Collider magnet moving system status report

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With input from many colleagues

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INTRODUCTION

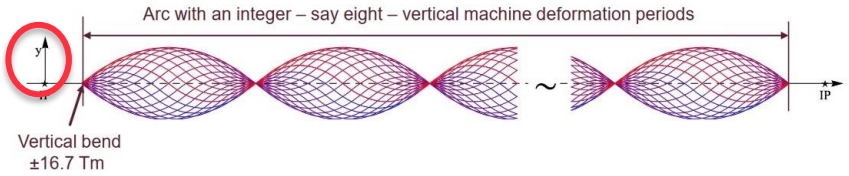
- Review of the work done so far – many points are already presented
- Mitigation requirements
- Collider magnets
- Moving the interconnections
- Support concepts
- Background:
  - Mitigation concept IMCC 2022 by C. Carli
  - Movers presentation IMCC 2023 by C. Accettura
  - Neutrino radiation model IMCC 2024 by C. Ahdida

MITIGATIONS REQUIREMENTS

The concept for baseline

Mitigation by "Wobbling"

- Wobbling of machine in vertical direction – part of MAP proposal?
  - Time-dependent mechanical deformation of ring around arc (including chromatic compensation, matching section and FMC arc cells
  - High precision movement system
  - Impact on optics?
- For 10 TeV com collider with 10 km circumference and say 4.8 km arcs



- Combination of pieces of parabola – two pieces with opposite curvature one period
- Say 8 periods 660 m long periods generating angles between -1 mrad and + 1 mrad
- Magnetic field (average) bending in vertical ±0.11 T
- Excursion (maximum total) ±150 mm
- Replaces vertical Gaussian angle distribution with rms opening of ≈0.0086 mrad by about rectangular distribution within ±1 mrad

=> About two order of magnitude reduction of peak dose rates

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Courtesy of Christian Carli

Mitigation fundamentals:

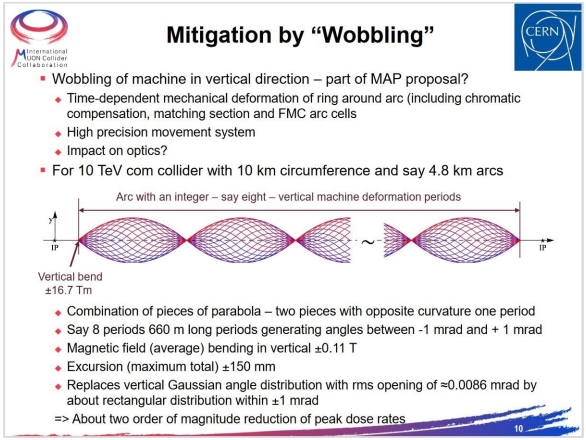
- **By C. Ahdida & J. Manczak**
- More than 100 steps leads to saturation(overlapping) within ±1 mrad range
- Range is 2 mrad, i.e. from +1 to -1 mrad per year
  - A period(two opposing parabolas) per two years
- This leads to appr. 48h between the steps(200 days of operation)
- Mitigation only applied vertically!(Y-axis on the image)

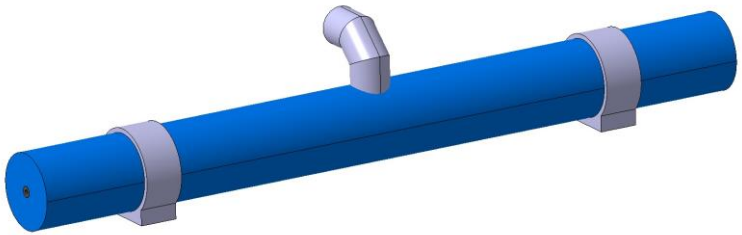
Questions:

- If 48h between the steps, is this acceptable in the most radiated area?(dose varies on the surface)
- Are there periods with no mitigation requirement?

