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Collaboration

Proton driver summary

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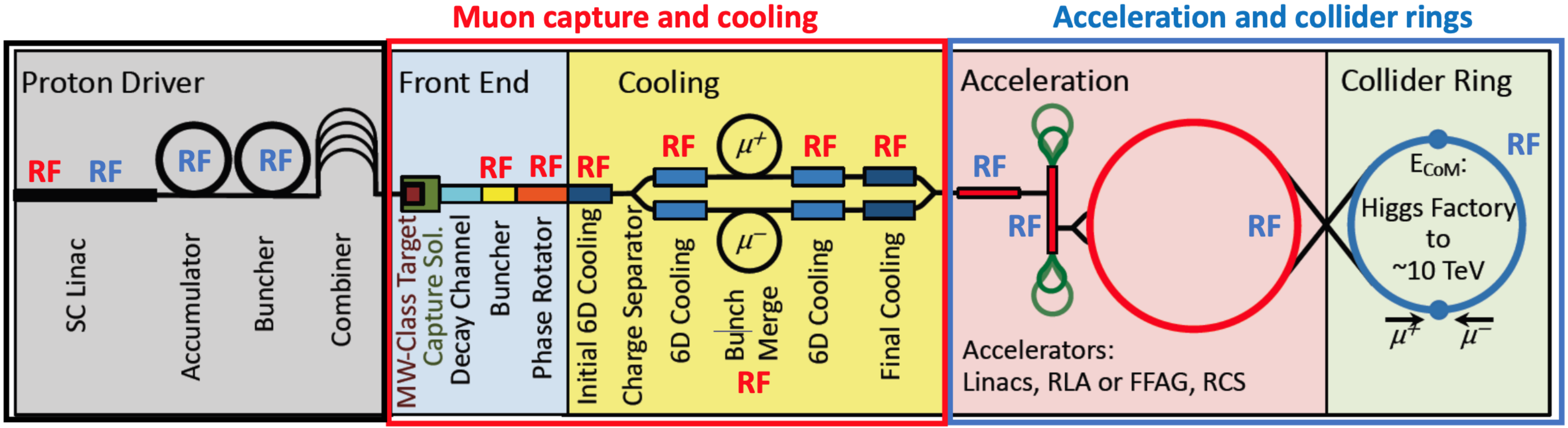
3nd Community meeting of the International Muon Colliders Design Study – Oct. 2021

Setting the scene



Courtesy of A. Grudiev et al.

A first tentative parameter table

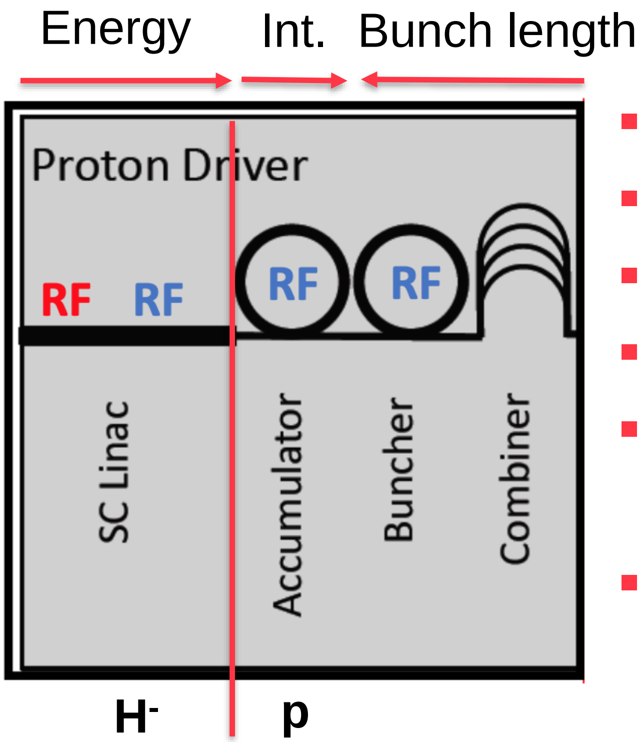
Baseline:
- 2 MW
- (eventually 4 MW)
- Linac + 2 rings
- (FFA as option)
- Final energy to be decided

Courtesy of J.P. Delahaye et al.

