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

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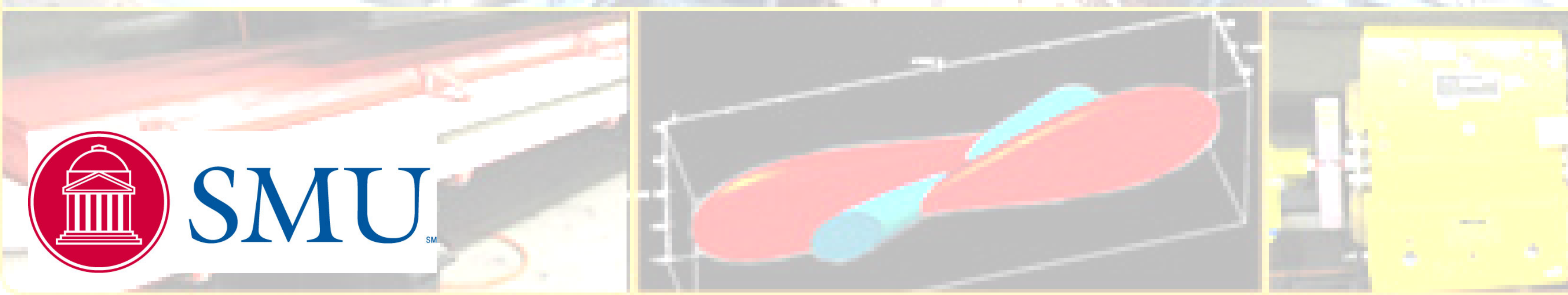


Outline

- 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, ...

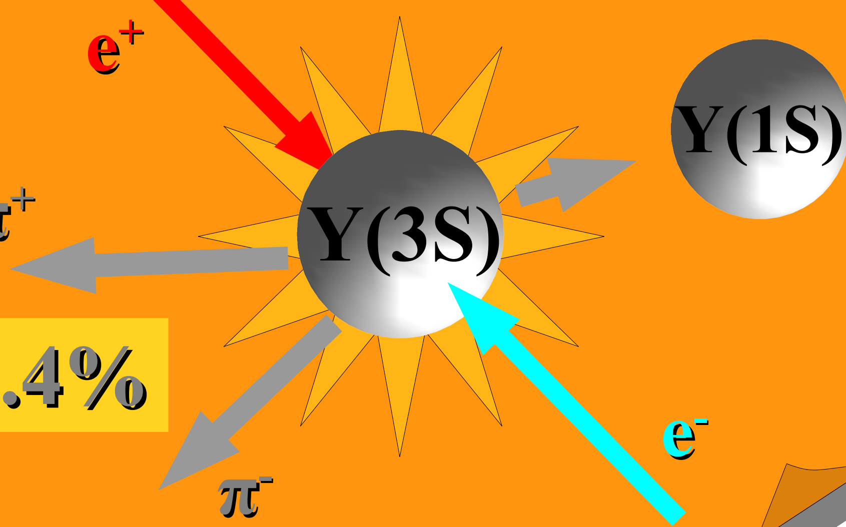
Most recently, Yeghiyan calculated from an effective theory that:

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

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.

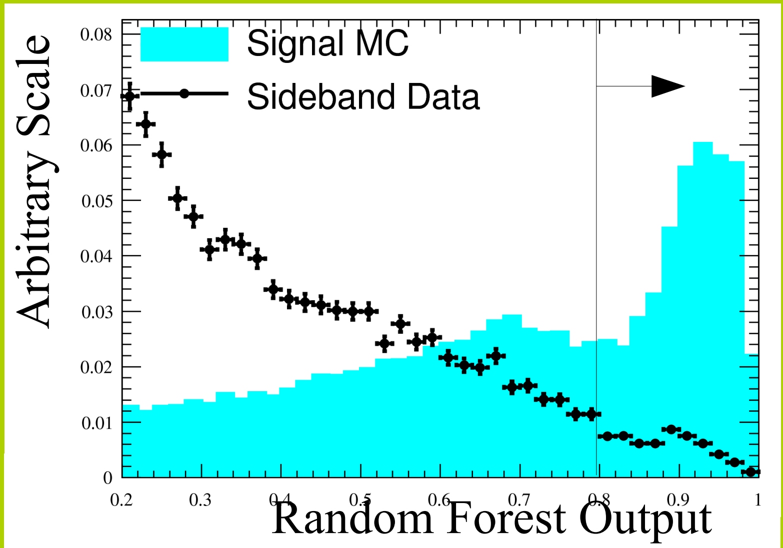
Measurement Technique

"Tag" on the di-pion transition from Υ(3S)



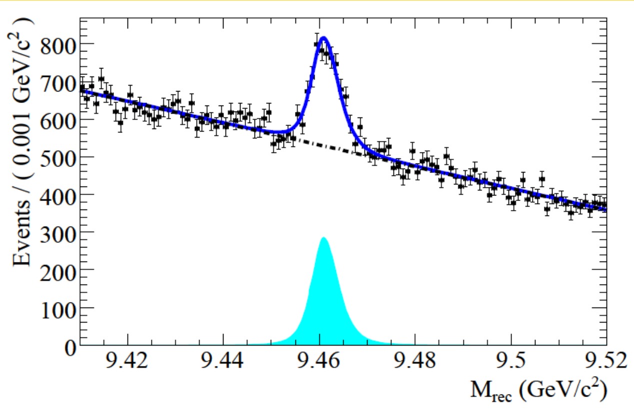
4.4%

Reject background with a random forest (decision tree algorithm)



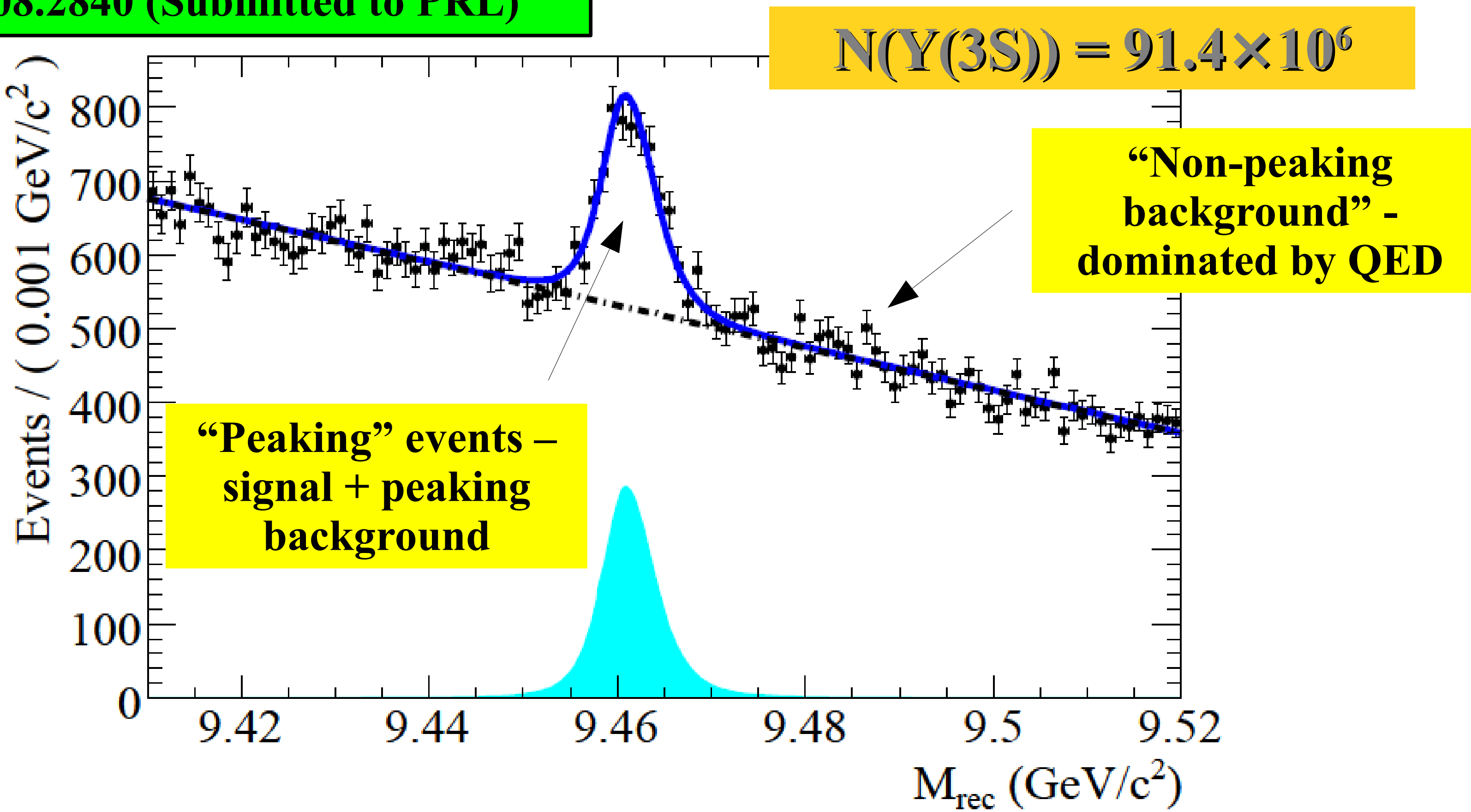
$\varepsilon_{sig}^{total} = 17\%$

Fit for a peak in the mass recoiling against the pions



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

arXiv:0908.2840 (Submitted to PRL)



