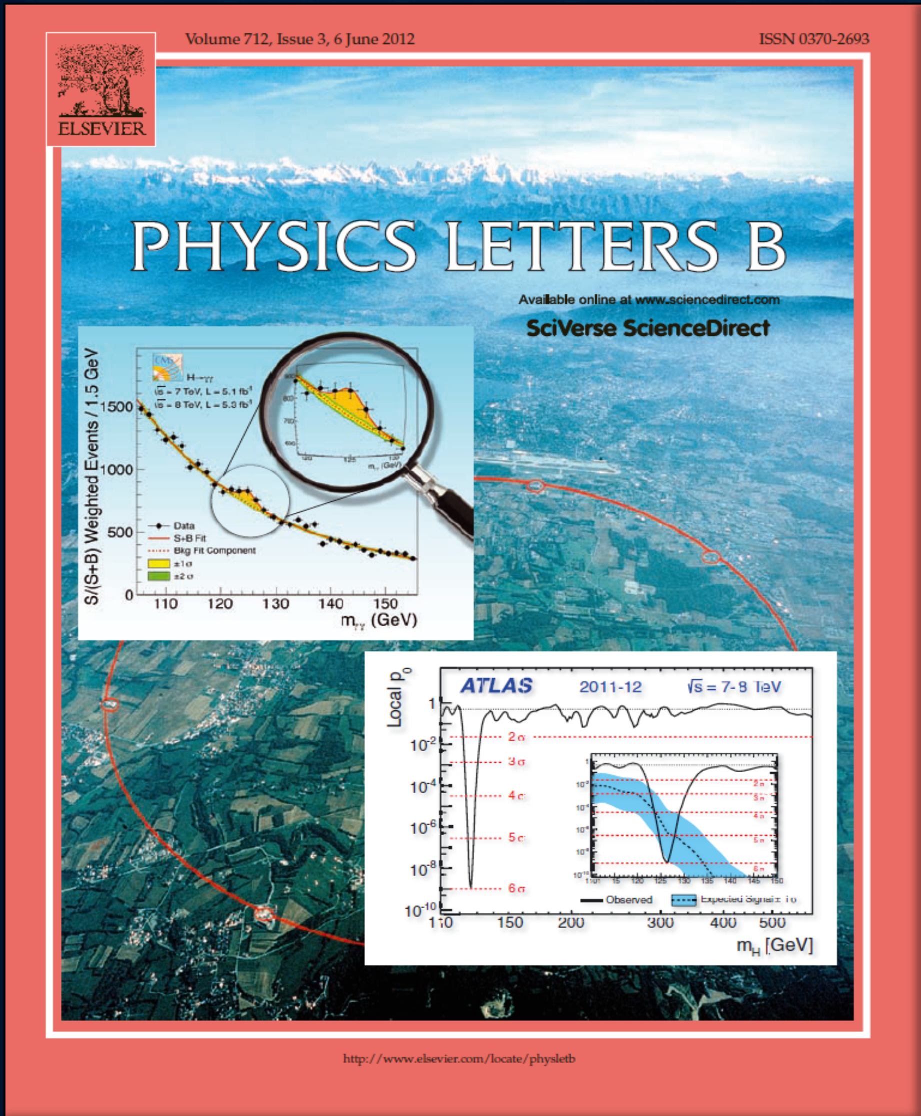
Highlights from EPS HEP 2013

Stockholm, July 22, 2013
Sergio Bertolucci
CERN

EPS HEP 2013

- Beautiful venue, fantastic weather, perfect organization
  THANK YOU!
- Large attendance (>750 participants), very broad scientific program, a lot of excellent presentations given by young colleagues

One year with a Higgs…



CERN

A productive year…

- ATLAS:

  http://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
  - Phys. Lett. B 716 (Discovery)
  - arXiv:1307.1432 Sub. Phys. Lett. B (Spin)
  - arXiv:1307.1427 Sub. Phys. Lett. B (Couplings)
  - ATLAS-CONF 2013-040 (Spin)
  - ATLAS-CONF 2013-029 ($\gamma\gamma$)
  - ATLAS-CONF 2013-031 (WW*)
  - ATLAS-CONF 2013-013 (ZZ*)
  - ATLAS-CONF-2013-079 (VH→bb)
  - ATLAS-CONF-2013-072 (H→$\gamma\gamma$ diff. σ)
  - ATLAS-PHYS-PUB 2012-001/002 (HL-LHC)
- CDF + D0:

  http://tevnphwg.fnal.gov/
  - arXiv:1207.6436 – Phys. Rev. Lett 109 (Evidence H→bb)
  - arXiv:1303.6346 – Subm. Phys. Rev. D (Combination – Couplings)
  - D0 note 6387-CONF (Spin 2+ studies)
- CMS:

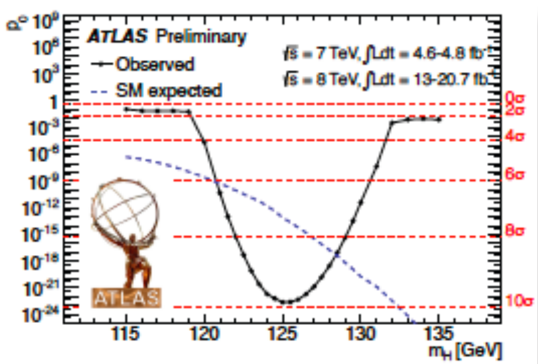
  http://cms.web.cern.ch/org/cms-papers-and-results
  - Phys. Lett. B 716 (Discovery)
  - arXiv:1212.6639 – Phys. Rev. Lett. 110 (ZZ*, Spin)
  - CSM-PAS-HIG-13-016 (Properties $\gamma\gamma$)
  - CMS-PAS-HIG-13-018 (ZH→Z-invisible)
  - CMS-PAS-HIG-13-005 (Couplings)
  - CMS-PAS-HIG-13-012 (H → bb)
  - CMS-PAS-HIG-13-001 ($\gamma\gamma$)
  - CMS-PAS-HIG-13-002 (ZZ*, Spin)
  - CMS-PAS-HIG-13-003 (WW*)
  - CMS-PAS-HIG-13-004 ($\tau\tau$)
  - CMS-NOTE-2012-006 (HL-LHC)
- LHC-XS Higgs wg:

  http://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections
  - arXiv:1307.1347 (Yellow Report 3: σ, BR and coupling and spin/CP-fit models)

material form excellent parallel session talks !

Happy Birthday, Mr. Higgs

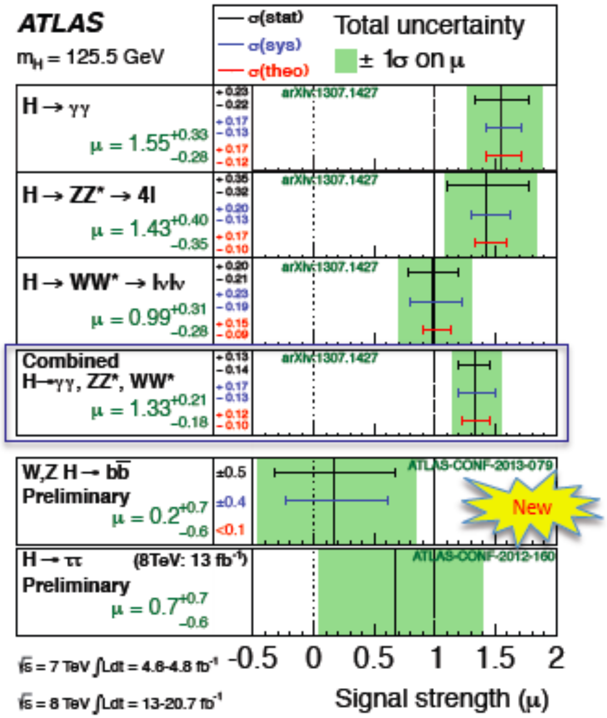
- It's been a great year for the Higgses (both Peter and the Boson)!
- Long journey in one year:
  - Established the existence of new particle beyond any doubts (LHC+Tevatron)
  - Mass measured to 0.50% precision, i.e. better than top (or any other) quark mass! (ATLAS+CMS)
  - It is a 0^{++} boson responsible for EWSB, as evident from its relative couplings to W/Z vs. γ (ATLAS+CMS)
  - Established couplings to the third-generation fermions (CMS+Tevatron)
  - Nearly excluded negative couplings to fermions (CMS)
  - Big 5 → big 6: thanks to ttH (bb, $\gamma\gamma$, and $\tau\tau$)
- See more in Fabio Cerutti's talk (next)

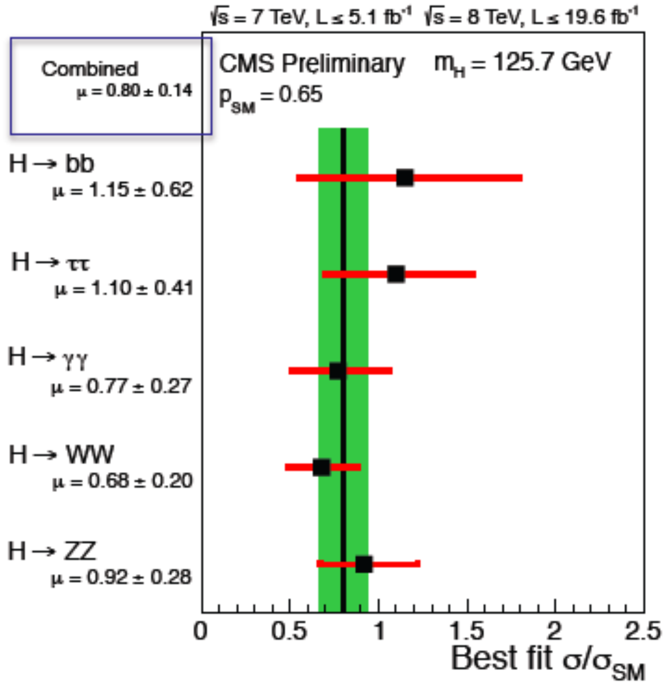


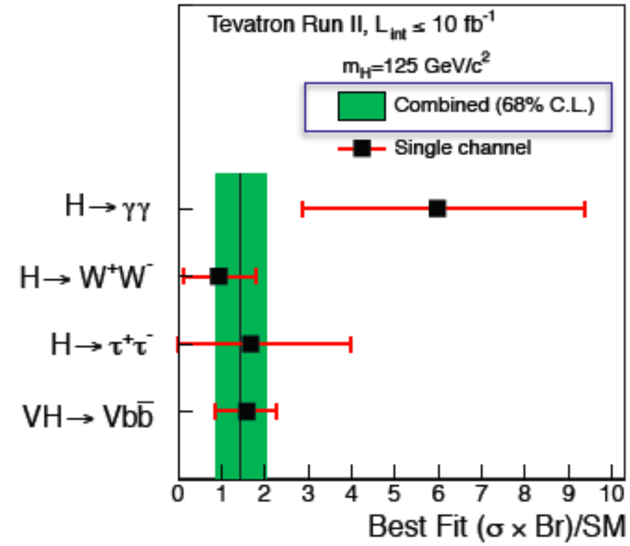
CMS PAS HIG-13-005

Combination	Significance (m_H = 125.7 GeV) Expected (pre-fit)	Expected (post-fit)	Observed
H→ZZ	7.1 σ	7.1 σ	6.7 σ
H→γγ	4.2 σ	3.9 σ	3.2 σ
H→WW	5.6 σ	5.3 σ	3.9 σ
H→bb	2.1 σ	2.2 σ	2.0 σ
H→ττ	2.7 σ	2.6 σ	2.8 σ
H→ττ and H→bb	3.5 σ	3.4 σ	3.4 σ

The signal Strength μ



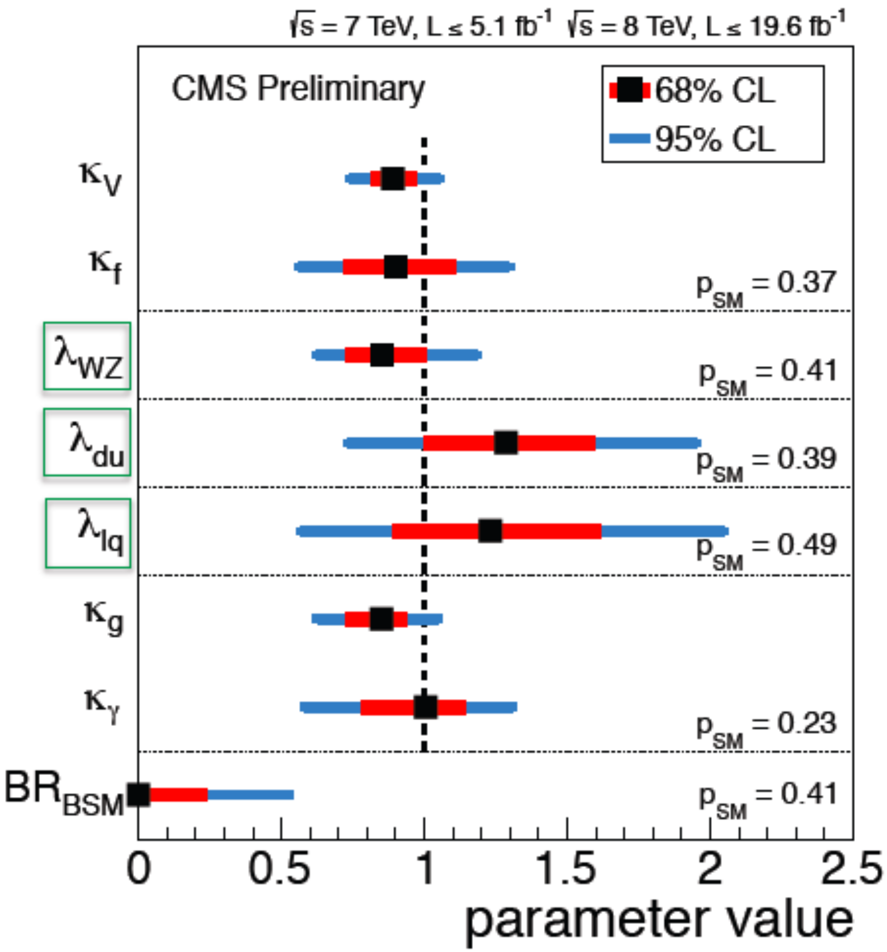


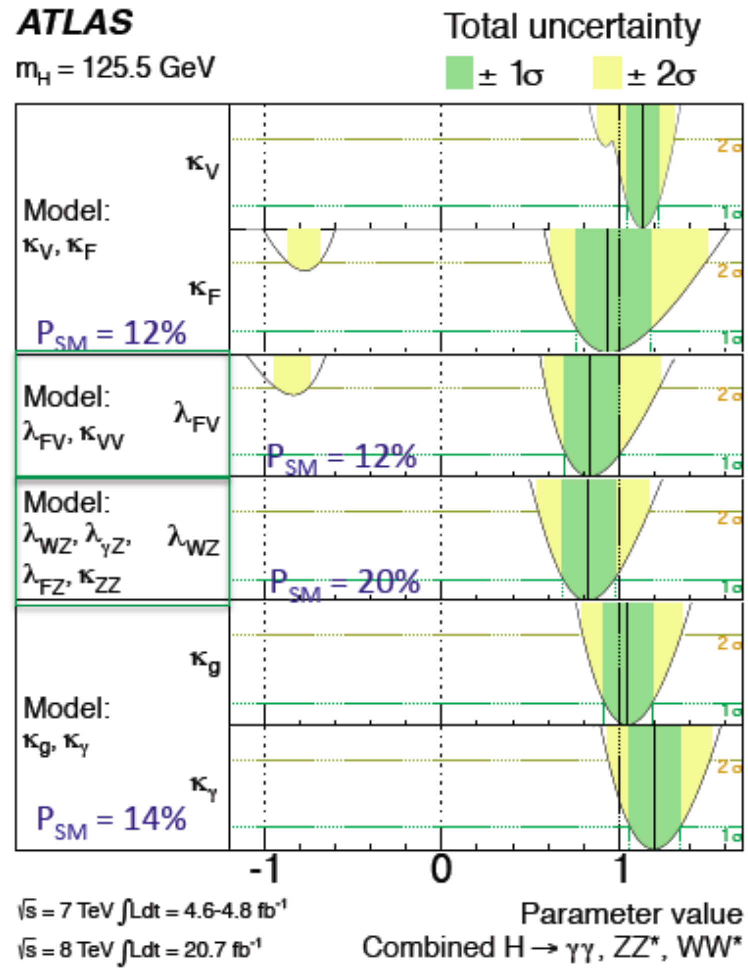


- Combined μ → Best accuracy but no strong physics motivation:
  - **ATLAS** (γγ, **WW*** and **ZZ***) μ = (**1.33 ± 0.20**) (1.23±0.18 including bb and ττ)
  - **CMS** (γγ, ττ, **bb**, **WW*** and **ZZ***) μ = (**0.80 ± 0.14**)
  - **TEVATRON** (**bb**, γγ, ττ, **WW***) μ = (**1.44 ± 0.60**)

Compatible with SM Higgs boson expectation: Accuracy ~ 15%

Couplings Overview



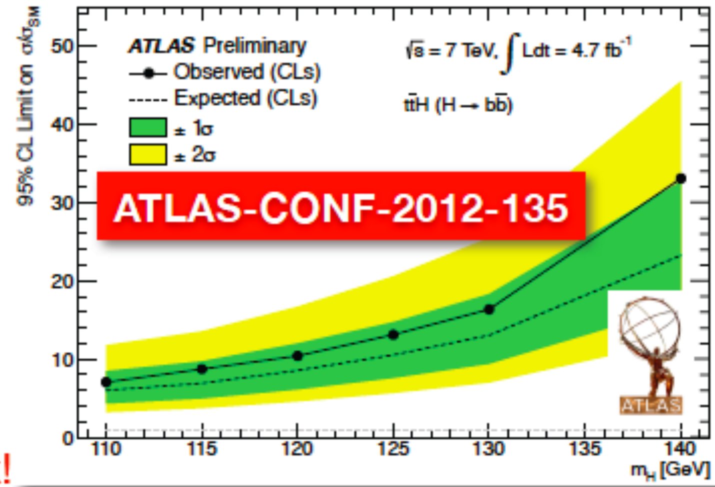


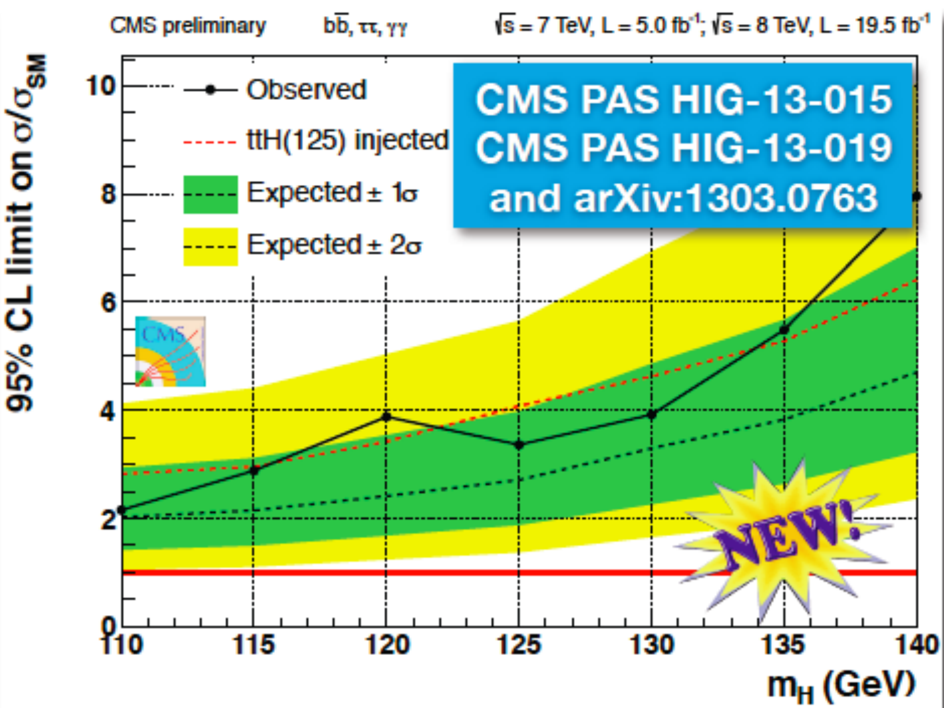
- Different *Sectors* of the New Boson Couplings tested: P_{SM}>12%

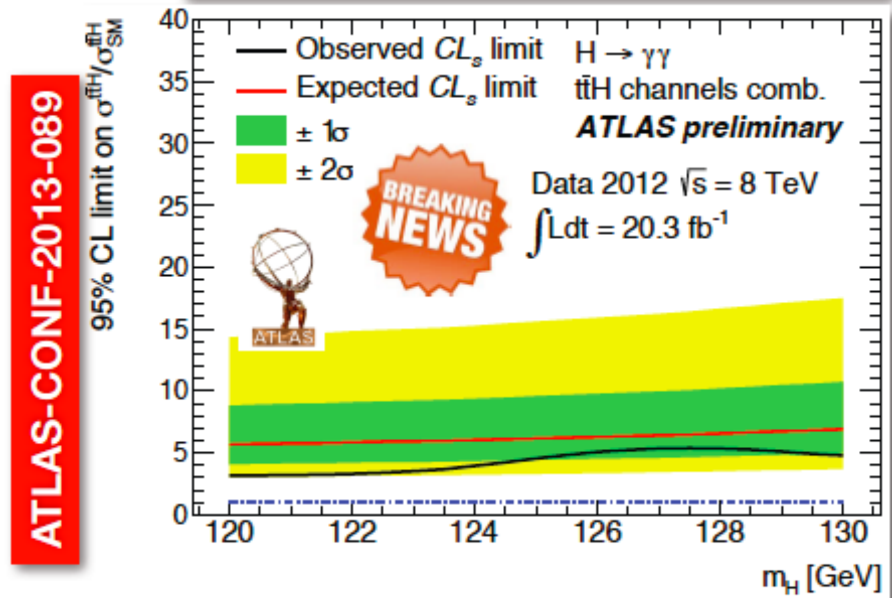
<u>All compatible with SM Higgs expectations</u>

Preparing the future: ttH

- CMS combined results:
  - **μ < 3.4 (2.7 expected)**
- Would improve even more when additional channels are added and combined with ATLAS (once the analysis is updated)
- Closing on the SM Higgs boson sensitivity!
  - Soon to become the 6th of the "big" channels and can be moved into "visible" category of my talk!

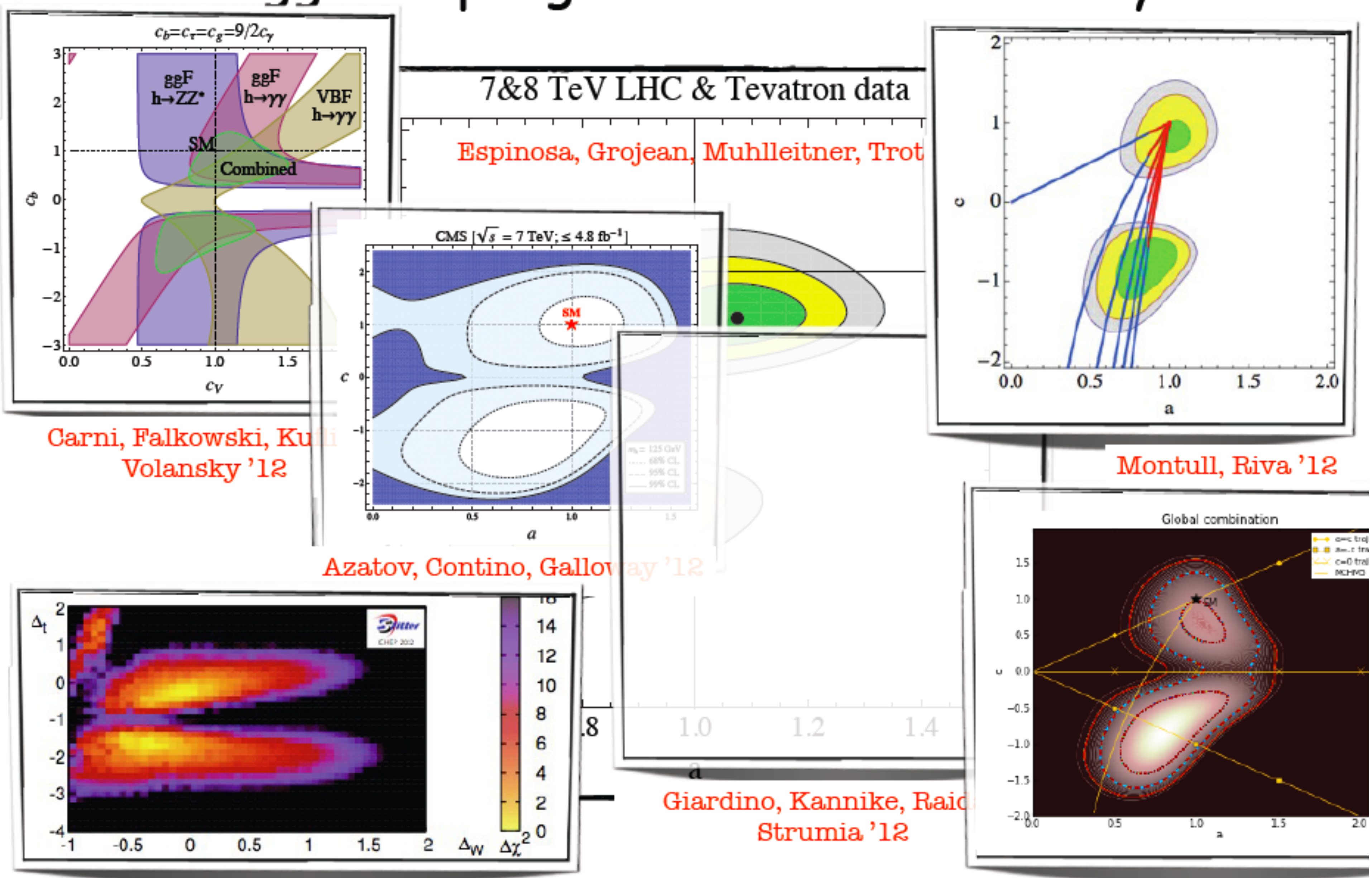






Breaking news - brand new ATLAS ttH(γγ) 8 TeV result: **μ < 5.3 (6.4 exp.)**

Higgs coupling fits: test of unitarity



Carni, Falkowski, Kuflik, Volansky '12

Espinosa, Grojean, Muhlleitner, Trott

Montull, Riva '12

Azatov, Contino, Galloway '12

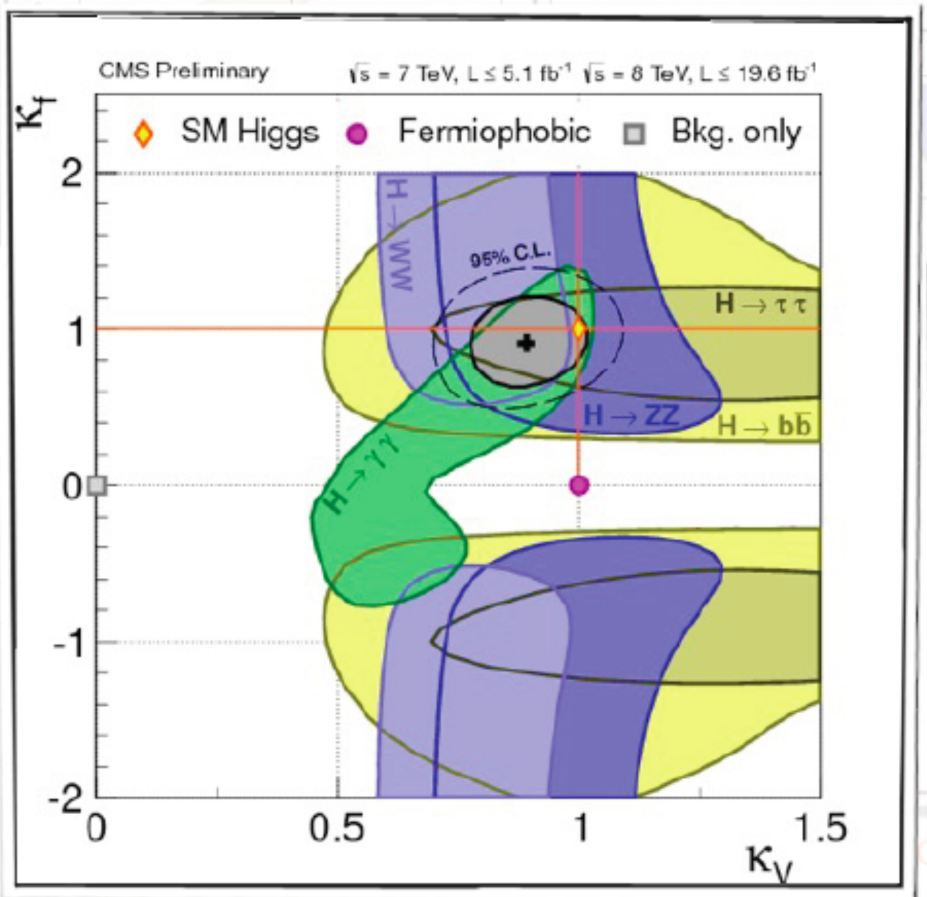
Giardino, Kannike, Raidal, Strumia '12

Plehn, Rauch '12

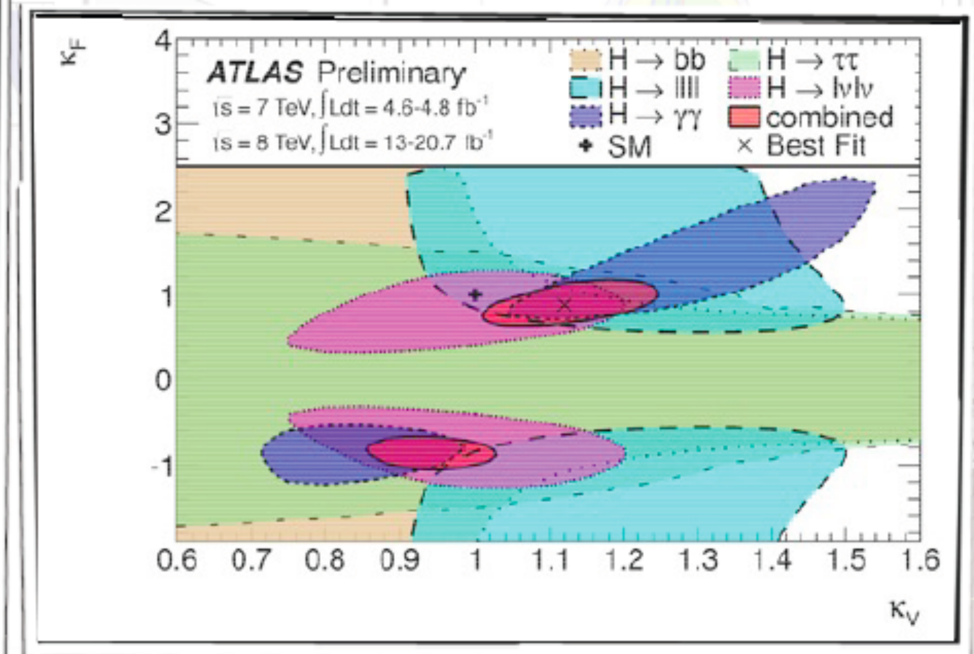
Ellis, You '12

Higgs coupling fits: test of unitarity

don't leave it in the hands of theorists!



CMS

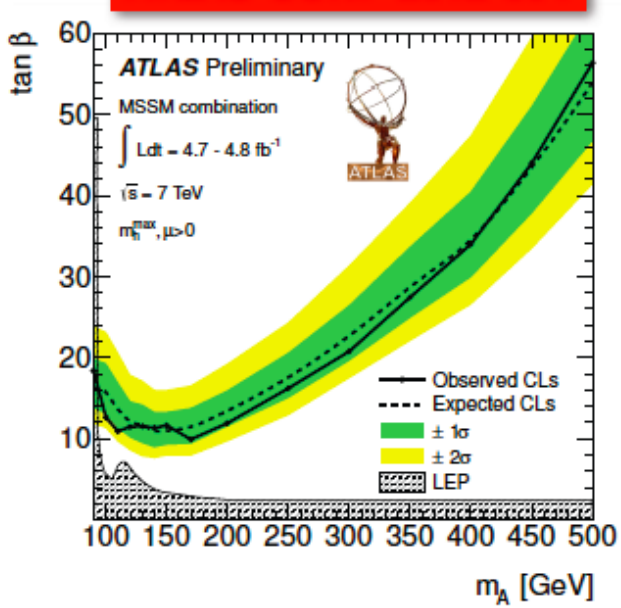


ATLAS

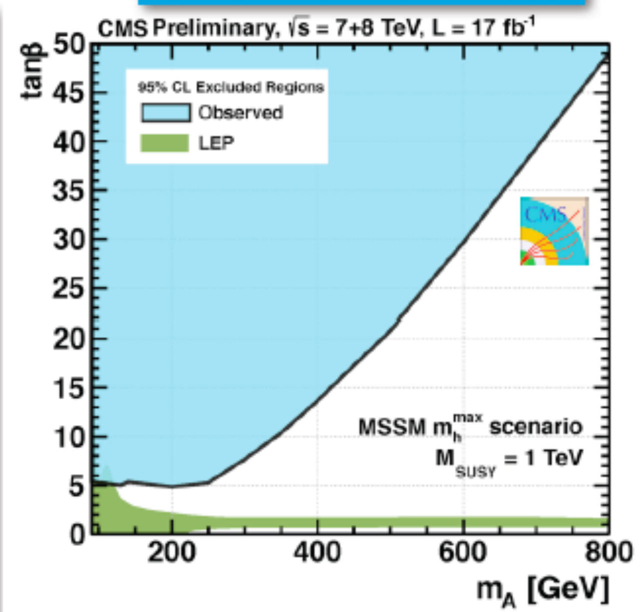
MSSM Higgs Searches

- Most recent results on the H/A($\tau\tau$), including the new LHCb search exploiting τ's in the forward region
- Also, limits on charged Higgs from top decays in $\tau\nu$ (ATLAS+CMS) and cs (ATLAS) channels and search for NMSSM $h \to a^0a^0 \to 4\mu$ (CMS, D0), 4γ (ATLAS) and $a_1 \to 2\mu$ (ATLAS & CMS), as well as Υ(1S,2S) $\to a^0\gamma \to \tau\tau\gamma$, $\mu\mu\gamma$ (BaBar, Belle); and $gg\gamma$, and $ss\gamma$ (BaBar)

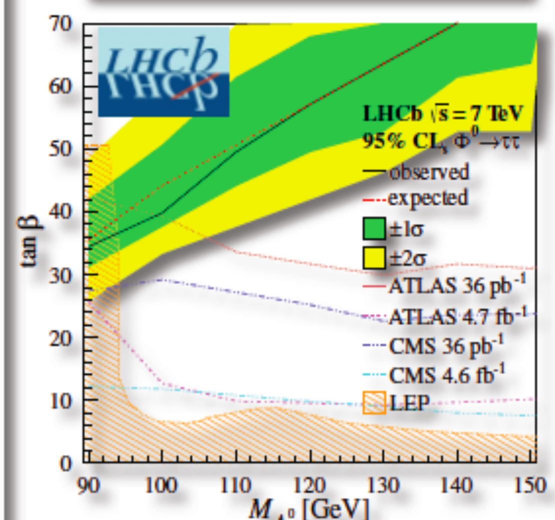
ATLAS-CONF-2012-094



CMS PAS HIG-12-050



LHCb Collaboration arXiv:1304.2591



In full transition from this….

