Neutrinos, Cosmology

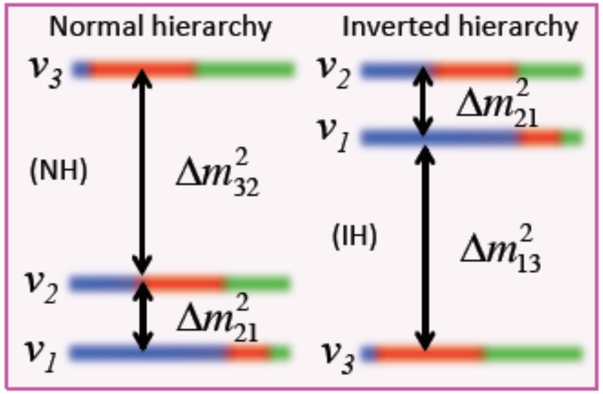
Δm^2, Θ_{ij} measured. Q: hierarchy? CP phase δ, More then 3?

T2K Neutrino Oscillations: Current Status

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} \mathrm{Re}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin^2\left(\tfrac{1}{4}\Delta m^2_{ij}\frac{L}{E}\right) + 2\sum_{i>j} \mathrm{Im}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin\left(\tfrac{1}{2}\Delta m^2_{ij}\frac{L}{E}\right)$$

Oscillation Probability

L: source-detector distance
E: neutrino energy

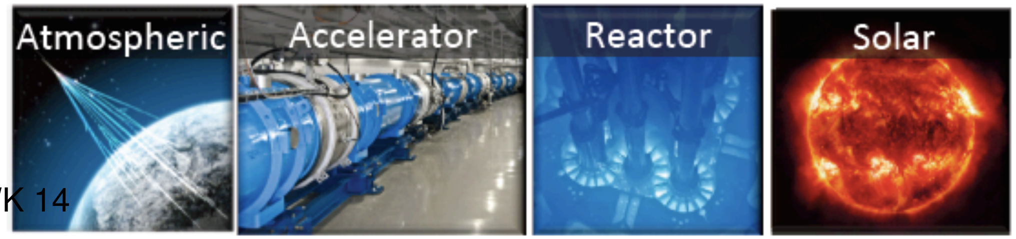


$c_{ij} = \cos\theta_{ij}$
$s_{ij} = \sin\theta_{ij}$

$$U_{PMNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\Delta m^2_{21} = 7.58^{+0.22}_{-0.26} \times 10^{-5}\,\mathrm{eV}^2$

$\left|\Delta m^2_{32}\right| = 2.35^{+0.12}_{-0.09} \times 10^{-3}\,\mathrm{eV}^2$



P.de Perio, Moriond EWK 14

SK, MINOS, K2K, *T2K*: $\sin^2(2\theta_{23}) > 0.95$ (90% CL)

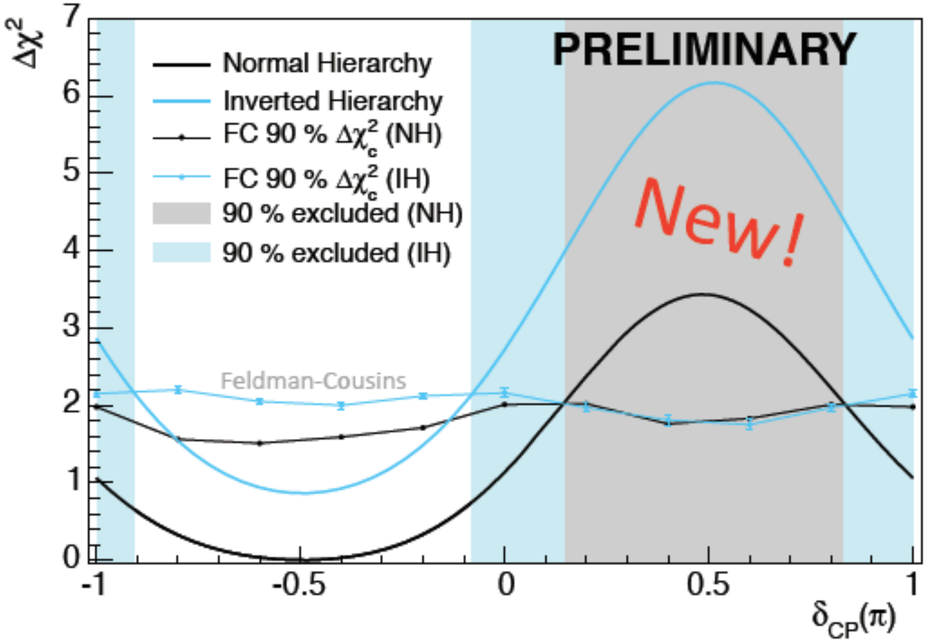
T2K, MINOS; DB, RENO, DC: $\sin^2(2\theta_{13}) = 0.098 \pm 0.013$

