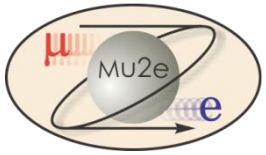


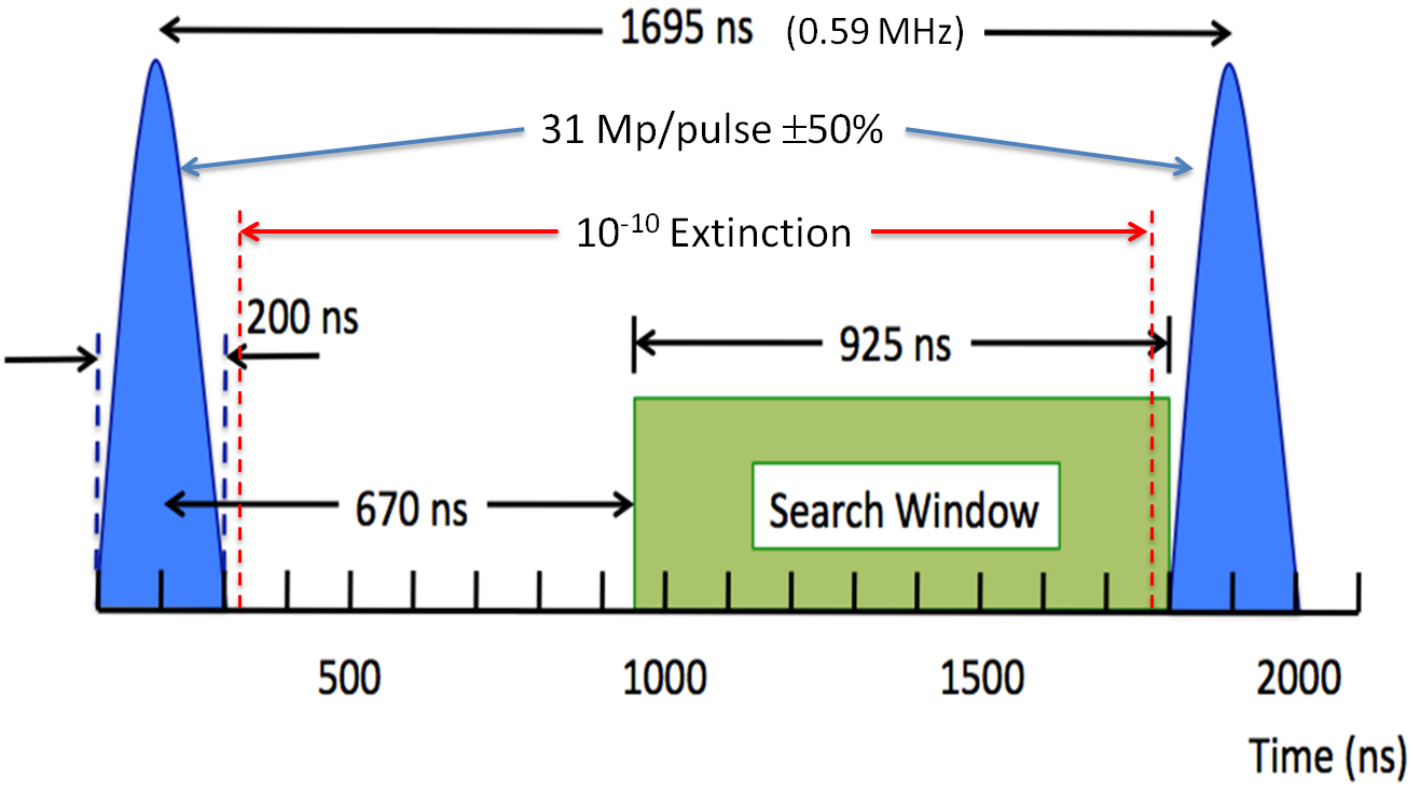
Mu2e Extinction Systems

Peter Kasper

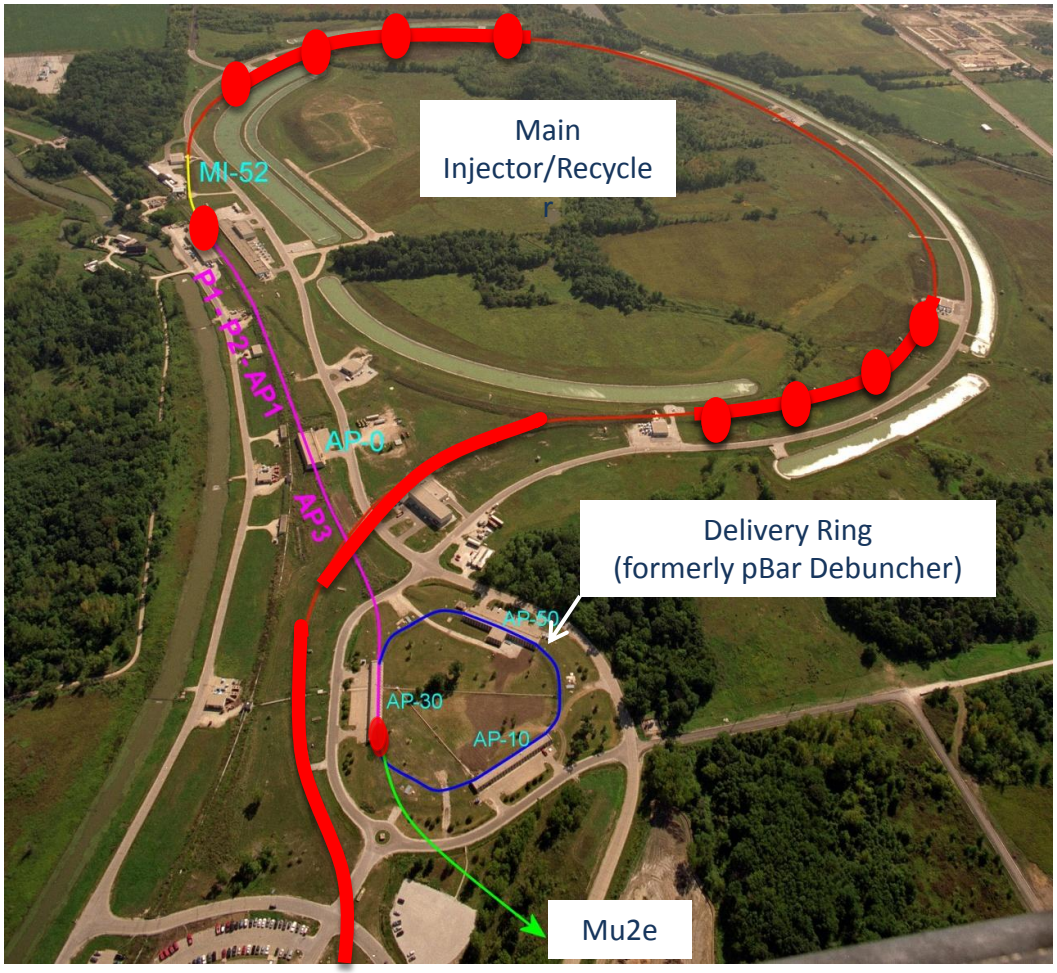
NuFACT 2012

Extinction

- Ratio of “out-of-time” to “in-time” beam



Overview: Proton Delivery



Booster

- One Booster batch (4×10^{12} protons) is injected into the Recycler.
- It is divided into 4 bunches.
- These are extracted one at a time to the Delivery Ring
  - Period = 1.7 μsec
- As a bunch circulates, it is resonantly extracted to produce the desired beam structure.

