Introduction to POFPA

Physics Opportunities with Future Proton Colliders

- Members
- Mandate
- Meetings
- Trends in discussions
- Possible framework for recommendations

http://cern.ch/pofpa

We want your input!

Members of POFPA

- Alain Blondel
- Leslie Camilleri
- Augusto Ceccucci
- JE (Convener)
- Mats Lindroos
- Michelangelo Mangano (Secretary)
- Gigi Rolandi

Mandate of POFPA

- The definition of the physics opportunities that could be provided by the possible development and upgrades of the present Proton Accelerator Complex
- Composed of seven members
- The group may create working teams on specific physics topics
- The group reports to the DG
- Its findings will be discussed in the Executive Board
- (May form basis for report to Strategy Group)

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Background Documents

- SPSC Villars meeting
- Previous analysis of physics opportunities with an upgrade of the LHC luminosity (hep-ph/0204087)
- Opportunities in neutrino, muon and kaon physics with a high-intensity proton driver reviewed by the ECFA/CERN Study Group
- Megawatt proceedings, NUFACT05, ISS@CERN Sept 22/23/24
- Opportunities in nuclear physics to be based on the programme that will be recommended by the INTC
- NuPAC@CERN Oct 10/11/12
- **Close liaison with the PAF Working Group**
  - many common meetings, cross-participation by individual members

The Story so far …

Present accelerator	Replacement accelerator	Improvement	INTEREST FOR: LHC upgrade	ν physics beyond CNGS	RIB beyond ISOLDE	Physics with k and μ
Linac2	Linac4	**50 → 160 MeV** **$H^+ \rightarrow H^-$**	+	0 (if alone)	0 (if alone)	0 (if alone)
PSB	>2.2 GeV RCS* for HEP	1.4 → >2.2 GeV 10 → 250 kW	+	0 (if alone)	+	0 (if alone)
	>2.2 GeV/ mMW RCS*	1.4 → >2.2 GeV 0.01 → 4 MW	+	++ (super-beam, β-beam ?, ν factory)	+ (too short beam pulse)	0 (if alone)
	>2.2 GeV/50 Hz SPL*	1.4 → >2.2 GeV 0.01 → 4 MW	+	+++ (super-beam, β-beam, ν factory)	+++	0 (if alone)
PS	RSS*/** for HEP	>30 GeV Intensity **x** 2	++	0 (if alone)	0	+
	5 Hz RCS*/**	>30 GeV 0.1 → 4 MW	++	++ (ν factory)	0	+++
SPS	1 TeV RSS*/ **	0.45 → 1 TeV Intensity **x** 2	+++	?	0	+++

RCS=Rapid Cycling Synchrotron
RSS=Rapid Superconducting Synchrotron
SPL=Superconducting Proton Linac

* with brightness x2
** need new injector(s)

HIP report & R.Garoby

Specific Charges

- Assess the likely physics objectives of LHC upgrades and non-collider experiments from 2010 onwards, taking into account the likely objectives of other physics laboratories
- Analyse the capabilities of the various development and upgrade options of the overall CERN proton complex discussed by PAF to address these physics objectives, for each option and physics programme separately
- Identify any detector R&D that would be needed if these experimental objectives are to be realized
- Identify synergies of R&D with other CERN studies and projects, as well as with activities outside CERN
- **NB: not charged to look into linear colliders**

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Reporting Schedule

- Report to the DG results from the above studies before the end of 2005. Subsequent discussions in the Executive Board should be helpful to define a priority orientation
- Define a preferred scenario together with a suggested implementation schedule, staged in time, and provide a preliminary estimate of the necessary resources (budget, man-power and expertise) needed to carry out the corresponding experiments. A first presentation is expected by mid-2006 as an input for the critical decisions by the management in 2006 on a possible Linac4
- Recommendations will initially be rather tentative and will ultimately be formulated, around 2010, using the findings of this working group and taking into account the global status of high-energy physics plans and projects
- To which should be added the Council Strategy Group on a Possible Roadmap for the Future of European Particle Physics
  - Symposium in February, Meeting in May

Programme of Meetings

- Meetings with PAF to understand accelerator options
  - Linac4 (160 MeV), RCS, SPL (4 GeV?)
  - PS+ (60 GeV), SPS+ (1 TeV)
- DG & CSO
- SLHC (luminosity upgrade)
- Neutrino physics (Guido Altarelli, Jacques Bouchez)
- Nuclear physics (Carsten Riisager)
- Kaon physics
- Heavy ion collisions and fixed-target

  (Jürgen Schukraft, Carlos Lourenço, Urs Wiedemann, Gerhard Mallot)

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Tentative Chapter Headings

- Top-level priorities

  Milestones, criteria, long lead-time R&D projects?
- LHC luminosity upgrade (SLHC)

  Physics arguments, preferred scenario(s)

  Comments on energy upgrade (DLHC)
- Neutrino physics

  Utility of different accelerators for different options
- Other physics

  kaon physics, muon physics, fixed-target physics with heavy ions, other fixed-target physics, nuclear physics, other ideas
- Supplementary Comments

  Lepton accelerators

Remarks on the LHC Upgrade

- For survey, see hep-ph/0204087:
  - E.g., more sensitive studies of a light Higgs boson and better searches for a heavy Higgs boson,
  - better electroweak measurements – e.g., of TGVs
  - searches for new physics – e.g., supersymmetric particles and new gauge bosons.
- Increasing LHC luminosity to 10^{35} $cm^{-2}s^{-1}$ would require modifications to the ATLAS and CMS detectors
  - E.g., inner tracking systems
- Likely to cost 30 to 50% of the initial capital costs.
- Radiation-hard electronics are available.
- Sensor development is underway (Hamamatsu, RD50): solution by 2008?
- Power distribution needs further study.

SLHC Physics Reach Compared

Summary of reach and comparison of various machines …

Only a few examples …. in many cases numbers are just indications ….

