Charm in the Sky

On prompt atmospheric lepton fluxes

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First PhD thesis in astroparticle at UU:

- M. Thunman: 'High energy leptons in astroparticle and charm quark physics', 1996

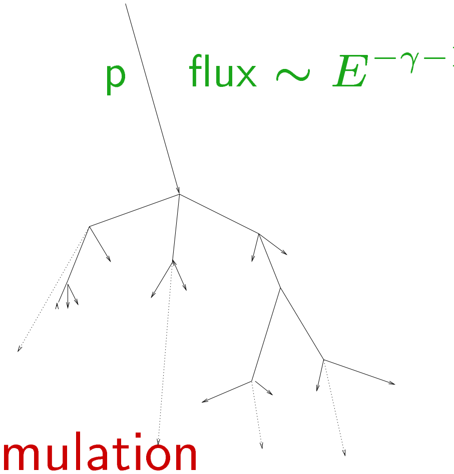
Master theses in astroparticle physics:

- R. Söderberg: 'Cold dark matter' 1991
- J. Edsjö: 'Neutrino-induced muon fluxes from neutralino annihilations in the sun or earth', 1993
- M. Larfors: 'The charm of colour octet fields - a study of quark production in fragmentation processes', 2004

This talk:

- Predicted lepton fluxes from charm produced in pert./non-pert. QCD
- Why flux of Volkova et al. is dubious and too large
- New model for non-perturbative charm production $\Rightarrow$ low fluxes

Atmospheric lepton fluxes



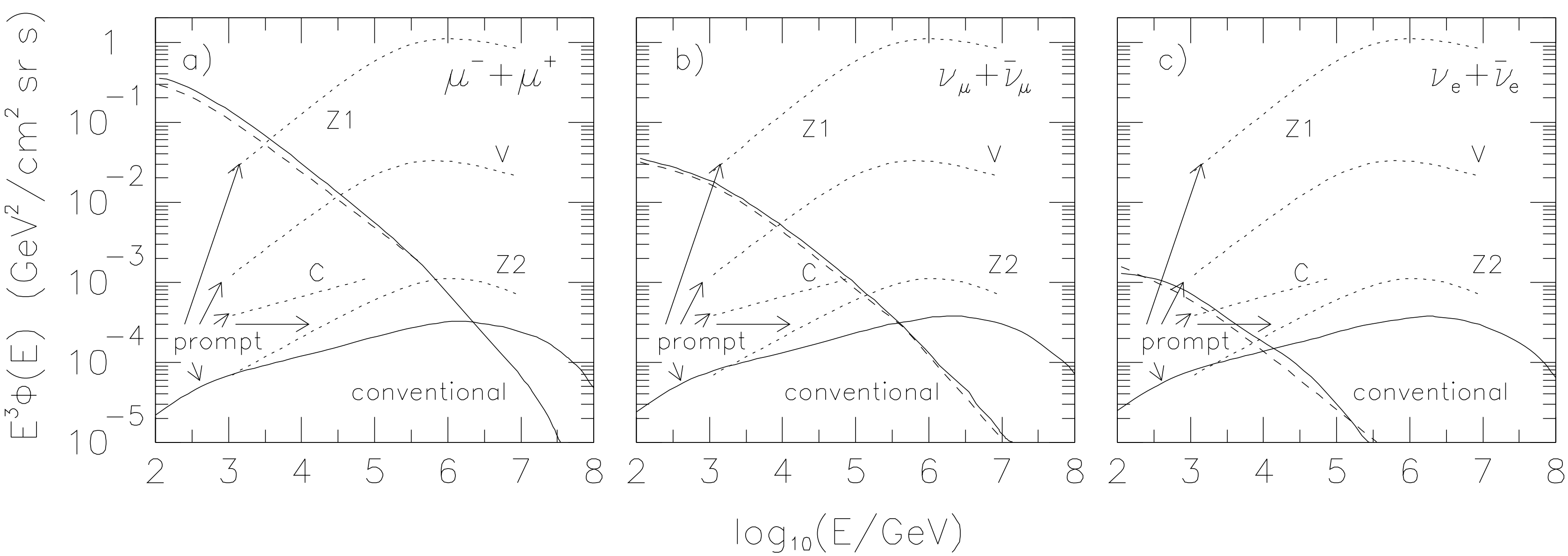
$p + A \to M + X$

$\hookrightarrow \ell^{+/-} + \nu_l(\bar{\nu}_l) + Y$

conventional = from π,K decays; prompt = from charm decays

TIG (Thunman,Ingelman,Gondolo, Astropart.Phys.5 (1996) 309) cascade simulation

PYTHIA: pert.QCD $gg \to c\bar{c}$, $q\bar{q} \to c\bar{c}$ and parton showers ⊕ Lund hadronisation



Large differences from charm production!!

