

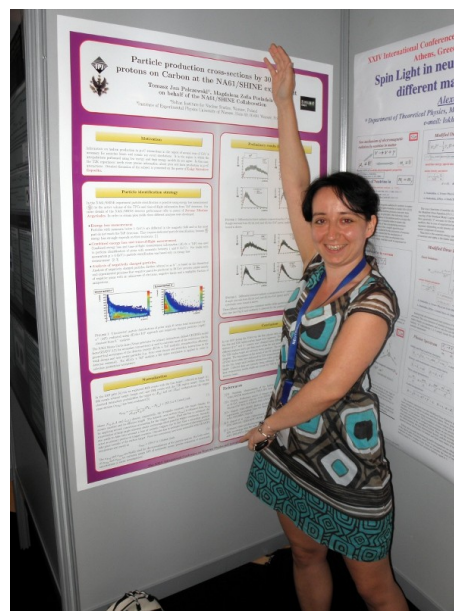
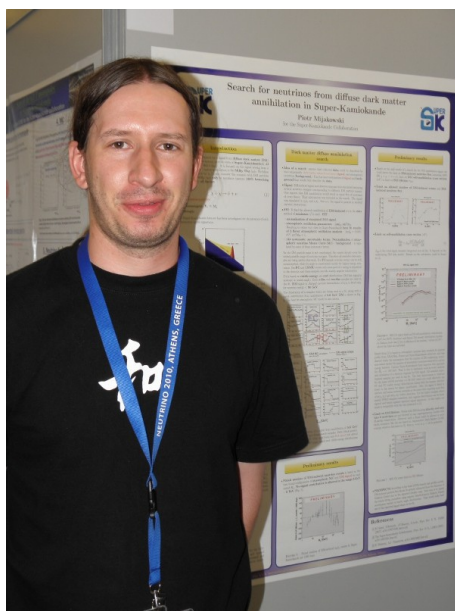
# Konferencja NEUTRINO 2010

najciekawsze wyniki



część II

Justyna Łagoda



# Wybrane tematy

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- **OPERA** – odkrycie  $\nu_\tau$  *appearance*? (Osamu Sato)
- detektory ciekłoargonowe
  - ▶ **ICARUS** i **Double LAr** @ CERN PS (Alberto Guglielmi)
  - ▶ Fermilab/DUSEL (Mitchell Soderberg)
  - ▶ Japonia (Takuya Hasegawa)
- inny ciekawy projekt detektorowy
  - ▶ **GADZOOKS!** (Mark Vagins)
- przyszłość **wiązek neutrinowych** – co dalej po wiązkach konwencjonalnych?
  - ▶ superwiązki (Ken Sakashita)
  - ▶ fabryki neutrin (Kenneth Long)
  - ▶ wiązki beta (Elena Wildner)

# *Appearance i disappearance*

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- oscylacje neutrin
  - ▶ eksperymenty *disappearance*
    - obserwowany jest ubytek neutrin z wiązki neutrin o znanym zapachu
    - np. neutrina słoneczne, atmosferyczne, reaktorowe, większość eksperymentów akceleratorowych
  - ▶ eksperymenty *appearance*
    - poszukiwane jest pojawienie się neutrina o zapachu, którego pierwotnie w wiązce nie było
    - np. neutrino taonowego w wiązce neutrin mionowych
- **OPERA** – to detektor w laboratorium Gran Sasso (Włochy) poszukujący oddziaływań neutrin taonowych w wiązce CNGS wysyłanej z CERN

# OPERA i CNGS

## wiązka CNGS

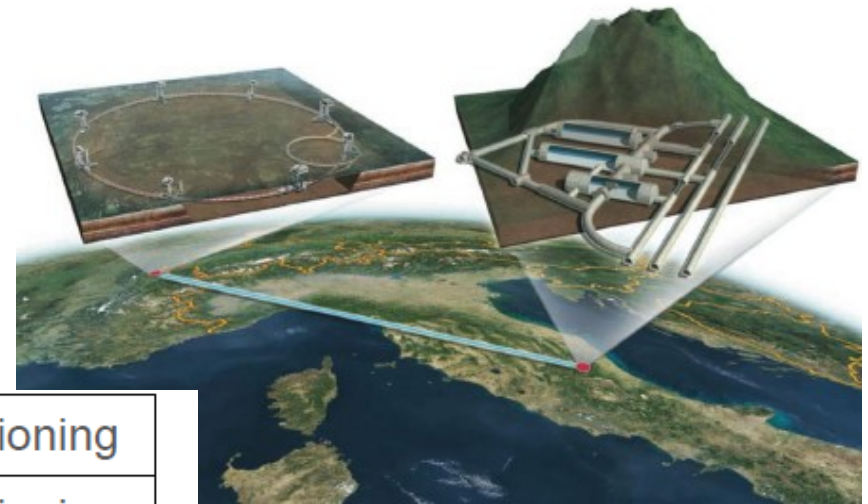
$\langle E \rangle$	17 GeV
L	730 km
$(\nu_e + \bar{\nu}_e) / \nu_\mu$ (CC)	0.87%
$\bar{\nu}_\mu / \nu_\mu$ (CC)	2.1%
$\nu_\tau$ prompt	negligible

Expected neutrino interactions for 1.25kton  
22.5x10<sup>19</sup> pot

- ~ 23600  $\nu_\mu$  CC + NC
- ~ 205  $\nu_e + \bar{\nu}_e$  CC
- ~ 115  $\nu_\tau$  CC ( $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$ )

## Zebrane dane

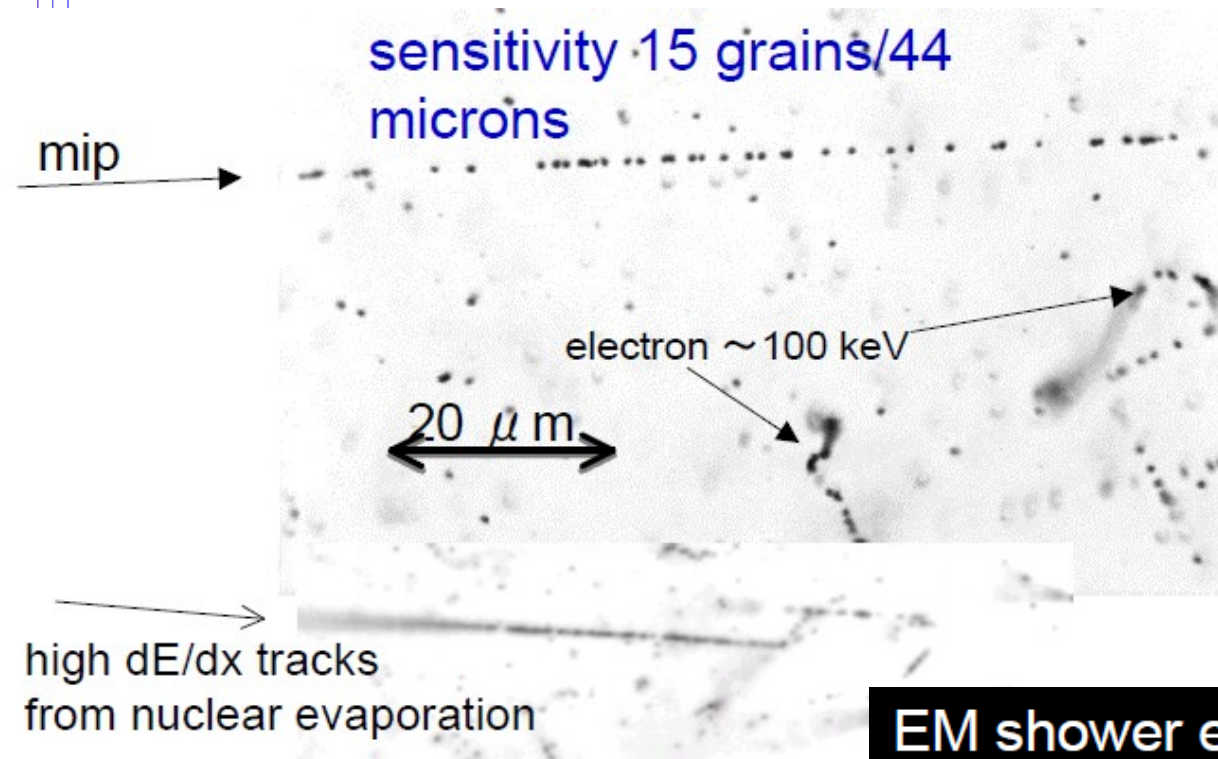
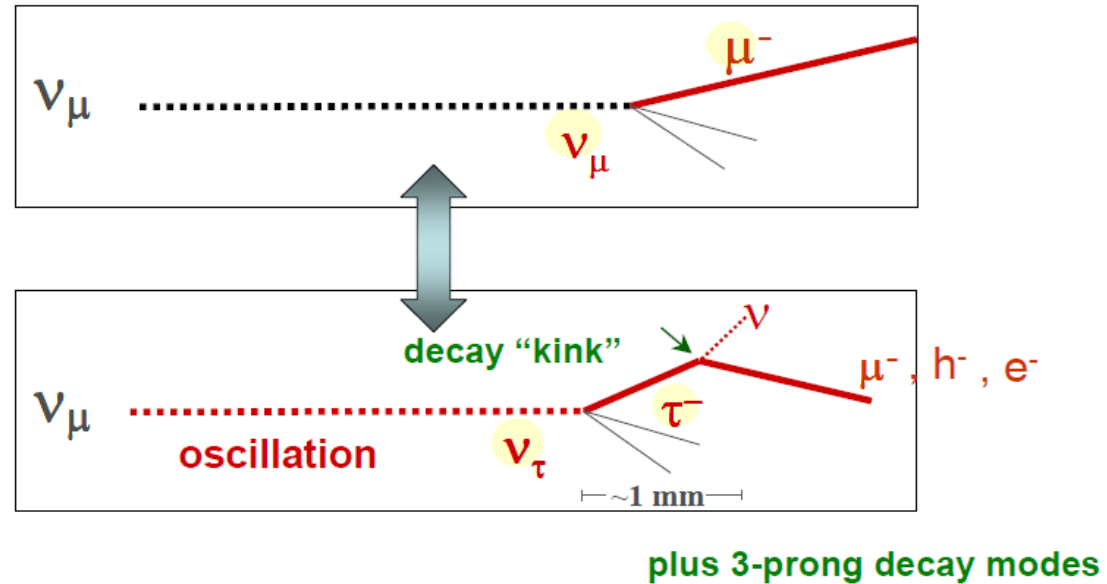
2006	0.076x10 <sup>19</sup> pot	no bricks	Commissioning
2007	0.082x10 <sup>19</sup> pot	38 ev.	Commissioning
2008	<b>1.78x10<sup>19</sup> pot</b>	<b>1698 ev.</b>	<b>First physics run</b>
2009	<b>3.52x10<sup>19</sup> pot</b>	<b>3693 ev.</b>	<b>Physics run</b>
2010	<b>0.81x10<sup>19</sup> pot (6 Jun)</b>	<b>706 ev.</b>	<b>Physics run</b>



# OPERA

## metoda detekcji

obserwacja załamania toru (*kink*) - rozpad taonu (odległość między wierzchołkami rzędu 1mm)



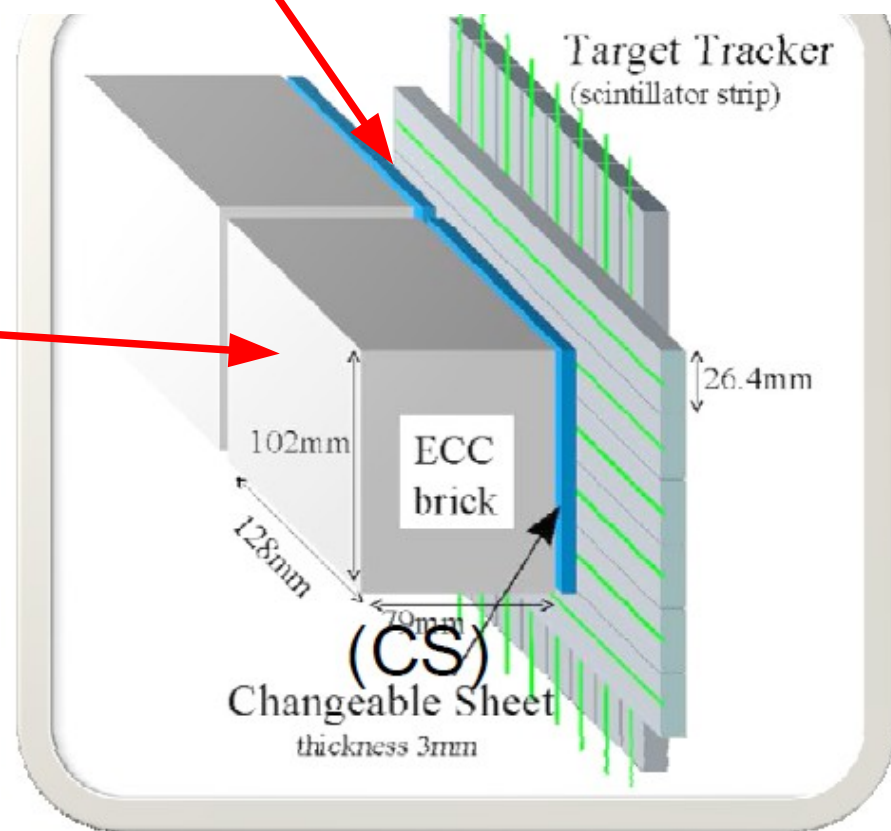
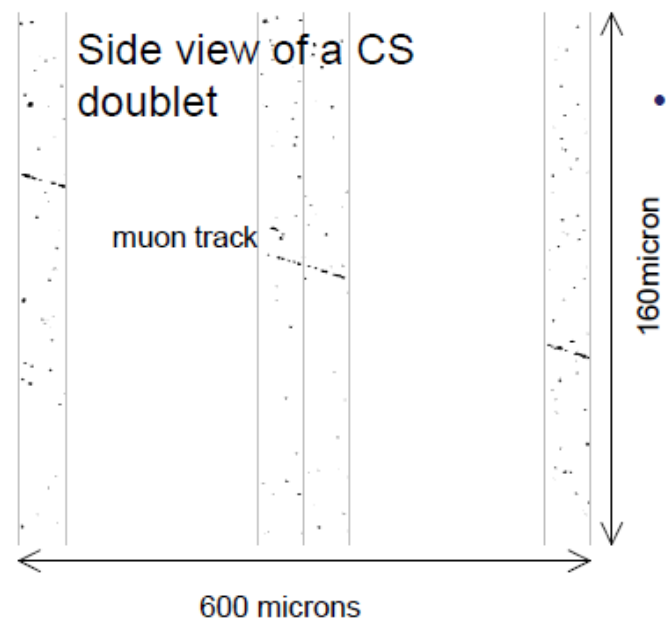
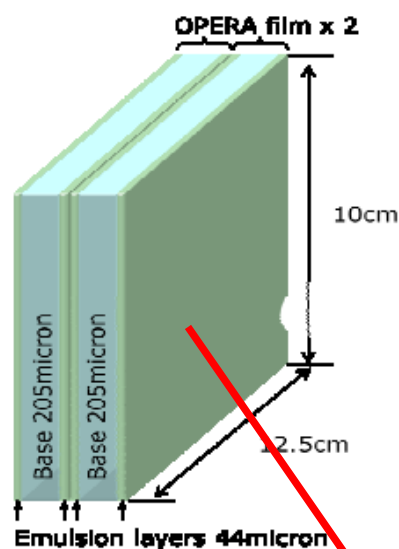
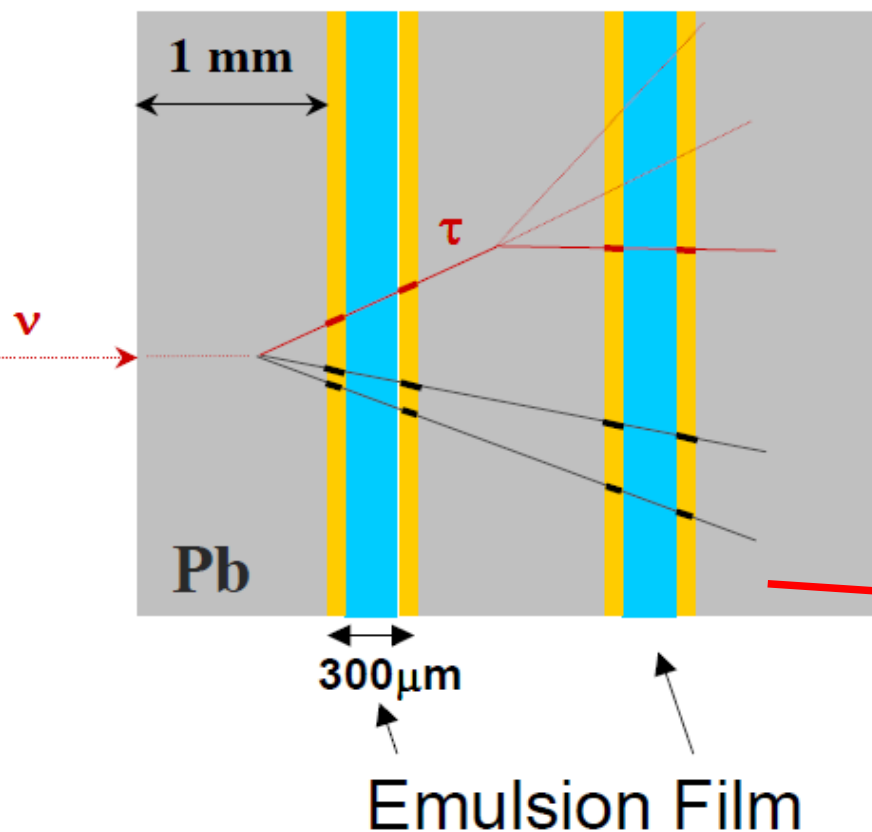
## emulsje jądrowe

Momentum measurement by Multiple Coulomb Scattering... up to 6 GeV/c  
...in the lead/emulsion film sandwich and comparison with electronic detector measurements

EM shower energy measured by shower shape analysis and Multiple Scattering method

# TARGET

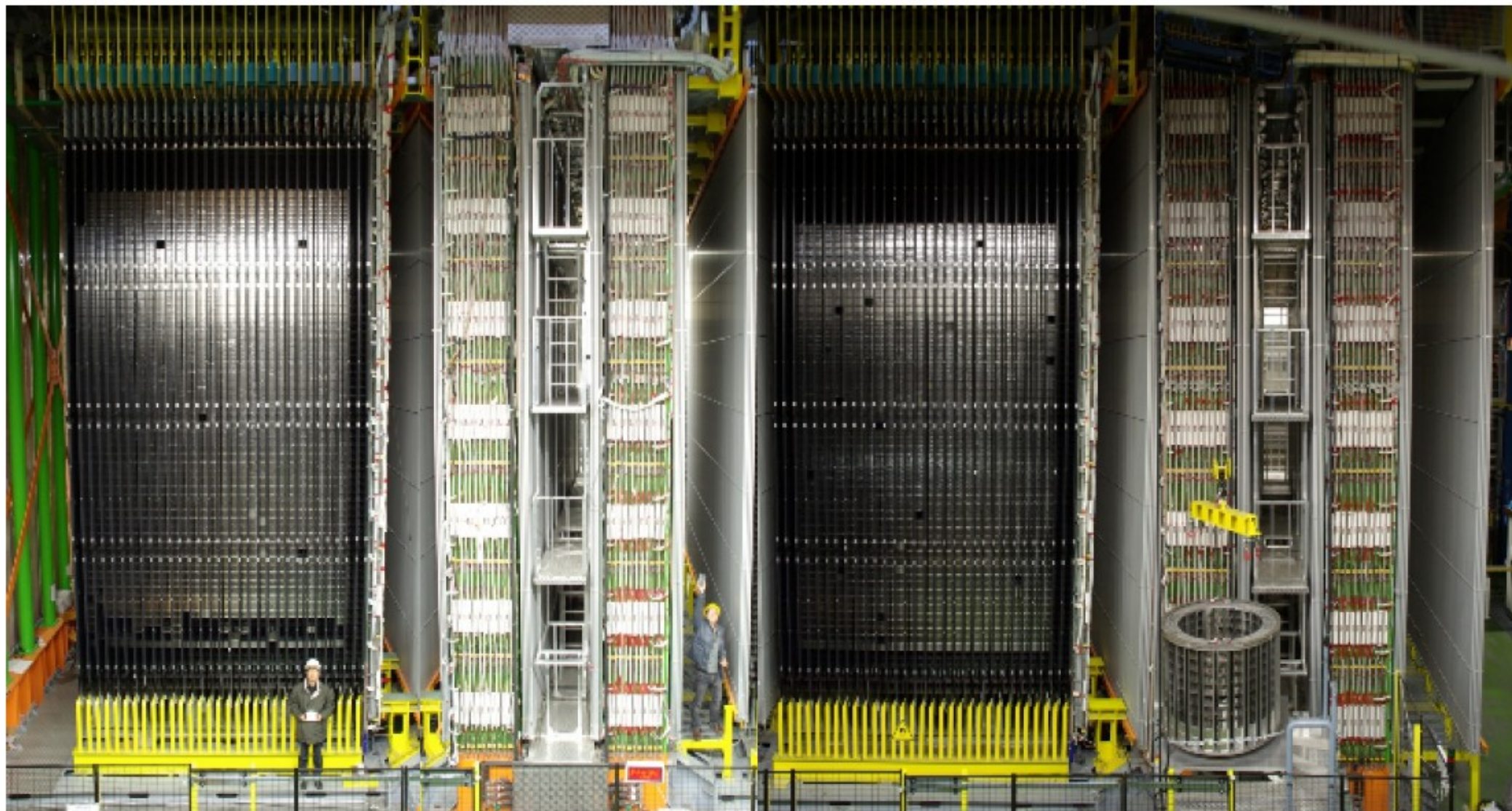
The heart of the experiment:  
THE ECC TARGET BRICKS



