CERN

Preliminary Power Estimates for the FCC-hh

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Contents

- What is important & how to obtain it
- FCC Operation with the LHC in mind
- Power estimation for the different systems
- Energy Efficiency
- Next steps & Conclusions

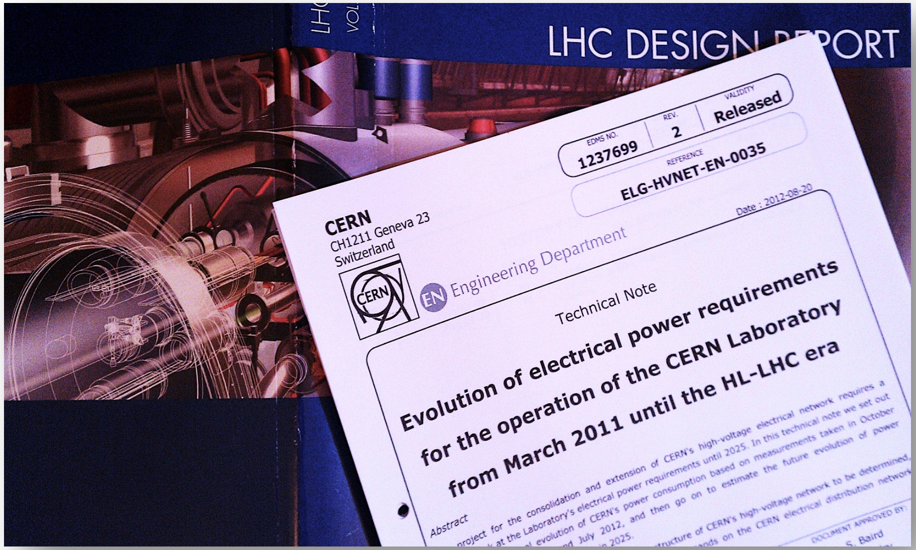
Power & Energy Consumption

- For the design of a collider or any machine two energy related parameters are important
  - **The Energy Consumption**
    - Will in the end determine the **cost to run the collider**
    - Can be divided in actual **running and base energy consumption**
  - **Installed Power**
    - This is will **dimension the infrastructure** and is **determined by the installed equipment**

- This work unit should provide a realistic estimate for both
  - Initially an estimate for the FCC-hh which will be refined when more precise information becomes available
  - Later also for the FCC-ee, but perhaps using directly design data

The Initial Estimation Strategy

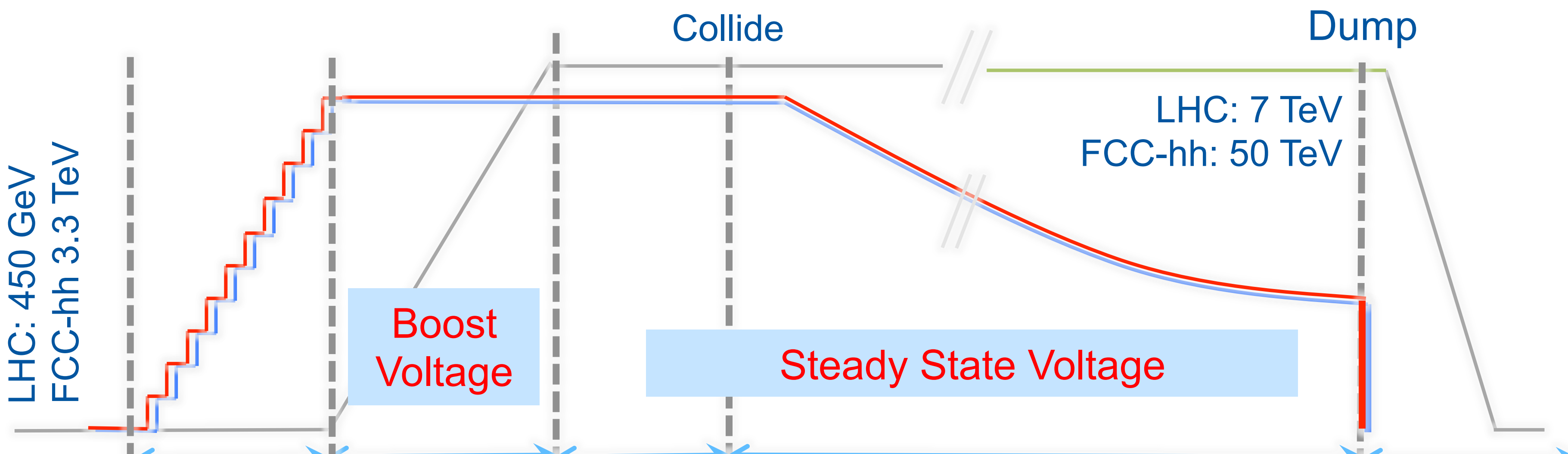
- If the data for the estimates is not yet available, then apply intelligent scaling from a reference machine, the LHC



