Beam Dynamics Challenges of Beam Delivery System for Linear Collider

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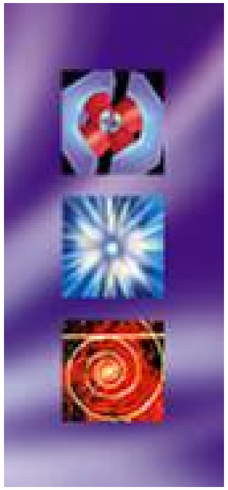
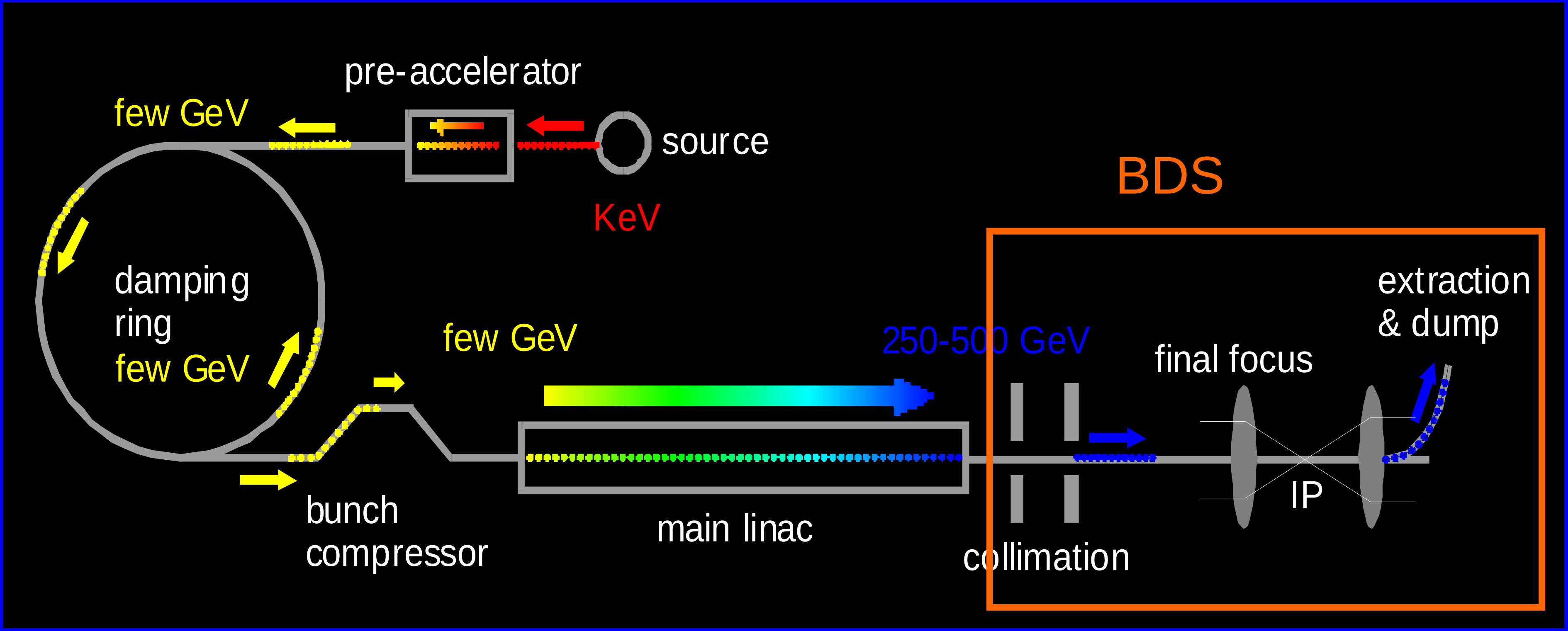


