Initial- and Final-State Radiation of Dark Photons

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Work in progress with

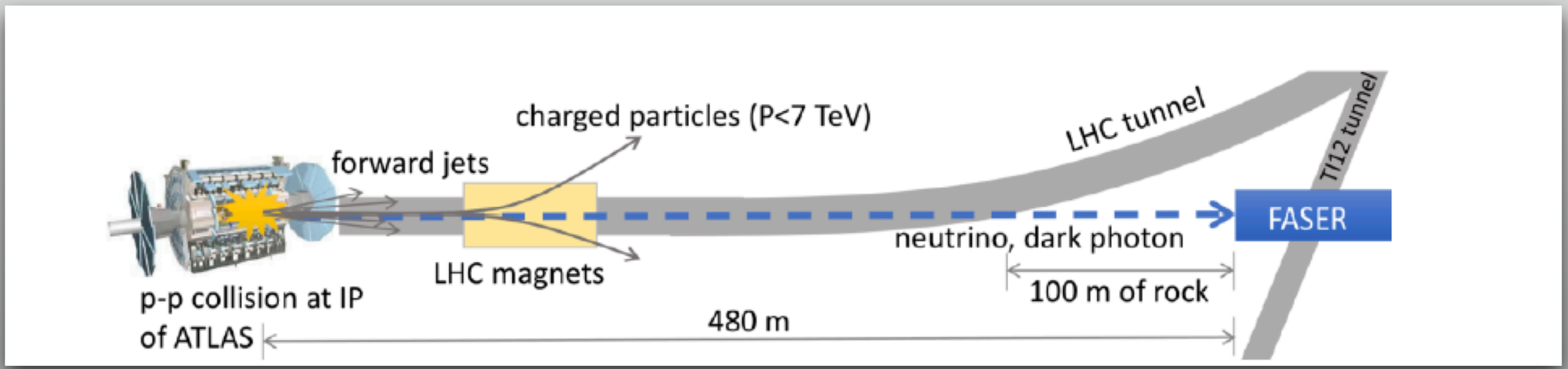
Felix Kling

Aidin Masouminia, Simon Plätzer (Herwig Collaboration)

Two crucial BSM ingredients for BSM searches in forward direction

Production of BSM particles

Decay of BSM Particles



[FASER Collaboration]

Decay of BSM Particles

→ Lifetime + Branching Ratios

Vector particles (dark photons, B-L, …)

- DarkCast arXiv 1801.04847 Ilten, Soreq, Williams, Xue
- arXiv 2201.01788 Foguel, PR, Zukanovich

Scalar particles

- arXiv 1809.01876 Winkler

Axial Vectors

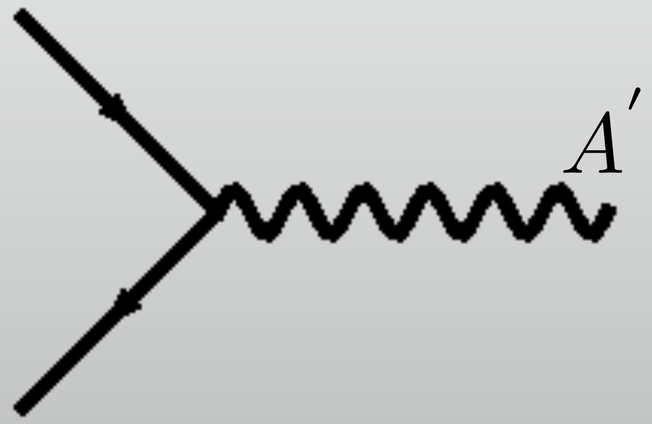
- DarkCast arXiv 2206.08563 Baruch, Ilten, Soreq, Williams

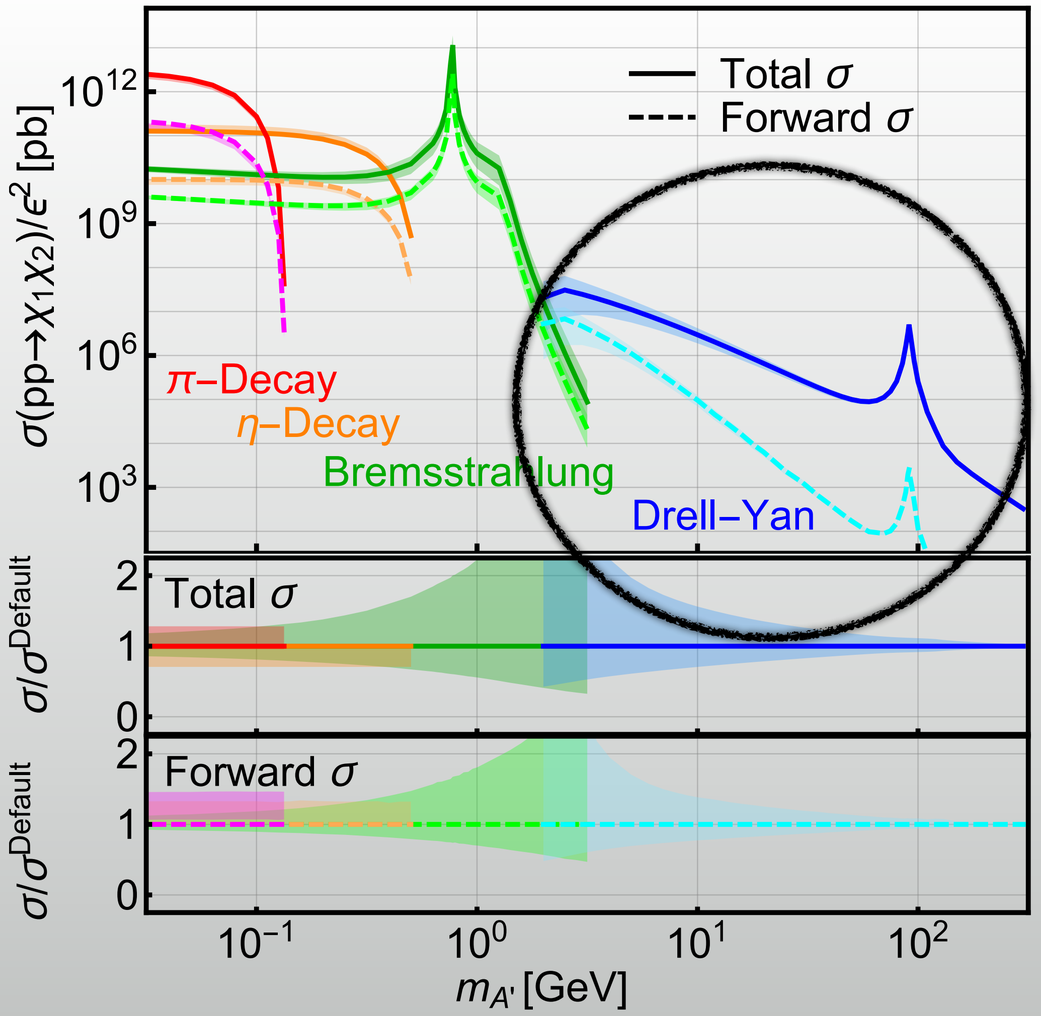
Robust description, data-driven

Less robust, Little to no data available

Production of BSM particles

- Drell-Yan → sub-dominant





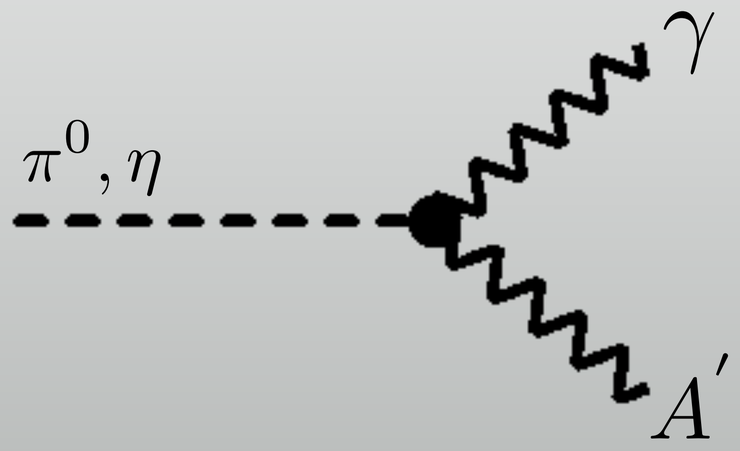
$$\mathcal{L} = -\frac{\epsilon}{2} F_{\mu\nu} X^{\mu\nu}$$

