Background Estimation for LLP Detectors

Slides by Benjamin Nachman
(With minor adaptations from me)

(with lots of discussion with Vava Gligorov, Simon Knapen,
Michele Papucci, Dean Robinson
and the rest of the CODEX-b collaboration)

Feb. 19, 2021

Anubis
Collaboration Meeting

Motivation

Dedicated LLP detectors can be complementary to ATLAS/CMS/LHCb because even though they have smaller acceptance, they have a smaller/zero background

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In order to be sure that the background is truly smaller (aim is usually “zero”), we need to perform careful simulations!

This is hard because in order to get a small background, we need to have a very thick shield in front of the detector.

Challenge

Simulating many ten's of Lambdas
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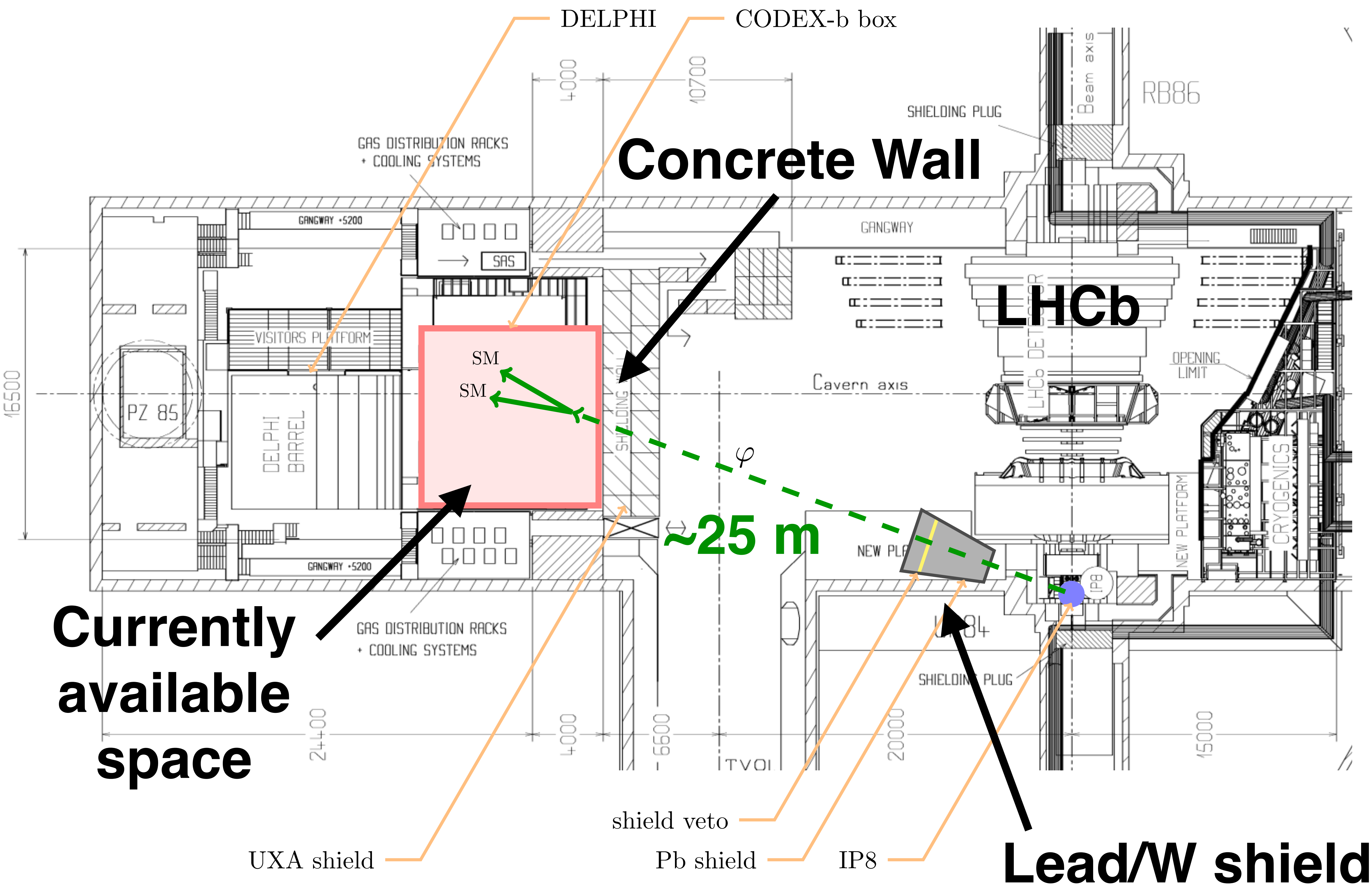
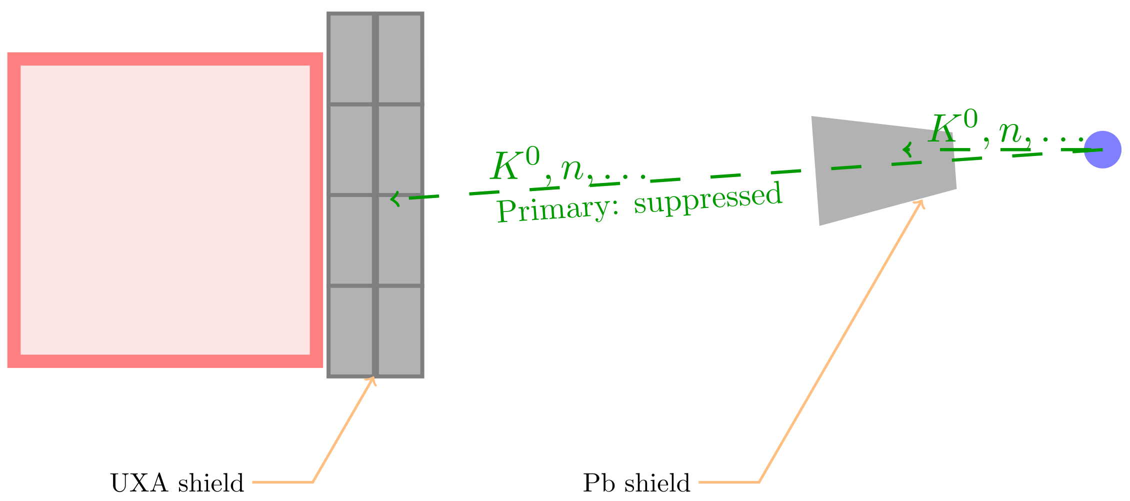
of absorber is not practical.

