Protons, electrons and muons

A. Alekou
University of Oxford and John Adams Institute
androula.alekou@physics.ox.ac.uk

Many thanks to my supervisors:
F. Ptochos (UCy), J. Pasternak and K. Long (Imperial College London),
Y. Papaphilippou (CERN), R. Bartolini and A. Seryi (Oxford University)


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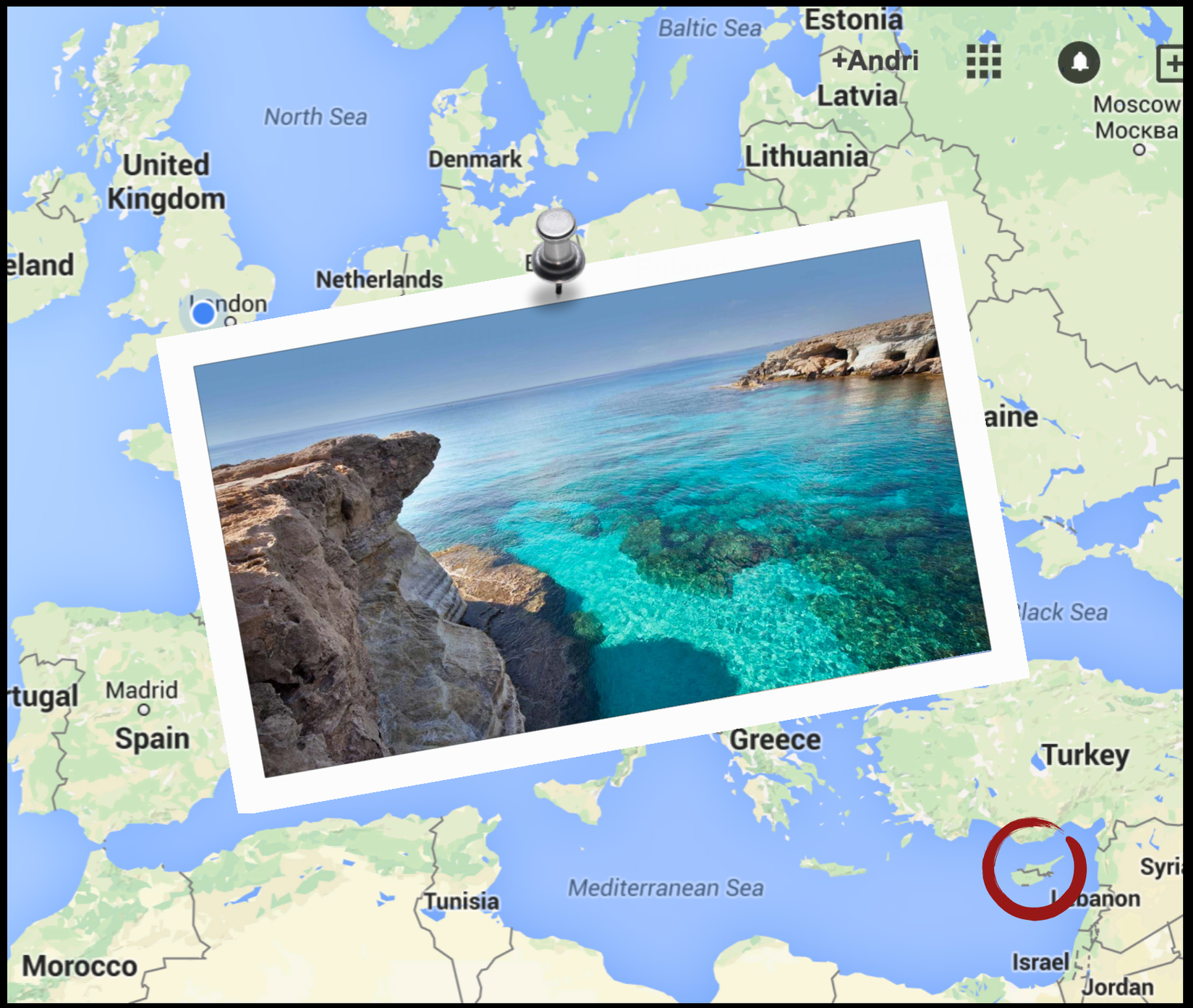
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- COMET/PRISM, muon decelerator
- Mu2e, PSI, Switzerland, detector calibration test run

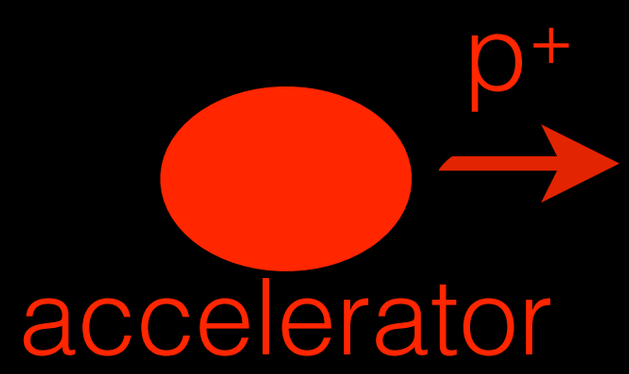
- R&D and simulations
- running experiment

Neutrino Factory

Neutrino Factory

Future project. Aims to produce high intensity neutrino beams to determine mass hierarchy and measure neutrino parameters in unprecedented precision [1]


accelerator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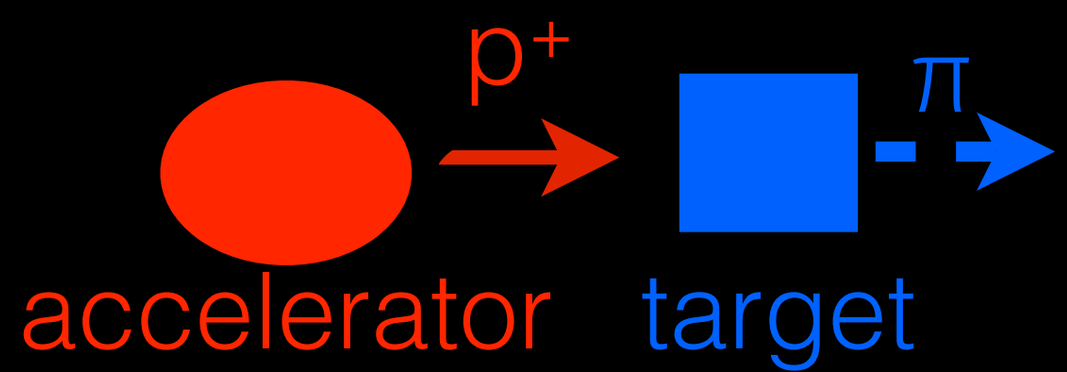
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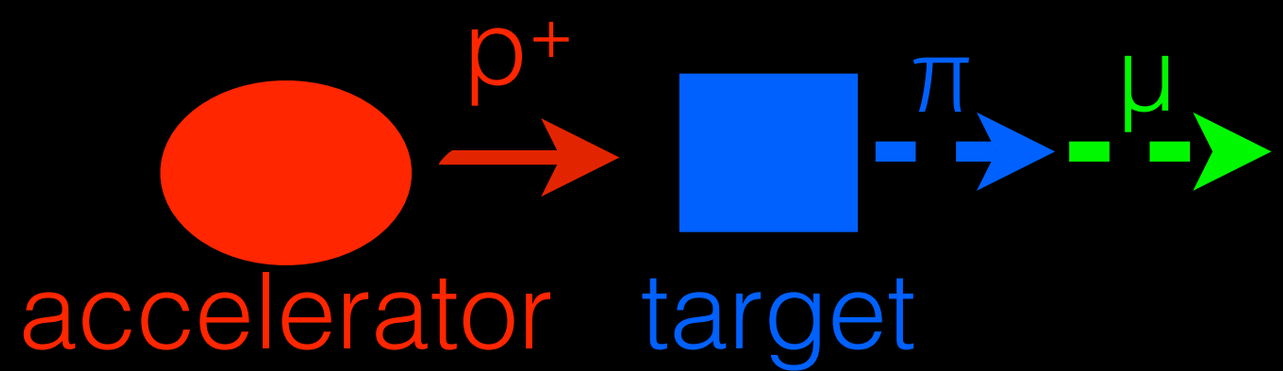
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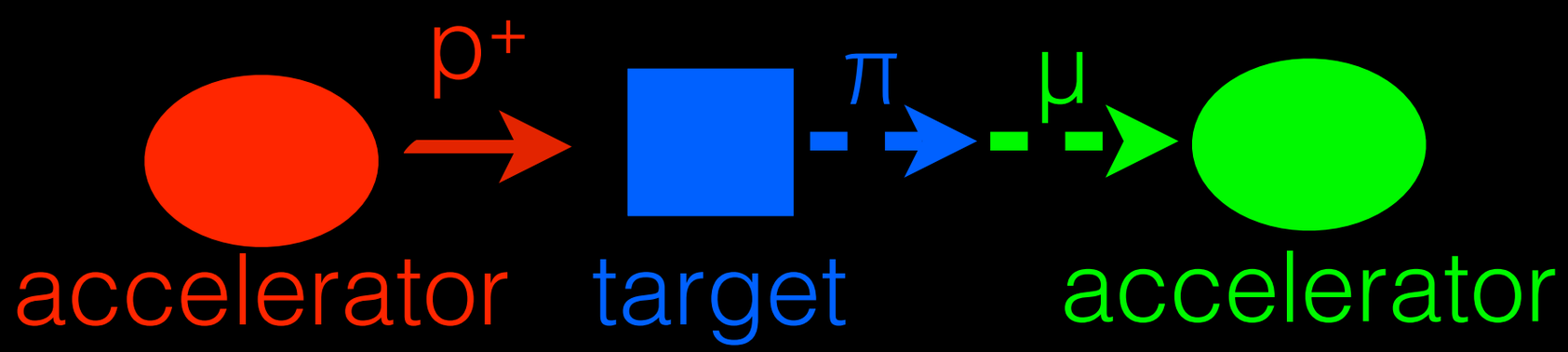
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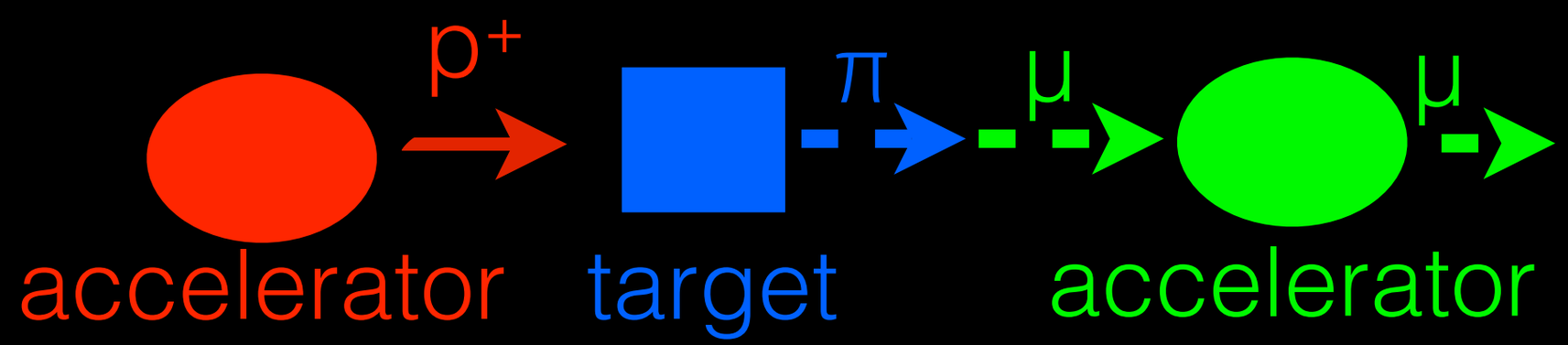
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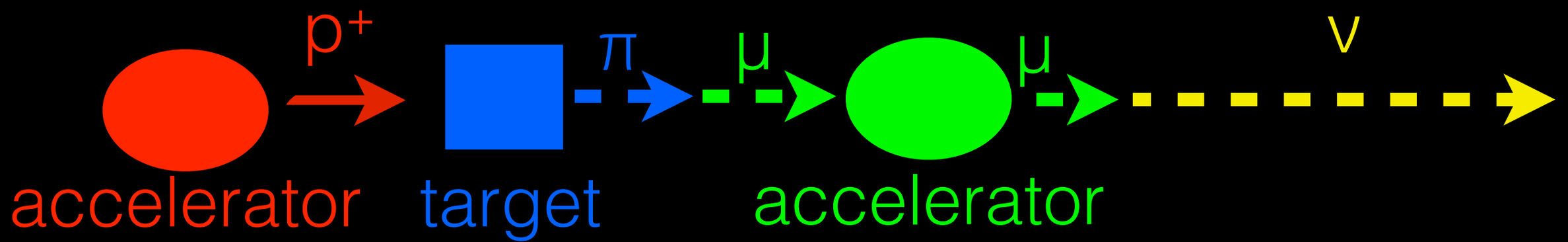
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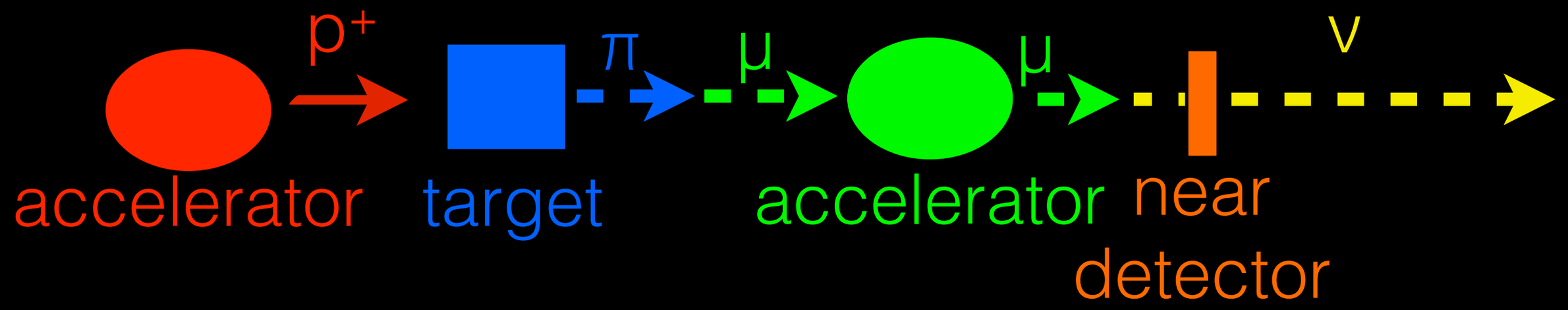
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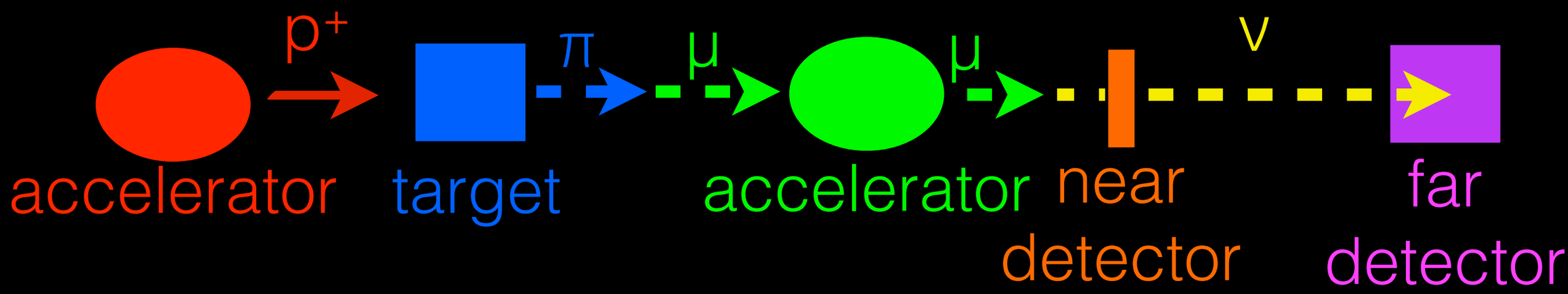
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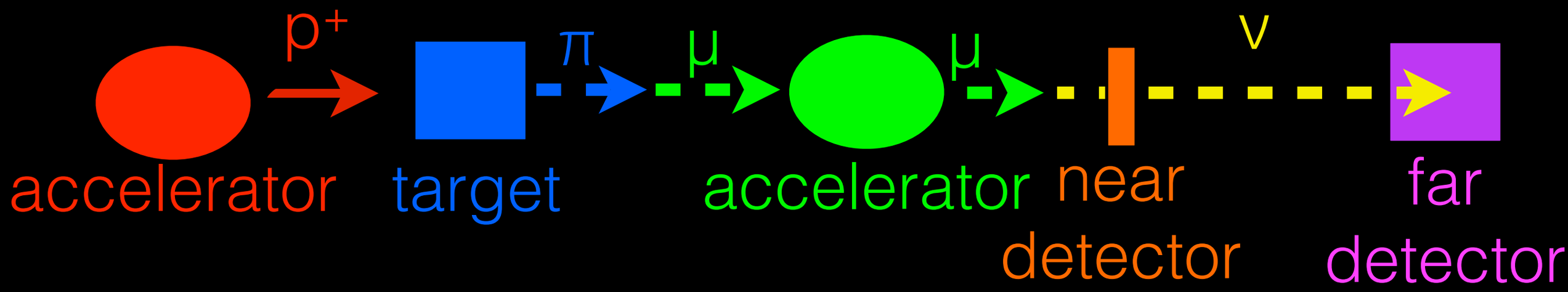
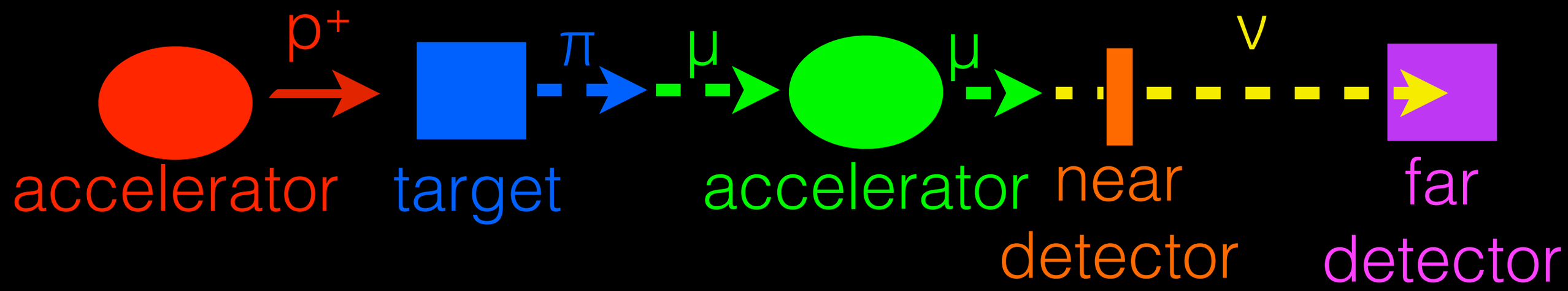
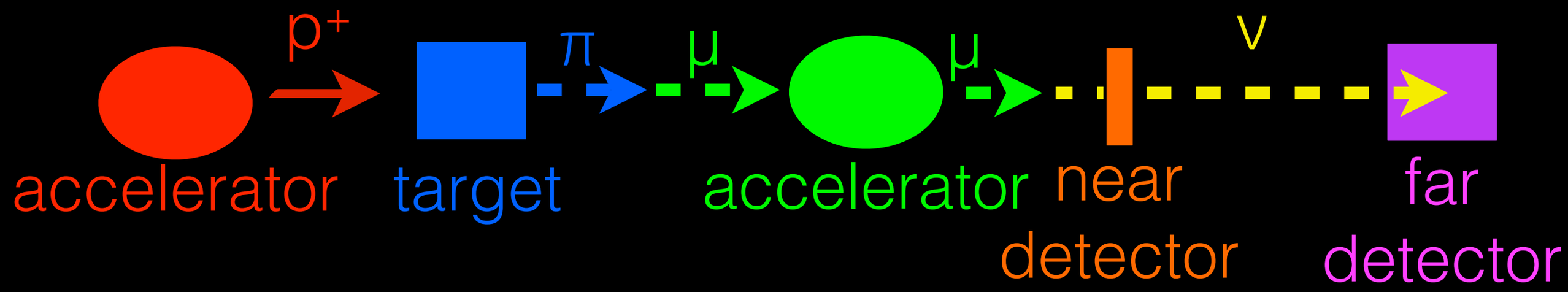


Problem: when muons are produced they occupy a large transverse phase-space



Problem: when muons are produced they occupy a large transverse phase-space

In order for muons to fit within acceptance of downstream accelerator, phase-space needs to reduce



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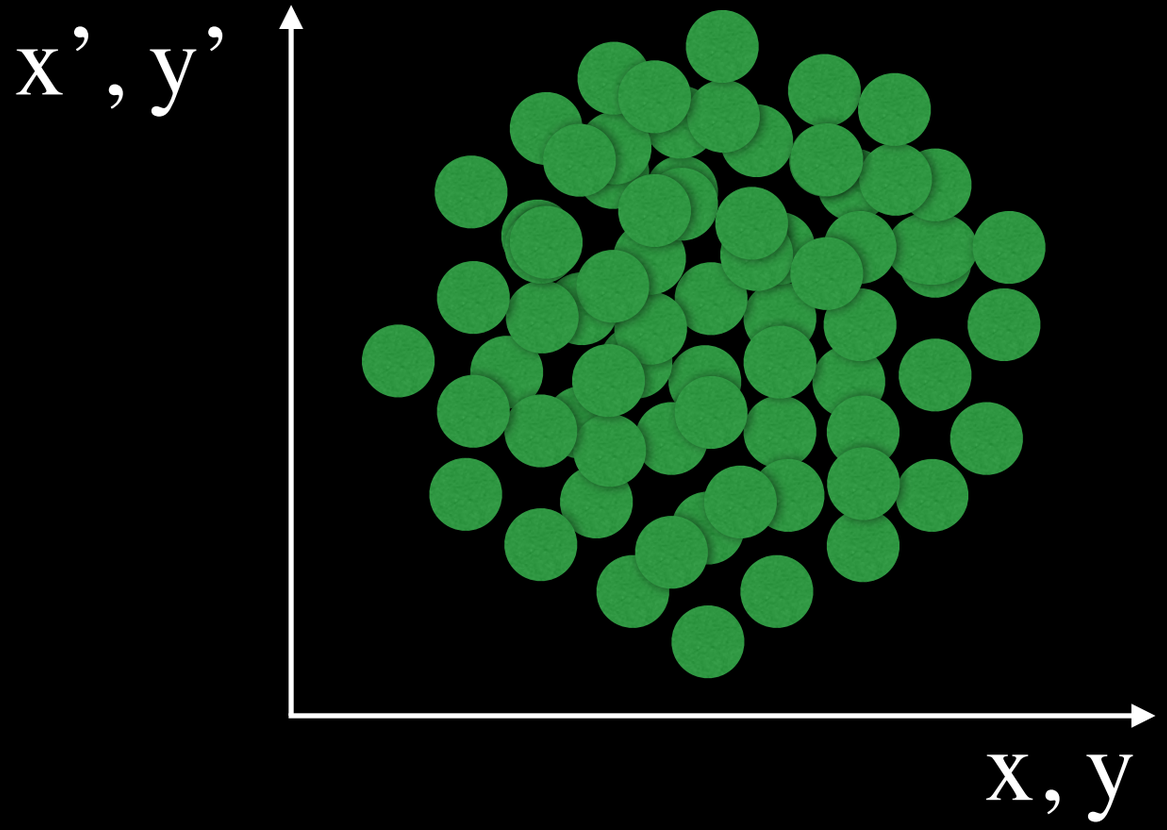

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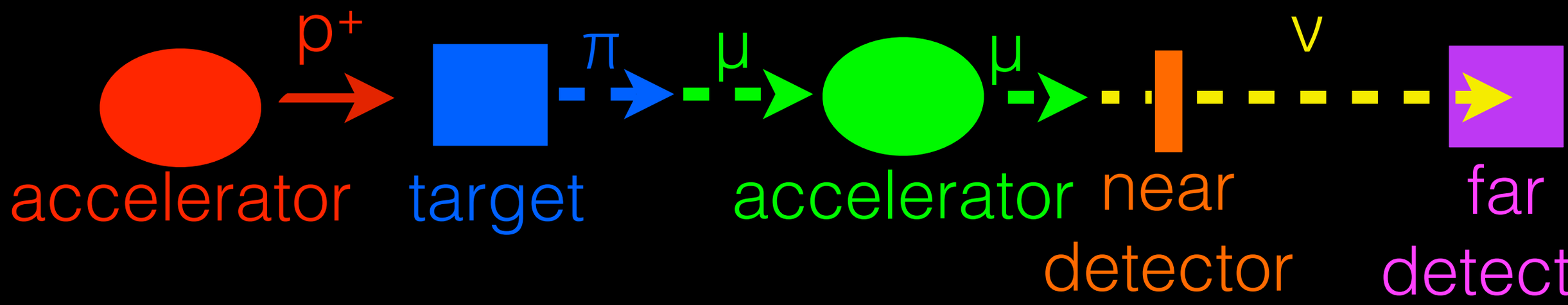

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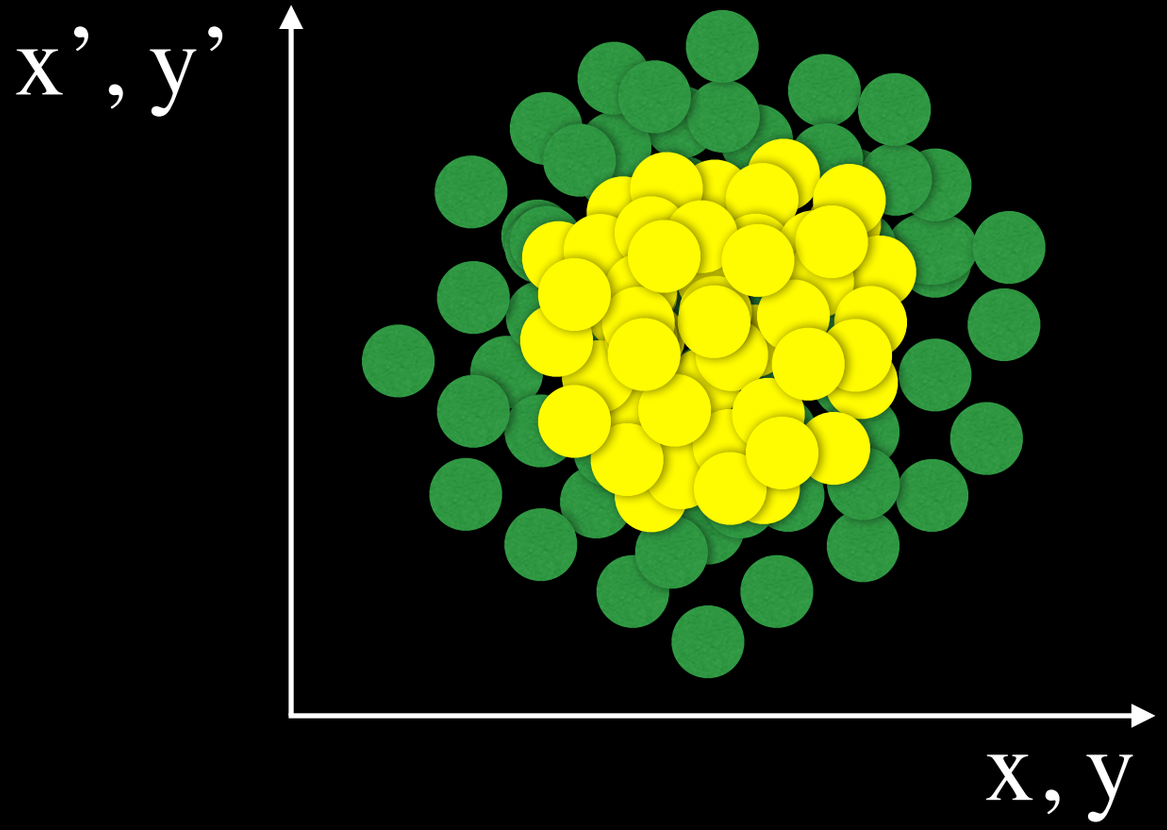

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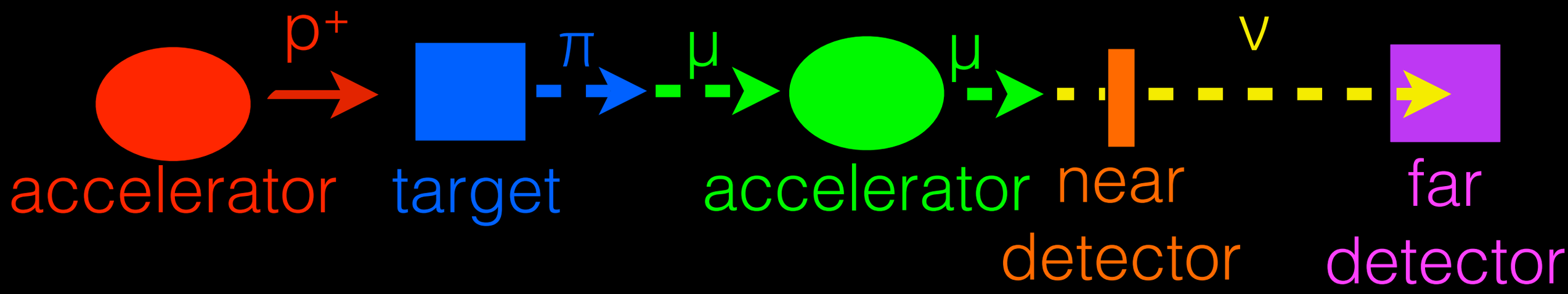

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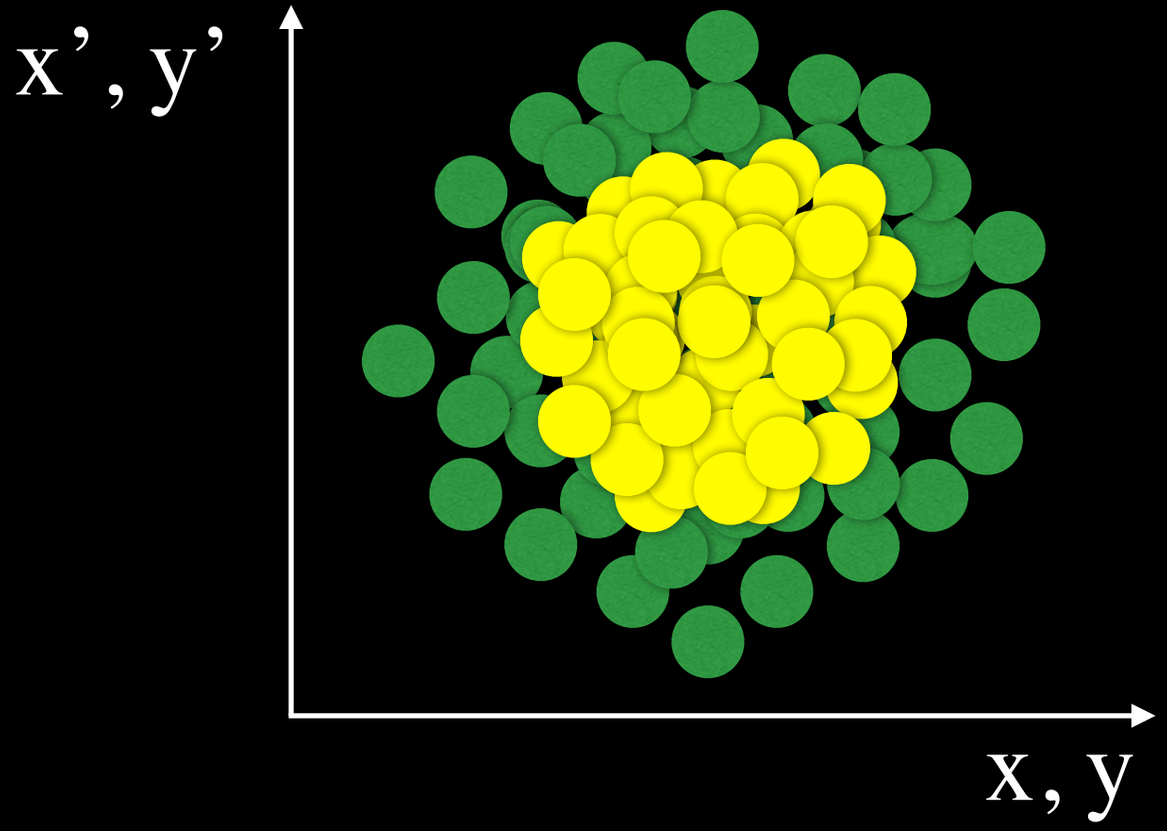


In order for muons to fit within acceptance of downstream accelerator, phase-space needs to reduce

…but muons decay very fast so only viable technique is **ionisation cooling**

Ionisation Cooling

Ionisation Cooling

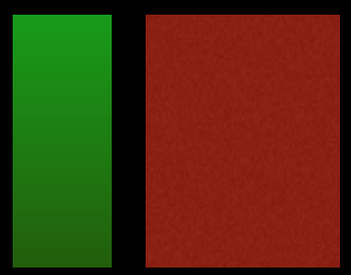
Muons pass through absorbers;
momentum decreases in all directions

Absorber

Ionisation Cooling

Muons pass through absorbers;
momentum decreases in all directions

Muons pass through RF cavities; momentum
restored only in longitudinal direction



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RF cavity

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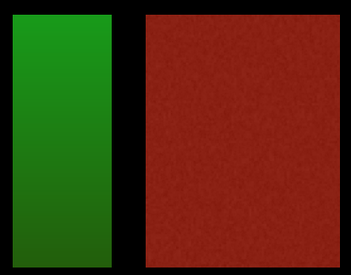
Repeat many times



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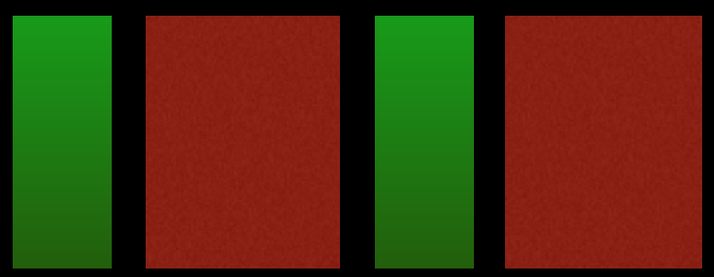

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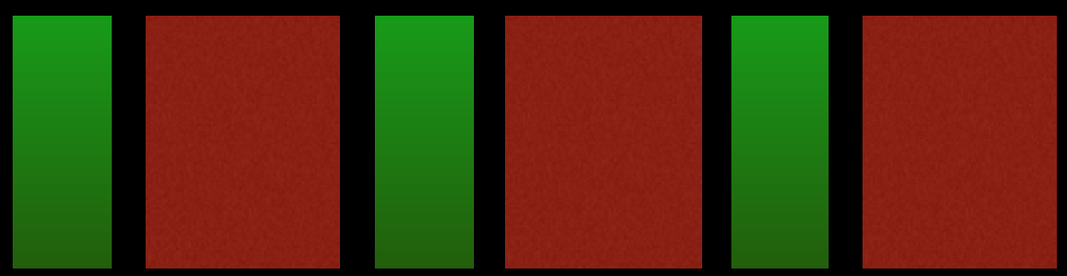

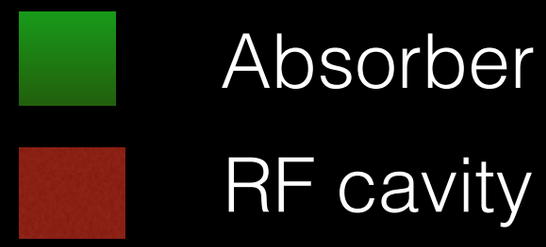

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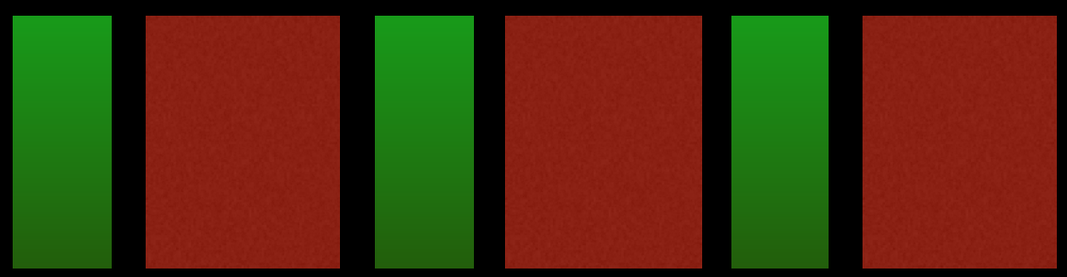
Repeat many times

Net effect: transverse emittance reduction



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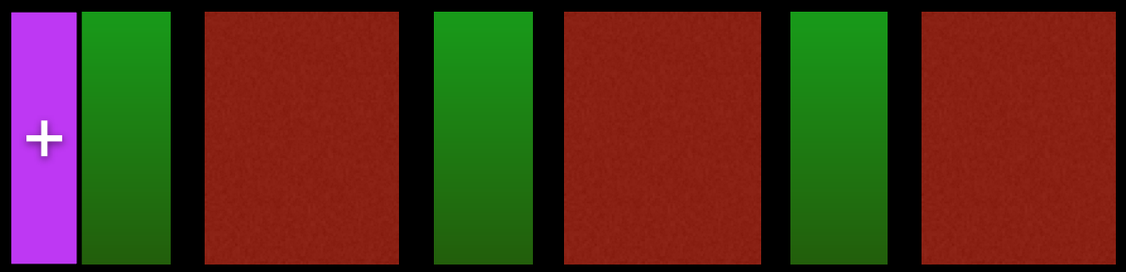

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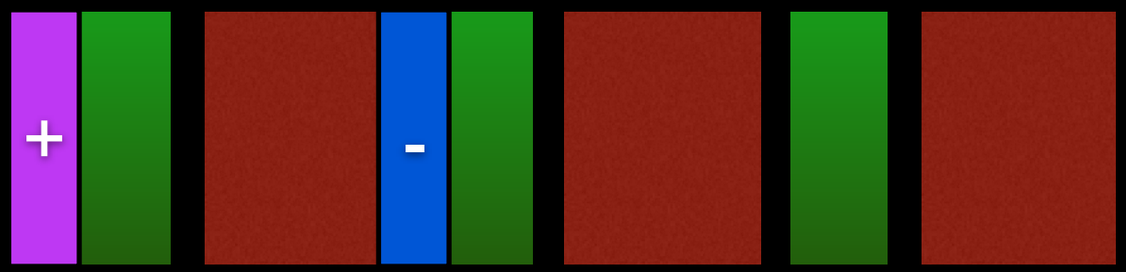

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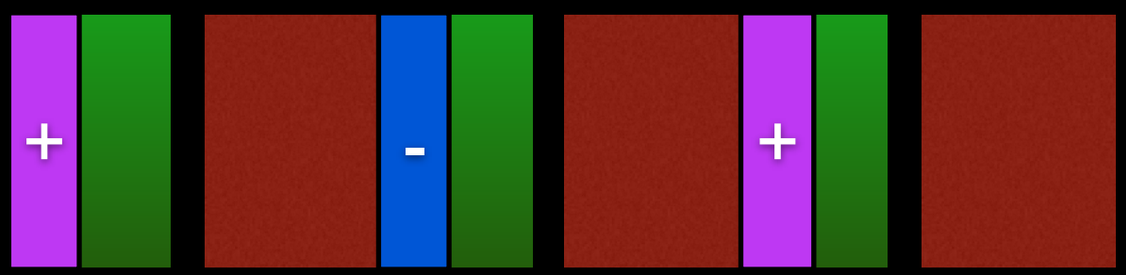

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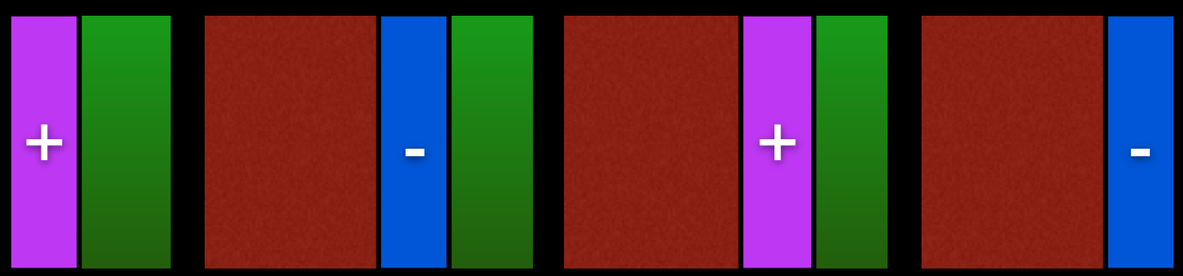

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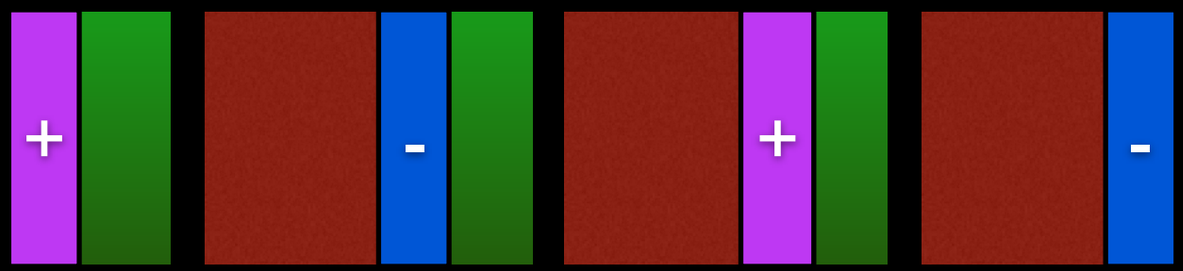
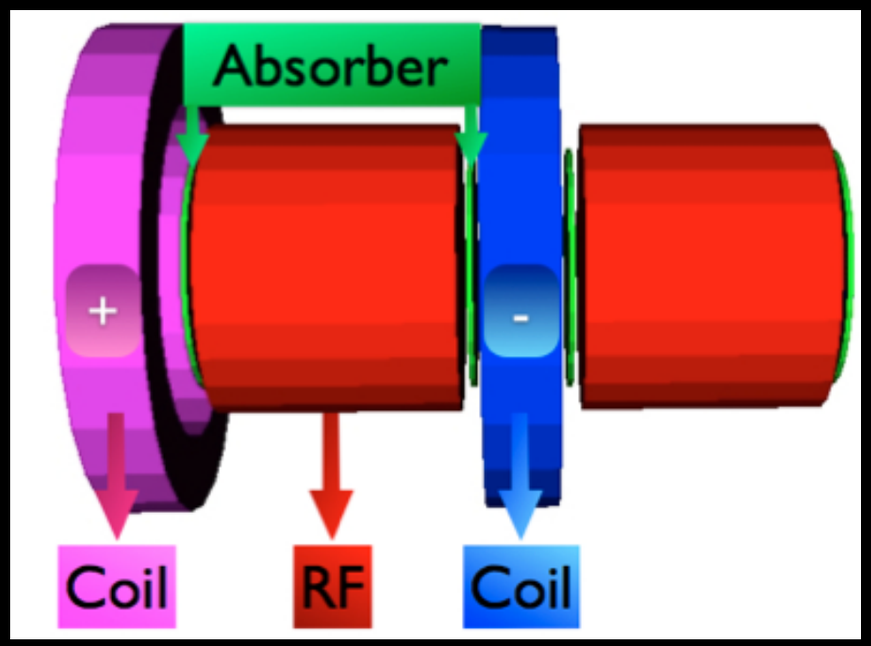
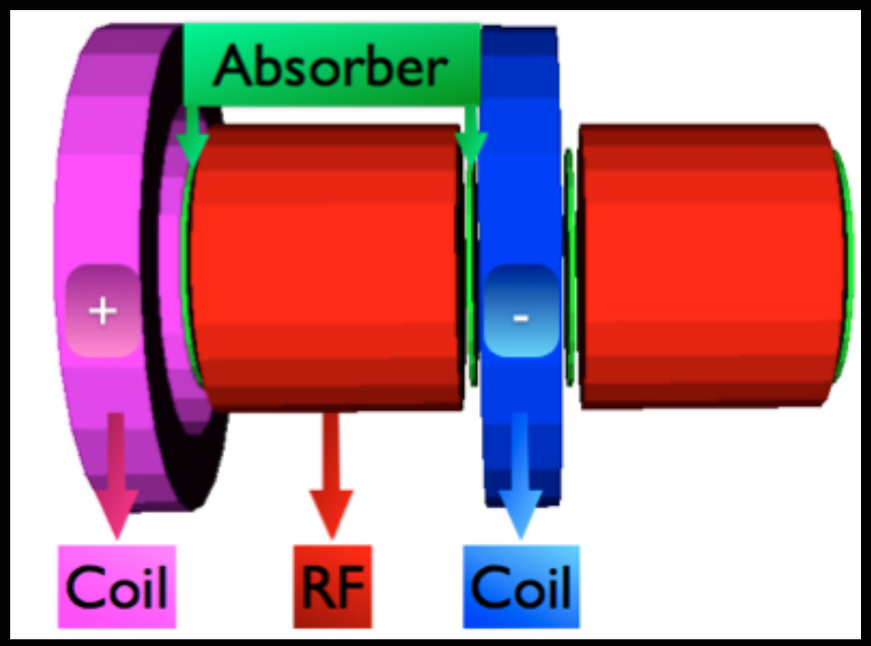


Reference Cooling Lattice



Reference Cooling Lattice

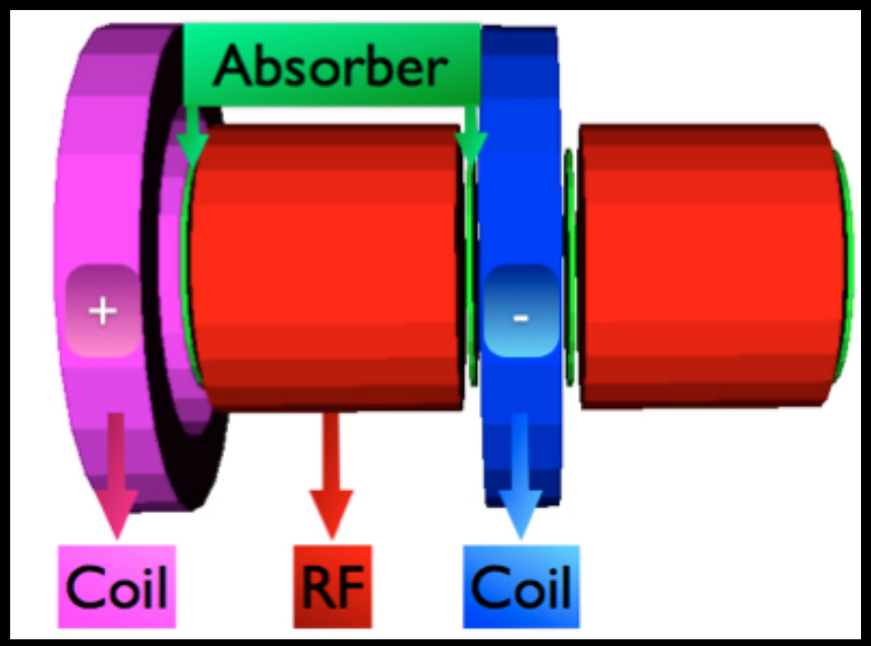
Reference ionisation cooling lattice of NF reduces successfully transverse emittance



Reference Cooling Lattice

Reference ionisation cooling lattice of NF reduces successfully transverse emittance

...but has very large magnetic field at end of RF cavities...