…to that


11:34
KENYA
PERTILE
NGAMOLE
MUTAI
TSEGAY
CHINA
USA
ABDIRAHMAN
MORA

Preparing for the marathon

Need:

- Better theoretical tools
- Keep pushing precision measurements of the SM parameters

The NLO revolution

Why NLO?

- Accurate Theoretical Predictions
  - shape and normalization
  - first error estimate
- Large Corrections : check PT   Higgs
- Opening of new channels
- Effect of extra radiation
  - jet algorithm dependence

Amazing progress in the last few years

➡ Large multiplicities relevant for LHC

- Improved techniques for loop
- High level of automation

talk by Zvi Bern

Experimenter's wish-list

Process ($V \in \{Z, W, \gamma\}$)	Comments
Calculations completed since Les Houches 2005	
1. pp $\to VV$jet	WWjet completed by Dittmaier/Kallweit/Uwer [4,5]; Campbell/Ellis/Zanderighi [6]. ZZjet completed by Binoth/Gleisberg/Karg/Kauer/Sanguinetti [7]
2. pp $\to$ Higgs+2jets	NLO QCD to the gg channel completed by Campbell/Ellis/Zanderighi [8]; NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier [9, 10]
3. pp $\to VVV$	ZZZ completed by Lazopoulos/Melnikov/Petriello [11] and WWZ by Hankele/Zeppenfeld [12] (see also Binoth/Ossola/Papadopoulos/Pittau [13])
4. pp $\to t\bar{t}b\bar{b}$	relevant for $t\bar{t}H$ computed by Bredenstein/Denner/Dittmaier/Pozzorini [14, 15] and Bevilacqua/Czakon/Papadopoulos/Pittau/Worek [16]
5. pp $\to V$+3jets	calculated by the Blackhat/Sherpa [17] and Rocket [18] collaborations
Calculations remaining from Les Houches 2005	
6. pp $\to t\bar{t}$+2jets	relevant for $t\bar{t}H$ computed by Bevilacqua/Czakon/Papadopoulos/Worek [19]
7. pp $\to VVb\bar{b}$,	relevant for VBF $\to H \to VV$, $t\bar{t}H$
8. pp $\to VV$+2jets	relevant for VBF $\to H \to VV$ VBF contributions calculated by (Bozzi/)Jäger/Oleari/Zeppenfeld [20–22]
NLO calculations added to list in 2007	
9. pp $\to b\bar{b}b\bar{b}$	$q\bar{q}$ channel calculated by Golem collaboration [23]
NLO calculations added to list in 2009	
10. pp $\to V$+4 jets	top pair production, various new physics signatures
11. pp $\to Wb\bar{b}j$	top, new physics signatures
12. pp $\to t\bar{t}t\bar{t}$	various new physics signatures
Calculations beyond NLO added in 2007	
13. $gg \to W^*W^*$ $\mathcal{O}(\alpha^2\alpha_s^3)$	backgrounds to Higgs
14. NNLO pp $\to t\bar{t}$	normalization of a benchmark process
15. NNLO to VBF and Z/γ+jet	Higgs couplings and SM benchmark
Calculations including electroweak effects	
16. NNLO QCD+NLO EW for W/Z	precision calculation of a SM benchmark

CLOSED

- Final goal: Really automatic NLO calculations

zero cost for humans

  - Specify the process (input card)
  - Input parameters
  - Define final cuts

- Automatic NLO calculation "conceptually" solved
  - in a few years a number of codes (among others)

Blackhat+Sherpa		GoSam + Sherpa/MadGraph
MadLoop+MadFKS	CutTools	OpenLoops+Sherpa

✓ compete on precision, flexibility, speed, stability, ...

✓ many features : uncertainties, ...

Best solution still to emerge, but not more NLO wish-list, do it yourself!

- Individual calculations still relevant! ✓ open the way to new methods

NNLO the new frontier

- Some measurements to few percent accuracy

✓ $e^+e^- \to 3\,\text{jets}$

$e^-p \to (2+1)\,\text{jets}$

✓ $pp \to V$

$pp \to \text{jets}$ partial

$pp \to V + \text{jets}$

✓ $pp \to t\bar{t}$

$\mathcal{O}(\alpha_s^2)$

Match experimental accuracy
Extract accurate information

- Some processes with still (potentially) large NNLO corrections

✓ $pp \to H$

✓ $pp \to \gamma\gamma$

$pp \to VV$

$pp \to H + \text{jets}$ partial

meaningful comparison
solid estimate of uncertainties

Keep Theorists employed after all the automatic machinery at NLO...

Global electroweak fit

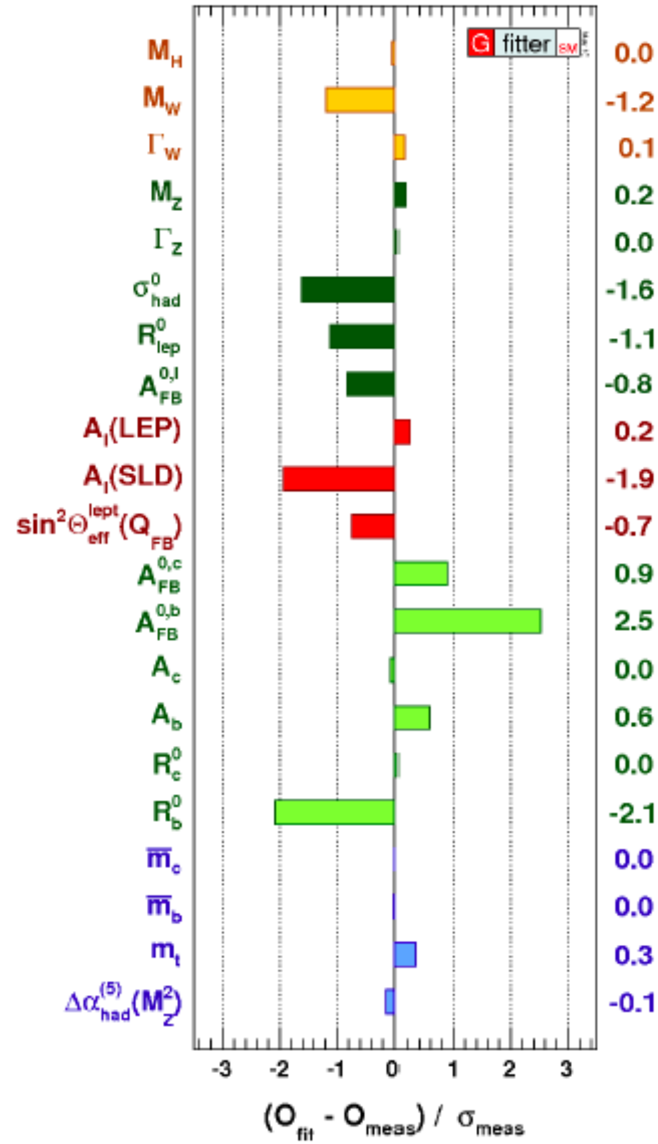
Complete fit:
χ^2_{min} = 20.7 for 14 degrees of freedom.

Pull values for the different observables are shown on the right.

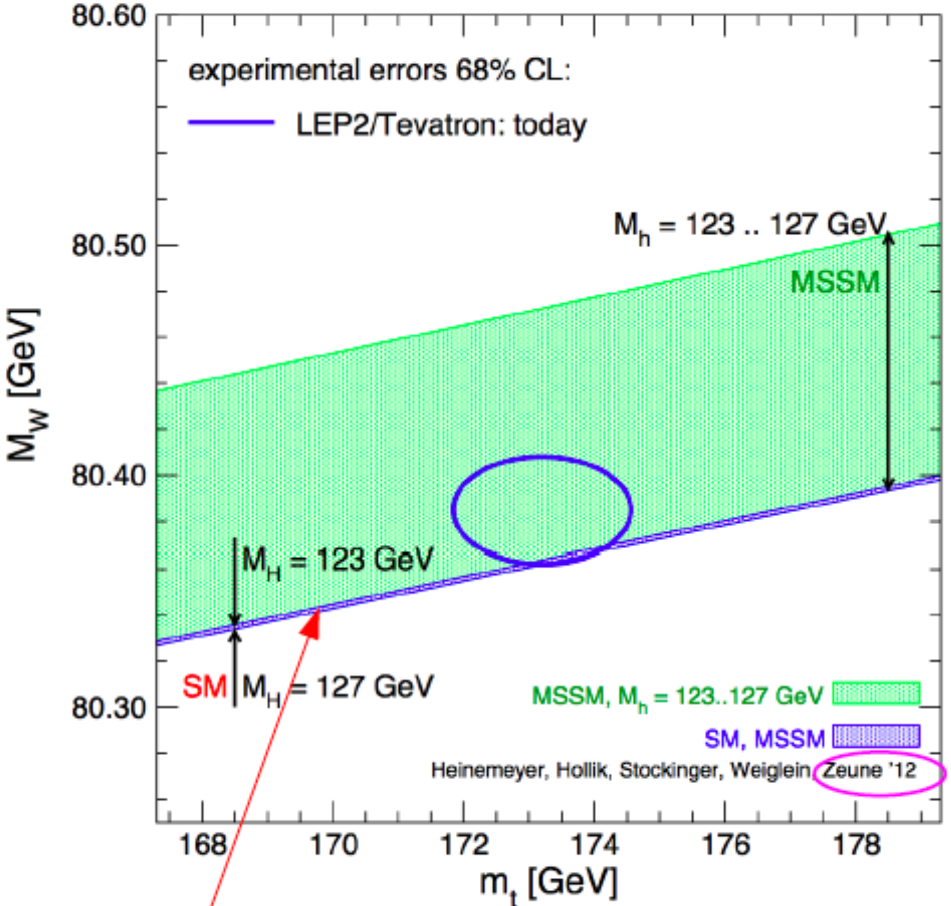
- no value exceeds 2.5 sigma
- largest individual contribution to χ^2 from FB asymmetry of bottom quarks.

Overall good agreement between precision data and standard model.

As is well known, some tension between A_l(SLD) and $A_{FB}^{0,b}$ from LEP.

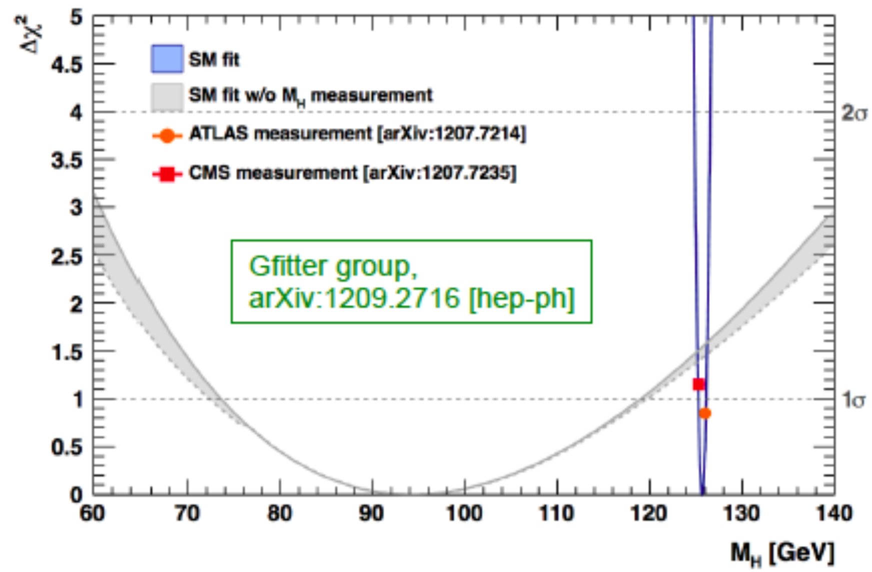


W boson mass



In the context of the standard model, the mass of the new boson discovered by ATLAS+CMS is inside this blue band.

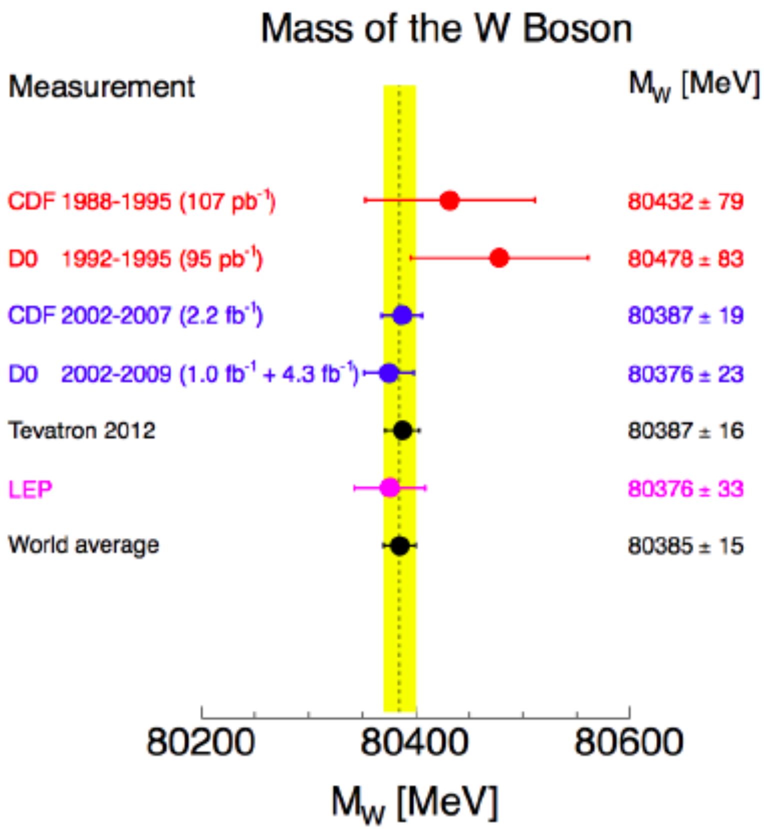
Comparison of indirect constraints on the Standard Model Higgs boson and the direct measurements of the mass of the new boson discovered by ATLAS and CMS:



Consistent at the 1.3 σ level.

W boson mass

Current state of the art:



Projections:

DØ: analyse full data set
significantly extend eta coverage
=> 15 MeV uncertainty
(not including improvements in PDFs)

CDF: analyse full dataset
=> 10 MeV uncertainty
(including improvements in PDFs; which are expected from measurements of W charge asymmetry)

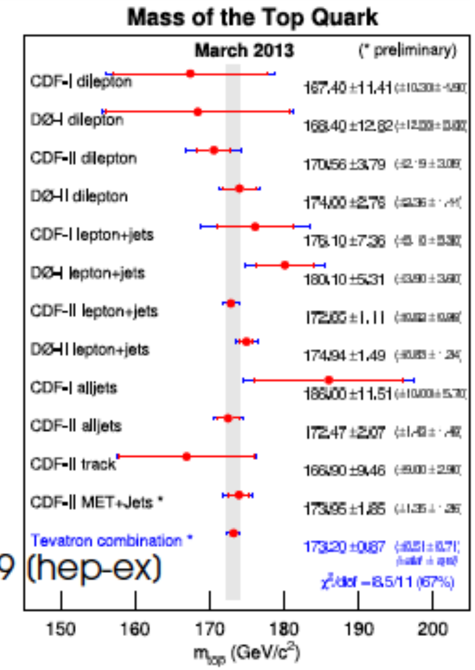
LHC: 10 MeV to 5 MeV, ultimately

Current measurements of boson p_T, rapidity spectra
W charge asymmetry,
W+c jet (c.f. QCD plenary on Wednesday), ...
are critical steps toward this goal.

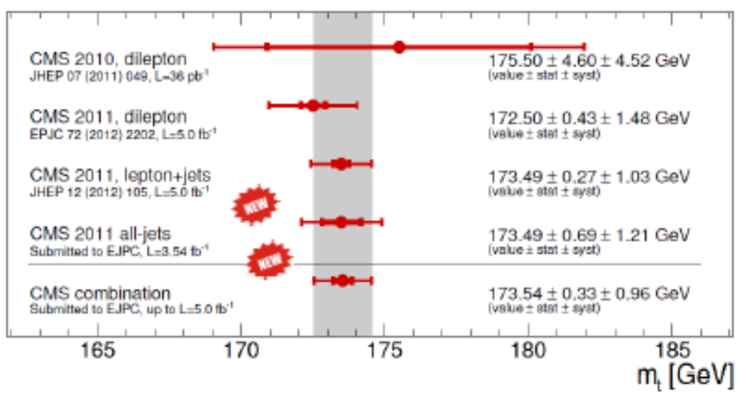
The next "quantum leap" in precision could come from a machine like e.g. TLEP (0.5 MeV uncertainty).

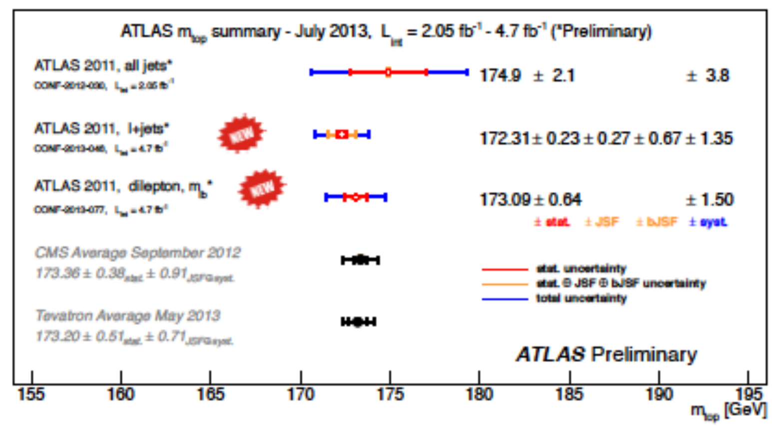
- Tevatron still provides the best mass measurement, with an uncertainty of 0.5%.
- Best single LHC measurement (from CMS) reaches 0.6%.
- Updated LHC mass combination in progress.

→ Harmonise systematic treatment e.g. generator modeling.



arXiv:1305.3929 (hep-ex)

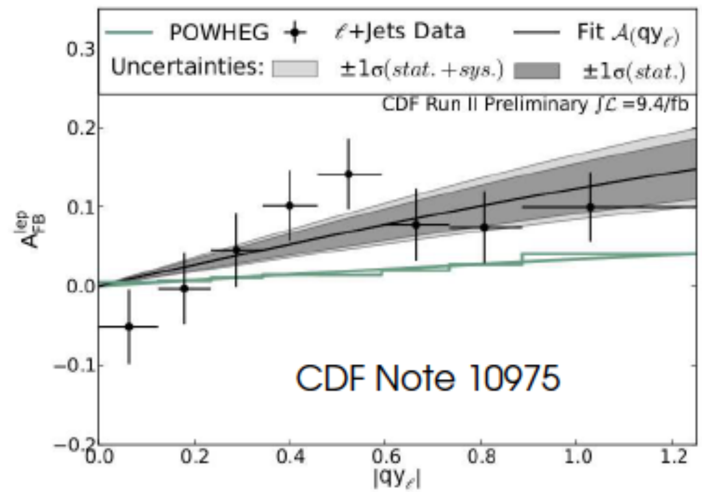




- $A_{FB}^{t\bar{t}}$ measurement requires full reconstruction of $t\bar{t}$ system.
- Alternative method based on y of lepton from leptonic W decay.

$$A_{FB}^{\ell} = \frac{N(q_\ell y_\ell > 0) - N(q_\ell y_\ell < 0)}{N(q_\ell y_\ell > 0) + N(q_\ell y_\ell < 0)}$$

- $A_{FB}^{\ell} \approx 0.5 \cdot A_{FB}^{t\bar{t}}$ if no t polarization.
- Can also use events with jets out of acceptance (3-jet bin).



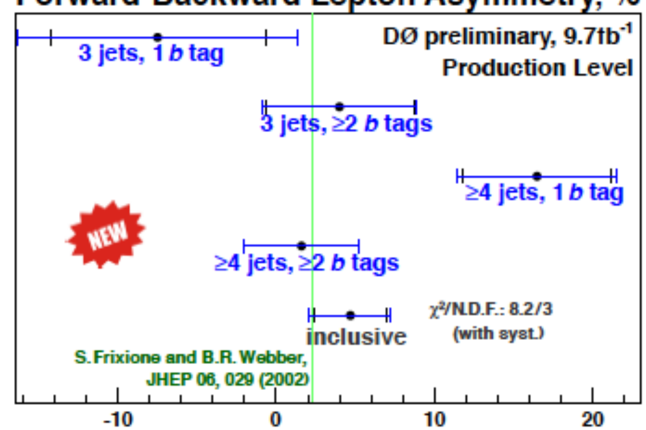
CDF Note 10975

CDF: $A_{FB}^{\ell} = 0.094^{+0.032}_{-0.029}$

D0: $A_{FB}^{\ell} = 0.047 \pm 0.023(\text{stat})^{+0.011}_{-0.014}(\text{syst})$

- CDF result approximately 2σ above SM prediction.
- D0 measurement consistent with SM (and CDF) within errors.

Forward-Backward Lepton Asymmetry, %



D0 note 6394-CONF

The AdS/CFT correspondence

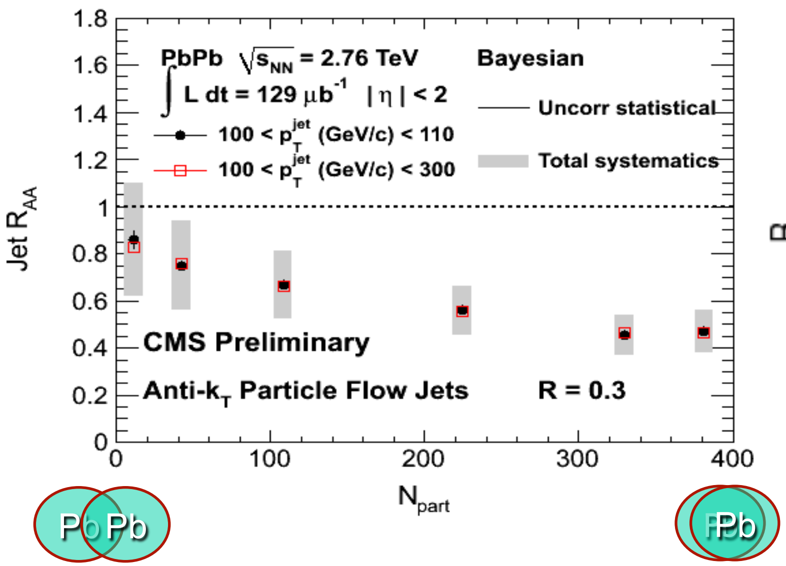
$\mathcal{N}=4$ Super Yang-Mills theory	$\equiv$	Superstrings on $AdS_5 \times S^5$
strong coupling nonperturbative physics very difficult		(semi-)classical strings or supergravity 'easy'
weak coupling 'easy'		highly quantum regime very difficult

- New ways of looking at nonperturbative gauge theory physics...
- Intricate links with General Relativity...
- Has been extended to many other cases

R. Janik, Z. Bern

Jets in Pb+Pb collisions

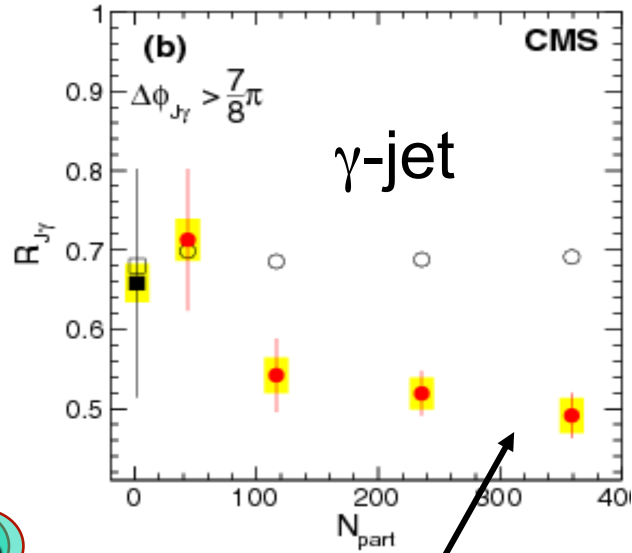
Jet cross section suppressed, dependence on centrality:



$$R_{AA} = \frac{dN^{AA}_{jets}/dp_T}{\langle N_{coll}\rangle\, dN^{pp}_{jets}/dp_T} = \frac{dN^{AA}_{jets}/dp_T}{\langle T_{AA}\rangle\, d\sigma^{pp}_{jets}/dp_T}$$

CMS PAS HIN-12-004

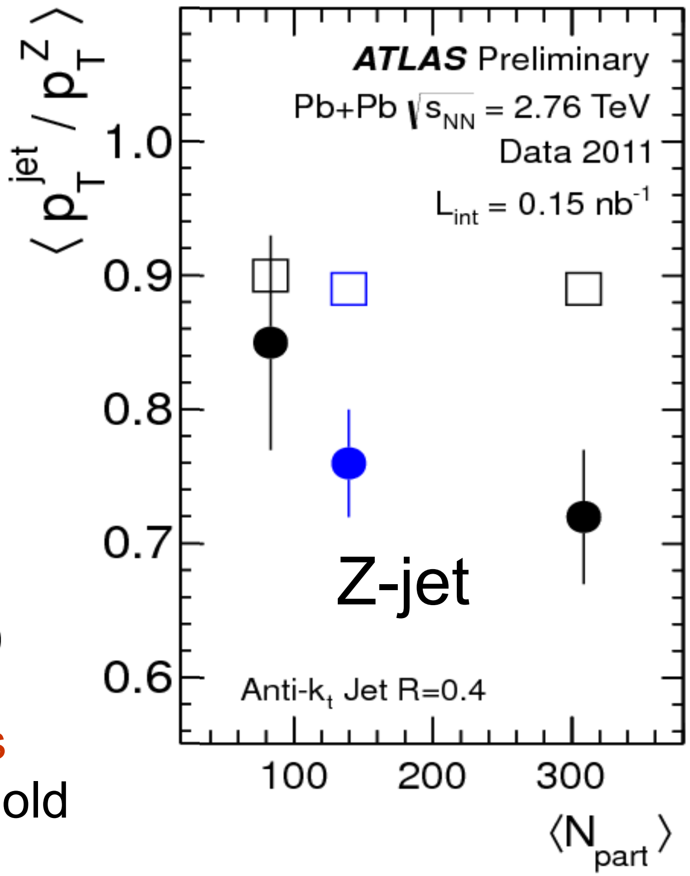
$R_{J\gamma}$ = fraction of photons with jet partner >30 GeV/c



Less jet partners found above threshold

~20% of photons lose their jet partner

PLB 718 (2013) 773

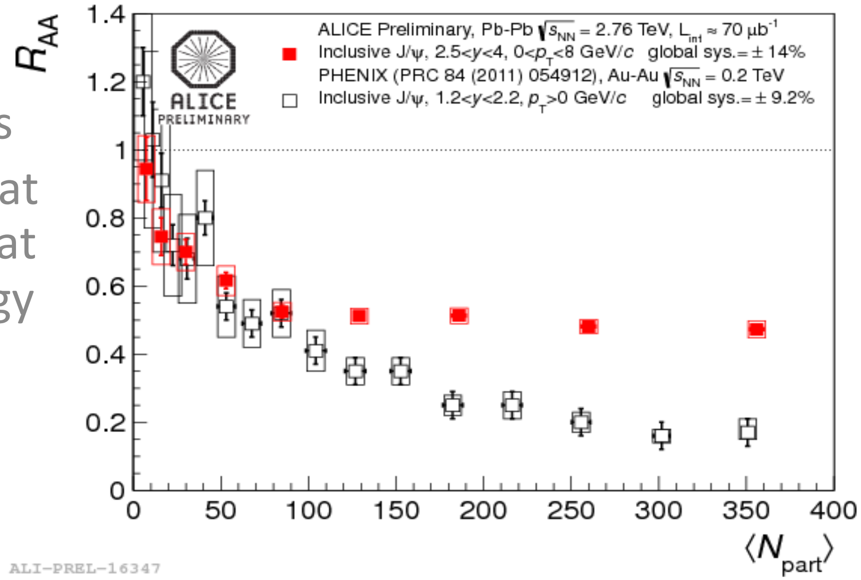


Increasing energy loss vs. centrality

ATLAS-CONF-2012-119

J/psi in Pb-Pb and p-Pb

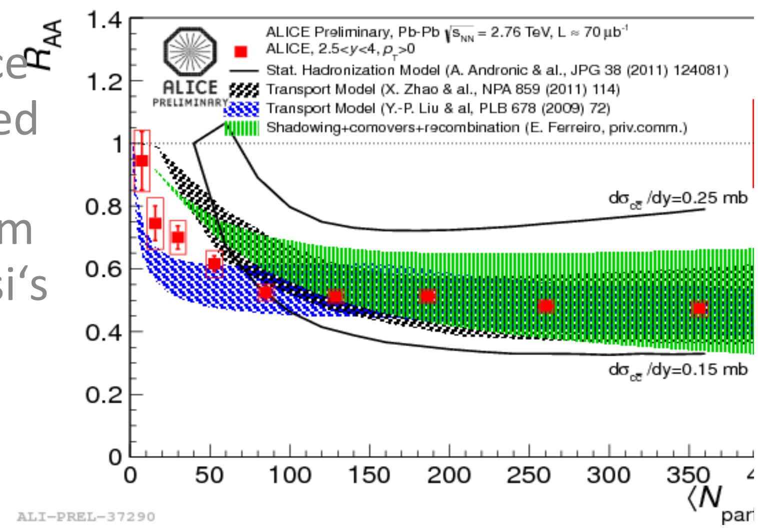
Higher J/psi yields in Pb-Pb collisions at the LHC wrt RHIC, at mugh higher energy densities!

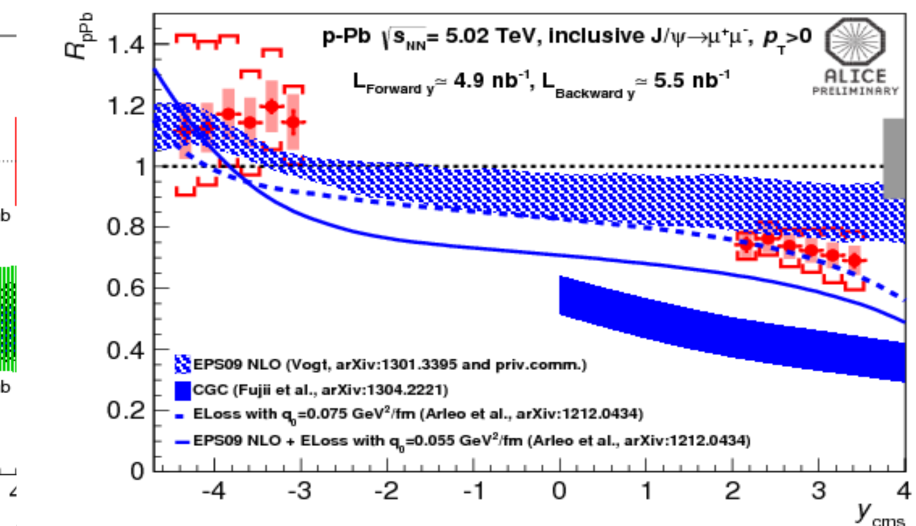


NEW !!!

Now measured also in p-Pb collisions, to disentangle initial state effects, from cold nuclear matter

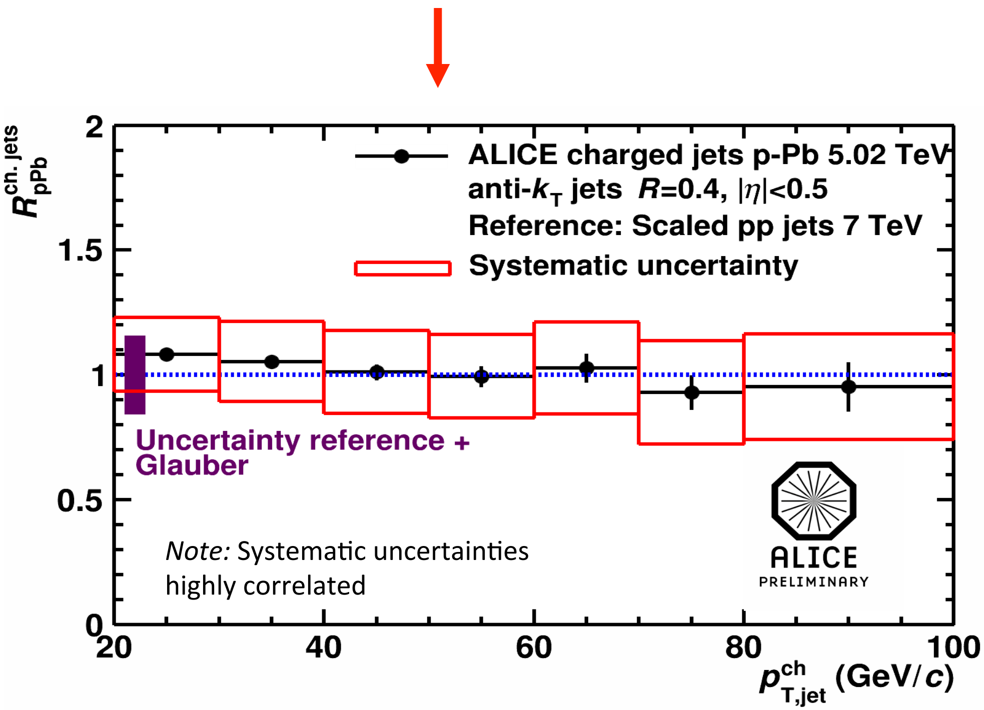
Described by (re)generation models: abundance of quasi-thermalized charm in the deconfined medium produces NEW J/psi's



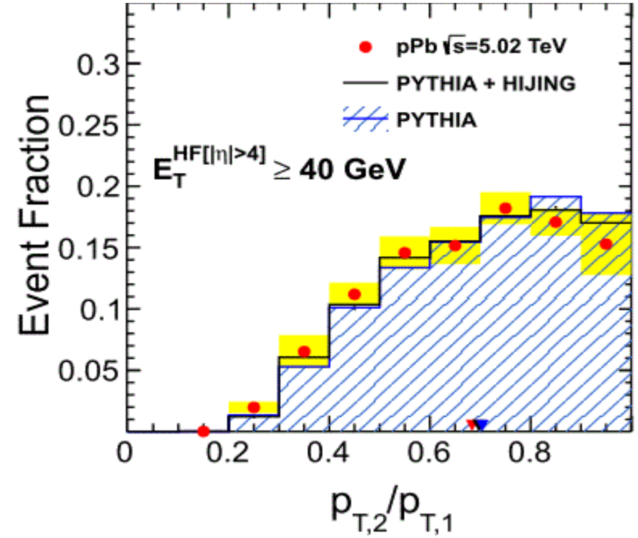


Jets in p+Pb collisions

Charged jets: ratio of p_T-spectra in p+Pb and p+p

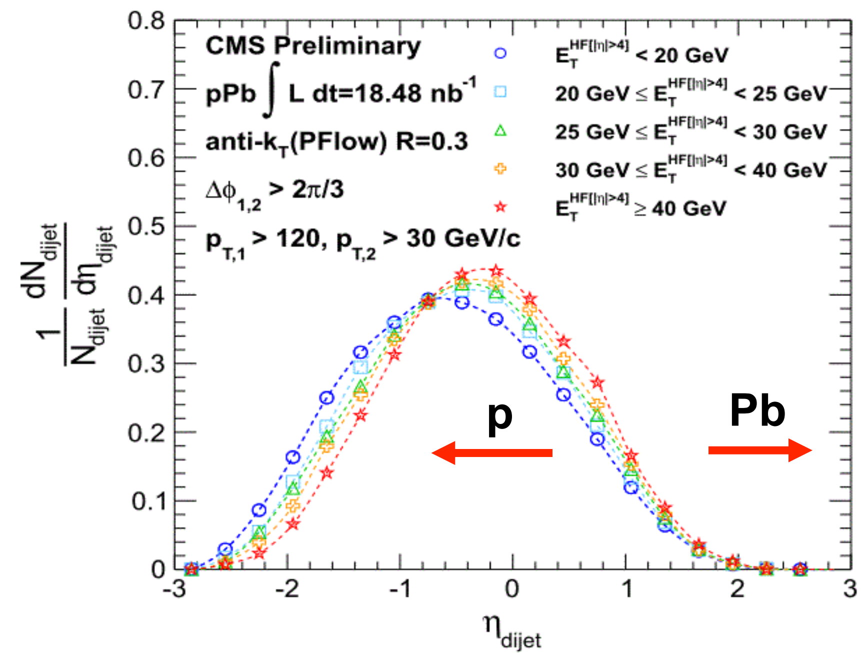


Consistent with unity: no strong modification of charged jets in cold nuclear matter, no strong influence of nPDF.



