FORESEE: Updates and Expanded Model Library

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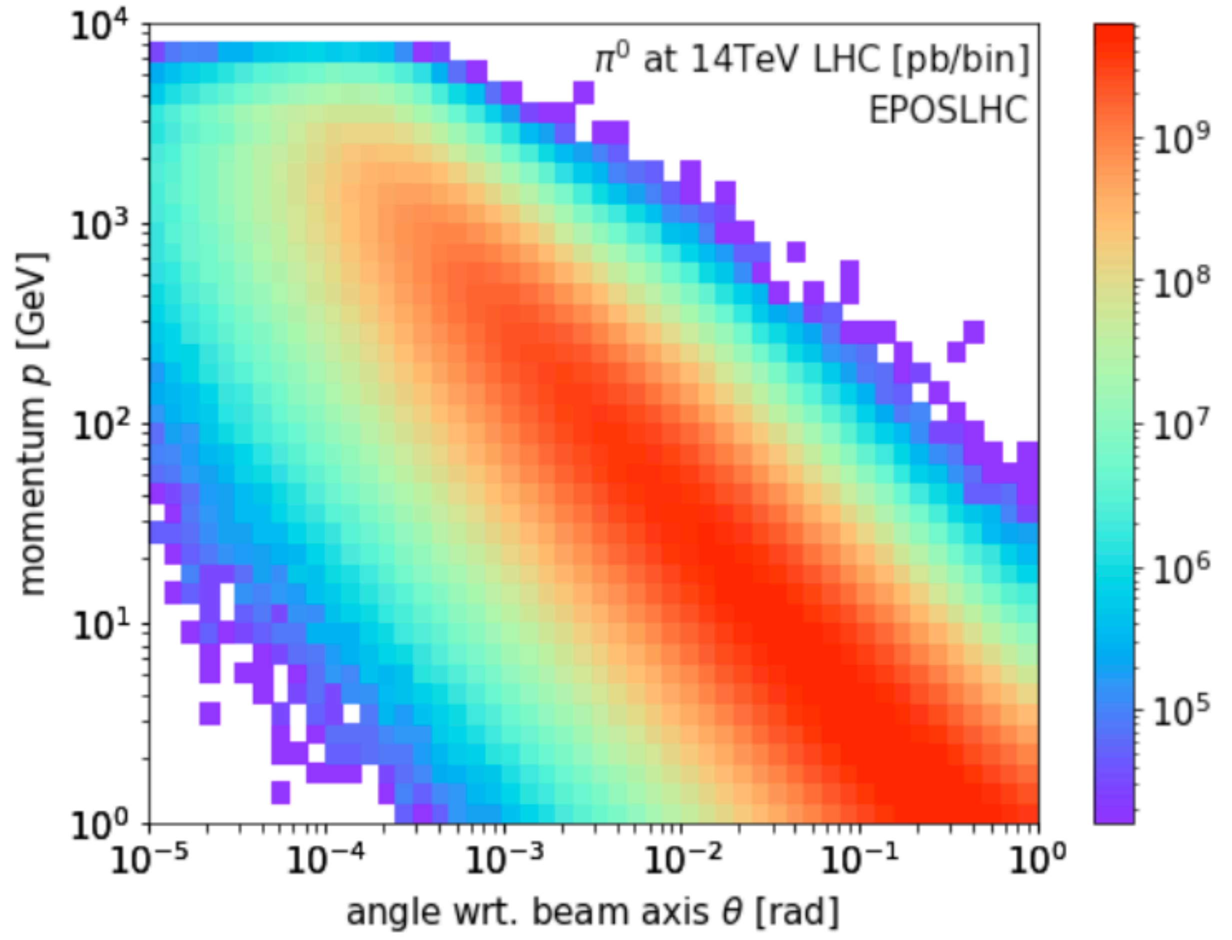
FORESEE

- A python based tool that enables LLP searches at forward detectors.
- SM fluxes available for 13.6, 14, 27, and 100 TeV.
- Provides an HEPMC file with signal events.
- Based on arXiv:2105.07077 by Felix Kling and Sebastian Trojanowski.
- New members: Jyotismita Adhikary and R.M.A.
- Latest version v1.3.0 available on Github.

How does FORESEE work?

