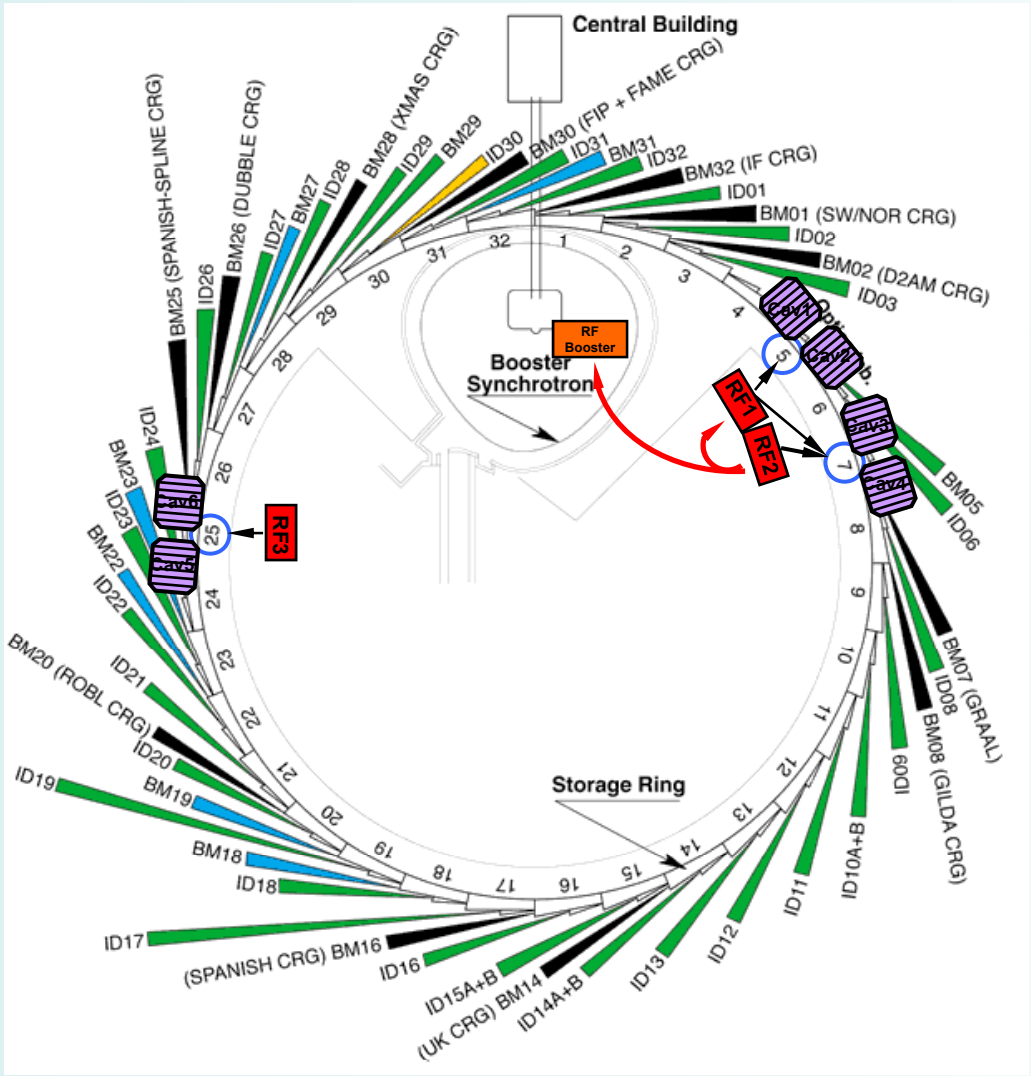
Outline

- Upgrade Program. **Why ? What is changing ?**
- Review of different Transmitter options.

  Klystron, IOT, Solid State Amplifier.
- Comparison of the options.
- Conclusion.

Upgrade Program



Increase photon flux and brilliance of electron beam

- **Increasing the beam current up to 300mA.**
- **Prepare for possible further increase to 500mA.**

Presently: **3 RF sections (cell 5-7-25)**
in each: 2 x 5 cell NC cavity (not HOM damped)
Total 6 cavities with 2 couplers each.

