Istituto Nazionale
di Fisica Nucleare

Guided discussion on muon technologies and possible synergies between them

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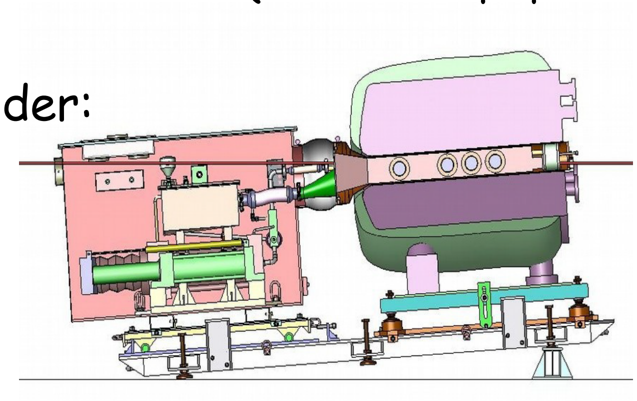
A remind of session agenda

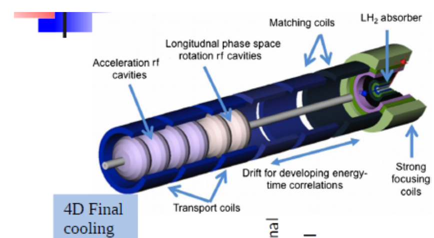
Muon ionization cooling results and prospects	*Kenneth Long*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	17:20 - 17:40	
Current experimental activities on Muonium	*Ryoto Iwai*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	17:40 - 18:00	
Muon cooling at J-PARC	*Shusei kamioka*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	18:00 - 18:20	
Muon cooling at PSI	*Giuseppe Lospalluto*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	18:20 - 18:40	
High energy muon production and acceleration challenges TBA)	*Daniel Schulte*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	18:40 - 19:10	
Guided discussion on muon technologies and possible synergies among them	*Maurizio Giorgio Bonesini*	
Palazzo Franchetti, Venezia, Istituto Veneto di Lettere, Scienze ed Arti - Palazzo Franchetti	19:10 - 19:40	

Aim of this roundtable

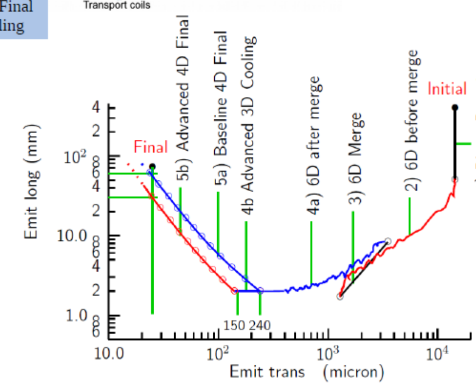
- Try to pin-point synergies between different sides of muon beam technologies used in very different field
  - From applied physics (archeometry, solid state physics, …) with low energy muons to fundamental physics (beyond SM) at muon colliders (multiTeV $\mu^+\mu^-$ colliders)
- Try to focuss on still pending R&D issues for muon collider:



  - Targetry (MERIT @CERN, 2007 demonstrated that a > 4 MW Hg jet target is feasible)



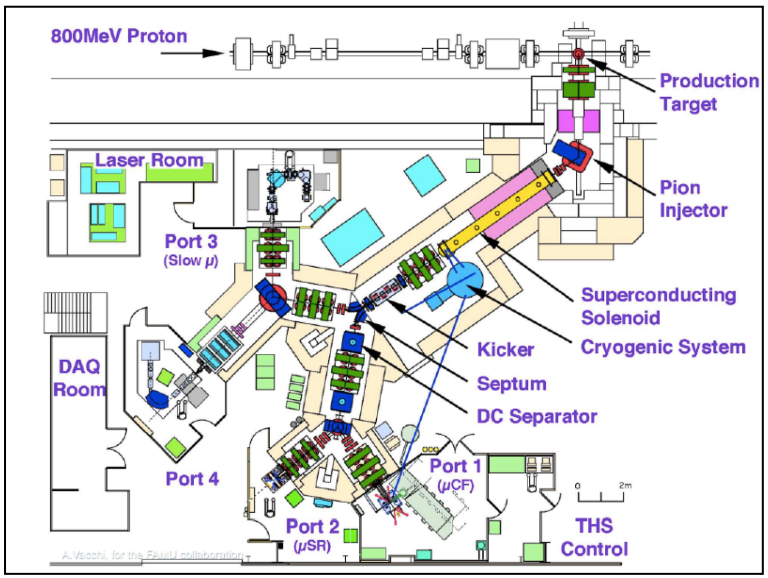
  - Cooling of muon beams: many different issues from ionization cooling to mu-cool at PSI



