Challenging brilliance and lifetime issues with increasing currents

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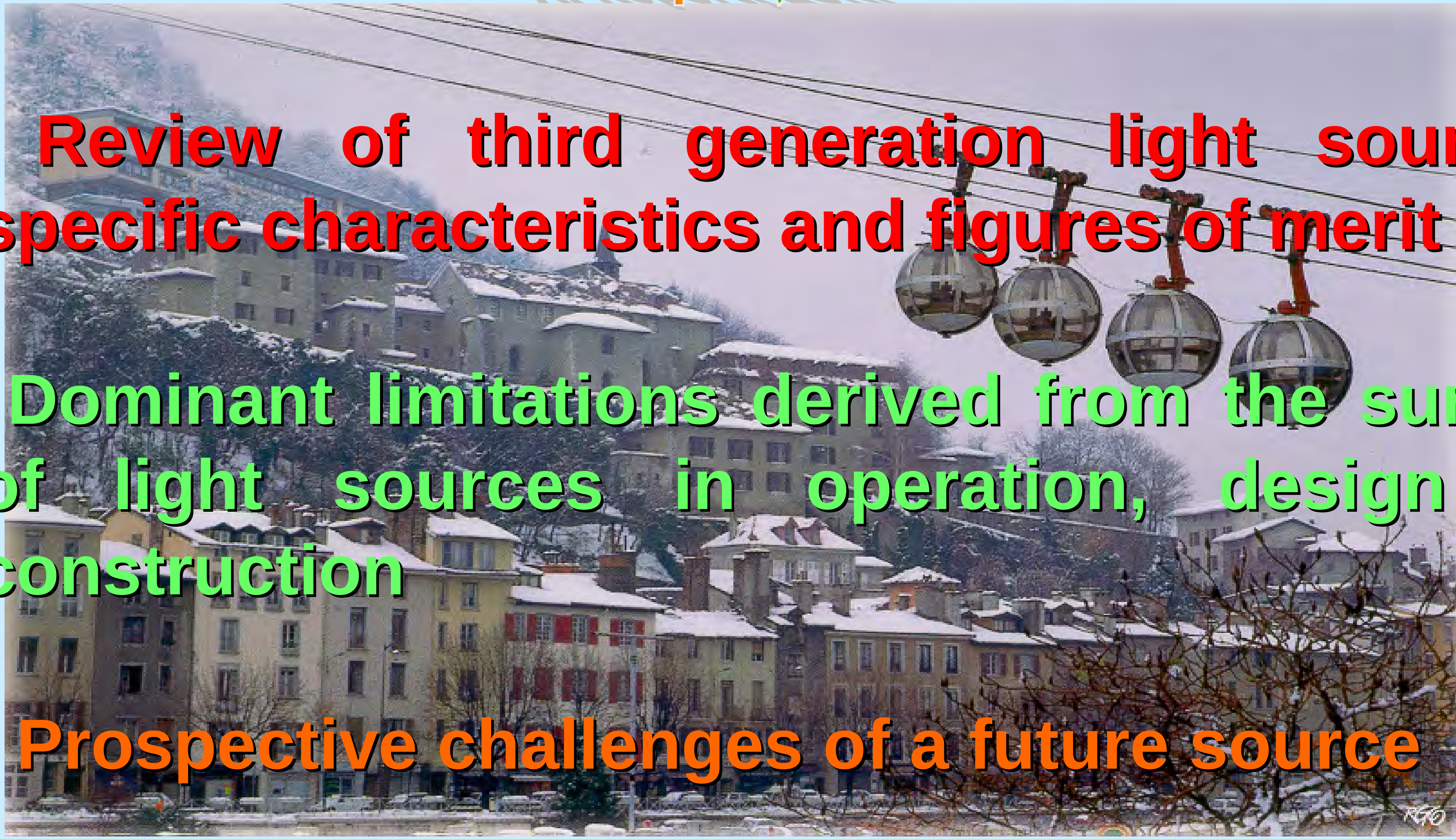


- Review of third generation light sources specific characteristics and figures of merit
- Dominant limitations derived from the survey of light sources in operation, design or construction
- Prospective challenges of a future source

Figures of merit

Third generation light sources are characterised by:

- low emittances
- high currents
- small ID gaps
- short bunches

High brilliance $$B \approx \frac{\text{photons/sec}}{\sigma_x \sigma'_x \sigma_z \sigma'_z} f(E, g, B)$$

and spectral flux per unit surface

Performance limitations

These requirements may induce a significant deterioration of the photon beam quality:

☛ **Short lifetimes due to the high bunch density lead to a reduced integrated brilliance and to a non-constant heat load**

☛ **Blowing-up the vertical emittance or lengthening the bunch to increase the lifetime spoils the brilliance**

Performance limitations (cont')

☞ Collective effects limit the current and /or blow-up the longitudinal and transverse bunch dimensions which in turn degrades the brilliance

☞ The trend towards lower gaps and the resulting vacuum chamber tapering contributes to the increase of the impedance and to the reduction of the current thresholds and associated brilliance

Light Sources survey

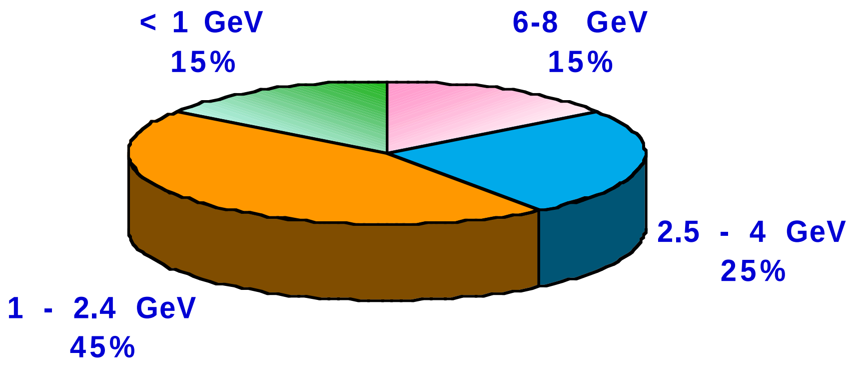
Drawn from the questionnaire sent to synchrotron radiation laboratories

