





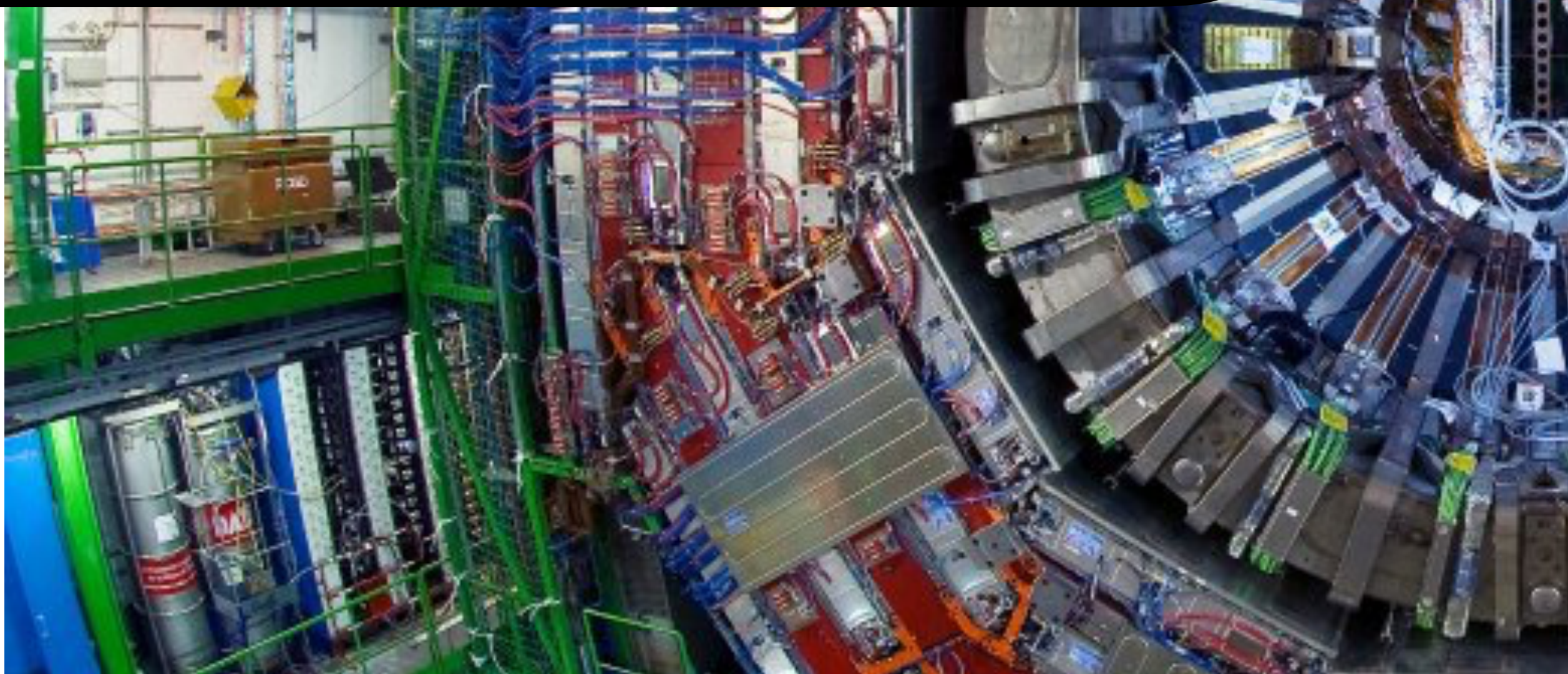
Boosting hidden light new physics at the LHC and beyond

Nhan Tran
Fermilab

Fermilab 50th Anniversary Symposium and Users Meeting
June 8, 2017



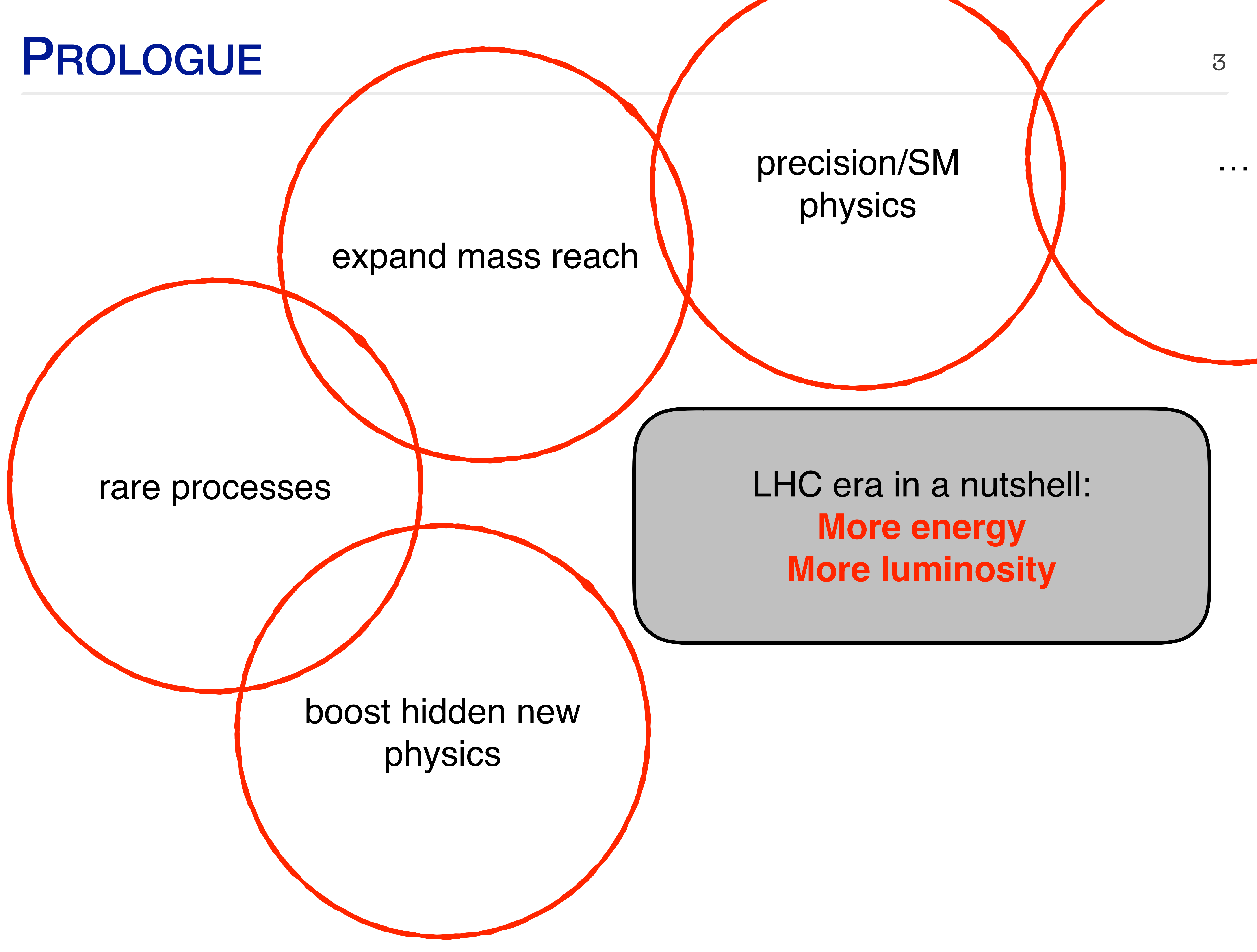
CMS & ATLAS:
A very broad and significant
physics program



LHC era in a nutshell:
More energy
More luminosity

Thanks to the LHC for
impressive performance!

SEE SAL'S TALK FOR MORE DETAILS!



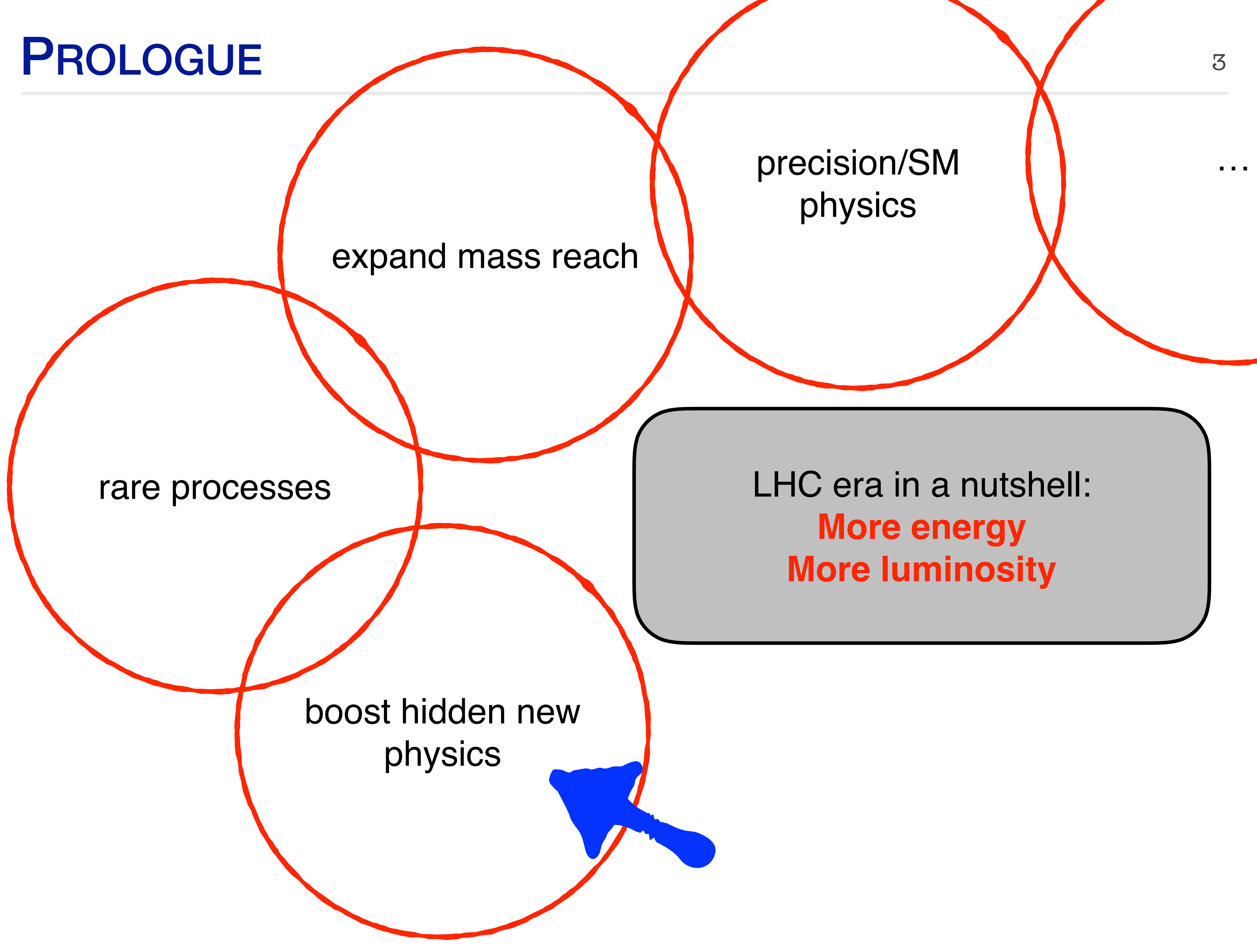
precision/SM
physics

expand mass reach

rare processes

boost hidden new
physics

LHC era in a nutshell:
More energy
More luminosity



**Tools for more energy
and luminosity**

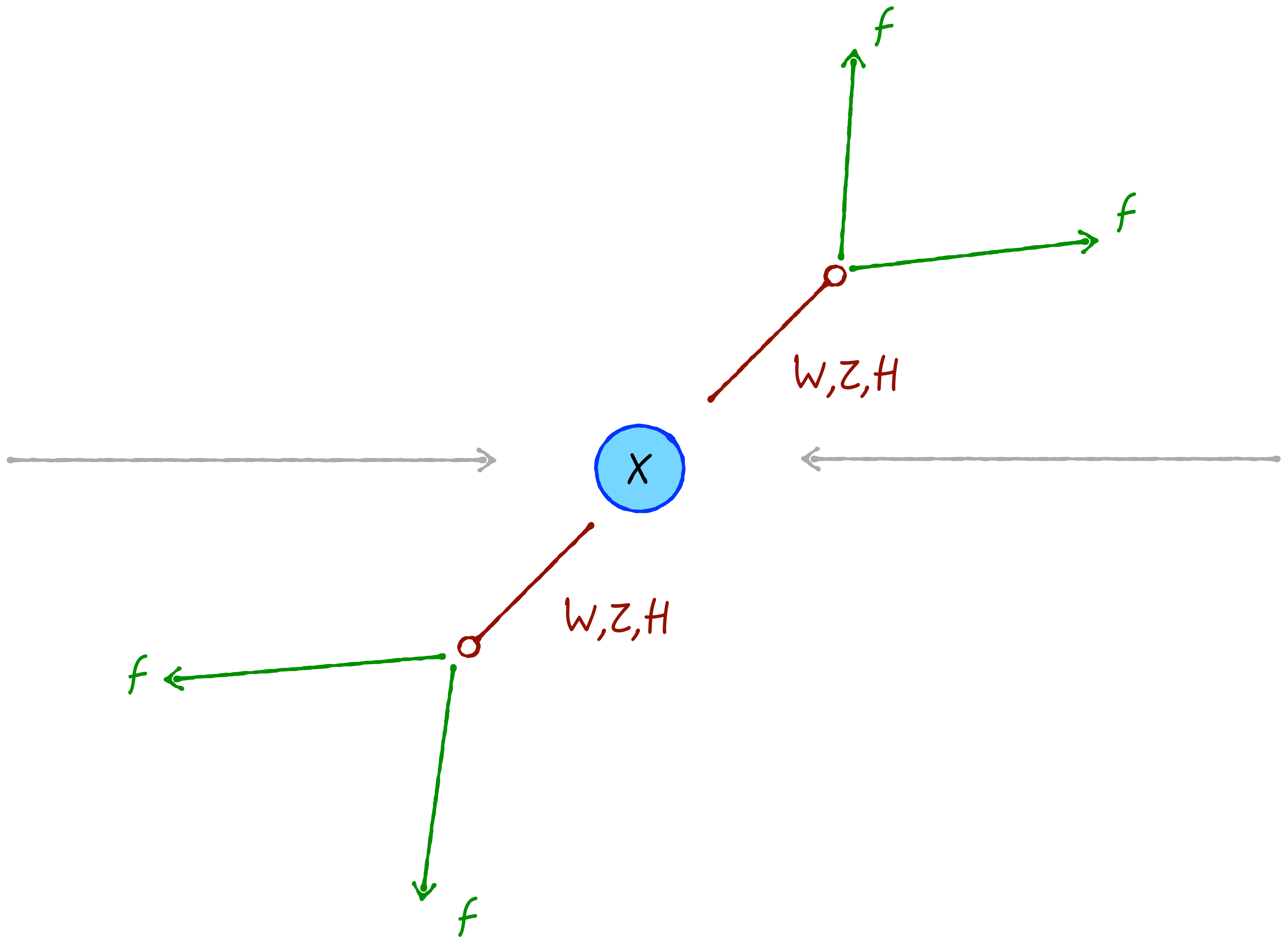
***A retro* search for hidden physics
&
mission impossible**

**the DM connection,
coming full circle**

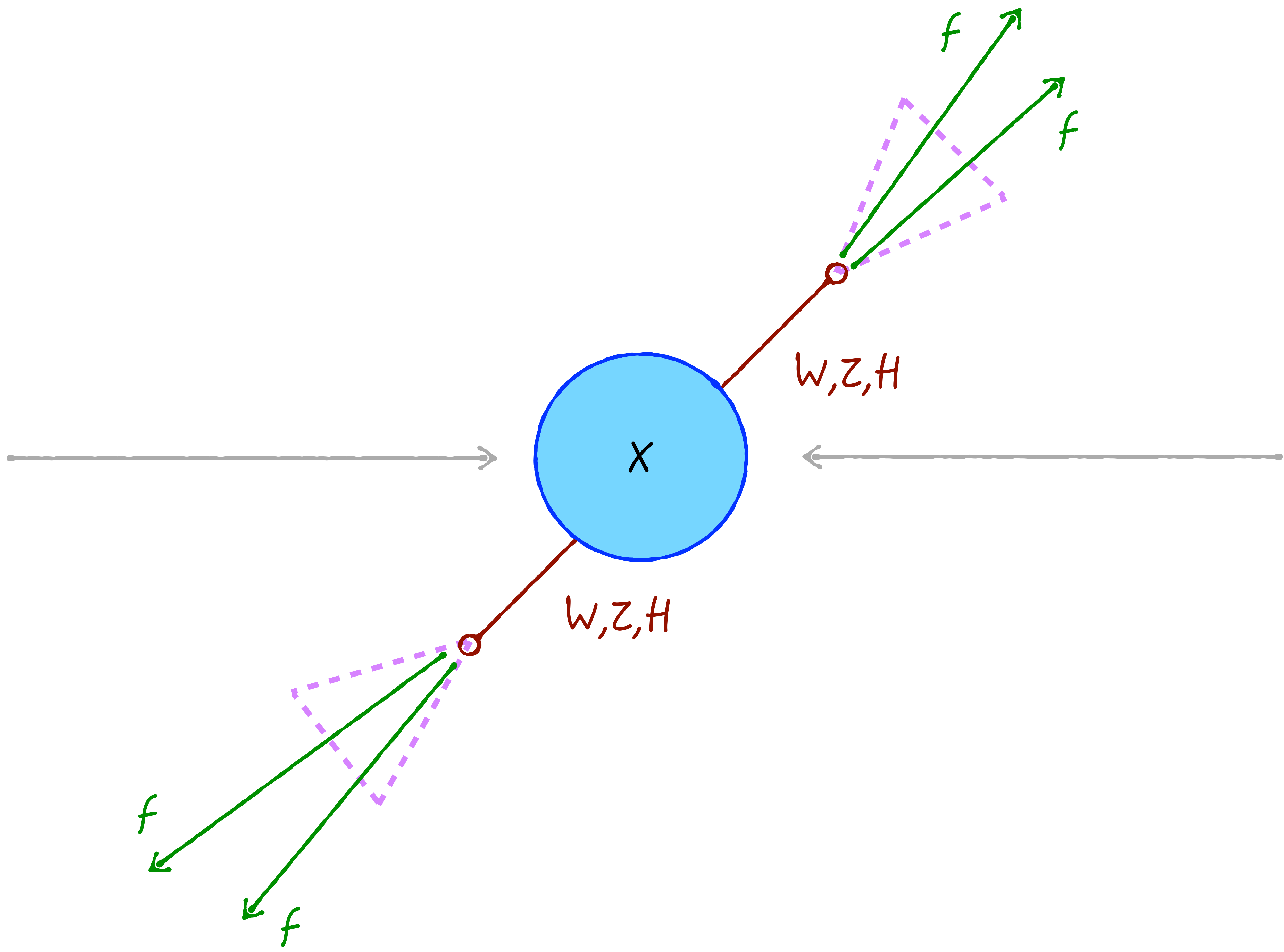
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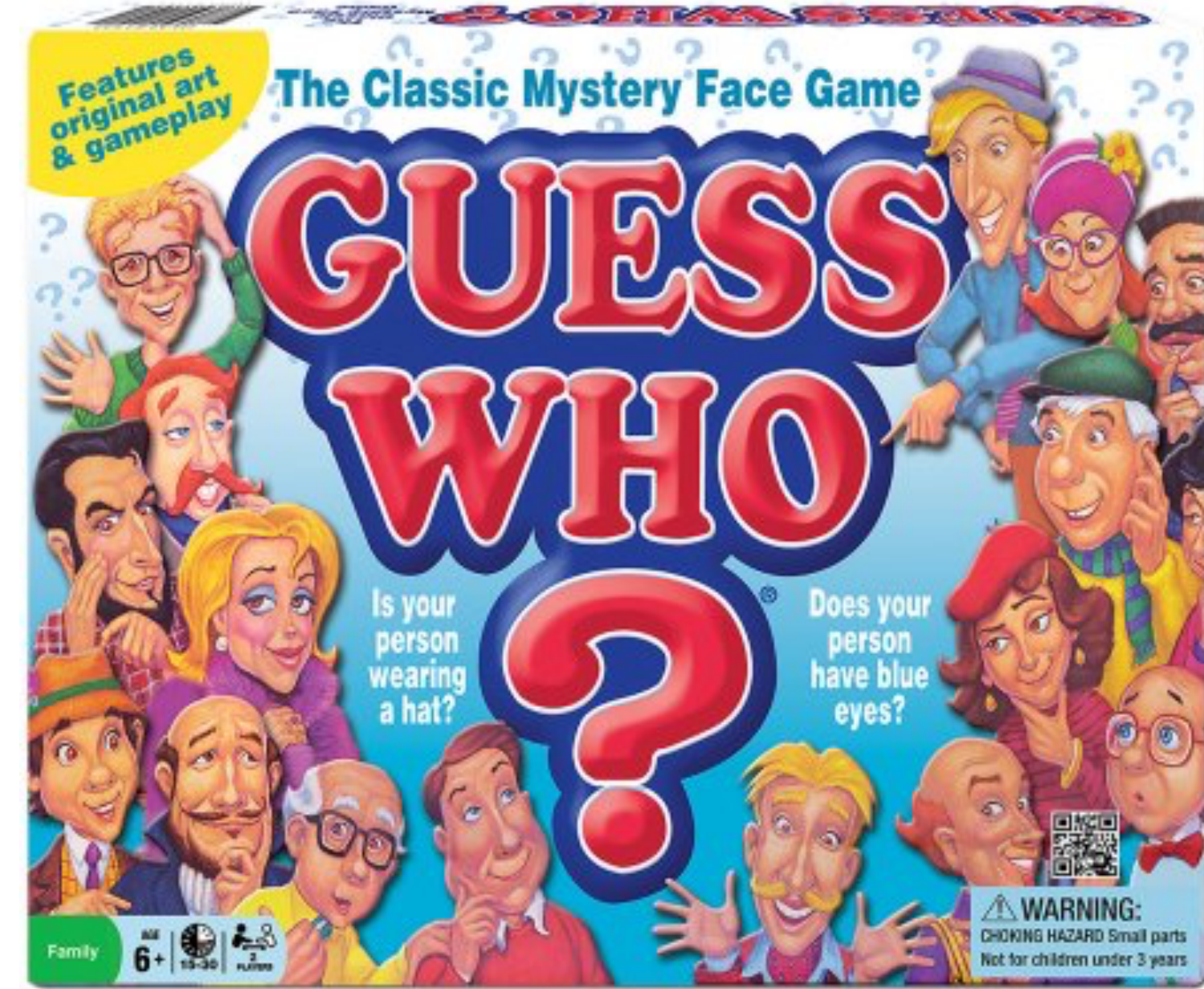
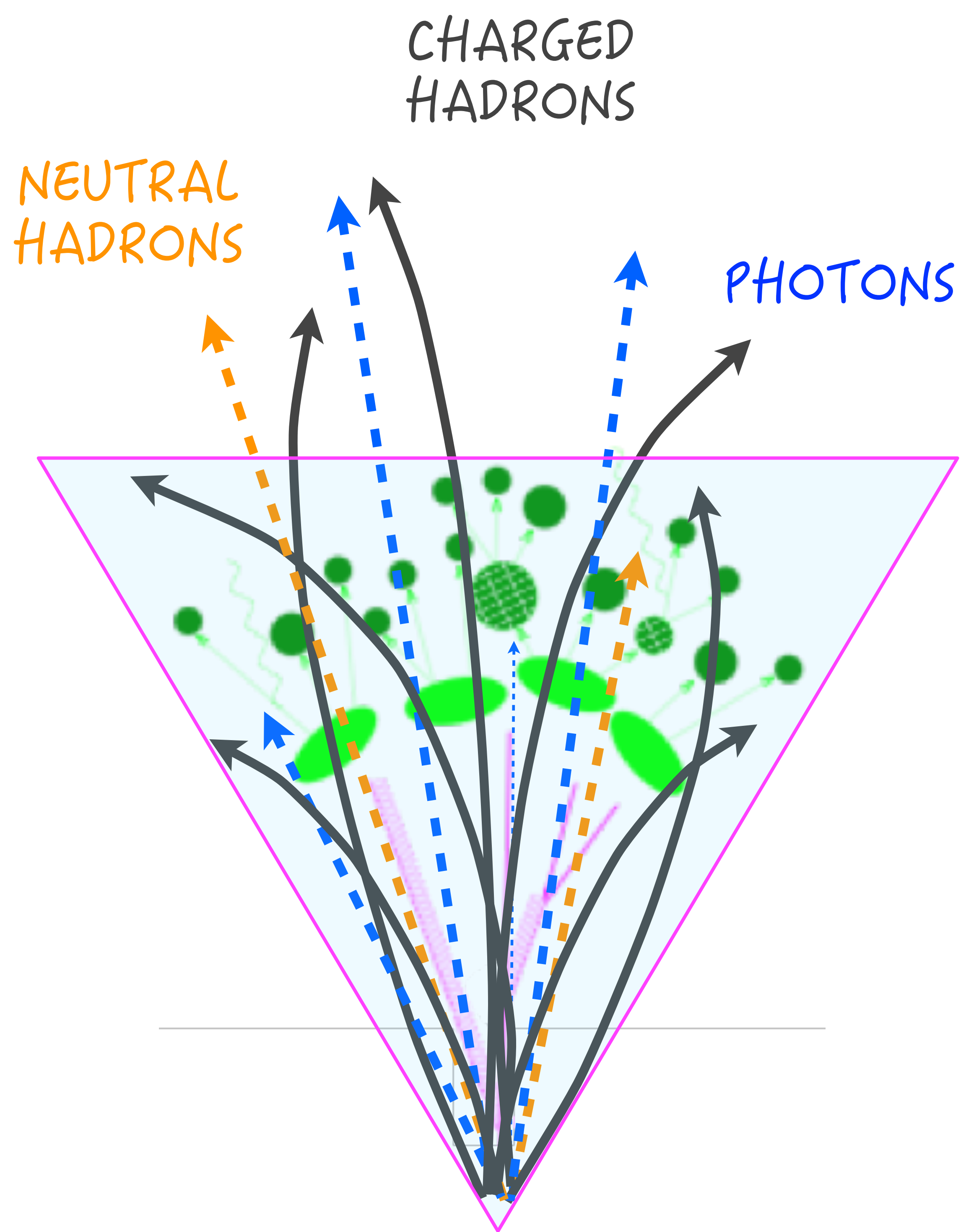
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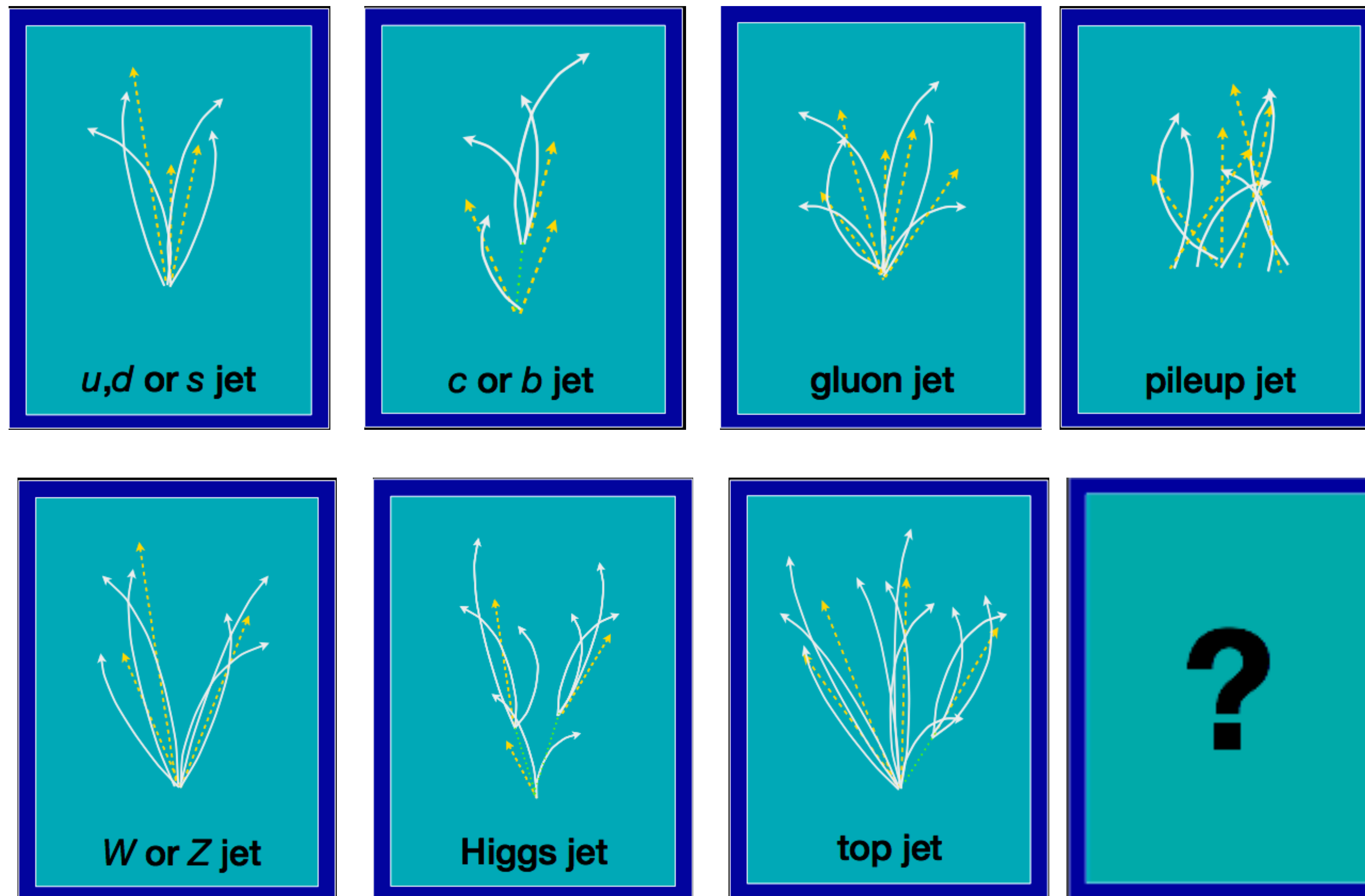


