Piero Zucchelli
CERN

BETA-BEAMS

Idea, Progress, Feasibility

CERN-EP/2001-056
HEPEX-0107006
(Subm. To PLB)
http://cern.ch/Piero.Zucchelli/files/betabeam/nnn02.ppt

GUIDELINES

1. Neutrino beams from a different perspective
2. The “Beta-Beam” Concept
3. Insight on the radioactive ions production
4. Acceleration schemes
5. Neutrino physics impact

Previous talks, tables and some sources:
http://cern.ch/Piero.Zucchelli/files/betabeam

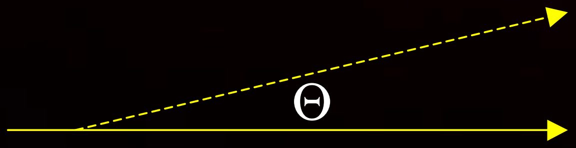
Focussing Properties

The focussing properties are given only by:
- the divergence of the parent “beam”
- the Lorentz transformations between different frames

$$P_T = p_T$$

$$P_L = \Gamma\,(\,p + p \times \cos\theta\,)$$

from which, on average (if spinless)



$\Theta \approx 1/\Gamma$ (it depends ONLY on parent speed!)

$E \approx \Gamma E_0$ E_0 =daughter particle energy when parent is at rest

where. In the forward direction,

$E \approx 2\Gamma E_0$ (I.e. same rest-frame spectrum shape multiplied by 2Γ)

LBL Requirement

maximum neutrino flux for a given $\Delta m^2 \approx E/L \approx \Gamma E_0/L$.

The neutrino flux onto a “far” detector goes like $\Phi \approx \Gamma^2/L^2$; Therefore

$$\Phi \approx (\Delta m^2)^2/E_0^2.$$

At a <u>given parent intensity</u>, low energy decays in the CMS frame are the most efficient in achieving the “LBL requirement”, and independently of the Γ factor.

We want to observe neutrino <u>interactions</u>, therefore:

$$N = \Phi \times \sigma$$

If we assume to be in the regime where $\sigma \propto E$ (>300 MeV for ν_μ)

$$N \approx (\Delta m^2)^2\, \Gamma/E_0$$

And acceleration enters into the game;

The “Quality Factor” QF of a
“non-conventional” neutrino beam is Γ/E_0

The BETA-BEAM

1. Produce a Radioactive Ion with a short beta-decay lifetime

2. Accelerate the ion in a conventional way (PS) to “high” energy

3. Store the ion in a storage ring with straight sections.

4. It will decay. $\bar{\nu}_e$ (ν_e) will be produced.

Muons:
Γ~500
E_0~34 MeV
QF~15

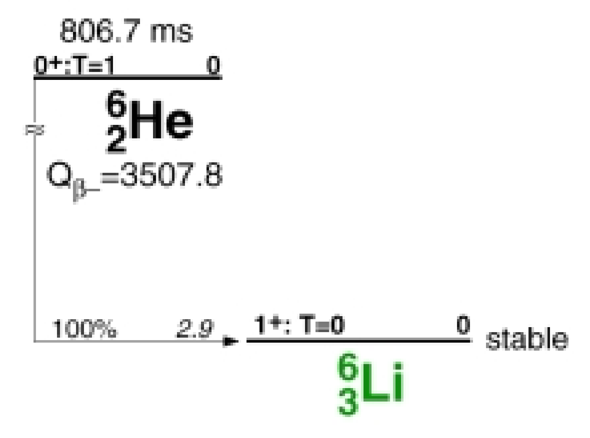
- SINGLE flavour
- Known spectrum
- Known intensity
- Focussed AND Low energy!
- “Better” Beam of $\bar{\nu}_e$ (ν_e)

^{6}He Beta-:
Γ~150
E_0~1.9 MeV
QF~79

^{18}Ne Beta+:
Γ~250
E_0~1.85 MeV
QF~135

The “quality factor” QF=Γ/E_0 is bigger than in a conventional neutrino factory. In addition, production & acceleration (500000× more time) are simpler.

The Anti-Neutrino Source



Consider $^6He^{++} \rightarrow {}^6Li^{+++}\ \bar{\nu}_e\ e^-$

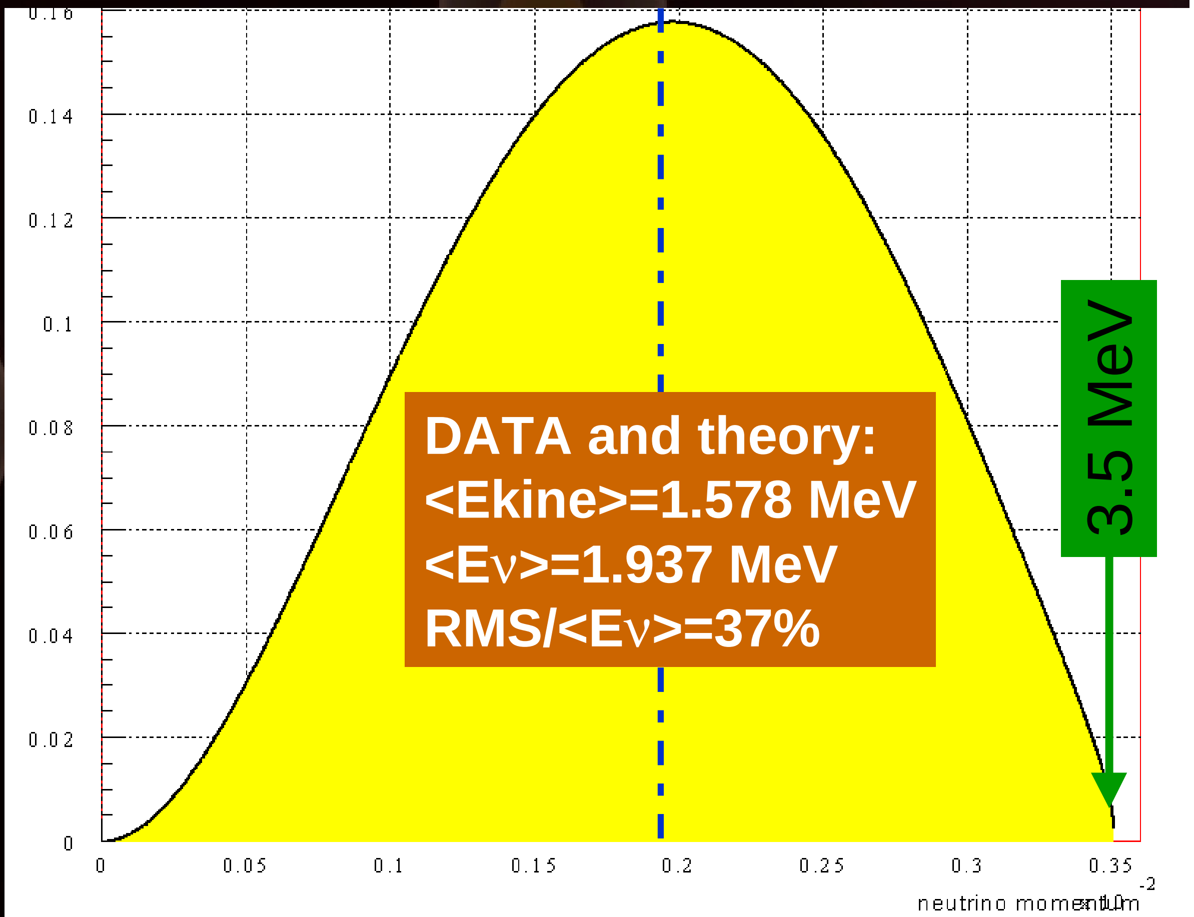
Q=3.5078 MeV   T/2 ≈ 0.8067 s

1. The ion is <u>spinless</u>, and therefore decays at rest are isotropic.

2. It can be produced at high rates

3. The neutrino spectrum is known on the basis of the electron spectrum.

B.M. Rustand and S.L. Ruby, Phys.Rev. 97 (1955) 991
B.W. Ridley Nucl.Phys. 25 (1961) 483



DATA and theory:
<Ekine>=1.578 MeV
<Eν>=1.937 MeV
RMS/<Eν>=37%

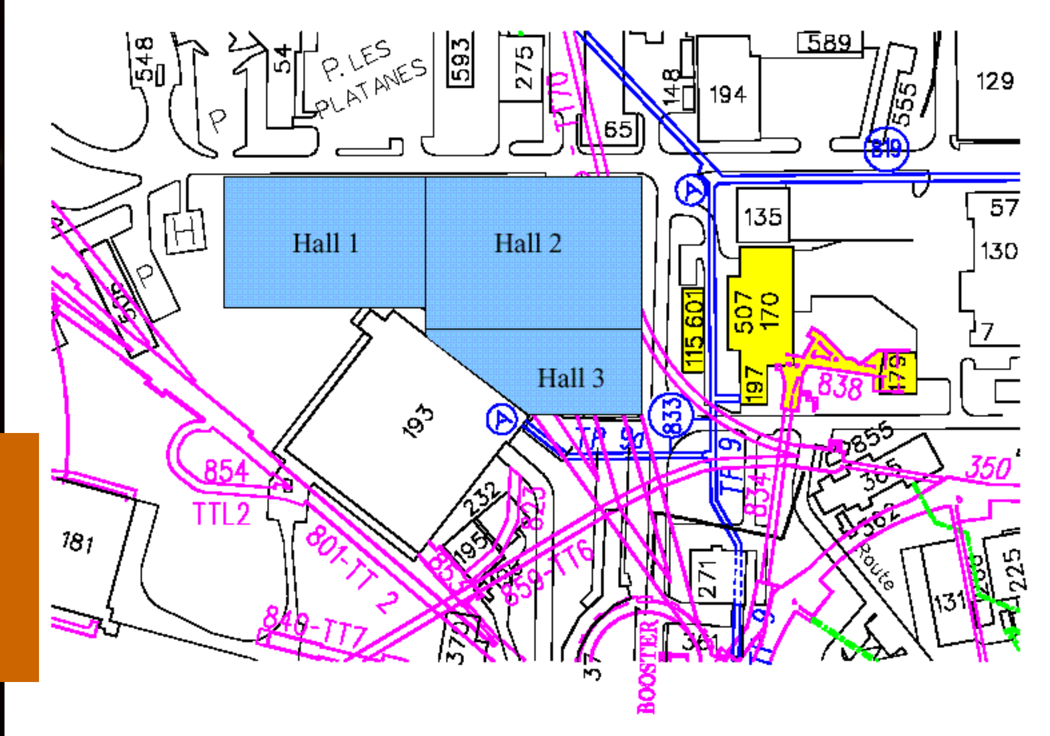
The Anti-Neutrino Source

High ^{6}He production rates are possible in the “Second Generation Radioactive Nuclear Beam Facility at CERN” based on the SPL. (CERN/EP 2000-149)

