

# Co słyszeć w fizyce cząstek?

## Model Standardowy (Nobel'99)

- oddziaływania i cząstki ( $t$ ,  $\nu_\tau$ )
- precyzja pomiarów ( $g_\mu-2$ )
- poszukiwanie higgosa (LEP 2001)

## Oscylacje neutrin

- Super-Kamiokande

## Przyszłość - LHC

- higgs
- SUSY
- wyższe wymiary

## Pominę:

### Detektory kaskad atm.:

*Agasa, Auger, CASA, Kascade*

### Teleskopy neutrinowe:

*Amanda, Antares, Nestor*

### Detektory na satelitach:

*AMS*

### Detektory WIMPów:

*Cresst, Dama, CDMS, Genius  
Edelweiss, + 20 innych*

Grzegorz Wrochna

Instytut Problemów Jądrowych w Świerku

<http://cern.ch/wrochna>

# Unifikacja oddziaływań

Wielki Wybuch   Inflacja   Anihilacja   Bariogeneza   Nukleosynteza   Rekombinacja

$10^{-43}$  s

$10^{-32}$  s

$10^{-10}$  s

$10^{-4}$  s

100 s

300000 lat



$10^{-35}$  m  
 $10^{19}$  GeV

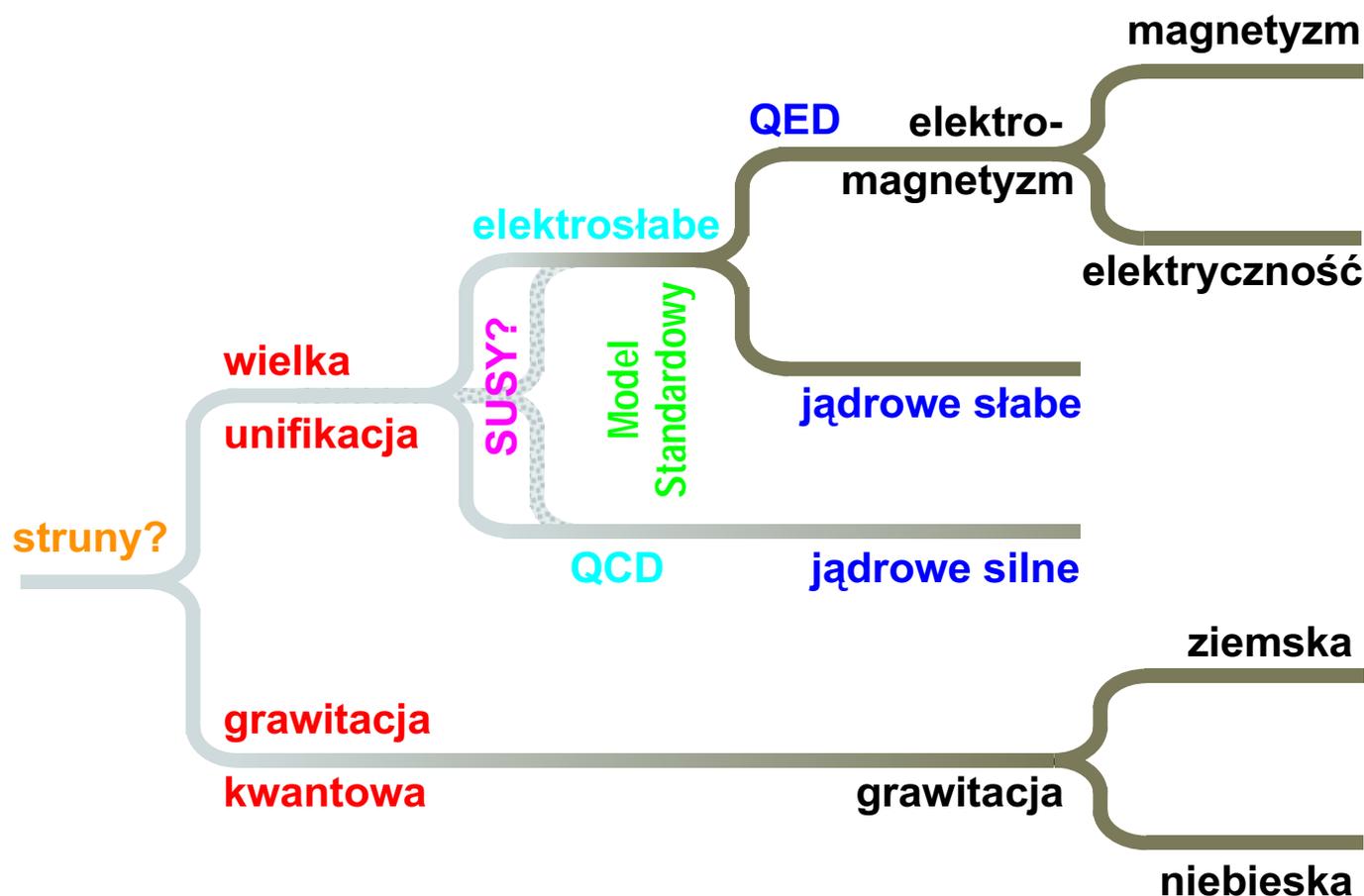
$10^{-32}$  m  
 $10^{16}$  GeV

$10^{-18}$  m  
 $10^2$  GeV

$10^{-16}$  m  
1 GeV

$10^{-15}$  m  
1 MeV

$10^{-10}$  m  
10 eV



QED - elektrodynamika kwantowa  
QCD - chromodynamika kwantowa

# Oddziaływania elementarne

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## Grawitacja — ogólna teoria względności

znakomicie potwierdzona na dużych skalach  
**ale** nic nie wiemy o grawitacji w skali mikro

## Elektromagnetyzm — elektrodynamika kwantowa

najdokładniejsza ze znanych teorii mikroświata  
sprawdzona z dokładnością do  $10^{-10}$

## Teoria oddziaływań elektroślabych

sprawdzona do  $<1\%$ ,  
**ale** nie wyjaśnia dlaczego cząstki mają masę  
najlepszy pomysł: **mechanizm Higgsa**,  
**ale** przewidywana cząstka Higgsa jeszcze nie odkryta

## Oddziaływania silne — chromodynamika kwantowa

dobrze pracuje w dużych energiach,  
**ale** nie umiemy wykonać rachunków analit. dla małych energii

Połączenie teorii oddziaływań elektroślabych  
(+ mechanizm Higgsa) z chromodynamiką kwantową

## Model Standardowy

znakomicie opisuje wyniki wszystkich eksperymentów,  
**ale** ... jest **brzydki**.

# Elementary particles

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quarks, spin 1/2						charge
<b>u</b>	up 2.7 MeV	<b>c</b>	charm 1.2 GeV	<b>t</b>	top 174 GeV	<b>+2/3</b>
<b>d</b>	down 5 MeV	<b>s</b>	strange 100 MeV	<b>b</b>	beauty 4.2 GeV	<b>-1/3</b>

leptons, spin 1/2						charge
<b><math>\nu_e</math></b>	neutrino e < 15 eV	<b><math>\nu_\mu</math></b>	neutrino $\mu$ < 170 keV	<b><math>\nu_\tau</math></b>	neutrino $\tau$ < 18 MeV	<b>0</b>
<b>e</b>	electron 511 keV	<b><math>\mu</math></b>	muon 106 MeV	<b><math>\tau</math></b>	tau 1.78 GeV	<b>-1</b>

+ antiparticles with opposite charges

bosons, spin 1							
<b><math>\gamma</math></b>	photon m=0	<b><math>Z^0</math></b>	boson Z 92.2 GeV	<b><math>W^\pm</math></b>	boson W 80.4 GeV	<b>g</b>	gluon m=0

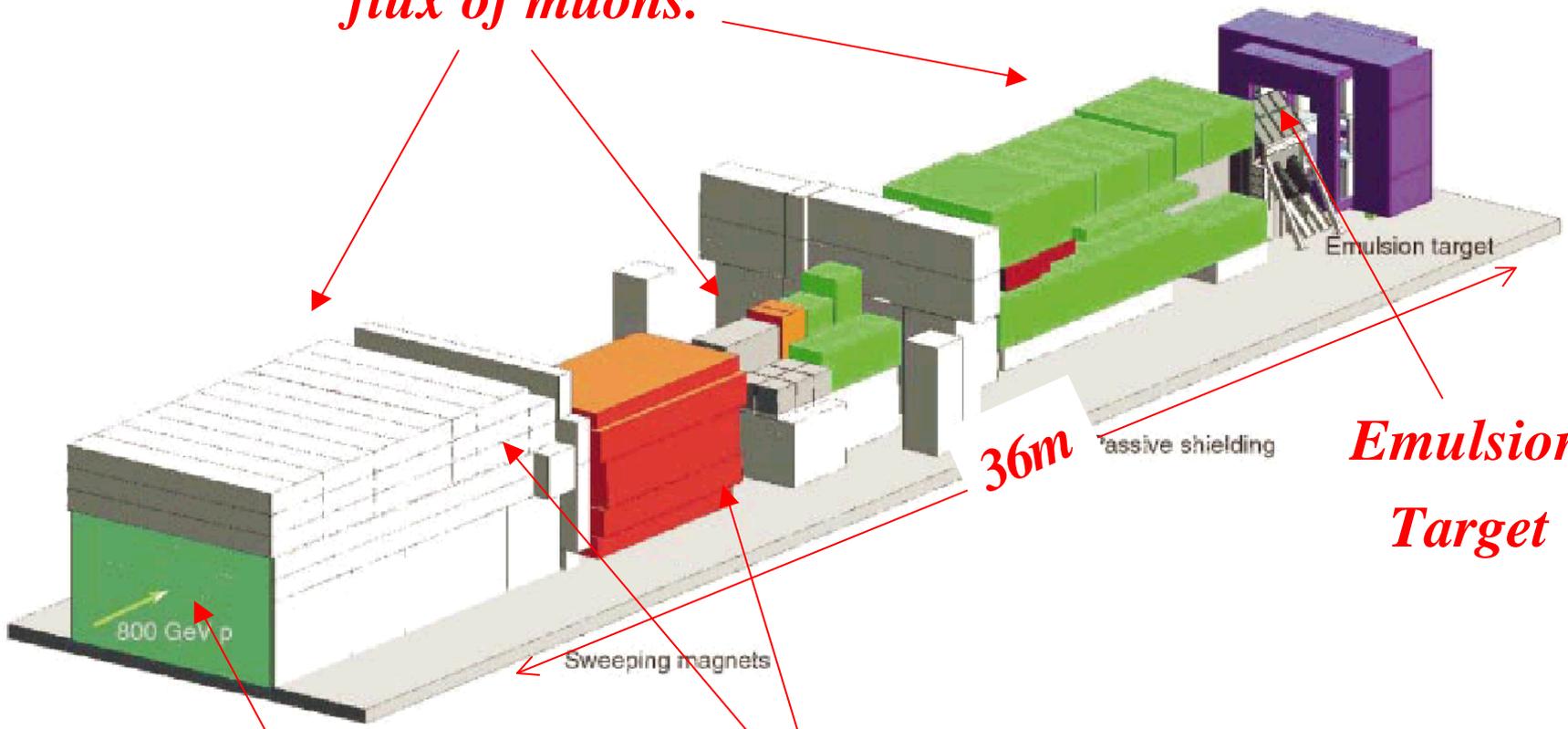


**DONUT**

# Prompt Neutrino Beam Line

*Shielding to protect emulsion from the high flux of muons.*

*Spectrometer*



*Primary Target*

*Sweeping Magnets*

*Emulsion Target*

*36m*

passive shielding

Emulsion target

Sweeping magnets

800 GeV

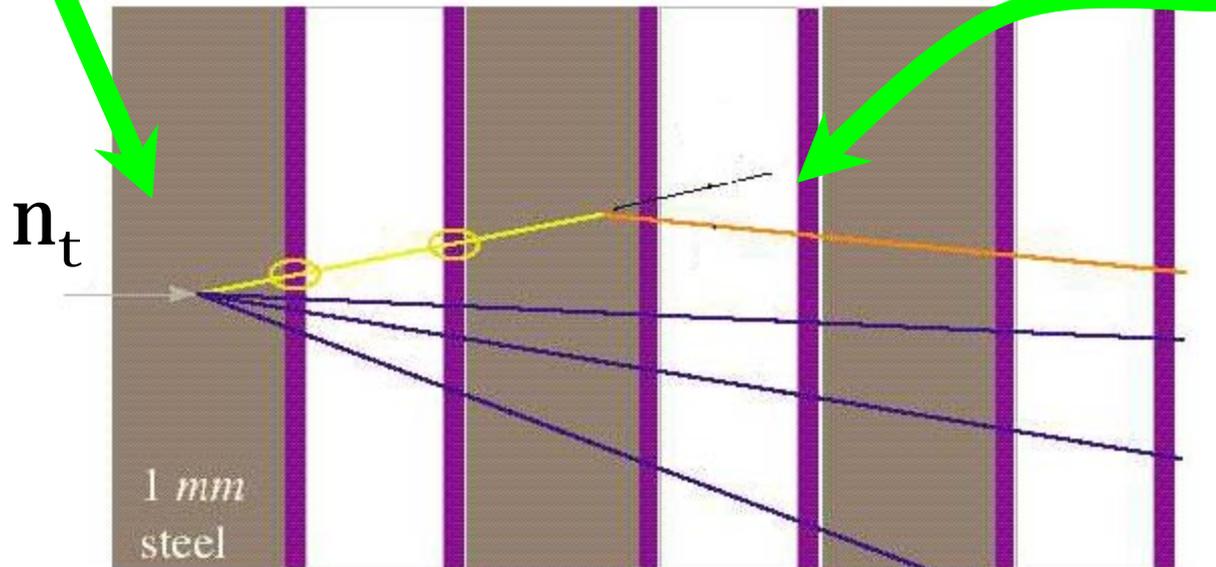


**DONUT**

# interaction selection

- No  $e$ ,  $m$  from primary vertex
- Tau ID:  $\sim 76\%$  have visible track

86% of decays are single charge



“kink”  $> 5$  mrad  
(mean 110 mrad)

