ASIC Needs for Muon Colliders

David Christian
Fermilab
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Muon Collider Motivation

- Lepton colliders provide known initial state & calculable reactions.
  - Point particles
  - No strong interaction
- Electron energy in a circular machine is limited by synchrotron radiation.
  - Goes like $(1/\text{mass})^4$
  - Muon mass is ~200 times greater than electron mass.
  - A circular machine with (multi) TeV beams is not ruled out and may be much less expensive than an electron linac.
- Beam energy spread in any electron machine is limited by beamstrahlung.
- Higgs coupling is proportional to mass.
  - H → $\mu^+\mu^-$ is enhanced by ~4000 with respect to e^+e^-
  - Muon collider Higgs factory could measure Higgs full width directly.

The Problem: Muons Decay

- No easy source of muons to accelerate:
  - Need a high power proton accelerator to create enough muons to be worthwhile.
  - Need to “cool” the muons quickly before they decay (τ = 2.2 μsec).
  - Time dilation helps once muons are accelerated (lifetime in lab frame = $\gamma\tau$; γ=E/m).
- Beam lifetime determined by decays.
  - ~1000 useable turns (independent of E, since revolution time increases w/E (assuming same magnet strength), but so does γ).

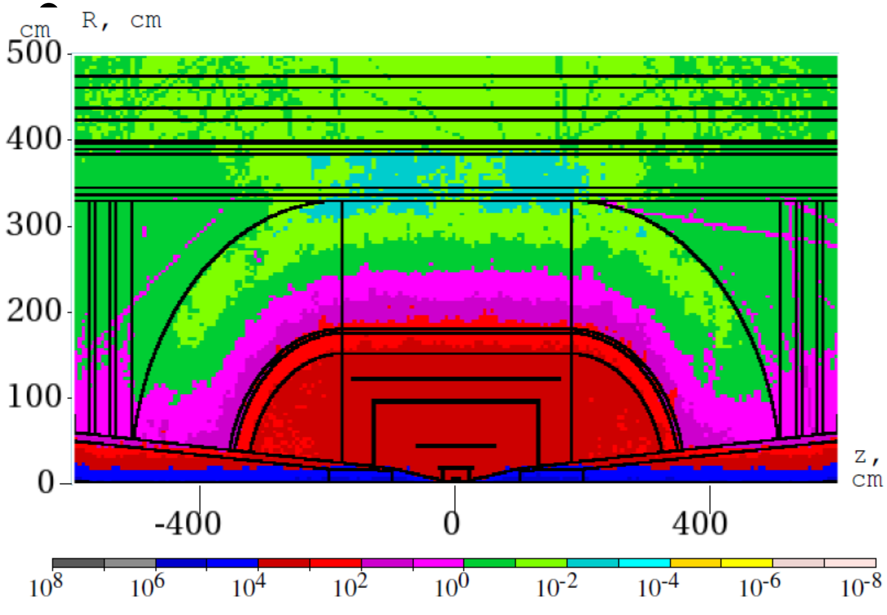
The Problem: Muons Decay

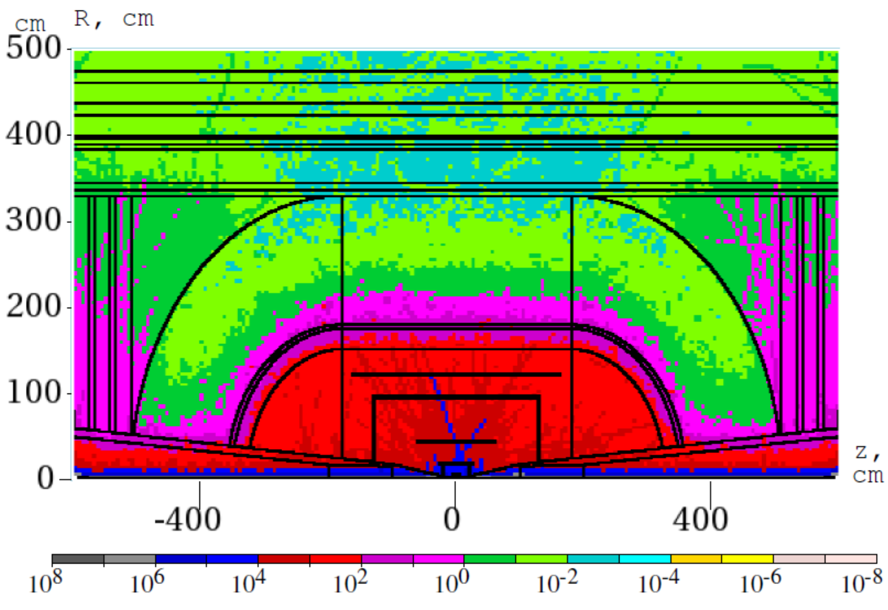
- Muons decay to electrons (& neutrinos).
  - Electron gets ~1/3 of muon energy
    - Electrons are swept to inner beam pipe by bend magnets.
    - They radiate synchrotron photons as they go (tangent to electron trajectory).
    - Photons interact with material, yielding neutrons
  - Designers talk in terms of decays/m (in 1^{st} turn)
    - 400,000 decays/m/bunch for 2.2E12/bunch @ 750 GeV
    - 5,000,000 decays/m/bunch for 2.2E12 @ 66 GeV (~equal power)
  - This is a problem both for the machine & for a detector.
    - Need to protect superconducting coils from heat load.
    - Need to worry about radiation damage and material activation in accelerator and in detector components.
    - Need to worry about background signals in detector.