- Easy & Rough scaling
  - LHC Size x 4
  - LHC Energy x 7

- However for some parts a more intelligent and more precise scaling can already be applied

Assumed Operational Cycle

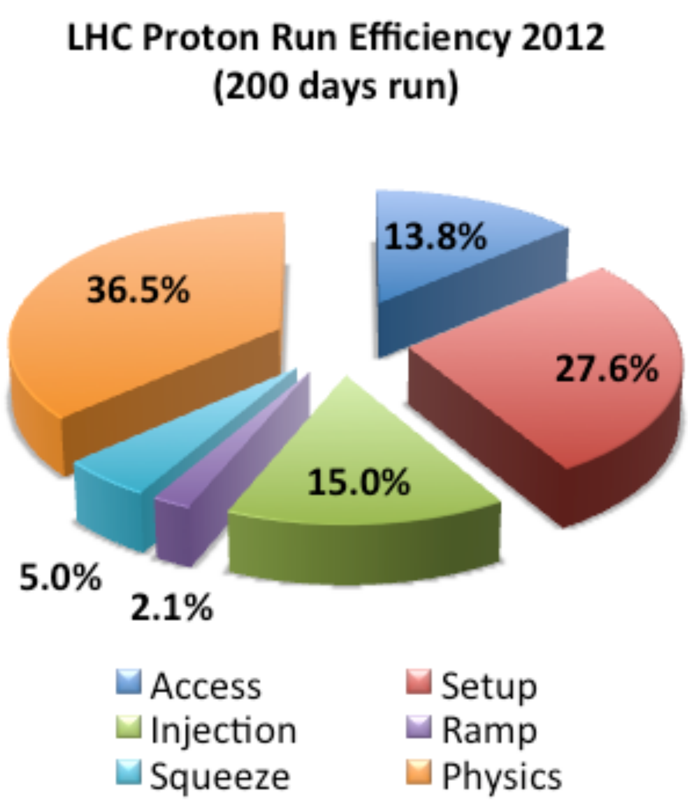


	Injection	Ramp	Squeeze & Adjust	Stable beams for physics	Ramp down & Prepare
LHC	8 - 30 min	25 min	20 min	0 – 30 hours	45 min
FCC-hh	**60 min (?)**	**30 – 40 min**	**30 min**	**0 – 15 h**	**50 – 60 min**
	Injectors cycling	dI/dt Magnets & Circuits Inductance of magnets Length of circuits		Beam life time & Luminosity burn-off Reliability of systems	Similar as for Ramp & Squeeze

The actual turn-around time for the FCC-hh not yet estimated

FCC-hh Operation: LHC as Example

- LHC in 2012 had a rather good beam availability, considering the machine complexity and the principles of operation



