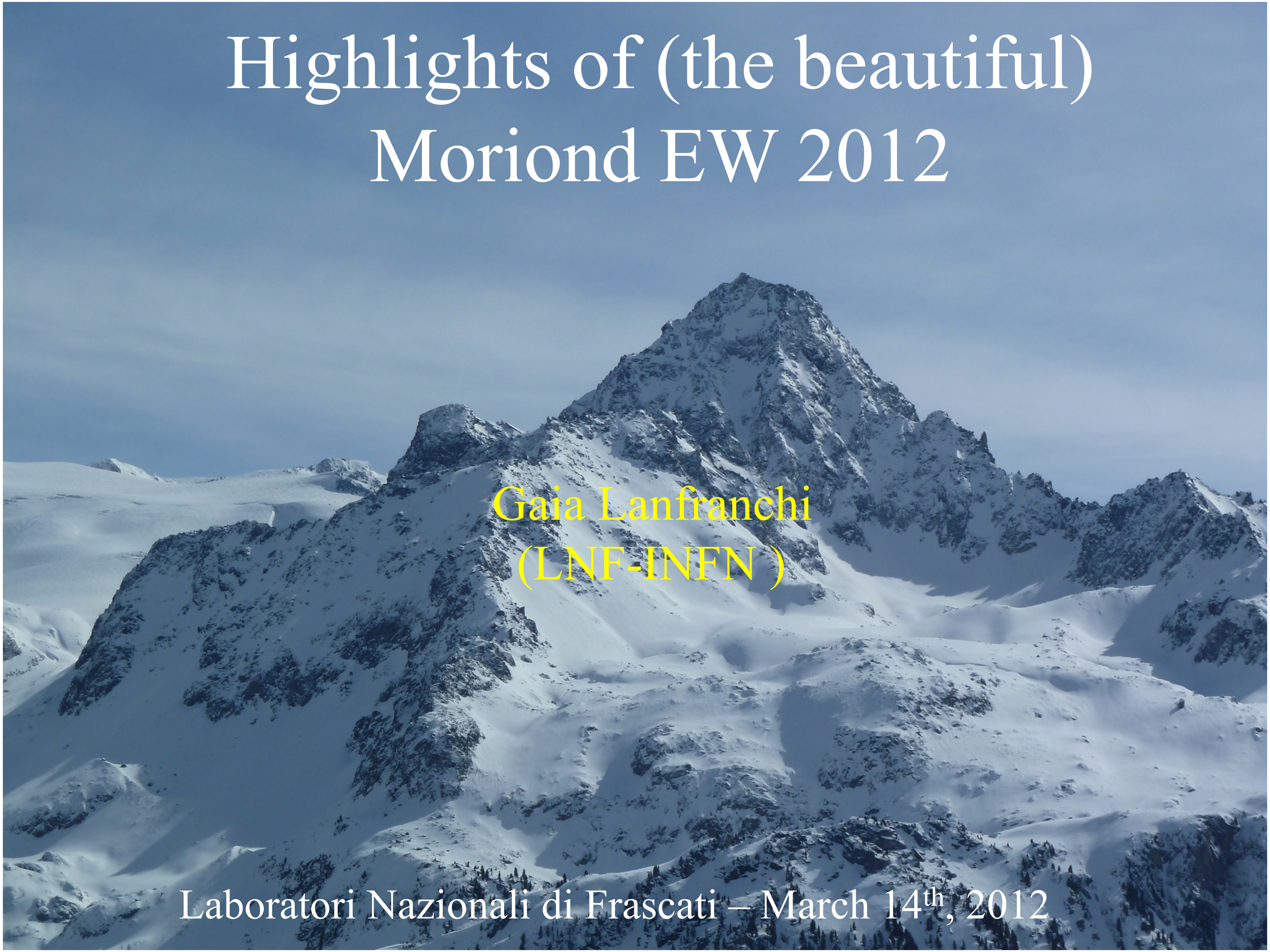


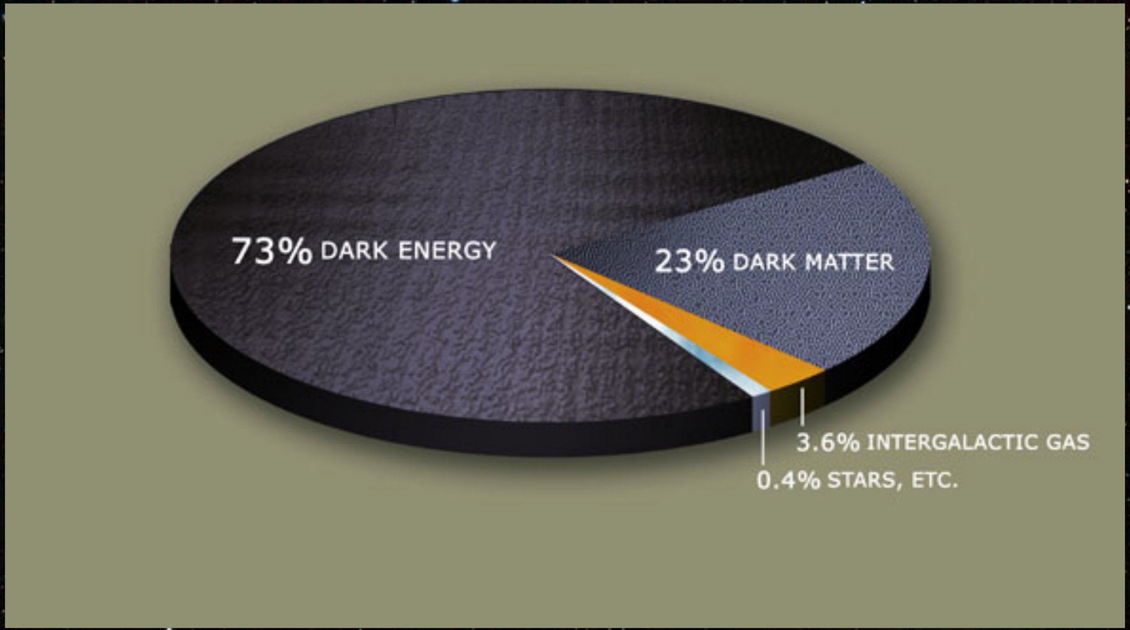
Highlights of (the beautiful) Moriond EW 2012

Gaia Lanfranchi
(LNF-INFN)

Laboratori Nazionali di Frascati – March 14th, 2012

Moriond Summary (in four points)

1. **We live in a world where only 4% of the matter is known**
2. **What is known is not self-contained (hierarchy problem, CKM parameters, masses, etc)**
3. **But the (standard) model we use to describe it works (even too) well**
4. **And more general models are being constrained (or ruled out) by the experimental results.**



However it is clear that:

1) **Dark matter,**
2) **Higgs,**
3) **Stability of SM (SUSY, etc.)**
4) **Precision EW measurements**
5) **Flavor sector**
6) **Neutrino sector**

are all related!

→ the true model has to explain all together

→ we need (more and more) a strong connection between experimental and theory communities and among communities working on different topics in order to have a (as much as possible) clear picture of the situation.

Moriond EW 2012 has been a lively and intense conference, 188 participants (CMS, ATLAS, CDF, D0 Spokespersons, CMS and ATLAS physics coordinators, high level theorists and many (many!) young researchers from 25 countries

Outline:

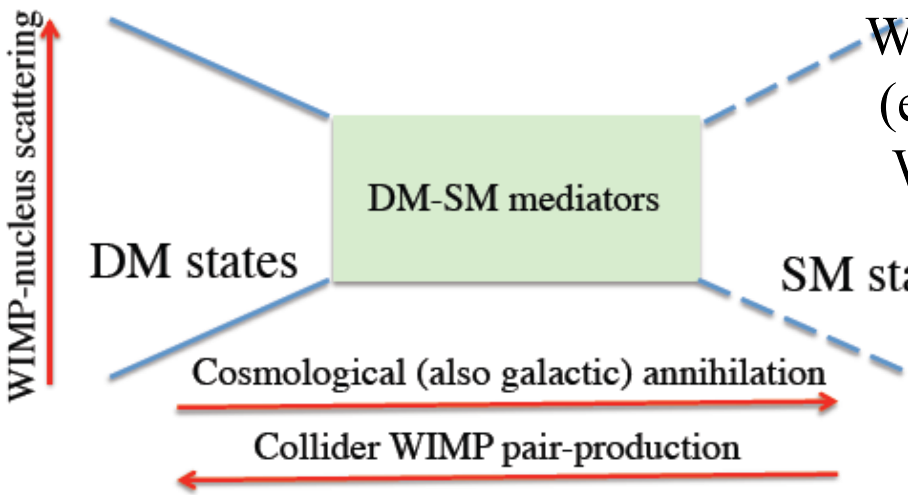
1) Dark matter,
2) Higgs,
3) Stability of SM (SUSY, etc.)
4) Precision EW measurements
5) Flavour sector
6) Neutrino sector

Dark matter direct searches

In the era of precision cosmology we know that:

1. There is substantial body of evidence for DM at different distance scales.
2. It is 6 times more abundant than baryons and contributes ~1/4 of the total energy budget.

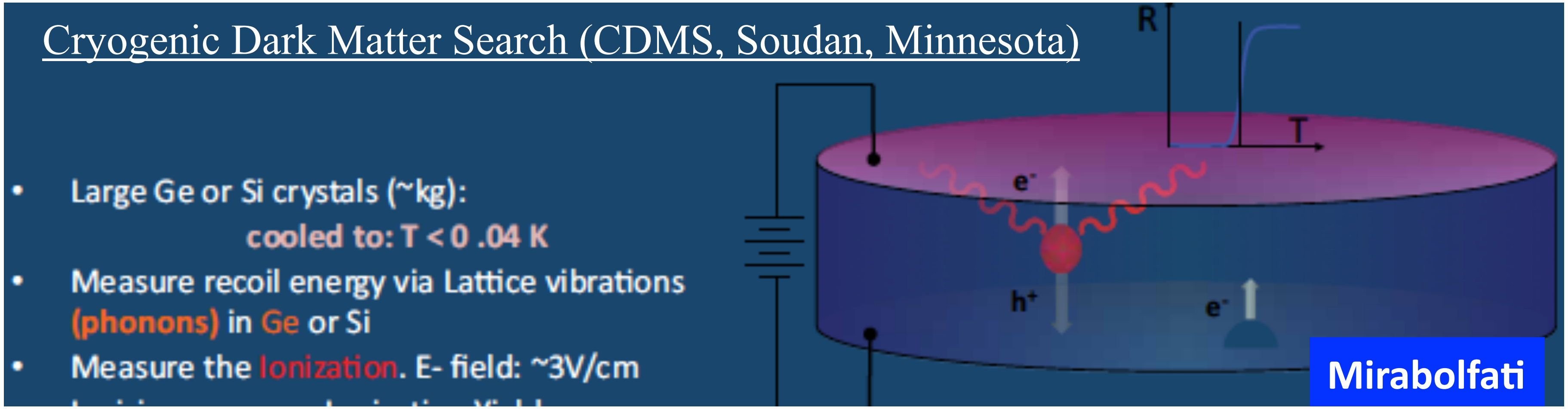
- One of the most outstanding problems today; connects collider physics with direct searches & indirect detection
- We know that there is dark matter but we dont know what it is.
- Candidates: “standard” (WIMP, axion) & “nonstandard” (sterile neutrino, gravitino, axino,…)



What is inside the green box? (eg what forces mediate WIMP and SM ?

WIMPS detection is challenging

1) WIMP-nucleus scattering:
- low recoil of the nucleus (~10 keV)
- very low interaction rate
- background, background and background (underground experiments)



WIMPS detection challenging

KIMS experiment
(Korea Invisible Matter Search)

S. C. Kim

KIMS experiment ?

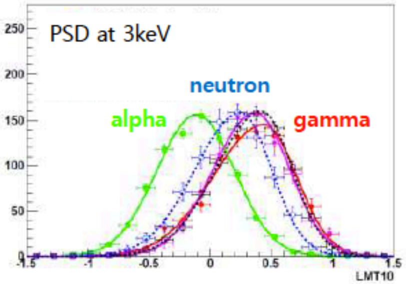
CsI(Tl) scintillator

Well-known, widely-used technique

Large atomic number, Cs (133), I (127)
Good for coherent scattering (A^2 scaling)

High spin expectation value for proton
Sensitive to SD interaction

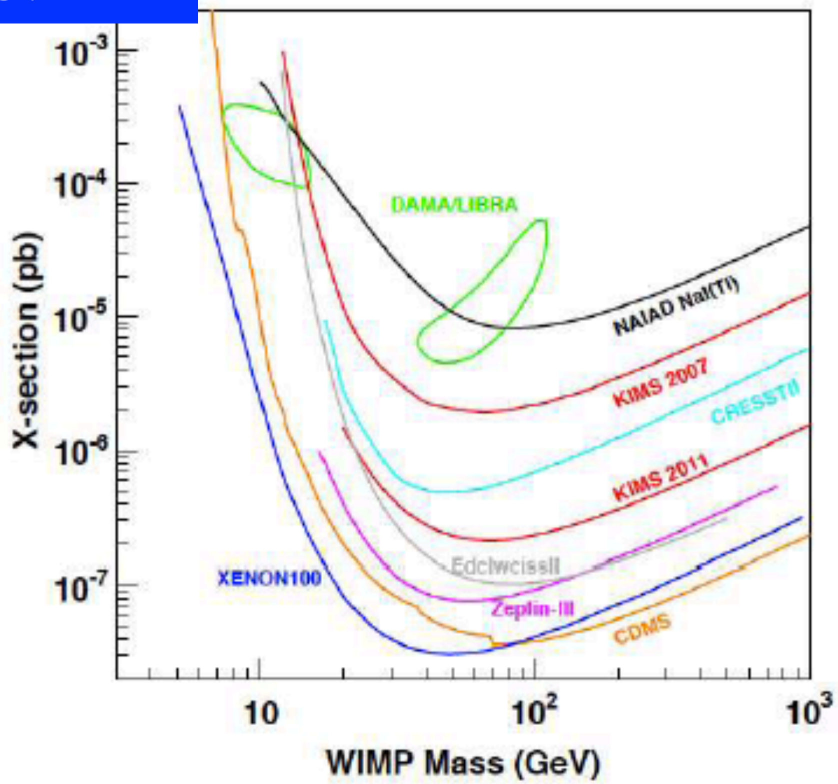
Discrimination of nuclear recoil
events by PSD analysis



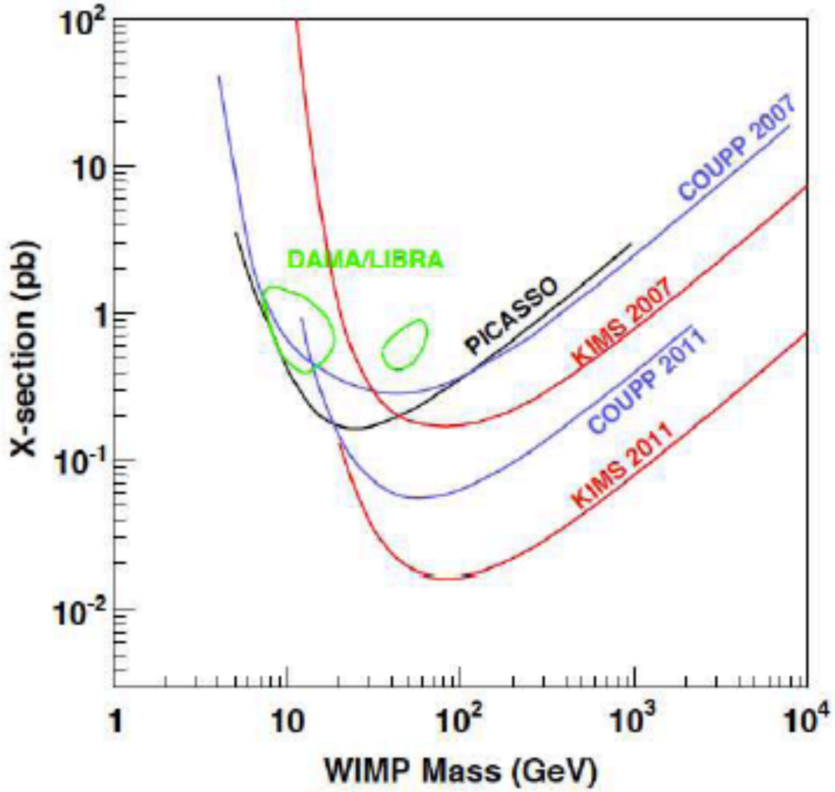
But, some inherent backgrounds
like Cs134, Cs137, Rb87

WIMPS-nucleus cross section: upper limits

S. C. Kim



Spin-Independent interaction



Spin-dependent proton interaction

Search of WIMPS at the LHC:

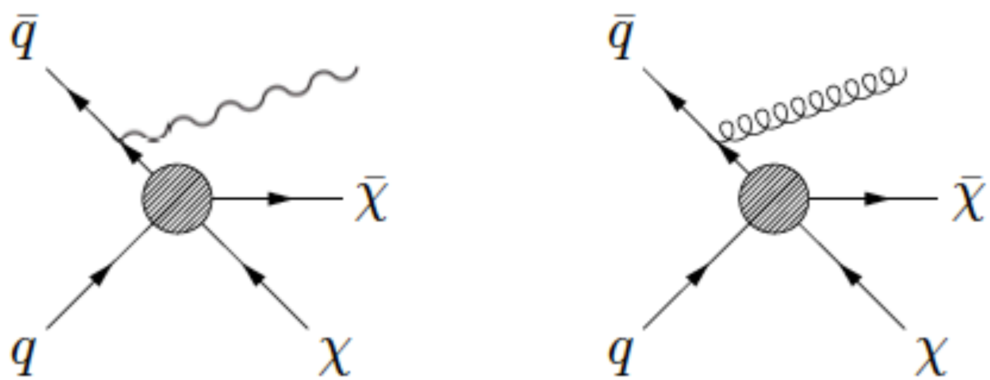
PRODUCTION OF DARK MATTER AT CMS

Steve Worm

- Search for evidence of pair-production of Dark Matter particles (χ)

Direct Detection (t-channel) *Collider Searches (s-channel)*

- Dark Matter production gives missing transverse energy (MET)
- Photons (or jets from a gluon) can be radiated from quarks, giving monophoton (or monojet) plus MET

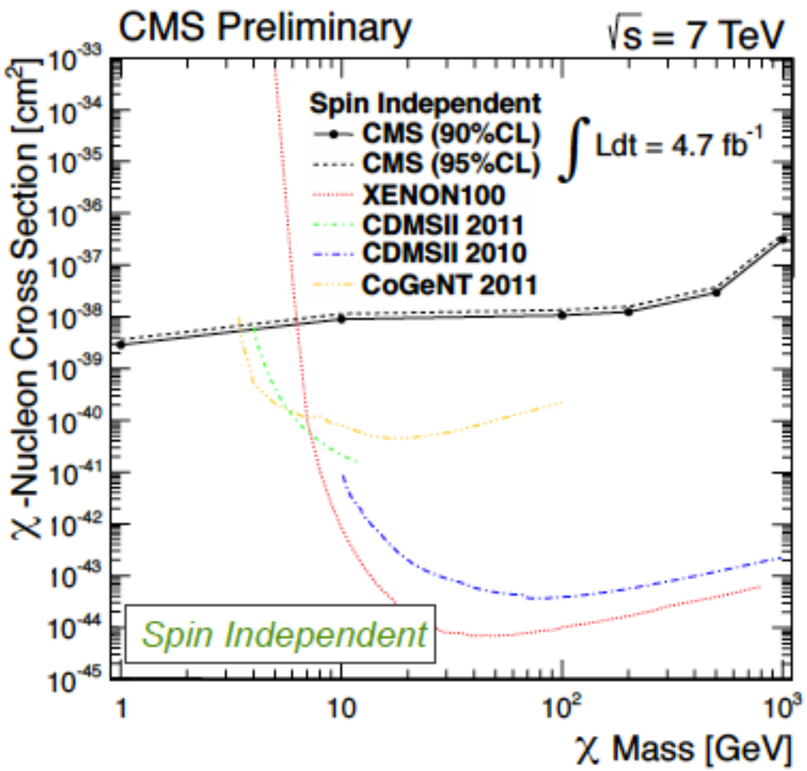


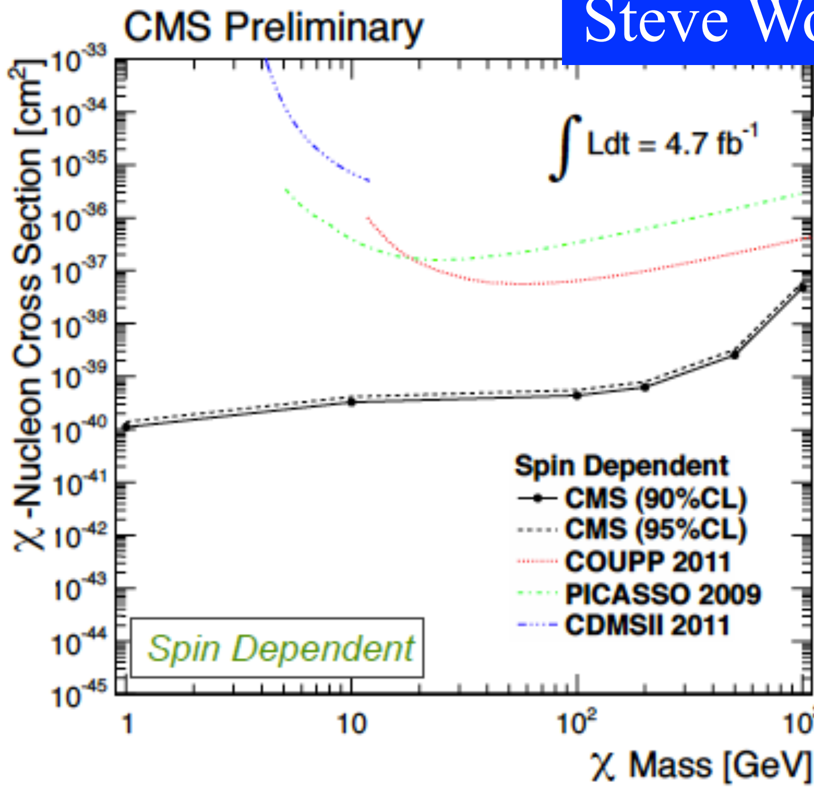
Monophoton + MET *Monojet + MET*

Search of WIMPS at the LHC:

Mono photon: spin independent and spin dependent limits from CMS:

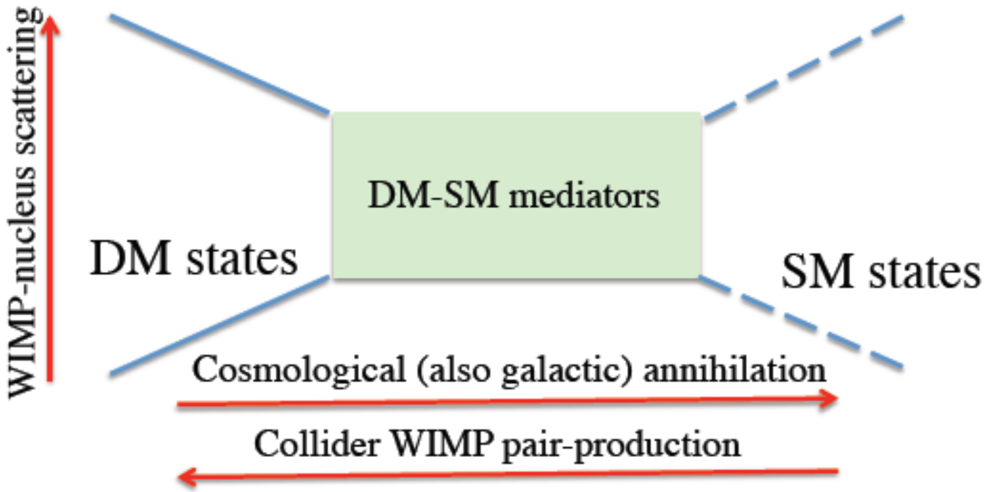
Steve Worm





CMS in only one year improves the limit of spin independent cross section below 10 GeV and of spin dependent cross section in the whole range

Which is the mechanism of WIMP annihilation?



Maxim Pospelov

EW mediation: Z bosons

First model of WIMPs constructed: heavy neutrino N annihilating to SM states via virtual Z. NN → Z* → SM for small m_N and NN→ ZZ, WW for m_N above di-boson threshold. (Lee; Weinberg; Zeldovich,

→ However Lep1 provided strong constraints on Z→NN with the measurement of Γ_{inv}
→ N(neutrinos) = 2.984 ± 0.008 (but 2 σ away from 3, A. Blondel)

Which is the mechanism of WIMP annihilation?

EW mediator: Higgs

Maxim Pospelov

A discovery of the SM(-like) Higgs with mass of ~ 125 GeV will wipe out many DM models with m_{DM} < 50 GeV that use Higgs particle for regulating its abundance in a fairly model-independent way. (this point was made repeatedly in recent literature Mambrini; Raidal, Strumia; X.-

$$R = \Gamma_{\text{SM modes}}/(\Gamma_{\text{SM modes}}+\Gamma_{\text{DM modes}})$$

Any theorist model-builder who wants to play with sub-50 GeV WIMPs may "run out of SM mediators" and will be then bound to introduce new mediation mechanisms, such as new [scalar] partners of SM fermions, new Higgses and/or new Z'. Light mediators have been also dubbed "dark forces".

Existence of new mediator forces – especially light mediators – can change "usual" WIMP phenomenology in a profound way.

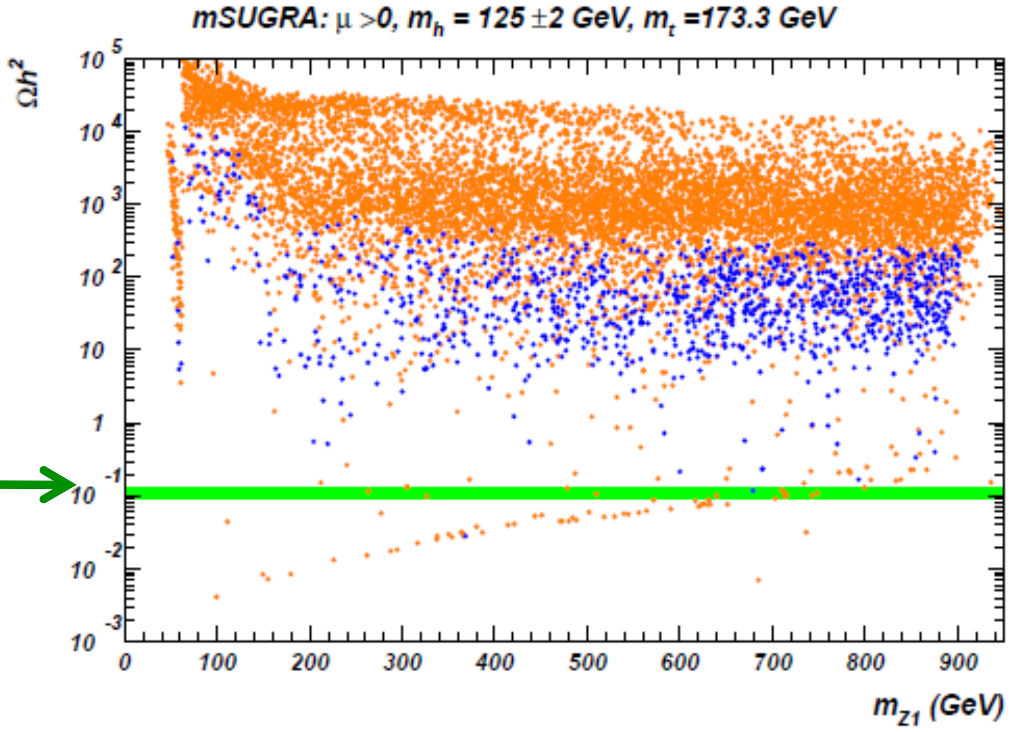
Example of interconnection between fields

Higgs at 125 GeV with SM rates if confirmed will push DM candidates up (not compatible with relic density)

Problematic: Dark Matter (neutralino)

(Baer et al, 1202.4038)

Allowed by WMAP



W. Buchmuller

DM abundance typically much too large; blue: $m_0 < 5$ TeV, orange: $5\ \text{TeV} < m_0 < 20$ TeV: green: allowed by WMAP

What about “The Boson”?