Part of the solution: Shielding

- Tungsten inserts (“nozzles” to stop gammas (generates neutrons).
- Borated polyethylene cladding to absorb neutrons (+ concrete outside of detector).
- Need to optimize!
- Can reduce gamma flux by about a factor of 500.

Nikolai Mokhov@ 2011 Muon Collider Workshop: Total dose w/shielding





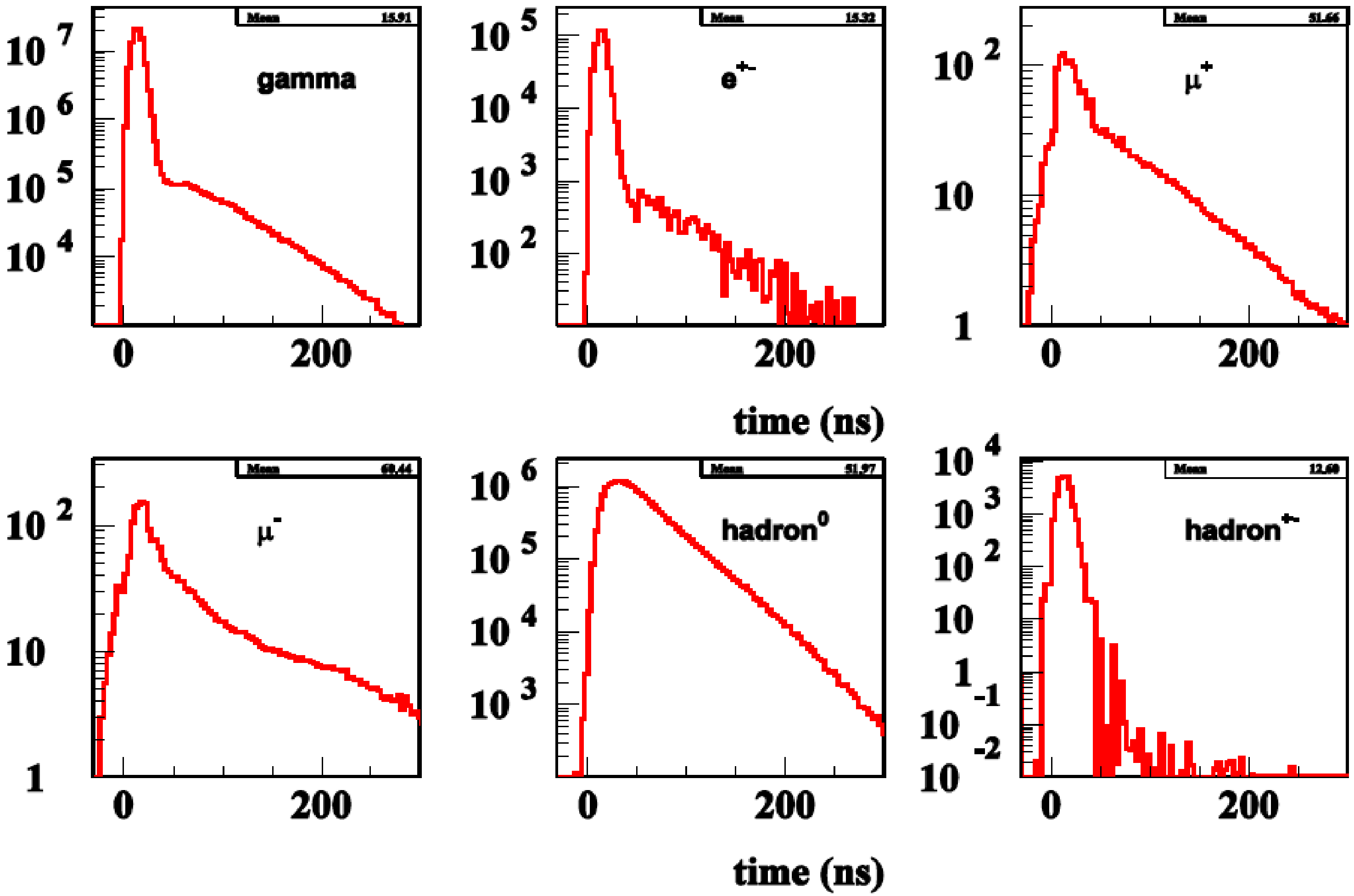
Maximum neutron fluence and absorbed dose in the innermost layer of the silicon tracker for a one-year operation are at a 10% level of that in the LHC detectors at the luminosity of 10^{34} $cm^{-2}s^{-1}$