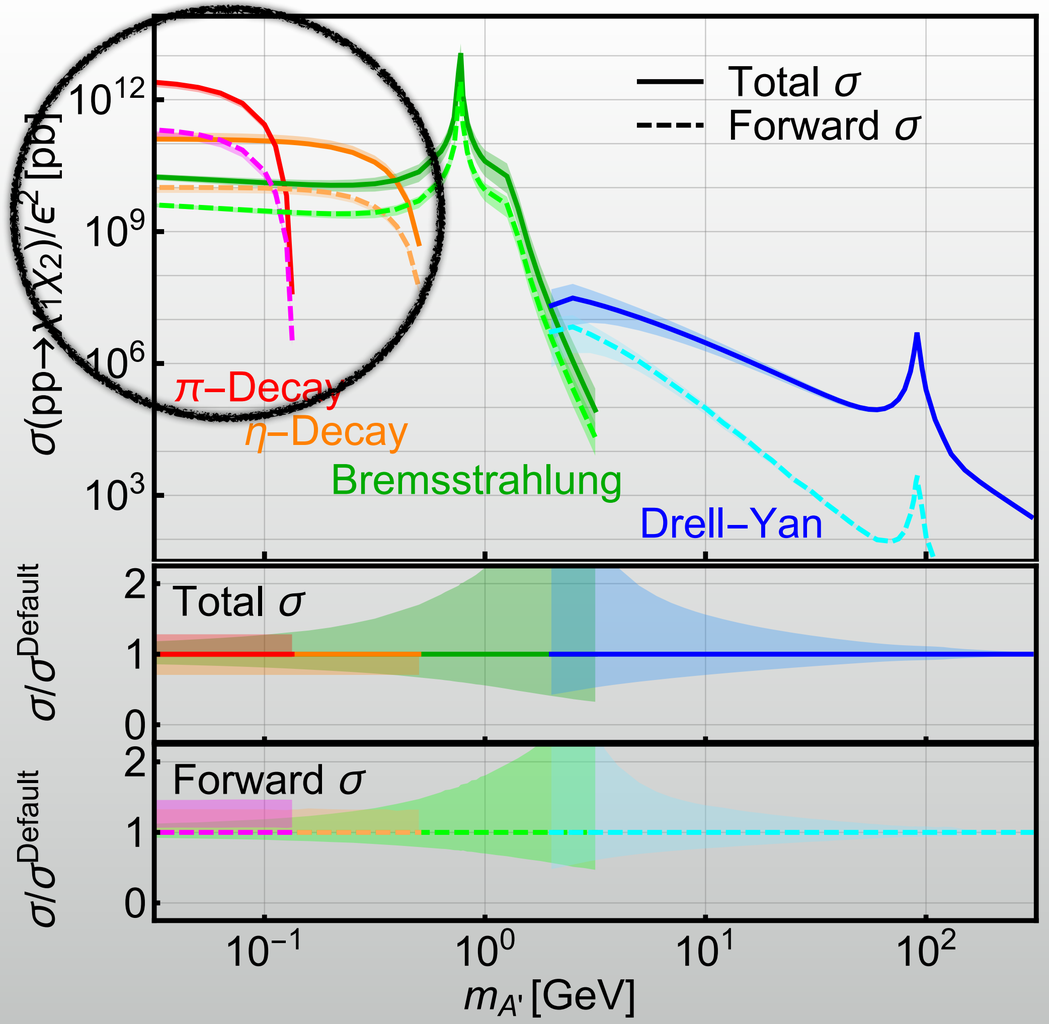
arXiv 1810.01879

A. Berlin, F. Kling

Production of BSM particles

- Drell-Yan → sub-dominant
- Meson decays → in lower mass range





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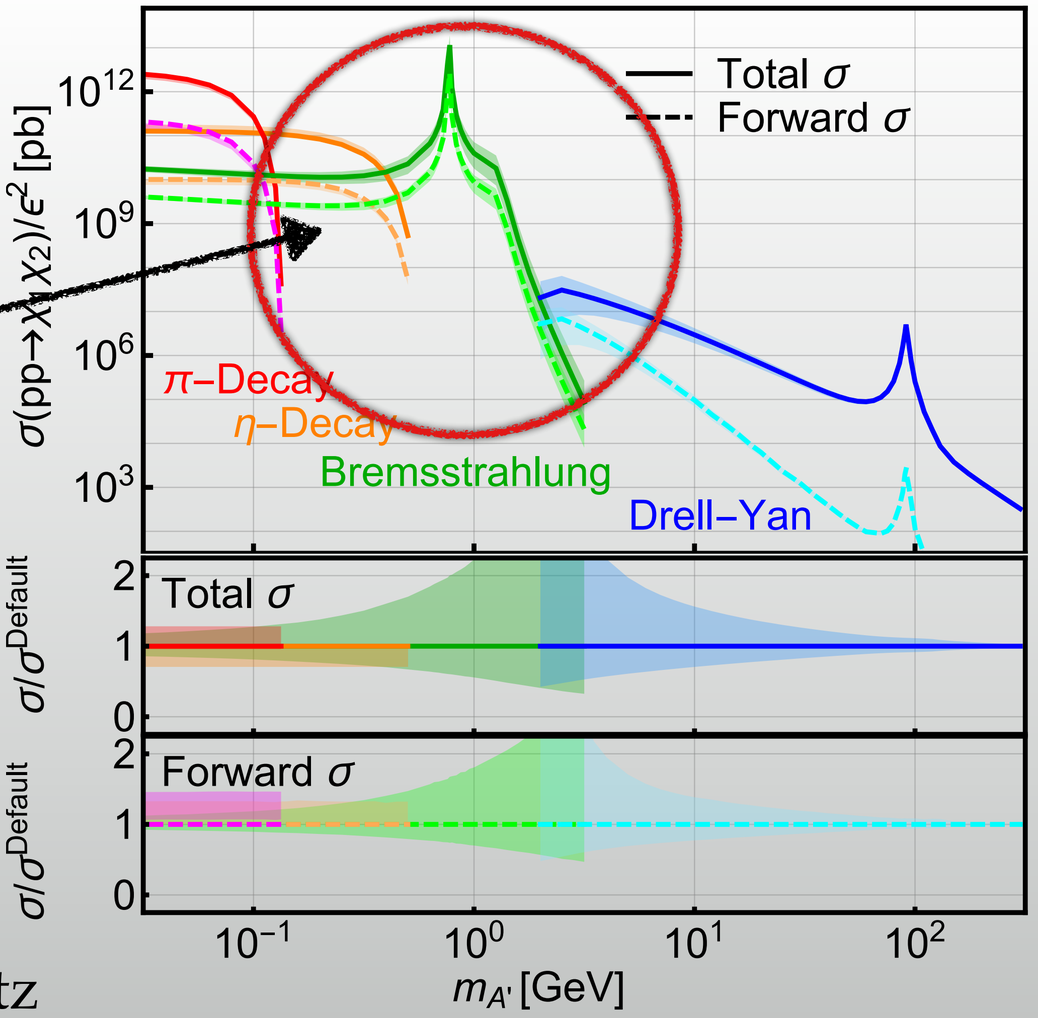
Production of BSM particles

FPF range



- Drell-Yan → sub-dominant
- Meson decays → in lower mass range
- Bremsstrahlung

→ arXiv 1311.3870 Blümlein, Brunner

→ Recent developments:

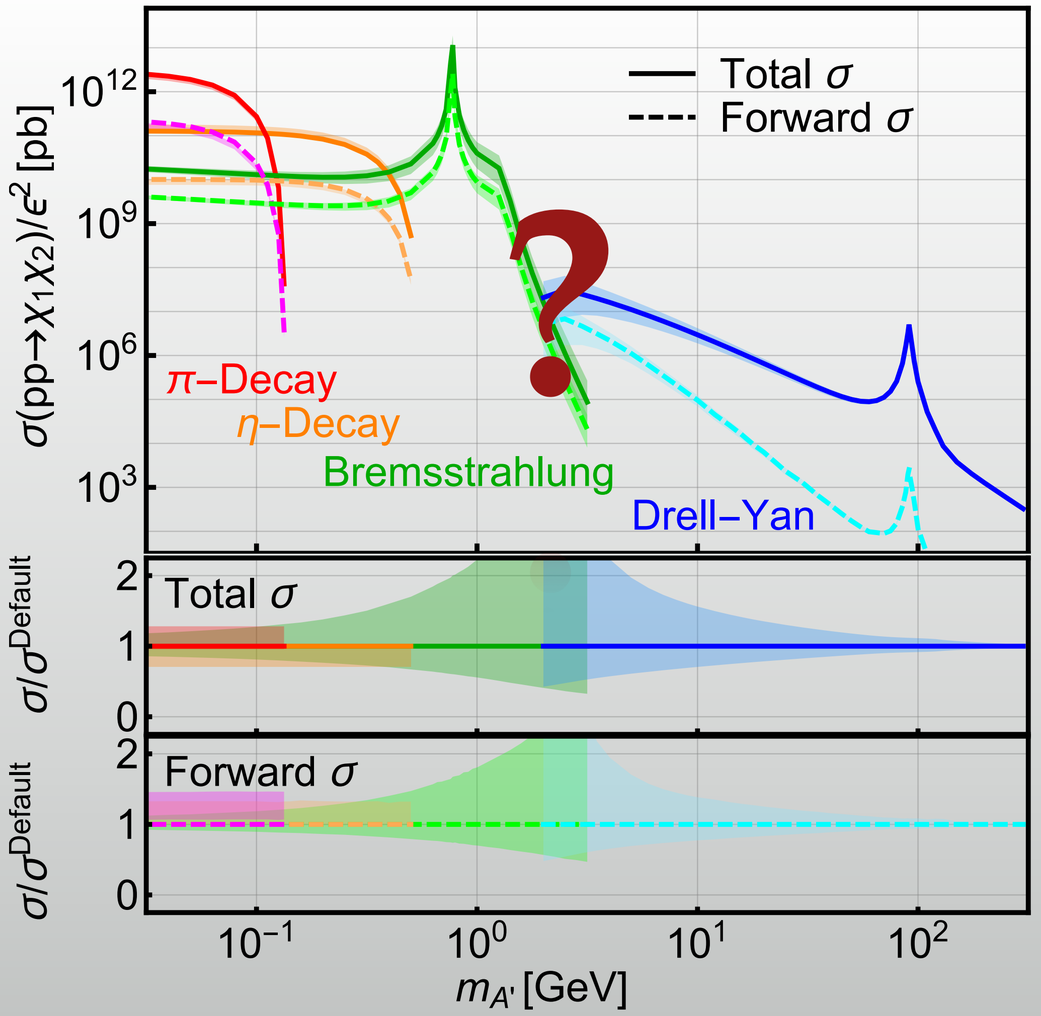
- arXiv 2108.05900 S. Foroughi-Abari, A. Ritz
- + more about it → **Next Talk by Saeid!**

arXiv 1810.01879
A. Berlin, F. Kling

Production of BSM particles

- Drell-Yan → sub-dominant
- Meson decays → in lower mass range
- Bremsstrahlung
- Is there more than this?