Units are TeV (except $W_L W_L$ reach)
$\int Ldt$ correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λ compositeness	30	40	40	50	100	100	400
TGC λ_γ (95%)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach (from precision measurements)

Approximate direct mass reach :

- $\sqrt{s}$ = 14 TeV, $L=10^{34}$ (LHC) : up to ≈ 6.5 TeV
- $\sqrt{s}$ = 14 TeV, $L=10^{35}$ (SLHC) : up to ≈ 8 TeV
- $\sqrt{s}$ = 28 TeV, $L=10^{34}$: up to ≈ 10 TeV
- $\sqrt{s}$ = 28 TeV, $L=10^{35}$: up to ≈ 11 TeV

F. Gianotti, High Luminosity WG, 31/8/2004

New Higgs Physics @ SLHC

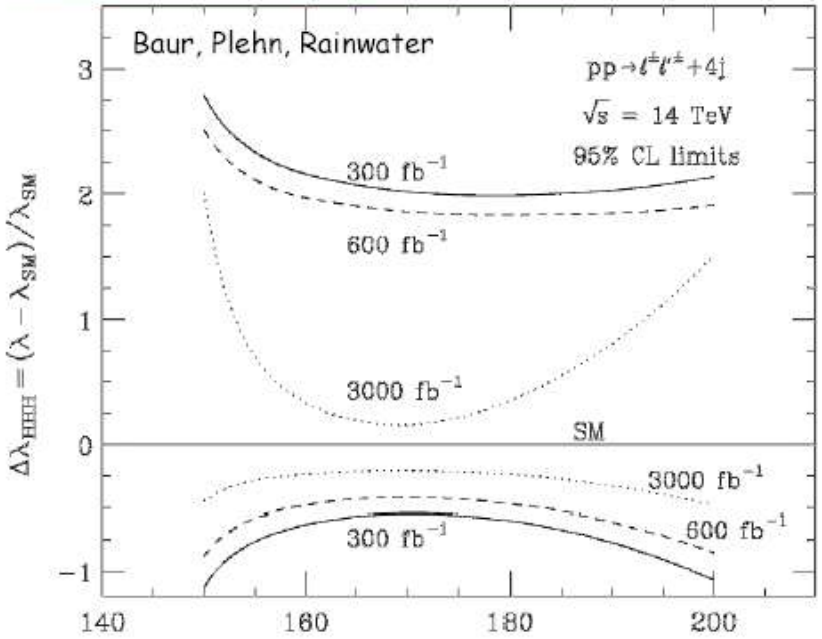
Rare Higgs decays at SLHC

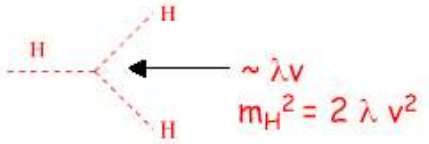
Channel	m_H	S/√B LHC (600 fb^{-1})	S/√B SLHC (6000 fb^{-1})
$H \to Z\gamma \to ll\,\gamma$	~ 140 GeV	~ 3.5	~ 11
$H \to \mu\mu$	130 GeV	~ 3.5 (gg+VBF)	~ 7 (gg)

BR ~ 10^{-4} both channels

→ additional coupling measurements : e.g. Γ_μ / Γ_W to ~ 20%

Higgs self-couplings at SLHC ?





$HH \to W^+ W^- W^+ W^- \to l^\pm\nu\ jj\ l^\pm\nu\ jj$

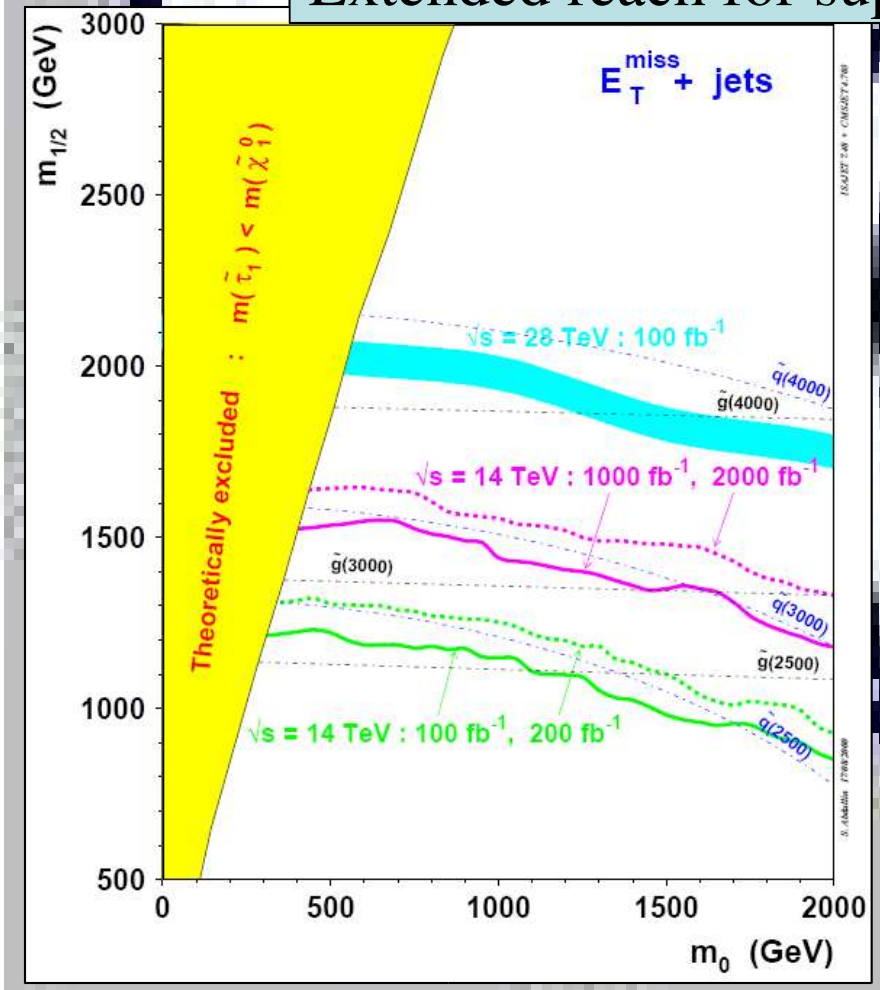
LHC: λ= 0 may be excluded at 95% CL.