Total dose ~1% of HL-LHC both for ionizing and non-ionizing radiation.

Detector Requirements

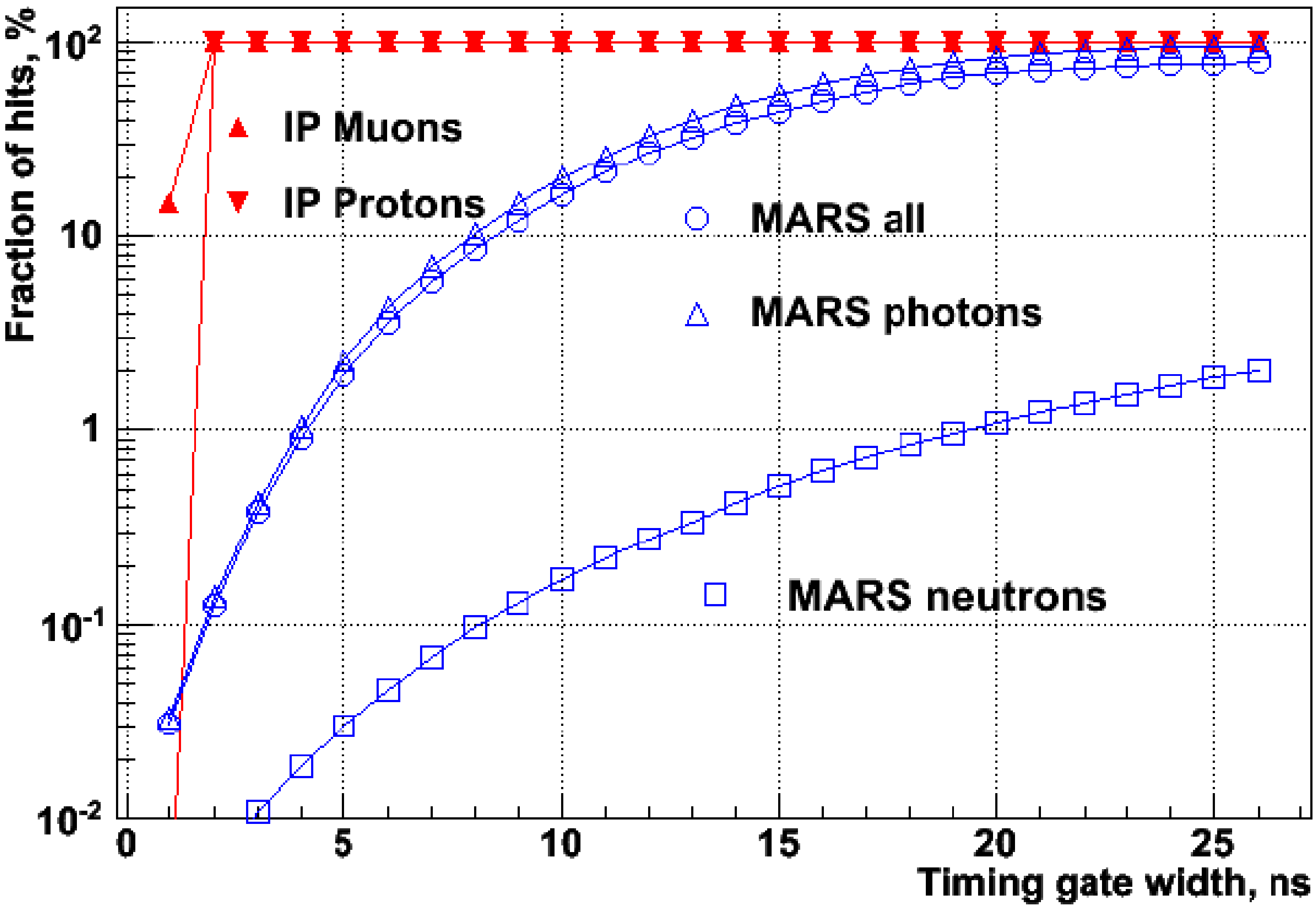
- Instantaneous background rate is high since all backgrounds are concentrated in a small number of beam crossings (~10 kHz vs. 25 MHz for HL-LHC).
- High granularity is required (to keep occupancies low) – ASICs can help control cost.
- Very good time resolution is crucial.