21 competitors entered for the raffle

Somewhat arbitrary analysis

- 2nd and 3rd generation sources on an equal footing
- Some projects not included
- Different challenges for low and high energy machines

Energy range



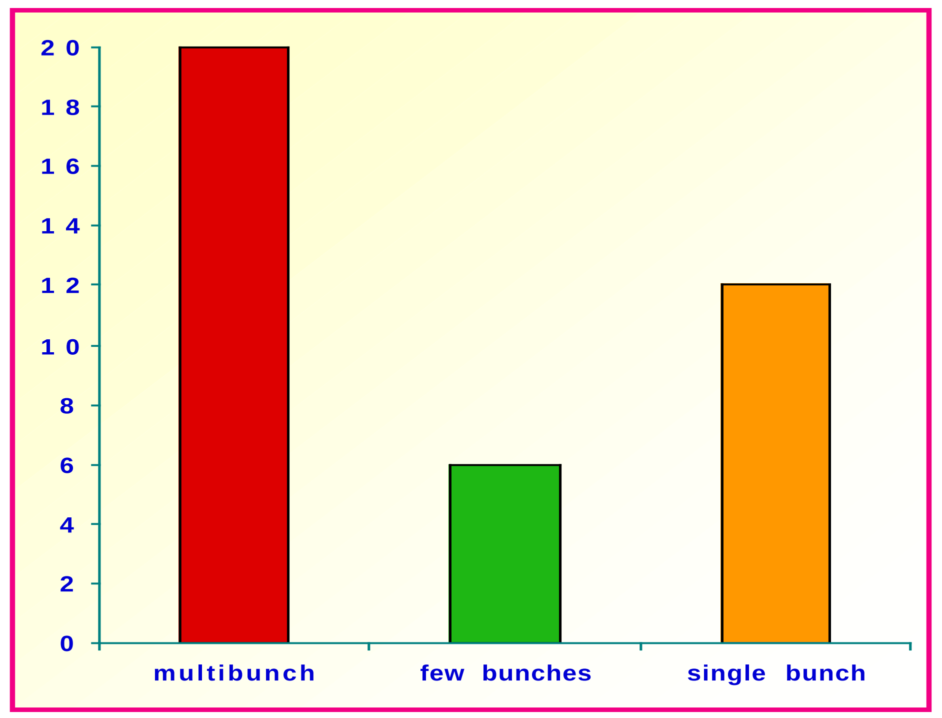
Lifetime issues are more critical for low energy machines

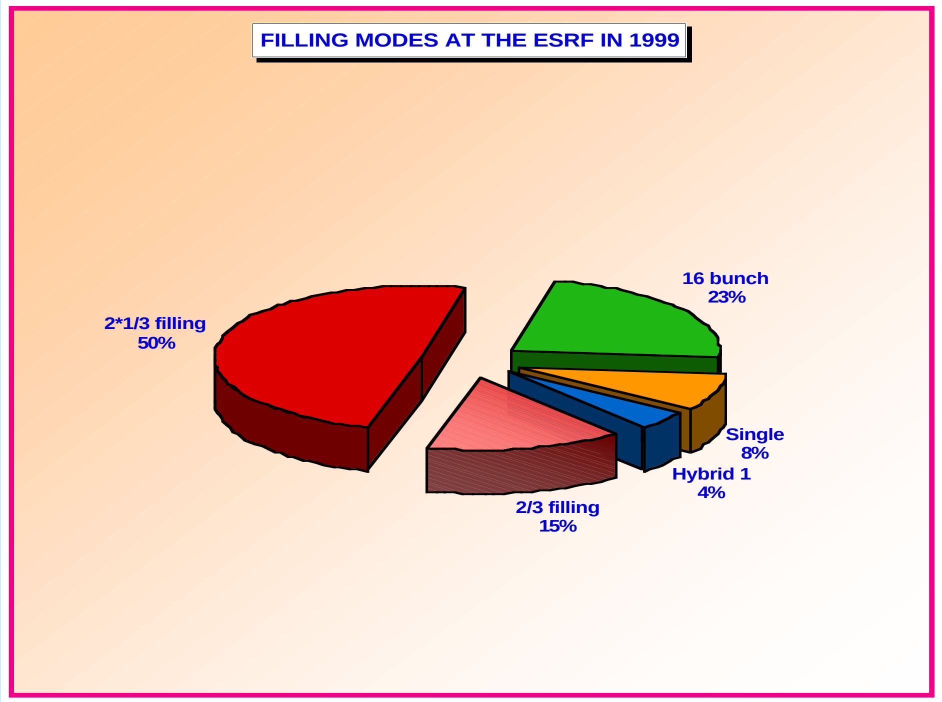
Gas scattering
Touschek scattering

Radiation power handling is an issue for high energy machines

Operating modes

High intensity multibunch and time structure modes
⇨ difficulties to simultaneously serve the different user communities





