Evaluation of the Slow Extraction Survey

5th Slow Extraction Workshop

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Background

- Survey compiled by Florian Kühteubl & Dale Prokopovich
  - Based on the survey from the Slow Extraction Workshop 2016
- Initially part of the iFAST-REX collaboration
  - Project lead: P. Forck
  - Parameter collection: August - September 2021
- Expansion to the Slow Extraction Workshop
  - Close alignment with Masahito Tomizawa
  - Parameter collection: December 2021 - January 2022
- Updates in January 2024
  - Will be included in a future report

Goal of the survey:

Collect the 'status quo' of SX for all facilities and use the collection as baseline for future collaborations/common developments

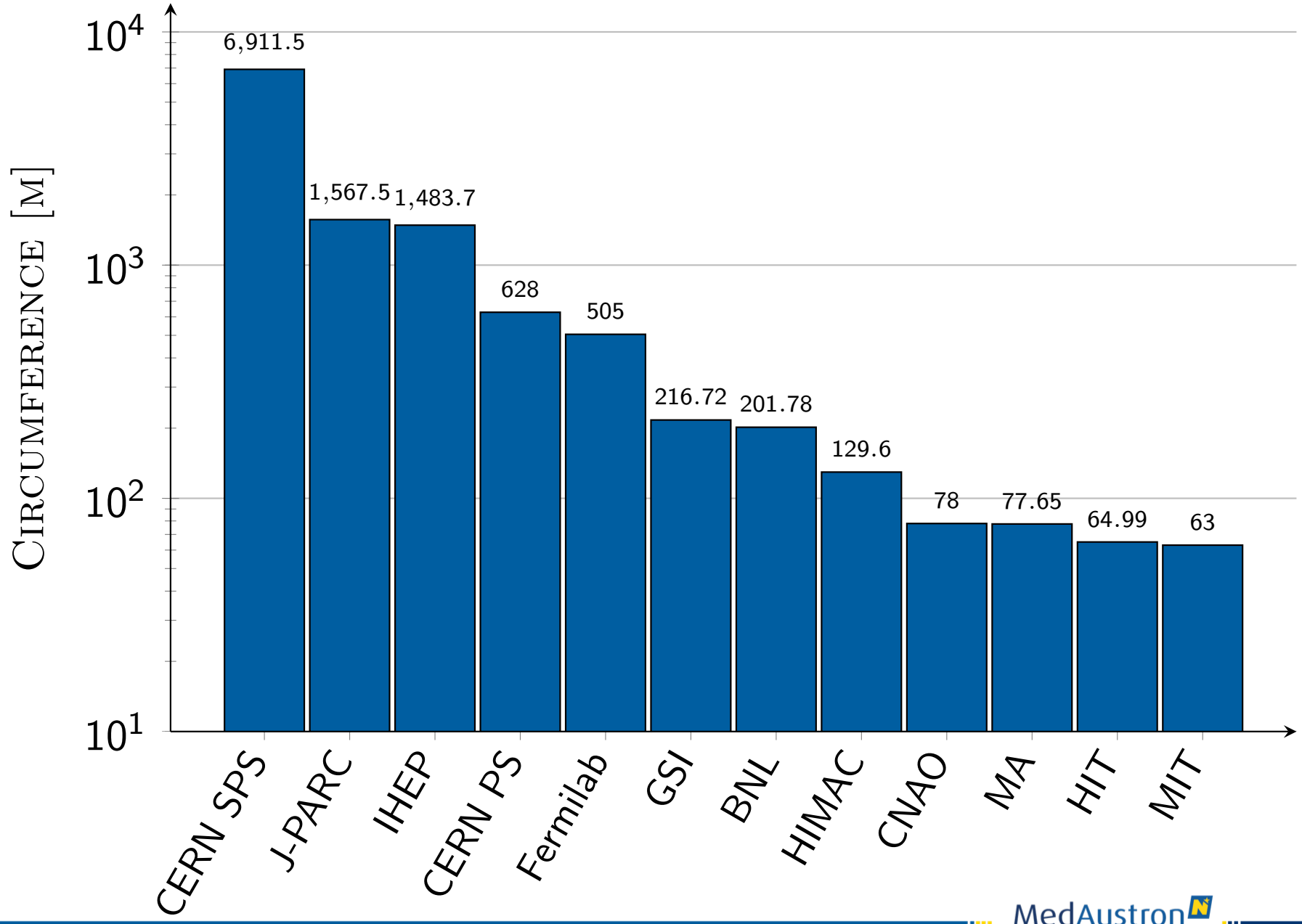
Participants

- Brookhaven National Laboratory (BNL)
- European Organization for Nuclear Research (CERN)
- Centro Nazionale di Adroterapia Oncologica (CNAO)
- Fermi National Accelerator Laboratory (Fermilab)
- Helmholtzzentrum für Schwerionenforschung (GSI)
- Heavy Ion Medical Accelerator in Chiba (HIMAC)
- Heidelberger Ionenstrahl-Therapiezentrum (HIT)
- Institute for High Energy Physics (IHEP)
- Japan Proton Accelerator Research Complex (J-PARC)
- MedAustron (MA)
- Marburger Ionenstrahl-Therapiezentrum (MIT)

