LHC入射器アップグレードのためのPSB空洞とダンパー空洞の国際共同研究
INTERNATIONAL COLLABORATION ON CERN PSB RF UPGRADE AND PS DAMPER CAVITY FOR LHC INJECTOR UPGRADE

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10 PSB cavities

PS Damper cavities

アウトライン-RF Collaboration for LHC Injector Upgrade

目的

- **PSB（PSブースター） RF systemsの更新/アップグレード**
  - possibly using wideband, multi-harmonic, solid-state driven Magnetic Ally-FT3L loaded cavities
- **PSの縦方向カップルドバンチ不安定性のダンパー空洞の開発**

核となる技術:

- **Wideband Cavity using Magnetic Alloy,Finemet-FT3L**
- **Solid State Amplifiers**

Collaboration 内容

- PSB 空洞の**cavity-beam interactions**
  J-PARC MR でのduring LS1 期間中のビーム試験、PSBでの試験。
- 半導体アンプの耐放射線性試験
- **CERN PS用longitudinal damper**
- feed-forward **beam loading 補償**

RF Collaboration for LHC Injector Upgrade

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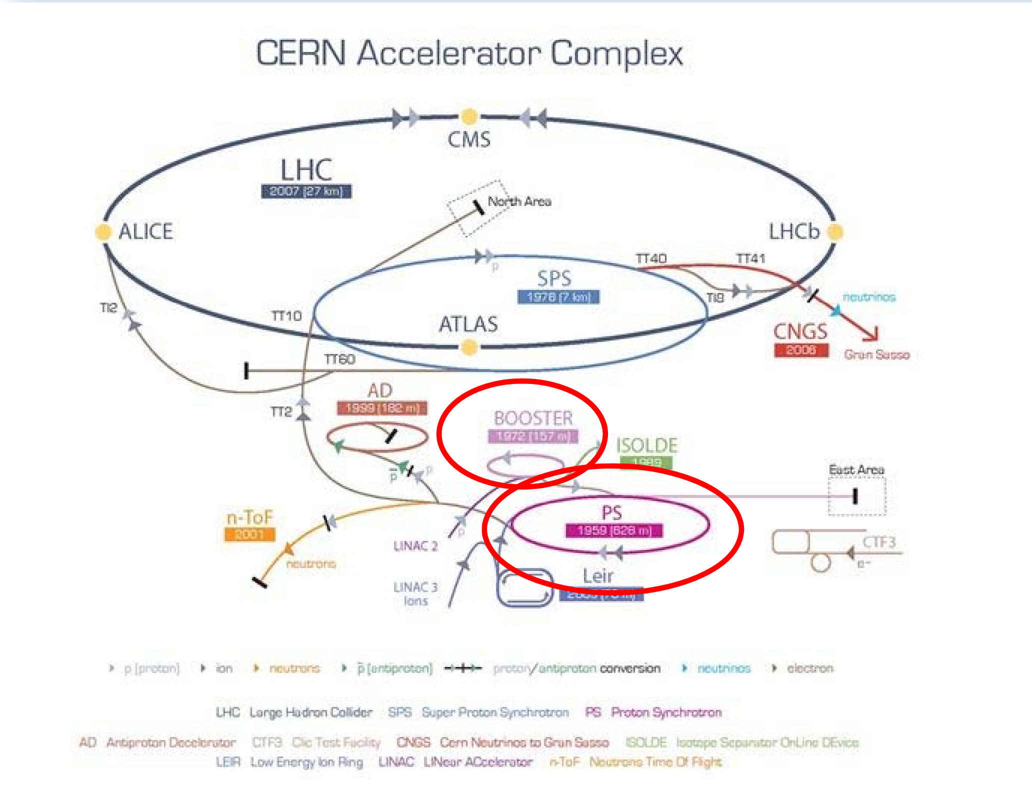


oy,Finemet-FT3L

eam interactions

plifier

per for the CERN PS

led bunch instability

orward beam compensation

– J-PARC wideband cavities handles 1E14 ppp in MR with Feed Forward compensation in LS1

J-PARCのMagnetic Alloy 空洞

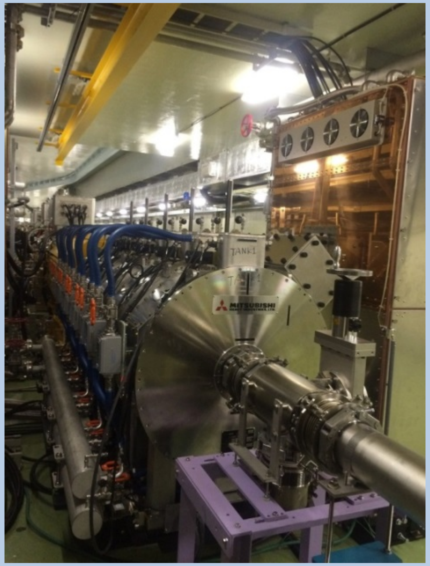
J-PARCでは金属磁性体空洞がRCSとMRの両者で使われている

- 高勾配->

  コンパクトな3 GeV RCSの実現

  FT3L空洞によるMR高繰り返し (2.48 sec-> faster than 1.3sec cycle !)
- 広帯域 -> J-PARC RCSでの2次高調波混合

