FCC-*hh* Background Estimates

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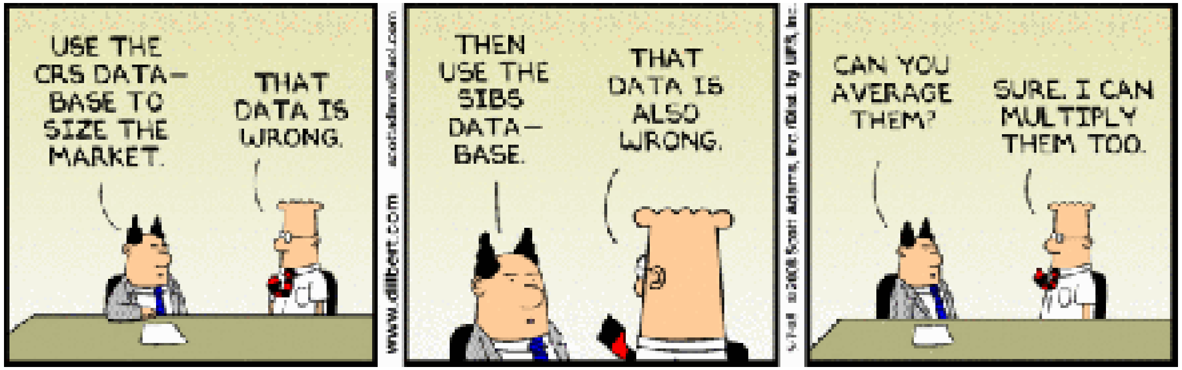
BACKGROUND SIMULATION APPLICATION

Background Simulation Program

- Physics processes by FLUKA
  - De facto standard for background calculations
- Validated against ATLAS Run-1 measurements
- Apply to FCC-*hh*
- Predictions only as good as simulation inputs, e.g. geometry, truly represents reality

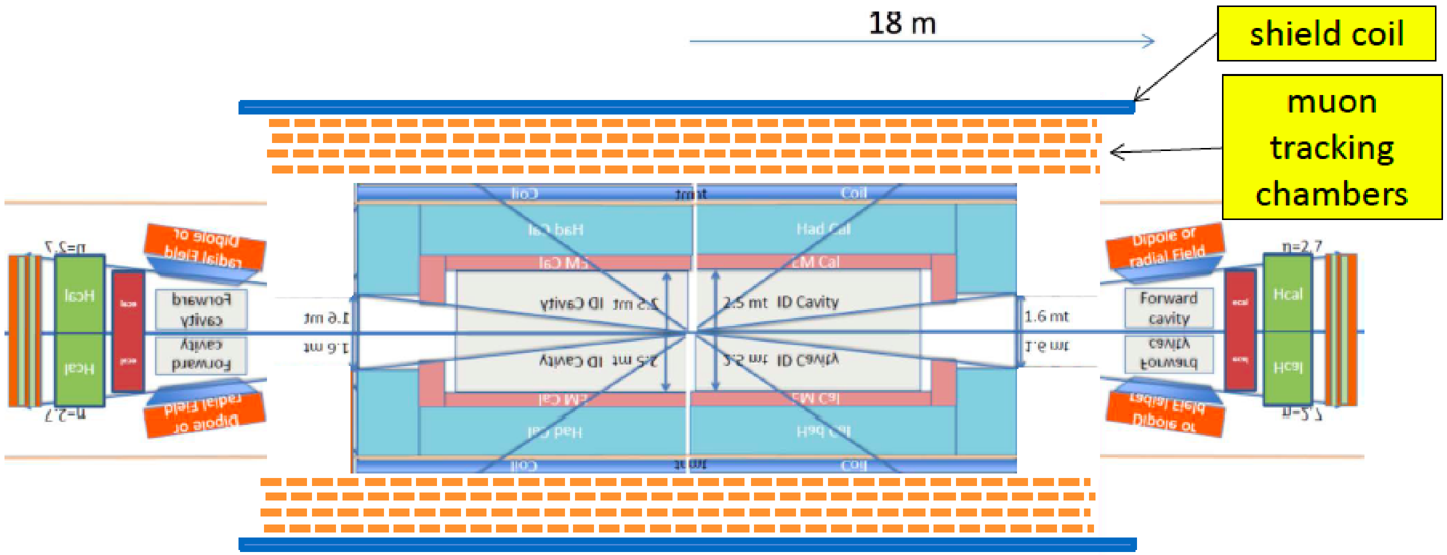


Simulation Geometry

- Based on "Option 2"
  - Twin solenoids: main + shielding
  - Dipoles in forward regions
- Detectors (material similar to those in ATLAS)
  - Tracker
  - EM calorimeter
  - Hadronic calorimeter
  - Muon detector
- No final-focus quadrupole, other beam line elements or beam line shielding

