A complete 6D beam cooling scheme for a Muon Collider

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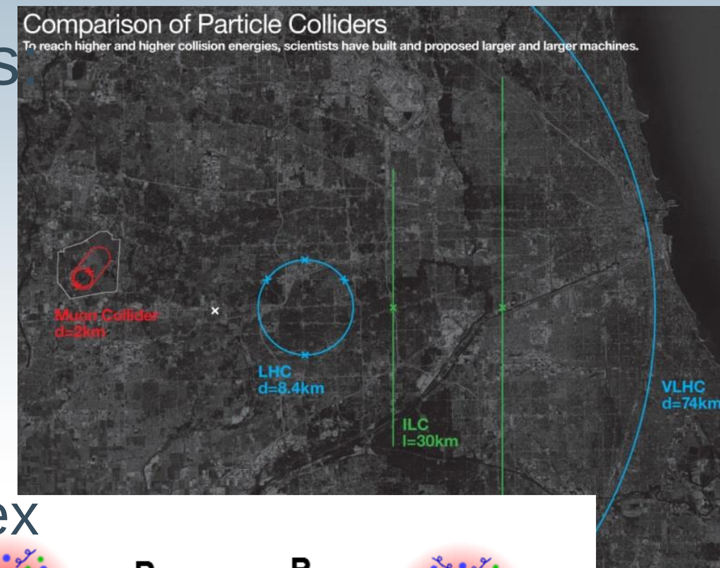
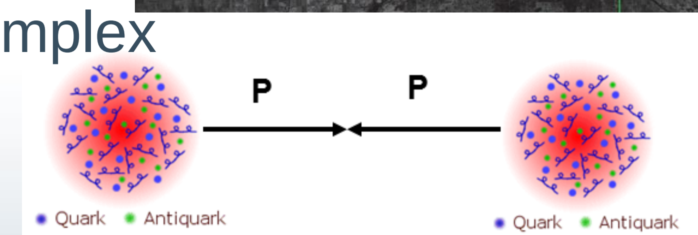
Outline

- Introduction to Muon Collider
- Challenge: Ionization cooling
- Design & simulation of a 6D cooling channel for a Muon Collider
- Review key lattice parameters
  - Required rf cavity frequency, voltage, B-field, absorber length
- Technology challenges
- Conclusion

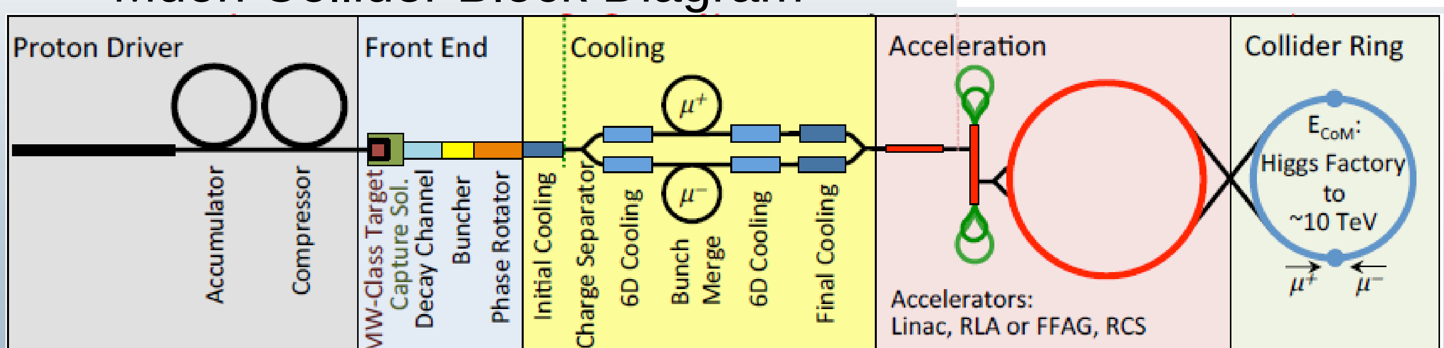
Muon Collider

- A path to energy-frontier with muons
  - Radiative processes are far from limiting (as for electrons)
  - Can build a compact, high-energy, circular accelerator
  - Collide point particles rather than complex objects