Power	Process	# days
Steady State 43%	Stable beams	36.5%
	Squeeze	5%
	Setting up Squeeze	1.5%
Dynamic 3%	Ramping	2%
	Setting up Ramp	1%
Low 19%	Injection	15%
	Setting up Injection	4%
Base 35%	Access	13.8%
	Setting up remainder	21.2%

165 days to be added (technical stops, Hardware and Beam Commissioning, Machine developments)

Different Types of Power requirement

- Steady State Power (43% of the time)
  - The power required when the FCC is running nominally in stable beams
- Dynamic Power (3% of the time)
  - The power required to bring the beam up to high energy, when all circuit are ramping (up & down)
  - Maximum at the end of the ramp up
- Base Power (35% of the time)
  - The power required when the FCC is in ‘standby mode’

- Installed Power
  - The power that can be drawn from the wall plug by all devices

Items (being) Included

- Magnet circuits
  - Cold: main dipoles, main quads, IP dipoles, IP quads, sextupoles, correctors, Septa
  - Warm: Collimation quadrupoles,...
  - (Water-cooled) DC cables
  - Power Converters
- RF acceleration system
- Cryogenic system
- Cooling & Ventilation
- Experiments
- General Services

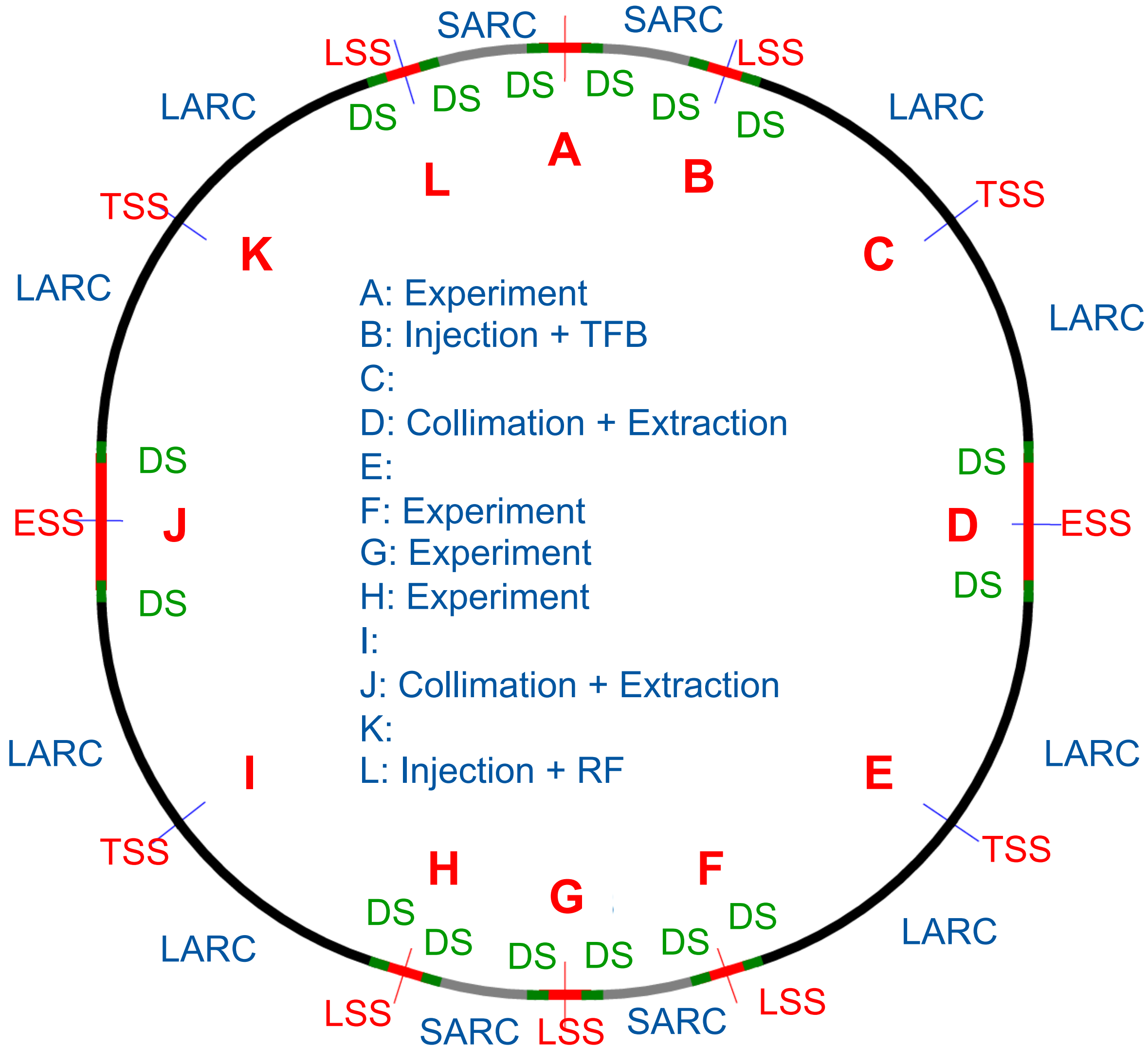
Magnet Circuits

- Scaling optics from LHC
  - The optic cell length for the FCC-hh is taken to be twice as long as LHC
  - Same dipole length as for the LHC
  - The arc quadrupole length is increased by a factor 2
