12 GeV Beam Physics and Hall-D

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Outline

- Summary of the January 2007 Beam Physics Review
- 12 GeV CDR design
- Non-linear effects: Multipoles
  - Emittance Growth
  - Halo
- Aperture and Occupancy
  - Minimizing Beam Steering
- Beyond the CDR design
  - Relaxing $M_{56} = 0$ requirement in the Arc.
  - Minimizing β in Spreader/Recombiner by moving new cyro-modules to front of north linac.

January 2007 Beam Physics Review

A. Hutton (Chair/JLAB), V. Lebedev (FNAL), D. Douglas (JLAB), M. Borland (ANL)

Internal review of the studies to date of the 12 GeV CDR design. With special attention paid to CD-4, initial physics and "out-years" physics requirements.

CD-4 Requirements and Expectations

		12 GeV			
		Expected		CD-4	
End-stations		ABC	D	ABC	D
Energy	(GeV)	>6	>10	>6	>10
Current	(μA)	>0.002	>0.002	0.002	0.002
ε_x	(nm-rad)	<6	<7	-	20
ε_y	(nm-rad)	<2	<2	-	20
$\delta p/p$	(% RMS)	<0.02	<0.02	-	-
HALO	(ppm)	<30	<30	-	-

Initial Physics Beam Requirements and Expectations

		12 GeV			
		Expected		Initial Requirements	
End-stations		ABC	D	ABC†	D
Energy	(GeV)	11	12	11	12
Current	(μA)	85	5	85	5
ε_x	(nm-rad)	<6	<7	10	50
ε_y	(nm-rad)	<2	<2	5	10
$\delta p/p$	(% RMS)	<0.02	<0.02	0.05	0.5
HALO	(ppm)	<30	<30	100	100

† Values for ABC represent the most stringent of the three requirements.

Out-Years Physics Beam Requirements and Expectations

		12 GeV			
		Expected		Final Requirements	
End-stations		ABC	D	ABC†	D
Energy	(GeV)	11	12	11	12
Current	(μA)	85	5	85	5
ε_x	(nm-rad)	<6	<7	10	10
ε_y	(nm-rad)	<1	<2	5	5
$\delta p/p$	(% RMS)	<0.02	<0.02	0.05	0.5
HALO	(ppm)	<30	<30	100	10

† Values for ABC represent the most stringent of the three requirements.

Summary-The 12 GeV Upgrade

The 12 GeV upgrade is not a green field design, doubling of energy is achieved by:

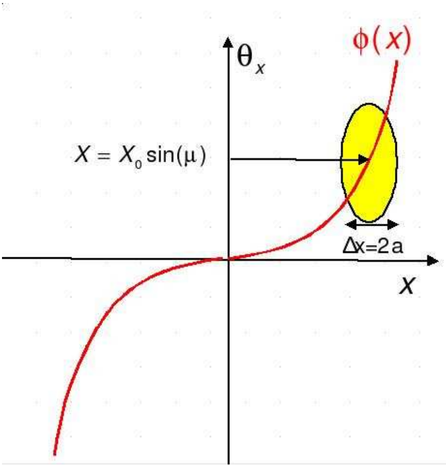
- adding 10 new 100 MeV cryomodules (to the 40 existing)
- adding a 10th Arc, resulting in an additional 0.5pass of acceleration for the new D end-station
- Re-use as much of the existing machine as possible
    - Use the original 4 GeV transport lattice and hardware
    - Modify magnets if needed, last resort design/build new magnets
        - C to H dipole conversion on 2m and 3m Arc magnets
        - New 4m dipoles for Arc10
        - New stronger quadrupole (MQR) for beam matching
        - Some new dipoles for the Spreader and Recombiners

