Summary of the Electroweak and Searches Working Group (Part 1).

Introduction
SM and BSM Higgs Searches
Non-SUSY Searches

David South (DESY)
Andreas Weiler (DESY)
Hwi Dong Yoo (Purdue University)

HELMHOLTZ ASSOCIATION

XX International Workshop on Deep-Inelastic Scattering and Related Subjects

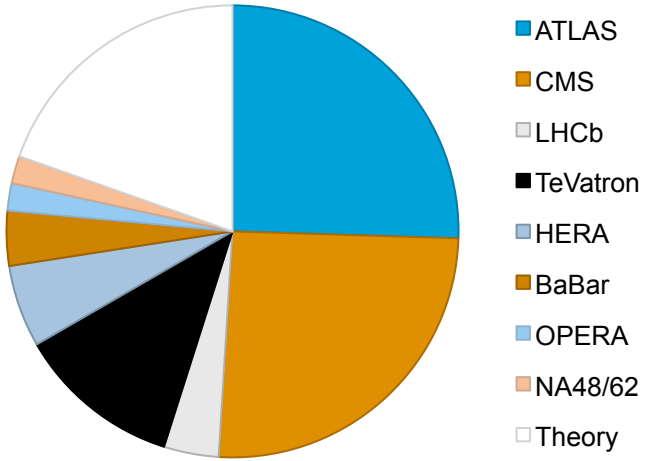
26-30 March 2012, University of Bonn

DESY

Electroweak and Searches Parallel Sessions

- 51 talks in total, including joint sessions with the Structure Functions and Heavy Flavour groups
- The agenda was broken down as follows:
  - SM Higgs
  - BSM Higgs
  - Non-SUSY Searches

  } covered in this talk
  - SUSY Searches
  - W and Z Properties
  - W and Z Production (covered in SF summary)
  - Exotic Top
  - Exotic Heavy Flavour (covered in HF summary)



- Many new results shown (often more than 10 analyses in one talk!), impossible to give them all justice
  - Apologies to those missed or only briefly shown

The TeVatron

- The sun finally sets on the TeVatron after 25 years of data taking
- 12 fb^{-1} of p-pbar collisions delivered to CDF and D0, latest results now using 10 fb^{-1} of good data on tape

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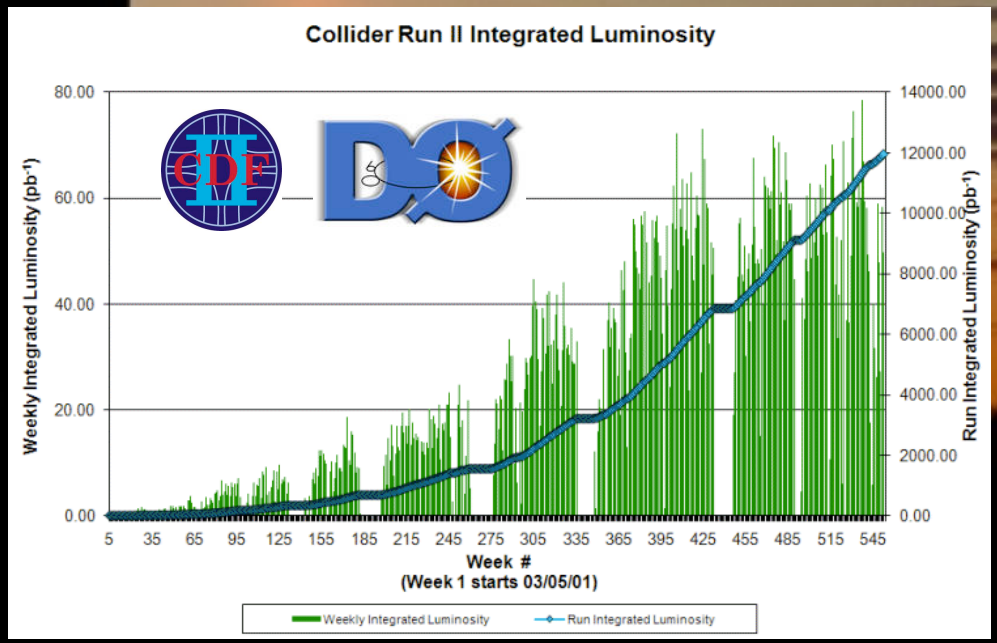
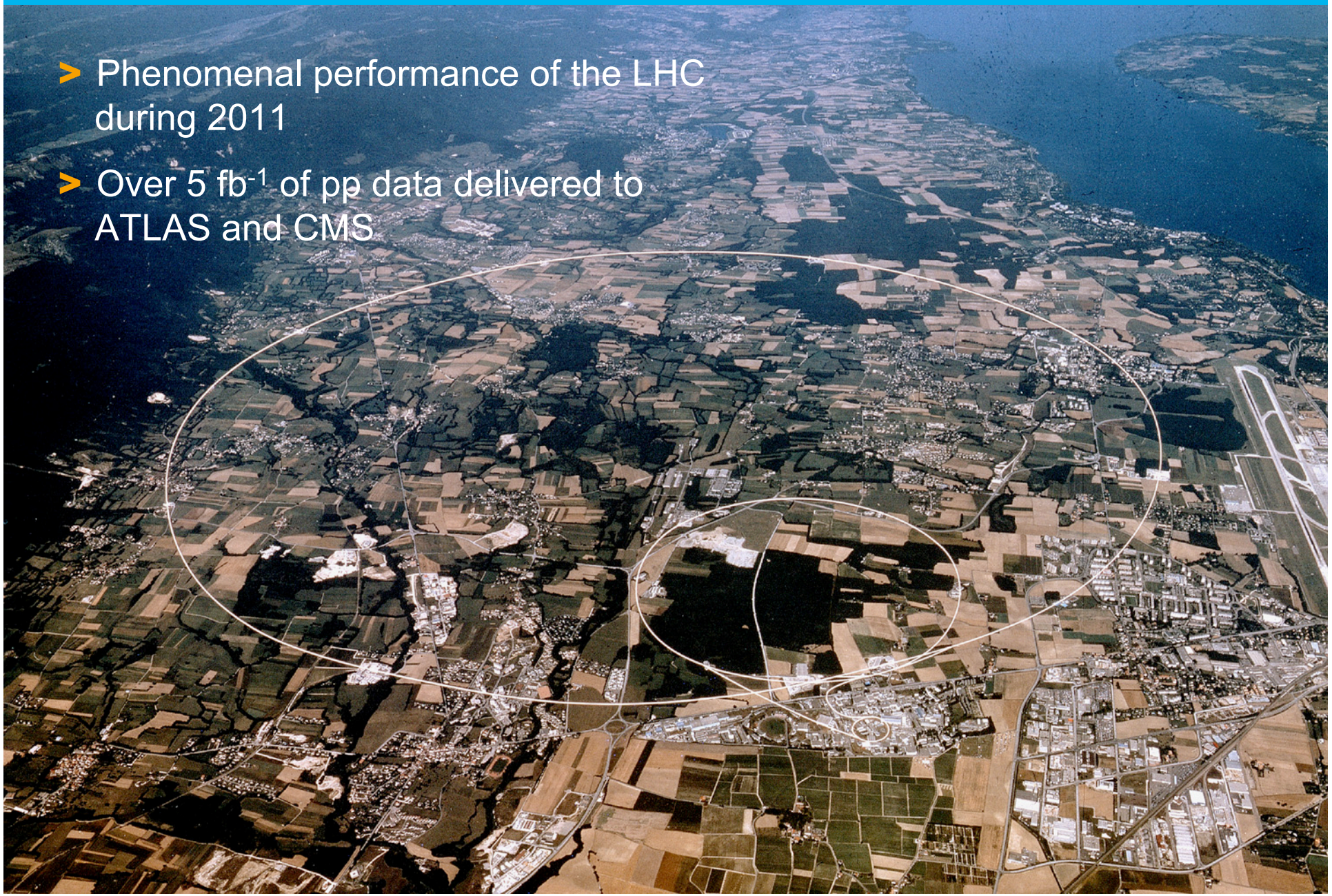


- Legacy results now coming out of the collaborations using the up to the full data set

The LHC



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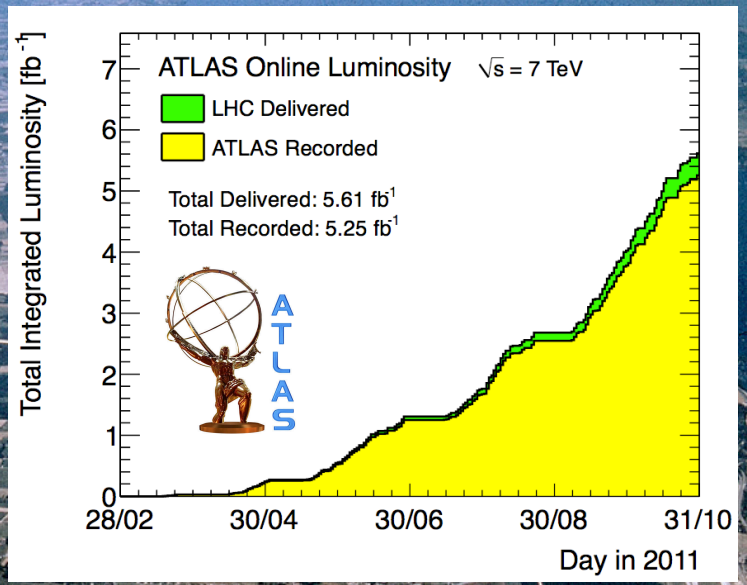
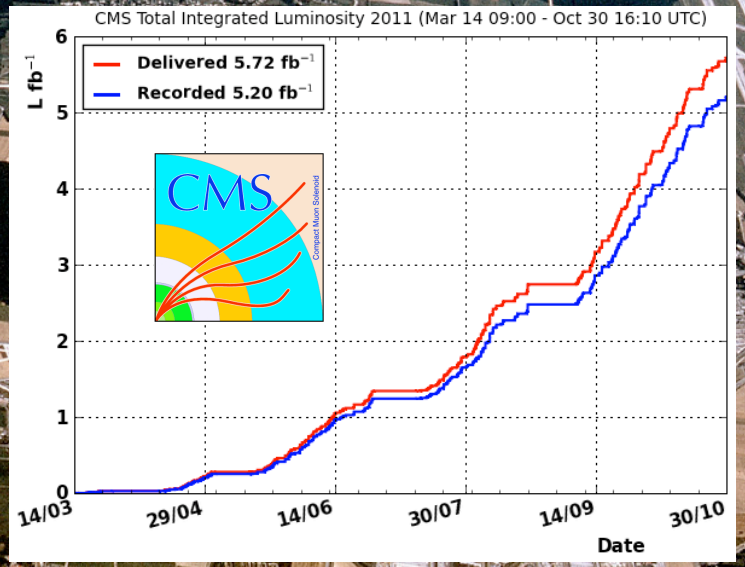
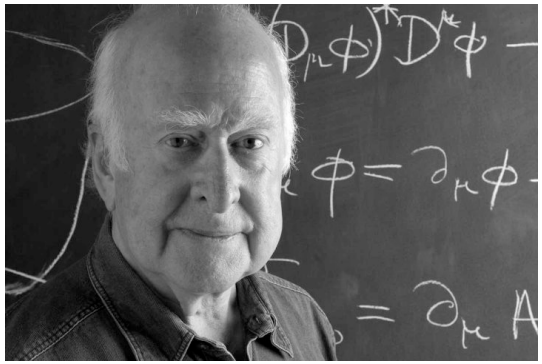




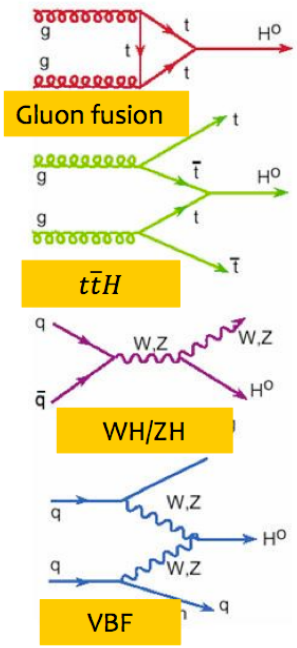
- Many of the results in our session already include most of this data