Present nominal RF configuration:

- **RF1 powers 4 cavities.**
- **RF3 powers 2 cavities.**

High level of Redundancy

- **RF2 possible backup for RF1 or RF booster.**
- **No Backup for RF3, but it is possible to deliver 200mA with 4 cavities.**

Towards 300mA

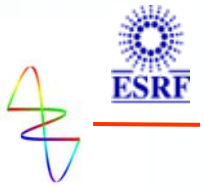
Project: **Replacement of each five cell cavity by 3 single cell NC cavity (HOM damped).**
Total 18 cavities with 1 coupler each.
For a better RF distribution and efficiency reasons, the analysis will be done on the basis of 16 cavities.

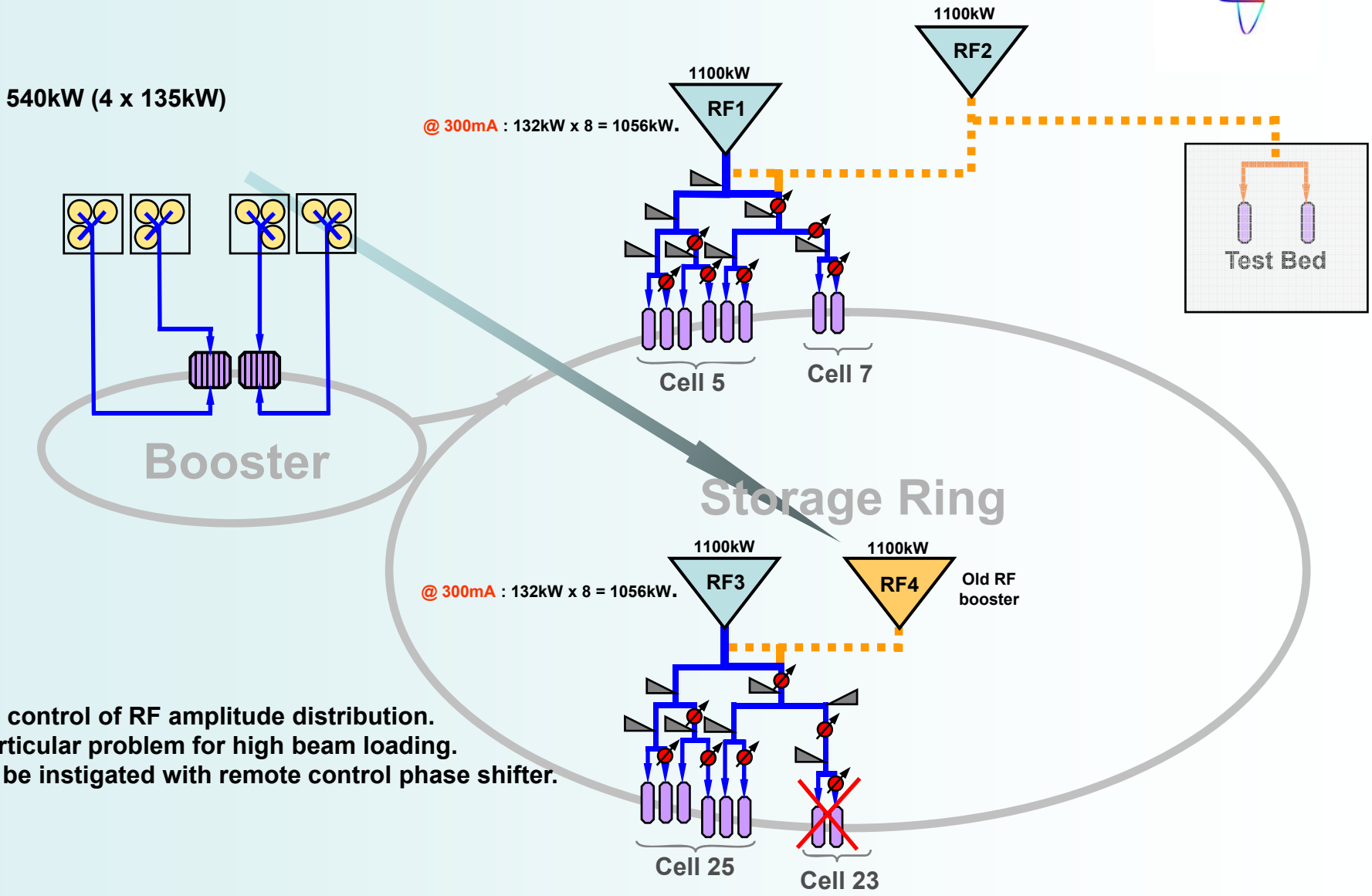
TOP UP with RF Booster

- ✓ Up to now, in few bunch mode, the vertical emittance is deliberately increased to keep an acceptable Lifetime
- ✓ Top-Up Injection mode will allow constant current for a poor Lifetime and back to low vertical emittance.
  Injection every 5 – 15 minutes, not below 5mn
- ✓ Keep RF ready to switch ON as fast as possible with minimum power consumption in stand-by state
- ✓ Solid State Amplifier is perfectly suitable for such a use :
  Only few seconds from OFF state to RF high
- ✓ Accelerating voltage = 7MVolt with 2 cavities
  Pcopper [460kW] + Pbeam @ 5mA [26kW]
  Ptotal= 486kW
  4 Solid State Amplifiers = 4 x 135kW = 540kW