  - Muon acceleration

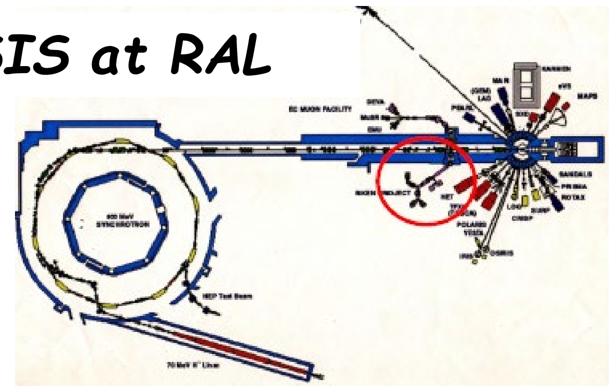
The common ingredient

- The common ingredient is that we start always with low energy muons (eV-100 MeV/c)
- We aim at different applications:
  - Applied physics, fundamental atomic physics, archeometry at RIKEN-RAL, PSI or (see A. Hillier talk on …)
  - High energy muon colliders (see D. Schulte talk)
- But some problems are common, eg cooling (see K.Long dedicated talk on MICE)
- Justa a flash on a long standing workhorse: RIKEN-RAL a joint UK-JP effort in UK

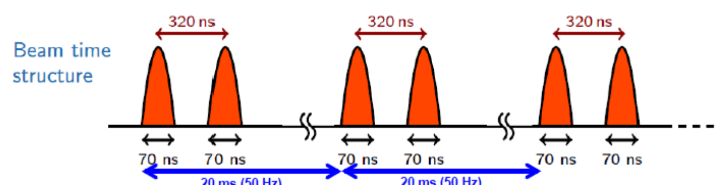


RIKEN-RAL facility

ISIS at RAL



800 MeV p accelerator , 200 mA, 50 Hz

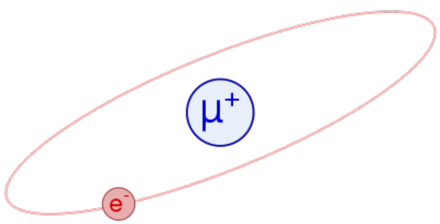


Tunable momentum: 20-120 MeV/c

Flux m^-: $7x10^4$ muons/s; double pulse

Muonium experimental activities

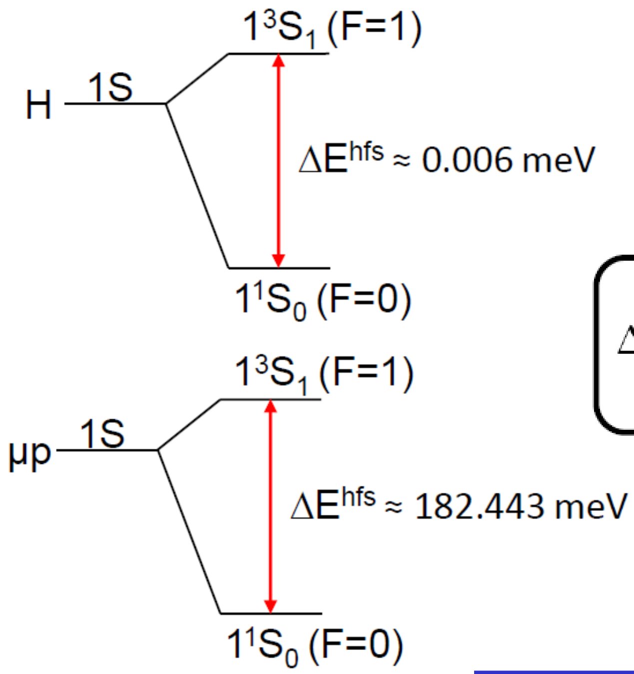
Muonio in Italian, not the nice summer resort in Finland , but