12 GeV Optics; Review of 6 GeV Optics

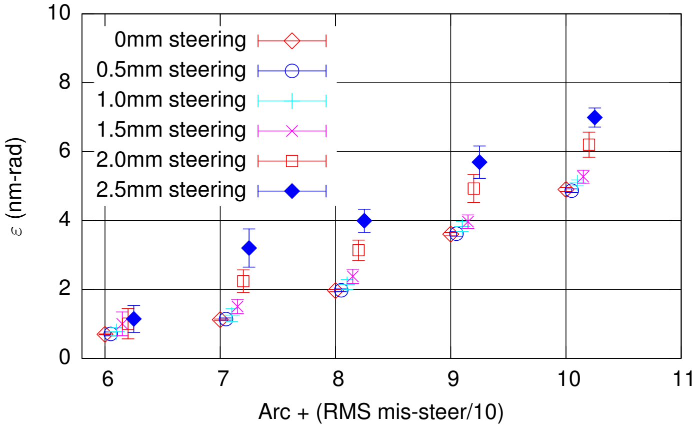
- Spreader-Arc-Recombiner Section
  - Spreader
    - Achromatic vertical bend (to separate different energies)
    - Matching section
  - Arc
    - 180° horizontal achromatic bend
    - Arc1 & Arc2 tuned for high dispersion to provide energy centriod and spread monitoring
    - Arc3→Arc10 four super-periods, each with four FODO cells
  - Recombiner
    - Matching section
    - achromatic vertical bend back to linac level (mirror image of Spreader)
  - The whole system is globally isochronous
- Linacs
  - 25 RF+quadrupole zones
  - First pass, 120° phase advance for each FODO cell
- Courant-Snyder Matching
  - 6 GeV mainly uses Recombiner matching quads

Magnetic Field Specifications

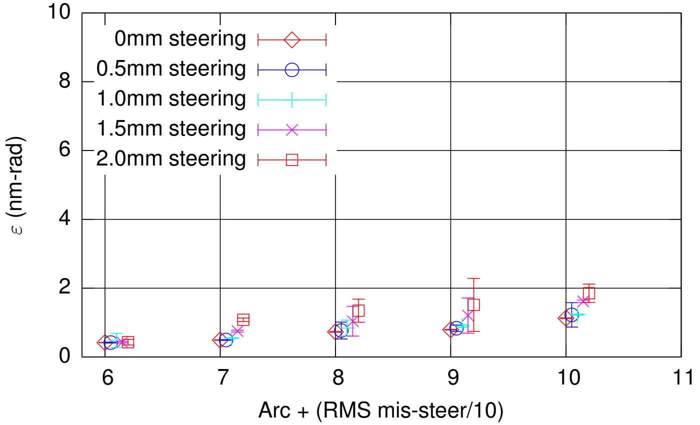
- Beam quality is a result of the magnetic field quality (linearity or lack there of) of all the magnetic elements traversed by the beam.
- Large intrinsic beamsize will sample greater amount of non-linearities (multipoles) then small intrinsic beams.
- Large RMS centroid off design orbits will sample greater amount of non-linearities (multipoles) then on design orbits.