No visible di-jet imbalance compared to p +p

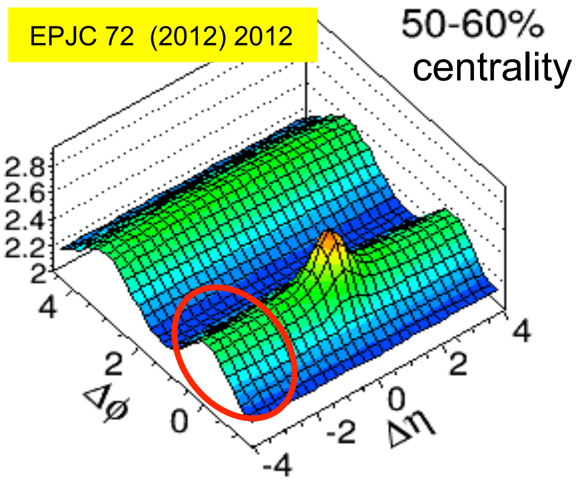
CMS PAS HIN-13-001



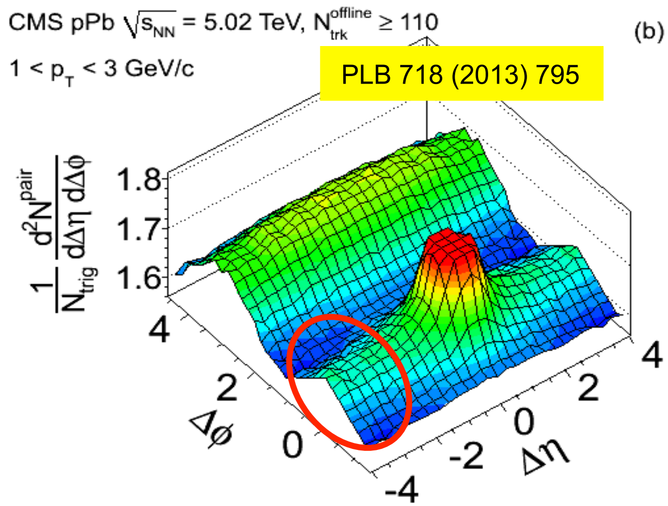
However, di-jet η distribution is strongly shifting vs. “centrality”

Long-range correlations: Pb+Pb, p+Pb, p+p

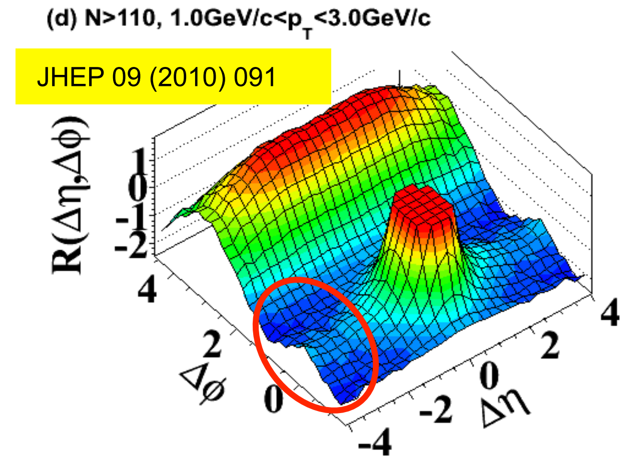
Pb+Pb 2.76 TeV



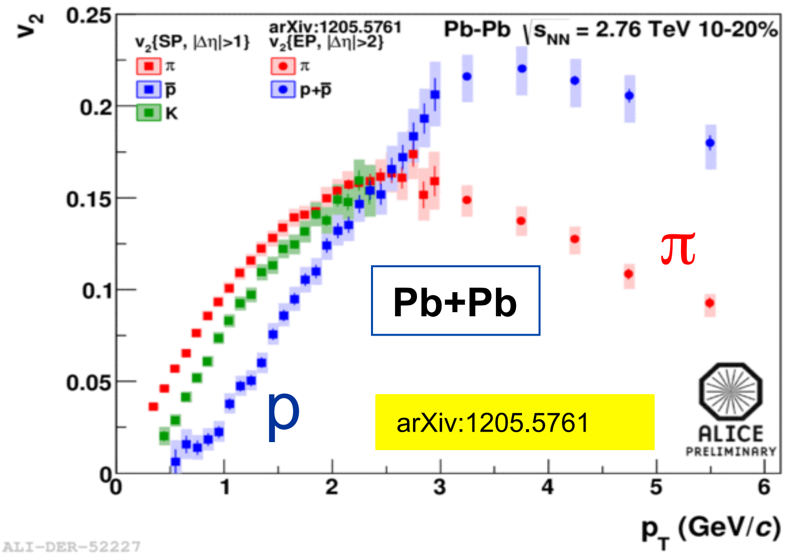
p+Pb 5.02 TeV

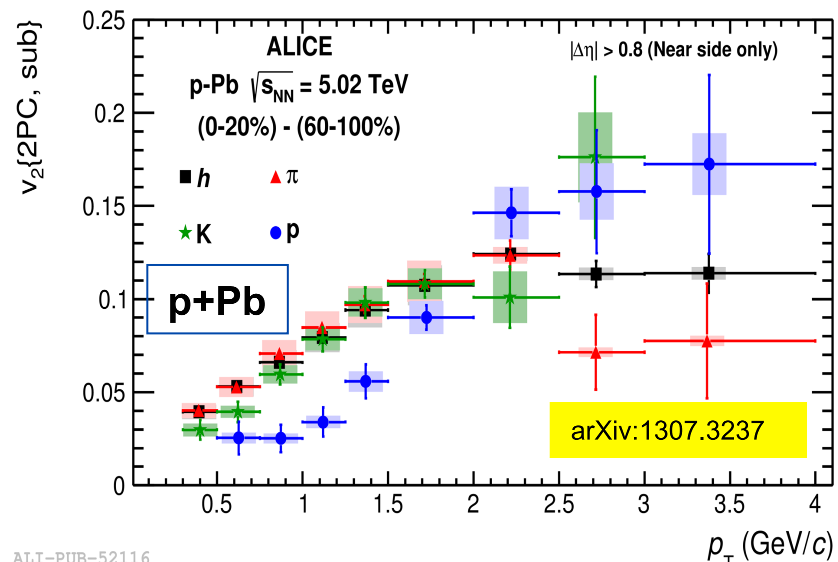


p+p 7 TeV



Mass ordering of second Fourier-coefficient (v_2):



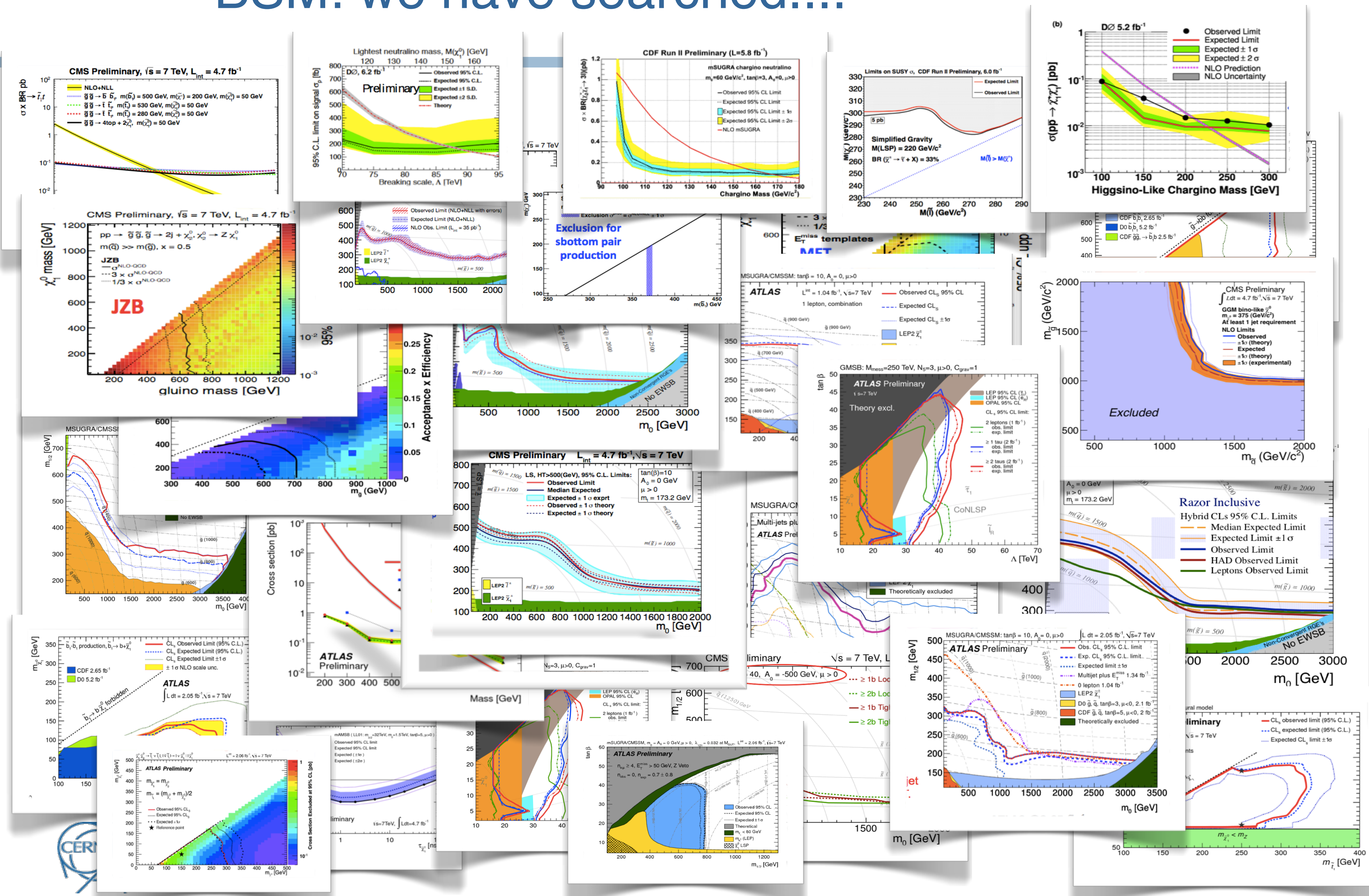


Striking similarities!

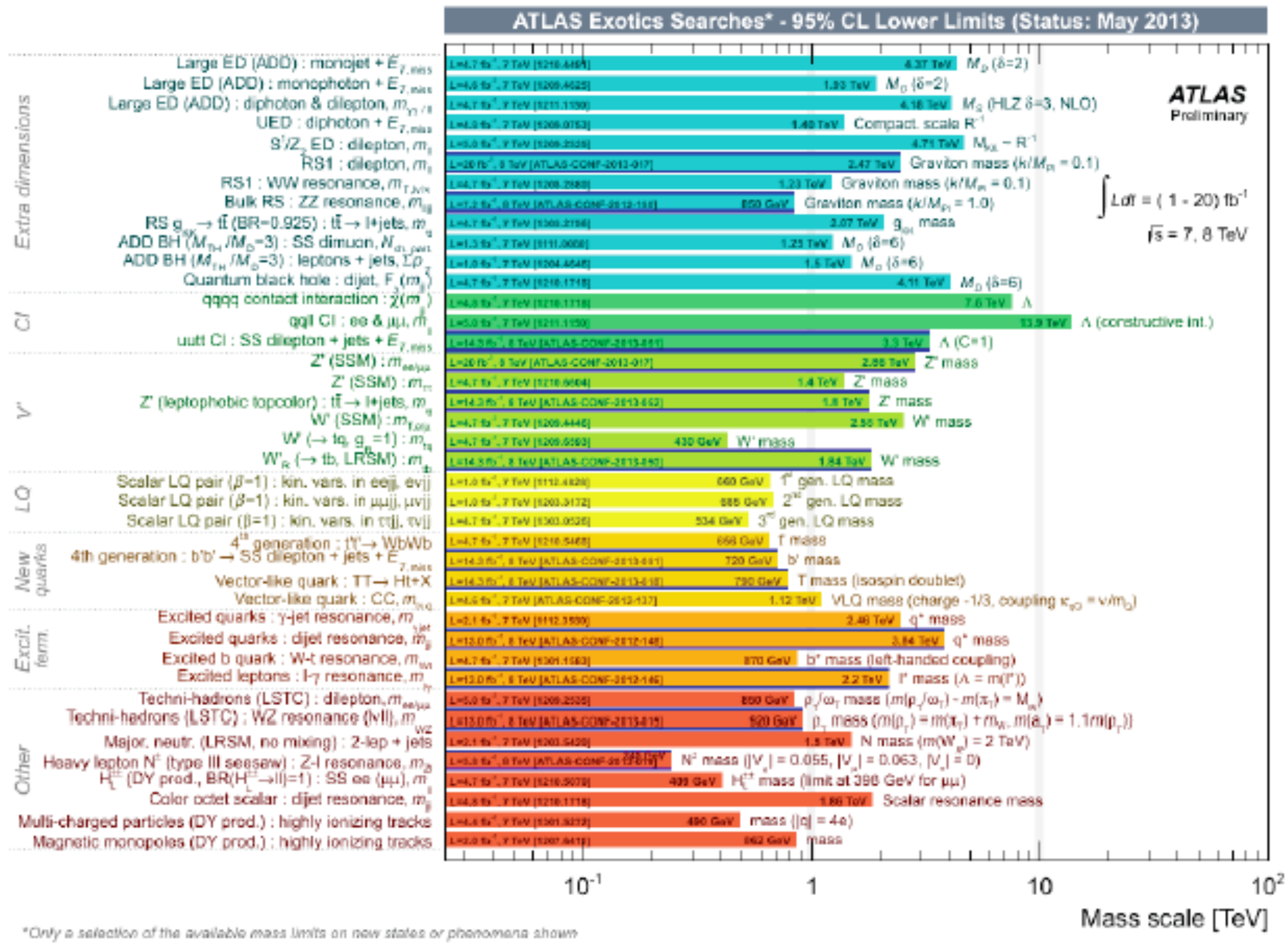
Looking for BSM effects

- …with searches
- ….with precision measurements
- …with rare (and reliably predicted) decays

BSM: we have searched....



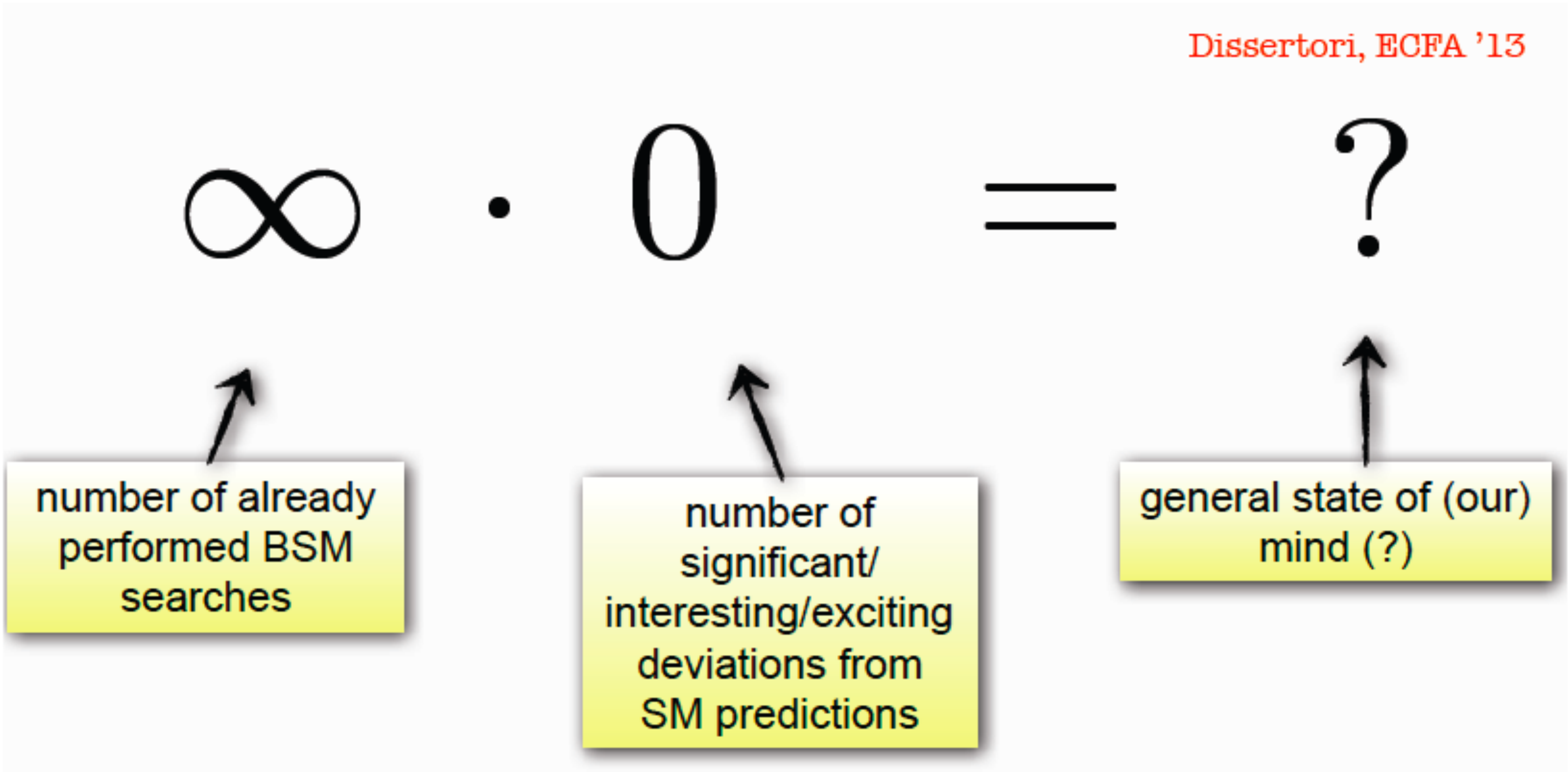
…and exotics



ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)
ATLAS
Preliminary
∫Ldt = (1 - 20) fb⁻¹
√s = 7, 8 TeV
Extra dimensions
CI
V'
LQ
New quarks
Excit. ferm.
Other
Large ED (ADD) : monojet + E_T,miss
Large ED (ADD) : monophoton + E_T,miss
Large ED (ADD) : diphoton & dilepton
UED : diphoton + E_T,miss
RS1 : dilepton
RS1 : WW resonance
Bulk RS : ZZ resonance
Quantum black hole : dijet
qqqq contact interaction
Z' (SSM)
Z' (leptophobic topcolor)
W' (SSM)
Scalar LQ pair
4th generation
Vector-like quark : TT→ Ht+X
Excited quarks : γ-jet resonance
Excited quarks : dijet resonance
Excited b quark : W-t resonance
Excited leptons : l-γ resonance
Techni-hadrons (LSTC) : dilepton
Techni-hadrons (LSTC) : WZ resonance (lvll)
Major. neutr. (LRSM, no mixing) : 2-lep + jets
Heavy lepton N± (type III seesaw) : Z-l resonance
Color octet scalar : dijet resonance
Multi-charged particles (DY prod.) : highly ionizing tracks
Magnetic monopoles (DY prod.) : highly ionizing tracks
4.37 TeV
1.93 TeV
4.18 TeV
1.40 TeV
4.71 TeV
2.47 TeV
1.23 TeV
850 GeV
2.07 TeV
1.25 TeV
1.5 TeV
4.11 TeV
7.6 TeV
13.9 TeV
3.3 TeV
2.86 TeV
1.4 TeV
1.8 TeV
2.55 TeV
430 GeV
1.84 TeV
660 GeV
685 GeV
534 GeV
656 GeV
720 GeV
790 GeV
1.12 TeV
2.46 TeV
3.84 TeV
870 GeV
2.2 TeV
850 GeV
920 GeV
1.5 TeV
409 GeV
1.86 TeV
490 GeV
862 GeV
Graviton mass
Z' mass
W' mass
1st gen. LQ mass
2nd gen. LQ mass
3rd gen. LQ mass
b' mass
T mass (isospin doublet)
q* mass
b* mass (left-handed coupling)
Scalar resonance mass
mass
10⁻¹
1
10
10²
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena shown

Conclusions: Executive Summary

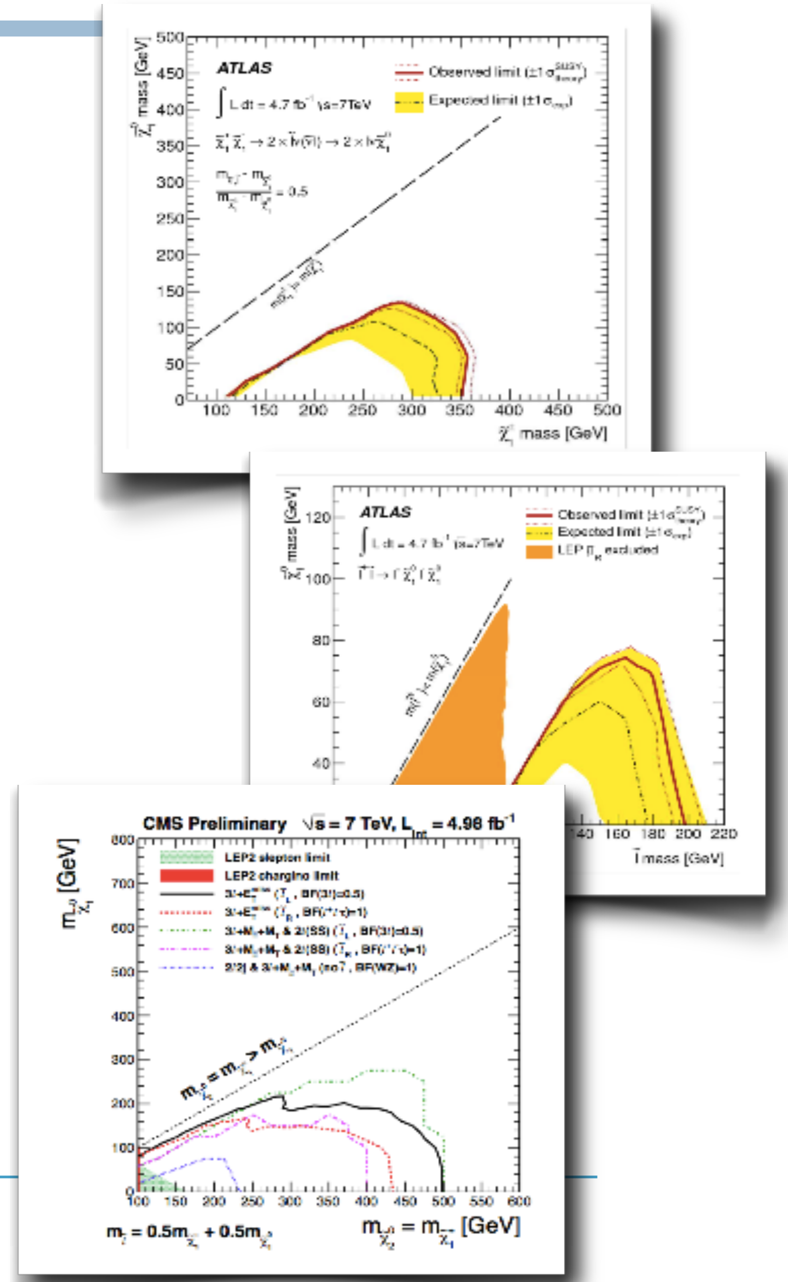
The LHC leaves us with the deepest mathematical pb:



Understanding the scalar sector of the SM
will help us grasping what lays beyond the SM

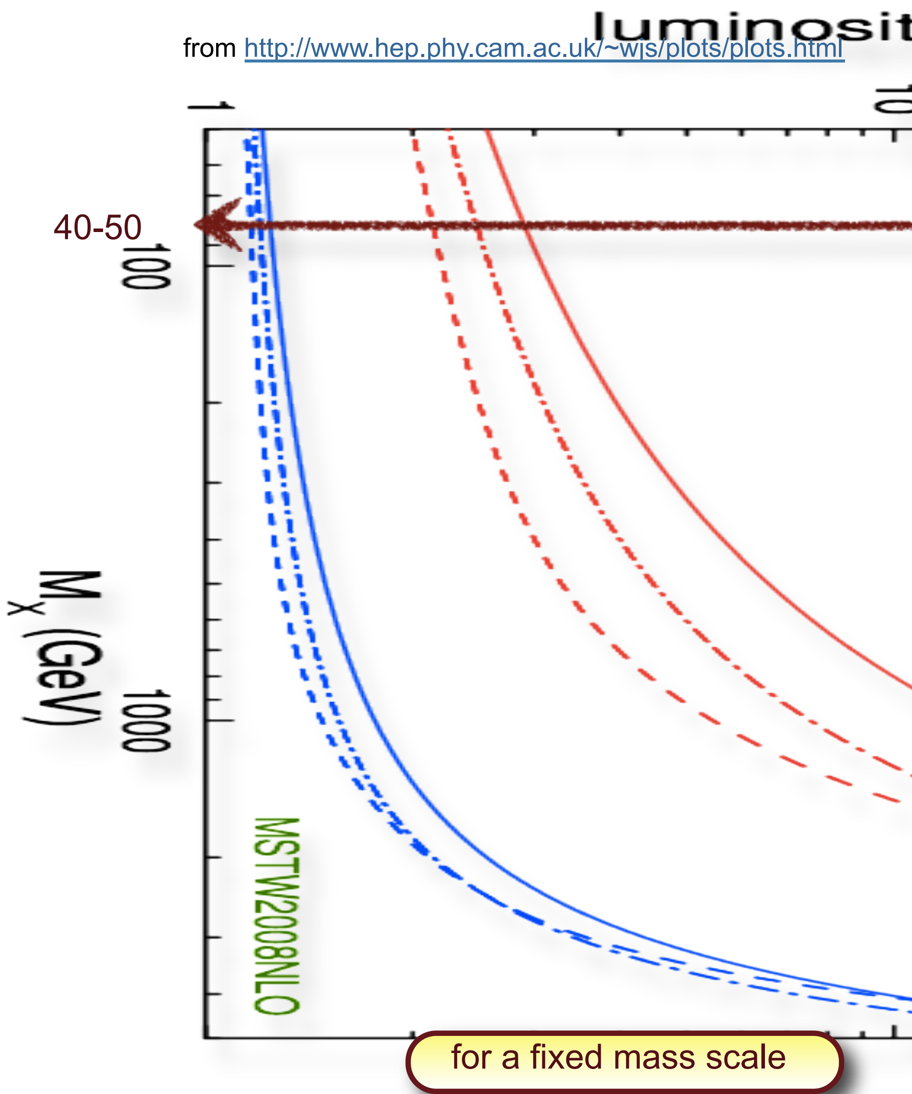
SUSY health

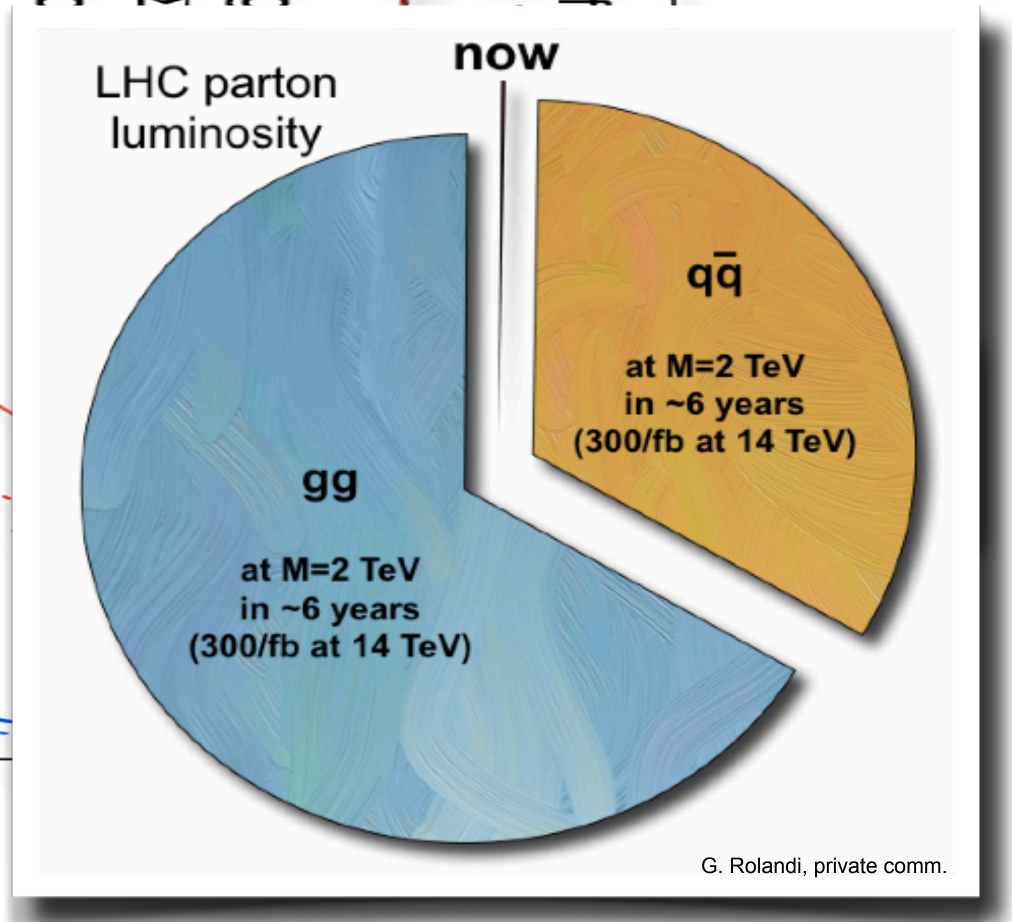
- The experiments have already explored a very vast range of masses and parameters
- Though, too early to declare SUSY's death, since there remain important parameter regions to be explored, and because
    - Difficult or impossible to give "absolute" limits, since basically always assumptions involved
    - limits quickly degrade or disappear when raising m(LSP) beyond several hundreds of GeV
    - inclusive searches often assume degenerate 1st and 2nd generation squarks. Limits decrease (by several hundreds of GeV) if this is given up
    - simplified models make strong assumptions on branching ratios, masses of intermediate states
    - theory uncertainties (cross sections/scales/pdfs, initial state radiation)



Parton luminosities

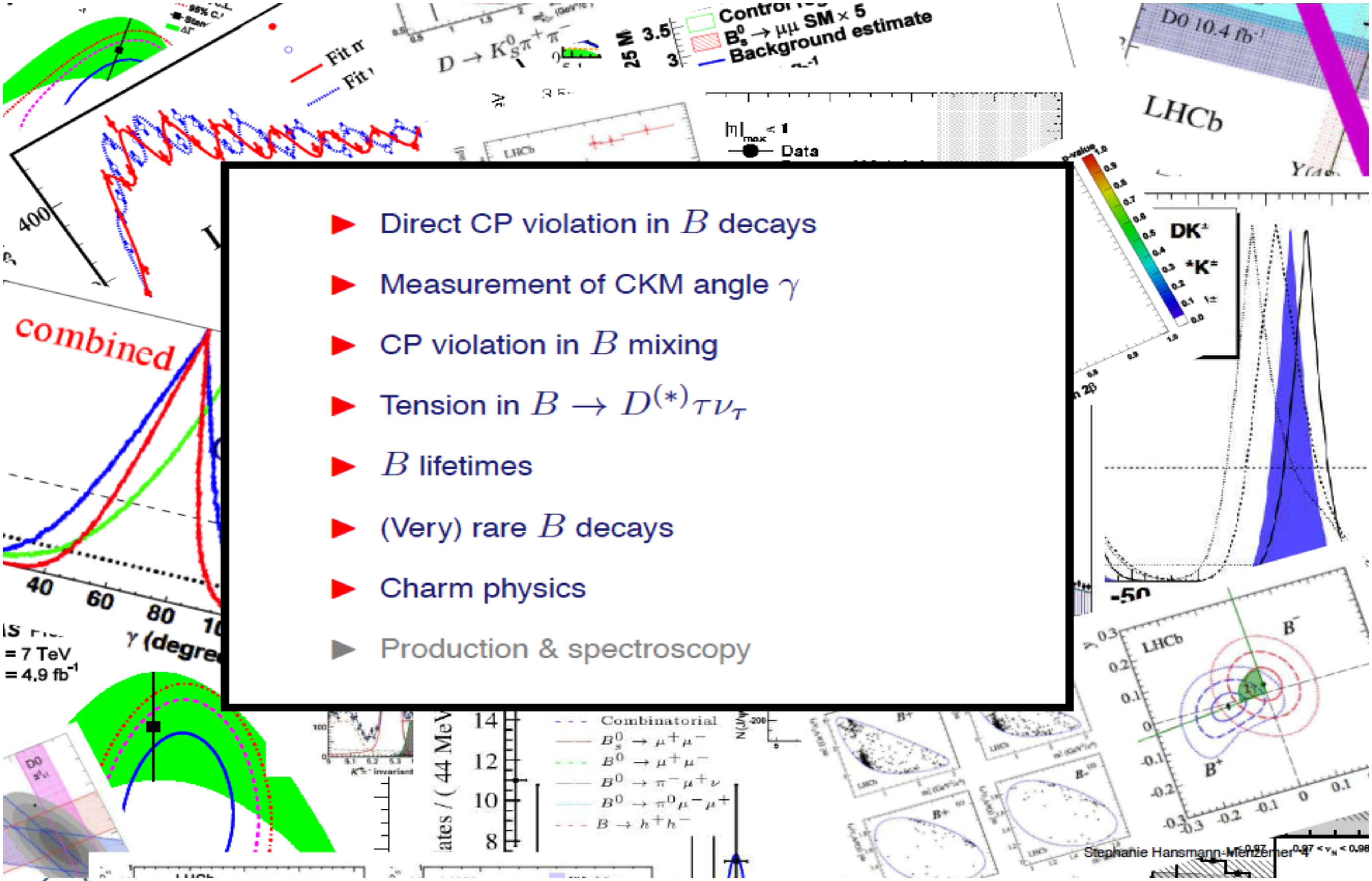
from http://www.hep.phy.cam.ac.uk/~wjs/plots/plots.html