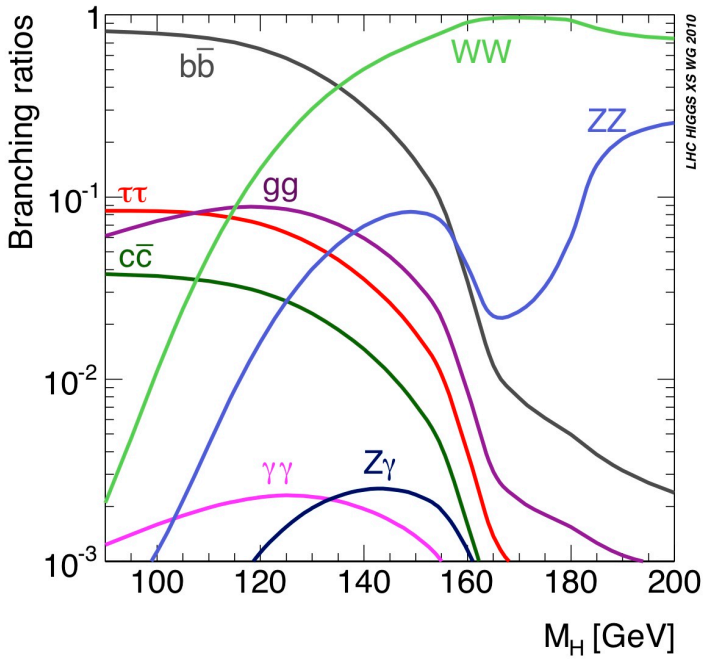
Where else to start? The SM Higgs

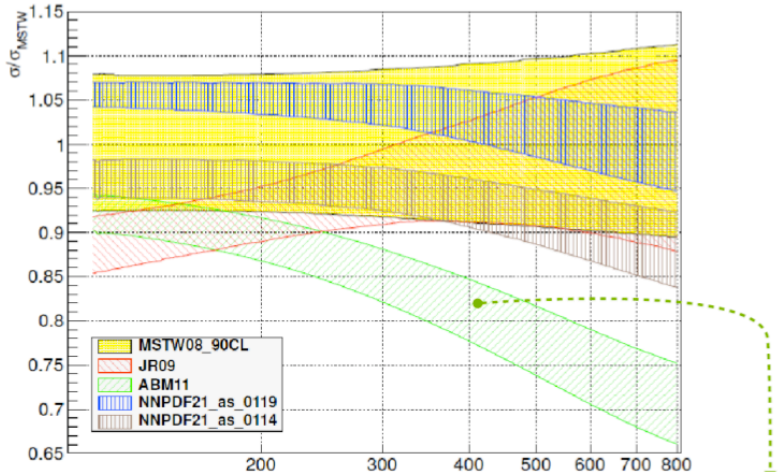
Franz Herzog



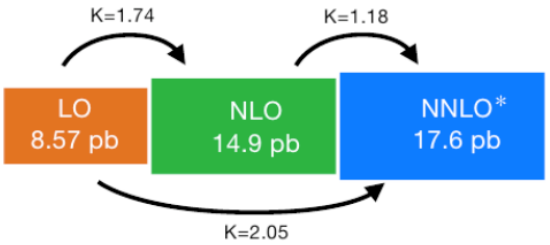
- The EWSB mechanism which gives fermions mass and explains the heavy W and Z bosons







- Nice overview of given by Franz on the status of the current SM Higgs theory
- Production cross section under control
- Gluon fusion:
  - Large kFactors
  - PDF differences



Higgs searches at the LHC: Impressive and substantial

Channel	Higgs mass range (GeV)	$\int \mathcal{L}dt$ (fb^{-1})	Reference
Low m_H, good mass resolution			
$H \to \gamma\gamma$	110-150	4.9	arXiv:1202:1414
$H \to ZZ^{(*)} \to 4l$	110-600	4.8	arXiv:1202:1415
Low m_H, limited mass resolution			
$H \to WW^{(*)} \to lvlv$	110-600	4.7	CONF-2012-012
$H \to \tau\tau(\mathrm{ll}, \mathrm{lh}, \mathrm{hh})$	100-150	4.7	CONF-2012-014
$VH, H \to b\bar{b}$	110-130	4.7	CONF-2012-015
High m_H			
$H \to ZZ \to llvv$	200-600	4.7	CONF-2012-016
$H \to ZZ \to llqq$	200-600	4.7	CONF-2012-017
$H \to WW \to lvqq$	300-600	4.7	CONF-2012-018

- Full spectrum of production and decay models covered by ATLAS (top) and CMS (bottom) analyses
- Multiple decay channels and analysis sub-channels investigated

channel	mass range (GeV)	M_H resolution
H → γγ	110 - 150	1-2%
H → ττ → eτh/μτh/eμ + X	110 - 145	20%
H → ττ → μμ + X	110 - 140	20%
WH → eμτh/μμτh + ν	110 - 140	20%
(W/Z)H → bb	110 - 135	10%
H → WW → ℓνℓν	110 - 600	20%
WH → W(WW*) → 3ℓ3ν	110 - 200	20%
H → ZZ→ 4ℓ	110 - 600	1-2%
H → ZZ→ 2ℓ2q	(130 - 164) + (200 - 600)	3%
H → ZZ→ 2ℓ2τ	190 - 600	10-15%
H → ZZ→ 2ℓ2ν	250 - 600	7%

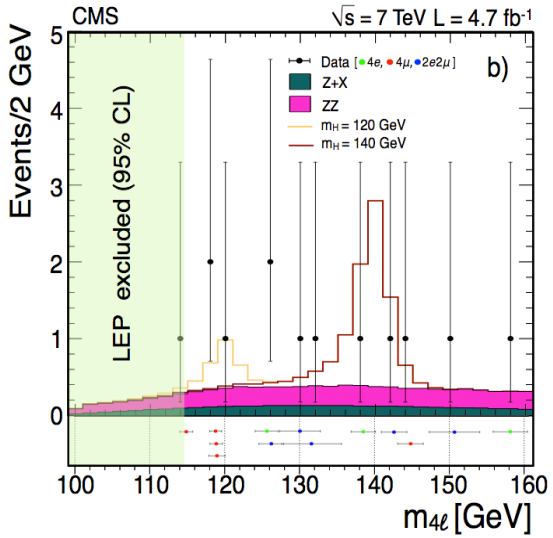
- A brief look here on only two decay channels:
- ZZ → 4 leptons
- H→ γγ

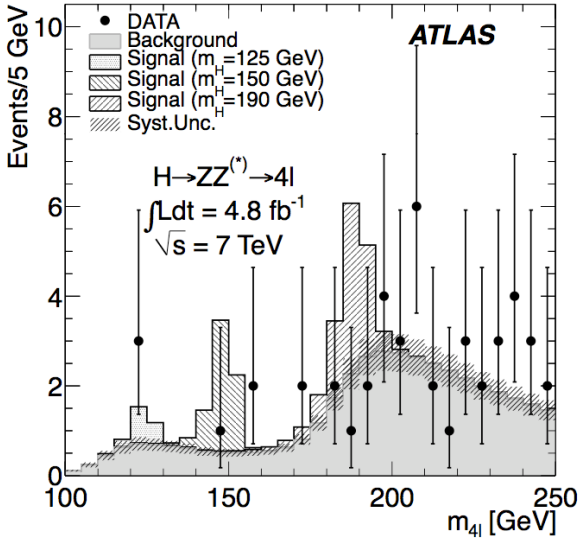
Prolay Kumar Mal
Pietro Govoni

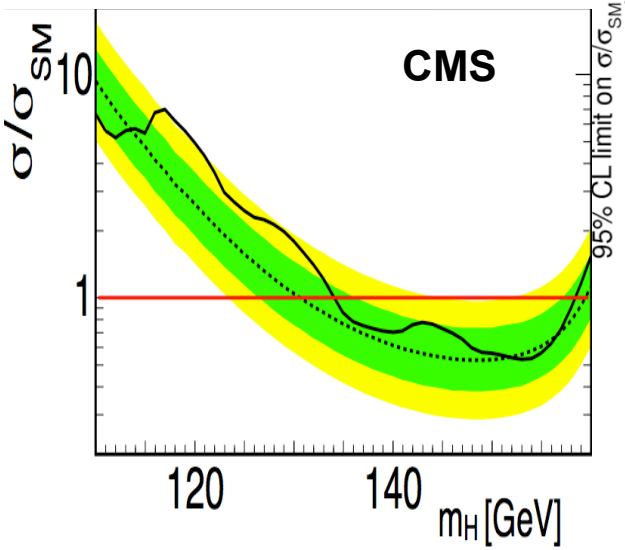
Higgs to ZZ with 4 charged lepton decay

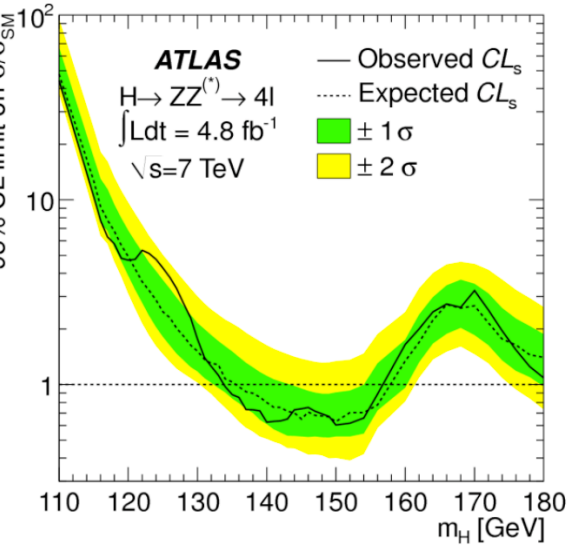
Prolay Kumar Mal
Pietro Govoni

- Clean channel: 2 high mass pairs of isolated electrons or muons with a **narrow mass peak** and **small background**
- Select **4 leptons** of appropriate charge and flavour combination
- Interesting events around 120 GeV
- Significance of excess at lower masses:
  - CMS: local significance 2.5σ
  - ATLAS: local significance 2.1σ
- Globally much less significant





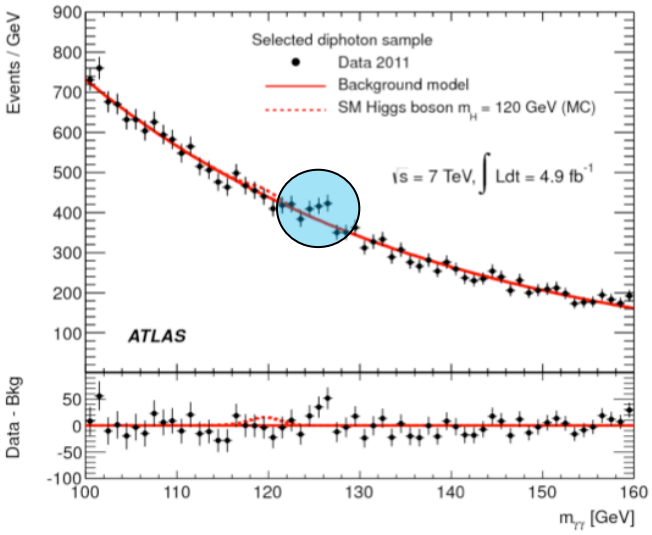


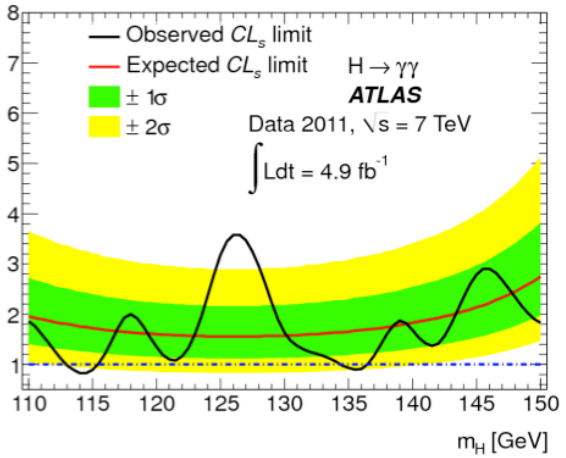


Higgs to γγ

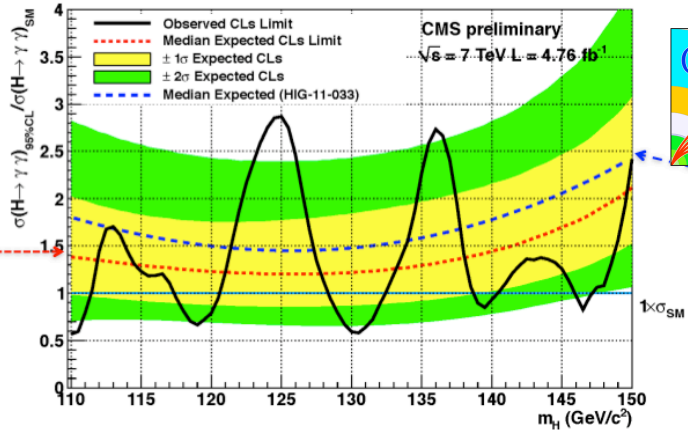
Prolay Kumar Mal
Pietro Govoni

- Small branching ratio, 0.1%, but clean signature and good mass resolution
- Analysis divided into different catagories:
  - ATLAS: 9 orthogonal categories having different $m_{\gamma\gamma}$ resolutions
  - CMS: VBF tagged + 4 event classes according to BDT decision (resolution, photon ID, kine variables..)
- Channel displaying excess with largest local significances 2.8σ / 2.9σ for ATLAS / CMS





