eRD19: Simulations of machine induced backgrounds – Progress report

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Generic EIC Detector R&D Review Meeting

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Scope of the eRD19 project

- Investigate the critical issue of backgrounds induced by the operation of the machine
  - Beam-gas interactions
  - Synchrotron radiation
  - Beam halo
- Use simulation studies to provide first quantitative estimates and information regarding the above backgrounds assuming various EIC facility scenarios
- Provide critical information for future considerations of shielding, etc.

Overview of work for current period of review

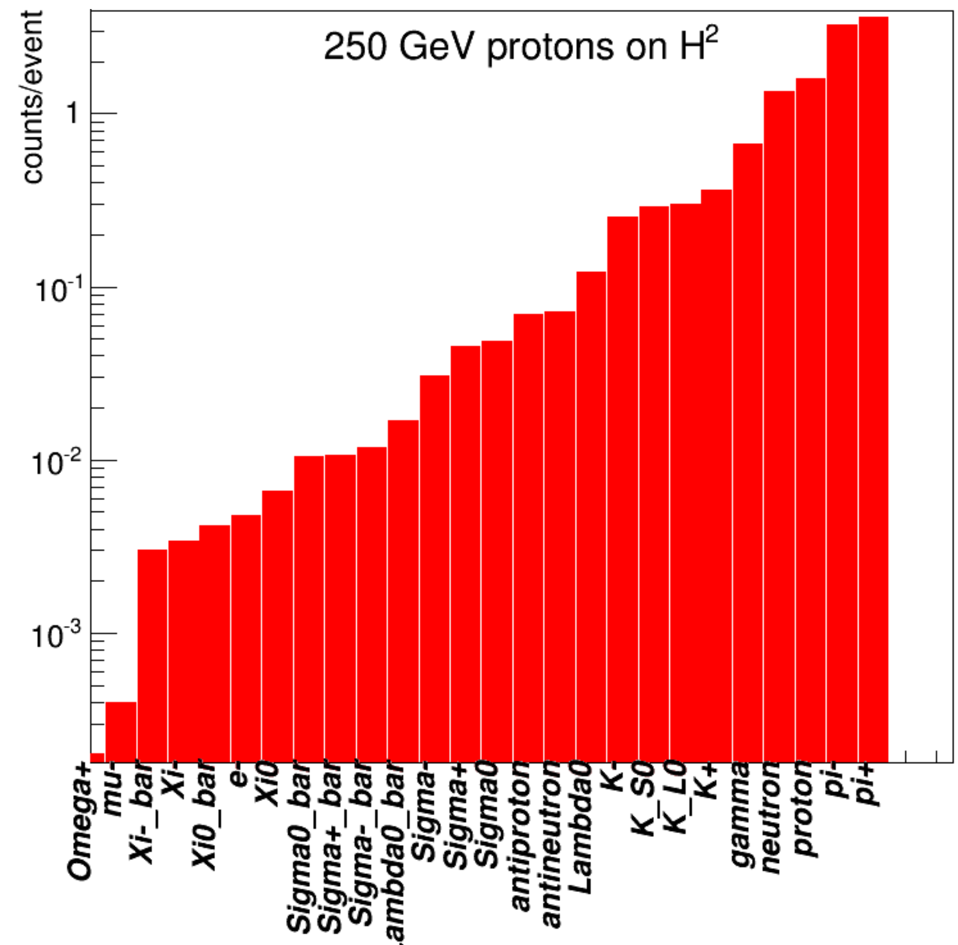
- Focus on proton beam-gas interactions
- Use currently available Monte Carlo simulation codes to model background processes
  - Dpmjet for p+A background
  - Pythia for e+p physics signal
- Embed simulated physics events into full simulation of the eRHIC IR region and detector
  - EicRoot – our GEANT implementation of eRHIC and detectors
- Look into impact and frequency of background events on the detector operation and related analyses

Baseline background simulations

- Strategy:
  - Simulate stand-alone p+A collisions (dpmjet3)
  - Displace vertex of collisions along the beam orbit in a given IR setup
  - Send modified event record into EicRoot and track the produced particles through the IR and into the detector
    - Interaction of particles with magnet material is suppressed (thus suppressing backscattering)
- Metrics:
  - Overall rate of particles hitting the detector
  - Probability of background event overlapping with physics event
  - Investigating what areas of the detector get hit the most and by what type of particle
- p+A cross section is large compared to e+p cross-section
  - $p+H^2$ (250 GeV p) → 60 mb (not including elastic)
  - p+Ar (250 GeV p) → 600 mb (not including elastic)
  - e+p (10 x 250 GeV) → 0.05 mb

Baseline background simulations

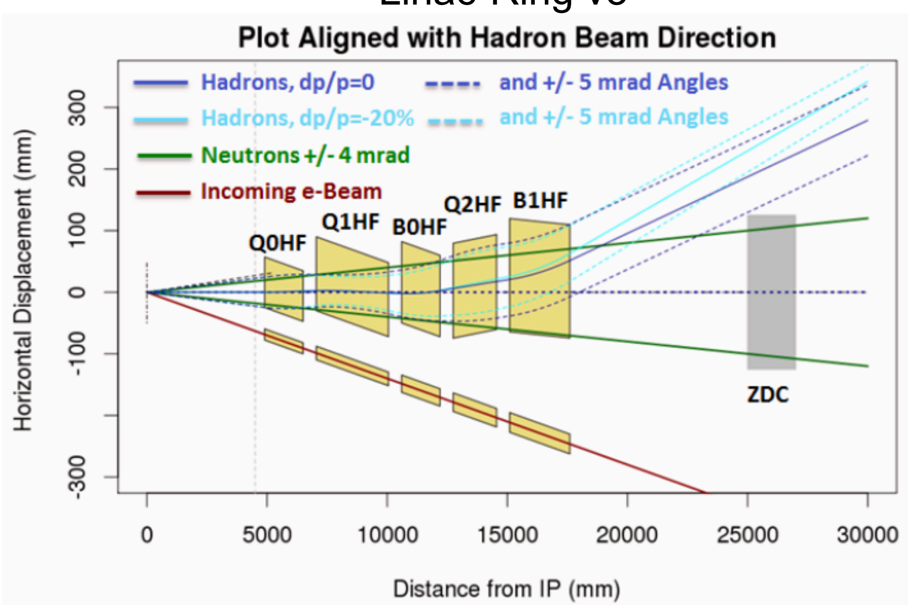
- Simulate fixed target p+H^2 collisions (p at 250 GeV)
  - Choose H^2 because RHIC vacuum group claim that at least 90% of residual gas in pipe is H^2



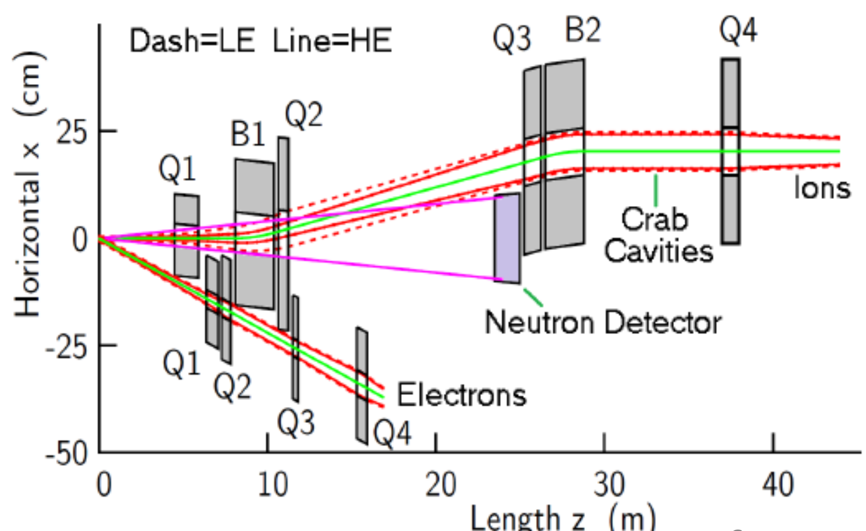
Where do background event particles go?