FASER

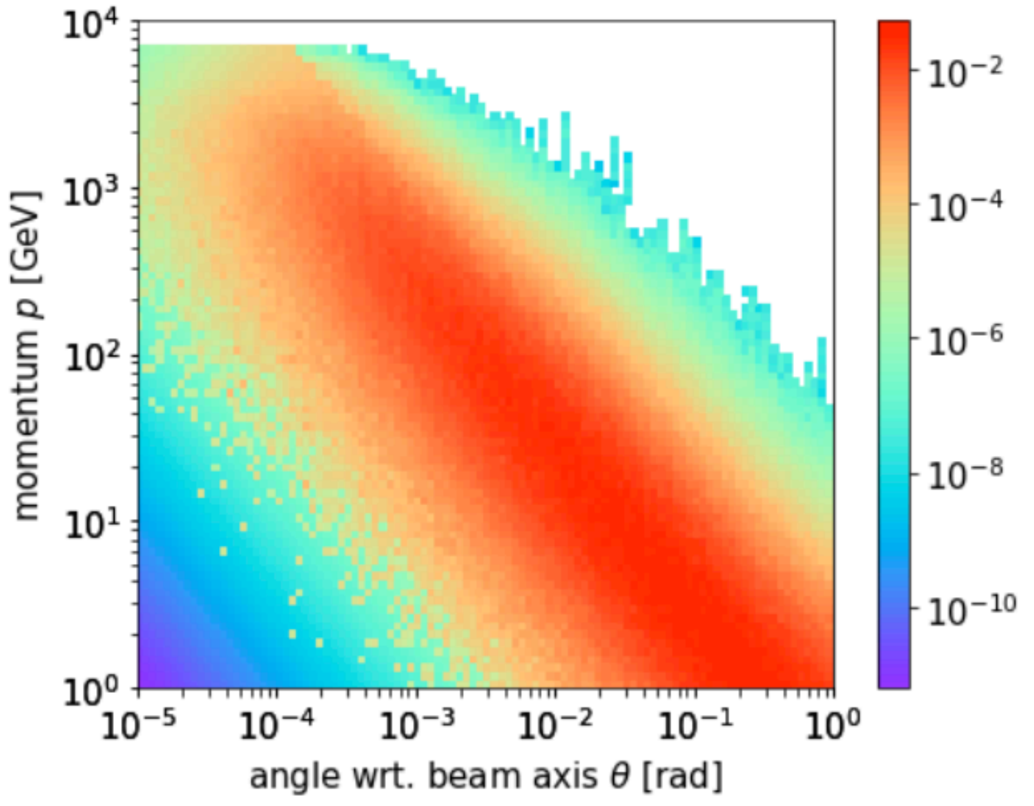


1. Hadron spectra (π, η, K, D, B, …) from dedicated MC generators (EPOS, QGSJET, SIBYLL, PYTHIA)

2. Specify model (production, lifetime, LLP decay BR)

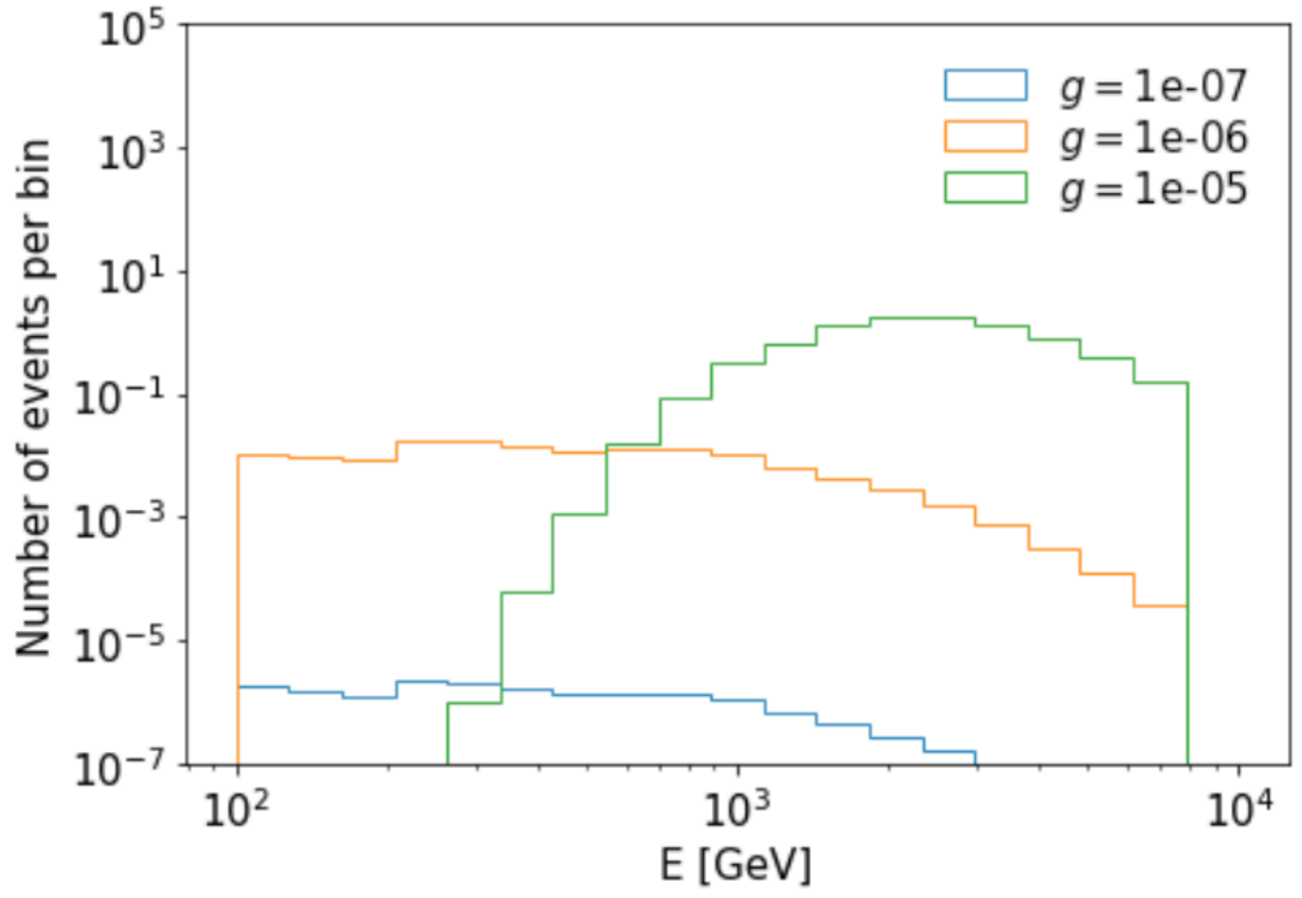
```
model.add_production_2bodydecay(
    pid0 = "111",
    pid1 = "22",
    br = "2.*0.99 * coupling**2 * pow(1.-pow(mass/self.masses('111'),2),3)",
    generator = "EPOSLHC",
    energy = energy,
    nsample = 50
)
```

3. Sample decay of hadrons into LLPs



4. Specify detector (position, geometry, luminosity)

5. Sample LLP decays in detector



6. Save unweighted event sample as HEPMC.

Slide from F.Kling

FORESEE v1.3.0 - What's new

- Many new updates in the latest version.
- Improved treatment of flux uncertainty.
- Uses better SM flux estimates for light and heavy hadrons.
- Generalized 3 body decays now available.
- Optimized back-end calculation to improve speed dramatically (x100).
- Expanded list of validated and updated models.
- We thank the many people who contributed their favorite models to FORESEE.

Systematics

- The SM flux uncertainty was one of the biggest sources of systematics from the theory side.
- LLP flux is derived from the SM flux. Hence a good control of the latter is required.
- A lot of work was done by many others to refine the flux estimate.
- See also Max Fieg's talk in the other parallel session.

Systematics - Light Hadrons

- Previously we were using EPOS, SYBILL, QGSJET for light hadron (π, η, η', K) production.
- Each generator provides only a central prediction.
- Authors of 2309.08604 have a new tuning for Pythia, for forward light hadron production. Max Fieg, Felix Kling, Holger Schulz, Torbjörn Sjöstrand
- The new tune is fit to LHCf data.
- PYTHIAforward also provides a data driven uncertainty estimate.

