Colliders and the Machine Detector Interface

M. Sullivan
SLAC National Accelerator Laboratory

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Hong Kong University of Science and Technology Jockey Club Institute for Advanced Study

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Outline

- **Brief (incomplete) history of colliders and IRs**

- **Present machines**

- **Future machines**

  - *ee*

  - **PP colliders**

  - *e*P

Outline (2)

- **MDI issues**
  - **Detector acceptance**
  - **Final Focus elements**
  - **Backgrounds**
    - **Synchrotron Radiation**
    - **Beam particle**
    - **Luminosity**
  - **Other (heating, HOM, vacuum, …)**
- **Summary**
- **Conclusion**

Matter – Antimatter Colliders

- **The first matter - antimatter collider was AdA located at Frascati, Italy and then moved to Orsay (1961-1964)**
- **Colliders got into the spotlight when SPEAR at SLAC together with the fixed target experiment at Brookhaven (BNL) discovered the Charmed quark (quickly confirmed by ADONE at Frascati)**
- **SPEAR went on to find two more charmed meson resonances as well as the production of the Tau lepton and the threshold of D meson production**
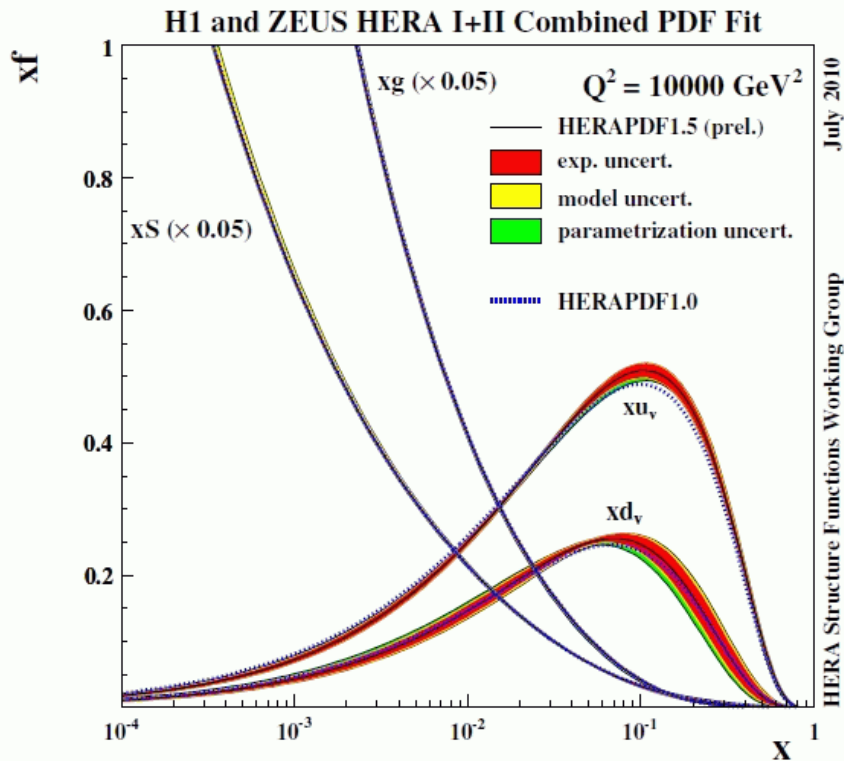
Matter – Antimatter Colliders (2)

- e^+e^- storage ring colliders became the rage in the mid 1970s with the construction and start of:
  - VEPP-2M (INP Novosibirsk 1974) (1.4 GeV)
  - DORIS (DESY Hamburg 1974) (10 GeV)
  - PETRA (DESY 1978) (42 GeV)
  - CESR (Cornell U. 1979) (12 GeV)
  - PEP (SLAC 1980) (29 GeV)
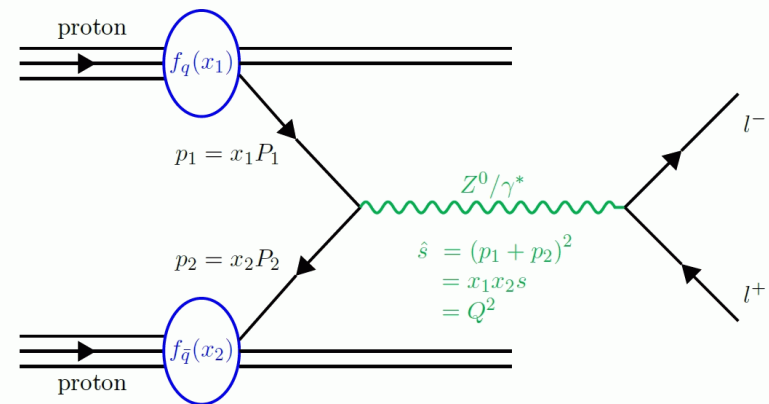
Matter – Antimatter Colliders (3)