Dissertori, Krakov 2012

Flavour Physics

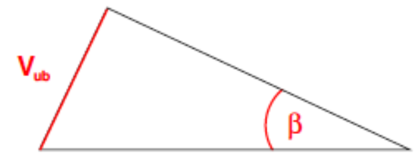


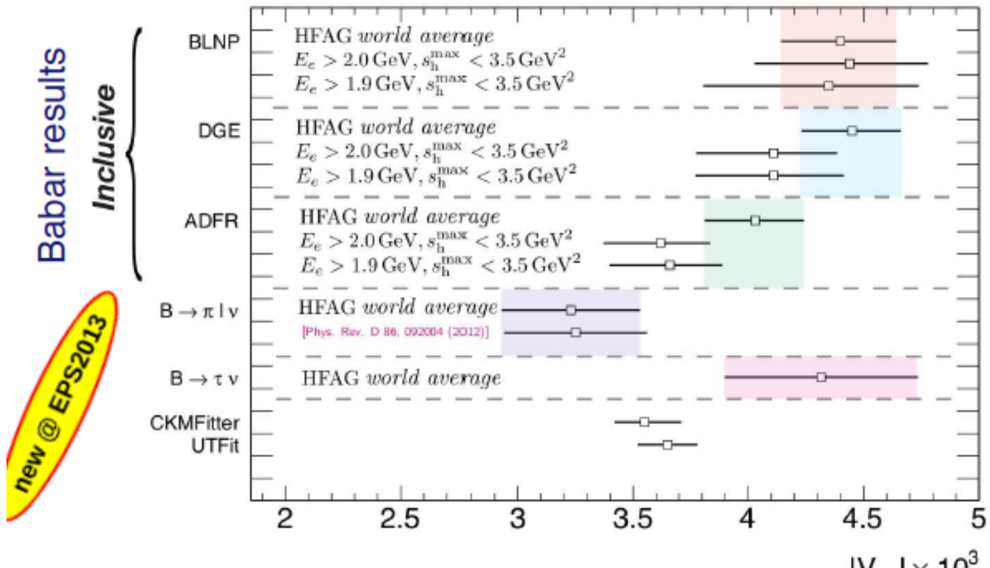
- Direct CP violation in B decays
- Measurement of CKM angle γ
- CP violation in B mixing
- Tension in $B \rightarrow D^{(*)}\tau\nu_\tau$
- B lifetimes
- (Very) rare B decays
- Charm physics
- Production & spectroscopy

Flavour

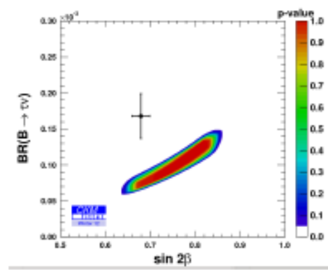
Summary of V_{ub}

Access to V_{ub} via inclusive semileptonic decays, exclusive semileptonic decays or fit to CKM triangle ($\sin 2\beta$)





plot from talk from F. Bernlocher

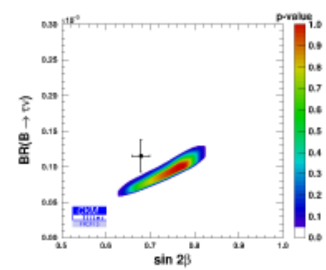


ICHEP 2012

BELLE result

on $BR(B^+ \to \tau\nu)$

(PRL 110 131801)



tensions decreased with recent data

Quest for $B^0_{(s)} \to \mu^+\mu^-$

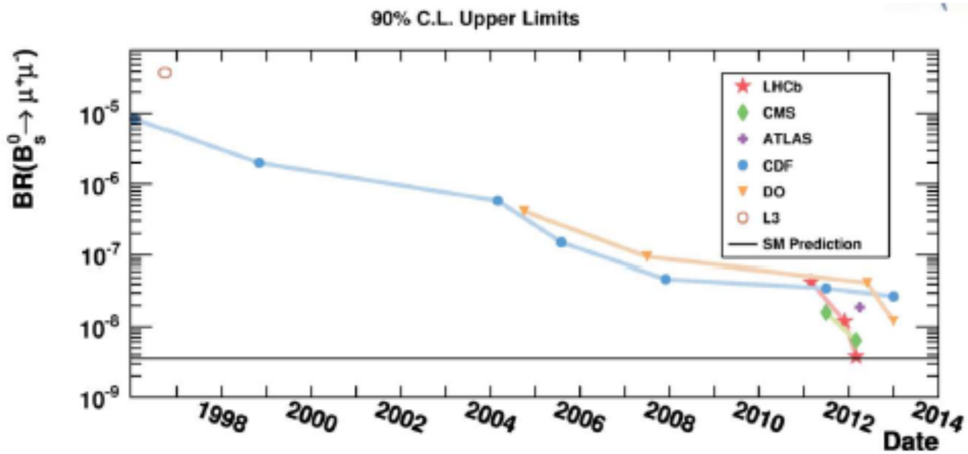
LHCb: Phys Rev Lett 110 (2013) 021801 (2.1 fb^{-1})

CMS: J. High Energy Phys 04 (2012) 033 (5.0 fb^{-1})

ATLAS: ATLAS-CONF-2013-076 (5.0 fb^{-1})

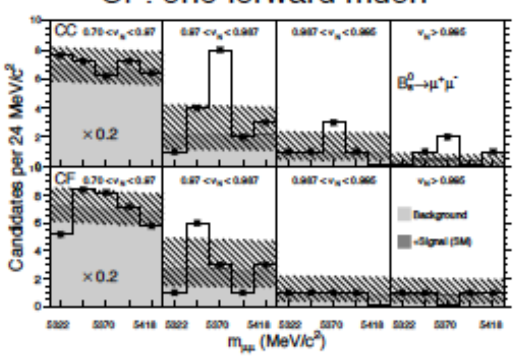
CDF: Phys. Rev. D 87, 072003 (2013) (9.7 fb^{-1})

D0: Phys. Rev. D87 07.2006 (2013) (10.4 fb^{-1})



CC: two central muons

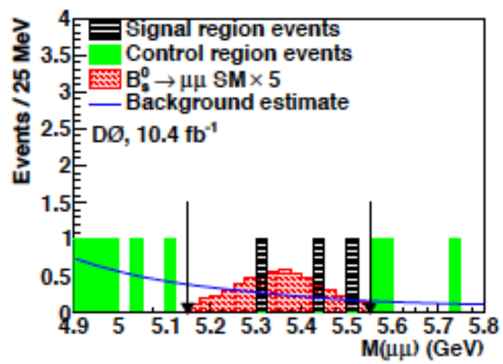
CF: one forward muon



95% CL:

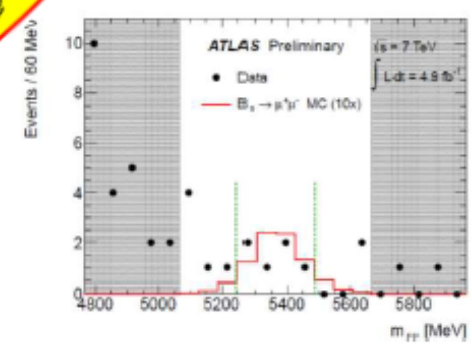
BR($B_s \to \mu^+\mu^-$) < 3.1 × 10^{-8}

new @ EPS2013



95% CL:

BR($B_s \to \mu^+\mu^-$) < 1.5 × 10^{-8}



95% CL:

BR($B_s \to \mu^+\mu^-$) < 1.5 × 10^{-8}

Updated Results

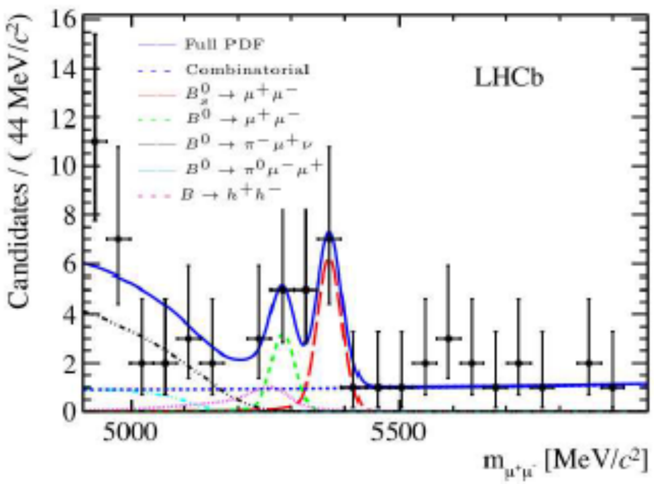
- $2.1 \rightarrow 3.0\ \text{fb}^{-1}$
- more variables in BDT

- $5.0 \rightarrow 25\ \text{fb}^{-1}$
- cut base selection $\rightarrow$ BDT
- new & improved variables (PID)

expected sensitivity: $3.7 \rightarrow 5.0\ \sigma$

new @ EPS2013

arXiv:1307.5024



$\text{BR}(B_s \rightarrow \mu^+\mu^-) = (2.9\ ^{+1.1}_{-1.0}(\text{stat})\ ^{+0.3}_{-0.1}(\text{syst})) \times 10^{-9}$

$\rightarrow 4\ \sigma$

$\text{BR}(B^0 \rightarrow \mu^+\mu^-) < 7.4 \times 10^{-10}$ at 95% CL

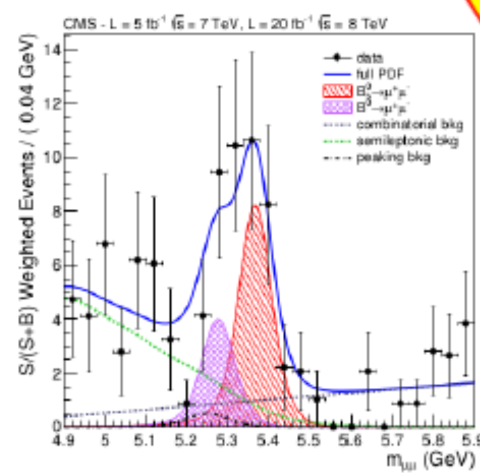
$\text{BR}(B^0 \rightarrow \mu^+\mu^-) = (3.7\ ^{+2.4}_{-2.1}(\text{stat})\ ^{+0.6}_{-0.4}(\text{syst})) \times 10^{-10}$

$\rightarrow 2.0\ \sigma$

expected sensitivity: $4.8\ \sigma$

new @ EPS2013

arXiv:1307.5025



$\text{BR}(B_s \rightarrow \mu^+\mu^-) = 3.0\ ^{+1.0}_{-0.9} \times 10^{-9}$

$\rightarrow 4.3\ \sigma$

$\text{BR}(B^0 \rightarrow \mu^+\mu^-) < 1.1 \times 10^{-9}$ at 95% CL

$\text{BR}(B^0 \rightarrow \mu^+\mu^-) = 3.5\ ^{+2.1}_{-1.8} \times 10^{-10}$

$\rightarrow 2.0\ \sigma$

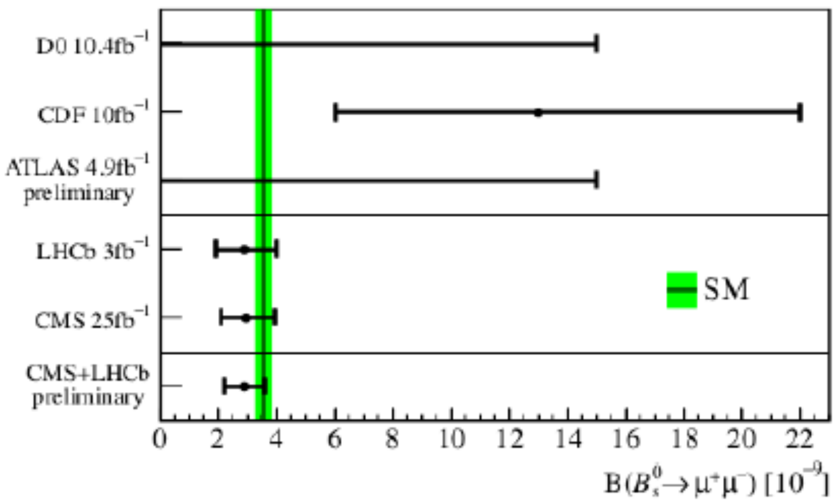
Combined LHCb + CMS Result

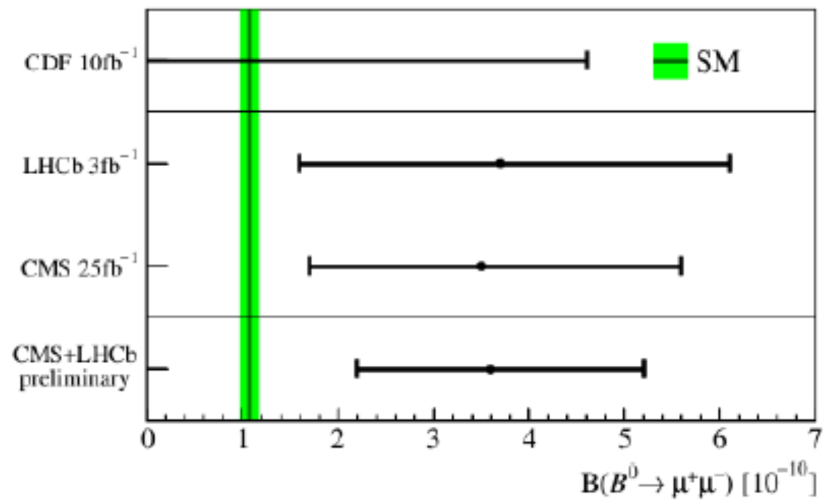
new @ EPS2013

Observation:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

$$\mathrm{BR}(B^0 \to \mu^+\mu^-) = 3.6^{+1.6}_{-1.4} \times 10^{-10}$$

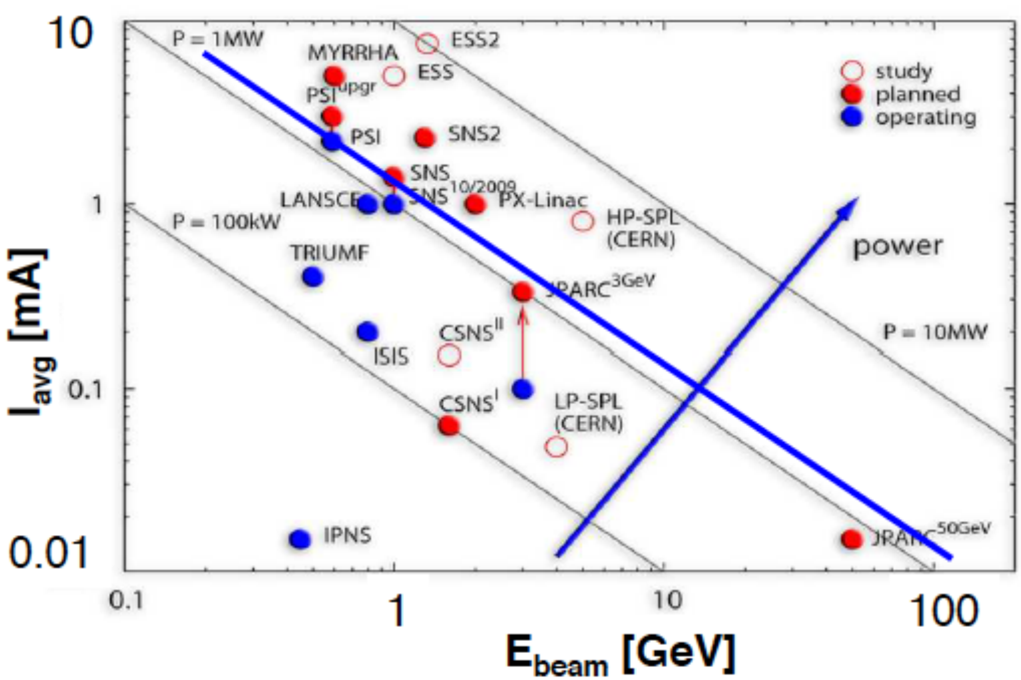


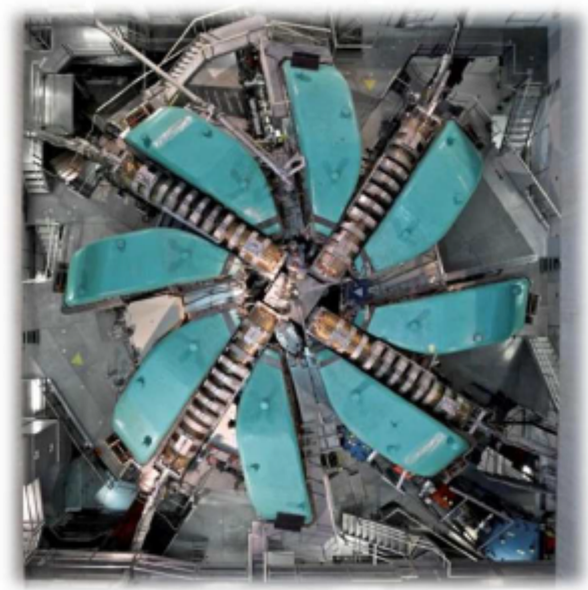


LHCb-CONF-2013-012, CMS-PAS-BPH-13-007

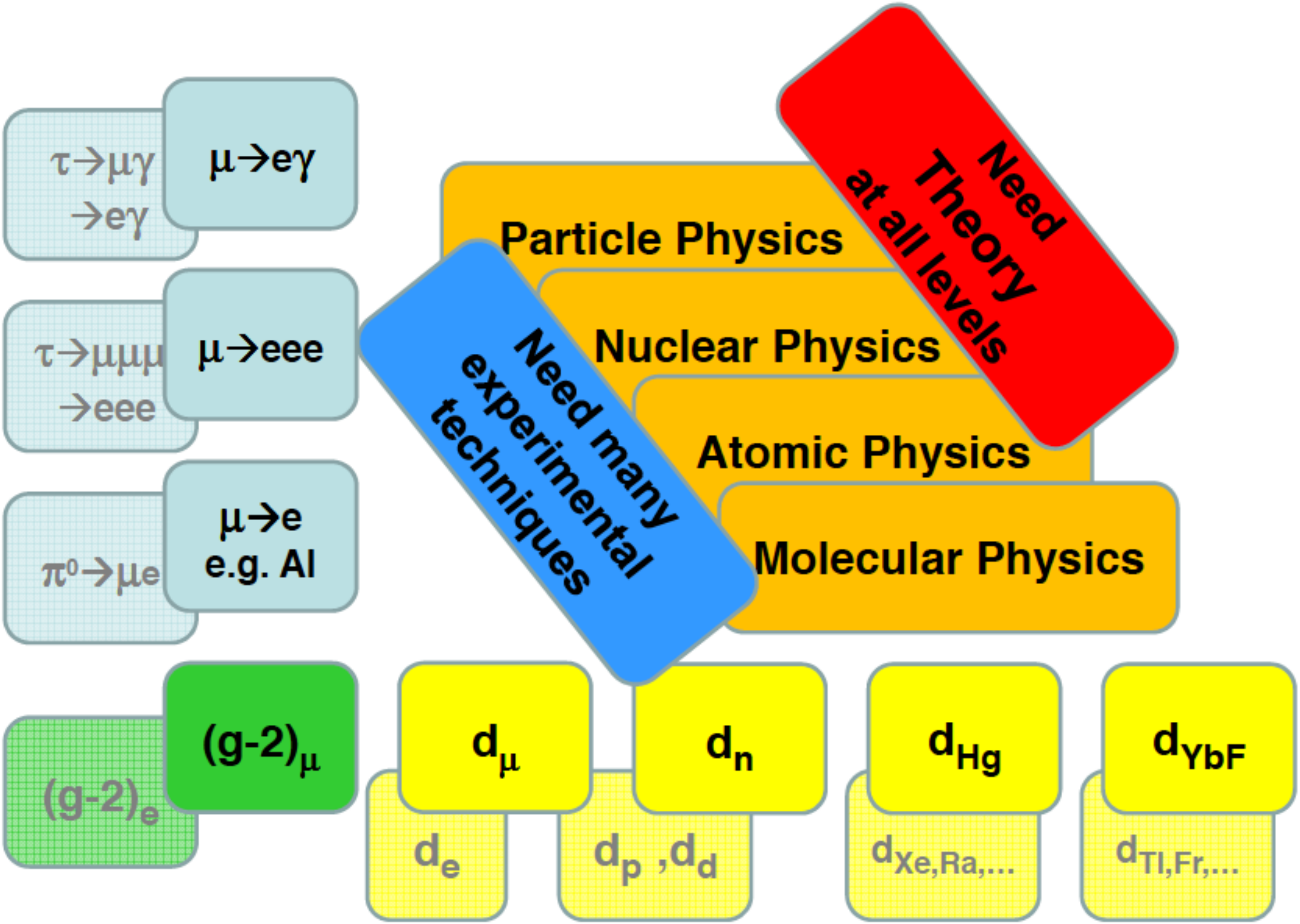
Charged Lepton Flavor and Dipole Moments

K.Kirch, ETH Zurich – PSI Villigen, CH





The 1.4 MW ring cyclotron at PSI


τ→μγ
→eγ
μ→eγ
τ→μμμ
→eee
μ→eee
π⁰→μe
μ→e
e.g. Al
(g-2)e
(g-2)μ
Particle Physics
Nuclear Physics
Atomic Physics
Molecular Physics
Need Theory at all levels
Need many experimental techniques
dμ
de
dn
dp ,dd
dHg
dXe,Ra,...
dYbF
dTl,Fr,...

cLFV Searches: Current Situation

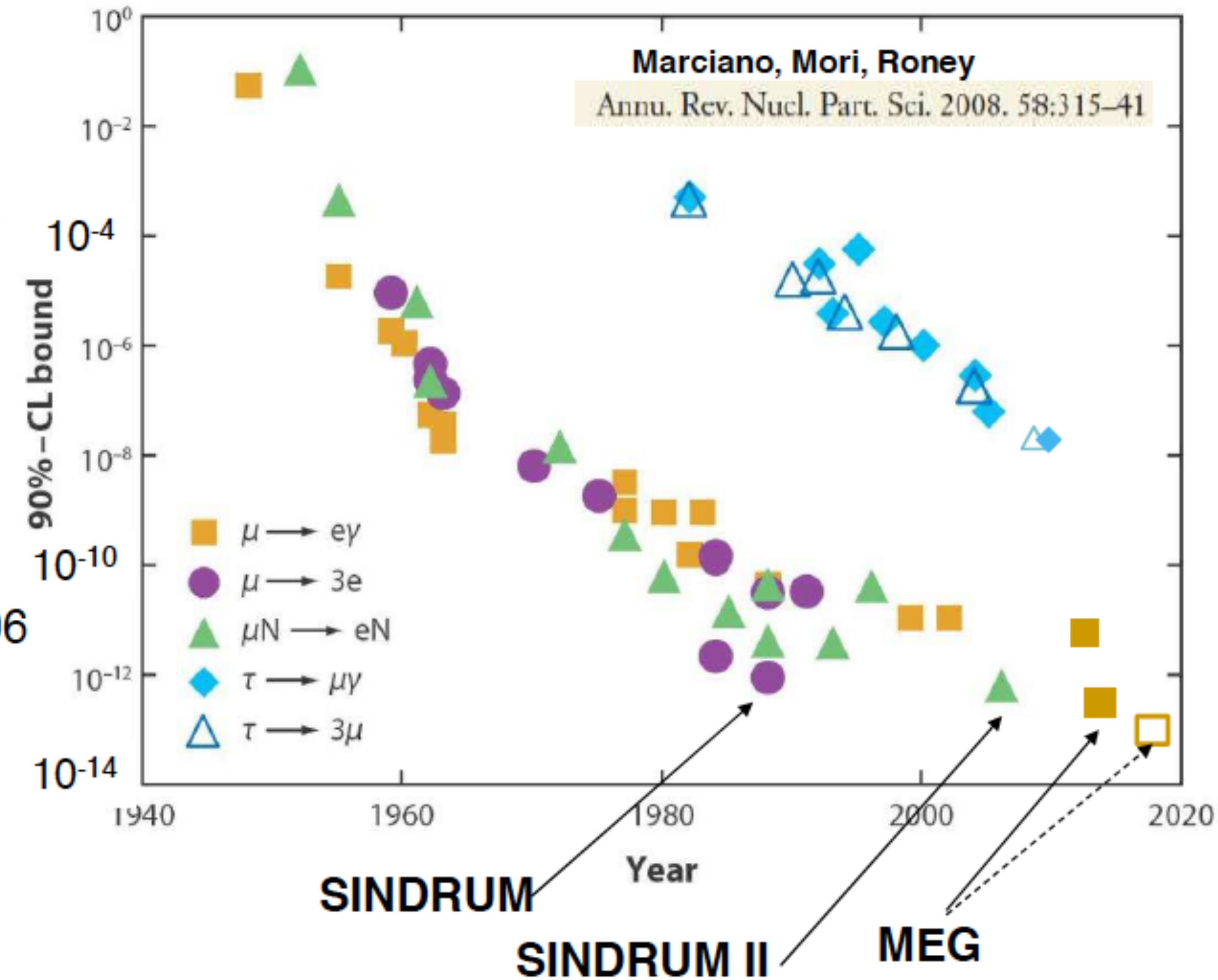
The present best limits on LFV come from PSI muon experiments

$\mu^+ \rightarrow e^+ee$
BR $< 1 \times 10^{-12}$
SINDRUM 1988

$\mu^- + Au \rightarrow e^- + Au$
BR $< 7 \times 10^{-13}$
SINDRUM II 2006

$\mu^+ \rightarrow e^+ + \gamma$
BR $< 5.7 \times 10^{-13}$
MEG 2013

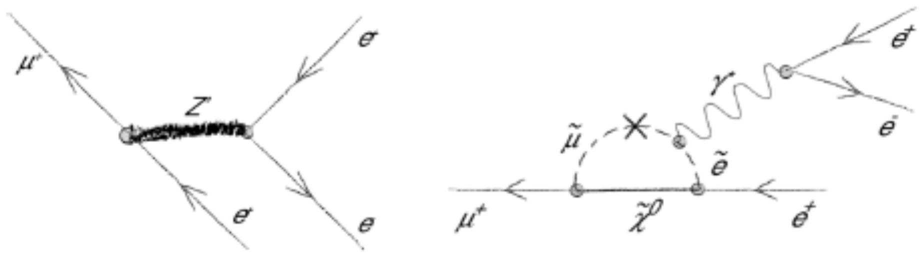
[90 % C.L.]

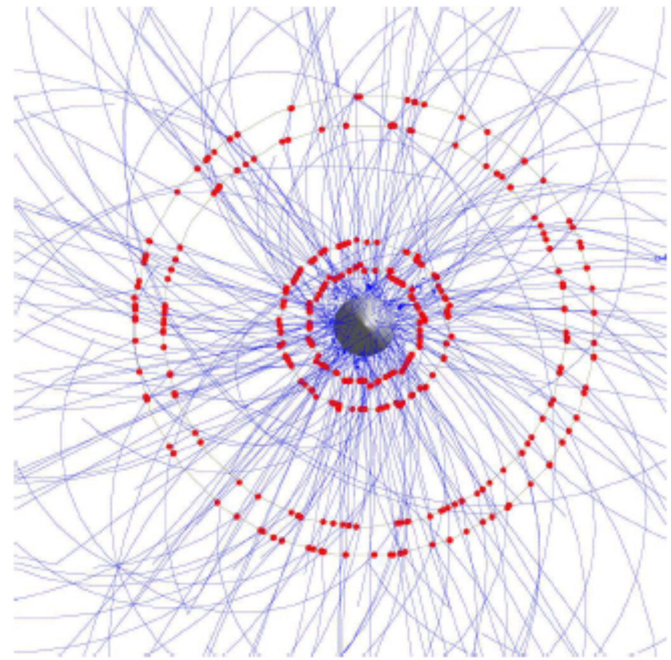


Mu3e Experiment at PSI

Experiment:

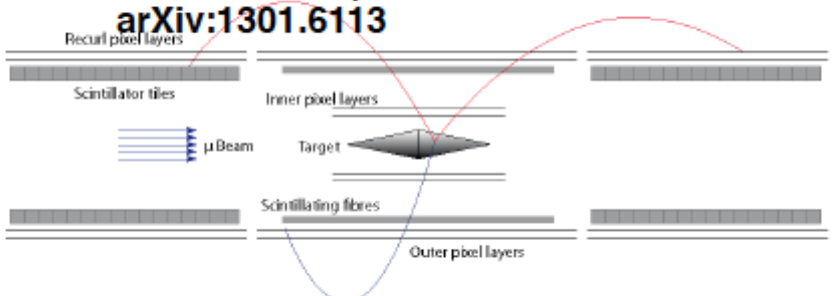
- Search for LFV decay: $\mu \rightarrow eee$
- Single event sensitivity better than 10^{-16}
- Muon rate $>10^9$ per second
- 100 electron tracks within 50ns





all silicon HV-MAPS silicon detector

Research Proposal:
arXiv:1301.6113

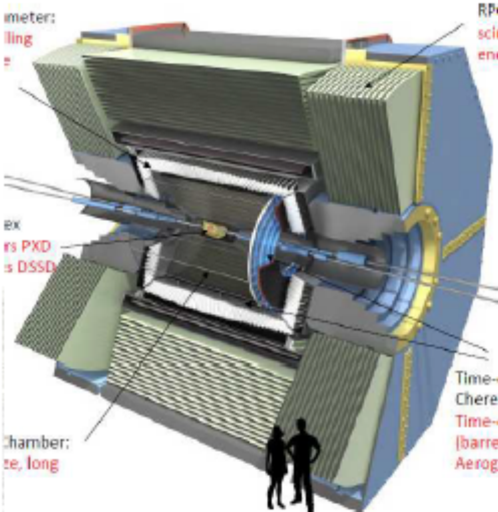


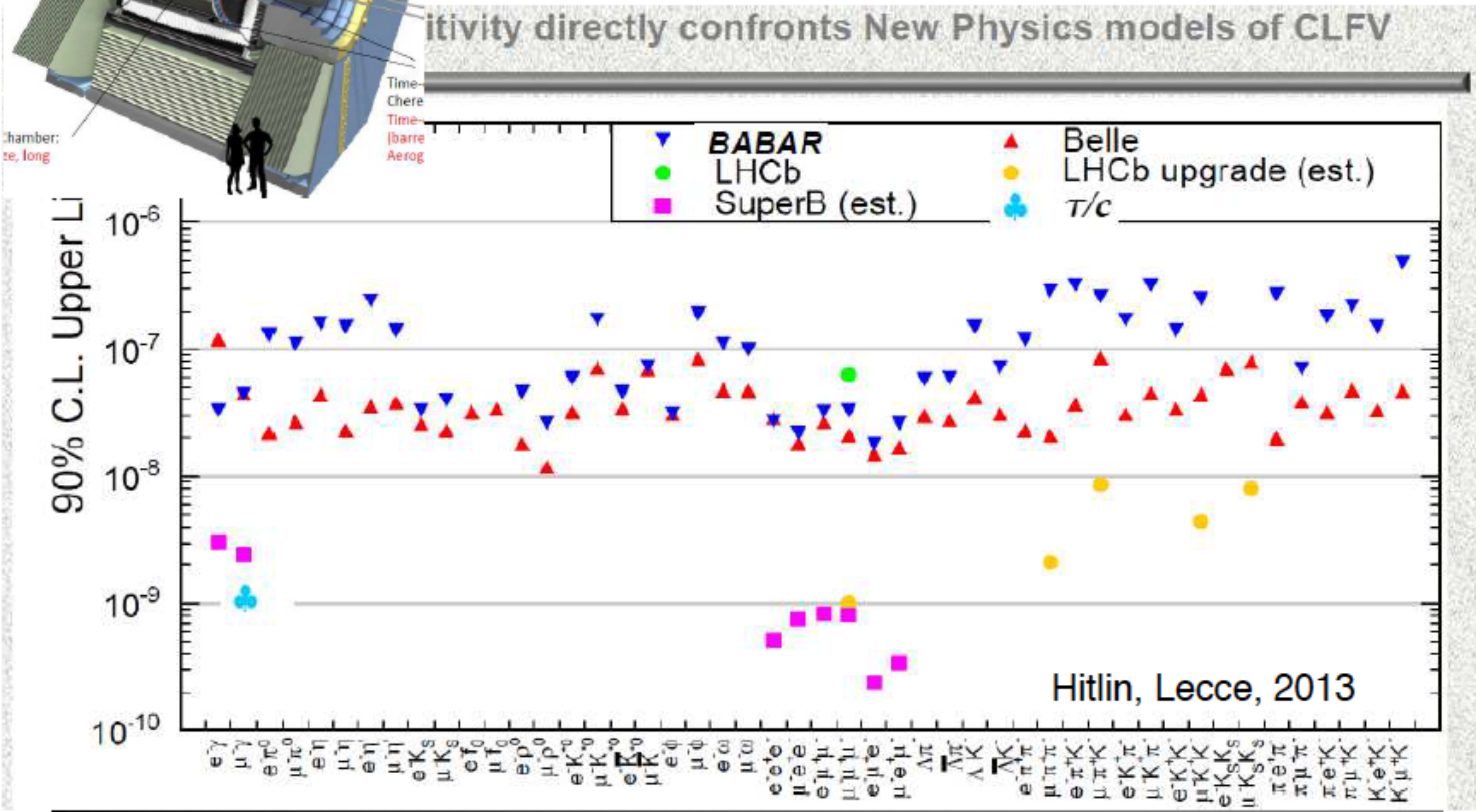
Courtesy: A. Schoening

Detector Requirements:

- good momentum resolution (B=1 T)
- good vertex resolution (→ accidentals)
- good timing resolution (→ accidentals)

Belle-II and LHCb upgrade





Rough estimate of numbers of researchers, in total ~500 (with some overlap)

Neutrons ~200

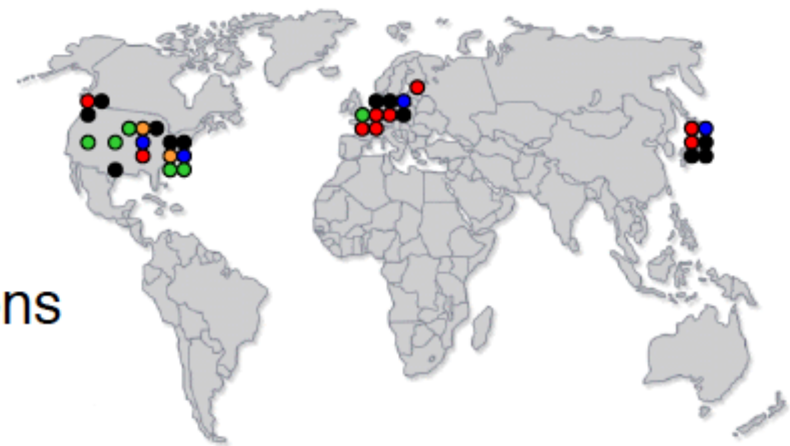
- @ILL
- @ILL, @PNPI
- @PSI
- @FRM-2
- @RCNP, @TRIUMF
- @SNS
- @J-PARC

Molecules ~50

- YbF@Imperial
- PbO@Yale
- ThO@Harvard
- HfF+@JILA
- WC@UMich
- PbF@Oklahoma

Atoms ~100

- Hg@UWash
- Xe@Princeton
- Xe@TokyoTech
- Xe@TUM
- Xe@Mainz
- Cs@Penn
- Cs@Texas
- Fr@RCNP/CYRIC
- Rn@TRIUMF
- Ra@ANL
- Ra@KVI
- Yb@Kyoto