KamLAND; SNO, SK: $\sin^2(2\theta_{12}) = 0.857 \pm 0.024$

Towards Dirac CP Phase

Joint $\nu_\mu + \nu_e$ Analysis: Constraints on δ_{CP}

Likelihood ratio fit to both $\nu_\mu + \nu_e$ event samples



Accounting for correlations in the parameter space

$(\theta_{23}, \theta_{13}, \delta_{CP}, \Delta m^2_{32})$

Including constraint from reactor experiments *Daya Bay, RENO, Double Chooz*

$\sin^2 2\theta_{13} = 0.095 \pm 0.010$ (PDG 2013)

	90% CL Inclusion
NH	$\delta_{CP} \in [-1.18, 0.15]\pi$
IH	$\delta_{CP} \in [-0.91, -0.08]\pi$

PRELIMINARY

T2K hints toward $\delta_{CP} = -\pi/2$

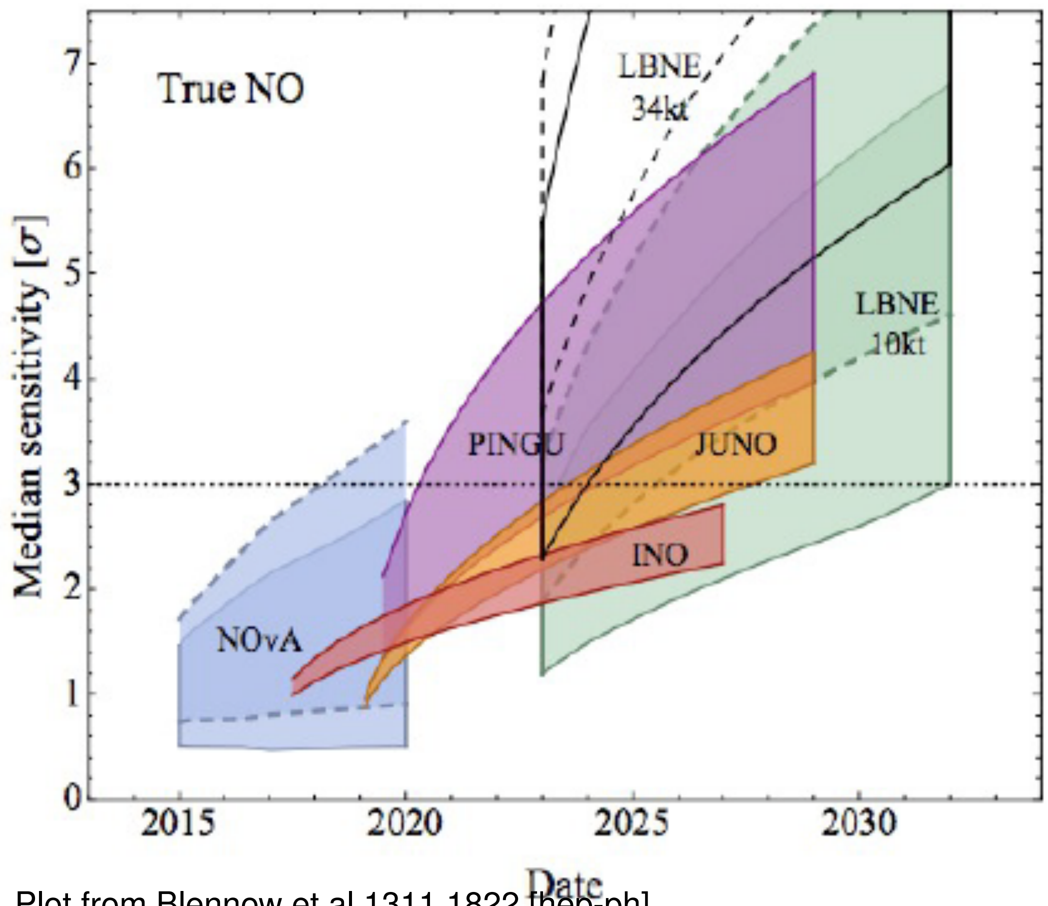
15 / 38

P.de Perio, Moriond EWK 14

Rencontres de Moriond, March 17, 2014 Patrick de Perio: T2K Neutrino Oscillation Results 15

Towards Mass ordering (hierarchy)

Future sensitivity rejecting IH with oscillation experiments long term perspective; input δ etc varied:



Talk P. Coloma, Moriond EWK 14, Plot from Blennow et al 1311.1822 [hep-ph]

$N_\nu = 3$ hypothesis succesful re most earth based data.