MAGNETS

The concept for baseline





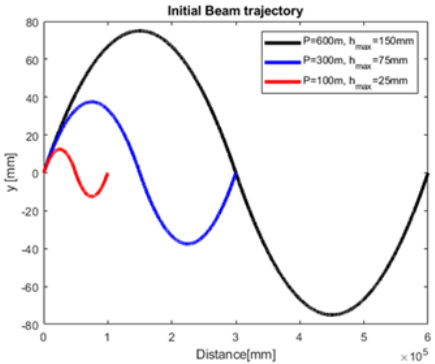
Magnet details:

- B. Caiffi et al: Collider magnets study
- Assumes 5 m dipole
- Beam aperture(5σ): Ø47 mm
- Magnet movers based so far on 10 m dipole –
  - The shorter the magnet, the more motors and cabling
  - The shorter the magnet, the smaller the movements for lay-out change
- m ≈ 2450 kg/m (HL-LHC D2 & W-shield)
- Supports at 1/6*L from the ends
- Reducing stroke, and thus period length, requires increase of vertical field by the same factor w.r.t. the baseline
- Vacuum barrier anchoring on a moving magnet

Questions:

- Can two beam lay-outs fit one magnet position?
  - Half the number of physical magnet movements
- Position tolerance of the magnets?

INTERCONNECTIONS



Interconnection details:

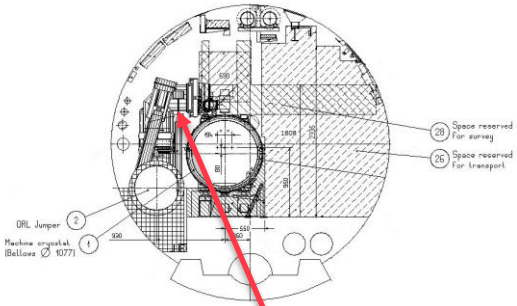
- Bellows see angular movement, < 1 mrad, and offset, appr. 0.13 – 0.9 mm, depending on the magnet position on the period, due to lay-out change(100 m period, 10 m magnet)
  - Movement based on same speed for all jacks
  - Jacks can be also driven with different speed
- Leads and splices over the interconnection see the same movement – design with care but is feasible
- Running magnets into opposite extreme positions will destroy bellows!(and leads, splices)
  - Can be solved mechanically
  - Can be solved with control system

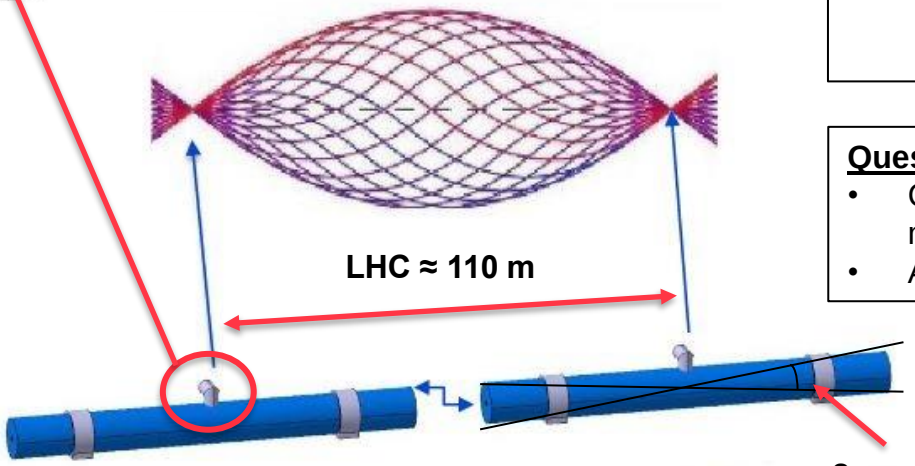
Questions:

- Other features of the interconnection?

Assumptions based on the LHC interconnections!

