A Next-Generation Muon g-2 Experiment

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The Muon Magnetic Dipole Moment $(g-2)_\mu$
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The University of Glasgow

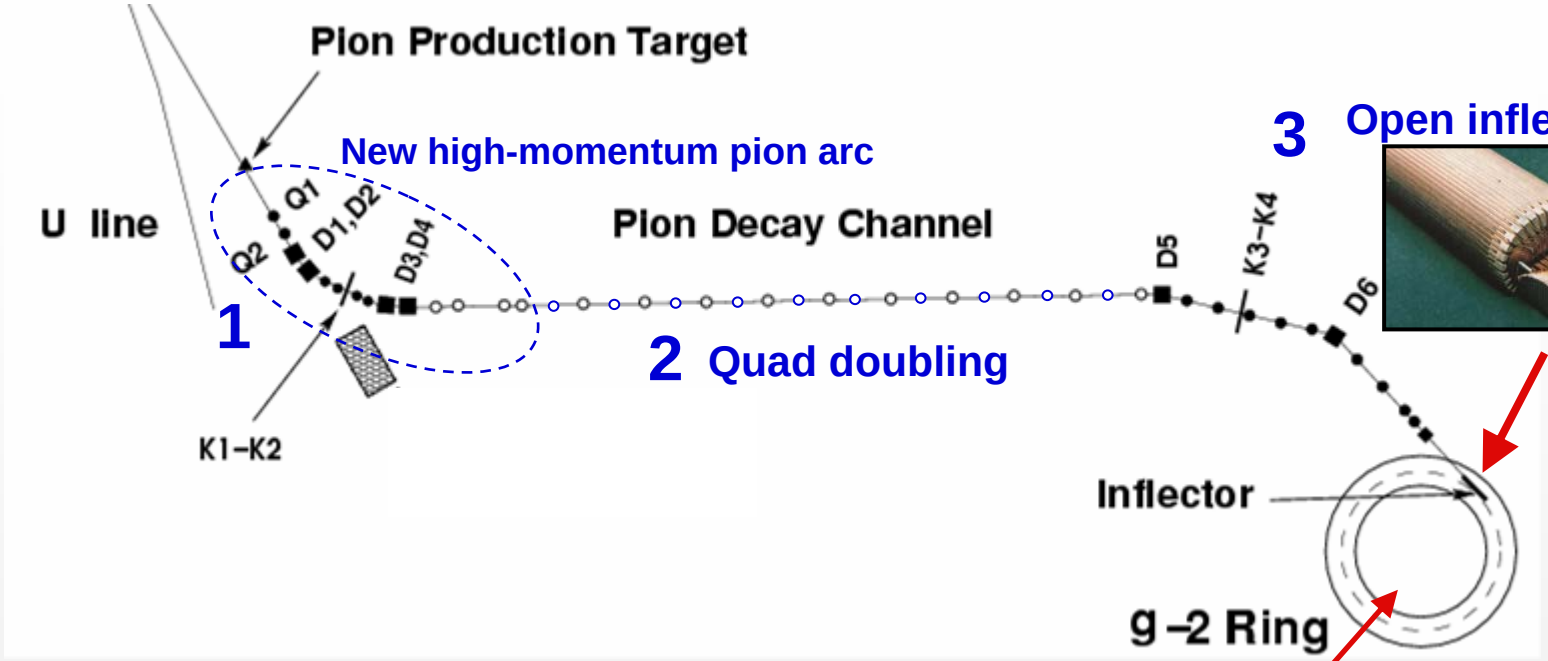
- **A few interesting experimental details**
- **Political realities**
- **Opportunities as a Community**

First, let's define our goals
(considering that Experiment and Theory are now both ~0.5 ppm)

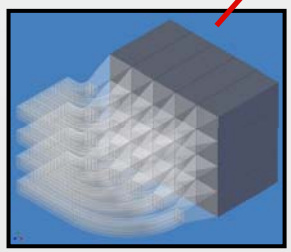
- **E969 aimed for 0.2 ppm overall error**
- **"Conservative" upgrade could to go 0.25 ppm**
- **"Legacy" effort is aiming at 0.14 ppm overall error**

Theory: How ambitious might we be in, say, 10 years time ?

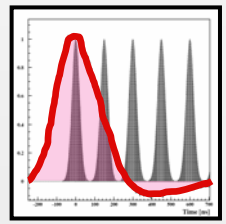
E969 proposal: More Muons. Our plan in 5 steps

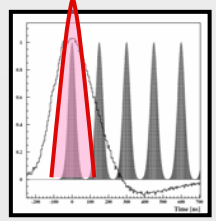


- x 5 more muons
- Pion flash reduced (eliminated)
- Segmented detectors
- Systematics reduced