→ **This Talk!**



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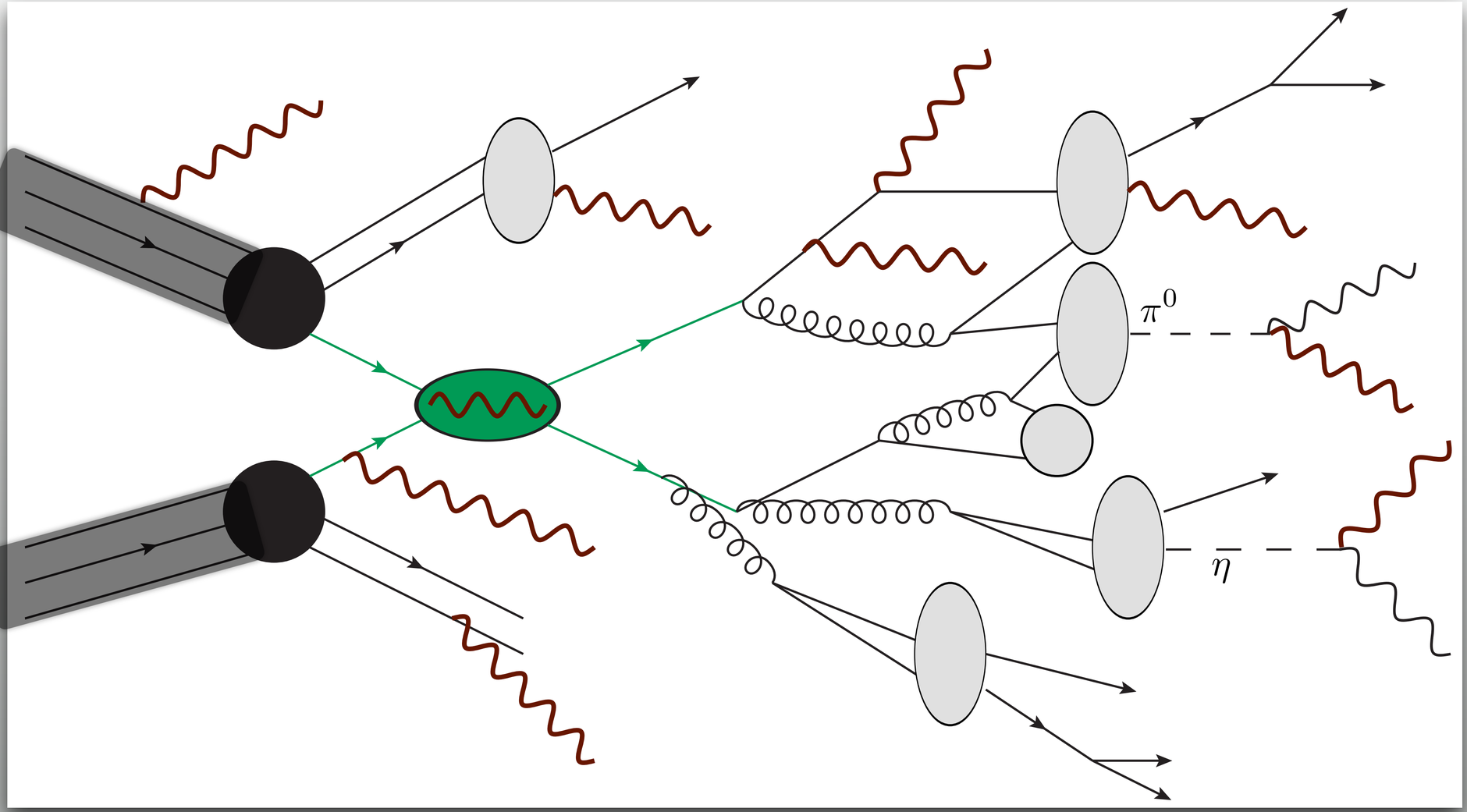
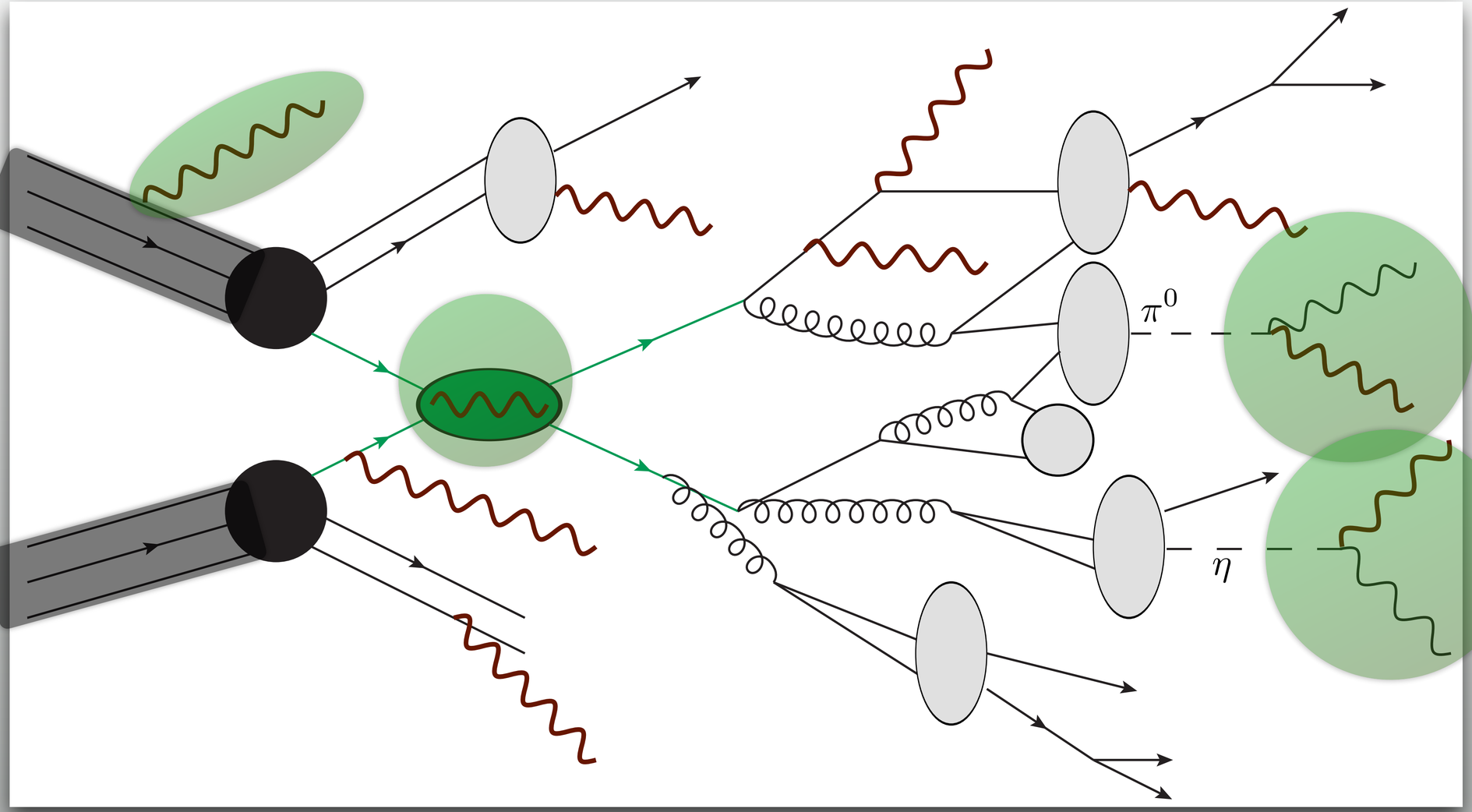
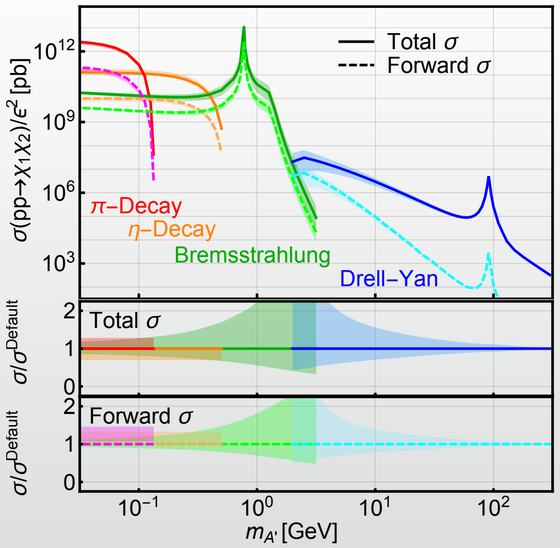
Additional Production Modes?