Peaking Background: 2444 ± 123 events

Signal Yield: -118 ± 105 ± 124

$BR(\Upsilon \rightarrow invisible) = (-1.6 \pm 1.4 \pm 1.6)\times 10^{-4}$

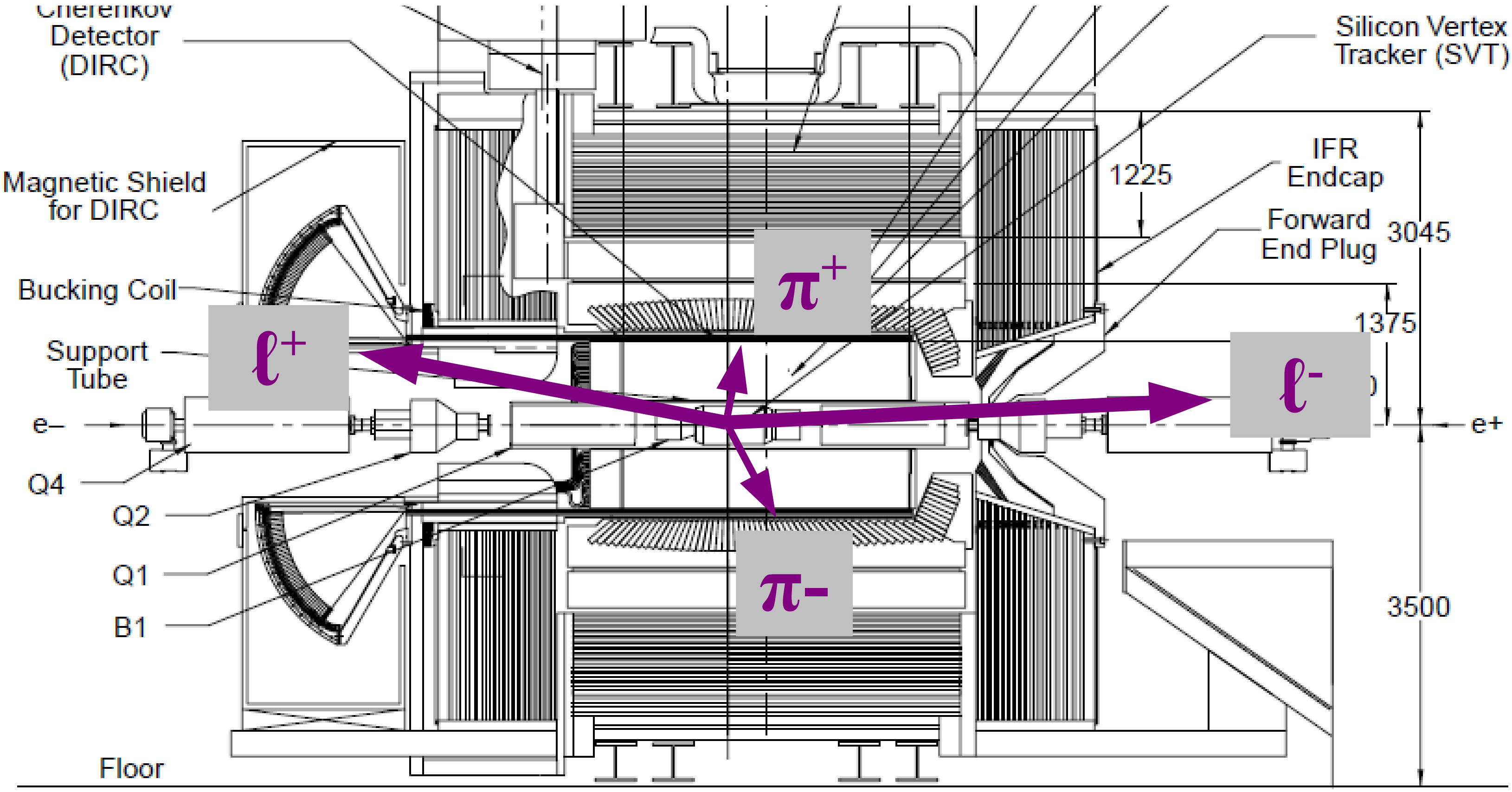
Why Care About $\Upsilon \rightarrow \nu\bar{\nu}$?

- 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 $\Upsilon \rightarrow e^{+}e^{-}$ 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
± 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 single largest effects (± 2.1% and ± 4.0%)

The total systematic uncertainty is about 5%

Pursuing the Invisible

Assumptions for this Study

- 100x more Υ(3S) at Super-B

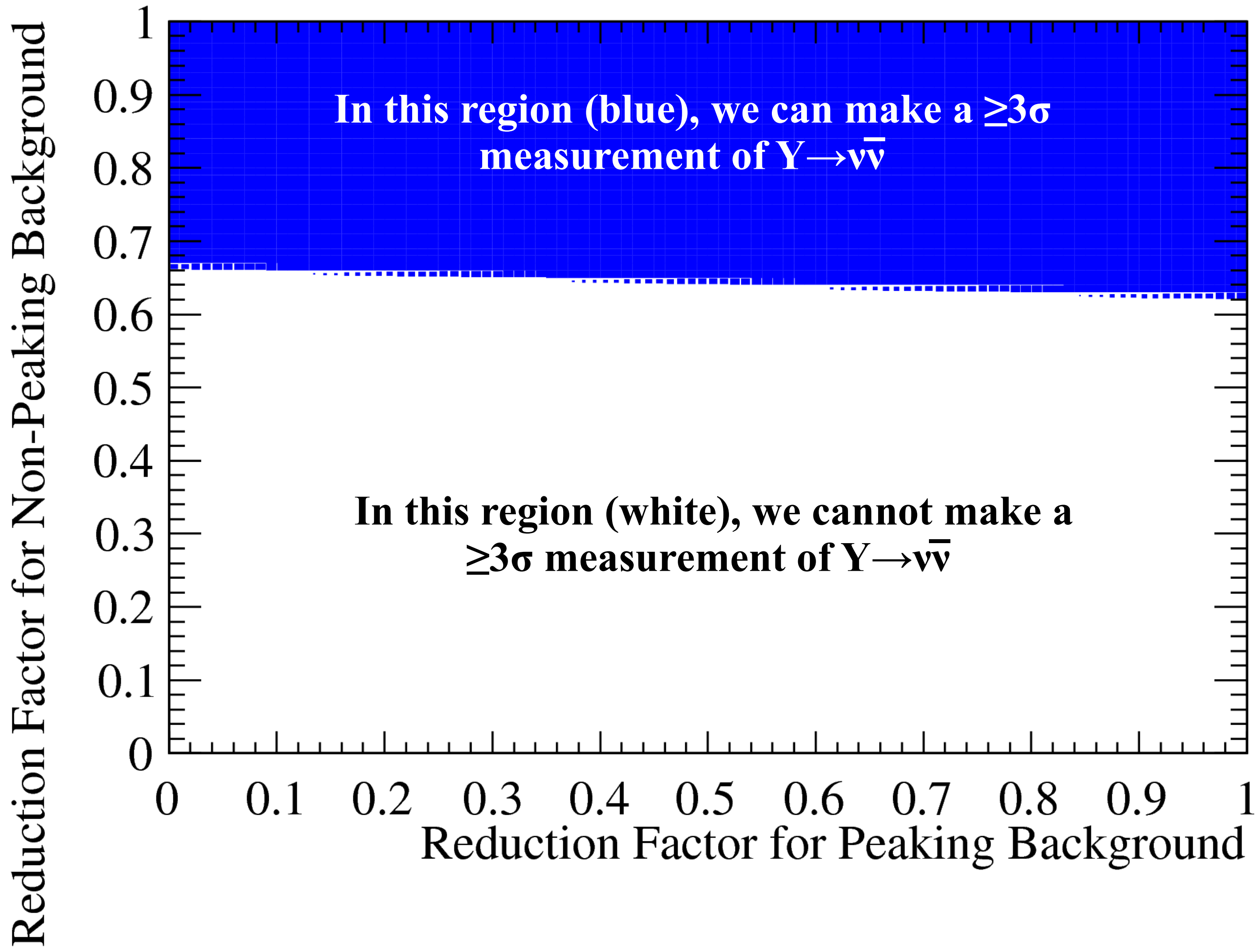
~few months running at full luminosity

- 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?