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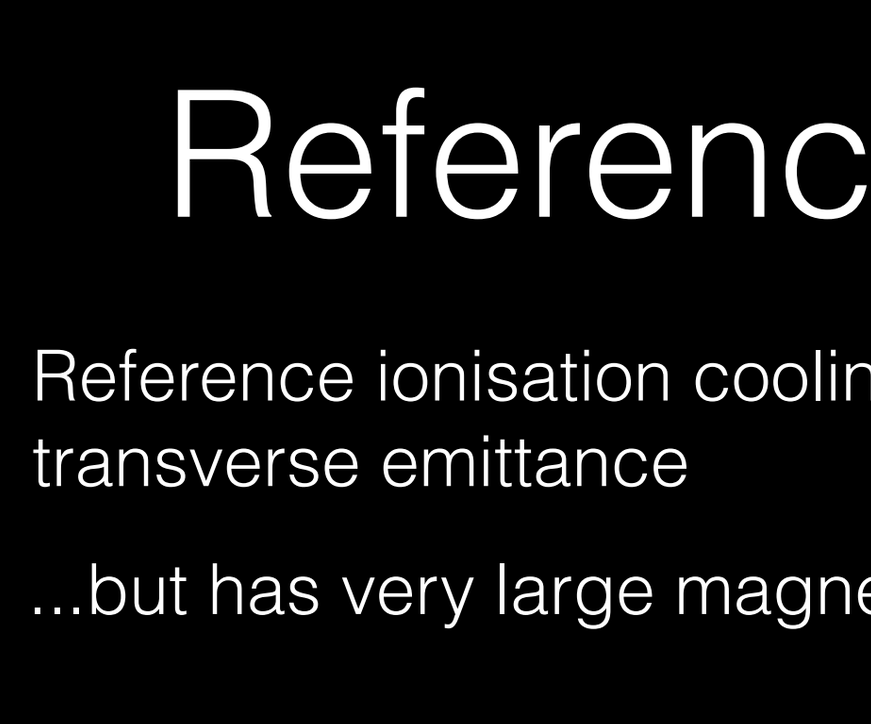
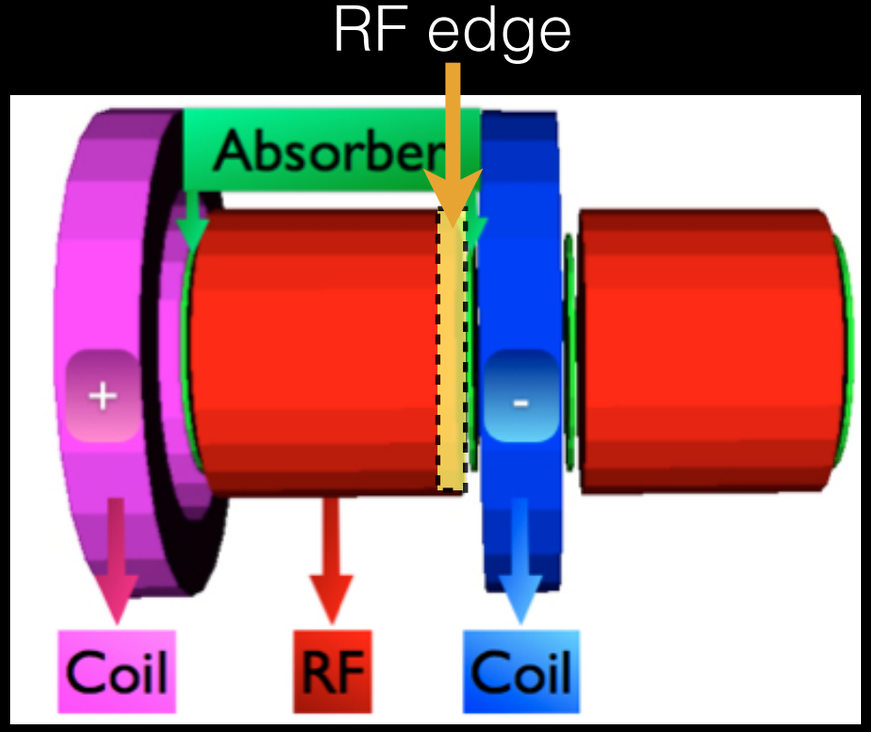


Reference Cooling Lattice

Reference ionisation cooling lattice of NF reduces successfully transverse emittance

...but has very large magnetic field at end of RF cavities...

...and recent studies indicated that high magnetic field at end of RF cavities can lead to RF breakdown



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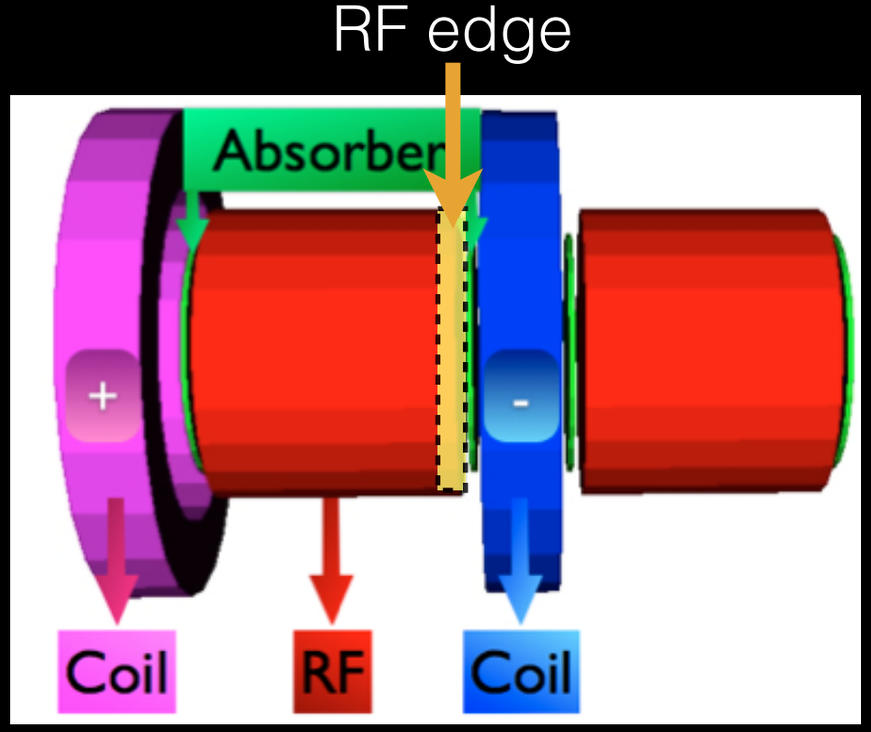
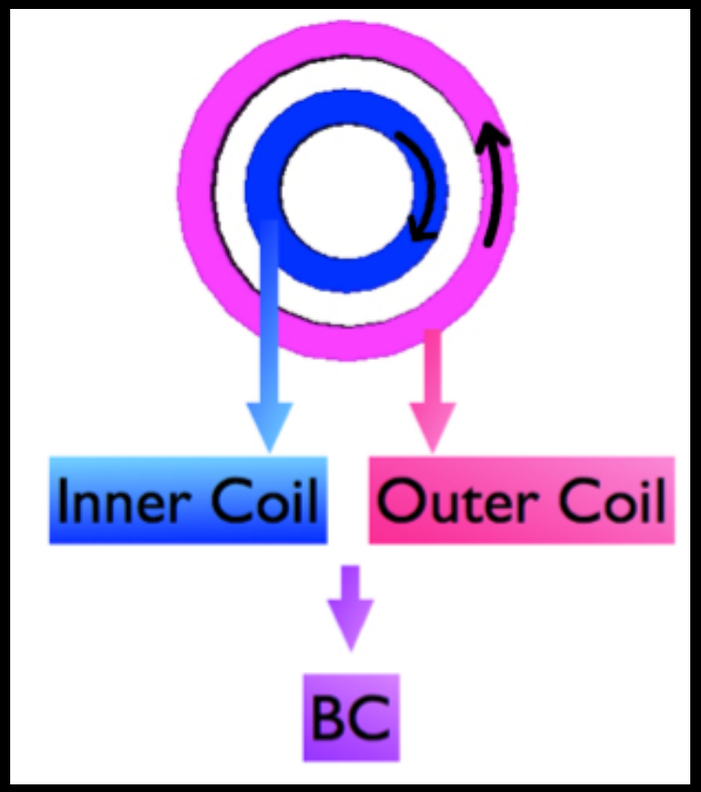


Need to find alternative lattice that:

a) reduces significantly magnetic field at RFs
b) without compromising emittance reduction and muon transmission

Bucked Coils Lattice

- **IDEA**: Proposed and designed a new lattice that uses a pair of co-axial and opposite polarity coils, called Bucked Coils (BC), rather than a single one



Pair of Bucked Coils (BC): co-axial and with opposite polarities

Bucked Coils Lattice

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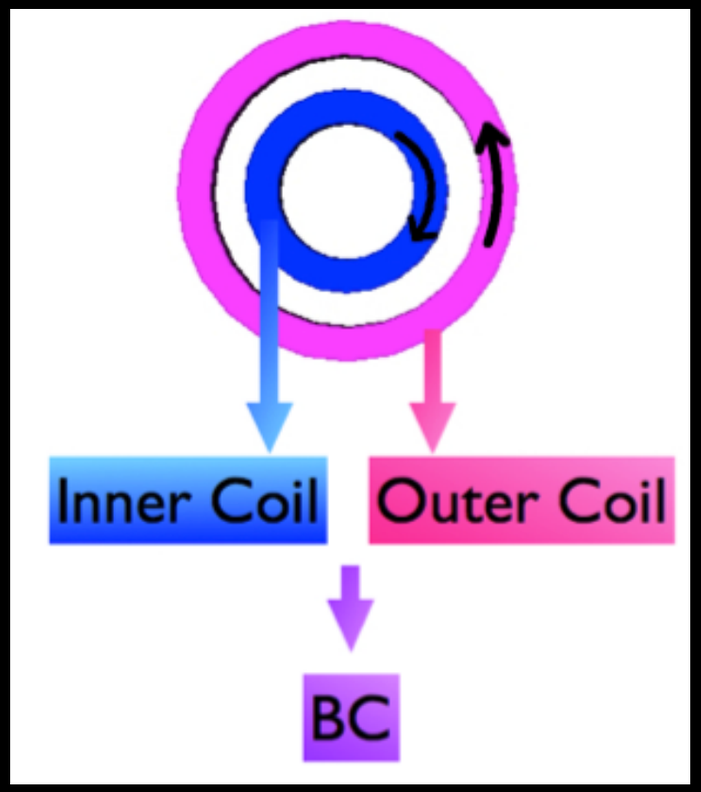
...and with every repetition of the BC pair the polarity alternates



Pair of Bucked Coils (BC): co-axial and with opposite polarities

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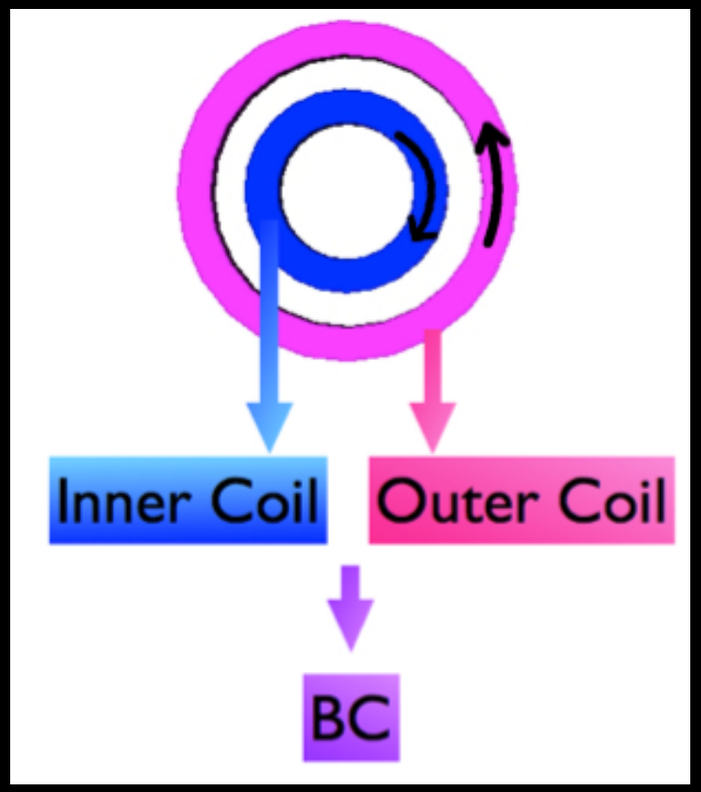
- **IDEA**: Proposed and designed a new lattice that uses a pair of co-axial and opposite polarity coils, called Bucked Coils (BC), rather than a single one

...and with every repetition of the BC pair the polarity alternates



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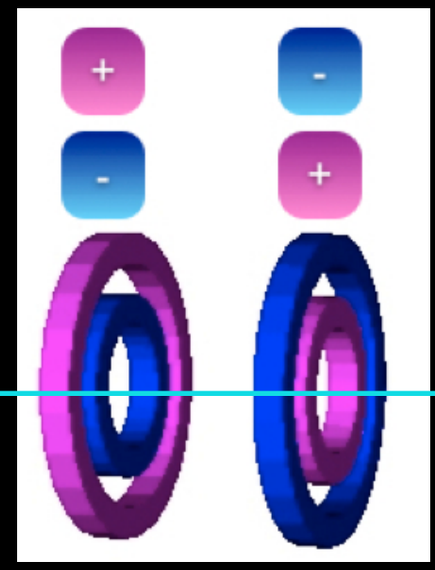

Polarity of BC alternates with every repeat

Ref: [2], [3], [4]

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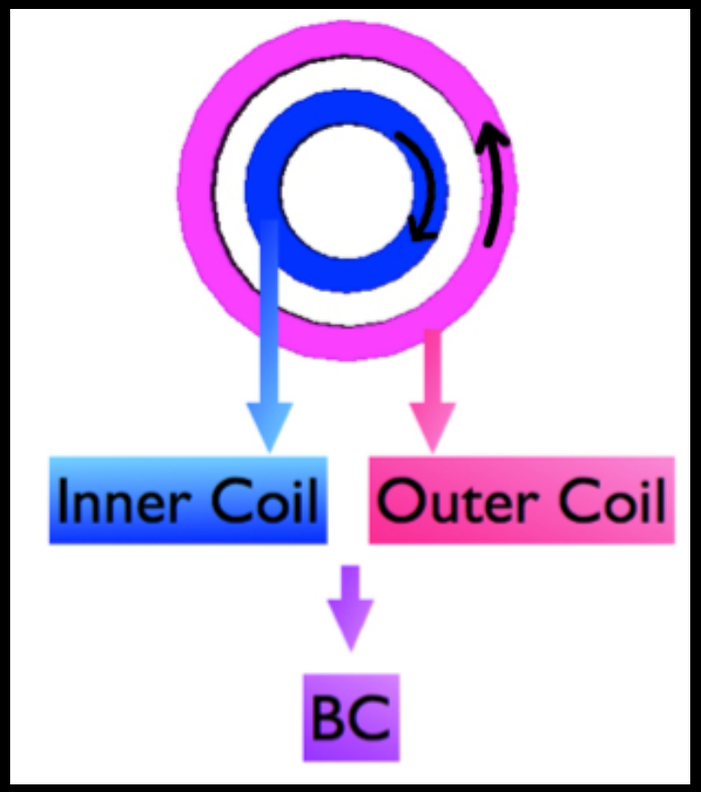

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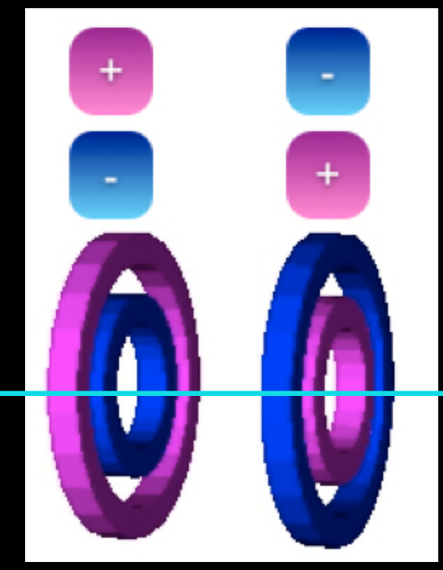

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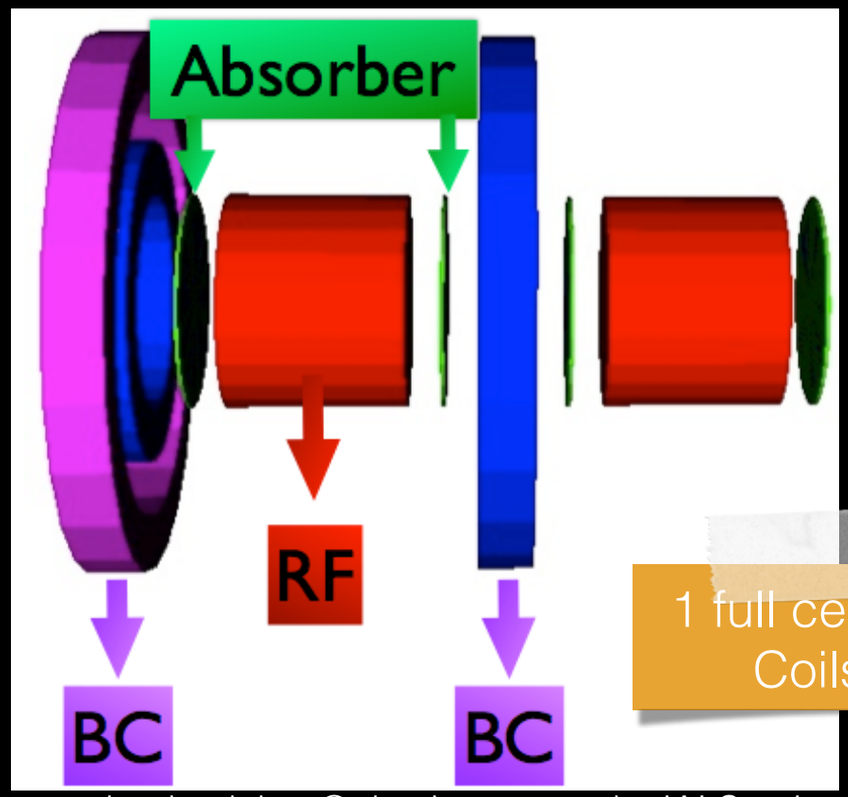
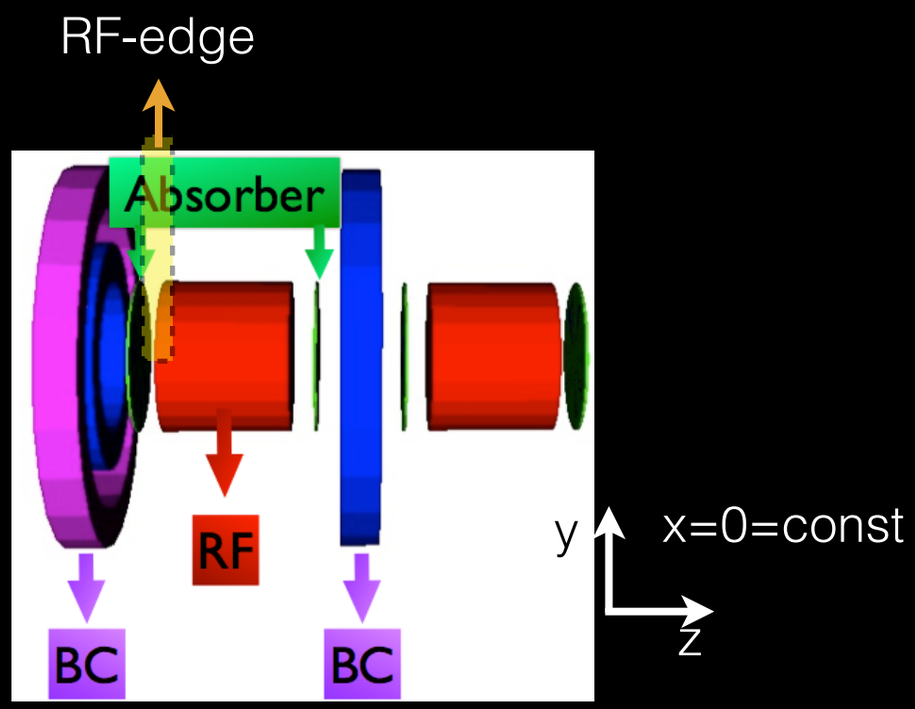


1 full cell of Bucked Coils Lattice

Ref: [2], [3], [4]

Magnetic field



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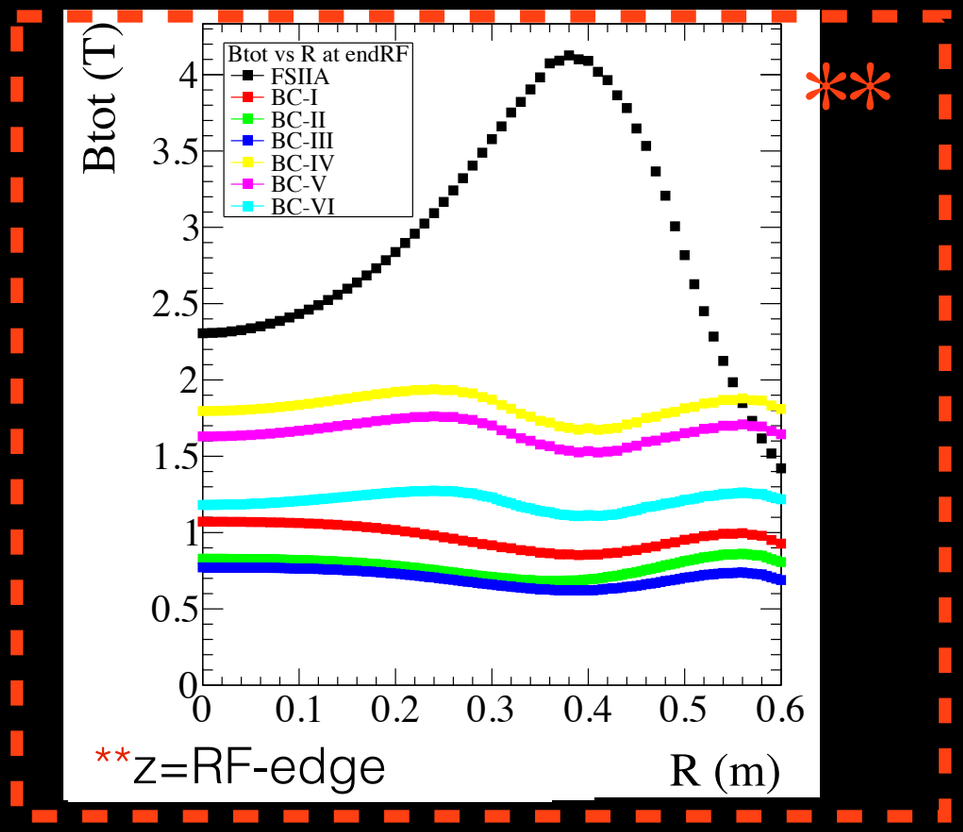
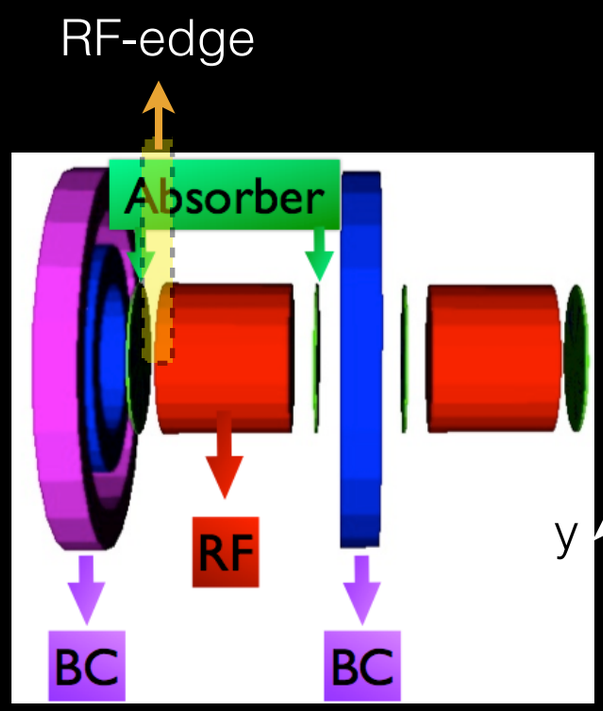
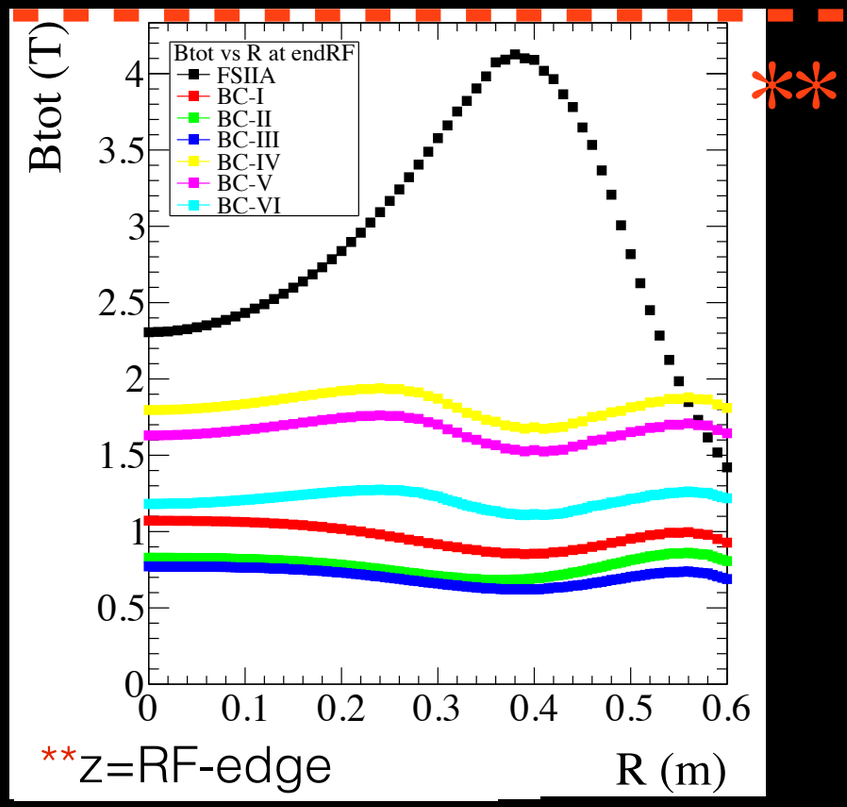


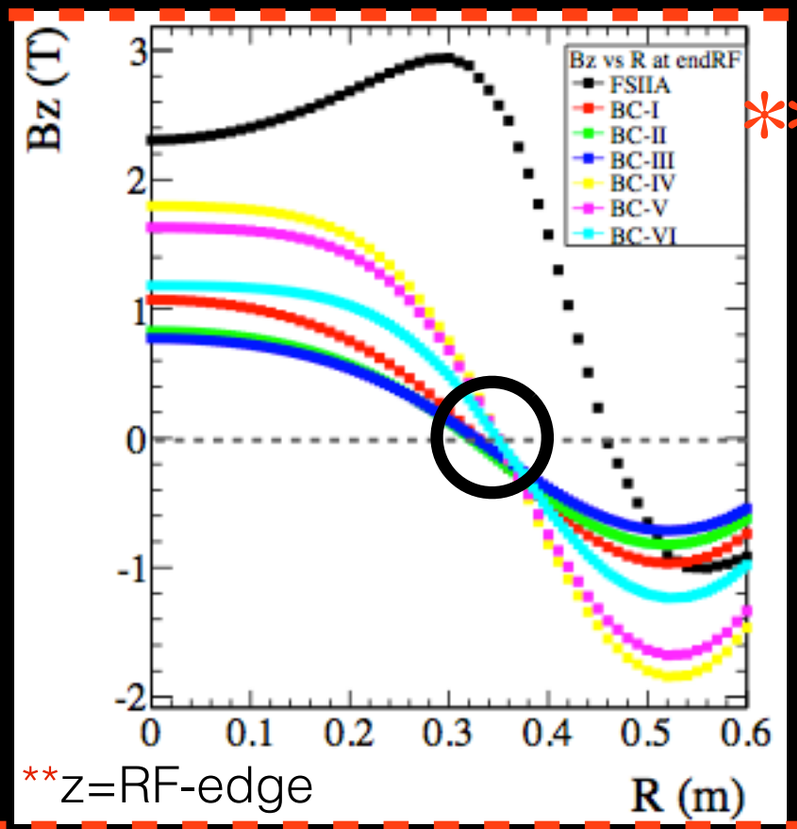
Reference
BC versions



- Edge of RFs, B_{tot}:
  - Reference>4 T
  - BCs: x2-5 lower

Magnetic field





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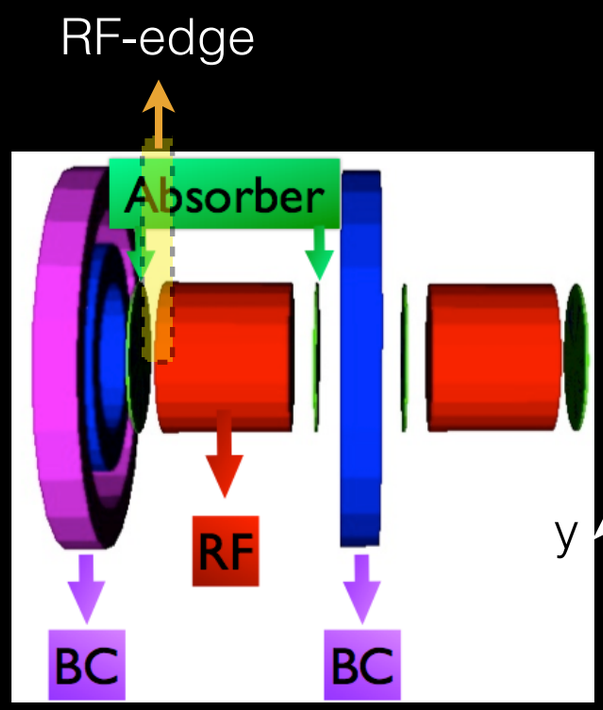

- Edge of RFs, B_{tot}:
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  - BCs: x2-5 lower
- Edge of RFs, B_z at R=35 cm (RF iris):
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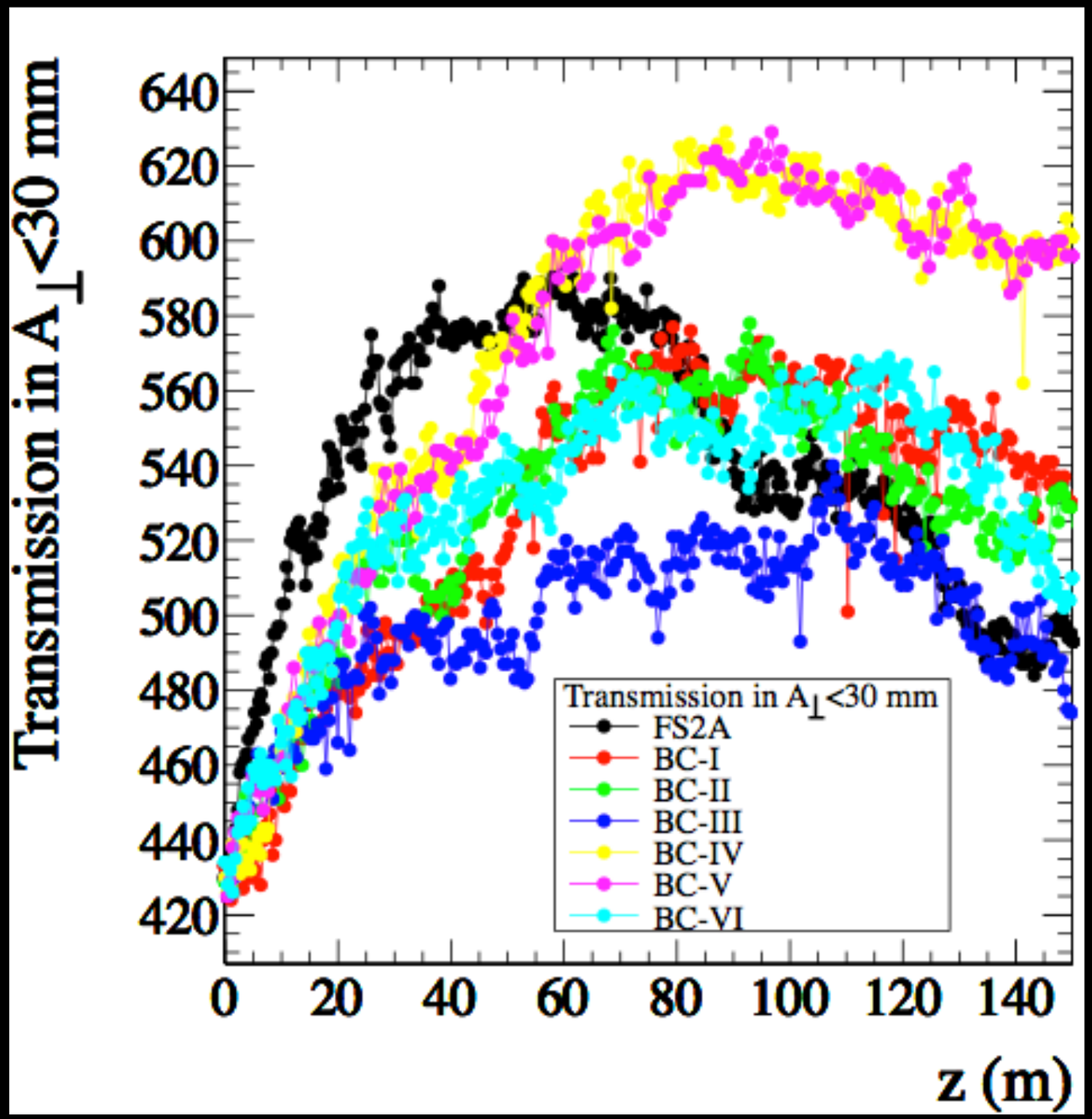
  - **BCs: 0 T**

Cooling efficiency

- **BC: best transmission within 30 mm of A_T***



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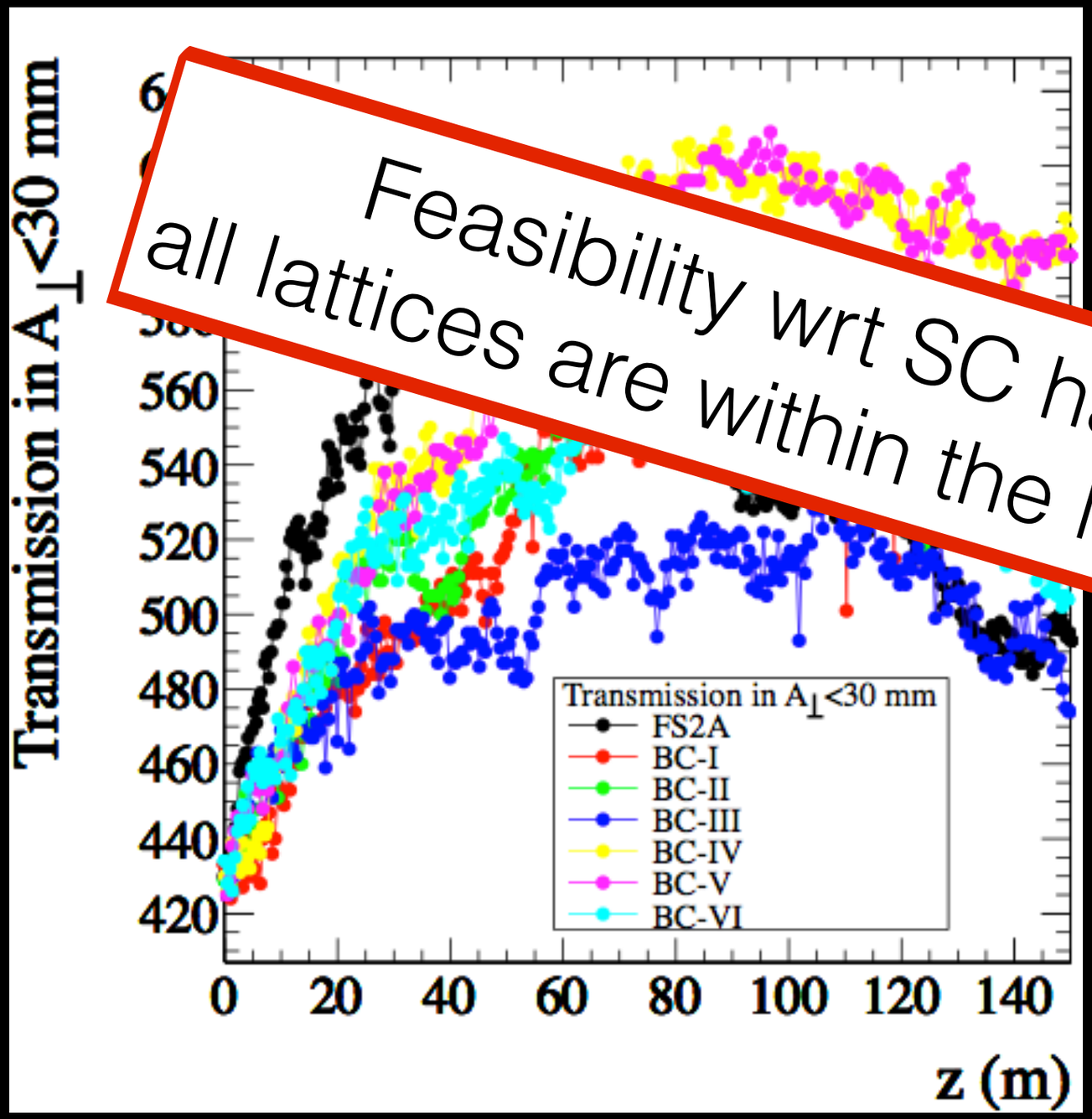

Feasibility wrt SC has been studied:
all lattices are within the limits of SC operation

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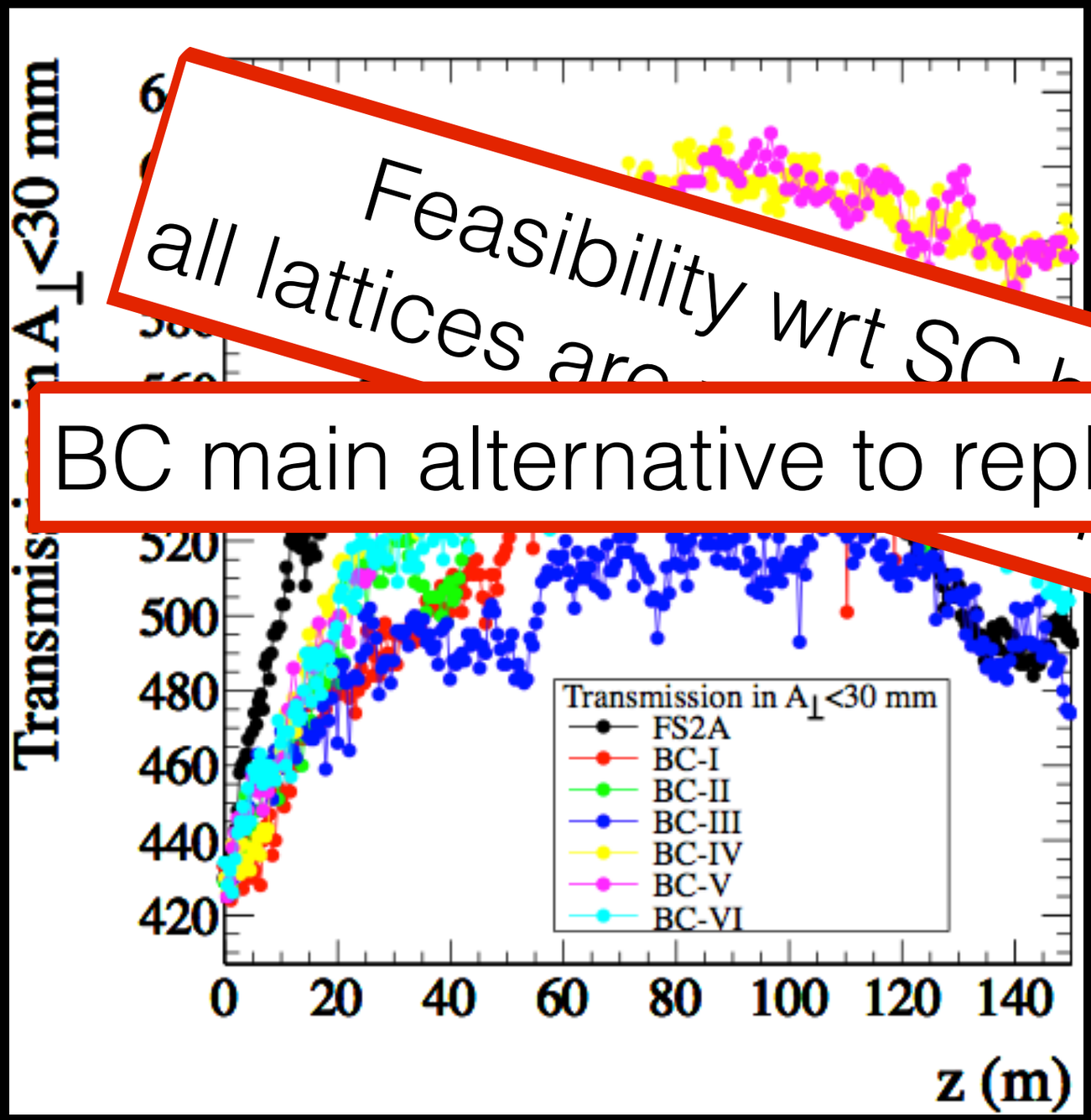