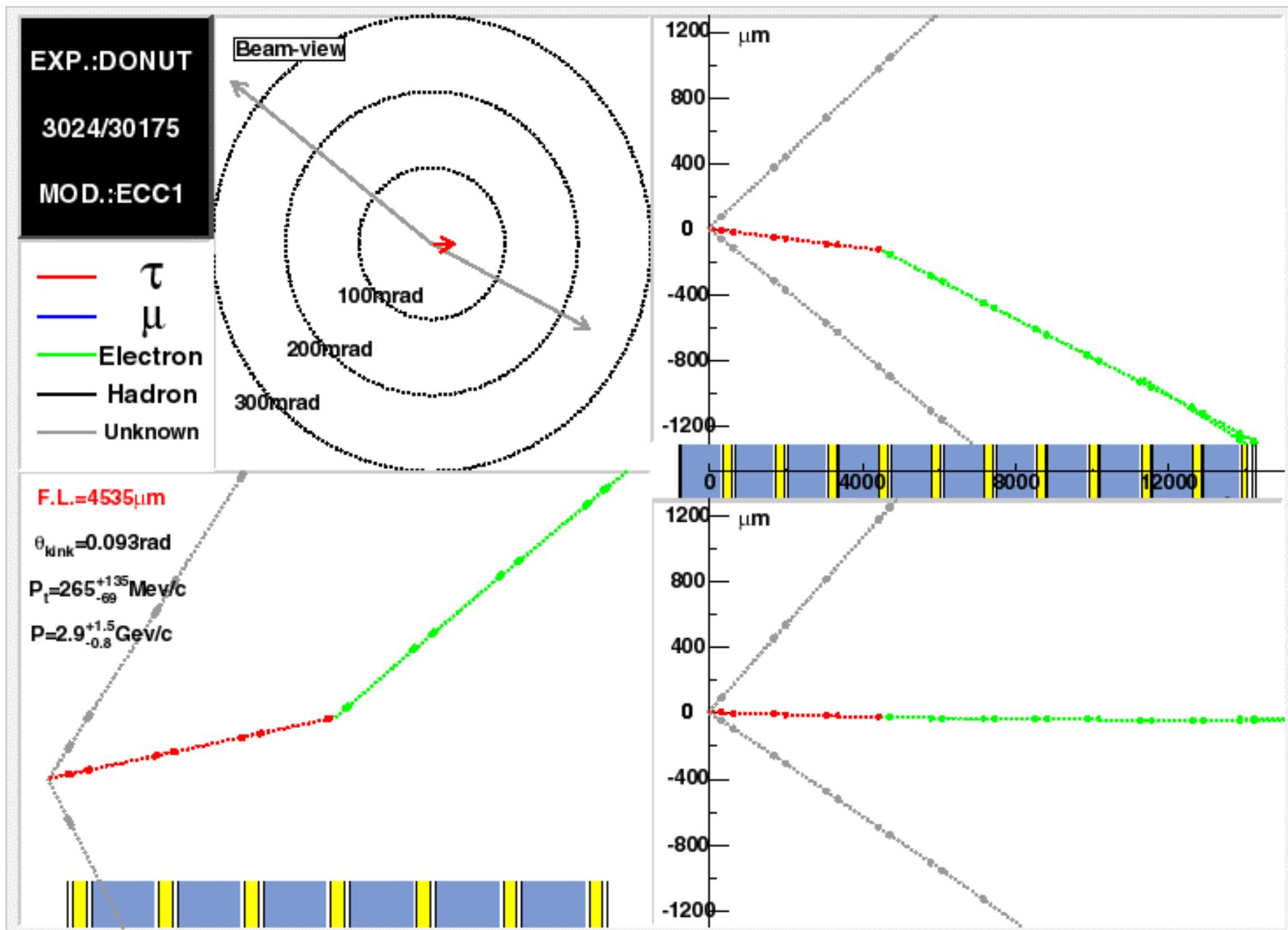
$p_{\text{daughter}} > 1$  GeV/c

$p_t > 250$  MeV/c

for hadron daughter

$> 100$  MeV/c

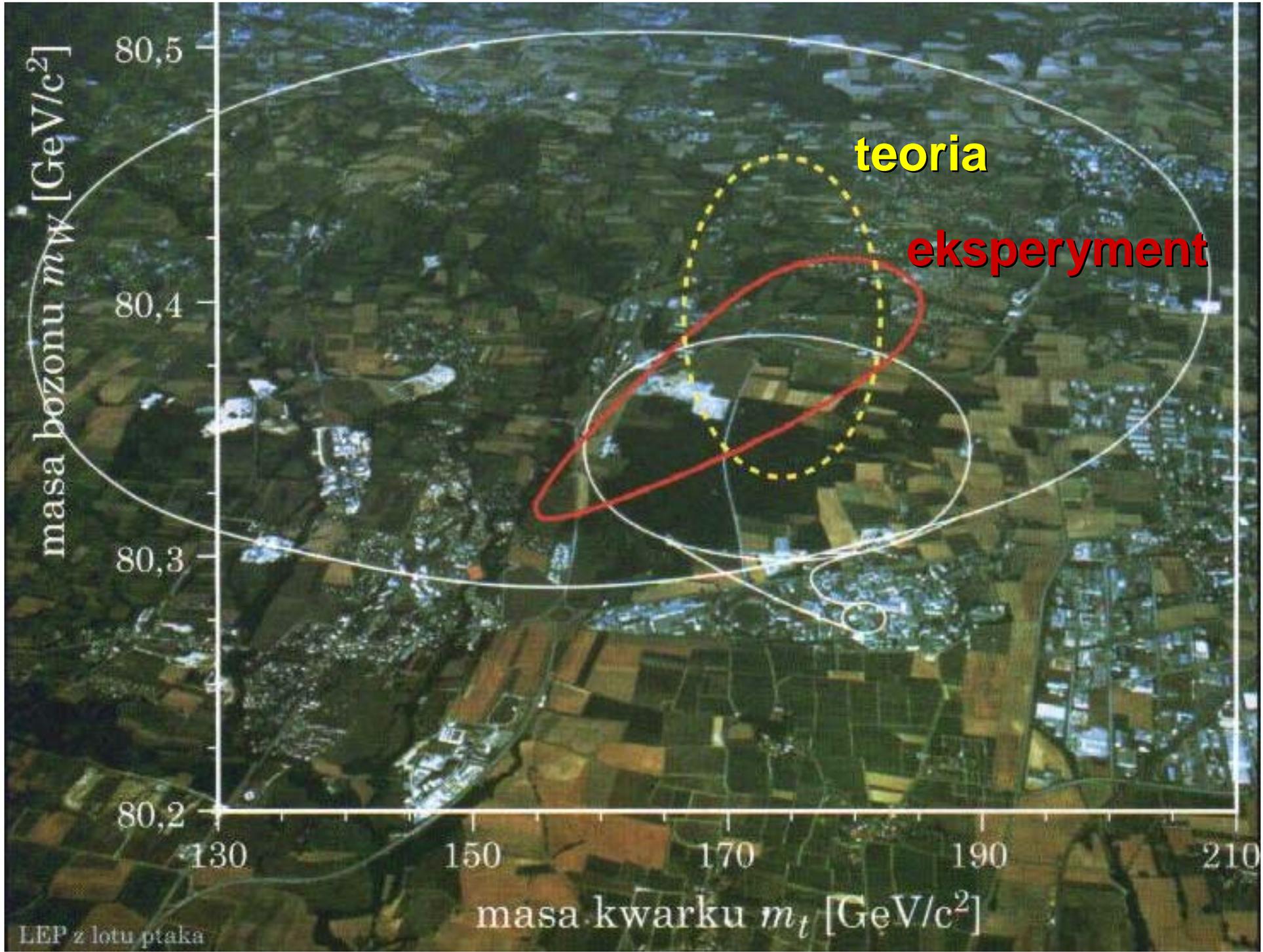
for lepton daughter



**Nobel Prize 1999 in physics**  
**Gerardus 't Hooft     Martinus Veltman**



**for developing calculus of particle physics in the 70-ties**



# Fit to all Electroweak Data

Summer 2001

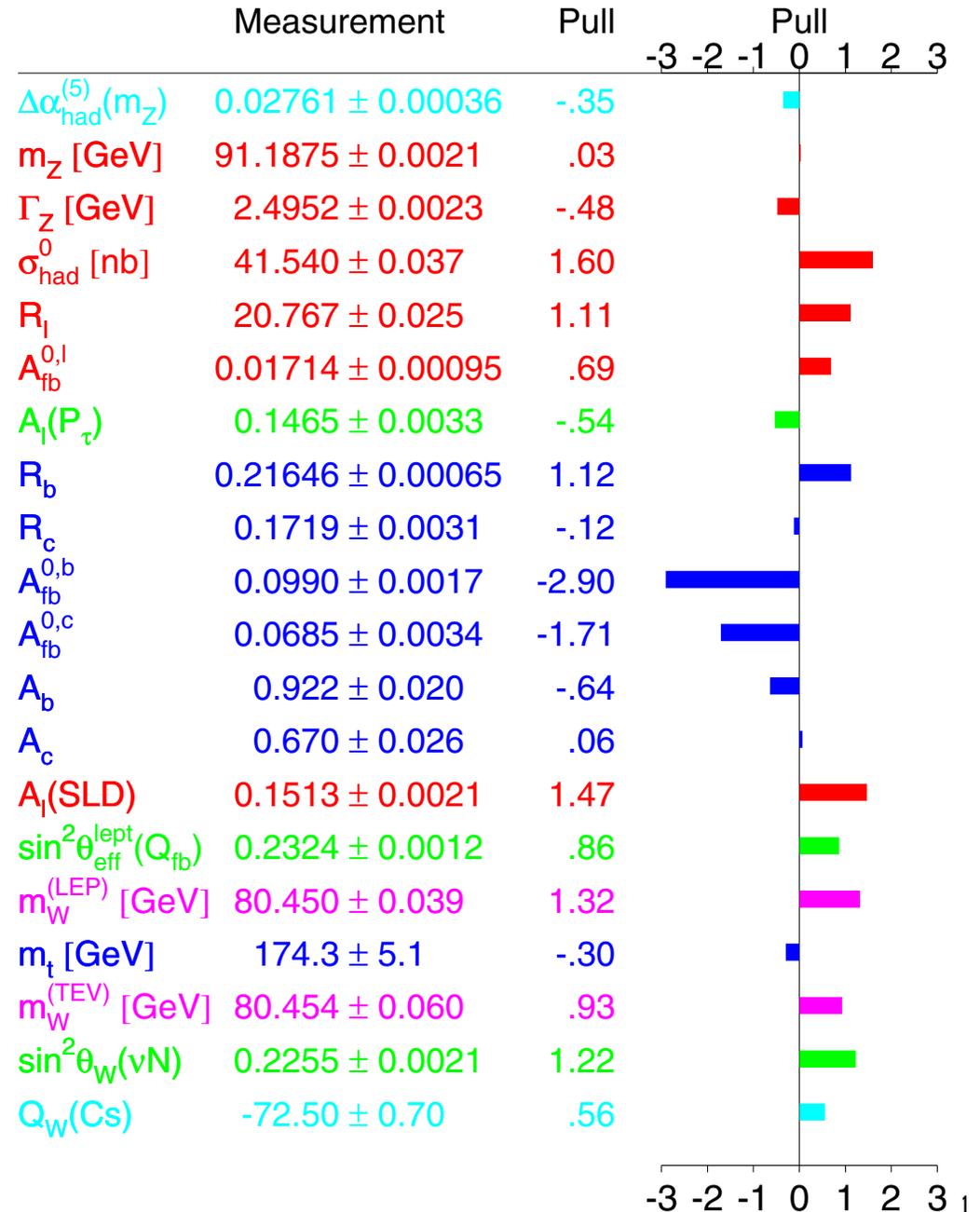
Full electroweak fit of all measurements, including  $M_W$  and  $M_{top}$

Overall consistency  $\chi^2/d.o.f$  is 22.9/15 (8.6% probability)

Sizeable contribution to  $\chi^2$  comes from quark asymmetries

Acceptable overall consistency

→ go on to see what fit says about  $M_H$



# Anomalny moment magnetyczny mionu

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$$\mu = g \cdot \frac{e}{2mc} \cdot \frac{h}{2}$$

$$g \approx 2$$

$$a_{\mu} = \frac{g-2}{2}$$

$$a_{\mu}^{\text{exp}} = 11659202 \cdot 10^{-10}$$

$$a_{\mu}^{\text{teor}} = 11659159 \cdot 10^{-10}$$

$$\Delta = (43 \pm 16) \cdot 10^{-10}$$

Rozbieżność prawie  $3\sigma$ .

Czyżby ślad fizyki spoza Modelu Standardowego?

# Muon Anomalous Magnetic Moment $g-2$

Logashenko

Brookhaven E821 at “magic”  $\gamma=29.3$

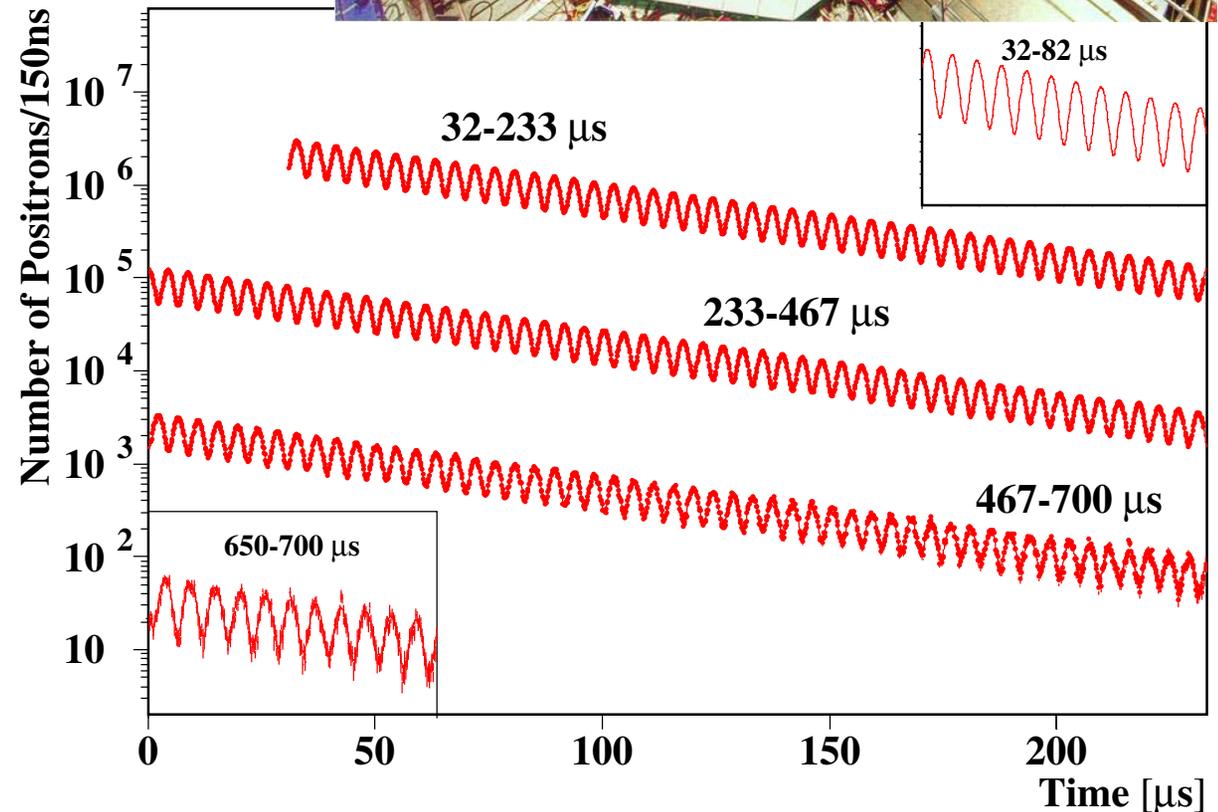
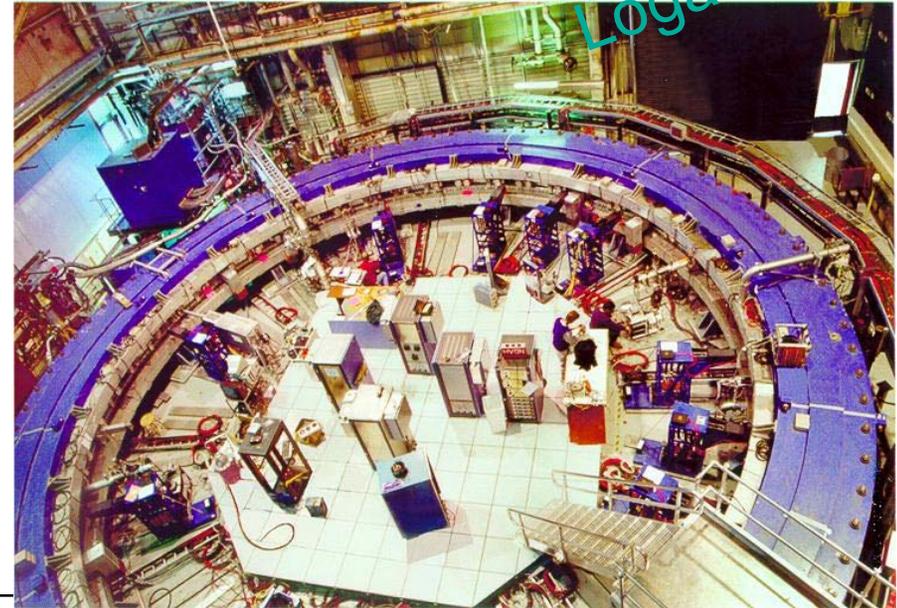
$$\frac{g-2}{2} = a_\mu = \frac{\omega_a m_\mu c}{e \langle B \rangle}$$

$\omega_a$  muon spin precession frequency

$\langle B \rangle$  mean bending field

Observe time spectrum of  $e$  with  $E_{lab} > 2$  GeV from the  $\mu$  decay

$\langle B \rangle$  from NMR probes - fixed & trolley-mounted - find mean proton NMR frequency  $\omega_p$



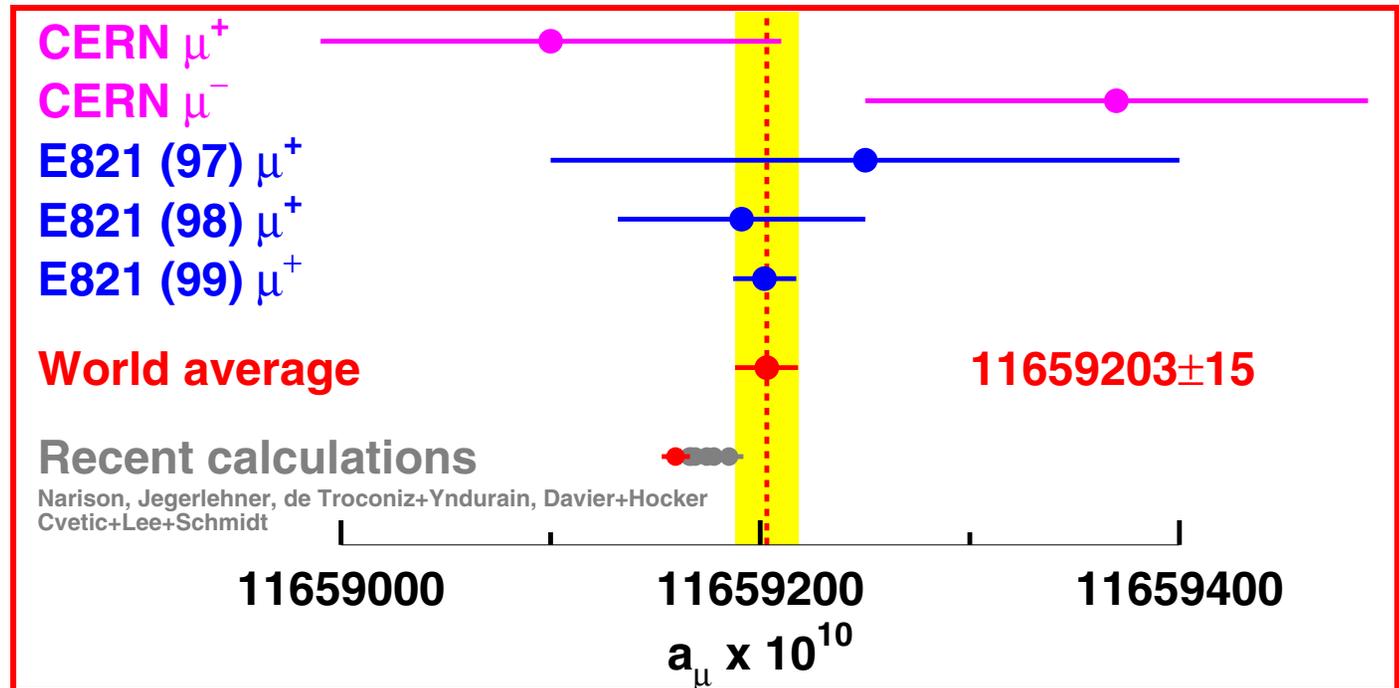
# A “g-2 Crisis”?

Physicists Announce Possible Violation of Standard Model of Particle Physics

BNL News Release  
8 February 2001

New E821  
measurement  
dominates world  
average

Experimental  
precision  
comparable to  
theoretical  
uncertainty – *and  
error should halve*



New measurements have provided a powerful stimulus to theory

**The Standard Model lives on, for now...**

# Constraining the SM Higgs?

Fit to all electroweak data in Standard Model framework

Theory uncertainty includes effect of complete fermionic two-loop  $M_W$ : small effect for  $M_W$ , controversial problem for

$$\sin^2 \theta_{\text{eff}}^{\text{lept}} = \kappa_W \left( 1 - \frac{M_W^2}{M_Z^2} \right)$$