MORE ENERGY



MORE ENERGY

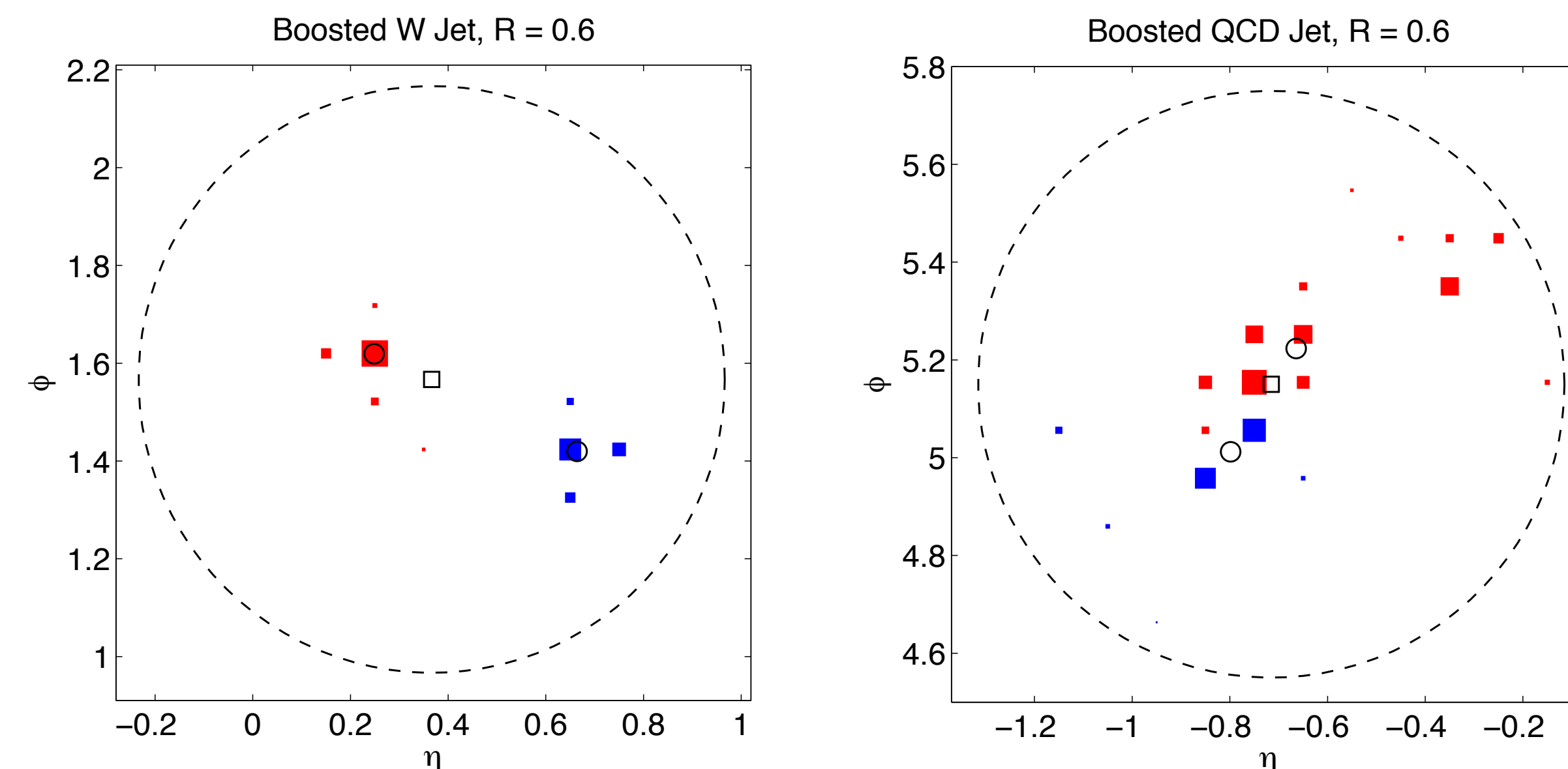
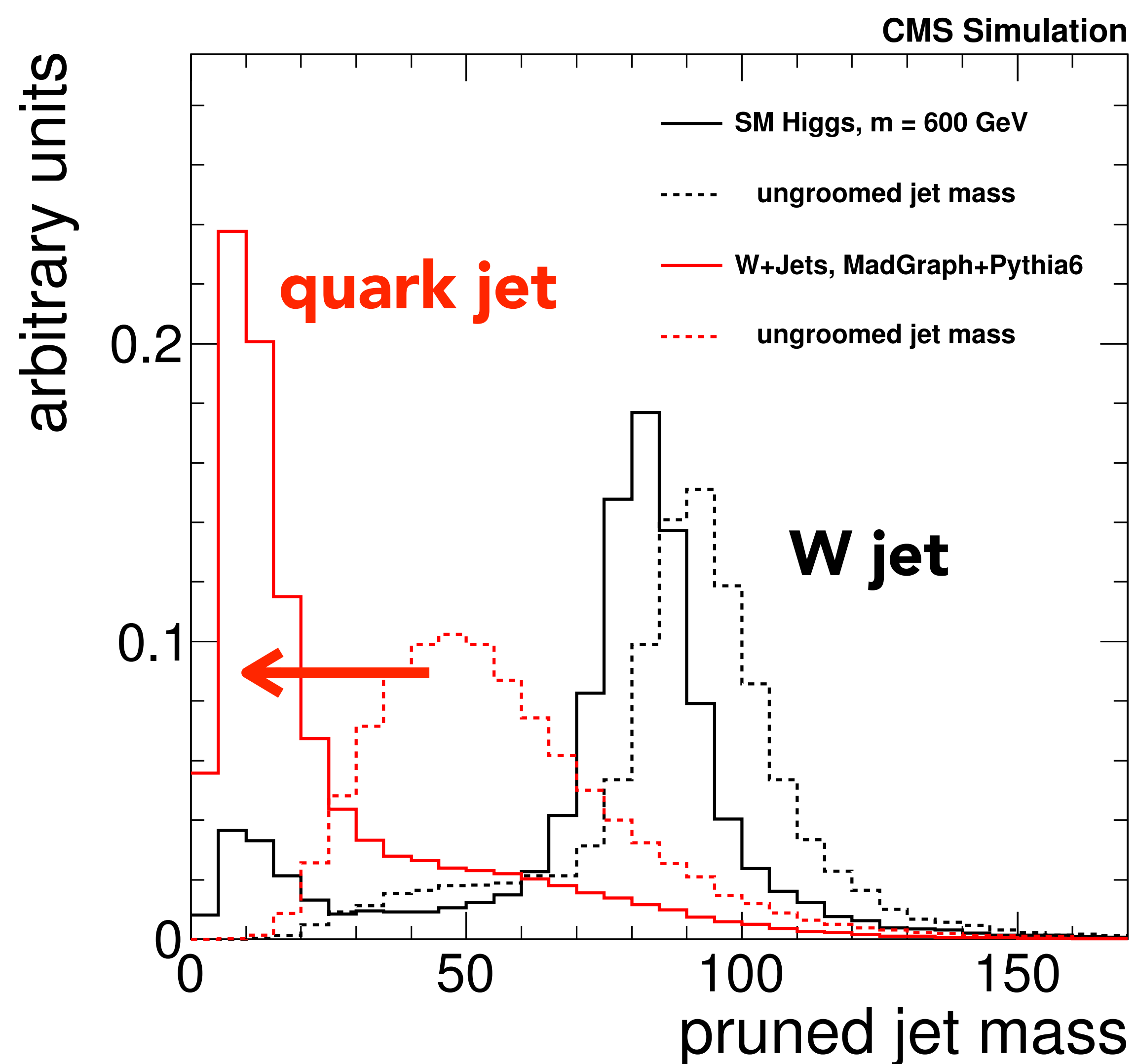




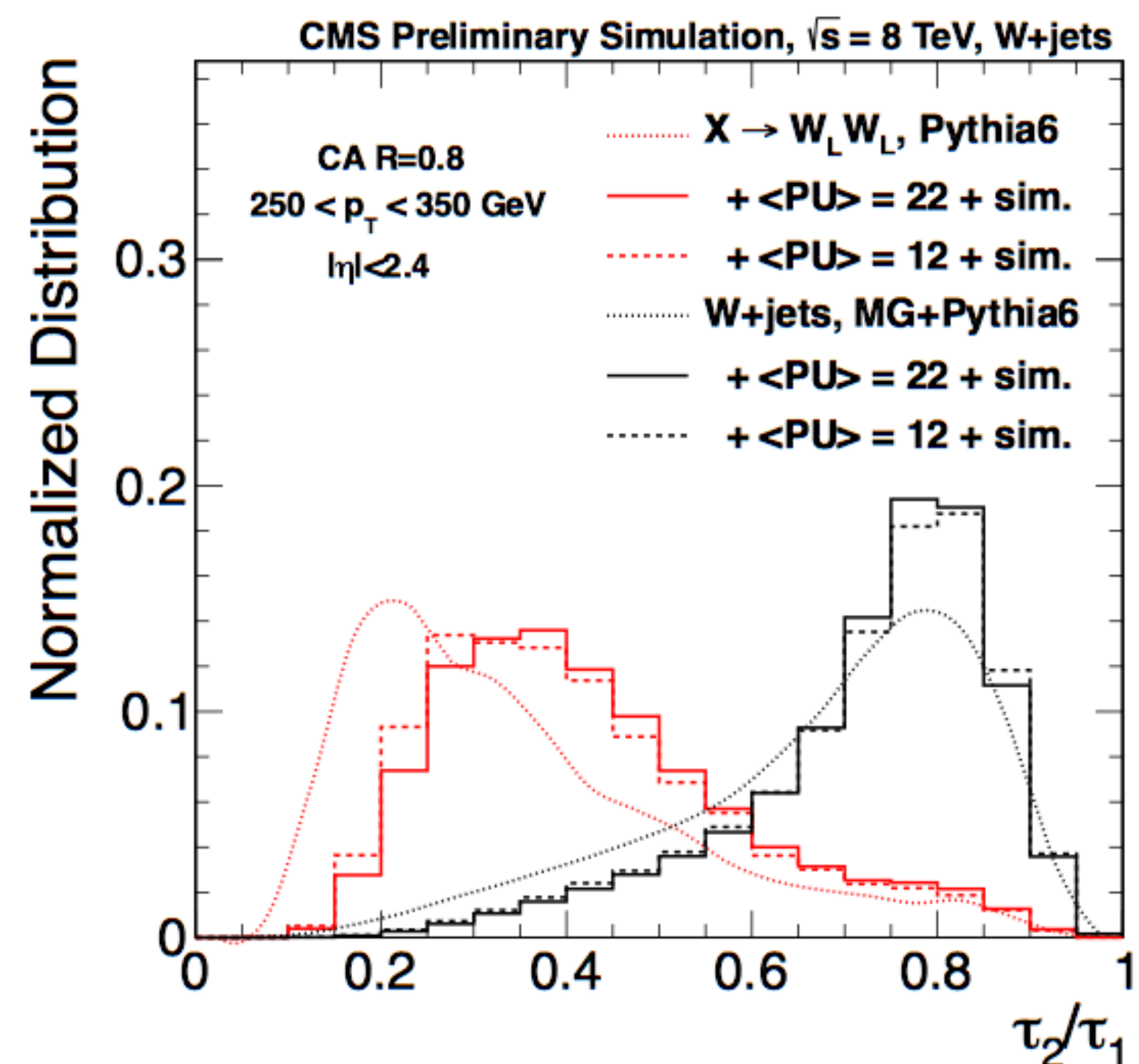
A RELATIVELY NEW SUBFIELD
(FIRST PHENO PAPERS ~2008)

VERY SUCCESSFULLY IMPLEMENTED IN CMS AND ATLAS, MANY PERFORMANCE
PAPERS, AND BROAD RANGE OF ANALYSES, O(50)
QCD MEASUREMENTS + SEARCHES (SUSY, EXOTICS,...)

jet (groomed) mass:
a very powerful discriminator



how prong-y are these jets?



example: N-subjettiness

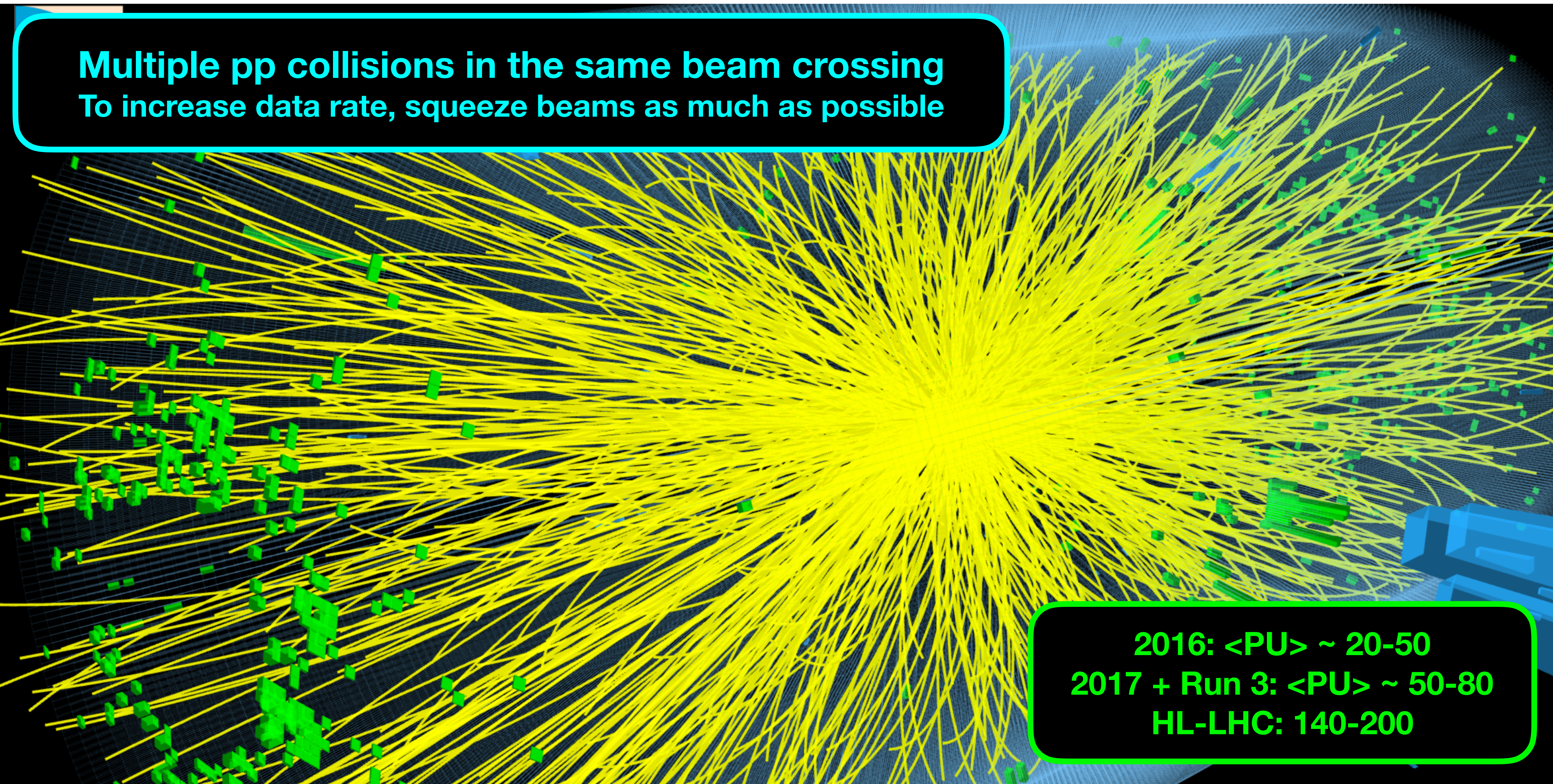
MORE LUMINOSITY = PILEUP

11

**PILEUP IS THE GREATEST EXPERIMENTAL CHALLENGE GOING FORWARD,
IT AFFECTS EVERYTHING.**

detector design, object performance and physics sensitivity
radiation damage to detectors, degrades energy/position measurements, lost untriggered events forever

Multiple pp collisions in the same beam crossing
To increase data rate, squeeze beams as much as possible



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**Jet substructure techniques rely on pulling apart the jet and
characterizing QCD radiation.**

Mitigating pileup uses the same ideas over the entire event!