The 'Generic' Linear Collider

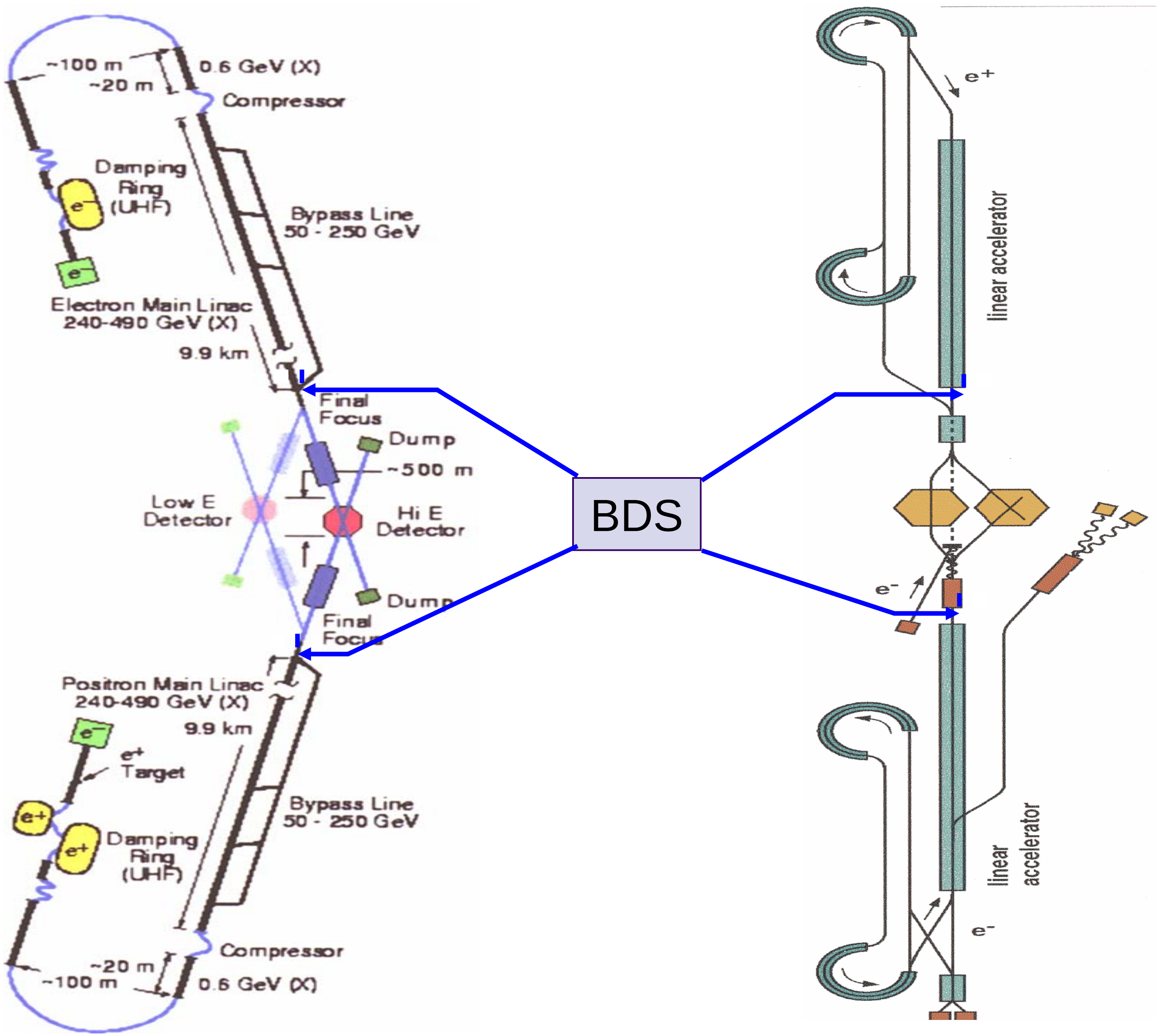


Each sub-system pushes the state-of-the-art in accelerator design

N.Walker

NLC Layout

TESLA Layout



Beam Delivery System (BDS) Functionality

- Reduce the beam sizes to nanometer level to produce the luminosity → Final Focus System
- Remove any particles that are far from the beam core to reduce the unacceptable backgrounds in the detector → Collimation System
- Ensure that the extremely small beams do in fact collide at the IP → Ground Motion, Vibrations, Feedback….
- Must provide protection for the detector and the beamline components against mis-steered beams and must safely transport the collided beams to beam dumps → Extraction Lines
- Provision for second Interaction Region → Beam Switchyard
- It should also provide suitable optics locations and instrumentation for monitoring the beam parameters of the Linac & collided beams → Beam Diagnostics

