Muon cooling
for the Higgs Factory?

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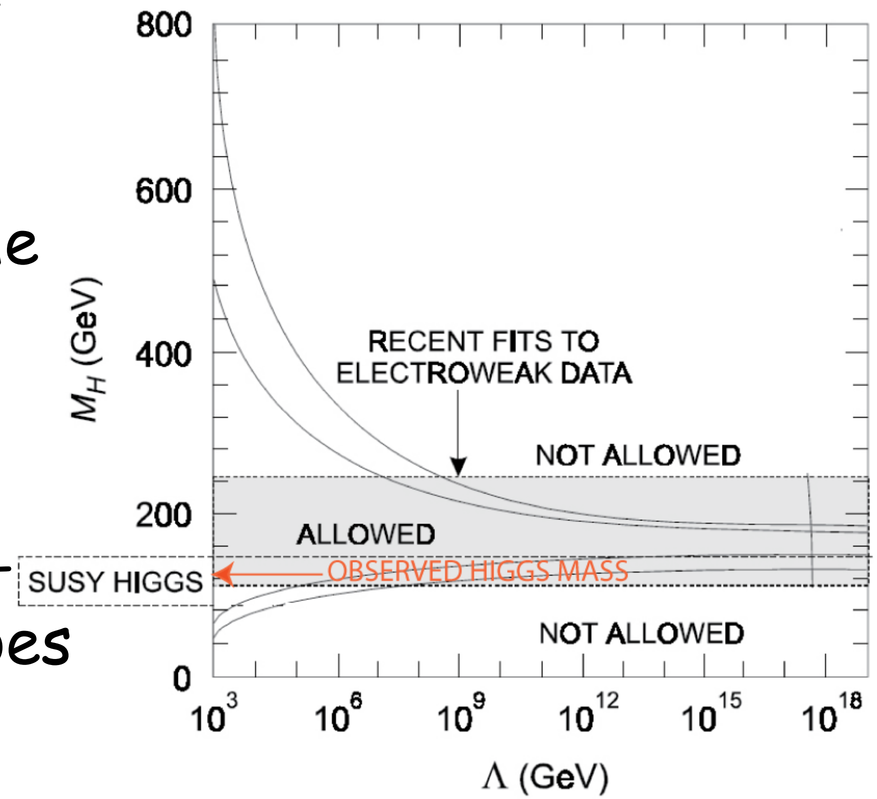
The myth of symmetry breaking at TeV scale

- It had been widely argued by very influential theorists that "new physics" must also necessarily appear at the TeV scale, one of the the main reasons for arguing for the necessity of a nearby SUSY.
- This was based on the argument that the otherwise divergent self-interaction of the Higgs sector does require a cutoff at the TeV scale.



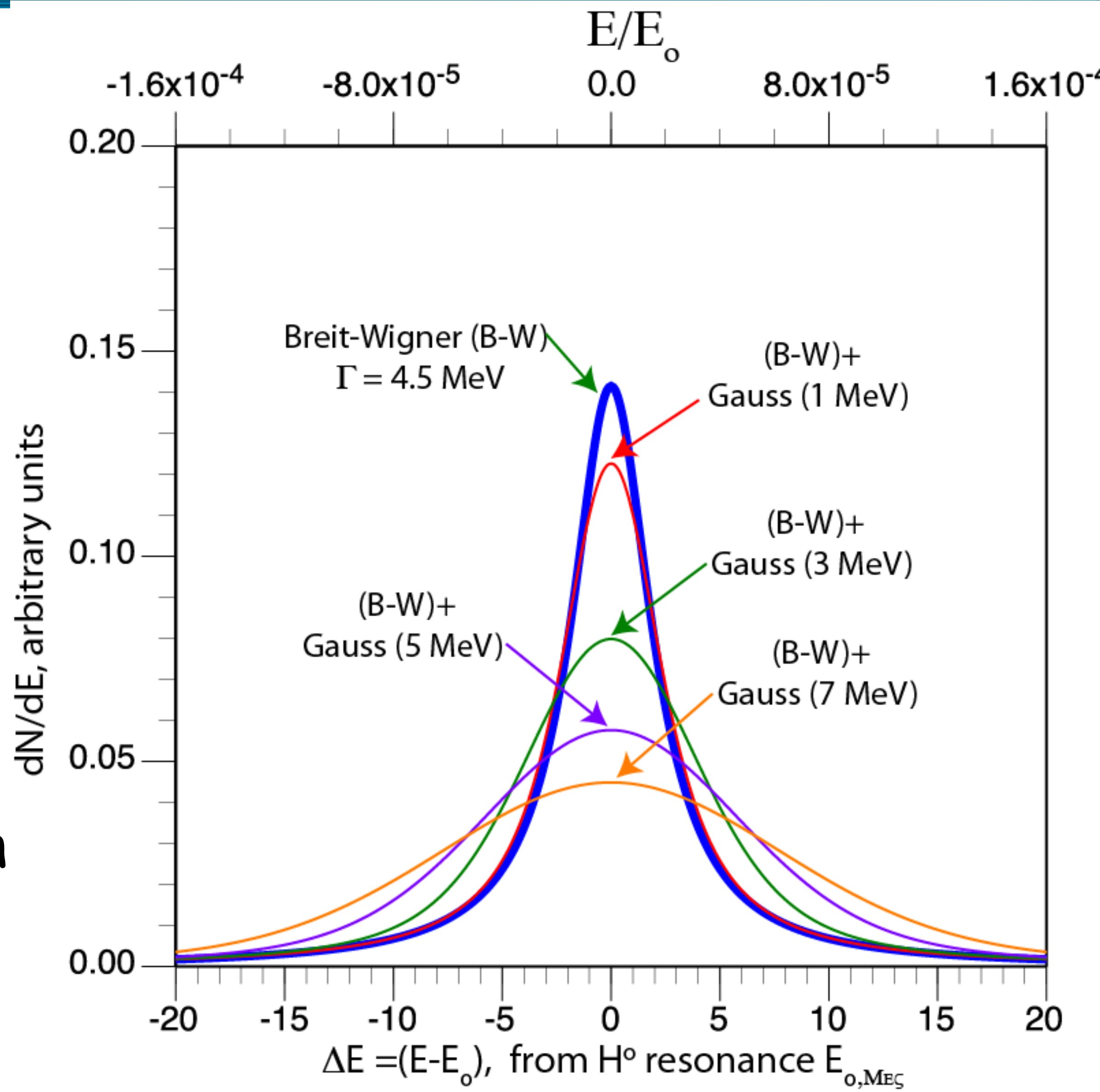
- However, this does not hold for the recently observed Higgs mass of 125 GeV, since now stability conditions may allow without novelties a legitimate cutoff up to the Planck Mass.
- *Thus, there may be only one standard model (SM) Higgs to be confirmed experimentally and no need of the "no fail theorem".*

The future of LHC/Higgs

- During the next twenty years (!) CERN plans to pursue the hadronic production of the Higgs related sector and of the possible existence of SUSY. The existence of additional Higgs particles is assumed as unlikely within the LHC energy range.
- Therefore studies will concentrate on the properties of the already discovered mass. The High Luminisity-LHC will already be a sort of "Higgs factory", able to perform relatively accurate (typically ± 10%) measurements.
- There are plenty of opportunities to check the couplings since a 125 GeV SM Higgs boson has several substantive branching fractions : **B** (**bb**) 60%, **B** (**WW**) 20%, **B** (**gg**) 9%, **B** (ττ) 6%, **B** (**ZZ**) 3%, **B** (**cc**) 3%, etc.
- **B** (**γγ**) with 0.2% is also substantive due to the high mass resolution and relatively low background.

The Higgs width and the Standard Model

- In particular, like in the case of the Zo, the determination of the H_o width will be crucial in the determination of the nature of the particle and the underlying theory: the SM prediction is only ≈4 MeV, a formidable task!
- Cross section is shown here, convoluted with a Gaussian beam distribution
- Signal is not affected only if the rms beam energy width is ≤ a few MeV.



Possible alternatives

- What precision is needed in order to search for possible additional deviations from the SM, under the assumption that there is no other additional "Higgs" state at the LHC ?
- Predicted ultimate LHC accuracies for "exotic" alternatives

R.S. Gupta et al.	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a],
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

Ultimate at LHC
1 ab= 10^{-42} cm^2

$$\frac{g_{hbb}}{g_{h_{SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$$

SUSY tan(β)>5

$$\frac{g_{hff}}{g_{h_{SM}ff}} \quad \frac{g_{hVV}}{g_{h_{SM}VV}} \quad \simeq \quad 1 - 3\% \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$$

Composite Higgs

$$\frac{g_{hgg}}{g_{h_{SM}gg}} \simeq 1 + 2.9\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2, \qquad \frac{g_{h\gamma\gamma}}{g_{h_{SM}\gamma\gamma}} \simeq 1 - 0.8\% \left(\frac{1\ \mathrm{TeV}}{m_T}\right)^2$$

