Machine Detector Interface Issues

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KEK Accelerator Workshop 2020

January 30-31

KEK, Japan

Outline

- **Introduction**
- **Detector Issues**
- **Beam Tails**
- **Machine Issues**
- **Other Issues**
- **Conclusion**

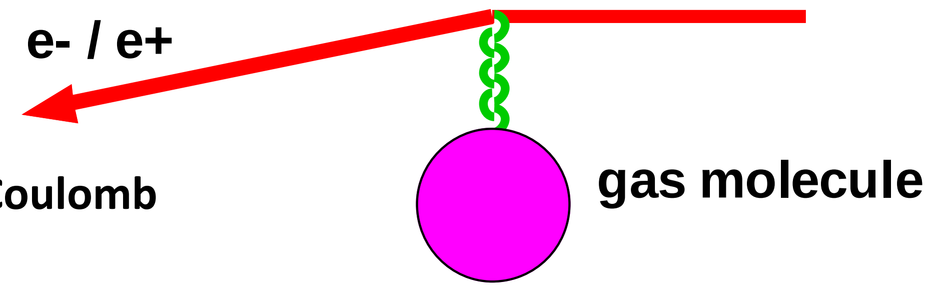
Introduction

- KEK
  - KEK has continuously pushed the frontier of e+e- colliders
  - Tristan was the largest and highest energy collider until the SLC and LEP
  - KEKB pioneered crab cavity technology and large angle collisions
  - KEKB also set and achieved (x2!) a design goal of 1×10^{34} luminosity
    - This was a very high number in the early 1990s
- SuperKEKB continues this tradition
  - Very large angle collision (83 mrad)
  - Nano-beam collision
  - Lowest β_y^* of any collider (1 mm)
- Design parameters
  - 200 nm β_y^*
  - Lumi of 8×10^{35}
  - Beam currents of 2.6 x 3.6 A
    - These will be the highest colliding beam currents ever

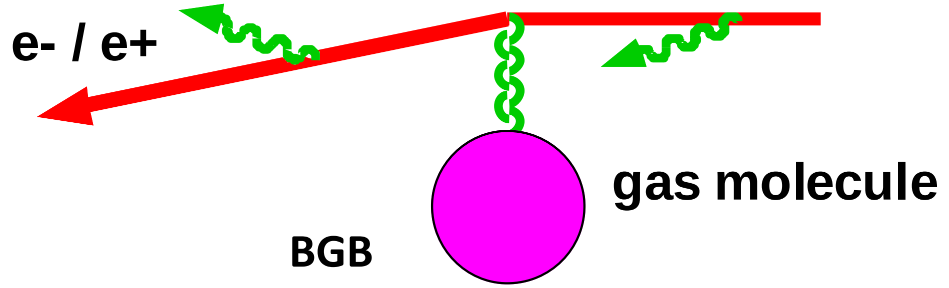
Detector Features

- **Detector acceptance as large as possible**
  - **Usually down to about 15 deg (300 mrad)**
- **Solenoidal magnetic field**
  - **The large crossing angle complicates the beam trajectories in this field**
- **Small radius central beam pipe (1 cm)**
  - **This means that vertex detectors are very close to the beam**
- **The final focus magnets are very close (actually inside) the detector**

Some Detector Issues



Coulomb



BGB

- **Beam Backgrounds**
  - **Coulomb (elastic scattering)**
  - **Beam-gas (inelastic scattering)**
  - **Touschek (inter-bunch scattering)**
  - **Luminosity related**
  - **Beam-beam**
  - **Non-gaussian beam tails**
    - **The beam tail is generated by the above interactions as well as by other effects**
    - **Non-gaussian beam tails can be quite large**
    - **The e^+e^- beams have very large damping terms from SR**
  - **Collimation is necessary and crucial in order to control the above backgrounds as well as the SR background from the beam tail**

