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Istituto Nazionale di Fisica Nucleare

Toward a universal coalescence model for antideuteron production

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Work in progress

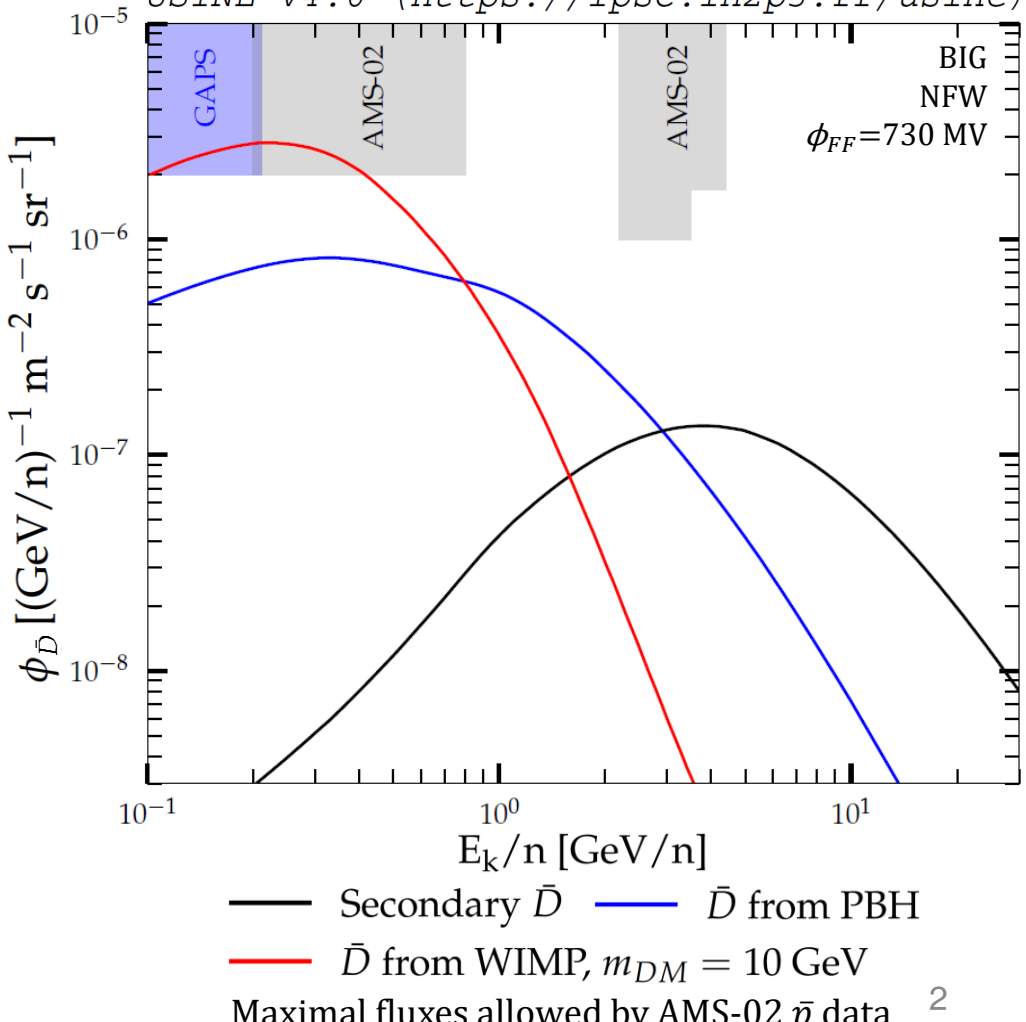
Why (galactic) antideuterons?

- **Galactic antideuterons** ($\bar{D}$) → one of the **cleanest channels** for **indirect DM detection**, both for WIMPs and primordial black holes (PBHs)

Donato et al. 2000, Barrau et al. 2002,
DeRomeri Donato Maurin LS Tolino 2025*: accepted by PRD → see *A. Tolino's talk

Relatively small background expected from standard astrophysical processes, especially at energies $\lesssim$ GeV

Plot by LS, made with
USINE V4.0 (https://lpsc.in2p3.fr/usine)



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- Experiment are searching for $\bar{D}$:

➢ **AMS-02** → on the International Space Station
AMS collaboration 2021

➢ **GAPS** → balloon-borne experiment, to be launched
Aramaki et al. 2016

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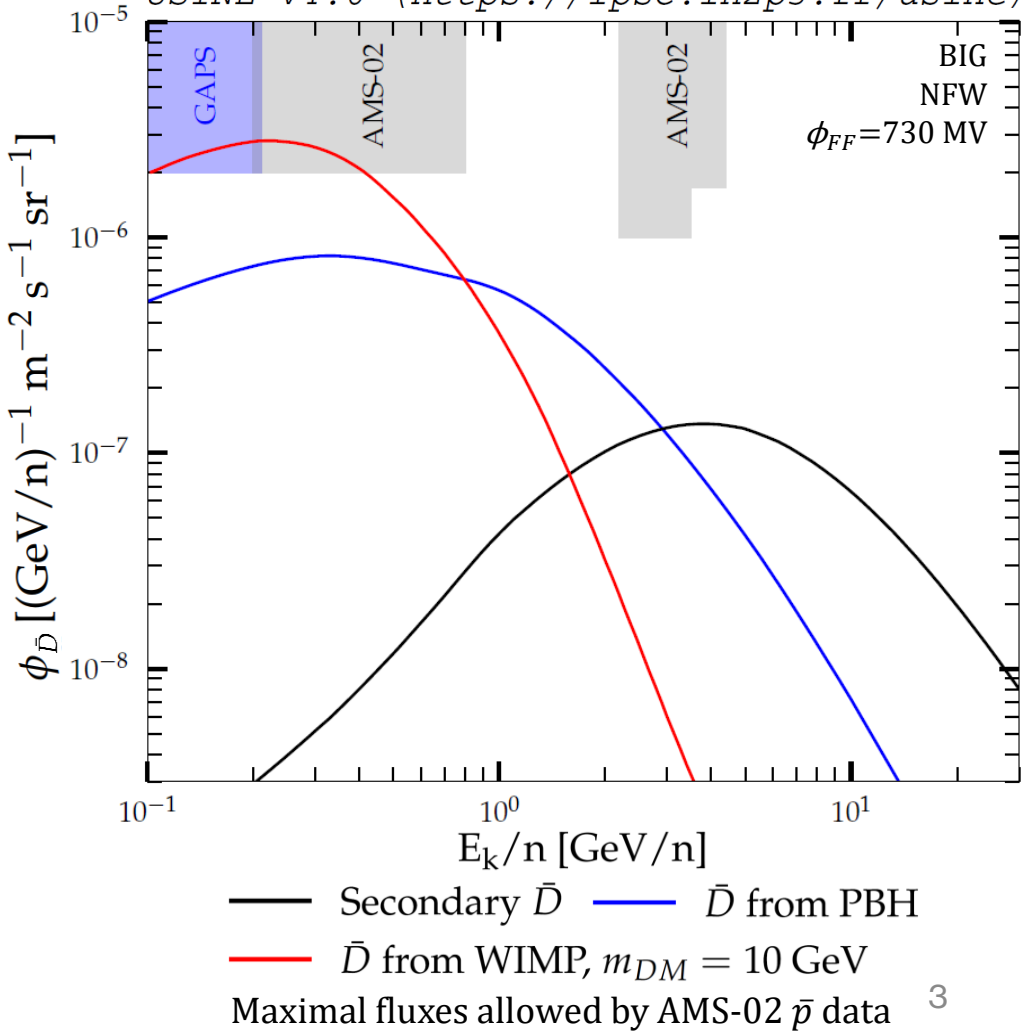
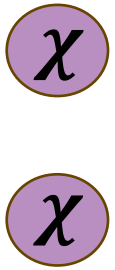


Galactic $\bar{D}$ production

Origin	Production mechanism	New physics?	Detected?	Hadronic origin?
Primary $\bar{D}$	**WIMP** annihilation, **PBH** evaporation	**YES**: BSM/exotic sources	**NO**	**NO**: non-hadronic initial state
Secondary $\bar{D}$	Cosmic ray **inelastic scattering** on the interstellar medium	**NO**: standard astrophysical processes	**NO**	**YES**: hadronic collision

$\overline{D}$ production mechanisms

WIMP annihilation



Donato et al. 2008 *Cirelli et al. 2011*

$\overline{D}$ production mechanisms

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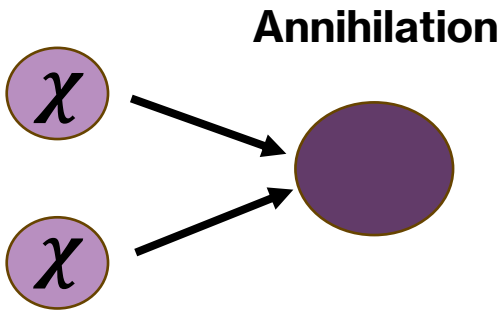

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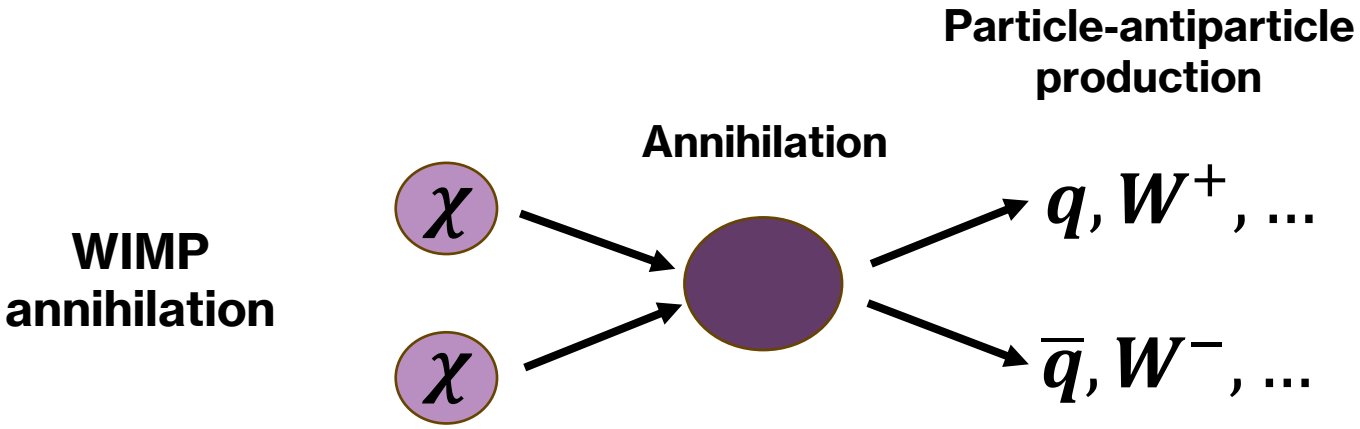