Top partners

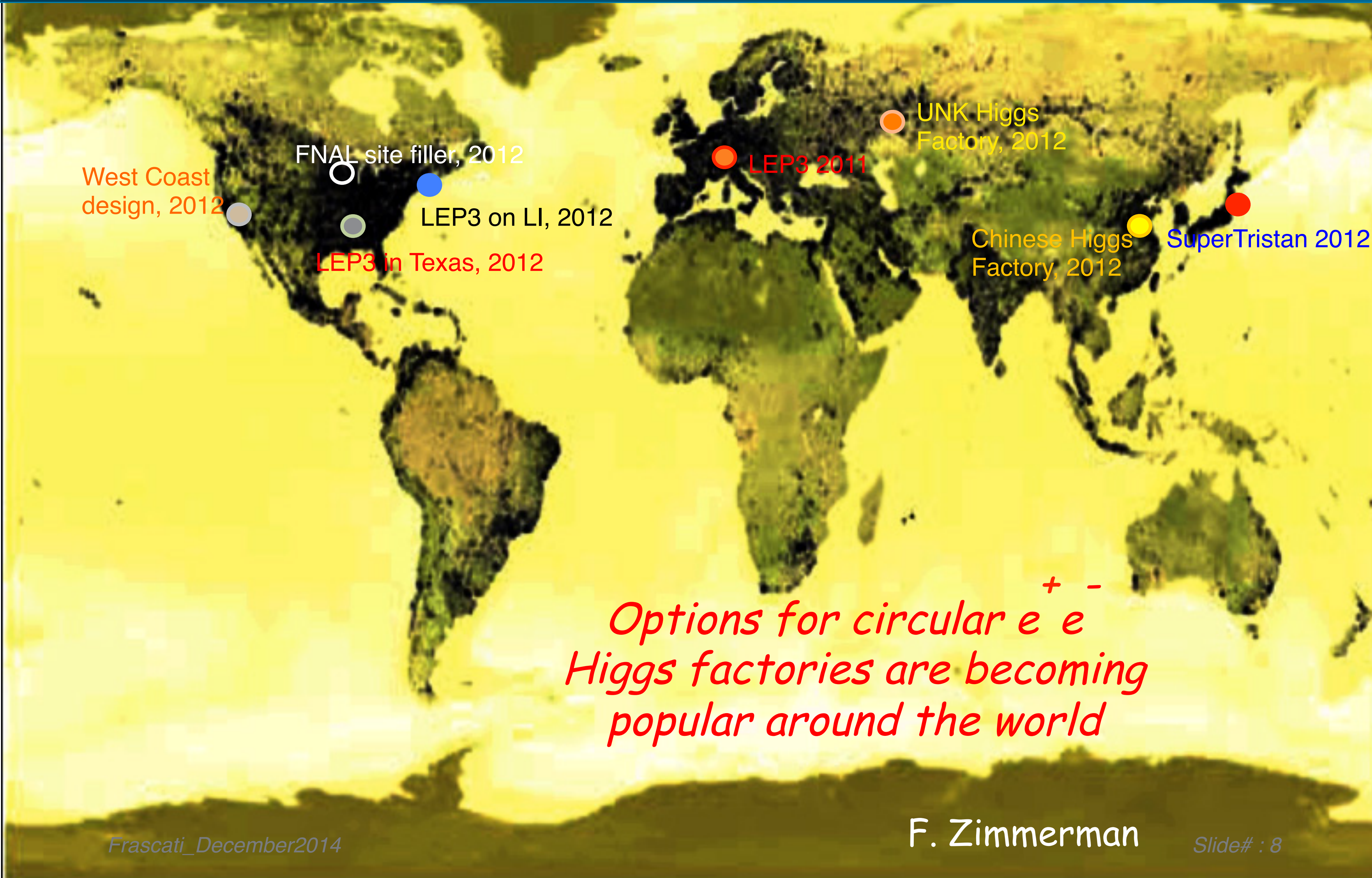
- Sensitivity to "TeV" new physics for "5 sigma" discoveries may need per-cent to sub-per-cent accuracies on rates.

The Higgs particle after the CERN-LHC

Studying the Higgs beyond LHC ?

- The scalar sector is definitely one of the keys to the future understanding of elementary particle physics.
- After the p-pbar discovery of the Z^o , the detailed studies at LEP and SLAC in very clean conditions have been a necessary second phase.
- *A similar second phase may be also necessary for the H_o .*
- In the case of the H_o, it would be necessary to produce a very large number of events/year in very clean experimental conditions. Two future alternatives are hereby compared:
  - A e^+e^- collider at $L > 10^{34}$ and a $Z+H_o$ signal of ≈ 200 fb. The circumference of a new, LEP-like ring is of about≈ 80 km.
  - A $\mu^+\mu^-$ collider at $L > 10^{32}$ and a H_o signal of ≈ 20'000 fb in the s-state. The collider radius is much smaller, only ≈ 50 m, but the novel "muon cooling" is necessary.

The first option: a huge $e^+ e^-$ LEP like ring.



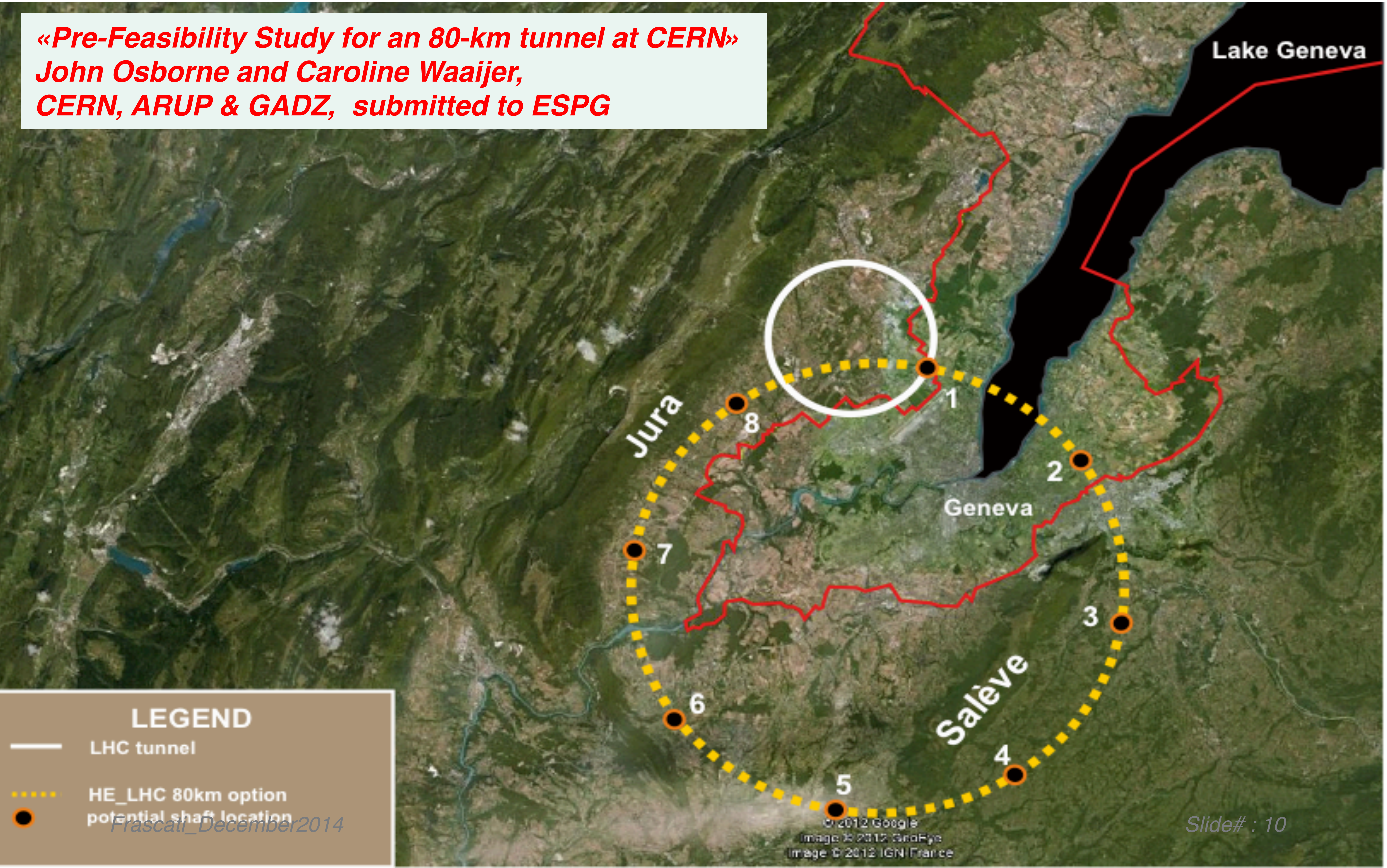
Options for circular $e^+ e^-$ Higgs factories are becoming popular around the world

F. Zimmerman

Super Tristan

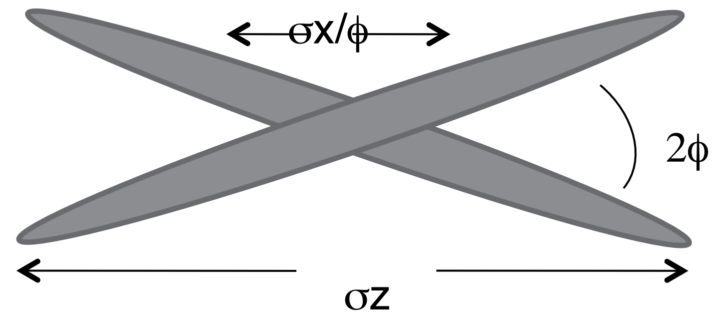
TLEP tunnel in the Geneva area

«Pre-Feasibility Study for an 80-km tunnel at CERN»
John Osborne and Caroline Waaijer,
CERN, ARUP & GADZ, submitted to ESPG



Requirements for the Higgs with a e^+e^- collider

- The luminosity is pushed to the beam-strahlung limit.
- Collisions are at an angle, but with fewer bunches than for a B-Factory: a nano-beam scheme



- Luminosity (several x 10^{34} cm^{-2} s^{-1}), costs and power consumption (≈100 MW) are comparable to those of a linear collider ILC.
- In order to reach luminosity (factor ≈ 1000 x LEP2) and power consumptions (factor 5 x LEP2) the main cures are
  - Huge ring (80 km for SuperTristan or for T-LEP)
  - Extremely small vertical emittance, with a beam crossing size the order of 0.01 *μ* (it has been 3 *μ* for LEP2)
- *The performance is at the border of feasibility (E_{cm}≈ 250 GeV).*
- *However the H_o width of ≈4.0 MeV cannot be detected.*

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Super-Tristan vs ILC

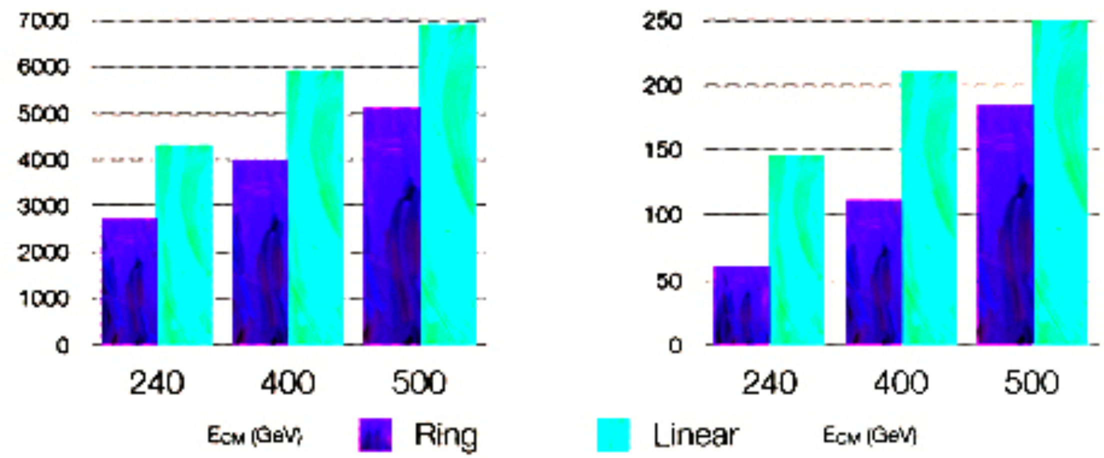
Ring or Linear?