  大強度ビームの安定した加速

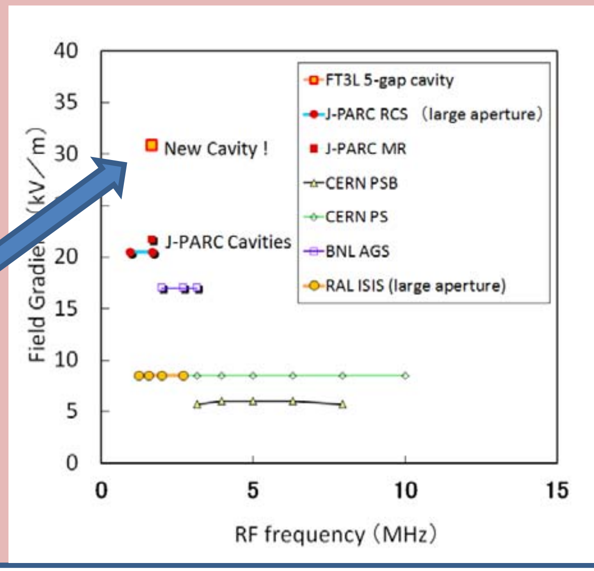


New FT3L cavity
In J-PARC MR
（installed in 2014）

テストベンチで32 kV/m を実現（New Record!）

この夏に更に4台入れ替え

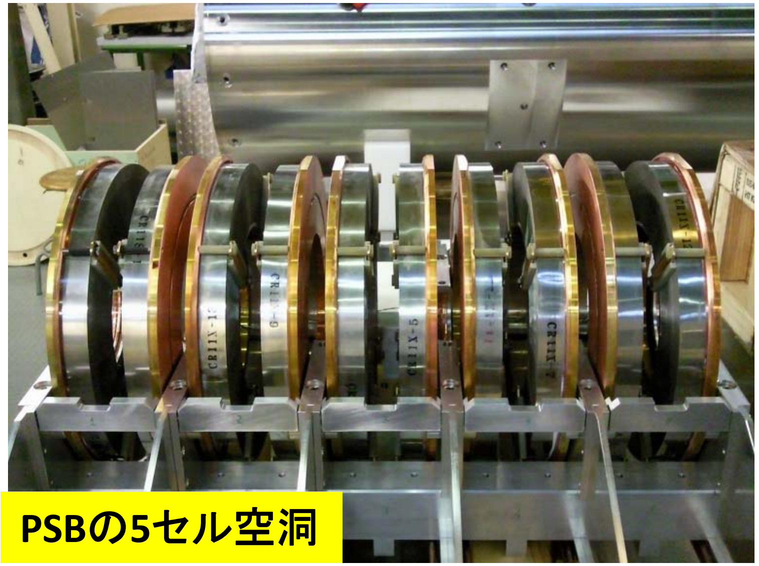
cavities of proton rings

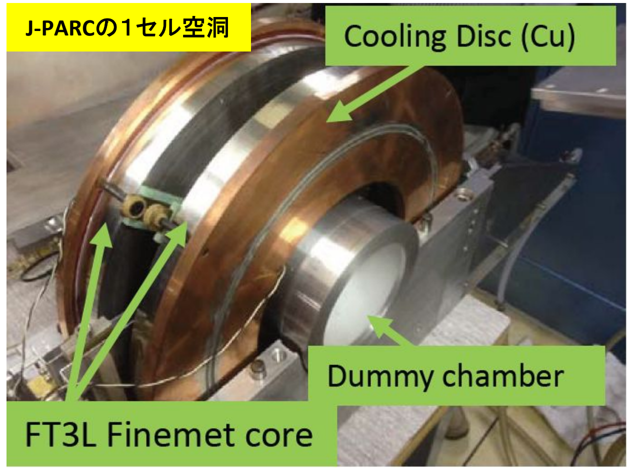


PSB/PSのMagnetic Alloy 空洞

金属磁性体空洞

- 高勾配->
  - PSB空洞の置き換え
  - PSののダンパー空洞
- 広帯域 ->
  - PSB : dual harmonic acceleration
  - PS : Multi-mode damper cavity。
- 安定した impedance
  - 半導体アンプで駆動
- 多数の空洞セル (24-36 cell / PSB)
  - Down timeの低減
- コスト: フェライトバイアス電源, 真空管, 陽極電源の更新が不要





RF Collaboration for LHC Injector Upgrade

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- **Consolidation/upgrade of the PSB RF systems** possibly using wideband, multi-harmonic, solid-state driven RF cavities
- Development and installation of **a longitudinal damper in the PS**