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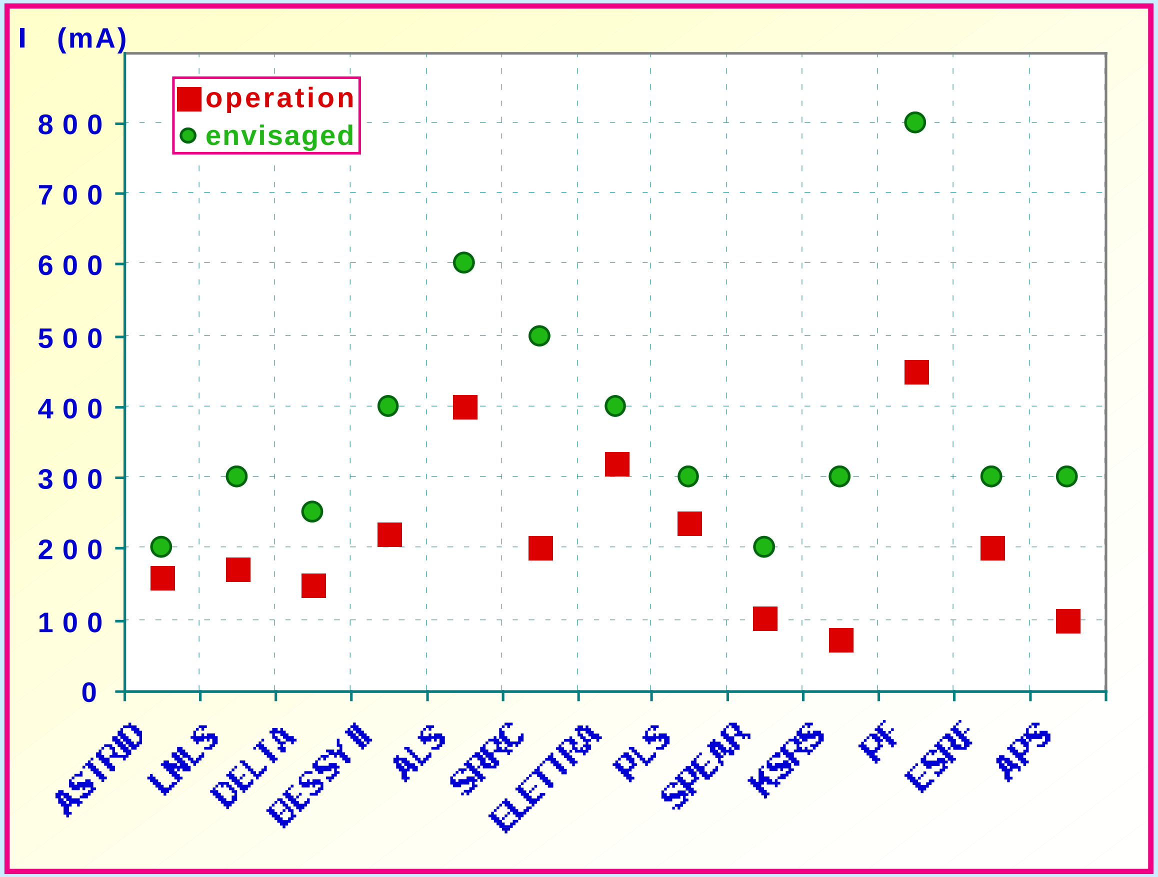
Intensity trend

Having reached their design goals, the majority of sources in operation plan an intensity increase in their R&D programme

Enhanced importance of collective effects



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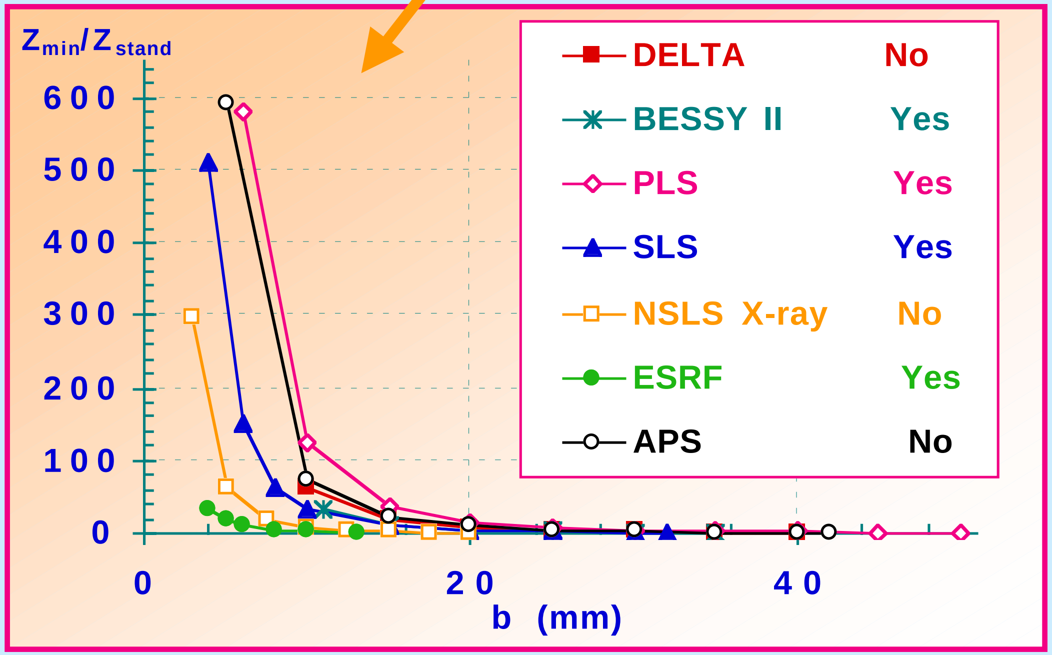
Coupled bunch instabilities