Construction

E_{CM} (GeV)	Ring	Linear
240	2700	4300
400	4000	5900
500	5090	6900

Site Power (MW)

E_{CM} (GeV)	Ring	Linear
240	60	146
400	111	210
500	185	250

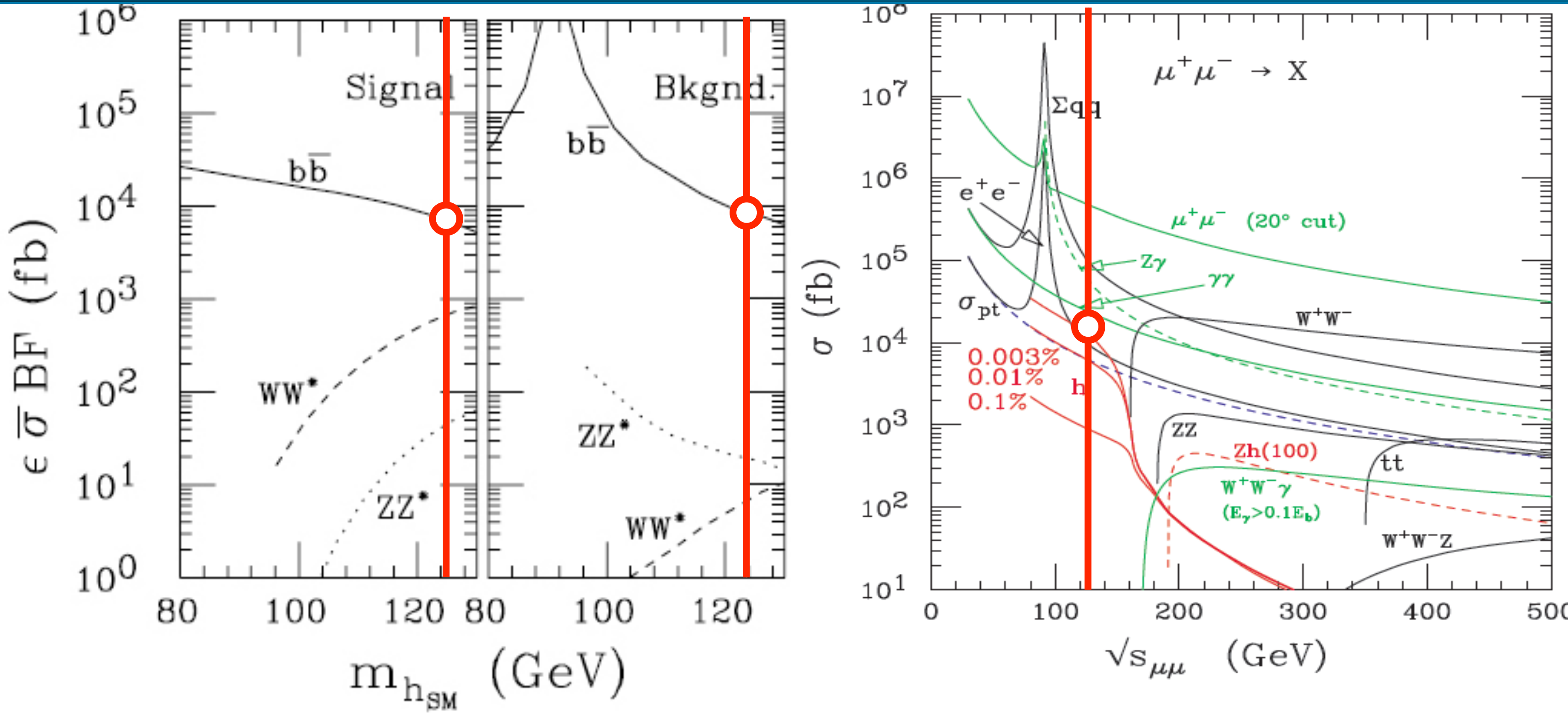


Linear collider and circular ring have comparable costs and power consumptions
The more conservative ring alternative is preferred.

The second option: a $\mu^+\mu^-$ collider ?

- The direct H^o cross section is greatly enhanced in a $\mu^+\mu^-$ collider when compared to an e^+e^- collider, since the s-channel coupling to a scalar is proportional to the lepton mass.
- Like in the well known case of the Z^0 production, the H^o scalar production in the s-state offers conditions of unique cleanliness .
- An unique feature of such process — if of an appropriate luminosity — is that its actual mass, its very narrow width and most decay channels may be directly measured with accuracy.
- Therefore the properties of the Higgs boson can be detailed over a larger fraction of model parameter space than at any other proposed accelerator method.
- A particularly important conclusion is that it will have greater potentials for distinguishing between a standard SM and the SM-like H_o of SUSY or of other than any other collider.

A muon collider after the discovery of the Higgs



- A $\mu^{\pm}$ collider with adequate muon cooling and L > 10^{32} cm^{-2} s^{-1} .
- Decay electron backgrounds are important: : 2 x 10^{12} $\mu^{\pm}$ decays produce 6.5 x 10^{6} collimated $e^{\pm}$ decays/meter with E_{ave}≈ 20 GeV.
- The very narrow resonant signal (4.5 MeV ,Γ/M_H =3.6 x 10^{-5} for the SM) will dominate over most non resonant backgrounds.

Cooling with non Louvillian particle Accelerators

- Already at MURA in the fifties it was realised that some beam phase-space compression may be often necessary from the source to the collision point (O'Neill, Piccioni, Symon).
- *Liouville theorem*: whenever there is an *Hamiltonian* (i.e. for a force derivable from a potential) then the six dimensional phase space is preserved, namely, at best $\Delta V/dt = 0$.
- Therefore we need some kind of *dissipative non-Liouvillian drag force* working against the particle speed and not derived from an Hamiltonian. Several alternatives are possible:
  - *Synchrotron radiation*: but only for electrons and positrons;
  - *Electron cooling*: an electron beam bath travelling with a speed equal to the one of the circulating beam (Budker)
  - *Stochastic cooling:* statistcal fluctuations (Van Der Meer)
  - *Ionization cooling*: dE/dx losses are added to the beam
- With any of such methods and with accelerating cavities replacing the losses, one can compress the phase-space volume.

From antiprotons to muons

- Cooling is essential whenever secondary particles are produced from initial collisions and later accelerated for instance to be accumulated in a storage ring.
- A well known case is the one of antiprotons, in which both stochastic and electron cooling have been vastly used. P-pbar colliders have permitted the discoveries of W/Z and the Top.
- Ionization cooling is specific for muons, since they have only electromagnetic interactions with matter
- The muon lifetime may be long enough to offer with the help of cooling a reasonable number of $\mu^+ \mu^-$ collisions with a collider at the Higgs resonance in the s-state and about 62.5 GeV/beam..
- The idea has been discussed by Budker and Skrinsky in the seventies. A comprehensive analysis has been given f.i. by Neuffer in the early nineties.