ε_x growth due to synchrotron radiation and multipoles

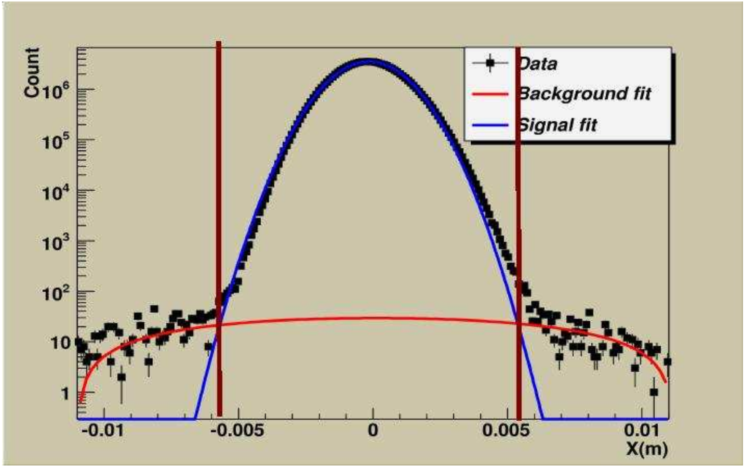


ε_y growth due to synchrotron radiation and multipoles

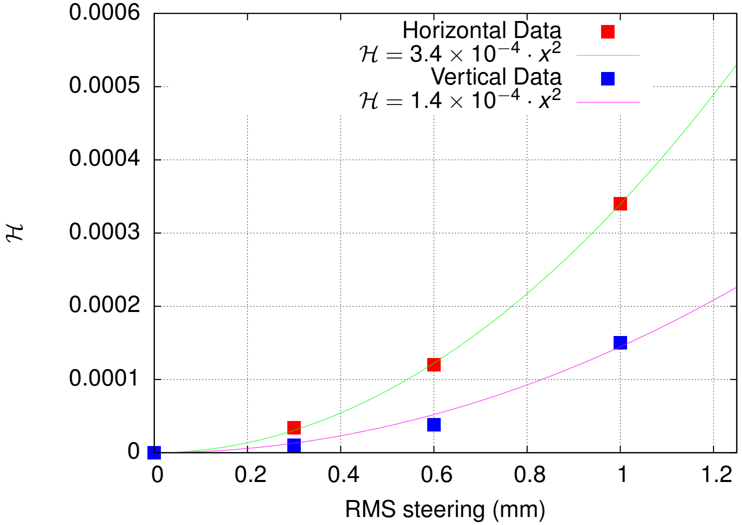


Halo Formation due to non-linearities

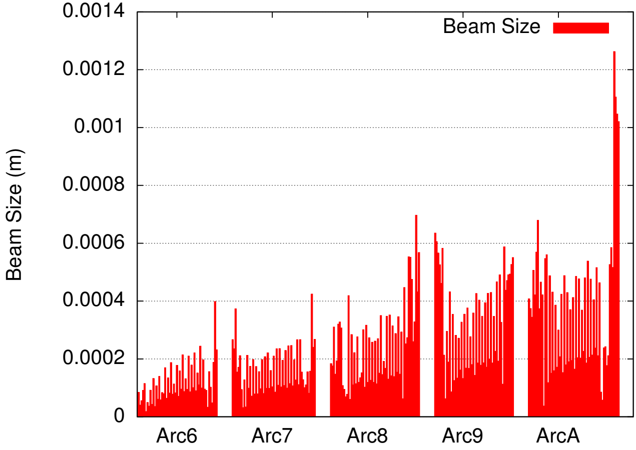
10^8 particles tracked from Arc6 through to the Hall-D radiator.



Halo as a function of the RMS beam orbit



Beam Size

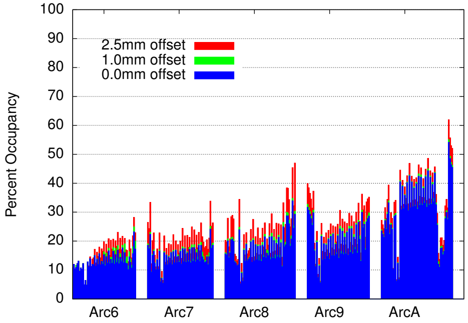


Beam Size
Beam Size (m)
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Arc6
Arc7
Arc8
Arc9
ArcA

Beam Occupancy

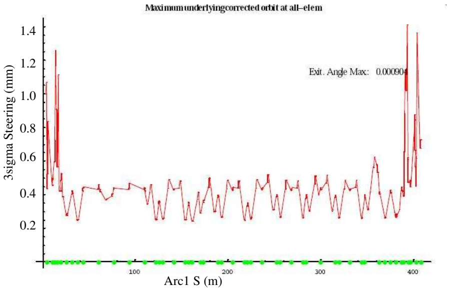
$$\text{Occupancy} = \frac{4\sigma + 1\,mm}{r_{pipe}}$$

- Is ± 1 mm steering sufficient?
- Is 4σ sufficient?



Beam Steering

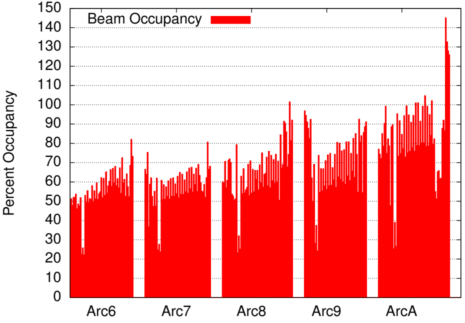
- Recent studies on determining the best RMS orbit for the 12 GeV design show that ± 1 mm steering is optimistic.
- Steering is dominated by the “roll” in the dipoles (spreaders/recombiners/arcs), where 1 mrad tolerance is used.