Luminosity Issues

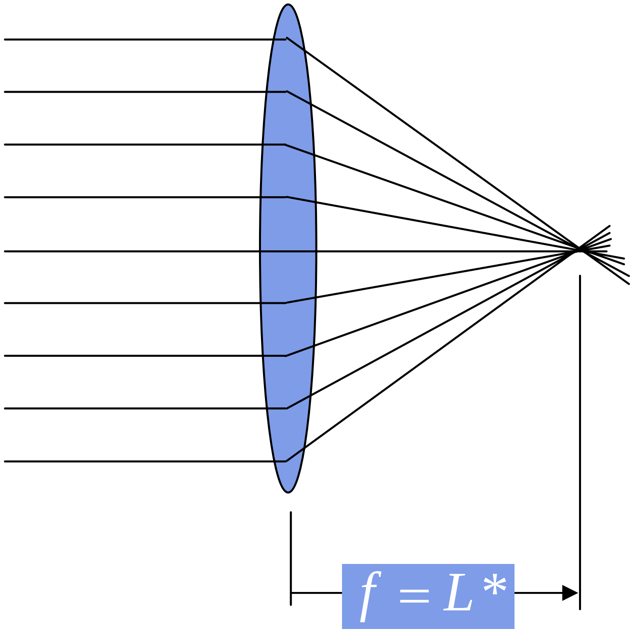
$$L = \frac{n_b N^2 f_{rep}}{4\pi \sigma_x \sigma_y} H_D$$

f_{rep} much lower in LC than in traditional storage ring
LEP: 44 kHz
LC: 5-120 Hz

Achieve L by focusing to small beams at the IP
LEP: 130x6 μm^2
LC: (200-500)×(3-5) nm^2

Achieved @ ~50 GeV
SLC σ_y = 500 nm
FFTB σ_y = 40 nm

Final Focusing



$$L^* \approx 2-4\,\mathrm{m}$$

$$\sigma_y = \sqrt{\varepsilon_{n,y}\beta_y/\gamma}$$

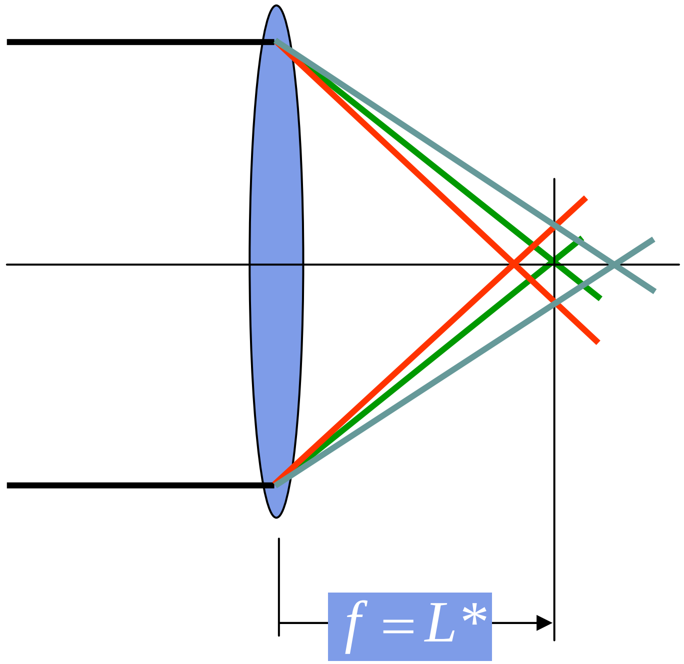
$$\sigma_y \approx 2-5\,\mathrm{nm} \Rightarrow \beta_y \approx 100-300\,\mu\mathrm{m}$$

at final lens β_y ~ 100 km

short f (L^*) requires very strong fields :

- Quadrupole gradients ~ 200-300 T/m
- Such a strong lens introduces very high chromatic aberrations and can increase beam size several times.

