DUNE: o maior experimento de física de neutrinos com argônio líquido

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EBN
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UNICAMP FAPESP CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

Os neutrinos são evasivos

- Neutrinos ***são as partículas mais abundantes do Universo, depois dos fótons***
- São partículas que poderiam explicar ***porque o Universo existe ainda hoje***

Os neutrinos são evasivos

- Neutrinos ***são as partículas mais abundantes do Universo, depois dos fótons***
- São partículas que poderiam explicar ***porque o Universo existe ainda hoje***
- **Mas porque os fisicos perceberam a necessidade da existencia dos neutrinos só em 1930??**
- **E porque descobrimos os neutrinos só em 1956??**
- **E porque os neutrinos carregam muitos mistérios ainda hoje?**

Neutrinos?

Cerca de 100 bilhoes de neutrinos produzidos no Sol travessam cada cm² do nosso corpo, cada segundo!

Neutrinos?

...e talvez um deles interage dentro do nosso corpo ao longo da nossa vida!


Não travessam só o nosso corpo,
Mas a Terra inteira

E o Universo todo… quase sem serem disturbados!!!

E o Universo todo… quase sem serem disturbados!!!

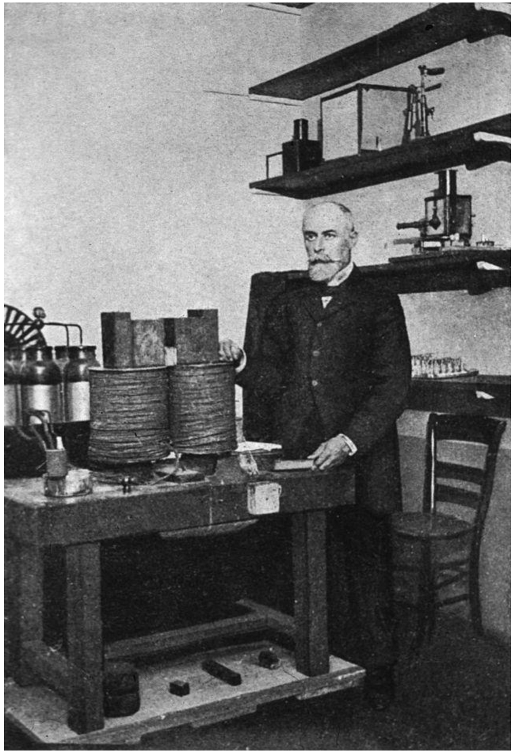
Por essa razão os neutrinos são chamados de particuals fantasmas

Vamos voltar no tempo 100 anos atras para entender como os fisicos descobriram os neutrinos

e vamos ver o que acontece no infinitamente pequeno e no decaimento dos núcleos radioativos

A radioatividade e os neutrinos

- Em 1896 Bequerel descobriu a radioatividade no Uranio (...mas foi mesmo ele que descobriu?)



...Abel Niépce de Saint-Victor

- Claude Félix Abel Niépce de Saint-Victor (1805-1870) era um fotografo e experimentador francês;
- Por volta de 1850 Saint-Vitor trabalhava no desenvolvimento da fotografia colorida usando sais metálicos sensíveis à luz, **incluindo sais de urânio**
- ***Em 1857*** ele observou que sais de uranio conseguiam impressionar emulsões fotográficas mesmo no escuro e depois de muitos meses;
- Saint-Victor entendeu que o uranio estava emitindo ***um novo tipo de radiação invisível ao olho***;
- " ... this persistent activity ... cannot be due to phosphorescence, for it [i.e., phosphorescence] would not last so long, according to the experiments of ***Mr. Edmond Becquerel***; it is thus more likely that it is a radiation that is invisible to our eyes, as Mr. Léon Foucault believes, ..."

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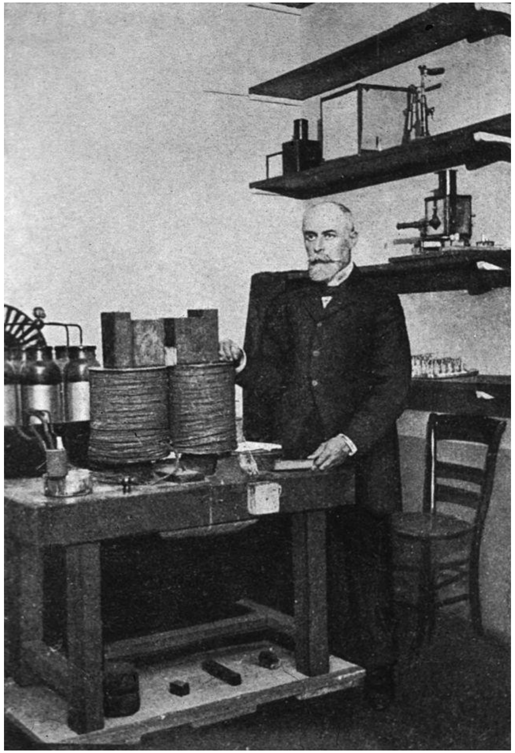

A radioatividade e os neutrinos

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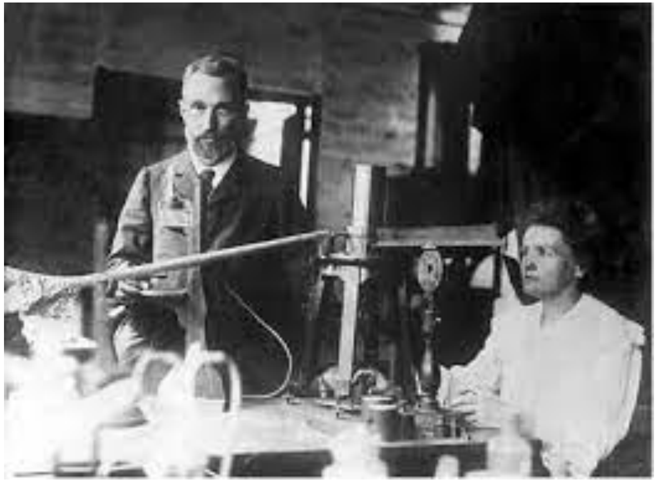
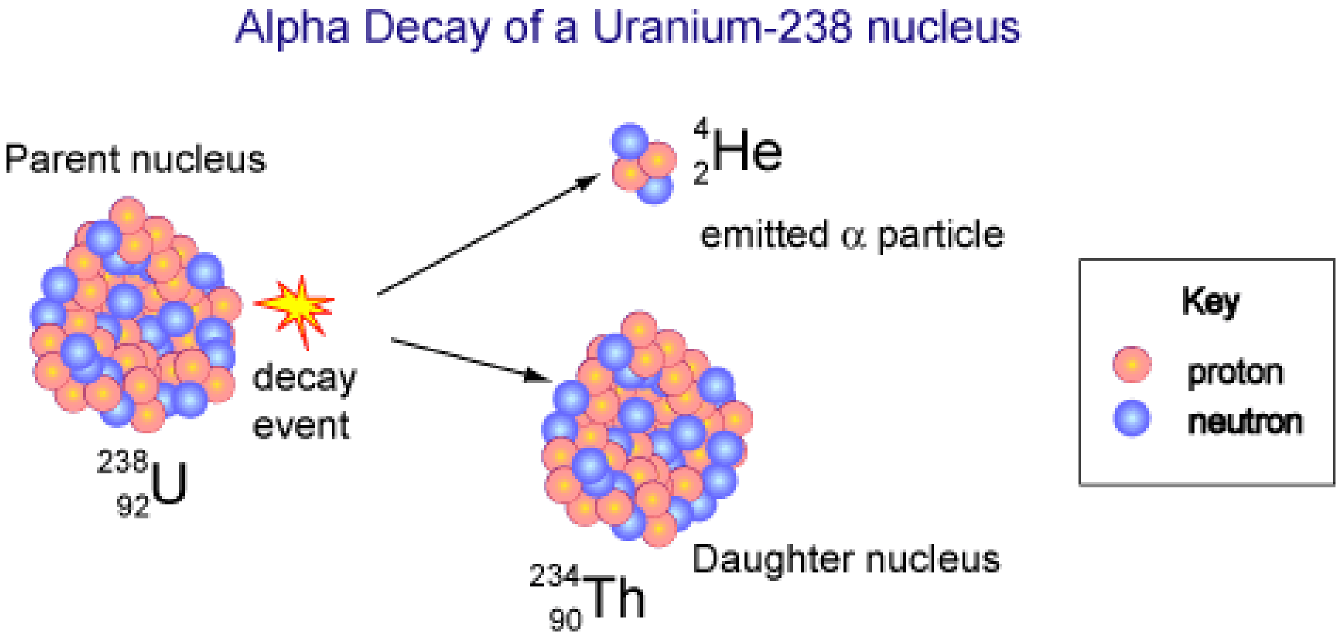
- Marie e Pierre Curie descobriram a radioatividade no Tório e nos novos elementos Polônio (Marie Curie era Polonês) e Radio



A radioatividade e os neutrinos

- Em 1896 Bequerel descobriu a radioatividade no Uranio (com alguma contribuição de um obscuro fotografo...)
- Marie e Pierre Curie descobriram a radioatividade no Tório e nos novos elementos Polônio (Marie Curie era Polonês) e Radio
- Em 1899 Rutherford classificou as emissões radioativas em α e β. De acordo com quanto penetram no alumínio (em em todos os materiais)
- Em 1900 foi descoberta tambem a emissão γ (ainda mais penetrante das outras duas)

Decaimento α



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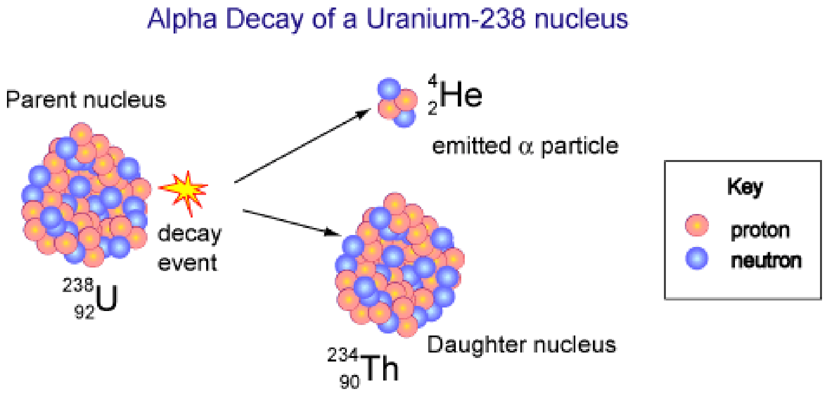
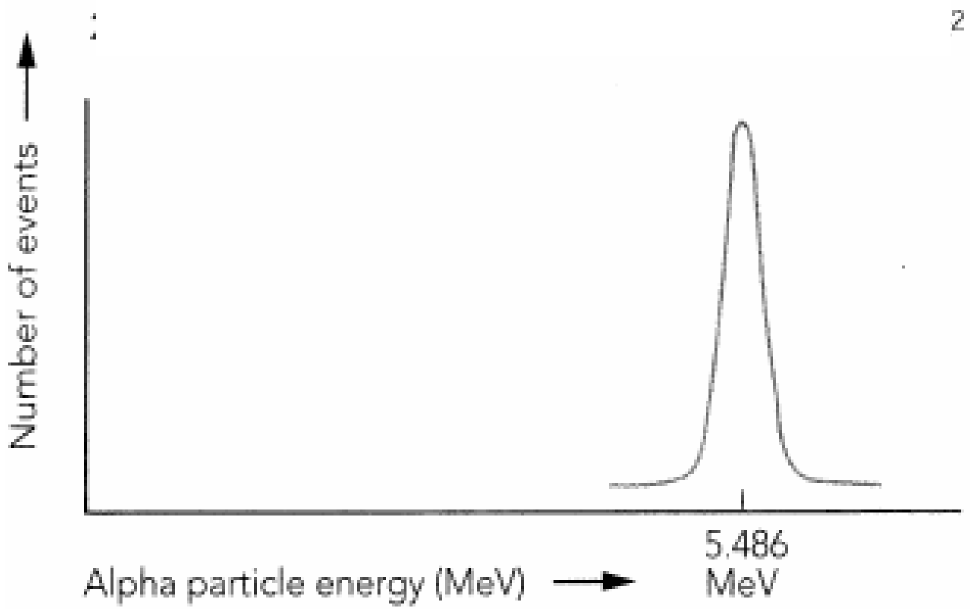
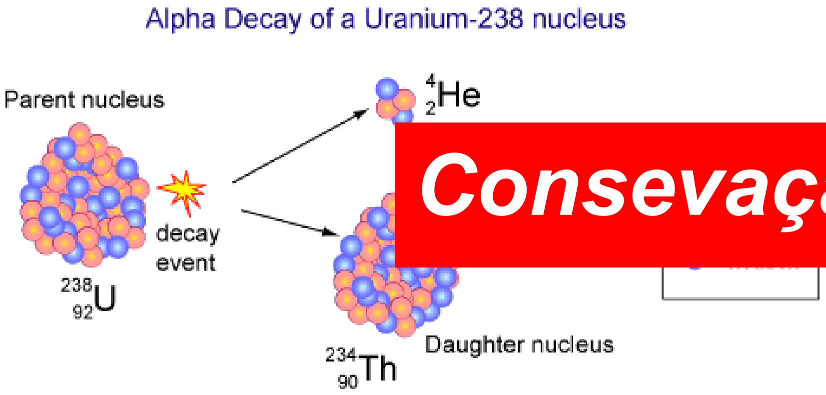


Energia da particula α



Decaimento α



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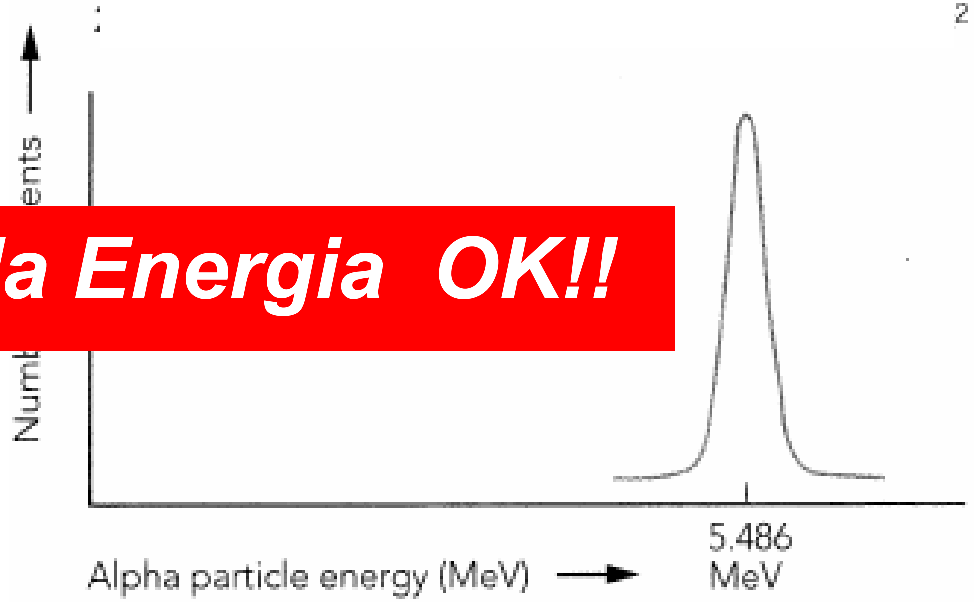
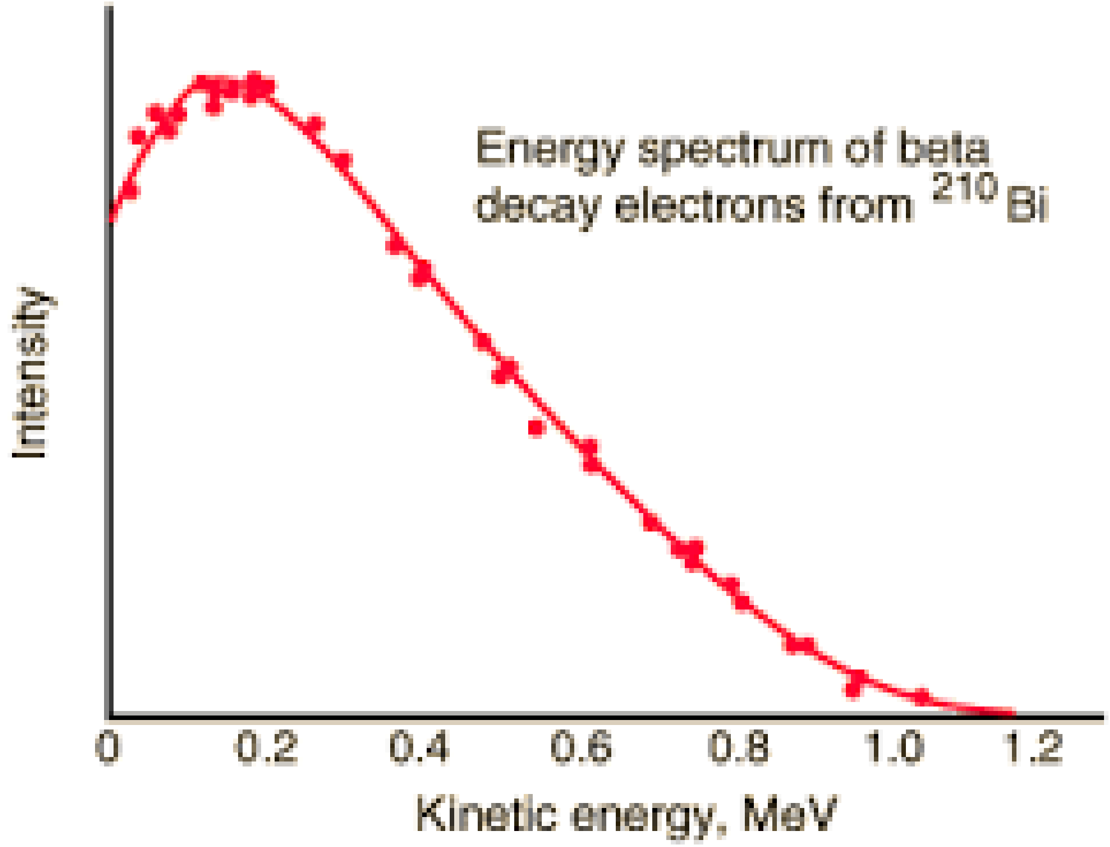


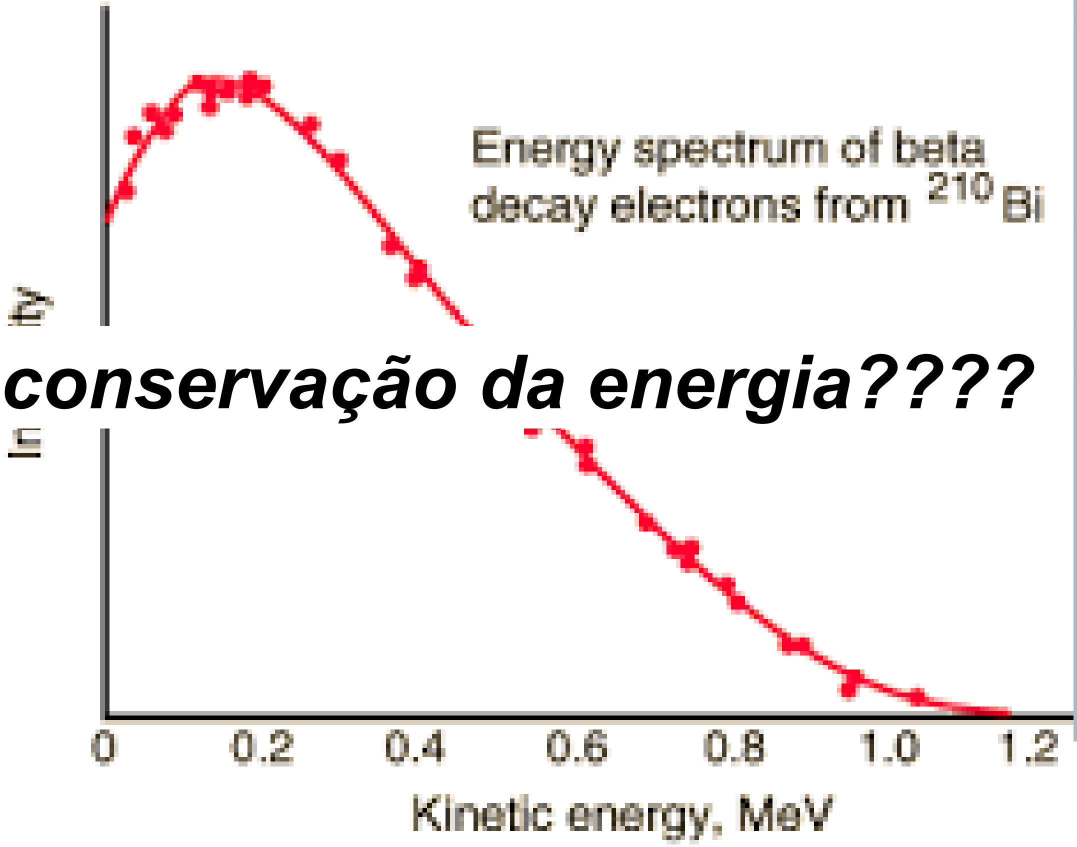
Consevação da Energia OK!!

