Summary of Lepton-Photon 2011: Part I (on the light stuff)

Kam-Biu Luk

RPM, September 27, 2011

Outline

- Apology: selection of materials is subject to personal bias and limited knowledge of the field

- Contents:
  - Neutrino Physics
    - Status of some Double Beta-decay experiments
    - Results on solar neutrinos
    - Results and prospects for neutrino oscillation
  - Flavor Physics
    - Lepton sector
    - Quark sector
  - Dark Matter
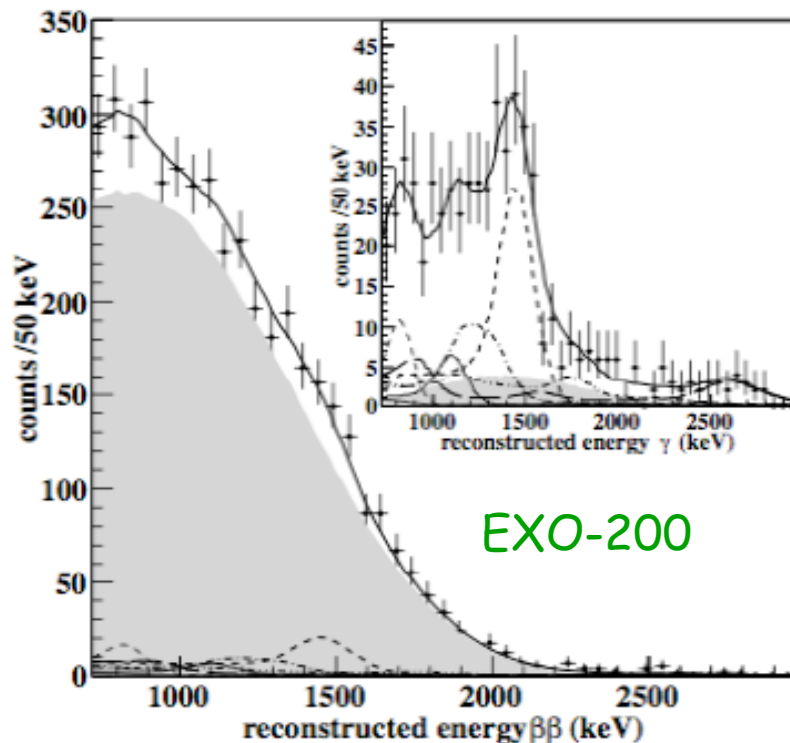
Neutrino Physics

Double Beta-decays

In 2011:

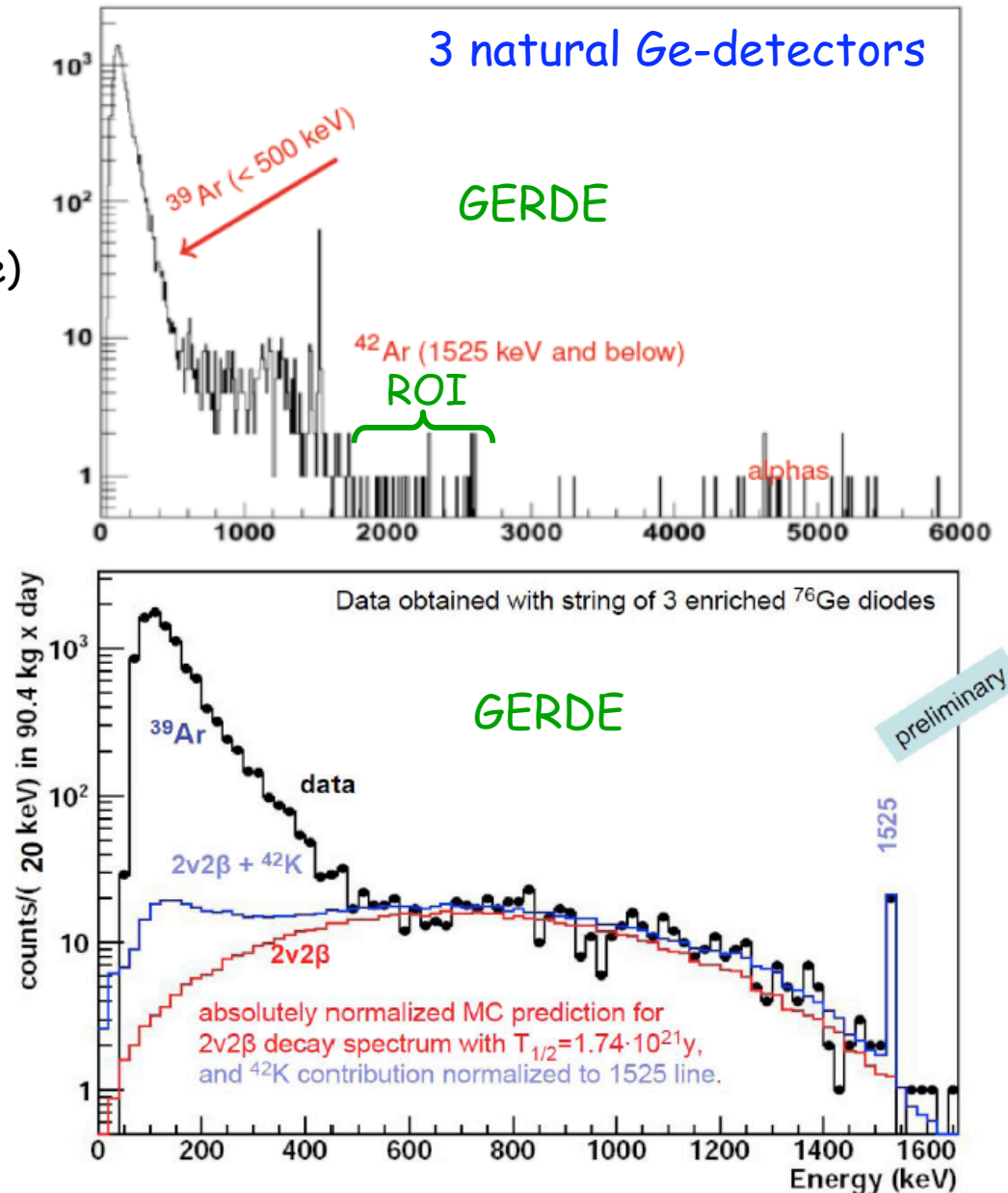EXO-200: 200 kg of Xe
        (80% enriched in ^{136}Xe)
GERDE: enriched ^{76}Ge
KamLAND-Zen: 400 kg of Xe
        (91.7% enriched in ^{136}Xe)
CANDLES III: 350 g ^{48}Ca

3 natural Ge-detectors

GERDE

^{39}Ar (< 500 keV)

^{42}Ar (1525 keV and below)

ROI

alphas

EXO-200

Data obtained with string of 3 enriched ^{76}Ge diodes

preliminary

GERDE

^{39}Ar

data

2v2β + ^{42}K

2v2β

1525

absolutely normalized MC prediction for
2v2β decay spectrum with $T_{1/2}$=1.74·10^{21}y,
and ^{42}K contribution normalized to 1525 line.

First observation of 2nu decay of Xe-136,
N. Ackerman et al., arXiv:1108.4193

Solar Neutrinos : Matter Effect

- ## Borexino on ^{7}Be (2011)
  - 741 days vs 192 days (2008)
  - Reduced systematic error by 2

$46.0 \pm 1.5\text{(stat)} {}^{+1.5}_{-1.6}\text{(syst)/day/100t}$

- Confirmed MSW-LMA in the Vacuum-dominated region.
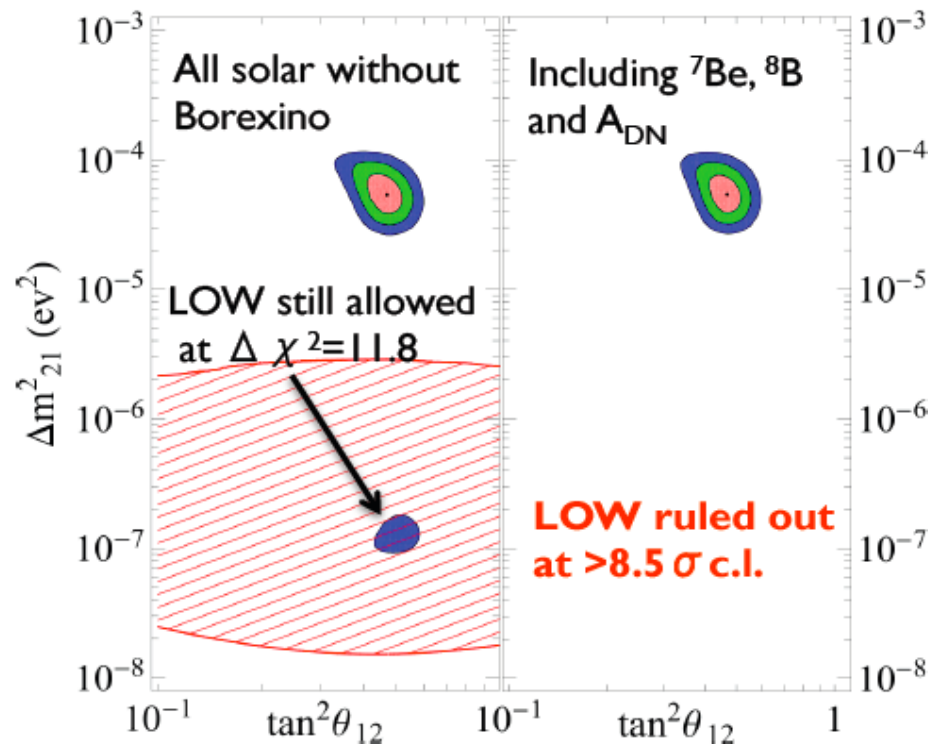- CNO contribution to solar luminosity < 1.7% at 95% C.L.
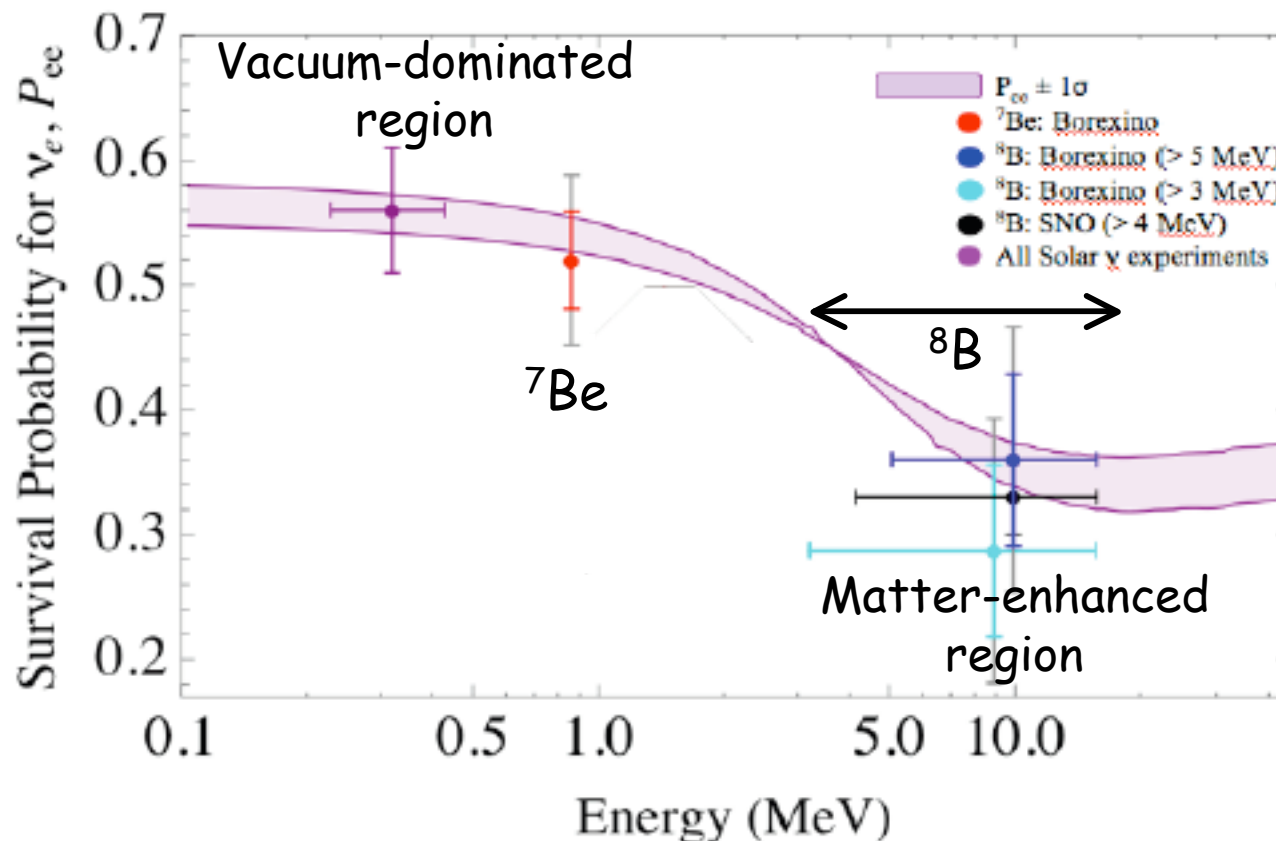
Solar Neutrinos : Day/Night Asymmetry

