CRs and neutrinos from blazars with nuclei injection

[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

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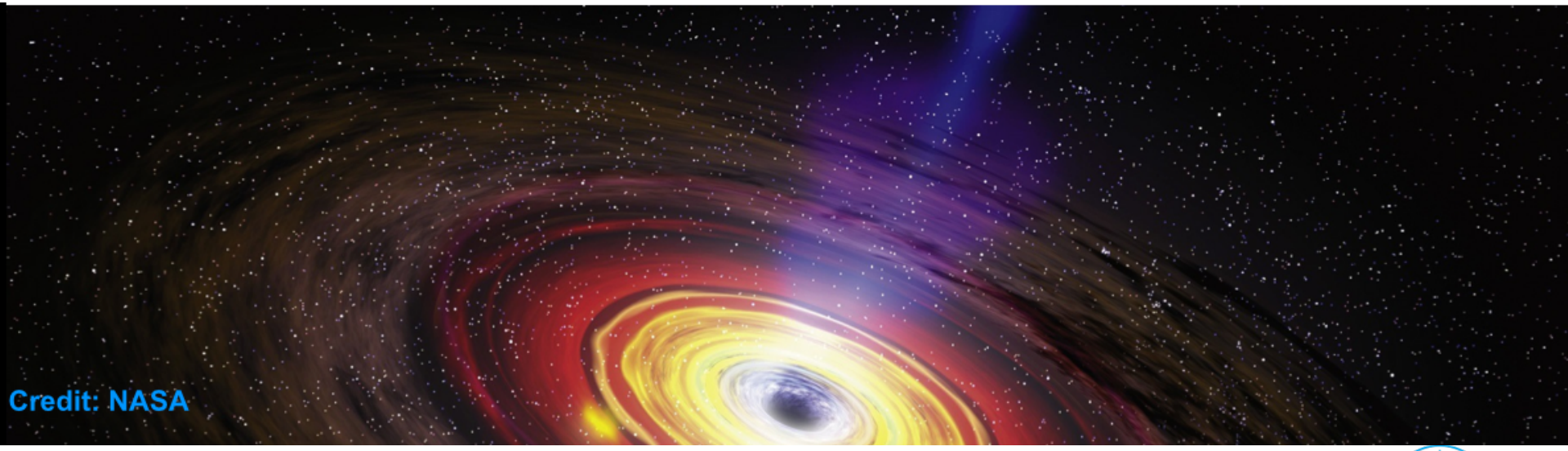
Introduction

- Are blazars the source of UHECR and/or astrophysical neutrinos?
- Pierre Auger Observatory results indicate a mixed composition at high energies

Simulate interactions of nuclei with target photon field using NeuCosma [Bearwald et al 2012]

- BL Lacs and FSRQs have different photon fields and geometries

Different modelling of BL Lacs and high-luminosity FSRQs



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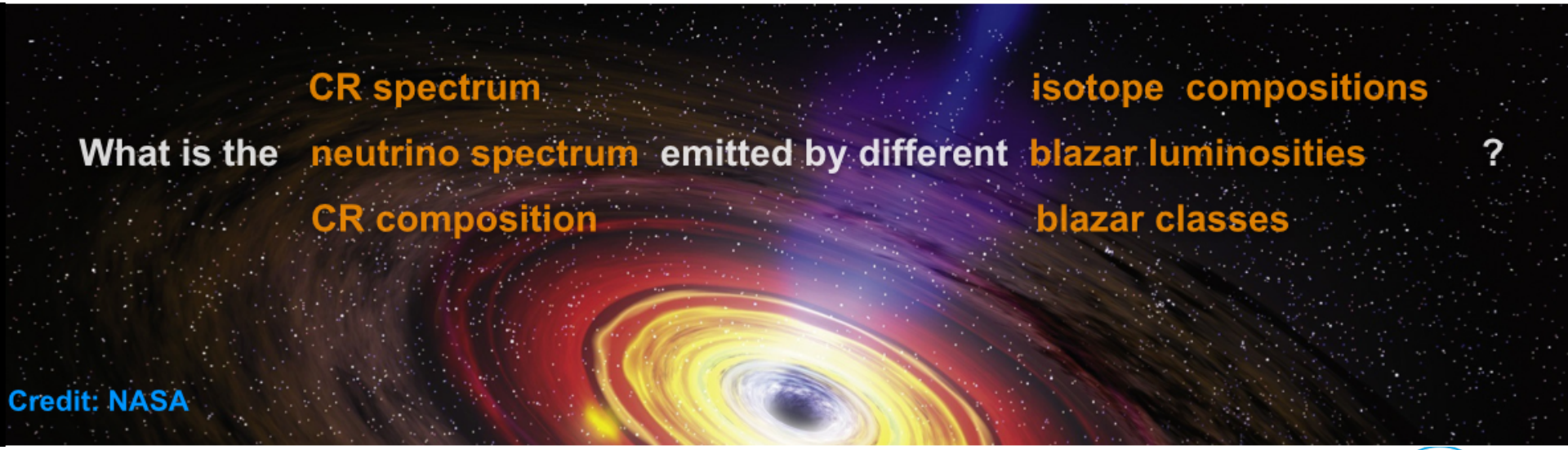


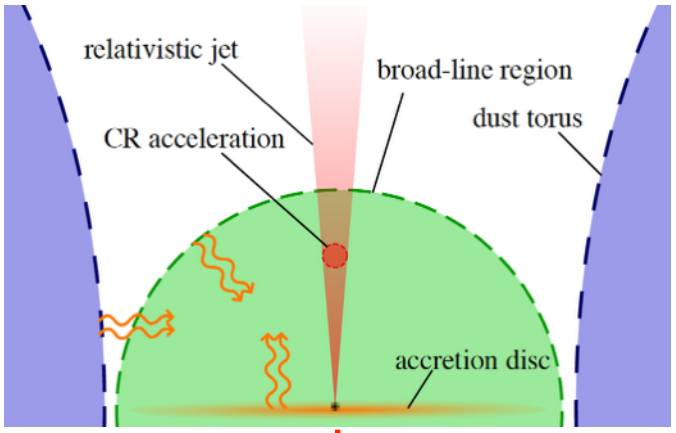
Blazar classes and the blazar sequence

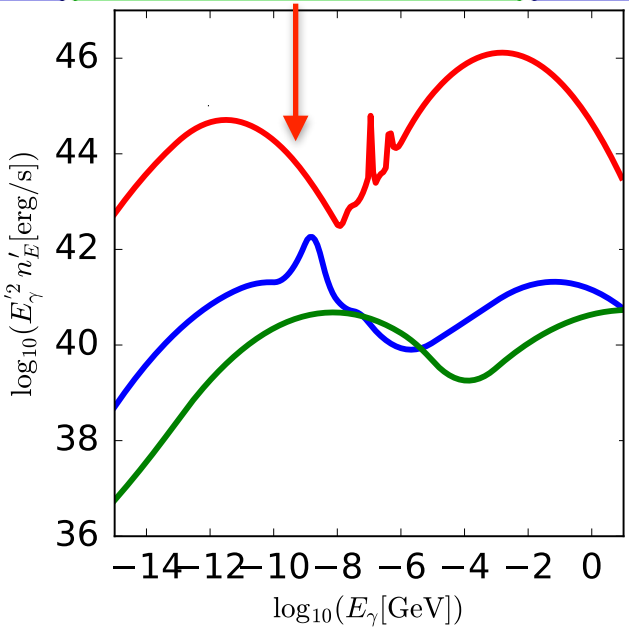
- Non-thermal spectral energy distribution (SED)
  - Low-*E* peak (synchrotron)
  - High-*E* peak (e^- inverse Compton or hadronics)

[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

- **FSRQs**
  - High broadline luminosity
  - Modelled by a broadline region (BLR) exposed to radiation from an accretion disk
  - May be obscured laterally by a dust torus (DT)

High-luminosity FSRQ





[Murase et al 2014]

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  - High broadline luminosity
  - Modelled by a broadline region (BLR) exposed to radiation from an accretion disk
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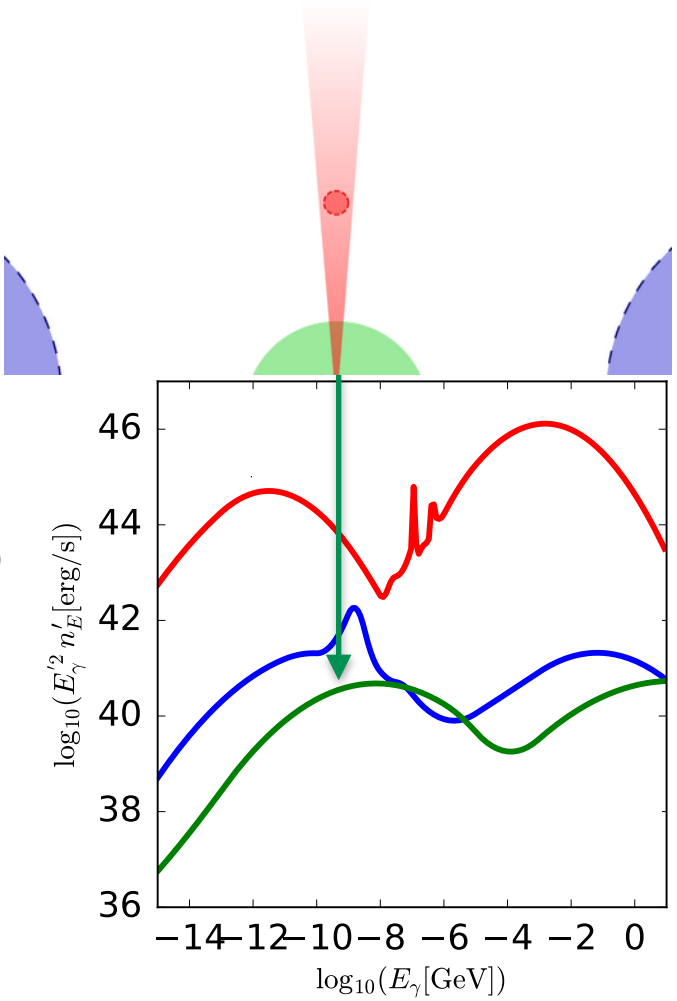
- **BL Lacs**
  - Low broadline luminosity
  - We will neglect any regions surrounding the jet