Observed exclusion:
113-115 GeV and, 134.5-136 GeV



Expected from MVA analysis Improvement ~20%

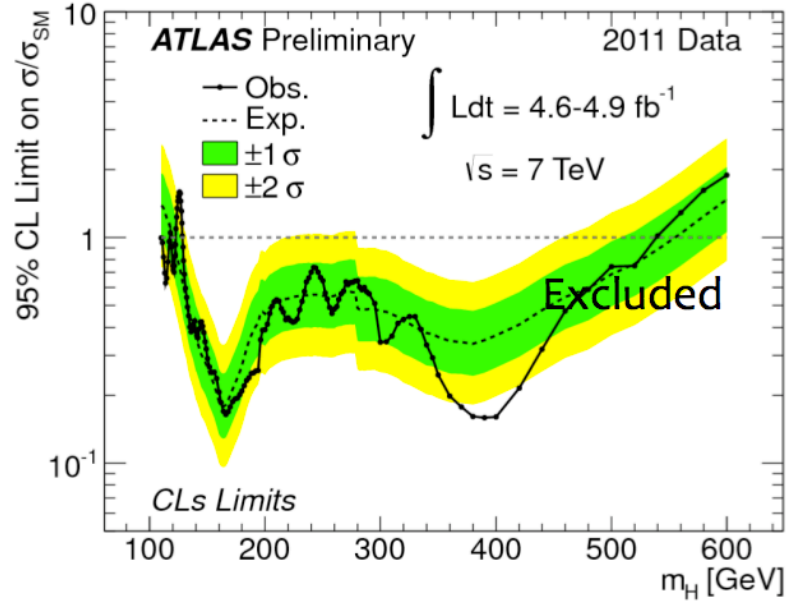
new

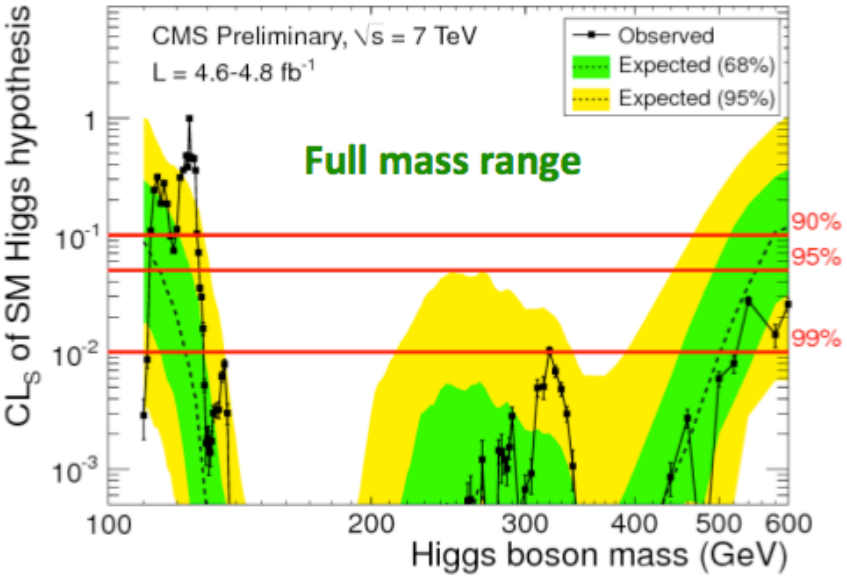
Expected from cut based analysis

- **Excluded at 95% CL**:
  110.0-111.0, 117.5-120.5, 128.5-132.0, 139.0-140.0, 146.0-147.0 GeV
- Cut based and cross-check MVA analysis give **consistent results**

LHC Higgs results: combined channels

Prolay Kumar Mal
Pietro Govoni





- Results from ATLAS and CMS for combined channels, using all 2011 data
- Observed exclusion @ 95% CL:
  - ATLAS: 110-117.5, 118.5-122.5, 129-539 GeV
  - CMS: 127.5-600 GeV
- Expected exclusion @ 95% CL:
  - ATLAS: 120-555 GeV
  - CMS: 114.5-543 GeV

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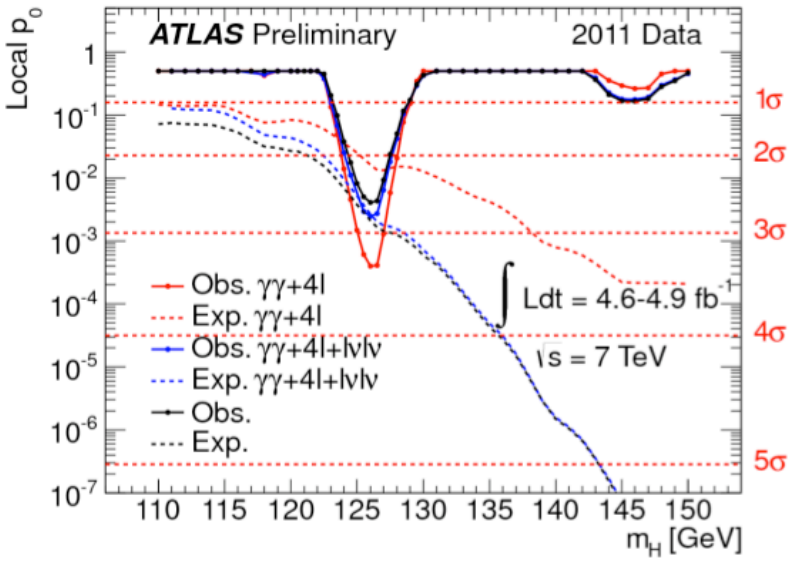

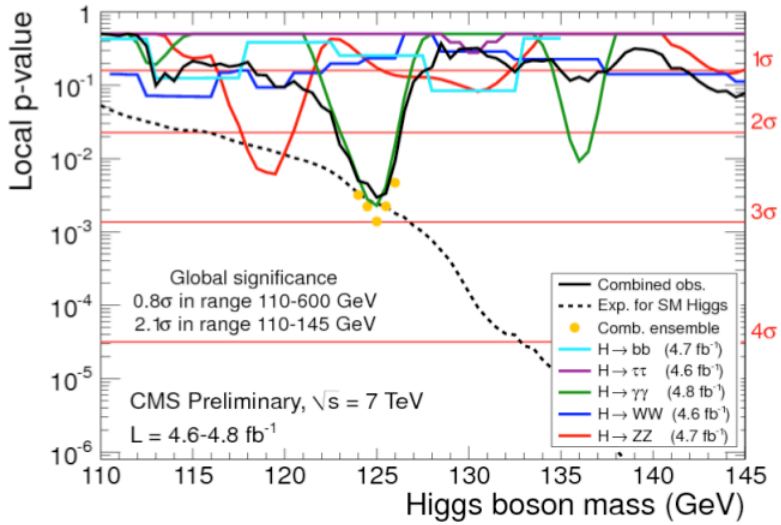

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- Expected exclusion @ 95% CL:
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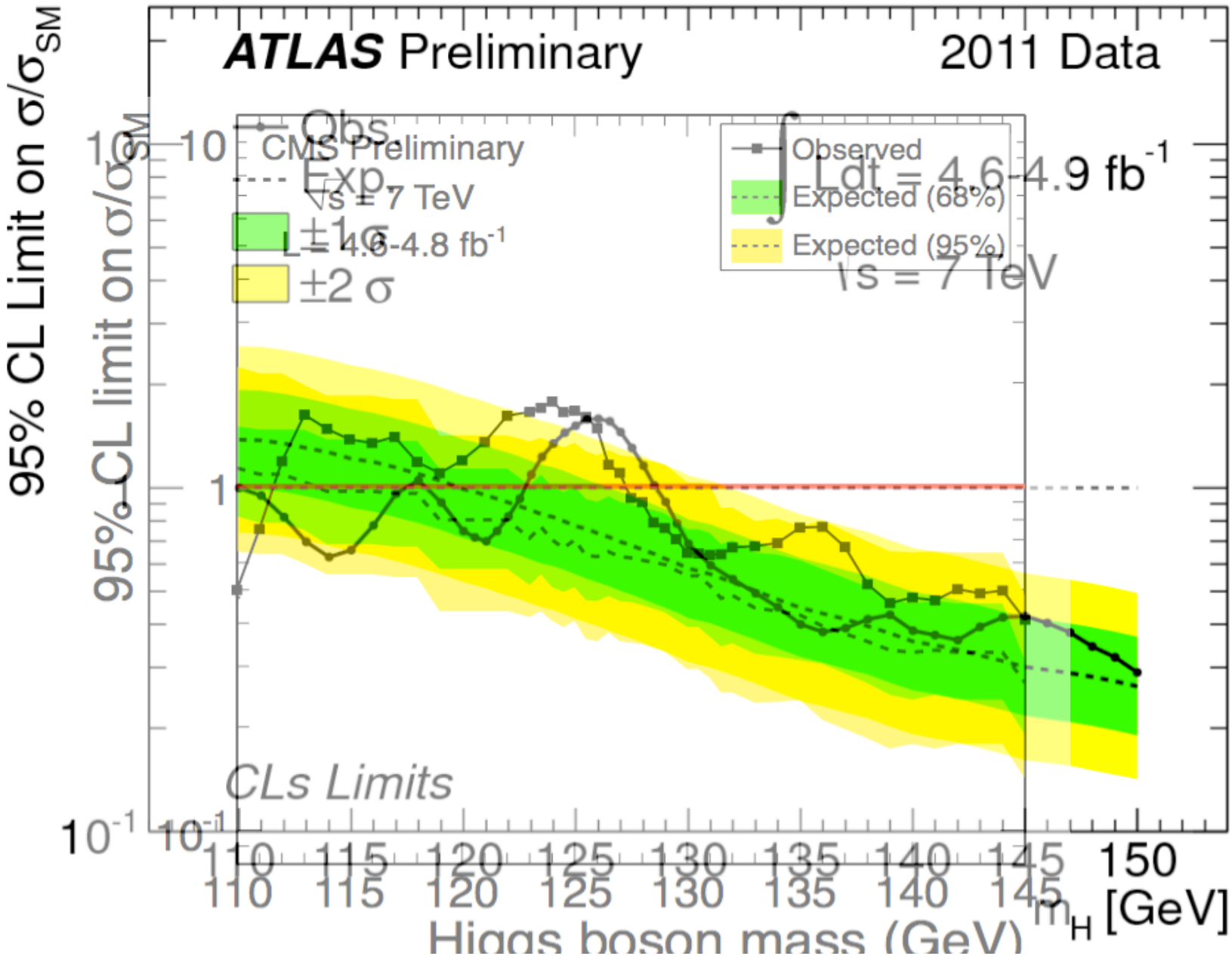
- Significance of excess at low mass
  - ATLAS: local significance @ 126 GeV: 2.5σ all channels (3.5σ for γγ + 4l)
  - CMS: local significance @ 125 GeV: 2.8σ
  - Significantly lower for both experiments once "look elsewhere effect" taken into account

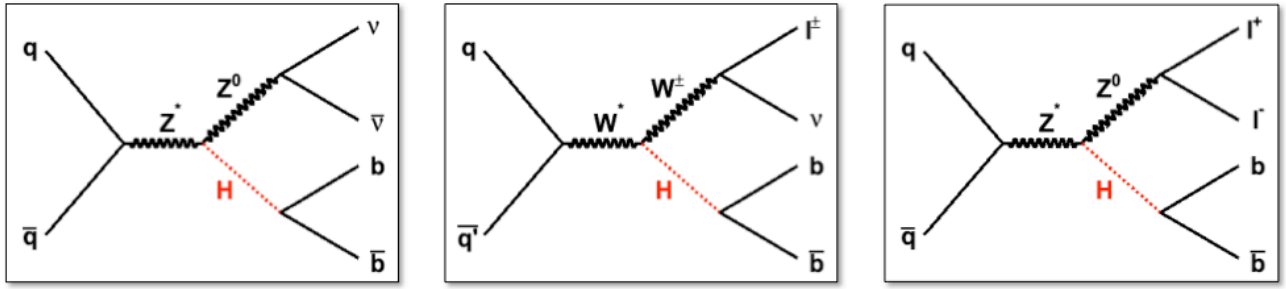
As a final snapshot..