**2016: $\langle \text{PU} \rangle \sim 20\text{-}50$
2017 + Run 3: $\langle \text{PU} \rangle \sim 50\text{-}80$
HL-LHC: 140-200**

asymptotic behavior

vertexing information

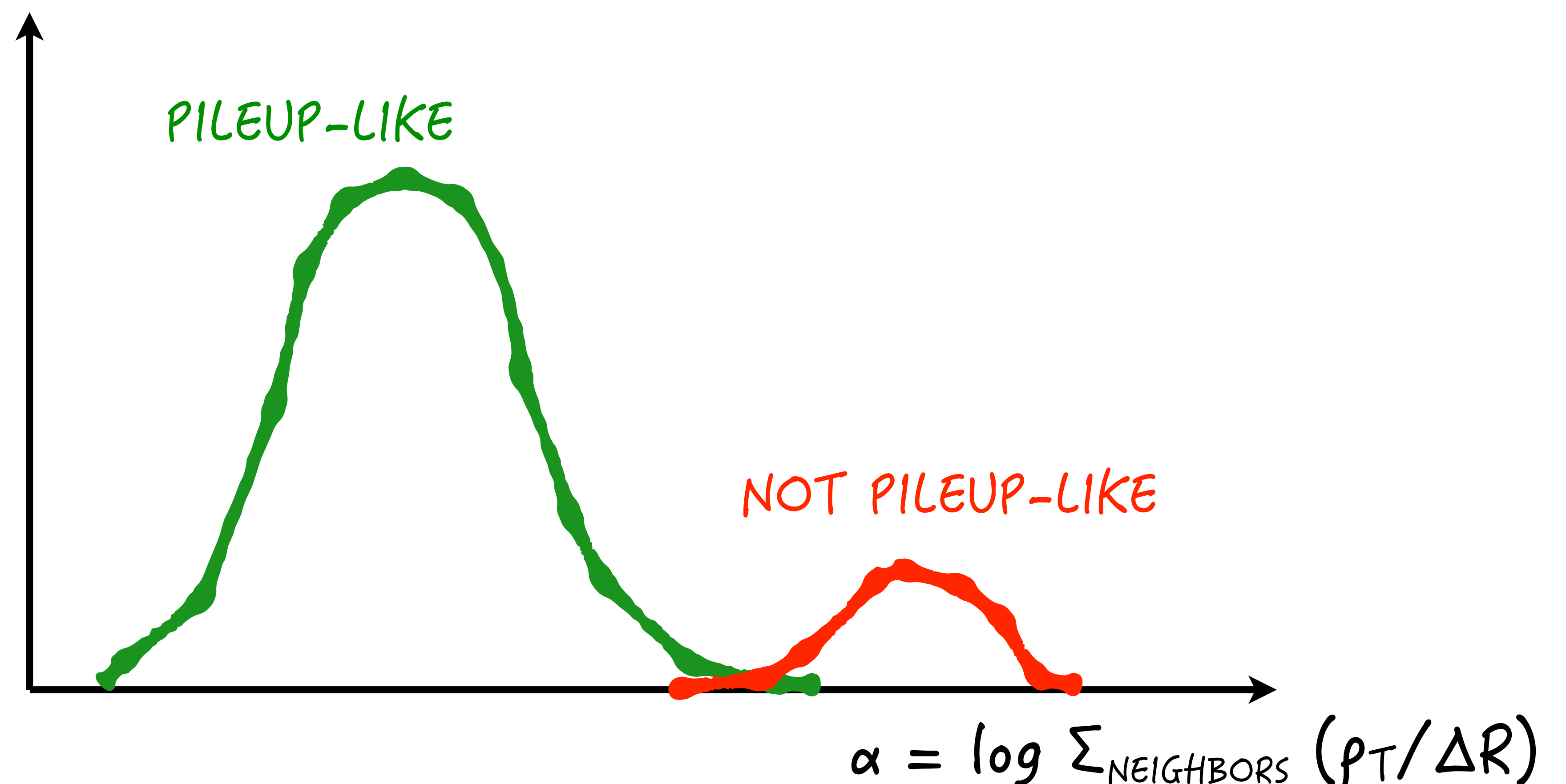
collinear QCD radiation

precision timing

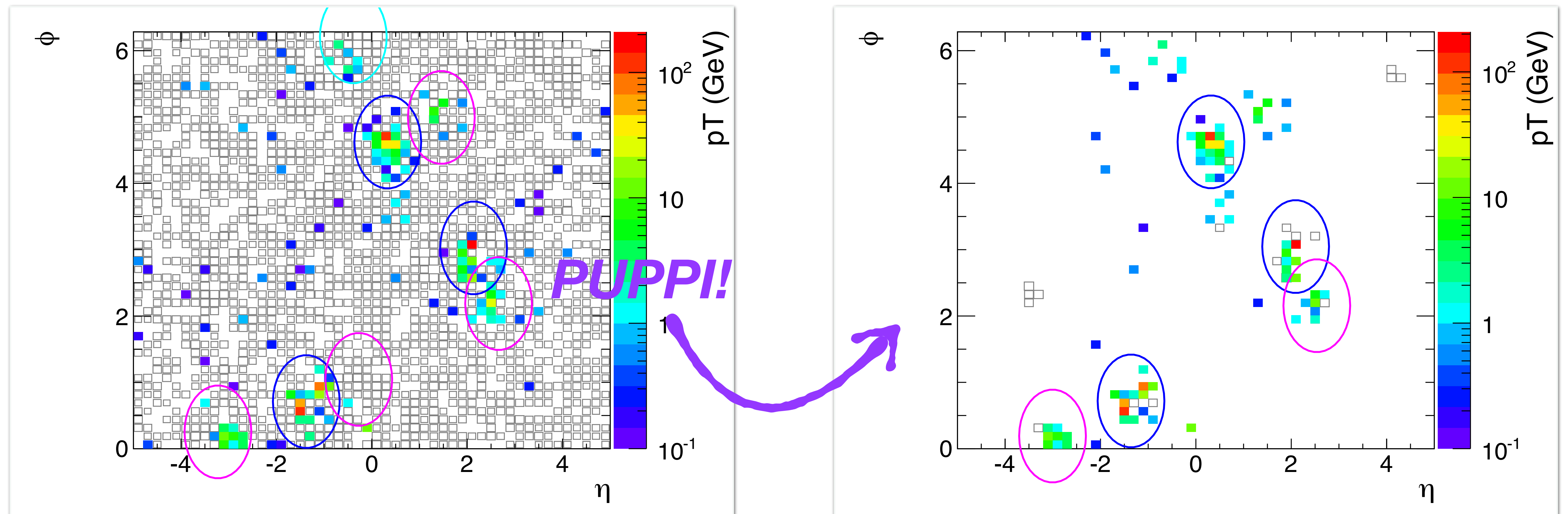


A general **framework**, that assigns on a **per particle** basis a weight for **how likely** a particle is to be from pileup

key insight: using the QCD ansatz (e.g. radiation profile) to infer neutral particles as pileup



PUPPI DEMONSTRATES LARGE GAINS, EVEN FOR CURRENT 2016 DATASET



Puppi integrated into current and future CMS plans

Many spring conference analyses with PUPPI

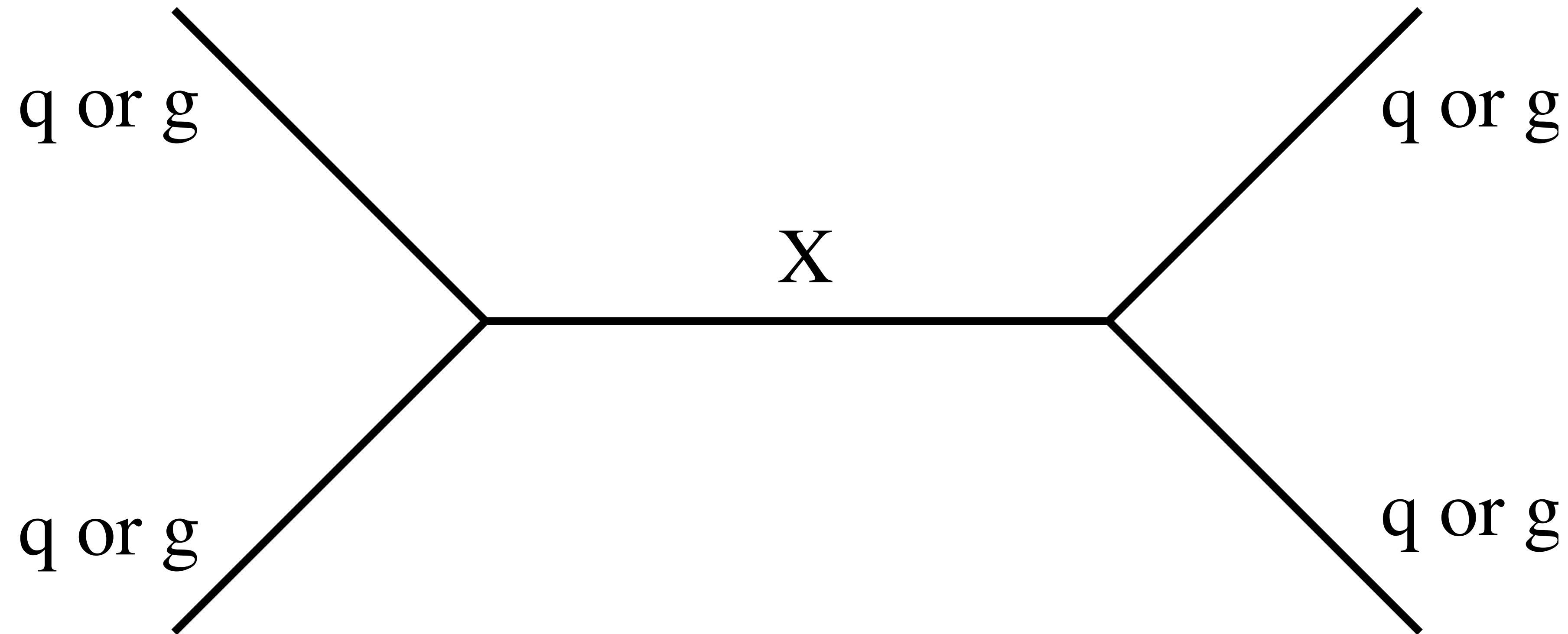
Part of 2017 full commissioning pipeline

HL-LHC design studies using PUPPI for performance studies

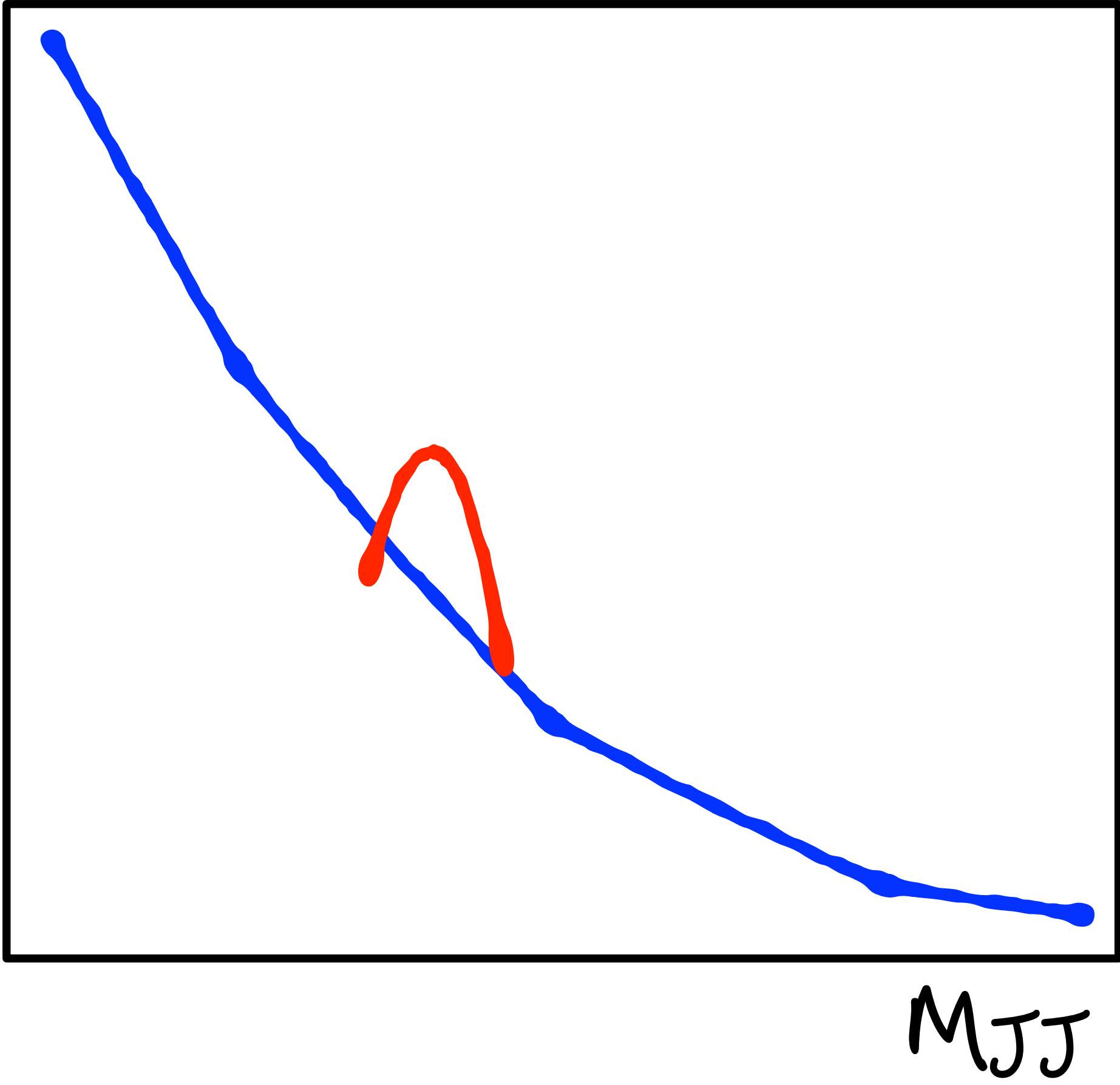
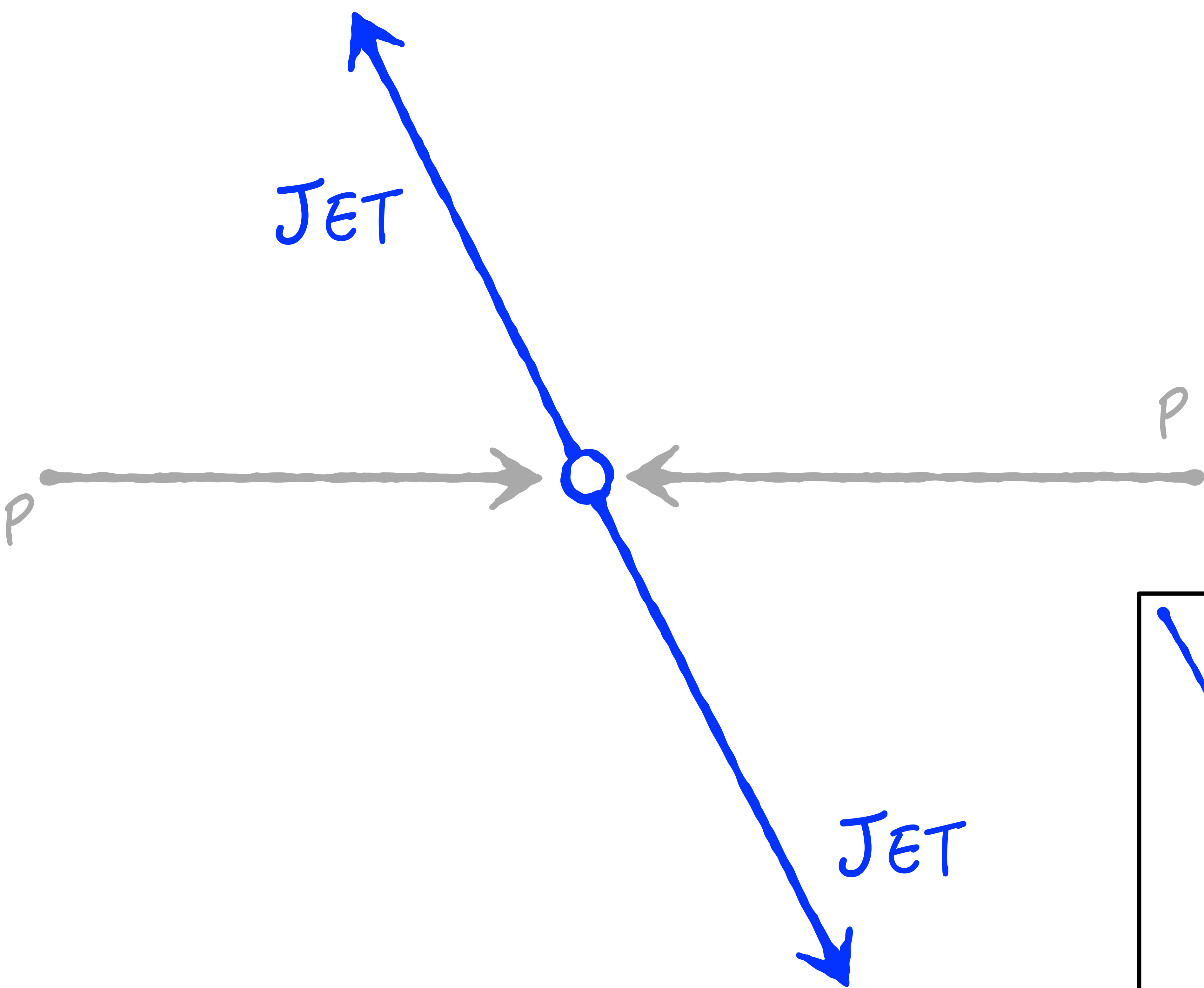
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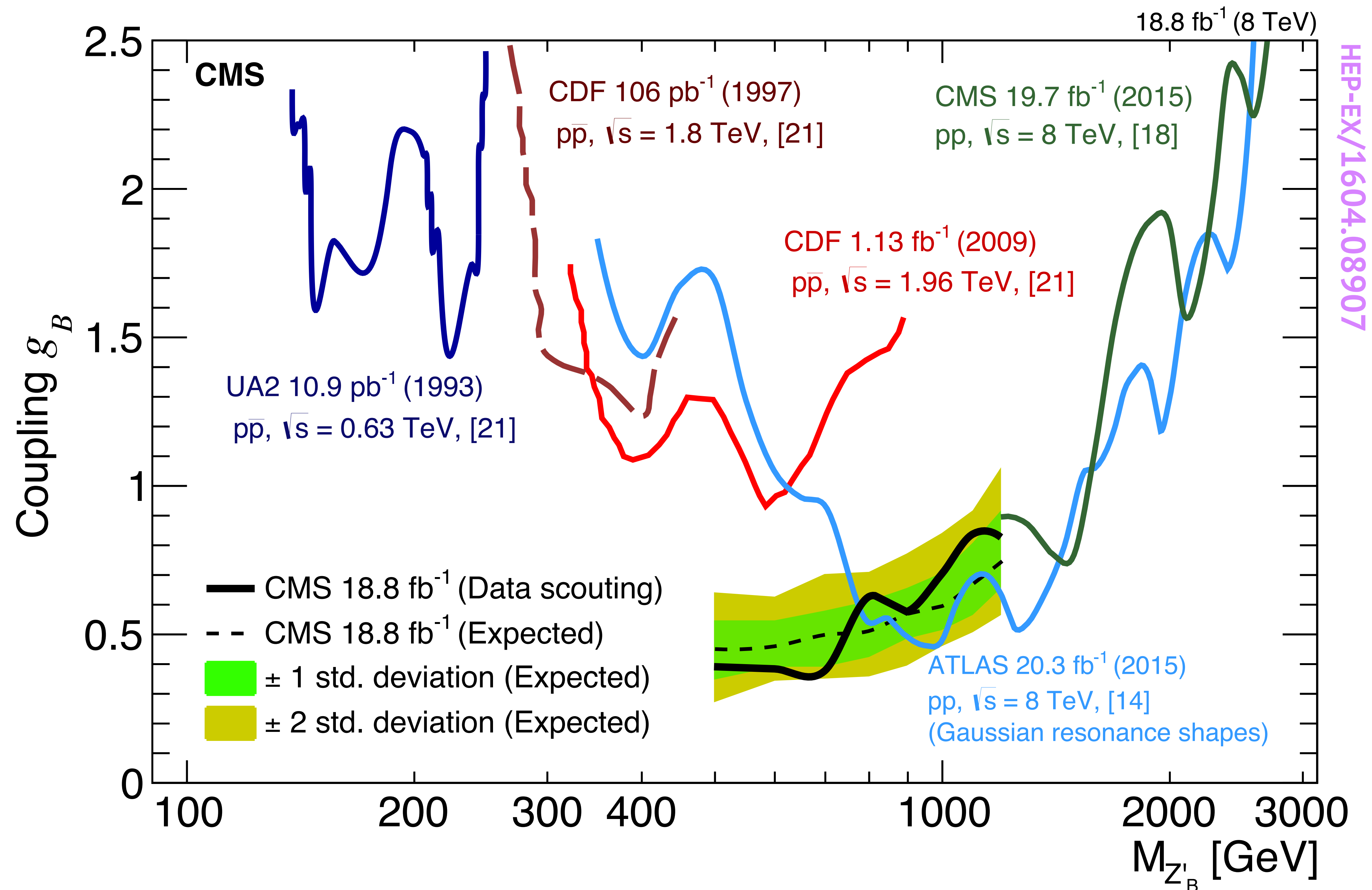
the DM connection,
coming full circle



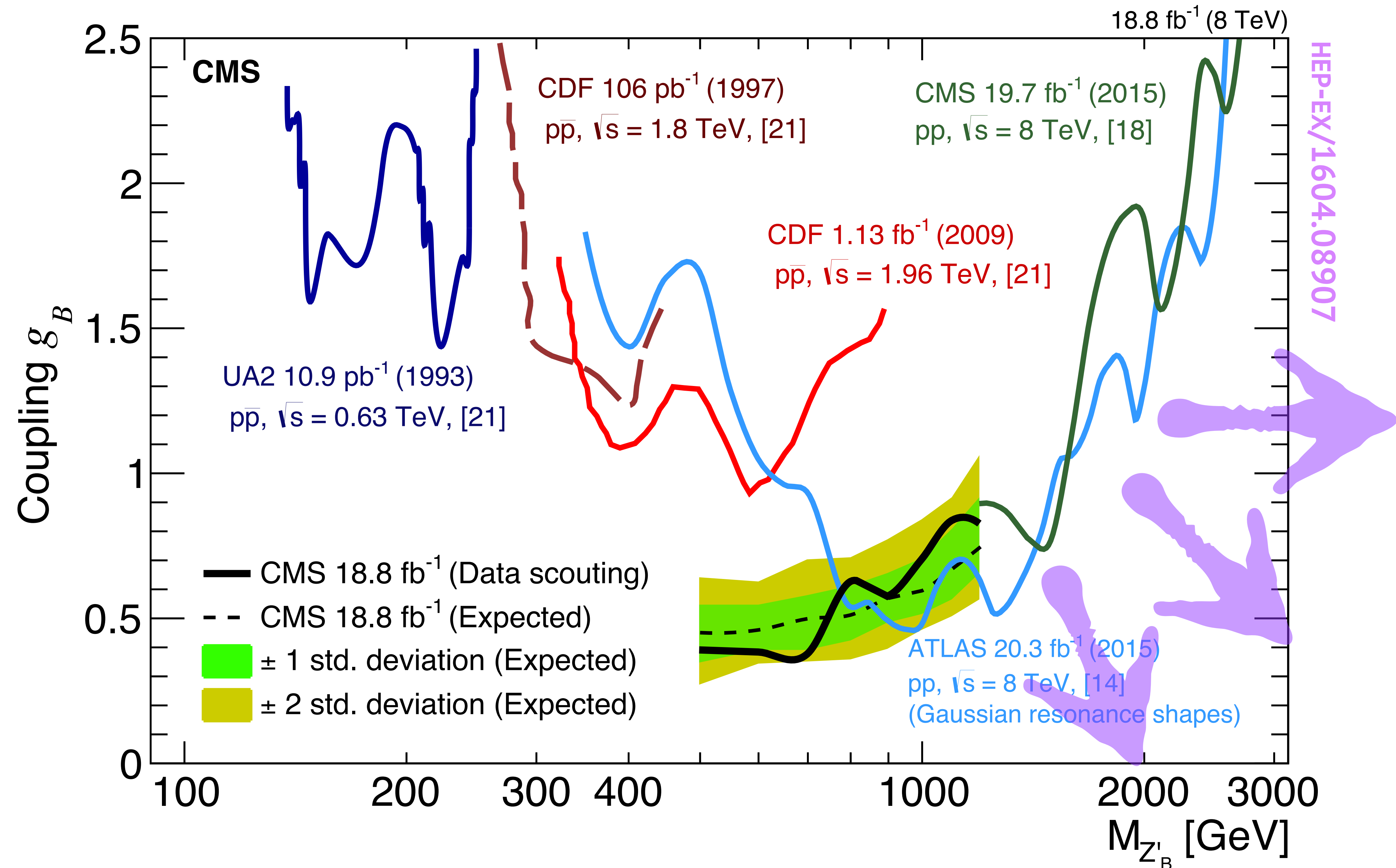
ACCESSES A **RICH AND BROAD RANGE** OF NEW PHYSICS MODELS...
Extra dimensional models, composite Higgs, extended Higgs sectors.