Beam Occupancy: Unofficial

Occupancy = $\frac{\sqrt{2}6\sigma+2.5mm+2.5mm}{r_{pipe}}$

- 6σ for halo free beam, 5σ 2D Gaussian has about 1ppm loss at 5σ.
- $\sqrt{2}$ for off design $\varepsilon\beta$
- 2.5 mm steering, from calculations
- 2.5 mm keep clear



Possible Improvements to the CDR design

Going beyond the 12 GeV CDR the following new designs are being investigated:

Move Hot Cryomodules to front of North Linac The larger gradient at the start of the Linac results in smaller βs in spreader and recombiner. ($$)

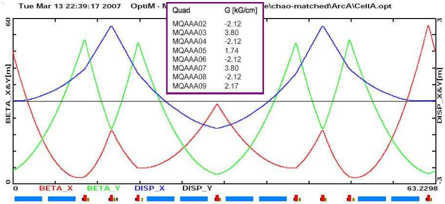
Change to 150° phase advance in the Linac Results in smaller βs in Spreader section. (FREE!!!)

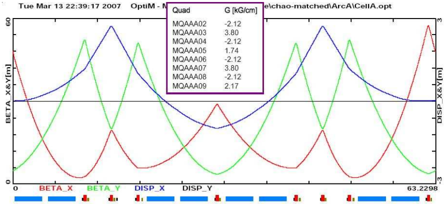
Relax isochronous requirement Energy spread is ten times larger for the 12 GeV machine, this allows for larger bunchlength and some M_{56} in the Arc.

- **Double Bend Achromat (DBA) with existing magnet locations** By retuning the existing Arc into a DBA the emittance growth is reduced by about a factor of 1.7/arc. (FREE!!!) But is it tunable/operable?
- **Green Field DBA in Arc9 and ArcA** By redesigning Arc9 and ArcA with about twice the number of quadrupoles and dipoles, the emittance growth can be squashed by a factor of 8. ($$$$$)

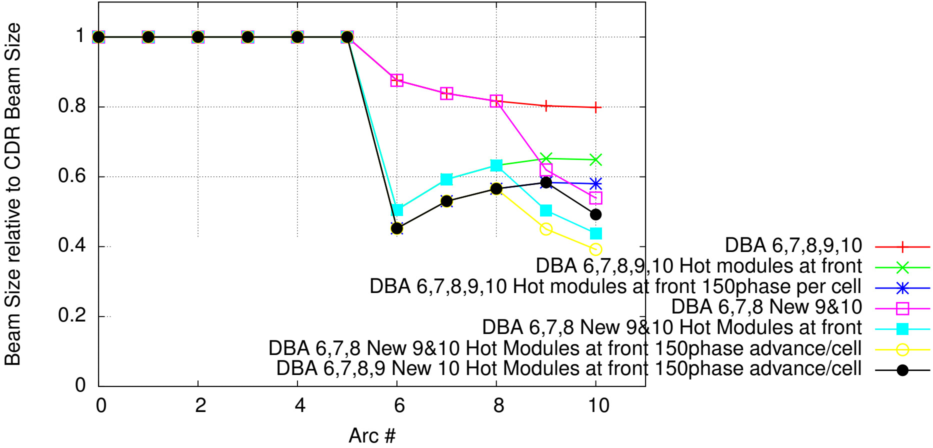
Standard CDR 12 GeV optics. Dispersion (blue) goes negative to maintain $M_{56} = 0$ through the arc.

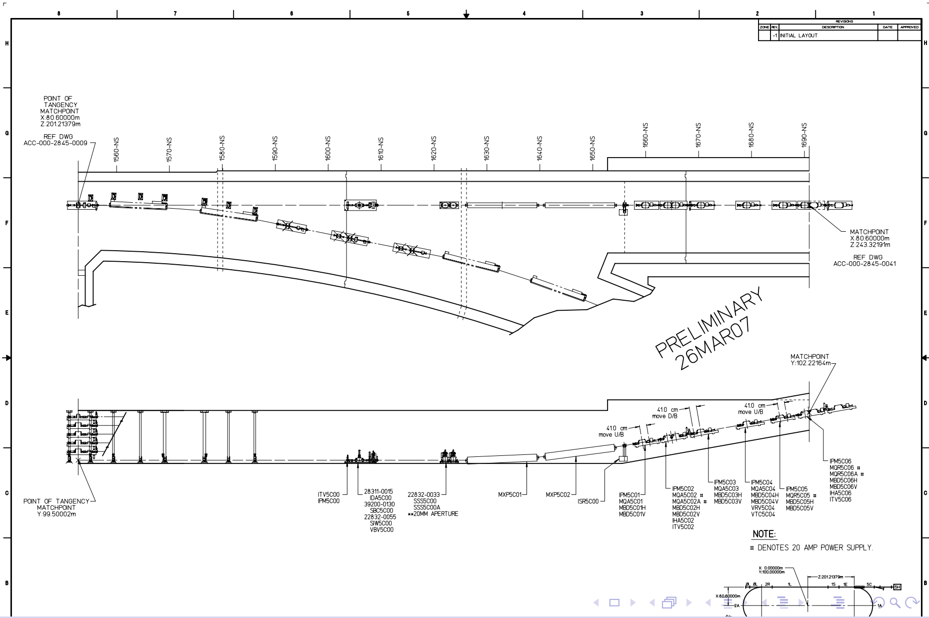
New Double Bend Achromat optics. Magnets in same location and type. $M_{56} \neq 0$ and lower H functions across the arc. Overall reduction in ε growth of 1.7 through the arc.





