In Pursuit of the Invisible: Measuring $\Upsilon \to \nu \bar{\nu}$ at Super-B

Steve Sekula

Southern Methodist University

Presented at the XI Super-B Workshop

November 30, 2009

- The lure of the invisible - *predictions*
- The challenge of the invisible – *systematics*
- Pursuing the invisible - *approaches*

The Lure of the Invisible

Predictions for $\Upsilon \rightarrow \nu\bar{\nu}$

THE STANDARD MODEL

$$BR(\Upsilon(1S) \rightarrow \nu\bar{\nu}) = \frac{N_\nu G_F^2}{48\pi}\left(1 - \frac{4}{3}\sin^2\theta_W\right)^2 \frac{f_{\Upsilon(1S)}^2 M_{\Upsilon(1S)}^3}{\Gamma_{\Upsilon(1S)}}$$

$$BR(\Upsilon(1S) \rightarrow \nu\bar{\nu}) = (1.03 \pm 0.04) \times 10^{-5}$$

From Yeghiyan (see Reference Backup Slide)

LOW-MASS DARK MATTER

Fayet, McElrath, Yeghiyan, ...

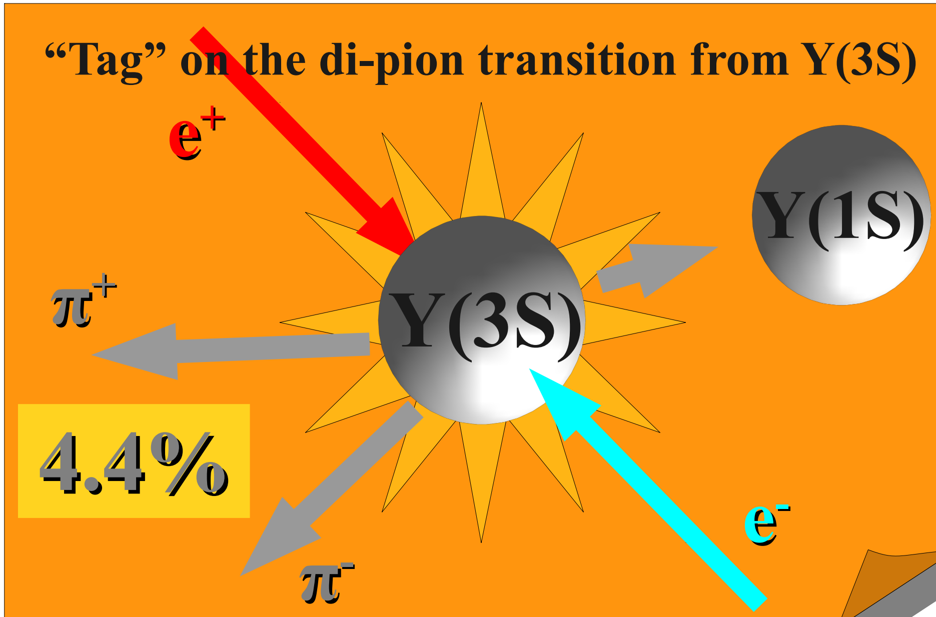
Most recently, Yeghiyan calculated from an effective theory that:

$$BR(\Upsilon(1S) \rightarrow \phi\bar{\phi}) = \frac{C_3^2}{\Lambda_H^4} \frac{f_{\Upsilon(1S)}^2}{48\pi\,\Gamma_{\Upsilon(1S)}}\left(M_{\Upsilon(1S)}^2 - 4m_\phi^2\right)^{3/2}$$

where the production of the dark matter is mediated by heavy degrees of freedom whose mass scale is Λ_H and where C_3 is the (real-valued) Wilson coefficient for the term in the effective theory that leads to this final state.

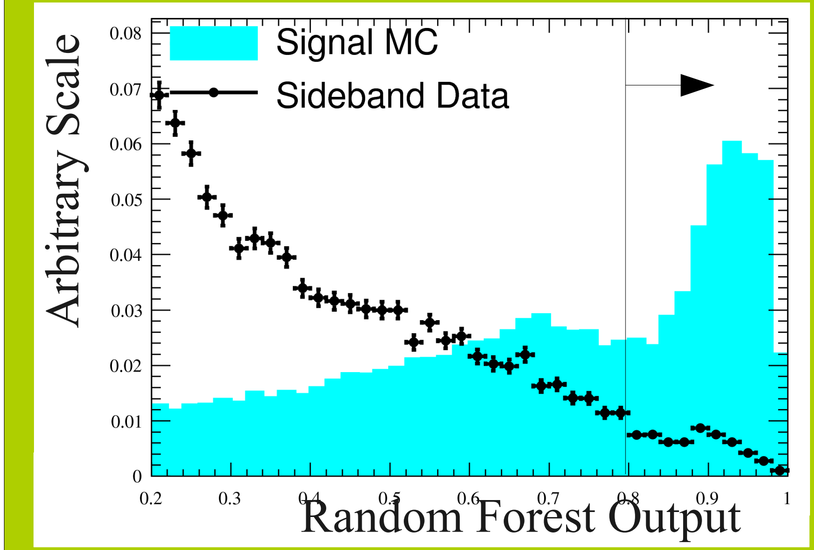
Measurement Technique

“Tag” on the di-pion transition from Y(3S)



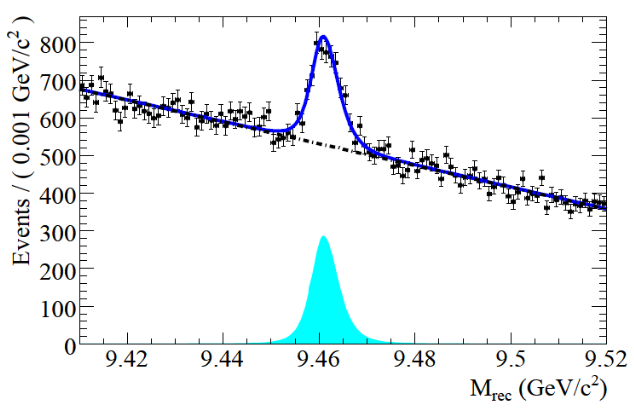
4.4%

Reject background with a random forest (decision tree algorithm)



$\varepsilon_{sig}^{total} = 17\%$

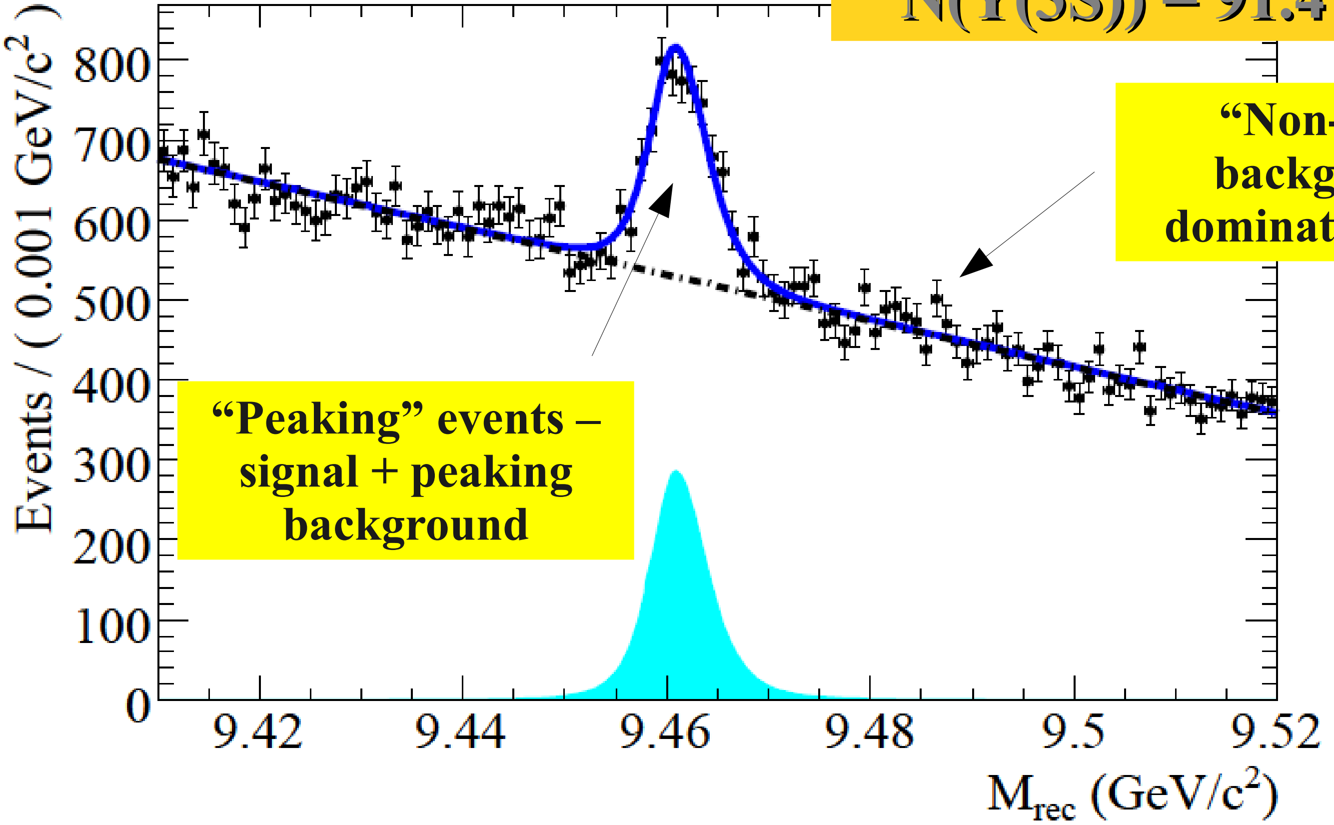
Fit for a peak in the mass recoiling against the pions