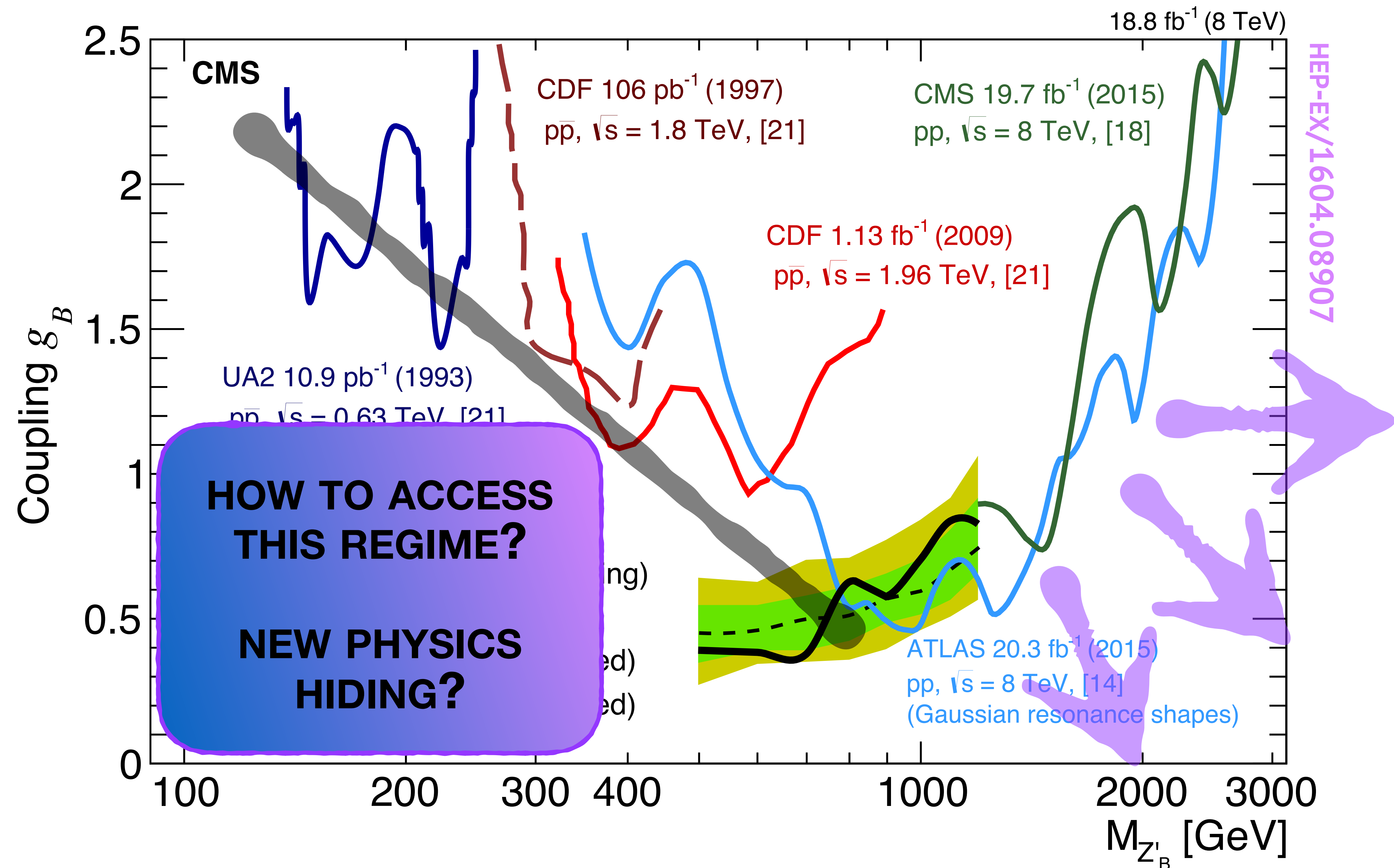
A CLASSIC PROGRAM AT HADRON COLLIDERS

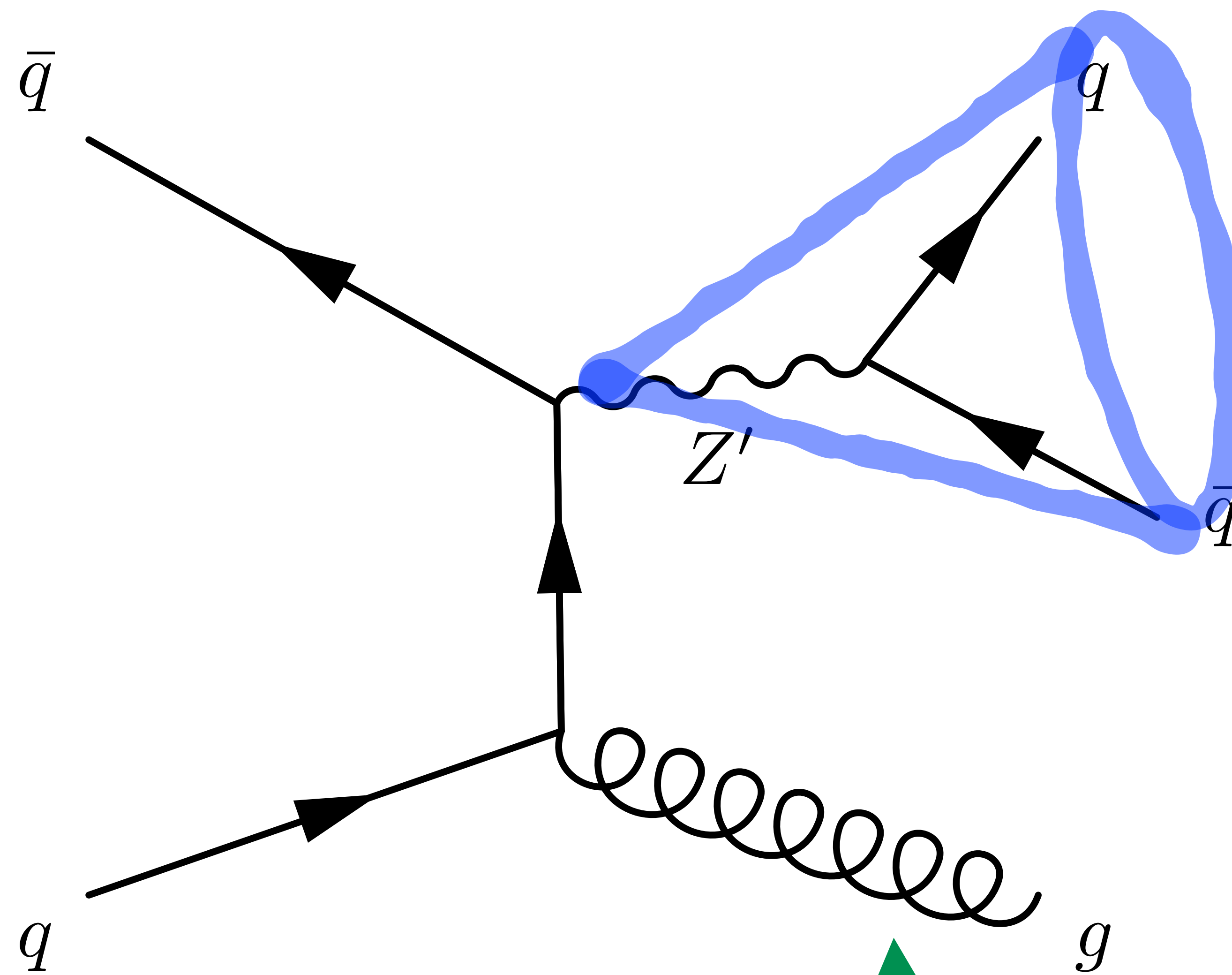


A CLASSIC PROGRAM AT HADRON COLLIDERS



A CLASSIC PROGRAM AT HADRON COLLIDERS





**single jet
substructure signal**

use a very hard ISR jet to get
you above trigger thresholds!



KINEMATIC SELECTIONS:

PUPPI JET

HIGH ENERGY ($P_T > 500$ GeV)

TRIGGER:

HIGH ENERGY EVENT
($\Sigma P_T > 800$)

BKG: QCD

SM CANDLES: W/Z + JETS

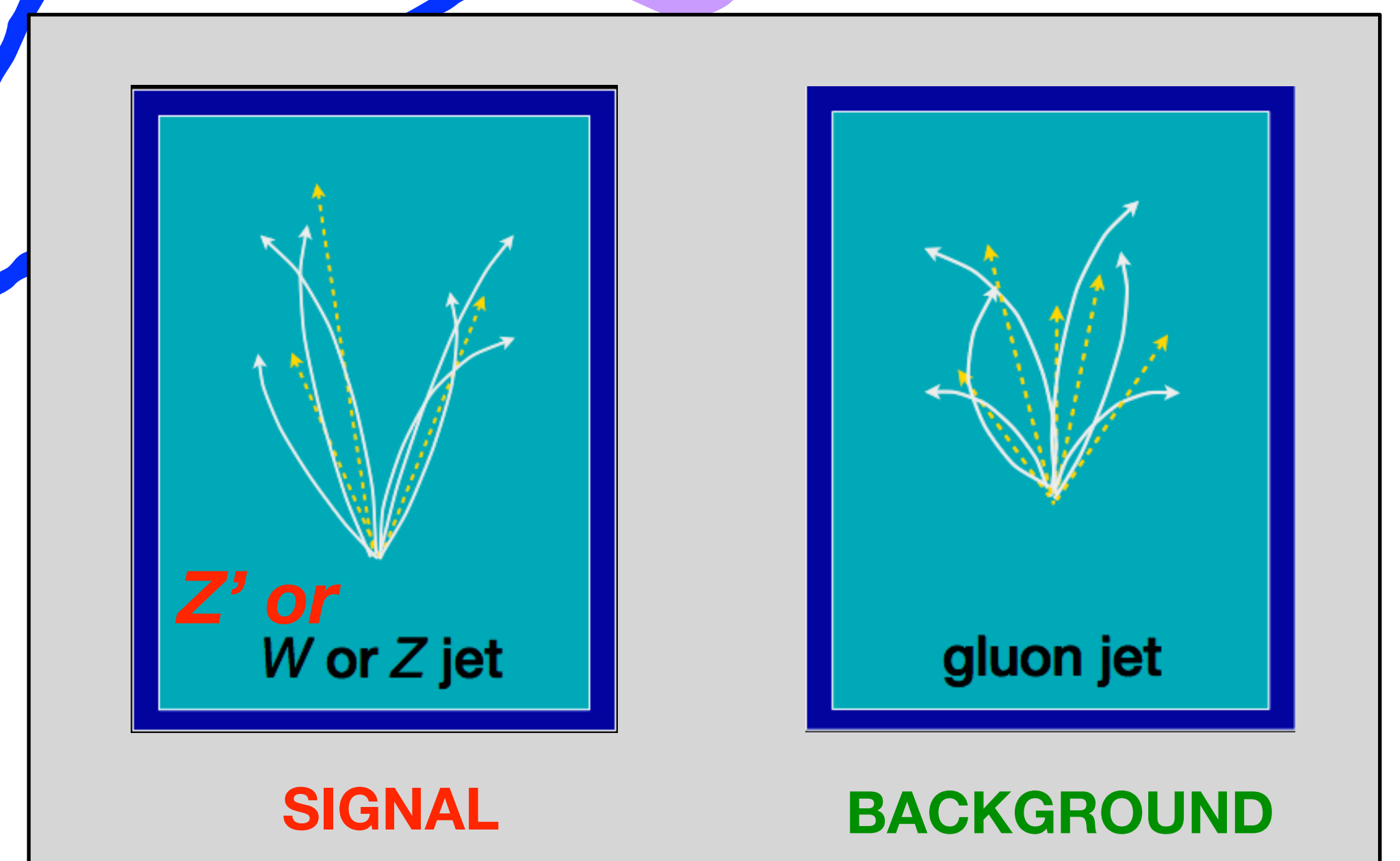
q/g



Z'

q

q



SUBSTRUCTURE SELECTIONS:

JET MASS

“2-PRONG SELECTION”: T_{21}^{DDT}

[PUPPI'ED INPUTS]



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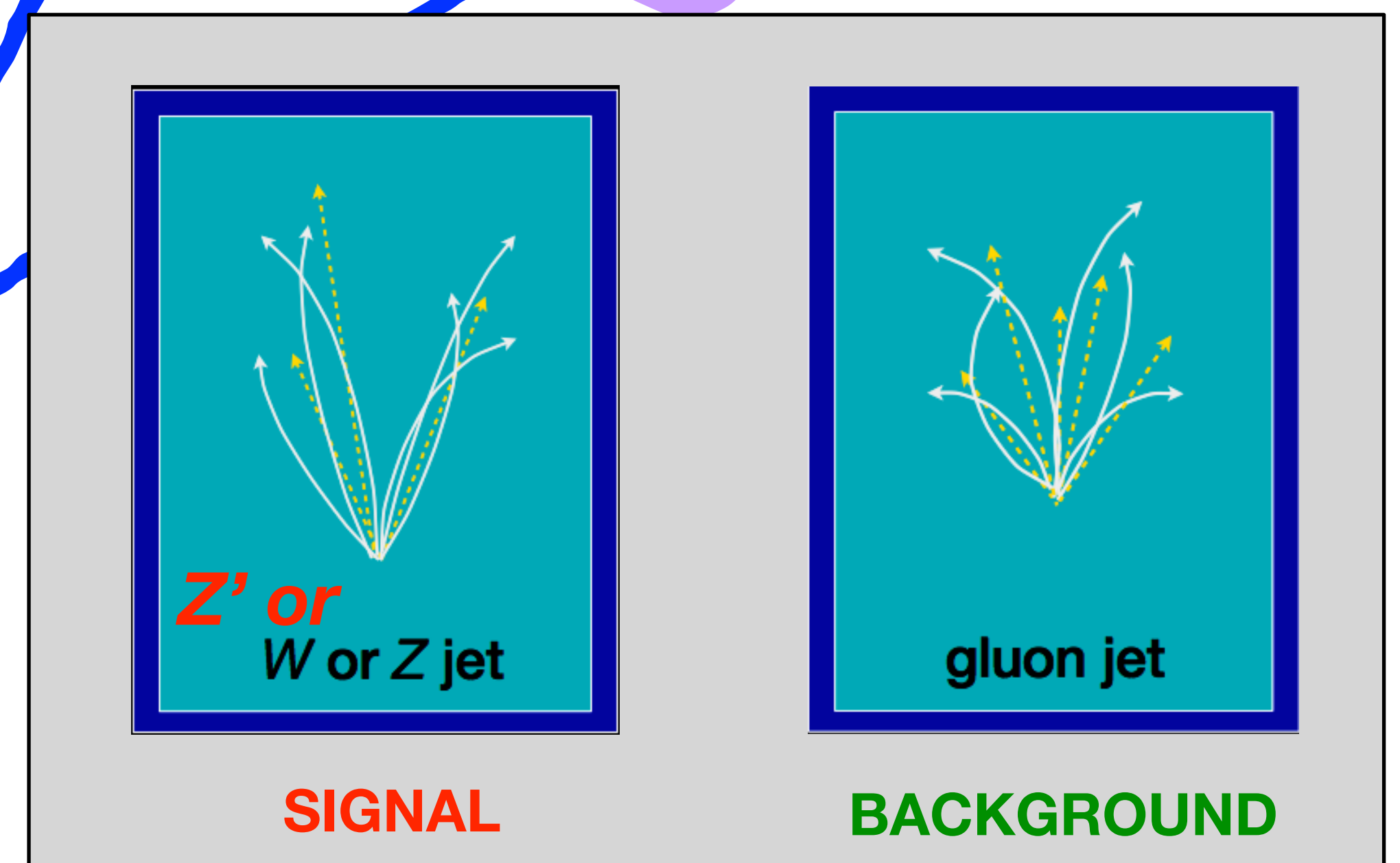
q/g

REQUIRES SOME NEXT LEVEL
JET SUBSTRUCTURE METHODS

Z'

q

q



SUBSTRUCTURE SELECTIONS:

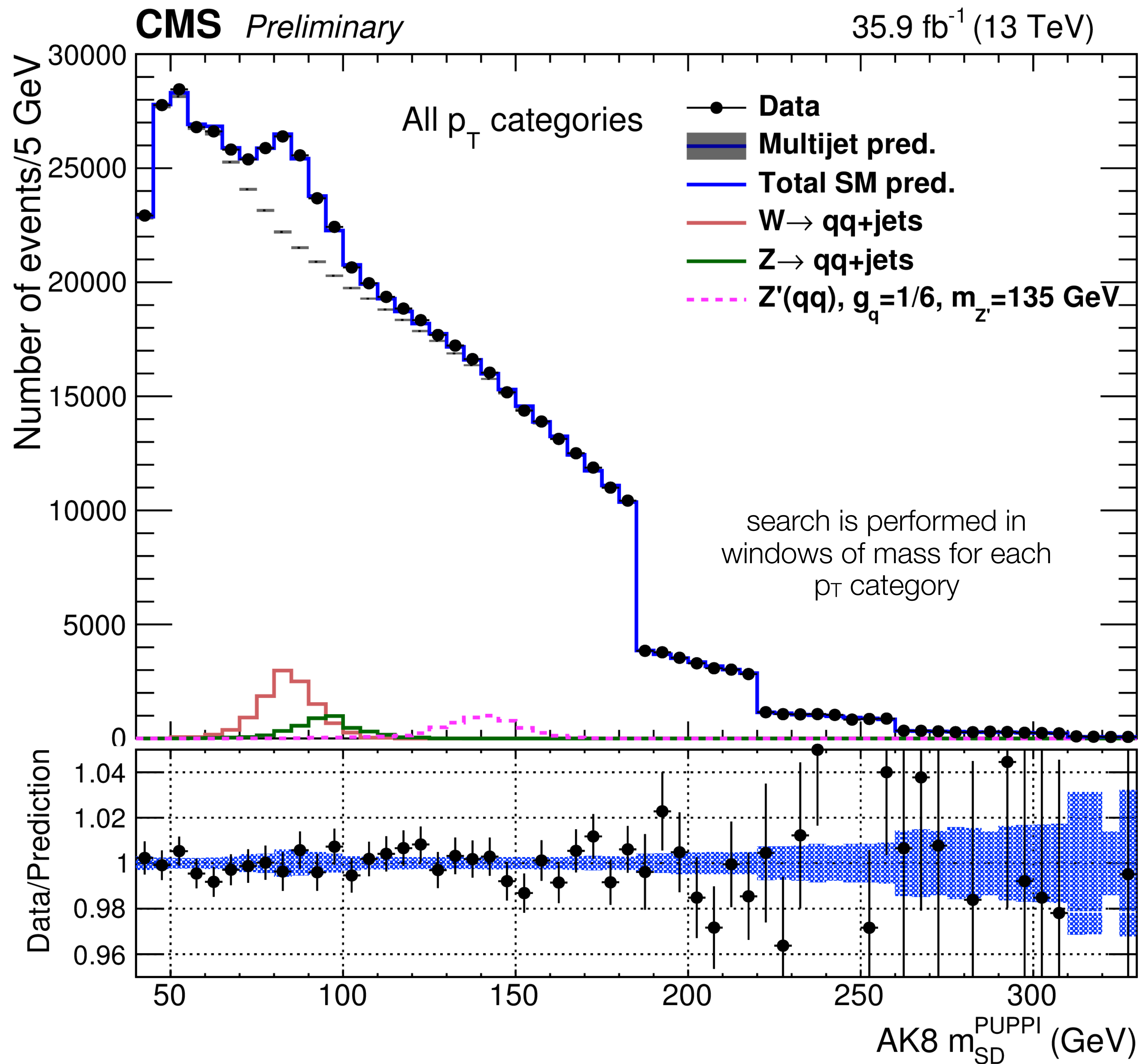
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LIGHT DIJET RESONANCES