Systematics – Light Hadrons

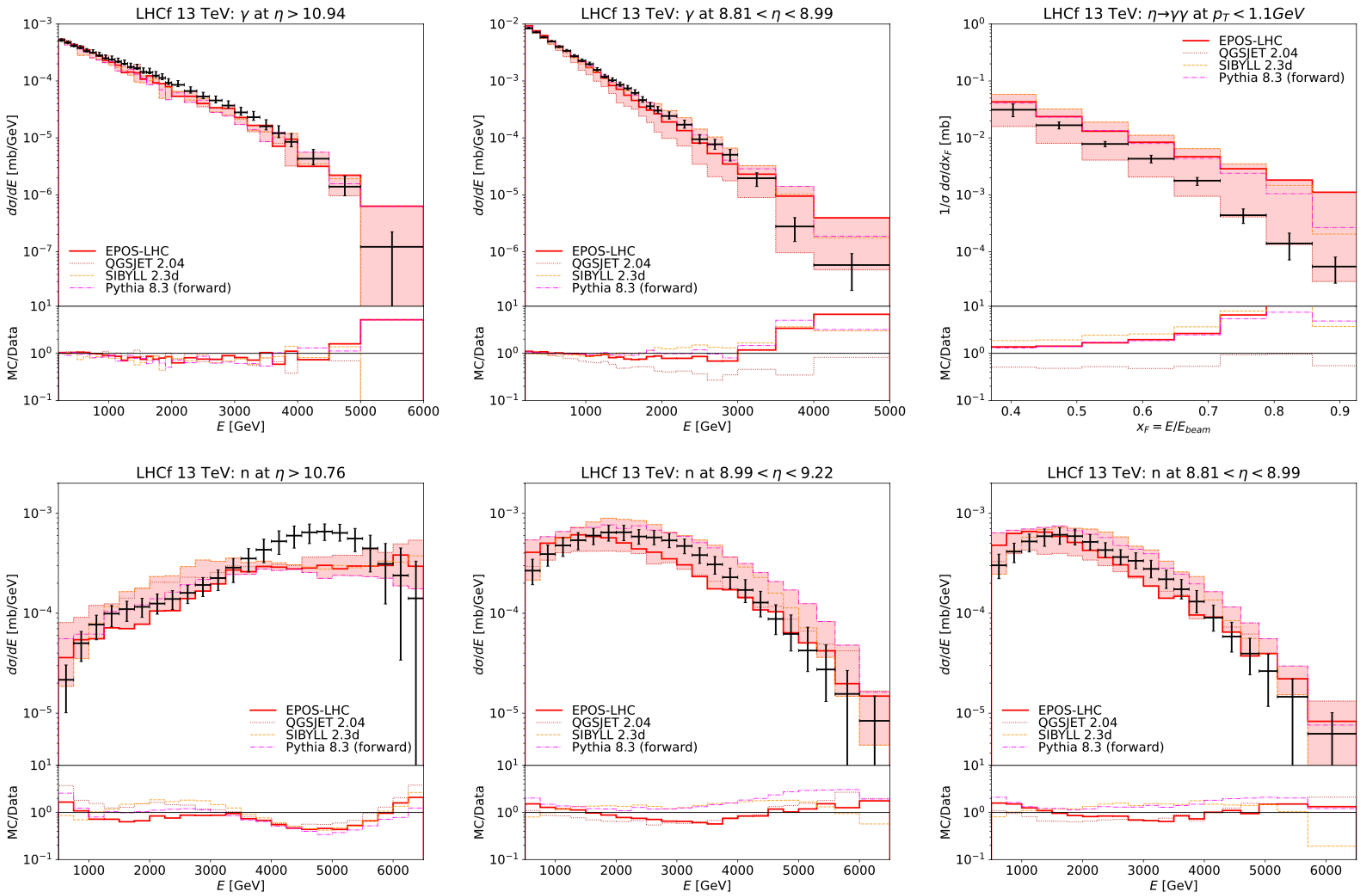


FIG. 1. Forward Particle Energy Spectra at LHCf and Model Predictions. We show the forward spectrum of photons (upper left and upper central), η-mesons (upper right) and neutrons (bottom) as measured by LHCf in different pseudorapidity bins, and compare it to the predictions of different generators. The shaded bands correspond to the spread of generator predictions (formed by `EPOS`, `SIBYLL`, `QGSJET` and `PYTHIAforward`) and tuning uncertainties. We also show ratio between the the central prediction from the different generators (MC) to the data.

2402.13318

Systematics - Heavy Hadrons

- Heavy hadron (B, D) production suffers from large uncertainties due to a lack of available data on forward heavy.
- In 2309.12793, a state-of-the-art QCD calculation that include radiative corrections were presented. Luca Buonocore, Felix Kling, Luca Rottoli, Jonas Sominka
- They use POWHEG+PYTHIA to model charming beauty forward production.
- Renormalization and factorization scale variation gives and estimate on the uncertainty.
- They fit to data from LHCB.

Systematics – Heavy Hadrons

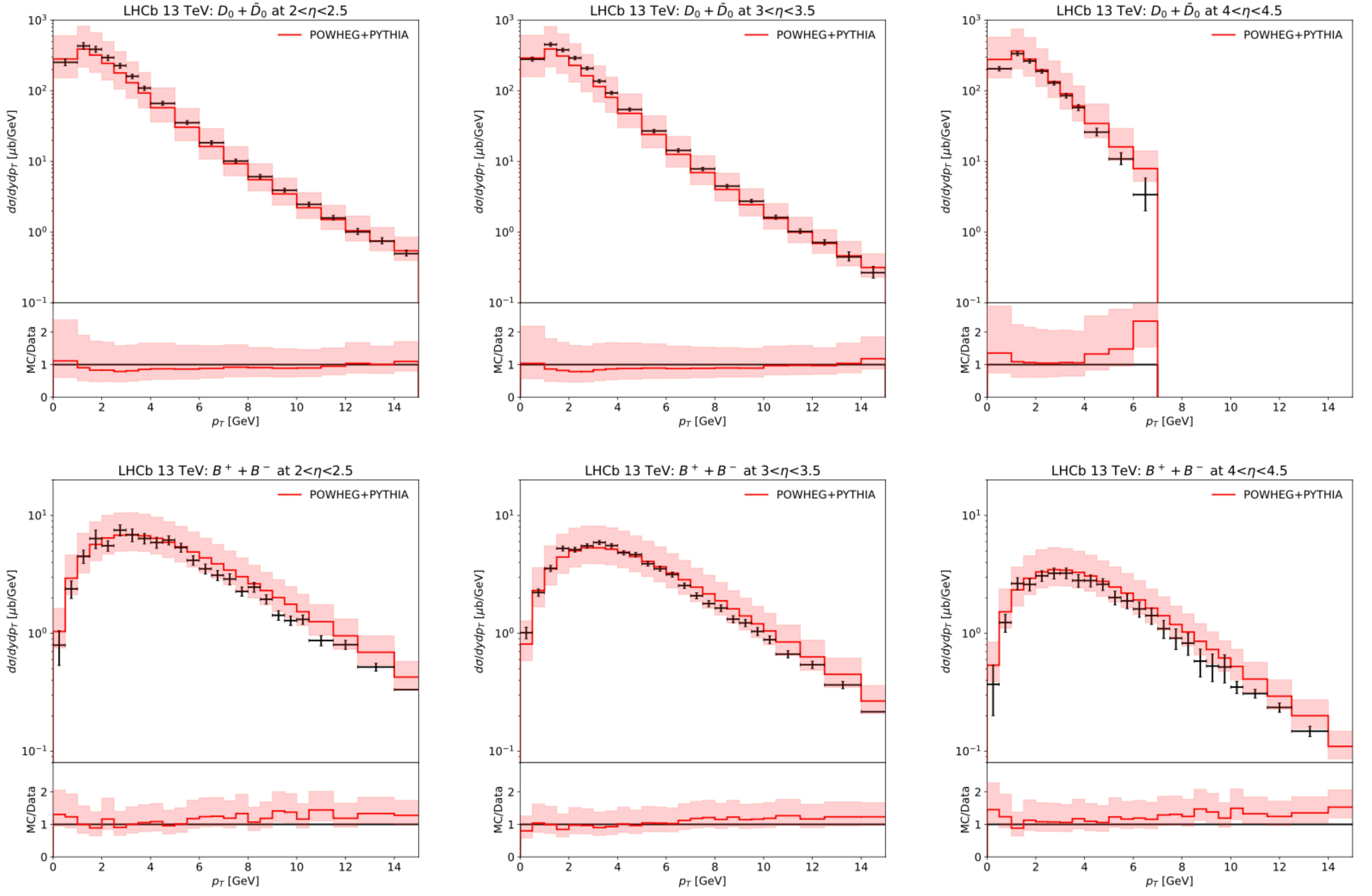


FIG. 2. Heavy Hadron Transverse Momentum Spectra at LHCb and Model Predictions: We show the transverse momemtum spectrum of $D^+ + D^-$ (top) and $B^+ + B^-$ (bottom) mesons as measured by LHCb in different pseudorapidity bins, and compare it to the predictions of `POWHEG+Pythia 8`. The shaded bands correspond to the scale uncertainty. As before, we also show ratio between the central prediction from `POWHEG+Pythia 8` (MC) to the data.

Systematics in FORESEE

- FORESEE now contains the updated fluxes
  - EPOS, SYBILL, QGSJET, PYTHIAforward for light hadrons.
  - POWHEG+PYTHIA for heavy hadrons.
- LLP flux is now derived from all the available generators.
- FORESEE outputs an HEPMC event file with multiple weights corresponding to each generator.