- Track particles though the magnet lattice
- Consider a particle to hit the detector if a space point for the track is found that has simultaneously:
  - $-4.5 < z < 4.5$ m
  - Radius from beamline > 2 cm (outside of beam pipe)
- Note that we do not have a magnet design before the detector (from the proton beam perspective)
  - As a first approximation, the setup downstream from the detector has been mirrored through the IP

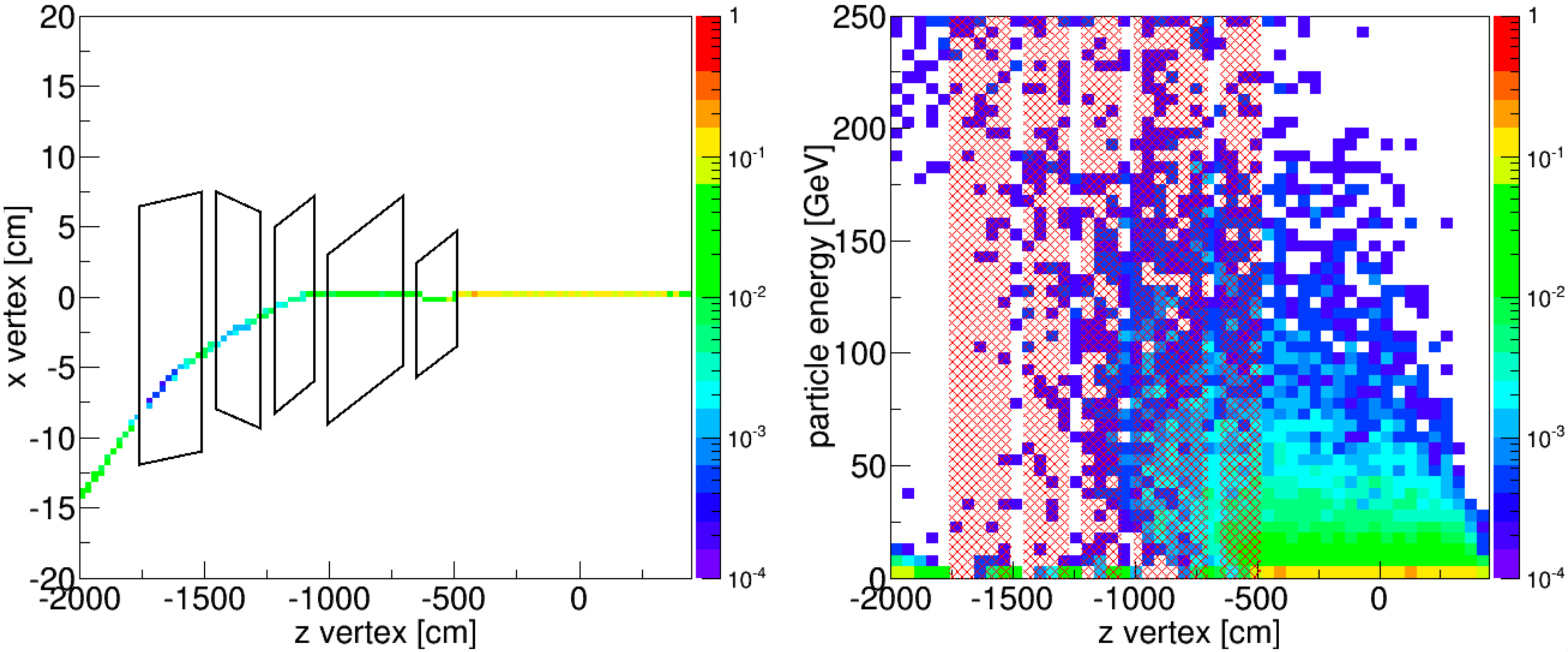
Linac-Ring v3



Ring-Ring v2

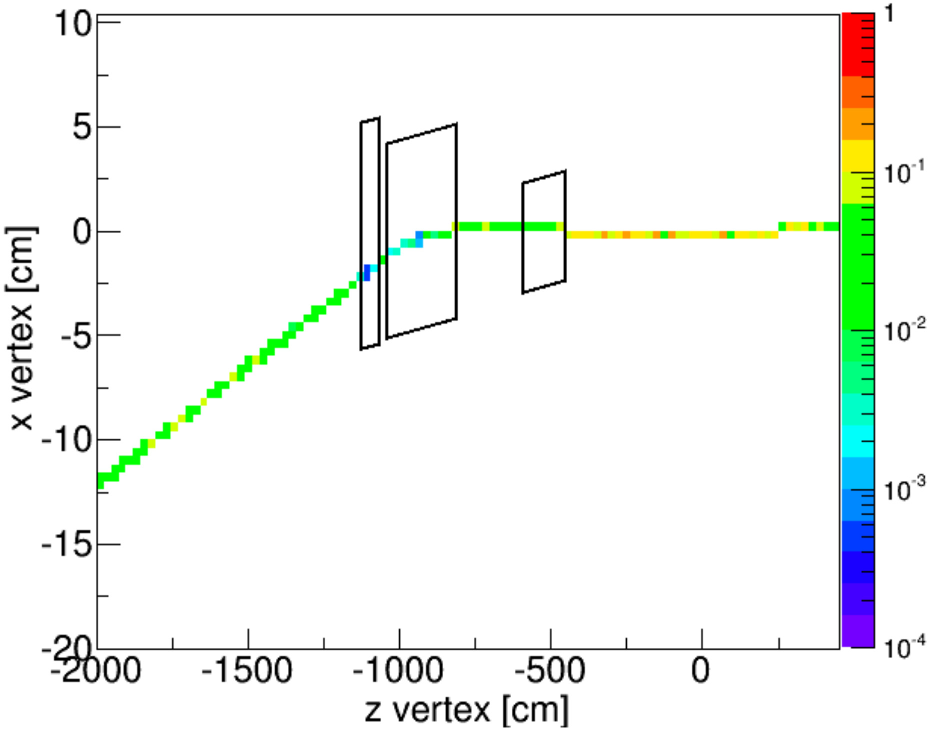


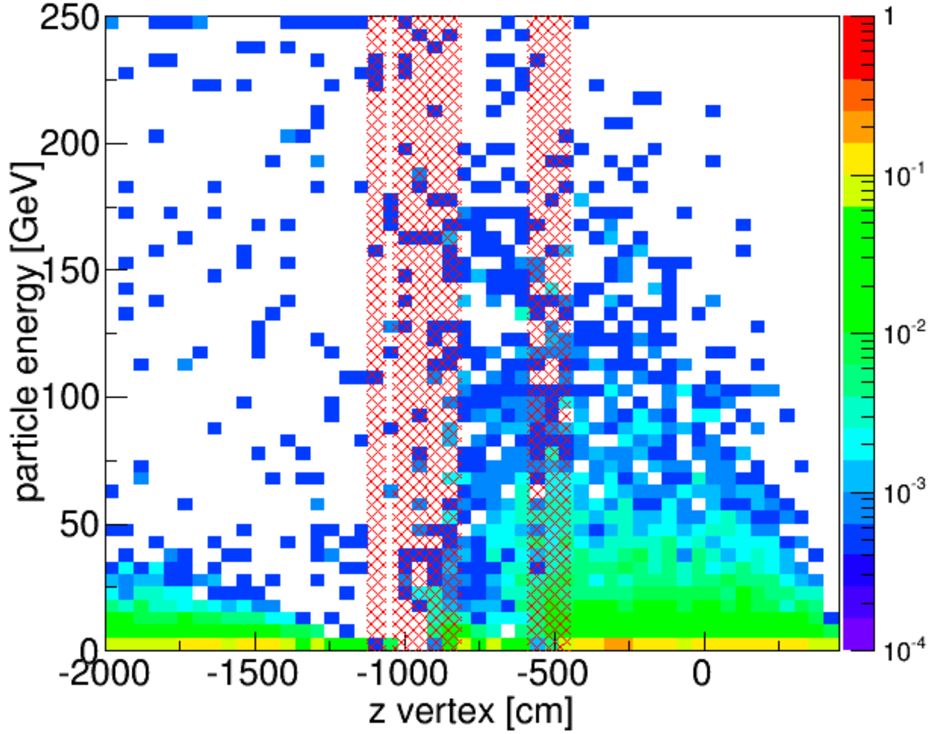
Where do background events that **hit** the detector come from (Linac-Ring design)?