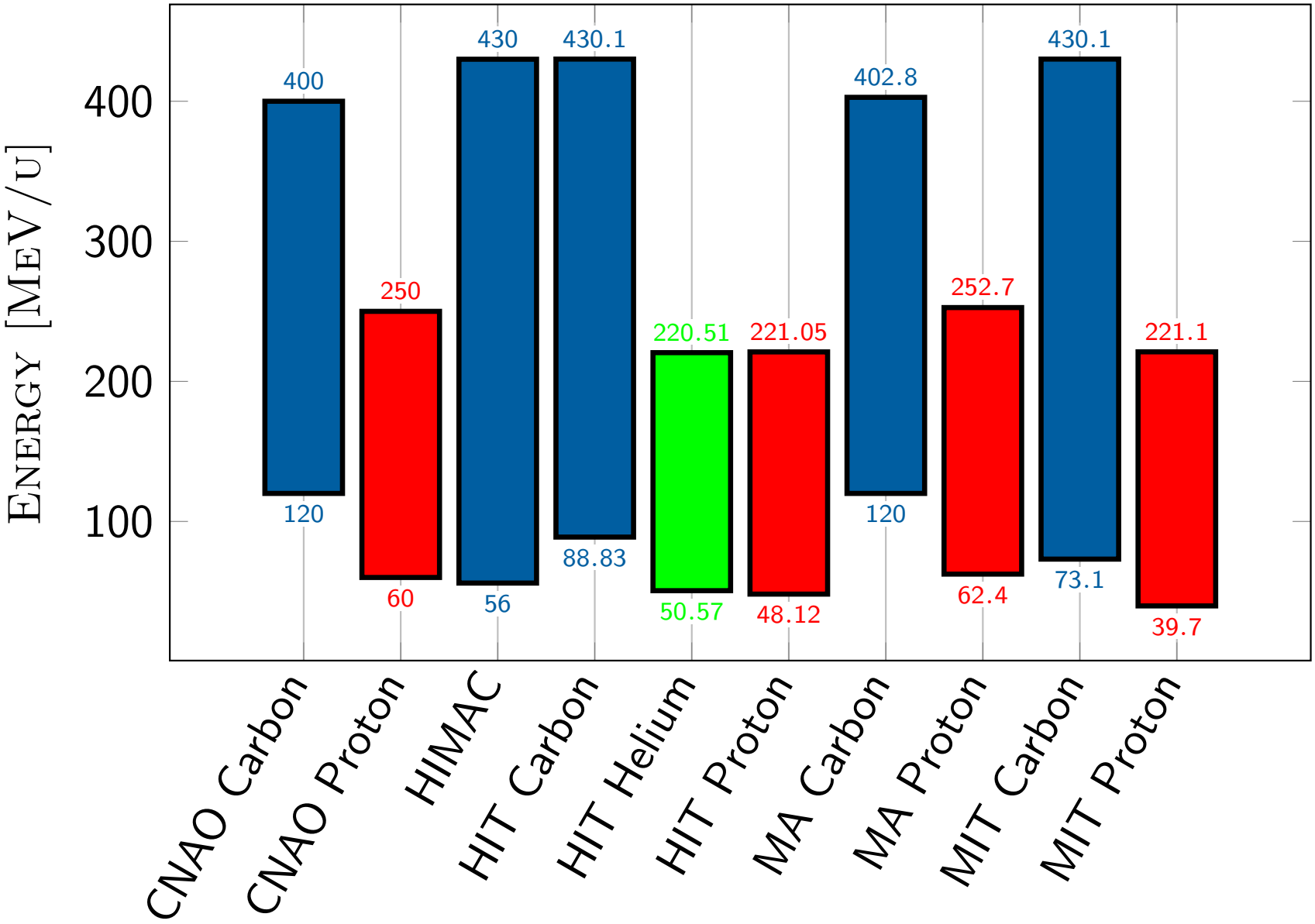
General Information

	Name	Particle type(s)	Extraction method(s)	Bunched?
BNL	AGS Booster	Proton all ions until Uranium	Tune Sweep (ramping quads and dipoles)	✓or ✗
CERN	PS and SPS	Proton	COSE	✗
CNAO	Synchrotron	Proton Carbon	Betatron Core RFKO	✗ ✓
Fermilab	Delivery Ring (Mu2e)	Proton	Tune Sweep	✓
GSI	SIS-18	Proton all ions until Uranium	Tune Sweep RFKO	✓or ✗ ✓
HIMAC	Synchrotron	Carbon	RFKO	✓
HIT	HIT-Accelerator	Proton Carbon Helium	RFKO	✓
IHEP	Synchrotron U-70	Proton	Longitudinal RF phase noise	✗
J-PARC	Synchrotron	Proton	Tune Sweep	✓or ✗
MA	Synchrotron	Proton Carbon	Betatron Core	✗
MIT	IONTRIS (Siemens)	Proton Carbon	RFKO	✓