More on detector backgrounds

- Beam pipe "scrubbing"
  - The SR from the electron and positron beams "digs out" the gas molecules imbedded in the beam pipe metal
    - This generates gas pressure around the ring "dynamic gas pressure" which can be 10-100 times (or more!) higher than the zero-current base pressure
- Synchrotron Radiation is a major background from the beams
  - Direct hits on the central beam pipe is the first concern
    - These hits are usually coming from beam particles in the high sigma region where there is great uncertainty as to what the actual hit rate will end up being (More on this)
    - The direct hit rate generally sets the radius of the central beam pipe
    - Direct hits are much more difficult to mask out when the crossing angle is large
  - High beam currents force us to worry about secondary scattering
    - Forward as well as backward one bounce scattering
    - In some cases tertiary (2 bounce photons) can be an issue if the source has a very high incident photon rate
    - Usually these rates are not very high and can be ignored but too many hits from a single crossing can swamp a detector by making too much occupancy

Beam Tails

- **The core of the beam is assumed gaussian in all 3 dimensions and we believe this is a good approximation**
- **However, any sort of interaction or perturbation of the beam particles can result in a beam particle getting out of this 3D gaussian distribution**
- **For electron (and positron) beams this "out of the envelope" beam particle, in many cases, has an excellent chance of damping back into the core distribution before it hits the dynamic aperture limit of the ring or hits a collimator and is lost**
  - Synchrotron radiation damping is very strong

Beam Tails (2)

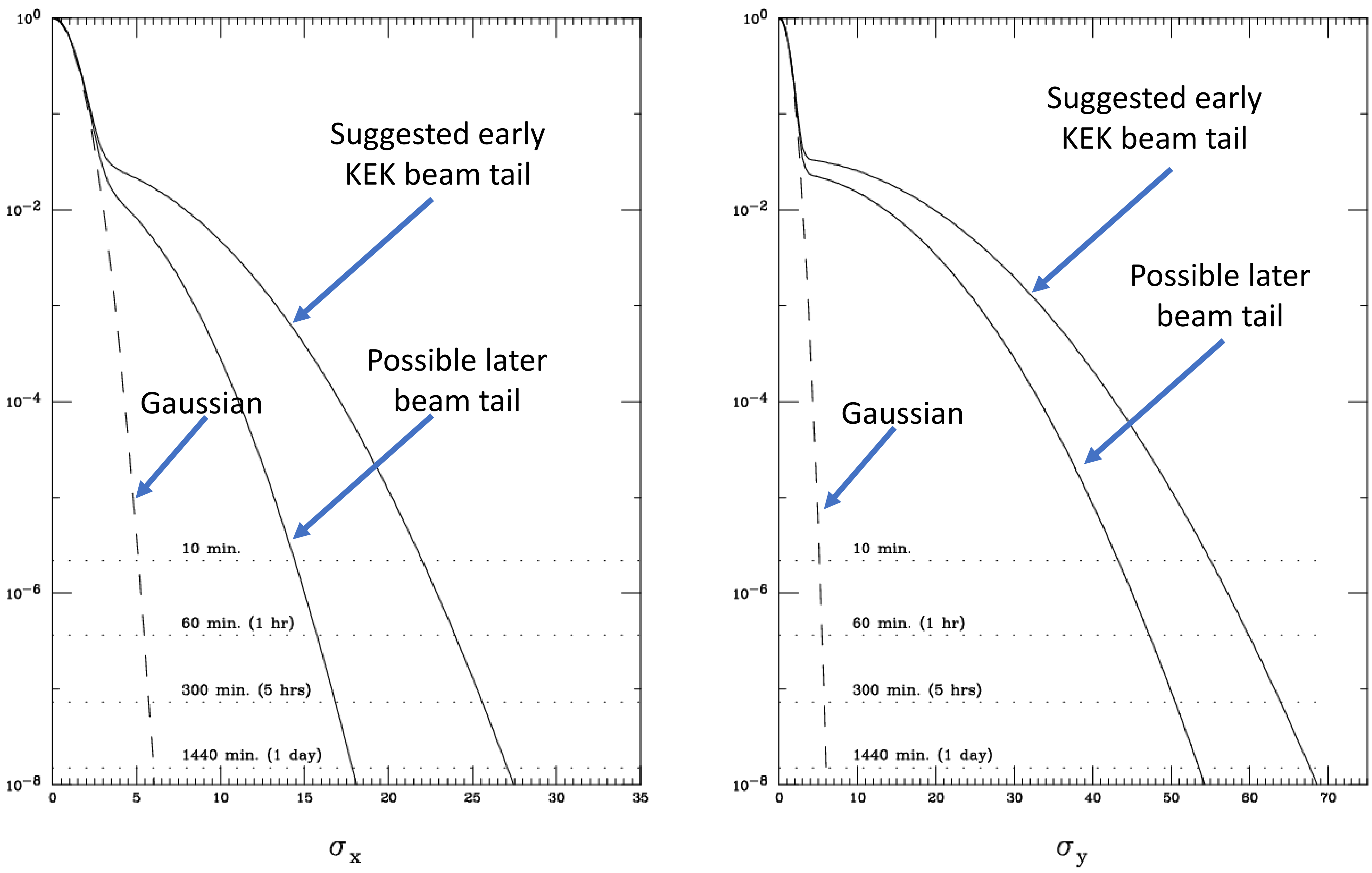
- What this essentially means is that sources of beam particle perturbation or interaction are constantly pushing beam particles out into the high beam sigma region (out into the non-gaussian tail) and SR is constantly pulling (damping) most of these particles back into the core distribution
- The result is a semi-stable distribution of beam particles out in the high sigma non-gaussian tail in all 3 dimensions
- The larger the dynamic aperture – the more beam sigmas the particle can be in and still stay in the machine
  - Machine designs strive to make the dynamic aperture as large as possible

