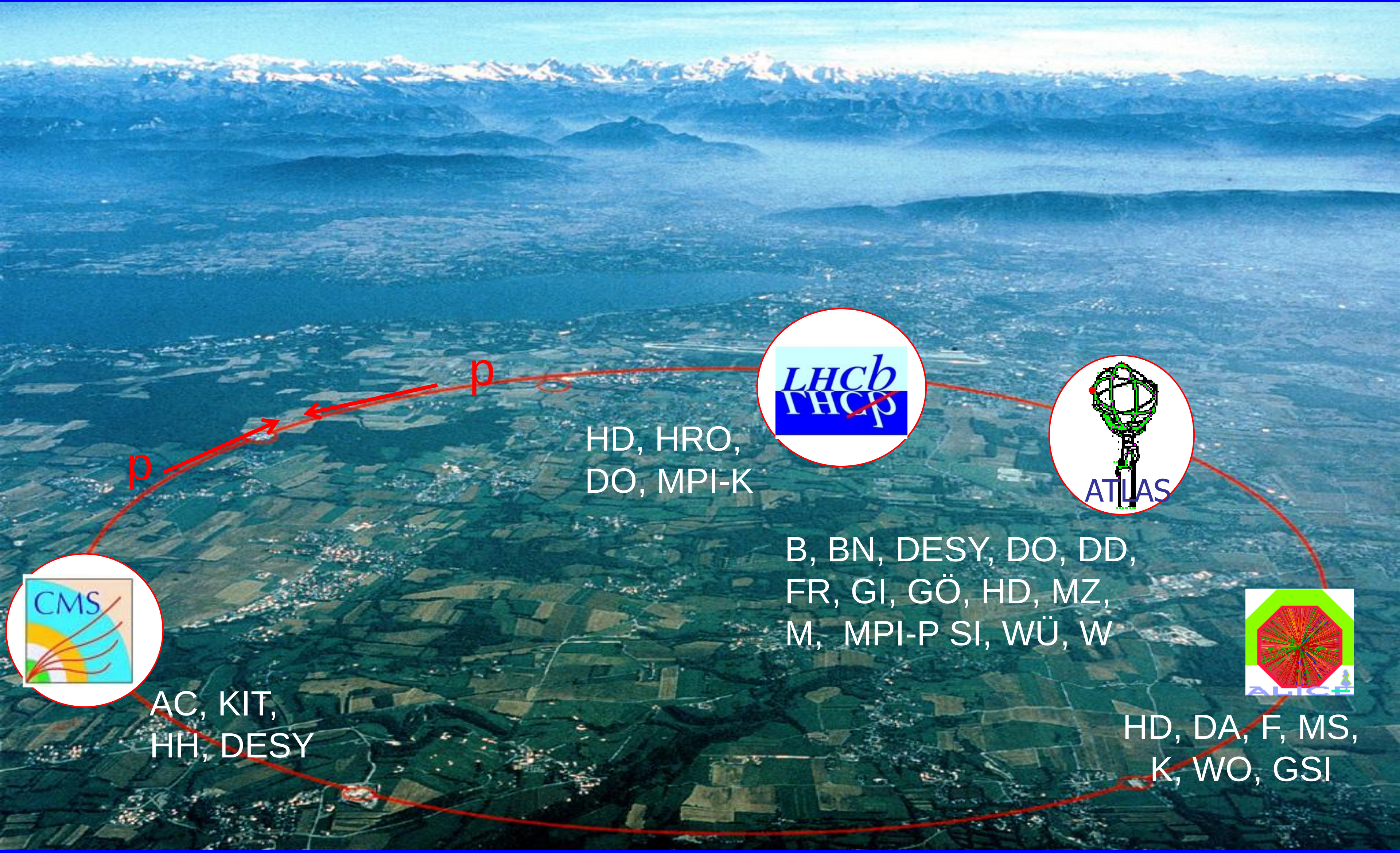
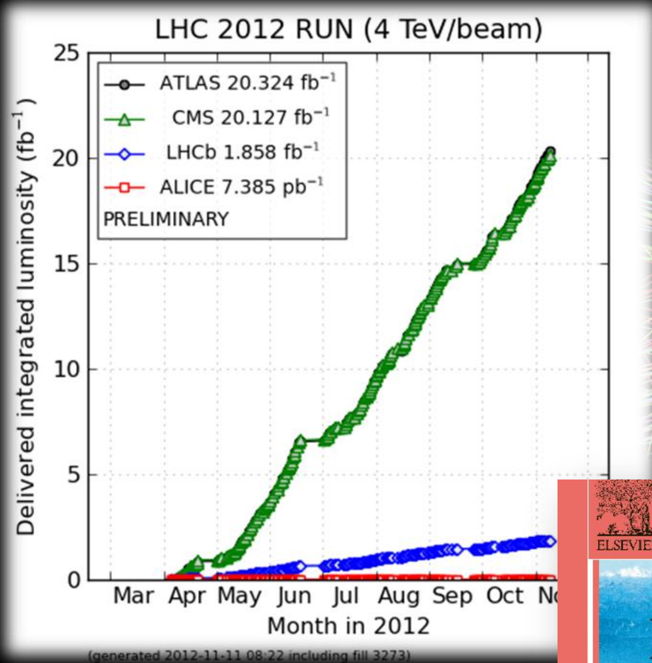
LHC Performance and Results



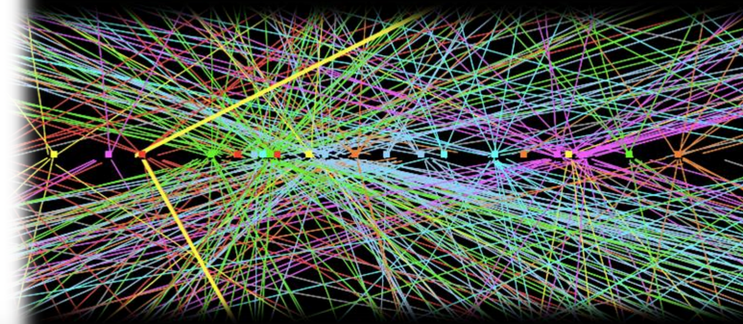
Ulrich Uwer • Physikalisches Institut • Universität Heidelberg

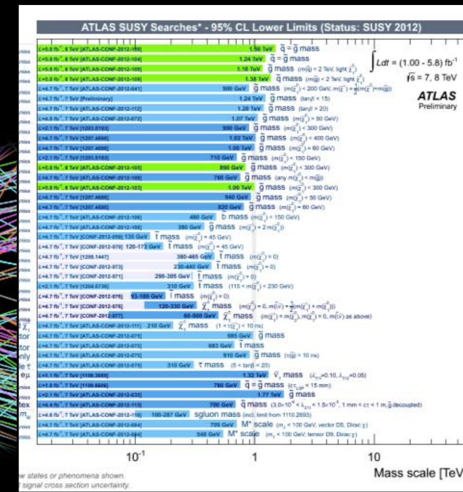
LHC produced fireworks of data

Outline

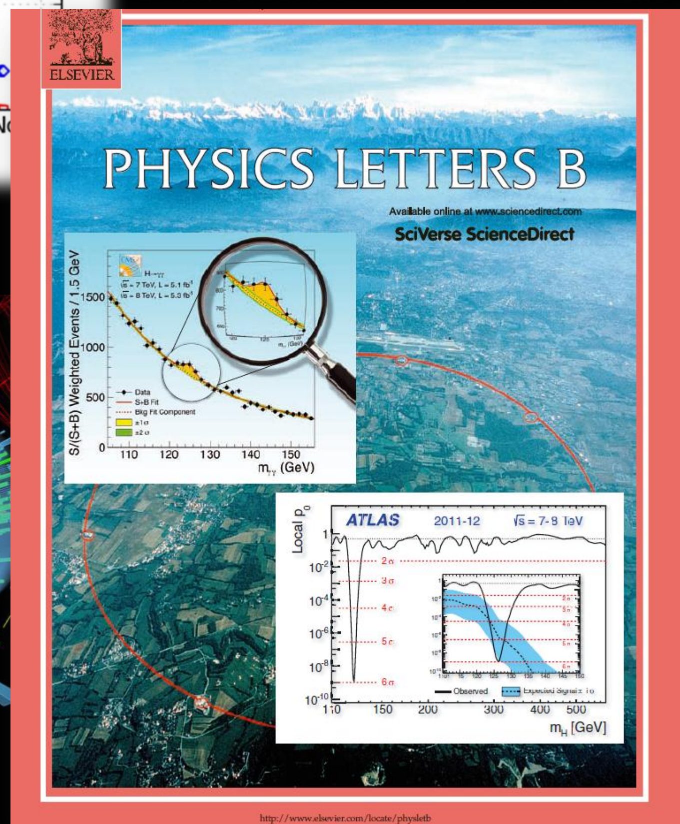


LHC 2012 RUN (4 TeV/beam)
ATLAS 20.324 fb^{-1}
CMS 20.127 fb^{-1}
LHCb 1.858 fb^{-1}
ALICE 7.385 pb^{-1}
PRELIMINARY
Delivered integrated luminosity (fb^{-1})
Mar Apr May Jun Jul Aug Sep Oct No
Month in 2012
(generated 2012-11-11 08:22 including fill 3273)

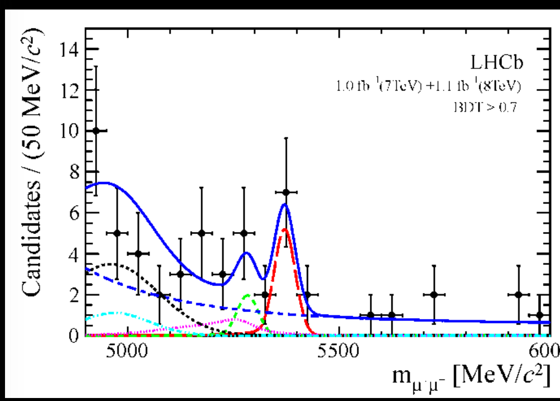




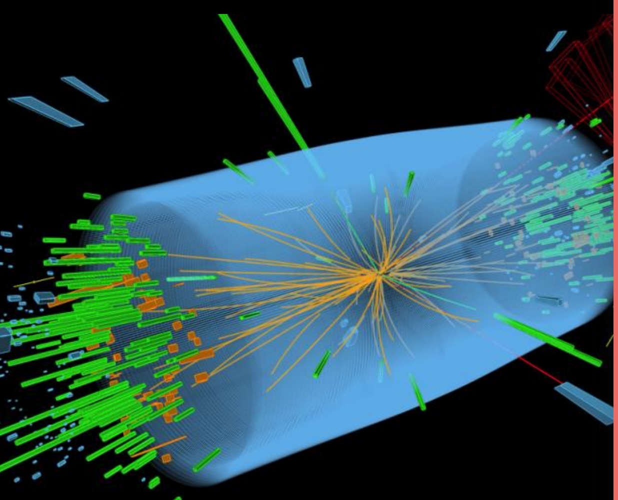
ATLAS SUSY Searches* - 95% CL Lower Limits (Status: SUSY 2012)
ATLAS
Preliminary
Mass scale [TeV]



ELSEVIER
PHYSICS LETTERS B
Available online at www.sciencedirect.com
SciVerse ScienceDirect
S/(S+B) Weighted Events / 1.5 GeV
$m_{\gamma\gamma}$ (GeV)
ATLAS
2011-12
$\sqrt{s}$ = 7-8 TeV
Local p_0
m_H [GeV]
http://www.elsevier.com/locate/physletb



LHCb
1.0 fb^{-1}(7 TeV) +1.1 fb^{-1}(8 TeV)
BDT > 0.7
Candidates / (50 MeV/c^2)
$m_{\mu^+\mu^-}$ [MeV/c^2]

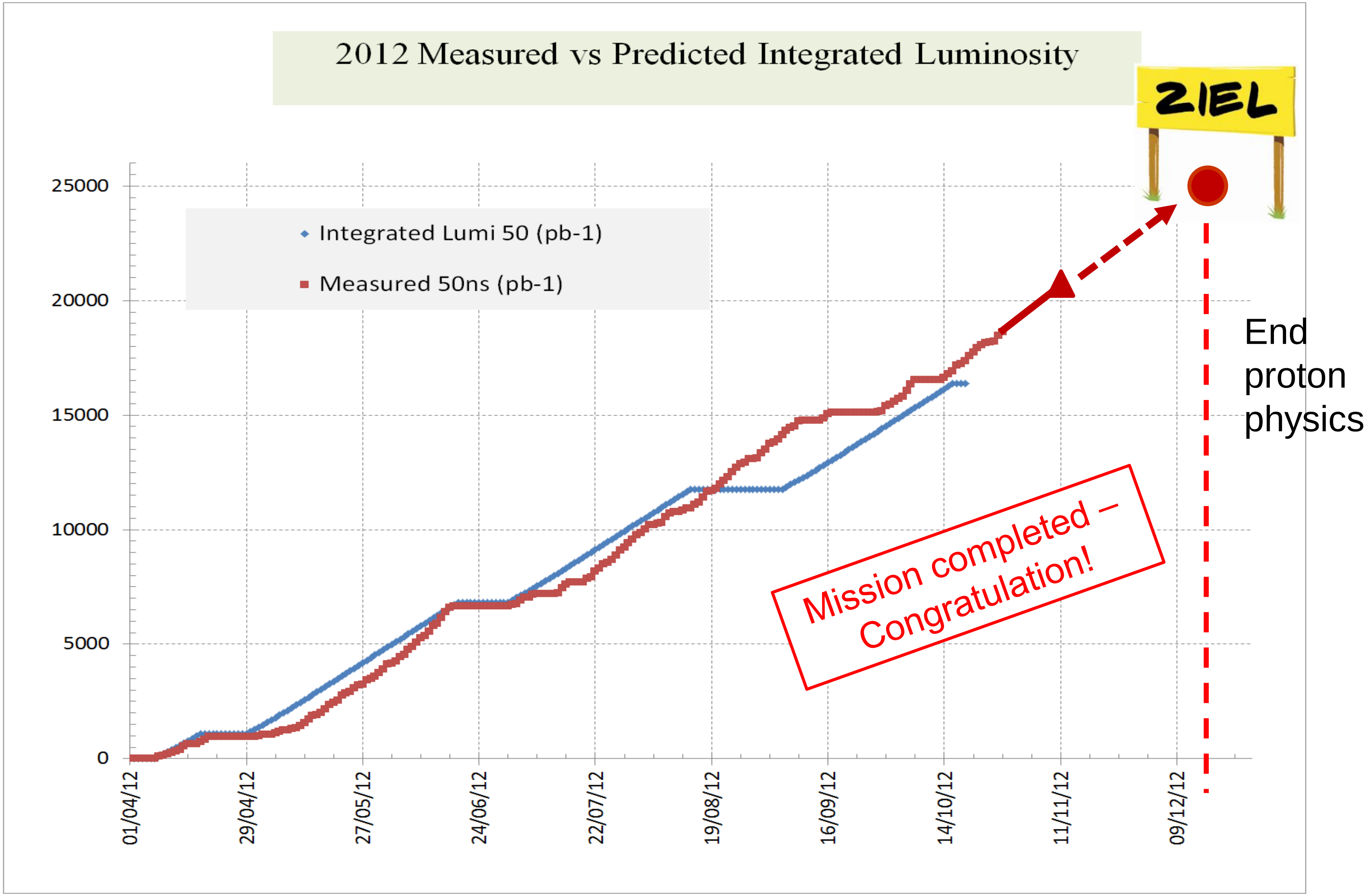


LHC priorities for 2012:

- enough lumi (~15/fb) to discover Higgs
- machine experiments to run after LS1
- Prepare for p-Pb running

Luminosity Production

S.Meyers, CERN Oct RRB



Key to high luminosity

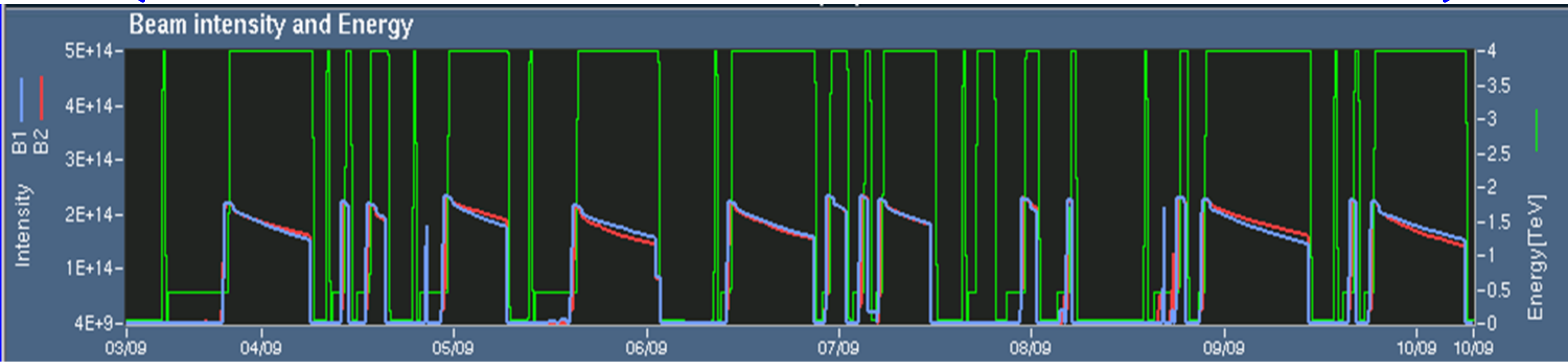
- **Current:** PS at limit of beam stability, injecting ~1.9×10^{11} ppb
  In LHC: beam instabilities, beam induced heating.
- **Reduction of β*** ↔ tighter collimator settings
  (Effective aperture reduced from 14 to 10.5σ . Operation tricky…).

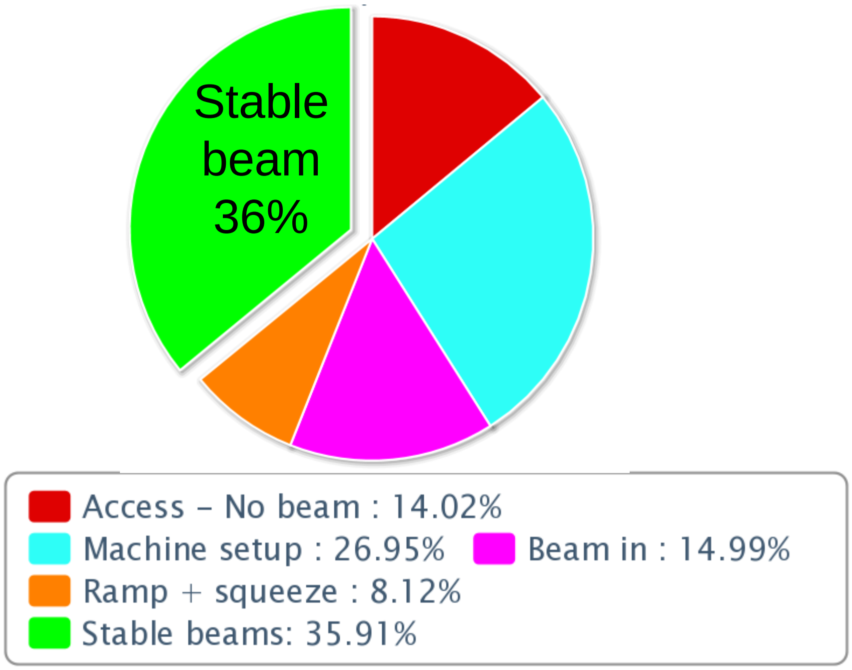
Parameter	2010	2011	2012	Nominal
N (10^{11} p/bunch)	**1.2**	**1.45**	**1.58**	1.15
No. bunches	368	1380	1380	2808
Bunch spacing ns	150	75 / 50	50	25
ε (μm rad)	**2.4-4**	**1.9-2.4**	**2.2-2.5**	3.75
β* (m)	3.5	1.5 → 1	0.6	0.55
L ($cm^{-2}s^{-1}$)	**2×10^{32}**	**3.5×10^{33}**	**7.7×10^{33}**	10^{34}

Beam intensity = 1.6× design value at 4 TeV.

LHC Operation

Week 36: 3rd to 10th Sept; Delivered luminosity 1.02 fb^{-1} (max. 1.35 fb^{-1})





Down-time:

- Cryogenics/compressors
- Beam instrumentation, BLMs, QPS
- PS problems

Operation problems:

- Beam induced heating (BSRT, MIK)
- UFOs
- **Losses due to beam tails**
- **Beam instabilities (emittance blow-up)**

➡ Beam losses at squeeze & adjust

LHC Shutdown Work

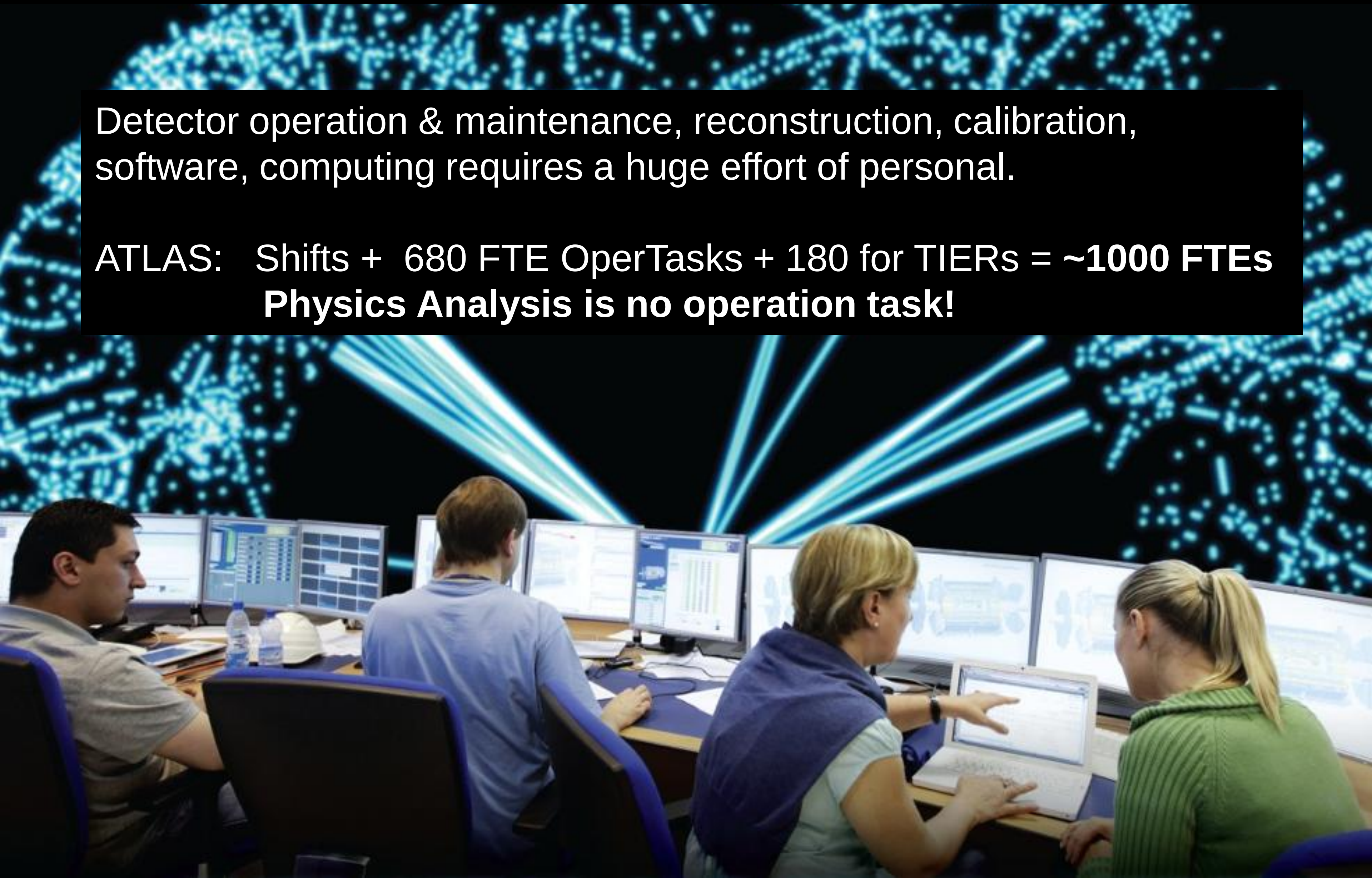
Prepare machine for high-energy (>13 TeV).