Present Measurement of $\Upsilon \to \nu\bar{\nu}$

arXiv:0908.2840 (Submitted to PRL)

$N(\Upsilon(3S)) = 91.4\times10^6$



“Non-peaking background” - dominated by QED

“Peaking” events – signal + peaking background

Peaking Background: 2444 ± 123 events

Signal Yield: -118 ± 105 ± 124

$BR(\Upsilon \to \text{invisible}) = (-1.6 \pm 1.4 \pm 1.6)\times10^{-4}$

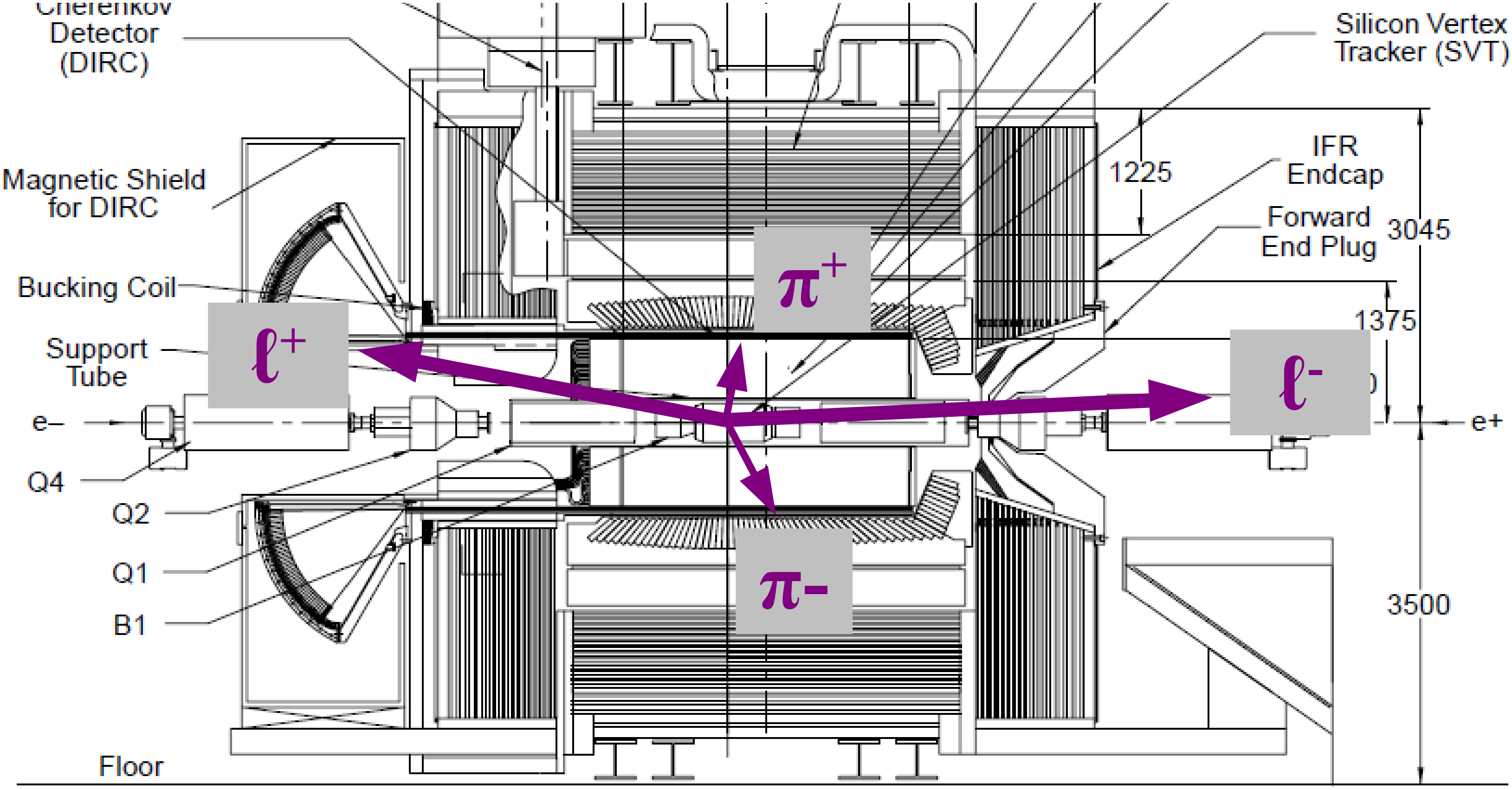
Why Care About $\Upsilon \rightarrow \nu\bar{\nu}$?

- Fundamental physics
  - We haven't measured an invisible meson decay
  - This is a straight-forward but rare process in the SM
    - a whole order-of-magnitude of discovery is left!
- Enabling other measurements
  - Measuring this will be challenging
  - Meeting this challenge may make other work easier
  - I will elaborate more on this at the end

The Challenge of the Invisible

A Discussion of Peaking Background

- Peaking background dominated by $Y \rightarrow e^+e^-$ and $\mu^+\mu^-$
  - 4% from $\tau^+\tau^-$ and <1% from hadrons



A Breakdown of Current Uncertainties

	🟦 2444.0	*Green boxes indicate uncertainties that improve with statistics; yellow indicate those which could improve by other means.*
	🟩 ± 28.0	Due to statistics in a control sample (manifests as uncertainty in correction to peaking background)
	🟩 ± 14.0	ibid. (manifests as a fit yield uncertainty on control sample events)
	🟨 ± 22.0	Due to limitation on knowledge of the different trigger efficiencies for control/invisible events
	🟨 ± 15.7	Due to limitation on knowledge of the rate at which hadronic Υ(1S) decays mimic the invisible signature
	🟨 ± 0.9%	Due to limitation on knowledge of the Level 3 trigger efficiency for signal(-like) events
The single largest effects	🟨 ± 2.1%	Due to limitation on knowledge of the Level 1 trigger efficiency for signal(-like) events
	🟨 ± 4.0%	Uncertainty on the Random Forest selection efficiency for signal(-like) events