**Stack of  
57 OPERA films,  
56 lead plates ( $10 X_0$ )**

# OPERA detector 150,000 ECC 1.25kton target

~3'100 m.w.e. overburden, ~1 cosmic  $\mu$  /  $m^2 \times$  hour



Target area

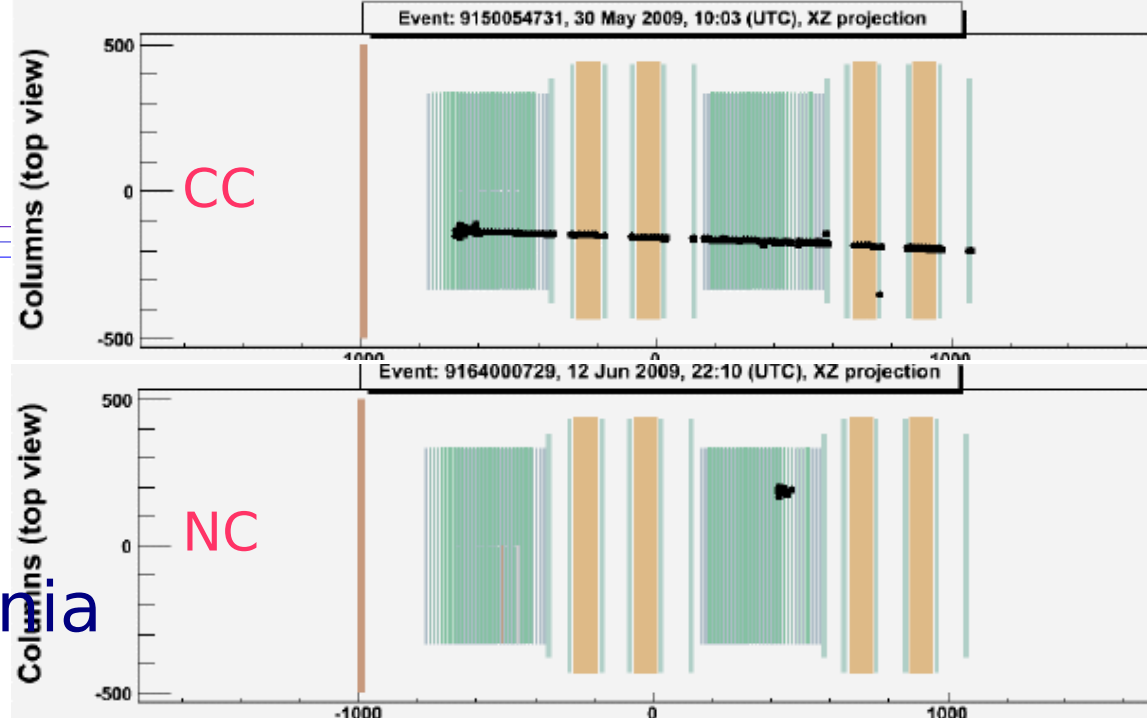
Muon  
spectrometer

pole 1.52T, detektory RPC  
oraz komory dryfowe  
(rozdzielczość 300  $\mu$ m,  $\Delta p/p < 25\%$ )

# Zbrane dane

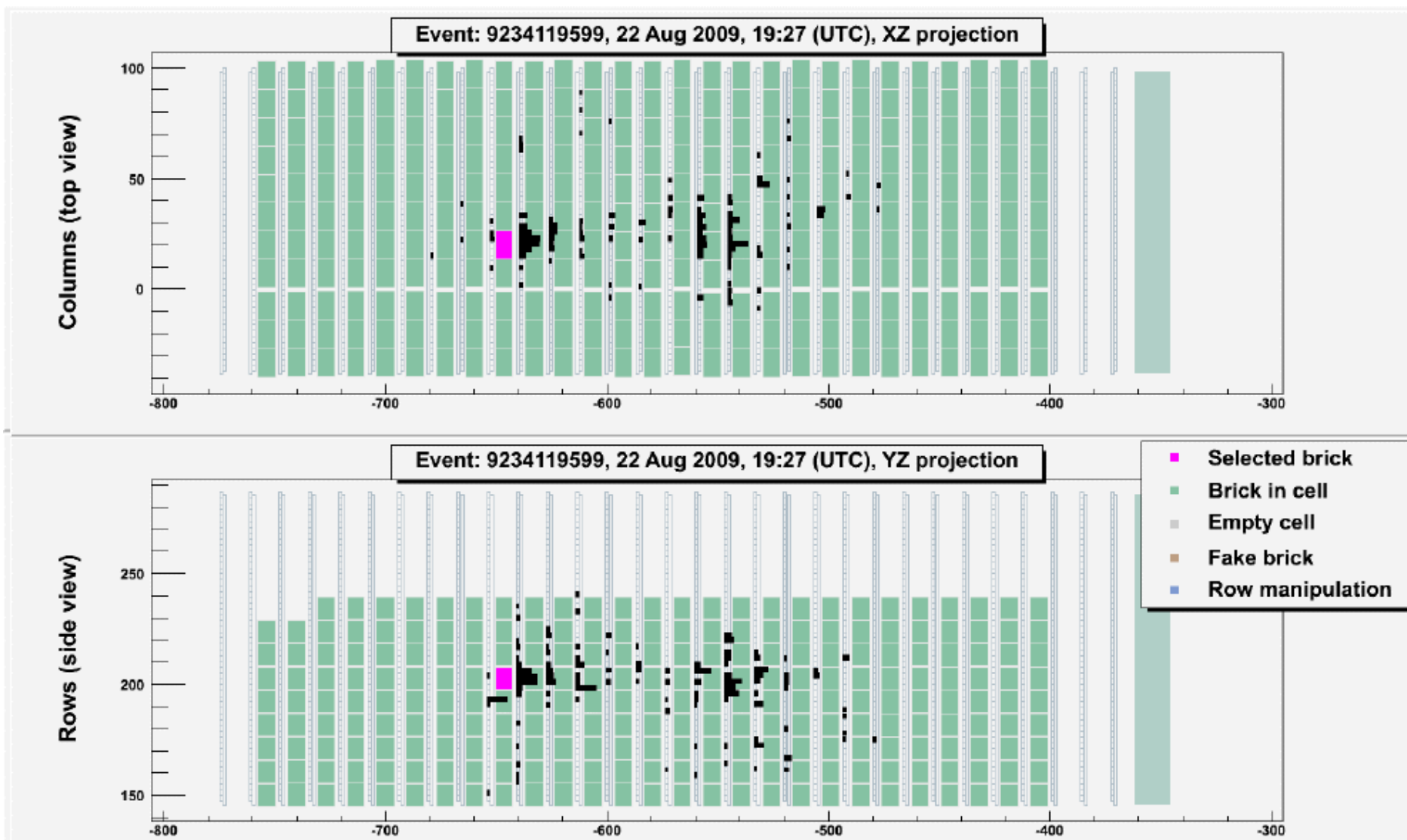
- w ciągu 2008 i 2009 roku zebrano 5391 przypadków
- efektywność znajdowania wierzchołka  $\sim 60\%$
- po zanalizowaniu 60% danych znalezione **1921** oddziaływania neutrin (wierzchołków)
- poszukiwanie rozpadu taonu (wierzchołków wtórnych) przeprowadzono dla **1088** przypadków (187 NC)
  - ▶ to 35% wszystkich oddziaływań z lat 2008-2009, co odpowiada  $1.85 \cdot 10^{19}$  POT
- dla tej liczby oddziaływań i  $\Delta m_{23}^2 = 2.5 \cdot 10^{-3} \text{ eV}^2$  przy maksymalnym mieszaniu OPERA spodziewa się

**0.5 przypadku  $\nu_\tau$**

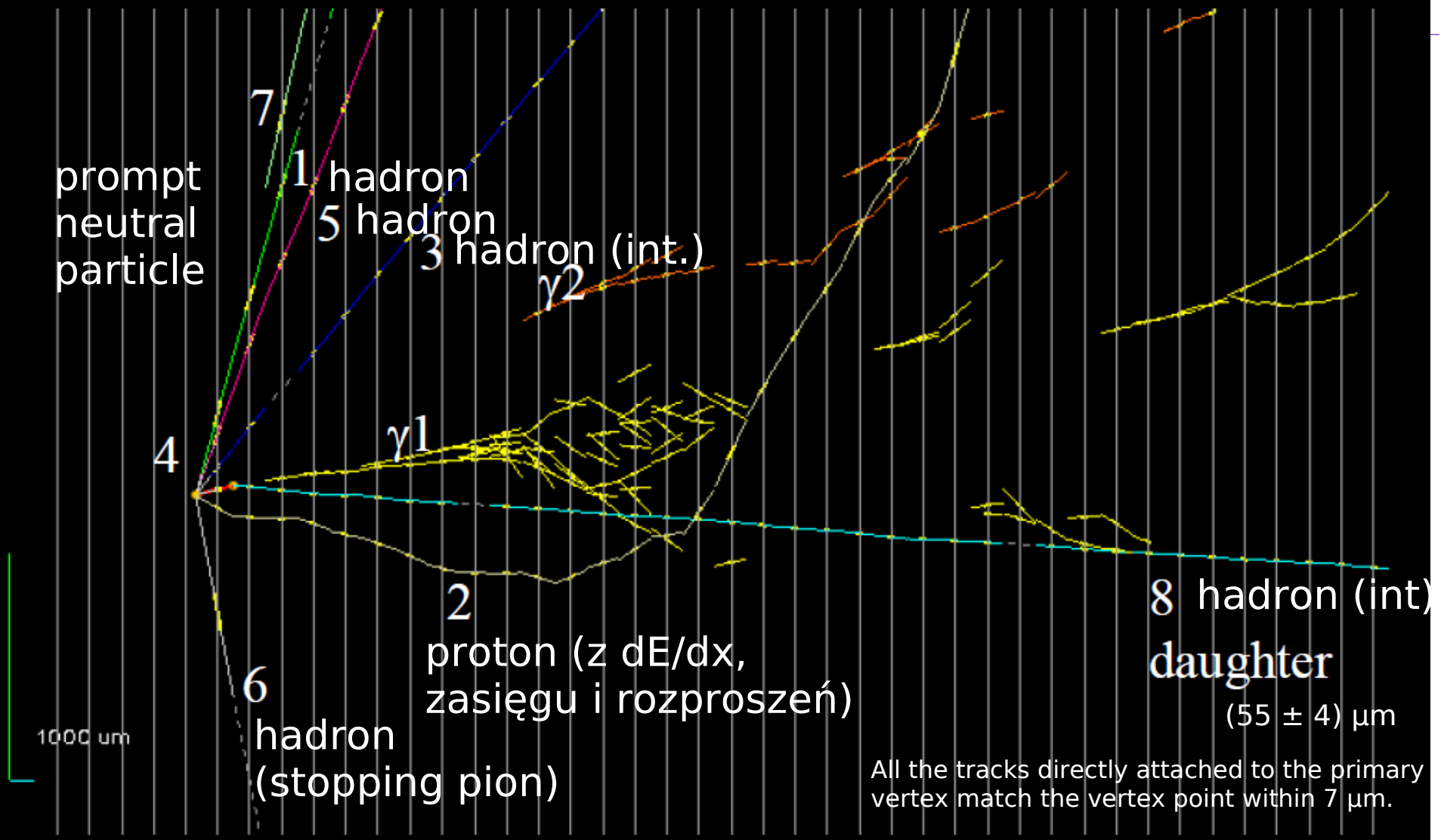




# Muonless event 9234119599, taken on 22 August 2009, 19:27 (as seen by the electronic detectors)



# Side view



prawdopodobieństwo błędnej identyfikacji hadronów 1,5,6: ~0.1%  
fotony  $\gamma$  z dużym prawdopodobieństwem pochodzą z wtórnego wierzchołka

# OPERA: cięcia

VARIABLE	AVERAGE	Selection criteria
kink (mrad)	$41 \pm 2$	$>20$
decay length ( $\mu\text{m}$ )	$1335 \pm 35$	within 2 lead plates
P daughter (GeV/c)	$12^{+6}_{-3}$	$>2$
Pt (MeV/c) at decay vertex	$470^{+230}_{-120}$	$>300$ ( $\gamma$ attached)
missing Pt (MeV/c) at primary vertex	$570^{+320}_{-170}$	$<1000$
$\phi$ (deg)	$173 \pm 2$	$>90$

odrzuca niskoenergetyczne piony z oddziaływań CC

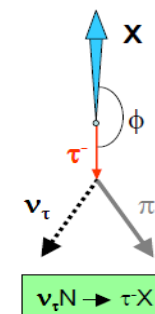
odrzuca oddziaływania hadronów (pionów)

odrzuca oddziaływania NC

odrzuca piony powstające w NC

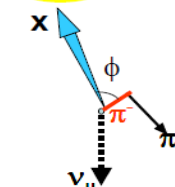
Signal :  
 $\phi = 180^\circ$

$\tau$ -decay



BG:  
small  $\phi$

kink



# Rekonstrukcja i identyfikacja

Vertex tracks followed down (through several bricks) to assess the muonless nature of the event. Residual probability of  $\nu_{\mu}$  CC event (due to a possibly undetected large angle muon)  $\sim 1\%$ . **“Nominal” value of 5% assumed**

- The event passes all cuts, with the presence of at least 1 gamma pointing to the secondary vertex, and is therefore a candidate to the  $\tau \rightarrow 1$ -prong hadron decay mode.
- A fit of the invariant mass of the two detected gammas yields a mass consistent with the  $\pi^0$  mass value (see table below).
- The invariant mass of the  $\pi^- \gamma \gamma$  system has a value (see below) compatible with that of the  $\rho$  (770). The  $\rho$  appears in about 25% of the  $\tau$  decays:  $\tau \rightarrow \rho (\pi^- \pi^0) \nu_{\tau}$ .

$\pi^0$ mass	$\rho$ mass
$120 \pm 20 \pm 35$ MeV	$640^{+125}_{-80} {}^{+100}_{-90}$ MeV

# Analiza tła

- Prompt  $\nu_\tau$  ~  $10^{-7}/\text{CC}$
- Decay of charmed particles produced in  $\nu_e$  interactions ~  $10^{-6}/\text{CC}$
- Double charm production ~  $10^{-6}/\text{CC}$
- Decay of charmed particles produced in  $\nu_\mu$  interactions ~  $10^{-5}/\text{CC}$
- Hadronic reinteractions ~  $10^{-5}/\text{CC}$

 załamanie toru udające  
rozpad

 podobne topologie  
rozpadu i czasy życia

We observe 1 event in the 1-prong hadron  $\tau$  decay channel,  
with a background expectation (estimating a  $\sim 50\%$  error for each component) of:

0.011 events (reinteraction)

0.007 events (charm)



$0.018 \pm 0.007$  (syst) events 1-prong hadron

all decay modes: 1-prong hadron, 3-prongs + 1-prong  $\mu$  + 1-prong  $e$  :

$0.045 \pm 0.020$  (syst) events total BG

(here we add up the errors linearly)

By considering the 1-prong hadron channel only, the probability to observe 1 event due to a background fluctuation is **1.8%**, for a statistical significance of **2.36  $\sigma$**  on the measurement of a first  $\nu_\tau$  candidate event in OPERA.

If one considers all  $\tau$  decay modes which were included in the search, the probability to observe 1 event for a background fluctuation is **4.5%**.  
This corresponds to a significance of **2.01  $\sigma$** .

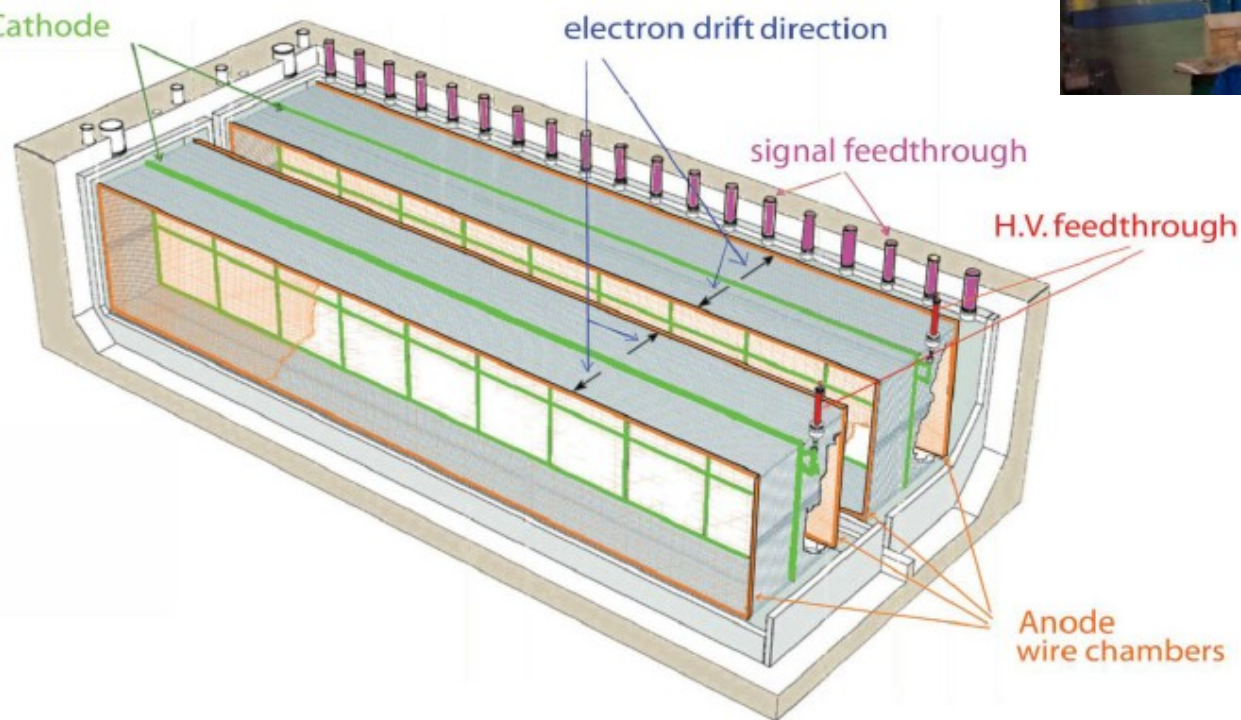
# OPERA – konkluzje

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- znaleziono pierwszego kandydata na oddziaływanie neutrina taonowego powstałego w wyniku oscylacji, o znaczoneści statystycznej ok.  $2\sigma$
- obserwacja ta pozwala na wykluczenie z 90% CL wartości  $\Delta m^2_{23} > 7.5 \cdot 10^{-3} \text{eV}^2$  (przy pełnym mieszaniu)
- więcej danych wciąż czeka na przeanalizowanie
  
- w tym samym laboratorium, na wiązce CNGS, stoi jeszcze jeden detektor, który może poszukiwać neutrin taonowych (i nie tylko)

# Tymczasem w hallu B...

**ICARUS** – komora projekcji czasowej wypełniona ciekłym argonem



- Two identical modules
  - $3.6 \times 3.9 \times 19.6 \approx 275 \text{ m}^3$  each
  - Liquid Ar active mass:  $\approx 476 \text{ t}$
  - Drift length = 1.5 m
  - HV = -75 kV  $E = 0.5 \text{ kV/cm}$
  - $v_{\text{drift}} = 1.55 \text{ mm}/\mu\text{s}$



# LAr-TPC performance

Fundamental for  $\nu_{\mu}-\nu_e$  oscillation search!

