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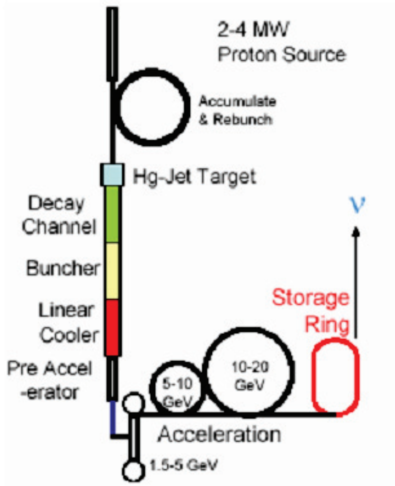
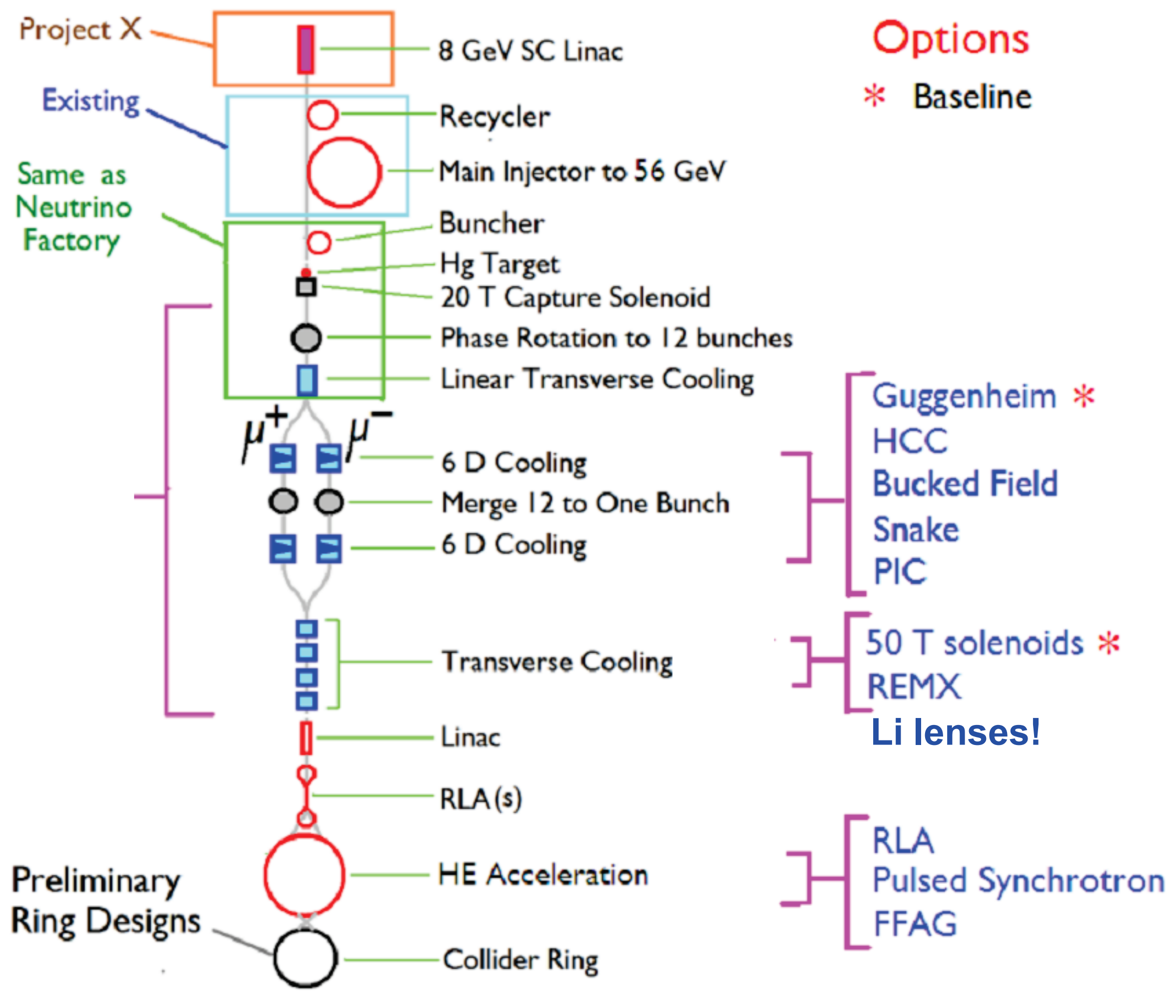
Design & Simulations Overview

NF & MC Baseline Schemes





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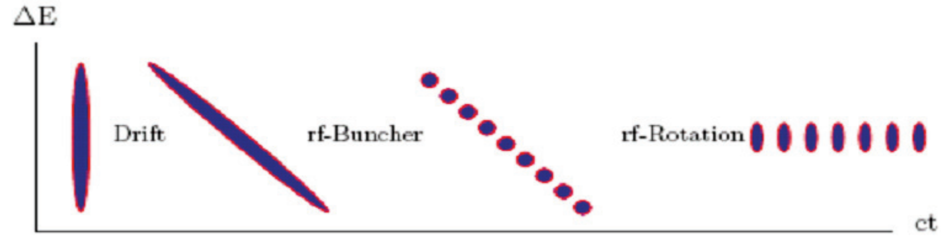
Where We Were (a Year Ago)



Front end

- **Muon production:**

  - Extensively studied. Simulations predicted only weak dependence of the pion yield on the proton energy but rather on the beam power.
  - MERIT experiment underway