Twin Solenoid + Dipoles

2. Option 2: Twin Solenoid + Dipoles

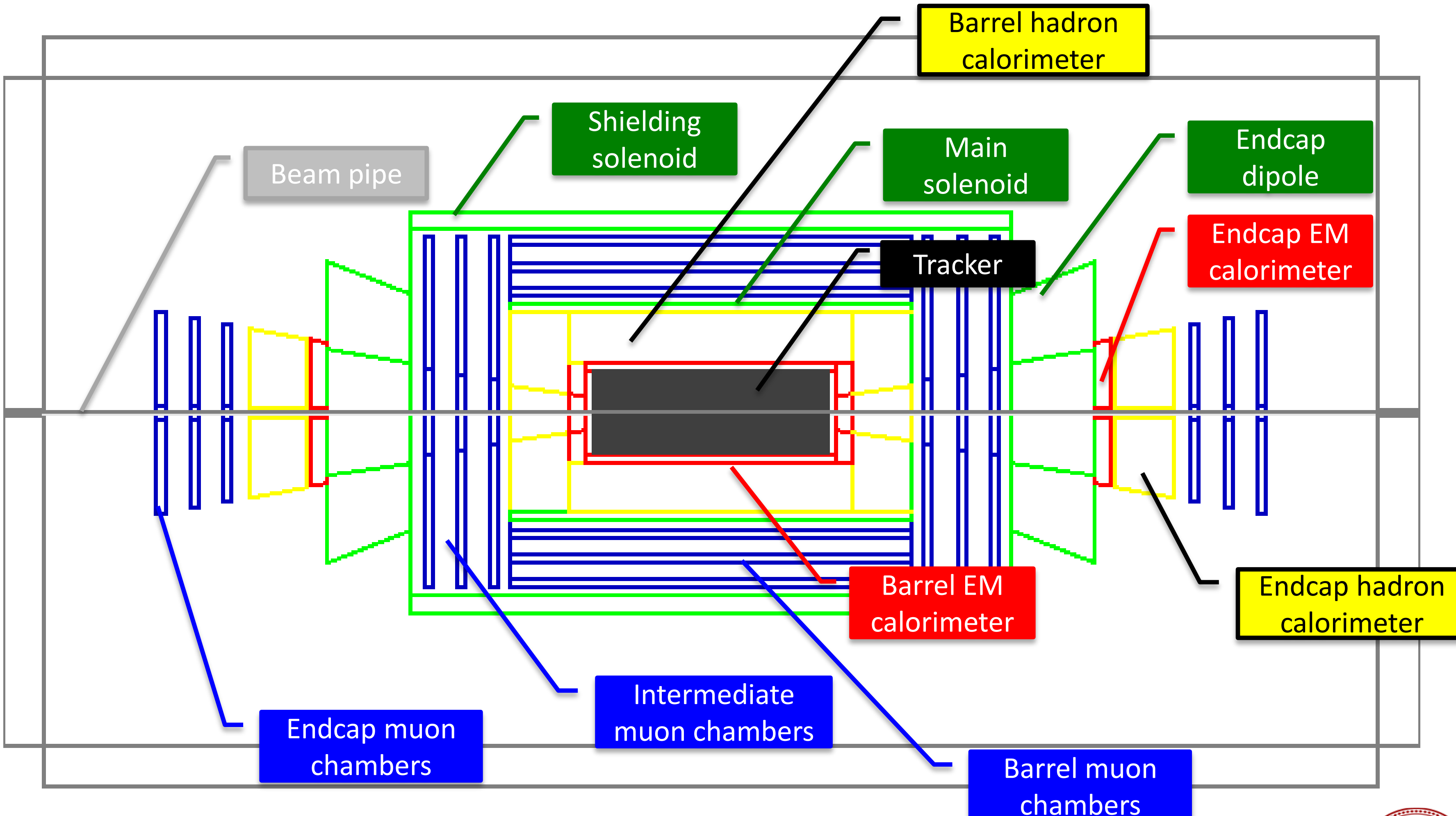


Twin Solenoid: a 6 T, 12 m dia x 23 m long main solenoid + an active shielding coil