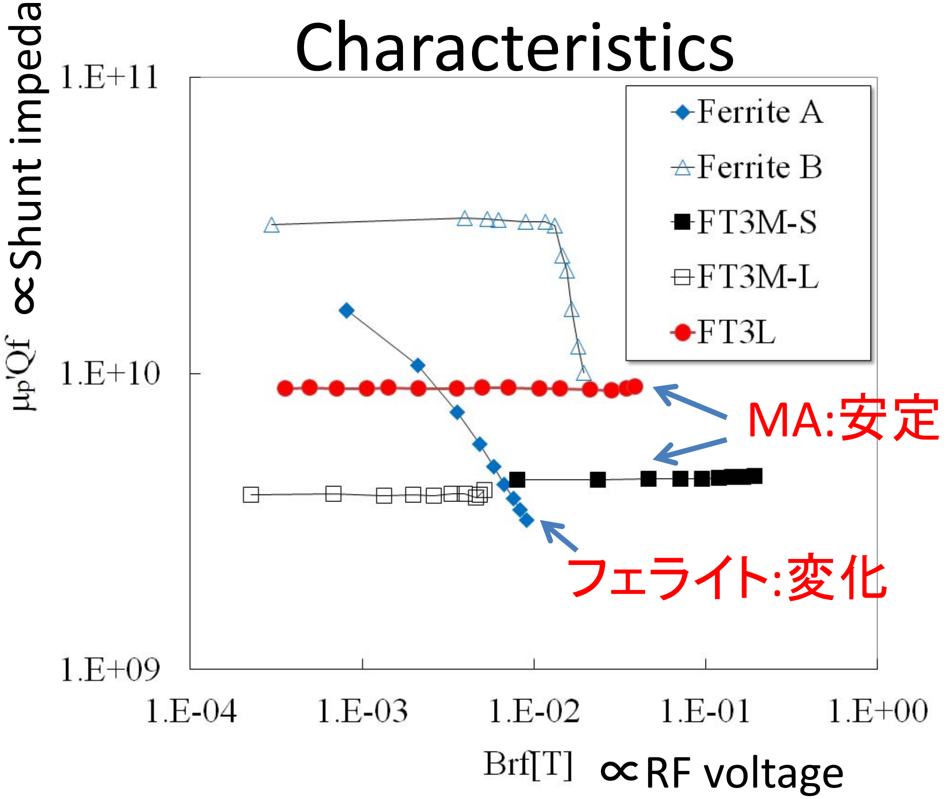
核となる技術:

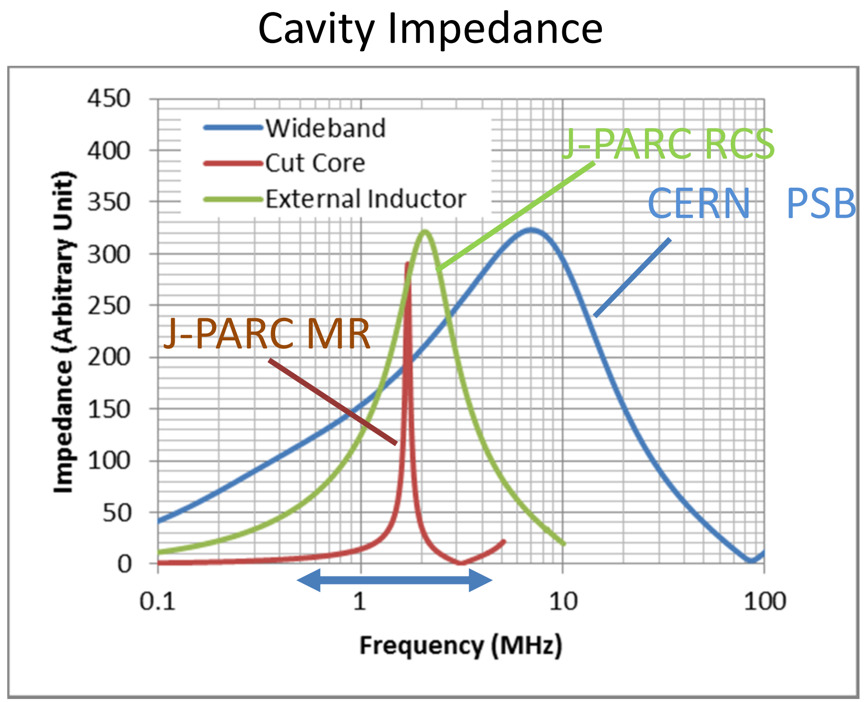
- **Wideband Cavity using Magnetic Alloy,Finemet-FT3L**
- **Solid State Amplifiers**

Collaboration activities

- Studies on the PSB multi-gap wideband **cavity-beam interactions**
  - Beam Studies at J-PARC MR during LS1 & PSB
- Study **radiation damage on solid-state RF amplifier**
  - Radiation damage test at J-PARC MR
- Study, design and prototype **a longitudinal damper for the CERN PS**
  - Wideband cavity system to damp the longitudinal coupled bunch instability
- Collaboration on the conceptual design of feed-forward **beam compensation schemes** for FINEMET® cavities
  - J-PARC wideband cavities handles 1E14 ppp in MR with Feed Forward compensation in LS1

Magnetic Alloy空洞





MA Cavity: V=Z(f) x I_{RF} Simple！

Ferrite cavity: V=Z(f, ferrite bias, temperature, B_{RF},) x I_{RF}

Existing RF systems in the PSB

Three systems are presently installed in the machine:

基本波

C02

- Frequency range — 0.6 (*1.0) – 1.8 MHz
- Gap Voltage — 8 kV
- Installed in sections — 7L1 and 10L1

