MuonGun

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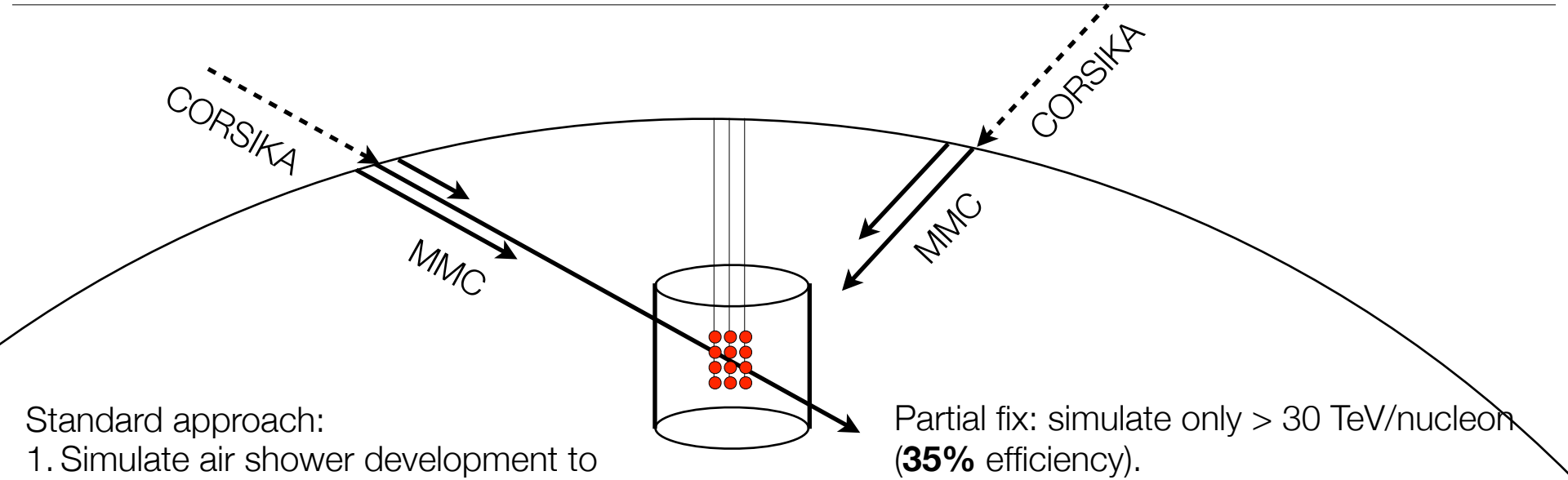
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Ancient history (2013)

Standard background simulation



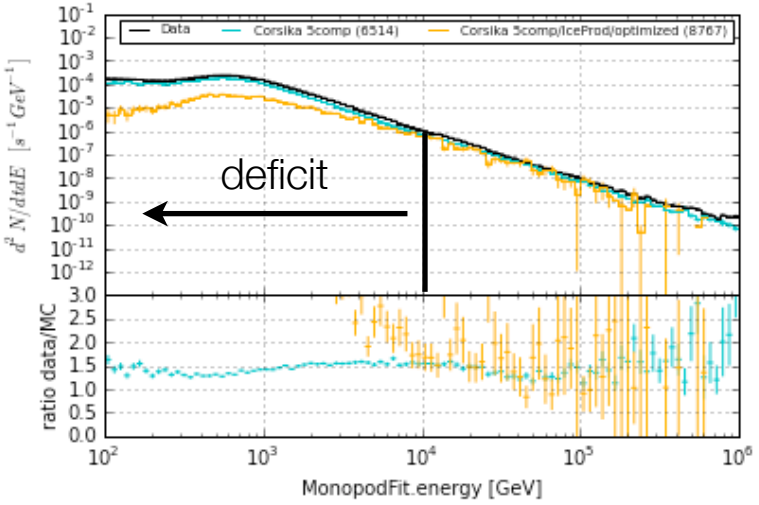
Standard approach:

1. Simulate air shower development to ground level (CORSIKA)
2. Propagate muons to depth (MMC)
3. Weight events according to a primary flux model (e.g. Hoerandel, Gaisser-Hillas)

Simulating an unbiased spectrum is **inefficient**: with E^{-2} primaries from 600 GeV/nucleon, **< 3%** of showers reach the sampling surface.