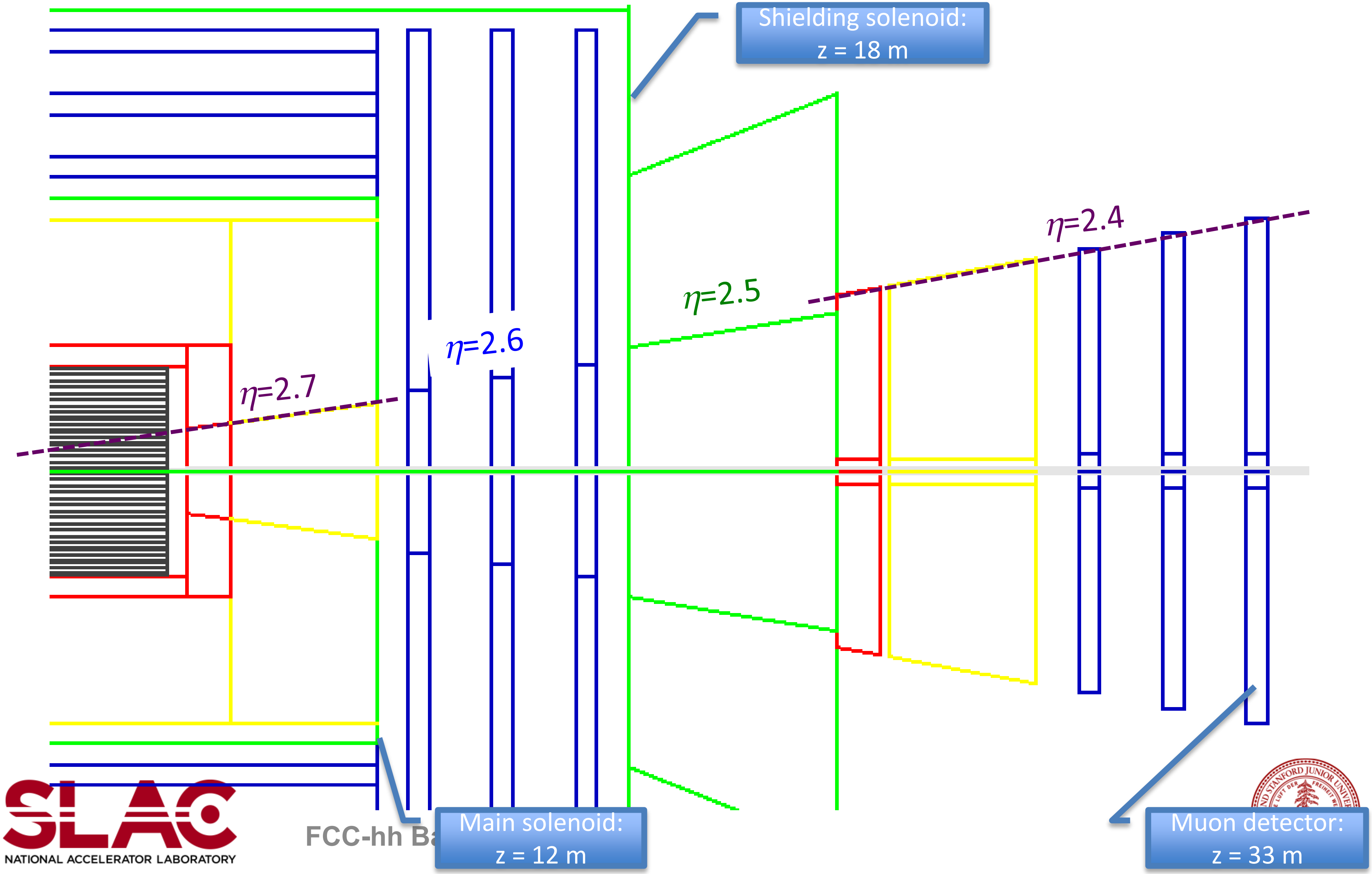
Important advantages:

- ✓ **Nice Muon tracking space:** area with 2 to 3 T for muon tracking in 4 layers.
- ✓ **Very light:** 2 coils + structures, ≈ 5 kt, only ≈ 4% of the option with iron yoke!
- ✓ **Much smaller:** system outer diameter is significantly less than with iron .

Simulation Geometry



Rapidity Coverage

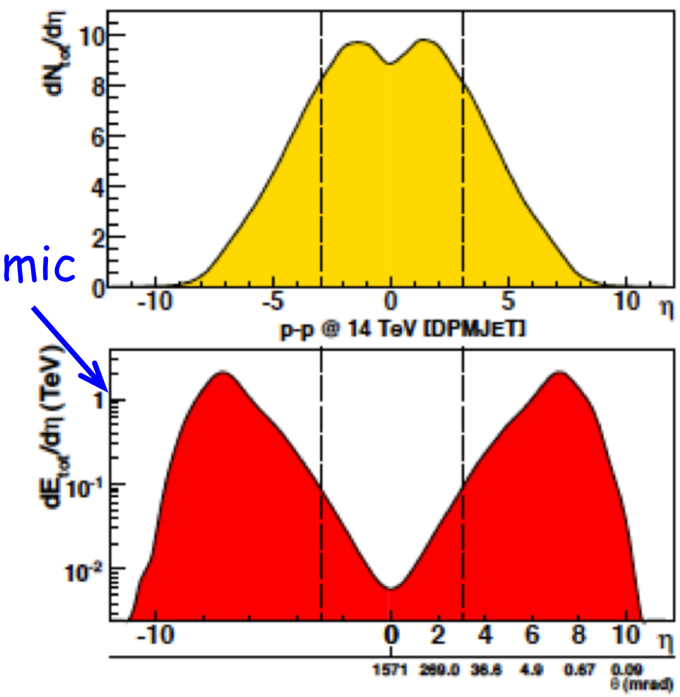


SOME GENERAL COMMENTS

η Dependence of Background

- <u>Multiplicity</u> flat in central η and falling for large η
- Outgoing <u>energy</u> peak at larger η
  - η_{peak} ~ 7 – 8 for $\sqrt{s}$ = 14 TeV

Note logarithmic scale



- Background typically much more benign in barrel region than in endcap / forward regions