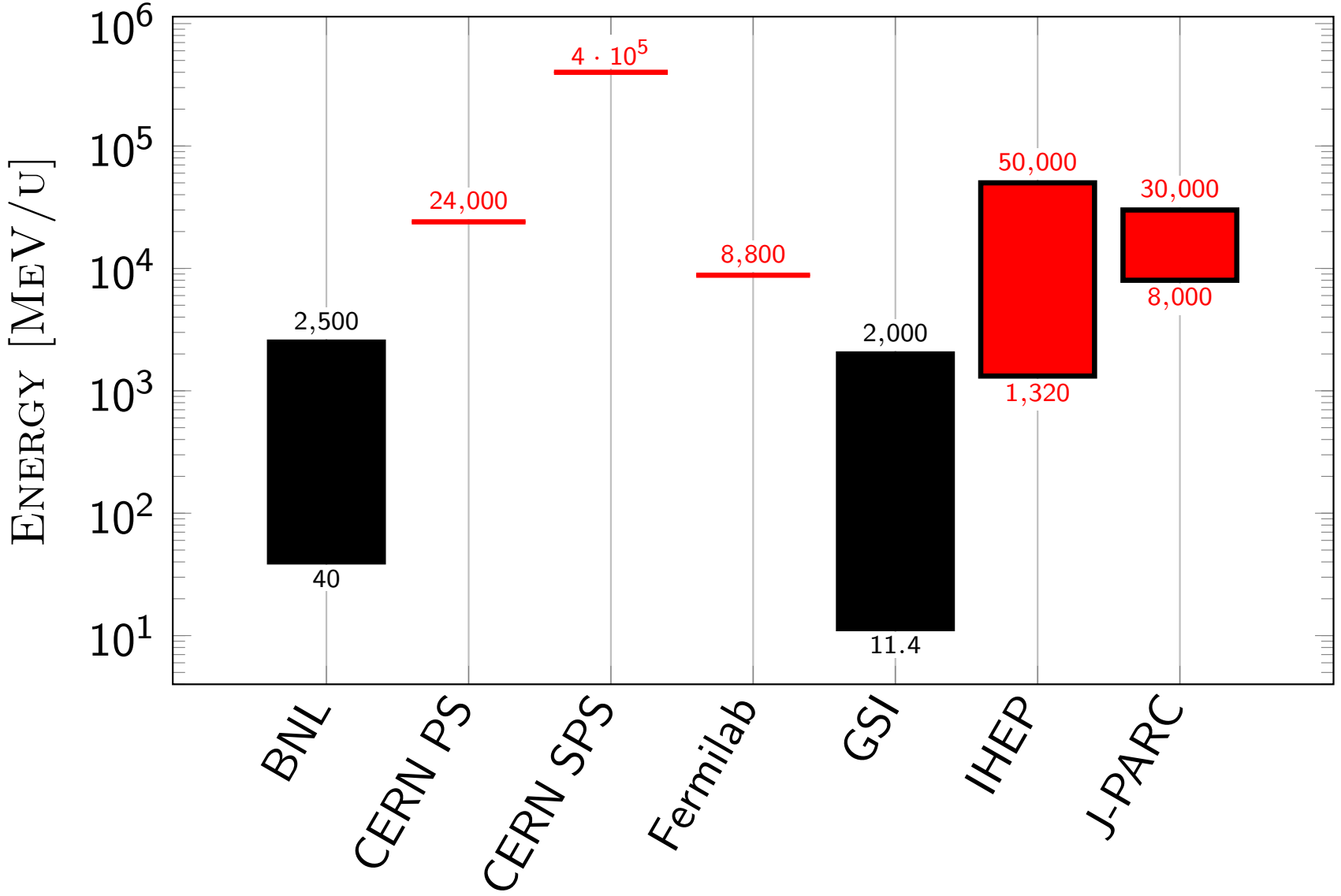
Accelerator Circumference



Energy range - medical-focused facilities



Energy range - research-focused facilities



Extraction Parameter - medical-focused facilities

			Horizontal tune → Resonance	Horizontal chromaticity	Mom. offset [‰]	Mom. spread [‰]
CNAO	Betatron	Proton	1.672 → 5/3	-4.0	-25/8.5	0.8*
		Carbon			-20/8.5	0.8*
	RFKO	Proton		-1.0	-25/8.5	0.4*
		Carbon			-10/8.5	0.25*
HIT		Carbon	1.68 → 5/3	-0.7 ± 0.05	0	≈ 2
		Helium	1.685 → 5/3			N/A
		Proton	1.688 → 5/3			≈ 2
HIMAC			3.681 → 11/3	-0.7	0	0.1
MA			1.676 → 5/3	-4.0	-20/8.5	1.15**
MIT		Proton	1.715 → 5/3	N/A	0	1
		Carbon	1.698 → 5/3			1.2