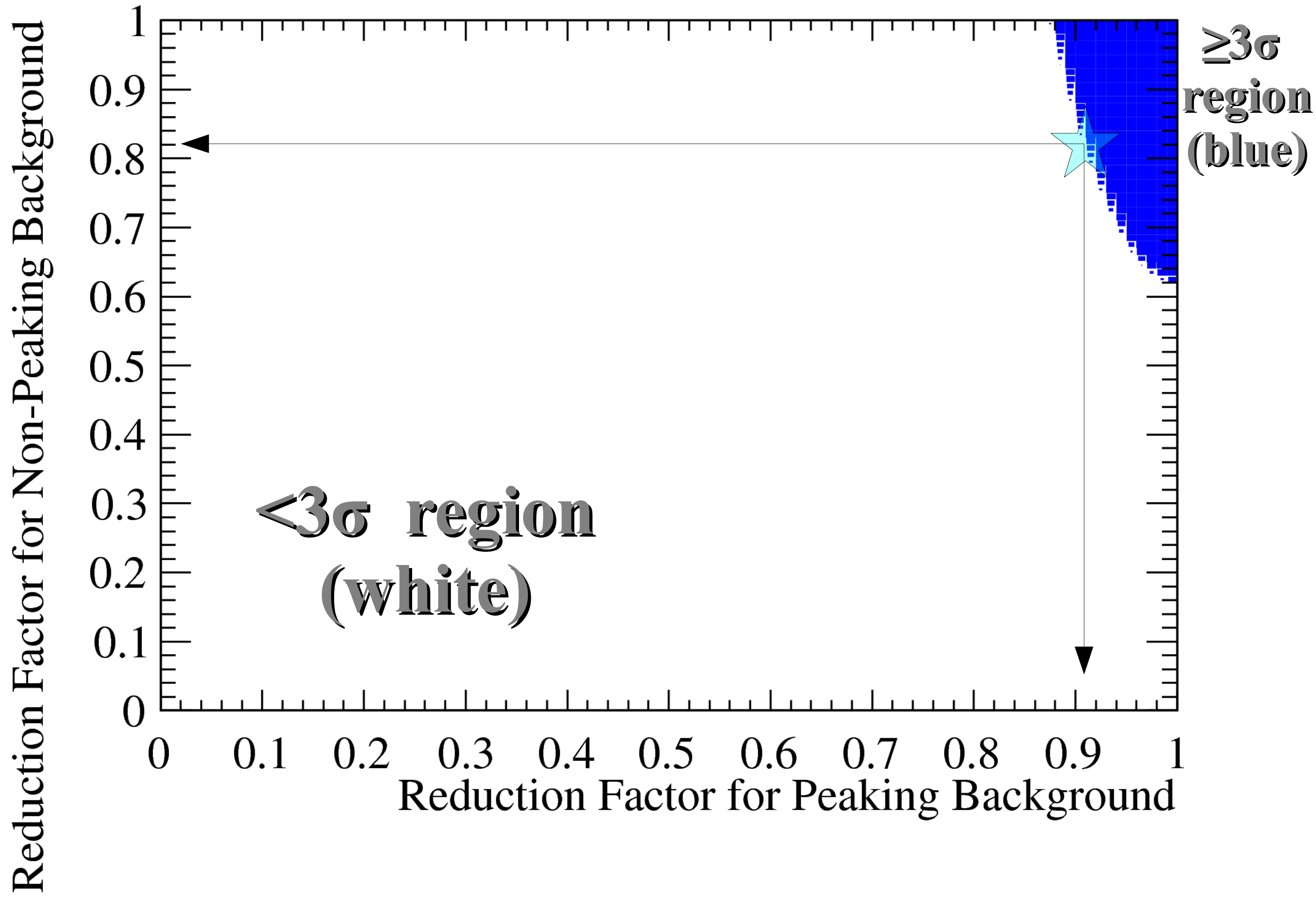
Background Reductions – Part I

Considering ONLY statistical uncertainties



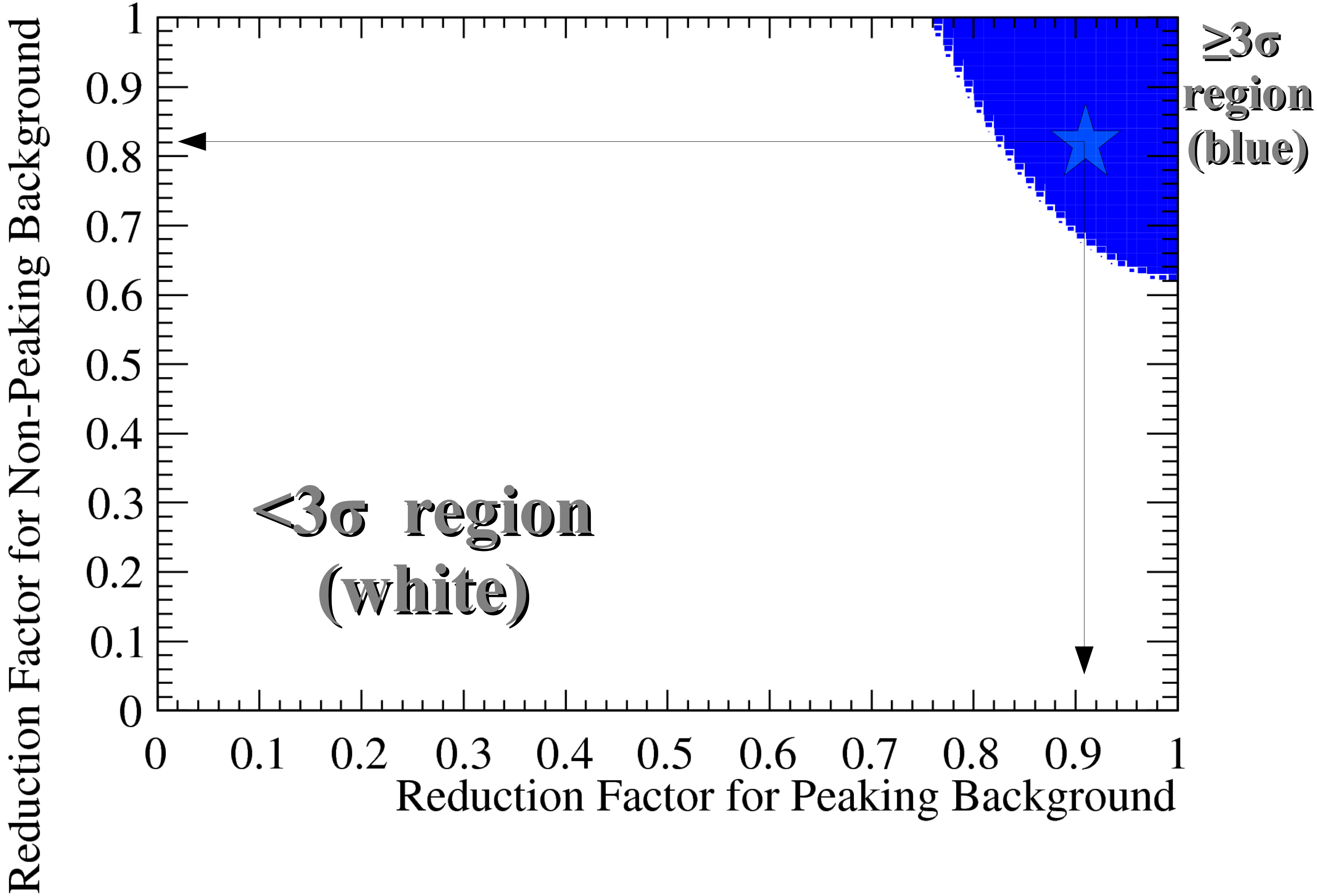
Background Reductions – Part II

Considering statistical AND systematic uncertainties



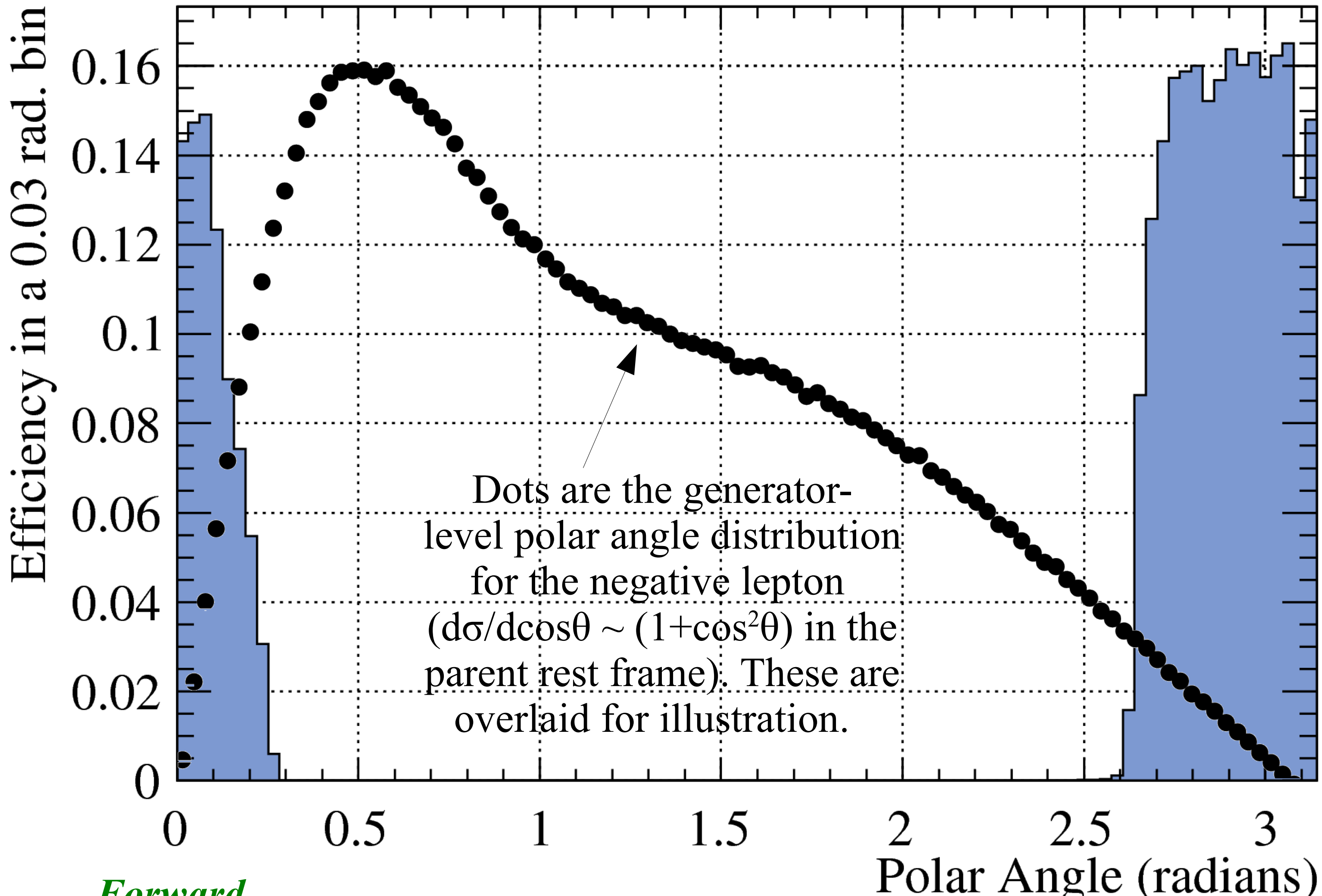