Systematics in FORESEE

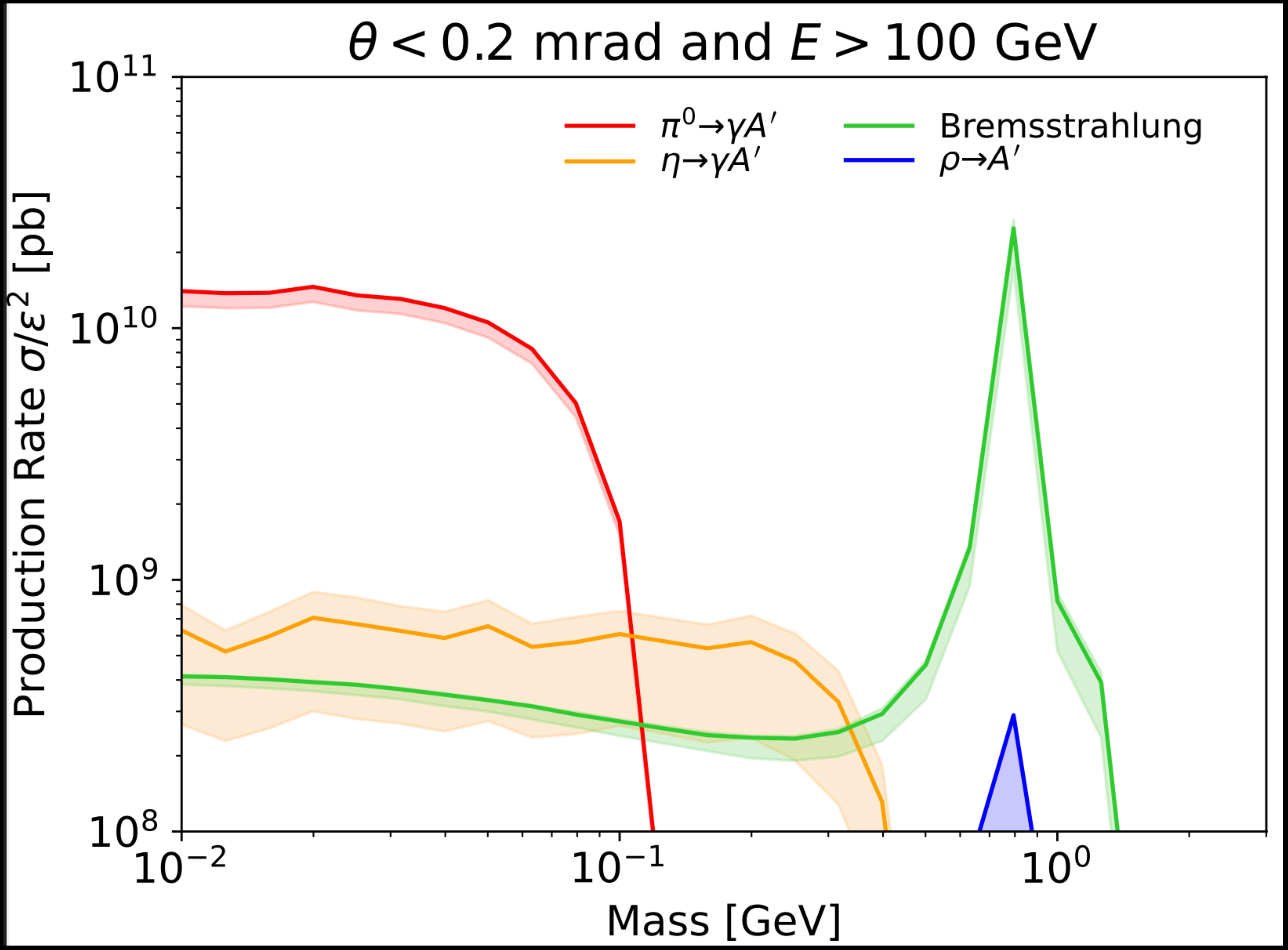
```
HepMC::Version 2.06.09
HepMC::IO_GenEvent-START_EVENT_LISTING
E 0 -1 -1. -1. -1. 0 -1 1 1 0 0 4 2.2276340696057026 2.069882044310121 3.3766898938132206 2.3814033324624284
N 4 "EPOSLHC" "SIBYLL" "QGSJET" "PYTHIA"
U GEV MM
C 2.2276340696057026 0.
F 0 0 0 0 0 0 0 0 0
V -1 0 9.1912706031 0.6637628444 1949.6544248775 0 1 2 0
P 1 32 0.0747724729 0.0053998181 3872.3369830726 3872.3369889631 0.1999999931 2 0 0 -1 0
P 2 22 -0.0461608546 0.0633386516 1242.7409922223 1242.7409946937 0.0 1 0 0 0 0
P 3 22 0.1209333266 -0.0579388336 2629.5959449733 2629.5959483925 -4.31584e-05 1 0 0 0 0
E 1 -1 -1. -1. -1. 0 -1 1 1 0 0 4 2.2276340696057026 3.553611348187718 1.9719943914393716 2.33715698685754
N 4 "EPOSLHC" "SIBYLL" "QGSJET" "PYTHIA"
U GEV MM
C 2.2276340696057026 0.
F 0 0 0 0 0 0 0 0 0
V -1 0 29.7122564704 4.2400076253 3361.0868187718 0 1 2 0
P 1 32 0.2770014106 0.0395287411 4437.6525755383 4437.6525888666 0.1999999978 2 0 0 -1 0
P 2 22 0.1560795746 0.0495292308 3677.4082810638 3677.4082847096 4.31584e-05 1 0 0 0 0
P 3 22 0.1209218238 -0.0100004914 760.2440991609 760.2441088434 -1.07896e-05 1 0 0 0 0
```

