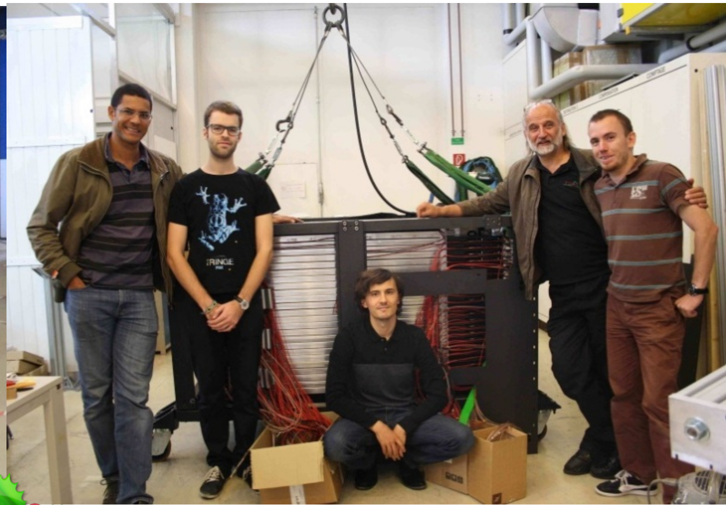
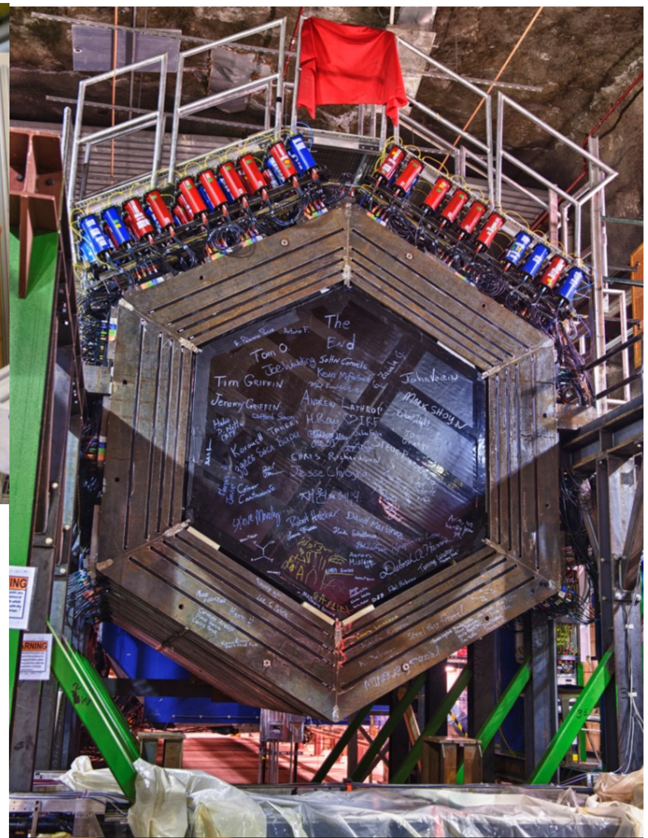
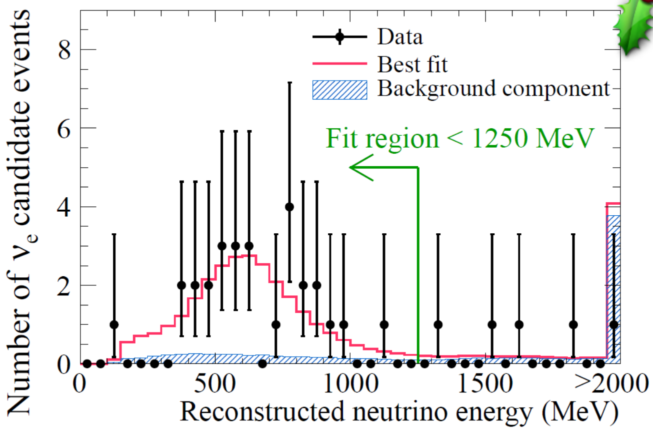






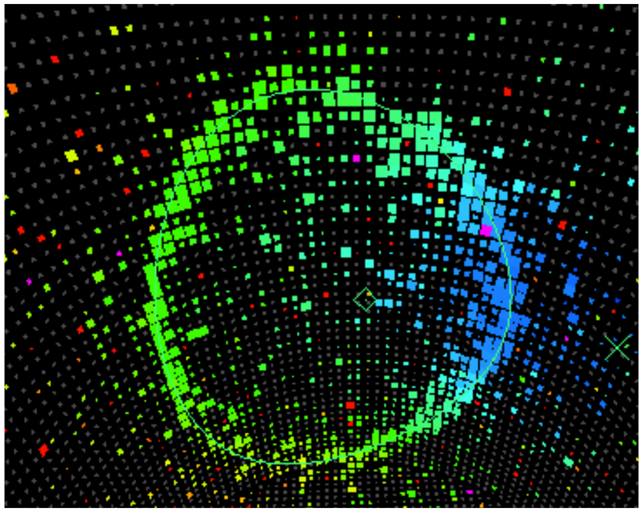
Fête de fin d'année 2013

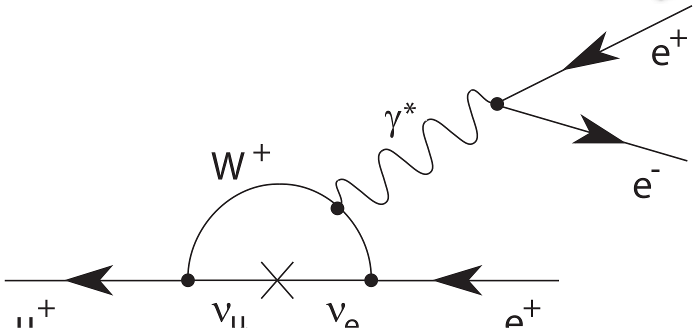
Neutrinos *and Mu3e*

Jeudi 19 décembre 2013

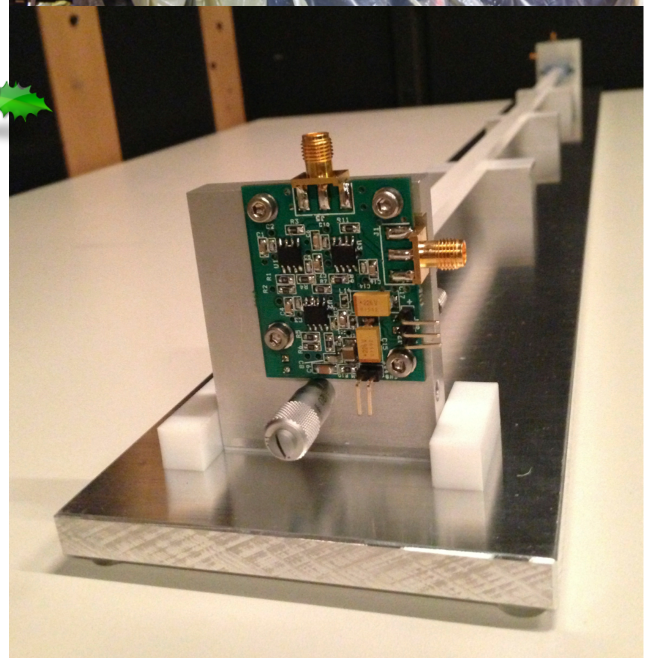
Mark Rayner and Melody Ravonel

for the **Neutrino Group**





$$\sim \left(\frac{\Delta m_\nu^2}{M_W^2} \right)^2 \Rightarrow BR\left(\mu^\pm \to e^\pm e^+ e^-\right) < 10^{-50}$$



The Neutrino Group

Prof. Alain Blondel
Alessandro Bravar

Doctoral students
Ruslan Asfandiyarov
Antoinetta Damynova
François Drielsma (new)
Leïla Haegel (new)
Alexis Haesler
Carlos Martin Mari (new)
Enrico Scantamburlo

Postdoctoral researchers
Yordan Karadzhov
Alexander Korzenev
Etam Noah Messomo
Melody Ravonel S.
Mark Rayner

AIDA/LBNO
Detector R&D for next gen. experiments

MICE
Neutrino Factory &
Muon Collider R&D

Minerva
Neutrino interaction
model measurements

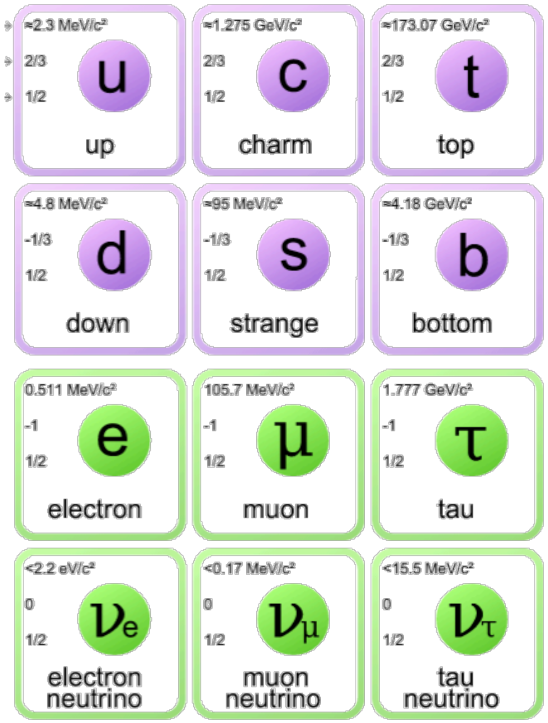
Mu3e
Lepton flavour violation

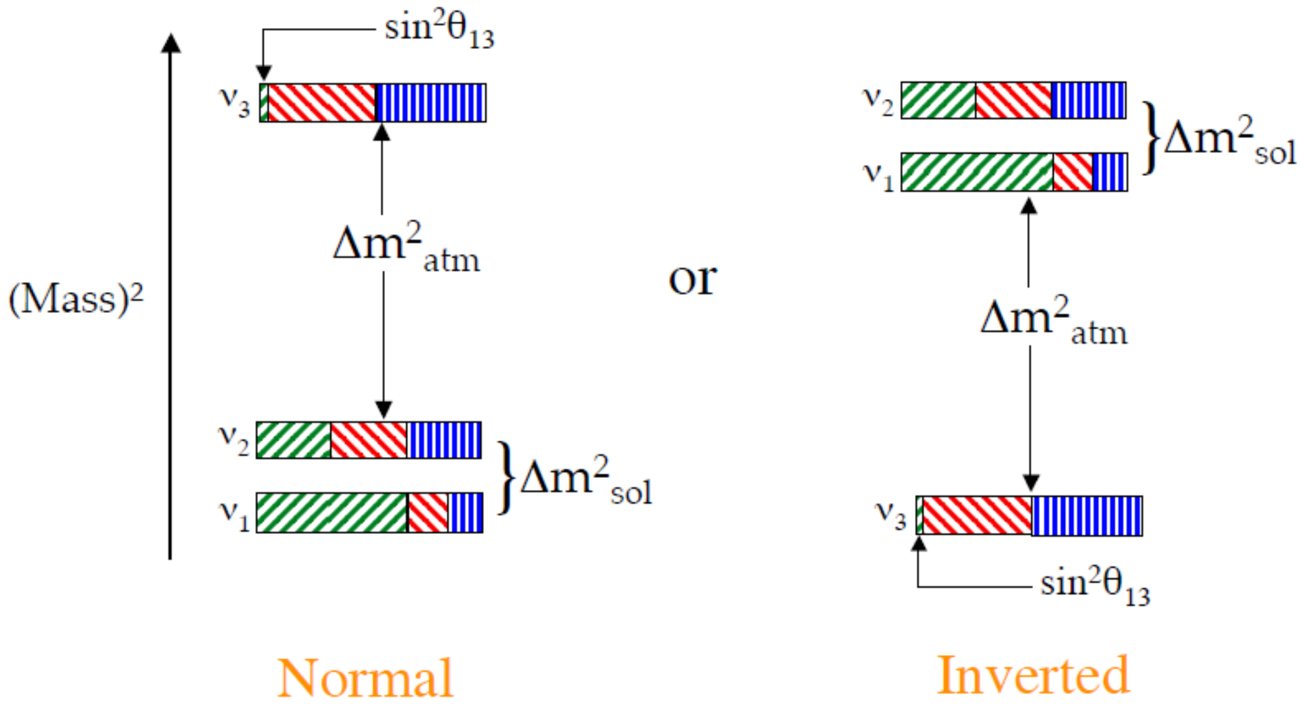
NA61
Hadro-production measurements for T2K

T2K
Discover nue appearance, sterile neutrinos
Measure θ_{13}, θ_{23}, Δm^2_{23}, δ_{CP}

Neutrinos come from a plethora of sources

- From a few seconds after the **Big Bang** (300 per cm^3 everywhere)
- From **the sun** (70 billion per cm^2)
- From **the earth's core**, **nuclear reactors** and **supernovae**
- From **cosmic rays** smashing apart nuclei in the atmosphere
- And at EeV with very low fluxes from **active galactic nuclei**
- And from pion decays from **cosmic rays interacting with the CMB**



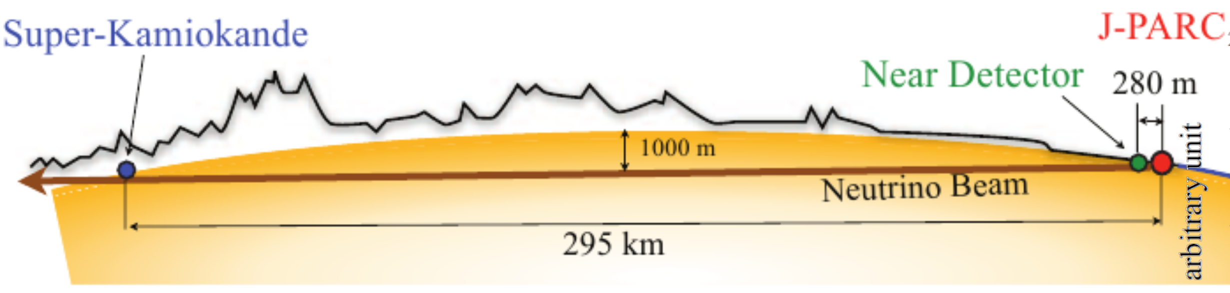


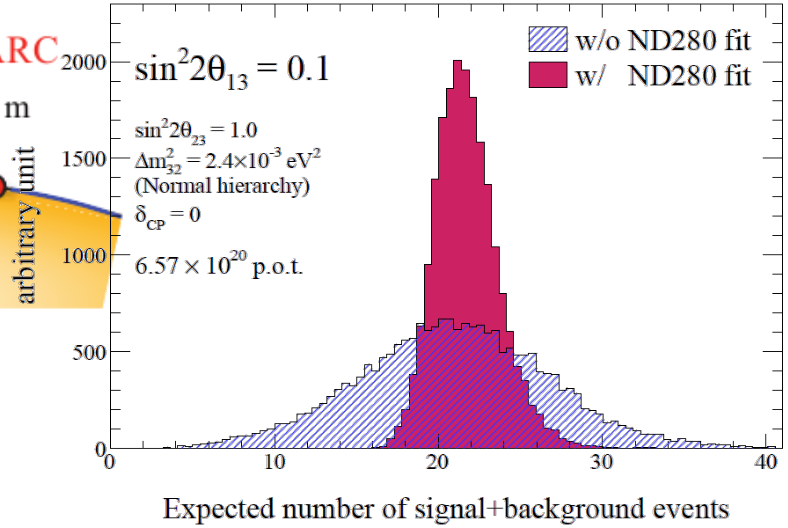
Mass hierarchy? Mixing angles?
CP violation? Dirac or Majorana? Sterile neutrinos?