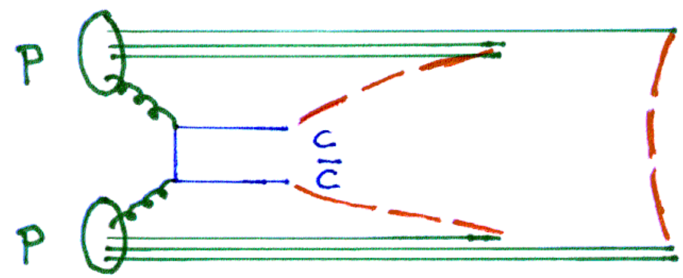
Zas,Halzen,Vazques 1993: Z1 for $\sigma(charm) = 0.1\,\sigma(inelastic)$

Z2 for $\sigma(charm) = \sigma(c\bar{c})$ pQCD

V = Volkova et al.: non-pert. 'quark-gluon string' model, scaling in x_F distr.

Charm production

Most charm data (σ_{tot}, $d\sigma/dx_F$) reproduced by
THEORY: pQCD (LO,NLO,parton showers) $\to c\bar{c}$
Model: fragmentation function / MC



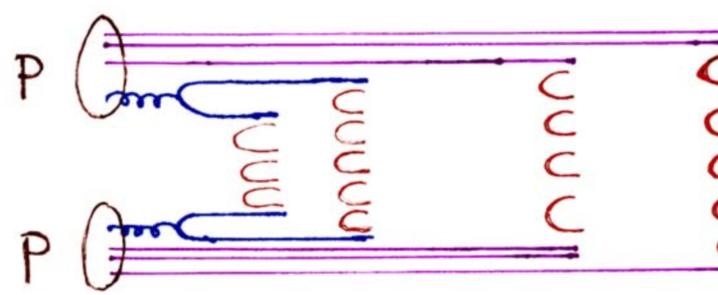
Some details require non-trivial soft QCD effects:

- leading ($x_F \to 1$) $D^{\pm}$, Λ_c $\leftrightarrow$ string drag effect (or intrinsic charm)
- charmonium $\leftrightarrow$ soft colour exchanges

No need to replace pQCD theory by simple model for charm quark production!

Volkova et al. (1980–2002): ‘quark-gluon string’ model, Regge with ‘cut’ pomerons
Normalisation:

$$\sigma(E_p) = \begin{cases} 0.48(\log E_p - 3.075) & \text{for } pp \to D\bar{D}\ X \\ 0.07(\log E_p - 0.84) & \text{for } pp \to \Lambda_c \bar{D}\ X \end{cases}$$