Extinction Systems

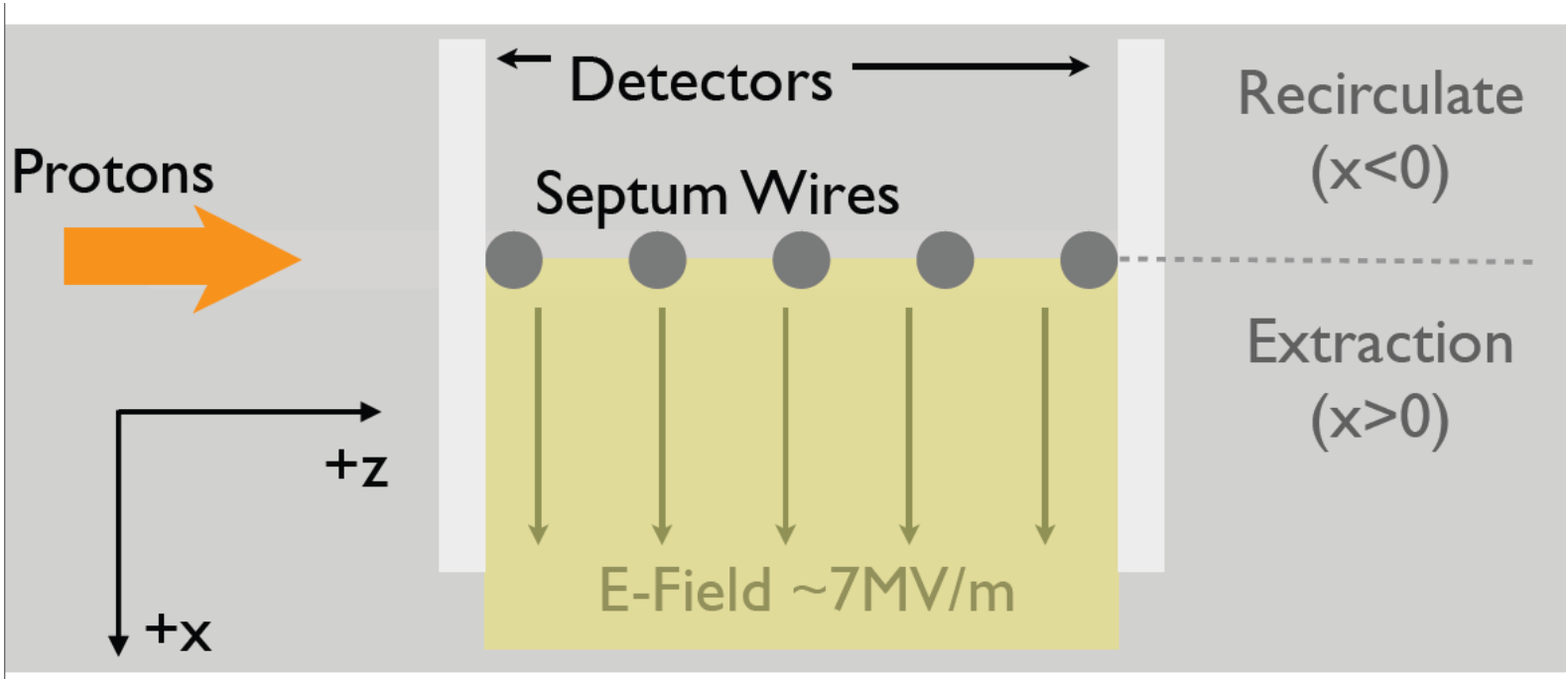
- In ring
  - Beam delivery technique automatically gives good extinction < 10^{-5} going into the Delivery Ring
  - May degrade to 10^{-4} during the spill
- In beam line
  - System of dipoles and collimators
  - Additional factor of 10^{-7} should be possible
- Monitoring
  - Need to show that 10^{-10} has been achieved

Delivery Ring

- Start with < 10^{-5} level of extinction going into the Delivery Ring, so the issue is how will it grow during the spill.
- Effects considered
  - RF noise
  - Intrabeam scattering
  - Beam loading
  - Beam-gas interaction
  - Scattering off of extraction septum Dominant