Decaimento β



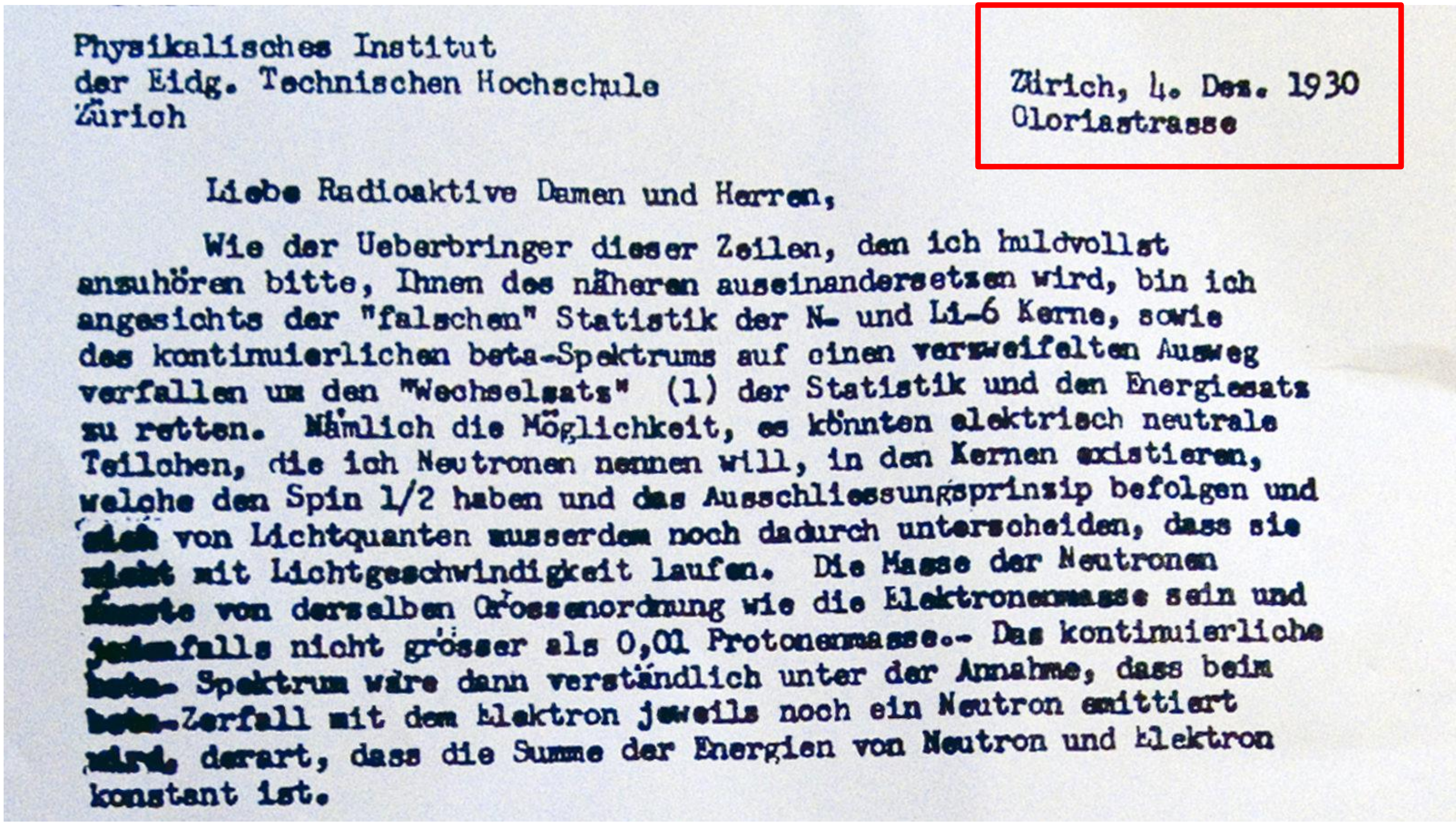
As emissões β, que foram identificadas serem eléctrones, apresentam um espectro continuo de energia!!!

Decaimento β



E a conservação da energia????

Hipothese do Pauli: a particula fantasma!



Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

[This is a translation of a machine-typed copy of a letter that Wolfgang Pauli sent to a group of physicists meeting in Tübingen in December 1930. Pauli asked a colleague to take the letter to the meeting, and the bearer was to provide more information as needed.]

Copy/Dec. 15, 1956 PM

Open letter to the group of radioactive people at the
Gauverein meeting in Tübingen.

Copy

Physics Institute of
the ETH Zürich

Zürich, Dec. 4, 1930

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, because of the "wrong" statistics of the N- and Li-6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" (1) of statistics and the law of conservation of energy. Namely, the possibility that in the nuclei there could exist electrically neutral particles, which I will call neutrons, that have spin 1/2 and obey the exclusion principle and that further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton mass. - The continuous beta spectrum would then make sense with the assumption that in beta decay, in addition to the electron, a neutron is emitted such that the sum of the energies of neutron and electron is constant.

Now it is also a question of which forces act upon neutrons. For me, the most likely model for the neutron seems to be, for wave-mechanical reasons (the bearer of these lines knows more), that the neutron at rest is a magnetic dipole with a certain moment μ. The experiments seem to require that the ionizing effect of such a neutron can not be bigger than the one of a gamma-ray, and then μ is probably not allowed to be larger than $e \cdot (10^{-13}\mathrm{cm})$.

But so far I do not dare to publish anything about this idea, and trustfully turn first to you, dear radioactive people, with the question of how likely it is to find experimental evidence for such a neutron if it would have the same or perhaps a 10 times larger ability to get through [material] than a gamma-ray.

I admit that my remedy may seem almost improbable because one probably would have seen those neutrons, if they exist, for a long time. But nothing ventured, nothing gained, and the seriousness of the situation, due to the continuous structure of the beta spectrum, is illuminated by a remark of my honored predecessor, Mr Debye, who told me recently in Bruxelles: "Oh, It's better not to think about this at all, like new taxes." Therefore one should seriously discuss every way of rescue. Thus, dear radioactive people, scrutinize and judge. - Unfortunately, I cannot personally appear in Tübingen since I am indispensable here in Zürich because of a ball on the night from December 6 to 7. With my best regards to you, and also to Mr. Back, your humble servant

signed W. Pauli

[Translation: Kurt Riesselmann]

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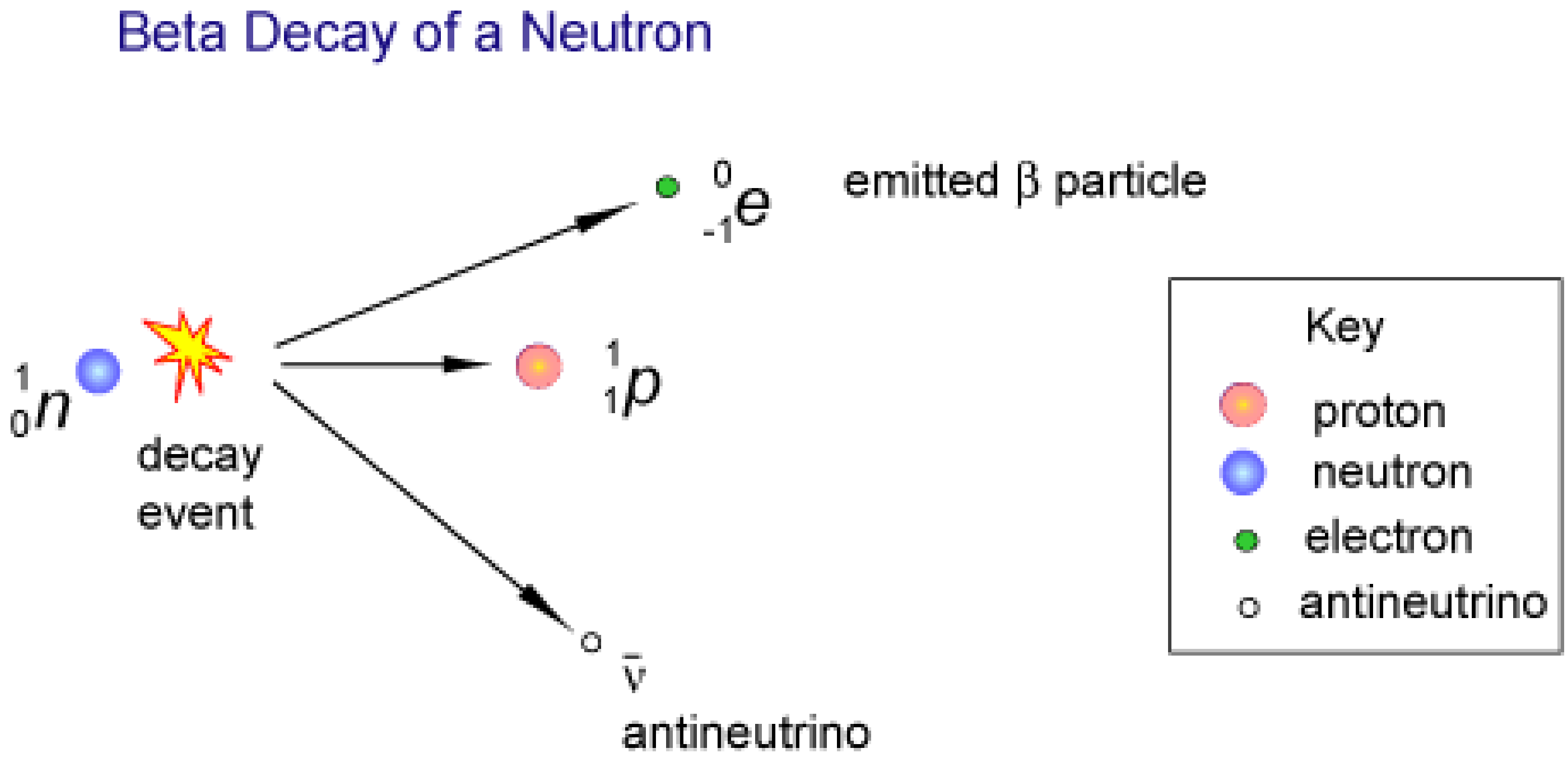
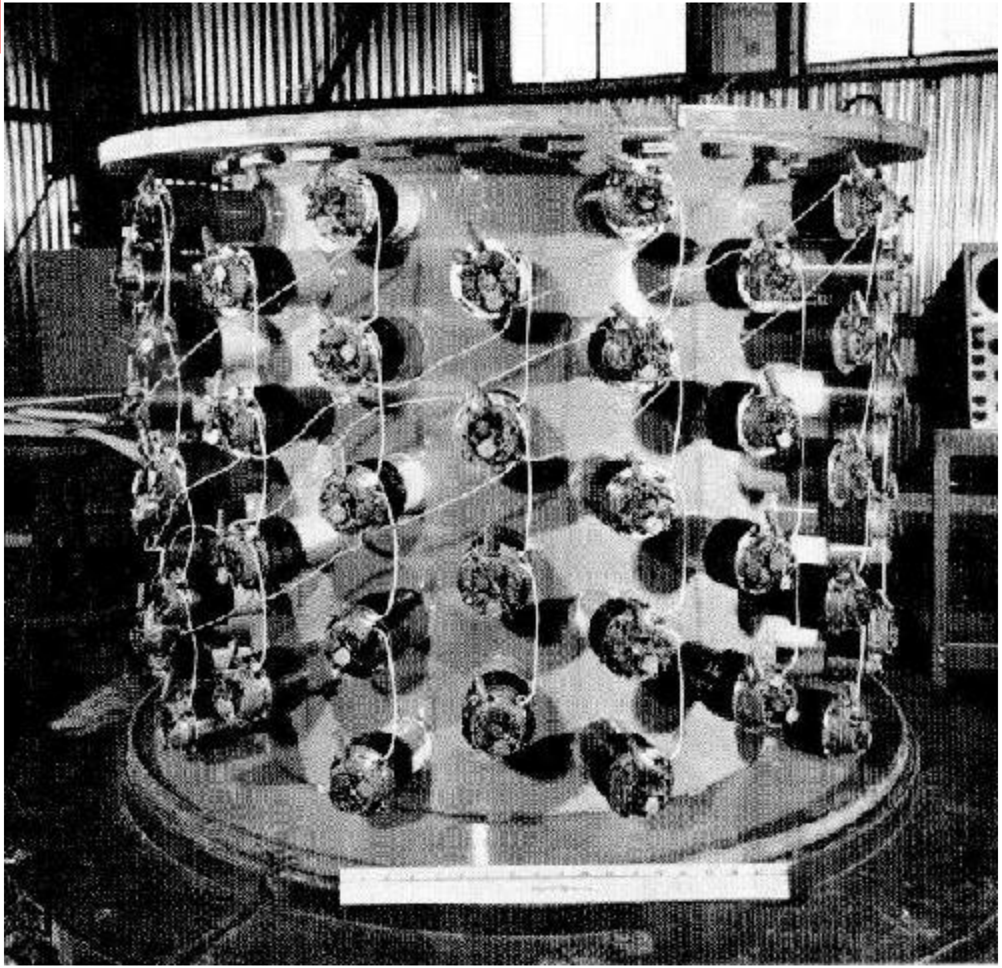
A Teoria de Fermi do decaimento β (1934)



A descoberta do neutrino



Mas neutrinos foram descobertos só em 1956 por Raines e Cowen!
Premio Nobel 1995

Em 1976 Lederman, Schwartz e Steinberger descobriram um segundo tipo de neutrino o ν_μ
Premio Nobel 1988

Em 2000 foi descoberto um terceiro tipo de neutrino o ν_τ (DONUT Coll. Fermilab)

O neutrino descoberto por Reines e Cowan é o neutrino ν_e

Raines e Cowen

Inverse beta decay:

$$\bar{\nu_e} + \mathrm{p} \rightarrow n + e^{+}$$

- Pensaram em usar ***uma bomba atômica*** como fonte de neutrinos (do tamanho da bomba usada em Hiroshima)
- O chefe da divisão de física (Kellogg) de Los Alamos convenceu em usar um reator nuclear
- O alvo dos neutrino eram dois tanque de agua ~ 200 kg + 40 kg de $ClCd_2$ com 4 camadas de cintiladores em

Raines e Cowen

é um tipo de evento paranormal que se manifesta em um ambiente no qual existem ocorrências físicas, tais quais, chuva de pedras, movimentação, aparecimento e desaparecimento de objetos, sons, pirogenia, luzes, entre outras. Pode envolver até ataques físicos (Wikipedia)

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Três partículas fantasmas

- ***Tres neutrinos. Cada um ligado e associado com um dos tres leptons (Electron, Muon e Tau)***
- ***Sem carga eletrica***
- ***Interagem muito pouco com as outras particulas, só atraves da interação fraca***
- ***Sem massa (quase…)***