For reference, the ATLAS calorimeter is ~10 Lambda
and it takes O(min) for the highest energy particles

Example: CODEX-b



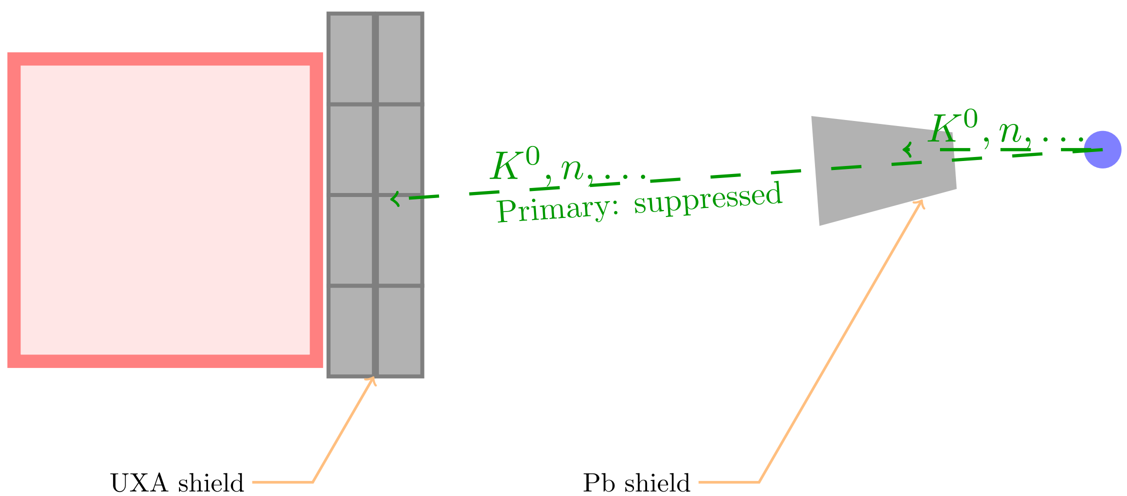
Backgrounds



Neutral particles punching through the shield

Rate is small, but flux is large (!)

Backgrounds



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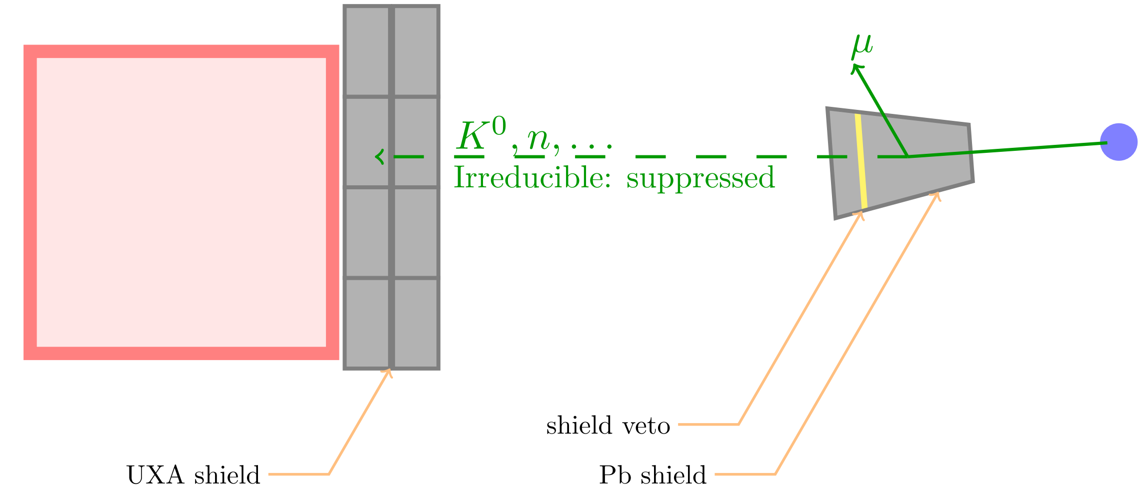

Neutral particles produced in the shield

(Can be also be from neutrinos - more on that shortly)