- **The 1980s saw a continuation of new e^+e^- colliders and now $P\bar{P}$ colliders started to get into the act**
  - **Tristan (KEK Japan 1986) (64 GeV)**
  - **SLC (SLAC 1988) (92 GeV)**
  - **LEP (CERN 1989) (92-206 GeV)**
  - **SppS (CERN 1981) (~600 GeV)**
  - **Tevitron (FermiLab 1992) (~1.9 TeV)**

Matter - Antimatter

- **The early 90s also saw a new collider HERA at DESY (1992) (up to 28 GeV positrons on 680 GeV protons). This *e*P collider measured some very important functions of the proton structure. Namely, how much of the proton is antimatter.**

- **Drell and Yan had already indicated that if there is antimatter in the proton then that would explain the then observed dilepton production in PP collisions**

- **Now PP colliders could also use matter – antimatter collisions to look for new physics**
  - $P\bar{P}$ **annihilations use all of the available energy in the collision but events with total annihilation of a P and a $\bar{P}$ are very rare**

H1 and ZEUS HERA I+II Combined PDF Fit

$Q^2 = 10000 \text{ GeV}^2$

July 2010

- HERAPDF1.5 (prel.)
- exp. uncert.
- model uncert.
- parametrization uncert.
- HERAPDF1.0

$xg \; (\times 0.05)$

$xS \; (\times 0.05)$

xu_v

xd_v

HERA Structure Functions Working Group

The Parton Distribution Functions (left) where the sea distribution (xS in the plot) contains antimatter allowing PP colliders to search for new particles through the Drell-Yan process below

proton → $f_q(x_1)$

$p_1 = x_1 P_1$

Z^0/γ^*

l^-

$p_2 = x_2 P_2$

$\hat{s} = (p_1 + p_2)^2$
$= x_1 x_2 s$
$= Q^2$

l^+

$f_{\bar{q}}(x_2)$

proton

Even though there are very few sea partons with a large X value one can still get some events that use almost all of the collision energy

Factories

- **After initially discovering new particles (ϕ, charm states, τ, bottom states) it becomes important to study these particles more thoroughly by obtaining a large number of events. These machines needed high luminosity.**
  - **DAϕNE (INFN, Frascati 1999) (1 GeV)**
    - **Strange**
  - **Tau-Charm (BEPC-II, IHEP 2008) (7.2 GeV)**
    - **Charm and Tau lepton**
  - **PEP-II and KEKB, SLAC and KEK 1998) (11 GeV)**
    - **B mesons**
- **New Physics can be found from factories if decay rates or branching fractions do not match predicted values from Standard Model calculations**

Current Colliders

- **Currently we have two PP colliders**
  - **RHIC (BNL, Brookhaven 2000) (500 GeV)**
    - **Only doing ion collisions now**
  - **LHC (CERN, 2008) (13 TeV)**
    - **PP and ions**
- **BEPC-II is still running**
  - **Tau-charm**
- **SuperKEKB is about to turn on (KEK) (11 GeV)**
  - **B mesons**

The birth of MDI

- Before the Factories, accelerators were generally designed with some regard for the detector but mostly just to get the accelerator to work (final focus elements were generally outboard of detectors)

- The Factory machines forced a much more careful study of the issues between the Accelerator and the Detector primarily because the machine elements were now placed inside the detector volume and this directly affected the acceptance of the detector

- In addition, factories need high beam currents and this increases all of the beam related backgrounds requiring a much more integrated approach. Detectors began to make requirements on the machine design throughout the ring and not just at the interaction region (collimators had always been used but now careful studies were performed to make sure the collimators were located successfully)

MDI issues

- **Up to now, the factories have been lower energy machines (<~10 GeV) with very high beam currents (>1 A)**

- **However, all present and new *ee* machines are essentially factory designs**

- ***e*P designs have many of the *ee* MDI issues because of the electron beam with extra complications added in from the hadron beam (i.e. more neutrons)**

- **An addition, current and future *ee* machines are aiming for higher energies and unprecedented luminosities**