Invited guest at Moriond EW was Francois Englert from the Brout-Englert-Higgs mechanism.
Everybody wanted to give him some recognition in the talks
Conclusion: a big confusion about the boson name….

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With Up To 10/fb
With CDF

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Tevatron searches for BSM Brout-Englert-Higgs (BEH) Bosons

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EBHGHK properties

[Englert, Brout; Higgs; Guralnik, Hagen, Kibble]

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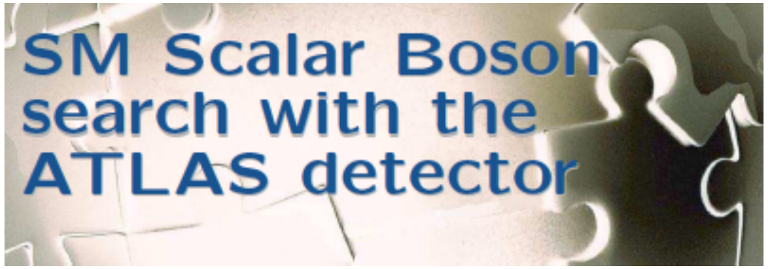

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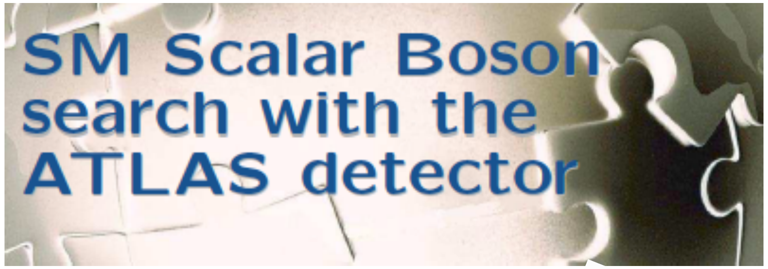

THE BOSON

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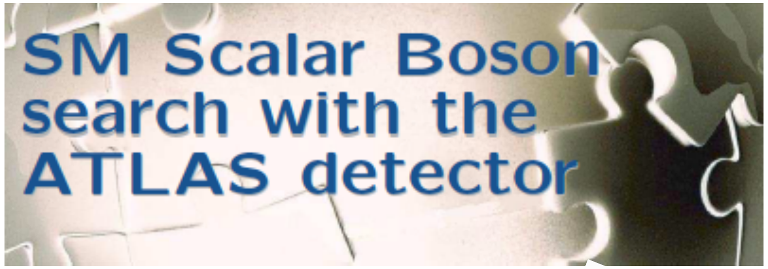

EBHGHK properties
[Englert, Brout; Higgs; Guralnik, Hagen, Kibble]

How shall we study X(125)?

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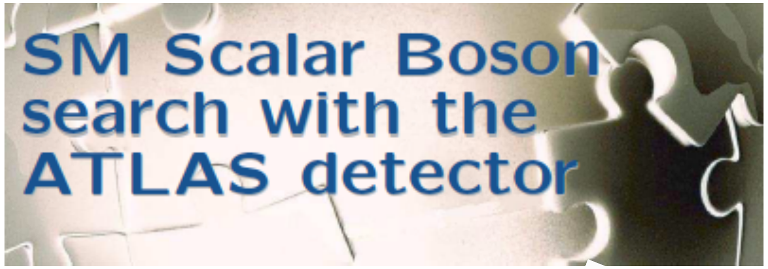


EBHGHK properties
[Englert, Brout; Higgs; Guralnik, Hagen, Kibble]

How shall we study X(125)?

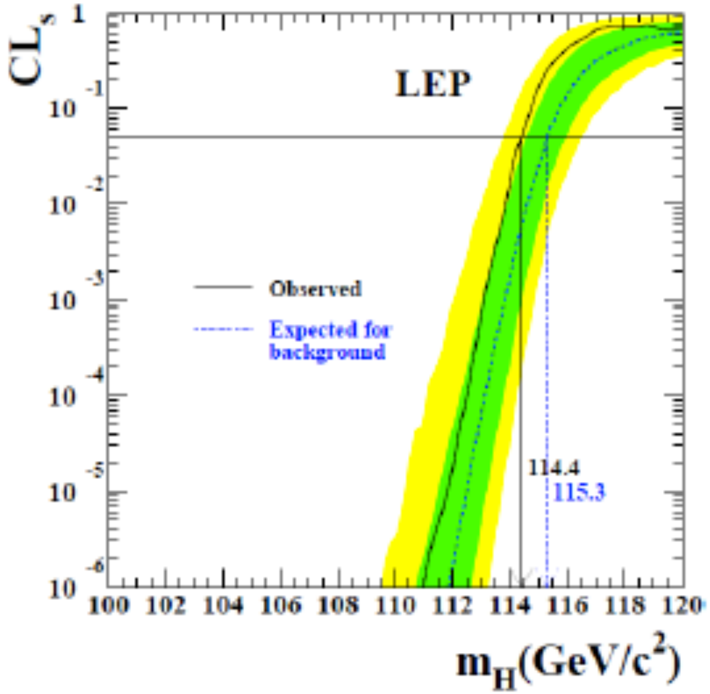
THE BOSON

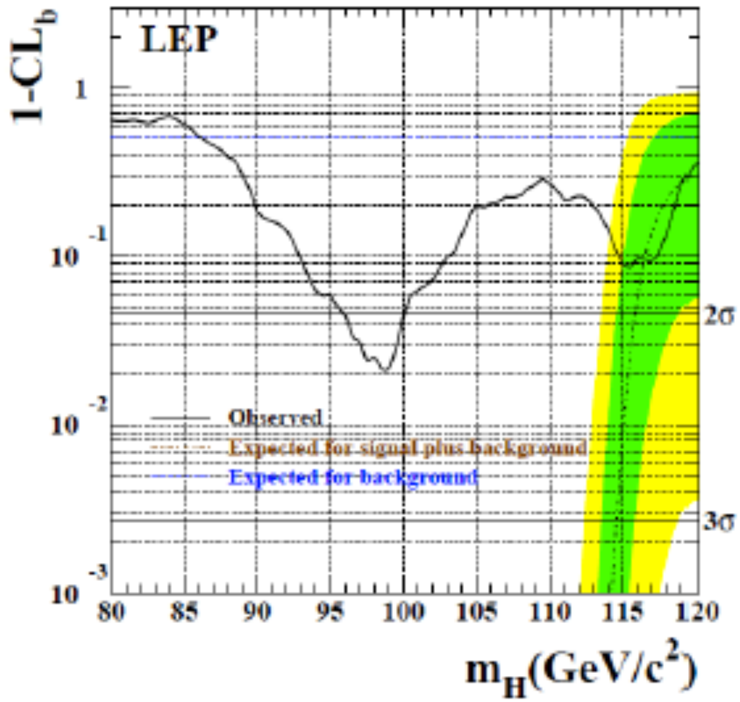
the SM scalar of EBH et al

Jean Francois Grivaz

“The Boson”

What LEP told us (direct searches)

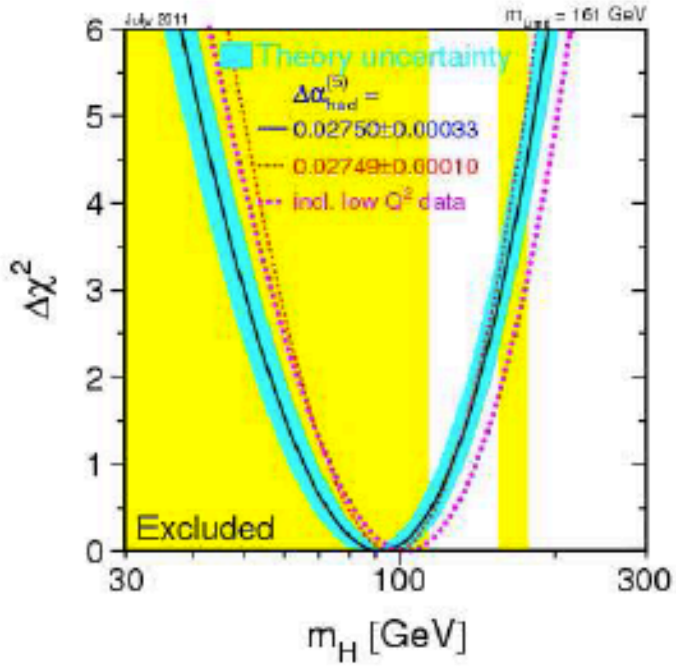


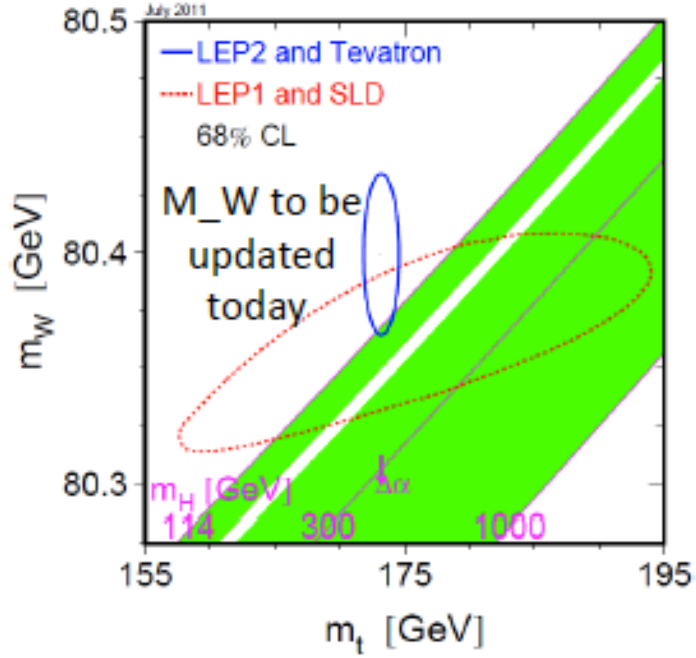


$e^+e^- \rightarrow HZ^{(*)}$
At 95% CL:
Scalar boson mass > 114.4 GeV
(But also > 113.8 GeV at > 99% CL)

Data excess consistent with expectation for a scalar boson with a mass of ~116 GeV
The p-value is close to 10%
The excess around 98 GeV is inconsistent with the SM

What LEP/SLD and Tevatron precision measurements tell us





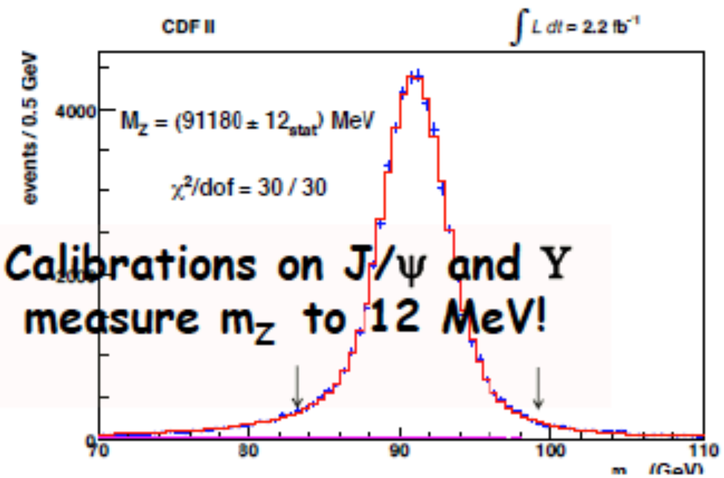
From the LEPEWWG Summer-11 (no LHC results, no recent M_W)

Scalar boson mass = 92 +34 -26 (68% CL)
At 95% CL: mass < 161 GeV, but also > ~ 50 GeV

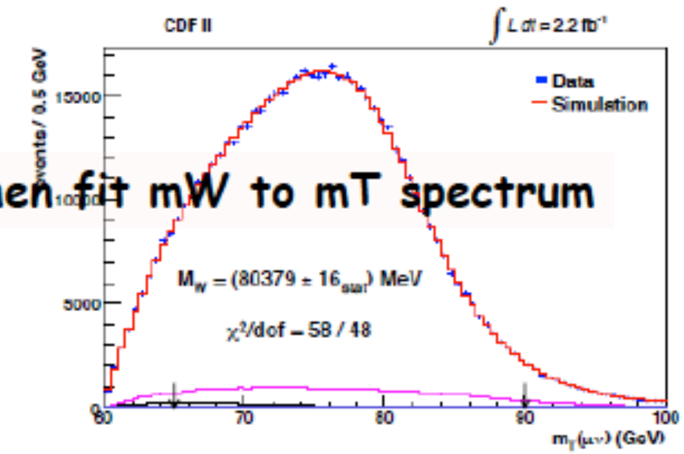
Since the discussion is about the SM SB, only the mass range 114 to 161 GeV will be considered

Impressive improvement on the measurement of W mass at the Tevatron

New 'best' result from CDF



Calibrations on J/ψ and Υ measure m_Z to 12 MeV!



Then fit mW to mT spectrum

Source	Uncertainty 2.2 fb^{-1} (MeV)
Lepton energy scale	7
Lepton energy resolution	2
Recoil energy scale	4
Recoil energy resolution	4
Lepton removal	2
Backgrounds	3
p_T(W) model	5
PDFs	10
QED radiation	4
Total systematics	*15*
W statistics	12
Total	***19***

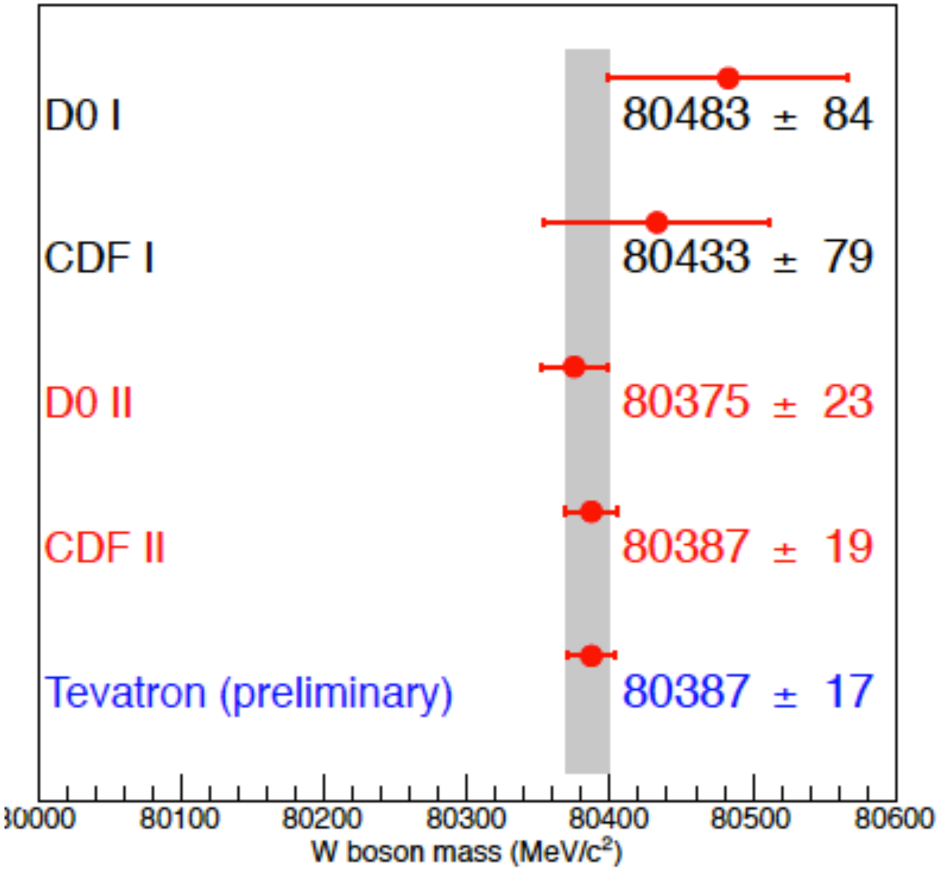
Largest systematics is from QCD initial/final radiation etc... 10 MeV (comp. QED 4 MeV !)

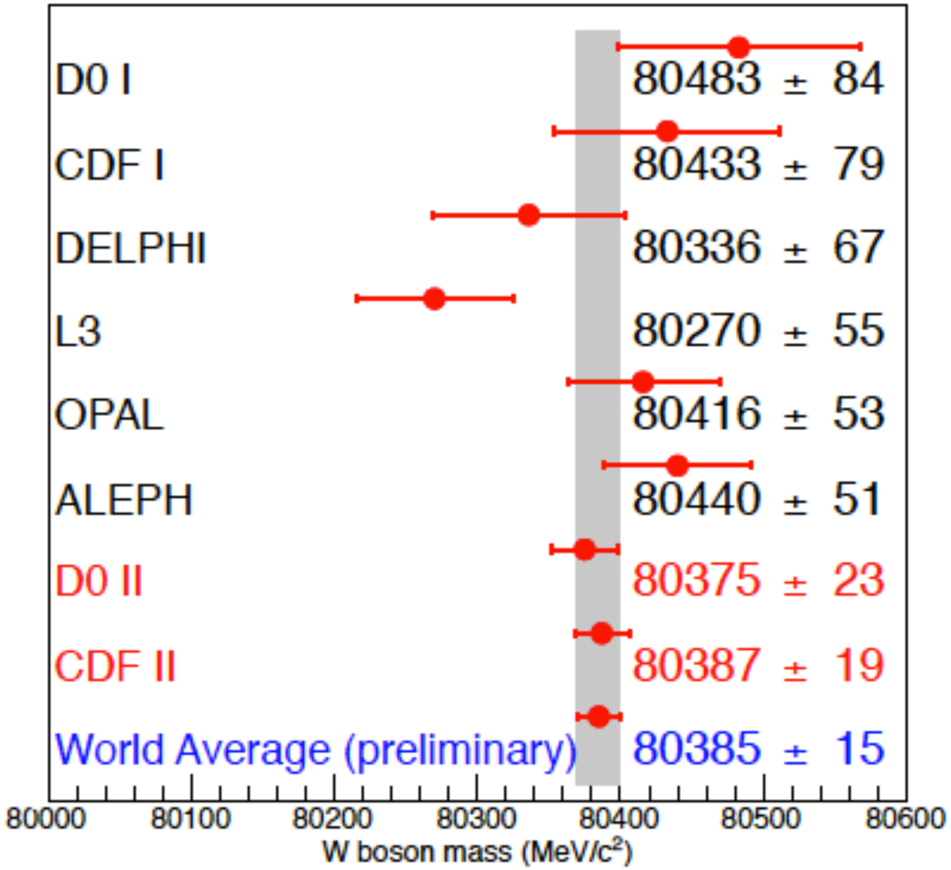
Bo Jayatilaka

Impressive improvement on the measurement of W mass at the Tevatron

Tevatron and world combinations

Bo Jayatilaka





nb: 2009 world average
M_W = 80399±23 MeV

Impact on the EW predictions of the Higgs mass

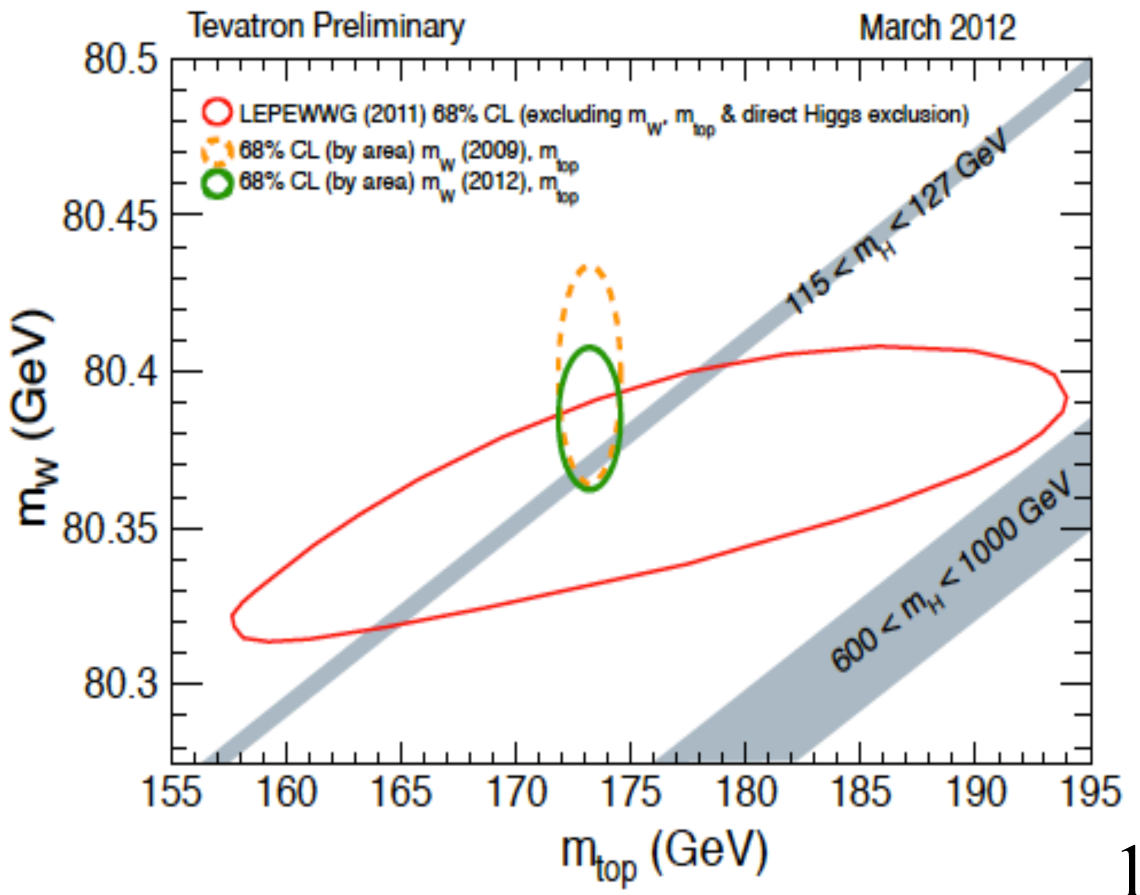
W mass vs. top mass

With $M_W = 80385 \pm 15$ MeV

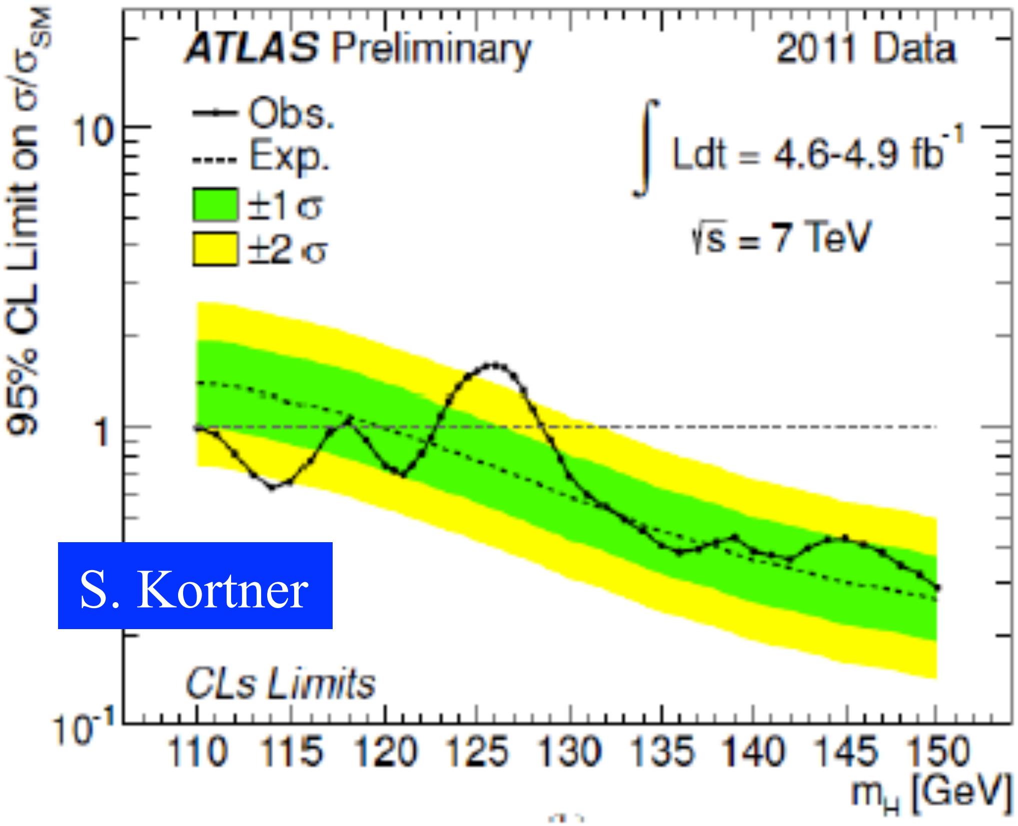
$M_H = 94^{+29}_{-24}$ GeV
$M_H < 152$ GeV @95% CL

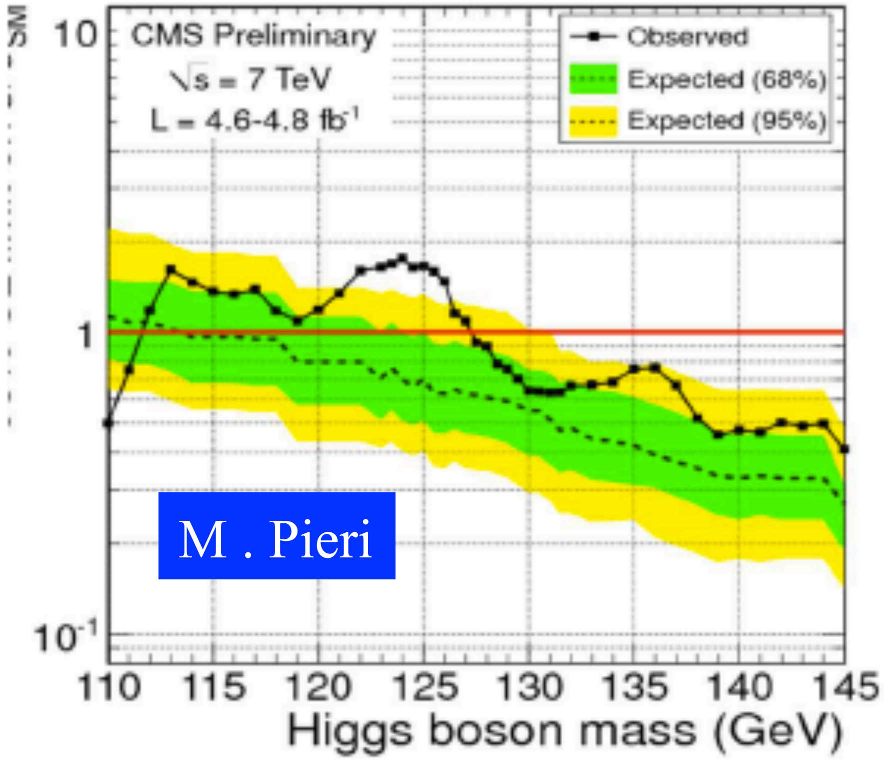
LEPEWWG/ZFitter

It was (2009):
$M_H = 92\ ^{+34}_{-26}$ GeV
$MH_< 161$ GeV @ 95% CL



LHC: the big picture





On the high mass side:

ATLAS/CMS exclude masses above 129/127.5 GeV

On the low side:

ATLAS excludes almost the whole mass range from 110 to 122.5 GeV

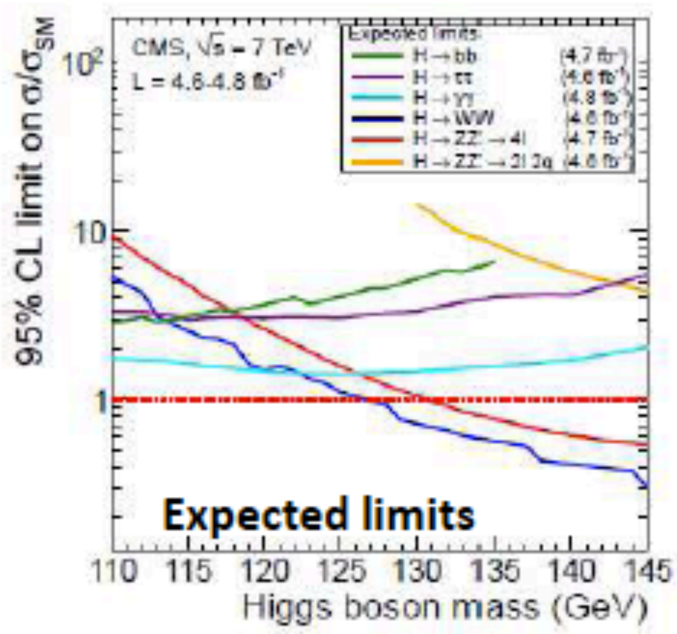
CMS excludes masses only below 111 GeV and has an excess above

LHC: channel by channel

Sensitivity of the various searches at low mass:

Above ~123 GeV, WW dominates the sensitivity.