Known Sources

Additional Production Modes?





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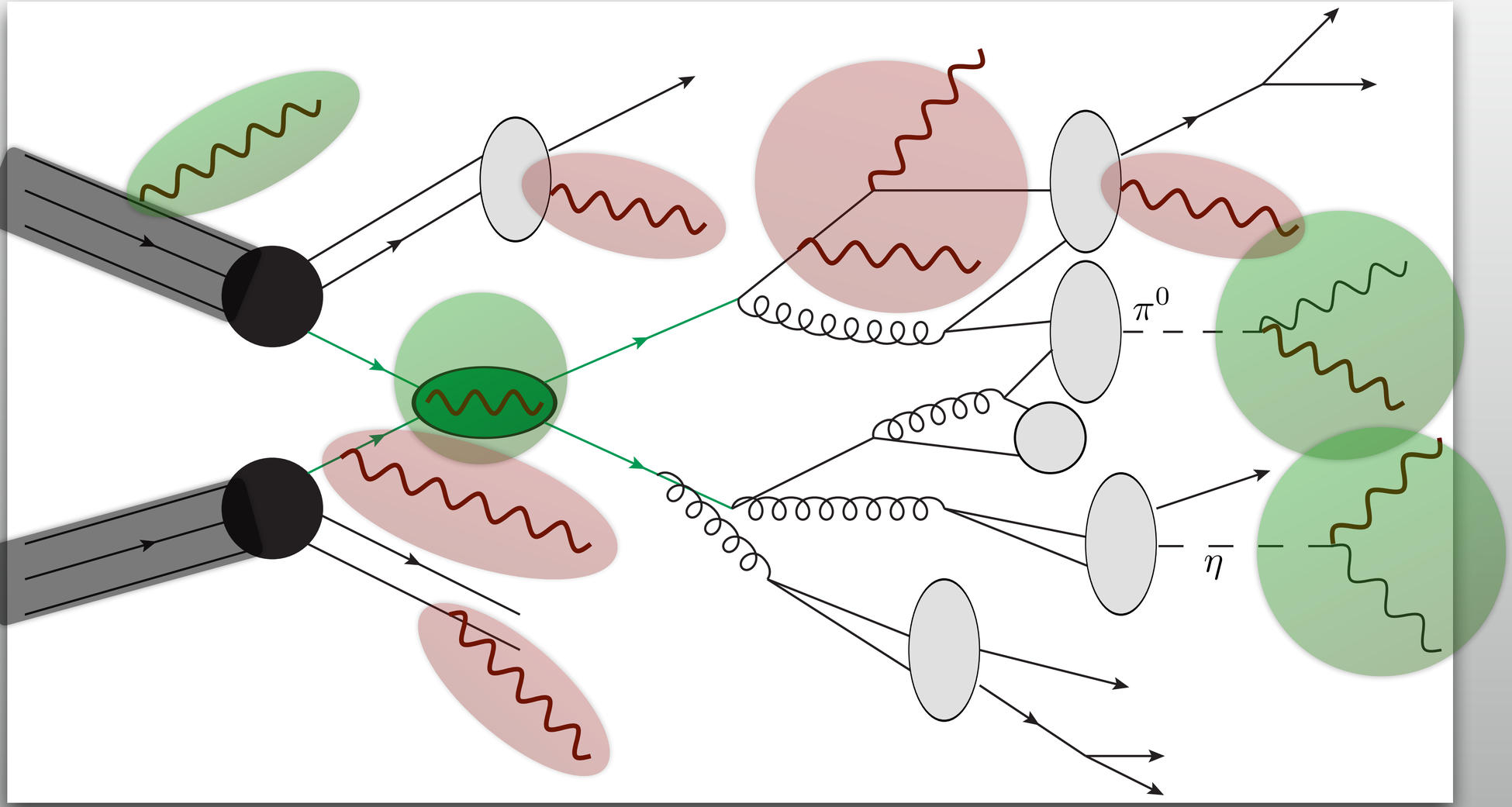
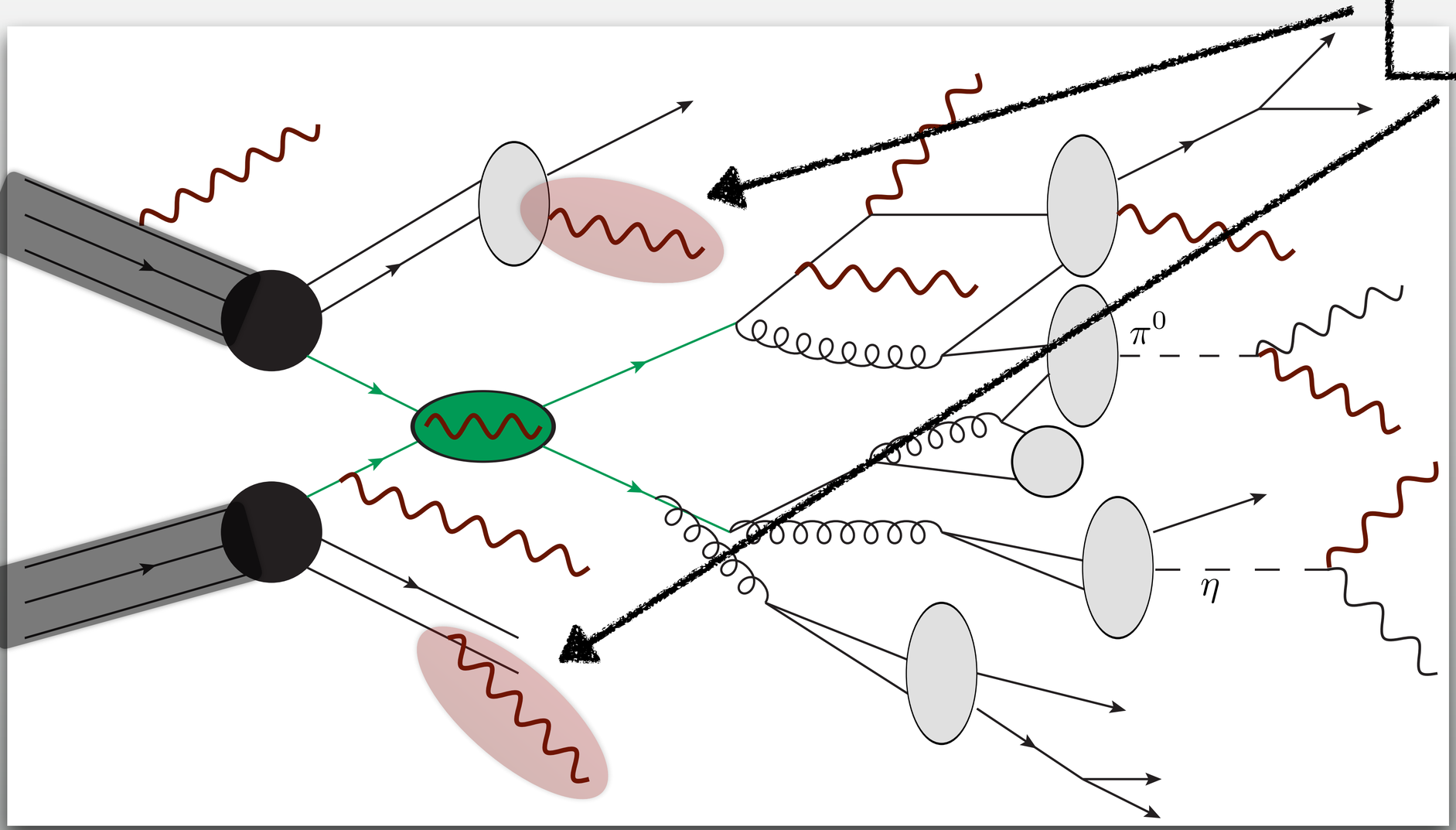


Additional Production Modes?