CRYOGENICS





Baseline is LHC-type cryogenic line with periodic connections to magnets:

- Distance between connections(the “jumper”) at most appr. 100 m
- LHC design for the jumper cannot accommodate magnet height change as in the muon collider arc – must be placed at period start and end points.
  - It must be able to accept angular movements! (±1 mrad)

Questions:

- Can the jumper accommodate angular movement? Can it be designed for that?
- Are there other options for the cryogenic line?

Based on the LHC!

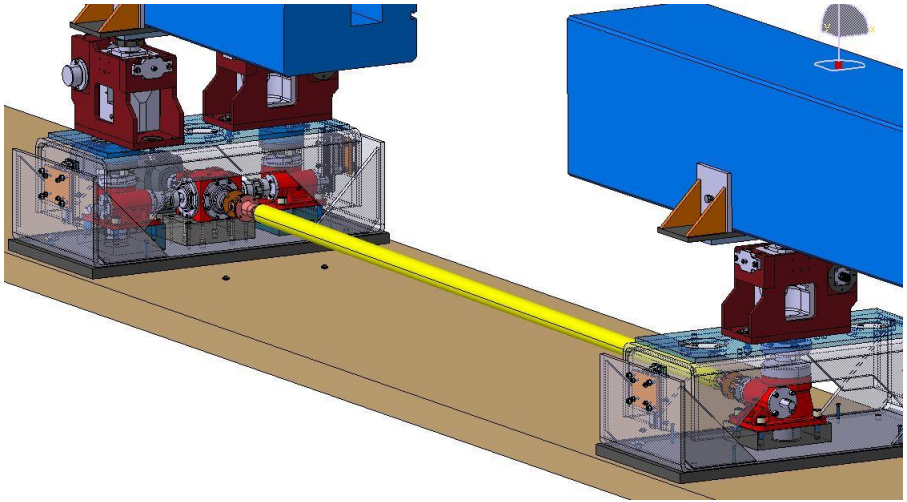
CONCEPT SPECIFICATION

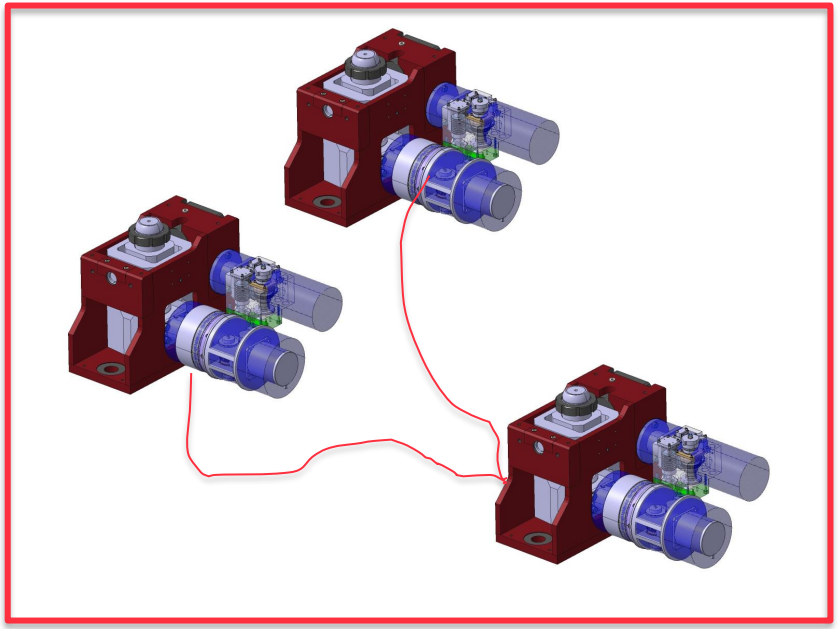
collection of input from previous slides

BASELINE FOR THE MOVER SYSTEM:

- 100 steps for the beam per year (0.02 mrad) = every 2 days with 200 days of operation
- Fitting 2 beam lay-outs per physical magnet position -> physical movement every 4 days
  - Loss of operation = movement time/96 hours -> time in hours for movement ≈ percentage of operation. Target value?
- Steps for magnet = 2 mrad/50 (= 0.04 mrad)
  - For 10 m dipole on a 100 m period, the angular movement leads into a minimum vertical step of 133 µm.
  - Tolerance of magnets' positions after movement? (0.004 mrad = 13 µm on a jack)
- Period length defined by cryogenic supply would be appr. 100 m
  - 1/6 of the original period
  - Leads to 6x the original vertical field, 0.11 T -> 0.67 T
  - Leads to 1/6 of the original stroke, thus to ± 25 mm vertical stroke
- Interconnection must be protected from the vertical deviation

HOW TO PROTECT THE INTERCONNECTION?





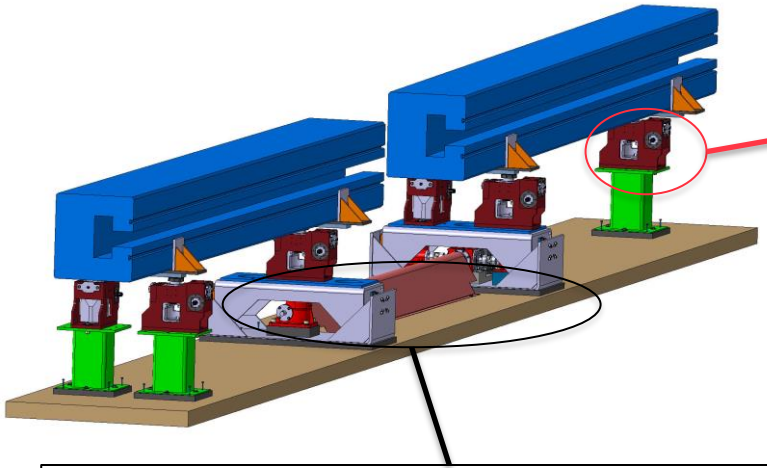
Option 1: Mechanical protection

- Connect vertical jacks across the interconnection
- Use common platform
- Mechanical stoppers across the interconnection

Option 2: Control system based or “mixed”

- Movement monitoring
- Limit switches
- Deformation measurement for rigid connection

OPTION 1: TWO JACK SYSTEMS



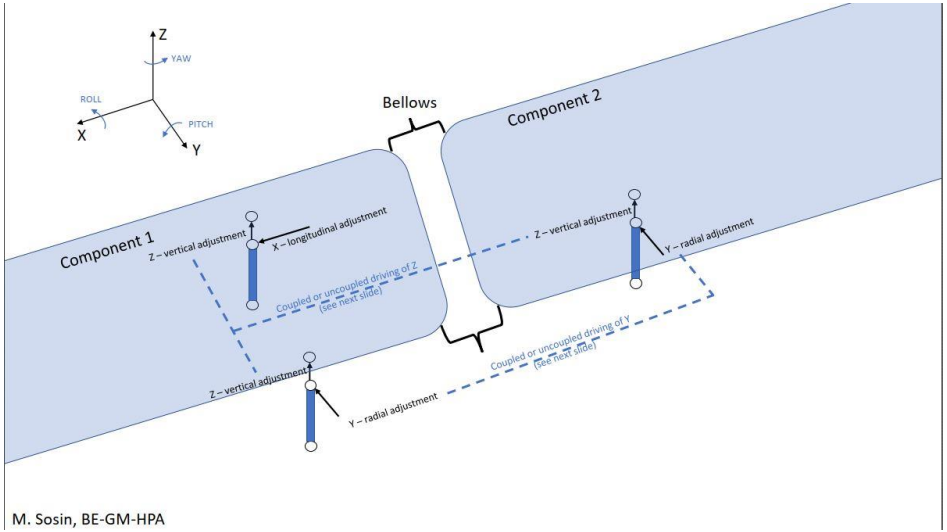
- 6 D-o-F alignment and corrections by HL-LHC jack
  - Sufficient for required movement
  - No development cost
  - 6 motors per magnet for corrections
    - May be 5 if longitudinal is not required
  - HL-LHC jack small motorized movement protects interconnection