T2K

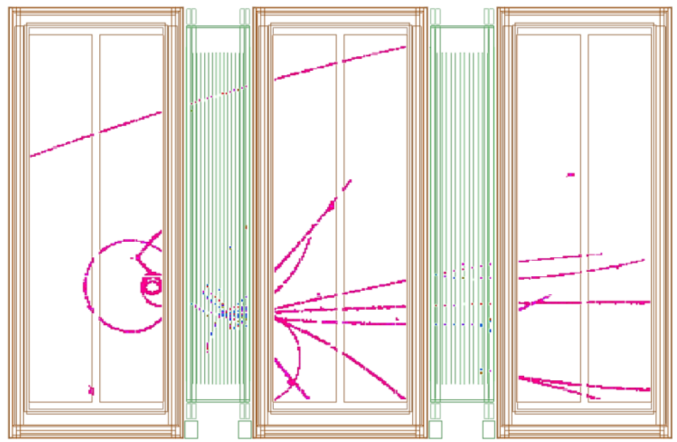
Melody Ravonel Mark Rayner
Enrico Scantamburlo Leïla Haegel

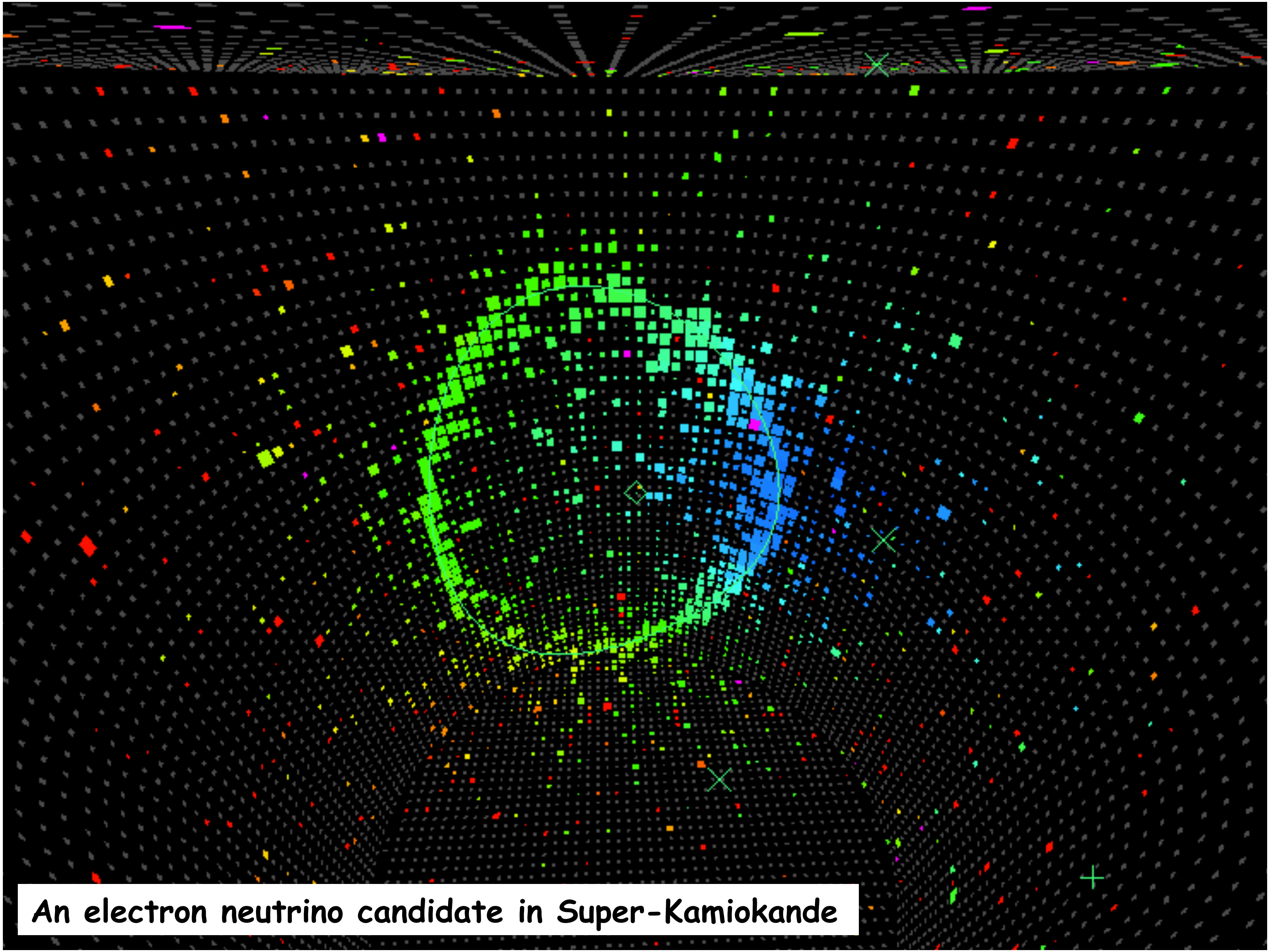
- Off-axis (narrow Enu spectrum) long baseline **accelerator neutrinos**



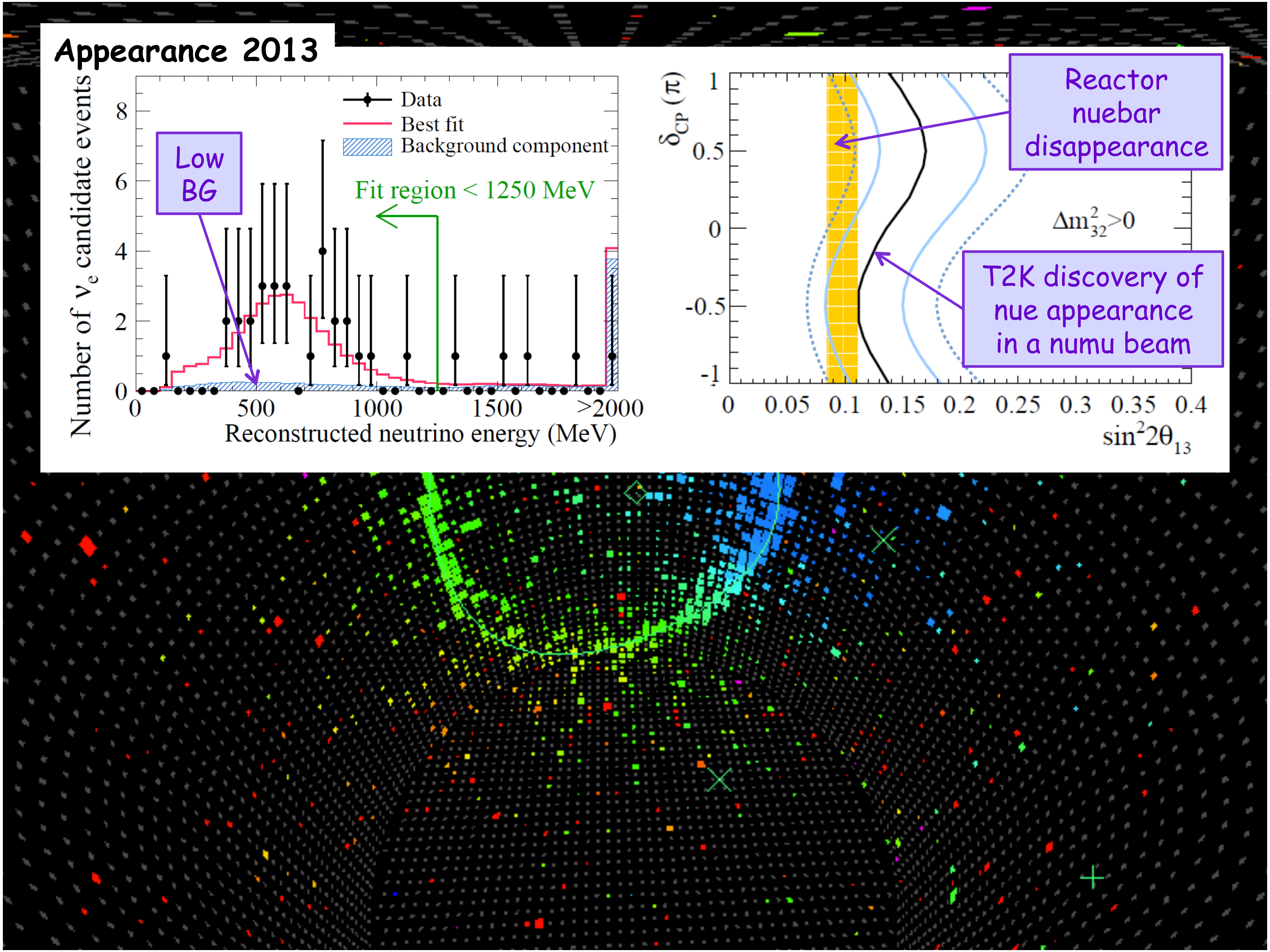


- 3 key papers published this year
  - Discovery of nue appearance → θ_{13}
  - A world class constraint on numu disappearance → θ_{23}, Δm^2_{23}
  - World's best model independent numu CC differential xsec (Melody's thesis)
- Geneva contributions
  - **Near detector** systematics
  - Kalman filter vertexing
  - **Cross-section** tools and analyses
  - **Time Projection Chamber** MMs