At lower masses, $\gamma\gamma$ takes over



Production mechanisms:

ggF: WW, ZZ, $\gamma\gamma$

VH: bb

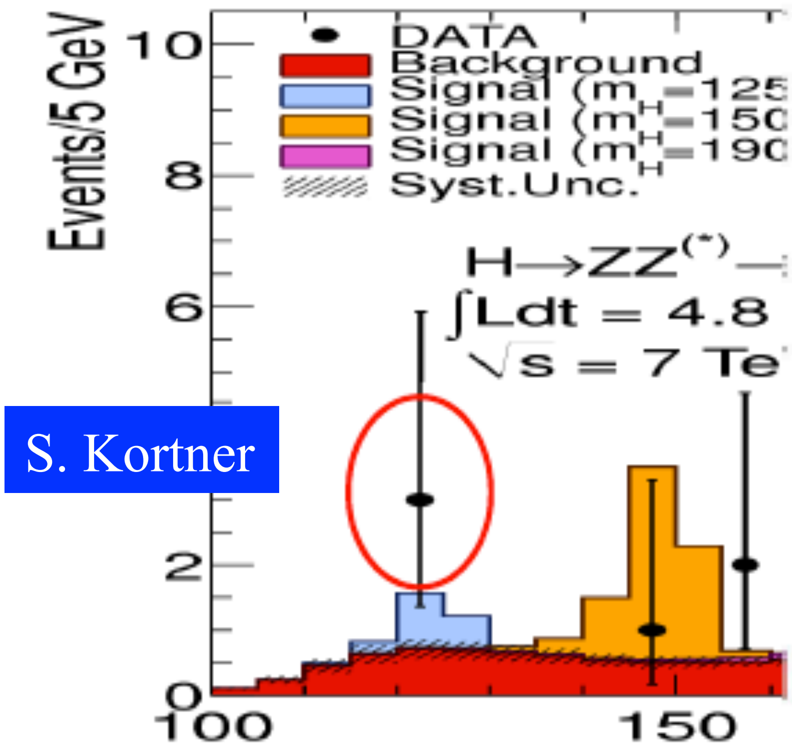
VBF: $\tau\tau$ (highest sensitivity)

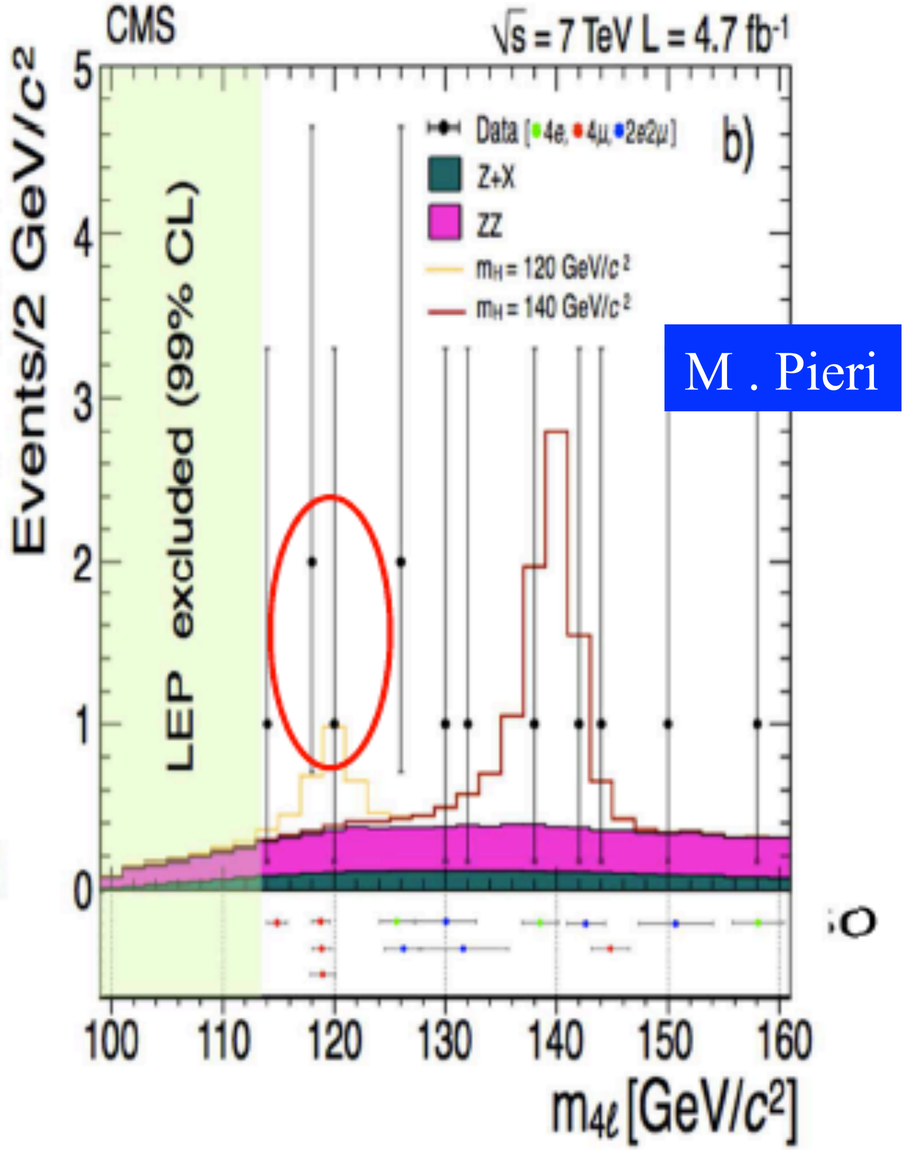
The bb/$\tau\tau$/WW modes
have poor mass resolution (especially WW)

The $\gamma\gamma$ and ZZ$\rightarrow$ 4l modes
have excellent mass resolution

ZZ has very low background:
a single event has a large local impact

High resolution channels: ZZ



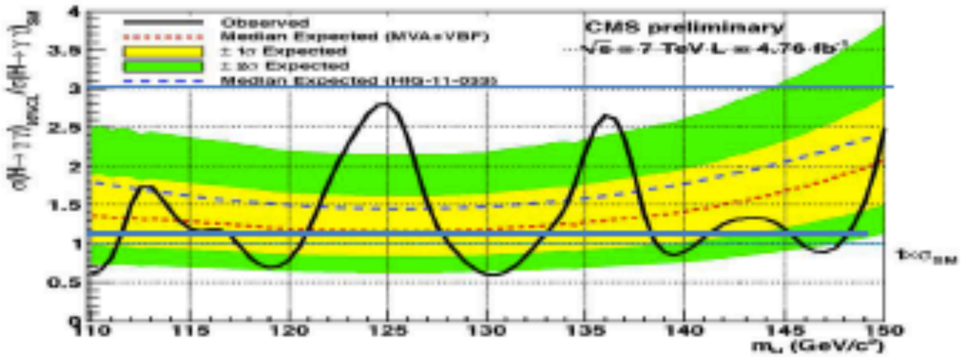


Background conditions seemingly quite different

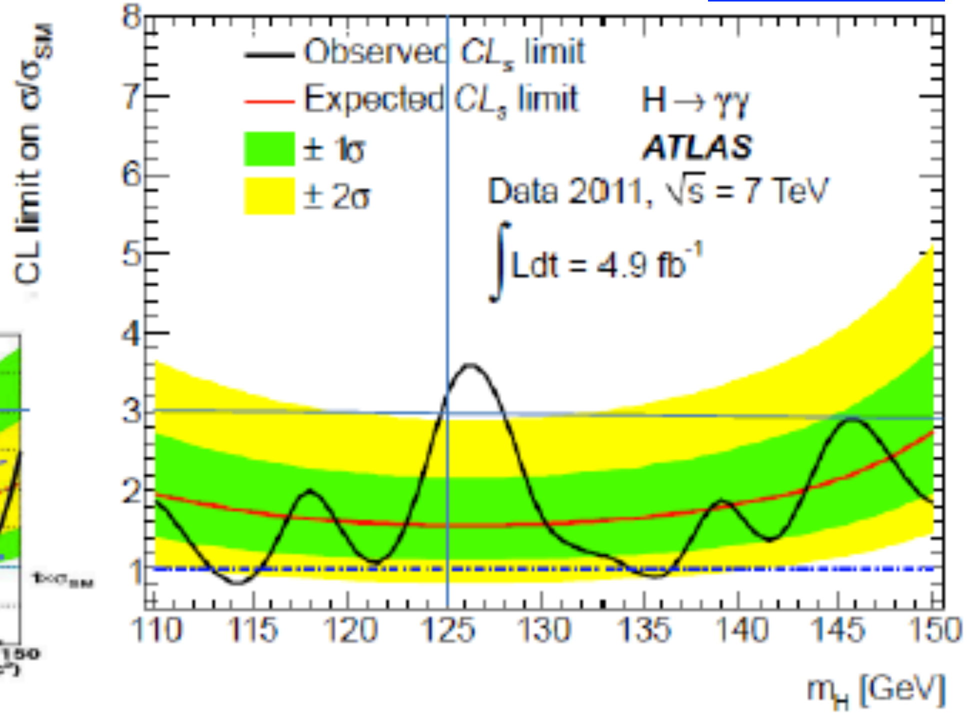
(Note the different bin sizes)

High resolution channels: γγ

S. Kortner

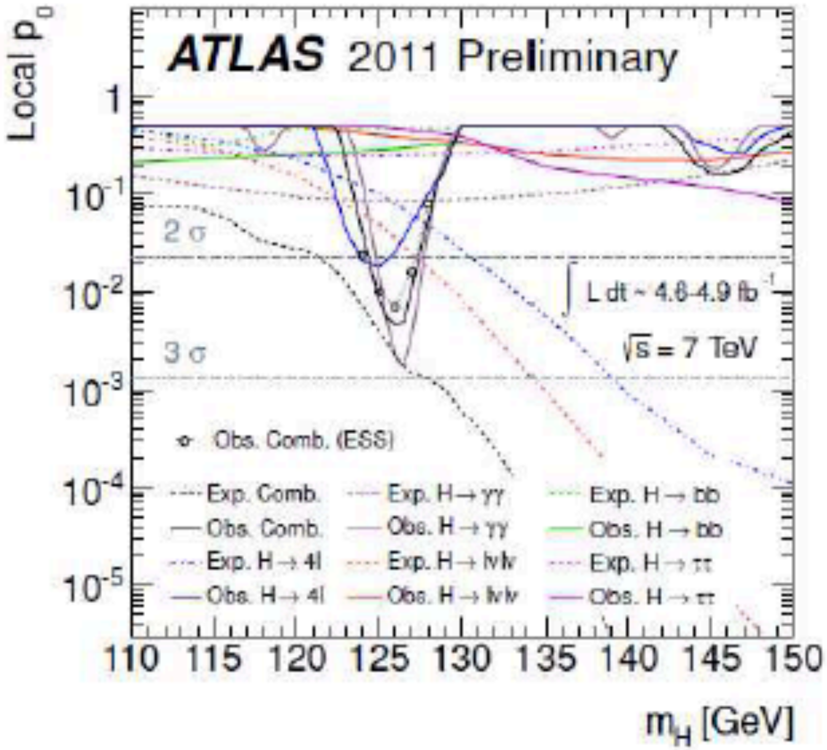


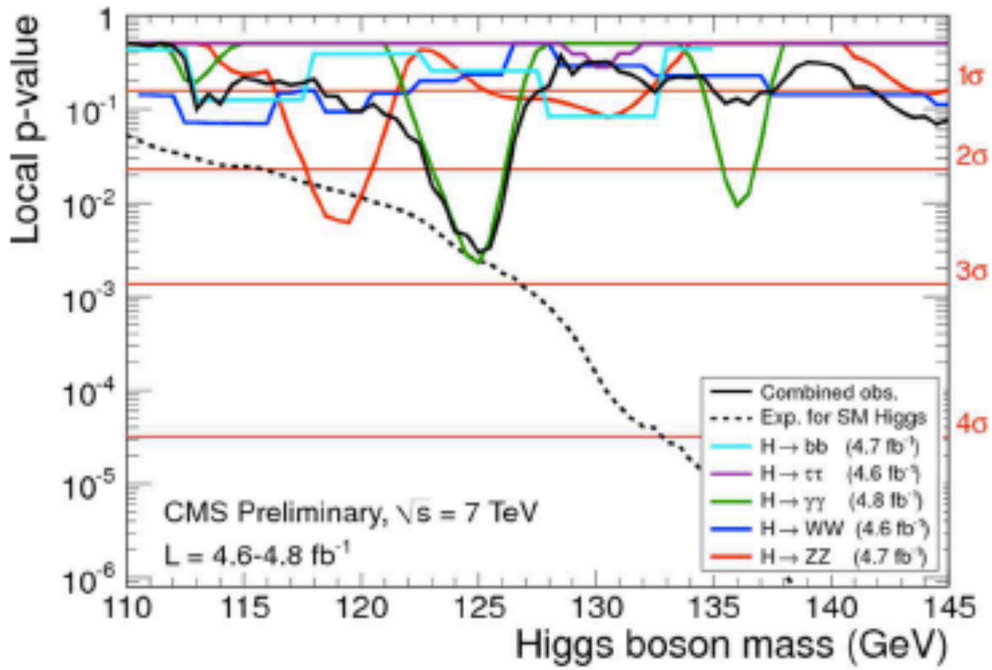
M . Pieri



Interesting feature (again) around 125 GeV: time to look at p-values…

Is there a (hint of a) signal ?



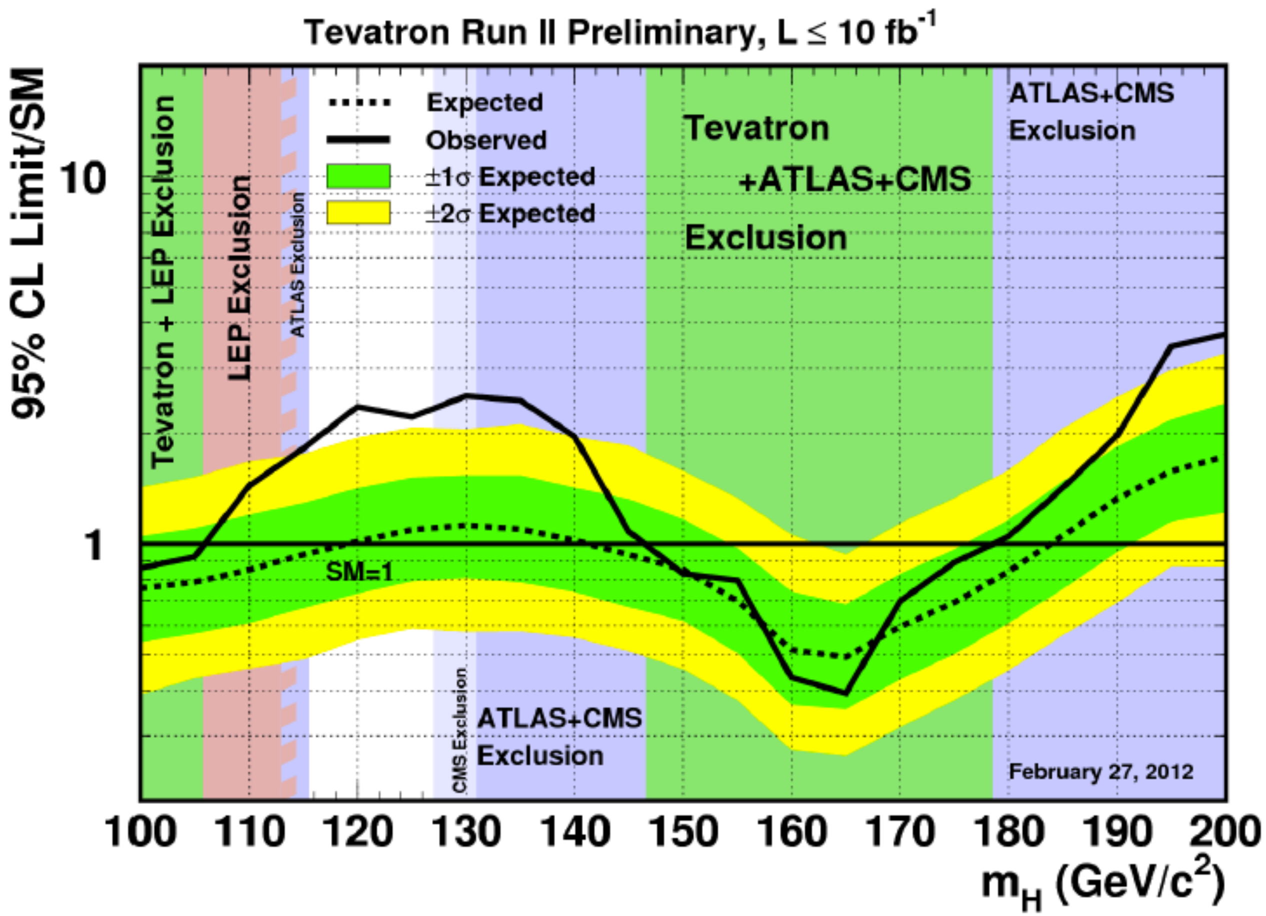


γγ: 2.8σ at 126 GeV
ZZ: 2.1σ at 125 GeV)
WW/bb/ττ: very little
Combined: 2.5σ at 126 GeV

γγ: 2.9σ at 125 GeV
ZZ: 2.5σ at 119.5 GeV
WW/bb: not much… ττ: nothing
Combined: 2.8σ at 125 GeV

2.5/2.8 sigmas are substantially reduced by LEE (1%→ 10%).
but the excess appear at (about) the same mass and in the same channels

Tevatron: the big picture



Although the plot include all channels, bb and WW are largely dominant (cross-over from bb to WW around 130 GeV)

95% CL exclusion sensitivity close or below the SM prediction through the whole mass range from 100 to 180 GeV

Clear exclusion around the region of maximal sensitivity (147-179) GeV

Broad data excess (>2 σ) from 115 GeV to 140 GeV (consistent with a signal)

What about the nature of the boson?

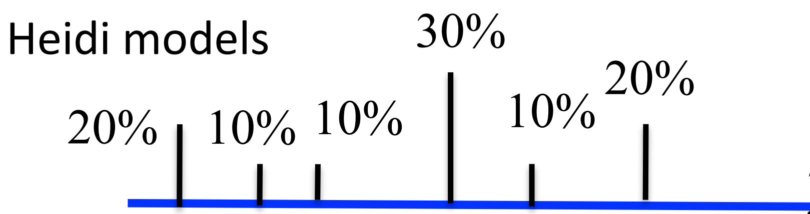
We should wait until the 125 GeV effect is either killed or established:
→A particle decaying in two photons is not spin 1 and more probably spin=0
→Is it elementary? Does it have all properties of the SM Higgs boson?
→Its discovery would eliminate a great number of hypotheses….

1) Heidi models:

J. J. van der Bij

The idea that there is a single Higgs particle peak is an assumption, for which there is no basis in theory or experiment.

Since the Higgs field is in some way different from other fields, a non-trivial density is quite natural.
The scientific goal regarding EW symmetry breaking is therefore to measure the Kallen-Lehmann spectral density of the Higgs propagator.



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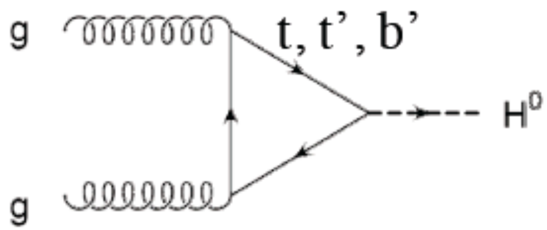
Sridhara Dasu

2) SM with fourth generation

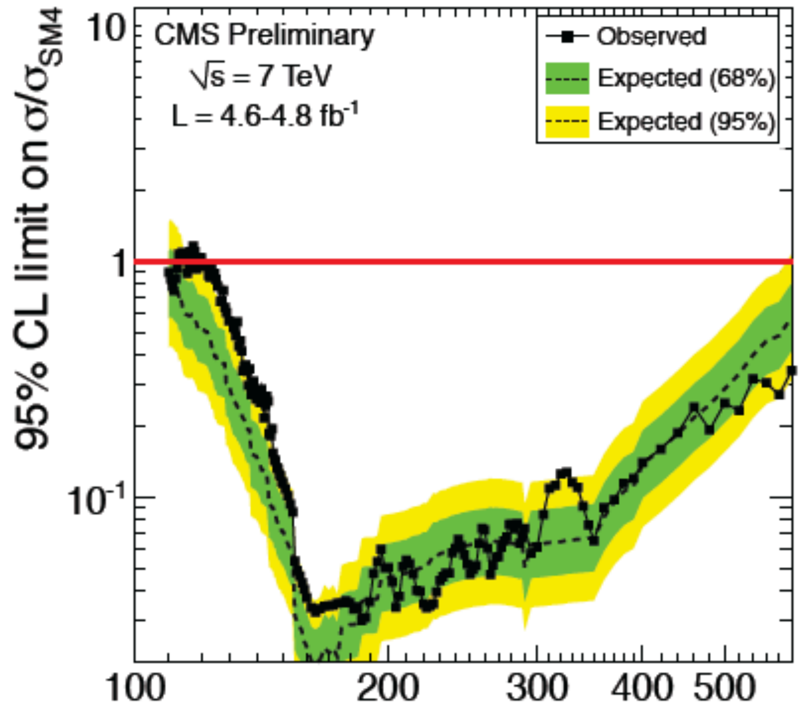
Significantly increased production rates resulted in exclusion of most of the parameter space for models with a fourth generation of fermions

Benchmark fourth generation quark masses of ~600 GeV



σ_{SM4} = 10–4 x σ_{SM} for M_H 110–600 GeV

Most of the space M_H > 120 GeV excluded



3) Higgs in MSSM

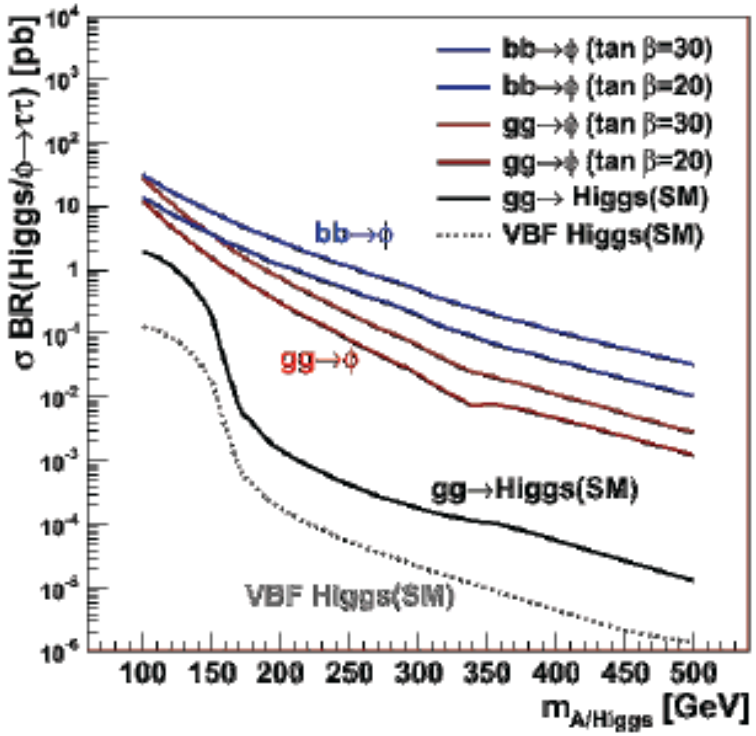
MSSM Higgs

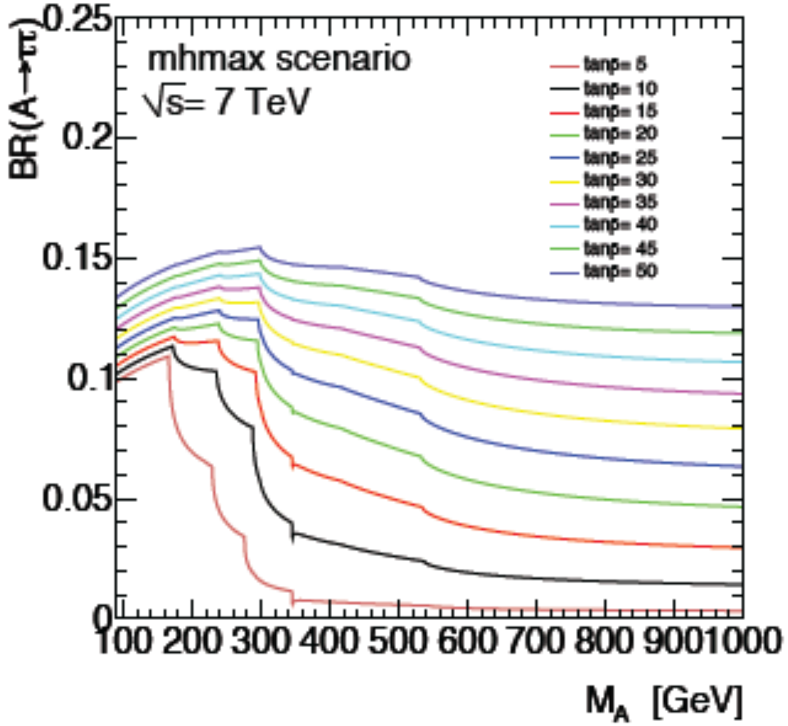
Sridhara Dasu

- Higgs sector in SUSY theory is more complicated
  - Need 2 higgs doublets each with 4 degrees of freedom
    - Results in the Standard Model like Higgs (h^0)
    - Plus, two neutral higgs (A^0, H^0) and charged ($H^\pm$)
    - However, only 2 parameters (M_A, $\tan\beta$ – ratio of the two doublets)
    - Masses of higgs and Z related
    - Search in (M_A, $\tan\beta$) plane
- Neutral Higgs
  - Look for $\phi=(h^{0,} A^0, H^0)$ in decays to tau-leptons
- Charged Higgs
  - Look for $H^\pm$ in top decays