T. Neuffer Particle Accelerators 1983 Vol. 14 pp. 75-90

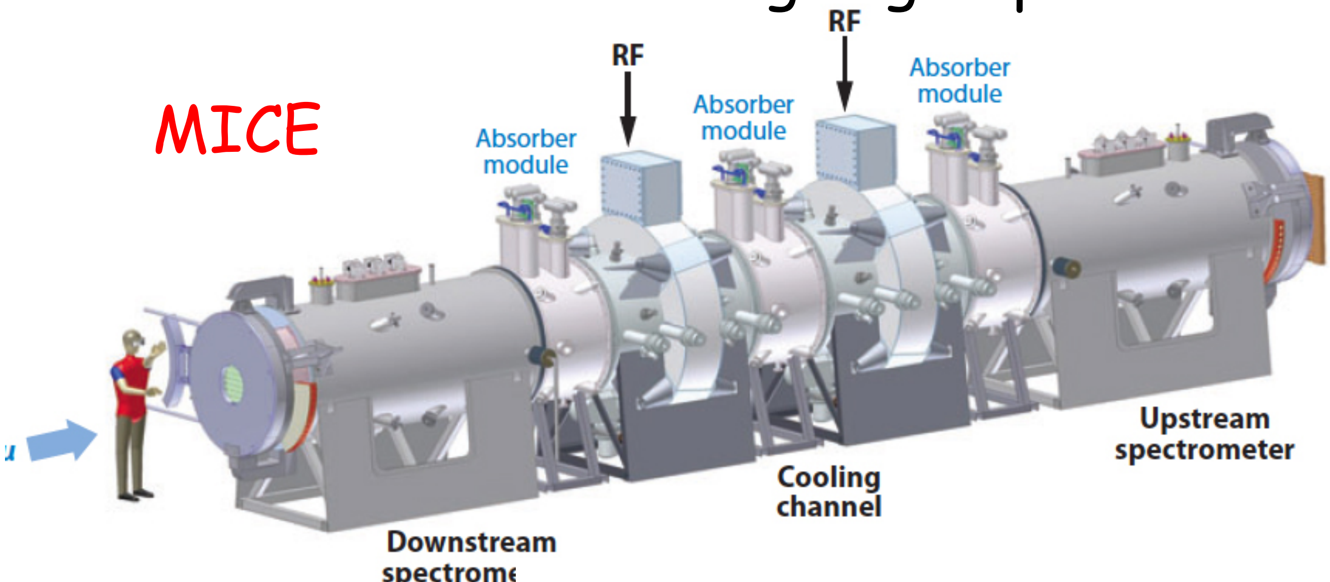
Ionization cooling of muons

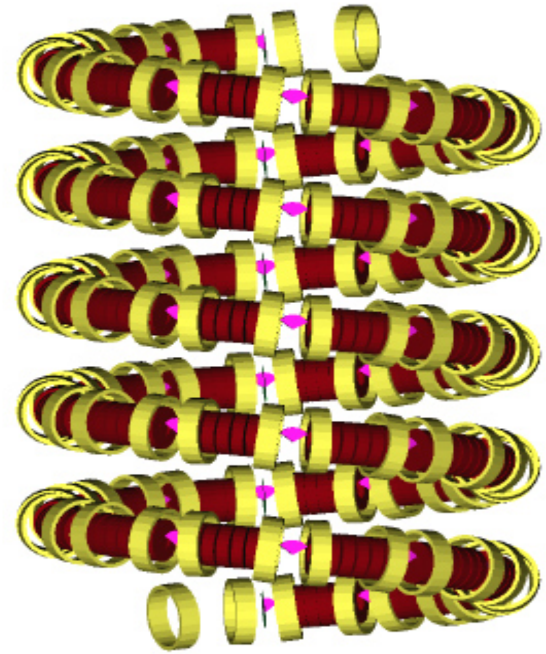
- This method, called "dE/dx cooling" closely resembles to the synchrotron compression of relativistic electrons — with the multiple energy losses in a thin, low Z absorber substituting the synchrotron radiated light.
- The main feature of this method is that it produces an extremely fast cooling, compared to other traditional methods. This is a necessity for the muon case.
- Transverse betatron oscillations are "cooled" by a target "foil" typically a fraction of g/cm^2 thick. An accelerating cavity is continuously replacing the lost momentum.
- Unfortunately for slow muons the specific dE/dx loss is increasing with decreasing momentum. In order to "cool" also longitudinally, chromaticity has to be introduced with a wedge shaped "dE/dx foil", in order to reverse (increase) the ionisation losses for faster particles.

Early cooling scenarios

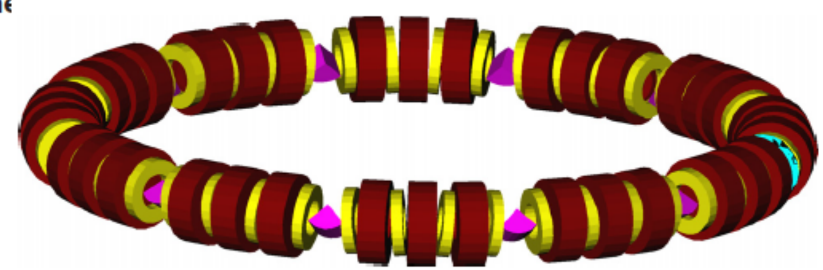
- Most scenarios during the late ninety were based on single-pass linear cooler, in which a large number of RF cavities restore the energy lost in the low Z absorbers (for instance LH2 or LiH) and in the ionization cooling. However cooling rings have also been considered. MICE is an on going experiment.

MICE





Guggenheim channel



Cooling rings (Balbekov, Palmer)

Previous studies on muon cooling

- Over the past decade, there has been significant progress in developing the concepts and technologies needed to produce, capture, cool and accelerate **O(10^{21})** muons per year.
- Extensive studies have been performed about 20 years ago in the US and elsewhere and widely discussed in several international workshops.
- Conclusions were that cooling was possible for instance with :
  - A 3 TeV collider and L = 7 x 10^{34} cm^{-2} s^{-1}
  - A 600 CeV collider and L = 10^{33} cm^{-2} s^{-1}
  - A Higgs factory at 110 GeV and 2.2 x 10^{31} cm^{-2} s^{-1}
  - A neutrino factory (NF), where high-energy muons decay to produce an intense beam of neutrinos and antineutrinos
- The recent discoveries of the Higgs particle at 125 GeV and the observation of the sin(θ_{13}) neutrino oscillation mechanism have strongly revived also the interest for these studies.

A large amount of work already on Higgs factory physics

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- C. Ankenbrandt et al.,"Status of muon collider research and development and future plans," Phys. Rev. ST Accel. Beams 2 (1999) 081001, http://prst-ab.aps.org/abstract/PRSTAB/v2/i8/e081001
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The experimental realization of an initial cooling experiment to ensure full 6D cooling of muons

A next step

- Physics requirements and the studies already undertaken with muon cooling suggest that the next subsequent specific physics programme *could be the practical realization of a full scale cooling demonstrator capable of the full cooling capability in three dimensions .*
- Indicatively this corresponds to the realization of a cascade of unconventional but *very small rings of few meters radius*, in order to achieve the theoretically expected longitudinal and transverse emittances with asymptotically cooled muons.
- In order to demonstrate this "initial cooling experiment" muons may be produced by an existing accelerator at low intensity.
- All other conventional facilities, namely (1) the high intensity proton accelerator,(2) the pion/muon production target, (3) the subsequent muon acceleration and (4) the accumulation in a storage ring may be constructed later and only after the success of the initial cooling experiment has been confirmed.

Muon cooling ring: transverse emittance

- The emittance ε_N evolves whereby dE/dx losses are balanced by multiple scattering (Neuffer and McDonald):

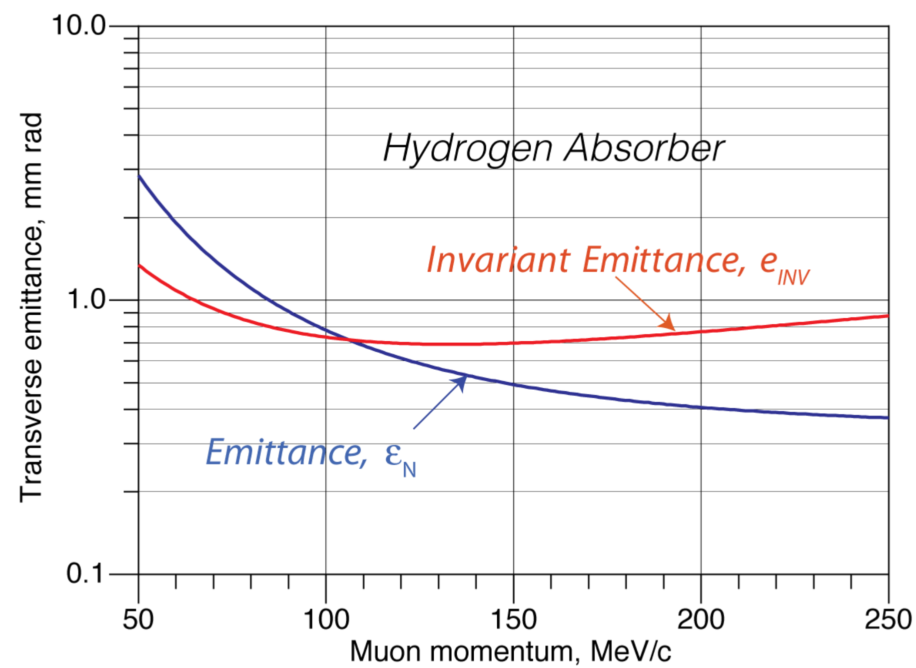
$$\frac{d\varepsilon}{dz} \approx \underbrace{\frac{\varepsilon}{\beta^2 E}\frac{dE}{dz}}_{\text{Cooling}} + \underbrace{\frac{\beta^*(13.6)^2}{2\beta^3 E m_\mu X_o}}_{\text{Scattering}} \to 0$$

β^* = beta at cross
m_μ, β_μ = mu values
X_o = Rad. Length
dE/dz = ioniz. Loss

- The cooling process will continue until an equilibrium transverse emittance has been reached:

$$\varepsilon_N \to \frac{\beta^*(13.6\ \ MeV/c)^2}{2\beta_\mu m_\mu}\frac{1}{\left(X_o\, dE/dz\right)}$$

- The equilibrium emittance ε_N and its invariant $\varepsilon_N/\beta\gamma$ are shown as a function of the muon momentum.
- For H_2 and β^*= 10 cm, $\varepsilon_N/\beta\gamma \leq$ 700 mm mr from 80 to 300 MeV/c



For a 125 GeV collider and β^*= 5 cm bunch equil. transverse size is ≈ 240 μ

Muon cooling ring: longitudinal emittance

- *Longitudinal* balance is due to heat producing straggling balancing dE/dx cooling. A dE/dx radial wedge is needed in order to exchange longitudinal and transverse phase-spaces.
- Balancing heating and cooling for a Gaussian distribution limit:

Intrinsic Energy loss — Wedge shaped absorber — Straggling

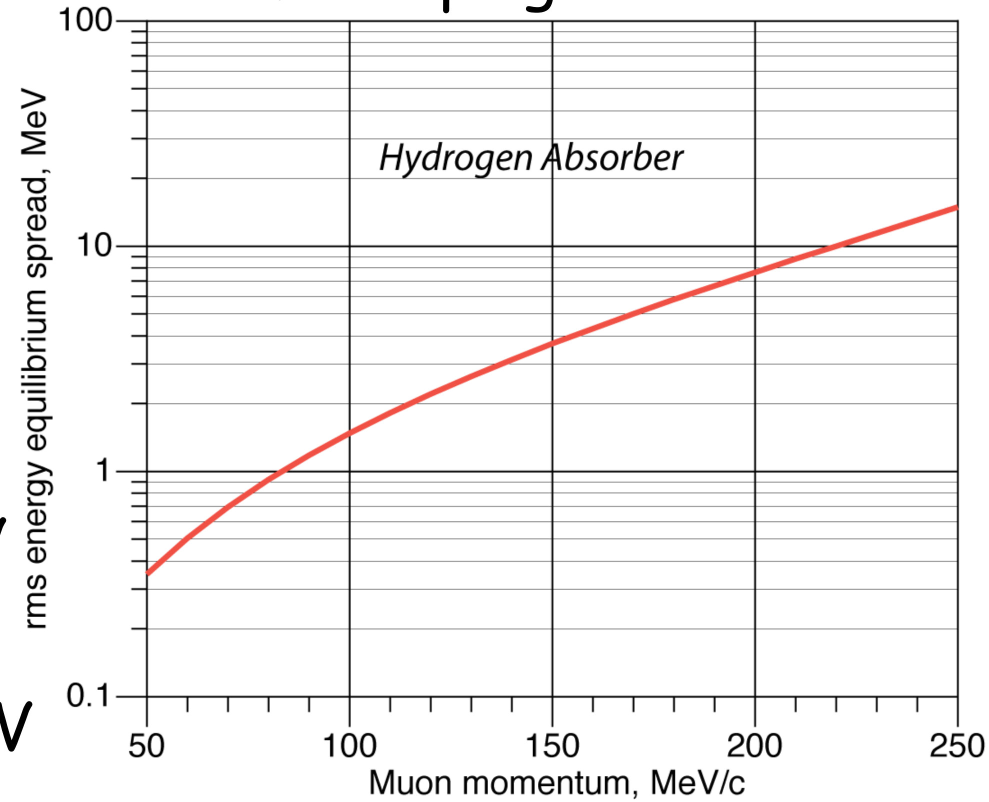
$$\frac{d(\Delta E)^2}{dz} = -2(\Delta E)^2\left[f_A \frac{d}{dE}\left(\frac{dE_o}{ds}\right) + f_A \frac{dE}{ds}\left(\frac{d\delta}{dx}\right)\frac{\eta}{E\delta}\right] + \frac{d(\Delta E)^2_{straggling}}{dz}$$