Ions-Muons ~200

- @BNL
- @FZJ
- @FNAL
- @JPARC

Solids ~10

- GGG@Indiana
- ferroelectrics@Yale

Direct Detection of WIMPs: Principle

- Elastic collisions with nuclei in ultra-low background detectors
- Energy of recoiling nucleus: *few keV to tens of keV*

Astrophysics

$$\frac{dR}{dE_R} = N_N \frac{\rho_0}{m_W} \int_{v_{\min}}^{v_{\max}} d\mathbf{v}\, f(\mathbf{v})\, v \,\frac{d\sigma}{dE_R}$$

Particle physics

$$v_{\min} = \sqrt{\frac{m_N E_{th}}{2 m_{\mathrm{r}}^2}}$$

N_N = number of target nuclei in a detector

ρ_0 = local density of the dark matter in the Milky Way

$f(v)$ = WIMP velocity distribution in lab frame

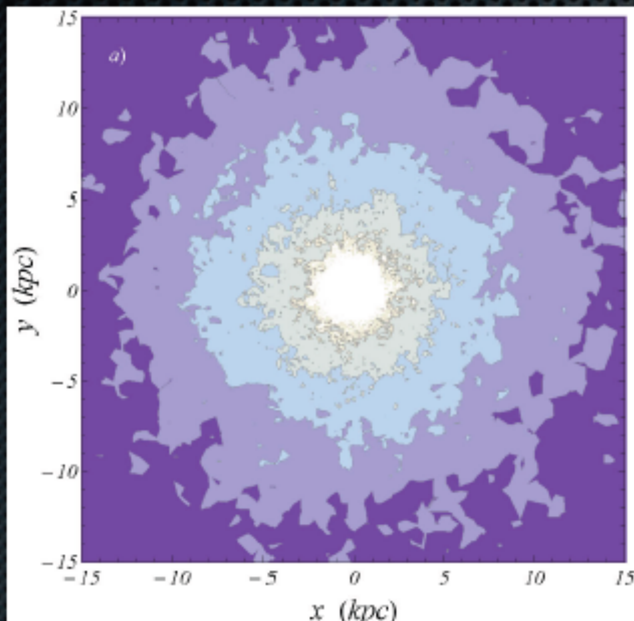
m_W = WIMP-mass

σ =cross section for WIMP-nucleus elastic scattering

L. Baudis

Astrophysics

Density map of the dark matter halo
rho = [0.1, 0.3, 1.0, 3.0] GeV cm^{-3}

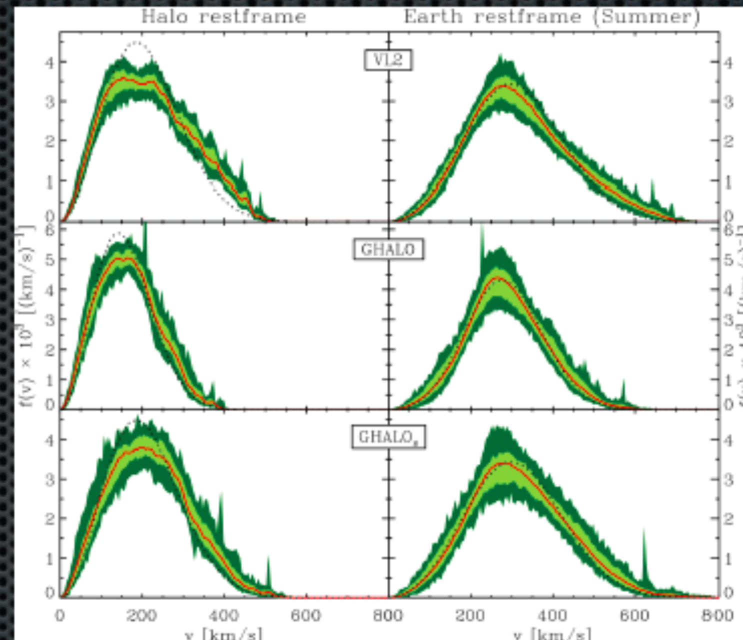


High-resolution cosmological simulation with baryons: F.S. Ling et al, JCAP02 (2010) 012

$$\rho_{halo} \sim 0.3\,\mathrm{GeV}\cdot\mathrm{cm}^{-3}$$

=> WIMP flux on Earth:
~10^5 $cm^{-2}s^{-1}$ (M_W=100 GeV)

Velocity distribution of WIMPs in the galaxy



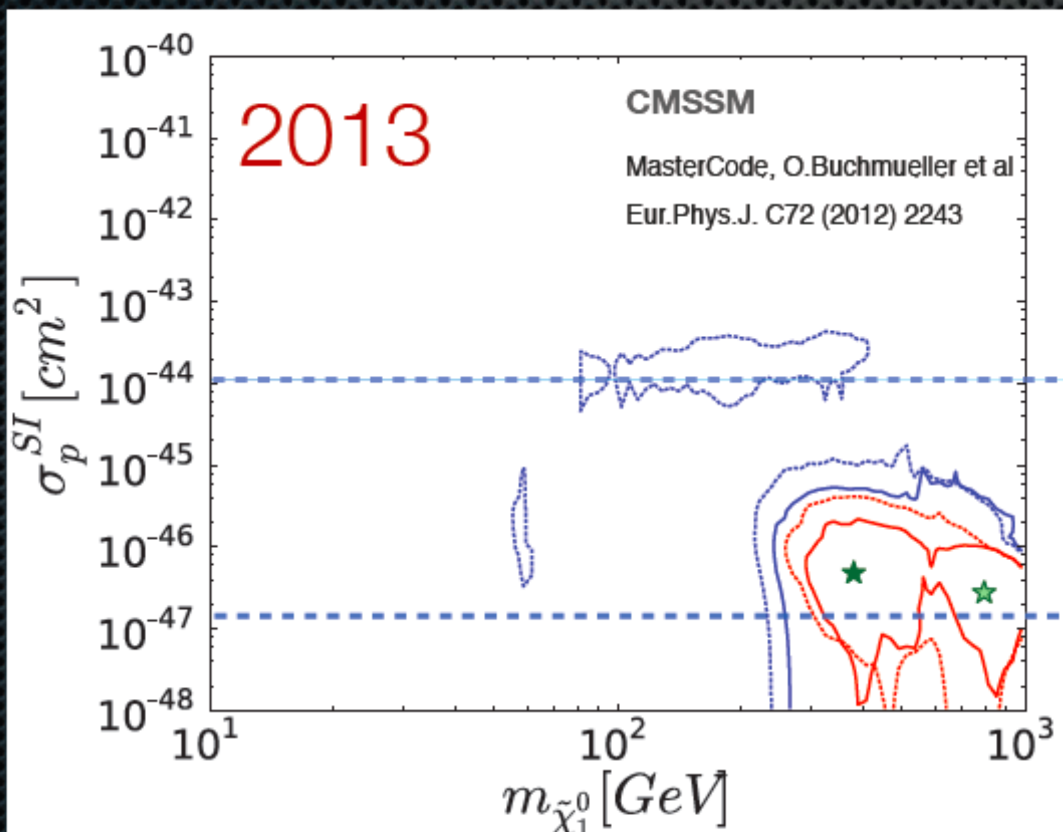
Halo restframe Earth restframe

M. Kuhlen et al, JCAP02 (2010) 030

- From cosmological simulations of galaxy formation: departures from the simplest case of a Maxwell-Boltzmann distribution
- However, a simple MB distribution is a good approximation, and yields conservative results

Particle physics

- SUSY: scattering cross sections on nucleons down to ~ 10^{-48} cm^2(10^{-12} pb)
- Here example in CMSSM, after LHC 5/fb, XENON100 and Bs->μμ

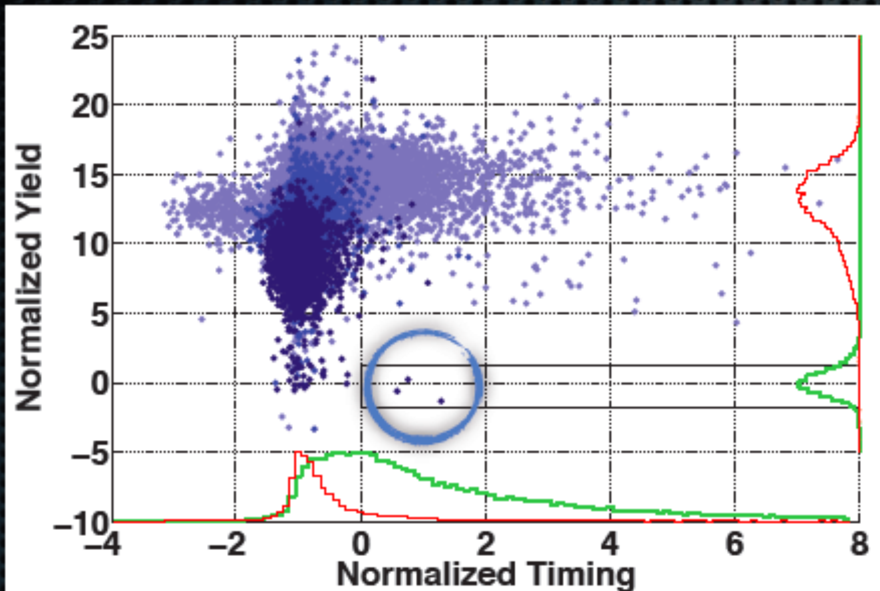


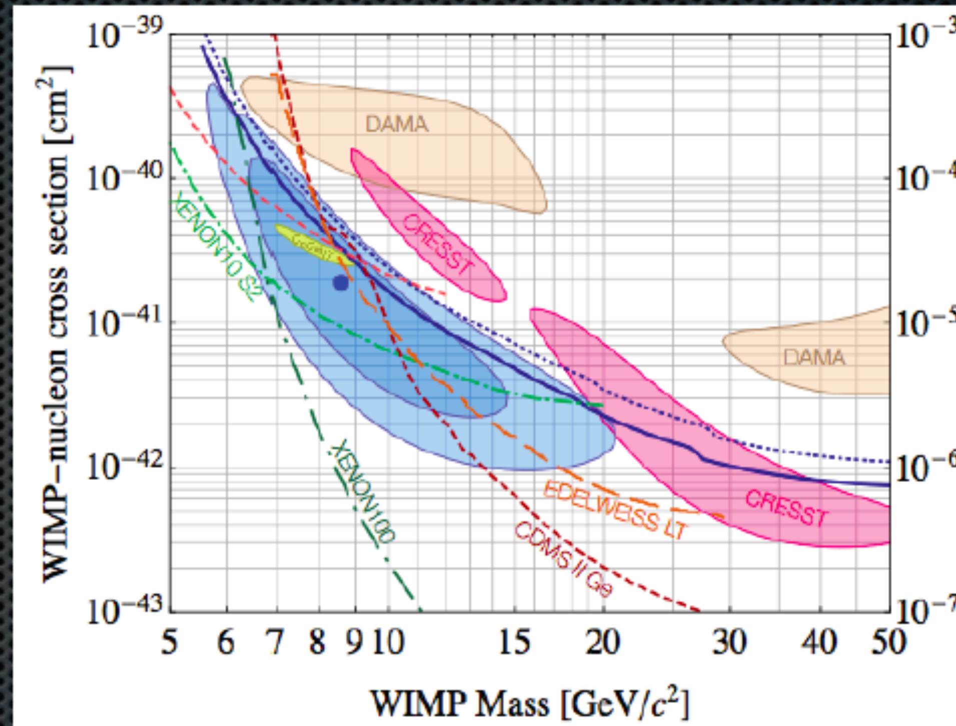
L. Baudis

The world wide wimp search

New results from CDMS-Si

arXiv:1304.4279v2 [hep-ex] 4 May 2013





140 kg d exposure

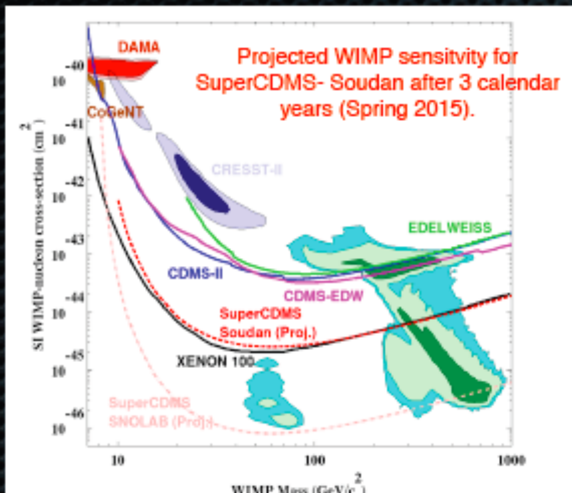
3 events detected, 0.7 expected

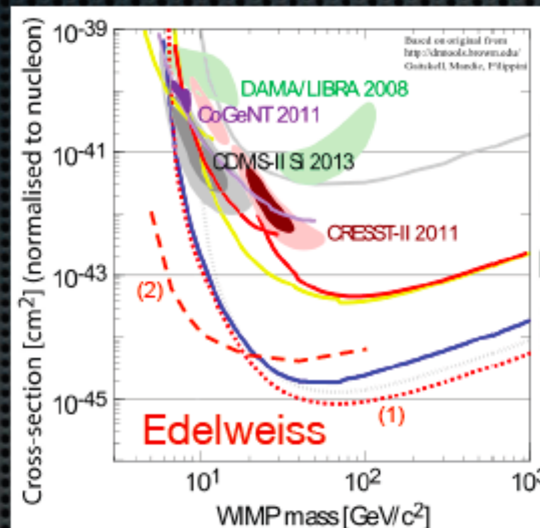
likelihood analysis: 0.19% probability for known background-only hypothesis

best fit: 8.6 GeV, 1.9 x 10^{-42} cm2

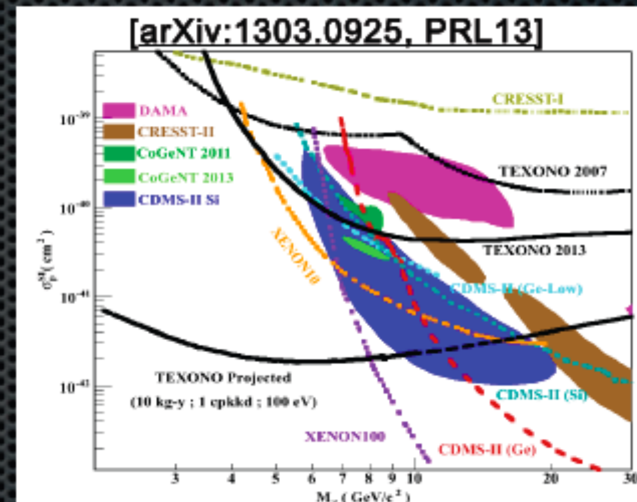
Analysis ongoing of low-threshold run (CDMS-lite) at Soudan with one Ge detector

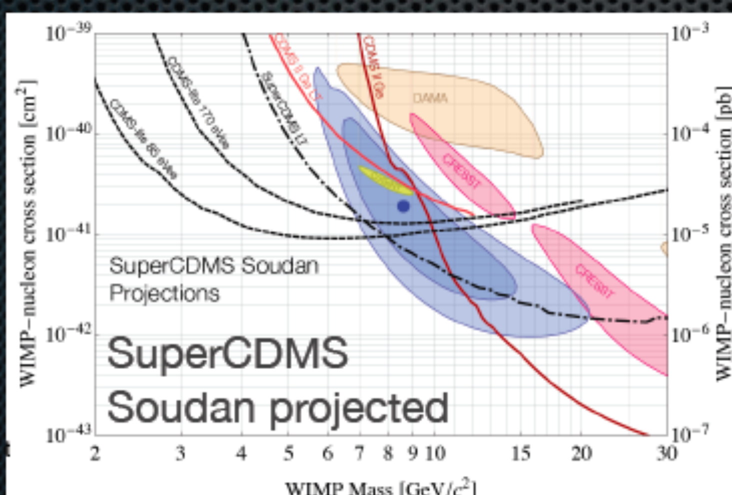
Projections: Cryogenic Experiments

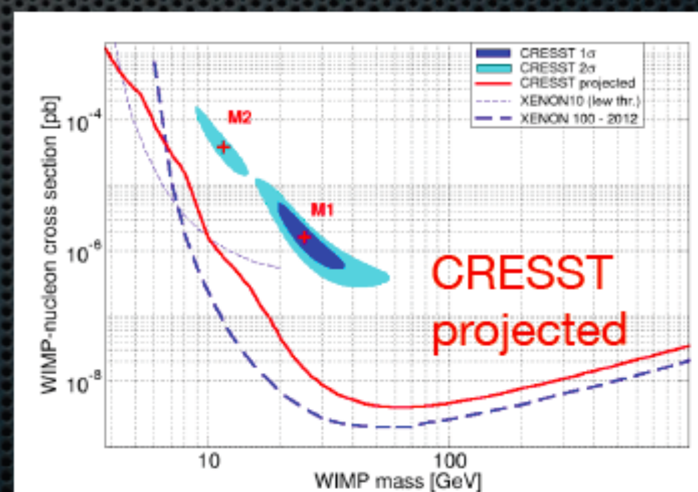




Texono: 1 kg Ge, E_{th}=500 eV

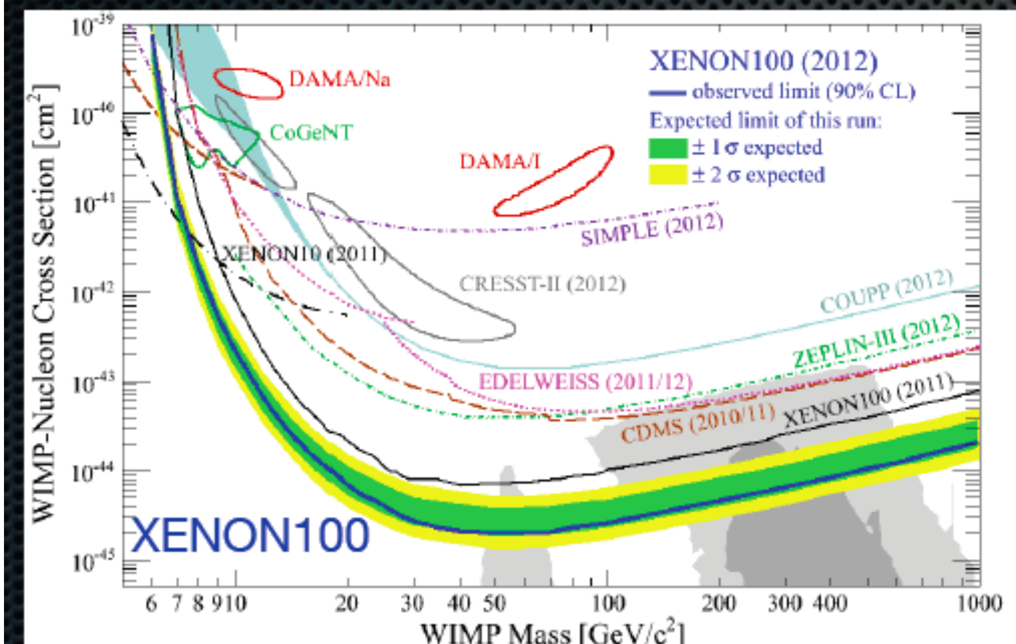




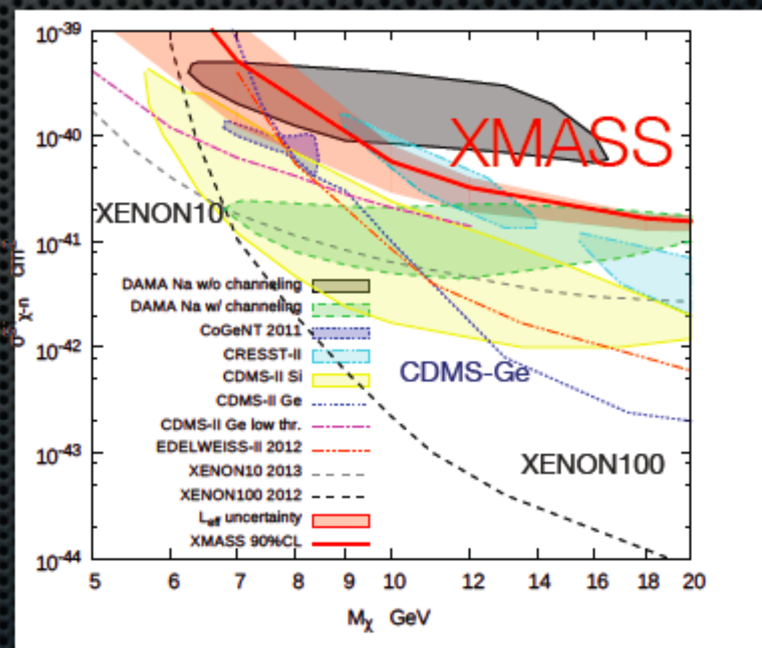


Noble liquid recent results: spin-independent cross section

XENON100: Phys. Rev. Lett. 109 (2012)

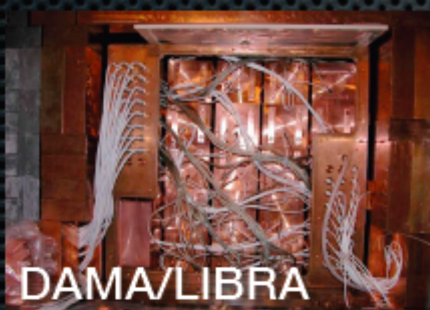


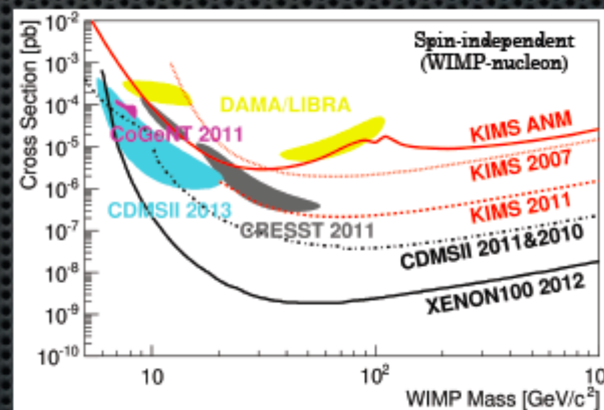
XMASS: Phys. Lett. B 719 (2013)

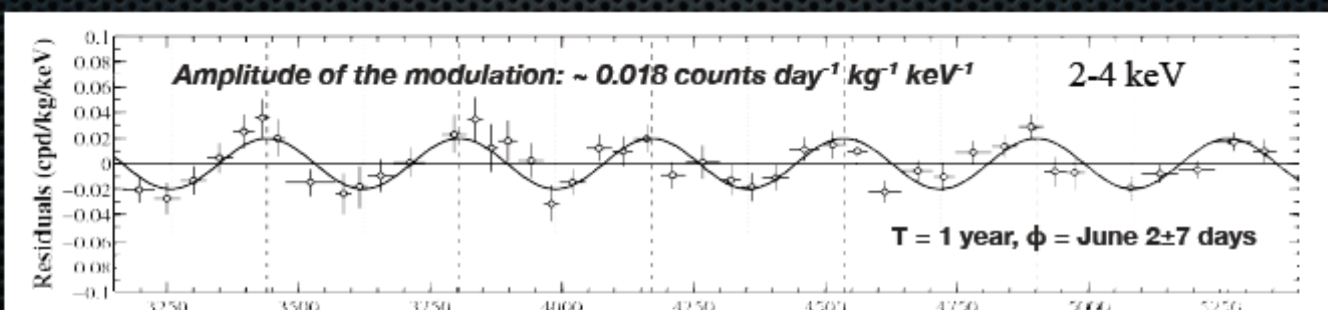


Room temperature scintillators

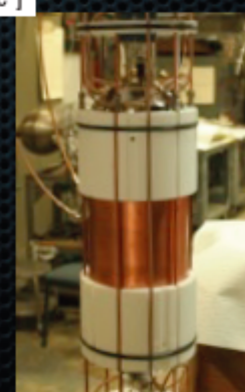
- **NaI**: DAMA/LIBRA 250 kg at LNGS; time variation in the event rate with: T = 1 yr, phase = June 2±7 days, A = 0.018 events/(kg keV day)
- **CsI**: KIMS 103.4 kg at Yangyang laboratory; ER vs. NR discrimination based on time structure of events; does not confirm DAMA/LIBRA in an annual modulation search
- **NaI**: ANAIS, 250 kg, under construction at LSC; DM-Ice, proposed 250 kg at the South Pole





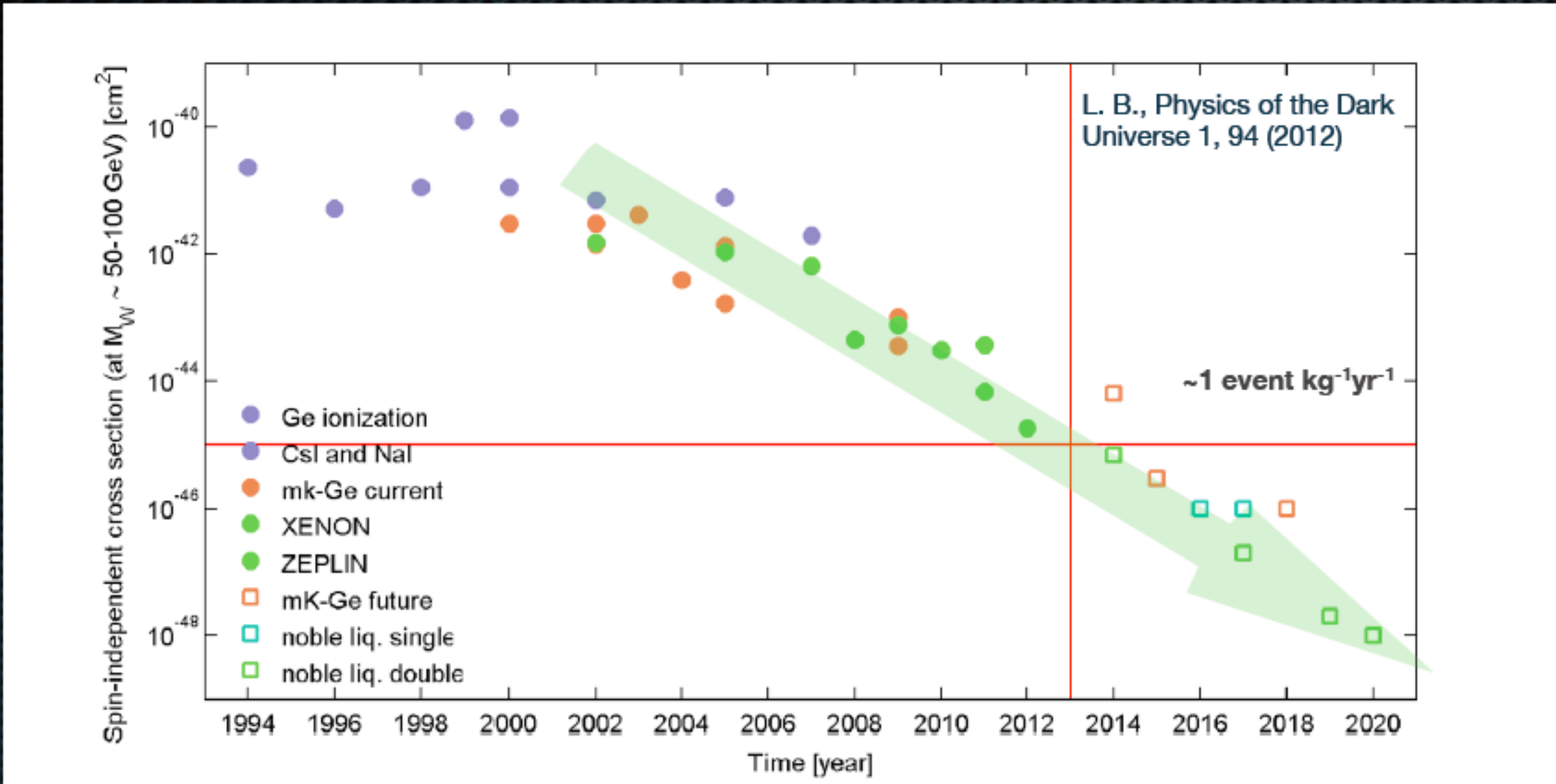


R.Bernabei et al, Eur.Phys.J. C67



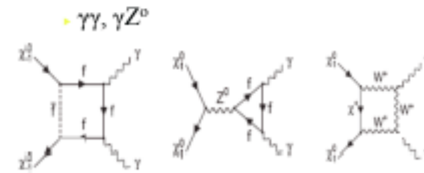
DM-Ice
17 kg NaI as feasibility study within IceCube 2.4 km deap

WIMP search evolution in time



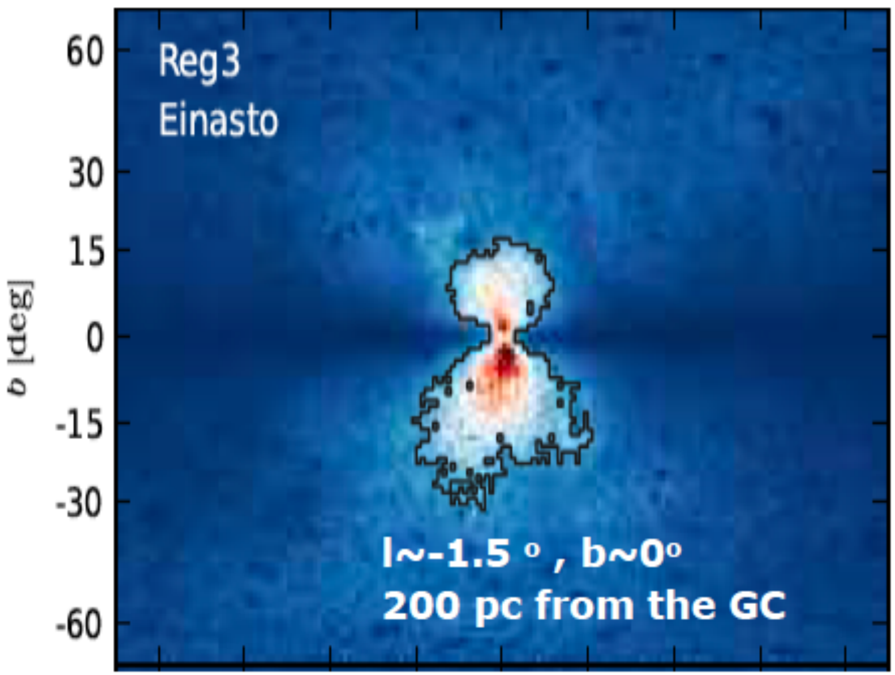
About a factor of 10 every 2 years!
Can we keep this rate of progress?