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BC main alternative to replace the reference lattice

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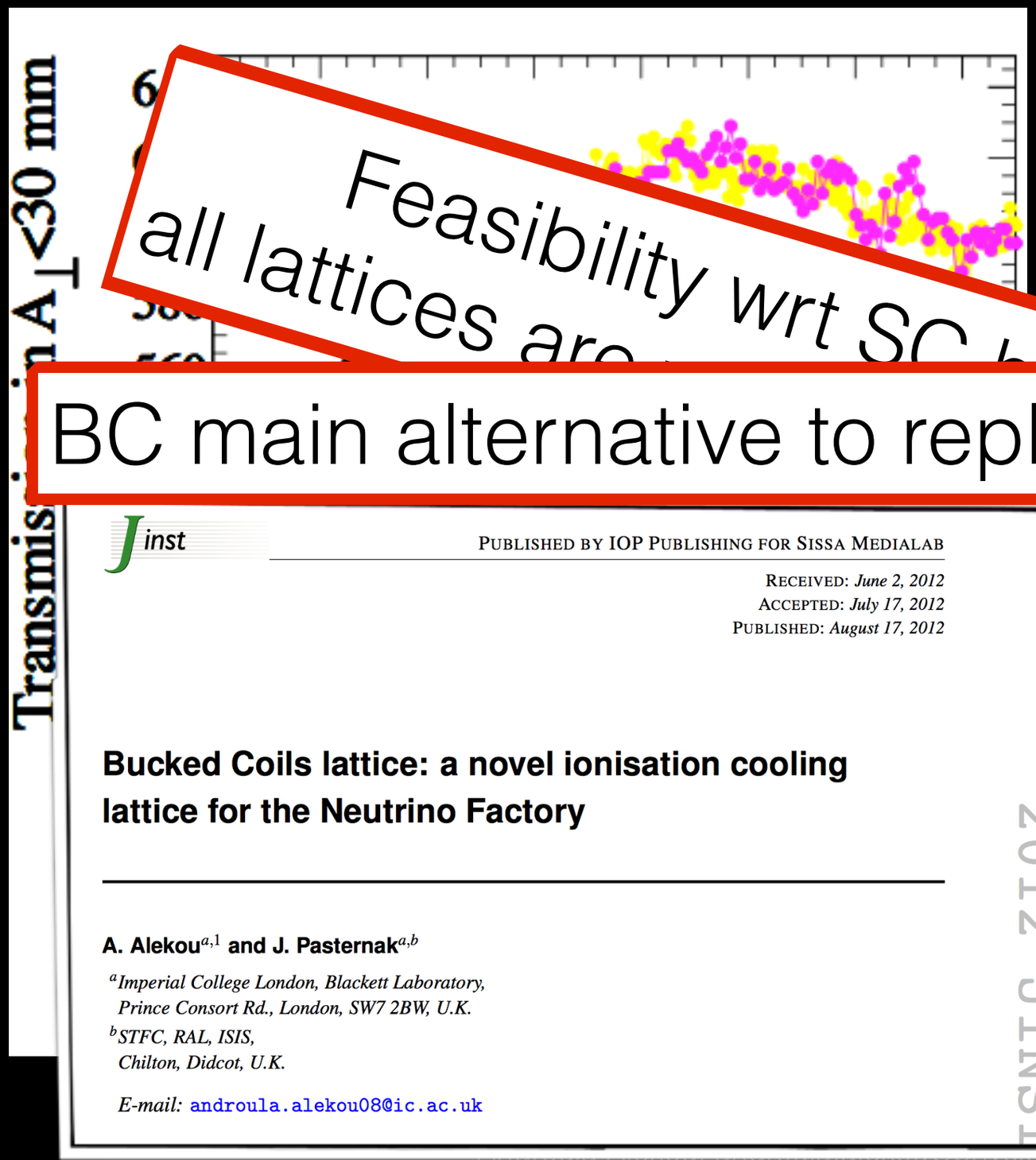

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Main goal: feasibility study of new European research infrastructure able to host a deep (~1,5 km) underground neutrino detector (mass: ~ 10^5 – 10^6 tons) for fundamental research in particle and astroparticle physics

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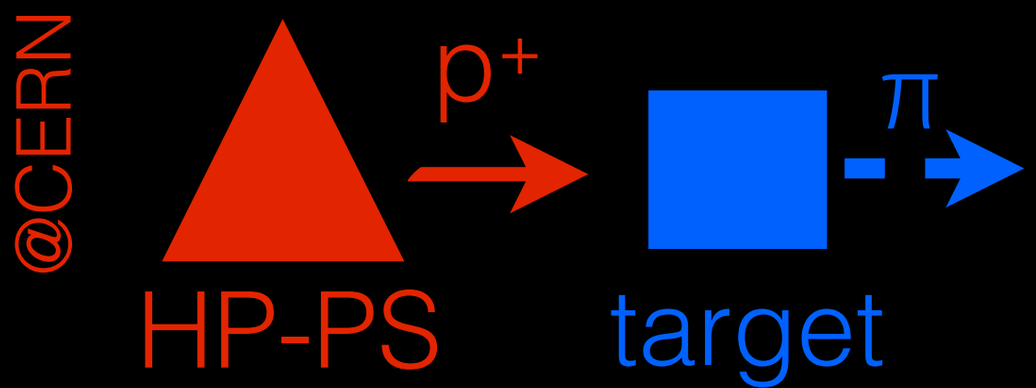

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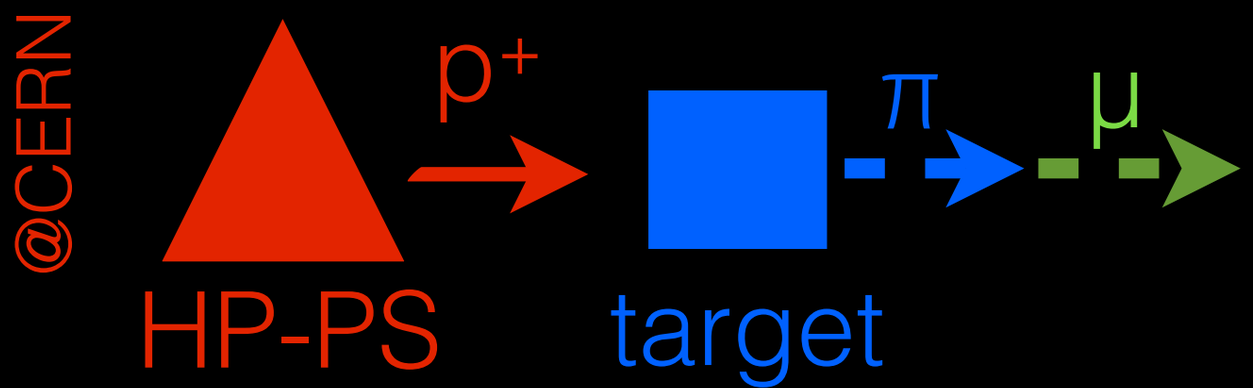

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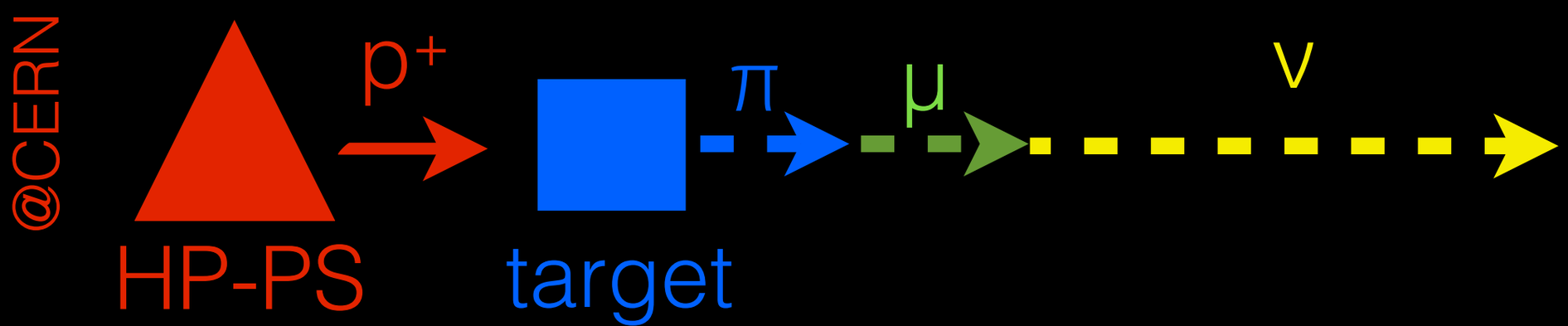

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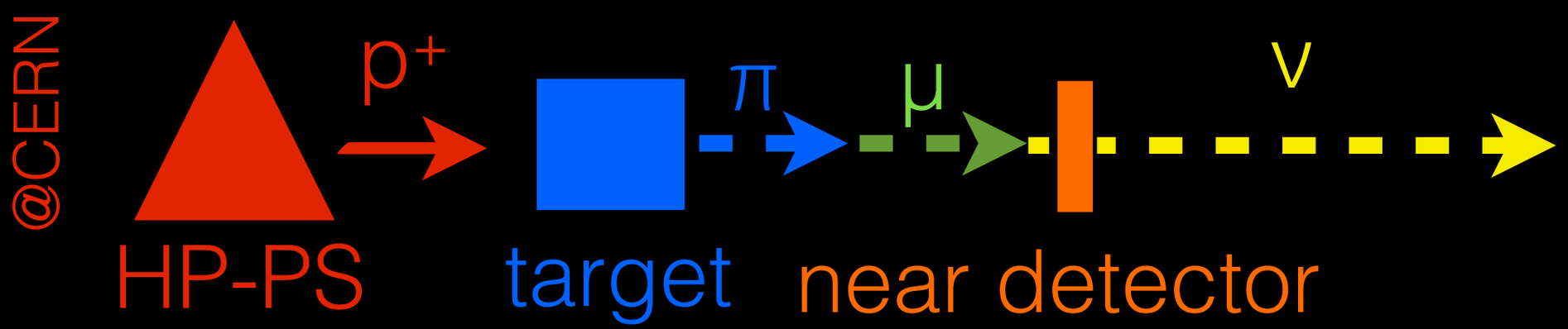

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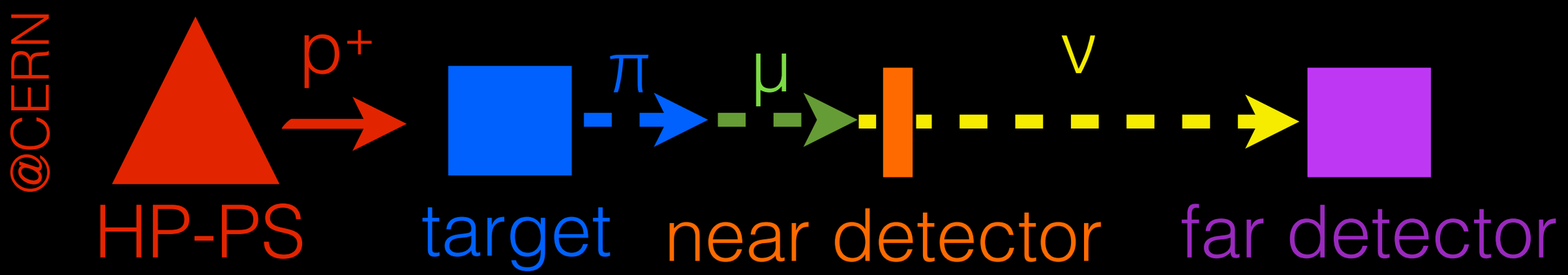

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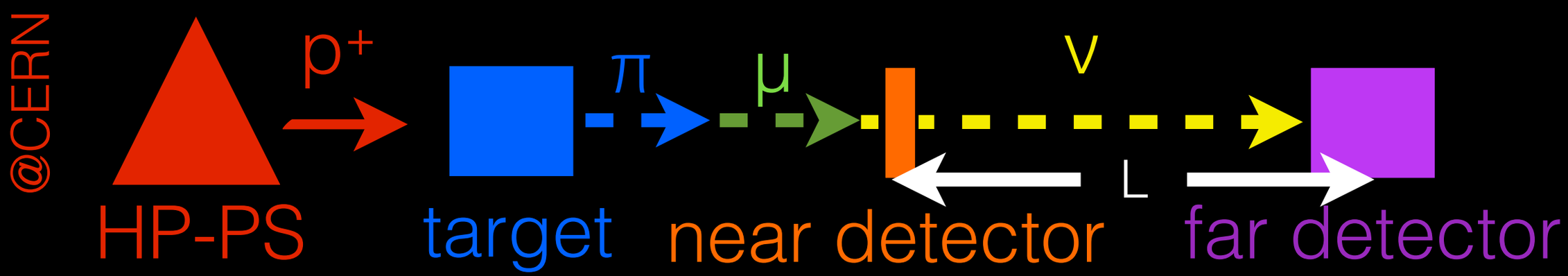

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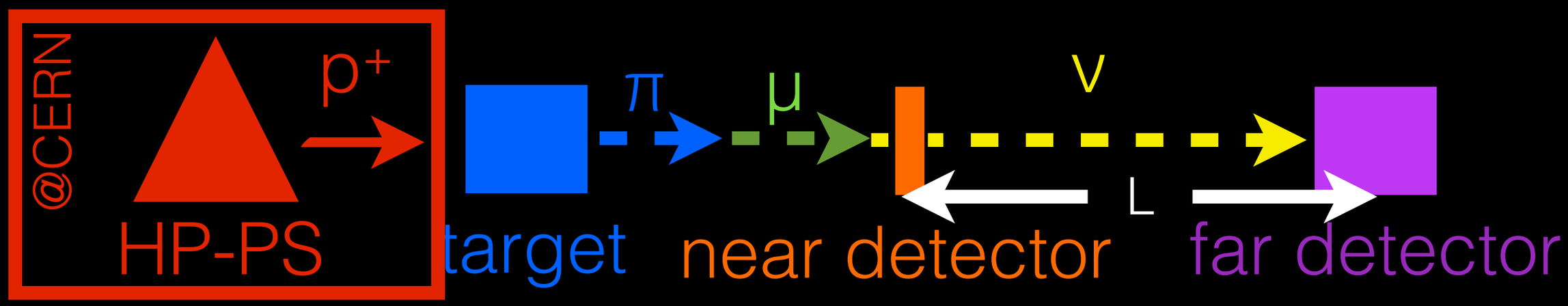

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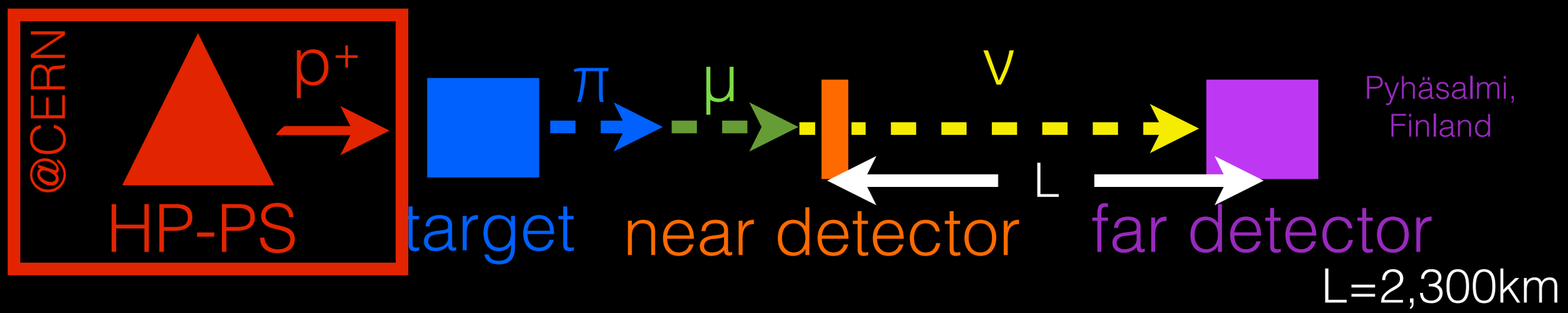

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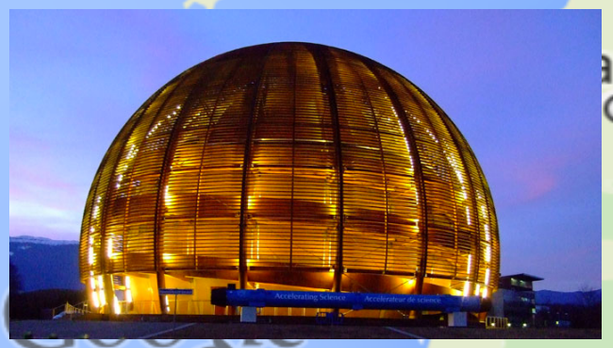

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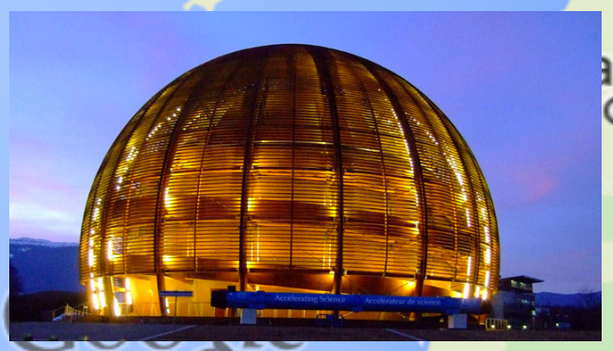

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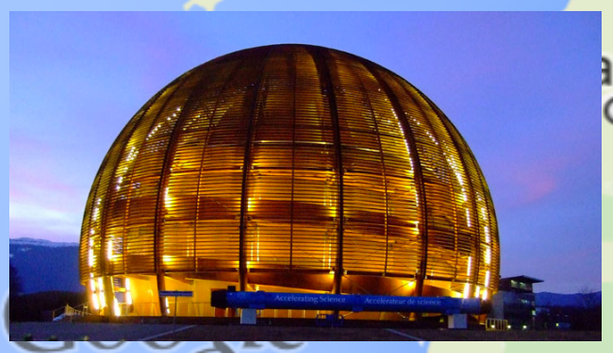


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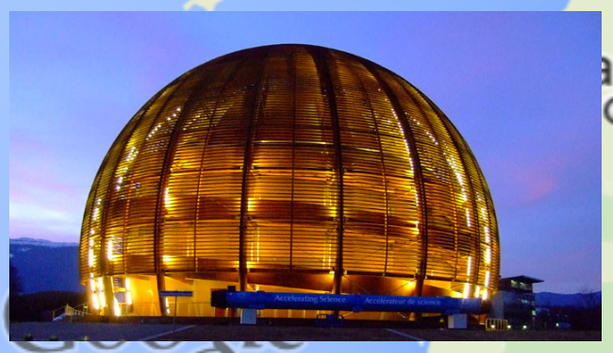

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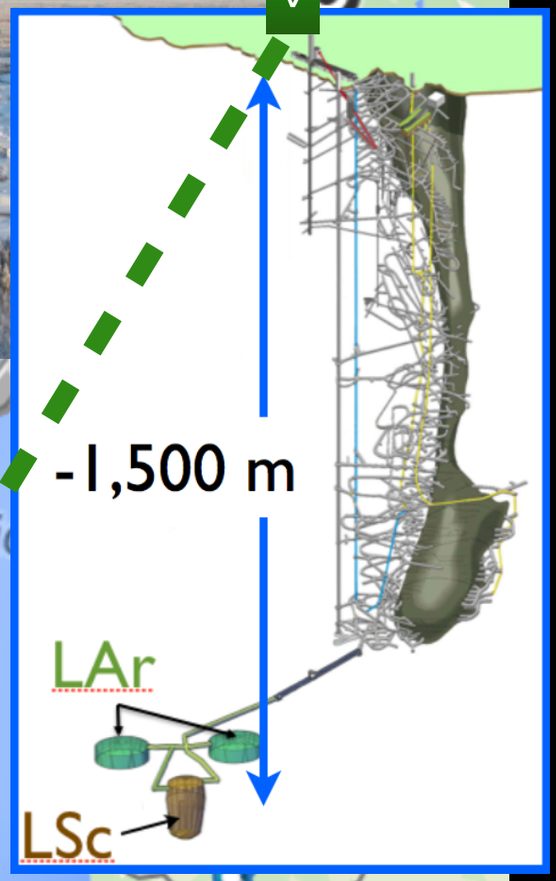

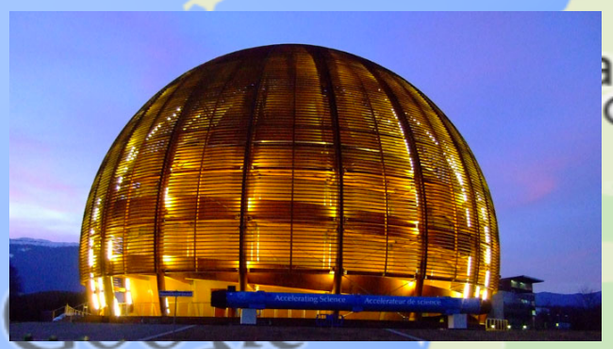

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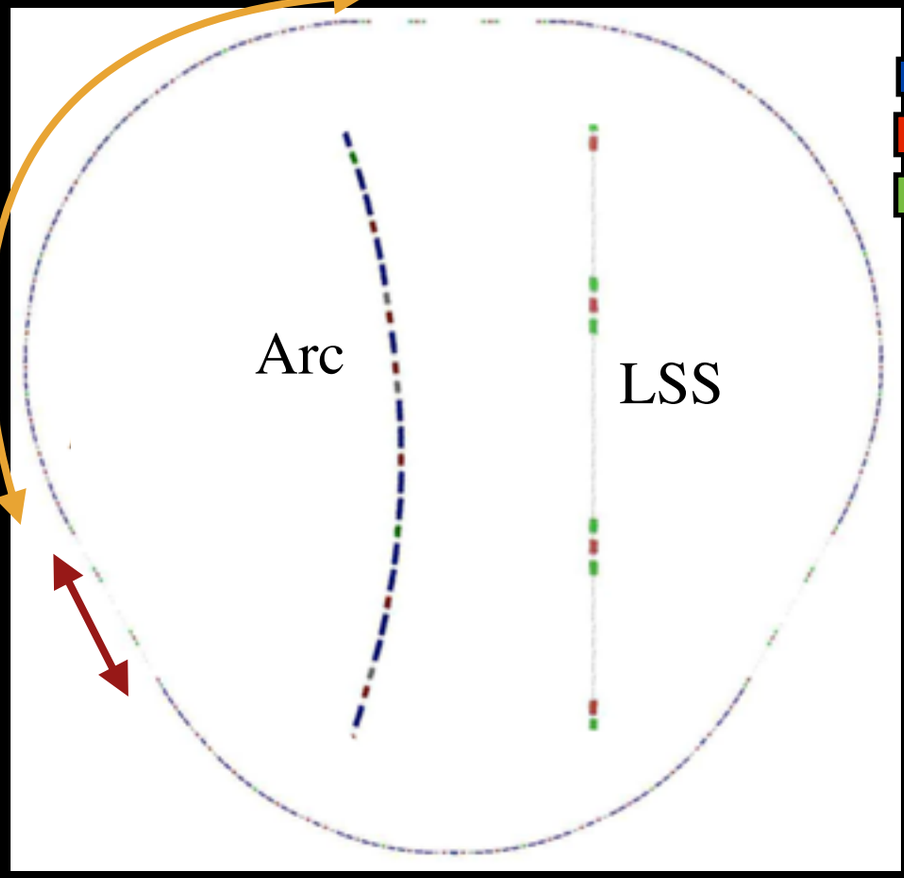
HP-PS

- 3-fold symmetry
- 3 Long Straight Sections (LSS):
  - a) injection/extraction
  - b) collimation
  - c) RF cavities
- Protons final energy: 50 GeV

Arc

LSS



Bending elements
Focusing quads
Defocusing quads

L_{Total}=1256 m
L_{Arc}=333.2 m
L_{LSS}: 87.7 m

HP-PS: High Power Proton Synchrotron

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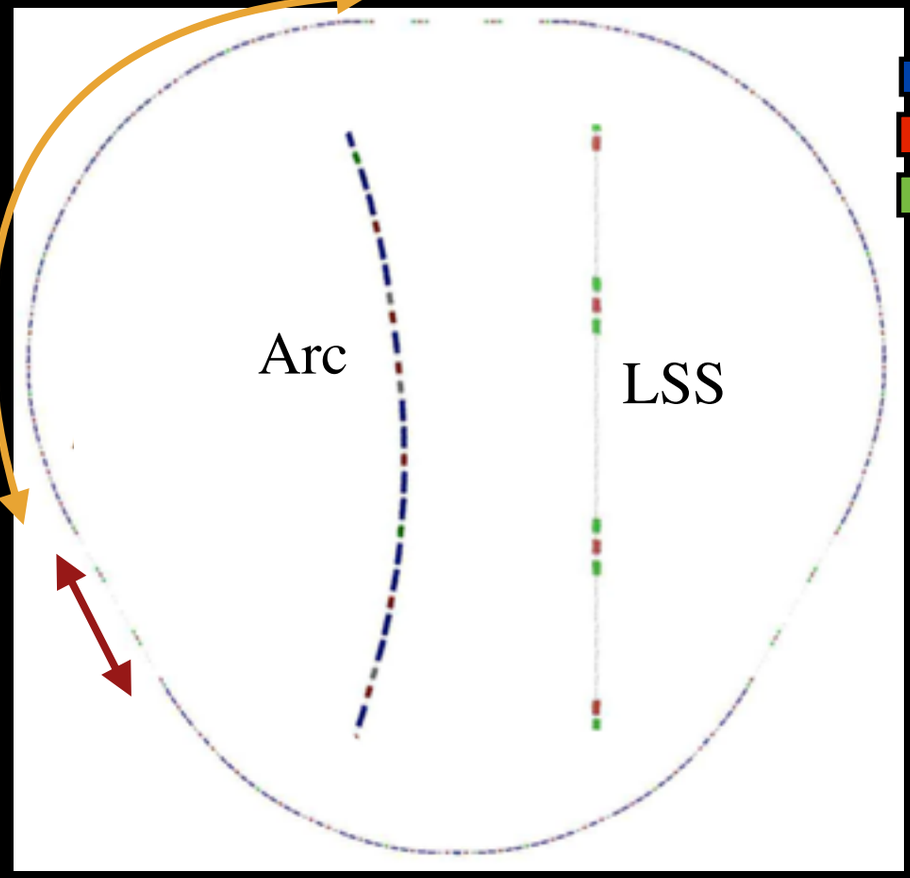

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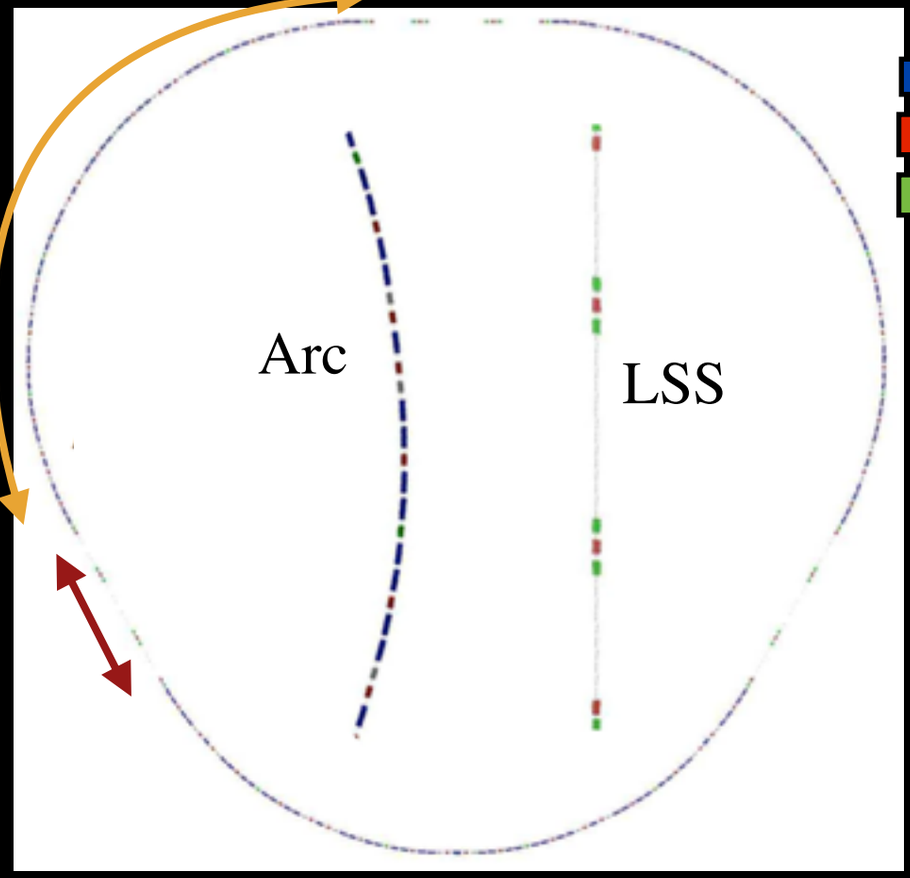

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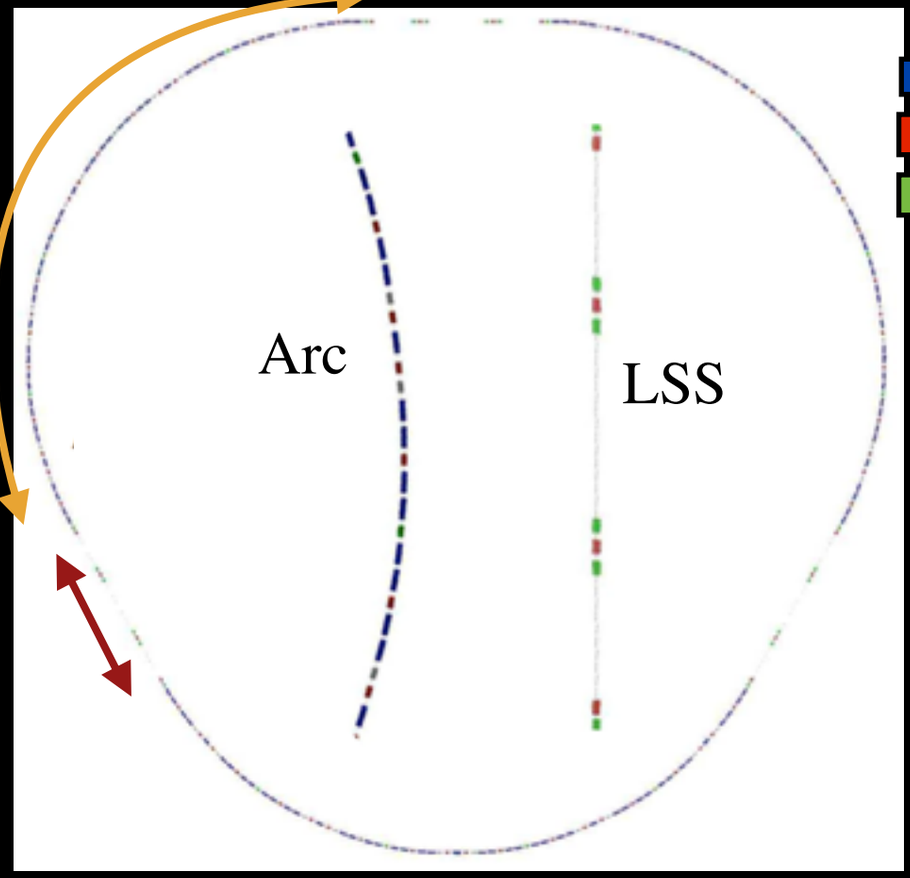

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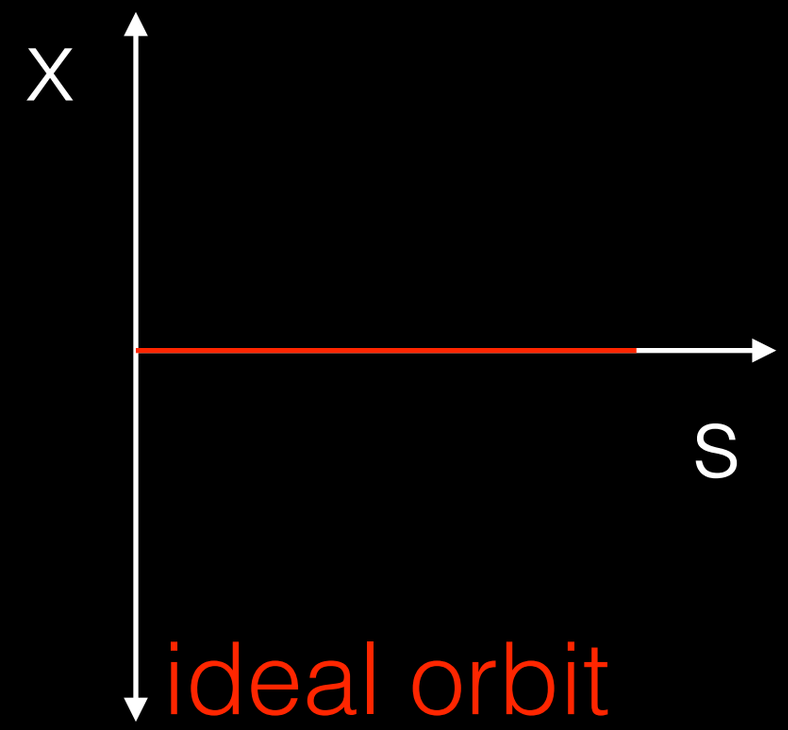

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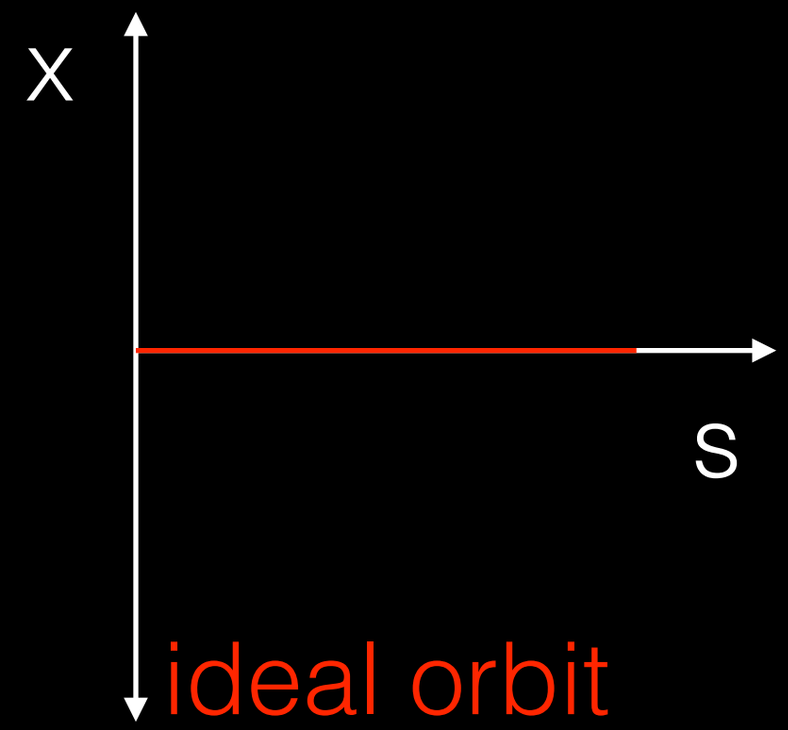

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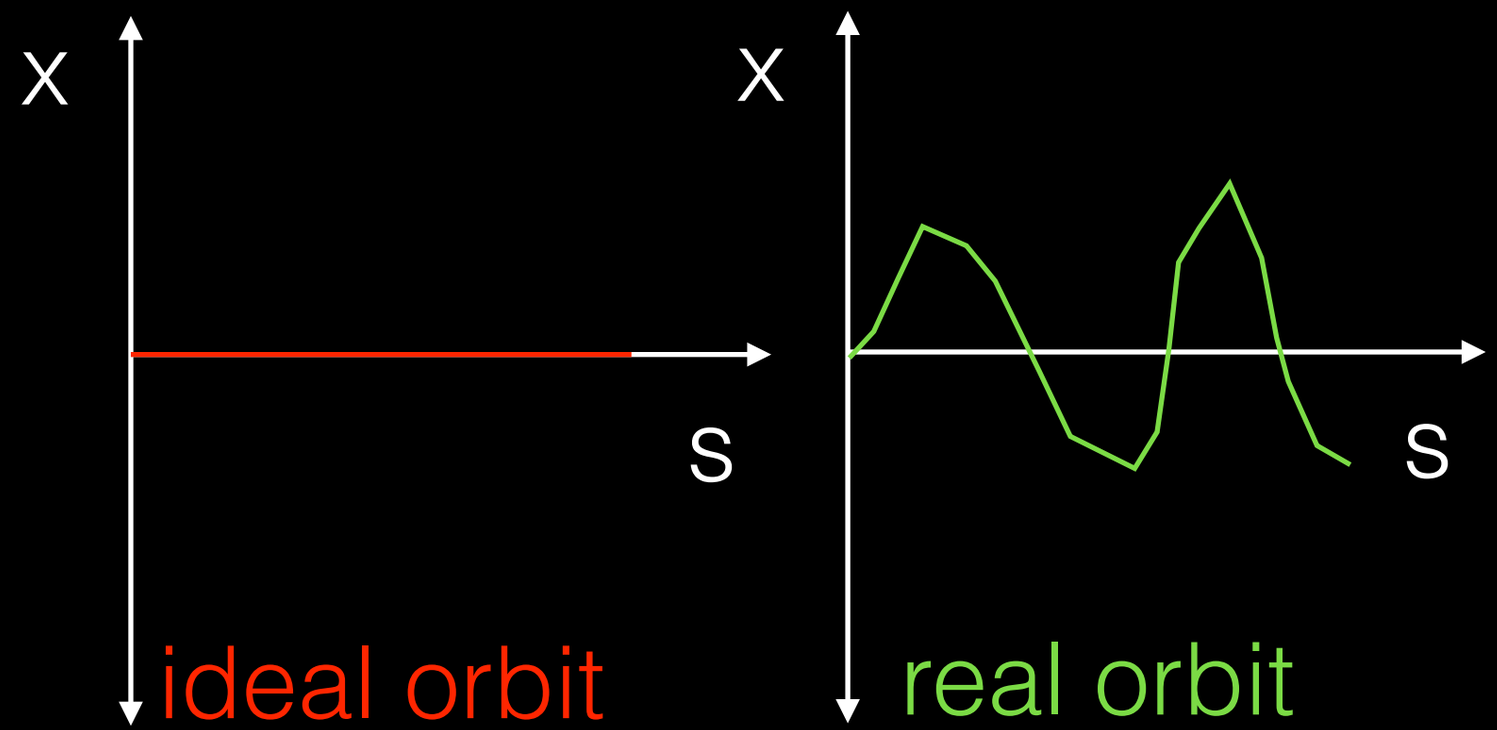

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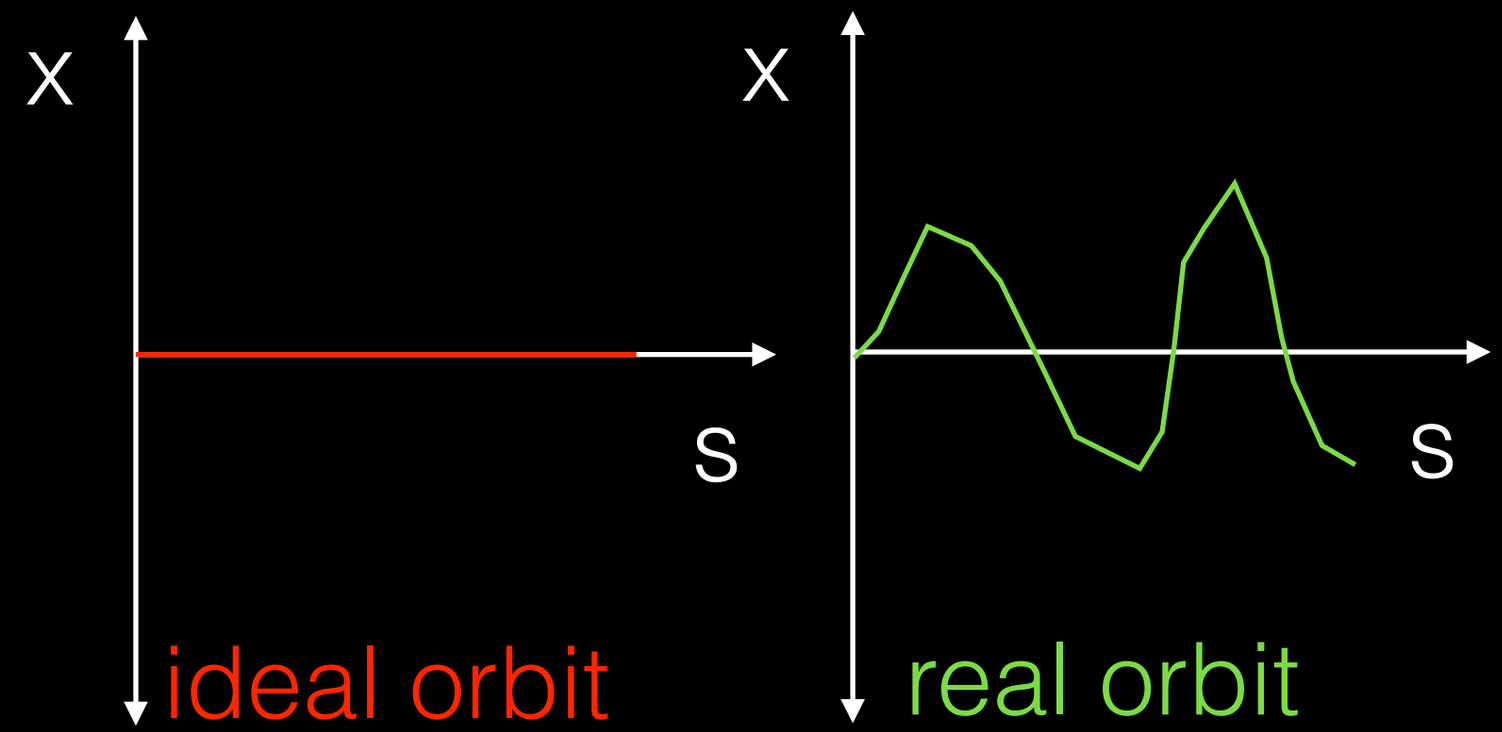

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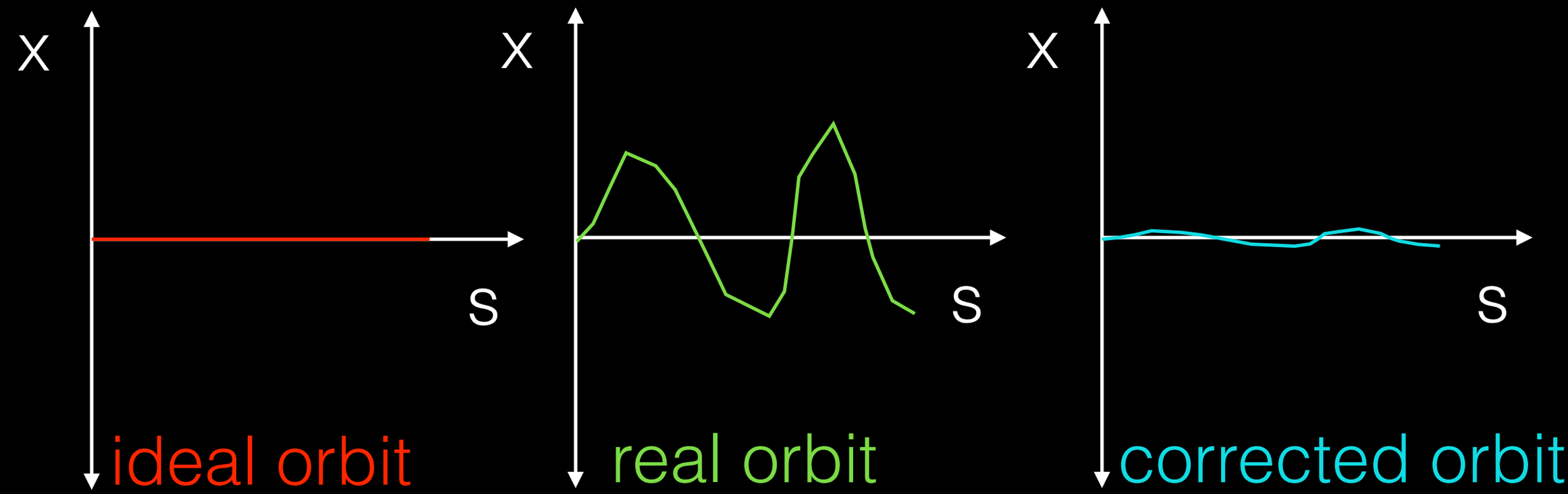

