Flavour physics: recent discoveries and questions for the future

Durham

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Silvia Pascoli

IPPP - Durham

The flavour ”group” at IPPP

Patricia Ball

Mike Pennington

Marco Pappagallo

Roman Zwicky

Gareth Jones

Aoife Bharucha

Athanasios Dedes

Steve Abel

Silvia Pascoli

Sergio Palomares−Ruiz

Tom Underwood

Christopher Orme

Steven Rimmer

- B physics activity at IPPP
- research at IPPP in neutrino physics

1 – B physics

Flavour physics presents a large number of precision results on B, D and K decays, confirming the SM predictions for flavour and CP-violation.

- Precision determination of CKM parameters:

  tree level processes

  processes which in the SM are loop-dominated (? New physics)

Once new physics is discovered at the LHC, flavour physics will play a determinant role in unveiling its coupling constants.

P. Ball, G. Jones, R. Zwicky

- P. Ball and R. Zwicky have studied of FCNC transitions $B \to V\gamma$. The CP-asymmetry is sensitive to New Physics, while BR can be used to extract γ from the data.

- NP in B mixing was searched for by Ball and Fleischer, who studied the impact of the first measurement of ΔM_s at Tevatron.
C.S. Kim (visiting professor in 2006) put constraints on warped extra-dimensions and Z' models.

- Ball and Zwicky first proposed in 2005 and then Ball extracted the form factor in $B \to \pi l \nu$ (BaBar) and determined precisely $|V_{ub}|$.

- Hadronic input parameters: Ball and Zwicky determine the meson distribution amplitudes on the light-cone used in QCD factorisation.

- Zwicky with Bigi and Uraltsev looked at the impact of soft charm quarks in $B \to X_c l \nu$.

L. Edera*, M. Pappagallo, M. Pennington

- Dalitz plot analyses help in modelling the final states interactions. The first large scale application of this multi-dimensional analyses to the $D \longrightarrow K\pi\pi$ channel has just been completed with the FOCUS group. With members of BaBar this analysis procedure is being applied to several other key decay modes.

- Pappagallo is a member of BaBar. L. Edera* is a member of FOCUS.

2 – Other flavour related activities

- Network participation: FLAVIAnet (M. Pennington is coordinating the UK contribution of Durham and Southampton).

- Past Workshops since 2005:

BaBar Meeting, Durham, 4-6 April 2005

BEACH 2006, Lancaster, 2-8 July 2006

Workshop on Light-Cone Distribution amplitudes, Durham, 28-30 September 2006

- Workshops planned for 2007:

LHCb Upgrade workshop, Edinburgh, 11-12 January 2007

UK Hep Forum: Flavour Physics, Coseners House, 21-22 June 2007

- Collaboration in experimental activities: Collaboration with LHCb, BaBar, Belle, Focus.

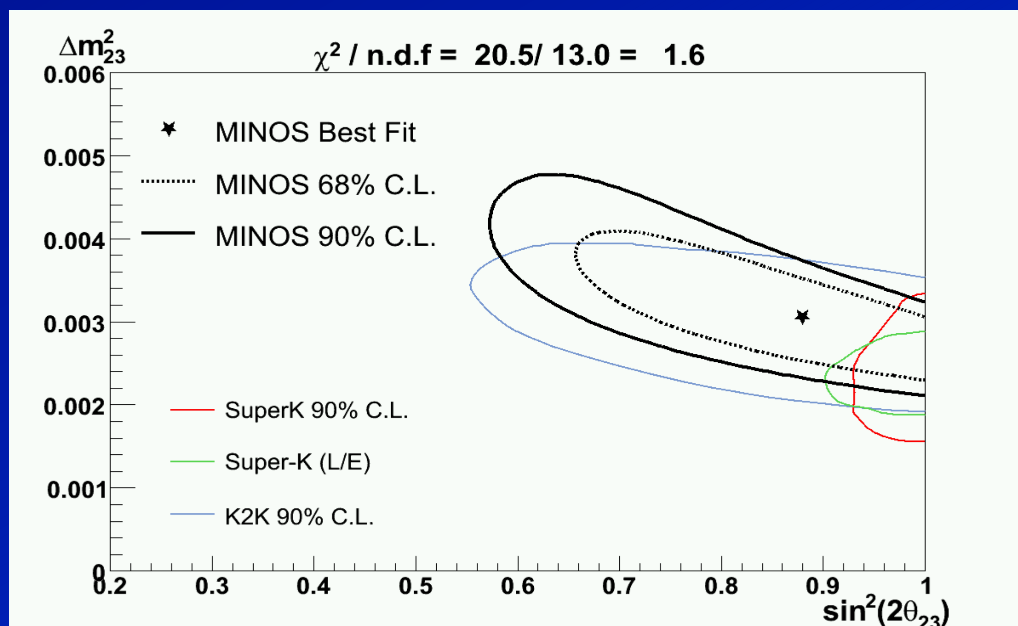
Participation in the review of flavour physics in the UK.