Need equivalent calculations for Z widths and effective mixing angle

Freitas, Hollik, Walter, Weiglein

From EW fit, obtain

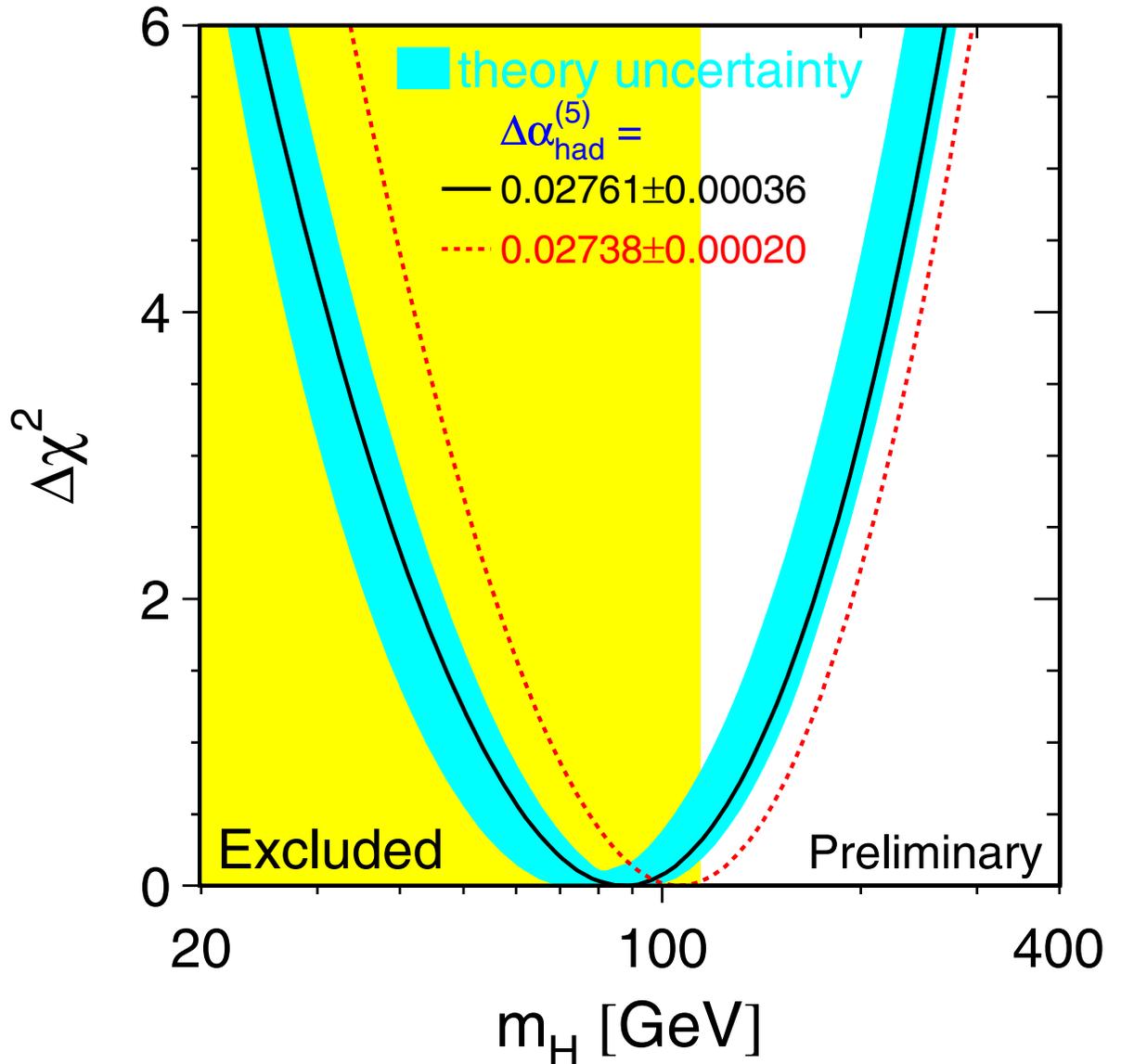
$$M_H = 88_{-35}^{+53} \text{ GeV}$$

$$M_H < 196 \text{ GeV (95\% CL)}$$

If use alternative theory-driven

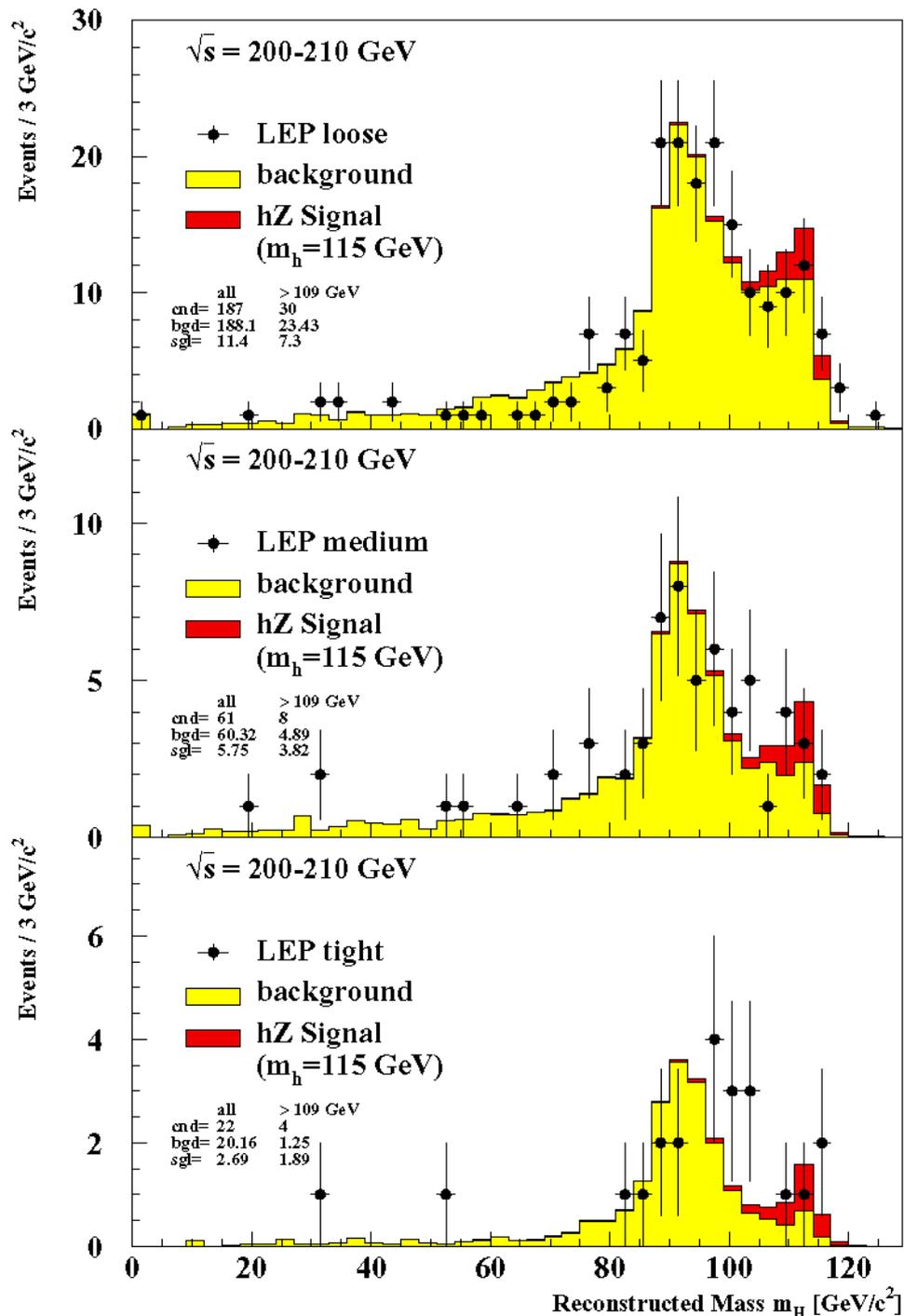
$$\Delta\alpha_{\text{had}} = 0.02738 \pm 0.00020$$

limit moves to 222 GeV



# Higgs search

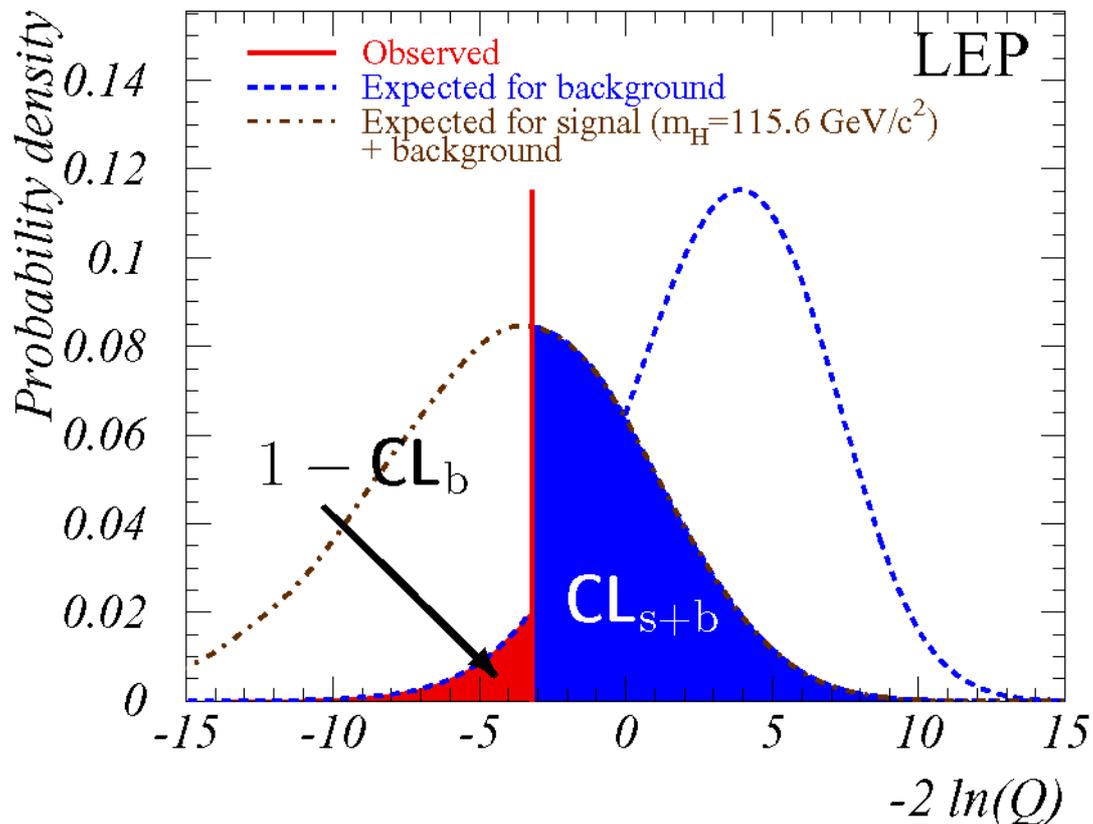
## Reconstructed mass distributions



$$Q = \frac{P(\text{data} \mid \text{singal} + \text{background})}{P(\text{data} \mid \text{background})}$$

## LEP combined result

**Observation** vs. simulated experiments for  
b-only, b+s ( $m_h = 115.6 \text{ GeV}$ )

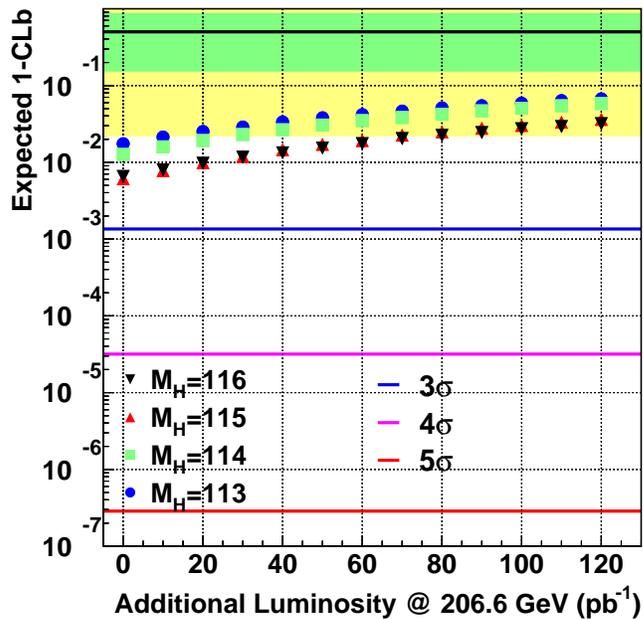


Compatibility with

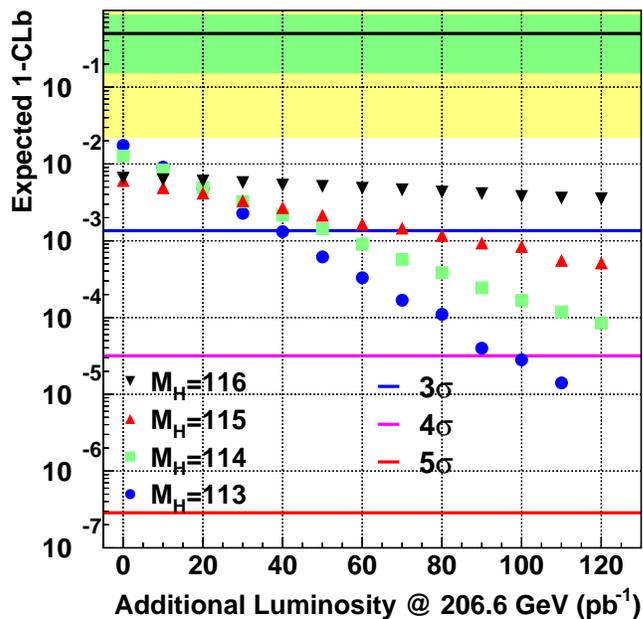
→ **background**,  $1 - CL_b = 3.5\%$

→ **background +  $m_h = 115.6 \text{ GeV}$** ,  $CL_{s+b} = 43.5\%$

## Case 1: Accumulating Background-Only:



## Case 2: Accumulating Background+Signal:



LEP-wide Higgs searches

# Oscylacje neutrin

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## Teleskop neutrinowy Super-Kamiokande

- 50 000 ton wody
- 11 000 fotopowielaczy

rejestrujących promieniowanie Czerenkowa  
produktów oddziaływania neutrin

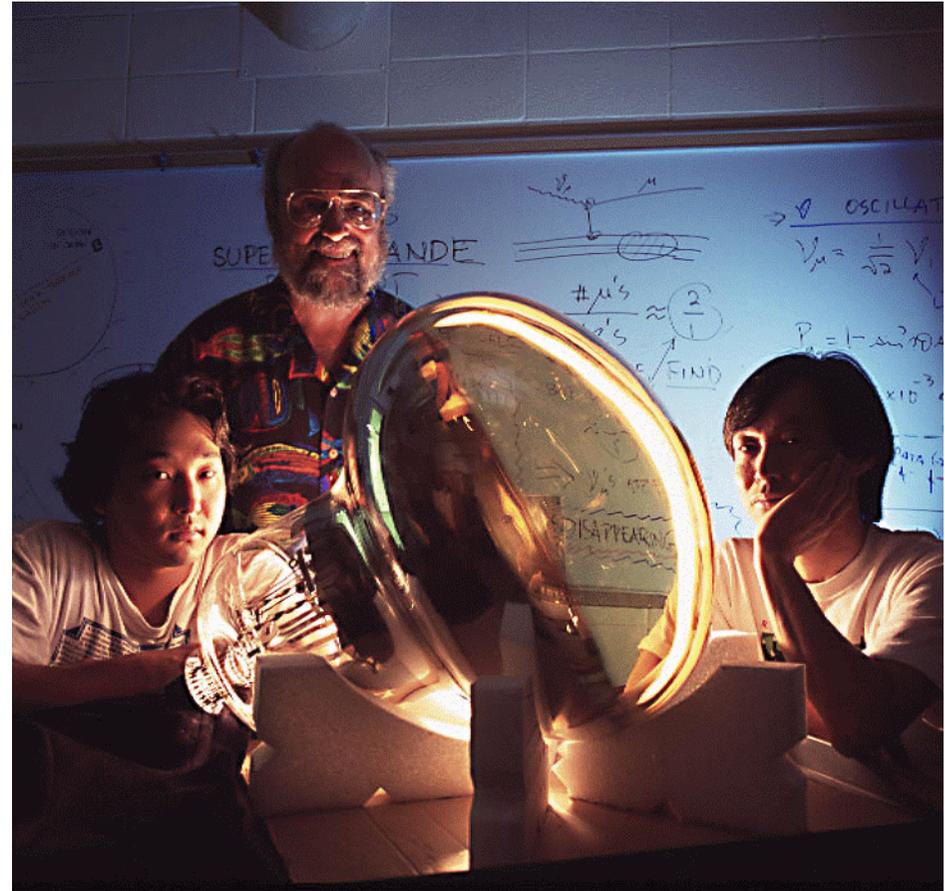
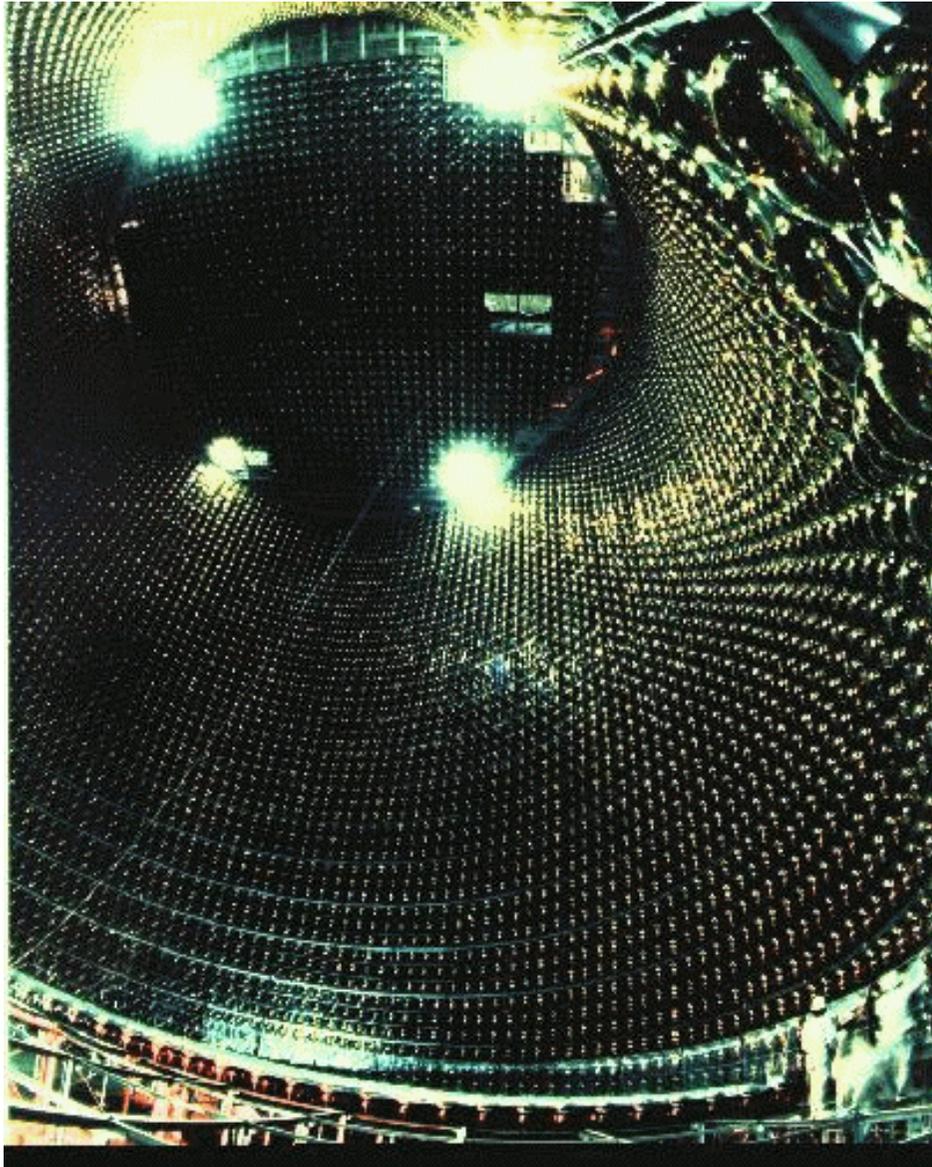
Detekcja neutrin słonecznych, atmosferycznych i z supernowych

Obserwacja oscylacji neutrin  $\Rightarrow$

**neutrino mają masę!**

— największe odkrycie fizyki cząstek ostatnich lat

# Super Kamiokande



Fotopowielacze rejestrują promieniowanie Czerenkowa cząstek poruszających się w wodzie



# Mieszanie neutrin

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Stany własne zapachu  $\nu_e, \nu_\mu, \nu_\tau$ , nie muszą być tożsame ze stanami

własnymi masy  $\nu_1, \nu_2, \nu_3$ , np.

$$\begin{bmatrix} \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \nu_2 \\ \nu_3 \end{bmatrix}$$

Jeżeli  $\nu_2, \nu_3$  mają różne masy to ich względne fazy w  $\nu_\mu, \nu_\tau$  oscylują z różnymi częstotliwościami.

W ten sposób  $\nu_\mu = \nu_2 \cos \theta + \nu_3 \sin \theta$

może przeewoluować do  $-\nu_2 \sin \theta + \nu_3 \cos \theta = \nu_\tau$

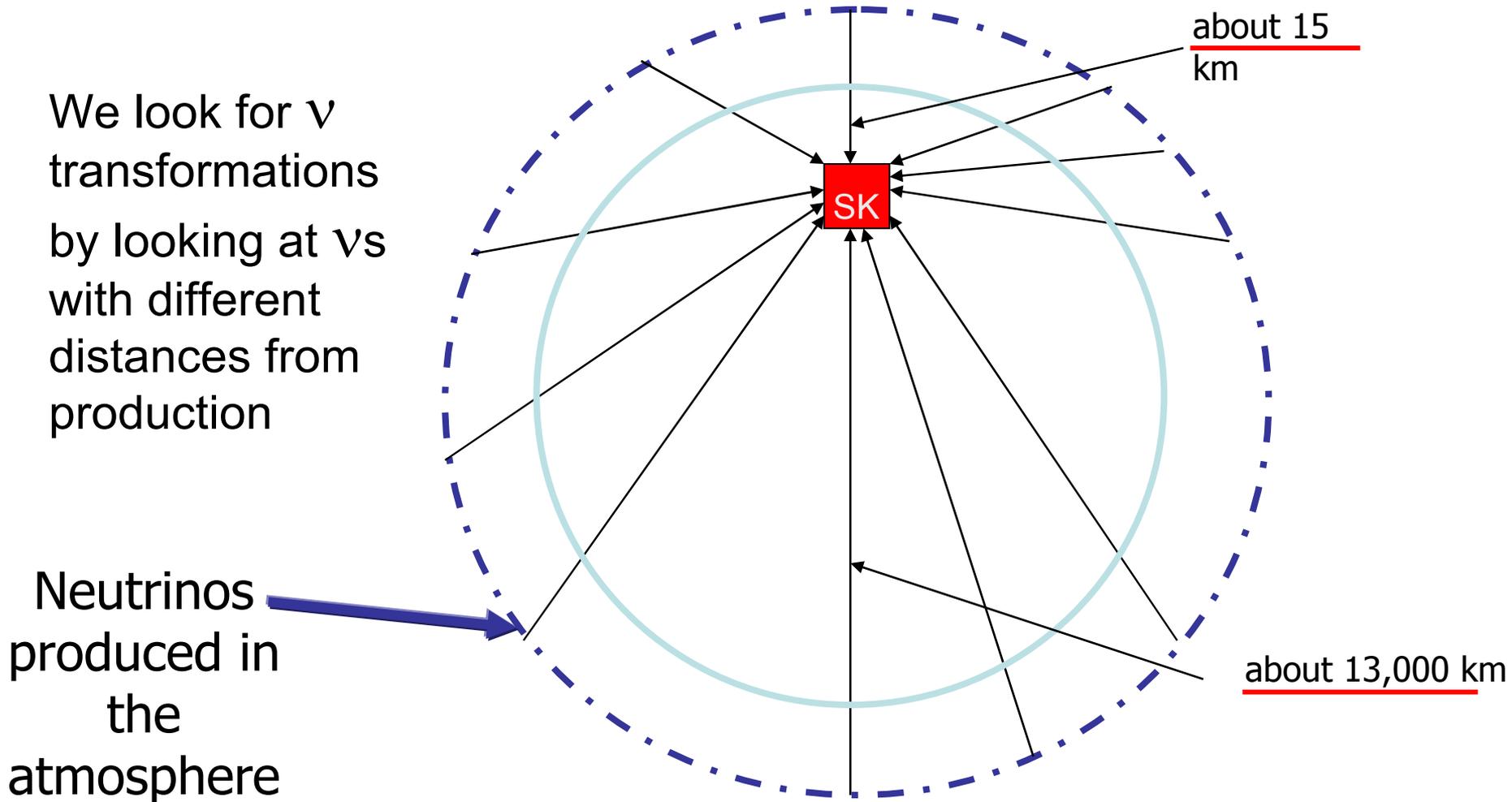
Atmosferyczne  $\nu_\mu$  obserwujemy jako  $\nu_\mu$  i  $\nu_\tau$ .