Background Reductions – Part III

Considering statistical AND reduced systematic uncertainties



Peaking Background

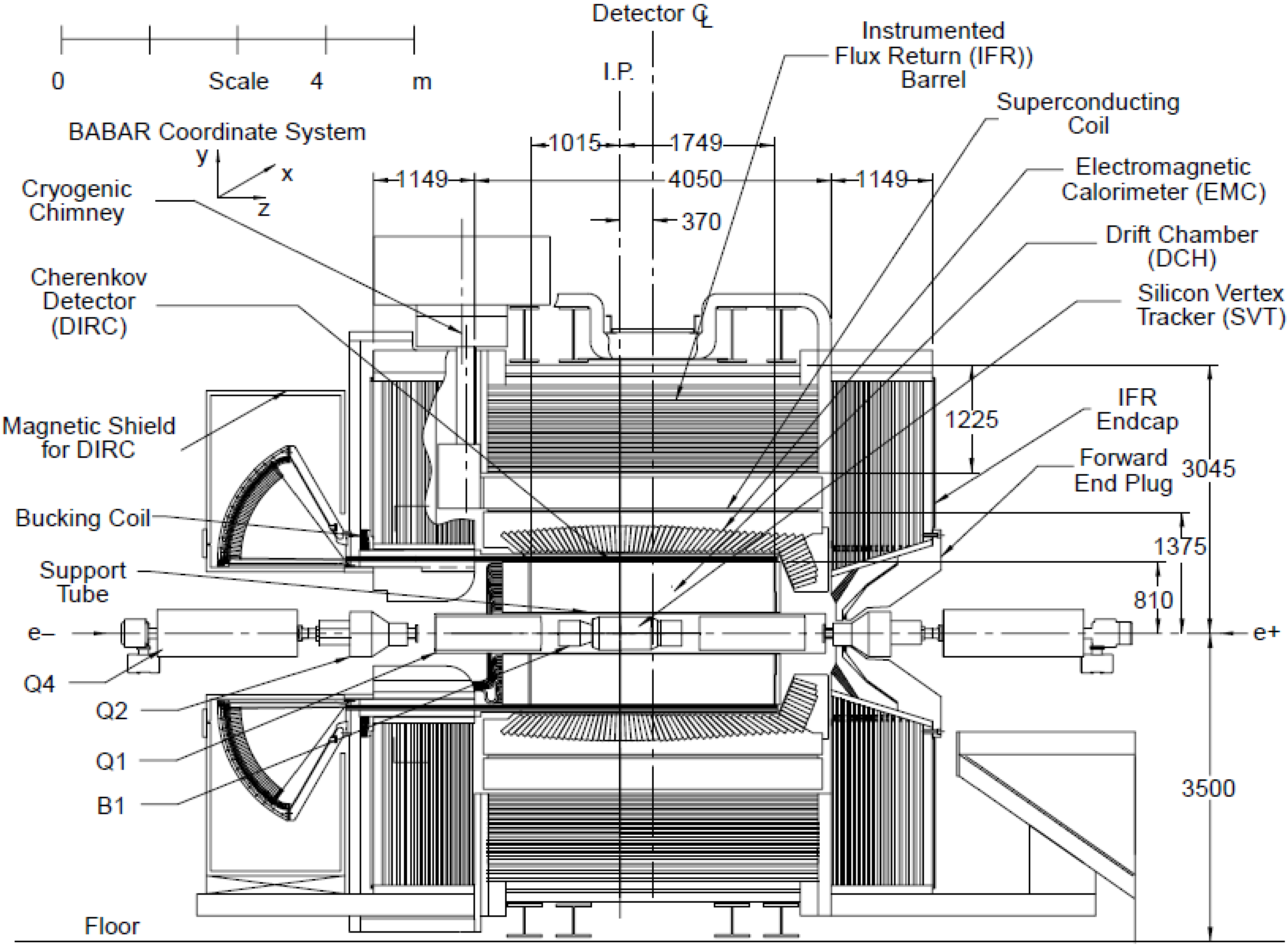
Efficiency for selecting an $\Upsilon \rightarrow \ell^+\ell^-$ event as "invisible" vs. polar angle of negatively-charged true lepton