Beam Pipe

- (Radially) thin beam pipe is O(1) interaction length at η_{peak} due to glancing incidence angle
  - Flange: near normal incidence ➔ "thin"
- Small radius near IP for physics performance
- Larger radius (away from IP) ➔ shower initiation point further away in z
  - $r = 3\ cm$ for $z < 7.5\ m$ and $6\ cm$ for $z > 7.5\ m$

z(m)	r = 3 cm	5	10	15
$\eta = 4$	0.8	1.4	2.7	4.1
5	2.2	3.7	7.4	11
6	6.1	10	20	30
7	16	27	55	82

Inside barrel

After endcap

Barrel Tracker

- Two broad categories of background
  - Direct *p*-*p* interaction products
    - Multiplicity slow function of $\sqrt{s}$
    - Dose per particle insensitive to particle energy
  - Back scatter from calorimeters
    - Inner part of calorimeter acts as shield against outer part of calorimeter
    - Larger inner radius ➔ lower background density
- Background probably not much worse than in LHC (for the same luminosity)
  - Beware end of barrel staves, i.e. high η

Barrel Calorimeter

- Self shielding (but every shield is also a source)
  - Rapid decrease in background farther from IP
- Radiation damage concerns primarily for sensors at inner radius locations
  - Degree of vulnerability depends on sensor: LAr, crystals, plastic scintillators, Si, etc
- Front-end electronics concerns greatly reduced if located at outer radius
  - Not obviously a problem if embedded within calorimeter

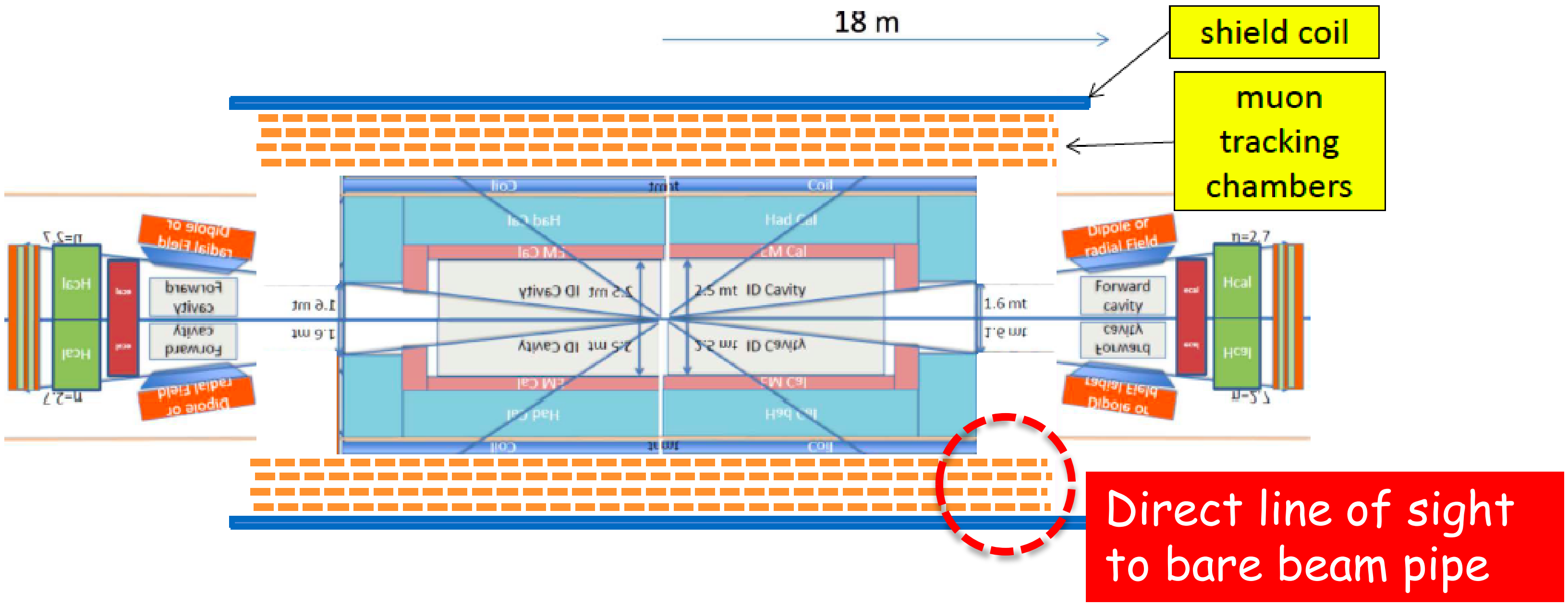
Barrel Muon Detector

- Calorimeter expected to provide better shielding in FCC-*hh* than in LHC
  - Calorimeters becoming thicker to contain hadronic showers of high p_T hadrons in FCC-*hh*
  - Background dominated by min-bias events
    - Slow rise in jet and particle energy
    - Shower length ~ $log(E)$
- Expect tolerable background when shielded by calorimeter

"Common understanding"
10 λ at LHC→12λ at 100 TeV
(including ~1λ EM in front)