W ogólności:

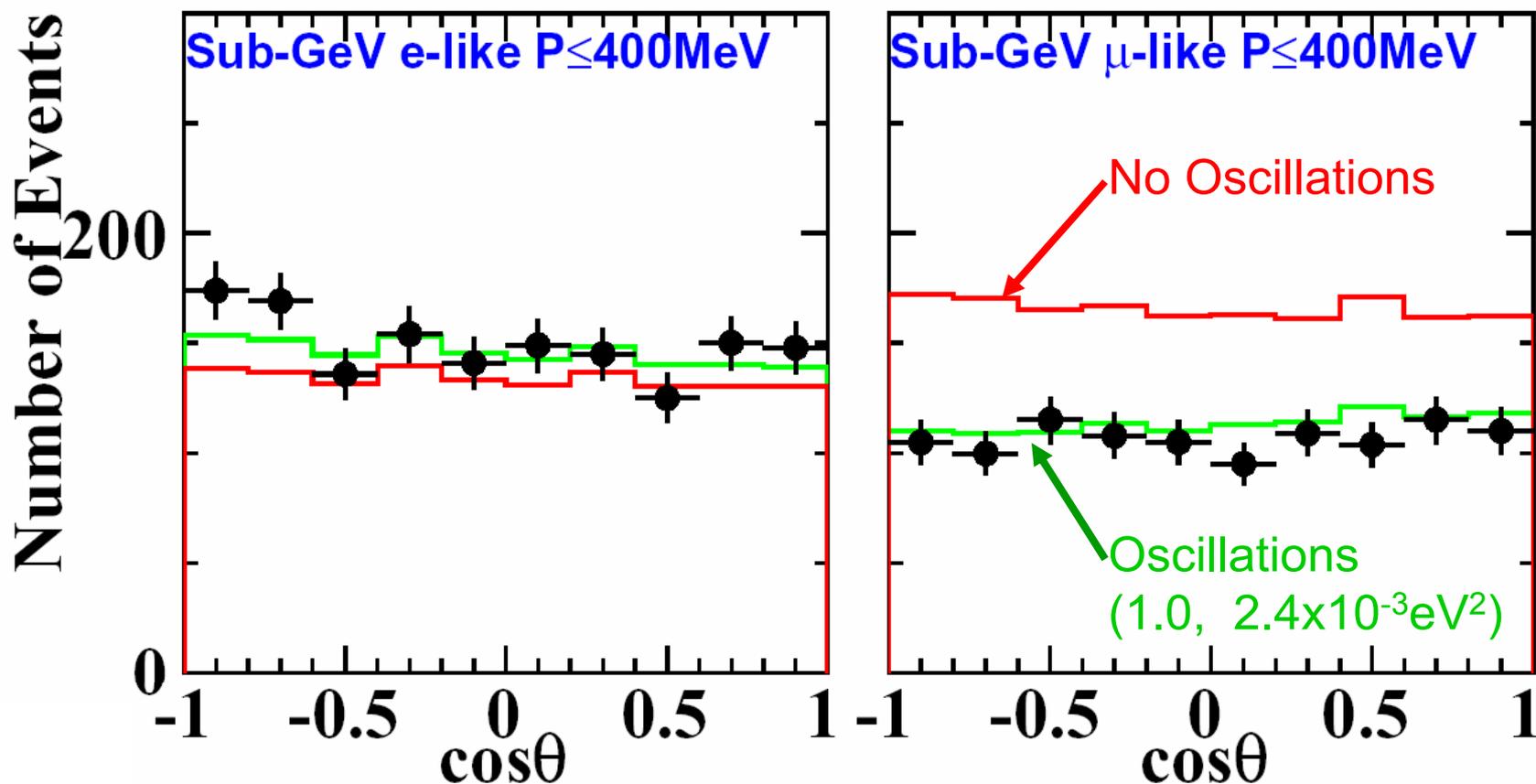
$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} \circ & \circ & \circ \\ \circ & \circ & \circ \\ \circ & \circ & \circ \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

Słoneczne  $\nu_e$  obserwujemy jako  $\nu_e, \nu_\mu$  i  $\nu_\tau$ .

# Atmospheric Oscillations

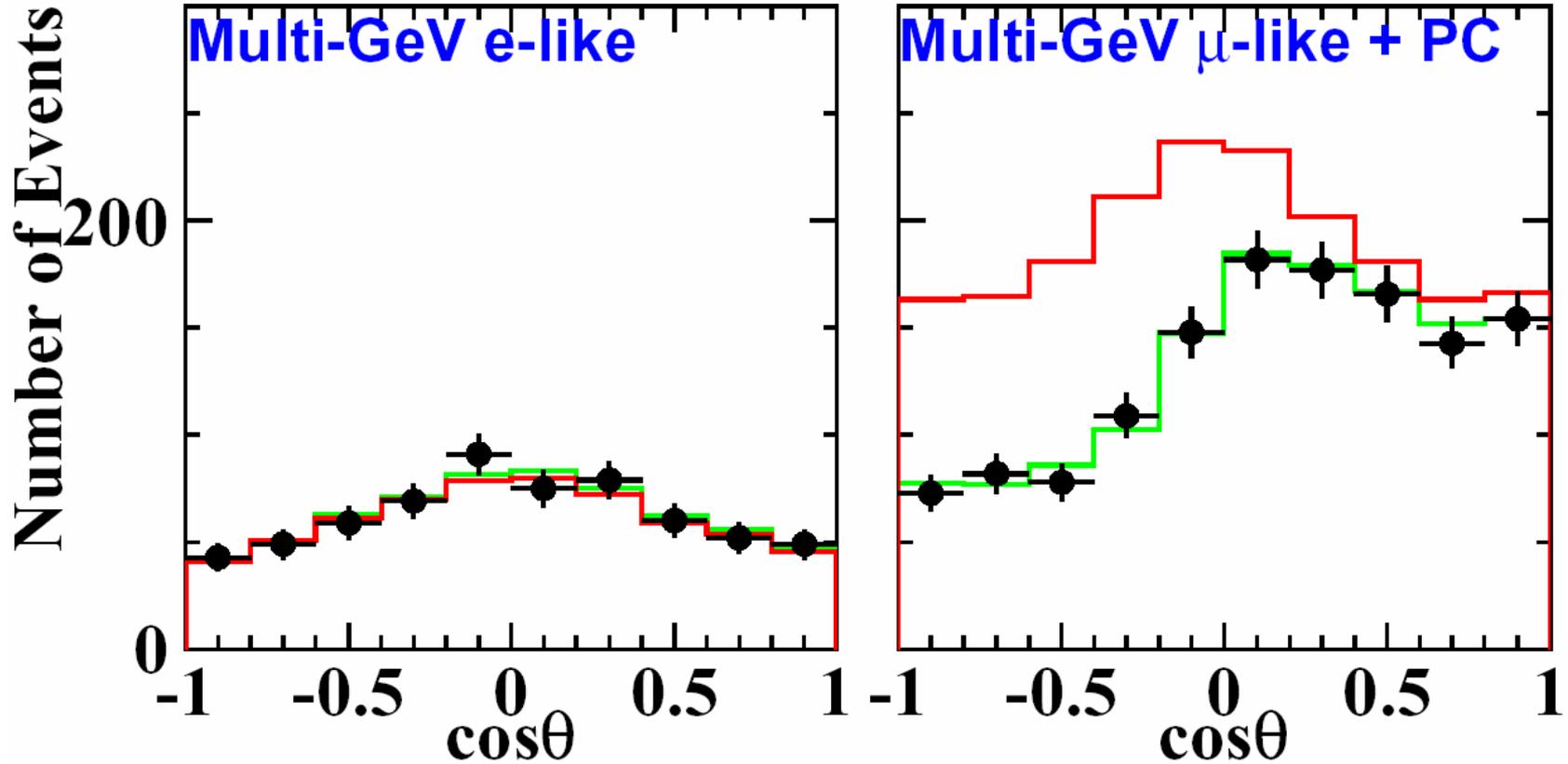


# Low Energy Sample

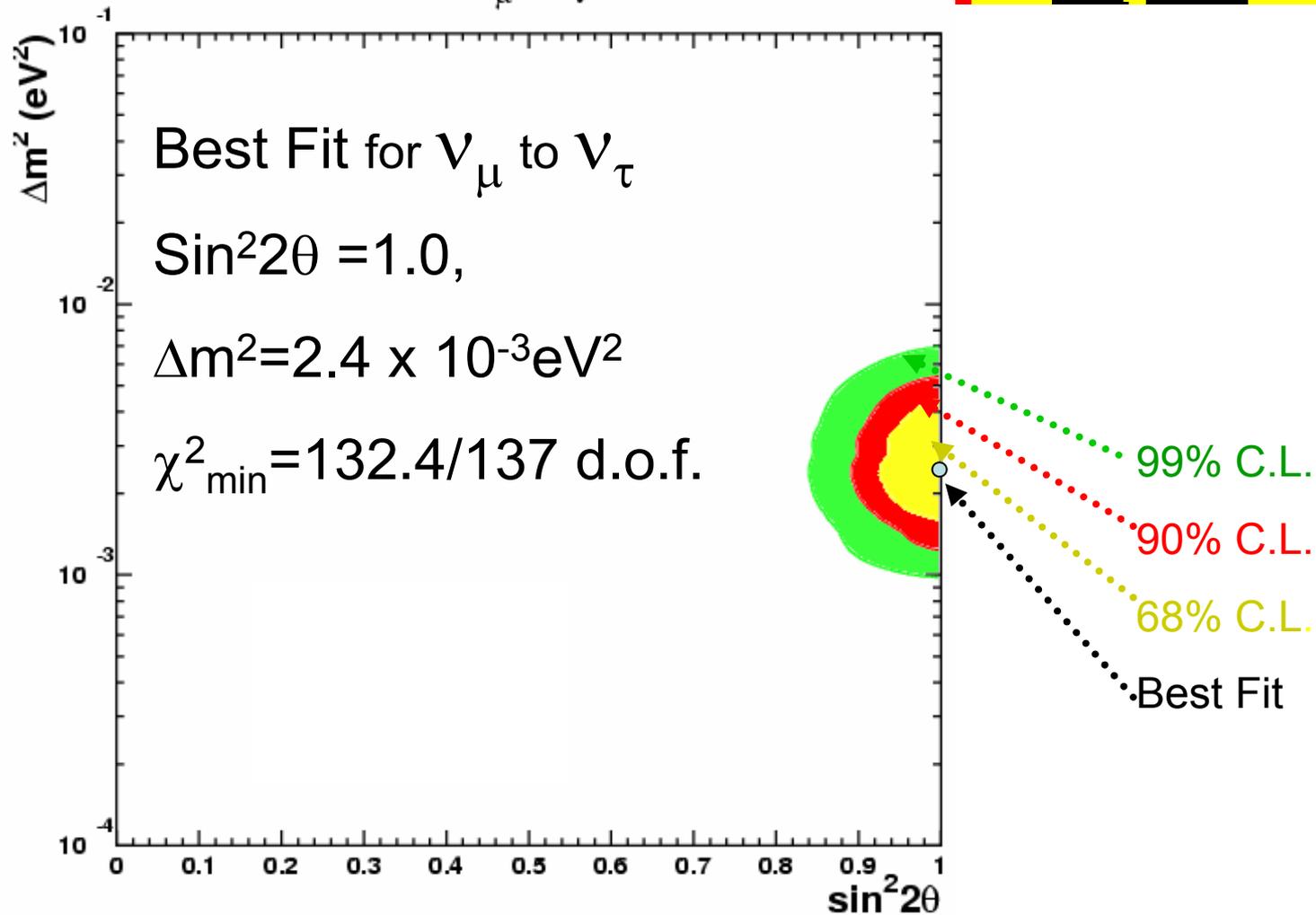


Global  $\chi^2_{\min} = 132.4 / 137$  d.o.f for  $\nu_{\mu}$  to  $\nu_{\tau}$   
at  $(\sin^2 2\theta, \Delta m^2) = (1.00, 2.4 \times 10^{-3} \text{ eV}^2)$

# Multi-GeV Sample

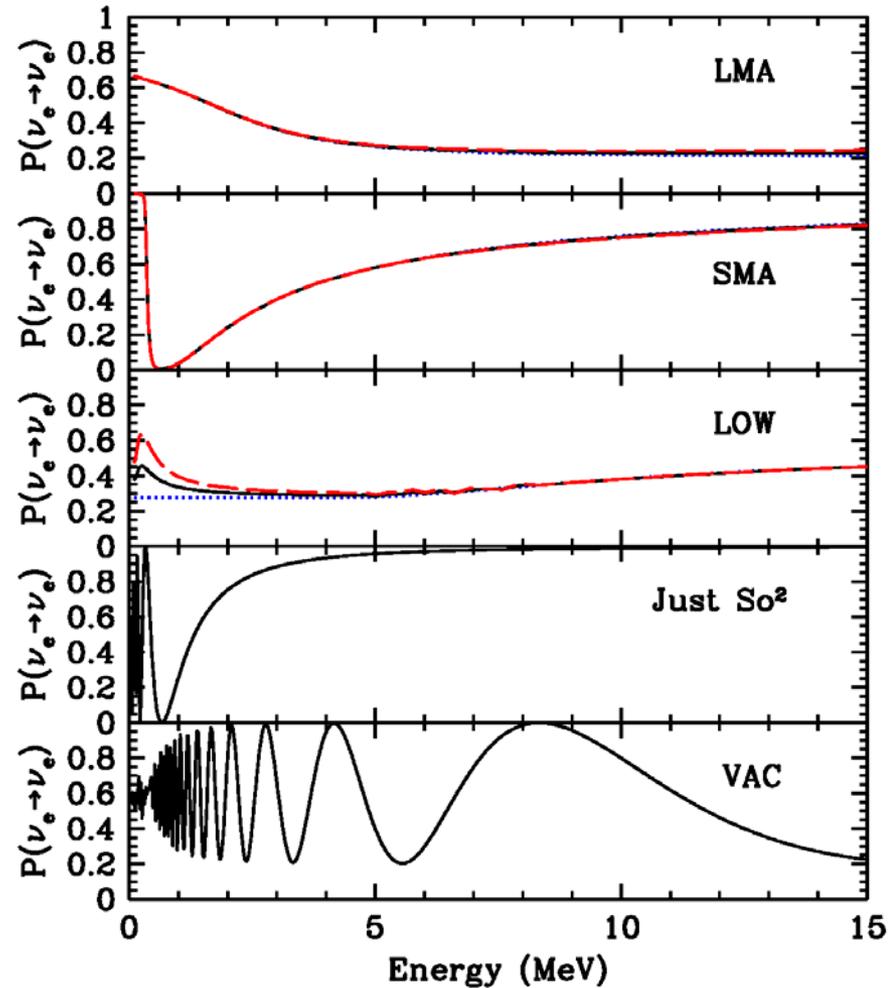
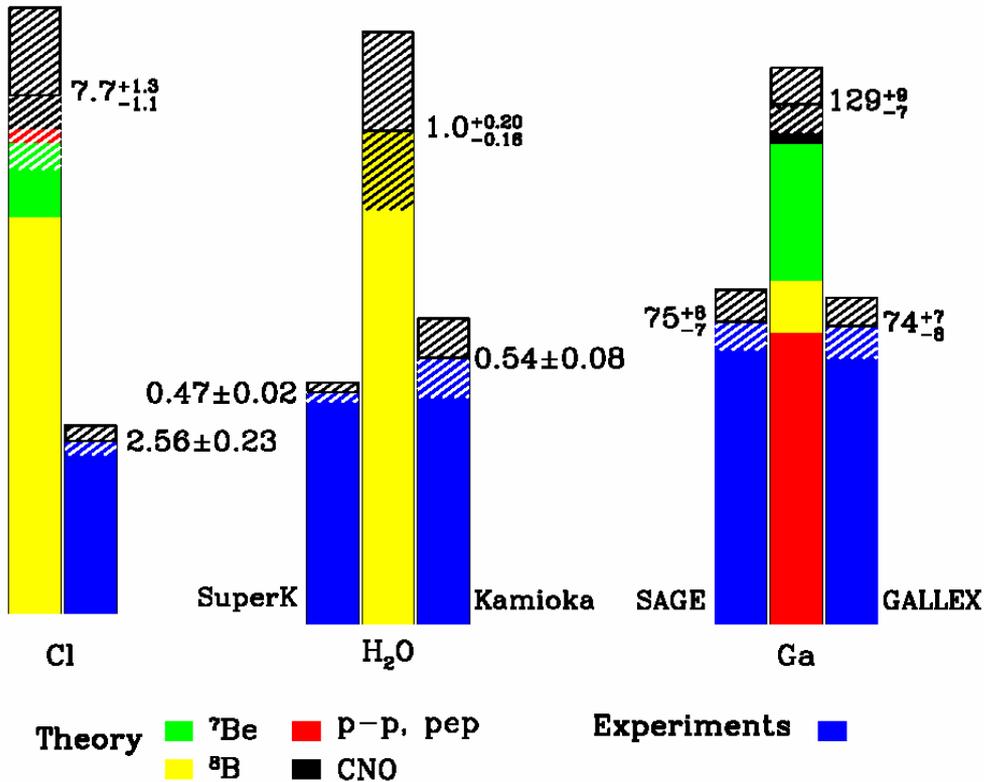