MSSM ϕ(h, H, A)

- Enhanced coupling to b-quarks and τ-leptons
  - Production rate enhanced × $\tan^2\beta$
    - Gluon fusion with b,t loops + associated b quark production
  - Decays to b-quark and τ-lepton pairs enhanced at all masses



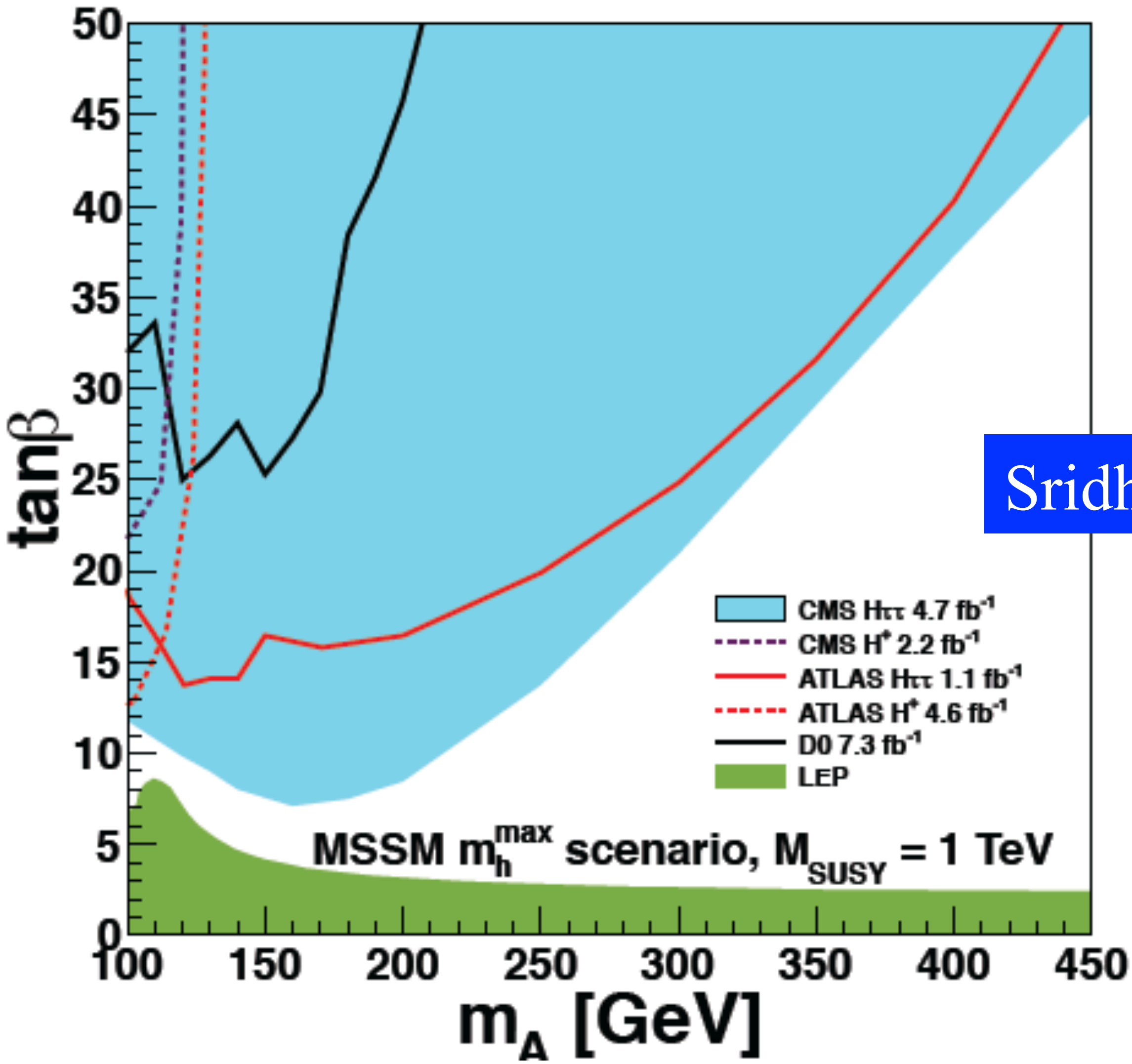


MSSM Higgs Summary

arXiv:1202.4083

ATLAS CONF 2012-11

CMS PAS HIG-11-019



Sridhara Dasu

Consequences of a 125 GeV Higgs on constrained MSSM scenarios

Nazila Mahmoudi

If the excess will be confirmed by more data, what are the consequences?

- In the SM, the Higgs mass is essentially a free parameter
- In the MSSM, the lightest CP-even Higgs particle is bounded from above:
  $M_h^{max} \approx M_Z |\cos 2\beta| +$ radiative corrections $\lesssim 110 - 135$ GeV
- Imposing M_h places very strong constraints on the MSSM parameters through their contributions to the radiative corrections

$\rightarrow$ Calculation of M_h^{max} in different constrained scenarios

What is the problem?

W. Buchmuller

Tree level bound on Higgs boson mass,

$$m_{h^0} < m_Z |\cos 2\beta| \ ,$$

hence $\mathcal{O}(100\%)$ quantum corrections to $m^2_{h^0}$ required,

$$125^2 \simeq 91^2 + 86^2 \ ;$$

in MSSM via top/stop loops ($m_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$; X_t: stop mixing parameter; $\tan\beta \gg 1$),

$$\frac{m_Z^2}{m_{h_0}^2} = \left[1 + \frac{3}{2\pi^2}\frac{y_t^4}{g_1^2+g_2^2}\left(\log\frac{m_S^2}{m_t^2} + \frac{X_t^2}{m_S^2}\left(1 - \frac{X_t^2}{12\, m_S^2}\right)\right)\right]^{-1} ,$$

decreases only logarithmically with m_S; large stop masses required!

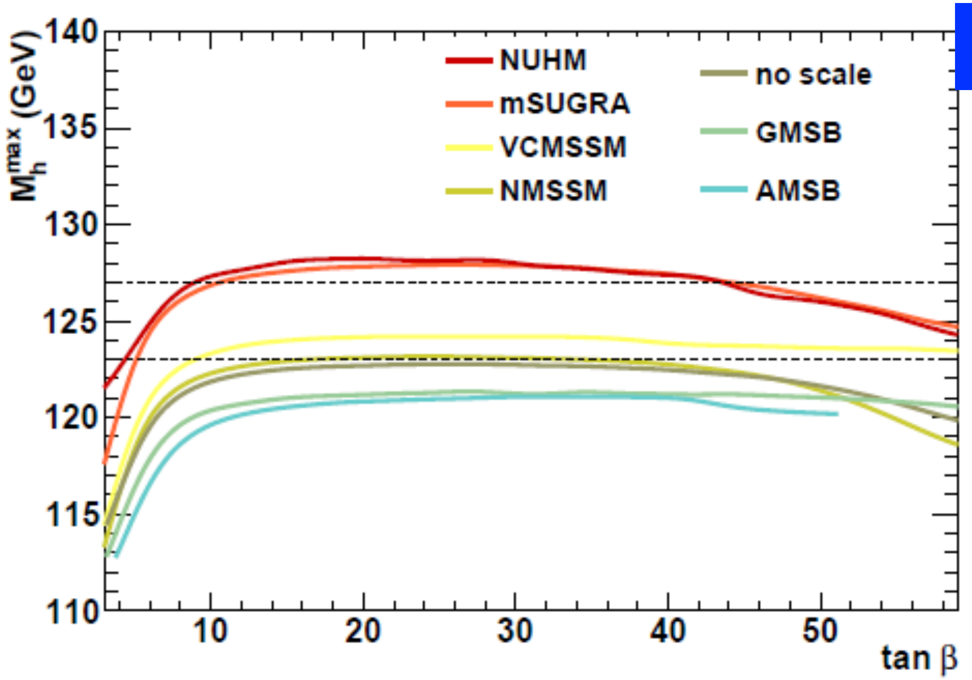
Large quantum corrections from top/stop

An Higgs of 125 GeV in SUSY is not "natural" and requires a lot of fine-tuning

Maximal Higgs masses computed in several constrained models

Maximal Higgs masses

Nazila Mahmoudi



A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162

model	AMSB	GMSB	mSUGRA	no-scale	cNMSSM	VCMSSM	NUHM
$M_h^{\max}$	121.0	121.5	128.0	123.0	123.5	124.5	128.5

End of AMSB and GMSB in their minimal versions!

An Higgs of 125 GeV put severe constraints on all the more constrained SUSY models!

If confirmed, most of the more constrained SUSY models will be ruled out….

How shall we study X(125)?

Blondel

At LHC?

It is there, and will do it.

The question: with which precision? O(10%) or worse (assume $600 fb^{-1}$)

Effect of pile-up?. Etc. etc.

do we need another machine to study more properties or more precisely?

Performance on couplings self couplings and invisible width?

At a linear collider ?

For 125 GeV Higgs, peak cross-section at ~250 GeV = $m_H + m_Z + 30$ GeV

But.. 250 GV of accelerastion and luminosity at that energy still requires a large amount of power and superb alignment. *Cost?*

At a small e+ e- machine? LEP3 in LHC tunnel (see next slides)

Much easier and cheaper than LC but not expandable.

At a muon collider ?

Feasibility study ongoing. Not an easy machine!

Ionization cooling (MICE experiment)

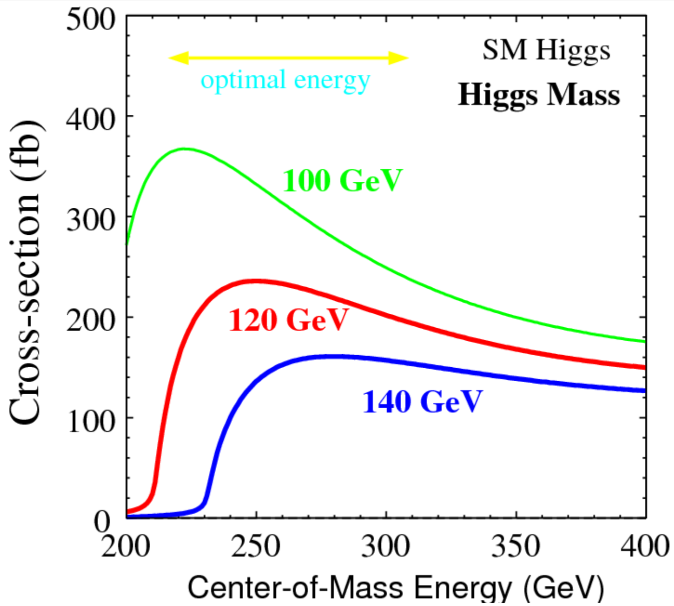
Virtue: s-channel production $\mu^+ \mu^- \to H$, exquisite energy calibration and very small energy spread if needed.

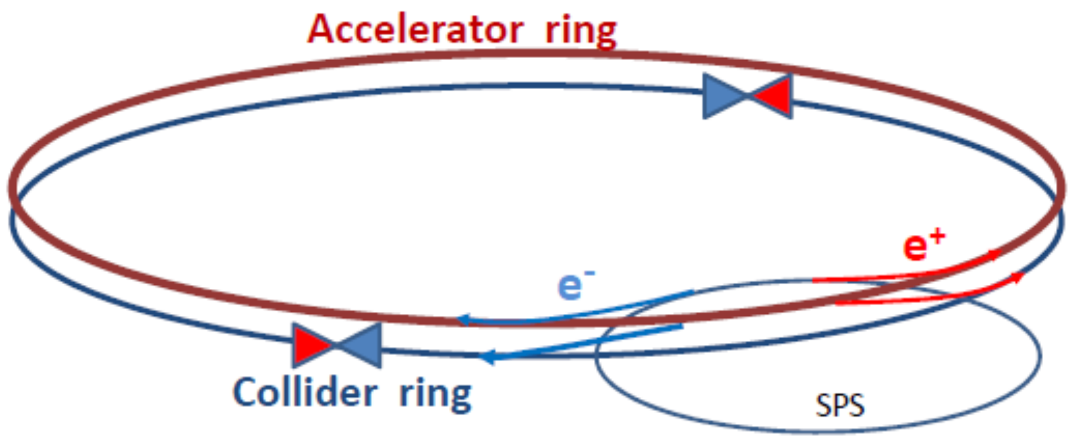
LEP3 Scheme arXiv:1112.2518

Blondel

LEP operated at 104.5 GeV/beam with
$L = 10^{32}$ /cm^2/s, (peak luminosity)
τ_b = 6h beam life-time
P_{SR}= 20 MW Synchrotron Radiation power

Modify parameters (reduce beam sizes by more focusing)
to increase instantaneous luminosity without increasing intensity too much
$L = 1.5\ 10^{34}$ /cm2/s, (peak luminosity)
τ_b = 12 min beam life-time
P_{SR}= 50 MW Synchrotron Radiation power
Inject continuously using ancellary accelerator.
➔ $L = 1.5\ 10^{34}$ /cm2/s 2 10^4 ZH events per year





The beauties of (weak-scale) SUSY

Sabine Kraml

- **Solution to the gauge hierarchy problem**

  Needs light stops, light higgsinos, somewhat light gluino

- **Gauge coupling unification**

  TeV-scale fermionic states → could be split SUSY

- **Radiative EWSB, light Higgs**

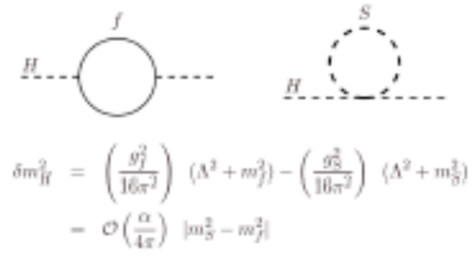
  heavy top effect
  m_h>115 GeV prefers heavy stops (finetuning prize of LEP)
  electroweak precision measurements prefer heavy SUSY

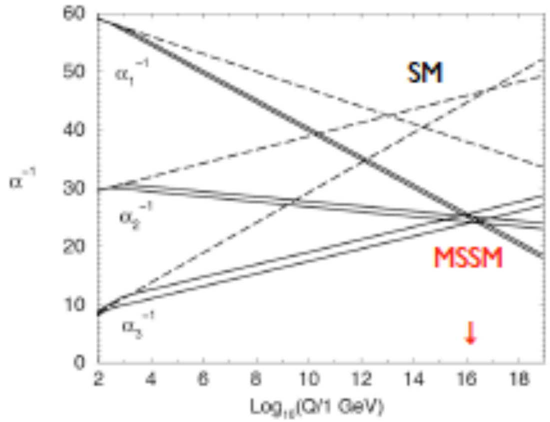
- **Cold dark matter candidate**

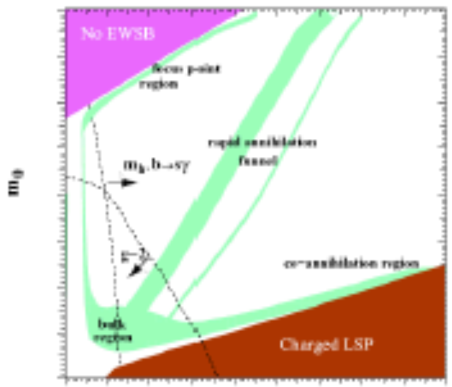
  TeV-scale LSP could do the job, just needs
  some efficient annihilation mechanism, e.g.
  higgsino LSP

- **Very rich collider phenomenology**

  Well, this entirely depends on phase-space ...
  and for the time being we are just running at 1/2 force

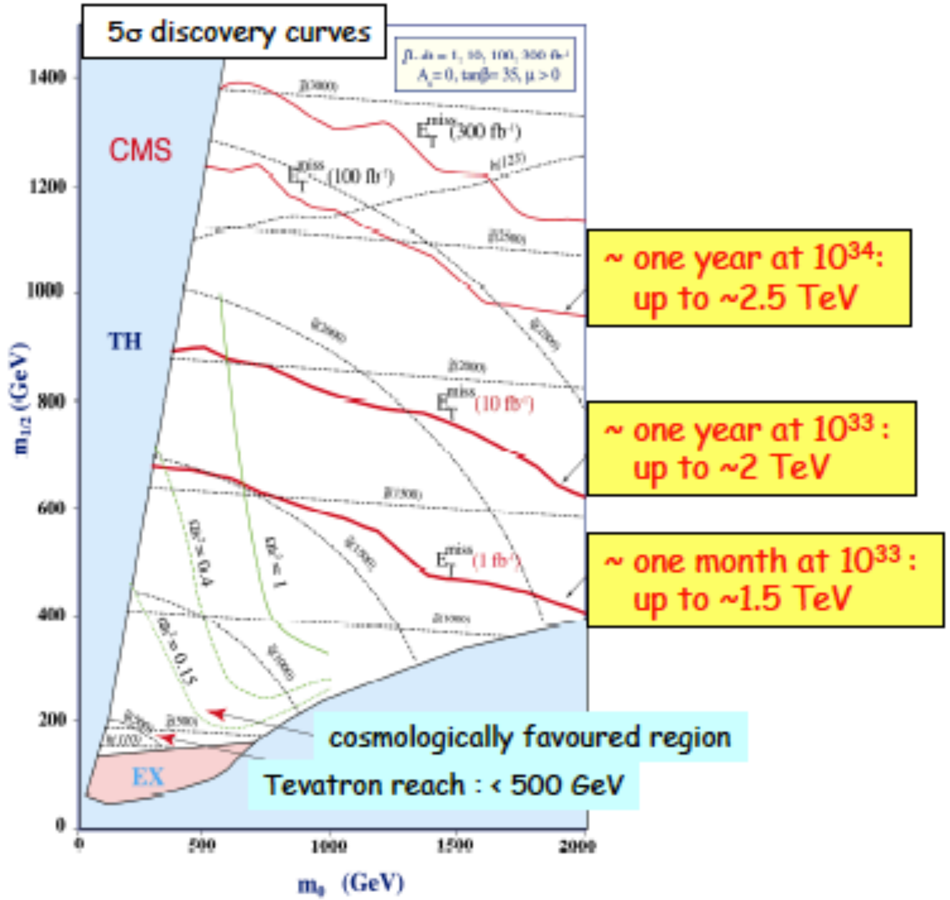


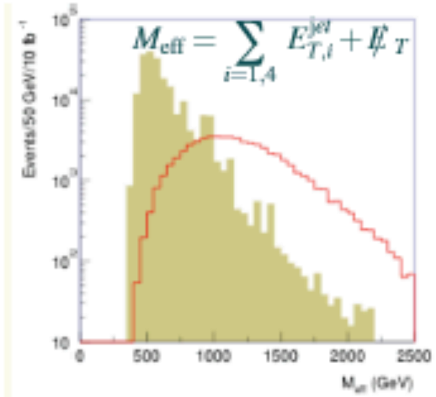


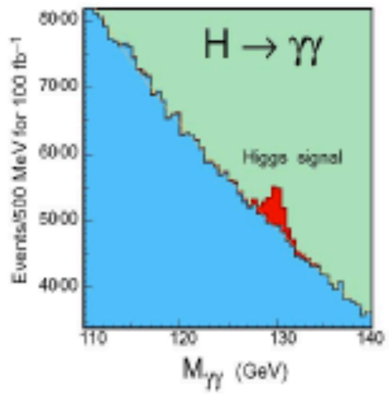


Before LHC turn-on

Very optimistic view: if SUSY is light (as we of course all expect...!) it will be discovered early on.



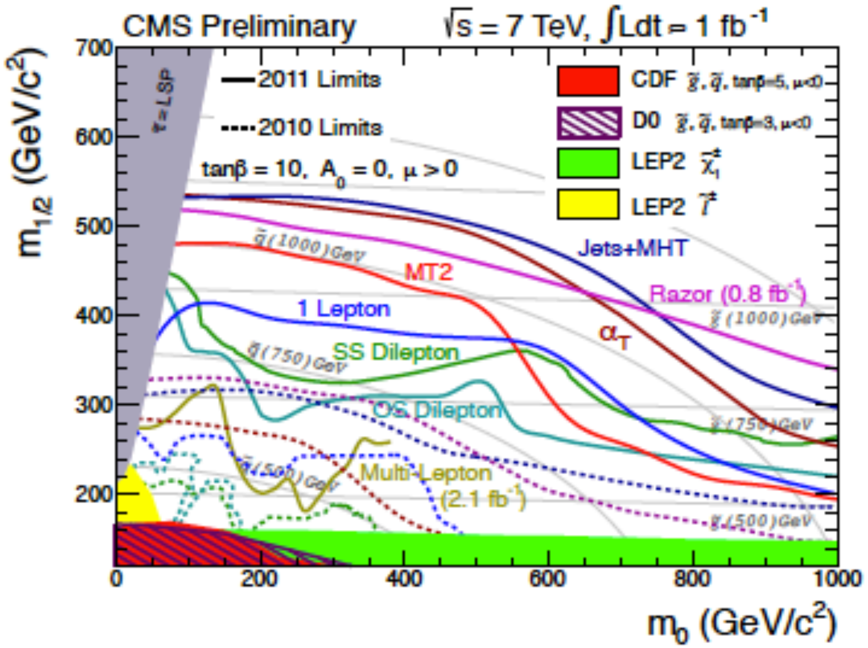




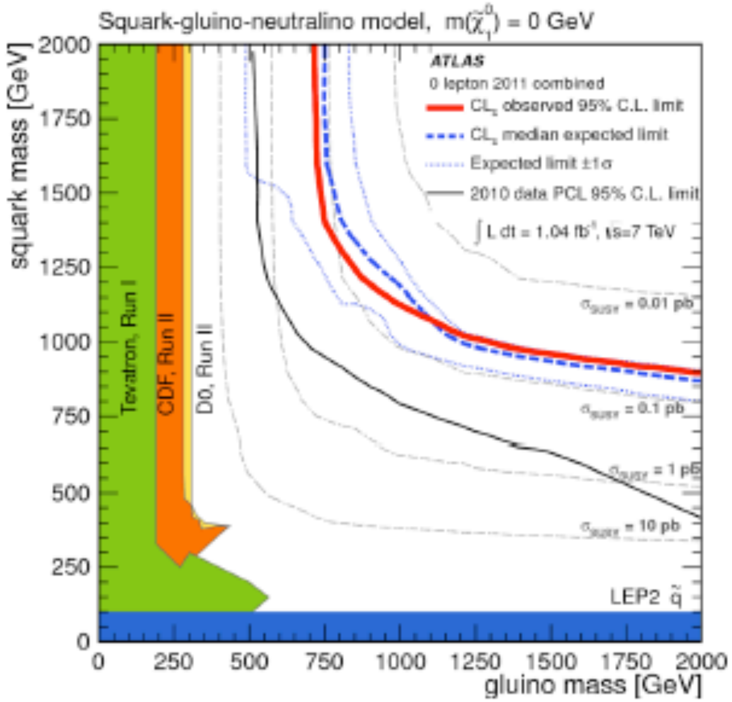
Much easier than discovering the Higgs...

SUSY after one year at the LHC: no evidence of any excess

ATLAS, arXiv:1109:6572



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS



Direct search limits are pushed higher and higher → M_{SUSY} > 1 TeV ?

In addition, precision flavor physics shows no sign of BSM → M_{SUSY} > O(10) TeV ?

Is SUSY in trouble ?

In the theory community there is a clear transition from simplistic & constrained models to more general SUSY models (more free parameters can accommodate the absence of any signal..)

Let's consider the

"phenomenological MSSM" (pMSSM)

- The pMSSM is a 19-dimensional parametrization of the MSSM that captures most of its phenomenological features. It encompasses and goes beyond a broad range of more constrained SUSY models.