- Borexino: 385.5 days and 363.6 nights:

$$A_{dn} = 2\frac{R_n^{^7Be} - R_d^{^7Be}}{R_n^{^7Be} + R_d^{^7Be}} = \frac{R_{diff}}{R}$$
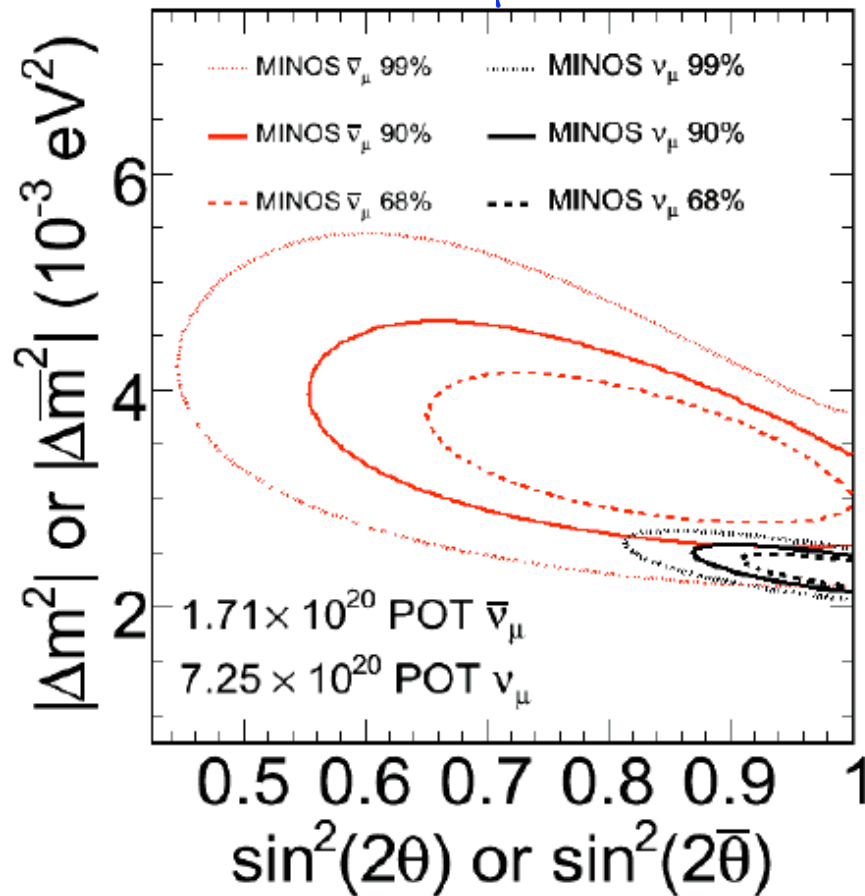
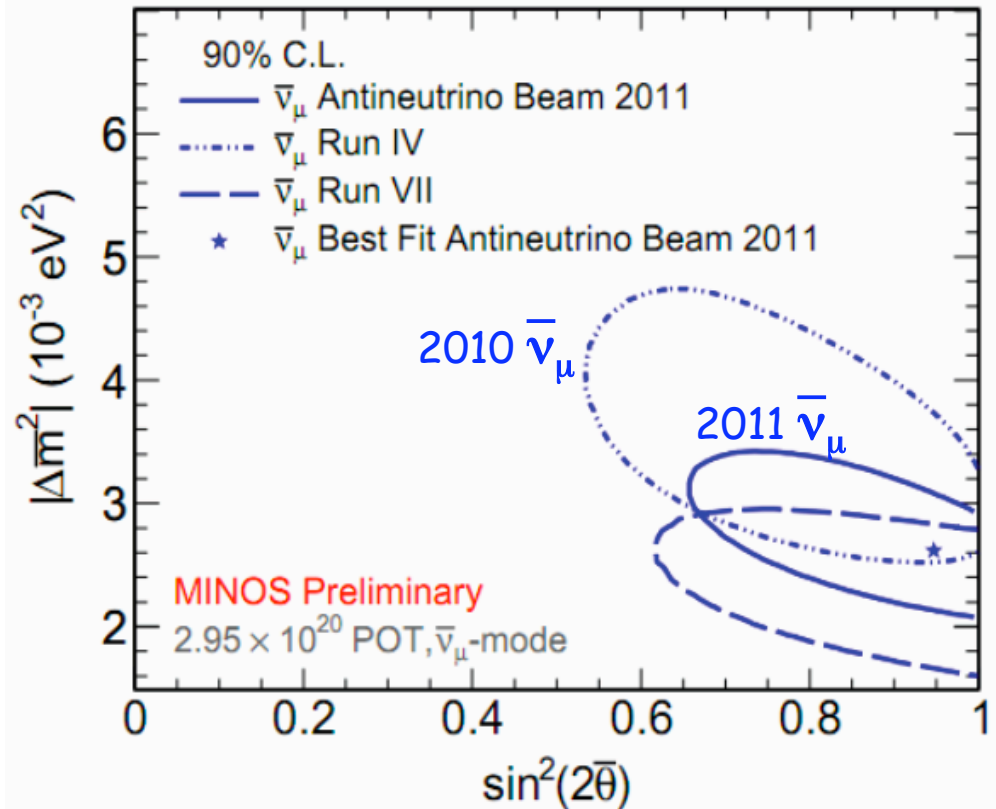$A_{dn} = 0.001 \pm 0.012(\text{stat}) \pm 0.007(\text{syst})$

- Borexino and the other solar-neutrino results can single out the LMA region without KamLAND
  - No need to assume CPT invariance between ν_e and $\bar{\nu}_e$ anymore.

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MINOS: New Result on $\bar{\nu}_\mu$ Oscillation
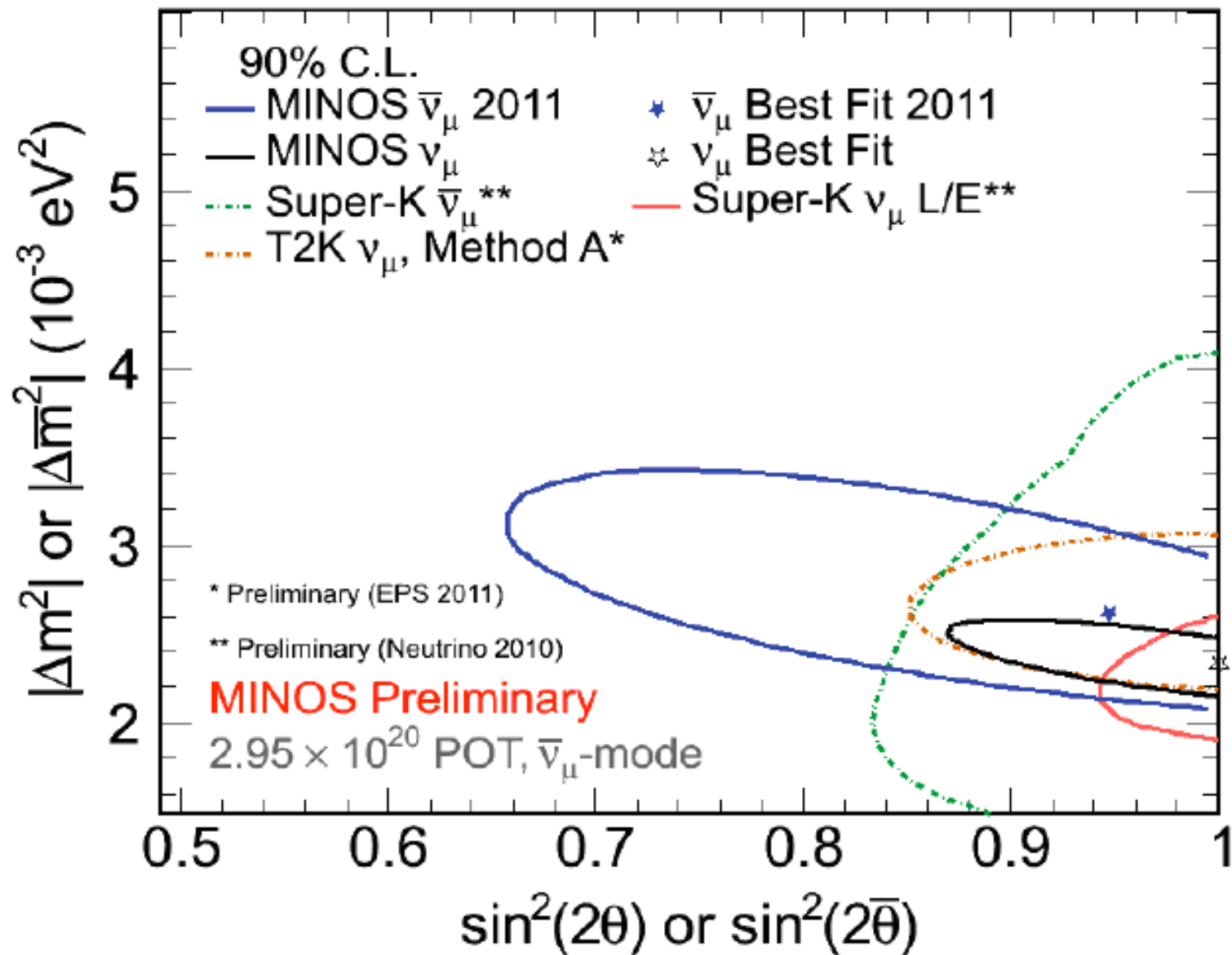
2010 $\bar{\nu}_\mu$ result

PRL**107**,021801(2011)

Best fit values:

$\Delta m^2 = [2.62^{+0.31}_{-0.28} \pm 0.09(\text{sys})] \times 10^{-3}$ eV^2
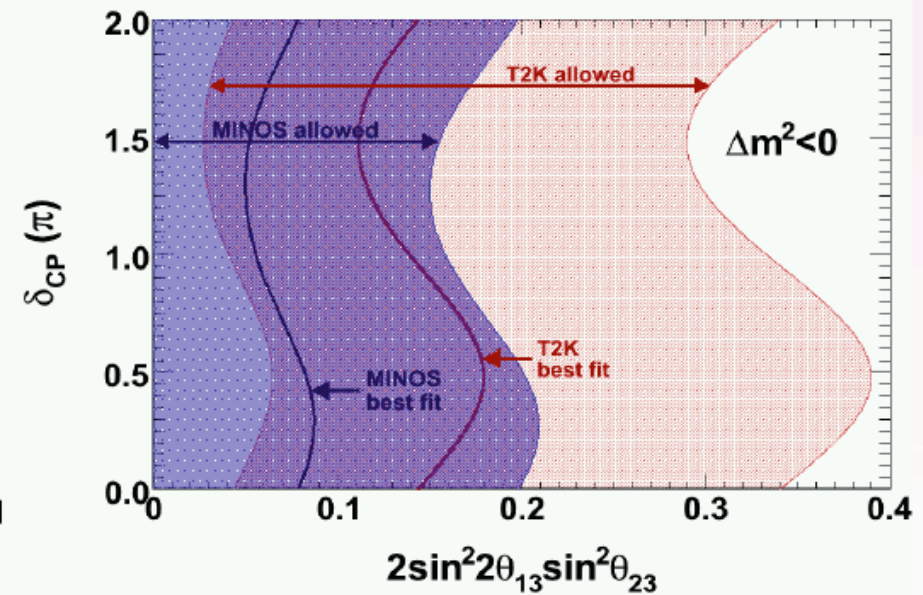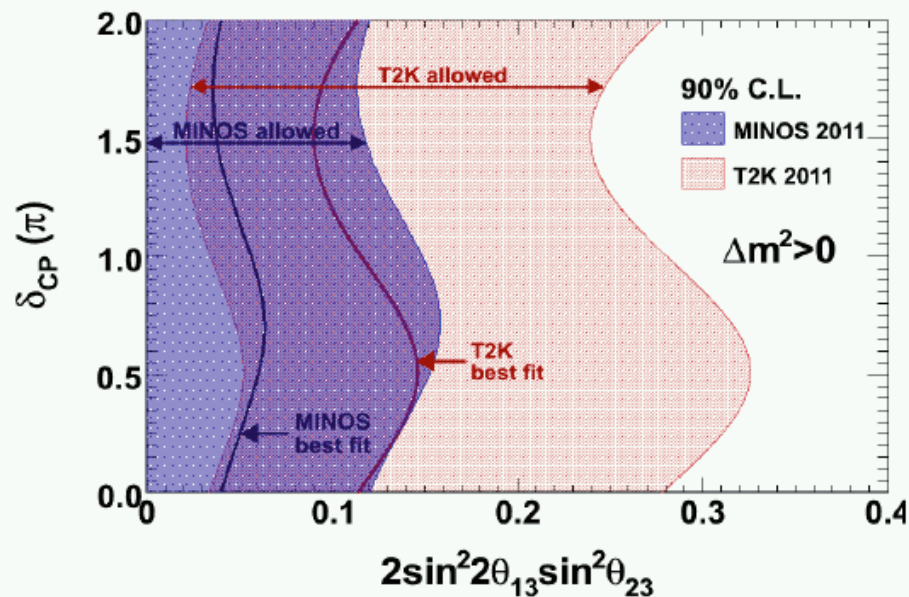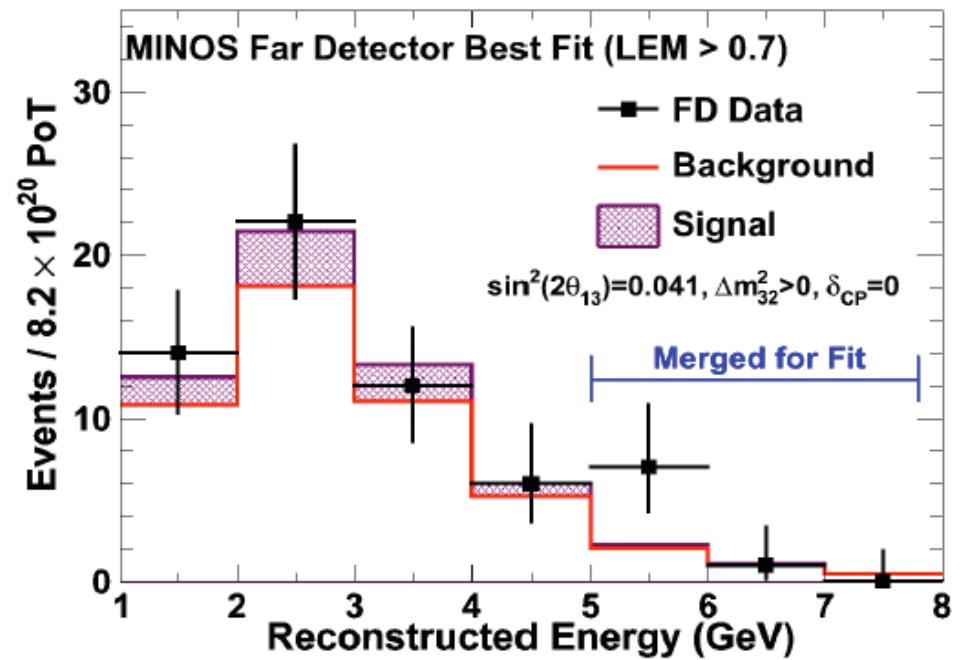
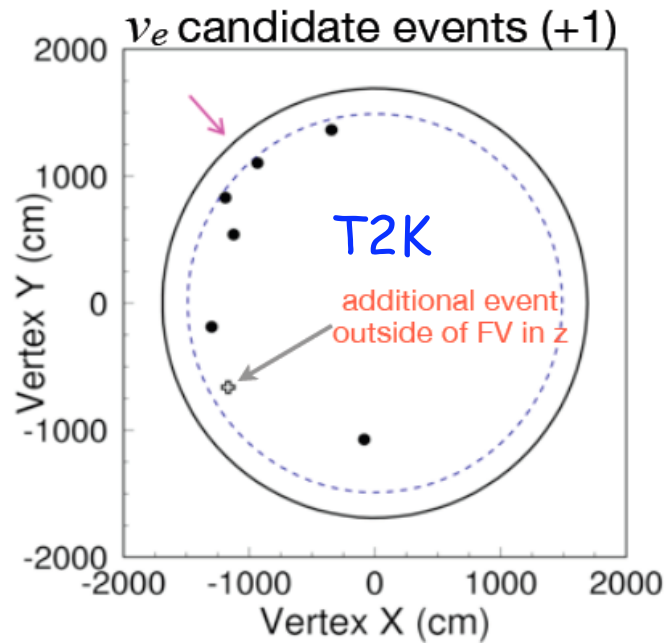$\sin^2 2\theta_{23} = 0.95^{+0.10}_{-0.11} \pm 0.01(\text{sys})$

Tension between $\bar{\nu}_\mu$ and ν_μ results is gone.