Muon veto *in middle of shield* is critical

One solution: transfer matrices

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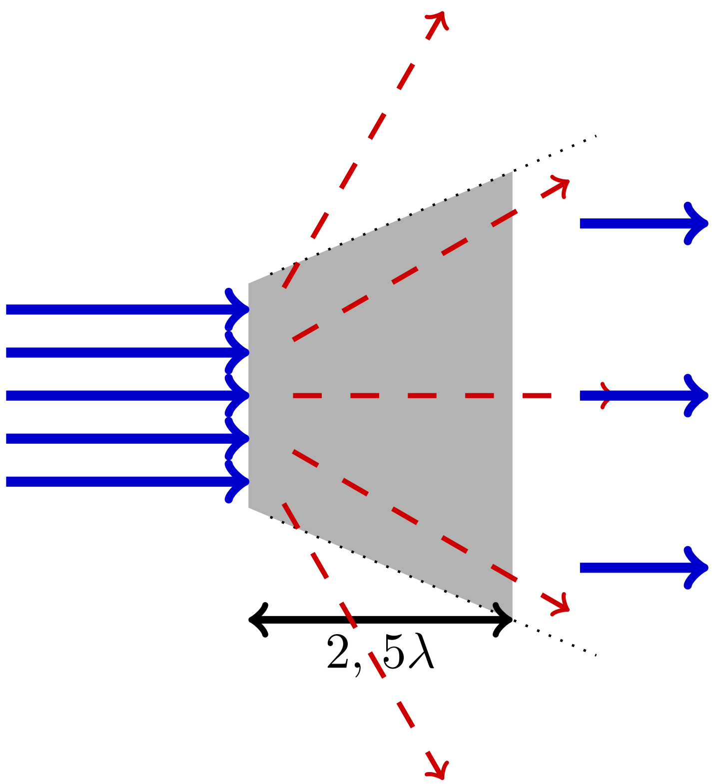
Conservatively, angular rescattering within ~23 degrees is all assigned to be forward



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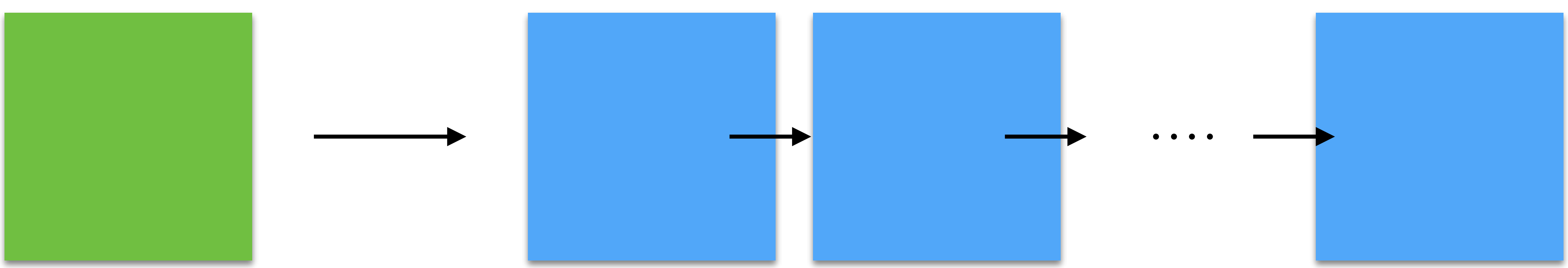
Pythia

Geant4 (use shield physics list for high precision)



Mix and match matrices for Pb, W, concrete, and air as needed

Outgoing particles

(Weighted carefully to for high-precision in tails)