The total systematic uncertainty is about 5%

Pursuing the Invisible

Assumptions for this Study

- 100x more Υ(3S) at Super-B

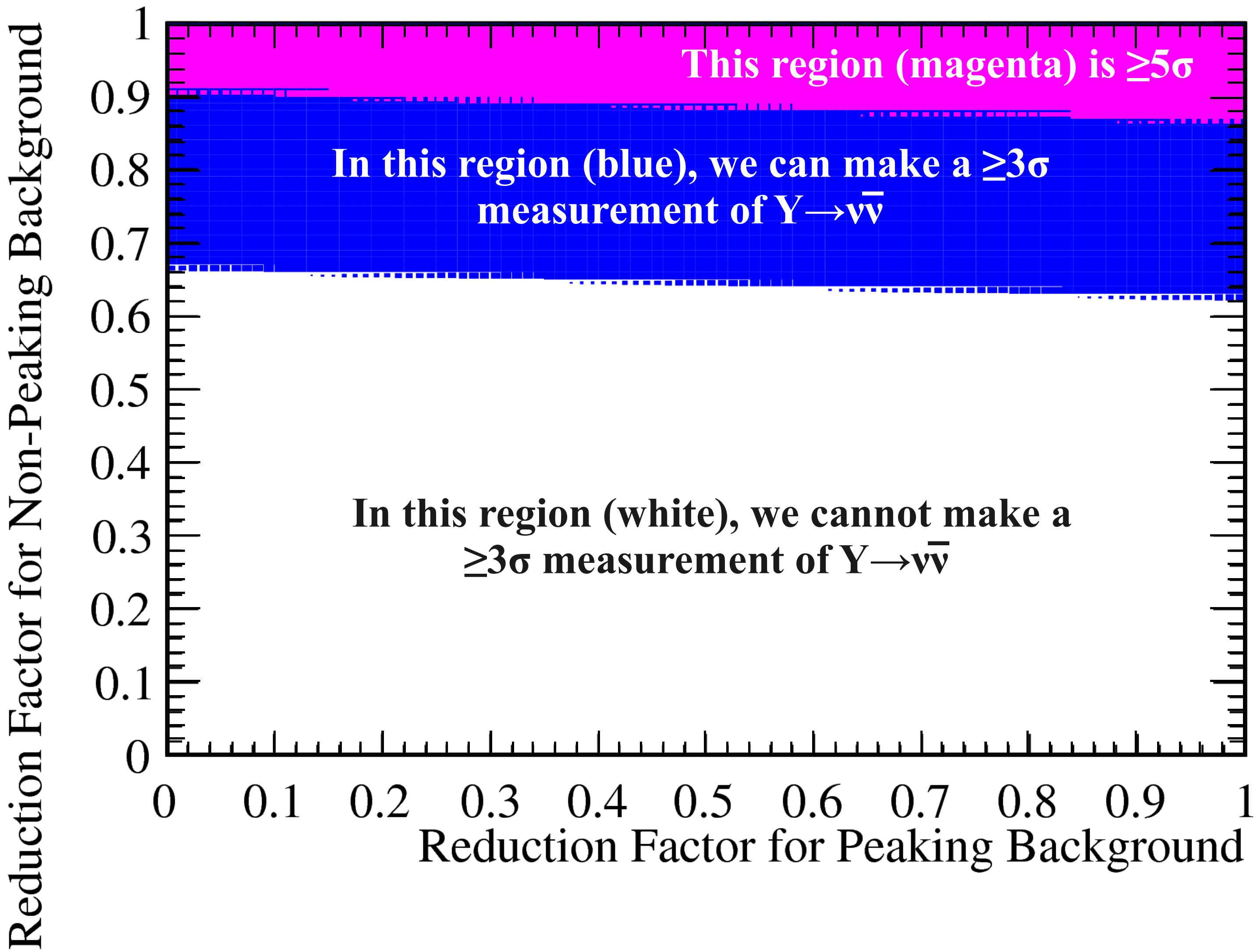
~few months running at full luminosity

- Similar trigger configuration for this running
  - need low-p_T 2-track triggers to catch the pions
- Systematic errors
  - two cases: stay the same as now (unlikely!), or improve by a factor of 2 (likely!)
- Detector design
  - similar to current fiducial coverage, with upgrades/replacements to appropriate systems that yield similar performance

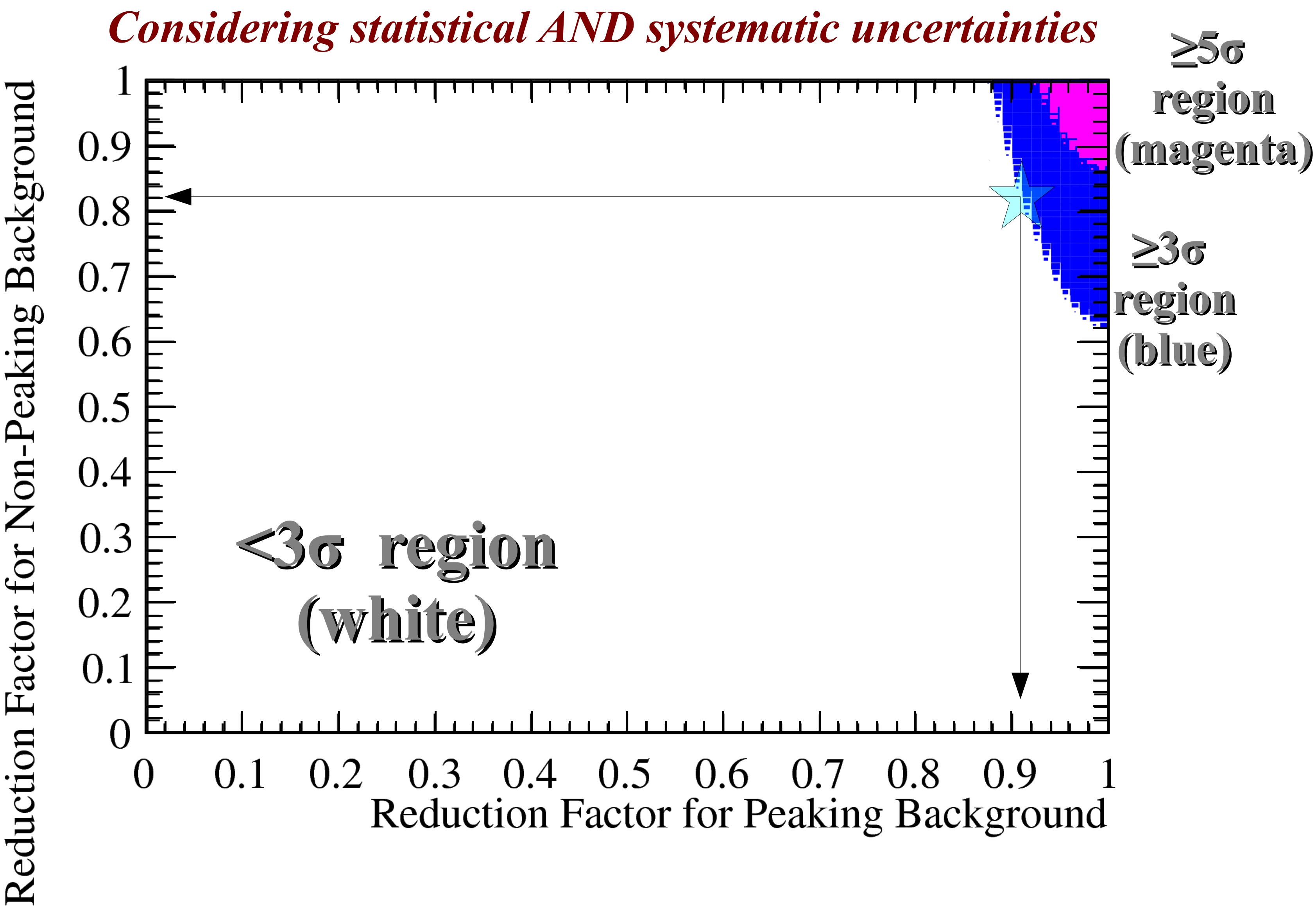
Question: by how much would we need to reduce either the non-peaking or peaking background (or both) in order to achieve at least a 3σ-significant measurement?