Muon Collider Block Diagram

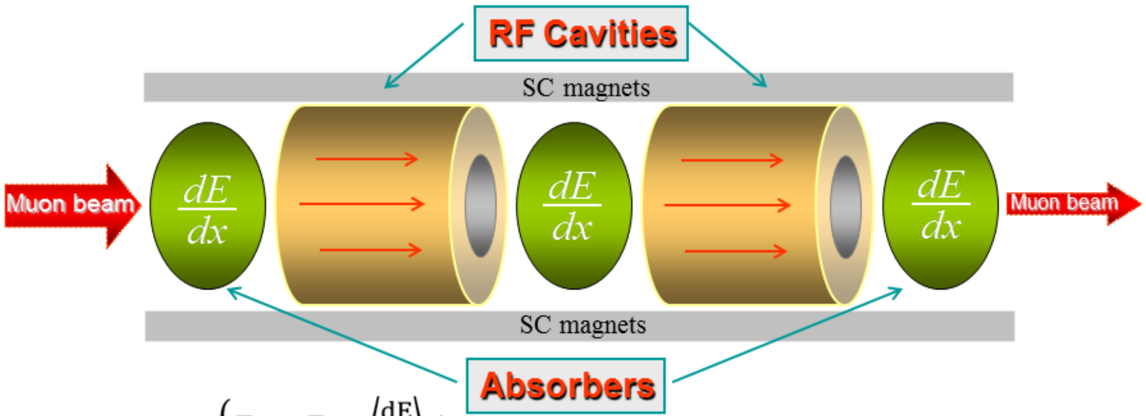


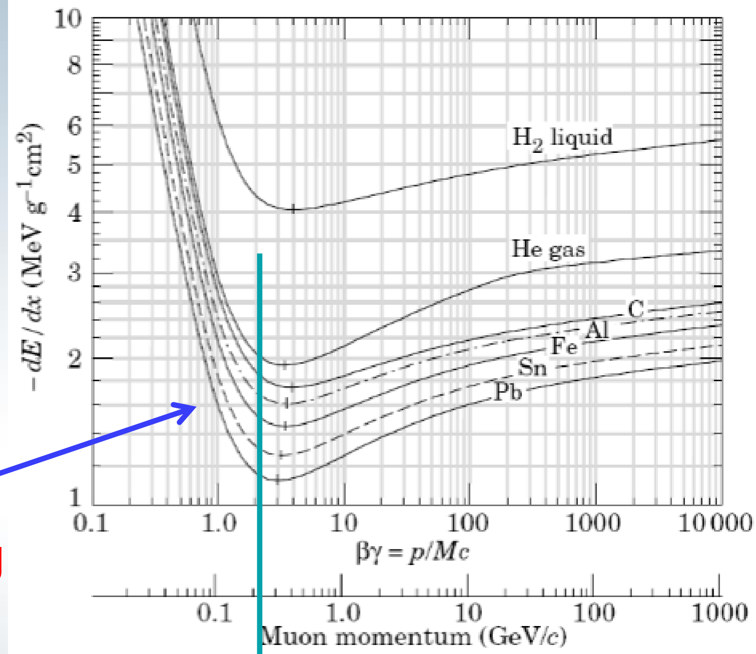
- Muon beams are produced as tertiary beams: $p \rightarrow \pi \rightarrow \mu$

Technical Challenges

- Muon beam is “born” with high emittance
- Cooler beams would allow fewer muons for a given luminosity
  - Reducing experimental background
  - Reducing radiation from muon decays
  - Allowing smaller apertures in machine elements and so driving the cost down
  - BUT, muons decay fast (2 μs at rest) so any beam manipulation has to be done quickly
- GOAL: Produce a high-intensity muon beam whose 6D phase-space is reduced by 10^6 from its value at the target.