3 – Neutrino oscillations

We have experimental evidence for neutrino oscillations (solar, KamLAND, atmospheric, K2K, MINOS neutrino data).

For ex., the probability of ν_μ oscillating into ν_τ is:

$$P(\nu_\mu \rightarrow \nu_\tau) = |\langle \nu_\mu | \nu, t \rangle|^2 \quad \simeq \quad \sin^2 2\theta \quad \sin^2\left(\frac{\Delta m^2_{31}}{4E} L\right)$$



MINOS, March 2006

Neutrino oscillations are crucial in our understanding of neutrino physics:

NEUTRINOS ARE MASSIVE AND THEY MIX.

The explanation of neutrino masses requires physics beyond the Standard Model.

What do we know?	And what do we still need?
2 mass squared differences: $\Delta m^2_{\rm atm} \sim 2.5 \times 10^{-3}\,{\rm eV}^2$, $\Delta m^2_{\odot} \sim 8 \times 10^{-5}\,{\rm eV}^2$	The mass ordering and scale
2 angles: $\theta_A \sim 45^o$, $\theta_\odot \sim 30^o$,	$\theta_{13} < 12^o$ CPV phases δ and Majorana.

The main areas of research in Neutrino Physics are:

1. PHENOMENOLOGY: determining neutrino parameters (m_i, θ_i, δ, α_{ij}, N_ν, nature), by analysing the available data and the capabilities of different experimental setups.
2. THEORY: explaining the origin of neutrino masses and of the flavour structure, by considering see-saw models and alternative mechanisms of neutrino mass generation.
3. COSMOLOGY/ASTROPHYSICS: linking Neutrino Physics to Cosmology and Astrophysics in the Early Universe and in astrophysical objects as supernovae.

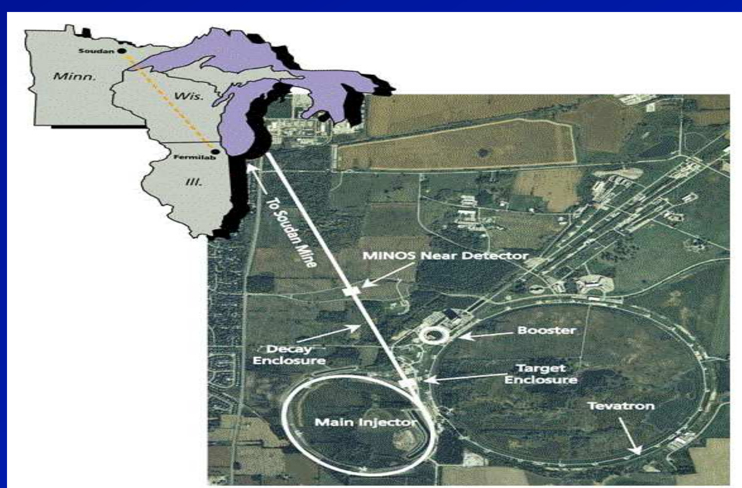
4 – Long baseline experiments (PHENOMENOLOGY)

S. P., S. Palomares-Ruiz and C.Orme

In the future long-base line experiments could, in addition to measure θ_{13},

- provide information on the type of ordering
- possibly measure the CP-violating phase δ.