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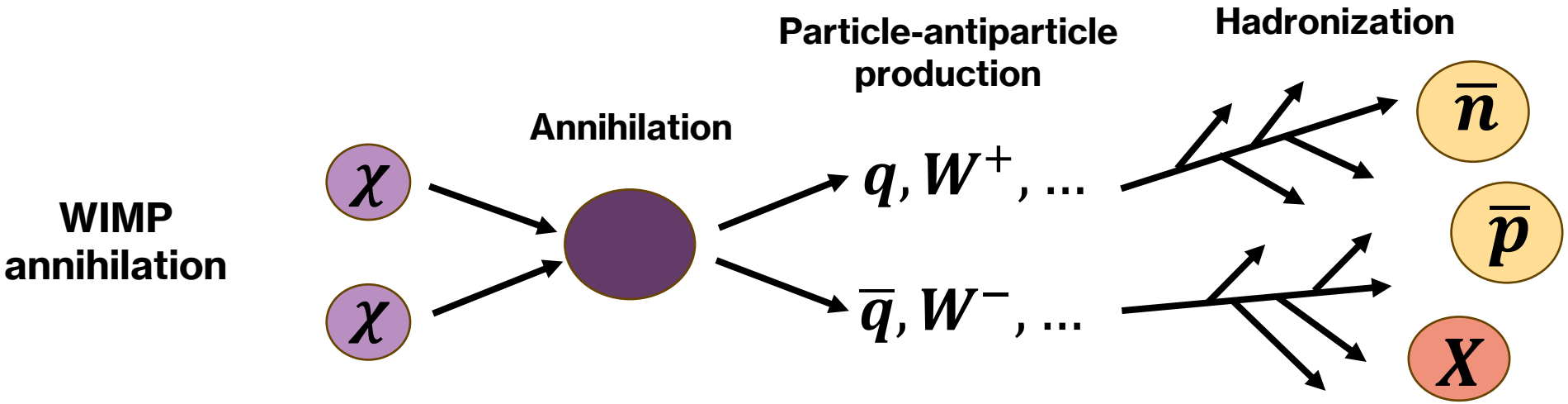

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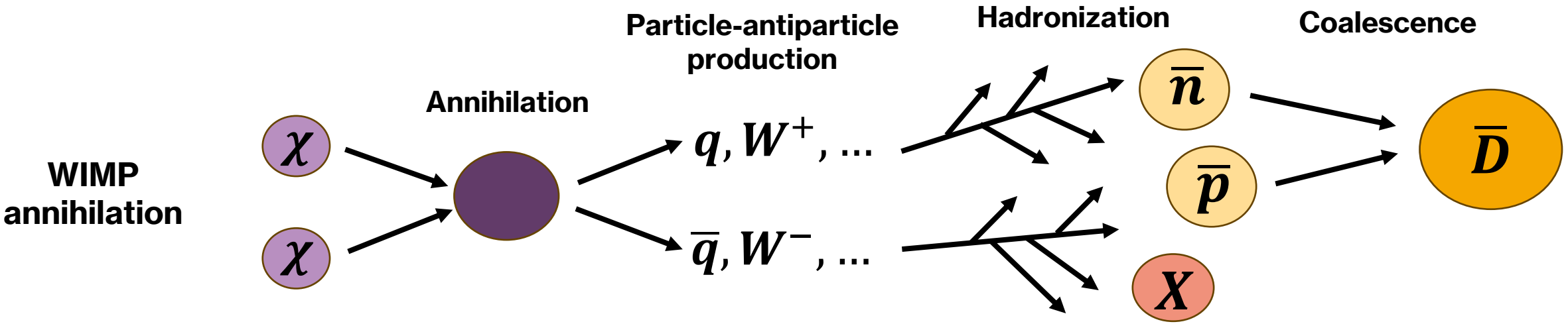

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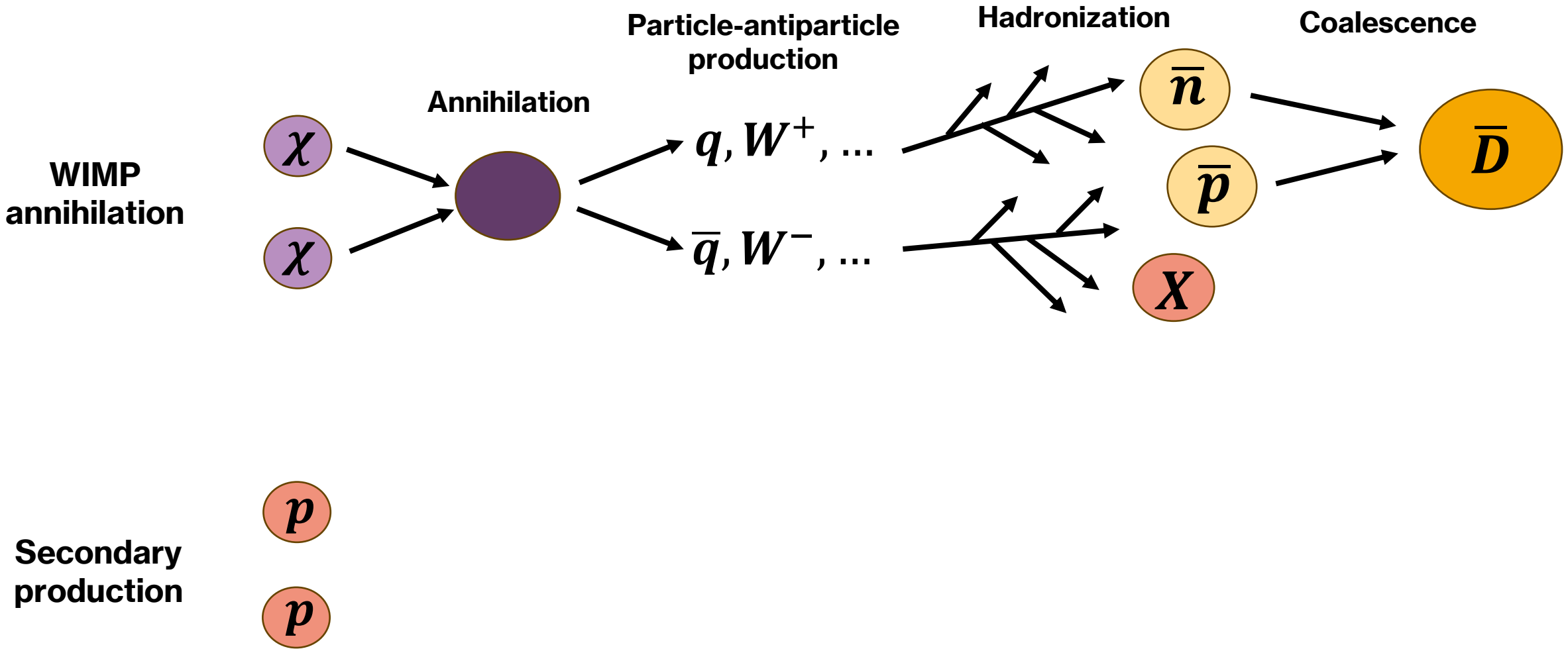