- Three jack system to drive interconnection <u>height</u> change with one motor
  - This system cannot offset magnet ends
  - One 0.12 kW motor
  - Commercial components
  - Height around 400 mm

Pros and cons:

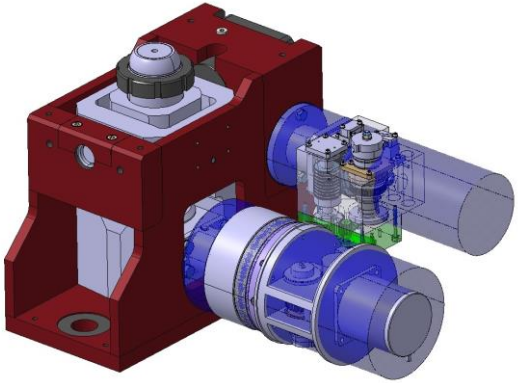
\+ No jack development
\+ May require only one motor for lay-out change
– Space penalty
– Steel structures for HL-LHC jacks
– May require 5 or even 6 motors for corrections, altogether 6 or 7 motors per magnet

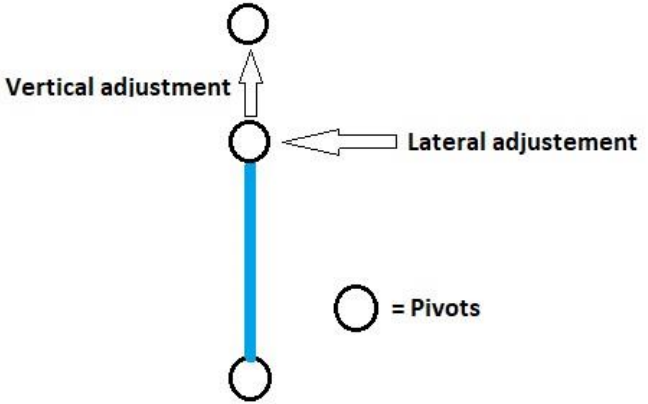
OPTION 2: NEW JACK CONCEPT



- Concept proposal by Mateusz Sosin CERN BE-GM
- Mechanically connected jacks for vertical movement
  - Drive with one motor
  - Add **clutches** to allow correction for height and tilt driven by same motor
- Add one motor for longitudinal and two for lateral corrections
  - 4 motors in total, 3 if radial alignment can be coupled and 2 if no longitudinal correction is required

NEW JACK OPTIONS





Option 2A: Modified LHC jack

+ Designed for similar loads
+ Coupling motions results in max 4, min 2 motors
– Modify vertical movement
– Modify for connected vertical movement

Option 2B: New jack development

+ Can be designed to specification from start
+ Coupling motions results in max 4, min 2 motors
+ External design possible
– Complete development program = time

TO BE STUDIED

- Design of most promising solution
- Mechanical behavior
  - Between steps
  - Friction
  - Wear
  - Done with the mock-up
- Level of control system for the required accuracy
  - Including the measurement system
  - Done with the mock-up
- Leads and splice behaviour?
  - With separate test set-up
- EMC compatibility
  - Testing of individual components(unless already certified)
- Radiation compatibility
  - Testing of individual components?(unless already certified)

FUTURE ACTIONS

- Specification definition AND approval
  - Followed by concept selection
- Launch detailed design of the concept
  - Mechanical system design can be launched following concept selection
- Control and measurement system definition
- Testing campaign for the mover mechanical system components
  - Individual components, interconnection mock-up to test the mechanical components together
  - Investigate the possibilities of a full system study with digital twin
- Design verification and production drawings for mechanical system (– five years cumulated from design launch)
  - Collider magnet development time is much higher
- Production + software
  - Time for the development of the measurement system not known!
- Series system testing
  - Fully representative mock-up for mechanical system, use also with magnet testing in string

CONCLUSIONS

- How often beam must be replaced? Every 48 h?
- How often we have to move the magnets? Every 96 h?
- The period length is 100 m?
- What is the required movement and the required accuracy?
- Developing a new jack system is most space efficient
- Collider magnet development takes much longer – delivery in 17 – 26 years
- We need a realistic mock-up to test the system behaviour
- Measurement system depends on the required accuracy – thus may be substantial development and cost

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MuCol

Thank you for your attention!