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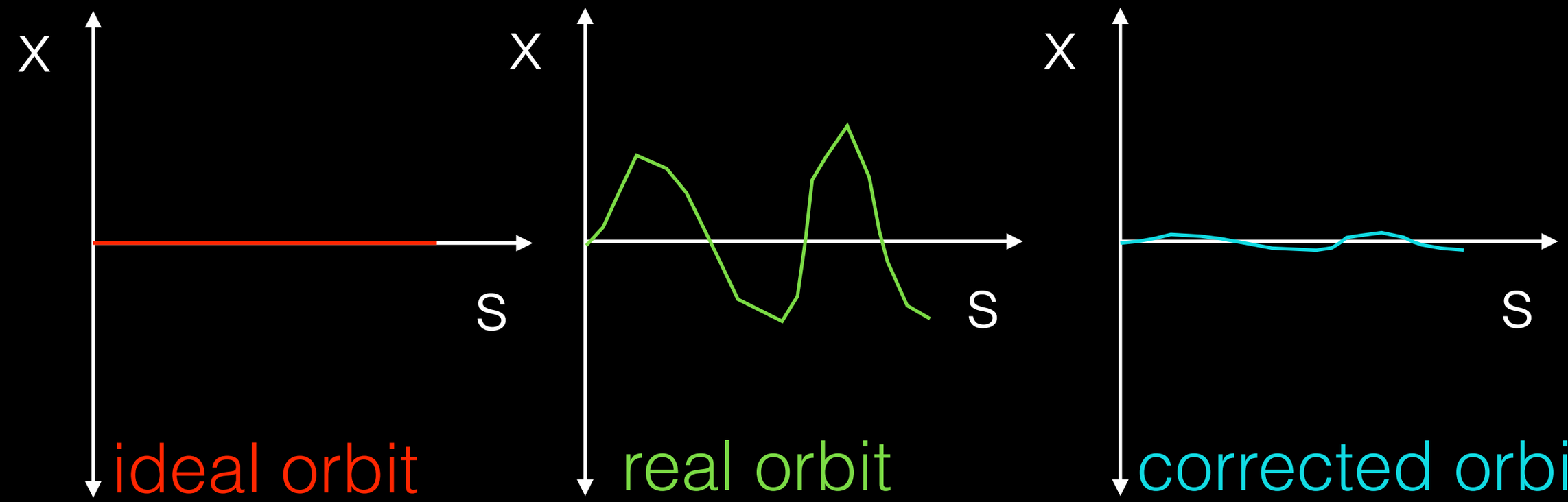

- Corrector magnets needed to reduce orbit distortion magnitude
- Need to check if correctors strengths needed for HP-PS are within limit

Orbit correction (2/2)

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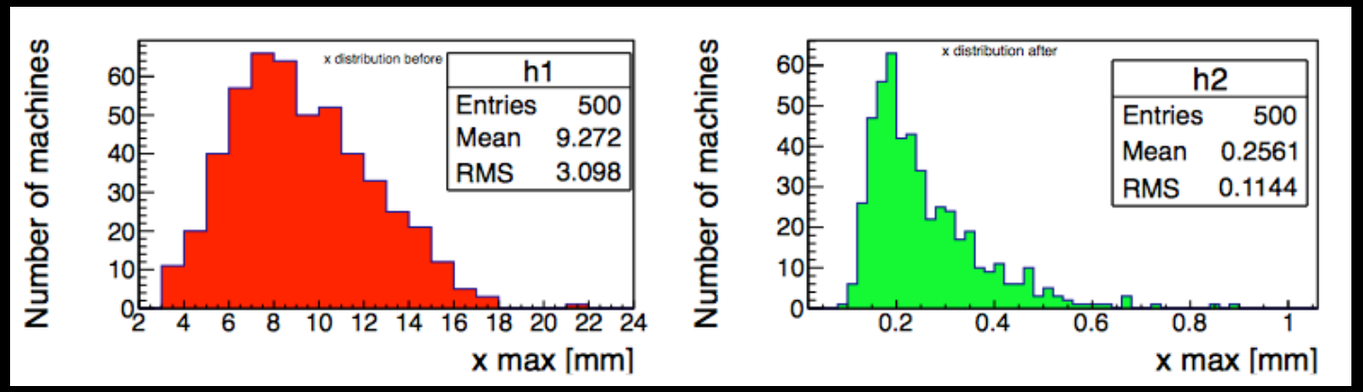

Before Correction After Correction

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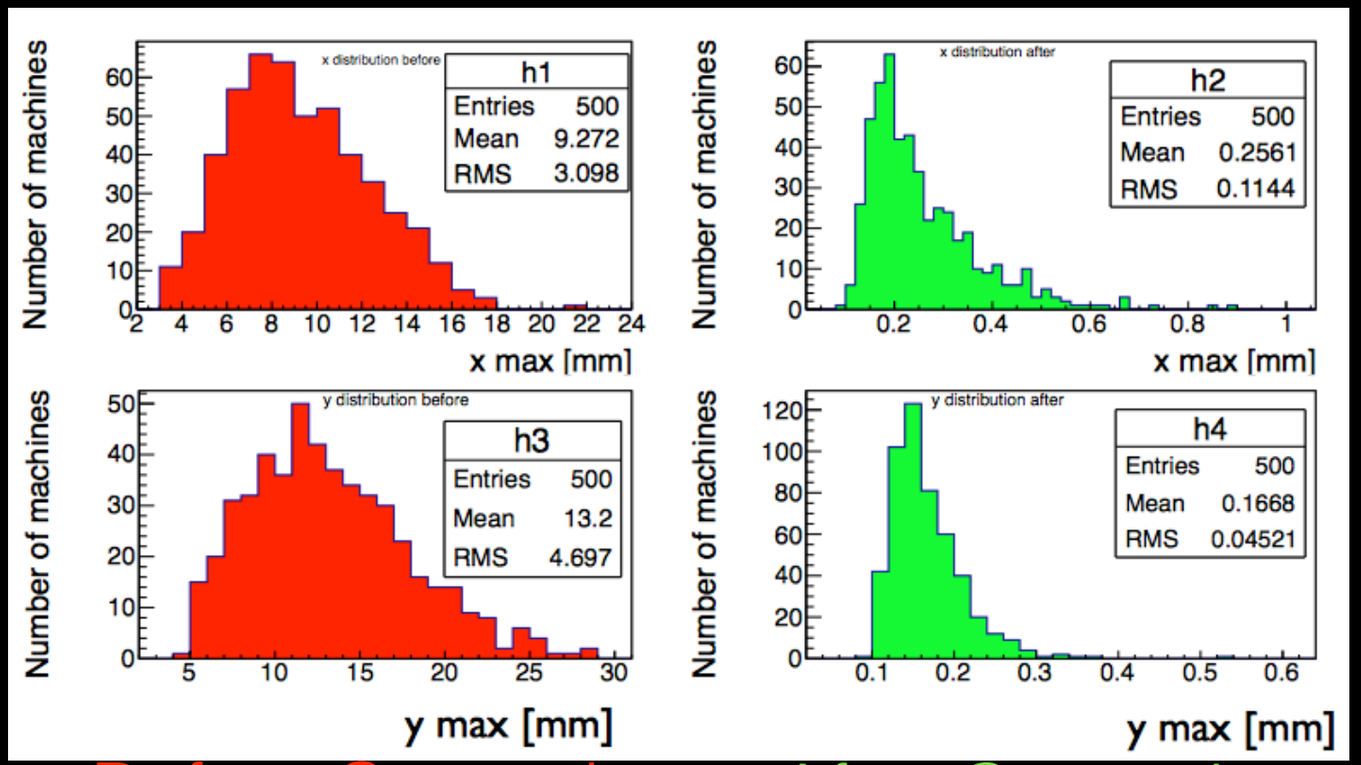

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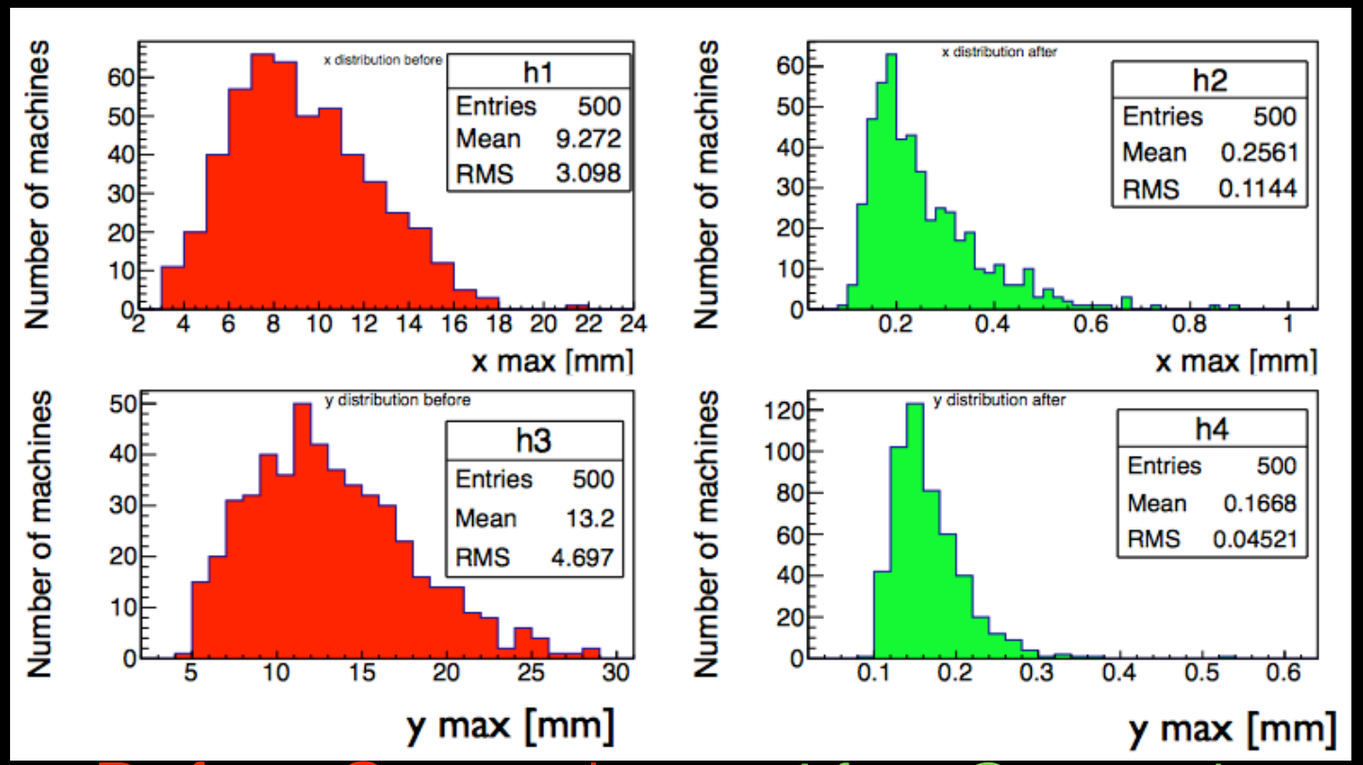

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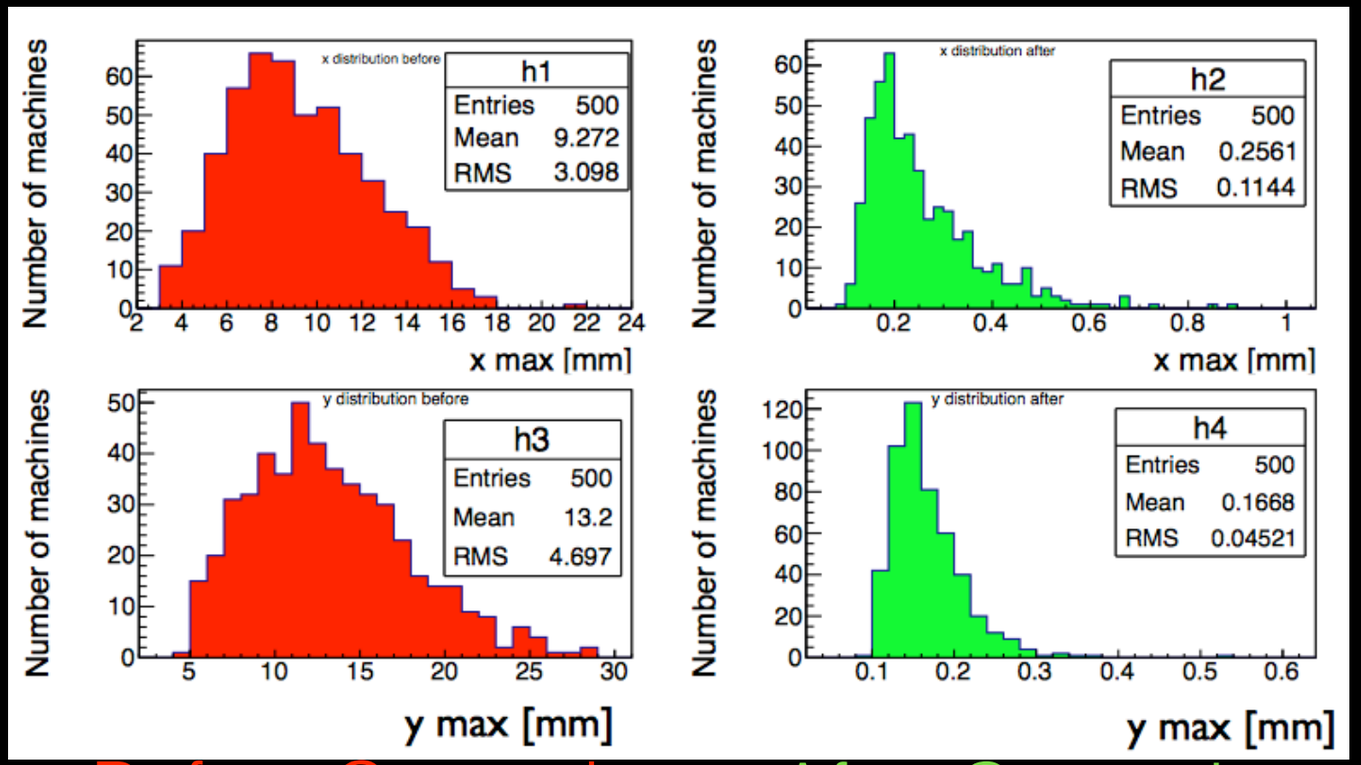

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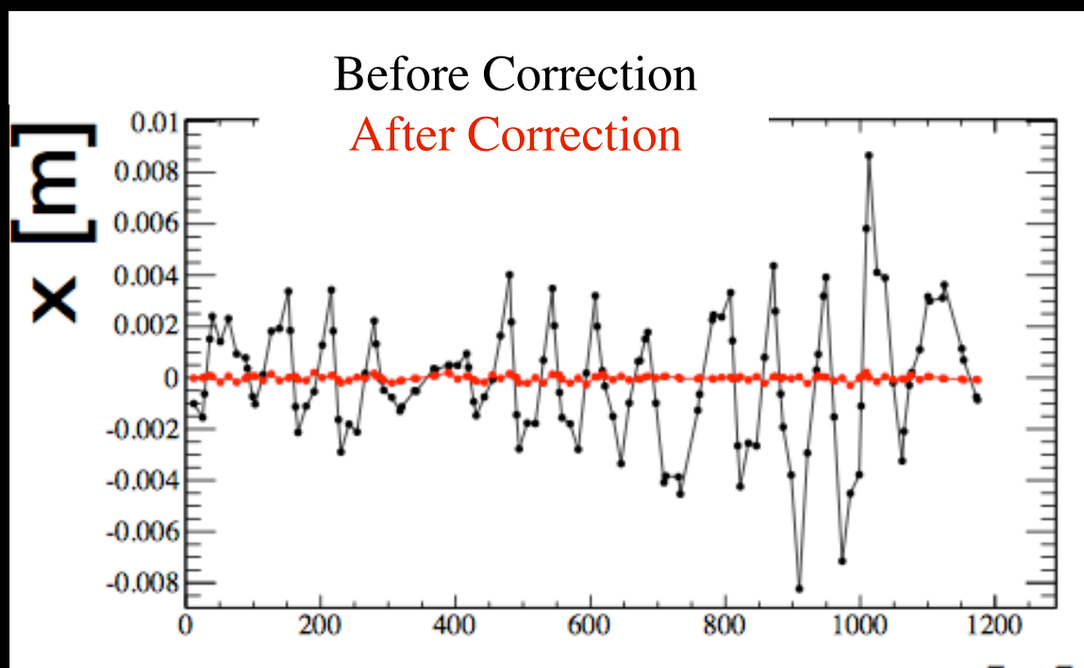

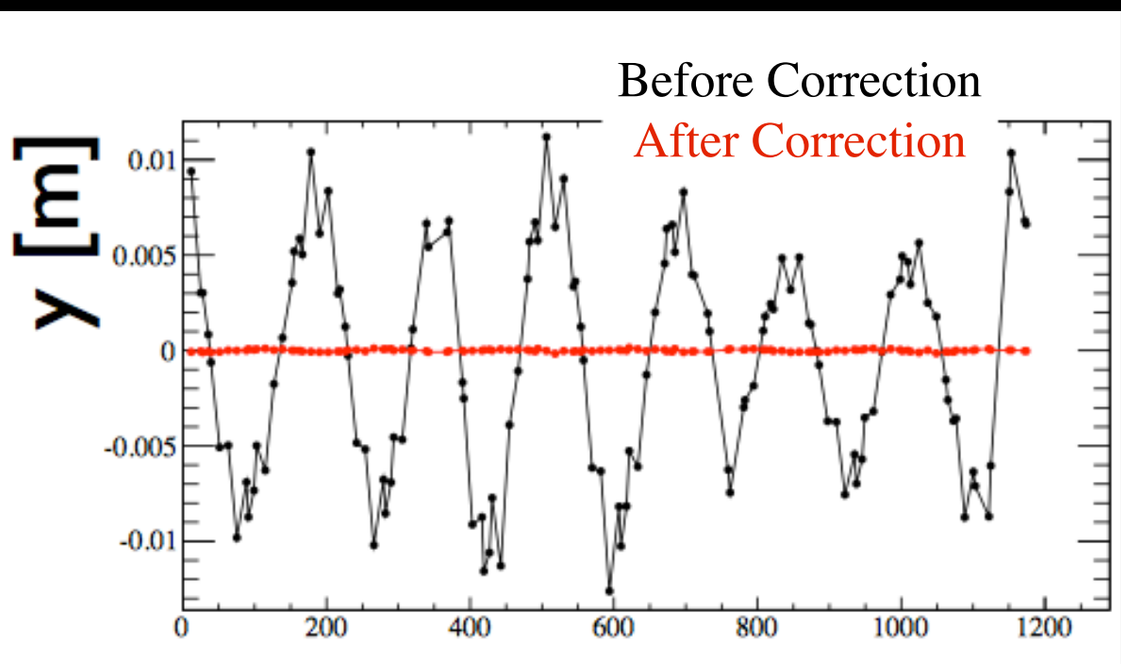

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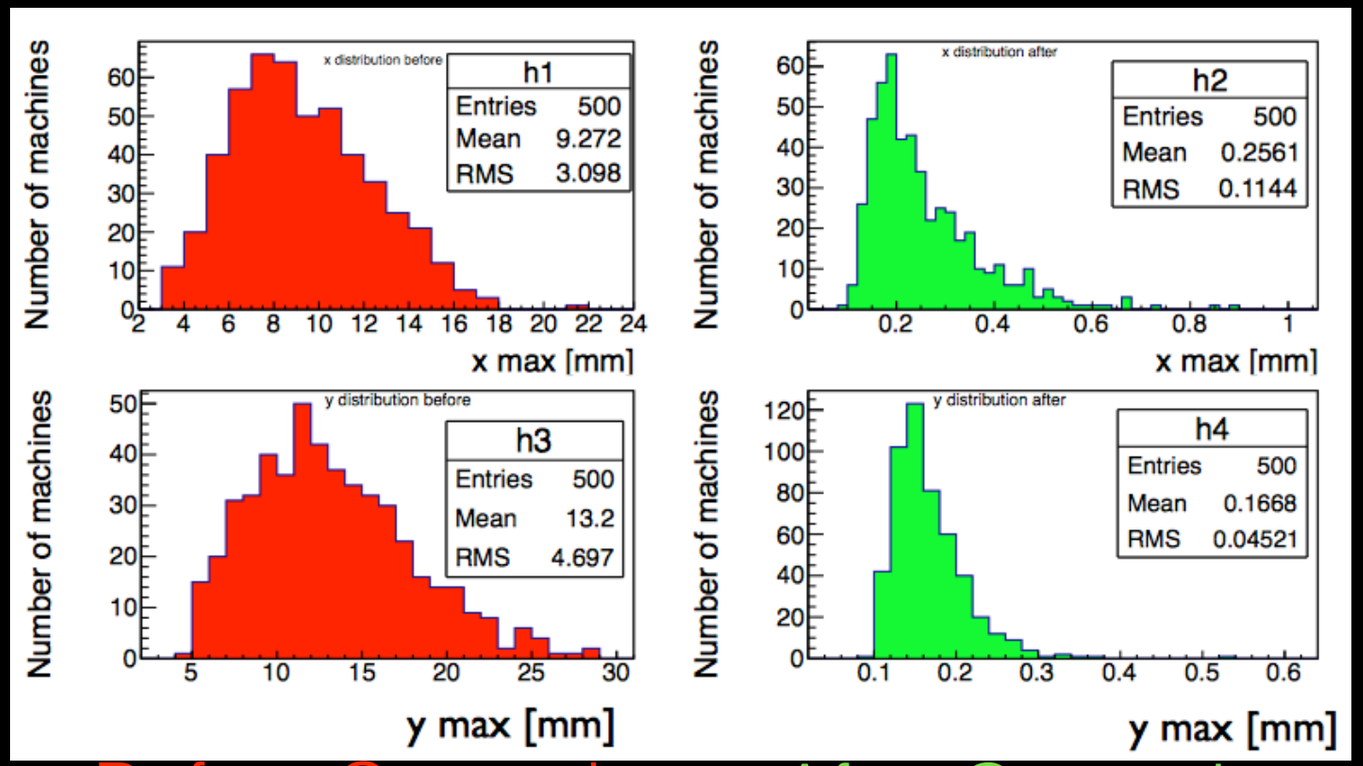

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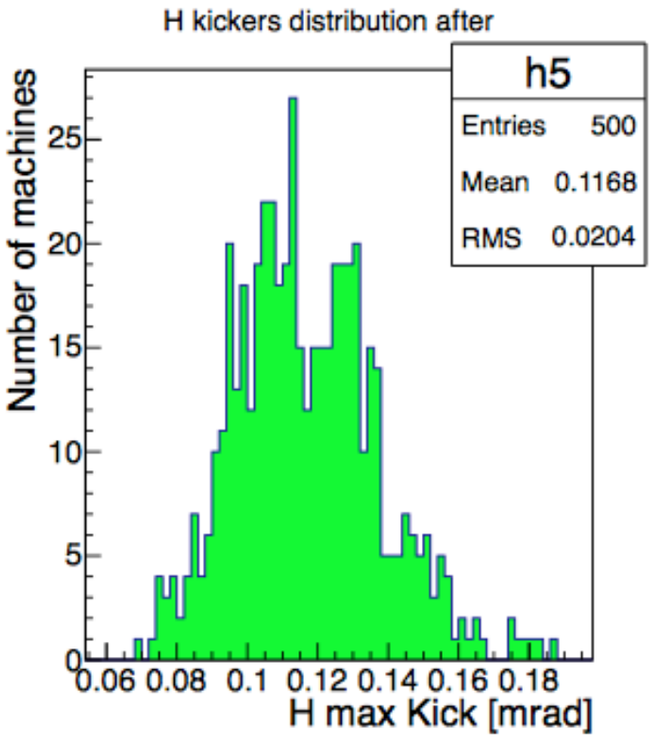

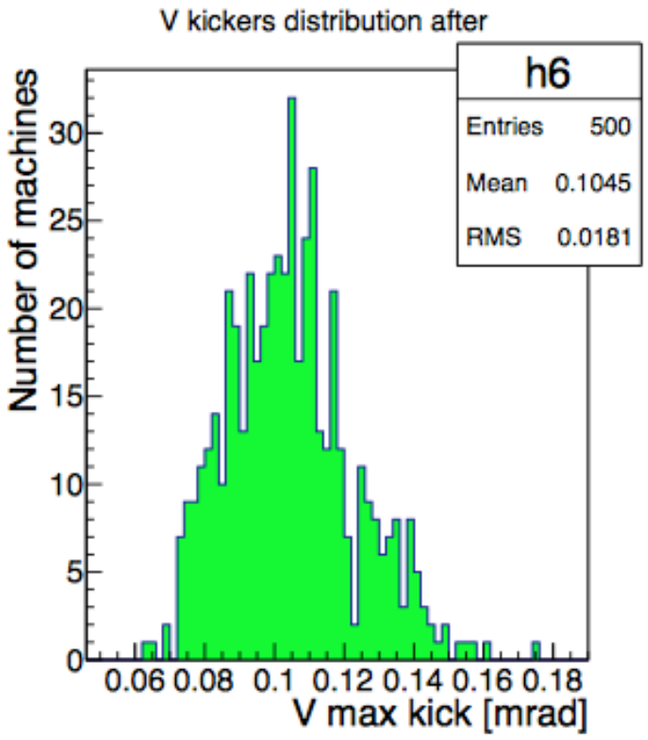

Correctors' strength needed <0.2 mrad (~0.05 T for E=50 GeV), i.e. well within the limits [7]

Collimators

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- Why do we need collimators?

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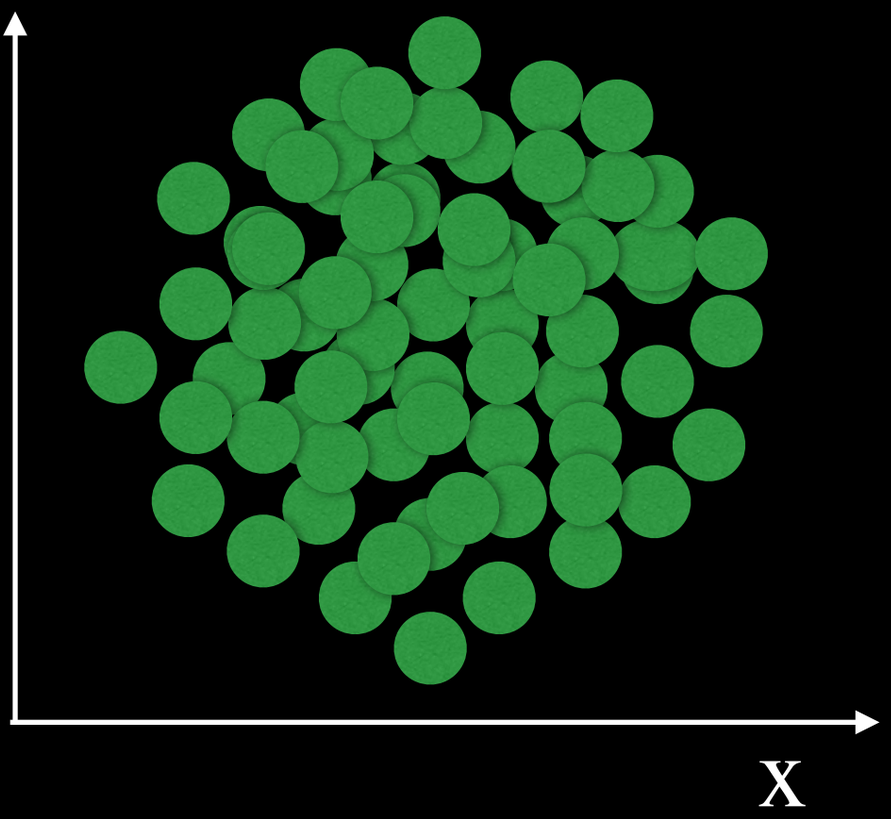

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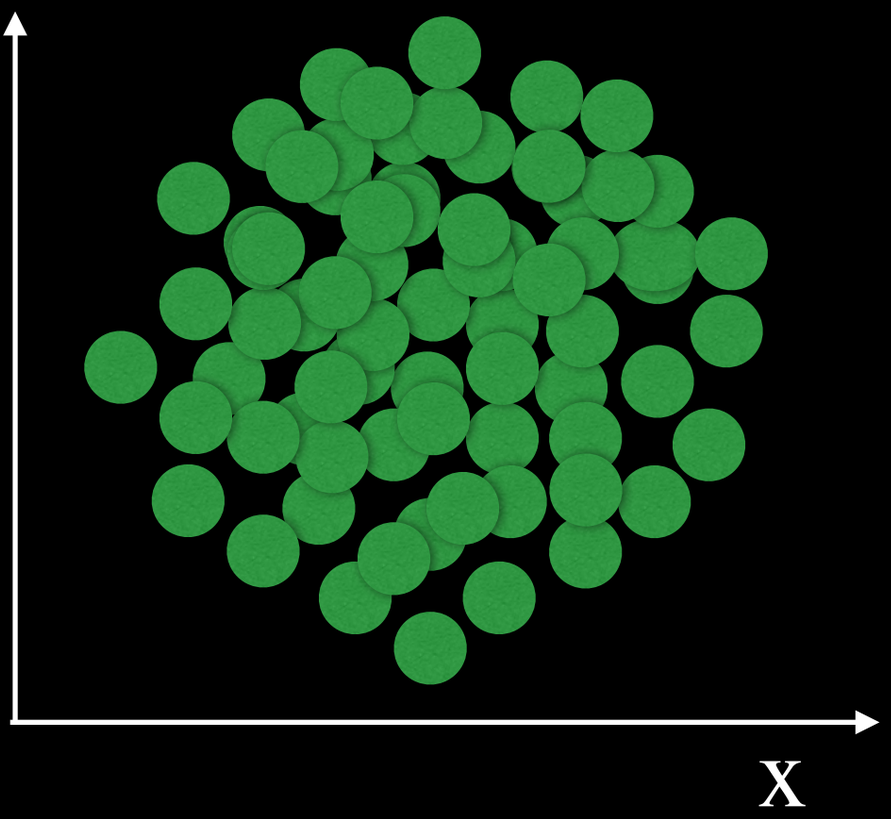

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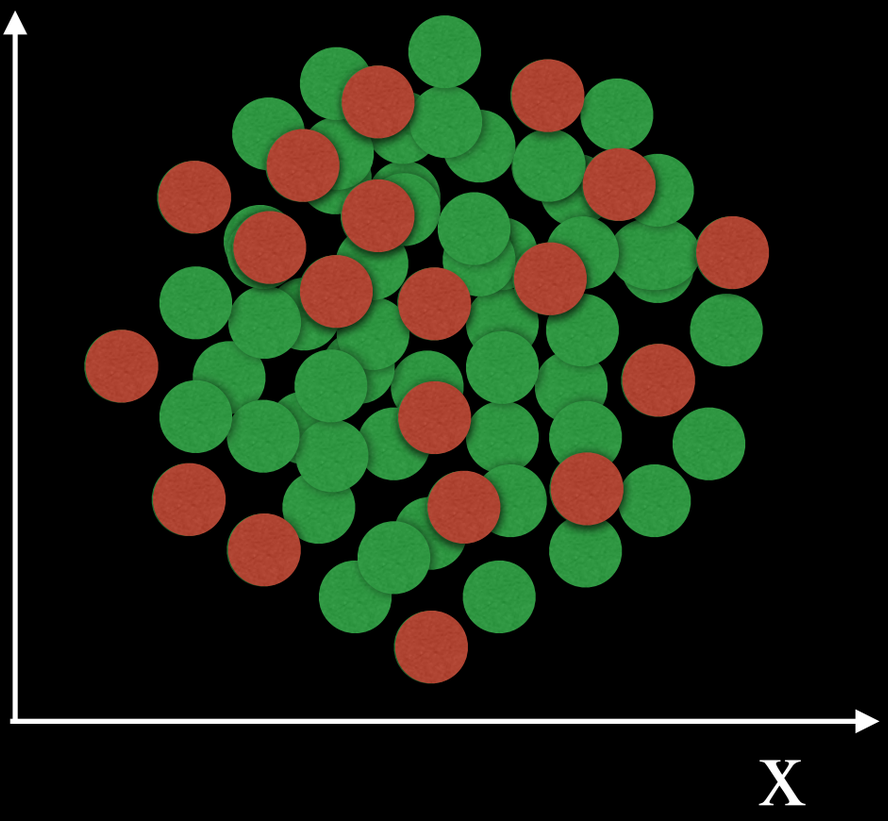

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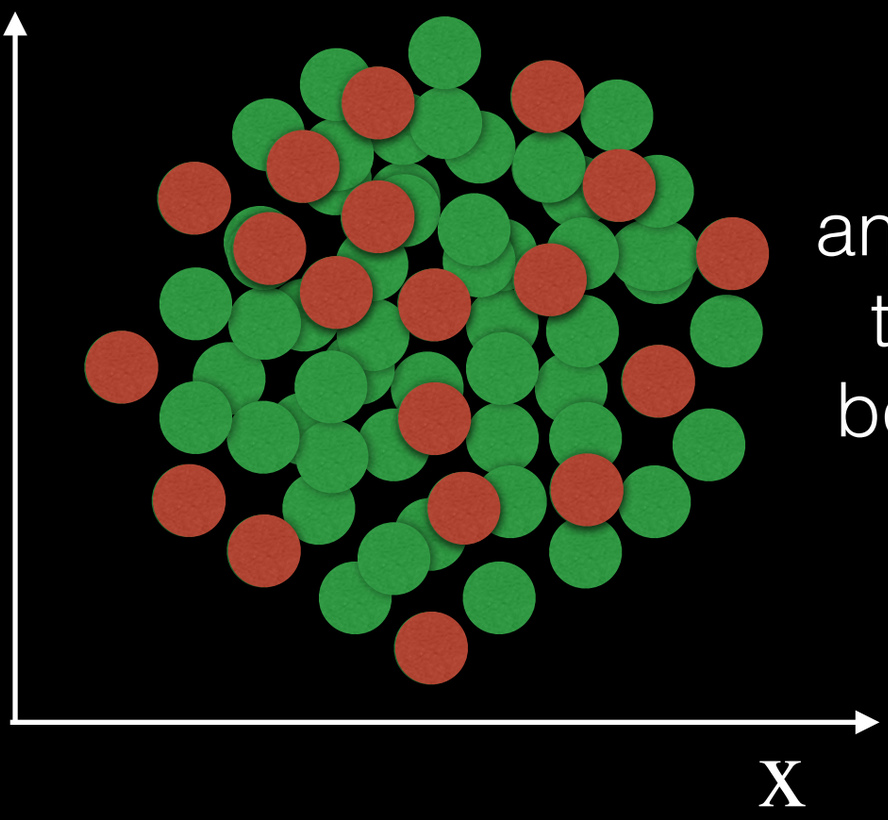

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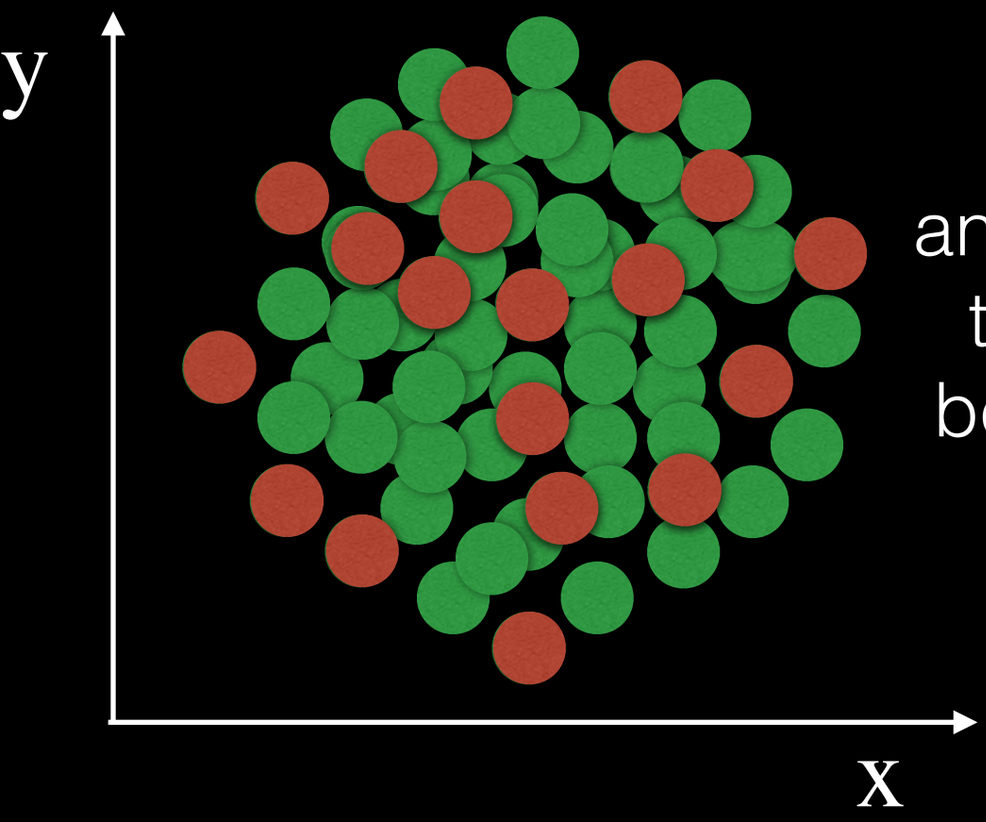

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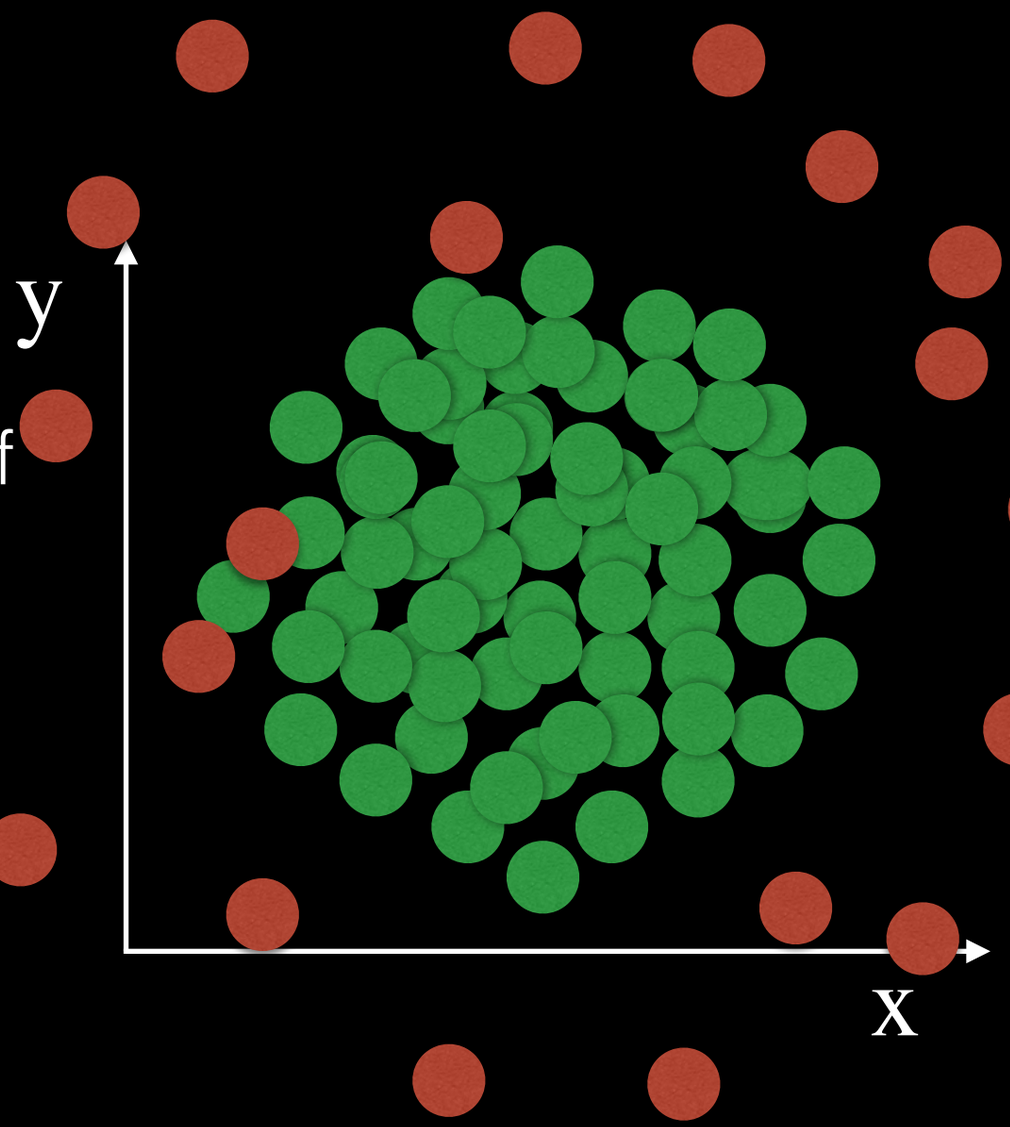

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  - to prevent halo particles from hitting the superconducting magnets of the HP-PS ring (avoid magnets quenching)
  - to limit equipment irradiation close to the beam
  - to localise slow losses in controlled way in properly equipped locations: dedicated LSS (Long Straight Section) for transverse collimation

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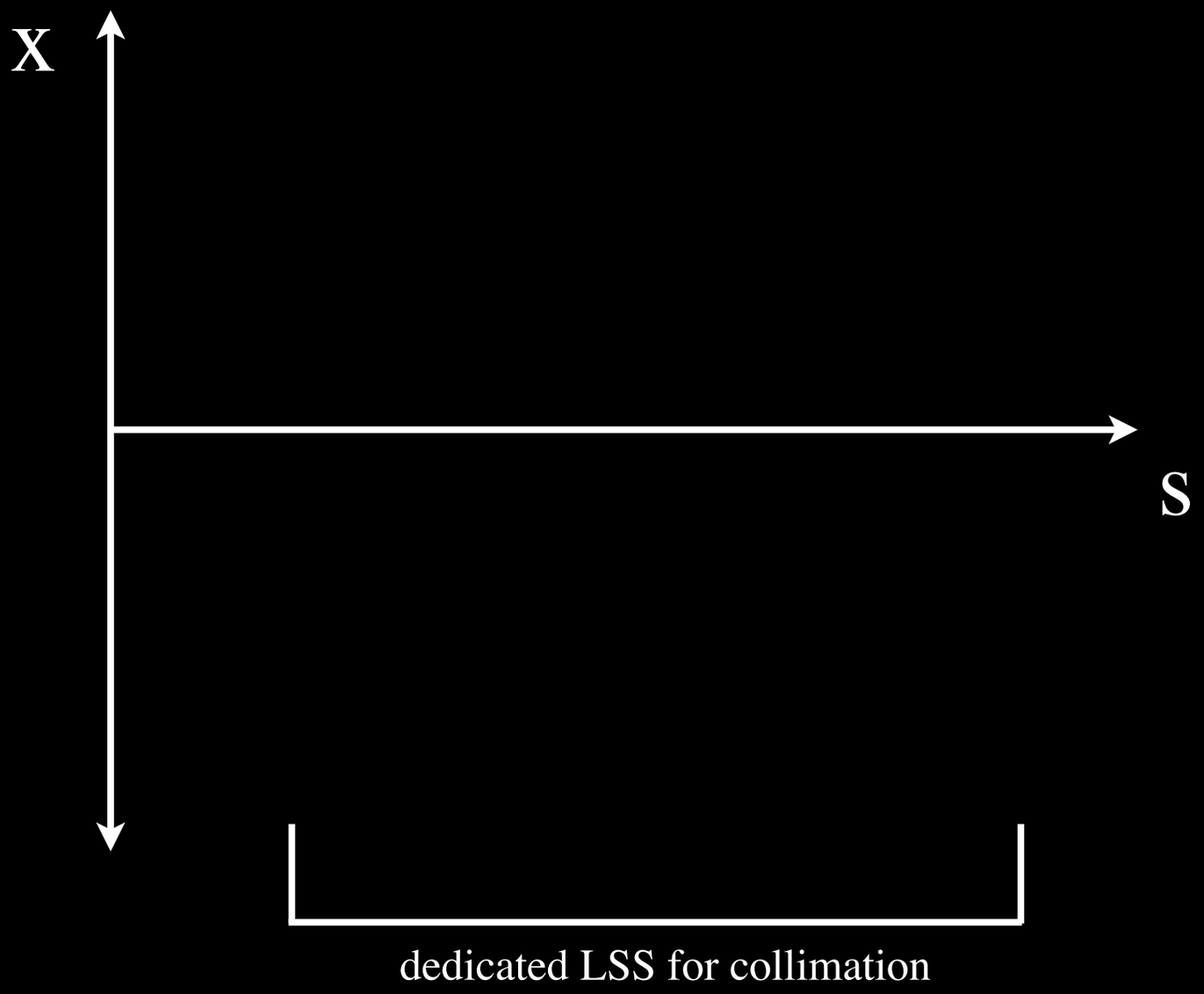