Feasibility study by Lars Mohrmann:

Partial fix: simulate only > 30 TeV/nucleon (**35%** efficiency).
New problem: missing low-energy primaries => deficit of low-energy muons



Muons are interchangeable

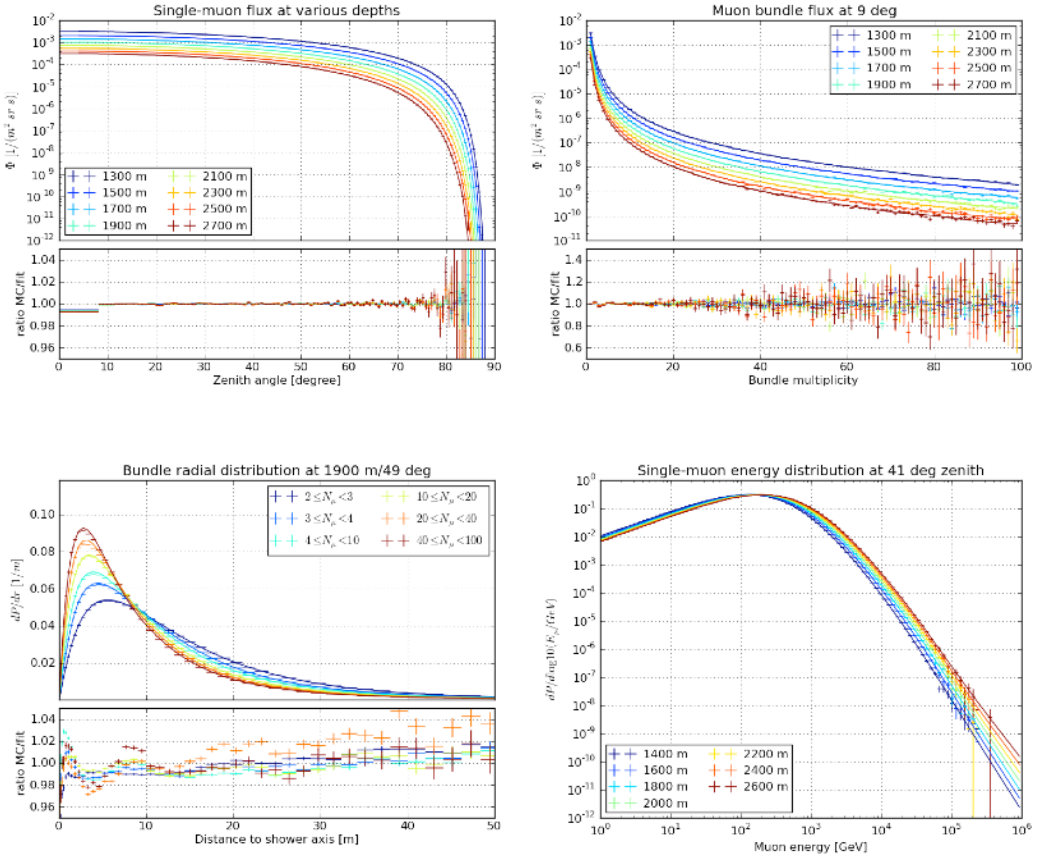
Work in terms of muon bundles instead of cosmic-ray primaries.

To get a parameterization of the muon bundle flux:

1. Simulate lots and lots of cosmic rays (~50e10)
2. Propagate bundles to depth
3. Tabulate the muon distribution
    1. For each bundle:
        1. Vertical depth
        2. Zenith angle
        3. Number of muons
    2. For each muon in the bundle:
        1. Distance from bundle axis
        2. Energy
4. Fit the distribution!

Given a parameterization, you can calculate correct weights for muon bundles generated by any scheme you like!

Example: Hoerandel flux, SIBYLL hadronic interactions, March 31st atmosphere



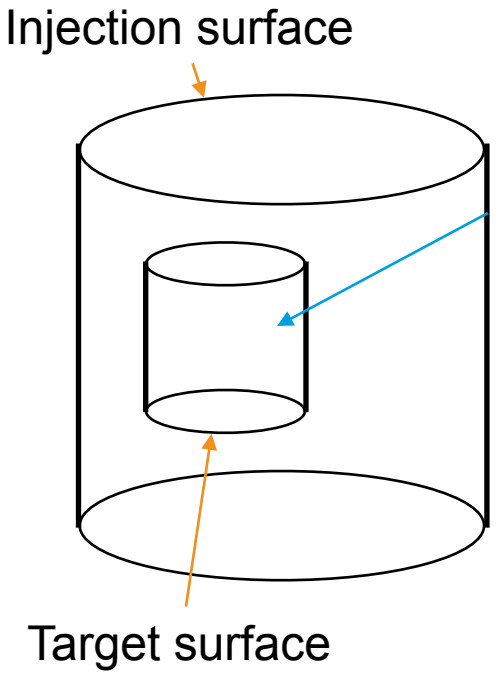
(fit to tensor-product B-spline surfaces with Photospline)