Results on ν_μ and $\bar{\nu}_\mu$ Disappearance

Search For ν_e Appearance: θ_{13}

ν_e candidate events (+1)

T2K

additional event
outside of FV in z

MINOS Far Detector Best Fit (LEM > 0.7)

- ■ FD Data
- — Background
- ▨ Signal

$\sin^2(2\theta_{13})=0.041$, $\Delta m^2_{32}>0$, $\delta_{CP}=0$

Merged for Fit

90% C.L.
- MINOS 2011
- T2K 2011

$\Delta m^2>0$

T2K allowed
MINOS allowed
T2K best fit
MINOS best fit

$\Delta m^2<0$

T2K allowed
MINOS allowed
T2K best fit
MINOS best fit

Mixing Parameters From Global Fit

TS, Tortola, Valle, 1108.1376

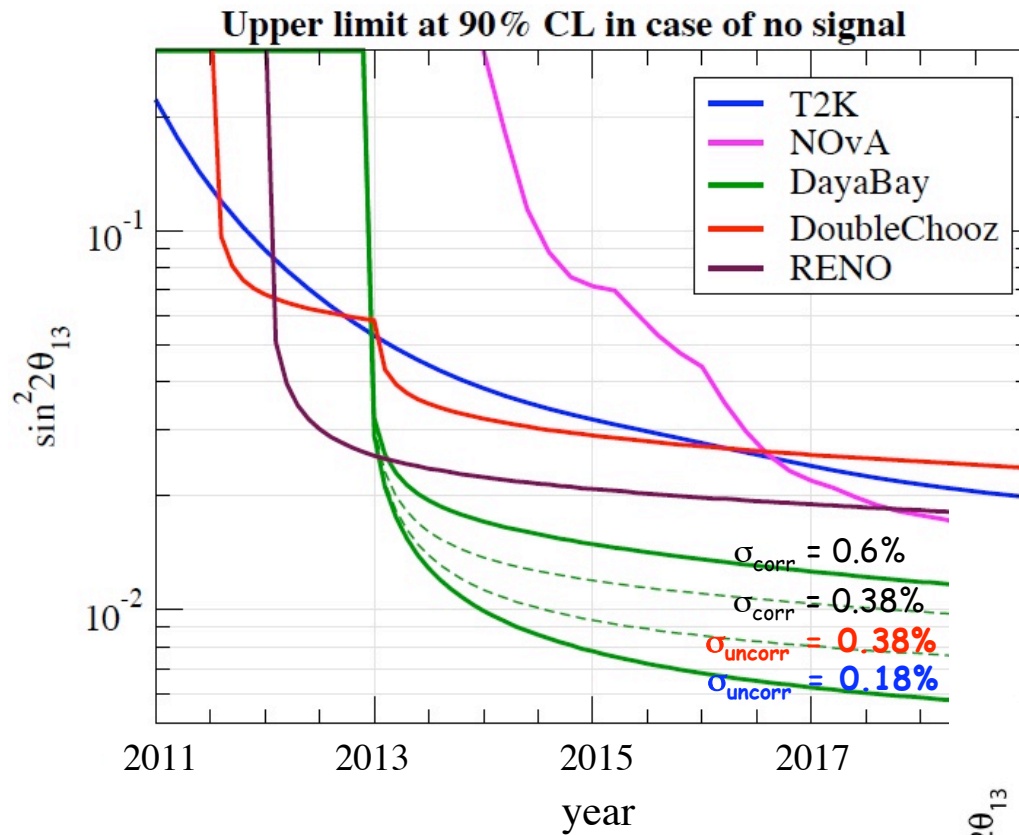|	best fit $\pm 1\sigma$	3σ range	prec@3σ	
$\frac{\Delta m^2_{21}}{10^{-5}\text{eV}^2}$	$7.59^{+0.20}_{-0.18}$	7.09–8.19	7%	KamLAND
$\frac{\Delta m^2_{31}}{10^{-3}\text{eV}^2}$	$2.50^{+0.09}_{-0.16}$ $-(2.40^{+0.08}_{-0.09})$	$2.14-2.76$ $-(2.13-2.67)$	12%	MINOS
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$	0.27–0.36	14%	SNO
$\sin^2\theta_{23}$	$0.52^{+0.06}_{-0.07}$ 0.52 ± 0.06	0.39–0.64	24%	SuperK
$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$ $0.016^{+0.008}_{-0.006}$	0.001–0.035 0.001–0.039	120%	T2K + global data
δ	$\left(-0.61^{+0.75}_{-0.65}\right)\pi$ $\left(-0.41^{+0.65}_{-0.70}\right)\pi$	$0-2\pi$	–	

upper: normal hierarchy, lower: inverted hierarchy

A hint that $\theta_{13} > 0$?
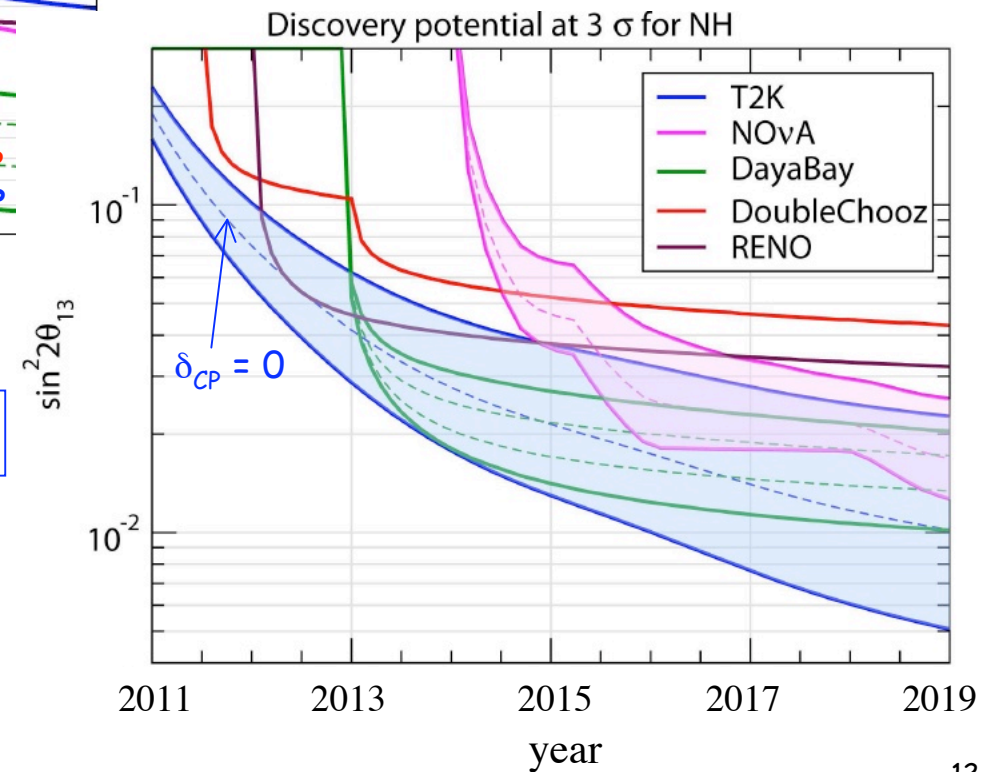
Prospects For Determining θ_{13}

- T2K will resume data taking in December 2011.
  - Power is a concern

- MINOS still has an additional 3×10^{20} p.o.t. of $\bar{\nu}$ being analysed + present running
  - will end data taking in March 2012, effectively 30% more data

- Reactor-based experiments have begun data taking
  - DayaBay: two detectors in a near hall on August 15, 2011
    8 detectors in 2 near & 1 far halls in summer of 2012

  - Double Chooz: one detector in far hall since April 13, 2011
    with near and far detectors in January 2013

  - RENO: one detector in near and one in far hall on August 1, 2011.

- Determining θ_{13} is the focus of studying neutrino oscillation for the next few years.

Pinning Down θ_{13}

Upper limit at 90% CL in case of no signal

Legend:
- T2K
- NOvA
- DayaBay
- DoubleChooz
- RENO

$\sigma_{corr} = 0.6\%$
$\sigma_{corr} = 0.38\%$
$\sigma_{uncorr} = 0.38\%$
$\sigma_{uncorr} = 0.18\%$

y-axis: $\sin^2 2\theta_{13}$
x-axis: year (2011, 2013, 2015, 2017)

Mezzetto & Schwetz, J.Phys.G37(2010)103001

Start dates subject to change.

Discovery potential at 3 σ for NH

Legend:
- T2K
- NOvA
- DayaBay
- DoubleChooz
- RENO

$\delta_{CP} = 0$

y-axis: $\sin^2 2\theta_{13}$
x-axis: year (2011, 2013, 2015, 2017, 2019)

Flavor Physics

Charged-lepton Flavour Violation

- MEG (2009+2010):
  $Br(\mu^+ \rightarrow e^+ \gamma) < 2.4 \times 10^{-12}$
- Goal in 2012: ten-time improvement.

MEG 2010
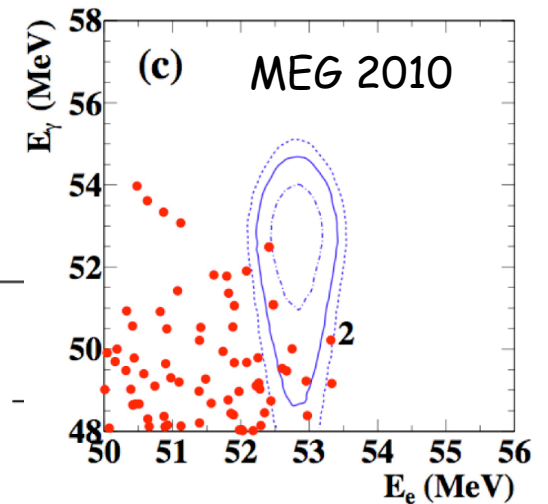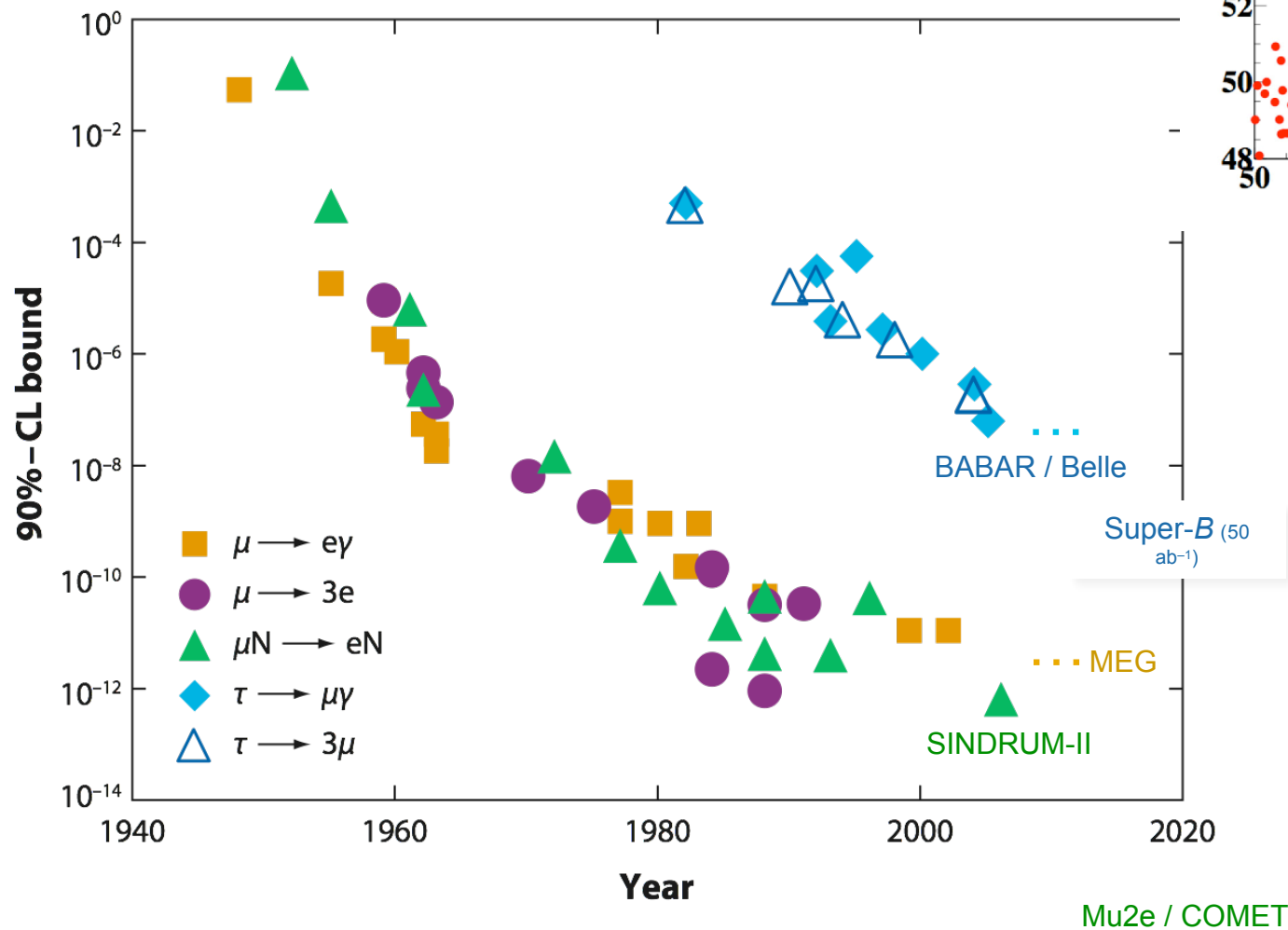
Muon g-2

- Hadronic vacuum polarization (hvp), dominating the theoretical uncertainty, was obtained from the cross section of $e^+e^- \to$ hadrons at low energy.