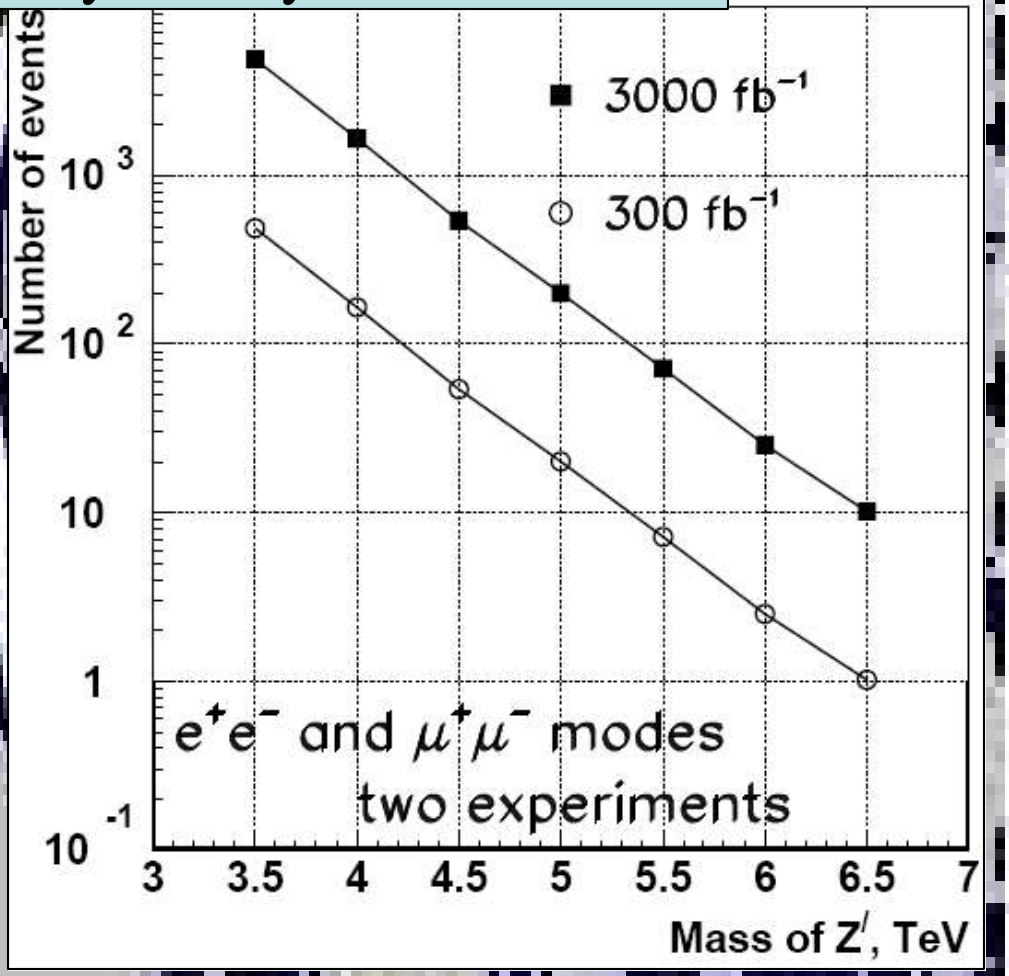
SLHC: λ may be determined to 20-30% (95% CL)

Comparable to √s = 0.5 TeV LC , not competitive with CLIC (precision up to 7%)