SSA at SOLEIL

Transmitter System – Klystron 1100kW



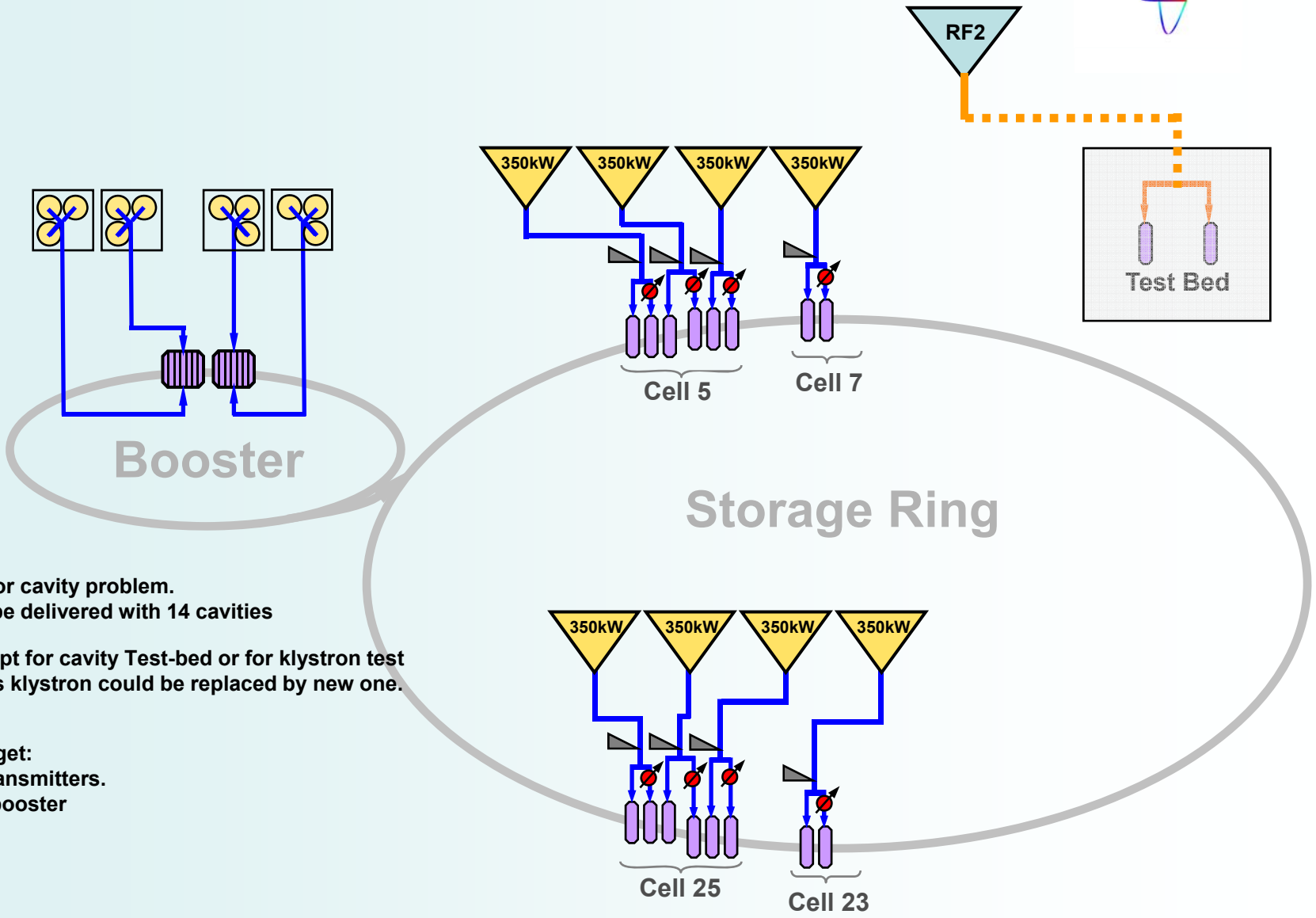


No control of RF amplitude distribution.
Particular problem for high beam loading.
To be instigated with remote control phase shifter.

Transmitter System – Klystron 1100kW

- ✓ **Only 2 Transmitters 1100kW Klystron could cope with the total power for 300mA required for 16 single cell cavities**
- ✓ **Very Low Cost - Re-use of former transmitters**
- ✓ **Very High Level of transmitter Redundancy - Not true for cavity**
- ✓ **No Modularity - Loss benefit of 16 cavities**
  If troubles with one cavity, not easy to back for normal operation
- ✓ **Problem of RF distribution – Need to insert High Power phase shifters**
- ✓ **The super Klystron TH2089 was optimized for steady operation on LEP accelerator. Difficult tuning for large dynamic range, prone to instabilities**
- ✓ **Only one Supplier for this type of Klystron.**
  TH2089 klystron Tube produced until 2020, and then ?
  We can predict the death of our RF system after 12 years from 01/01/2007

Transmitter System – Klystron 350kW



- Transmitter or cavity problem.
  - ⇨ 300mA can be delivered with 14 cavities
- Old RF2 if kept for cavity Test-bed or for klystron test
  Optionally its klystron could be replaced by new one.

⇨ Total to budget:
- ✓ 8 x 350kW transmitters.
- ✓ 4 x SSA for booster

Transmitter System – Klystron 350kW

- 8 Transmitters 350kW Klystron

✓ **Thales is motivated to develop a new 350kW Klystron based on the state of the art technology KGP family**
Vk/Ik = 58kV/10A Va=35kV 6 cavities

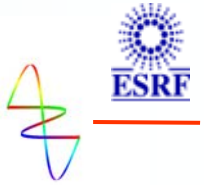
✓ **Expected Price 1.3M€ for a complete transmitter w/o circulator**
- **4 circulators can be re-used**