MDI concerns stem from factory designs

- **Detector acceptance**
  - **Final Focus elements are as close to the IP as possible**
  - **Low angle detector acceptance is reduced**
    - **For the new *e*P collider designs forward acceptance becomes a critical item forcing accelerator design changes (JLAB with JLEIC and BNL with eRHIC)**

Synchrotron radiation sources

- **Close final focus elements mean stronger magnetic fields**
  - SR from the FF magnets (quadrupole radiation) becomes an important detector background
  - FF magnets close to the IP mean less space to design masking solutions
  - In addition, the downstream FF magnets have to be protected from the upstream FF SR (especially if they have cold bores)

Secondary SR sources

- **The new and current machines have higher energy beams or higher beam currents (or both!)**

- **This means that SR intensity and energy spectra are higher than before in almost all cases**

- **Blocking the SR sources from directly hitting the detector (mainly the central beam pipe) is the first step**

- **But then secondary radiation (one bounce and/or tip scattering) becomes the dominant source of SR background in the detector (also backscattering ala HERA)**

- **These secondary background sources can become quite serious in the new regime of high energy and high current beams**

Vertical beam focusing
(side view)

Horizontal beam focusing
(plan view)
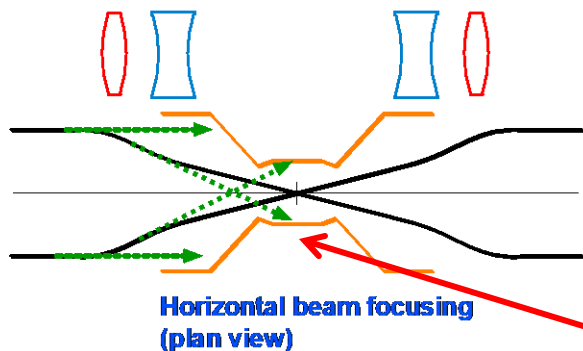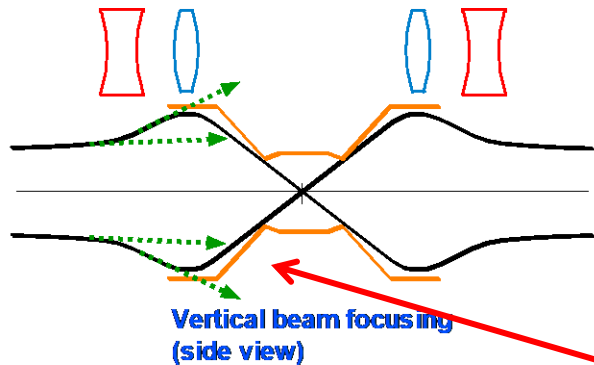
Photons generated from the final focus quadrupoles have to be masked away from the central beam pipe. The vertical focusing element is usually closest to the IP and easier to mask. The horizontal focusing magnet is farther back and must over-focus in order to compensate for the defocusing of the vertical focusing magnet. These photons are more difficult to mask.

Mask tip

10 - 100 um
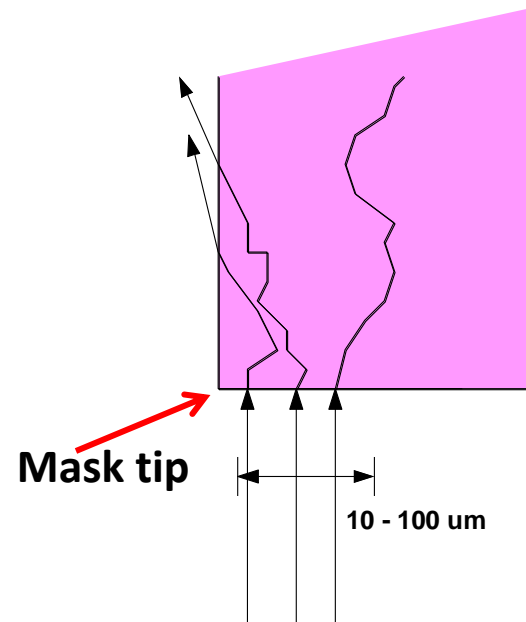
Photons that strike near the tip of a mask have a chance to scatter through the tip and then hit the central beam pipe
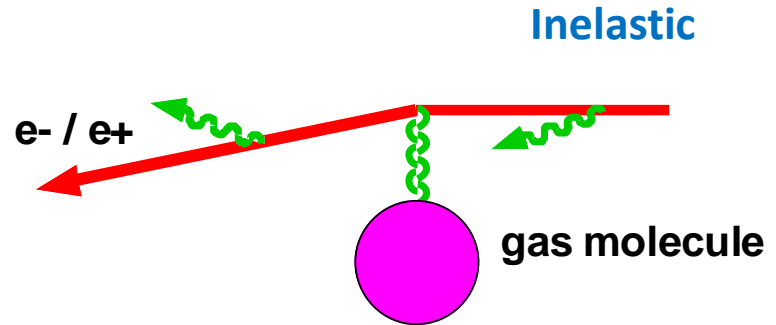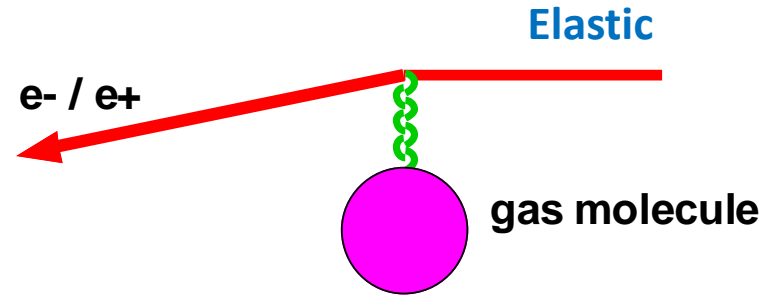
Beam particle Backgrounds