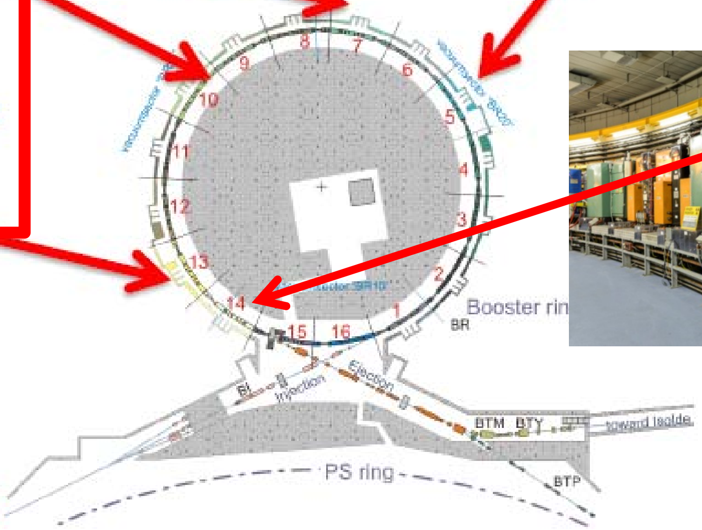
C16

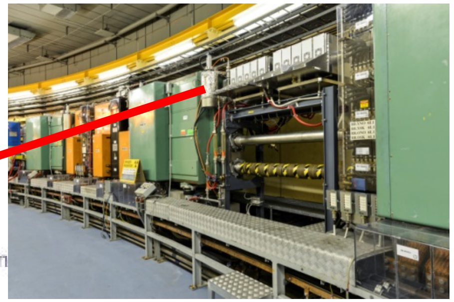
- Frequency range — 6.0 – 16 MHz
- Gap Voltage — 6 kV
- Installed in section — 5L1

二次高調波

C04

- Frequency range — 1.2 (*2.0) – 3.8 MHz
- Gap Voltage — 8 kV
- Installed in section — 13L1





Finemet cavities may (will) work as C02 & C04 systems

** Frequency with injection from LINAC4*

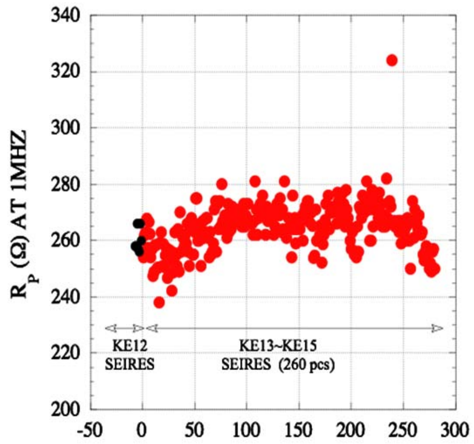
M. Poluzzi @ Finemet review

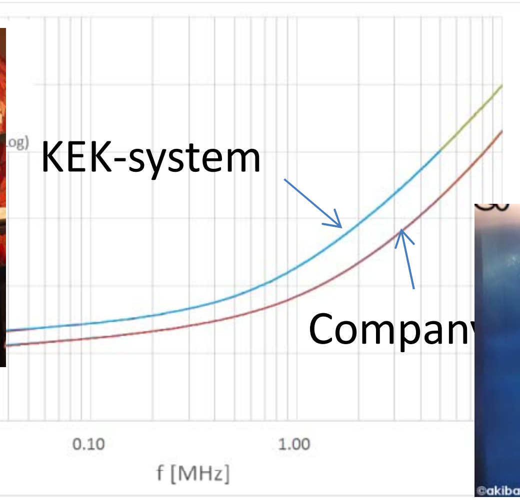
Magnetic Alloyの量産

- J-PARCの磁場中熱処理炉は順調に稼働。280 枚のFT3Lコアを1.5 年で製造。
- J-PARC MR の製造は終了
- オーブンのオーバーホールも終了
- コアの製造能力も実証。製造結果も良好。

J-PARCの磁場中熱処理炉により性能の向上

Magnetic annealing oven for nano-crystallization



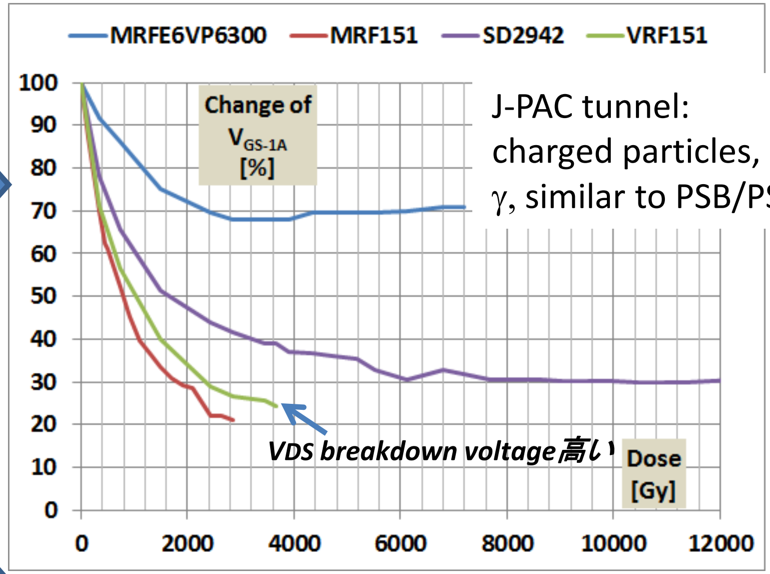


KEK-made cores will reduce temperature of cavity core.