ONDE SÃO PRODUZIDOS

Big Bang

10^{-4} eV

Reatores

~ MeV

Terra

~ 4MeV

Sol

0.1 → 14 MeV

Supernova

10 → 50 MeV

Aceleradores

1 → 20 GeV

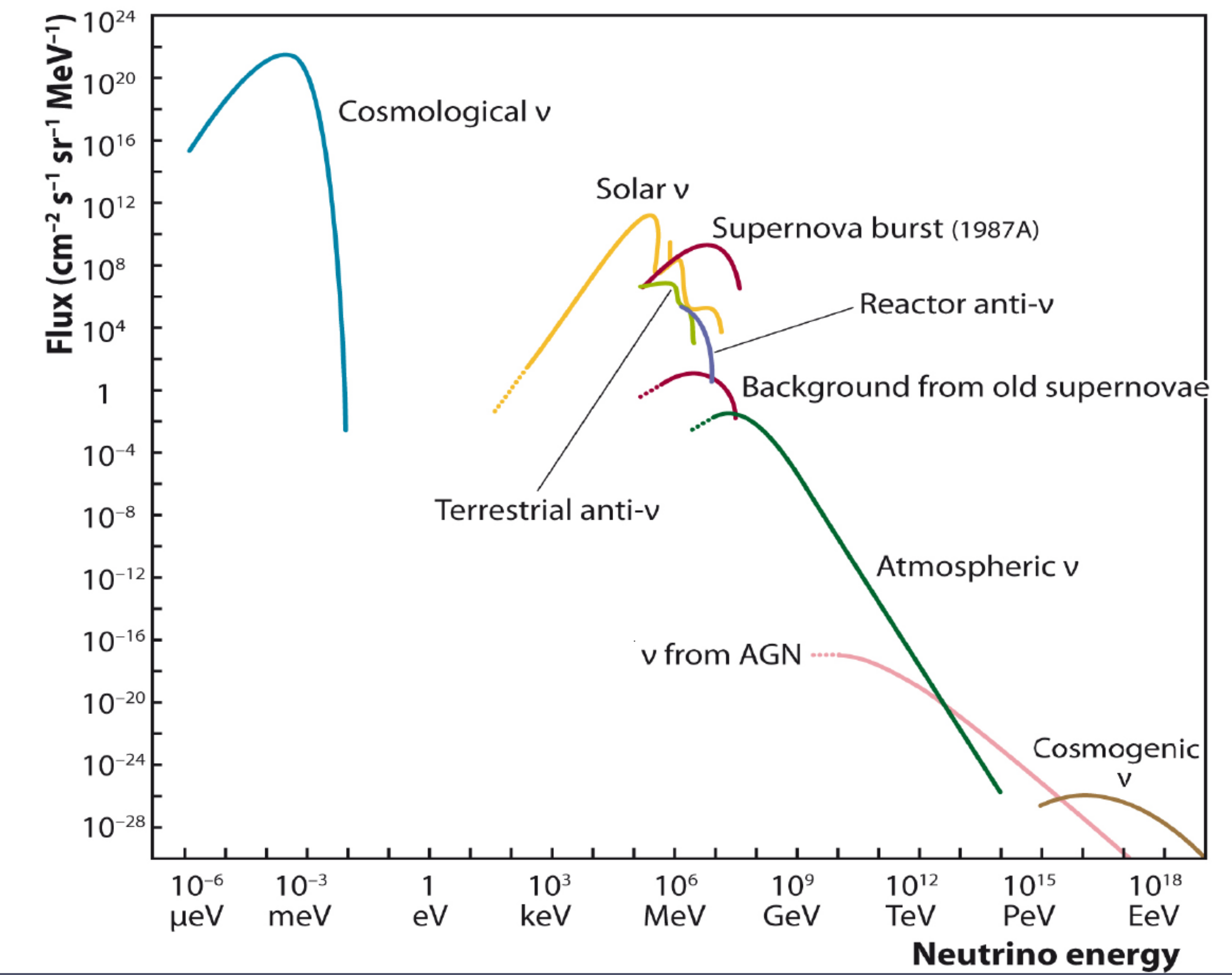
Atmosféricos

100 MeV → 10^{20} GeV

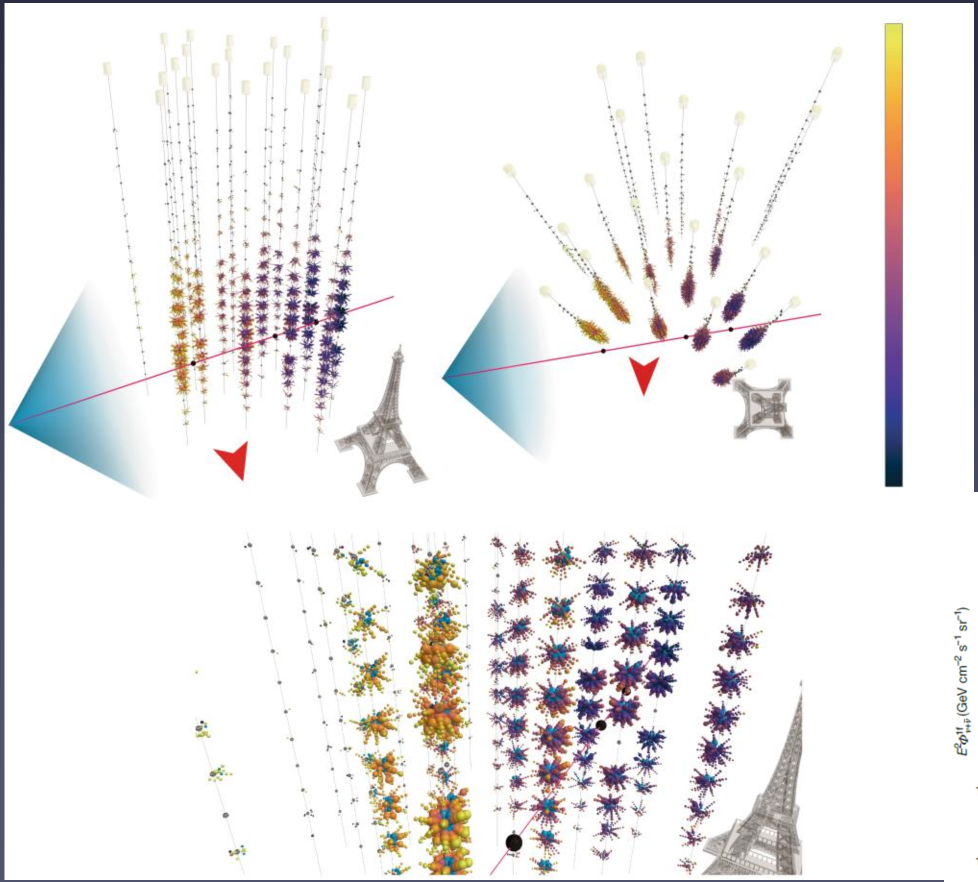
$$^{40}K \rightarrow ^{40}Ca + e^{-} + \bar{\nu}_e$$

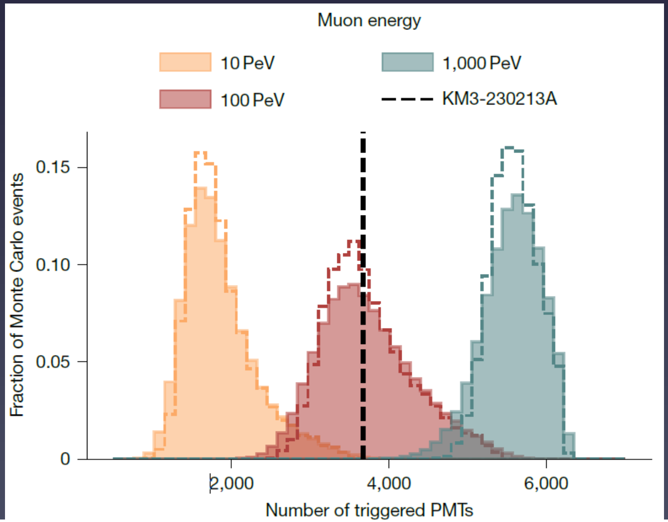
Credit: A.A. Machado

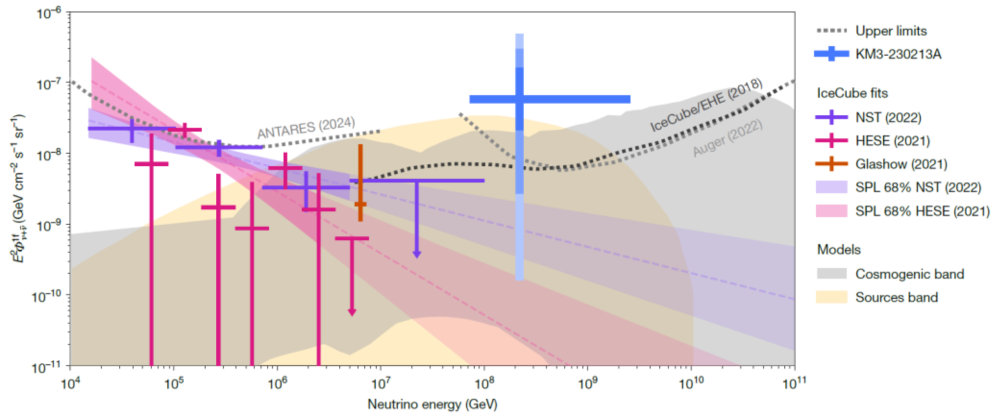
Neutrinos reaching the Earth



>120 PeV neutrino @ KM3net







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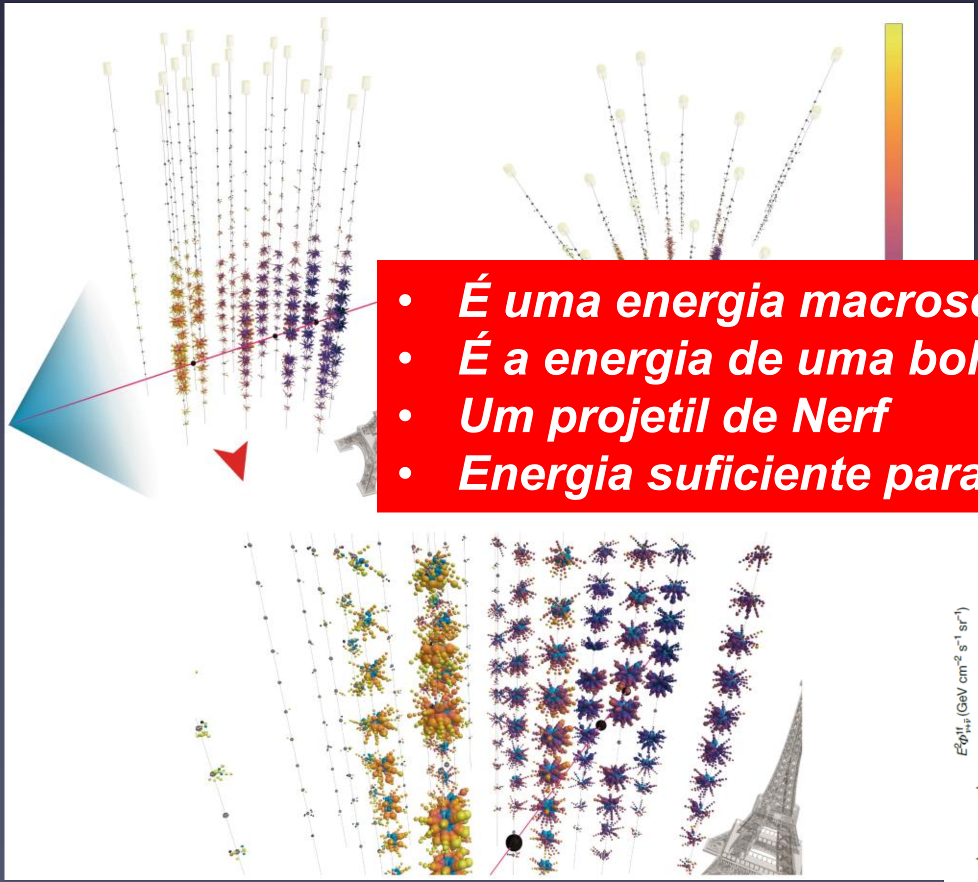
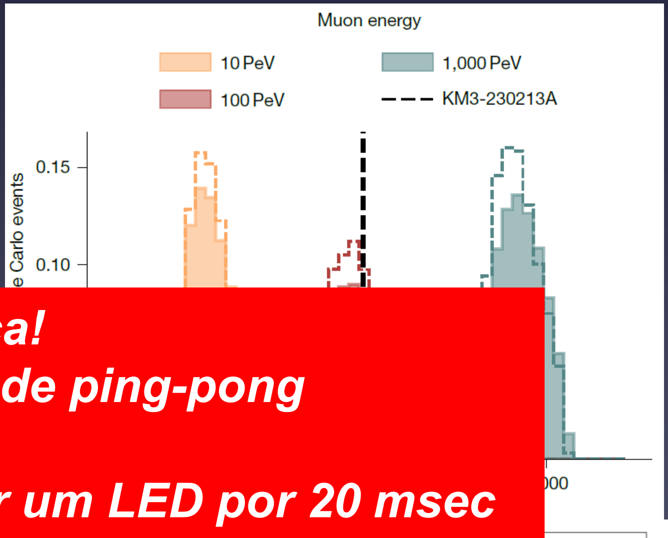
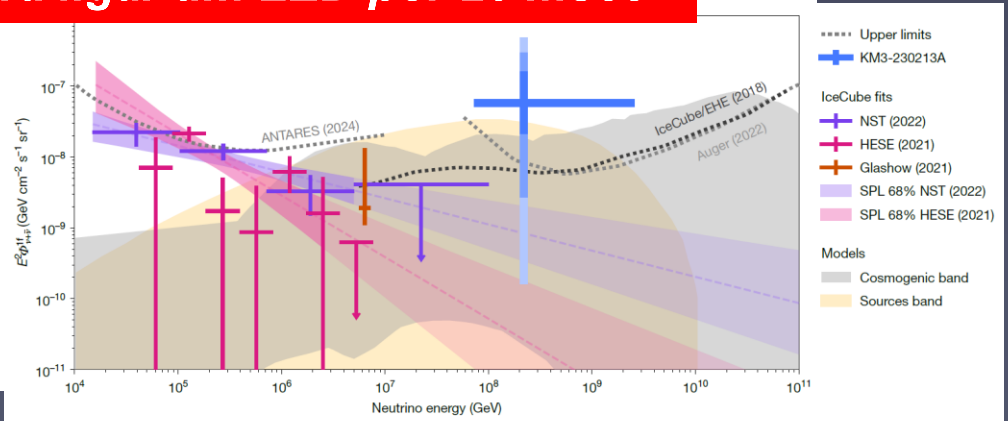




- *É uma energia macroscópica!*
- *É a energia de uma bolinha de ping-pong*
- *Um projetil de Nerf*
- *Energia suficiente para ligar um LED por 20 msec*

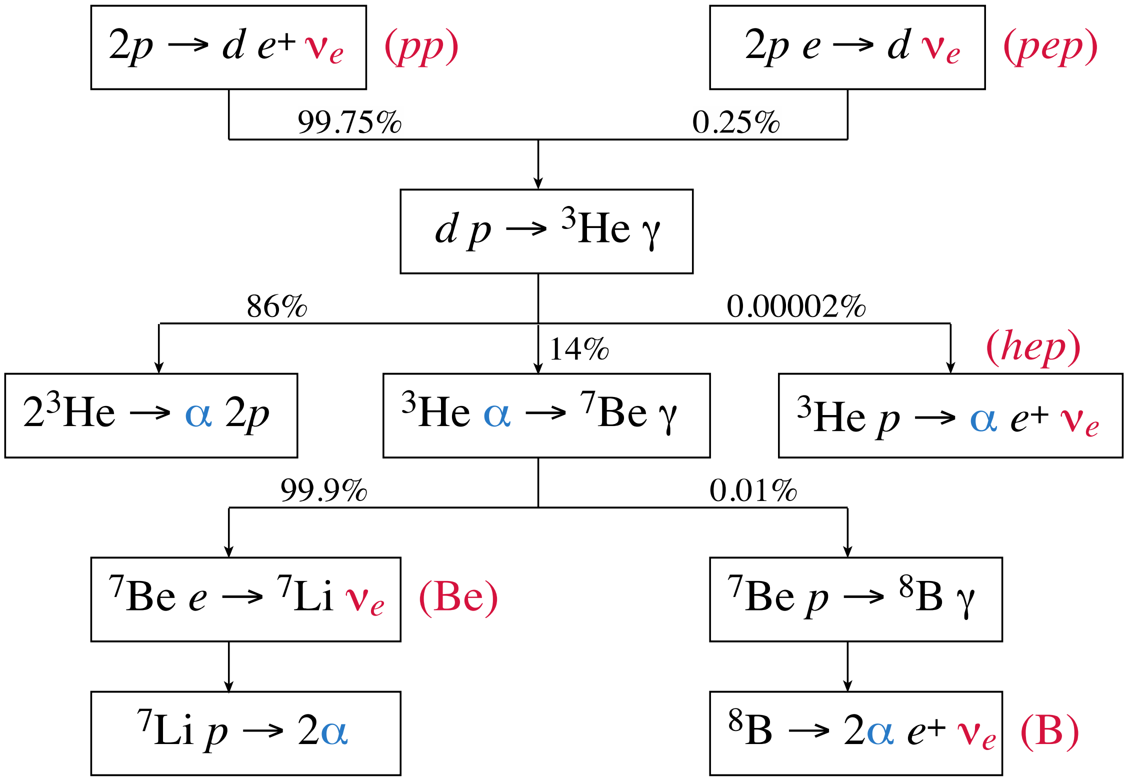


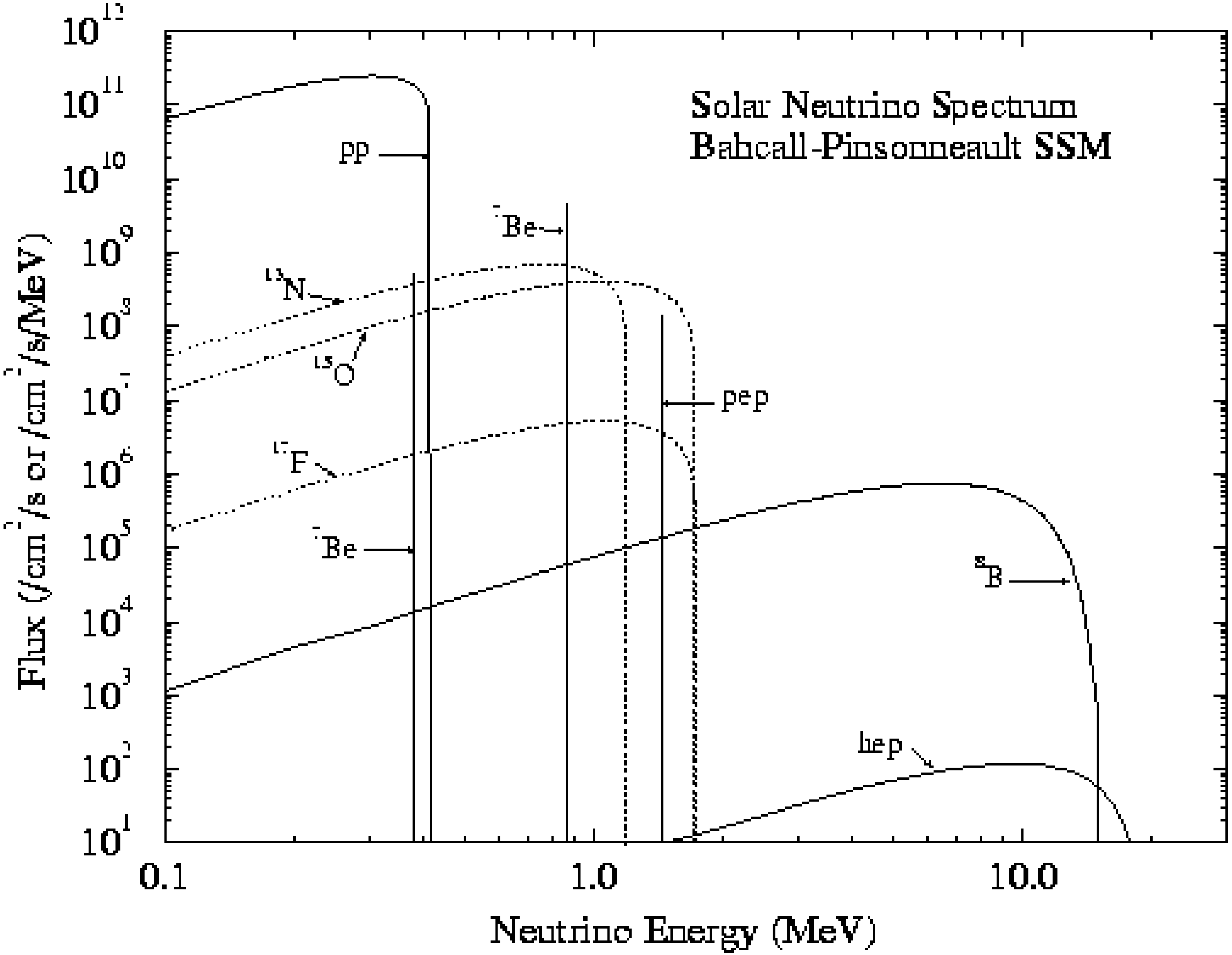
A anomalia do neutrino solar

Neutrinos são produzidos no centro do Sol por meio dessa reações

Carregam informações do estado do coração do Sol e levam 8 minutos para chegarem na Terra