- **There are several processes that need to be calculated that all involve backgrounds from a beam particle**
  - **Particle – particle interaction inside a beam bunch**
    - **Touschek**
    - **Inter-beam scattering (IBS)**
  - **These scattering events populate the high sigma region of a beam bunch with particles that tend to get lost in the IR because the beam beta functions are largest in the final focus magnets**
    - **Careful beam tail collimation at places outside of the IR are needed**

Beam particle bkgds (2)

- **Beam particle interaction with a gas molecule**
  - **Coulomb scattering (elastic)**
  - **Beam-Gas interaction (inelastic)**
    - A carefully constructed collimation scheme is needed to minimize these backgrounds
    - Also as good a vacuum as possible around the ring and especially upstream of the detector

Elastic

e- / e+

gas molecule

Inelastic

e- / e+

gas molecule

Luminosity backgrounds

- **The B-factories were the first to encounter significant backgrounds from luminosity**
  - **Radiative Bhabhas**
    - **Low angle γs and off-energy beam particles**
  - **Two-photon e^+e^-**
    - **Sets the inner radius of the beam pipe**
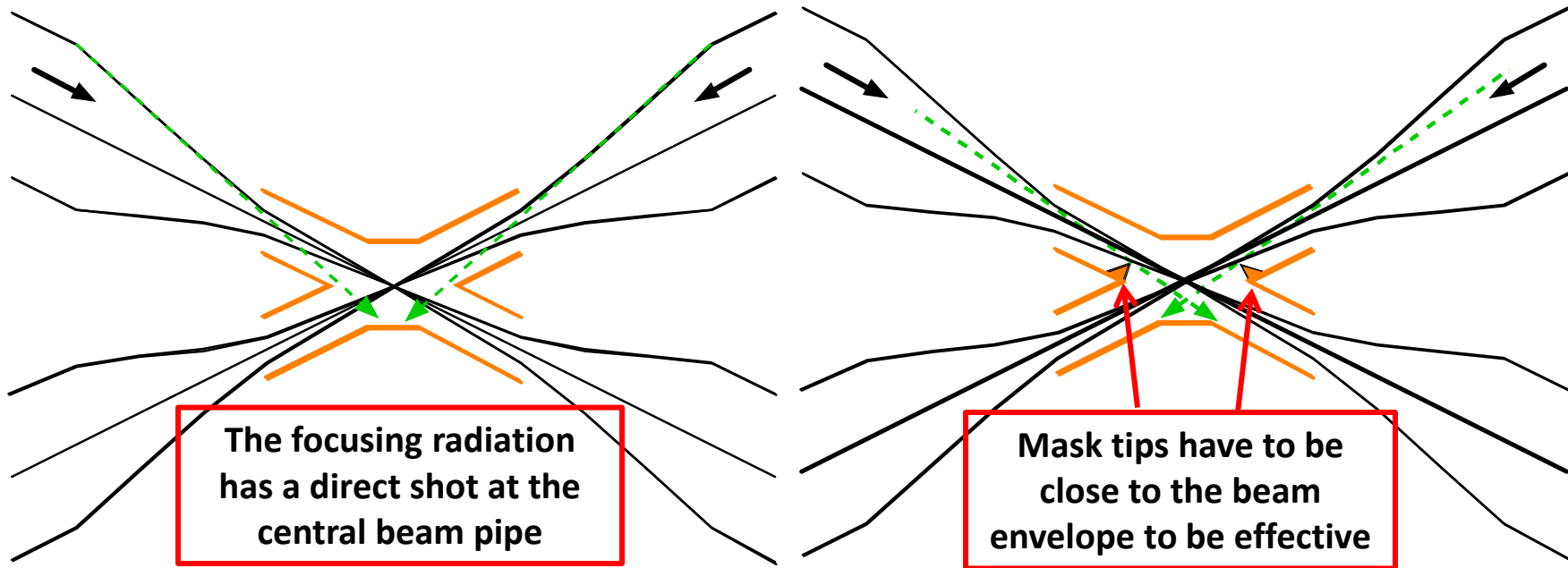- **These bkgds increase with increasing luminosity**
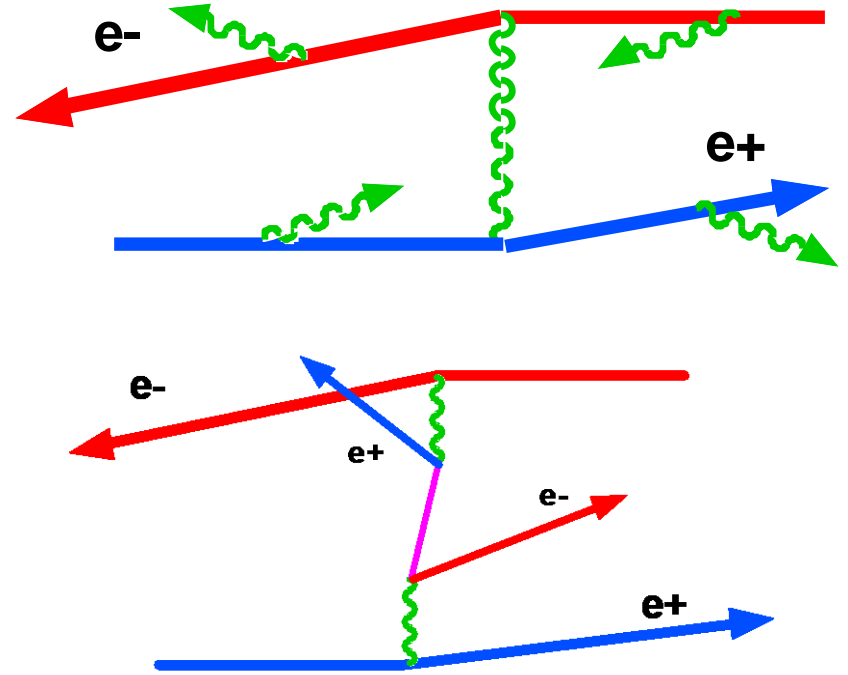
Other MDI issues

- ## HOM heating
  - **This is always an issue especially for crossing angle or separate storage ring collider designs**
- ## Image current heating
  - **The beam produces an image charge on the walls that travels with the beam. This image current has an I^2R power loss based on the resistivity of the wall which is a function of frequencies related to the bunch length**
- ## Vacuum pressure