半導体アンプ

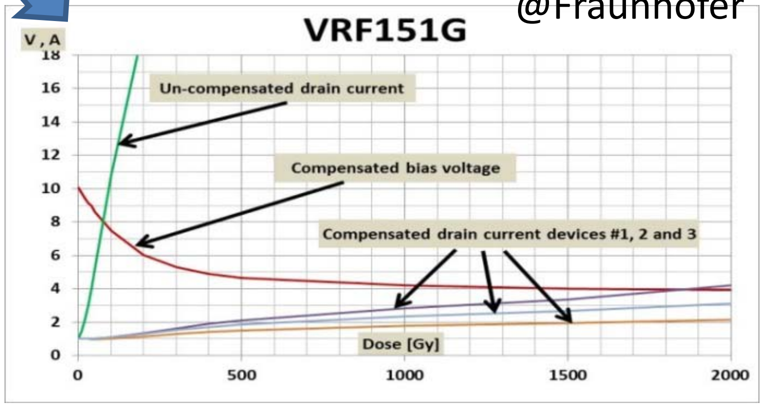
J-PARC

- 放射線の影響
  - Tests at J-PARC & Fraunhofer
  - FETの選択（2kGy以上、耐電圧）
  - Compensation of radiation
- 信頼性向上
  - アンプの改良(冷却系,コネクター,,)
  - PS/PSBアンプの仕様の確定



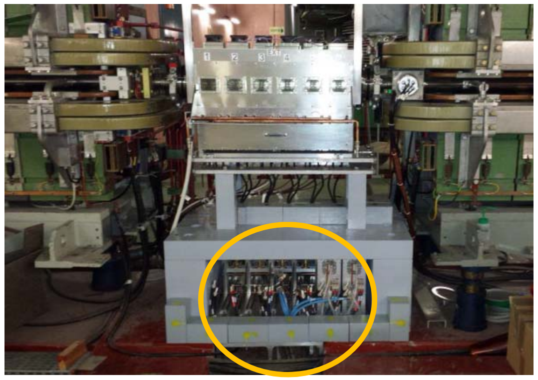
J-PAC tunnel: charged particles, n, γ, similar to PSB/PS

Compensation of radiation effect @Fraunhofer



PSB RF section: 1- 40 Gy/yr

KEKで2台PS用のアンプを製造.



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Core Technology :

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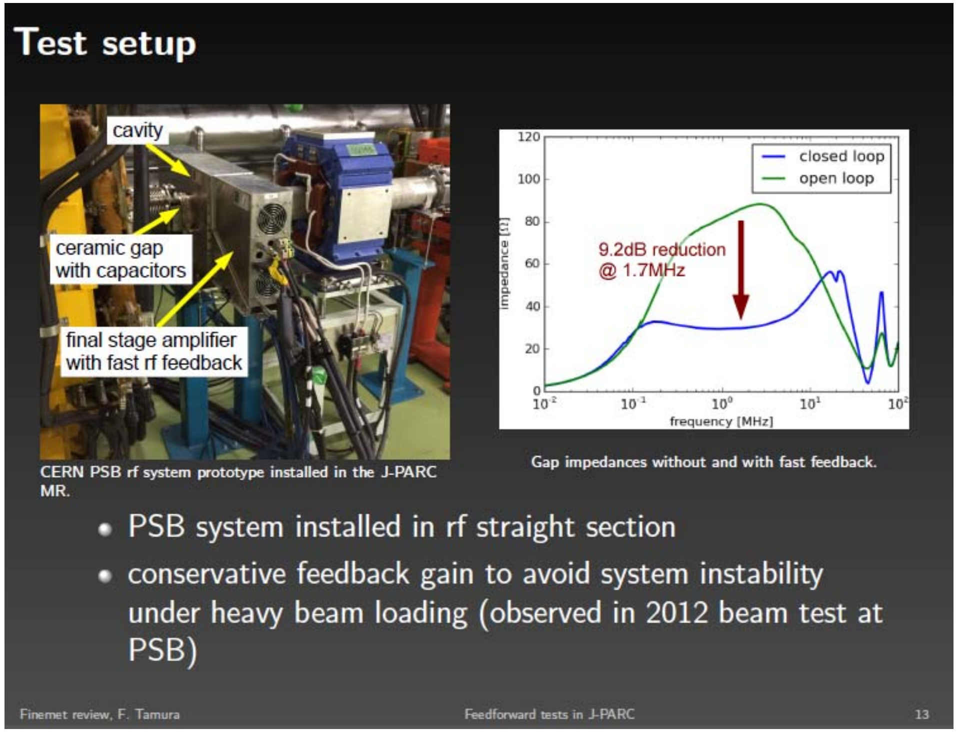
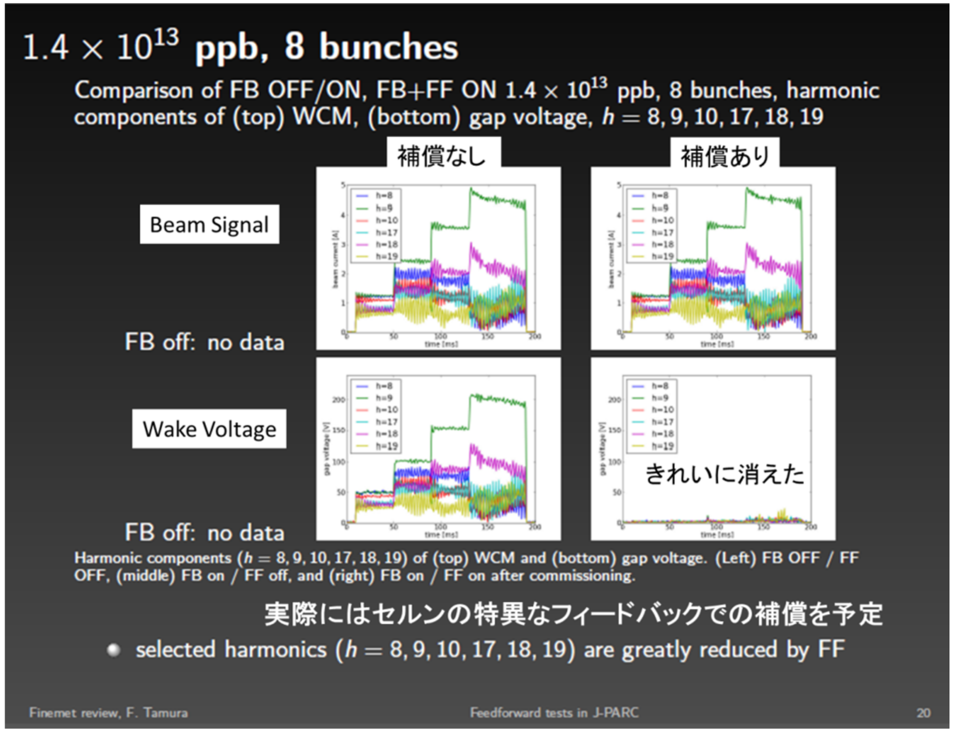
- **CERN PS用longitudinal damper**
- ~~feed-forward~~ **beam loading 補償**
  feedback