System			Driver			Front-End	Cooling			Acceleration			Collider	Total
Sub-system			Driver Linac H- (SPL like)		Accum &Comp		Initial	6D (2 lines)	Final (2 lines)	Injector Linac	RLA	RCS	Ring	
Reference expert			F.Gerigk		?	D.Neuffer	C.Rogers	D.Stratakis	C.Rogers	A.Gogagz		S.Berg	E.Gianfelice	
			NC	SC										
Beam (system exit)	Energy	GeV/c	0.16	5	5	0.255	0.255	0.255	0.255	1.25	62.5	1500	1500	
	# bunches (μ+ or μ-)	#	40 mA		1	12	12	1	1	1	1	1	1	
	Charge/bunch	E12			500	3.60	2.57	7.27	4.43	3.59	3.05	2.22	2.20	
	Rep Freq	Hz	5	5	5	5	5	5	5	5	5	5	5	
	Norm Transv Emitt	rad-m				1.5E-02	3.0E-03	8.3E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05	
	Norm Long Emitt	rad-m				4.5E-02	1.5E-02	1.9E-03	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	
	Pulse/Bunch length	m	2.2 ms		0.6 (2ns)	1.1E+01	1.1E+01	9.2E-02	9.2E-02	4.6E-02	2.3E-02	2.3E-02	5.0E-03	
	Power (μ+ and μ-)	W	6.40E+04	2.2E+06	2.0E+06	1.8E+04	1.3E+04	3.0E+03	1.8E+03	7.3E+03	3.1E+05	5.4E+06	5.3E+06	
RF cavities	Technology		Linac4HP	SC		0	NC	Vacuum	NC	SRF	SRF	SRF	SRF	
	Number of cavities	#	23	244		120	367	7182	32	52	360	2694	?	11074
	RF length	m	46	237		30	105	1274	151	82	1364	2802	?	6091
	Frf	MHz	352	704	4 ?	326to493	325	325-650	20-325	325	650-1300	1300	800	4 to 1300
	Grf	MV/m	1-3.7	19 - 25		20	20 to 25	19-28.5	7.2-25.5	20	25 to 38	35	?	7 to 35
	Magnetic Field	T	0	0		2	3T	1.7-9.6	1.5-4	0	0	0	0	0 to 9.6
	Installed RF field	MV	169	5700		434	2618	30447	1836	1640	50844	98062	250	1.92E+05
	Energy gain	MeV	160	4840		0	0	0	0	1250	62500	1437000	0	1.51E+06
	Recirculations	#	1	1		1	1	1	1	1	4.5 to 5	13 to 23	1000	1 to 1000
	RF Power	MW	25	282		?	?	?	?	52	360	48	?	?
RF power sources	Technology		klystron	klystron						Klytron-IOT				
	Cavities/Power Source	#	23	244		4				1 to 2	1 to 2			
	RF Pulse (beam) duration	ms	2.42	2.42		4.08E-04	5.04E-04	4.08E-03	5.64E-04	6.36E-04	3.72E-02	1.28E+00	8.70E-01	
	Prf/Power Source	MW	11.7	2.47						1	1			
	Total Power Sources	#	17	244		30				52	341			?
	Installed RF Power	MW	34	352		164				52	341			?
	Total RF Energy	MJ	2.99E-01	3.00E+00		3.35E-01	1.55E-01	4.26E-01	1.56E-02	8.63E-03	3.66E-01	6.13E+00	0.00E+00	10.74

Basic elements

H- source and **accumulator and combiner complex**
10^{14}-10^{15} protons in ns-long bunch



- H^- source → high intensity
- Few GeV → Superconduting Linac (SNS,ESS)
- Accumulator
- Buncher
- Combiner → target delivery system