Beam Tails (3)

- **Initially, during machine commissioning, the main sources of beam particle interaction are beam-gas collisions (this is the scrubbing phase)**
    - **The luminosity is low, the tune shifts are low, the beam currents are low**
  - **All beam pipes have gas molecules imbedded probably throughout the metal**
  - **Baking out the vacuum chambers gets rid of the surface and near surface gas molecules and is very important (especially for water!)**
  - **But the x-rays from the SR are much more penetrating and these photons will get to molecules that are deeper in the metal and give them the energy they need to migrate to the surface and outgas**
  - **The outgassing rate decreases with time as the gas molecules embedded in the metal are gradually removed**
  - **Remember that this applies to the entire inner beam pipe surface**
  - **The strike surface of the SR beam cleans up fairly quickly but the scattered x-rays from the strike point must also clean up the rest of the beam pipe inner surface**

Some Non-gaussian Beam Tail Distributions

The larger beam tail distribution has about 3.5% of the total particles of the bunch



Beam Tails (4)

- As the initial outgassing diminishes and the beam lifetime increases the accelerator team can start raising the beam currents
  - This, of course, increases the outgassing again and a balance must be struck to keep the backgrounds at an acceptable level for data taking
  - As the currents increase so do the other beam particle perturbation terms
    - The luminosity contribution increases as the lumi goes up (this one we want!!)
    - The Touschek lifetime can drop – increasing the background from this source
    - Beam-beam effects become important
    - Even beamstrahlung can become important
- As the machine performance improves the initial sources of non-gaussian particles diminishes but new sources become larger and more important
- So, there is always a non-gaussian beam tail distribution in the machine
    - Especially in high current rings