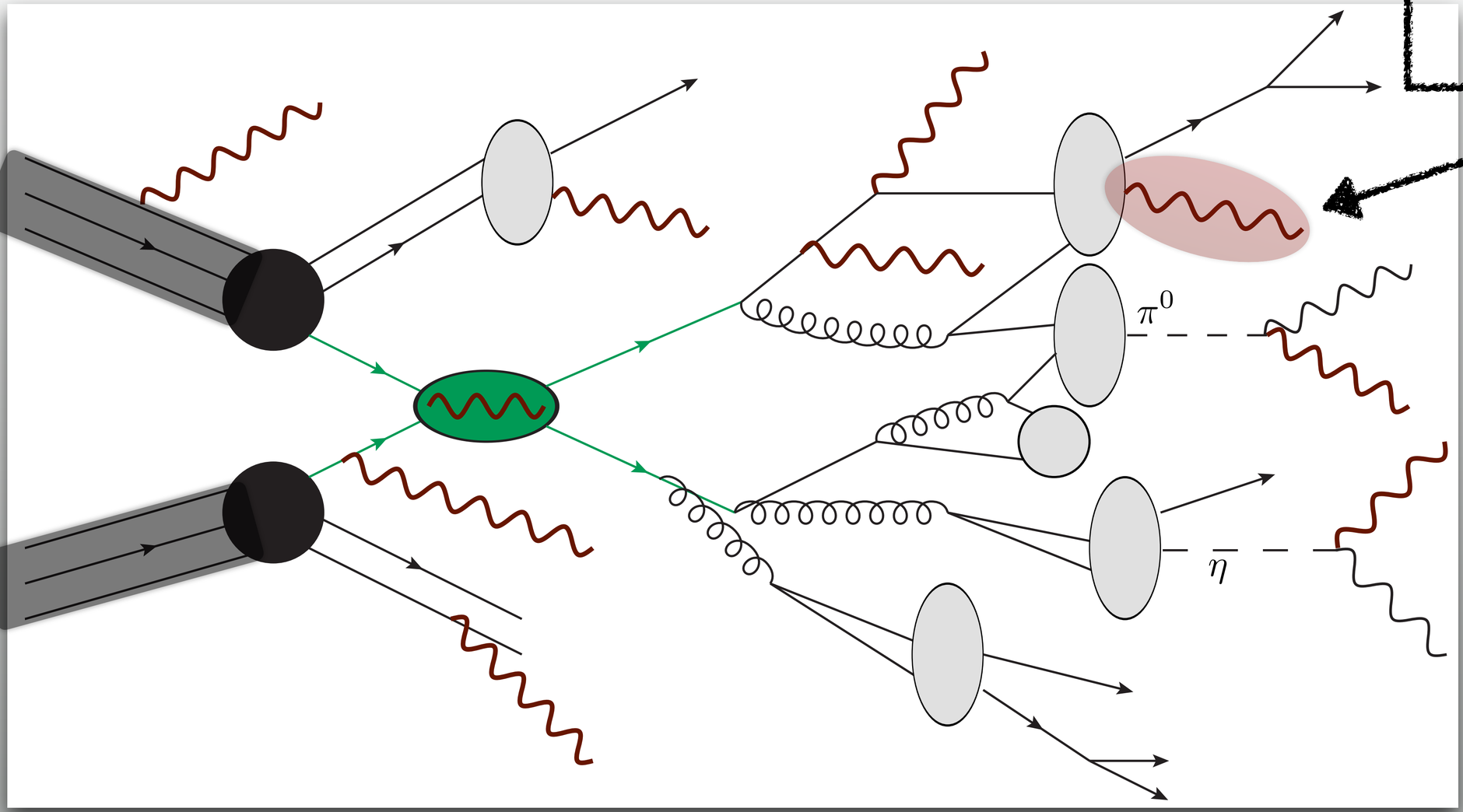


Beam remnants

Before or as part of hadronization

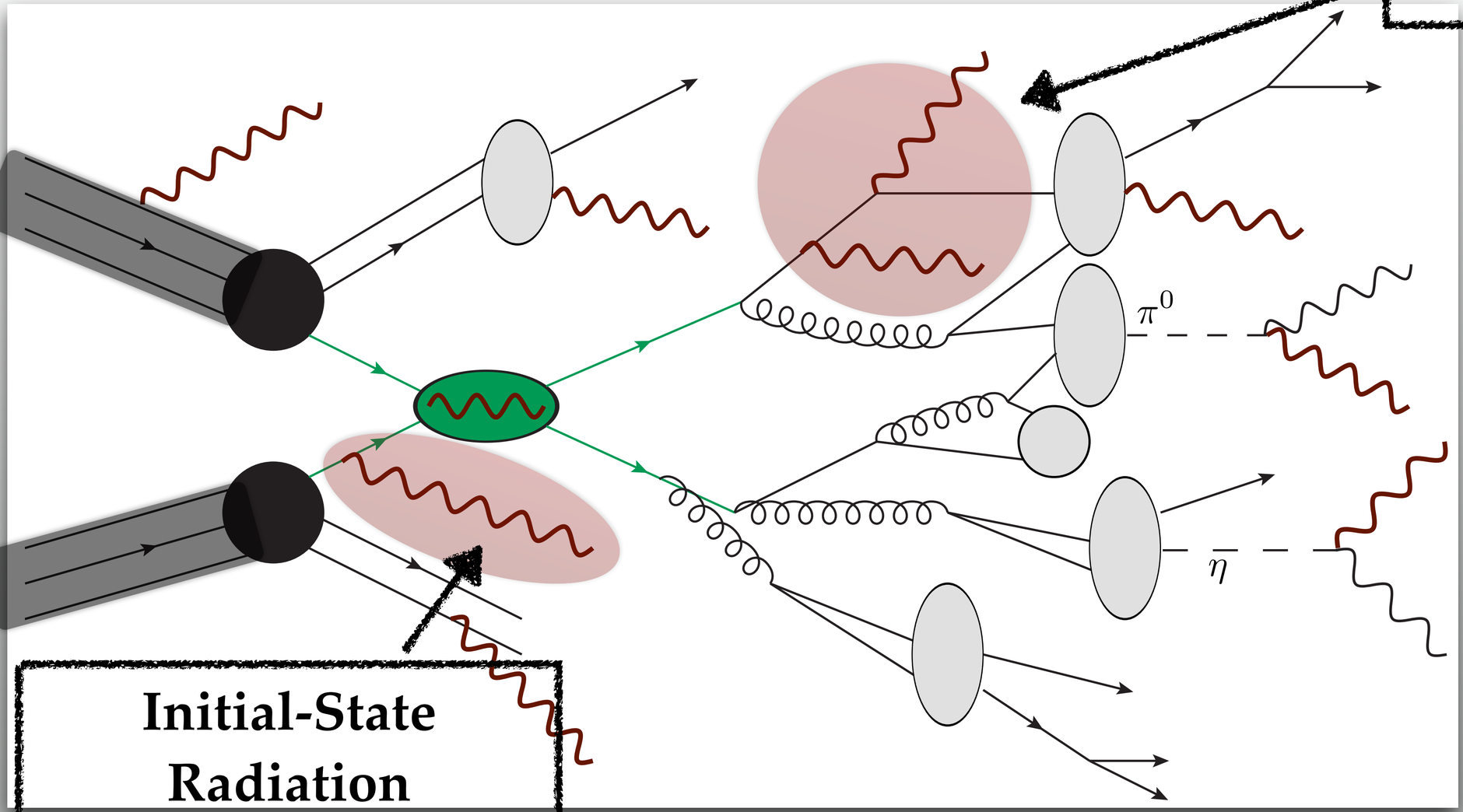
Additional Production Modes?

Part of Hadronization



Additional Production Modes?

Final-State Radiation



Initial-State Radiation

Focus of this talk!

Difficulties

(Probably true for many production modes)

Identify relevant processes

Calculation

Validity

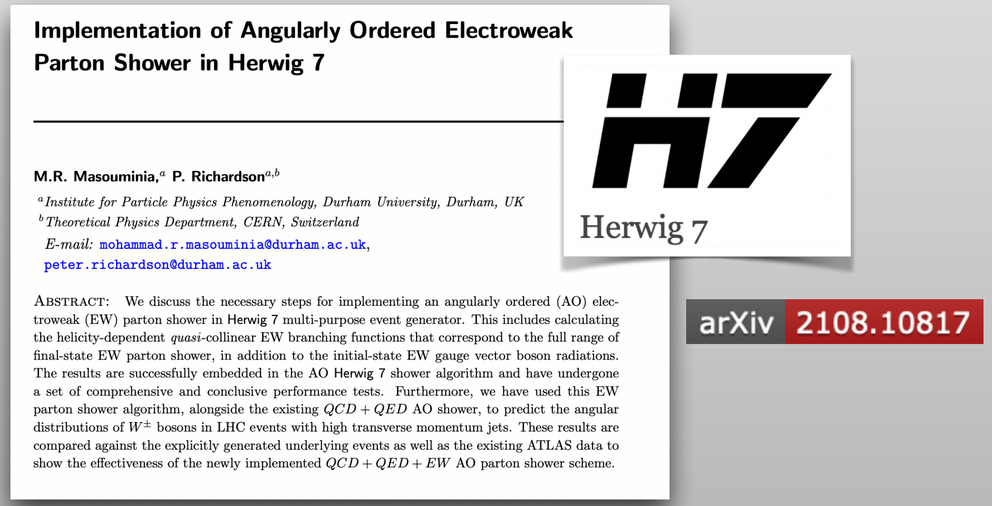
Difficulties

(Probably true for many production modes)

Identify relevant processes

Calculation

Validity



Implementation of Angularly Ordered Electroweak Parton Shower in Herwig 7

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[a] *Institute for Particle Physics Phenomenology, Durham University, Durham, UK*
[b] *Theoretical Physics Department, CERN, Switzerland*

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Abstract: We discuss the necessary steps for implementing an angularly ordered (AO) electroweak (EW) parton shower in Herwig 7 multi-purpose event generator. This includes calculating the helicity-dependent *quasi*-collinear EW branching functions that correspond to the full range of final-state EW parton shower, in addition to the initial-state EW gauge vector boson radiations. The results are successfully embedded in the AO Herwig 7 shower algorithm and have undergone a set of comprehensive and conclusive performance tests. Furthermore, we have used this EW parton shower algorithm, alongside the existing $QCD + QED$ AO shower, to predict the angular distributions of $W^{\pm}$ bosons in LHC events with high transverse momentum jets. These results are compared against the explicitly generated underlying events as well as the existing ATLAS data to show the effectiveness of the newly implemented $QCD + QED + EW$ AO parton shower scheme.

