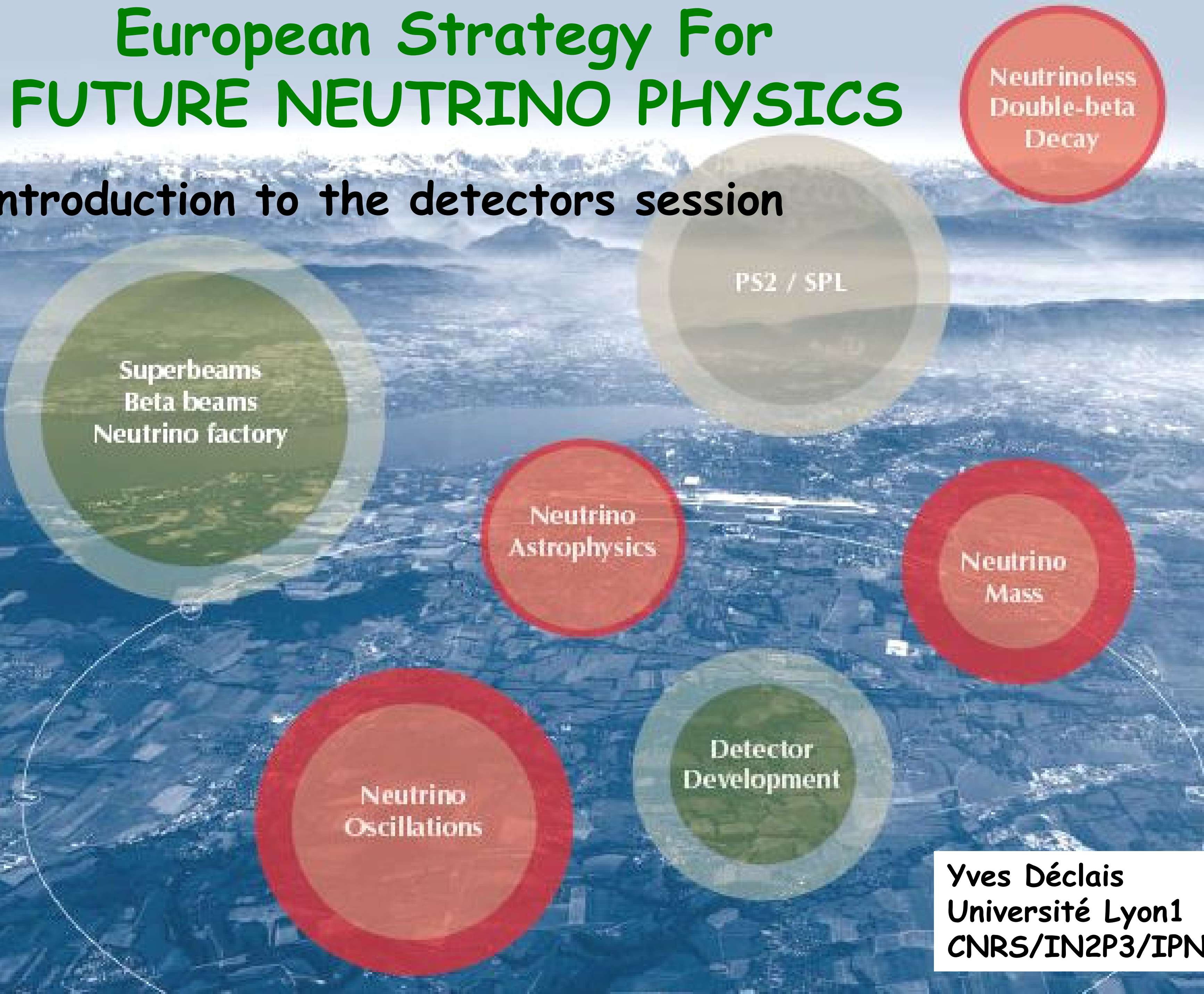
European Strategy For FUTURE NEUTRINO PHYSICS

Introduction to the detectors session



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Foreword:

• new generation of reactor experiment are being built following the detector concept used in the CHOOZ experiment (Th. Lasserre this workshop)
• in this session emphasis is given to detectors which can be used with a neutrino beam

- Magnetized Iron calorimeter
- Fully active plastic & liquid scintillator
- Liquid Argon TPC
- Water Cerenkov

"define the optimal neutrino programme based on the information available in around 2012 for precision neutrino experiments to commence data taking around 2020"