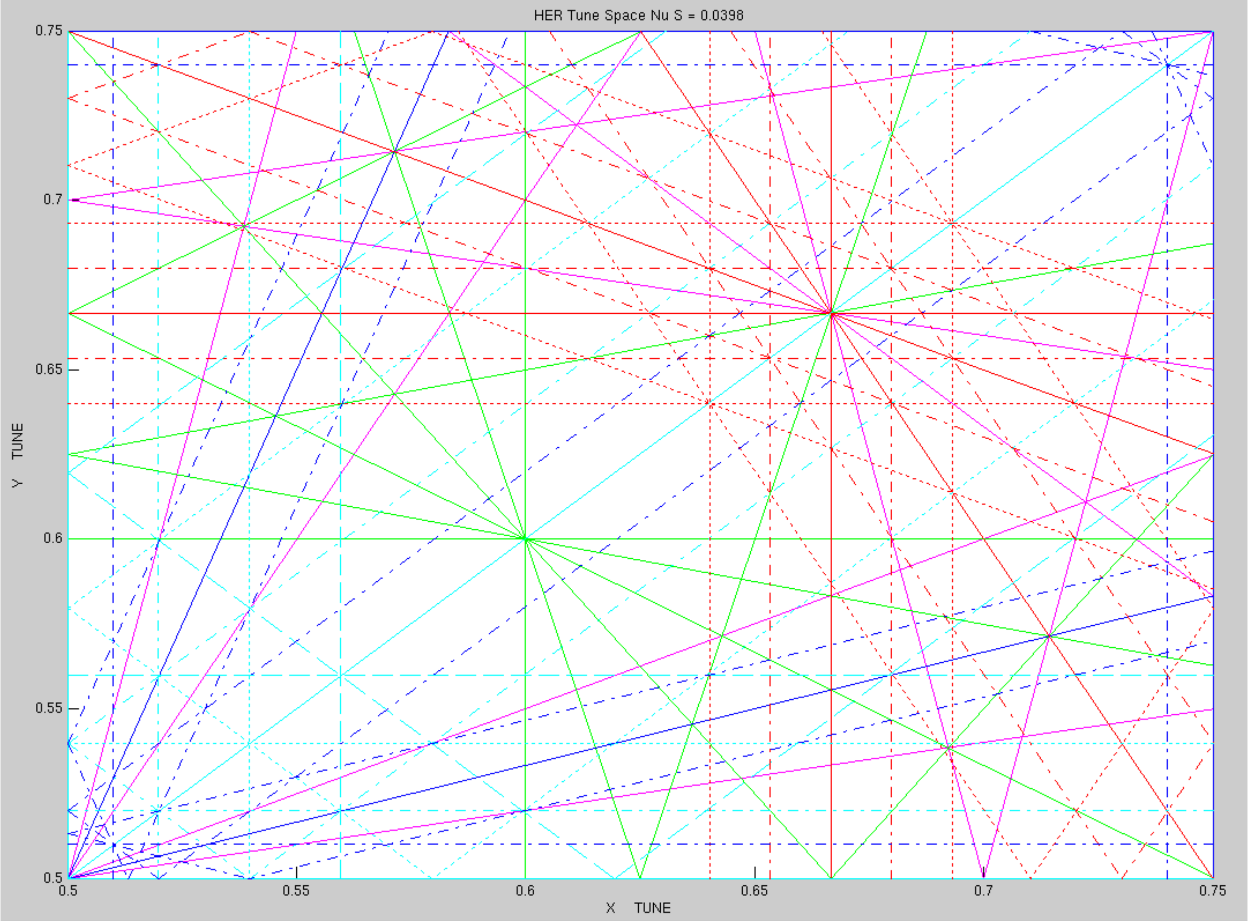
Accelerator Issues

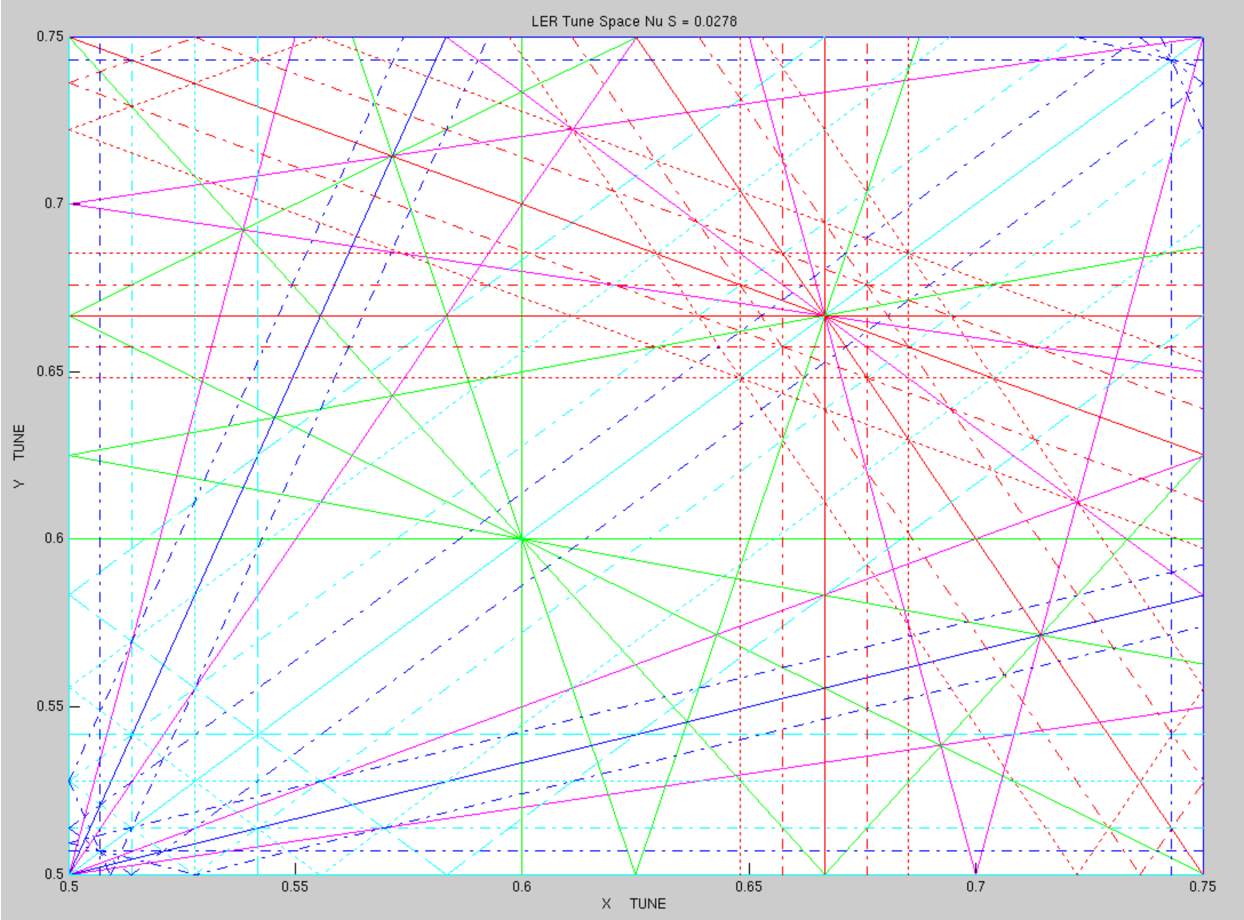
- High beam currents
  - 2.6 A for the 7 GeV electron beam
  - 3.6 A for the 4 GeV positron beam
- Short beam bunches
  - ~6 mm
    - HOM power around the ring
- Feedback systems
  - Bunch-by-bunch orbit stability
    - Transverse
    - Longitudinal
  - Luminosity
    - Maintain the beams in collision with feedbacks
    - Fast enough to compensate for final focus mechanical motion?

More Accelerator Issues

- **Clean injection**
  - **Minimize detector background**
  - **Maximize efficiency in order to keep up with short beam lifetimes**
- **Beam emittance**
  - **Minimize orbit deviations in quadrupoles**
  - **Control the dispersion functions**
- **Control the coupling**