- Tracking device

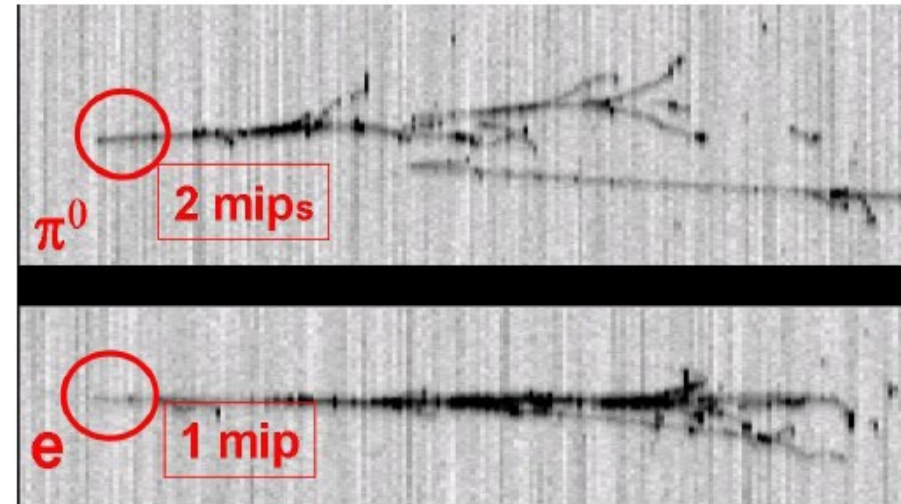
- Precise event topology
- Muon momentum via multiple scattering

- Measurement of local energy deposition  $dE/dx$

- $e/\gamma$  separation (2%  $X_0$  sampling)
- Particle ID by means of  $dE/dx$  vs range
- $e/\pi^0$  discrimination at  $10^{-3}$ , 90 % electron ident. eff. by  $\gamma$  conversion from vertex,  $\pi^0$  mass measurement and  $dE/dx$ .

- Total energy reconstruction of the events from charge integration

- Full sampling, homogeneous calorimeter with excellent accuracy for contained events

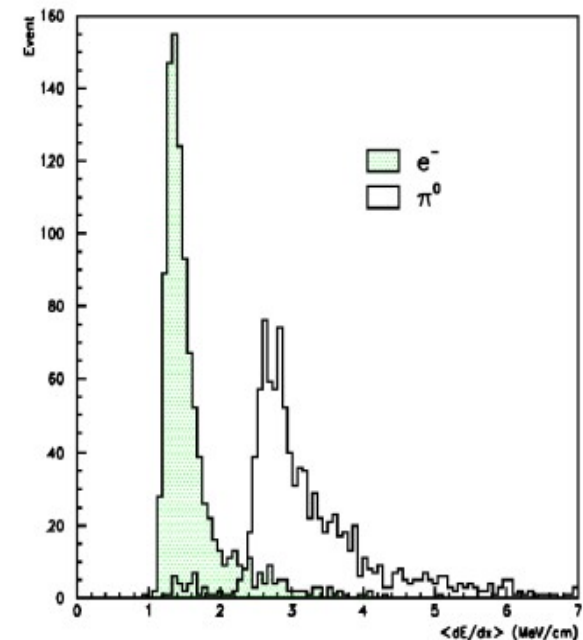


## RESOLUTIONS

Low energy electrons:  $\sigma(E)/E = 11\% / \sqrt{E(\text{MeV})} + 2\%$

Electromagn. showers:  $\sigma(E)/E = 3\% / \sqrt{E(\text{GeV})}$

Hadron shower (pure LAr):  $\sigma(E)/E \approx 30\% / \sqrt{E(\text{GeV})}$



# Uruchomienie detektora

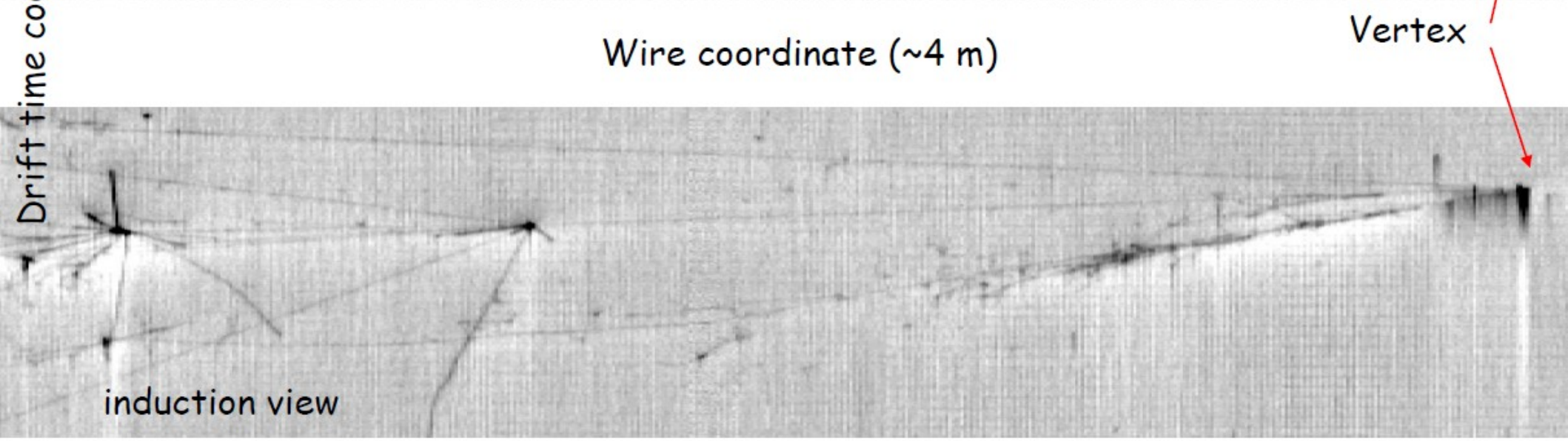
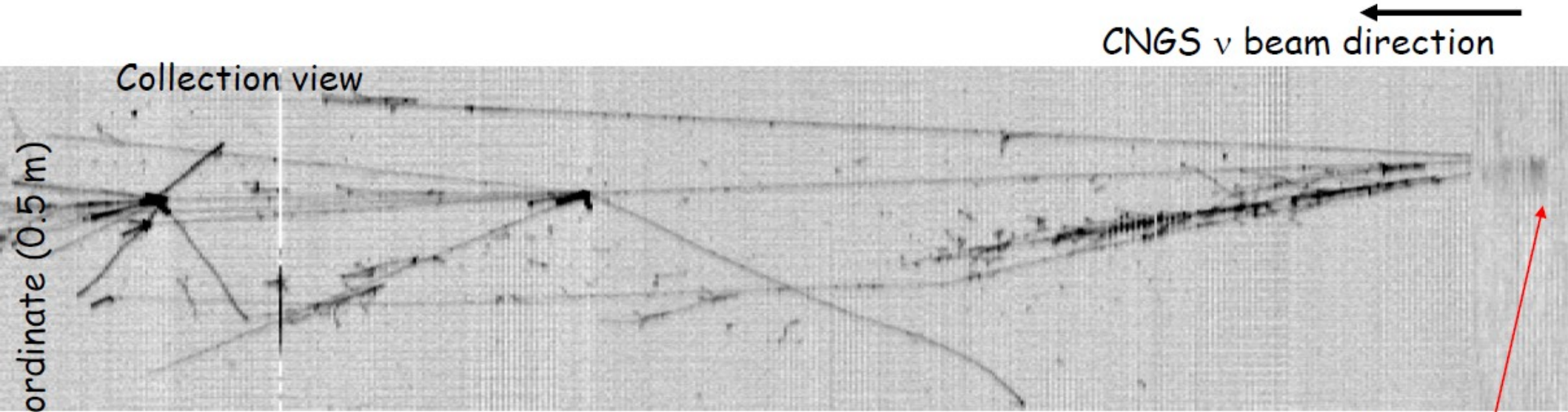
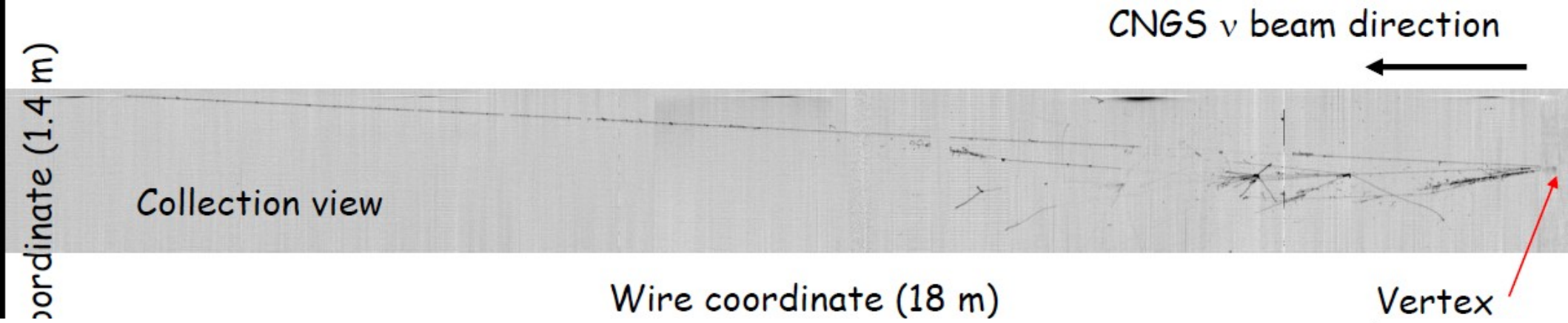
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Detector assembly completed by December 2009 including electronics and DAQ.

Cryogenic plant completed by March 2010 including deformation/temperature sensors of cryostat walls, overall process and control software.

Start-up with leak-tests in April: all safety and technical requirements fulfilled.

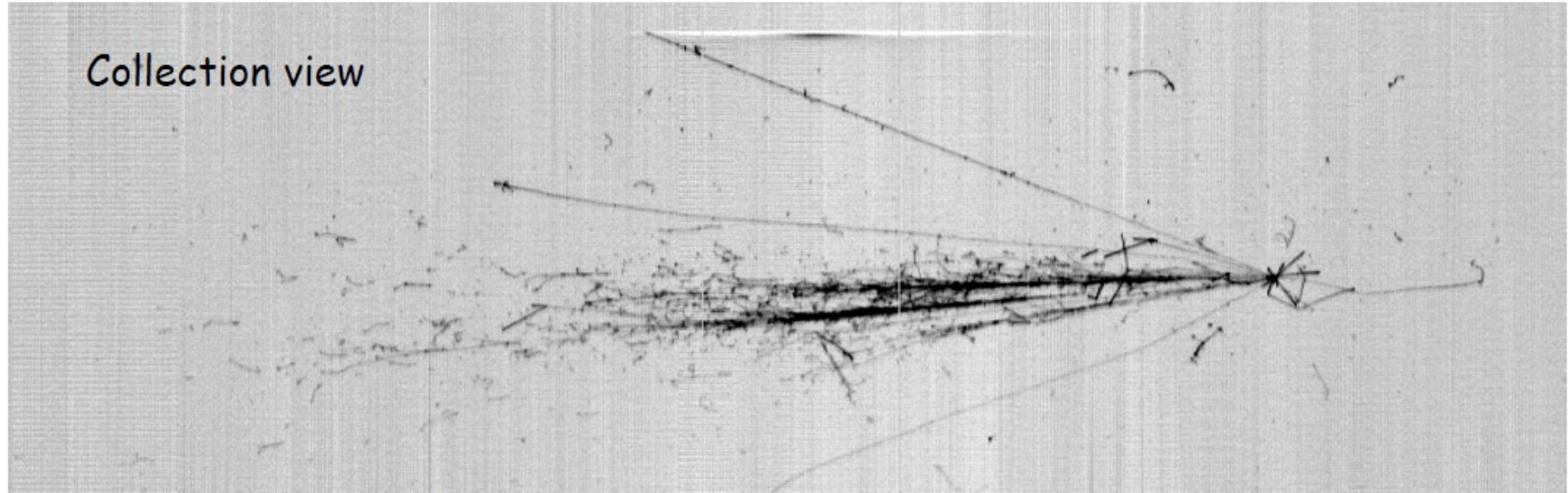
- Vacuum phase: the cryostats evacuation started on January 9<sup>th</sup>, 2010.
- Cooling phase: on April 14<sup>th</sup> the volume was filled with ultra-pure Argon gas, the liquid Nitrogen cool-down started on April 16<sup>th</sup>.
- Filling phase: on April 29<sup>th</sup> ultra-pure LAr was injected at a rate of  $\sim 2 \text{ m}^3/\text{hour}$ . On May 18<sup>th</sup> both modules were completely full.
- T600 commissioning: on May 27<sup>th</sup> HV and wire biasing and PMT's were turned on the West Cryostat. At 12.24 the first muon crossing track was recorded. On June 1<sup>st</sup> the East cryostat was also turned on.
- On May 28<sup>th</sup> at 19.54 the first CNGS neutrino interaction was observed.



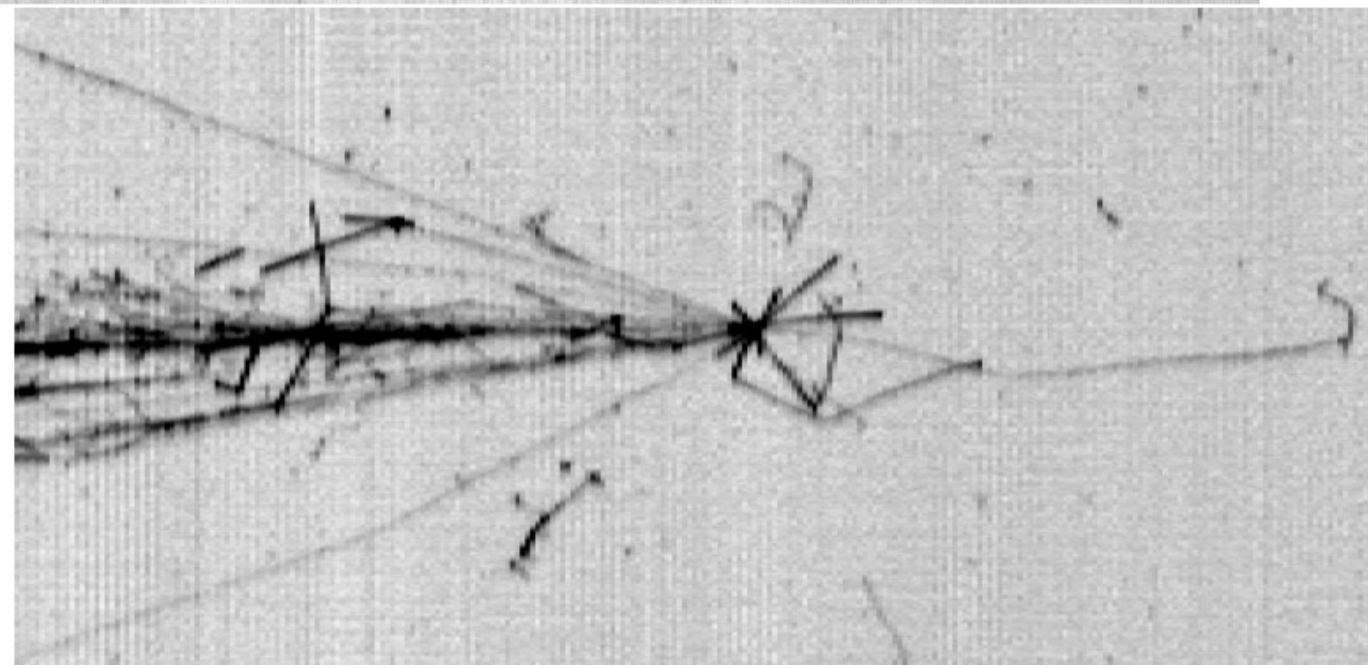
# The second CNGS neutrino interaction in ICARUS T600

CNGS  $\nu$  beam direction  
←

Drift time coordinate (1.4 m)



Wire coordinate (8 m)



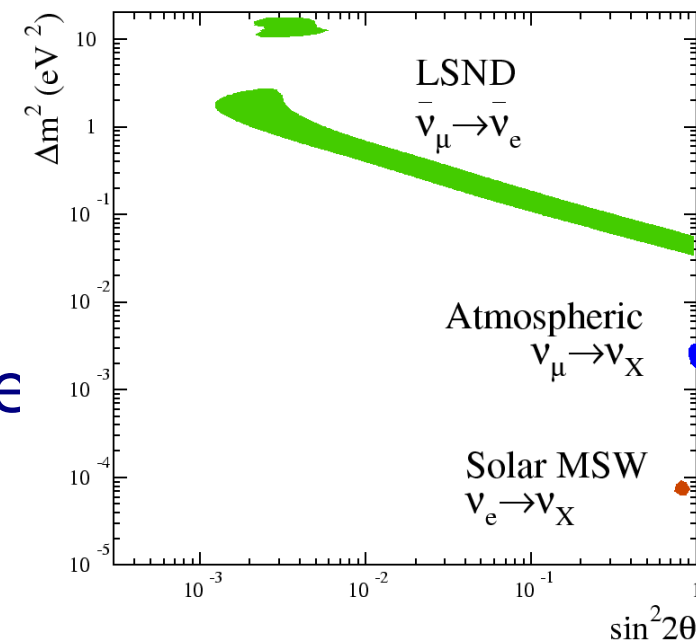
# Program ICARUSa

głównie rozwój technologii, ale poza tym:

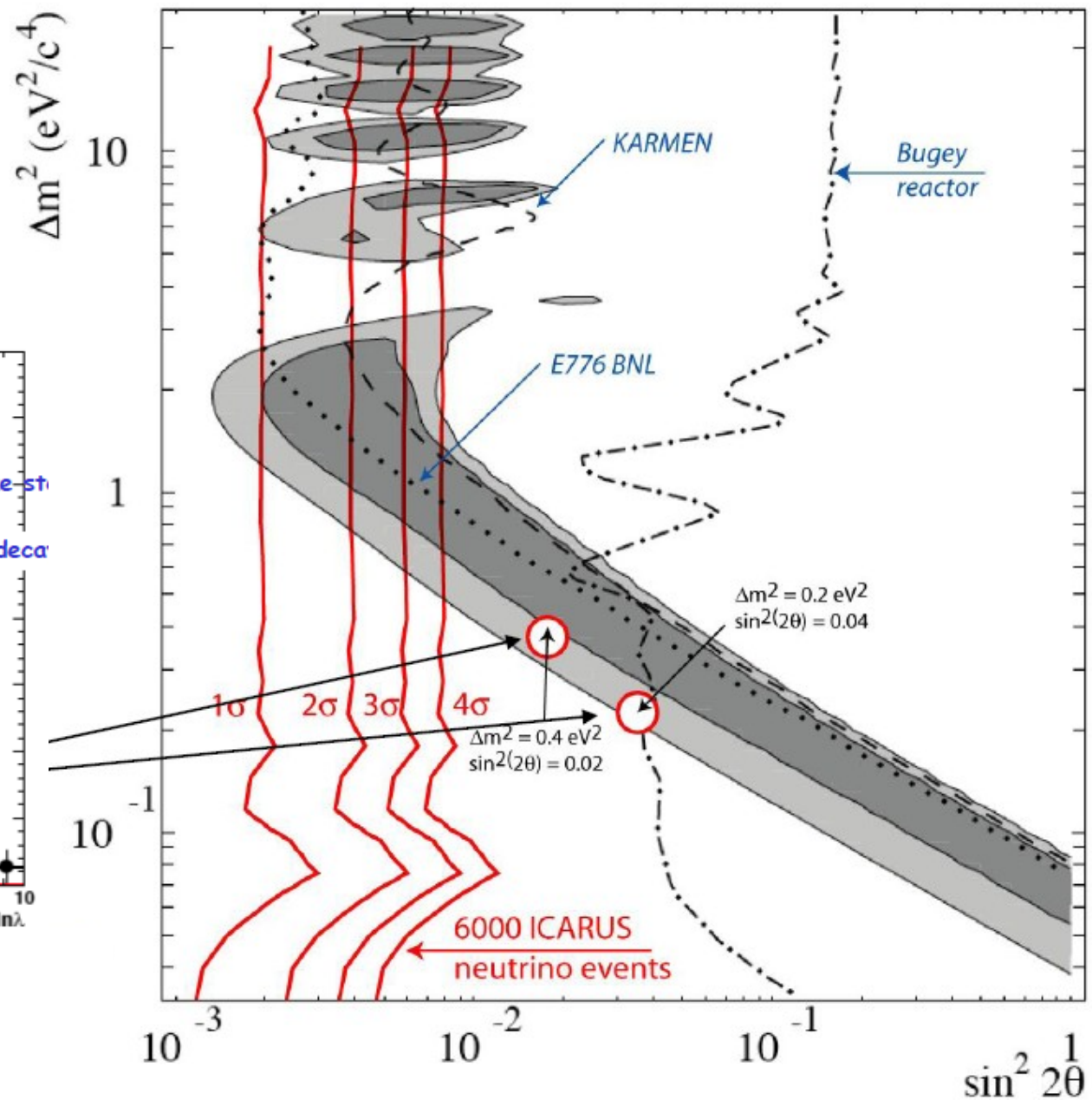
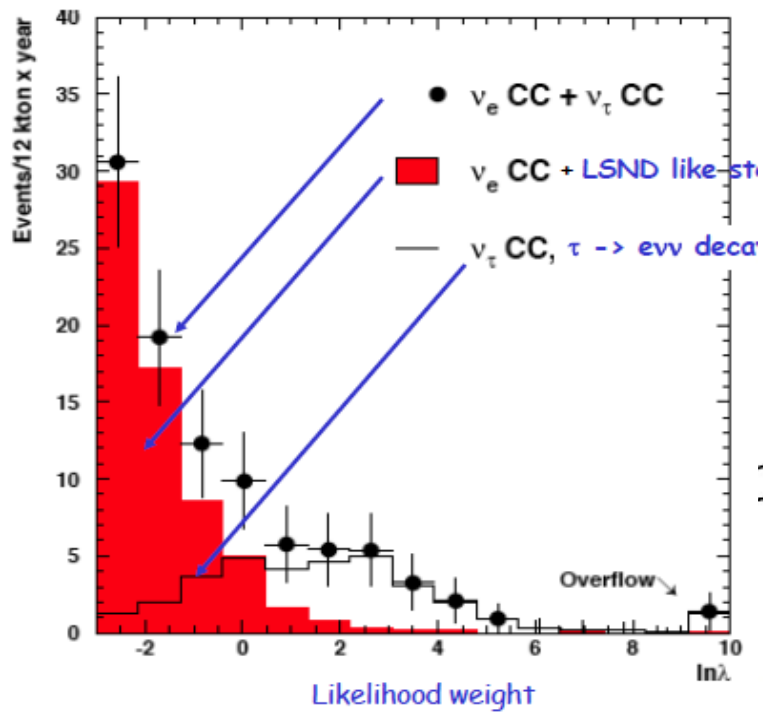
- neutrina atmosferyczne – ok. 100 przypadków/rok
- neutrina słoneczne o energii  $>8$  MeV
- rozpad protonu w kanałach egzotycznych, zwłaszcza z kaonem, lub o skomplikowanej topologii
- wiązka CNGS
  - ▶ monitorowanie neutrin mionowych (1200 przypadków/rok)
  - ▶ poszukiwanie neutrin taonowych
    - spodziewane jest **12** przypadków sygnału w kanale  $\tau \rightarrow \nu_e \nu_e$  przy  $12 \pm 3.4$  przypadkach oddziaływań neutrin elektronowych (dla 5000 zdarzeń)
    - emisja neutrina w rozpadzie  $\nu$  powoduje, że można próbować wydzielić te rozpady za pomocą cięć, z efektywnością ok. 50%
  - ▶ poszukiwanie neutrin sterylnych (efekt LSND)

# Efekt LSND

- eksperyment LSND badał wiązkę antyneutrino mionowych o energii 30 MeV
- zaobserwował nadwyżkę antyneutrino elektronowych, co odpowiadałoby oscylacjom przy  $\Delta m^2$  rzędu  $1 \text{ eV}^2$
- ale zmierzono też 2 inne  $\Delta m^2$ , w eksperymentach słonecznych i reaktorowych, oraz atmosferycznych i akceleratorowych z długą bazą
- neutrino są trzy rodzaje, co wiemy z pomiarów szerokości bozonu  $Z^0$
- czy istnieją neutrino nieoddziałujące sterylne?



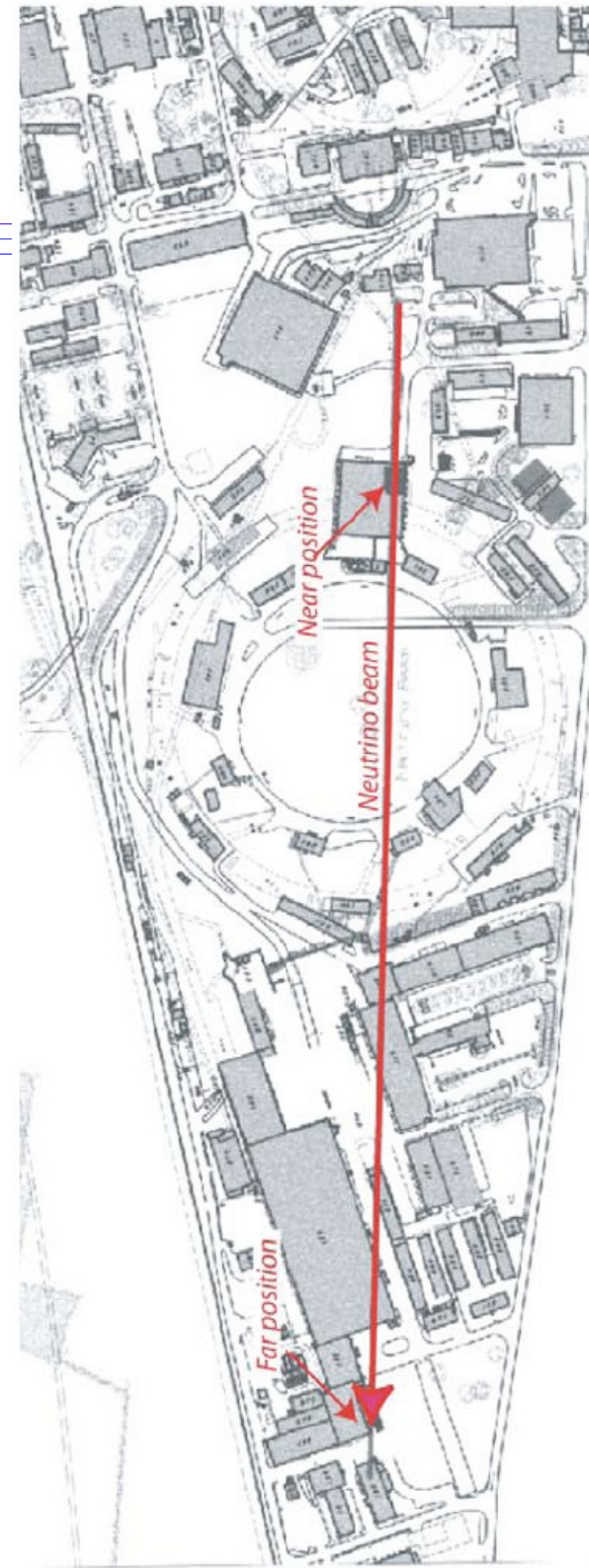
# Test efektu LSND



for 6000 raw CNGS neutrino

# Pomysł na pomiar efektu LSND

- pomysł Carla Rubbii:
  - ▶ 2 takie same detektory ustawione w odległości 127 i 850m od źródła neutrin
    - **redukcja błędów systematycznych** (nieznajomość wiązki, przekroje czynne i efekty detektorowe)
  - ▶ pomiar widma neutrin elektronowych
    - **widma powinny być identyczne, jeśli nie ma oscylacji** (pomijając efekt kąta bryłowego)
    - jeśli oscylacje zachodzą, będzie można zmierzyć  $\Delta m^2$  i  $\sin^2 2\theta$



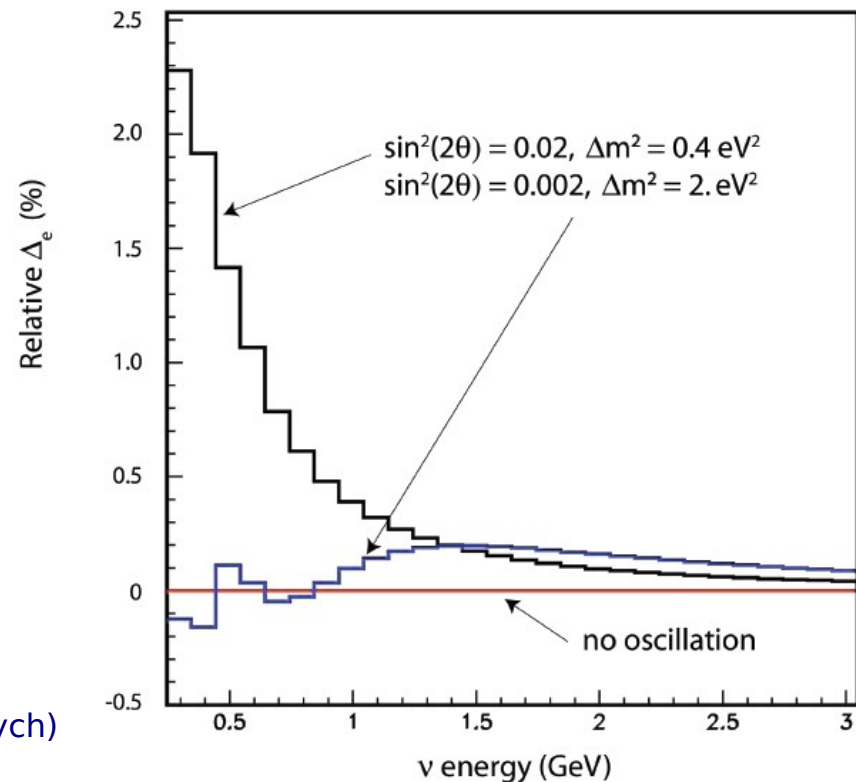
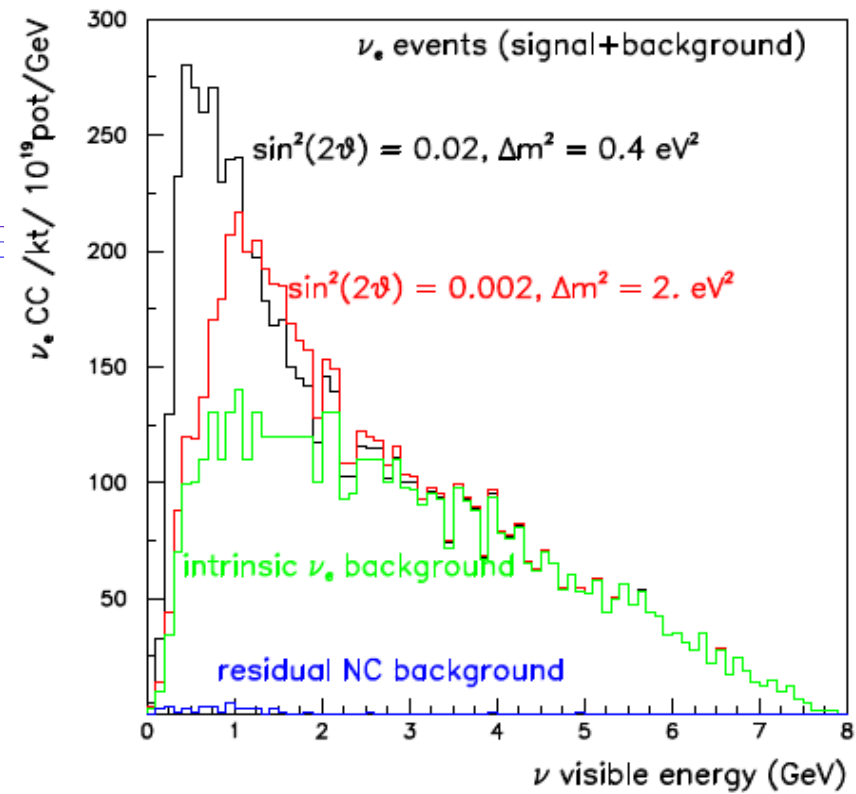


# Wiązka i detektory

- źródło neutron na PS w CERN (BEBC-PS180)
- detektory na powierzchni
  - ▶ **daleki** – klon ICARUSa (500 ton)
  - ▶ **bliski** – 45 razy większy strumień – wystarczy mniejszy detektor (150 ton)
- przy  $1.25 \cdot 10^{20}$  POT/rok – ok.  $6 \cdot 10^5$  przypadków w dalekim detektorze

$$\Delta_e = \left( \frac{N_e}{N_\mu} \right)^{far} - C_e \left( \frac{N_e}{N_\mu} \right)^{close}$$

korekcja wynikająca z odległości detektorów  
(inny kształt rozkładu energii neutron mionowych)





# Inne detektory LAr

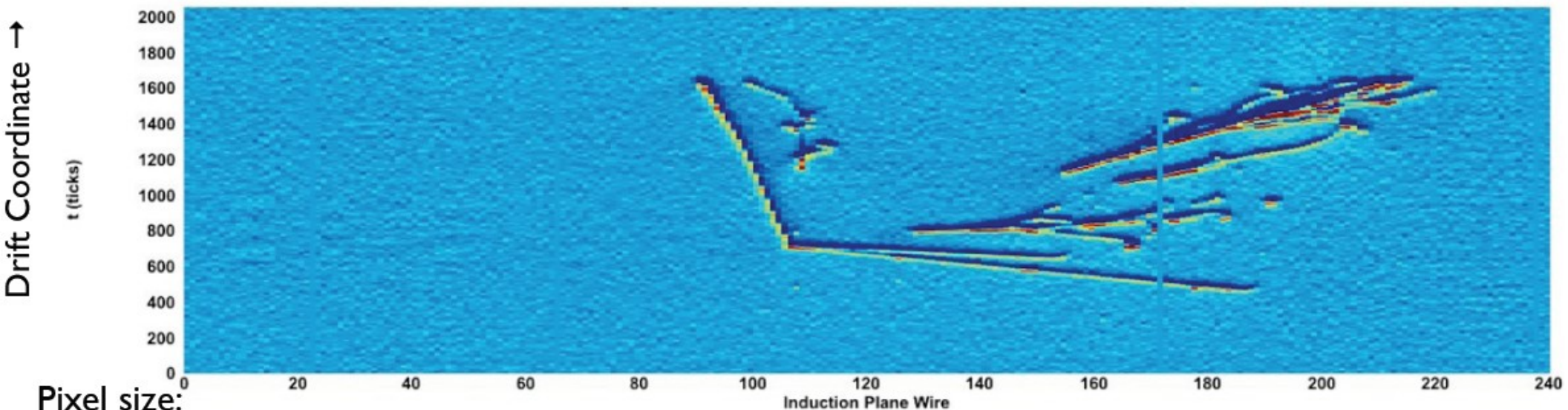
- Liquid argon provides a dense target for neutrino interactions, and ample ionization/scintillation for detection.
  - Particle identification comes primarily from  $dE/dx$  (energy deposited) along track.
    - ▶ Wire spacing of a few millimeters combined with digital sampling provides fine-grained resolution
    - ▶ Photons ( $2\times$  MIP  $dE/dx$ ) and Electrons ( $1\times$  MIP  $dE/dx$ ) can be cleanly separated
    - ▶ Topological cuts can further improve photon/electron separation
  - **Ideal for  $\nu_e$  appearance experiment**
    - ▶ Excellent signal (CC  $\nu_e$ ) efficiency and background (NC  $\pi^0$ ) rejection
  - Beautiful, bubble-chamber like events!
- 
- Europa: LAGUNA
  - Fermilab/DUSEL: Argoneut  $\rightarrow$  MicroBoone  $\rightarrow$  LBNE
  - Japonia: wielki detektor na wiązce T2K

# Ciekły argon w Fermilabie (etap 1)

ArgoNeuT

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330 $\mu$ s)
Light Collection	None

- ArgoNeuT is a test project at Fermilab to operate a LArTPC in a neutrino beam.
- Operated in NuMI beam at Fermilab, in front of MINOS near detector (for muon reconstruction).
- Goals:
  - ▶ Gain experience building/running LArTPCs in an underground setting.
  - ▶ Accumulate neutrino/antineutrino events (1st time in the U.S., 1st time ever in a low-Energy beam).
  - ▶ Develop simulation and reconstruction for LArTPCs, and compare MC with data.
- ArgoNeuT acquired  $\sim 1.4E20$  Protons On Target (P.O.T.), primarily in anti-neutrino mode
- Data is being used to develop techniques for reconstructing events in 3D



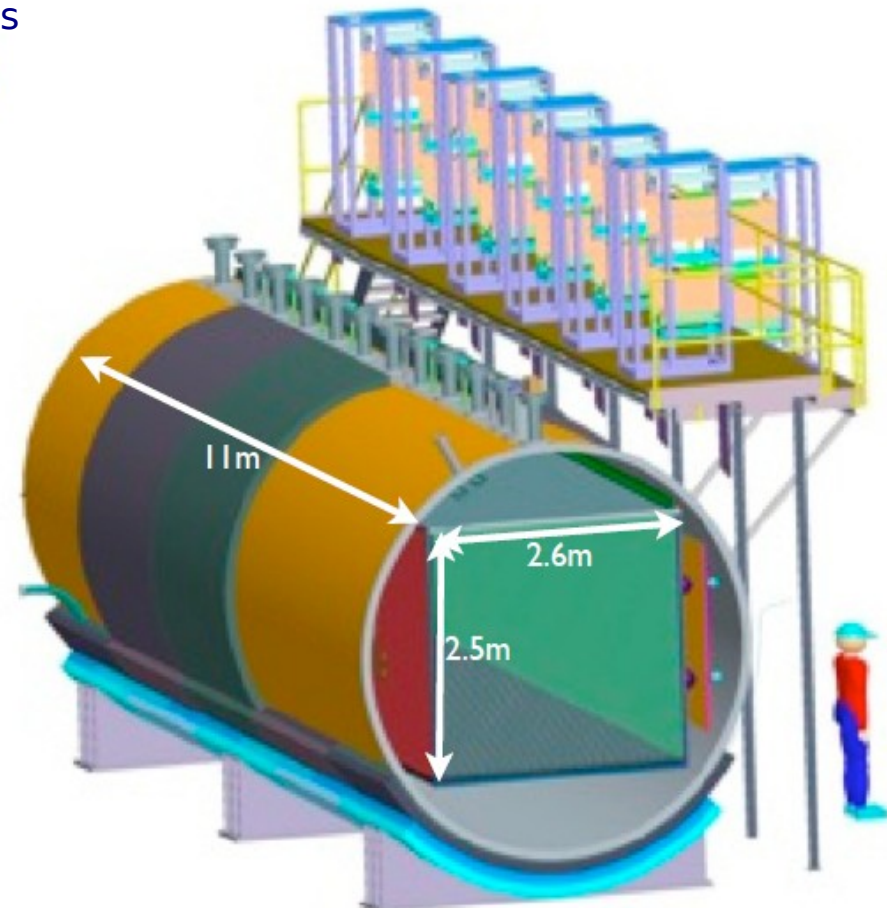
Raw Data

# MicroBooNE

- MicroBooNE\* is a LArTPC experiment that will operate in the on-axis Booster neutrino beam and off-axis NuMI neutrino beam on the surface at Fermilab.
- Combines timely **physics** with **hardware R&D** necessary for the evolution of LArTPCs.
  - ▶ MiniBooNE low-energy excess with respect to MiniBooNE the recognition of most of the channels is now becoming possible. This is an advantage in comparison to MiniBooNE, that was capable to positively identify only a fraction of the quasi-elastic events
  - ▶ Low-Energy Cross-Sections
  - ▶ Cold Electronics
  - ▶ Long-drift operation (strict demands on LAr purity)

Cryostat Volume	150 Tons
TPC Volume	90 Tons
# Electronic Channels	~9000
Wire Pitch	3 mm
Electronics Style (Temp.)	JFET (120 K)
Max. Drift Length (Time)	2.5m (1.5ms)
Light Collection	~30 8" Hamamatsu PMTs

- ★ Stage I approval from Fermilab directorate in June 2008
- ★ CD-0 (Mission Need) in October 2009
- ★ CD-1 (reviewed early March)
- ★ CD-2/CD-3a (Fall 2010)
- ★ Turn On (2012-2013)