* root mean square

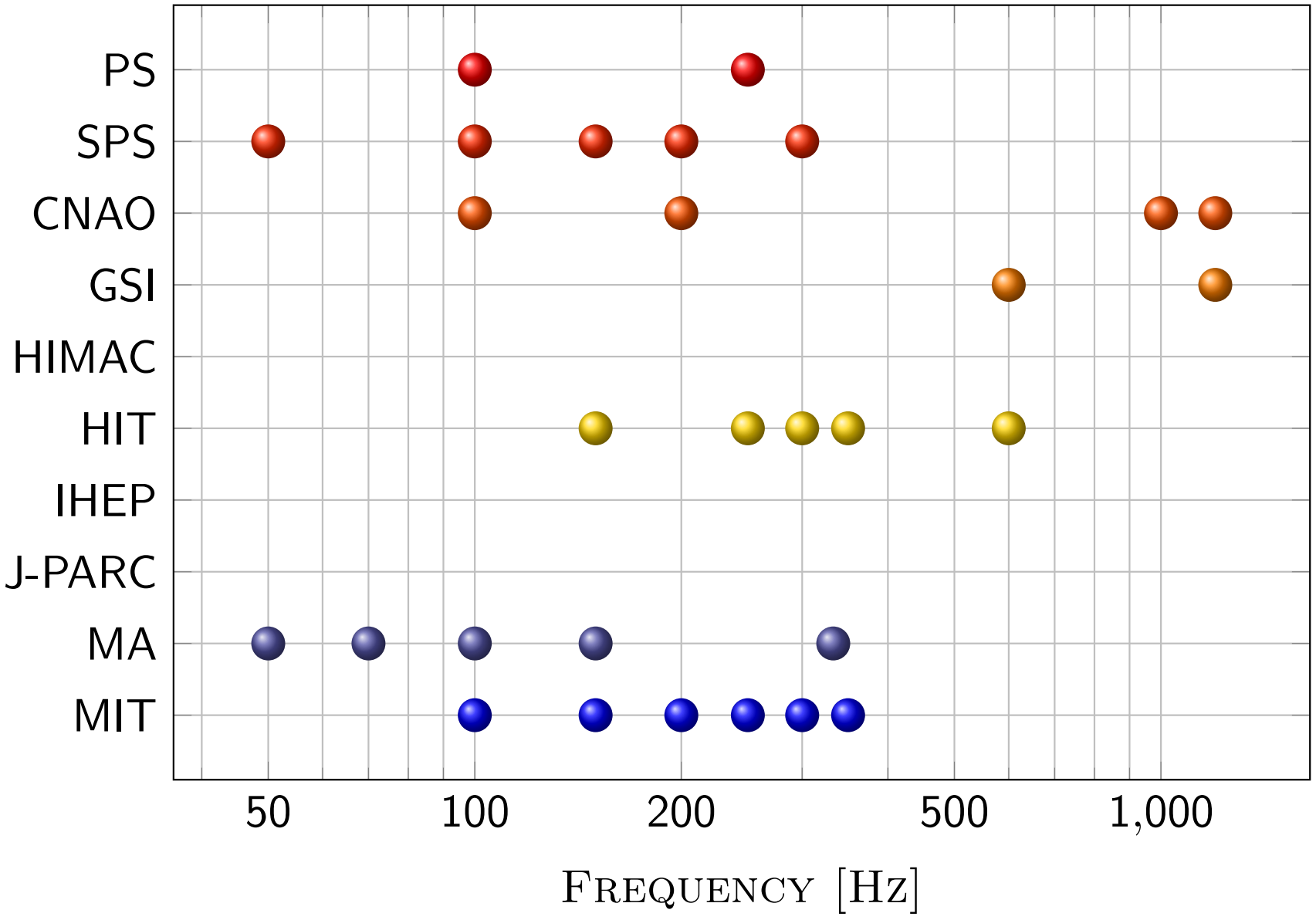
** uniform momentum distribution, $\sigma = \sqrt{dpp_{total}^2/12}$

Extraction Parameter - research-focused facilities

		Horizontal tune → Resonance	Horizontal chromaticity	Mom. offset [‰]	Mom. spread [‰]
BNL		4.7 to 4.5 → 13/3	-10 to -15	N/A	N/A
CERN	PS	6.323 → 19/3	-1.67	3	1.7*
	SPS	26.62 → 80/3	-33.5	1.5	0.87*
Fermilab		9.650 → 29/3	1	0	2
GSI		4.29 → 13/3	-4	0	0.5
IHEP		9.7 → 29/3	-15	-2.4	1.6 to 2
J-PARC		22.31 → 67/3	-2	0	2.9*