Transfer matrix

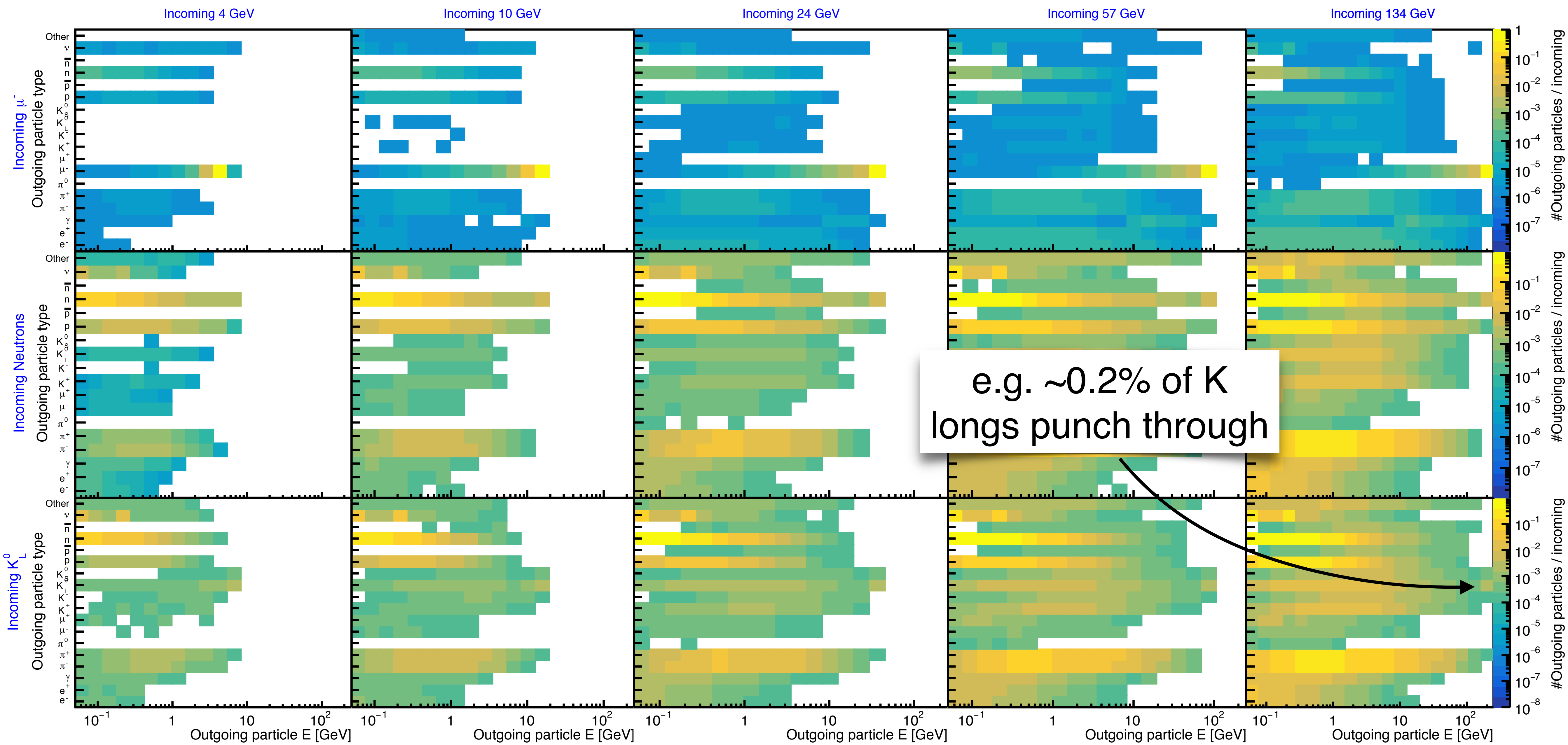
Binned in incoming/outgoing particle type, & (log) energy (in practice, one matrix per incoming type & energy bin)