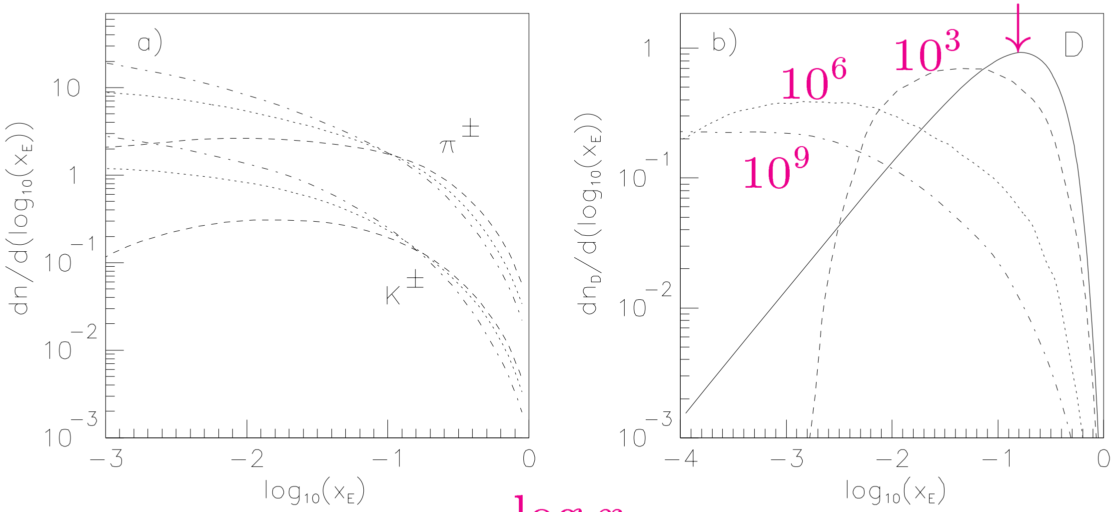
Shape: $f(x_F) \sim (1 - x_F)^{\alpha}$, $\alpha_D = 5$, $\alpha_{\Lambda_c} = 0.4$
from low-E_p data, but higher E_p
$\Rightarrow$ more 'sea'-strings $\Rightarrow$ full E_p not available in each string $\Rightarrow$ softer x_F-spectra!

$\sigma_{tot}(charm)$ may be OK at larger E_p, but model not compared to x_F-spectra

Importance of charm x_F distribution

TIG: $E_p = 10^3, 10^6, 10^9$ GeV

$(1 - x_F)^5$



$\log x_F$

Scaling in $x_F = E_h/E_p$

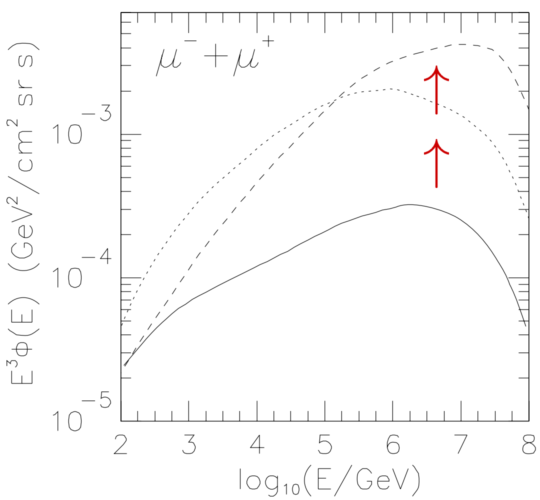
$$\frac{dN}{dx_F} = f(x_F) \sim (1 - x_F)^\alpha$$

(no E_p-dependence)

$\approx$ OK for π, K

badly violated for charm from pQCD

softer x_F for higher E_p

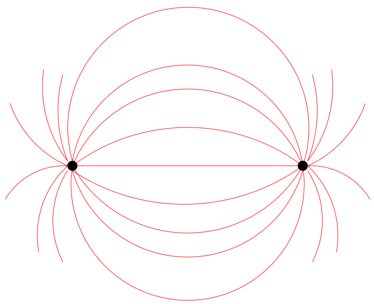


TIG rescaled to $(1 - x_F)^\alpha$ with $\alpha_D = 5$, $\alpha_{\Lambda_c} = 0.4$