Outline

1. Landscape of the neutrino program in around 2012
2. What are the possible scenarios for running in 2020
3. Proposed comparison tables for detectors
4. Organizational aspects

What could be known in around 2012 for the 3rd mixing:

1. Reactors ($\bar{\nu}_e$ disappearance): $Sin^2(2\theta_{13})$, 90% CL

- Double Chooz sensitivity : **~5 10^{-2}**
- Daya-Bay will be starting data taking

2. Accelerators (ν_e appearance)

- T2K could have integrated 750 kw x 22.5 kton
  ➔ sensitivity (normal hierarchy, integrated over δ_{cp}) **~2 10^{-2}**
- MINOS & OPERA cannot compete
- NOvA built and NUMI being upgraded

Whatever a positive or negative result will appear we will need:

- to **validate the result** with more statistics and new experimental data

➔ **upgrade an existing facility or build a new one (intensity frontier) equipped with new massive detectors**

to disentangle mass hierarchy and δcp for large $Sin^2 2\theta_{13}$

OR

to push away the limits beyond the sensitivity reached in around 2016

What could be known in around 2016:

1. **Reactors** (anti Nue disappearance): Sin²($2\theta_{13}$), 90% CL
   - Double Chooz sensitivity : **~3 10^{-2}**
   - Daya-Bay : **~1 10^{-2}**

   Assuming very low background (to be proven experimentally)

2. **Accelerators**

   (ν_e appearance, normal hierarchy, integrated over δcp)
   - T2K could have integrated 750 kw x 22.5 kton x 5 years

     ➔ sensitivity **~6 10^{-3}**
   - NOvA with NuMI upgrade (250 → 700kw)

     ➔ sensitivity **~1 10^{-2}**

New precision experiments should reach a sensitivity ≤ **1 10^{-3}**

<u>What consequence if a positive result is then appearing:</u>

- this result will have to be validated with more sensitive experiments
- disentangling mass hierarchy and δ_{cp} will require new facilities

  β beam ↔ NuFactory
  - high power proton driver can be the front end of such a facility
  - can we use the new planned detectors with such a facility

What could be known in around 2016:

1. **Reactors** (a

   Sin²($2\theta_{13}$), 90% CL

   - Double — **~3 10^{-2}**
   - Daya-B — **~1 10^{-2}**

2. **Accelerator**

   (ν_e appeara

   - T2K co — **~6 10^{-3}**
   - NOvA w — **~1 10^{-2}**

As quoted during the introduction session:

➢ **this sensitivity is given for 90% C.L.**
What should be the accuracy reached before to take any decision : 3σ, 4σ, 5σ ?

➢ **Such an important result should be over constraint: how many independent results would be needed ?**

Hard to believe that such a decision could be taken before the end of the 2020's

New precision experime... hould reach a sensitivity ≤ **1 10^{-3}**

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  ➢ high power proton driver can be the front end of such a facility

  ➢ can we use the new planned detectors with such a new facility

Parameters for the next generation of LBL experiments

could start early in the 2020's

- Machines beyond the intensity frontier: 1÷3 MW proton source ➔ **x 2 ÷3**

- Massive detectors : 100 ÷1000 kton

➢ **Water cerenkov**	**50** kton →	**500** kton		➔ **x 10**
➢ **Liquid Argon**	**.6** kton →	**100** kton		➔ **x ~150**
➢ **Magnetized Fe**	**5.4** kton →	**50-100** kton		➔ **x ~10÷20**
➢ **TASD**	**15** kton →	**50** kton		➔ **x ~ 4**

Both are really challenging, especially for the detectors:

- ➢ the main gain will be obtained in using massive detectors
- ➢ are there enough resource (funding!) for vigorous R&D

➔ this session is mainly devoted to scrutinize these aspects

Super Beam facilities planned/hoped in around 2020:

1. **JPARC (NP08 meeting, KEK road map):**
   - upgrade to 1.6 MW, 30 GeV protons
   - Possible baselines (same beam line)
     - Kamioka 295 km, 2.5° off-axis, 2x270 kton Water Cerenkov
     - Okinoshima 655 km, 0.8° off-axis, 100 kton LAr TPC
     - Korea 1000 km, 2.5° off-axis, 2x270 kton Water Cerenkov

2. **Fermi Lab : Project X**
   - New intense source : 2.3 MW , 120 GeV protons
   - New beam line pointing to DUSEL : 1300 km
     on-axis ➔ broad band beam
   - Detectors being studied:
     - Water Cerenkov : ≥ 3 x 100 kton (fiducial)
     - LAr TPC : 5 kton → 25 kton → ≥25 kton