  - The gradients, hence currents have been scaled accordingly

- Circuits are defined such that the stored energy is not excessive
  - If one dipole circuit for a long arc then 16.5 GJ stored energy.
  - By splitting the circuit in 4 reduced to 4 GJ
  - Still a factor 4 higher than for LHC with 1 GJ

Baseline Layout & LHC Scaling

	No.	Length [m]
LARC	8	7918
SARC	4	3210
DS	16	428
LSS	6	1498
ESS	2	4280



Baseline Layout & LHC Scaling

	No.	Length [m]	Cell length [m]	Number of Cells	Dipoles per Cell	Quads per Cell	Total Dipoles	Total Quads	Total Length [m]
LARC	8	7918	214	37	12	2	3552	592	63344
SARC	4	3210	214	15	12	2	720	120	12840
DS	16	428	214	2	9	2	288	64	6848
LSS	6	1498	214	7		2		84	8988
ESS	2	4280	214	20		2		80	8560
Total				**470**			**4560**	**940**	**100580**

Including also the other magnets such as IP dipoles, IP quadrupoles, correctors, injection and extractions septa,…

Preliminary Estimates for Magnet Circuits

Point	Straight Section	Dispersion Suppressor	Arcs	Power Conv.	Steady State Power [kW]	Wall Plug Power [kW] 85% eff.
A	LSSA-Expt	DSLA + DSRA	LA + AB	288	5564	6545
B	LSSB-Inj	DSLB + DSRC	BC	274	4492	5285
D	ESSD	DSLD + DSRD	CD + DE	538	21145	24876
F	LSSF-Expt	DSLF + DSRF	EF	293	5500	6471
G	LSSG-Expt	DSLG + DSRG	FG + GH	288	5564	6545
H	LSSH-Expt	DSLH + DSRH	HI	293	5500	6471
J	ESSJ	DSLJ + DSRJ	LI + JK	538	21145	24876
L	LSSL-Inj	DSLL + DSRL	KL	274	4492	5285
			Total	**2786**	**73401**	**86354**