- Repair non-conform interconnects.
  - *10-15 % of interconnections to be opened and to be re-welded.*
- Consolidate **ALL** interconnects with new design.
  - *10'170 interconnects*.
- Finish pressure release valves DN200.
  - *4 sectors: 2-3, 4-5, 7-8, 8-1*
- Repair He leaks.
- Radiation to electronics mitigation.

Detector Operation

Detector operation & maintenance, reconstruction, calibration, software, computing requires a huge effort of personal.

ATLAS: Shifts + 680 FTE OperTasks + 180 for TIERs = **~1000 FTEs**
Physics Analysis is no operation task!



German Participation

~780 Physicists

	PhD	PhD Students	at CERN
ATLAS	308	212	ca. 40
CMS	123	91	ca. 20
LHCb	17	27	7

In addition:
Undergrad students, engineers, technicians

Most important German functions

ATLAS

Deputy CB-Chair: G. Herten (FR)

Computing Coordinator: H. v. d. Schmitt (MPI)
Run Coordinator: S. Zimmermann (FR)

Physics convenors
S. Glazov (DESY) - Standard Model
T. Kuhl (DESY) - Monte Carlo
M. Cristinziani (BN) - Top } until
S. Kortner (MPI) - Higgs } 10/2012

CMS

Deputy CB-Chair: M. Kasemann (DESY)

Tracker Coordinator: H. Hartmann (KIT)
Deputy TechCoord.: W.Zeuner

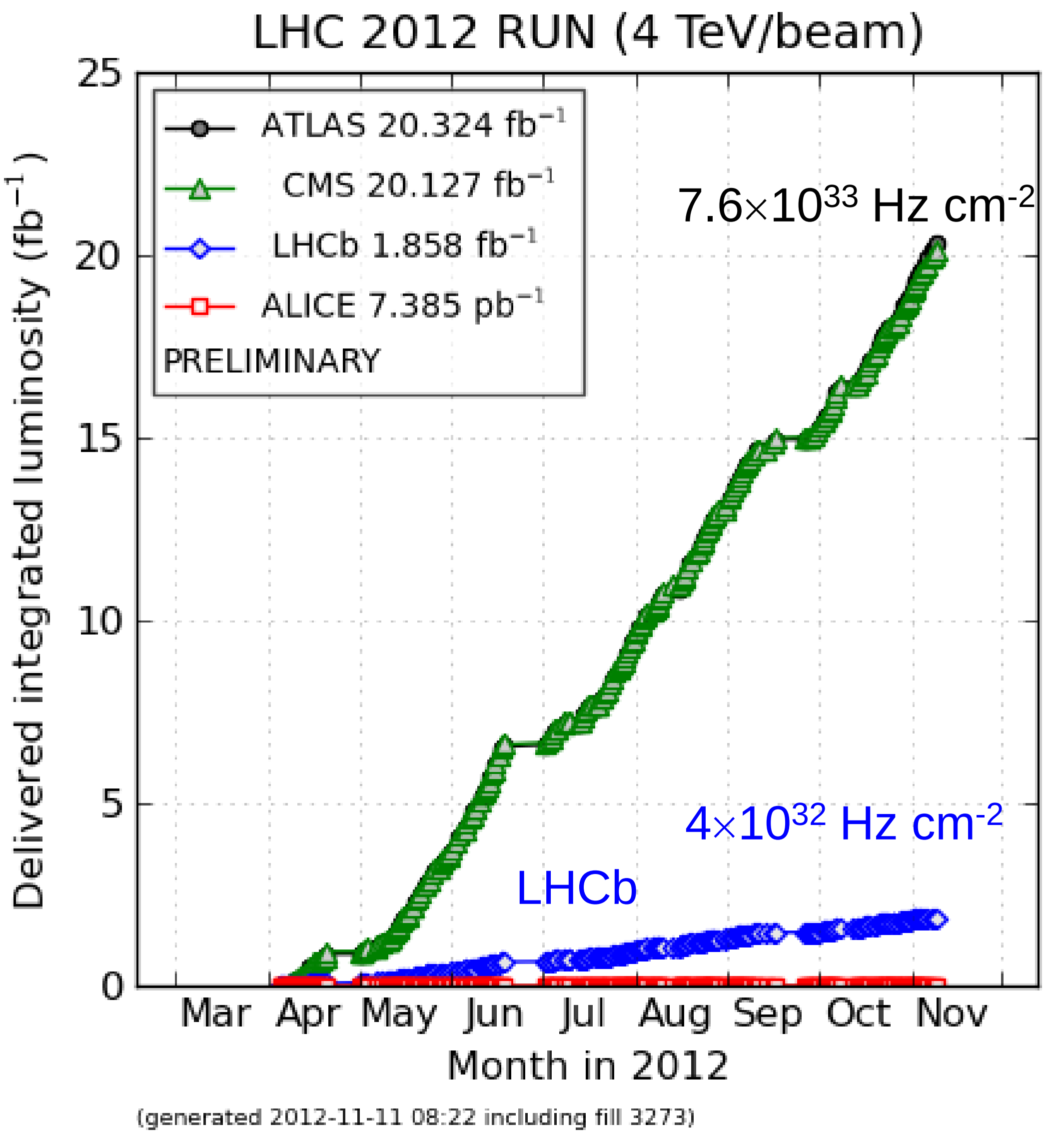
LHCb

CB-Chair: B.Spaan (DO)

Tracking Coordinator: J. v. Tilburg (HD)
Deputy Trigger Coordinator: J.Albrecht (DO)

Physics convenor
S.Hansmann-Menzemer(HD)-BtoCharmonium

Data Taking



Experiment	ε_{DATA}	(all good)
ATLAS	93.6%	(93.7%)
CMS	93 %	(90%)
LHCb	94.6%	(99%)

"Factory mode"

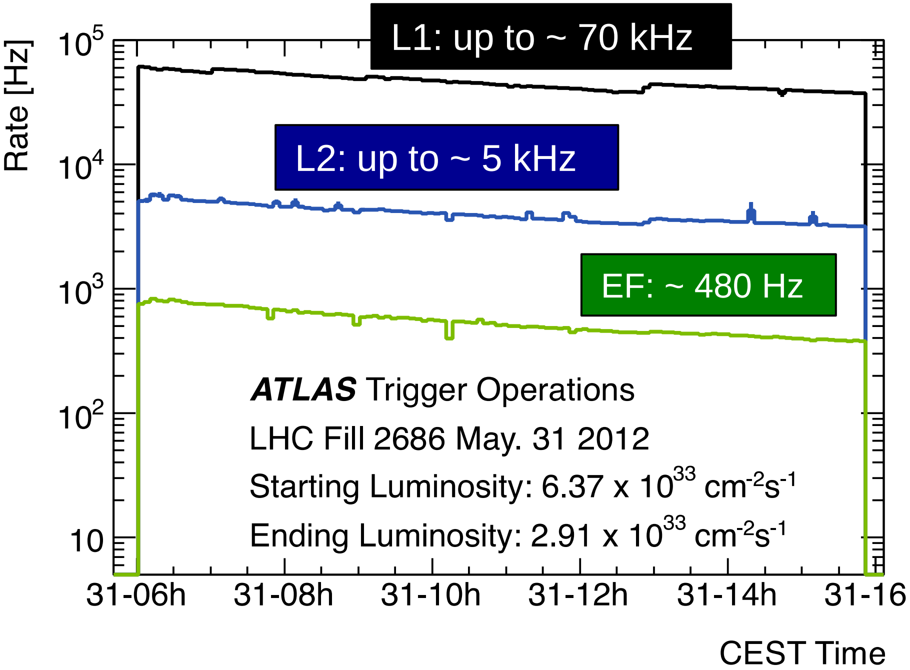
Sub-detector channel
availability: 96…100%

Triggering, Parking & Deferring

ATLAS & CMS: L1 leveling

- Core triggers prompt reconstruction
- Parked triggers delayed reconstruct.

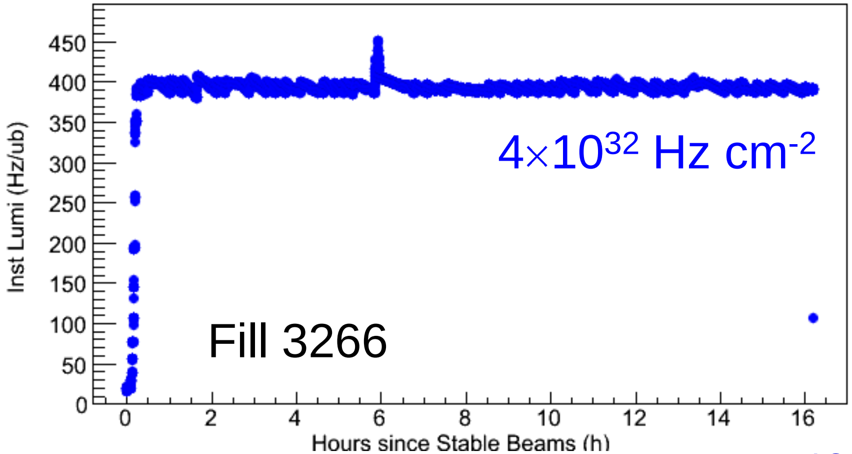
	Core	Parked
ATLAS	370 Hz	110 Hz
CMS	400 Hz	300…600 Hz



LHCb: Luminosity leveling

- HLT prompt triggers
- HLT deferred triggers (to disk): filtered between fills (~20%)

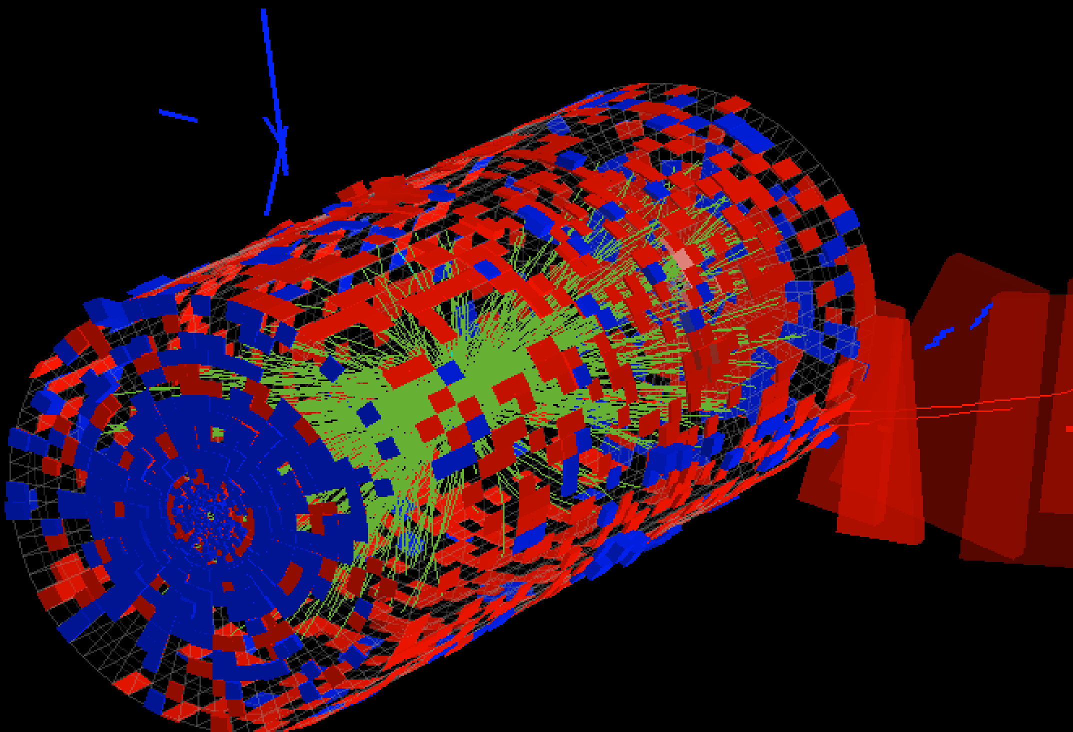
Event recording: 5000 Hz

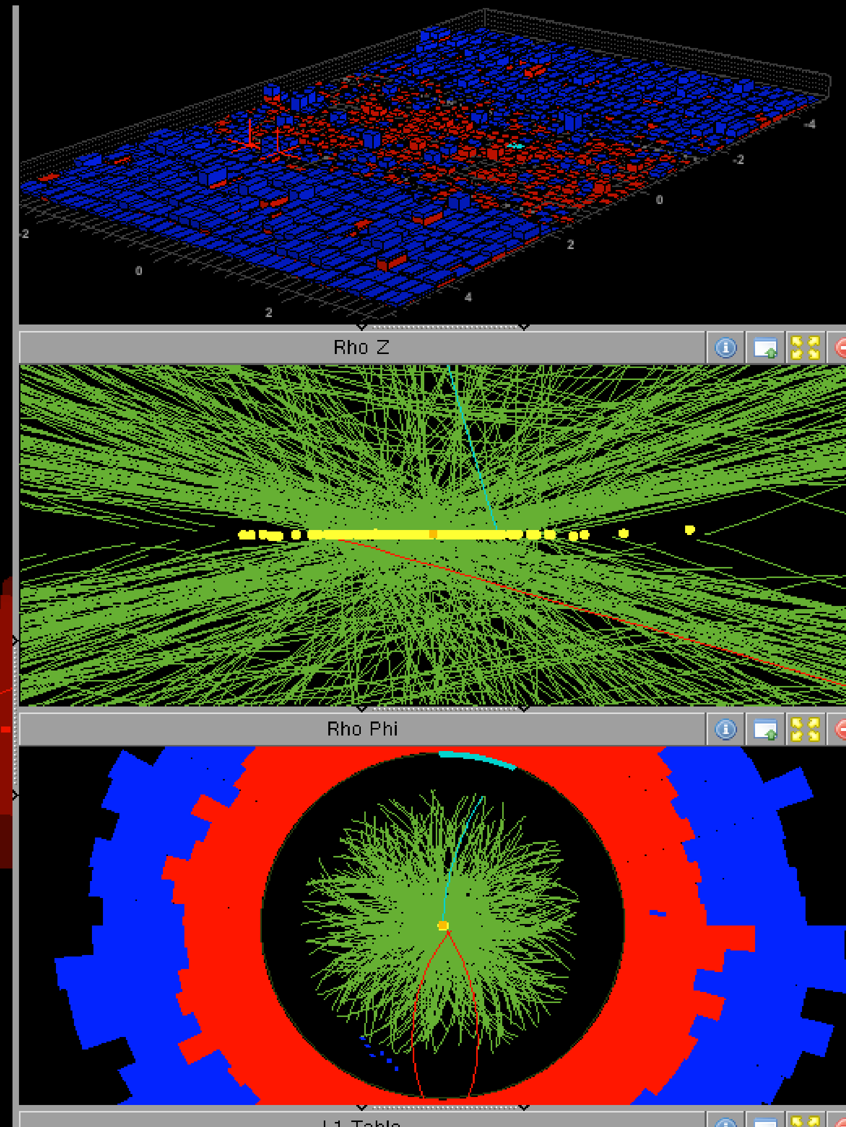


Event reconstruction with large Pile-Up

7.6×10^{33} Hz cm^{-2} ⇔ $<\mu>$ ~ 38

Design ~ 20

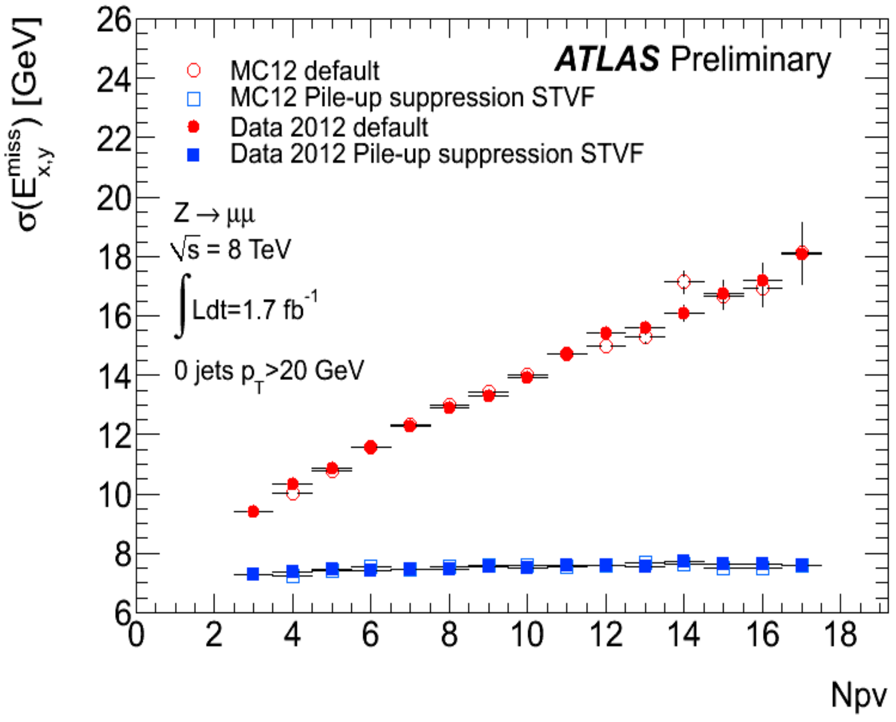




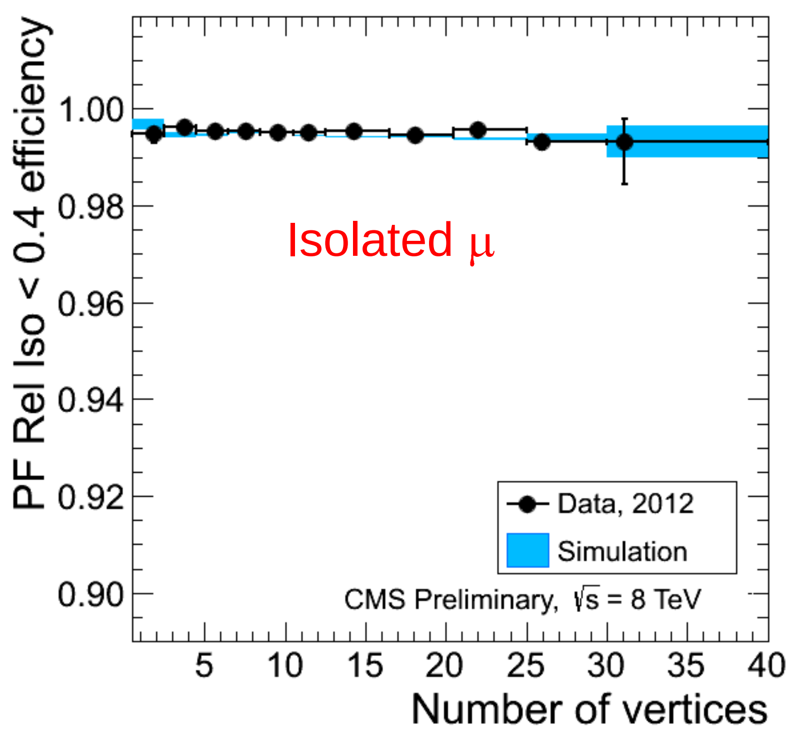
Event with 78 reconstructed vertices and 2 muons…

Pile-Up Handling

E_T^{miss} resolution



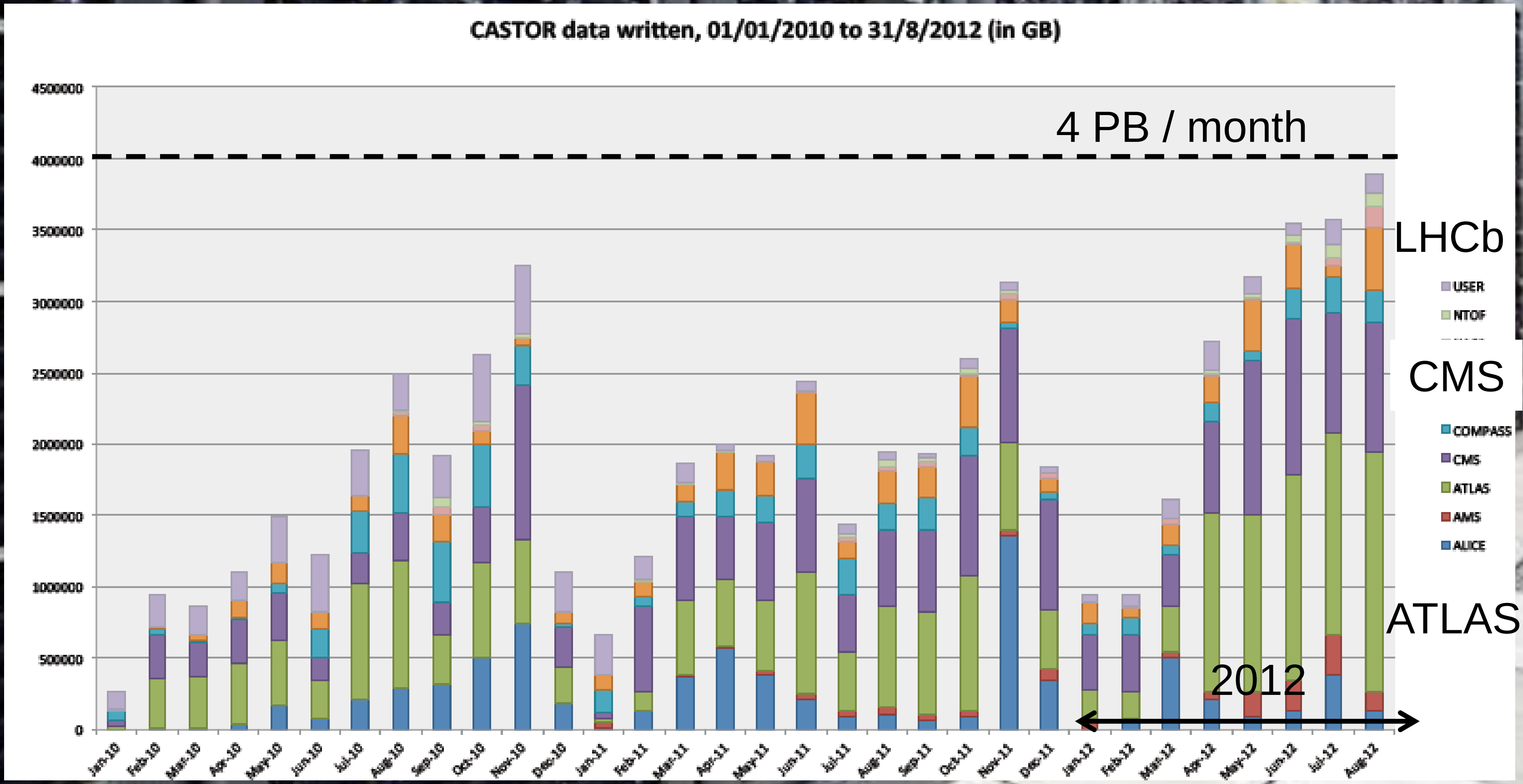
Particle Flow Isolation



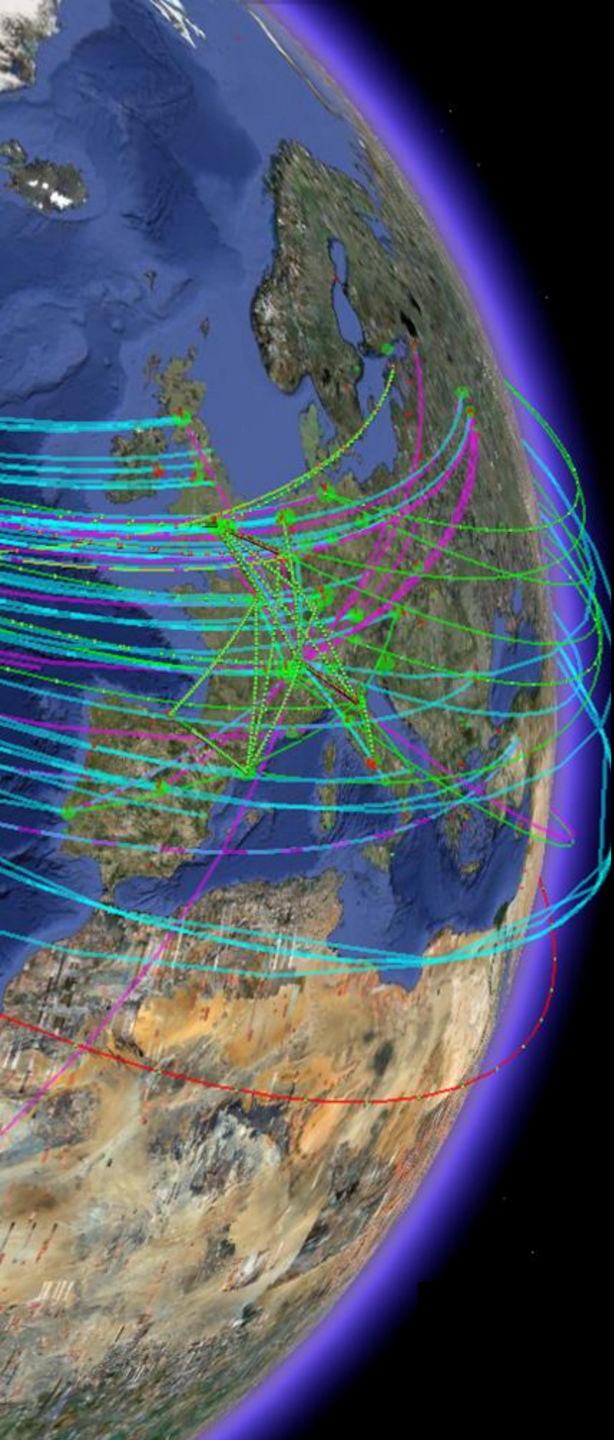
Detector performance under high pile-up condition is surprising.