Background Reductions – Part I

Considering ONLY statistical uncertainties

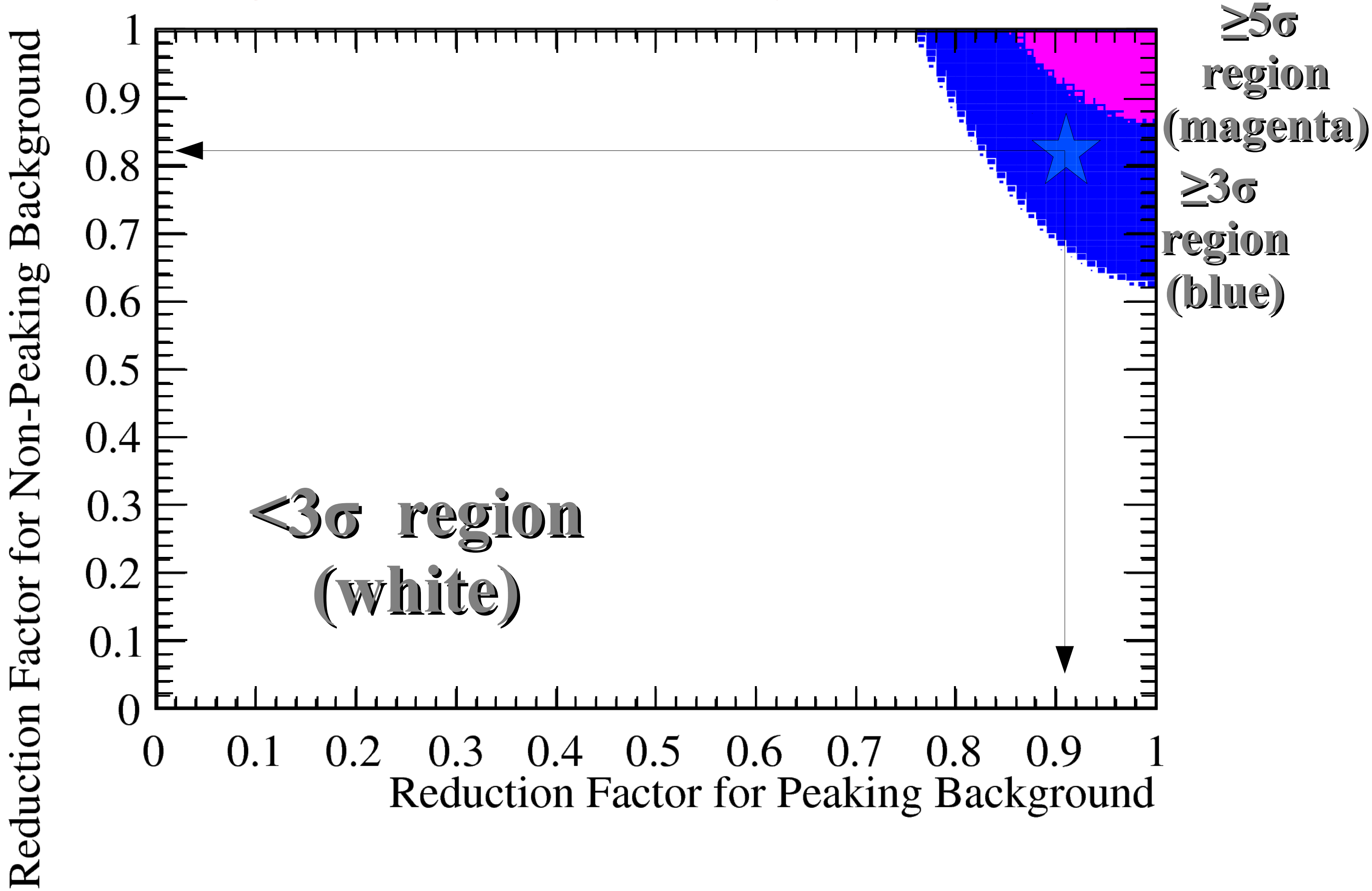


Background Reductions – Part II



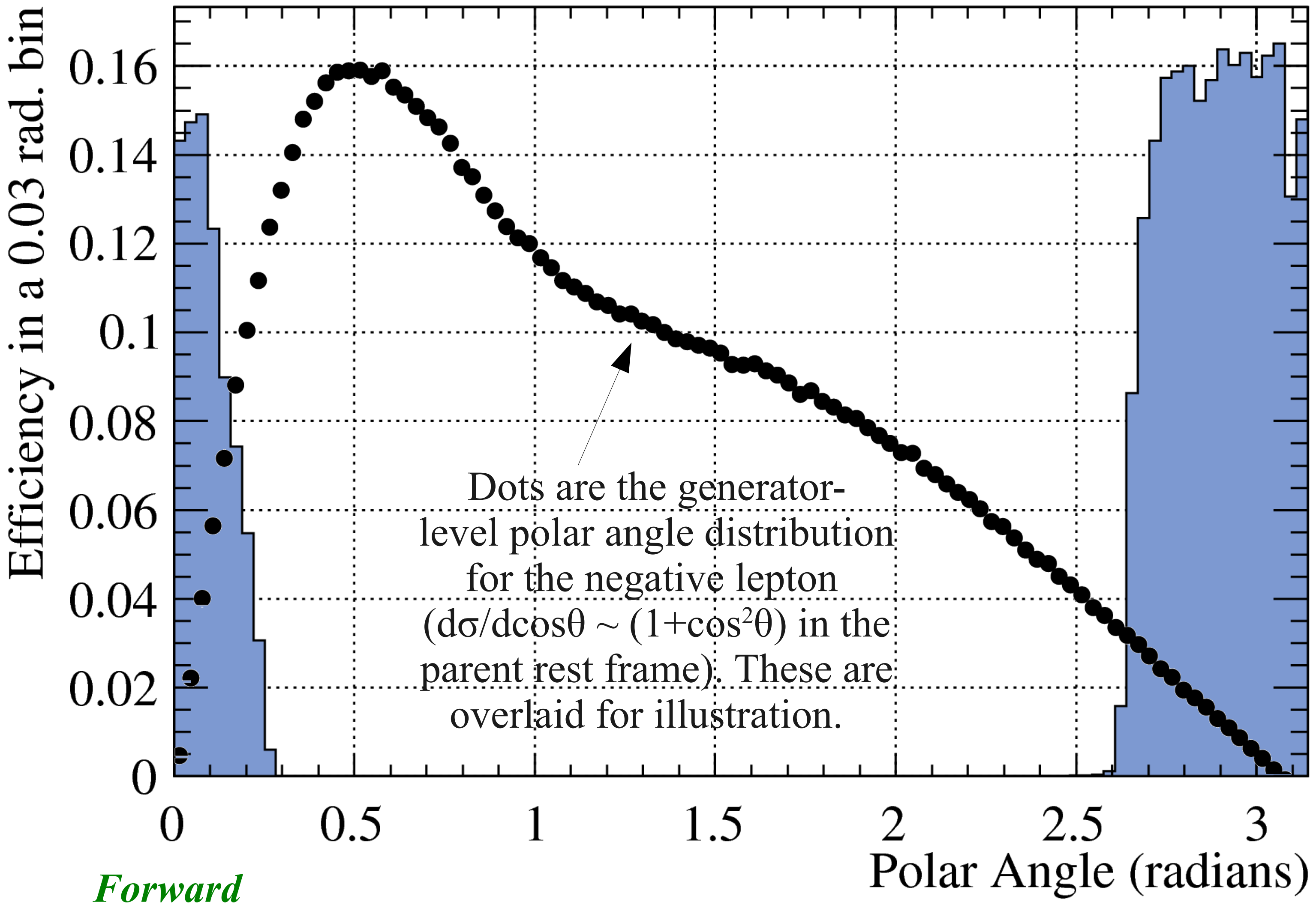
Background Reductions – Part III

Considering statistical AND reduced systematic uncertainties



Peaking Background

Efficiency for selecting an $\Upsilon \rightarrow \ell^+\ell^-$ event as "invisible" vs. polar angle of negatively-charged true lepton

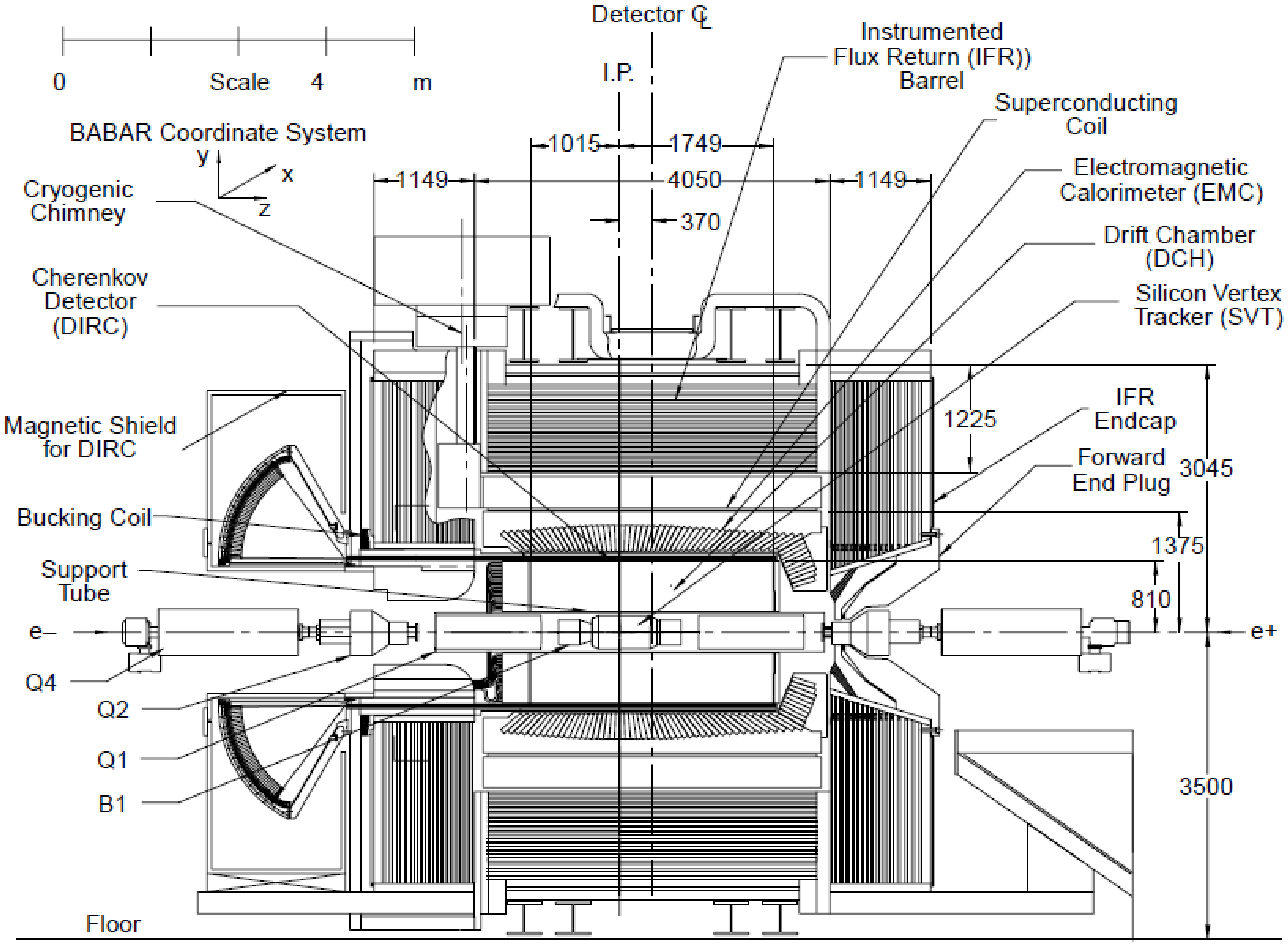


Dots are the generator-level polar angle distribution for the negative lepton ($d\sigma/d\cos\theta \sim (1+\cos^2\theta)$ in the parent rest frame). These are overlaid for illustration.