Both in favour of:
- ~ on-axis beam ➔ broad band beam ➔ spectrum shape analysis
- long baseline ➔ Mass hierarchy determination ➔ improves δ_{cp} sensitivity

Super Beam facilities planned/hoped in around 2020 (cntd):

3. CERN

- New injection chain for LHC: Linac4, LP-SPL, PS2
  - ✓ SPS → 2.2 10^{20} pot/year ~1MW
    - ➔ refurbishing CNGS facility
  - ✓ PS2 (nominal) : 320 kW
  - ✓ LP-SPL : 120 kW
- Possible baselines
  - ➢ Any of LAGUNA sites:

Name	Type	Envisaged Depth (m.w.e)	Distance from CERN (km)	Energy 1st osc. max (GeV)
Fréjus (F)	Road tunnel	$\simeq$ 4800	130	0.26
Canfranc (ES)	Road tunnel	$\simeq$ 2100	630	1.27
Umbria (IT)	Green field	$\simeq$ 1500	665 ($\simeq$ 1.0°OA)	1.34
Sieroszowice (PL)	Mine	$\simeq$ 2400	950	1.92
Boulby (UK)	Mine	$\simeq$ 2800	1050	2.12
Slanic (RO)	Salt mine	$\simeq$ 600	1570	3.18
Pyhasalmi (FI)	Mine	$\simeq$ 4000	2300	4.65

Can the road to the intensity frontier be opened at CERN in time ?

HP-SPL & PS2++ Needed for being able to compete !

Which baseline?
Longer are favoured for mass hierarchy determination

Which detectors can cope with such a wide range of energy

Performance table

The facility and the baseline drives the energy range and resolution

		channels			facilities						features			performance	
	E range	μ	e	τ	NF	LENF	High γ βB	Low γ βB	off-axis SB	Wide band SB	B field	mass Kton	near detector	E resol	Eff & bkg
MIND															
TASD															
LAr															
WC															

NF = Neutrino factories
LENF = Low energy neutrino factory
High γ βB = High gamma beta beam
Low γ βB = Low gamma beta beam
Off-axis SB = Off-axis Super Beam
Wide band SB = Wide band Super Beam

Is a small scale dtector (wrt far detector) valuable for efficiency and background study

Synergies table

- beam composition study
- Xsection measurements
- Pid studies
- background studies

European contribution to a program in Japan or in US

	synergies with astroparticle	near detector physics	experimental sites	Interplay with program in other regions
MIND				
TASD				
LAr				
WC				

Non accelerator physics:
- proton decay
- atmospheric neutrinos
- SuperNovae
- …

Depth constraint wrt:
- induced background
  ➔ correlated with Astroparticle synergy
- data rate induced by cosmic rays

Cost feasibility table

	cost/Kton	cost driver	feasibility driver	key R&D points	requirements on site
MIND					
TASD					
LAr					
WC					

	How to use existing detectors to understand performance	Required test beam measurements to understand performance	R&D towards cost reduction	R&D towards technological challenges	Intermediate steps towards full scale detector	Expertise in Europe	Possible R&D activities at CERN
MIND							
TASD							
LAr							
WC							

« To begin the process of establishing a roadmap for a coherent European participation in future Neutrino Physics »

Since the year 2000 many initiatives have been developed in Europe and at CERN:

Non accelerator physics oriented

ApPEC (2001)
Astropicle Physics European Coordination
Group of 13 national funding agencies

ASPERA (2006)
Astroparticle ERA-NET
Network of government agencies
for coordinating and funding
national research efforts in Astroparticle Physics

LAGUNA
Design of a new infrastructure
in Europe to host very large
volume new instrument

Accelerator physics oriented

ISS
report published

EuroNu
FP7 design study
High Intensity
ν Oscillation Facility in Europe
WP5
Detector Performance

RECFA
Coordination group
For detector R&D
DevDet
WP5
Coordination Office
for neutrino detectors

1) Interplay between the 2 fields:
   should we maintain an 'interlock'

2) A lot of papers have been produced, it is time now to build up an *energetic programme incorporating design, R&D and costings* for the new generation of massive detectors :
   Can CERN foster such an activity as it has been done for the LHC detectors