# Super-Kamiokande - atmospheric $\nu$



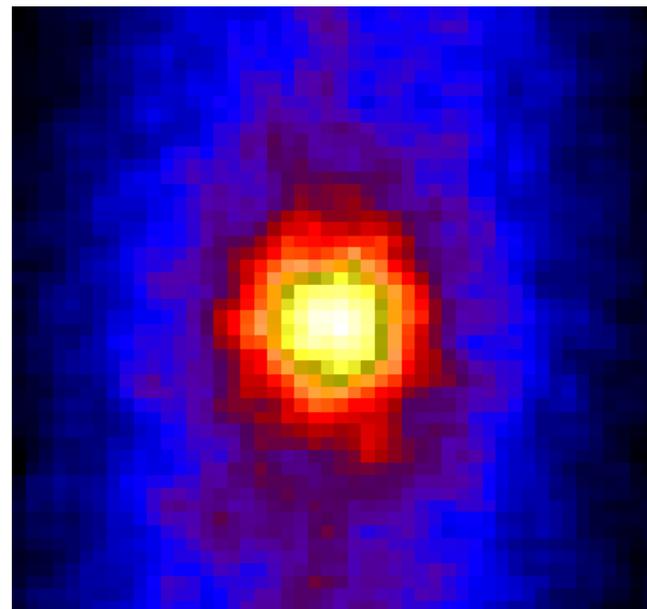
# The Solar Neutrino Problem

Total Rates: Standard Model vs. Experiment  
Bahcall-Pinsonneault 2000

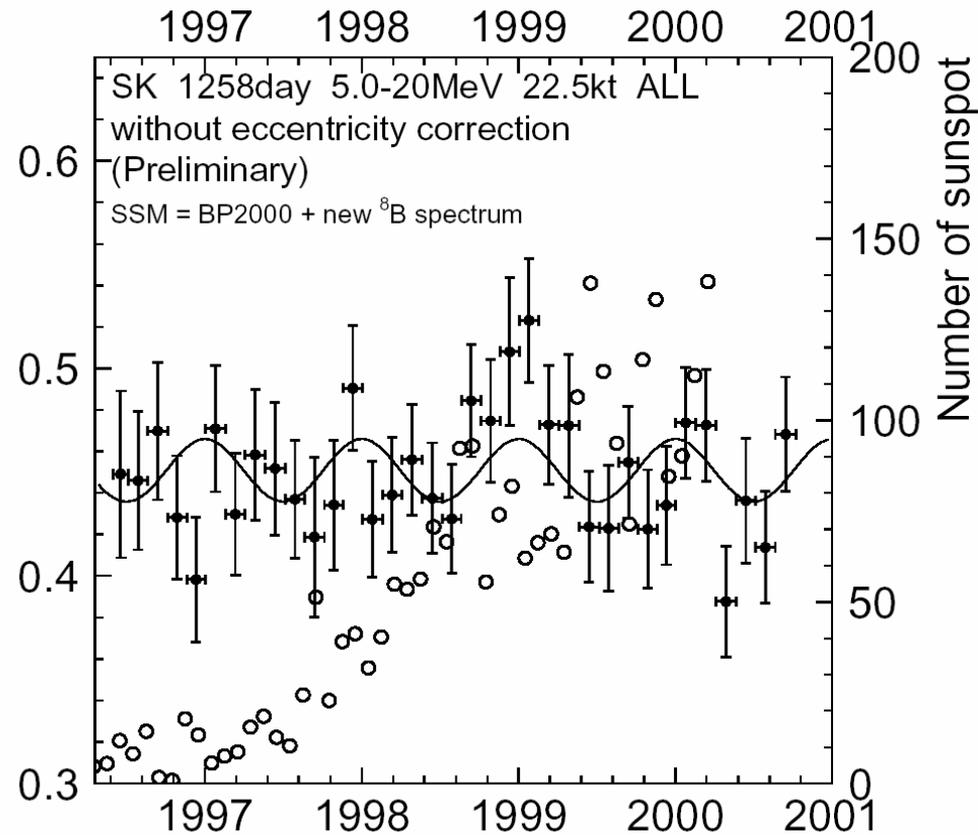
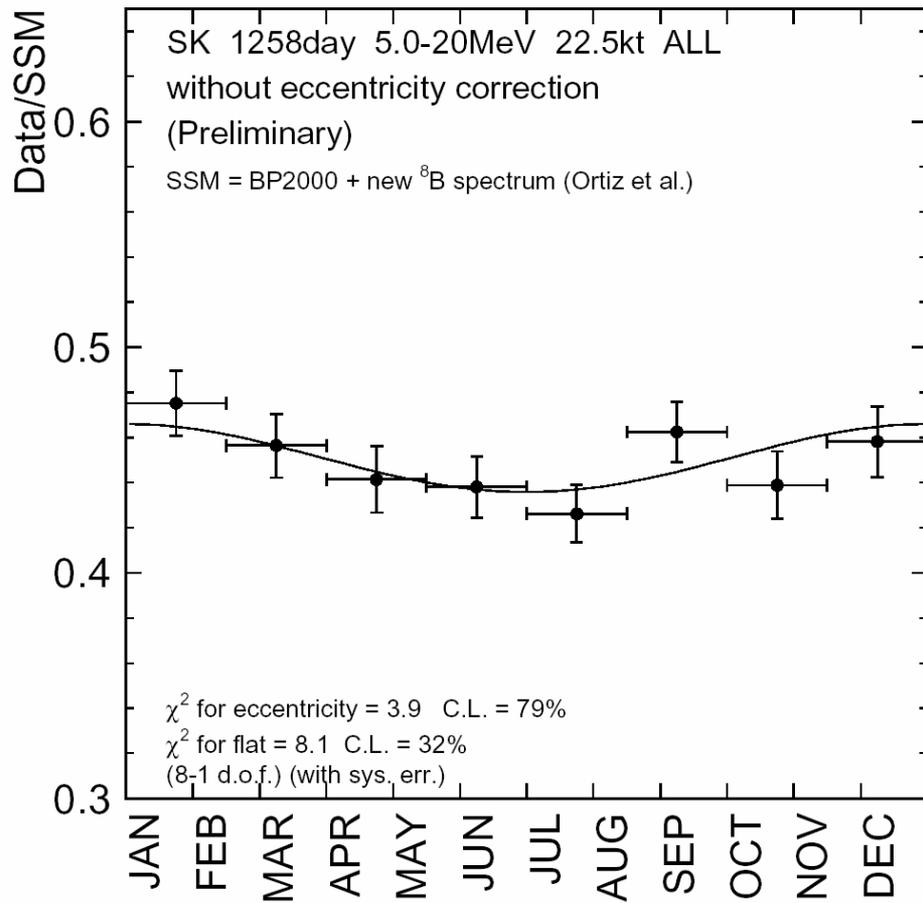


# Solar Neutrinos in Super-K

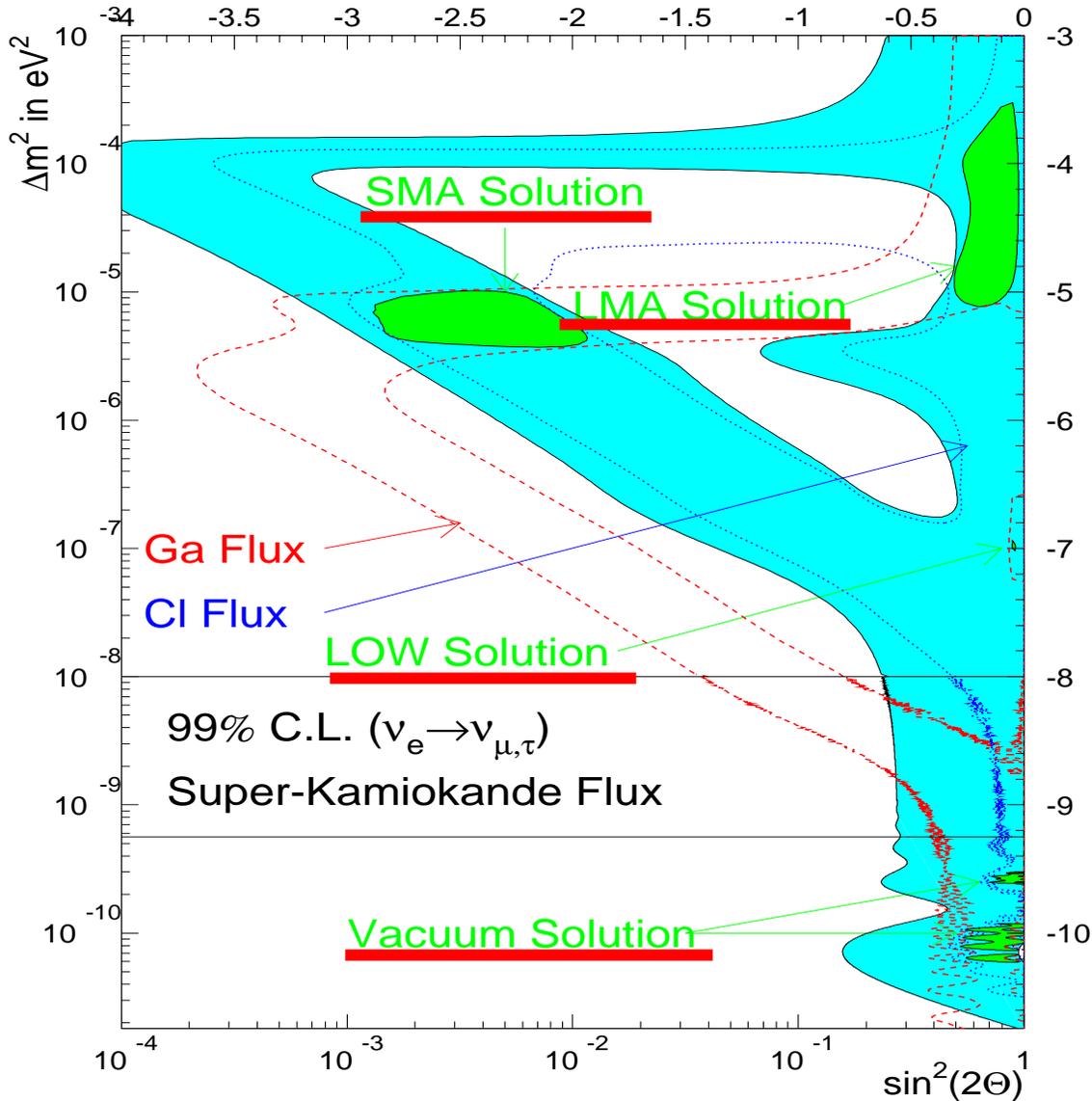
- 1258 day sample (22.5 kiloton fiducial volume)
- Super-K measures:
  - The flux of  $^8\text{B}$  solar neutrinos
  - Energy spectrum and direction of recoil electron
    - Energy spectrum is flat from 0 to  $T_{\text{max}}$
  - The zenith angle distribution
  - Day / Night rates
  - Seasonal variations



# Seasonal/Sunspot Variation

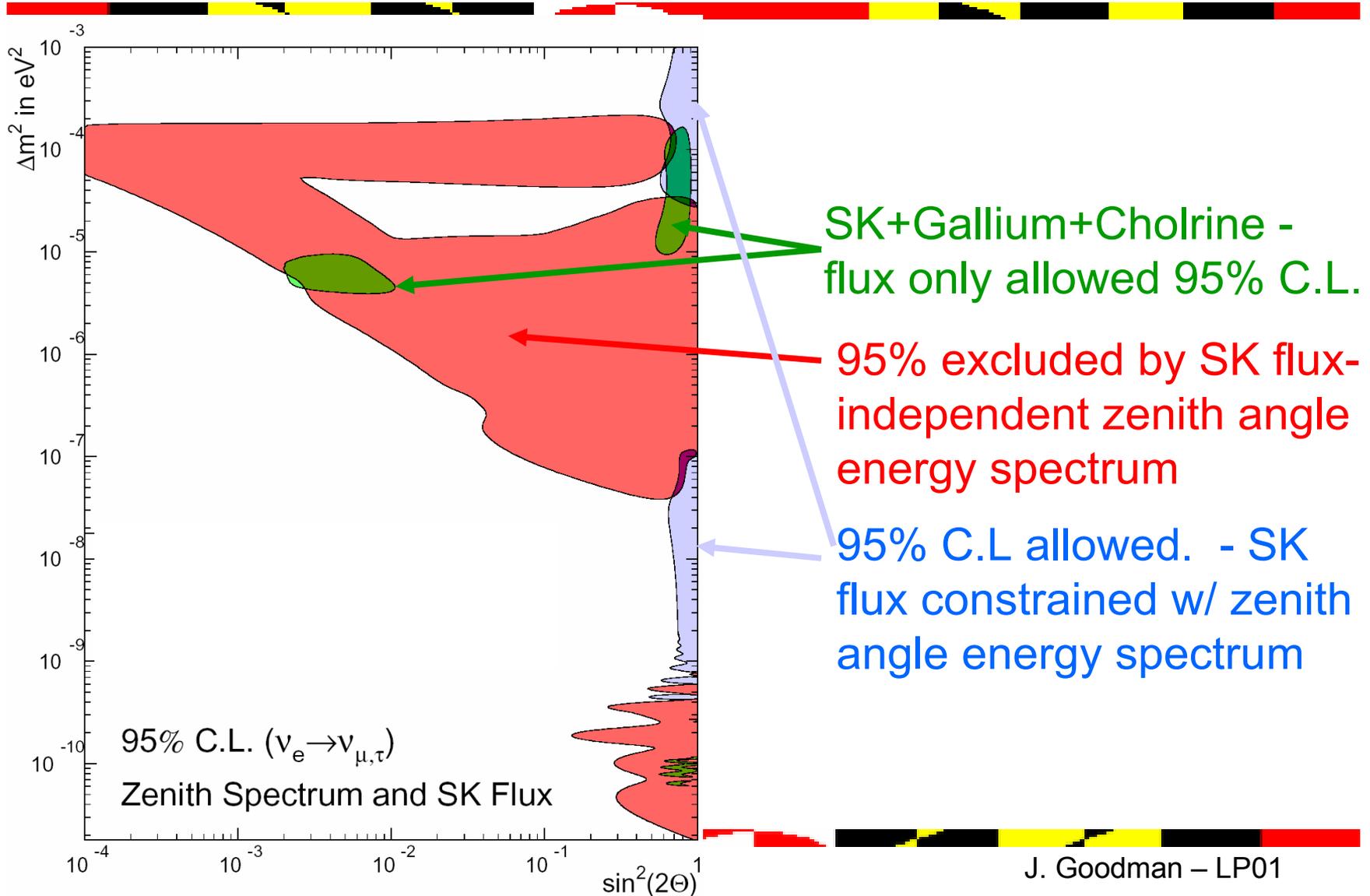


# Oscillation parameters based on flux of Homestake, GALLEX, SAGE and SK



$\nu_e \rightarrow \nu_{\mu}(\nu_{\tau})$   
99% C.L.

# Combined Results $\nu_e$ to $\nu_{\mu,\tau}$



# Macierze mieszania

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Macierz mieszania neutrin okazuje się być ~biliniowa:

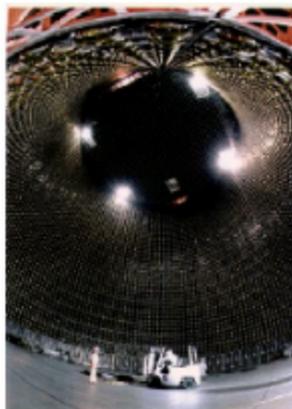
$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

zupełnie różna od macierzy mieszania kwarków:

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} \sim 1 & \lambda & \sim A\lambda^3 \\ -\lambda & \sim 1 & A\lambda^2 \\ \sim A\lambda^3 & -A\lambda^2 & 1 \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

gdzie  $\lambda=0.224$ ,  $A\lambda^2=0.0036$

# K2K = 1st Generation Long Baseline Experiment



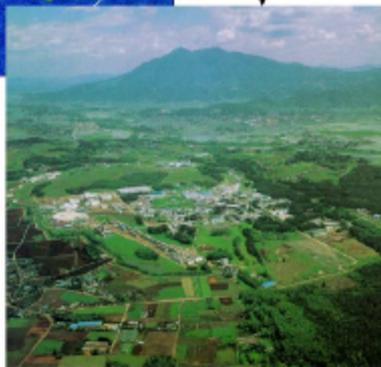
## Super Kamiokande

Water Cherenkov detector

Total mass: 50 kton

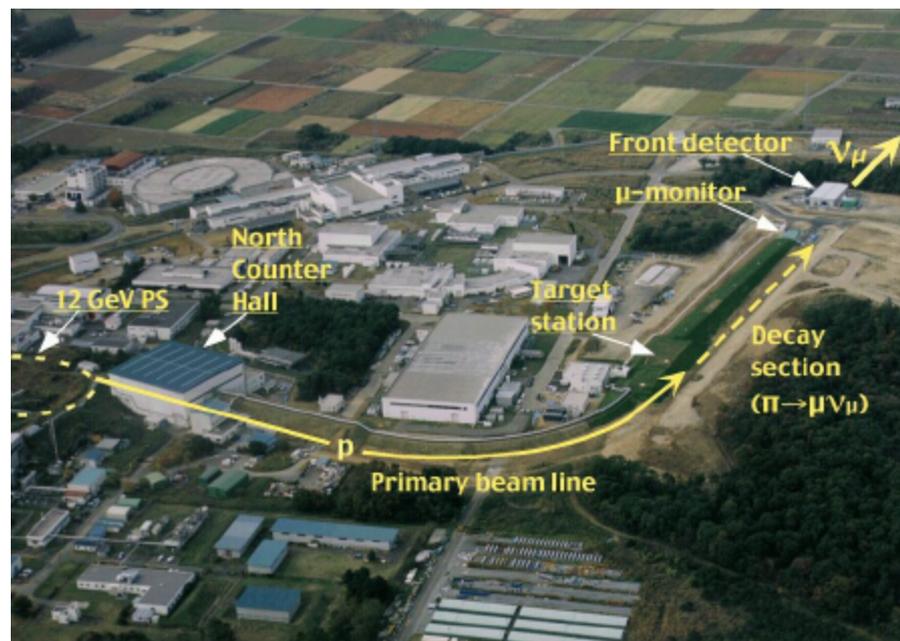
Inner mass: 32 kton

Fiducial mass: 22.5 kton



KEK

- Accelerator: 12 GeV proton synchrotron
  - Beam intensity:  $6 \times 10^{12}$  protons / pulse
  - Repetition: 1 pulse / 2.2 sec
  - Pulse width: 1.1 ns (9 bunches)
- Horn-focused wide-band beam
  - Average neutrino energy: 1.3 GeV
- Near detector: 300 m from the target
- Far detector (Super-Kamiokande): 250 km from the target
- Goal:  $10^{20}$  protons on target



## Katastrofa w Super-Kamiokande 12.11.2001

Pęknięcie fotopowielacza wywołało  
falę uderzeniową 60 Atm,  
która zniszczyła 7000  
z 11000 fotopowielaczy

20M\$/20ms

Odbudowa: 5000 fotopowielaczy  $\Rightarrow$  wyższy próg na  $\nu$  słoneczne i supernowe,  
ale wystarczający do atmosferycznych, K2K i rozpadu protonu

# Ostatnie wydarzenia

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## NA48 (CERN), KTeV (Fermilab)

Obserwacja bezpośredniego łamania CP dla kaonów

$$\text{Re}(\varepsilon'/\varepsilon) = (17.7 \pm 1.8) \cdot 10^{-4}$$

- $\varepsilon$ :  $K^0_L \rightarrow K^0_S \rightarrow \pi\pi$  — łamanie CP przez mieszanie kaonów
- $\varepsilon'$ :  $K^0_L \rightarrow \pi\pi$  — bezpośrednie łamanie CP

⇒ bariogeneza

## BELLE (KEK, Tsukuba), BABAR (SLAC, Stanford)

Obserwacja łamania CP dla kwarków b (w rozpadach  $B^0_d$ )

$$\sin 2\beta = 0.59 \pm 0.14$$

⇒ bariogeneza

## RHIC (Brookhaven)

Uruchomienie akceleratora ciężkich jonów RHIC

130 GeV na parę nukleonów

badanie plazmy kwarkowo-gluonowej

⇒ wczesne fazy Wszechświata

## CDF, D0 (Fermilab)

Rozpoczęcie "run II" TeVatronu — 2 TeV

Poszukiwanie higgosa do 180 GeV

# Particle physics today

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The Standard Model precisely describes both electroweak and strong interactions. No significant deviation from its predictions was observed so far.