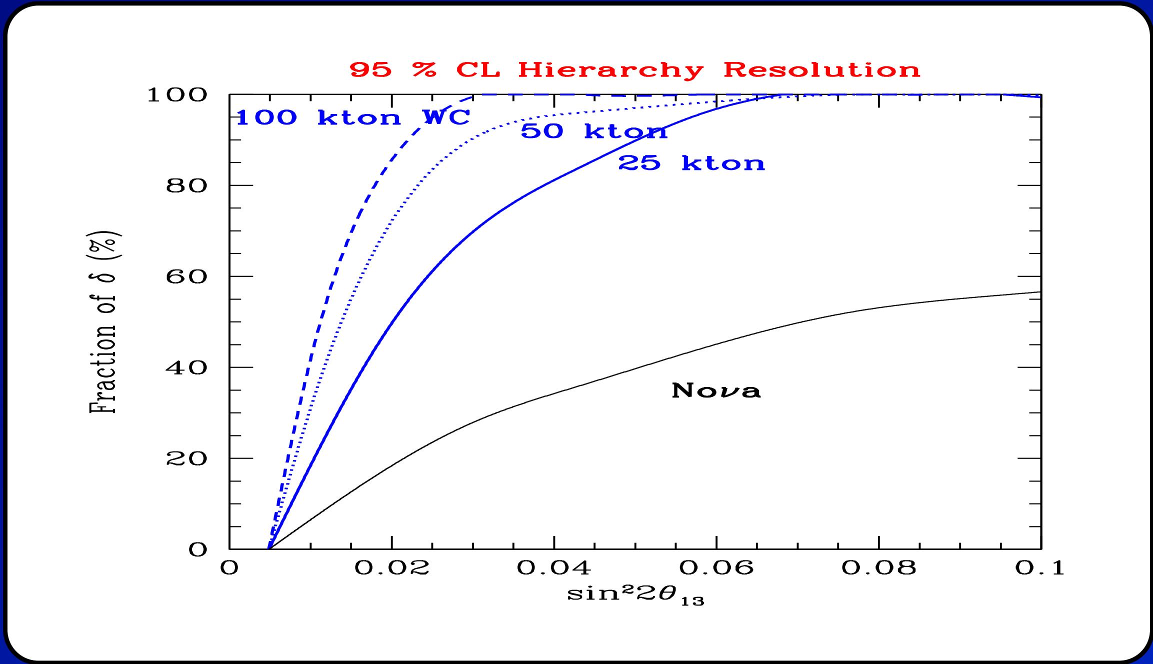
MINOS & NOvA



T2K

Related UK experimental activity: MINOS, T2K, ν-factory.

- S.P., O. Mena and S. Palomares-Ruiz studied the capabilities of NOνA in determining the type of neutrino mass hierarchy.



- S.P., with O. Mena and S. Geer, is studying the reach of a "low-energy" neutrino factory in case of large θ_{13}.

- S.P., O. Mena, C. Orme, S. Palomares-Ruiz are considering the synergy between beta-beams and superbeams (T2K) in determining the neutrino parameters.

5 – Leptogenesis (COSMOLOGY) in neutrino mass models (THEORY)