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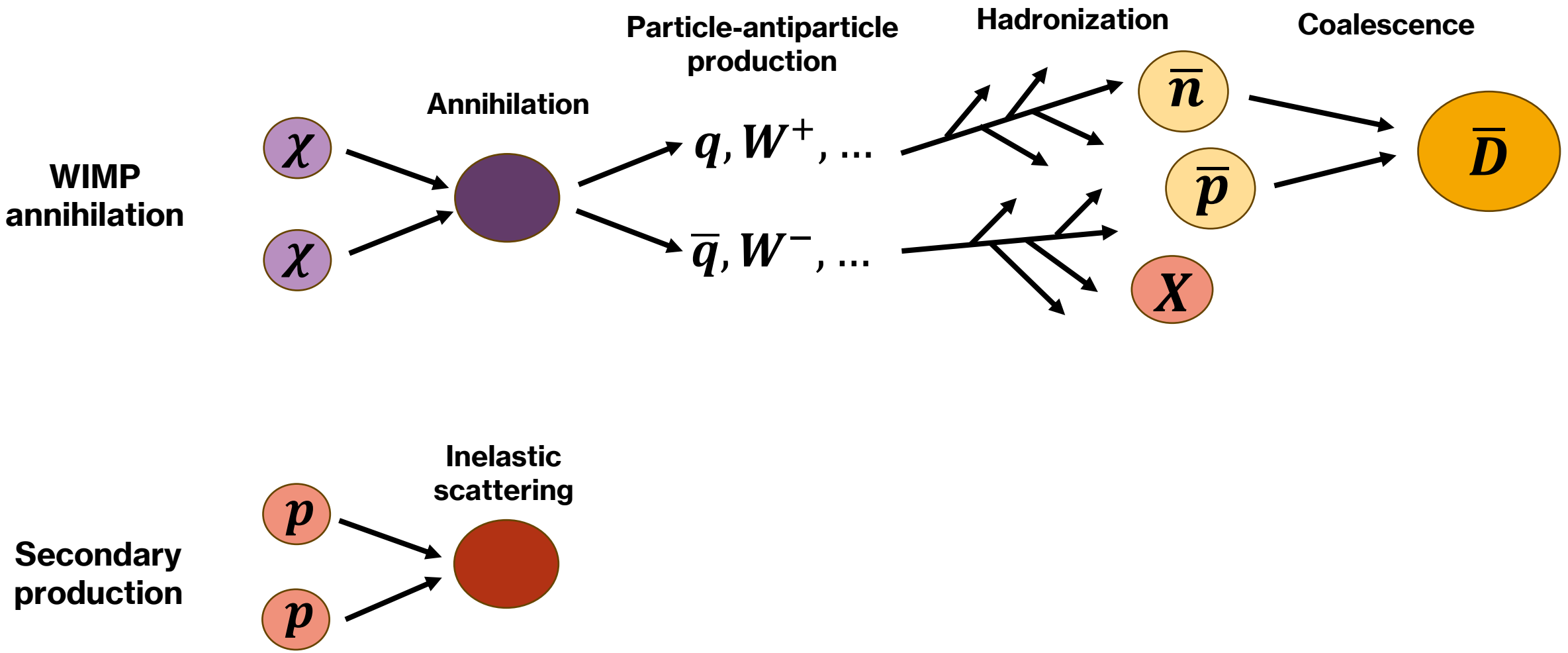

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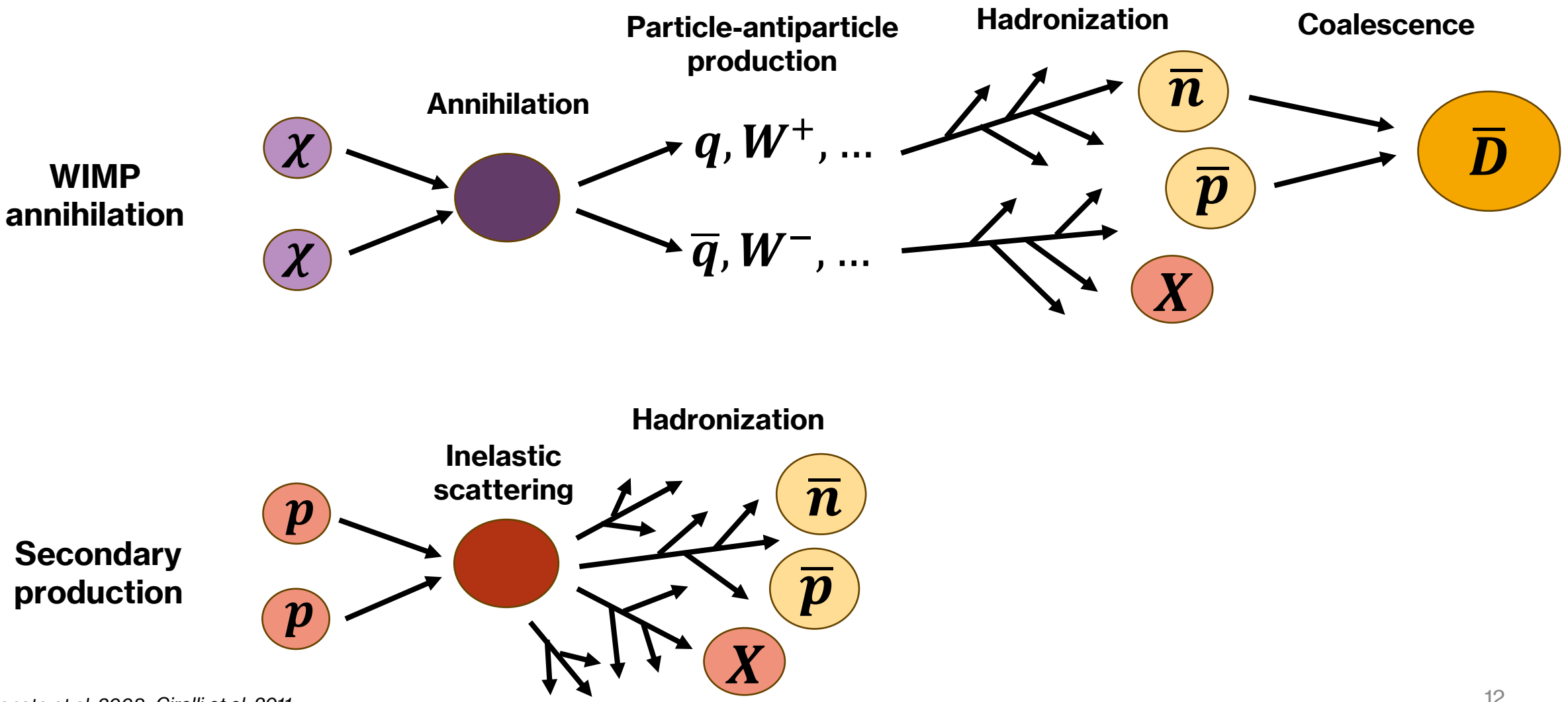