Final Focusing: chromatic aberration



chromatic aberration

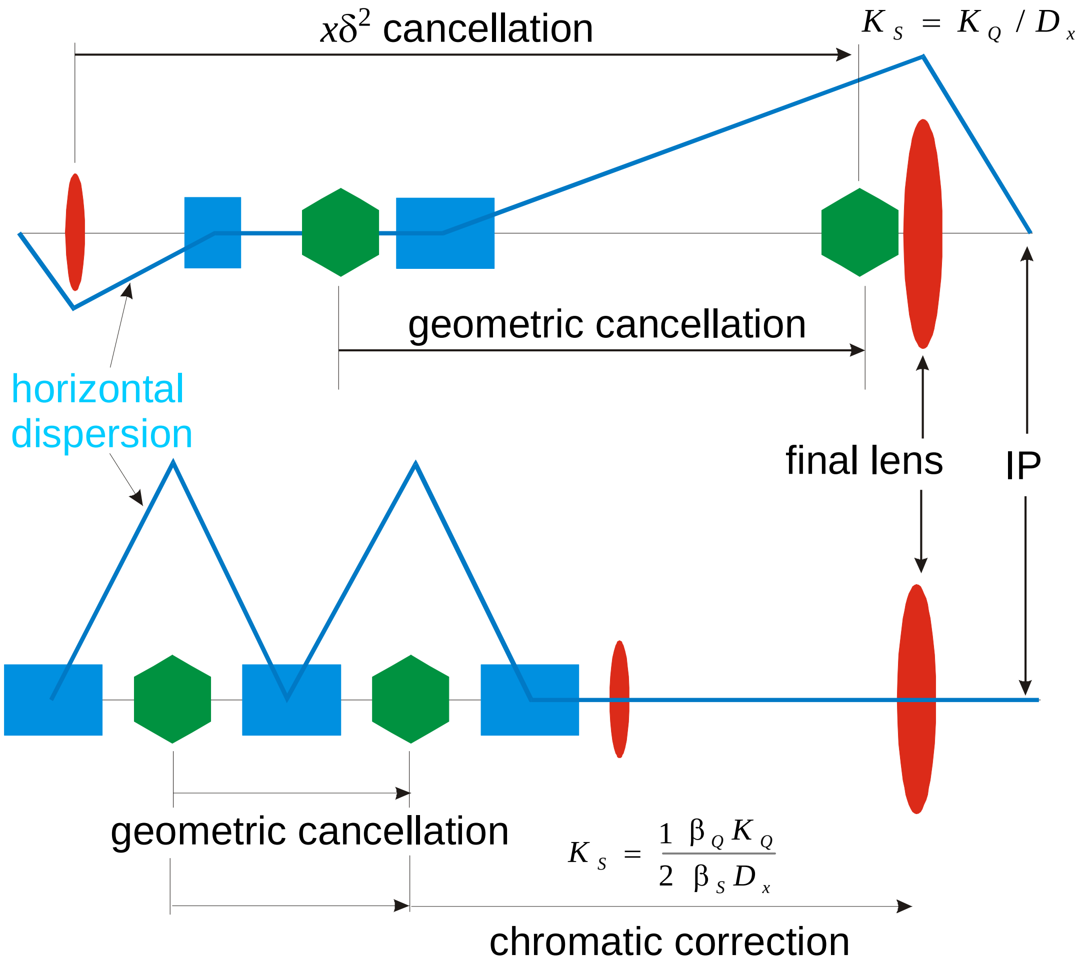
$$\frac{\Delta\sigma_y^*}{\sigma_y^*} \approx \frac{L^*\delta_{\text{RMS}}}{\beta_y^*}$$

typical parameters: $\delta_{\text{rms}} \approx 0.3\%$, $L^* \approx 3$ m, $\beta^*_y \approx 0.1$ mm

→ $\Delta\sigma_y^* \approx 100\sigma_y^*$

- Chromaticity must be corrected using strong sextupole magnets
- Chromatic correction performed using sextupoles in a region of non-zero dispersion (dipoles required..SR…ε_x?)
- Minimisation of chromatic and geometric aberrations is principle design challenge