Septum Simulation

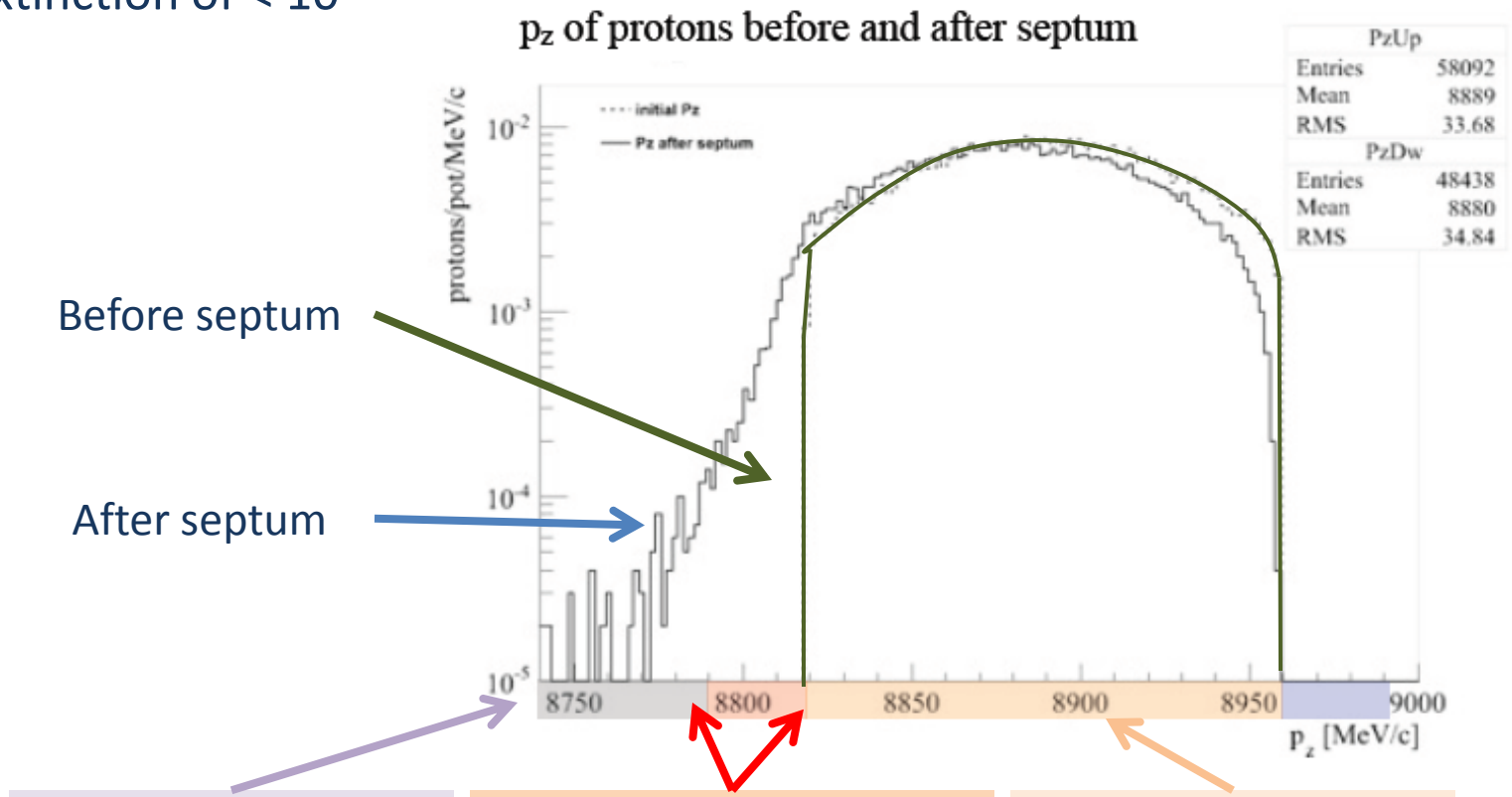
- Study how the septum affects beam in the delivery ring



Protons distributed uniformly over wire radius,

Septum Simulation

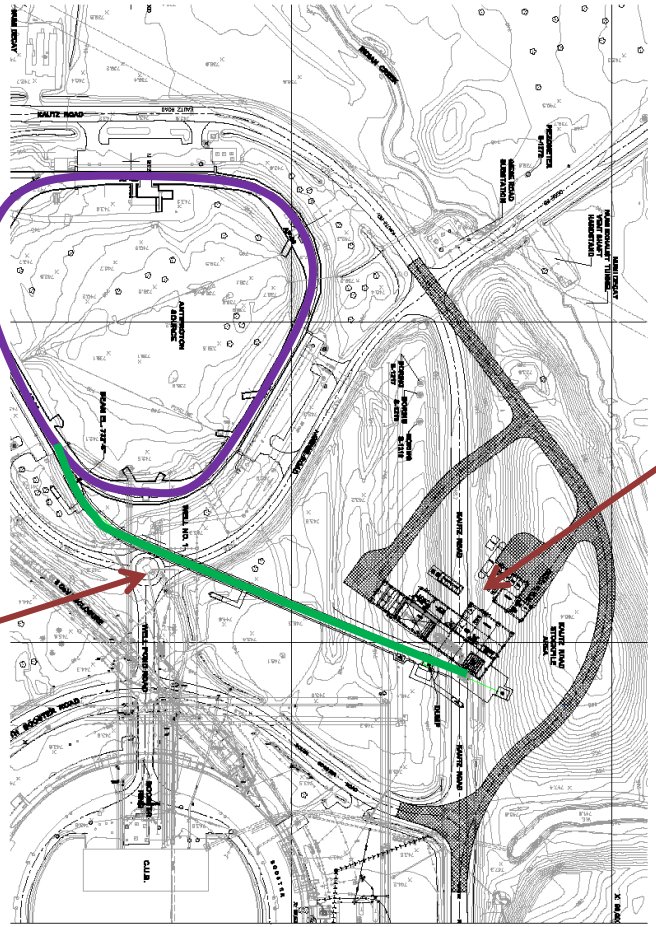
Preliminary estimate:
Extinction of < 10^{-4}