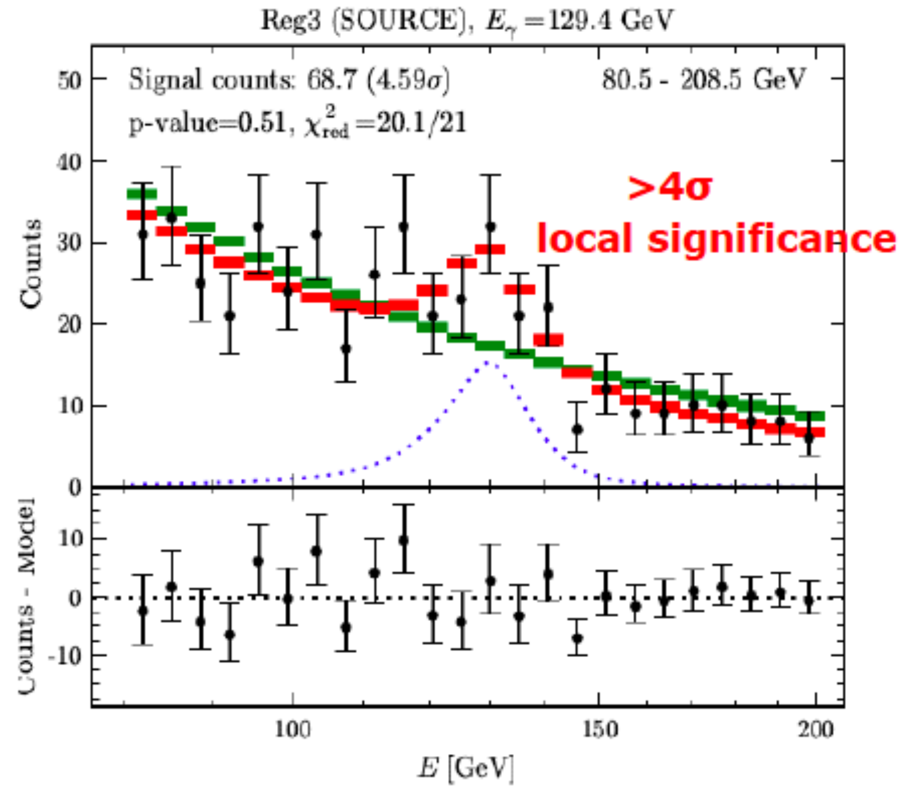
γ-ray lines Fermi LAT data



43 Months of Fermi public data

T.Bringmann et al [arXiv:1203.1312] C. Weniger arXiv:1204.2797v2





Target region : reg3 surrounding the Galactic center

Optimizing s/b in the energy 1-20 GeV , for variety DM profiles

If Dark Matter=> Br(γγ)≈3-4%

$$\chi\chi \rightarrow \gamma\gamma(\gamma Z) : M_\chi = 130(144)\ GeV$$

$$< \sigma v >= 1.3(3.1)\ 10^{-27} cm^3 s^{-1}$$

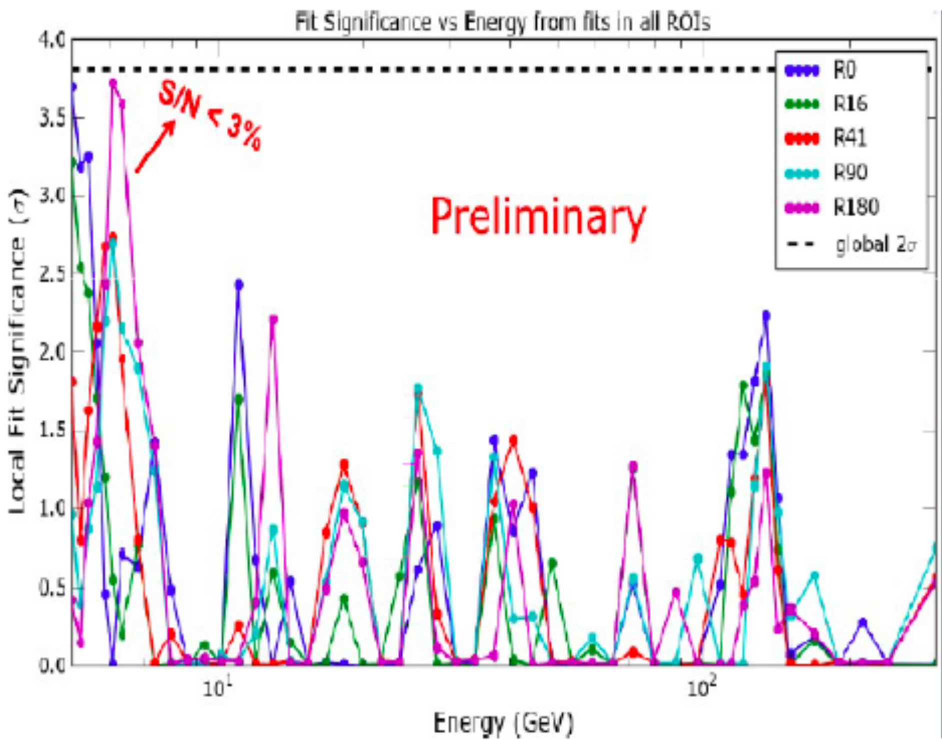
γ-ray lines - Fermi LAT ou slide suivant

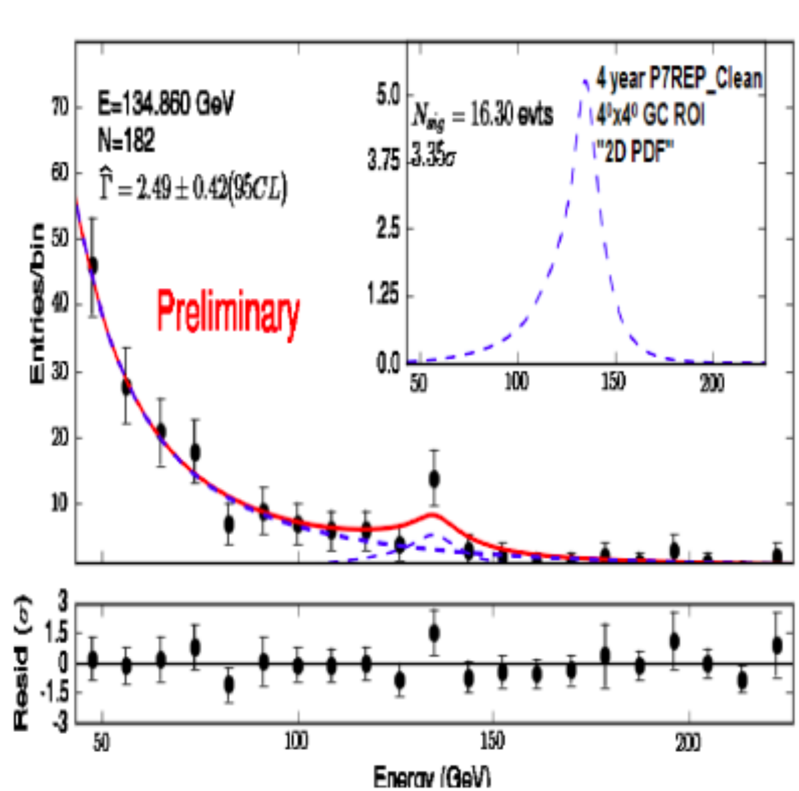
Fermi LAT, 4 years
- **new processing,**
- **new Regions of Interests (including Galactic Plane)**

No significant line structure found

Fermi LAT, 4 years
- **new processing, new analysis**
- **In the Galactic Center (4°×4°)**

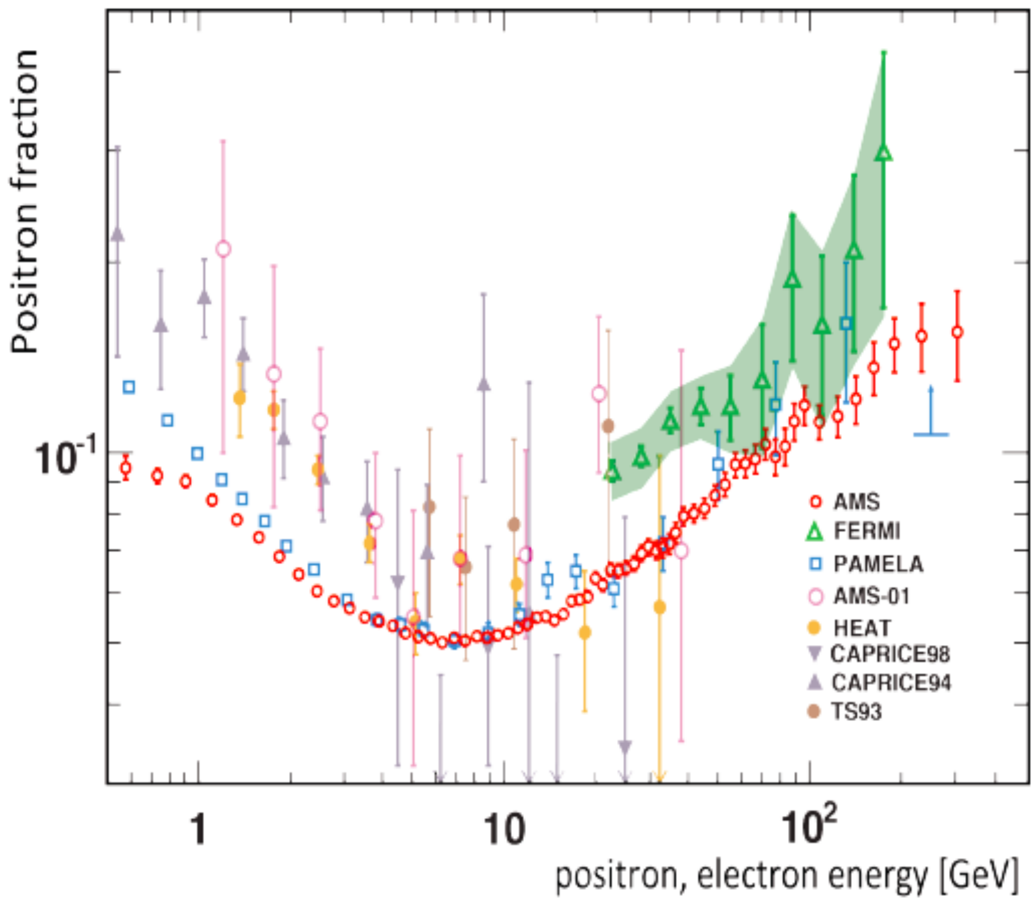
Line-like feature near 135 GeV (3.35 σ)

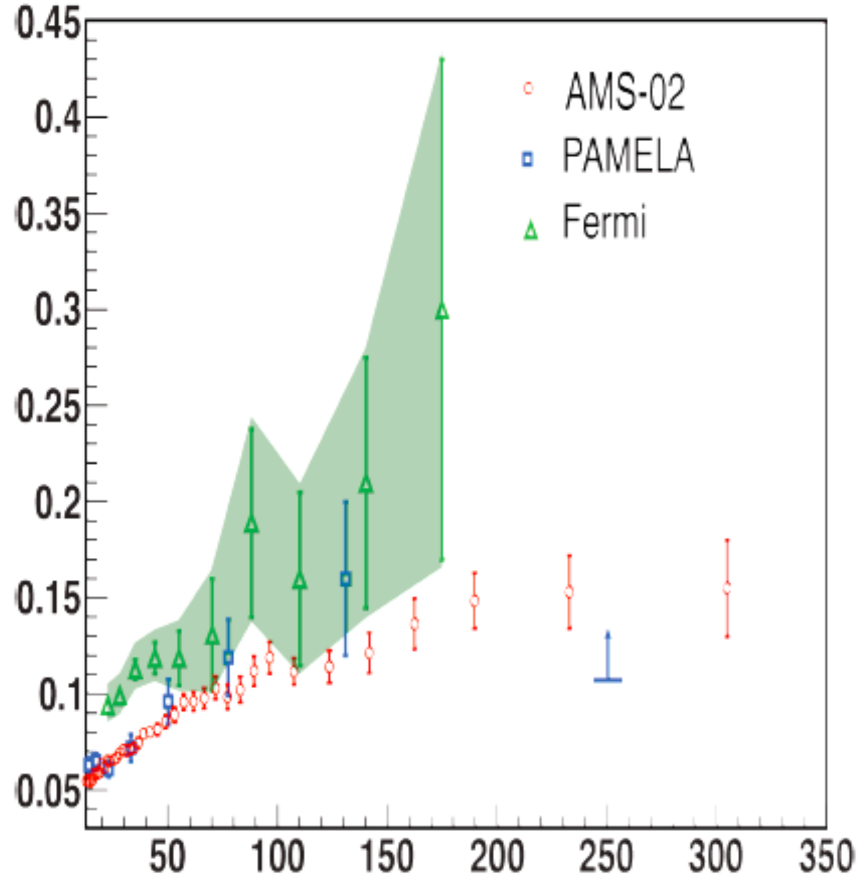




=> systematics studies on going (limb earth control)
A publication expected in one year

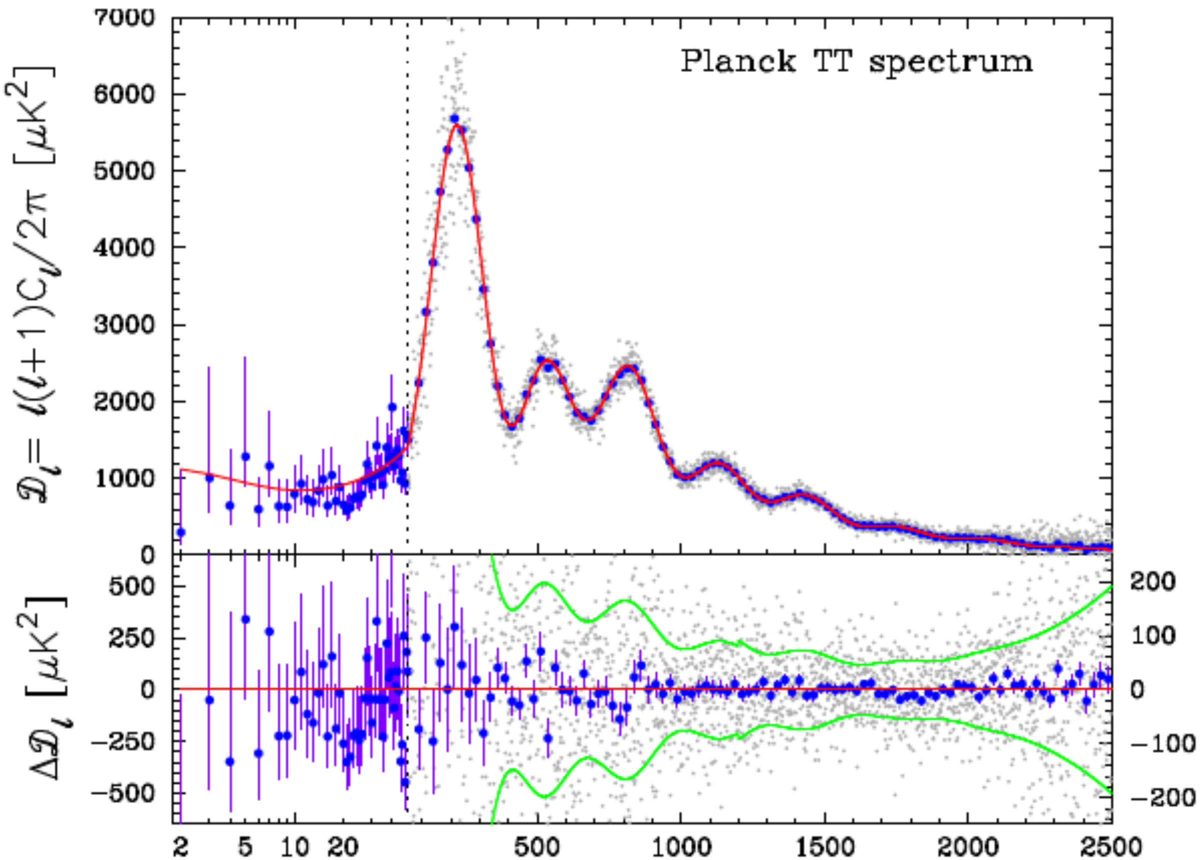
Positron fraction : measurement comparison





->e± Energy [GeV]

CMB power spectrum (Planck 2013)

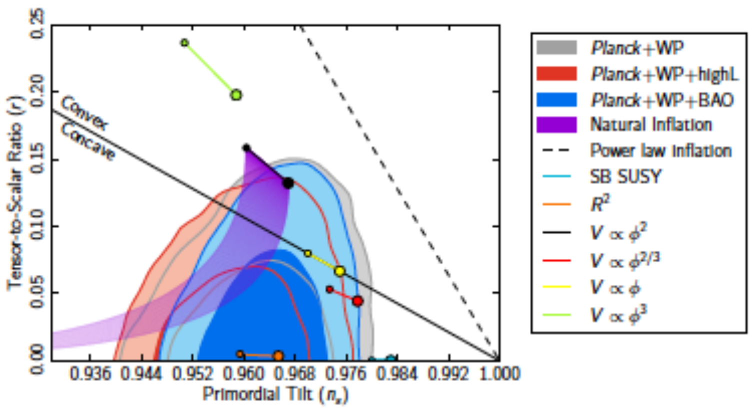


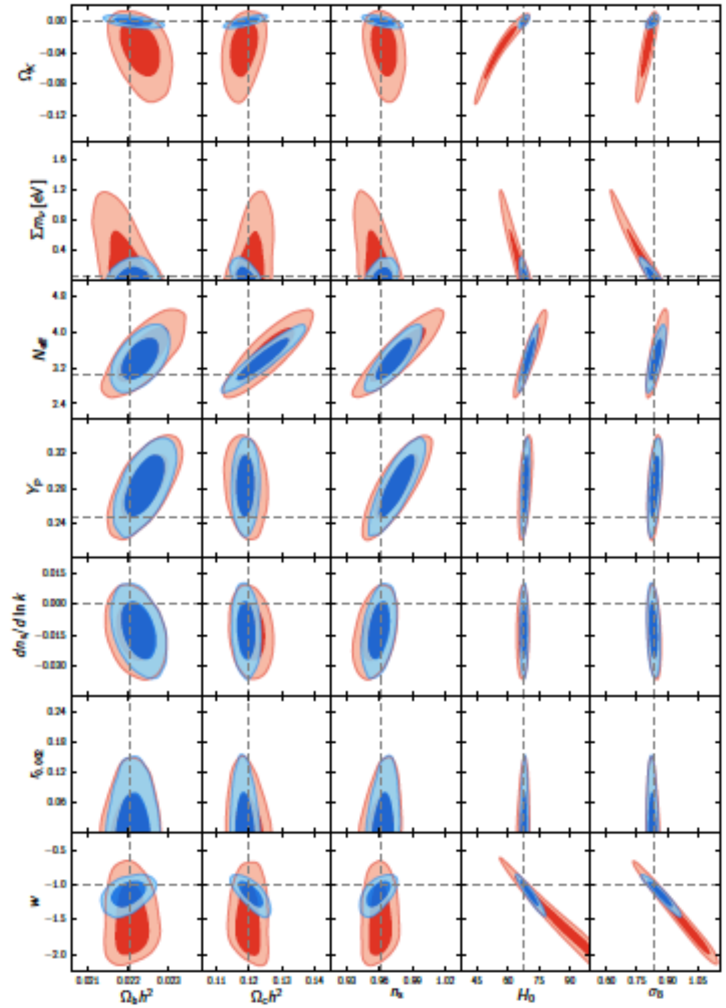
output of Planck likelihood - foregrounds subtracted

Hybrid method : map based ML (low ℓ) / pseudo-spectra (high ℓ) of masked raw maps

Summary of cosmology as measured using CMB + BAO

- The 6 parameter ΛCDM is a good fit !
- lower H_0 , larger Ω_m
- Flat universe : $100\Omega_K = -0.1 \pm 0.6$ (95% c.l.)
- $N_{eff} = 3.36 \pm 0.34$; $\Sigma m_\nu < 0.66$ (95
- dark energy : $w = -1.13 \pm 0.24$ (95% c.l.), compatible with Λ
- good agreement with BBN
- large angular scale $\sim 2\sigma$ “anomaly”
- $n_s = 0.96$ at more than 5σ, no evidence for running, limit on tensor modes





Planck 2013 results. XVI. (parameters) & XXII. (inflation constraints) - and others !

hot in the press !

Detection of B-mode Polarization in the Cosmic Microwave Background with Data from the South Pole Telescope

D. Hanson,[1] S. Hoover,[2,3] A. Crites,[2,4] P. A. R. Ade,[5] K. A. Aird,[6] J. E. Austermann,[7] J. A. Beall,[8] A. N. Bender,[1] B. A. Benson,[2,3] L. E. Bleem,[2,9] J. J. Bock,[10,11] J. E. Carlstrom,[2,3,4,9,12] C. L. Chang,[12,2,3] H. C. Chiang,[2,13] H-M. Cho,[8,7] A. Conley,[7] T. M. Crawford,[2,4] T. de Haan,[1] M. A. Dobbs,[1] W. Everett,[7] J. Gallicchio,[2] J. Gao,[8] E. M. George,[14] N. W. Halverson,[7,15] N. Harrington,[14] J. W. Henning,[7] G. C. Hilton,[8] G. P. Holder,[1] W. L. Holzapfel,[14] J. D. Hrubes,[6] N. Huang,[14] J. Hubmayr,[8] K. D. Irwin,[8] R. Keisler,[2,9] L. Knox,[16] A. T. Lee,[14] E. Leitch,[2,4] D. Li,[8] C. Liang,[2,4] D. Luong-Van,[2] G. Marsden,[17] J. J. McMahon,[18] J. Mehl,[2,12] S. S. Meyer,[2,9,3,4] L. Mocanu,[2,4] T. E. Montroy,[19] T. Natoli,[2,9] J. P. Nibarger,[8] V. Novosad,[20] S. Padin,[10] C. Pryke,[21] C. L. Reichardt,[14] J. E. Ruhl,[19] B. R. Saliwanchik,[19] J. T. Sayre,[19] K. K. Schaffer,[2,22] B. Schulz,[10,23] G. Smecher,[1] A. A. Stark,[24] K. Story,[2,9] C. Tucker,[5] K. Vanderlinde,[1,25,26] J. D. Vieira,[10] M. P. Viero,[10] G. Wang,[12] V. Yefremenko,[12,20] O. Zahn,[27] and M. Zemcov[10,11]

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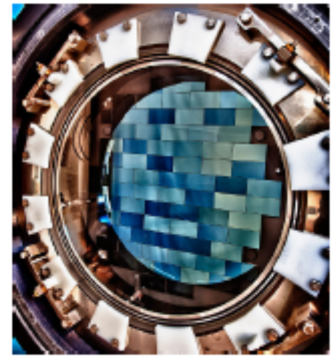
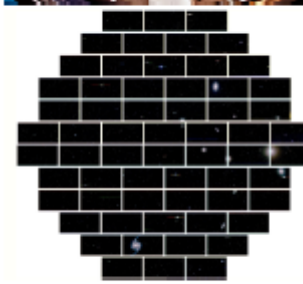
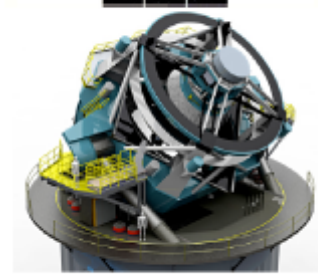
[10]*California Institute of Technology, Pasadena, CA, USA 91125*
[11]*Jet Propulsion Laboratory, Pasadena, CA, USA 91109*
[12]*High Energy Physics Division, Argonne National Laboratory, Argonne, IL, USA 60439*
[13]*School of Mathematics, Statistics & Computer Science, University of KwaZulu-Natal, Durban, South Africa*
[14]*Department of Physics, University of California, Berkeley, CA, USA 94720*

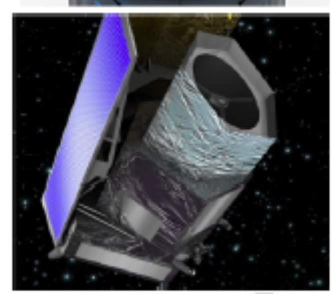
Paths for the future (I) : Wide field boulevard

- main motivation : dark energy properties
- wide field instruments needed to seach for rare events (SN), observe many objects (imagery : weak lensing, LSS/$P(k)$), spectro. : BAO)
- several on-going projects : KIDS (lensing,10xCFHTLens), BOSS,...
- starting : DES (3 deg^2 camera @@ 4m CTIO tel., 5000 deg^2 for weak lensing & LSS, SN), ...
- eBOSS/ MS-Desi (2014-2018 ?) : SDSS-IV BOSS-like spectrograph (same telescope or KPNO 4m)
- further up the road :
  - LSST : 8m telescope, camera with 3.5 deg fov (3.10^9pix read in 2s) camera ; SN, weak-lensing, BAO (photo-z)
  - Euclid : ESA space mission, visible imager + near-IR imager+spectro ; weak-lensing & LSS/BAO



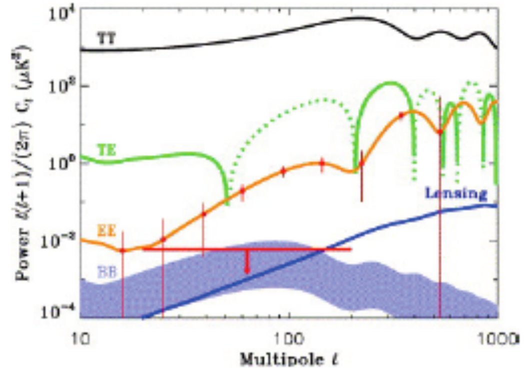


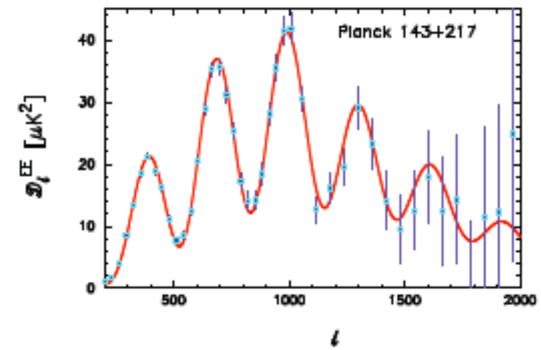


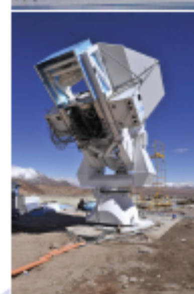


Paths for the future (II) : B modes avenue

- CMB polarization : E & B modes
- B modes generated by primordial GW (inflation probe !)
- challenging : very low amplitude, large angular scale (foregrounds)
- many projects on-going or coming soon :
  - space : Planck 2014 !
  - ground : QUIET, BICEP (1,2,3), Keck array, SPTpol, ACTpol, POLARBEAR, QUBIC, groundBird, ...
  - balloons : EBEX, SPIDER, PIPER, ...
  - intense detector & techniques R&D
  - longer term future : space missions (PIXIE (NASA), LiteBird (JAXA), CORE/PRISM (ESA))

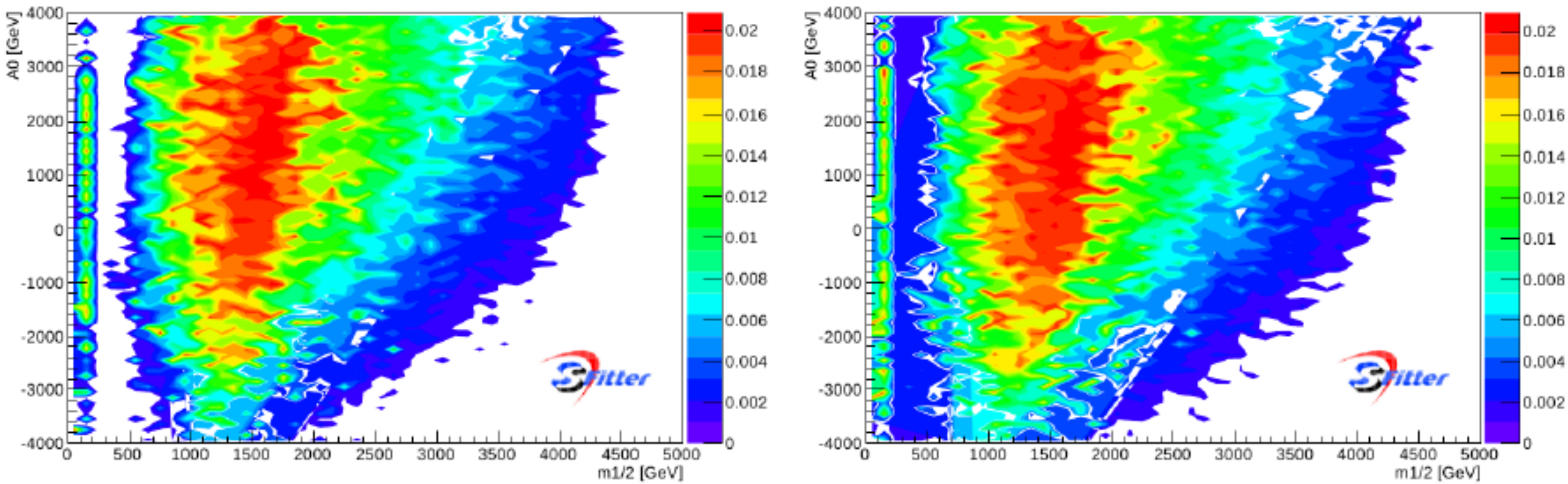






.. and many crossroads !

PRELIMINARY constraints on MSSM/MSugra parameters using : LHC data, Planck (left) / WMAP (right) Ω_m measurements & direct searches (Xenon100)

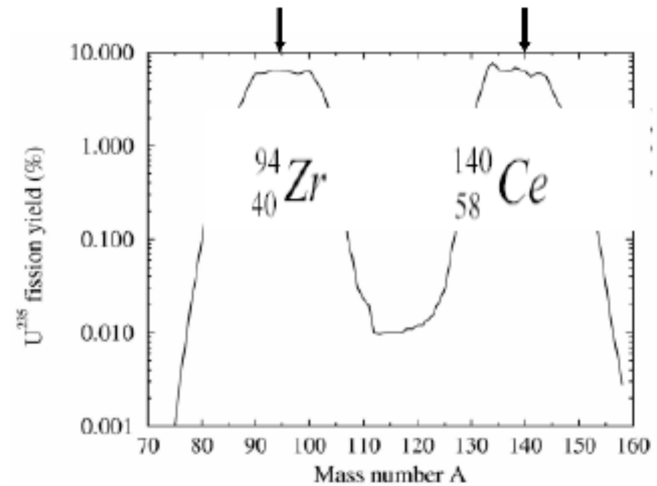


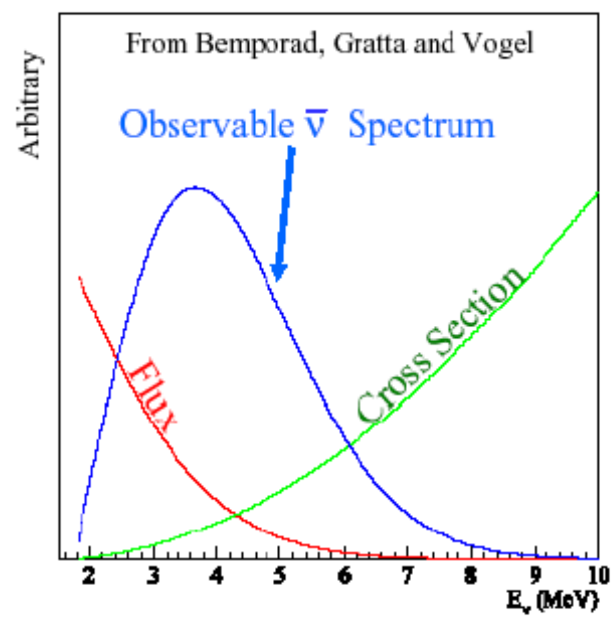
S. Henrot-Versillé & SFitter team, in preparation

Reactor neutrinos

- **Direct detection of neutrinos(50's)**
- **Oscillation:**
  - ⇨ **Early searches(70's-90's):**
    - ✓ Reines, ILL, Bugey, … Palo Verde, Chooz
  - ⇨ **Determination of θ_{12}(90's-00's):**
    - ✓ KamLAND
  - ⇨ **Discovery of θ_{13} (00's-10's): :**
    - ✓ Daya Bay, Double Chooz, RENO
- **Magnetic moments(90's-00's):**
  - ⇨ Texono, MUNU,…
- **Mass hierarchy(10's-20's):**
  - ⇨ JUNO, RENO-50
- **Sterile neutrinos(10's):**
  - ⇨ Nucifer, Stereo, Solid …

$${}^{235}_{92}U + n \rightarrow X_1 + X_2 + 2n$$

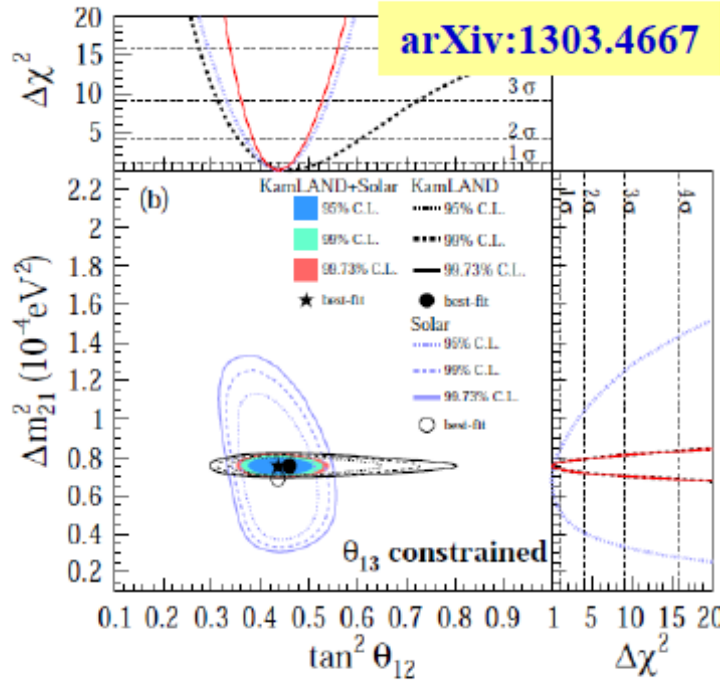


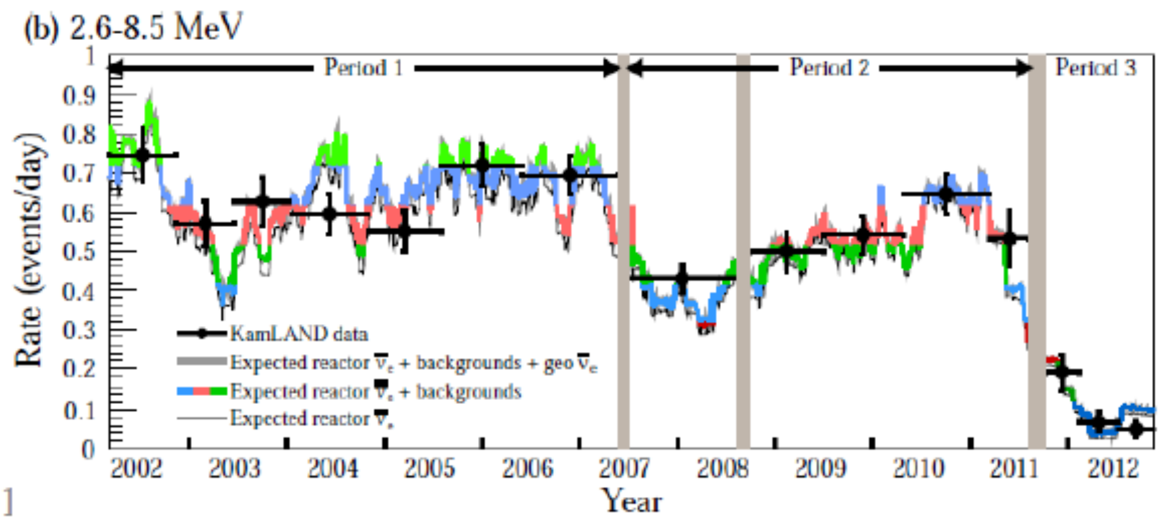


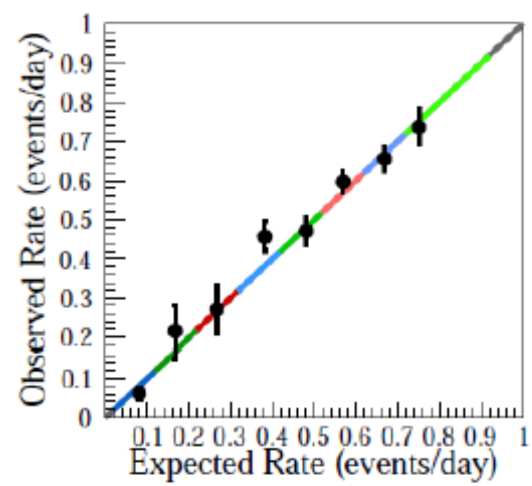
Latest KamLAND Results: θ_{12} & ΔM^2_{12}

- **Reactors are all off in Japan since Mar. 2011:**
  - ⇨ A unique opportunity for precise measurement of backgrounds

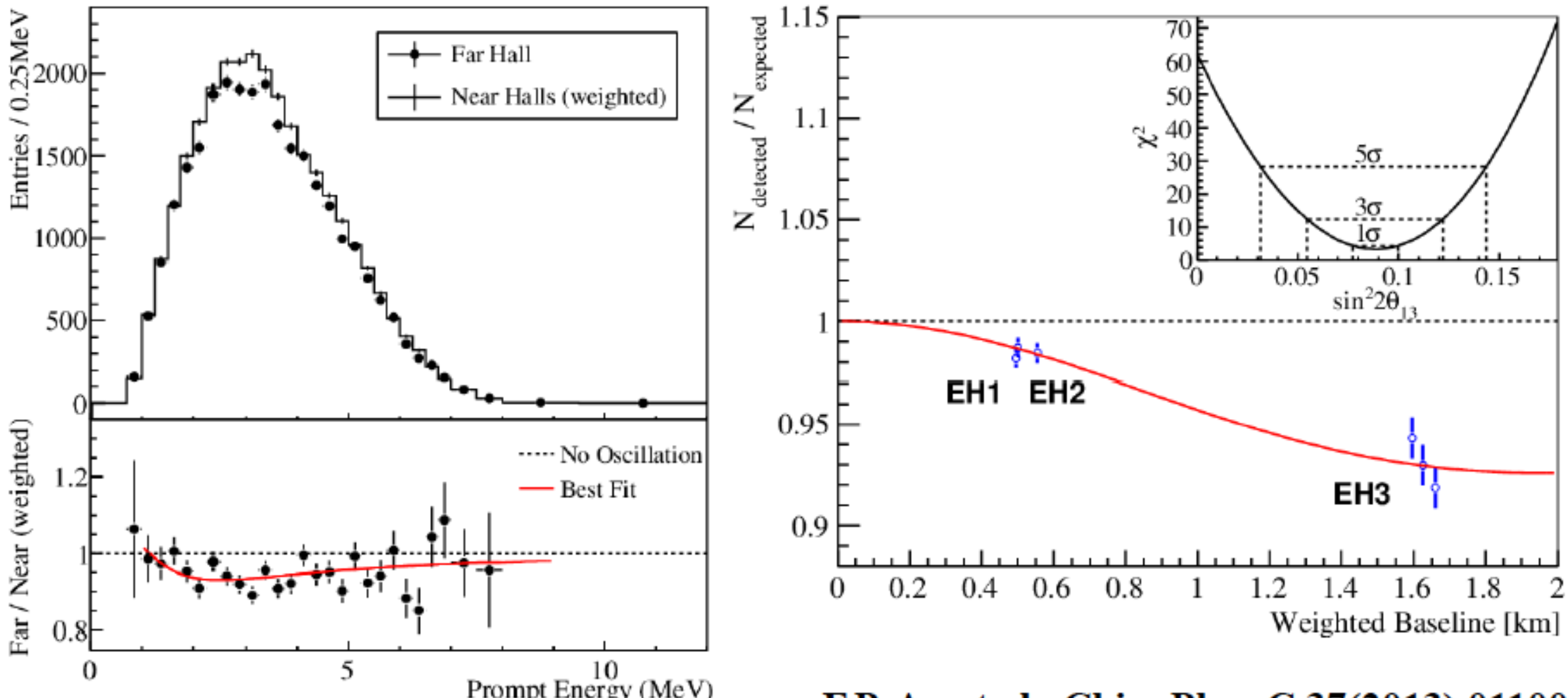
Data combination	Δm^2_{21}	$\tan^2\theta_{12}$	$\sin^2\theta_{13}$
KamLAND	$7.54^{+0.19}_{-0.18}$	$0.481^{+0.092}_{-0.080}$	$0.010^{+0.033}_{-0.034}$
KamLAND + solar	$7.53^{+0.19}_{-0.18}$	$0.437^{+0.029}_{-0.026}$	$0.023^{+0.015}_{-0.015}$
KamLAND + solar + θ_{13}	$7.53^{+0.18}_{-0.18}$	$0.436^{+0.029}_{-0.025}$	$0.023^{+0.002}_{-0.002}$







Daya Bay： Results(C)



F.P. An et al., Chin. Phys.C 37(2013) 011001

R = 0.944 ±0.007 (stat) ±0.003 (syst)

$\sin^2 2\theta_{13} = 0.089 \pm 0.010(stat) \pm 0.005(syst)$

χ^2/NDF = 3.4/4, 7.7 σ for non-zero θ_{13}

Rate+Shape analysis for (D) will be announced at NuFact in Aug. at IHEP

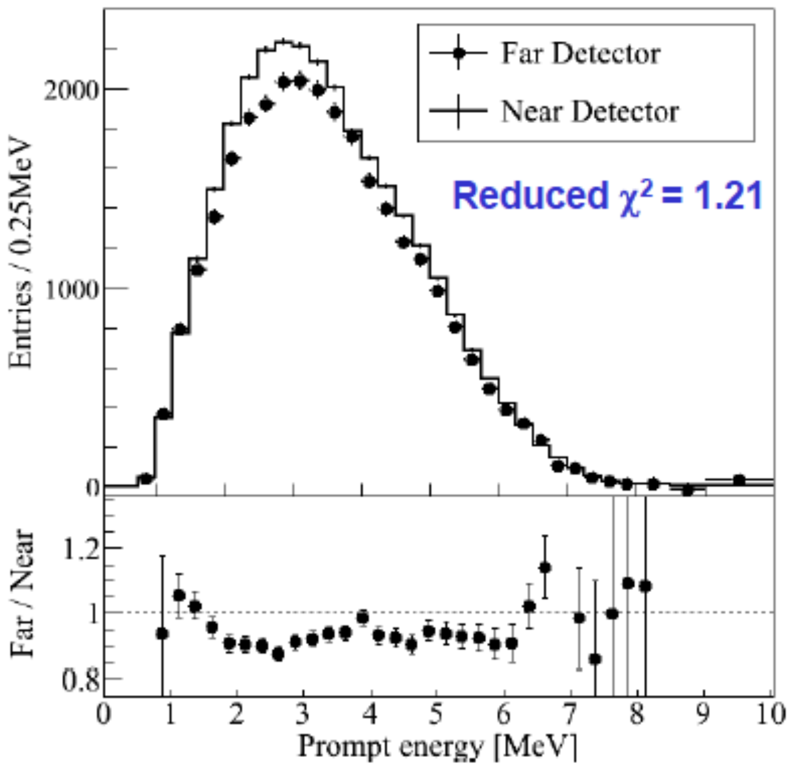
RENO Results

- First result in April 2, 2012.