- however, a few experiments exhibit deviations from the "standard" 3ν scenario:
  - LSND & MiniBooNE observe excesses of $\overset{(-)}{\nu}_e$ events in $\overset{(-)}{\nu}_\mu$ beams;
  - SBL reactors observe a deficit with respect to the expected $\bar{\nu}$ fission flux;
  - gallium experiments exposed to radioactive sources also find a deficit;
- sterile neutrino models fail to explain satisfactorily **all** the experimental data:

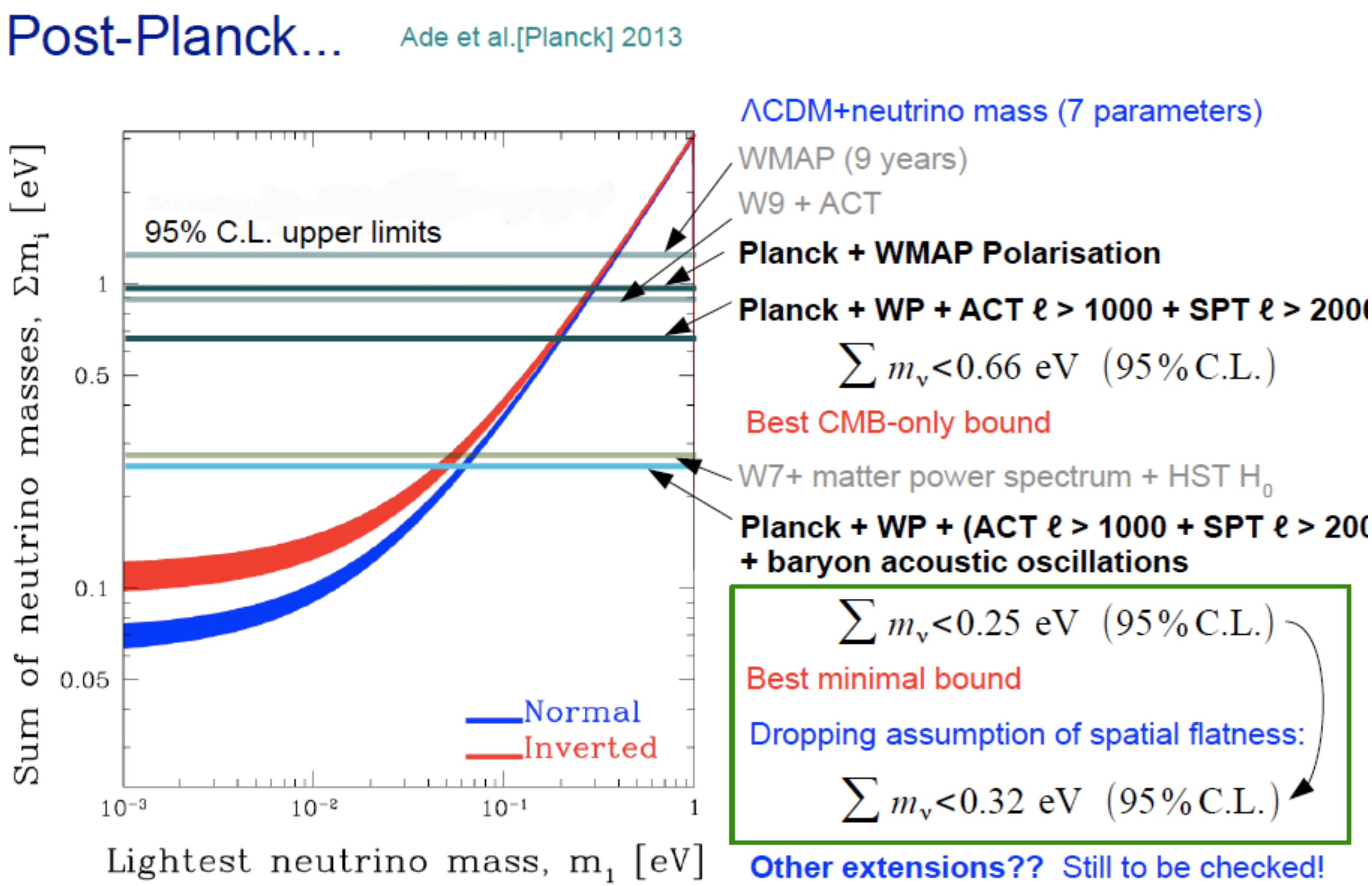
Requirement	(3+0)	(2+2)	(3+1)	(3+2)	(1+3+1)
Ordinary neutrino oscillation data	OK	NO	OK	OK	OK
$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$: SBL reactor & gallium data	NO	OK	OK	OK	OK
$\bar{\nu}_\mu \to \bar{\nu}_e$: LSND & MB $\bar{\nu}$ data	NO	OK	OK	OK	OK
$\nu_\mu \to \nu_e$: MB high-energy ν data	OK	POOR	POOR	OK	OK
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$: MB low-energy excess	NO	POOR	POOR	OK	OK
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$: disappearance data	OK	OK	NO	NO	NO
Constraints from cosmology	OK	NO	OK	NO	NO