## But:

- it has ~20 free parameters
- particle masses are generated by Higgs mechanism, not determined within the Standard Model
- Higgs particle was not observed so far
- Standard Model does not explain
  - existence of 3 generations of fermions
  - mixing between different generations

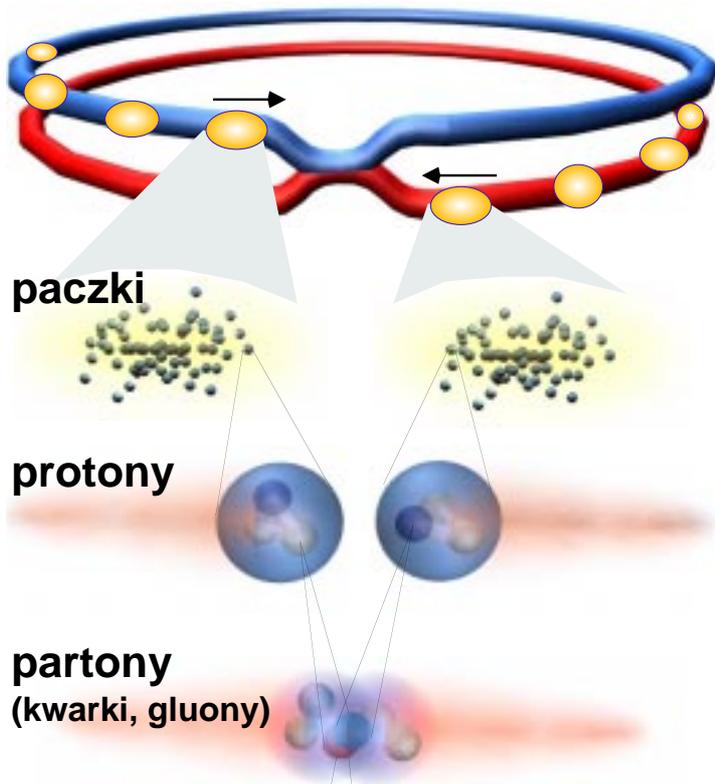
## Strategy for the near future:

- find Higgs particle or exclude its existence in the region allowed by theory (~1 TeV)
- look for deviations from the Standard Model
- search for new particles (~50 GeV — ~5 TeV)

## Needed tools

- **accelerator:** **LHC**
  - high energy: **14 TeV**
  - wide energy range: “for free” in **pp beams**
  - high luminosity:  **$10^{34} \text{cm}^{-2} \text{s}^{-1}$**
- **detectors:** **ATLAS, CMS, LHC-B, ALICE**
  - universal (e,  $\gamma$ ,  $\mu$ , jets, missing energy)
  - fine grained (large number of particles):  **$\sim 10^7$  channels**
  - fast (high luminosity): **25 ns bunch crossing**

# Zderzenia proton-proton w LHC



paczki

protony

partony  
(kwarki, gluony)

produkty  
zderzenia

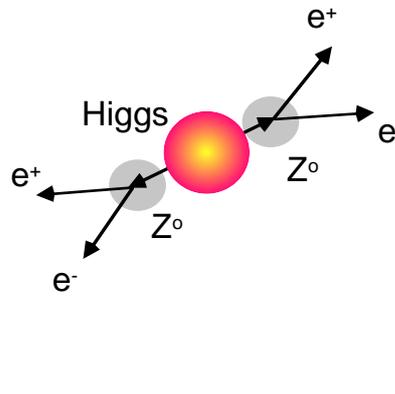
jet

jet

<b>energia</b>	<b>7+7 TeV</b>
<b>obwód</b>	<b>27 km</b>
<b>pole mag.</b>	<b>8.4 T</b>
<b>światłość</b>	<b><math>10^{34} \text{cm}^{-2}\text{s}^{-1}</math></b>
<b># paczek</b>	<b><math>2 \times 2875</math></b>
<b>#p / paczka</b>	<b><math>10^{11}</math></b>

**przecięcia paczek:**

<b>częstość</b>	<b>40 MHz</b>
<b>odstęp</b>	<b>25 ns</b>
<b>czyli</b>	<b>7.5 m</b>



**Przy nominalnej światłości w każdym przecięciu paczek znajdzie 10-20 zderzeń proton-proton.**



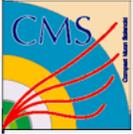
**LHC**

**CMS**

**ATLAS**

Area map of  
CERN site

- Legend:
- CERN sites
  - accelerator
  - LEP experiment
  - motorway
  - road
  - city
  - border



# Compact Muon Solenoid @ LHC

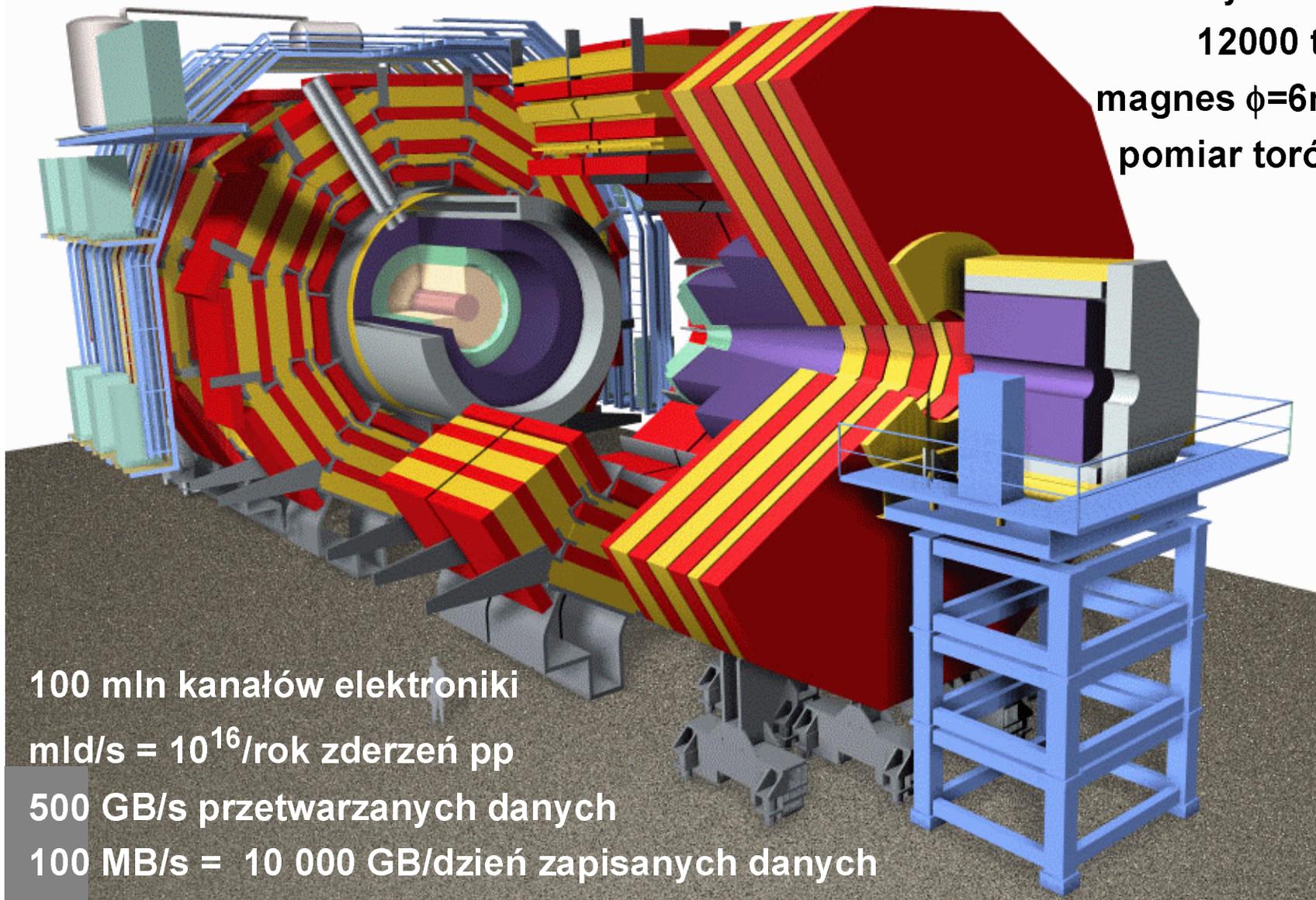
projekt i budowa 1990-2006

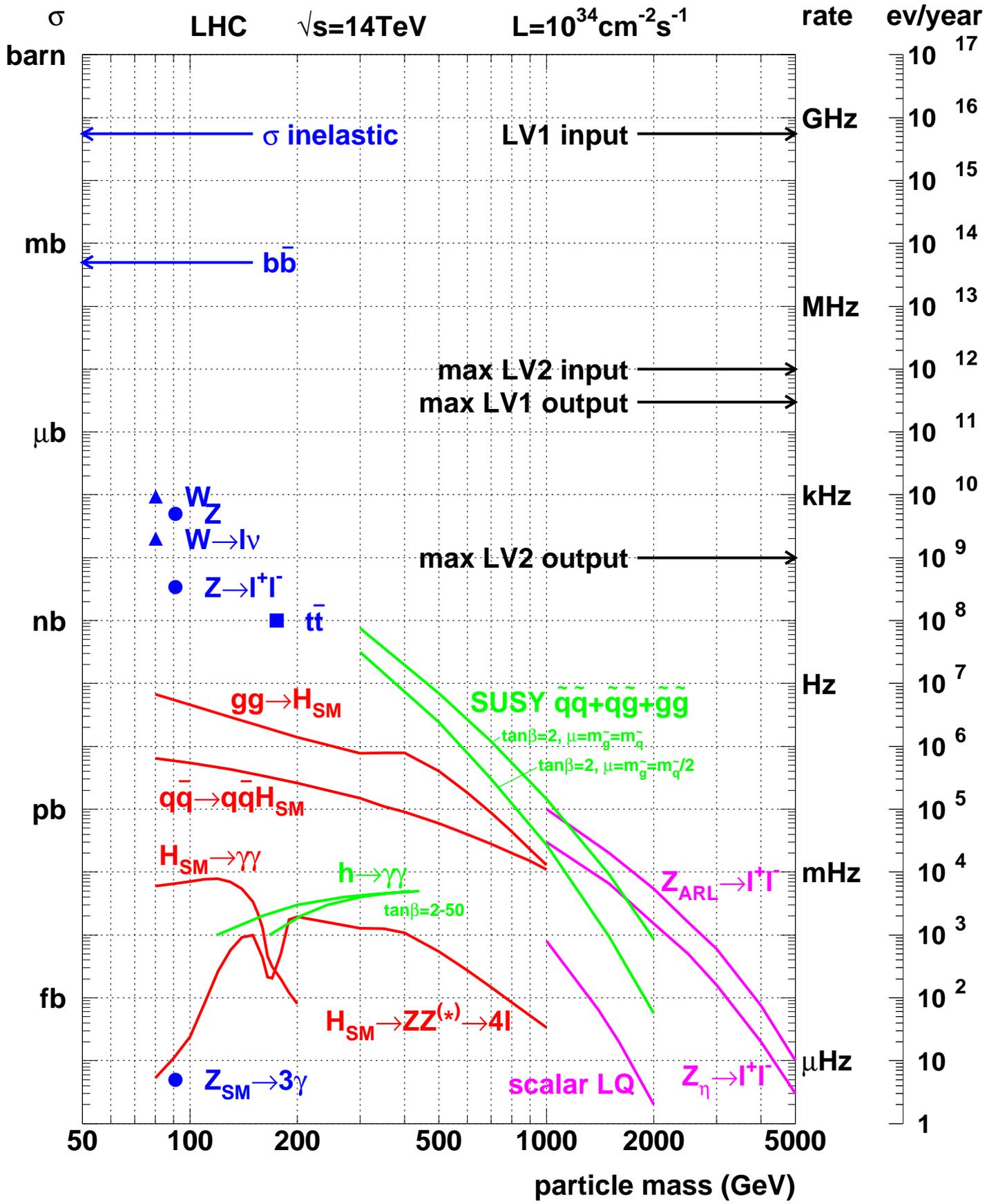
2000 fizyków z 30 państw

12000 ton, 22x15 m

magnes  $\phi=6\text{m}$ , 4T, 1000 A

pomiar torów 20-100 $\mu\text{m}$





# Selekcja przypadków

---

W ciągu 10 lat pracy LHC zajdzie  $10^{17}$  zderzeń pp.

Zaobserwowanie 10 “egzotycznych” przypadków może stanowić epokowe odkrycie “nowej fizyki”.

Należy jednak umieć odszukać owe **10** przypadków wśród wszystkich  **$10^{17}$** .

## Szukanie igły w stogu siana?

- typowa igła —  $5 \text{ mm}^3$
- typowy stóg siana —  $50 \text{ m}^3$

$$\text{igła} : \text{stóg} = 1 : 10^{10}$$

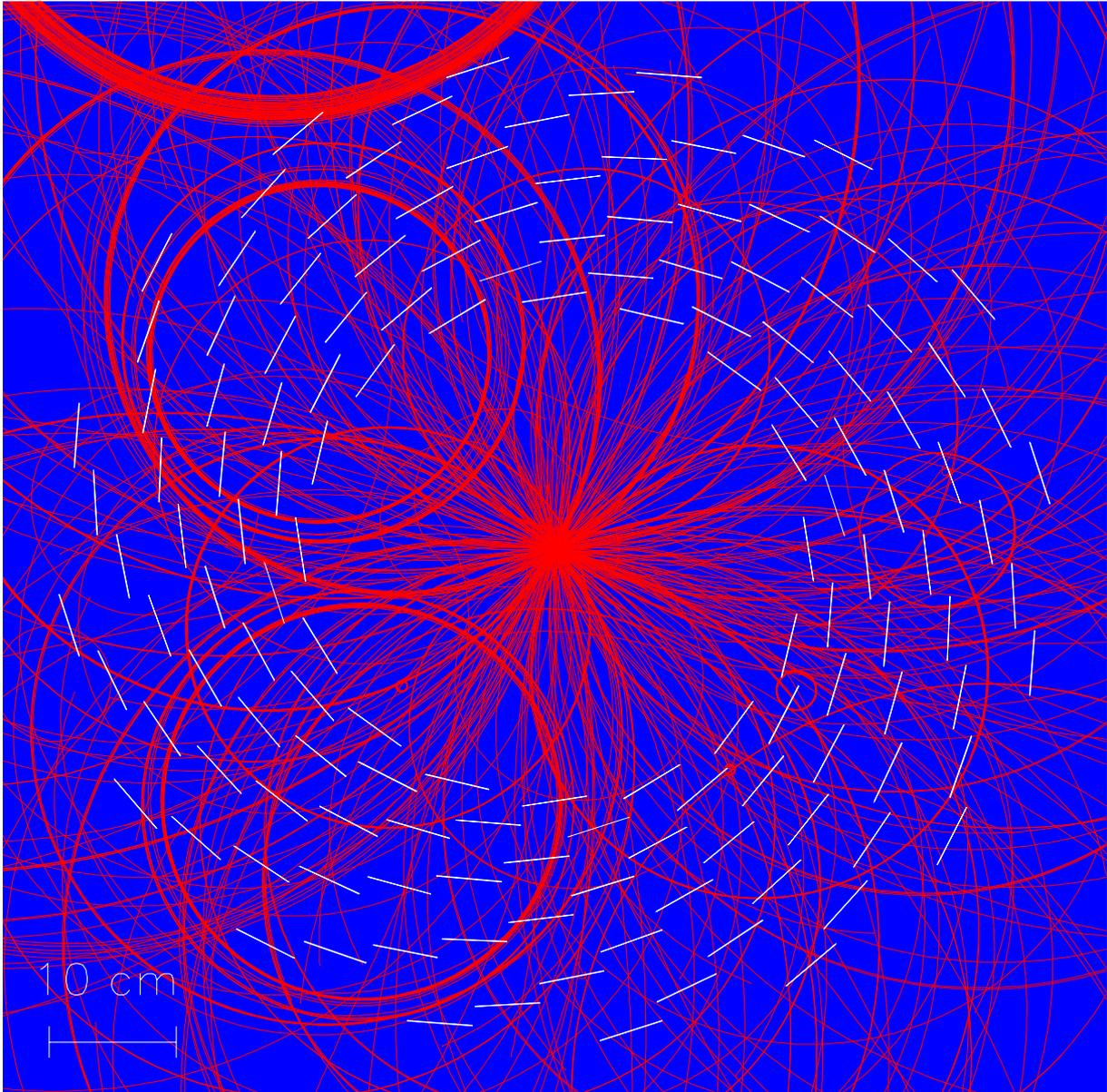
**Poszukiwanie “nowej fizyki” w LHC to szukanie igły w milionie stogów siana.**

# Łamigłówka

---

18 nałożonych zderzeń pp,  
widzianych przez wewnętrzną część krzemowego detektora  
mikropaskowego.

**Wśród nich rozpad cząstki Higgsa na 4 miony.**



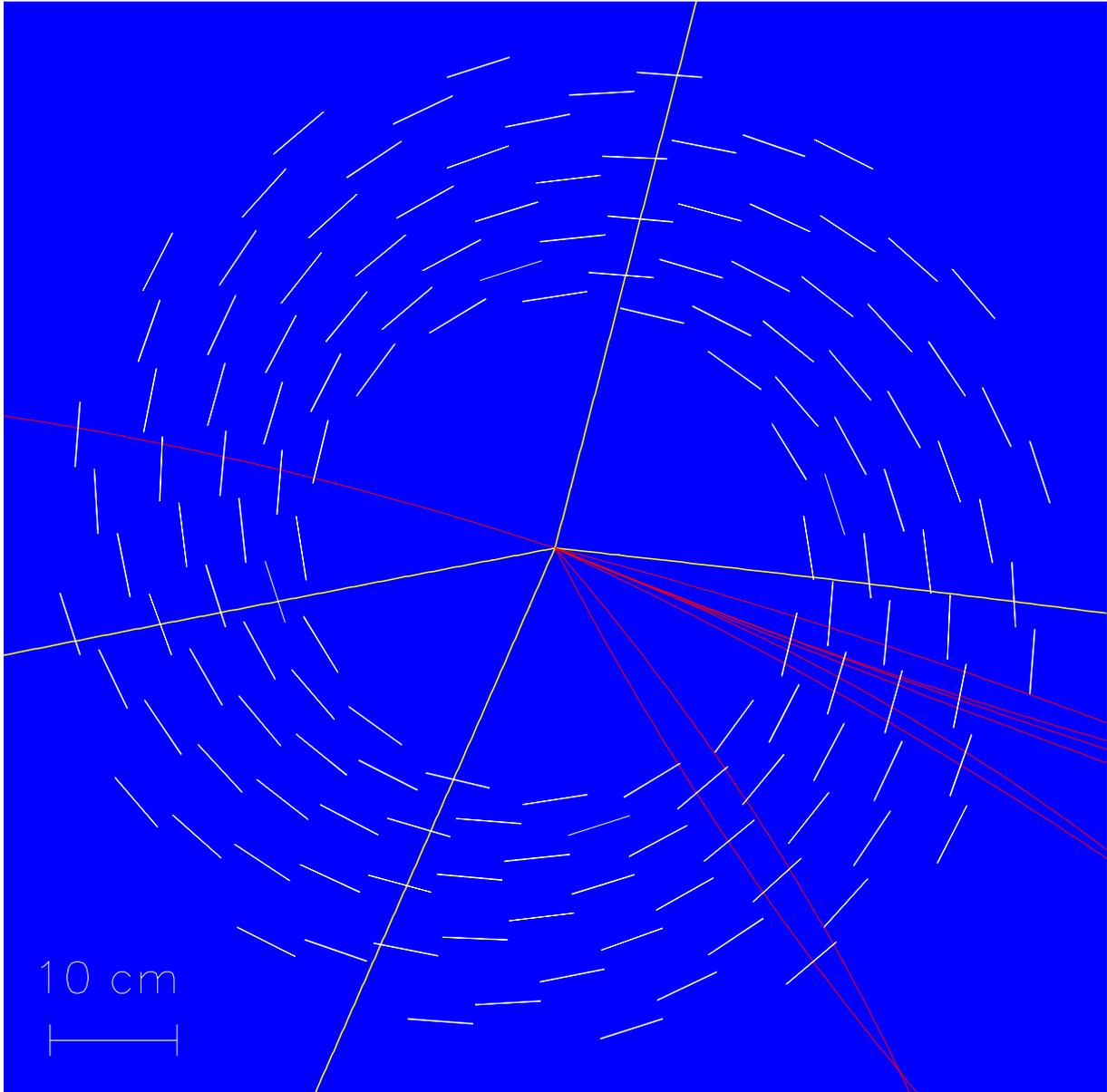
**Znajdź 4 proste ślady.**

# Rozwiązanie łamigłówki

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Zrekonstruowane ślady o  $p_t > 2 \text{ GeV}$ .