* uniform momentum distribution, $\sigma = \sqrt{dpp^2_{total}/12}$

Dominant beam ripples



Ripple control schemes

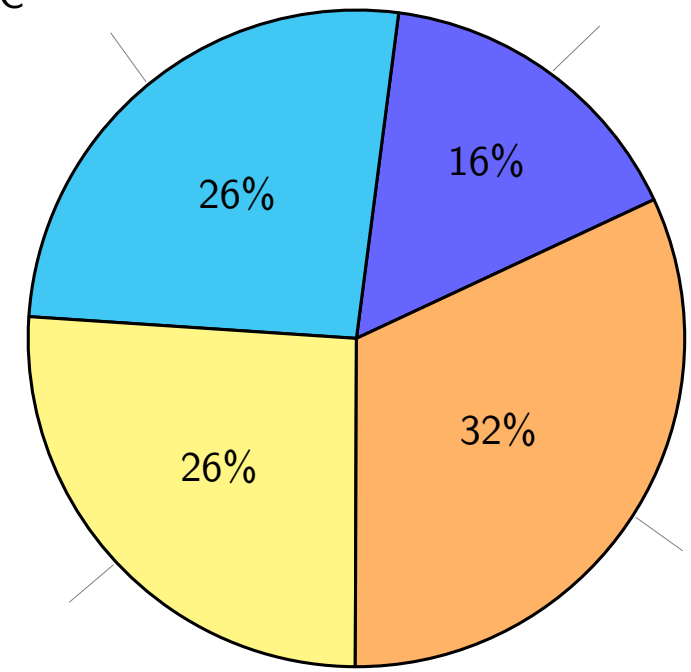
		HF empty bucket sweeping	RF channelling	Longitudinal RF noise	(Air core) quad
BNL		✓	✓	✗	✗
CERN	PS	✗	✓	✗	✗
	SPS	✗	✗	✗	✗
CNAO	Betatron	✓	✓	✗	✗
	RFKO	✗	✗	✗	✓
Fermilab		✗	✗	✓- Transverse RF	✓
GSI		✗	✓- Tune wobbling	✗	✗
HIMAC		✗	✗	✗	✗
HIT		✗	✗	✗	✗
IHEP		✗	✗	✓	✗
J-PARC		✗	✗	✗	✓
MA	Proton	✗	✓	✗	✗
	Carbon	✗	(✓)	✗	✗
MIT		✗	✗	✗	(✓)