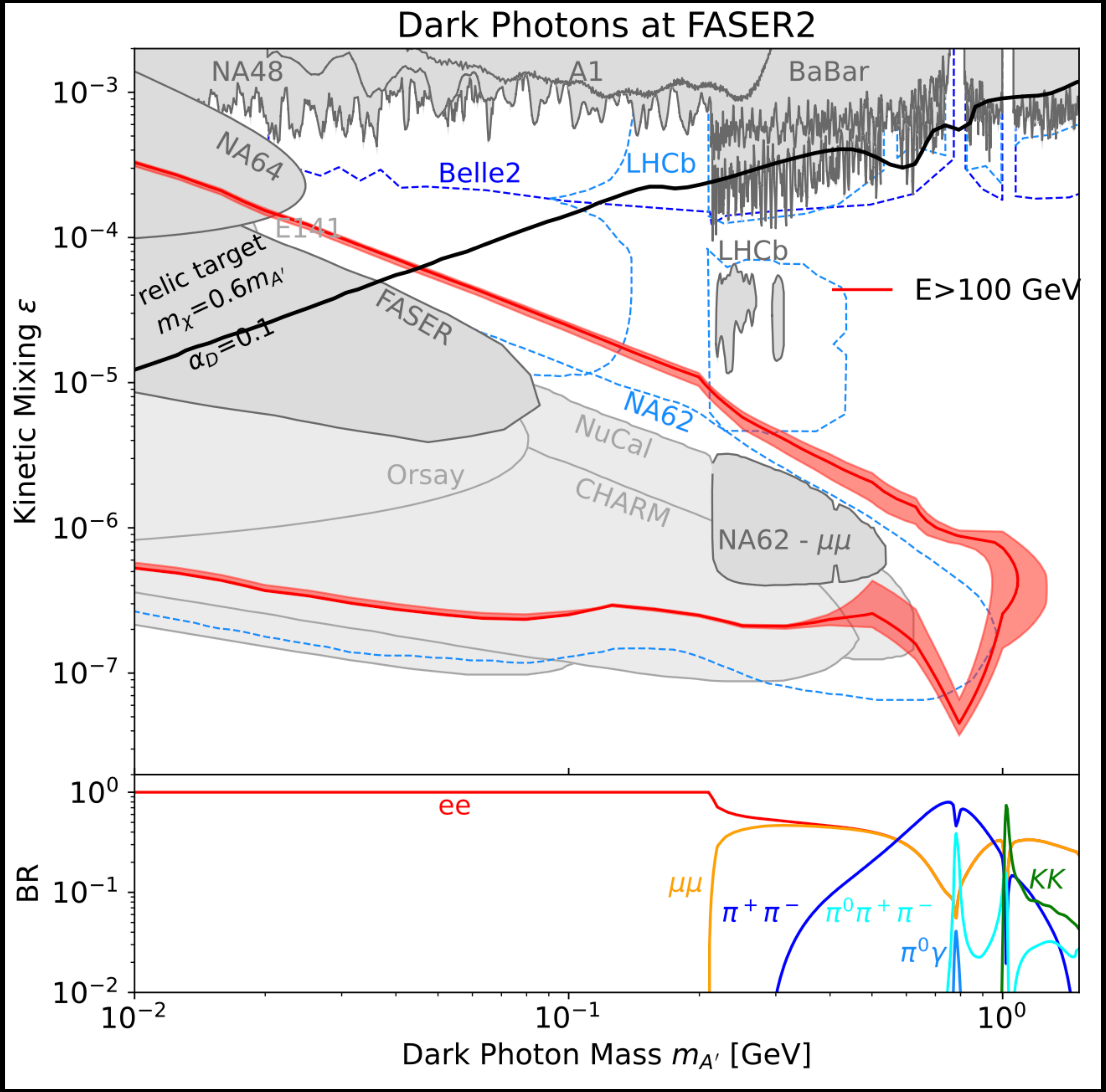
Light hadrons

Heavy hadrons

```
E 0 -1 -1. -1. -1. 0 -1 1 1 0 0 3 0.21053740282581848 0.32104259070263247 0.15504162027265228
N 3 "POWHEG-central" "POWHEG-max" "POWHEG-min"
U GEV MM
C 0.21053740282581848 0.
F 0 0 0 0 0 0 0 0 0
V -1 0 -34.1092739609 27.5566031482 1540.6441341902 0 1 2 0
P 1 32 -0.0848489912 0.0685488052 1184.0803130117 1184.080327537 0.1500000007 2 0 0 -1 0
P 2 22 -0.0987964873 0.0525809011 1159.4466344992 1159.4466399007 -2.15792e-05 1 0 0 0 0
P 3 22 0.0139474964 0.0159679039 24.6336753972 24.6336845211 1.3902e-06 1 0 0 0 0
E 1 -1 -1. -1. -1. 0 -1 1 1 0 0 3 0.21053740282581848 0.31973732958382955 0.15532070771622686
N 3 "POWHEG-central" "POWHEG-max" "POWHEG-min"
U GEV MM
C 0.21053740282581848 0.
F 0 0 0 0 0 0 0 0 0
V -1 0 -32.3499586719 -21.3674039029 3433.2221644441 0 1 2 0
P 1 32 -0.055606544 -0.0367285627 818.1993439114 818.199360375 0.1500000003 2 0 0 -1 0
P 2 22 -0.0211516177 0.0068666985 722.435466449 722.4354667913 -7.6294e-06 1 0 0 0 0
P 3 22 -0.0344549264 -0.0435952612 95.7638782464 95.7638943678 -2.336e-06 1 0 0 0 0
E 2 -1 -1. -1. -1. 0 -1 1 1 0 0 3 0.21053740282581848 0.332149098650756 0.1521164566744724
N 3 "POWHEG-central" "POWHEG-max" "POWHEG-min"
```

Systematics in FORESEE





Dark Photons at FASER2

$L = 3\text{ab}^{-1}$

Updated B hadron decays rates

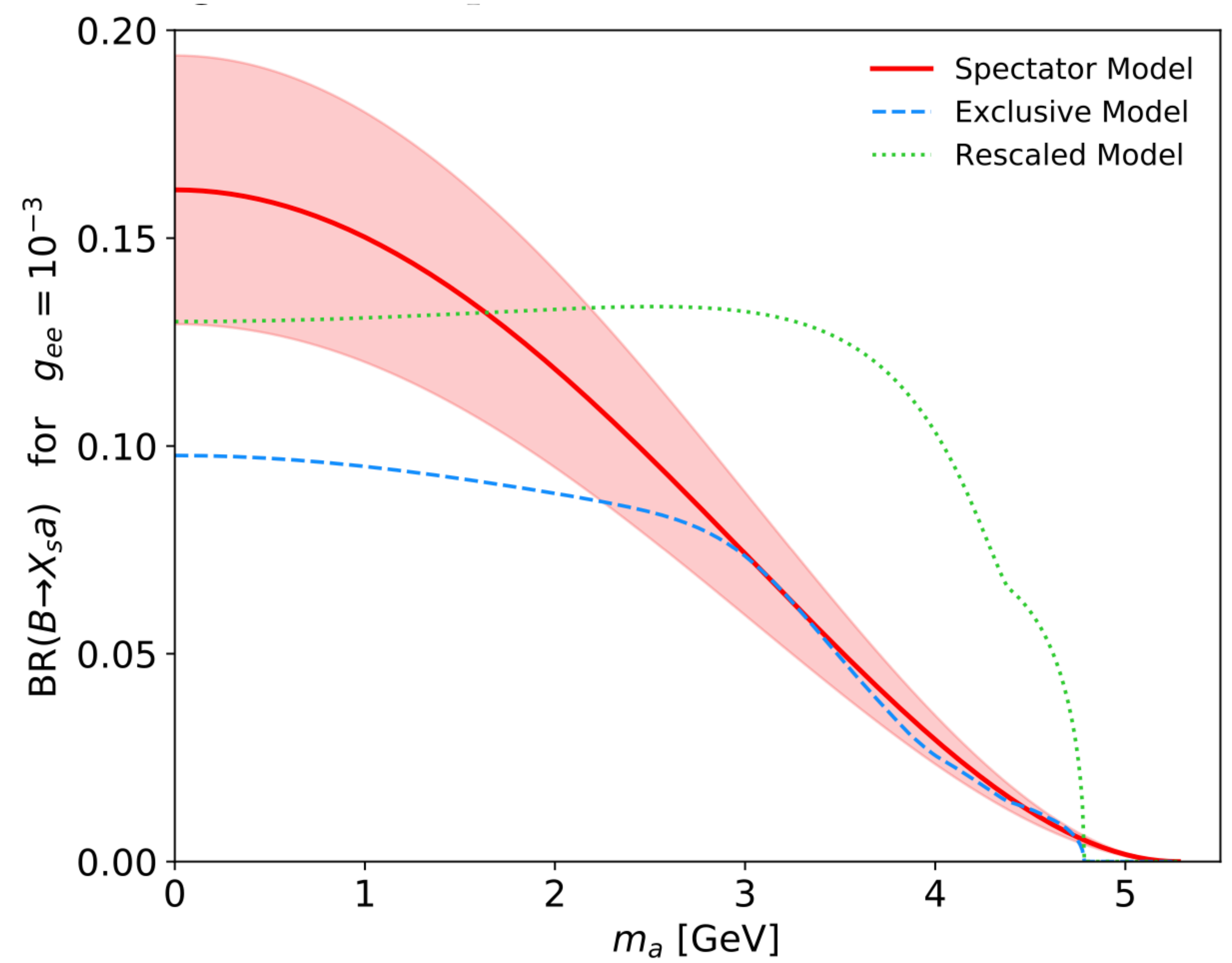
- Relevant for $B \to X_s\ LLP$.
- Previously we were using $b \to s$ quark formula with the rescaled model.
- Updated to B hadrons now.
- We use the spectator model, follows the mass dependence of the $b \to s\ LLP$ decay.