Unshielded Barrel Muon Detector

2. Option 2: Twin Solenoid + Dipoles



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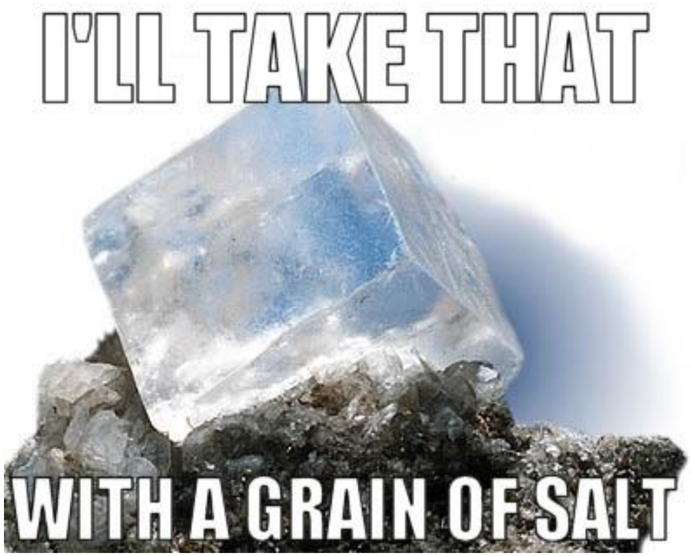
Endcap Background

- Very sensitive to details of beam-line geometry
  - Arbitrary choice of beam pipe diameter
  - No shielding in this simulation
  - No final-focus quadrupole
  - No masks / collimators
- Strong function of radius

