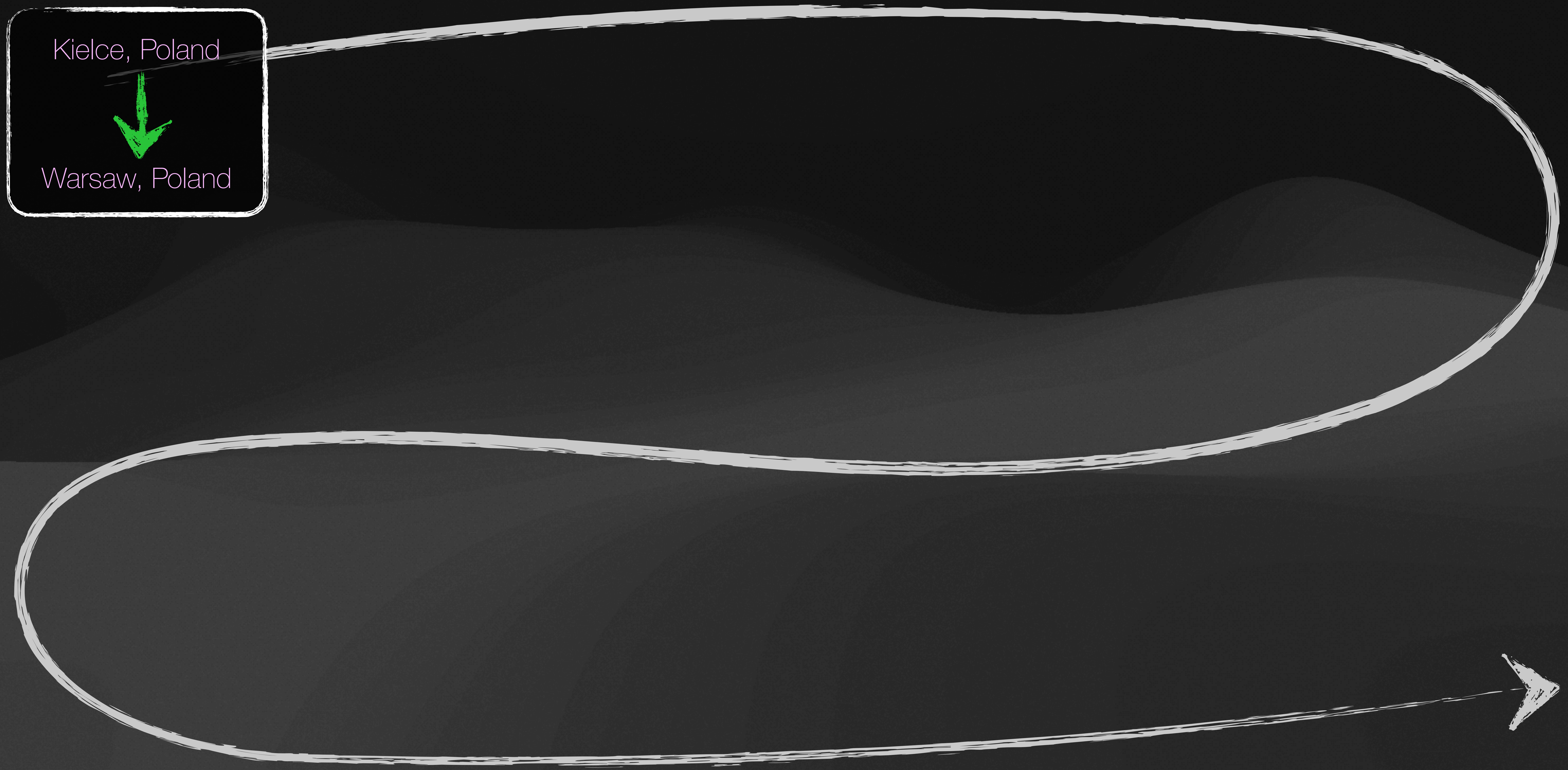
Jeremi Niedziela



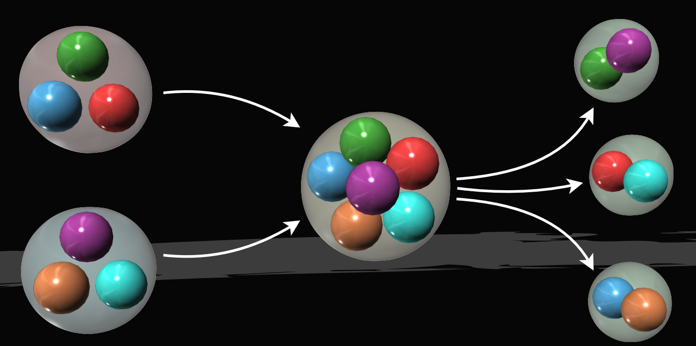
Jeremi Niedziela

2014

Kielce, Poland

Warsaw, Poland

CERN



PhD

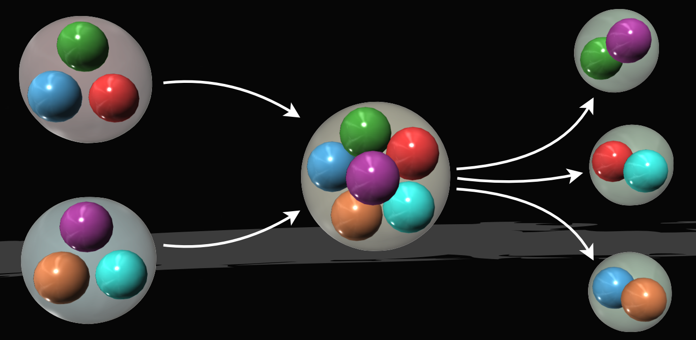
Baryon—antibaryon interactions