Ionization Cooling





- Absorbers: $\begin{cases} E \to E - \left\langle \frac{\mathrm{dE}}{\mathrm{dx}} \right\rangle \Delta s \\ \theta \to \theta + \theta_{\mathrm{rms}} \end{cases}$

ionization energy loss

Multiple Coulomb scattering

- RF cavities between cavities replace ΔE
- Net effect: reduction on transverse momentum (cooling)

$$\frac{d\varepsilon_n}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\varepsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_T(E_s)^2}{2E_\mu m_\mu c^2 L_R}$$

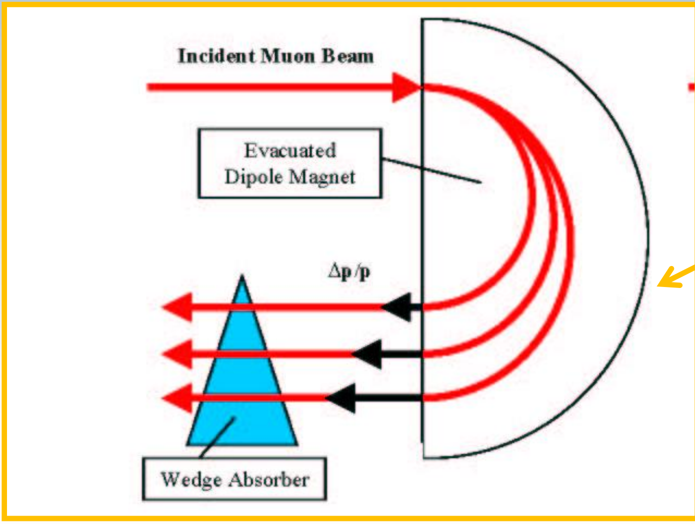
- Equilibrium Emittance: $\varepsilon_{N,\min} = \dfrac{\beta_T(E_s)^2}{2\beta m_\mu c^2 L_R \left|\frac{dE_\mu}{ds}\right|}.$

Ionization minimum is the optimal working point (≈200 MeV/c)

2 competing effects

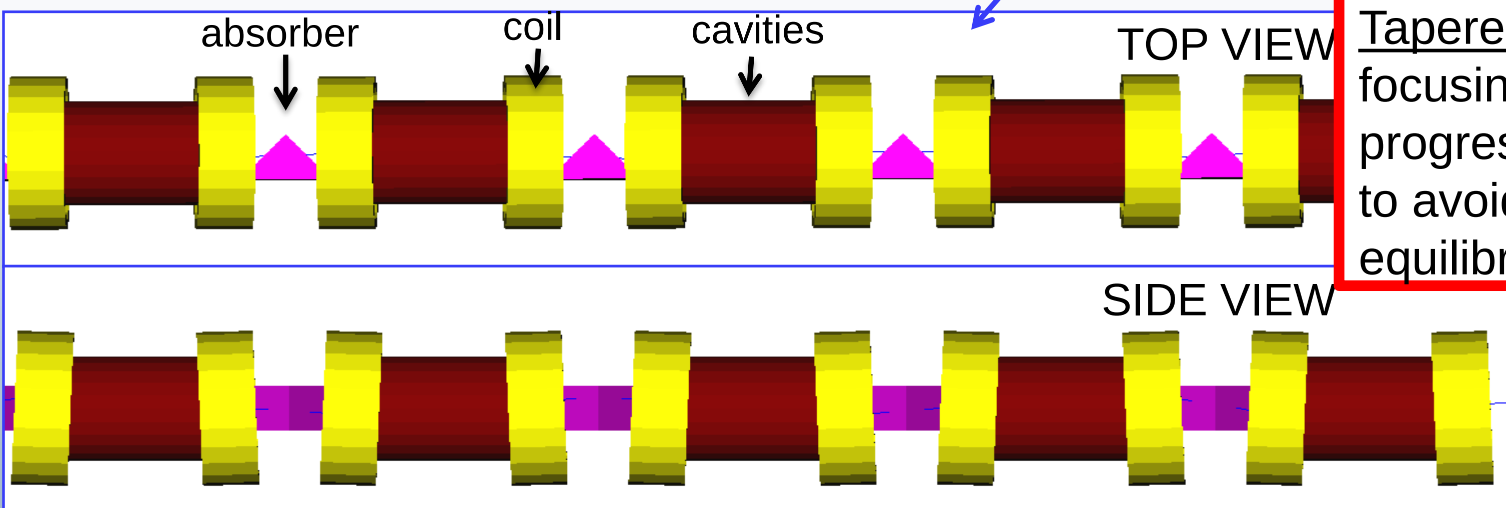
- We need strong focusing ($\beta_T \downarrow$), low Z material ($L_R \uparrow$)

6D Vacuum Cooling Channel (VCC)