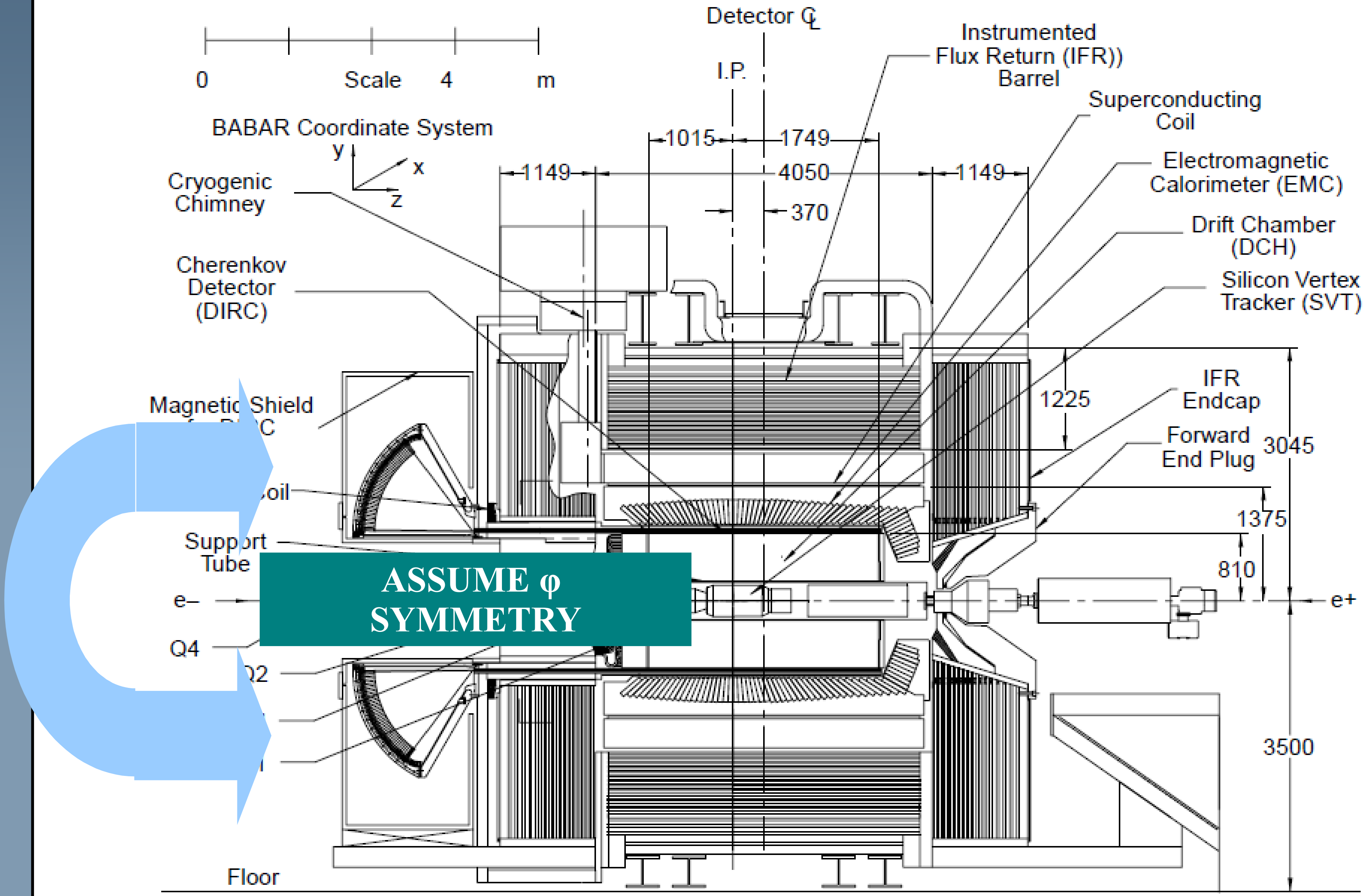
Forward Detector Region

Backward Detector Region

Peaking Background – cont.

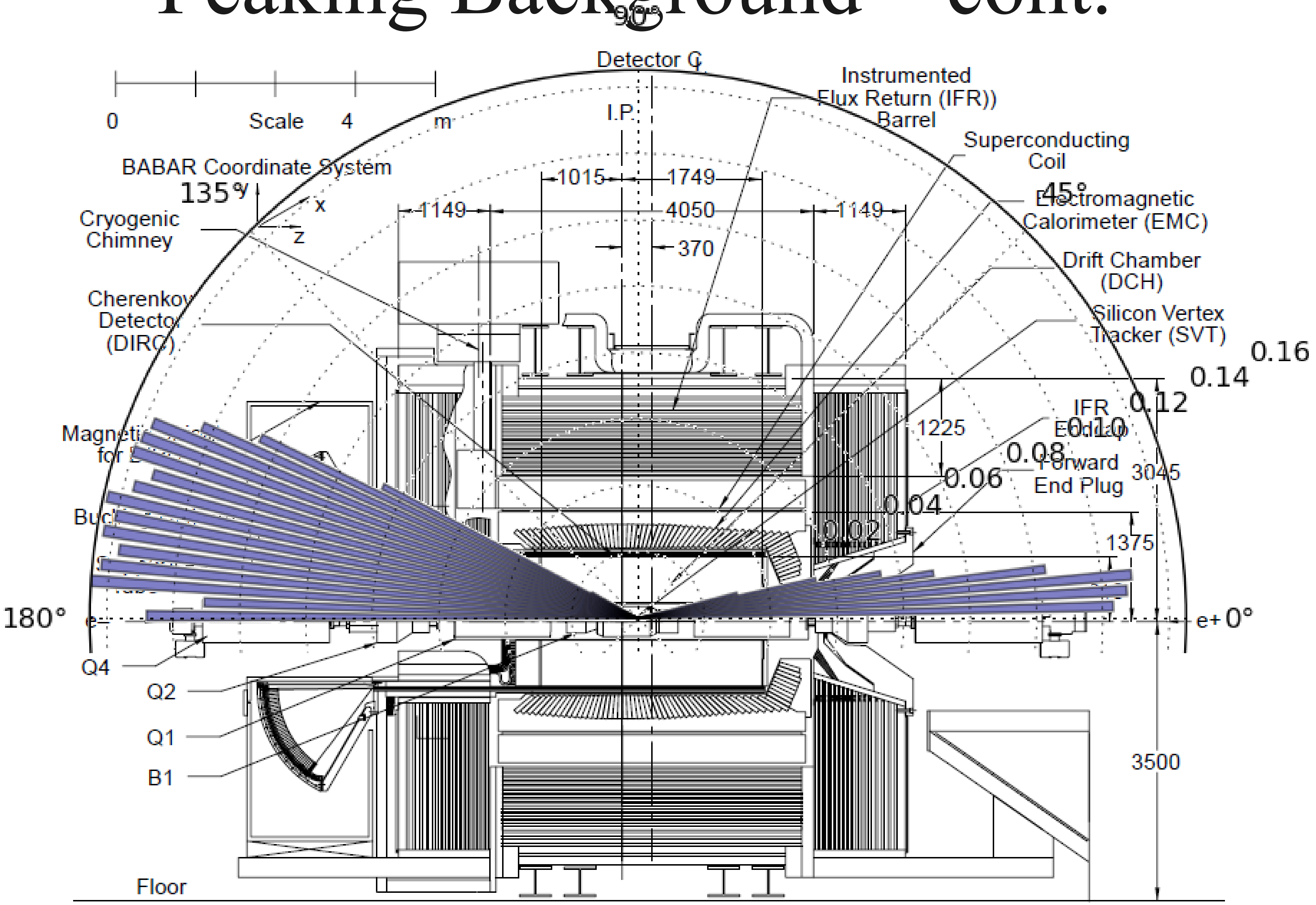


Peaking Background – cont.