- Shows a top view of the IR
- Plot the production vertex of a background collision
- Fill histogram **only** if particle **hits** the detector
- Color coding indicates number of particles/event hitting detector
- Most of the particles hitting the detector come from within the beampipe of the detector
- Most of the particles hitting the detector have an energy of 50 GeV or less

Where do background events that **hit** the detector come from (Ring-Ring design)?





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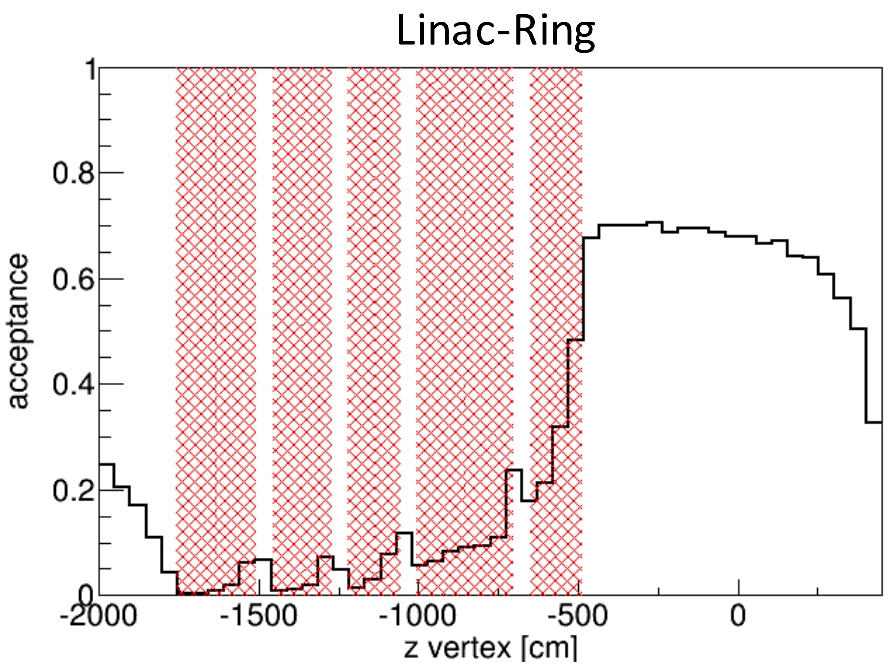
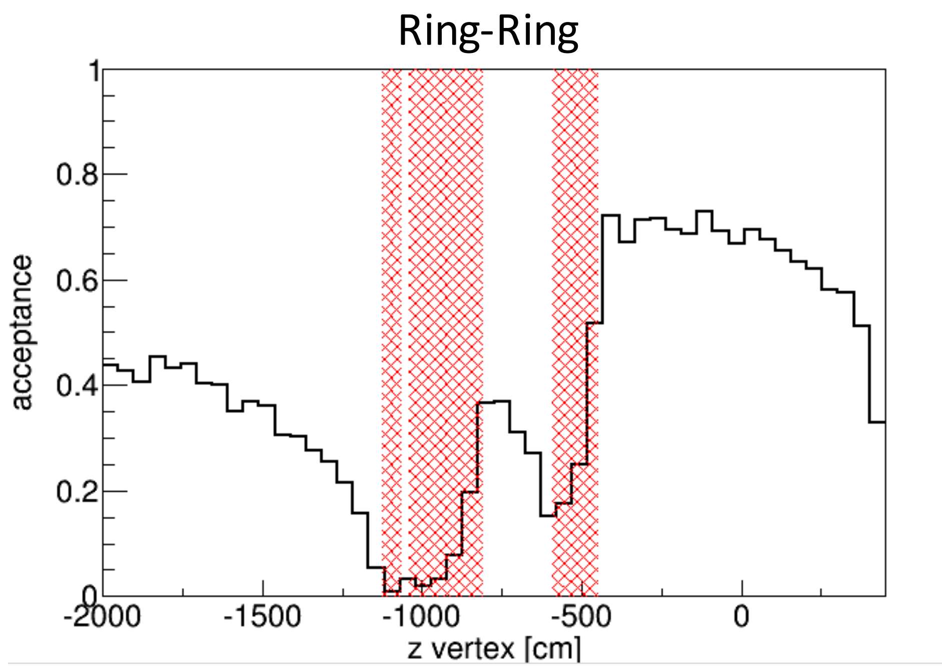
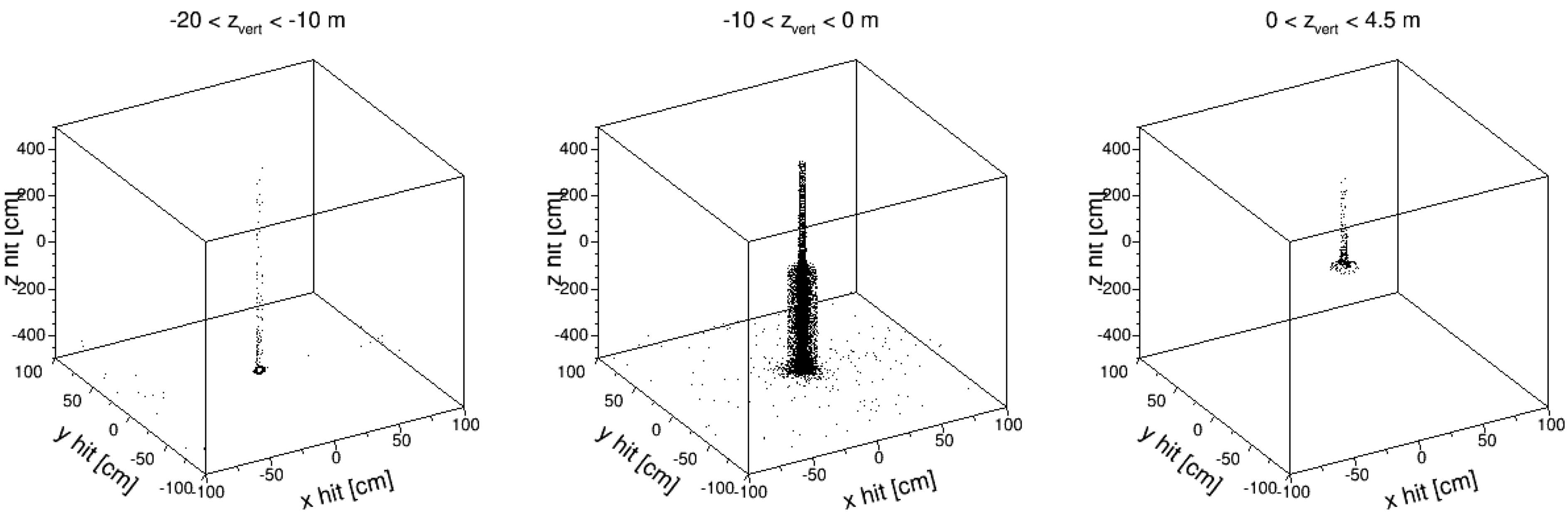
Geometrical acceptance along z