$\Rightarrow$ we are still quite far from the solution of the LSND puzzle!

Michele Maltoni <michele.maltoni@csic.es> **Moriond EW 2014, 17/03/2014**

Talk Maltoni, Moriond EWK 14

$m_\nu <$?



Talk Y.Wong, Moriond EWK 14

Effective number of light "sterile" species $N_{eff} =$? Contribution to energy density $\sum_{i=1}^{3} \rho_{i\nu} + \rho_X \propto (3.046 + \Delta N_{eff}))$

Placnk-inferred $N_{\rm eff}$ compatible with 3.046 at better than 2σ.

2σ error bars	*Planck*+WP		*Planck*+WP+BAO		*Planck*+WP+highL		*Planck*+WP+highL+BAO	
Parameter	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits	Best fit	95% limits
Ω_K	−0.0105	$-0.037^{+0.043}_{-0.049}$	0.0000	$0.0000^{+0.0066}_{-0.0067}$	−0.0111	$-0.042^{+0.043}_{-0.048}$	0.0009	$-0.0005^{+0.0065}_{-0.0066}$
Σm_ν [eV]	0.022	< 0.933	0.002	< 0.247	0.023	< 0.663	0.000	< 0.230
$N_{\rm eff}$	3.08	$3.51^{+0.80}_{-0.74}$	3.08	$3.40^{+0.59}_{-0.57}$	3.23	$3.36^{+0.68}_{-0.64}$	3.22	$3.30^{+0.54}_{-0.51}$
Y_P	0.2583	$0.283^{+0.045}_{-0.048}$	0.2736	$0.283^{+0.043}_{-0.045}$	0.2612	$0.266^{+0.040}_{-0.042}$	0.2615	$0.267^{+0.038}_{-0.040}$
$dn_s/d\ln k$	−0.0090	$-0.013^{+0.018}_{-0.018}$	−0.0102	$-0.013^{+0.018}_{-0.018}$	−0.0106	$-0.015^{+0.017}_{-0.017}$	−0.0103	$-0.014^{+0.016}_{-0.017}$
$r_{0.002}$	0.000	< 0.120	0.000	< 0.122	0.000	< 0.108	0.000	< 0.111
w	−1.20	$-1.49^{+0.65}_{-0.57}$	−1.076	$-1.13^{+0.24}_{-0.25}$	−1.20	$-1.51^{+0.62}_{-0.53}$	−1.109	$-1.13^{+0.23}_{-0.25}$

Talk Y.Wong, Moriond EWK 14 ,... but

Wong points out that a discrepancy in the determination of the Hubble parameter H_0 from Hubble space telescope and others

Parameter	*Planck* Best fit	*Planck* 68% limits	*Planck*+lensing Best fit	*Planck*+lensing 68% limits	*Planck*+WP Best fit	*Planck*+WP 68% limits
σ_8	0.8344	0.834 ± 0.027	0.8285	0.823 ± 0.018	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.45	$10.8^{+3.1}_{-2.5}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	68.14	67.9 ± 1.5	67.04	67.3 ± 1.2