Concept: Generate dispersion and cool via emittance exchange in a wedge absorber

Proposed solution: Rectilinear channel with tilted alternating solenoids and wedge absorbers

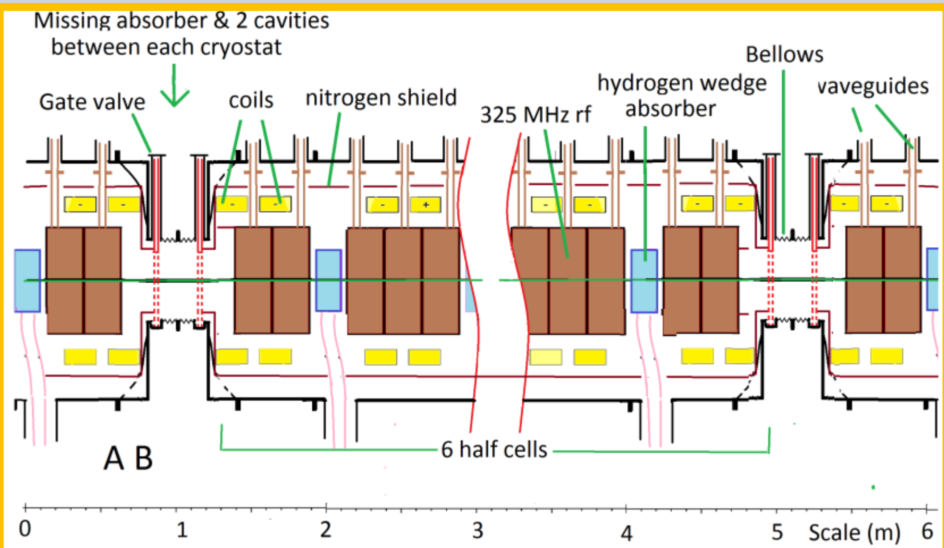


Tapered channel: The focusing field becomes progressively stronger to avoid reaching the equilibrium emittance.

D. Stratakis et al., Phys. Rev. ST AB 16, 091001 (2013)

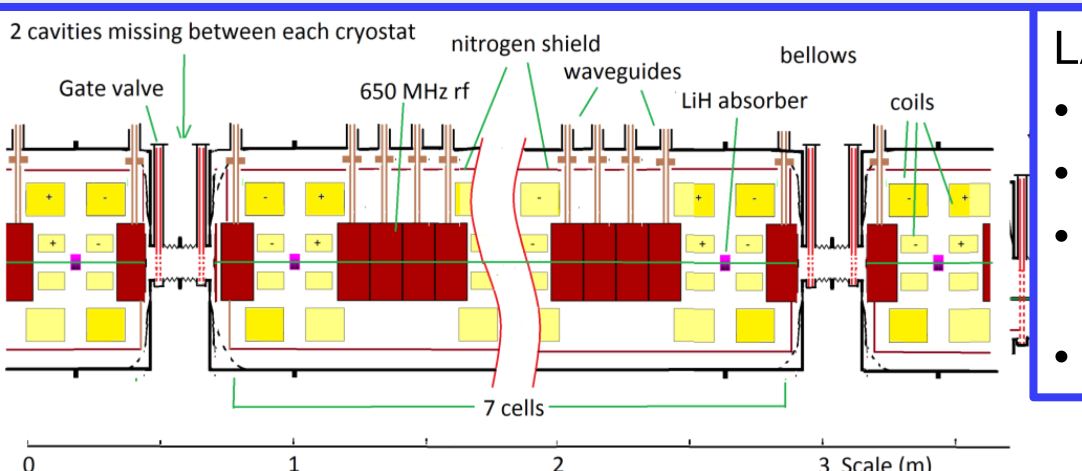
Cooling channel conceptual design

- Channel consist of 8 different stages



EARLY STAGES OF COOLING CHANNEL

- Magnet Req.: 3-8 T on coil
- RF Req.: 325 MHz at 22 MV/m
- Challenge: RF cavity needs to operate in strong field