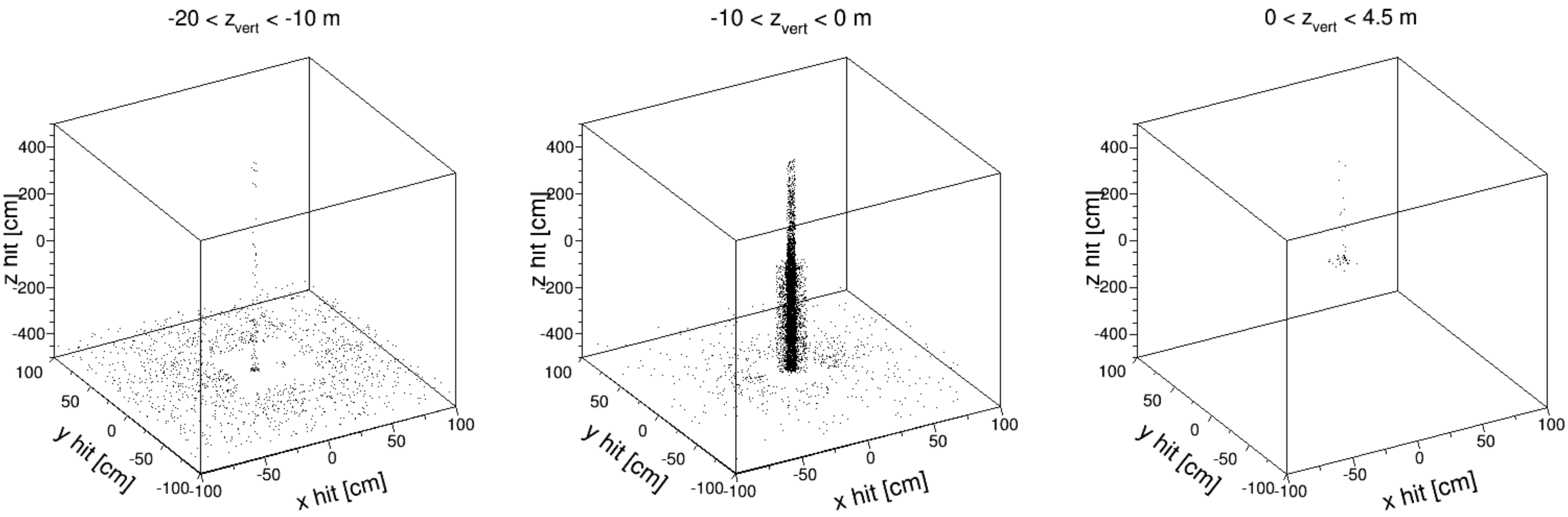
- Note that no mask or anything are in place
- Simply have the magnet constructions in the simulation
  - The bulk around the magnet is also arbitrary and needs to be investigated with a more realistic design
- The acceptance under the detector beampipe is common in both designs
- The dips in the acceptance are due to the magnet apertures

Where do the background particles hit the detector (Linac-ring)?



- Show the hit distribution (in x, y, z) in the detector for a given range of background event vertex position
- Most particles hit the barrel region of the detector

Where do the background particles hit the detector (Ring-ring)?



- Show the hit distribution (in x, y, z) in the detector for a given range of background event vertex position
- Most particles hit the barrel region of the detector
- Significant number of particles hit the detector endcap
- This is a start to look into required shielding
- The Linac-ring design has shielding provided by the magnets themselves

Calculating the rate of background events

- Estimate the luminosity of background collisions using the proton beam current and the gas density

$$L = \Phi \cdot \rho \cdot l$$

- The gas density is estimated from the vacuum at HERA of 10^{-9} mbar or 2.65×10^{7} molecules/cm^3
  - gas density assumed uniform along beam pipe
- Calculated for a gas length of 24.50 m

Machine Design	Rep. Rate [MHz]	Beam energy (e+p) [GeV]	Proton current [mA]	Background Lumi [x 10^{29} cm^{-2}s^{-1}]
Linac-ring (low risk)	9.4	13 x 275	415	1.8
Linac-ring (ultimate)	9.4	8.3 x 250	415	1.8
Ring-ring (baseline)	28.2	10 x 250	460	2.0
Ring-ring (ultimate)	114	10 x 250	937	4.1

- Bigger current means greater luminosity for background

A word on machine design plans

- Will show results for both linac-ring and ring-ring designs
- Note the difference between low risk/baseline and ultimate design
- Current BNL strategy is to put forth the lowest risk machine possible in both scenarios (linac-ring and ring-ring), and then plan to upgrade over time
  - Difference between linac-ring low risk and ultimate design is the implementation of CeC to shrink beam size and increase luminosity
  - Difference between ring-ring baseline and ultimate is to increase the rep. rate to drive up the luminosity (and cooling)