FSRQ / BL Lac



[Murase et al 2014]

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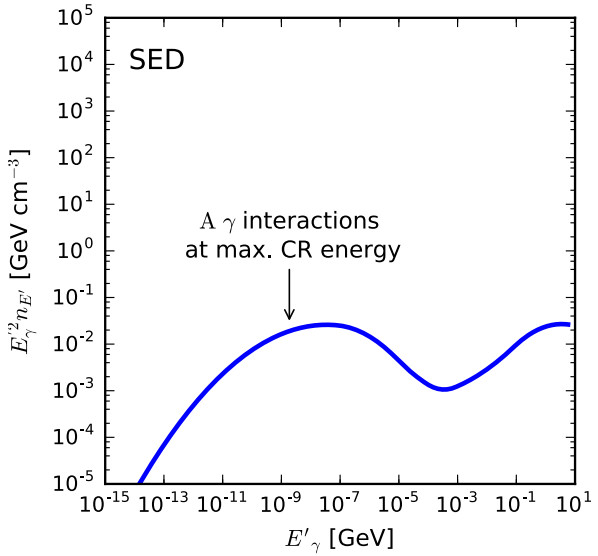
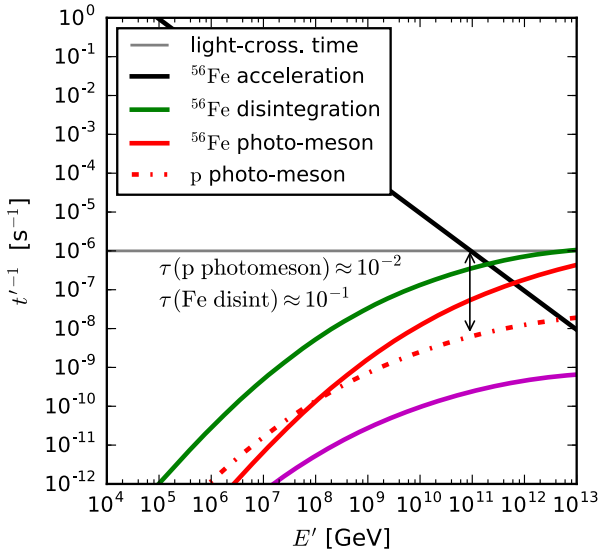
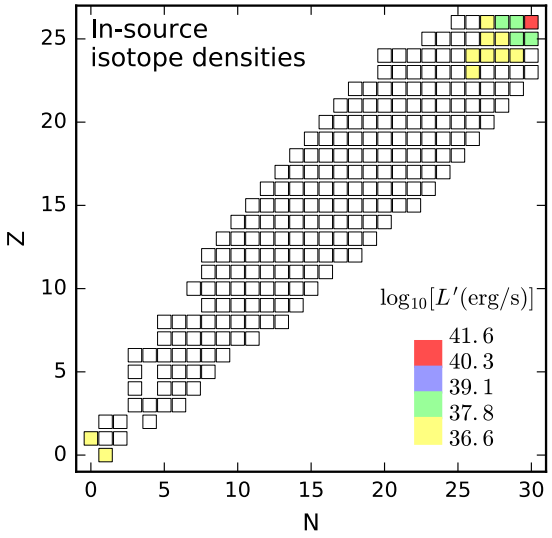
Nuclear regimes in the jet

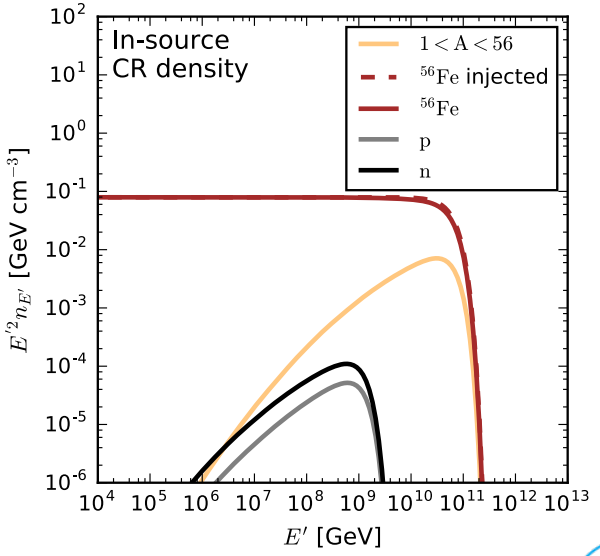
Low Luminosity:

Nuclear survival







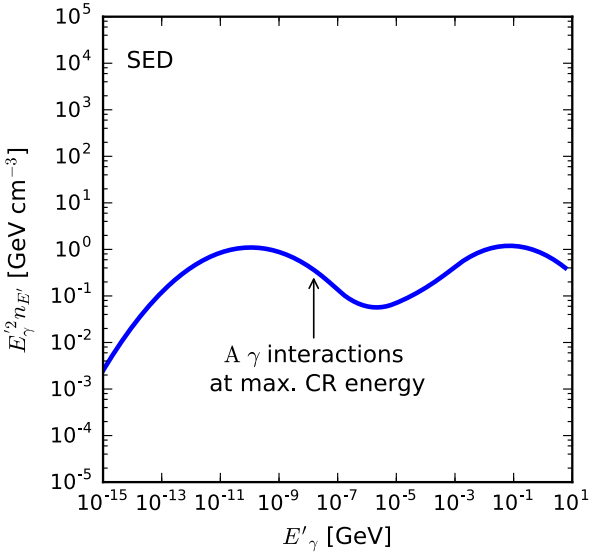


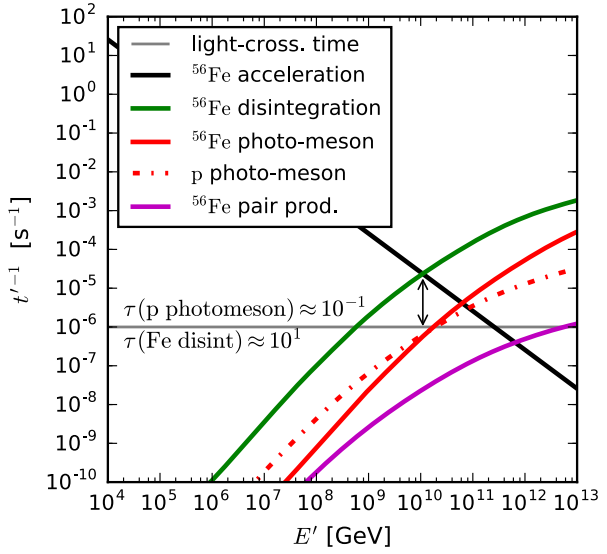
[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

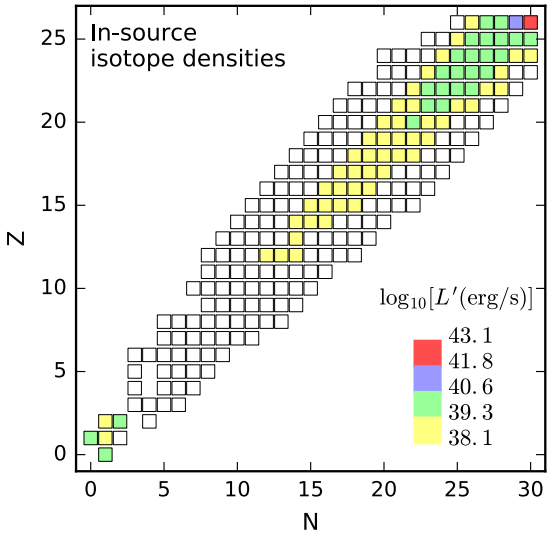
Nuclear regimes in the jet

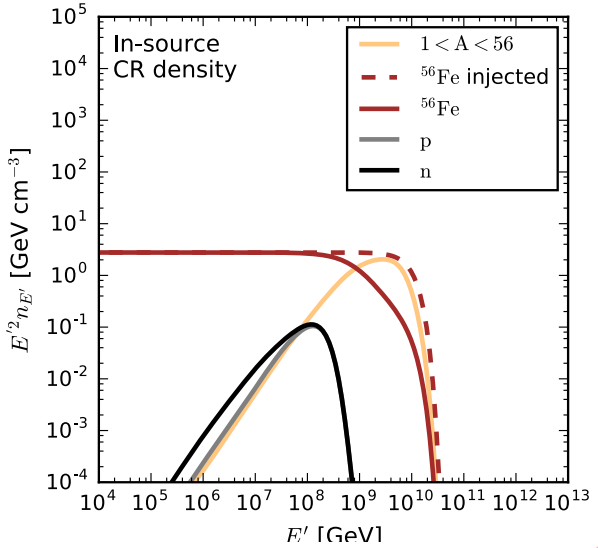
Interm. Luminosity:

Nuclear cascade









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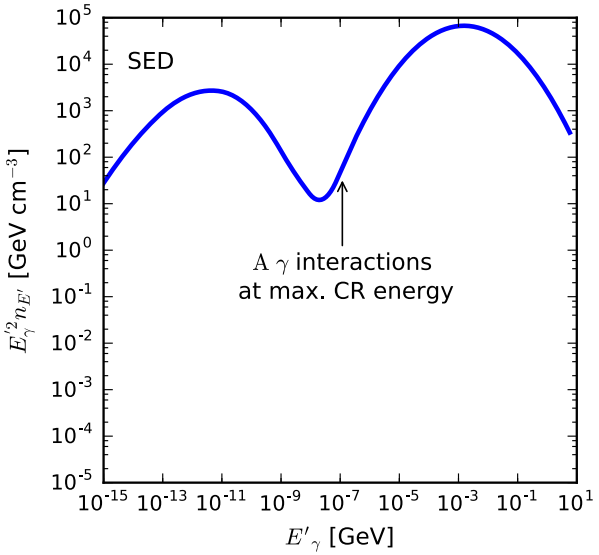
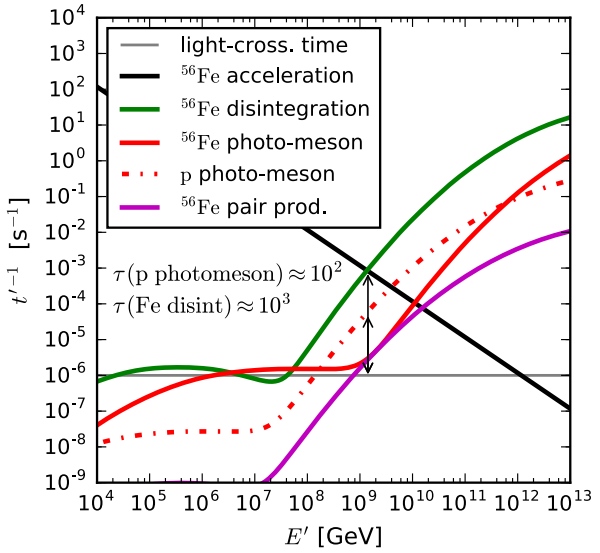
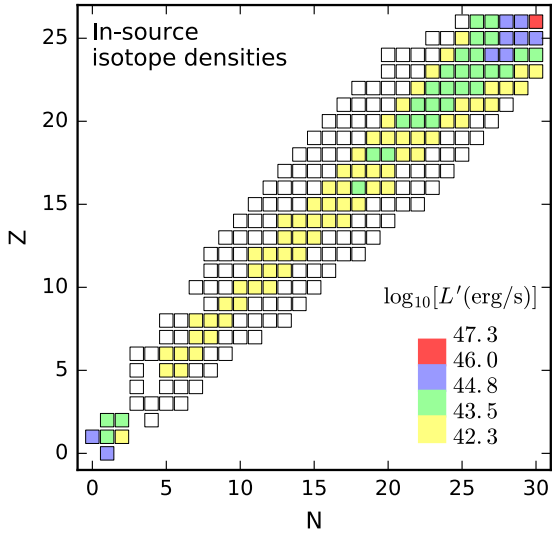
Nuclear regimes in the jet

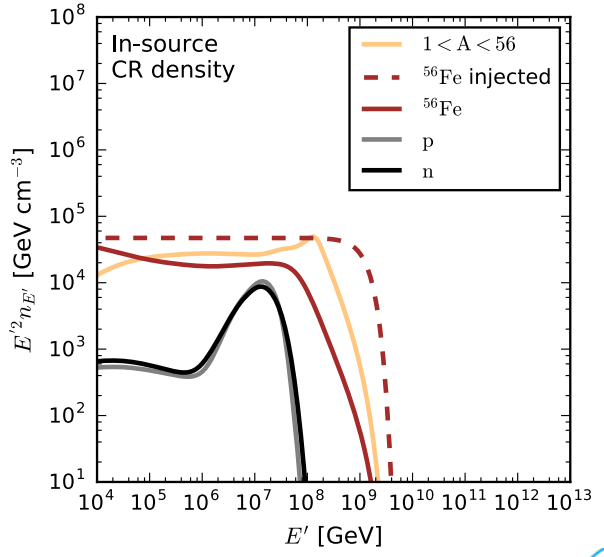
High Luminosity:

Optically thick









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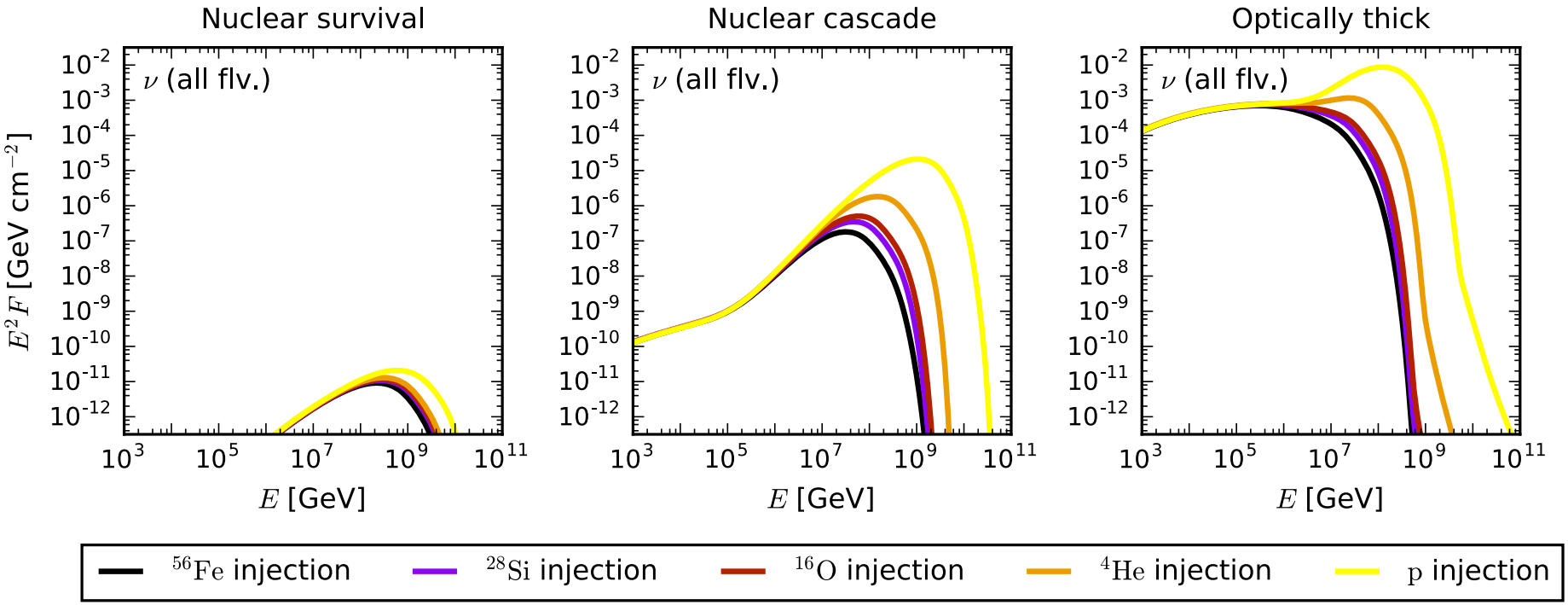
Neutrino emission from the jet