- New approach (BaBar):

  $e^+e^- \to$ hadrons $+ \gamma$
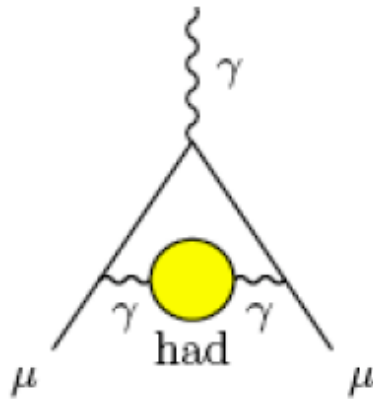
- hvp contribution to a_μ :
  $(685\pm4) \times 10^{-10}$

Status: summer 2011 (published results shown only)

JN 09 (e^+e^--based)
-299 ± 65

DHMZ 10 (τ-based)
-195 ± 54

DHMZ 10 (e^+e^-)
-287 ± 49

HLMNT 11 (e^+e^-)
-261 ± 49

BNL-E821 (world average)
0 ± 63

$a_\mu - a_\mu^{exp}$ $\times 10^{-11}$
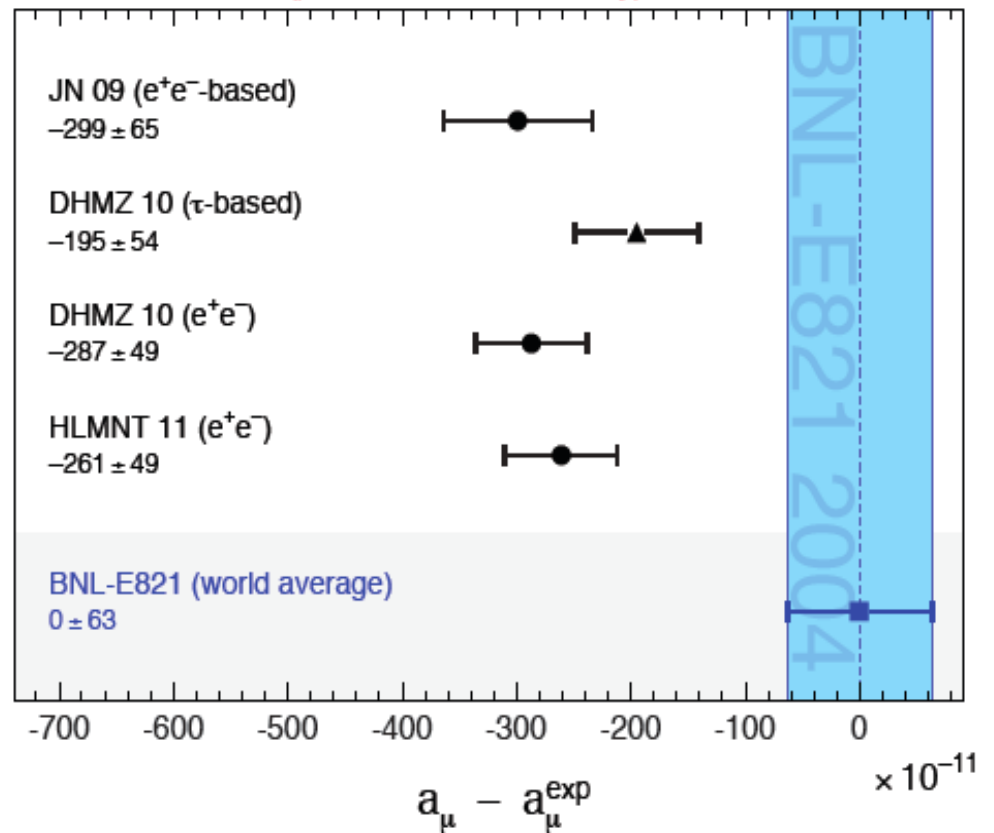
$a_\mu{}^{exp} - a_\mu{}^{SM} = (28.7\pm8.0) \times 10^{-10}$

Spin-exotic 1^{-+} $\pi_1(1600)$

- Forbidden in constituent quark model.
- Could be the lightest predicted $q\bar{q}g$ hybrid meson.
- COMPASS (2008)
  - 100 M $\pi^- + p \to \pi^+ \pi^- \pi^- + p$ events at 190 GeV

- CLEO-c (2011)
  - Very clean sample of $\Psi' \to \gamma\chi_{c1}$
  - Studied $\chi_{c1} \to \eta^{(')} \pi^+ \pi^-$
  - Found 4σ evidence of $\pi_1(1600)$
    - First time seen in charmonium decays
    - M = 1670 ± 30 ± 20 MeV/c2
    - Γ = 240 ± 50 ± 60 MeV
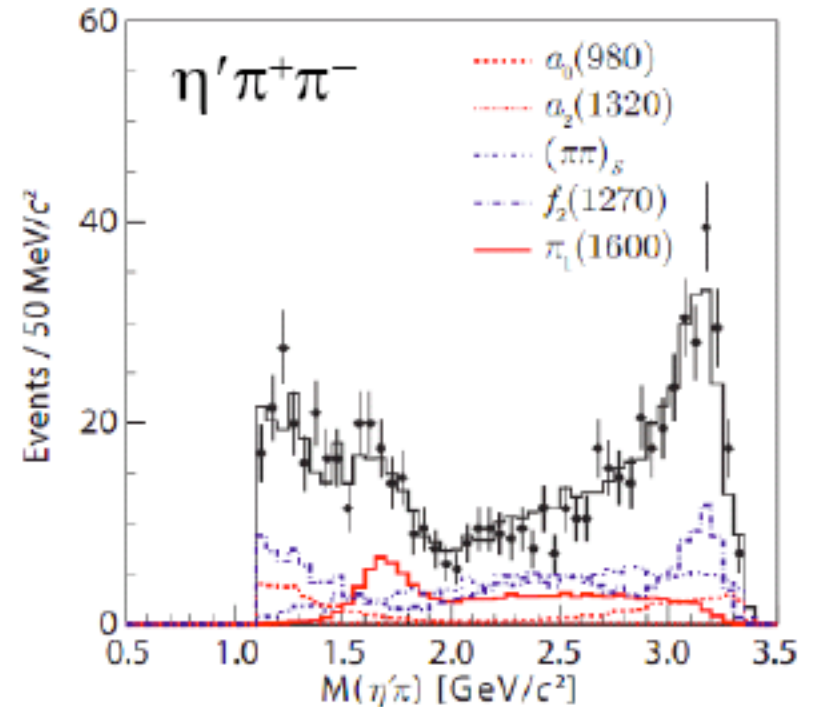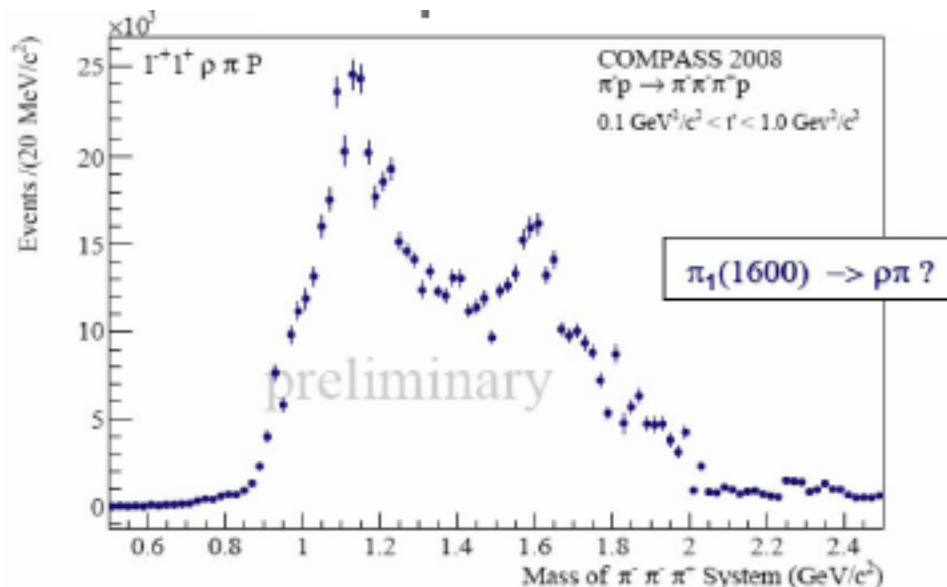
X(3872)

- First seen in B → KX, X → J/Ψ $\pi^+\pi^-$ by Belle in 2003
- Now confirmed by BABAR, CDF, D0, LHC-b, CMS
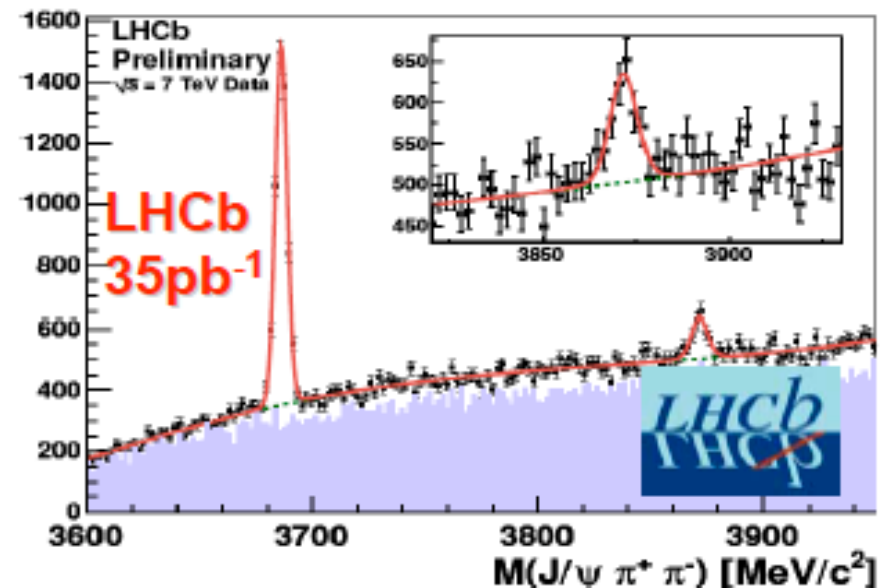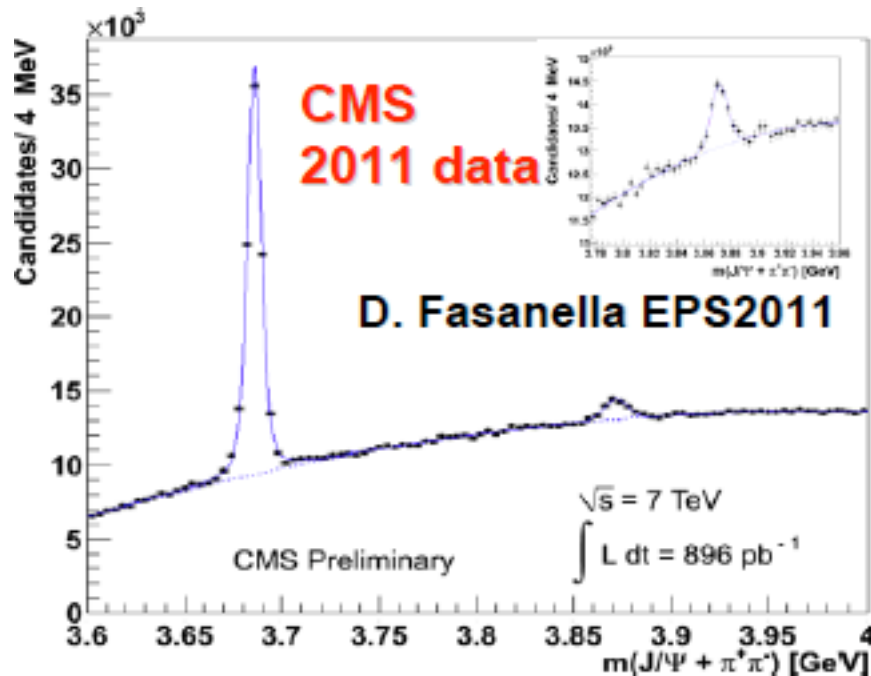
- Nature is unknown but not a conventional $c\bar{c}/cc$ state.
- Does not seem to have a charged partner.