Comparing overall background rates to physics rates

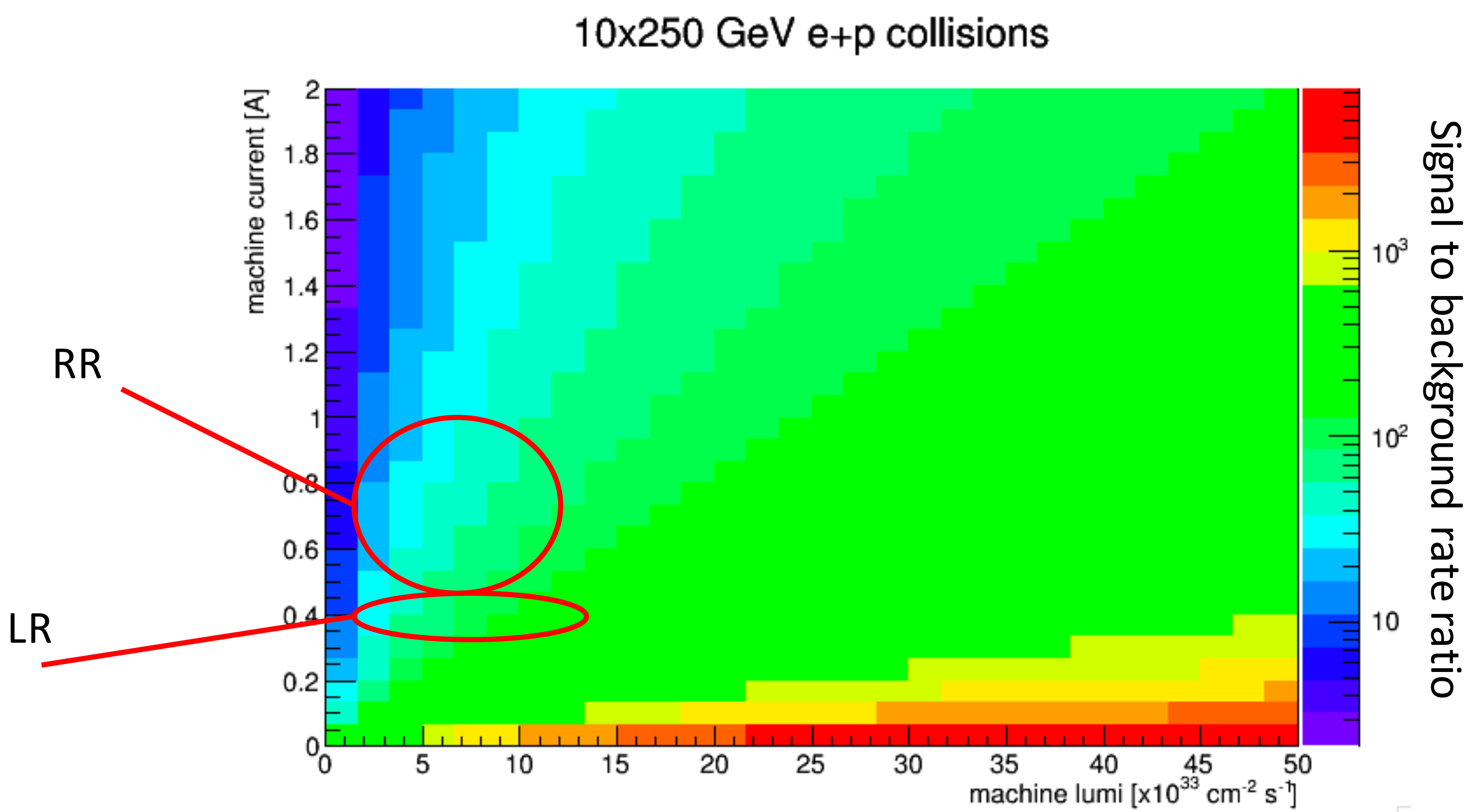
Machine Design	p+H^2 cross section [mb]	Background Lumi [x 10^{29} $cm^{-2}s^{-1}$]	e+p cross section [mb]	Machine Lumi [x 10^{33} $cm^{-2}s^{-1}$]
Linac-ring (low risk)	60	1.8	0.05	1.2
Linac-ring (ultimate)	60	1.8	0.05	14.4
Ring-ring (baseline)	60	2.0	0.05	1.1
Ring-ring (ultimate)	60	4.1	0.05	12.4

Machine Design	Background rate [kHz]	DIS rate [kHz]	Physics/BG ratio
Linac-ring (low risk)	11	58	5.3
Linac-ring (ultimate)	11	700	64
Ring-ring (baseline)	12	53	4.4
Ring-ring (ultimate)	25	603	24

- Linac-ring design has a better DIS to background rate than ring-ring

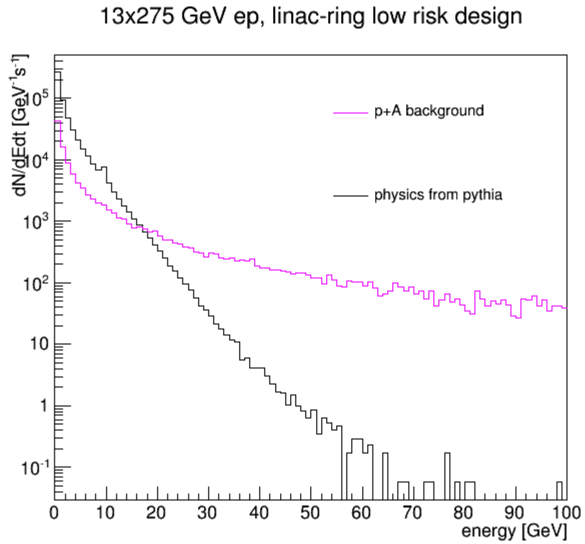
Visual of the signal to background rate ratio with varying beam current and machine luminosity

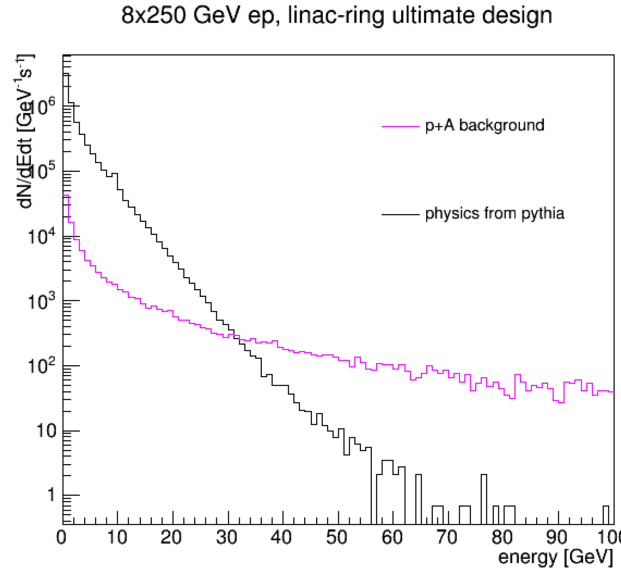
- Assume a gas density of 2.65 x 10^{10} molecules/cm^2 over 10m