- ➢ $dE/dz = f_A\, dE/ds$, where f_A is the fraction of the transport length occupied by the absorber, which has an energy absorption coefficient dE/ds
- ➢ η is the chromatic dispersion at the absorber and δ and $d\delta/dx$ are the thickness and radial tilt of the absorber
- ➢ the straggling (H2) is given by $\frac{d(\Delta E)^2_{straggling}}{dz} = \frac{\pi(m_e c^2)^2(\gamma^2+1)}{4\ln(287)\alpha X_o}$

Longitudinal balance (cont.)

- The thickness of the absorber must vary with the transverse position, producing the appropriate the energy dependence of energy loss, resulting in a decrease of the energy spread
- Energy cooling will also reduce somewhat the transverse cooling, according to the Robinson's law on sum of damping decrements.
- Energy equilibrium spread for liquid H_2 (McDonald):

$$(\Delta E)^2 = \frac{1.1 MeV^2 \gamma^3 \beta^4 \left(\gamma^2 + 1\right)}{\left(1 - \gamma^2 / 12\right)}$$

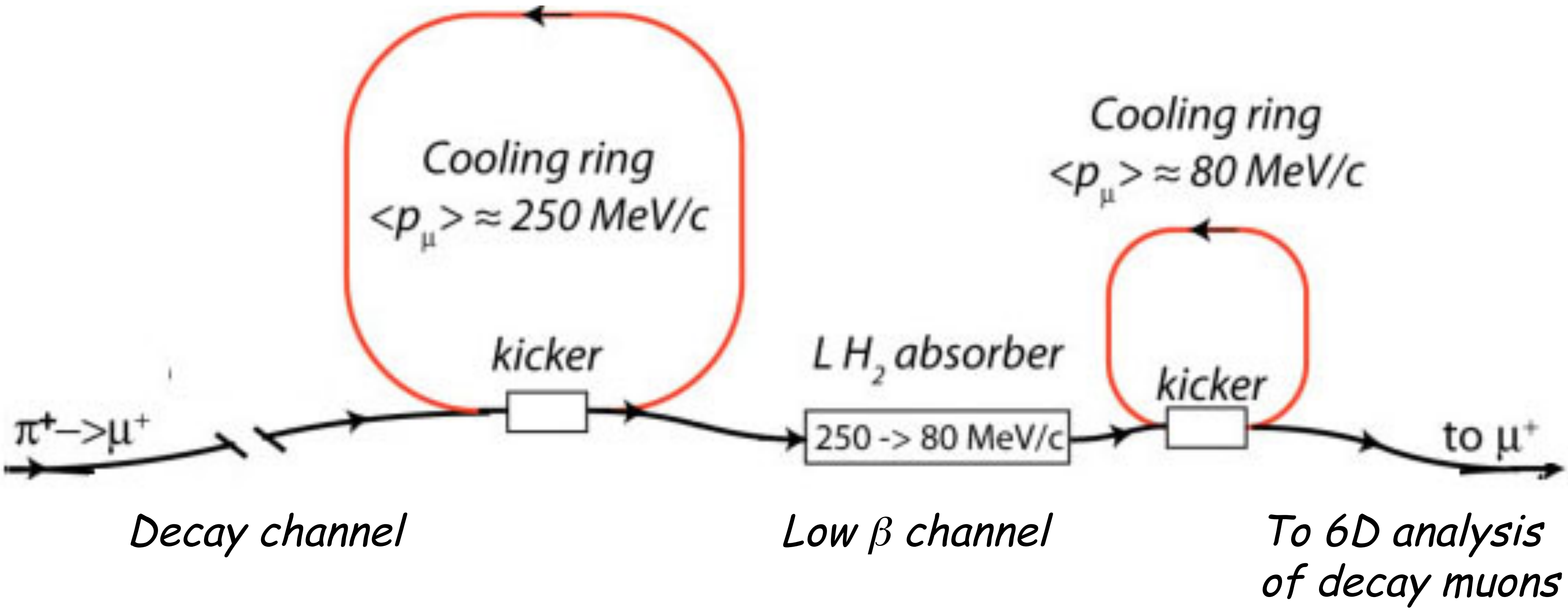


- A fast dependence from p_μ
  - $p_\mu \approx$ 220 MeV/c, $\Delta E_{rms} \leq$ 10 MeV
  - $p_\mu \approx$ 85 MeV/c, $\Delta E_{rms} \leq$ 1 MeV
  - $p_\mu \approx$ 50 MeV/c, $\Delta E_{rms} \leq$ 0.35 MeV

At an optimal muon producing momentum the energy spread is too wide for the Ho width !

The initial cooling experiment

- A single sign muon cooling arrangement with two rings , either μ+ or μ- is required and with few particles
- A low intensity pion-> muon beam is produced from an appropriate accelerator in the form of a very short pulse

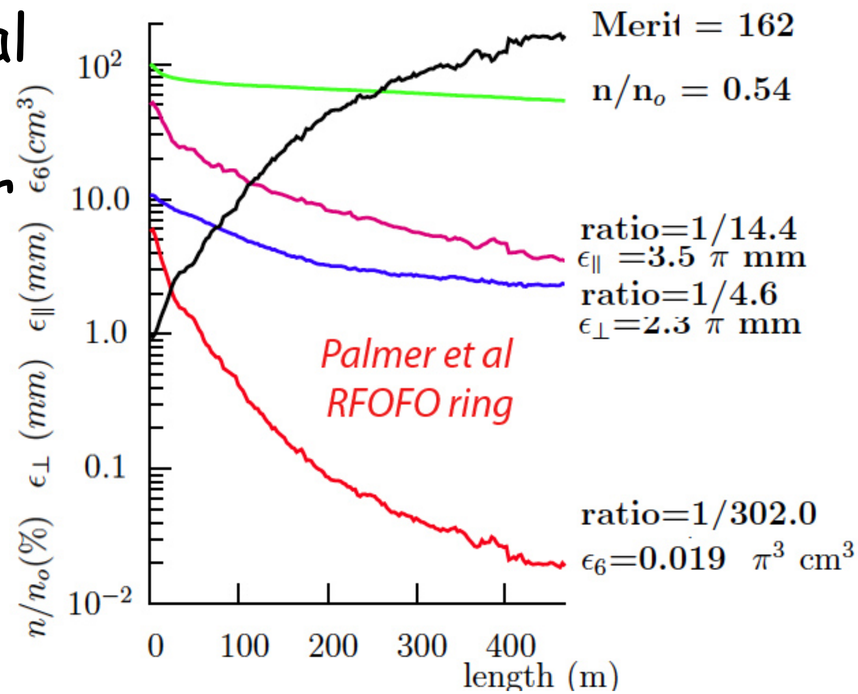


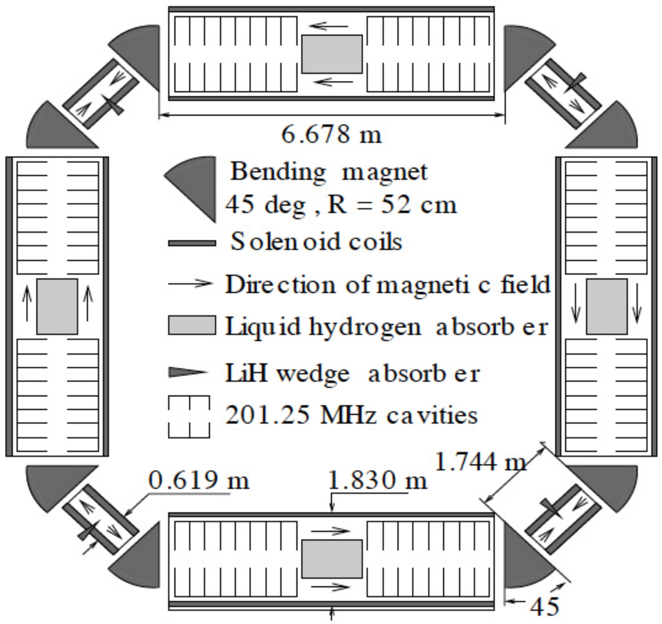
The proposed initial cooling experiment

- A first "wide band" cooling ring must collect the widest muon spectrum peaked around 200 - 400 MeV/c and to introduce a first major reduction in the transverse and longitudinal emittances (but still with $\Delta E_{rms} > 10$ MeV), namely:
  - solenoids instead of quadrupoles have a wider acceptance
  - with a few turns, only integer resonances are harmful
  - As a first cooler, the ionization absorber does not have to be made with LH_2: other solid materials (LiH) may be used.
- An intermediate LH_2 absorber ≈3 m long inside a low β* channel reduces the vector muon momenta by range.
- The resulting beam must then be extracted and its momentum substantially reduced to about 50-80 MeV/c.
- A second "deep freezer" cooling ring must ensure an adequate asymptotic beam straggling with $\Delta E_{rms} \leq 1$ MeV