  - **As low as reasonably possible upstream of the IR**
  - **The beam pipe from the last collimator to the IR must have very good vacuum as all gas interactions in this region will tend to crash into the detector (a bend magnet can help – especially BGB but Coulomb can still be a problem)**
- ## Injection backgrounds
  - **Continuous injection can double and perhaps triple the integrated luminosity compared to a coast and fill method (luminosity lifetime)**

Crossing angle masking

- **A large crossing angle makes shielding the central chamber from direct SR hits more difficult**
  - **SuperKEKB has the largest crossing angle of 83 mrad**

The focusing radiation has a direct shot at the central beam pipe

Mask tips have to be close to the beam envelope to be effective

Summary

- **The Interaction Region is one of the more interesting parts of an accelerator**
  - **There are many conflicting requirements that need to be optimally resolved**
  - **The accelerator needs to be able to produce the luminosity and the detector needs to be able to collect the physics**

Summary (2)

- **A good IR design should try to be as "flexible" as possible in order to "bend" and not "break" when slightly different running conditions or circumstances turn out to produce better machine and/or detector performance**

- **One needs to study around the chosen point for the IR design or in the large multi-parameter space near the design choices in order to find out where the "breaking points" are located**

Conclusion

- **First get a reasonably good IR design**
- **Then check for robustness**
- **Perhaps re-optimize**
- **Check again for robustness**
- **Keep iterating and rechecking especially after changes in the machine occur**

Thank You!