Exotic atom made of μ^+ and e^-

- *Talk of R. Iwai on activities at JPARC on muonium spectroscopy*
- *What about HFS splitting? How these measure compares with μ p for QED tests?*
- *Measurements may be synergic ?*
- *There may be a common ground for discussion ?*
- *Rich experimental activity centered on the measure of the proton Zemach radius at RIKEN-RAL (UK), PSI (CH), JPARC (JP) on μp*

Measurement of HFS with μp

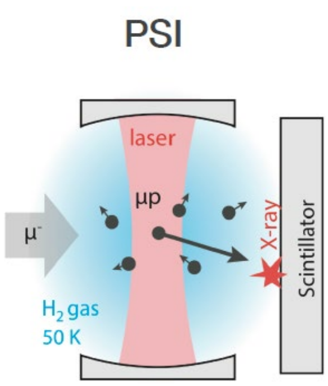


R_Z is then determined via QED with a precision up to 1%, more than enough to discriminate between different Hypothesis

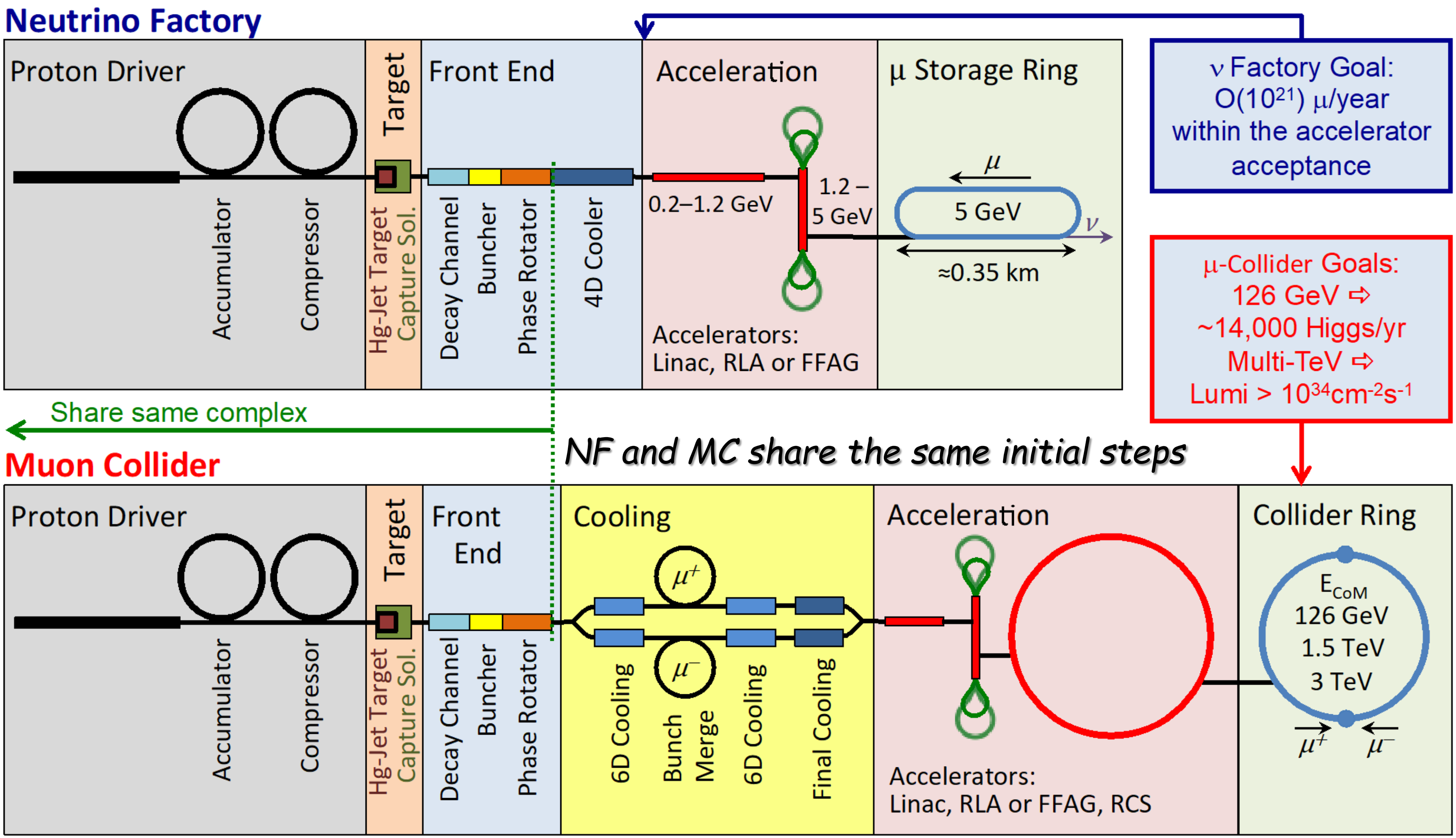
$$\Delta E_{hfs} = \frac{16}{3}\alpha^2 c R_\infty (\frac{\mu_2}{\mu_1})(\frac{\mu_1}{\mu_1^0})^2(1+\frac{m_e}{m_p})^{-3}) \times [1+\frac{3}{2}\alpha^2 - 2\frac{< r >_{Zemach}}{a_0} + \beta + \delta]$$