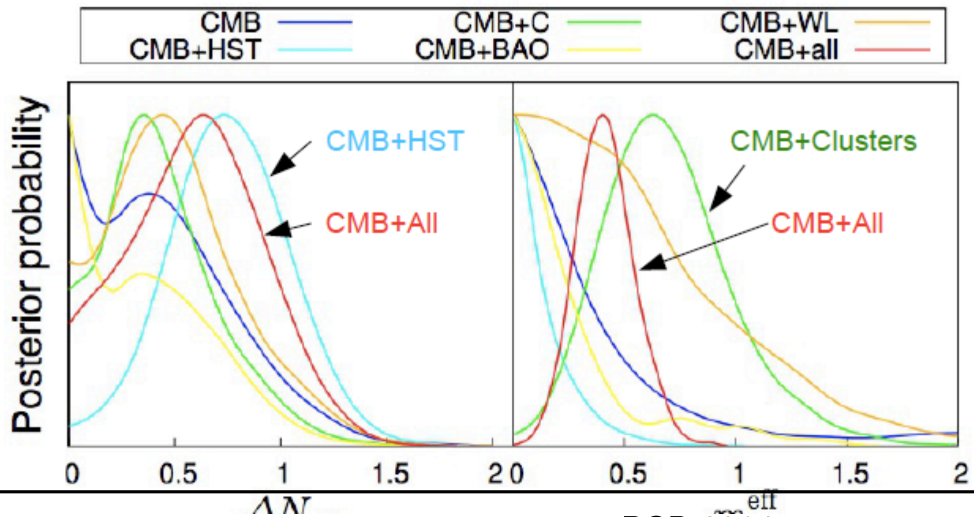
Hubble space telescope

$$H_0 = 73.8 \pm 2.4\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

Riess et al. 2011

Exploit the $N_{eff} - H_0$ degeneracy and introduce to a large N_{eff} to bring HST and Planck in line with one another.

could be resolved with fourth ν



CMB+all
(ΛCDM+ΔN_{eff}+m_s
8-parameter model)

$$\Delta N_{eff} = 0.61 \pm 0.30$$
$$m_s = (0.41 \pm 0.13)\ \mathrm{eV}$$

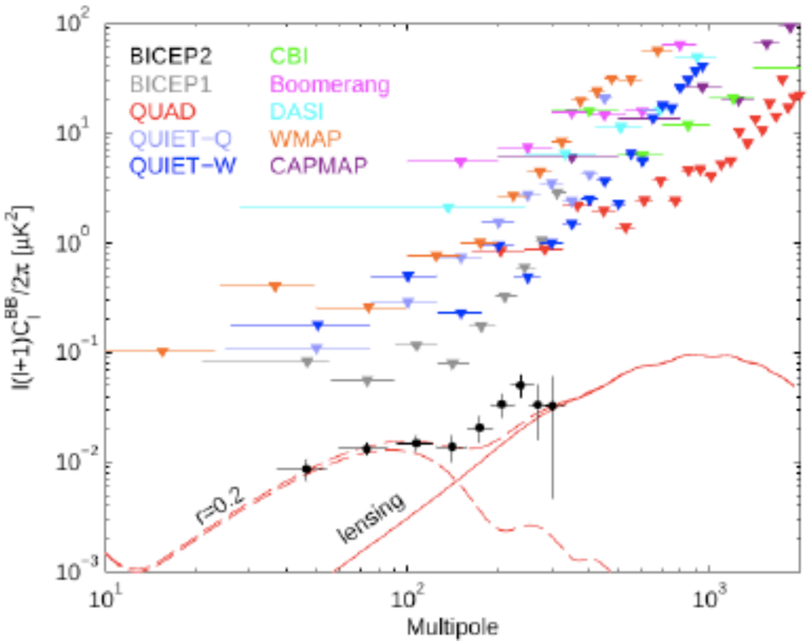
Hamann & Hasenkamp 2013
also Wyman et al. 2013,
Battye & Moss 2013