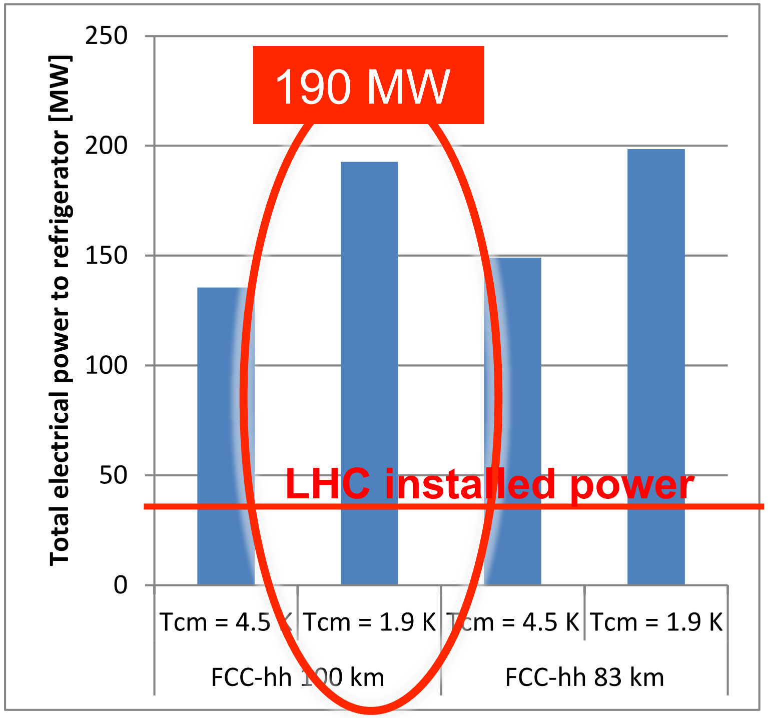
- Presently, no powering from the mid-Arc points C, E, I and K
- The Steady State wall plug power is 86 MW (43% of the time)
- The dynamic peak power is presently estimated at ~ 360 MW (3% of the time)

RF: A Rough Estimate

	LHC	FCC-hh	Unit
Frequency [MHz]	400.8	400.8	[MHz]
RF Voltage per beam	16	32	[MV]
Number of Cavities per beam	8	16	
RF Power per beam	4	8	[MW]
Installed Power per Cavity		1	[MW]
Cryo loss per cavity		15	[kW]
Cryo loss RF cavities		0.5	[MW]
Total Installed RF Power		**32**	**[MW]**

Cryogenics

- Choices to be made and investigated:
  - Temperature of cold mass: 4.5 K or 1.9 K ?
  - Beam screen temp 40 – 60 K
  - Non-conventional refrigeration (He-Ne mix) ?
- Challenges:
  - Long FCC sectors ~ 8 Km
  - Cryo plant capacity



Not taking into account cryo-distribution and operation overhead

Cooling & Ventilation

- Cooling:
  - Most of the power dissipation in warm magnets, cable and power converters, cryogenics, RF and experiments will have to be taken out by the cooling system.
  - LHC: 95 MW goes in cooling water for 20 MW installed.
  - FCC-hh: 338 MW goes in cooling water → **71 MW**

- Ventilation
  - Mainly to refresh tunnel air
  - LHC ventilation consumption was measured to be 14 MW on average
  - Presently assumed 4 x LHC → **56 MW**