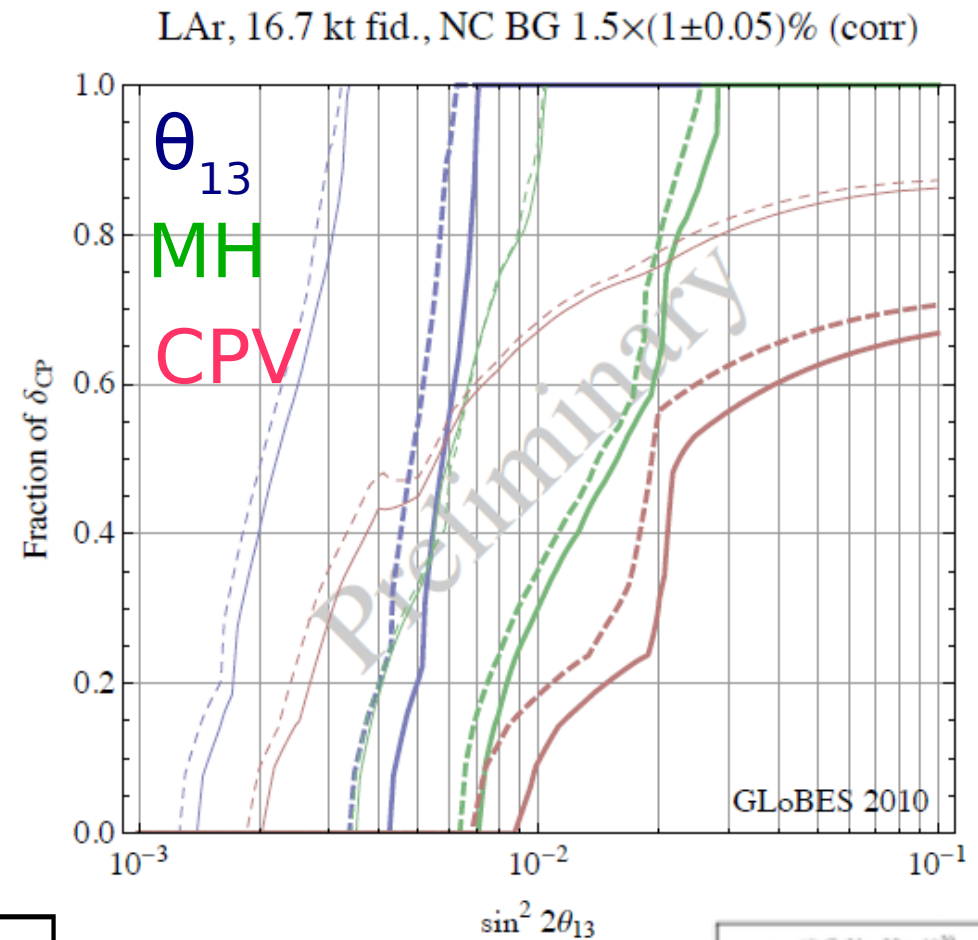
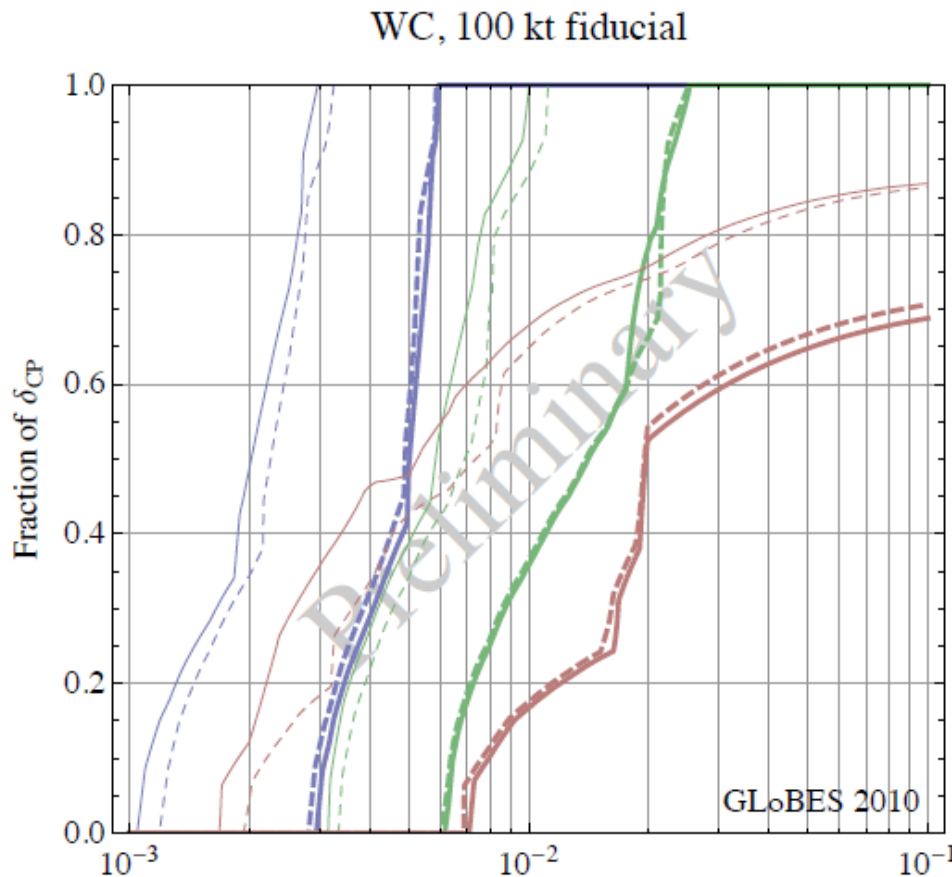


MicroBooNE Experiment  
(DOE/NSF Supported)

\*See poster from Vassili Papavassiliou

- Conceptual design for a ~20 kiloton **LBNE LArTPC** detector: in DUSEL (Homestake)
  - ▶ “Membrane” style cryostat (used in Liquefied Natural Gas shipping industry).
  - ▶ Alternative design with vacuum-insulated modular-style cryostat is also being considered.
  - ▶ Considering depths of 300, 800, and 4800 feet...(shallower depths allow possibility of drive-in access).

## DISCOVERY REACH

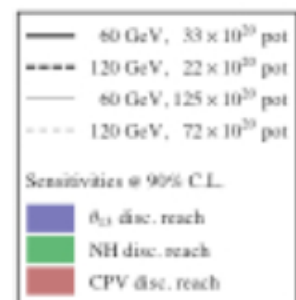


Cryostat Volume	25 kTons
TPC Fiducial Volume	16.8 kTons
# Readout Wires	~645000 (128:1 MUX)
Wire Pitch	3 mm
Electronics Style (Temp.)	CMOS (87 K)
Max. Drift Length (Time)	2.5m (1.4ms)
Light Collection	TRD

### ● LArTPC Plots Assume:

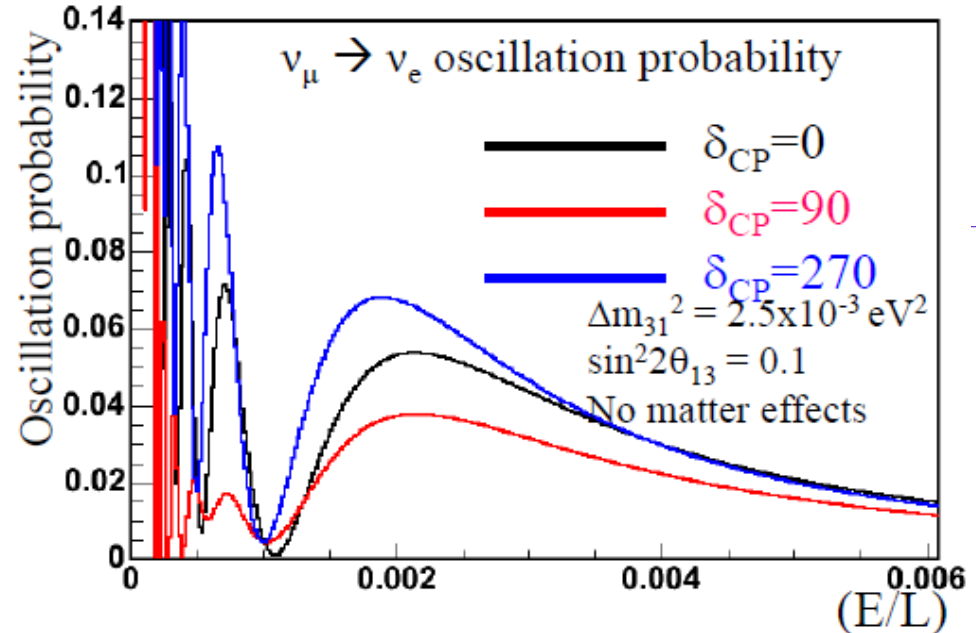
- ▶ WBB design for LBNE
- ▶ 85%  $\nu_e$  efficiency
- ▶ 5% background uncertainty

J. Kopp



# Japonia

Effect of CP Phase  $\delta$   
appears as



## – $\nu_e$ Appearance Energy Spectrum Shape

- \*Peak position and height for 1<sup>st</sup>, 2<sup>nd</sup> maximum and minimum
- \*Sensitive to all the non-vanishing  $\delta$  including  $180^\circ$



Spectrum measurement (1<sup>st</sup> and 2<sup>nd</sup> Oscillation Max.) with On-Axis beam with 5 years  $\nu$  beam run, then think next ( $\bar{\nu}$ ?)

## • Condition

- Need long baseline (>600km) to see 2<sup>nd</sup> Osc. max, since fixed neutrino energy
- Need On-Axis beam for wide energy coverage
- Need gigantic detector, since finite beam flux and long baseline

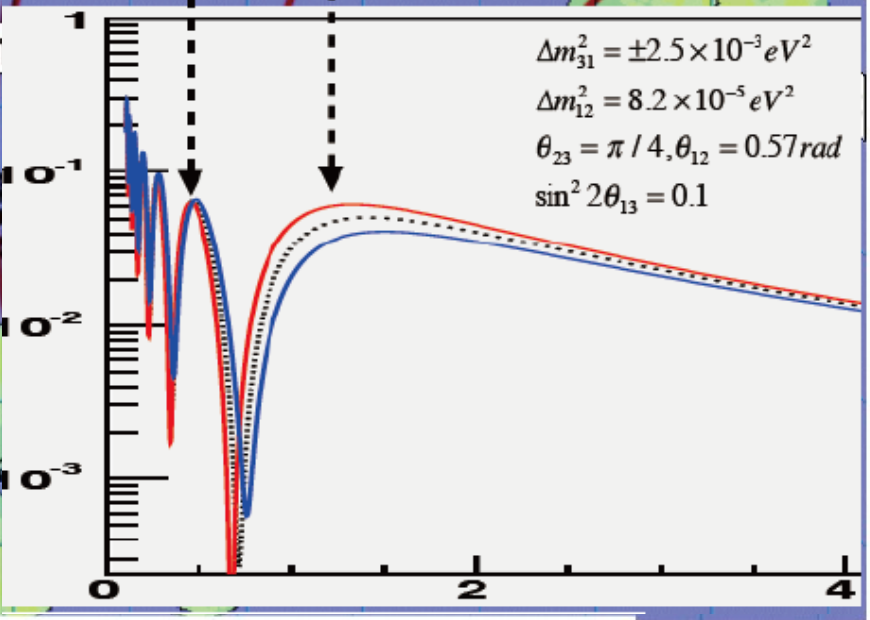
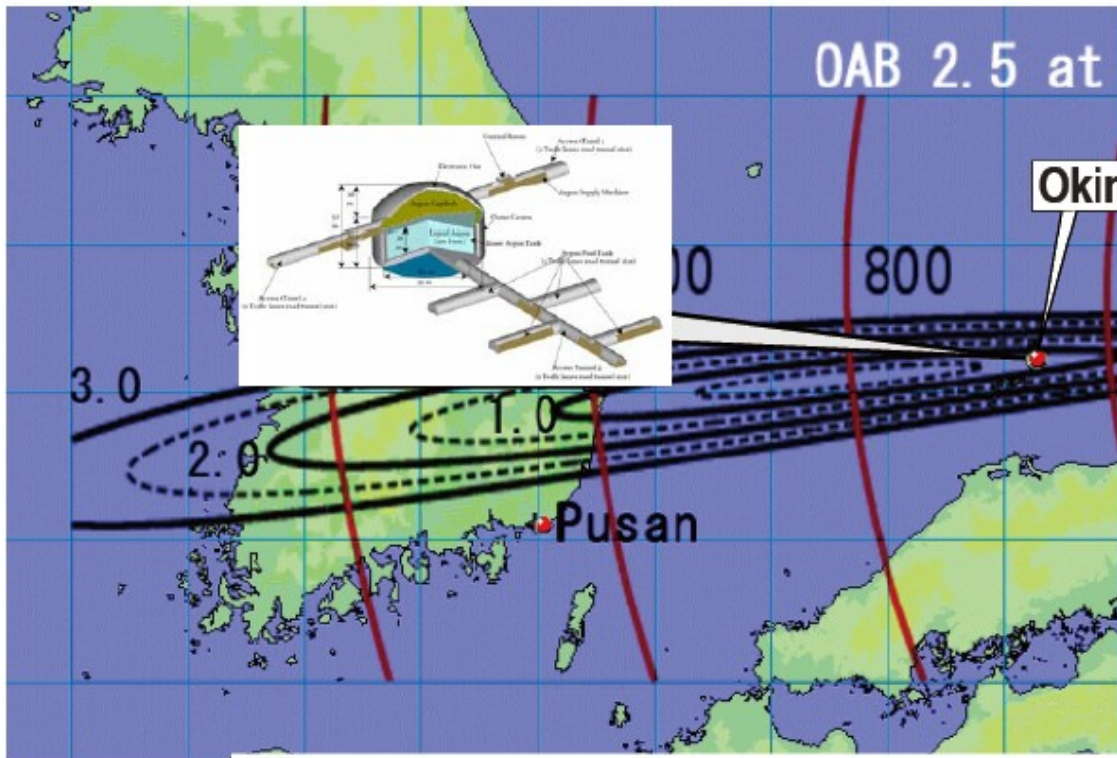
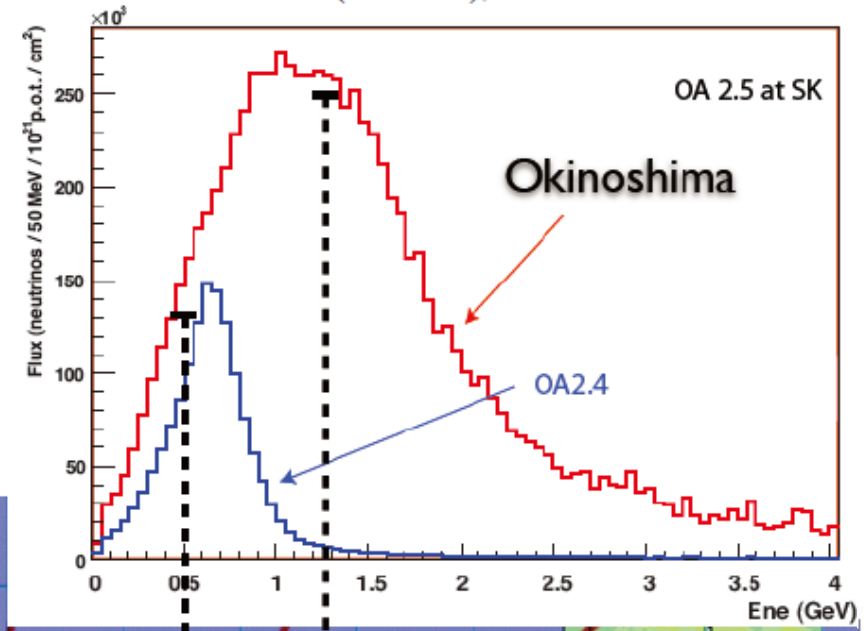


100 kton Giant Liquid Argon TPC @ Long Baseline, On-Axis

# J-PARC to Okinoshima

P32 proposal (Lar TPC R&D)  
 Recommended by J-PARC PAC  
 (Jan 2010), arXiv:0804.2111

Distance = 658 km  
 Off-axis angle = 0.76°  
 (2.5° @ SK)  
 100 kton liquid Argon



→ Extract  $\delta_{CP}$  from fit of 1<sup>st</sup> & 2<sup>nd</sup> maximum



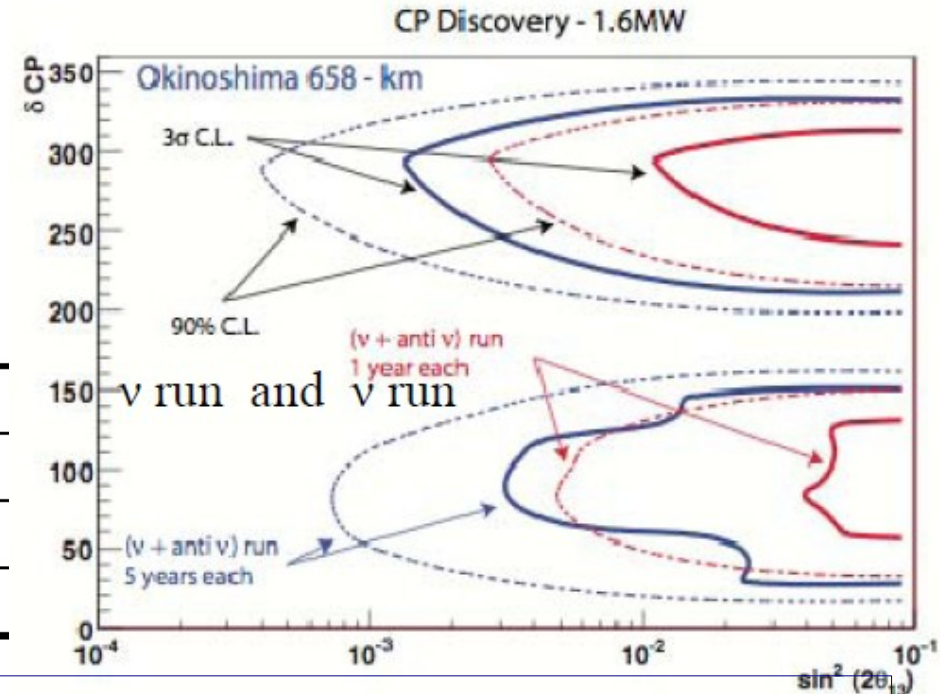
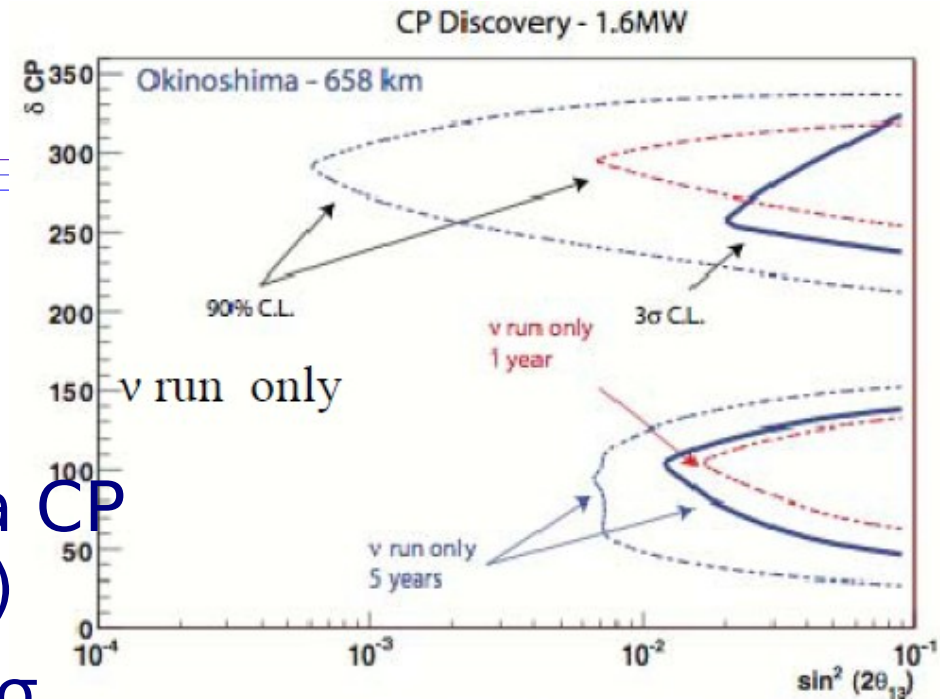
# J-PARC to Okinoshima