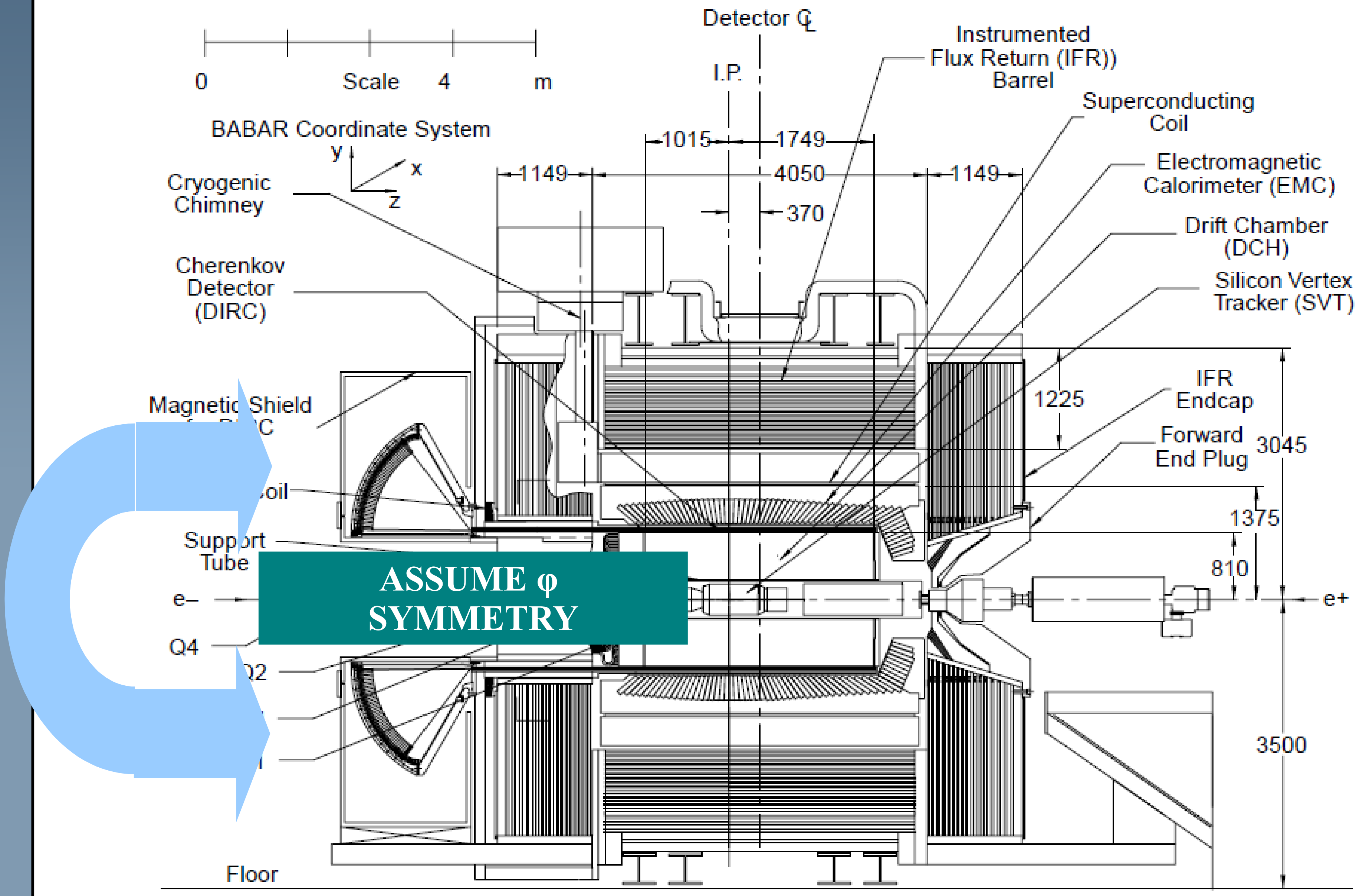
Forward Detector Region

Backward Detector Region

Peaking Background – cont.



Peaking Background – cont.



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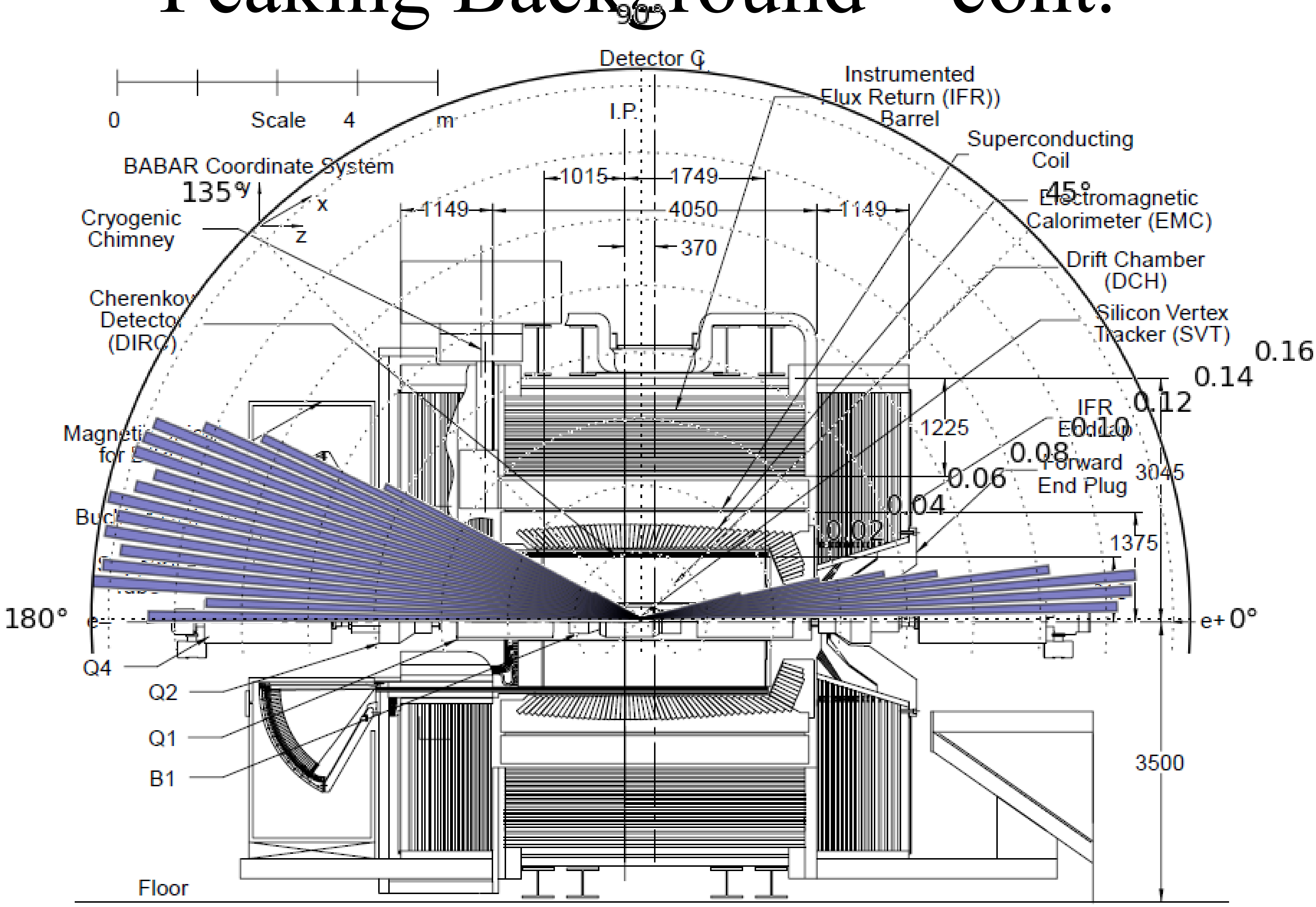