Examples of Searches for New Physics

Extended reach for supersymmetry and a Z' boson



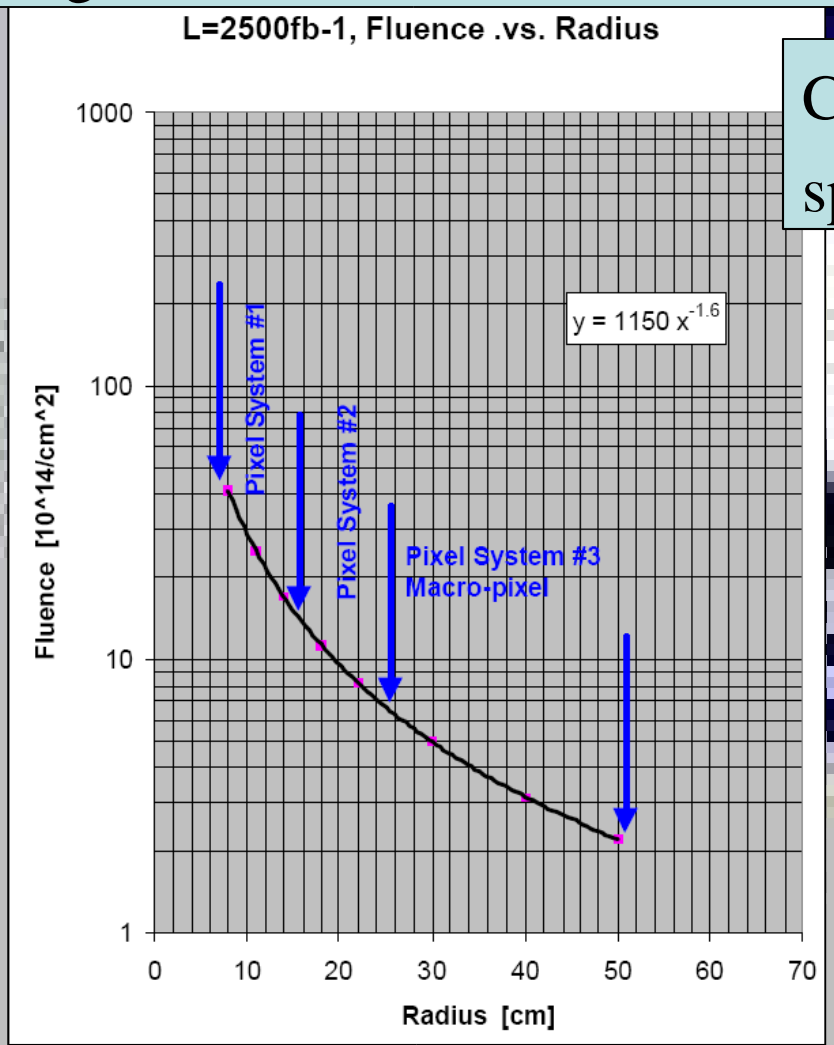


Additional LHC Remarks

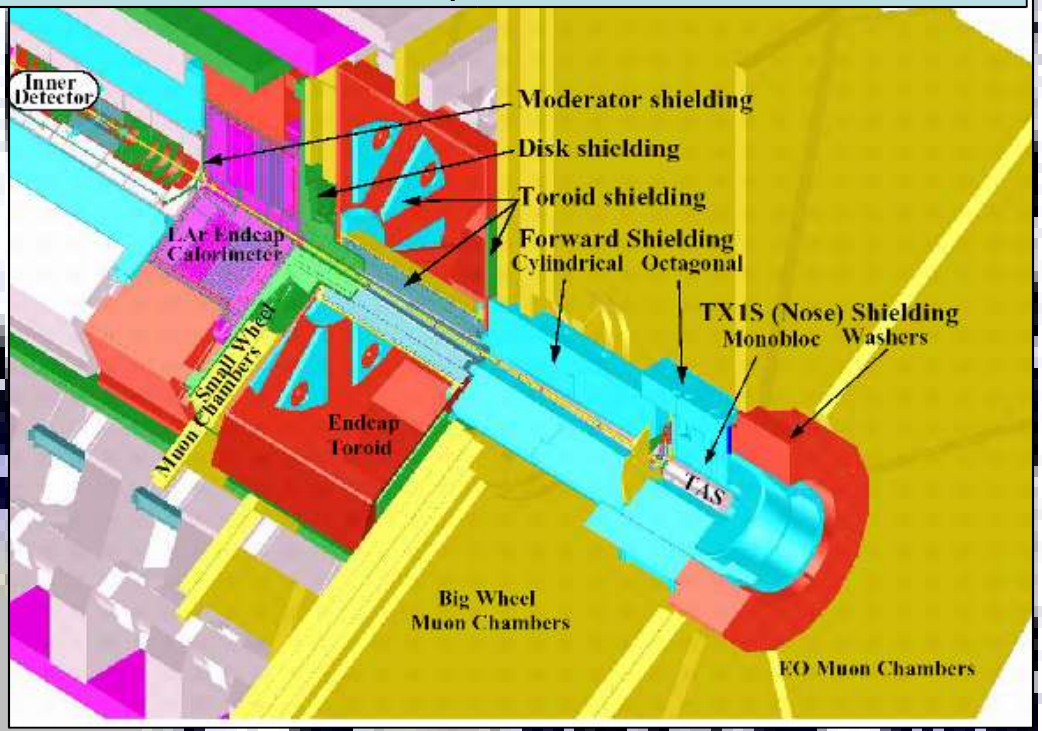
- Reducing β^* and minimizing the downtime are clearly desirable.
- The interaction regions for the SLHC have yet to be defined
  - Need significant R&D for focusing magnets, etc.
  - Layout may have significant implications for the experiments
  - Studies of the various options should be pursued aggressively
- The LHC experiments have expressed clear preferences for the spacing between beam crossings in any upgrade scenario
- Retaining the present planned spacing of 25ns would have been preferred, but factor 2 in luminosity may be gained by going to a spacing of 12.5ns
  - Modifications to the DAQ may cost another 10% of the initial capital costs of the experiments
- A spacing of 10 or 15ns (preferred for accelerators) would imply much more costly modifications to the experiments
- The final choice of upgrade scenario will require a global optimization of the combined accelerator and detector expenses

Detector Issues for the SLHC

High radiation in central tracker



Congested layout in forward direction: space for new low- β^* machine elements?



More SLHC Remarks

- Definition of preferred LHC upgrade scenario in 2010 will require some inputs from initial LHC operations.
  - E.g., neutron fluence, radiation damage and detector performance, as well as the early luminosity experience and physics results.
- PAF is discussing many possible scenarios for upgrading the LHC injector complex: Linac4 → SPS+
- Common element in all LHC luminosity upgrade scenarios is Linac4: on critical path for optimizing the integrated LHC luminosity