5 Segmented detectors





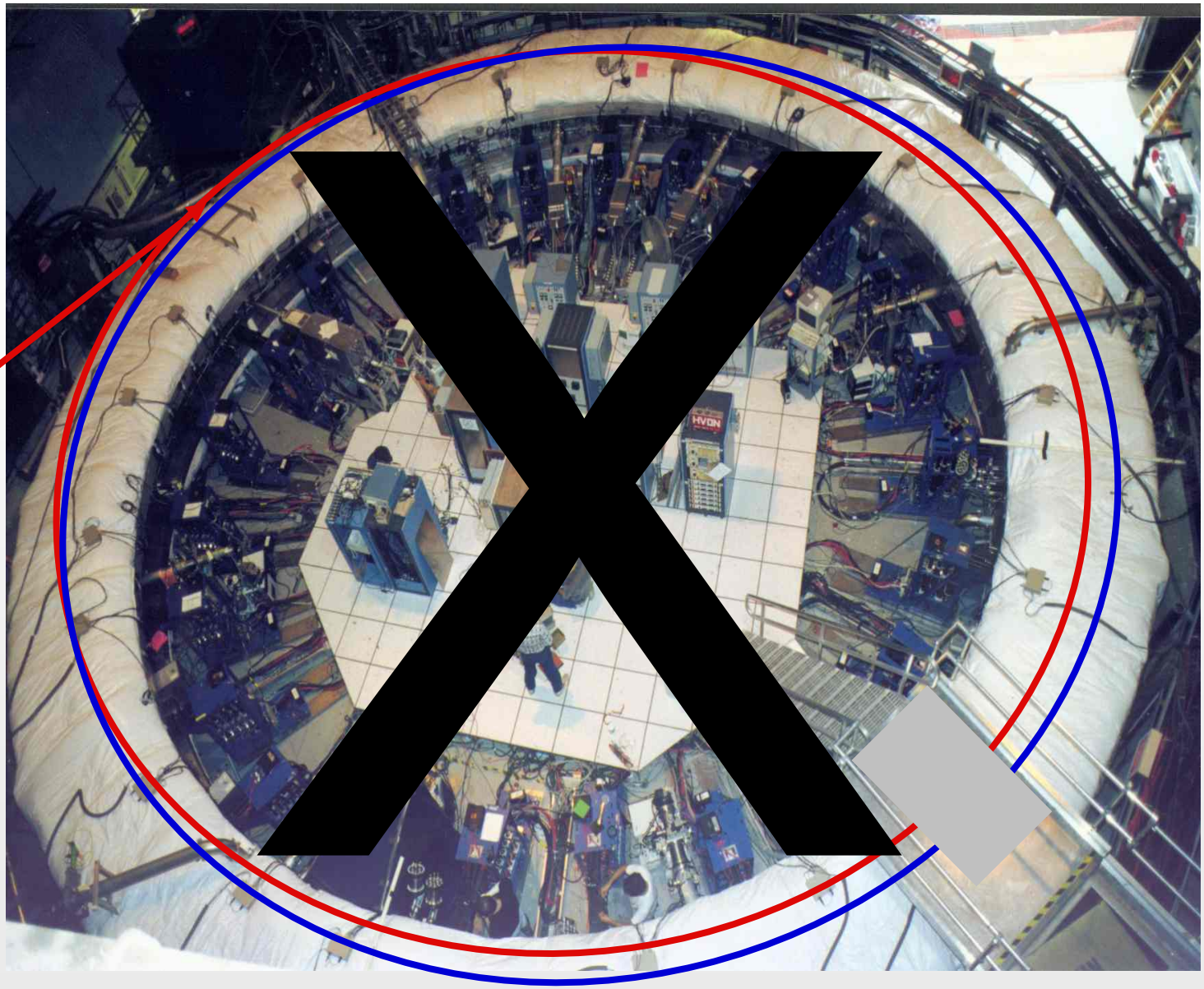
4 Improved kicker

Proposal / Politics / Planning / Patience

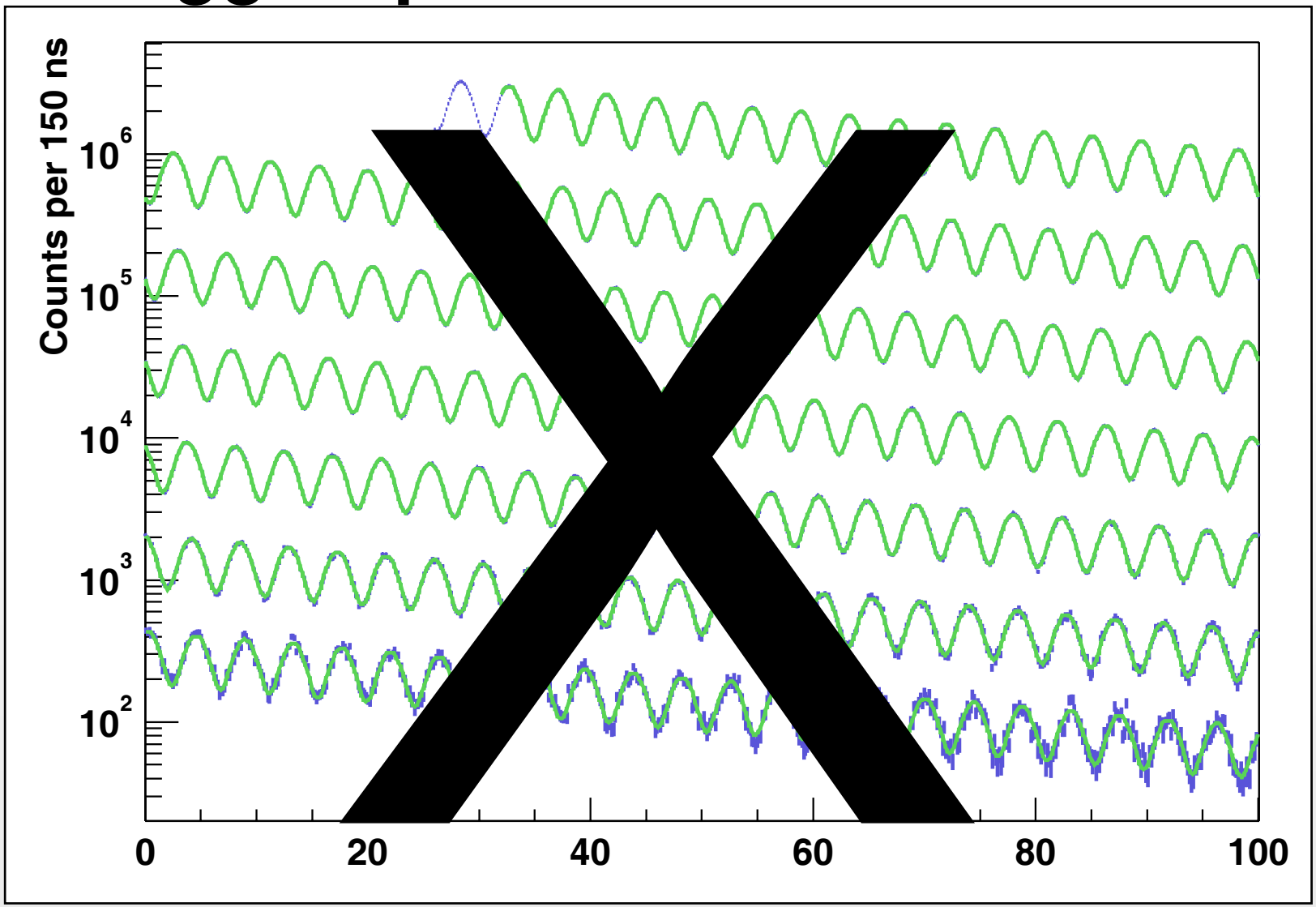
- **Fall 04:** E969 approved
  - Backward decay beam and novel analysis ideas
- **Mar 06:** P5* Panel -- HEP long range planning
  - Sept 06 report lists g-2 as 4th recommendation (behind ILC, LHC upgrades, long baseline neutrinos, dark matter/energy)
  - Re-evaluate after LHC start
- **Fall 06:** Updated HVP theory → 3.4 σ effect
  - g-2 getting renewed attention by community
- **May 07:** *Nuclear* Physics Long Range Plan process
  - Aim at "Legacy" experiment Goal: <u>0.14 ppm overall error</u>
  - Project included in New Standard Model Initiative

*Particle Physics Priority and Planning Panel

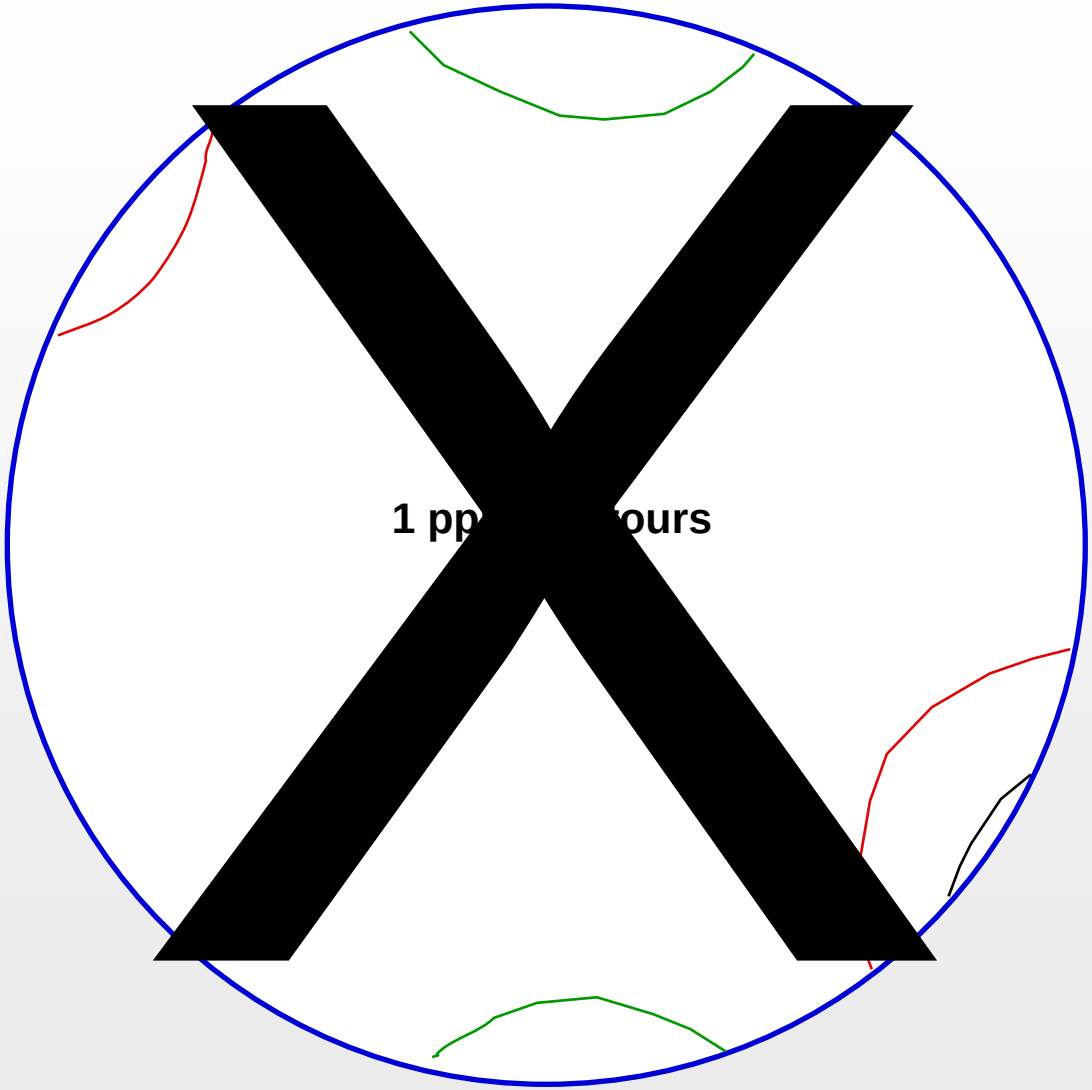
In this talk, no picture of the Storage Ring