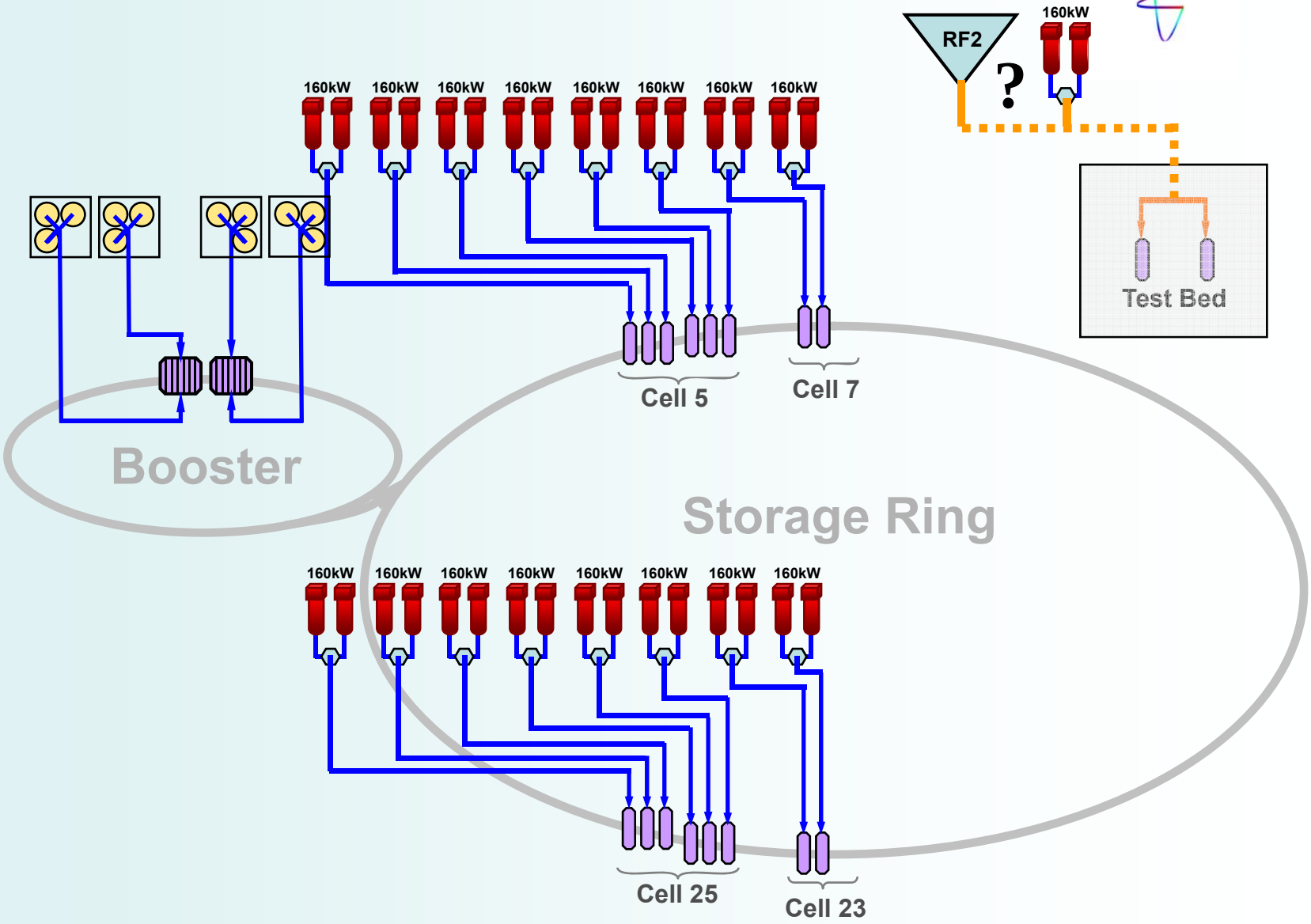
✓ **Stability hopefully improved with new design**