- **Capture/RF bunching/rotation:**

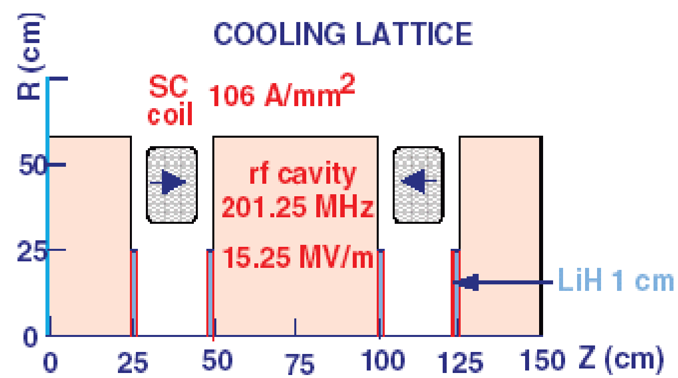
  - scheme employing RF cavities with different frequencies to capture muons in a long train of bunches and to level their mean energies developed (D.Neuffer)

Issues: RF in magnetic field; number of bunches;

- **Initial (transverse) cooling ($\varepsilon_{\perp N}$ >2cm → <1cm):**

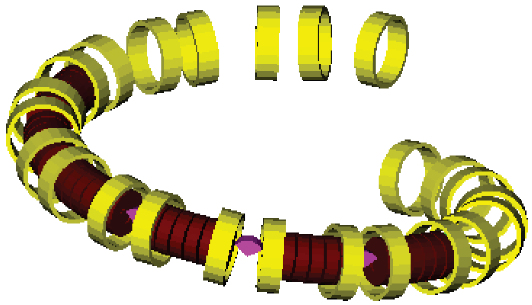
  - Alternating solenoid channel and its modifications.
  - MICE experiment in preparation

Issues: RF in magnetic field



Where We Were (cont'd)

6D Ionization cooling ($\varepsilon_{\perp N}$ 1cm → 0.5mm):

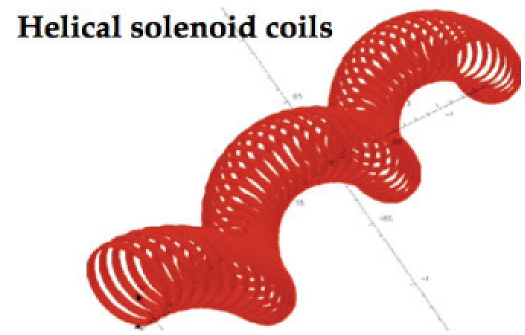


- **"Guggenheim" RFOFO channel**
  - simplified simulations O.K.

Issues: RF in magnetic field, simulations with real magnetic fields

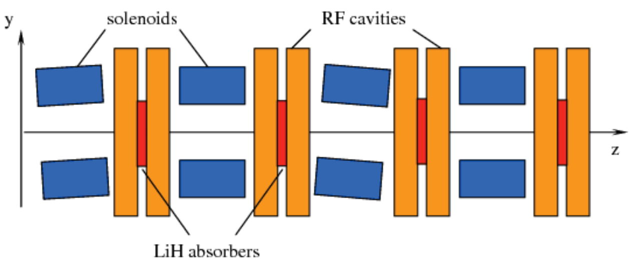
- **Helical Cooling Channel (HCC) with HPRF**
  - theory (Y.Derbenev & R.Johnson), simulations with G4BL (K.Yonehara).
  - V.Kashikhin's solution (helical solenoid) how to avoid too high transverse B-fields

Issues: incorporating RF into the channel, HPRF with ionizing beam



- **FOFO snake with block solenoids**
  - theory, planar lattice design (YA)

Issues: RF in magnetic field, realistic simulations



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Where We Were (cont'd)

Final cooling ($\varepsilon_{\perp N}$ 0.5mm → < 25μm):

- **High-field (50-60T) solenoid channel**

- simplified simulations with ICOOL (B.Palmer)

Issues: RF in magnetic field, no full lattice design

- **Li lens channel**

- lattice design & simulations (V.Balbekov)

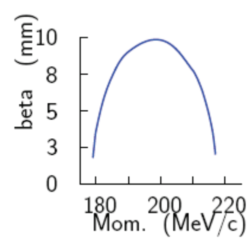
Issues: small momentum acceptance, performance limited by Li heating

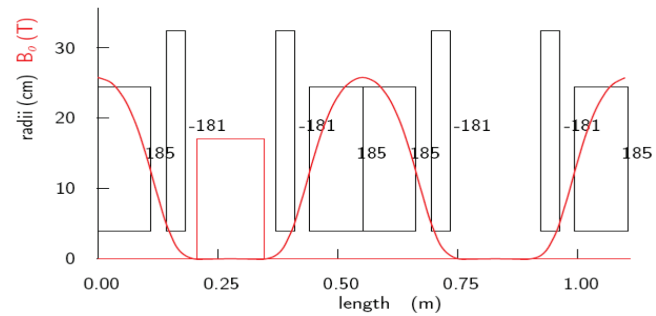
"brute force" methods

- **Low β lattice (R.Fernow)**

- lattice design & simulations

Issues: strong aberrations

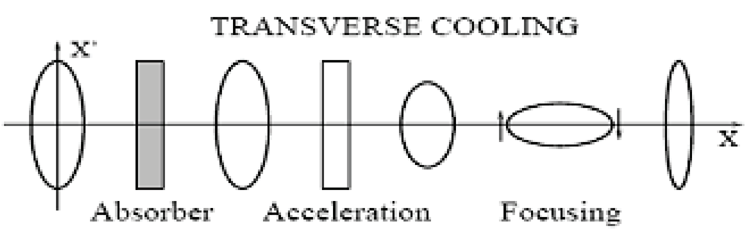




- **PIC (Parametric resonance Ionization Cooling - V.Balbekov, re-invented by Y.Derbenev & R.Johnson)**

- theory, several lattice designs

Issues: strong aberrations



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Where We Were (cont'd)

Muon Acceleration :