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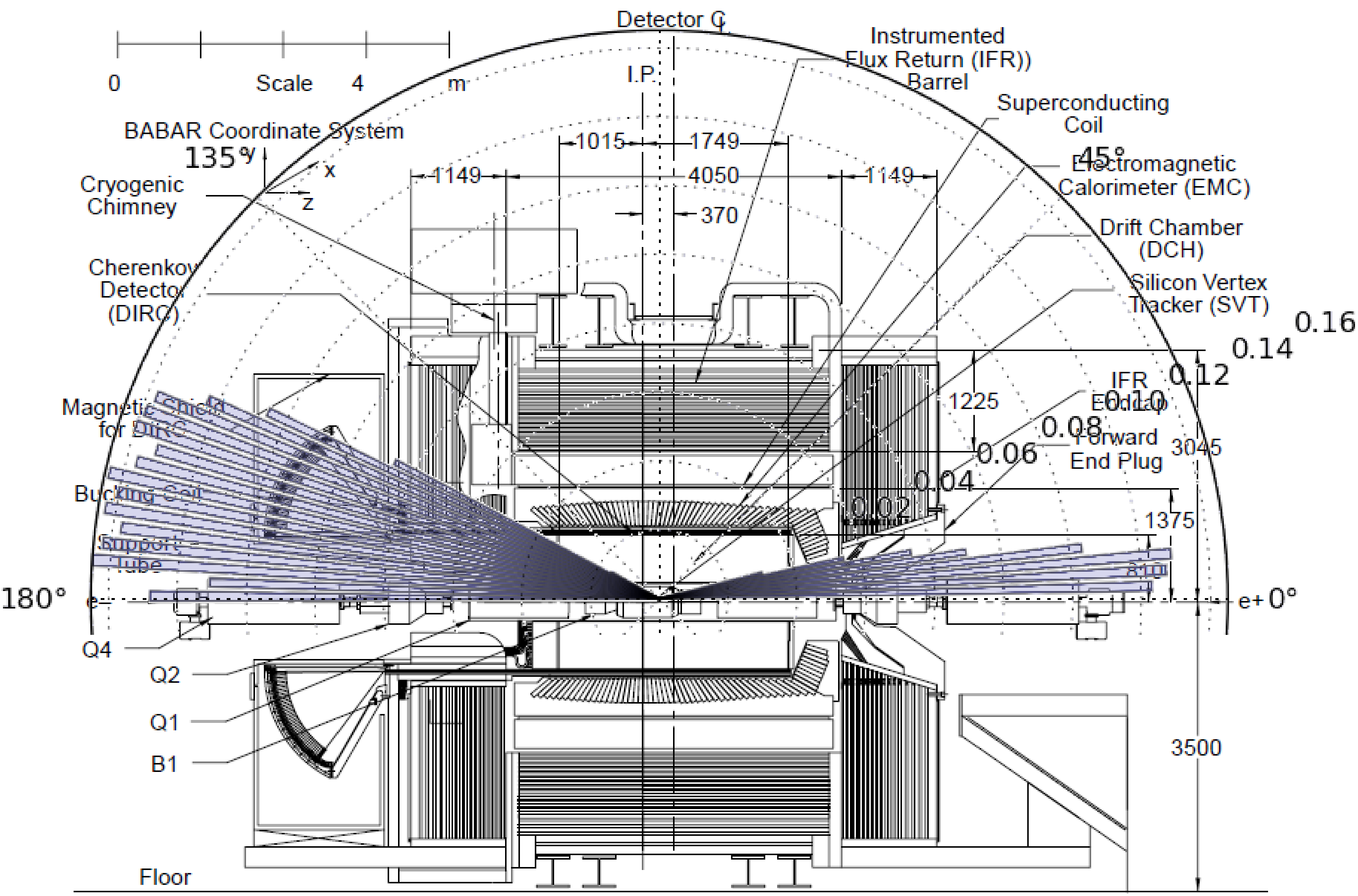
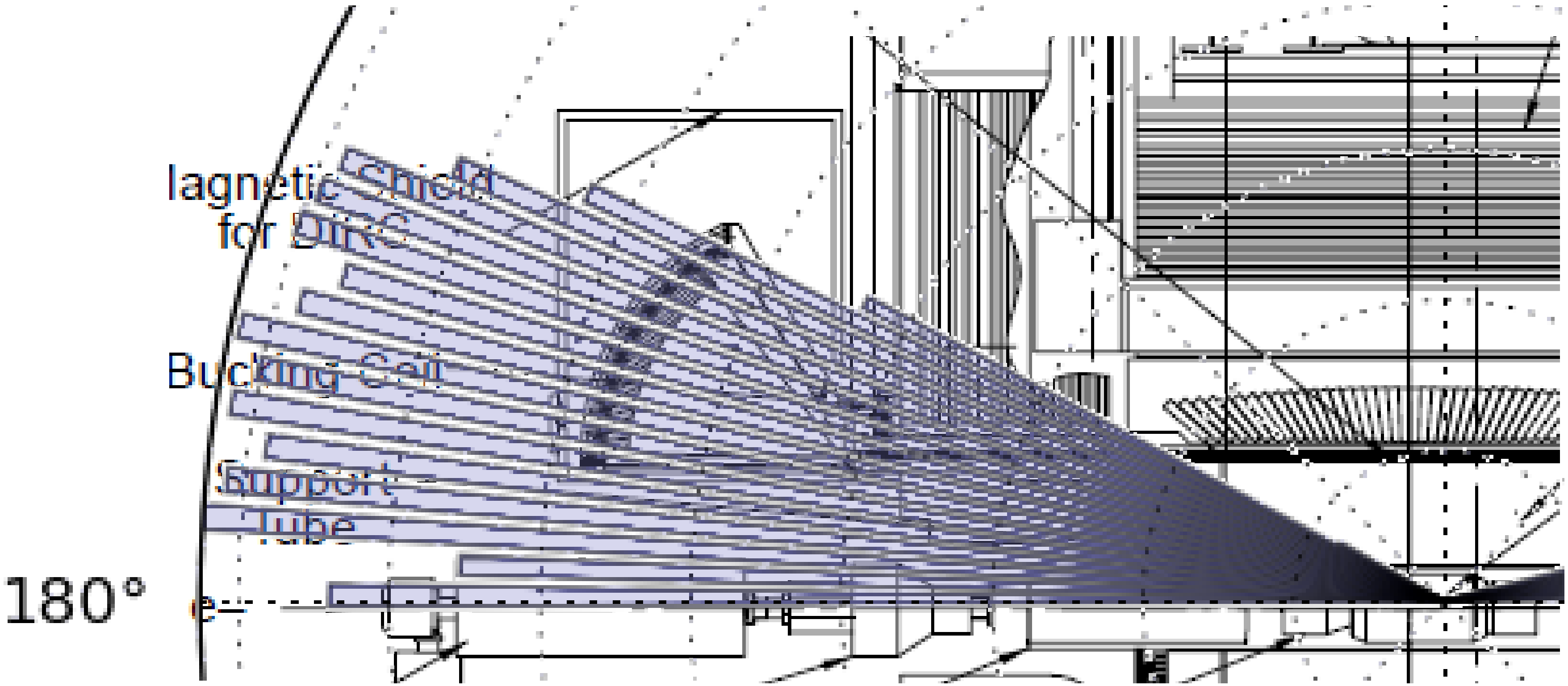


Peaking Background – A Discussion

- 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:
The Re-active SOB

This means either (a) finding a way to use the current (and future) DIRC with no major changes to the system or surrounding systems (e.g. counting excess DIRC photons) or (b) instrumenting the DIRC in some way to detect the passage of tracks (a calorimeter or scintillator)