Other μp HFS projects

	FAMU (UK)	PSI (CH)	RIKEN (JP)
Method	transfer	diffusion	asymmetry
Laser	DFG-MIR 1-5 mJ		QCL-seeded ZGP-OPO > 20 mJ in development
Detection	X-rays	X-rays	electrons
Beam	pulsed	continuos	Pulsed

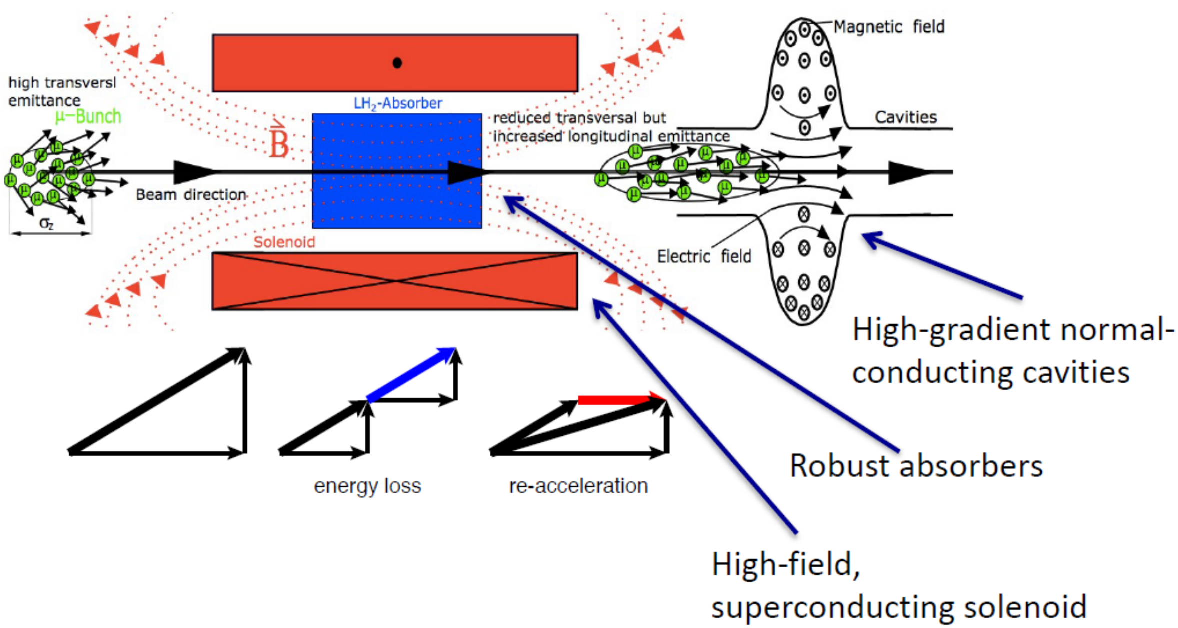


The US Muon Accelerator Program (MAP)



The cooling Issue

- For new high intensity low energy muon beams (PSI, JPARC) and high energy muon colliders the reduction in phase space is an essential asset
- Usual cooling techniques, as radiation cooling, laser cooling, stochastic cooling, … may not be applied to muons as t is ~.2 ms
  - at very low muon energies (10 eV)   muCOOL approach (10^{10} decrease in phase space density with 10^{-3} efficiency)
  - At higher muon energies (100 MeV) see ionization cooling (MICE)



