# Introductory Remarks: Origin of Nutrino Masses

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**Nufact11- WG1**

# Seesaw Paradigm

- **Scale of neutrino masses**
- **New fermions:**

  **Majorana:** **Type I and III**

  **Dirac:** **Inverse**

- **No new fermions: Type II**

- **Scale : LHC accessible or not ?**

# Flavor pattern

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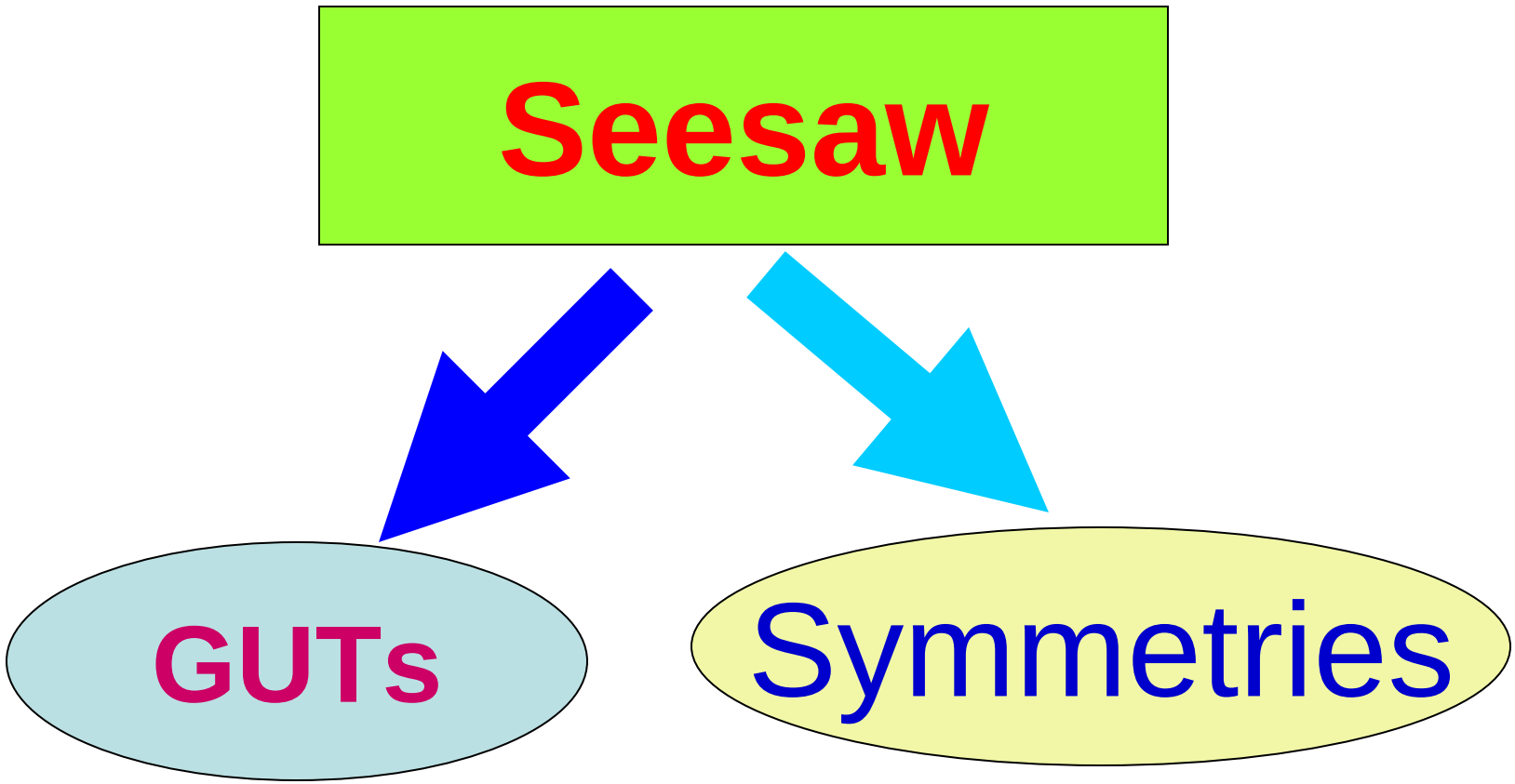