So what does the Tevatron have to say?

Kyle Knoepfel

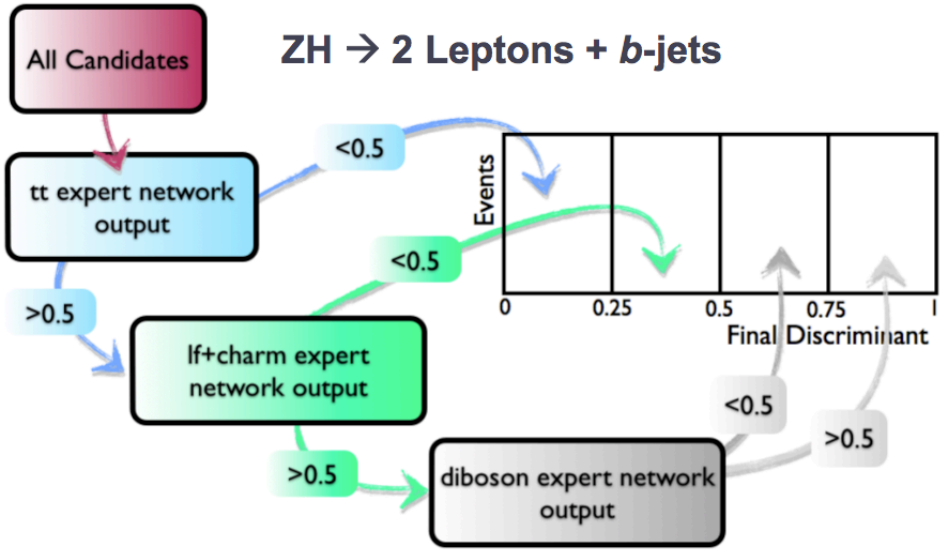
- LHC sensitivity is driven by gg → H → VV and γγ final states in the Higgs mass region not yet excluded
- TeVatron analyses now focus on low mass region $m_H < 135$ GeV, concentrating on associated VH production with H → bb decays

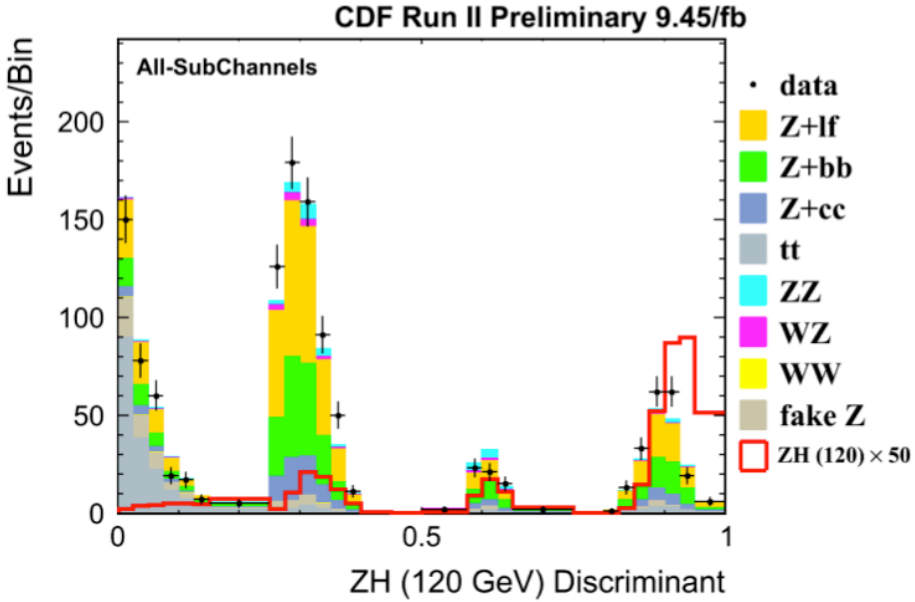


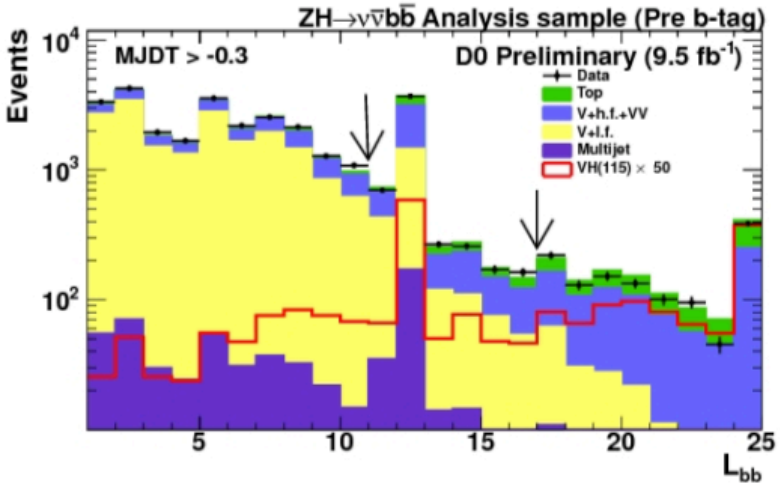
Analysis	No. of Leptons	Missing E_T?	No. of b-Jets
$ZH \to \nu\bar{\nu} + b\bar{b}$	0	Yes	2
$WH \to \ell\nu + b\bar{b}$	1	Yes	2
$ZH \to \ell^+\ell^- + b\bar{b}$	2	No	2

- In addition to 20% more *cf* 2011 results, several analysis improvements
  - Triggers, improved analysis methods, relaxed cuts to increase signal acceptance, more sophisticated multivariate algorithms for S/B separation, improved b-tagging…

Improved techniques in the TeVatron Higgs searches







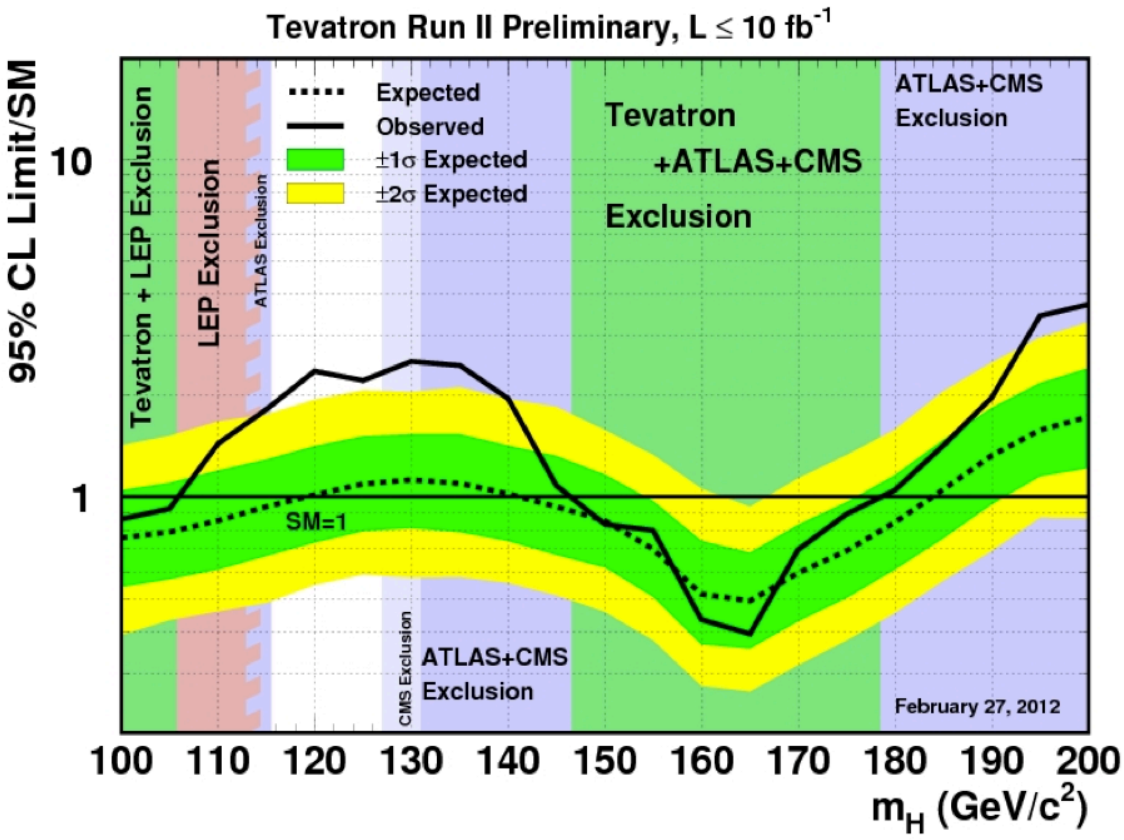
- D0 – L_b BDT
  - Continuous output ranked into 12 operating points, based on purity

	New Tag Efficiency	Old Tag Efficiency
B-jets	50 – 70%	45 – 65 %
LF jets	0.5 – 4.5%	0.5 – 4.5 %

Kyle Knoepfel

Summary of TeVatron Results.. and everyone else

- TeVatron exclusion:
  - Obs.: 100 < m_H < 106 GeV and 147 < m_H < 179 GeV
  - Exp.: 100 < m_H < 119 GeV and 141 < m_H < 184 GeV
- Quantifying the TeVatron excess:
  - Broad region over that seen by the LHC experiments
  - Local significance 2.7σ
  - Global significance: 2.2σ