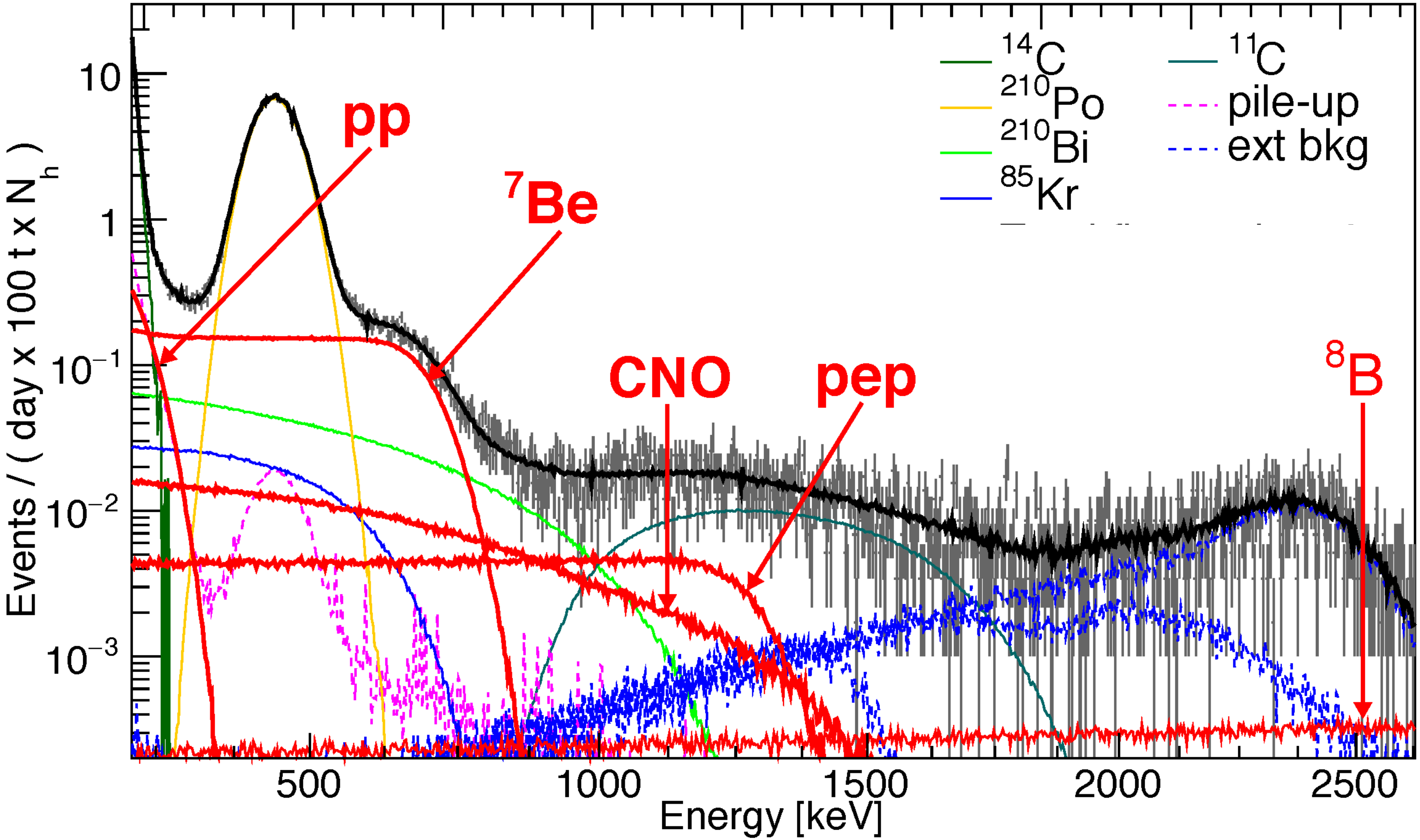
Os fotons levam 10,000 anos para chegar a superficie do Sol!!!





Solar Neutrino Spectrum
Bahcall-Pinsonneault SSM
pp
7Be
13N
15O
pep
17F
7Be
8B
hep
Flux (/cm²/s or /cm²/s/MeV)
Neutrino Energy (MeV)
0.1
1.0
10.0
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1

BOREXINO experiment



A anomalia do neutrino solar

No final dos anos 60 Davis fez um experimento para detectar neutrinos do Sol e se deu conta que eram muito menos que o esperado

Este resultado foi confirmado por muito outros experimentos!!!

Expected signal

Experiment	Reaction	E_{th} (MeV)	ν fluxes	Running time	R^{exp}	R^{BP00}
Homestake	$\nu_e {}^{37}\mathrm{Cl} \to {}^{37}\mathrm{Ar}\ e$	0.814	mainly ^{8}B	1970 – 1994	2.56 ± 0.23	7.6 ± 1.3
SAGE	$\nu_e {}^{71}\mathrm{Ga} \to {}^{71}\mathrm{Ge}\ e$	0.233	all	1990 – 2003	69.1 ± 5.7	128 ± 9
GALLEX				1991 – 1997	77.5 ± 7.7	
GNO				1998 – 2003	62.9 ± 5.9	
Borexino	$\nu e \to \nu e$	0.862	^{7}Be	2007 – 2008	49 ± 5	74 ± 4
		3.0	^{8}B, *hep*	2007 – 2009	2.4 ± 0.4	5.05 ± 0.9
Kamiokande		6.75		1987 – 1995	2.80 ± 0.36	
SK		4.75		1996 – 2001	2.35 ± 0.06	
SNO		5.2		1999 – 2003	2.31 ± 0.21	
	$\nu_e d \to ppe$	6.9			1.67 ± 0.08	
	$\nu d \to pn\nu$	2.2			5.17 ± 0.38	

Experimental value

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R. Davis Jr recebe o Premio Nobel em 2002

Experimental value

A anomlia do neutrino atmosferico

- A Terra é constantemente atingida por raios cosmicos (principalmente protons e He)
- As interações de raios cosmicos produzem Pions (e alguns Kaons)
- Os pions carregados decaem produzindo muons e neutrinos

$$\pi^+ \rightarrow \mu^+ \nu_\mu \qquad \pi^- \rightarrow \mu^- \bar{\nu}_\mu$$

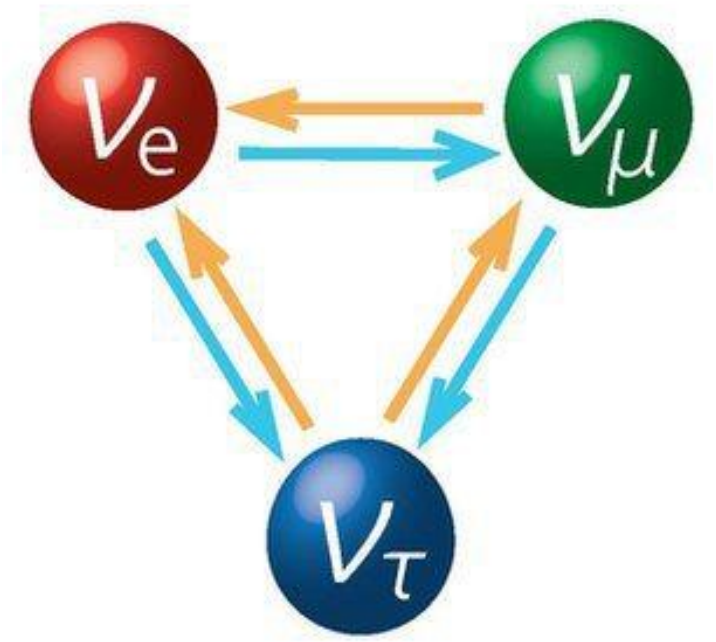
- Os muons decaem produzindo electrons e neutrinos:

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu \qquad \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

- Seria esperado detectar, em media, dois neutrino μ cada neutrino e. Entretanto a razão é 1!!!

...e agora????

Oscillações de neutrinos



- ***Os tres neutrinos tem uma massa muito pequena, mas não zero como previsto do Modelo Padrão das Particulas***

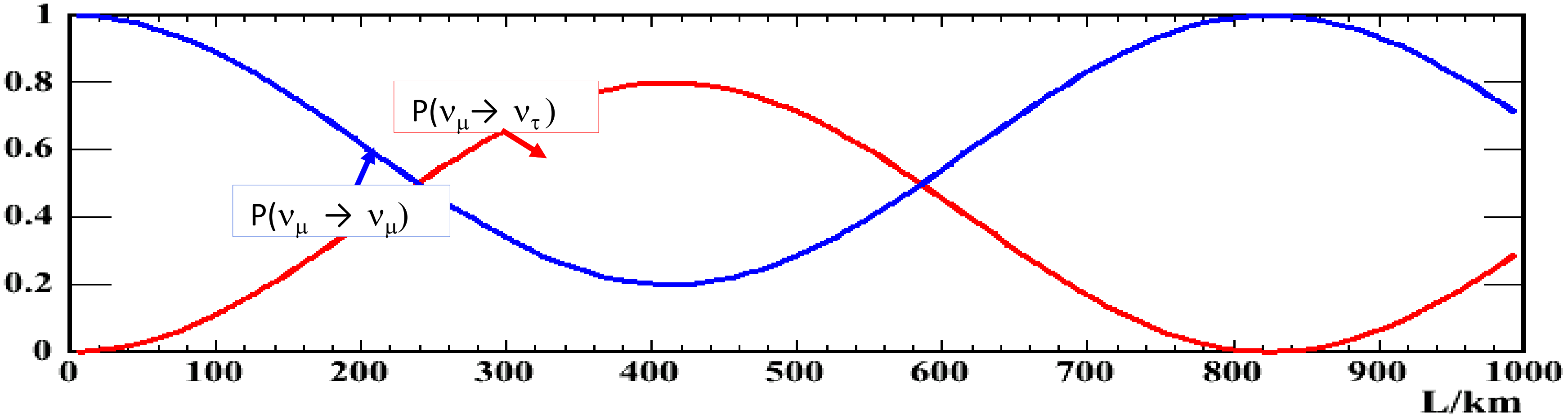
- ***Esta circumstancia permite aos neutrinos de oscillar***

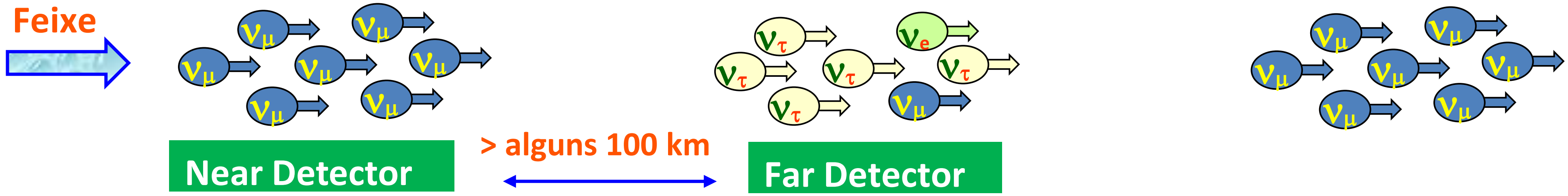
- ***Neutrinos produzidos como, por exemplo, neutrinos ν_μ podem ser detectados como neutrinos ν_e***

Oscilações Neutrinos

- **a probabilidade de oscilação**

$$P(\nu_\mu \to \nu_\tau) = \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2[\mathrm{eV}^2]L[\mathrm{km}]}{E_\nu[\mathrm{GeV}]}\right)$$





Credits : Mark Thomson

Oscilações Neutrinos

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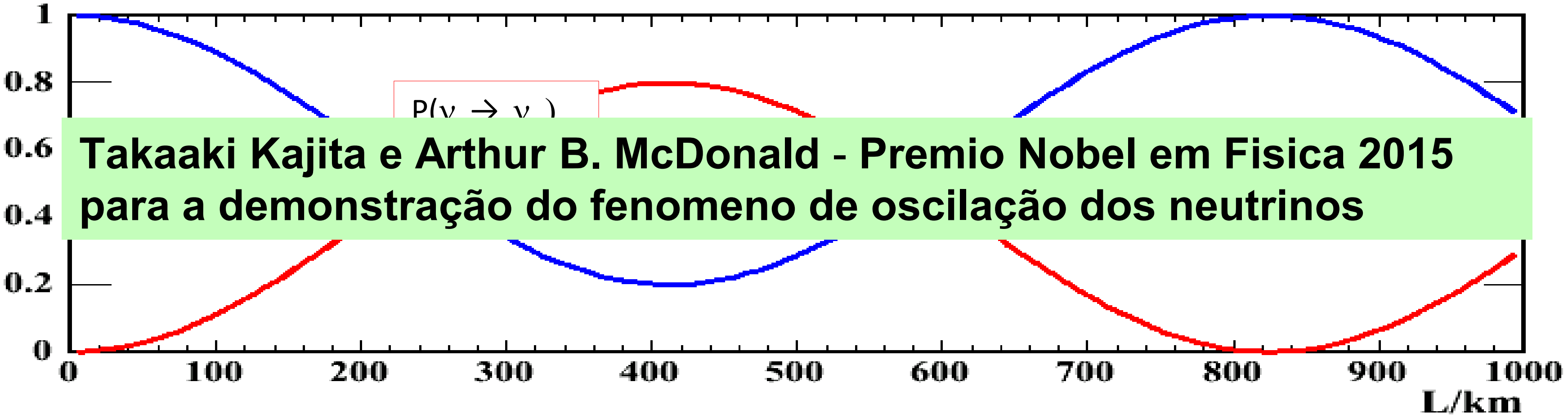
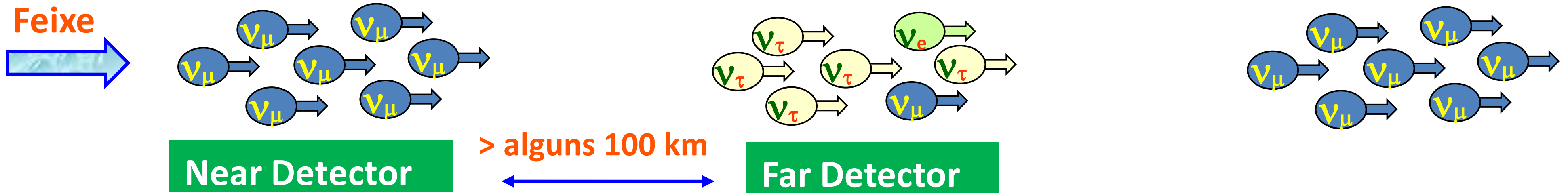


Takaaki Kajita e Arthur B. McDonald - Premio Nobel em Fisica 2015 para a demonstração do fenomeno de oscilação dos neutrinos



Credits : Mark Thomson

NEUTRINO 2024

As of today: Oscillation of 3 massive active neutrinos is clearly the dominant effect:

If neutrinos have mass: $|\nu_l\rangle = \sum U_{li} |\nu_i\rangle$

For 3 Active neutrinos.

Flavor (e, μ, τ)

Mass 1,2.3

Pontecorvo-Maki-Nakagawa-Sakata matrix

$$U_{li} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

(Double β decay only)

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{-i\alpha_2/2} & 0 \\ 0 & 0 & e^{-i\alpha_3/2+i\delta} \end{pmatrix}$$

? ✓ ✓ ✓ ?

Atmospheric, Accel. | CP Violating Phase | Reactor, Accel. | Solar,Reactor | Majorana CP Phases

where $c_{ij} = \cos\theta_{ij}$, and $s_{ij} = \sin\theta_{ij}$

Range defined for Δm_{12}, Δm_{23} ✓

For two neutrino oscillation in a vacuum: (a valid approximation in many cases)

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

MSW

Interactions with high electron density can influence the process in the sun and the earth

From A. McDonald talk at Neutrino 2024

SUMMARY OF OSCILLATION RESULTS FOR THREE ACTIVE ν TYPES

Particle Data Group

$\sin^2(\theta_{12}) = 0.307 \pm 0.013$

$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}\ \mathrm{eV}^2$

Solar, Reactor

$\sin^2(\theta_{23}) = 0.539 \pm 0.022 \quad (S = 1.1) \quad$ (Inverted order)

$\sin^2(\theta_{23}) = 0.546 \pm 0.021 \quad$ (Normal order)

$\Delta m^2_{32} = (-2.536 \pm 0.034) \times 10^{-3}\ \mathrm{eV}^2 \quad$ (Inverted order)

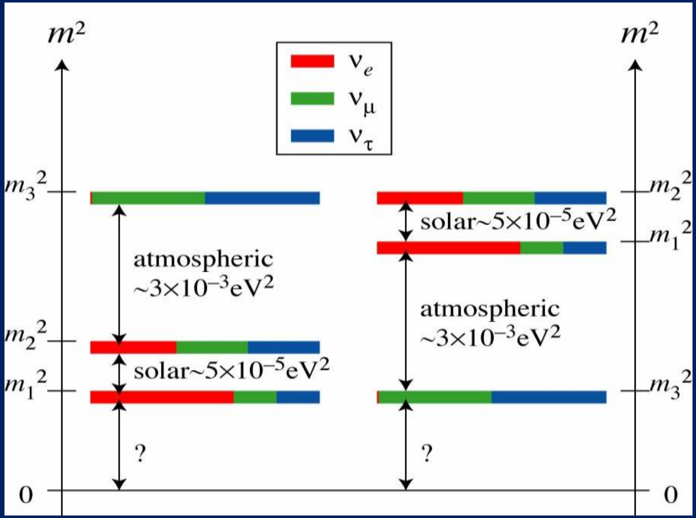
$\Delta m^2_{32} = (2.453 \pm 0.033) \times 10^{-3}\ \mathrm{eV}^2 \quad$ (Normal order)

Atmospheric,Accelerator

$\sin^2(\theta_{13}) = (2.20 \pm 0.07) \times 10^{-2}$

Reactor, Accelerator

Mass Hierarchies



Normal Inverted

Future objectives:

- δ_{CP}
- θ_{23} max?
- Hierarchy?
- Majorana ν?
- Absolute mass
- Sterile ν?