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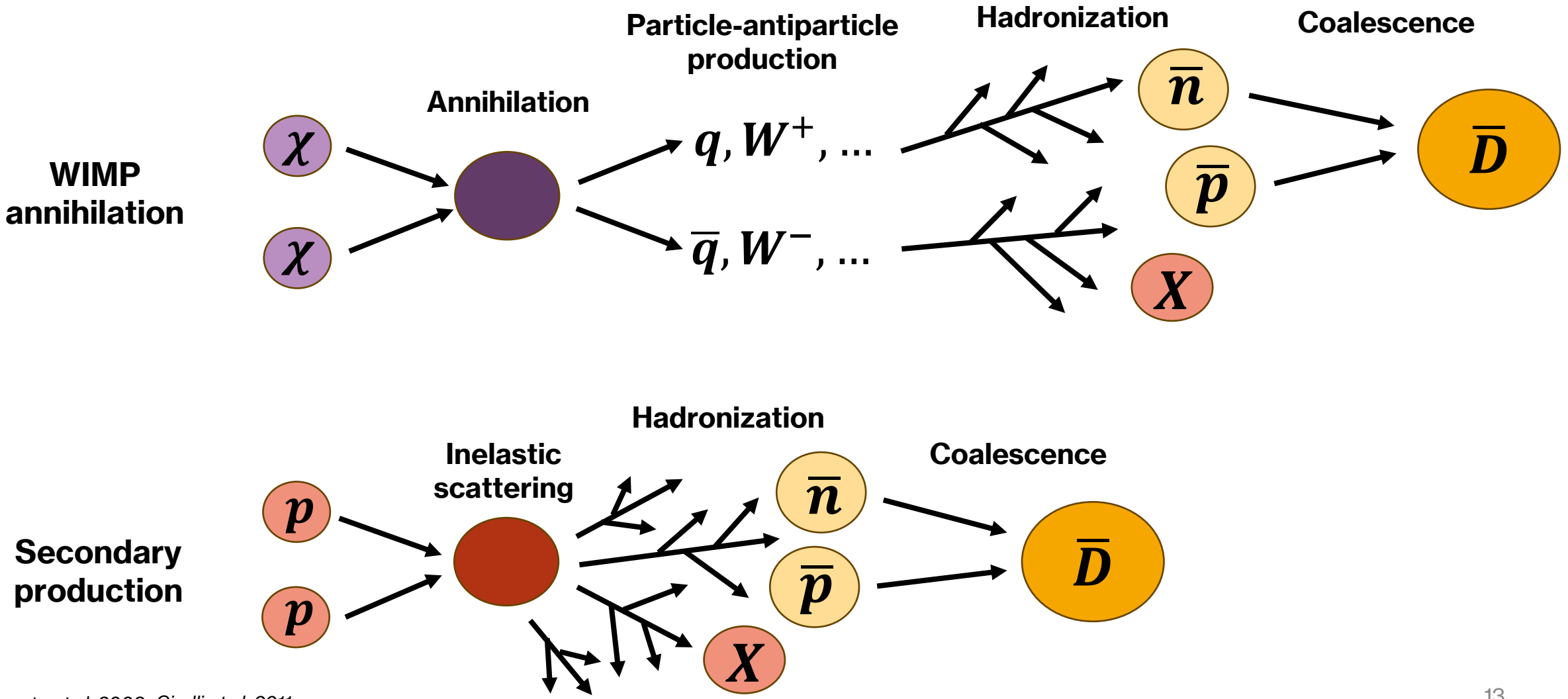