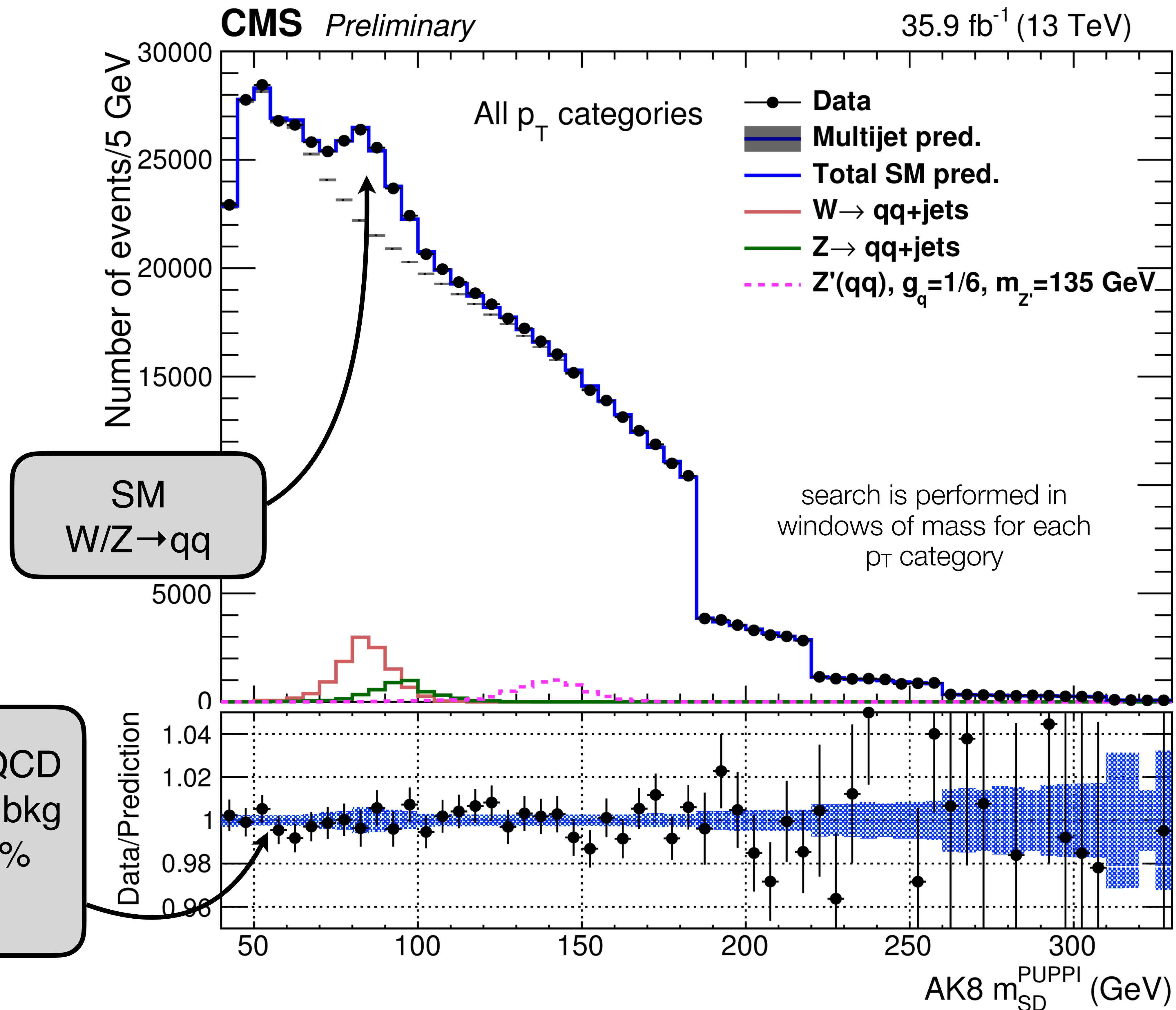
SEE CRISTINA SUAREZ'S NP TALK! 20

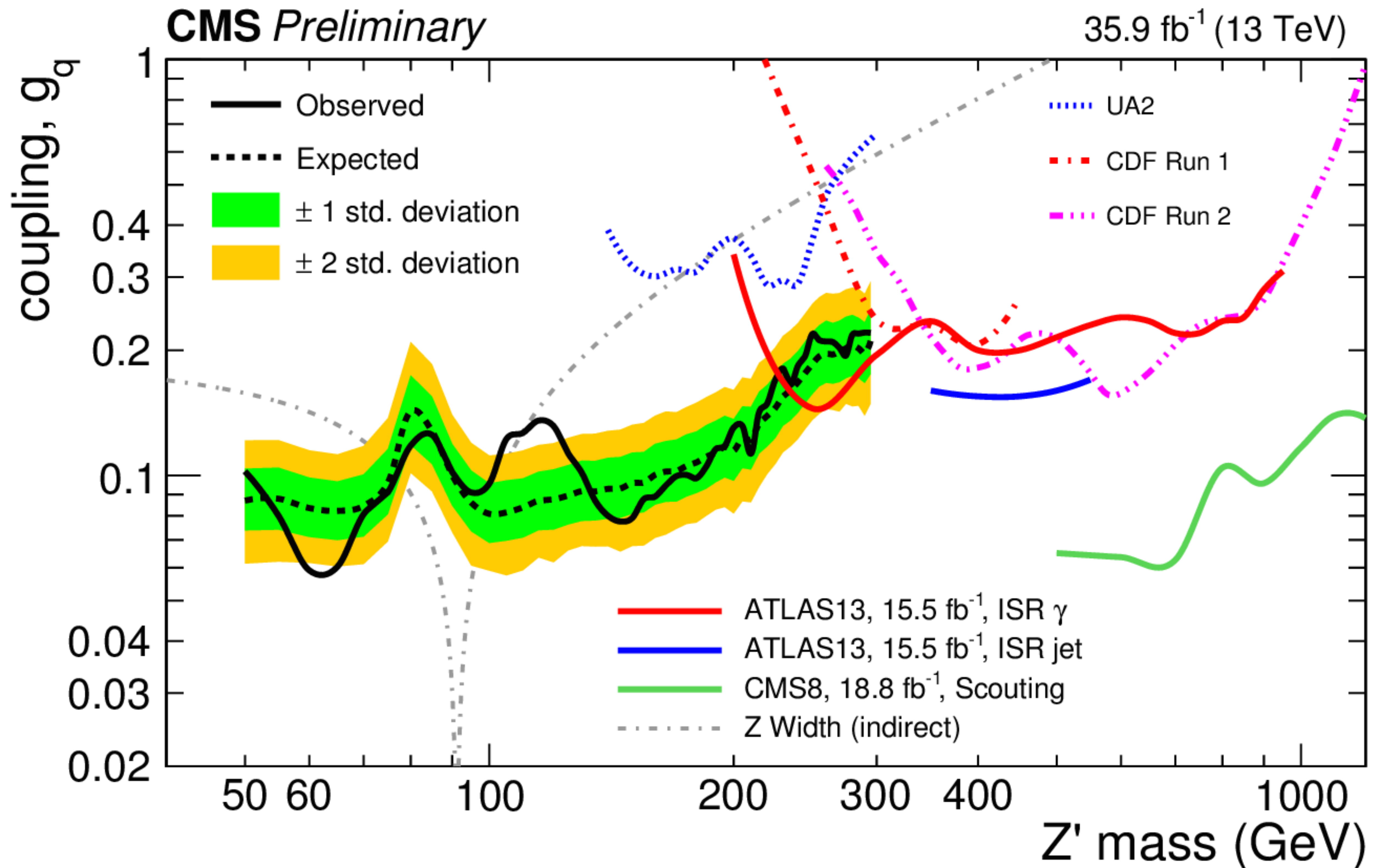


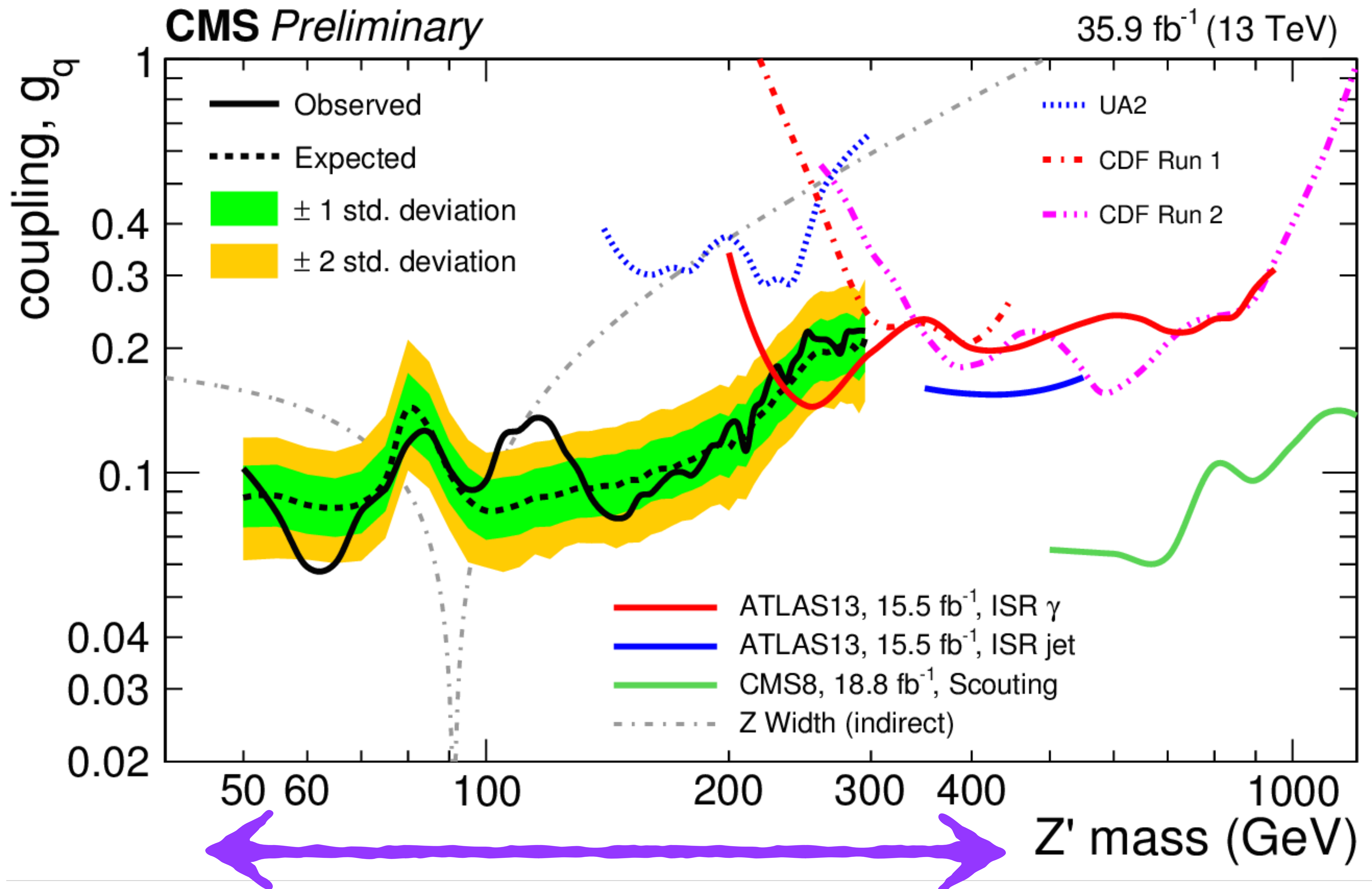
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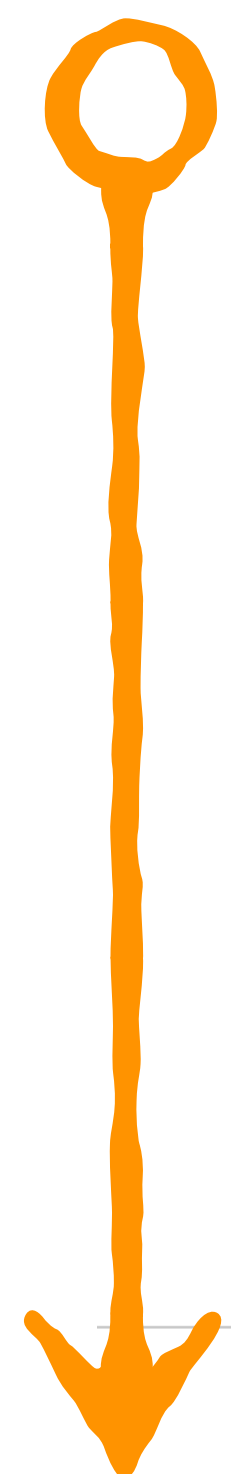
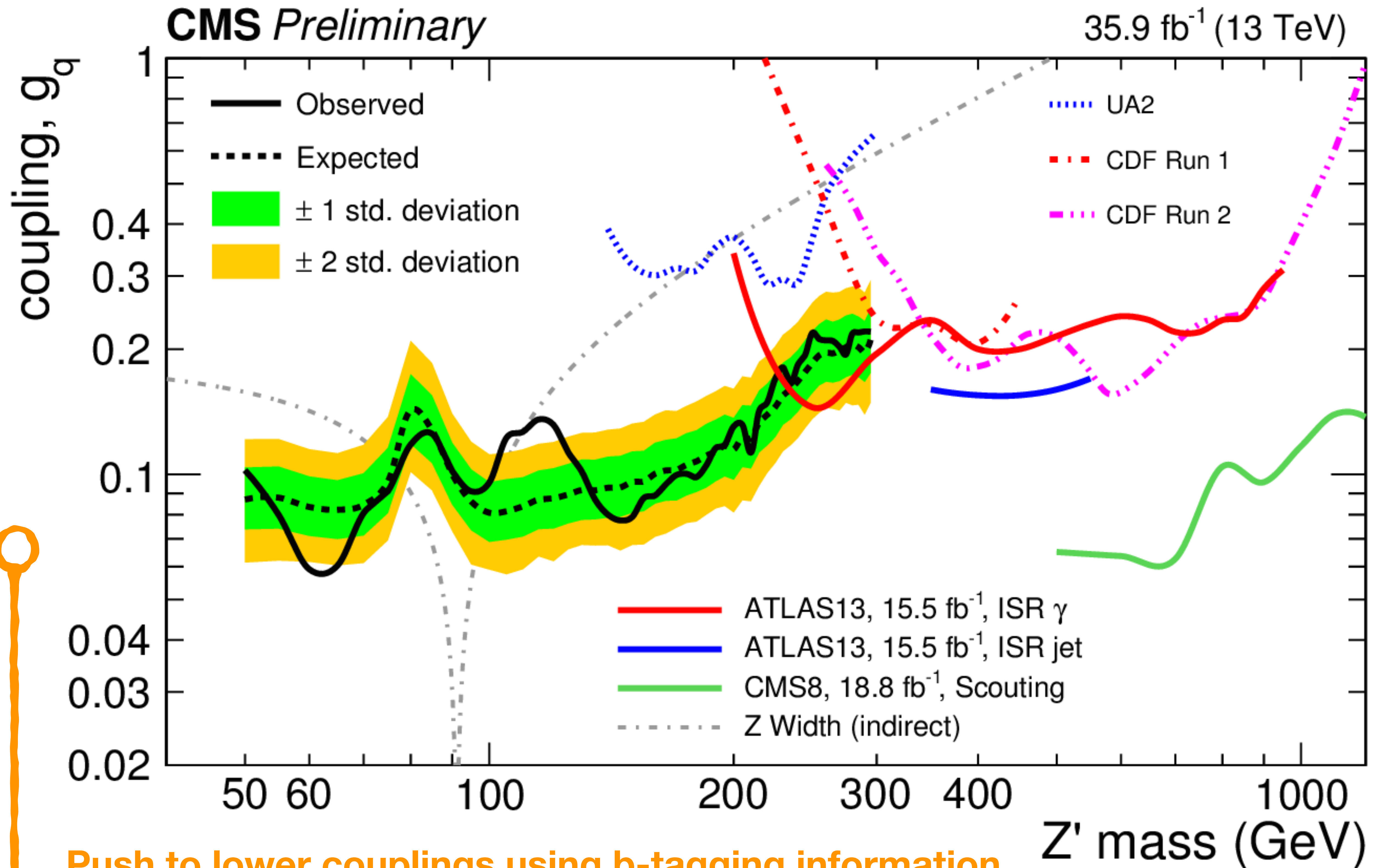
SEE CRISTINA SUAREZ'S NP TALK! 20







Covers comparable dynamic range to traditional dijet searches!



Push to lower couplings using b-tagging information...
where relevant? how about at 125 GeV? 😊

$GG \rightarrow H \rightarrow BB$ 

MAD PROPS: JAVIER DUARTE, CATERINA VERNIERI
SEE CATERINA'S W&C ON JUNE 30 FOR MORE! 22

HIG-17-010

Back story:

Gluon fusion Higgs to bb has long been considered **impossible** at the LHC

Overwhelming QCD backgrounds, hard to trigger on

...but let's use our new tools!