Comments on LHC Energy Upgrade

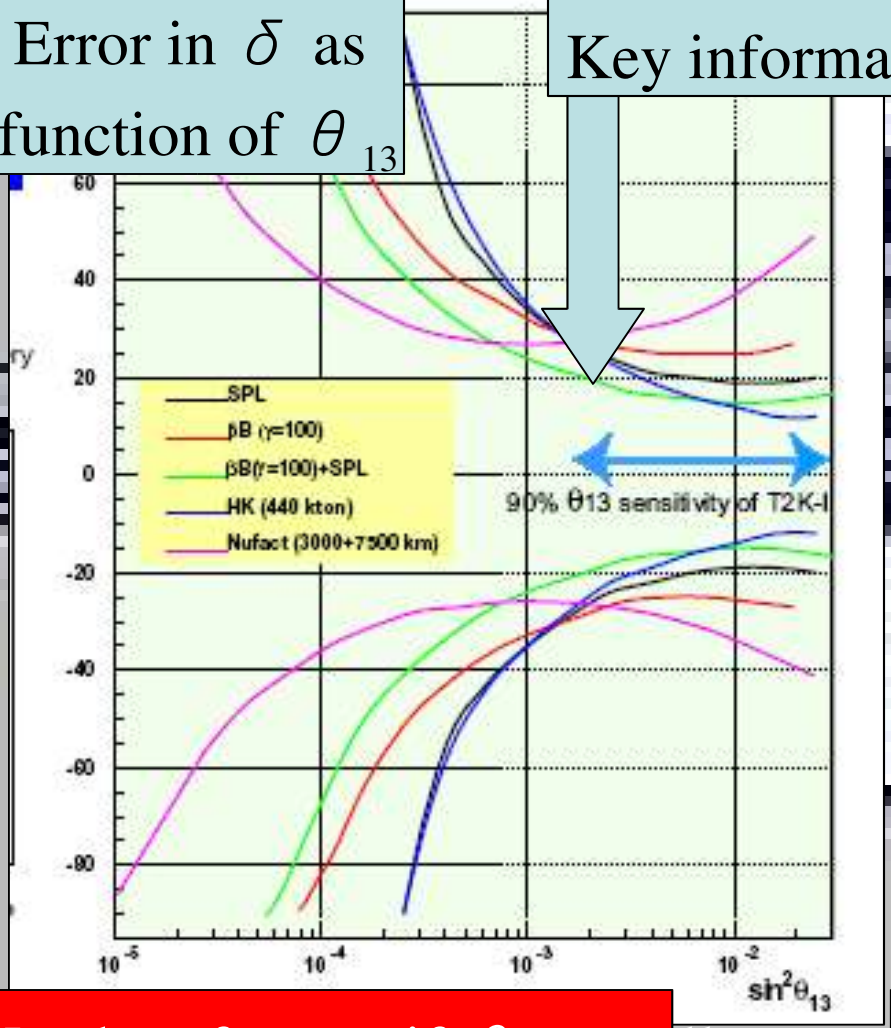
- Many scenarios for new physics at the LHC would benefit from doubling centre-of-mass energy: DLHC
- Project should be assessed in light of the early LHC physics results, along with the ILC and CLIC
- Some of the scenarios for upgrading CERN's proton accelerator complex would have particular benefits if the DLHC were to be envisaged.
  - E.g., superconducting SPS+, able to reach 1 TeV, would be needed as an injector to the DLHC
  - This would, in turn, presumably require a superconducting PS+, able to achieve around 60 GeV

Personal Remarks on Neutrinos

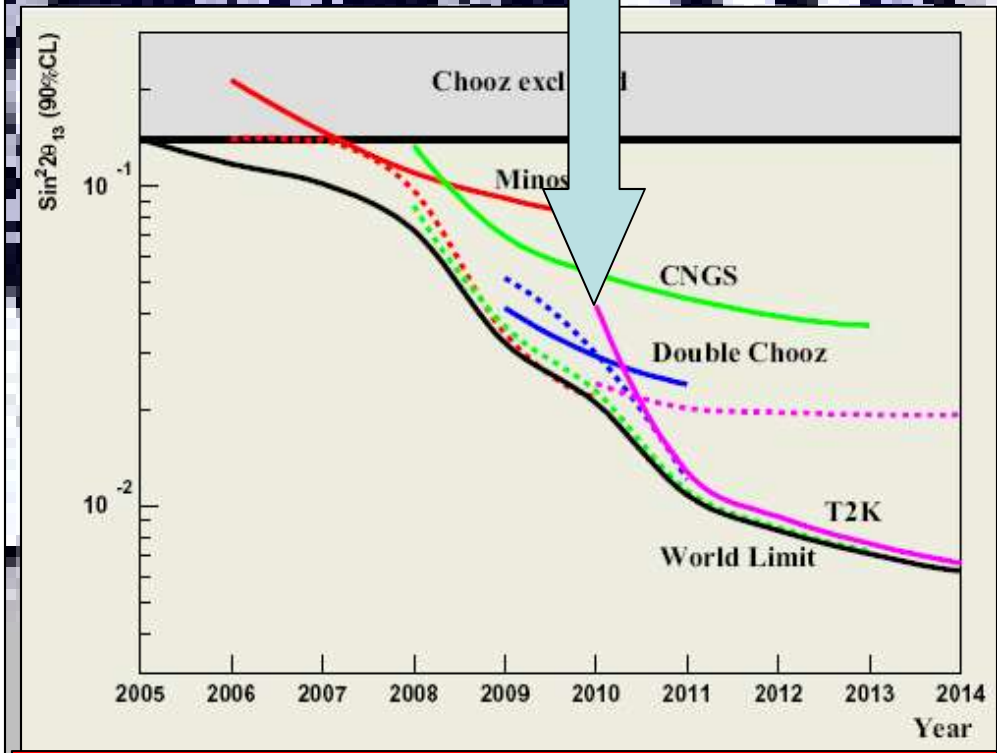
- Discovering CP violation in neutrino physics would be a suitable high-level goal for CERN.
- If $\sin^2 \theta_{13} > 10^{-2}$, may be possible to measure δ using superbeam/ β beam + megaton water Cerenkov detector
- Neutrino factory with two distant detectors (magnetized-iron or liquid Argon?) of several dozen kilotonnes at very long baselines would be needed to measure δ if $\sin^2 \theta_{13} < 10^{-3}$

How to measure δ ?