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Your questions please?

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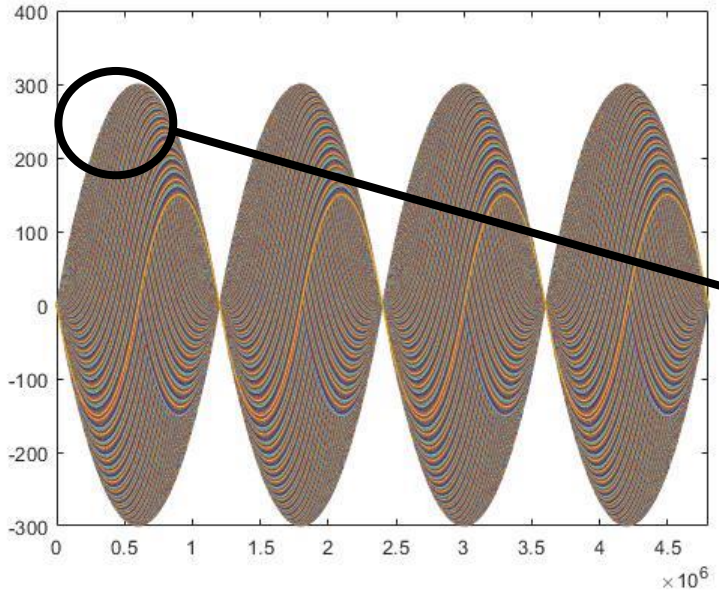
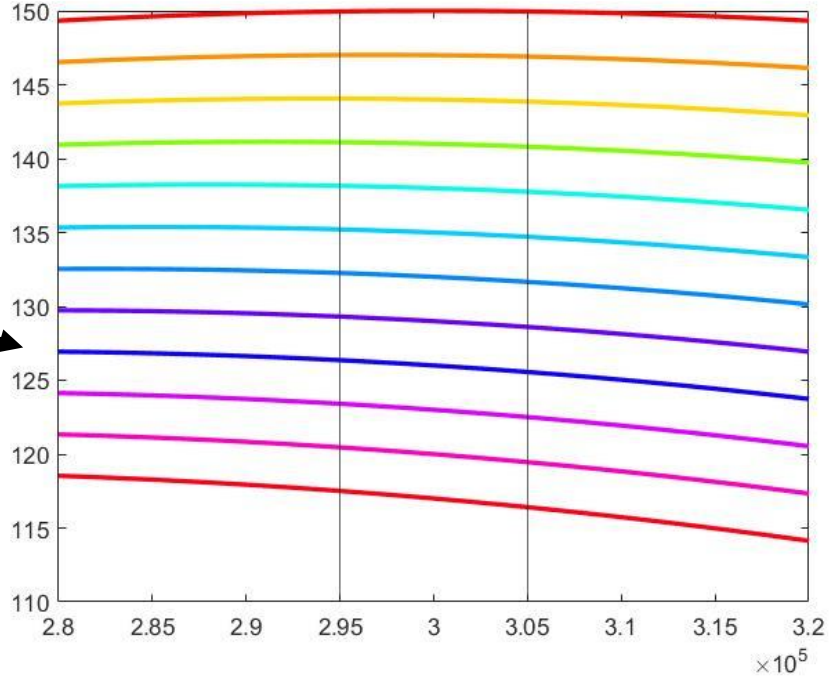
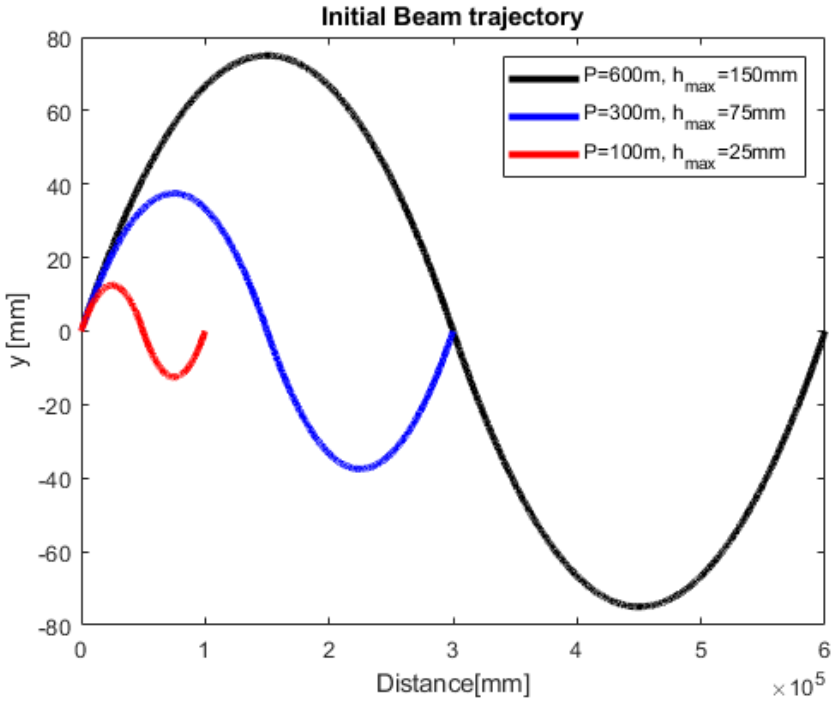
SPARE SLIDES