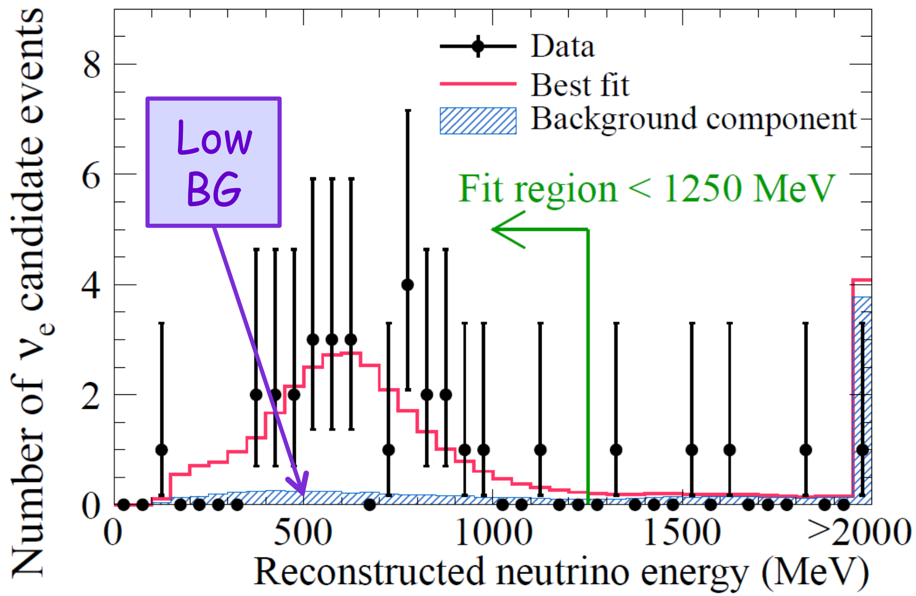


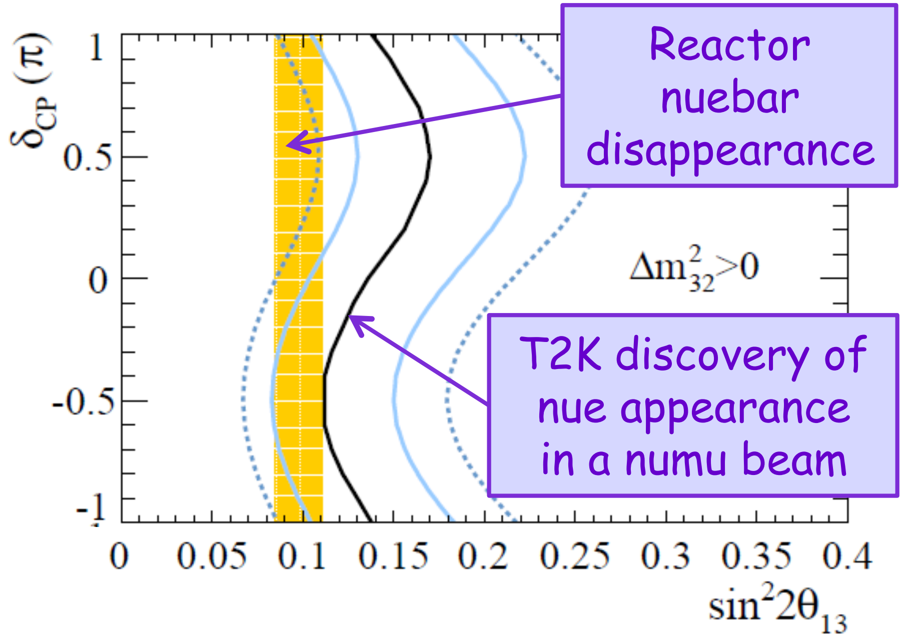


An electron neutrino candidate in Super-Kamiokande

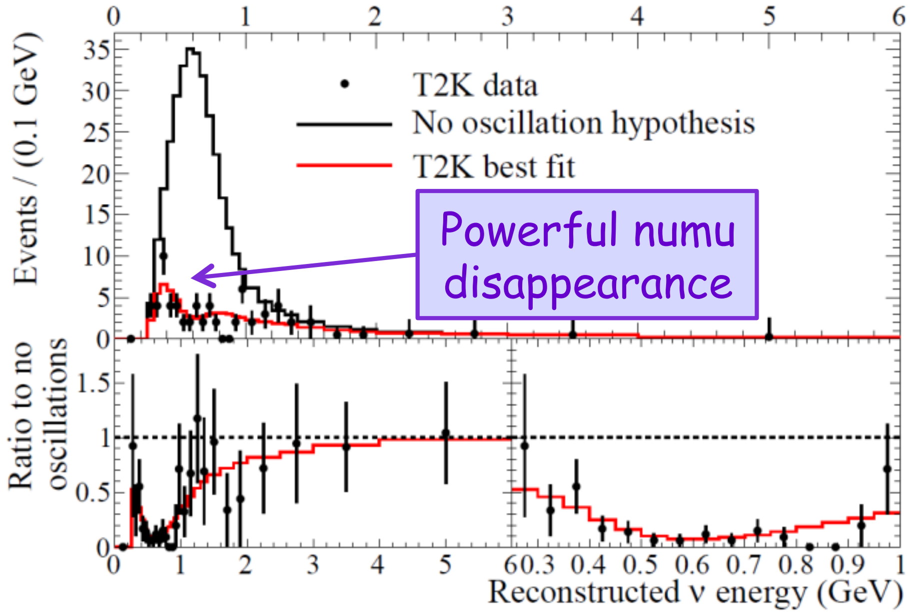

Appearance 2013
Data
Best fit
Background component
Low BG
Fit region < 1250 MeV
Number of ν_e candidate events
Reconstructed neutrino energy (MeV)
0
500
1000
1500
>2000
2
4
6
8
δ_{CP} (π)
1
0.5
0
-0.5
-1
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
$\sin^2 2\theta_{13}$
$\Delta m^2_{32}>0$
Reactor nuebar disappearance
T2K discovery of nue appearance in a numu beam

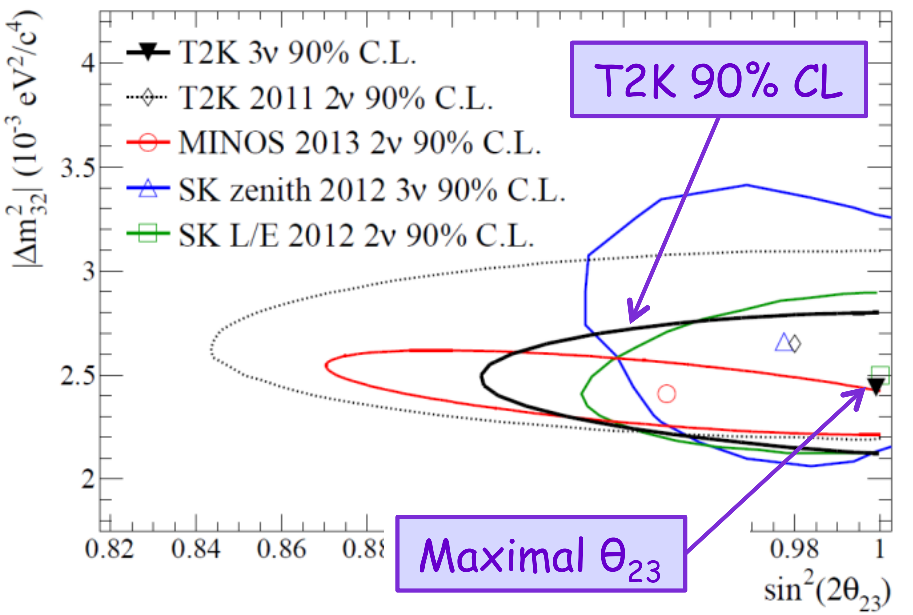
Appearance 2013

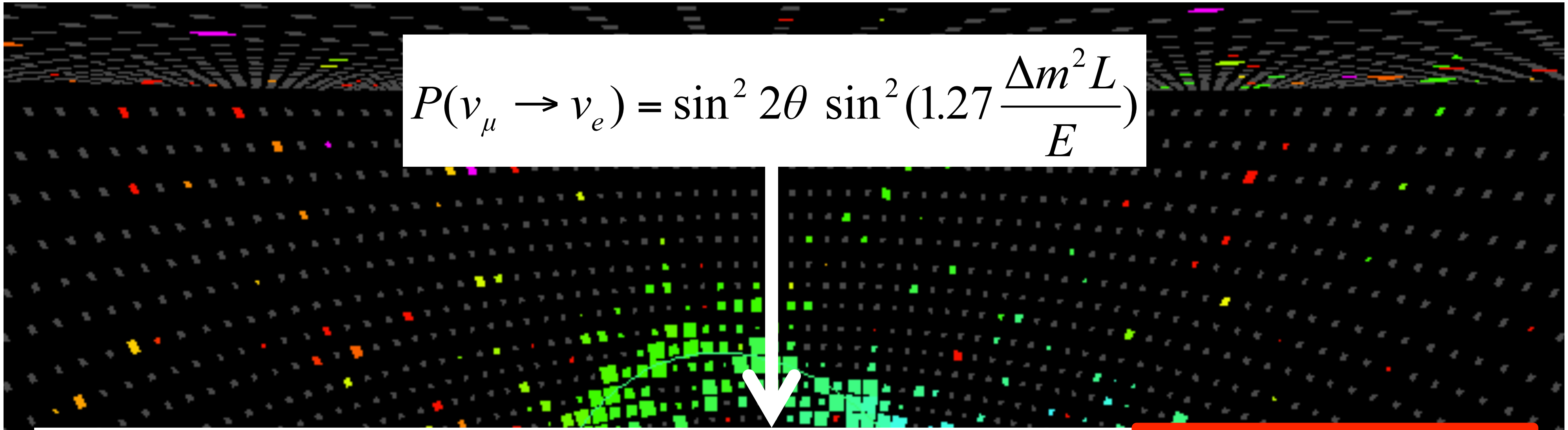




Disappearance 2013







$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \, \sin^2\left(1.27 \frac{\Delta m^2 L}{E}\right)$$

We are now entering a precision era in neutrino physics

Flip sign for antinu
➔ CP sensitivity

$$P(\nu_\mu \rightarrow \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2}\left(1 - 2S_{13}^2\right)\right)$$

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

$$+4S_{12}^2 C_{13}^2 \left\{C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta\right\} \sin^2 \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \frac{aL}{4E} \left(1 - 2S_{13}^2\right)$$

Matter effects
➔ Hierarchy ??

How can we reduce the systematics from ~10% to 2%?

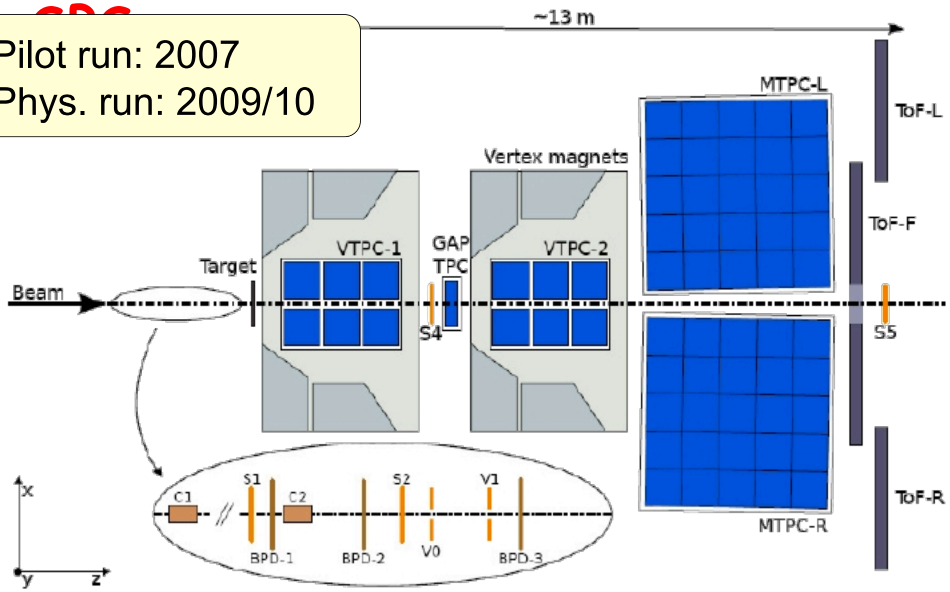
Problematic systematic #1
Target hadroproduction

NA61

Alexander Korzenev
Alexis Haesler

NA61/SHINE at CERN

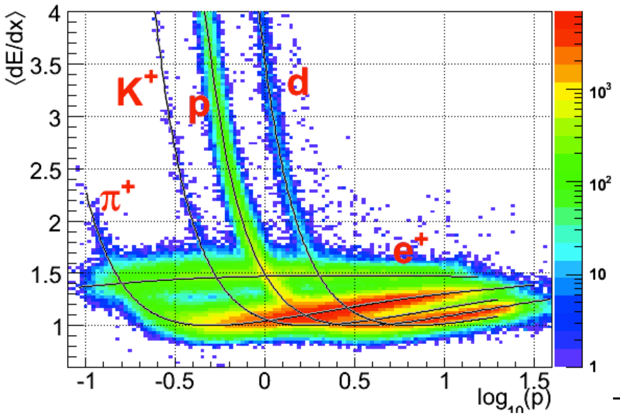
Pilot run: 2007
Phys. run: 2009/10



Data with the ***graphite target***

- Cross sections measurements for p±, K±, K^0_S, L and protons
- Cover ~90% of the phase space of T2K
- Thin target analysis
- T2K replica target analysis

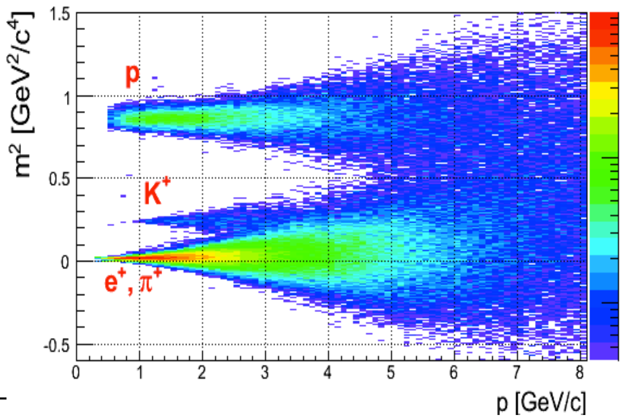
Energy loss in TPC (*dE/dx*)



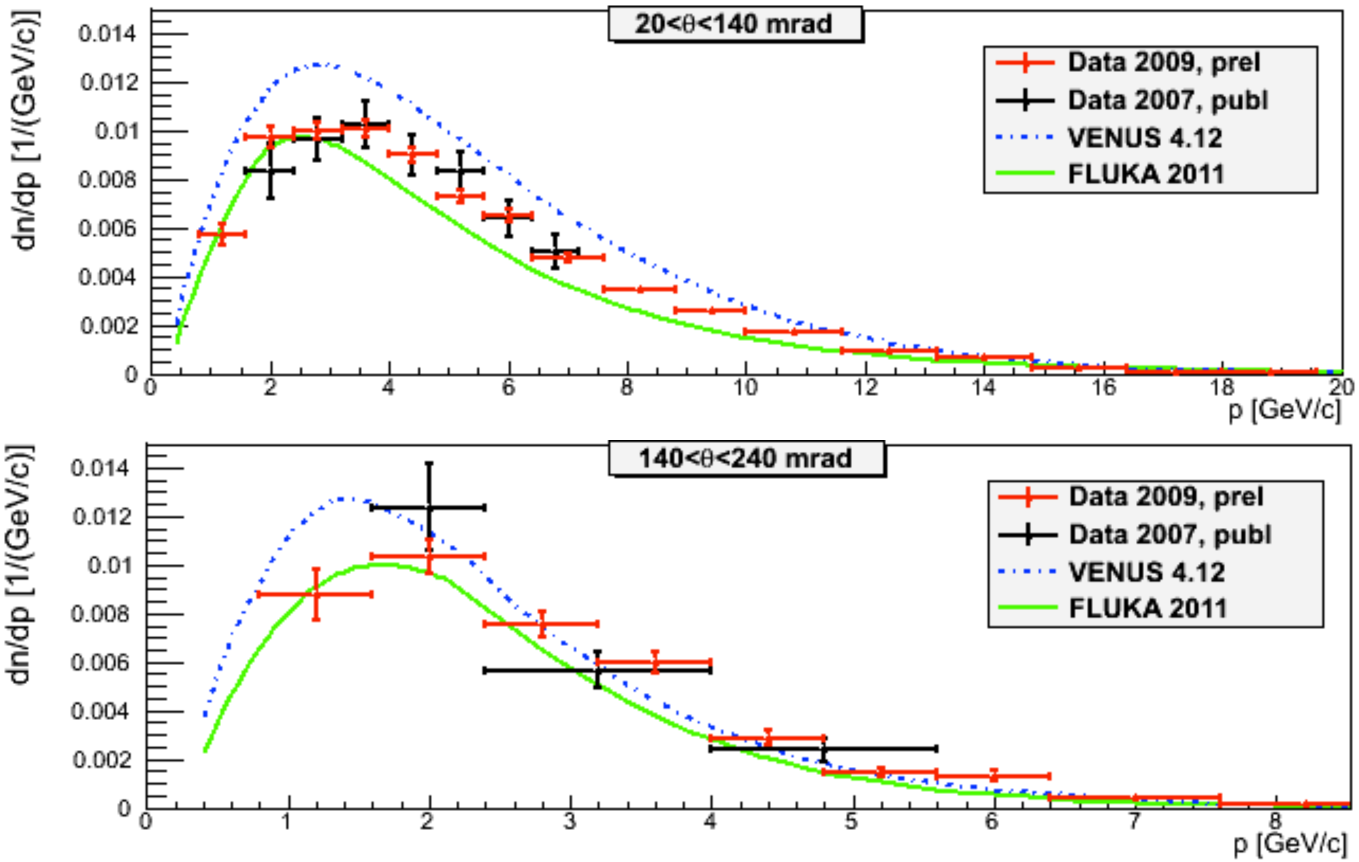
PID in NA61

- ToF detector by UniGe **(Bravar)**
- Energy loss in TPC

Time-of-Flight (ToF)