- pomiar  $\sin^2 2\theta_{13}$  do 0.001 (rzęd wielkości lepiej niż T2K)
- pomiar  $\theta_{13}$  z błędem 0.01, możliwość zbadania łamania CP dla  $\sin^2 2\theta_{13} > 0.01$  (>90% CL)
- stwierdzenie łamania CP  $> 3\sigma$  dla  $\sin^2 2\theta_{13} > 0.02$

Events in 100 kton, 658 km, 5 years @ 1.66 MW

No Osc.	$\nu_\mu$ CC	$\nu_e$ CC	$\bar{\nu}_\mu$ CC	$\bar{\nu}_e$ CC
<b>5 years</b>	<b>82000</b>	<b>750</b>	<b>1460</b>	<b>35</b>

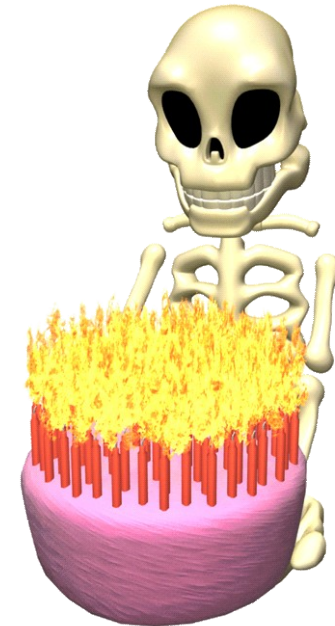
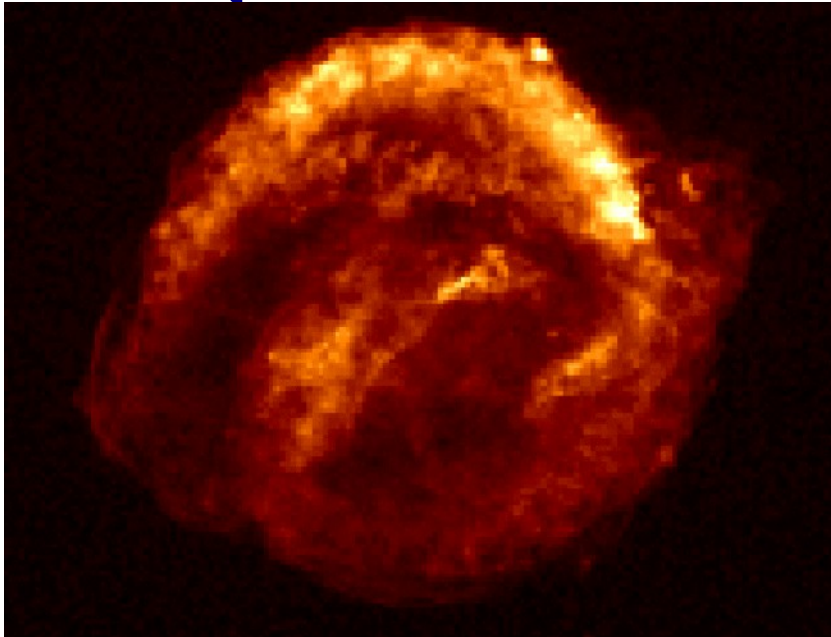
$\delta_{CP}$ (deg)	<b>0</b>	<b>90</b>	<b>180</b>	<b>270</b>
<b><math>\sin^2 2\theta_{13} = 0.1</math></b>	2867	2062	2659	3464
<b><math>\sin^2 2\theta_{13} = 0.05</math></b>	1489	1119	1342	1908
<b><math>\sin^2 2\theta_{13} = 0.03</math></b>	942	506	829	1266



Testy w KEK trwają - detektory testowe 10 i 250l, w CERN - 3l dwufazowy

# Japonia – neutrina z supernowych

wszystkie detektory neutrinowe czekają na supernową, ale...



od SN1987A minęło ponad 20 lat  
od supernowej w naszej Galaktyce (ostatnia w 1604)  
ponad 400 lat

# Supernowe

---

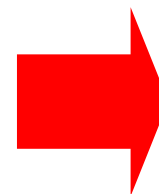
- bliskie supernowe zdarzają się rzadko
- ale we Wszechświecie wybuch supernowej zdarza się co sekundę
- neutrina w nich produkowane tworzą rozproszony strumień, znany jako *diffuse supernova neutrino background* (DSNB) lub *supernova relic neutrinos* (SRN)
- w 2003 r. Super-Kamiokande opublikowało ograniczenia na ten strumień – Phys.Rev.Lett. 90 061101 (2003)
- wynik był niestety ograniczony przez tło i nie znaleziono nadmiaru przypadków w spodziewanym zakresie energii

So, experimental DSNB limits are approaching theoretical predictions. Clearly, reducing the remaining backgrounds and going lower in energy would be extremely valuable.

Note that all of the events in the present SK analysis are singles in time and space.



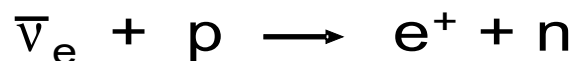
And this rate is actually very low... just three events per cubic meter per year.



GADZOOKS!

Gadolinium  
Antineutrino  
Detector  
Zealously  
Outperforming  
Old  
Kamiokande,  
Super  
!

How can we identify neutrons produced by the inverse beta process (from supernovae, reactors, etc.) in really big water Cherenkov detectors?



Much beyond the kiloton scale, you can forget about using liquid scintillator,  $^3\text{He}$  counters, or  $\text{D}_2\text{O}$ !

Without a doubt, at the 50 kton+ scale the only way to go is a solute mixed into the light water...

Beacom and Vagins,  
Phys. Rev Lett.,  
93:171101, 2004

# Gadolinin

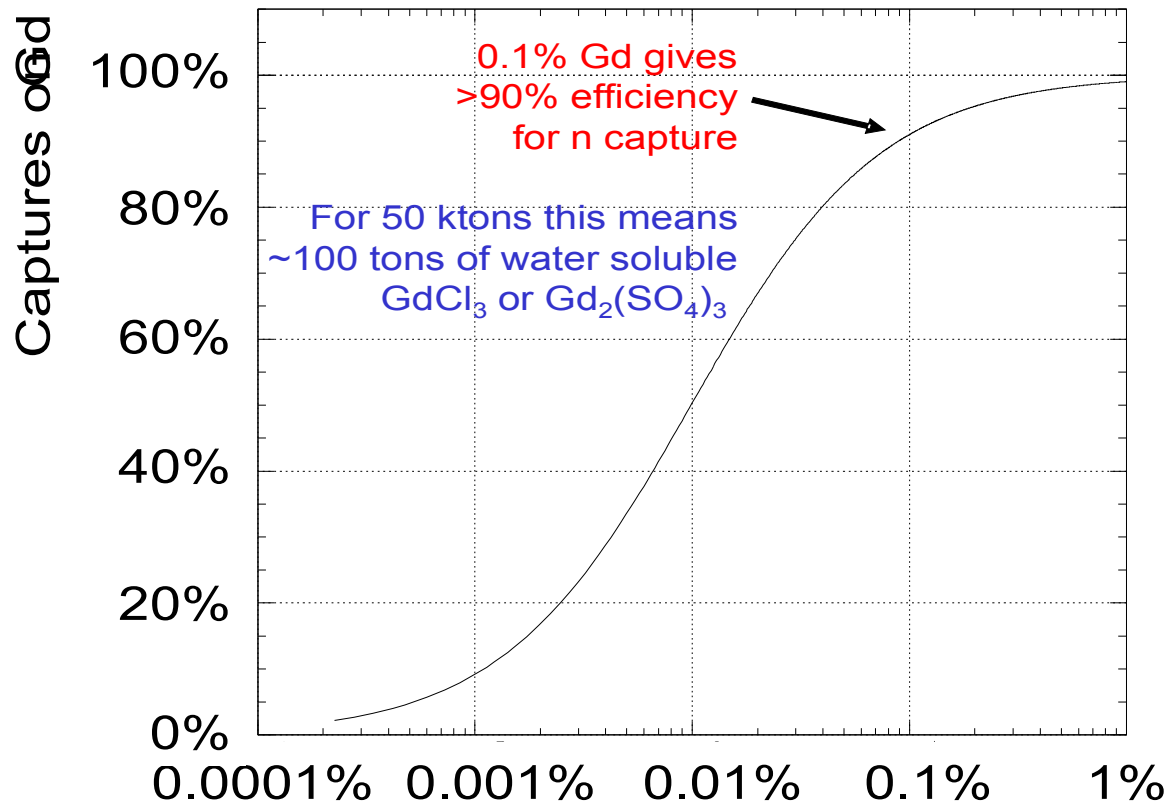
We eventually turned to the best neutron capture nucleus known – gadolinium.



- $\text{GdCl}_3$  and  $\text{Gd}_2(\text{SO}_4)_3$ , unlike metallic Gd, are highly water soluble
- Neutron capture on Gd emits a 8.0 MeV  $\gamma$  cascade
- 100 tons of  $\text{GdCl}_3$  or  $\text{Gd}_2(\text{SO}_4)_3$  in Super-K (0.2% by mass) would yield >90% neutron captures on Gd
- Plus, they are easy to handle and store.

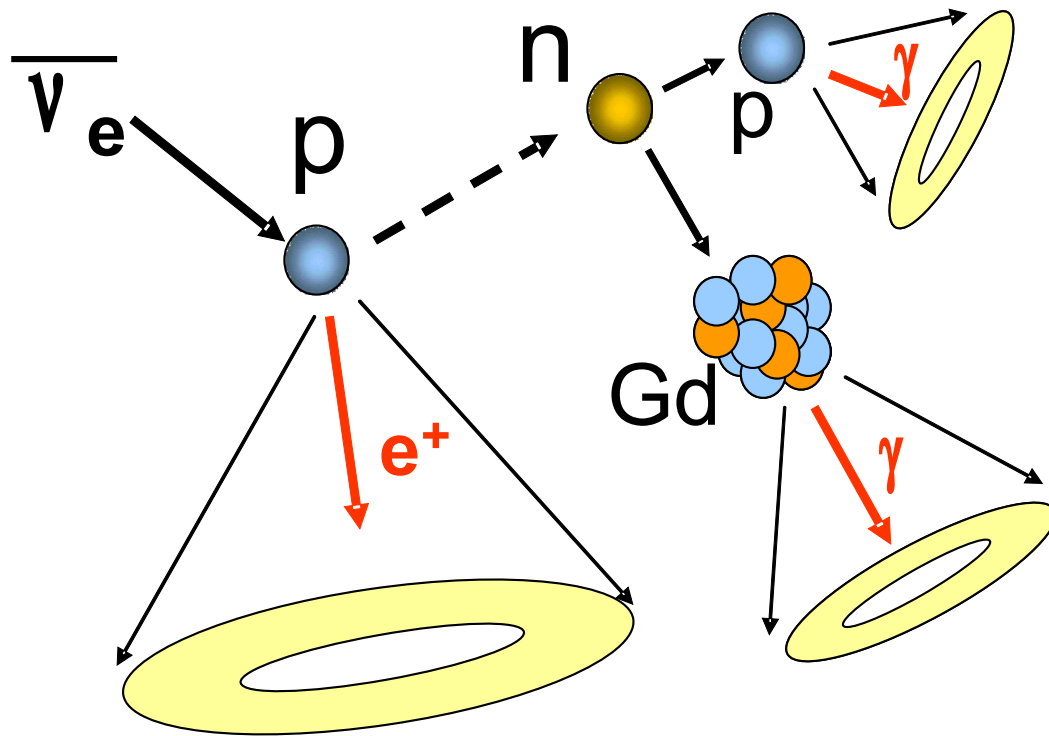


Neutron Captures on Gd vs. Concentration



In 1984: \$4000/kg -> \$400,000,000  
In 1993: \$485/kg -> \$48,500,000  
In 1999: \$115/kg -> \$11,500,000  
In 2010: \$5/kg -> \$500,000

# Neutron tagging in Gd-enriched WC Detector



Positron and gamma ray  
vertices are within  $\sim 50\text{cm}$ .

$\bar{\nu}_e$  can be identified by delayed coincidence.

Possibility 1: 10% or less

$n+p \rightarrow d + \gamma$

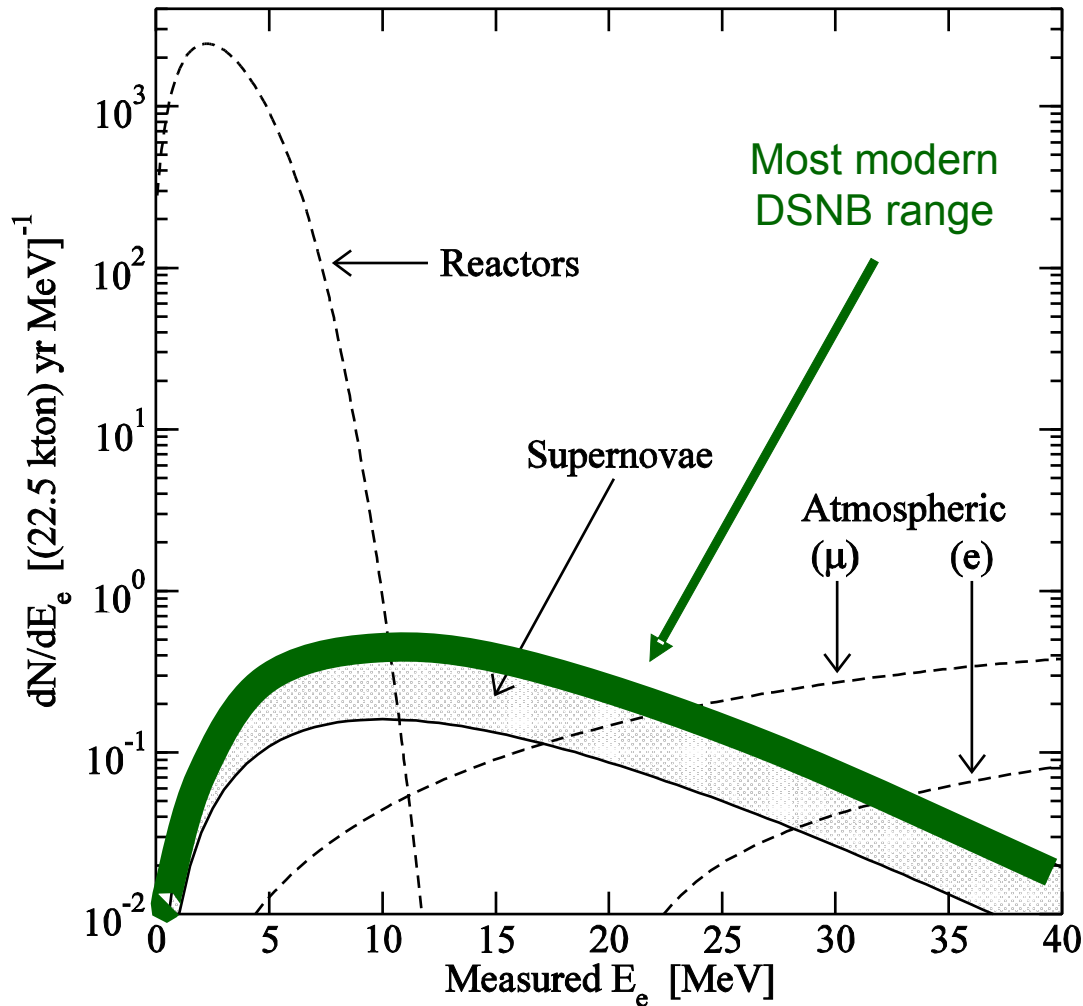
2.2 MeV  $\gamma$ -ray

Possibility 2: 90% or more

$n+Gd \rightarrow \sim 8\text{MeV } \gamma$

$\Delta T = \sim 30 \mu\text{sec}$

Here's what the coincident signals in Super-K with  $\text{GdCl}_3$  or  $\text{Gd}_2(\text{SO}_4)_3$  will look like (energy resolution is applied):



spatial and  
temporal separation  
between prompt  $e^+$   
Cherenkov light and  
delayed Gd neutron  
capture gamma  
cascade:

$$\lambda \approx 4 \text{ cm}, \tau \approx 30 \mu \text{ s}$$

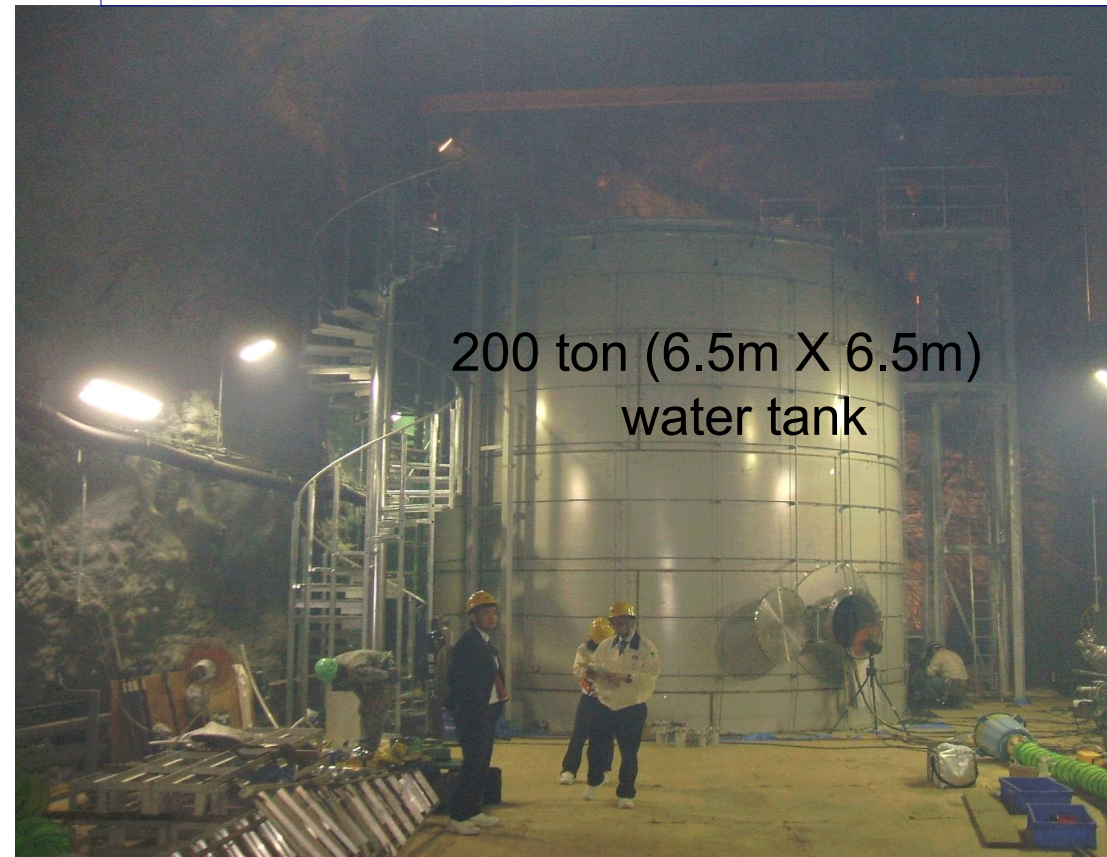
→ A few clean events/yr  
in Super-K with Gd

In a nutshell: adding 100 tons of soluble Gd to Super-K would provide at least two brand-new signals:

Over the last seven years there have been a large number of Gd-related R&D studies carried out in the US and Japan:

1) Discovery of the diffuse supernova neutrino background [DSNB], also known as the “relic” supernova neutrinos (up to 5 events per year)

2) Precision measurements of the neutrinos from all of Japan’s power reactors (a few thousand events per year)  
Will improve world average precision of  $\Delta m^2_{12}$



200 ton (6.5m X 6.5m)  
water tank

EGADS Cavern as of June 8, 2010

N.B.: This is the only neutron detection technique which is extensible to Mton scales, and at minimal expense, too: ~1% of the detector construction costs



# Wiązki neutrinowe

---

podwójne zadanie:

- dalsze badania z wiązkami konwencjonalnymi, które już są dostępne
- a jednocześnie:

opracowywanie rozwiązań na przyszłość, ich projektowanie i budowa

- ▶ wielkie detektorów (kilo- i megatony)
- ▶ megawatowe, efektywne wiązki

superwiązki  
fabryki neutrin  
wiązki beta

# Droga do superwiązek

- to wiązki konwencjonalne (neutrino z rozpadów pionów i kaonów), ale przy mocy akceleratora rzędu MW