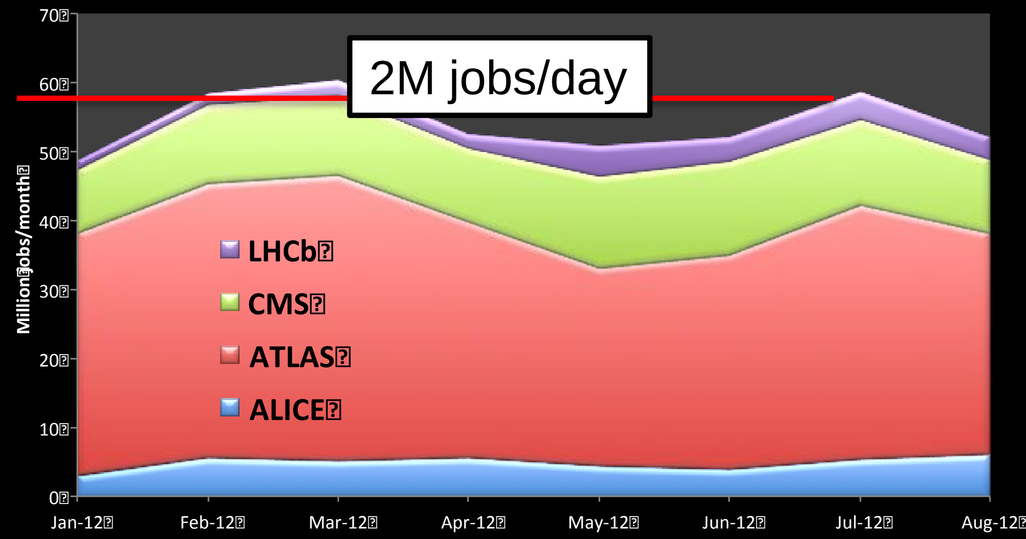
Huge efforts to keep reconstruction inside CPU/memory budget.

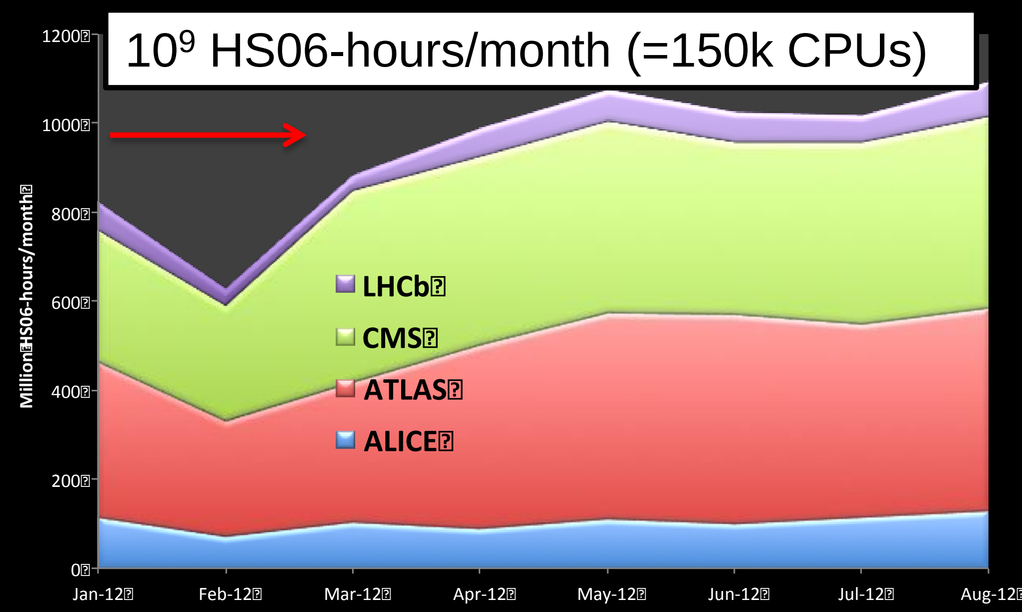
Data storage



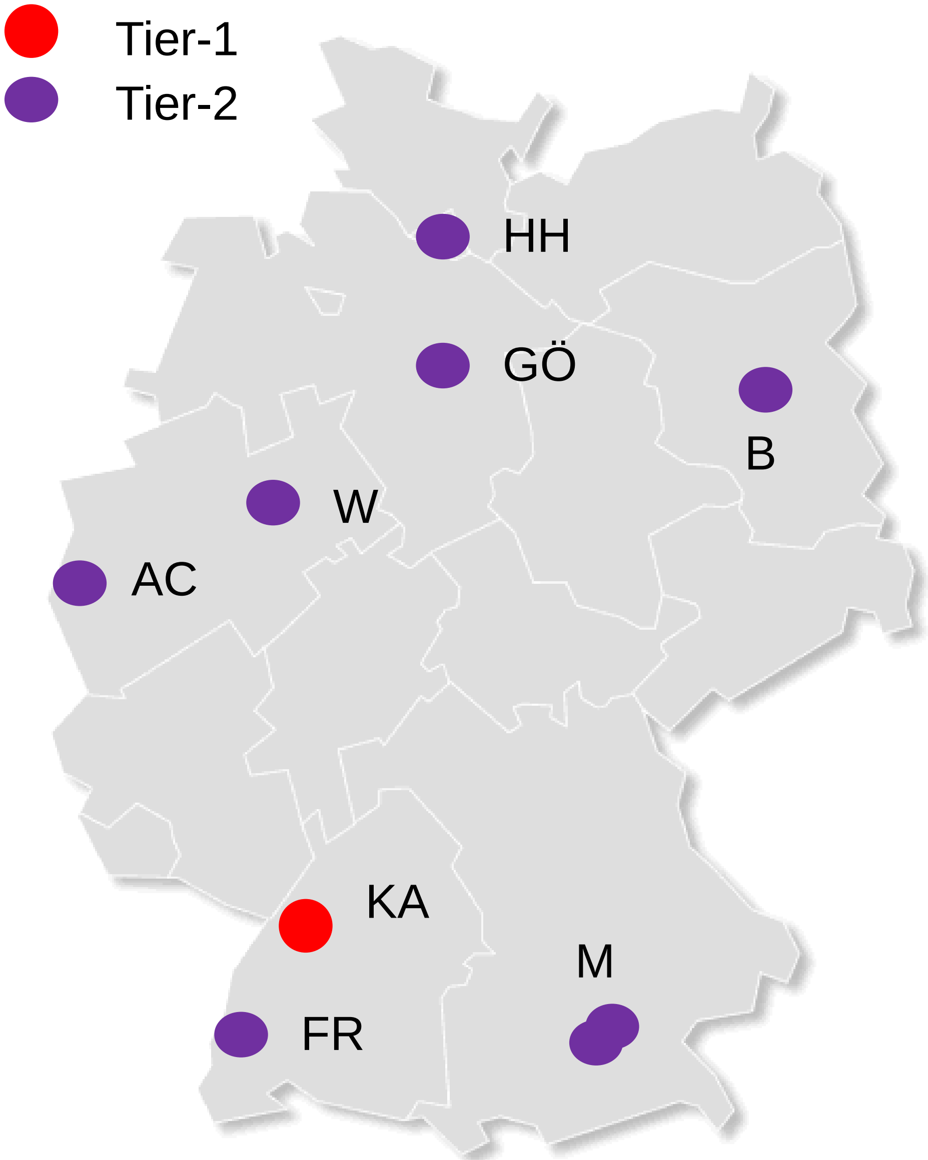
Grid Computing







LHC Computing Deutschland



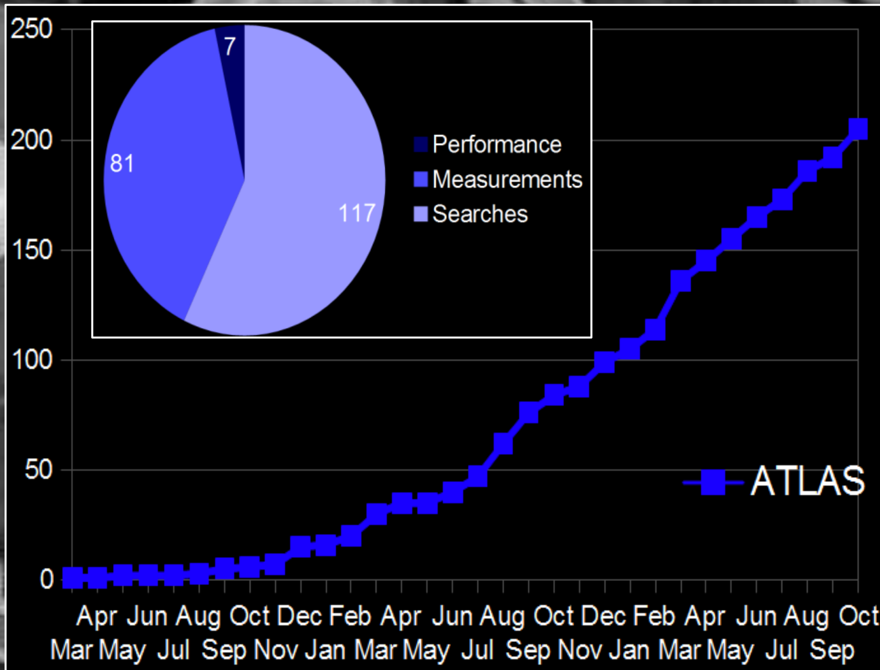
Experiment	D-share (target)	
ATLAS	12.5%	Tier-1 & Tier-2
CMS	10 %	
LHCb	16.6 %	Tier-1

2012: Pledges fulfilled.

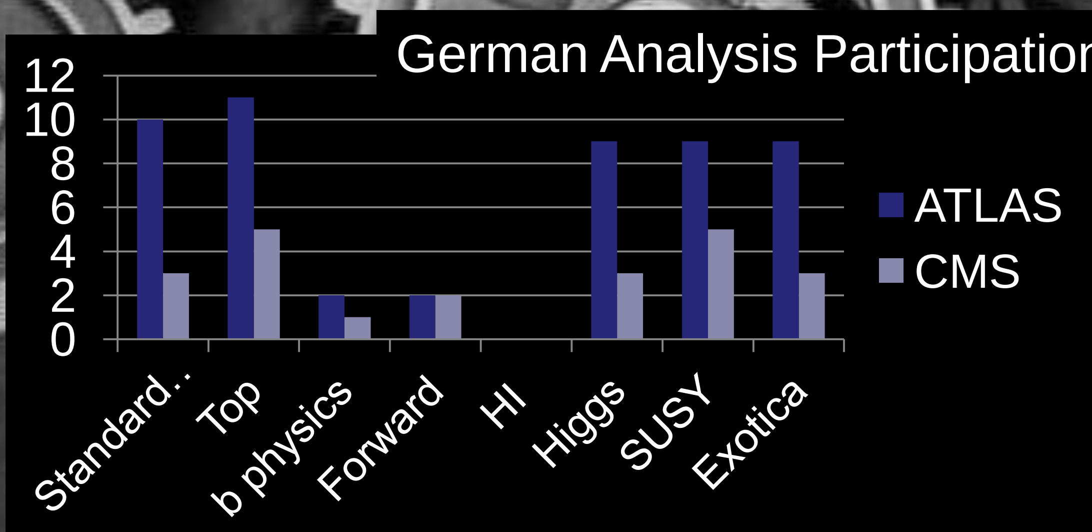
2013: GridKa faces increasing demands from experiments. First shortages (disks!).
2014: Trend will continue
.
2015: Large data increase

University Tier-2's need hardware replacement. Resources for 2013 provided by BMBF, afterwards ???

"Production" of Physics Results



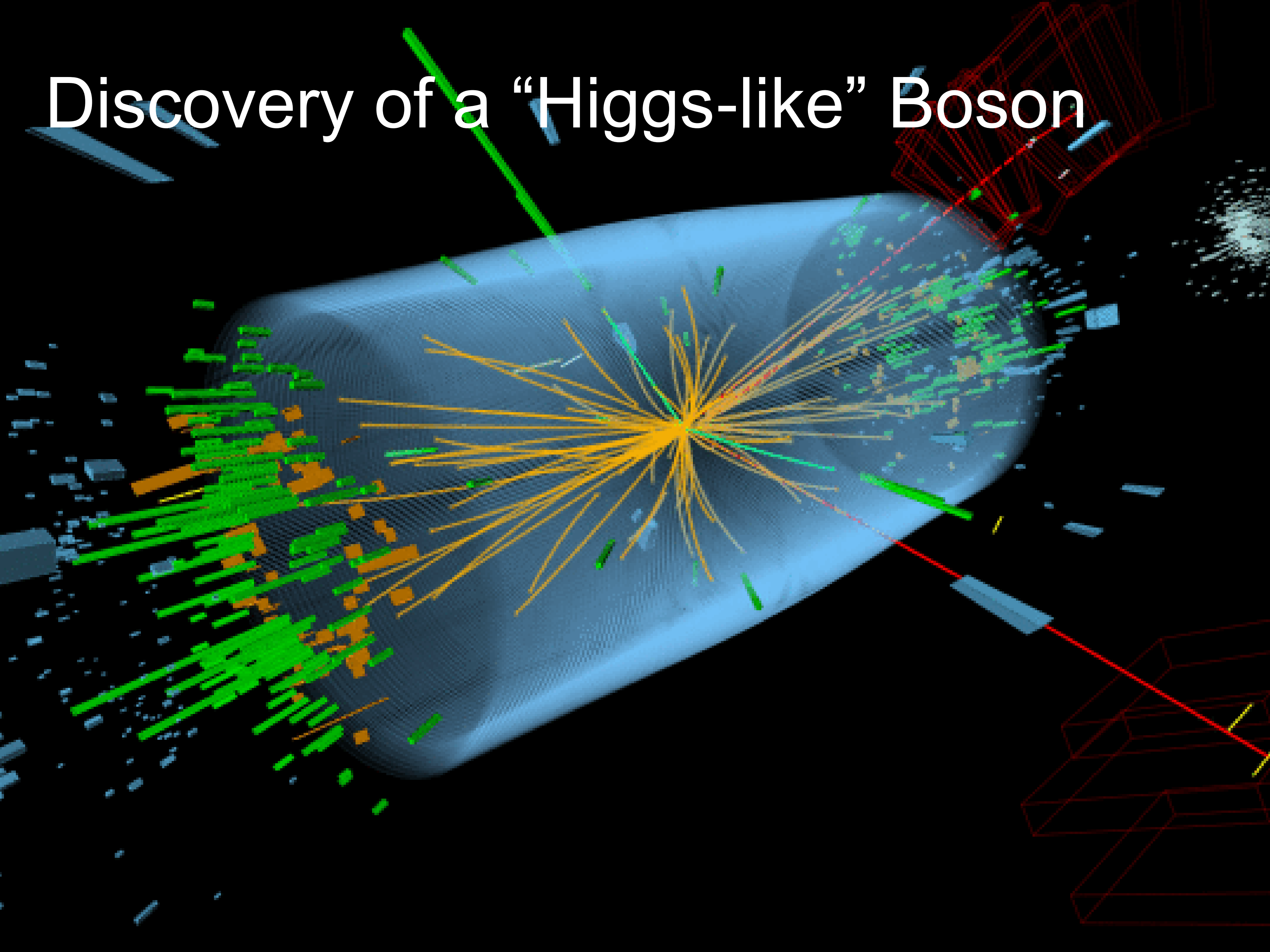
Exp	Papers
ATLAS	208
CMS	188
LHCb	72



LHCb:

Mixing & t-dep. CPV
Gamma
D-mixing & CPV
QCD

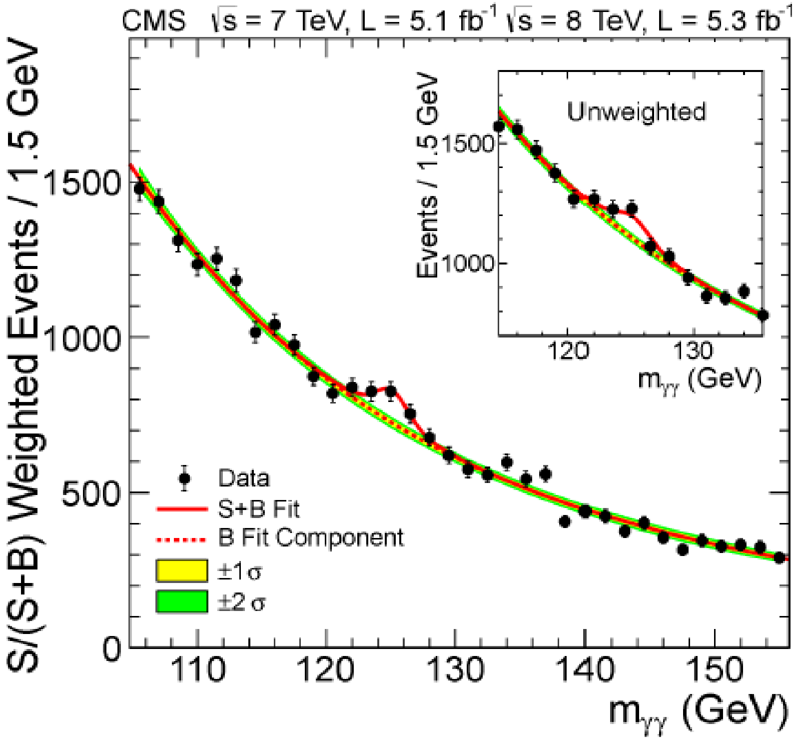
Discovery of a “Higgs-like” Boson



Discovery of a “Higgs-like” Boson

Status July 2012

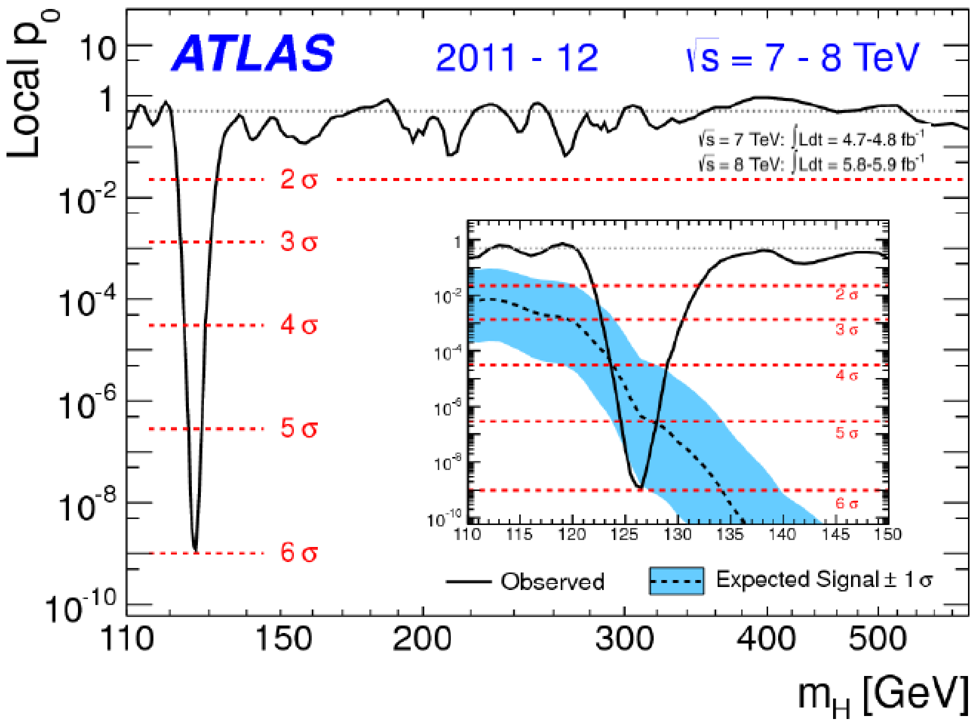
Search performed in
$H \to \gamma\gamma$, ZZ, WW, $\tau\tau$, bb



Combined significance: 5.0σ

m = 125.3 ± 0.4 ± 0.5 GeV

Search performed in
$H \to \gamma\gamma$, ZZ, WW

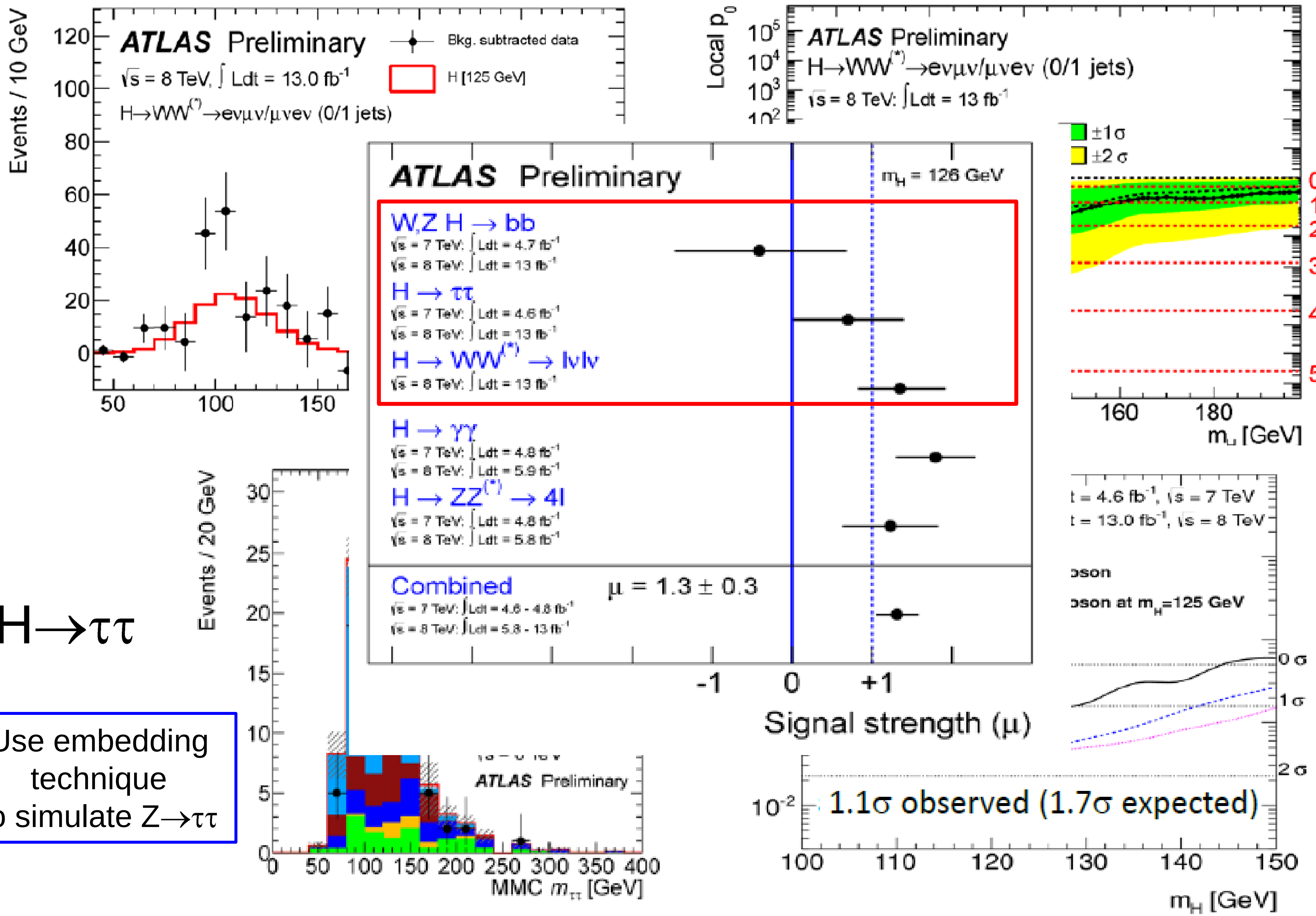


Combined significance: 5.9σ

m = 126.0 ± 0.4 ± 0.4 GeV


'We have it!'