- **FFAG**

- lattice design, simulations

- EMMA in preparation

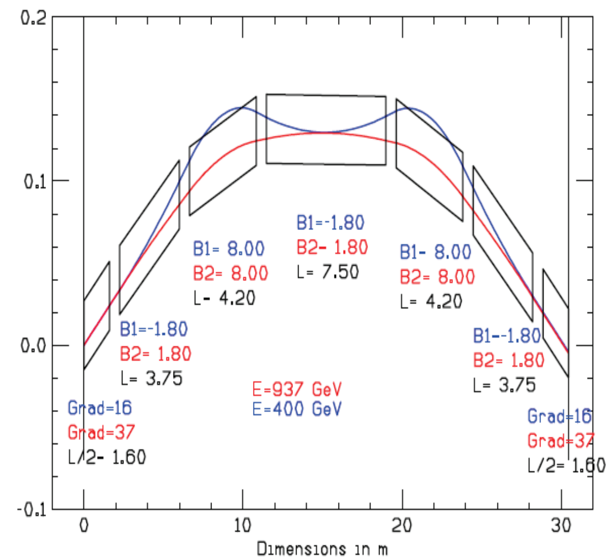
- **RLA**

- various options for linac and arcs studied (A.Bogacz)

- **Fast Ramping Synchrotrons (D.Summers)**

- Scheme and lattice design for 30GeV → 400GeV → 0.75TeV tandem

Particle Paths in a 400 to 750 GeV Hybrid Half Cell



Dipoles oppose at injection, then act in unison at extraction.

No problem expected with acceleration in NF,
there may be issues with acceleration of high-intensity bunches in MC

Where We Were (cont'd)

Muon Collider Ring

- **Optics design**

- two 1996 designs for 2TeV, β^*=3mm, α_c~10^{-5} (K.Oide and A.Garren et al.)

Issues: high sensitivity to errors (β_{max}~900km and 300km respectively), too strong sextupoles in Oide's design, too small momentum acceptance in A.Garren's design)

- "Dipole first" optics (YA & Eliana) 0.75TeV, β^*=1cm, α_c~10^{-4}

Issues: insufficient DA, unknown effect of the IR dipoles on detector

- New attempts by Bogacz & Derbenev, Carol & Snopok

- **Detector protection**

- Background simulations, shielding design based on A.Garren's optics (N.Mokhov)

- **Magnets**

- LHC upgrade design is a good first approximation
- Open mid-plane magnets designed (R.Gupta) with B=13-16T

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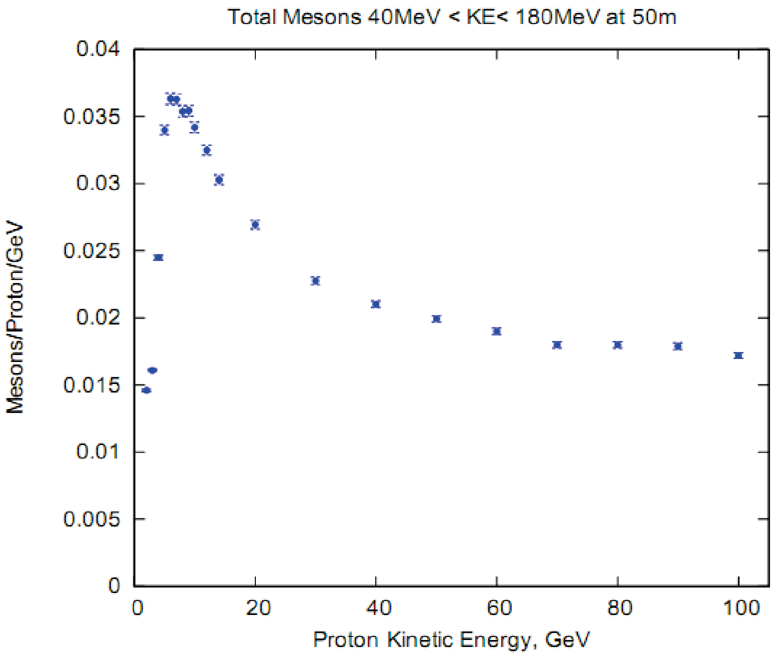
Recent Activities - Front End

Meson production in Hg target (H.Kirk)

- optimization for every proton energy
- new version of MARS code used
- important results for choice of the p-driver parameters (a strong argument in favor of 8 GeV)



P-driver options (just for reference):

- Project-X 8 GeV linac + accumulator/compressor rings (C.Ankenbrandt, M.Popovic)
- 8 GeV Fast Ramping Synchrotron with 600MeV injector (D.Summers)
- One of the above + acceleration to 56 GeV in MI (D.Neuffer)
- 21 GeV Fast Ramping Synchrotron with 2 GeV injector (D.McGinnis, V.Lebedev) + rebunching ring

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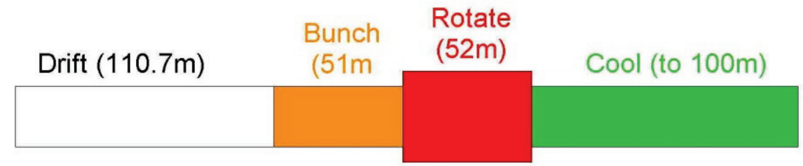
Muon Bunching/Rotation (D.Neuffer)



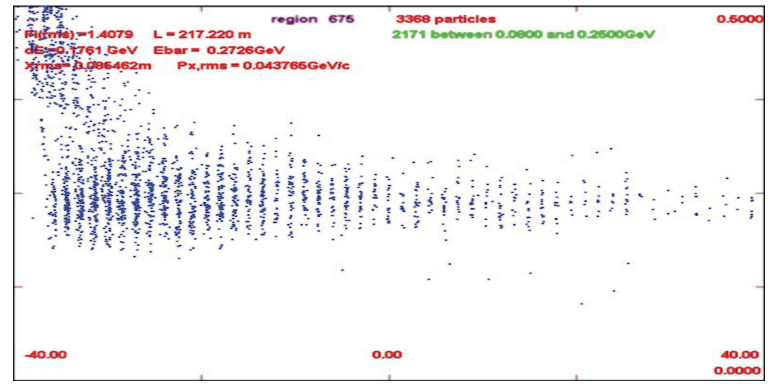
Optimization of the baseline scheme:

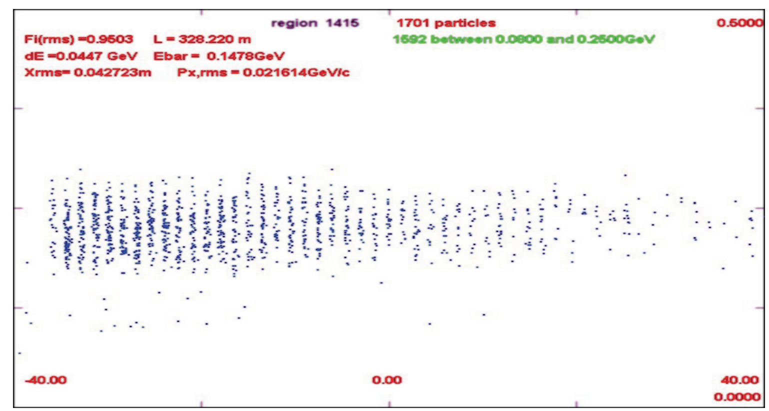
- **alternating solenoids in the rotator (to provide a kind of magnetic insulation) ⇒**
- **increase in RF voltage (10MV/m → 15MV/m) ⇒**

- capture efficiency 0.2μ/p → 0.25 μ/p at Ep=24GeV

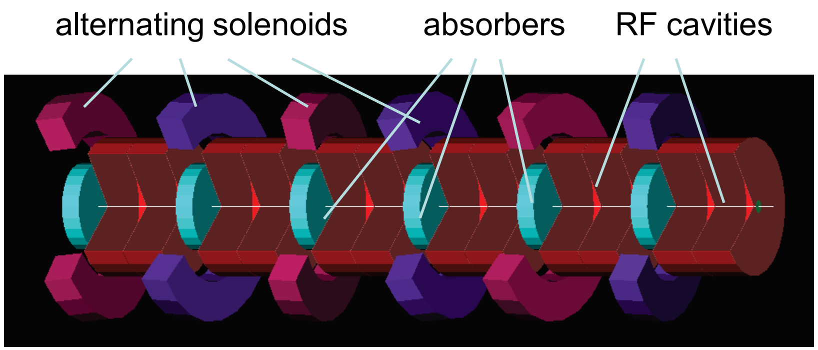
- smaller number of bunches (12) containing 80% of μ's

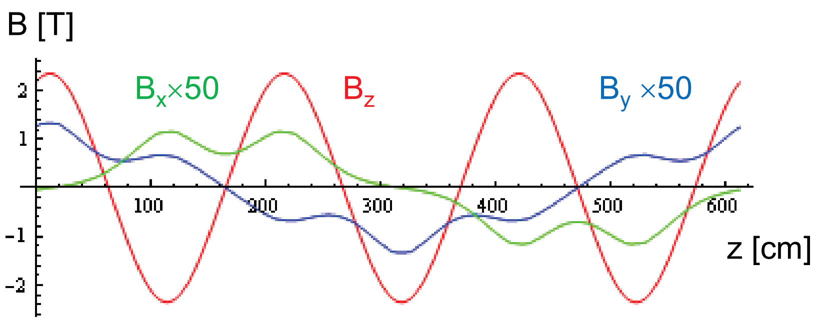
- **increase in mean momentum (220MeV/c → 280MeV/c) allows to pack muons in even smaller number of bunches**

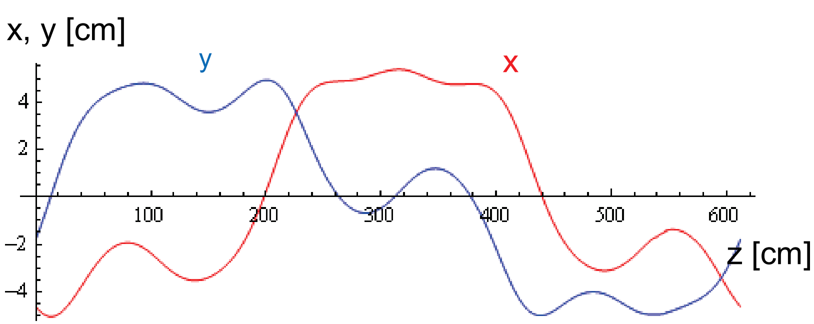




FOFO Snake for Initial Cooling (YA)

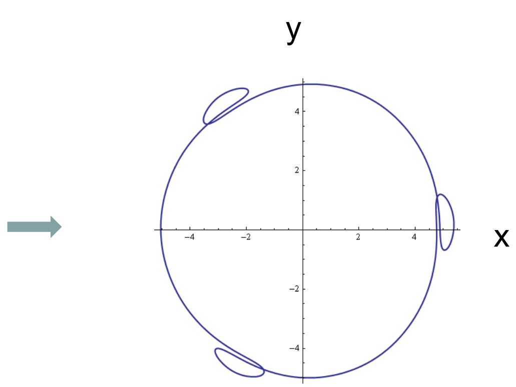






Periodic orbit for p=200MeV/c

- The idea: create rotating $B_{\perp}$ field by periodically tilting solenoids, e.g. with 6-solenoid period.
- Periodic orbits for μ+ and μ- look exactly the same, just shifted by a half period (3 solenoids).
- With tune $Q_{\perp}$>1 (per period) $\mathbf{r}\cdot\mathbf{D}$>0 ⇒ muons with higher momentum make a longer path ⇒ longitudinal cooling achieved even with planar absorbers