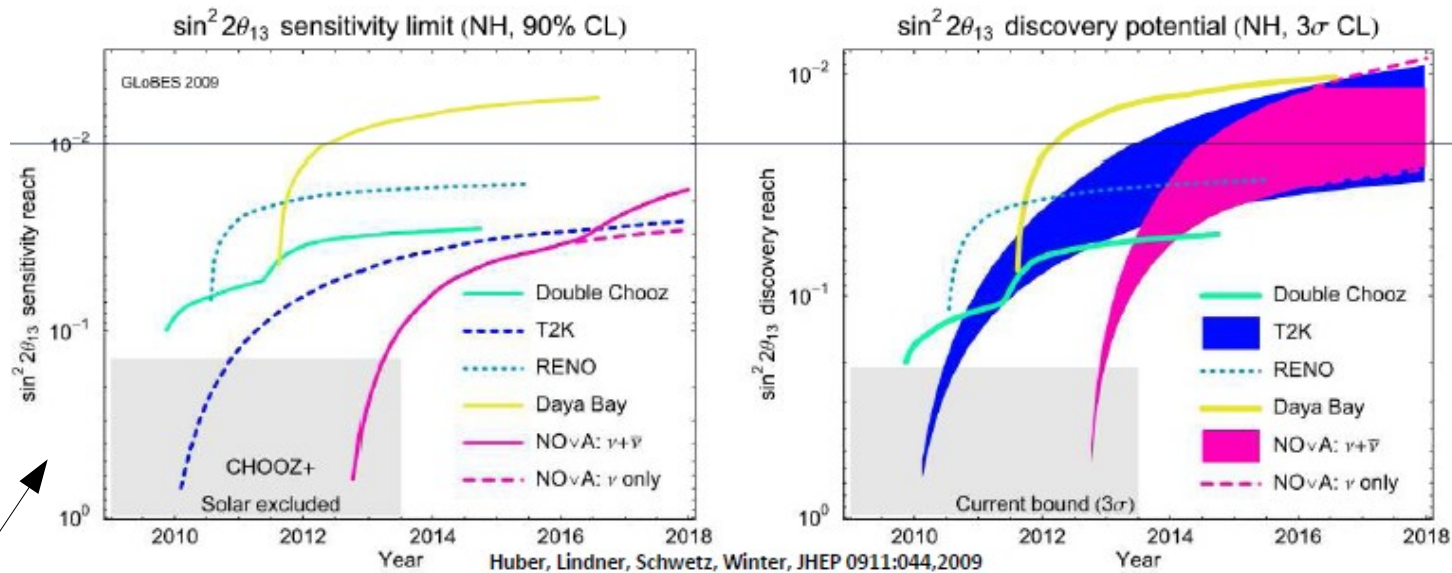
already existing or upgrade existing acc/beam-line
  construct new one

	motivation	Beam Power [MW]	$\nu$ beam facility	detector	baseline [km]	$\nu$ energy (peak $E_\nu$ )	experimental method
JPARC-Okinoshima	<b>CPV, <math>\theta_{13}</math> (hierarchy)</b>	1.66	existing	100kton LArTPC	658	WBB (1.2GeV)	1st, 2nd max
JPARC-Kamioka	<b>CPV, <math>\theta_{13}</math></b>	1.66	existing	540kton W.C.	295	NBB (0.7GeV)	ratio of $\nu$ and $\bar{\nu}$
FNAL-DUSEL	<b>CPV, <math>\theta_{13}</math>, hierarchy</b>	0.7	need new one	~300kton WC. and/or ~50kton LArTPC	1300	WBB (3GeV)	1st, 2nd max
		2.1					
CERN-Frejus	<b>CPV, <math>\theta_{13}</math></b>	4 (HP-SPL)	need new one	~440kton W.C.	130	on-axis low energy (0.2GeV)	ratio of $\nu$ and $\bar{\nu}$
CERN-Pyhasalmi	<b>CPV, <math>\theta_{13}</math>, hierarchy</b>	1.6 (HP-PS2)	need new one	100kton LArTPC	2300	WBB (3GeV)	1st, 2nd max

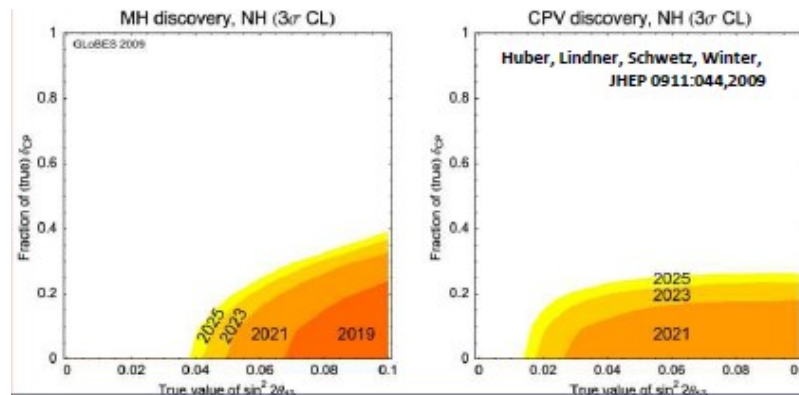
*Future super beam  $\nu$  oscillation experiments are promising to explore and discover CPV in lepton sector because we know how to build and cost of super beams*

# Możliwości superwiązek

NH = normal  
mass  
hierarchy



odwrotna skala

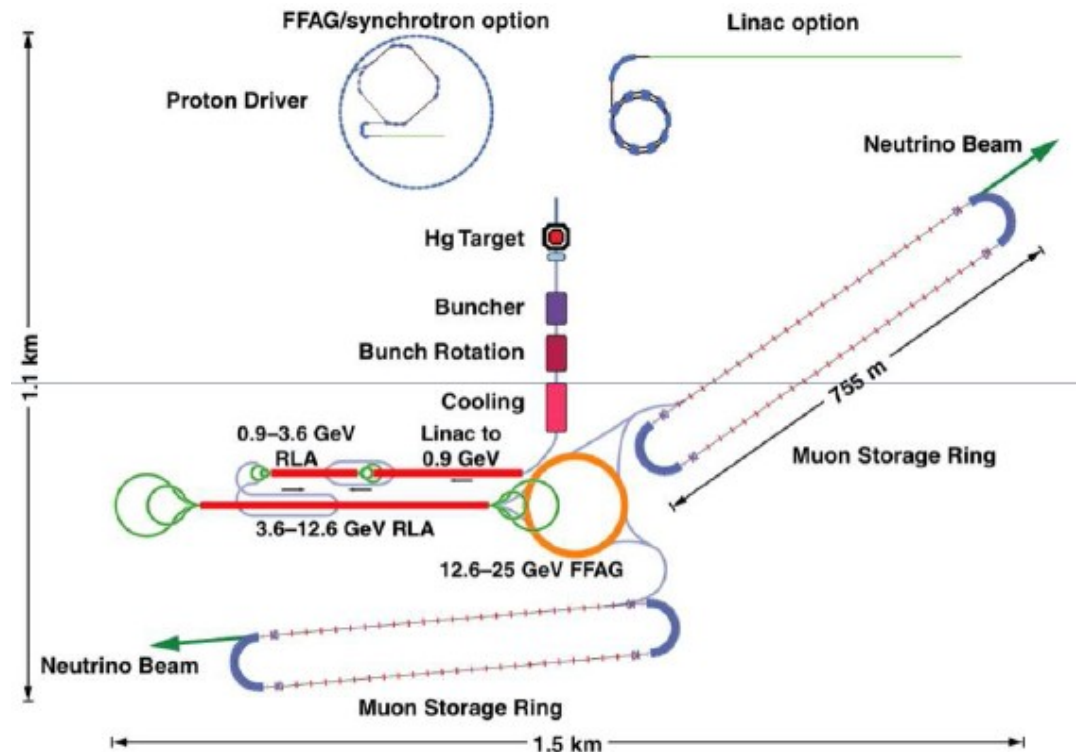


- żeby zejść do niższych wartości, trzeba czegoś innego:
  - ▶ fabryki neutrin

# Fabryki neutrin

- neutrino z rozpadów zmagazynowanych mionów

Stored $\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$	
Disappearance	Appearance
$\bar{\nu}_e \rightarrow \bar{\nu}_e \rightarrow e^+$	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu \rightarrow \mu^+$
	$\bar{\nu}_e \rightarrow \bar{\nu}_\tau \rightarrow \tau^+$
$\nu_\mu \rightarrow \nu_\mu \rightarrow \mu^-$	$\nu_\mu \rightarrow \nu_e \rightarrow e^-$
	$\nu_\mu \rightarrow \nu_\tau \rightarrow \tau^-$



- sygnał w postaci leptonu o nieprawidłowym znaku
  - ▶ detektory z polem magnetycznym

# Wyzwania

- proton driver

Parameter	Value	Comment
Beam power	4 MW	Production rate
Beam energy	5-15 GeV	Optimum pion production
Bunch length	$2 \pm 1$ ns	Pion/muon capture

- **Challenges:**

- High power; short proton bunch length at  $\sim 10$  GeV

- **IDS-NF approach:**

- Consider two 'generic' options:

- **LINAC:**

- Possible development option for SPL (CERN) or Project-X (FNAL)
- Requires accumulator/compressor rings

- **Rings:**

- Development option for J-PARC or RAL or possible 'green-field' option
- Requires bunch compression

- tarcza i róg magnetyczny

- ▶ strumień rtęci, pręty wolframowe, proszek wolframowy – MERIT

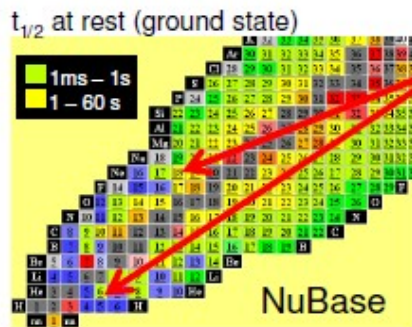
Parameter	Value	Comment
Jet velocity	20 m/s	Reformation of jet
Field at i/p	20 T	Pion collection
Field at exit of capture	1.75 T	Pion focusing

- tworzenie wiązki mionów – MICE, MuCOOL

- zbieranie i przyspieszanie mionów – EMMA

# Wiązki beta

- neutrina z rozpadów radioaktywnych izotopów krążących w pierścieniu akumulującym



6He and 18Ne

8Li and 8B

Suitable pairs

- Beta-active isotopes
  - Production rates
  - Life time
  - Dangerous rest products
  - Reactivity (Noble gases are good)

- Accelerate parent ion to relativistic  $\gamma_{\max}$ 
  - Boosted neutrino energy spectrum:  $E_{\nu} \leq 2\gamma Q$
  - Forward focusing of neutrinos:  $\theta \leq 1/\gamma$
- Pure electron (anti-)neutrino beam!
  - Depending on  $\beta^{+}$ - or  $\beta^{-}$ - decay we get a neutrino or anti-neutrino
  - Two different parent ions for neutrino and anti-neutrino beams
- Physics applications of a beta-beam
  - Primarily neutrino oscillation physics and CP-violation (high energy)
  - Cross-sections of neutrino-nucleus interaction (low energy)

# Projekt EURISOL

intensywne badania nad produkcją i zbieraniem jonów

**$^{18}\text{Ne}$  Isotopes is not possible to produce with ISOL technology: New Ideas are needed!!!**

60 GHz pulsed ECR  
 Linac, 100 MeV  
 RCS, 1.7 GeV

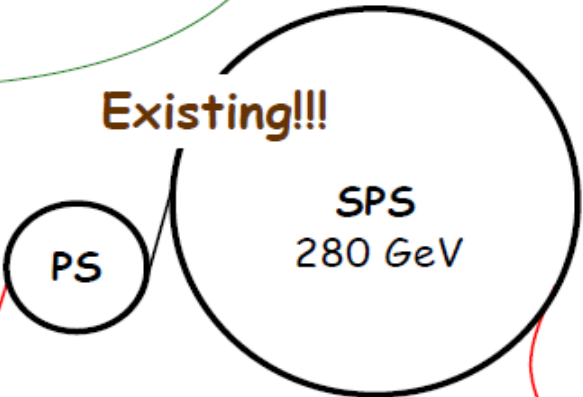


Existing!!!

$\nu$ -beam to Frejus  
 Decay ring  
 $B_p \sim 500 \text{ Tm}$   
 $B = \sim 6 \text{ T}$   
 $C = \sim 6900 \text{ m}$   
 $L_{ss} = \sim 2500 \text{ m}$   
 $^6\text{He}: \gamma = 100$   
 $^{18}\text{Ne}: \gamma = 100$

Ion Linac 25 MeV, 7 Li and 6 Li  
 Ion production  
 ISOL target, Collection  
 PR 8B/8Li

60 GHz pulsed ECR  
 Linac, 100 MeV  
 RCS, 1.7 GeV



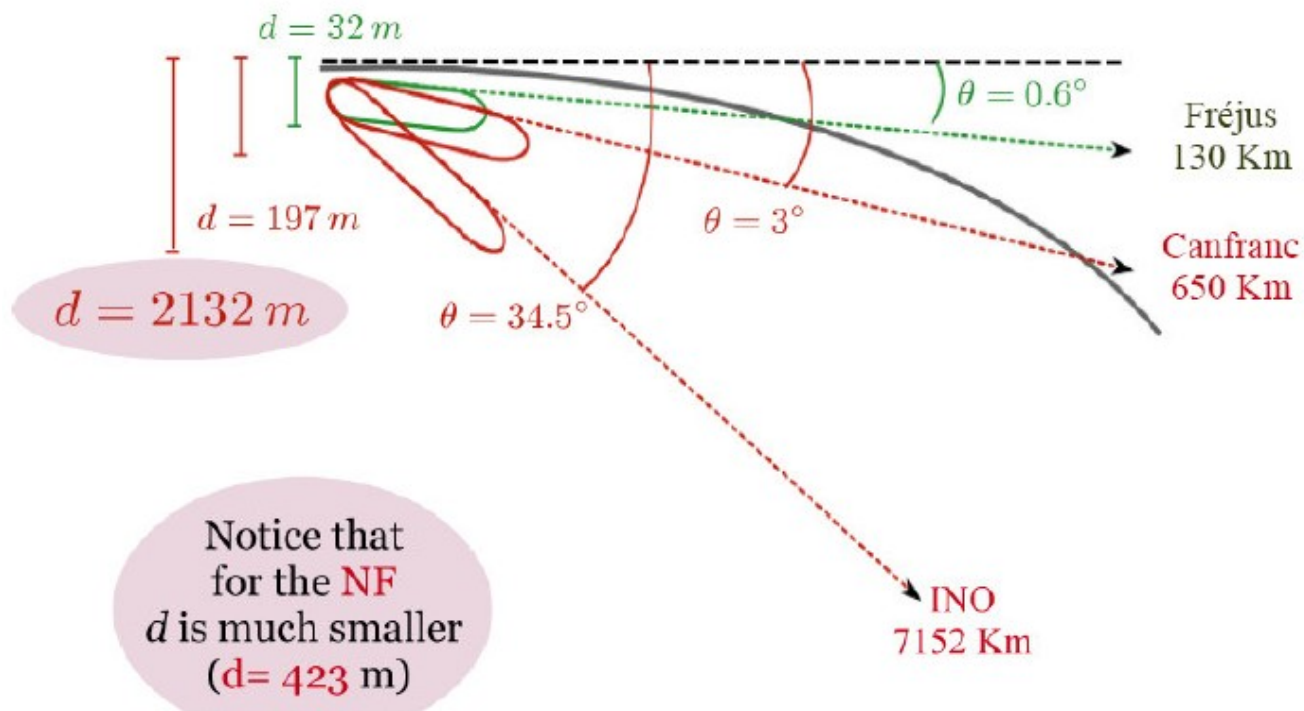
Existing!!!

$\nu$ -beam to GranSasso/Canfranc

Decay ring  
 $B_p \sim 500 \text{ Tm}$   
 $B = \sim 6 \text{ T}$   
 $C = \sim 6900 \text{ m}$   
 $L_{ss} = \sim 2500 \text{ m}$   
 $^8\text{Li}: \gamma =$   
 $100 \text{ } ^{18}\text{B}: \gamma = 100$

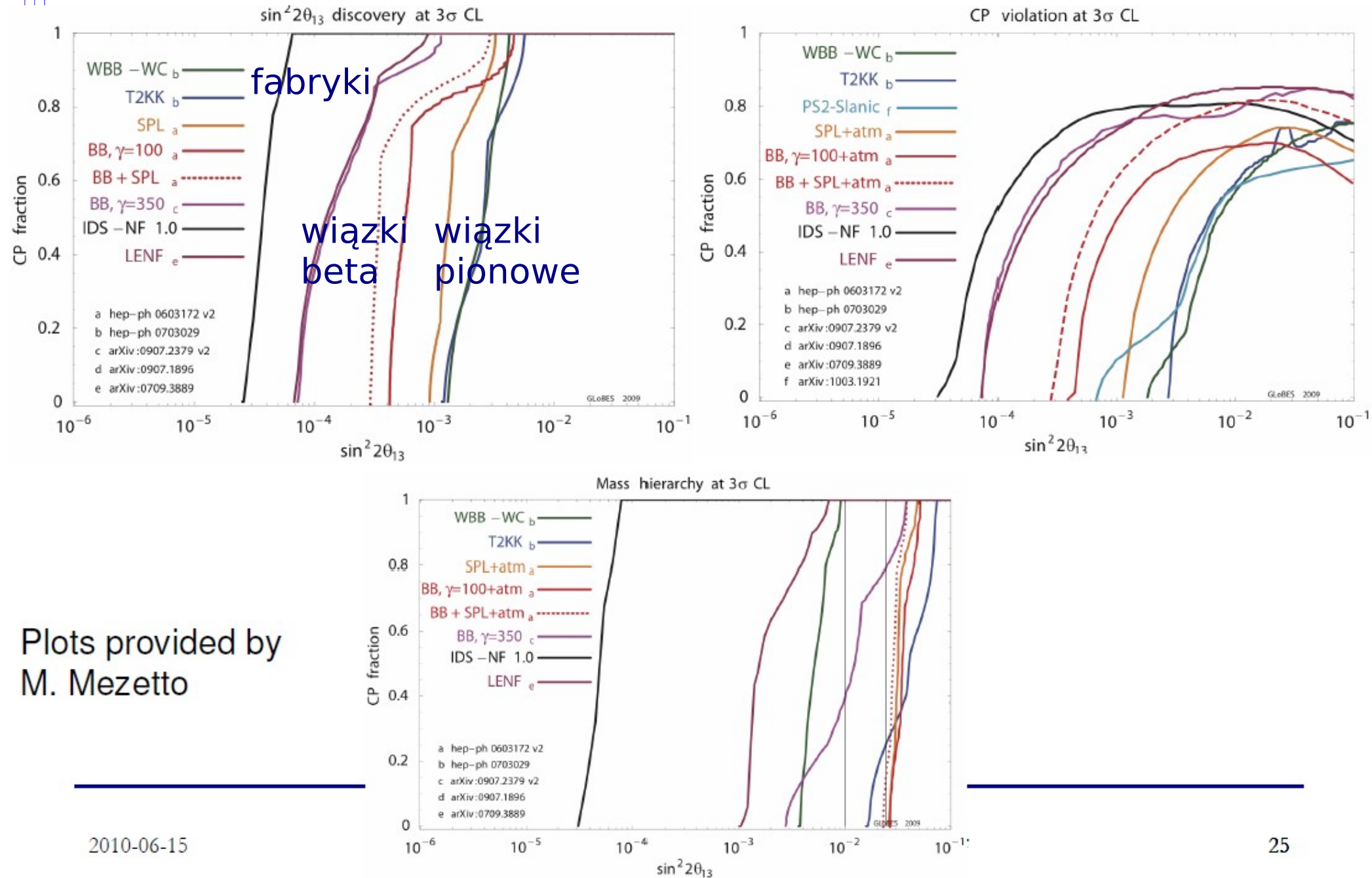
# Rozpady krążących jonów

- pierścień (?) rozpadowy
  - ▶ rozmiary - kilka kilometrów
  - ▶ głębokość - zależy od odległości do dalekiego detektora