Increase of resistive wall impedance with small gap IDs

$$Z \propto \frac{1}{b^3}\,\delta\sqrt{\frac{\omega}{\omega_0}}$$

$$\delta = \text{skindepth} \propto \sqrt{\text{resistivity}}$$



Choice of vacuum vessel material

Stainless steel worse than Al or Co by a factor 5 - 7

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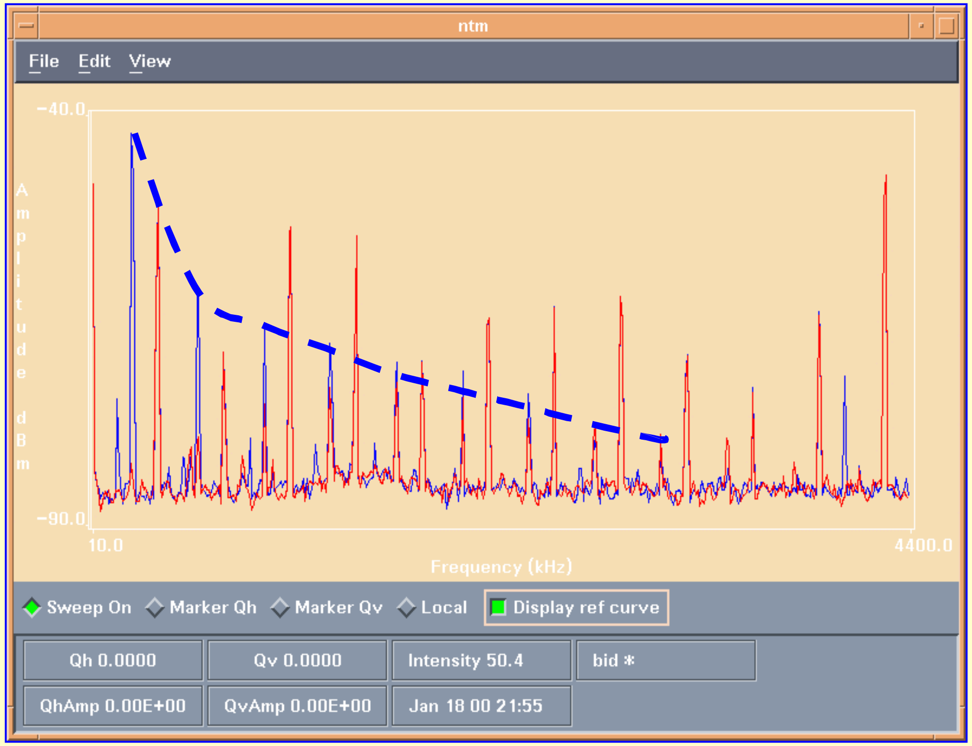
CBI: Resistive wall

Signature of RW instability



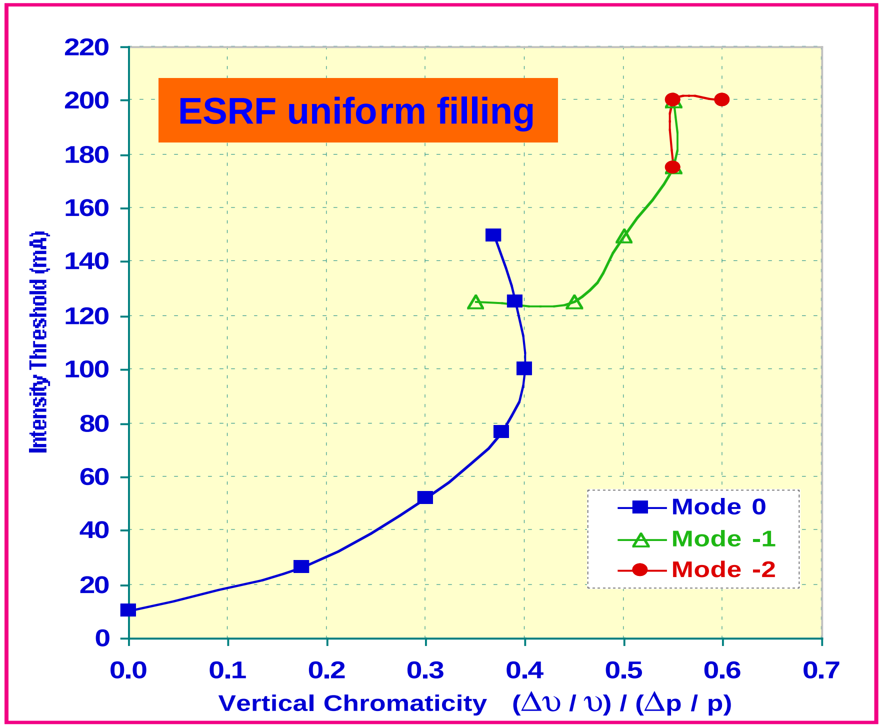
Cures

➢ Pushing the spectrum of the unstable mode towards > 0 frequency region by chromaticity over-compensation

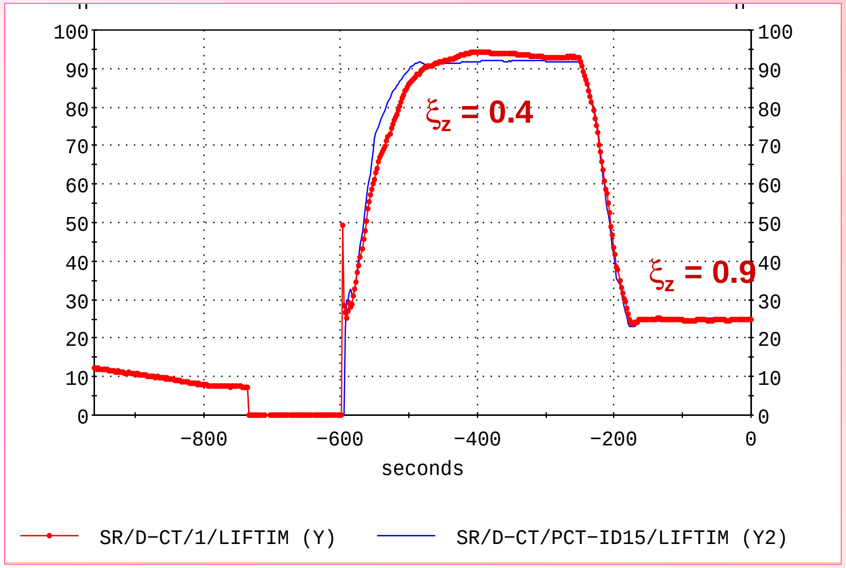
➢ Using a feedback system

CBI: Resistive wall (cont')