Error in δ as function of θ_{13}



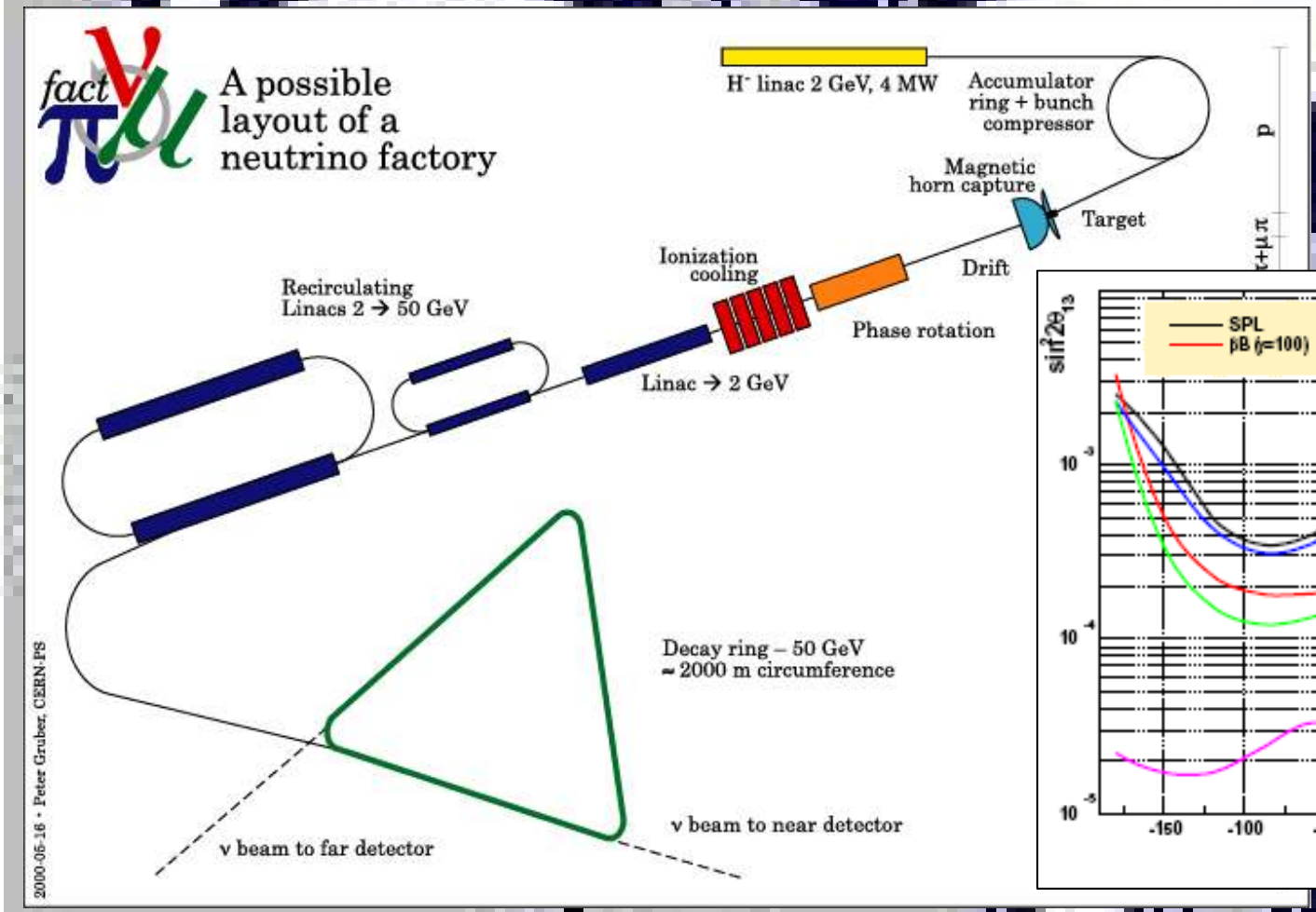
Key information from Double-Chooz/T2K

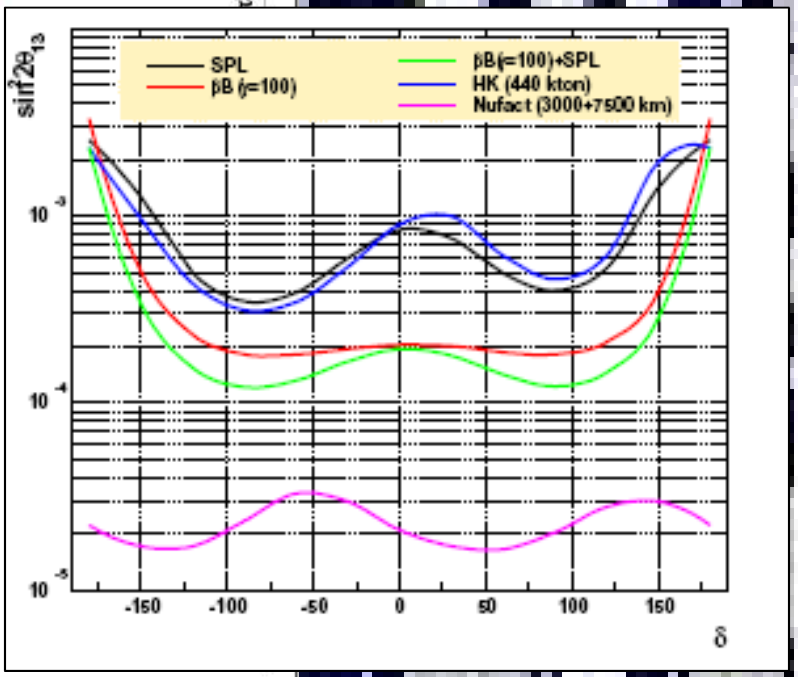


Need ν factory if θ_{13} small

How soon will we know size of θ_{13}?

The Ultimate ν Weapon





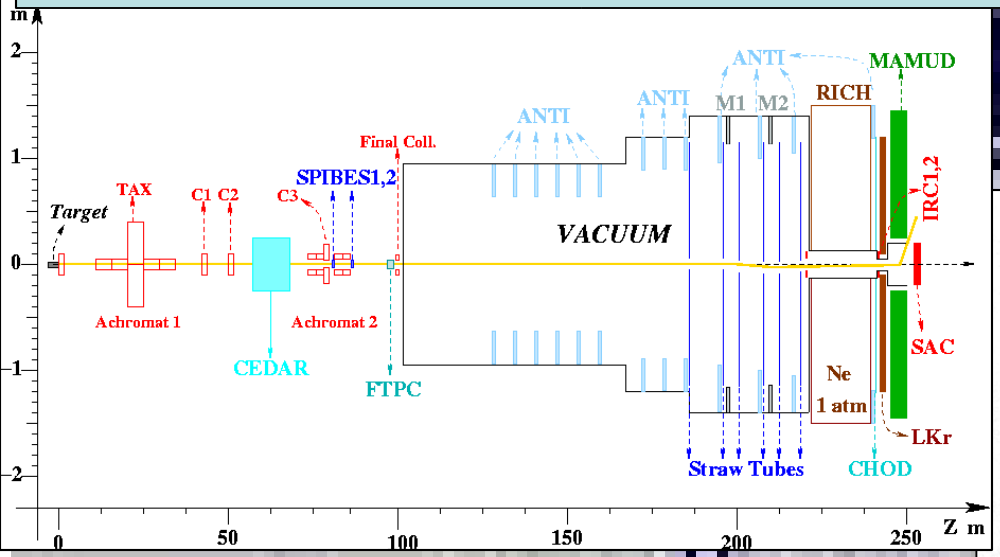
ν factory has unparallelled sensitivity to θ_{13}