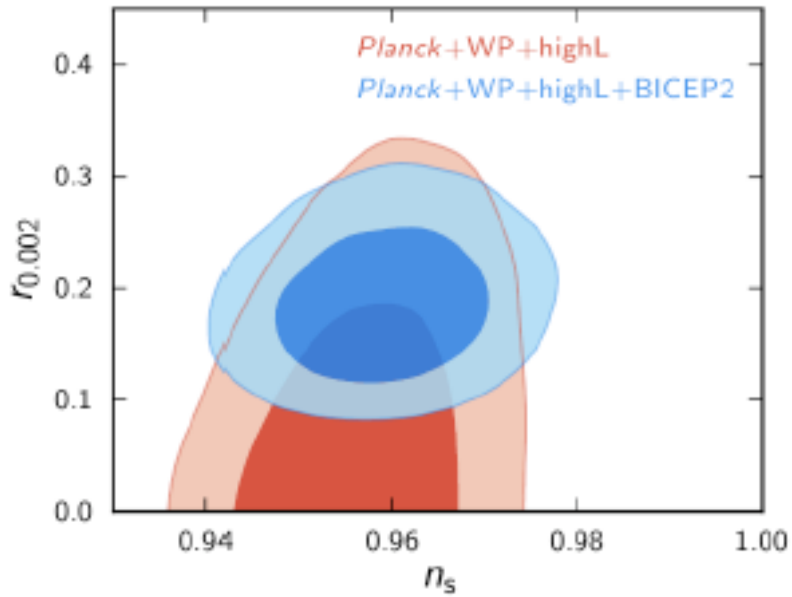
arXiv.org > astro-ph > arXiv:1403.3985

Astrophysics > Cosmology and Nongalactic Astrophysics

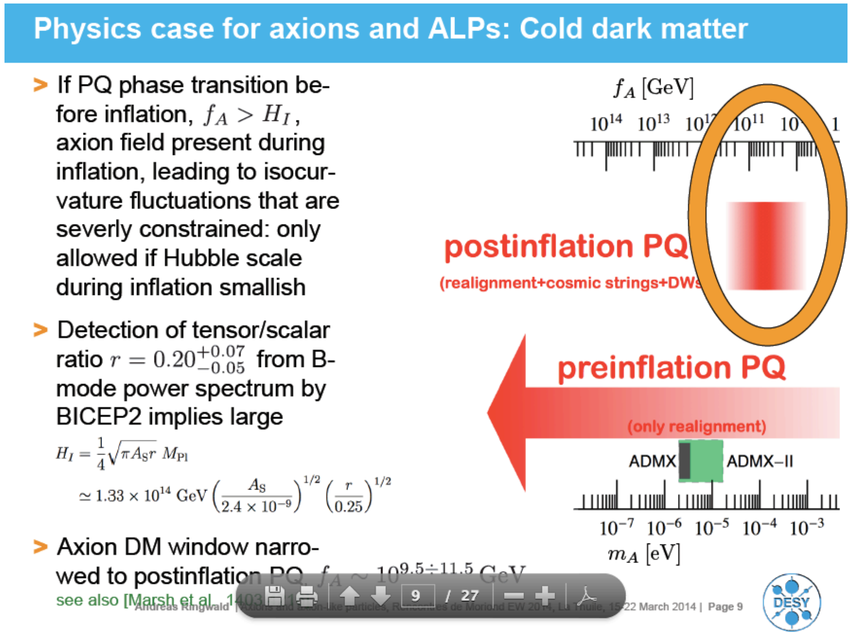
BICEP2 I: Detection Of B-mode Polarization at Degree Angular Scales

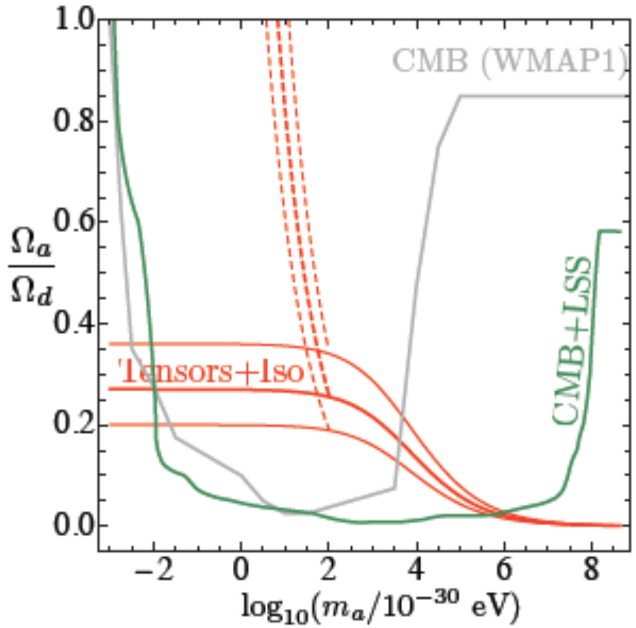
Comments in talks J.Hamann, A.Ringwald, O.Perdereau, Moriond EWK 14





The Biceps2 measurement (if real) has implications for axions, weakly interactling particles that appear e.q . in dark matter models





Talk by A Ringwald, Moriond EWK14, and plot by Marsh et al 1403.4216

Theory Concluding Comments

As we discussed the ”hot” and vastly different topics, we encountered the established, the unprecise and the unknown.

Many excting topics not covered (dark matter, astroparticles, gravitation, TeV-scale model building ..)

It is clear that fundamental physics is always ”research in progress”.

It is also clear that many exciting questions remain, that can be tackled in a combined effort of theory and experiment.

We need your ideas.

Part III - Outlook for HEP experiments and machines

- The SM has been built in a continuum of 50 years of experimental and theoretical progresses. It is supported nowadays by two pillars: the EWK and CKM precision global consistency checks.
- We want to shake those pillars w/ improved precision and test the predictions made possible out of the global consistency checks.
- Top quark physics: LHC is a top factory. Its basic properties are measured with increasingly better control of systematics effect.
- Higgs physics: the beginning of a quest. Invaluable window for NP, make a global consistency check of the couplings, determine the shape of the scalar potential. Opening to cosmology, the scalar field brings a no-additional-parameter inflation model.
- Flavour is a central problem of Physics. Flavour Physics might be the solution... Again the beginning of a quest with the precision era. Future facilities to measure neutrinos properties.
- We should not forget in this landscape smaller scale projects and HEP-related dark matter searches.