Examples of wide angle cooling rings

- Some practical but still conceptual descriptions of RFOFO ring coolers by Balbekov and by Palmer
- The average muon momentum is 220 MeV/c and the approximate diameter ≈ 10 m.
- Acceptance ≈ ± 20 %



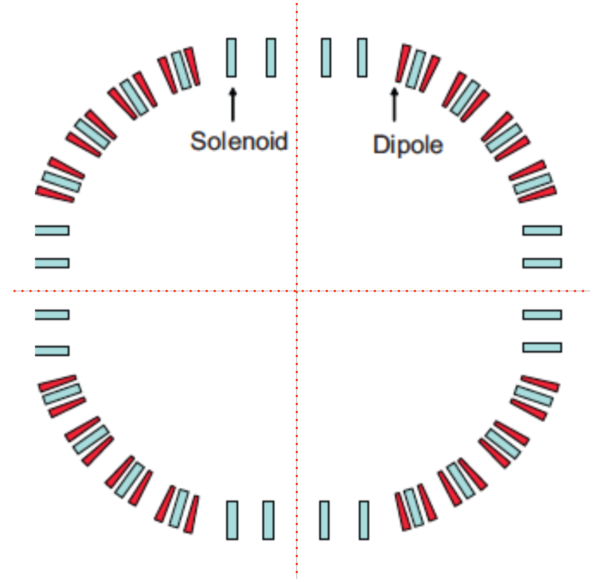


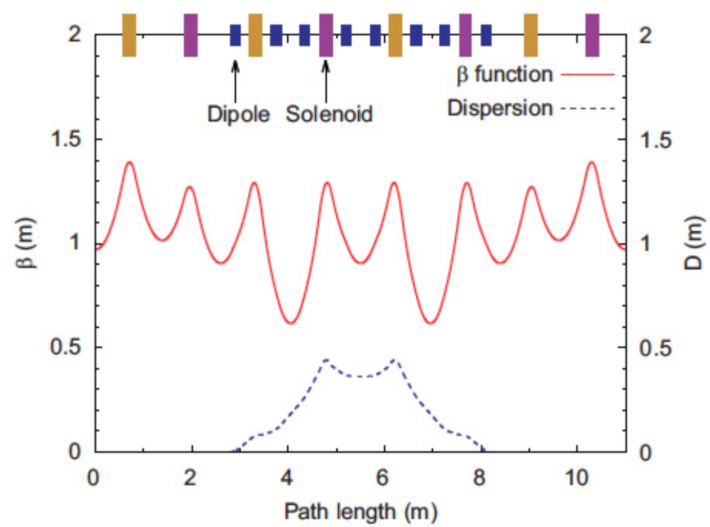
RFOFO Ring Parameters

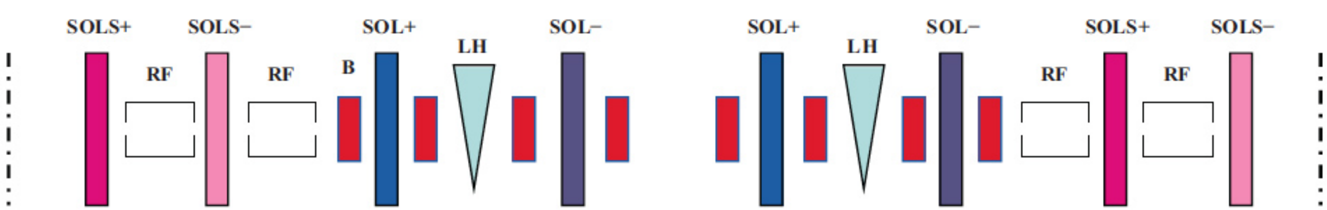
Circumference	m	33
Cells		12
Max Bz	T	2.7
Coil Tilts	deg.	2.6
Ave Momentum	MeV/c	220
Min Trans. Beta	cm	35-40
Dispersion	cm	8
Wedge Absorber Material		H_2
Central thickness	cm	28.6
Wedge angle	deg	100
RF Cavities/cell		6
Frequency	MHz	201.25
Gradient	MV/m	12

A straightforward design for the achromatic cooling ring

- A realistic study is the one of Garren et al. (NIM, 2011).
- The four-sided ring has four 90° arcs with 8 dipoles separated by solenoids.
- Arcs are achromatic both horizontally and vertically. The dispersion is zero in the straight sections between the arcs.
- Injection/extraction kickers are used in a straight section; a superconducting flux pipe is used for the injected beam.

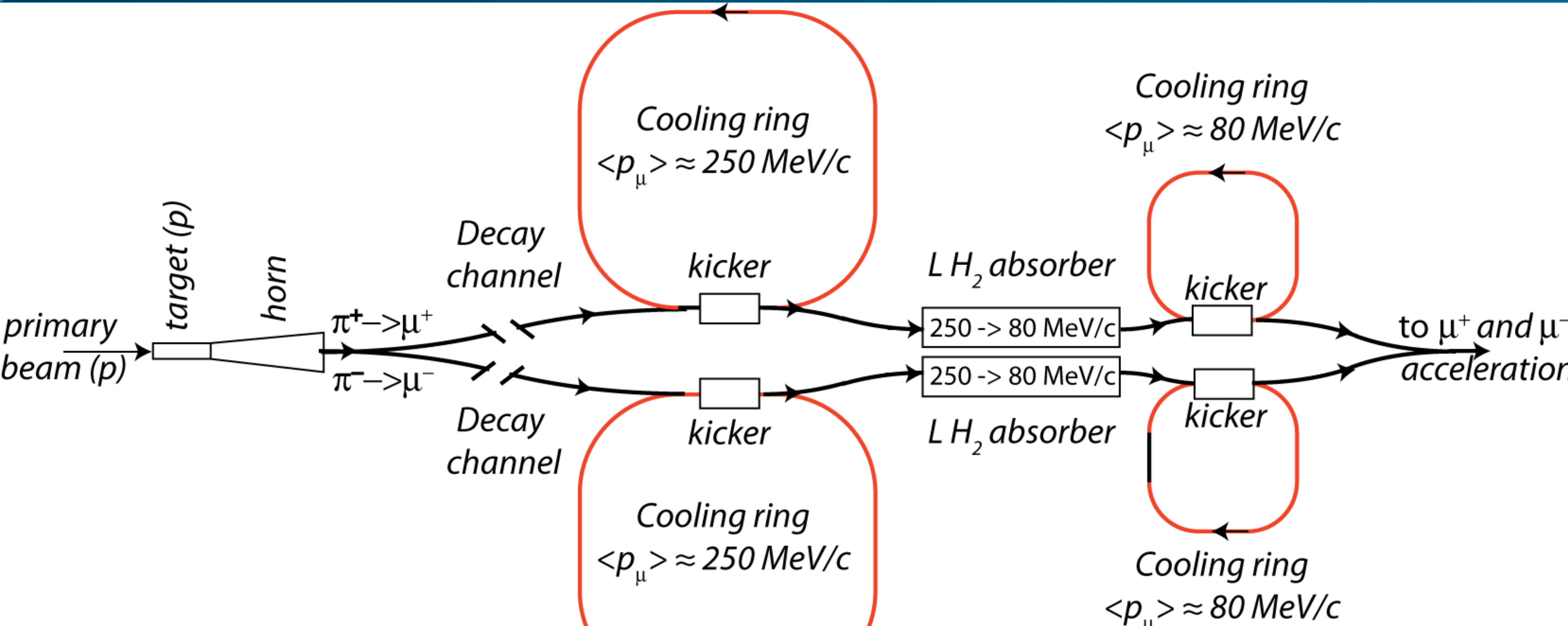






From the initial cooling experiment to a milli-mole of cooled muons

From the initial cooling experiment to the final setup



Bunch length L_b= ±0.4 m,

$$\Delta p = m_\mu \varepsilon_n^z / L_b \approx 1 MeV/c$$

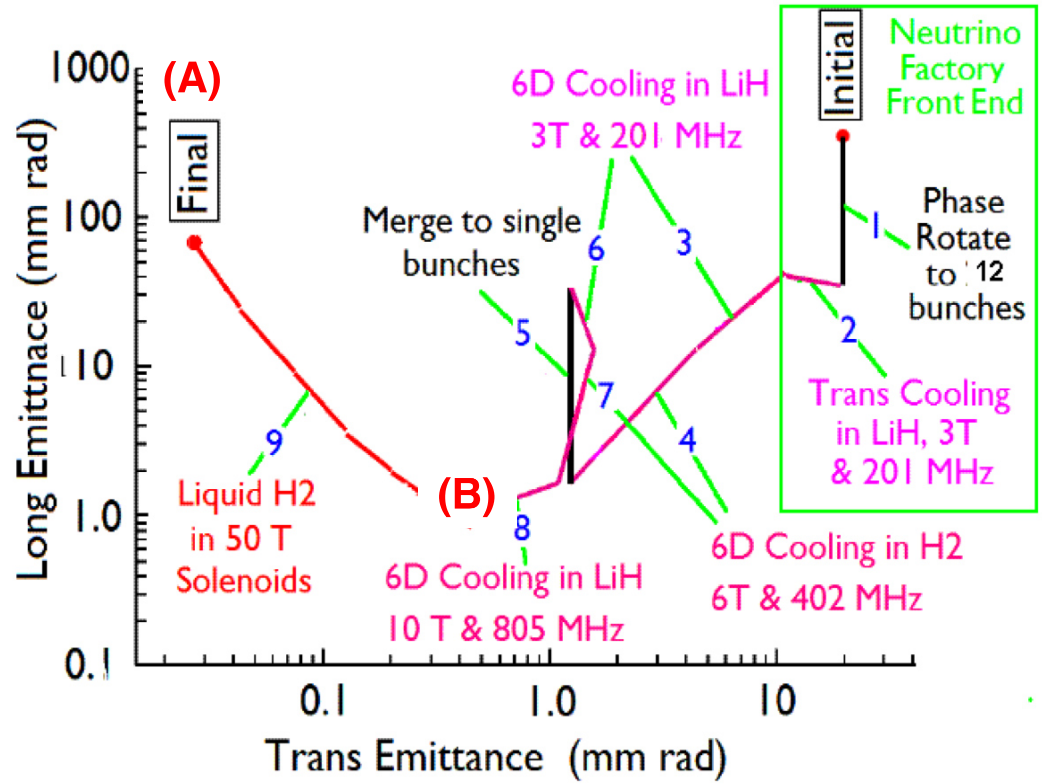
- The intensity may be further increased by constructing a stack of several superimposed PS-Booster like cooling rings
- Separate momentum windows are matched to rings with dE/dx