ATLAS Update at HCP

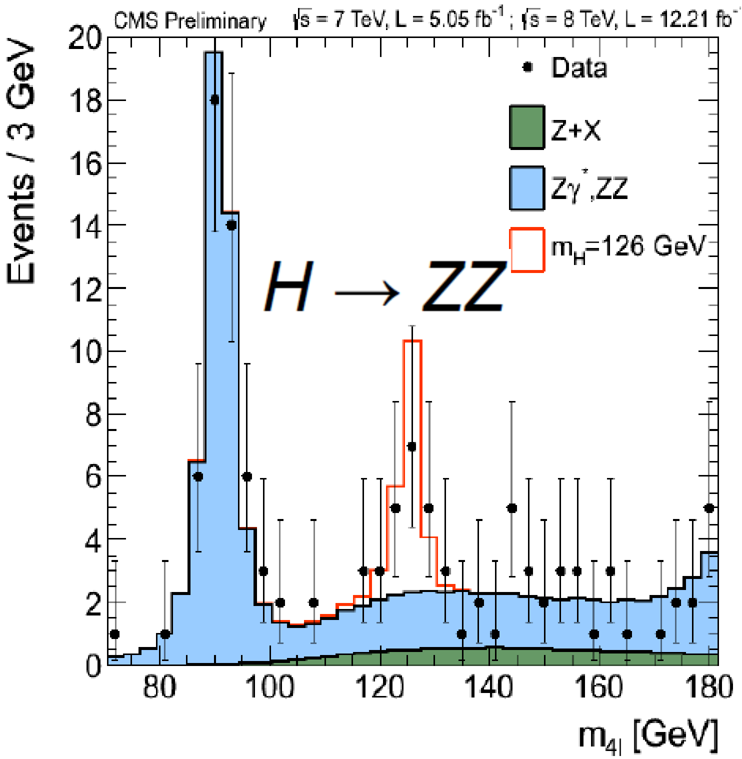


H→ττ

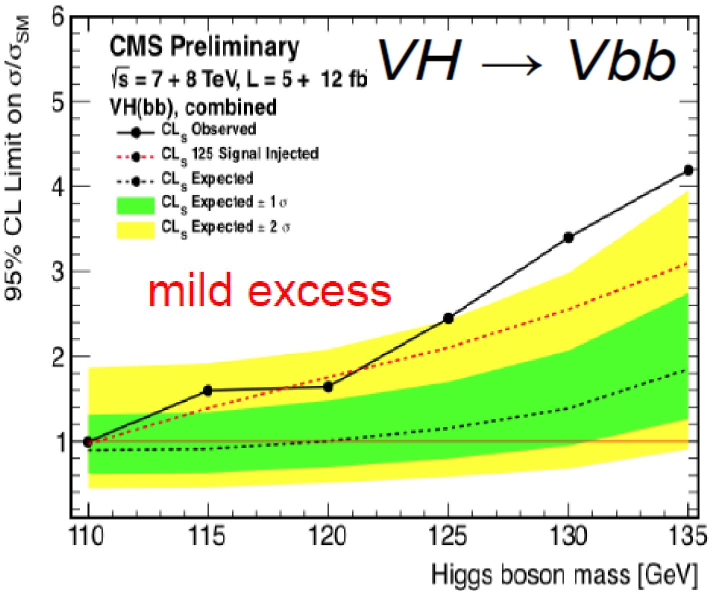
Use embedding technique to simulate Z→ττ

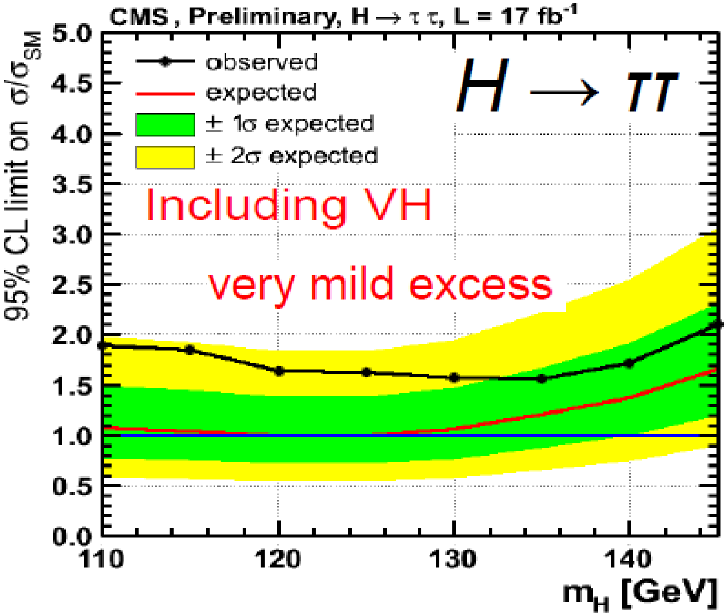
CMS Update at HCP

C. Paus



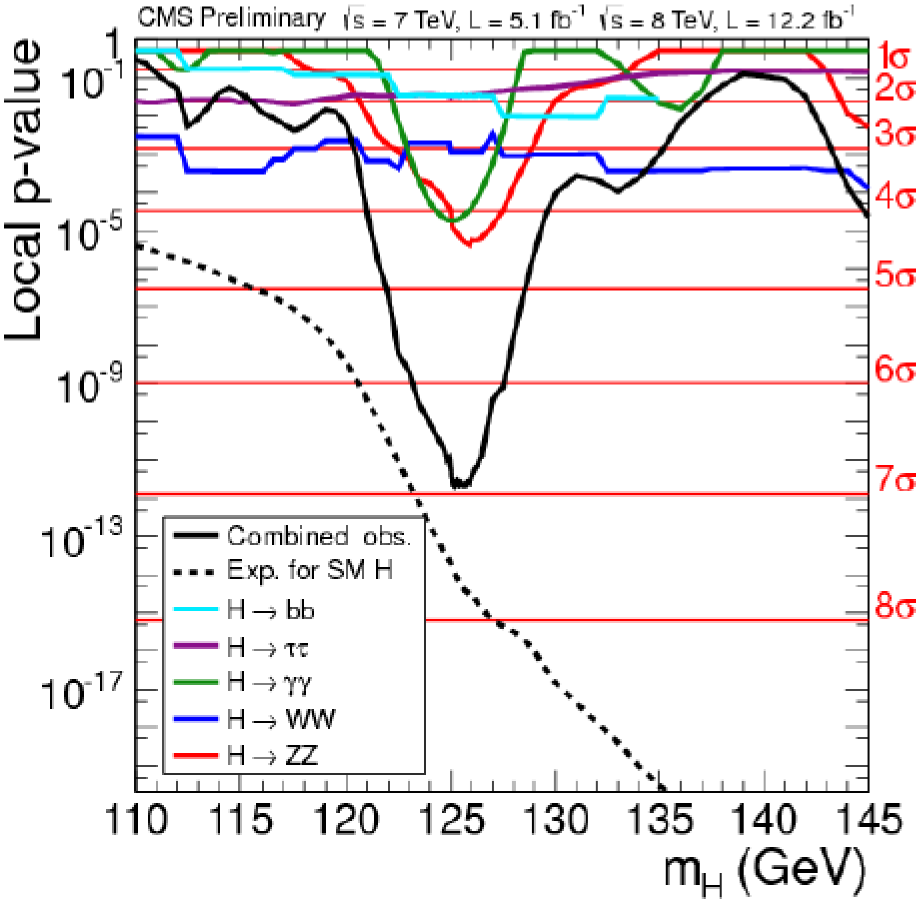
p-value analysis: 4.6σ

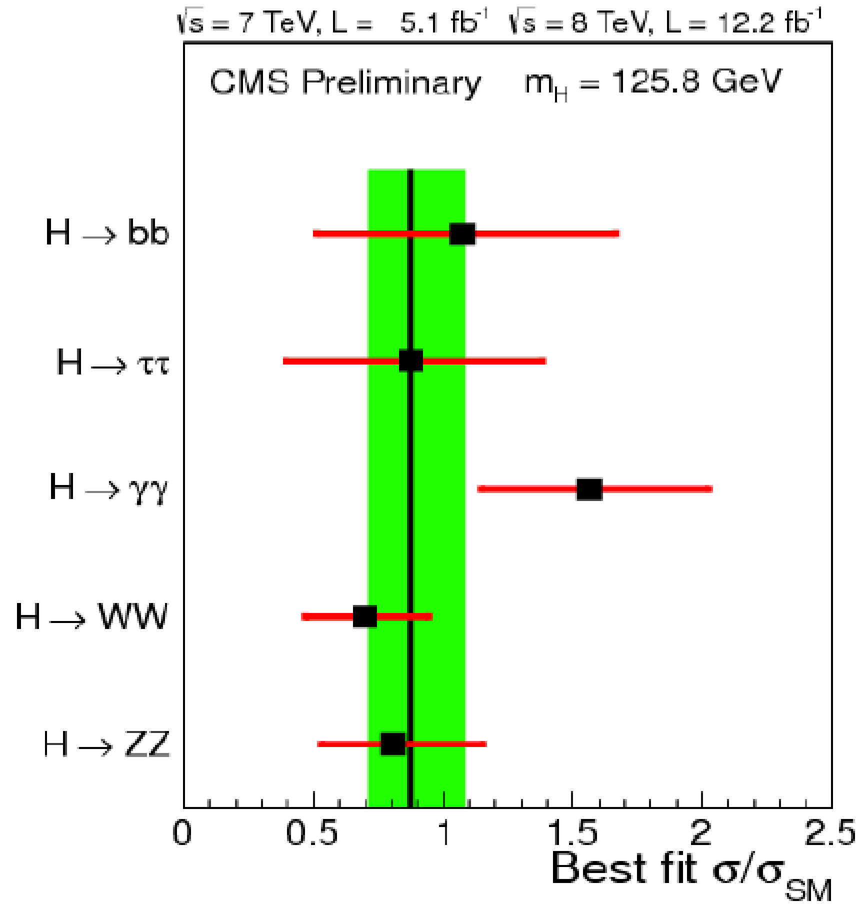




CMS Update at HCP

Slide from C. Paus



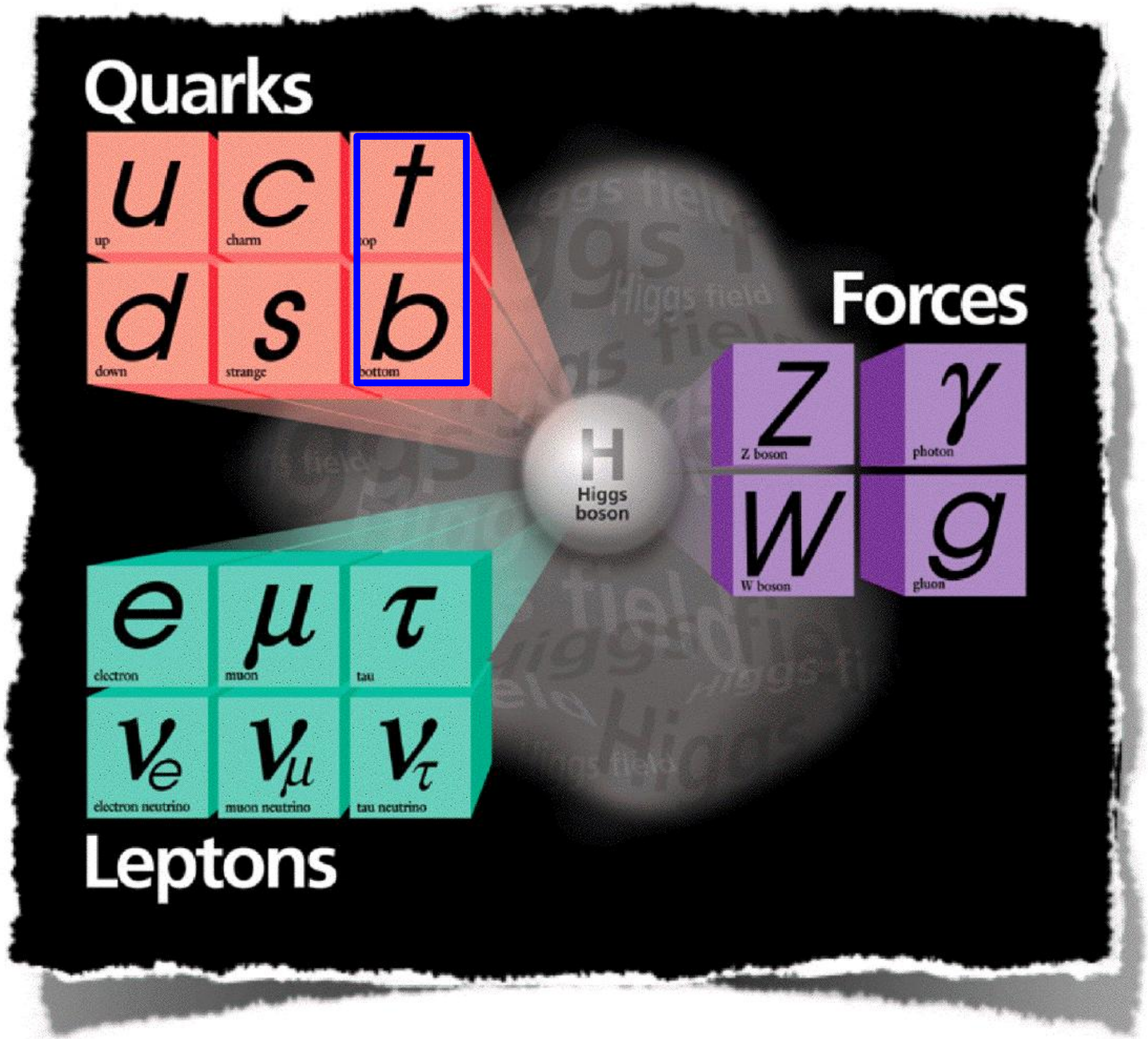


Overall significance and signal strength

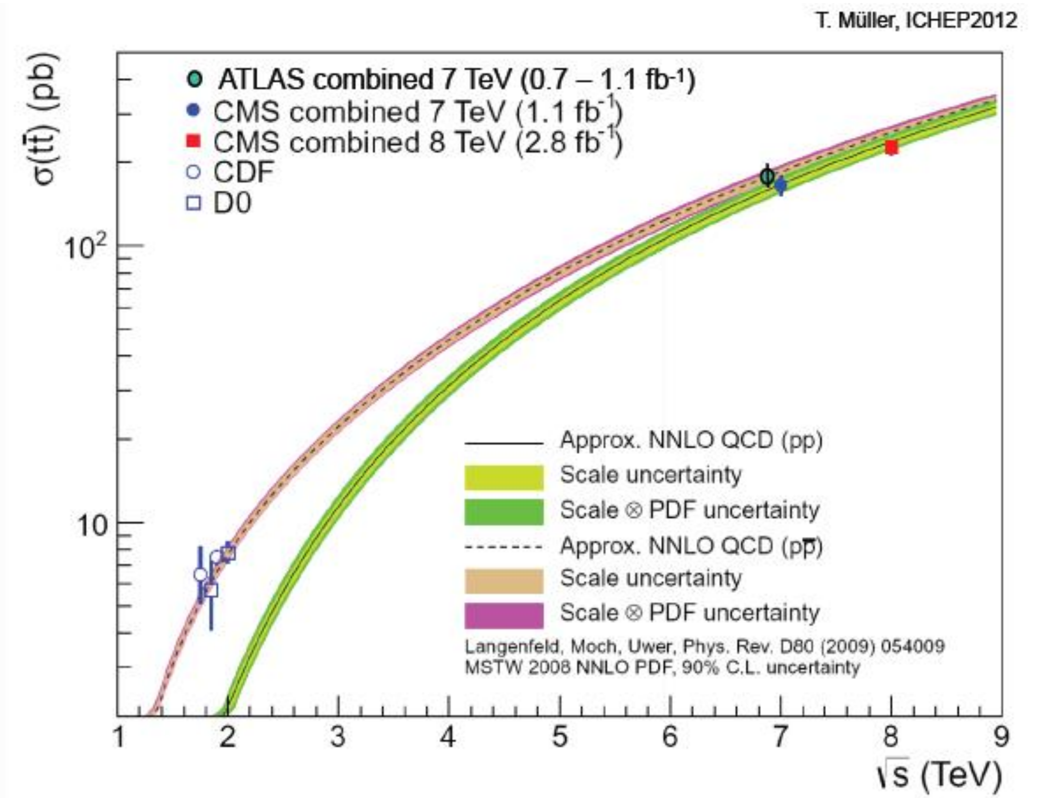
– observed: 6.9; expected: 7.8 [signal strength: 0.88 ± 0.21]

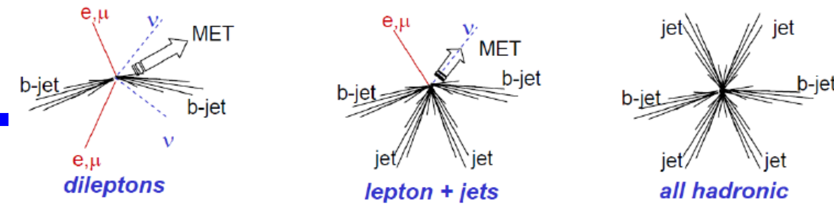
m_χ = 125.8 ± 0.4(stat) ± 0.4 (syst) GeV

Standard Model Tests

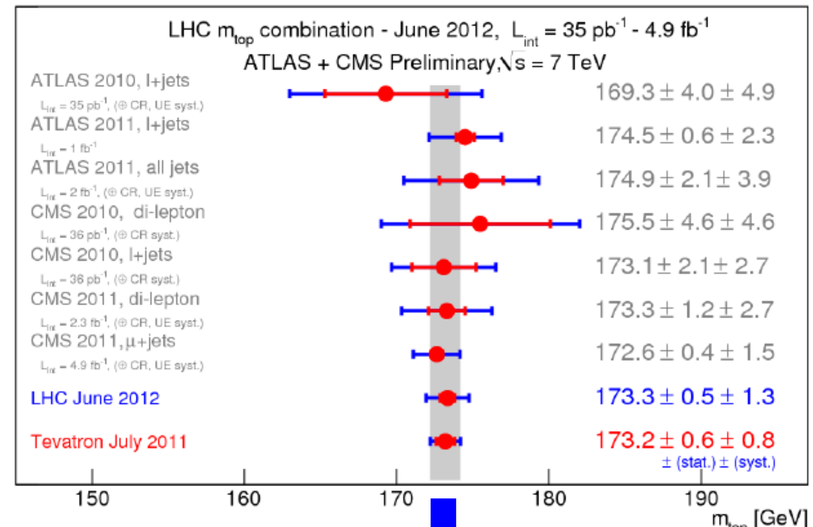


$t\bar{t}$-Production …





… top mass



8 TeV

CMS 2.8/fb (Comb. Lept+jets & di-lept)

$$\sigma_{t\bar{t}} = 227 \pm 3\,(\text{stat.}) \pm 11\,(\text{syst.}) \pm 10\,(\text{lumi})\ \text{pb}$$

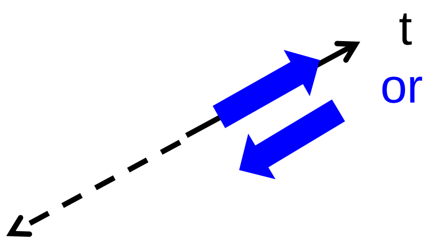
ATLAS 5.8/fb (Lept+jets)

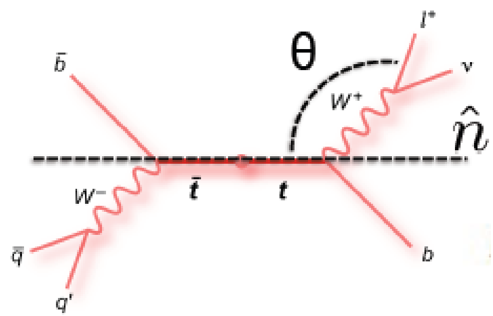
$$\sigma_{t\bar{t}} = 241 \pm 2\,(\text{stat.}) \pm 31\,(\text{syst.}) \pm 9\,(\text{lumi.})\ \text{pb}$$

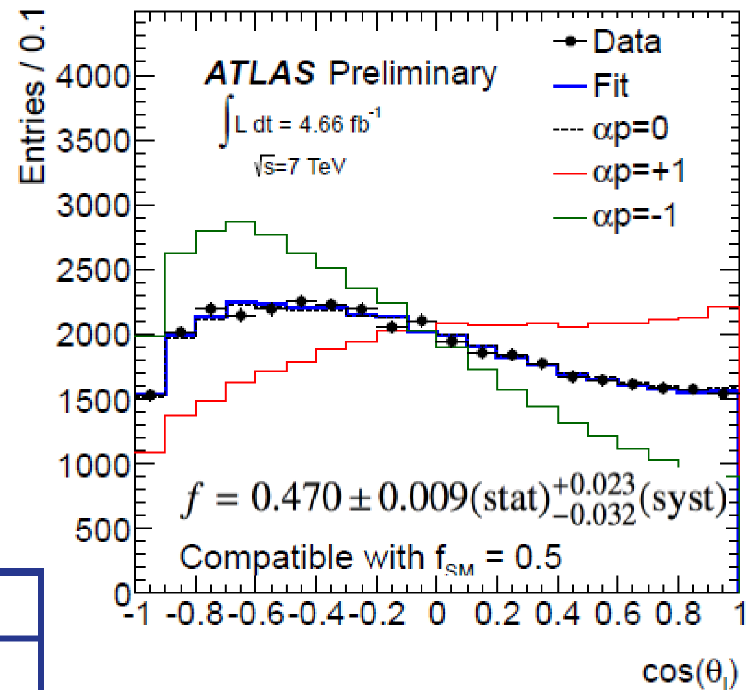
	Top Mass (GeV)
Tevatron	$173.2 \pm 0.6 \pm 0.8$
LHC	$173.3 \pm 0.5 \pm 1.3$

… more on $t\bar{t}$ production

Top-quark polarization:







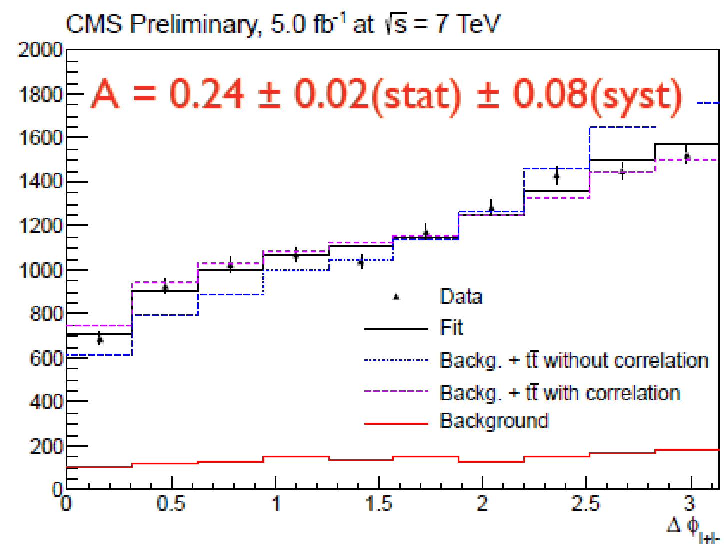
W polarization:

	F_0	F_L
ATLAS	0.66 ±0.06 ±0.07	0.33 ±0.03 ±0.03
CMS	0.567 ±0.074 ±0.047	0.393 ±0.045 ±0.029

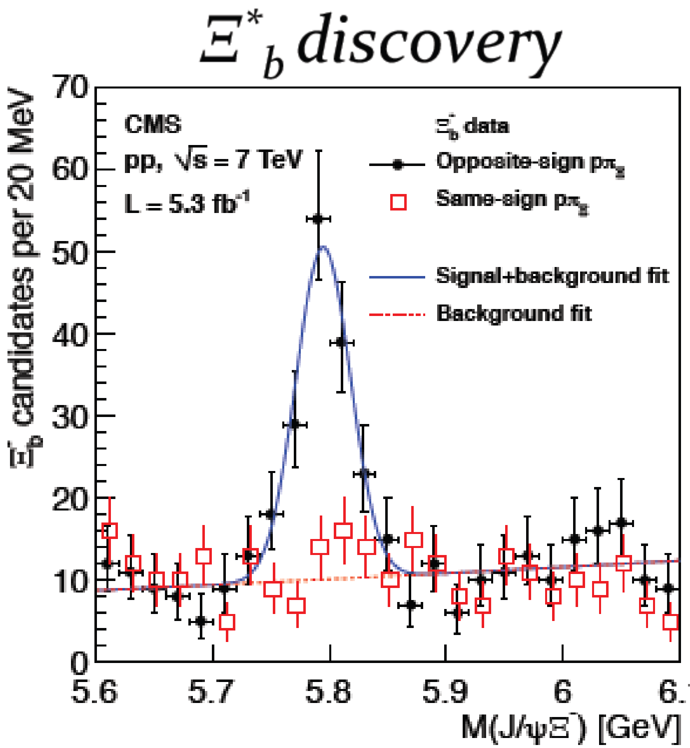
Spin correlation in tt:

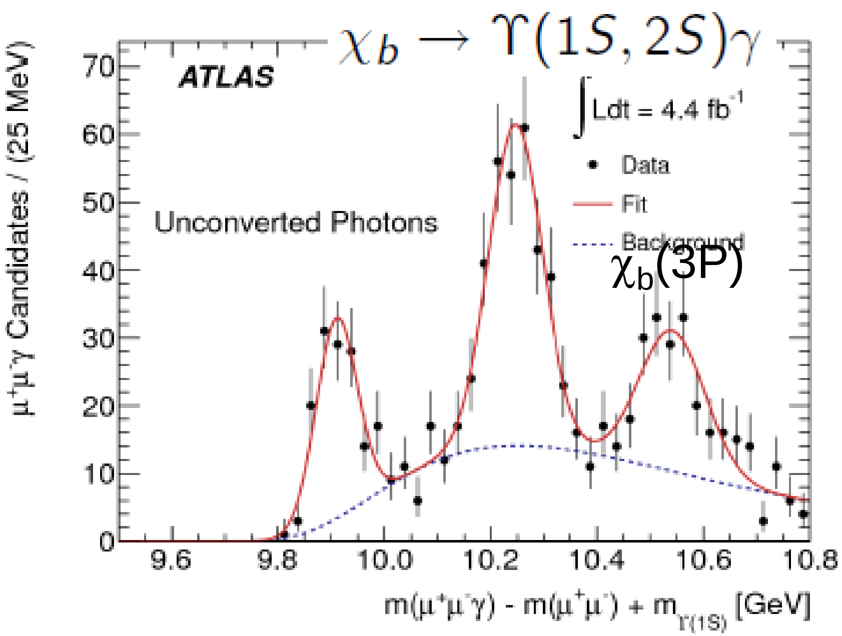
$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\downarrow\uparrow) - N(\uparrow\downarrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\downarrow\uparrow) + N(\uparrow\downarrow)}$$

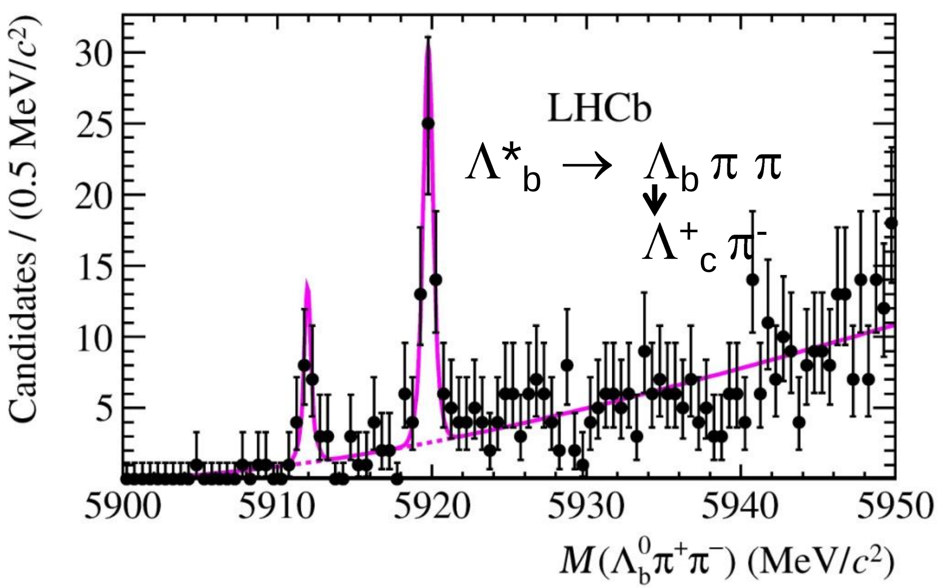
Correlation of lepton angles ϕ



B Physics – New States

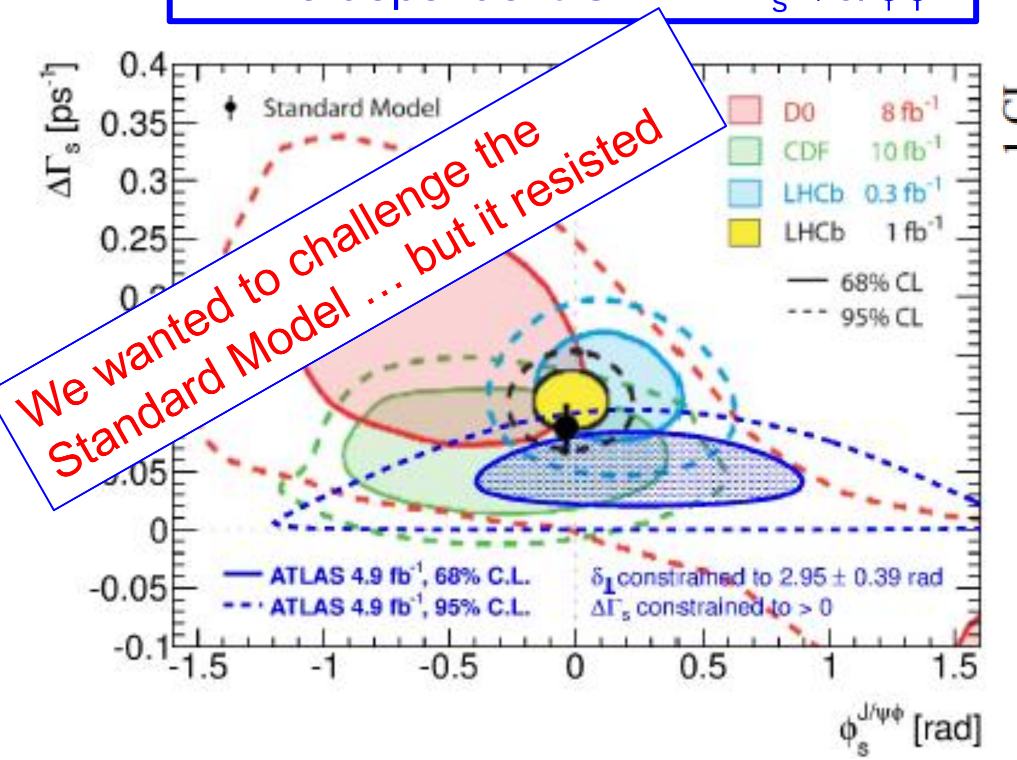




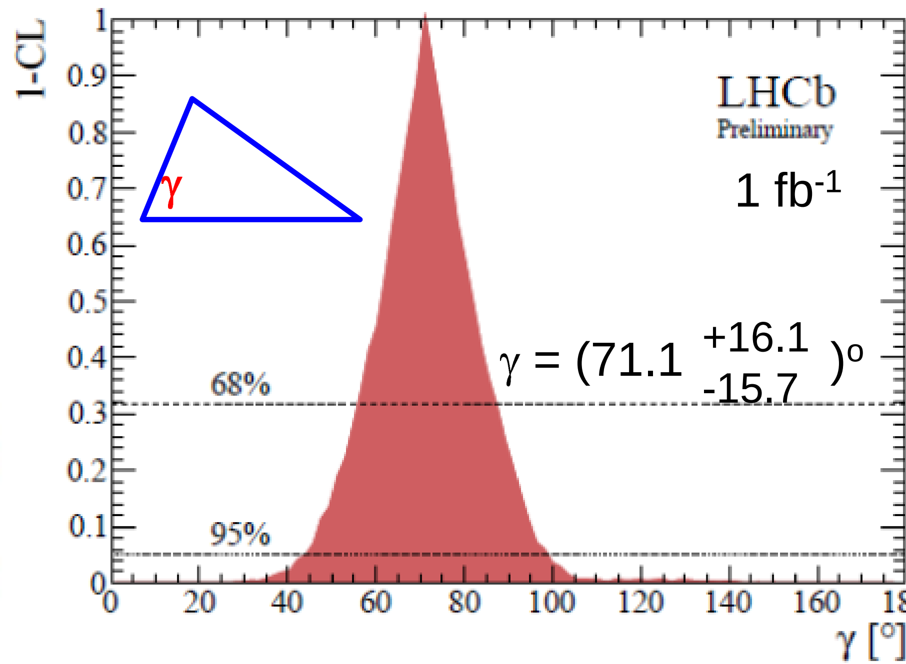


B physics – CP Violation

Time-dependent CPV in $B_s \to J/\psi\phi$



CP violation in $B^{\pm} \to DK^{\pm}$: Angle γ



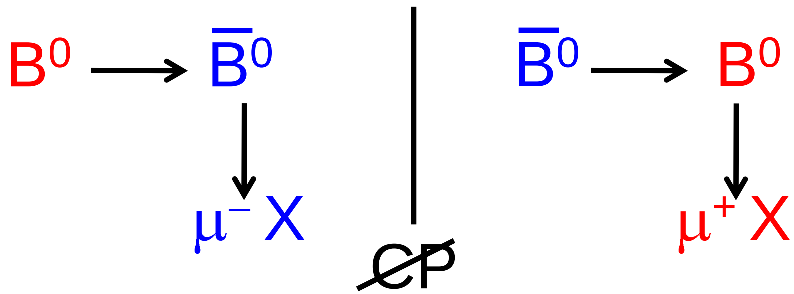
LHCb: $\phi_s = -0.001 \pm 0.101 \pm 0.027$ rad

ATLAS: $\phi_s = 0.22 \pm 0.41 \pm 0.10$ rad

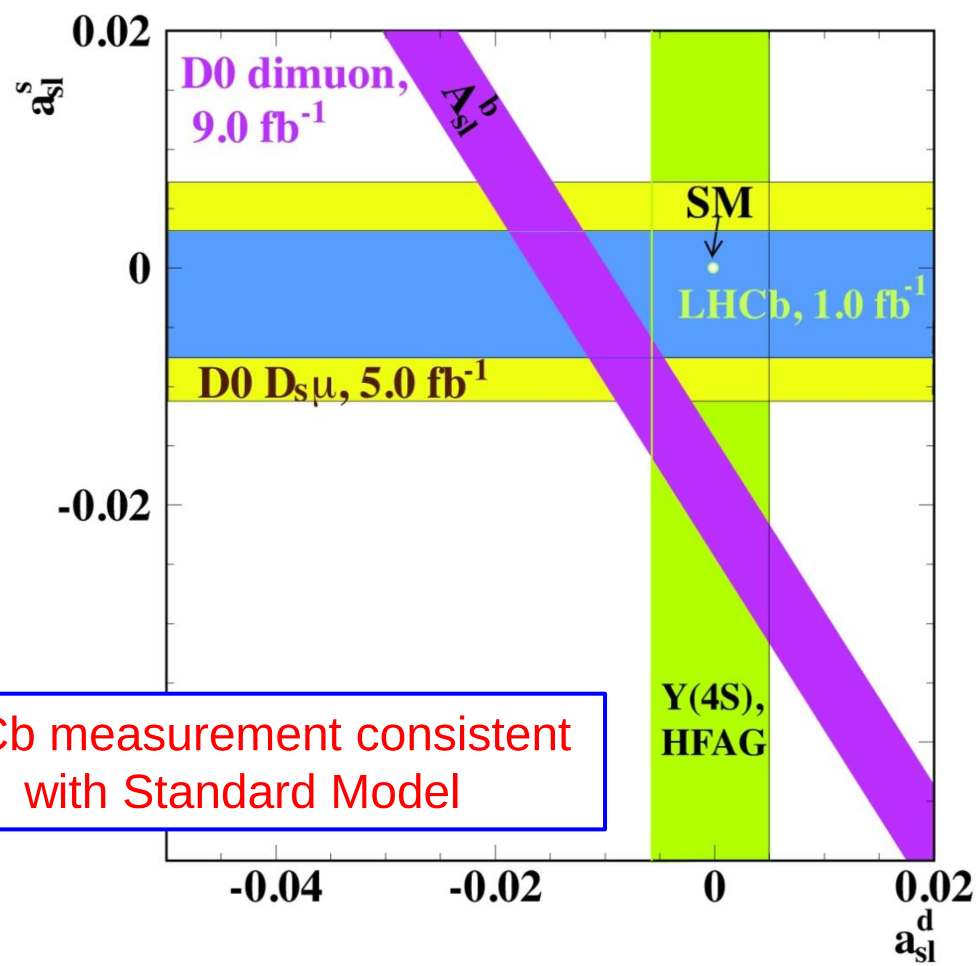
CMS: $\Delta\Gamma_s = 0.048 \pm 0.024 \pm 0.003\ (ps^{-1})$

Comparable w/ individual results from BABAR/BELLE w/ only 1 /fb

CP Violation in Mixing



$$a_{sl}^{q} \equiv \frac{\Gamma(\bar{B}_q^0 \rightarrow \mu^+ X) - \Gamma(B_q^0 \rightarrow \mu^- X)}{\Gamma(\bar{B}_q^0 \rightarrow \mu^+ X) + \Gamma(B_q^0 \rightarrow \mu^- X)}$$

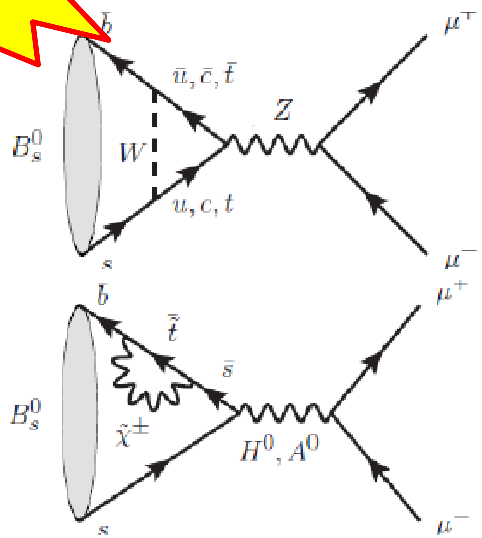


LHCb measurement consistent with Standard Model

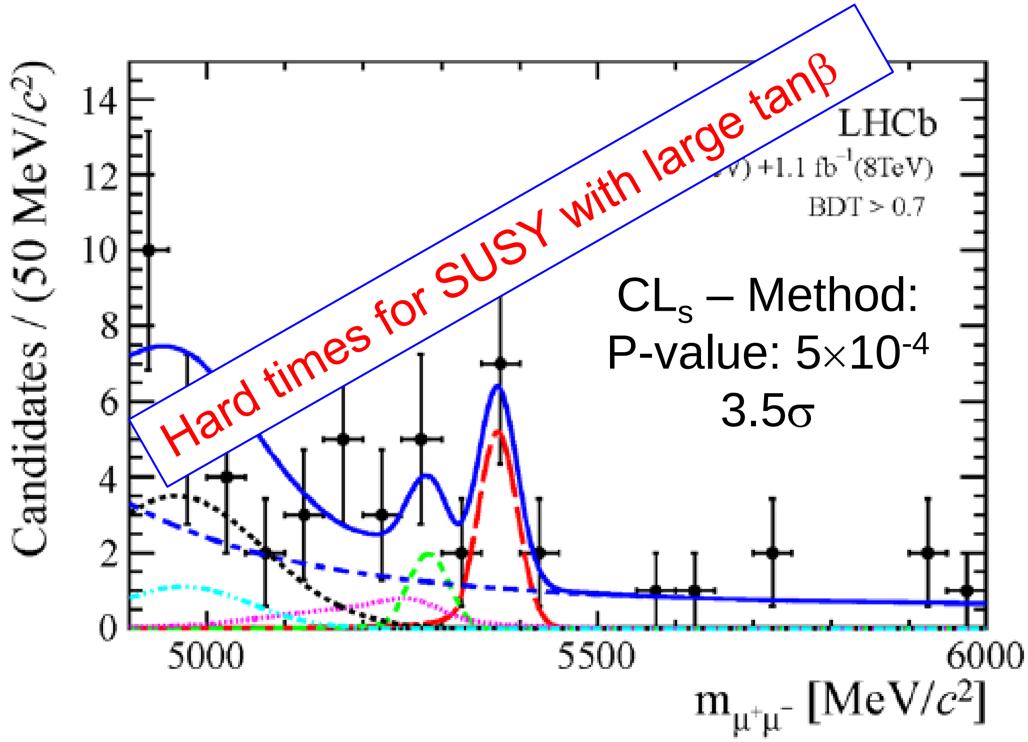
Evidence for $B_s \to \mu^+\mu^-$

J. Albrecht, HCP 2012

New



SM: BR = $(3.54 \pm 0.30) \times 10^{-9}$



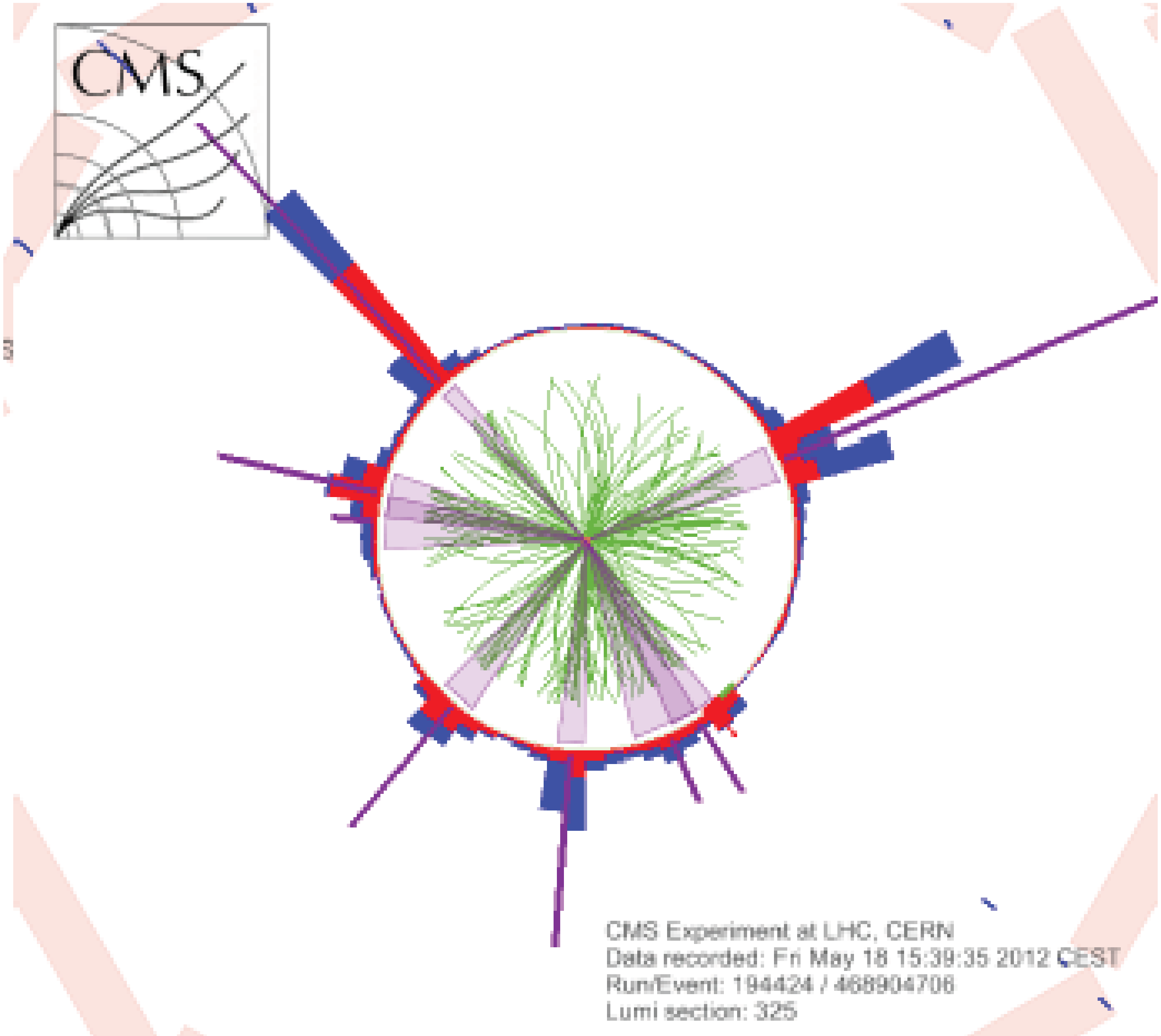
$$BR(B_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

CMS: < 7.7 $\times 10^{-9}$ (95% CL)
ATLAS: < 22 $\times 10^{-9}$ (95% CL)

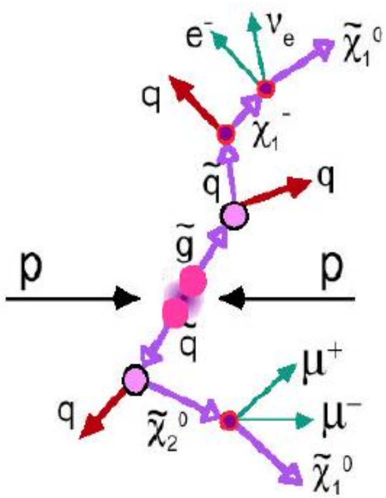
Also very nice:

LHCb: BR($K_s \to \mu\mu$) < 9 (11) $\times 10^{-9}$ @ 90 (95)% CL (35 times improved limit)

New Physics Searches



SUSY Searches

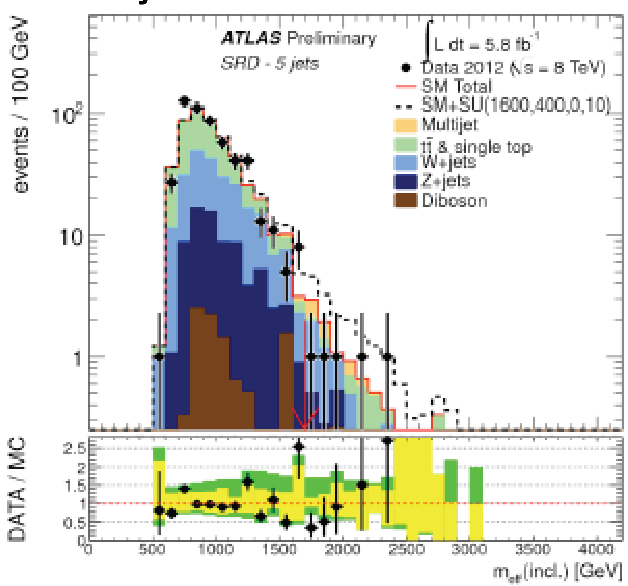


“Classical” inclusive searches:

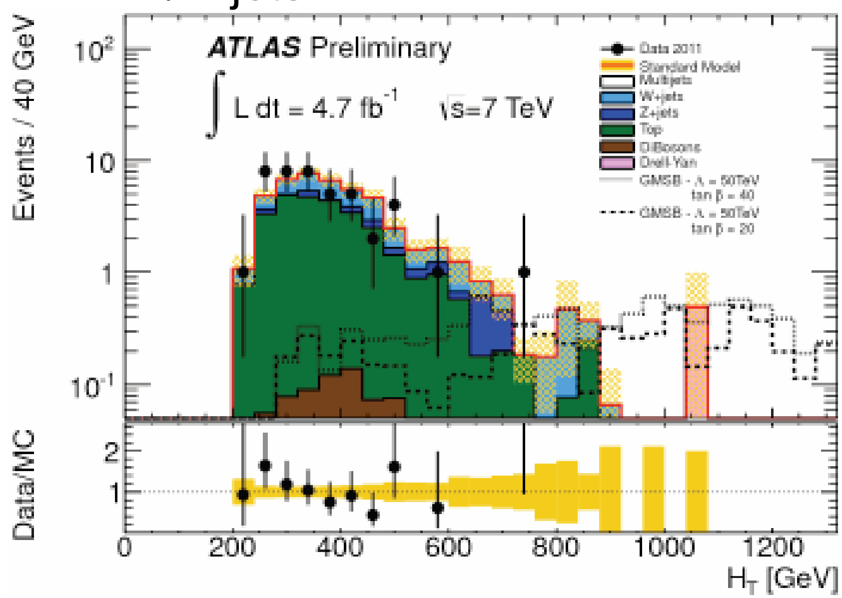
- Jets + Missing transverse energy (MET)
- Leptons + Jets + MET

No excess seen → Model dependent limits

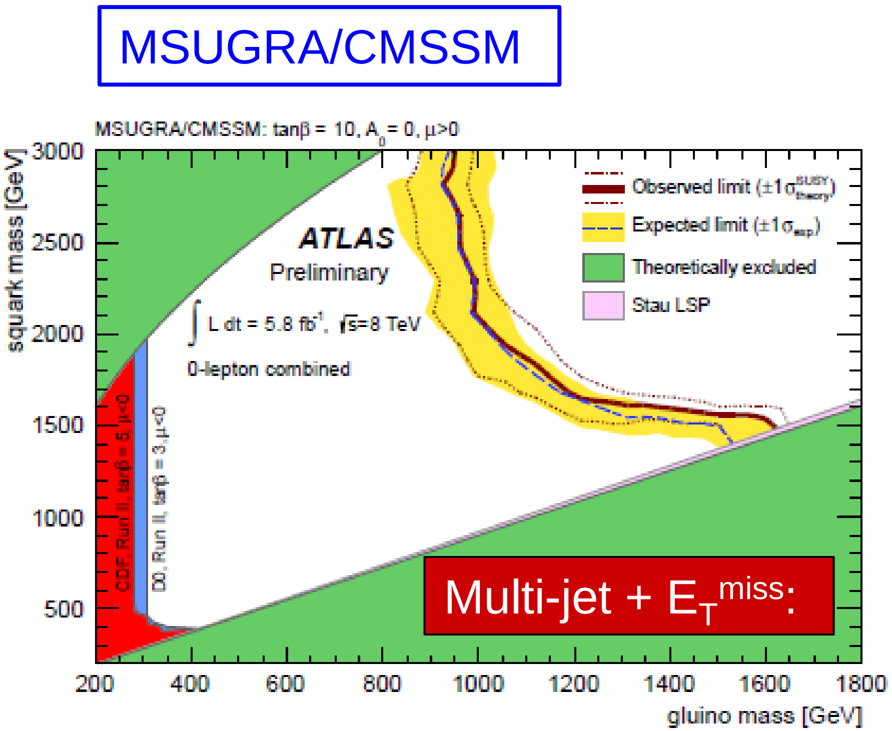
5 jets + MET

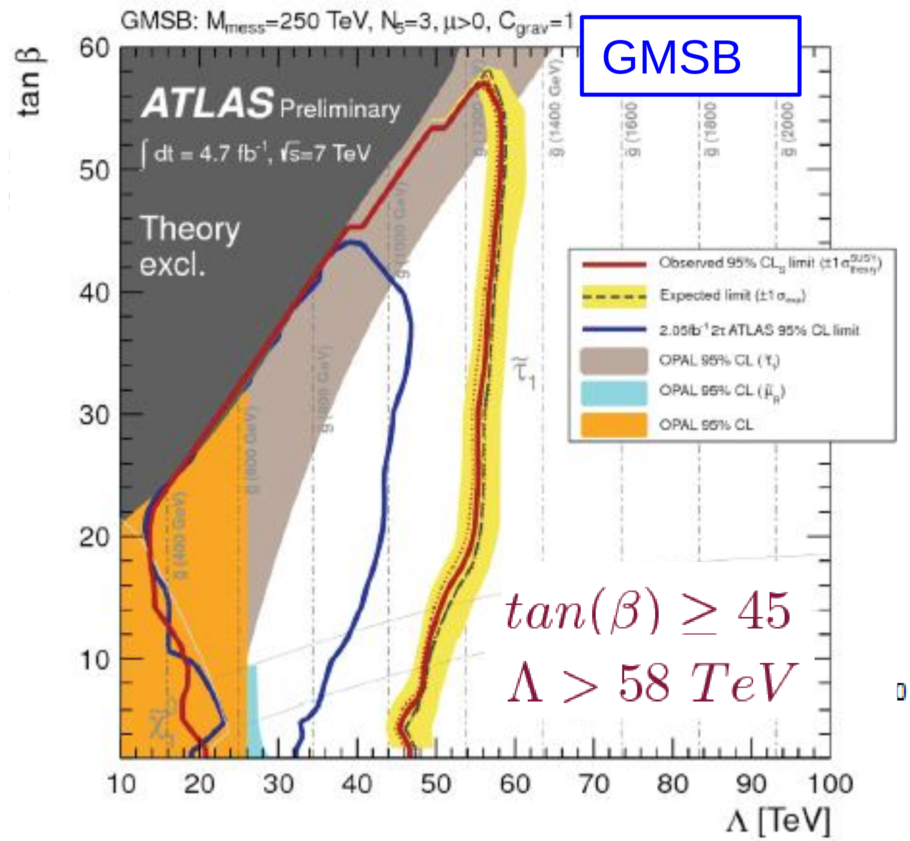


1τ + jets + MET



Model dependent limits

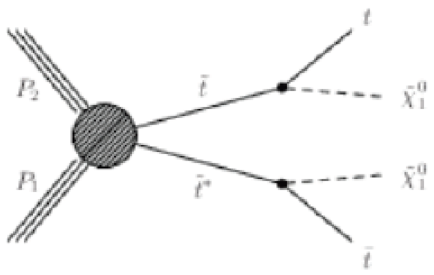




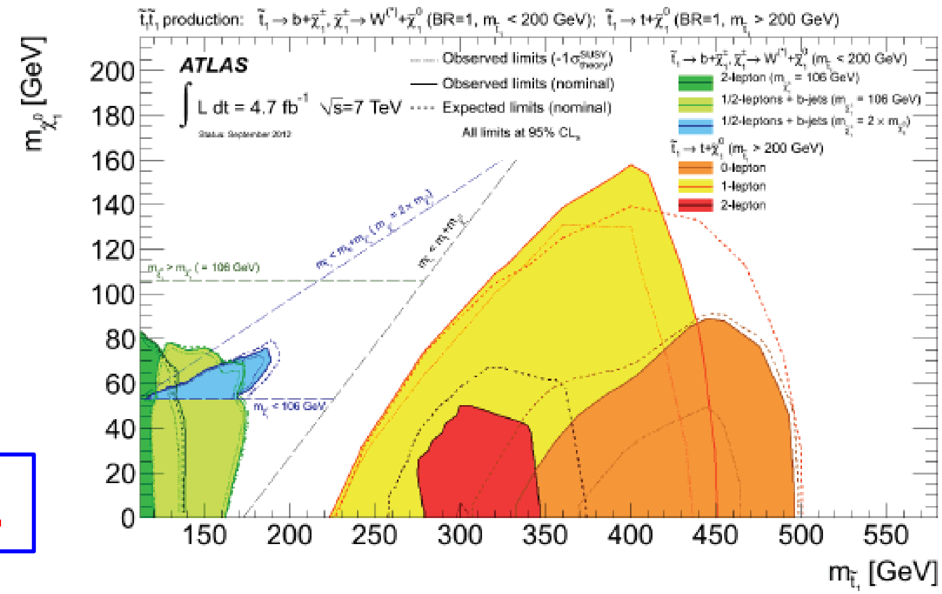
- Constraints apply only to first generation:
  $\rightarrow$ sbottom and stop unconstrained.
- “Natural” SUSY: light stop/sbottom
  $\rightarrow$ requires exclusive searches

Exclusive SUSY Searches

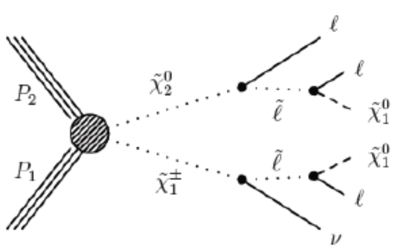
E.g.: stop production

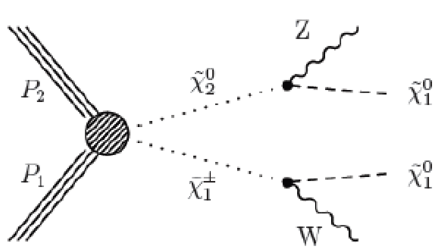


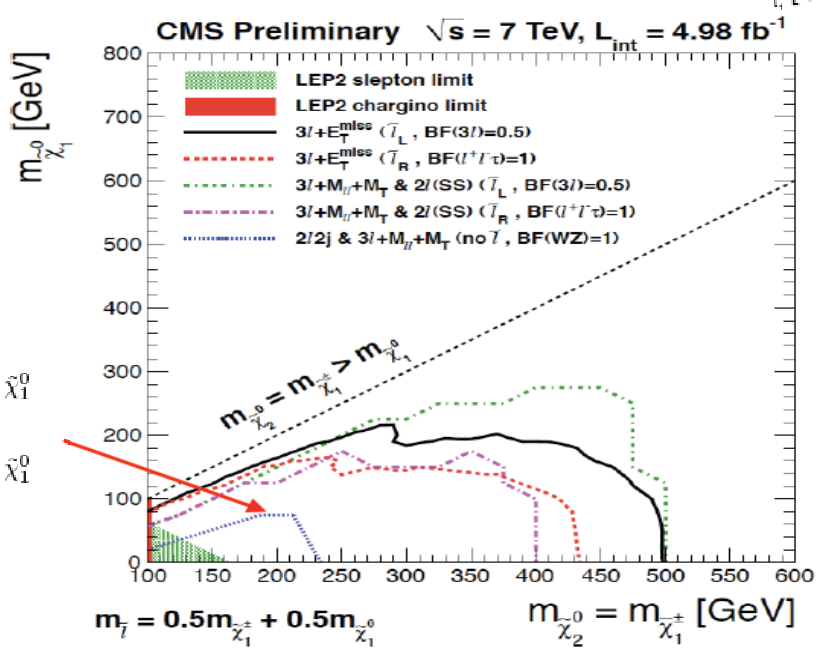
So far, no excess seen either.

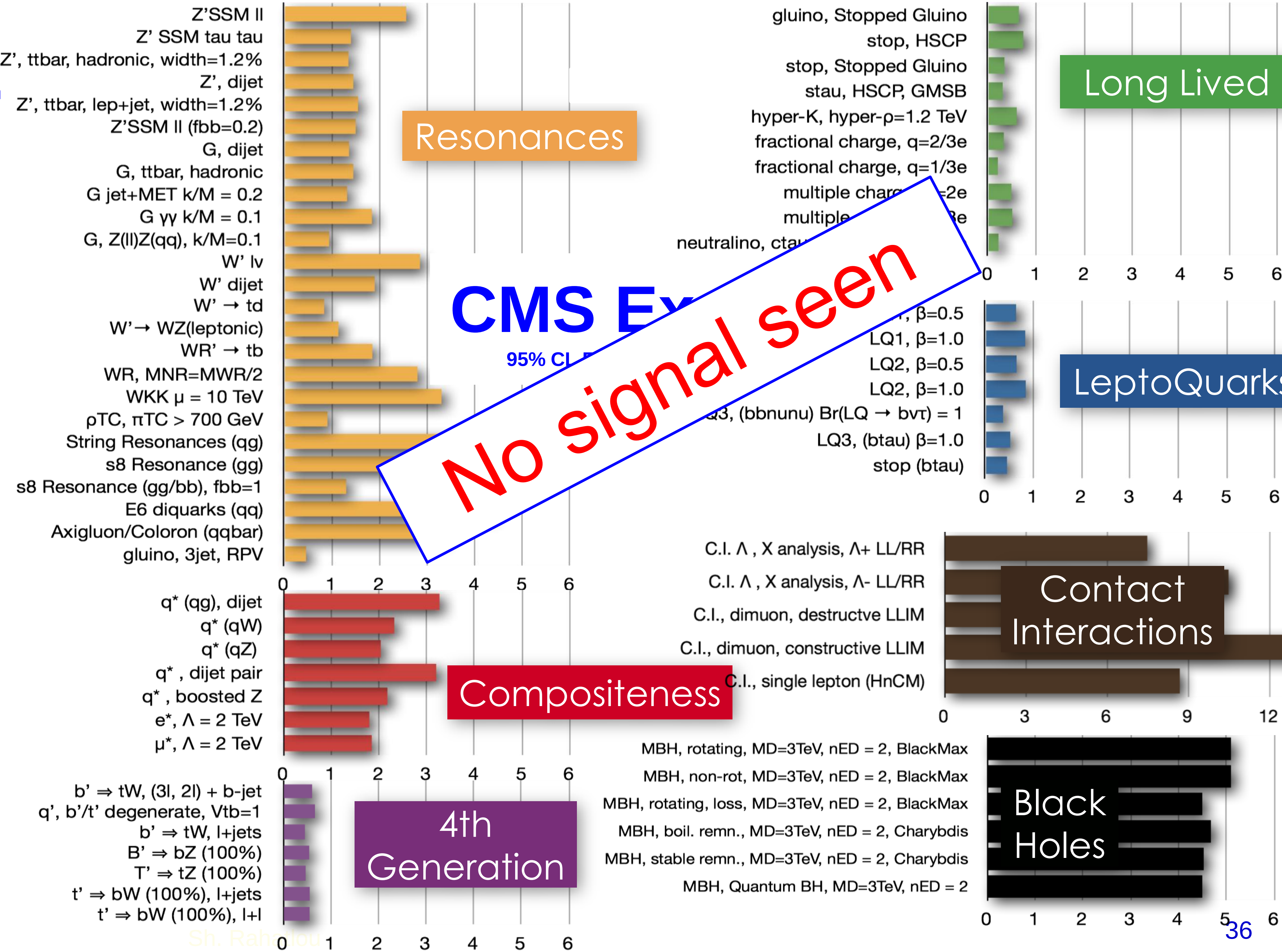


E.g.: Gaugino production



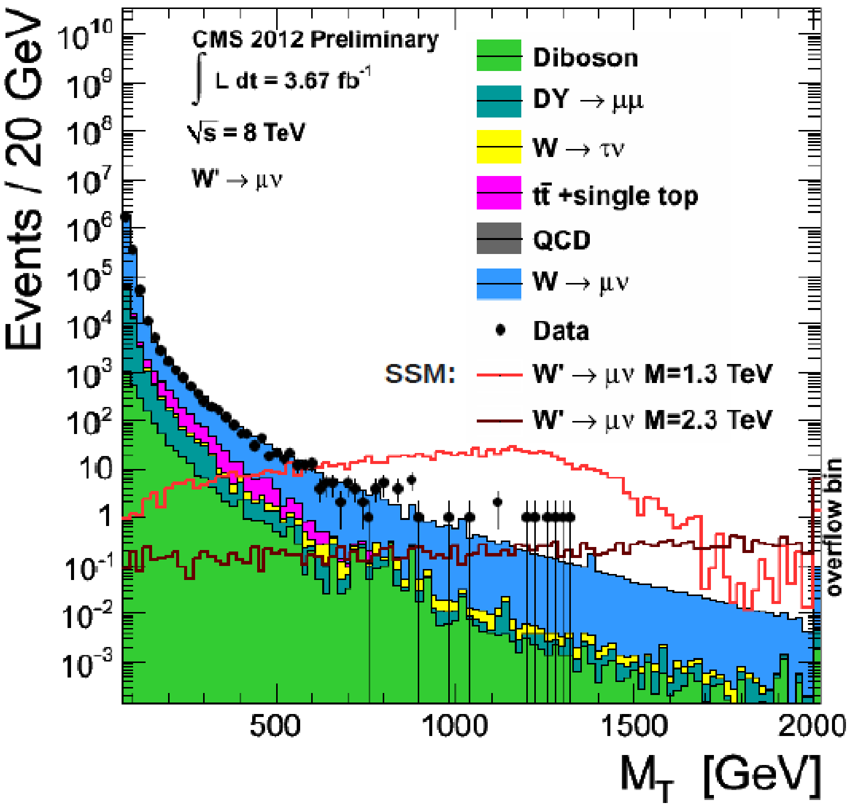




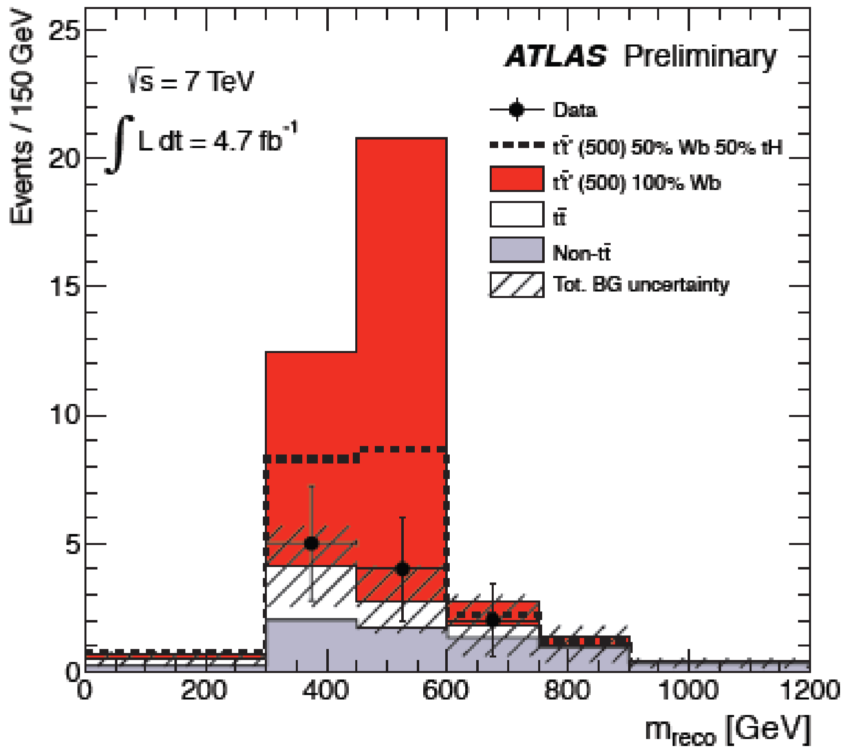

CMS Ex
95% CL
No signal seen
Resonances
Z'SSM ll
Z' SSM tau tau
Z', ttbar, hadronic, width=1.2%
Z', dijet
Z', ttbar, lep+jet, width=1.2%
Z'SSM ll (fbb=0.2)
G, dijet
G, ttbar, hadronic
G jet+MET k/M = 0.2
G γγ k/M = 0.1
G, Z(ll)Z(qq), k/M=0.1
W' lv
W' dijet
W' → td
W'→ WZ(leptonic)
WR' → tb
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
s8 Resonance (gg/bb), fbb=1
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
0 1 2 3 4 5 6
Compositeness
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
0 1 2 3 4 5 6
4th Generation
b' ⇒ tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' ⇒ tW, l+jets
B' ⇒ bZ (100%)
T' ⇒ tZ (100%)
t' ⇒ bW (100%), l+jets
t' ⇒ bW (100%), l+l
0 1 2 3 4 5 6
Long Lived
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
fractional charge, q=2/3e
fractional charge, q=1/3e
0 1 2 3 4 5 6
LeptoQuarks
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3, (btau) β=1.0
stop (btau)
0 1 2 3 4 5 6
Contact Interactions
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., dimuon, destructve LLIM
C.I., dimuon, constructive LLIM
C.I., single lepton (HnCM)
0 3 6 9 12
Black Holes
MBH, rotating, MD=3TeV, nED = 2, BlackMax
MBH, non-rot, MD=3TeV, nED = 2, BlackMax
MBH, rotating, loss, MD=3TeV, nED = 2, BlackMax
MBH, boil. remn., MD=3TeV, nED = 2, Charybdis
MBH, stable remn., MD=3TeV, nED = 2, Charybdis
MBH, Quantum BH, MD=3TeV, nED = 2
0 1 2 3 4 5 6

Search for W', Z', t'