Classical and Novel Final Focus

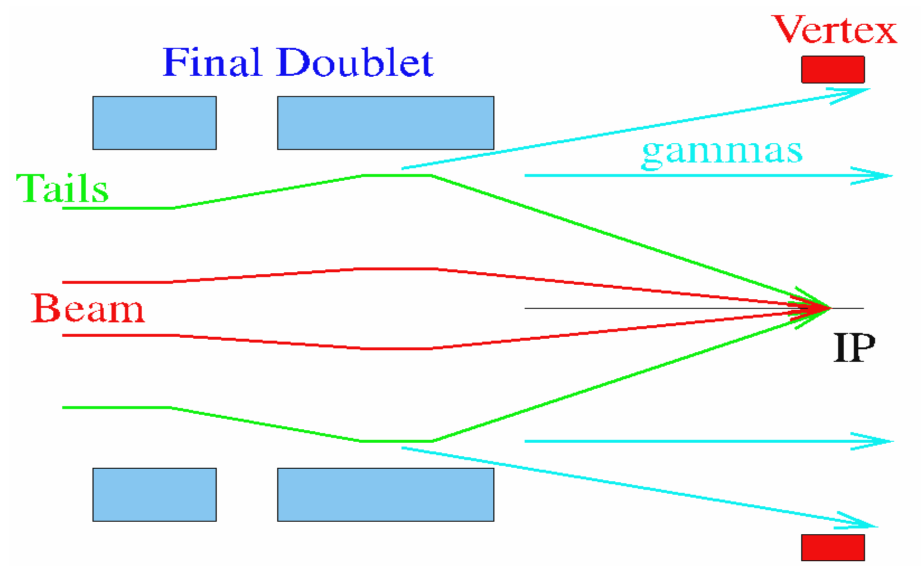


Local correction with D' at IP
[*Raimondi & Seryi*, 2000]
(NLC/GLC, CLIC)

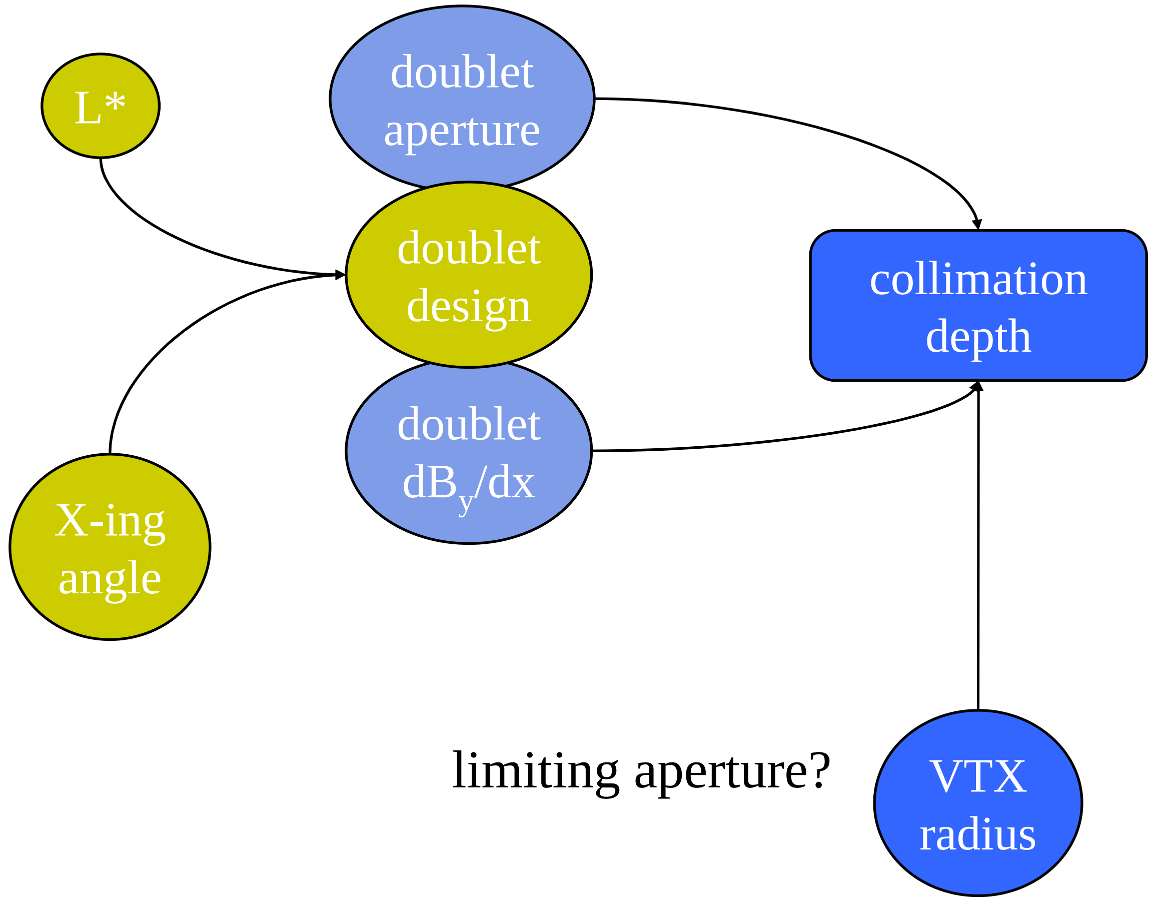
Non-local correction (CCS)
[*Brown*, 1985]
(SLC,FFTB,TESLA TDR)