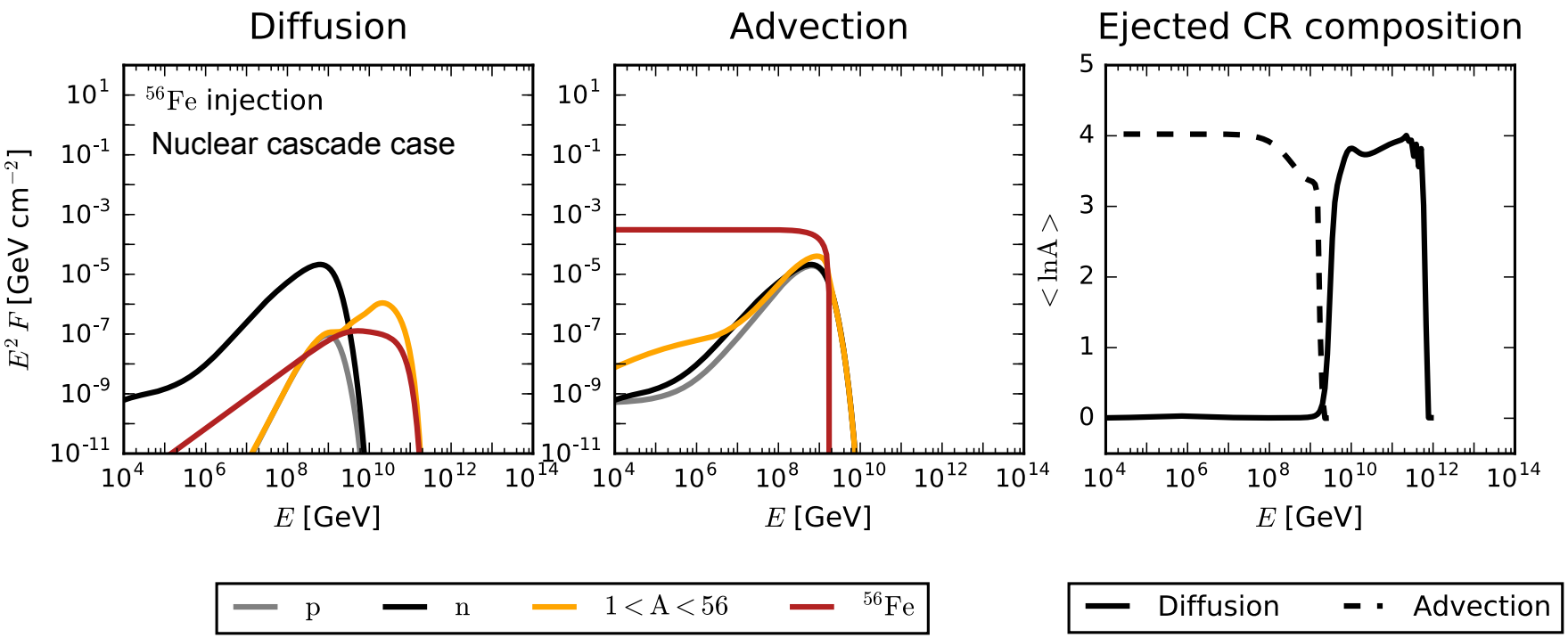


[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

Jet model — CR escape

> Magnetic confinement
> Rate proportional to Larmor radius

> Escape limited only by cooling [Murase et al 2014] or disintegration



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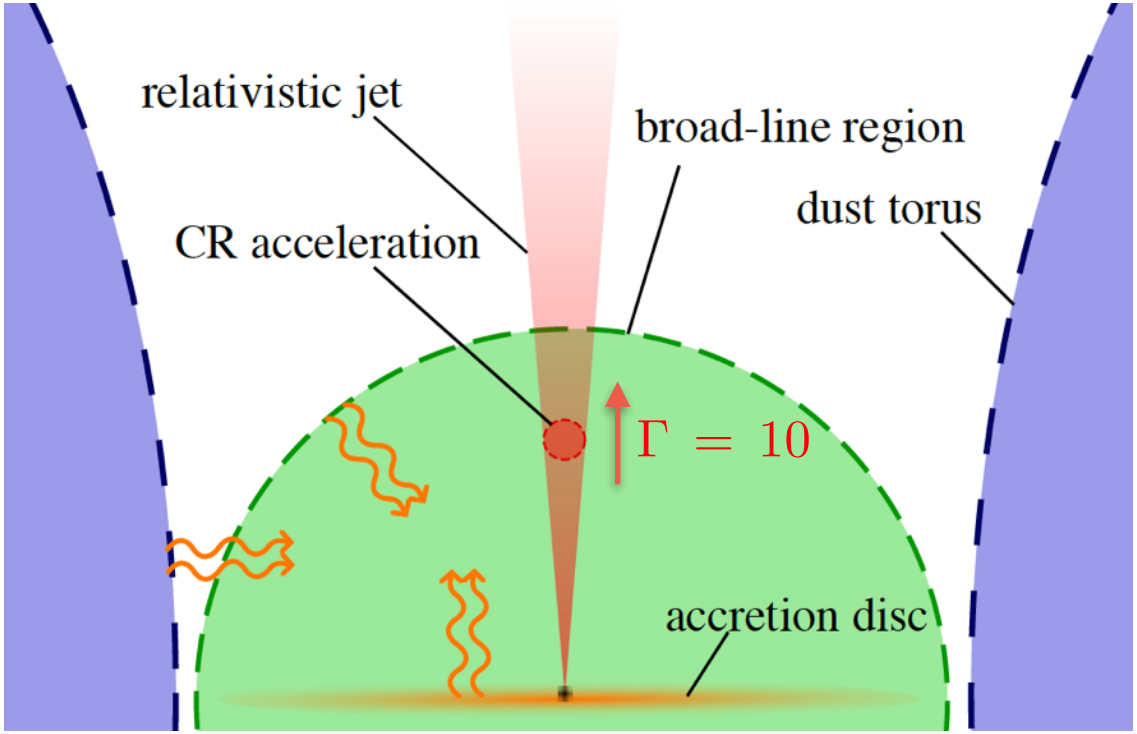
A model for High-Luminosity FSRQs



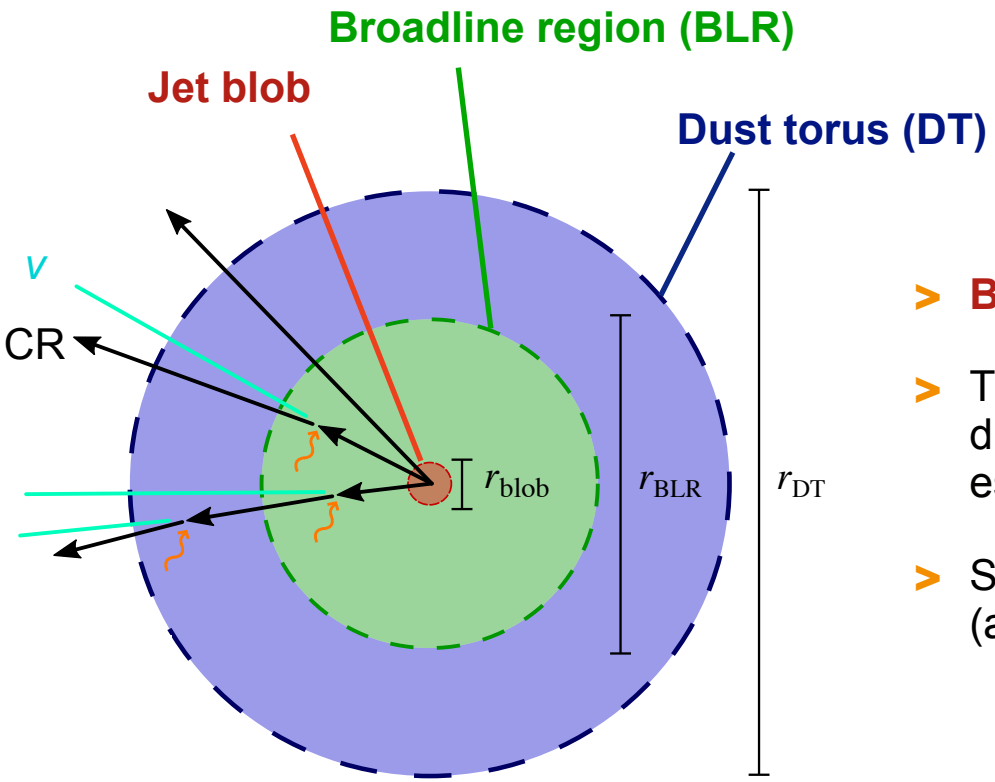
$$r_{\rm BLR} \propto r_{\rm disk} \propto \sqrt{L}$$

Murase et al, PRD 90 (2014)
Ghisellini et al MNR AS 387 (2008)

Jet blob inside BLR for bright FSRQs

A model for High-Luminosity FSRQs

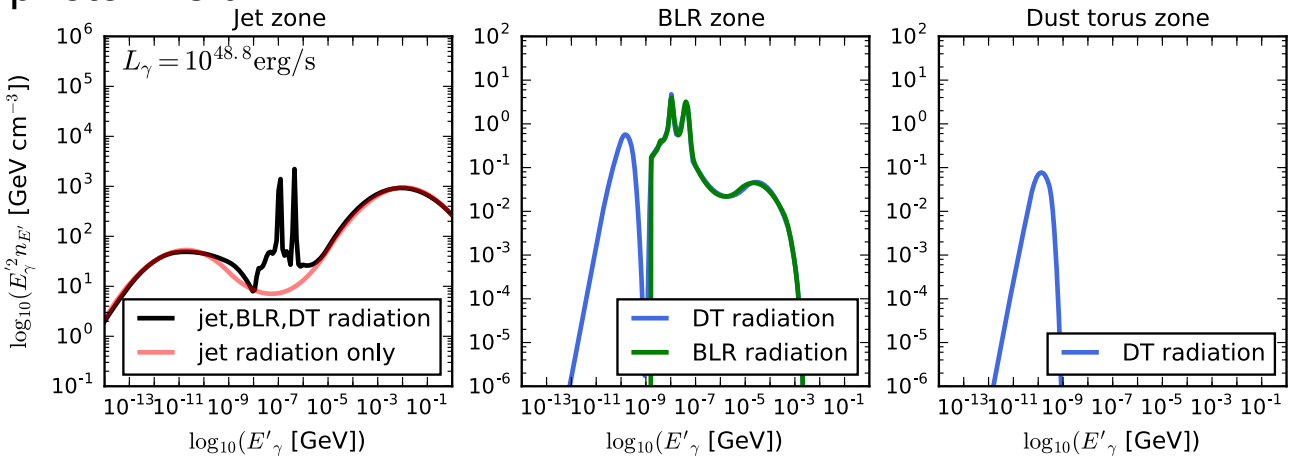
Simulation setup



- **Blob** simulation halts at $t' = t'_{flare} \sim 10^6 \mathrm{s}$
- The escaping CR are Lorentz boosted and dumped into the **BLR** where they interact or escape into the **DT**
- Simulation runs until $t = r_{DT}/c$ (all CR will have decayed or escaped)