- Parameters defined at the weak scale

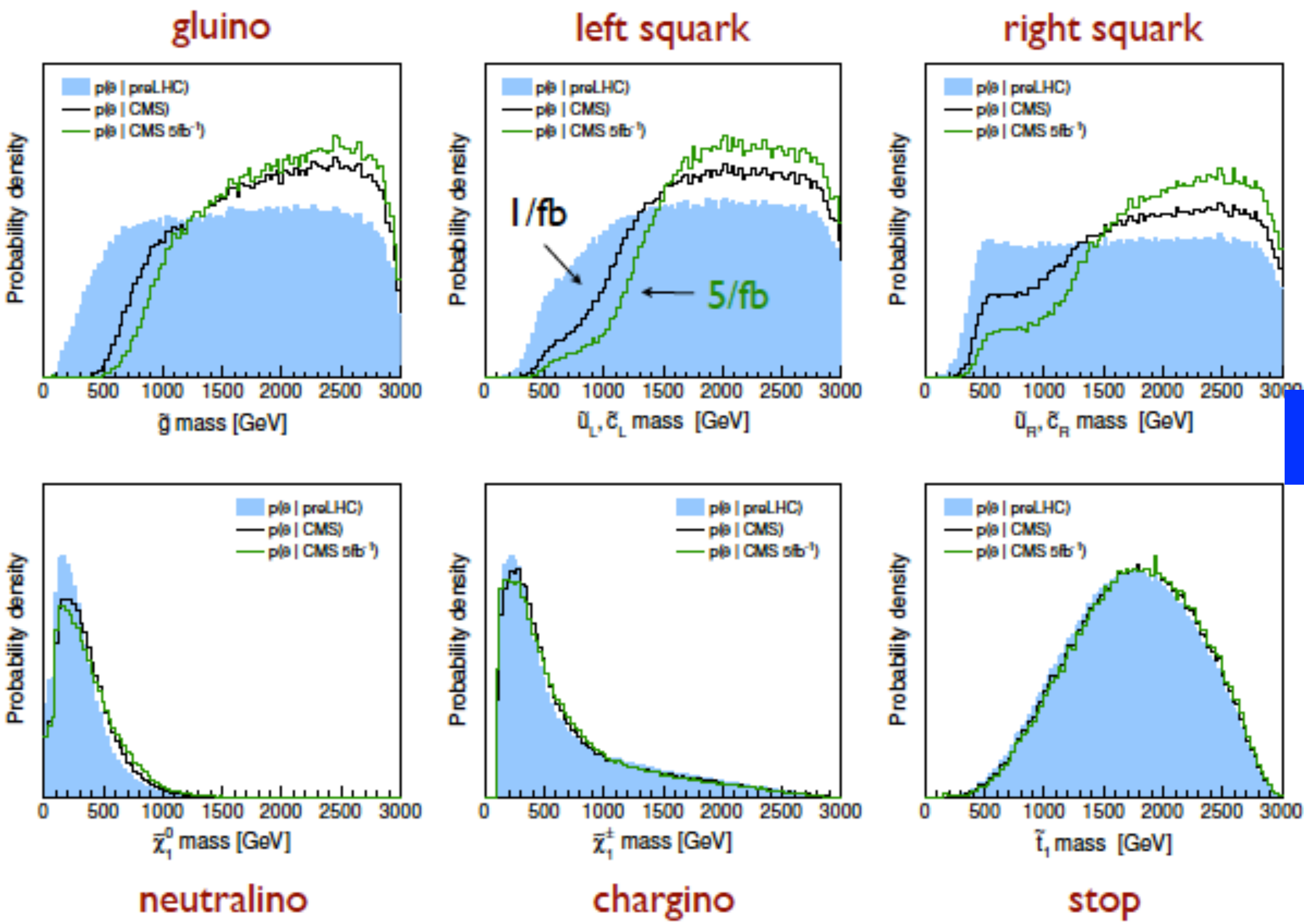
  - the gaugino mass parameters M_1, M_2, M_3;
  - the ratio of the Higgs VEVs $\tan\beta = v_2/v_1$;
  - the higgsino mass parameter μ and the pseudo-scalar Higgs mass m_A;
  - 10 sfermion mass parameters $m_{\tilde{F}}$, where $\tilde{F} = \tilde{Q}_1, \tilde{U}_1, \tilde{D}_1, \tilde{L}_1, \tilde{E}_1, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3$ (imposing $m_{\tilde{Q}_1} \equiv m_{\tilde{Q}_2}$, $m_{\tilde{L}_1} \equiv m_{\tilde{L}_2}$, etc.),
  - 3 trilinear couplings A_t, A_b and A_τ ,

Sabine Kraml

Assumptions: no new CP phases, flavor-diagonal sfermion mass matrices and trilinear couplings, 1st/2nd generation degenerate and A-terms negligible, lightest neutralino is the LSP.

Pioneering work
C.F. Berger et al., arXiv:0812.0980

Maximum likelihood fit including also precision measurements in the EW and flavor sectors (BR($b\rightarrow s\,\gamma$), BR($B_s\rightarrow\mu\mu$), BR($B\rightarrow\tau\nu$), Δa_{μ},, m_{top} etc)



Sabine Kraml

SUSY signals are pushed up (but still in the LHC reach)

SUSY after one year at the LHC:

Sabine Kraml

Conclusions

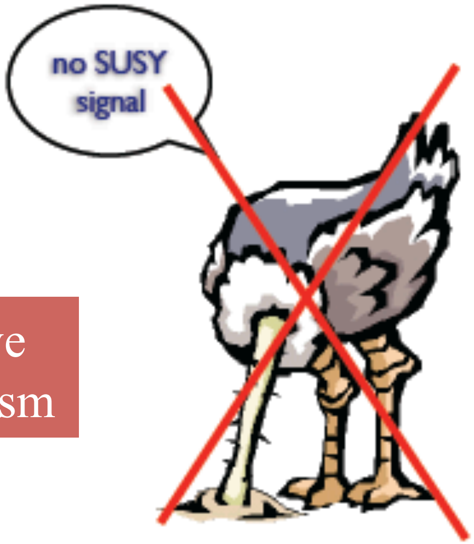
- LHC results are pushing squark and gluino mass limits to ~1 TeV; expectations for early discoveries were too optimistic

fact

- Current searches are not (yet) sensitive to

denial

  - ★ Small mass differences → soft jets, low E_T^{miss}
  - ★ Compressed spectra in general
  - ★ Mainly electroweak production
  - ★ Mainly stop/sbottom production



- Plenty of room where SUSY can hide

  besides, EW fits and flavor physics actually prefer heavy SUSY (inverted hierarchy, heavy 1st/2nd generation squarks)

tentative optimism

- SUSY DM stays compelling case

  interesting complementarity between LHC and DD

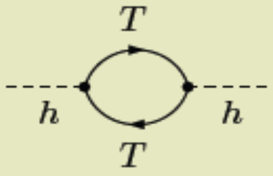
- We definitely need [the means] to interpret LHC results in terms of a wide range of models, including pMSSM.

acceptance

Flavor Structure in the SM and Beyond

$$\mathcal{L}_{\text{EFT}} = \Lambda_{\text{UV}}^2\, \Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\text{SM}}^{\text{gauge}} + \mathcal{L}_{\text{SM}}^{\text{Yukawa}} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\text{UV}}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\text{UV}}^2} + \dots$$

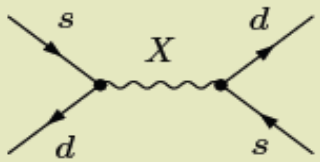
electroweak symmetry breaking ⇓ Higgs mass



$$\sim \frac{g_T^2}{16\pi^2}\Lambda_{\text{UV}}^2$$

no fine-tuning ⇓

⇓



$$\sim \frac{g_X^2}{\Lambda_{\text{UV}}^2}$$

bounds on flavor mixing ⇓ assuming *generic* flavor structure

$\Lambda_{\text{Higgs}} \lesssim 1$ TeV $\qquad \Lambda_{\text{flavor}} \gtrsim 10^3$ TeV

Neubert

Possible solutions to flavor problem explaining $\Lambda_{\text{Higgs}} << \Lambda_{\text{flavor}}$:

(i) $\Lambda_{\text{UV}} >> 1$ TeV: **Higgs fine tuned**, new particles too heavy for LHC

(ii) $\Lambda_{\text{UV}} \approx 1$ TeV: quark flavor-mixing protected by a **flavor symmetry**

The more NP scale is shifted up
the more indirect searches in flavor sector become important

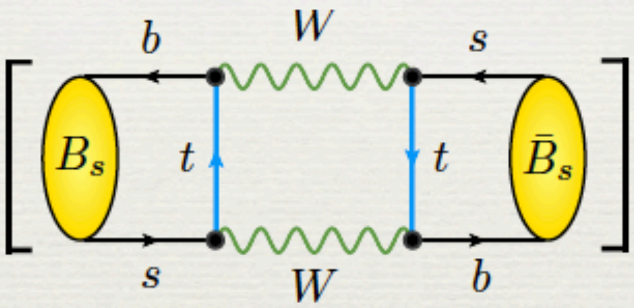
$B_{(s)}$ mixing has been an important problem since 25 years….

U. Haisch

Standard Model & Beyond

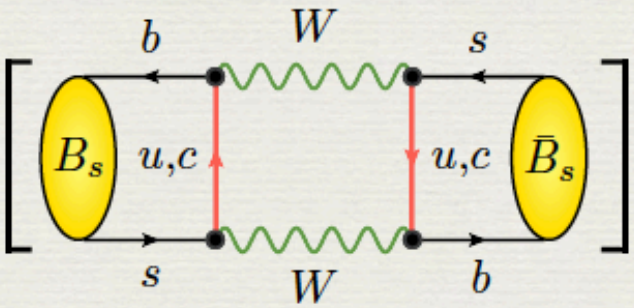
- B_s–$\bar{B}_s$ oscillations encoded in elements M_{12} & Γ_{12} of hermitian mass & decay rate matrices (CPT $\Rightarrow$ $M_{11} = M_{22}$, $\Gamma_{11} = \Gamma_{22}$). In Standard Model (SM) leading effects due to electroweak box diagrams:

$(M_{12})_{SM} \propto \text{Re}$



dispersive part arising from "off-shell" top quark

$(\Gamma_{12})_{SM} \propto \text{Im}$



absorptive part related to "on-shell" light up-type quarks

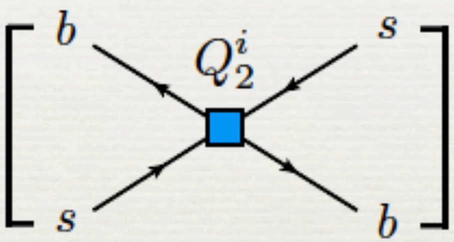
… because it is very sensitive to new particles via loops:

A. Lenz

Standard Model & Beyond

- Generic, sufficiently heavy new physics (NP) in M_{12} (Γ_{12}) can be described via effective $\Delta B = 2$ ($\Delta B = 1$) interactions:

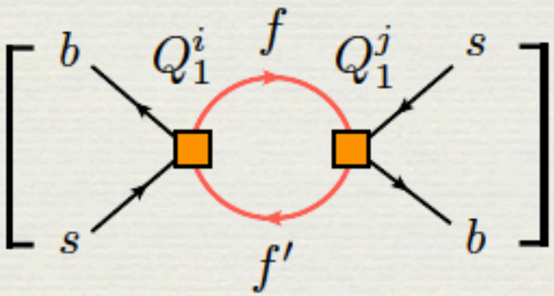
$$(M_{12})_{NP} \propto C_2^i \left[\quad \right] \sim \frac{1}{\Lambda_{NP}^2}$$



NP scale

very sensitive to new particles:
SUSY, extra dimensions, ...

$$(\Gamma_{12})_{NP} \propto C_1^i C_1^j \, \mathrm{Im} \left[\quad \right] \sim \frac{1}{(4\pi)^2} \frac{1}{\Lambda_{NP}^4}$$



free of NP (?), since coefficients would also give B decays into light final states X ($M_X < m_b$)

loop factor

Very interesting hints of deviations from SM predictions in recent past mostly in the Bs sector (ϕs and A_{SL}) from Tevatron

SM Predictions vs. Data

U. Haisch

	SM predictions [Lenz & Nierste, 1106.6308]	data before 2011
ΔM [ps^{-1}]	17.3 ± 2.6	17.70 ± 0.08 [CDF]
$\Delta\Gamma$ [ps^{-1}]	0.087 ± 0.021	$0.154^{+0.054}_{-0.070}$ (0.9σ) [CDF & DØ]
$\phi_{\psi\phi}$ [°]	-2.1 ± 0.1	-44^{+17}_{-21} (2.3σ) [CDF & DØ]
A^{b}_{SL} [10^{-4}]	-2.1 ± 0.4	-85 ± 28 (3.0σ) [DØ]
a^{s}_{fs} [10^{-5}]†	1.9 ± 0.3	-1200 ± 700 (1.7σ)

Deviations from SM predictions by 2-3 σ

.. But LHCb is quickly solving the issue:

→ phis is now in good agreement with SM (within the uncertainty)

Pete Clarke

- LHCb has presented new preliminary results using the full 2011 data (1 fb^{-1})
- From an analysis of the $J/\psi\phi$ channel we find:

$$\Gamma_s = 0.6580 \pm 0.0054(\text{stat.}) \pm 0.0066(\text{syst.})\ ps^{-1}$$
$$\Delta\Gamma_s = 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.})\ ps^{-1}$$
$$\phi_s = -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.})\ \text{rad.}$$

- From an analysis of the $J/\psi\pi\pi$ channel we find:

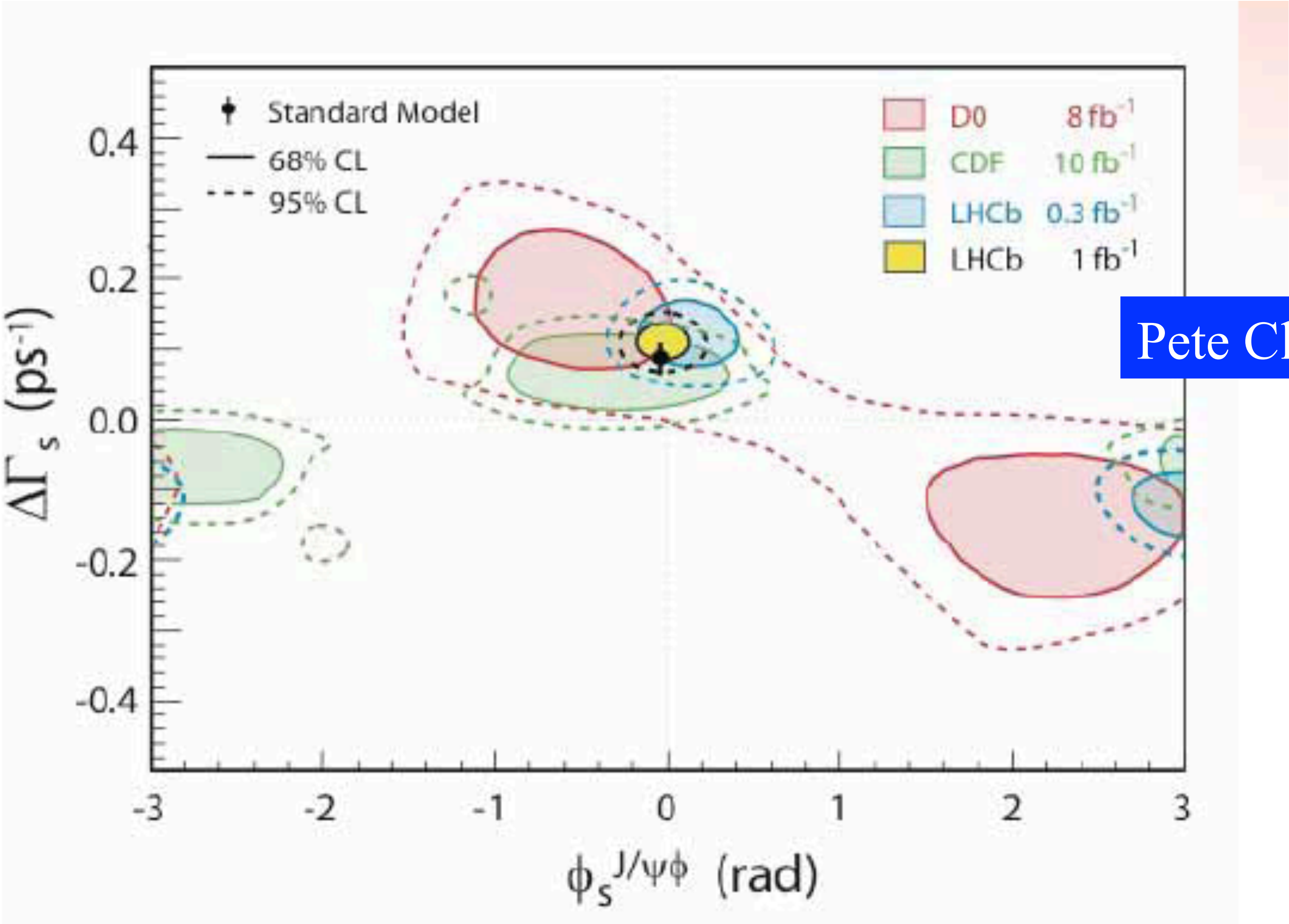
$$\phi_s = -0.02 \pm 0.17(\text{stat.}) \pm 0.02(\text{syst.})\ \text{rad}$$

- Combining both results we find:

$$\phi_s = -0.002 \pm 0.083(\text{stat.}) \pm 0.027(\text{syst.})\ \text{rad.}$$

- We resolve the 2-fold ambiguity and find: $\Delta\Gamma_s > 0$

Mixing induced CPV phase phis: pictorial view of CDF, D0 and LHCb results



Pete Clarke

Fully compatible with SM predictions

Asl still shows an (increasing) deviation from SM predictions

SM Predictions vs. Data

	SM predictions [Lenz & Nierste, 1106.6308]	data before 2011	data after 2011
ΔM [ps^{-1}]	17.3 ± 2.6	17.70 ± 0.08 [CDF]	17.73 ± 0.05 [CDF & LHCb]
$\Delta\Gamma$ [ps^{-1}]	0.087 ± 0.021	$0.154^{+0.054}_{-0.070}$ (0.9σ) [CDF & DØ]	0.123 ± 0.030 (1.0σ) [LHCb]
$\phi_{\psi\phi}$ [°]	-2.1 ± 0.1	-44^{+17}_{-21} (2.3σ) [CDF & DØ]	1.7 ± 10.0 [LHCb]
A^b_{SL} [10^{-4}]	-2.1 ± 0.4	-85 ± 28 (3.0σ) [DØ]	-79 ± 20 (3.9σ) [DØ]
a^s_{fs} [10^{-5}]†	1.9 ± 0.3	-1200 ± 700 (1.7σ)	-1300 ± 800 (1.5σ)

But it is very difficult to explain it without seeing any deviation in phis (cross-checks of this measurement are needed)

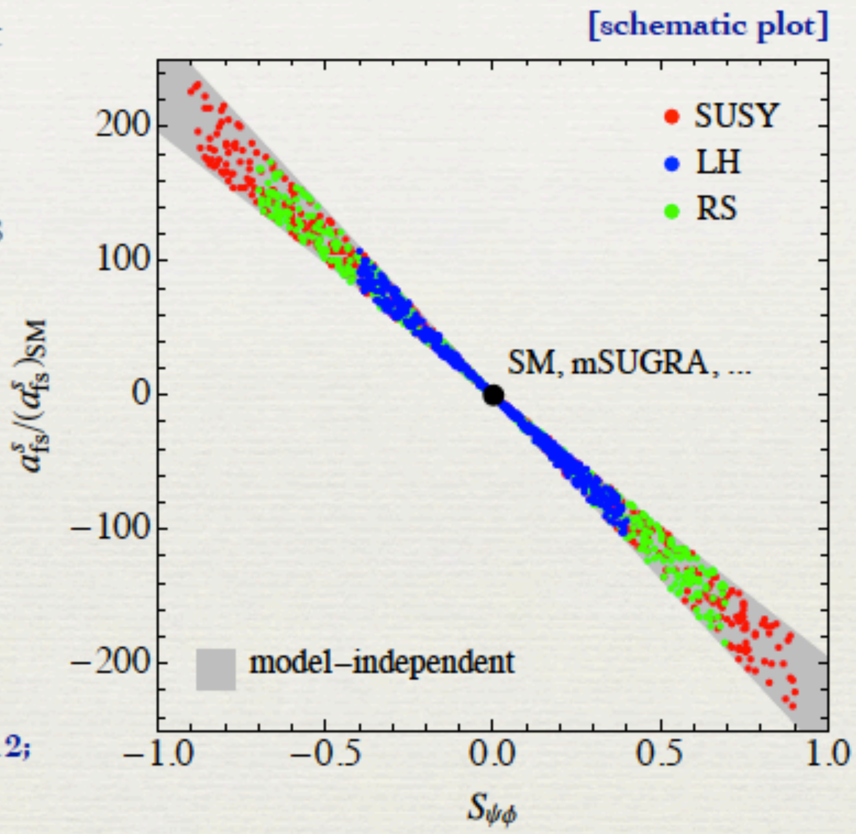
If NP in M_{12}, Which Kind?

- In all NP models without direct CPV in decay (like SUSY, little Higgs (LH), Randall-Sundrum (RS) scenarios, ...), observables a^s_{fs} & $S_{\psi\phi}$ strongly correlated:

$$\frac{a^s_{fs}}{(a^s_{fs})_{\rm SM}} \approx -240\,\frac{S_{\psi\phi}}{R_M}\,,$$

$$R_M = 1.05 \pm 0.16$$

[see e.g. Ligeti, Papucci & Perez, hep-ph/0604112;
Blanke et al., 0805.4393, 0809.1073;
Altmannshofer et al., 0909.1333;
Casagrande et al., 0912.1625; ...]

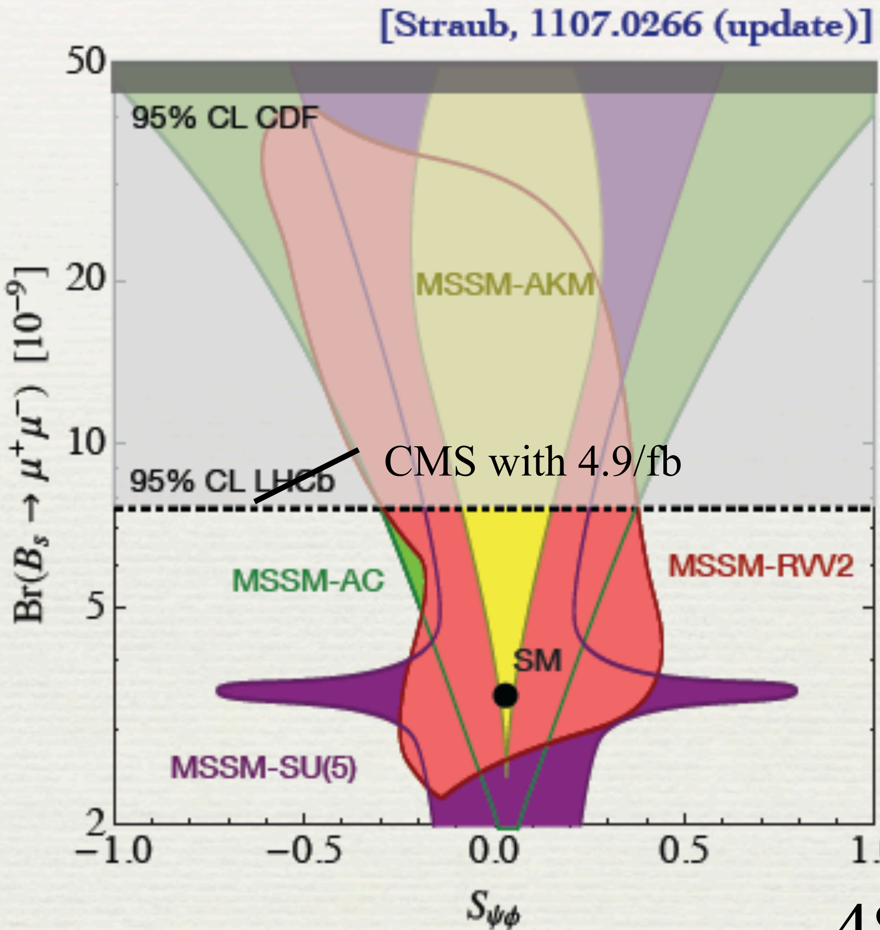


Correlations among different flavor measurements are important to pin down the BSM dynamics: for example phis vs BR(Bs→μμ)

If NP in M_{12}, Which Kind?

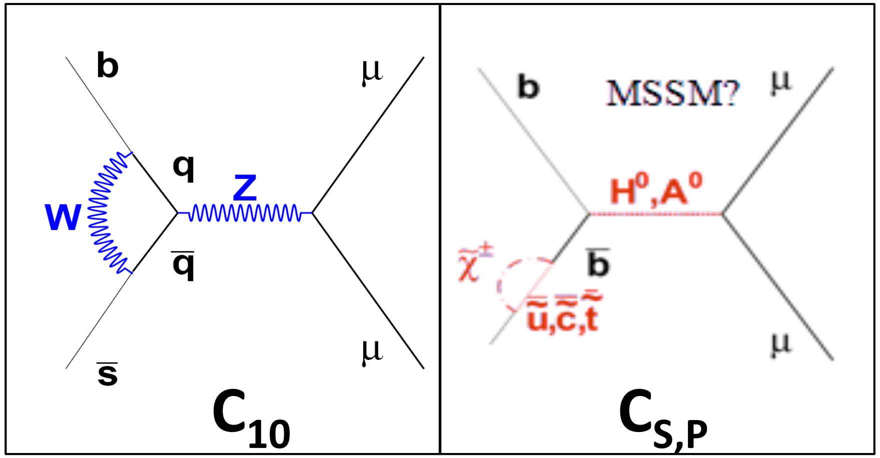
- Even a clear signal of NP in B_s mixing will not allow to pinpoint nature of beyond-SM dynamics. One needs to study correlations with other channels such as $B_s \to \mu^+\mu^-$

Unfortunately, given great performance of LHC, one starts walking on thin ice ...