  - **Controls the vertical spot size**
- **Control beam size**
  - **Beam blowup**
    - **One beam blowing up the other beam**
    - **Both beams blowing up from the collision**
- **Tunes**
  - **Tune footprint**

PEP-II HER tune plane

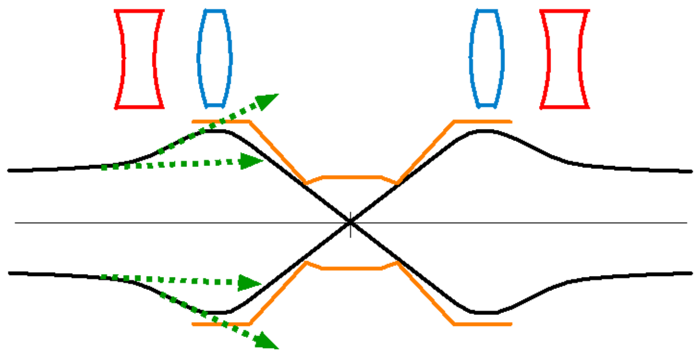




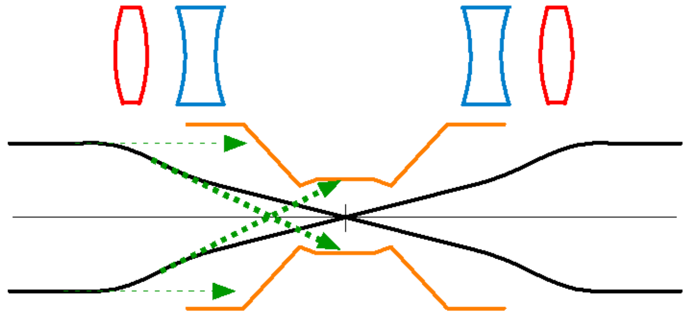
PEP-II LER tune plane

More on accelerator issues

- **Luminosity**
  - **Low β_y^***
  - **The accelerator team may discover they can go to lower β_y^* or β_x^* values. Then the β_y or β_x max is larger in the FF quads making more SR at larger distances from the beam axis in the FF quads.**
- **Continuous injection**
  - **Low backgrounds**
  - **Collimators can help here but clipping off too much injected beam can harm injection efficiency**