Example of K^+ multiplicities for 2007 & 2009



- 2007 results on $p^\pm$, K^+ ➔ beam MC of T2K
- No model perfectly describes nature
- **With data 2009 improvement in precision (statistics and systematics) by a factor 2-3 as compared to data 2007**
- Measurements for $p^\pm$, $K^\pm$, K^0_S, L, p
- Analysis of data for NuMI target (Fermilab) at 120 GeV/c is ongoing

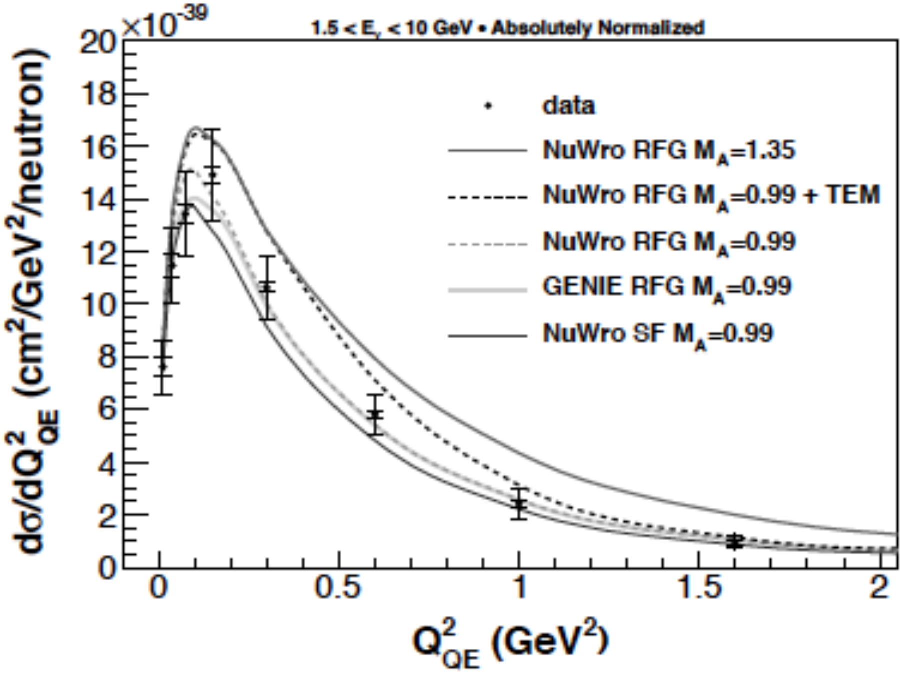
Problematic systematic #2
Neutrino interaction model

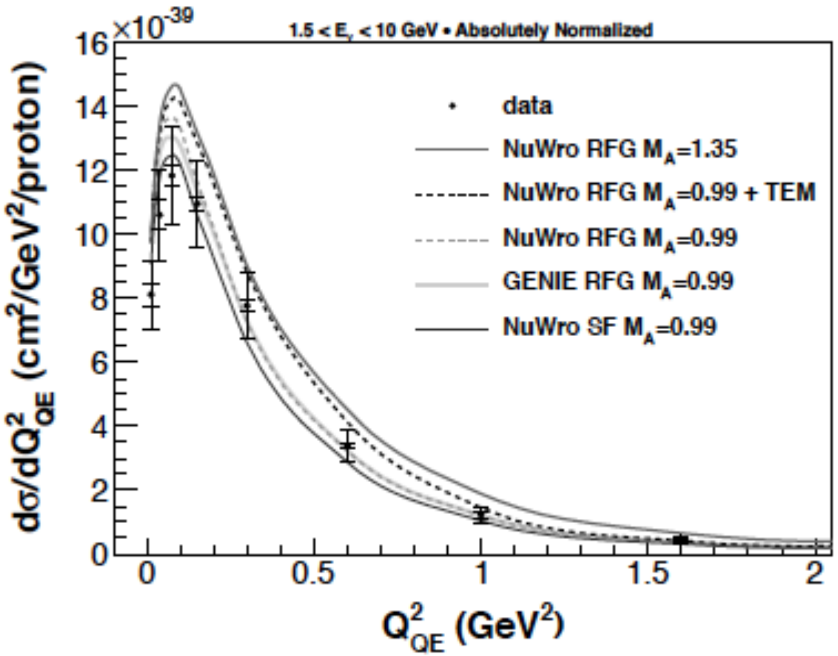
MINERvA

Alessandro Bravar
Carlos Martin Mari

- Experiment located at Fermilab, downstream the MINOS experiment
- **Neutrino cross section measurements with different nuclear targets**
  - **Pb, Fe and C**
  - **➔ study nuclear effects**

nu and antinu results on C in 2013

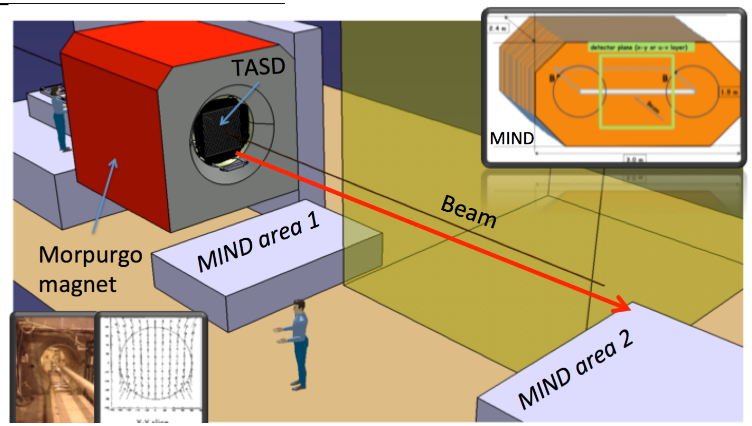




AIDA/LBNO

Etam Noah Messomo

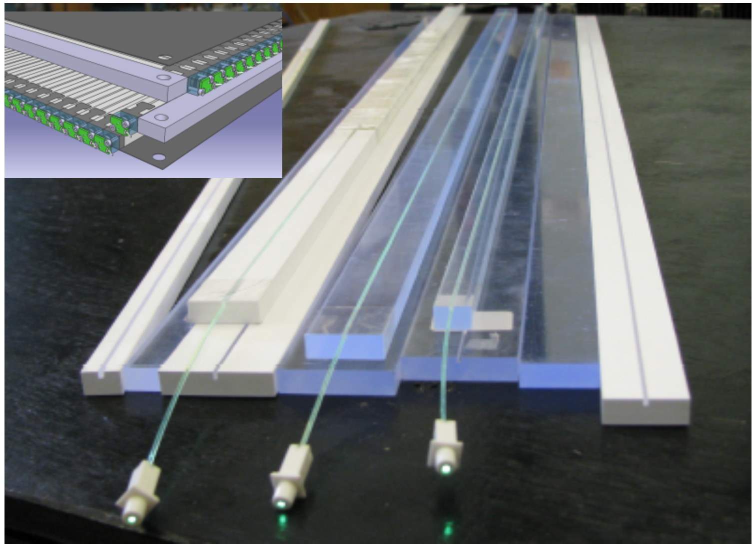
- ***AIDA*** (Advanced European Infrastructures for Detectors at Accelerators) – Projet en **faisceau** pour **2015**:
  - ***Magnetized Iron Neutrino Detector (MIND):*** identification de la charge des muons;
  - ***Totally Active Neutrino Detector (TASD):*** séparation muons/électrons dans un champ magnétique.
  - Projet **présenté** au **comité SPS** au CERN en **Juin 2013**.
- **LBNO** (Long Baseline Neutrino Oscillation):
  - CERN vers Pyhäsalmi en Finlande (2300 km);
  - **Etude** du **détecteur proche** (800 m de la cible);
  - Concept applicable à d'autres projets futurs (HyperK, nuSTORM, LBNx): **TPC** et **scintillateur solide intégré** dans **un réservoir sous pression**.

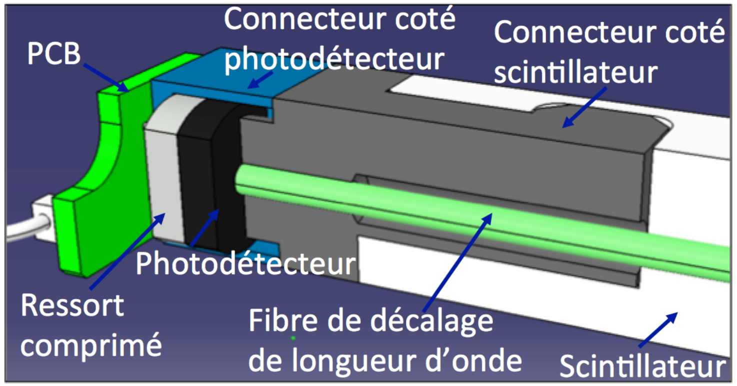


AIDA: prototype neutrino detectors

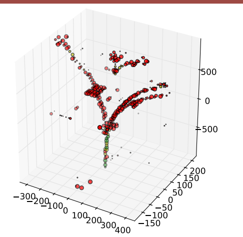
Mécanique

- Prototypage connecteur: F. Cadoux, D. La Marra.
- Design module: F. Cadoux.
- Production: INR Russie.

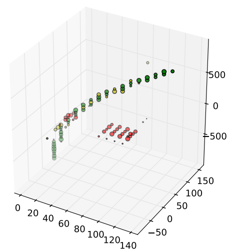




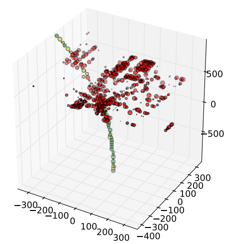
Simulations TASD



5 GeV electron

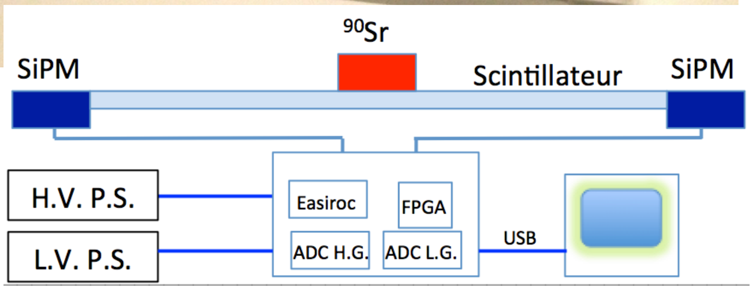


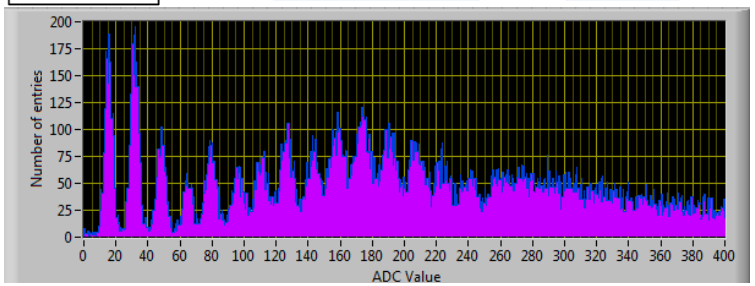
5 GeV muon



5 GeV proton

Electronique





MICE

Yordan Karadzhov
Ruslan Asfandiyarov
François Drielsma

EMR is a fully active scintillator detector (1m^3, 2832 triangular bars, dual readout)

Goal: to study low energy muons, pions, electrons from MICE muon beam.

Main purpose: particle identification and range measurement; complimentary: study of stopping properties of muons and pions, nuclear capture.

- Construction was completed at UNIGE on the 6th of September this year.