Collimation Issues

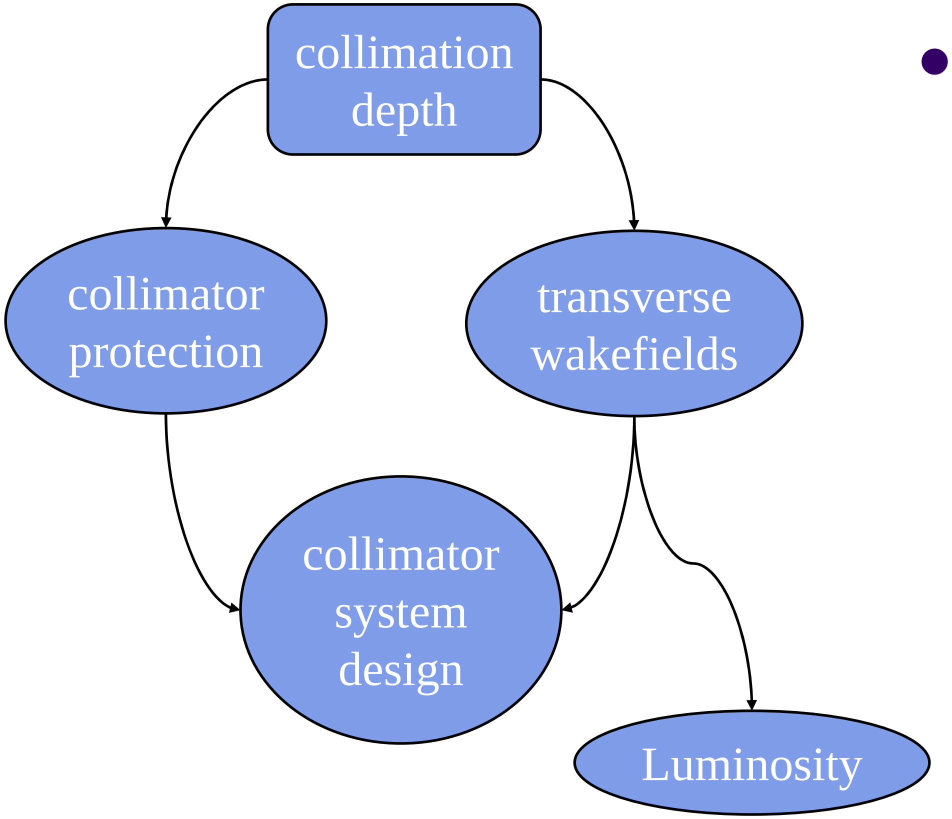
- Must efficiently remove ‘halo’ by physically scraping it away
- IR layout and choice of FFS optics defines collimation requirements (synch. radiation etc.)
- Mechanical collimator jaws with typical gaps of tens of beam σ (few hundred μm to ~1 mm)
- Constraints:
  - must not degrade luminosity (optical aberrations, collimator wakefields)
  - mechanical protection issues (typical average beam power densities are several $GW.mm^{-2}$)



