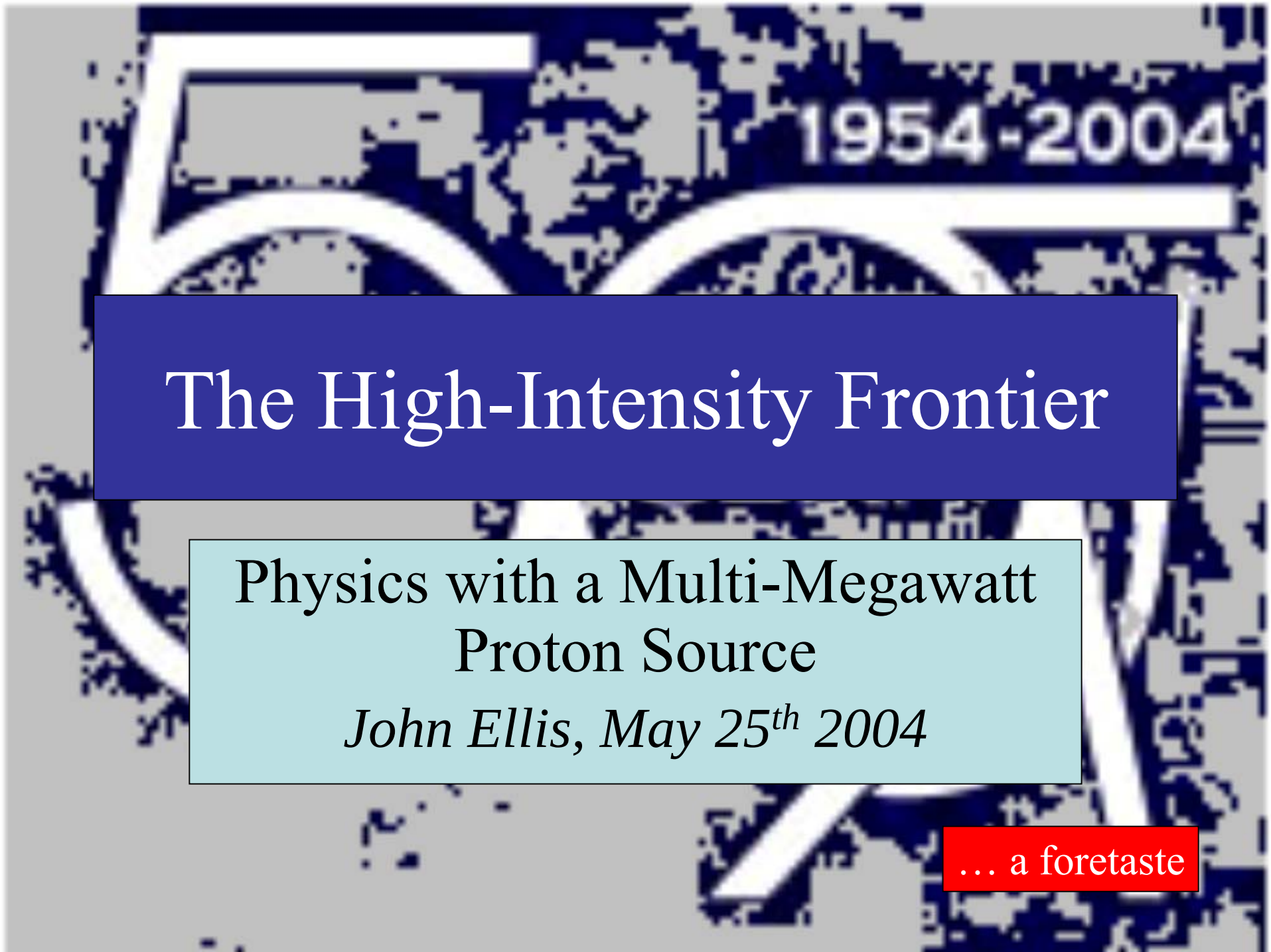


The High-Intensity Frontier

Physics with a Multi-Megawatt Proton Source

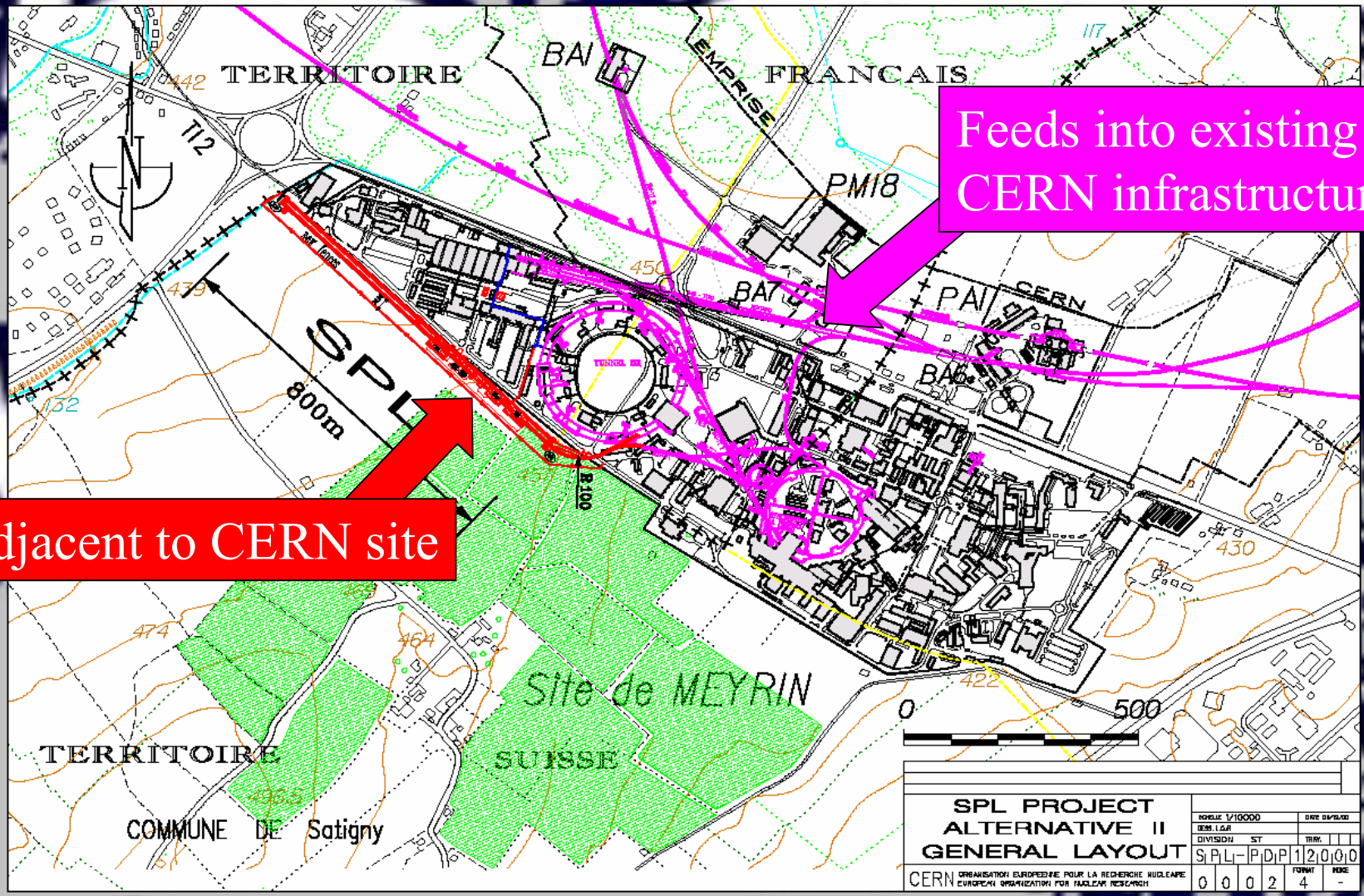
John Ellis, May 25th 2004

… a foretaste

The High-Intensity Frontier

- Exploration and understanding
  - Novel phenomena
  - Rare processes
  - High statistics
- Active option in front-line physics: factories for
  - Z, B, τ/Charm, K, antiproton, anti-Hydrogen
- Megawatt → new opportunities for
  - nuclear, ν, muon, kaon physics

Possible Layout of SPL at CERN



Feeds into existing CERN infrastructure

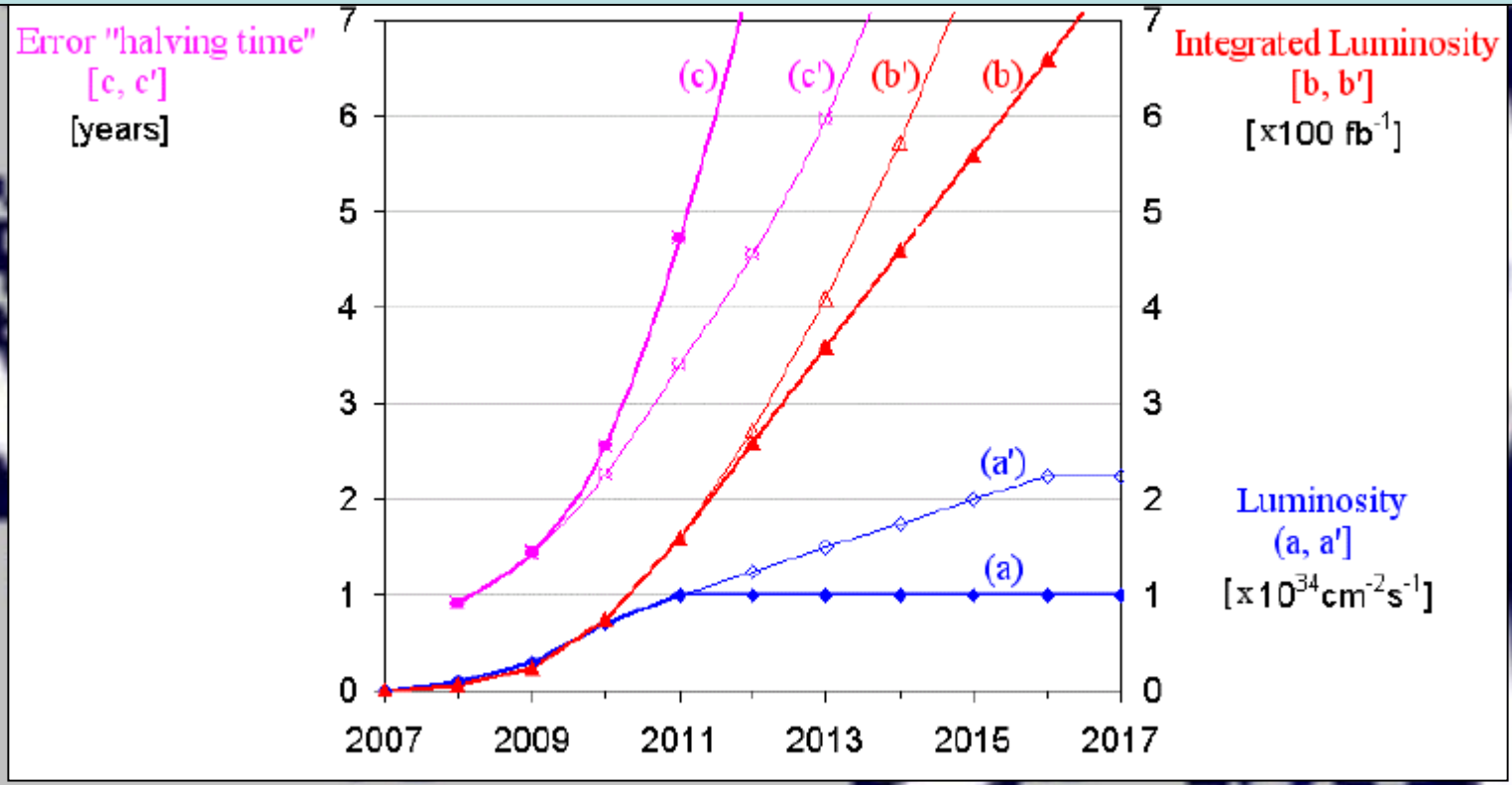
Adjacent to CERN site

SPL @ CERN Wish List

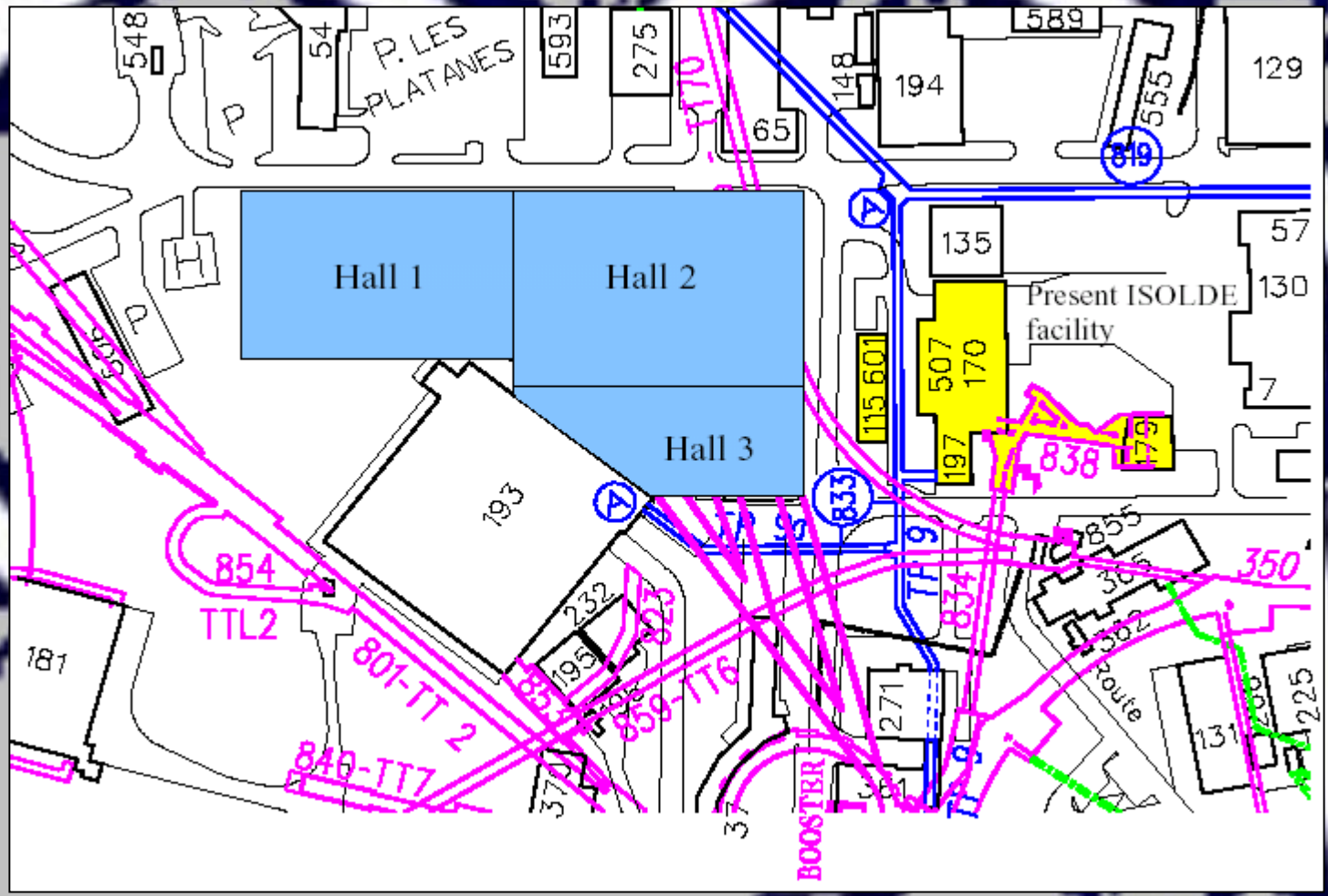
USER	CERN COMMITMENT *	USERS' WISHES	
	Short term	Medium term *[~ asap !]*	Long term *[beyond 2014]*
LHC	Planned beams	Ultimate luminosity	Luminosity upgrades
Fixed Target (COMPASS)	4.3⑨$10^5$ spills/y ?	6⑨$10^5$ spills/y	
CNGS	4.5⑨$10^{19}$ p/year	Upgrade ~ ⑨ 2	
ISOLDE	1.92 μA **	Upgrade ~ ⑨ 5	
Future beams			> 2 GeV / 4 MW
EURISOL			1-2 GeV / 5 MW