Part III - Tentative Timeline for HEP.

Immediate future (up to ~2022)

- LHC Run II - It starts ~now w/ unprecedented energy in the center-of-mass. Search for new phenomena (a lot of hope) and refine in precision the physics outcome of Run I.

- LHCb upgrade and SuperKEKB: the former is disjoint from the LHC upgrade. Meant to cope with the luminosity upgrade of the Run III. SuperKEKB is a *B*-factory equipped w/ a new detector Belle II. Commissioning next year. Both are expected to analyse 50 times the current statistics: the precision era for quark flavour physics. BES (chinese charm factory) is still running.

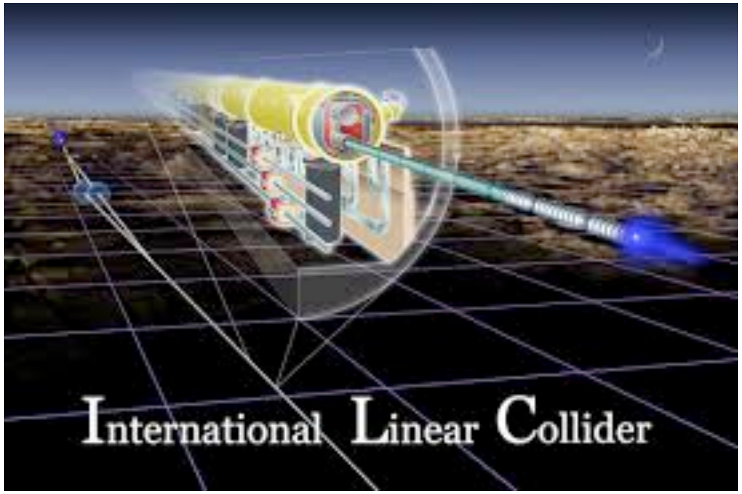
Main (selected) Projects on the Table:

- LHC High Luminosity: likely to happen. 3000 /fb at 13/14 TeV (now 25 /fb at 7/8 TeV).
- e^+e^- linear collider (90 - 800 GeV), known as ILC.
- e^+e^- circular collider (90 - 375 GeV), known as FCC-*ee*.
- proton-proton circular collider (100 TeV), known as FCC-*pp*
- e^+e^- linear collider (3 TeV), known as CLIC.
- Long Baseline neutrinos.

Part III - Selected projects for HEP.

Few comments in order for e^+e^- linear collider

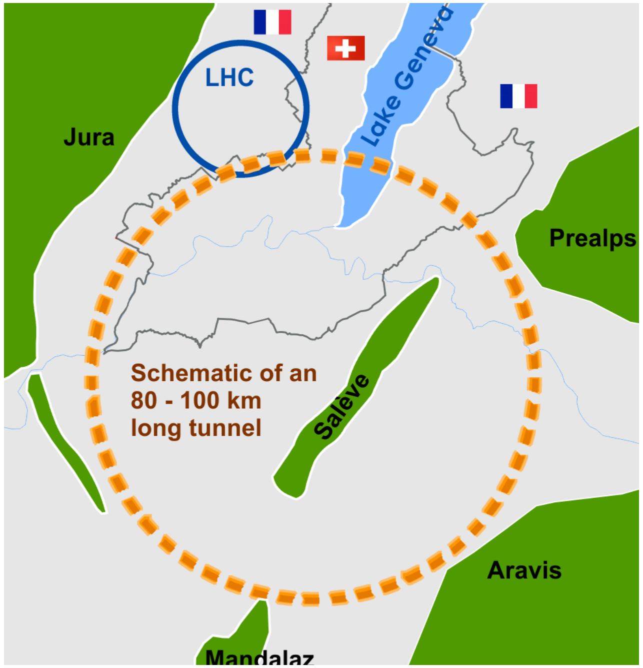
- Physics Case established since 15 years: m_W, m_t , H properties and couplings (including trilinear), VV at high energy.
- Cold technology for accelerating cavities (< 800 GeV). They are mature since year ~2000.
- ~31 km baseline. Lumi 10^{34} $cm^{-2}s^{-1}$
- Japan declared interest.
- http://www.linearcollider.org/ILC/Press/Images-and-graphics

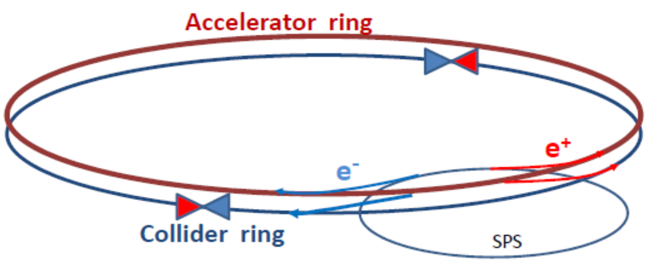


Part III - Selected projects for HEP.