V. Gligorov, S. Knapen, B. Nachman, M. Papucci, D. Robinson, 1810.03636

Transfer Matrices

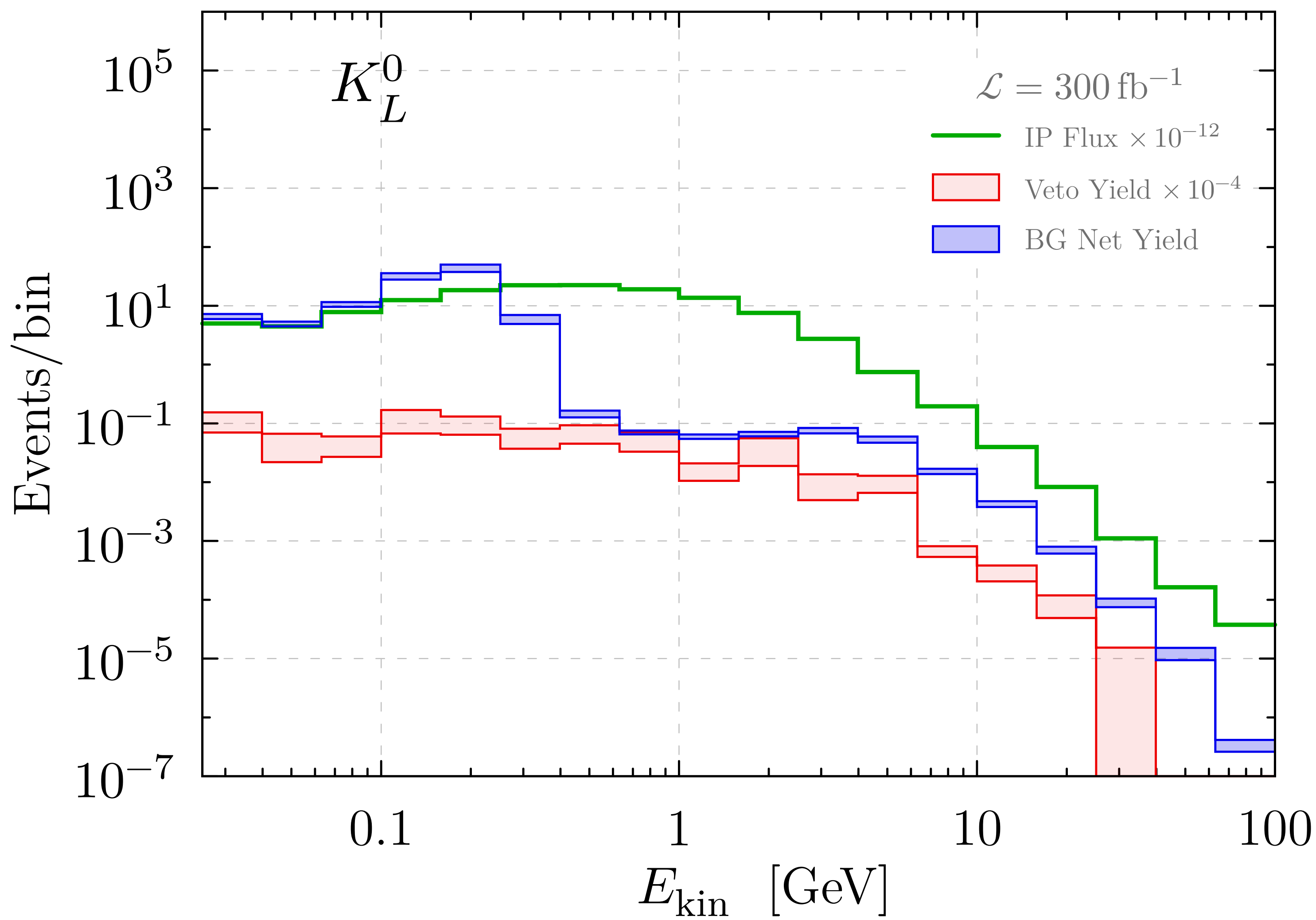
5 lambdas of W

Higher energy →



(this is just a sample - many particles / energies not shown)

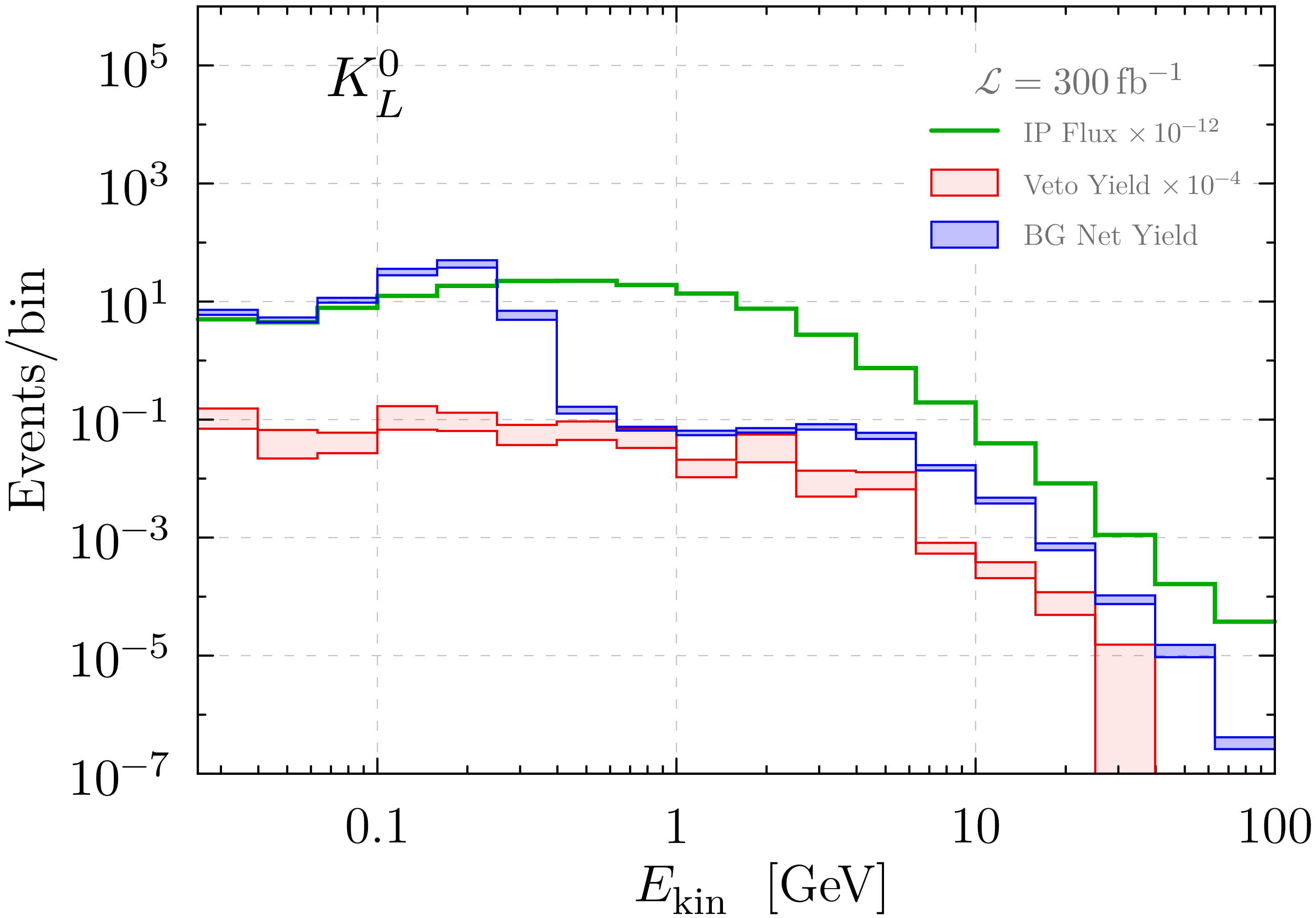
Convolved predictions



Pythia + Geant4
for K long

(We also have matrices conditioned on muons so we can study correlated production)

Convolved predictions



Pythia + Geant4 for K long

(We also have matrices conditioned on muons so we can study correlated production)

Repeat for protons, anti-protons, neutrons, anti-neutrons, muons, anti-muons, electrons, positrons, K long, K short (for fun), photons, pi+, pi-, K+, K-.