Wśród nich dobrze widoczne 4 miony z rozpadu Higgsa.

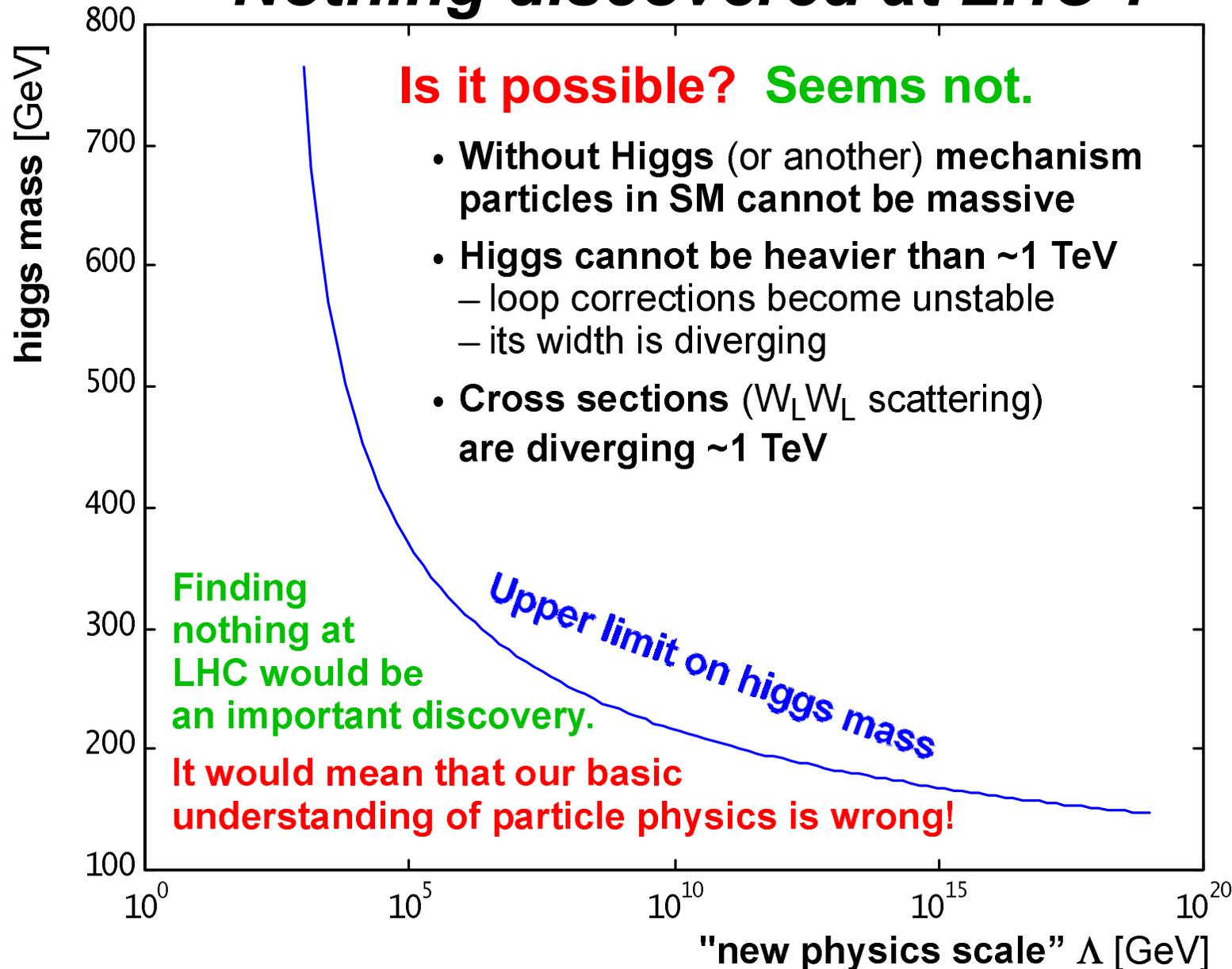


Rozwiązanie możliwe jeśli zajętość detektora  **$\sim 1\%$**

→ powierzchnia mikropaska  **$\sim 1 \text{ mm}^2$**

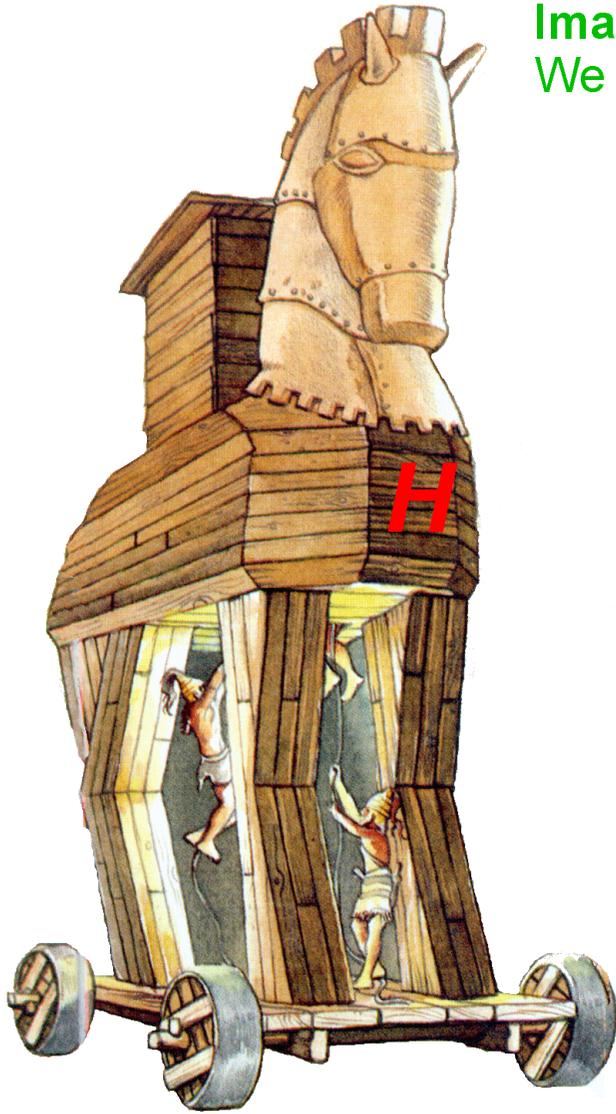
→  **$> 10^7$**  kanałów odczytu

# Nothing discovered at LHC ?



# SM higgs — The Trojan **H**orse

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Imagine, that we turn on LHC and we find just SM higgs. We will behave like Trojans finding the Wooden Horse:

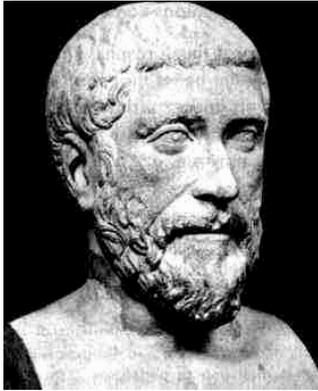
- We will announce it to the world.
- We will celebrate our great victory.
- There will be laurel wreaths for heroes (Nobel) and festivities for the crowd,
- TV shows and newspaper covers ...

*But this will be the beginning of the end ...*

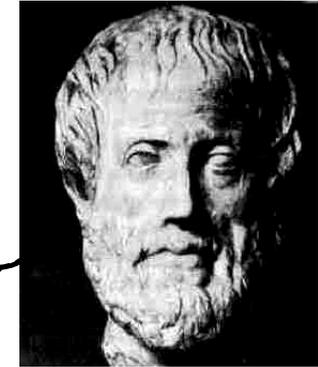
We will be left with

- the **Standard Model** which works perfectly, but we do not understand why,
- the **Higgs mechanism** which we do not know where it comes from,
- **nonunified forces, random symmetries, and ~20 arbitrary parameters,**
- with no hint what is behind,
- no idea what to do next ...

# Philosophers on Supersymmetry

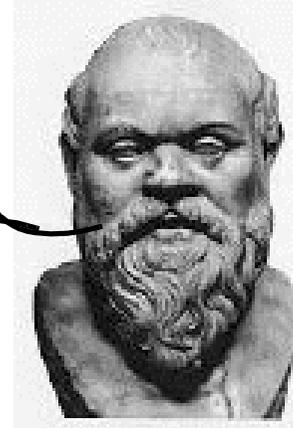


Each **fermion** has corresponding **boson** and vice versa.



Each **discovered** particle has **undiscovered** supersymmetric partner.

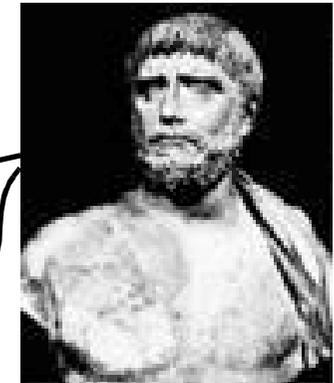
Each **existing** particle has **nonexistent** supersymmetric partner.



**No** supersymmetric particle have been discovered so far.

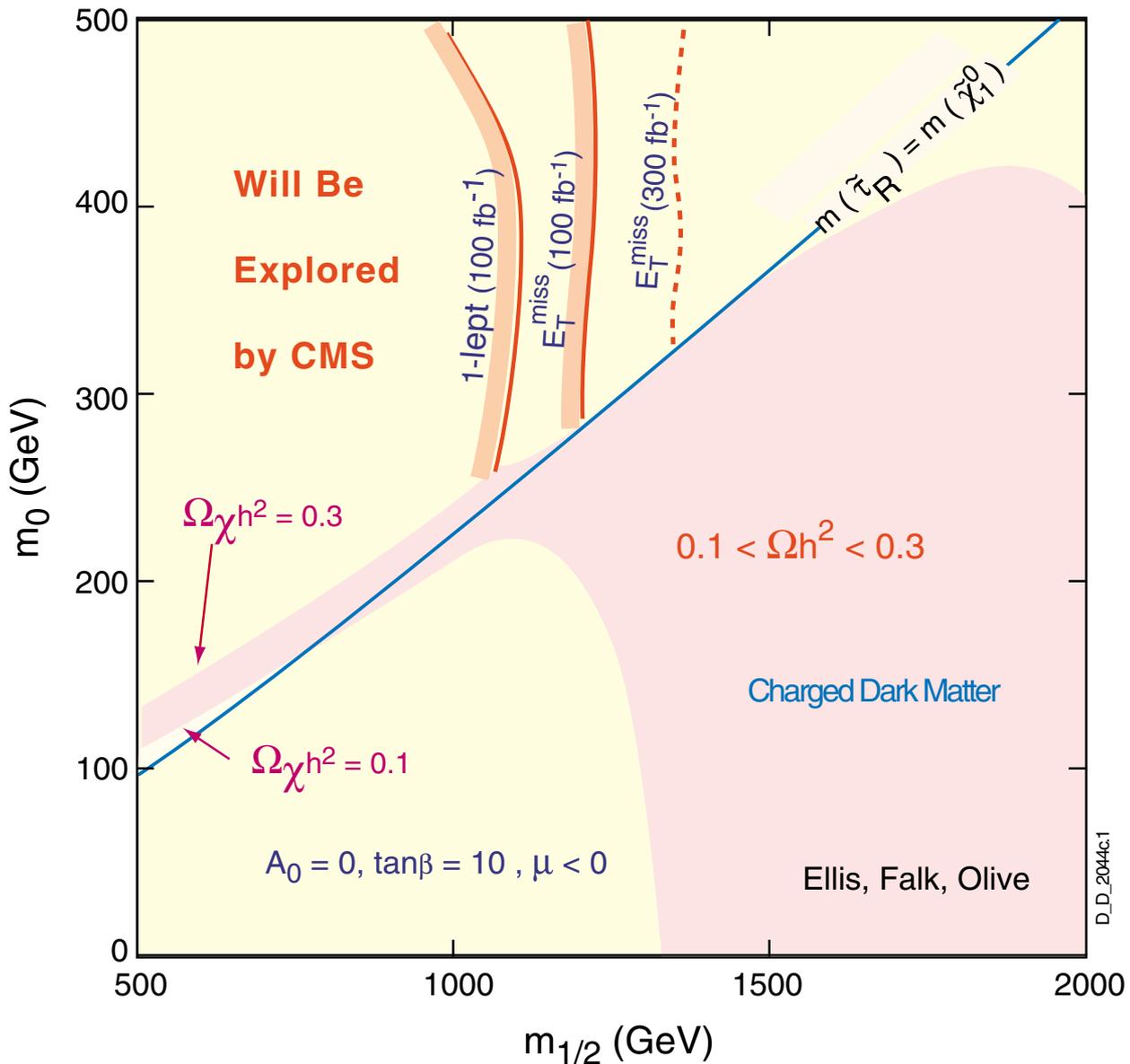


**Half** of all particles predicted by supersymmetry have been already discovered.

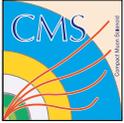


# Relic $\tilde{\chi}_1^0$ density contours in mSUGRA

- after inclusion of  $\tilde{\tau}_R \tilde{\chi}_1^0 + \dots$  co-annihilation channels -
- upper limit on cosmologically acceptable  $m(\tilde{\chi}_1^0)$
- reach at LHC/CMS in various final state topologies



→ upper limit on  $m_{1/2} \approx 1400$  GeV  
 thus on  $m(\tilde{\chi}_1^0) \approx 600$  GeV



# Hierarchy problem

## Two fundamental scales:

- Electroweak —  $M_{EW} \sim 10^2-10^3$  GeV
- Planck —  $M_{Pl} \sim 10^{19}$  GeV

## Observation:

- $M_{EW}$  is established experimentally
  - EW interactions are tested down to distances  $1/M_{EW} \sim 10^{-17}$  cm
- $M_{Pl}$  is just a number
  - gravity tested only down to  $\sim 1$  mm, far away from  $1/M_{Pl} \sim 10^{-35}$  m

## Solution: cut the Gordian Knot!

- There is only one fundamental scale:  $M_{EW}$
- $M_{Pl}$  is just an effective constant
- Its high value is caused by additional spatial dimensions, compactified at radius  $R \sim 1$  mm



# 4+n dimensional gravity (ADD)

N.Arakani-Hamed, S.Dimopoulos, G.Dvali,  
hep-ph/9803315

R — compactification radius

$M_S$  — 4+n dimensional “Planck scale”

## Gravitational potential in 4+n dim space

for small distances  $r \ll R$

$$V(r) = \frac{m_1 m_2}{M_S^{n+2}} \cdot \frac{1}{r^{n+1}}$$

for large distances  $r \gg R$

$$V(r) = \frac{m_1 m_2}{M_S^{n+2} R^n} \cdot \frac{1}{r}$$

This becomes the Newton's law  
with

$$M_{Pl}^2 = M_S^{n+2} R^n$$

Let us put  $M_S \sim M_{EW}$   
(no hierarchy!)

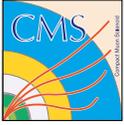
$$R = 10^{\frac{30}{n} - 17} \text{ cm}$$

$n=1 \rightarrow R=10^8 \text{ km}$

- Solar System distances,  
gravity very well tested

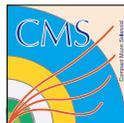
$n=2 \rightarrow R=0.1 \text{ mm}$

- just beyond the current limits



# *ADD phenomenology*

- “Tower” of graviton excitations  $k \cdot m_1$   
where  $m_1 = 400 \text{ eV}$  for  $n=1$
- ADD gravitons couple to momentum tensor and therefore contribute to most of SM processes
- Gravitons can propagate through other dimension  
 $\Rightarrow$  graviton emission apparently violate energy conservation
- Graviton spin of 2 can point to other dimension  
 $\Rightarrow$  apparent spin 0, 1 or 2
- Cross sections are divergent with  $s$   
 $\Rightarrow$  explicit cut-off required



# ADD signatures & limits

- **Supernova cooling** (Kamiokande  $\nu$ )

- $M_S > 30$  TeV (n=2)
- $M_S > 4$  TeV (n=3)

- **Cosmic diffuse  $\gamma$  radiation** ( $G \rightarrow \gamma\gamma$ )

- $M_S > 100$  TeV (n=2)
- $M_S > 5$  TeV (n=3)

- **LEP2:  $e^+e^- \rightarrow \gamma G, ZG$**

- $M_S > 1.2$  TeV (n=2)
- $M_S > 0.8$  TeV (n=4)

- **LEP2:  $e^+e^- \rightarrow G \rightarrow ZZ, ff, \gamma\gamma, WW$**

- $M_S > 1.2$  TeV

- **HERA:  $ep \rightarrow G \rightarrow ep$**

- $M_S > 0.81 - 0.93$  TeV

- **Tevatron:  $e^+e^- \rightarrow G \rightarrow e^+e^-, \gamma\gamma$**

- $M_S > 1.0 - 1.1$  TeV

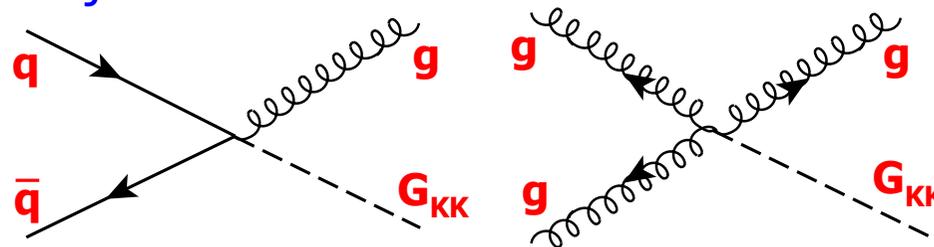
**Expected:**

- **Tevatron run II:  $e^+e^- \rightarrow gG$**

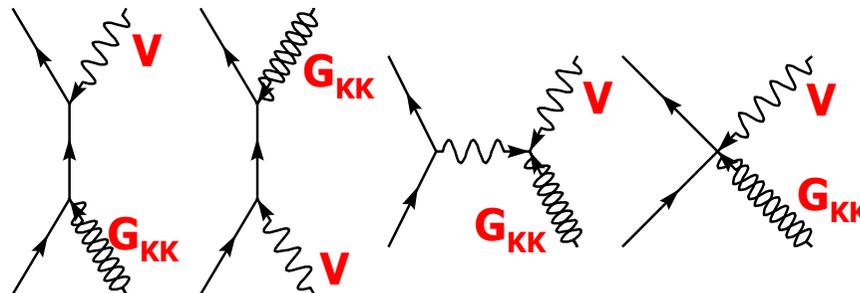
- $M_S > 1.4$  TeV (n=2)
- $M_S > 1.15$  TeV (n=3)
- $M_S > 1.0$  TeV (n=4)