No “wiggle” plots



No magnetic field uniformity maps



Instead, a few technical developments toward a next-generation experiment

For E821, a limiting factor was the hadronic flash at injection

(prompt pions, then delayed neutron captures)

Several systematics are affected by this initial pulse

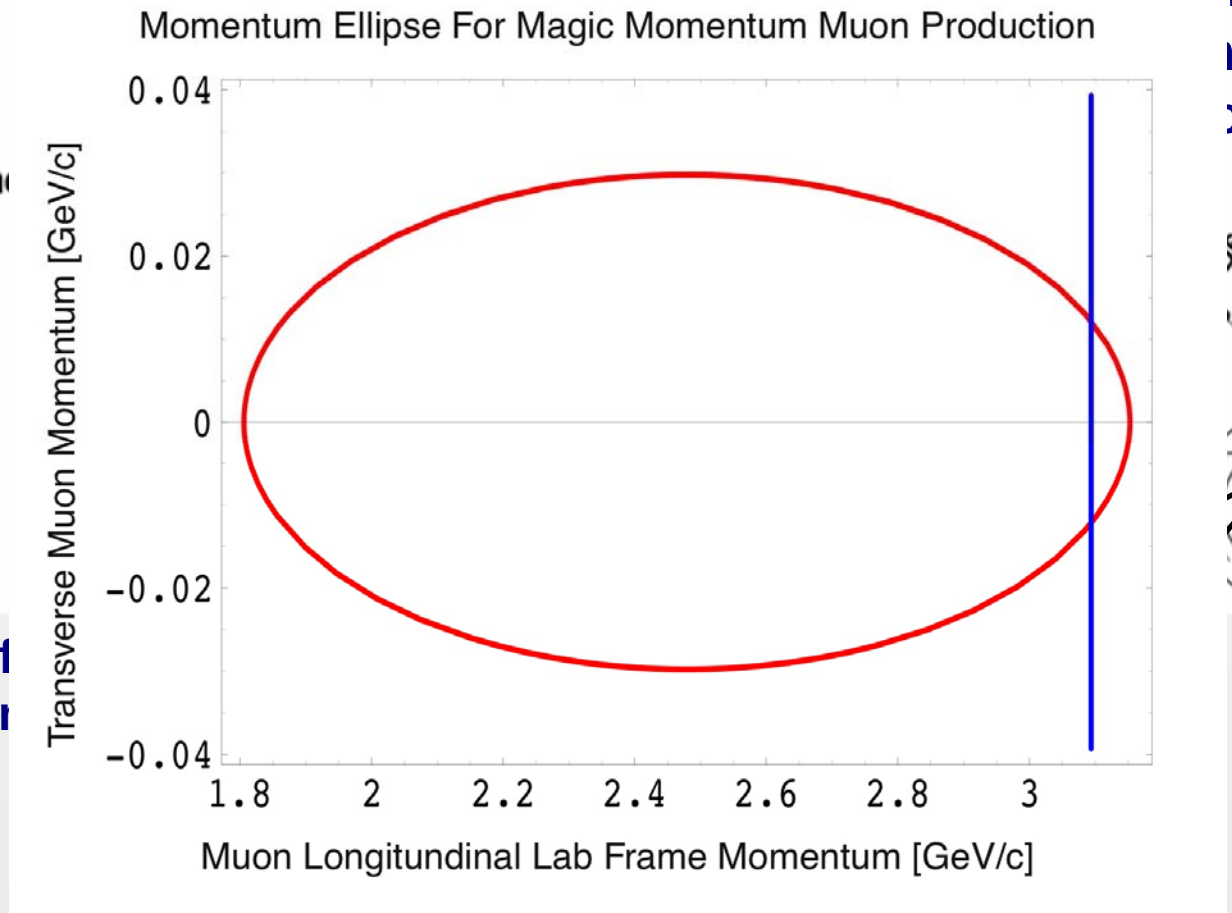
(gain, time stability; pileup extraction, start time of fits)

PMTs had to be switched off and on for every fill

Question 1:

How do we get rid of the pions ?

The current “forward-decay” beam $\pi^- \rightarrow \mu^- \bar{\nu}_\mu$



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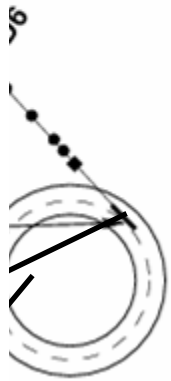

The hadronic f
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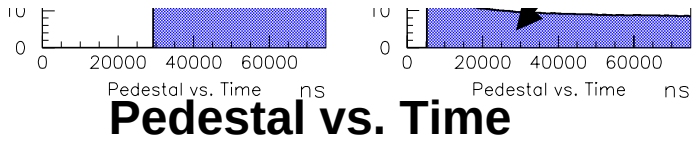
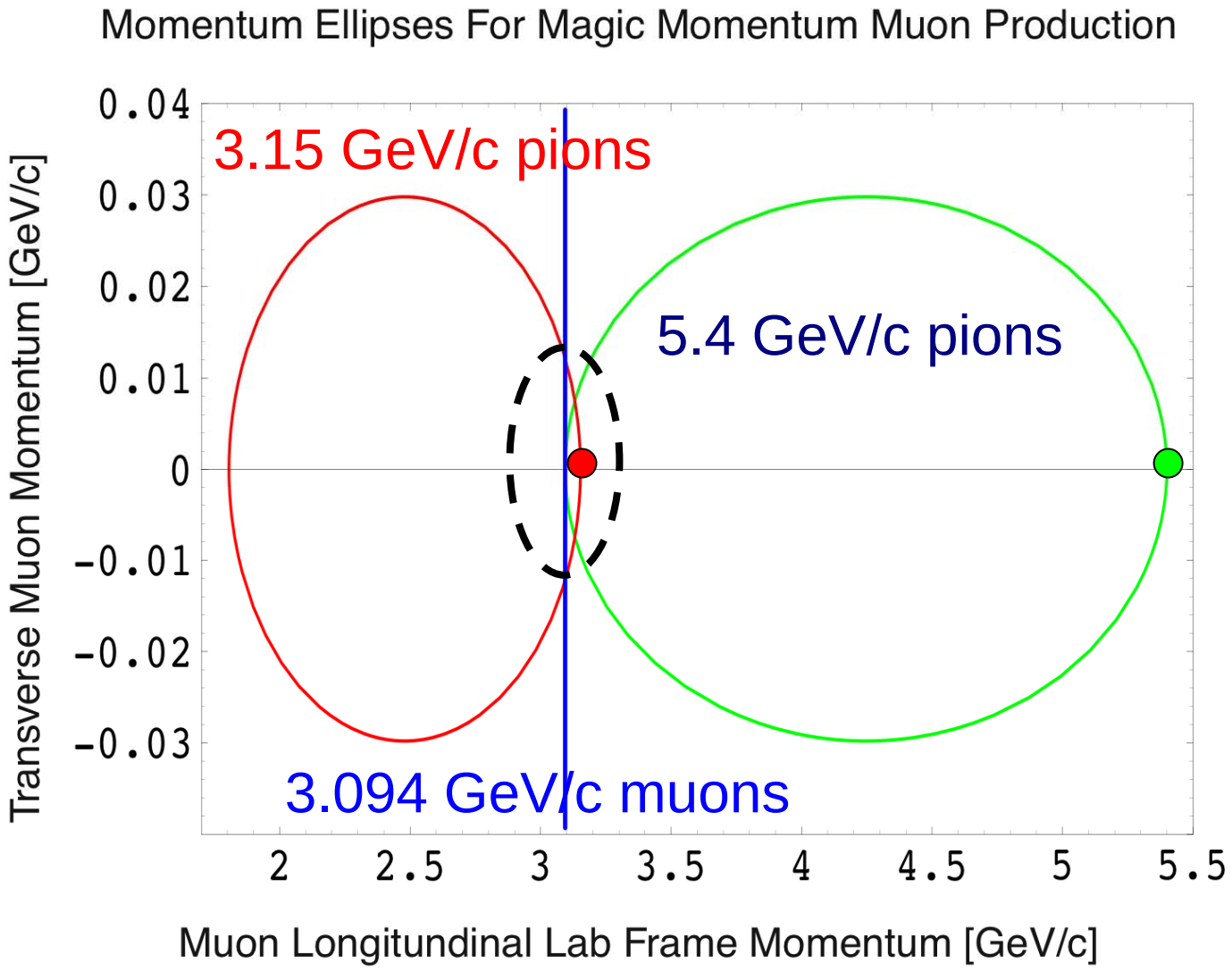