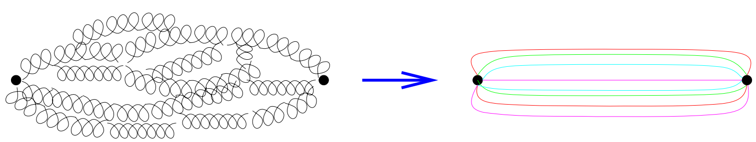
gives factor ~ 20 larger flux

Note: no conserved integral of E^3-weighted flux

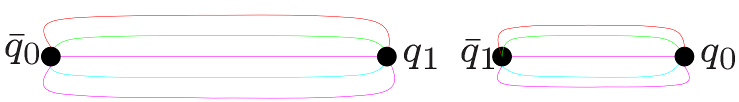
Reminder: Lund string model



EM: dipole $\Rightarrow$ field $\rightarrow \infty$



QCD: $q\bar{q}$ colour dipole,
gluon self-interaction $\Rightarrow$ flux tube

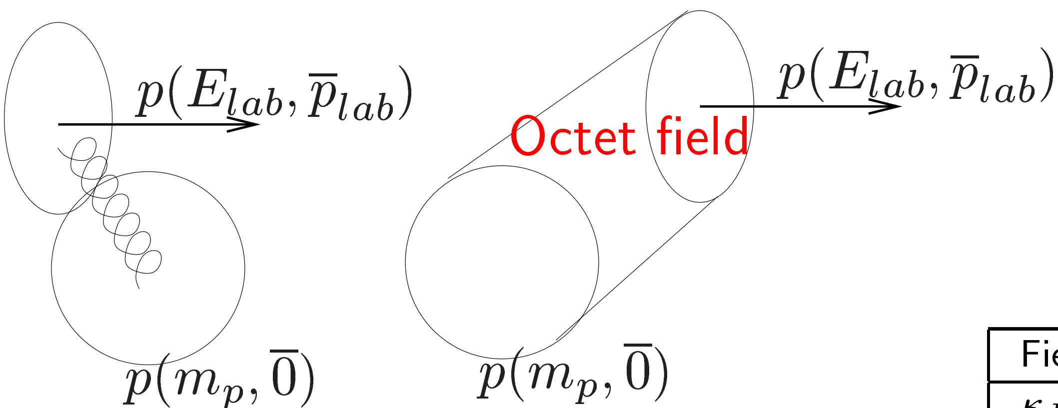


Lund string fragmentation:
$q\bar{q}$ pairs from field energy

- Gluon self interaction $\Rightarrow$ colour flux tube
  Description: relativistic massless string
- Colour triplet string between $\mathbf{3}$ and $\bar{\mathbf{3}}$ (q and $\bar{q}$)
  $\hookrightarrow$ potential $V_3(r) = \kappa_3\, r$, $\kappa_3 \approx 1\text{GeV/fm}$
- Fragmentation of string to hadrons:
  new $q\bar{q}$ formed from field energy
  $\hookrightarrow$ $\mathbf{3}$–$\bar{\mathbf{3}}$ screens field
  $q\bar{q}$ produced virtually in a point
  'eats' field energy $\rightarrow$ on-shell
  $\rightarrow$ quantum mech. tunnelling $\Rightarrow$ $P(q\bar{q}) \propto e^{-\frac{\pi}{\kappa}}$
  OK for $q = u, d, s$
  charm suppression $\frac{P(c\bar{c})}{P(u\bar{u})} \approx 10^{-11}$

New model: Colour cctet string creation

Octet string created by gluon exchange between two hadrons



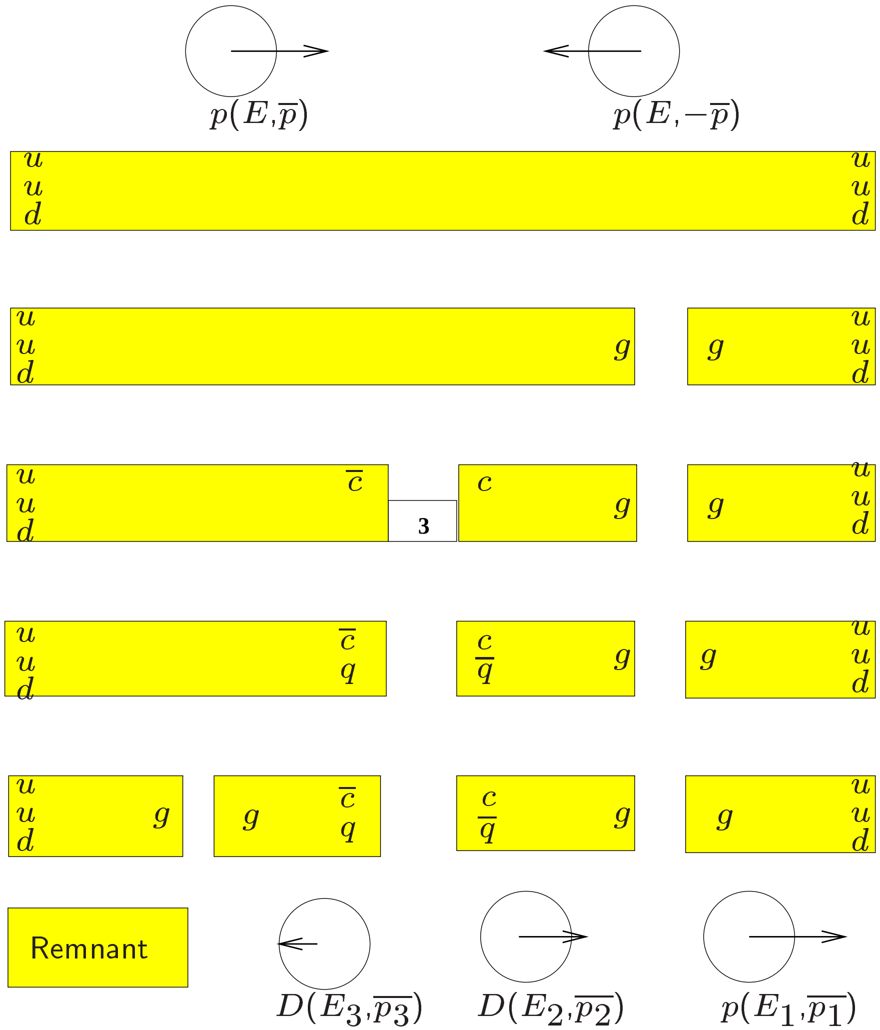
Large probability for gluon exchange when hadrons overlap