$$GG \rightarrow H \rightarrow BB$$

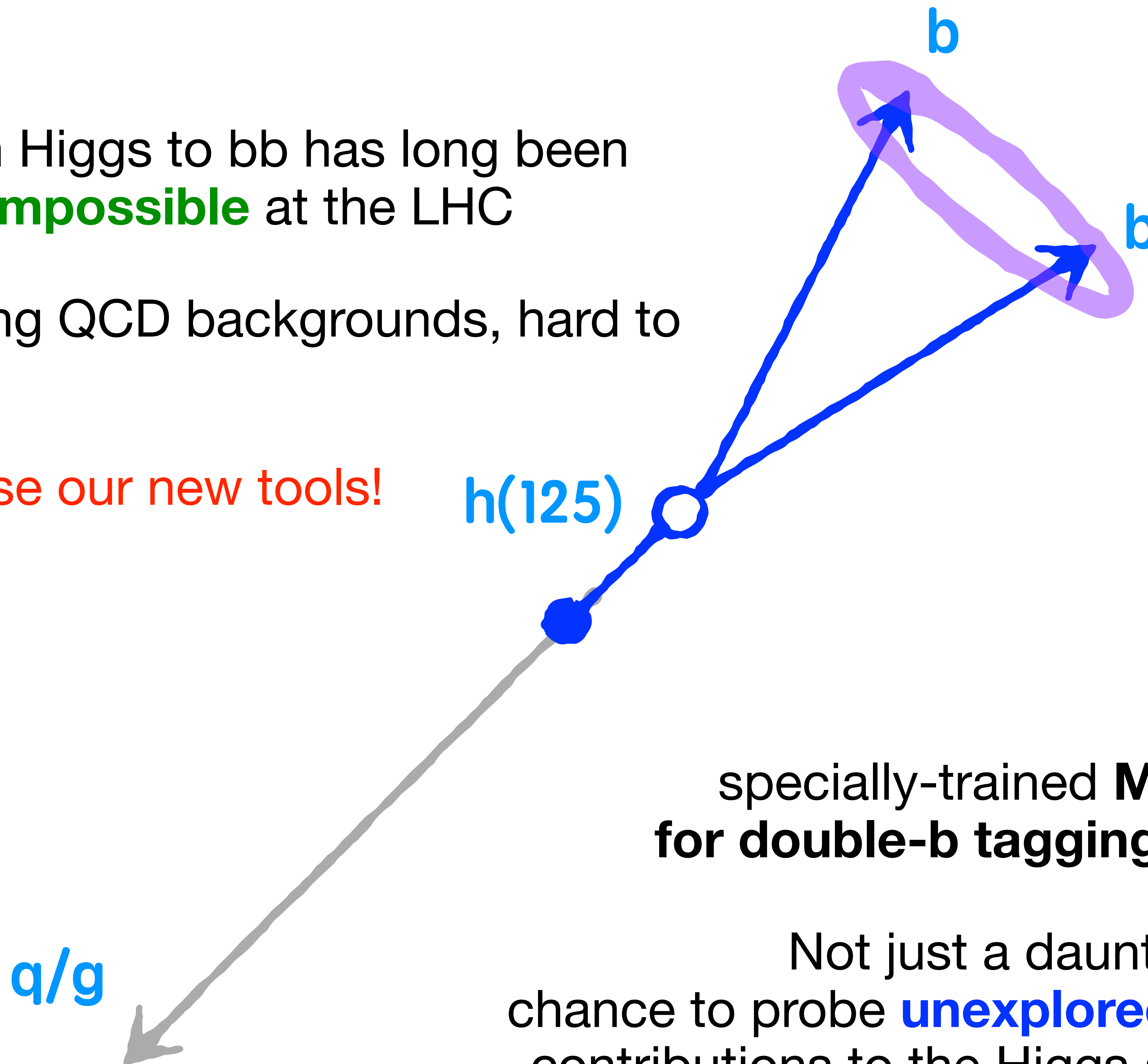


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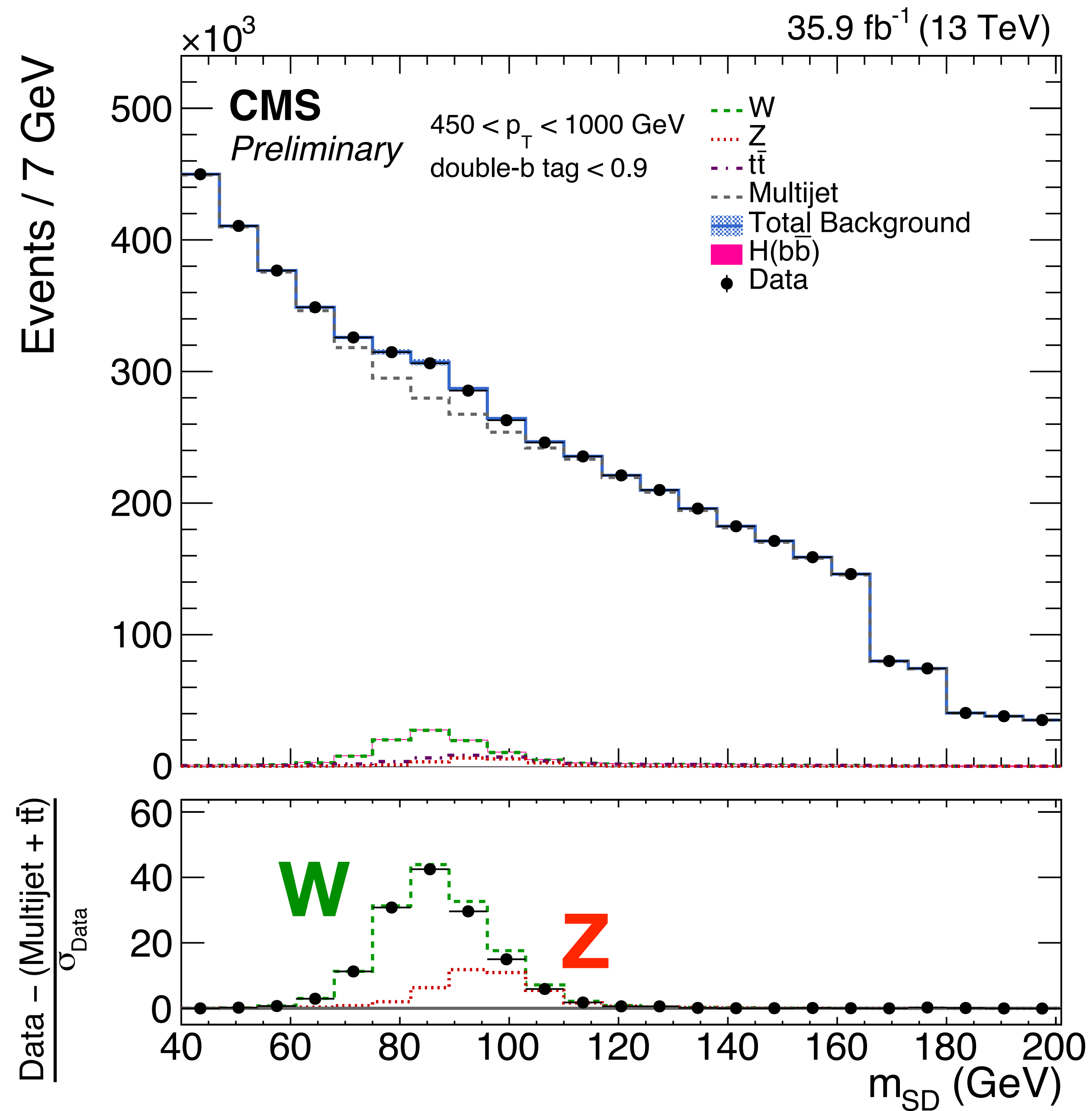
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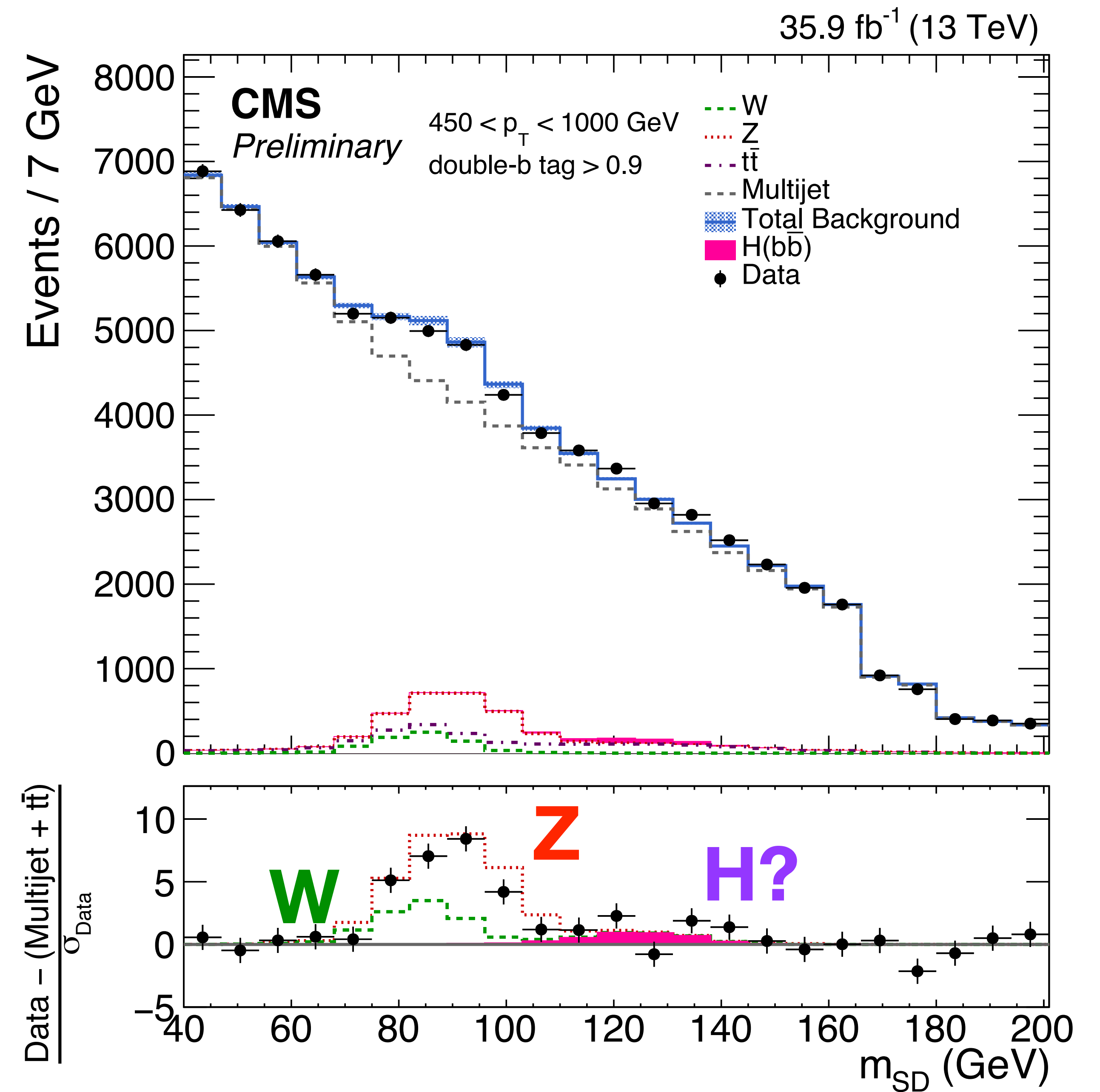
specially-trained **ML techniques**
for double-b tagging in a single jet

Not just a daunting challenge,
chance to probe **unexplored** new physics
contributions to the Higgs at very high p_T

anti-double-b tagged

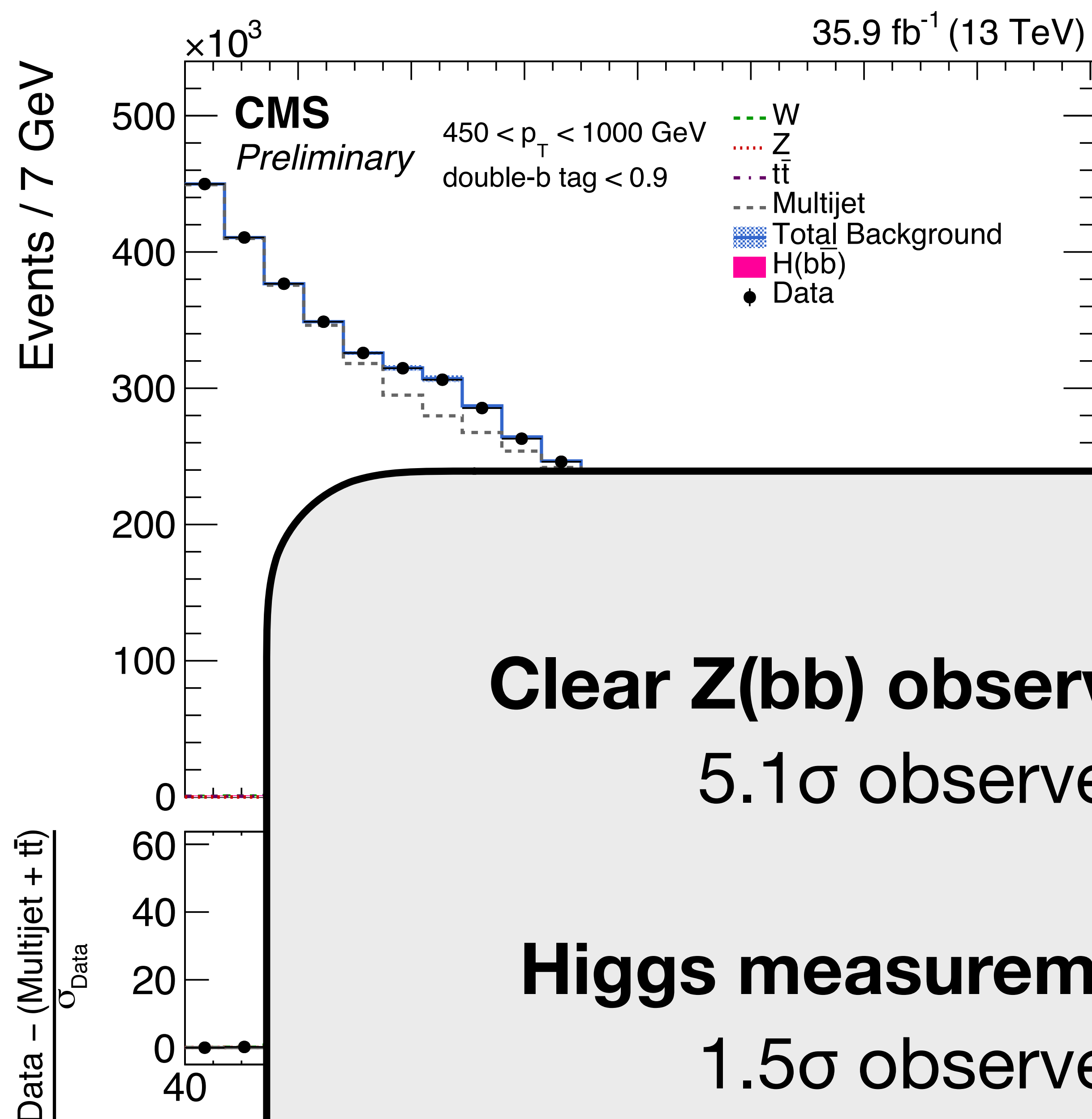


double-b tagged

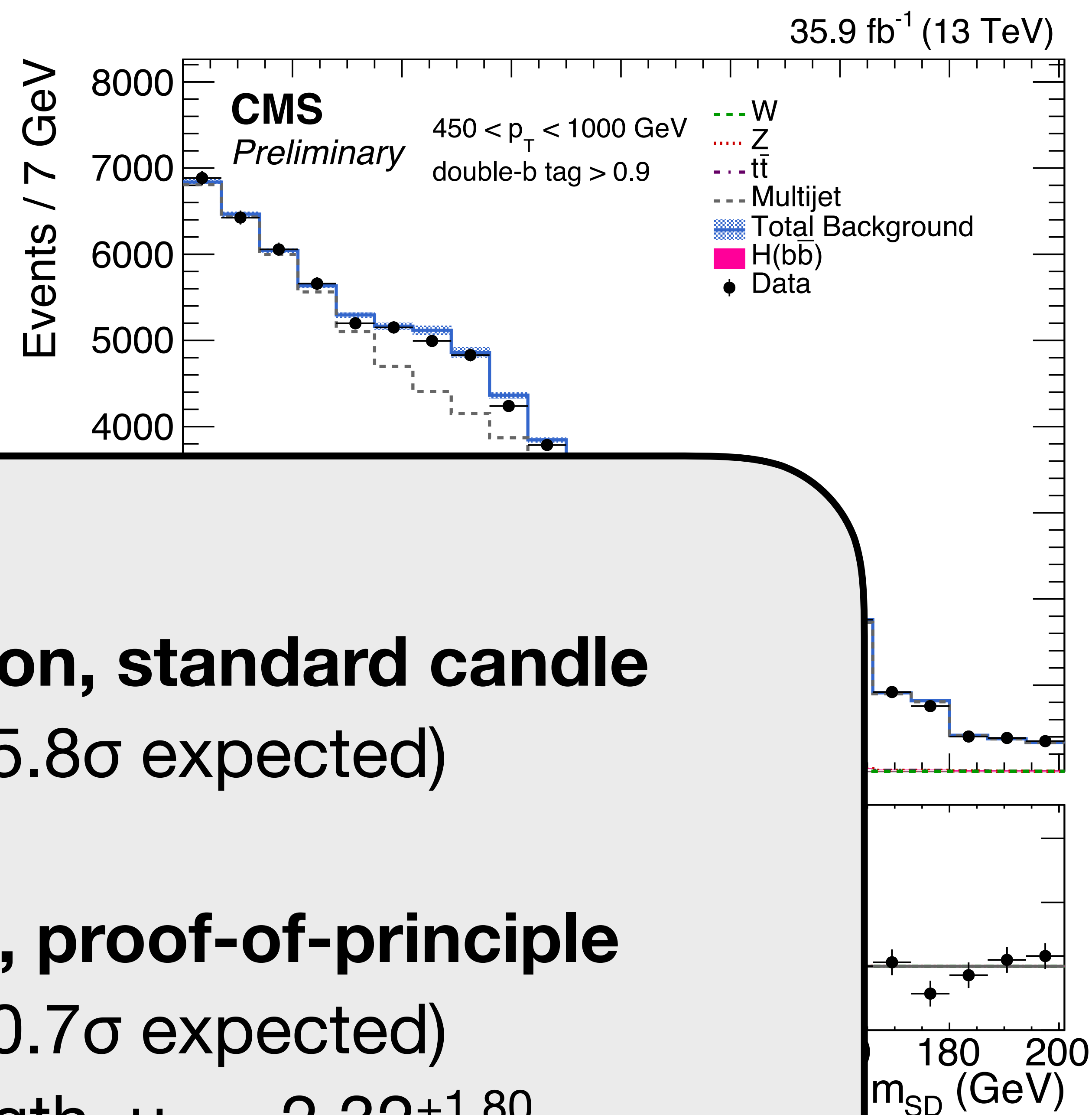




anti-double-b tagged



double-b tagged



Clear Z(bb) observation, standard candle
5.1σ observed (5.8σ expected)

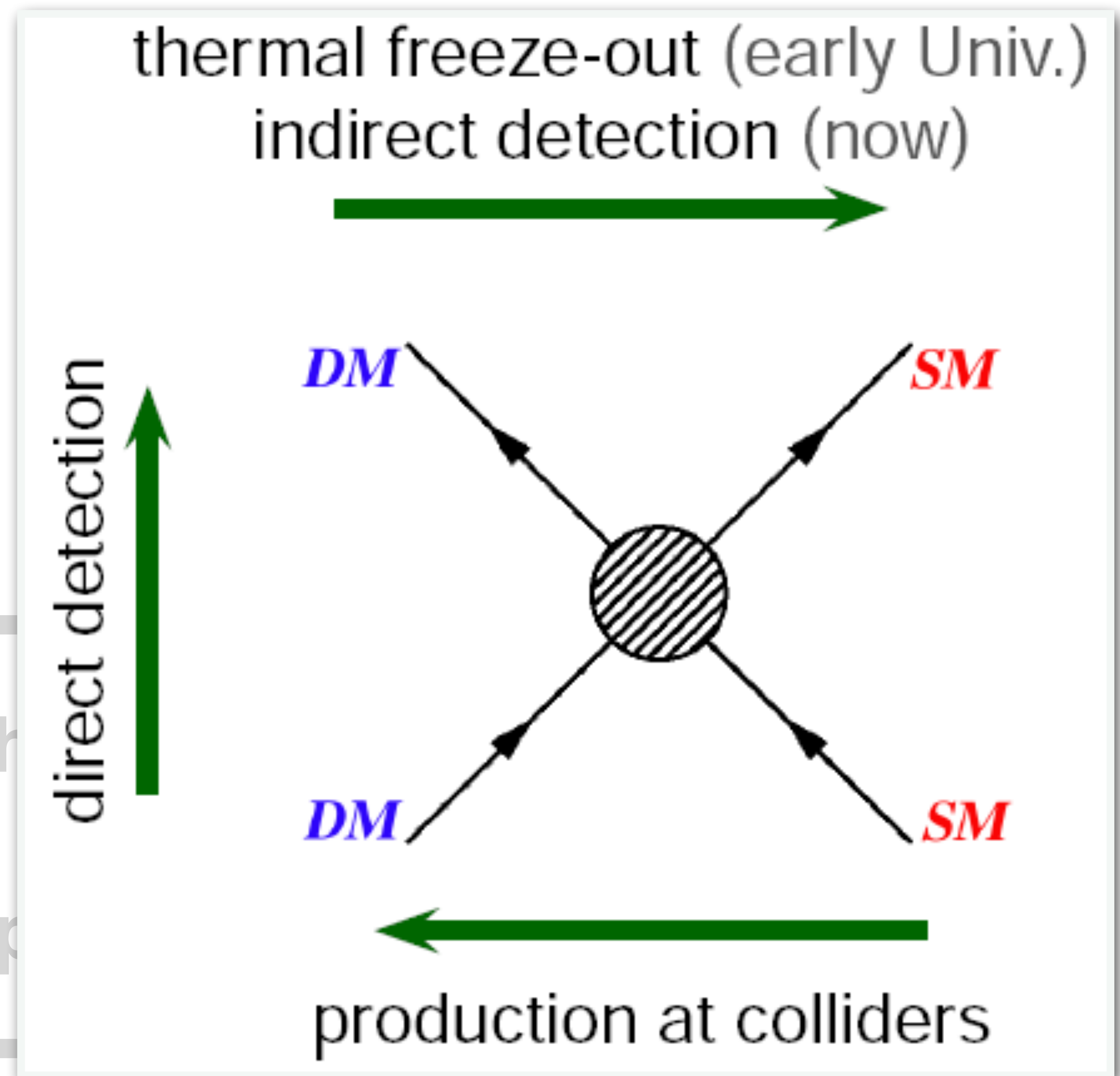
Higgs measurement, proof-of-principle
1.5σ observed (0.7σ expected)

SM Higgs signal strength, $\mu_H = 2.32^{+1.80}_{-1.57}$

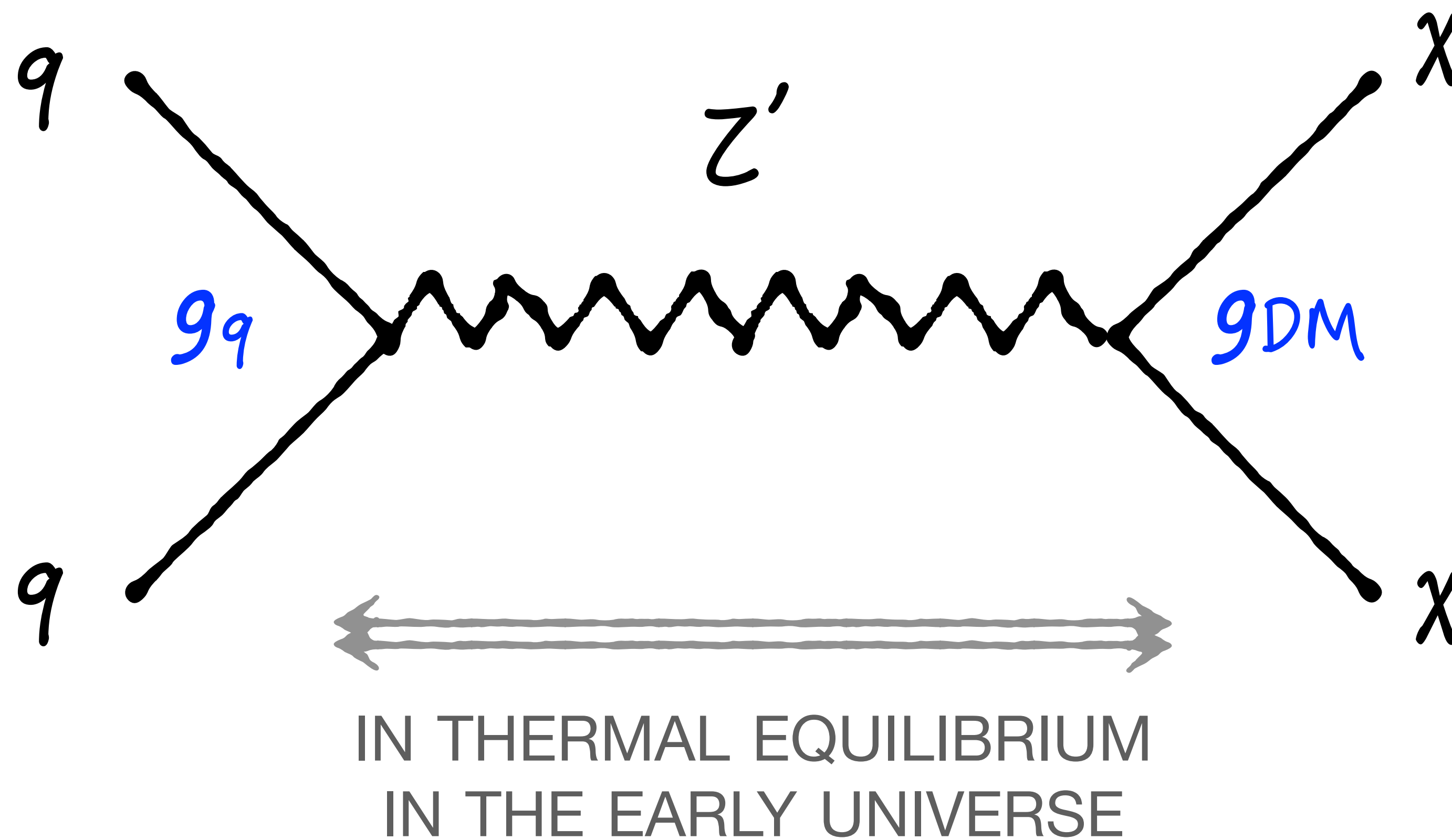
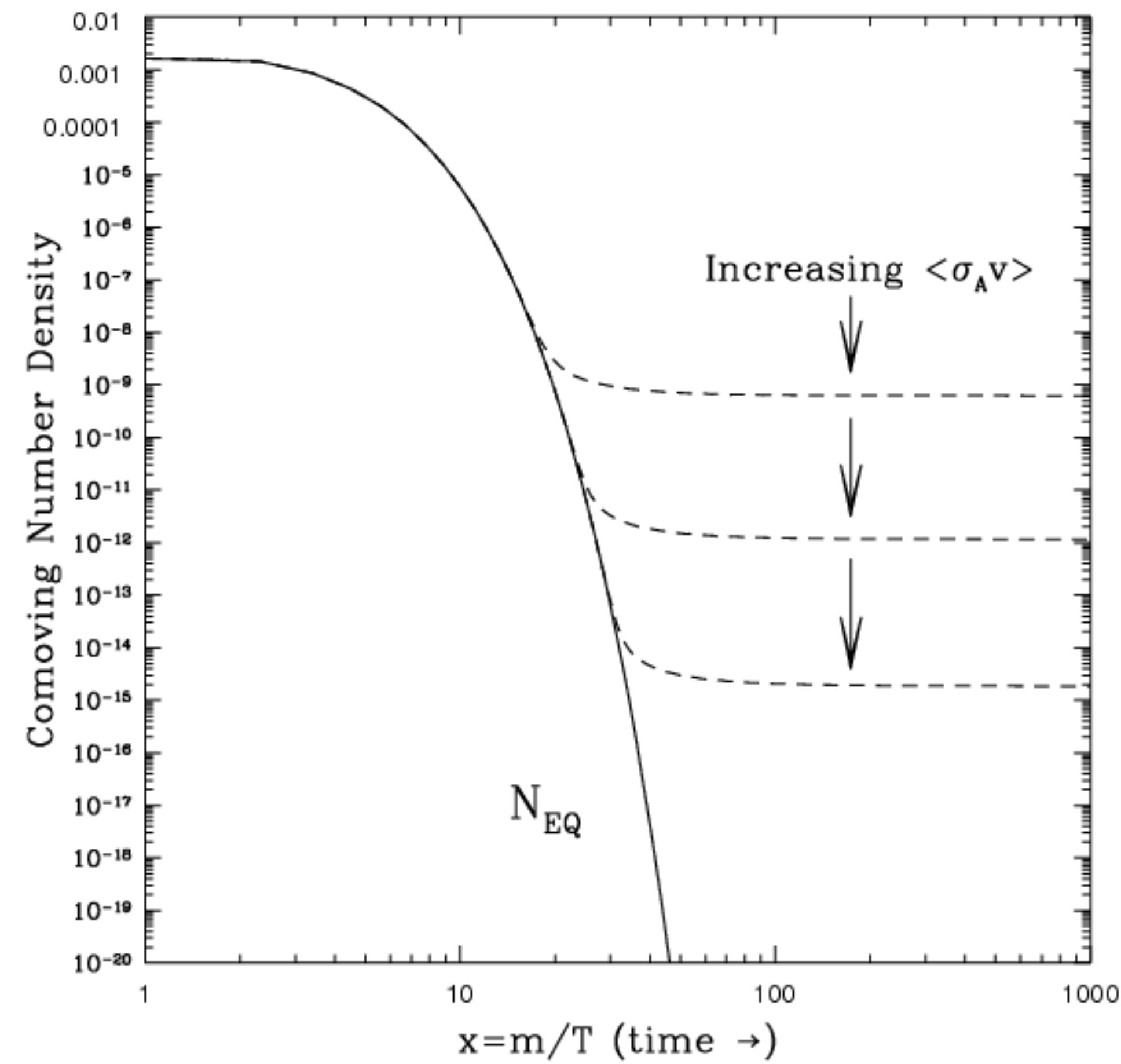
Tools for more energy
and luminosity