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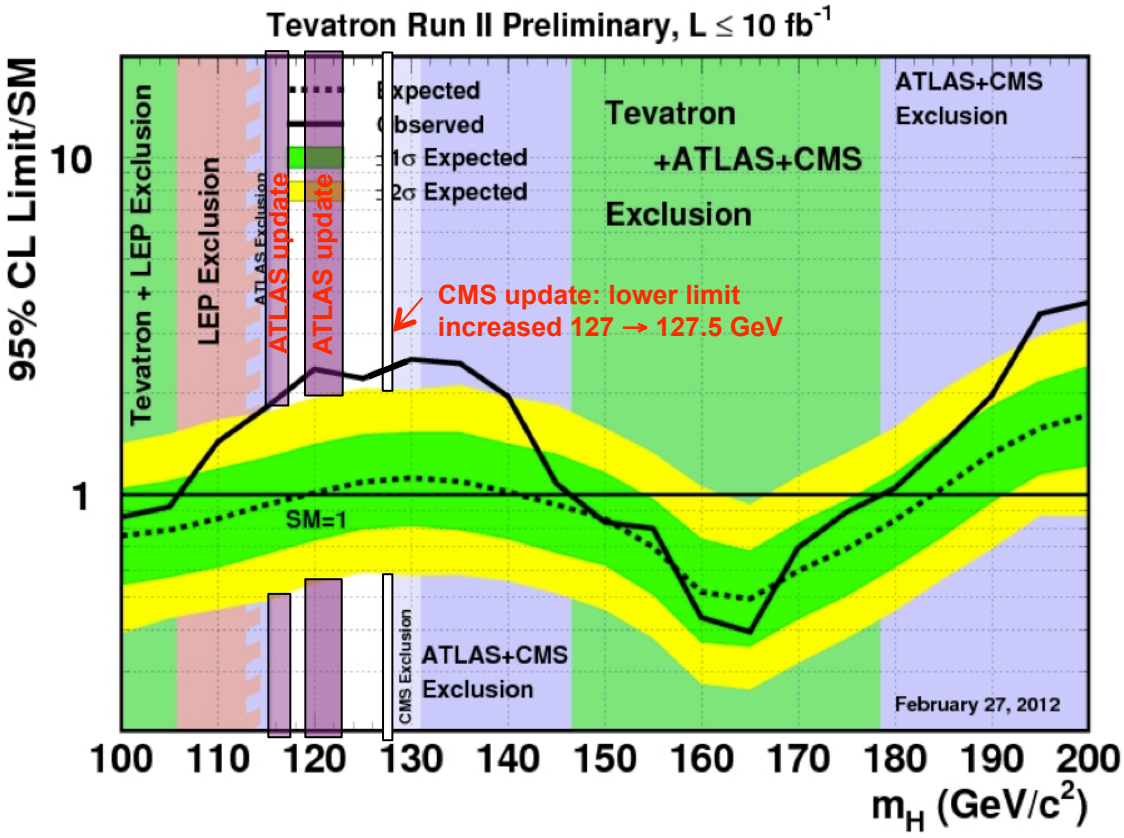
- Quantifying the TeVatron excess:
  - Broad region over that seen by the LHC experiments
  - Local significance 2.7σ
  - Global significance: 2.2σ
- Regions <u>not</u> excluded by ***any*** experiment
  - 117.5 < m_H < 118.5 GeV
  - 122.5 < m_H < 127.5 GeV

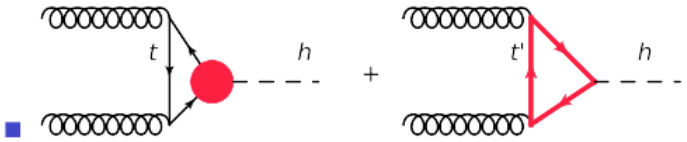


On to the BSM Higgs

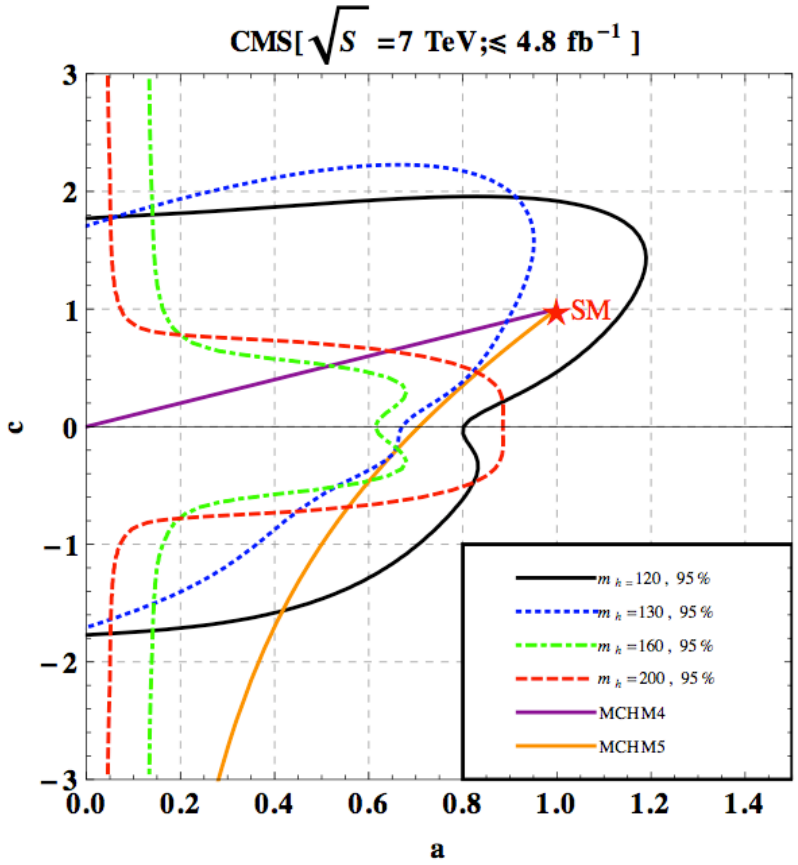
Aleksandr Azatov

- Discussion of composite Higgs models in talk by Aleksandr
- Introduces mixing between the SM fermions and composite fermions + Higgs

- New physics will unveil itself in the modification of the SM Higgs couplings



- Two types of corrections: formfactor of the top Yukawa coupling, direct contribution form the composite top partners t'



More information in e.g. arXiv:1202.3415

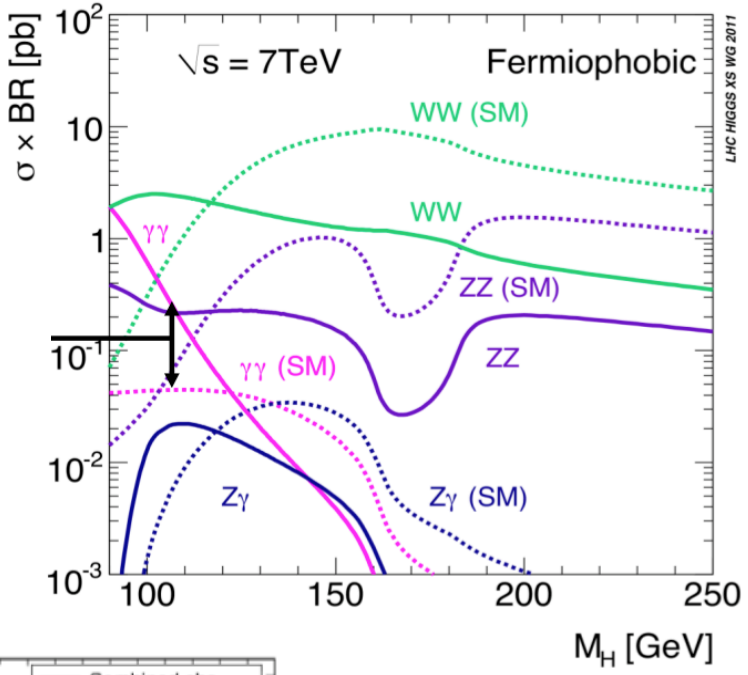
- Results from ATLAS, CMS and TeVatron on several BSM Higgs models:

4th gen fermion Higgs couplings, Fermiophobic Higgs, Charged + Neutral Higgs in MSSM, doubly-charged Higgs, ...

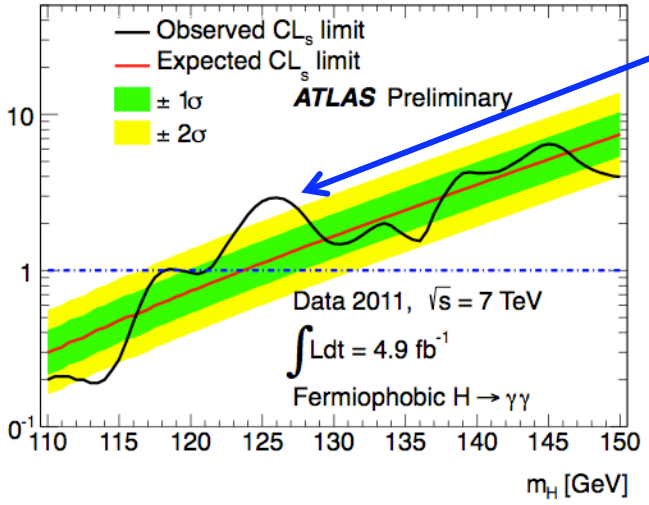
Searches for a fermiophobic Higgs

Javier Fernandez
Bruno Lenzi

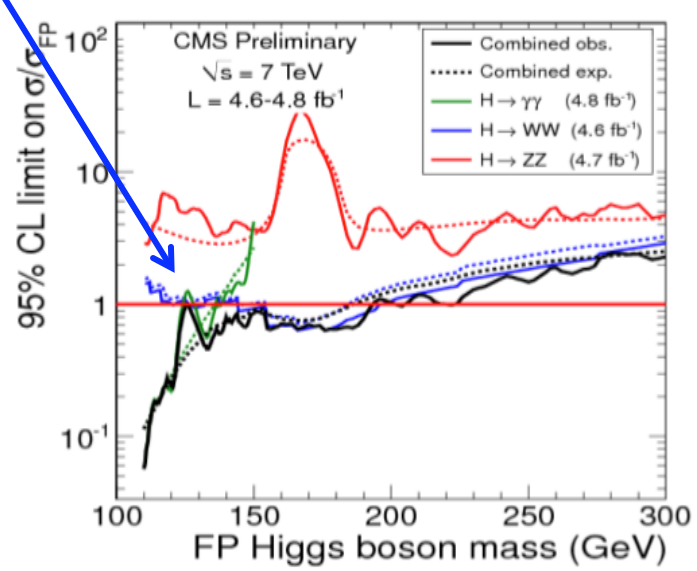
- VBF or VH associated production only: ggH production forbidden
- Remaining channels enhanced with respect to SM Higgs, where H→ γγ increases by an order of magnitude
- Same event selection as in SM Higgs search



Small excess in same region as SM Higgs



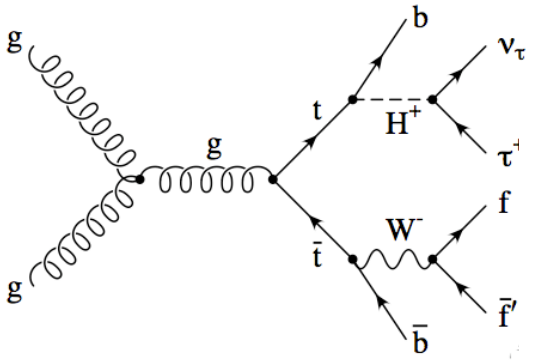
ATLAS: extend excluded region down to 110 GeV wrt to SM H→ γγ search



CMS: include γγ together with WW and ZZ: exclude M_H< 190 GeV and excess diluted

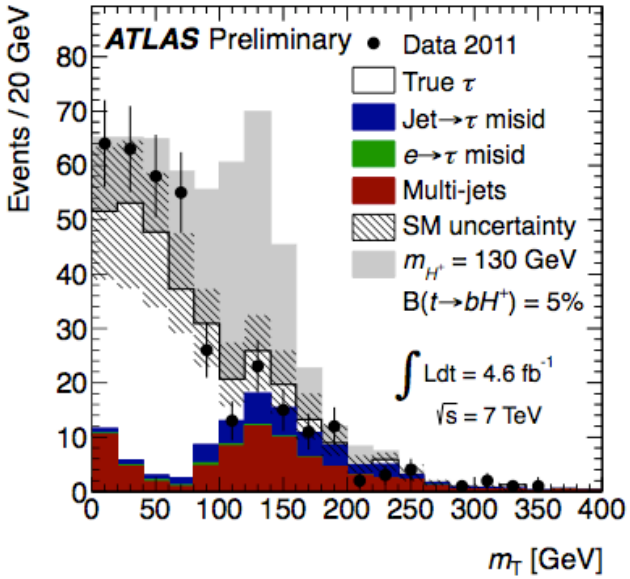
Search for a charged Higgs

Javier Fernandez
Bruno Lenzi

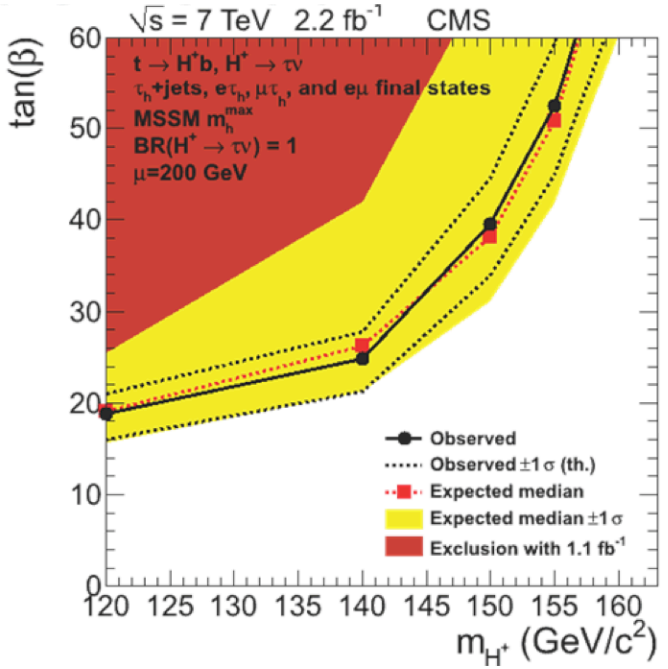


ATLAS: Hadronic tau decay + 4 jets

Sample	Event yield (τ+jets)
True τ (embedding method)	210 ± 10 ± 44
Misidentified jet→ τ	36 ± 6 ± 10
Misidentified $e \rightarrow \tau$	3 ± 1 ± 1
Multi-jet processes	74 ± 3 ± 47
$\sum$ SM	330 ± 12 ± 65
Data	355
$t \rightarrow bH^+$ (130 GeV)	220 ± 6 ± 56
Signal+background	540 ± 13 ± 85