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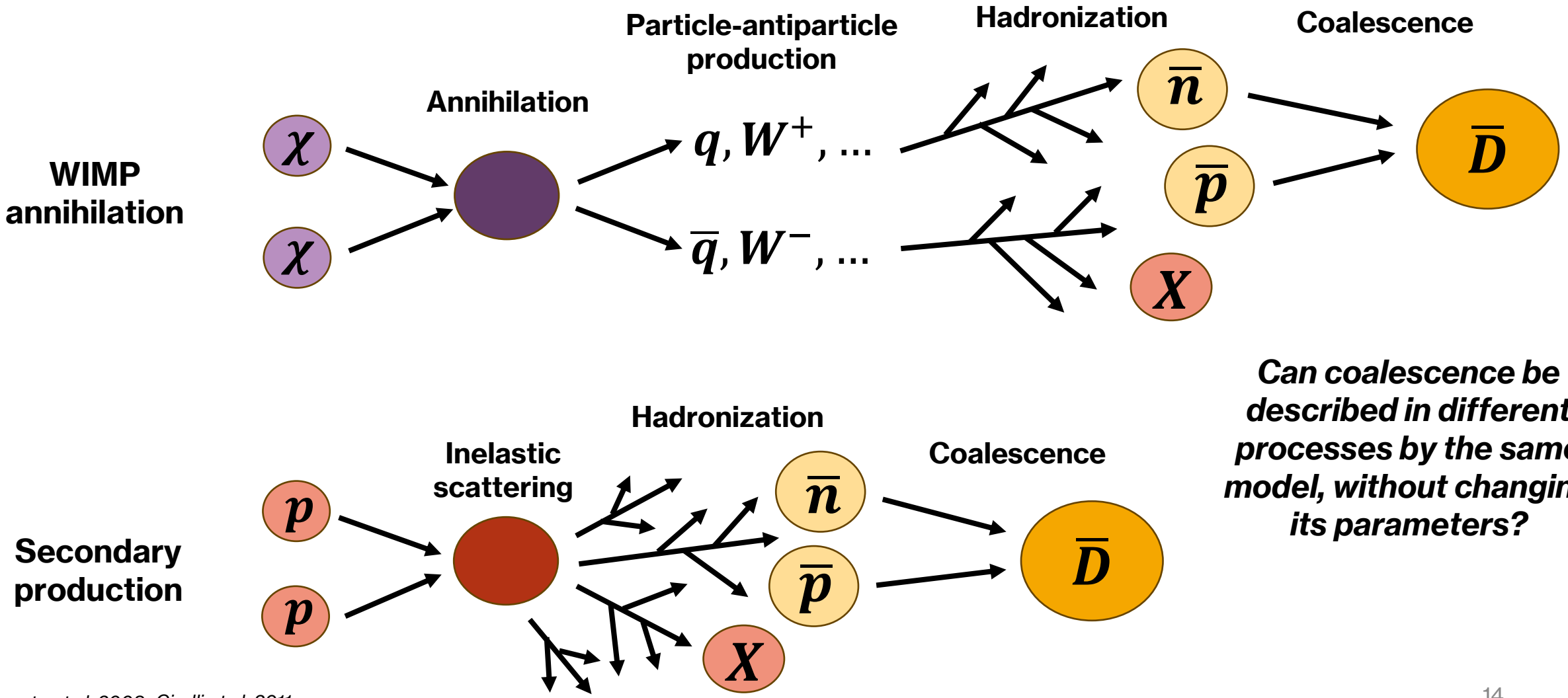
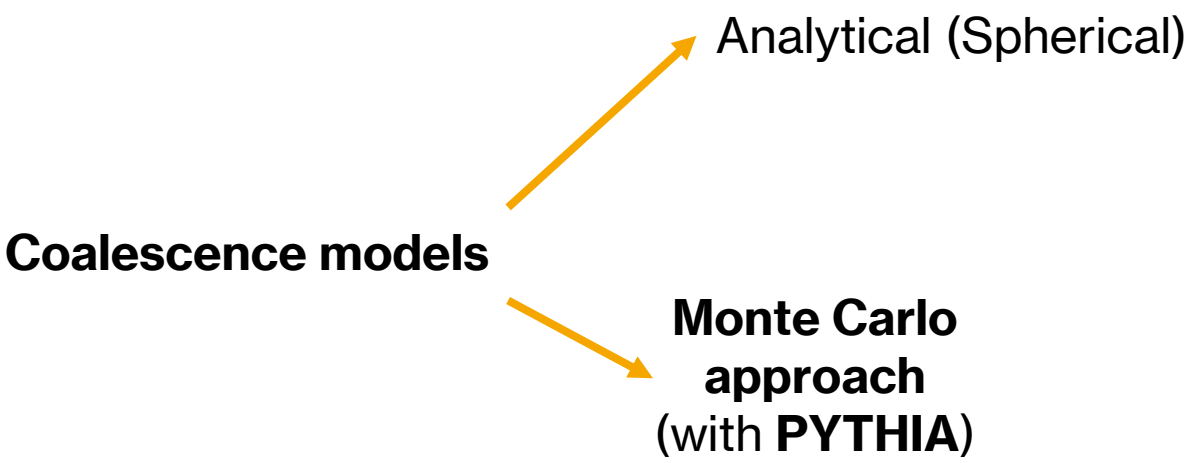


Can coalescence be described in different processes by the same model, without changing its parameters?

Donato et al. 2008 *Cirelli et al. 2011*

Coalescence models



Fornengo et al. 2017 , *PYTHIA collaboration 2022*

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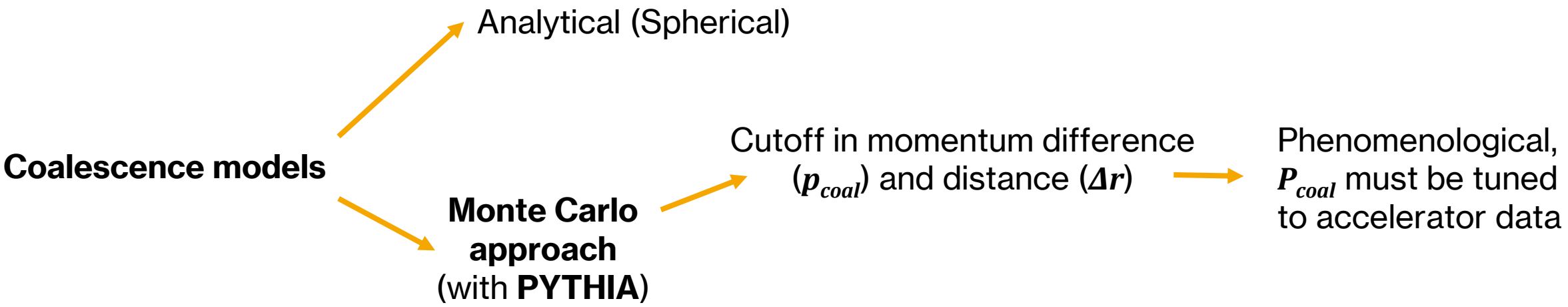