A retro search for h
&
mission imp

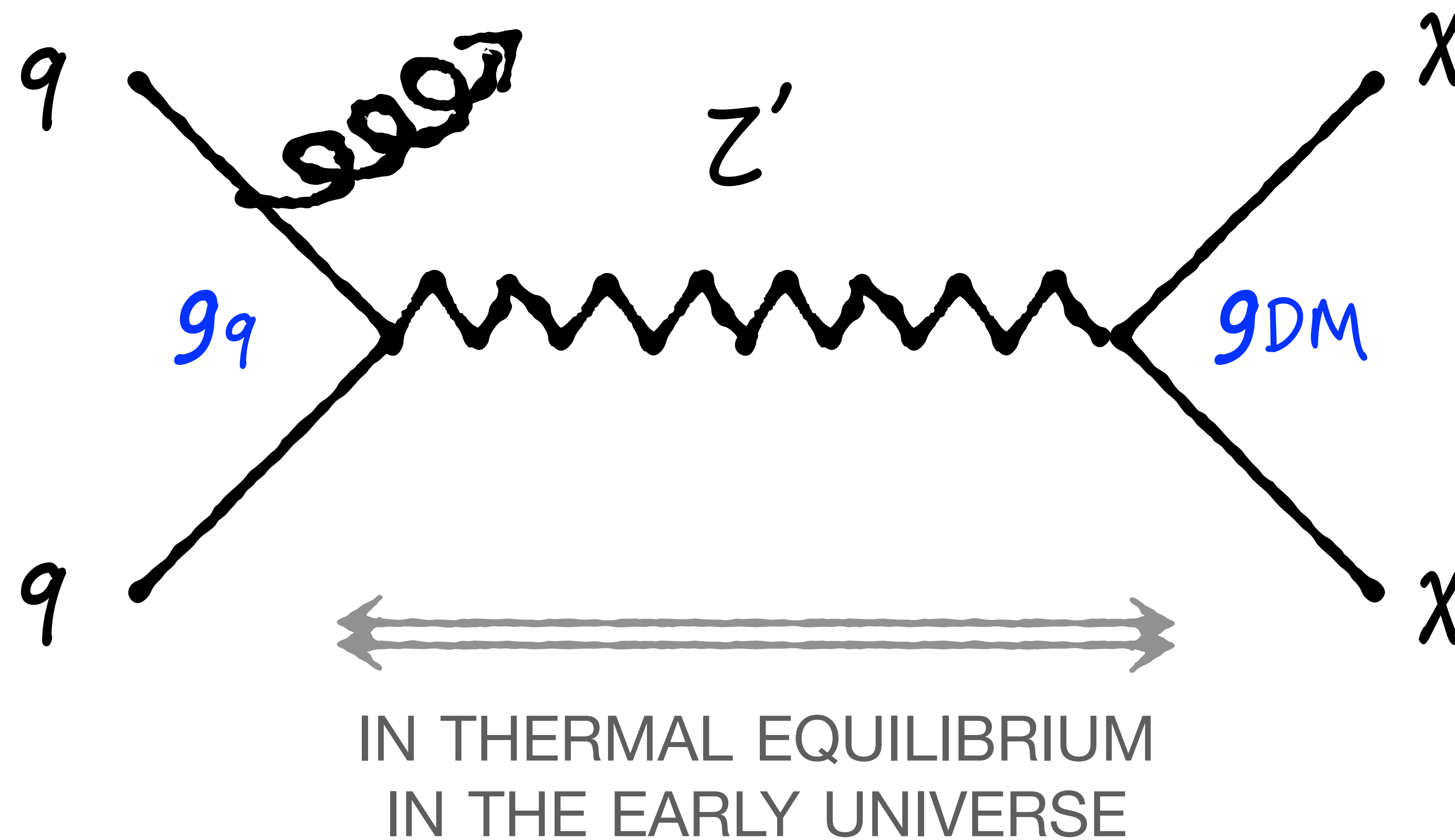
(a popular diagram)



**the DM connection,
coming full circle**

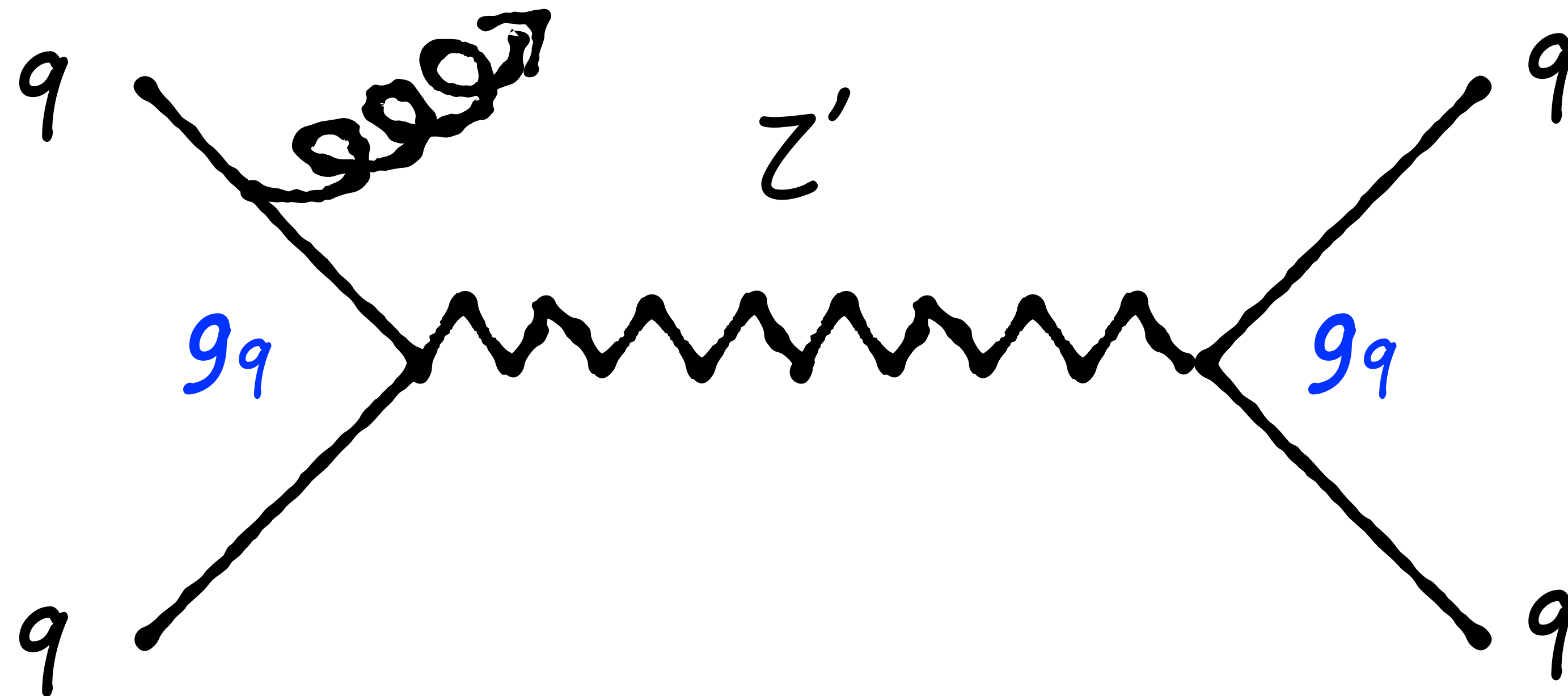


MONO-JET



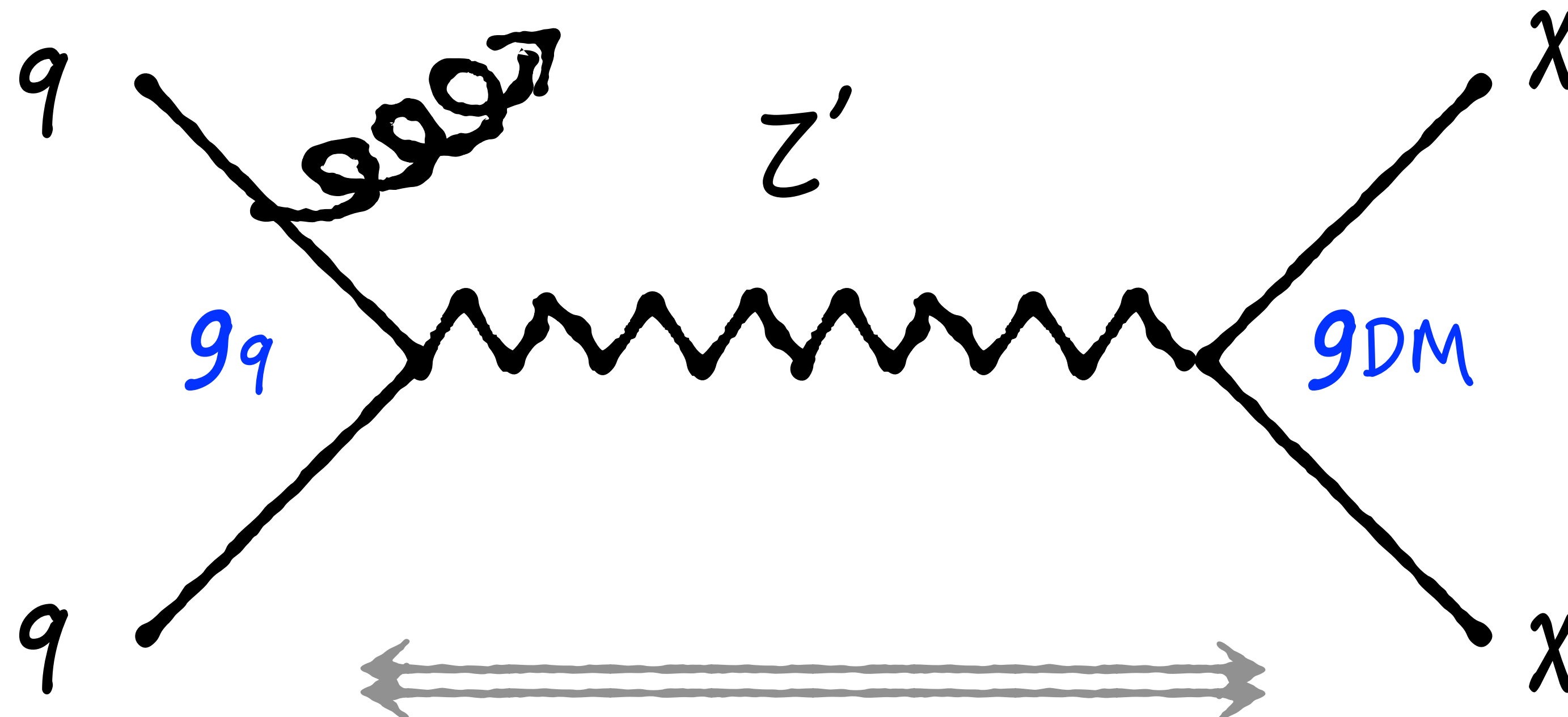
important when
 $m_{Z'} > 2 \times m_\chi$

DIJETS



dominant when
 $m_{Z'} < 2 \times m_\chi$

MONO-JET

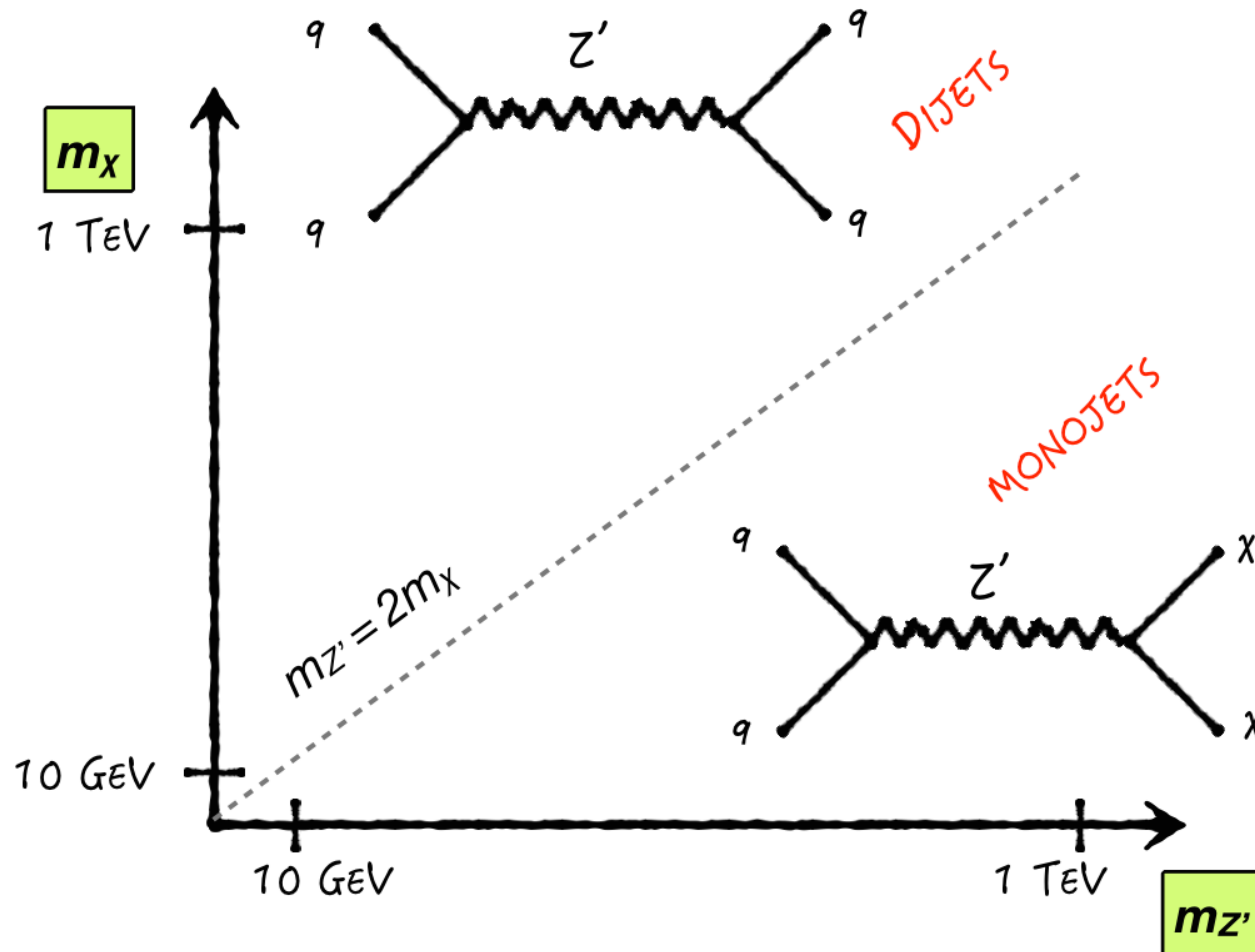


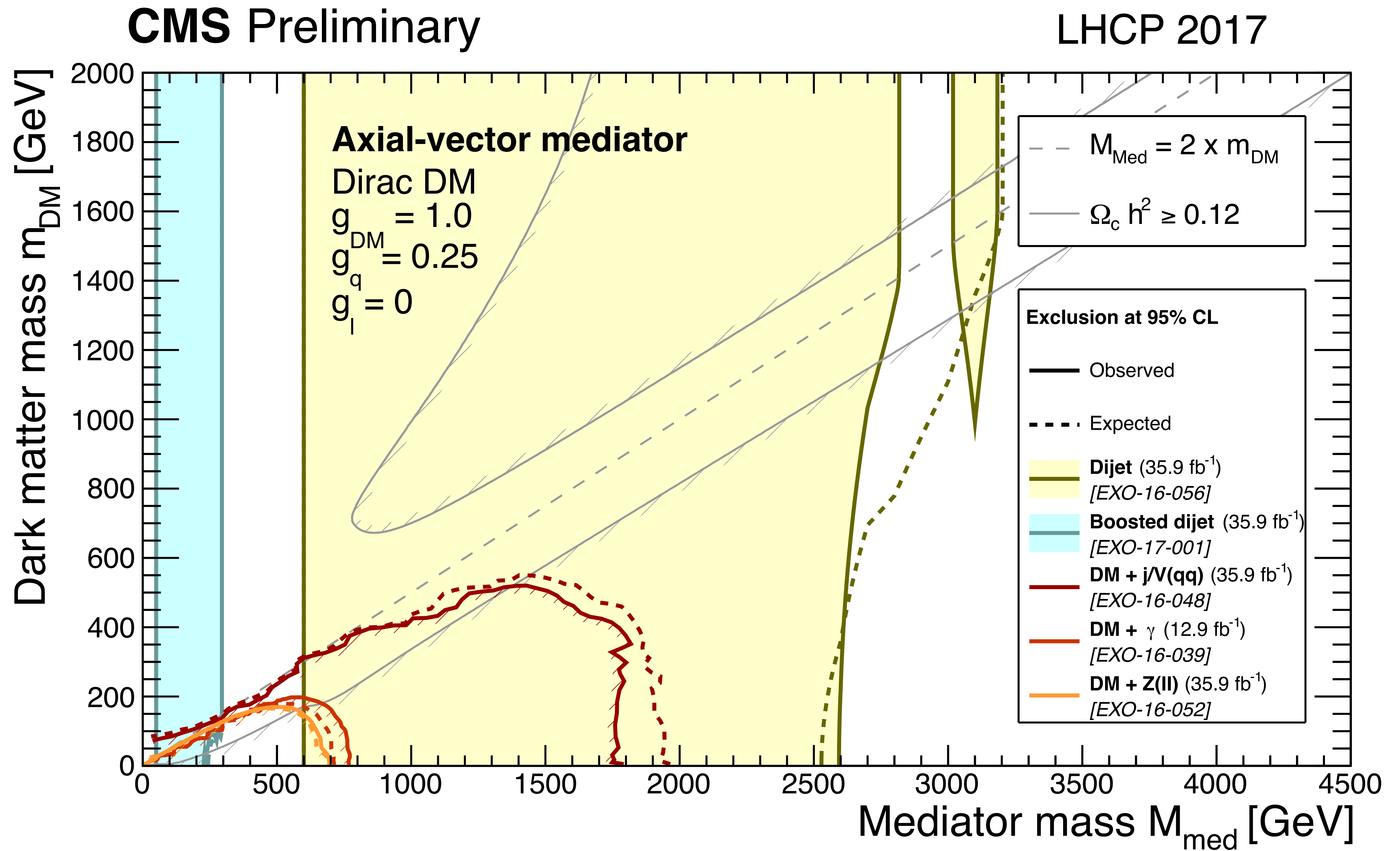
important when
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IN THERMAL EQUILIBRIUM
IN THE EARLY UNIVERSE