Extinction Beam Line

Delivery Ring

Extinction Beam Line

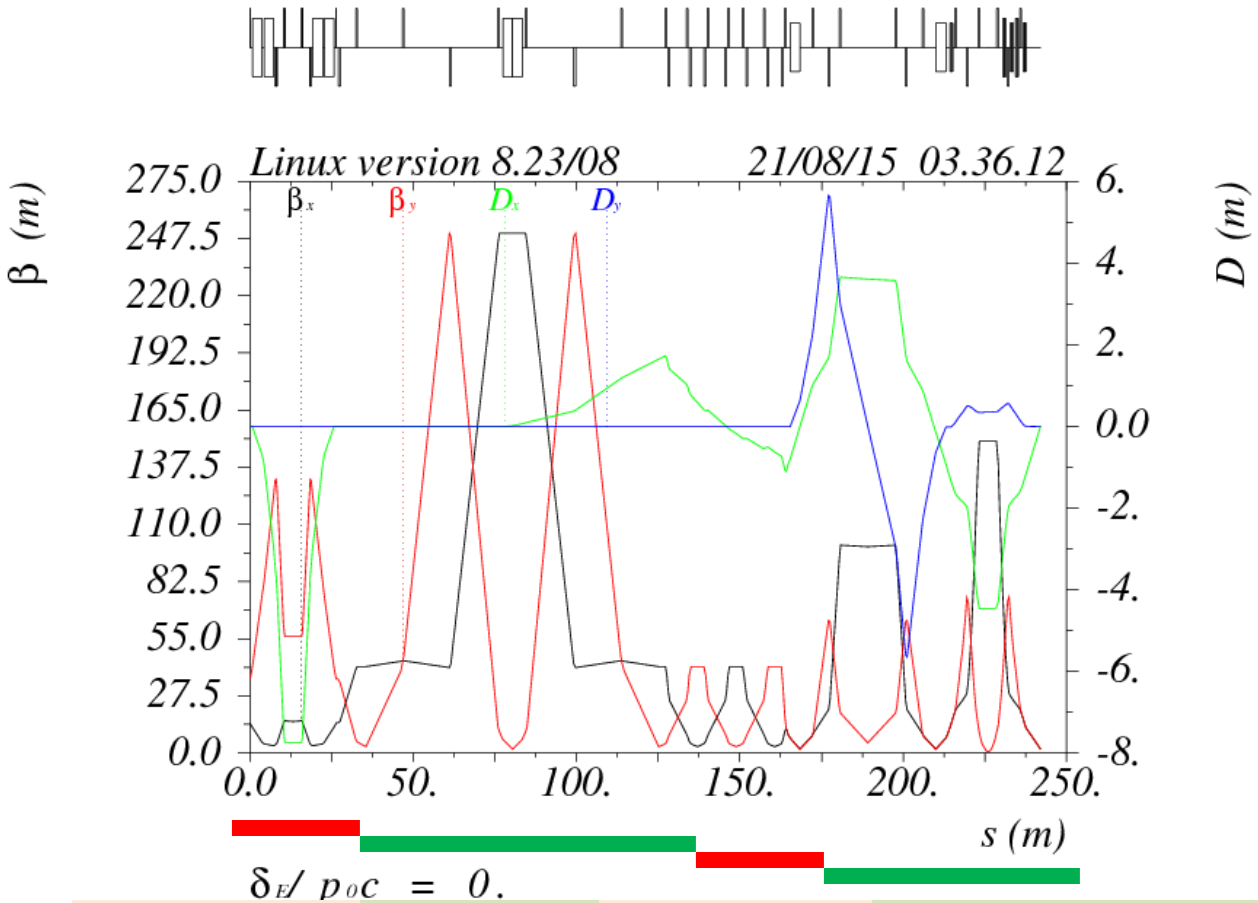


Mu2e Experiment

Beam Line Modules

- Upstream of extinction dipole
  - Collimation to define beam line admittance to 50 π-mm-mr
- AC dipole region
  - Bend plane: β=250m
  - Non-bend plane: waist
- Extinction collimation
  - Minimize transmission of scraping particles
- Post-extinction
  - High dispersion region for momentum collimation.

Extinction Beam Line Optics



Momentum collimation	AC Dipole section	Collimation section	Momentum collimation and targeting optics

Generic Extinction Analysis

- Assume beam occupies entire admittance
- Assume pulsed kicker that deflects out-of-time beam into a collimation system
- Assume that the beam line admittance is equal to the collimation channel's admittance

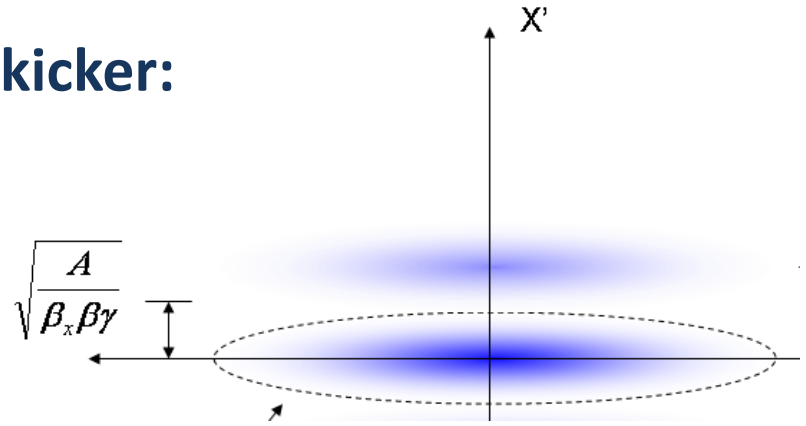
Angle to extinguish beam

$$\Delta\theta = 2\sqrt{\frac{A}{\beta_x \beta\gamma}}$$

At collimator:

Beam fully extinguished when deflection equals *twice* full admittance (*A*) amplitude

At kicker:



Magnet Considerations

Complexity scales with stored energy

Bend strength to extinguish: $$(Bl) = 2(B\rho)\sqrt{\frac{A}{\beta_x \beta\gamma}}$$

Stored Energy: $$U \propto B^2 Lwg = \frac{(BL)^2}{L} wg \propto \frac{1}{\sqrt{\beta_x L}}$$

$\propto \beta_x^{-1/2}$ $\propto \beta_x^{1/2}$ $\propto L^{1/2}$

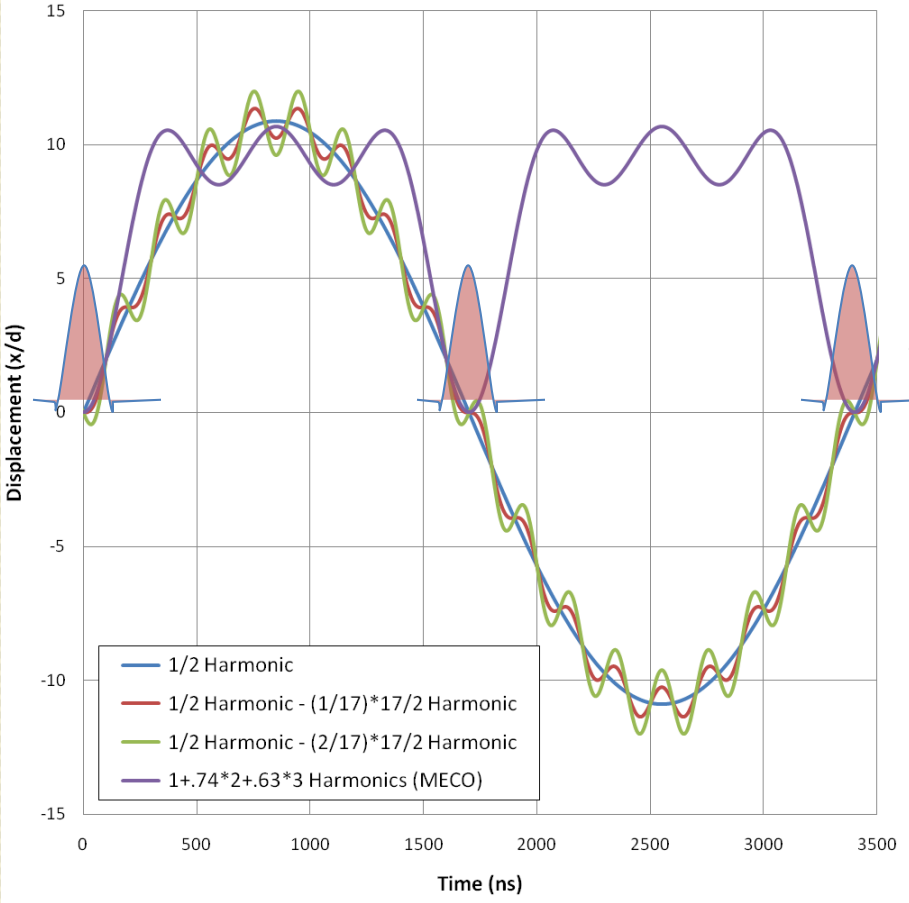
$\Rightarrow$Large β_x, long weak magnets