Possible Upgrades of LHC

Increase luminosity – but beware of integrated radiation dose



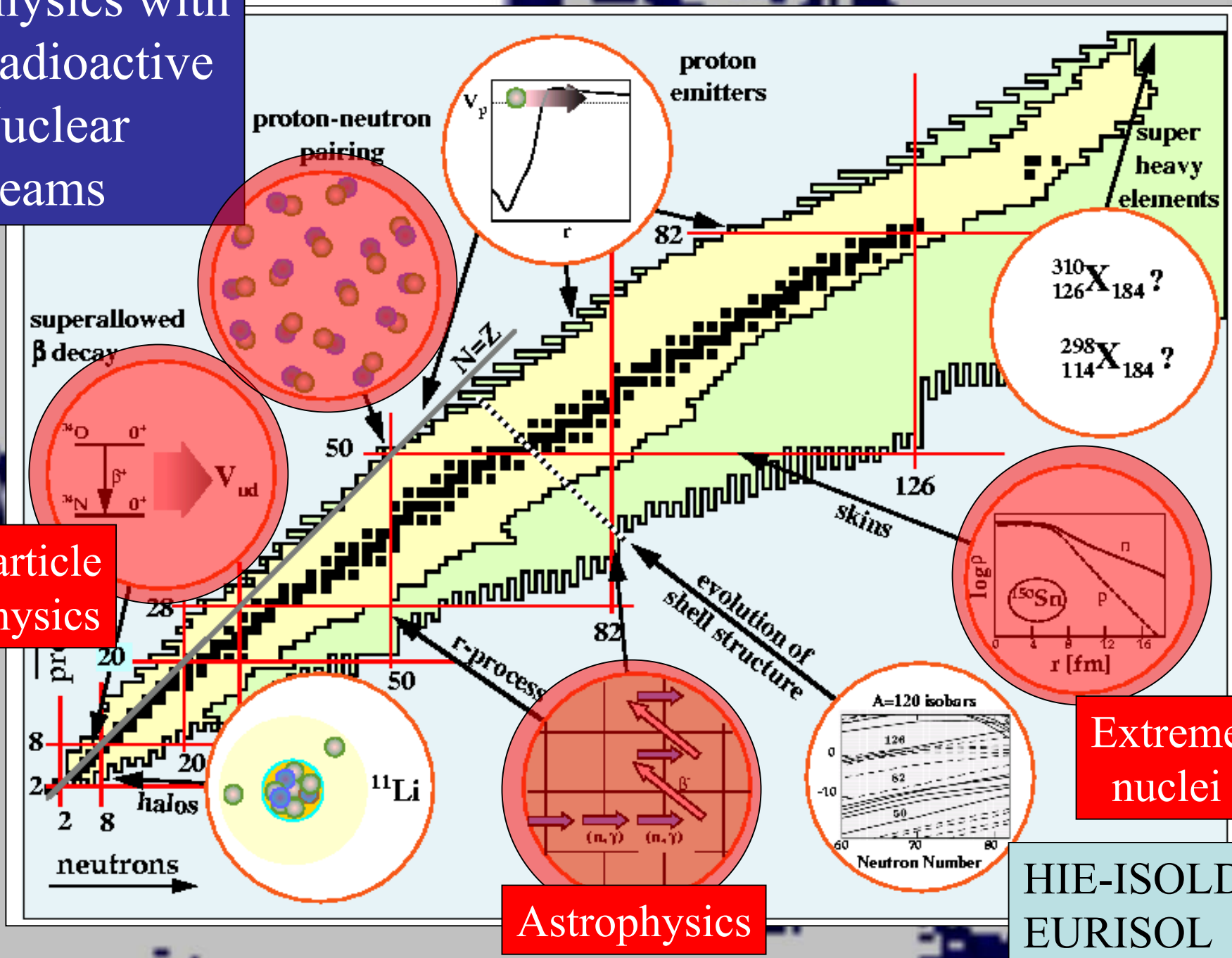
Possible EURISOL Site @ CERN



Nuclear Physics:
agenda of HIE-ISOLDE & EURISOL

- The limits of nuclear existence:
  - neutron & proton drip lines,
  - superheavy elements,
  - extreme nucleonic matter
- Nuclear astrophysics:
  - rp-process, r-process
- Probes of Standard Model:
  - CKM, P, T, CP
- Materials science:
  - radioactive spies, curing chemical blindness,
  - positron annihilation studies,
  - applications to biomedicine, etc.