## Real Graviton Emission

Monojets at hadron colliders

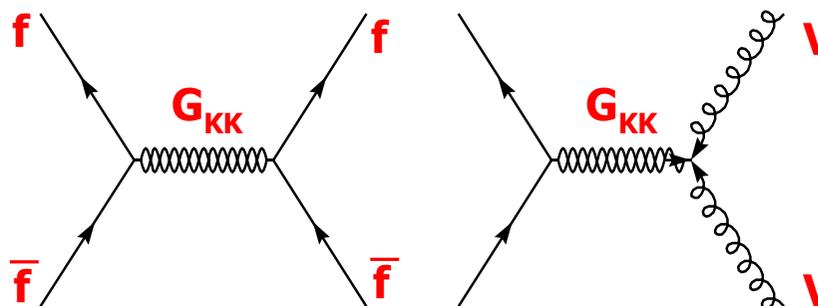


Single VB at hadron or  $e^+e^-$  colliders



## Virtual Graviton Emission

Fermion or VB pairs at hadron or  $e^+e^-$  colliders



Ka  
mc  
COI

FoI  
+

+

Sir  
en  
in  
vie

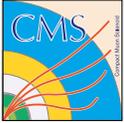
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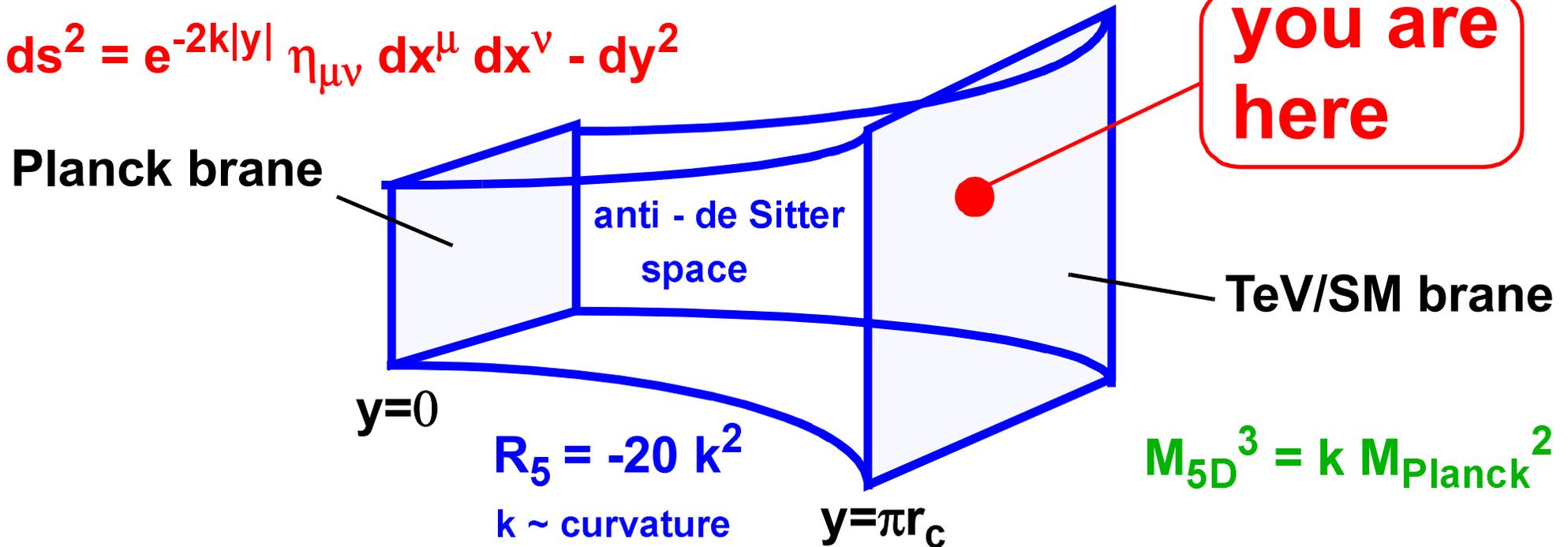
20



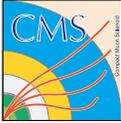
# Warped Extra Dimensions

Randall, Sundrum, PRL 83, 3370 (1999)

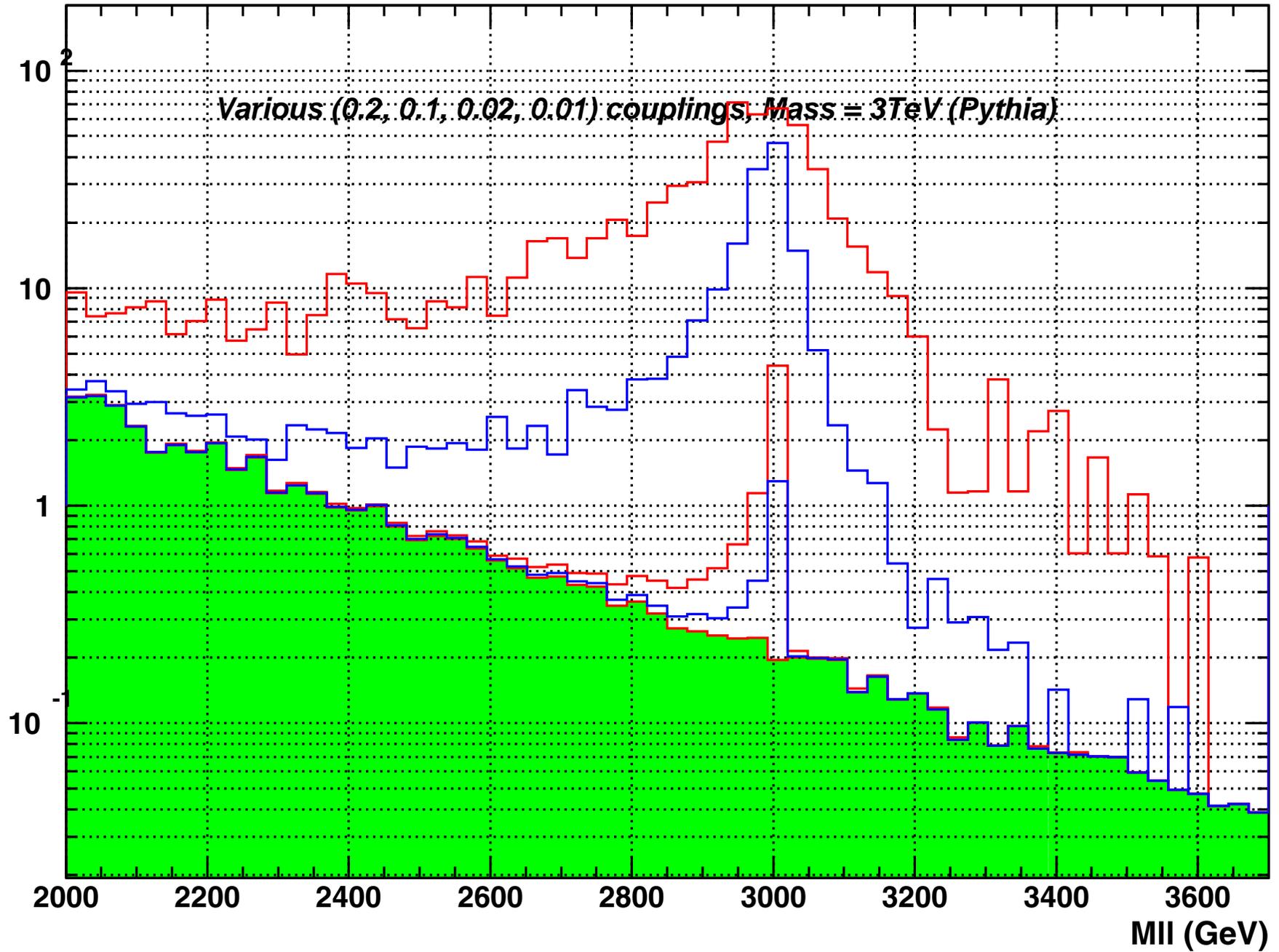
$$ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$



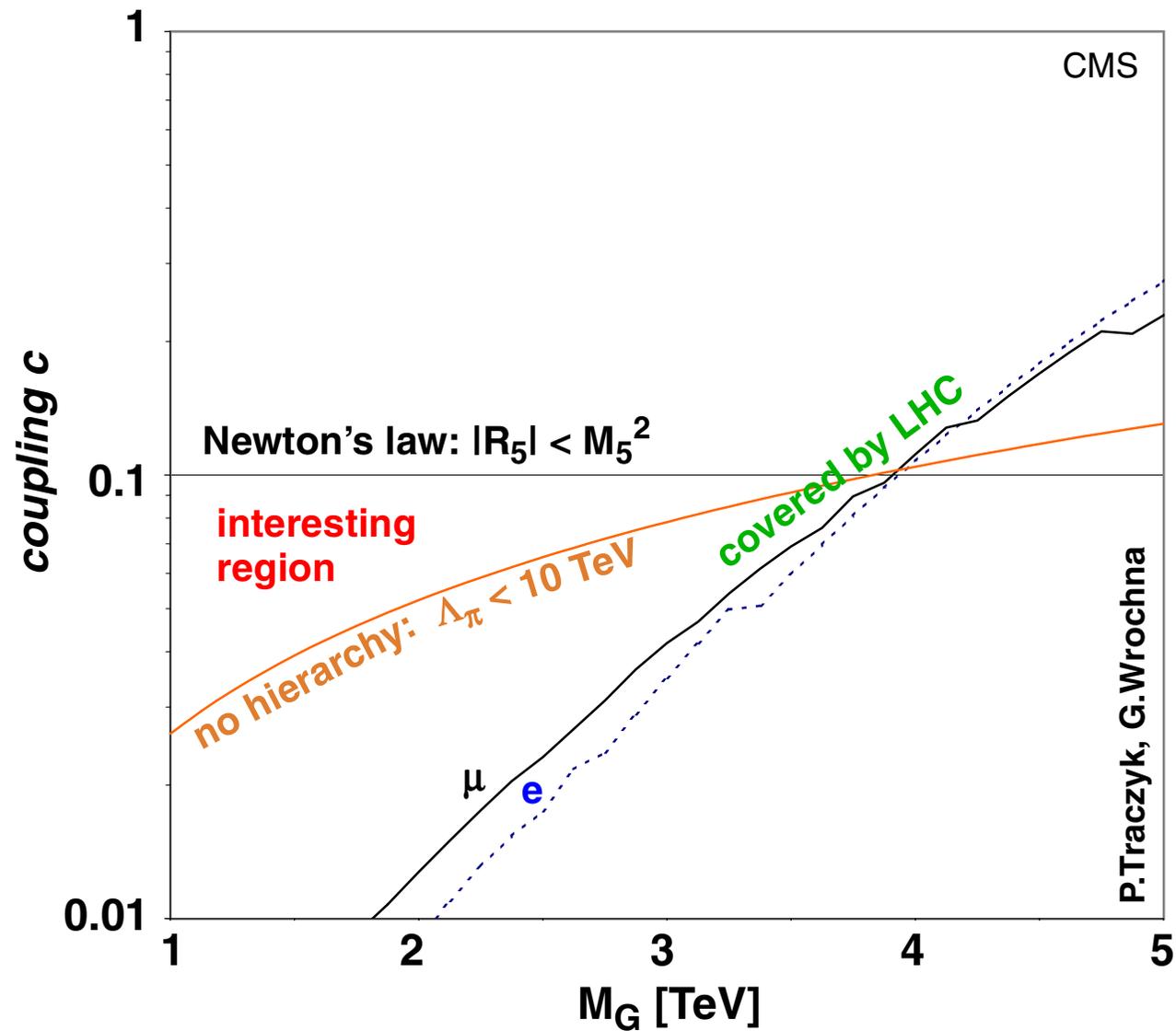
- Gravity strong at  $y=0$  and falls like  $\exp(-ky)$
- Gravity scale  $\Lambda_\pi = M_{\text{Planck}} \exp(-k\pi r_c) \sim \text{TeV}$  — no hierarchy
- Graviton resonances  $m_n = x_n k \exp(-k\pi r_c)$ ,  $J_1(x_n)=0$
- $M_{\text{Planck}}/M_{\text{electroweak}} \Rightarrow kr_c \sim 11-12$
- Newton's law  $\Rightarrow |R_5| < M_{5D}^2 \Rightarrow \text{coupling } c < 0.1$



# Coupling **0.2**, **0.1**, **0.02**, **0.01**

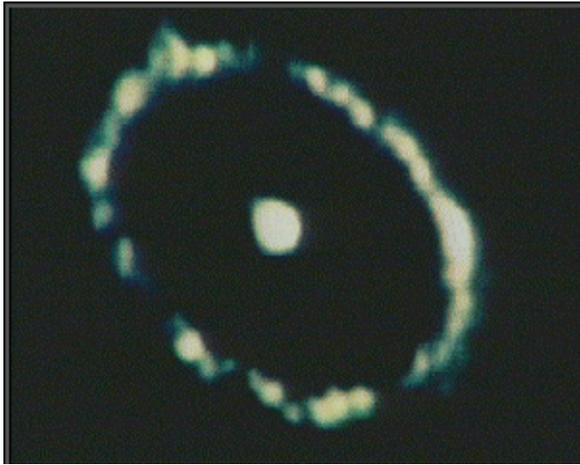


# Randall - Sundrum gravitons at LHC

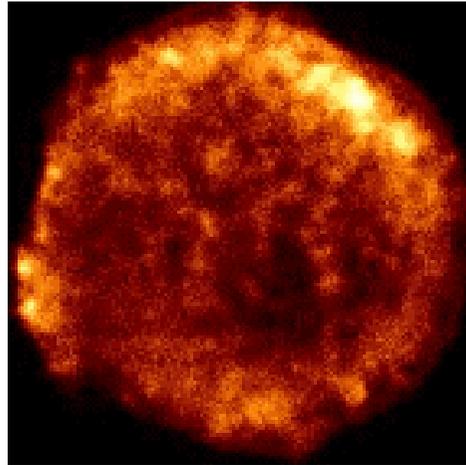


# Cosmic Particle Accelerators

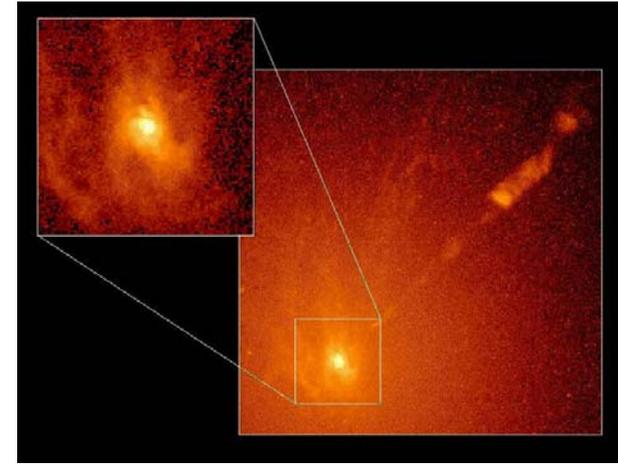
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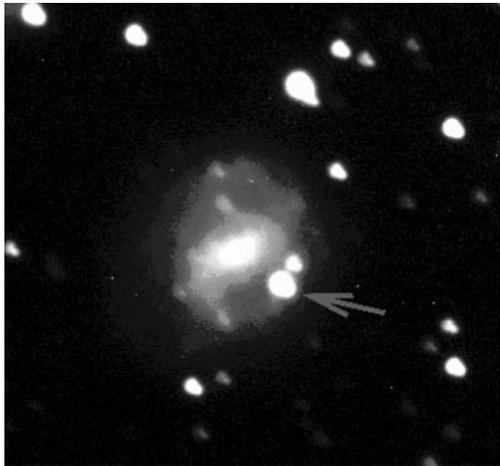
Supernovae



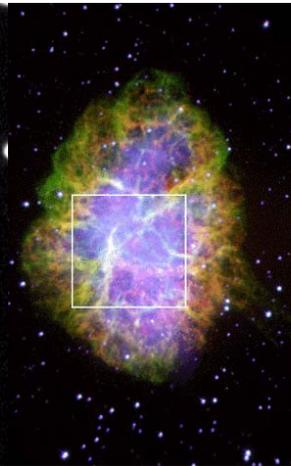
Supernova remnants



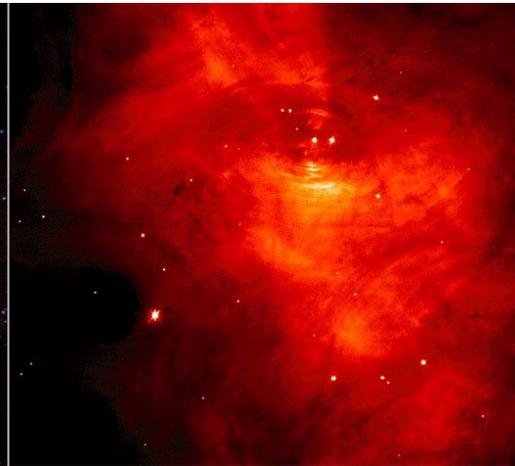
Active Galactic Nuclei



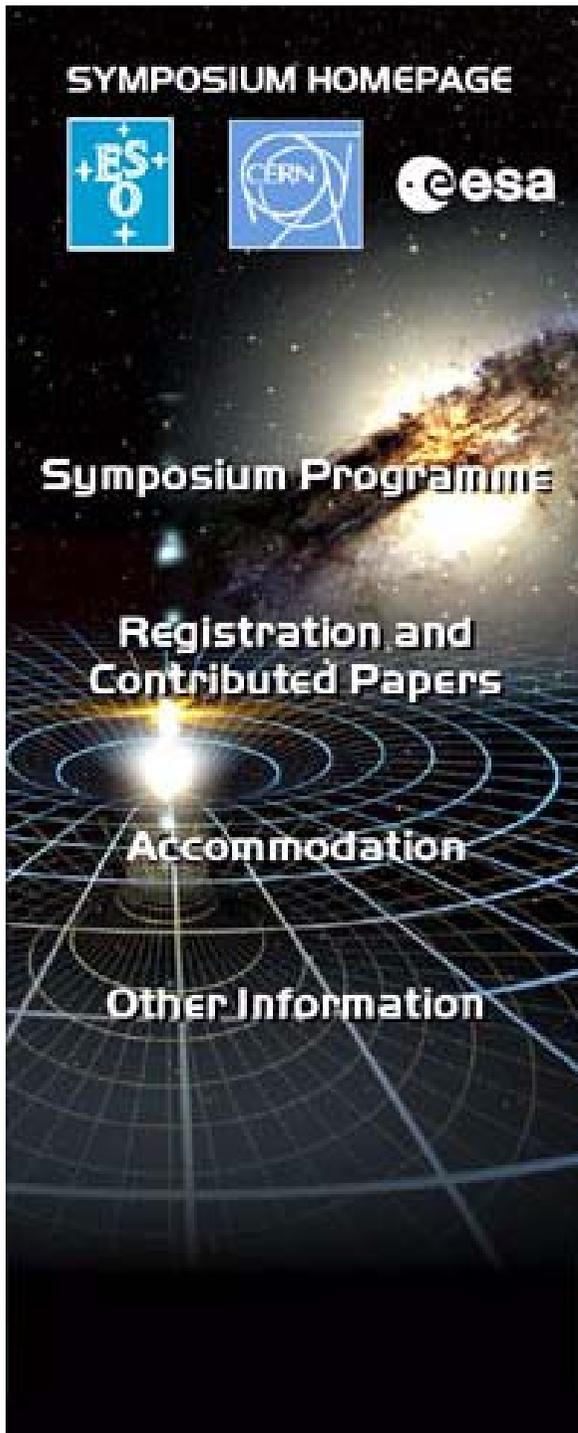
Gamma Ray Bursts



Pulsars, Plerions



Microquasars



# ESO-CERN-ESA Symposium on Astronomy, Cosmology and Fundamental Physics

Garching bei München, Germany

March 4-7, 2002

The connections between Astronomy, Cosmology and Fundamental Physics are well known, and become closer every day. Recent exciting developments in these fields include the structures in the cosmic background radiation, evidence for an accelerating Universe, searches for dark matter candidates, evidence for neutrino oscillations, space experiments on fundamental physics, and discoveries of extrasolar planets. ESO, CERN and ESA are thus involved in scientific endeavours and technologies which overlap considerably. This joint Symposium is the first to be co-organized and co-sponsored by all three organizations.

The symposium is meant to give a broad overview of scientific areas of interest to the communities of the three organizations: current observational cosmology including the microwave background fluctuations and new constraints on the cosmological parameters, searches for dark matter, high energy astrophysics (sources and backgrounds), recent developments and prospects in particle physics, fundamental physics from ground and space, extrasolar planets, and future perspectives at ESO, CERN and ESA.

<http://www.eso.org/gen-fac/meetings/symp2002/>