$B_s \rightarrow \mu^+\mu^-$

(or how to investigate the Higgs sector via indirect searches)



- Very rare FCNC decay, with only contributions from $C^{(\prime)}_{10}$ (axial), $C^{(\prime)}_{S}$ (Higgs, scalar) and $C^{(\prime)}_{P}$ (pseudo-scalar)
  - Standard Model
    - C_S and C_P negligible
    - C_{10} dominates, but helicity suppressed
    - $BR_{SM} = (3.2 \pm 0.2) \times 10^{-9}$

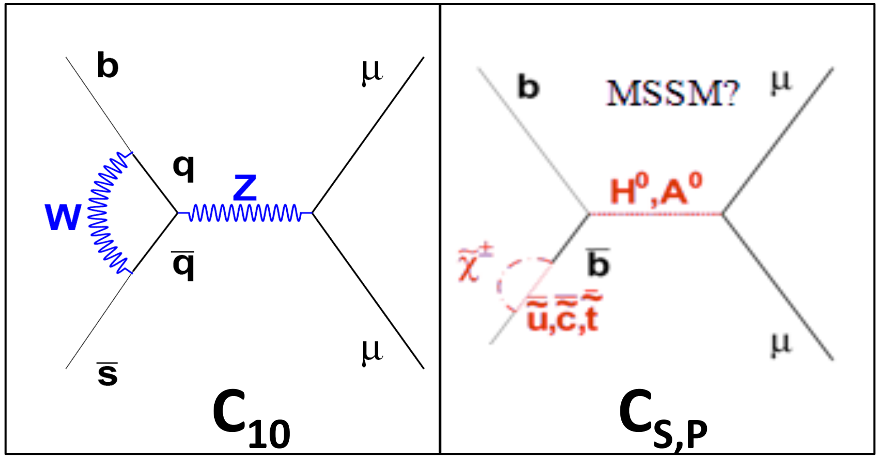
Buras et al., JHEP 10 (2010) 009

  - Can be strongly enhanced in many NP models
    - e.g. MSSM with large tanβ

$$BR \propto \left(C_{S,P}^{MSSM}\right)^2 \propto \frac{\tan^6\beta}{M_A^4}$$

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

(or how to investigate the Higgs sector via indirect searches)



- Very rare FCNC decay, with only contributions from $C^{(')}_{10}$ (axial), $C^{(')}_{S}$ (Higgs, scalar) and $C^{(')}_{P}$ (pseudo-scalar)
  - Standard Model
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    - C_{10} dominates, but helicity suppressed
    - $BR_{SM} = (3.2 \pm 0.2) \times 10^{-9}$
  - Can be strongly enhanced in many NP models
    - e.g. MSSM with large tanβ
- Published experimental results:

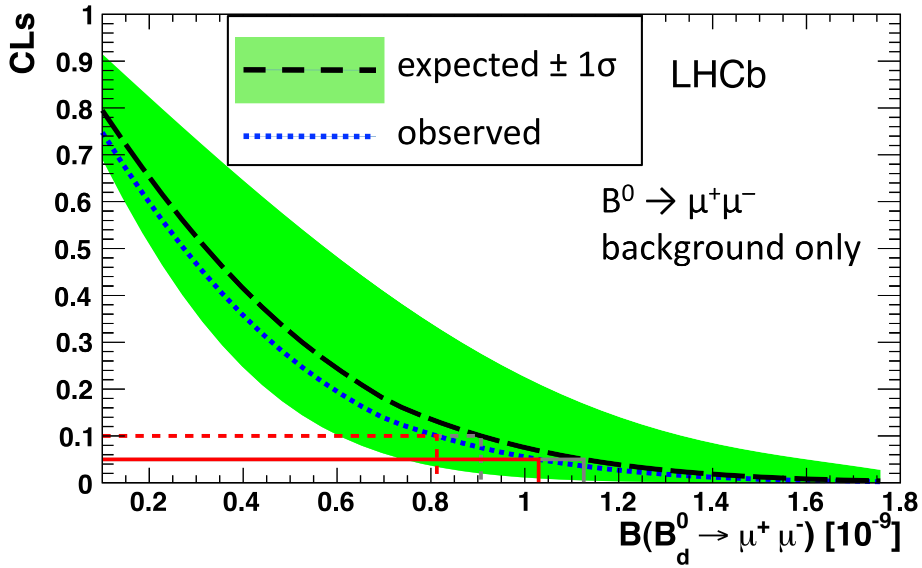
	CDF	D0	CMS	LHCb
Luminosity (fb^{-1})	6.9	6.1	1.14	0.37
95% CL limit (10^{-9})	40	51	19	14
Value (10^{-9})	18^{+11}_{-9}			

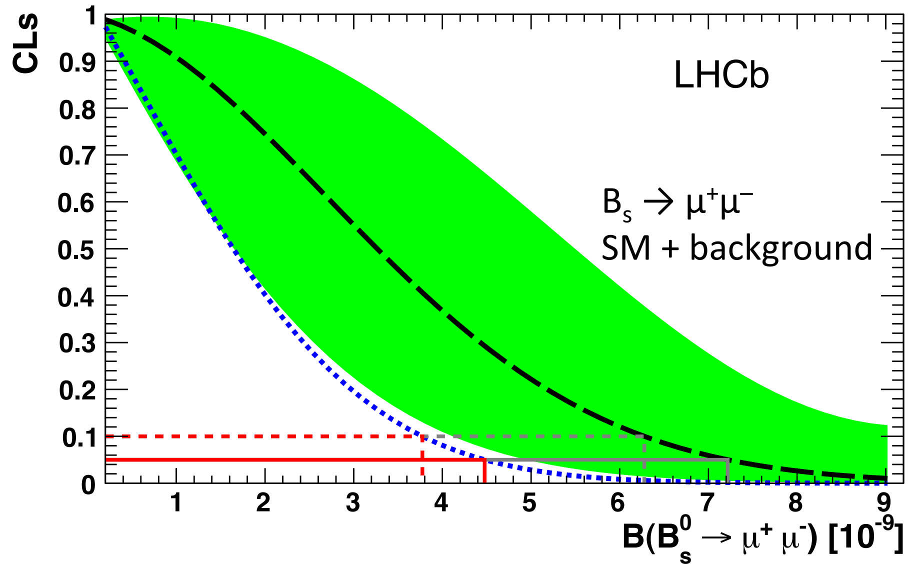
LHCb, PLB 708 (2012) 55

$B_{(s)} \to \mu^+\mu^-$

LHCb-PAPER-2012-007
to be subm. to PRL

J.A. Hernando Morata



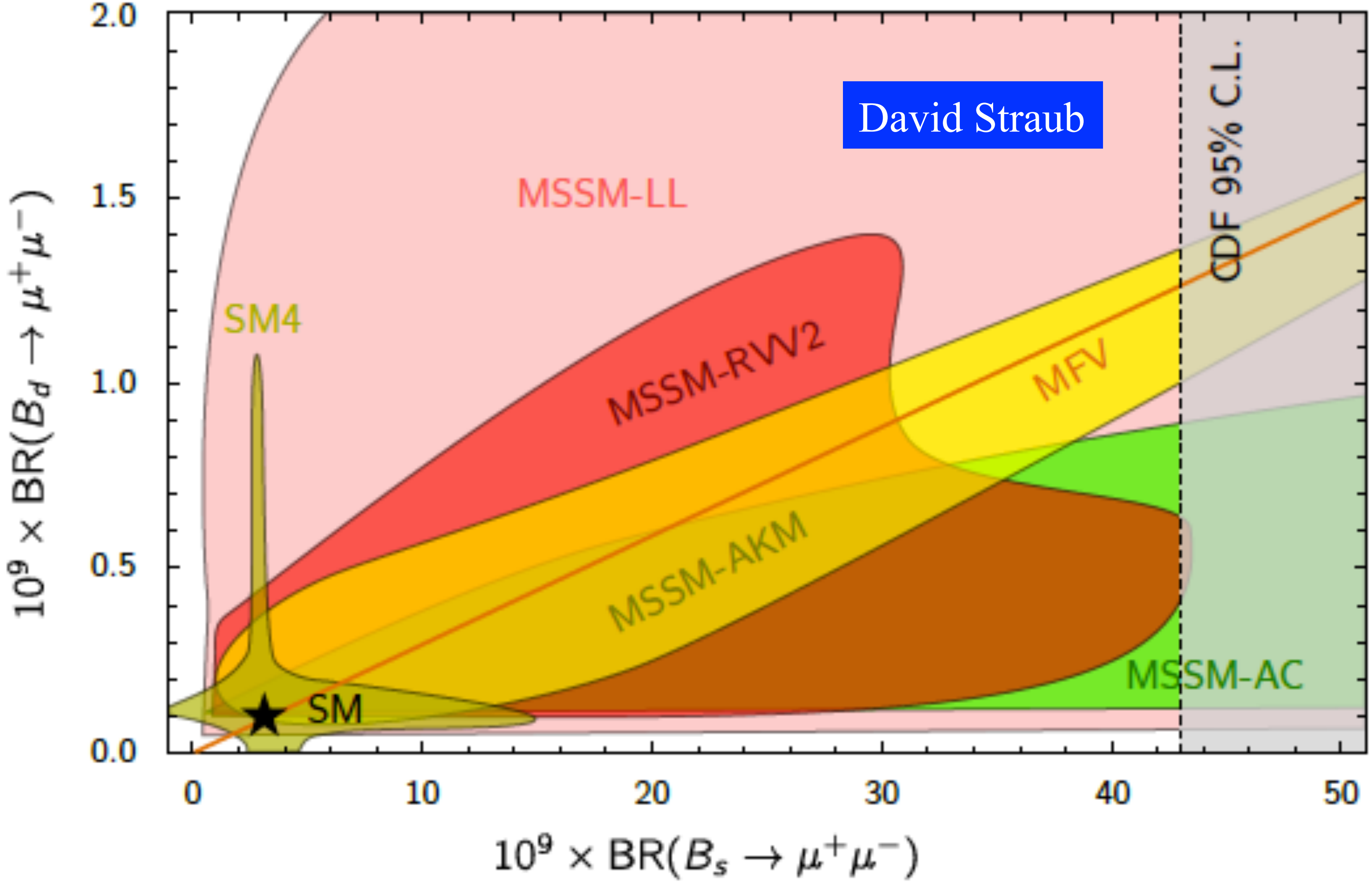


New preliminary results in 2012		CDF	CMS	ATLAS	LHCb	SM
	Luminosity (fb^{-1})	10	4.9	2.4	**1**	
BR($B^0 \to \mu^+\mu^-$)	95% CL upper limit (10^{-9})	4.6	1.8		**1.03**	0.10 ± 0.01
BR($B_s \to \mu^+\mu^-$)	95% CL upper limit (10^{-9}) Value (10^{-9})	31 13^{+9}_{-7}	7.7	22	**4.5** $0.8^{+1.8}_{-1.3}$	3.2 ± 0.2

Best $B_s \to \mu^+\mu^-$ limit, approaching SM

Impact on the Bs→μμ result on new physics models

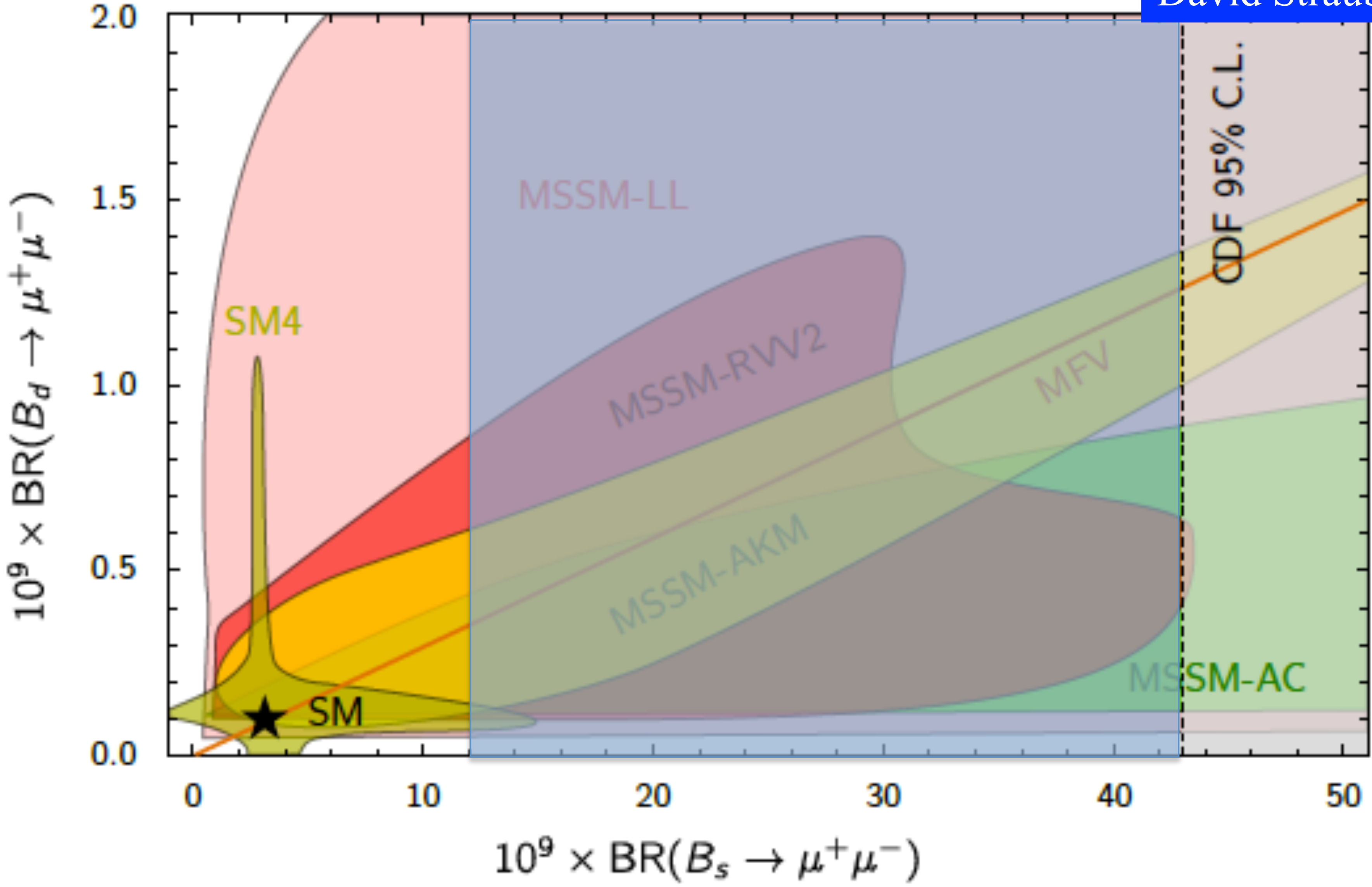
12 months ago (moriond 2011)



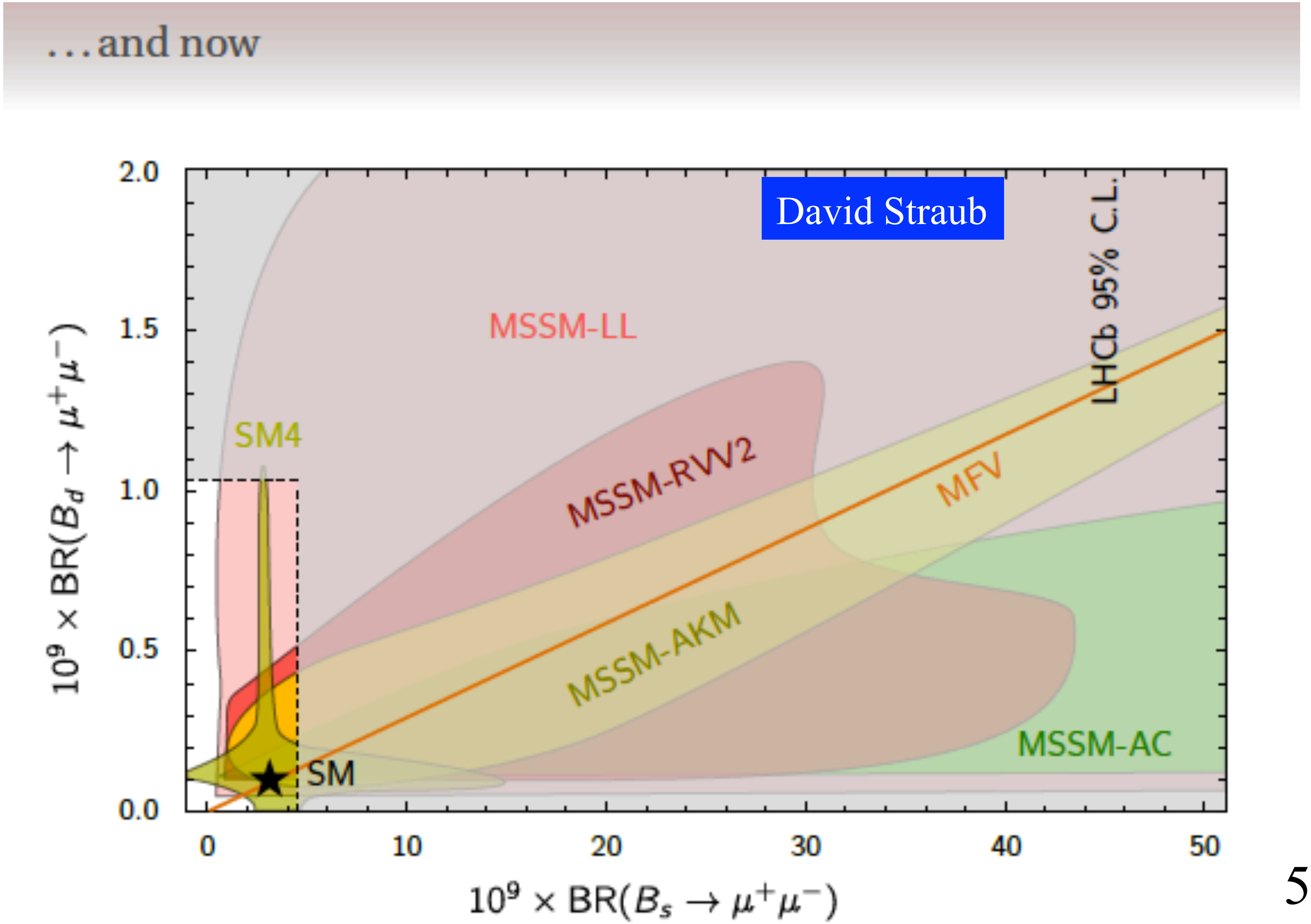
Impact on the Bs→μμ result on new physics models

6 months ago (EPS 2011)

David Straub



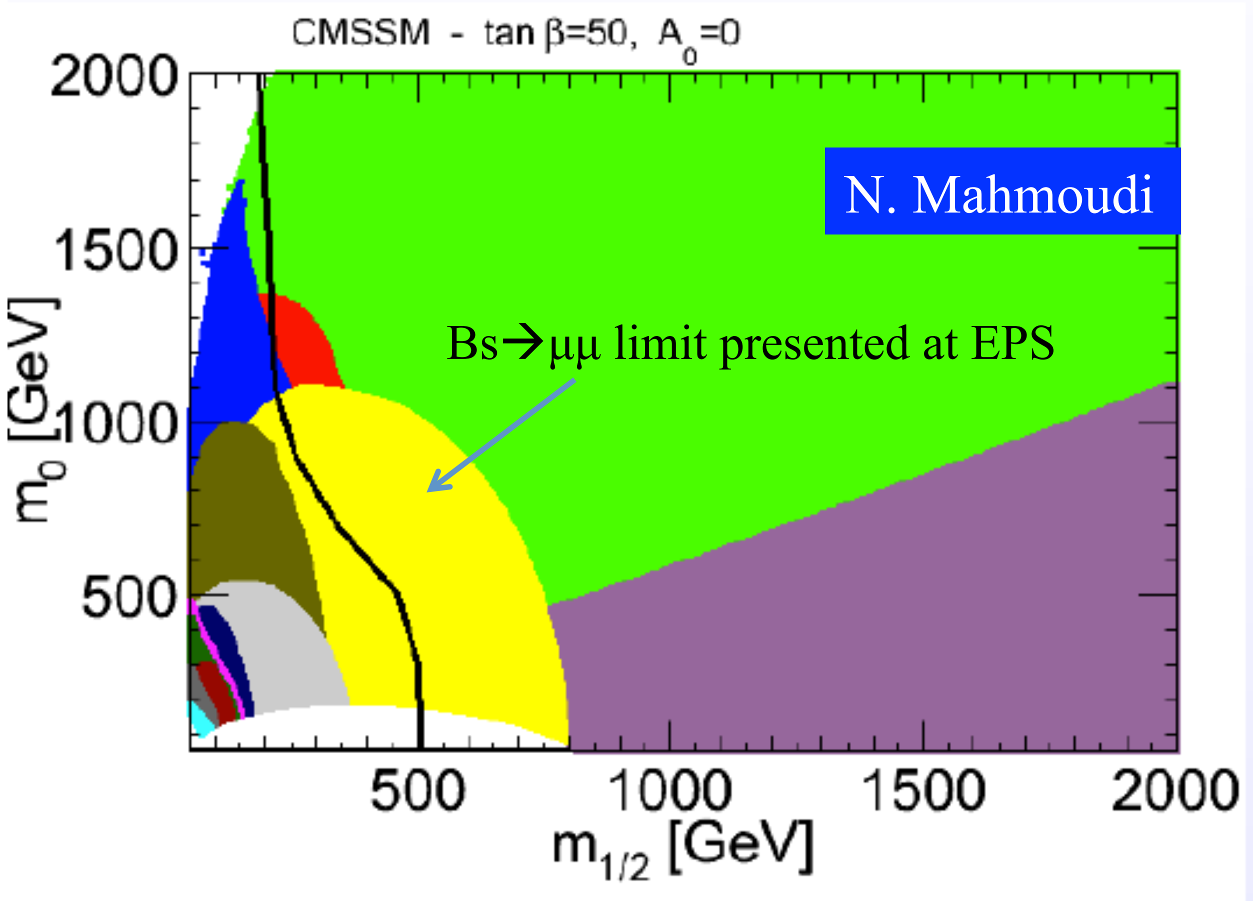
Impact on the Bs→μμ result on new physics models



Interplay between direct and indirect searches

m_0= universal scalar mass parameter

$m_{1/2}$ = universal gaugino mass



Black line: CMS exclusion limit with 1.1 fb^{-1} data

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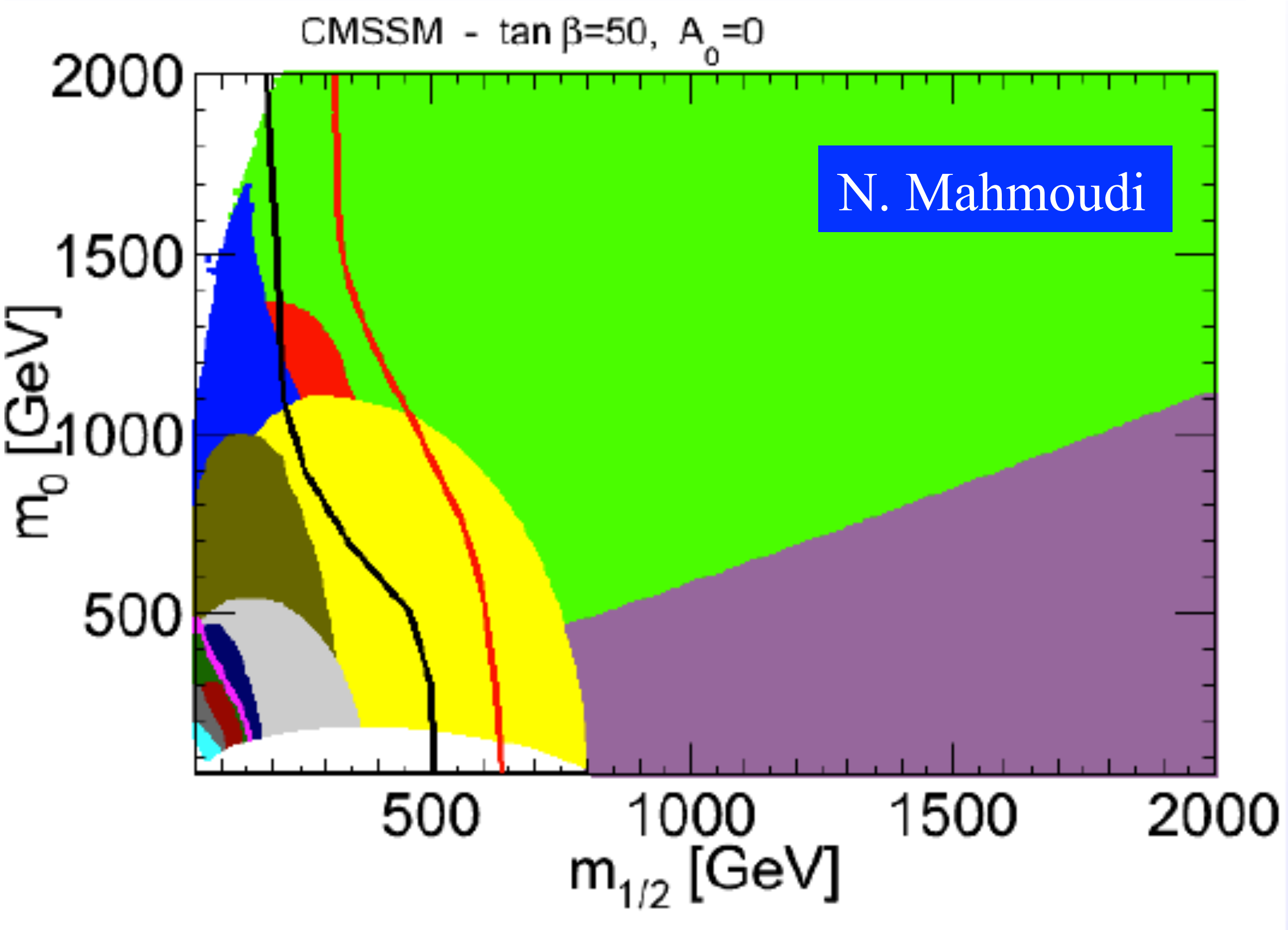