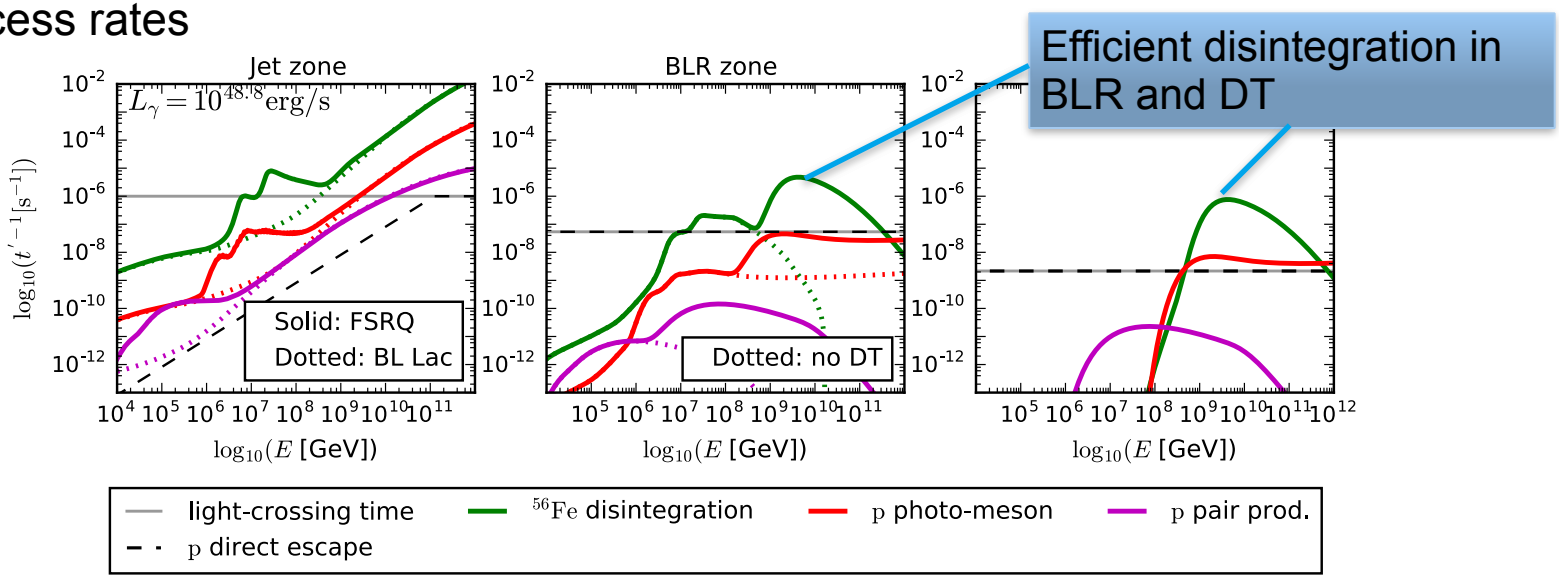
A model for High-Luminosity FSRQs

- Static photon field



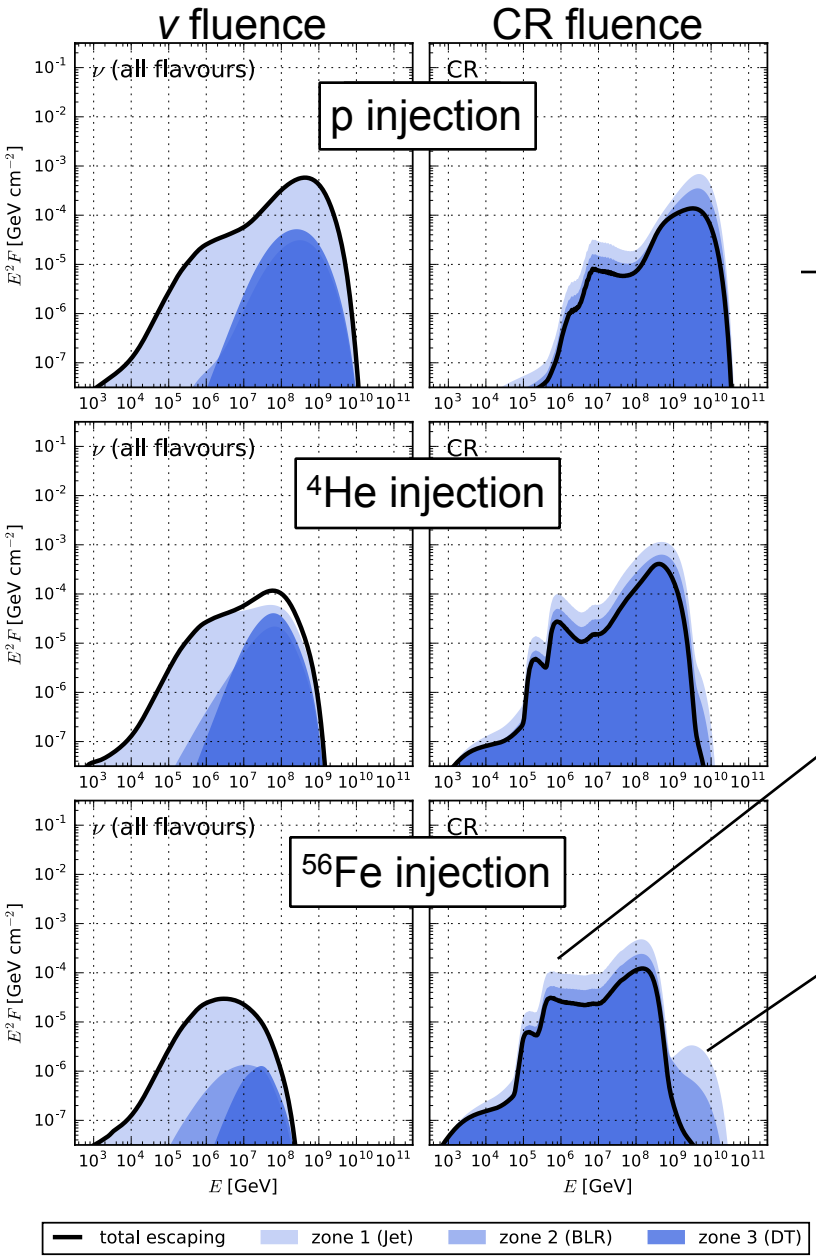
[Murase et al 2014]

- Process rates



[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

High-Luminosity FSRQs — Ejected spectra



Diffusive escape assumption

Higher E_{max} for lighter injection compositions

Mostly neutrons at low energy

Iron nuclei above 10^9 GeV disintegrate in the BLR and DT before escaping

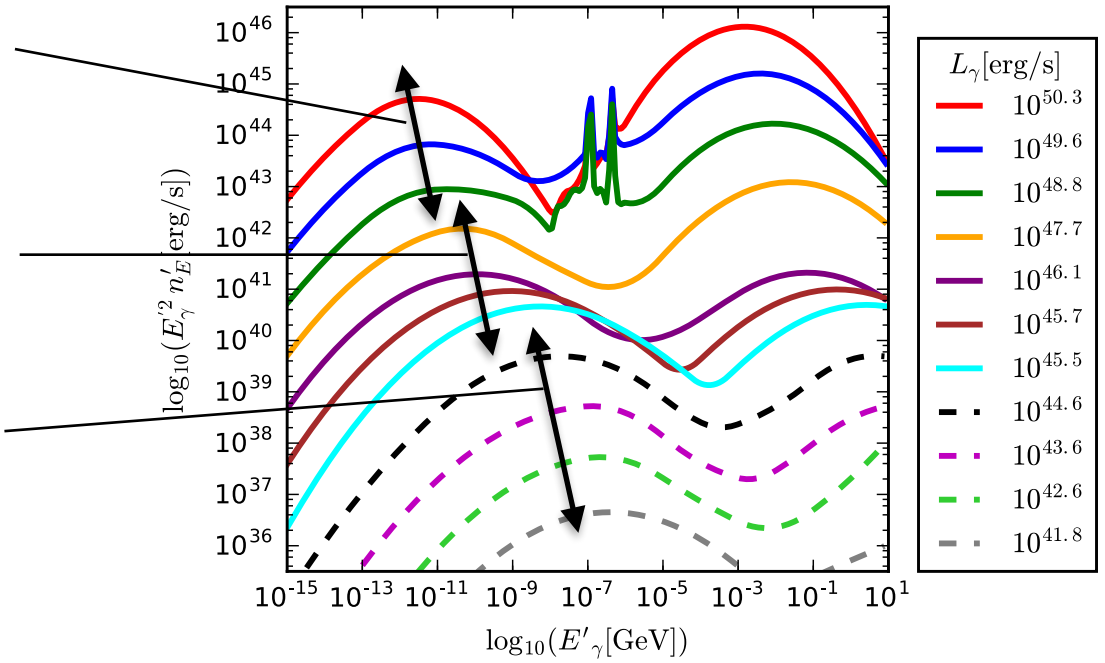
[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