CONVENTIONAL
TODAY
TECHNOLOGY
ASSUMPTIONS

Physics reference number:

5×10^{13} ^{6}He/s every 8s

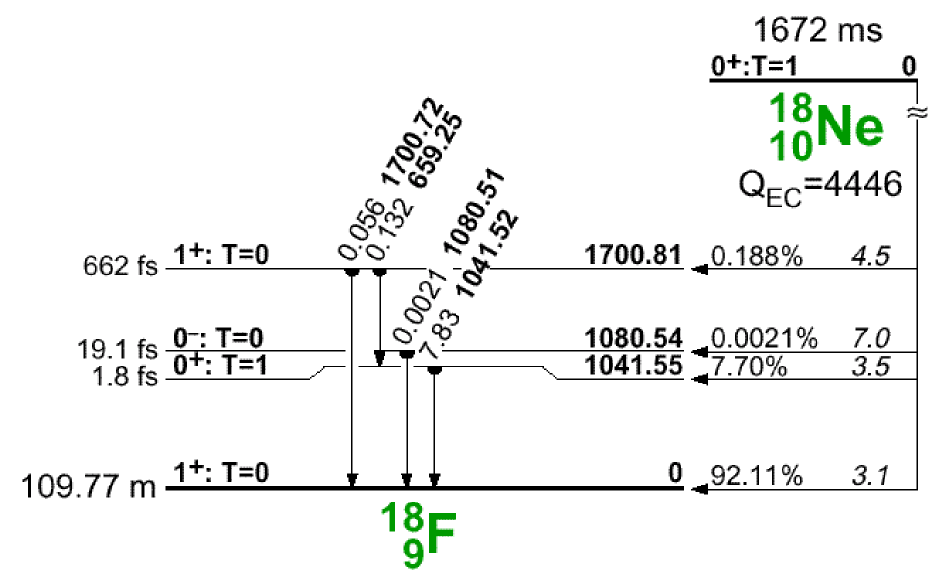


The Neutrino Source

Possible neutrino emitter candidate: ^{18}Ne (spinless!)

The same technology used in the production of ^{6}He is limited in the ^{18}Ne case to ~10^{12} ions/s.
Despite it is reasonable to assume that a dedicated R&D will increase this figure, this intensity is used as “today” reference.

Issues:
MgO less refractory,
heat dissipation



Physics reference number:

10^{12} ^{18}Ne/s every 8s

Possible β^- emitters

U. Köster, EP-ISOLDE

Isotope	Z	A	A/Z	$T_{1/2}$	$Q_{\beta\ (gs>gs)}$	$Q_{\beta\ eff.}$	$E_{\beta\ av.}$	$E_{\nu\ av.}$	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@ 450 GeV/p)
6He	2	6	3.0	0.807	3.5	3.5	1.57	1.94	582
8He	2	8	4.0	0.119	10.7	9.1	4.35	4.80	1079
8Li	3	8	2.7	0.838	16.0	13.0	6.24	6.72	2268
9Li	3	9	3.0	0.178	13.6	11.9	5.73	6.20	1860
11Be	4	11	2.8	13.81	11.5	9.8	4.65	5.11	1671
15C	6	15	2.5	2.449	9.8	6.4	2.87	3.55	1279
16C	6	16	2.7	0.747	8.0	4.5	2.05	2.46	830
16N	7	16	2.3	7.13	10.4	5.9	4.59	1.33	525
17N	7	17	2.4	4.173	8.7	3.8	1.71	2.10	779
18N	7	18	2.6	0.624	13.9	8.0	5.33	2.67	933
23Ne	10	23	2.3	37.24	4.4	4.2	1.90	2.31	904
25Ne	10	25	2.5	0.602	7.3	6.9	3.18	3.73	1344
25Na	11	25	2.3	59.1	3.8	3.4	1.51	1.90	750
26Na	11	26	2.4	1.072	9.3	7.2	3.34	3.81	1450

Possible β^+ emitters

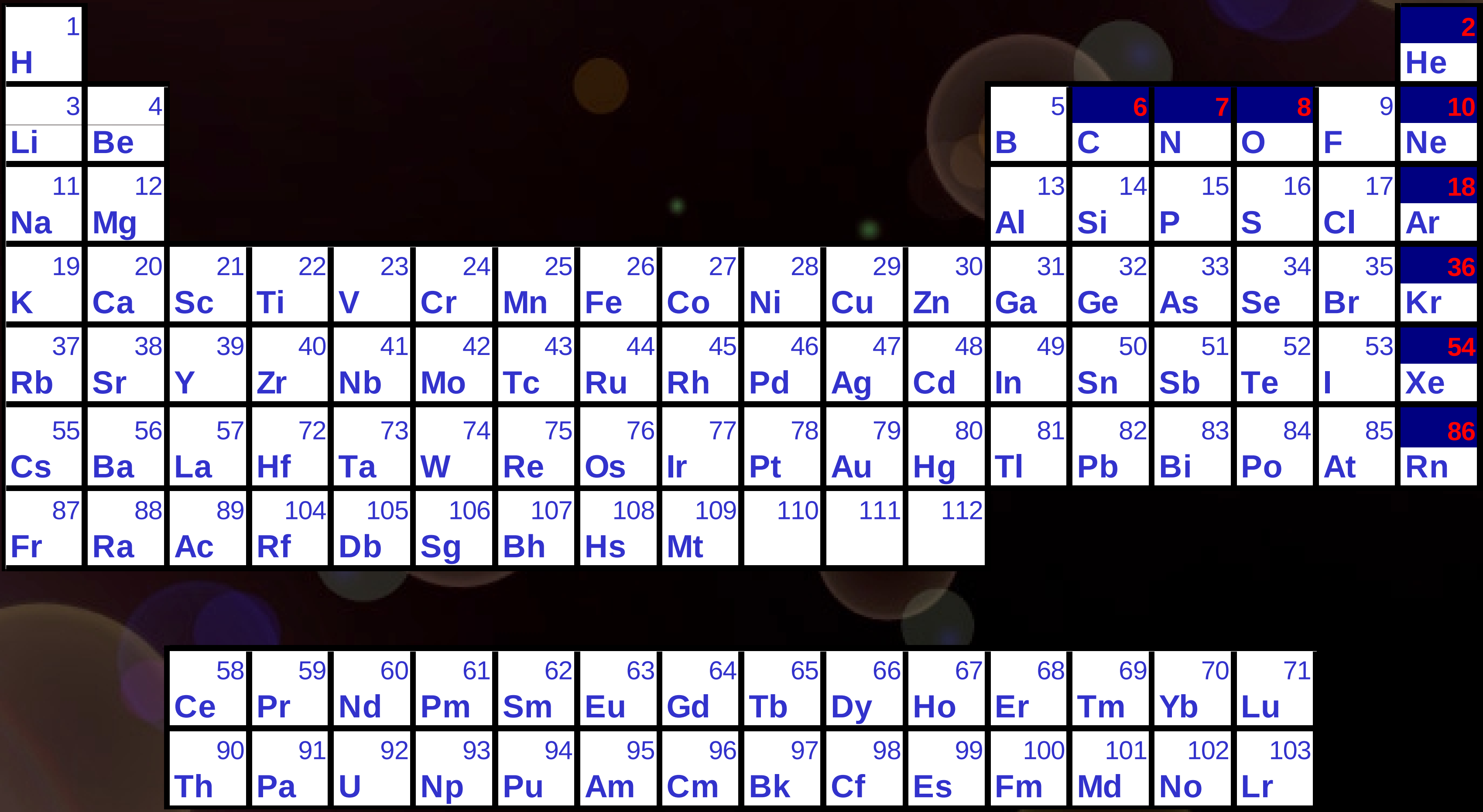
U. Köster, EP-ISOLDE

Isotope	Z	A	A/Z	$T_{1/2}$	Q_{β} (gs>gs)	Q_{β} eff.	E_{β} av.	E_{ν} av.	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@450 GeV/p)
8B	5	8	1.6	0.77	17.0	13.9	6.55	7.37	4145
10C	6	10	1.7	19.3	2.6	1.9	0.81	1.08	585
14O	8	14	1.8	70.6	4.1	1.8	0.78	1.05	538
15O	8	15	1.9	122.2	1.7	1.7	0.74	1.00	479
18Ne	10	18	1.8	1.67	3.4	3.4	1.50	1.86	930
19Ne	10	19	1.9	17.34	2.2	2.2	0.96	1.25	594
21Na	11	21	1.9	22.49	2.5	2.5	1.10	1.41	662
33Ar	18	33	1.8	0.173	10.6	8.2	3.97	4.19	2058
34Ar	18	34	1.9	0.845	5.0	5.0	2.29	2.67	1270
35Ar	18	35	1.9	1.775	4.9	4.9	2.27	2.65	1227
37K	19	37	1.9	1.226	5.1	5.1	2.35	2.72	1259
80Rb	37	80	2.2	34	4.7	4.5	2.04	2.48	1031

U. Köster, EP-ISOLDE

“Easy” ISOL elements

Elements compatible with a “cold-body” ECR ion source

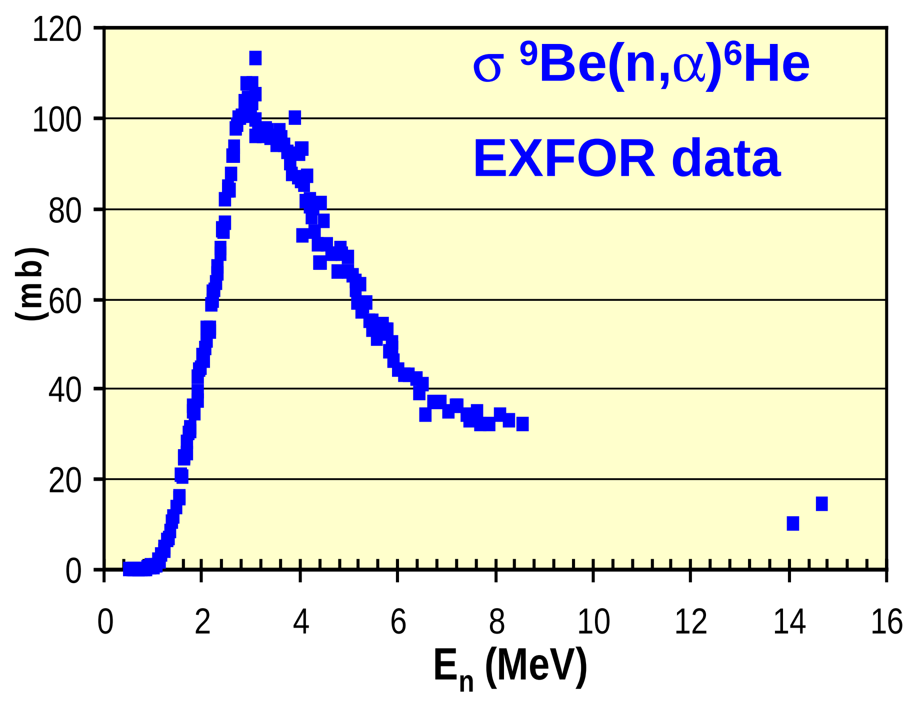


1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112						
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