2309.12793

Luca Buonocore, Felix Kling, Luca Rottoli, Jonas Sominka

$$\mathcal{L}_{\phi sb} = g_{\phi sb}\phi\left(\bar{s}_L b_R + \bar{b}_L s_R\right) .$$

$$BR_{B\to X_s\phi} = \frac{1}{\Gamma_B}\frac{(m_B^2 - m_\phi^2)^2}{32\pi\, m_B^3}\,|g_{\phi sb}|^2$$

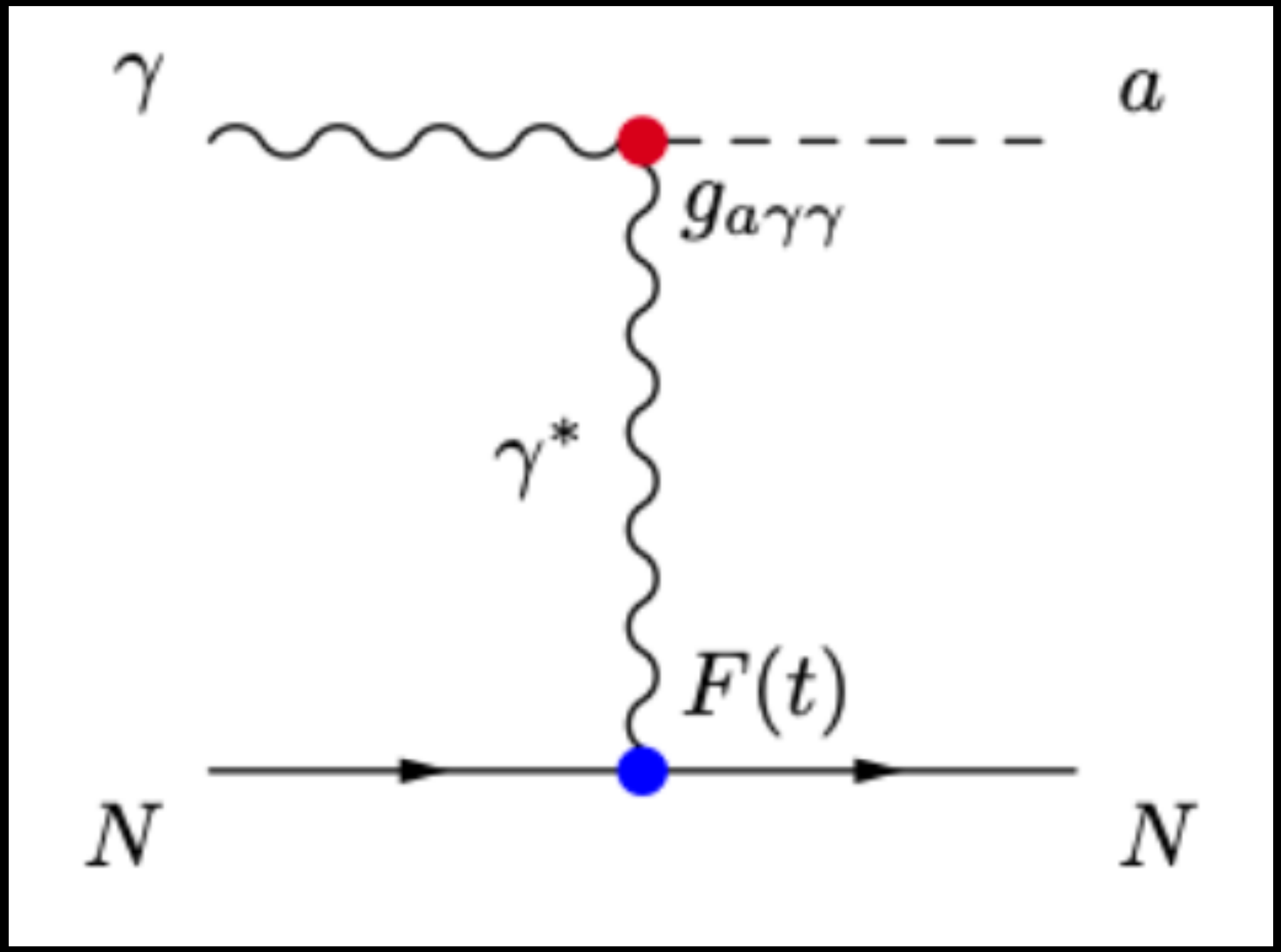


3 Body Decays

- This can be a relevant channel for production (e.g: MCP, M -> $\gamma\ \chi\ \chi$).
- And also for decays (e.g: HNL -> $\nu\ e\ e$).
- Previously required a differential BR ($q = (p_{\chi_1} + p_{\chi_2})^2$, $\theta =$ angle between p_{χ_1} in rest frame of $(p_{\chi_1} + p_{\chi_2})$ and direction of $(p_{\chi_1} + p_{\chi_2})$ in rest frame of M).
- Now it is more general, can just specify a decay chain: A>BC, C>DE.

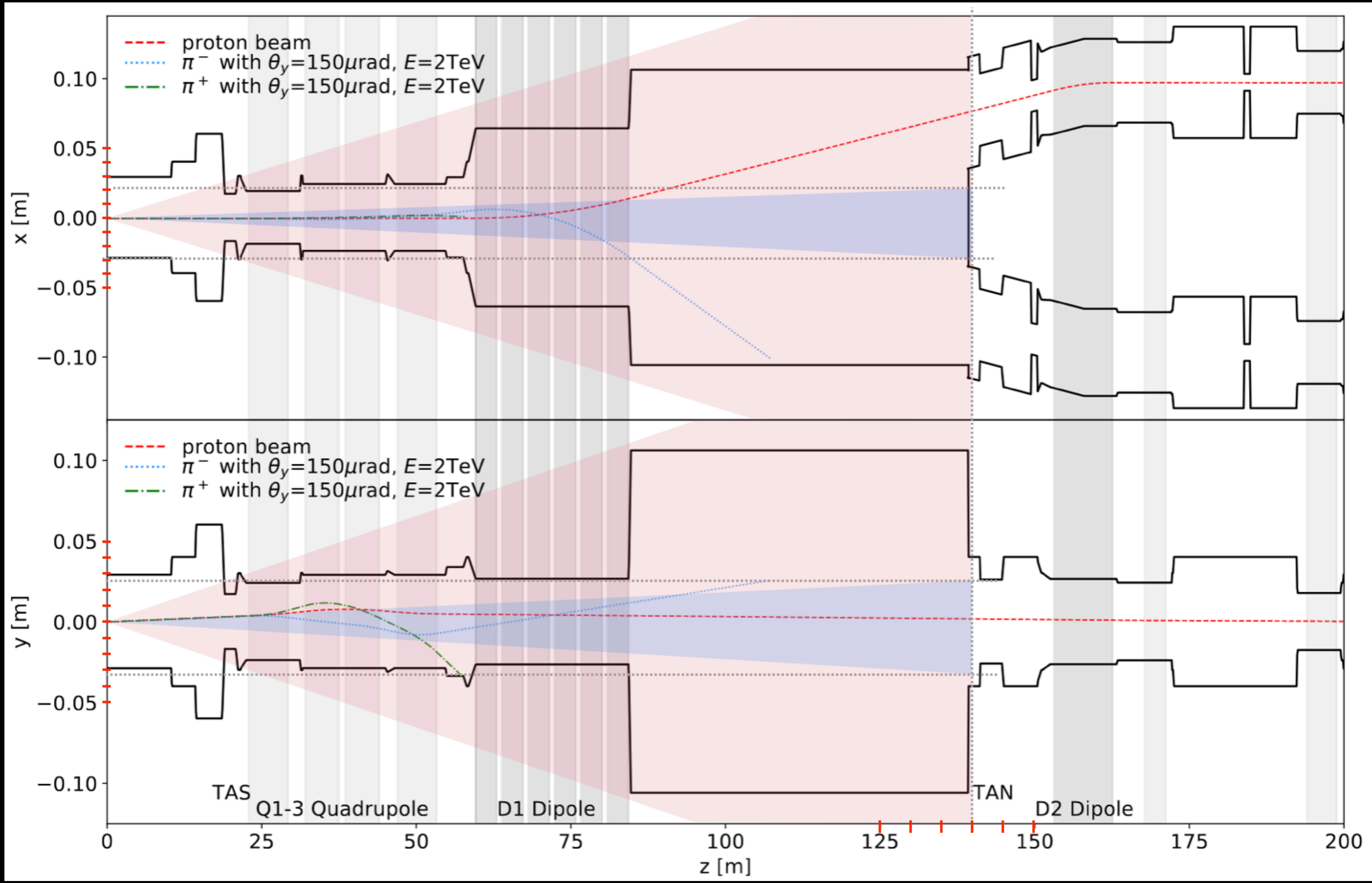
Validation of Primakoff Process

- Relevant for models with ALPs coupling to photons.
- Photon -> ALP conversion takes place inside materials.
- Location and target material are important considerations, as they can effect the event rate.