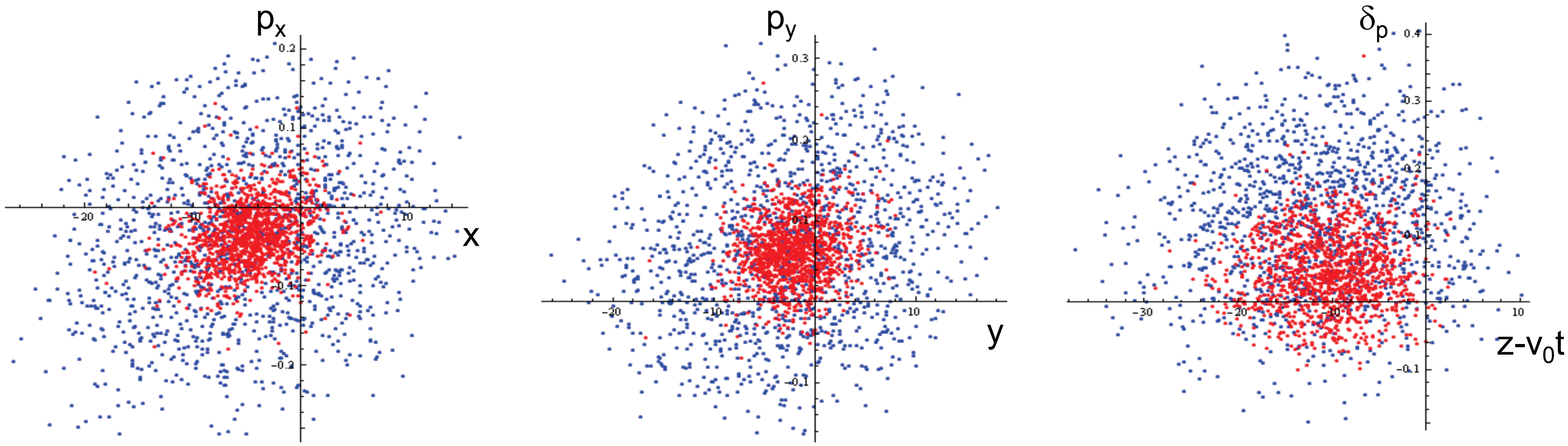


FOFO Snake for Initial Cooling (YA)

Particular example:

Solenoids: L=24cm, Rin=60cm, Rout=92cm, pitch 7mrad, $B_z$max=2.35T (p=200MeV/c)
RF: 200 MHz pillbox 2x36cm, Emax=16MV/m
Absorbers: 15cm LH2 planar
Equilibrium emittances, ε_{iN}[cm]: 0.32, 0.45, 0.69 (w/o windows)

Tracking: initial emittances [cm]: 2.05, 2.13, 3.75
w/o stochastic effects and decay survival over 25 periods (153m) 97%



This channel is also an option for basic 6D-cooling

Guggenheim Simulations (P.Snopok)

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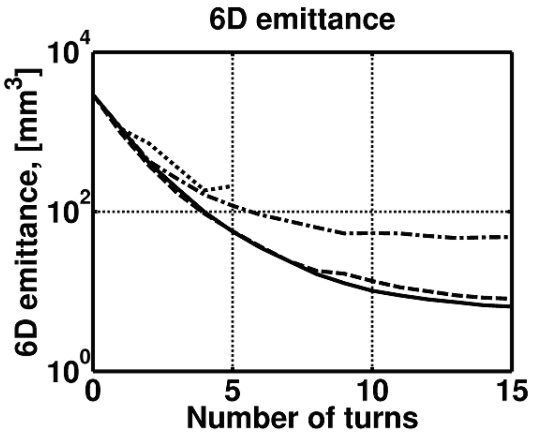
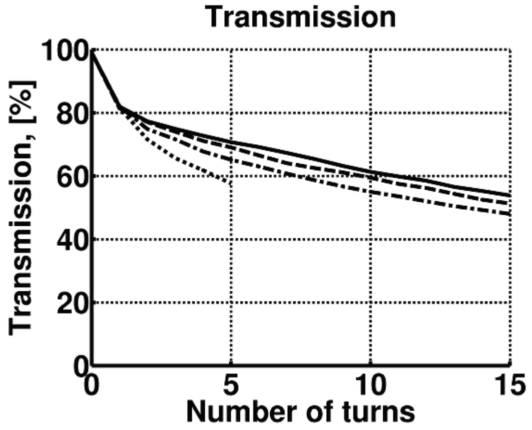
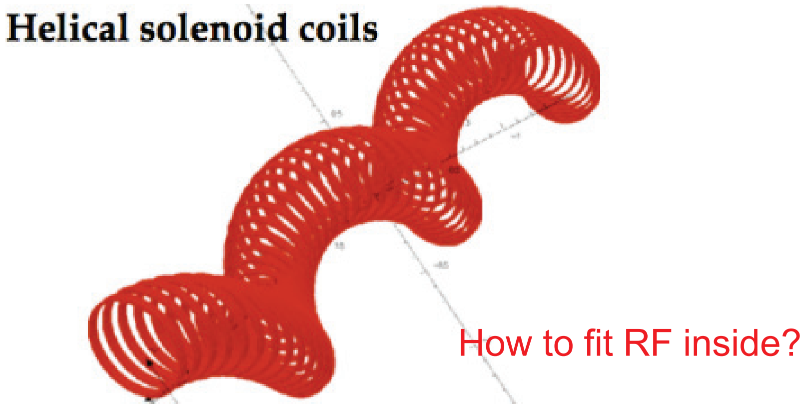
Four simulations are considered:

- Original RFOFO lattice
- Ideal Guggenheim (shielding between layers, single turn)
- "Realistic" Guggenheim (shielding between layers, single turn, RF cavities with windows, absorbers with windows)
- 5-layer "fair" Guggenheim (no shielding, all 5 layers contributing, all windows)

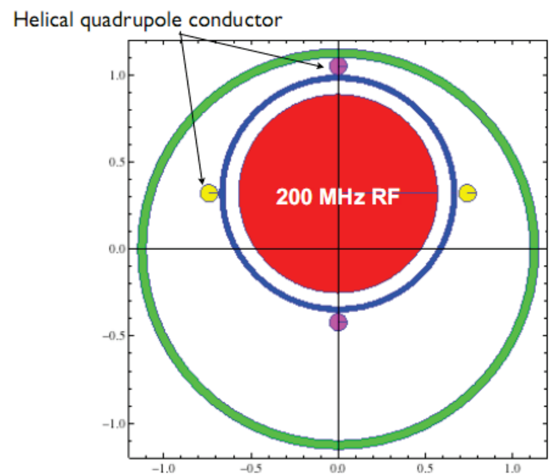




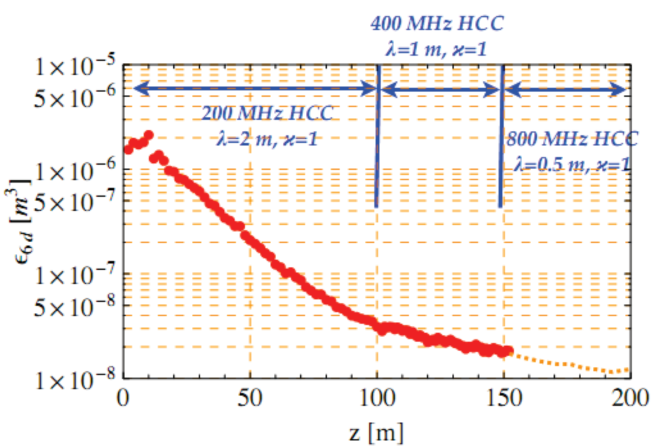
Helical Cooling Channel



New design
Introduce helical quadrupole conductors
to generate optimum field gradient



- **New ideas how to increase the required HCC inner radius:**
  - Quad coils + counter-solenoid (K.Yonehara)
  - Additional wedge absorbers (V.Balbekov) - abandoned
- **New ideas for RF in HCC:**
  - Travelling wave structure (L.Thorndahl)
  - Dielectric-filled cavities (M.Popovic)
  - Toroidal cavities (V.Balbekov) - abandoned



Final cooling

- **Li lenses revisited**

- D.Cline, K.Lee and A.Garren considered Li ring

- V.Lebedev has some practical ideas

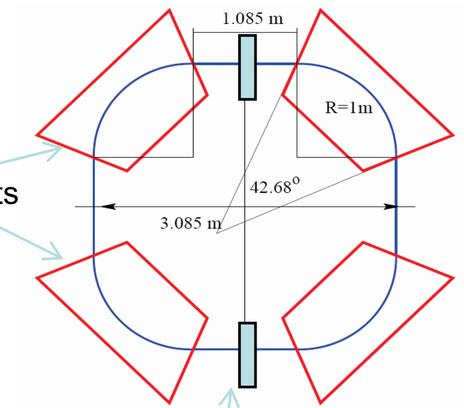
- **Parametric resonance structures (PIC)**

- "proof-of priciple" simulations with ICOOL by Palmer and Fernow, but w/o addressing the aberrations issue

- "Epicyclic HCC" proposed by Derbenev with purportedly smaller aberrations and larger dispersion to facilitate their correction

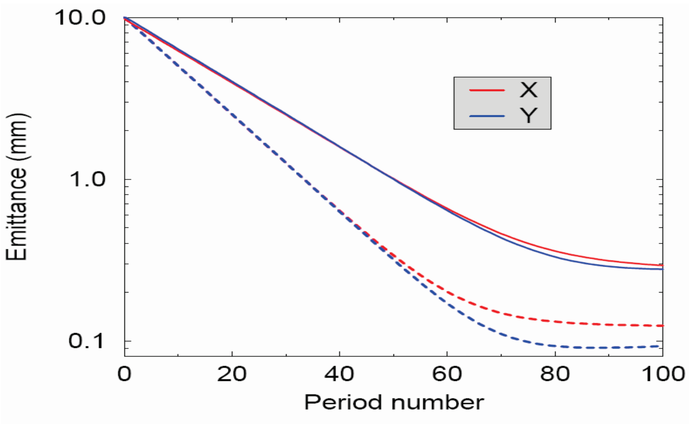
- "Fringe-focusing" ring cooler proposed by Balbekov (can it be "guggenheimed"?)

Qx=Qy=1



Sector magnets

absorber



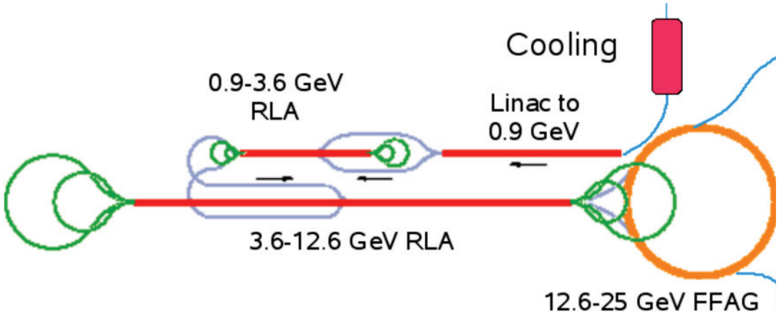
8.9 MeV/absorber

13.3 MeV/absorber

(380Mev/c, no stochastic effects)