^{6}He production by ^{9}Be(n,α)

^{9}Be(n,α)^{6}He reaction favorable:

- **Threshold: 0.6 MeV**
- **Peak cross-section 105 mb**
- **Good overlap with evaporation part of spallation neutron spectrum: $n(E) \sim \sqrt{E} * \exp(-E/E_e)$**
- **E_e: 2.06 MeV for 2 GeV p on Pb**
- **BeO very refractory**



^{6}Li(n,p)^{6}He reaction less interesting:

- **Threshold: 2.7 MeV**
- **Peak cross-section 35 mb**
- **Li compounds rather volatile**

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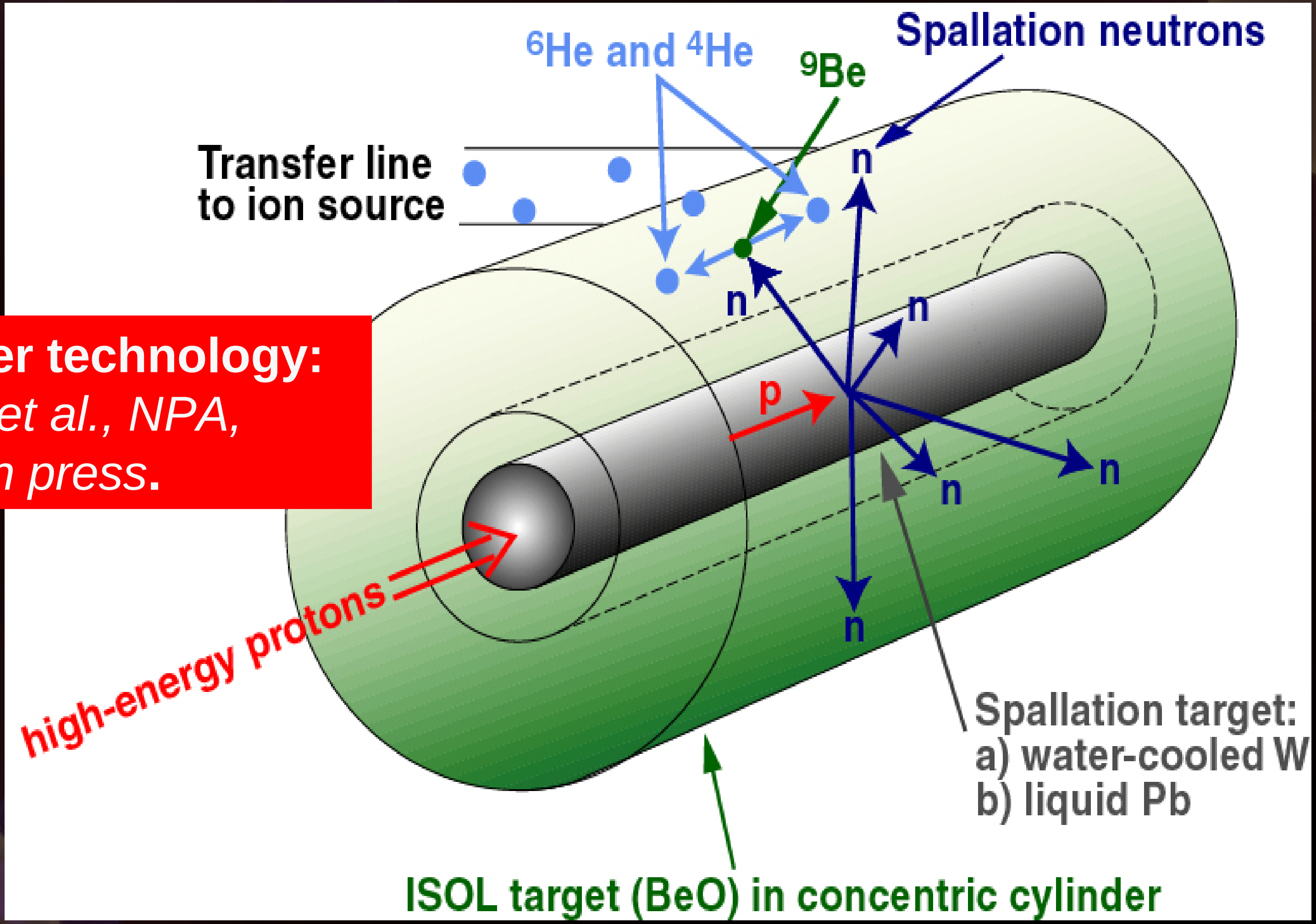
^{6}He production by ^{9}Be(n,α)



Converter technology:
J. Nolen et al., NPA, RNB-5, in press.

Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

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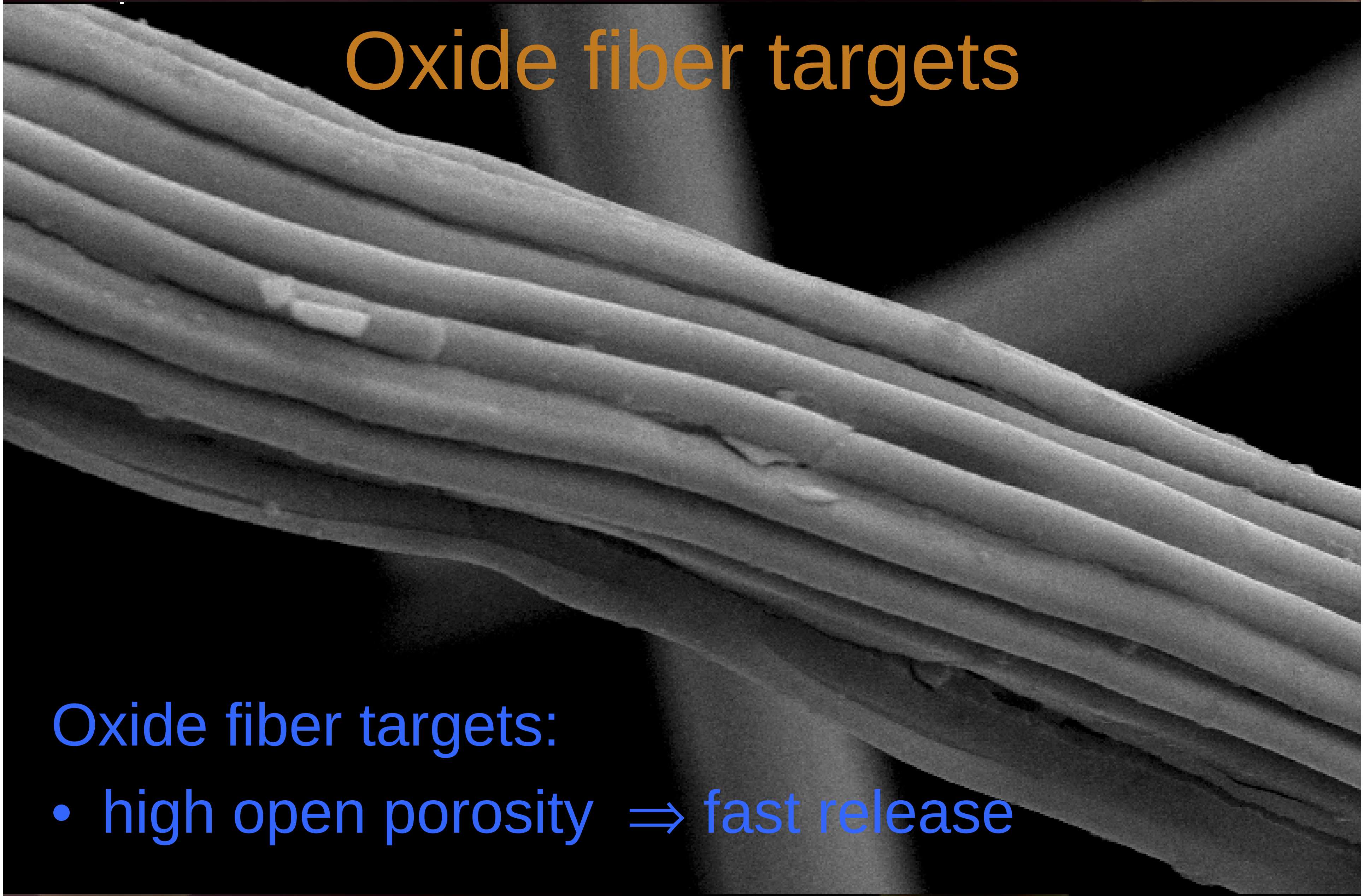
^{6}He production by ^{9}Be(n,α)

Converter scenario:

- 60 cm long liquid Pb or water-cooled W converter
- 100 µA of 2.2 GeV proton beam
- about 20 to 40 neutrons produced per incident proton (dependent on converter diameter, see: ***G.S. Bauer, NIM A463 (2001) 505***)
- thereof about half in suitable angle and energy range
- BeO fiber target in 5 cm thick concentric cylinder around converter
- packed to 10% theoretical density (very conservative)
- production rate: roughly 5E13 per s (requires MC calculation!)

Oxide fiber targets

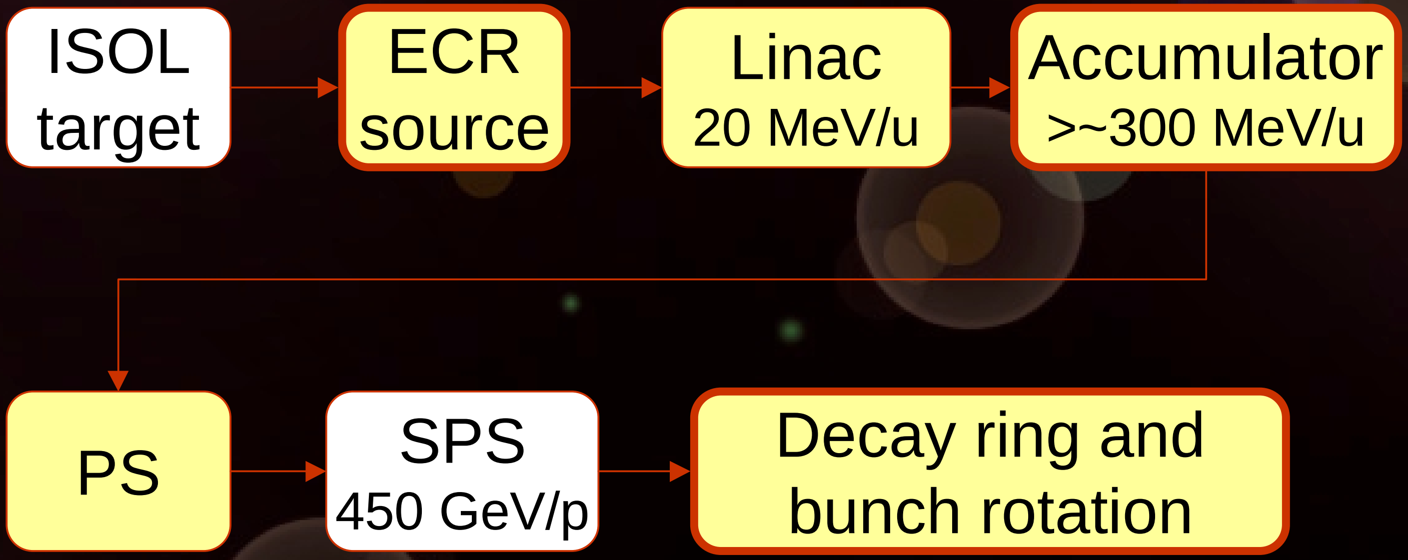


Oxide fiber targets:

- high open porosity ⇒ fast release

M. Lindroos

The Acceleration EXAMPLE



ISOL target

ECR source

Linac 20 MeV/u

Accumulator >~300 MeV/u

PS

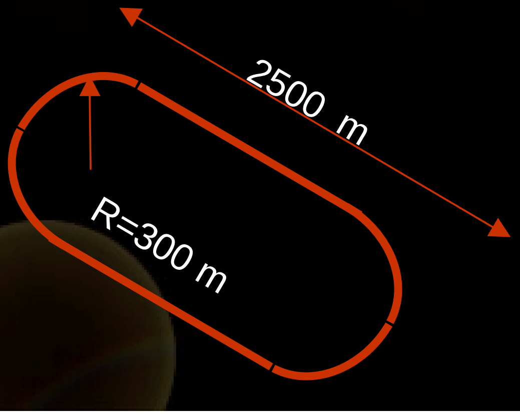
SPS 450 GeV/p

Decay ring and bunch rotation

Bunch rotation is the crucial issue for atmospheric background control

Physics reference numbers:

65%Transmittance into the decay ring
Γ=150 for ^{6}He
Acceleration cycle into the storage ring: 8s



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Parameters

	Intensity out	*Bunch length*
Target	5 10^13 p/s	
EBIT	2 10^13 p/pulse	50 microseconds

	Cycle length (s)	*Phys. Emittance ej.*	*E_{kin} at ejection (GeV/u)*	*beta*gamma*	*Delta Q inj.*
RFQ+LINAC		9	0.02		
Booster	1	40	0.3	0.86	0.85
PS	0.8	5.7		6	0.5
SPS	5	0.32	100	108	

	Intensity out (10^13)	*Particles lost (10^13)*
RFQ+LINAC	2	
Booster	1	1
PS	0.7	0.3
SPS	0.55	0.15

All emittances are 95% (4 sigma) in units of Pi mm mrad Total cycle time 8 seconds

M. Lindroos

PS

- Acceleration of ions for injection into SPS
  - 5-10 GeV/u
- Challenges:
  - High tune shift (0.3-0.5) at injection
  - Losses during acceleration are critical in CERN PS
  - Transport and collimation of two ion species

The Storage Ring

M. Lindroos

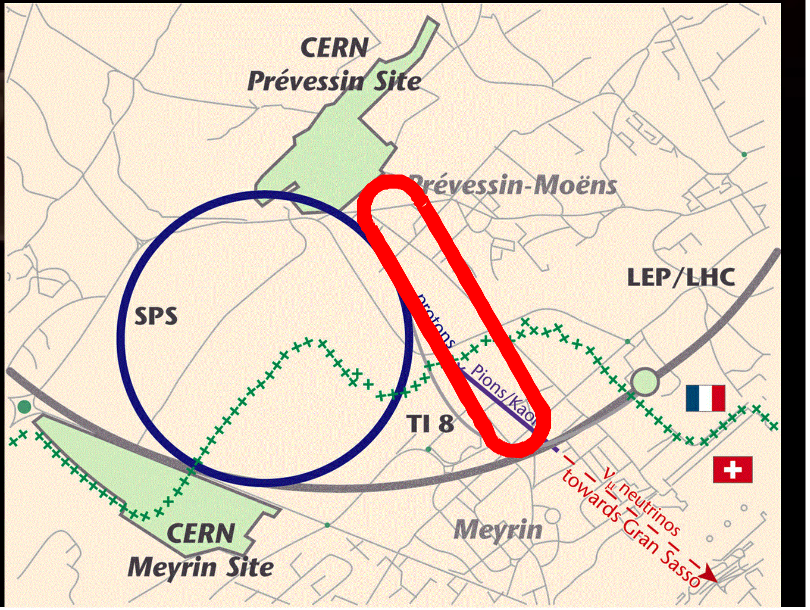
straight section relative length fixed to 2500 m (~SPS diameter). The ring is essentially flat below ground.

B x radius	1500	Tm
B field	5	T
radius of curvature	300	m
straight section length	2500	m
ring length	6885	m
Relative straight section length	36%	

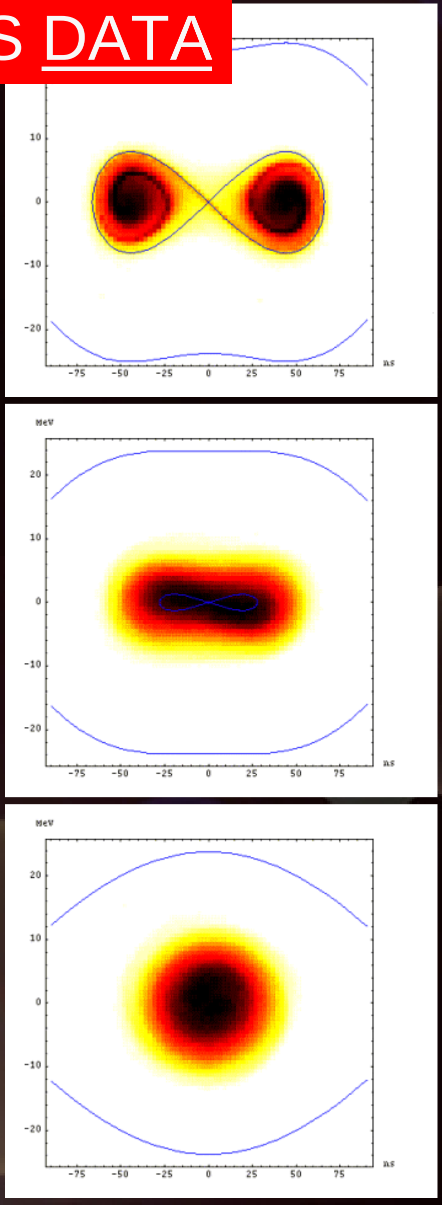
	5T curvature	
radius	300	m
straight	2500	m
field	600X3100	m2

Physics reference numbers:

36% (X2) useful decays
100kW into the storage ring
Bunch rotation: 15 ns length



Bunch stacking and storage ring



SPS DATA

- Bunch Stacking Scheme:
  - Particles in single bunch from SPS
  - Bunch merging with slip-stacking
  - Fast kickers in decay ring

- Storage ring requirements
  - High intensity single bunch of 15 ns length
  - Two RF systems for beam merging and bunch rotation

- Challenges
  - High Energy electron cooling system?
  - Beam loading in RF cavities
  - Transport and collimation of two ion species

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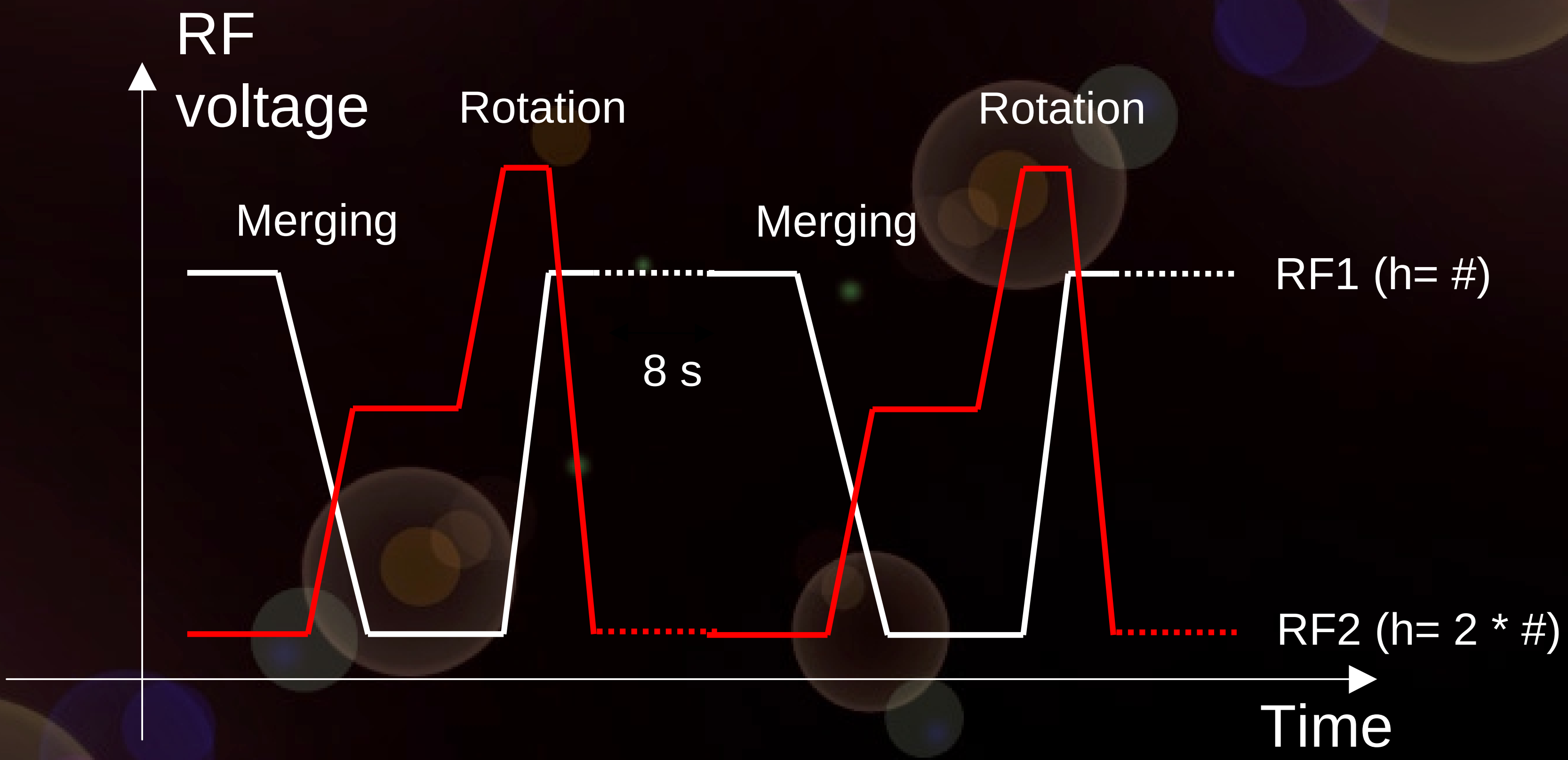
DR RF manipulation



The Storage Ring

Is a 5T bending feasible at all in a “hot” environment?