Bottomonium Family

- Belle observed the $h_b(nP)$ states in

$$\Upsilon(5S) \to \text{'miss'} + \pi^+ \pi^-$$

using missing mass method.
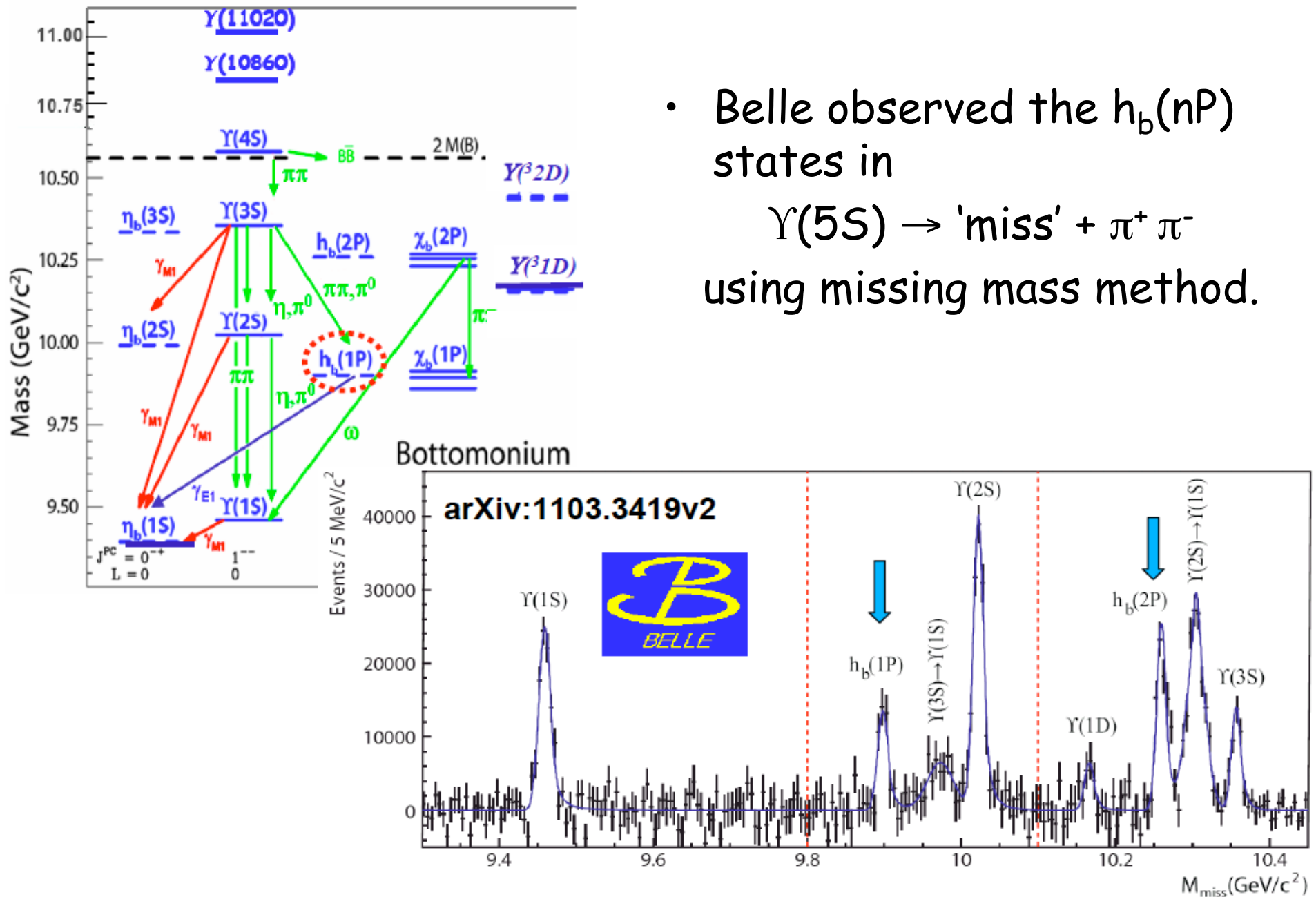
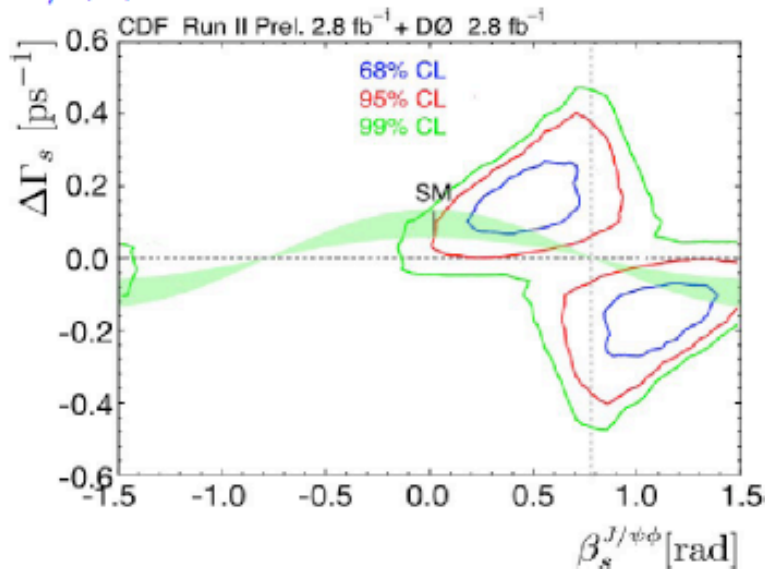# CKM Matrix in 2011: High Precision
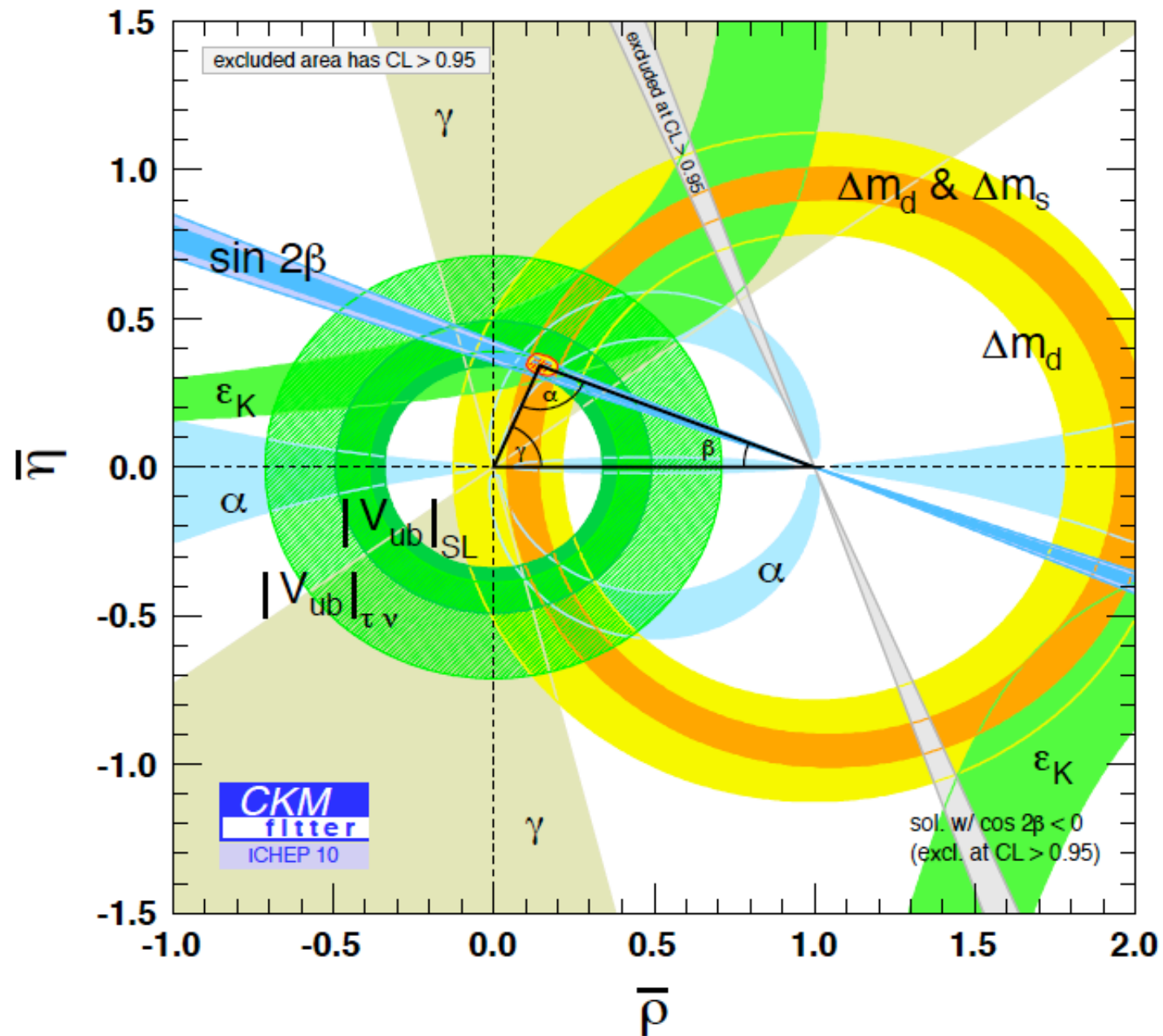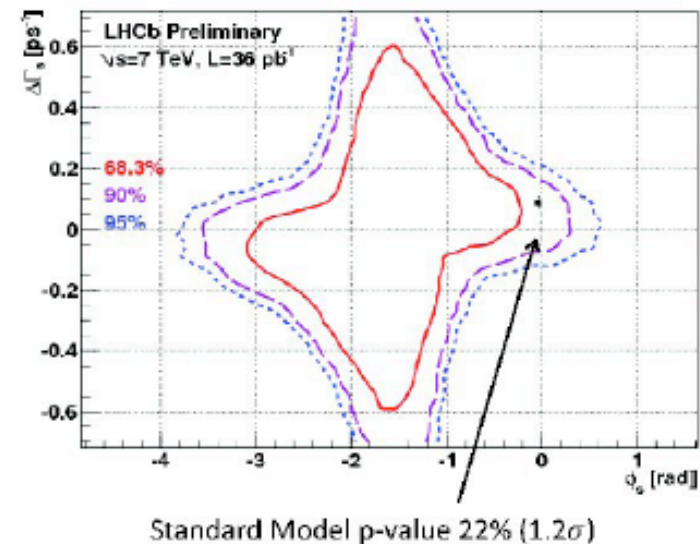
Hints of New Physics ?

$B \to \tau\nu$
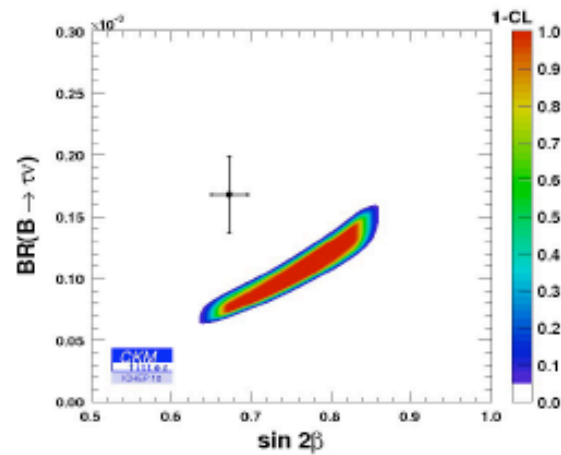
Like-sign dimuon asymmetry
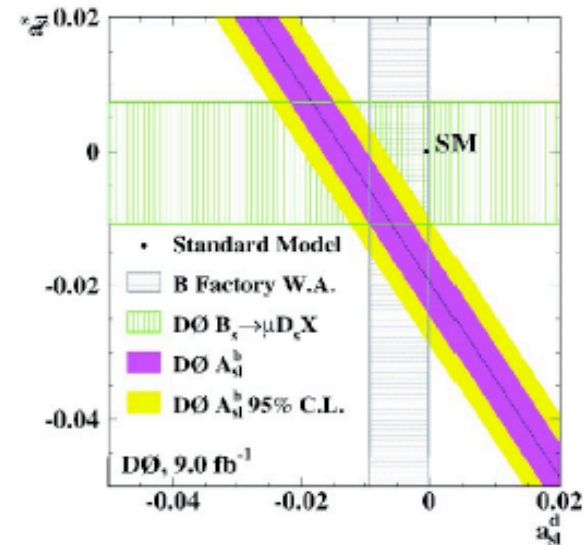
$J/\psi\phi$ at Tevatron

$J/\psi\phi$ at LHCb

Assymmetry of Same-sign Dimuon

DO found: $A_{sl} = (-0.787\pm0.172\pm0.093)\%$,
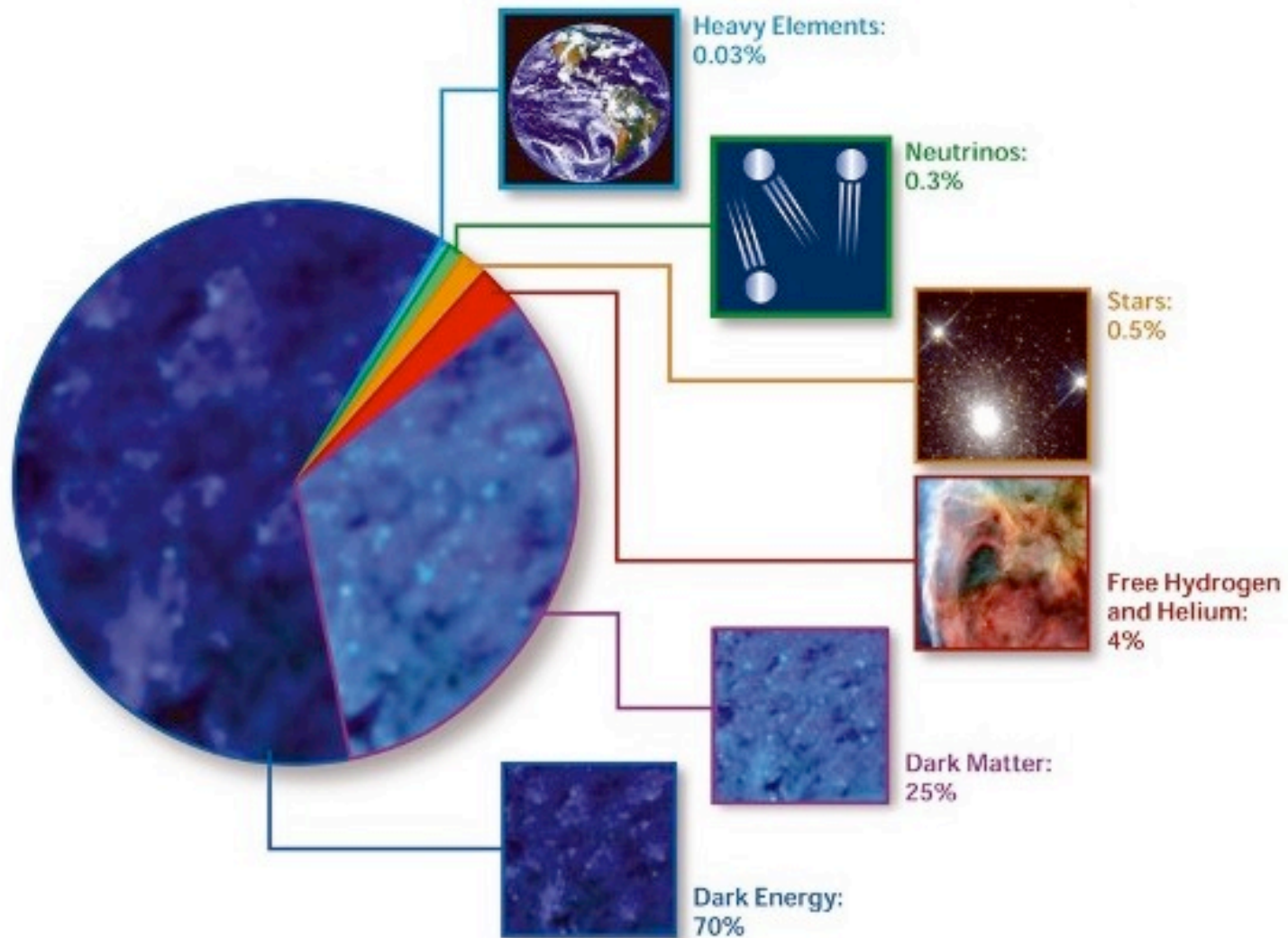a 3.9 σ deviation from expectation [$(-0.023\pm0.005)\%$].

Events with small impact
parameter seem to be
responsible for the
disagreement.