(✓) = experimental/in testing

Used feedback/feedforward systems

Both:
Fermilab
HIT Proton
HIT Carbon
HIT Helium
J-PARC

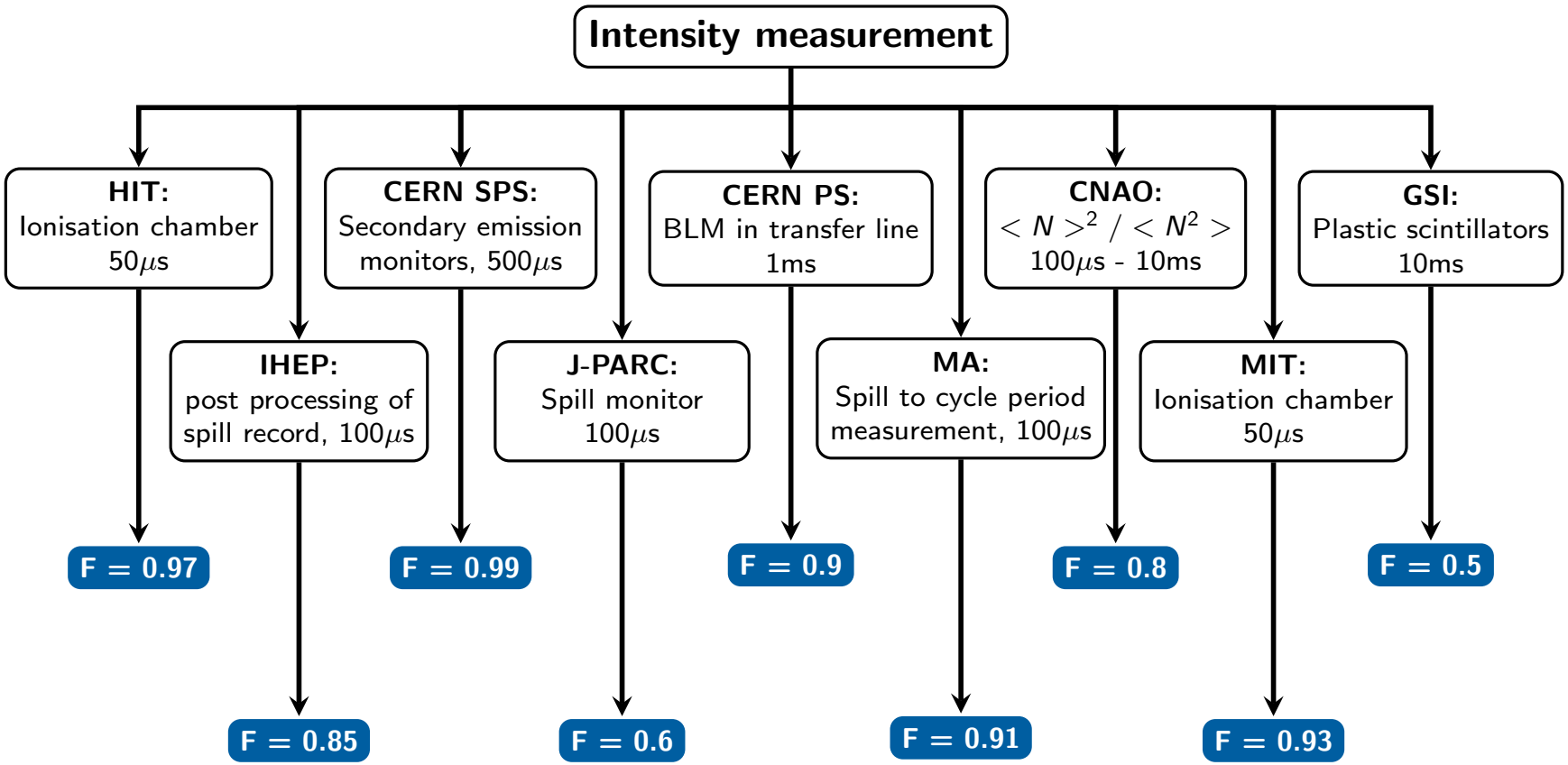
Feedforward:
CERN SPS
MIT Proton
MIT Carbon



Feedback:
CNAO RFKO Proton
CNAO RFKO Carbon
GSI
HIMAC
IHEP

None:
BNL
CERN PS
CNAO Betatron Core Proton
CNAO Betatron Core Carbon
MA Proton
MA Carbon

Duty Factor



Common definition of duty factor:

$$DF = \frac{<I>^2_{10\ \mathrm{ms}}}{<I>^2_{10\ \mathrm{ms}} + \sigma^2_{10\ \mathrm{ms}}}$$