Muon Acceleration

- **Design of the baseline NF accelerator chain is mainly done**



- **Various modifications of RLA considered**

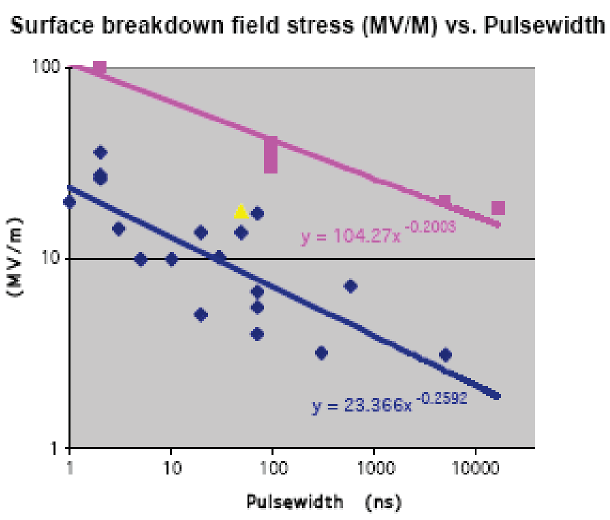
- pulsed optics in linacs and multiple "droplet" arcs ⇒ up to 12 passes
- FFAG arcs in both racetrack and "dogbone" configurations

- **Fast Ramping Synchrotrons**

- D.Summers considers energies beyond 1TeV

- **High-Gradient Induction Linac?**

- "Dielectric Wall Accelerator" (G.Caporaso, LLNL) may be an efficient way to accelerate single high-intensity bunches



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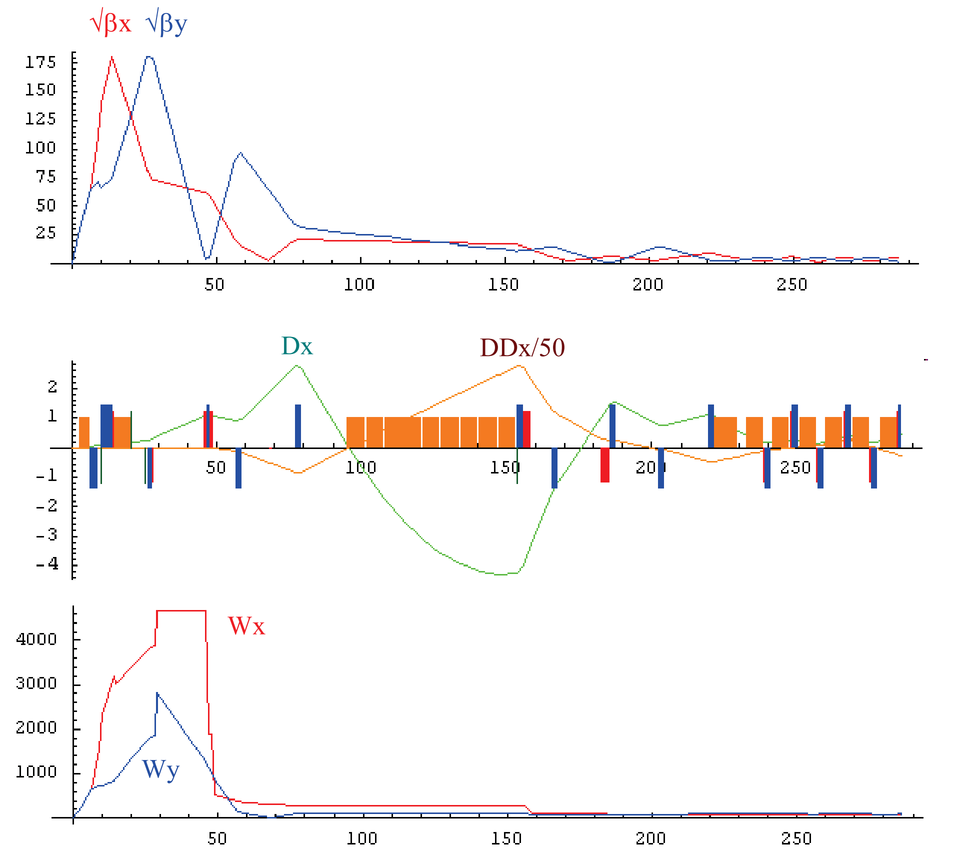
Collider Ring Optics

- **Nonlinear correctors in the 0.75TeV "dipole first" lattice adjusted. Basic parameters:**

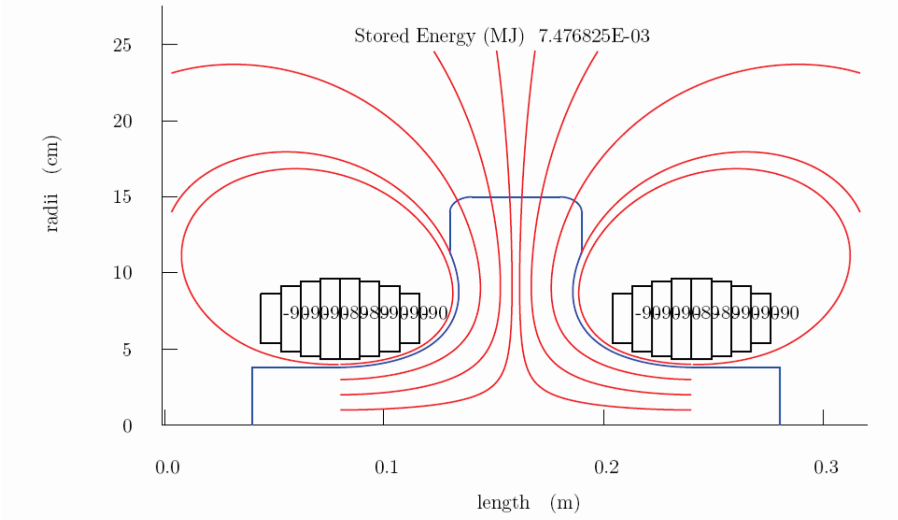
- β^* = 1cm
- β_{max}=32km
- momentum compaction =$5.5 \cdot 10^{-5}$
- circumference = 3.1km
- momentum acceptance ±0.63%
- Dynamic Aperture ≥ 3σ for $\varepsilon_{\perp N}$=25μm