Two main physics initiatives

- The achievable equilibrium emittances can be compared with the expectations of two main physics alternatives:

➢ *(A) multi TeV muon collider* at $L > 10^{34}$ and with large $dp/p \approx 2$ %. The equilibrium emittances are too large transversely and too small longitudinally. This can be compensated with a final cooling with 50 T solenoids

➢ *(B) 125 GeV Higgs factory.* with extremely small $dp/p \approx 10^{-4}$ %. Transverse and longitudinal cooling are acceptable/

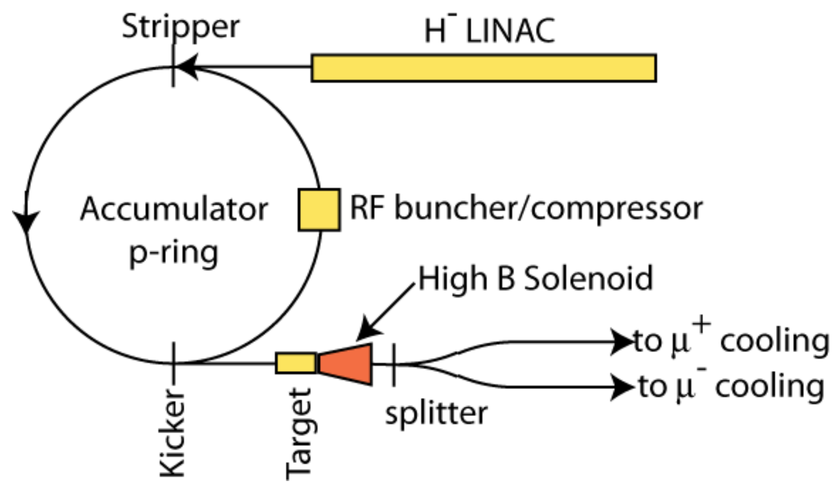


A.N. Skrinsky, T.V . Zolkin /NIM A 608 (2009) 42-47

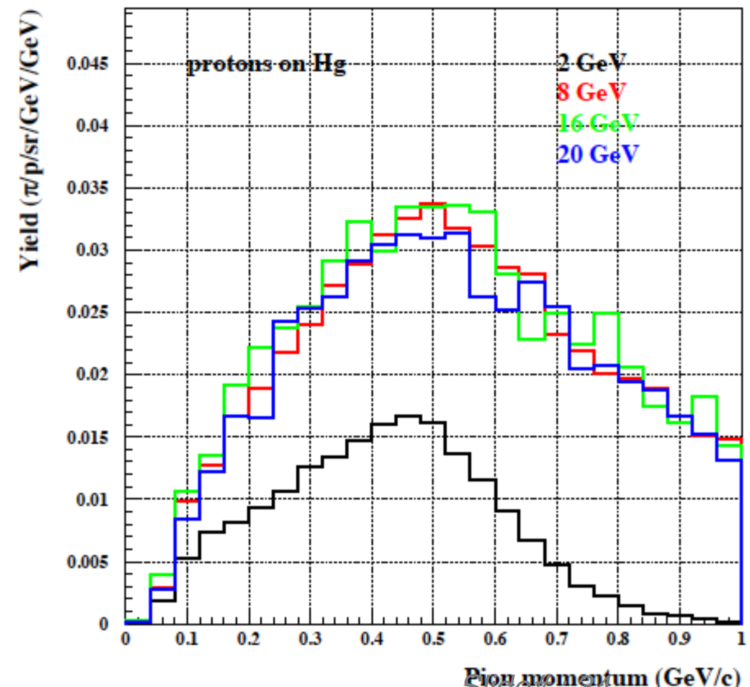
D. Neuffer, FERMILAB-CONF-12-389-APC (2012)

A high-intensity H- source to a p-compressor ring

- A tight p bunch may be realized with the help of an accumulation storage ring, starting from the H- beam produced by a LINAC and stripped to p in order to produce a number of short pulses finally condensed into a single short bunch.



Linac beam data					
Proton Energy:	2	8	16	20	GeV
Proton Power:	5	5	5	5	MWatt
protons/s:	1.56E+16	3.91E+15	1.95E+15	1.56E+15	
Repetition rate:	15	15	15	15	s-1
protons/pulse:	1.04E+15	2.60E+14	1.30E+14	1.04E+14	
pi+/p (50-800 MeV/c):	4.27E+13	1.04E+14	1.09E+14	1.01E+14	
pi-/p (50-800 MeV/c):	2.19E+13	1.02E+14	9.64E+13	9.48E+13	
mu+/p(150-300 MeV/c):	8.54E+12	2.08E+13	2.19E+13	2.02E+13	
mu-/p (150-300 MeV/c):	4.38E+12	2.03E+13	1.93E+13	1.90E+13	
protons/y (1y=10^7 s):	1.56E+23	3.91E+22	1.95E+22	1.56E+22	
mu+/y(150-300 MeV/c):	1.28E+21	3.13E+21	3.28E+21	3.03E+21	
mu-/y (150-300 MeV/c):	6.56E+20	3.05E+21	2.89E+21	2.84E+21	



Pion production and decay to muons

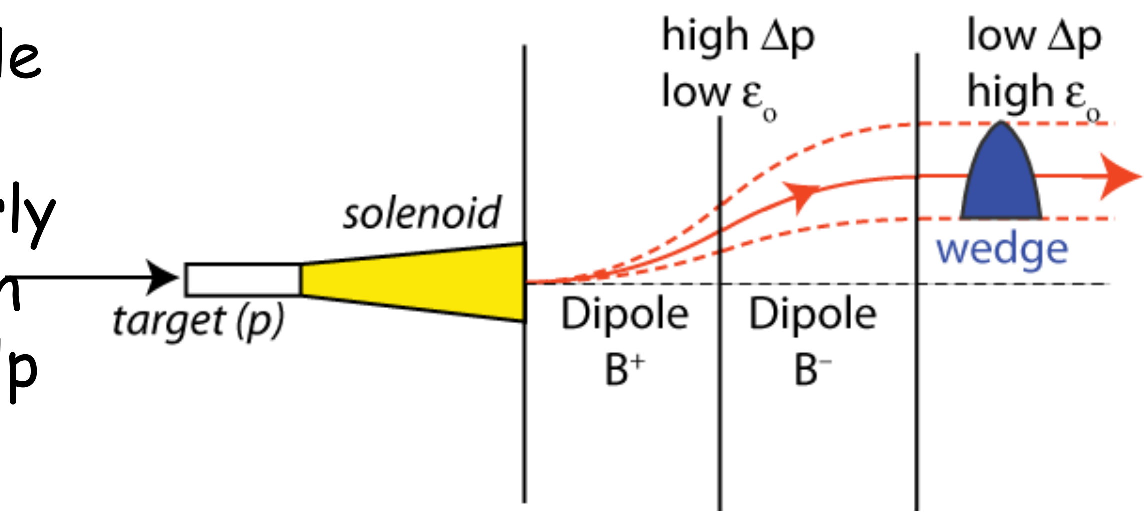
- A high field 20-T solenoid should collect secondary particles at about 100 mr off-axis angle to separate protons from pions. The MERIT/CERN experiment has successfully injected a Hg-jet into a 15-T solenoid.
- The best focussing is realized with secondaries in a axially symmetric solenoidal field following the Bush theorem. Particles of both signs are focussed and they can then be later separated magnetically. By reducing the field the rotational motion is converted into the longitudinal one, according to $p_\perp = p_\perp^o \sqrt{B/B_o}$ and $p_\dagger$ is reduced correspondingly. Therefore $\langle p_\dagger \rangle \approx 150$ MeV/5 ≈ 30 MeV/c

Nominal muon data		
Momentum:	220.0	Mev/c
Kinetic Energy:	138.2	Mev
Beta:	0.90	
Gamma:	2.304	
Lifetime:	5.061	μ s
Mu decay length:	1368.	m
Tranverse		
Average pt, at target:	150.0	MeV/c
Rms angle:	681.8	mrad
Length, at target:	5.000	cm
Radius, at target:	8.523	mm
Emittance:	5.811	mm x rad
Normalized transv. emitt:	12.06	mm x rad
Longitudinal		
Nominal p:	220.0	Mev/c
Spread, deltap:	±44.00	MeV/c
Min. p:	176.0	Mev/c
Max. p:	264.0	Mev/c
Bunch, 1/2 length:	1.567	ns
Normalized long. emitt.:	195.1	mm x rad

M. ANKENBRANDT et al. PRST-AB 2 081001 (1999)

Matching cooling rings to proton beam

- The muon spectrum for cooling must be optimized with the energy spectrum as produced by the high energy protons.
- Muons will be produced by an appropriate high power proton accelerator of a few GeV kinetic energy. The resulting optimum muon momentum is in the order of 200-500 MeV/c.
- For protons of above a few GeV, secondary spectra are roughly proportional to the actually produced beam power.
- In order to match the p_μ production to an acceptable smaller Δp_μ spread in the cooling ring, a first, an early "Liuvillian" compression can be performed with the help of a dEdx compensating wedge