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Can be a dangerous background from free propagating particles scattering off the last few lambda

Canonical example is strange muoproduction of kaons

(the equivalent for Anubis would be neutrinos from rock)

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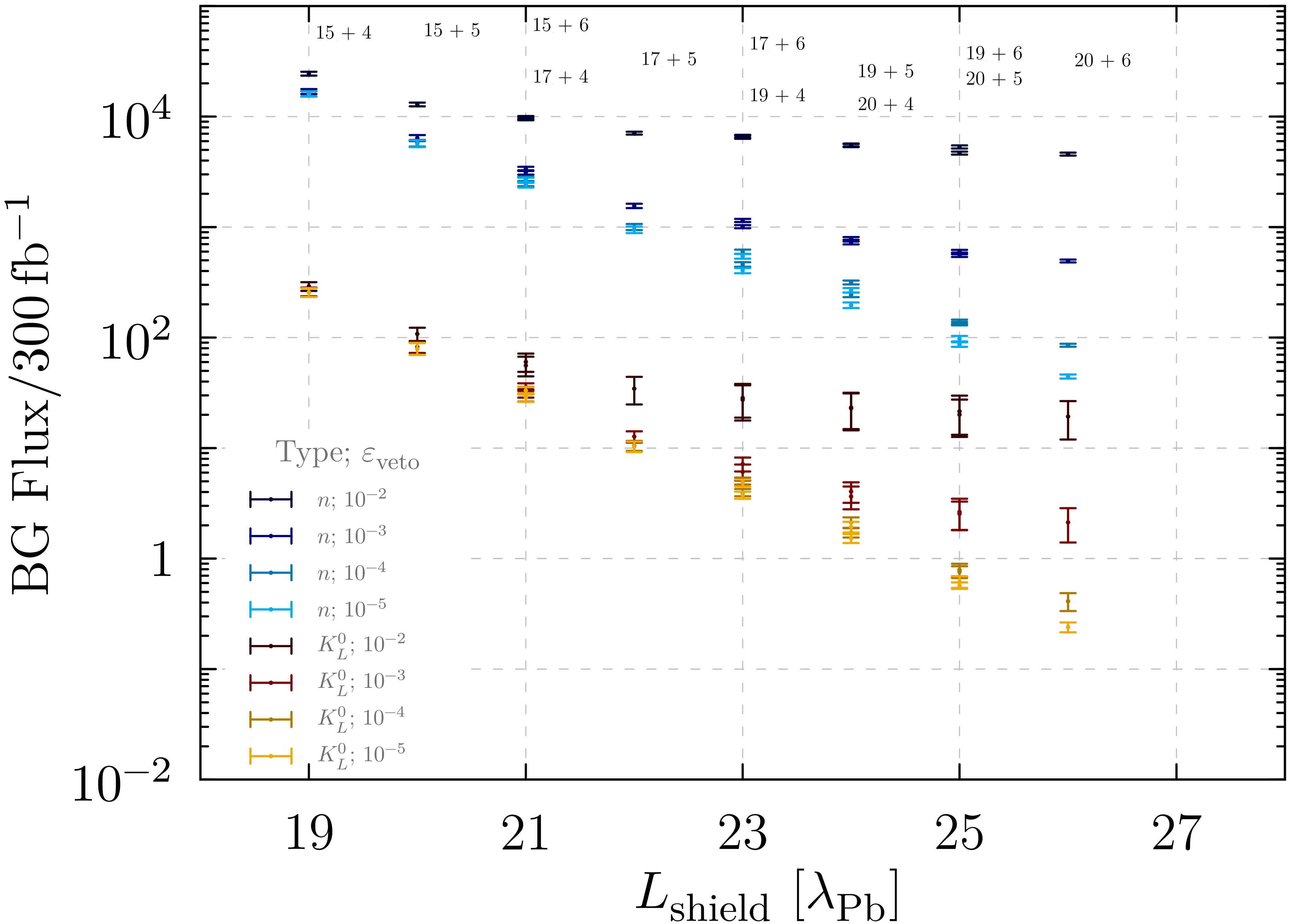
Can be a dangerous background from free propagating particles scattering off the last few lambda

Canonical example is strange muoproduction of kaons

Obviously, the interaction cross section is tiny, but there are *lots* of them so important to be careful (important for AL3X, but not so much for CODEX)

A last word about secondaries



Flattening out is because of secondaries from the shield.
(CODEX / AL3X address this with in-shield vetos)

Full prediction

(Example numbers for CODEX-b, we have the same for CODEX-β and AL3X)