S. Abel, D. Cerdeño*, A. Dedes, S. P., V. Page, T. Underwood

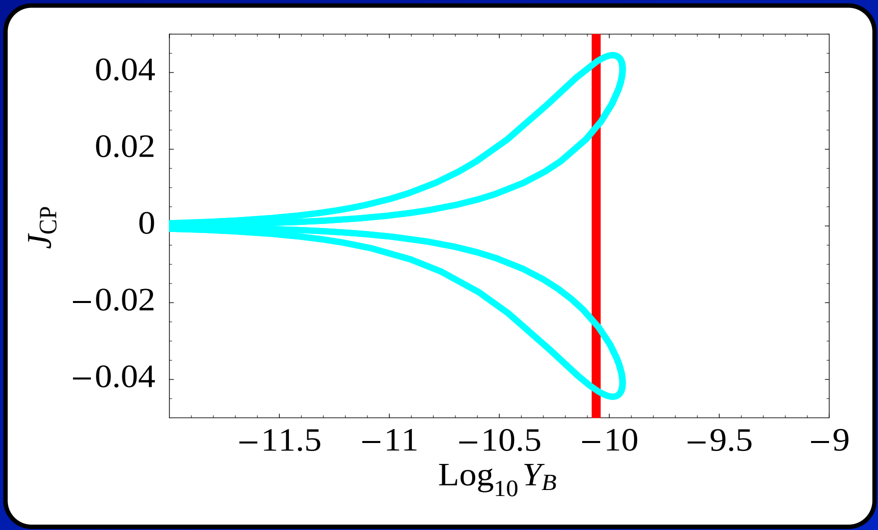
We know that there are more baryons than antibaryons in the Universe (baryon asymmetry): $Y_B \sim 10^{-10}$. What is its origin?

- In see-saw models, it can be explained by the decay of N preferably into antileptons than leptons. This produces a lepton asymmetry and consequently a baryon one.
- The same Ns are responsible for generating the neutrino masses via the see-saw mechanism.

Possible UK experimental activity involved: T2K, ν-factory, SuperNEMO, COBRA, LHC.

- **1.** Is there a connection between the parameters of leptogenesis and the ones we measure in neutrino physics, in standard See-saw Type I?

Very recently, S.P. with S.T. Petcov, A. Riotto, found an exciting new possibility for linking the low energy phases to the high energy ones due to previously neglected flavour effects.



- **2.** S. Abel and V. Page have analysed the case of Dirac leptogenesis in supergravity models which incorporate naturally light Dirac neutrinos.

- **3.** Dirac Leptogenesis was also considered by D. Cerdeno, A. Dedes, T. Underwood. They proposed a minimal, L conserving, phantom sector of the SM leading to Viable Dirac neutrino masses, Successful baryogenesis (through Dirac leptogenesis), Interesting ‘invisible’ Higgs phenomenology for the LHC (discussions ongoing with University of Manchester experimentalists), undergoing study on dark matter candidates.

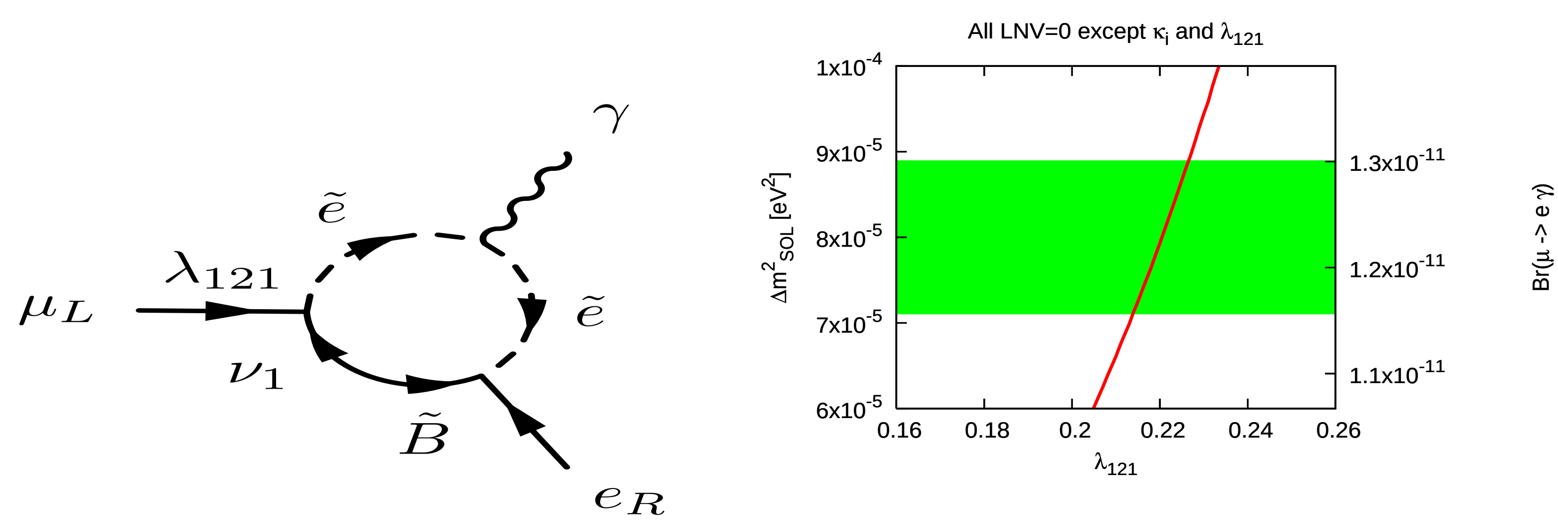
- **4.** T. Underwood, with A. Pilaftsis, is considering the large flavour effects in resonant leptogenesis . The study of approximate symmetry in models with RH neutrinos at the EW scale is underway from the phenomenological point of view (neutrino oscillations, LFV decays, LHC).