Herwig 7

arXiv 2108.10817

→ BSM massive particles can easily be added:

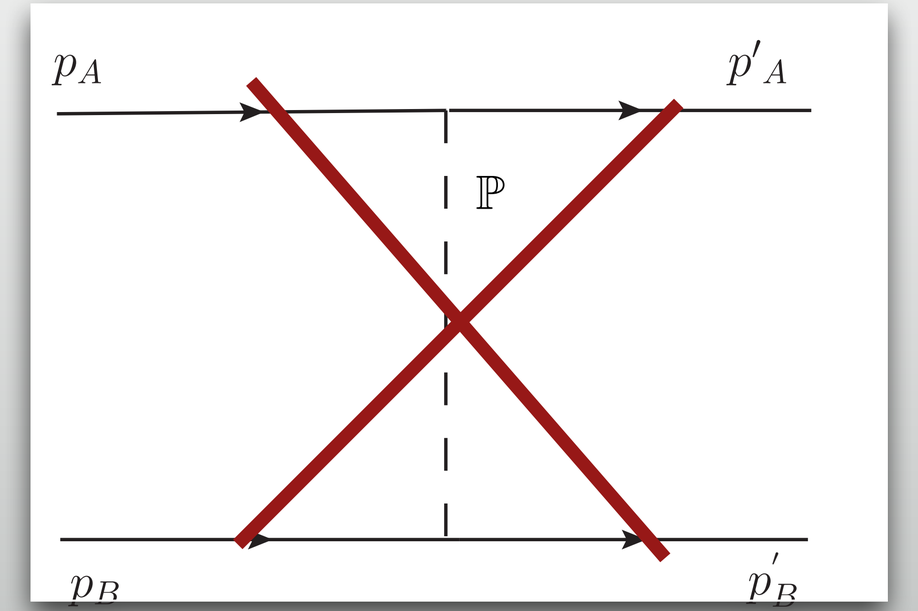
Dark photons, U(1) gauge extensions, dark scalars,…

Identify relevant processes

$$q \to qA'$$
$$(qq) \to (qq)A'$$

?

Elastic pp collision



Single- and double diffractive events

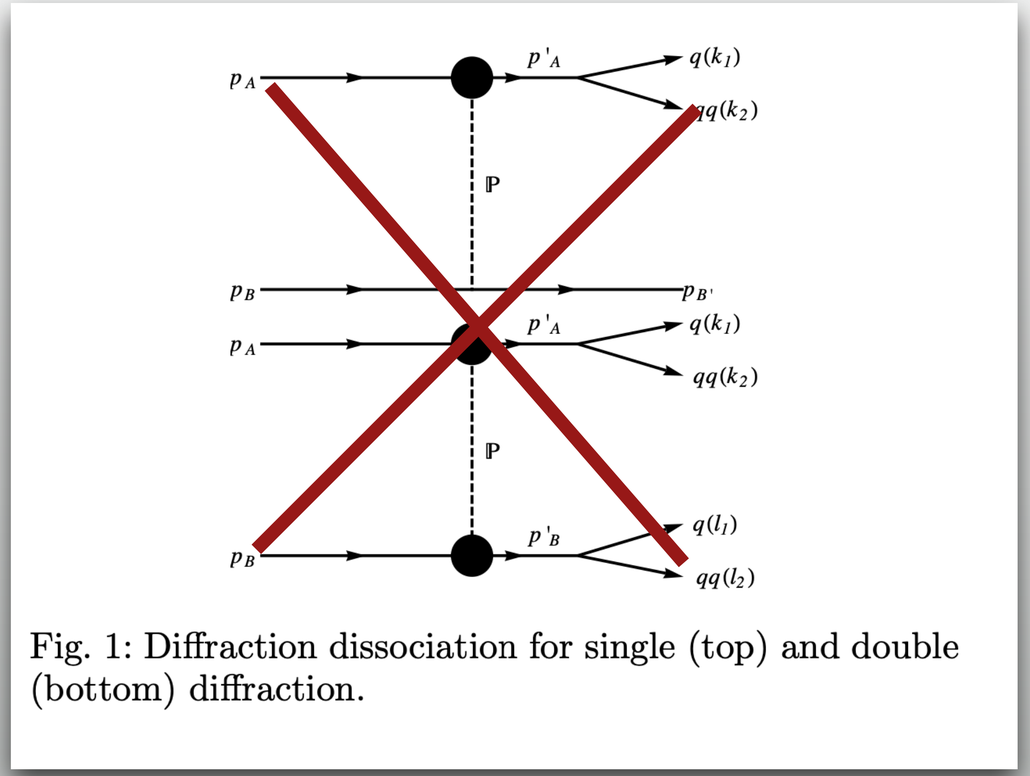


Fig. 1: Diffraction dissociation for single (top) and double (bottom) diffraction.

→ **Relevant: Processes where partons scatter!**

→ **Like QCD 2-to-2 processes**

arXiv 1612.04701
Gieseke, Loshaj, Kirchgaeßer

Note: Not only one but many partons interact in pp collision

Modelling in Herwig

Herwig 7

Dijet-like Event $qq' \to qq' +$

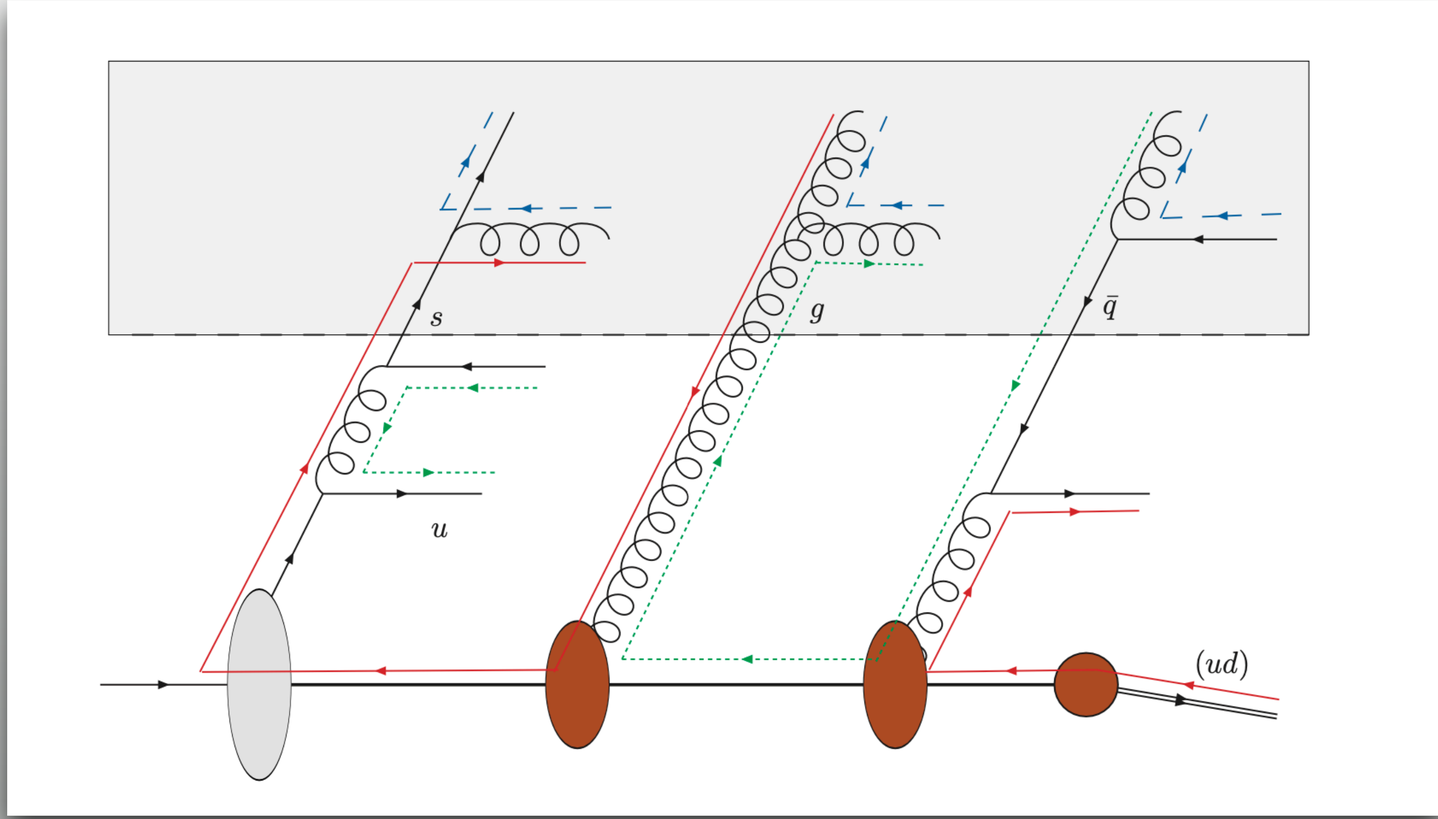
Multiple Partonic Interactions (MPI)