Small threshold currents
⇨ large chromaticities



⇨ lifetime reduction



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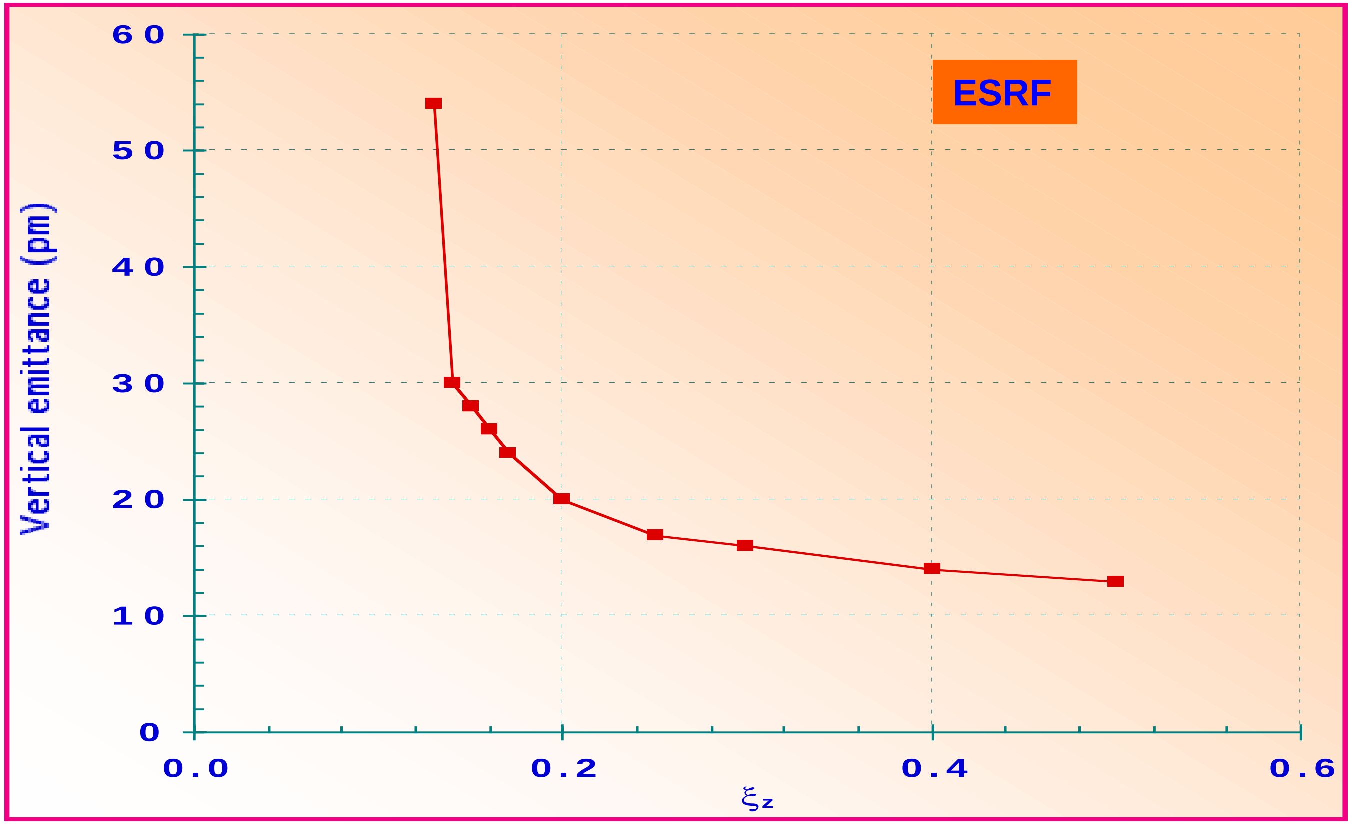
CBI: Resistive wall (cont')