Physics with Radioactive Nuclear Beams



Particle physics

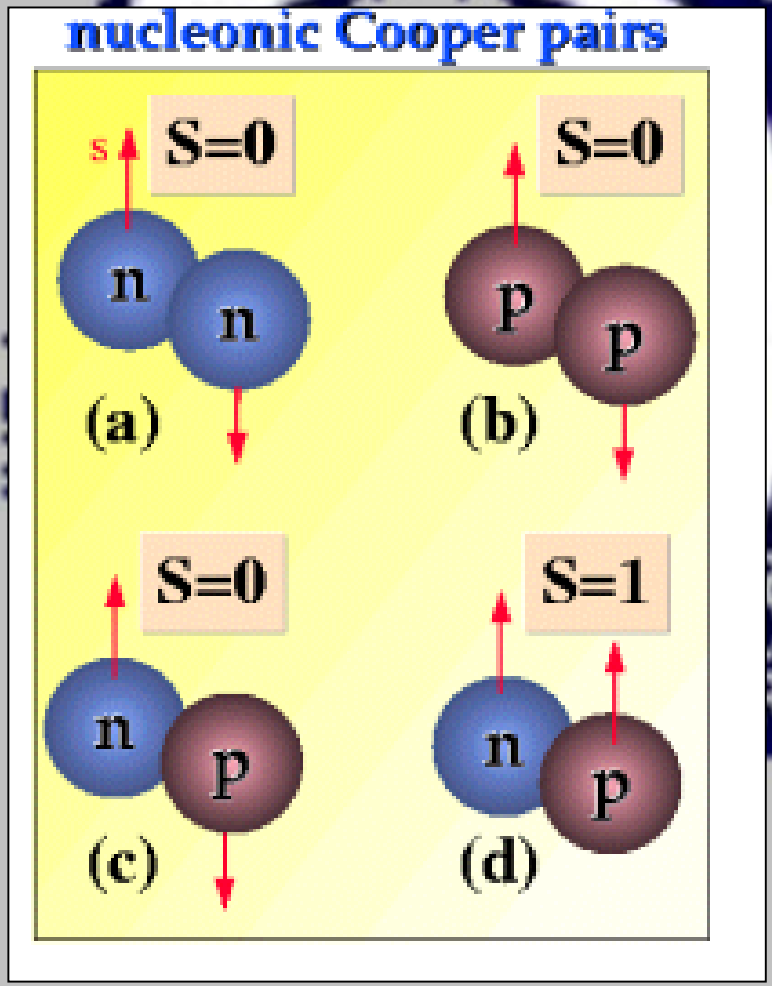
Extreme nuclei

Astrophysics

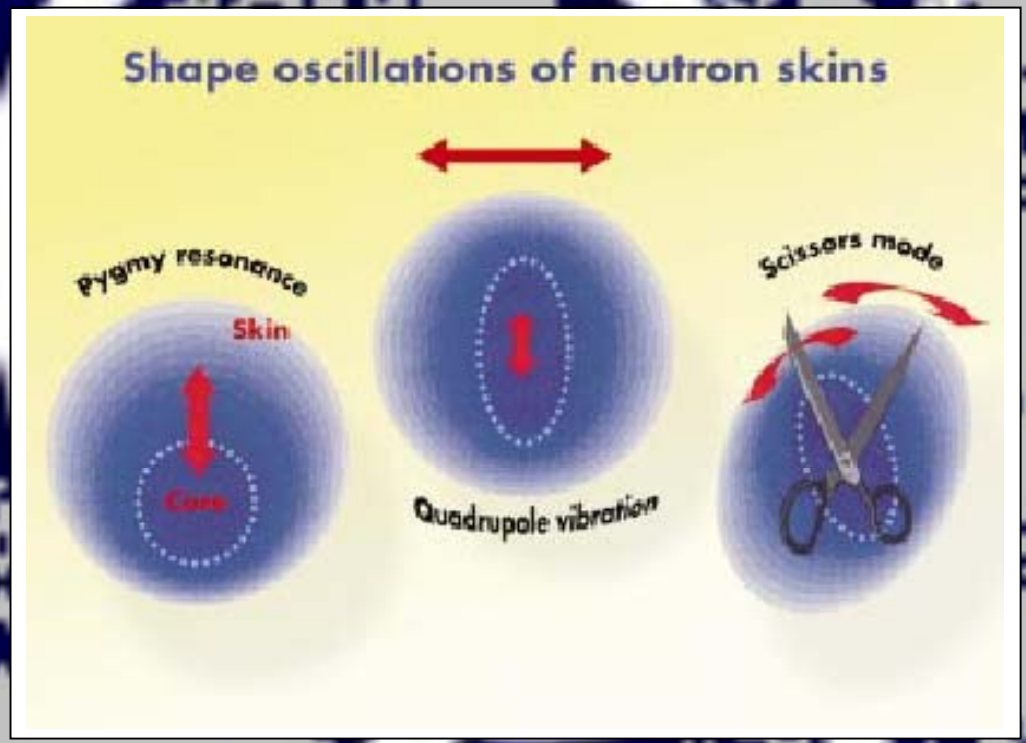
HIE-ISOLDE
EURISOL

Issues in Nuclear Physics

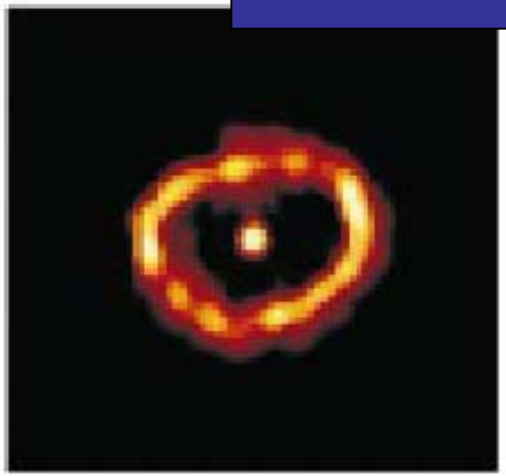
Proton-rich nuclei



Neutron-rich nuclei



Nuclear Astrophysics

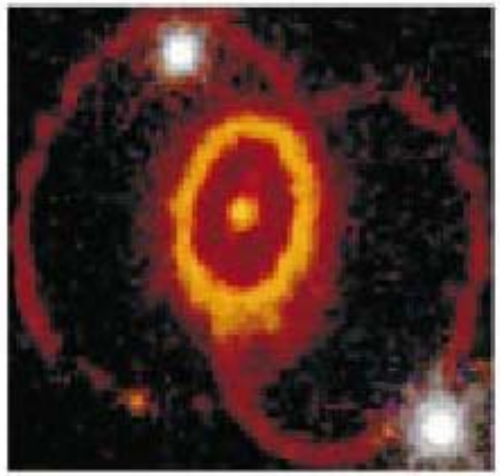


proton drip line

rp-process path

neutron drip line

r-process path

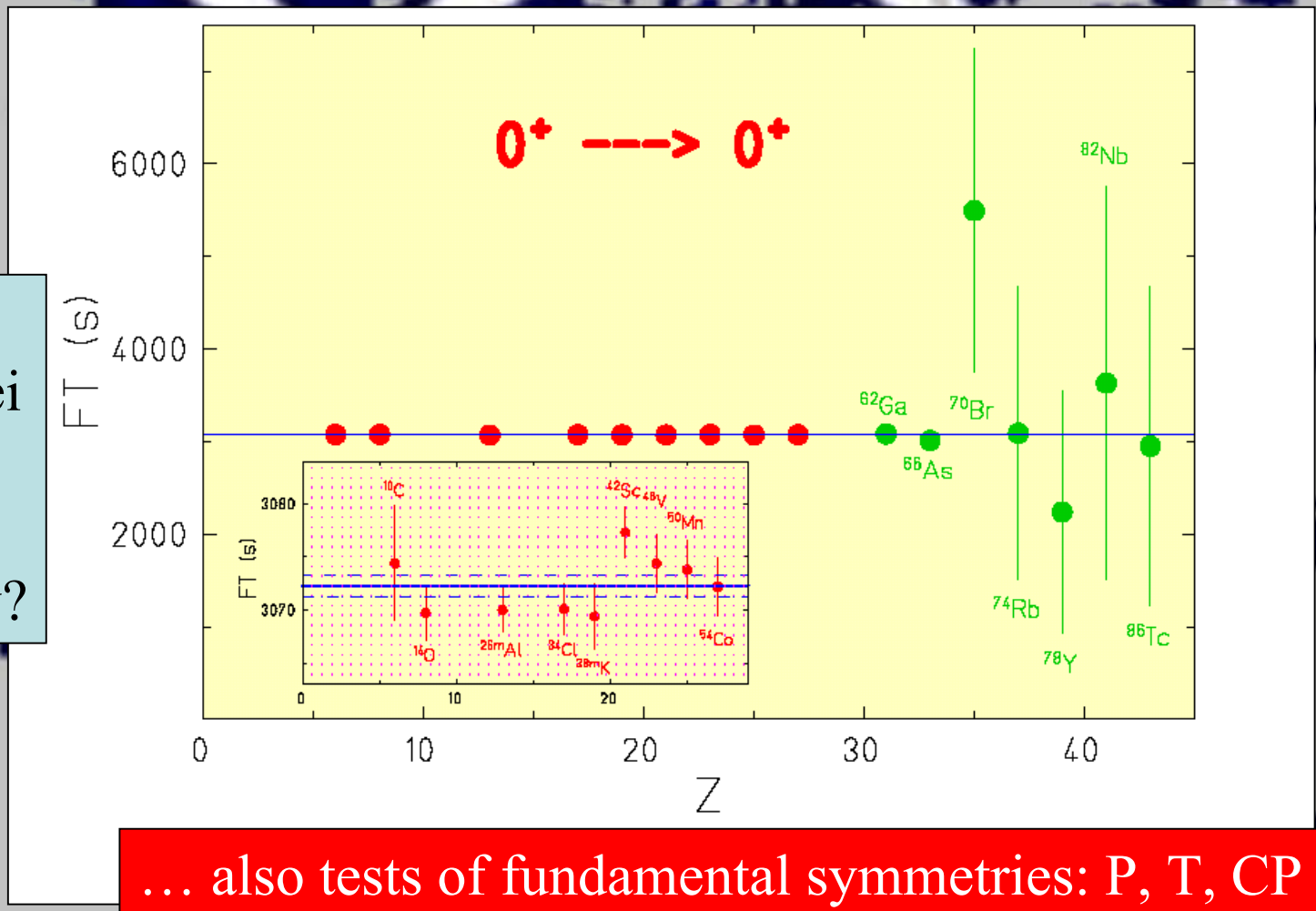


Proton number

Neutron number

Tests of CVC hypothesis: Probe Standard Model

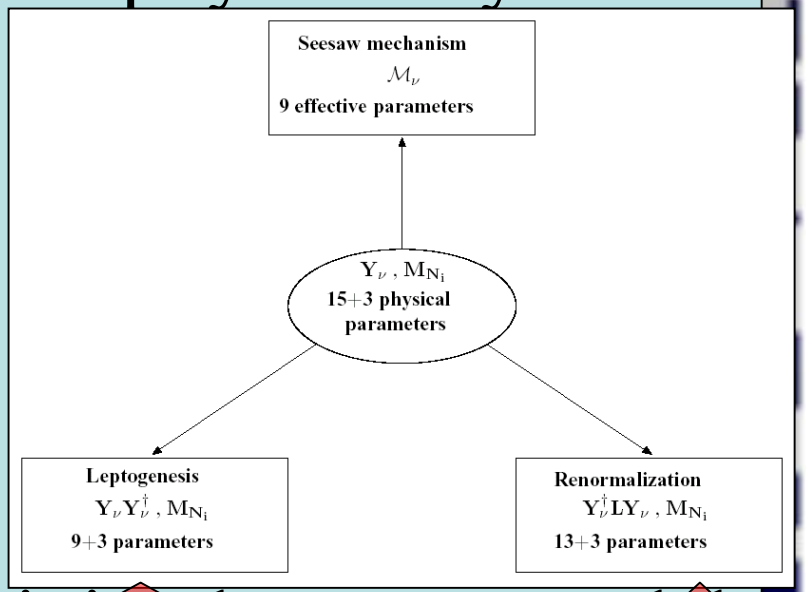
- $\langle 0^+|\beta|0^+\rangle$ in *mirror* nuclei
- $V_{ud}^{\ 2} = G_V/G_F$ (cf μ lifetime)
- CKM unitarity?



… also tests of fundamental symmetries: P, T, CP

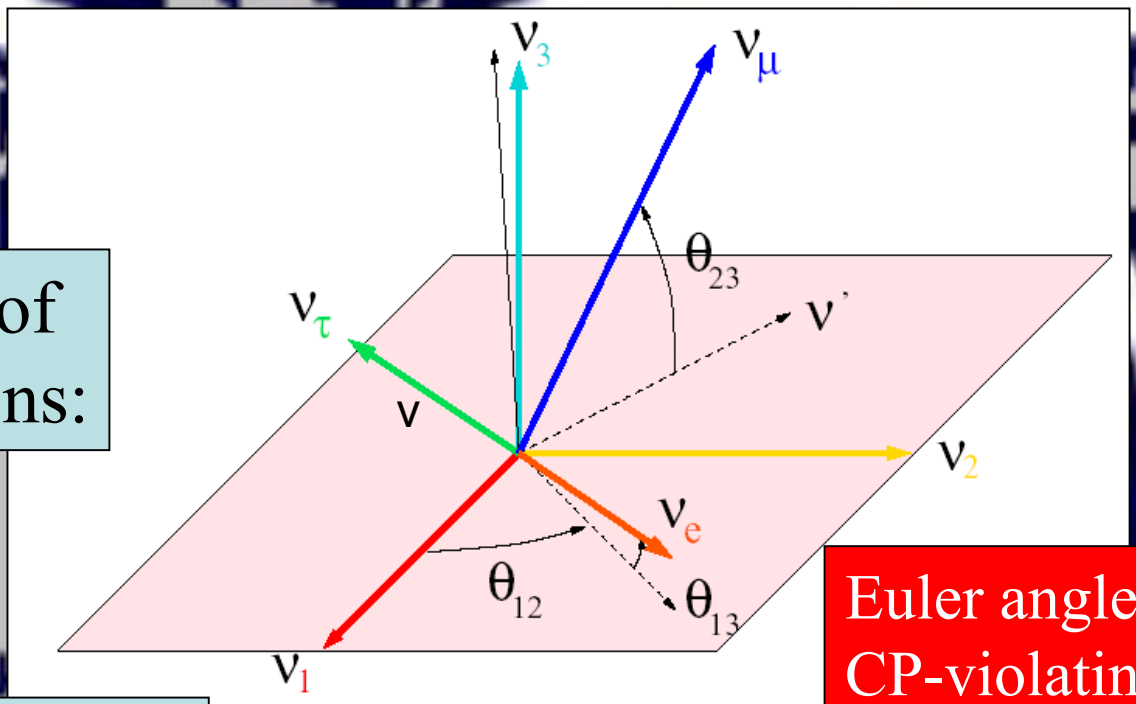
Neutrino Physics

- ν oscillations first evidence for physics beyond the Standard Model
- Still unknown parameters:
  - mixing angle Θ_{13}
  - CP-violating phase δ
  - Sign of Δm^2
- Many other parameters in minimal seesaw model
  - Total of 18: responsible for leptogenesis?
- Some accessible in rare muon processes



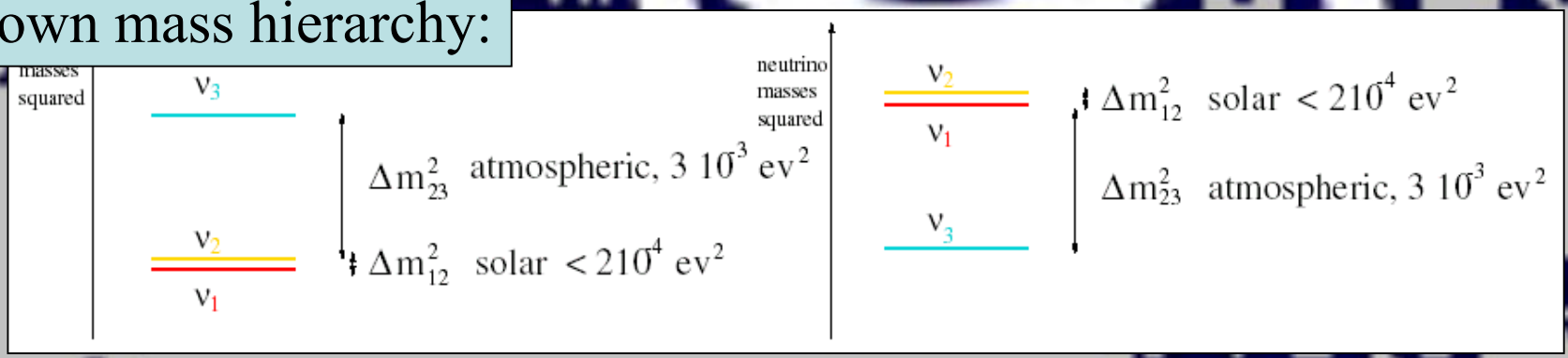
ν Oscillation Parameters

Geometry of ν oscillations:



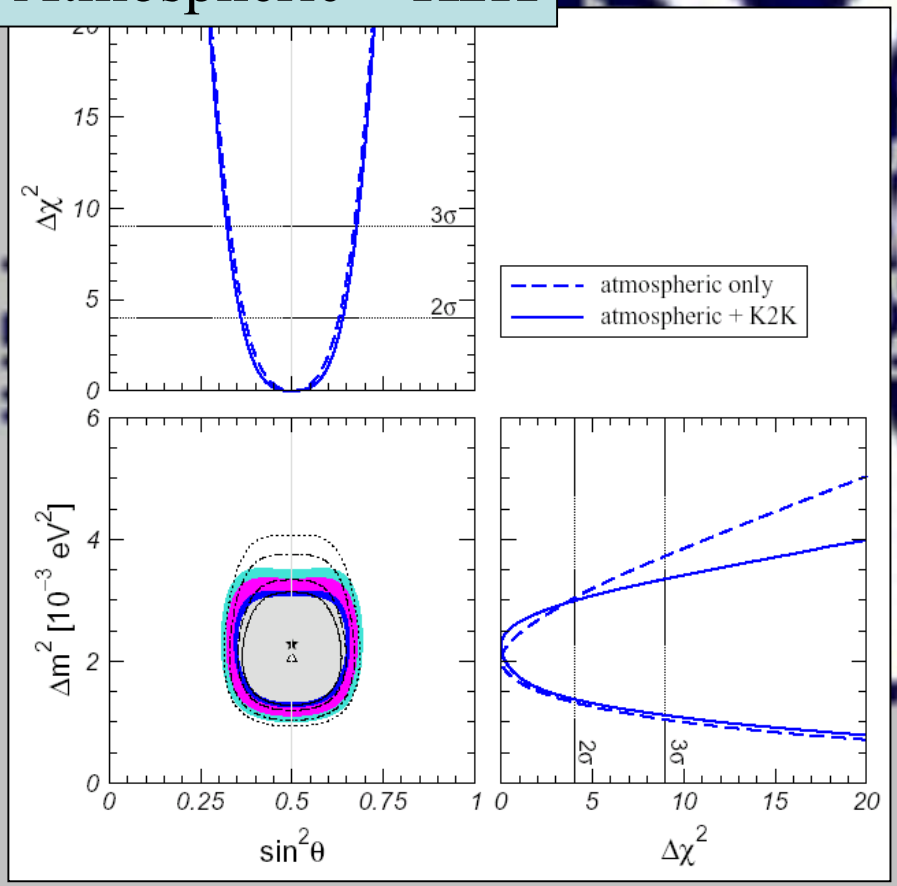
Euler angles + CP-violating phase

Unknown mass hierarchy:

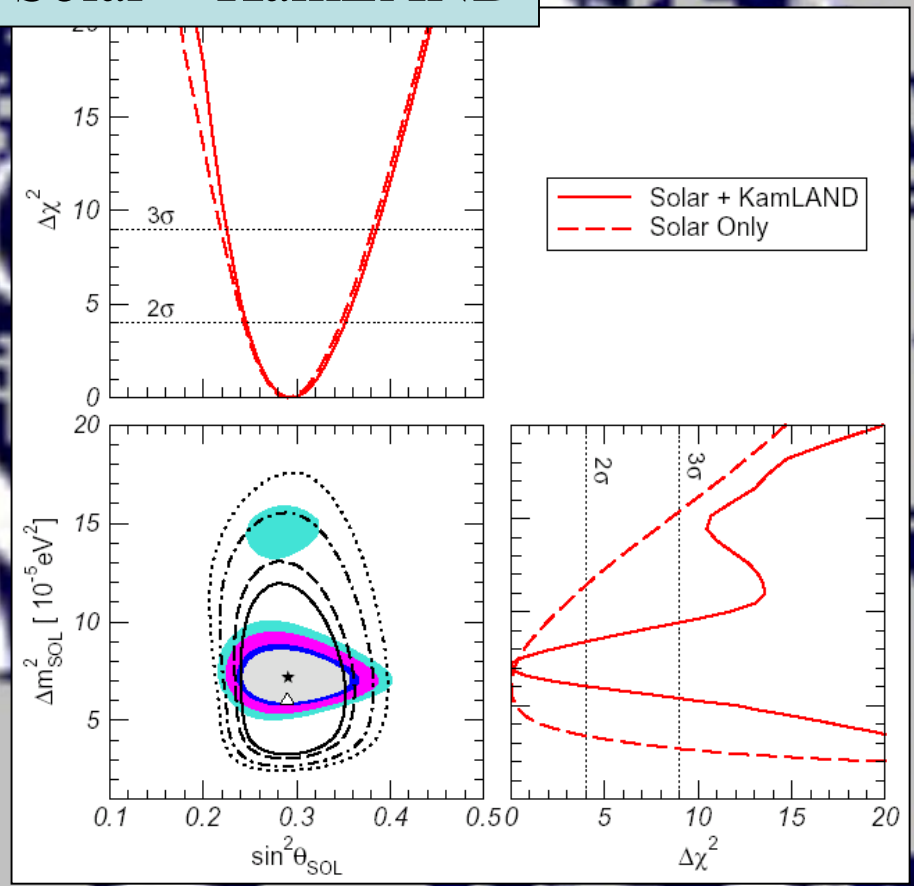


Status of ν Oscillations

Atmospheric + K2K



Solar + KamLAND

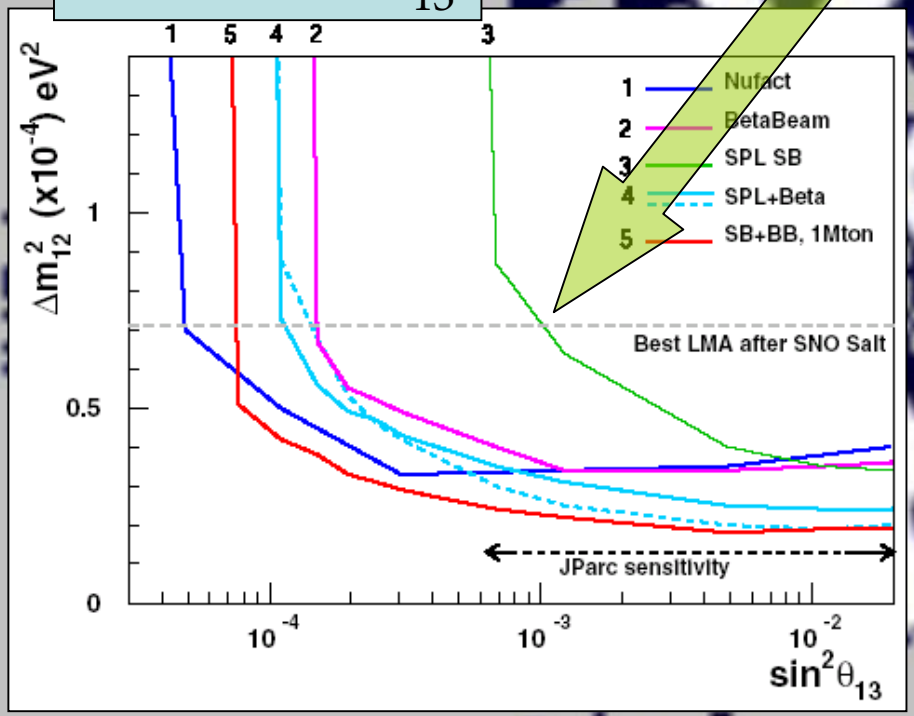


ν Oscillation Facilities @ CERN

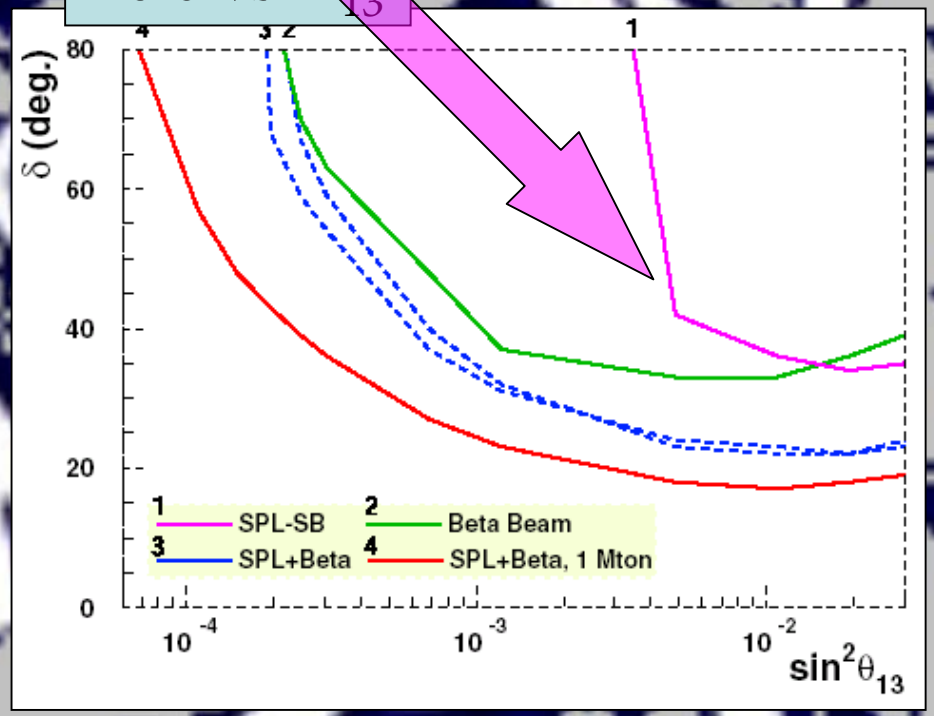
- CNGS:
  - ν beam from SPS: τ production
- Superbeam?
  - intense ν beam from SPL
- β beam?
  - signed electron (anti) ν beams from heavy ions
- ν factory?
  - muon and electron (anti) ν beams from μ decay