Jeremi Niedziela

2014

Kielce, Poland

Warsaw, Poland

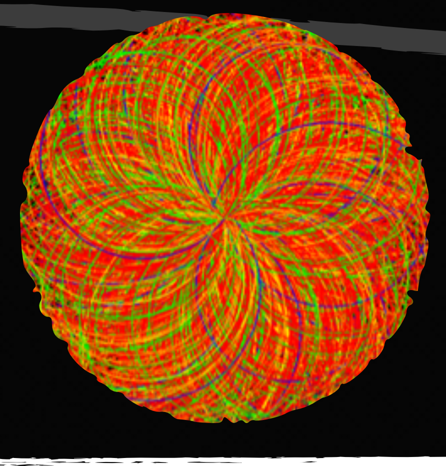


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



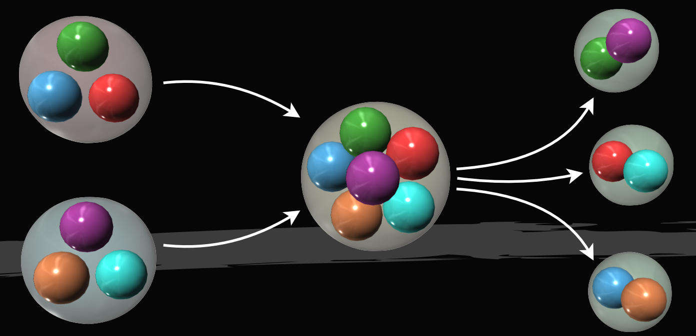
Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