⇨vertical emittance blow-up



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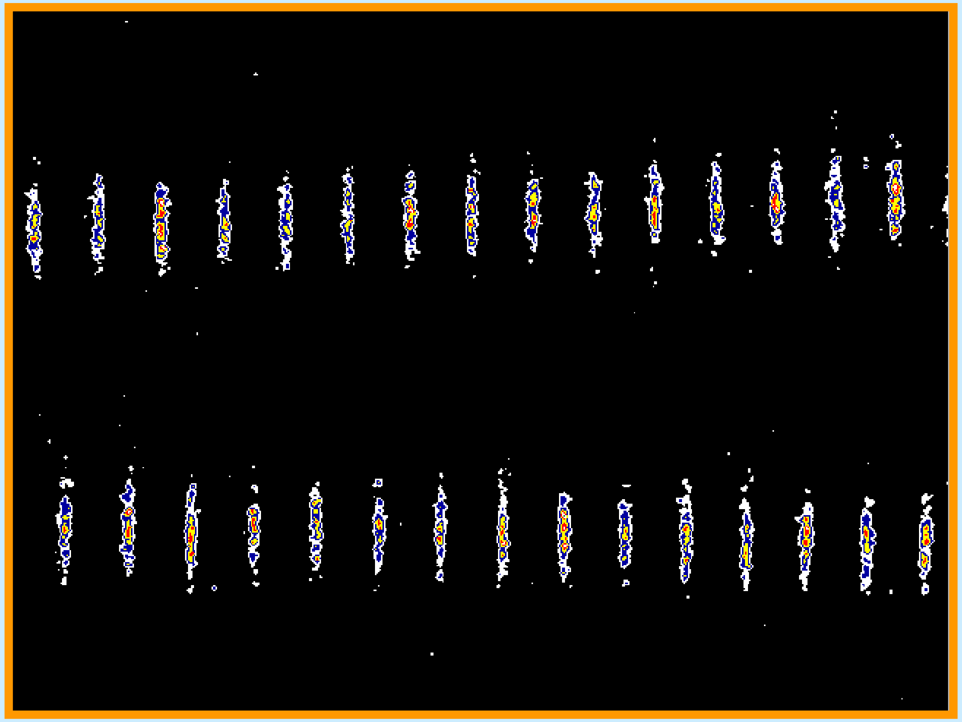
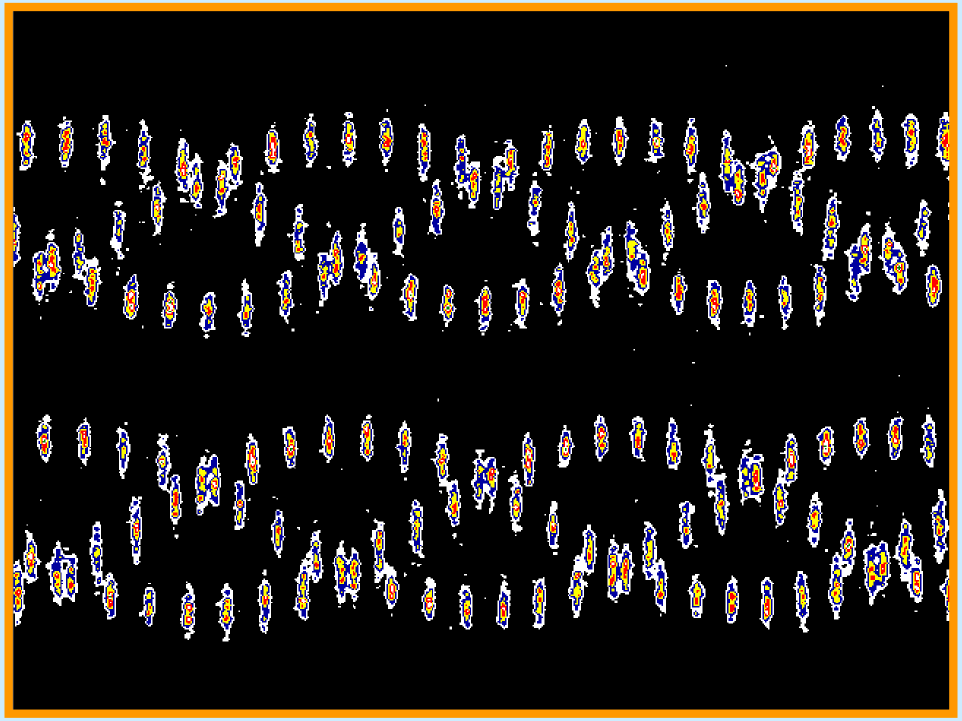
Coupled bunch instabilities (cont')

HOMs in RF cavities are the dominant source of instabilities for all machines





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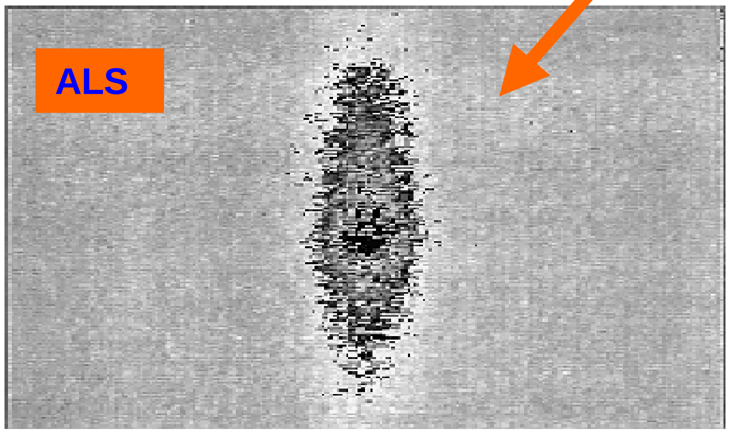
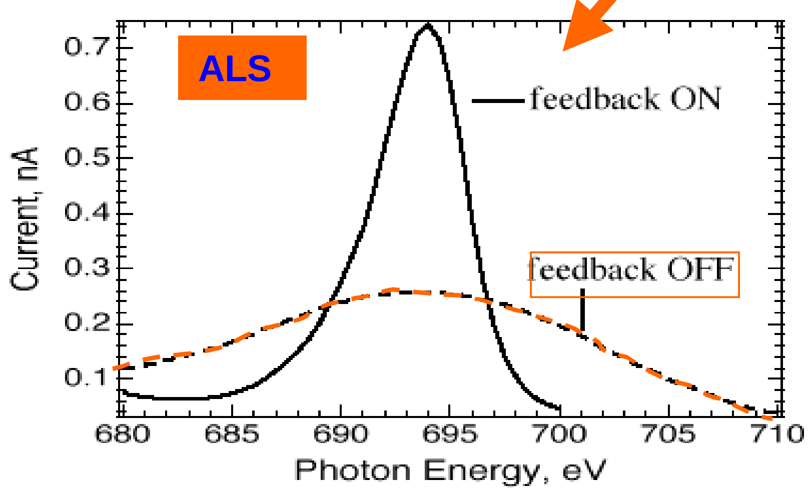
CBI: HOMs

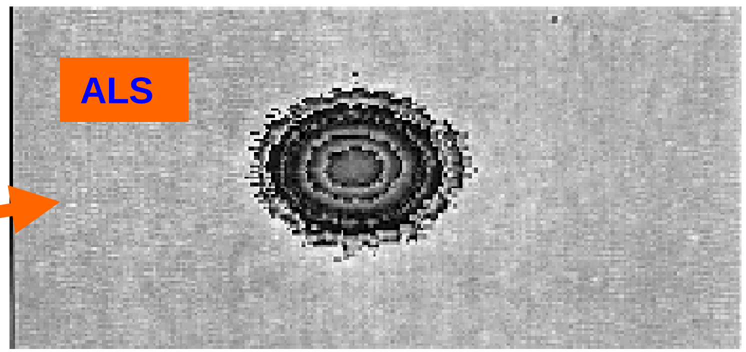
⇨Increase in transverse emittance and energy spread