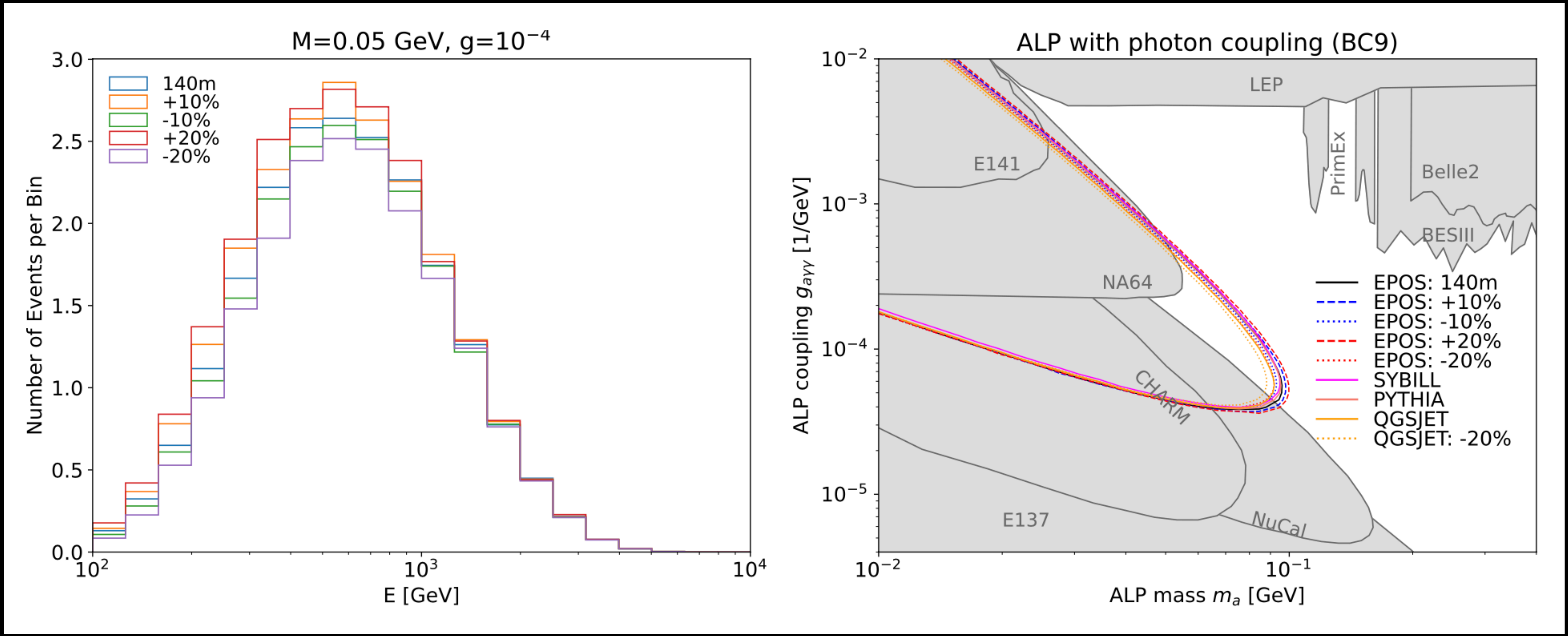
Validation of Primakoff Process

- Photon -> ALP conversion takes place exclusively in the neutral particle absorber (TAN), ~140m from IP for FASER (blue cone).
- For FASER2 this is more of a problem (red cone).



Validation of Primakoff Process

- Further away from IP, Event rate at FASER(2) goes up
- So critical to understand where the photon -> ALP conversion takes place



ALP-photon model

$L = 60\text{fb}^{-1}$

Validation of Primakoff Process

- ALP conversion probability is $P = \dfrac{\sigma_{Prim}}{\sigma_{conv}}$
  - σ_{conv} = SM XS for e^+e^- pair production in material.
- Previously for FASER, we used iron (5.25 barn), but actual target material is copper (6.46 barn).
- For FASER2, more materials can act as target.