Few comments in order for e^+e^- circular collider

- Emerged in the last couple of years. Embodied in Future Circular Collider CERN project.
- 80-100 km circumference. Lumi at the Z pole 10^{36} $cm^{-2}s^{-1}$ (!).
- Physics Case: *Z, W*, top and *H* physics (in the event nothing new is seen at LHC Run II). Given the expected precision, calculations at three loops are necessary.
- Design study undergoing for the european strategy examination in 2018.
- http://tlep.web.cern.ch/

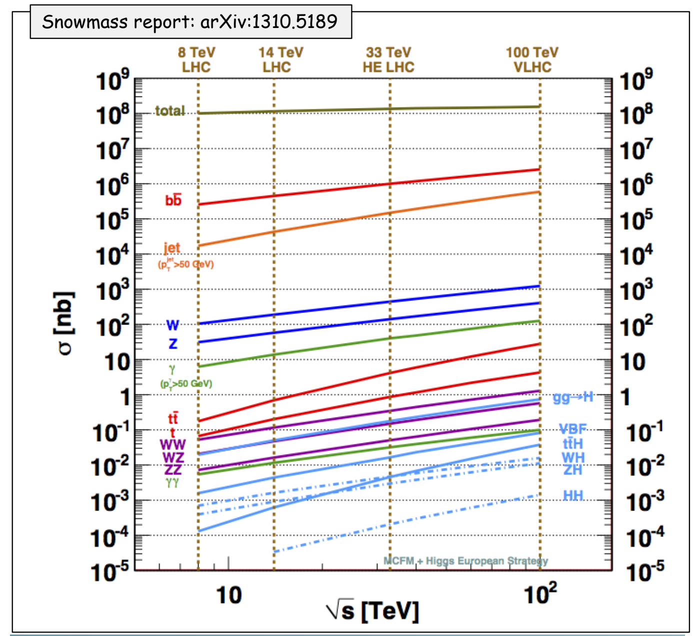


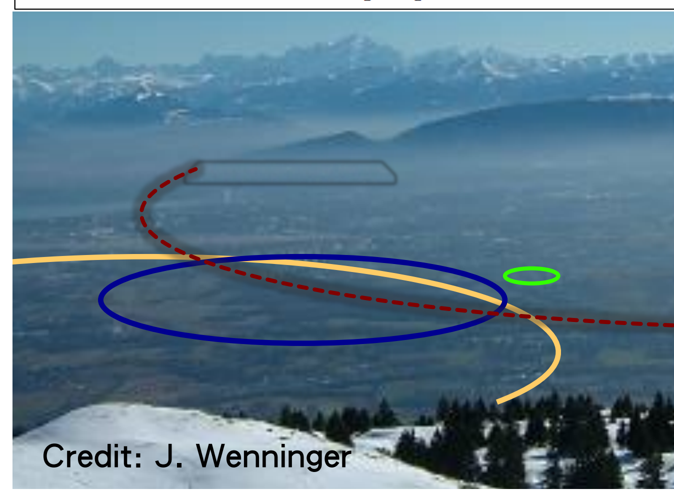


Part III - Selected projects for HEP.

Few comments in order for pp circular collider

- Same tunnel. Same idea as LEP/LHC complex. Embodied in Future Circular Collider CERN project.
- 100 TeV Lumi of 5. 10^{34} $cm^{-2}s^{-}$. Main challenge is as for LHC the magnets (16-20 T required).
- Physics Case: multiply LHC cross-sections by factors 7 to 60 for physics process vs 1.25 for total pp. In particular, the shape of the scalar potential can be accurately measured.
- Design study undergoing for the european strategy examination in 2018.
- http://tlep.web.cern.ch/content/fcc-hh





Part III - Concluding remarks

- You're studying Particle Physics and Cosmology in fascinating times.

- The modern Physics provides a mature and motivated view of the Nature at the scale of the elementary interactions below the TeV scale.

- That makes a very solid ground.

- There's so much more to understand. This is/will happen in facilities opened worldwide, theory and experiment intricated. Research requires a global network. Transmitting the knowledge too. We've tried today! And will hopefully build more in the future.

- Hope you enjoyed your afternoon.