Estimated Improvements in Beam Size for non-CDR design configurations

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1570-NS
1580-NS
1590-NS
1600-NS
1610-NS
1620-NS
1630-NS
1640-NS
1650-NS
1660-NS
1670-NS
1680-NS
1690-NS
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PRELIMINARY 26MAR07
MATCHPOINT Y:102.22164m
41.0 cm move D/B
41.0 cm move U/B
41.0 cm move U/B
POINT OF TANGENCY MATCHPOINT Y:99.50002m
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IPM5C00
28311-0015
IDA5C00
39200-0130
SBC5C00
22832-0055
SIW5C00
VBV5C00
22832-0033
SSS5C00
SSS5C00A
**20MM APERTURE
MXP5C01
MXP5C02
ISR5C00
IPM5C01
MQA5C01
MBD5C01H
MBD5C01V
IPM5C02
MQA5C02 #
MQA5C02A #
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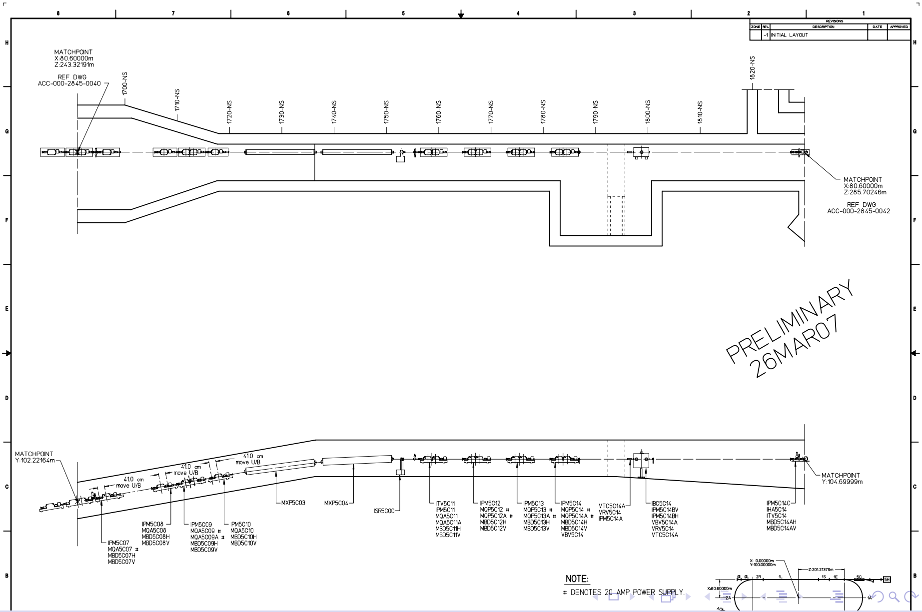
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26MAR07
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move U/B
41.0 cm
move U/B
41.0 cm
move U/B
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MXP5C04
ISR5C00
IPM5C07
MQA5C07 #
MBD5C07H
MBD5C07V
IPM5C08
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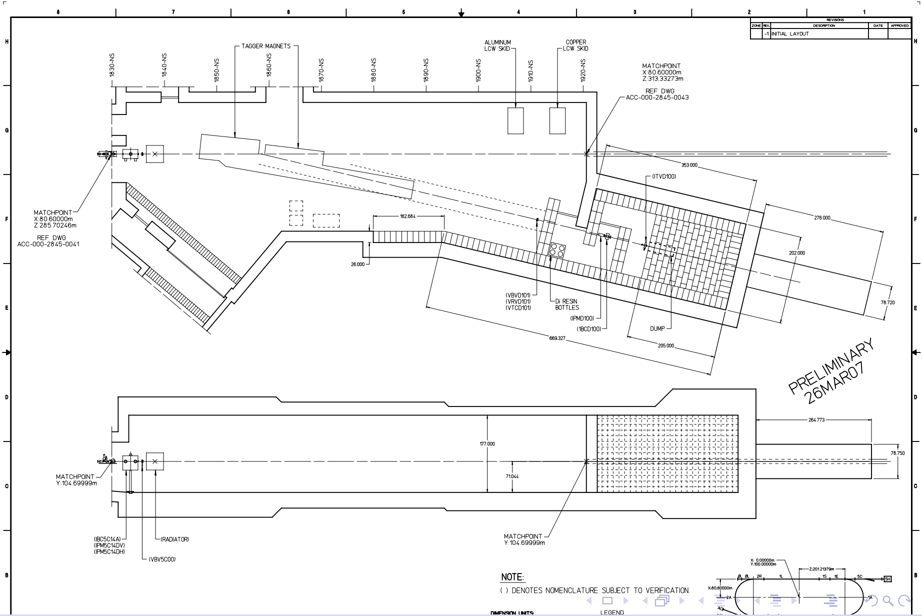
# DENOTES 20 AMP POWER SUPPLY.