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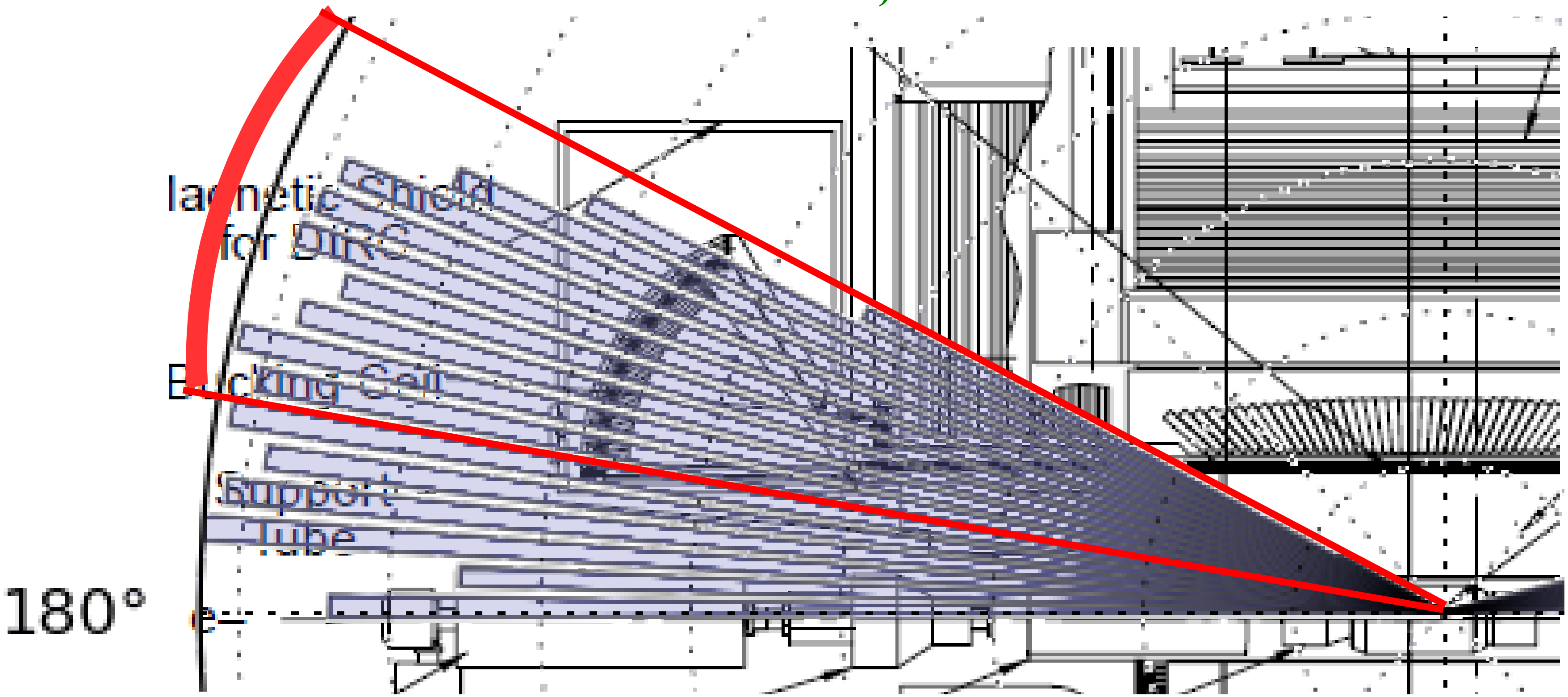
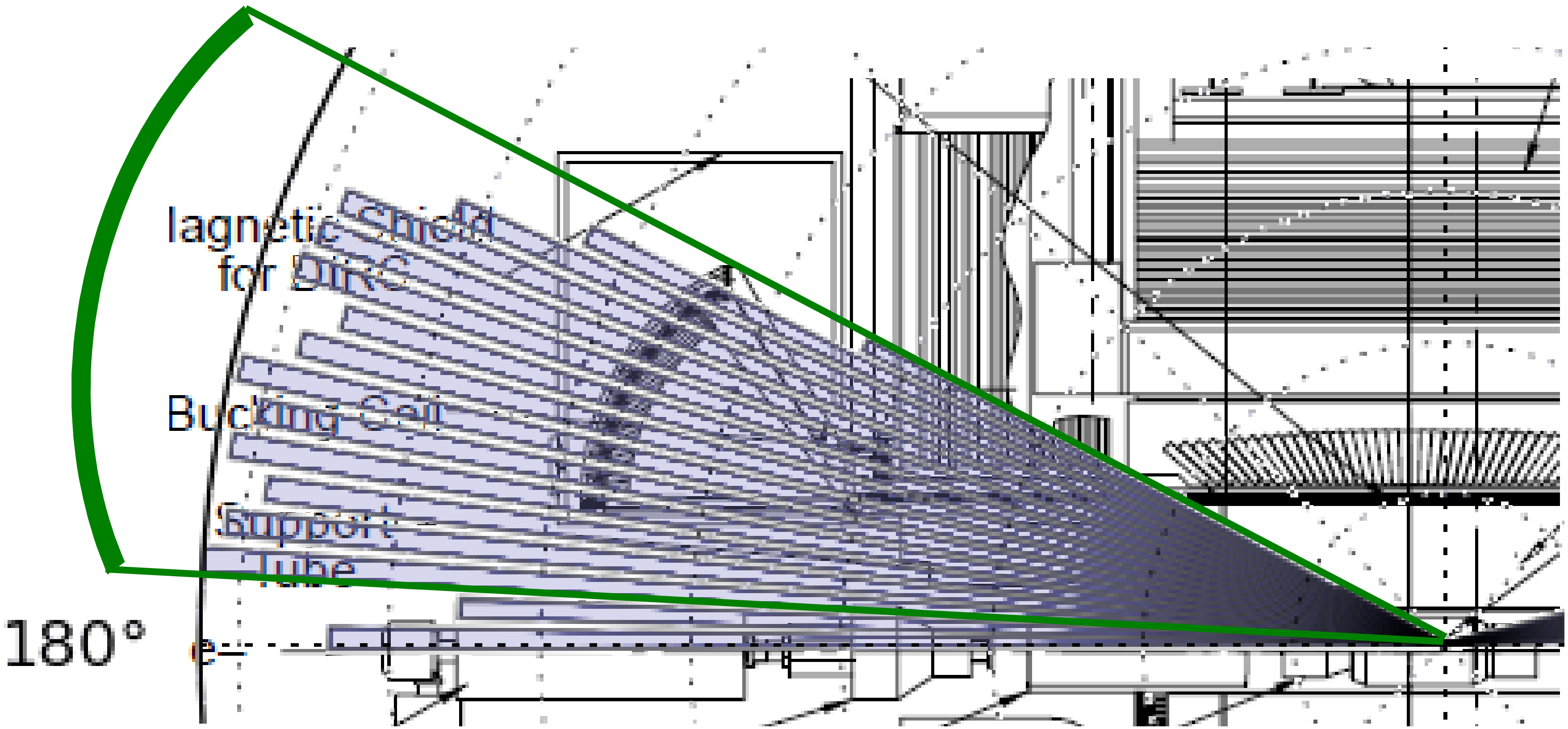


For this scenario, I will estimate the impact of a 90% reduction in events if either true lepton lies in the region enclosed above.

Scenario B: Close the Gap

This means instrumenting the back-end of the detector with something – hopefully inexpensive – and store information about energy deposition for later vetoing.



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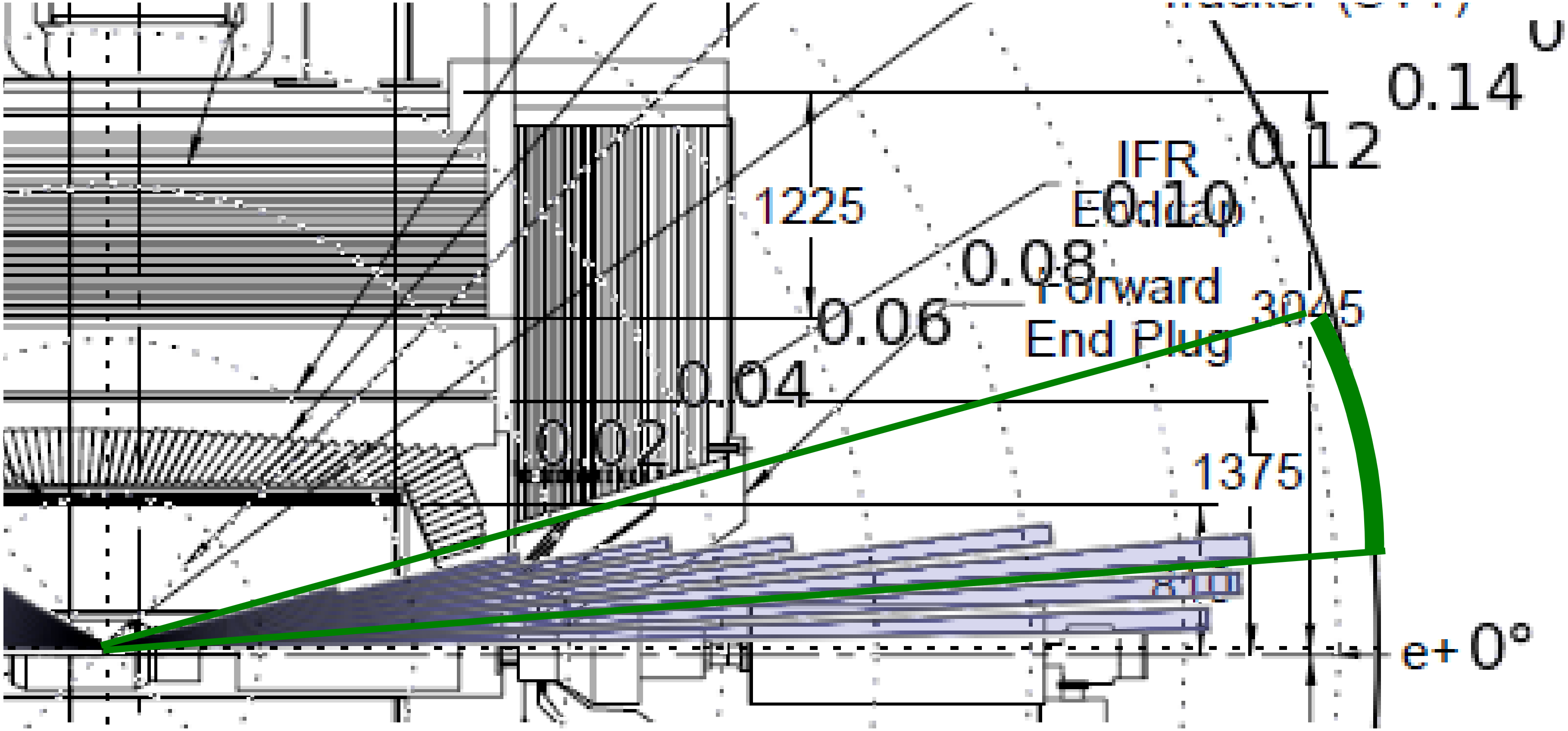