- Predicted by 2HDM (eg MSSM) and Higgs triplet models
  - For $m_{H+} < m_t$: dominant production in top quark decays
  - For tan $\beta > 3$, preferred decay, mode is $H^{\pm} \rightarrow \tau^{\pm}\nu$
- No significant signal seen, derive limits on the branching ratio BR($t \rightarrow H^+b$) < 2-3%
  - Shown as a function of tan β for all final states combined from the CMS analysis

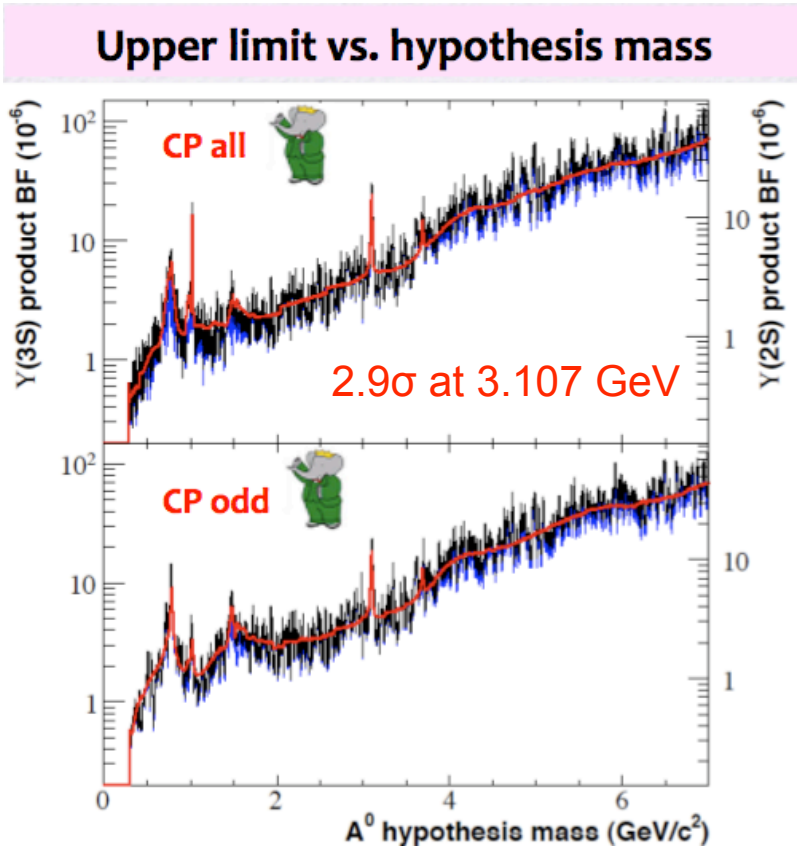


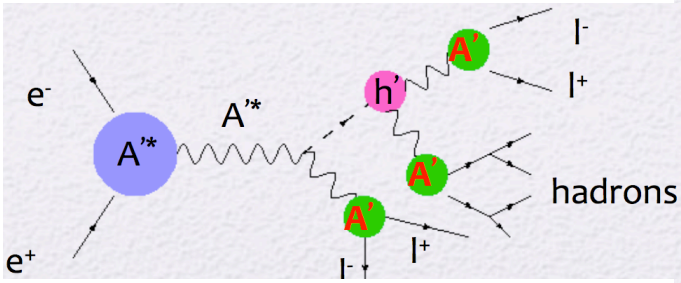
➔ See also talk from Emilien Chapon on TeVatron BSM Higgs searches

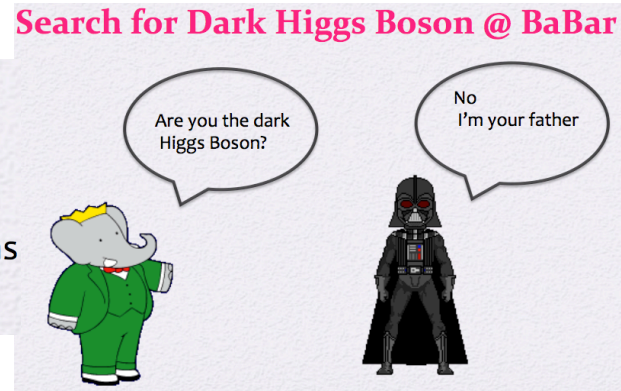
BaBar Higgs searches

Valentina Santoro

- Two searches for novel light Higgs performed at BaBar using their e^+e^- collision data
- Light CP–odd Higgs can be directly produced in transition $\Upsilon(nS) \rightarrow \gamma A^0$, where A^0 decays to SM particles
- No significant signal seen for $A^0 \rightarrow$ hadrons: Upper limits are calculated at 90% CL
  - One of the most significant signals noted on plot
- See Valentina's talk for details on the search for the *dark Higgs* and *dark photons*:







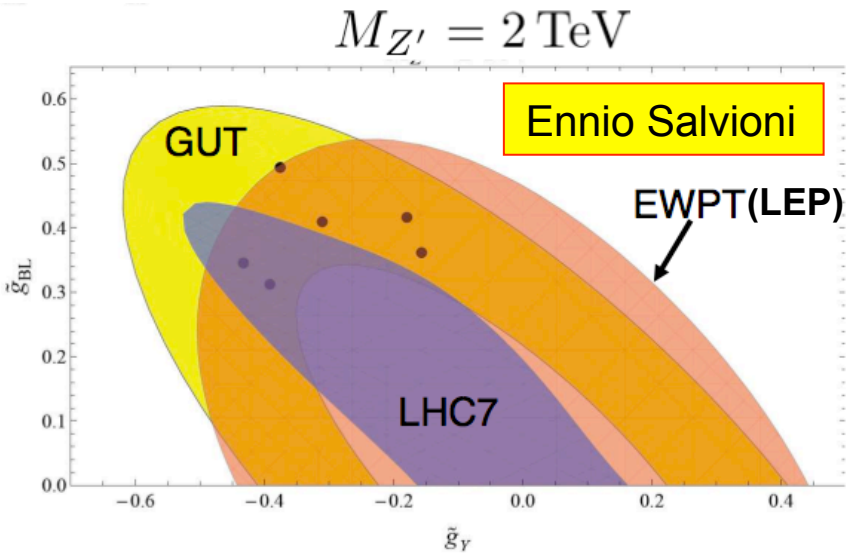
Moving on to exotic, non-SUSY searches

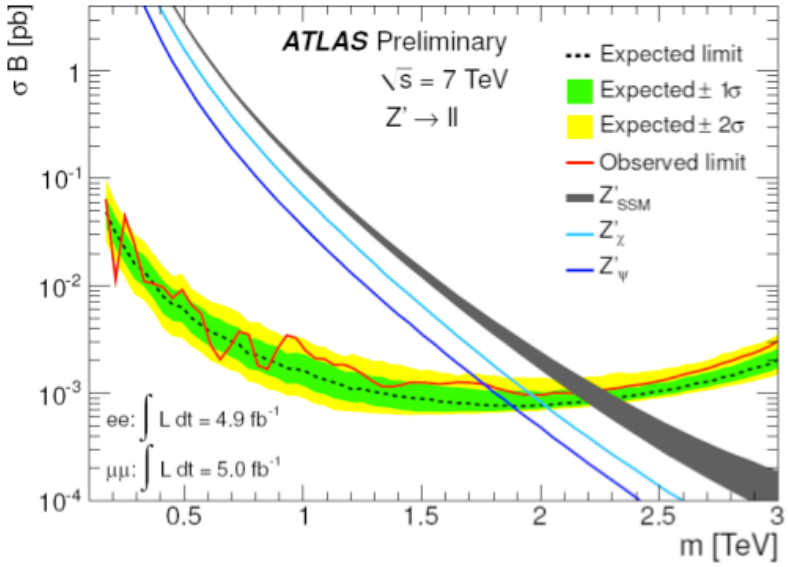
- Many non-SUSY searches going on, not just at the LHC or the TeVatron
- Some models discussed in the EW working group included:
  - New Z' and W' bosons, and other di-lepton resonances
  - Heavy neutrino + W_R production
  - Large extra dimensions
  - Narrow resonances in the 2 and 4 jet spectrum
  - Long live particles and heavy stable charged particles
  - Same sign leptons and black hole searches
  - Excited quarks and leptons
  - Leptoquarks and contact interactions
  - t-tbar and diboson resonances
  - Heavy quarks and 4th generation fermions ... *and more !*
- I pick out only a few today, and refer you to the talks in the Tuesday afternoon sessions for more results

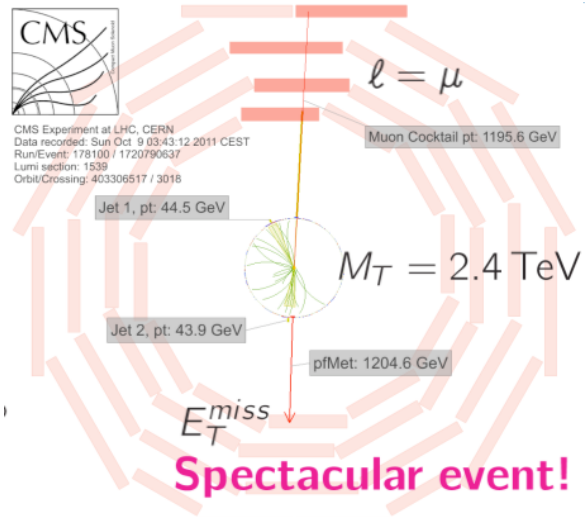
Search for new vector bosons *Z'* and *W'*