Experiments & General Services

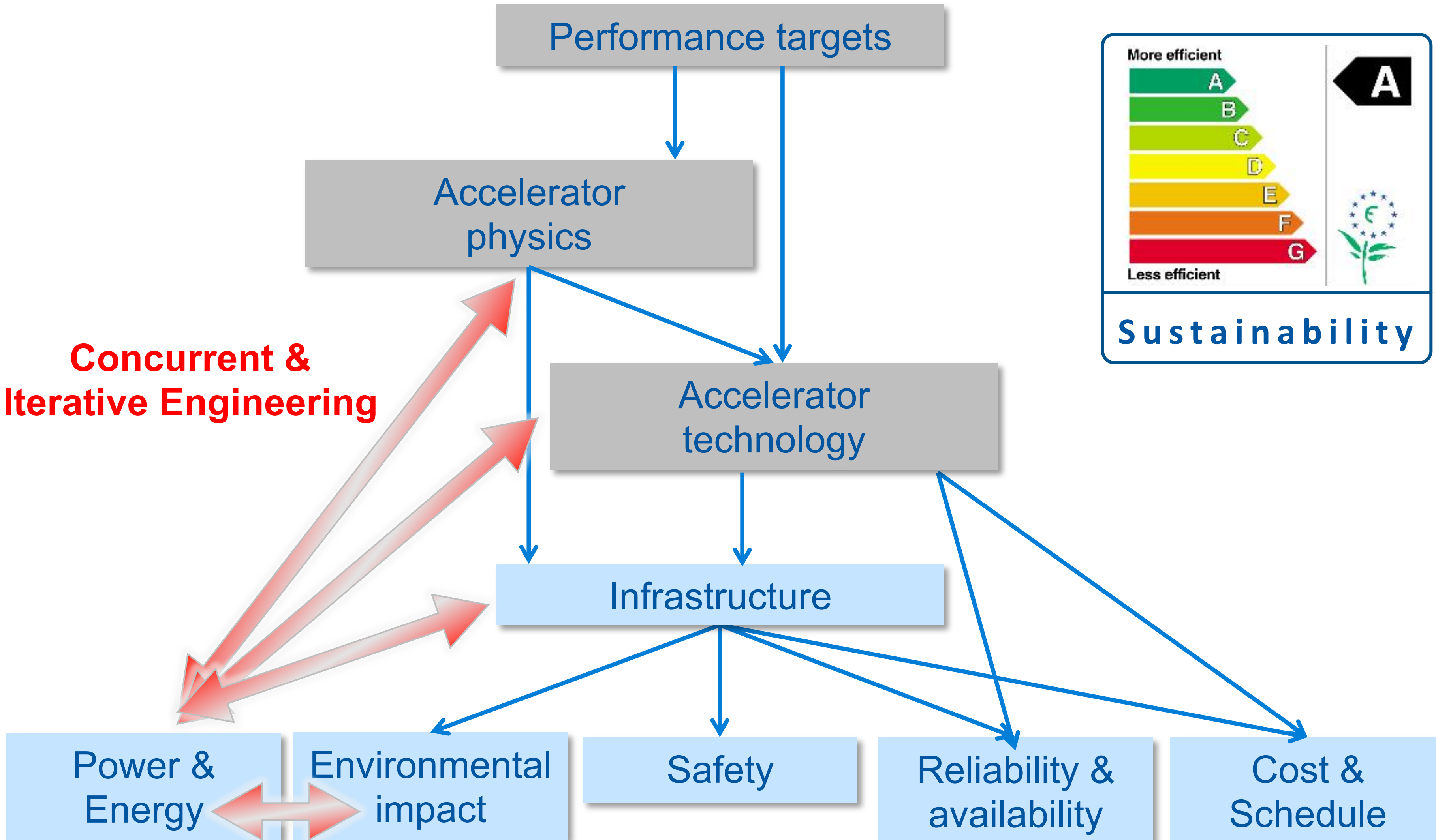
- Experiments:
  - LHC design → 22 MW
  - Experiment size does not scale fully with energy, but also depends on detector technology advances
  - Rough estimate for FCC-hh → **30 MW**

- General Services:
  - Low power distribution
  - Alarm system, vacuum pumping, tunnel lighting, …
  - At LHC this about 13 MW
  - Simple size scaling: 4 x LHC → **52 MW**

Summary Table

Items	LHC Steady State Power [MW]	FCC-hh Steady State Power [MW]	Comment
Magnet Circuits	20	86.4	Wall-plug, worked out estimate
RF	18	32	Rough estimate
Cryogenics	32	190	To be revisited/refined
Cooling	20	71	Power in cooling water
Ventilation	14	56	Rough, 4 x LHC
Other Machine	2.5	10	Rough, 4 x LHC
General services	13	52	Rough, 4 x LHC
Experiments	22	30	(10 + 10 + 5 + 5)
Total	**147.5**	**527.4**	

Energy Efficiency



Courtesy of Ph. Lebrun

Energy Efficiency

- Keep energy efficiency in mind during the design stage
  - Nice example: progress made for Klystron efficiency

- Evaluate choices made in a machine context and not in a system basis

- Balance initial investment against operating cost
  - A non-energy efficient equipment may be cheap to construct, but will be expensive in the long term

- Can we recuperate energy and re-use it ?