- Endcap results should be treated as qualitative at best



BACKGROUND ESTIMATES

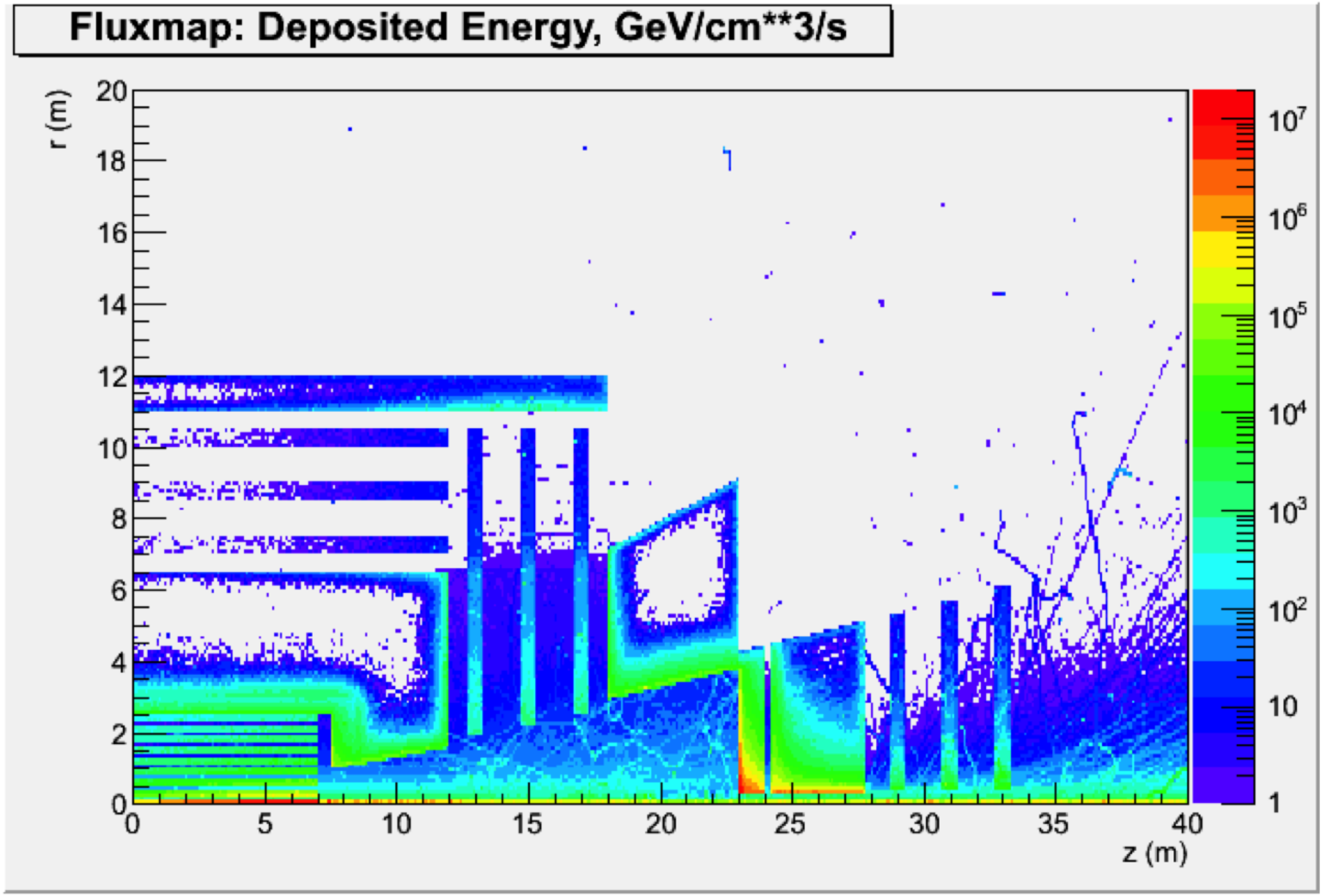
Simulation Inputs

- Events
  - Generated by Phojet
  - $\sqrt{s}$ = 100 *TeV*
- Normalization assumptions
  - σ_{pp} = 100 *mb*
  - "*year*" = 10^7 *sec*
  - Instantaneous luminosity = 10^{36} $cm^{-2}\ s^{-1}$
  - Rescale to suit your assumptions

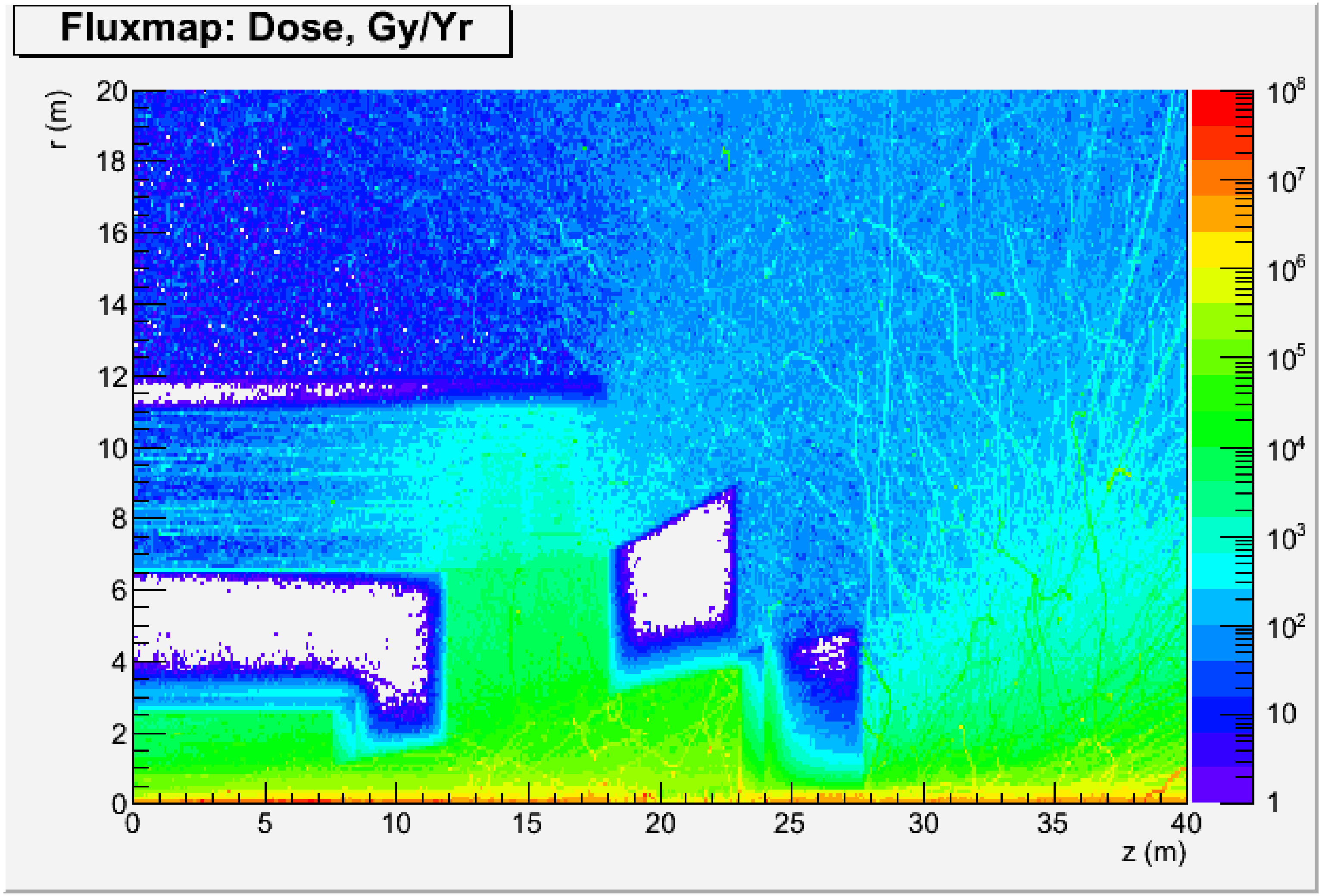
Simulation Outputs

- 2-D distributions in (*r*,*z*)
  - Implied azimuthal symmetry
- Energy deposition map reflects simulation geometry
- Dose and fluence maps for background
  - Directly read off value at any (*r*,*z*)
  - Take slice at given *z* and plot as function of *r* or vice versa