BG species	Particle yields: Net ($E_{\mathrm{kin}}^{\mathrm{neutral}} > 0.4\,\mathrm{GeV}$)	Particle yields: Shield veto rejection (total)	Particle yields: Shield veto rejection ($\pm/0$ correlation)	Net yield
γ	0.54 ± 0.12	$(8.06 \pm 0.60) \times 10^4$	$(2.62 \pm 1.03) \times 10^3$	–
n	58.10 ± 4.63	$(4.59 \pm 0.15) \times 10^5$	$(3.45 \pm 0.51) \times 10^4$	–
n ($> 0.8\,\mathrm{GeV}$)	2.78 ± 0.25	$(1.03 \pm 0.06) \times 10^5$	$(7.45 \pm 1.92) \times 10^3$	$\lesssim 1$
$\bar{n}$ (no cut)	$(3.24 \pm 0.72) \times 10^{-3}$	34.40 ± 25.80	$(7.44 \pm 2.20) \times 10^{-2}$	$\ll 1$
K_L^0	0.49 ± 0.05	$(1.94 \pm 0.74) \times 10^3$	55.00 ± 19.30	$\lesssim 0.1$
K_S^0	$(6.33 \pm 1.39) \times 10^{-3}$	93.90 ± 45.80	0.74 ± 0.19	$\ll 1$
$\nu + \bar{\nu}$	$(5.69 \pm 0.00) \times 10^{13}$	$(7.35 \pm 0.12) \times 10^6$	$(5.69 \pm 0.00) \times 10^{13}$	–
$p^\pm$	$(2.07 \pm 0.26) \times 10^2$	$(9.24 \pm 0.36) \times 10^5$	$(9.24 \pm 0.36) \times 10^5$	–
$e^\pm$	$(4.53 \pm 0.02) \times 10^3$	$(4.38 \pm 0.02) \times 10^7$	$(4.38 \pm 0.02) \times 10^7$	–
π^+	34.70 ± 2.27	$(2.96 \pm 0.20) \times 10^5$	$(2.96 \pm 0.20) \times 10^5$	–
π^-	31.40 ± 2.12	$(2.68 \pm 0.19) \times 10^5$	$(2.68 \pm 0.19) \times 10^5$	–
K^+	0.83 ± 0.30	$(3.08 \pm 1.24) \times 10^3$	$(3.08 \pm 1.24) \times 10^3$	–
K^-	0.23 ± 0.12	$(1.12 \pm 0.63) \times 10^3$	$(1.12 \pm 0.63) \times 10^3$	–
μ^+	$(1.04 \pm 0.00) \times 10^6$	$(1.04 \pm 0.00) \times 10^{10}$	$(1.04 \pm 0.00) \times 10^{10}$	–
μ^-	$(8.07 \pm 0.01) \times 10^5$	$(8.07 \pm 0.01) \times 10^9$	$(8.07 \pm 0.01) \times 10^9$	–

Full prediction

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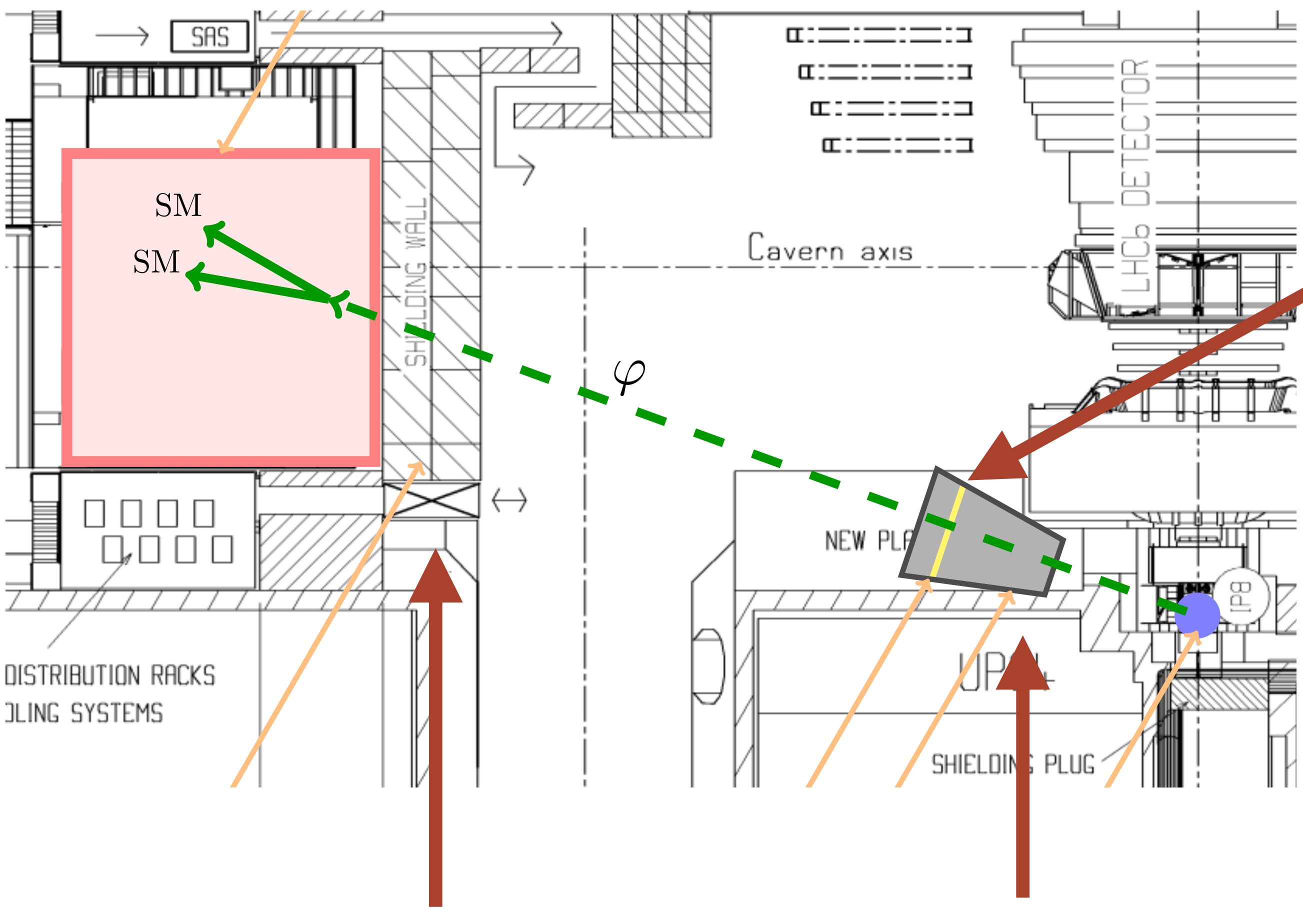