Next Steps

Requires input from other WPs

- Estimation based on actual lattice and magnet design
  - Decide on actual circuit size (stored energy and dI/dt)
  - Estimate DC –cable length (resistive losses)
  - Establish peak power estimates
- Refine the RF needs
- Iterate on Cryogenics, Cooling & Ventilation
- Get estimates from Experiments
- Derive required installed power from estimates together with the geographical distribution
- How much of the consumed power is dissipated in air or water water in view of recuperating energy
- Define operational scenario with injection, ramp, collision and turn-around time to estimate the cost to run the FCC-hh
- Apply a similar approach to FCC-ee

Conclusion

- A preliminary rough estimate for the FCC-hh steady state power is available from ‘intelligent’ scaling with LHC as reference
  - Much work is still ahead
  - Refining the estimate is an iterative process and requires more and more precise data
  - Progress will depend on availability of solid data
- Energy Efficiency and perhaps energy recuperation are important topics to address with the aim to keep operation cost within reasonable limits and avoid wasting energy
  - Iterative Engineering with Energy Efficiency in mind

FCC

hh ee he

Thank you for your attention...

Spare Slides

Magnetic Circuits & Power

Circuit type	Number of circuits	Nominal Current /A	Steady Voltage /V	Boost Voltage /V	Steady Power per circuit /kW	Peak Power per Circuit /kW	Total Steady Power /kW	Total Peak Power /kW
Inner Triplet Quads	16	17000	13	5	221	306	3536	4896
Main Dipoles	40	16300	10	400	163	6683	6520	267320
Main Quads	48	16000	13	20	208	528	9984	25344
DS IPQ	128	8000	6	2	48	64	6144	8192
IPD	12	8000	6	2	48	64	576	768
IPQ	204	8000	6	2	48	64	9792	13056
Injection Septum	2	8000	6	2	48	64	96	128
Extraction Septum	2	8000	6	2	48	64	96	128
IT Trims	16	2000	6	2	12	16	192	256
Spool Correctors	72	1600	8	2	12.8	16	922	1152
Lattice Correctors	256	1600	8	2	12.8	16	3277	4096
IT Optics Correctors	48	1600	8	8	12.8	25.6	614	1229
IT Orbit Correctors	24	1600	8	8	12.8	25.6	307	614
Warm orbit Correctors	108	600	70	5	42	45	4536	4860
IPQ Orbit Correctors	204	320	8	2	2.56	3.2	522	653
Warm Quads	54	200	2250	5	450	451	24300	24354
Orbit Correctors	1552	160	8	6	1.28	2.24	1987	3476
Total	**2786**						**73401**	**360522**

Courtesy of P. Collier

Assumed Main Dipole Parameters

	LHC	FCC-hh	Units
Aperture	50	50	[mm]
Magnetic Length	14.3	14.3	[m]
Current	11850 / 12480	16260	[A]
Field	8.33 /9	16	[T]
Stored Energy	6.93 / 8.11	35.75	[MJ]
Inductance	98.7 / …	271.7	[mH]
Weight	27.5	33.33	[Tonnes]

Assumed Main Quadrupoles Parameters

	LHC	FCC-hh	Units
Aperture	56	50	[mm]
Magnetic Length	3.1	6	[m]
Current	11870	16000	[A]
Field	223	450	[T/m]
Stored Energy	0.784	2.82	[MJ]
Inductance	11.4	22.2	[mH]
Weight	6.5	9.62	[Tonnes]