QCD 2-to-2

$qq \to qq$

$gg \to gg$

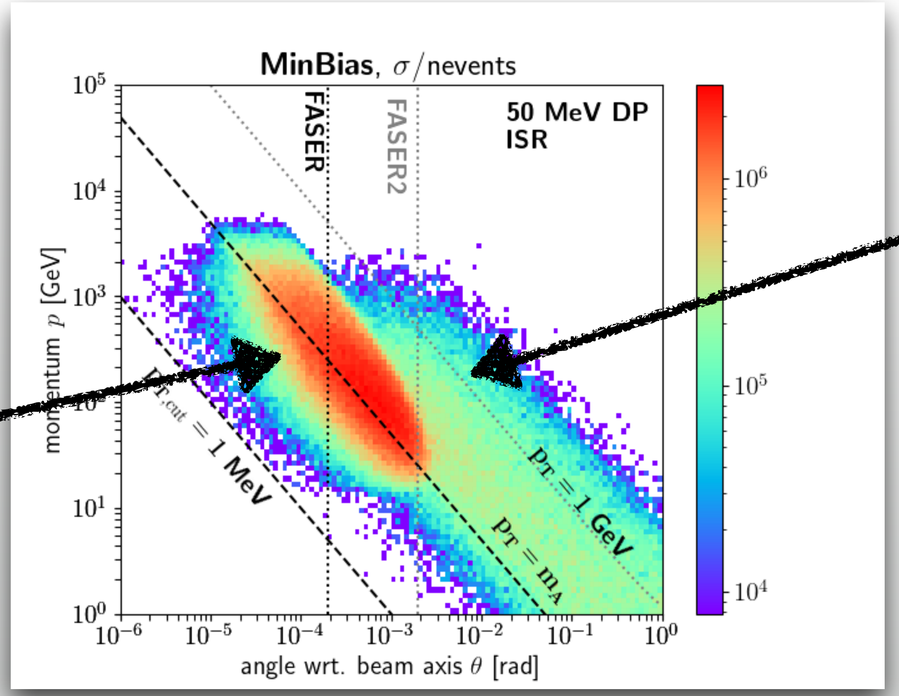
$gq \to gq \ldots$



arXiv 0803.3633

Bähr, Gieseke, Seymour

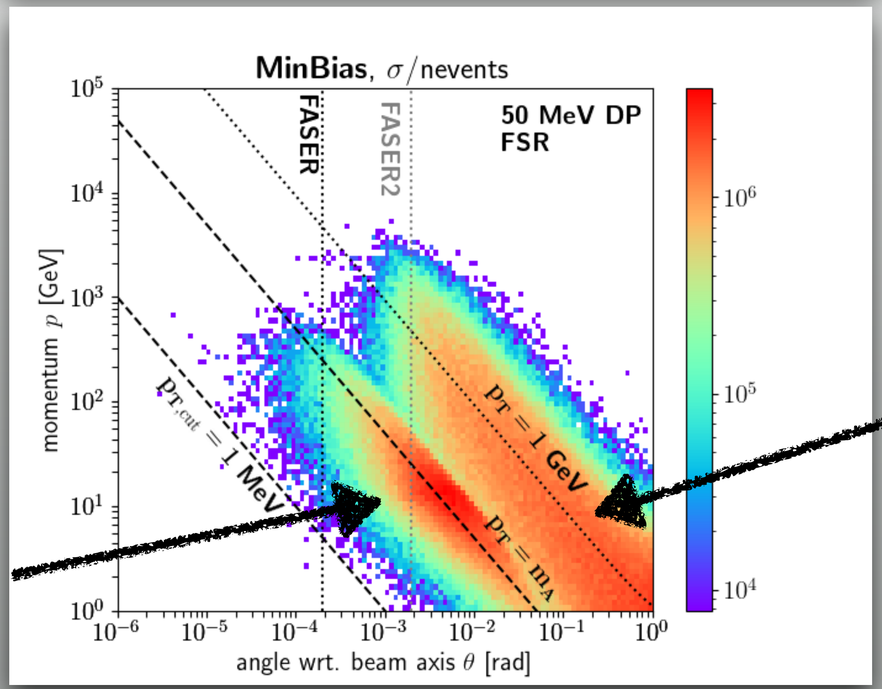
ISR



MPI

Dijet-like event

FSR



MPI

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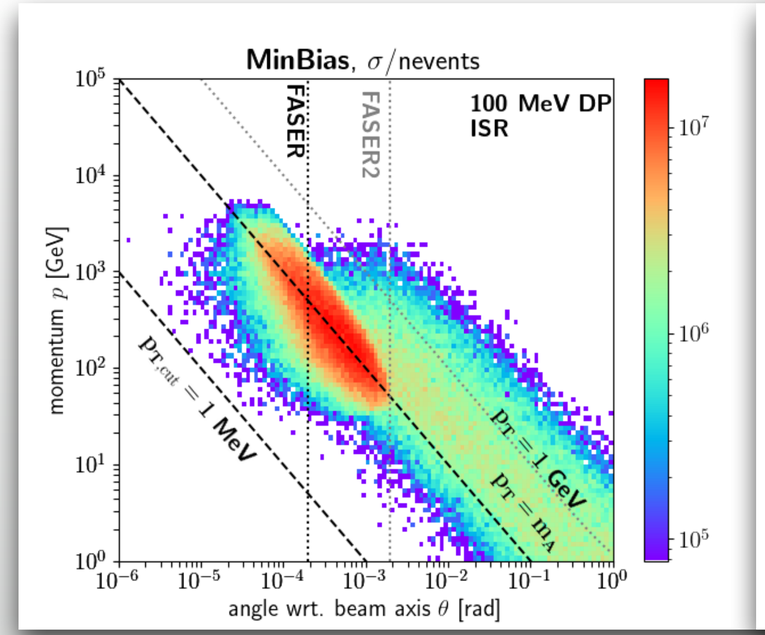
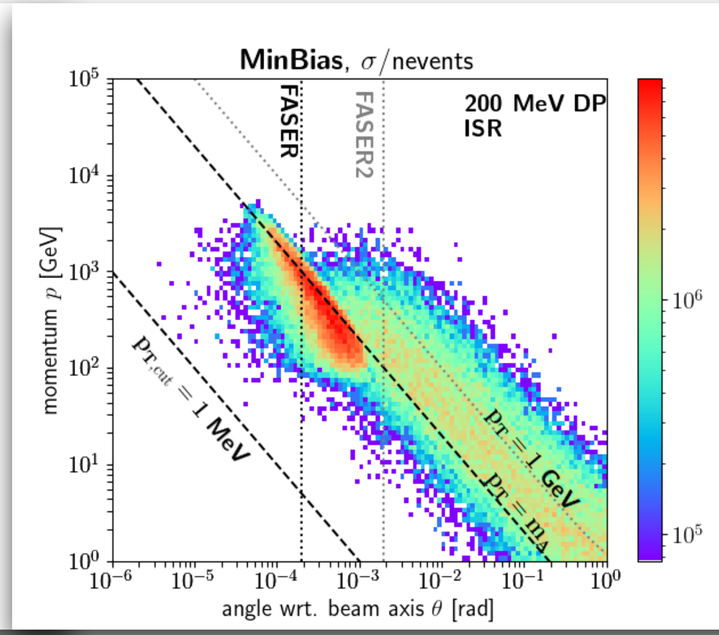