- **Challenge:**
  High intensity short bunches @ low rep. rate

Outstanding studies

- H^- source : needs further studies/R&D
- Linac BD: ESS linac as most recent example
  - Basic lattice can be deduced from existing machines

- Rings BD lattice design. Collective effects. Intensity limitations. Delivery recombiner system
  - H^- stripping : input from SNS
  - Beam stability with short bunches and low rep.rate

- FFA full design → Collective effects specific to FFA
  - Magnet design requires particular attentions

Work Package Description

Workpackage Description
Revise design of proton driver for 4 MW operation based on Linac, Accumulator and Compressor and delivery system. Investigate the potential limitations to reach such power. Provide a preliminary lattice for the rings and the linac. Explore state-of-the art main systems, with particular attention to the H- source and the ring H- injection. Investigate an alternative FFA based scheme. Investigate the possibility of a proton driver test stand.

Very tentative and educated guess initial planning

- 2021-2022 :
  - Wrap-up of previous studies and performances of existing and future similar proton sources.
  - Define preferred rings schemes : w. or w/o acceleration in accumulator.
  - Identify studies with the BD work package to define possible energy intervals if any wrt to collective effects
  - Specify dedicated studies for FFA option wrt collective effects
  - Revise existing design of Linacs → needs to define final emittance (spot size on target)
- 2022 :
  - revision of state of the art of H^- sources and define best promising source technology
  - preliminary ring lattice design and target delivery system
  - conceptual design of recombination scheme → revision of MAPS
  - FFA first lattice design
  - Improved studies of collective effects
- 2023:
  - Definition of the preferred energy range
  - Integration of linac and rings in real geometry
- 2024
  - conceptual design of proton complex

Initially proposed Tasks and Resources

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1	Linac+Accumulator	Resource estimate			
		staff [FTEy]	postdoc [FTEy]	PhD [FTEy]	material [kEuro]
	Linac design to extrapolate to 4 MW Study and preliminary lattice design for accumulator	0.1*3	1*3	1*3	50
	Investigate existing H-source	0.1*3		1*3	
	Investigations on H- injection and stripping techniques	0.1*3		1*3	

2	Compressor/Buncher	Resource estimate			
		staff [FTEy]	postdoc [FTEy]	PhD [FTEy]	material [kEuro]
	Study and preliminary lattice design for compressor	0.1*3	0.8*3	1*3	50
	Study of target delivery system		0.2*3		

3	FFA option	Resource estimate			
		staff [FTEy]	postdoc [FTEy]	PhD [FTEy]	material [kEuro]
	Study and preliminary design FFA based option	0.1*3	1*3	1*3	50

Working hypothesis

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Initial proposal further reduced to some key aspects for which currently the project cannot secure resources

Proof of concept

- Preliminary lattice design for accumulator (and linac)
- H- source exploration
- **Preliminary design of compressor (and target delivery system)**
- Addressing fundamental charge density limit
- FFA option as alternative

	Staff FTEy	Postdoc FTEy	Student FTEy	Material kEuro	Sum MEuro
	5.7	13	15	0	3.45

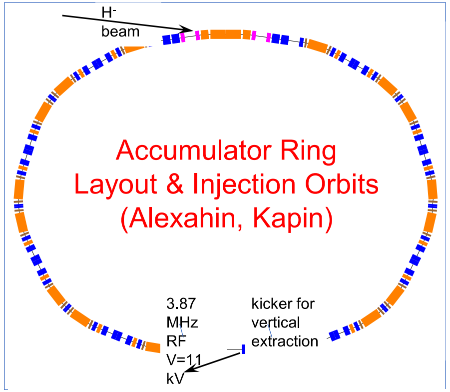
Quenched into (for the moment): Preliminary design of compressor (+ target delivery system

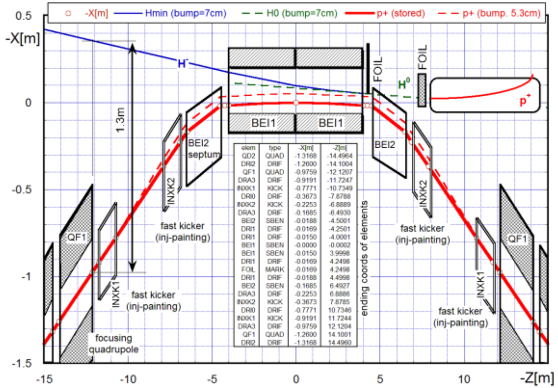
→ Define beam on target (time structure, transverse distributions, etc..)