Cures

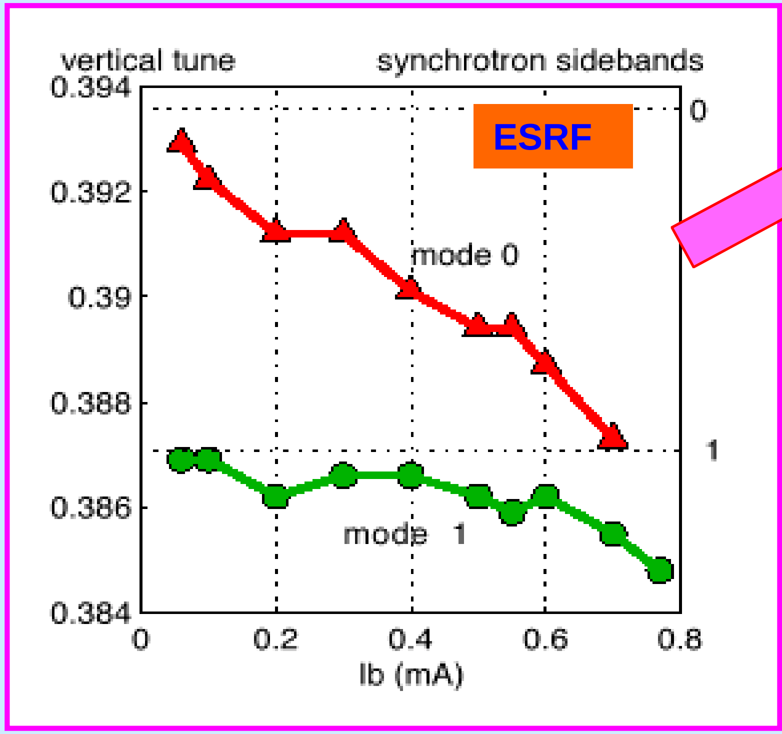
- ➢Temperature regulation(17)
- ➢Partial filling
- ➢HOM dampers (7)
- ➢Feedbacks (7)



ESRF

Single bunch issues

Reduction of the threshold current due to the occurrence of mode merging at low chromaticity



Increased chromaticity

↓

Dynamic acceptance and lifetime reduction

Small gap vacuum vessels lead to a decrease of the threshold

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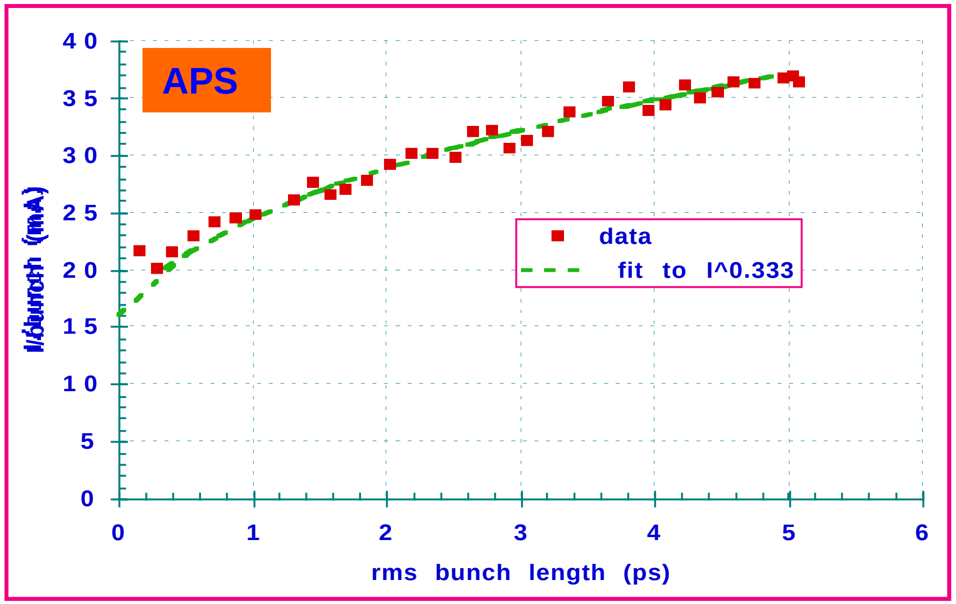
Single bunch issues (cont')