Accelerator,Reactor, Atmospheric

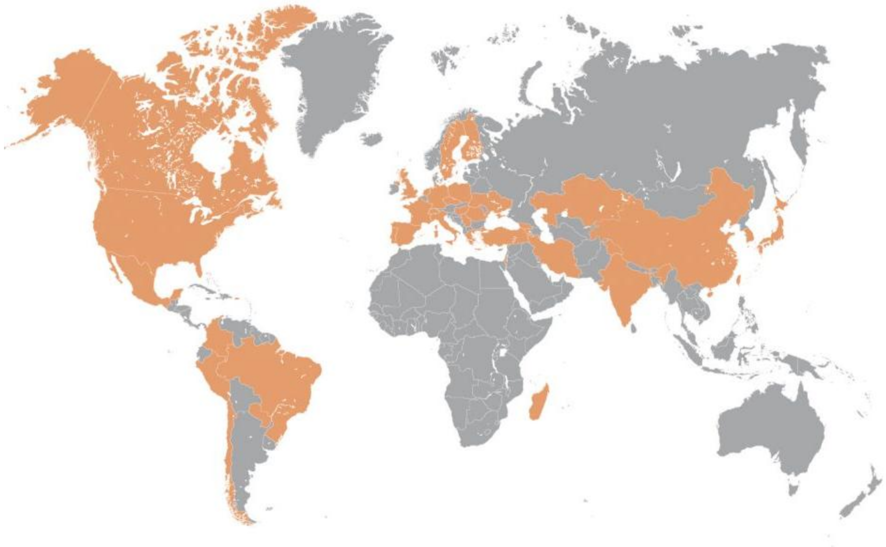
$0\nu\beta\beta$, Cosmology, Electron spectrometers,

Accelerator,Reactor, Atmospheric

A. McDonald

DUNE Collaboration

March 2025



Countries → 39

Members → 1760

Latin America → 85 +

Institutions → 249

Latin America → 28 +

DUNE: scientific program

Fundamental questions still open in particle and astroparticle physics:

Physics of neutrino oscillation:

- ✓ CP violation in the lepton sector (related to matter-antimatter asymmetry)
- ✓ Mass hierarchy
- ✓ Precision oscillation physics to test the 3-flavor paradigm

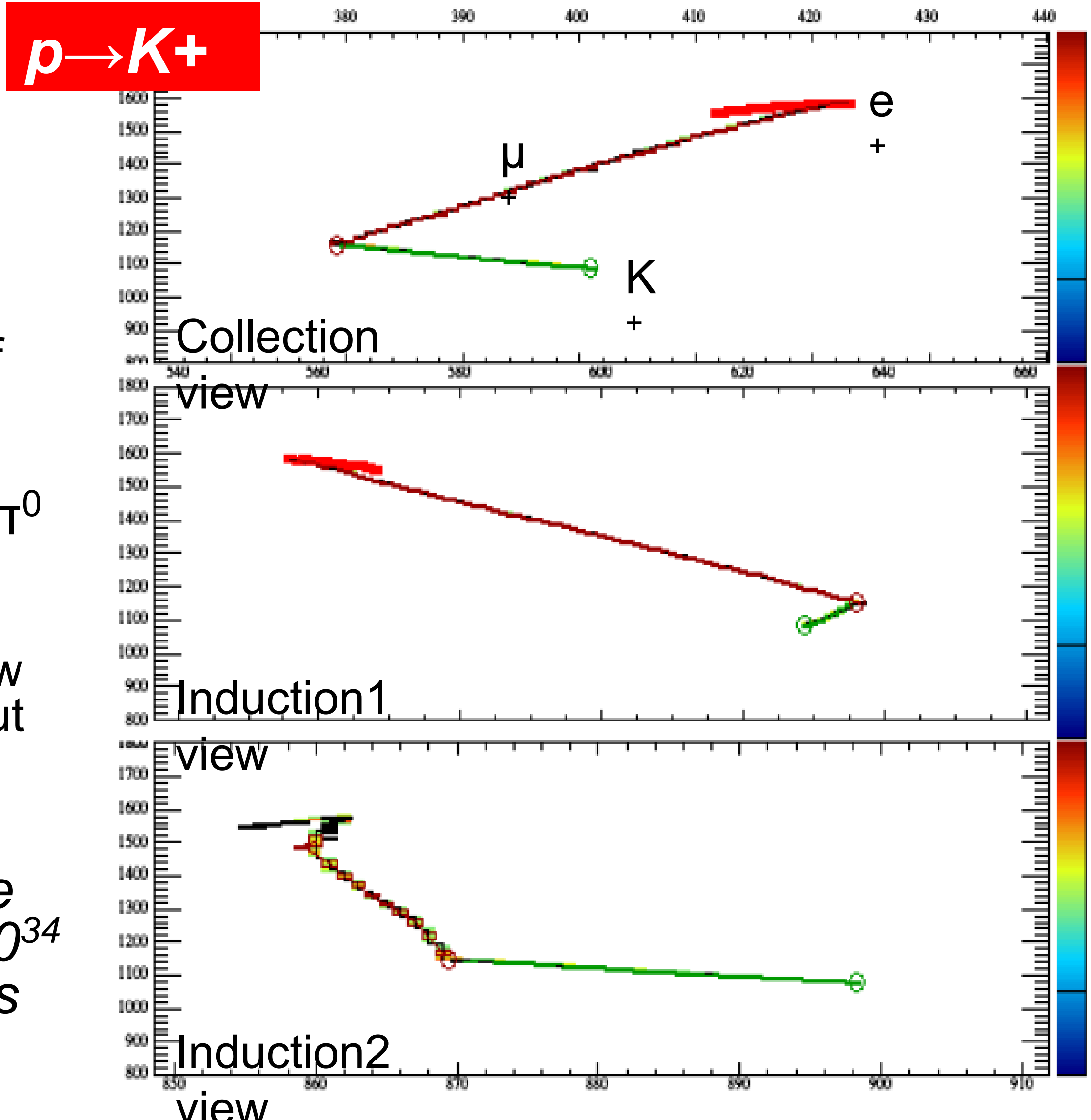
Nucleon decay

- ✓ Predicted beyond Standard Model theories [but not yet seen]
- ✓ for example, the favored mode of SUSY models: $p \to K^+ \overline{\nu}$

Physics and astrophysics of supernova explosion

Proton Decay

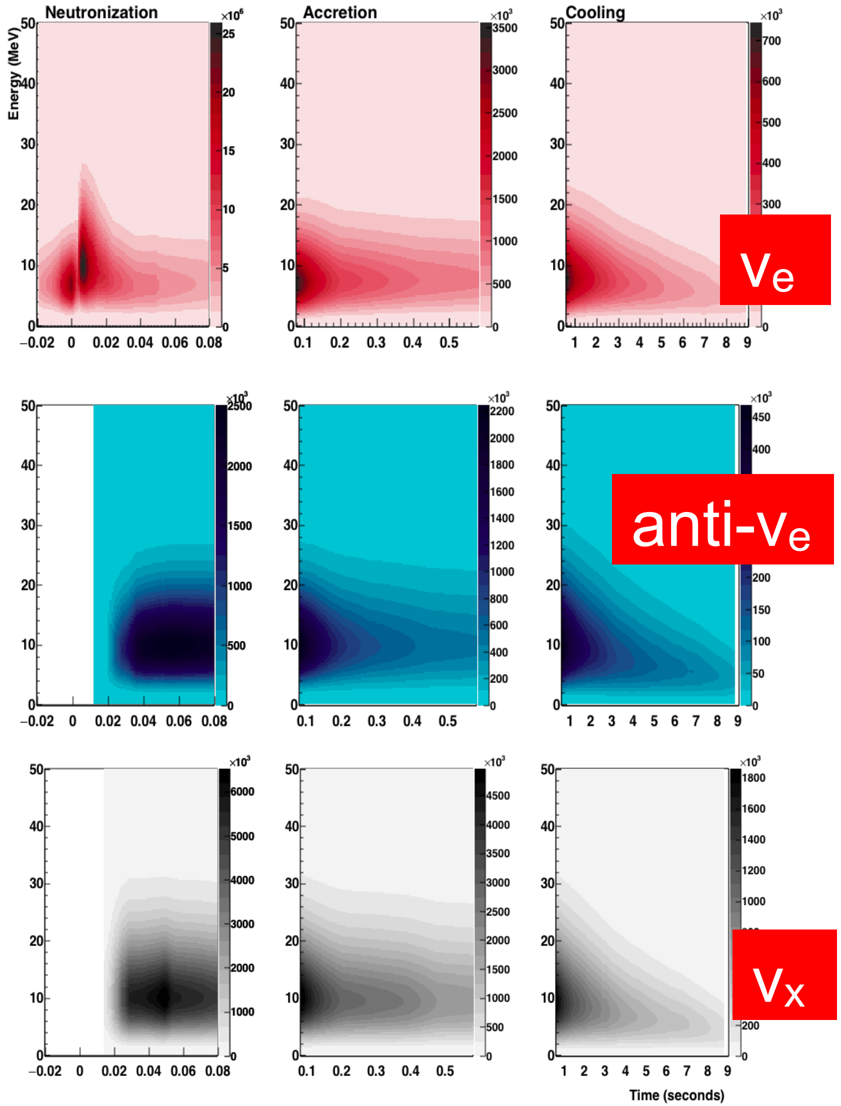
- The DUNE FD will be highly sensitive ***to several possible nucleon decay modes*** complementing the capabilities of *large water detectors*
- GUT models present two benchmark decay modes, $p \rightarrow e^{+}\pi^{0}$ and ***p→K+v*** *(dominant in most SUSY models)*
  - In p→K+v =>kaon is typically below Cherenkov threshold in a water, but easily identified by its distinctive dE/dx signature in a LarTPC
- *A lower limit on the proton lifetime in the p→K+v channel of 1.3 × 10^{34} years can be reached in ten years*



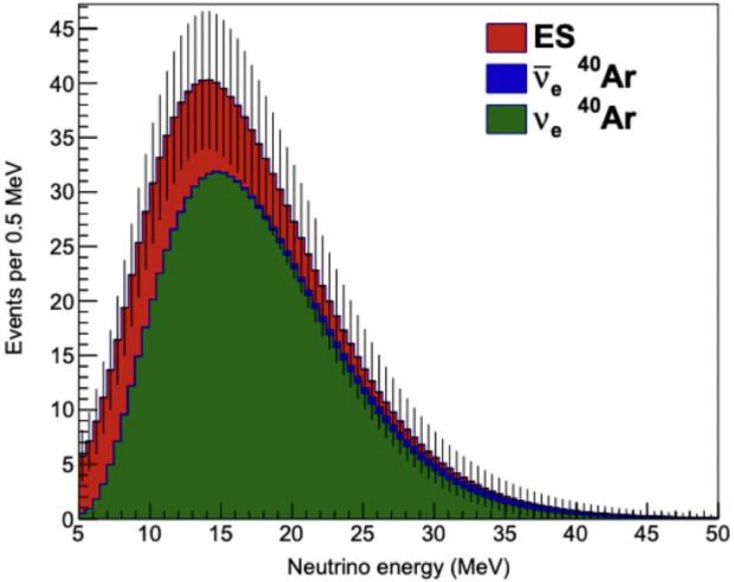
SuperNova neutrinos

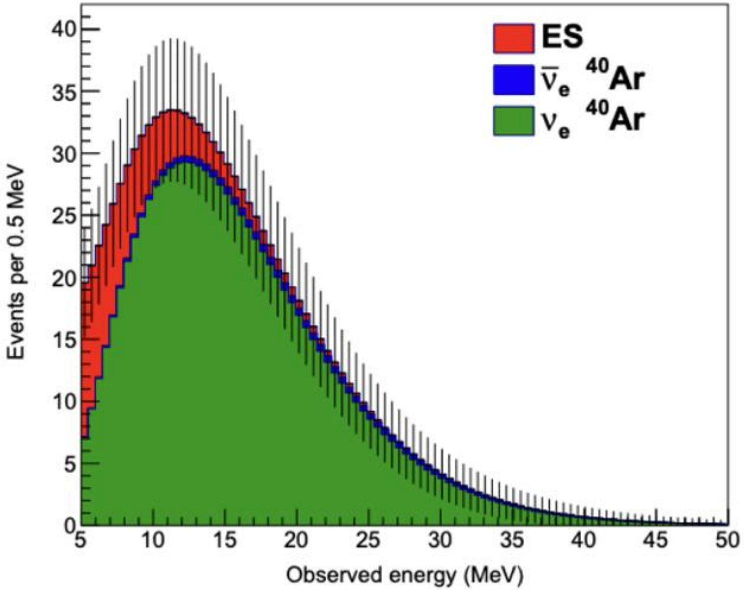
- DUNE Far Detector will be sensitive to neutrinos from *around 5 MeV to a few tens of MeV* => CC interactions of neutrinos in this range create ***few cm electron tracks in liquid argon***
- DUNE is primarily sensitive to ν_e => *unique capability among existing and proposed supernova neutrino* (tipically sensitive to anti-ν_e through IBD)
  - $\nu^{e}+{}^{40}Ar\rightarrow e^{-}+{}^{40}K^{*}$

- ***Possibility to observe the peak of neutronization***



Expected Supernova burst signal





40 kton LAr & 10 kpc SN
"Garching model"
Computed with SNOwGLoBES

Channel	Garching
$\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^*$	882
$\bar{\nu}_e + ^{40}\text{Ar} \rightarrow e^+ + ^{40}\text{Cl}^*$	23
$\nu_X + e^- \rightarrow \nu_X + e^-$	142
Total	1047

EPJC 81 (2021) 423

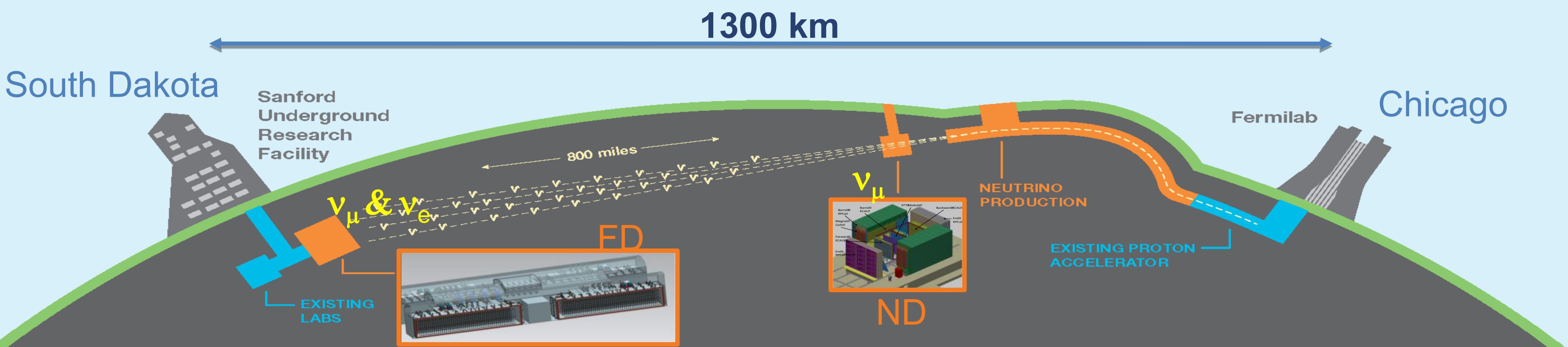
DUNE – Deep Underground Neutrino Experiment

O **DUNE** consiste de:

1. Um intenso feixe **(MW)** de neutrinos produzido no Fermilab.
2. Um detector próximo ao feixe – Fermilab
3. Detector subterrâneo de **(70,000 t)** de massa - SURF, South Dakota

   (4 modulos de 10kton de massa ativa cada; single phase e dual phase)