Is it due to B_s ?
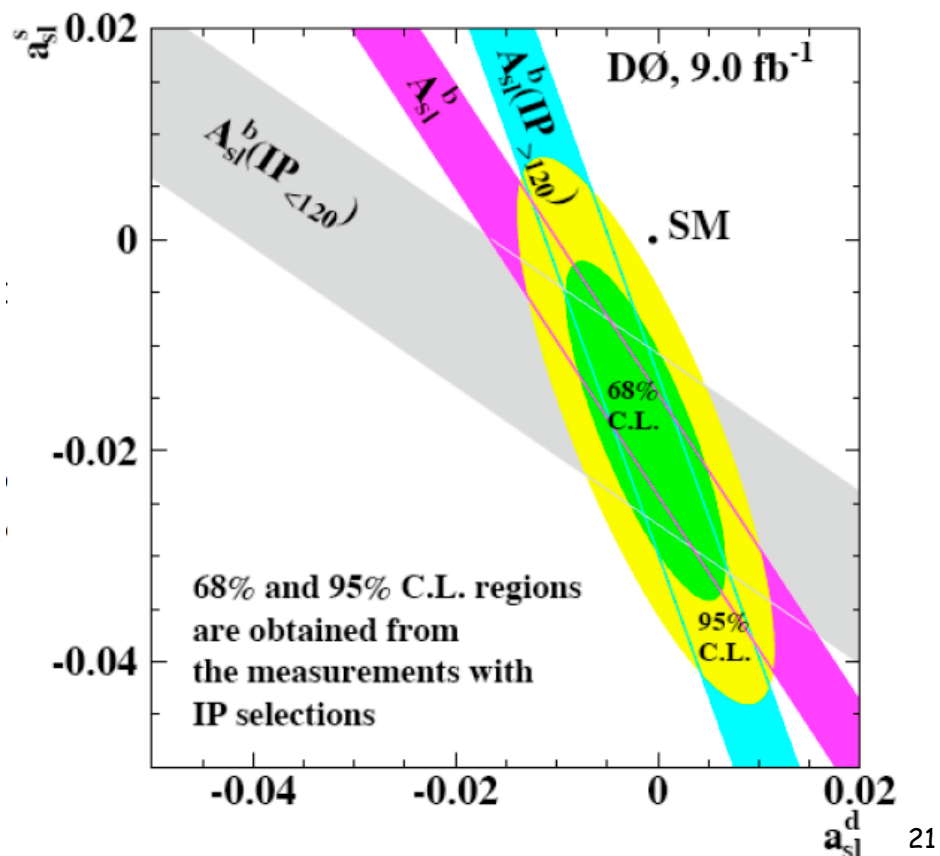
Dark Matter

Constituents of Present Universe

Heavy Elements:
0.03%

Neutrinos:
0.3%

Stars:
0.5%

Free Hydrogen and Helium:
4%

Dark Matter:
25%

Dark Energy:
70%

What is Dark Matter?

Unveiling Dark Matter

WIMPs as particles:
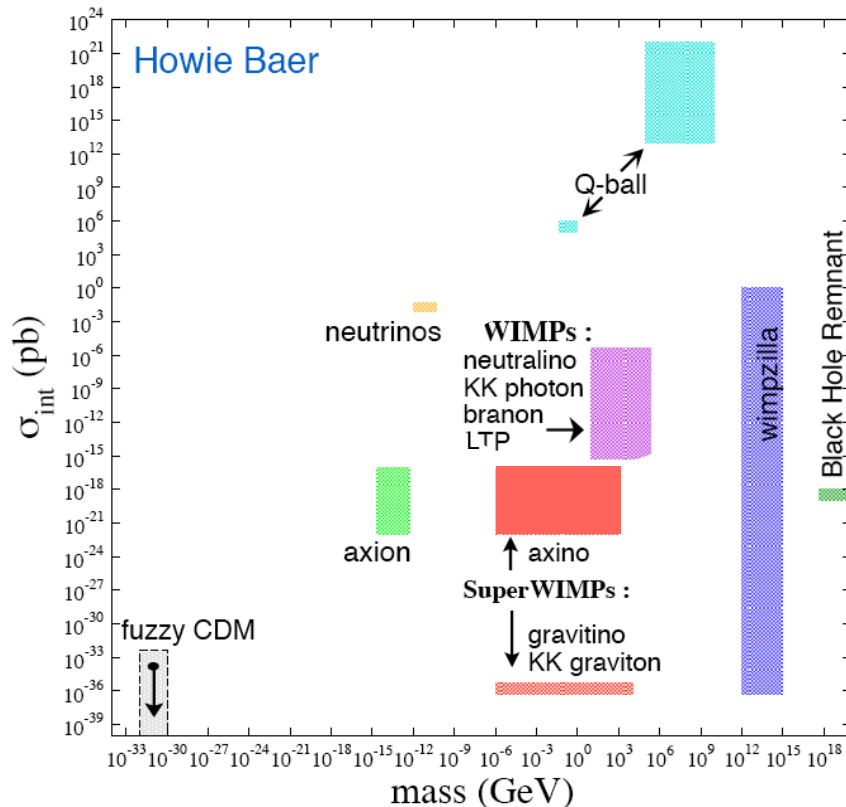
Direct Search:
- Detect WIMPs on Earth by elastic scattering
- Determine local density of WIMPs

Indirect Search:
- Probe WIMPs outside of Earth
- Annihilation of slow WIMPs
- Detect final-state particles on Earth or in space

Accelerator Search:
- Produce and detect WIMPs directly

- Discovery with accelerators may have nothing to do with WIMPs.
- Discovery of direct search may not be a particle.

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Indirect Detection of Dark Matter

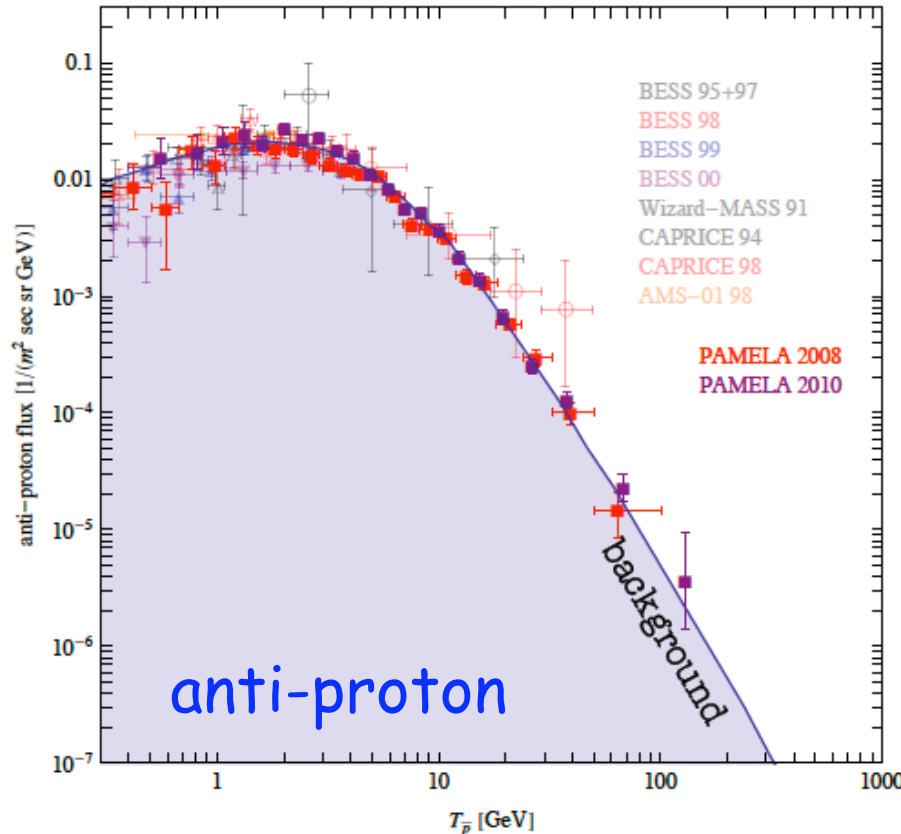- Look for final-state particles from annihilation of dark-matter in the Universe.
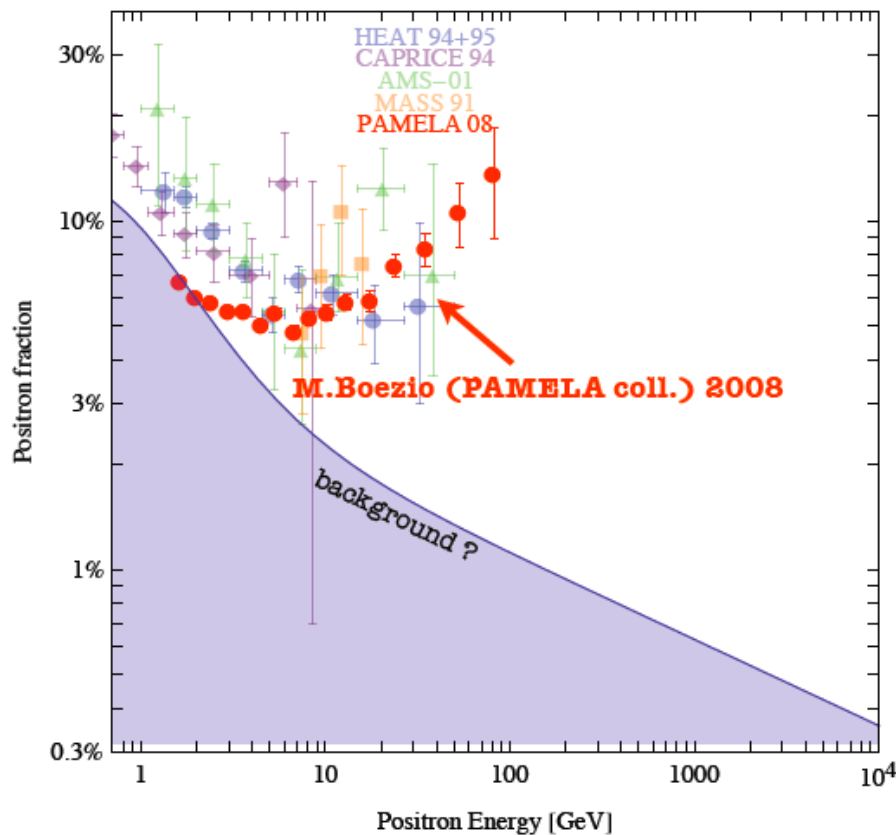
$$\text{positron fraction} = \frac{N_{e+}}{N_{e+} + N_{e-}}$$
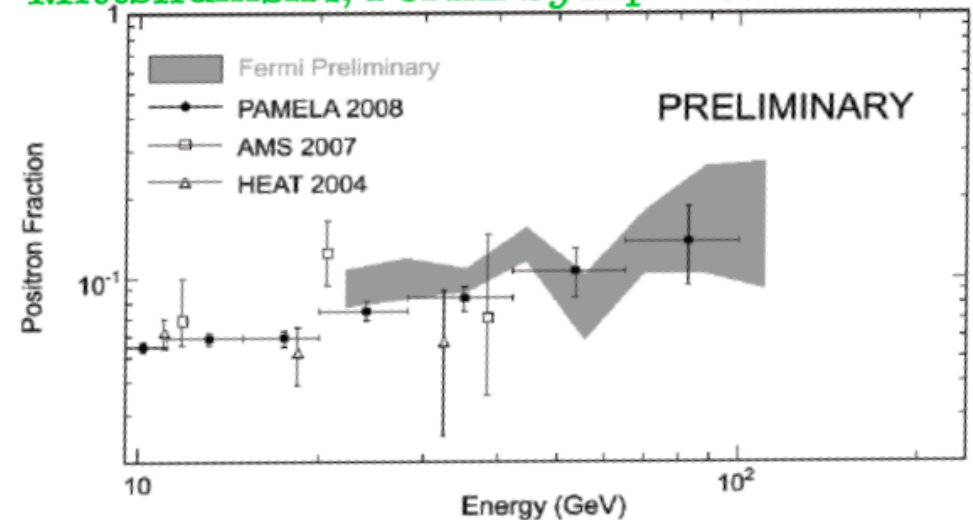
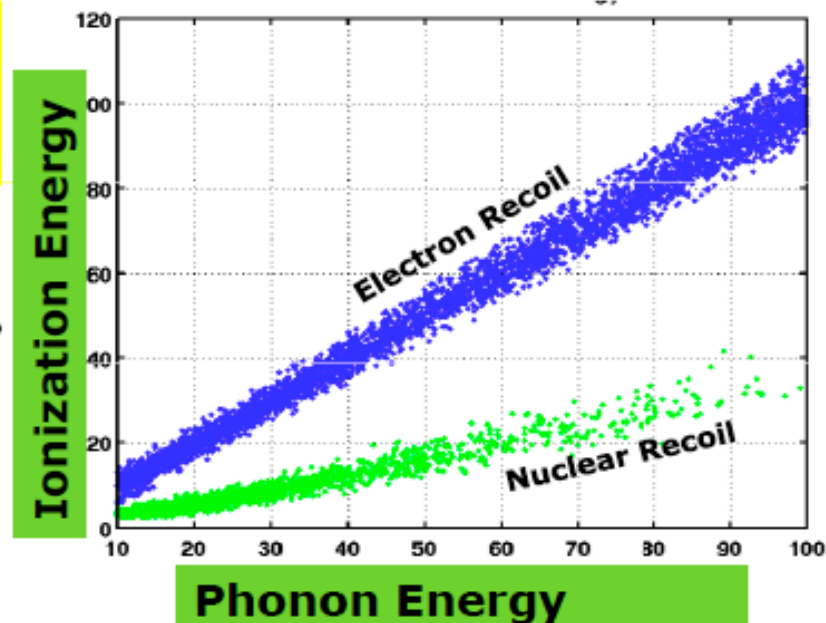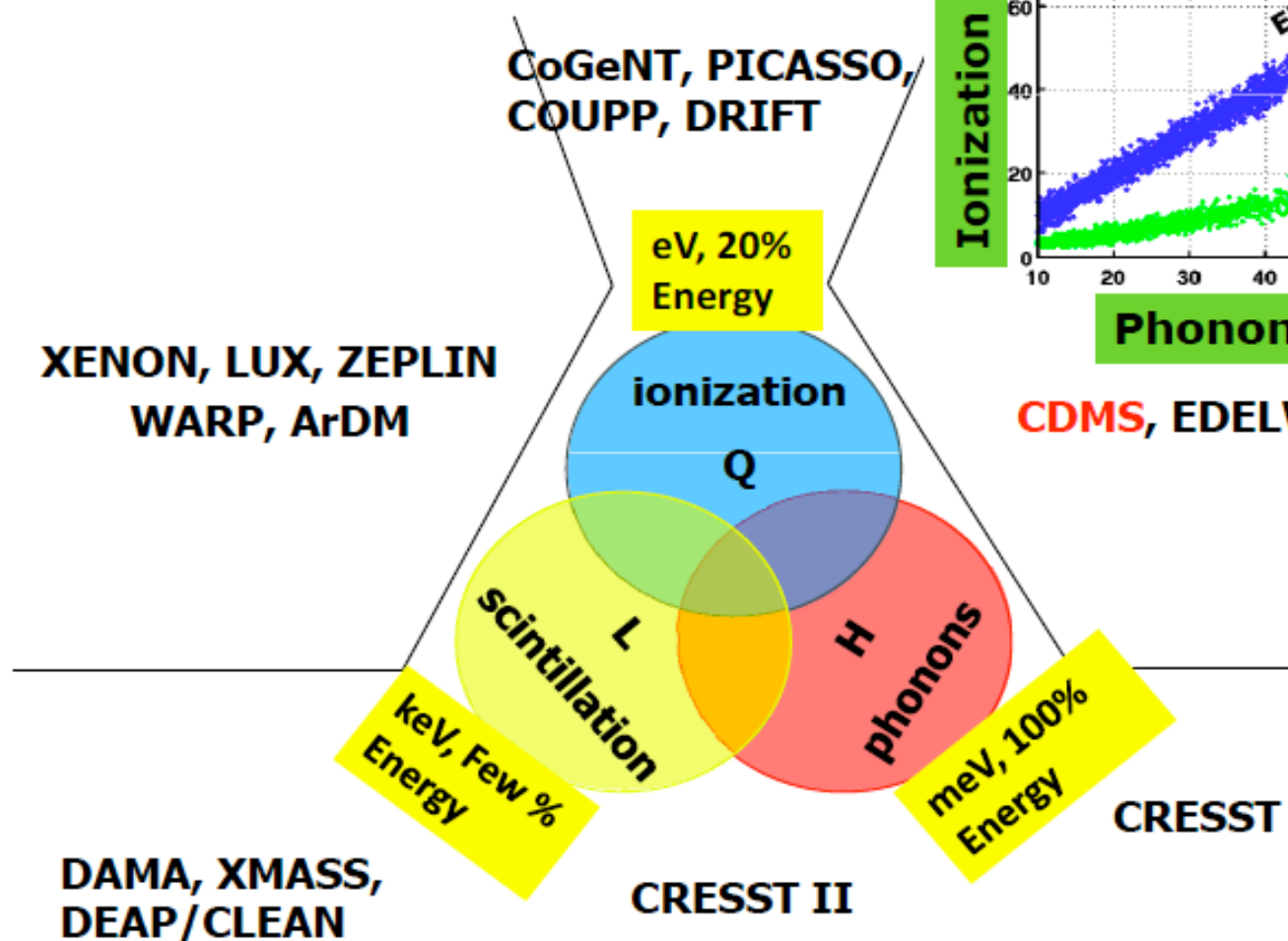
Hints of dark matter ?