Beam Test at J-PARC MR during LS1

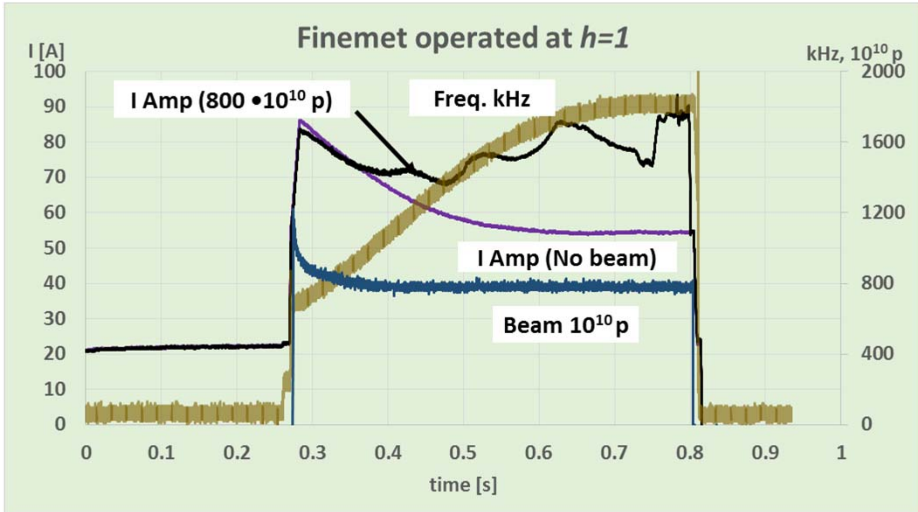


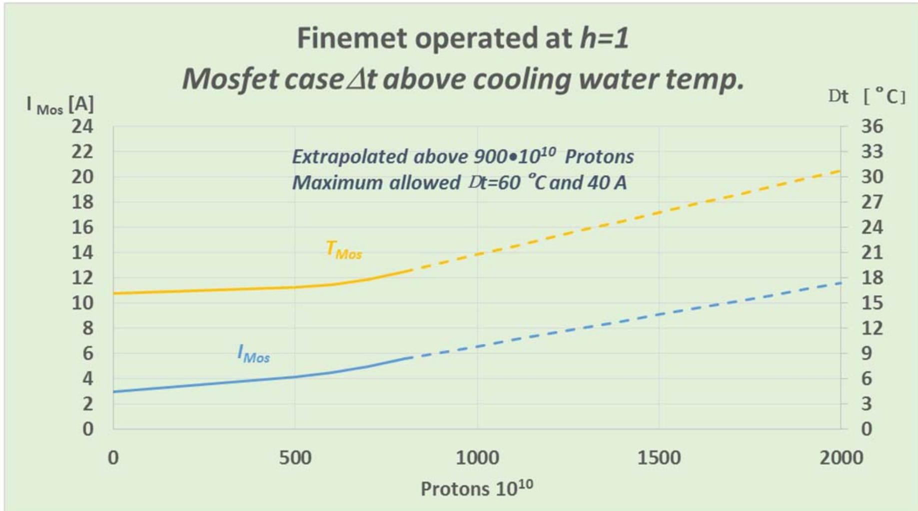


1.4×10^{13} protons were handled by a single AMP system !