MinBias, σ/nevents
100 MeV DP
ISR
FASER
FASER2
momentum p [GeV]
angle wrt. beam axis θ [rad]
p_T,cut = 1 MeV
p_T = 1 GeV
p_T = m_A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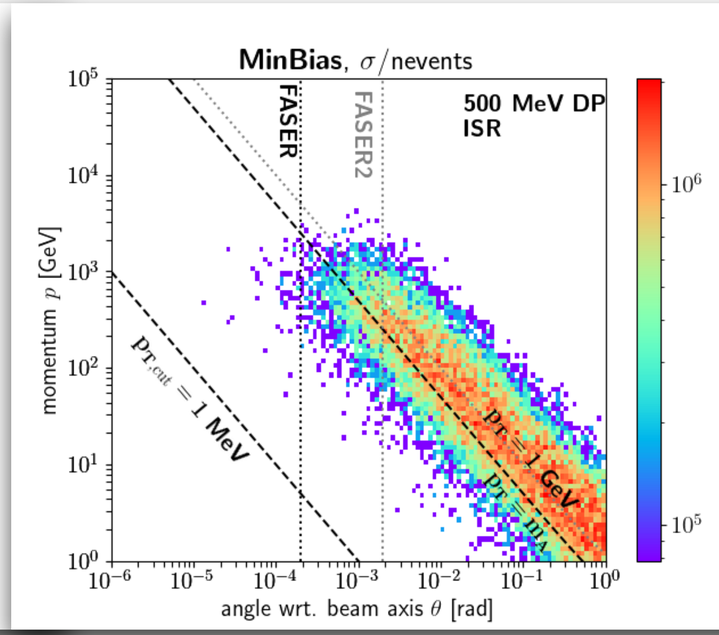
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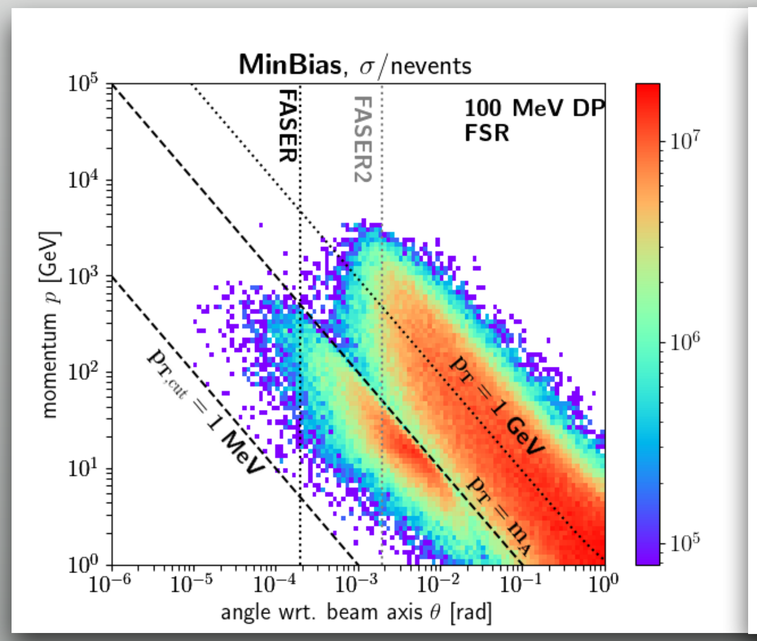
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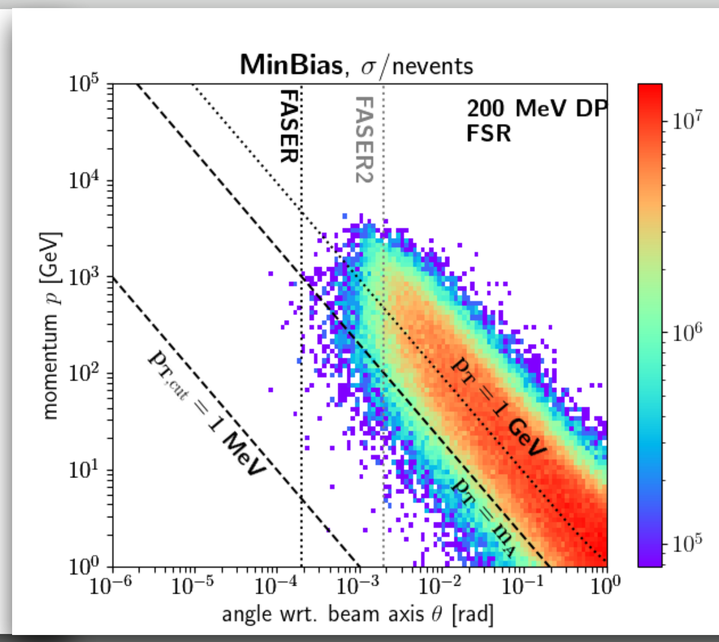
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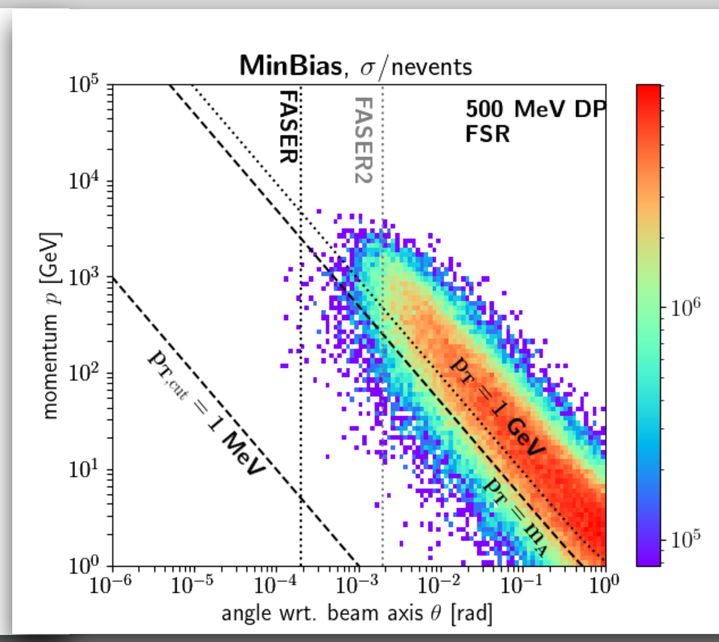
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500 MeV DP
FSR
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p_T,cut = 1 MeV
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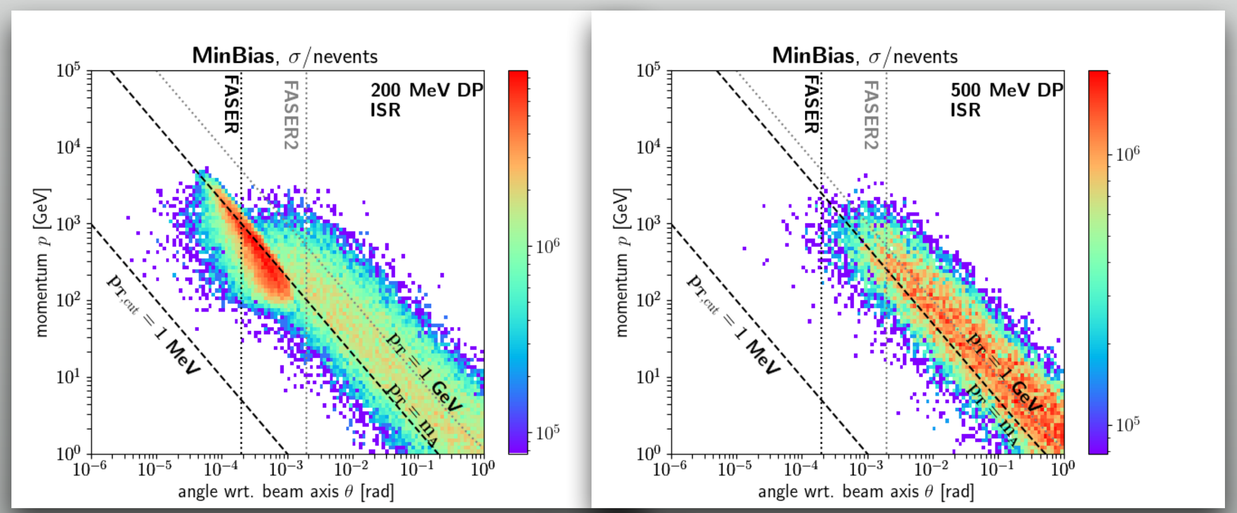
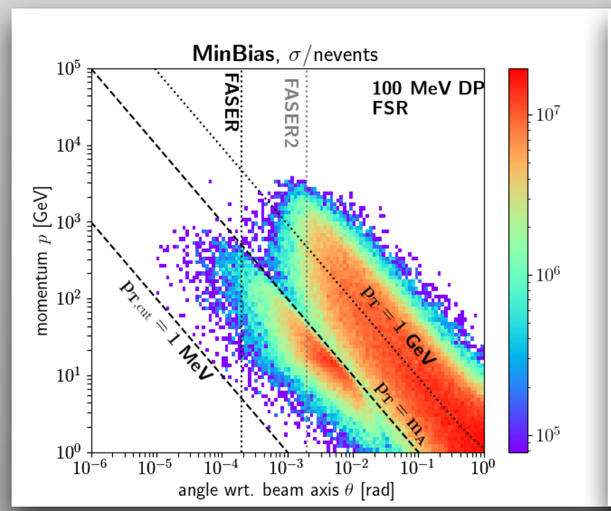
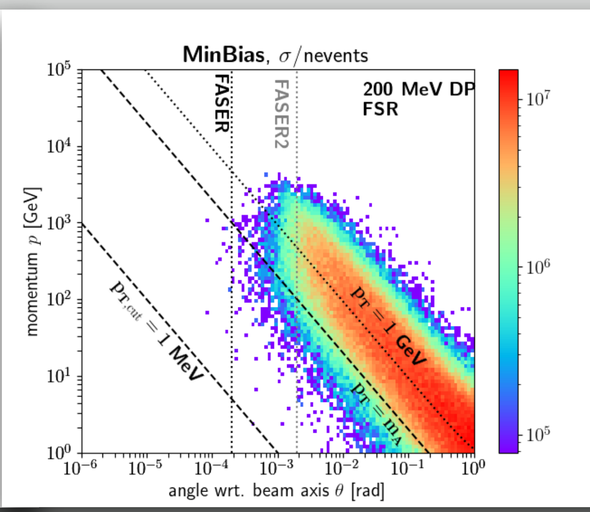
Validity

- Why does MPI in ISR only start above $p > 10$ GeV
- Why does MPI vanish in both cases for higher masses and p_T
- Are ISR and Bremsstrahlung related?



ISR





FSR

Conclusions

- Progress in both Decay & Production of BSM Particles
- Decay of vector particles (dark photons,…) well described
- Production of dark photons not at all!

→ Especially in the range relevant for FPF

→ How relevant are additional production modes

→ Do we fully understand Bremsstrahlung?

Saeid's Talk!