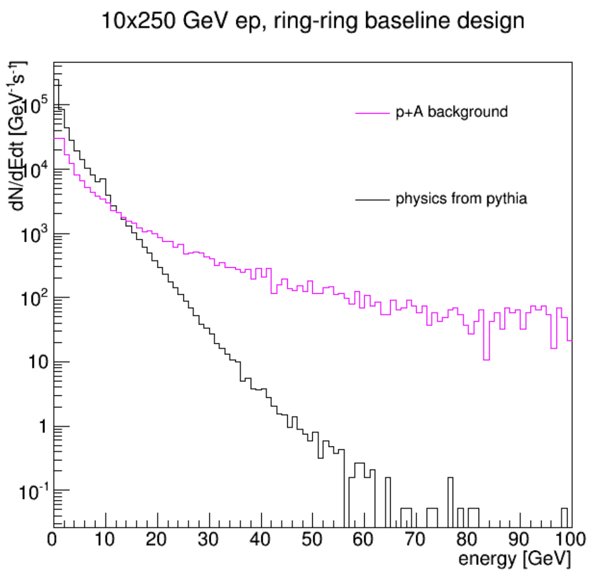
Comparing the energy spectra of background and DIS normalized by overall rates

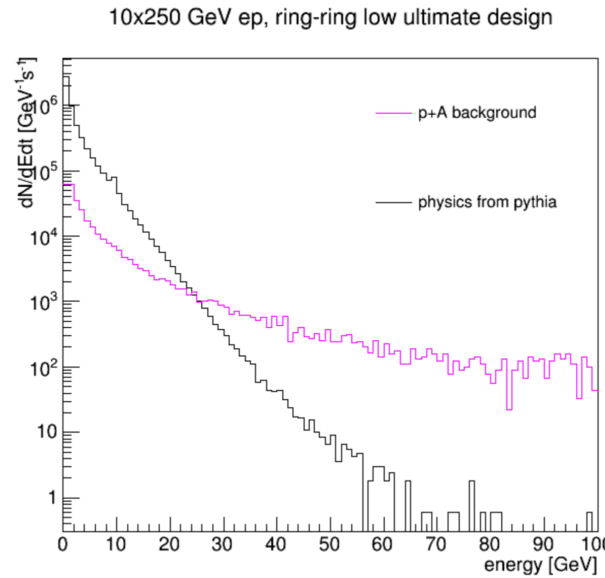
Linac-ring





Ring-ring





Estimate the probability that a beam-gas event from a bunch will enter the detector within an event timing window

- Use previously described simulations to estimate the acceptance correction for getting a background event
  - Require particles from the background event (at least one) entering the detector volume
  - Require the time of flight from the production vertex to the detector volume be within an event timing window (currently set to 10 ns)
  - The acceptance correction is then calculated by the fraction of generated events that make it into the detector volume within this time window
- Calculate the number of interactions expected per bunch
- Apply the correction to the expected number of interactions per bunch to estimate the number of interactions per bunch that will produce particles that enter the detector during a beam crossing
- Use the above number to calculate the probability of a background event leaving signal in the detector during a beam crossing (assuming Poisson statistics)

Numbers

For beam-gas

Design option	N_p	f_b [MHz]	p-beam rate [kHz]	Number of interactions per bunch	Number of interactions per bunch in acc
Linac-ring (base)	3e11	9.4	11	1e-3	5e-4
Linac-ring (ult)	3e11	9.4	11	1e-3	5e-4
Ring-ring (base)	1.11e11	28.2	24.5	9e-4	4e-4
Ring-ring (ult)	5.6e10	114	55.6	5e-4	2e-4

For DIS

Design option	DIS rate [kHz]	Number of interactions per bunch
Linac-ring (base)	58	6e-3
Linac-ring (ult)	700	7e-2
Ring-ring (base)	53	2e-3
Ring-ring (ult)	603	5e-3

Summary

- Set up code infrastructure to study beam-gas effects for different facility designs
- Performed simulations of the background physics process for proton beam-gas interactions
- Looked at where events occur that contribute the most to hits in the detector
  - For two different design options
  - Information can be used to determine placement of masks/shields
- Quantified the rate of background hits in the detector and compared to rates from DIS phsyics
- Quantified the number of interactions per bunch expected for background collisions as well as physics events

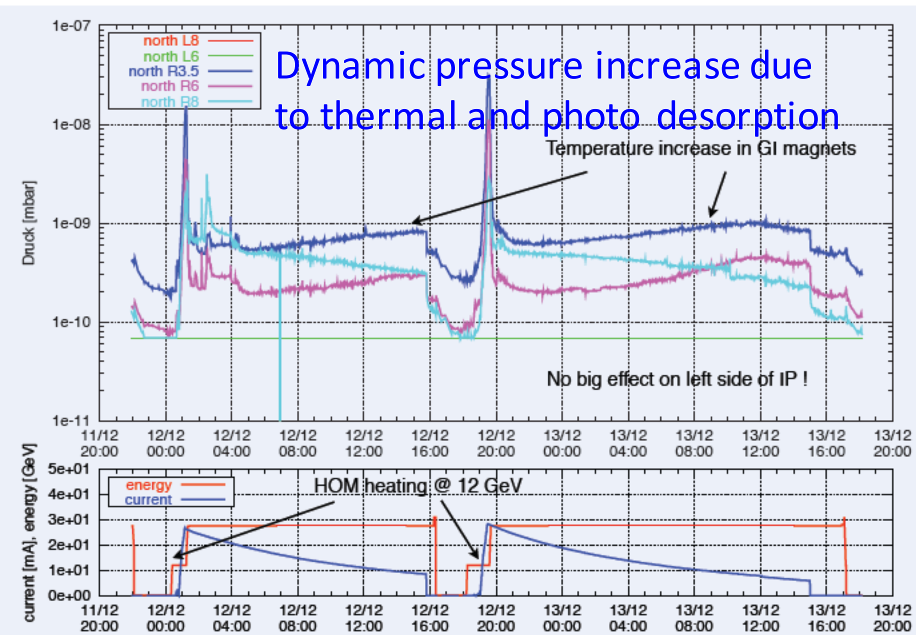
Expected Future Improvements

- Include secondaries produced from interaction with the magnet bulk, etc.
  - Reconsider the physical size of the magnets around the aperture
- Repeat the study for lower beam energies
- Fold in simulations with higher gas mass for a realistic gas composition
- Look more differentially into the composition of the particles and where they hit the detector
  - Like photons from background hitting the endcap calos
- Start pushing on synchrotron radiation studies