Background is spread out in time



Background in detector in 1st turn – 1.5 TeV (Higgs Factory is similar)

Tight timing can *greatly* reduce background



(Terentiev)

Beam Background Studies in Tracking System

- Simulated in ILCroot 4 detectors with different timing capabilities:
  - **Det. A** – No time information (integrates all hits).
  - **Det. B** – Acquires data in a fixed 7 ns time gate (minimal timing capabilities).
  - **Det. C** - Acquires data in a 3 ns time gate tuned to distance from IP (advanced timing capabilities).
  - **Det. D** - Acquires data in a 1 ns time gate tuned to pixel distance from IP (extreme timing capabilities.)

Reconstructed Background Tracks (from Kalman filter)

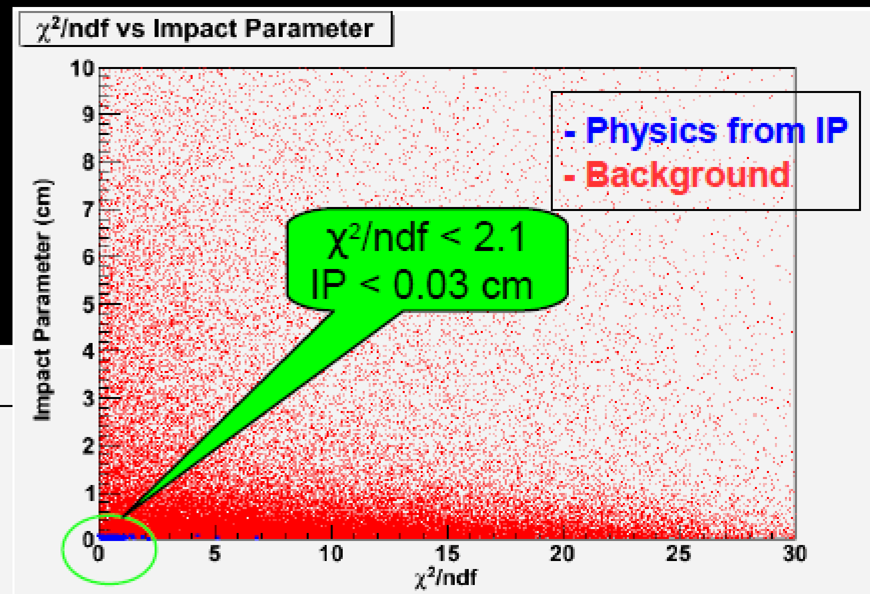