1. Uma grande **colaboração internacional** (mais de **1000** pesquisadores em mais de **32** países)

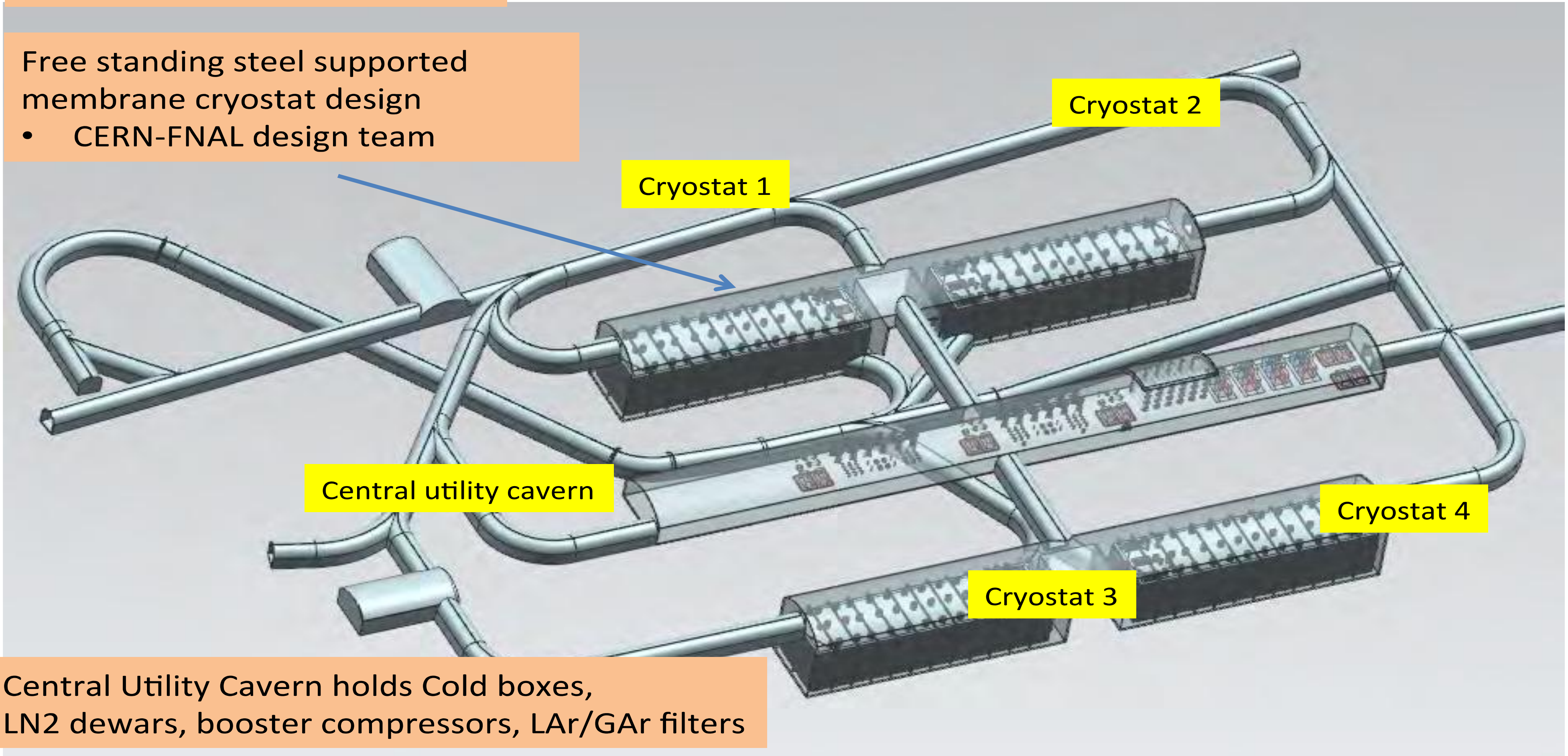


Far Detector – Cryostat / Cryogenic Systems Layout

Each Cryostat holds 17.1kt LAr

Free standing steel supported membrane cryostat design

- CERN-FNAL design team



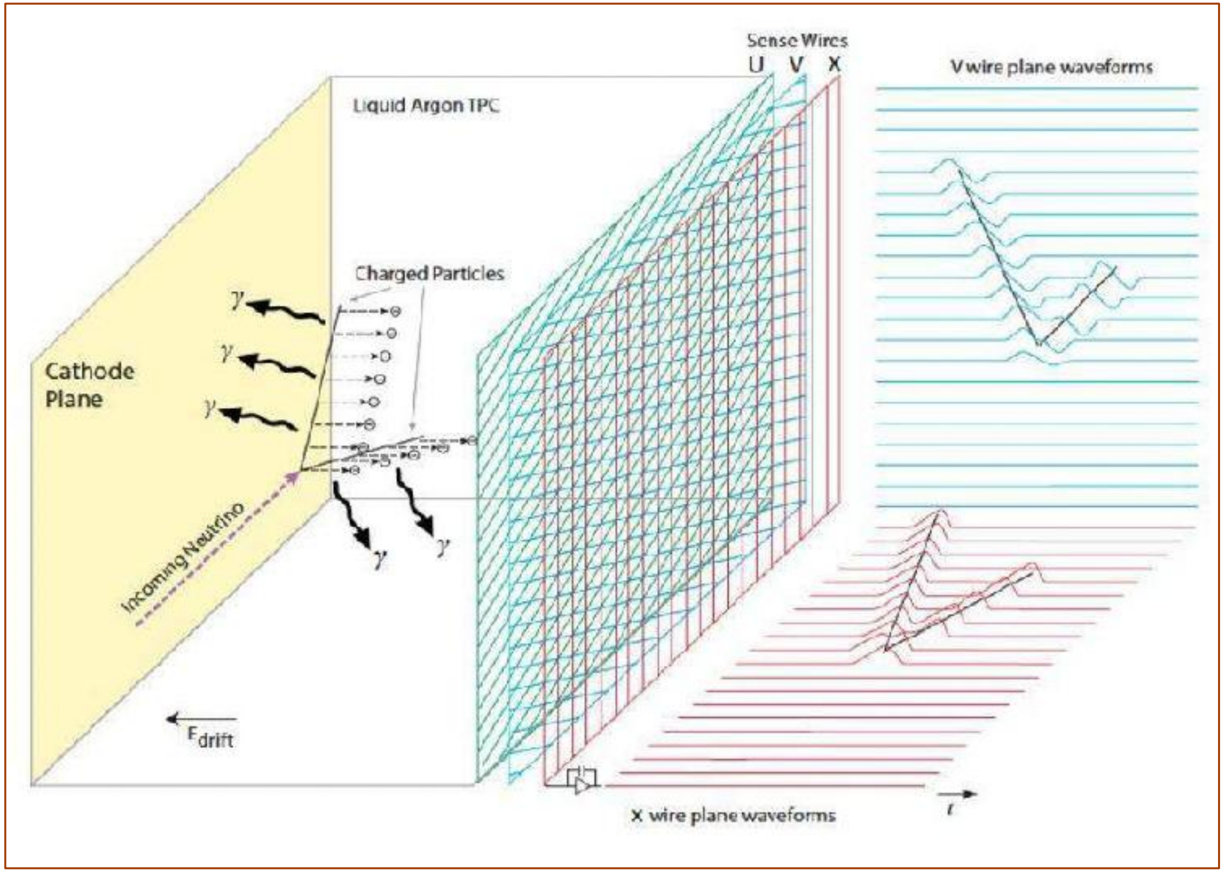
Central Utility Cavern holds Cold boxes,
LN2 dewars, booster compressors, LAr/GAr filters

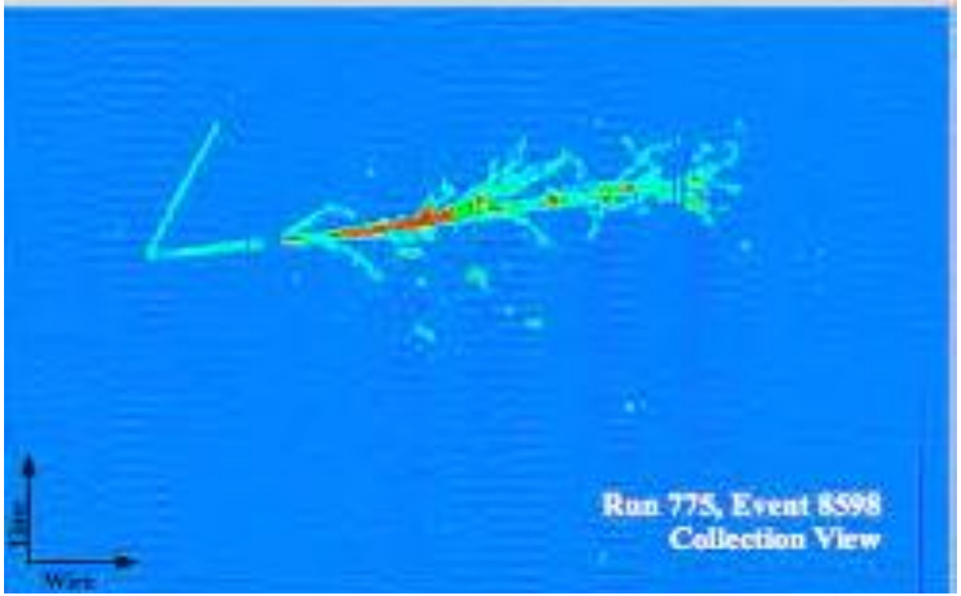
Construindo DUNE

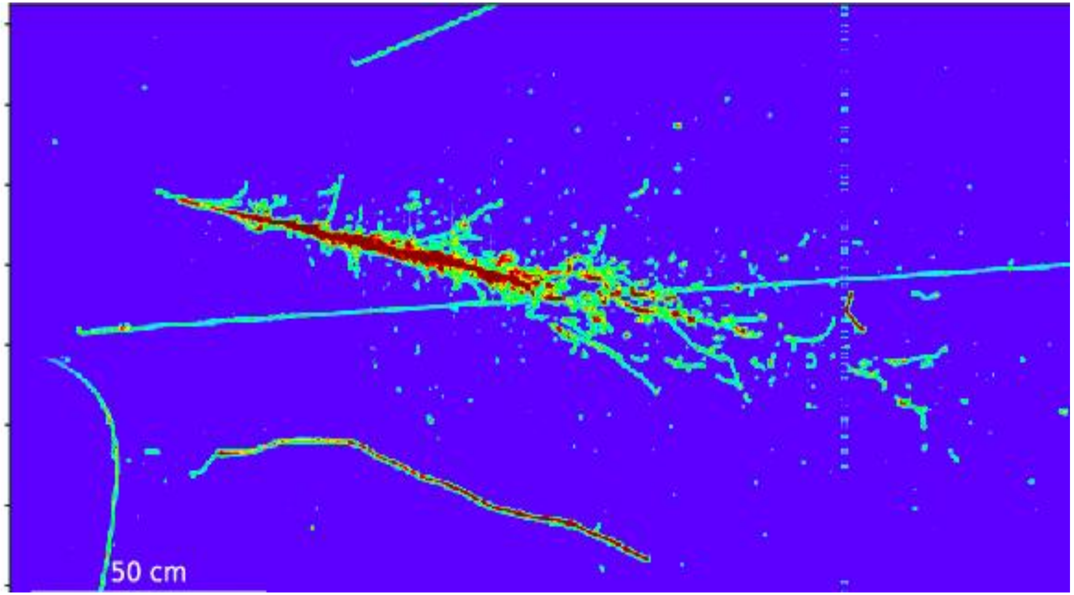
- Cavernas prontas!
- Infraestrutura pronta no começo do 2026
- Criostato a caminho… Instalação 2026
- Detectores começam instalar em 2026-2027
- Aragon liquido em 2028
- Fisica com raios cósmicos em 2029
- Fisica com feixe de neutrinos em 2031

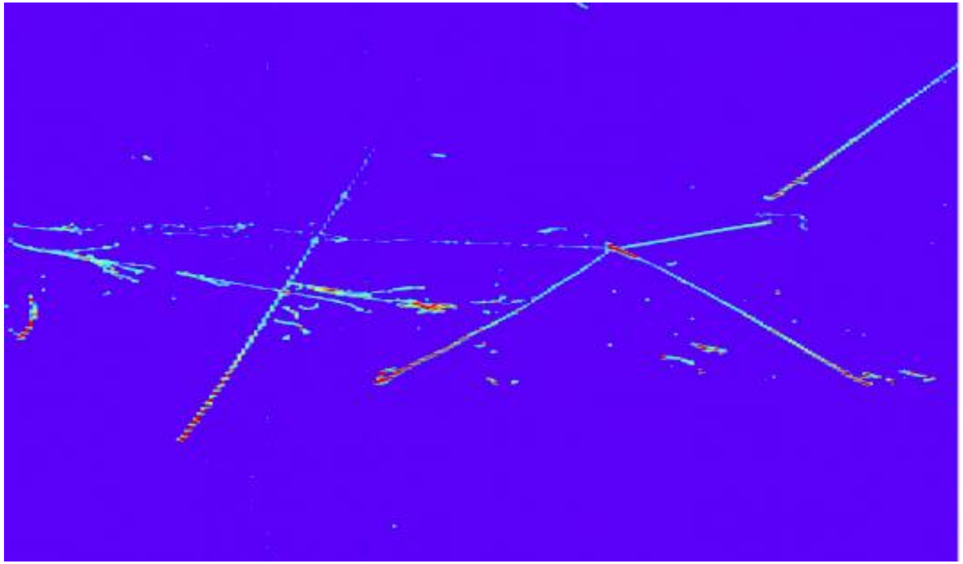
Liquid argon Time Projection Chamber

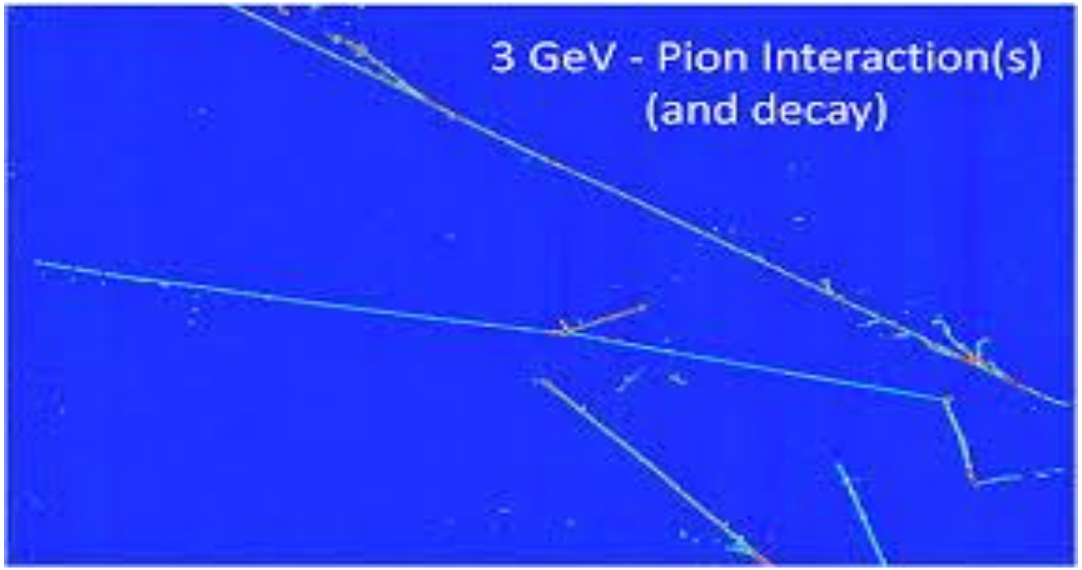
Partículas carregadas em LAr produzem elétrons de ionização livres e luz de cintilação (128 nm)	
Os elétrons de ionização derivam em um campo elétrico intenso e uniforme (~500 V/cm) em direção aos planos de fio de leitura ⬇ Reconstrução 3D + Medidas Calorimétricas	Os fótons VUV se propagam e são transformados em fótons VIS ⬇ Determinação t_0 + Medidas Calorimétricas