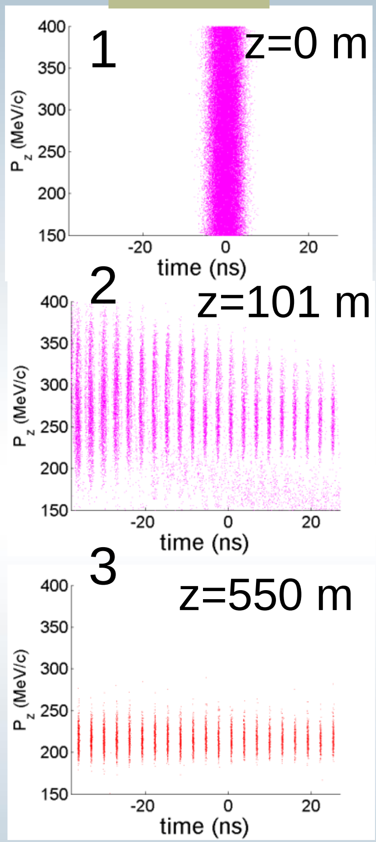


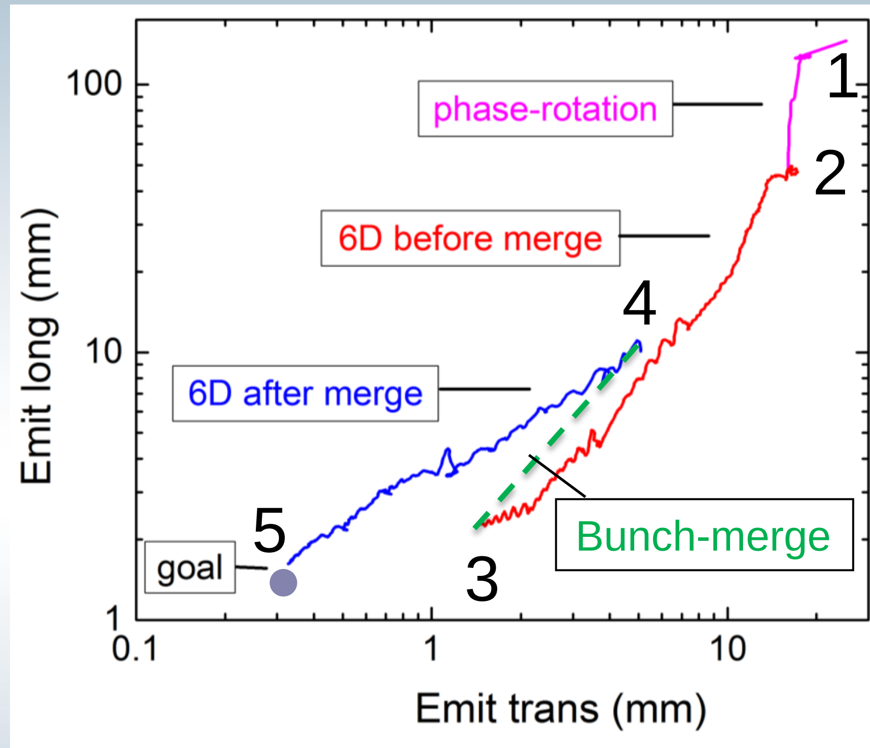
LATE STAGE OF COOLING CHANNEL

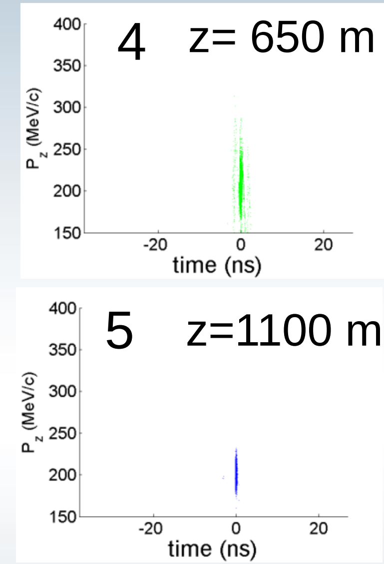
- Magnet Req.: 9-15 T on coil
- RF Req.: 650 MHz at 28 MV/m
- Challenge 1: RF cavity needs to operate in strong field
- Challenge 2: Magnet feasibility