Collimation



Collimation System Design

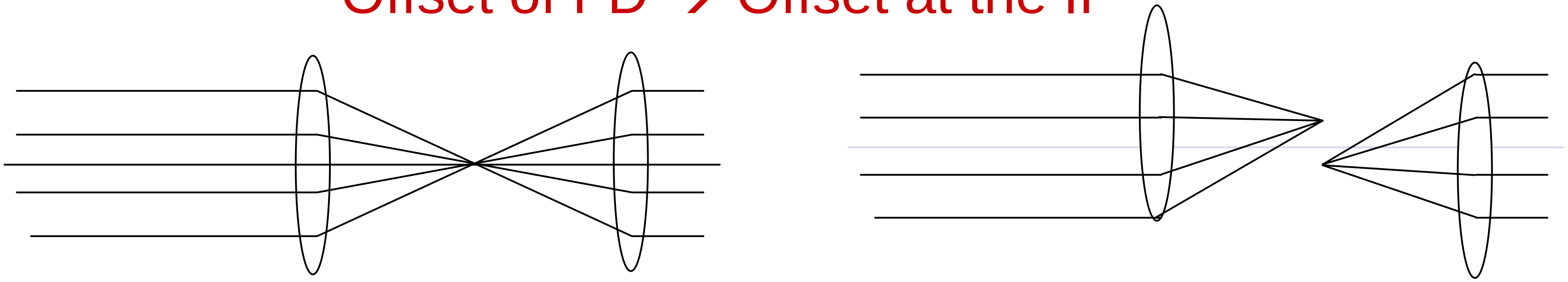


- Constraints:
  - $\Delta\varepsilon/\varepsilon$ from wakes at collimators should not degrade luminosity
  - beam size at collimator should be large to prevent damage

Stability Issues

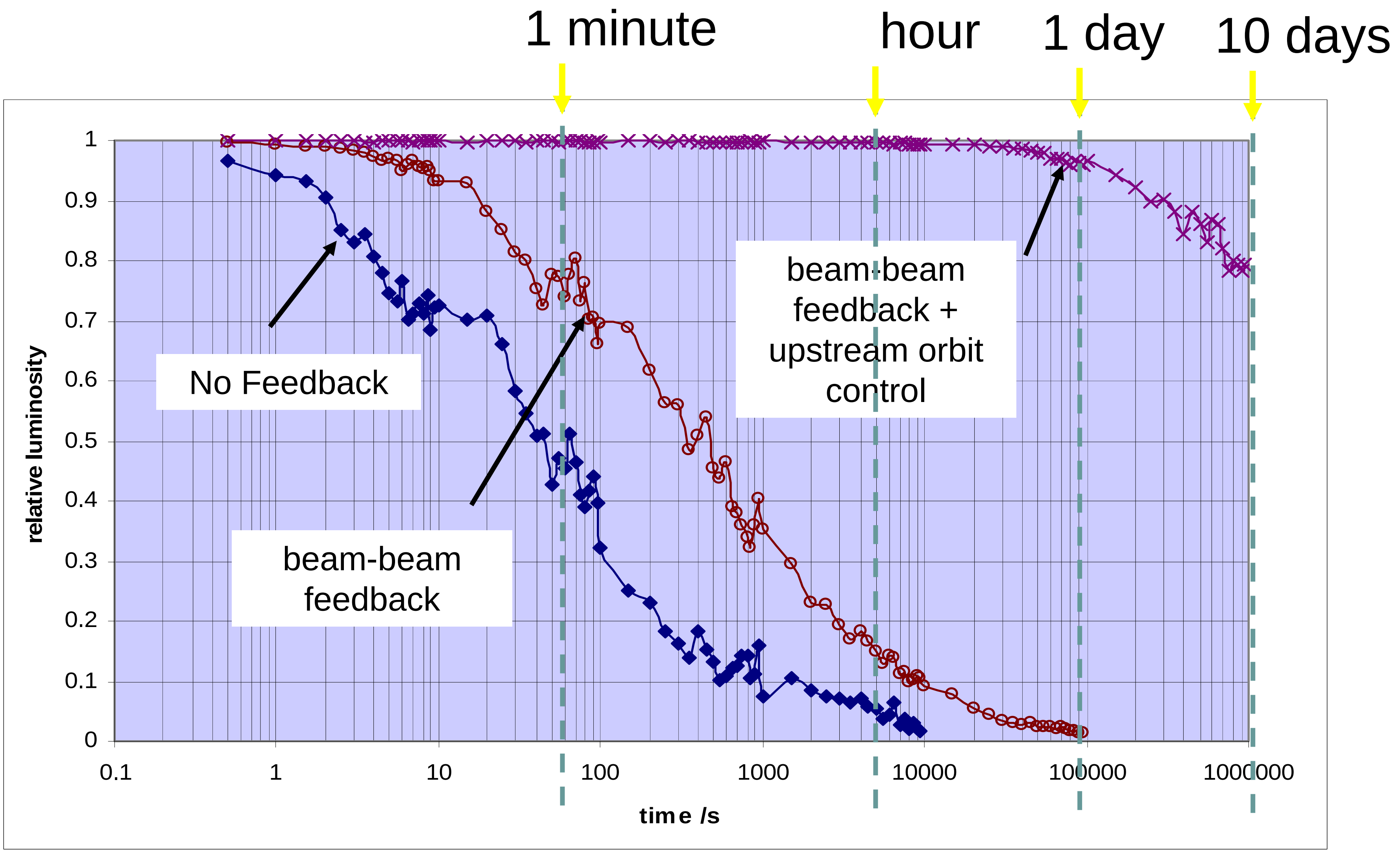
Parallel-to-point focusing of the final doublet