Black line: CMS exclusion limit with 1.1 fb^{-1} data

Red line: CMS exclusion limit with 4.4 fb^{-1} data

Interplay between direct and indirect searches

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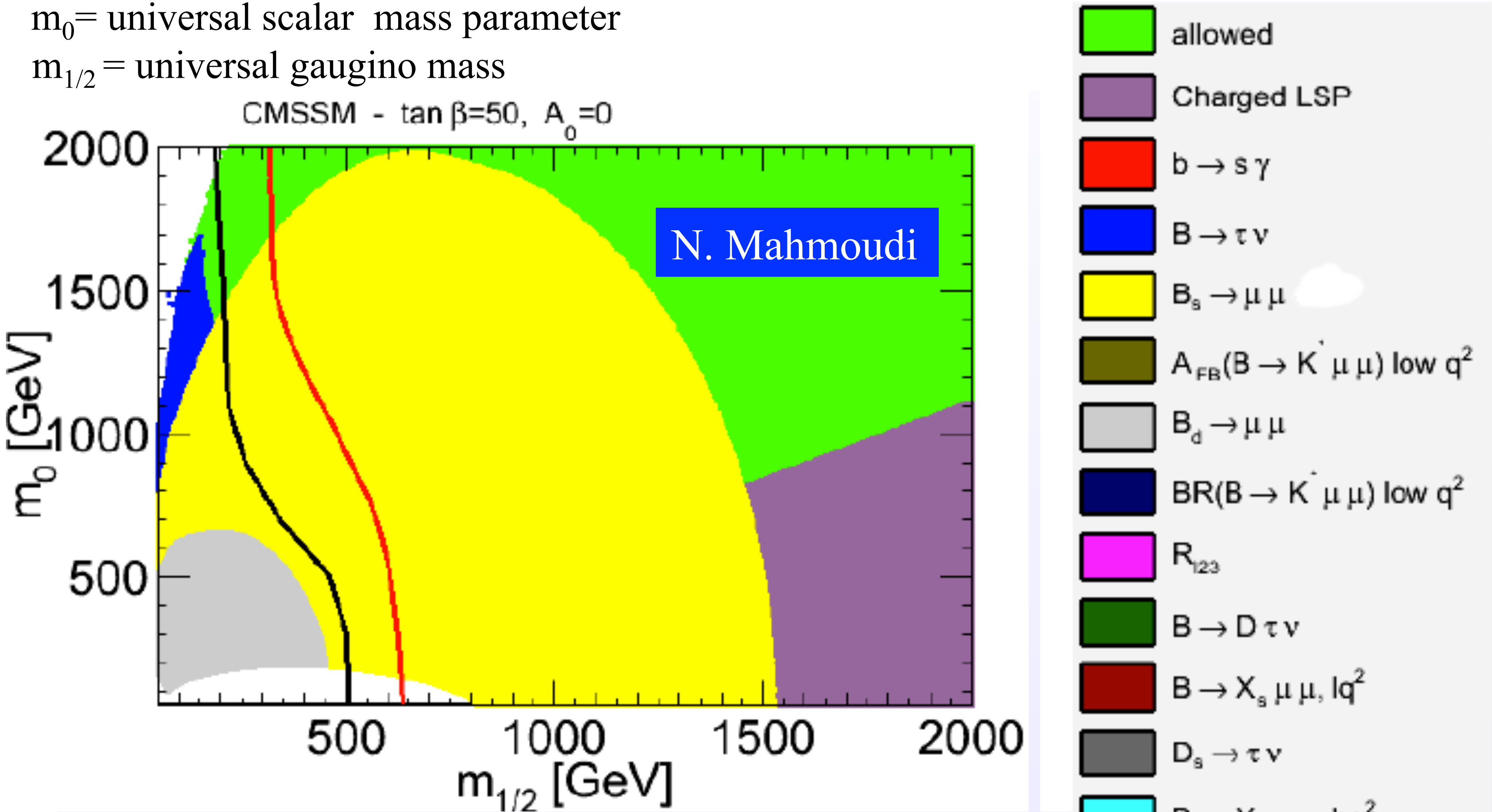
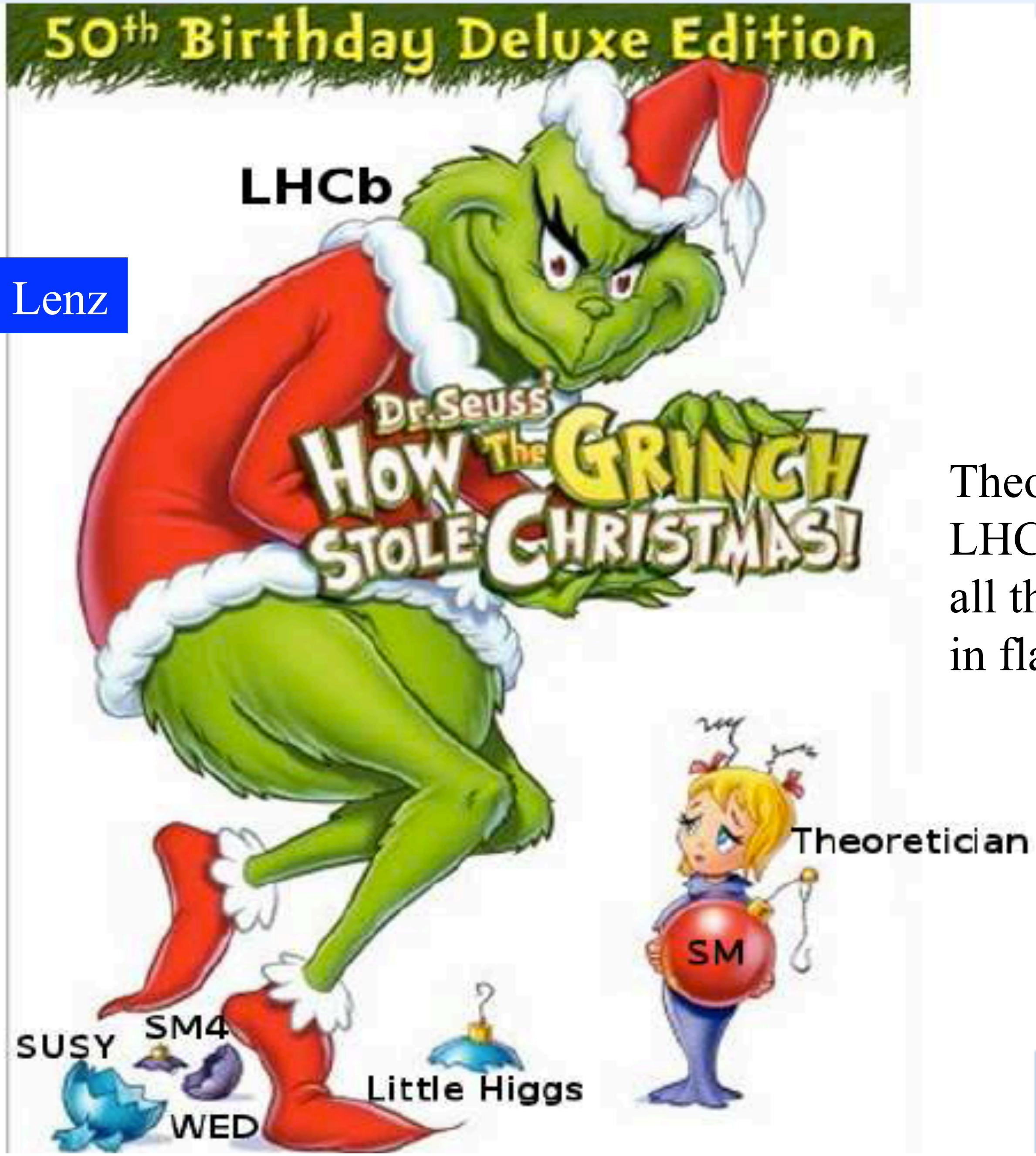


Black line: CMS exclusion limit with 1.1 fb^{-1} data
Red line: CMS exclusion limit with 4.4 fb^{-1} data
New LHCb limits for $BR(B_s \to \mu^+\mu^-)$ and $BR(B_d \to \mu^+\mu^-)$

TeVatron gave us many presents, and then ...

Alex Lenz



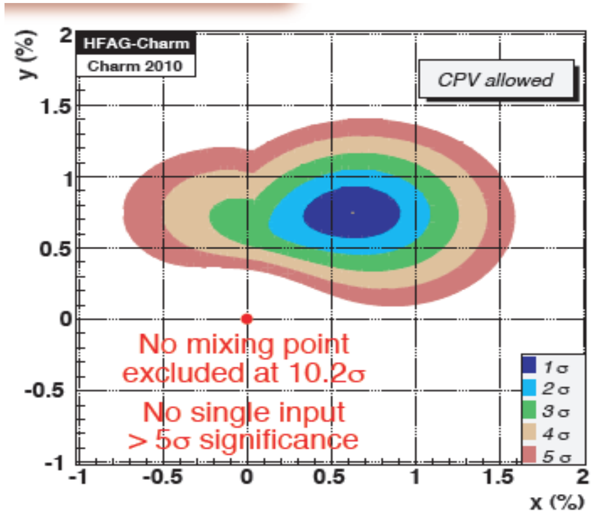
Theorists are angry with LHCb as it is wiping out all the hints of new physics in flavor sector

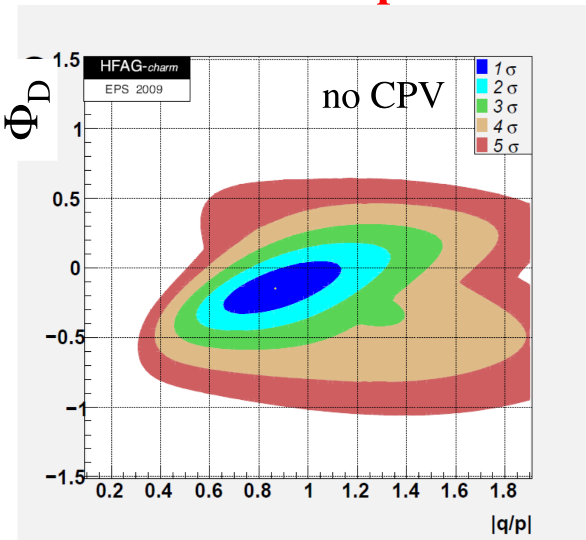
CPV in charm

Large $D^0 - D^0$ mixing discovered in 2007 and the new LHCb and CDF results about CP violation in charm are giving new impetus to this field.

Situation up to September 2011:

"No-mixing" excluded at 10.2 σ: **All measurements pre-LHCb consistent with no CPV:**





Present constraints on CPV weak because CPV ~ $x_D \sin(2\varphi_D)$ and x_D~1%
→required sub-0.1% precision for CPV sensitivity!

Direct CPV in $D^0 \to \pi^+\pi^-$, K^+K^-:

CPV in mixing (indirect) can be related to direct CPV via the relation:

$$A_{CP}(h^+h^-) = a_{CP}^{\text{dir}}(h^+h^-) + \frac{\langle t \rangle}{\tau} a_{CP}^{\text{ind}}(h^+h^-)$$

$\langle t \rangle/\tau = 1$ at B factories, ~2.5 at CDF (displaced trigger)

Independent of the final state

Considering $\pi\pi$ or KK final states we can build the difference:

$$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = \Delta a_{CP}\,(\text{direct}) + \Delta\langle t \rangle/\tau \;\; a_{CP}^{\text{ind}}$$

Where: $$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

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- LHCb strategy: use $D^0 \to (\pi\pi, KK)$ decays tagged with $D^{*+} \to D^0 \pi^+$
- To first order
  - $A_{CP}(f)$ not affected by detection asymmetries
  - soft pion detection and D^* production asymmetries cancel in ΔA_{CP}
  - mixing-induced CPV components of $A_{CP}(f)$ largely cancel in ΔA_{CP}
  - U-spin symmetry predicts opposite direct CPV for K^+K^- and $\pi^+\pi^-$

Direct CPV in $D^0 \rightarrow \pi^+\pi^-, K^+K^-$:

CPV in mixing (indirect) can be related to direct CPV via the relation:

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HCP 2011: LHCb, 620 pb^{-1} : first evidence (3.5 σ) of CPV in charm:

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.82 \pm 0.21 \pm 0.11)\%$$

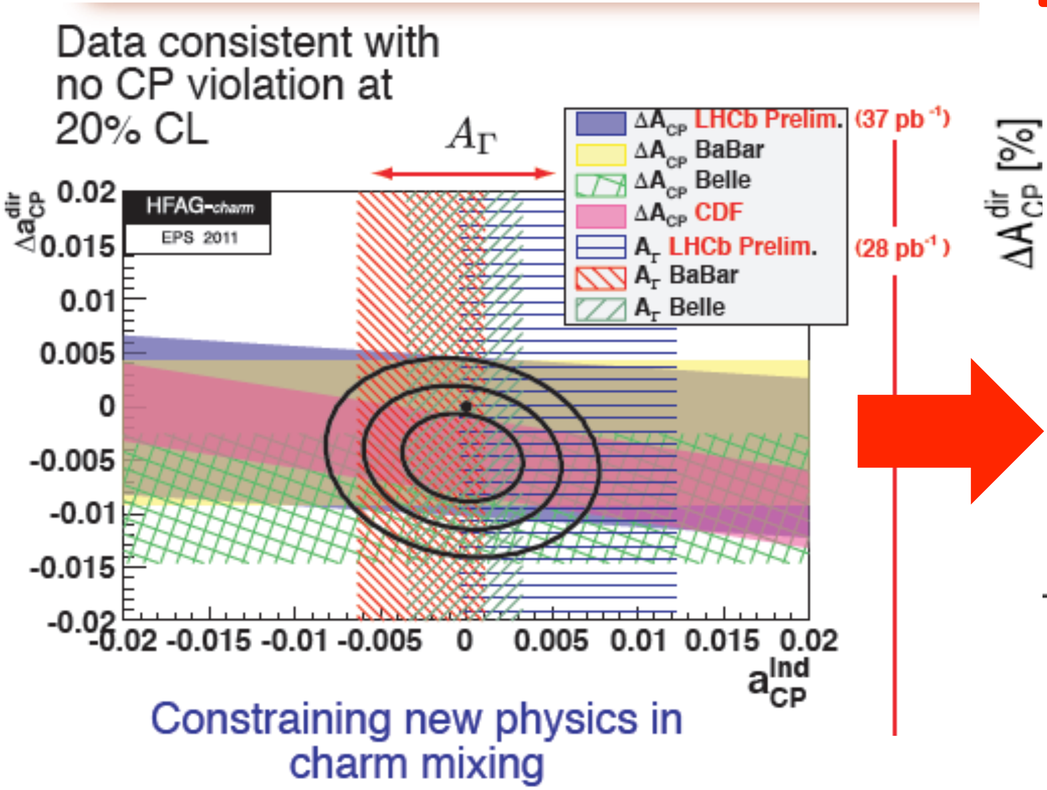
Moriond 2012: CDF, 9.6 fb^{-1}, confirms this result

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.62 \pm 0.21 \pm 0.10)\ \%$$

Combination of LHCb and CDF results in a 3.8 σ deviations from zero.

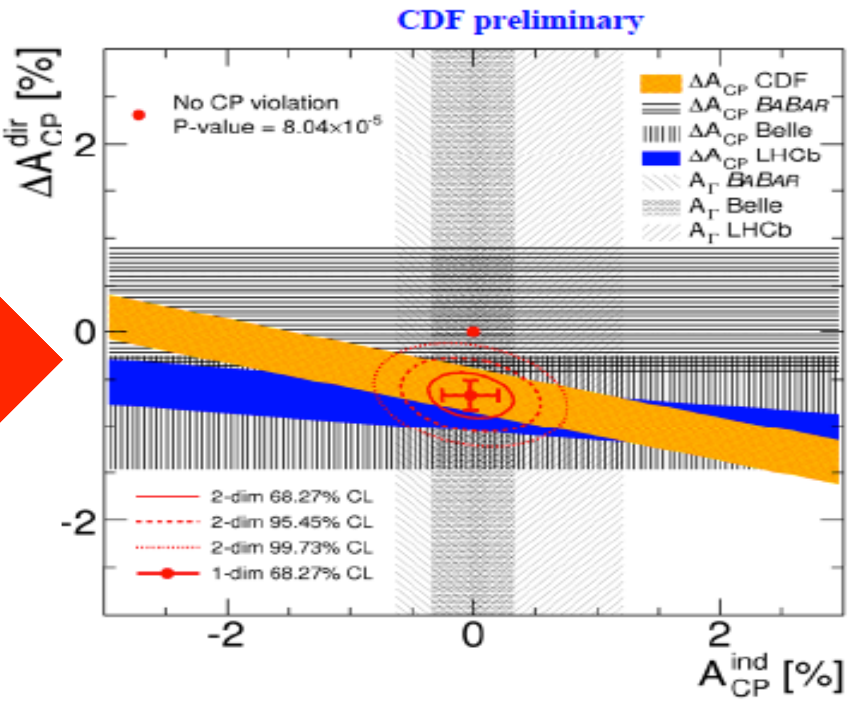
Direct CPV in $D^0 \to \pi^+\pi^-, K^+K^-$:

EPS 2011 – July 2011



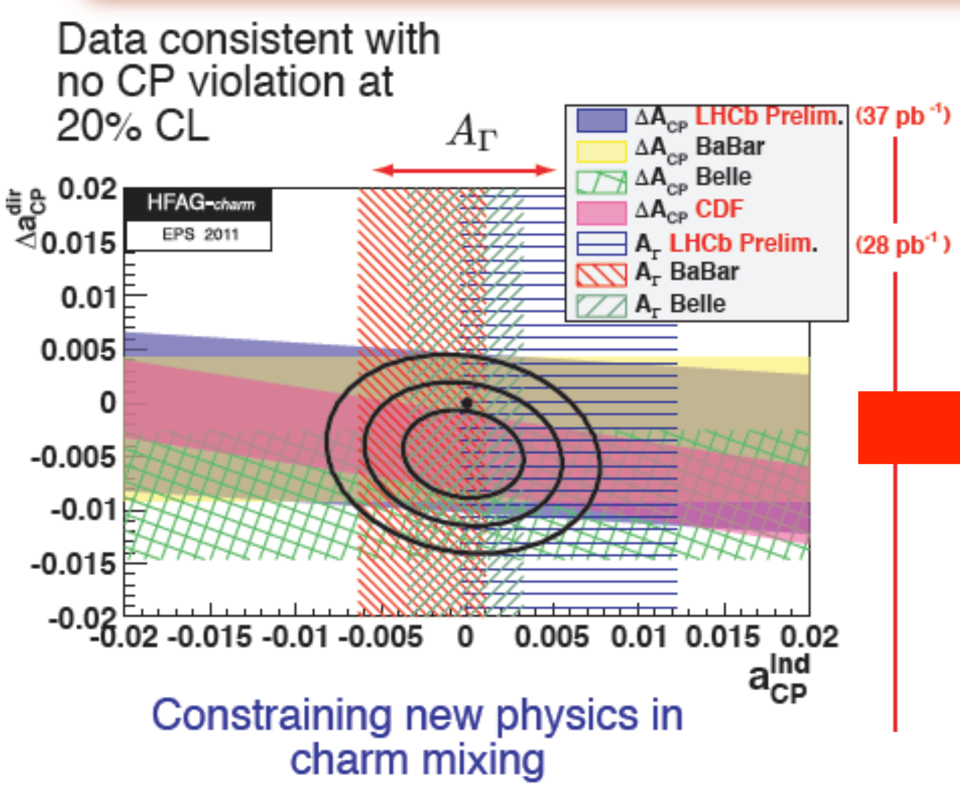
Moriond 2012 (6 months later)

CPV established at 3.8 σ level



Direct CPV in $D^0 \to \pi^+\pi^-, K^+K^-$:

EPS 2011 – July 2011



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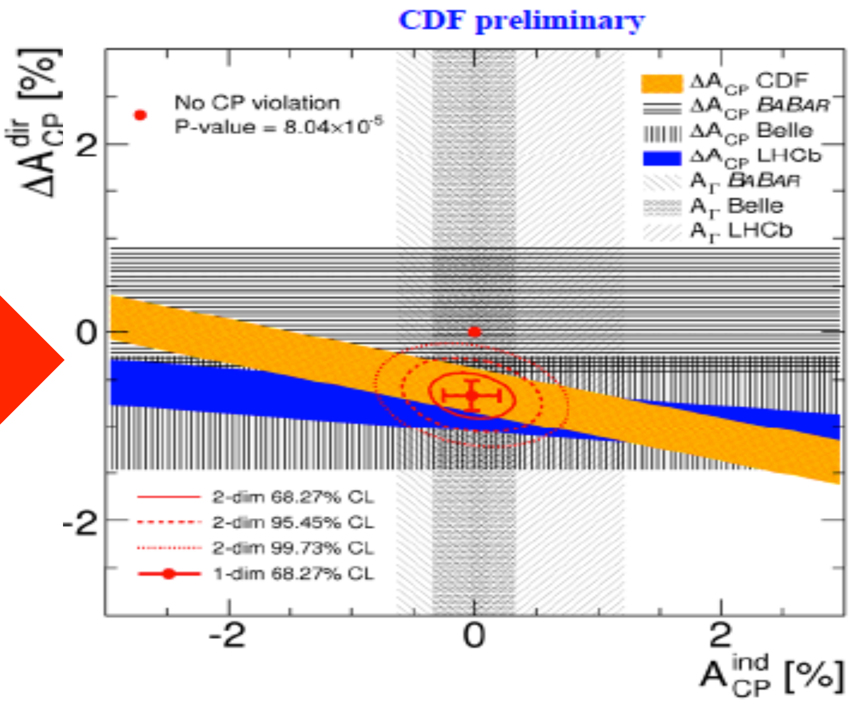


LHCb gave to the theorists a new present …

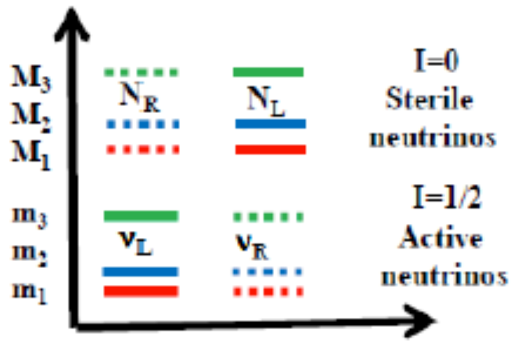
… but they don't know how to make the calculations

(too light to use HQE, too heavy to use chiral perturbation theory)

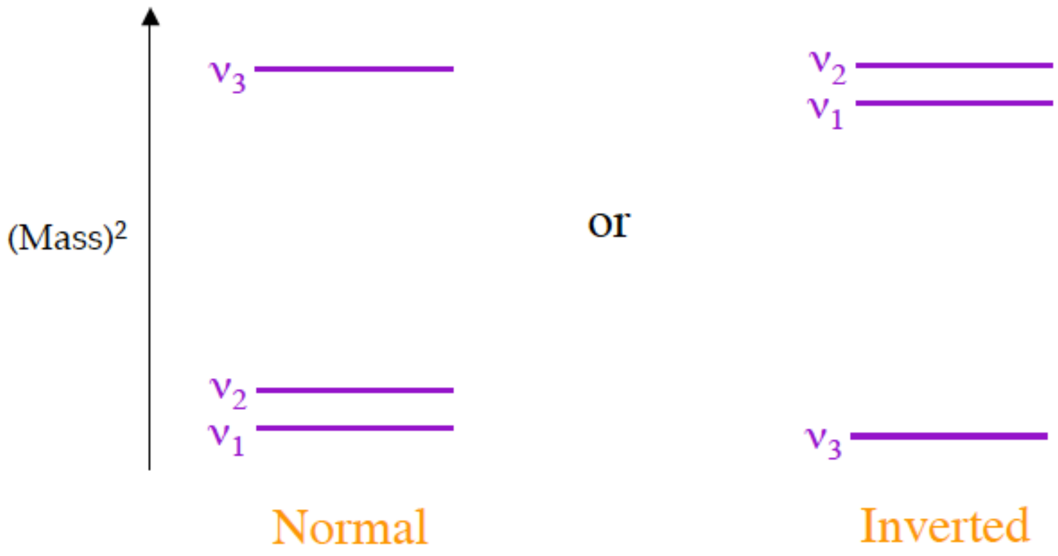
Their conclusion: CPV in charm can be either SM or New Physics

Neutrinos in SM are massless: massive neutrinos are new physics!

Neutrinos : the New Physics there is… and a lot of it!

SM	Dirac mass term	Majorana mass term	Dirac AND Majorana Mass terms
ν_L $\bar{\nu}_R$ I= $\frac{1}{2}$ $\frac{1}{2}$	ν_L ν_R $\bar{\nu}_R$ $\bar{\nu}_L$ $\frac{1}{2}$ 0 $\frac{1}{2}$ 0	ν_L ν_R $\frac{1}{2}$ $\frac{1}{2}$	
X 3 Families	X 3 Families	X 3 Families	
6 massless states	3 masses 12 states 3 active neutrinos 3 active antinu's 6 sterile neutrinos… 3 mixing angles 1 CP violating phase	3 masses 6 active states No steriles 3 mixing angles 3 CP violating phases 0νββ	6 masses 12 states 6 active states 6 sterile neutrinos… More mixing angles and CPV phases 0νββ → Leptogenesis and Dark matter

The (Mass)^2 Spectrum



$\Delta m^2_{21} \cong 7.4 \times 10^{-5}\ \mathrm{eV}^2$, $\Delta m^2_{32} \cong 2.3 \times 10^{-3}\ \mathrm{eV}^2$

$$\mathbf{U_{MNS}} : \begin{pmatrix} \sim \frac{\sqrt{2}}{2} & \sim -\frac{\sqrt{2}}{2} & \sin\theta_{13}\, e^{i\delta} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim -\frac{\sqrt{2}}{2} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim \frac{\sqrt{2}}{2} \end{pmatrix}$$

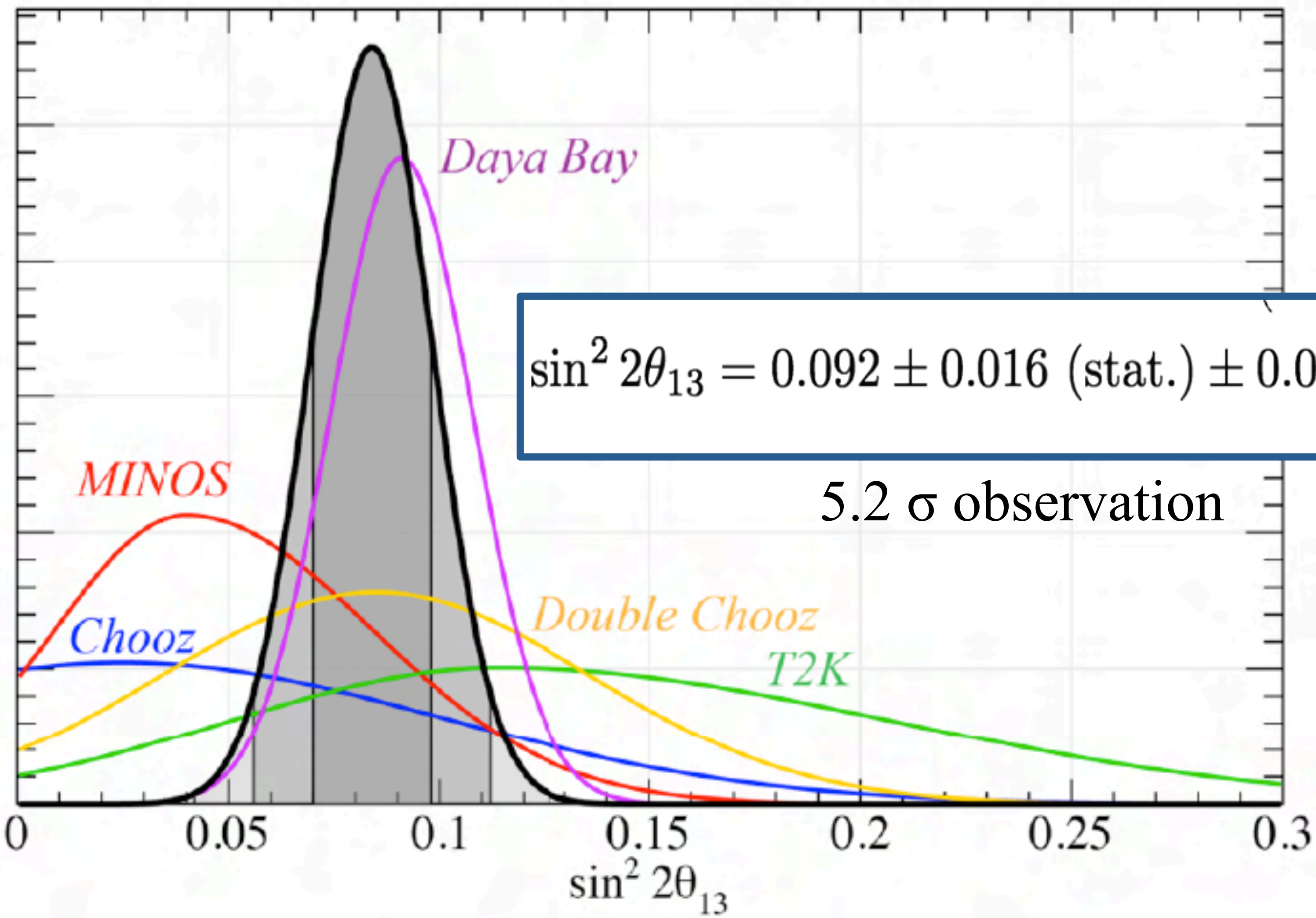
θ_{23} (atm) = 45°, θ_{12}(solar)=32°

θ_{12}(Chooz)<13°

→ Unknown or poorly known

θ_{13}, phase δ, sign of Δm_{13}

The Daya Bay result (breaking news at Moriond EW):