Sensitivities of Super & β Beams

To Δm^2 vs θ_{13}



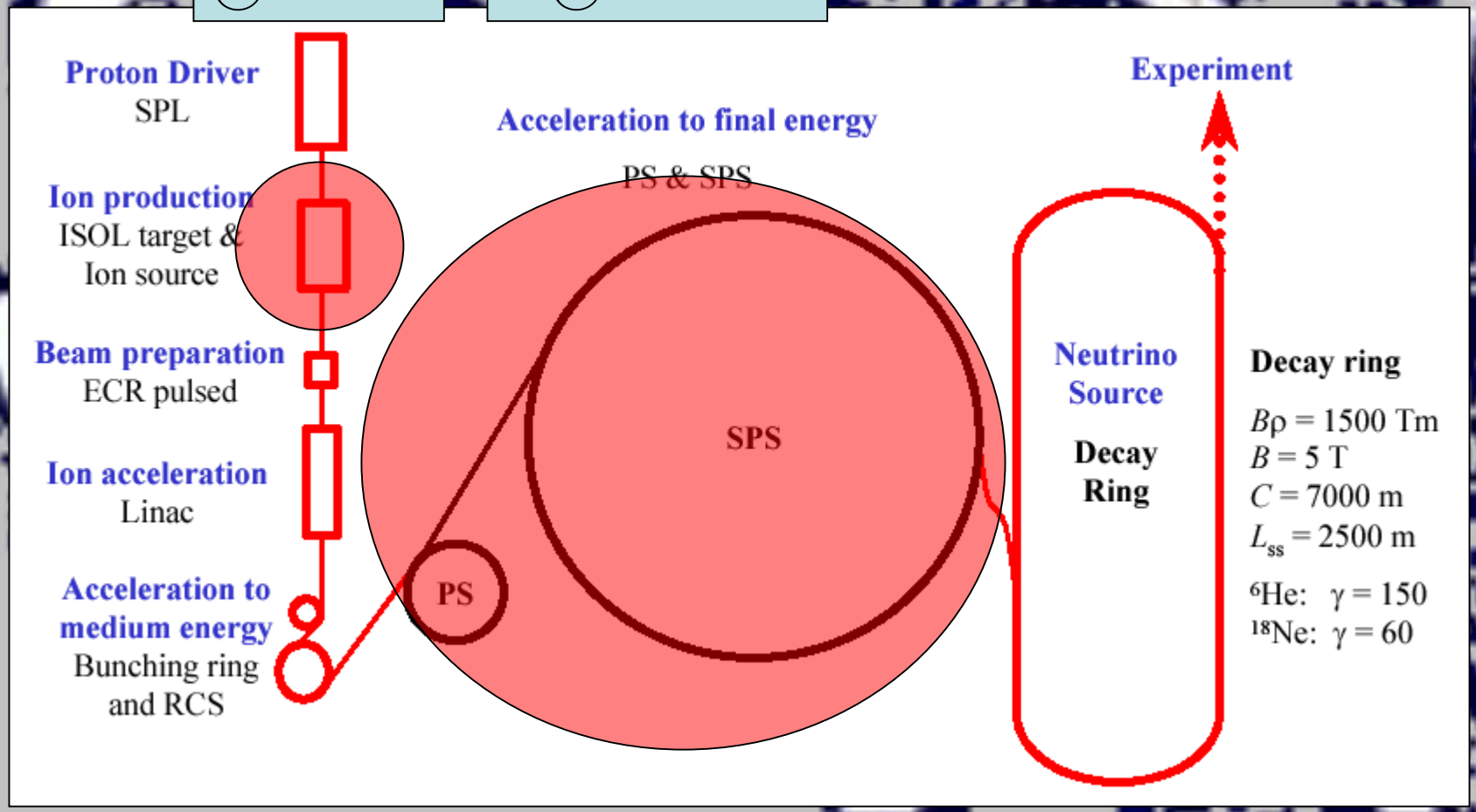
To δ vs θ_{13}



Schematic Layout of β Beam @ CERN

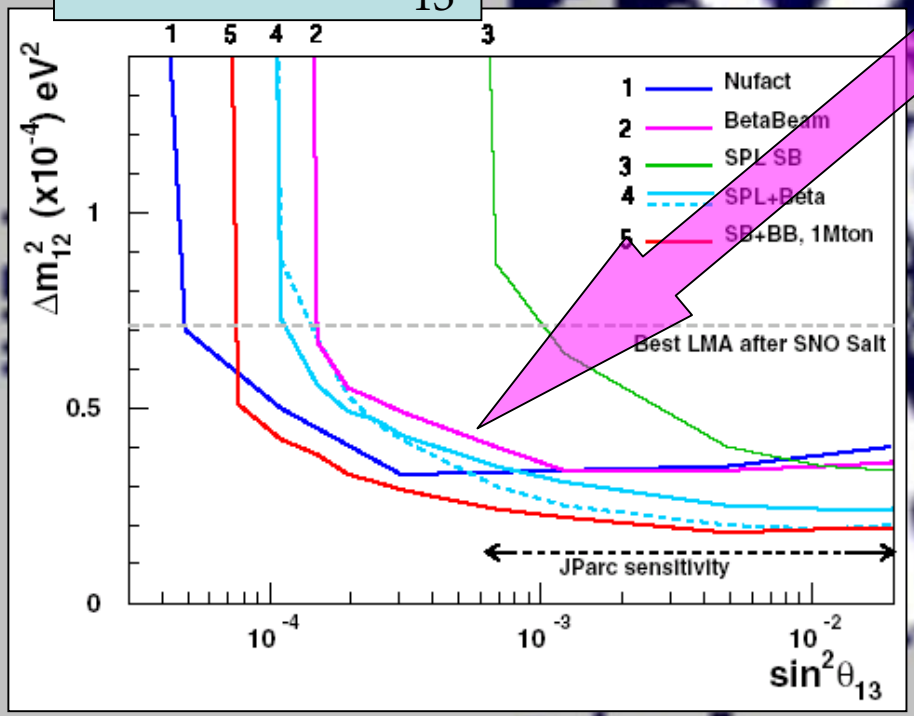
Expertise @ CERN

Infrastructure @ CERN

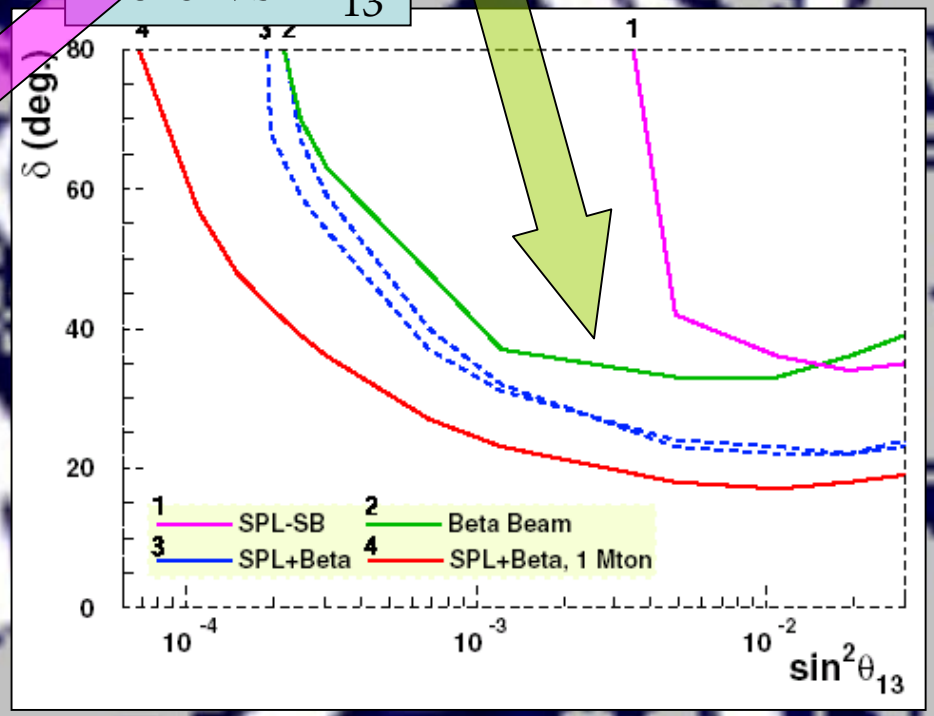


Sensitivities of Super & β Beams

To Δm^2 vs θ_{13}

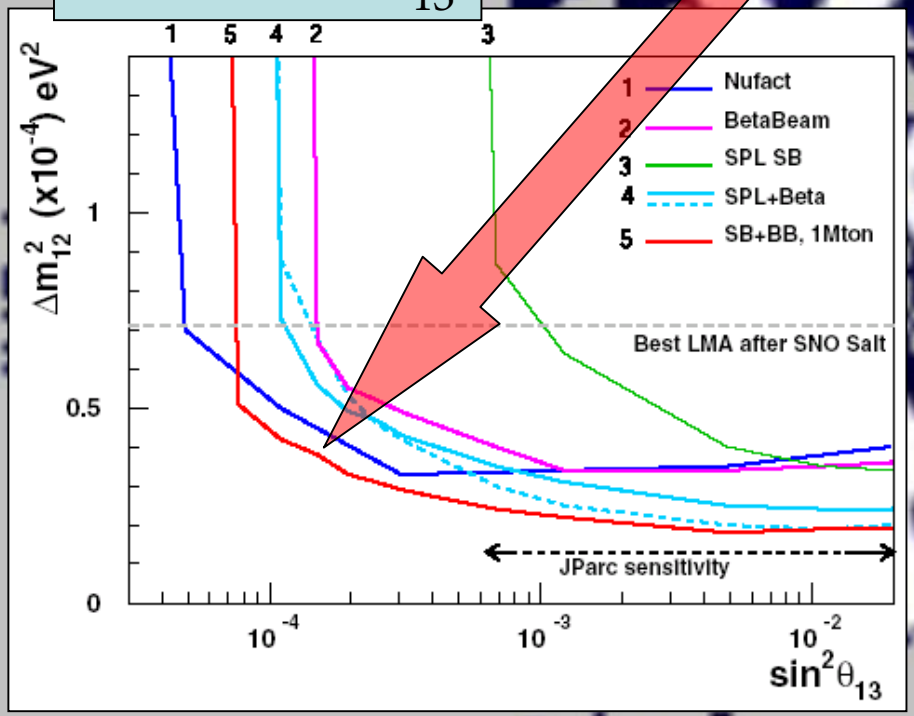


To δ vs θ_{13}

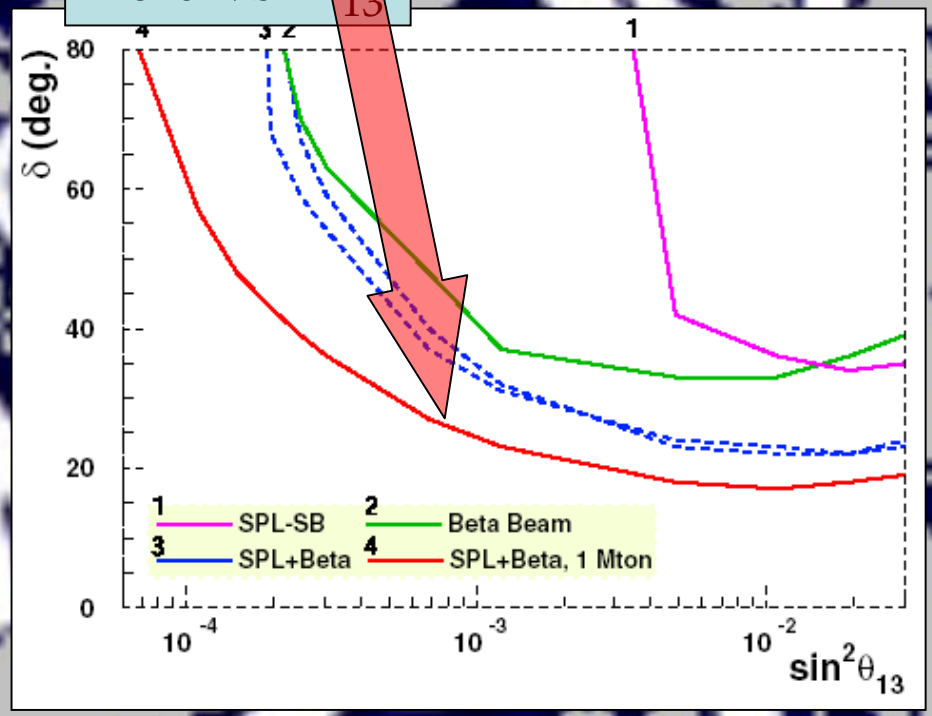


Sensitivities of Super & β Beams

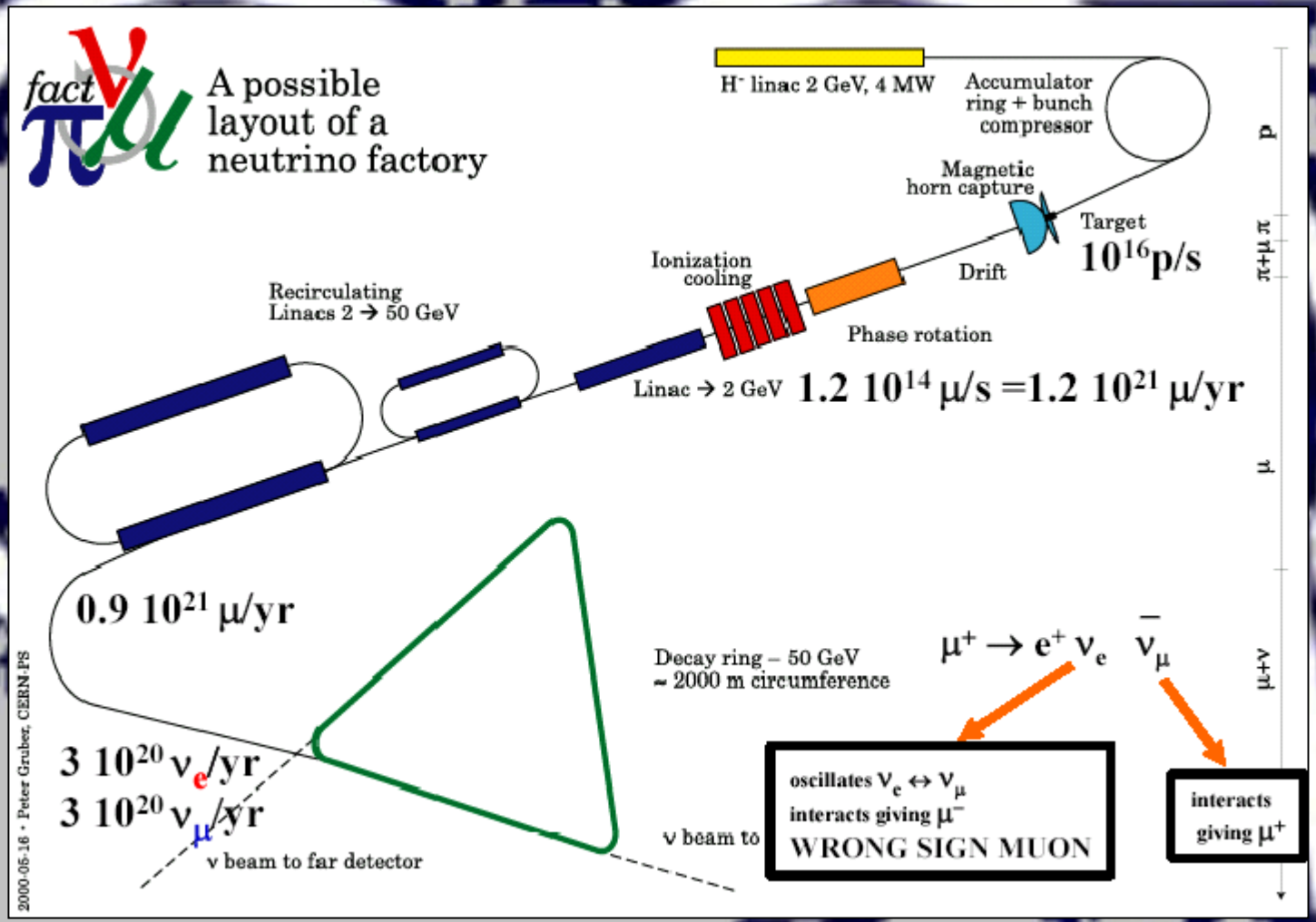
To Δm^2 vs θ_{13}



To δ vs θ_{13}

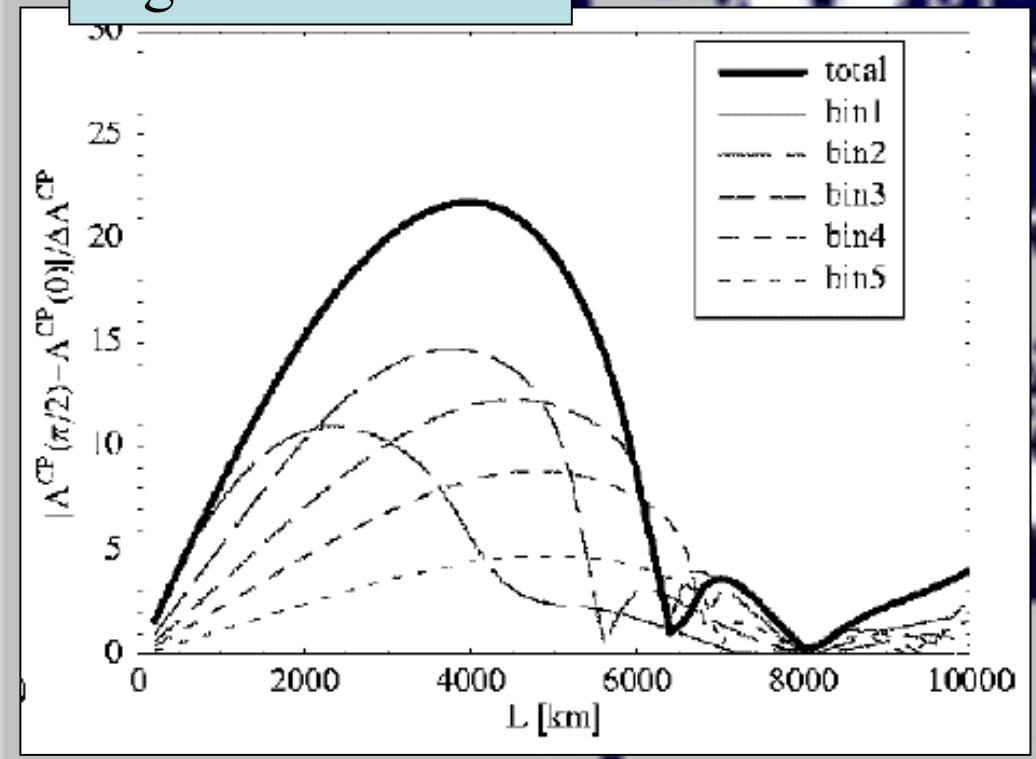


Schematic Layout of ν Factory @ CERN

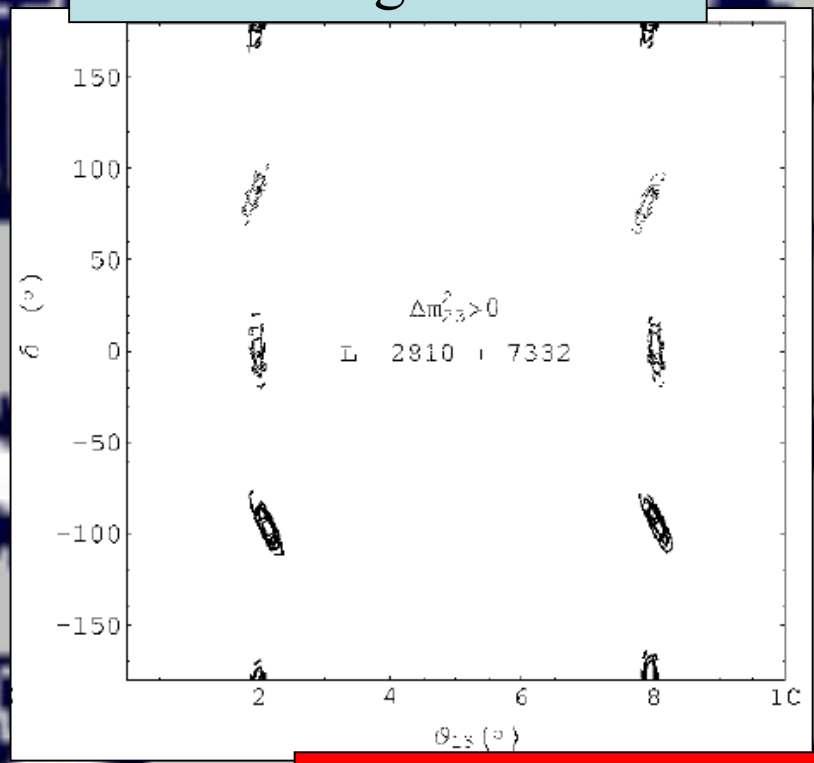


Neutrino Factory Sensitivity: CP-Violating Phase δ

Signal vs distance



Combine two distances to break degeneracies

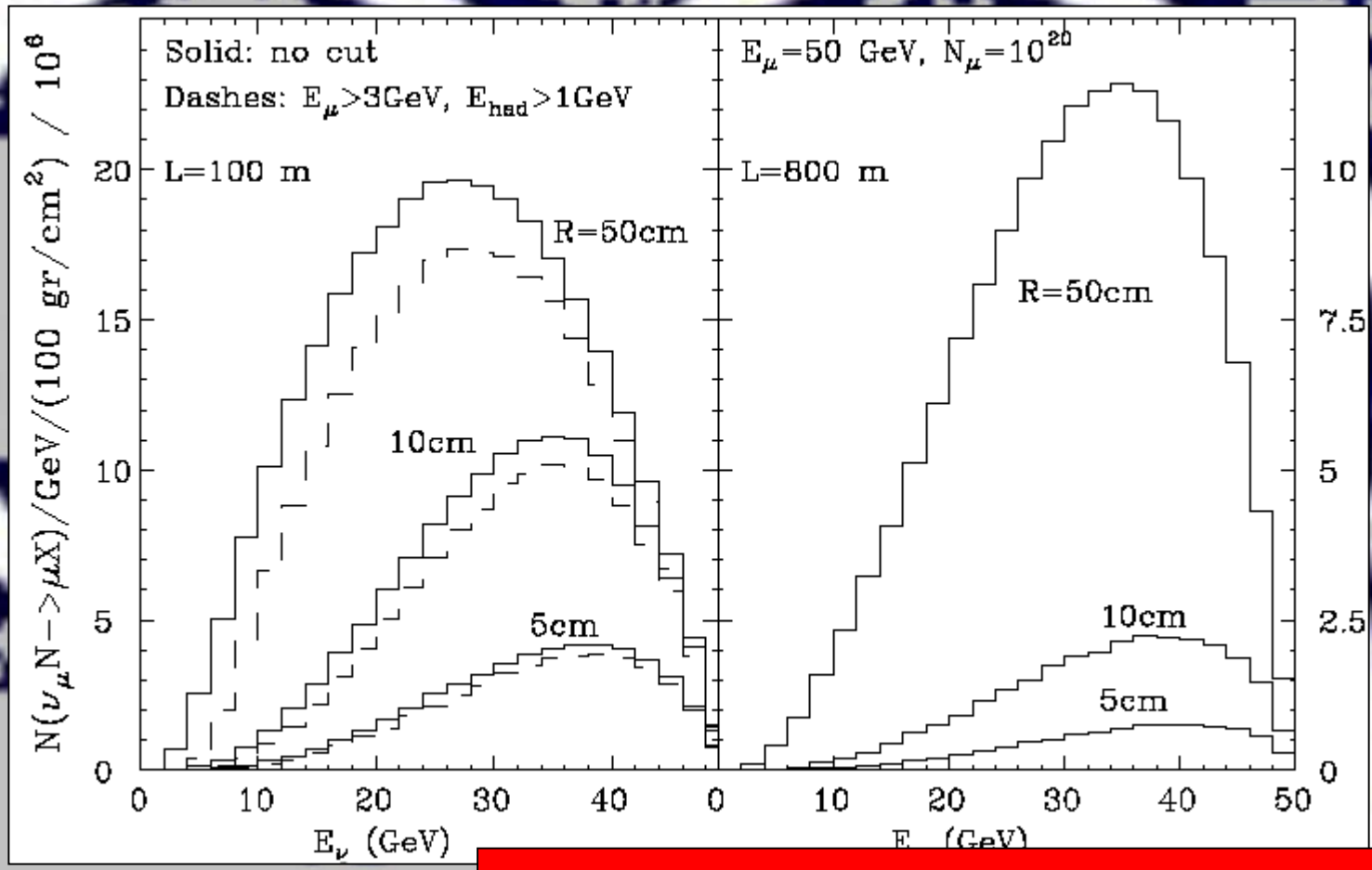


→ Pilar Hernandez

Neutrinos as Probes of Standard Model

- Enormous interaction rates in nearby detector
- Quark and antiquark densities
  - Polarized and unpolarized
  - e.g., strange quarks
- Extraction of α_s, $\sin^2 \theta_W$
- Charm production
- Polarization of Λ baryons
  - also probe of strange polarization