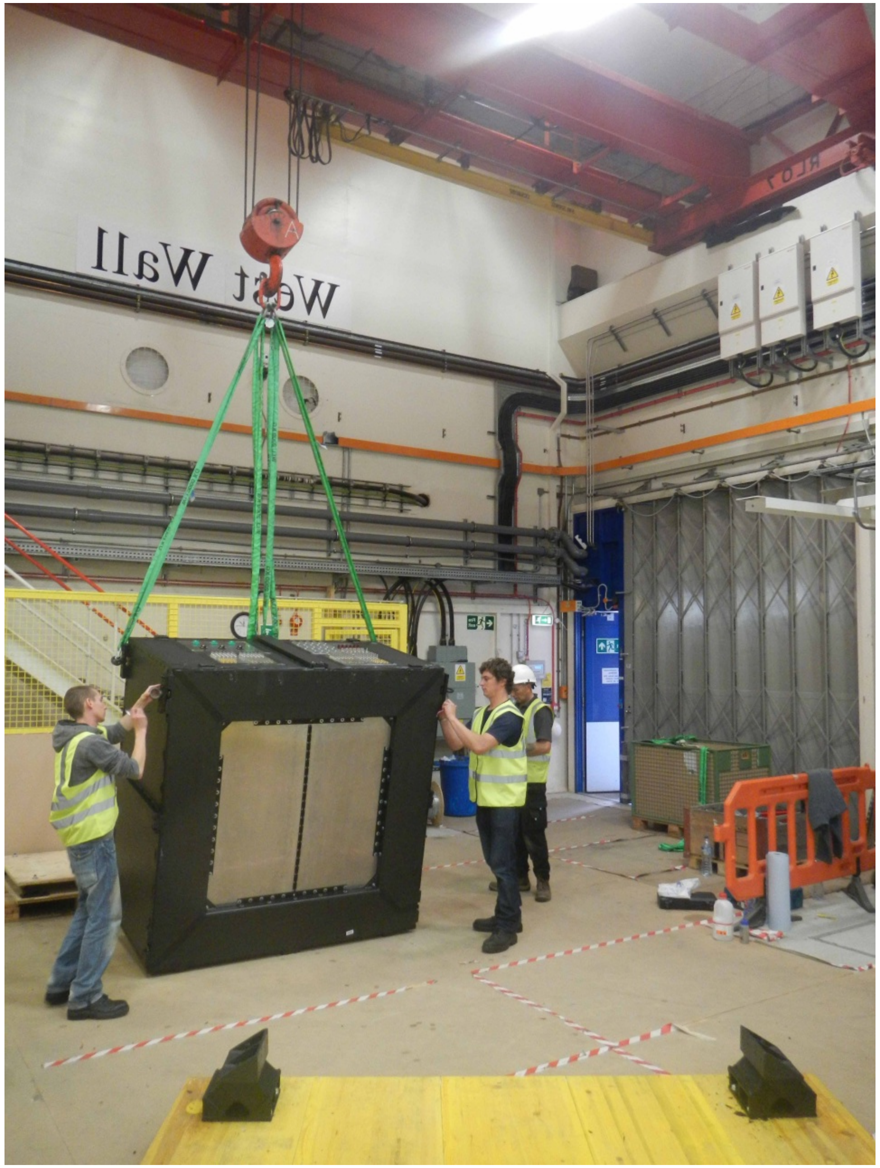
- On the 26th it was installed at Rutherford Appleton Laboratory in the MICE hall.

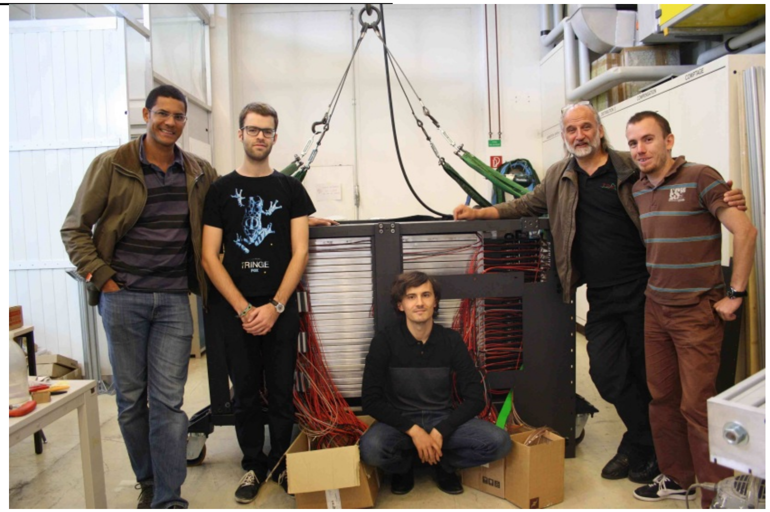
-During one month it was taking data with MICE beam (100-400 MeV/c).

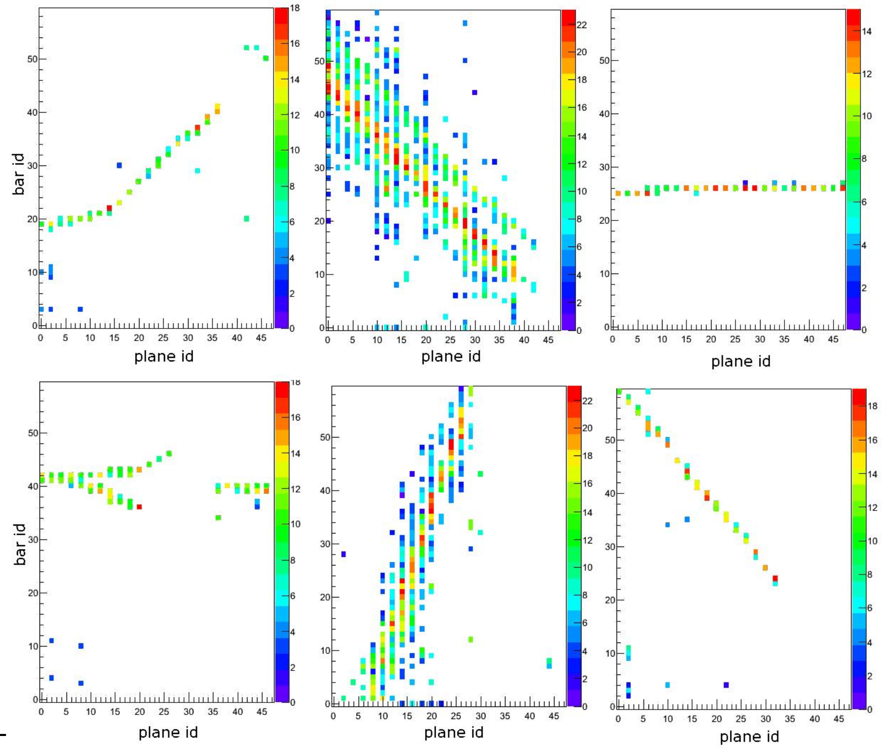
-The detector showed exceptional performance.

Thanks for the great work!

Electron-Muon Ranger installed in MICE!







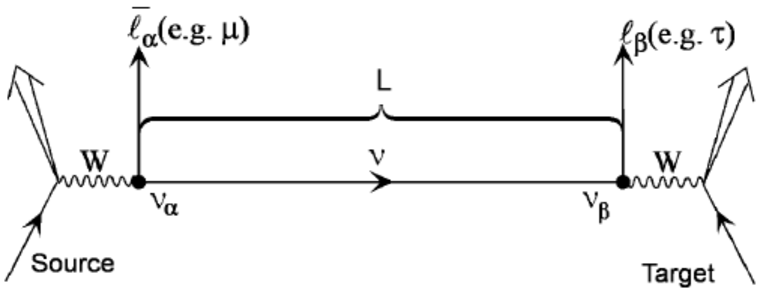
Mu3e at PSI: Lepton Flavour Violation

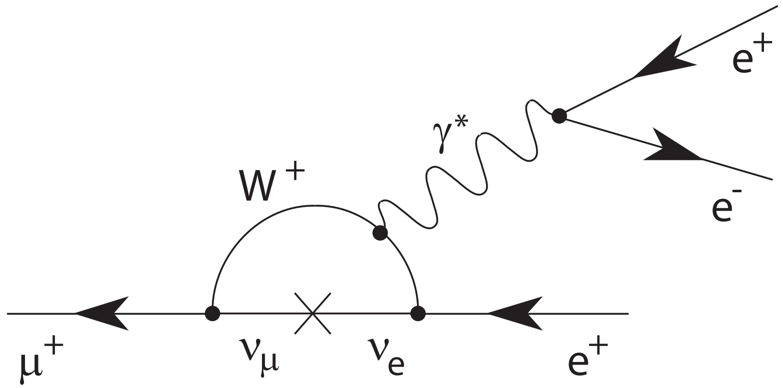
Alessandro Bravar
Antoinetta Damynova

With zero neutrino mass Lepton Flavor is strictly conserved

With nonzero mass charged LFV possible via loop diagrams

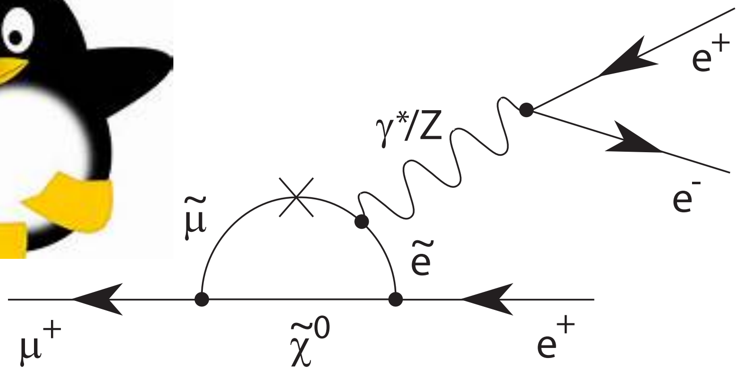
neutrino oscillations

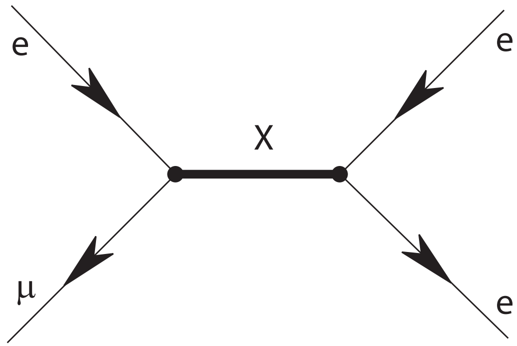




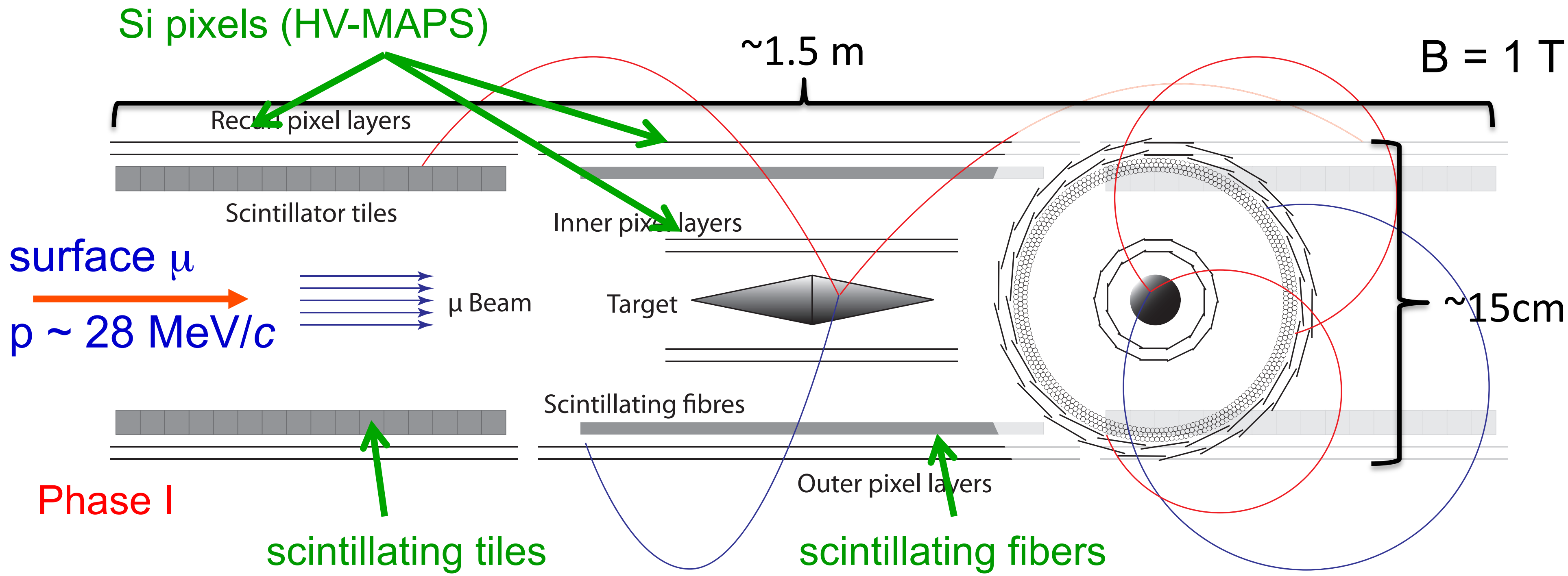
LFV addresses issues like

- origin of flavor
- neutrino mass generation
- CP violation





Mu3e Baseline Design



acceptance ~ 70% for $\mu^+ \rightarrow e^+ e^- e^+$ decay (3 tracks!)

thin, **fast**, **high resolution** detectors
(minimum material, maximum precision)