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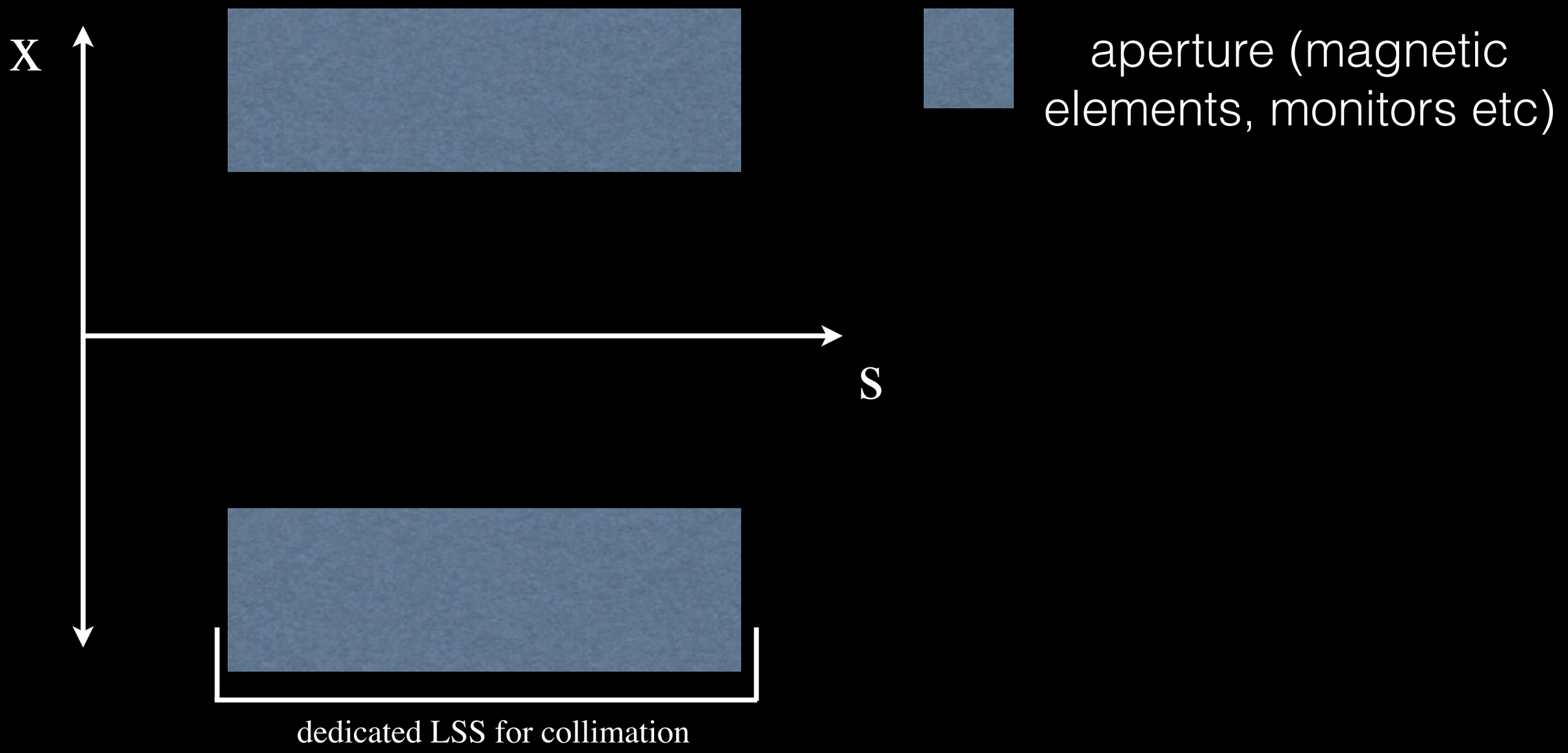

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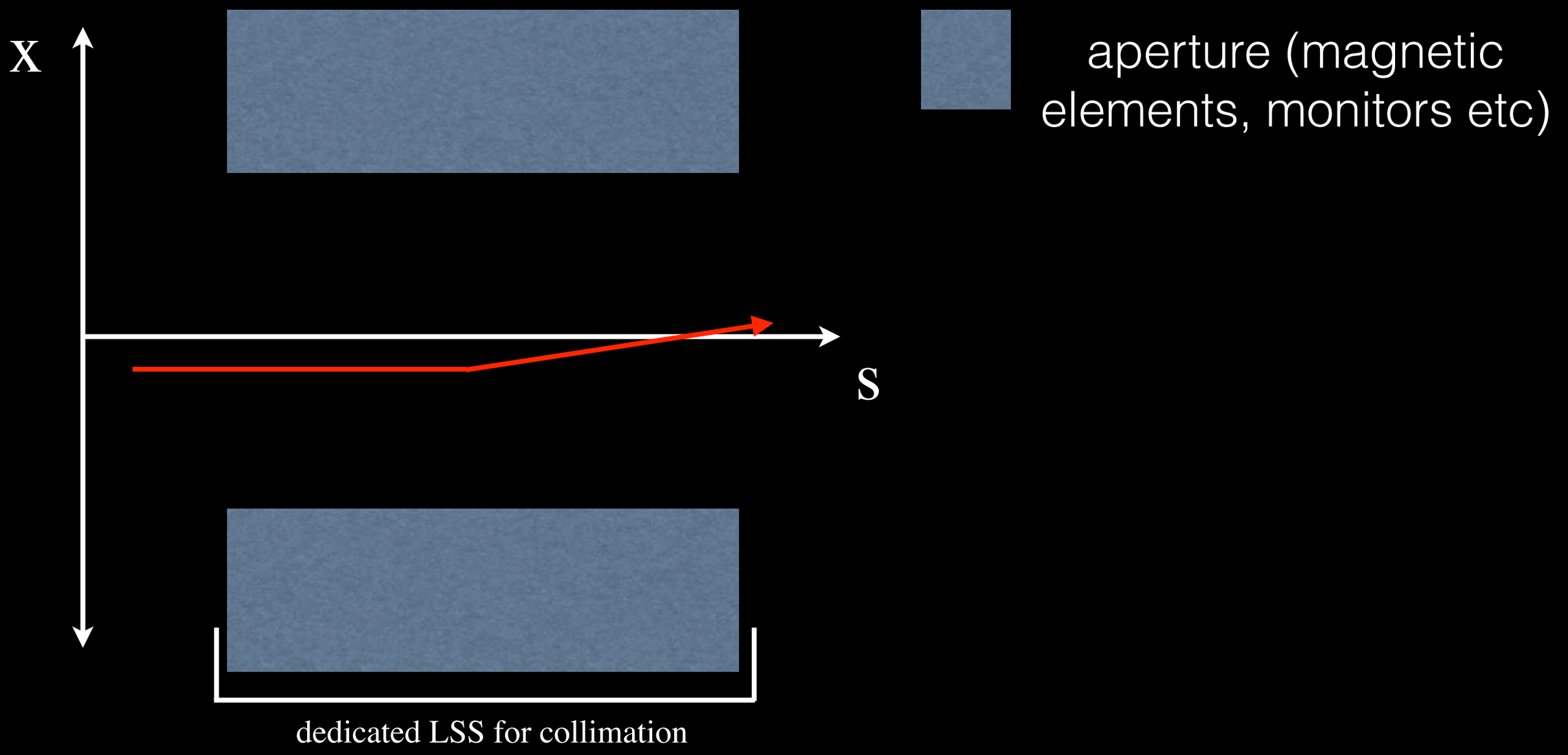

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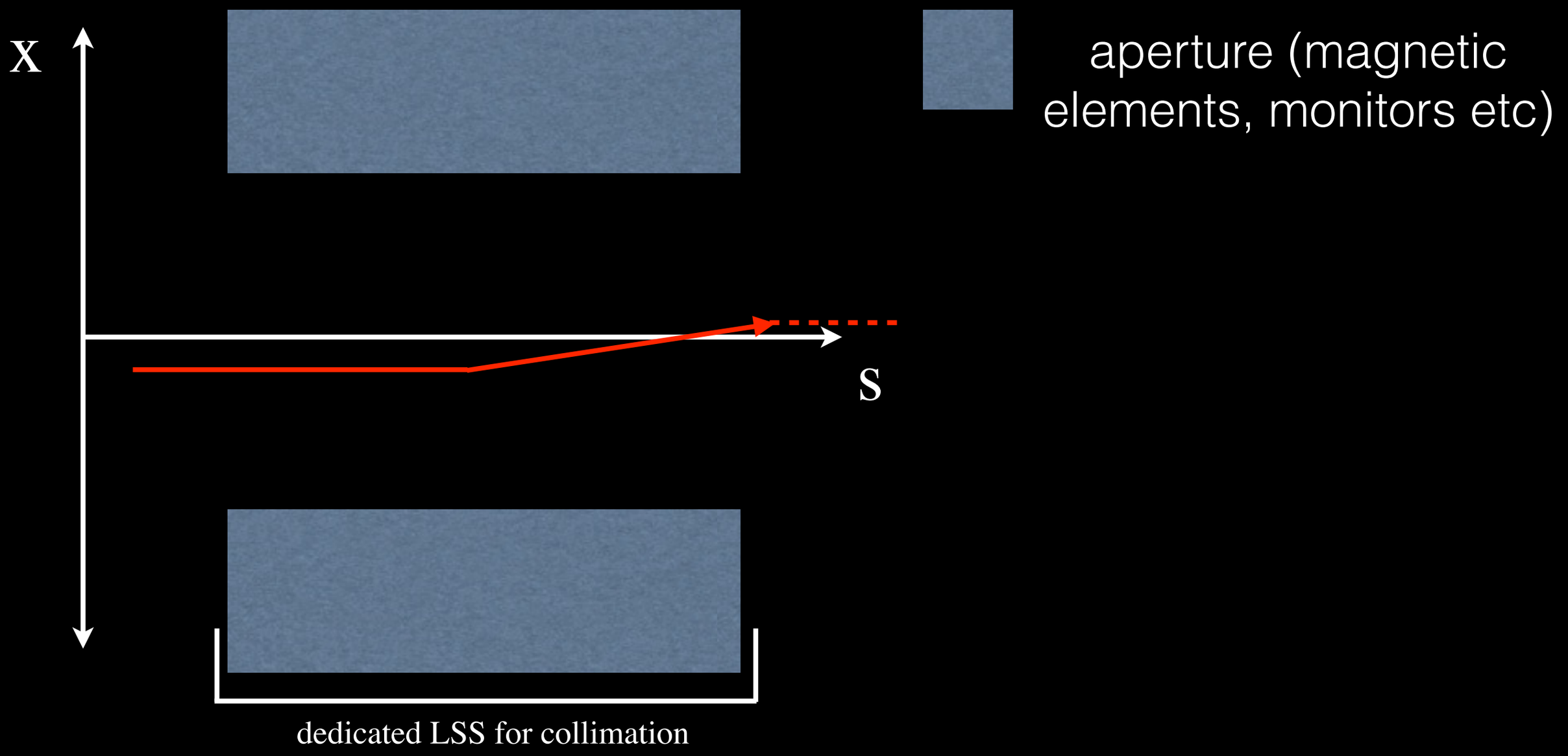

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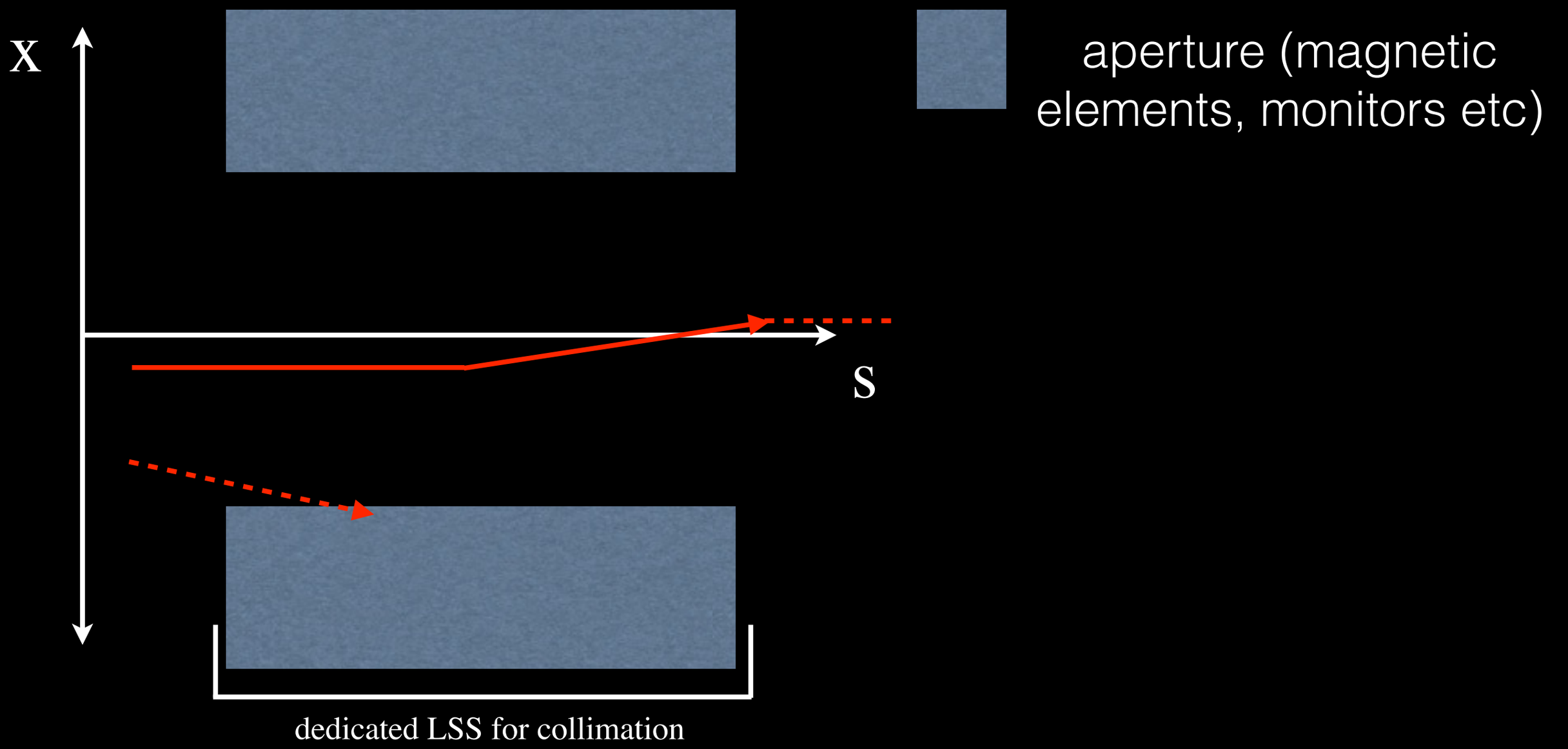

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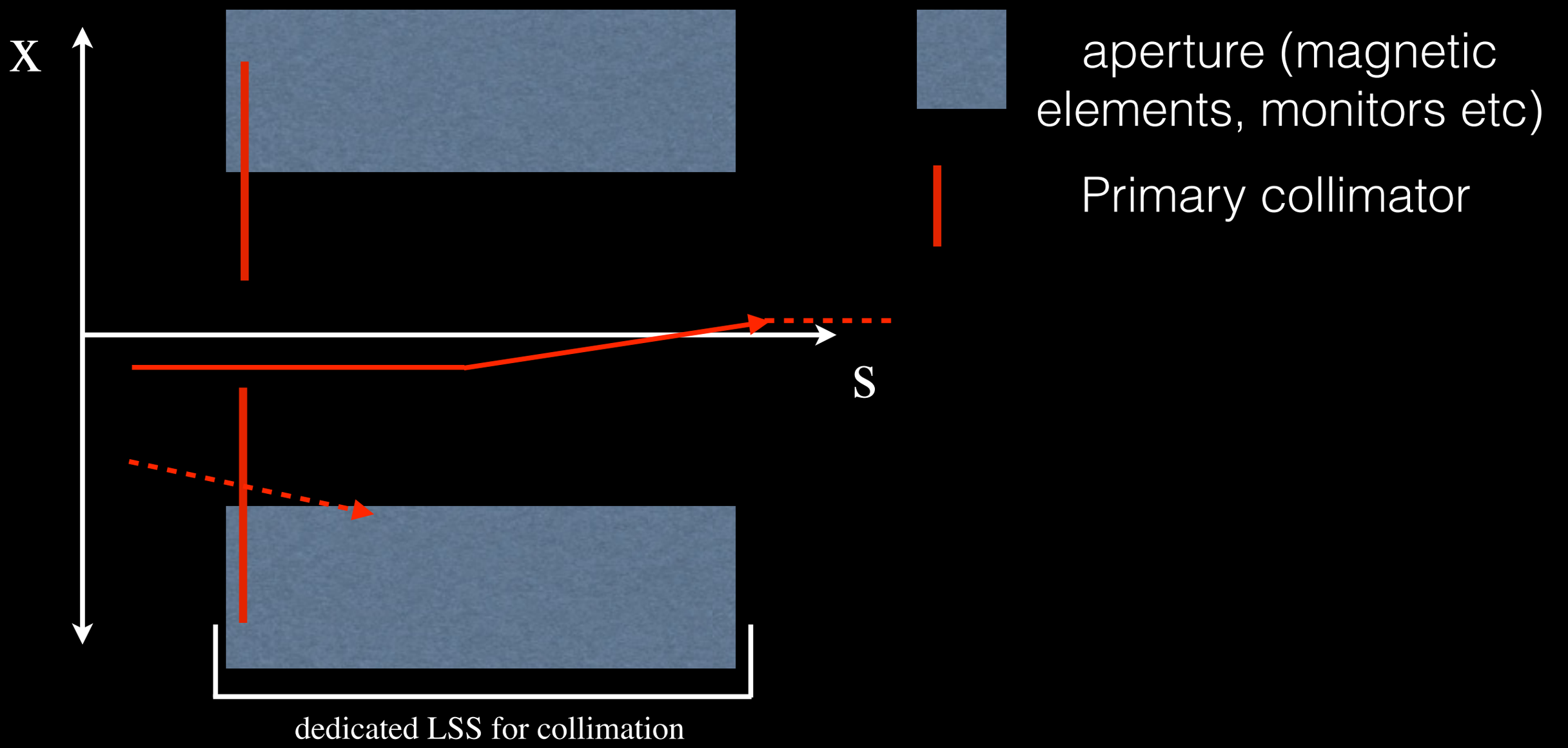

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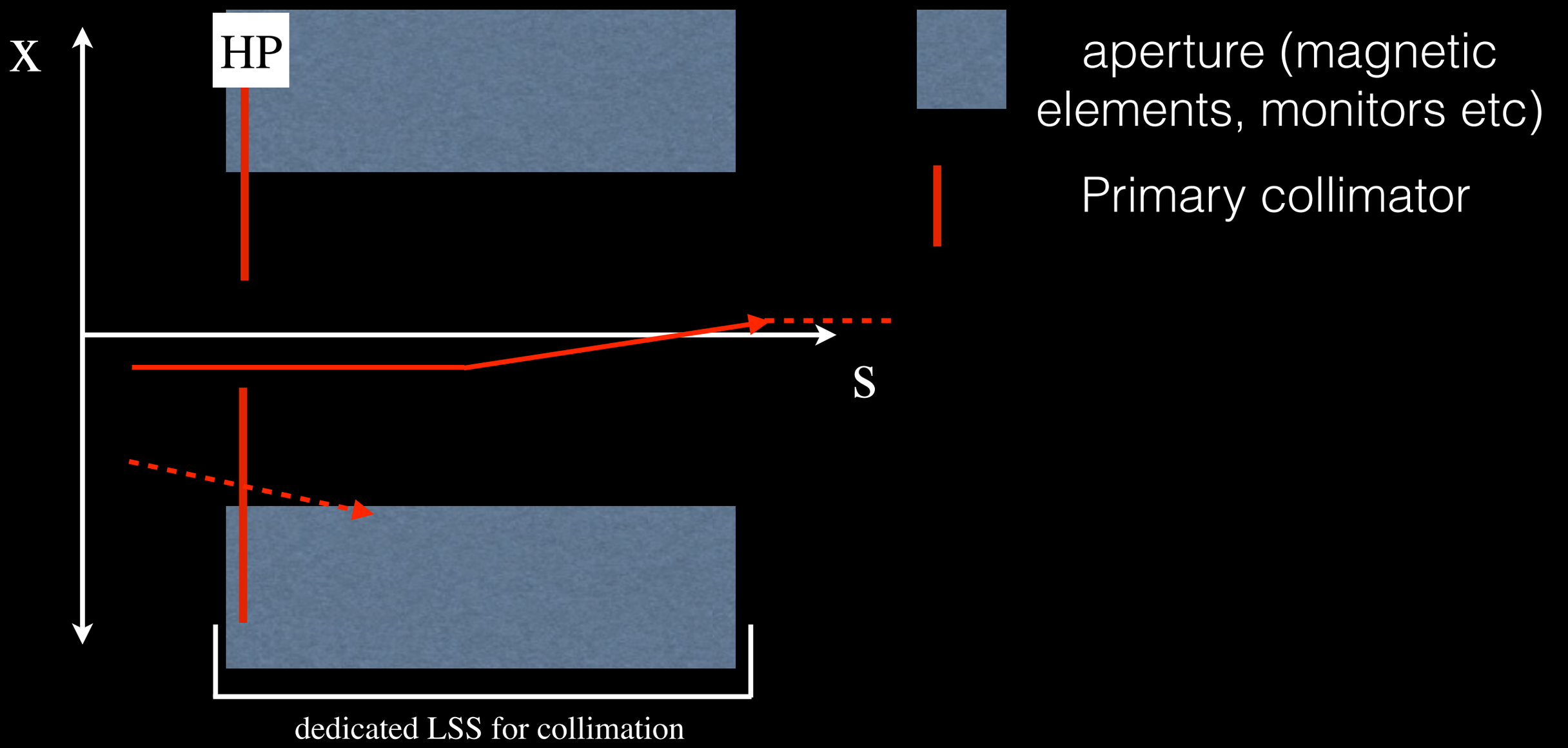

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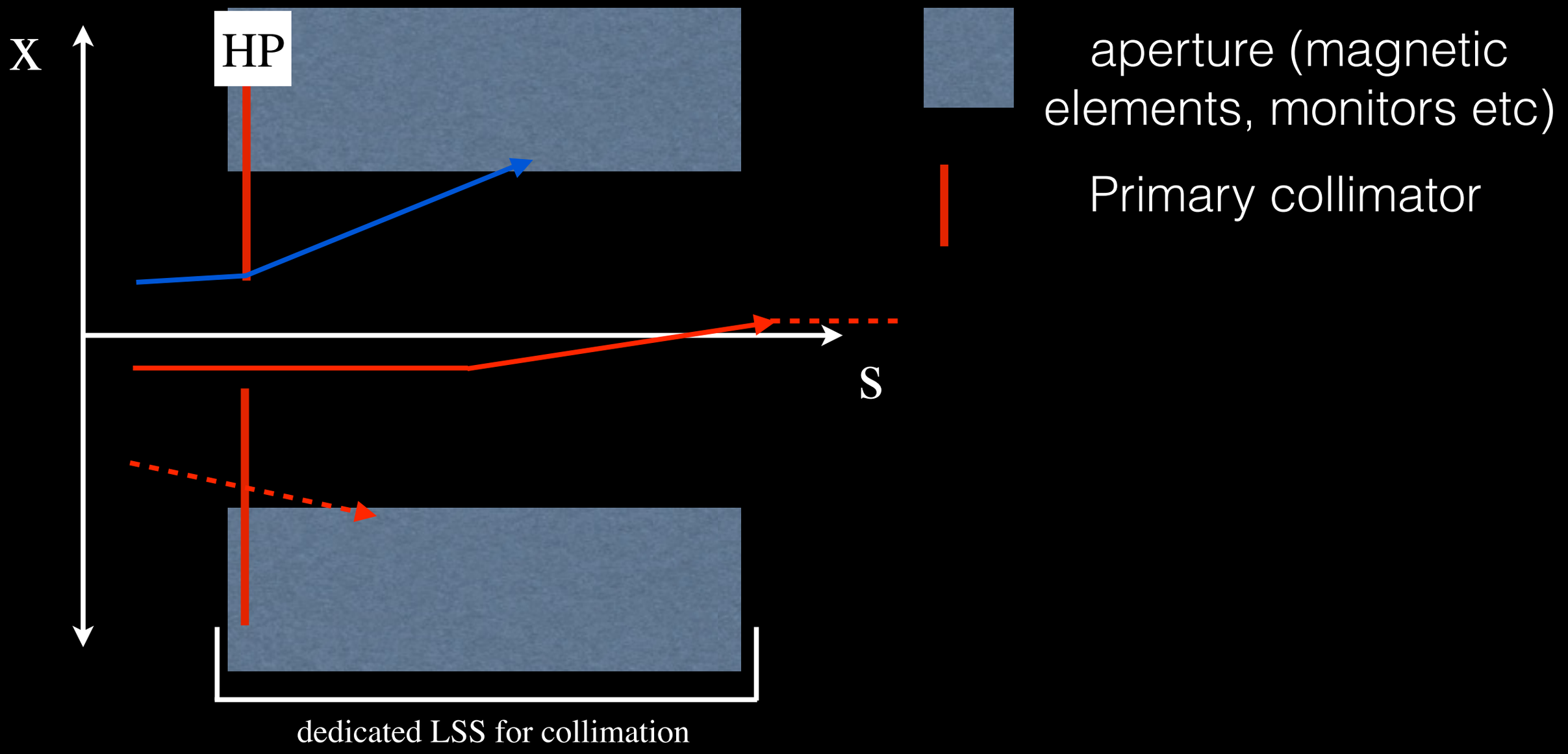

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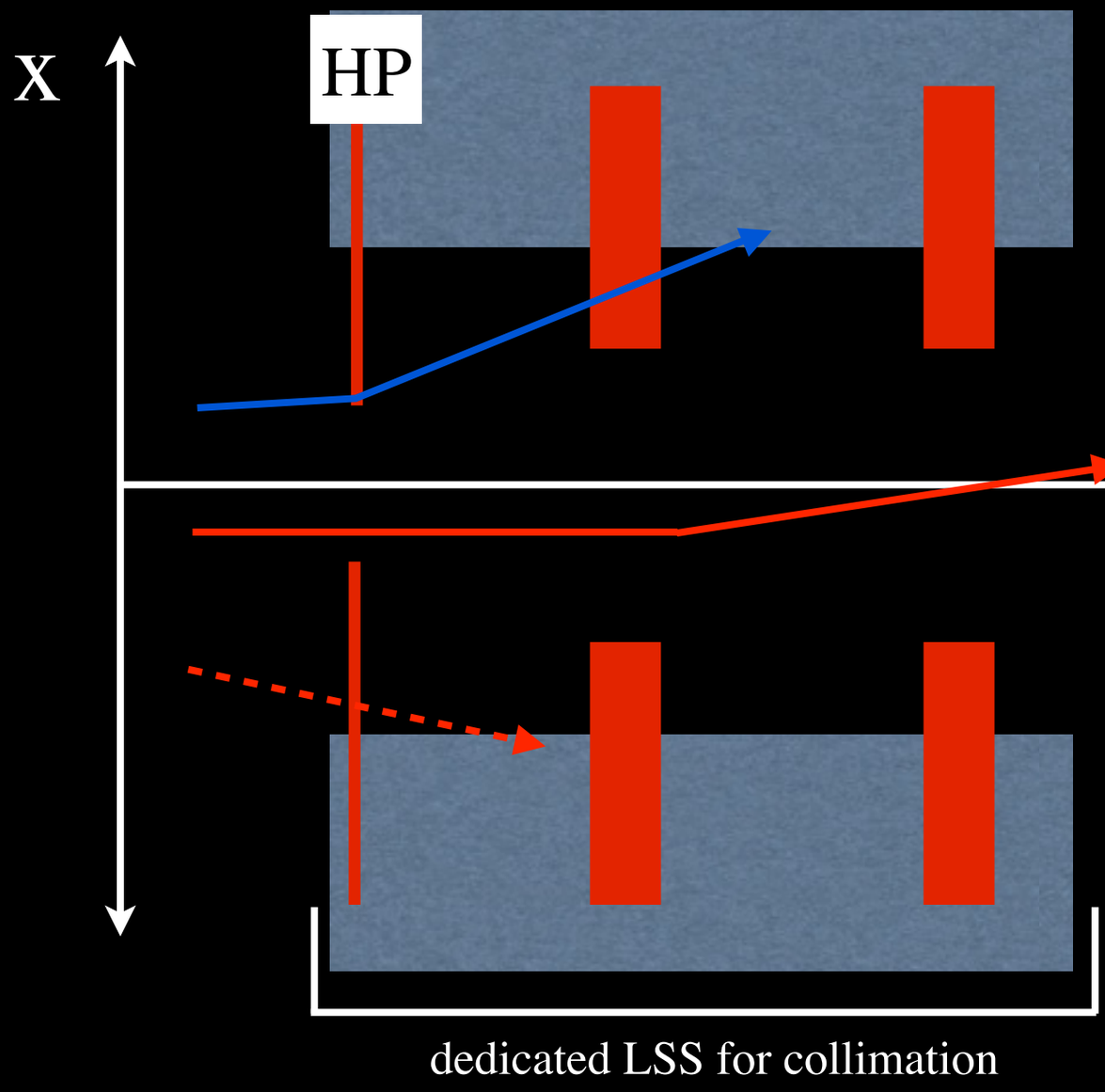

aperture (magnetic elements, monitors etc)

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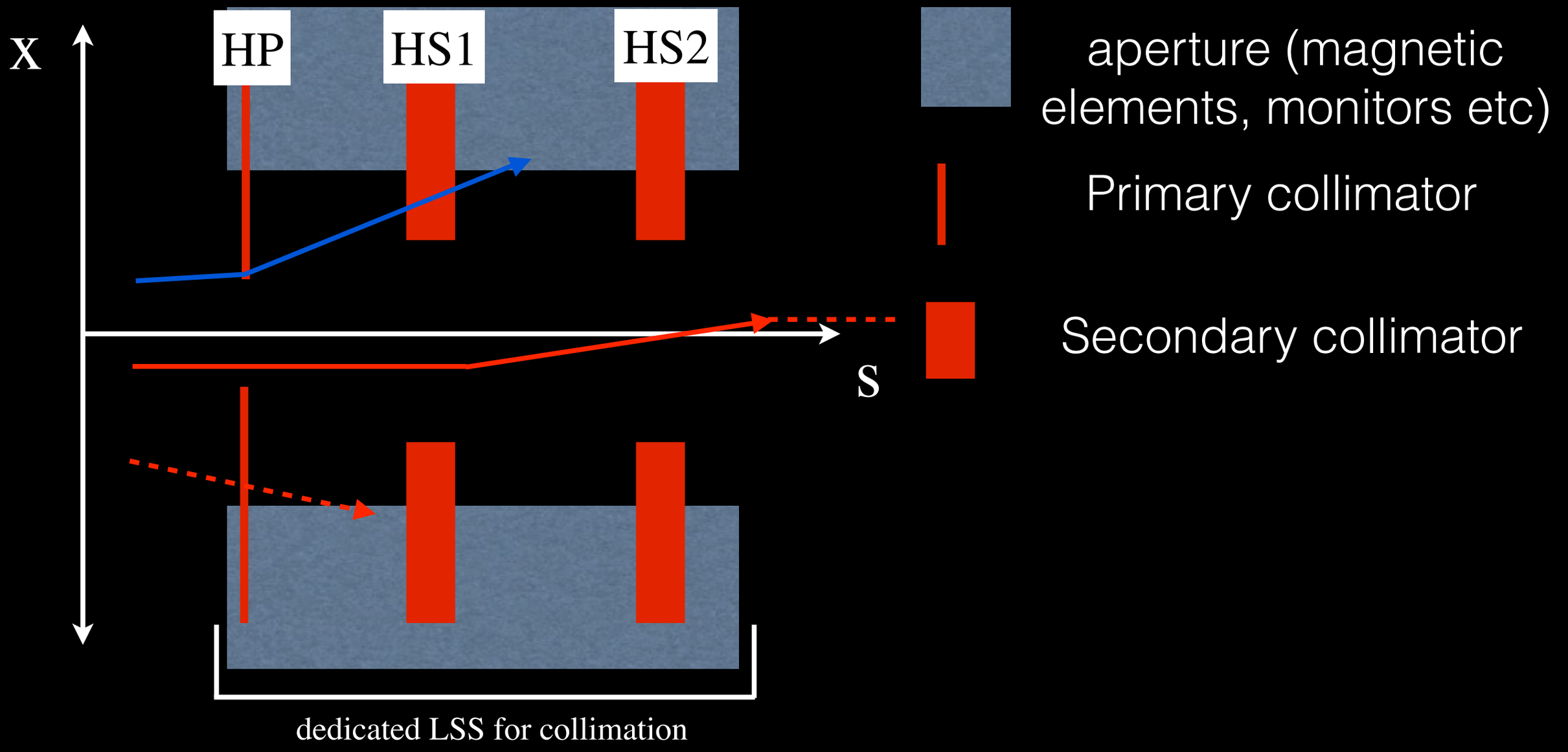

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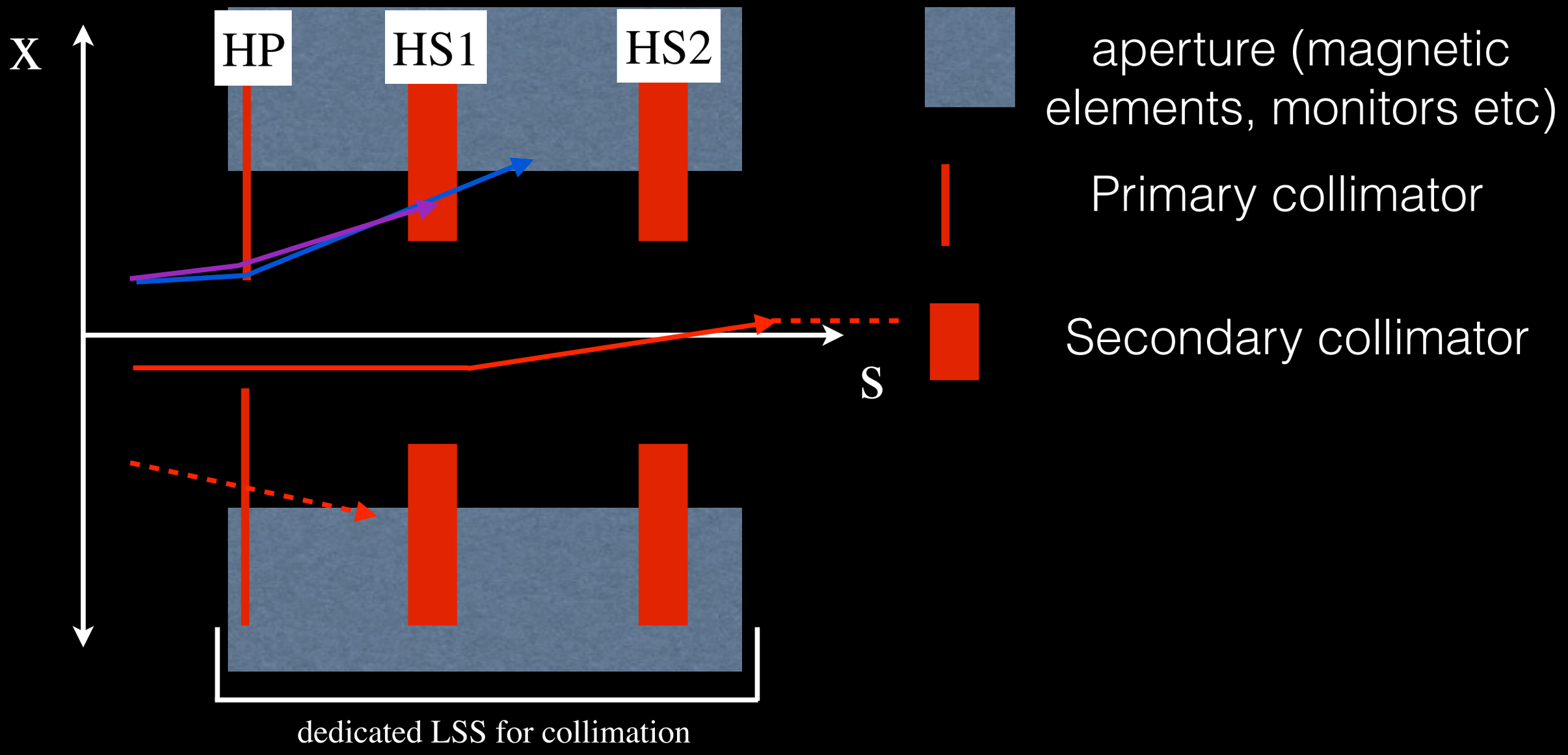

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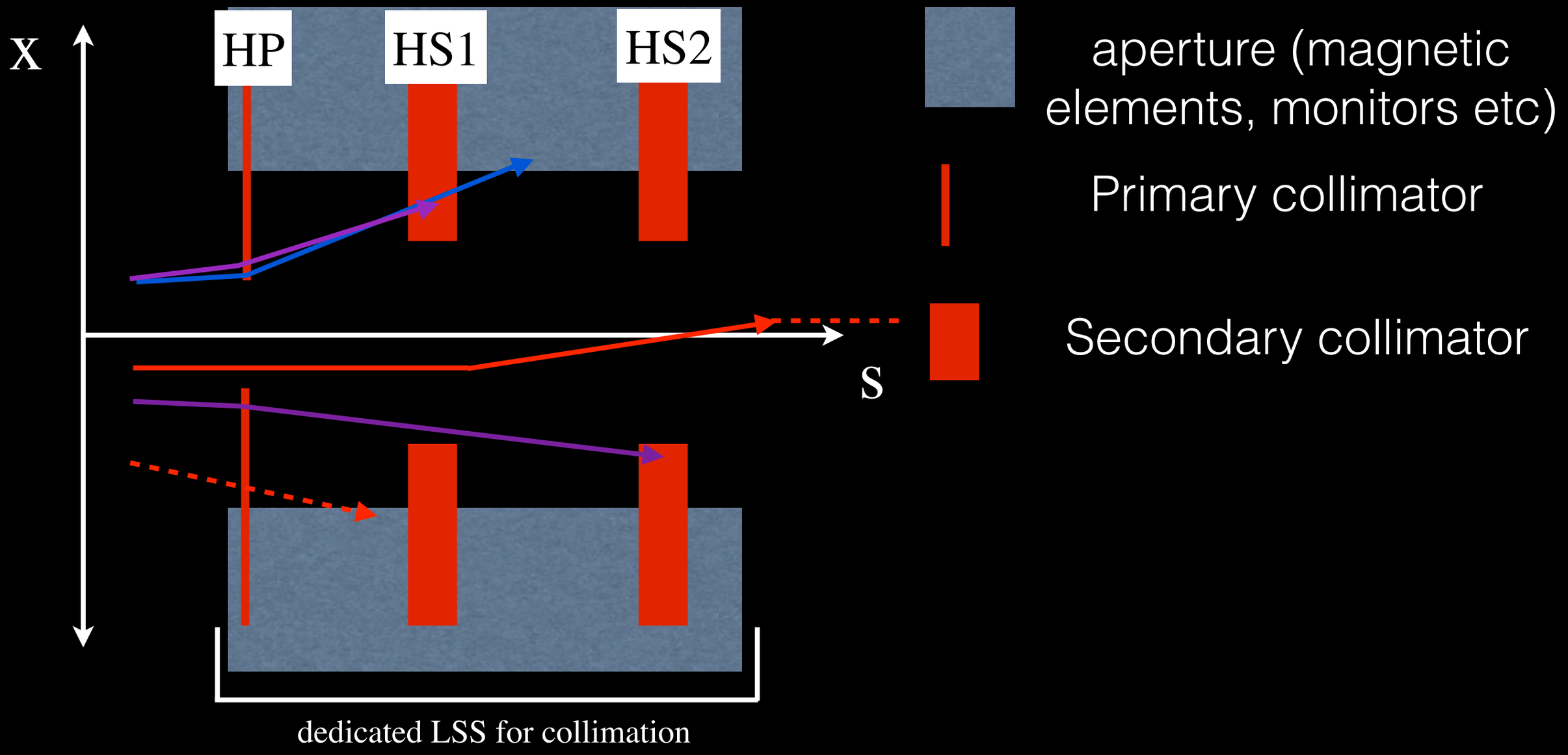

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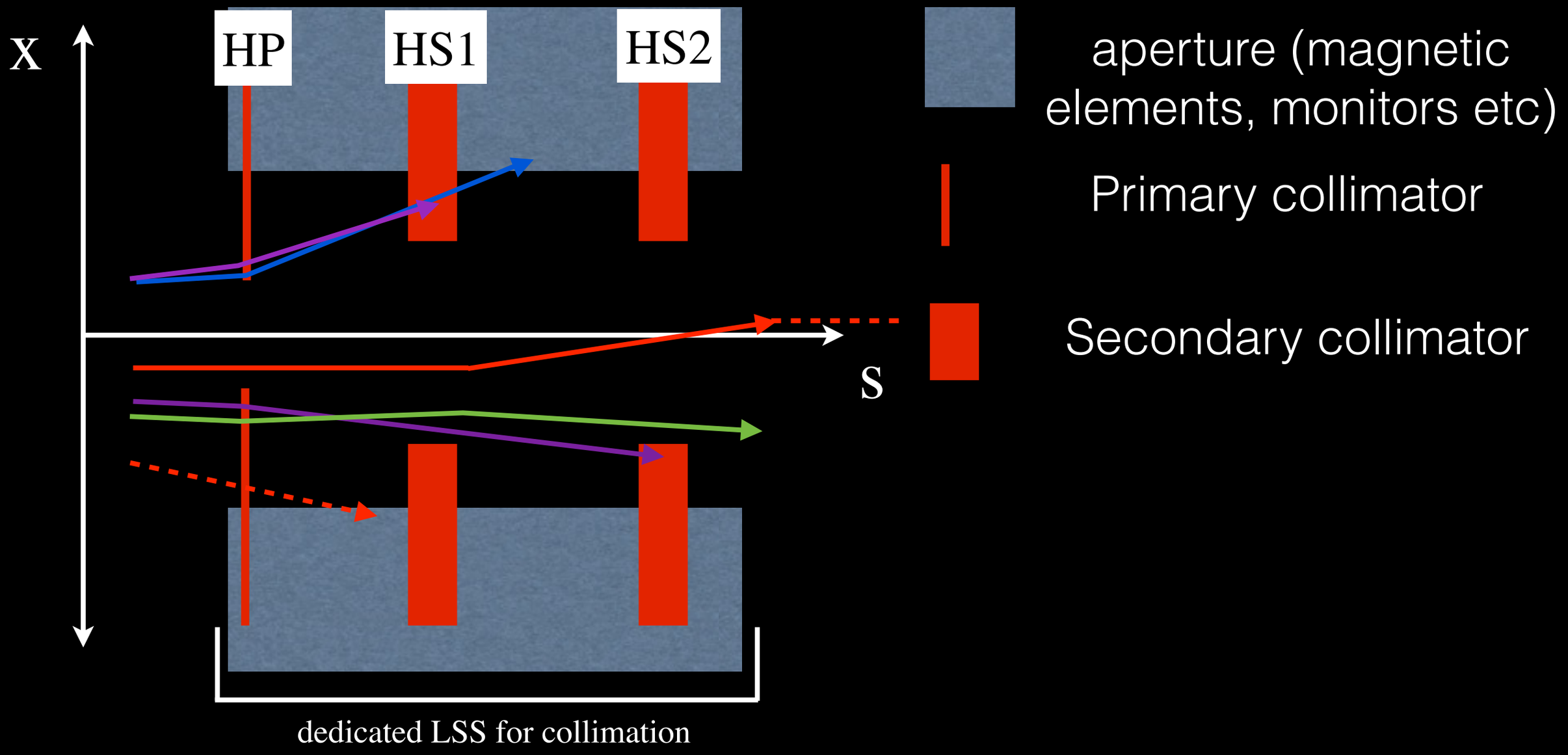