This is not even an original idea. See: Y. Becherini, A. Margiotta, M. Sioli, and M. Spurio. A parameterisation of single and multiple muons in the deep water or ice. *Astroparticle Physics*, 25(1):1 – 13, 2006.

MuonGun today

MuonGun modes

- simprod.segments.GenerateCosmicRayMuons:
  - GenerateCosmicRayMuons:
    - single muons, biased energy spectrum, realistic zenith/depth distribution
    - optionally, separate injection and target surfaces
    - **starting-event background**
  - GenerateSingleMuons:
    - single muons, biased energy spectrum, isotropic
    - **muon effective area**
  - GenerateNaturalRateMuons:
    - bundles, natural energy spectrum, natural zenith/depth distribution
    - **coincident background**



Target and injection can be any MuonGun::Surface (segment currently only supports cylinders)

Weighting with MuonGun

- You can use I3MuonGun::WeightCalculatorModule to
  - reweight MuonGun simulations to different flux models
  - combine MuonGun simulations aimed at different target surfaces, with different energy spectra, etc.
    - injection surfaces must match!

Flux parameterizations

CR flux	Hadronic model	Atmosphere
Physical fluxes		
GaisserH4a	SIBYLL 2.1	12 (SP winter)
	DPMJET (conventional only)	12 (SP winter)
	DPMJET (prompt only)	12 (SP winter)
Hoerandel5	SIBYLL 2.1	12 (SP winter)
BMSS (MUPAGE)	HEMAS	?
Pseudofluxes (useful only for weighting IC79-era CORSIKA)		
Standard5Comp	SIBYLL 2.1	12 (SP winter)
CascadeOptimized5Comp	SIBYLL 2.1	12 (SP winter)

Limitations

- There is no (working) biased bundle generation.
  - The curse of dimensionality is a thing. Who knew?
- The definition of multiplicity is rigid and based on MC truth.
  - True single-muon simulation systematically underestimates the rate of single-ish muon events (e.g. 100 TeV muon and two 300 GeV muons).
- Flux parameterizations integrate over an assumed CR composition.
  - Can’t treat composition uncertainties with weights.
- Flux parameterizations have never been updated.
  - Easy to do in 2013; IC79 simulation production stored all CORSIKA outputs. Now, requires dedicated simulation (but much simpler than full IC simulation chain).
- Bundle parameterization is lossy.
  - e.g. no intra-bundle correlations beyond multiplicity.

Lessons learned

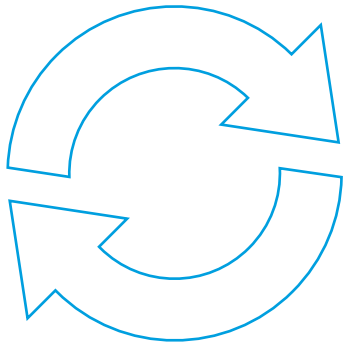
- MuonGun's primary function, sampling directly from the population of background-like showers, only [approximately] works for a specific class of event selections.
- Byproducts (Floodlight, Surfaces) were an unequivocal success.
- Parameterizations should be treated like any data product. If the input data are not easily reproducible, or the fitting procedure poorly documented, they are unlikely to be updated. Plenty of examples [that I should have learned from]:
  - secondary muon production in cmc
  - photonics/photospline tables
  - Cherenkov yield parameterizations for cascades & muons*
  - neutrino cross-sections*

* now more actively maintained

The future of MuonGun

- Unbiased bundles for coincident background are probably okay,
  - but: need updated flux parameterizations!
- “Floodlight” mode for muon effective area calculation is also fine.
- Targeted background simulation mode should be phased out, and replaced with:

- triggered CORSIKA



- [generative model that somehow skirts the curse of dimensionality]

Discuss