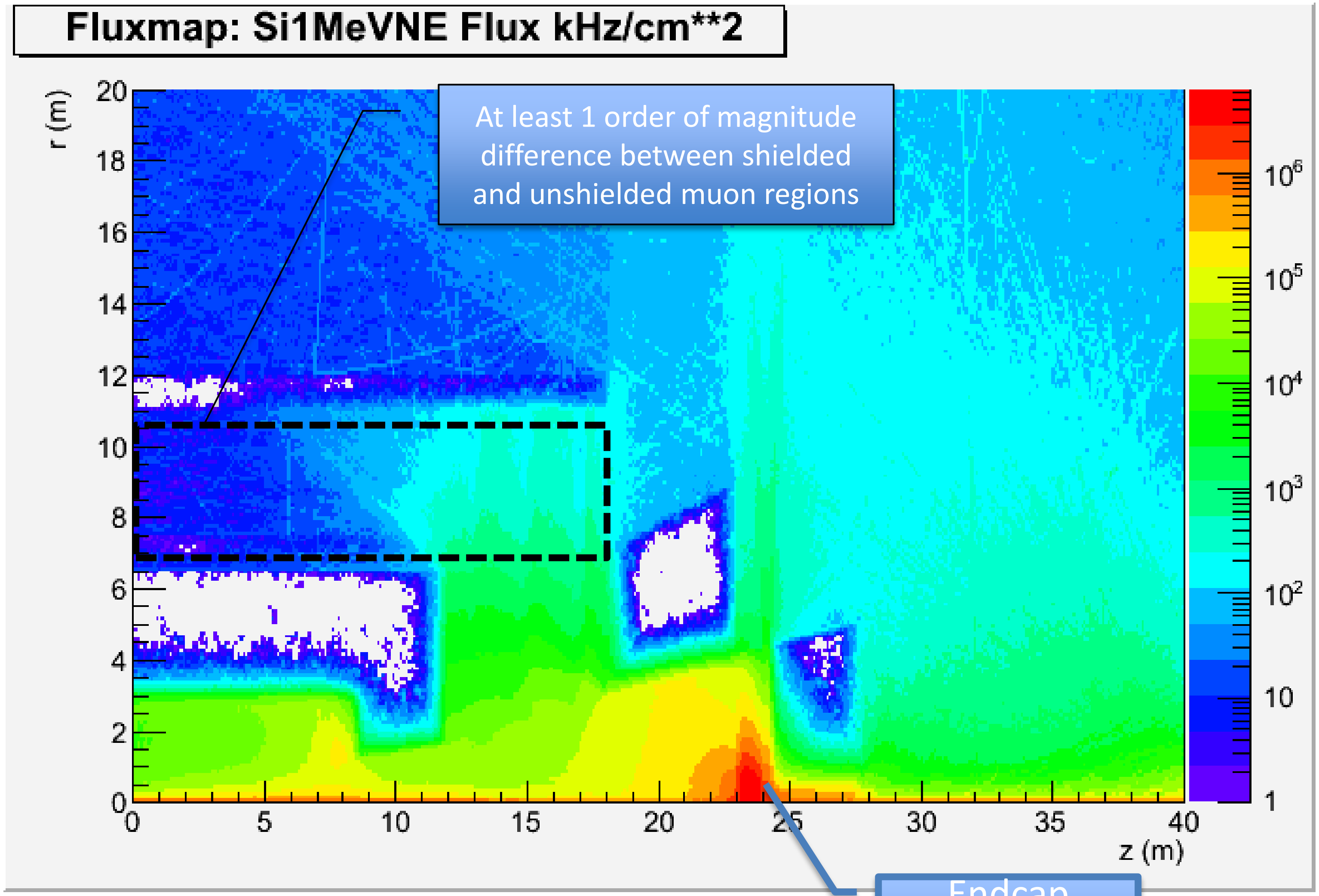
Energy Deposition



Total Ionizing Dose



1-MeV n_{eq} Fluence



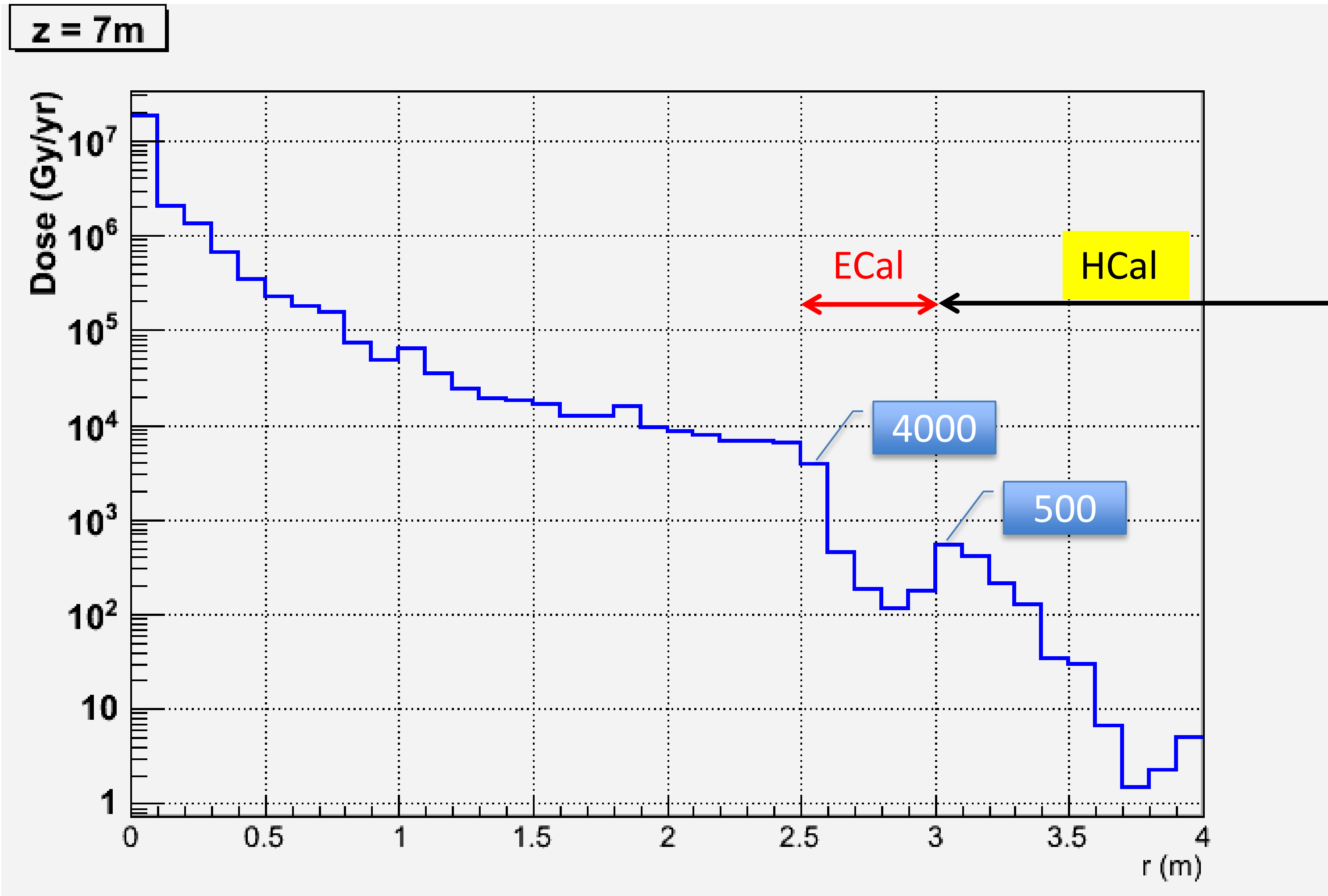
Tracker

- Background decreases with *r* and increases with *z*
  - Longer path length in beam pipe
- Highest background at end of first layer
  - Dose ~ 5 10^7 *Gy / year*
  - Fluence ~ 1.7 10^6 *kHz / cm^2*

- Results sensitive to input geometry
  - Aluminium beam pipe at *r* = 3 *cm*
  - First detector layer
    - *r* = 5 *cm*
    - Length = +/- 7 m
  - No service material

η ~ 5.5 (surely not a rational layout)

TID in Barrel Calorimeter



"Maximum" in Calorimeters

More reliable (Barrel) | Depends on position (Extended Barrel) | Very sensitive to beam line shielding etc (Endcap)

ECal

	Barrel	Extended Barrel	Endcap
Dose (Gy/year)	$4\ 10^3$	$6.5\ 10^4$	
Fluence (KHz/cm^2)	$6\ 10^4$	$2\ 10^5$	

~ 10x

HCal

	Barrel	Extended Barrel	Endcap
Dose (Gy/year)	$5\ 10^2$	$3\ 10^4$	
Fluence (KHz/cm^2)	$7\ 10^3$	$6\ 10^5$	

~ 100x

Muon Detector

- Relatively benign environment in shielded barrel region, i.e. $z < 12\ m$ in this layout
- Much worse background in unshielded barrel region, i.e. $12 < z < 18\ m$
- Endcap background strong function of geometry

	Barrel Shielded	Barrel Unshielded	Endcap
Dose (Gy/year)	100	1000	
Fluence (KHz/cm^2)	10	500	

CONCLUSION

Summary

- Background simulation application validated using ATLAS Run-1 data
  - Much can be done on back of envelop
- Final-focus quadrupole magnet and beam line shielding missing in FCC-*hh* geometry

  ➔ endcap predictions not to be trusted and therefore numerical results not reported here
- Barrel predictions more robust
  - Backgrounds likely tolerable
  - Avoid unshielded path from beam line

Suggestion

- More realistic layout in forward region depends on
  - Machine parameters such as luminosity, L*
  - Physics requirements such as η coverage
  - Beam line shielding (but shielding is also source)
- More reliable endcap background estimates
- Iteration likely to be required

- Do not worry too much about barrel now
- Technological advances in next decades will likely supersede any detailed planning today