Full vs Fast simulation of the bkg

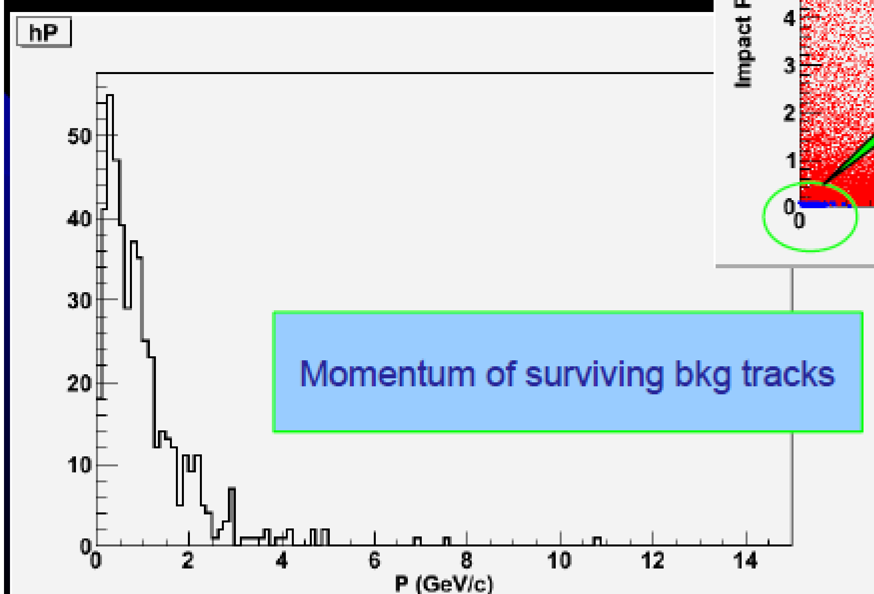
Detector type	Reconstructed Tracks (full simu)	Reconstructed Tracks (fast simu)
Det. A (no timing)	Cannot calculate	Cannot calculate
Det. B (7 ns fixed gate)	75309	64319
Det. C (3 ns adjusteble gate)	6544	4639
Det. D (1 ns adjusteble gate)	1459	881

Full reconstruction is paramount when combinatorics is relevant

Physics vs Background in Det. B:
A strategy to disentangle reconstructed tracks from IP

Full simulation of physics + bkg

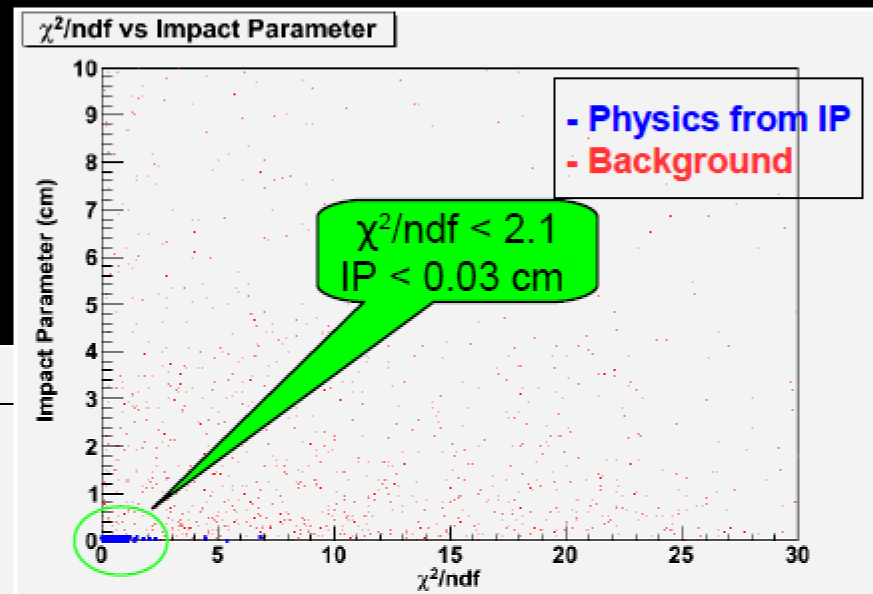


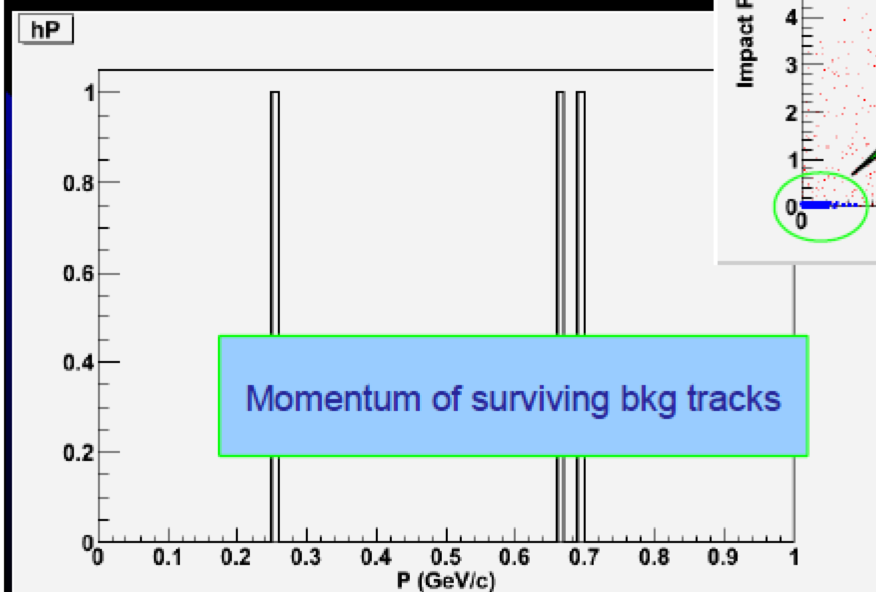


Det. B = Acquires data in a fixed 7 ns time gate

Physics vs Background in Det. D:
A strategy to disentangle reconstructed tracks from IP