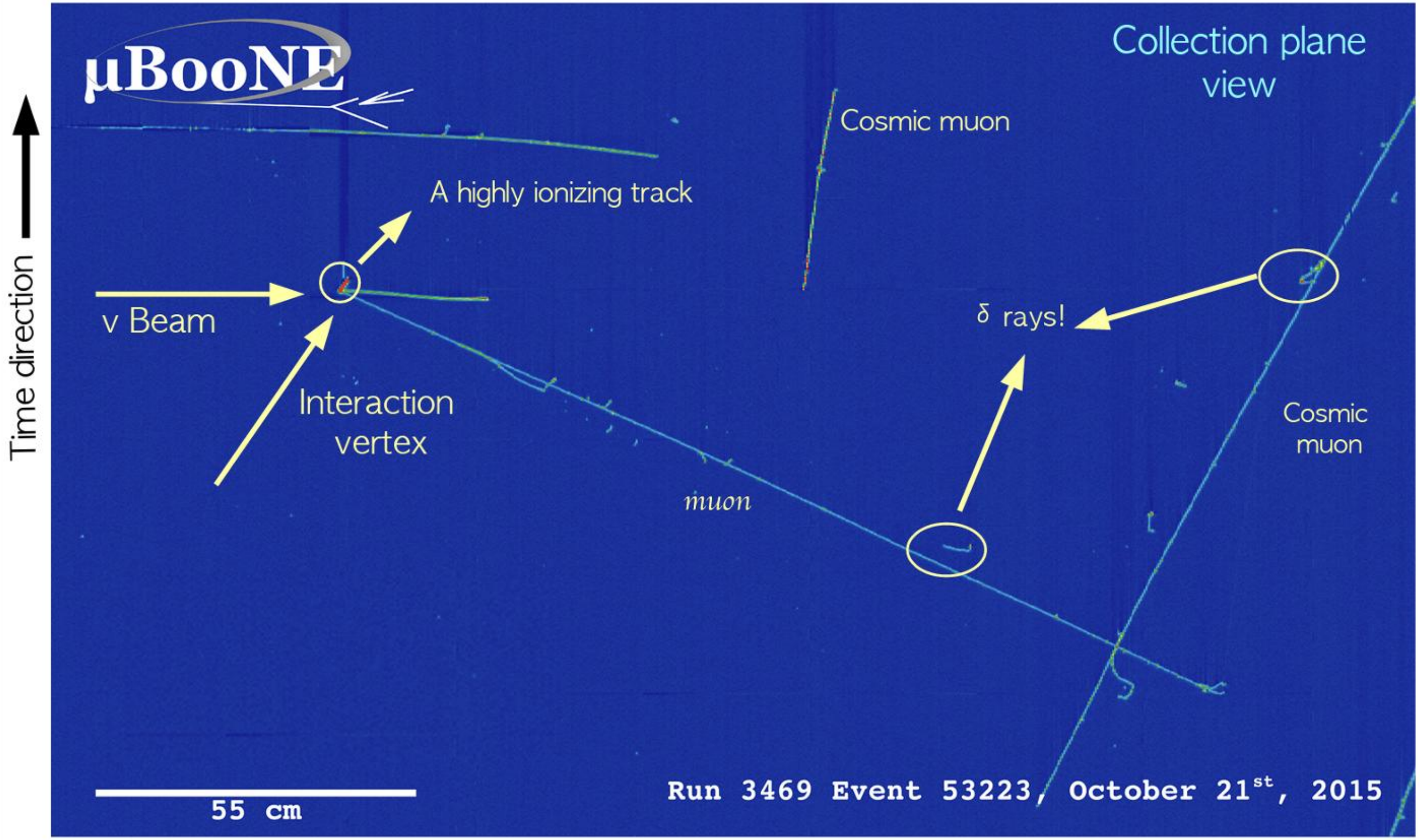

Run 775, Event 8598
Collection View
Wire


50 cm



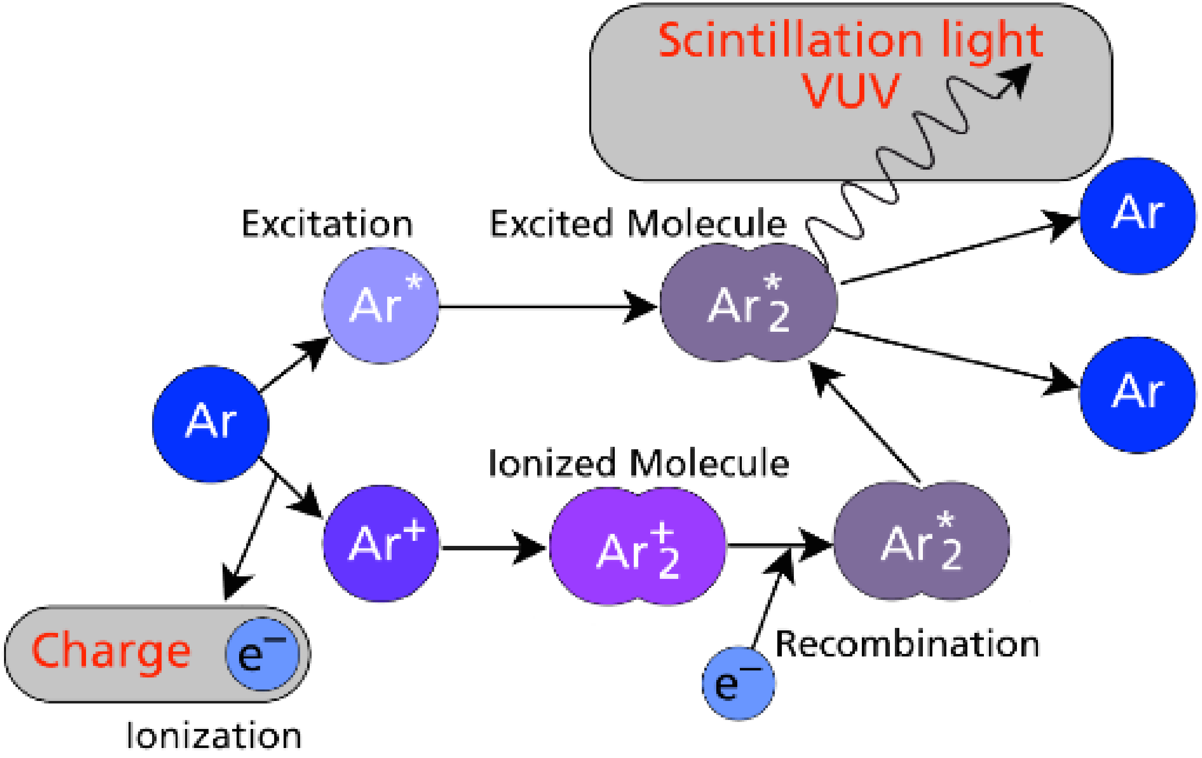

3 GeV - Pion Interaction(s)
(and decay)

Neutrino interaction



Slide: Sowjanya Gollapinni

A Luz dos neutrinos



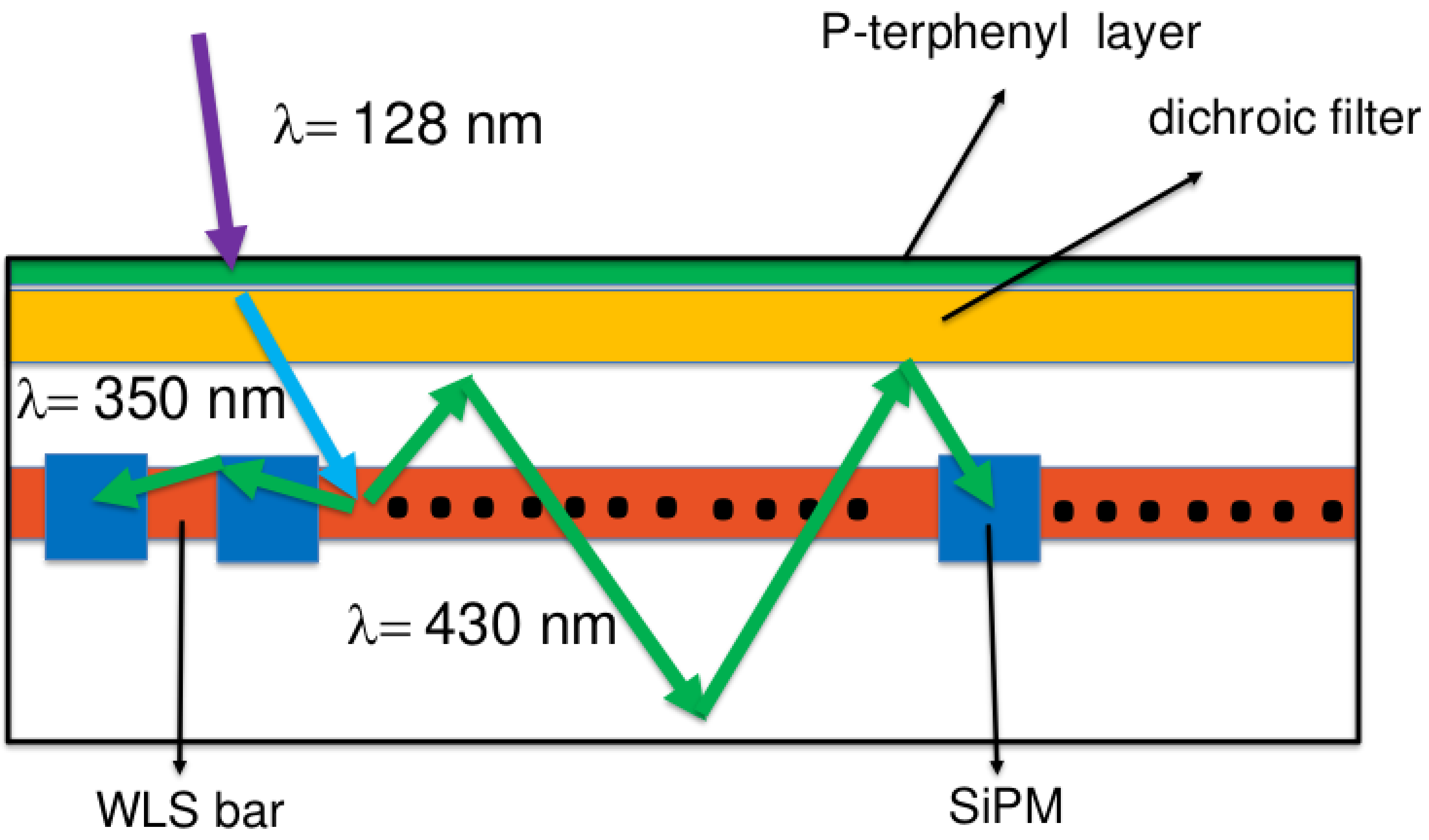
Em cada interação é produzida uma grande quantidade de luz

Detectar esta luz é muito importante e nos da inforamções sobre a energia, tipo particula que intergiu e tempo exato da interação

Nos (braileiros e latino americanos) tivemos a ideia de capturar esta luz em uma armadilha para detectala com mais facilidade e eficiencia

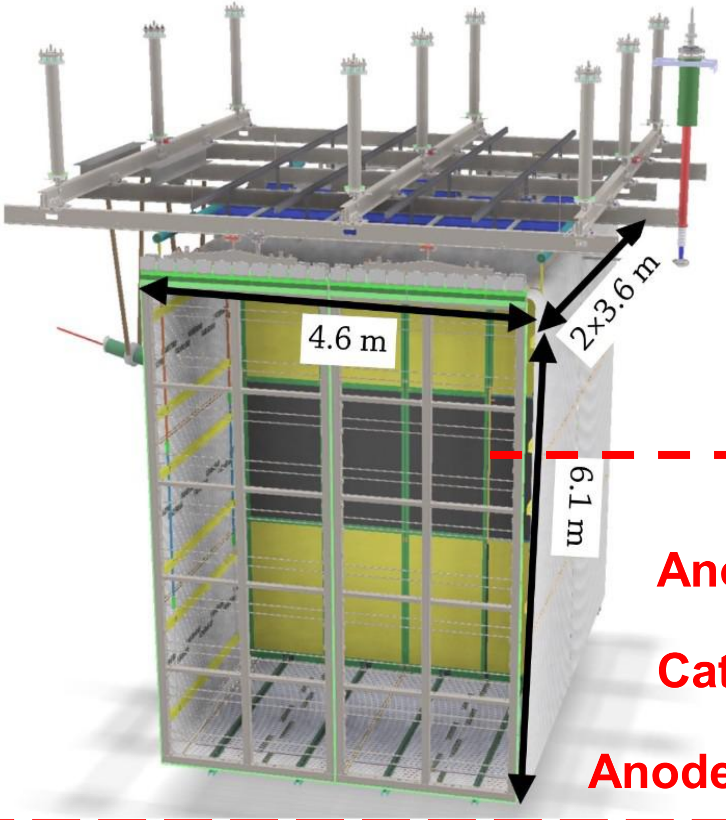
ARAPUCA para neutrinos!

ARAPUCA!



P-terphenyl layer
λ= 128 nm
dichroic filter
λ= 350 nm
λ= 430 nm
WLS bar
SiPM

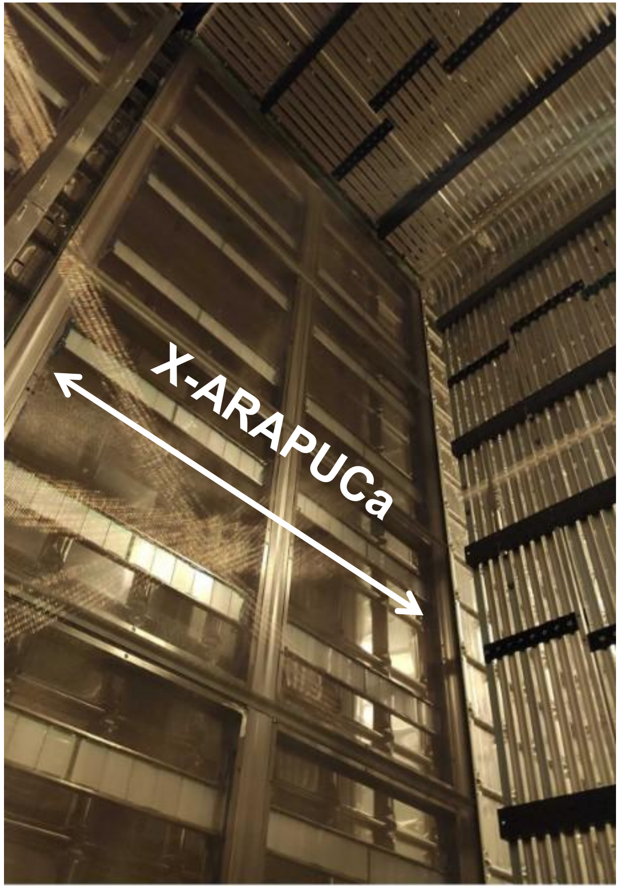
ProtoDUNE-HD no CERN



Anode

Cathode

Anode



40 modulos de X-ARAPUCAs 200 x 10 cm^2
Pre-montados no Laboratorio de Leptons@UNICAMP

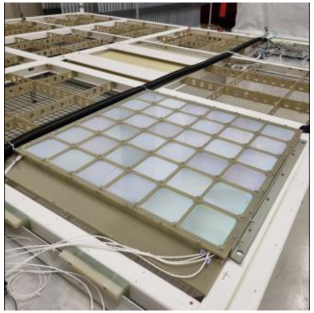
X-APRAUCA em protoDUNE

2024/2025

ProtoDUNE HD está em fase de análise de dados

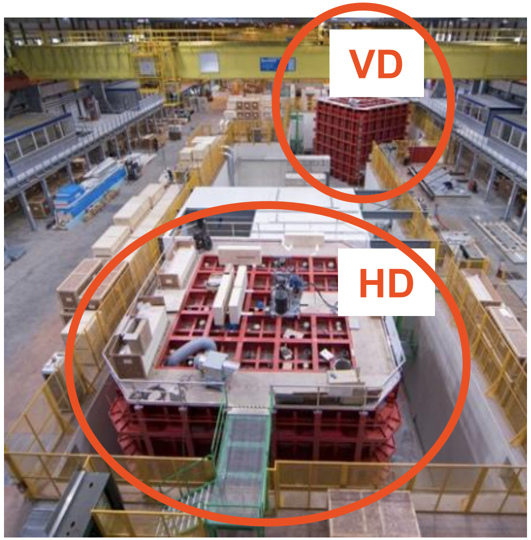
- Foram instalados 40 módulos de X-ARAPUCA em 4 APA, cada modulo e composto por 4 super células no ProtoDUNE HD.
- SiPM (Hamamatsu e FBK)
- Barras guias de luz (Eljen e Glass2Power).
- Todos os filtros OPTO

Courtesy A. Machado

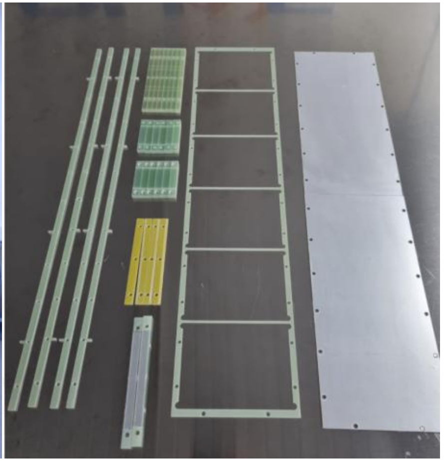


ProtoDUNE VD esta em fase de comissionamento

- X-ARAPUCA Megacell instaladas no catodo e na membrana.
- SiPM (Hamamatsu e FBK)
- Barras guias de luz (Glass2Power).
- Filtros: ZAOT e Photon Export

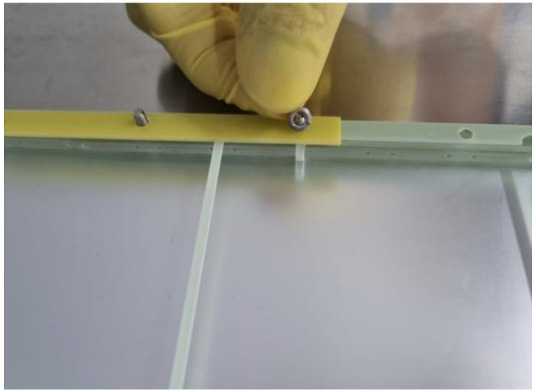


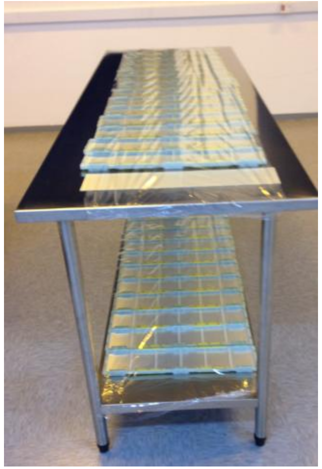
Todos os filtros das X-ARAPUCAs de ambos os protótipos foram evaporados no Laboratório de Léptons na UNICAMP

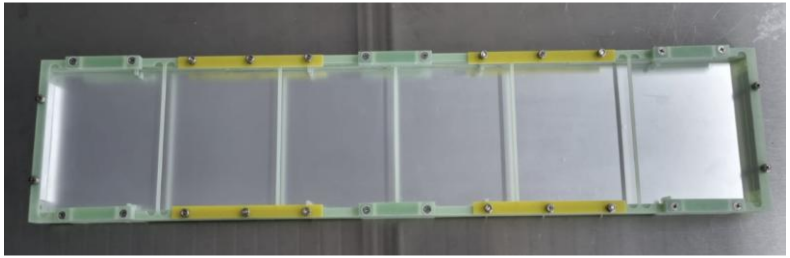


DEEP UNDERGROUND
NEUTRINO EXPERIMENT

200 supercelulas foram produzidas no Brasil e pre-montadas na UNICAMP





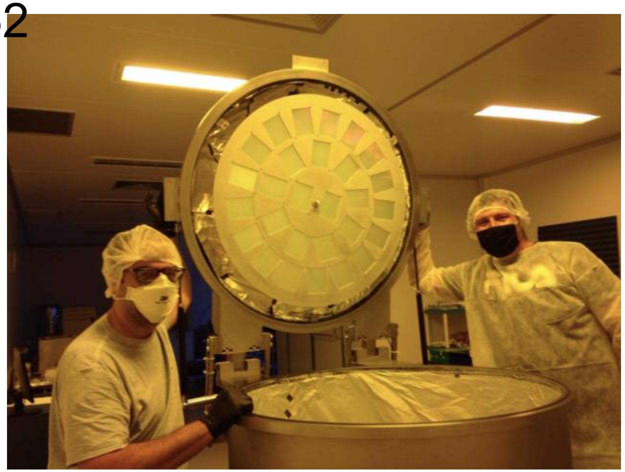


Courtesy A. Machado

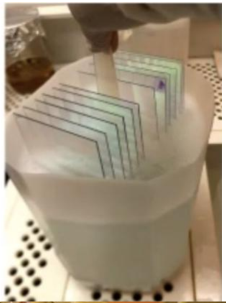
UNICAMP

LAB. LEPTONS

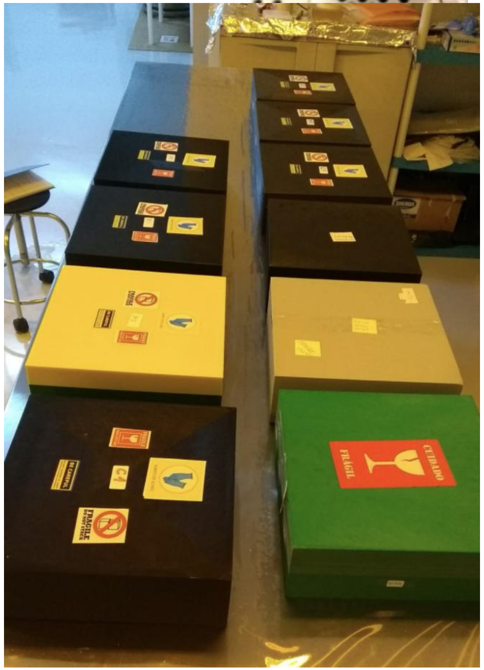
IF GW Eletrônica Quântica



LAB. LEPTONS



DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT



1400 filtros dicroicos
Produzidos pela empresa brasileira OPTO.

Limpeza dos filtros com agua de ionizável foi realizada pelo CTI (Brasil) - M.C.Bazetto e V. Pimentel

Centro de Tecnologia da Informação Renato Archer
UNIDADE DE PESQUISA DO MCTI

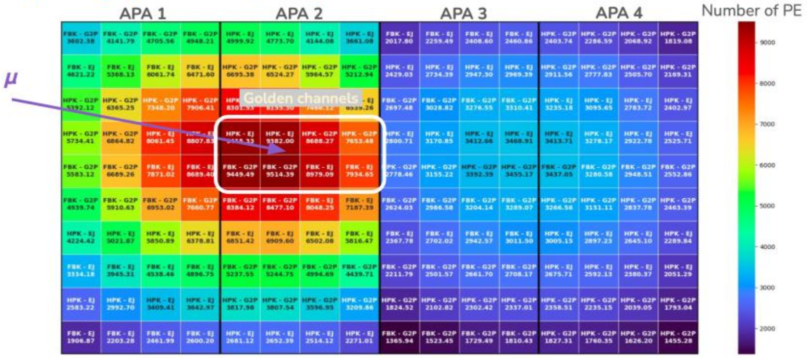
1100 filtros foram evaporado na evaporadora da sala limpa do Laboratório de Léptons na Unicamp
Desenvolvemos também o desenho e produção das caixas de transporte para os filtros.