Overall performance

z-pz

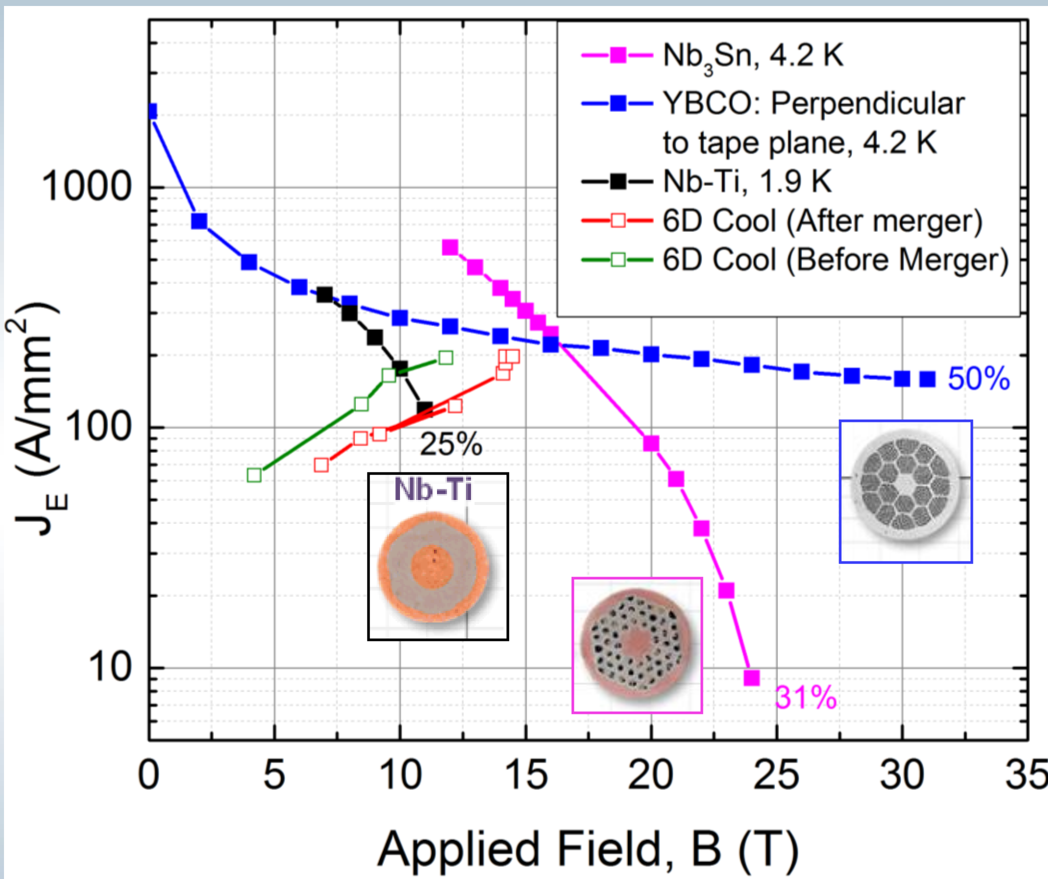




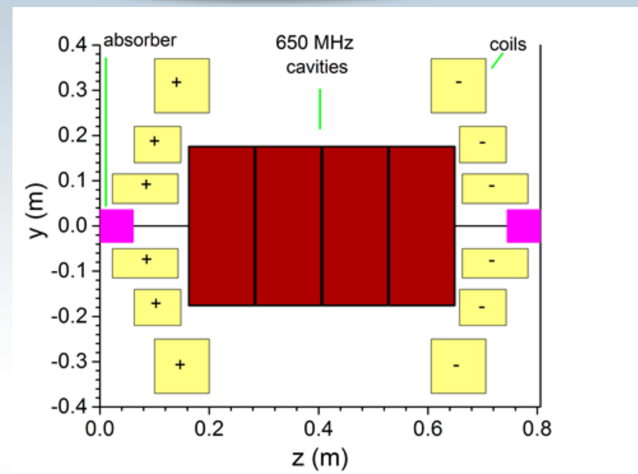


Parameters	Begin (2)	End (5)
Emittance, Transv. (mm)	17.38	0.28
Emittance, Long. (mm)	48.67	1.55
Transmission with decays	100%	18%