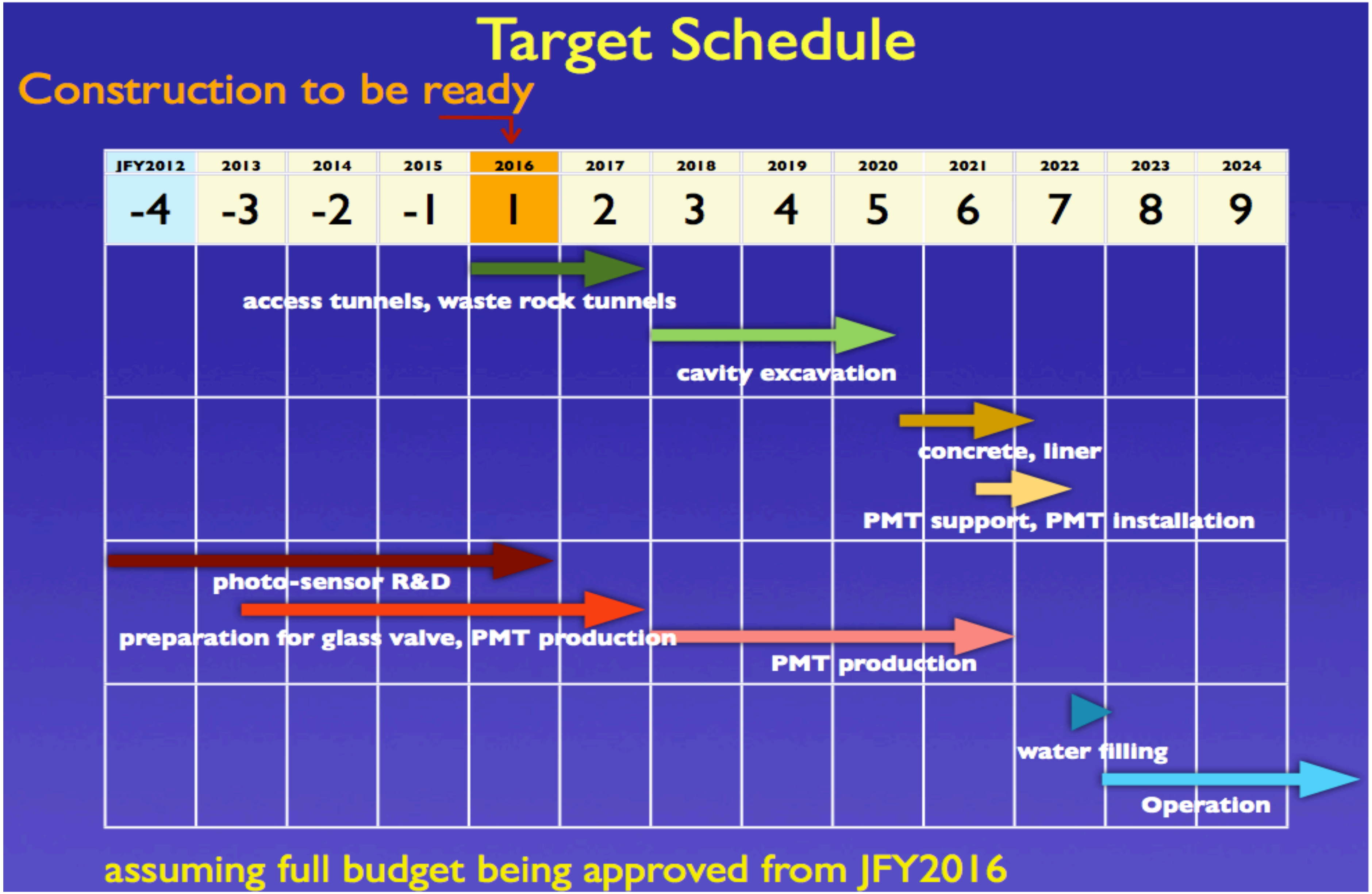
Hyper-K

A. Blondel
M. Rayner
M. Ravonel

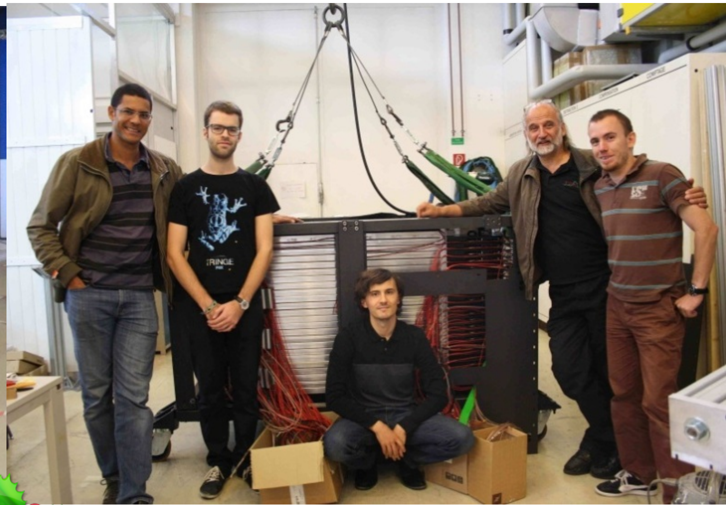
Physics Potential

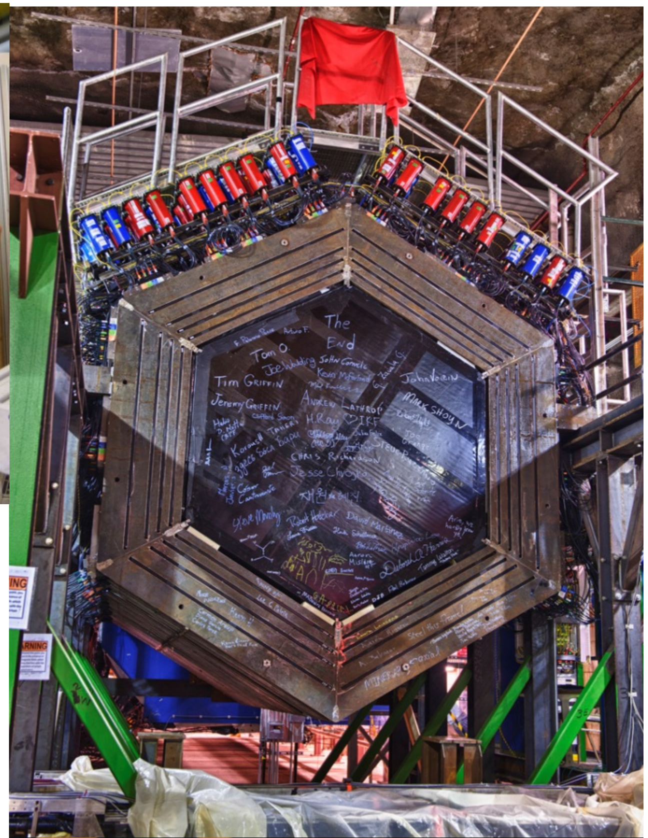
- x25 more fiducial volume than Super-K.
  - x25 more sensitive to
    - Proton Decay
    - Atmospheric neutrinos
    - Solar neutrinos
    - Supernova neutrinos
    - Cosmic neutrinos (and search for dark matters decaying to neutrinos)
- > ~1MW narrow band (off-axis) neutrino beam from J-PARC (KEK accelerator group is eager to the more ambitious goal)
  - T2K current: 240 kW (design: 750 kW)
  - x100 more sensitive neutrino experiment than today's T2K.

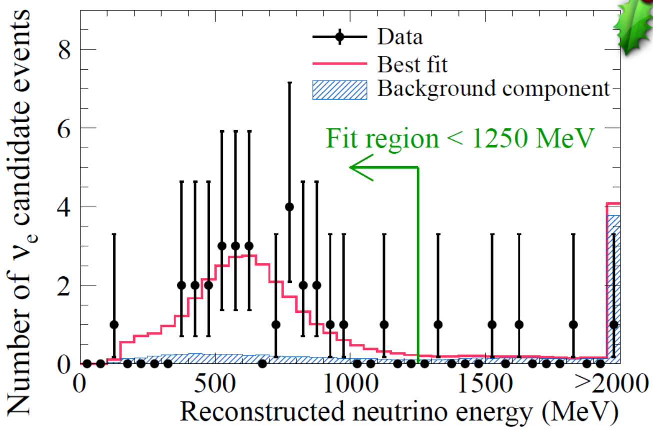
Hyper-K



Target Schedule
Construction to be ready
JFY2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
-4
-3
-2
-1
1
2
3
4
5
6
7
8
9
access tunnels, waste rock tunnels
cavity excavation
concrete, liner
PMT support, PMT installation
photo-sensor R&D
preparation for glass valve, PMT production
PMT production
water filling
Operation
assuming full budget being approved from JFY2016



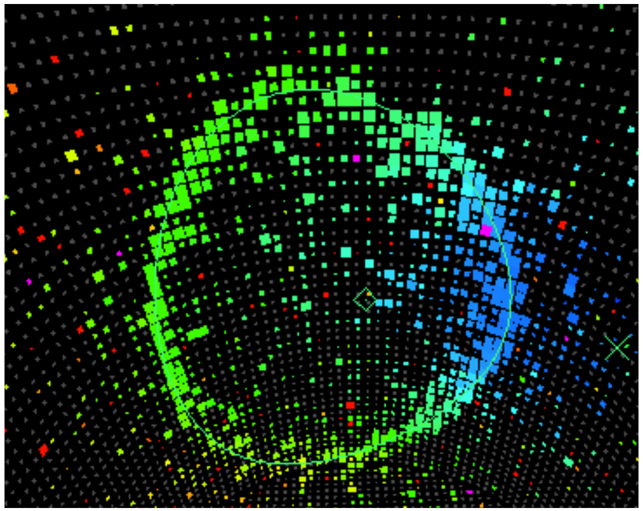


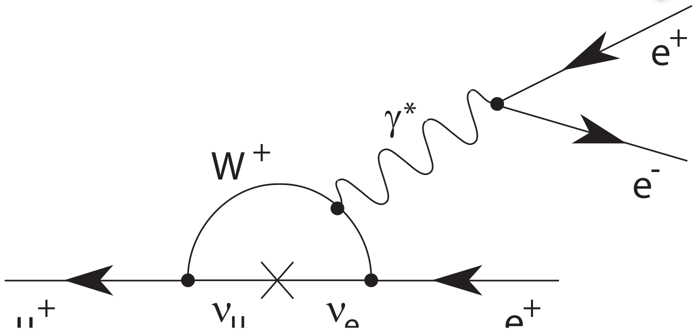


Joyeux Noël

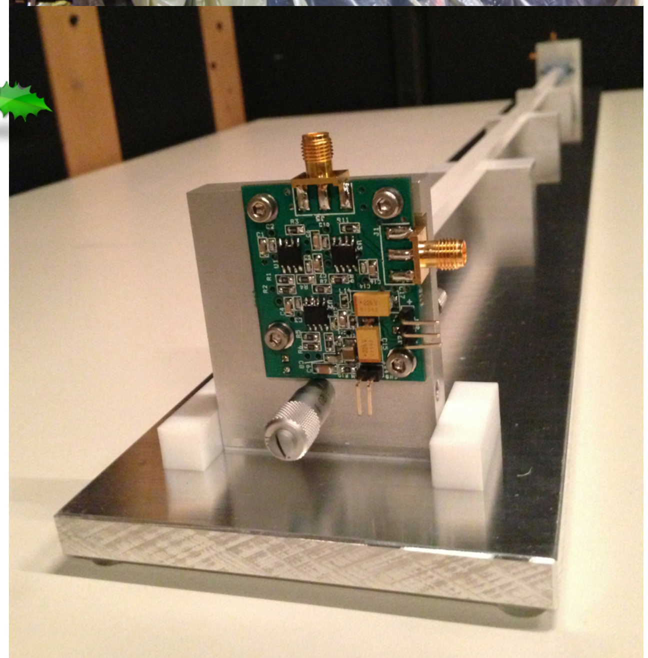
et Bonne Année

Many thanks to all who supported the Neutrino Group in 2013

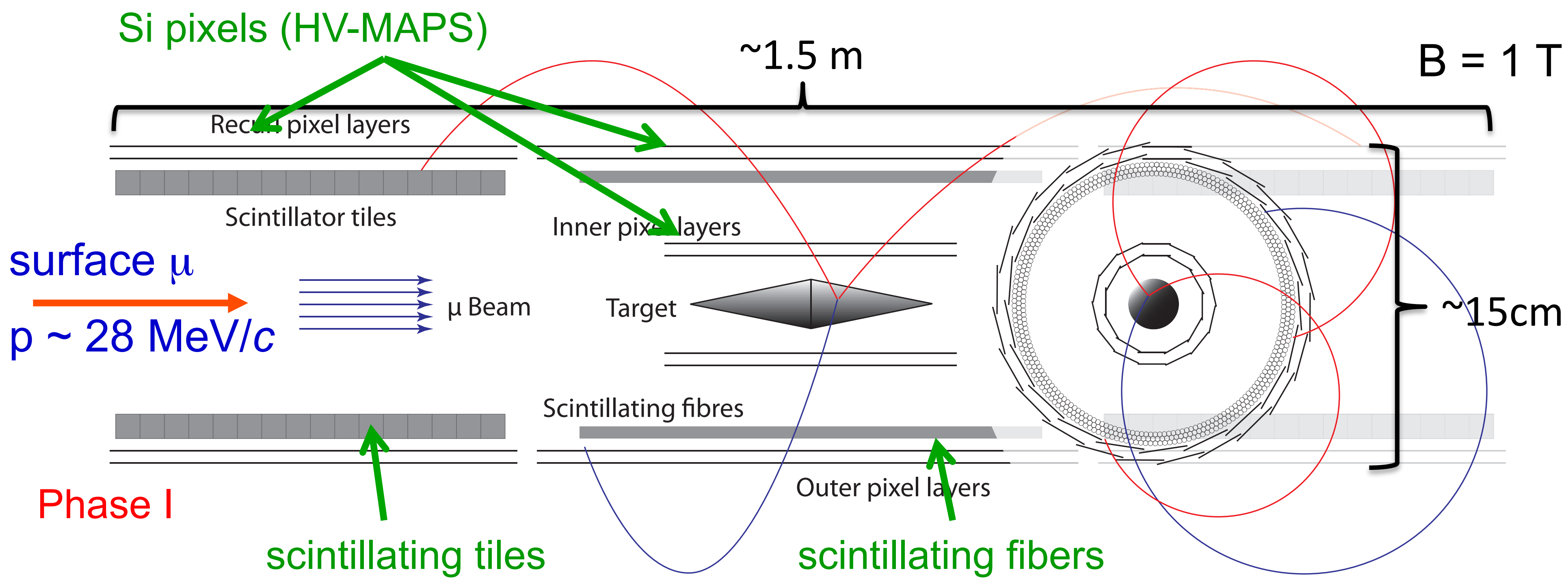




$$\sim \left(\frac{\Delta m_\nu^2}{M_W^2}\right)^2 \Rightarrow BR\left(\mu^\pm \to e^\pm e^+ e^-\right) < 10^{-50}$$