Difficulties in achieving short bunches

Bunch lengthening with increasing current



Independence of bunch length on α and E at large currents

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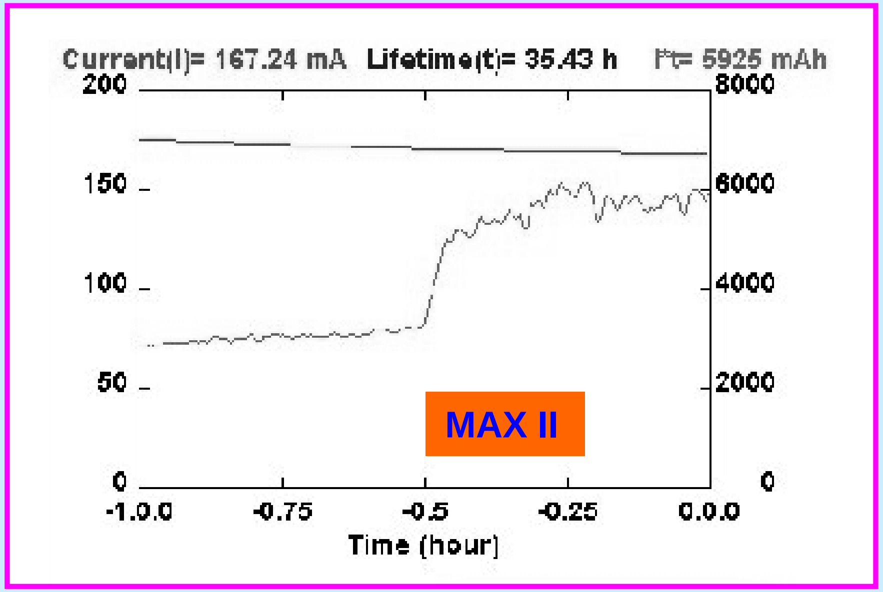
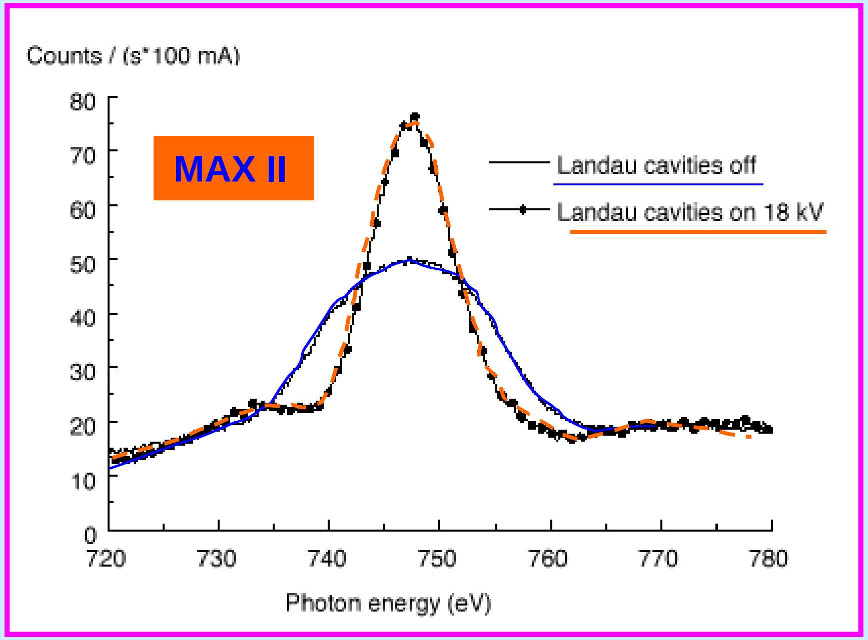
Harmonic cavities

More and more popular tool in low and medium energy machines to extend beam lifetime

Reducing the peak charge density by lengthening the bunch



Landau damping of CBI



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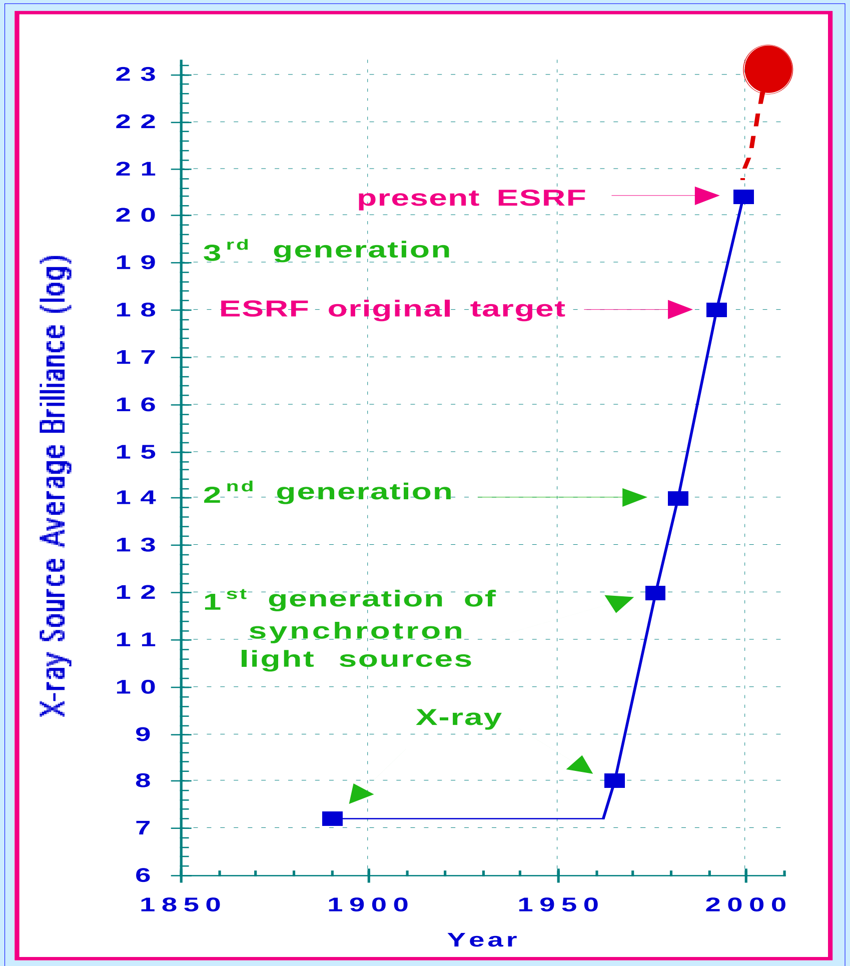
Challenges for future machines



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Still room for brilliance increase

Higher currents

Lower gaps

Challenges for future machines (cont')

Higher currents and lower gaps **0.5-1 A , 3-4 mm ?**

- **Mastering beam instabilities**
  - **HOM free cavity: validation of existing SC designs**
  - **Minimisation of impedance**
    - **Vacuum chamber material and fabrication, in-vacuum**
    - **Modelling of components, tapering of ID vessels**

- **Maintaining beam quality**
  - **Long lifetimes** — **top-up injection**
  - **Beam sizes** — **blow-up due to instabilities**
  - **Power handling** — **absorbers, stops, pumping**