The CR/neutrino blazar sequence

HL-FSRQ
(blob inside BLR)

FSRQ / LBL Lacs
(blob outside BLR or no BLR)

HBL Lacs
(no BLR)



Solid lines: [Murase et al 2014]
[Fossati et al 1998]

[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

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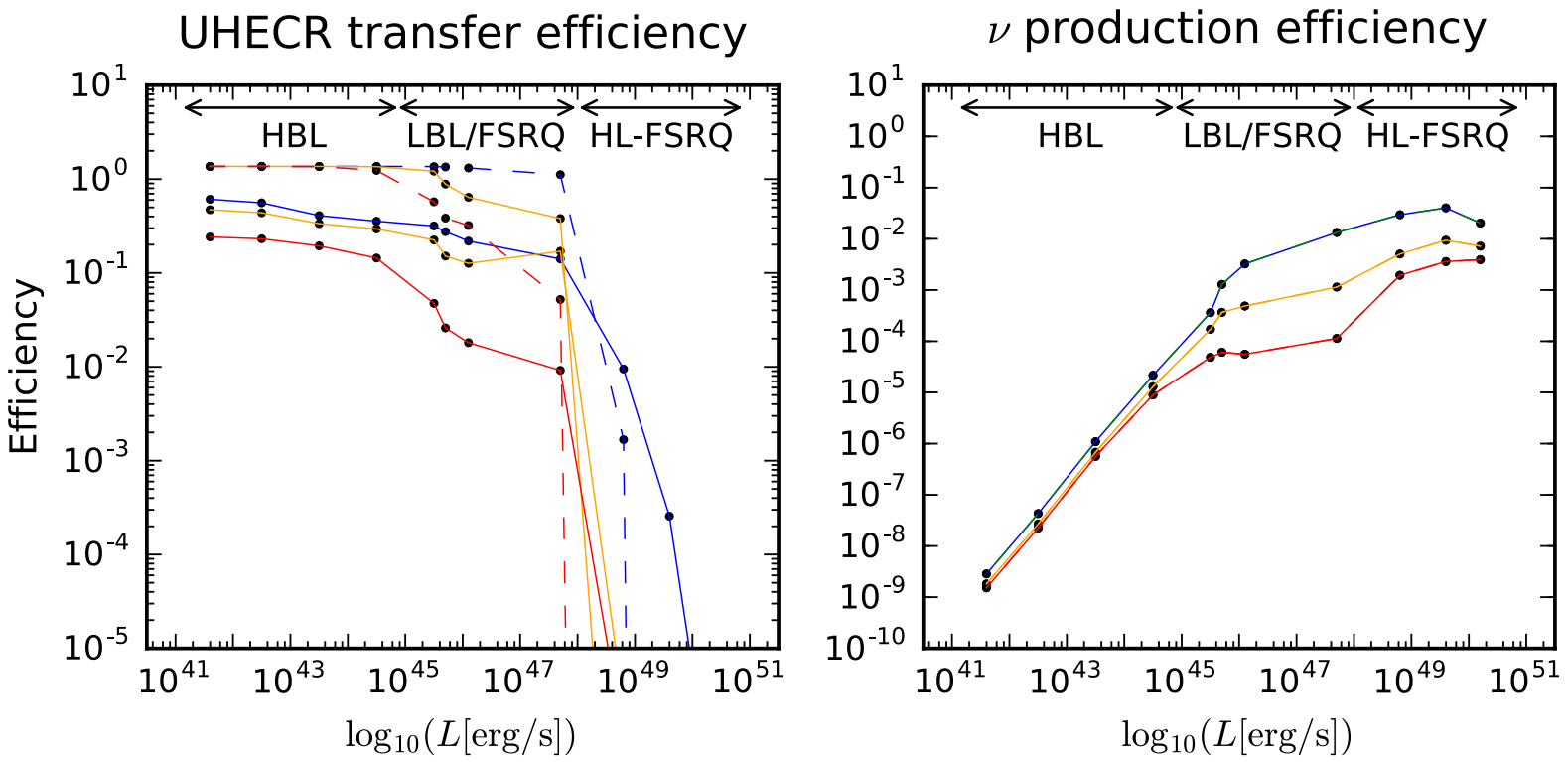

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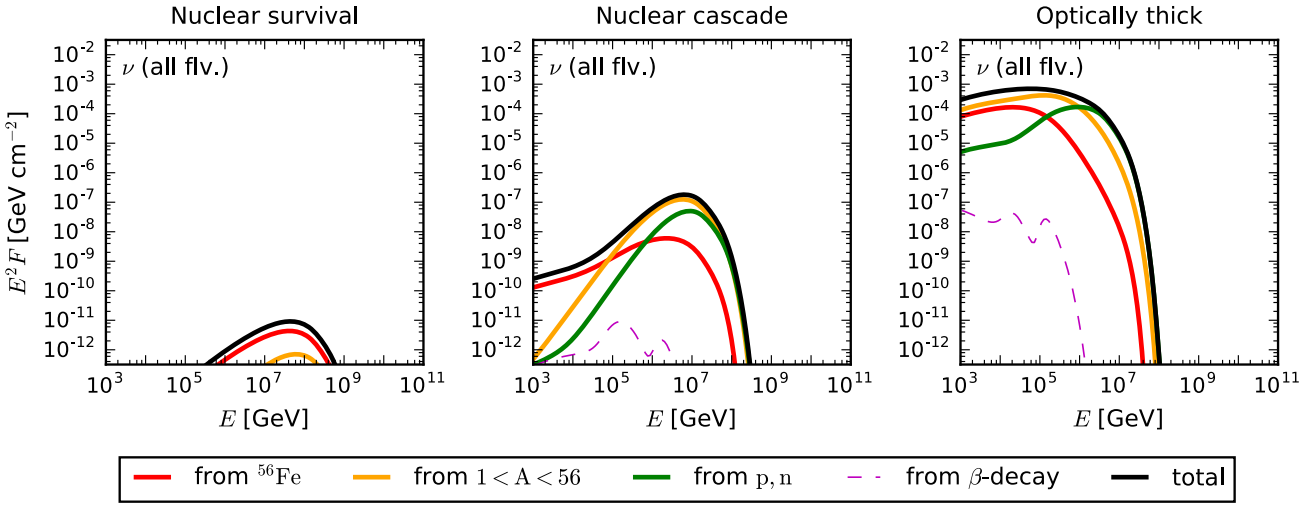
Conclusions

- We have quantified the UHECR and neutrino efficiency of blazar classes
  - HL-FSRQs and LBL Lacs are good neutrino emitters with low UHECR efficiency
  - HBL Lacs are good sources of UHECR, low neutrino production efficiency
- An injection composition heavier than protons provides a lower neutrino cutoff energy due to disintegration in the source
  - However, efficient disintegration at high energy may pose a problem in powering the UHECR **—> calculation of diffuse spectra to follow soon**