SSA technology & damper cavity are useful for other rings: J-PARC, RHIC

PSBでのビーム試験



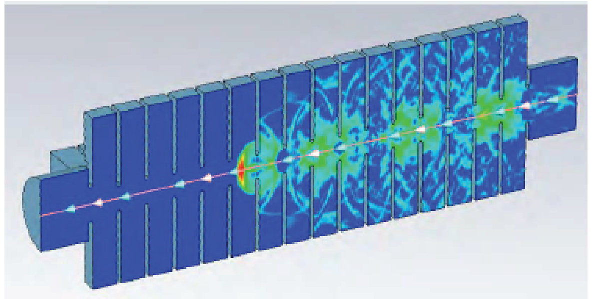


- 10^{13} pppまで加速
- CERNの ~86%) ユーザー運転に使用中（ H=2 cavity ）
- 順調に稼働中

Coupled bunch instability

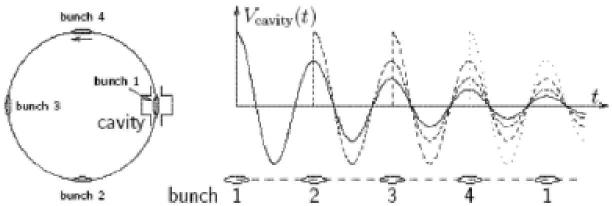
A charged beam in a particle accelerator, moving through a vacuum chamber, generates electromagnetic fields called **wakefields.**

Due to the causality principle, **wakefields generated by the head of a bunch act on particles at the tail**, modifying the beam dynamics and, under some conditions, leading to a growth of oscillations and driving instabilities.



This same mechanism can be used to describe the coupled bunch instabilities in which resonant modes, found e.g. in RF cavities, are excited by a bunch and act on the following ones .

The beam can be stable at low currents because "natural" damping effects (synchrotron radiation ....) can suppress unstable modes with small growth rates. **As more current is injected into a machine the growth rates increase producing instabilities.** Bunch oscillations will grow with time and we need to find some mechanisms to cure it.



Courtesy of A. Hofmann

Coupled bunch instabilities ->
beam "current limit" in the accelerator

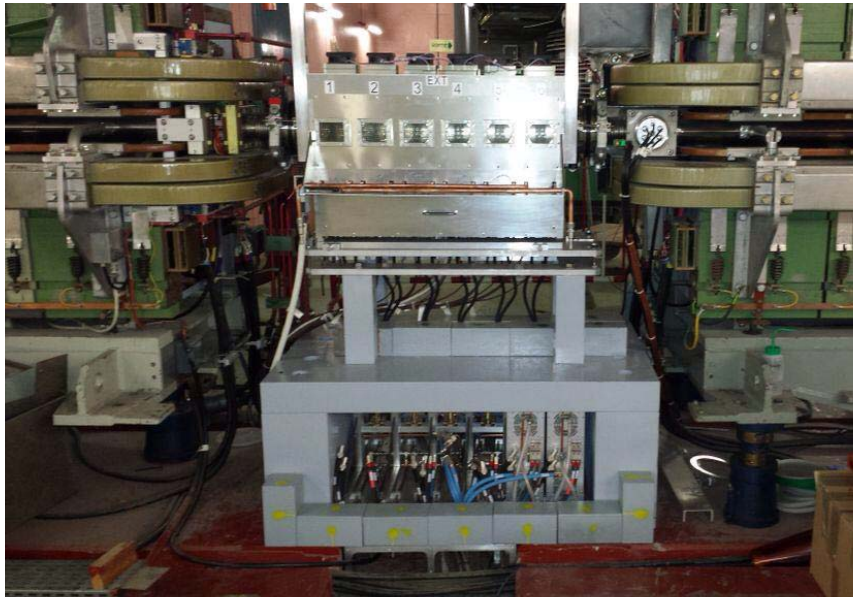
A possible solution: Feedback system to keep the beam stable at high currents. In particular, in case of coupled bunch instability, each unstable oscillation mode (determined by its frequency) needs a feedback system to work at that frequency. -> **Feedback system in frequency domain**

- Up to present intensities (achieved $1.8x10^{11}$ ppb at extraction) coupled bunch instabilities are damped using a feedback system limited to the first two dominant oscillation modes, but it will become insufficient for the beam parameters planned within the **LHC upgrade** (**$2.7x10^{11}$ ppb** at extraction, that is $20x10^{12}$ particles per beam).