Indirect Detection of Dark Matter II
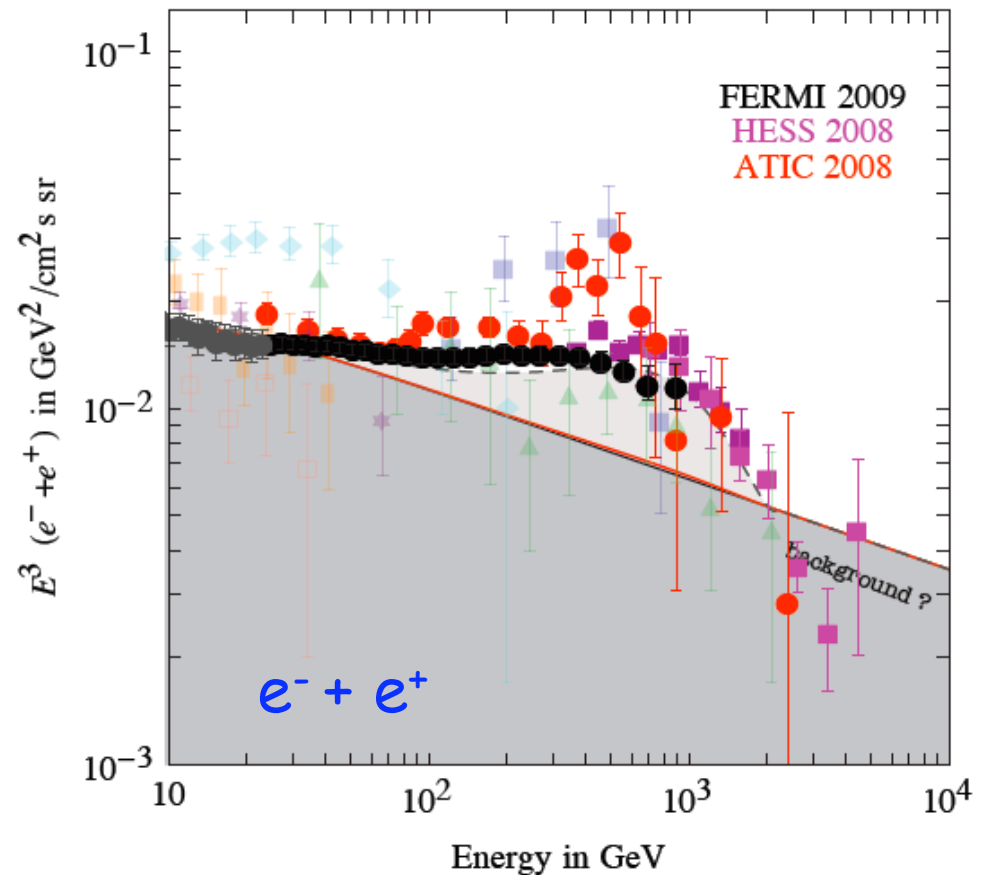
- No excess in both channels.
- Challenge: too many unknowns and uncertainties in astrophysics and particle physics to interpret the observations.
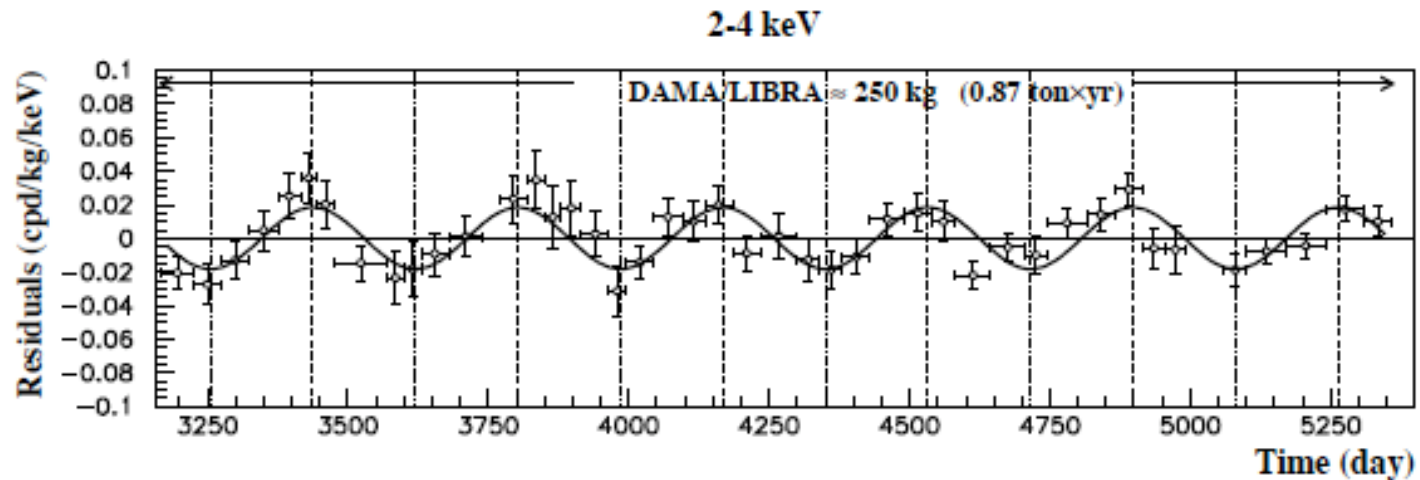
Direct Detection of Dark Matter

**Detection and Discrimination Methods**

CoGeNT, PICASSO, COUPP, DRIFT

XENON, LUX, ZEPLIN WARP, ArDM

CDMS, EDELWEISS

eV, 20% Energy

ionization

Q

scintillation L

H phonons

keV, Few % Energy

meV, 100% Energy

CRESST

DAMA, XMASS, DEAP/CLEAN

CRESST II

Ionization Energy

Electron Recoil

Nuclear Recoil

Phonon Energy

Evidence of Dark Matter ?

- DAMA @ LNGS (250 kg of ultra-pure NaI) observed annual modulation:
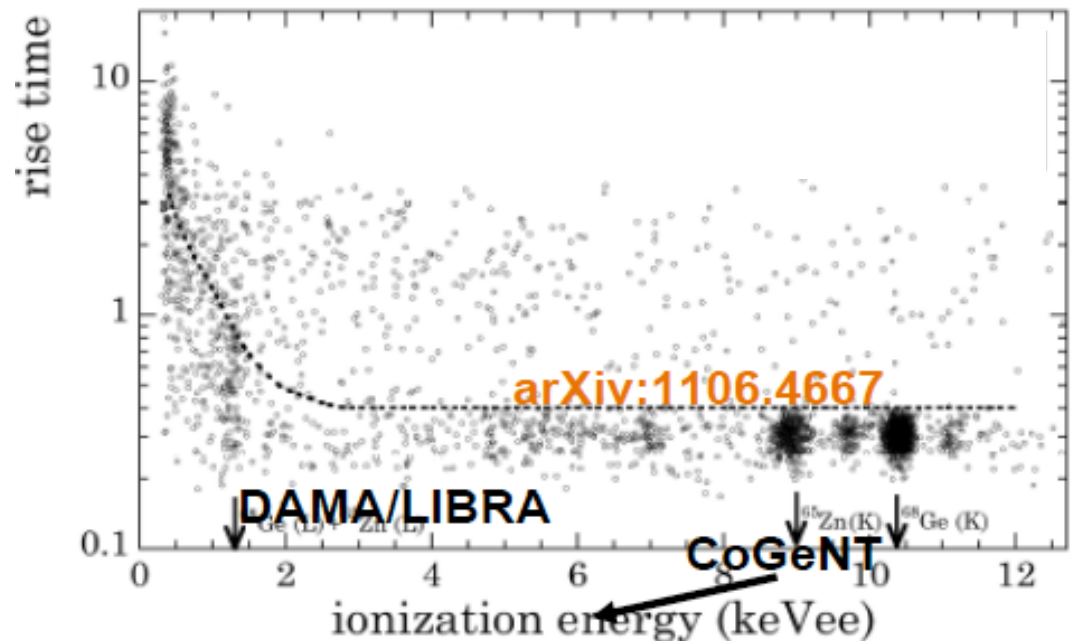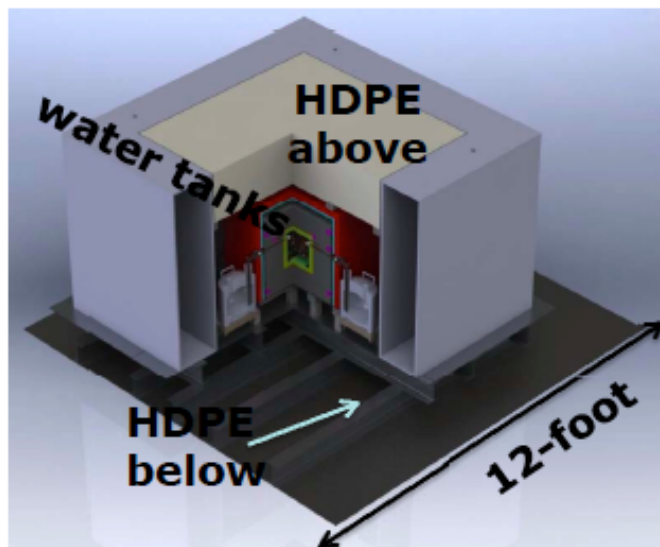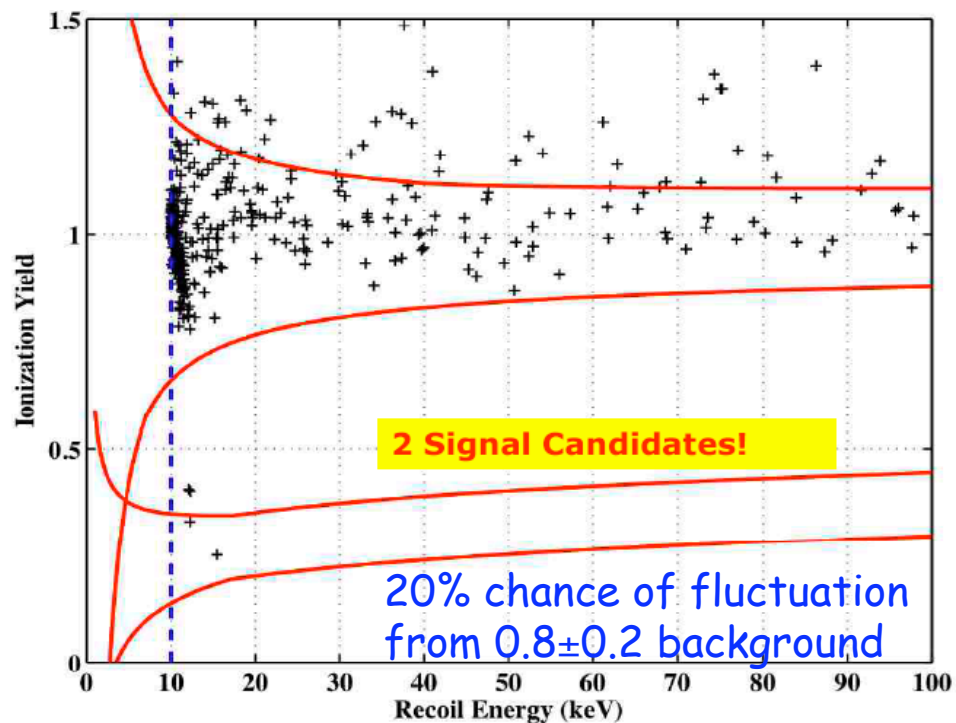

- Muons have annual modulation too:
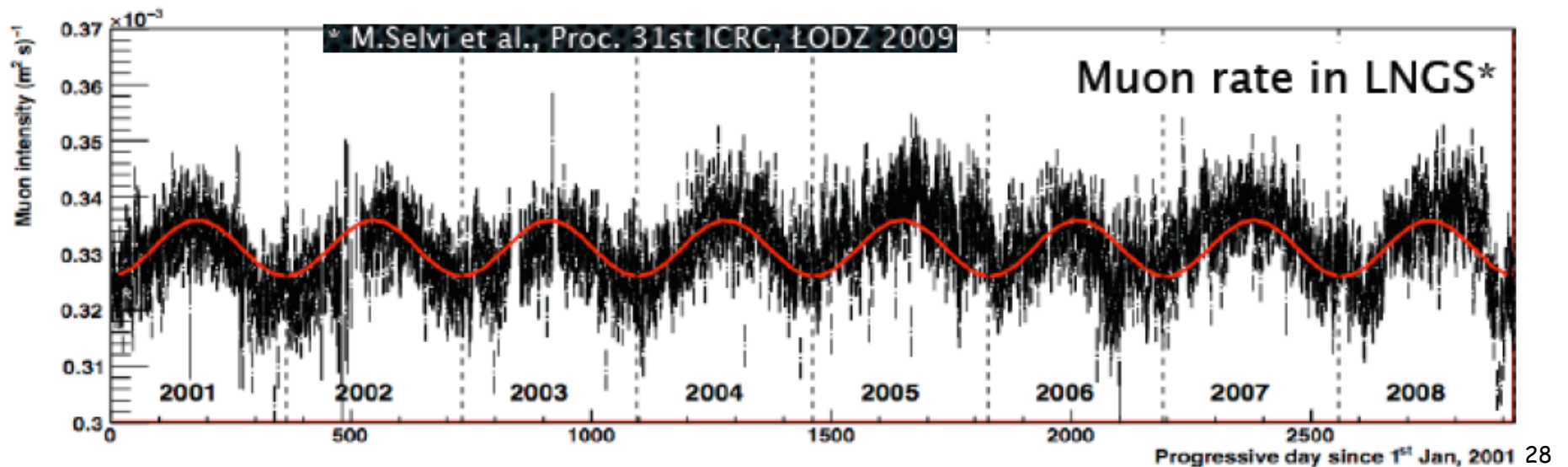
CoGeNT: Another Hint ?