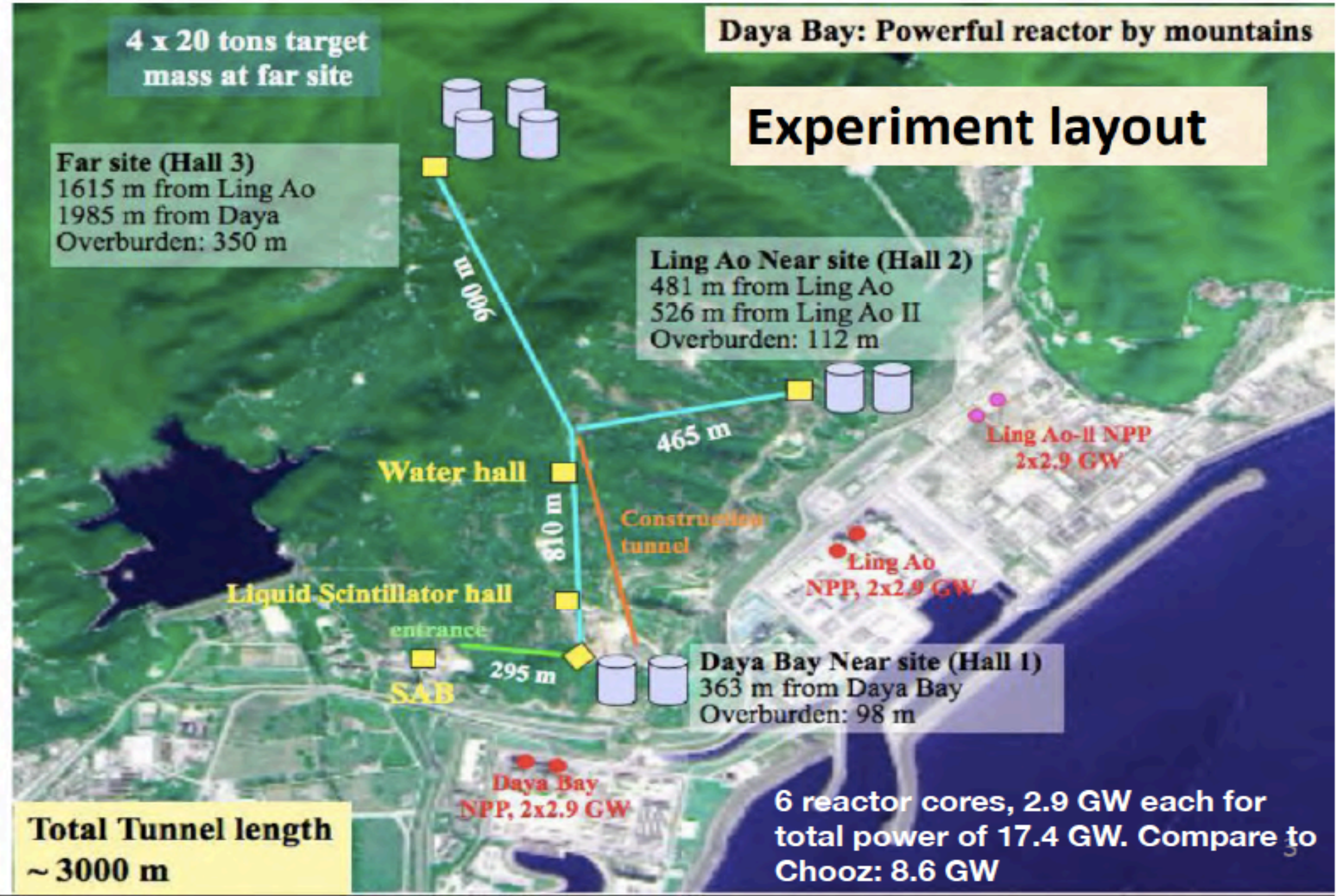


$$\sin^2 2\theta_{13} = 0.092 \pm 0.016\ (\text{stat.}) \pm 0.005\ (\text{syst.})$$

5.2 σ observation

Ideogram of recent θ_{13} results for normal hierarchy, $\delta_{CP}=0$, and maximal θ_{23}

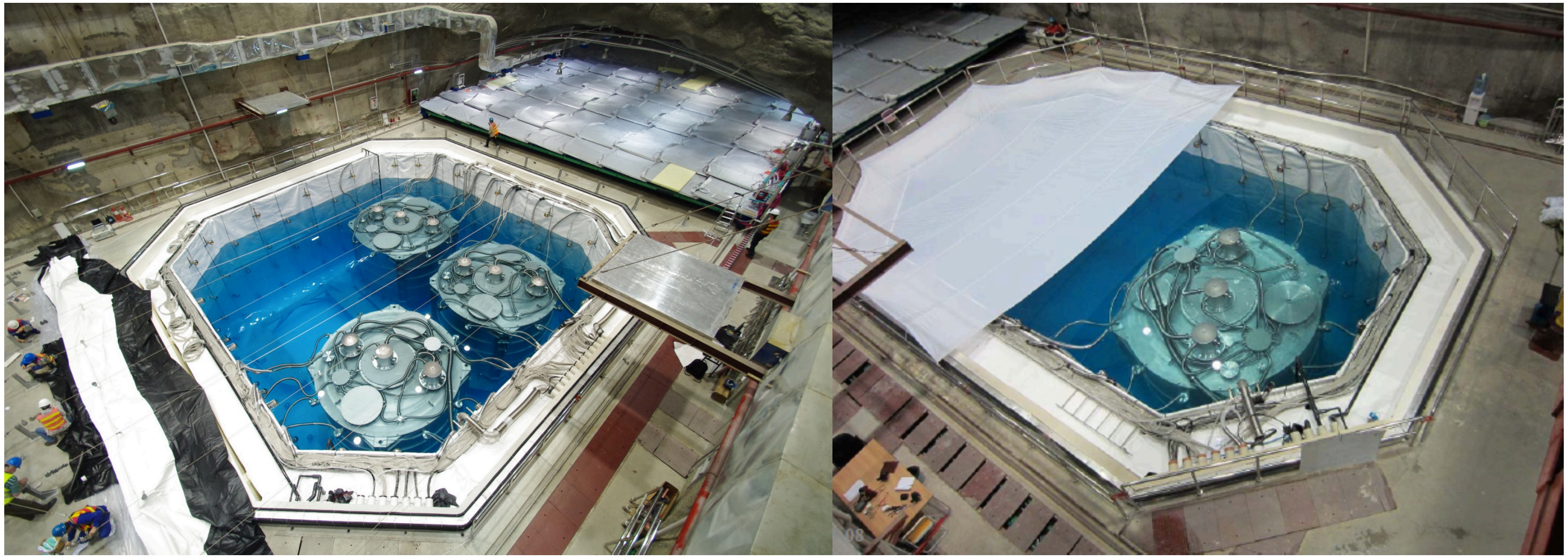
Electron Antineutrinos from six 2.9 GW reactors were detected in six antineutrino detectors deployed in two near (flux-weighted baseline 470 m and 576 m) and one far (1648 m) underground experimental halls.



They look for the survival probability of antineutrinos

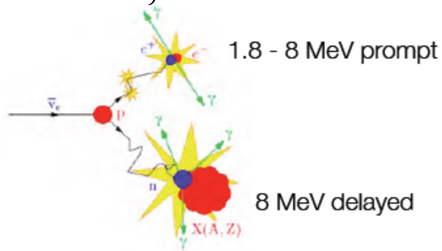
$$P_{\text{sur}} \approx 1 - \sin^2 2\theta_{13} \sin^2(1.267\Delta m^2_{31} L/E)$$

3 detectors installed in Hall3, 1 in Hall 2 and 2 in Hall 1



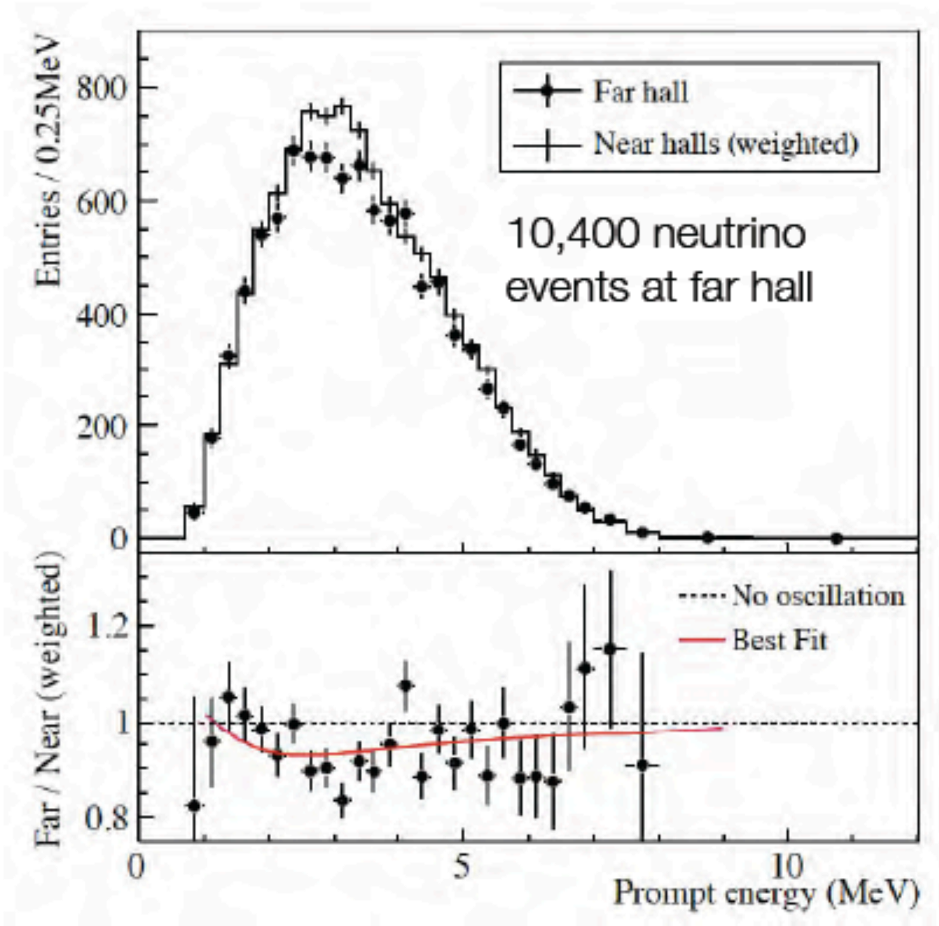
The ν_e is detected via the inverse β-decay reaction, $\overline{\nu}_e + p \rightarrow e^+ + n$, in a Gadolinium-doped liquid scintillator:

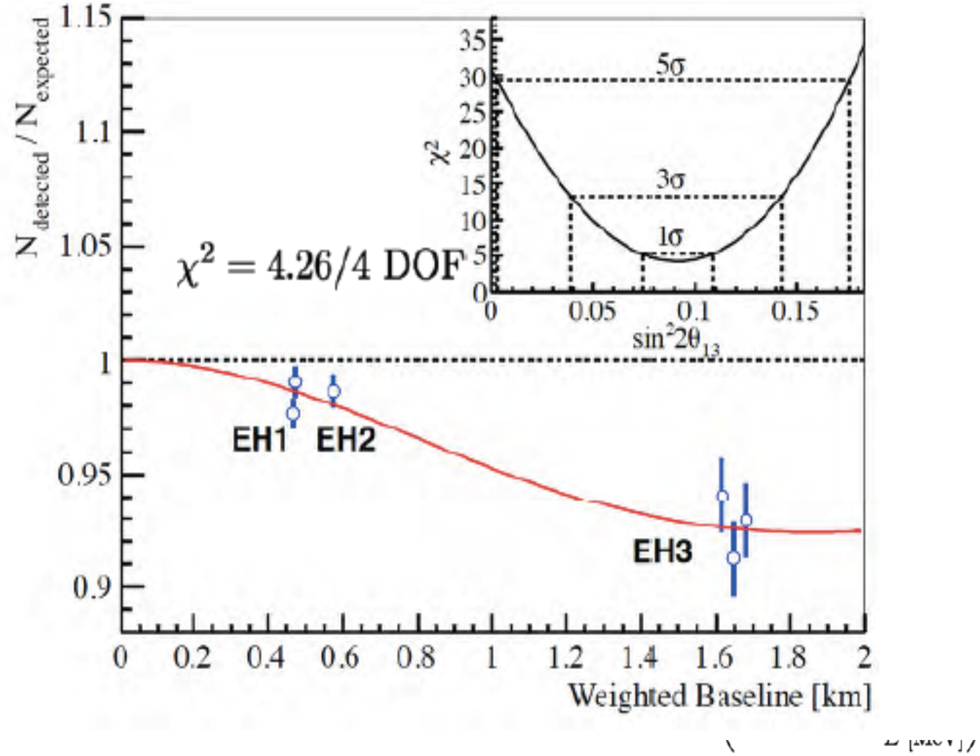
→ The coincidence of the prompt scintillation from the e^+ and the delayed neutron capture on Gd provides a distinctive νe signature.



The near-far arrangement of antineutrino detectors allows for a relative measurement by comparing the observed νe rates at various baselines. With detectors functionally identical, the relative rate is independent of correlated uncertainties and uncorrelated reactor uncertainties are minimized.

Neutrino candidates



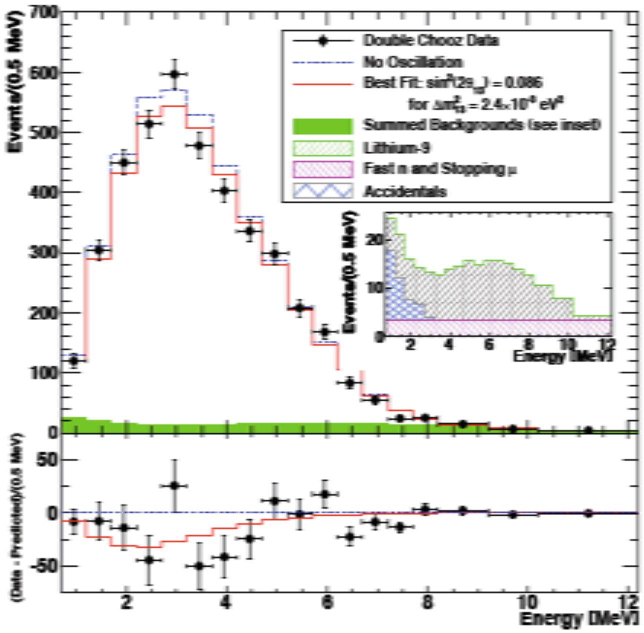


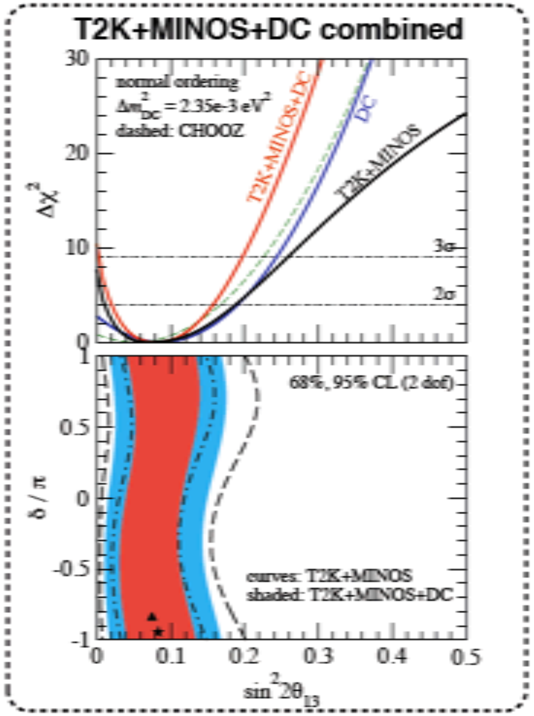
$$\sin^2 2\theta_{13} = 0.092 \pm 0.016 \text{ (stat.)} \pm 0.005 \text{ (syst.)}$$

Also results from MINOS and Double Chooz:

Fit results

(hep-ex) arXiv:1112.6353 / Submitted to PRL





DChooz

Rate-only fit : $\sin^2 2\theta_{13} = 0.104 \pm 0.030$(stat.) ± 0.076(syst.)

Rate+shape fit : $\sin^2 2\theta_{13} = 0.086 \pm 0.041$(stat.) ± 0.030(syst.)

→ No oscillation excluded by 94.6% C.L.

22

Tsunayuki, Double Chooz

Consequences of 3-family oscillations:

I There will be $\nu_\mu \leftrightarrow \nu_e$ and $\nu_\tau \leftrightarrow \nu_e$ oscillation at L_{atm}

$$P(\nu_\mu \leftrightarrow \nu_e)_{max} =\sim \tfrac{1}{2} \sin^2 2\theta_{13} + \ldots \text{(small)}$$

II There will be CP or T violation

CP: $P(\nu_\mu \leftrightarrow \nu_e) \neq P(\nu_\mu \leftrightarrow \nu_e)$

T : $P(\nu_\mu \leftrightarrow \nu_e) \neq P(\nu_e \leftrightarrow \nu_\mu)$

Boris Kayser

Why CP Violation (~~CP~~) In Neutrino Oscillation Would Be Very Interesting

It would establish that ~~CP~~ is not special to quarks.

A major motivation to look for it:

> Its observation would make it more plausible that —
>
> — the baryon-antibaryon asymmetry of the universe —
>
> — arose, at least in part, through **Leptogenesis**.

Leptogenesis

Boris Kayser

Explains the baryon-antibaryon asymmetry of the universe by CP-violating heavy neutrino decays.

Heavy ($m_N > 10^9$ GeV) Majorana neutrino → N; SM lepton → ℓ; SM BEH scalar boson → H

$$\Gamma\left(N \to \ell^- + H^+\right) \neq \Gamma\left(N \to \ell^+ + H^-\right)$$

This ~~CP~~ creates a ***lepton-antilepton*** asymmetry.

The SM Sphaleron process converts part of this asymmetry into the observed ***baryon-antibaryon*** asymmetry.

Generically, leptogenesis and light-neutrino ~~CP~~ imply each other.

(B.K. 1012.4469)

Reactors have no δ_{CP} or mass hierarchy dependence while long baseline experiments depend on both. Moreover:

$$P(\nu_\mu \rightarrow \nu_e) \sim \sin^2 2\theta_{13}$$

A conventional accelerator neutrino beam from π and K decay is mostly ν_μ, but has a ~1% ν_e contamination.

Studying $\nu_\mu \rightarrow \nu_e$ with a conventional beam would have been difficult if $\sin^2 2\theta_{13}$ had been less than 0.01.

…..This result opens new and exciting possibilities….

Getting our feet on (under) the ground:

A. Rubbia

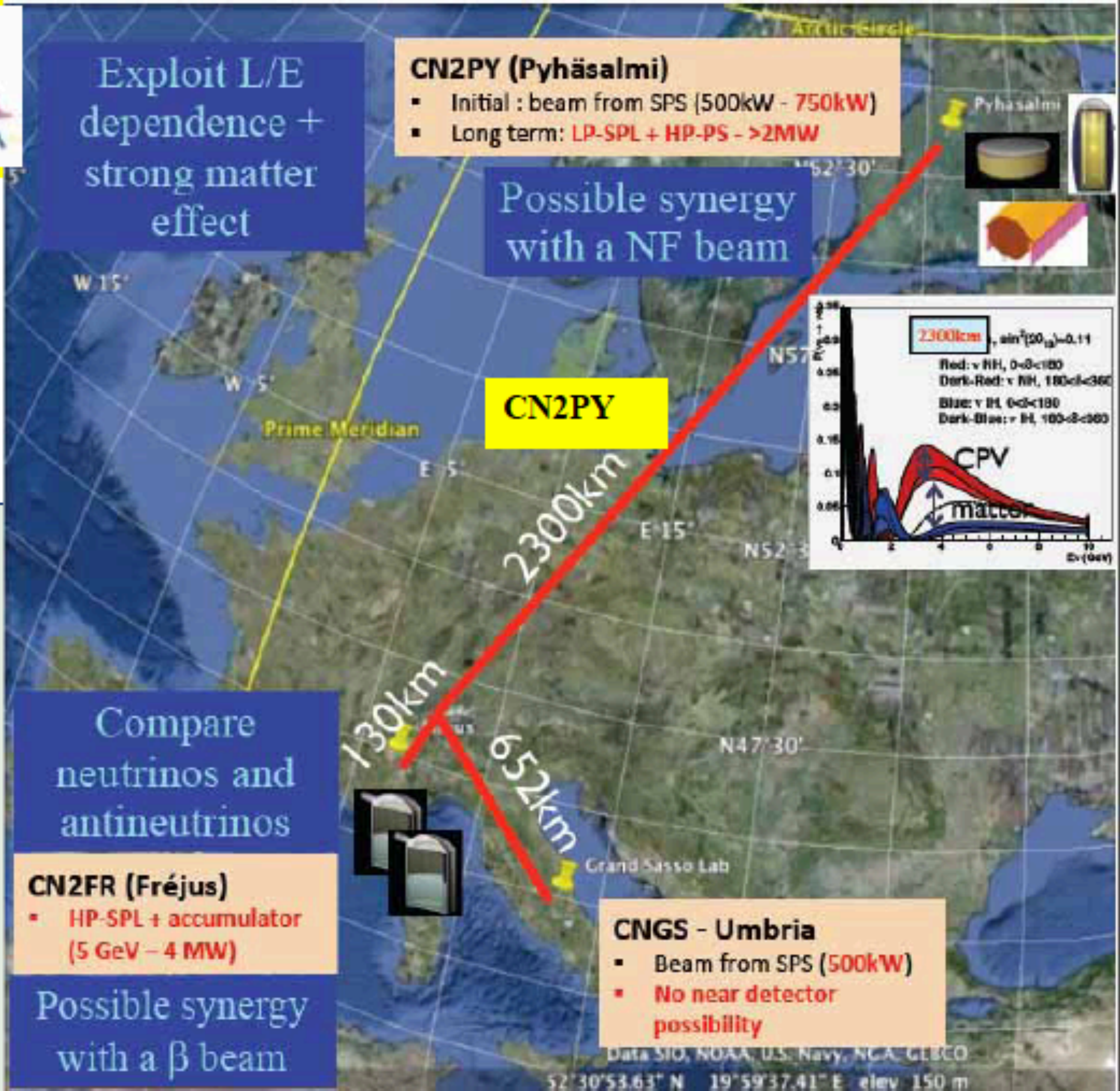
LAGUNA -LBNO
new FP7 design study
2011-2014

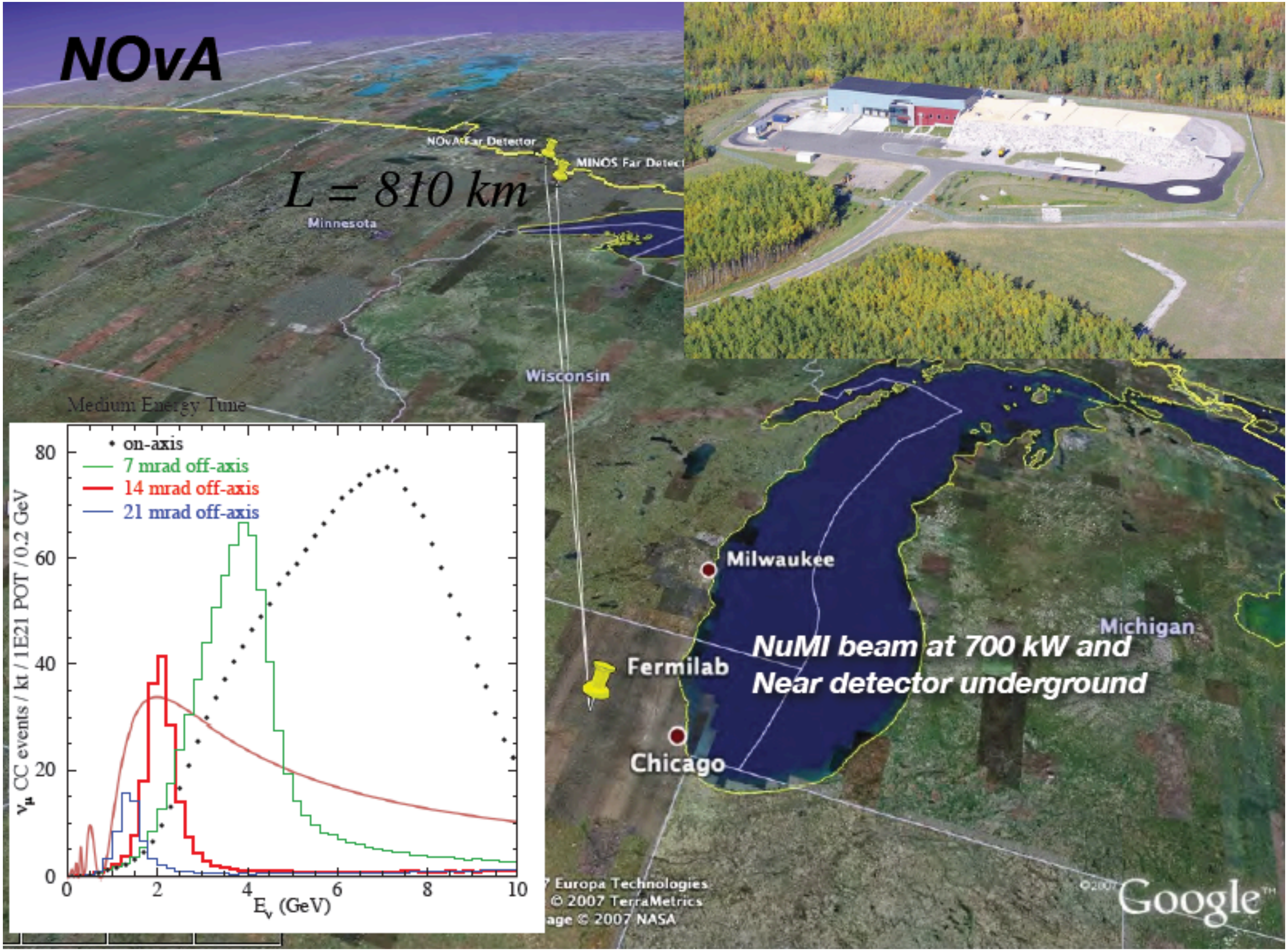
2 main options

Short distance: 130km
Memphys at Frejus
SPL+beta beam
CP and T violation

Long distance: 2300km
Pyhasalmi
Fine grain detector
e.g. 20kton fid. Larg
+ Magnetized detector
Long distance allows
rapid sensitivity to
sign(Δm^2_{13})

1st step easier: SPS C2PY
➔ consortium 1st priority
Nextsteps HP 50 GeV PS ...
...or neutrino factory





NOvA
NOvA Far Detector
MINOS Far Detect
L = 810 km
Minnesota
Wisconsin
Milwaukee
Michigan
NuMI beam at 700 kW and
Near detector underground
Fermilab
Chicago
Medium Energy Tune
on-axis
7 mrad off-axis
14 mrad off-axis
21 mrad off-axis
ν_μ CC events / kt / 1E21 POT / 0.2 GeV
E_ν (GeV)
0
20
40
60
80
0
2
4
6
8
10
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Google

Moriond Summary (in four points)

1. We live in a world where only 4% of the matter is known
2. What is known is not self-contained (hierarchy problem, CKM parameters, masses, etc)
3. But the (standard) model we use to describe it works (even too) well
4. And more general models are being constrained (or ruled out) by the experimental results.

However the amount of new results is amazing and the particle physics community is lively, healthy and strongly interconnected:
LHC is giving us an emormous set of results, new facilities are discussed
Things are evolving very quickly and it could be very likely to find in the coming years an unambiguous experimental result that can give us a new paradigm to interpret what we already know.