Other Physics Options

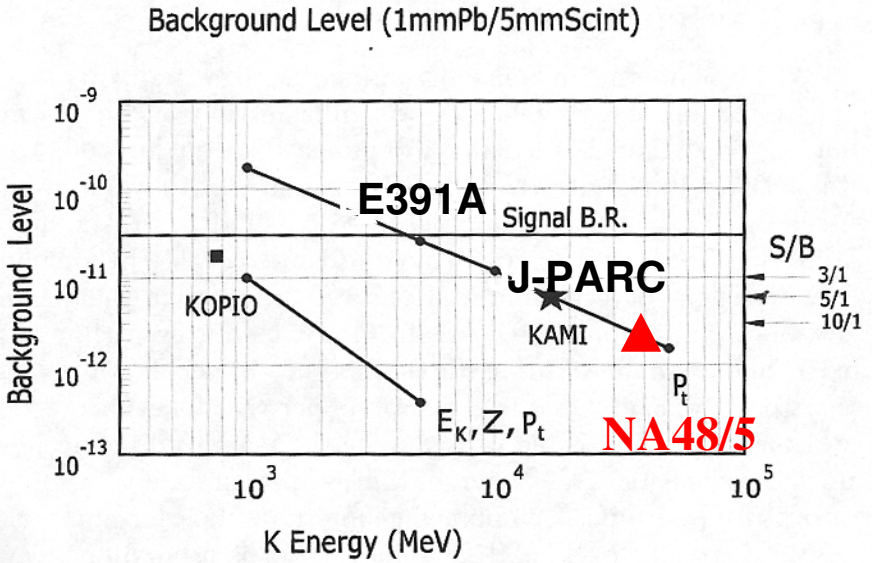
- Kaon physics:
  - K → $\pi \nu \nu$, πl^+l^- decays
- Heavy ions @ fixed target:
  - Probe for critical point?
- Continuation of COMPASS:
  - Generalized parton distributions
- Muon physics:
  - Use SPL to look for μ → e transitions?

K → π ν ν Decays: Tests of Standard Model

P-326 proposal for $K^+ \rightarrow \pi^+ \nu \nu$ @ CERN
aims at 80 events -
could reach 1000 events with 60 GeV PS+

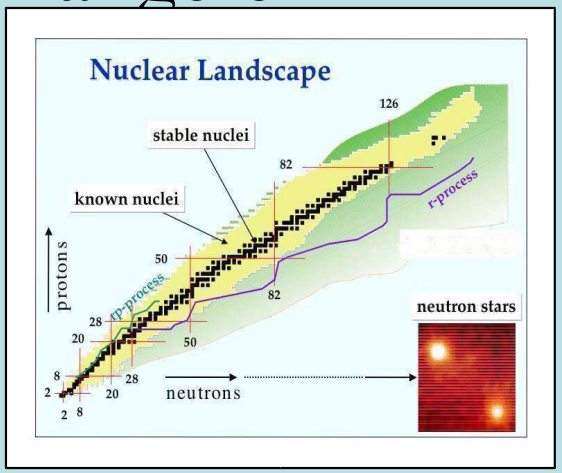


Possible future sensitivity
for $K^0 \rightarrow \pi^0 \nu \nu$ @ CERN



Nuclear Physics

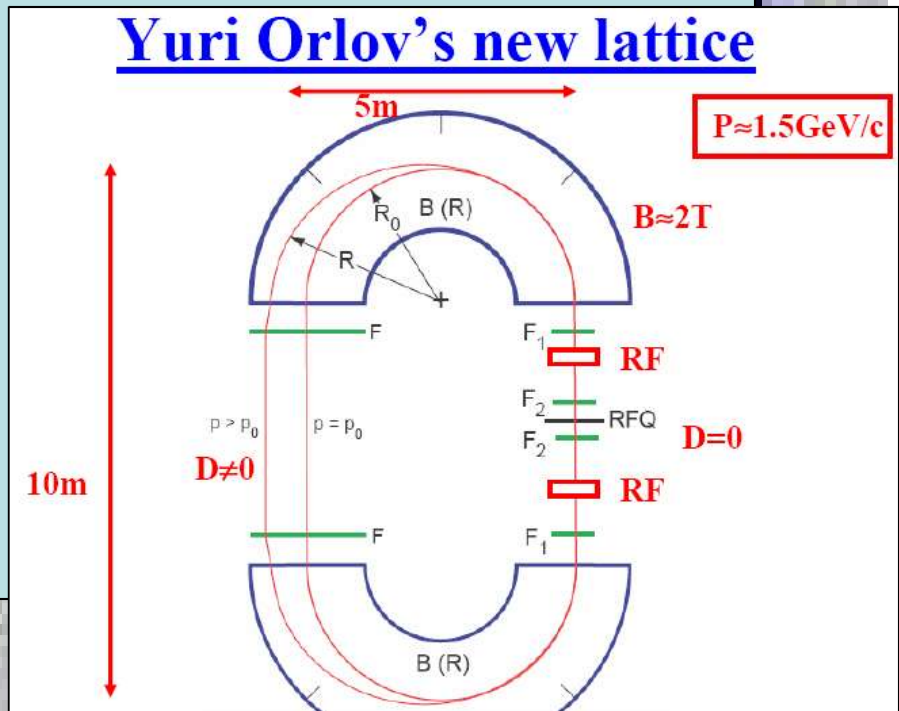
- ISOLDE provides a uniquely broad range of isotopes with fast change-overs
  - Nuclear structure
  - Nuclear astrophysics
  - Probes of Standard Model extensions