W' →μν



t' t̄' production



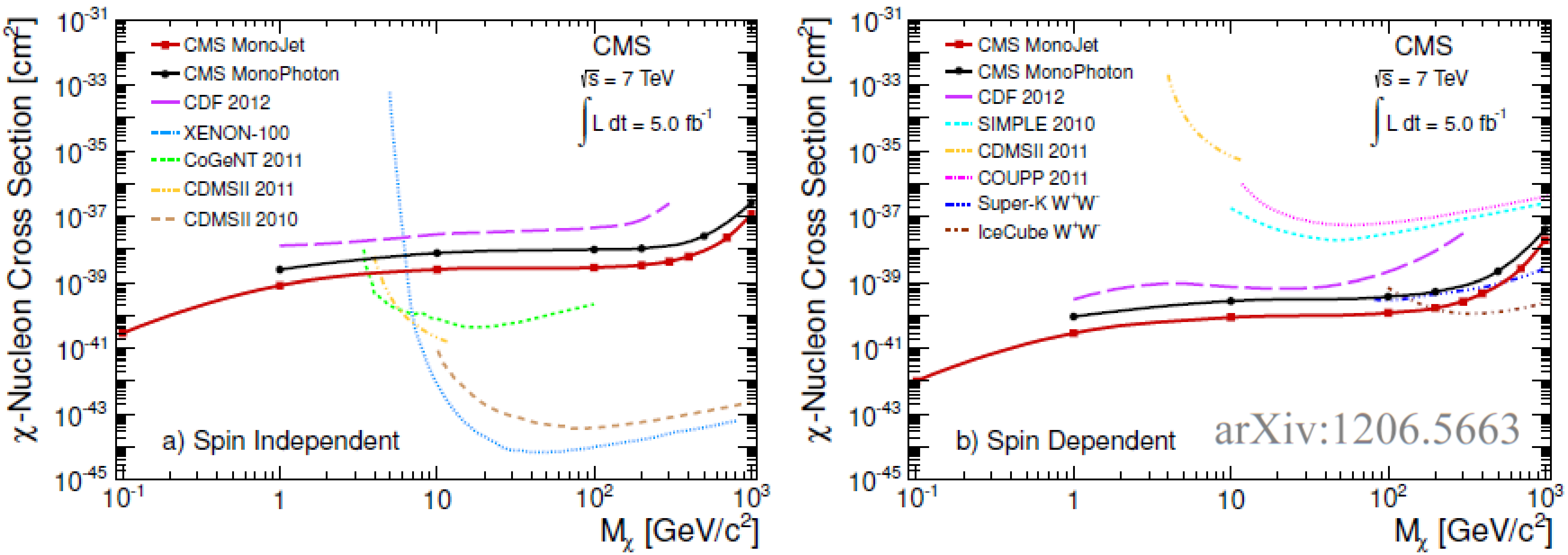
M(W') > 2.85 TeV
Similar: M(Z') > 2.59 TeV

t' masses < 656 GeV excluded
(assuming BR(t'→Wb)=100%)

Exotica – Dark matter searches

Mono-jet / mono-photon + miss ET:

- ISR used to tag invisible DM pair
- Limits on effective contact interaction scale turned into limits on $\sigma_{\chi N}$



Complementary to direct detection experiments


FUTURE

LHC Time-line

R. Heuer ICHEP 2012

2009 — Start of LHC

Run 1: 7 and 8 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity ← LS1

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2018 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Phase I Upgrades: Prepare detectors for increased luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2022 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Phase II Upgrades R&D starts now

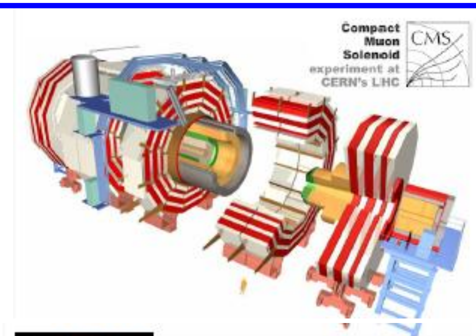
Run 4: Collect data until > 3000 fb^{-1}

2030

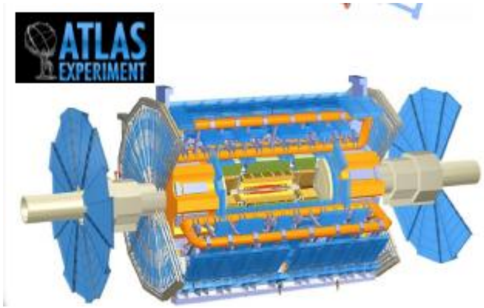
In-Situ Activities in Shutdown LS1

Completion, Maintenance & Consolidation

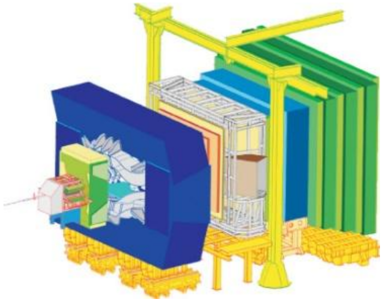
- Complete muon coverage (ME4)
- Improve muon operation (ME1),
  Relocation of DT electronics (AC)
- Replace HCAL photo-detectors (DESY)



- Installation of new pixel layer ILB
  (BN, SI,W, DO, GÖ, MPI, HD-ZITI)
- New Be+Alu beam-pipe
- Pxel services, cooling plant
- L1 Calo, FastTracKer,Topo Trigger (MZ,HD)
- Complete endcap extension muon chamb.
- Consolidation of calorimeter power supplies
- Upgrade magnet cryogenics



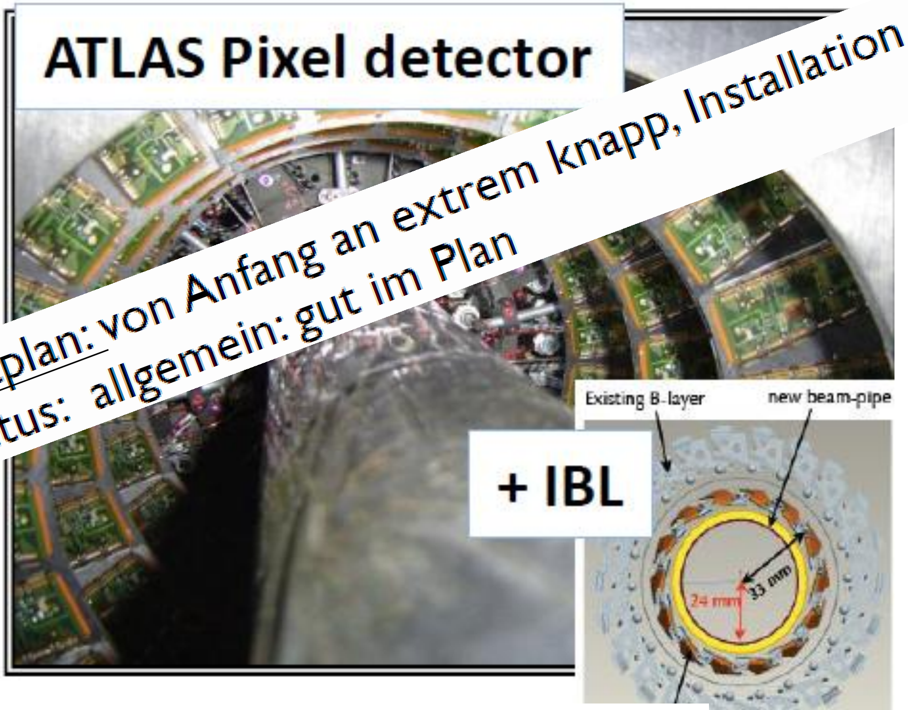
- Maintenance
- Prepare infrastructure for Upgrade



ATLAS Insertable Layer B

C.Goessling

Zeitplan: von Anfang an extrem knapp, Installation Ende 2013
Status: allgemein: gut im Plan



…ige Beiträge deutscher Gruppen :

Berlin / DESY:
- opt.Fasern
- Teststrahl

Bonn:
- FE-I4, FE- und Modultestsysteme
- Bump-Bonding, Modul-Entwicklung
- Teststrahl
- Serial-Powering-Konzept

Dortmund:
- planare Sensoren, slim edges,
- Strahlungsharte Sensoren, Teststrahl

Göttingen:
- FE- und Modultestsysteme
- DAQ-Software
- Teststrahl

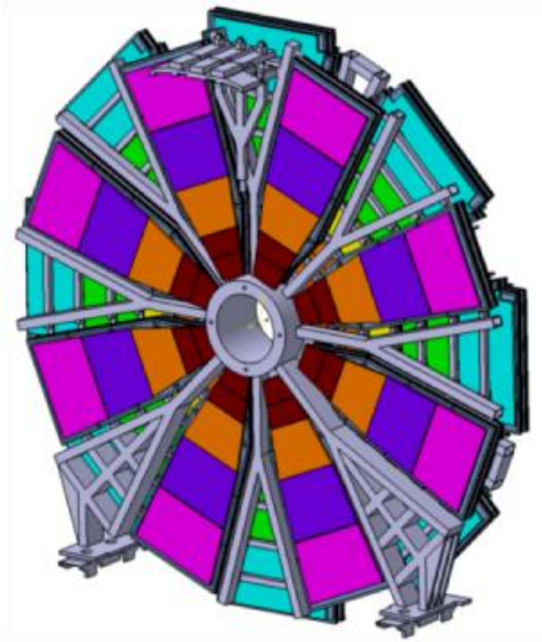
Siegen:
- optical links
- optochip

Wuppertal:
- Stave- Entwicklung, Mechanik-Entwicklung
- Modul-Placement
- Off-Detektor-Elektronik, DCS- System

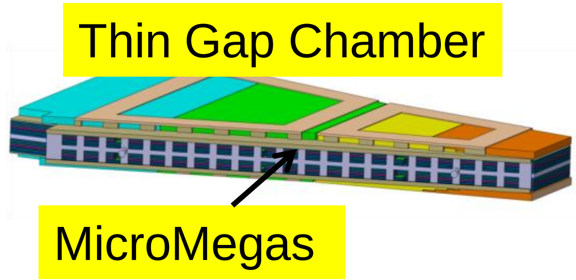
Wupp.+Heidelberg:
- Optolink, BOC

München (MPI):
- Design und Produktion planarer Sensoren

ATLAS Phase I - Projects



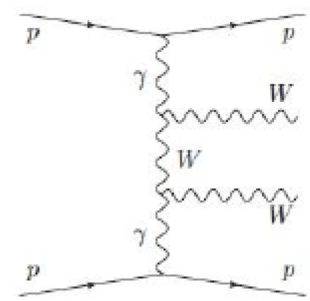
New small muon wheel:



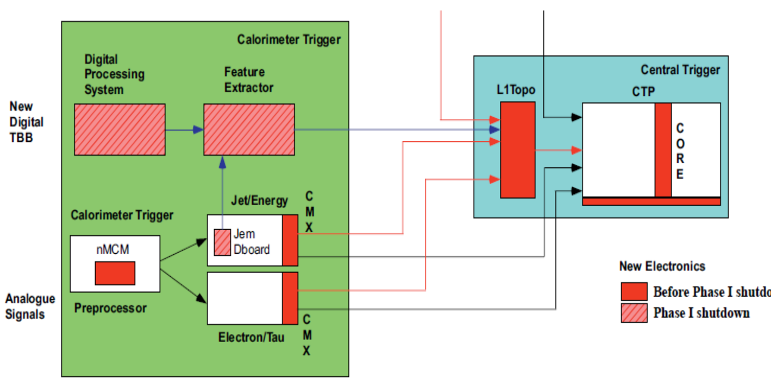
FR, LMU, Wü: Test Beams

ATLAS Forward Physics:

GI, W



Detect protons at ±210m:
3D Silicon as tracker



DD, HD

Calorimeter Trigger:

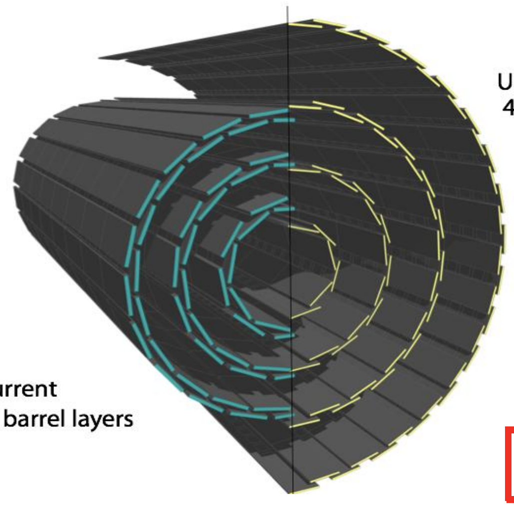
- improved MCM
- increase granularity
- signal processing at FE

HD, MZ

Central Trigger:

- Topological trigger
- FasTracKer (after L1)

CMS Phase I - Projects



Pixel detector

- Less material
- new readout chip
- extra layer,
- better radial distribution

Ready to install by end of 2016

4th layer in D: AC-IB, KIT, DESY, HH

L1-Trigger upgrade

- μTCA standard
- improve muon, calo and gobal trigger

[B. Lutz, CALOR2012]

HCAL

New photon-detectors: SiPMs
→ highly segmented readout

Start replacement in LS1

DESY

Muon detector

Relocation of DT readout& trigger electron.

Starts already in LS1

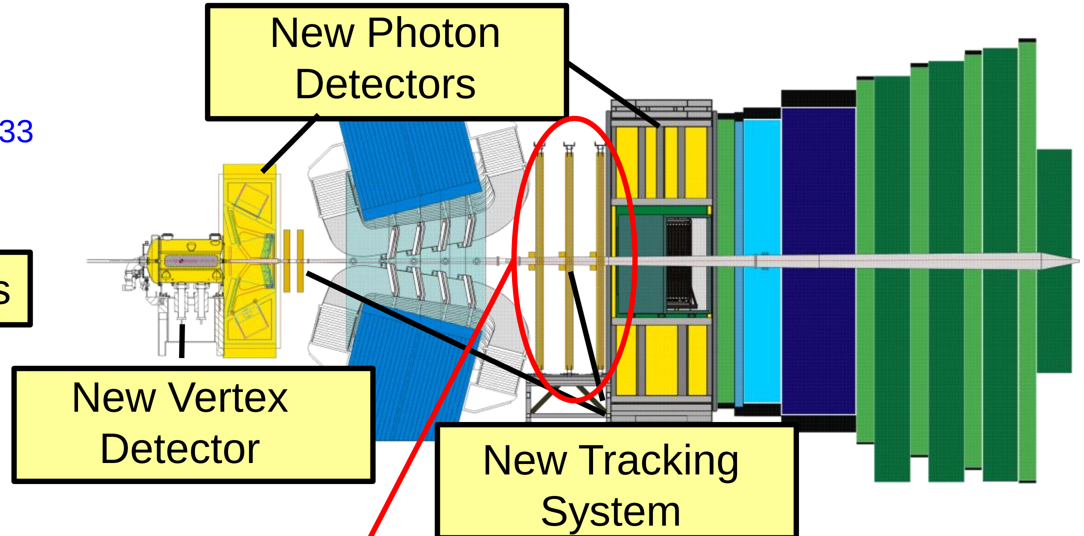
AC IIIA

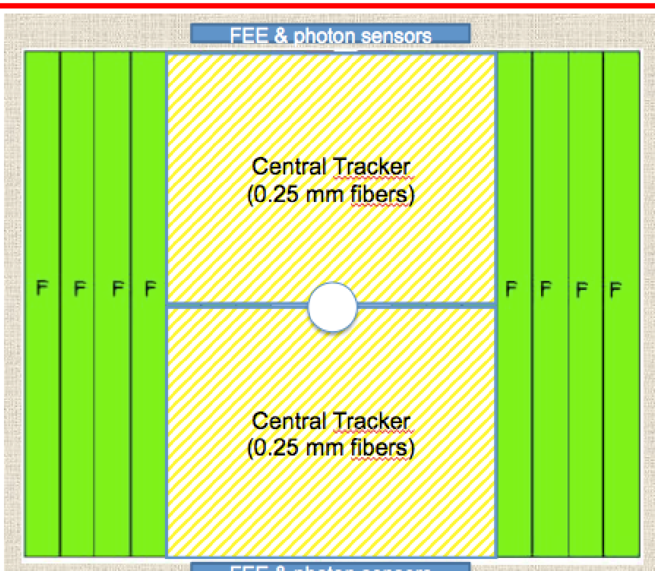
LHCb - Upgrade

Upgrade concept:

- Increase luminosity up to 2×10^{33}
- Readout every event:

  → new 40 MHz readout electronics
- HLT software trigger





Scintillating Fiber Tracker

2.5 m long fibers, 0.25 mm diameter
Readout w/ SiPMs

German participation: DO, HD

Preparation of High-Lumi Phase (II)

After 2022: L >5$\times$10^{34} (lumi leveling)
Pile-up > ~100

- Extreme multiplicities, too high for current trackers
- Detectors will have collected >300 1/fb (design goal) and suffer radiation damages (inner detectors).

$\rightarrow$ Replacement of inner tracking detectors

$\rightarrow$ Replacement of forward detectors

$\rightarrow$ Replacement of electronics

$\rightarrow$ New trigger concepts: precise timing!

R&D Program:
- New detector concepts
- New electronics
- New algorithms

⇩ Huge effort

<u>German participation:</u>

CMS: Tracker R&D within Central European Consortium
ATLAS: R&D for Pixel & Si Strips, calorimeter electronics

LHCb: running with phase I detector

Conclusion

- LHC is a fantastic physics factory …
- The discovery of the new boson is a triumph of our field, possible only because of long-term international effort.
- Higher LHC energy and more luminosity will open further windows for new measurements and discoveries: Need to prepare now!

German groups play a very important and visible role in the detector operation and in the analysis. But

- Operation of detectors (a must)
- Necessary upgrade work (a must for future)

leave less and less resources for data analysis.

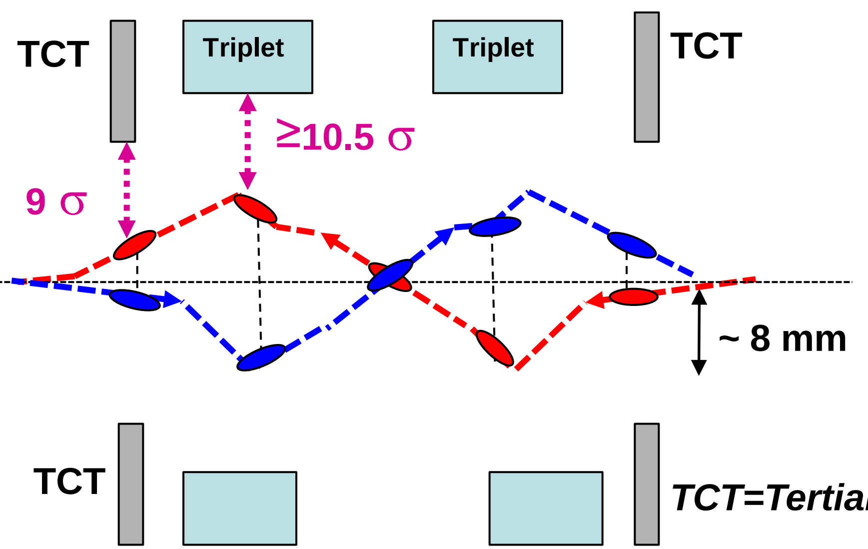
Additional Material

Limits on β*

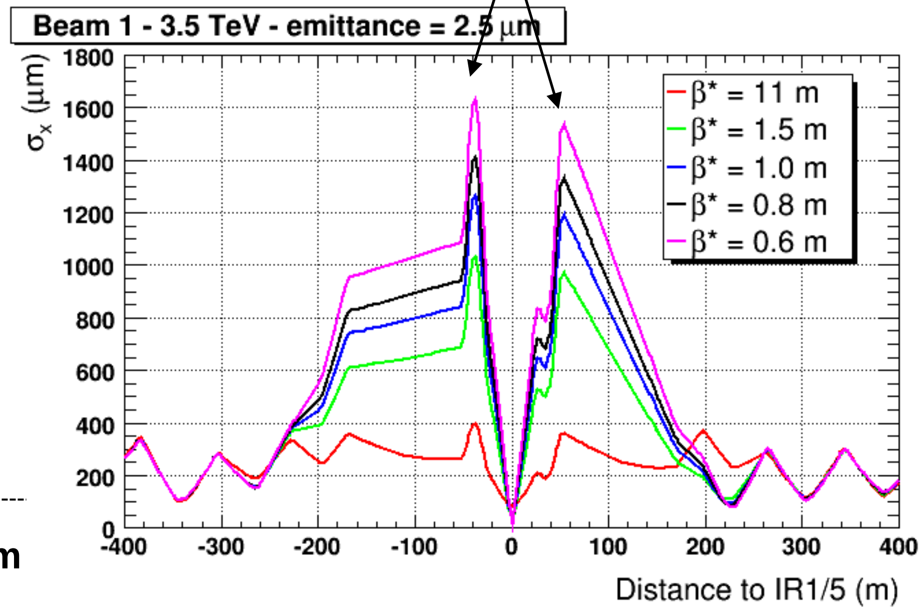
In the high luminosity IRs, the triplet quadrupoles define the <u>*machine aperture limit*</u> for squeezed beams, β* is constrained by:

- *the beam envelope,*
- *a margin TCT to triplet ,*
- *the **<u>crossing angle</u>** – separation of the beams at the parasitic encounters.*

$$\sigma_{triplet} \propto \sqrt{\frac{\varepsilon}{\beta^* \gamma}}$$

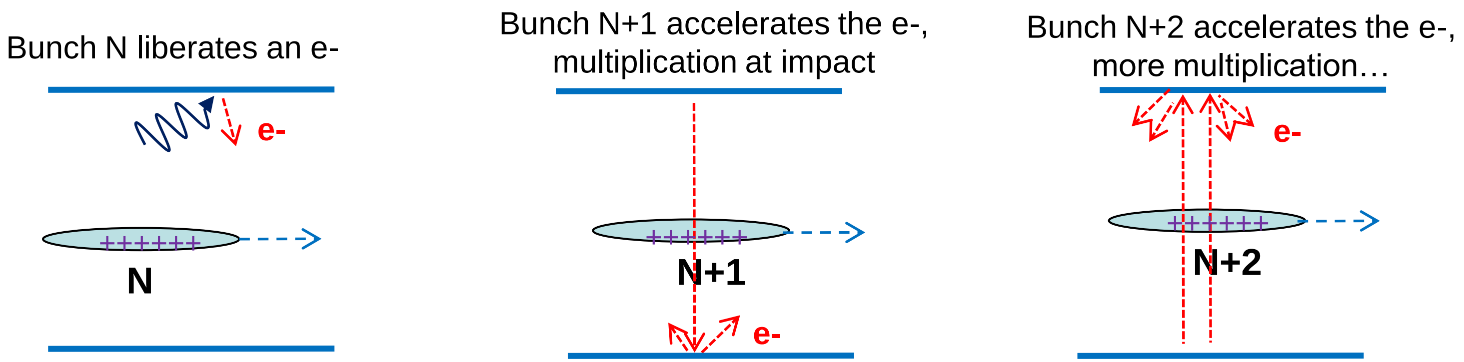


TCT=Tertiary Collimator



25 ns running

- 25 ns beams suffer from severe electron cloud effects ($\rightarrow$ vacuum rise & beam instabilities)