✓ **4 times more auxiliaries: expected decrease in MTBF**

✓ **Is the development of a new CW klystron still an up-to-date approach ?**

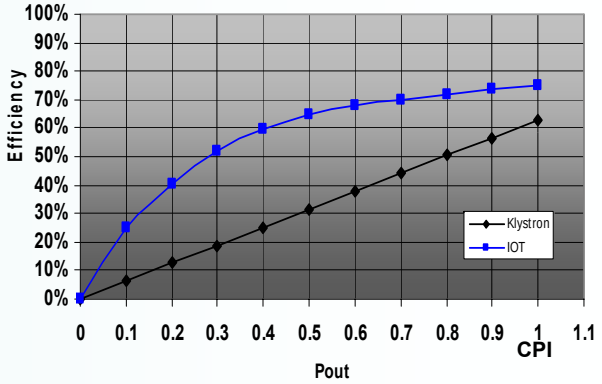
Transmitter System – IOTs 80kW





Transmitter System – IOTs 80kW

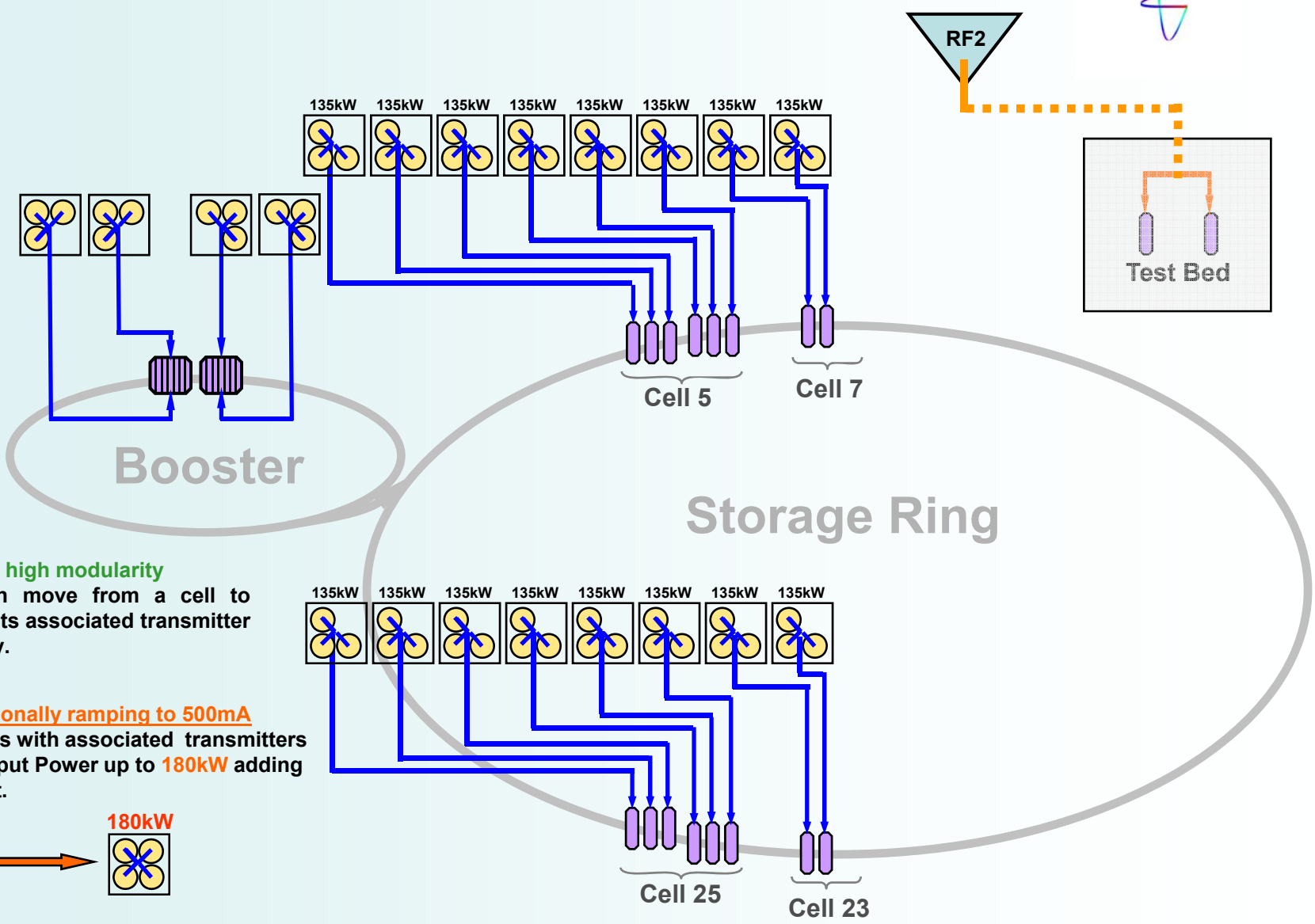
32 transmitters IOTs



- ✓ **Good Efficiency – doesn't drop so much when using down to 50% power**
- ✓ **Short device**
  - ⇨ **Short electrical length. Phase-Pushing factor reduced**
  - ⇨ **Much easier to replace compared to Klystron**
- ✓ **Need of circulators**
- ✓ **16 times more auxiliaries: expected bad impact on MTBF**
- ✓ **At the time being No 352MHz IOTs available on the Market**
  - **CPI manufactures an IOT for 250kW CW @ 267MHz (2KDW250PA)**
  - **350kW CW @ 352MHz ? Would be a good alternative to klystron**

CPI "Chalk River Tube"
250kW CW @ 267MHz

Transmitter System – SSA 135kW



Very high modularity

A cavity can move from a cell to another and its associated transmitter follows easily.