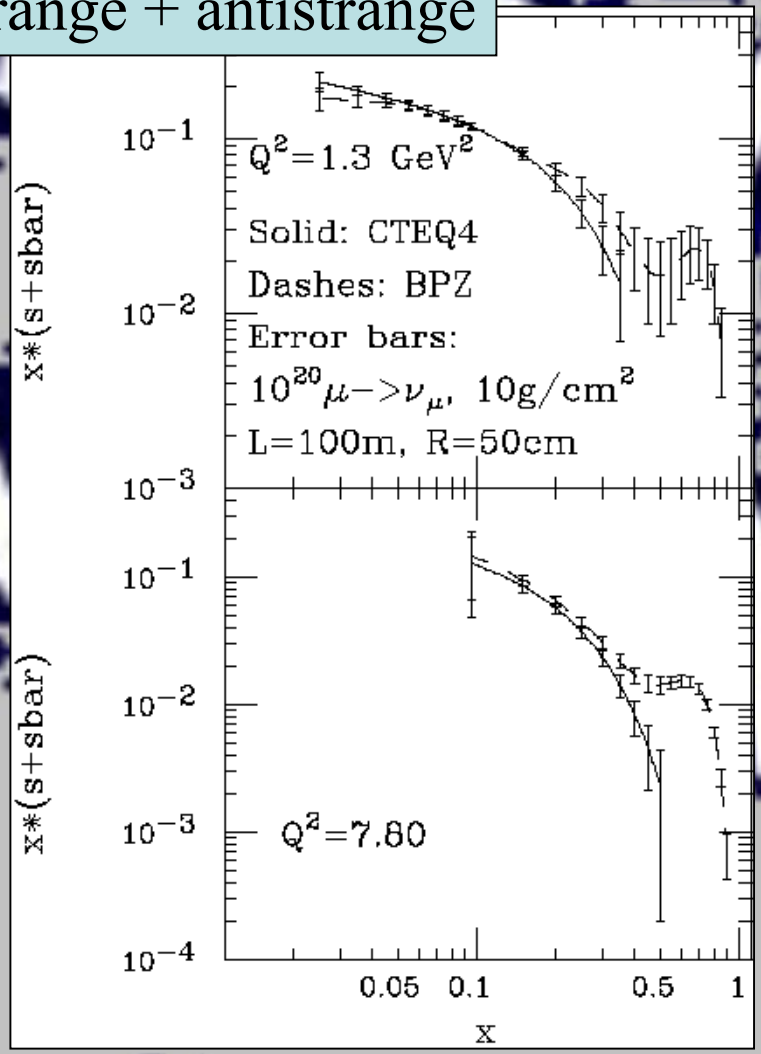
Event Rates in Nearby Detector



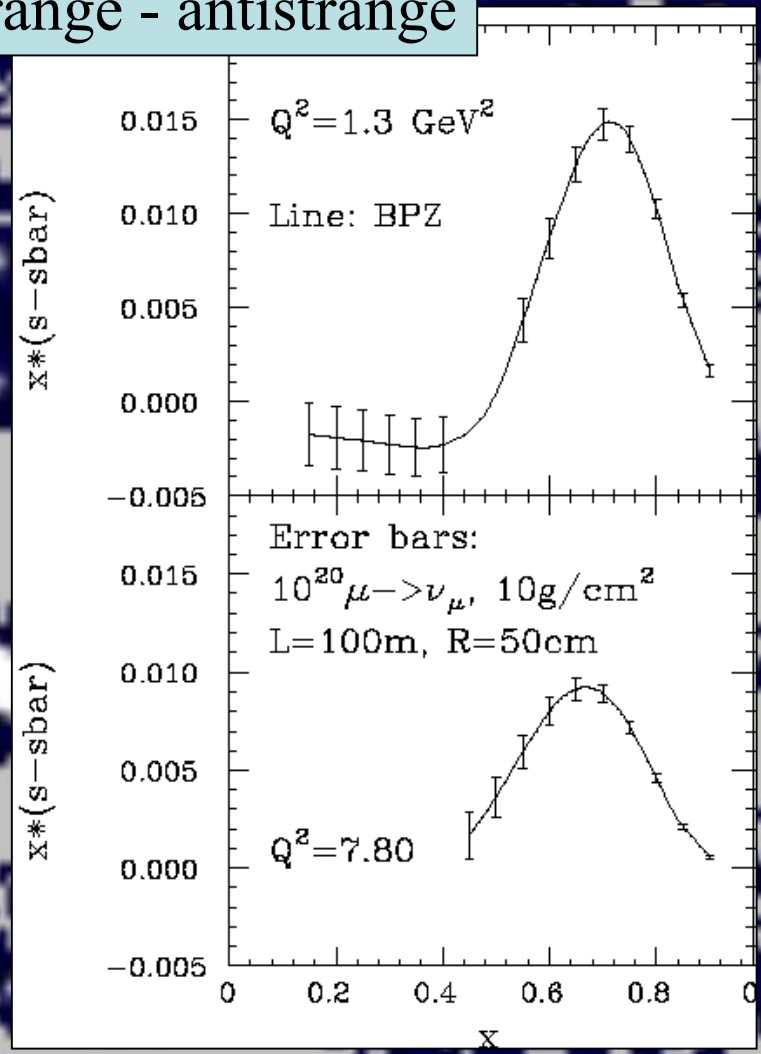
Millions of events – even in small detector

Measuring Strange Partons

Strange + antistrange

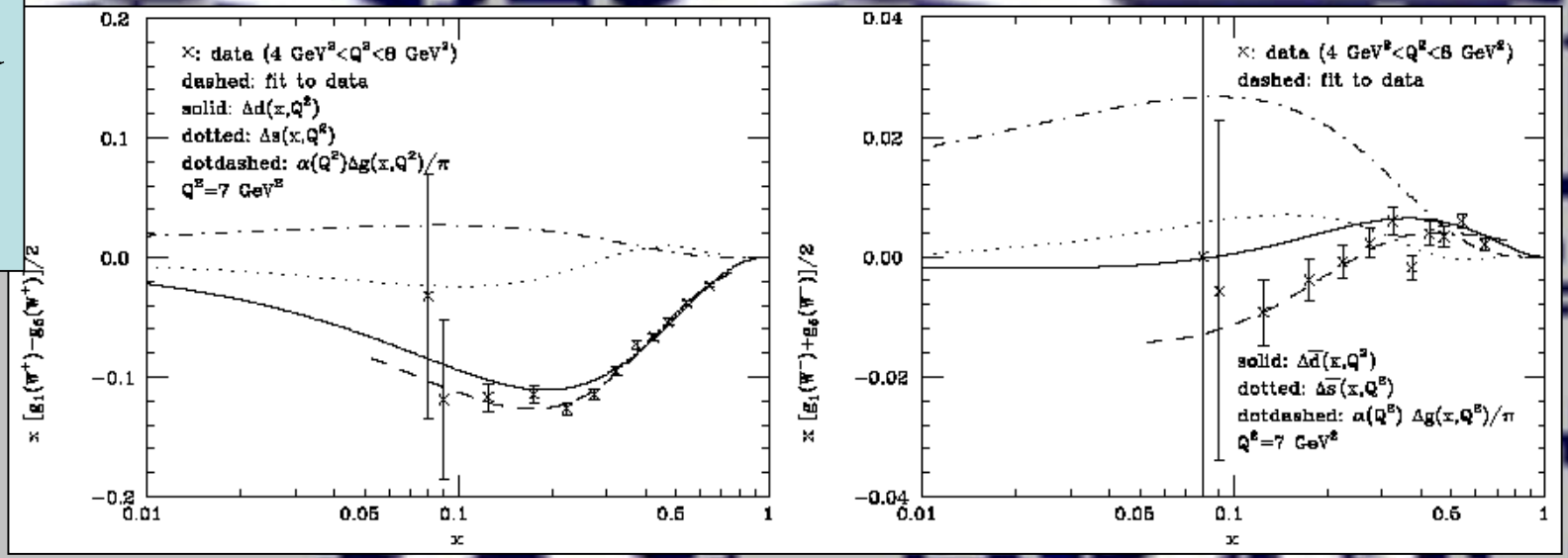


Strange - antistrange

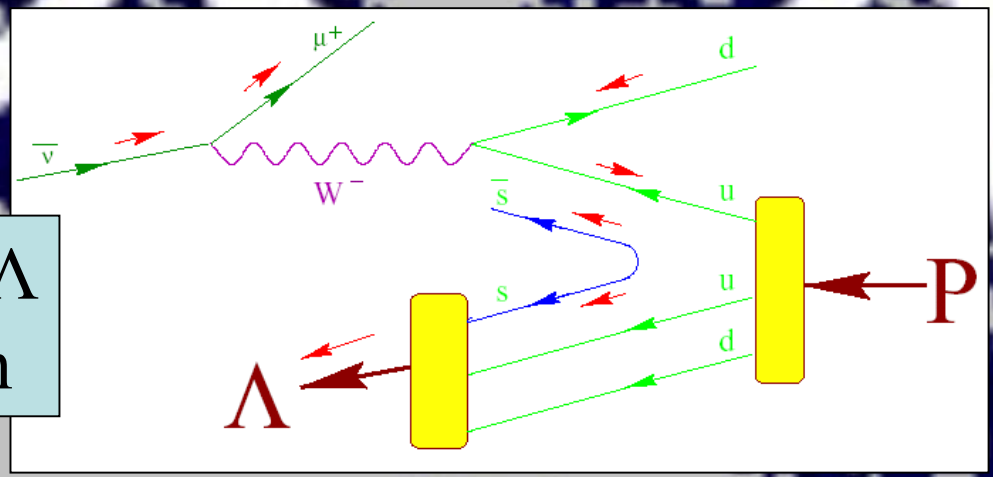


Handles on Strange Polarization

Polarized Structure functions



Final-state Λ Polarization



Muon Physics

- Megawatt produces many muons
- Rare μ decays

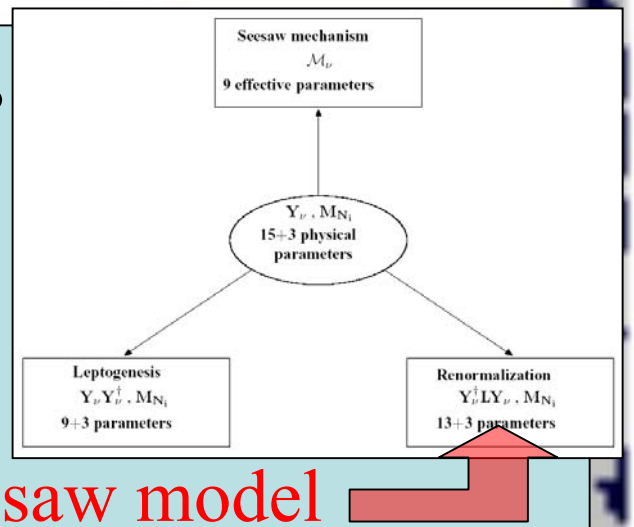
  μ → e γ, μ → eee, μ A → e A

  Expected in susy seesaw model

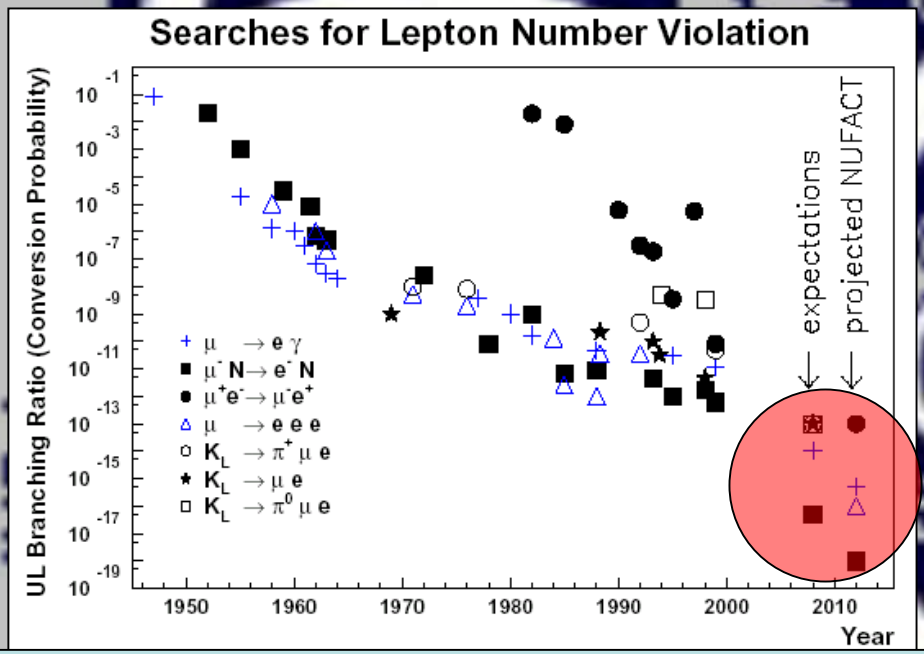
  Probe unknown parameters in seesaw model
- Dipole moments:

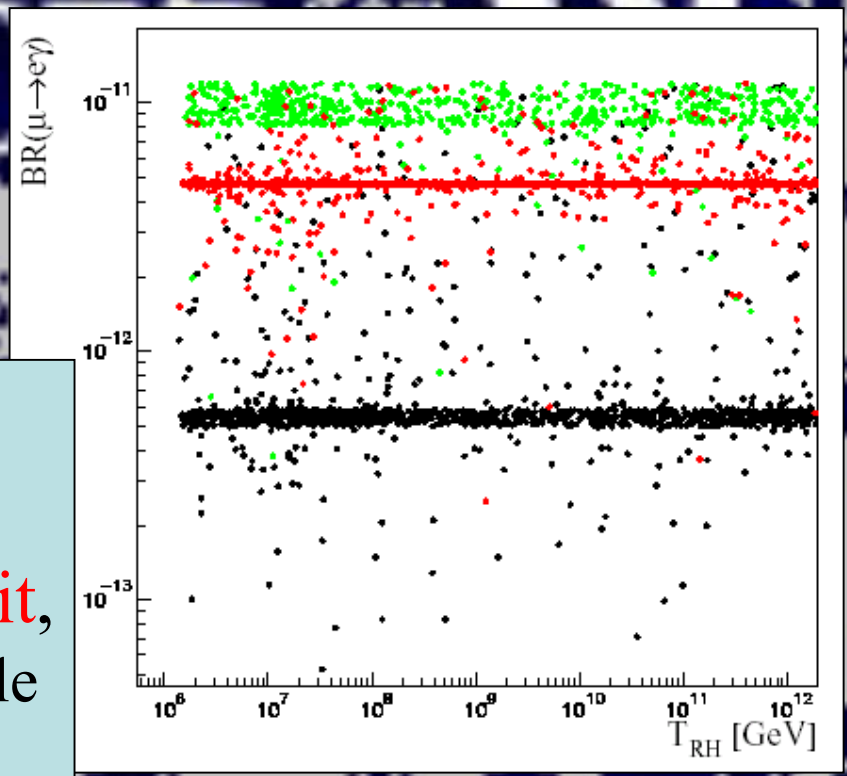
  $g_\mu - 2$, electric dipole moment, CPT tests
- Nuclear, condensed-matter physics:

  (radioactive) μ-ic atoms, muonium, μ-ic Hydrogen



$\mu \rightarrow e\gamma$ in Supersymmetric Seesaw





Many models predict

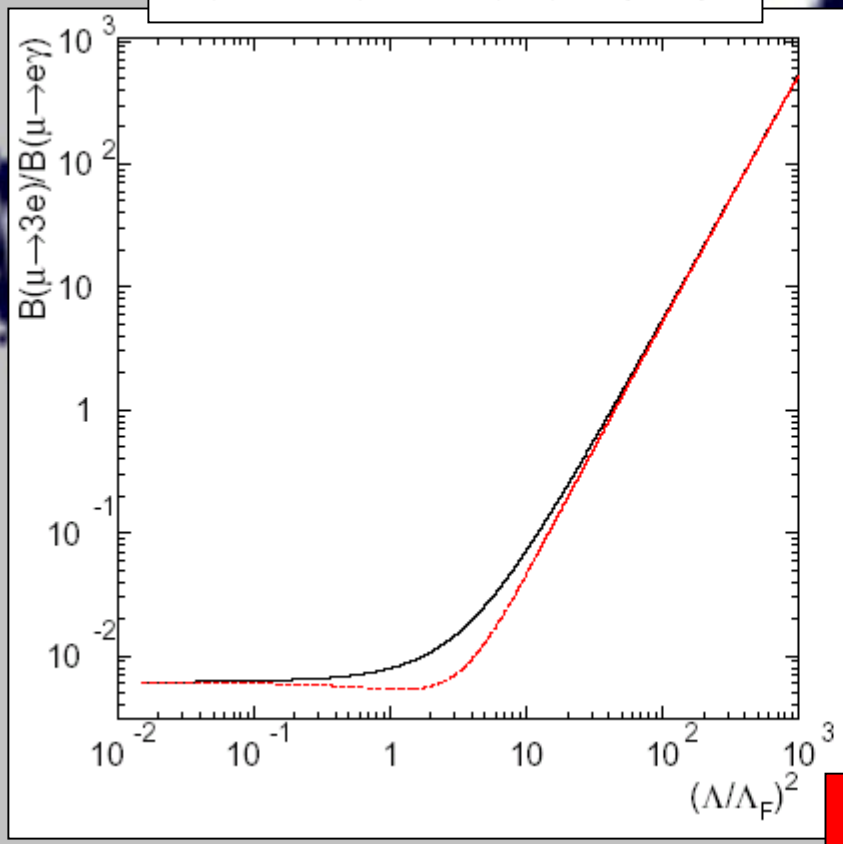
$\mu \rightarrow e\gamma$

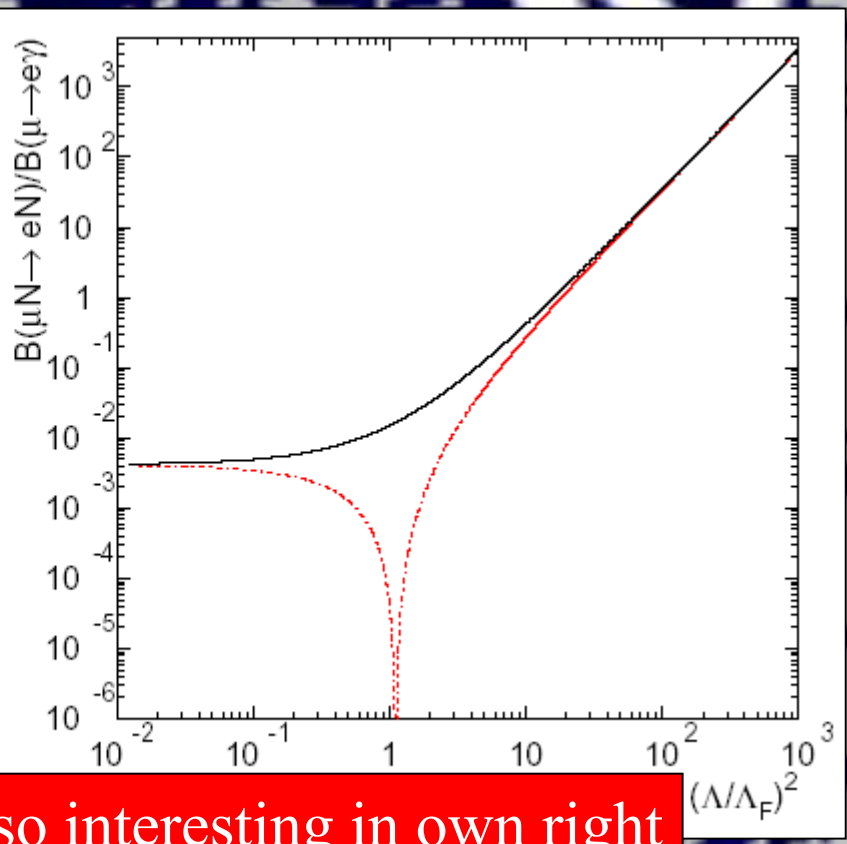
close to present experimental limit,

e.g., model where sneutrino responsible for inflation, baryogenesis

New Interactions:
$\mu \rightarrow e\gamma$ vs $\mu \rightarrow eee$, $\mu A \rightarrow eA$

$$\frac{B(\mu \rightarrow 3e)}{B(\mu \rightarrow e\gamma)} = \frac{1}{12(4\pi)^2}\left(\frac{\Lambda}{\Lambda_F}\right)^4$$

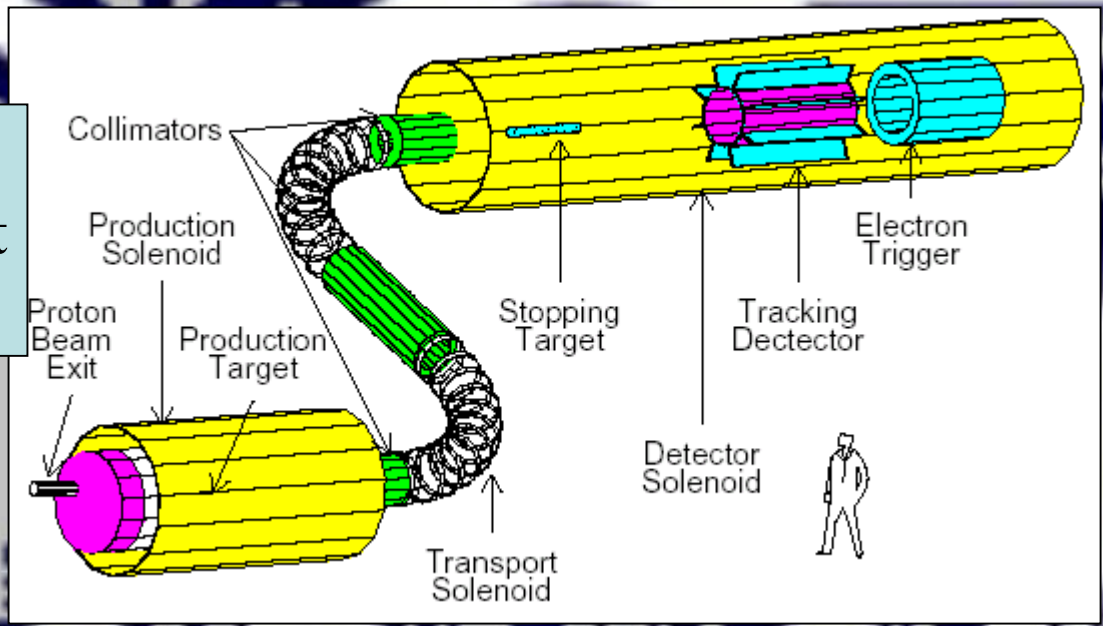




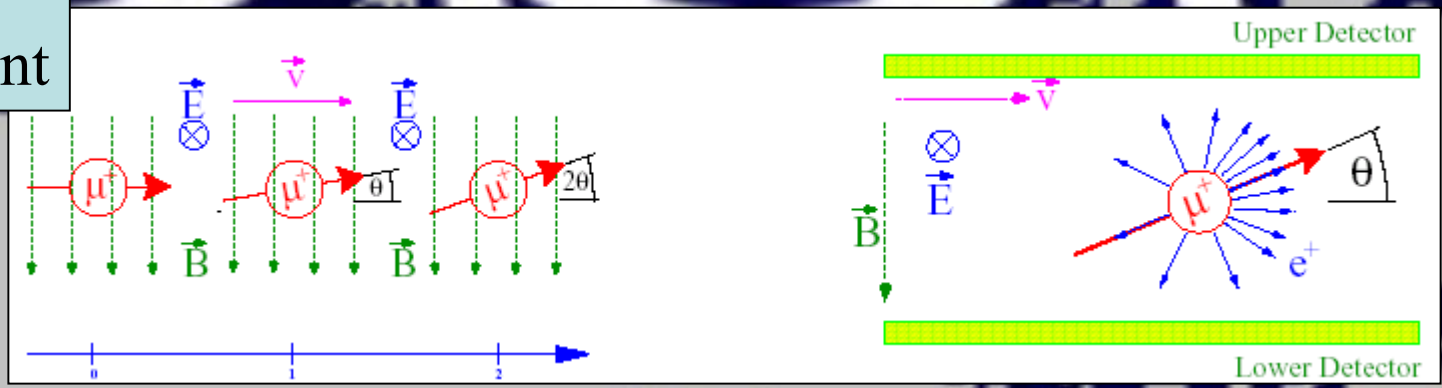
Also interesting in own right

Other Experiments: μA → eA, EDM

Planned layout of MECO experiment for μA → eA



Principle of EDM experiment



Muon Colliders?

- Extrapolate μ cooling technology
- Light Higgs Factory?

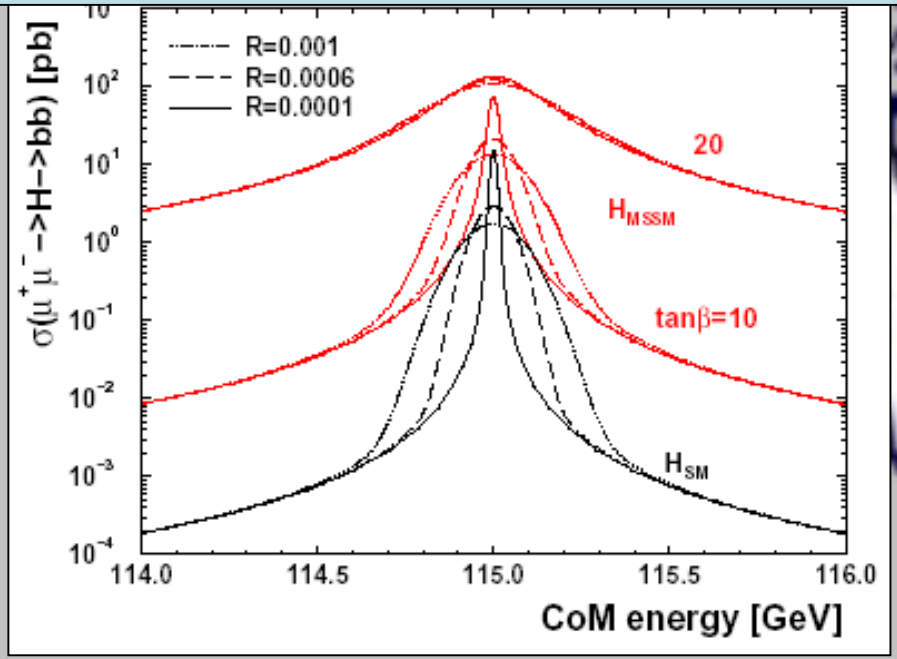
  Standard Model vs supersymmetry?
- Factory for heavier supersymmetric Higgses?

  New probes of CP violation?
- High-energy frontier?

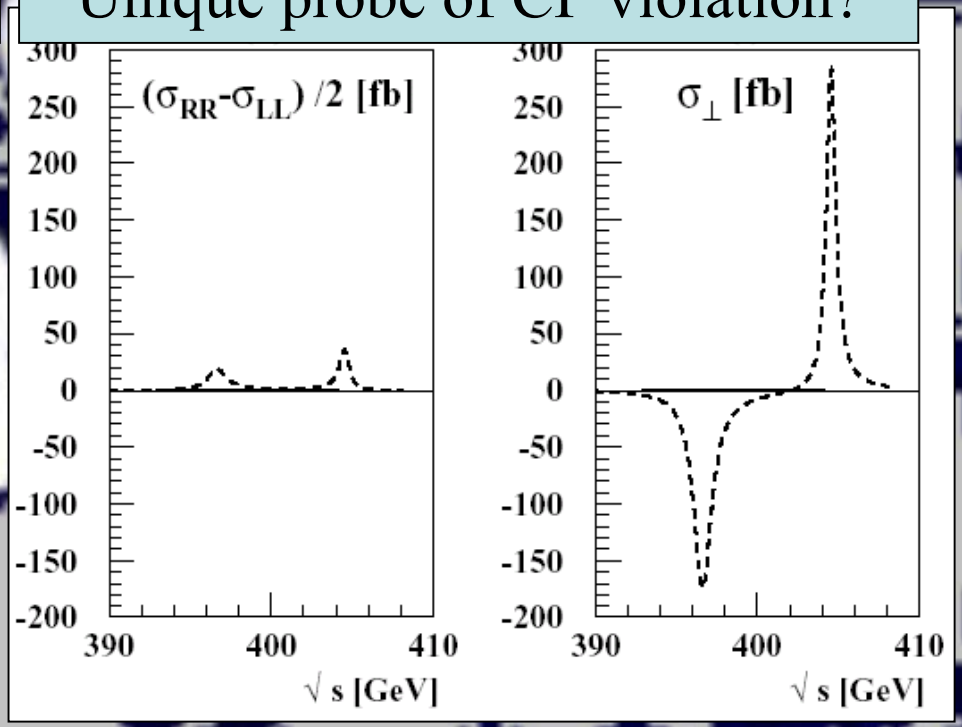
  Alternative to CLIC for multi-TeV lepton collisions?

Higgs Studies at Muon Colliders

First muon collider:
Detailed measurements
of light Higgs boson:
Standard Model vs supersymmetry



Second muon collider:
Detailed measurements
of supersymmetric Higgs bosons:
Unique probe of CP violation?

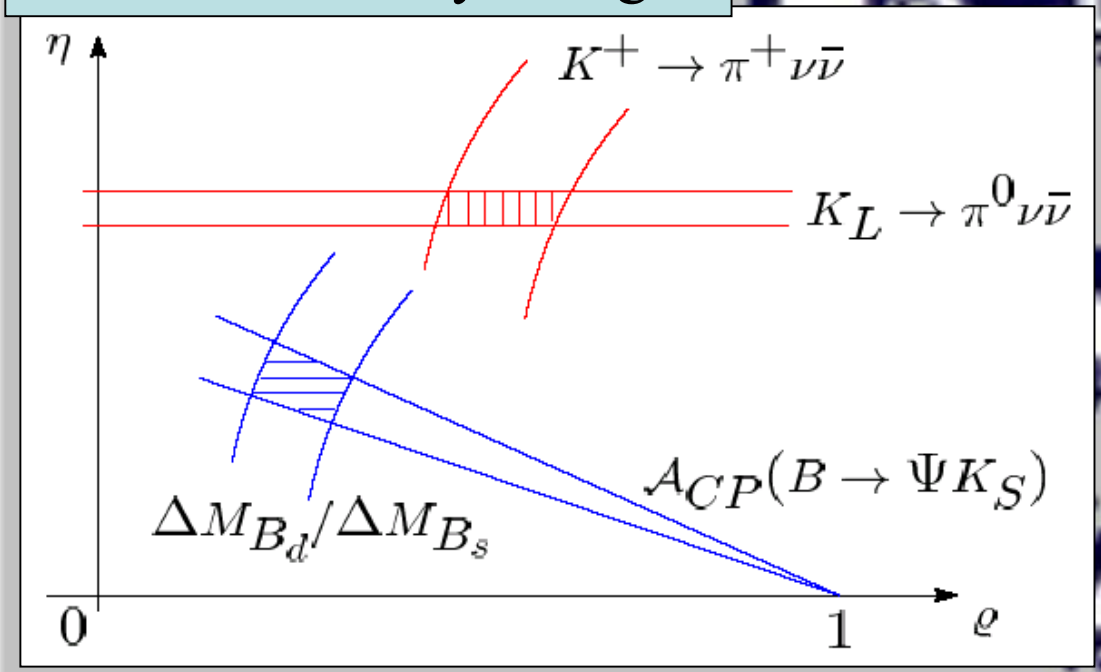


Rare K Decays

Many kaons produced if high-energy source or booster ring

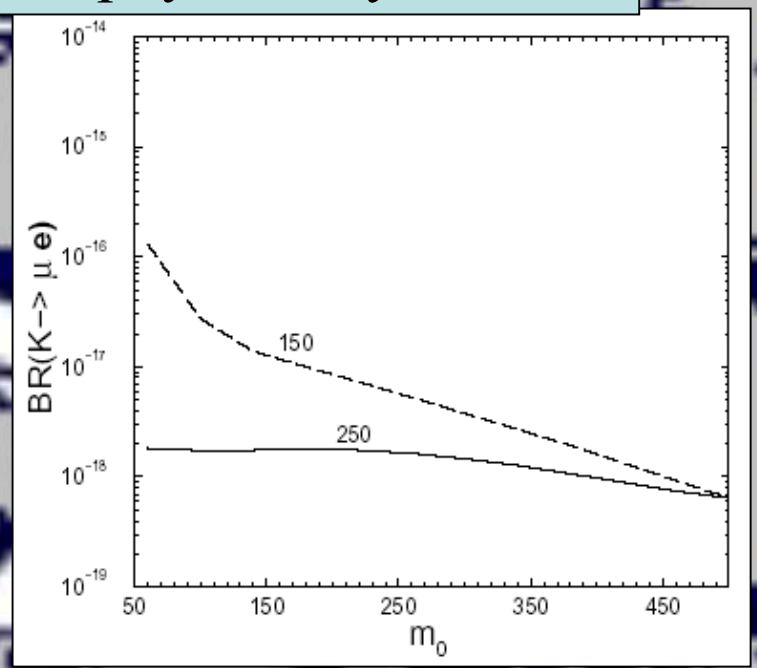
K → πνν:

Alternative window
on CKM unitarity triangle



K → μe:

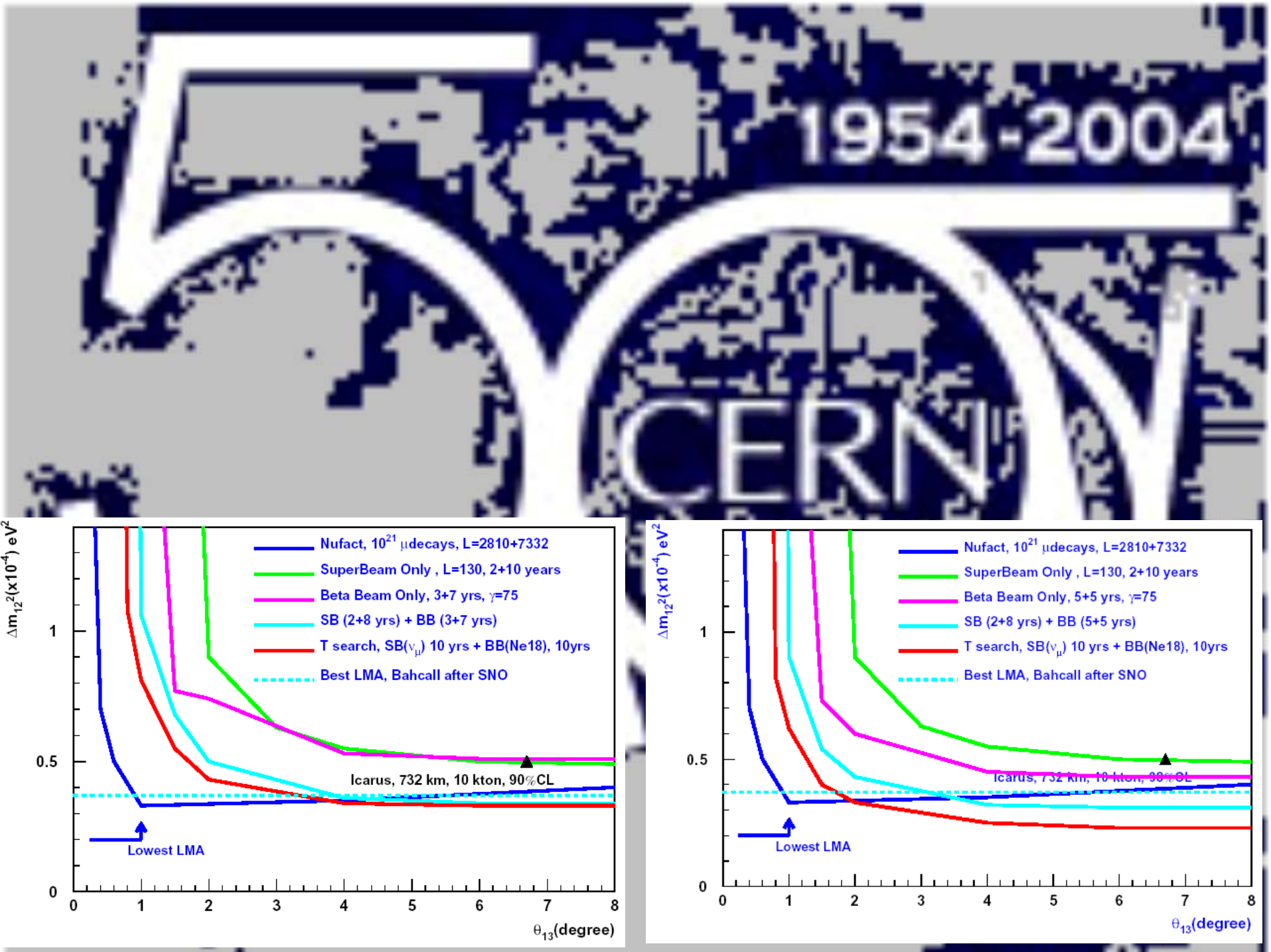
Possible window
on physics beyond SM



Physics with Megawatt

- Long-range programme in ν physics:
  superbeam, β beam, ν factory
- Complementary programme in μ physics:
  rare μ decays, μ properties, μ colliders?
- Next-generation facility for nuclear physics
  also tests of SM, nuclear astrophysics
- Synergy with CERN programme:
  LHC, CNGS ν, ISOLDE, heavy ions, β beam

Interesting project – and CERN would be a good place for it


1954-2004
CERN

Nufact, 10^{21} μdecays, L=2810+7332
SuperBeam Only , L=130, 2+10 years
Beta Beam Only, 3+7 yrs, γ=75
SB (2+8 yrs) + BB (3+7 yrs)
T search, SB(ν_μ) 10 yrs + BB(Ne18), 10yrs
Best LMA, Bahcall after SNO
Icarus, 732 km, 10 kton, 90%CL
Lowest LMA
$\Delta m_{12}^2(x10^{-4})$ eV^2
θ_{13}(degree)
0
0.5
1
0
1
2
3
4
5
6
7
8

Nufact, 10^{21} μdecays, L=2810+7332
SuperBeam Only , L=130, 2+10 years
Beta Beam Only, 5+5 yrs, γ=75
SB (2+8 yrs) + BB (5+5 yrs)
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Best LMA, Bahcall after SNO
Lowest LMA
$\Delta m_{12}^2(x10^{-4})$ eV^2
θ_{13}(degree)
0
0.5
1
0
1
2
3
4
5
6
7
8

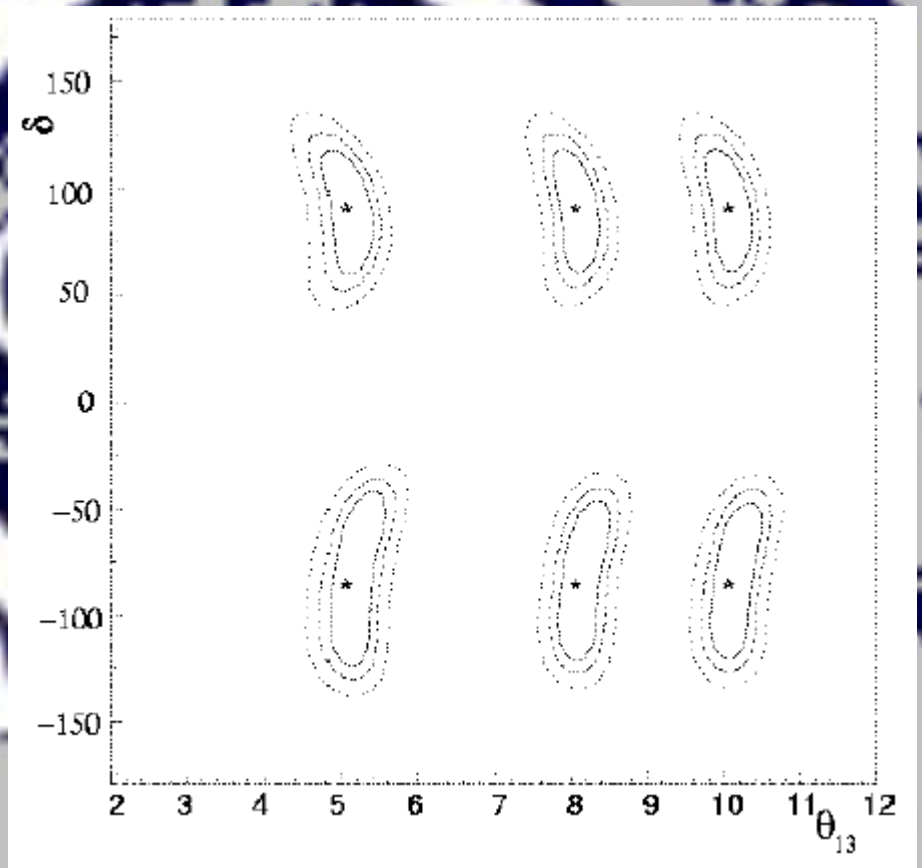
1954-2004

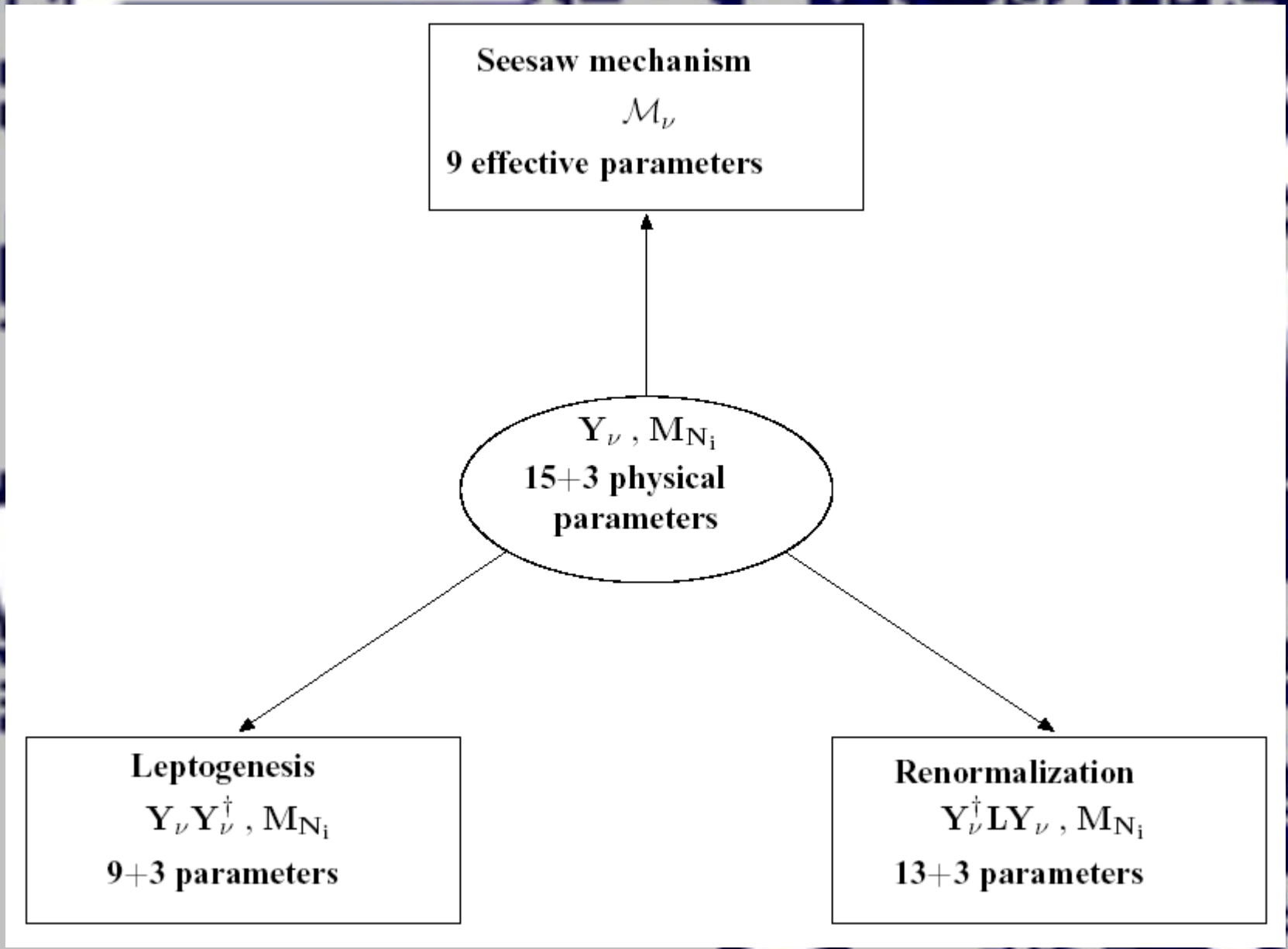
Possible characteristics of a beta beam optimized for the $\overline{\nu}_e$ interaction rate.

^{6}He ion production	5×10^{13}/s every 8 s
^{6}He collection efficiency	20%
^{6}He accelerator efficiency	65%
^{6}He maximum final energy	150 GeV/nucleon
$\overline{\nu}_e$ average energy	582 MeV
Storage ring total intensity	1×10^{14} ^{6}He ions
Straight section relative length	36%
Running time/year	10^7 s
Detector distance	100 km
$\langle E \rangle / L$	5.9×10^{-3} GeV/km
$\overline{\nu}_e$ interaction rate on H_2O	69/kton/year

Possible characteristics of a beta beam optimized for the ν_e interaction rate.

^{18}Ne ion production	1×10^{12}/s every 4 s
^{18}Ne collection efficiency	50%
^{18}Ne accelerator efficiency	82%
^{18}Ne maximum final energy	75 GeV/nucleon
ν_e average energy	279 MeV
Storage ring total intensity	1.3×10^{13} ^{18}Ne ions
Straight section relative length	36%
Running time/year	10^7 s
Detector distance	130 km
$\langle E \rangle / L$	2.1×10^{-3} GeV/km
ν_e interaction rate on H_2O	3.1/kton/year




Seesaw mechanism
$\mathcal{M}_\nu$
9 effective parameters
Y_ν , M_{N_i}
15+3 physical parameters
Leptogenesis
$Y_\nu Y_\nu^\dagger$, M_{N_i}
9+3 parameters
Renormalization
$Y_\nu^\dagger L Y_\nu$, M_{N_i}
13+3 parameters

Ideas about ν masses and mixing

Higher-order Higgs effect: $\frac{(H.L)(H.L)}{M} \rightarrow m_\nu \sim \frac{<0|H|0>^2}{M}$

Underlying Lagrangian: $\mathcal{L} = N_i^c (M_{\nu_D})_{ij} L_j + \frac{1}{2} N^c{}_i (M_{\nu_R})_{ij} N_j^c + h.c.$

Seesaw mass matrix: $\mathcal{M} = \begin{pmatrix} 0 & M_{\nu D} \\ M_{\nu D}^T & M_{\nu R} \end{pmatrix}$

ν mixing matrix:

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$