Conclusions

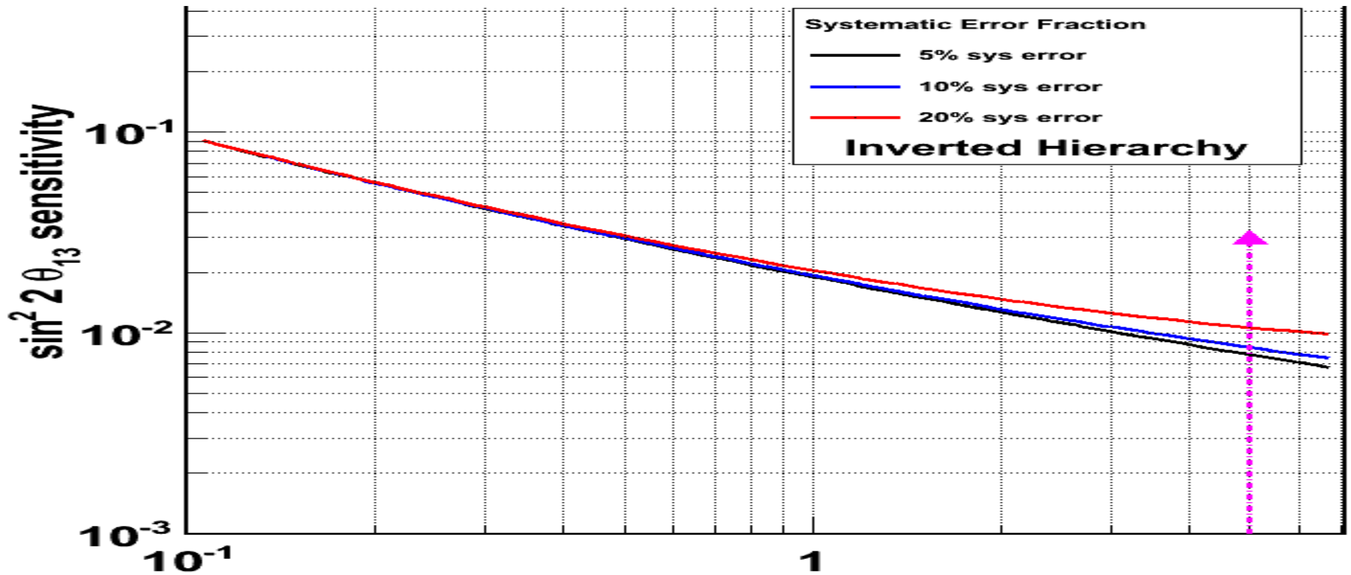
1) Non zero value for θ13 will open a new field of research which can be compared to CP violation studies in the quark sector:

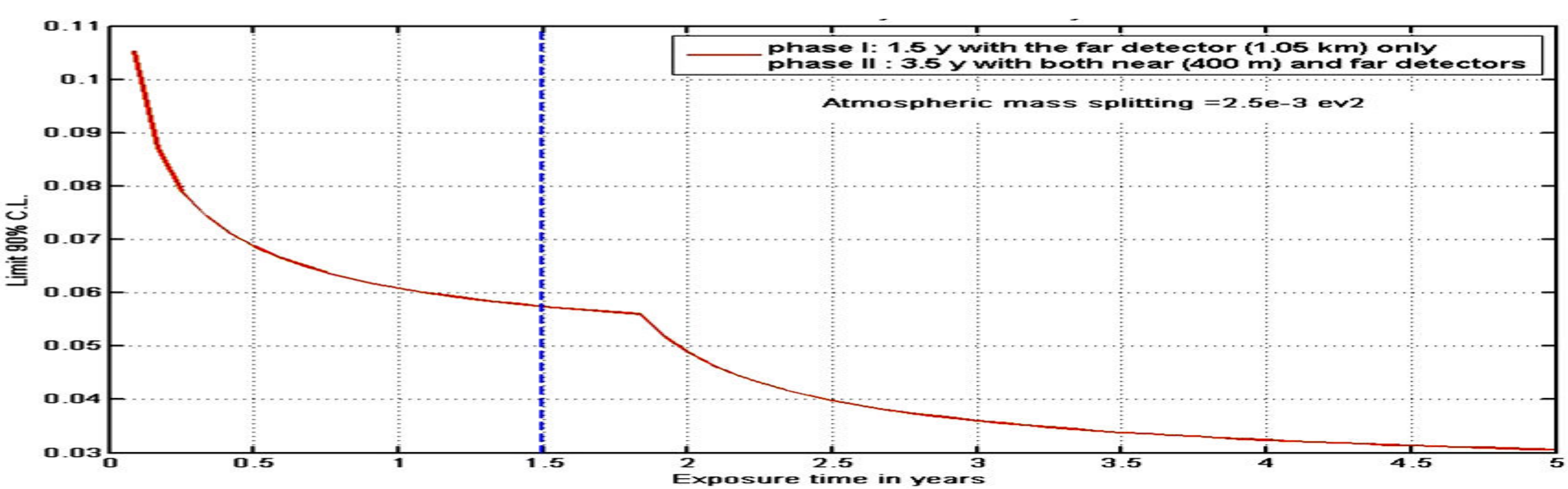
- Long term program ➔ be patient
- Precision neutrino experiments are very difficult
  ➔ be systematic