From D. Schulte talk

mu-COOL at PSI

PSI is leading physics with DC muon beams (28 MeV/c surface muons). Increase quality of μ+ beam (cooling) and improving muon rates (HiMB)

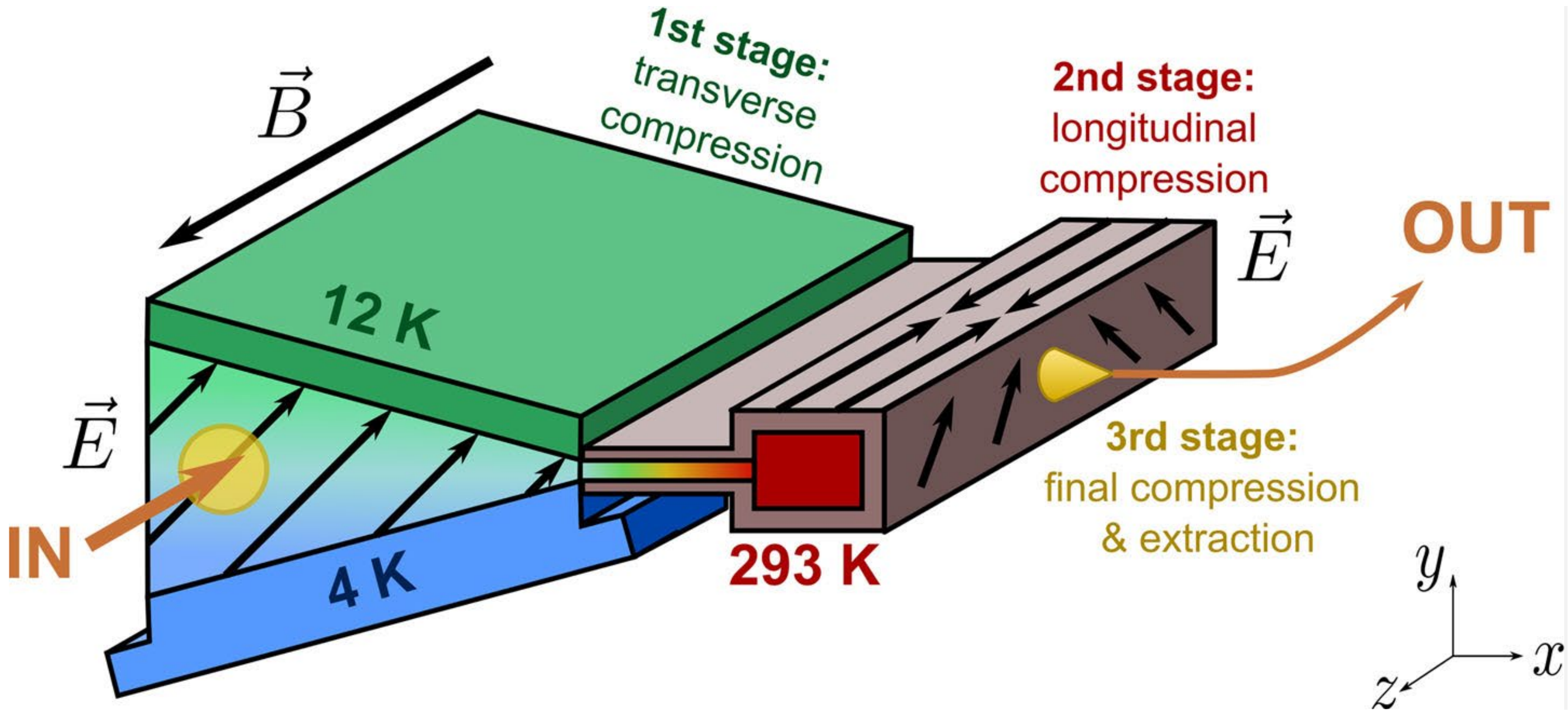
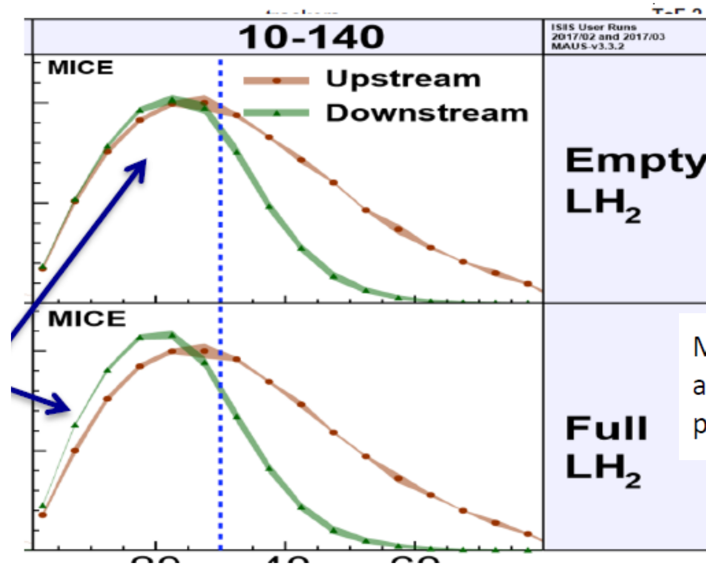