This problem is not new to LHC (3E14 protons at 7 TeV)

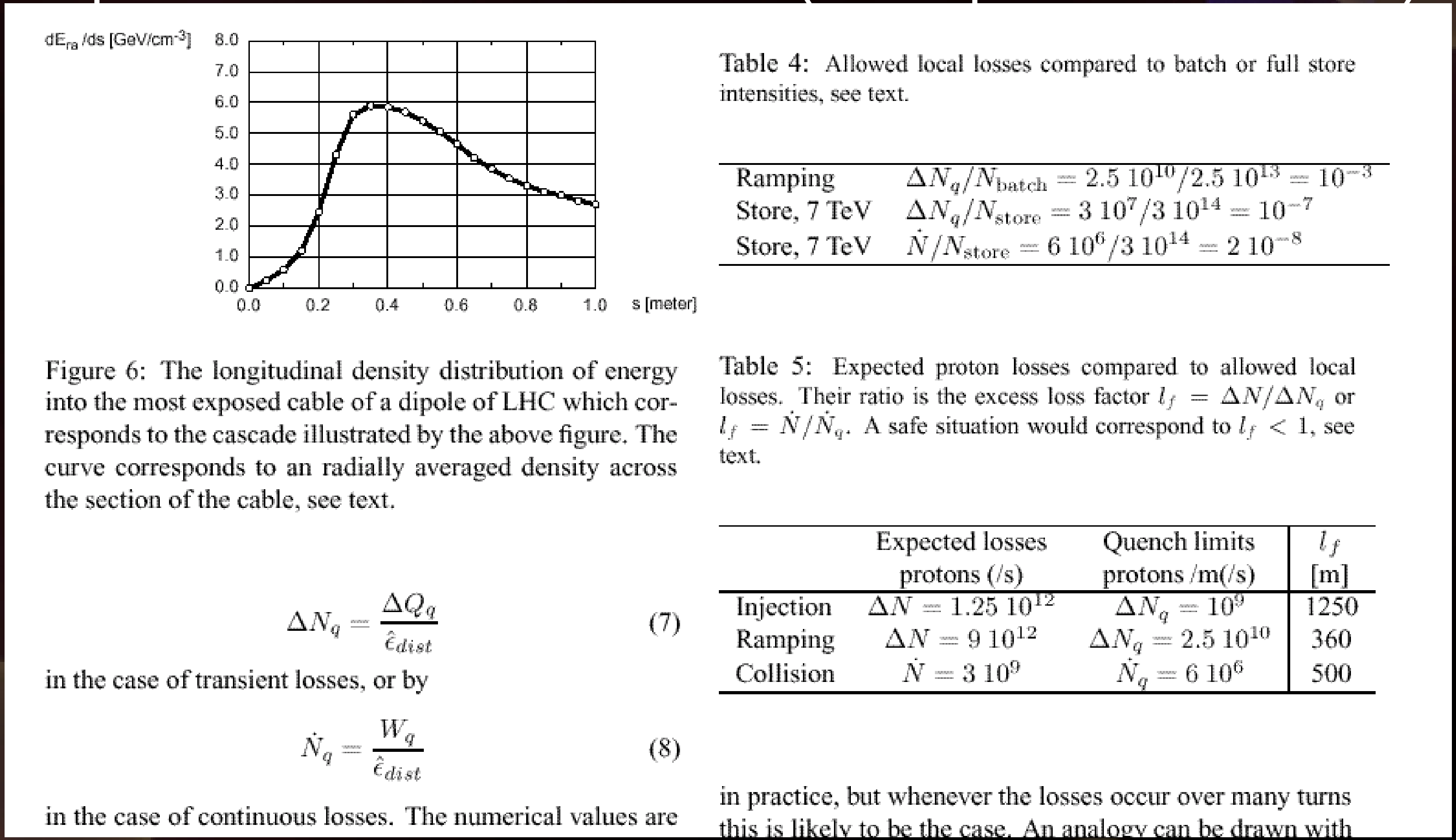


Figure 6: The longitudinal density distribution of energy into the most exposed cable of a dipole of LHC which corresponds to the cascade illustrated by the above figure. The curve corresponds to an radially averaged density across the section of the cable, see text.

$$\Delta N_q = \frac{\Delta Q_q}{\hat{\epsilon}_{dist}} \qquad (7)$$

in the case of transient losses, or by

$$\dot{N}_q = \frac{W_q}{\hat{\epsilon}_{dist}} \qquad (8)$$

in the case of continuous losses. The numerical values are

Table 4: Allowed local losses compared to batch or full store intensities, see text.

Ramping	$\Delta N_q/N_{\rm batch} = 2.5\ 10^{10}/2.5\ 10^{13} = 10^{-3}$
Store, 7 TeV	$\Delta N_q/N_{\rm store} = 3\ 10^{7}/3\ 10^{14} = 10^{-7}$
Store, 7 TeV	$\dot{N}/N_{\rm store} = 6\ 10^{6}/3\ 10^{14} = 2\ 10^{-8}$

Table 5: Expected proton losses compared to allowed local losses. Their ratio is the excess loss factor $l_f = \Delta N/\Delta N_q$ or $l_f = \dot{N}/\dot{N}_q$. A safe situation would correspond to $l_f < 1$, see text.

	Expected losses protons (/s)	Quench limits protons /m(/s)	l_f [m]
Injection	$\Delta N = 1.25\ 10^{12}$	$\Delta N_q = 10^{9}$	1250
Ramping	$\Delta N = 9\ 10^{12}$	$\Delta N_q = 2.5\ 10^{10}$	360
Collision	$\dot{N} = 3\ 10^{9}$	$\dot{N}_q = 6\ 10^{6}$	500

in practice, but whenever the losses occur over many turns this is likely to be the case. An analogy can be drawn with

Handling the proton beams much above the quench limit / Jeanneret, J B ;
Pres. at: 10th Workshop on LEP-SPS Performance,
Chamonix, France, 17 - 21 Jan 2000 CERN, Geneva, Feb 2000. [CERN-SL-2000-007-DI] - pp.162-168

The Storage Ring

The losses in the storage ring
are BELOW the "Allowed steady losses"
for the (unshielded)
7 Tesla LHC magnets.

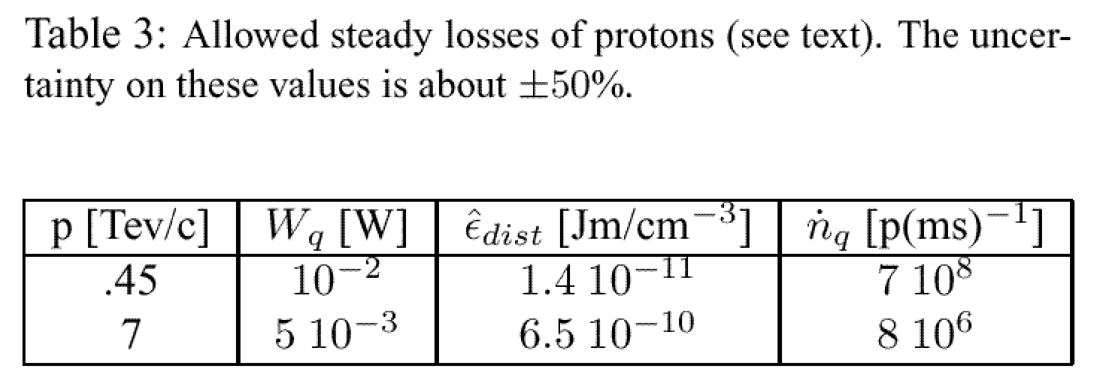


Table 3: Allowed steady losses of protons (see text). The uncertainty on these values is about ±50%.

p [Tev/c]	W_q [W]	$\hat{\epsilon}_{dist}$ [Jm/cm^{-3}]	$\dot{n}_q$ [p(ms)$^{-1}$]
.45	10^{-2}	$1.4\ 10^{-11}$	$7\ 10^{8}$
7	$5\ 10^{-3}$	$6.5\ 10^{-10}$	$8\ 10^{6}$

Stored 6He	1.00E+14	
Li production rate	8.22E+11	Li/s
Li losses	1.21E+08	Li/s/m
p equivalent losses at <u>150</u> GeV	7.26E+08	p/s/m
LHC Allowed local losses at <u>450</u> GeV	7.00E+08	p/s/m

Handling the proton beams much above the quench limit / Jeanneret, J B ;
Pres. at: 10th Workshop on LEP-SPS Performance,
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A Neutrino Physics Scenario

It is reasonable to assume that - in the next years -
savings issues will dominate the scenario in EURO - HEP.

A. *Imagine* a neutrino detector that could do **P**hysics
independently of a beam.

B. *Imagine* to build it, to run it, and to explore relevant
non-accelerator **P**hysics.

C. *Imagine* that, as soon as the SPL will be ready (~2010), you get a
superbeam shooting muon neutrinos onto it. If this will expand
the physics reach, and you're competitive with the other
world programs, you're ready to do it (known technology).

D. *Imagine* that you have PREPARRED and STUDIED an
option to shoot electron neutrinos onto the same detector. If the
next neutrino physics will demand it, you're ready to do it.

A Neutrino Physics Scenario

Is this PROGRAM conceivable?

A. the ~600 Kton UNO detector.

B. Supernovae, Solar, Atmospheric neutrinos. Proton Decay: $\theta_{12}, m_{12}, \theta_{23}, m_{23}$.

C. Frejus site and SPL Super-Beam: possibly θ_{13}

D. Frejus site, SPL Super-Beam and SPS Beta-Beam: possibly θ_{13} phase II, CP, T , CPT, near detector program.

Physics reference numbers:

L=130 km
Fiducial Mass=440 Kton, H_2O

SuperBeam Sinergy

The proton requirements of the SuperBeam are 1/8 of the ISOLDE@SPL (100uA for 1s every 8 s).

The ISOLDE@SPL plans 100 μA protons overall.

The Superbeam uses 2mA from the SPL.

Therefore:
The BetaBeam reduces the SuperBeam intensity by 0.6%.

Why Cherenkov?

You “just” need electron and muon identification.

Same requirement of the SuperBeam.