- CoGeNT @ Soudan
- Observed
  - excess events with the first point-contact Ge detector.
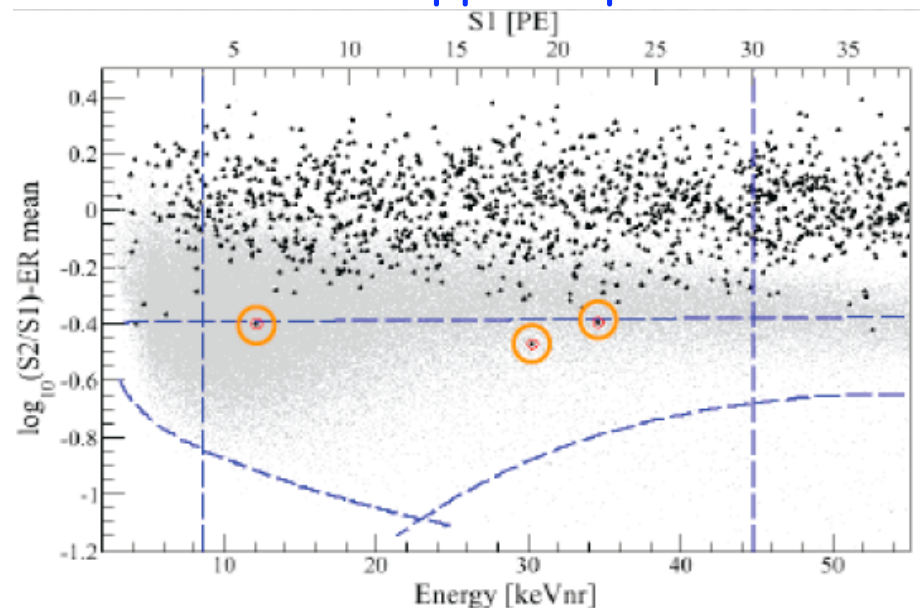 - 2.8σ annual modulation of unknown origin
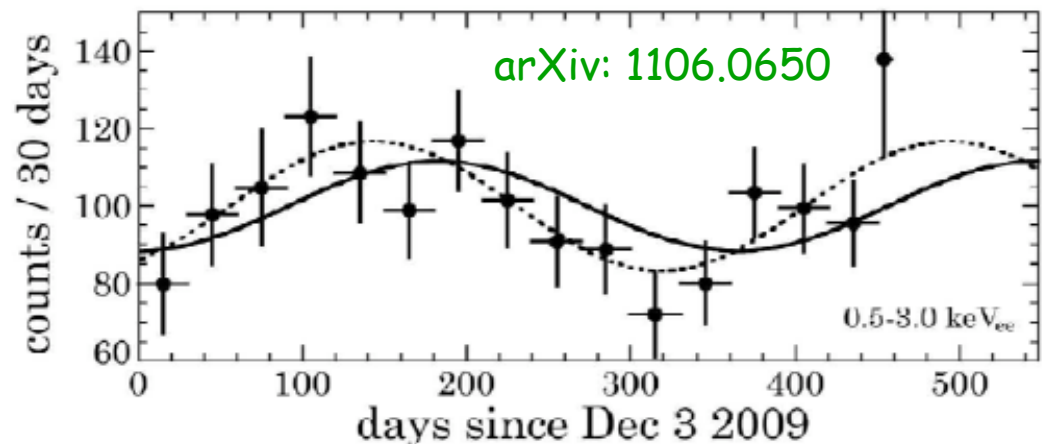
CDMS-II & XENON-100

- ## CDMS-II @ Soudan

  – cryogenic 4 kg Ge detector

  – ~keV threshold

  – excellent energy resolution, ~0.2 keV
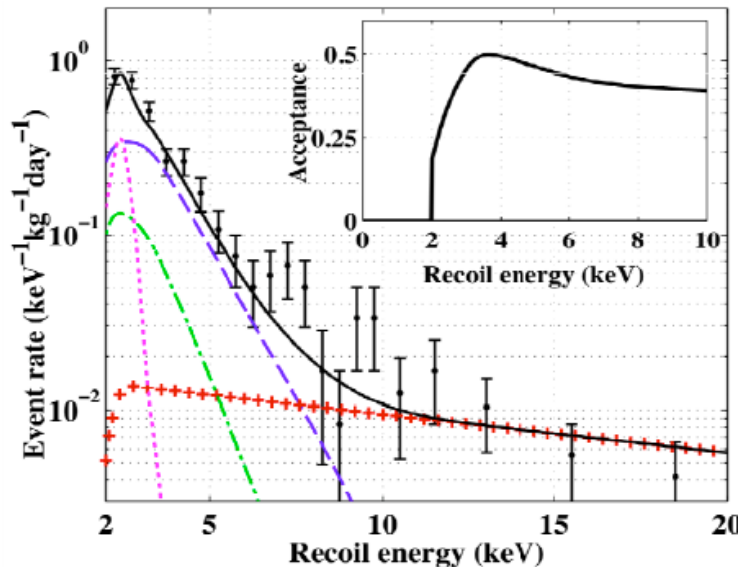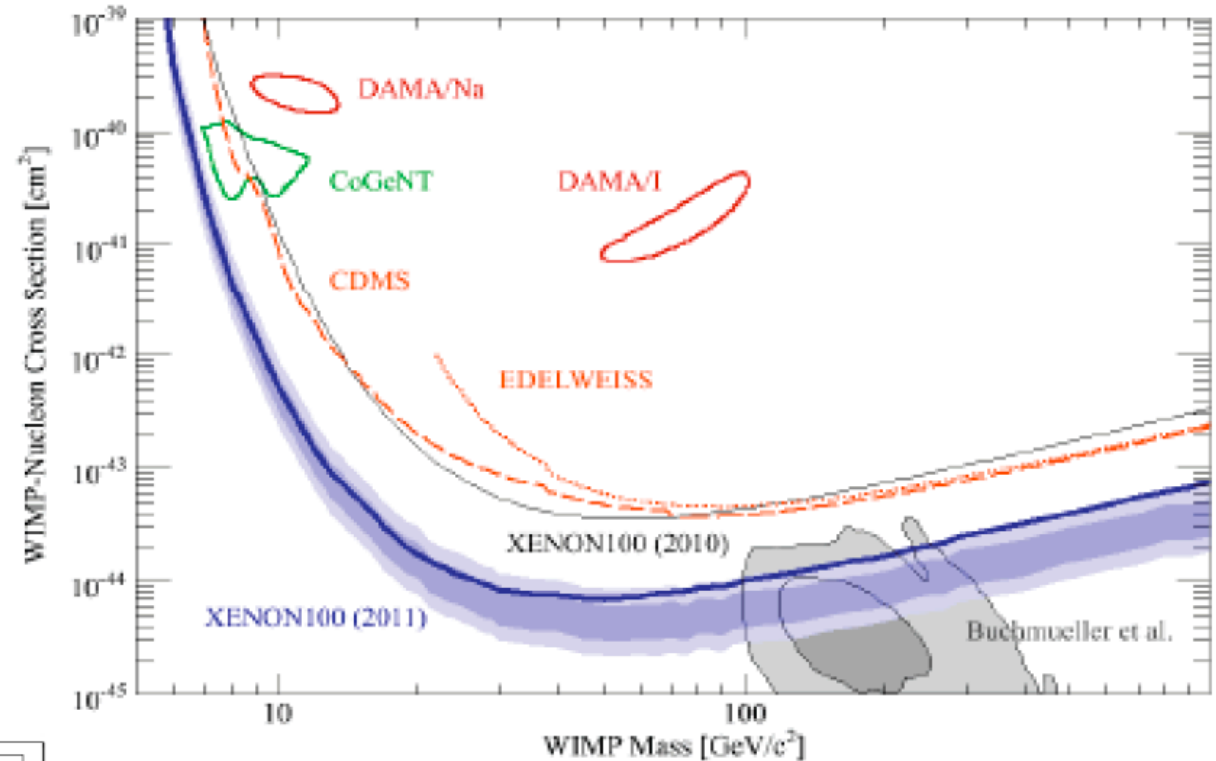
  – <~mm 3-d spatial resolution

- ## XENON-100 @ LNGS

  – 1500 kg-days exposure (1/2010 - 6/2010)

  – observed 6 candidates

    • 3 identified as noise

    • 3 candidates on top of 1.8 0.6 expected background

  – had a ~700 ppt Kr problem

What Have We Learned ?

- With no background subtraction limits, CDMS and XENON 100 rule out DAMA and CoGeNT


- Background increases exponentially at low energy
  - S/N gets worse
  - Low-energy candidates yield low-mass WIMPs
  - Takes time to understand the problems
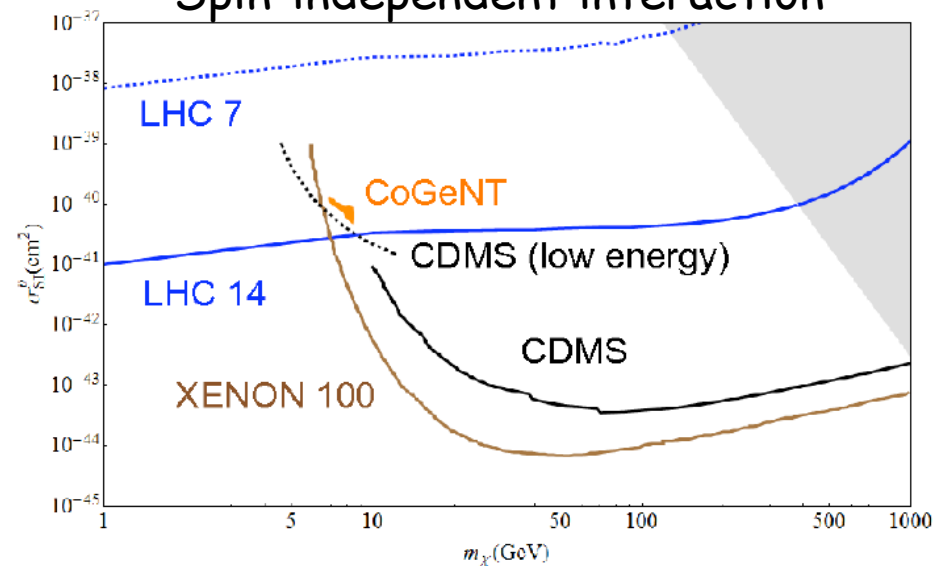
Search for Dark Matter with Accelerator

- Signature in collider experiments:
  - Long-live weakly interacting neutral particle, χ
  - Events with missing E_T

- Sensitivity:

Spin-dependent interaction

Spin-independent interaction
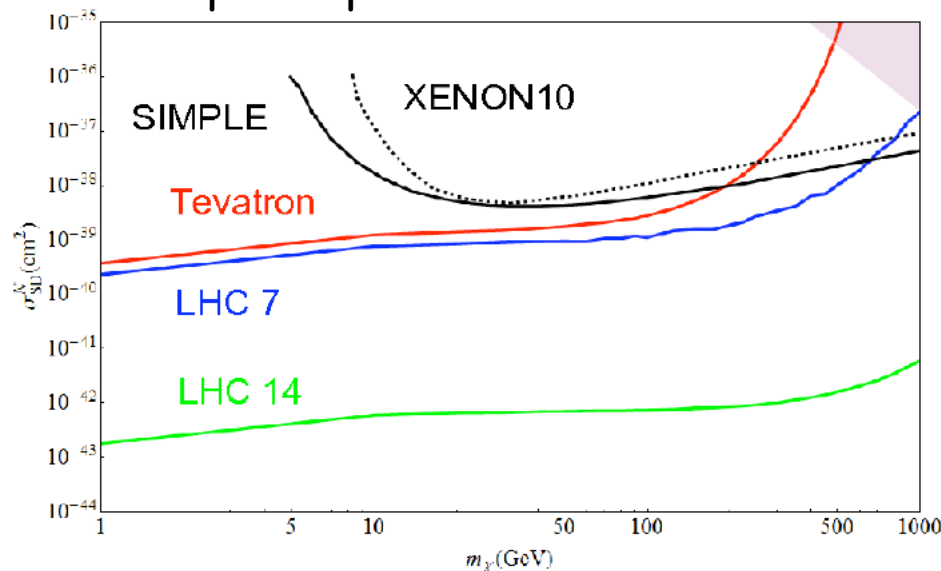
This is the window of opportunity for LHC.

LHC at 14 TeV can only help up to $m_\chi \sim 5$ GeV.