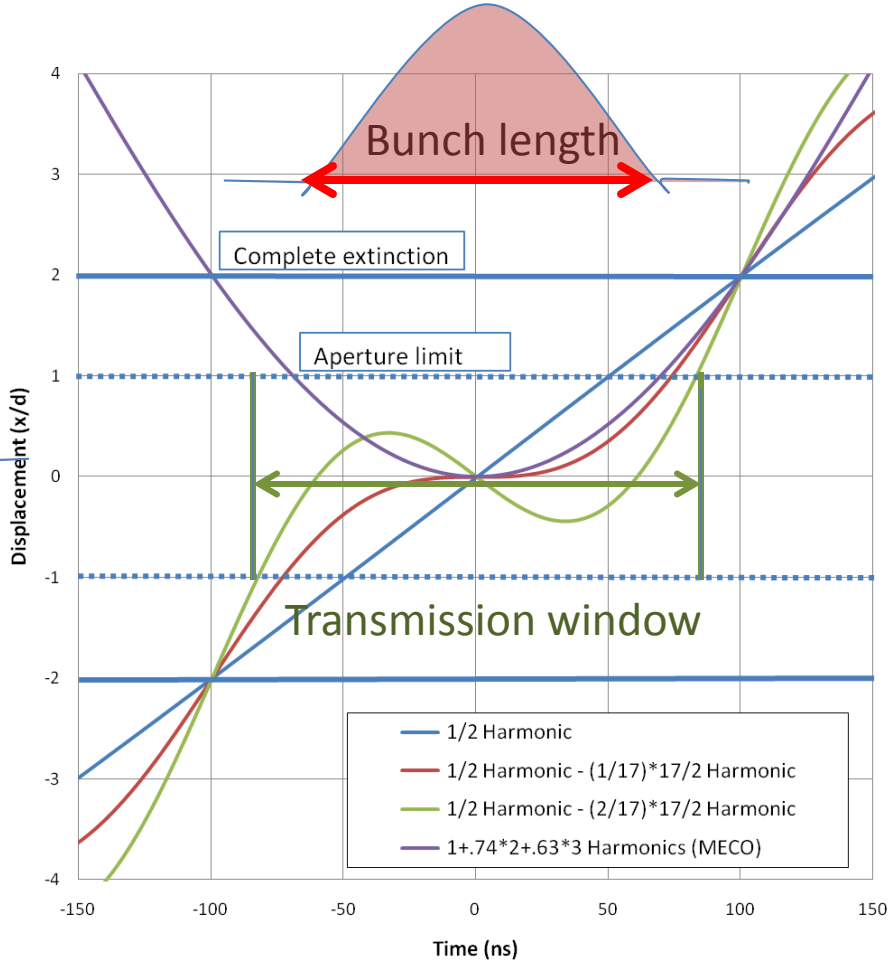
- Assume β_x=250m, L=6m
- Factor of 4 better than β_x=50m, L=2m

AC Dipole Wave Form

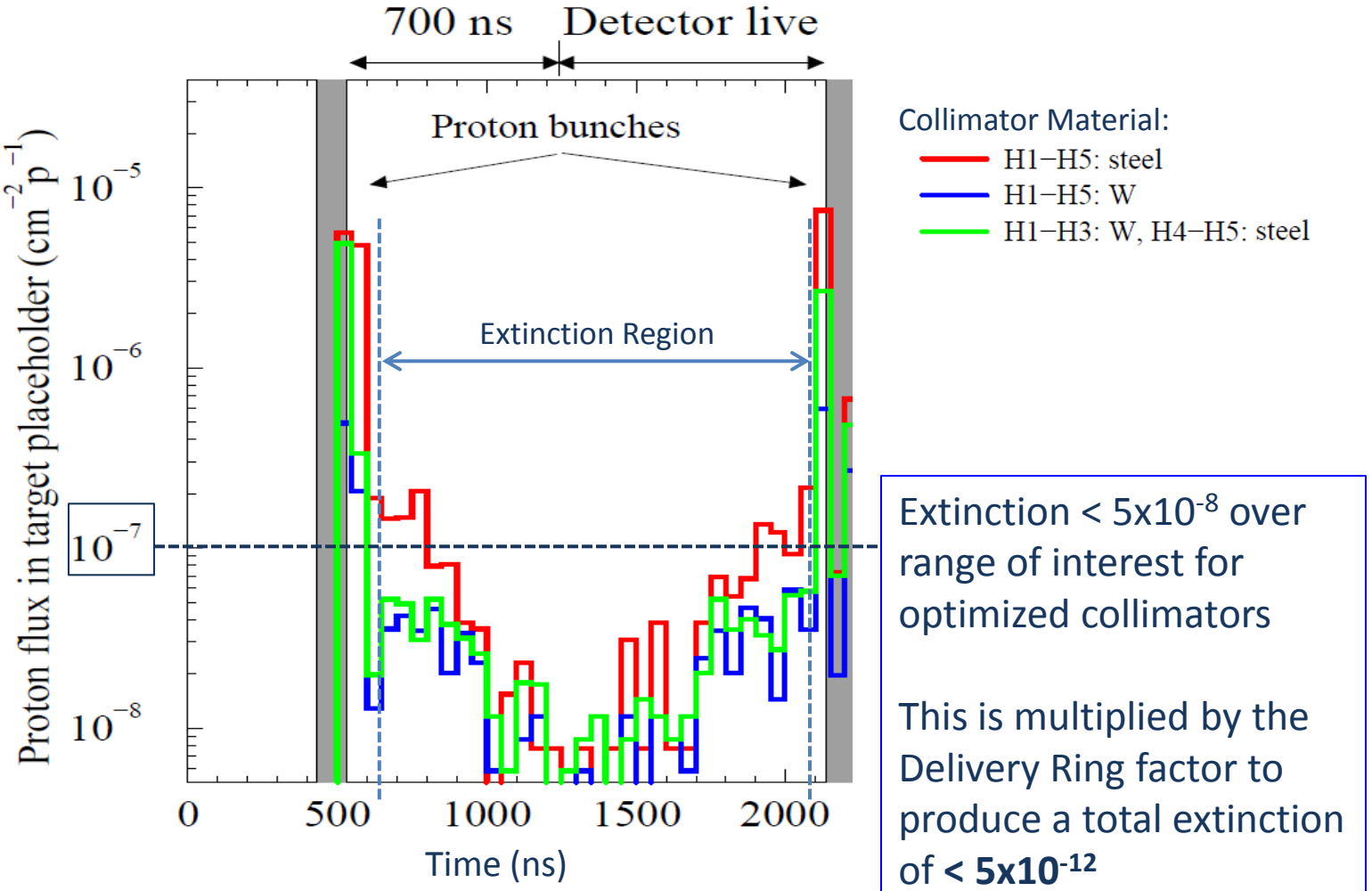
Of the options considered:

½ harmonic – (2/17) * 17/2 harmonic seems most promising





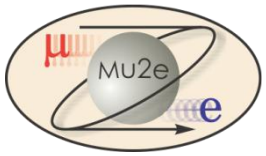
Proton flux *vs* time of flight



Extinction < 5×10^{-8} over range of interest for optimized collimators

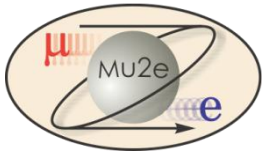
This is multiplied by the Delivery Ring factor to produce a total extinction of **< 5×10^{-12}**

Monitor Requirements



- Demonstrate 10^{-10} extinction
  - Assume ≈ 3 x 10^{7} protons/bunch
  - Not possible measure 10^{-10} with a single bunch
    - ⇒ Integrate over many bunches
  - Integration time should be < ≈ 1 hour
- Only protons hitting the target can cause backgrounds
  - Monitoring beam itself will lead to a potentially large over estimate of the background to the experiment
  - ⇒ Monitor target interaction products

Filter + Detector Strategy

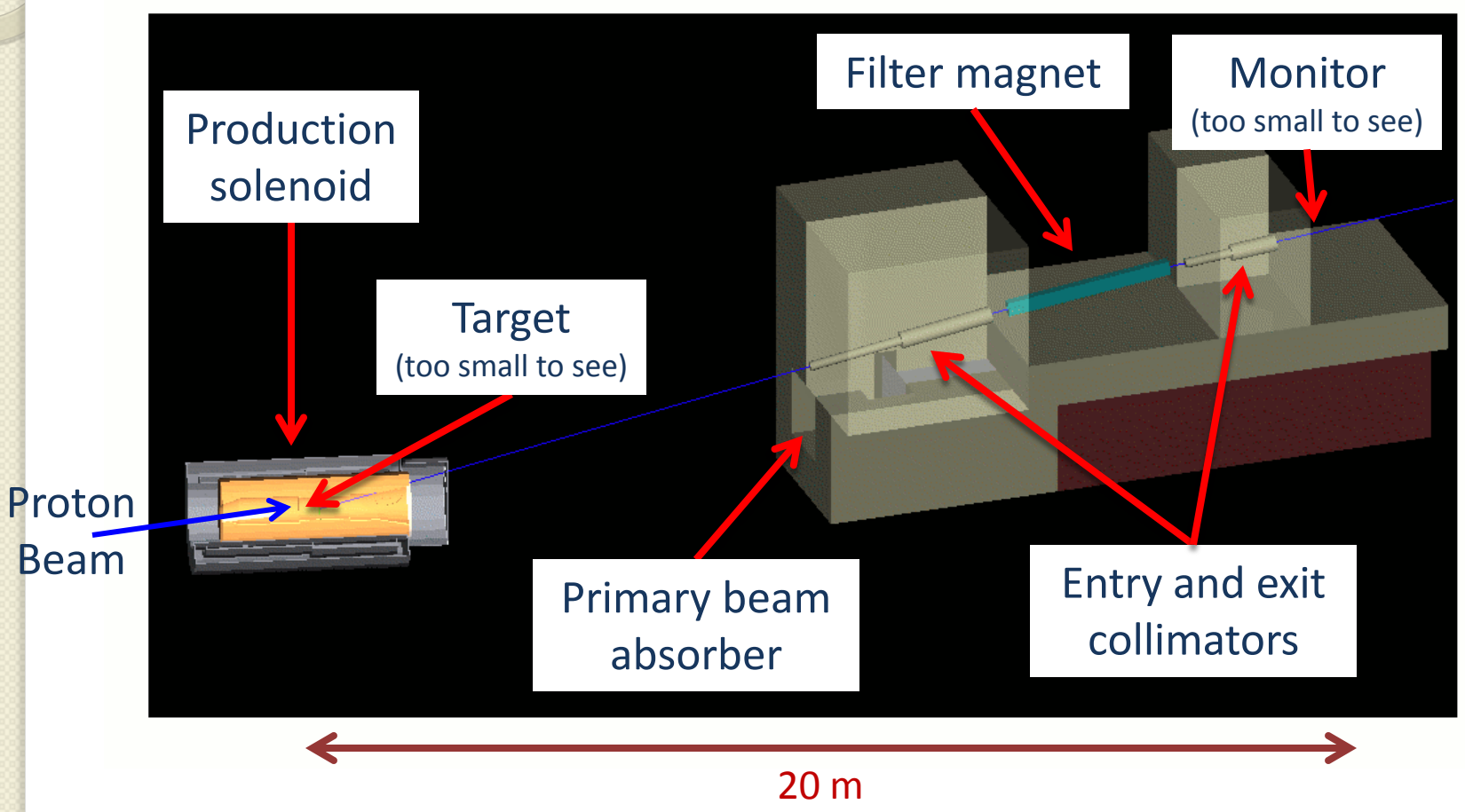


- Filter
  - Selects a sample of suitable secondaries and delivers them to the detector
  - Sets the per proton detector signal rate
  - Shields the detector from unwanted interaction products
- Detector
  - Measure “in-time” and “out-of-time” signal rates with equal or known relative efficiency
  - Must have LOW “out-of-time” backgrounds compared to signal rate