6 – Neutrino mass models in MSSM (THEORY)

A. Dedes, S. Rimmer, J. Rosiek*

The origin of neutrino masses and mixing was studied in the context of the MSSM with lepton number violation: $\kappa_i \, L_i H_u$ and $\lambda'_{ijk} \, L_i Q_j \bar{D}_k$.

The observed neutrino masses and mixing could be generated. LFV charged lepton decays were considered and found to be correlated to neutrino masses, as due to the same operators.



Related experimental activity: neutrino experiments, Babar, Belle, CLEO.

7 – ASTROPHYSICS: Ultra high-energy neutrinos

S. Palomares-Ruiz

UHE neutrinos carry information on the sources (and on extremes astrophysical processes) and on the cross sections at c.m. energy not otherwise accessible.

- S. Palomares-Ruiz reviewed the issue of the inference of the neutrino-nucleon cross-section above 10^{19} eV.
- He also studied, with L. A. Anchordoqui et al., a new process for generating high-energy (TeV) gamma-rays: photo-disintegration of PeV nuclei in an environment of ultraviolet photons followed by daughter de-excitation. A TeV neutrino counterpart from neutron decay might be observed at IceCube.

Related UK experimental activity: Auger, IceCube, HESS, ACORNE.

8 – Other lepton flavour related activities

- Network participation: ENTApP as part of ILIAS/N6; UK Neutrino Network; EU Network Quest for Unification (S. Abel, A. Dedes, S.P.); proposed UKIERI (S.P. PI for the UK side), proposed UK Neutrino Network (S. King PI, S.P. co-PI).

- Past Workshops:

$(\beta\beta)_{0\nu})$-decay phenomenology, Durham, 23-24 May 2005;

Nu-Mass, Durham, 18-19 December 2005;

New Trends in Particle Physics and Cosmology, Sheffield, 19-23 June 2006;

SUSSP61, St. Andrews, 8-23 August 2006;

- Workshops planned for 2007:

NUMMI07, Durham, January 10-12 2007 (ENTApP collaboration meeting).

- Collaboration in experimental activities:

S.P. is BENE deputy coordinator.

S.P. is part of UKNF.

participation in ISS on neutrino factory (S.P.).

9 – Conclusions

- The flavour ”group” at IPPP is very active and mainly divided into B physics and Neutrino physics.
- In B-physics, the research spans from the determination of the CKM parameters (both tree level and loop-processes) to the searches for New Physics processes.
- In neutrino physics, the IPPP activity increased significantly in the past 2 years. All the three areas, namely phenomenology, theory and cosmo/astrophysics, are actively researched.
- Many questions are still open and they will be addressed theoretically and by the extensive future experimental program.