Mu3e Baseline Design



acceptance ~ 70% for $\mu^+ \to e^+ e^- e^+$ decay (3 tracks!)

thin, **fast**, **high resolution** detectors
(minimum material, maximum precision)

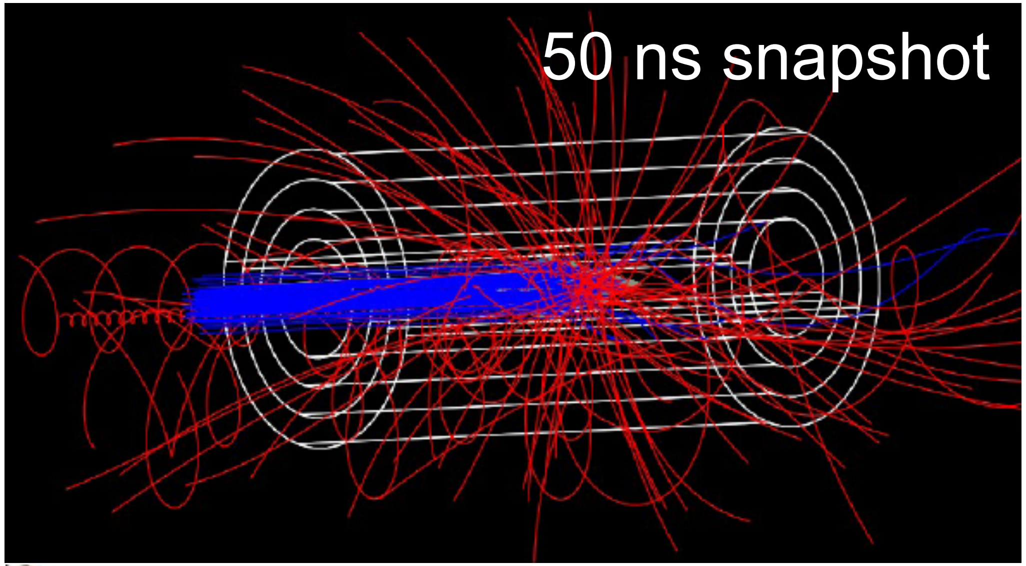
275 M HV-MAPS (Si pixels w/ embedded ampli.) channels

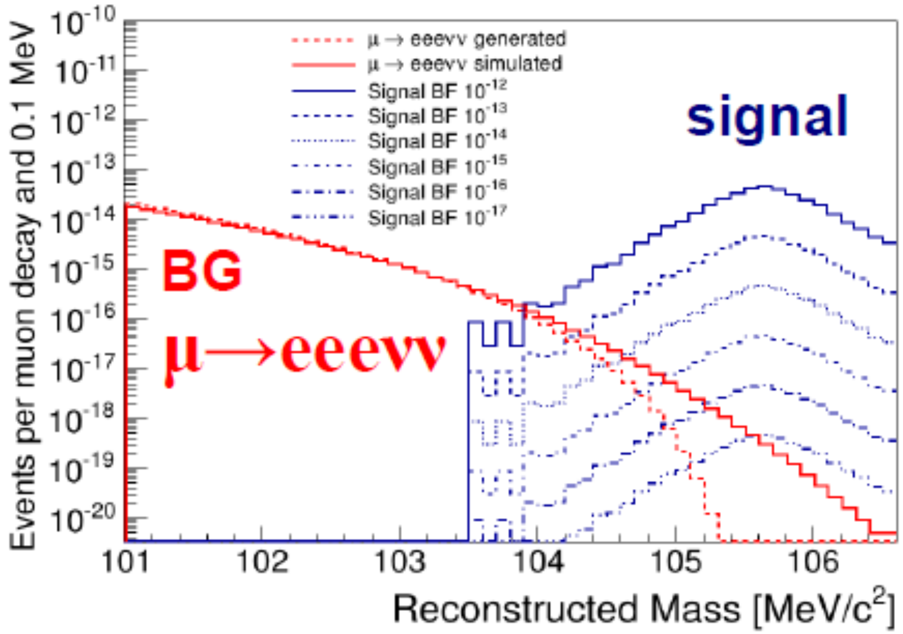
~ 10 k ToF channels (SciFi and Tiles)

How to Find $\mu^+ \rightarrow e^+ e^- e^+$ Decays

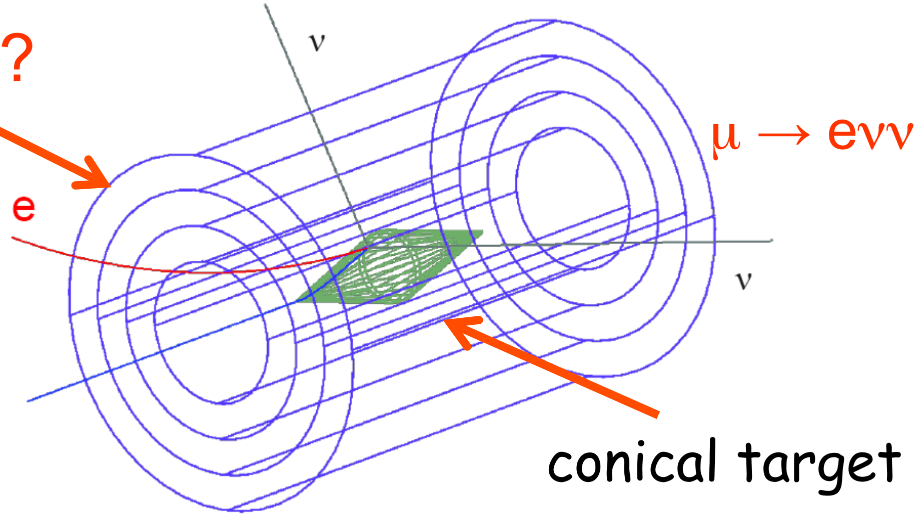
50 nsec time frames (Si "resolution") → 100 m decays @ 2 *10^9 m stops/s

challenge : isolate m → eee events



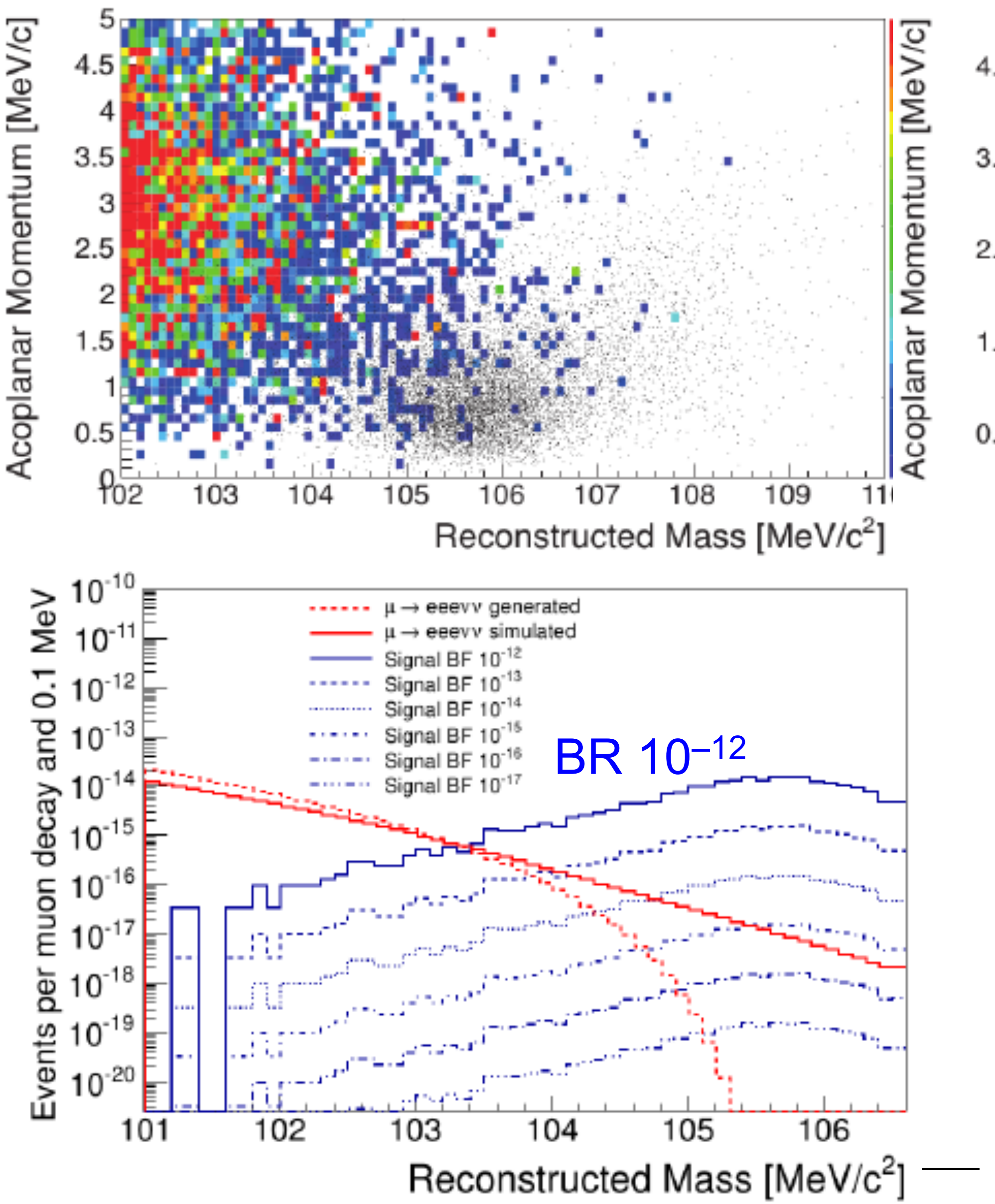


Δt ~ few 100 ps
Time of Flight
~ few 100 ps

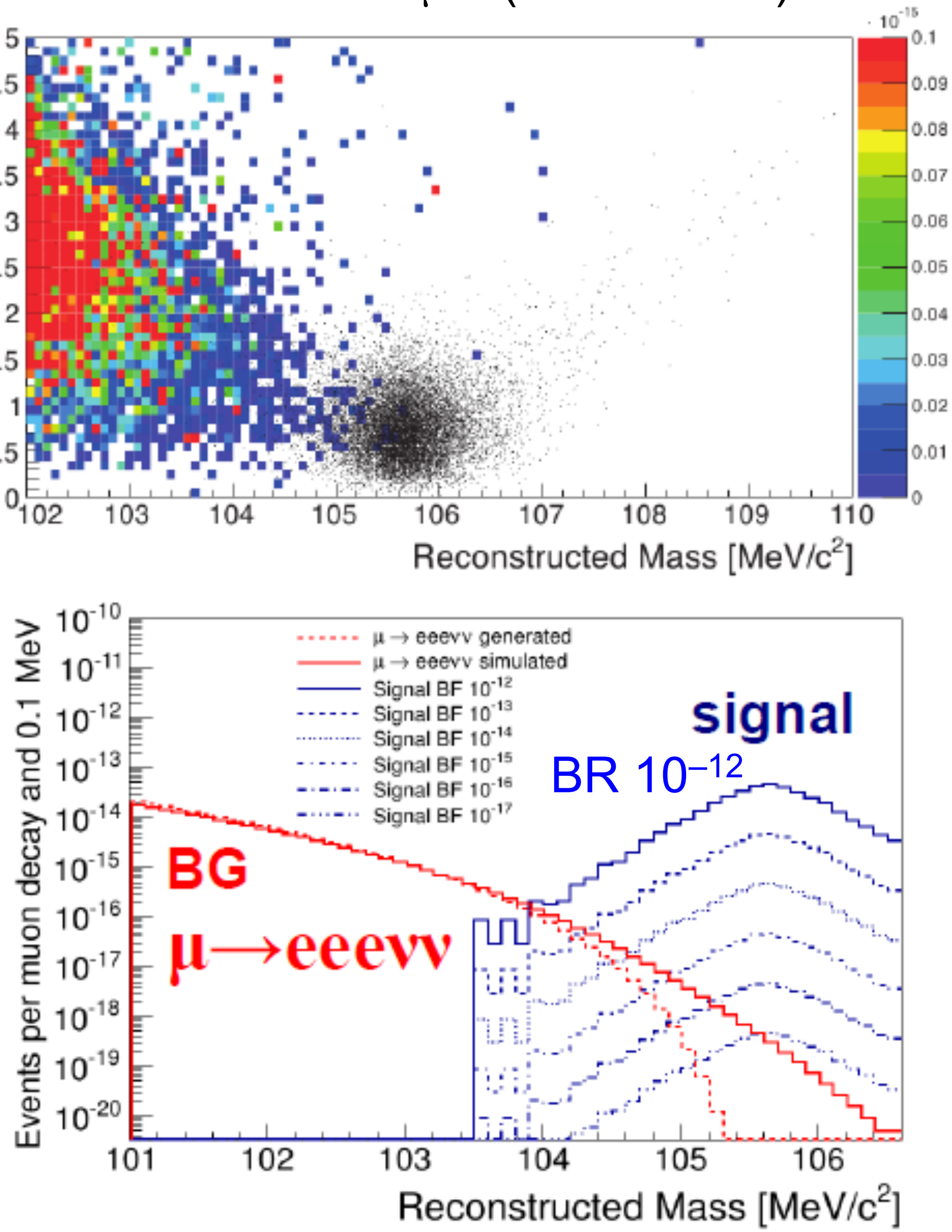


$\mu \rightarrow eee$ Signal Simulations

Phase IA: ~ 2×10^7 μ/s (central pixel)