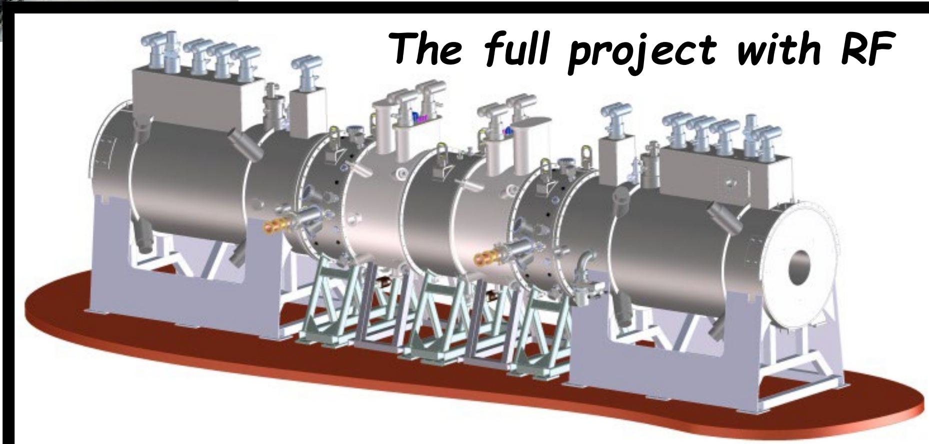
Fig. 1 Scheme of the proposed muon compression beam line. Muons from the secondary μ^+ beam enter the transverse compression stage, where they are first stopped in the helium gas and then compressed in transverse (y) direction by using the combination of a vertical temperature gradient and crossed electric and magnetic fields. After that, they enter the longitudinal compression stage, where they are compressed in the longitudinal (z) direction and then extracted into the vacuum

MICE (see tak by K. Long)



More particles at smaller amplitude with absorber in DS

MICE demonstrated the validity of ionization cooling for muons, but the ri-acceleration issue (RF with a demonstrator) is still an open issue