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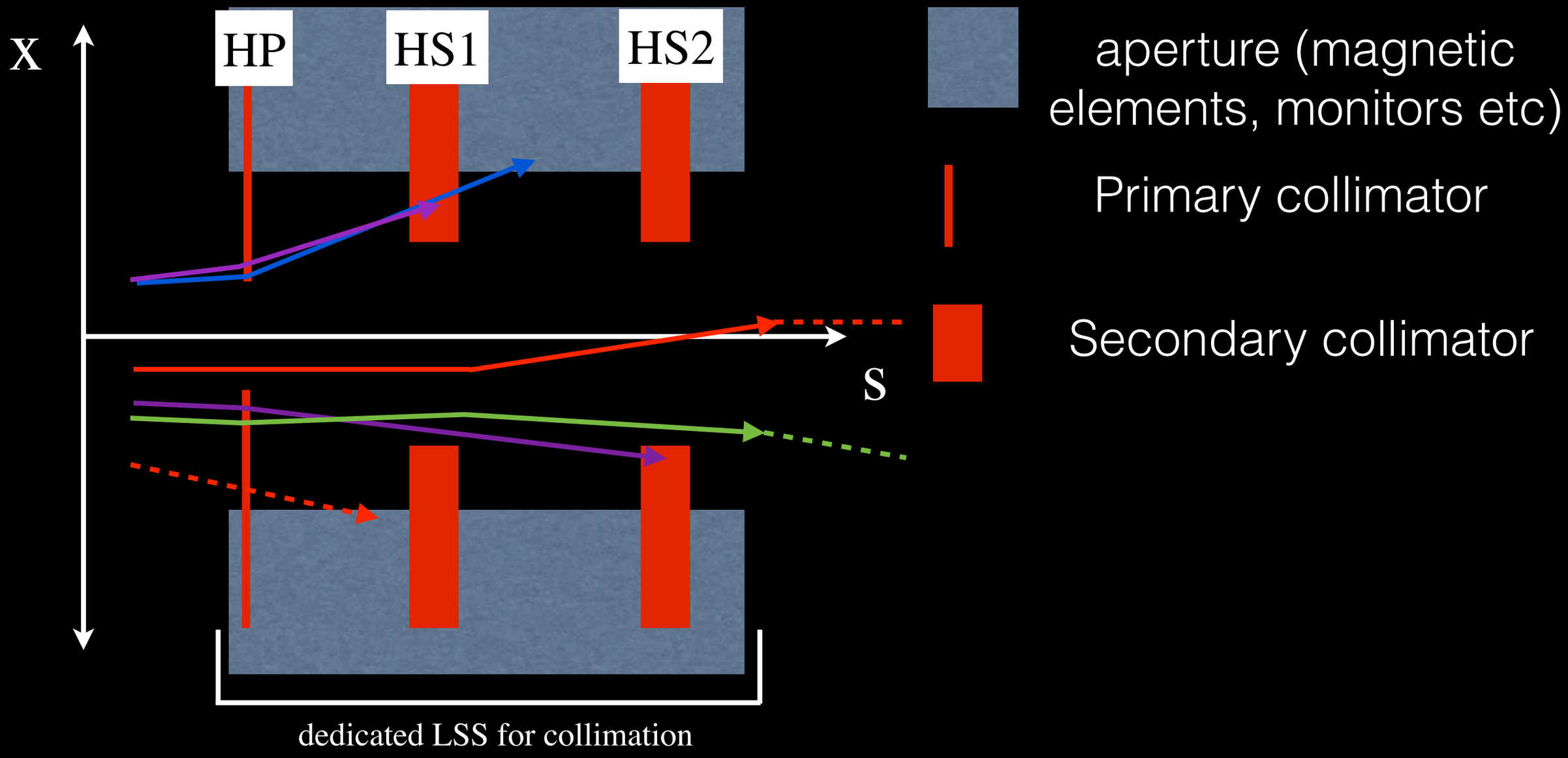

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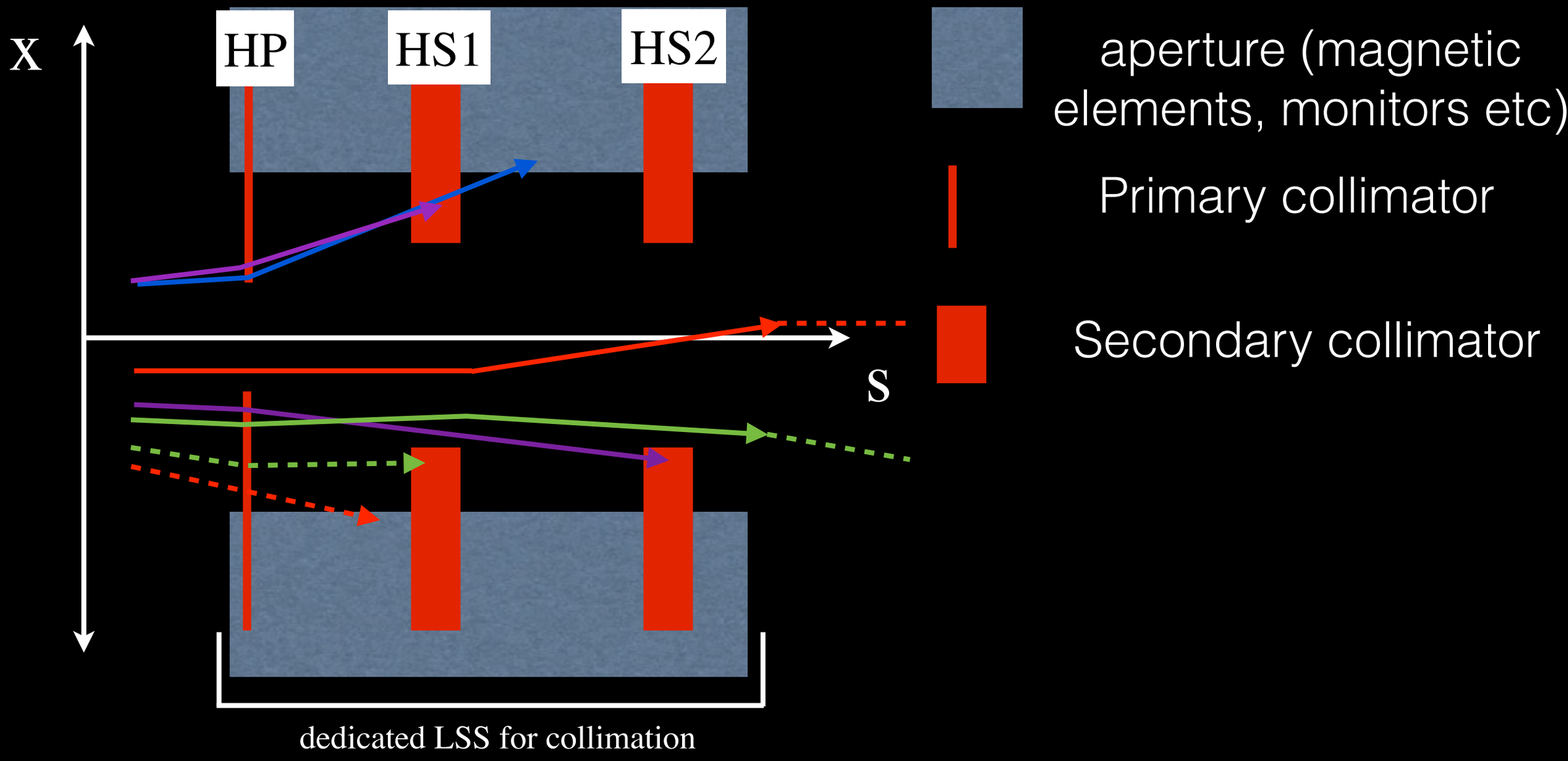

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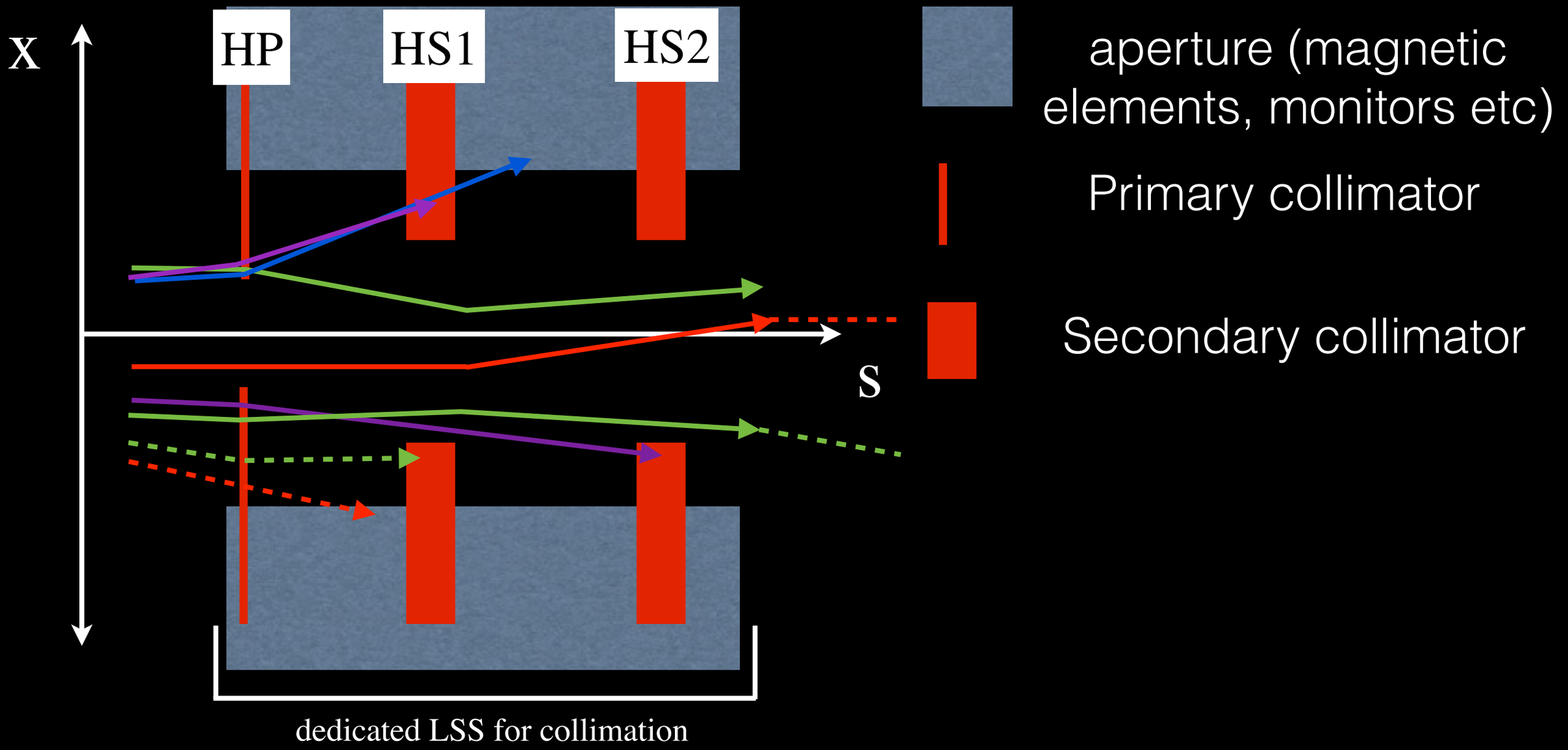

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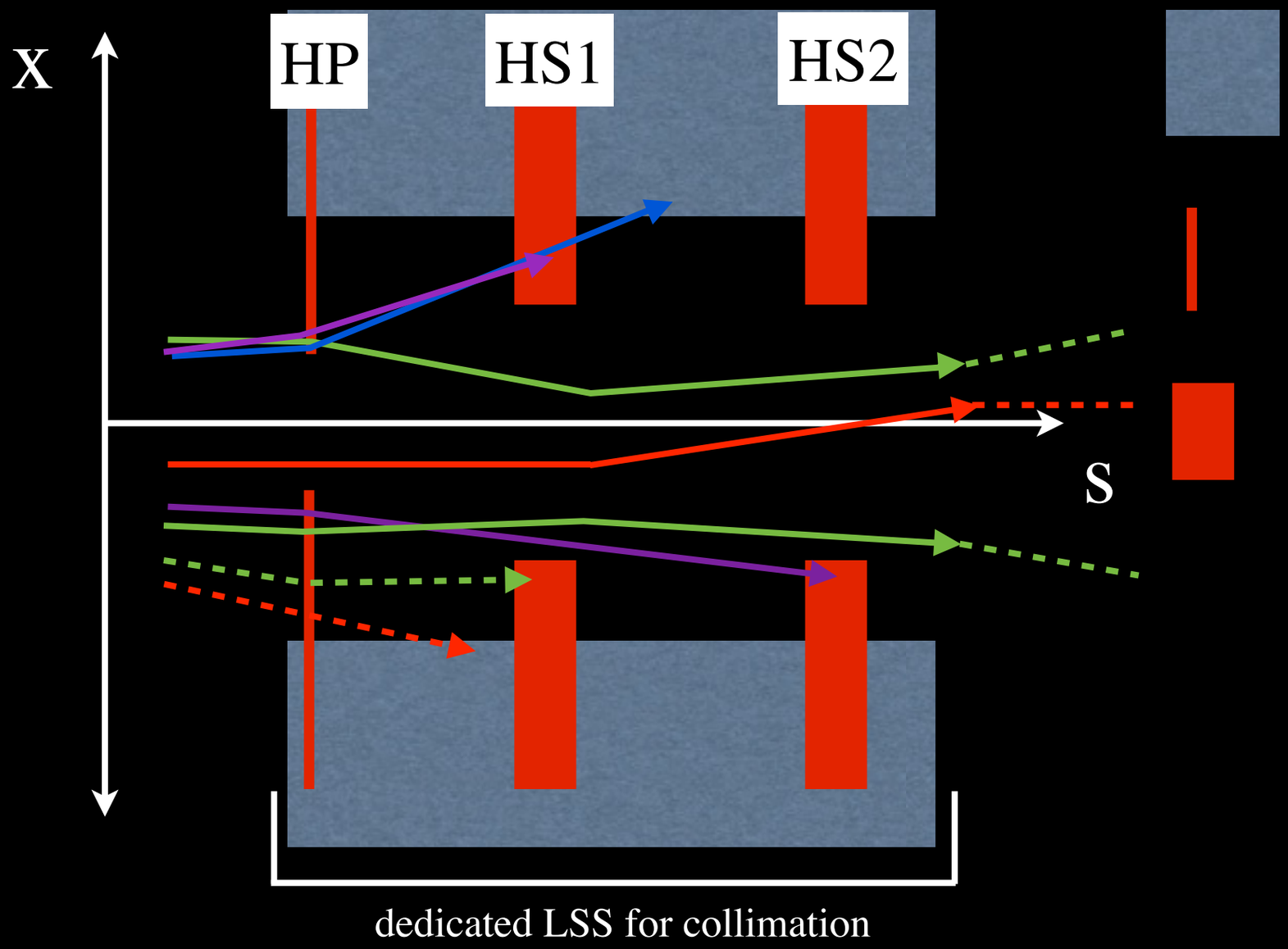

aperture (magnetic elements, monitors etc)

Primary collimator

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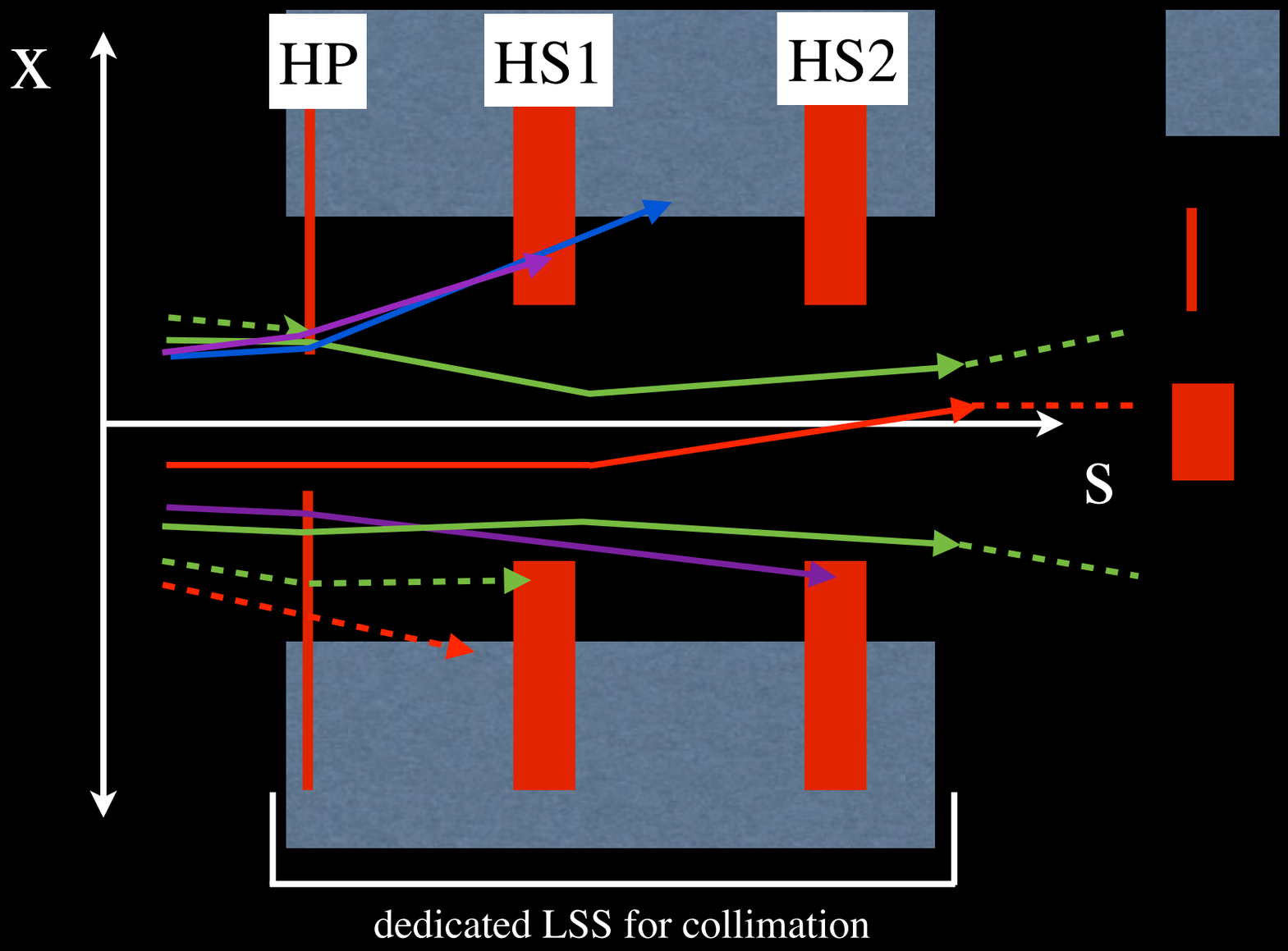

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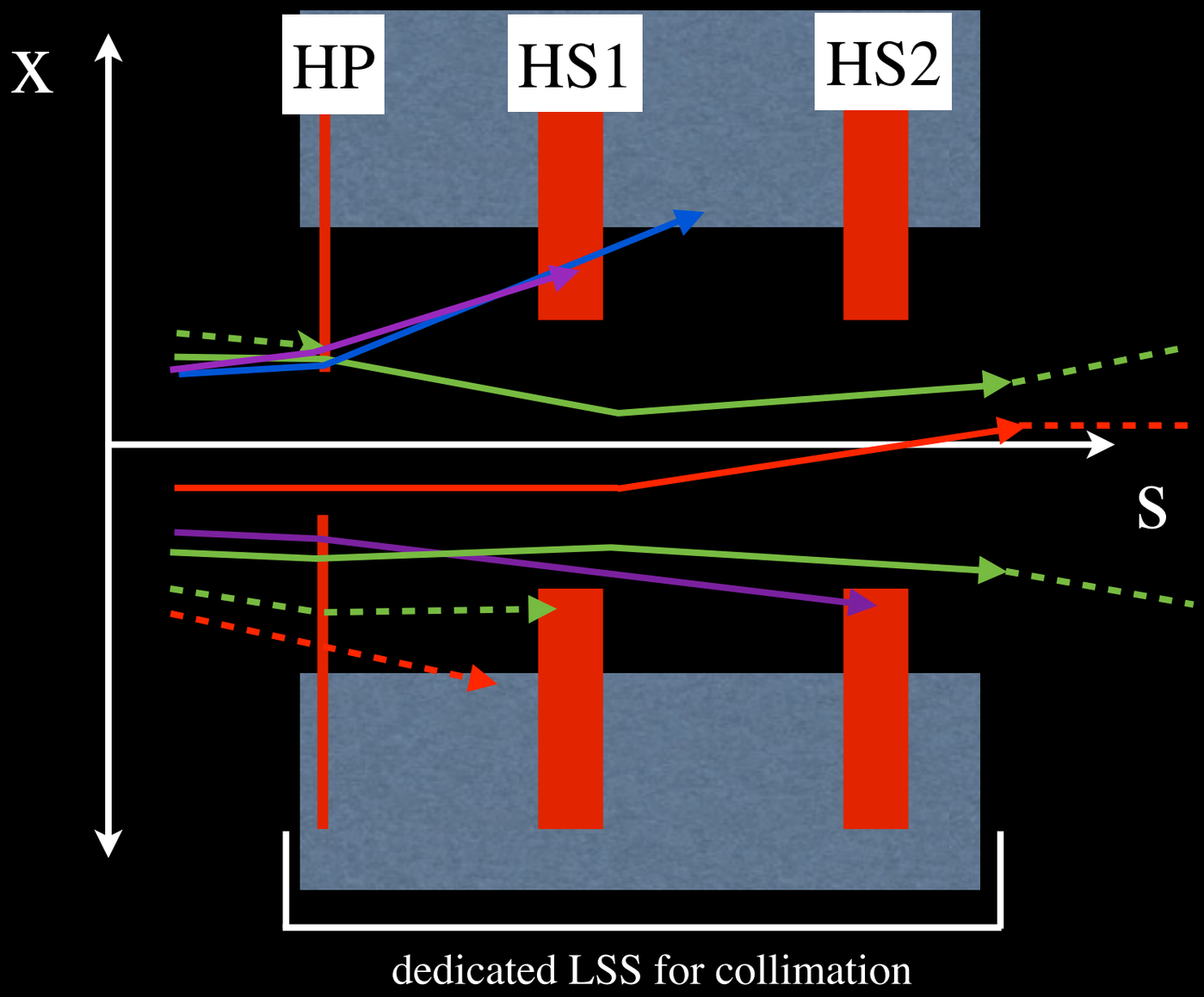


aperture (magnetic elements, monitors etc)

Primary collimator

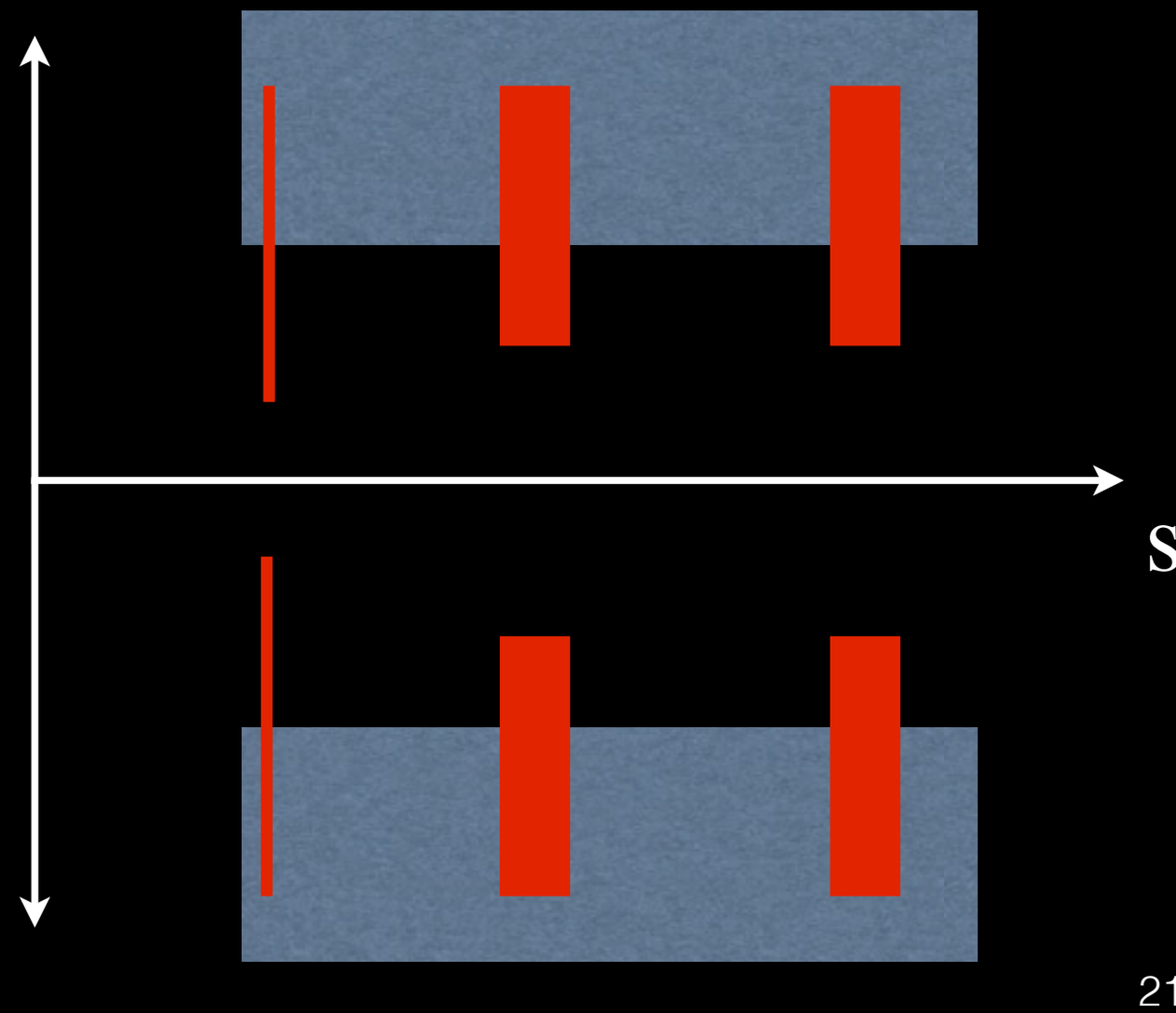
Secondary collimator

If particle:
- stops in aperture: lost
- stops in collimators: absorbed (e.g. green and purple)

LSS: Long Straight Section

Optimising Collimation Efficiency

Parameters:



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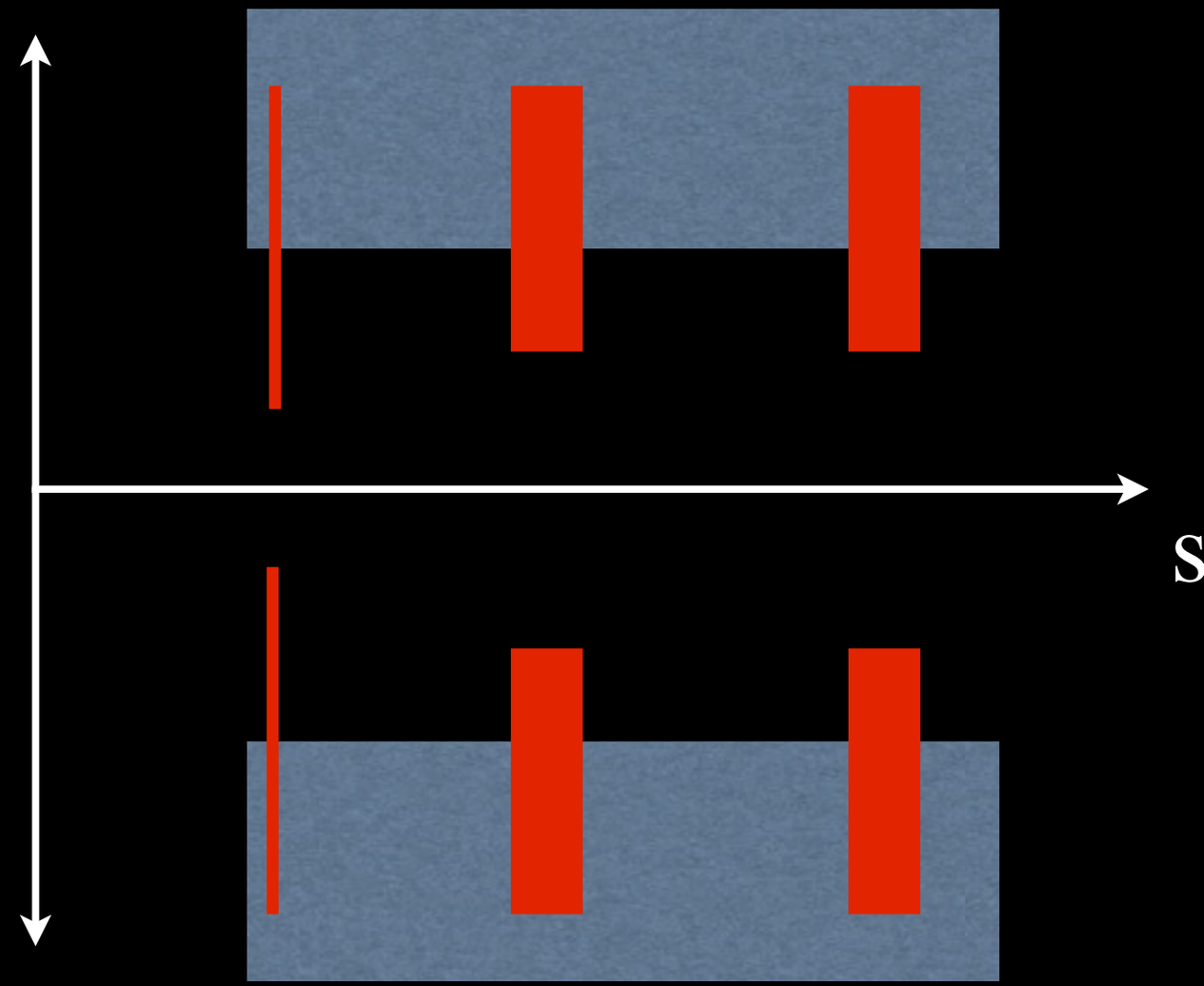

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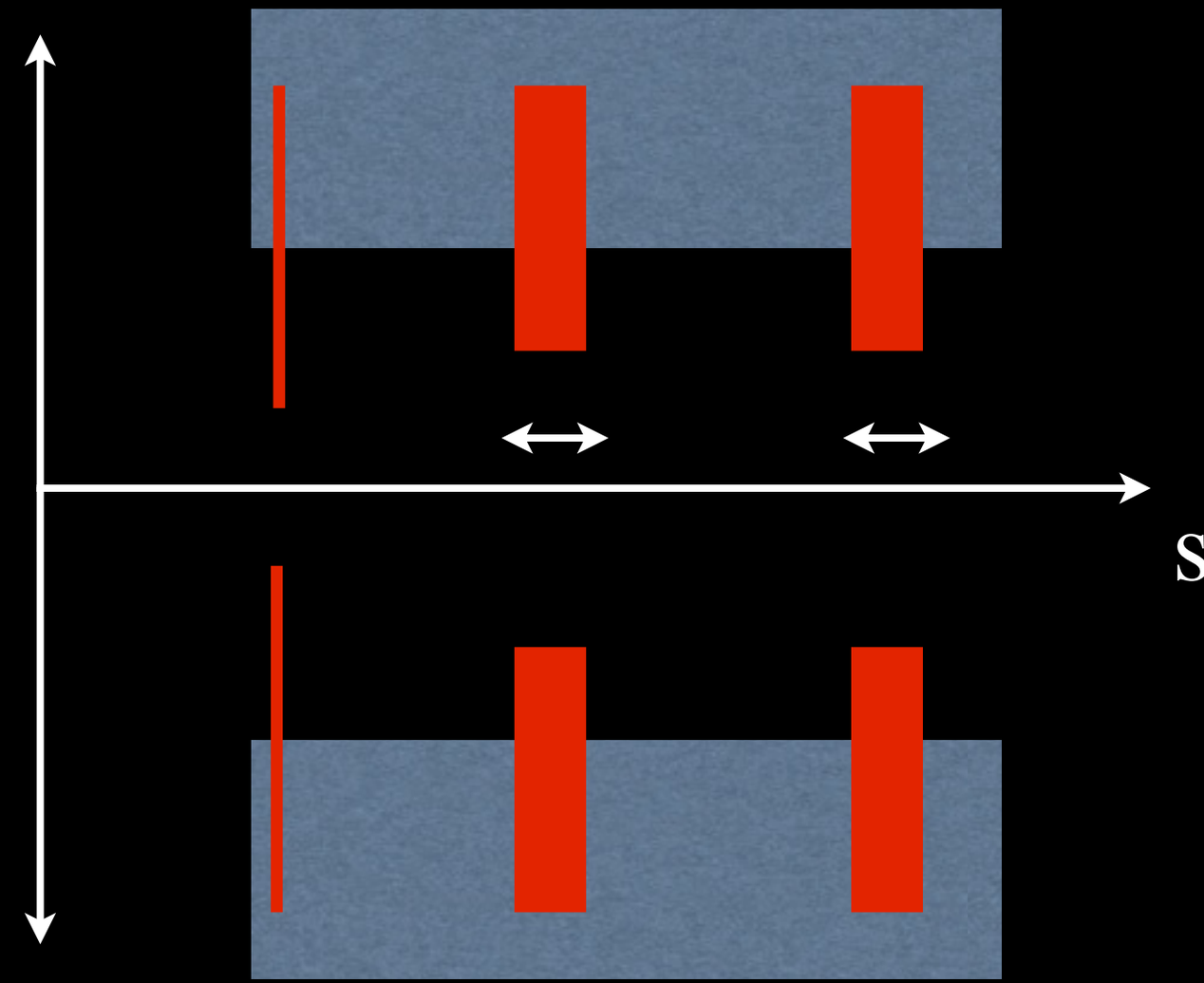

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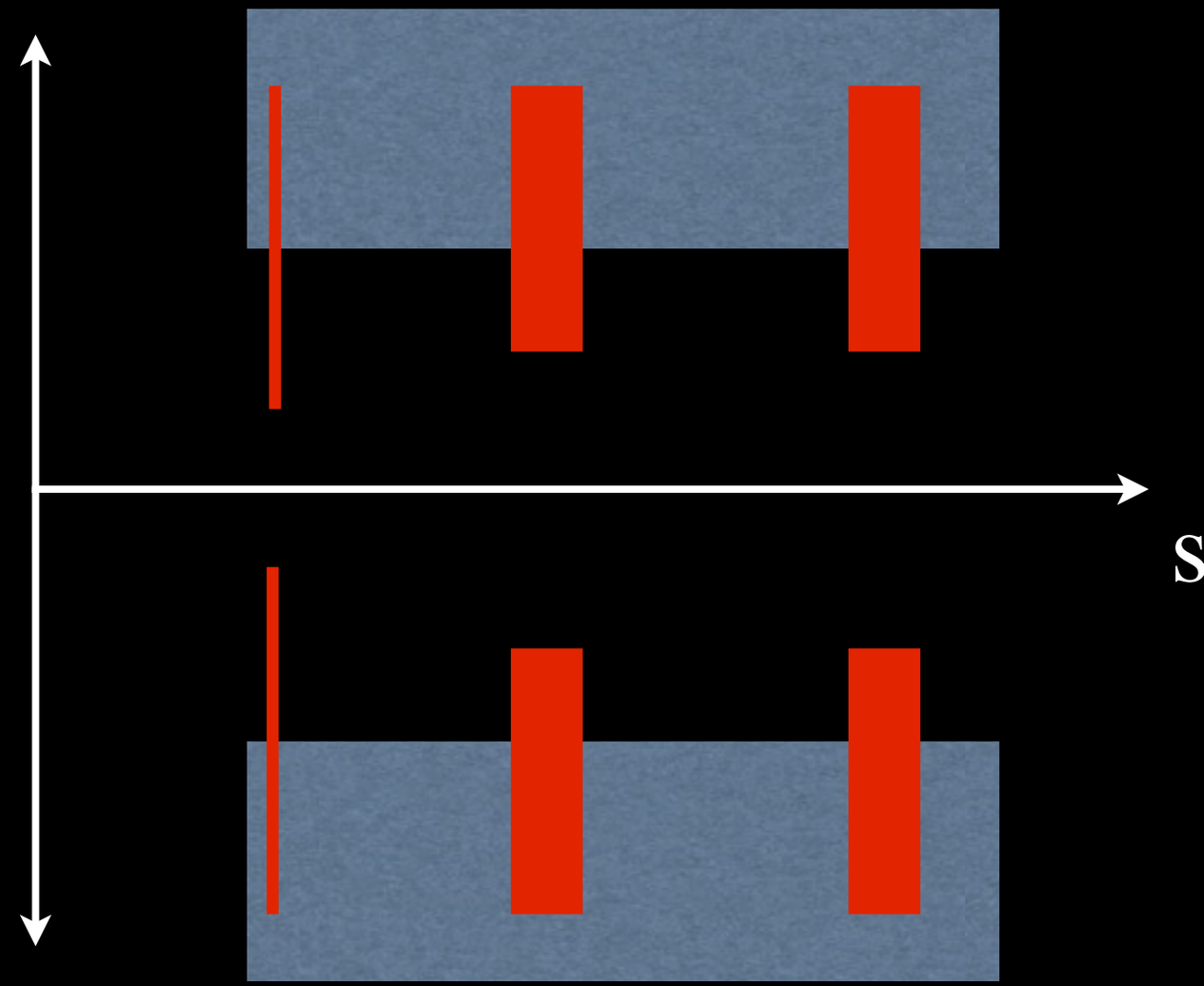

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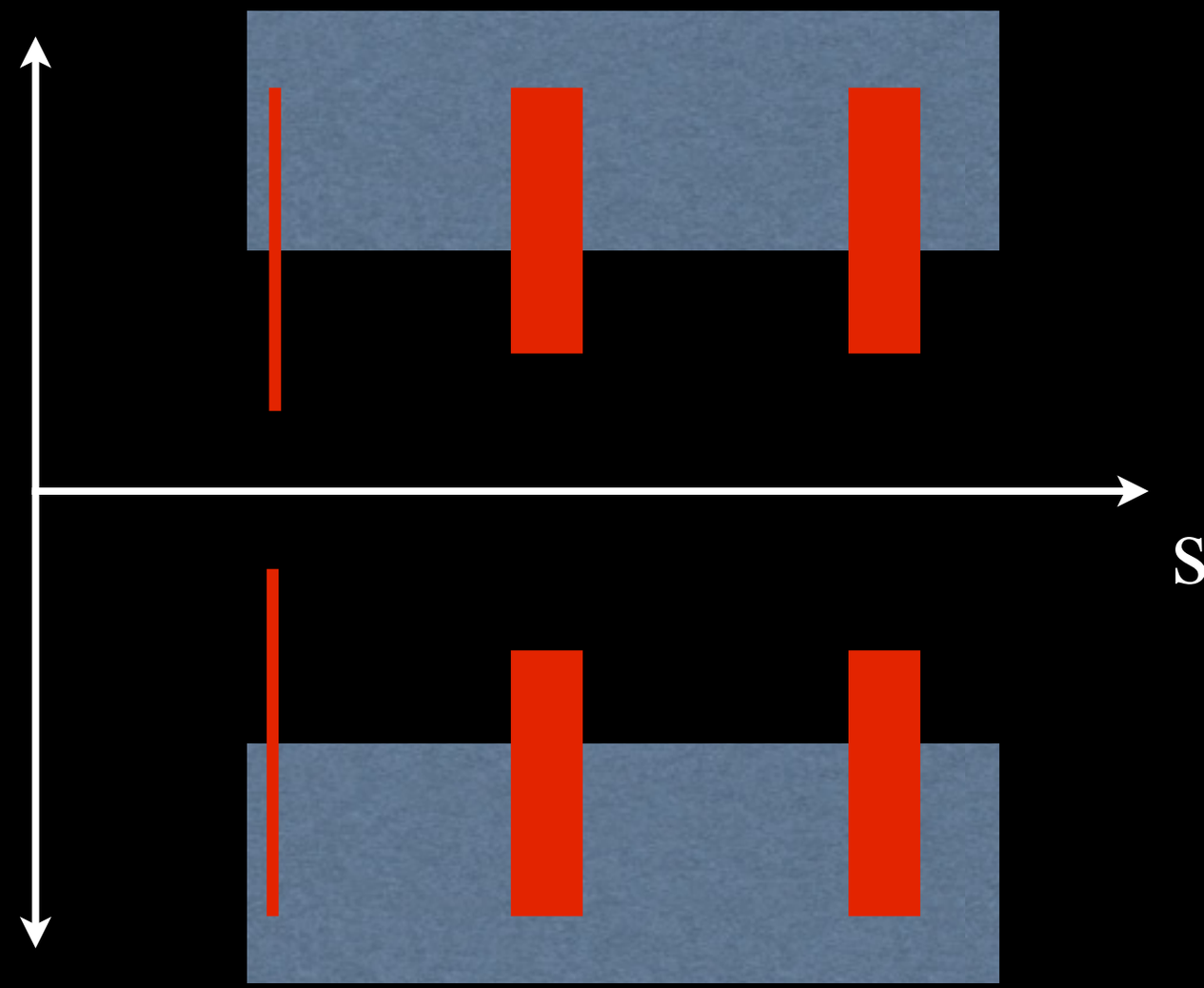

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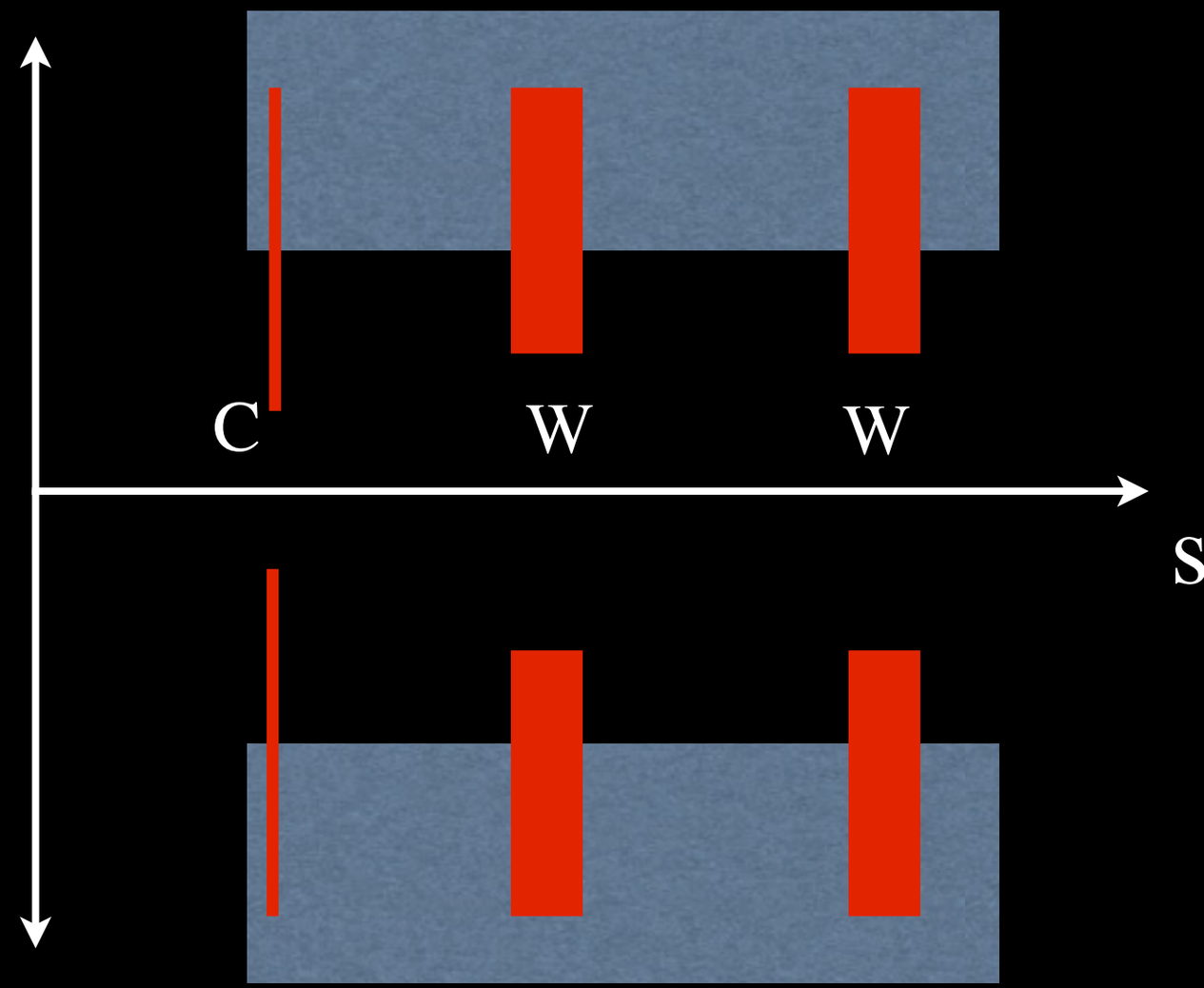