2014

CERN

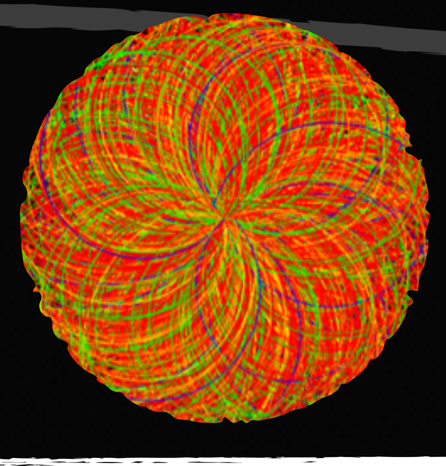


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



2017

ALICE

2018

CMS

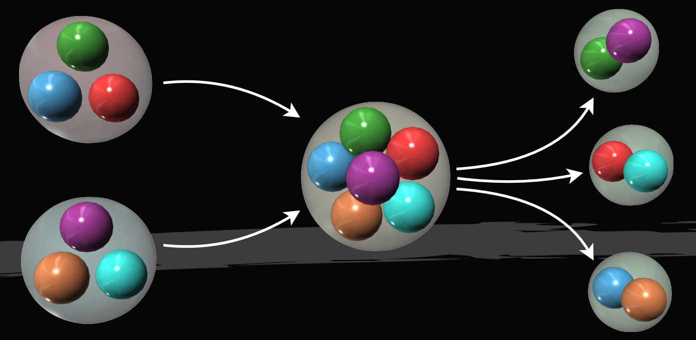
Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