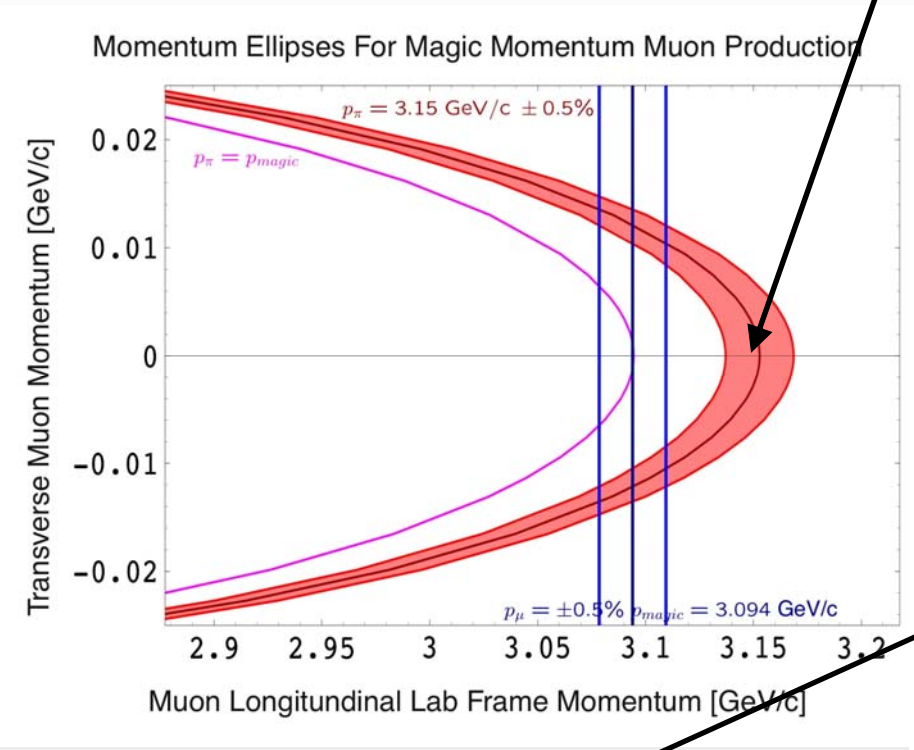
Far side

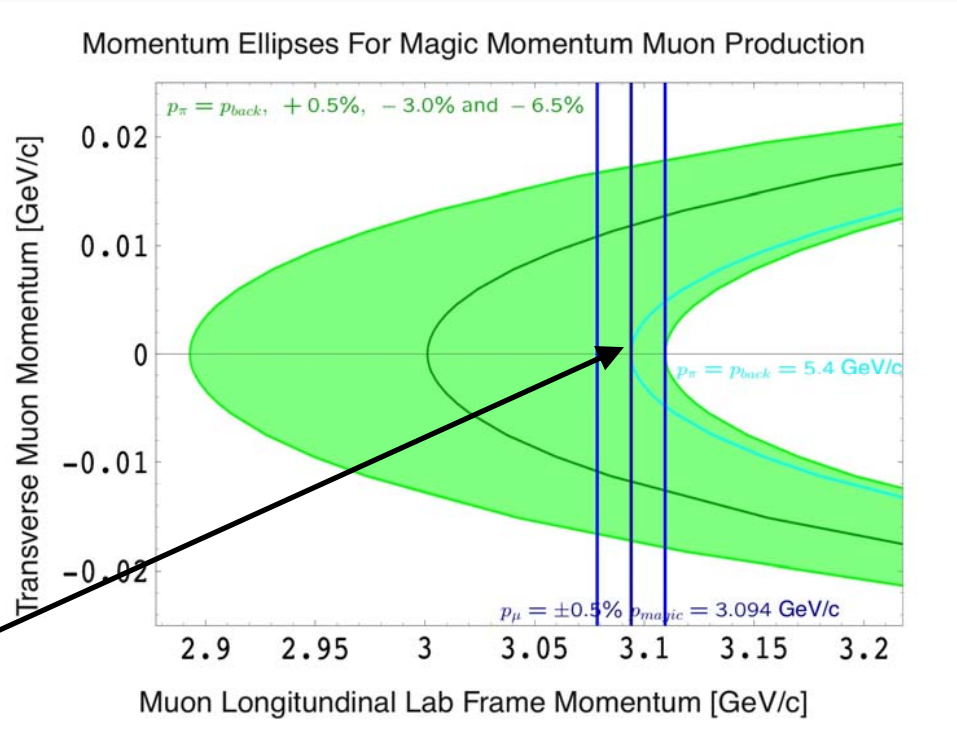
For E969, we considered the idea of backward muon production … the advantages are appealing



A wide momentum width, and true 180-degree decays can lead to higher polarization and more muon production … but, the Lorentz boost hurts

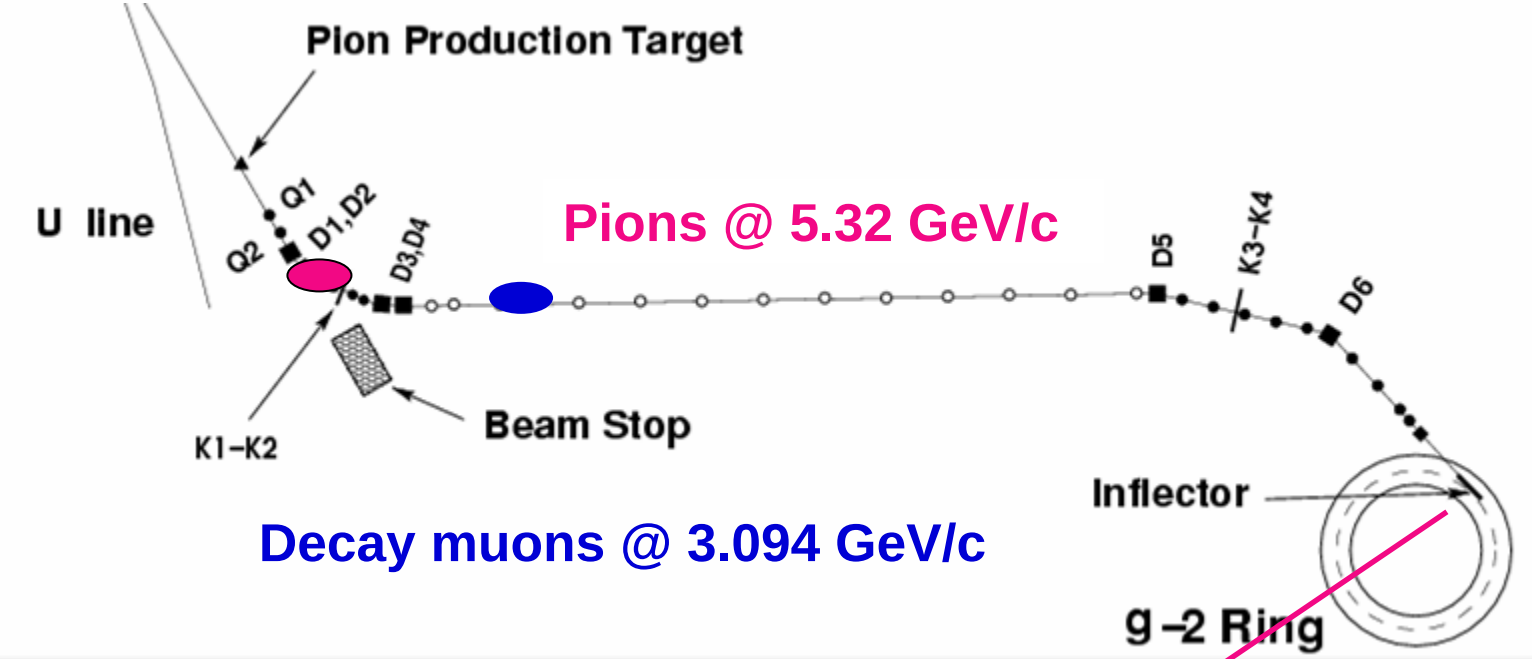
We could never work here at 0 degrees because the pions then enter the storage ring and swamp the detectors