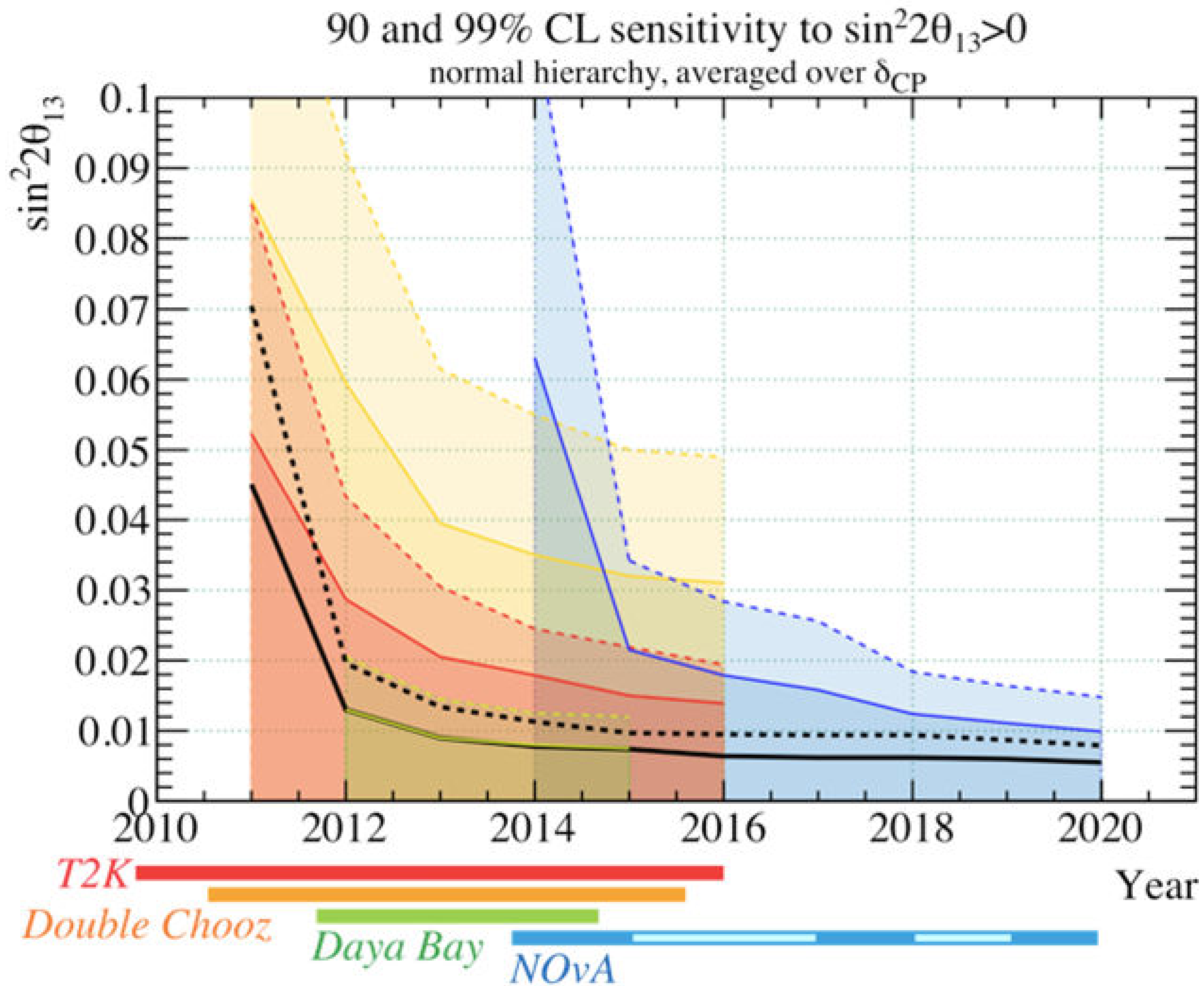
2) New massive detectors are a key issue in this experimental field:
- we need it before constructing any new 'factory'
- Cern can play a role in detectors R&D as it was done for the LHC detectors
- will be valuable even if the future neutrino facility would be built outside Europe