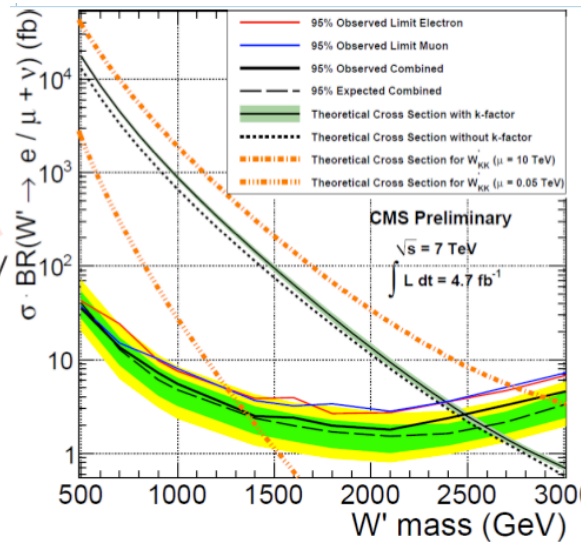
Antonio Policicchi
Martin Weber

- Nice review of Z' and W' models, by Ennio, relating to current LHC results







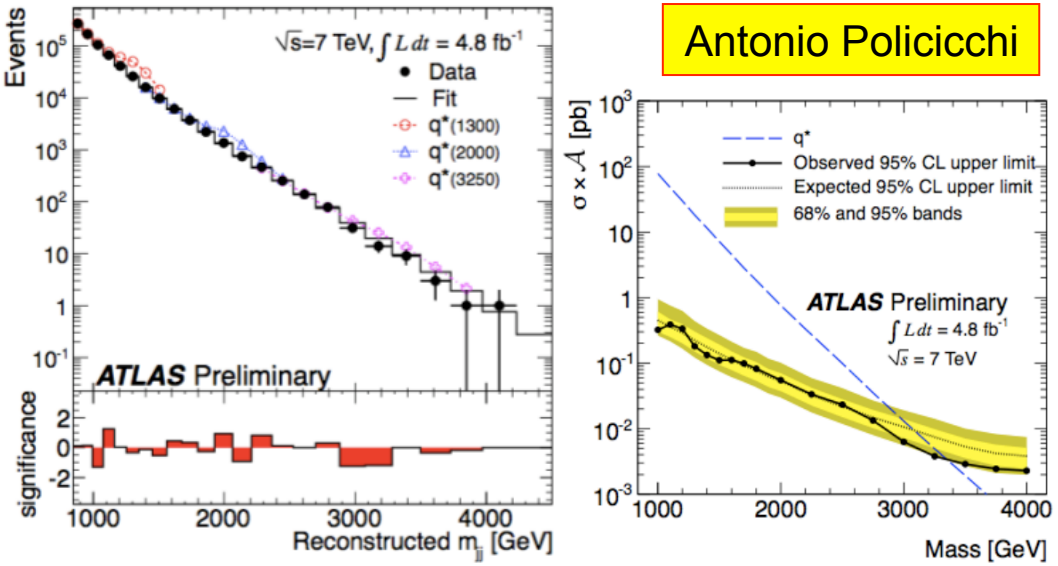


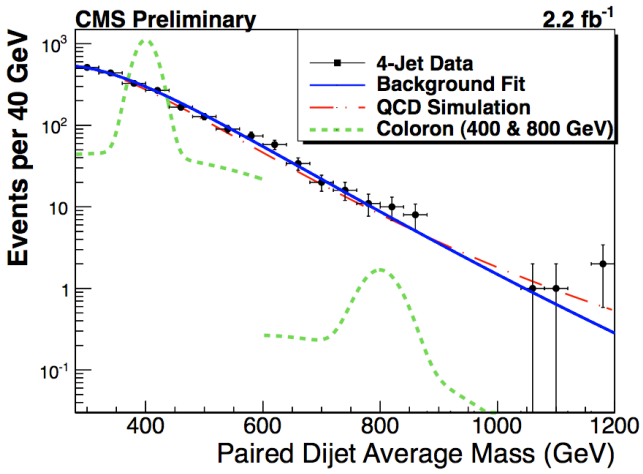
- Di-lepton decay Z' search, combined channels: ATLAS (CMS): $M_{Z'} > 2.21\ (2.32)$ TeV @ 95% CL
- Searches for W' also have with similar limits on the transverse mass now greater than 2 TeV

Searches for narrow resonances in di-jet and 4-jet events

- Measured ATLAS di-jet mass spectrum and angular distributions consistent with QCD, no excess observed
- Set limits on a variety of models, including excited quark, where $M_{q^*} > 3.35$ TeV

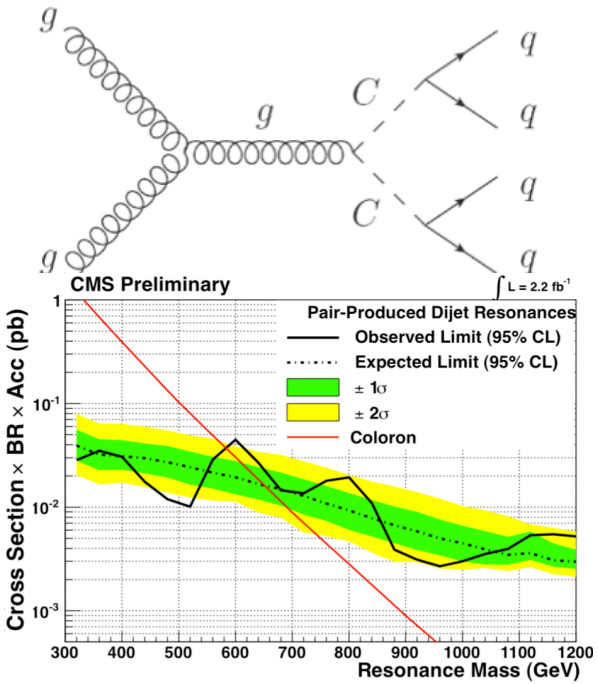
Antonio Policicchi



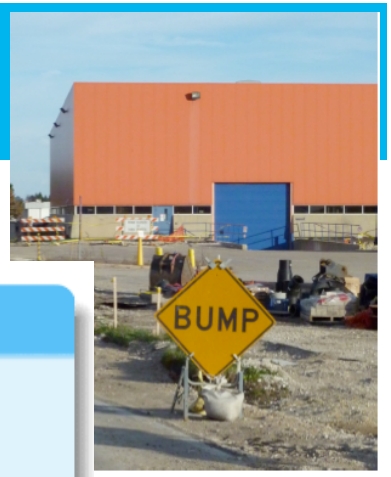


Martin Weber

- Also look for 4-jet final states, and identify di-jet pairs
- Search done by CMS, no excess observed, limits derived on Coloron production of $320 < M_C < 580$ GeV

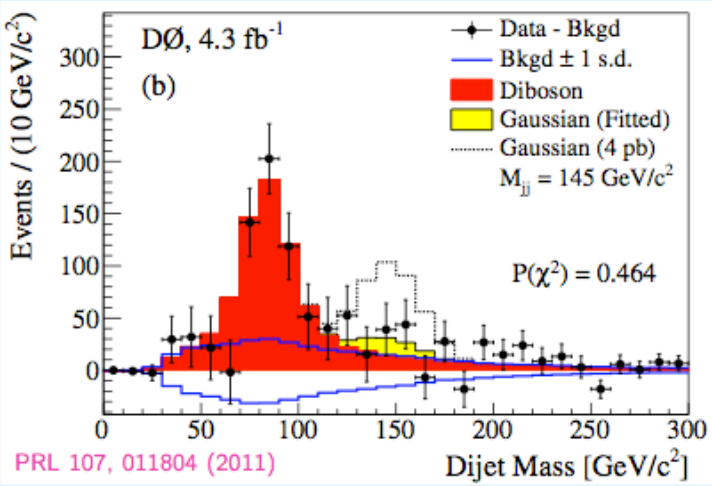


Di-jet mass spectrum of W + j j events



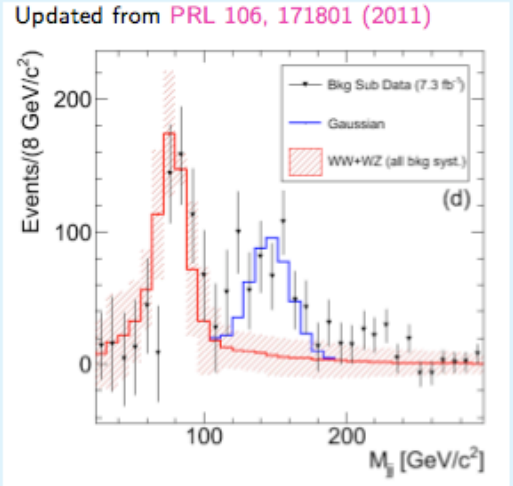
DØ ($4.3\,\mathrm{fb}^{-1}$)

- No excess seen.
- $\mathcal{P}(M_{jj} = 145\,\mathrm{GeV}, \sigma \times \mathcal{B} = 4\,\mathrm{pb}) = 8 \times 10^{-6}$.



CDF ($7.3\,\mathrm{fb}^{-1}$, $4.3\,\mathrm{fb}^{-1}$ published)

- Data is 4.1 standard deviations from expectation.
- $\sigma \times \mathcal{B} = 3.1 \pm 0.8\,\mathrm{pb}$

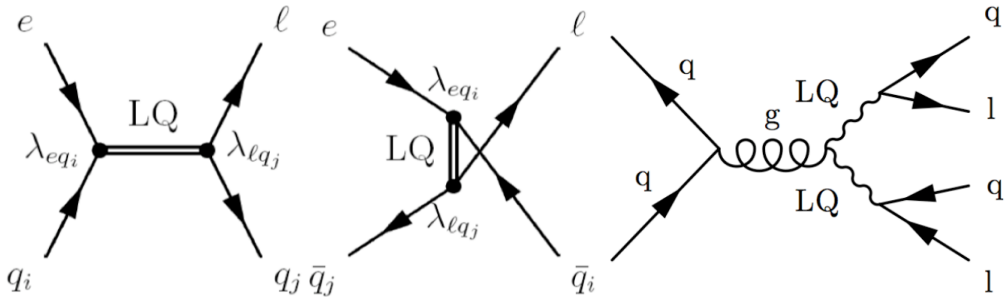


> CDF and DØ agree to disagree... CDF is performing several independent analyses with the full data set to make a final statement on the subject

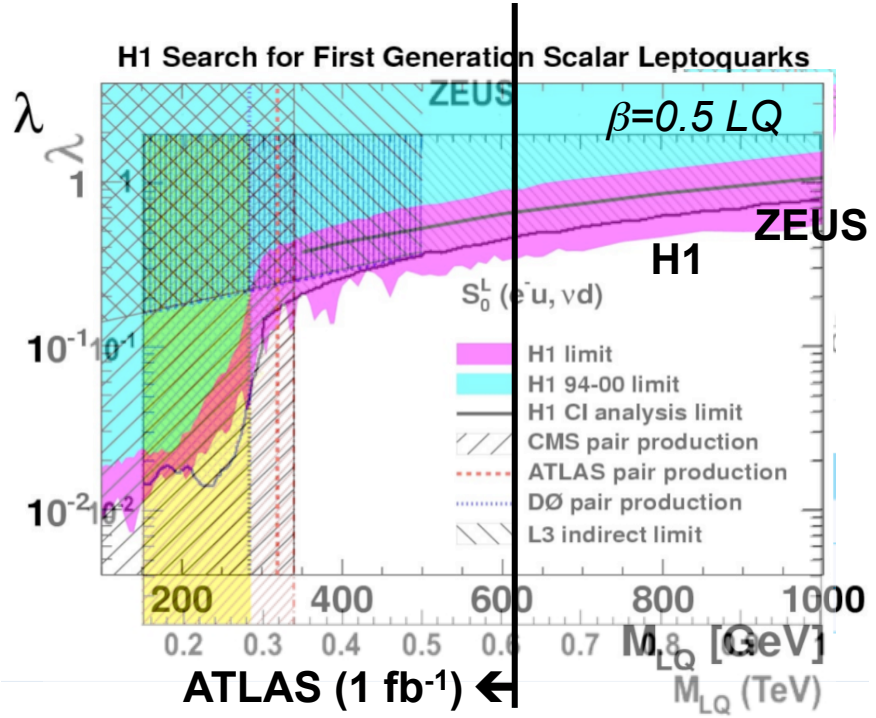
Emilien Chapon

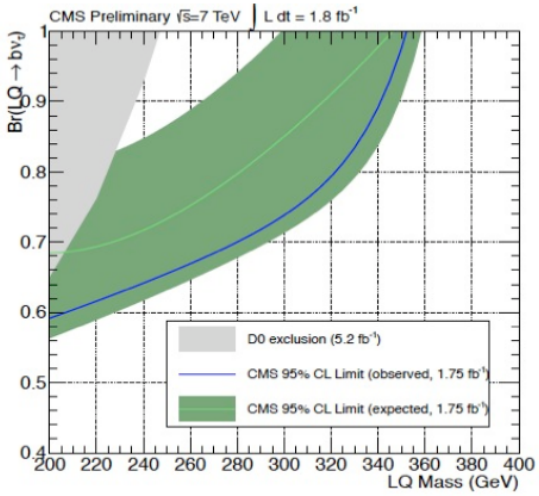
Search for leptoquarks in ep and pp collisions

- Complimentary searches from ep data at HERA and from hadron colliders



- HERA limits from single LQ production strongly depend on the coupling, λ; pair-production at TeVatron / LHC
- Some HERA limits still best for vector LQs