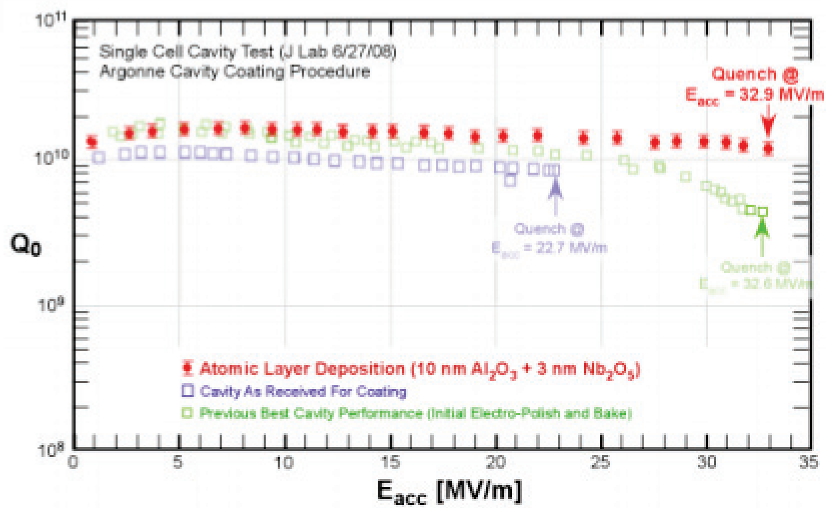
- **Work started on new design combining local IR chromaticity correction with non-interleaved special sections (Eliana)**



RF simulations

- **HPRF**
  - effect of ionization by accelerated beam (A.Tollestrup)
- **RF breakdown simulations**
  - "induced cyclic fatigue" due to energy deposition by electrons (BNL)
  - plasma formation and "exponential" growth due to field emission enhancement by local plasma potential (ANL)
- **Cures:**
  - "magnetic insulation" (R.Palmer)
  - atomic layer deposition (J.Norem)

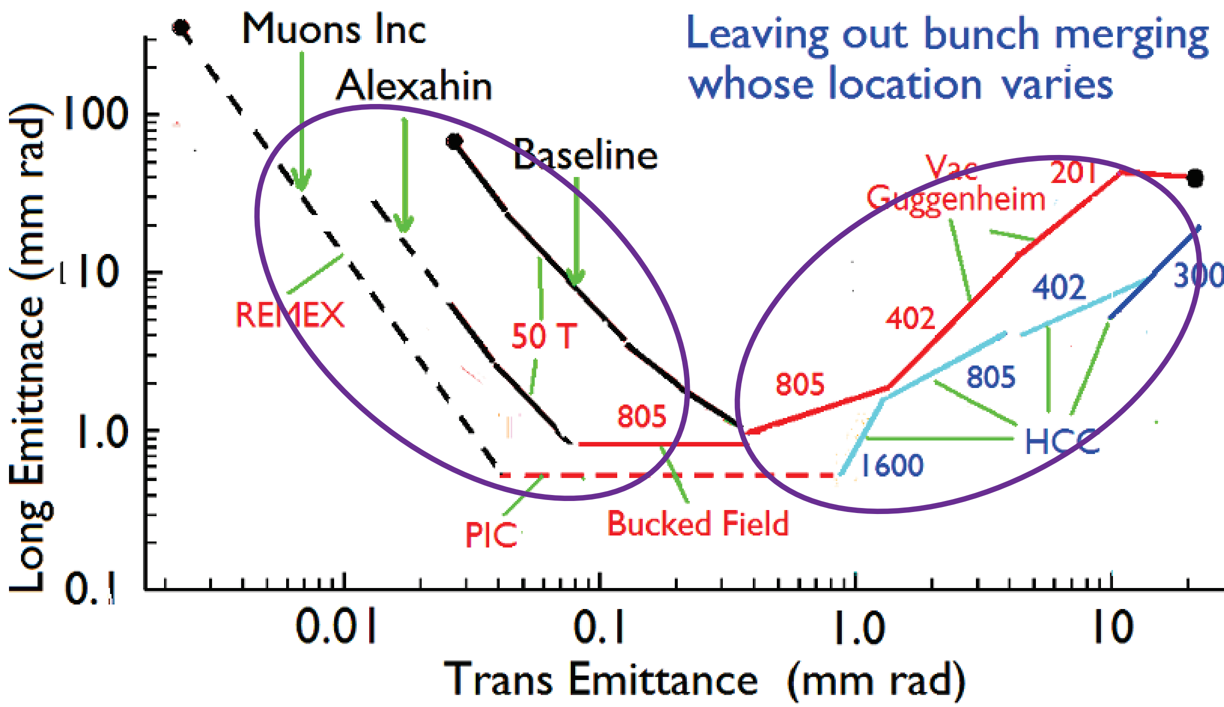




Summary

- **Significant progress in all areas of NF and MC projects**
  - front-end design optimized
  - encouraging results for FOFO snake, new HCC scheme
  - new ideas for final cooling (EpicyclicPIC, FringeFieldPIC)
  - MC lattice design meeting requirements
  - new versions of RLA and FS
  - better understanding of RF breakdown mechanism
- **NF IDS mature enough to produce CDR within ~3 years**
- **There are critical issues for MC, most notably with final cooling, that will be addressed in 5-year plan (R.Fernow)**
- **My apologies for not mentioning many important results**

Backup slide - Emittance Evolution



Final cooling **Basic 6D-cooling**