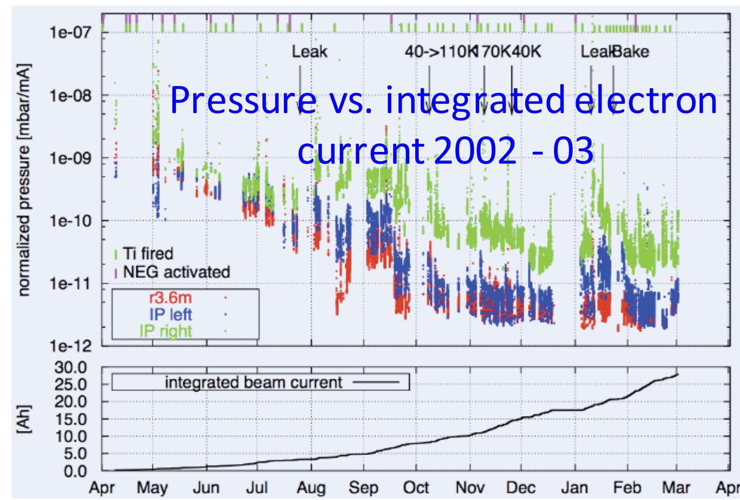
Backups

Some lessons from the HERA II upgrade

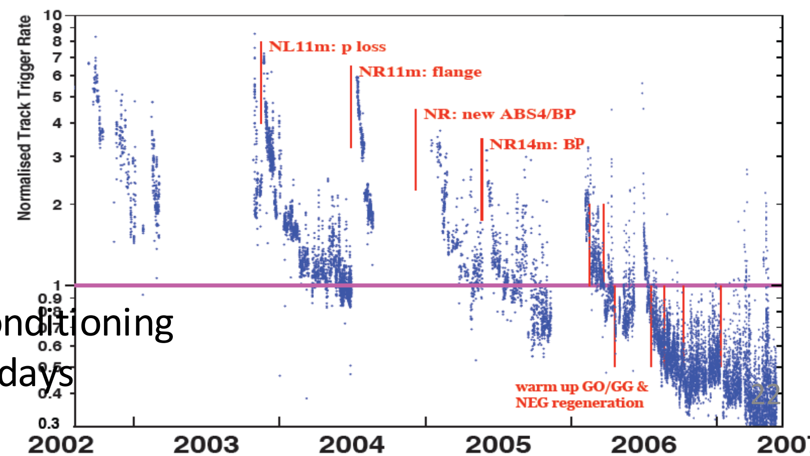
- Seemed to be a convoluted problem that combined heating of beam pipe and/or breaking of vacuum due to high levels of synchrotron radiation
  - Lead to dynamic pressure increase → greater proton beam-gas background
  - Needed long conditioning to clear out



Dynamic pressure increase due to thermal and photo desorption



Pressure vs. integrated electron current 2002 - 03



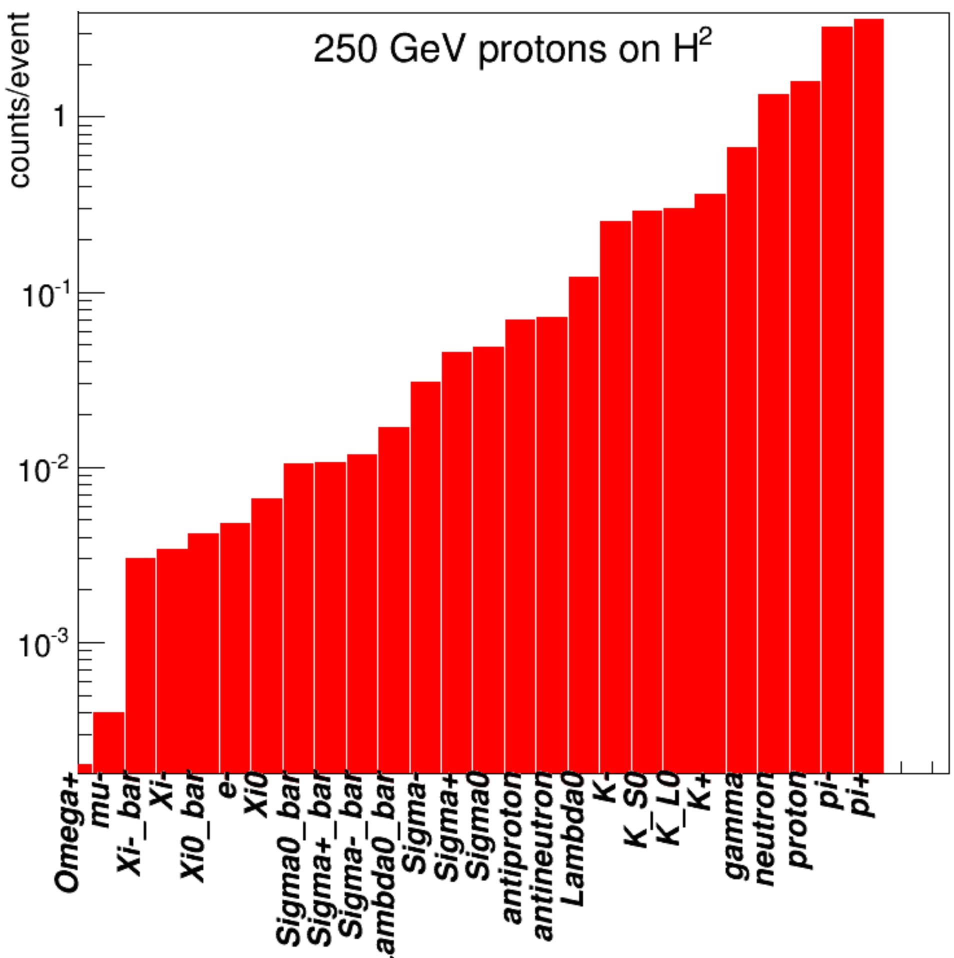
Proton Beam Gas Background

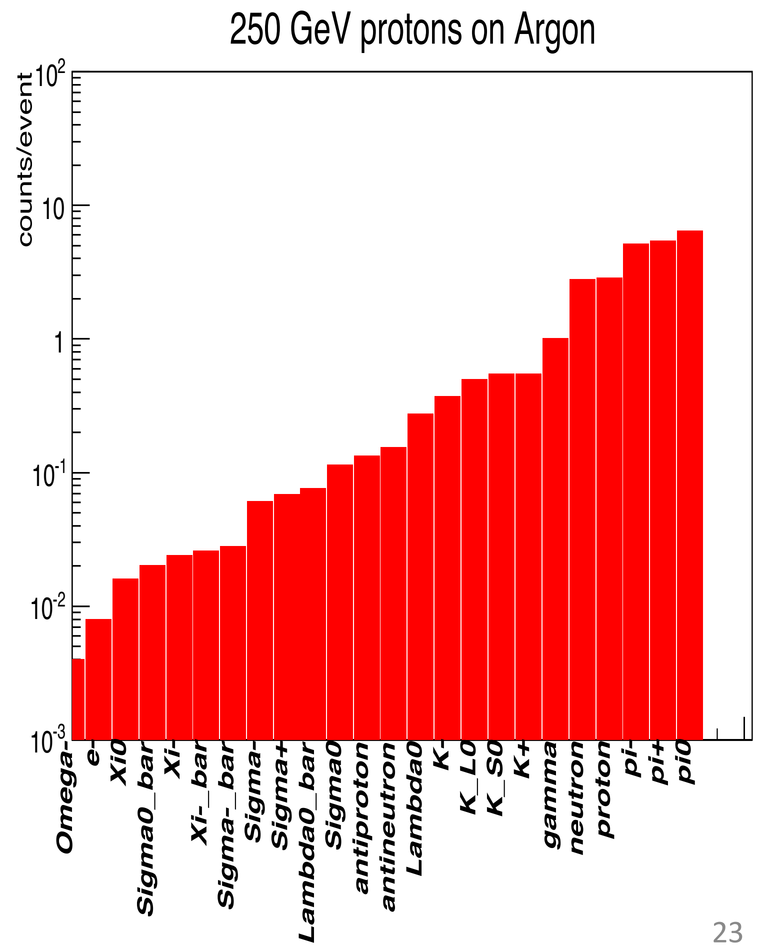
Two time constants for vacuum conditioning