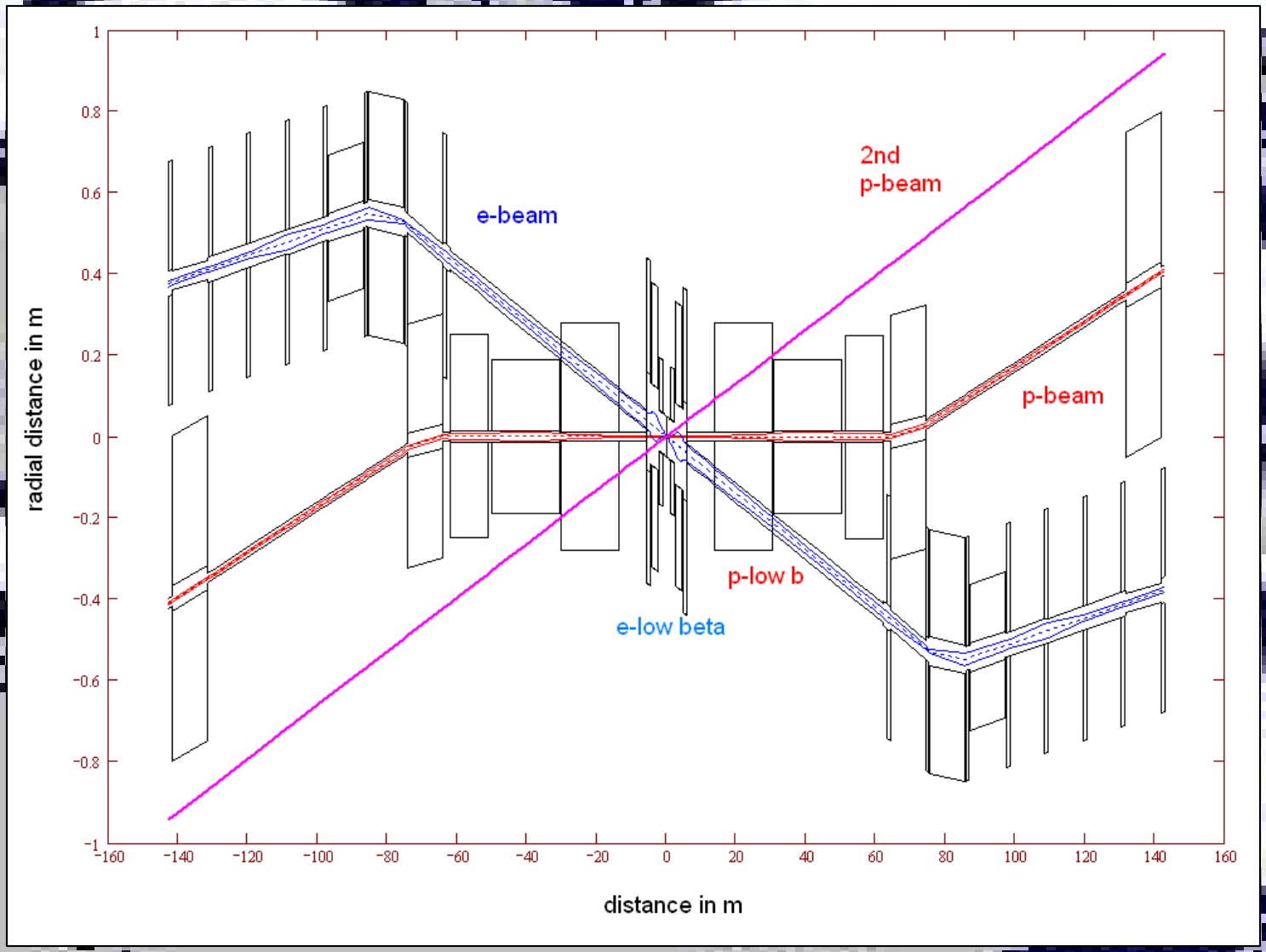
- Upgrade REX-ISOLDE to 10MeV/u: HIE-ISOLDE
- Next step: EURISOL: 4 MW @ 4 GeV
  - Driver for superbeam? β beam needs 200 KW

New Idea: Deuteron EDM?

- Measure the deuteron electric dipole moment with an accuracy ~ 10^{-29} e.cm using a 1.5 GeV/c storage ring.
- Polarized deuterons → LEIR ring for accumulation and bunching, then transfer to dedicated ring for experimental runs.
- Compatible with using LEIR for heavy ions for the LHC?
- Interesting project with good synergies with CERN's approved programmes?



e-p/e-ion Collider in LHC Tunnel?



Possible Framework for Report

- What are the minimal scenarios for a full exploitation of the LHC
- What are the additional elements/costs/etc required for a flavour physics programme (plus possibly QCD studies)
- In the above two frameworks, what are the extra requirements for a continued Relativistic HI Collisions programme
- What are the additional elements/costs/etc required for different options in neutrino physics:
  - super beam to Frejus
  - beta beam to Frejus
  - high energy beta beam (e.g. to LNGS)
  - high-power PS beam to LNGS
  - nuFact
- What are the additional elements/costs/etc required for Eurisol

Possible Top-Level Priority Statements

- Consider an upgrade to optimize the useful LHC luminosity, integrated over the lifetime of the accelerator, to be a high priority in choosing a strategy for upgrading CERN's proton accelerator complex.
- Consider that providing Europe with a forefront neutrino facility is the next priority for CERN's proton accelerator complex, whose potential interference with a future high-energy electron-positron collider will need to be assessed.

Possible Supplementary Remarks

- Other physics topics provide many interesting supplementary opportunities. However, will they have a priority high enough to alter whatever proton accelerator upgrade scenario might be preferred on the basis of the first two priorities?
- Maybe if substantial funding from outside the normal CERN budget would be available, e.g., for a new programme in nuclear physics within the EURISOL initiative.

Supplementary Concluding Remarks

- **Our mandate does not extend to lepton colliders**
- CERN would benefit from internal consideration of these options
- When the first LHC physics results become available, we will need to compare physics achievable with ILC or CLIC with that accessible to SLHC or DLHC
- CERN must also be prepared to assess the relative priorities of major investments in neutrino facilities, as compared to a future high-energy electron-positron collider

We want your input!