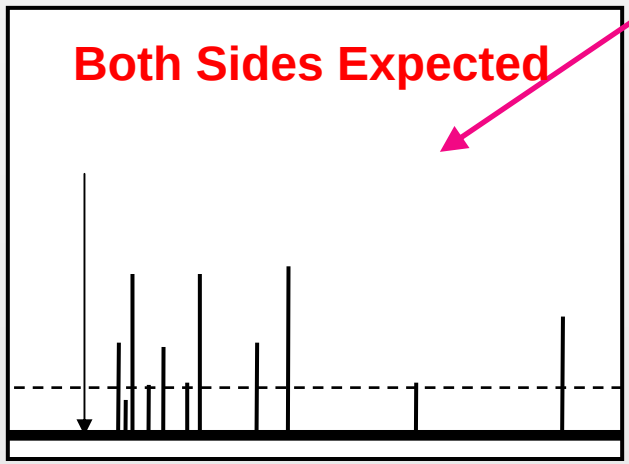


But in backward mode, all the pions have very different momentum than the muons, so 180 degrees is okay

"Plan A" for the new experiment uses a backward decay beam with large mismatch in π/μ momentum



We've now demonstrated an increase in muon production here, but a daunting task of building a new front-end achromatic arc looks difficult

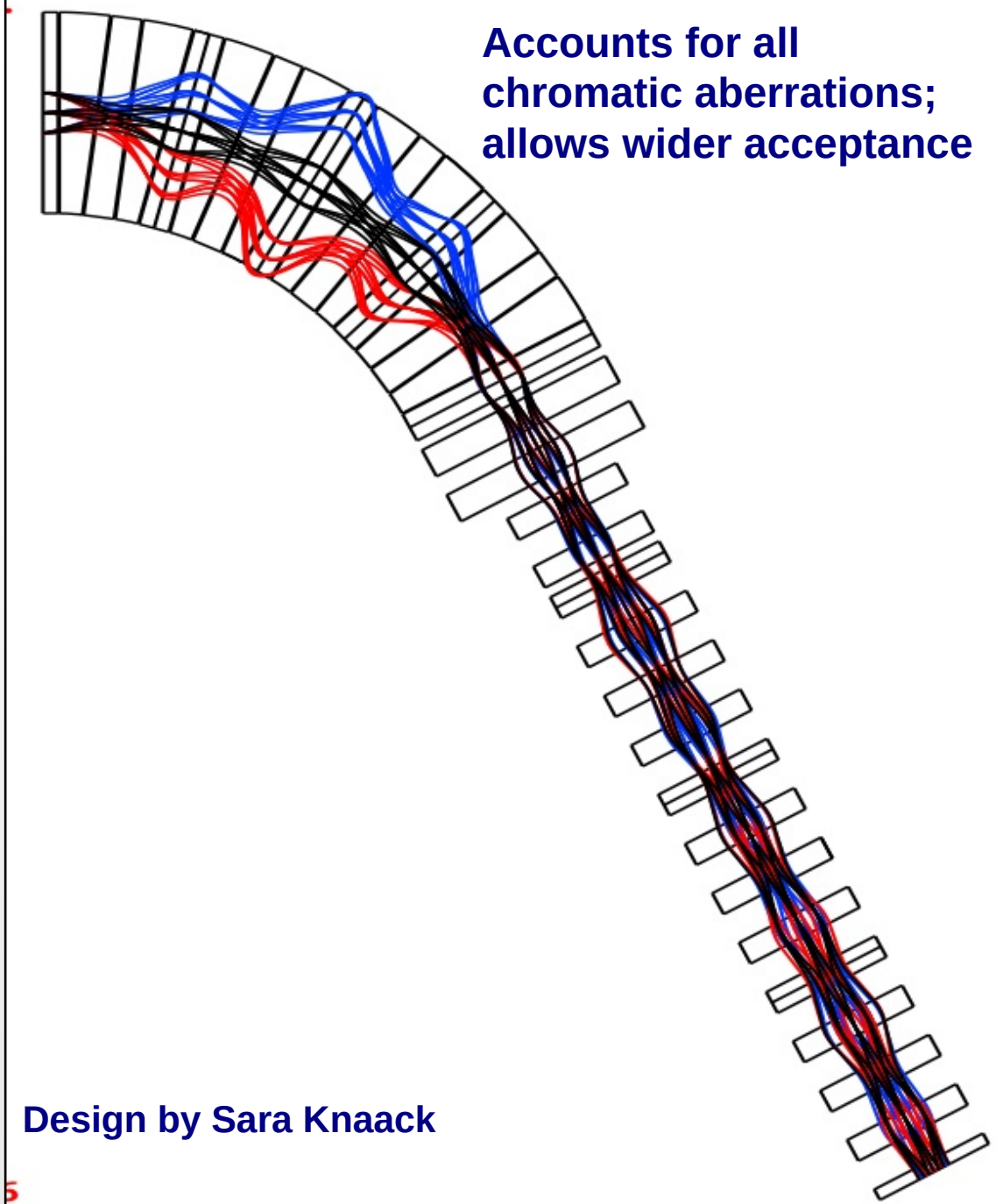


No hadron-induced prompt flash

x 2+ more muons (2007 est.)

2nd – order achromat with matching beamline section

- High fields require superconducting elements
- Cost looks high
- Space looks tight



Accounts for all chromatic aberrations; allows wider acceptance

Design by Sara Knaack

Instead, a few technical developments toward a next-generation experiment

E821 Final statistical error was 0.46 ppm

For 0.1 ppm "Legacy" experiment, that's > 20 times the counts

That's hard.