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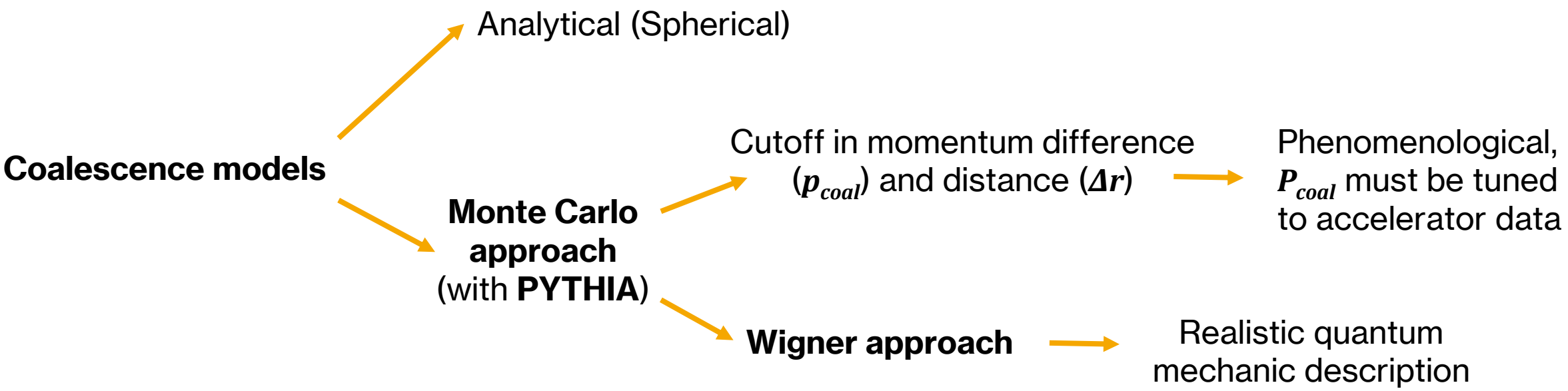


Fornengo et al. 2017 , *PYTHIA collaboration 2022* , *Kachelriess et al. 2019*

Wigner approach with Argonne v_{18} function

Mahlein et al. 2023 *Di Mauro et al. 2024*

- Full quantum mechanical-treatment based on the **Wigner function** derived from the **Argonne v_{18} nuclear wavefunction**
- **Completely tuned** on precise p, n inelastic scattering dataset: **no dependence on p_{coal}**
- Treated as a **probability distribution** in phase space for forming an antideuteron

  ✓ Argonne-Wigner validated in non-hadronic initial processes → ALEPH (e^+e^- → hadrons)

  ? **NOT yet tested in hadronic initial processes**

Probability to form a $\overline{D}$ — $\overline{D}$ Wigner function

$$\mathcal{P}(r,q) = \int_0^r \int_0^q dr\, dq\, \mathcal{D}(r,q)$$

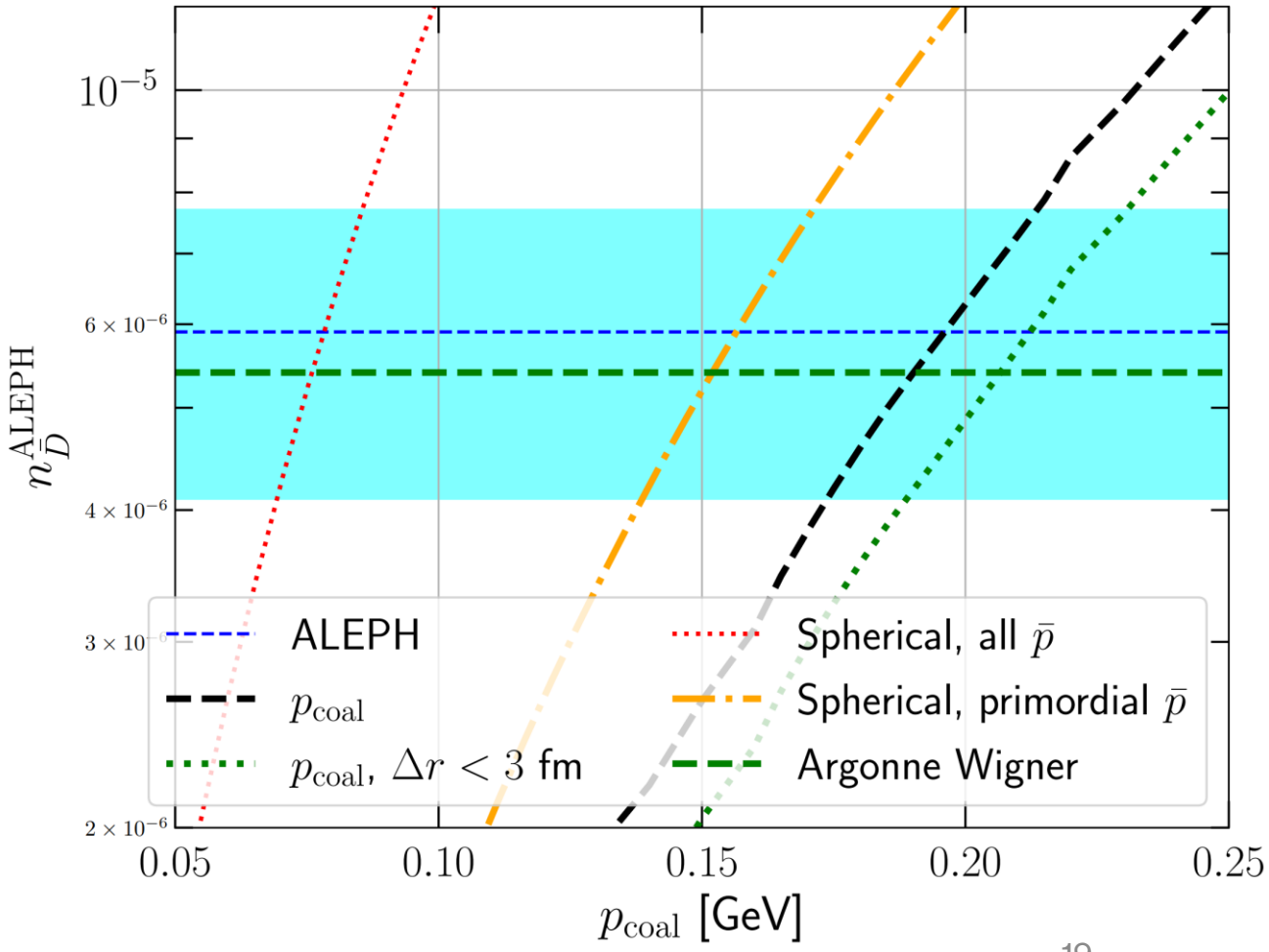
Distance and momentum difference of $\bar{p}$ and $\bar{n}$