Phase II: ~ 2×10^9 μ/s (full detector)



LFV Searches : Current Situation

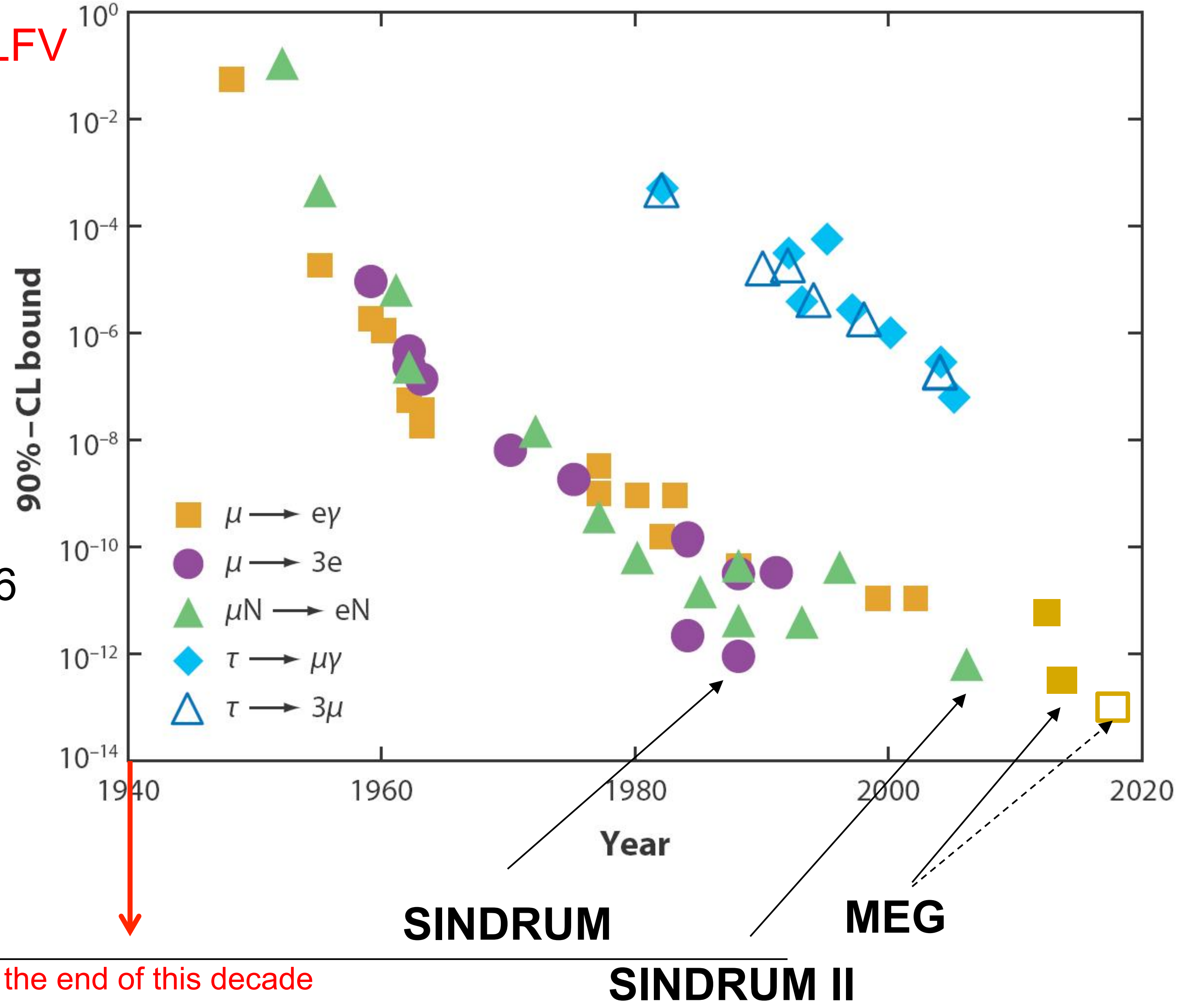
The best limits on LFV come from PSI muon experiments

$\mu^+ \to e^+e^-e^+$
BR < 1×10^{-12}
SINDRUM 1988

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

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

[90 % C.L.]



Sci-Fi Tracker - ToF

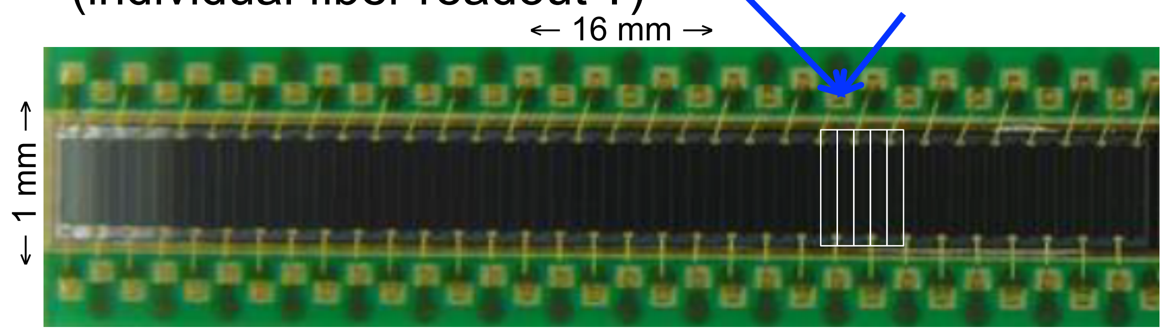
high spatial resolution (matching with silicon hits)

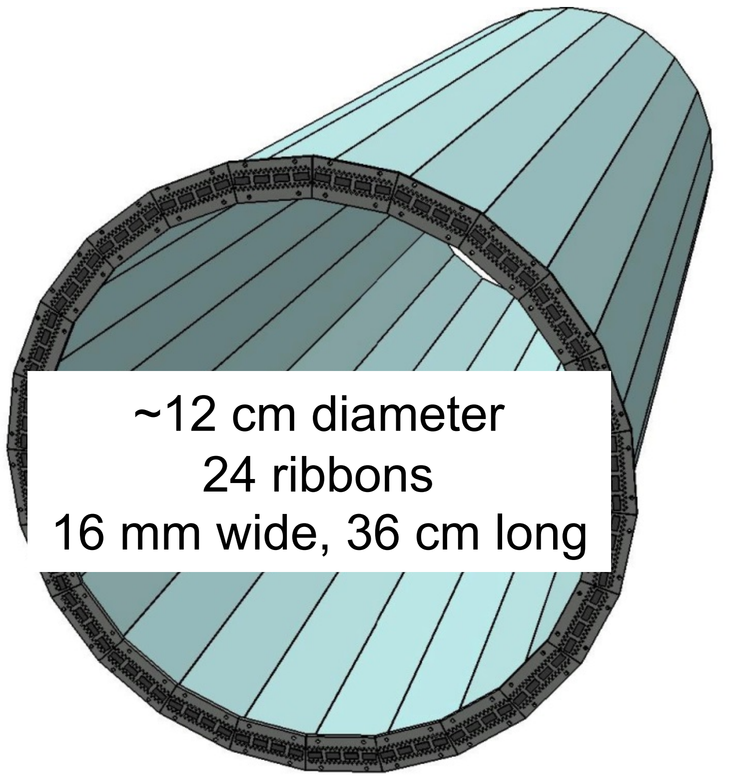
good time resolution < 500 ps

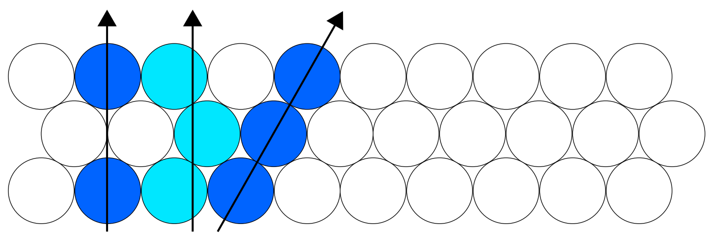
scintillating fibers 250 μm ∅ (3 staggered layers)

24 Sci-Fi ribbons (16 mm × 360 mm)

readout with Si-PMs arrays on both ends
- 64 channel monolithic device, ~3000 ch. total
- 250 μm "pitch", 50 μm cells
- common bias voltage
- (individual fiber readout ?)





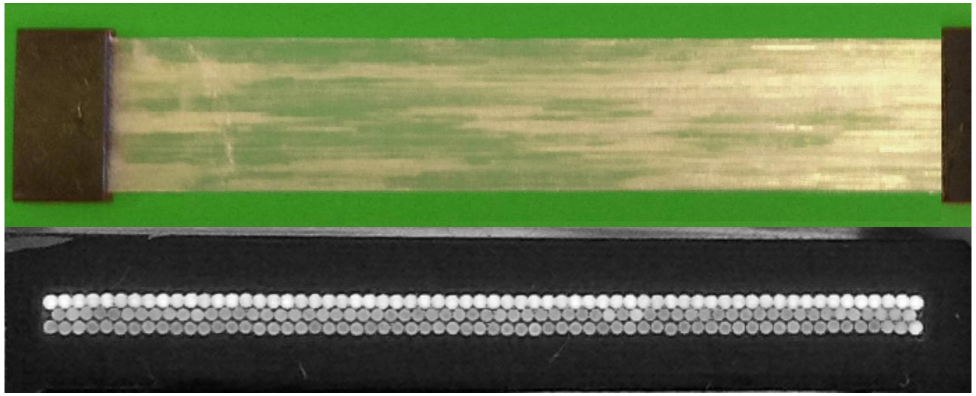


rate: several MHz / SciFi ch.

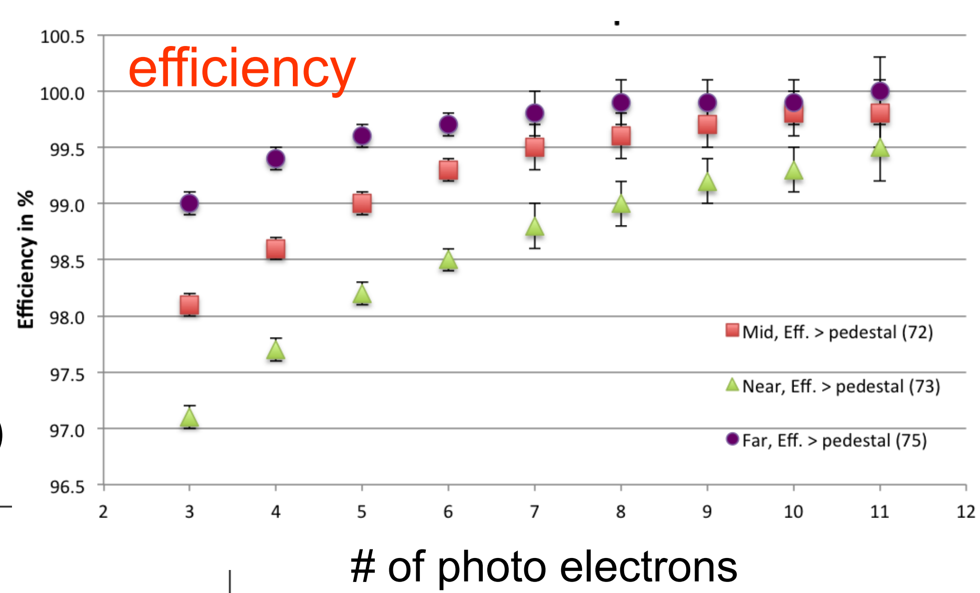
readout with the DRS waveform digitizer (custom ASIC)

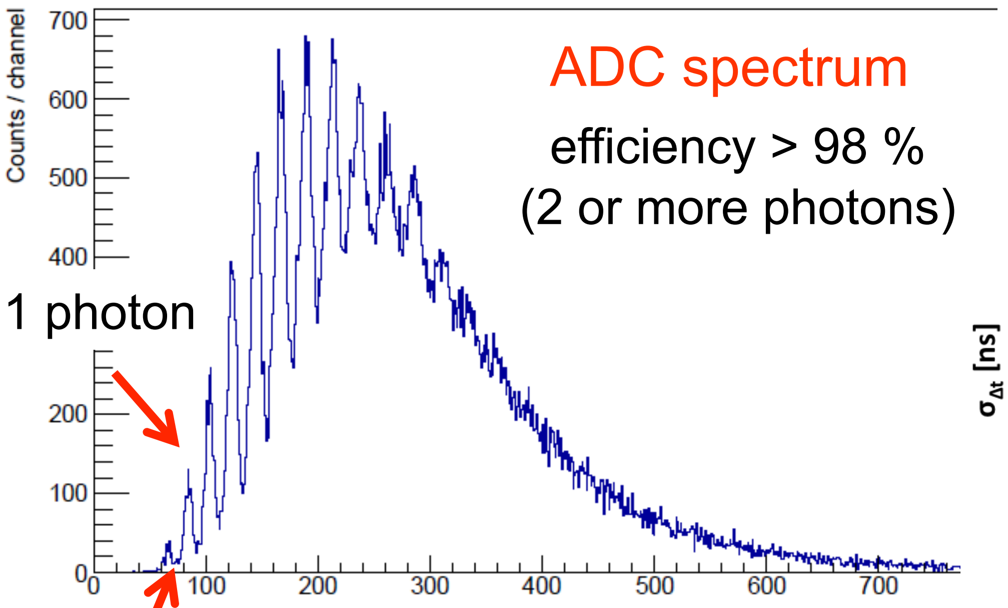
occupancy and optical cross talk?

SciFi Performance (preliminary)



readout on both sides with single channel
3 × 3 mm² 100 μm cell Si-PM (Hamamatsu)





pedestal
(inefficiency !)