Magnet Feasibility



e.g. Last Stage

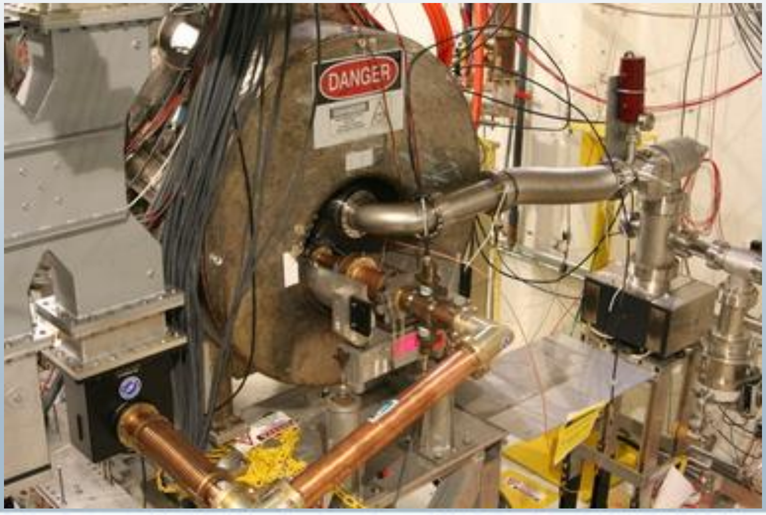


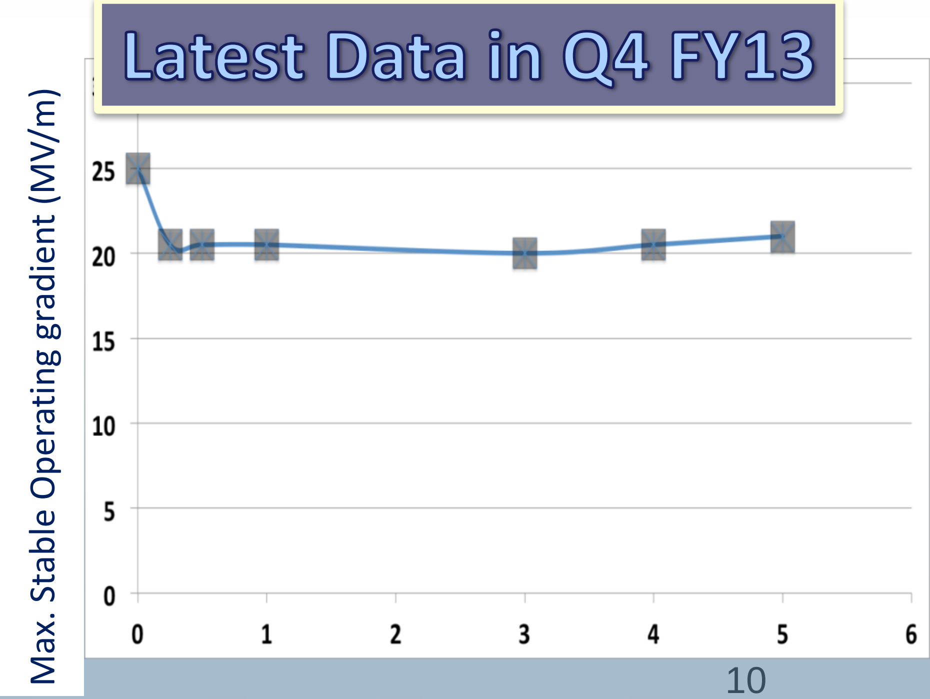
Here
Something from Franck?
Here
Something from Holger?

- Magnet requirements within Nb-Ti and Nb$_3$Sn limits?

Vacuum RF Feasibility

- Significant improvement over the original 805 MHz pillbox cavity
  - Operated in magnet: ~ 25 MV/m at B=0, 3 T
  - Re-run with RF pickup
    - Confirmed B=0 data
    - ~ 20-22 MV/m to 5T
    - **Below the needed 28 MV/m**





Summary

- We defined a concept for 6D cooling based on a rectilinear channel
- We specified the required magnets, cavities and absorbers for the cooling channel before & after the merger.
- Main challenges:
  - Operation of high-gradient rf cavities in multi-Tesla magnetic fields
  - Demand of coils with peak field near 15 T
- We are working closely with the technology development group to address those issues

VCC design group

Concept Leaders
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6D Theory & Simulation

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