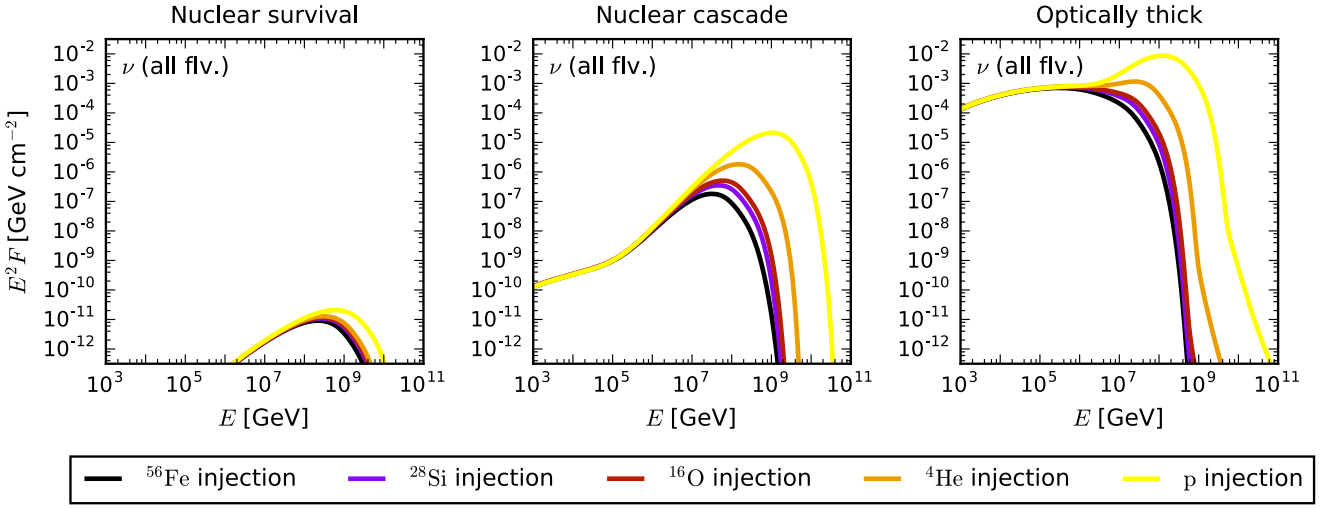
Backup

Neutrino emission from the jet

- Iron-56 injection



- Other isotopes



[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

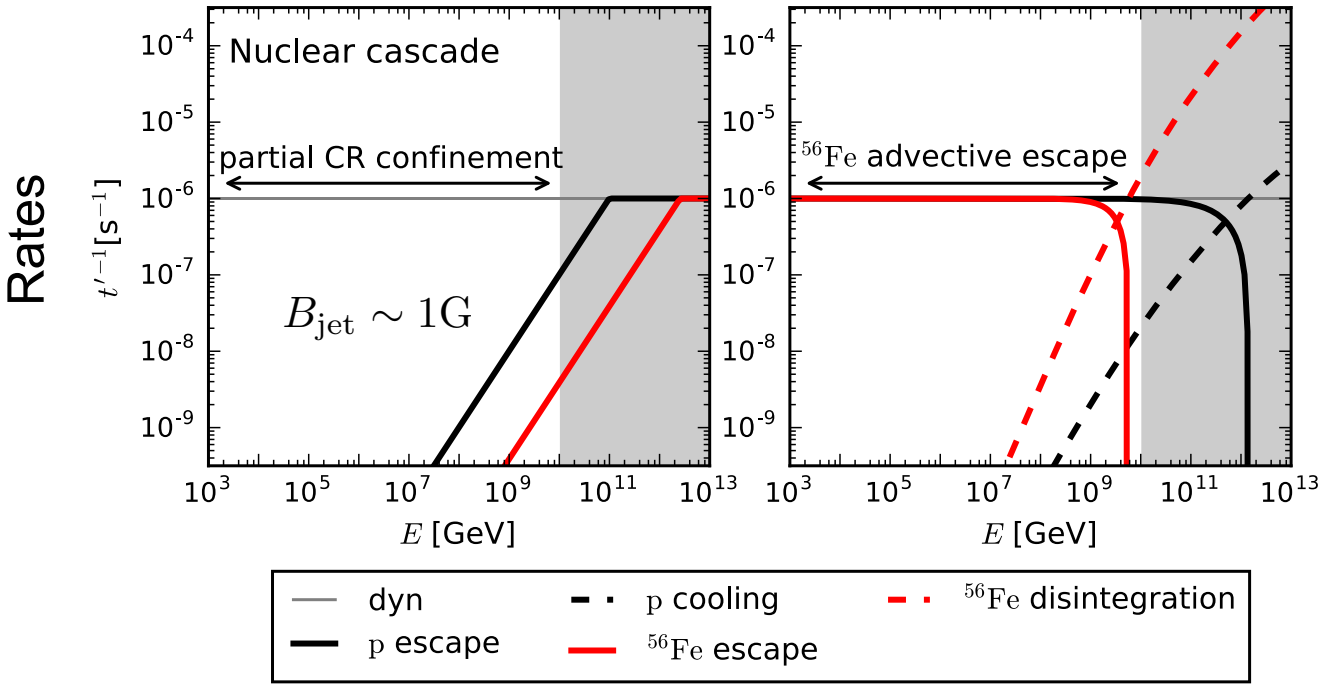
Jet model — CR escape

Escape partially limited by magnetic confinement
(rate proportional to Larmor radius)

Escape limited only by cooling
[Murase et al 2014]
or disintegration

Diffusion

Advection

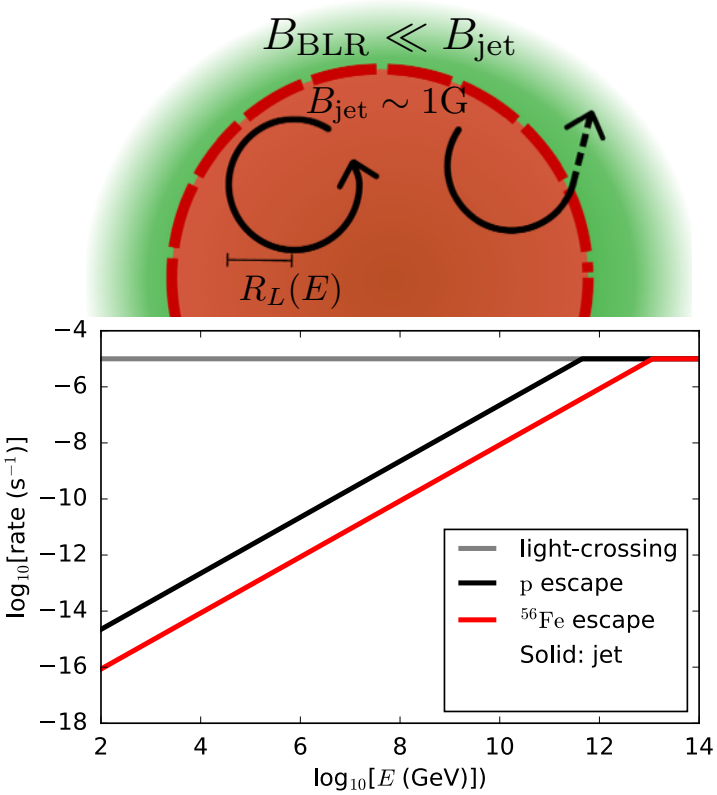


[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

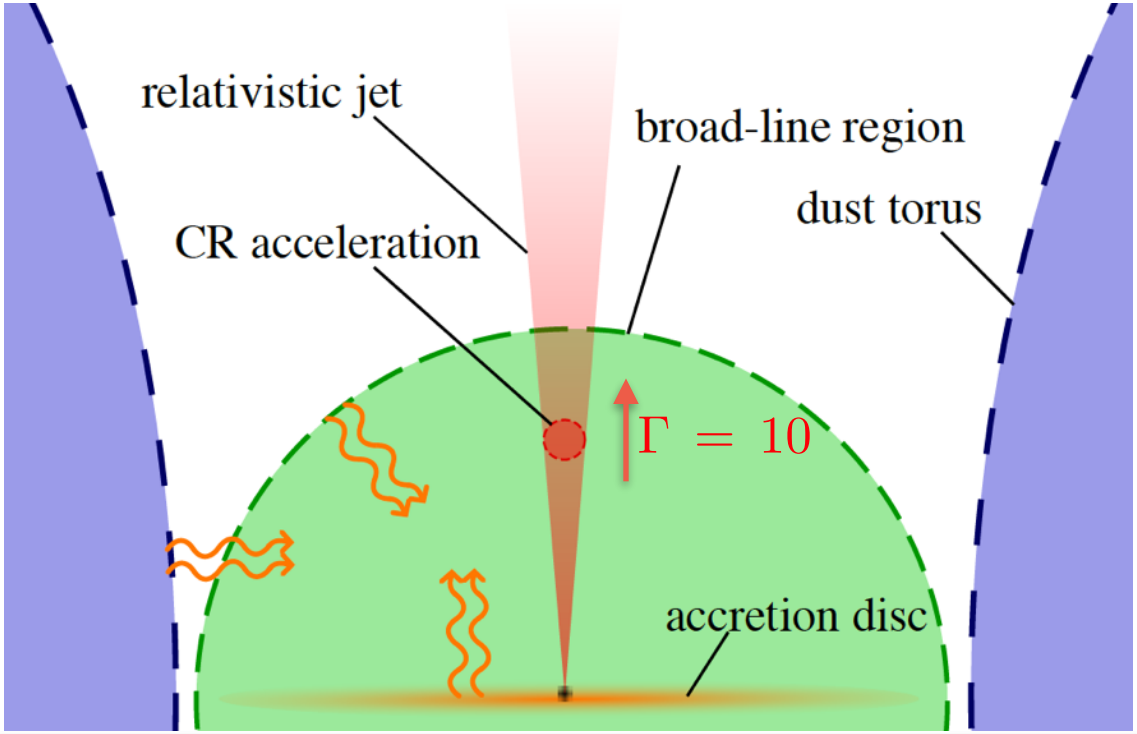
Jet model — CR escape

- Diffusion-dominated escape (Bohm-like)

$$t_{\rm esc}^{-1}(E) = t_{\rm light\text{-}cross}\frac{R_L(E)}{R_{\rm zone}} \propto \frac{E}{qB}$$



