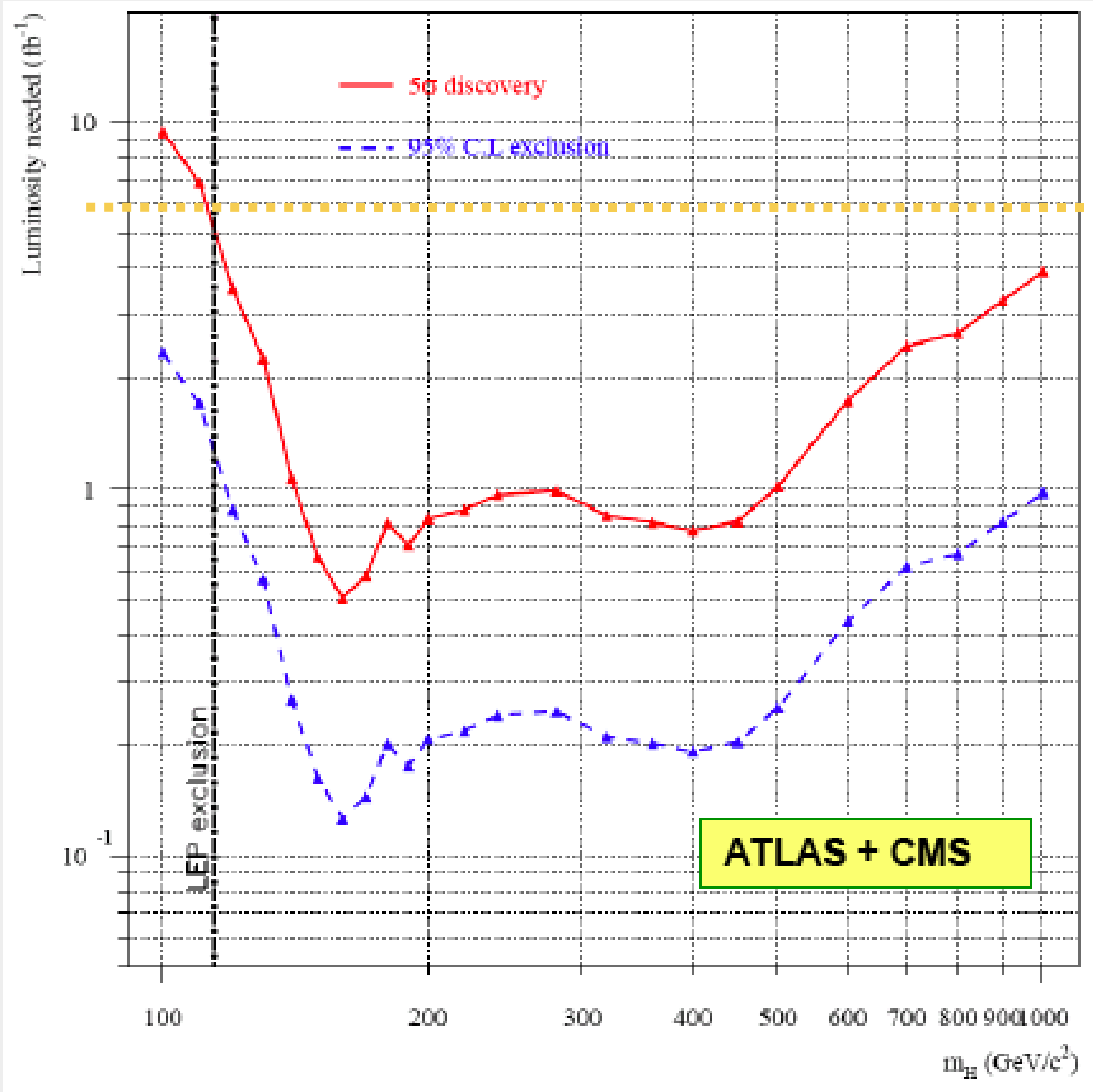
- The statistical combination of the results of the CMS analyses (HZZ, HWW) @ 1fb^{-1} shows that a SM Higgs in the mass range 140-230 GeV can be excluded

- The ATLAS and CMS combination of all the main analysis results shows that with 5fb^{-1} a High Mass Higgs 140-450 GeV can be discovered with 5σ significance





Ultimate sensitivity



$\int L dt = 6\ fb^{-1}$

- **With 6 fb^{-1} of LHC data will know if Higgs boson exists**
  - **in 2-4 years already (hopefully)!**

Conclusions

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- **If indeed new physics is at the TeV-scale, CMS (and ATLAS) should find it.**
- The early phase of data taking will be crucial
  - ***Determine the efficiency of L1 triggers***
  - ***Understand the HLT trigger***
  - ***Improve our understanding of the SM processes***
  - ***Search for new physics***

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- **There are open windows into BSM**
- **The list presented here is not complete, many other subjects will be studied**
- **But essential: put everything in place to get reliable results quickly when more luminosity will be available.**

Finally…

if you want to learn more

look between others to Beate Heinemanne lectures

http://www-atlas.lbl.gov/~heinemann/homepage/publictalk.html