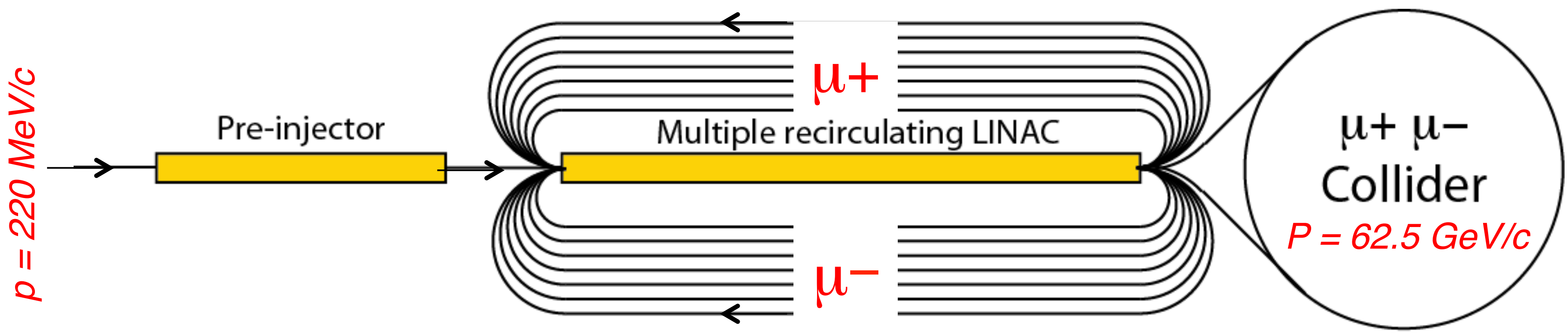


From wide Δp and narrow ε_o to narrow Δp and wide ε_o

From the fully cooled muons to the final storage ring

Acceleration to $H_o/2$ energy

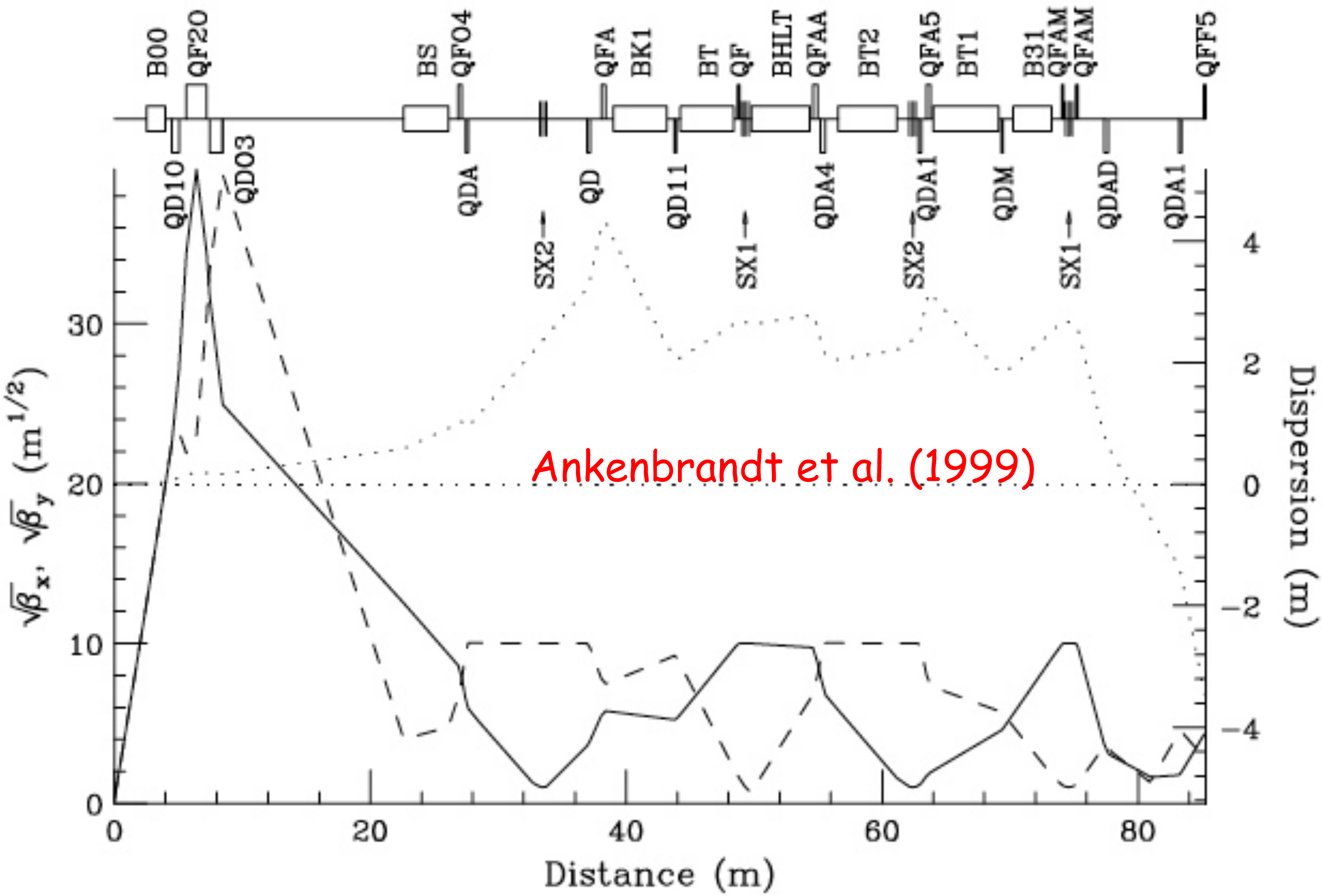
- In order to realize a Higgs Factory at the known energy of 125 GeV, an acceleration system is progressively rising the energy of captured muons to $m_{Ho}/2$, with the help of a series of several re-circulating RLAs.
- Adiabatic longitudinal Liouvillian damping from p_i = 0.22 GeV/c to p_f= 62.5 GeV/c (a factor $(p_f/p_i)^{1/4}$ =4.92), is increasing the final momentum spread Δp_f to 0.927 x 4.92 = 4.56 MeV/c and reducing the bunch length $L_{b,f}$ = ±0.4/4.92 = ±0.081 m.



Recirculating energy gain/pass = 62.5/8 = 7.75 GeV

Collider low beta structure

- Lattice structure at the crossing point, including local chromaticity corrections with $\beta_x = \beta_y = \beta^* = 5$ cm.



Ankenbrandt et al. (1999)

Eatimated performance of the Ho-factory (r ≈ 50 m)

- Two asymptotically cooled μ bunches of opposite signs collide in two low-beta interaction points with β*= 5 cm and a free length of about 10 m, where the two detectors are located.
- The bunch transverse rms size is 0.2 mm and the μ−μ tune shift is 0.086.
- A luminosity of 0.6 x 10^{32} cm^{-2} s^{-1} is achieved with 6.1 x10^{12} μ/bunch.
- The SM Higgs rate is ≈ 4400 ev/year in each detector. Higher rates (x4) are possible stacking two superposed cooling rings.

Proton accelerator rate:	15.00	s-1
Proton beam power	5.0	MWatt
Higgs mass:	125	GeV/c2
Final momentum:	62.50	Gev/c
Final gamma:	589.6	
Final lifetime:	1.295	ms
Mu decay length:	388.6	km
Average number of turns:	1110.	
Collider circumference:	**350.0**	**m**
Input muon momentum	220	MeV/c
Input momentum spread	± 20	%
Cooled momentum	80	MeV/c
Transverse inv. emittance cooled:	0.4600	π mmrad
Longitudinal inv. emittance cooled:	3.500	π mm rad
Initially produced muons/bunch:	2.032 E+13	
Cooled surviving fraction:	30.0	%
Colliding muons/bunch:	**6.09 E+12**	
Bunch transv. rms size:	197.5	microns
No effective luminosity turns:	555.2	
Crossings/sec: (at 15 hz)	8328.	
Luminosity :	**0.63 E+32**	**cm-2 s-1**
H_o cross section:	2.000E-35	cm2
H_o events/y (10^7 s)/ each cross:	**12610 (*)**	
Tune shift:	0.0864	
Final bunch half-length:	9.743	cm
Final Δp muon:	3.808	MeV
Final Δp/p muon:	6.093E-03	%
rms ΔE/E of H_o resonance:	8.616E-05	
Beam-beam intrinsic rms width:	**5.385**	**MeV**
Rms beam-beam signal surviving	35.0	%

(*) at zero beam-beam rms width

Conclusions

- The recent discovery of the Higgs particle of 125 GeV at CERN has highlighted the unique features of the direct production of a H^o scalar in the s-state, in analogy with the two steps of the Z with the PbarP and LEP programmes and where the mass, total and partial widths of the H^o can be directly measured with a remarkable accuracy and a very large number of events.
- *A high energy $\mu^+\mu^-$-collider is the only possible circular high energy lepton Higgs collider that can be easily situated within the existing CERN (or FNAL) sites.*
- A first step to could be the practical and experimental realization of a *full scale cooling demonstrator*, a relatively modest and low cost system but capable to conclusively demonstrate "ionization cooling" at the level required for a Higgs factory and eventually as premise for a subsequent multi-TeV collider and/or a long distance ν factory.

Conclusions

- The full realization of this Muon Factory requires two major and subsequent steps, namely
  - its 6D phase compression to a specified amount $\varepsilon_{6D} \approx 10^{-6}$ based on the demonstration of the initial cooling experiment with a chain of very tiny "warm" rings, followed by
  - the production and collection of a millimole of muons from an appropriate high intensity proton accelerator and
  - its acceleration and accumulation in an appropriate cooling ring at 62.6 GeV.
  - The luminosity may be further increased by constructing a stack of several superimposed PS-Booster like cooling rings and different pion momentum windows (Luminosity « N^2)
- The conventional facilities to realize the full facility should be constructed *only after this "initial cooling experiment" has been conclusively demonstrated,* eventually at a different location

Thank you !

The First Muon Collider (?)
125.5 GeV Higgs

David Neuffer

July 2012

Professional endorsement

New boson sparks call for 'Higgs factory'

Jul 5, 2012 15 comments

Former CERN boss Carlo Rubbia wants a muon collider

CERN's discovery of a new fundamental particle – most likely a Higgs boson – was barely hours old when physicists speaking at this year's Lindau Nobel Laureate Meeting in Germany argued the case for a new facility to measure its properties in detail. Speaking out in favour of a new machine was former CERN boss Carlo Rubbia, who shared the 1984 Nobel Prize for Physics for the discovery of the W and Z bosons. "The technology is there to construct a Higgs factory," he claimed. "You don't need €10bn; it could be done relatively cheaply."

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"With a Higgs of 125 GeV we need only a modest machine, perhaps not a large linear collider." Rubbia points out that muons colliding at a combined energy of roughly 125 GeV would suffice – just over half the energy of LEP and requiring a machine with a much smaller radius.