Thanks for your attention

Spare slides

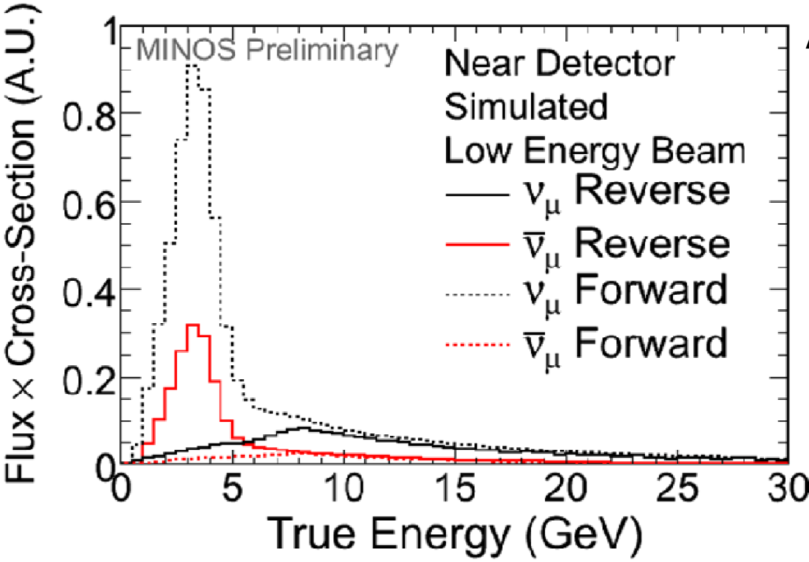

Systematic Error Fraction
5% sys error
10% sys error
20% sys error
Inverted Hierarchy
$\sin^2 2\theta_{13}$ sensitivity
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1


phase I: 1.5 y with the far detector (1.05 km) only
phase II : 3.5 y with both near (400 m) and far detectors
Atmospheric mass splitting =2.5e-3 ev2
Limit 90% C.L.
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Exposure time in years



90 and 99% CL sensitivity to sin²2θ13>0
normal hierarchy, averaged over δCP
sin²2θ13
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2010
2012
2014
2016
2018
2020
Year
T2K
Double Chooz
Daya Bay
NOvA

Measuring δ_{cp}



Running the beam in positive and negative polarity
And comparing the results

Careful optimization is needed

for the ν_μ contamination in the antineutrino run:

- increase with the proton energy
- increase with the off-axis angle

	neutrino run			antineutrino run		
Distance/Angle	ν_μCC ($\bar{\nu}_\mu$CC)	ν_eCC ($\bar{\nu}_e$CC)	$(\nu_e+\bar{\nu}_e)$ / $(\nu_\mu+\bar{\nu}_\mu)$	ν_μCC ($\bar{\nu}_\mu$CC)	ν_eCC ($\bar{\nu}_e$CC)	$(\nu_e+\bar{\nu}_e)$ / $(\nu_\mu+\bar{\nu}_\mu)$
CNGS 10 GeV , 400 GeV/c protons , 2.4×10^{20} pot/year						
665 km 1.3 deg	5733 (949)	187 (59)	3.7 %	2373 (2165)	139 (75)	4.7 %
665 km 0.85 deg	13648 (2213)	336 (112)	2.8 %	5221 (5381)	256 (139)	3.7 %
CNXX NOνA horns , 400 GeV/c protons , 2.4×10^{20} pot/year						
1544 km 0.25 deg	12181 (939)	96 (16)	0.9 %	2469 (5125)	37 (39)	1.0 %
CNXX NOνA horns , 50 GeV/c protons , 3×10^{21} pot/year						
1544 km 0.25 deg	23600 (333)	160 (7)	0.7 %	1267 (6467)	20 (40)	0.8 %
2300 km 0.25 deg	10667 (153)	73 (3)	0.7 %	573 (2933)	7 (20)	0.8 %

A. Rubbia, New Opportunities in the physics landscape at CERN, May 2009