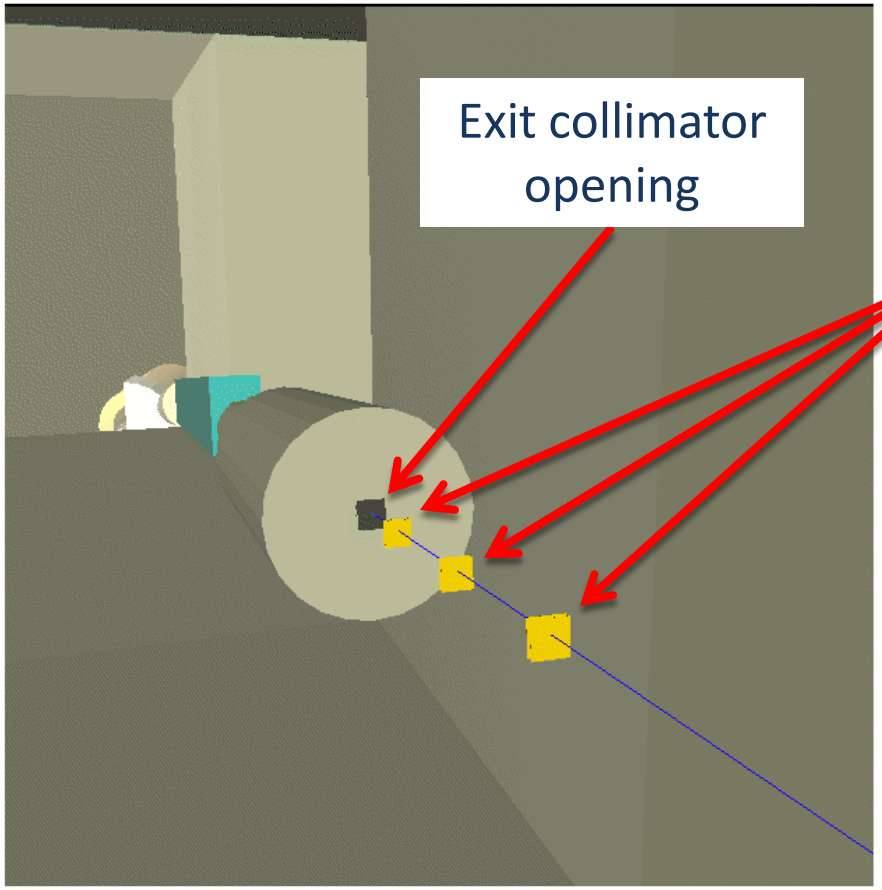
Two Schemes Under Consideration

- Pixel Tracker
  - Located above and behind the proton absorber
  - Samples 3 to 4 GeV/c positive charged secondaries
  - Pixel detectors reconstruct and count straight tracks with a well defined direction in 25ns time bins
- Mini Spectrometer
  - Located beside the proton absorber
  - Samples ~ 1 GeV/c positive charged secondaries
  - Magnetic spectrometer with 4 scintillator stations measures dE/dx, time of flight, and momentum of identified particle tracks

Filter for Pixel Monitor



Pixel Detector



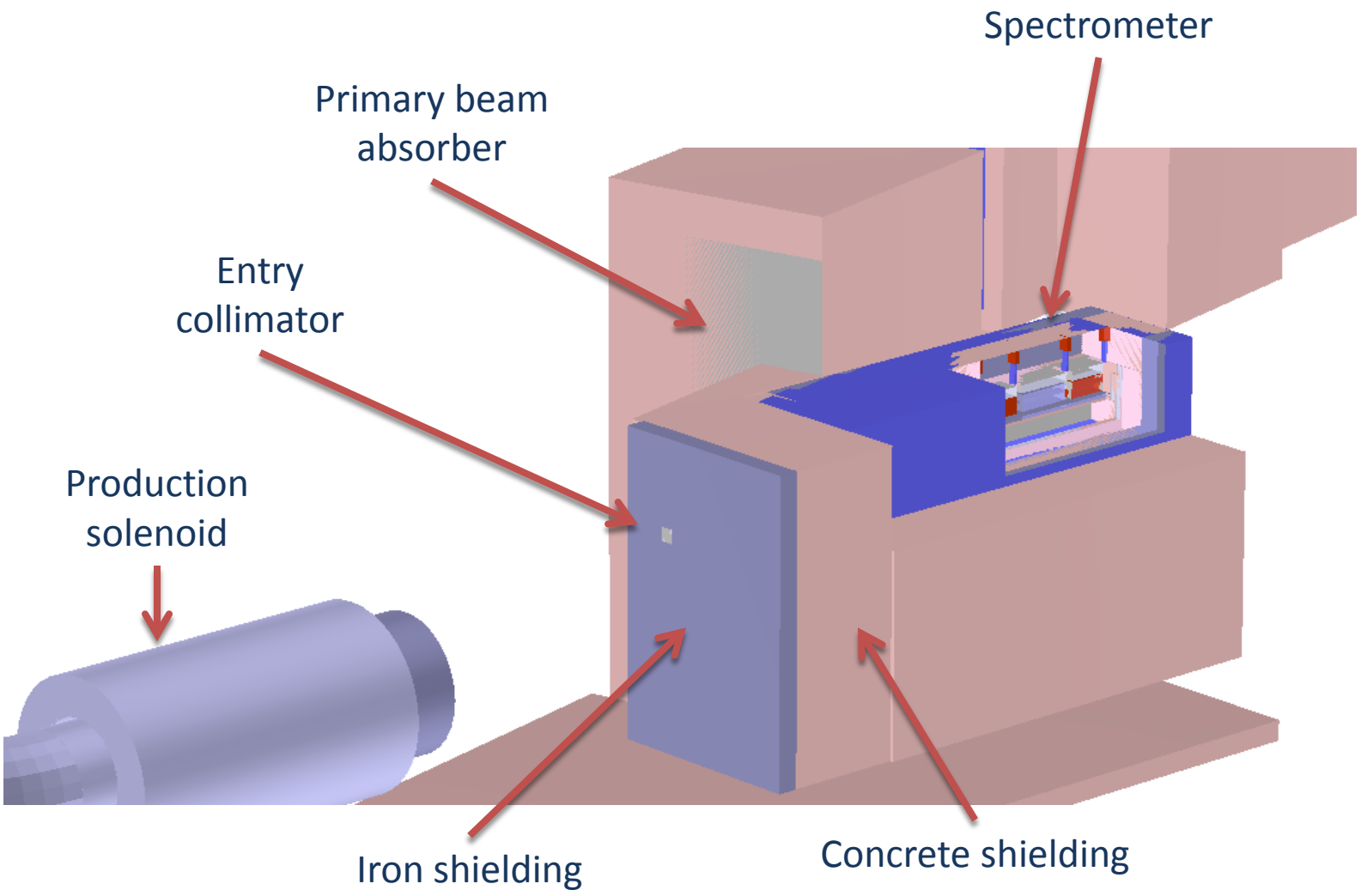
3 x 2 stations of Atlas style pixel detectors.

Each station is comprised of 4 2 x 2 cm FE-14 sensor chips with 26,880 250 x 50 µm pixels per chip