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COPPER LCW SKID
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Di RESIN BOTTLES
(IPMD100)
(1BCD100)
DUMP
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205.000
PRELIMINARY 26MAR07
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71.044
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(RADIATOR)
(VBV5C00)
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NOTE:
( ) DENOTES NOMENCLATURE SUBJECT TO VERIFICATION.
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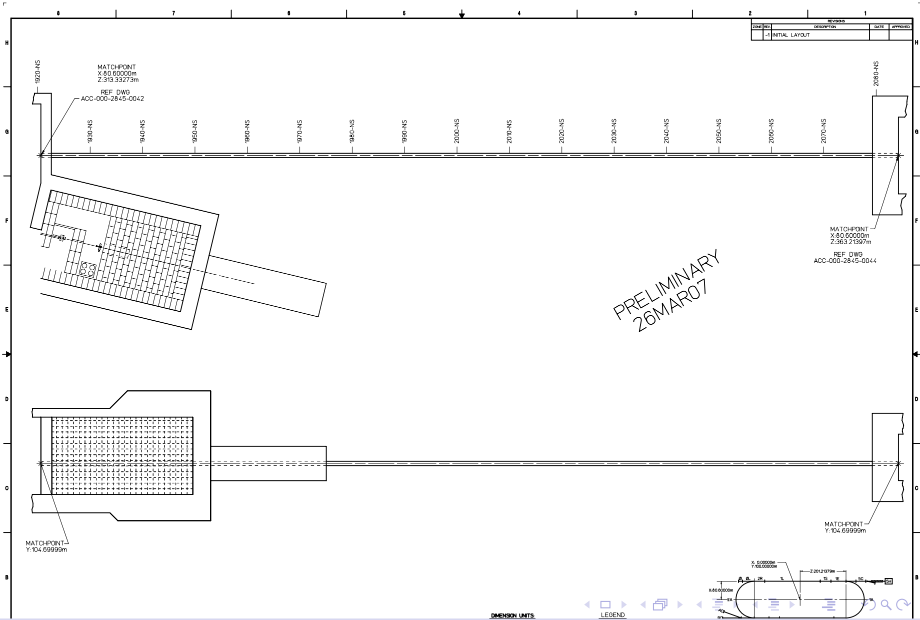
X:80.60000m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26MAR07
MATCHPOINT
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MATCHPOINT
Y:104.69999m
DIMENSION UNITS:
LEGEND

Summary

- CDR design achieves the required emittance and energy spread specifications but....
  - Hall-D out-years halo specification not meet.
  - Large beam sizes in recombiners.
- Work continues on making the “decks” reflect reality (**present** and future).
- Complete simulations of beyond-CDR options, once decks are throughly vetted.
  - Cost/benefit of the options will be evaluated at that time.
  - Tunability/operability of options to be evaluated.
  - Beam size and Halo determination
  - Smaller beam sizes will help reduce halo, but will not know if it is sufficient until simulations are performed.