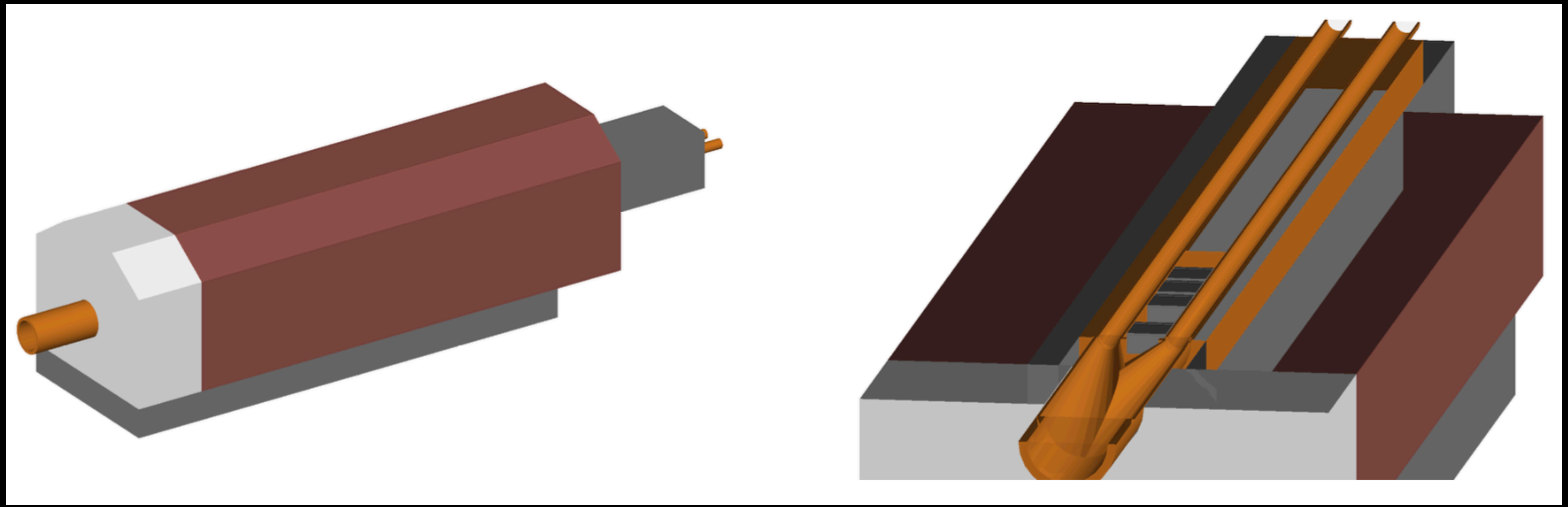


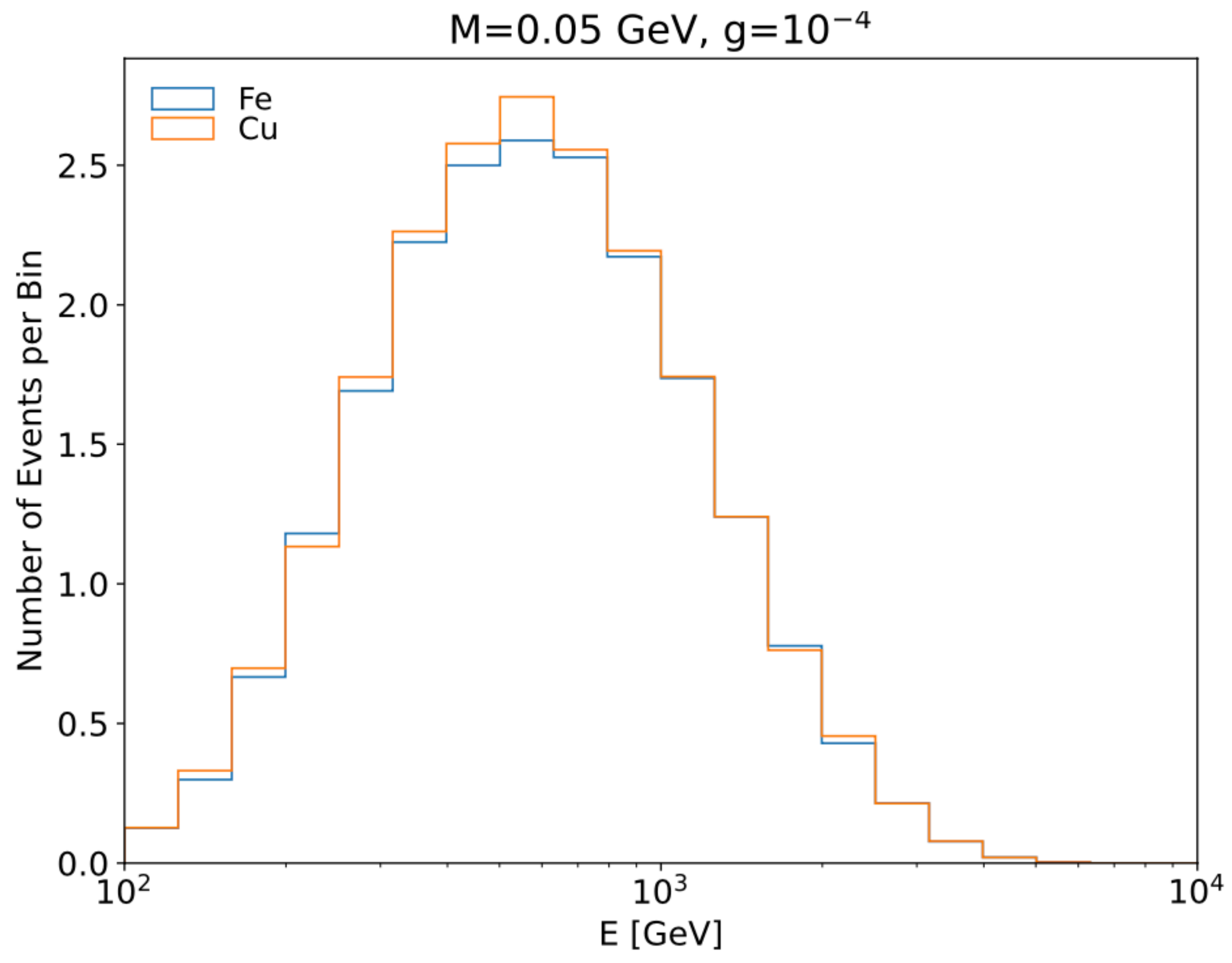
Image courtesy L. Nevay

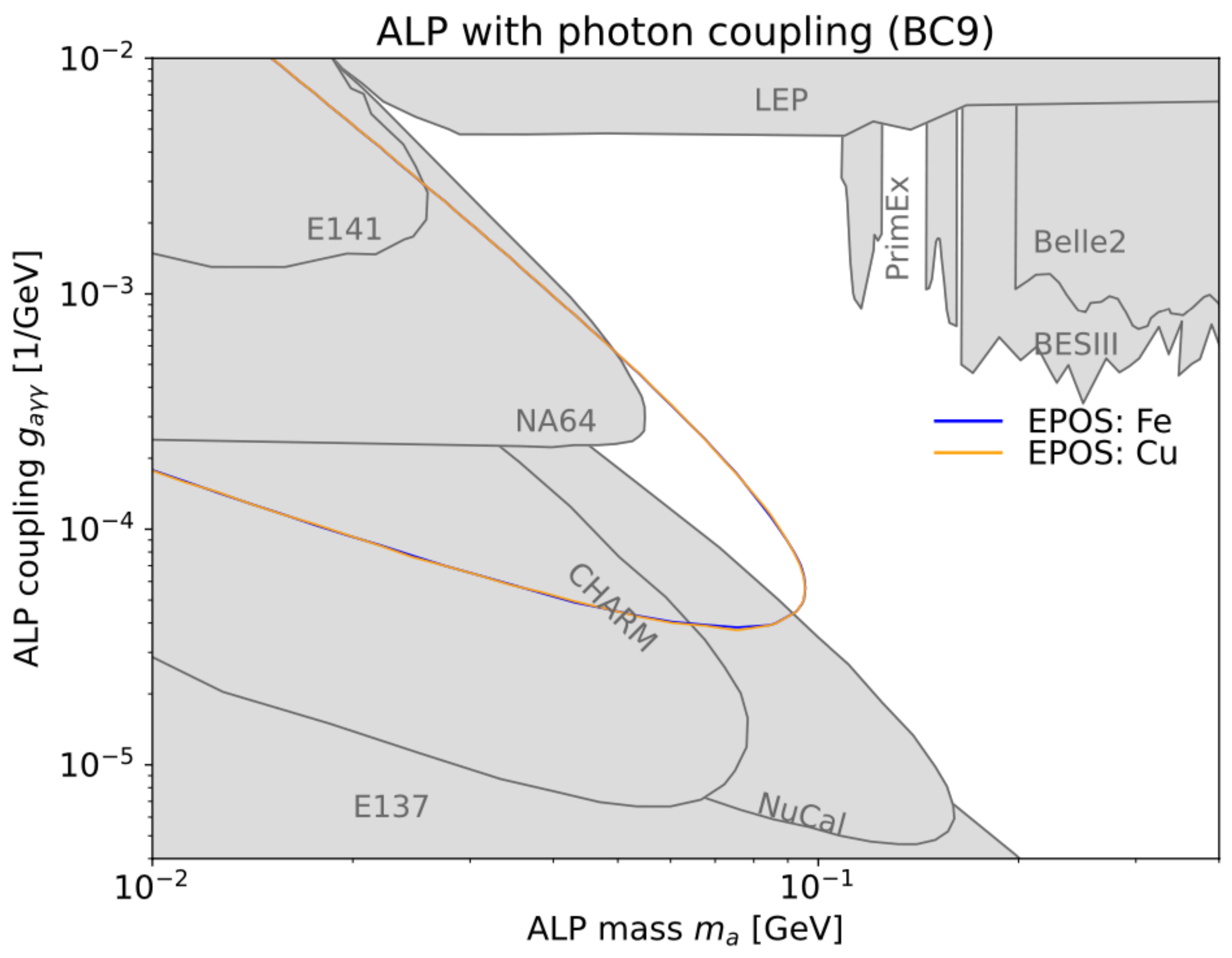
Validation of Primakoff Process

- Taking the ratio, the Z dependence is suppressed in the conversion probability.

- So almost similar event rates for material with similar Z,A.

- But a heavier target (maybe for FASER2) could have a larger impact on event rate.





ALP-photon model

Summary

- Many new updates available in the latest version of FORESEE v1.3.0.
- Better SM flux estimates making use of forward data from LHCf and LHCB.
- Flux uncertainties are now included, taking into account predictions from multiple generators.
- Updated BRs for production and decay of LLPs.
- 3 body decays now implemented in FORESEE.
- Dramatic speed-up in calculation (x100).

Validated Models

Summary

- FORESEE is a tool that helps bridge the gap between theorists and experimentalists.
- Can generate signal evens and also plot the sensitivity curves.
- If you want your model included in FORESEE, please contact us with your model notebooks*.
- We once again thank everyone who has contributed to the model library.

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