Full simulation of physics + bkg





Det. B = Acquires data in variable 1 ns time gate

Timing is also key to calorimetry

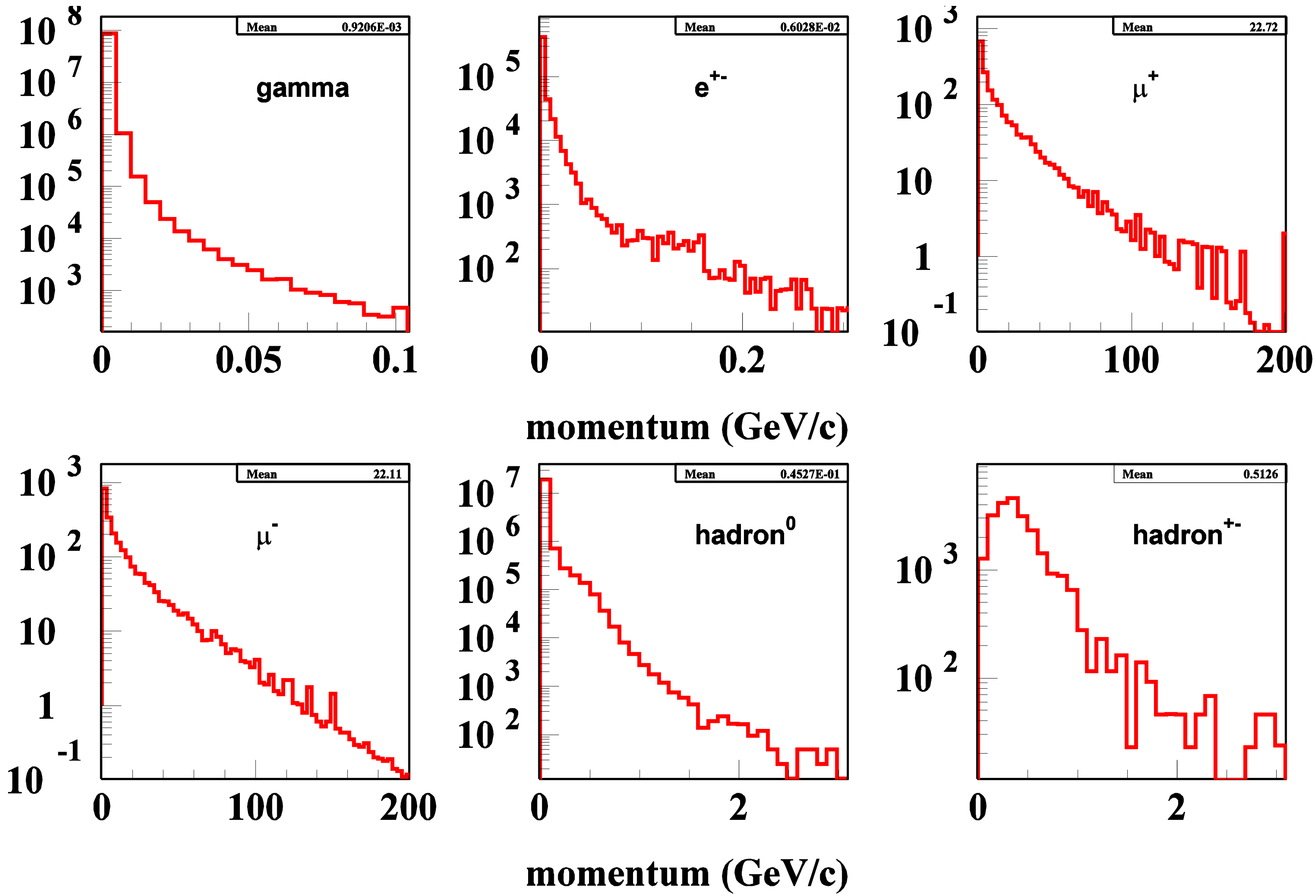
- Two studies have been done:
  - Pixelated digital calorimeter with 2ns “traveling wave gate” [R. Raja 2012 JINST 7 P04010]
  - Dual Readout Calorimeter with good timing (~10ns gate) [A. Mazzacane]