Scalar LQs	1st Gen		2nd Gen		3rd Gen	
β	1.0	0.5	1.0	0.5	1.0	0.5
ATLAS	660	607	685	595	-	
CMS	384	339	632	523	350	

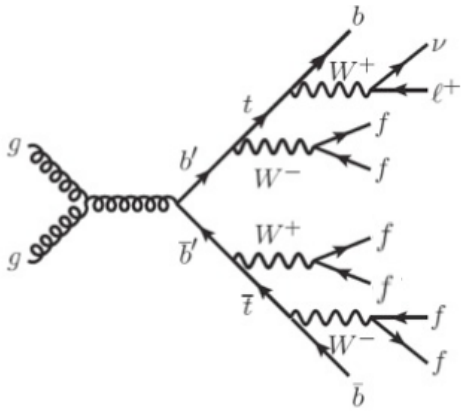
- First third generation LHC LQ search results from CMS

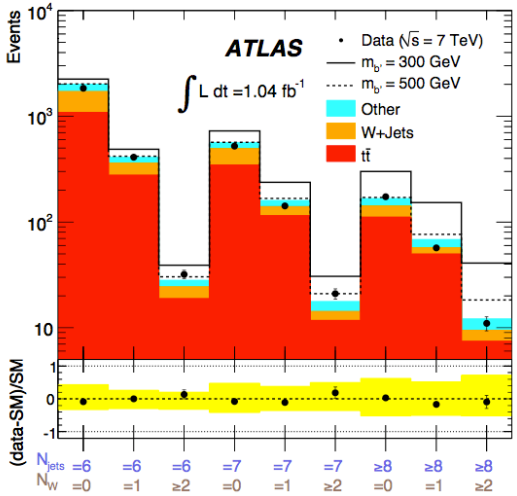
Stefano Antonelli
Sushil Chauhan
Hayk Pirumov
Antonio Policicchi

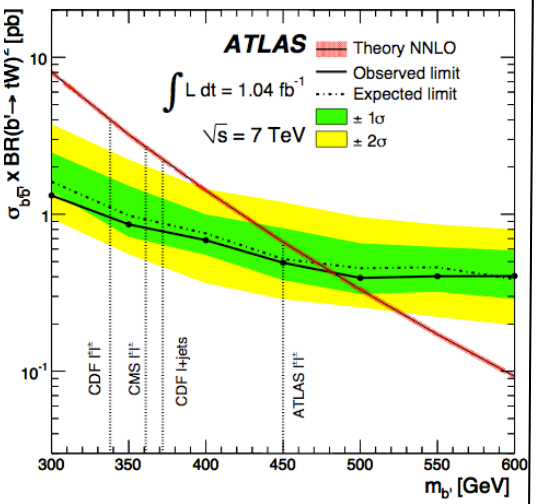
4th Generation Fermions / Stopped Heavy Stable Charged Particles

Sushil Chauhan
Jihang Zhong

- Event topologies with one lepton and many jets from W decays



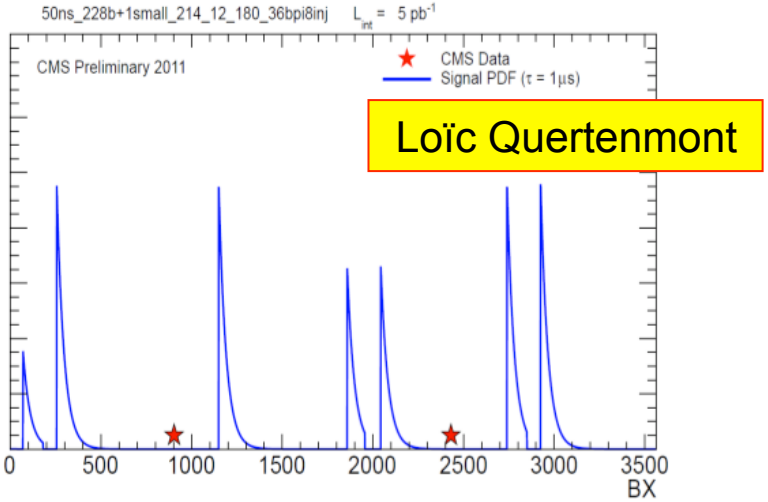




- Limit @ 95% CL (assuming BR(b'->Wt)=1) of $M_{b'} > 480$ GeV (470 GeV expected)

- Search for long lived particles stopped in CMS detector, by looking at decays triggered during time intervals when there were no pp collisions

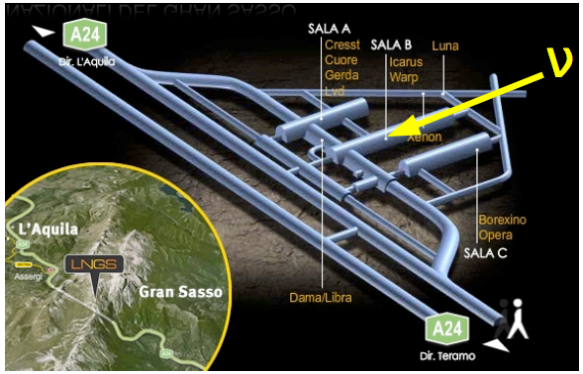
Loïc Quertenmont

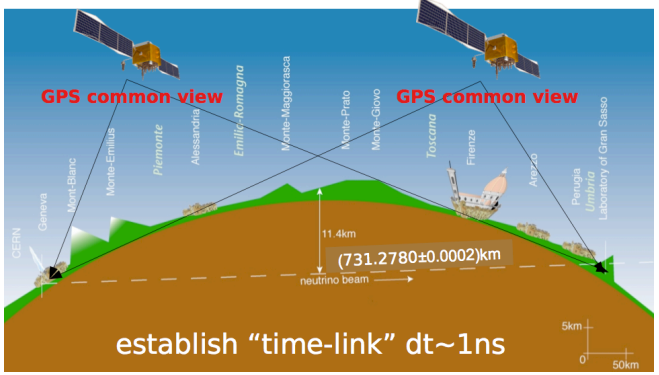


- For lifetimes from 10μs to 1000s:
- M_{gluino}-$M_{neutralino}$ > 100 GeV and Br(gluino → g + neutralino) =100%: M_{gluino} < 601 GeV @ 95% CL
- M_{stop}-$M_{neutralino}$ > 200 GeV and Br(stop → top + neutralino) =100%:
- M_{stop} < 337 GeV @ 95% CL

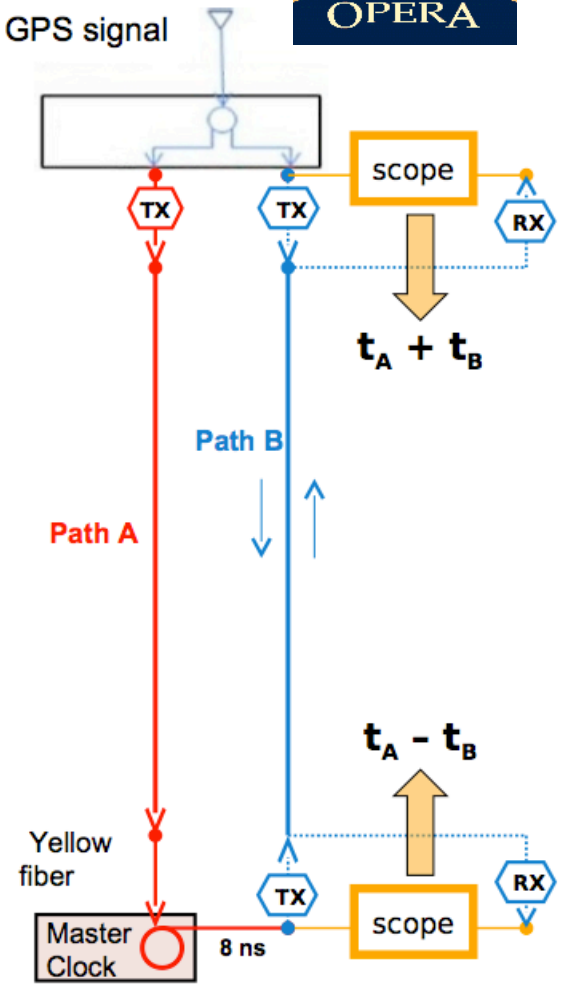
Measurement of the neutrino velocity with the OPERA detector in the CNGS beam

Torben Ferber





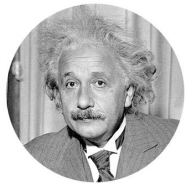
- Primary goal of the experiment: $\nu_\mu \rightarrow \nu_\tau$ oscillations
- Sep 2011: After taking into account known delays, two methods revealed time discrepancy of ~ 55 ns
- Nov 2011: Data from bunched beam running reveals consistent delay of ~ 62 ns
- Dec 2011-Feb 2012: two issues identified: oscillator used to produce the events time and connection of the optical fibre
- **March 28th**: Preliminary correction to the bunched beam data results in $\delta t = (-1.7 \pm 3.7)$ ns (stat. only), under the assumption that the two issues were stable during the bunched beam run (assumption motivated by a LVD-OPERA collaboration using cosmic muons): *New bunch beam data in May will confirm*.



- For the *very latest*: **http://agenda.infn.it/conferenceDisplay.py?confId=4896**

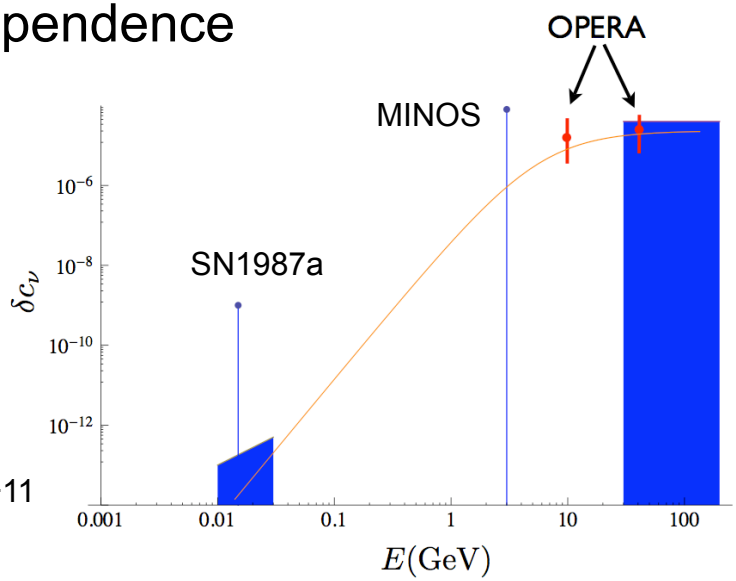
Impact of the (possible) OPERA results

Sergey Sibiryakov



- Violation of causality and the end of Special Relativity: hard to construct a theory.. but what about breaking Lorentz Invariance?
- Species dependent velocities, δc_a $\mathcal{L} = \bar{\psi}_a[i\gamma^0 D_0 + ic_a\gamma^i D_i - m_a]\psi_a + \dots$
  - Photon velocity normalised to 1
  - Theoretical background: As a consequence of the (yet unknown) theory of quantum gravity (space-time foam, gravity with anisotropic scaling, ...)

- Direct limits on $|\delta c_\nu|$ suggest an energy dependence
- Strong limits of other species
  - proton: $|\delta c_p| < 10^{-22}$ (CMB)
  - electron: $|\delta c_e| < 10^{-15}$ (LEP, Crab Nebula)
  - muon: $-\delta c_\mu < 10^{-11}$ (Crab Nebula)
- Lorentz Violation in neutrinos allowed, but not more than four orders of magnitude: $|\delta c_\nu| < 10^{-11}$



Summary of Part 1

- Full and comprehensive programme of searches in HEP
  - Some TeVatron analysis utilising compete data sets, more to come
  - Impressive number of 5 fb^{-1} LHC analyses, only a few months after data taken
- The SM Higgs still eludes discovery – but for how much longer?
  - Running out of places to hide: $117.5 < m_H < 118.5$ GeV and $122.5 < m_H < 127.5$ GeV
  - The LHC should give us the answer in 2012
- A few 2-3 sigma effects turning up in a few analyses..
  - We all look forward to the coming 8 TeV LHC data for clarification

    → **First collisions today !**