# Możliwości fabryk neutrin i wiązek beta



Plots provided by  
M. Mezzetto

# Neutrino 2012

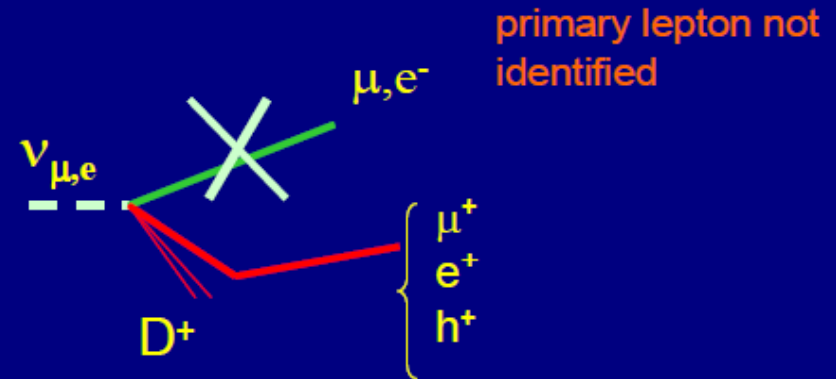
- Kyoto, 3-9 czerwca 2012
- EURO 2012
  - ▶ 8 czerwca  
- mecz otwarcia  
w Warszawie



**Dodatkowe slajdy**

# OPERA: tło od produkcji cząstek powabnych

Charmed particles have similar decay topologies to the  $\tau$  and similar lifetimes



- charm production in CC events represents a background source to all tau decay channels
- this background can be suppressed by identifying the primary lepton  
→ ~ 95% muon ID
- for the 1-prong hadronic channel  $0.007 \pm 0.004$  (syst) background events are expected for the analyzed statistics

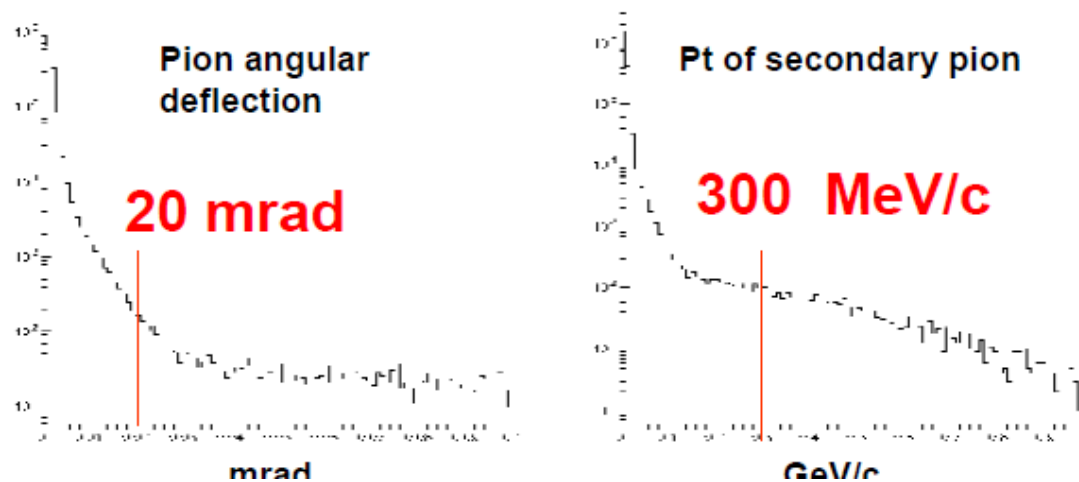
# OPERA: tło od oddziaływań wtórnych hadronów

- symulacja z użyciem Fluki
  - ▶ porównana z danymi zebranymi z wiązką testową pionów

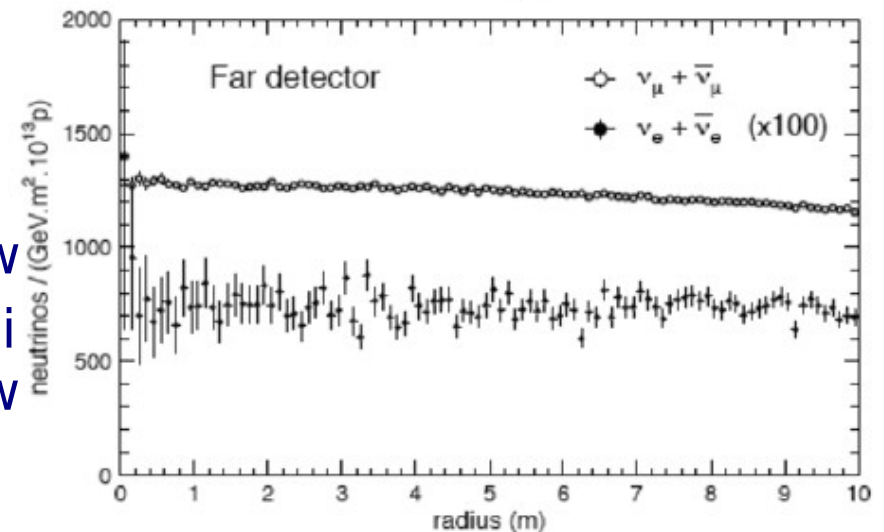
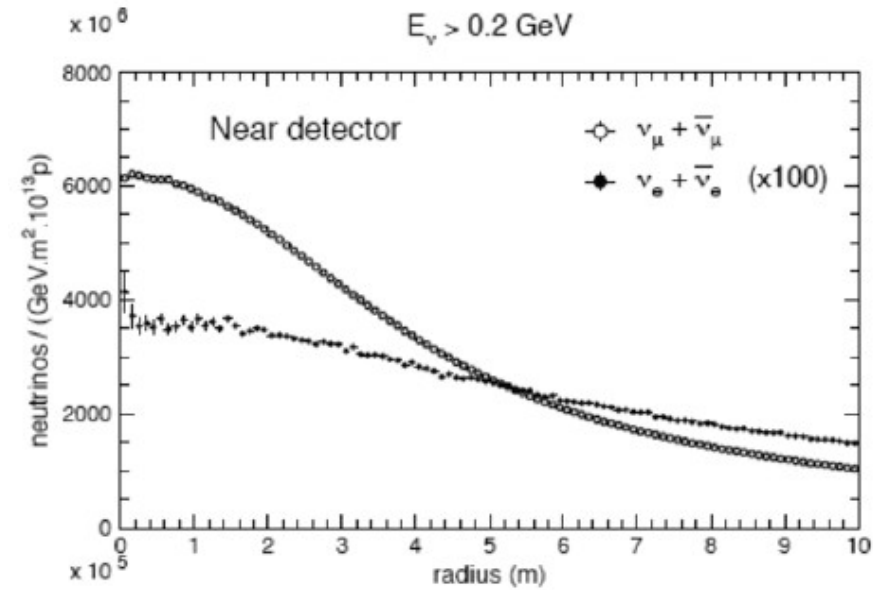
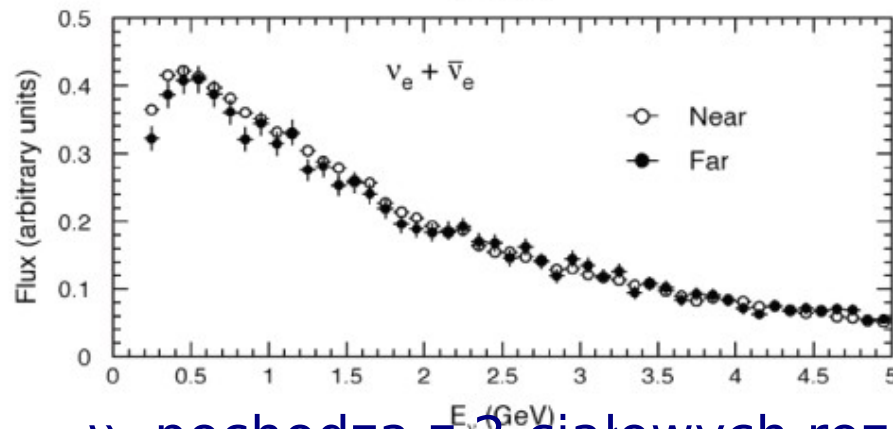
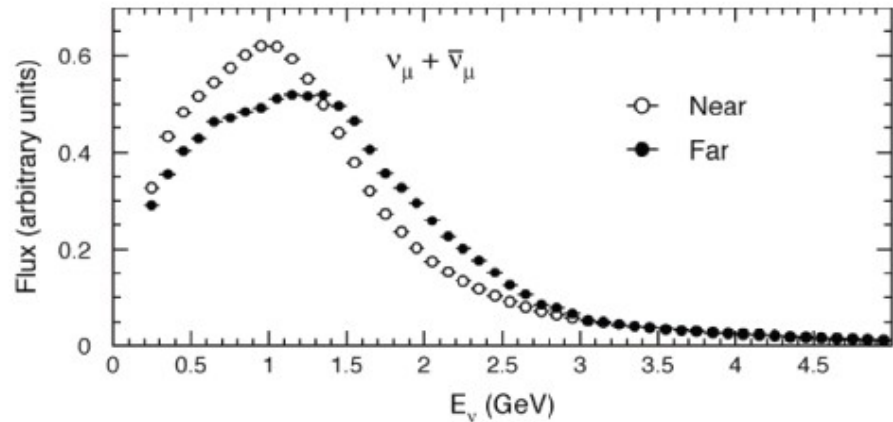
kink probabilities integrated over the  $\nu_\mu$  NC hadronic spectrum yield a BG probability of:

**$(1.9 \pm 0.1) \times 10^{-4}$  kinks/NC** (2 mm Pb)

Typical scattering distributions for : 5 GeV  $\pi^+$



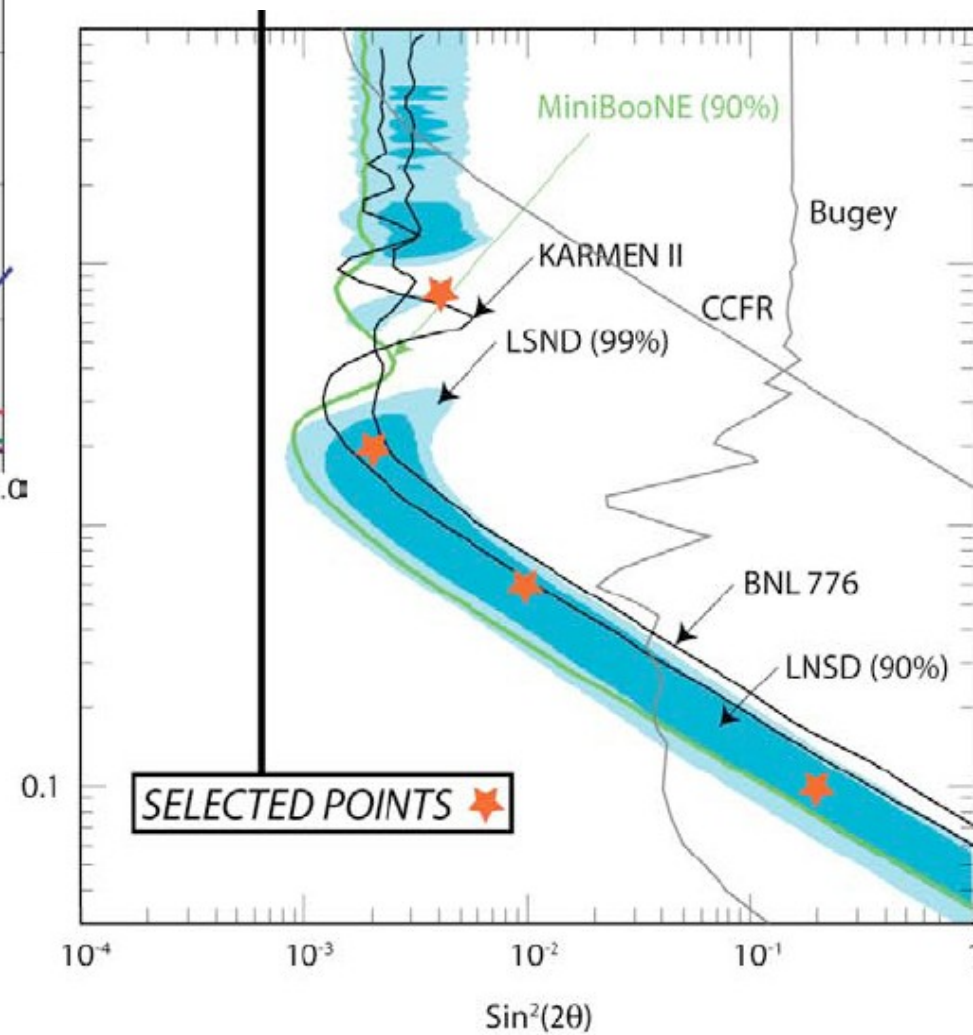
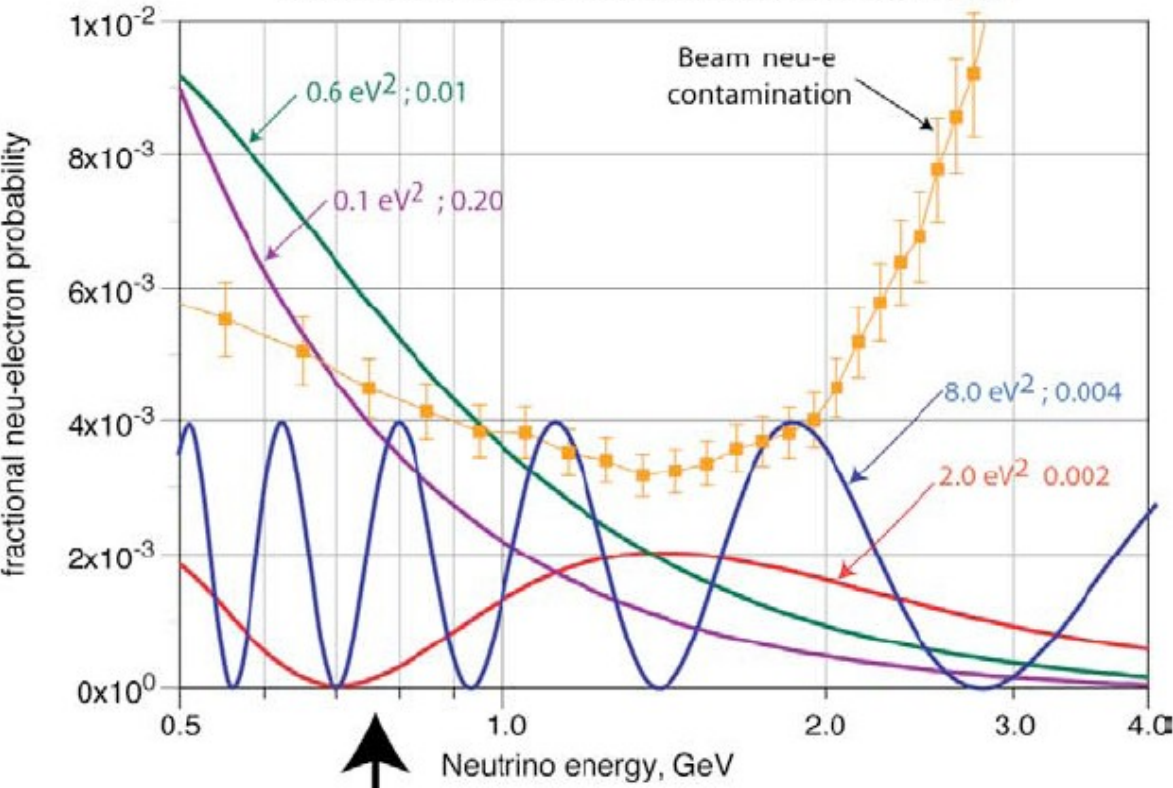
# Double LAr: strumienie neutrin



- $\nu_\mu$  pochodzą z 2-ciałowych rozpadów pionów, neutrina są skupione przy osi
- $\nu_e$  pochodzą z 3-ciałowych rozpadów kaonów i mionów, mają znacznie większy rozrzut kątowy
- można to zweryfikować mierząc profil wiązki

# Double LAr: Badanie zakresu LSND

Two neutrino oscillation pattern at 0.870 km



# Superwiązki

## Physics Motivation@Super beam LBL exp.

- ◆ discover  $\nu_\mu \rightarrow \nu_e$  appearance  $\rightarrow$  a finite  $\theta_{13}$



Current long-baseline(LBL)  $\nu$  osc. exp.  
with  $\sim 0.7\text{MW}$  beam power  
(T2K & NOvA)

NEUTRINOS

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & \boxed{?} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

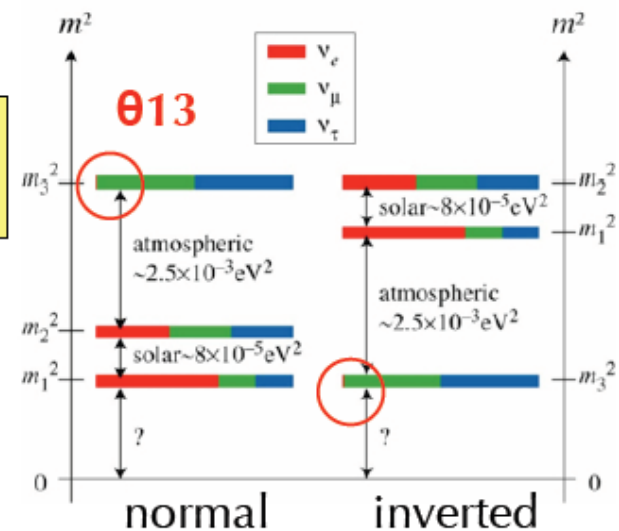
$U_{e3} = s_{13}e^{-i\delta}$

- ◆ CPV in lepton sector
- ◆ Mass hierarchy

$\nu_\mu \rightarrow \nu_e$  in future LBL exp. with  
*multi MW super beam and giant detector*

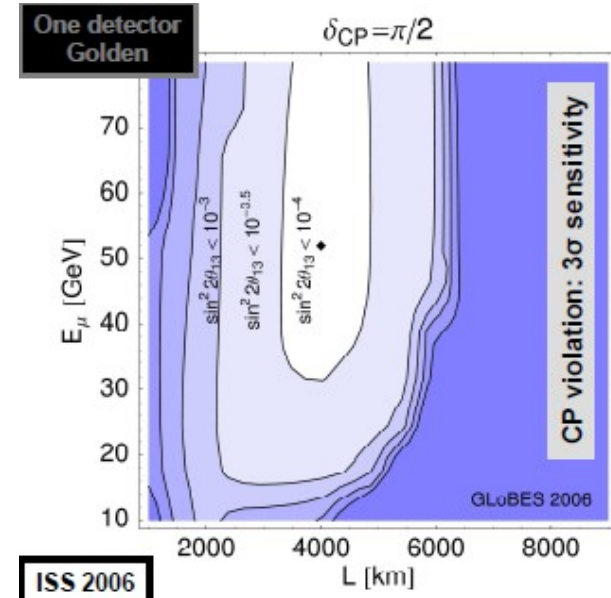
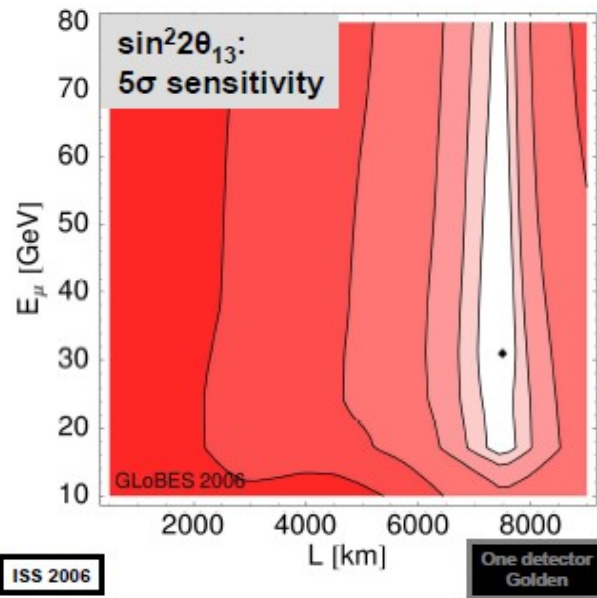
- ◆ precise measurement  $\rightarrow$  (e.g.) Is  $\theta_{23}$  maximal ?

- ◆ Dirac or Majorana
- ◆ Absolute Mass scale *non-accelerator  $\nu$  exp.*





# Optymalizacja fabryk neutrin



- 2000—5000 km; good sensitivity to CP violation
- 7000—8000 km; mass hierarchy,  $\theta_{13}$ , degeneracy resolution

- propozycje detektorów:
  - ▶ Magnetised Iron Neutrino Detector (100kton) – żelazo + scyntylatory lub RPC
  - ▶ Totally Active Scintillator Detector
  - ▶ Liquid Argon