Summary

- Muon Collider detector problems are dominated by background from muon decays.
- With shielding, total dose requirement is non trivial, but much lower than HL-LHC (~1%) – probably still too high for COTS electronics.
- High instantaneous background rate demands high detector granularity – ASICs can reduce cost.
- Backgrounds can be greatly reduced (*very tight*) timing cuts.
- Details will likely change as shielding strategy evolves.

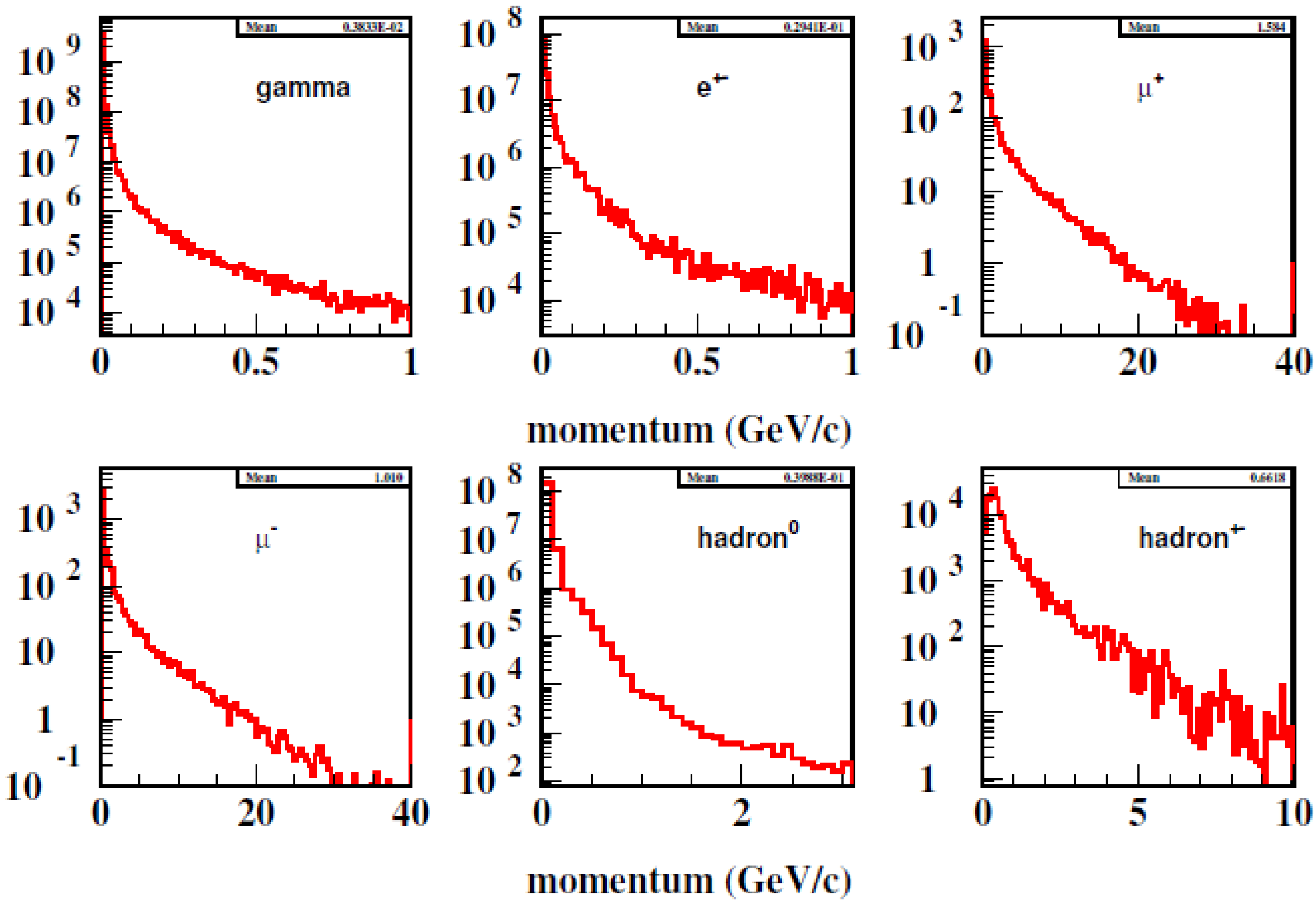
Additional Slides

Much of the background in 1.5 TeV Collider is soft – dE/dx cuts in tracker can help