Matching with ALEPH data ($e^+e^- \rightarrow$ hadrons)

In **Di Mauro et al. 2024**, $\bar{D}$ **multiplicities from PYTHIA** are compared to **ALEPH data** at **$\sqrt{s} = m_Z$**

Non-hadronic origin → clean benchmark for **WIMP annihilation** and **PBH evaporation** modeling

Di Mauro et al. 2024



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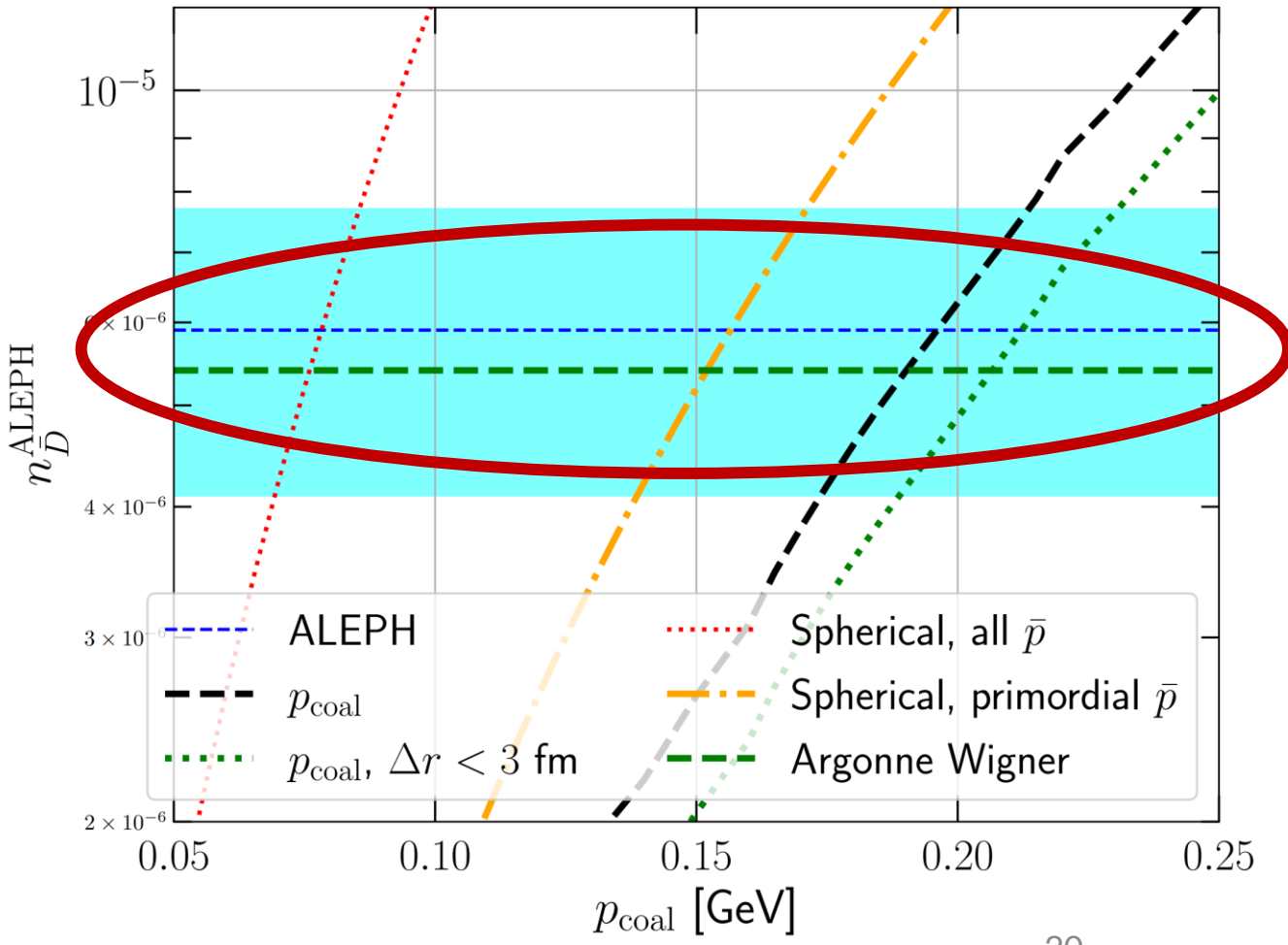
Non-hadronic origin → clean benchmark for **WIMP annihilation** and **PBH evaporation** modeling

The Argonne–Wigner approach matches ALEPH $\bar{D}$ multiplicity without further adjustment!

Theoretical uncertainties from coalescence parameter tuning are **significantly reduced for non-hadronic initial processes**

Di Mauro et al. 2024



Goals of our project

Test the **universality of Argonne-Wigner** coalescence model for different processes and energies regimes

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Compute new **secondary $\overline{D}$ production cross sections** with reduced coalescence uncertainty

Conclusions

The Argonne–Wigner approach has strong potential to **reduce theoretical uncertainties** in $\overline{D}$ production **across all production channels**

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For WIMP and PBH scenarios, coalescence is no longer a limiting source of uncertainty → *Di Mauro et al. 2024*

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For WIMP and PBH scenarios, coalescence is no longer a limiting source of uncertainty → *Di Mauro et al. 2024*

Establishing the **universality** of coalescence could significantly **reduce the uncertainty in the secondary $\overline{D}$ background**, leading to **more reliable cross sections and flux predictions**

Thanks for your attention