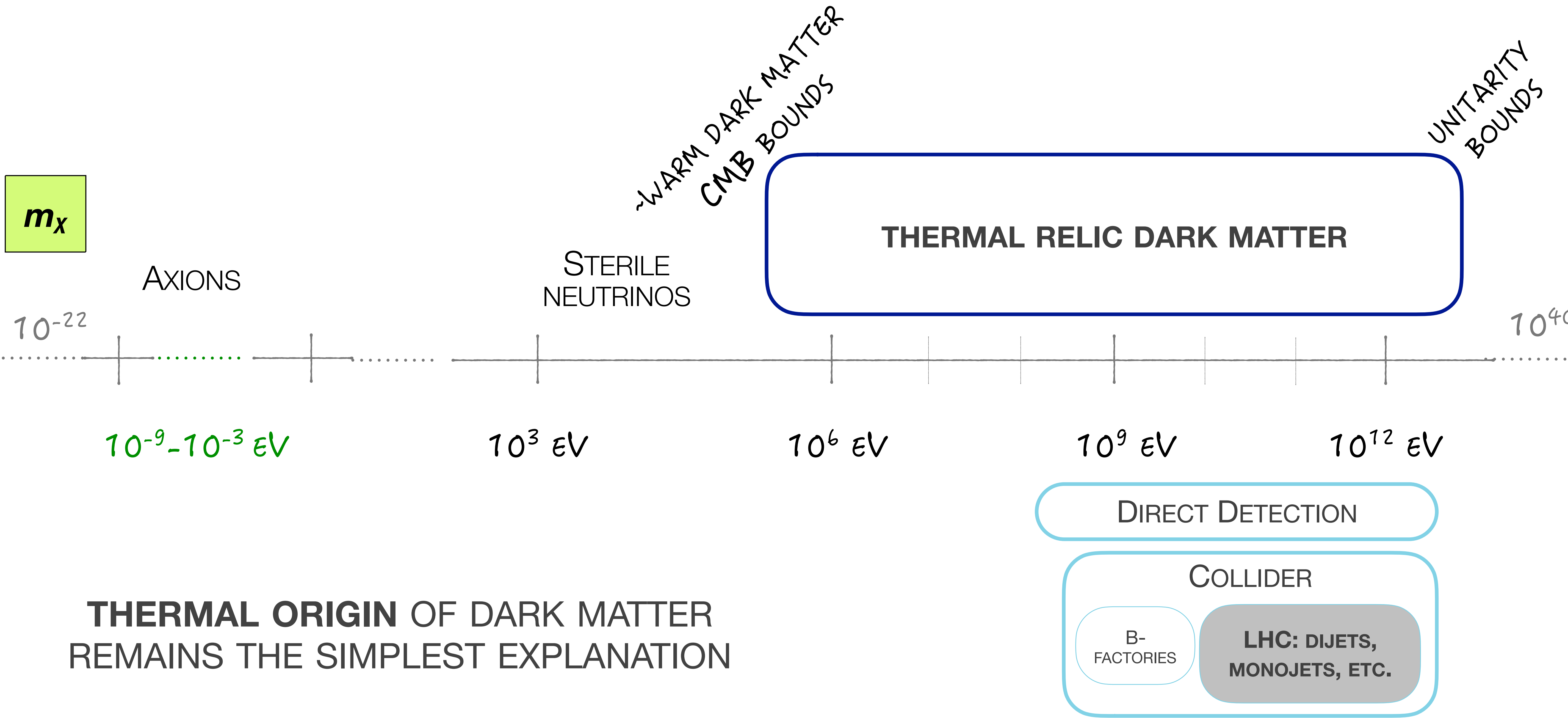
DARK MATTER COMPLEMENTARITY

26



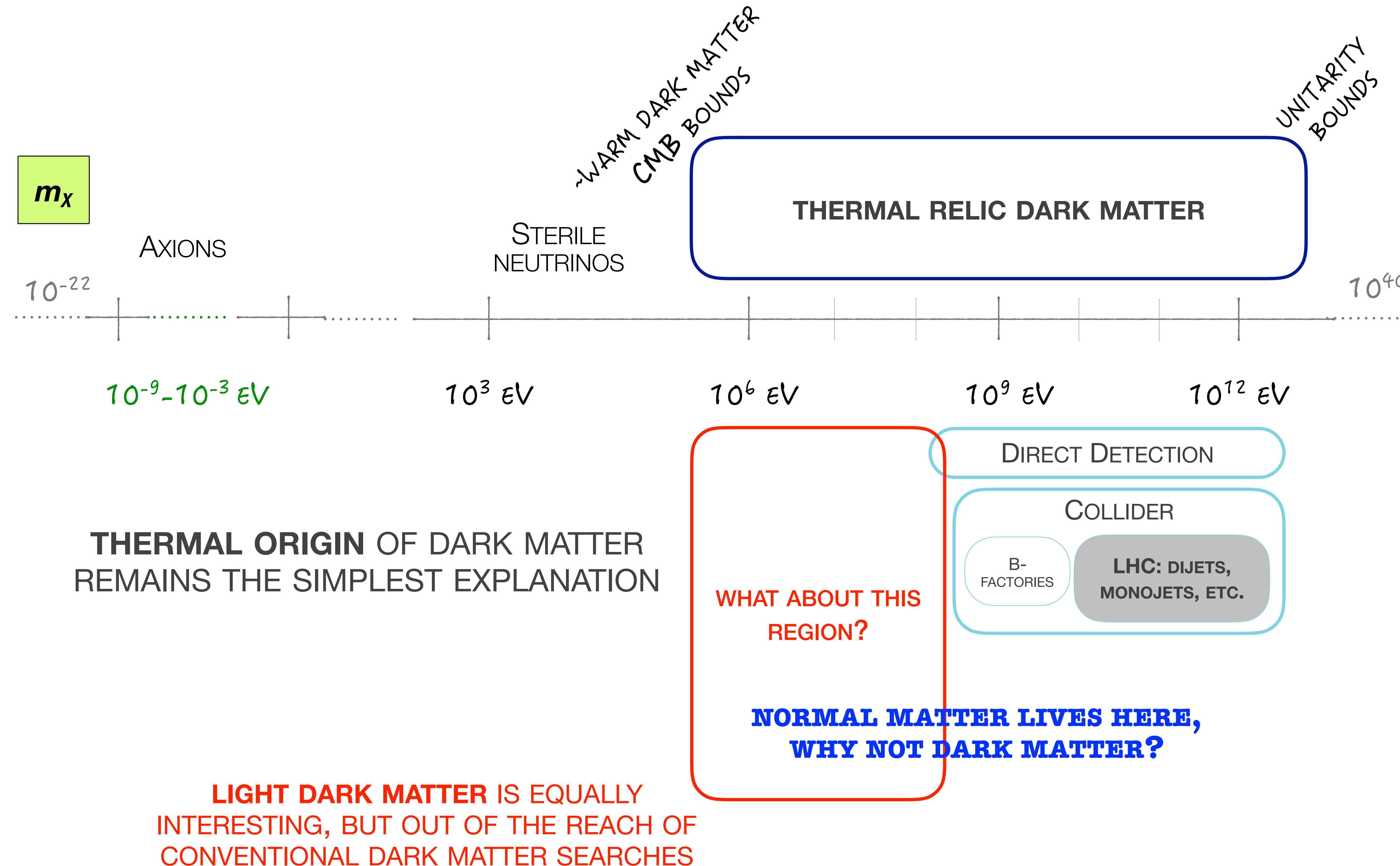


Zooming Out On Dark Matter



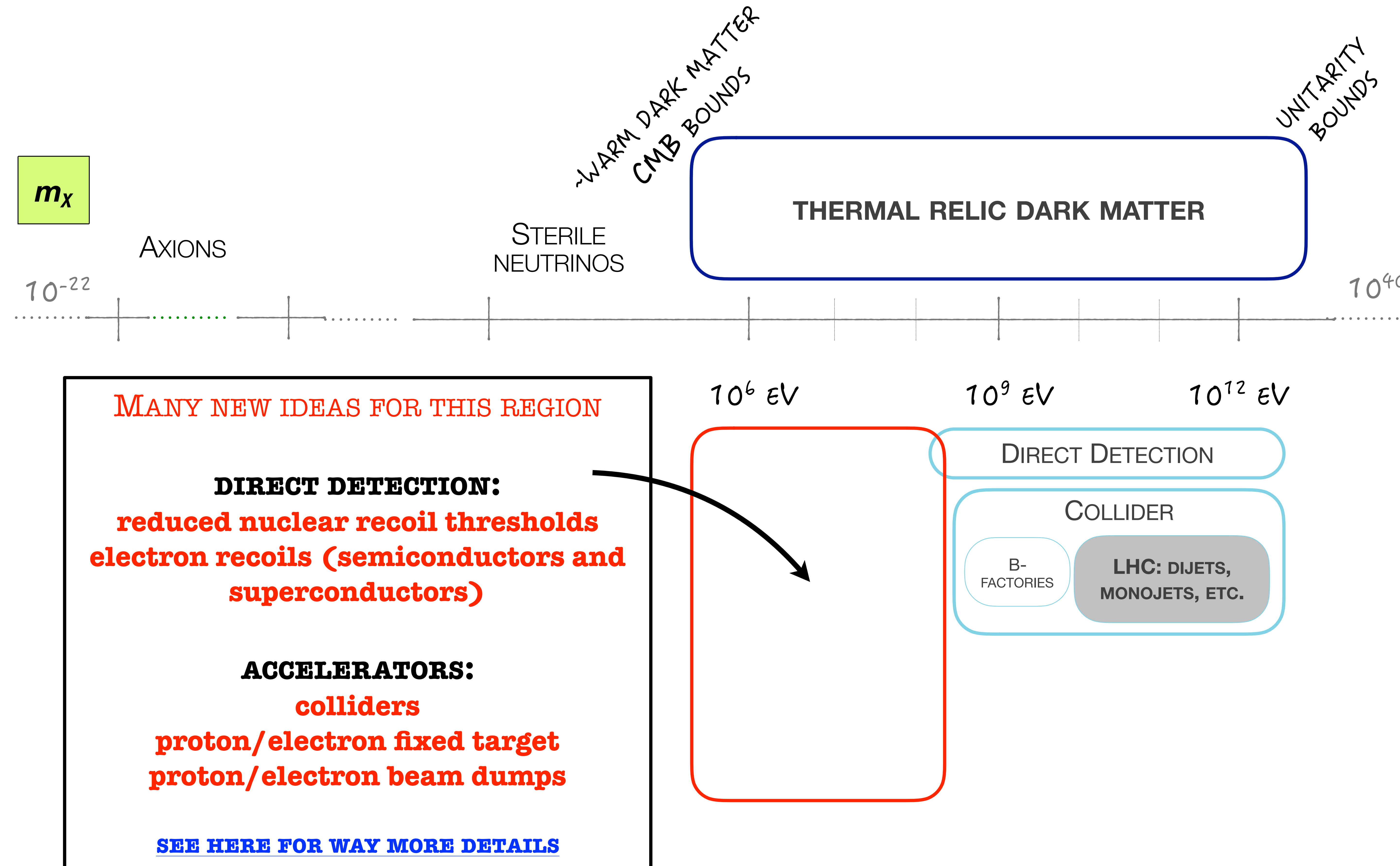
ZOOMING OUT ON DARK MATTER

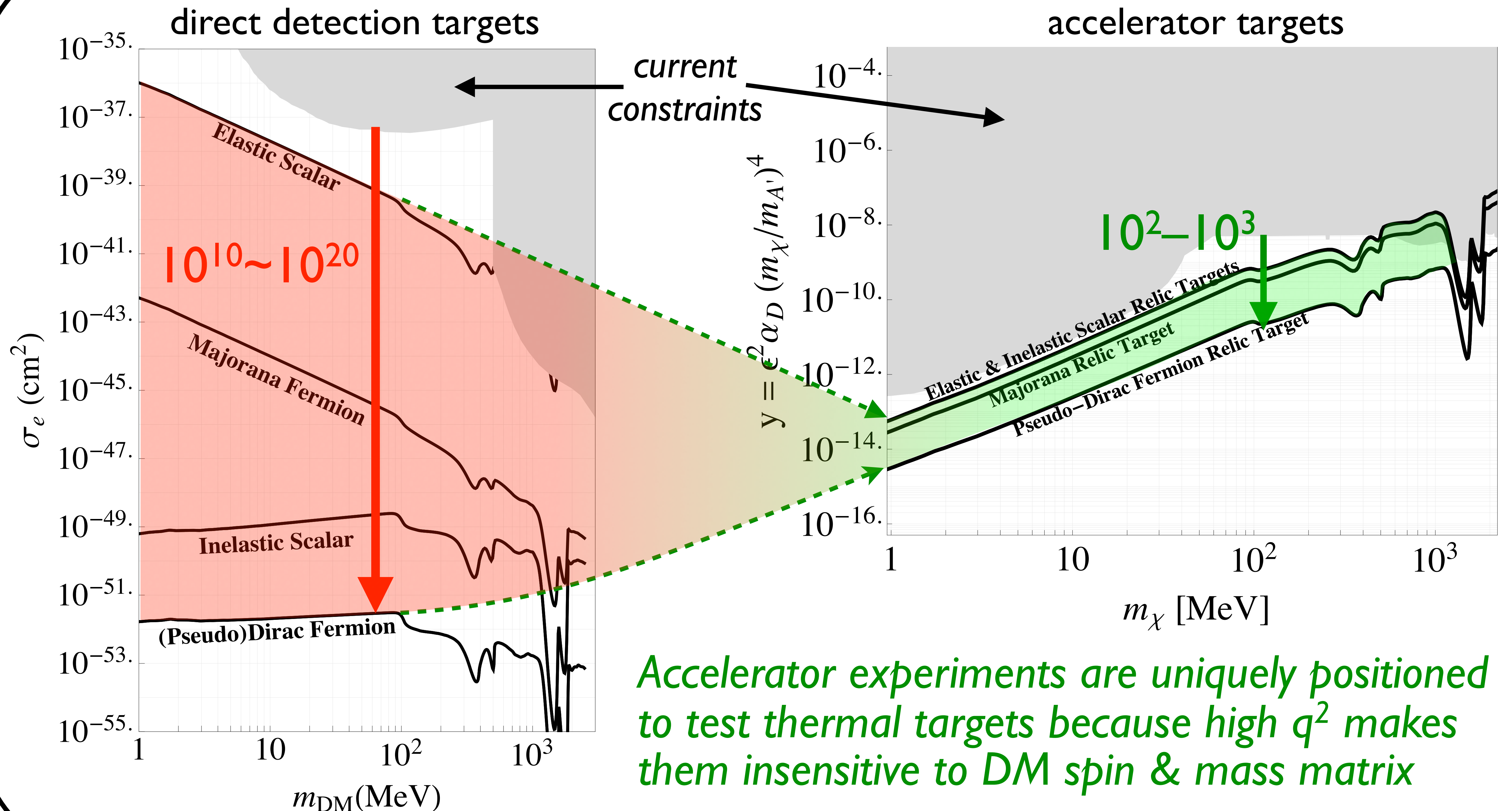
28



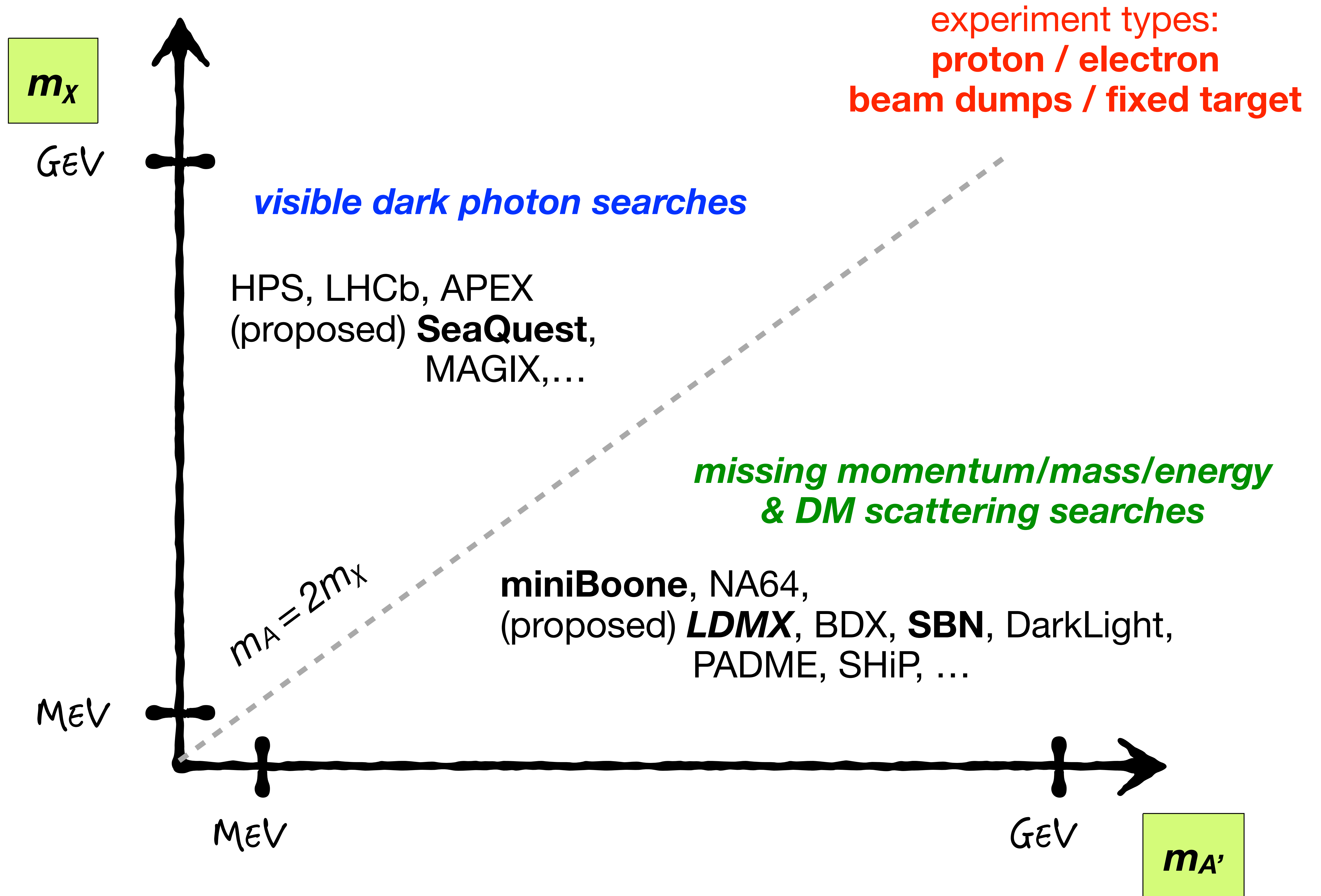
ZOOMING OUT ON DARK MATTER

29





TRANSLATION: **BOOSTING** THE DM INCREASES SENSITIVITY ACROSS MANY SCENARIOS

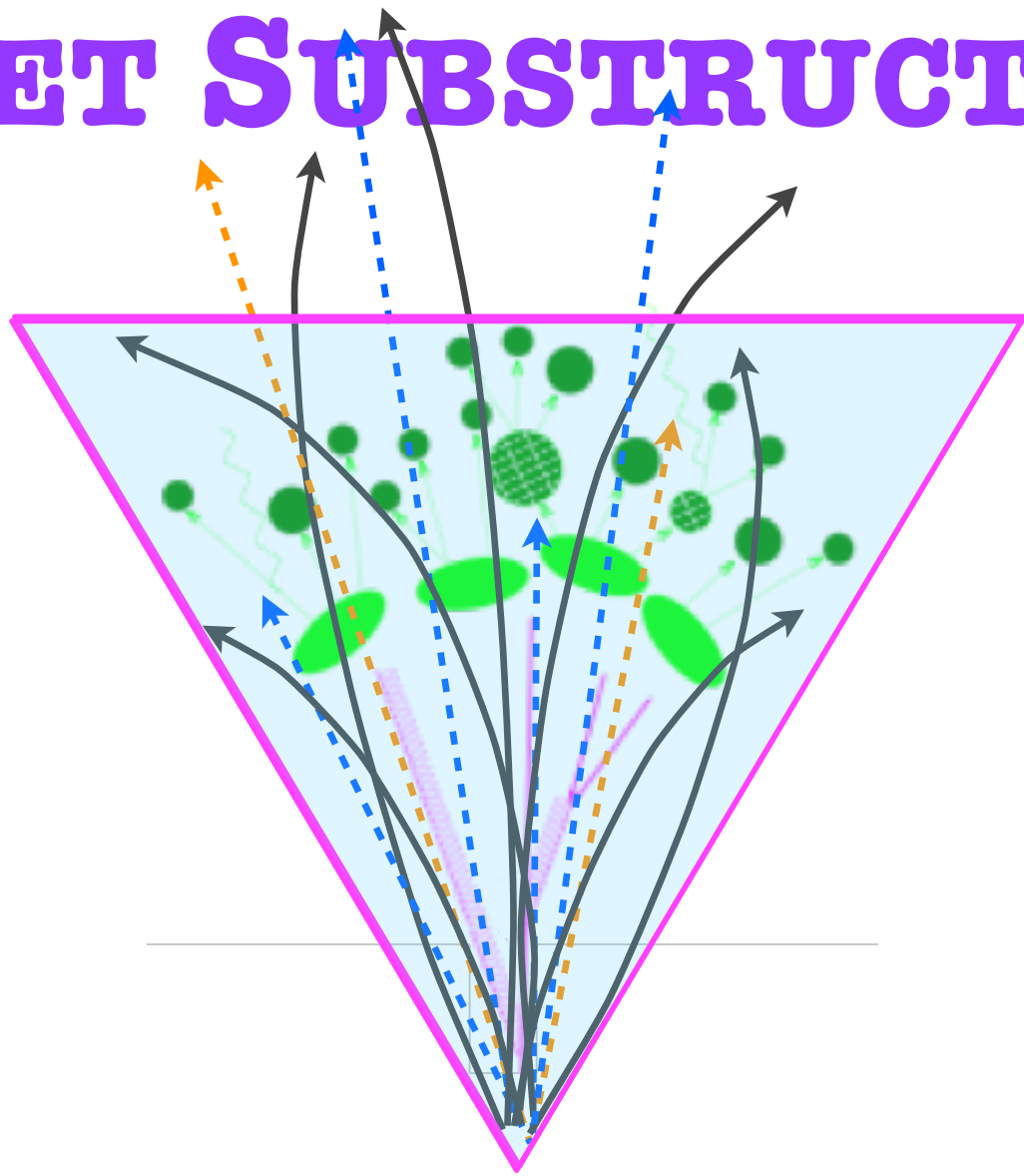


acknowledgements:

many great collaborators
***a lot* of US-CMS and URA members**
many of whom work at or with the LPC@FNAL

Tools for more energy
and luminosity

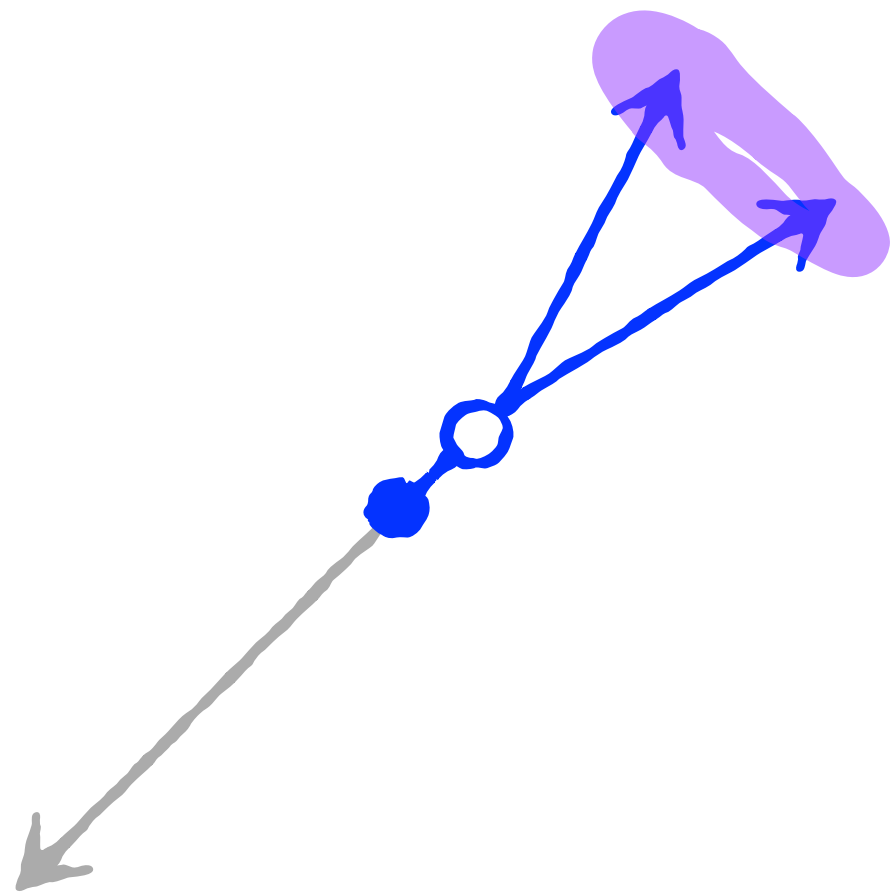
JET SUBSTRUCTURE



PUPPI

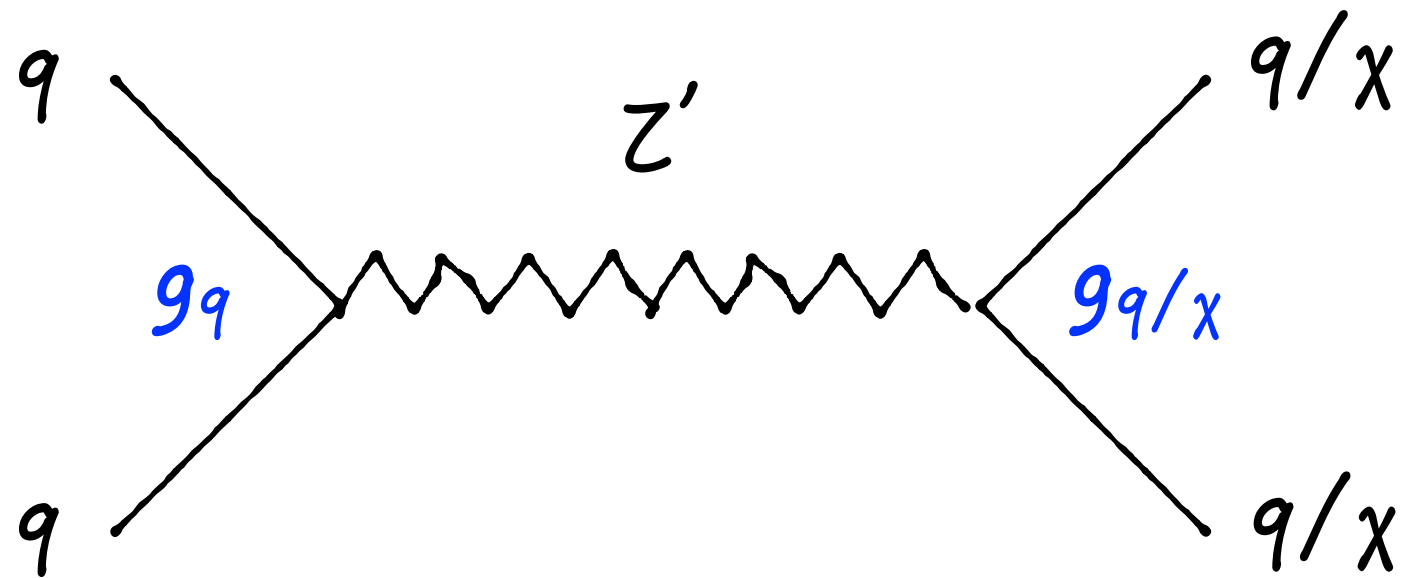


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LDMX

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