<u>You don’t need the charge identification.</u>

<u>You don’t need a magnetized detector.</u>

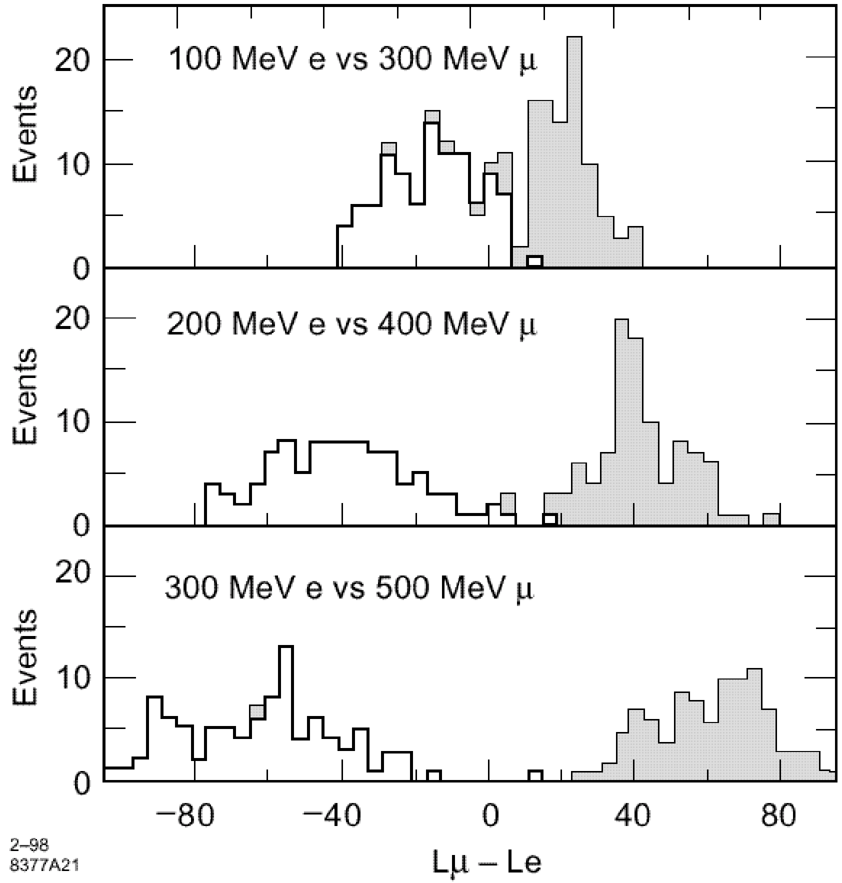


FIG. 21. The experimentally measured difference of the logs of likelihood. Shaded histogram represents muons; open histogram electrons.

The Far Detector Observables

D. Casper pointed out the analytical expression of the relative neutrino flux for **spinless** parents :

$$P = \frac{1-\cos(r)}{2}$$

$$\cos(r) = \frac{\cos(l)-\beta}{1-\beta\cdot\cos(l)}$$

$$\cos(l) = 1 - \frac{1}{2\pi {L/m}^2}$$

(Verified by Toy MC)

Distance (km)	Relative Flux (nu/m2)
1	7.1109E-03
12.5	4.5834E-05
50	2.8647E-06
100	7.1618E-07
130	4.2378E-07

The Far Detector Background

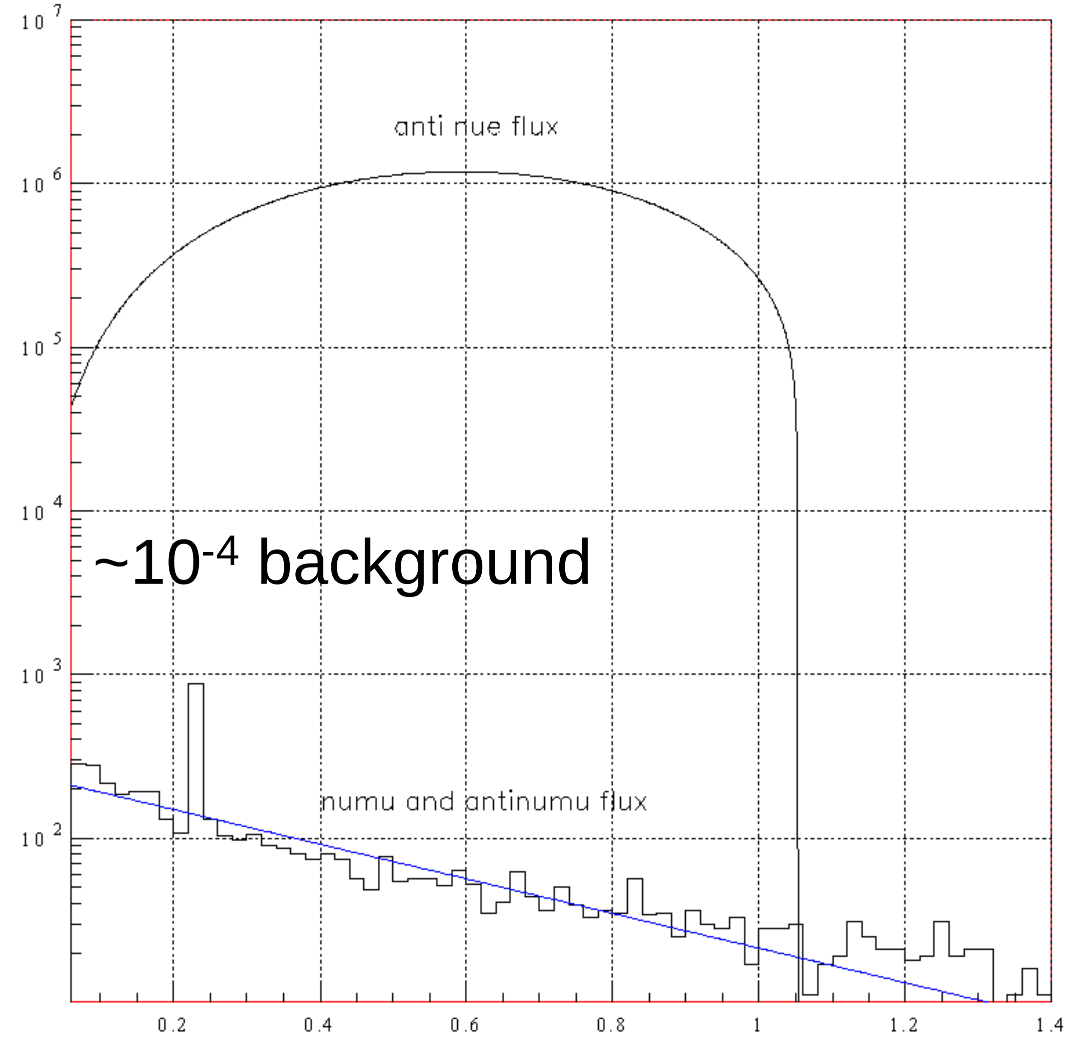
beam-related backgrounds due to Lithium interactions at the end of the straight sections

GEANT3 simulation,

3E6 proton interactions
onto a Fe dump,

tracking down to 10 MeV

100 mrad
off-axis and
130 km distance.
DIF and DAR
(K+) contributions



~10^{-4} background

Cross Sections

antineutrinos interactions on Oxygen are typically penalized by a factor ~ 5.

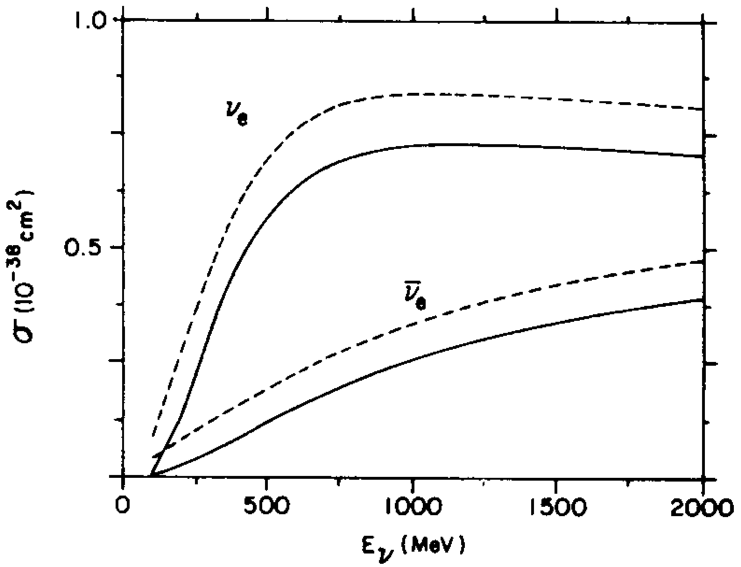


FIG. 1. Comparison of cross sections for electron neutrinos on neutrons and antineutrinos on protons. Solid curves for bound and dashed curves for free nucleons.

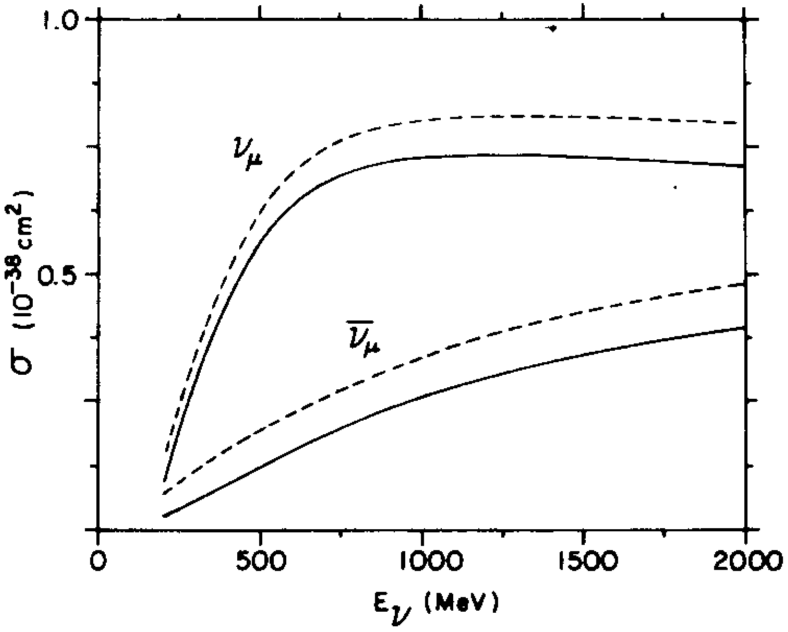


FIG. 2. Same as Fig. 1 for muon neutrinos.