UNICAMP

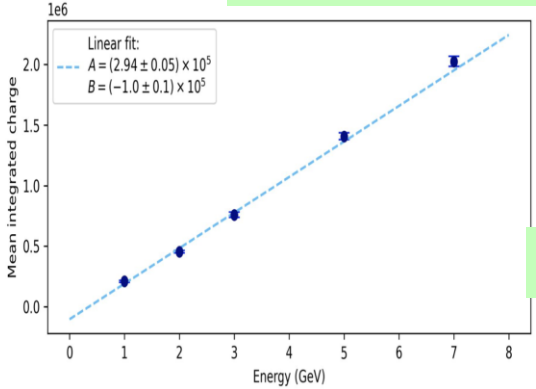
IFGW Eletrônica Quântica

ProtoDUNE-HD performance

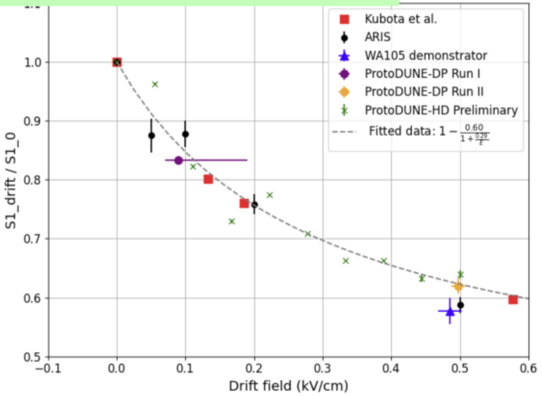
X-ARAPUCA efficiency



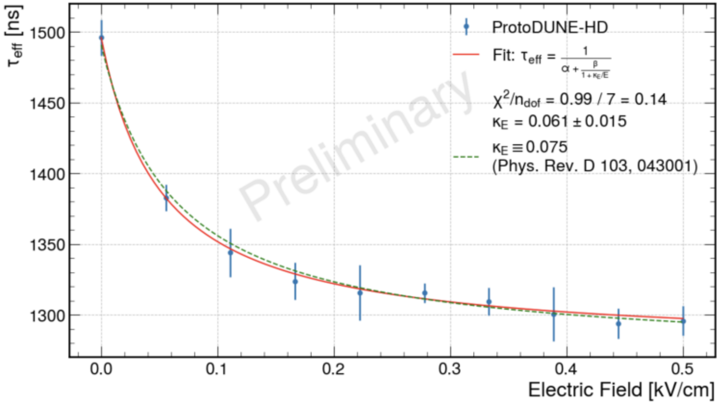
Light vs. beam energy

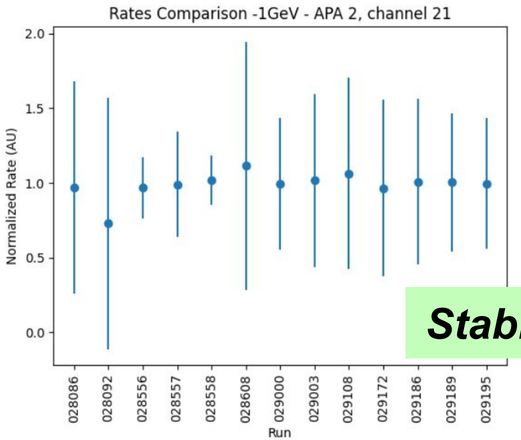


Light Yield vs. E field



Decay time scint. light vs. E field



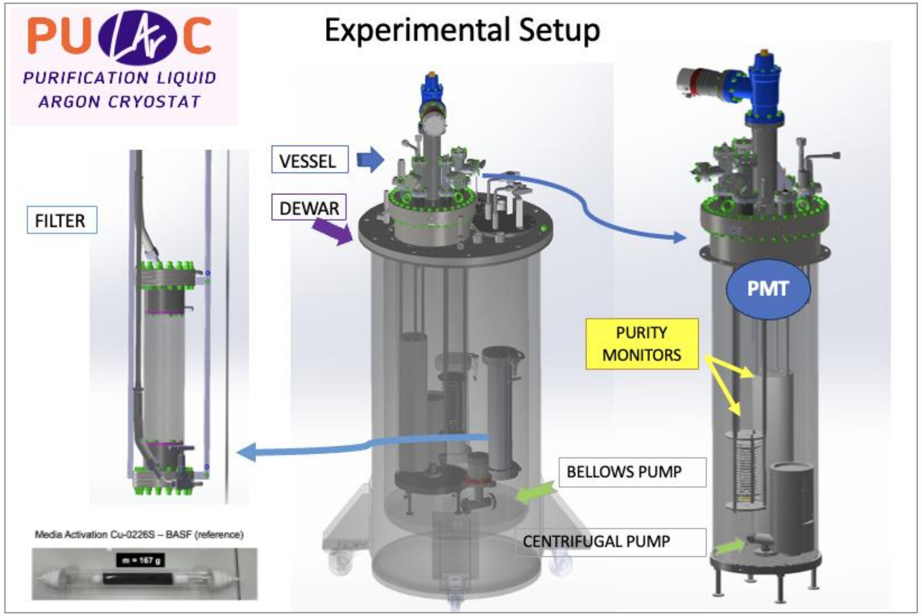


Stability of the response

X-ARAPUCA em DUNE

- A ARAPUCA, desenvolvida na UNICAMP e com a colaboração di muitos colegas Brasileiros e Latino Americanos foi escolhida pela Colaboração DUNE como o sistema de detecção de luz do far detector. Um dos maiores detetores de particulas nunca construído;
- Em 2025 começará a construção das X-ARAPUCAs para o Far Detector no laboratório de Leptons da UNICAMP;
- Será construídos 1,500 módulos. A maioria das componentes será fornecida por empresas Brasileiras. Outras componentes serão recebidas da Europa e dos EUA.
- As X-ARAPUCAs serão enviadas para o Dakota do Sul para a instalação.

LAr purification system – Phase 1



Maximum allowed contamination

Oxygen **< 50 PPT** Nitrogen **< 1 PPM**

Purificação do LAr

N_2 Contamination

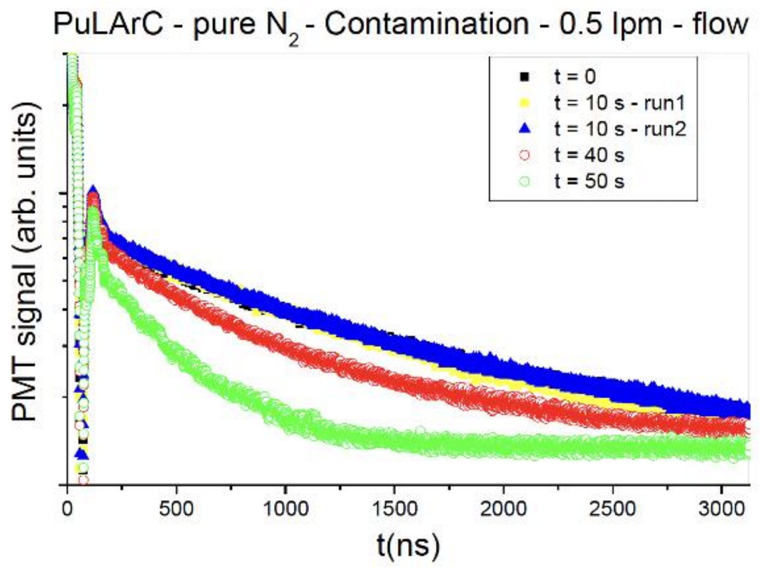
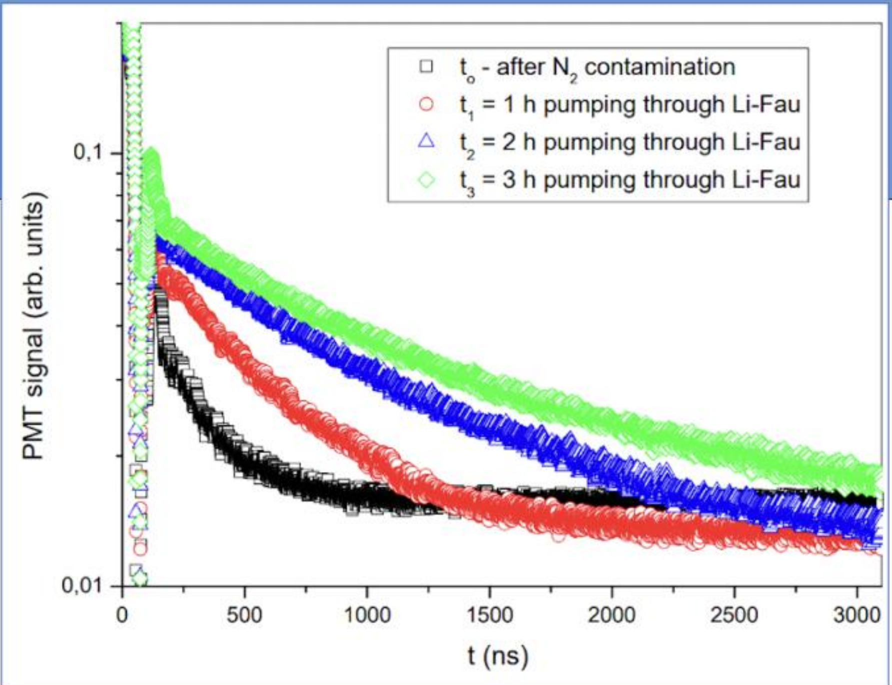


Figure 5. LAr scintillation light PMT signal as a function of time during the N_2 contamination.

N_2 Purification



Phase 2: Budget

Total: 45MUS$ (225MR$)

(3-4 year) 36 MUS$ - Y24 and Y25 – LBNF-DUNE

Main Partners and Funding:

- FAPESP: Funding Agency for São Paulo State (Sept 01, 2024)
- FINEP: Financial Agency for Studies and Projects (Federal) – Approved - Contract Signing.

Partners 9 MU$:

- Fermilab;
- Unicamp;
- Akaer;

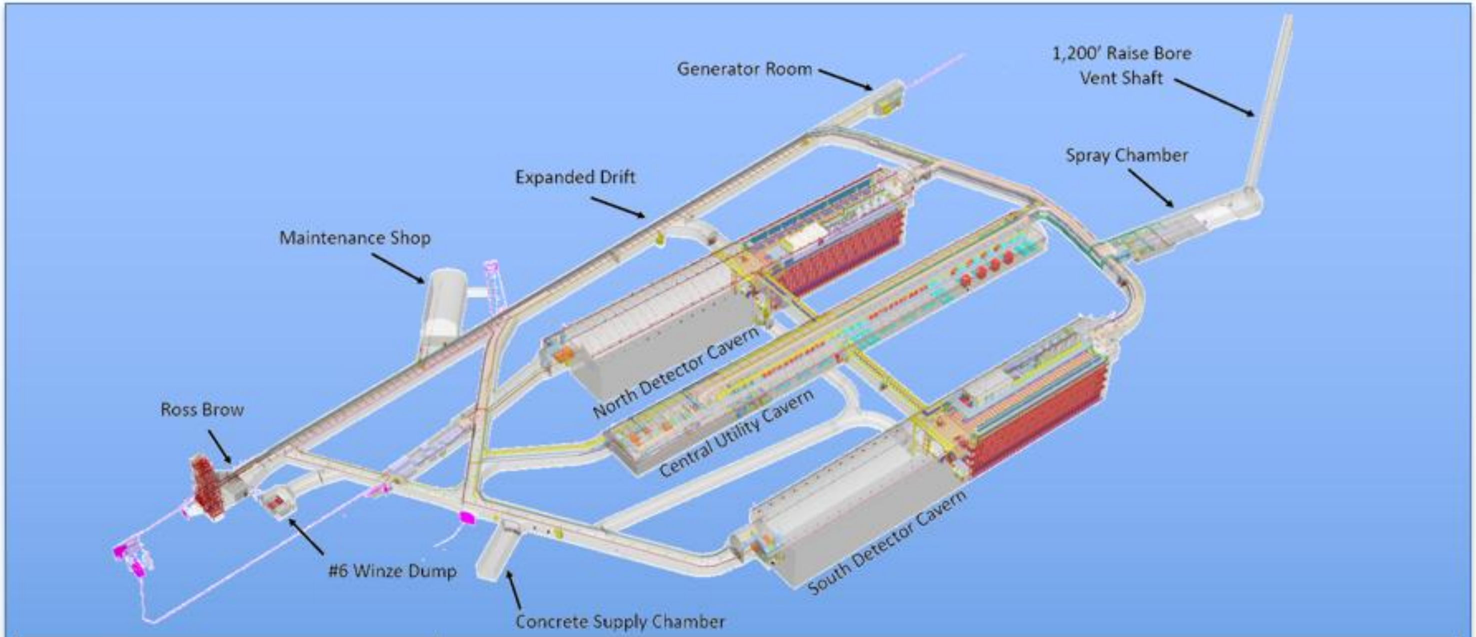
Institutional Support:
Ministry of Foreign Affairs – Itamaraty,
Federation of Industry of the State of São Paulo (FIESP-SP)
Industry Innovation Center of São Paulo State (SENAI-SP)

DUNE LBNF

Unprecedented scientific and technological opportunity to Brazil academia and industry that will reverberate for decades

Direct impact on society: Phase 1 involved more than **20 companies** – possibility of R&D Transfers to O&G industry, gas purification for medical usage, optoelectronic devices, large-scale filters, Dewars and low-T equipment.

DOE Project Scope – Far Site - Unicamp-SP-Brazil - In-kind contribution to LBNF-DUNE



WBS/Subproject	Scope
131.FSCFEXC/**FSCF-Excavation**	Project management, preliminary and final design, reliability/infrastructure upgrades, pre-excavation systems, and excavation work to support 4 detector modules.
131.FSCFBSI/**FSCF-Building & Site Infrastructure**	Project management, preliminary and final design, and construction of surface and underground utilities, and infrastructure outfitting of spaces for detector modules.
131.FDC/**Far Detectors and Far Site Cryogenic Infrastructure**	DUNE-US contributions to two DUNE detector modules; two cryostats & associated liquid argon; cryogenic systems to support two detector modules; installation and integration for two detector modules and cryogenic infrastructure

At the far site, the LBNF project scope includes committed critical in-kind contributions from:

- CERN – Membrane cryostats and portions of argon receiving facility (tanks)
- Brazil/UNICAMP – Argon purification and recirculation systems
- Switzerland/SERI – Argon condensing system
- Poland/WUST – Internal cryogenics systems

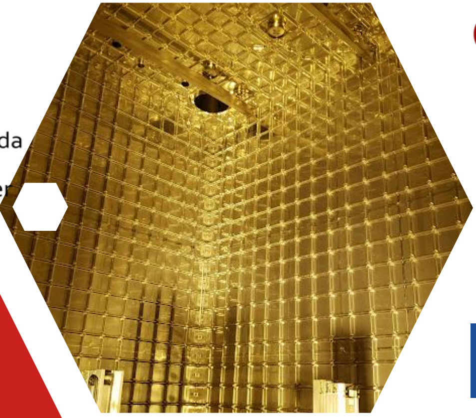
and the DUNE international collaboration, consortia, and partners.

DUNE

Thank you to all our partners!

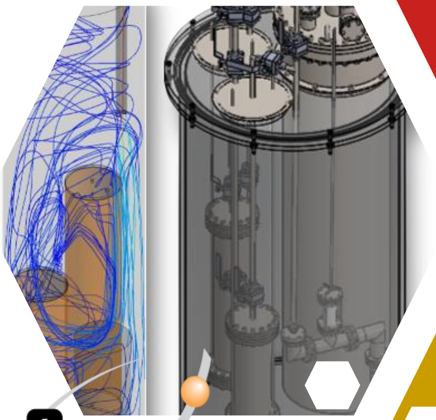
Phase 2

Engineering Research Center



Scientific Development

X-ARAPUCA: Photon Detection system optimization

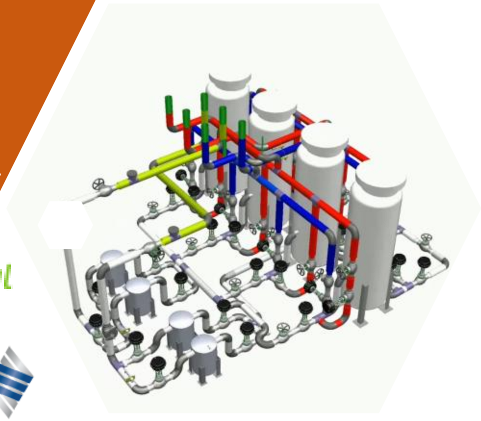


Engineering

LNBF/DUNE: Large Equipment R&D and Engineering

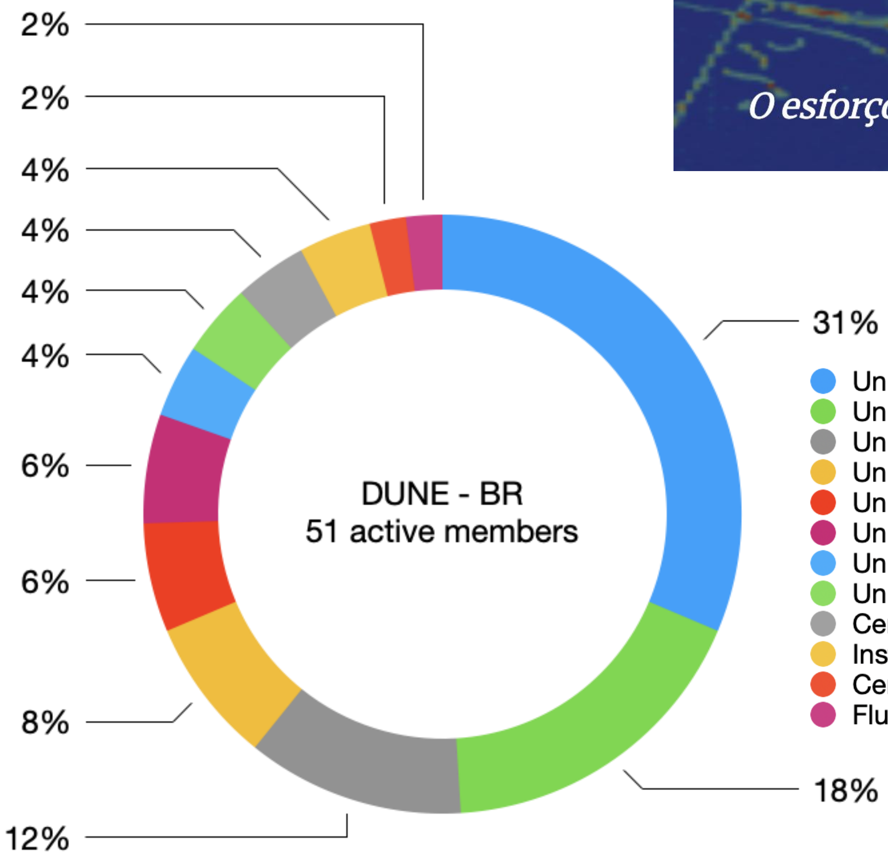
Research

Innovative Media, Fluid dynamics Studies, and PuLArC Operation



DUNE - BR

https://www.dune-br.org/



Obrigado pela atenção!


LAB.
LEPTONS