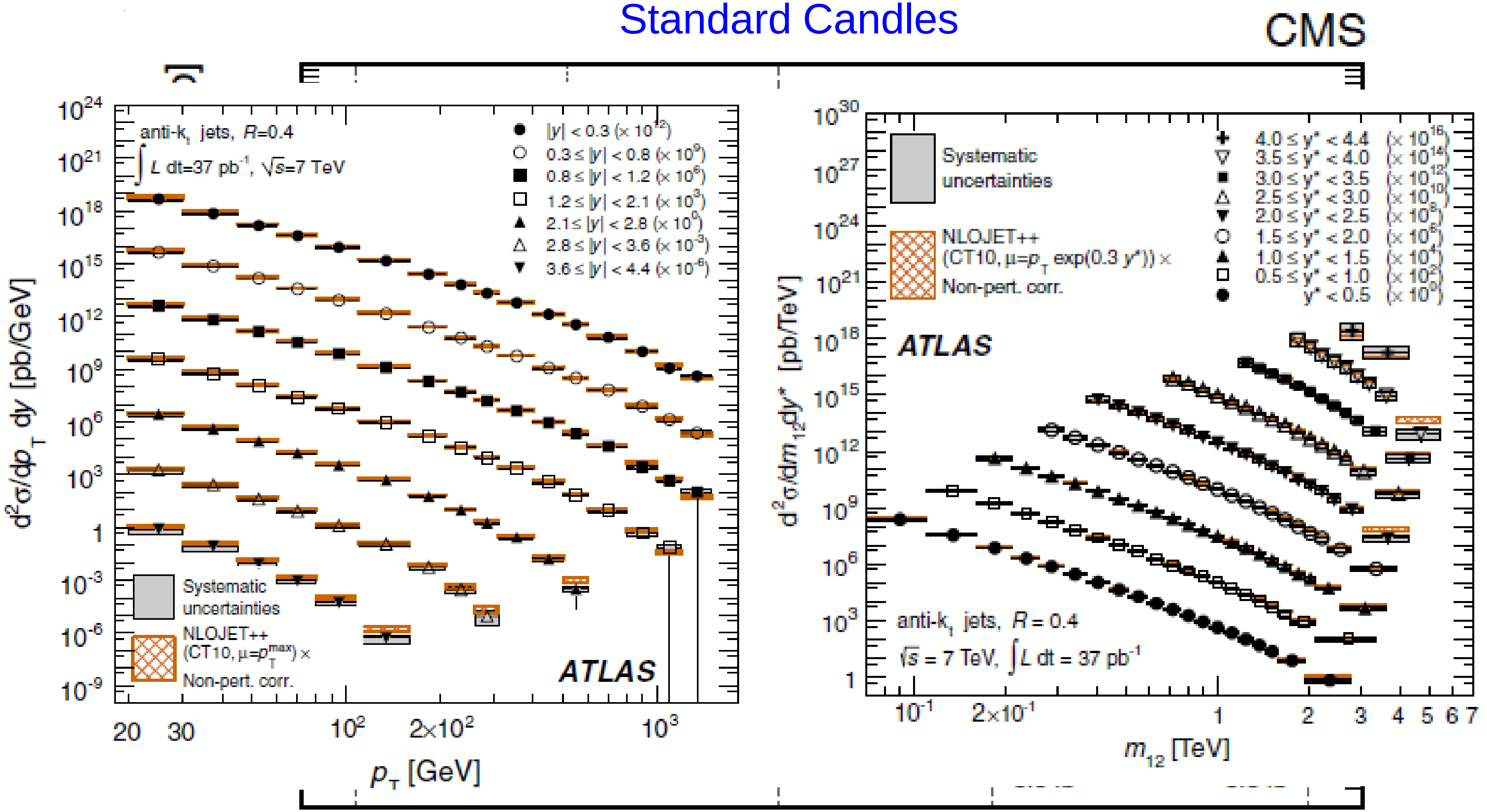


<u>25 ns tests before end of running:</u>

- Needs conditioning = “scrubbing runs”
- To study: e-cloud, heating, beam-beam related instabilities, UFOs
- Compare 25 ns and 50 ns w/ β^* leveling to 38 PU events

Production of electroweak Bosons

Standard Candles



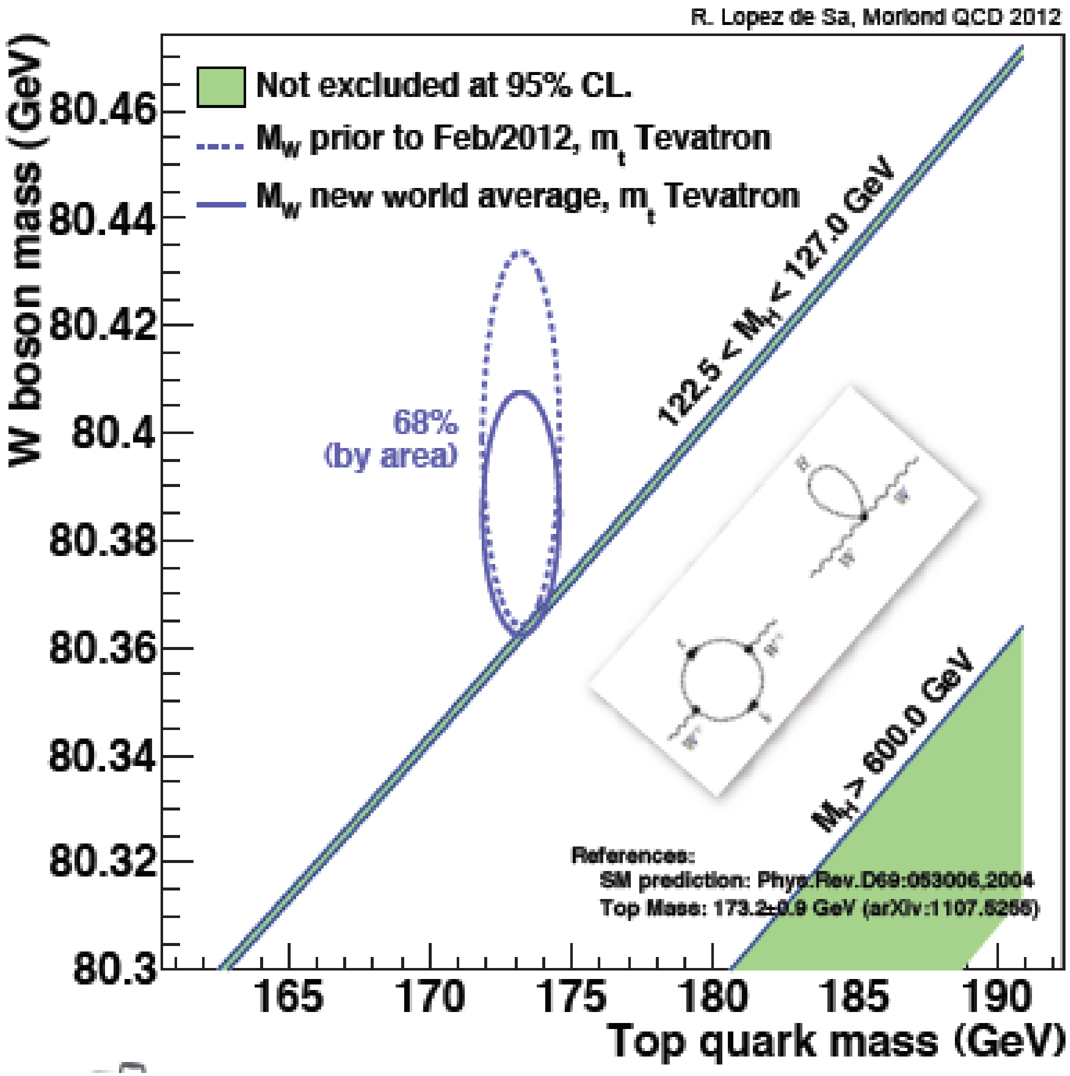
JHEP10(2011)132
JHEP01(2012)010
CMS-PAS-SMP-12-011 (W/Z 8 TeV)

PLB701(2011)535

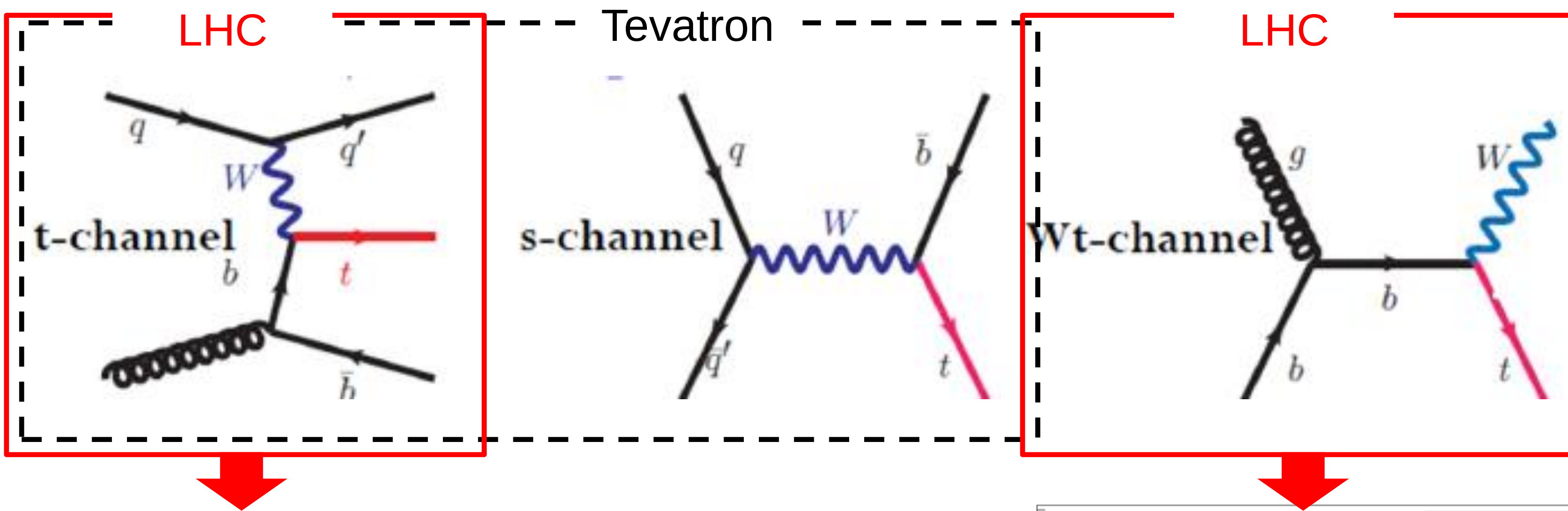
CMS-PAS-EWK-11-010 (WZ)
CMS-PAS-SMP-12-005, 007, 013, 014 (WW ZZ)

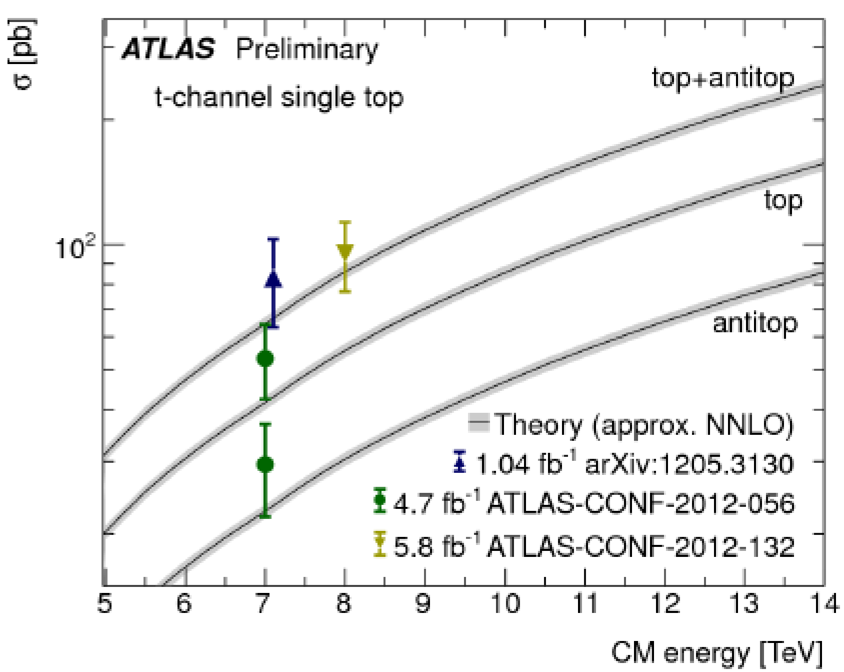
Standard Model works extremely well.

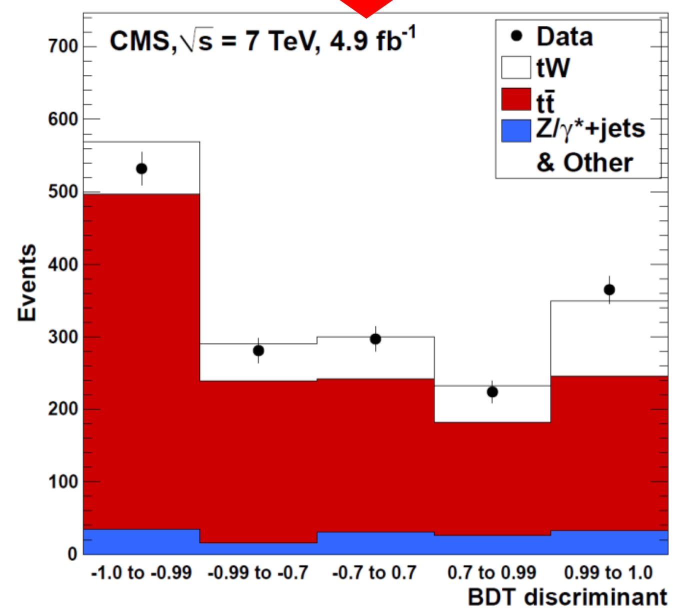
Higgs Constraints



Single Top Production







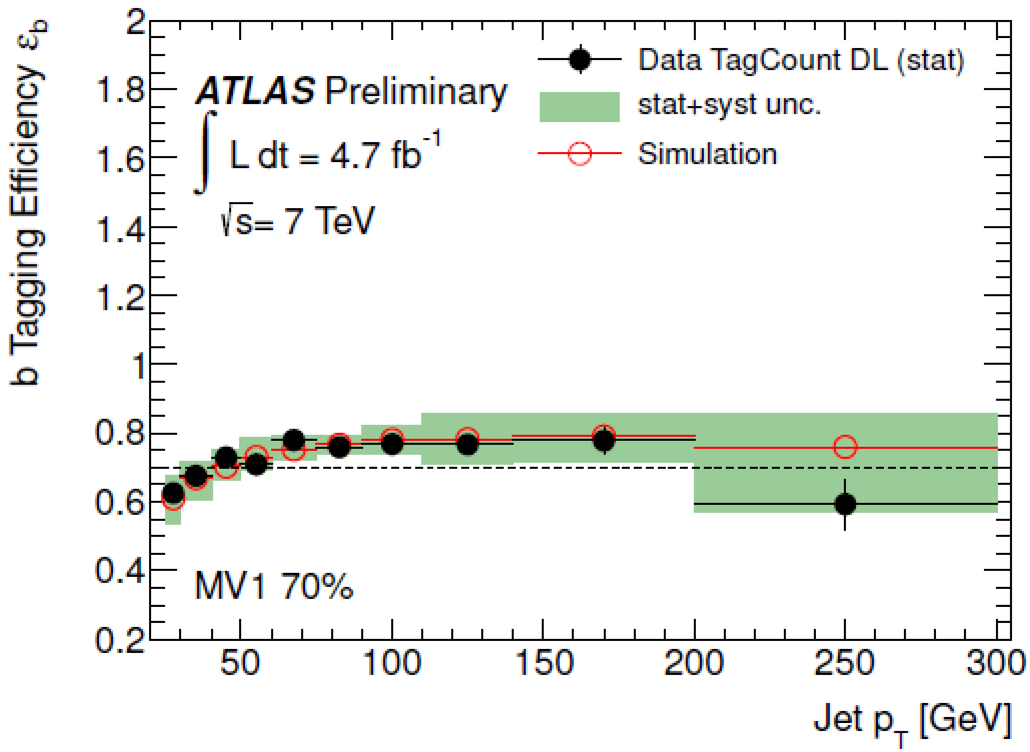
$\sigma = 16^{+5}_{-4}$ pb (4σ significance)

$V_{tb} = 1.01_{-0.13}$ (exp.) $_{-0.04}$ (th.)

$t\bar{t}$ Events as Calibration Signal

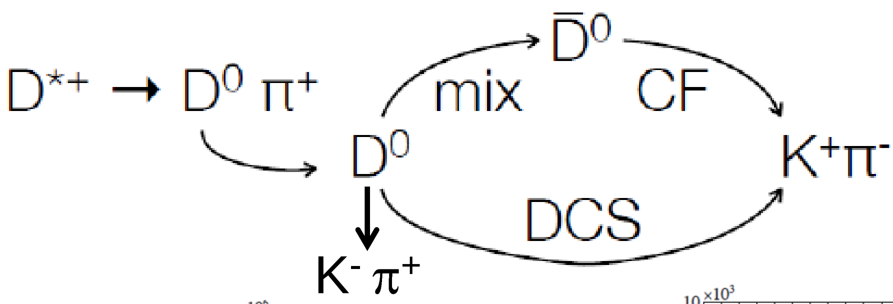
<u>b-tagging efficiency:</u>

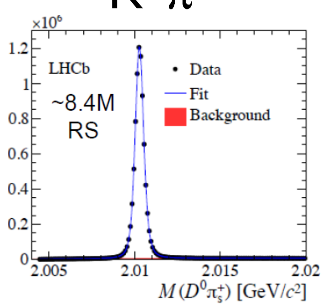
Count # b-tags in tt events
→ much reduced systematics

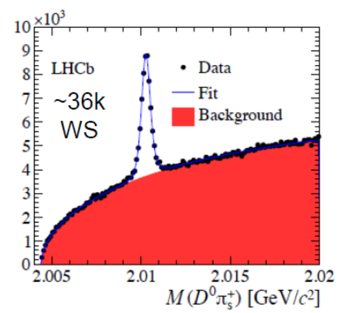


Detour: Charm Physics

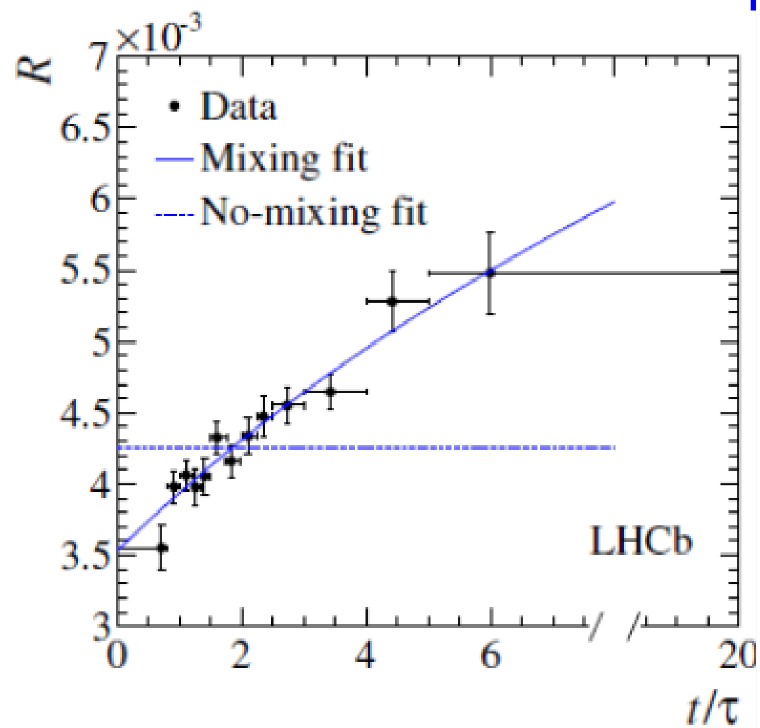
D^0 - D^0 mixing







$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}\, y' \frac{t}{\tau} + \frac{x'^2 + y'^2}{4} \left(\frac{t}{\tau}\right)^2$$



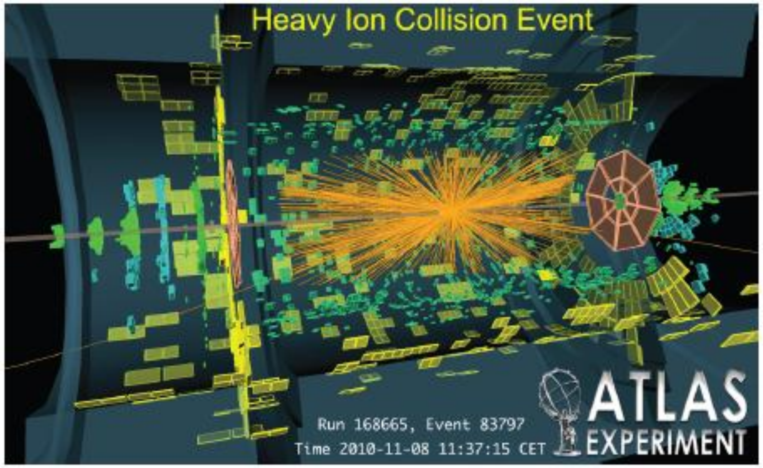
CP violation in D^0 decays

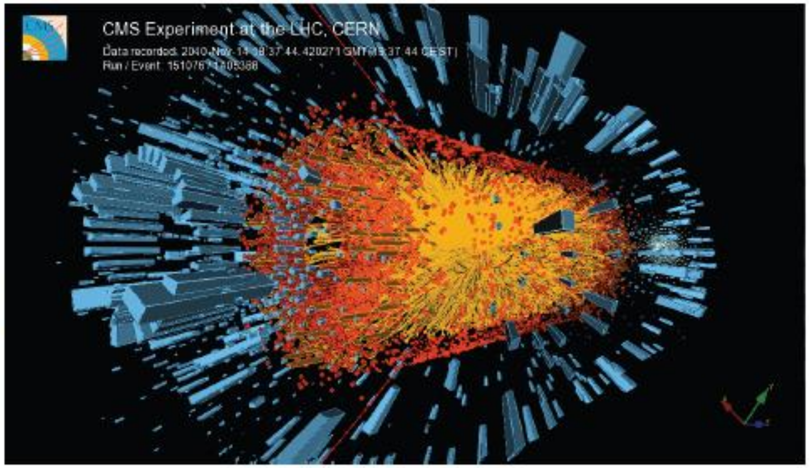
1st evidence (3.5σ) for CPV.
larger than expected

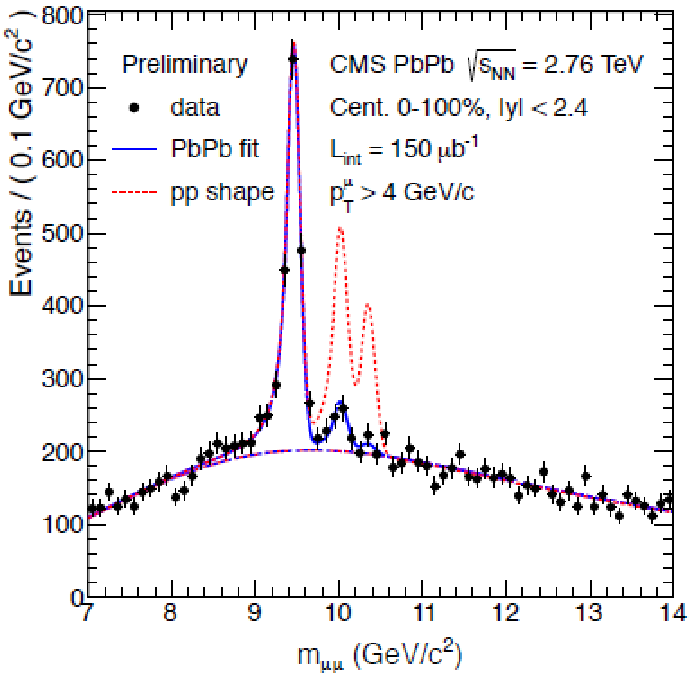
$\Delta A_{CP} = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$

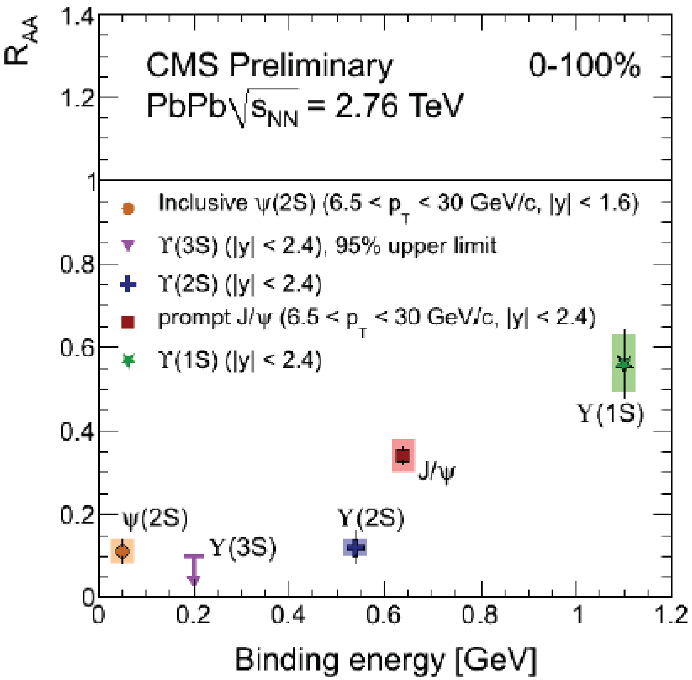
$\Delta A_{CP} = [\,-0.82 \pm 0.21_{stat} \pm 0.11_{syst}\,]\ \%$

Heavy Ion Physics









Melting Map