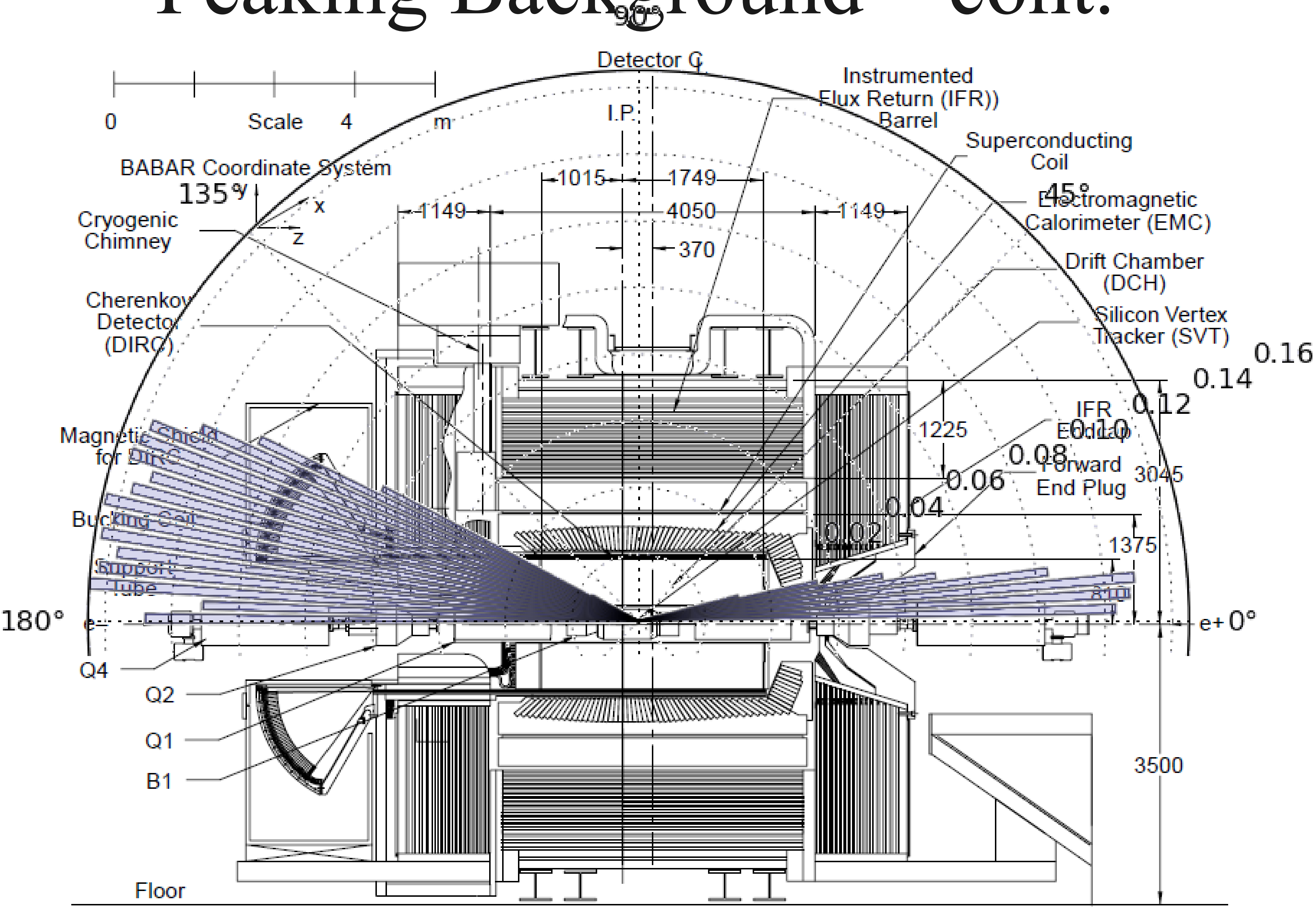


ASSUME φ SYMMETRY

Peaking Background – cont.



Peaking Background – cont.

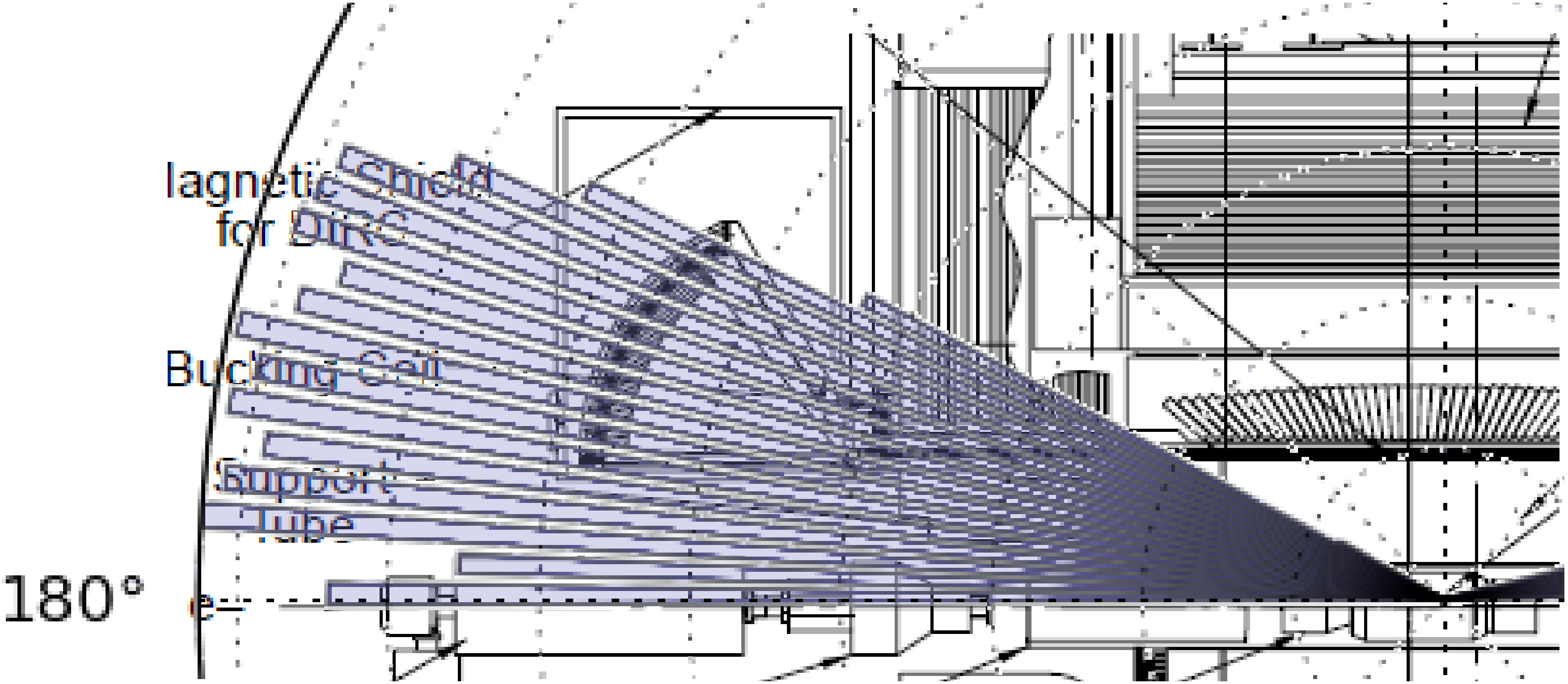


Peaking Background – A Discussion

- How can we further reduce peaking background?
  - we need additional instrumentation or handles
    - question: what can the DIRC SOB do for us?
- Is the benefit isolated to only peaking background?
  - No – QED background happens when the beam e^+ and e^- miss the detector, leaving only the $\gamma^*\gamma^*$ final state.
    - covering more of the solid angle will reject these events as well, though perhaps at a lower rate
    - beam lepton spectra peaked far forward (low scattering angle)

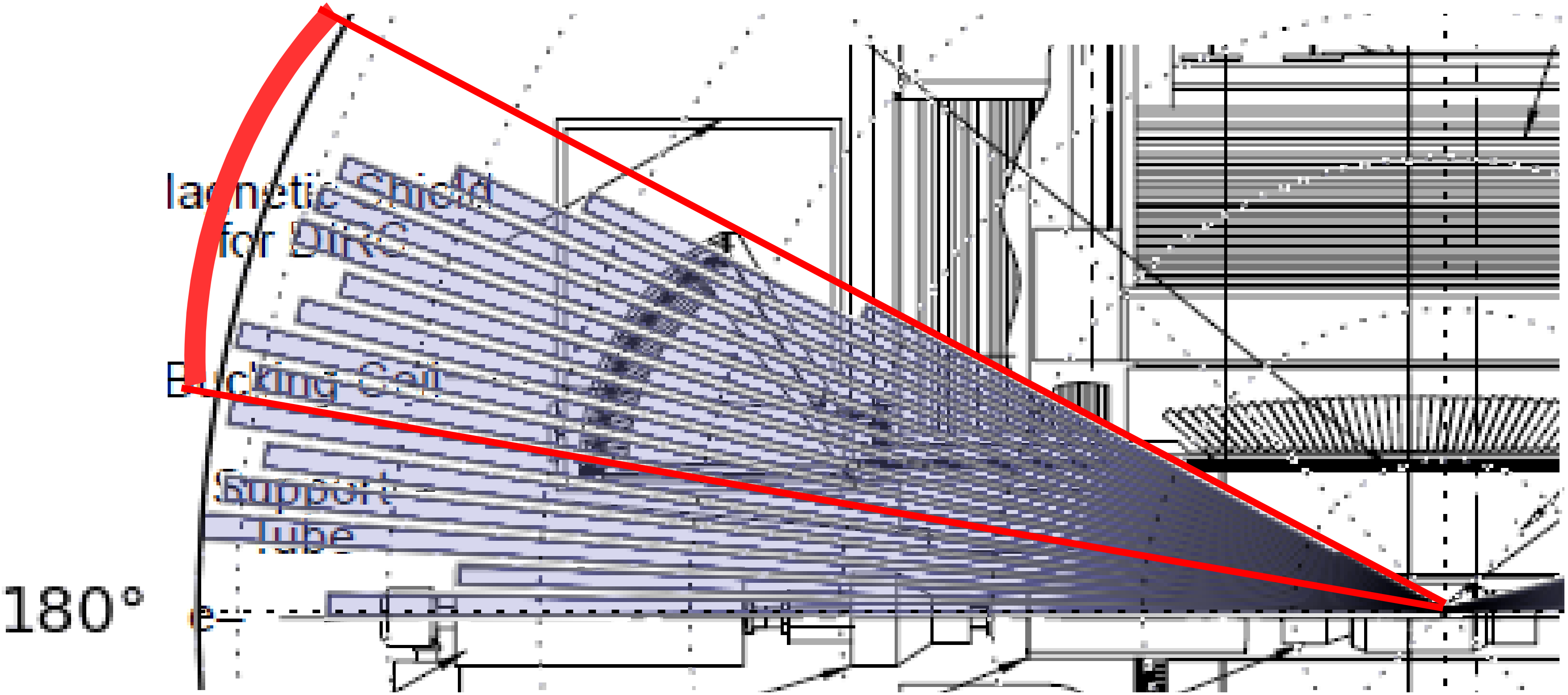
Scenario A:
Active Backward Calorimetry

This means finding a way to make the backward end of the detector re-active to the passage of charged particles.