- Field energy scales with Casimir operator
  $V_D(r) \propto C_D \Rightarrow \kappa_D \propto C_D$
- Higher order representations ($D =$ **3**, **8**...) have larger C_D
  $\Rightarrow$ less suppression of heavy objects
  e.g. charm quarks

Field	**3**, $\overline{\mathbf{3}}$	**6**, $\overline{\mathbf{6}}$	**8**	**10**, $\overline{\mathbf{10}}$	**15**
κ_D/κ_3	1	10/4	9/4	9/2	4
$\frac{P(c\bar{c})}{P(u\bar{u})}$	10^{-11}	10^{-4}	10^{-5}	10^{-3}	10^{-3}

charm suppression ‘only’
$\frac{P(c\bar{c})}{P(u\bar{u})} \approx 10^{-5}$ in octet field

New model: Colour octet string fragmentation

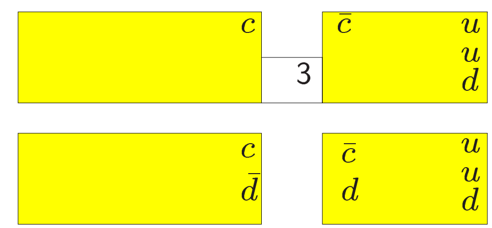


- Proton-proton collision, gluon exchange
  $\Rightarrow$ octet string between proton remnants

- String fragmentation by octet charges,
  gluon–gluon or $q\bar{q}'$–$q'\bar{q}$ $(3 \otimes \bar{3} = 1 \oplus 8)$
  i.e. $8 - \bar{8}$ which screen the field