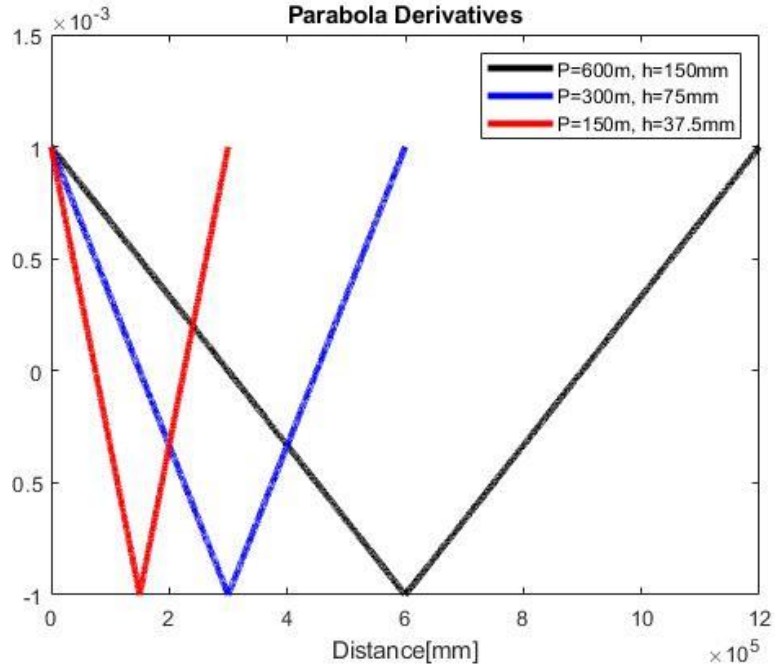
BEAM TRAJECTORIES vs. MAGNET MOVEMENTS



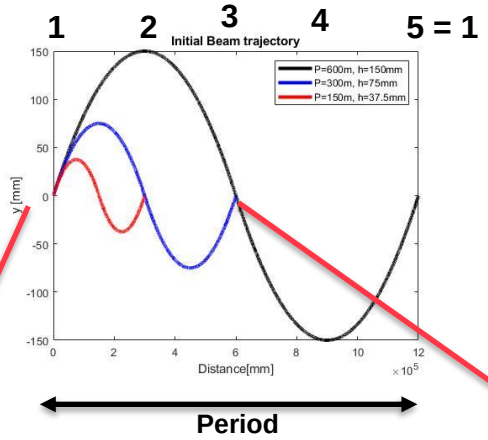


To be studied: how many beam trajectories could be fit into one magnet lay-out

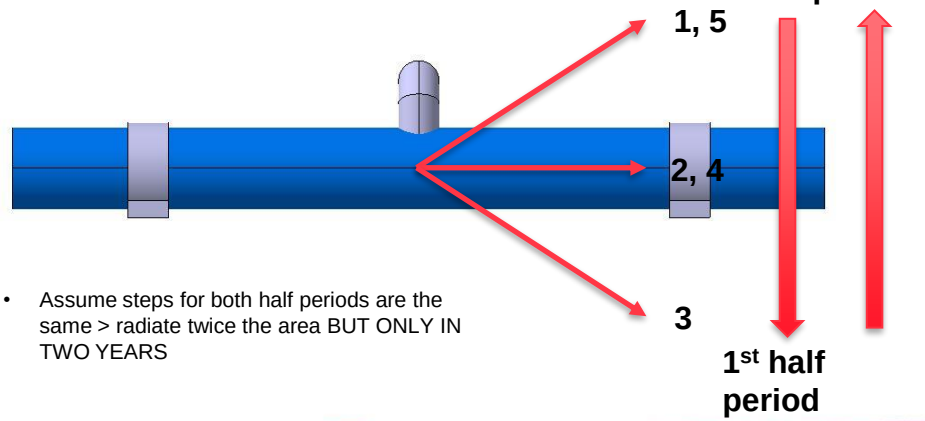

Initial Beam trajectory
P=600m, h_max=150mm
P=300m, h_max=75mm
P=100m, h_max=25mm
y [mm]
Distance[mm]
×10^5


Parabola Derivatives
×10^-3
P=600m, h=150mm
P=300m, h=75mm
P=150m, h=37.5mm
Distance[mm]
×10^5

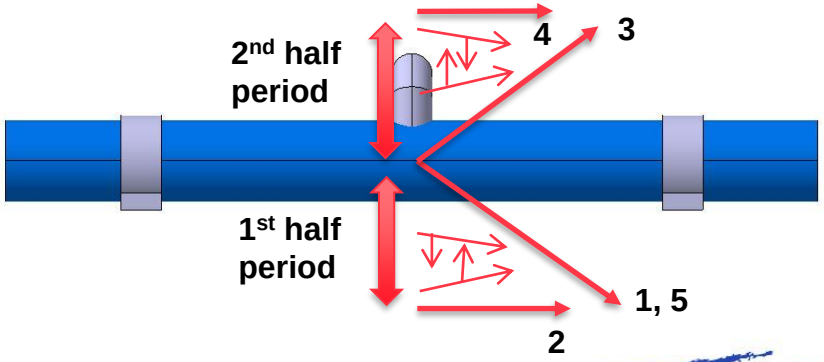
MAGNET MOVEMENTS



Magnets at period start/end



Magnets at period mid-point



- Assume steps for both half periods are the same > radiate twice the area BUT ONLY IN TWO YEARS

LAY-OUTS

Period	Steps	Magnet	Angular step magnet	Min jack step	Max jack step	Jack range
100 m	50	10 m	0.04 mrad	0.133 mm	0.9 mm	± 25 mm
100 m	100	10 m	0.02 mrad	0.067 mm	0.45 mm	± 25 mm
100 m	100	5 m	0.02 mrad	0.033 mm	0.23 mm	± 25 mm
600 m	50	10 m	0.04 mrad	0.133 mm	6 mm	± 150 mm