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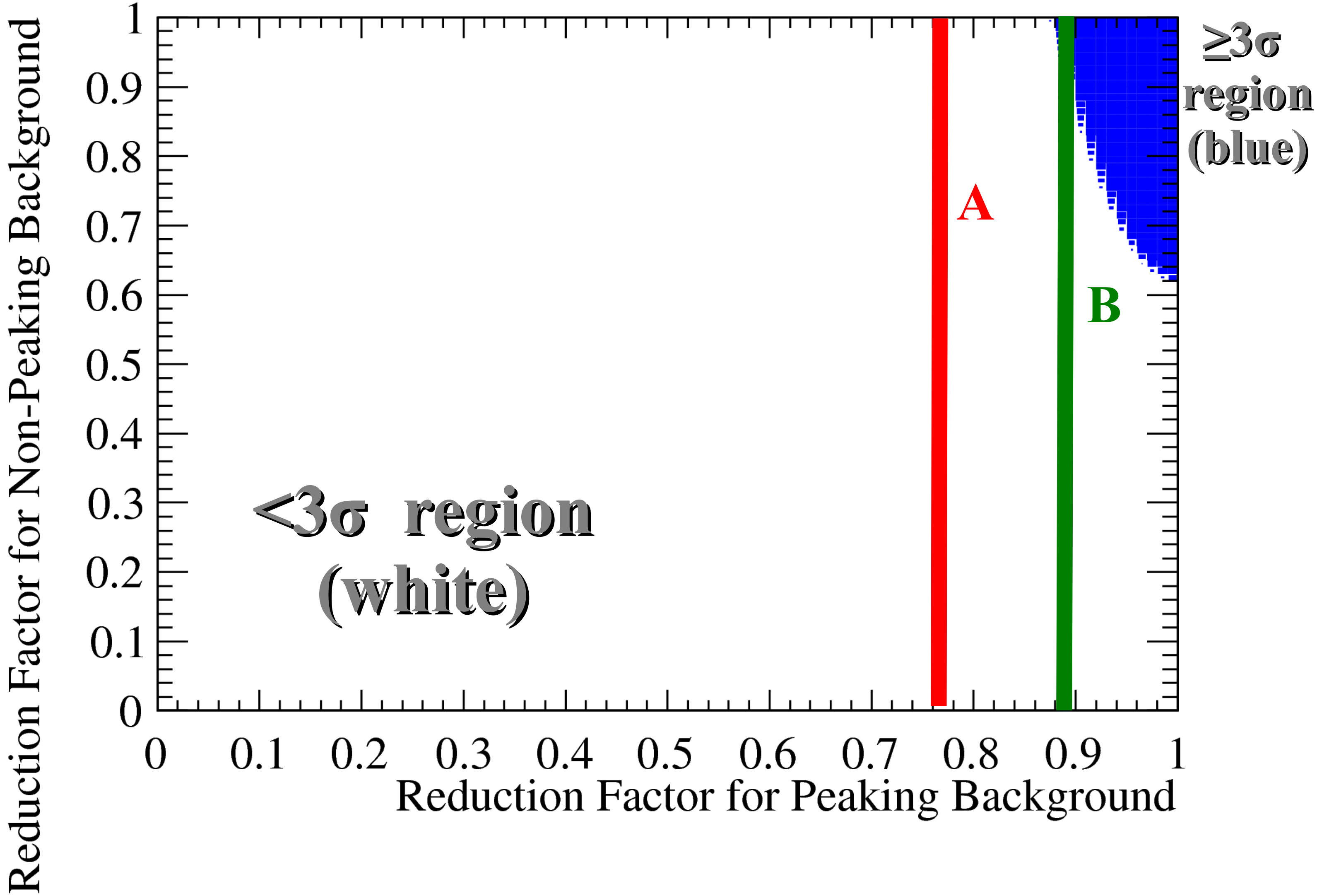
Scenarios: Impacts

Considering statistical AND systematic uncertainties



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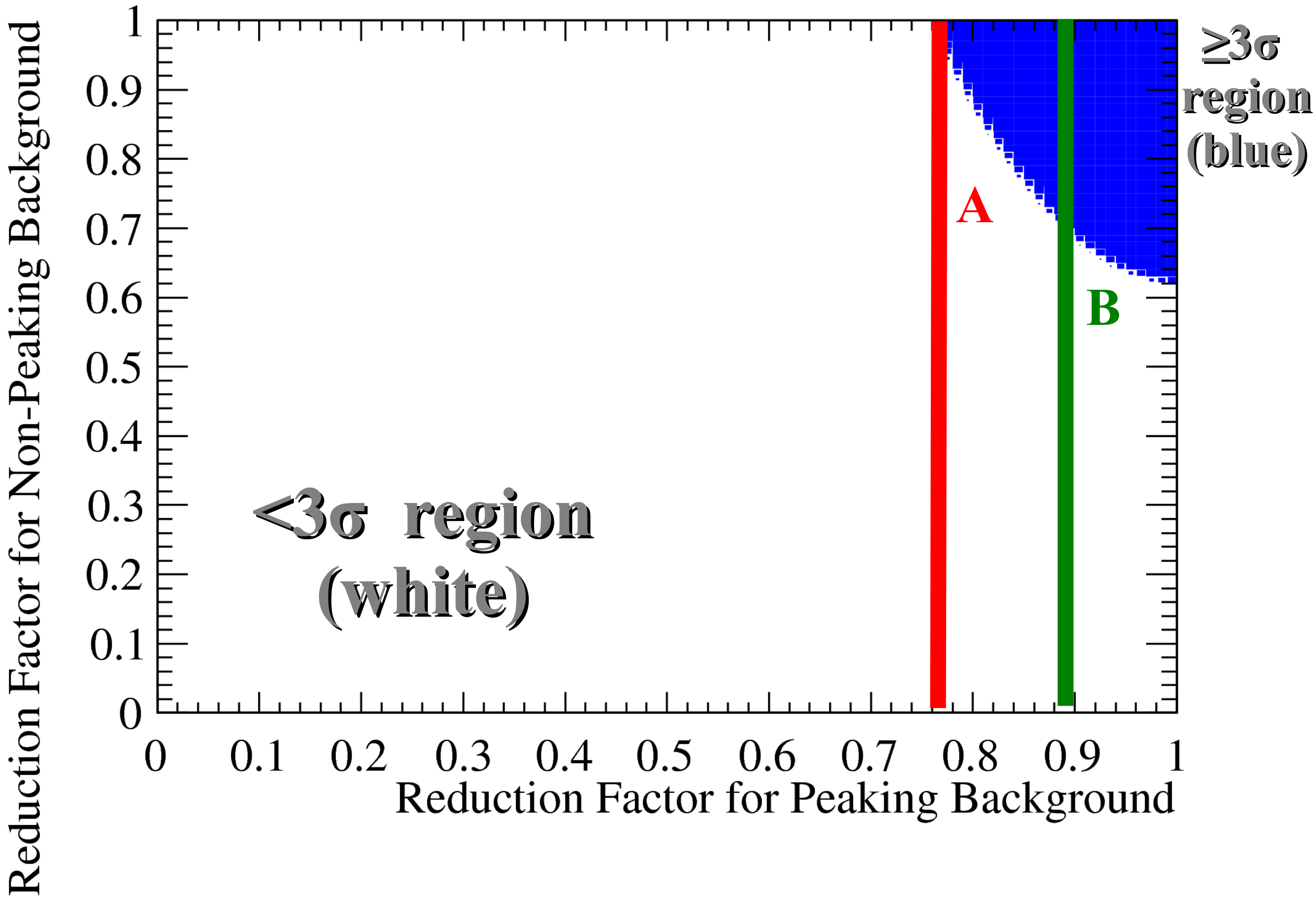

Comments on the Scenarios

- Scenario A: The Re-active SOB
  - It's something we can study with present data
  - 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

- $\Upsilon \rightarrow \nu\bar{\nu}$ 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
    - $B \rightarrow \ell\nu$, $B \rightarrow K^{(*)}\nu\bar{\nu}$ – **keystone measurements** for rare decay processes, complimentary to LHC physics

Backup Slides

Comments on Y(2S)

- Why haven't I talked about Y(2S)?
  - branching fraction to $\pi^+\pi^-$ is bigger by factor of 4
  - production cross-section 2x larger than Y(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.