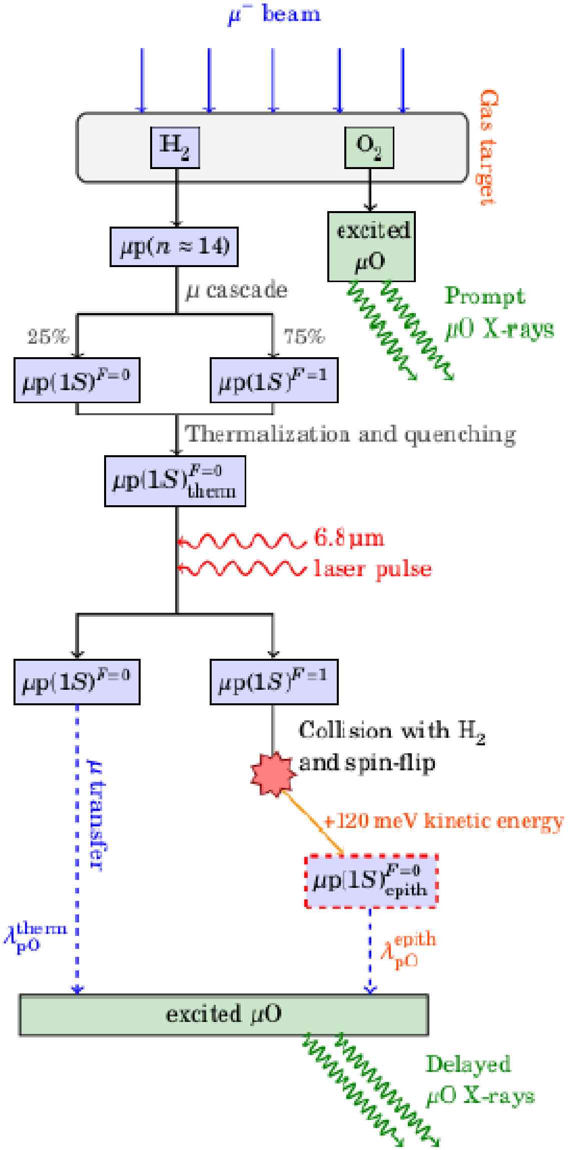
Some open questions for discussion

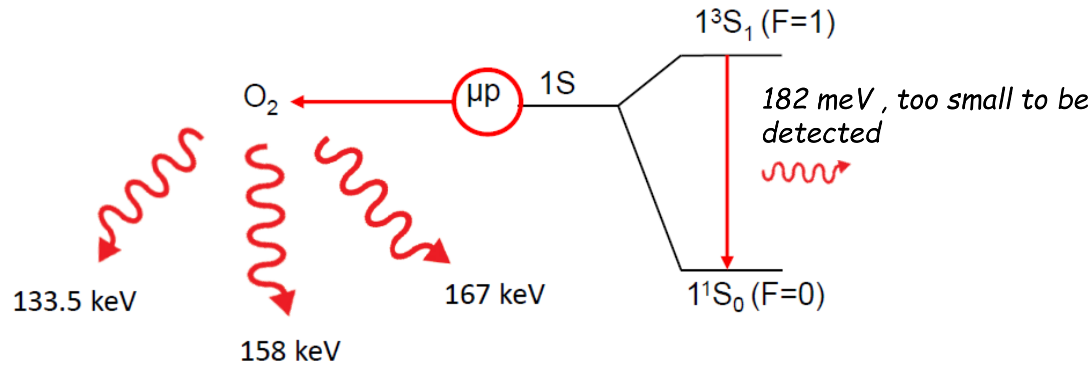
- At the end, HFS measurement with Mu and μp are precise QED tests? What are the cons & pros ?
- A question for discussion: what are cooling performances for USM muons at U and S lines at JPARC, compared eg to what obtained at muCOOL ?
- What about muon cooling from muCOOL to MICE ionization cooling?
- R&D needed for muon collider ? Where we are ?
  - Targetry
  - Muon cooling: 6D needed vs 4D from MICE
  - Acceleration options (FFGA still an option ?)
  - …
  - Need for a demonstrator of single cooling cell (MICE style) vs many cells
- There may be synergies between low energy muon beams R&D (eg PSI, RIKEN-RAL, JPARC) and R&D for beams for muon collider ?

Thank to the LOC for the possibility of REMOTE participation

Backup slides

The FAMU experimental method





1. *Create muonic hydrogen in a hydrogen gas target and wait for its thermalization;*
2. *Laser shot at resonance wavelength (λ_0 ~6.8μ): spin state of μ^-p from 1^1S_0 to 1^3S_1 , spin is flipped: μ^-p(↑↓) → μ^-p(↑↑) ;*
3. *De-excitation and acceleration: μ^-p(↑↑) hits a H atom. It is depolarized back to μ^-p(↑↓) and is accelerated by ~120 meV ~2/3 $\Delta E^{hfs}{}_{1S}$;*
4. *μ^- are transferred to heavier gas contaminant (O_2) with energy-dependent rate;*
5. *λ_0 is determined by maximizing the time distribution of μ^- transferred events.*
6. *At this point ΔE_{HFS} is determined from:* $\lambda_0 = hc/\Delta E^{1S}_{HFS}$ ~ 6.8 µ ~ 0.183 eV and then R_Z with a precision ~ 1%.