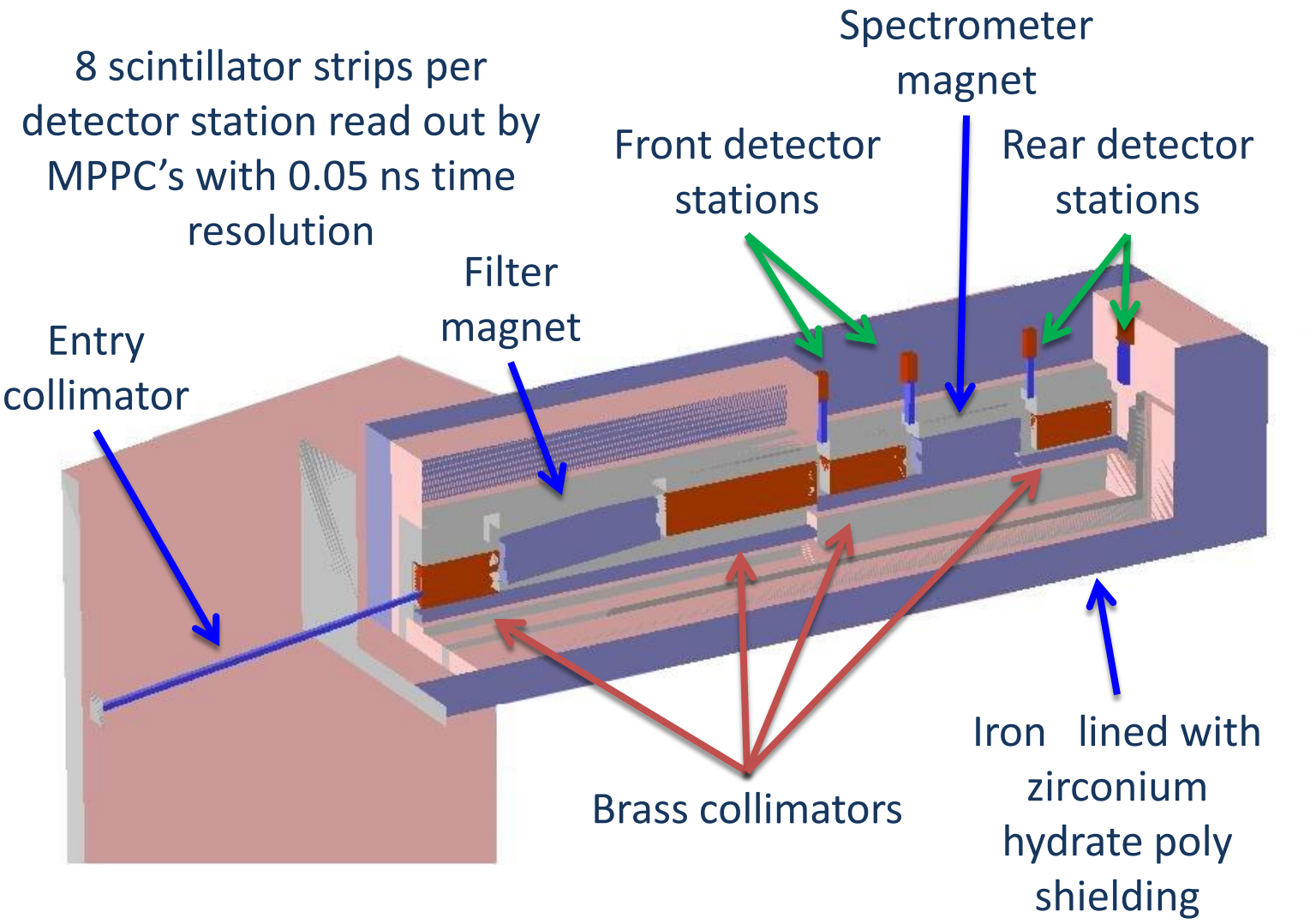
Pixel Detector Features

- Filter
  - Filter magnet is an existing permanent dipole
    - No cost and no maintenance
  - Locates detector outside target hall
    - Easy access for detector maintenance
    - Lots of room for shielding
    - Low radiation levels for detector + electronics
- Detector
  - Mature technology
    - Can piggy-back on ATLAS purchases
  - Simple reconstruction
    - Possible to reconstruct every signal track from every bunch in real time?

Mini Spectrometer Option



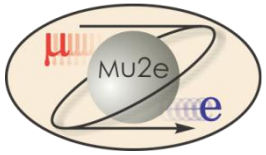
Mini Spectrometer Option



Mini Spectrometer Features

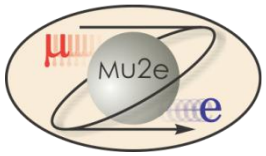
- Located inside target hall
  - Reduces civil construction costs
- Filter and spectrometer magnets obtained by cutting up an existing permanent dipole
- Detector provides more measurables
  - dE/dx + time of flight distinguishes π's and p's
  - Momentum measurement rejects low momentum background

Choice



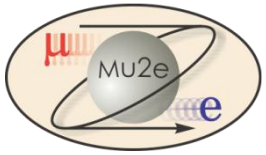
- Based on how well each design meets a comprehensive list of requirements
- Studies well advanced but have yet to be completed and documented

Requirements: Signal Rate



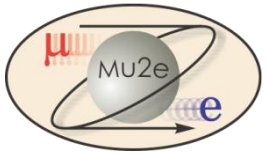
- Determined from beam intensity
  - 3×10^7 protons/bunch
  - Bunch rate: 0.6 MHz @ 33% duty factor
  - $\Rightarrow 2 \times 10^{16}$ in-time p.o.t./hr
  - 10^{-10} extinction $\Rightarrow 2 \times 10^6$ out-of-time p.o.t./hr
- To set a 90% C.L.
  - Need 2.3 expected out-of-time signal/hr
  - $\Rightarrow 1.2 \times 10^{-6}$ signal events per p.o.t.
- Pixels: 1.6×10^{-6} (limited by detector area)
- Spectrometer: 1.0×10^{-6} (pile-up effects)

Requirements: Background



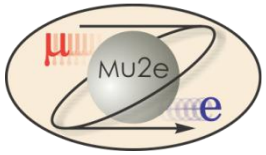
- Out-of-time background << a few events/hr
- Background sources
  - Cosmic rays
    - Pixels: 0.03 evts/hr Spectrometer: negligible
  - Late hits from in-time interactions
    - Flux is 1,000 times higher for Spectrometer but it can more easily reject them
    - Pixels can reject low momentum with a track quality and angle cuts
  - Induced radioactivity
    - Initial calculations suggest that it is negligible
  - Electronic noise
    - Pixels: negligible
    - Spectrometer: radiation damage may be an issue

Requirements: Reliability



- Sensitivity to protons missing the target
  - Out-of-time beam is flat over defining aperture
    - Possibly only about 1% will hit the target
    - Rest don't make experiment backgrounds
  - Both options insensitive ***if*** beam does not scrape on the Production Solenoid's heat and radiation shield
- In-time measurement linearity w.r.t. p.o.t./bunch must be well understood
  - Noise rates, Pile-up, Reconstruction errors and efficiency
  - Pixels expected to be linear
  - Spectrometer preliminary reconstruction has ~15% inefficiency and finds ~15% fake tracks

Requirements: Practicality



- Sensitivity to design parameters
  - Alignment tolerances
  - Production solenoid field strength
  - Pixel filter more vulnerable since collimators are embedded in bulk concrete but designed to accommodate placement errors of ~3 inches
- Diagnostics
  - Real time (low sensitivity) measurement
  - Background monitoring
  - Averaged bunch structure measurements
  - Sanity checks
  - Spectrometer provides more information and has better time resolution but will have to pre-scale in-time bunches
- Feasible : cost, construction, operating and maintenance
  - Pixels: Detector is cheaper, simpler, and easier to maintain
  - Spectrometer: Cheaper civil construction

Summary

- **Looks feasible**
- Need better understanding of out-of-time beam distribution at the production solenoid
- Will choose between monitor options in the couple of months