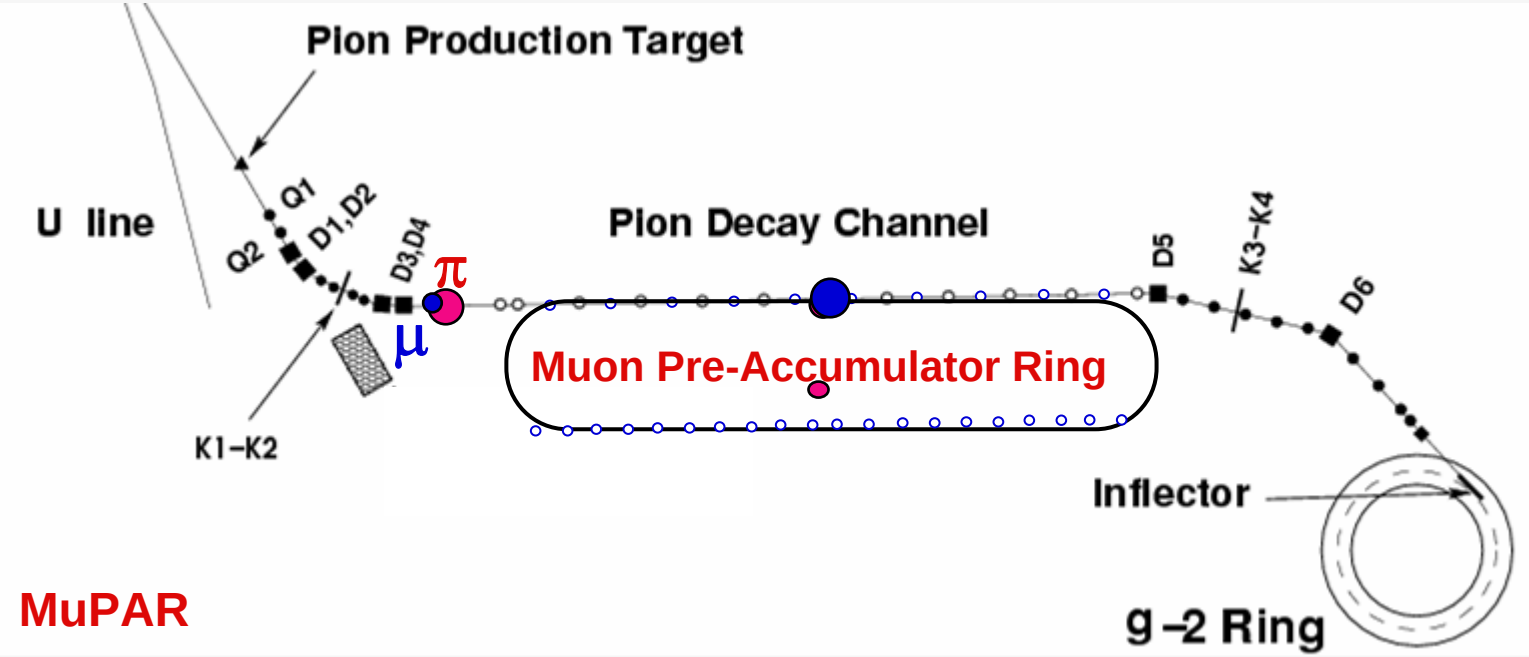
You need a new idea.

Question 2:

Where do the muons come from and how can we get (lots) more of them?

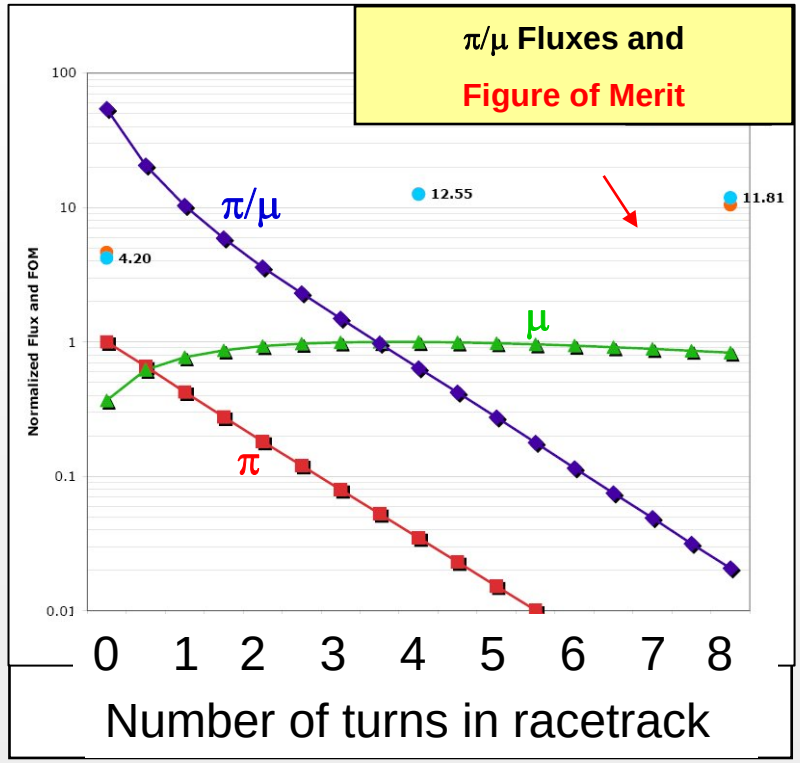
How to get more muons *AND* still avoid the flash

- The recipe is well known and simple:
  1. Take the 0-degree forward muons
     - High polarization, highest yield
  2. Make the beam line so long that all the pions decay away
- But, that's entirely impractical, unless you recycle



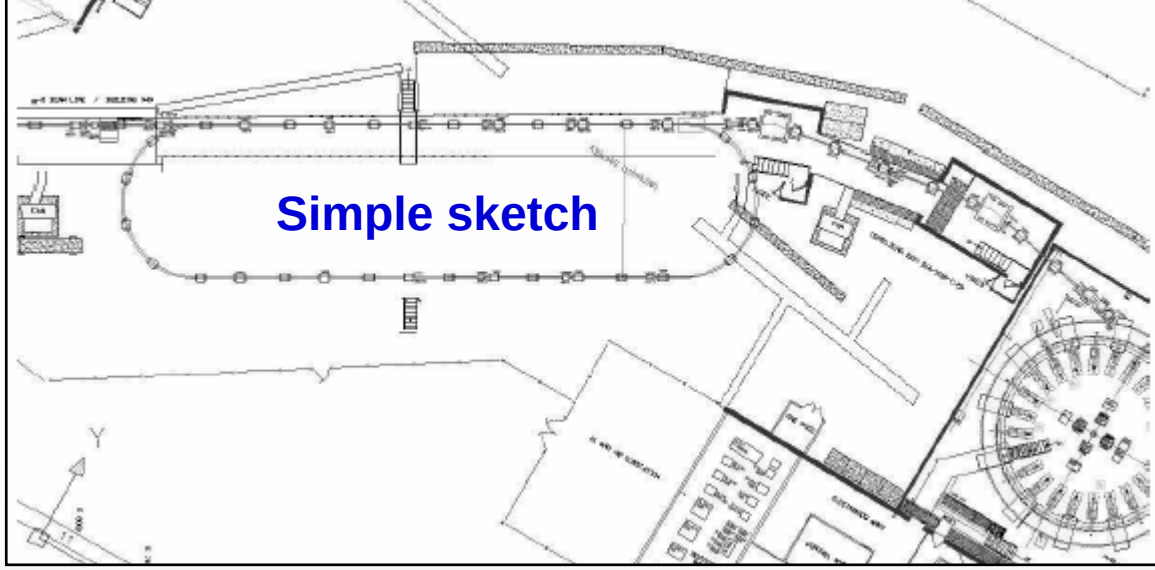
MAR: Muon Accumulator Ring

- Catch most muons in first 2 turns.
  - Although spin precesses, it's okay
- Rest of turns just reduce pions by decay time
- Figure of Merit NP^2 increased by factor of ~12 or more
- Fast "Switcher" magnet required to flick beam straight (default is stay in ring to avoid background)



MAR:
Muon Accumulator Ring

We have begun to look at:
- Practical lattice layout
- Fast switcher
- Selection of real elements
- Practical floorplan
- Shielding