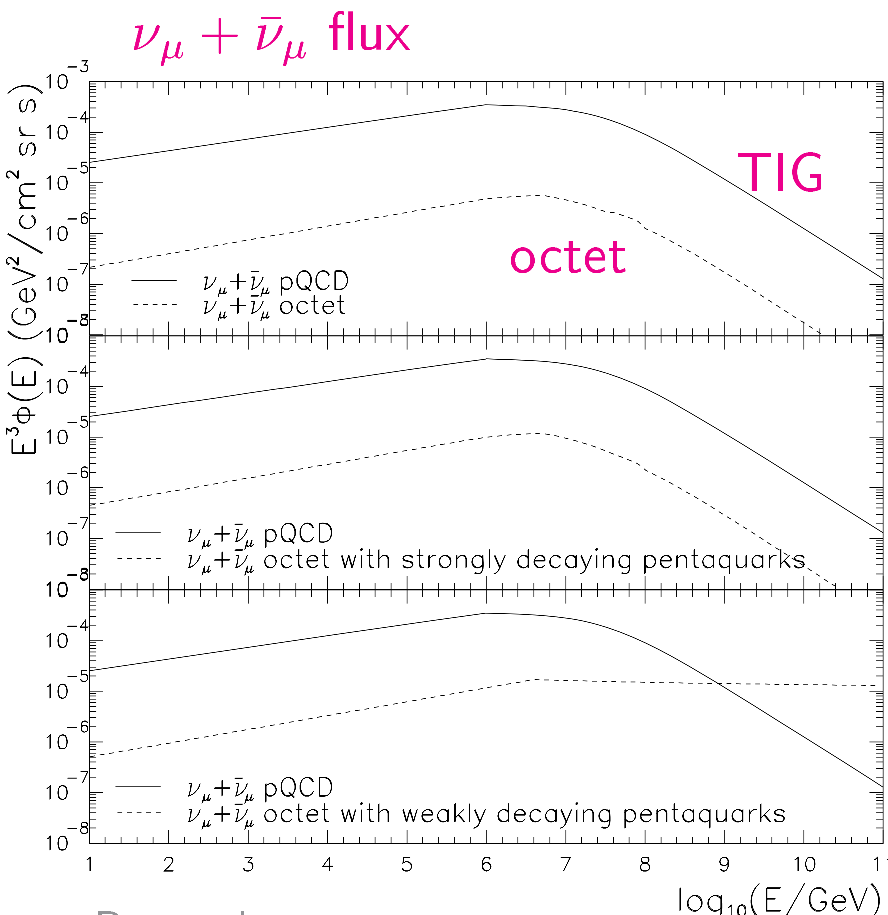
- Gluons absorbed in formed hadrons
  no glueballs yet, but could be added. . .

- $q\bar{q}'$–$q'\bar{q}$ in two steps $q\bar{q}$ plus $q'\bar{q}'$
  $\Rightarrow$ charm hadrons with hard x_F-spectrum
  $\Rightarrow$ pentaquark state $\Theta_c = udud\bar{c}$
  from proton remnant

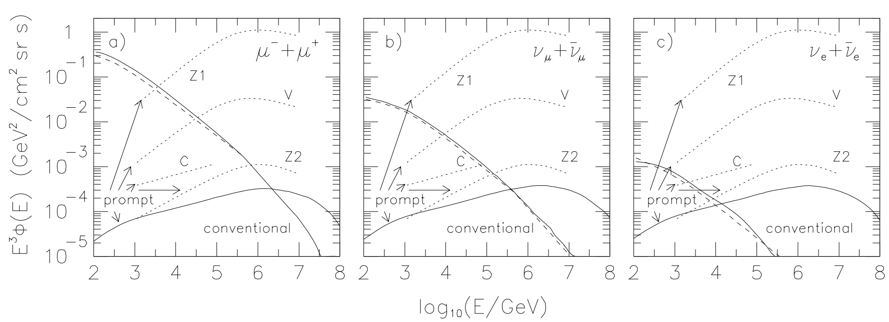


Example: leading proton, two charmed mesons
plus lower energy particles

Octet field contribution to atmospheric neutrinos



Remember:



$c\bar{c}$ from octet string hadronisation:

$\sigma(pp \to c\bar{c} + X) \approx 10^{-5}\sigma(pp \to X)$

$\to$ harder $x_F = E_D/E_p$ spectrum

With only known charm particles

$\Rightarrow$ factor ~ 50 lower flux than standard TIG

Including pentaquark Θ_c:

- strong decay $\Theta_c \to DN \to l\nu_l X$
  $\Rightarrow$ low flux
- weak decay $\Theta_c \to l\nu_l\Theta^+$, BR=20%
  $\Rightarrow$ eventually dominating *if* $\tau_{\Theta_c} \leq 10^{-14}s$
  but disfavoured by HERA data

Fluxes from charm remain small

should be $\approx$ as in TIG

Conclusions

- Volkova's model dubious
  w.r.t. x_F-dependence
  $\Rightarrow$ too large ν-flux

- New non-pert. QCD model
  for $c\bar{c}$ production
  $\Rightarrow$ very low ν-flux

- Best ν-flux estimate from pQCD
  $+$ well tested hadronisation model
  $i.e.$ TIG and its updates
  ($e.g.$ NLO pQCD)

Outlook

- Low atmospheric ν-flux
  $\Rightarrow$ low background for cosmic ν's

- Good news for ν-telescopes

- . . . lots of fun . . .