Scenario A:
Active Backward Calorimetry

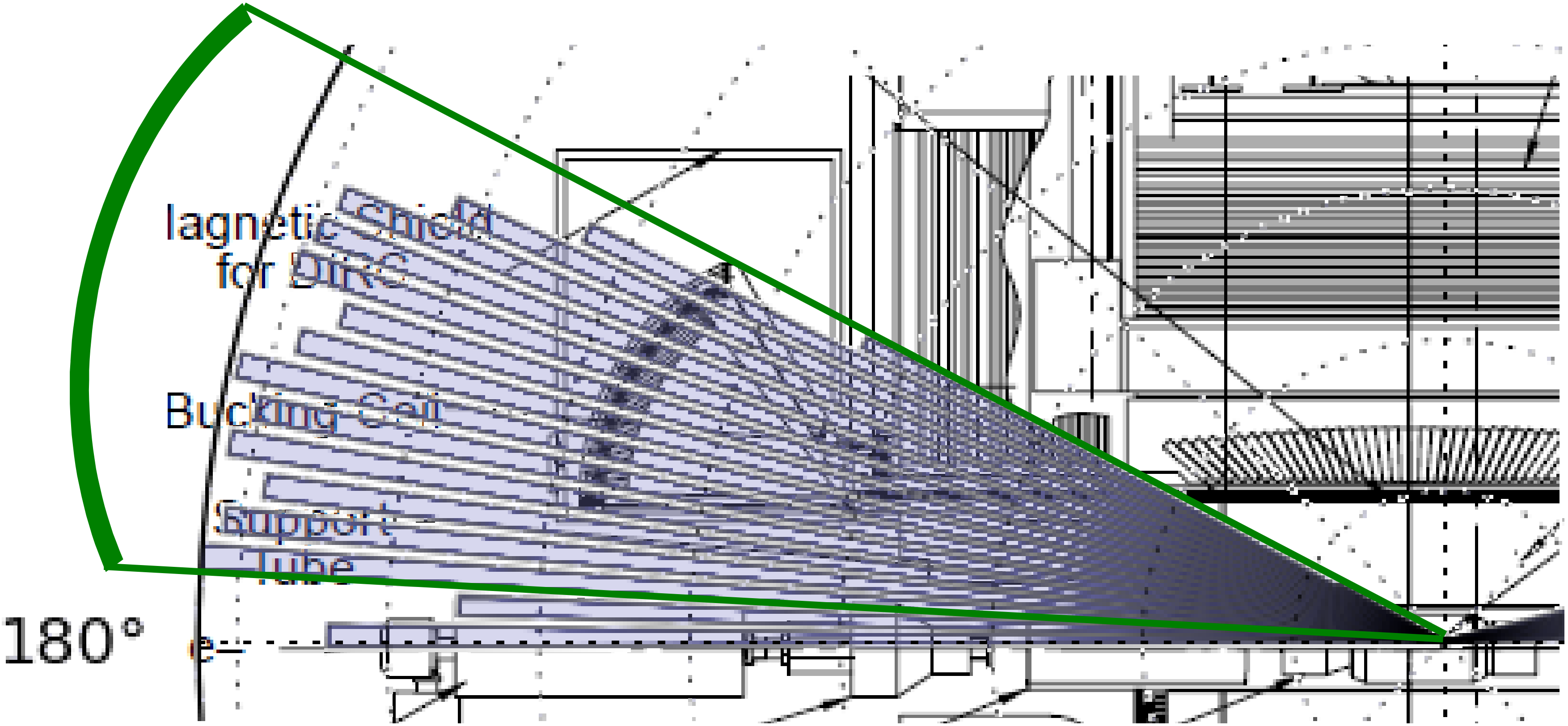
This means finding a way to make the backward end of the detector re-active to the passage of charged particles.



For this scenario, I will estimate the impact of a 90% reduction in events if either true lepton lies in the region enclosed above.

Scenario B: Close the Gap

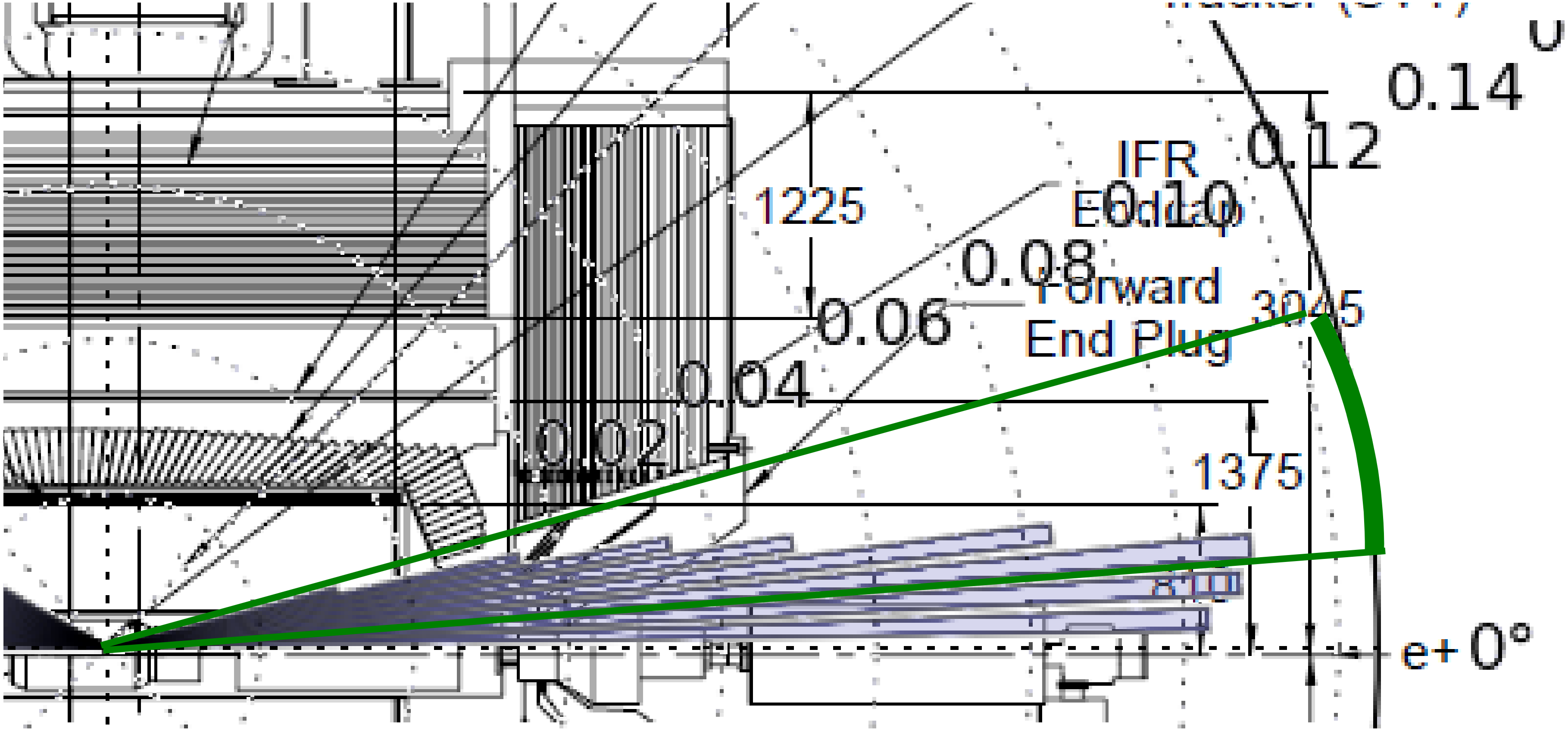
This means instrumenting both extreme ends of the detector with something – hopefully inexpensive – and store information about energy deposition for later vetoing.



For this scenario, I will estimate the impact of a 90% reduction in events if either true lepton lies in the region enclosed above.