Strawman design

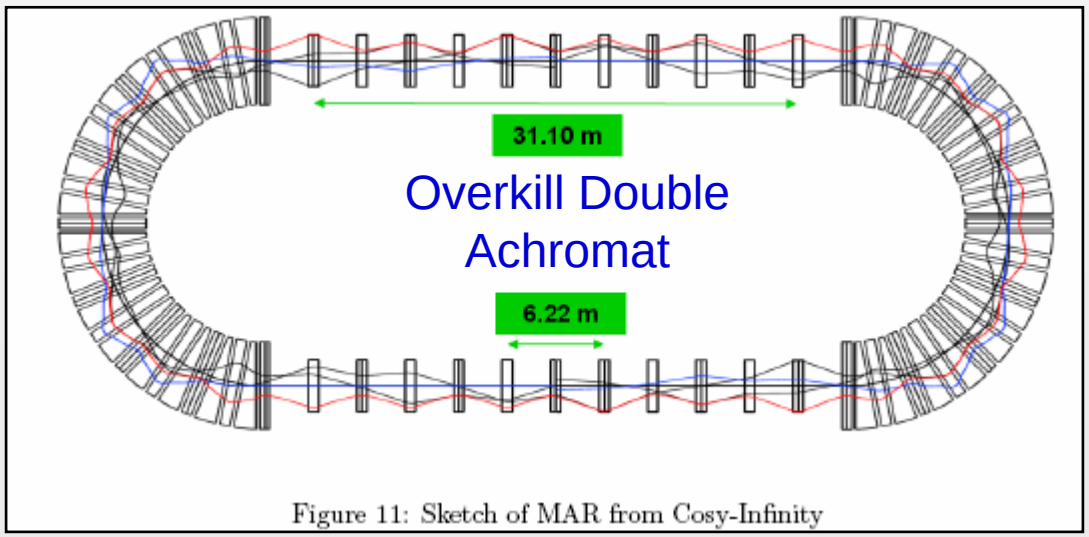
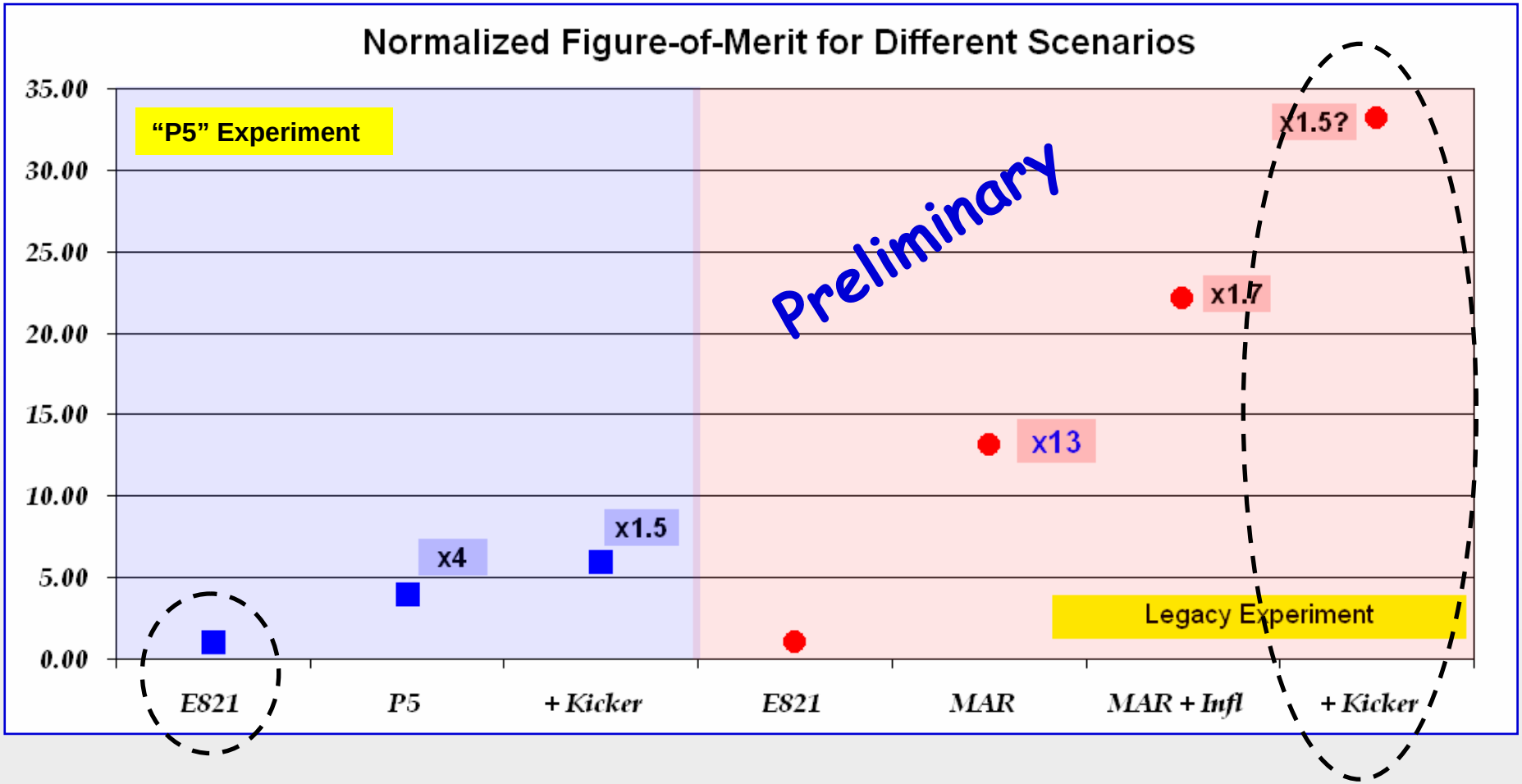


Figure 11: Sketch of MAR from Cosy-Infinity

Optimistic Summary



Huge improvement due to MAR needs confirmation and conceptual design

Studies: P. Kammel

Instead … a few interesting things that usually don't get presented

E821 analyzed data in the classic "event" mode

Most systematics related to "event" issues

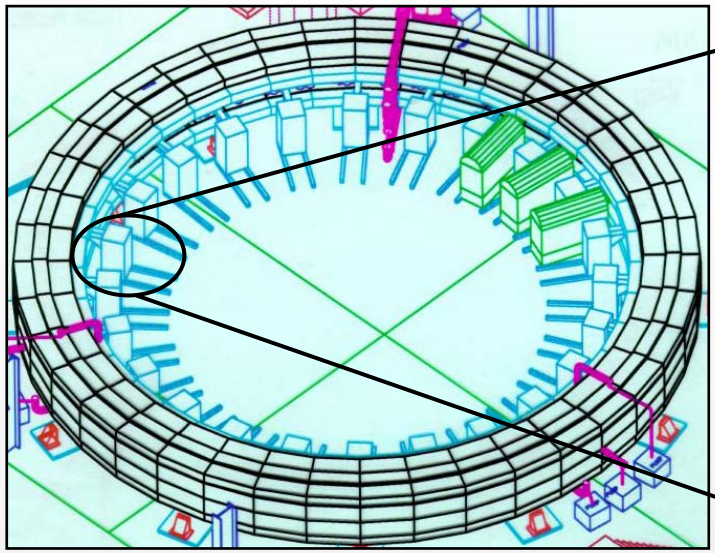
Like pileup

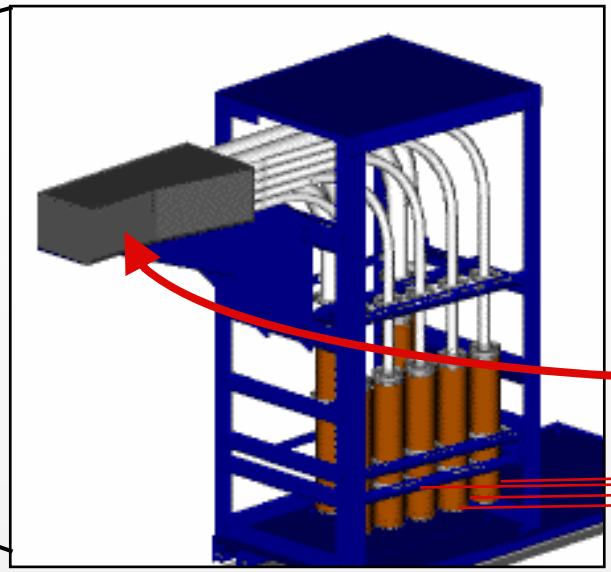
How can this be minimized when beam flux goes way up?