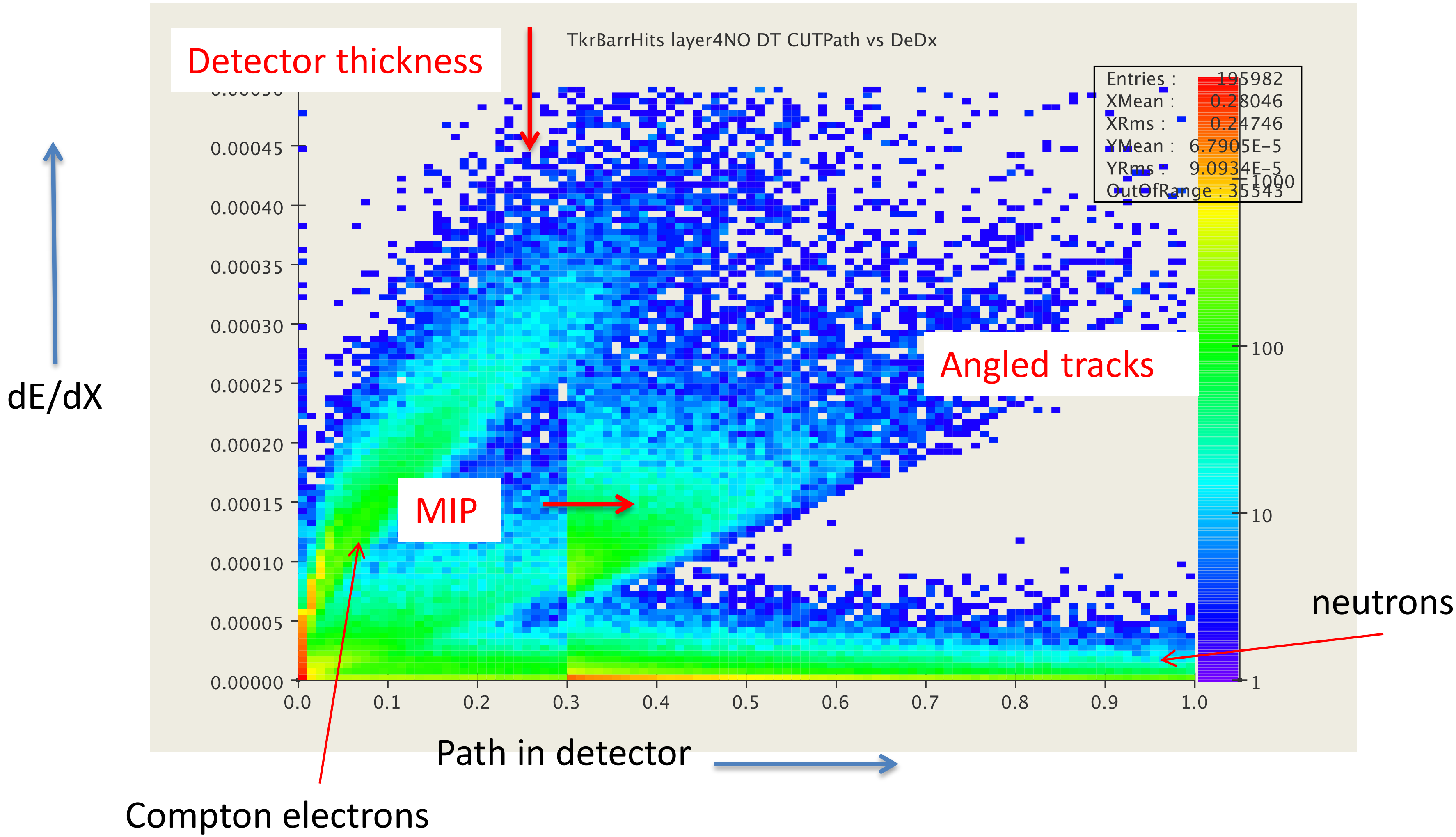
Background in detector in 1st turn (1.5 TeV CM) - Mokhov

Higgs Factory backgrounds are similar



Background in detector in 1st turn (125 GeV CM) - Stiganov

dE/dx in Layer 4 of SiD-style tracker



Background hits only (from Ron Lipton)