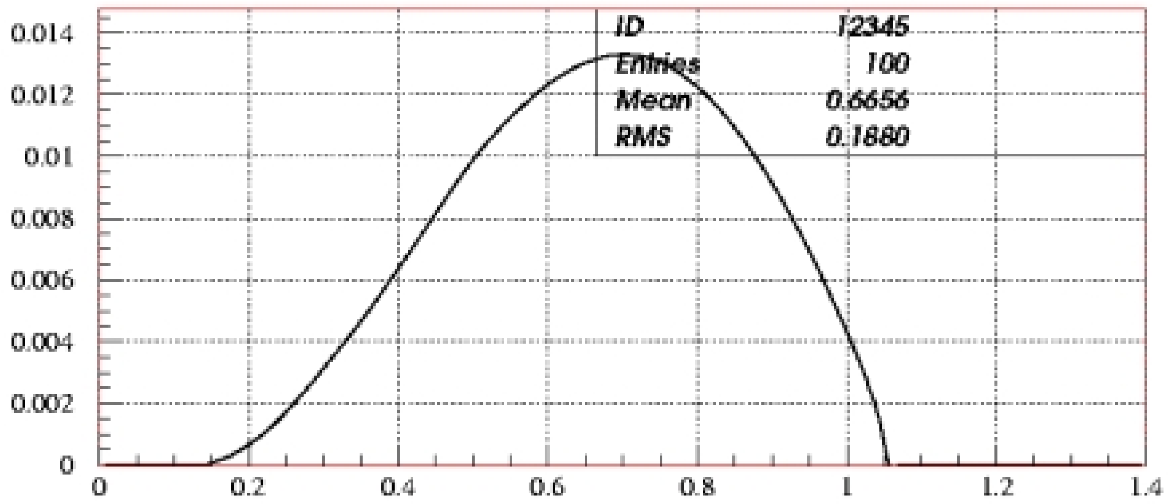
Free protons of H_2O are also included

T.K Gaisser and J.S. O'Connel, P.R.D34,3 (1986) 822.

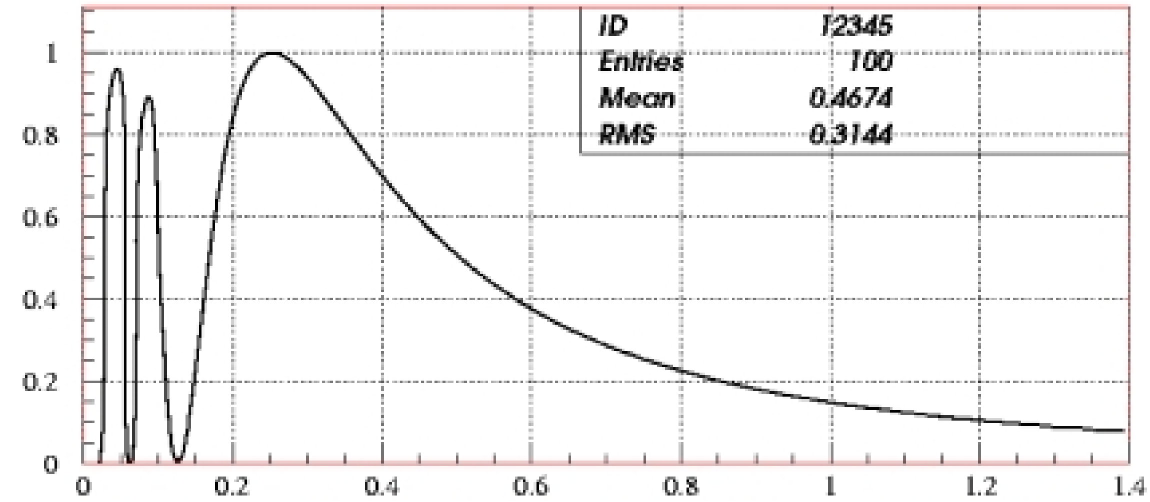
The Far Detector Interactions

Simple approach:

maximization of oscillation signal which corresponds to the hardest possible spectrum



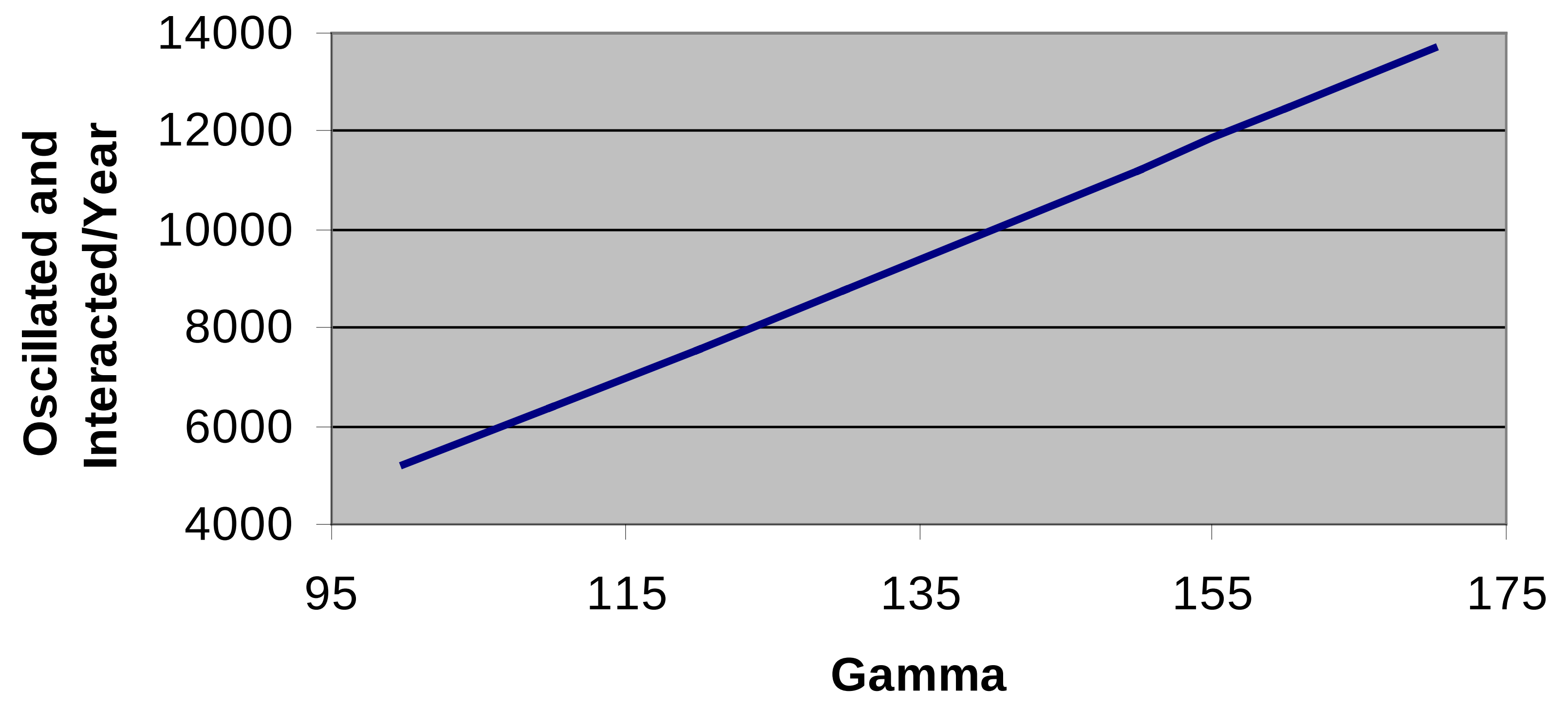
shp(x)*(anmcross(x)*2.+anmocross(x)*8.)/18.



sin(1.27*0.0024*130/x)**2

The Signal maximization

The signal coming from appearance anti ν_μ interactions in the hypothesis ($\sin 2\theta_{e\mu}=1.0, m_{13}=2.4E\text{-}3\ eV^2$). The SPS duty-cycle is assumed to remain constant to 8s.