A model for High-Luminosity FSRQs



$$r'_{\rm blob} = c\,t'_{\rm flare} = 3 \cdot 10^{16}{\rm cm}$$

$$r_{\rm BLR} \approx 10^{17}{\rm cm}\left(\frac{L_{AD}}{10^{45}}\right)$$

$$r_{\rm DT} \approx 25\, r_{\rm BLR}$$

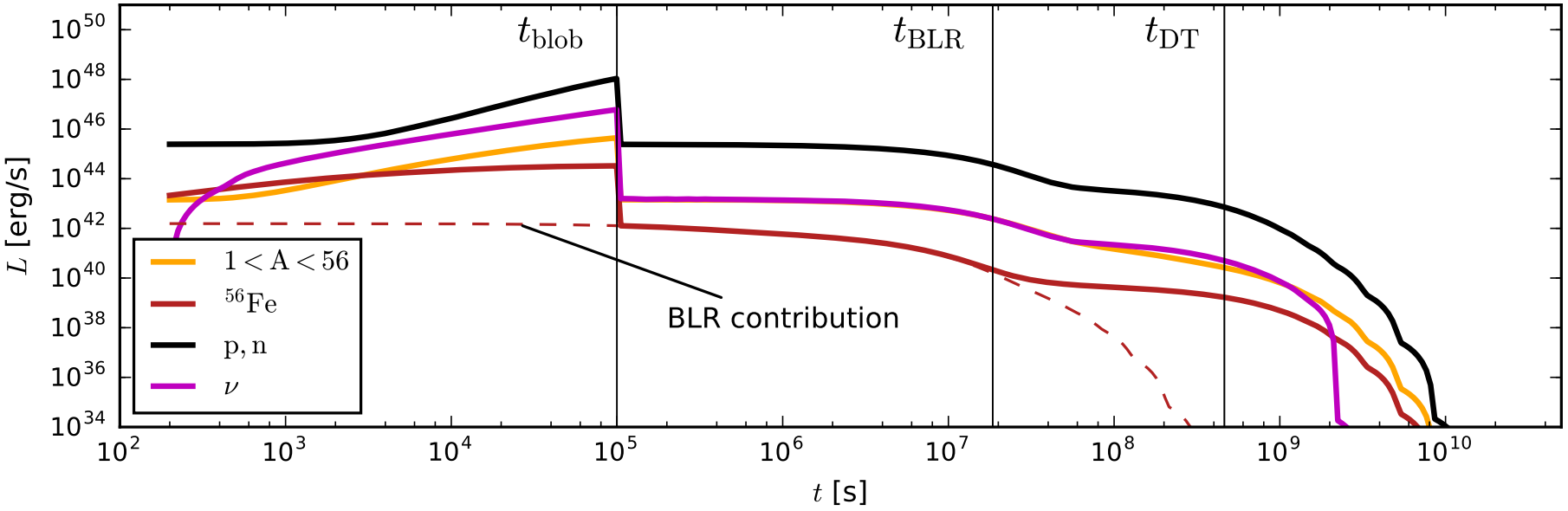
Murase et al, PRD 90 (2014)
Ghisellini et al MNR AS 387 (2008)

FSRQs: CR must go through zones 2 and 3

BL Lacs: CR go into space after escaping zone 1

A model for High-Luminosity FSRQs

> Lightcurves from the 3-zone model (example for $L_\gamma = 10^{49.1}\mathrm{erg/s}$)



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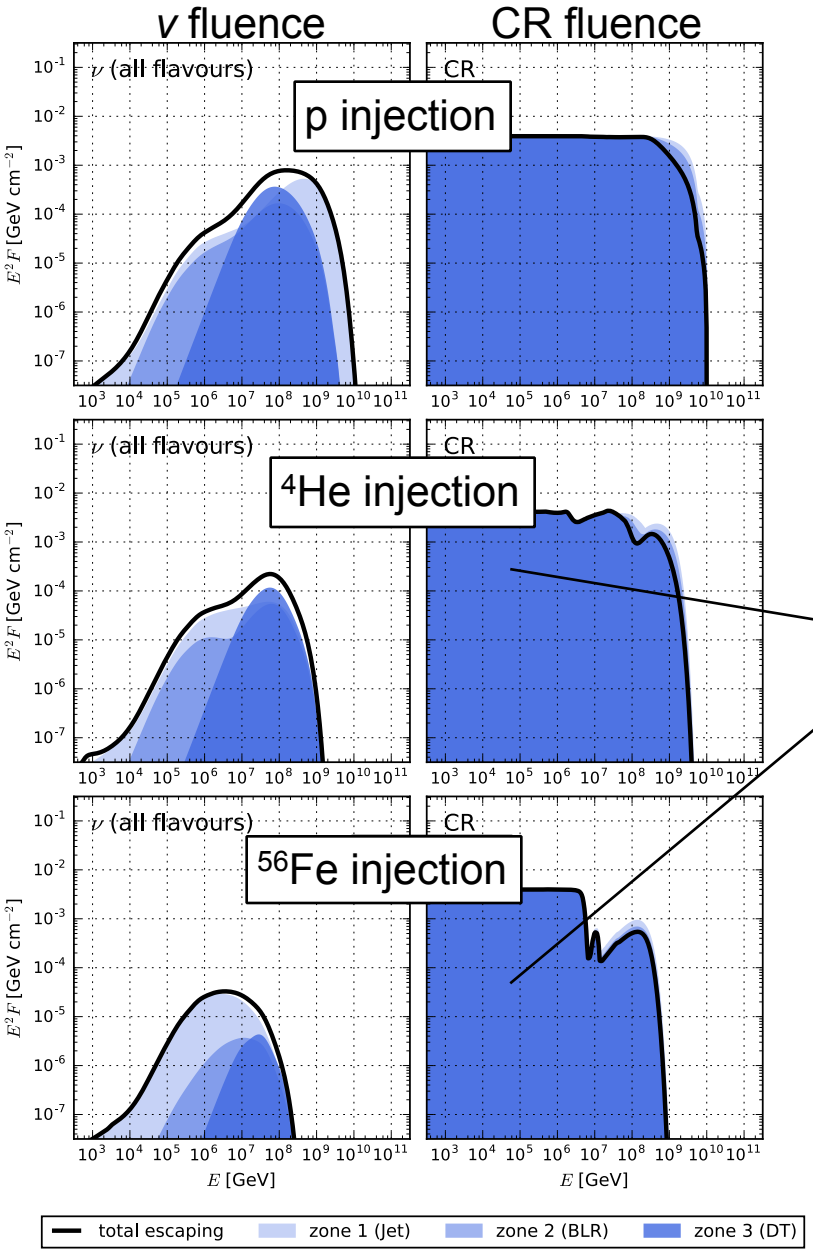
High-Luminosity FSRQs — Ejected spectra



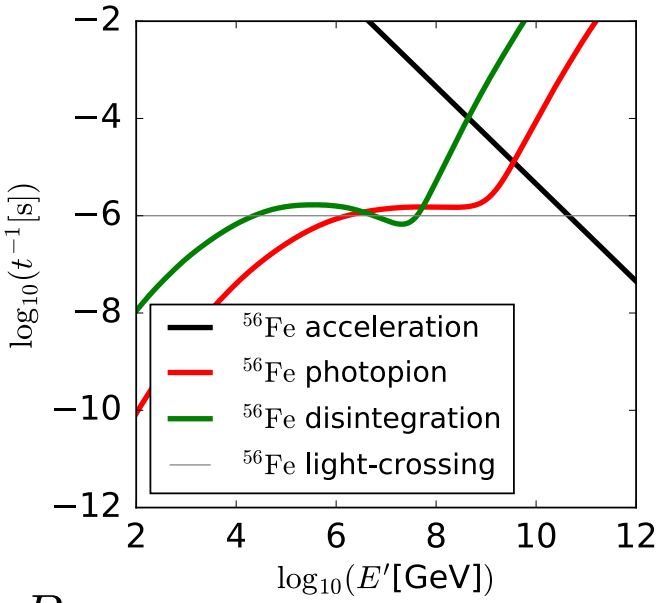
Advective escape assumption

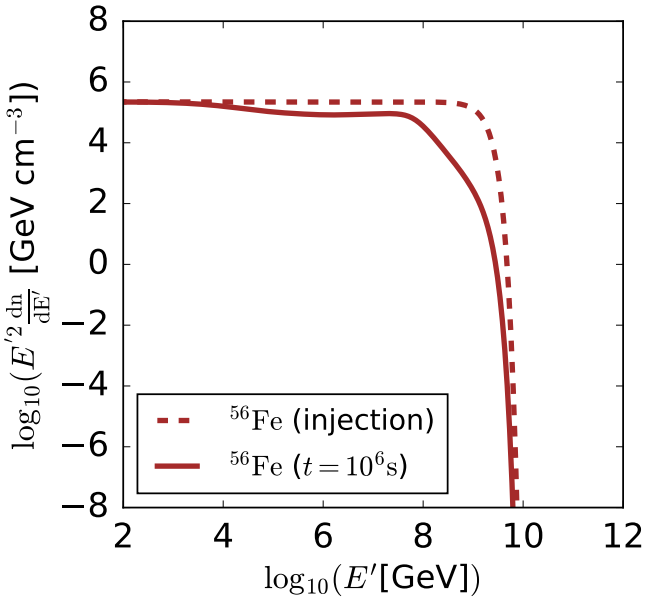
- Neutrino spectra unaffected
- At low energies the injected isotope escapes unscathed

Assumption leads to heavy composition at low energies

[XR, Fedynitch, Boncioli, Gao, Winter — in preparation]

Process rates





$$t^{-1}_{\mathrm{accel}}(E) = \eta \frac{c^2 ZeB}{E}$$

$$t^{-1}_{\mathrm{synch}}(E) = \left(\frac{Ze}{m}\right)^4 B^2 c^3$$

$$E^{\mathrm{max}}_{\mathrm{injection}} = E : \; t^{-1}_{\mathrm{acc}}(E) = \sum t^{-1}_{\mathrm{rad\ losses}}(E) + t^{-1}_{\mathrm{A}\gamma}(E) + t^{-1}_{\mathrm{disintegration}}(E)$$