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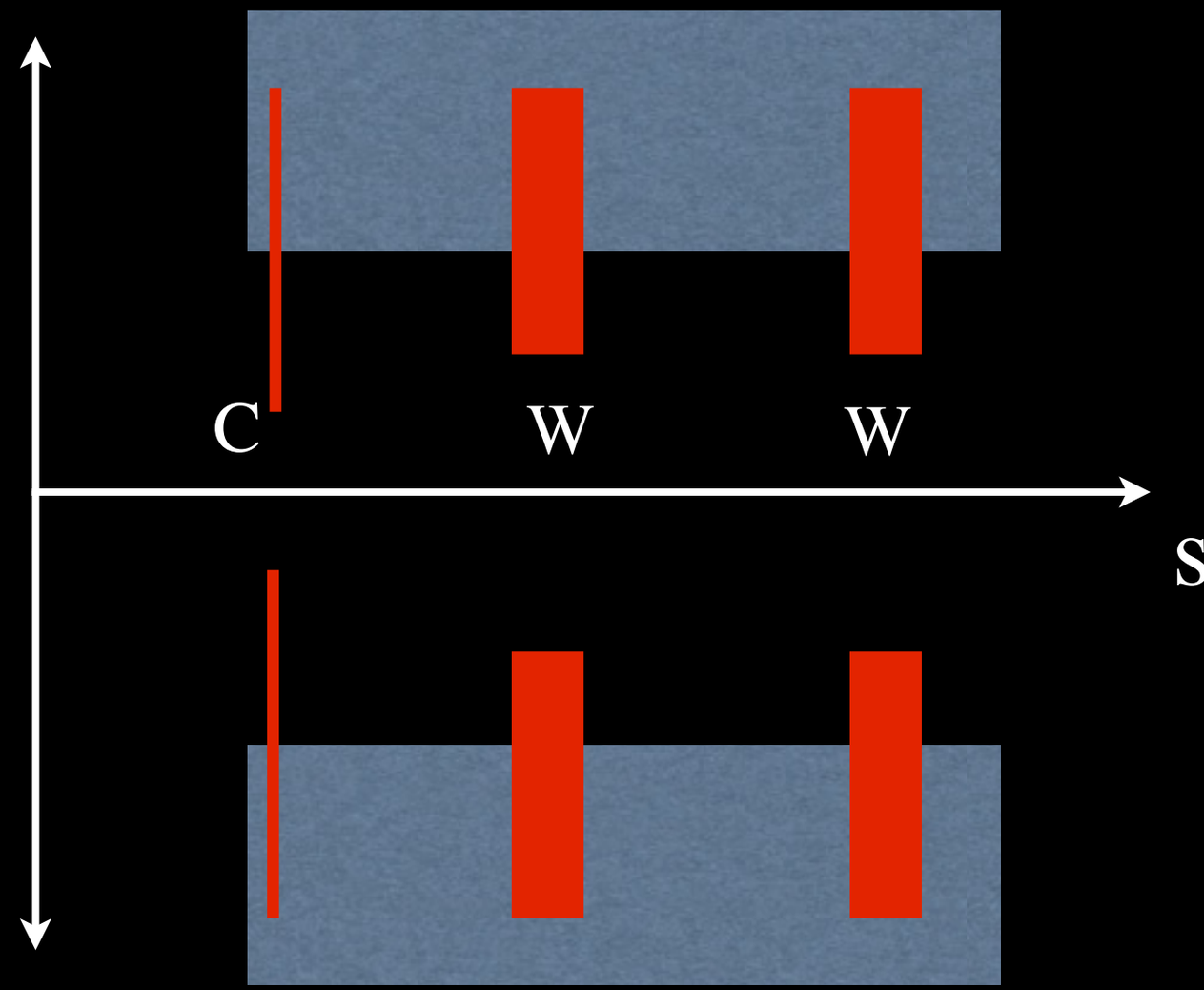
- collimators thickness
- collimators material (e.g. graphite (C), tungsten (W))
- jaw opening



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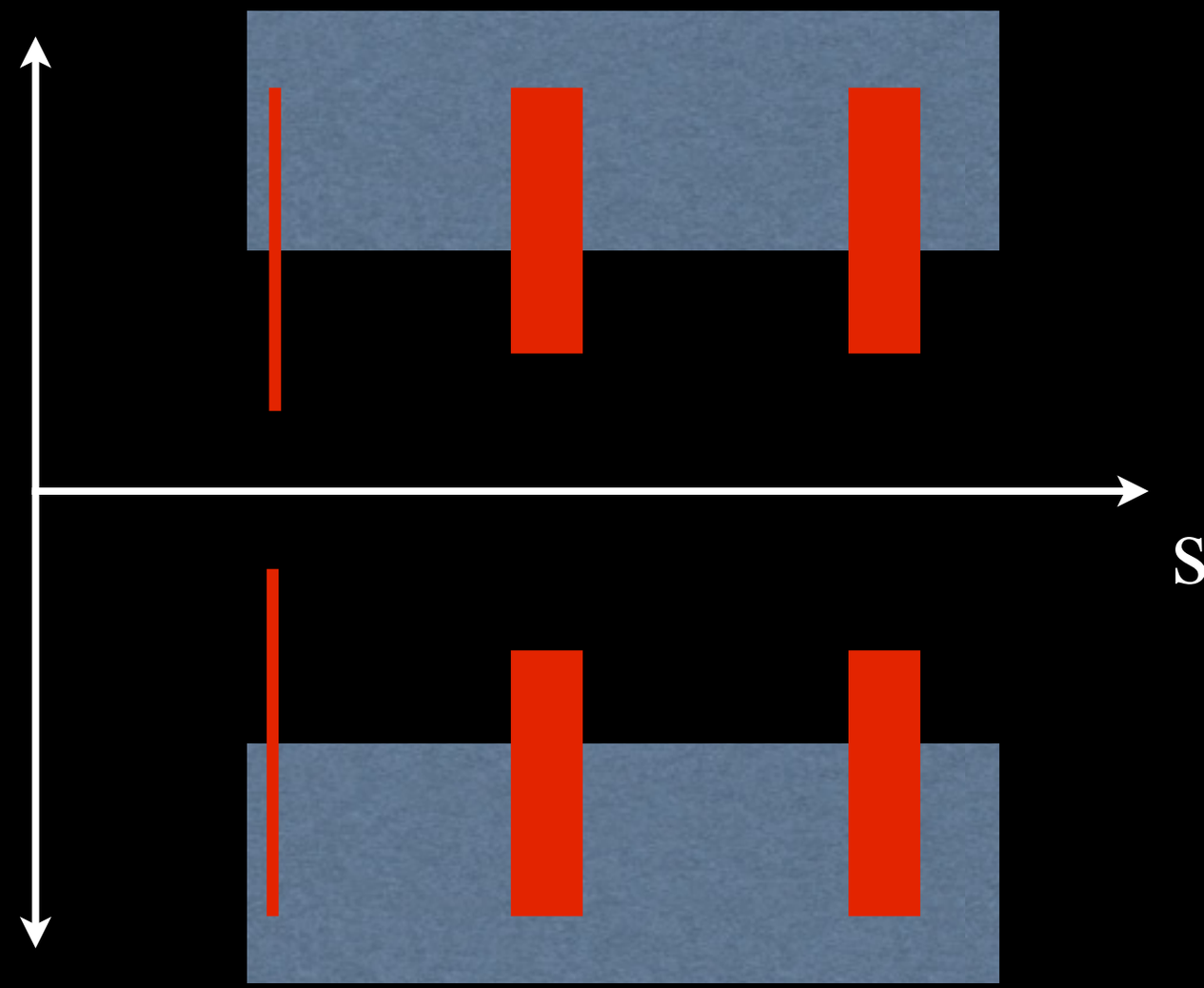

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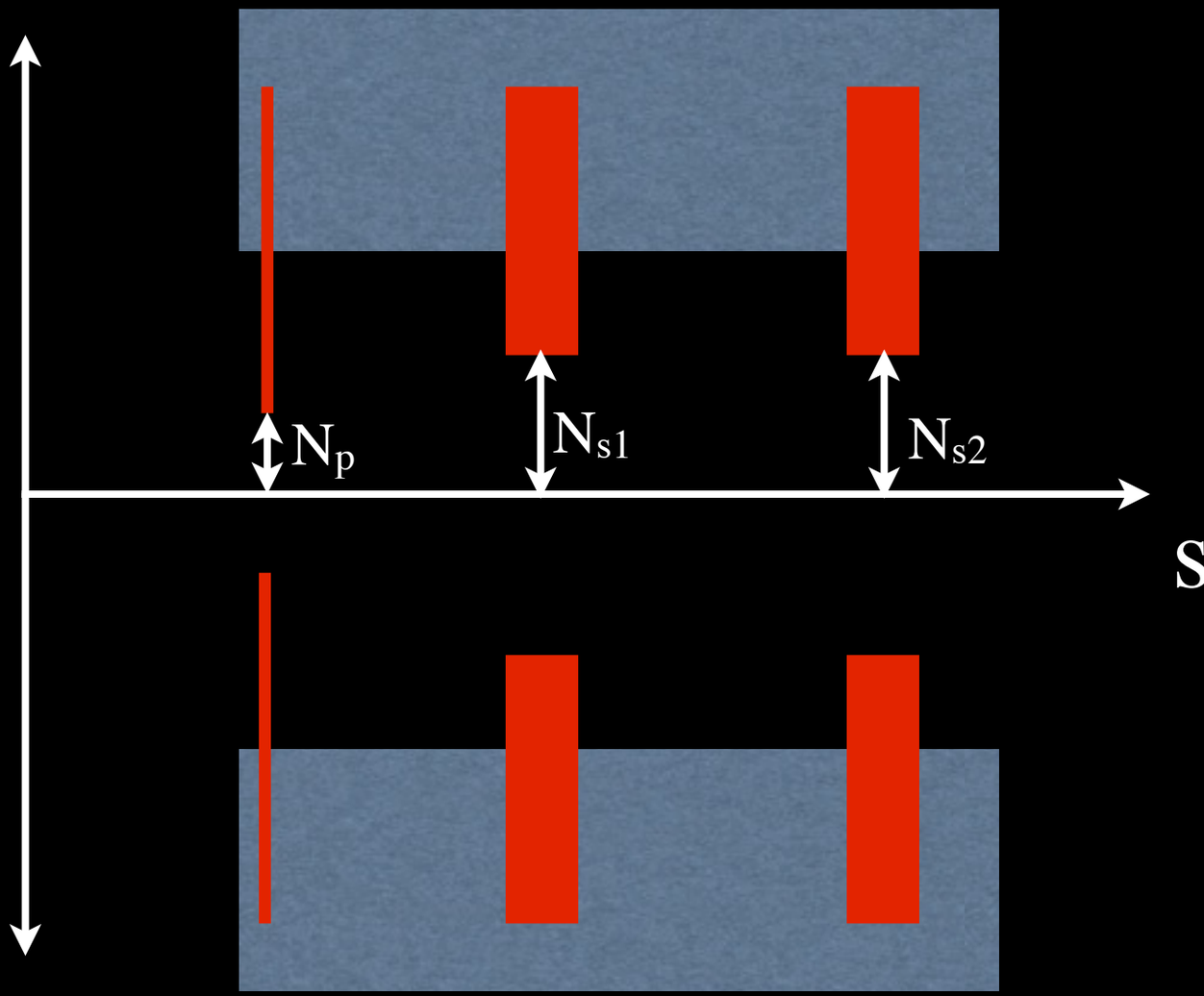

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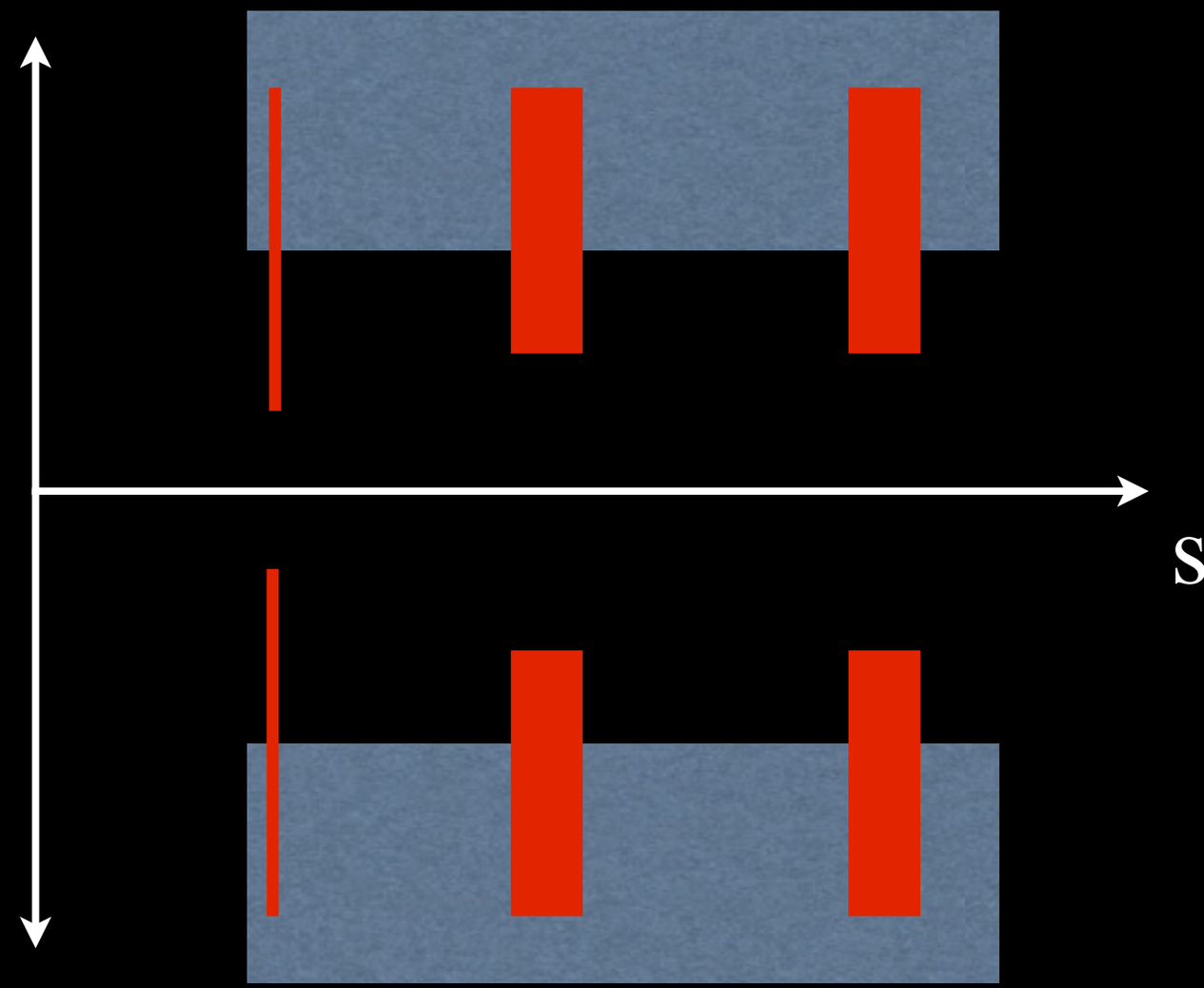

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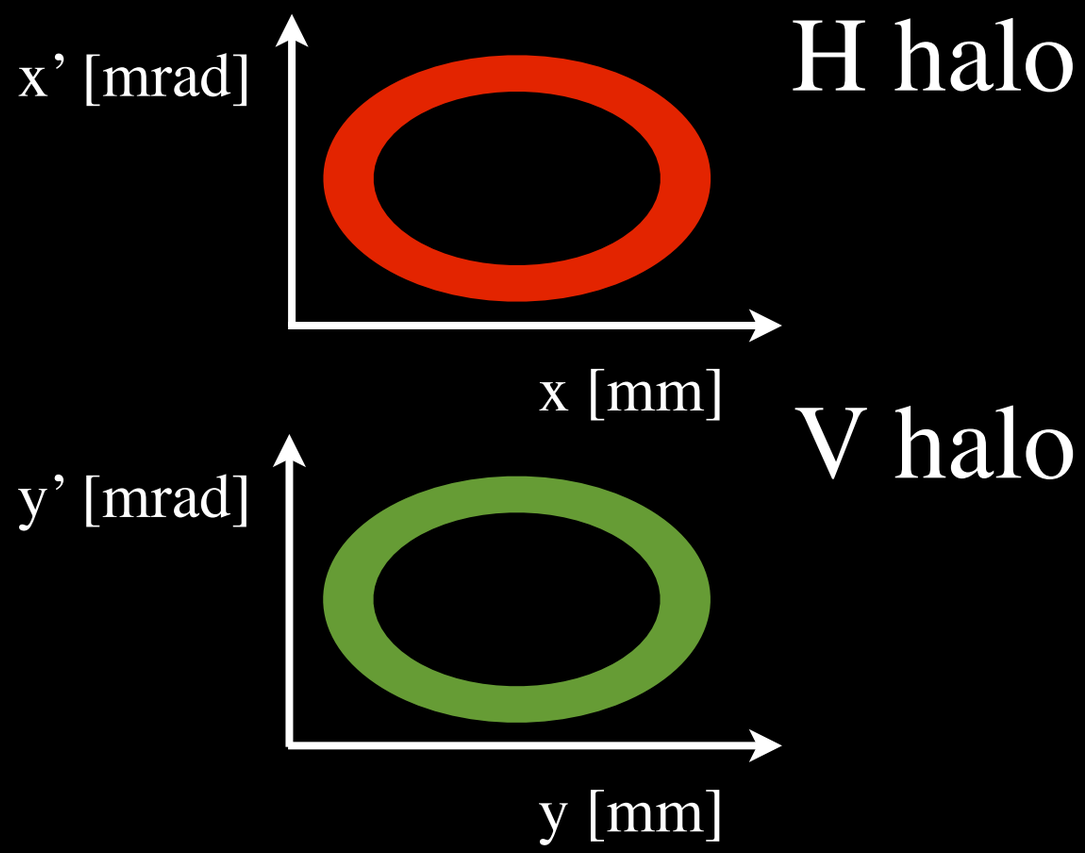

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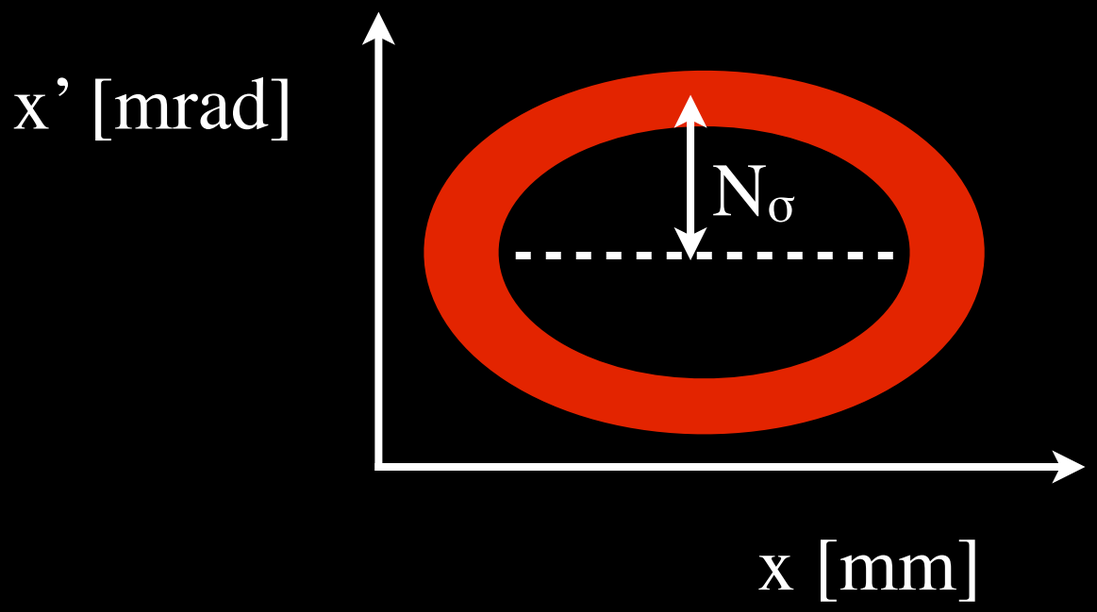
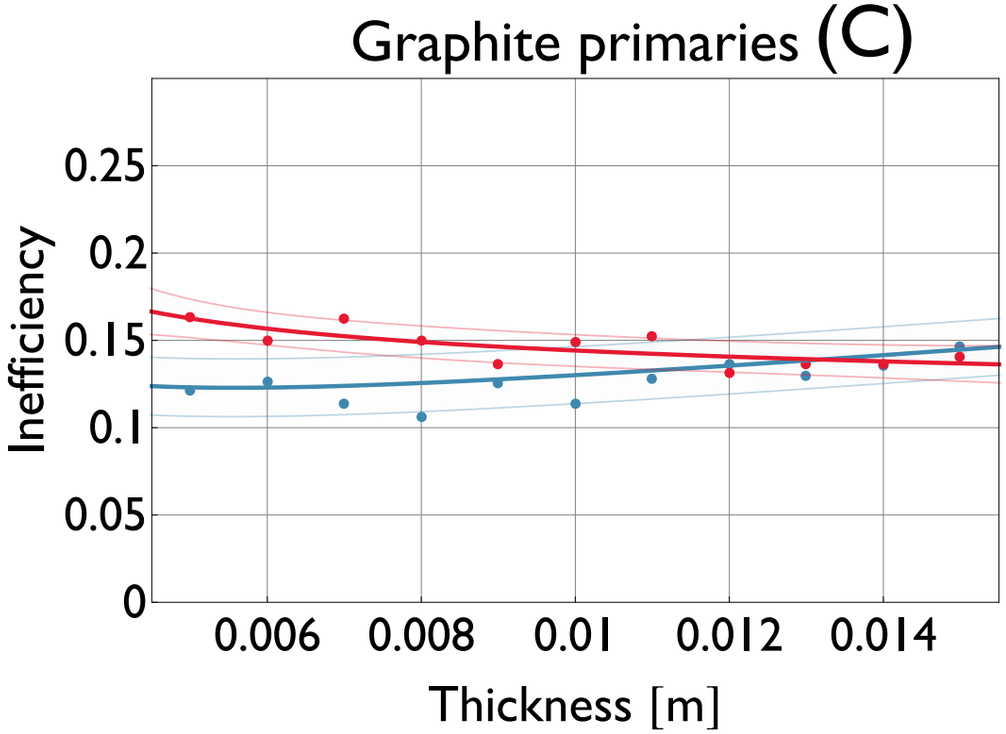
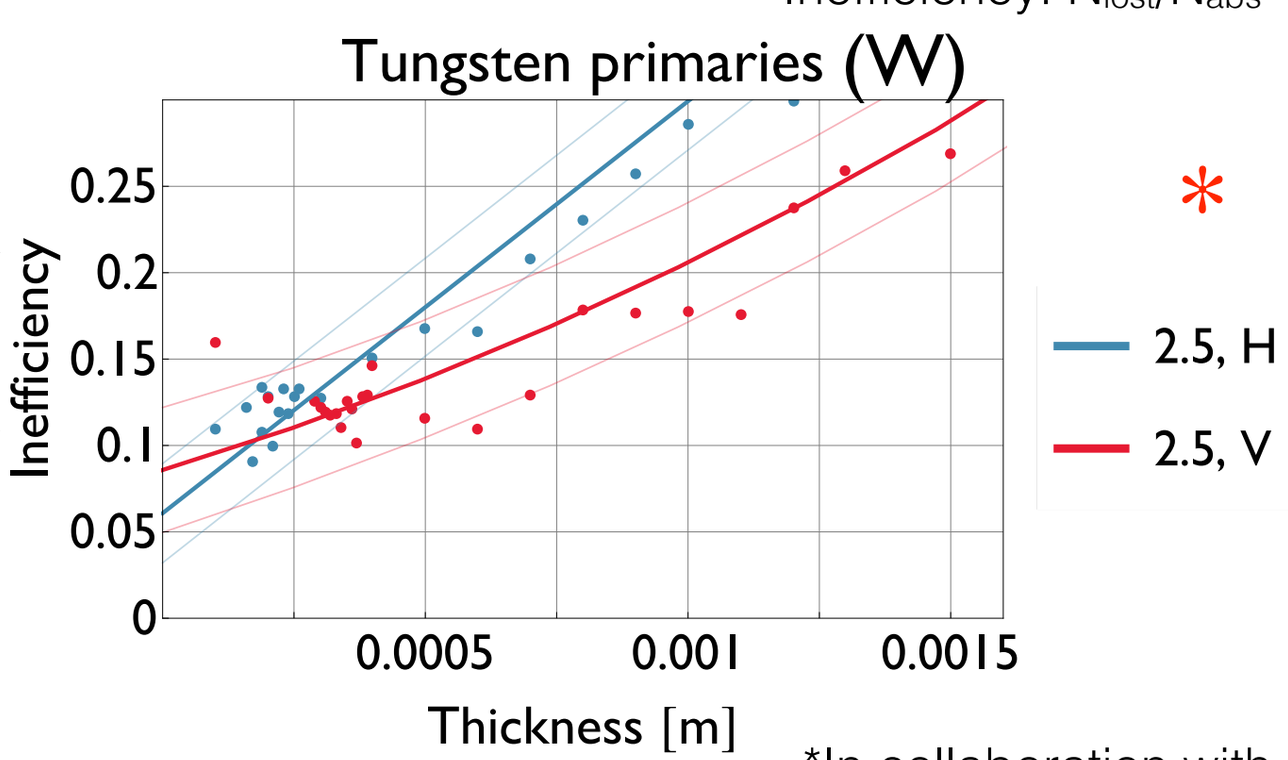
H halo



Thickness and material of primary collimators

Inefficiency: N_{lost}/N_{abs}





*In collaboration with Daniel Spitzbart

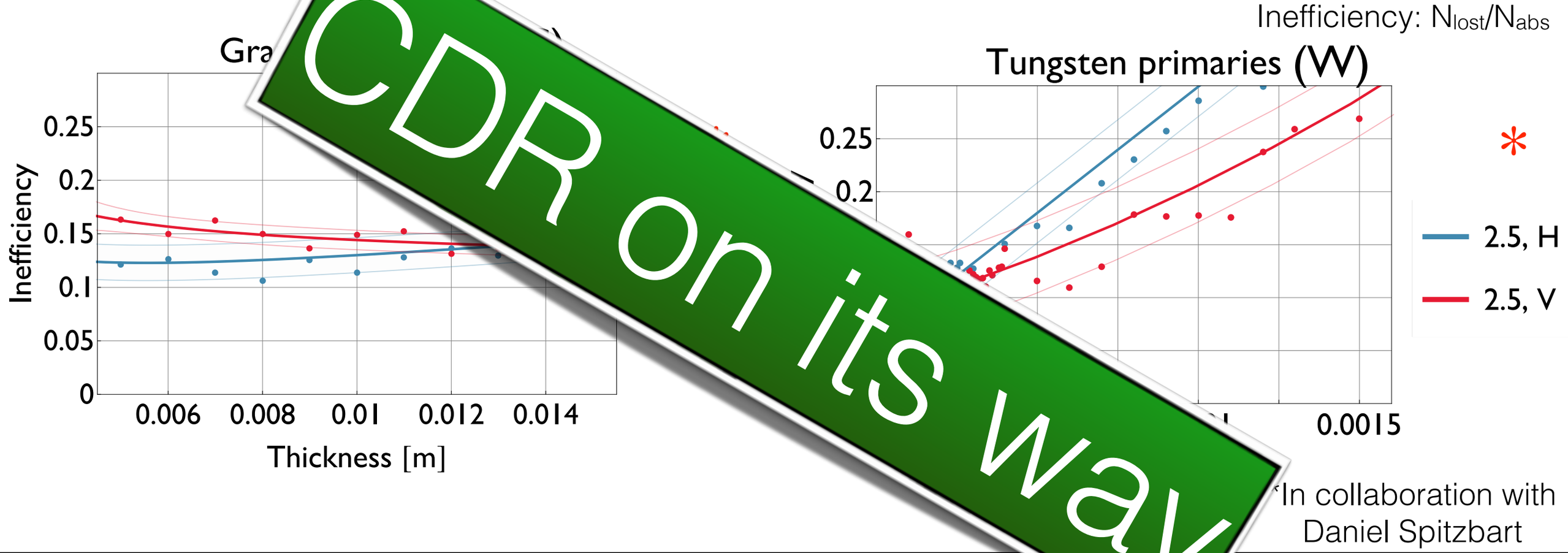
- W: Small inefficiency for very small thickness (feasibility)
- C: Small inefficiency for larger range of thickness

C chosen for primary collimators

W chosen for secondary collimators

[8]

Thickness and material of primary collimators



CDR on its way

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[8]

Timeline

BSci Physics
University of Cyprus & Fermilab

- Final year thesis, FNAL, CDF, “Upsilon Meson Polarisation”

PhD Particle and Accelerator Physics
Imperial College London

- 4D cooling, Neutrino Factory
- 6D cooling, Muon Collider
- MICE, RAL, UK, target calculations and beam commissioning
- COMET/PRISM, muon decelerator
- Mu2e, PSI, Switzerland, detector calibration test run

Postdoctoral Fellowship
CERN

- HP-PS, optics correction and collimation
- Fast Extraction machine development, SPS

Postdoctoral Fellowship
Oxford University & JAI

- Diamond upgrade
- FCC, final focusing triplet

- R&D and simulations
- running experiment

Diamond Light Source

Diamond Light Source

- High energy electrons can emit extremely bright and coherent beams of high energy photons via synchrotron radiation; powerful microscopes: the higher the energy the better the resolution ($E=h/\lambda$)

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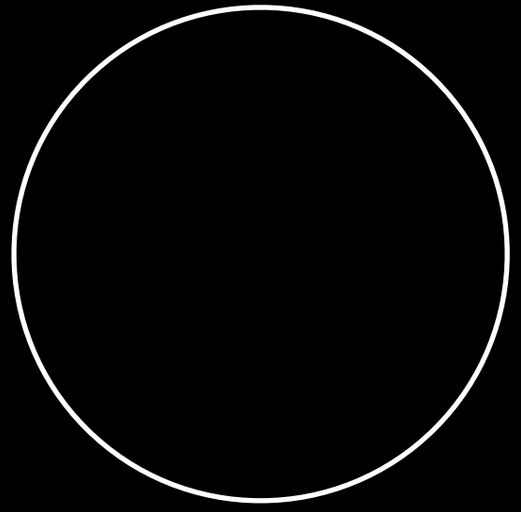

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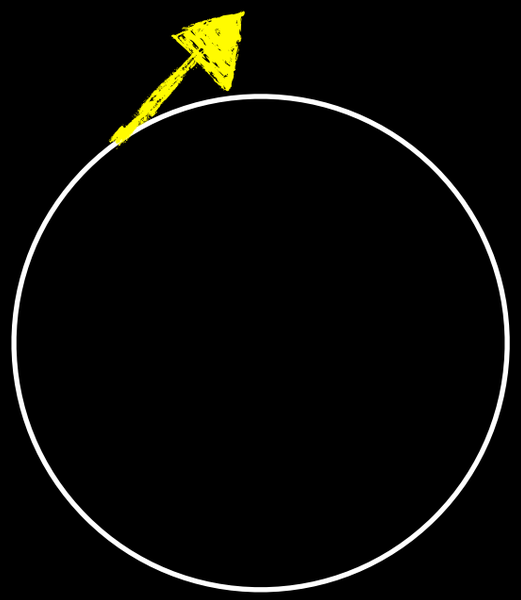

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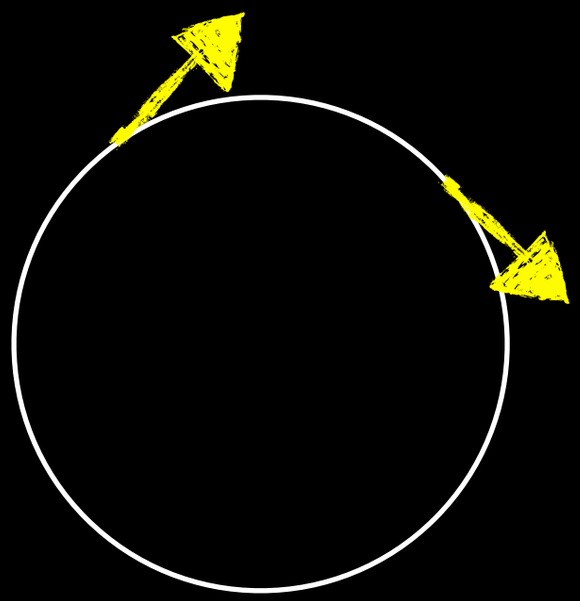

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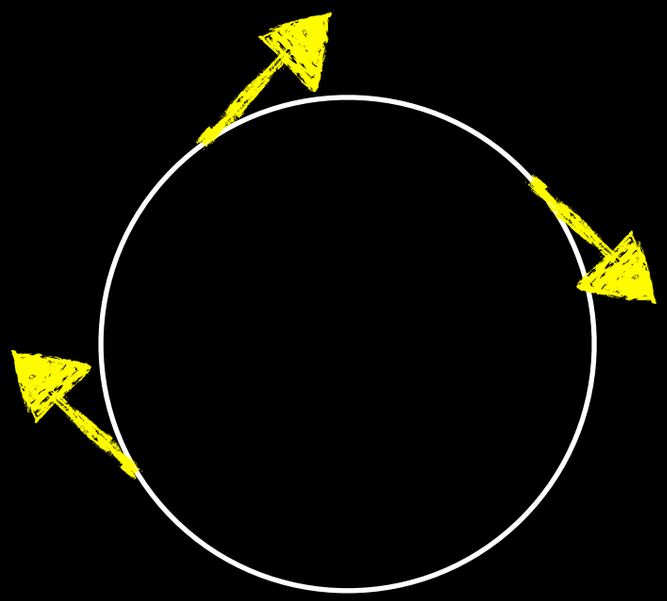

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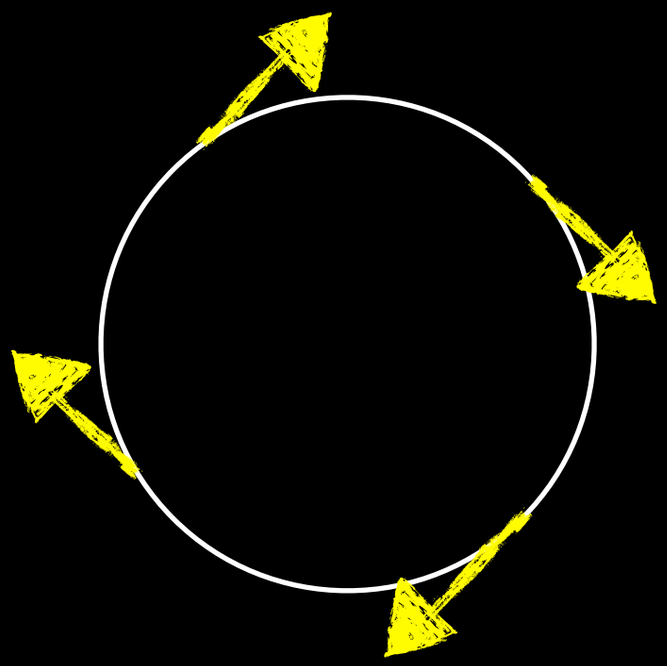

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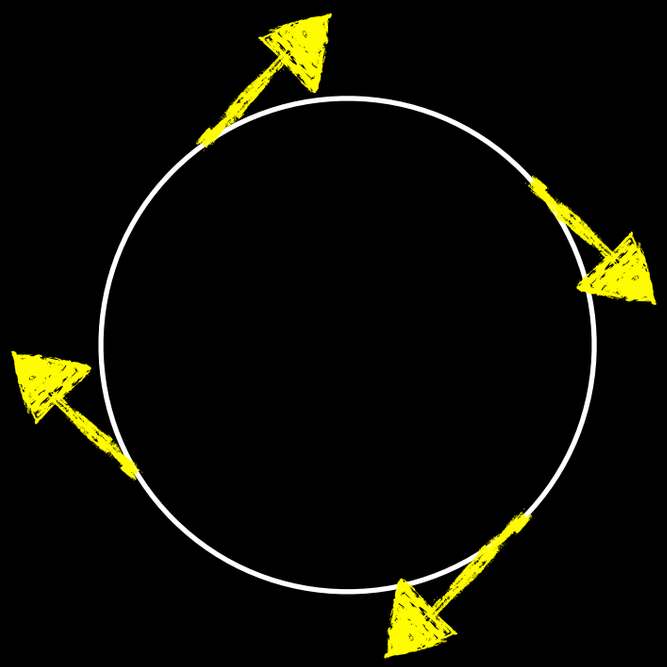

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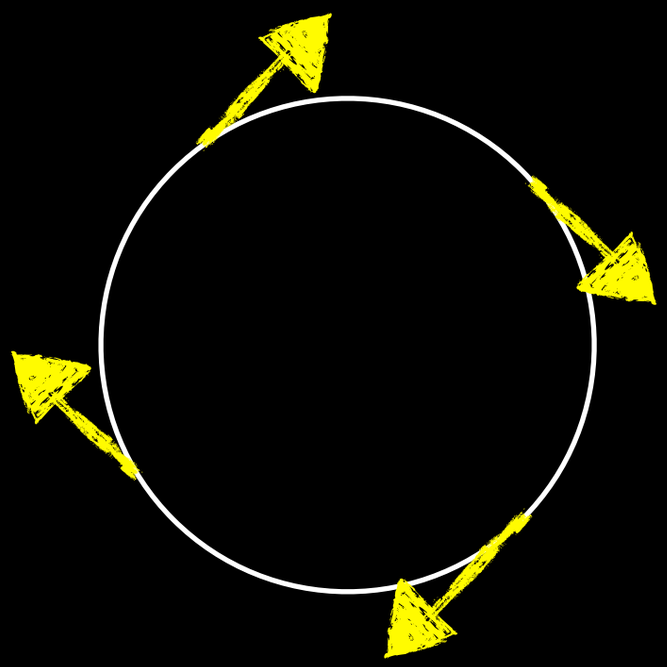

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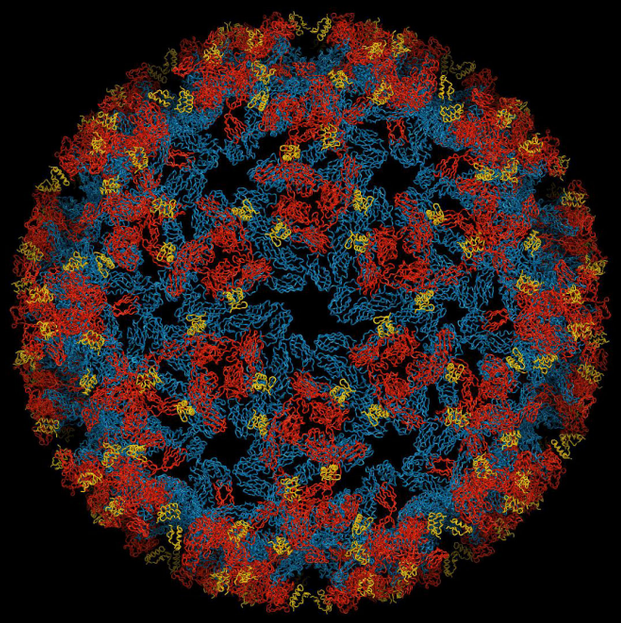

Protein modelling: Synchrotron light allows scientists to solve 3D structure of proteins e.g. the Chikungunya virus. Image credit: Voss et al., Nature (2010) 468, 709 (via Synchrotron Soleil, France)

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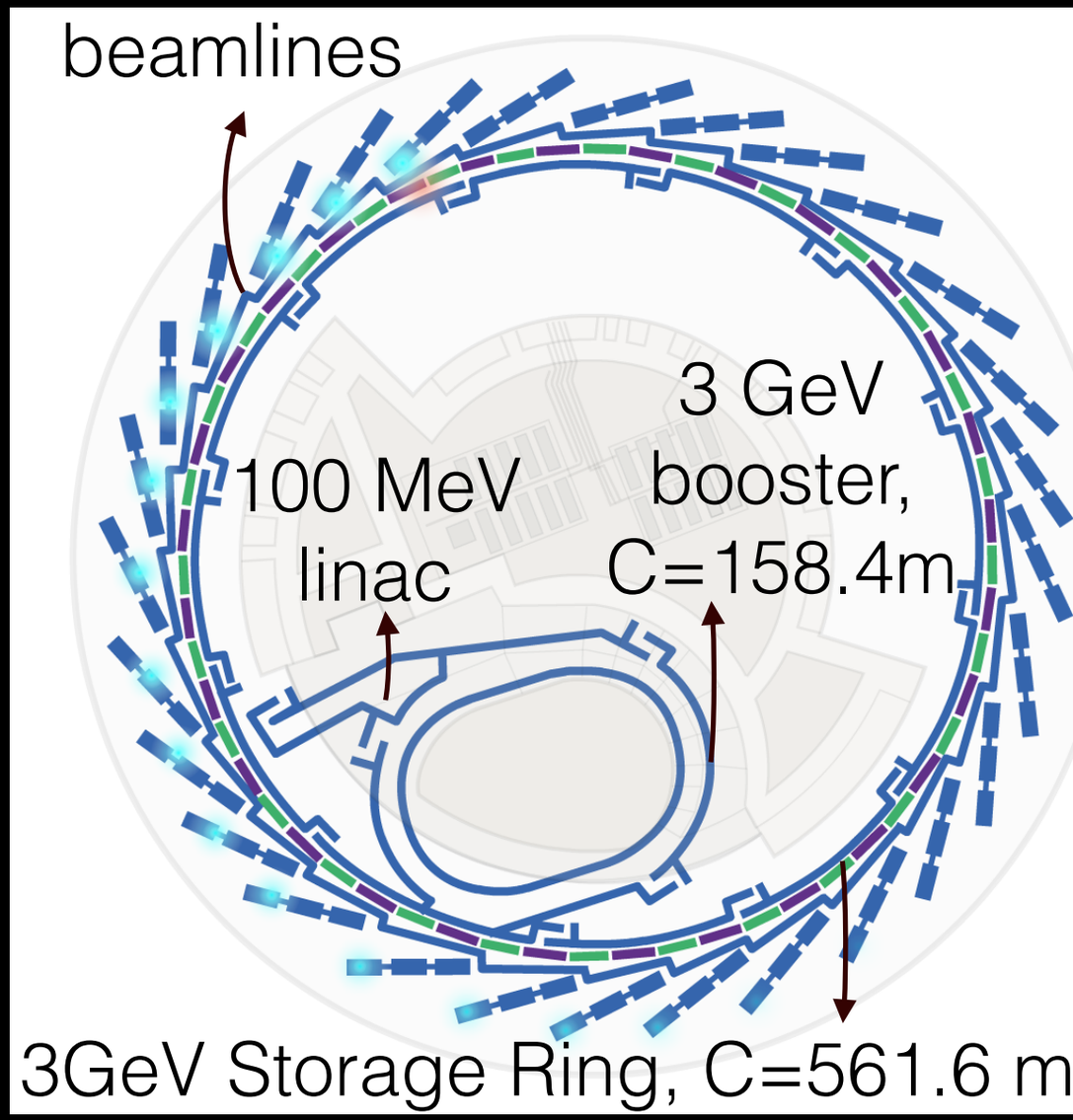