L. Ventura, Finemet Review 2014

CERN PSのダンパー空洞

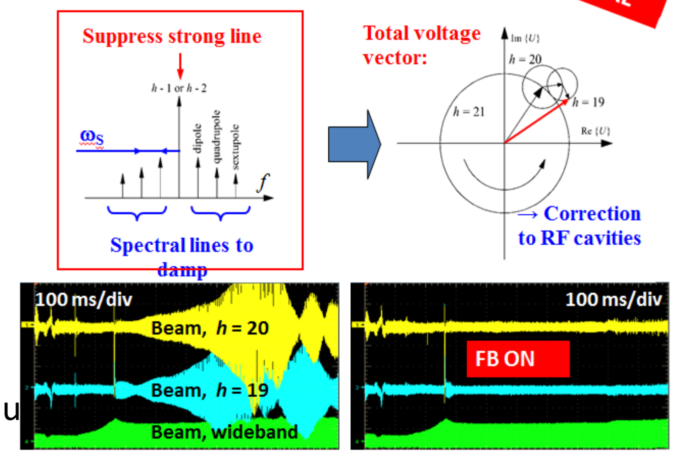
- Longitudinal Coupled Bunch Instabilityによるエミッタンス増加
- 現状：H19,20を対策
- LS2後：その他のモードも要対策=> Wideband damper！



Coupled-bunch feedback

- Actively reduce spectral components of the beam, no matter which impedance source excites them
- Global feedback working in frequency domain

GLOBAL



H. Damerau

20

Beam test using ferrite cavity (narrow band)

Instability はγT 通過後とFTでのbunch splitting で発生

広帯域器空洞と半導体アンプのダンパーをLS1中に設置. → 6台中2台を使って試験開始→モード別にエキサイトできることを確認！

Plans

2014-2105

Beam tests in PSB and PS to:

- ***Prove the principle and see limits and reli***
  - *Amplifiers.*
  - *Cavity cooling.*
  - *Radiation effects and compensation.*
  - *Beam/cavity interactions.*
  - *LL electronics*
    - *AVC functions.*
    - *Wake fields compensation.*
    - *Multi harmonic operation*
- ***Carry out new amplifier layout/design for:***
  - *Improved cooling.*
  - *Improved mechanical and electrical interfaces.*
- ***Get first prototypes from Japan (special contribution to come)*** -> Next year
- ***Select industrial partners for production and get prototypes from industry***
- ***Start final system design and integration in the PSB***

Decision about implementation end 2015.

to advise

Plans

2016-2017

- ***Finalize system design and integration in the PSB***
- ***Finalize PS damper***
  - *Automatics shielding displacement*
  - *Ease amplifier exchange.*
- ***Place the orders for electronic and mechanical parts.***
- ***Star production from CERN services.***
- ***Prepare a test place.***

2017-2018

- ***Production, acceptance, pre assembly and testing.***

2019 ***: LS2***

- ***Removal of existing systems, cabling and installation.***

2020

- ***Running in***

Other topics

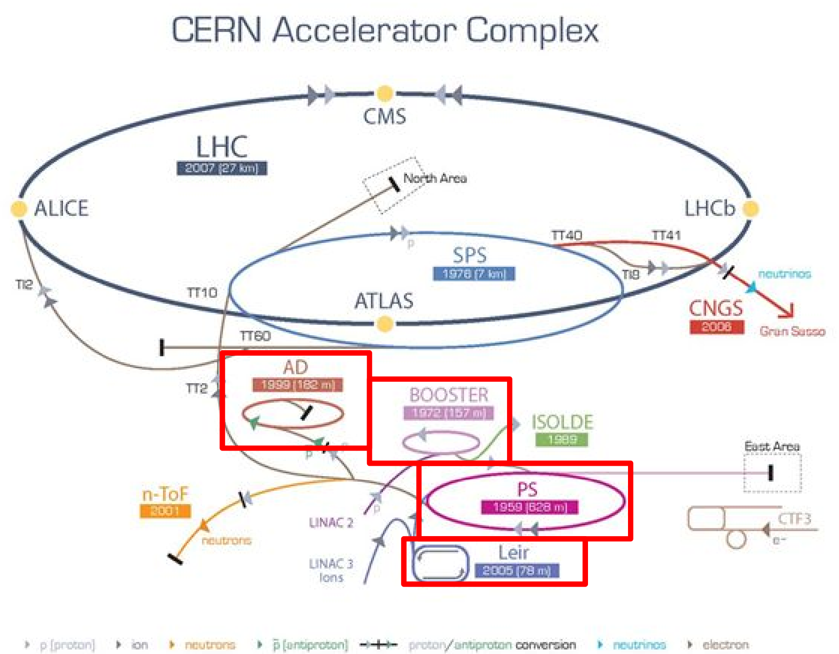
- CERNでの他の用途
  - ELENA anti-proton deceleration cavity
  - Replacement of AD CO2 RF System
  - FCC/CLICのキッカー電源Inductive adder with Finemet® Technology
- Future application for J-PARC
  - Feedback SSA for MW beam
- Medical acceleratorsへの技術応用
  - MedAustron, KHIMA in Korea

Universal cavity system !

Summary

- RFに関するコラボレーションは10年以上にわたり継続
  - 空洞：LEIRー＞PSB,PSーー＞ ELENA, AD
  - 半導体アンプはセルンからJ-PARCへ技術提供
- 現在LIU（LHC入射器アップグレード）への協力中
  - FT3L Finemet® coresの量産に協力
  - 今年度はPS Damper用に半導体アンプも製造
  - 半導体アンプ技術はJ-PARC MR feedback AMP にも使えそう→MW beam.

In this collaboration, experiences are circulating!



CERN　メイラン地区加速器の"広帯域化"！

First Magnetic Alloy Cavities
@CERN from 2005

Bldg.150の見学台から

Thank you!

Back up slides