Compress.	0.1*3y	1*3y		0	

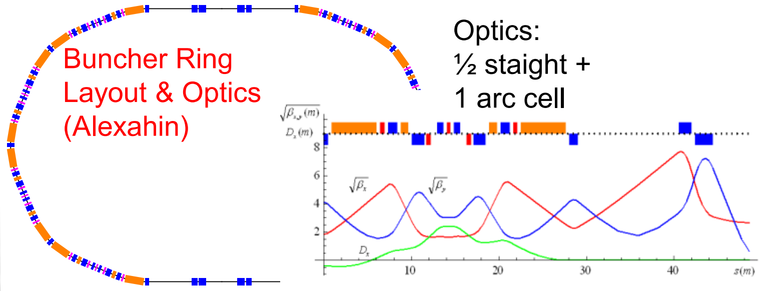
From MAPS studies

Proton Driver





Recommendations:
- *No showstoppers identified*
- *Adapt concept for likely proton source*



Optics:
½ staight +
1 arc cell

- ✓ Based on 6-8 GeV Linac Source
- ✓ Accumulator & Buncher Ring Designs in hand
- ✓ H- stripping requirements same as those established for Fermilab's Project X

Courtesy of M. Palmer

Next steps

- Foster discussion with other programs and look for other potential sources of man-power
  - Past collaborators ”not-yet” back in the study
  - EU funded programs : ESS proposal excellent start – EU proposal for including H^- source, accumulator and compressor included in ESSnuSB
  - ….
- Recover as much as possible from past studies
  - Recover MAPS studies (thanks to M. Palmer)
  - Revise past design
- Provide input for target design

ESS proposal for EU funding

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Proposal for a EU Horizon Europe Design Study 2022-2025

We are planning to submit in Spring 2022 a proposal to EU Horizon Europe for a Design Study of features of the ESSnuSB design not yet studied during 2019-2021, like the civil engineering, licensing and safety required at the ESS and Far Detectors sites, preparation of the ESSnuSB R&D phase and a conceptual design study of a 0.5 GeV nuSTORM race track ring for low energy neutrino cross-section measurements with the aim to deliver an Technical Proposal in 2025.

The plan would be to include resources in the requested budget for a conceptual design study of the Muon Collider proton-complex test-facility described above.

HORIZON-INFRA-2022-DEV01

Developing European Research Infrastructures to maintain global leadership

Deadline: **24 March 2022**

Topics	Type of Action	Budgets (EUR million) 2022	Expected EU contribution per project (EUR million)	Number of projects expected to be funded
Opening: 10 Nov 2021 Deadline(s): 24 Mar 2022				
HORIZON-INFRA-2022-DEV-01-01	RIA	24.00	1.00 to 3.00	10
Overall indicative budget		24.00		

Courtesy of T. Ekelof

Conclusions

- Operational experience from J-PARC and SNS proved that > 1 MW proton sources (drivers) are a reality

- Citing Frank:
  - **“There are no fundamental show-stoppers on the proton driver side”** → Also to go to 4 MW
  - “The technologies and the power ramp-up are challenging but can be solved by continued commissioning effort and gradual improvements (e.g. as done at SNS to ramp up the power, you should count 5-10 years to get to nominal)”
    - by Andrei and John : “**Technical and physics related challenges are there, but solutions have been found**”

- H^- sources and the accumulator - compressor rings are the most critical items

- In the designing of the μ-pd we will profit from experience of existing and operational machines and R&D already ongoing for the high-power proton sources in construction (PIP-II, ESS).

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Thank you very much for the discussions and inputs