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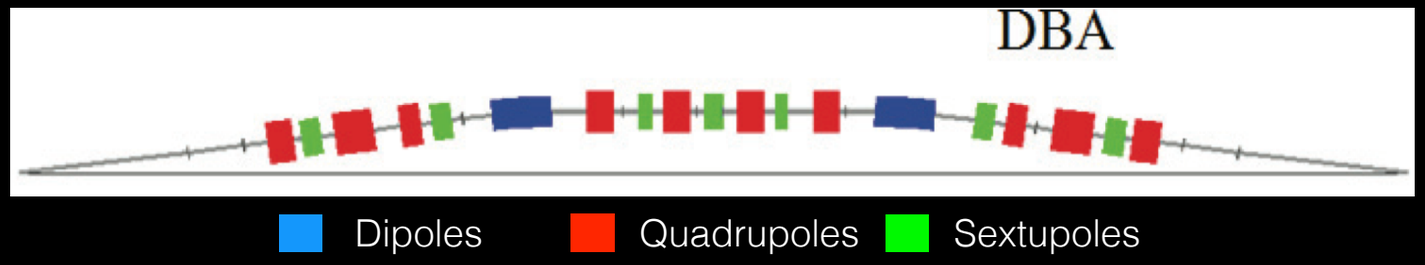
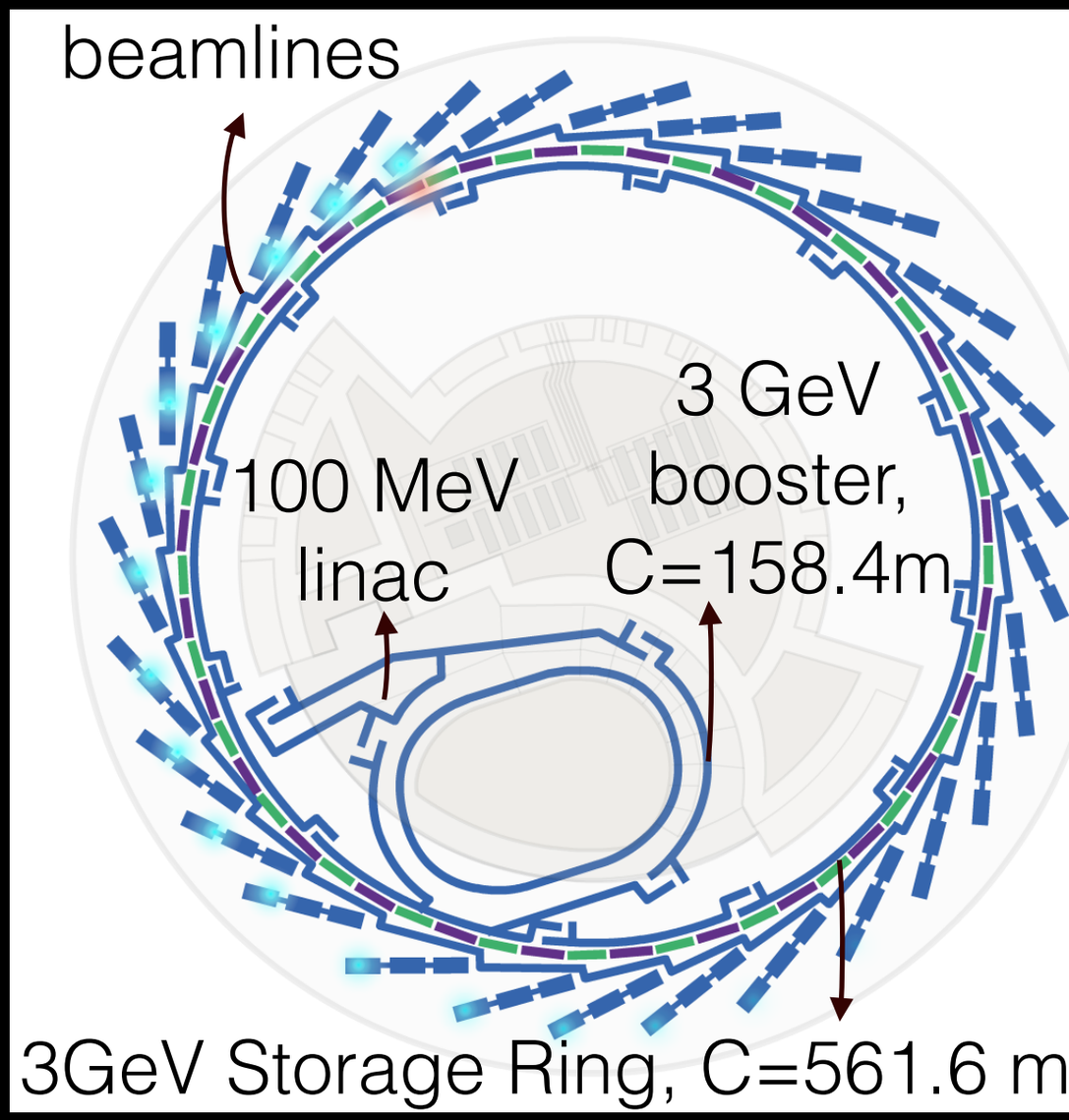
- Diamond Light Source (DLS) consists of 24 cells; straight sections+Double Bend Achromat (DBA)



DBA: bending section uses 2 dipoles; zero dispersion at entrance and exit of cell



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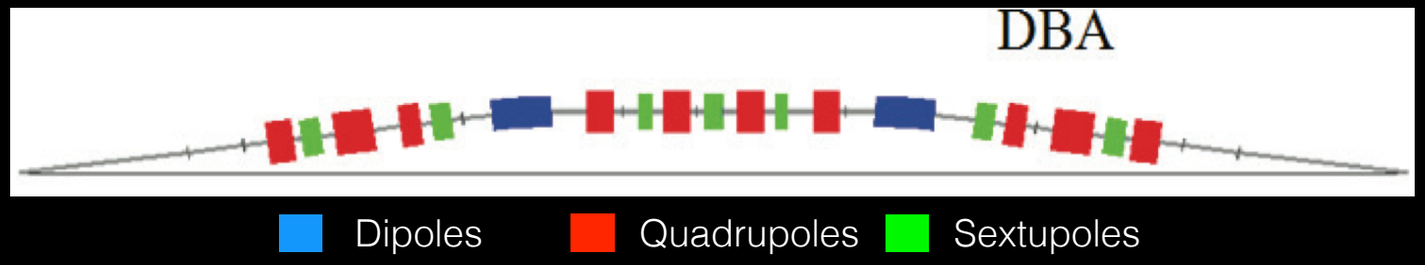

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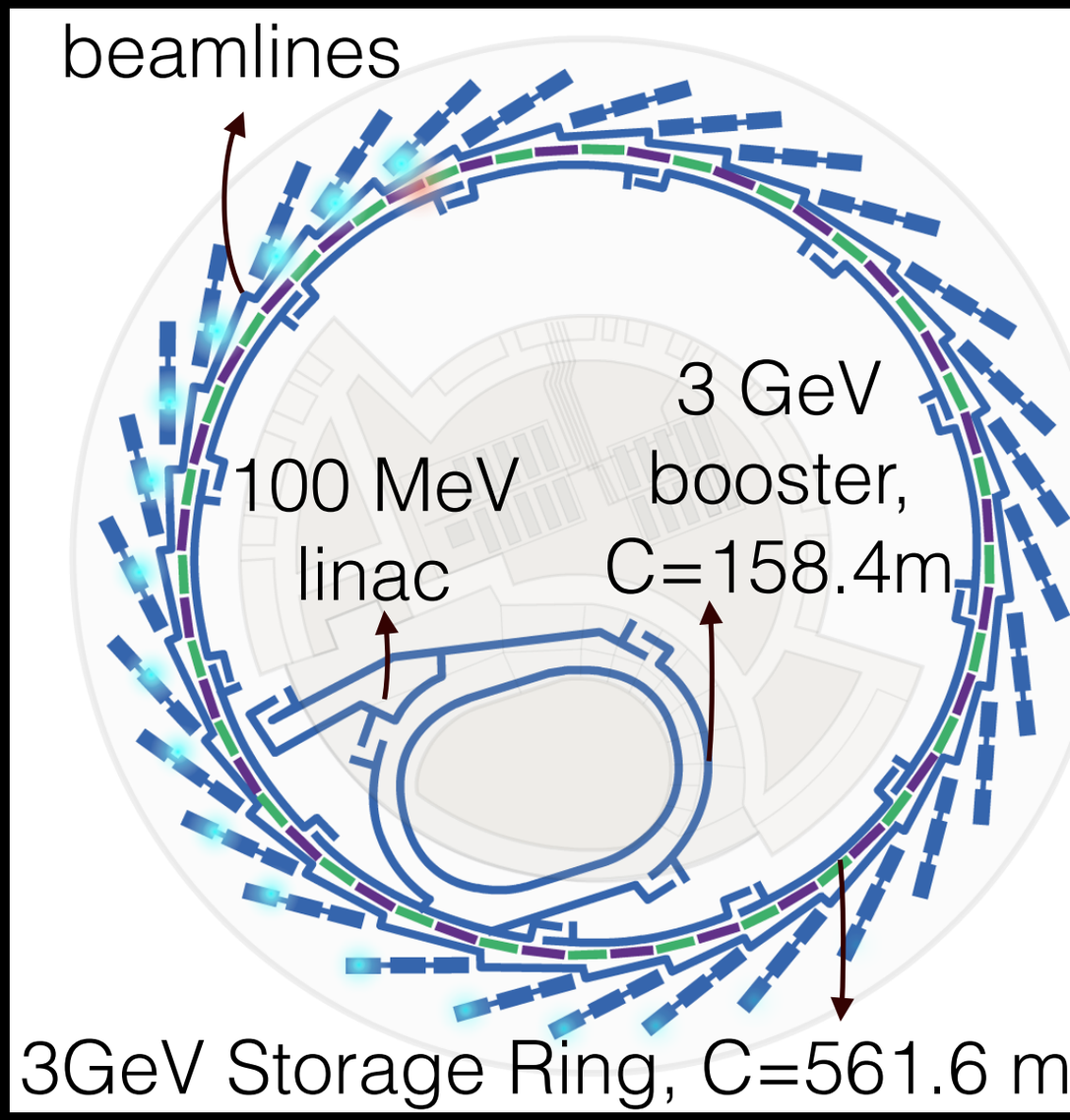
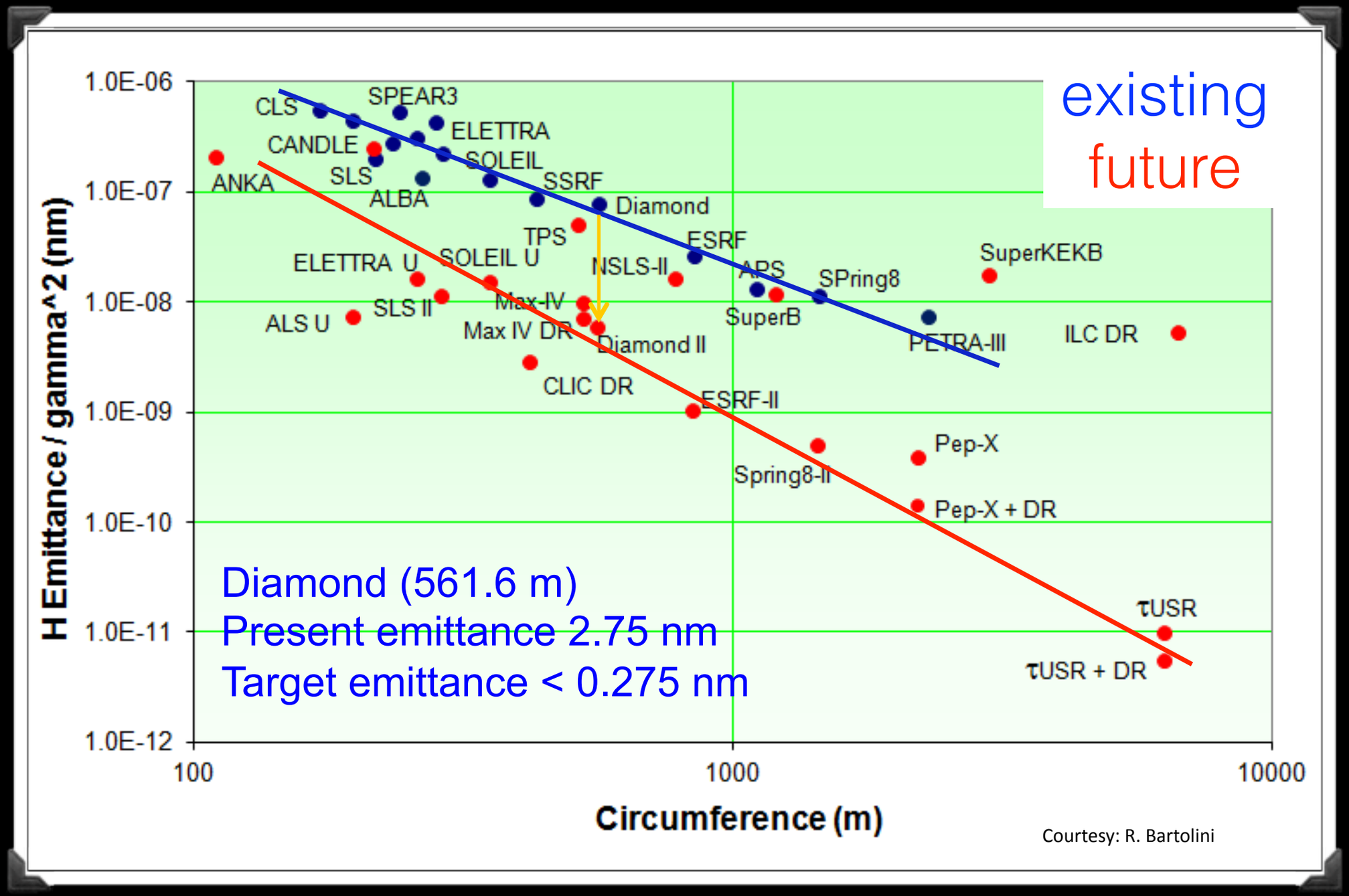
Operates since 2007 with nominal parameters:

- 2.7 nm H emittance (2nd best behind Advance Photon Source)
- 8 pm V emittance in 2012 (<2 pm world record in fall 2009)
- 300 mA reached in 2008



Motivation


existing
future
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1.0E-11
1.0E-12
H Emittance / gamma^2 (nm)
100
1000
10000
Circumference (m)
CLS
SPEAR3
ELETTRA
CANDLE
SOLEIL
SLS
ANKA
ALBA
SSRF
Diamond
TPS
ESRF
ELETTRA U
SOLEIL U
NSLS-II
APS
SPring8
SuperKEKB
SLS II
Max-IV
ALS U
SuperB
Max IV DR
Diamond II
PETRA-III
ILC DR
CLIC DR
ESRF-II
Pep-X
Spring8-II
Pep-X + DR
τUSR
τUSR + DR
Diamond (561.6 m)
Present emittance 2.75 nm
Target emittance < 0.275 nm
Courtesy: R. Bartolini

Motivation

- Upgrades SR facilities aim lower ε; increase brilliance and transverse coherent factor

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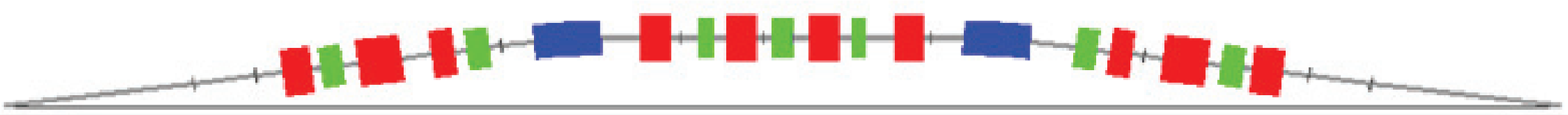

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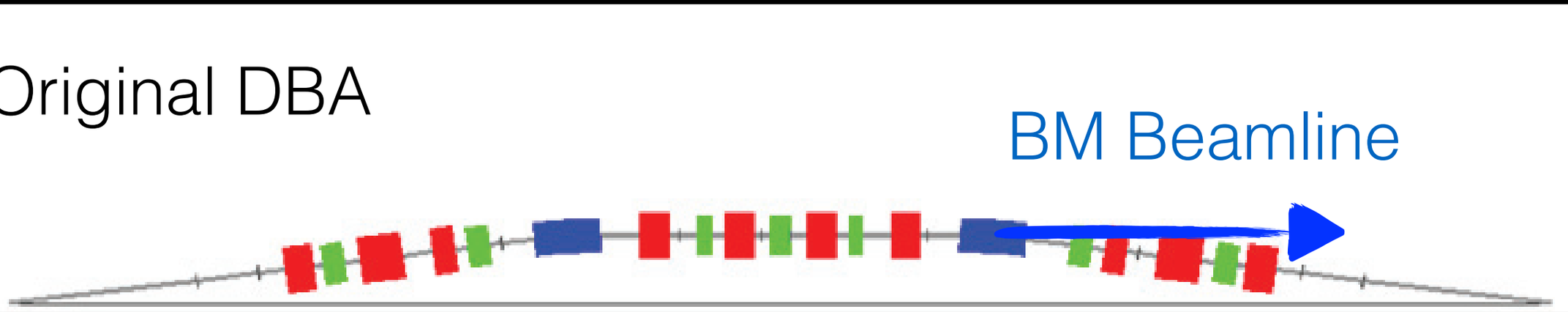

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Modified 4BA (DDBA): **additional straight** in mid of arc + ε reduction!

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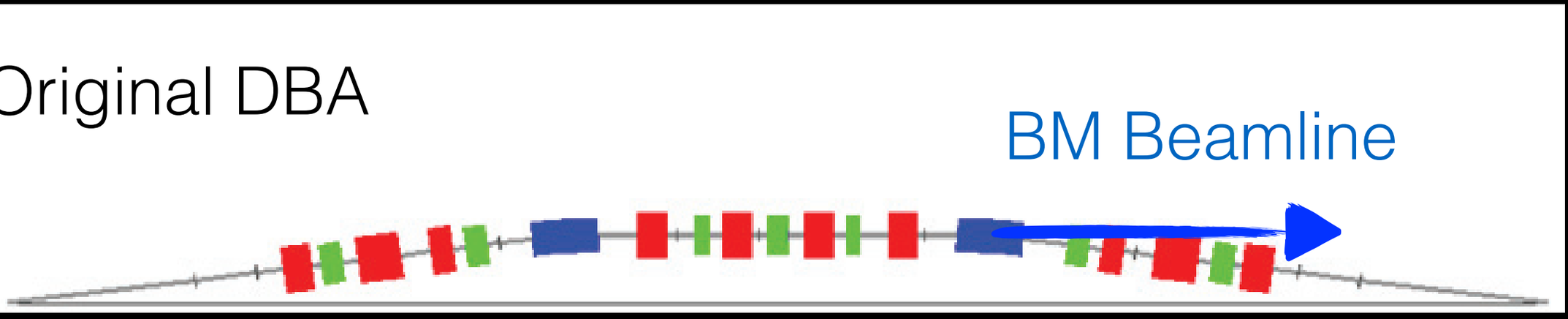

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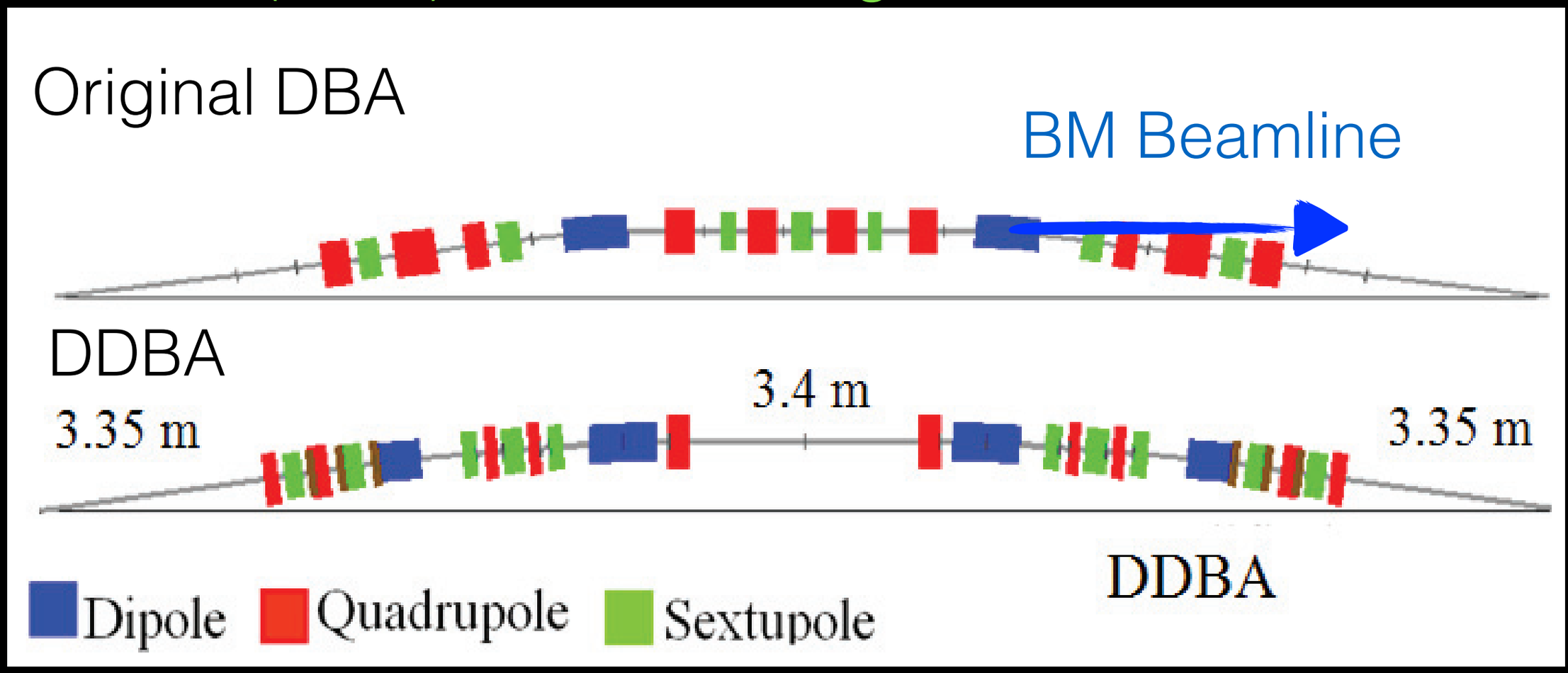

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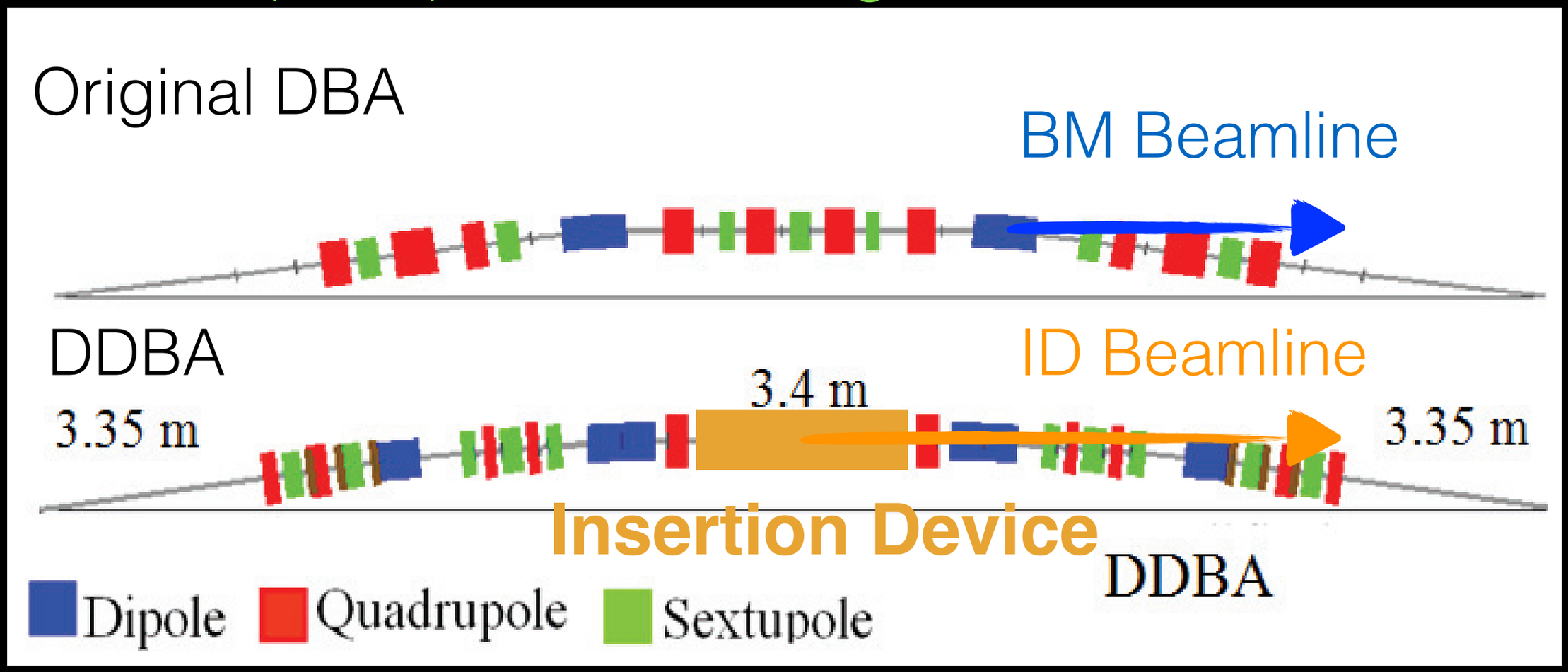

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- Insertion Device (ID) radiation sources more intense + attractive than bending magnet (BM) sources

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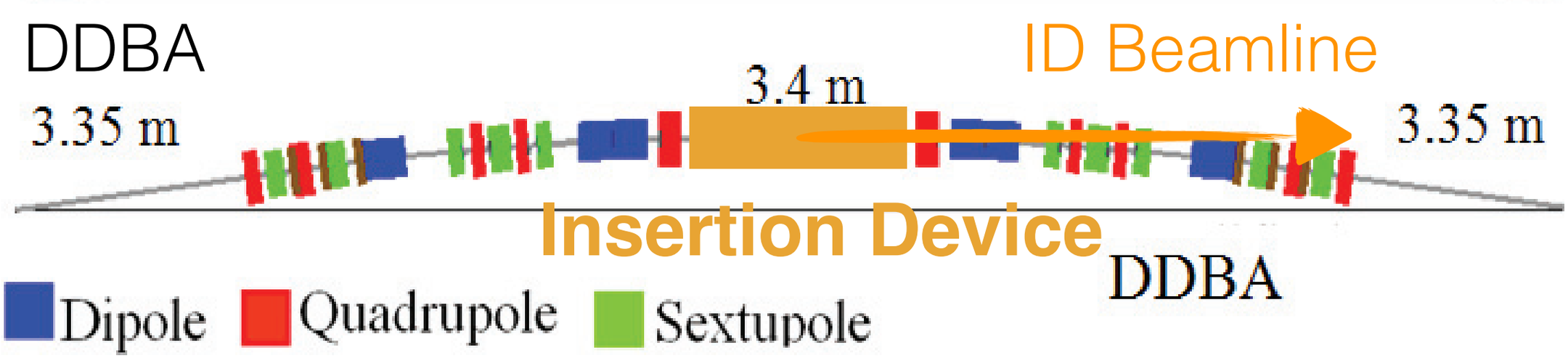
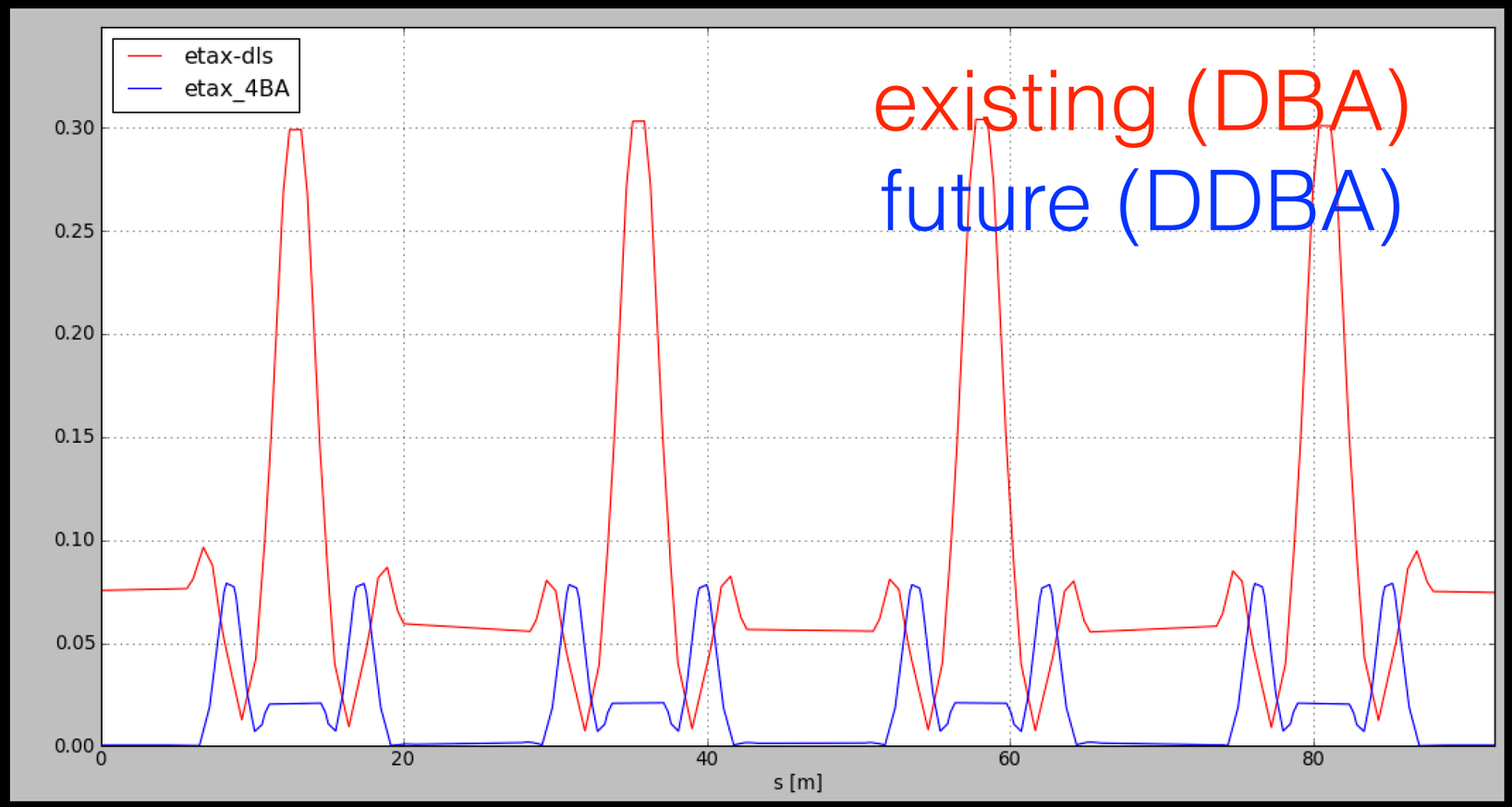
Origin

Double-DBA (DDBA or modified 4BA):
doubles capacity and reduces emittance by factor of 10!



Upgrade

Full lattice upgrade: replacement of existing 24 DBA cells with 24 DDBA cells



1 SPERIOD

Upgrade

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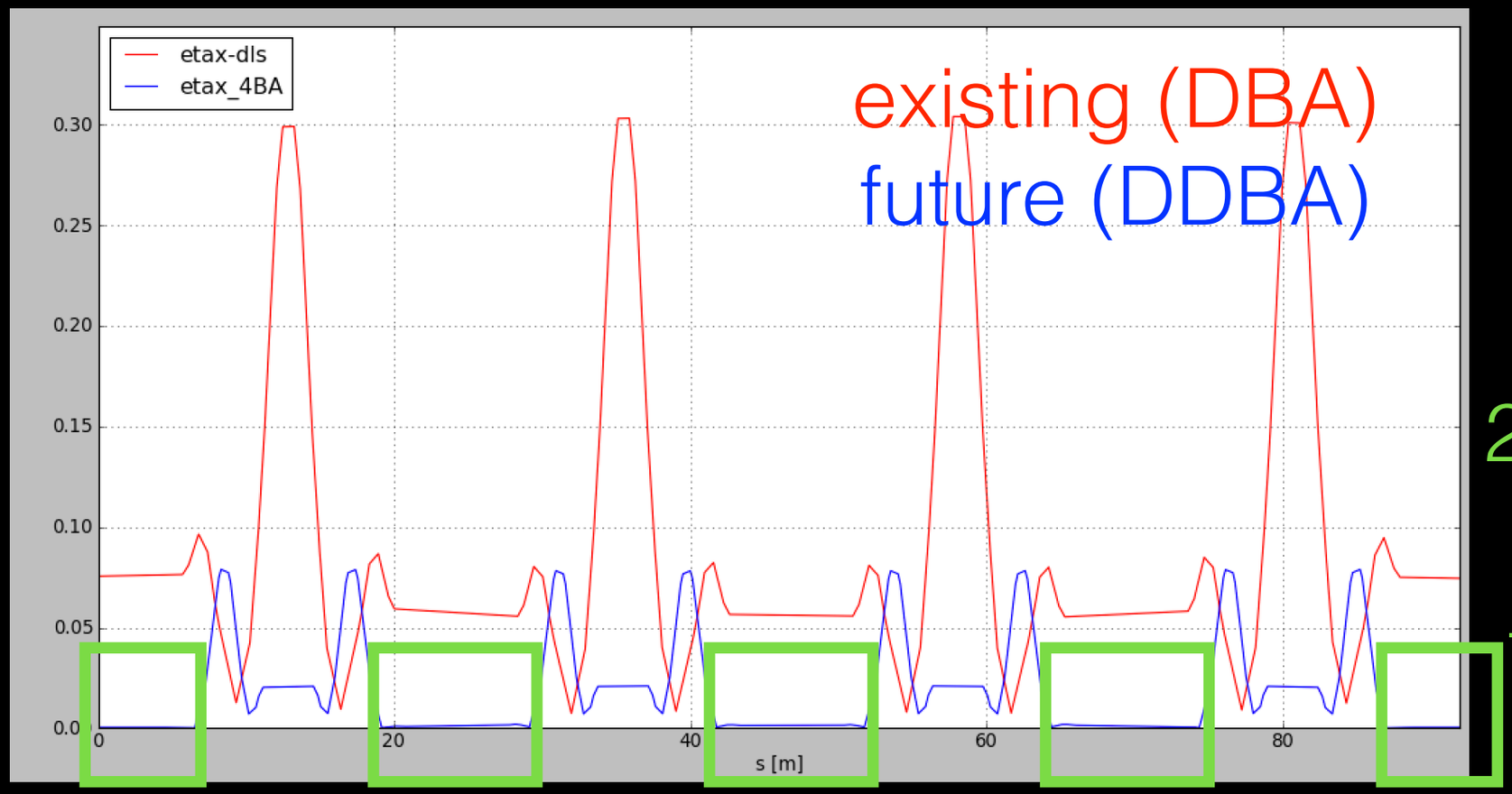


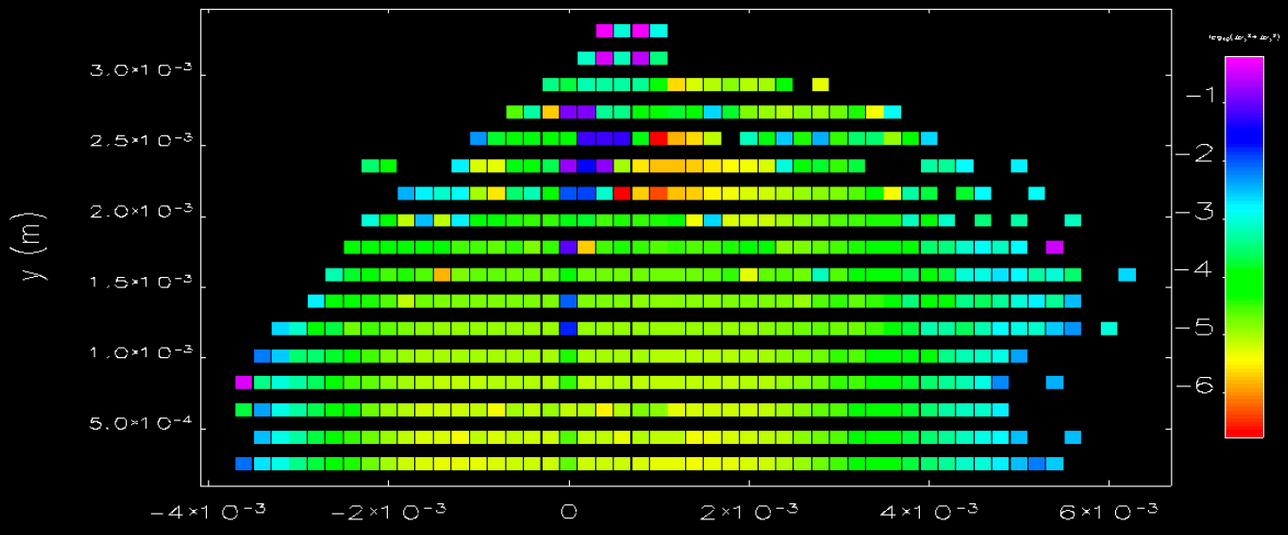
2x zero dispersion locations
—>2x number of IDs

1 SPERIOD

Upgrade

Although emittance of this lattice reduced by factor of 10, DA only (-4, 6)mm

y [m]



-4 mm x [m] 6 mm

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Although emittance of this lattice reduced by factor of 10, DA only (-4, 6)mm

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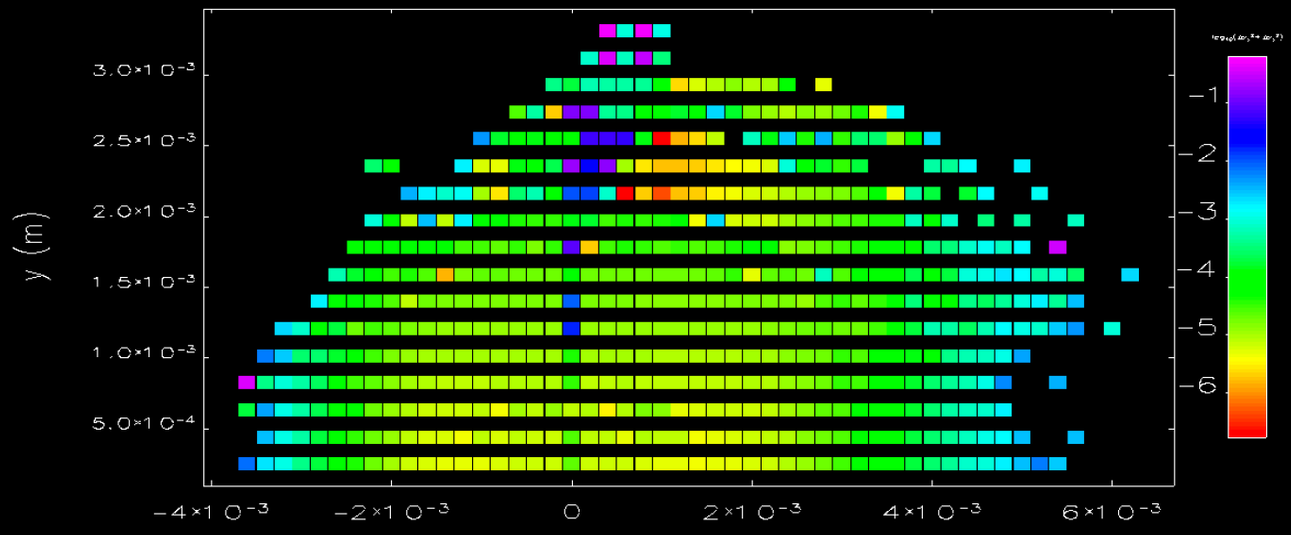


-4 mm x [m] 6 mm

Goal: increase DA to +-10 mm; cancel non-linear sextupole terms with phase advance manipulation


start here

start here

increase DA by cancelling non-linearities with phase advance manipulation

start here

large beta

increase DA by cancelling non-linearities with phase advance manipulation

start here

increase DA by cancelling non-linearities with phase advance manipulation

large beta

need strong quads

start here

increase DA by cancelling non-linearities with phase advance manipulation

large beta

need strong quads

large natural chromaticity

start here

increase DA by cancelling non-linearities with phase advance manipulation

large beta

need strong quads

large natural chromaticity

correct with strong sextupoles

start here

increase DA by cancelling non-linearities with phase advance manipulation

large beta

need strong quads

large natural chromaticity

correct with strong sextupoles

strong non-linearities

start here

increase DA by cancelling non-linearities with phase advance manipulation

large beta

need strong quads

large natural chromaticity

correct with strong sextupoles

strong non-linearities

DA reduction

start here

large beta

need strong quads

large natural chromaticity

correct with strong sextupoles

strong non-linearities

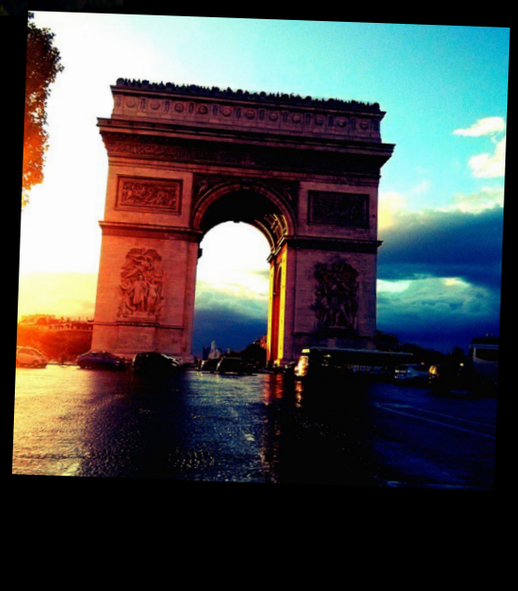
DA reduction

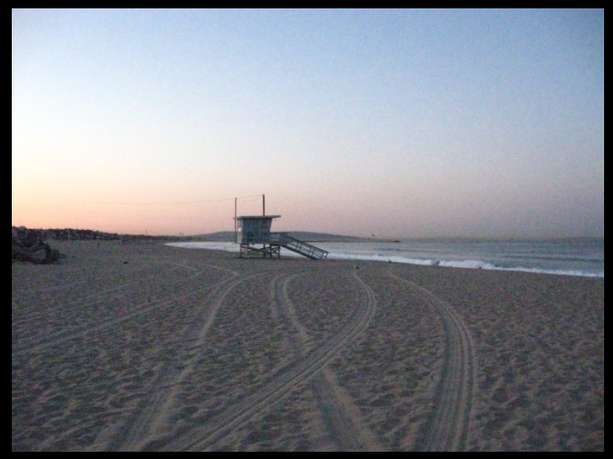
exit code error: wish me luck

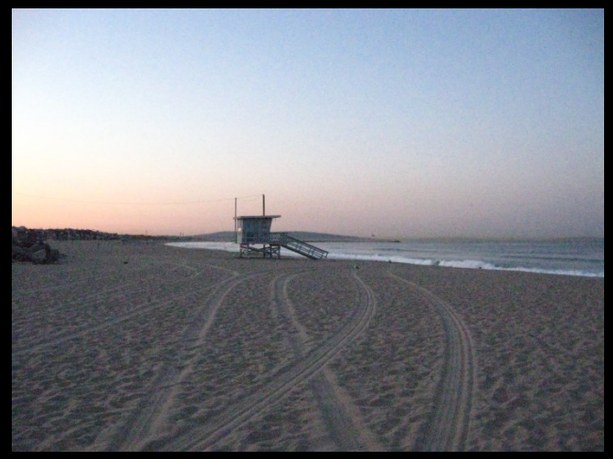
increase DA by cancelling non-linearities with phase advance manipulation

UNIX PEOPLE ARE HAPPY

Things I enjoy doing outside work








OHN TRAVOLTA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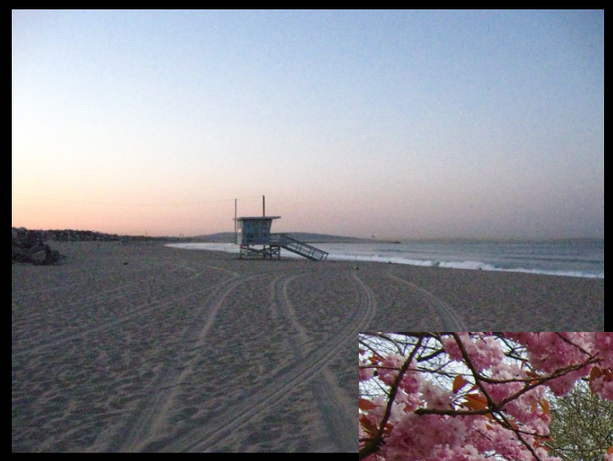


OHN TRAVOLTA


33
CERN Running Club
LEGEA


33
33


Surf
Soft
PRO


33
LEGEA


Surf
Soft
PRO


33


Surf
Soft
PRO


33
LEGEA

Thank you very much!

—Any questions?

References

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