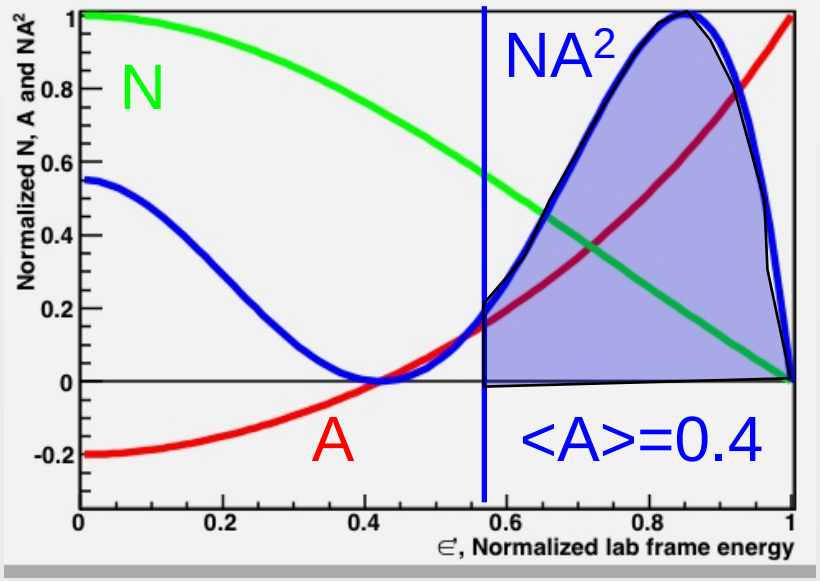
Question 3:

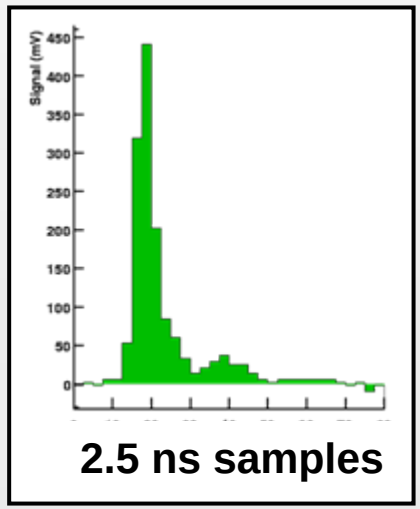
Any new ideas on how to take the data?

In E821, an “event” is an isolated electron above a threshold.

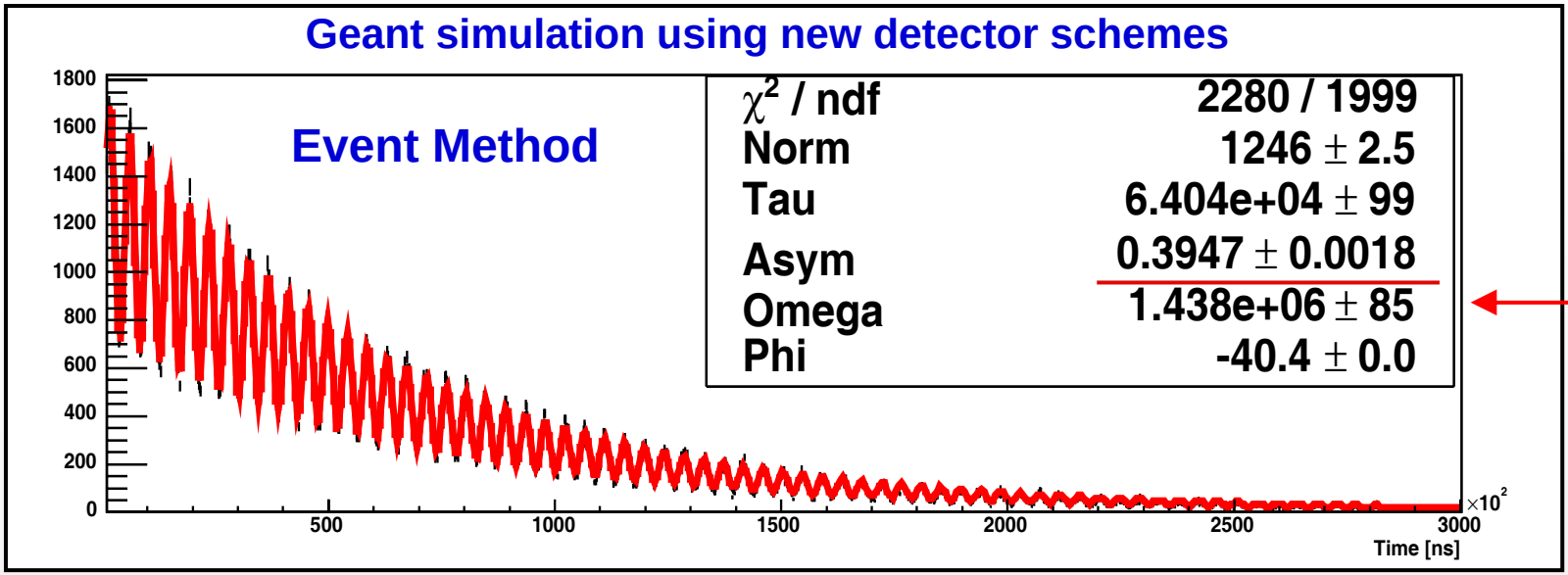


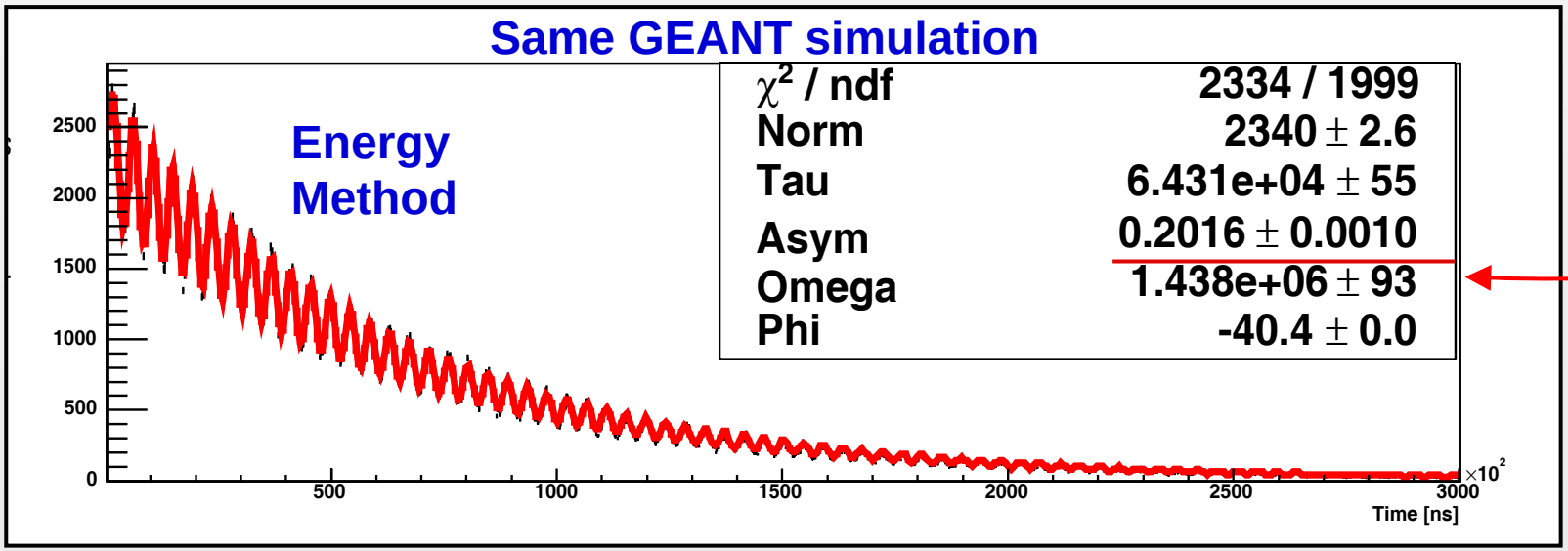






A complementary method of determining ω_a is to plot *Energy* versus *Time*





The new method is easy to implement with modern, available electronics

- No pileup … therefore not limited by rate

- Asymmetry lower (40% → 20%)
- Acceptance higher

} 10% lower statistical error

- Is complementary to standard Event method

Conclusions

- Improved muon g-2 is technically feasible
- Existing storage ring is major leftover resource
  - … and, perhaps, a few of us
- Forward path here, there or anywhere involves:
  - More muons (by schemes like I showed
  - Division of muons into more frequent, lower-intensity bunches (which I did not discuss)
  - Fast forward on detectors, electronics and DAQ environments compared to early ’90s (I did not discuss)
  - Reduction in systematics
    - Field: probes, absolute and relative calibrations, better centered beam with smaller CBO oscillations
    - Precession frequency: detector environment stability, pileup reduction, flash reduction
- The real push, however, may come from a very strong, coherent, consistent, theory statement
- And, by some “pressure” from our Collider experimental colleagues to set aside some resources for Low-Energy Precision Observables such as this one