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat) \pm 0.019(syst)$$

- A new result reported in March, 2013.

$$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat) \pm 0.015(syst)$$



$$R = \frac{\Phi^{Far}_{observed}}{\Phi^{Far}_{expected}} = 0.929 \pm 0.006(stat) \pm 0.009(syst)$$

Statistics:

-- about twice more data

Systematics:

-- Improved background estimation/reduction

(Li/He background, fast N, flasher removal)

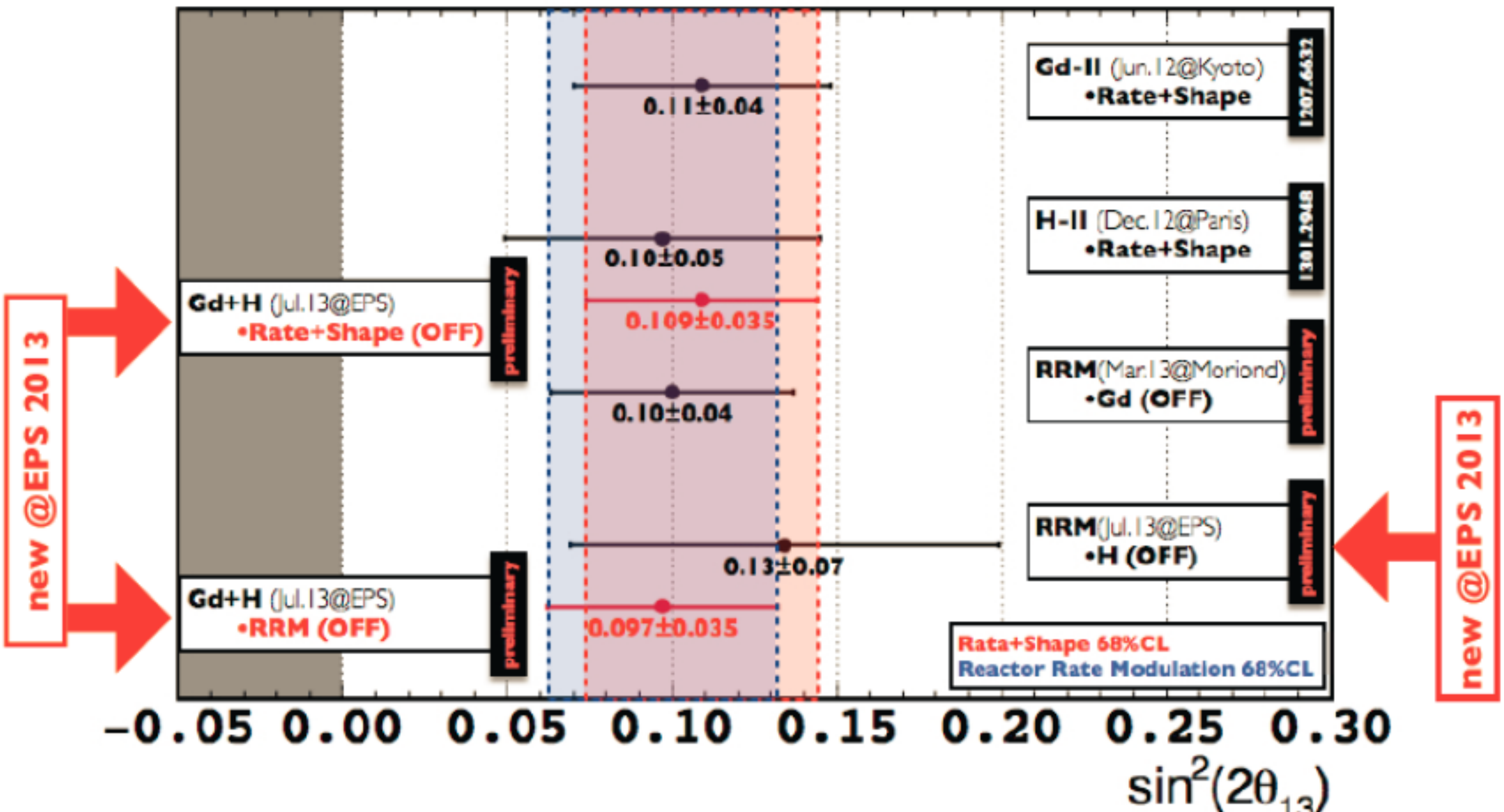
-- Improved energy scale calibration

For details, see Seon-Hee Seo's talk at NeuTel'13

Double Chooz: many results

4 measurements→ 2 combined (*Gd & H*) measurements

[**preliminary** correlations matrix→detector + flux + BG]



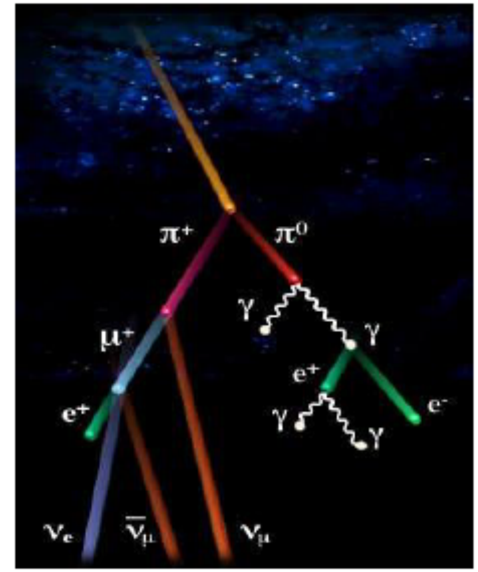
remarkable agreement (R+S & RRM) both Gd and H sample→**accuracy validation**

combined Gd & H individual measurements→**higher precision**

[DC internal validation cross-checks→(future) compare against Daya Bay & RENO]

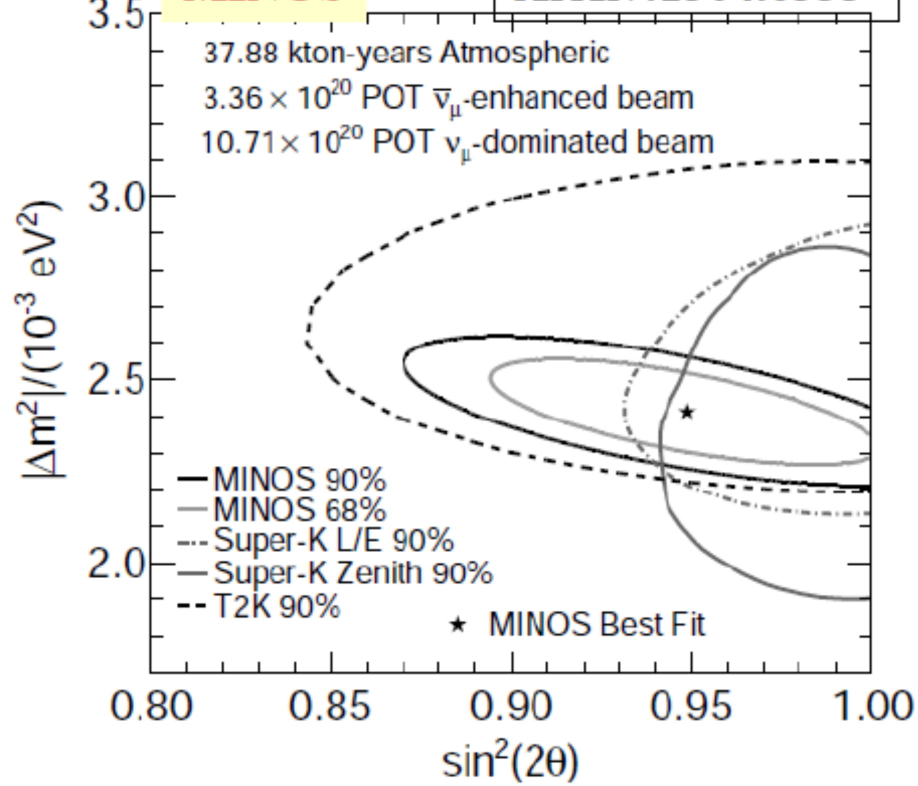
Anatael Cabrera (CNRS-IN2P3 & APC)

Atmospheric neutrinos



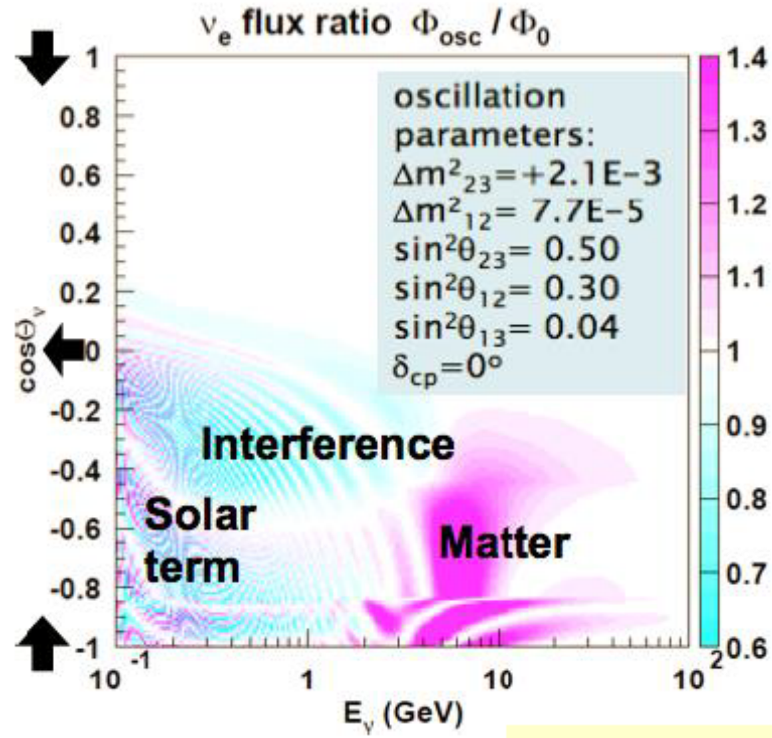
- Indications of anomaly (80's)
- Discovery of the neutrino oscillation by SuperK(98)
  - ⇨ Determination of θ_{23} & ΔM^2_{23}
  - ⇨ ν_μ oscillation: appearance of ν_τ
  - ⇨ Rejection of other explanations
- Current experiment:
  - ⇨ SuperK
- Main issues now:
  - ⇨ θ_{23} octant
  - ⇨ mass hierarchy
  - ⇨ CP phase
- Future experiments
  - ⇨ INO, PINGU, HyperK, …

MINOS ArXiv:1304.6335



Looking for sub-leading effects

- **Thanks to the huge statistics and large θ_{13}, we can look for:**
  - Mass hierarchy: enhanced high energy upward going ν_e due to the matter effect
  - Octant of oscillation: enhanced low energy ν_e due to the solar term
  - CP phase δ: interference between these two



Walter@NeuTel'13

$$\frac{\Phi(\nu_e)}{\Phi_0(\nu_e)} - 1 \approx P_2 \cdot (r \cdot \cos^2\theta_{23} - 1)$$

Solar term

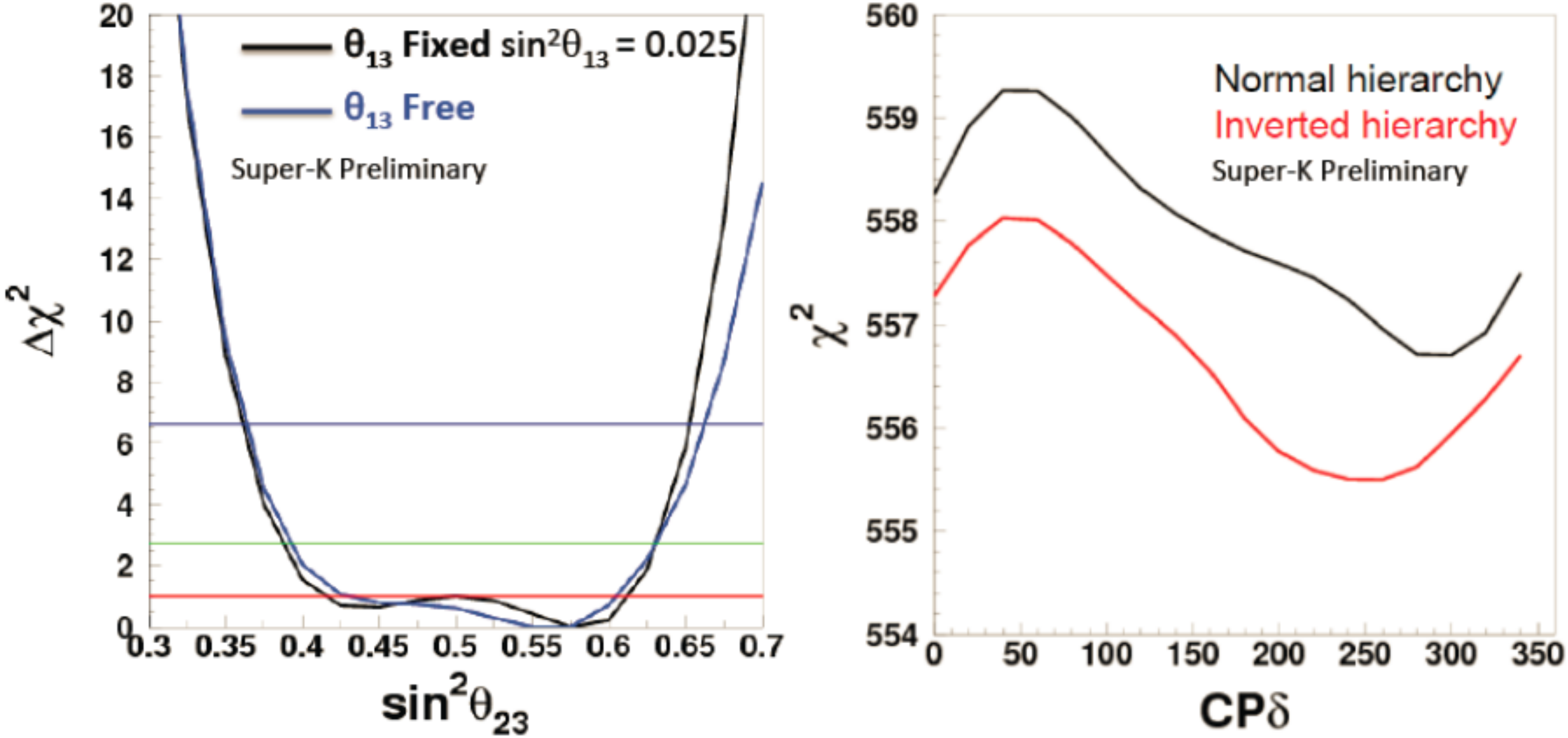
$$-r \cdot \sin\tilde{\theta}_{13} \cdot \cos^2\tilde{\theta}_{13} \cdot \sin 2\theta_{23} \cdot (\cos\delta \cdot R_2 - \sin\delta \cdot I_2)$$

interference

$$+2\sin^2\tilde{\theta}_{13} \cdot (r \cdot \sin^2\theta_{23} - 1)$$

Matter effect

Recent Super-K results

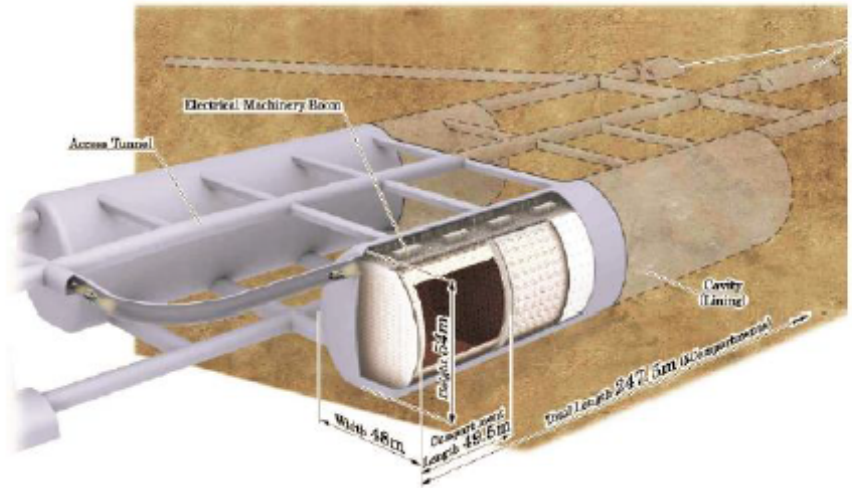


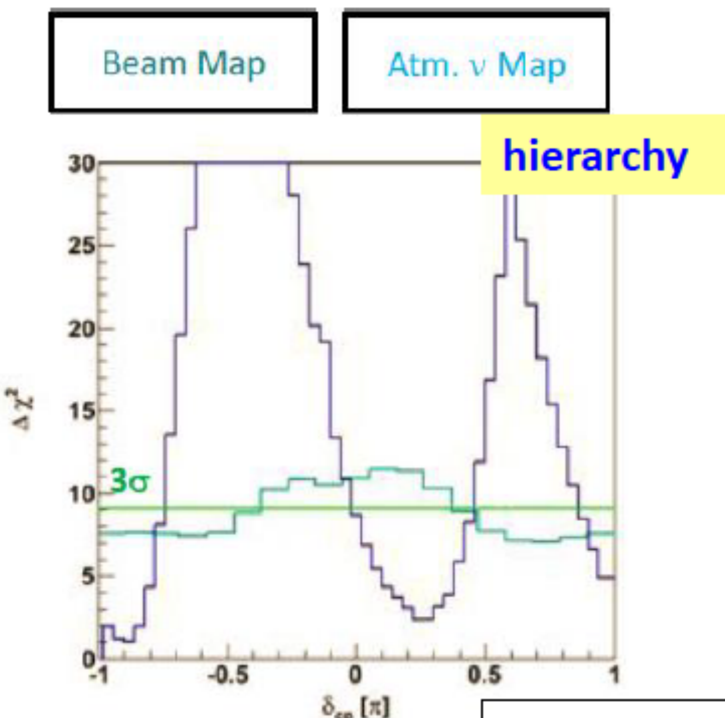
- Both free and constrained fits prefer 2nd octant
- 1.2σ preference for inverted hierarchy
  sensitivity is 0.9σ

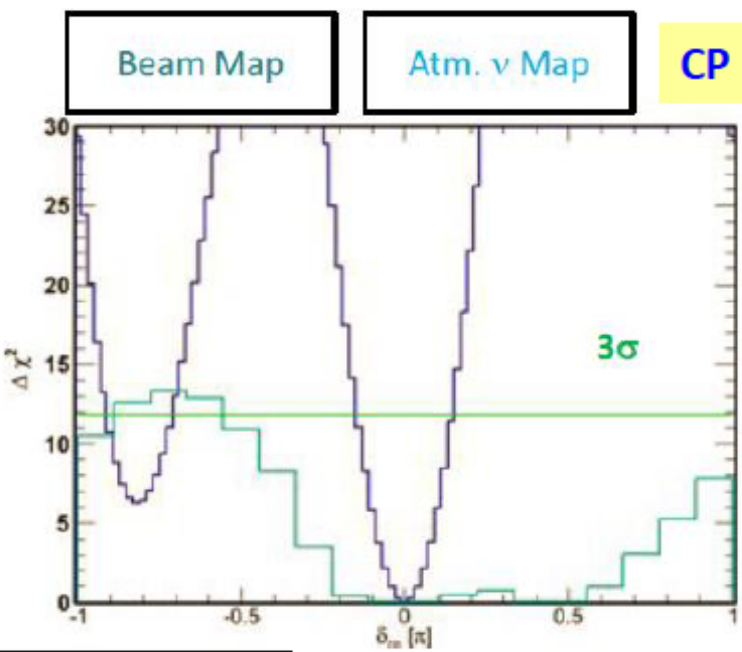
Not significant!

Future experiment: HyperK

- 1 Mt water Cerenkov detector
- 99000 20" PMT, 20% coverage
- Octant issue: $\Delta\sin^2\theta_{23} < 1\%$
- Mass hierarchy: complementary to T2HK
- CP: T2HK much better



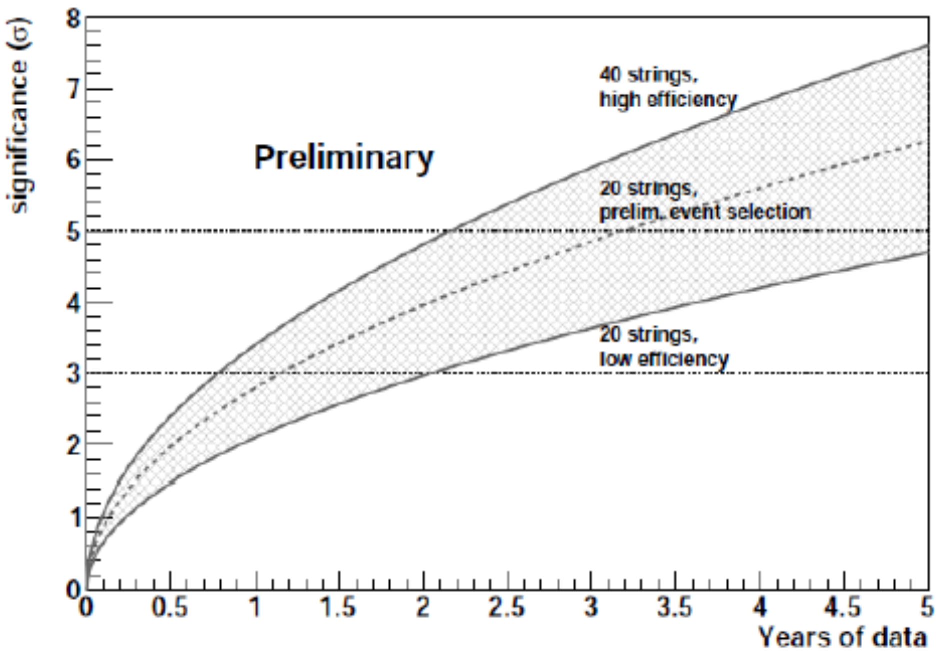


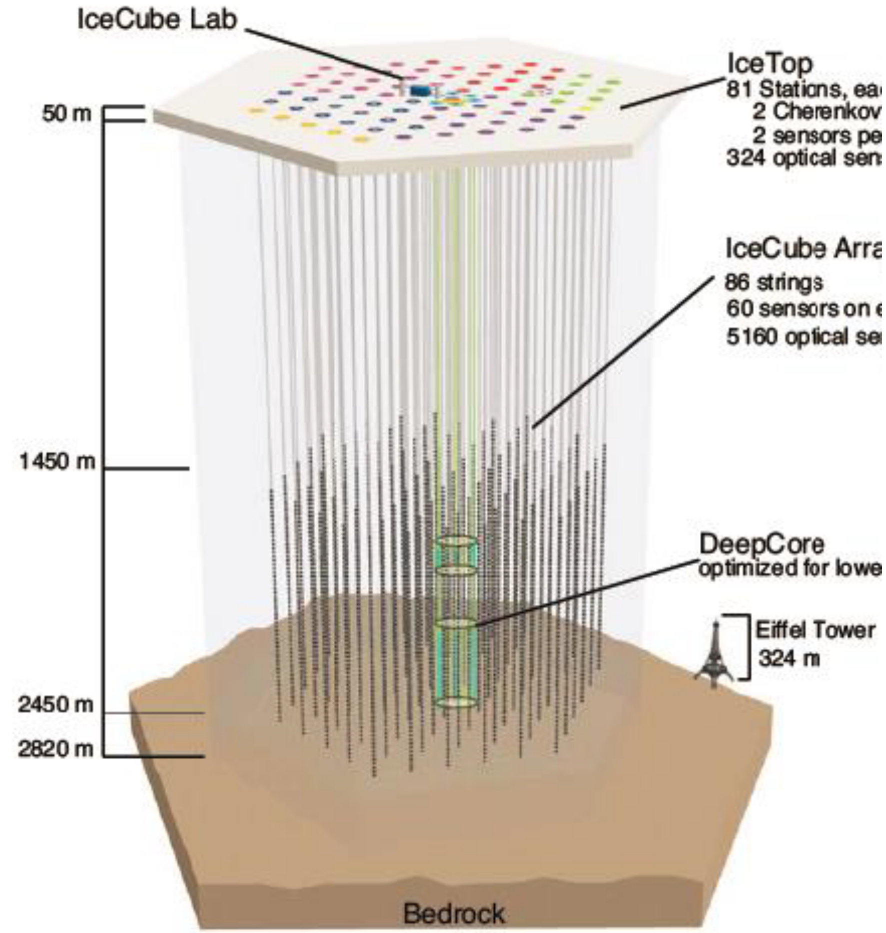


Wendell@HyperK open meeting 2012

Future experiment: PINGU

- A large ice Cerenkov detector with $E_{thresh} \sim 1$ GeV
  - ⇨ 20 strings with a spacing of 26 m
  - ⇨ Existing IceCube as the VETO
- Equivalent target mass: ~10 Mt
- Sensitivity: ~ 3σ in < 2 years (2020)

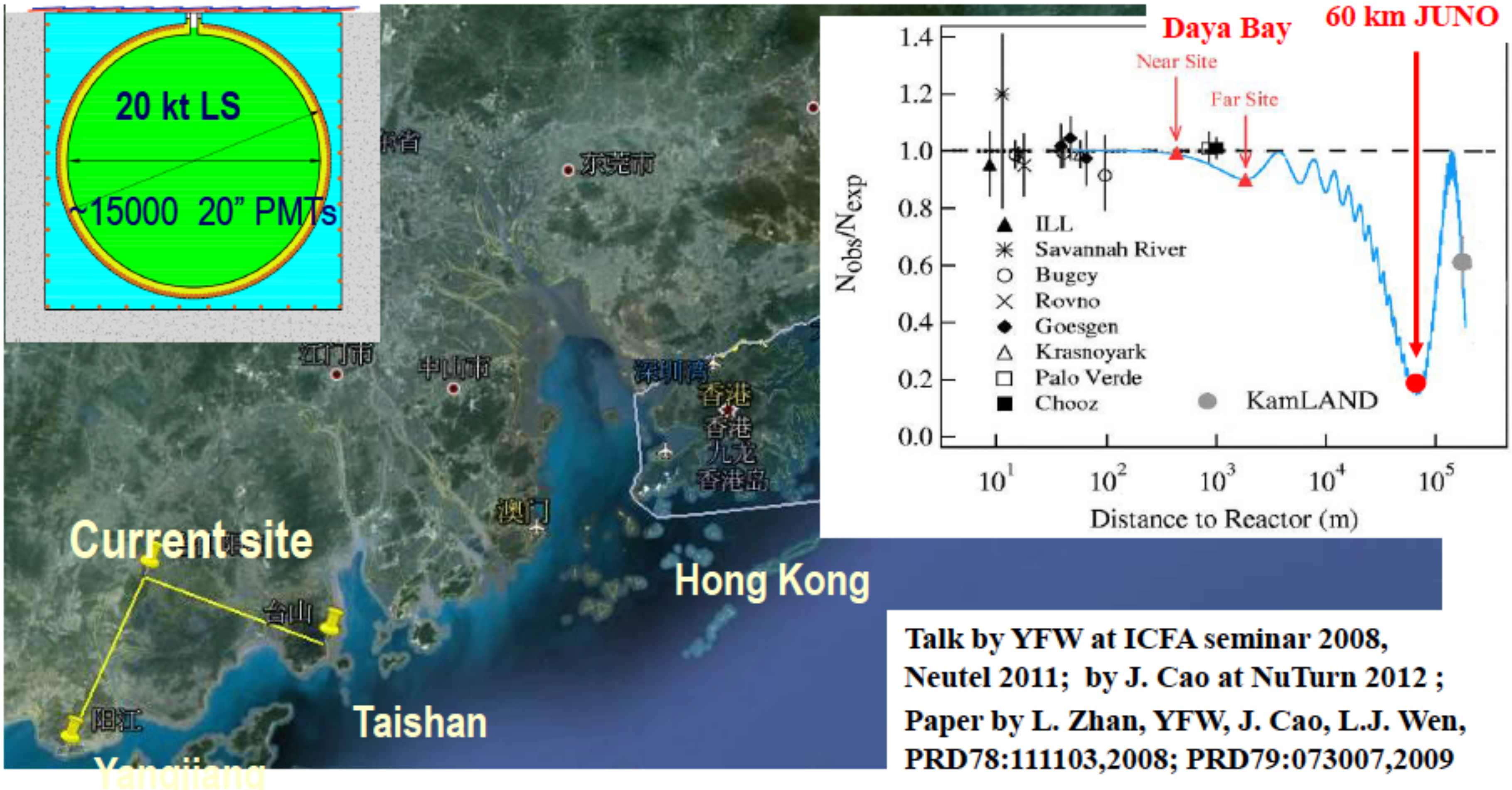




arXiv:1306.5846

Future Experiment: JUNO

	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	running	planned	approved	Construction	construction
power/GW	17.4	17.4	17.4	17.4	18.4



Talk by YFW at ICFA seminar 2008, Neutel 2011; by J. Cao at NuTurn 2012 ; Paper by L. Zhan, YFW, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009

Physics Reach

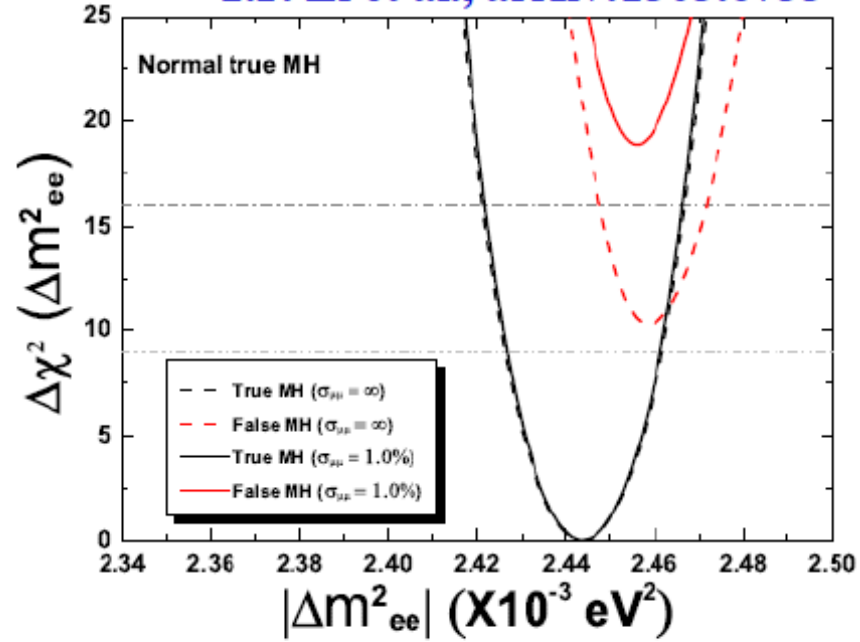
Thanks to a large θ_{13}

- **Mass hierarchy**
- Precision measurement of mixing parameters
- Supernova neutrinos
- Geoneutrinos
- Sterile neutrinos
- ……

	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	5%	0.7%
$\sin^2\theta_{23}$	5%	N/A
$\sin^2\theta_{13}$	14% → 4%	~ 15%

Detector size: 20kt
Energy resolution: 3%/√E
Thermal power: 36 GW

Y.F. Li et al., arXiv:1303.6733

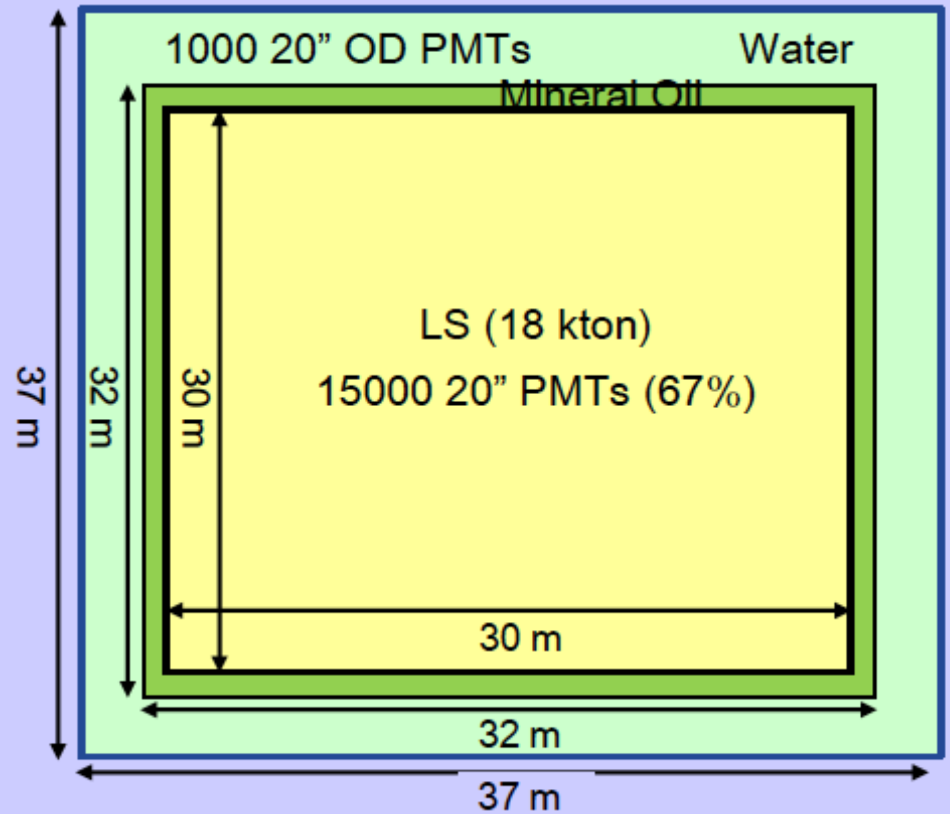


For 6 years, mass hierarchy cab be determined at 4σ level, if $\Delta m^2_{\mu\mu}$ can be determined at 1% level

RENO-50

- **RENO-50** : An underground detector consisting of 18 kton ultra-low-radioactivity liquid scintillator & 15,000 20” PMTs, at 50 km away from the Hanbit(Yonggwang) nuclear power plant

- **Goals** :
  - High-precision measurement of θ_{12} and Δm^2_{21}
  - Determination of neutrino mass hierarchy
  - Study neutrinos from reactors, (the Sun), the Earth, Supernova, and any possible stellar objects

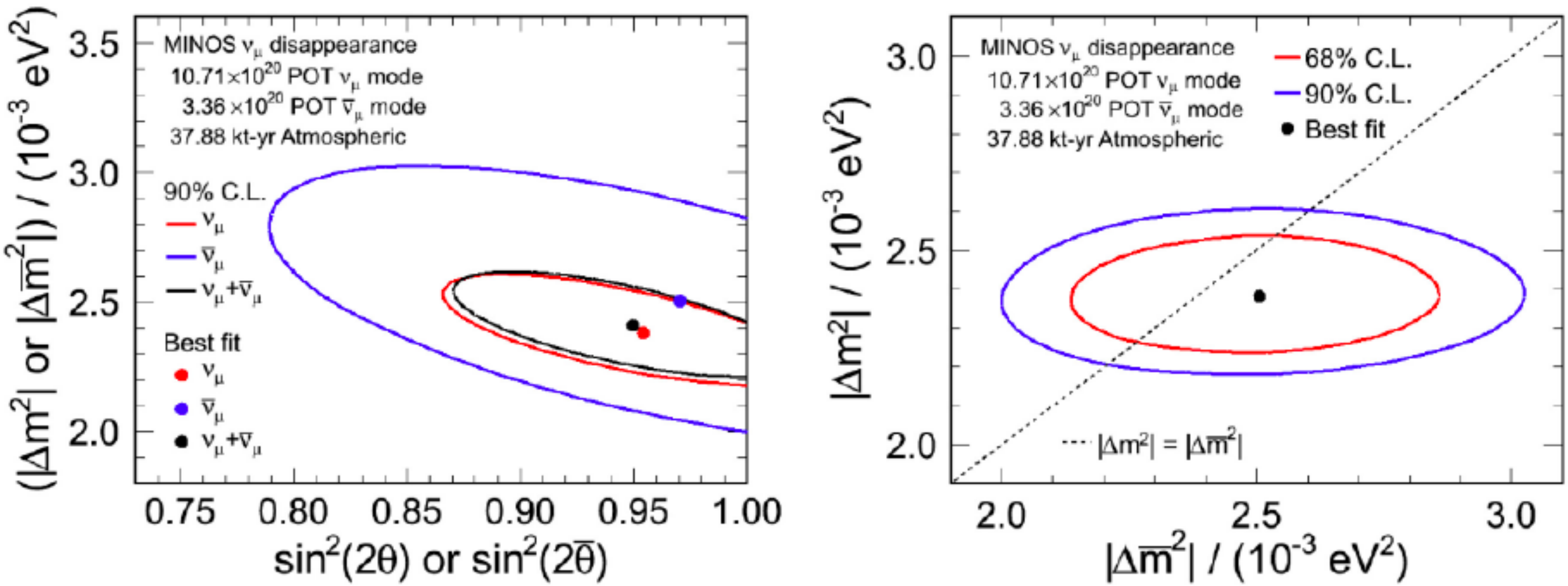


From Soo-Bong Kim

arXiv:hep-ex/1304.6335

MINOS ν_μ disappearance ν vs. $\bar{\nu}$

Leading measurement of $|\Delta m^2_{atm}|$ w/ 4.1% precision using accelerator and atmospheric ν's and $\bar{\nu}$'s.