Additionally ramping to 500mA

- ✓ **Add 2 Cavities with associated transmitters**
- ✓ **Enhance Output Power up to 180kW adding a 4th element.**

Transmitter System – SSA 135kW

16 Solid State Amplifiers

- ✓ Interest from Industrial Companies to manufacture Solid State Amplifier 352MHz High Power
- ✓ Benefit of SOLEIL experience
- ✓ No need of High Power circulator
- ✓ 1 Solid State Amplifier per cavity = 16 SSA with a Total of 8640 transistors
- ✓ No need of High Power RF phase shifter and Magic Tee
- ✓ No High Voltage – Ancillaries reduced (1 DC power supply 500kVA / SSA)
  ⇨ No X-rays
- ✓ Control very much simplified
- ✓ Very easy maintenance but requires careful follow-up of spare parts
- ✓ Very High Level of Redundancy

Comparison – Storage Ring Upgrade

3.2M€ for Booster upgrade isn't considered in the Purchase Cost

300mA upgrade	Re-use of existing 1100kW klystron	Klystron 8 x 350kW	IOTs (combined by 2) 32 x 80kW	Solid State Amplifier 16 Amplifiers
Device Availability	Until 2020	To be developed Based on KGP family	To be developed	Yes
Redundancy	Transmitter Yes Cavity under conditions	Yes 300mA possible w/ 7 TX 14 Cav	Yes 300mA possible w/ 30 TX 15 Cav	Yes 300mA possible w/ 15 TX 15 Cav
Modularity	No	Yes	Very good	Excellent
Reliability / MTBF	Average	Probably lower	Probably lower	MTBF → ∞
Maintenance Troubleshooting	Not Easy	Not Easy	Easy	Very Easy
Stability	Bad	Unknown	Unknown	Good
Possible 500mA	Yes (if 200kW/cav OK)	Yes (cost 1.5 M€)	No (add 4 cav)	Yes (cost 6M€)
Efficiency (300mA)	60% P=95%	58% P=75%	72% P=80%	55% P=95%
Elec. cost 10 years 6500h/year @ 82€ / MWh	18.7 M€	19.4 M€	15.6 M€	20.4 M€
Purchase Cost	transfer of TRA0 1.0 M€	8 x 350kW 10.4 M€	32 x 80kW 14.4 M€	16 x 135kW 12.8 M€
Circulator/combiner		8-4 0.6 M€	16-4 1.0 M€	Included
Maintenance Cost Base 10 years @ 6500h/year	1.0 M€ (2 x 1 klys)	2.8 M€ (8 x 1 klys)	3.2 M€ (32 x 1 IOT)	0.5 M€ (transistors + PS DC/DC)
Possession Cost	20.7 M€	33.2 M€	34.2 M€	33.7 M€

Conclusion

ESRF transmitter upgrade, assuming installation of 16 single cell cavities

1. With existing 1.1MW transmitters
   - SSA for the booster to optimize frequent Top-Up
   - Moving the booster klystron close to SRRF3
   - Re-establish redundancy to safeguard operation at upgraded current of 300mA

   BUT:
   - Still problem of unstable behavior of high power klystrons
   - The only left supplier predicts a production until 2020, but then ?

2. Three options for full RF transmitter upgrade
   - No significant difference in cost
   - IOTs: highest efficiency but no IOT available @ 352 MHz

   BUT:
   - SSA = Our preferred solution
     - ⇨ High Modularity, high Redundancy and high MTBF
     - ⇨ Simple and easy to maintain
     - ⇨ No High Voltage, no X-Rays
     - ⇨ SSA has a potential for mass production and to become cheaper as compared to tube solutions
     - ⇨ New transistors under development with higher efficiency

Acknowledgements

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