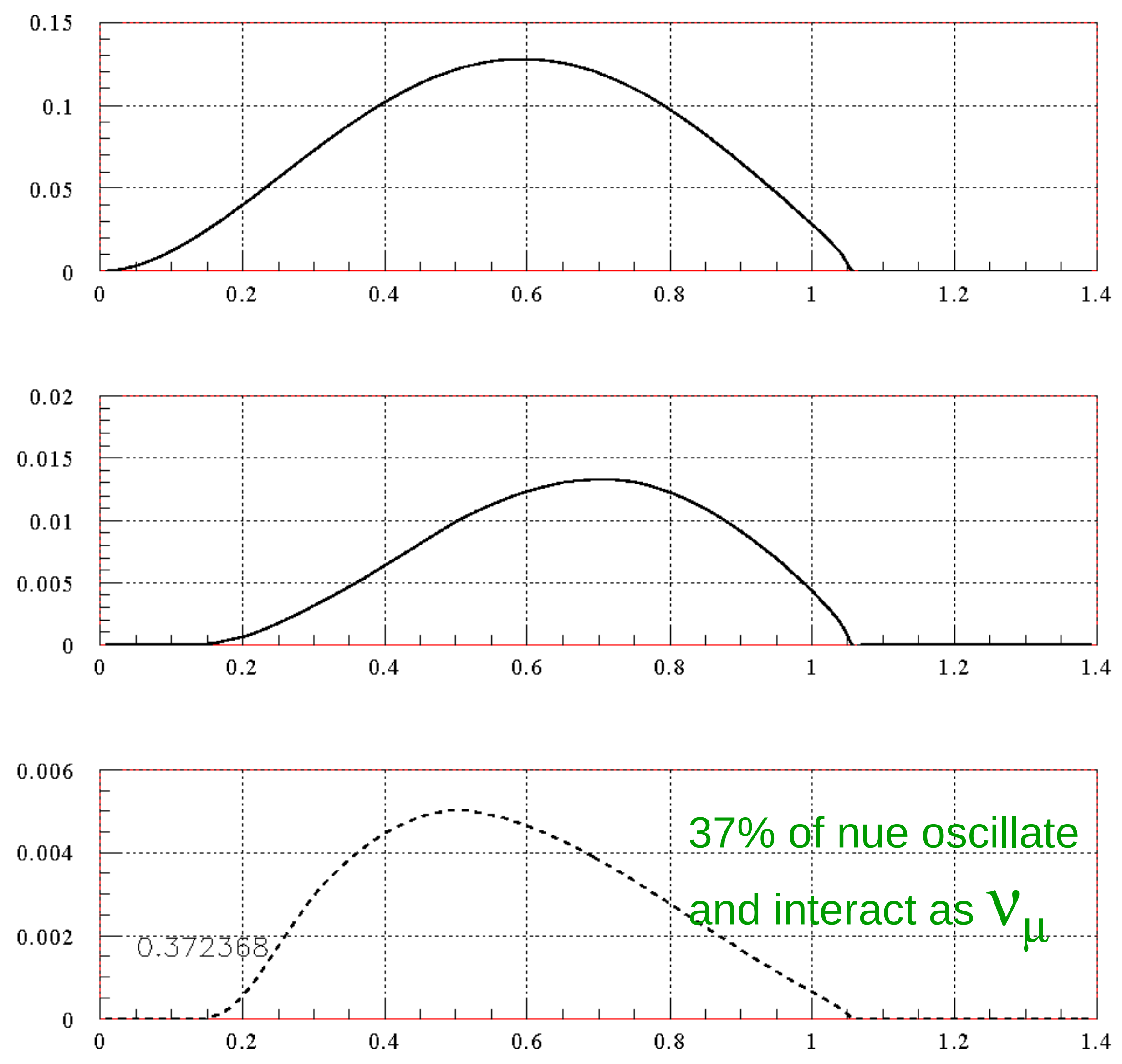


The Signal Spectrum

The beam

$\overline{\nu}_\mu$ interactions

Oscillated $\overline{\nu}_\mu$ interactions



37% of nue oscillate and interact as ν_μ

Anue Summary Numbers

Quantity	Value	Unit	Comments
SPS Cycle time	8	s	
accelerated 6He	1.0E+13	per cycle	
machine livetime	1.0E+07	s/year	
Produced 6He/year	1.3E+19		
Transfer efficiency	65%		
6He injected into storage ring per year	8.1E+18		
Straight section relative length	36%		
Gamma	150		
potential 6He decays	2.9E+18		in one straight section
Interaction rate/6He/kton	2.3E-17		130 km, G=150
Ring length	6885	m	
number of bunches	1		Single Bunch stacking
Bunch intensity	6.5E+12	6He	
Storage ring total intensity	1.0E+14	6He	1/(1-exp(-8/120))
Bunch spacing	22950	ns	
Bunch length	13	ns	
storage ring occupation	5.7E-04	bunch length/ring length	
Useful 6He decays	2.9E+18		cutoff in storage time
Betabeam anue Interactions	69	events/kton/year	
Betabeam anumu Interactions	68	events/kton/year	
Oscillation interactions (1.0,2.4E-3)	25	events/kton/year	
Signal emission time	5665	s	
Atmospheric Background	50	event/kton/year	
year	3.2E+07	s	
Detector fiducial mass	440	kton	
Atmospheric Background	4.0	events/year	no kinematical/angular cuts
Beam Background	1.1	events/year	
Anue interactions	30263	events/year	
Oscillation signal	11177	events/year	
Noise/Oscillation Signal	4.54E-04		no kinematical/angular cuts

The ν_e case

^{18}Ne Intensity feasible today is 20× lower than ^{6}He , HOWEVER:

1. ^{18}Ne, like all beta+ emitters, has a A/Z value smaller than
for ^{6}He and beta- emitters.

2. Therefore SPS can accelerate the ion up to
Γ=250 (250 GeV/nucleon) WITH THE SAME MAGNETIC FIELD
used for ^{6}He and Γ=150.

<Eν>=930 MeV !!!

3. For the same reasons explained for the antineutrino case, the
appearance search improves at large gamma despite the fact
<E>/L=7E-3 GeV/km

4. The quality factor Γ/E_0 gives a bonus of 1.7×, and the better cross-sections another factor ~ 5 ×. So, the initial gap of 20× is “JUST” a factor 2×

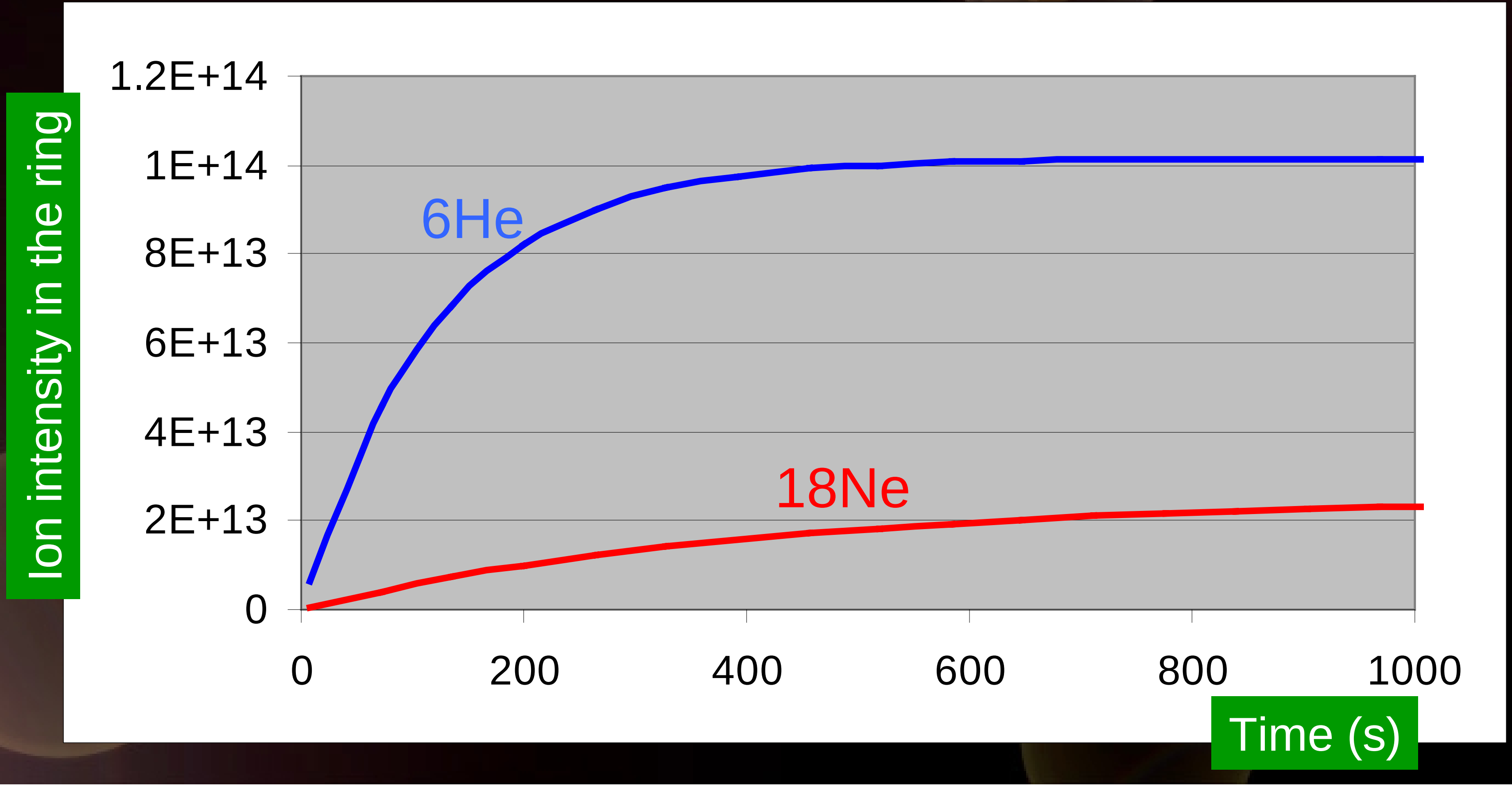
Nue Summary Numbers

Quantity	Value	Unit	Comments
SPS Cycle time	4.0	s	
accelerated 18Ne	5.0E+11	per cycle	
machine livetime	1.0E+07	s/year	
Produced 18Ne/year	1.3E+18		
Transfer efficiency	79%		
18Ne injected into storage ring per year	9.8E+17		
Straight section relative length	36%		
Gamma	60		
potential Ne18 decays	3.6E+17		in one straight section
Interaction rate/18Ne/kton	3.8E-18		130 km, G=150
Ring length	6885	m	
number of bunches	1		Single Bunch stacking
Bunch intensity	3.9E+11	18Ne	
Storage ring total intensity	9.7E+12	18Ne	1/(1-exp(-8/120))
Bunch spacing	22950	ns	
Bunch length	13	ns	
storage ring occupation	5.7E-04	bunch length/ring length	
Useful 18Ne decays	3.6E+17		cutoff in storage time
Betabeam QE nue Interactions	1.37	events/kton/year	
Betabeam QE numu Interactions	1.05	events/kton/year	
Oscillation interactions (1.0,2.4E-3)	0.94	events/kton/year	
Signal emission time	5665	s	
Atmospheric Background	50	event/kton/year	
year	3.2E+07	s	
Detector fiducial mass	440	kton	
Atmospheric Background	4.0	events/year	no kinematical/angular cuts
Beam Background	0.0	events/year	
Nue interactions	602	events/year	
Oscillation signal	413	events/year	
Noise/Oscillation Signal	9.68E-03		no kinematical/angular cuts

Comment on the “stacking option”

Vacuum lifetime
and debunching
reduce the effective
intensity of the beam.
Less problematic for ^{6}He

$$I^{n}_{TOT} = I_{Bunch}\,\frac{1-e^{nT/\Gamma T_{1/2}}}{1-e^{T/\Gamma T_{1/2}}}$$



Super-Beta-UNO

interaction rates

Beta-Beam nue: **15450 QE/Year @ 930 MeV @ 130 km**

Beta-Beam anue: **30,300 QE/Year @ 580 MeV @ 130 km**

Super-Beam numu: **9,800 QE/Year @ 260 MeV @ 130 km**

Super-Beam anumu: **2050 QE/Year @ 230 MeV @ 130 km**

Obviously: the SuperBeam lower energy is “better”. Still, the oscillation probability of the Beta-Beams are 37% (anue) and 22% (nue) respectively.
The SuperBeam has more beam-related background, but is much simpler to do.
Beta-beam detector backgrounds to be studied.

ONE DETECTOR, ONE DISTANCE, 2X2 BEAMS!

General Considerations

A. θ_{13} is just the starting step for super&beta-beams.

B. CP violation at low energy is almost exempt from matter effect, therefore particularly attractive (nue beta-beam, anue beta-beam).

H. Minakata, H. Nunokawa hep-ph0009091.

C. Who else can do T violation <u>without magnetic field and electron charge identification</u>? (nue beta-beam, numu super-beam). See Mauro’s talk.
CPT test to measure the sign of δm^2: anue beta-beam, numu super-beam.

D. If LSND is confirmed, 6 mixing angles and 3 CP violation phases are waiting for us! The smallness of the LSND mixing parameter implies high purity beams, the missing unitarity constraints will demand sources with different flavours.

$$P(\nu_\mu \to \nu_e; L) - P(\bar{\nu}_e \to \bar{\nu}_\mu; L) = 16 \frac{a}{\delta m^2_{31}} \sin^2 \frac{\delta m^2_{31} L}{4E} c^2_\phi s^2_\phi s^2_\psi (1 - 2s^2_\phi)$$
$$- 4 \frac{aL}{2E} \sin \frac{\delta m^2_{31} L}{2E} c^2_\phi s^2_\phi s^2_\psi (1 - 2s^2_\phi)$$

CPT Test:sign

T Test:δ

$$P(\nu_\mu \to \nu_e) - P(\nu_e \to \nu_\mu) = -8 \frac{\delta m^2_{21} L}{2E} \sin^2 \frac{\delta m^2_{31} L}{4E} s_\delta c^2_\phi s_\phi c_\psi s_\psi c_\omega s_\omega .$$

The “Feasibility” road

A. Deeper studies “UNO-like” based on full simulation of the “detector” backgrounds, beam optimization and physics analysis.

B. Deeper study of a complete realistic acceleration scheme

CONCLUSIONS

“Se son rose, fioriranno”.

“If they're roses, they will blossom”

“Si tiene barbas, San Antón, si no la Purísima Concepción”