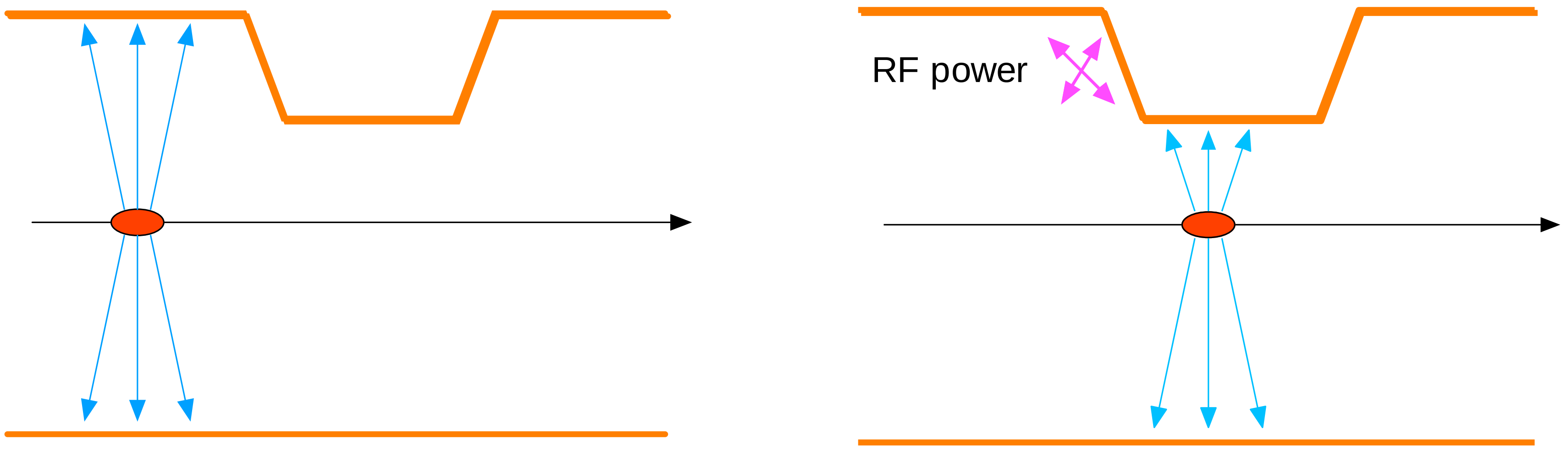
Vertical beam focusing
(side view)



Horizontal beam focusing
(plan view)

Closely spaced beam bunches

- When the bunch spacing gets close (~10 ns) the bunches can start to affect each other
  - This is one of the main reasons the beam pipe must have smooth, gentle geometry transitions
    - The PEP-II B-factory generally had a limit of 15 deg (1:12) for beam pipe transitions
  - The "left behind" RF power can interact with the next bunch
  - This bunch to bunch coupling must be controlled by feedback systems
  - Smooth transitions minimize this impedance effect



S. Novokhatski has much better pictures of this effect

Some Conclusions

- **The accelerator and detector teams need to work closely together to maximize the efficiency of the commissioning phase**
  - **The detector team wants to start taking data as soon as possible**
  - **The accelerator team wants to move to the design machine as quickly as possible**
- **These goals sometimes need a bit of give and take**
  - **Both teams eventually want the same thing – high luminosity and data taking at the same time**
- **The beam tail distributions will change as the machine becomes better understood, as the scrubbing continues, and as the accelerator approaches the design parameters**
  - **However, there will always be some form of non-gaussian tail distribution**

Summary

- These are exciting times!
- The SuperKEKB accelerator is truly a frontier machine
- Many features of this machine need to be better understood
  - No one has such a machine to explore this part of accelerator parameter space
- What is discovered here will be used in all future collider designs