- Short term after leaks 20 – 30 days
- Long term 600 days

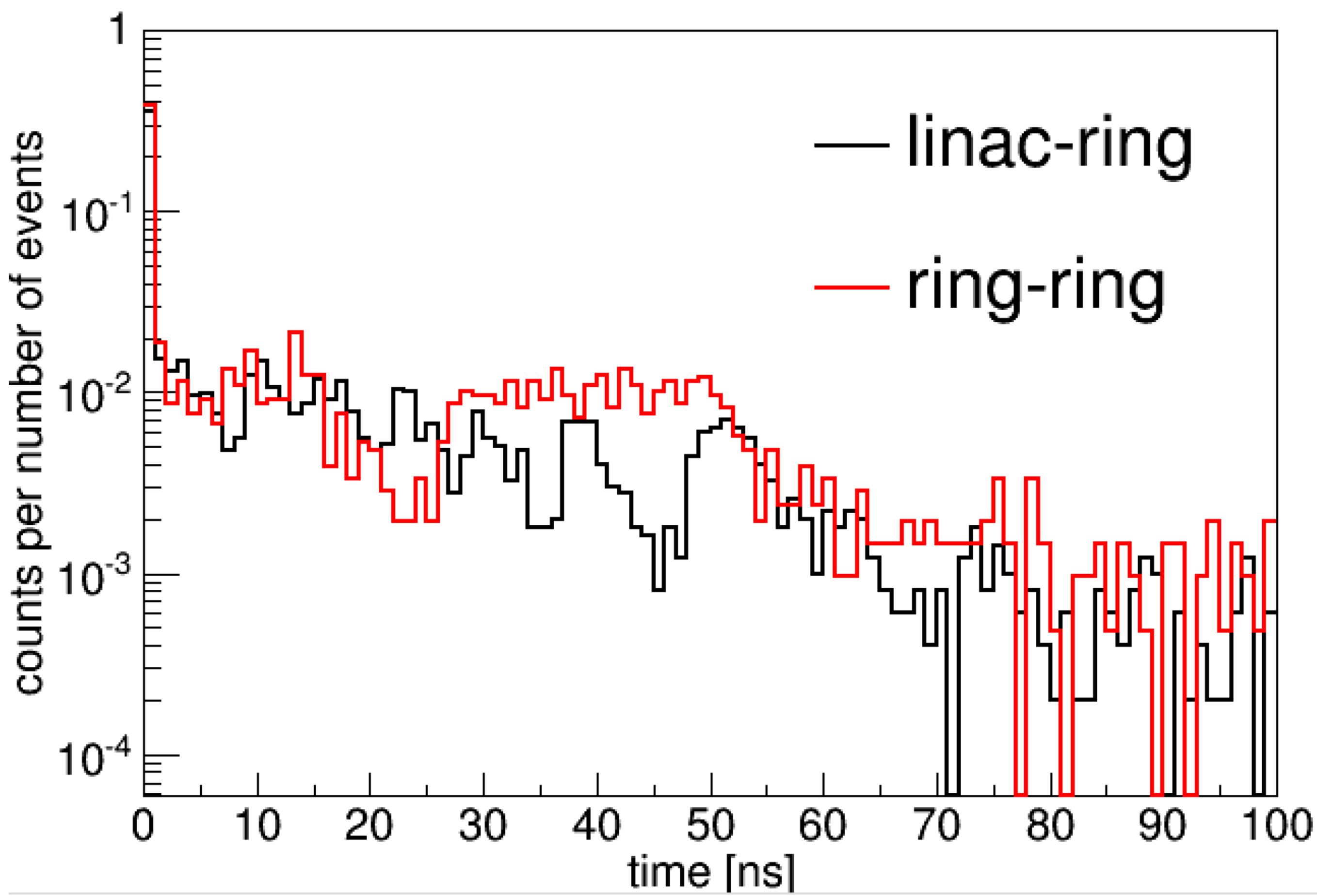
p+H^2 and p+Ar species distributions

- 250 GeV p beam in both cases



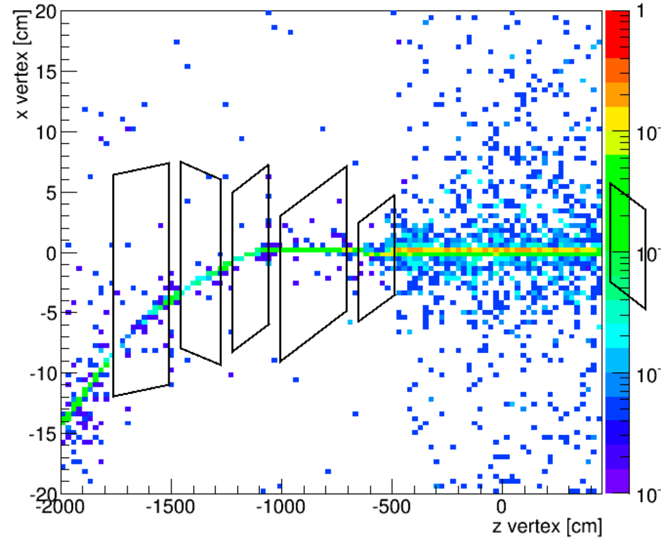


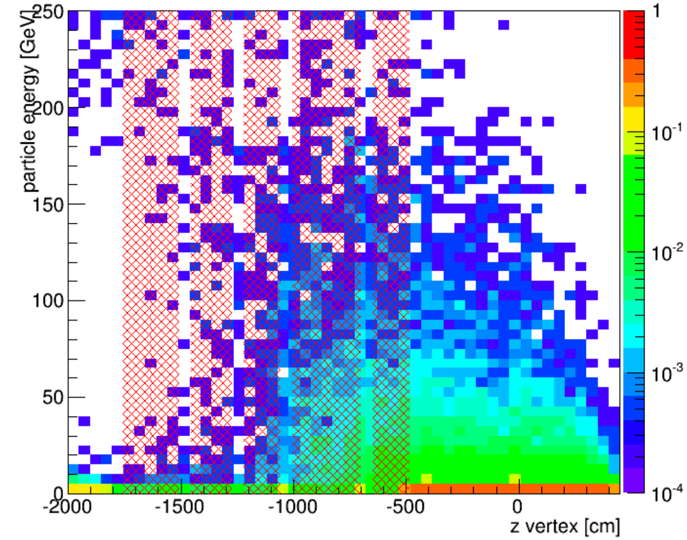
Timing Distribution of Background Particles Hitting the Detector



Where do background events that **hit** the detector come from?

LRv3





RRv2