# Origin of Neutrino mass

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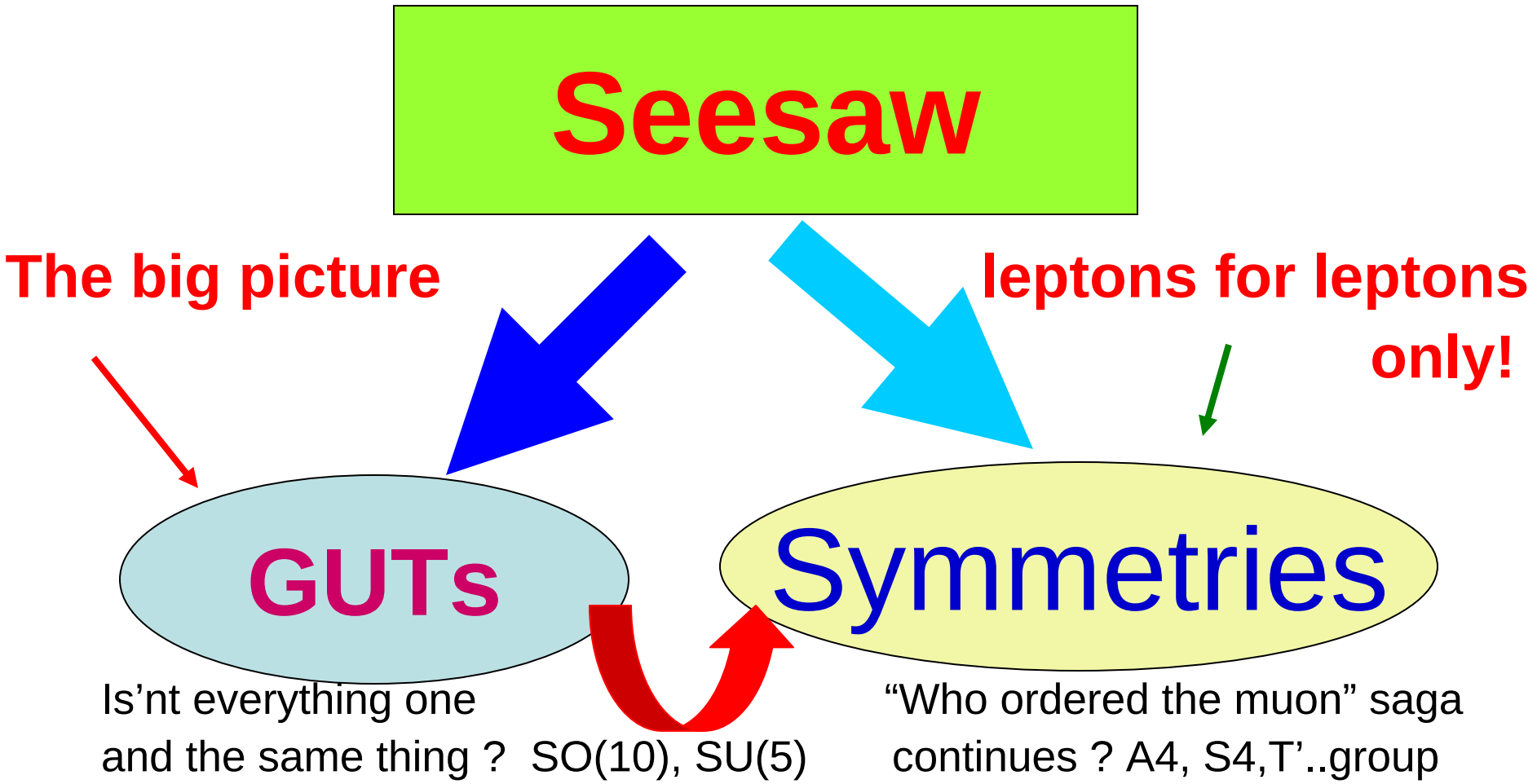

# Testing seesaw

- **Seesaw predicts Majorana masses**
- **Possibilities : Majorana, Dirac, pseudo-Dirac or Schizophrenic**
- **Sign of $\Delta m^2$ can provide crucial info.**

  ★ **Dirac: if LBL expts→ $\Delta m^2 < 0$ but no signal in nu-less d-beta decay ↓17 meV;**

- **Nu-less double beta decay or measurement of extragalactic neutrino flux ratio can distinguish schizophrenic from others !!**

# What else can sign of $\Delta m^2$ teach us ?

Suppose expts → +ve $\Delta m^2$
And +ve signal in nu-less d-beta decay:

★That would mean heavy particles at TeV scale→ ask LHC to look for it !!

★+ve $\Delta m^2$ and no signal in d-beta decay supports normal hierarchy→GUT type expectation

# Type and scale of seesaws

- **PMNS unitarity violation or NSI's**
- Type I and type II : No (regardless of scale)
- TeV scale Inverse seesaw: consistent model for both PMNS violation and NSI's.
- LBL → $\Delta m^2 > 0$ but $\beta\beta_{0\nu}$ signal above~17 meV

  Would suggest TeV seesaw scale:

★ **LHC important for determining scale** !!

# Symmetries: TBM, BM, TM,..

- Generic prediction: $\theta_{13} = 0$ and $\theta_{23} = \frac{\pi}{4}$ in sym limit; expect smaller $\theta_{13}$ < 0.05 from sym. Breaking either in charged lepton sector or nu-mass matrix itself for not quark lepton unified models
- Correlates $\theta_{13}$ value with departure of $\theta_{23}$ - $\frac{\pi}{4}$ from zero.

**Higher precision measurement of atm mixing angle important !**

# GUTs

- Scale can be real high or TeV- though “real high” scale renormalizable GUTs most predictive.
- Generically predict “larger $\theta_{13} > 0.07$
- There are deviations from $\theta_{23} = \frac{\pi}{4}$
- Hierarchy mostly normal- Neutrino Majorana
- Eventually, evidence for GUT picture will mostly be circumstantial- theoretical elegance **(It is the big picture !)** and predictivity etc.
- **True test of GUTs→ observation of proton decay** !

**Is there a pure neutrino test for GUTs ?**

# Other related issues

- Seesaw + SUSY→ observable $\mu \to e\gamma$
- non-observation does not say anything about seesaw;
- No SUSY at LHC + observation of $\mu \to e\gamma$ will imply low seesaw scale (TeV?)
- Some GUT type III seesaw models imply lower bounds on $\mu \to e\gamma$ --as upper bound keeps going down models will start falling (again only with susy)!!

# Model Questions for WG1

- More precise correlation between mixing angles themselves as well as solar to atm mass ratio

  as a way to test models !!
- More models for NSI's (other than TeV inverse seesaw- possibly radiative mechanisms ?)
- How to test GUTs using neutrinos alone-
- **Steriles would imply physics beyond simple seesaw as would signs of apparent CPT violation-**

  **construct sterile models to explain observations**
- **They will all throw light on the physics of nu mass**