Muon veto, after 2/3 of the shield
10^{-4} efficiency required

3 m concrete (~7λ) + 4.5 m Pb (20 λ + 5 λ) = ~32 λ

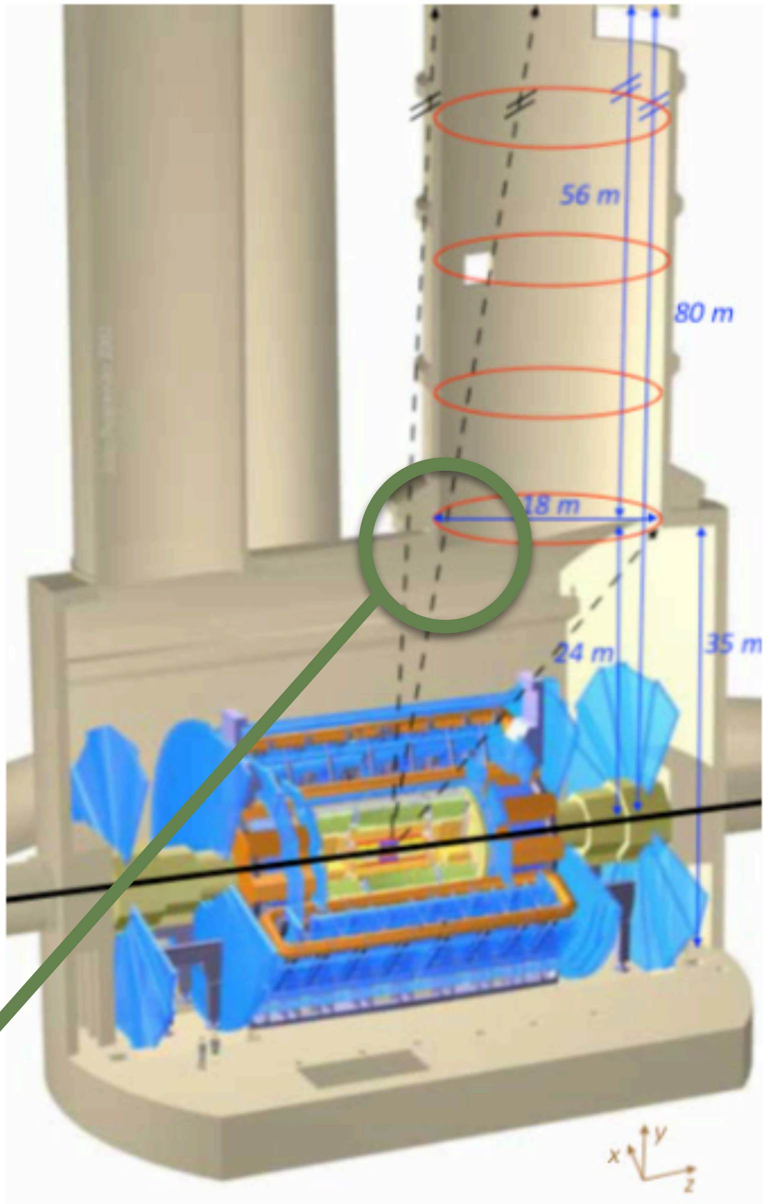
Validation

We have done a lot of validation of this approach.

- We have two independent implementations of the Geant4 code as well as the transfer matrix convolution.
- Where possible, we have checked the numbers against published cross sections (e.g. for muons and K longs)
- There has been an independent implementation of the CODEX-b space using the LHCb simulation framework (Gauss) which is in reasonable agreement.
- Background rates have been measured in the CODEX-b space and are about a factor of 10 lower than we predict (given a few O(1) conservative factors, this seems sensible)

Anubis back-of-envelope

- Anubis exposure is larger than CODEX-b, but let's assume they are similar for a moment
- 10 λ shielding from ATLAS HCAL for free
- Roughly need at least another 22 λ → 4 m of Pb



Think about secondaries in the rock

Conclusions and Outlook

All of the LLP detectors have common challenges.

Shielding is critical for background free setup

Our background simulation strategy
may be useful for others

(W,Pb <-> rock)

Questions?

Uncertainties

BG species	Particle yields			Net yield
	Net ($E_{\mathrm{kin}}^{\mathrm{neutral}} > 0.4\,\mathrm{GeV}$)	Shield veto rejection (total)	Shield veto rejection ($\pm/0$ correlation)	
γ	0.54 ± 0.12	$(8.06 \pm 0.60) \times 10^4$	$(2.62 \pm 1.03) \times 10^3$	–

We throw toys for the transfer matrices which allows us to propagate statistical uncertainties (50 toys)