Scenario B:
Close the Gap

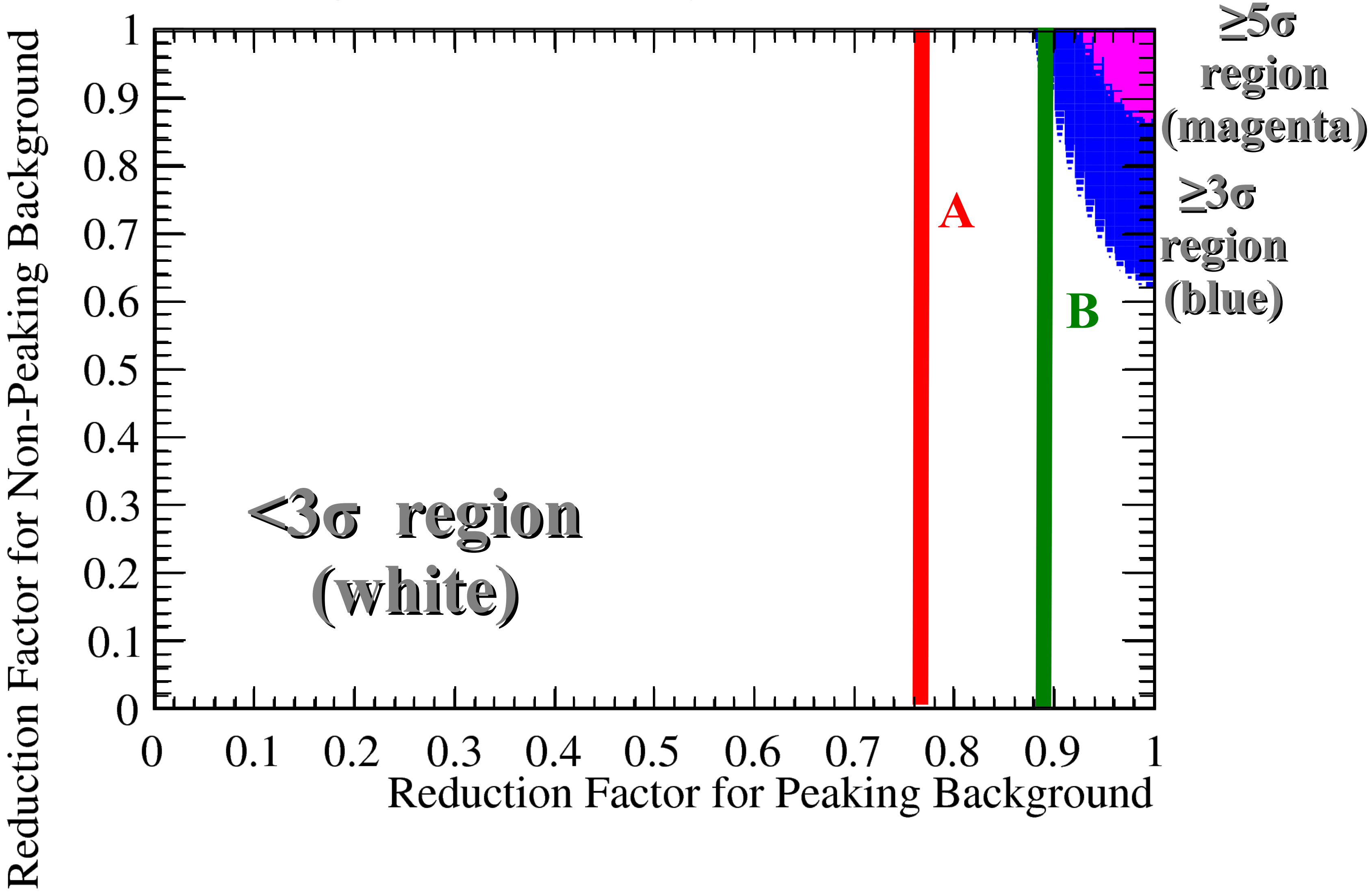
This means instrumenting both extreme ends of the detector with something – hopefully inexpensive – and store information about energy deposition for later vetoing.



For this scenario, I will estimate the impact of a 90% reduction in events if either true lepton lies in the region enclosed above.

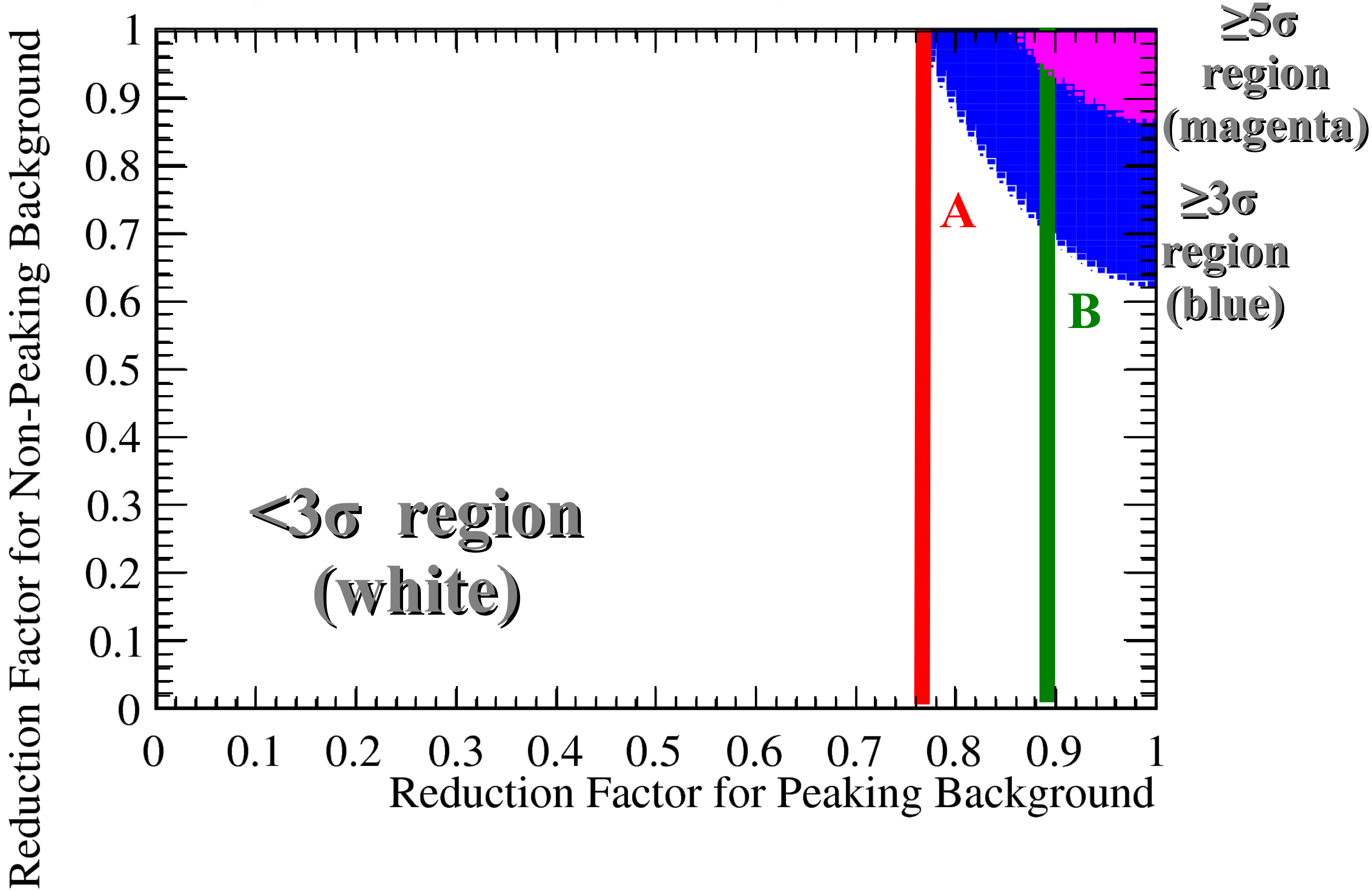
Scenarios: Impacts

Considering statistical AND systematic uncertainties



Scenarios: Impacts

Considering statistical AND reduced systematic uncertainties



Comments on the Scenarios

- Scenario A: Active backward calorimetry
  - It might be just enough to make the measurement
    - this statement assumes no other improvements
- Scenario B: Close the Gap
  - Requires a lot more work
  - Yields some flexibility in how hard to reject non-peaking background
    - might get much of that “for free” from this approach
  - Creates an opportunity for some detector R&D

Conclusions

- $\Upsilon \to \nu\bar{\nu}$ is within the grasp of Super-B
  - a test of a clean SM prediction
  - a "free" order-of-magnitude for discovery
- Evidence for this process requires work
  - reduce systematics, reduce backgrounds
  - need to think seriously about a veto in the "hole"
- Positive impact not limited to this final state
  - To the benefit of other analyses
    - $B \to \ell\nu$, $B \to K^{(*)} \nu\bar{\nu}$ – **keystone measurements** for rare decay processes, complimentary to LHC physics

Backup Slides

Comments on Υ(2S)

- Why haven't I talked about Υ(2S)?
  - branching fraction to $\pi^+\pi^-$ is bigger by factor of 4
  - production cross-section 2x larger than Υ(3S)
- Difficult to trigger
  - significantly lower p_T pions are produced here
- Systematics expected to be same scale
  - expect peaking background rate to be larger
  - means bigger contribution to yield uncertainty
- This mode needs careful thought and more work

How do we improve systematics?

- Trigger systematics
    - a dream:
        - a tool that easily lets you
            - remove trigger objects from data which are related to certain particles (e.g. hard leptons)
            - recycle the modified event through the actual hardware trigger, or a close *virtual* analog
            - measure the efficiency of the real trigger on the events
        - I once mentioned this dream to a trigger expert, as relates to our BaBar analysis
            - "You should have thought of that in 1995."
            - Well, I'm thinking of it now for Super-B, with intent to use it in 2015 or so.
- Others: MC models, etc. need study with BaBar data

References

- Experimental results

1. The BABAR Collaboration: B Aubert, “A Search for Invisible Decays of the Upsilon(1S),” 0908.2840 (August 19, 2009), http://arxiv.org/abs/0908.2840.

- Theory

Pierre Fayet, “Constraints on Light Dark Matter and U bosons, from psi, Upsilon, K+, pi0, eta and eta' decays,” hep-ph/0607318 (July 28, 2006), doi:doi:10.1103/PhysRevD.74.054034, http://arxiv.org/abs/hep-ph/0607318.

Bob McElrath, “Light Higgses and Dark Matter at Bottom and Charm Factories,” 0712.0016 (December 3, 2007), http://arxiv.org/abs/0712.0016.

Gagik K Yeghiyan, “Υ Decays into Light Scalar Dark Matter,” 0909.4919 (September 27, 2009), http://arxiv.org/abs/0909.4919.