Offset of FD → Offset at the IP



- Stability tolerances driven by nm beam sizes at the IP
- No (or little) difference between two FFS systems
- need to worry about
  - ~40-100 nm vibration amplitudes for most magnets
  - ~10 nm for a few sensitive magnets
  - ~nm for final lens (final doublet)
- Must have:
  - mechanical stabilisation
  - beam-based feedback

Long Term Stability: keeping beams in collision is not enough! Need to control the orbit in every magnet



Stability Issues : Ground Motion

- The ground motion model should take into account general information about the geology, tunnel depth (& the construction technique), urbanisation of the area, cultural noises inside the tunnel (& surface)……. Very complex!
- Fast motion - cannot be adequately corrected and causes beam offsets at the IP

  Slow motion - causes degradation of beam quality
- There has been already a good understanding of the ground motion and vibrations and is constantly being improved
- Feedbacks must : Mechanical, beam-based and beam-beam position feedback at IP are proposed

ASTeC Accelerator Physics Linear Collider Activities

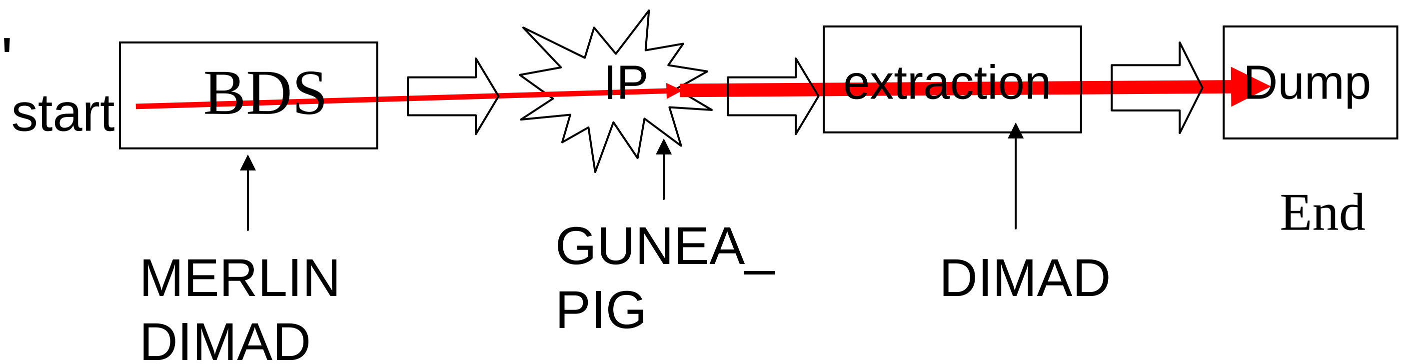
- As a part of LC-ABD programme, design expertise is being developed for
  - Final Focus Optimisation
  - Beam Collimation
  - Ground motion modelling
  - Beam extraction and IR issues
  - Beam-beam interaction
  - Start-to-end simulations

- Team is contributing to TESLA design at present and studying the NLC/GLC designs to be able to contribute to any technology decision

ASTeC Beam Transport simulations

- No single code exists for optics & collimation design.
- MAD, TRANSPORT, BETA, TURTLE, DIMAD implemented.
- MERLIN (with root graphics) for collimation simulations.
- For Extraction line studies, GUNEA_PIG & NLC version of DIMAD implemented.
- Currently BDS simulations to IP and through extraction line are set up.

"BDS-to-dump" simulations



All interfaced and controlled by Mathematica.

- Start-to-end simulations to be set up soon.