Outlook

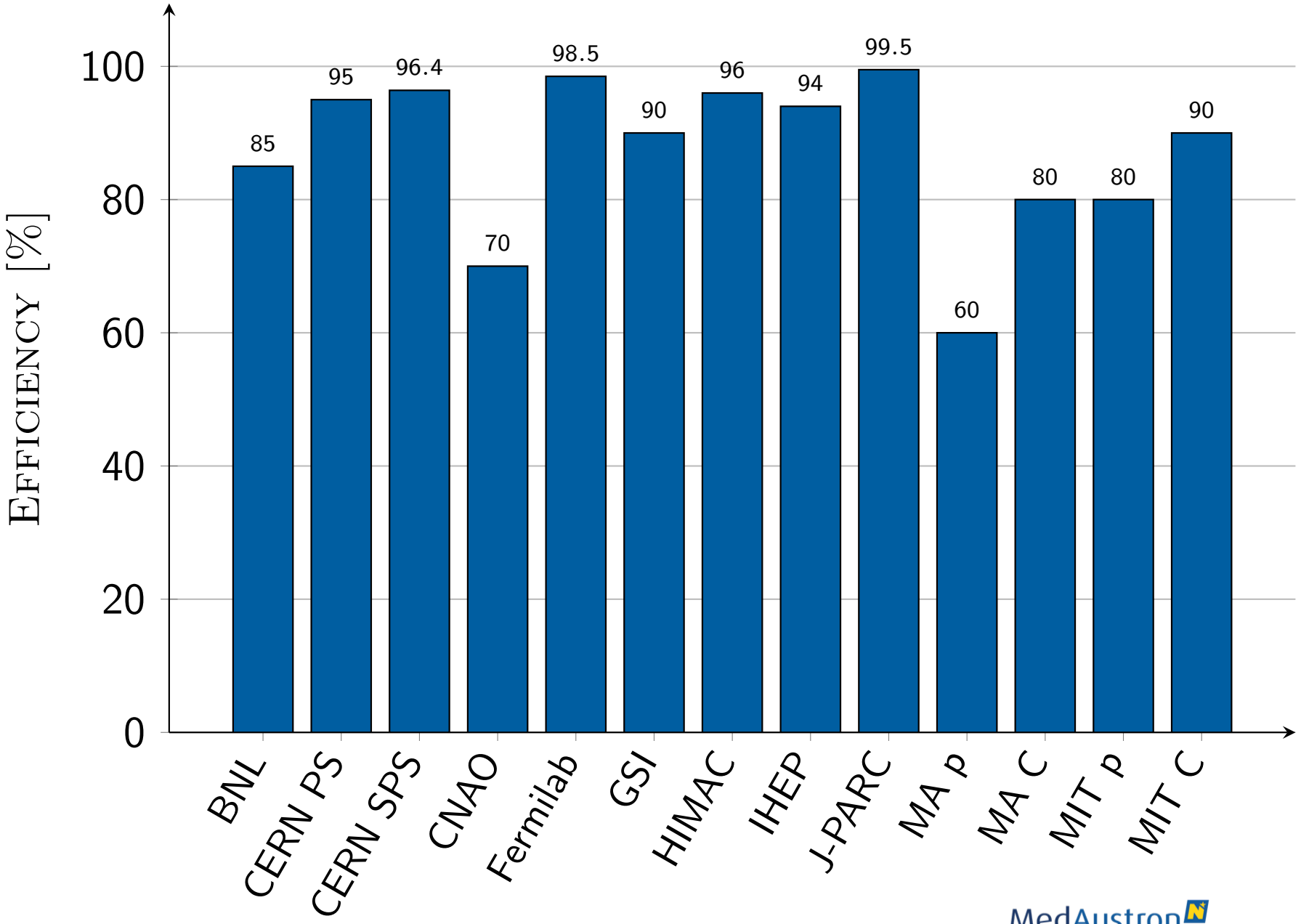
- Improvement of common parameter definitions (duty factor, extraction efficiency, non-delivery time, ...)
- Standardization of parameter evaluation
- Fostering discussions between the institutions in an open dialogue
- Update the survey to the status of January 2024

Please fill out the survey with your updates!

Link to survey

Thank you for your attention!

Extraction efficiency



Non-delivery time per spill