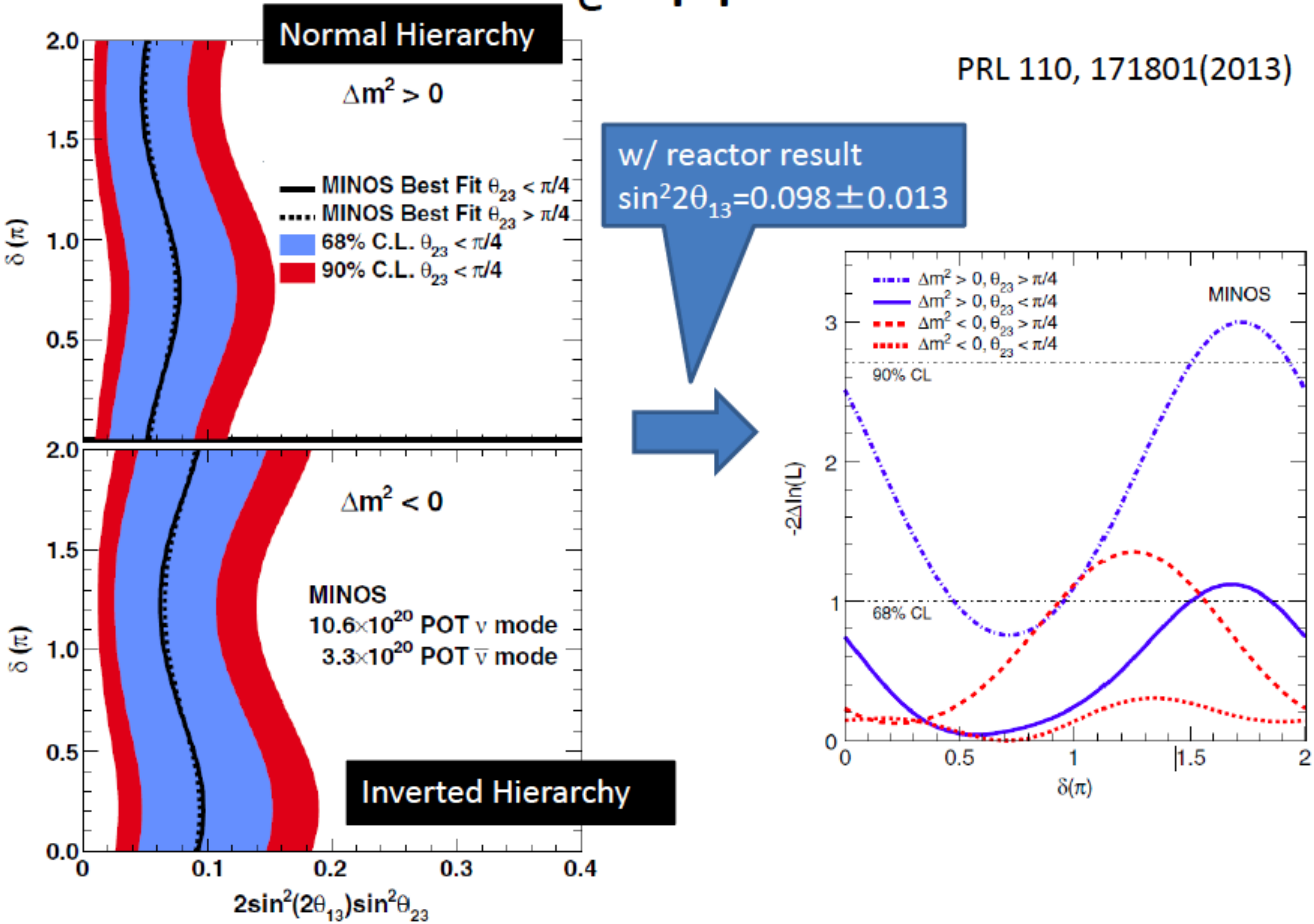
$$|\Delta\bar{m}^2| - |\Delta m^2| = 0.12^{+0.24}_{-0.26} \times 10^{-3}\text{eV}^2$$

- MINOS finds consistent values for neutrinos and antineutrino oscillation parameters measured via charged-current disappearance.

MINOS ν_e appearance

PRL 110, 171801(2013)

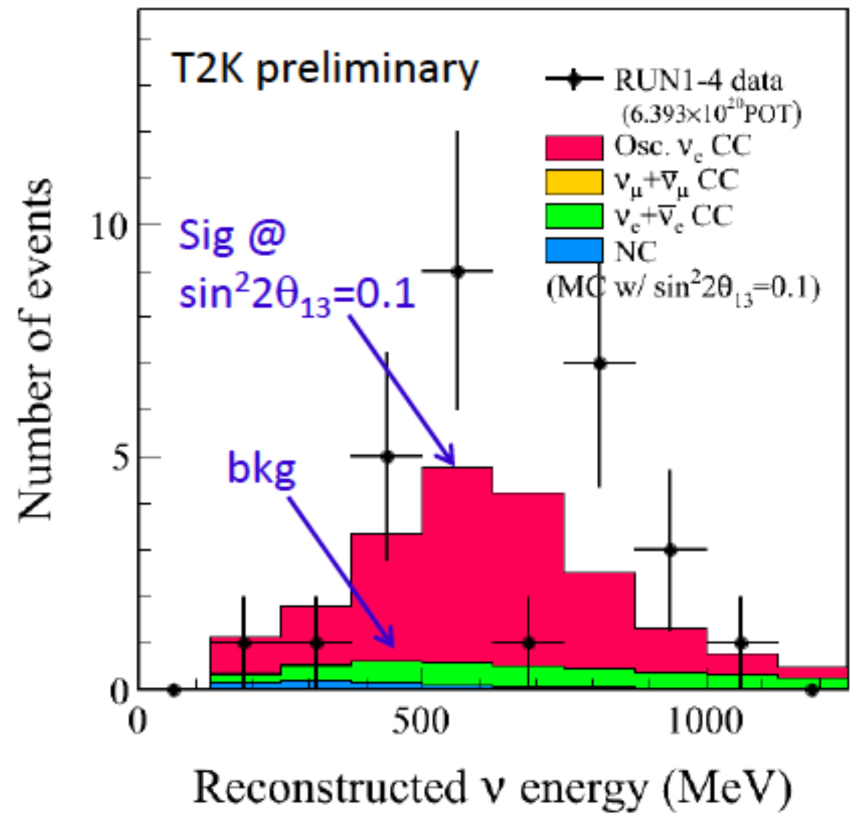
w/ reactor result
$\sin^2 2\theta_{13}=0.098\pm0.013$



T2K ν_e Appearance Updates from 2012

- The background rejection cut is improved using a new SK reconstruction algorithm. Number of BG events reduced from 6.4 to 4.6
- Near detector measurement is improved by using new event categories

	2012(*)	2013(now)
POT	3.010×10^{20}	6.393×10^{20} (~Apr 12)
Bkgs	3.3 ± 0.4	4.64 ± 0.51
Observed ν_e cand. Events	11	**28**
ν_e app. Significance	3.1σ	**7.5σ**

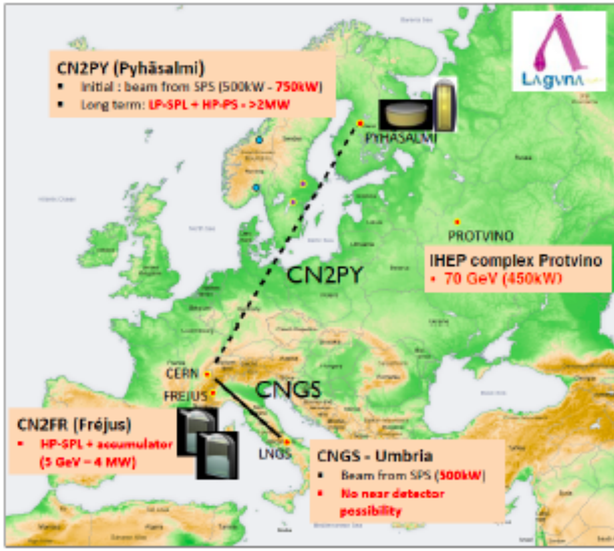


* 2012 result arXiv:1304.0841 (accepted by PRD)

World LBL Future Project

LAGUNA-LBNO 130km?~2,300km?

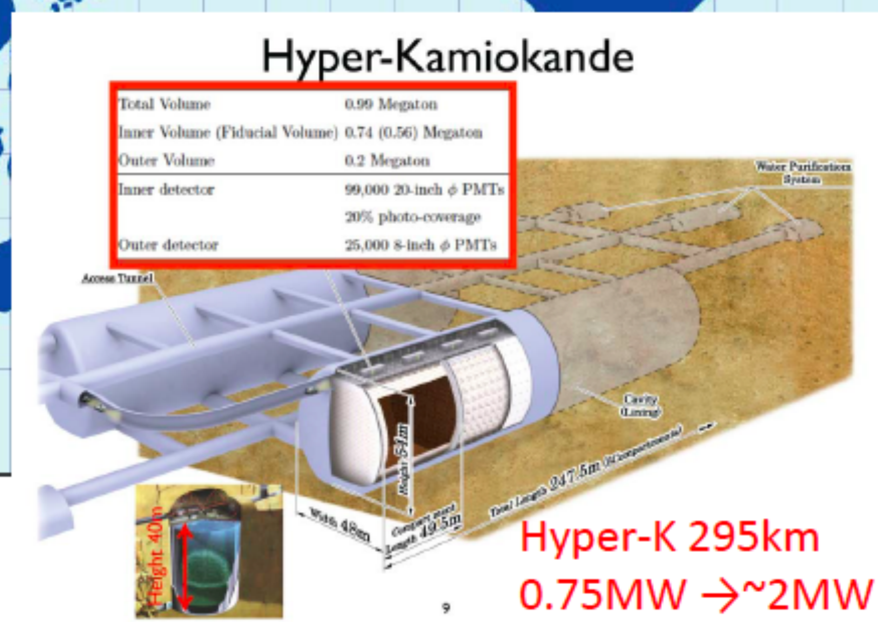
ESS+WC? 540km?



- **Detector options:** 20, 50, 100 kton LAr; 50 kton LSc and 540 kton WCD

LBNE 1300km

0.7MW, 10kt LAr →2.3MW, 35kt LAr



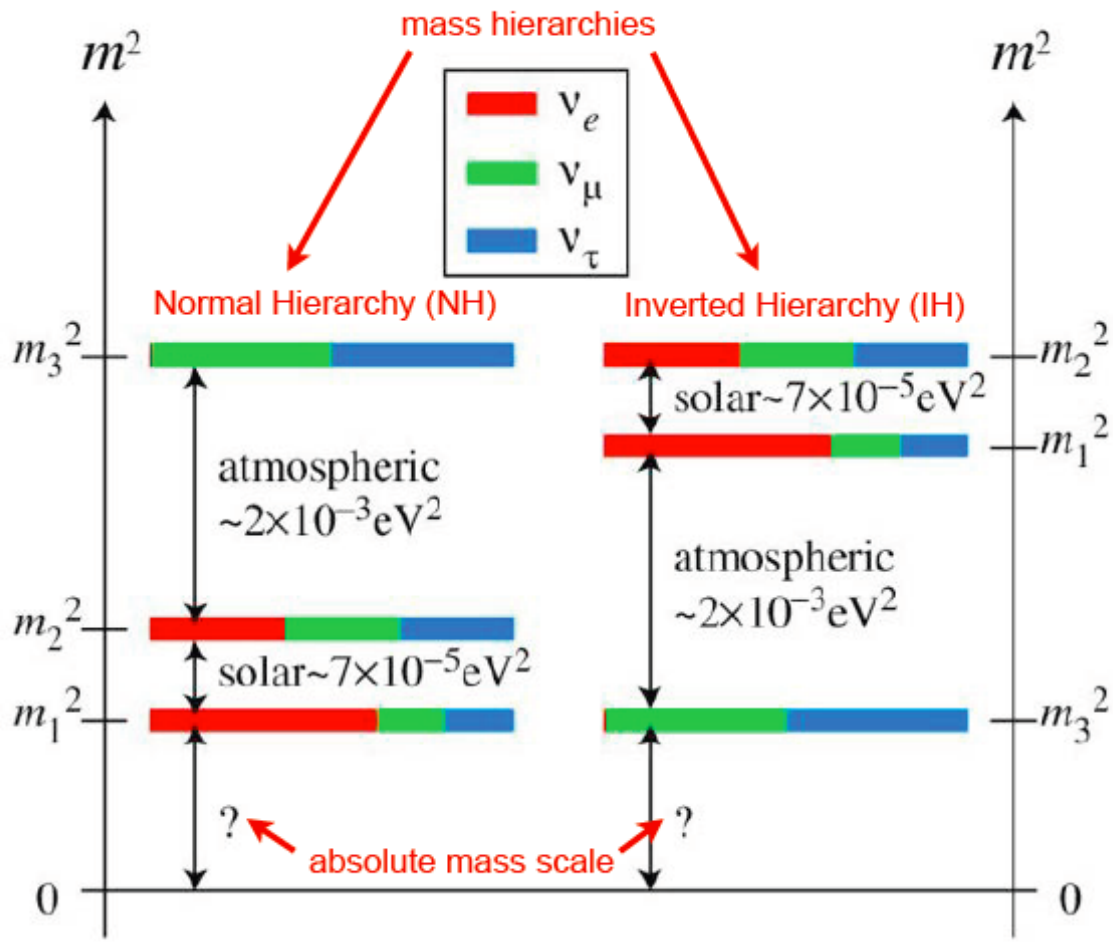
Hyper-K 295km

0.75MW →~2MW

Neutrino mass questions

Two main questions are directly related to neutrino masses:

1. absolute mass scale: i.e. mass of the lightest ν
2. degenerate ($m_1 \approx m_2 \approx m_3$) or hierarchical masses ($m_1 < m_2 \ll m_3$ or $m_3 \ll m_1 < m_2$)

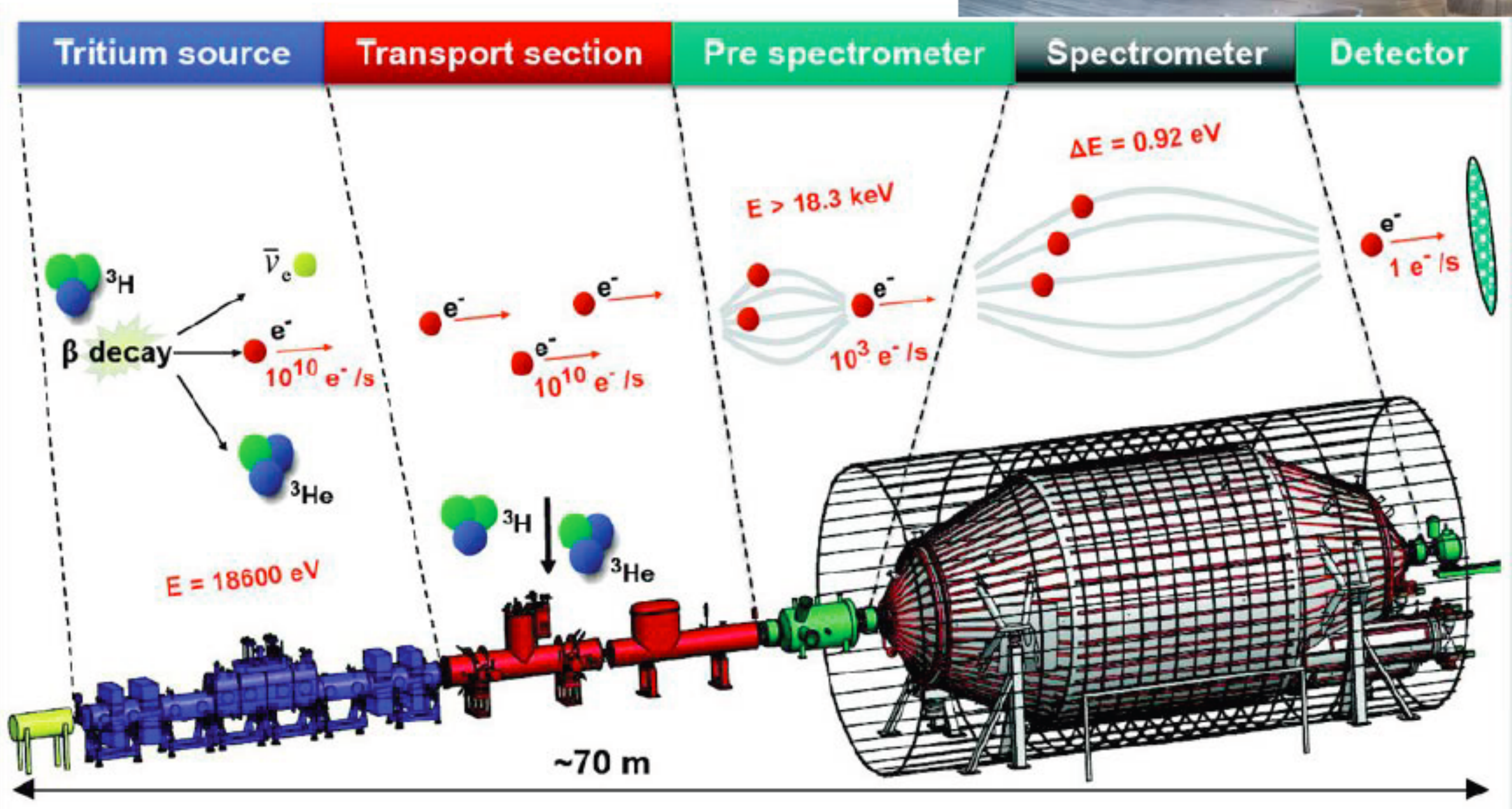


- Neutrino oscillation experiments are blind to the first but can solve the second: Daya Bay II, Reno II, T2K, Nova, LBNO, LBNE, PINGU, ORCA, ...

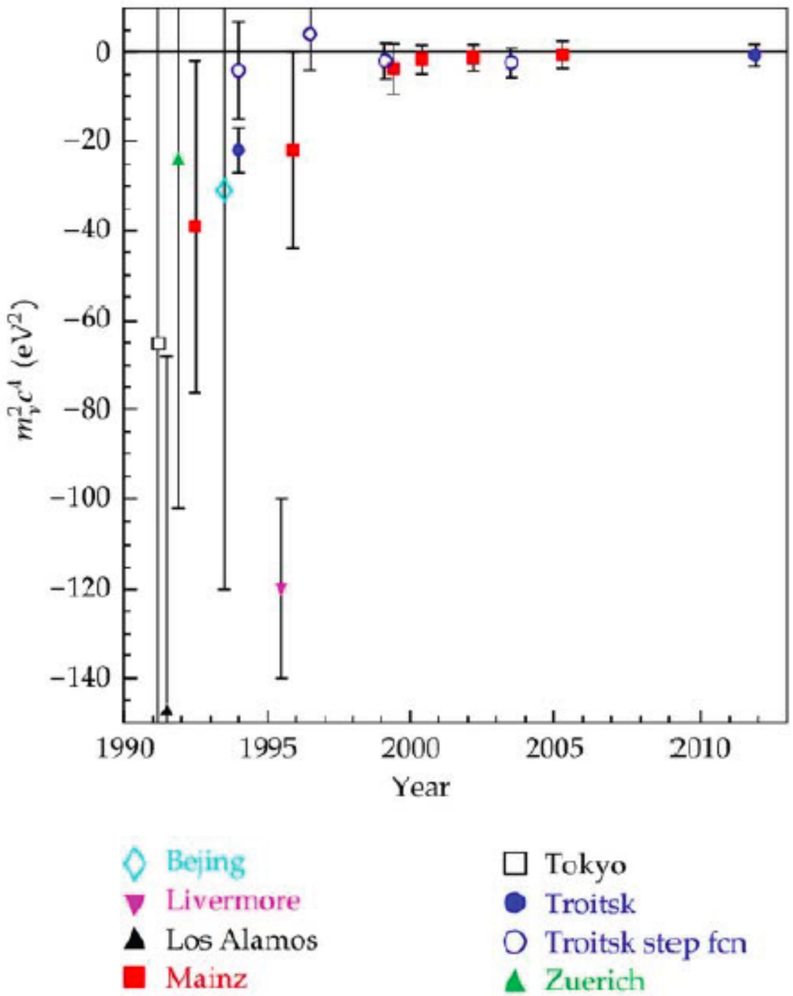
KATRIN

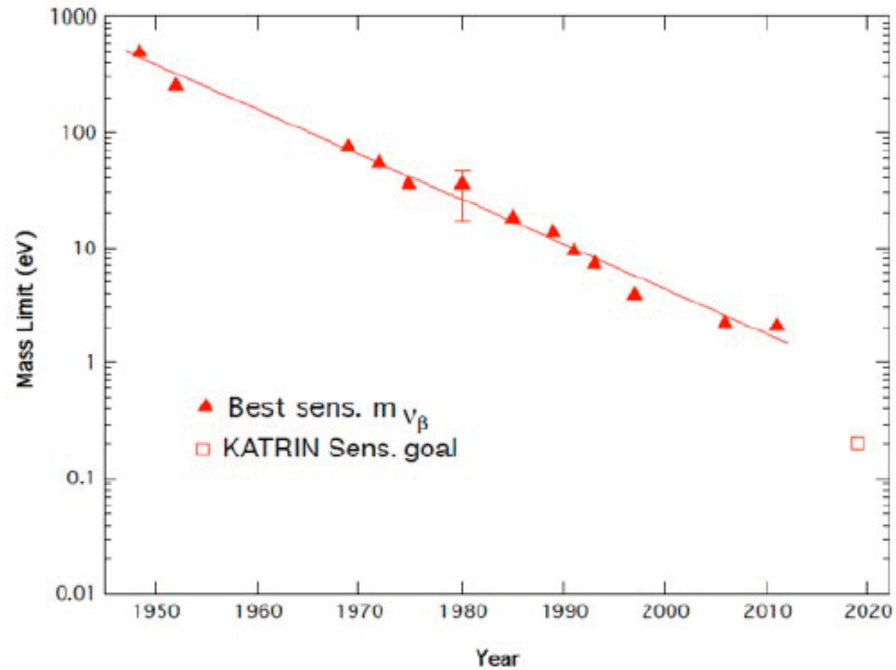
→talk M.Haag

- Large electrostatic spectrometer with gaseous ^3H source (Q=18.6keV)
- Expected statistical sensitivity: **m_{ν_e} < 0.2 eV 90% CL**
- Start data taking in **2014/2015**
- Presently under commissioning



Spectrometers progress





Double Beta Decay

Very rare nuclear decay

(A,Z) → (A,Z+2) + 2e- (+?)

which can occurr according
in different modes

0νββ decay (neutrinoless DBD):

→ violates lepton number by 2 units

→ experimentally not observed

→ $T_{0\nu\beta\beta 1/2}$ (^{76}Ge) > ~10^{25} y

→ Current bounds limit neutrino mass scale to $m_\nu \leq O(\mathbf{0.1 - 0.5})$ eV

→ Observation implies Physics beyond the standard model of particle physics

2νββ decay:

- allowed within Standard model,
  - 2nd order process in Fermi theory
- observed for 12 isotopes:
  - ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128,130}Te, ^{136}Xe, ^{150}Nd and ^{238}U
- First double beta plus decay: ^{130}Ba
- **$T^{2\nu\beta\beta}_{1/2}$ ~ $10^{(19-25)}$ y**
- Important constraint for nuclear matrix element calculation

"Exotic" decays:

→ for example X = J, i.e. Majoron

→ experimentally not observed (and no rumours!)

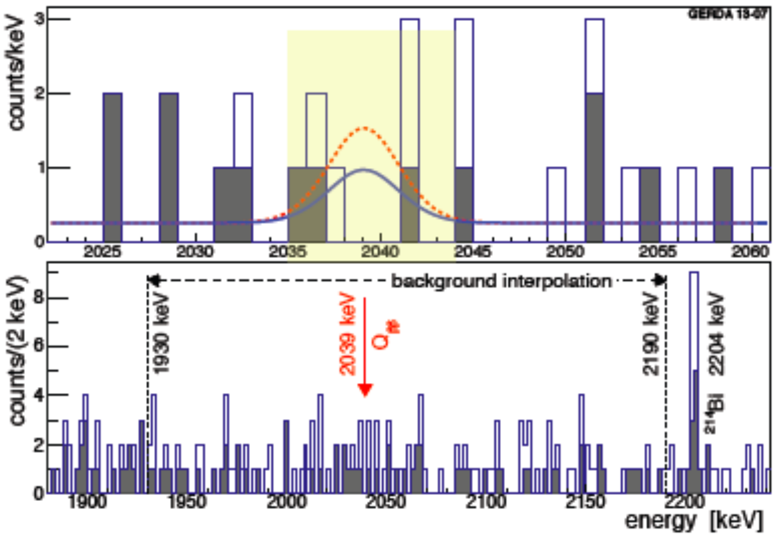
→ Best limit from: $T_{0\nu\beta\beta J}$
1/2 (^{128}Te) >
~ few 10^{24} ys

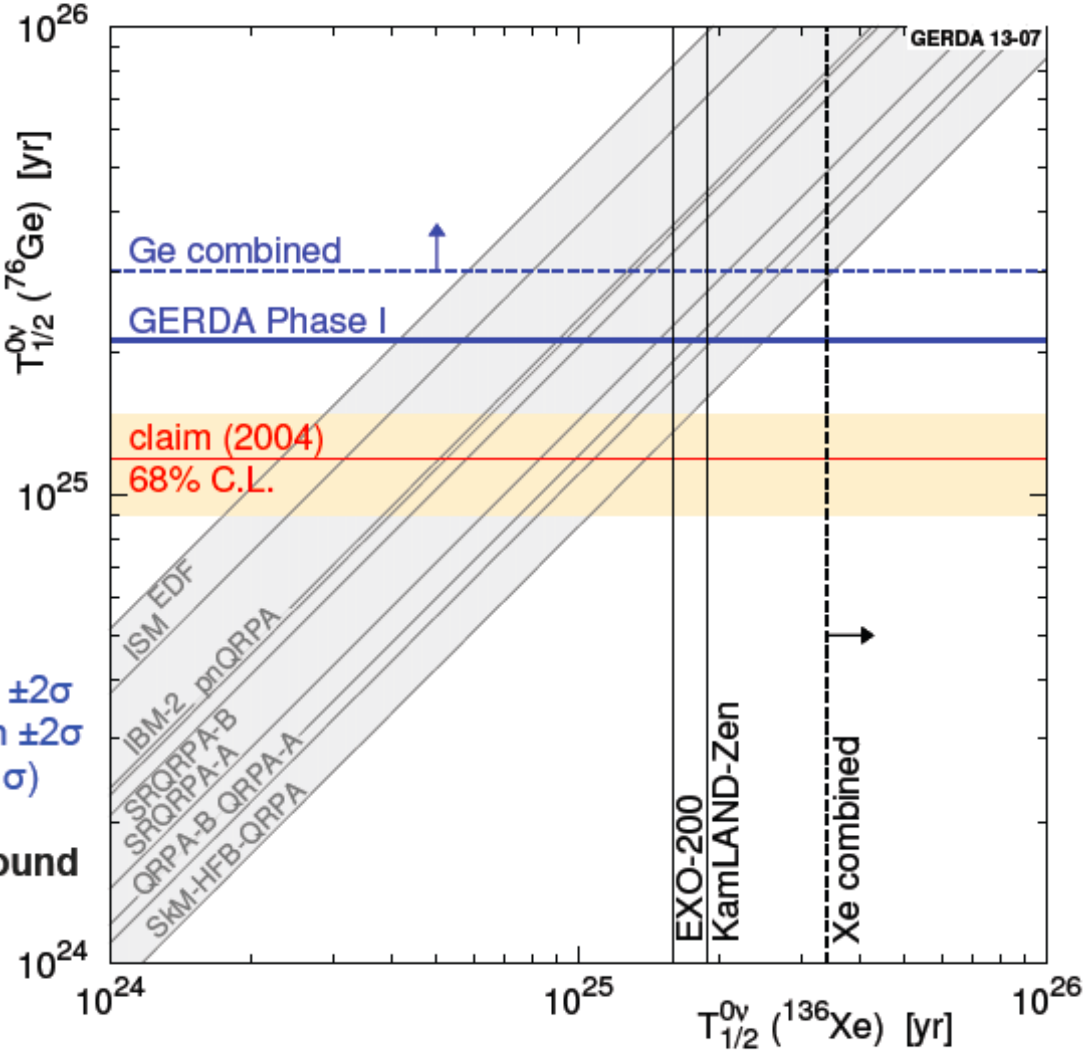
GERDA-I ββ(0ν) results and ^{76}Ge claim

GERDA Coll., arXiv:1307.4720

GERDA : **$T_{1/2}^{0\nu}$ > 2.1 x 10^{25} yr @ 90% CL**

GERDA combined w. IGEX & HdM: **$T_{1/2}^{0\nu}$ > 3.0 x 10^{25} yr @ 90% CL**





Best fit: $N^{0\nu}$ = 0, $N^{0\nu}$ < 3.5 cts @ 90% C.L.

For $T_{1/2}^{0\nu}$ = 1.19 x 10^{25} yr:

- Expected Signal (after PSD): 5.9 ± 1.4 cts in ±2σ
- Expected Bckgd (after PSD): 2.0 ± 0.3 cts in ±2σ
- Observed: 3.0 (0 in ±1σ)

Comparing H1(Claimed signal) to H0(Background only):

- P(H1)/P(H0)=$2\cdot 10^{-4}$
- Assuming H1: P ($N^{0\nu}$=0 | H1)=1%

→ Claim poorly credible

A reminder

Detectors are our eyes

We as a field need to maintain and develop detector expertise. Today's detector marvels are not automatically reproducible by the next generation. Three essential elements:

1. Training, organizing and stimulating participation in instrumentation schools
2. Experimenting, encouraging young experimentalists to do hands-on detector work especially in smaller, shorter scale experiments
3. Rewarding, giving proper recognition of excellence in instrumentation development in careers at universities and research institutions.

But not only.

In summary

- Lucky times for Physics!
- Unprecedented convergence of the extremes of the scales around a common set of questions
- A lot of beautiful **experimental results** to compare with **precise theory predictions**.
- We need to accelerate the reflection on **next steps**
- No time to idle: a lot of work has to be done

In summary

We will need

- Flexibility
- Preparedness
- Visionary global policies

- ...and a bit of luck!

Thank you!