2014

CERN

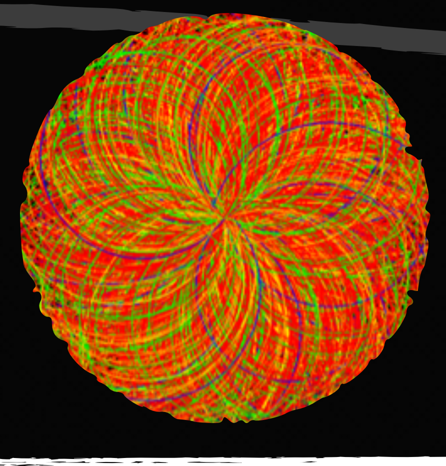


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



ALICE

2017

CERN Fellow

LbL + ALPs

2018

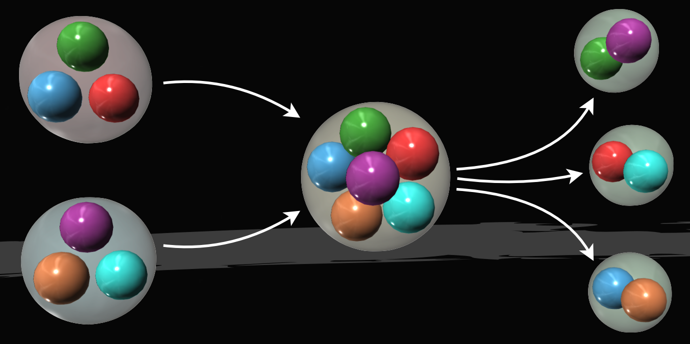
CMS

Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

2014

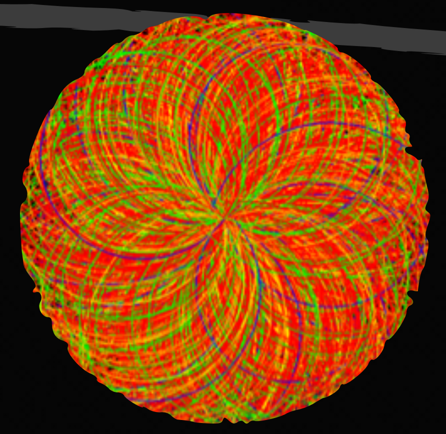


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach

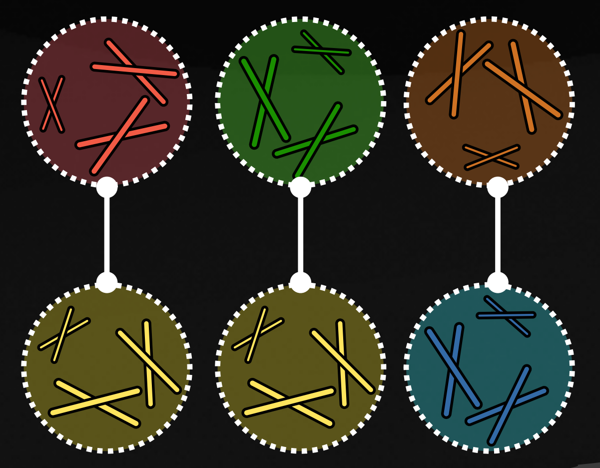


2017

CERN Fellow

LbL + ALPs

2018



CERN Fellow

HGCal clustering

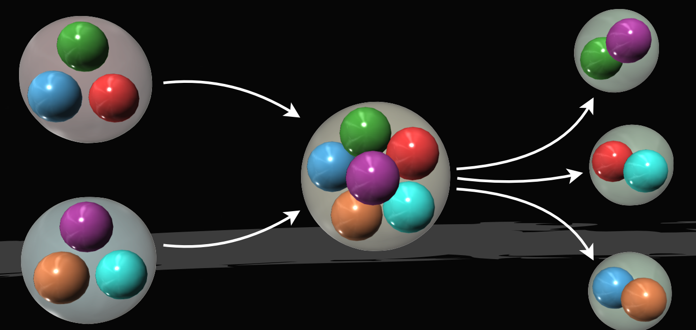
Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

2014

CERN

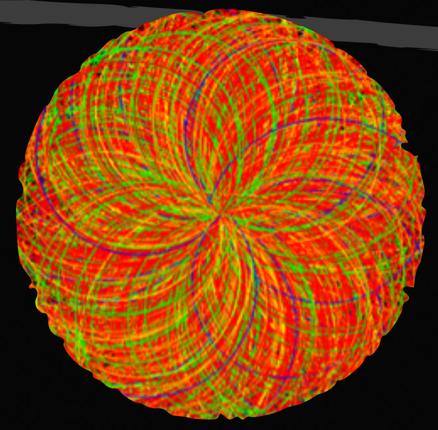


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



2017

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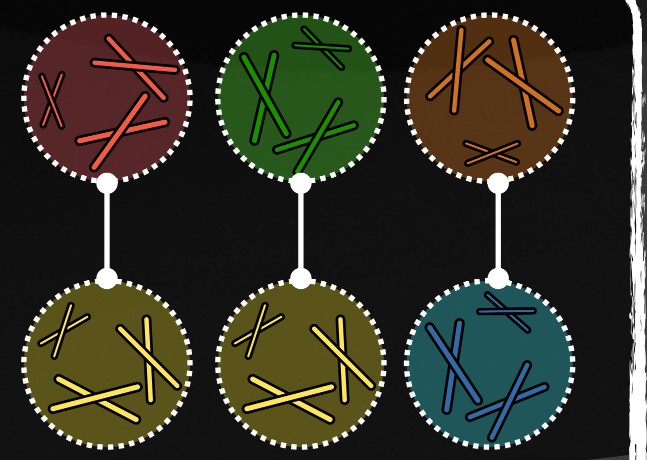
LbL + ALPs

2018

CMS

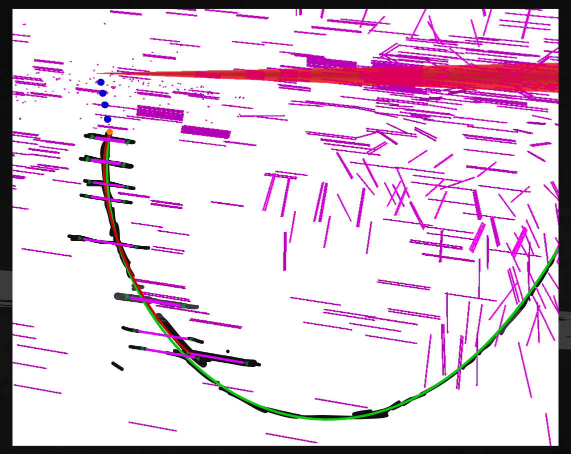


CERN Fellow

HGCal clustering

CERN Fellow

Disappearing tracks



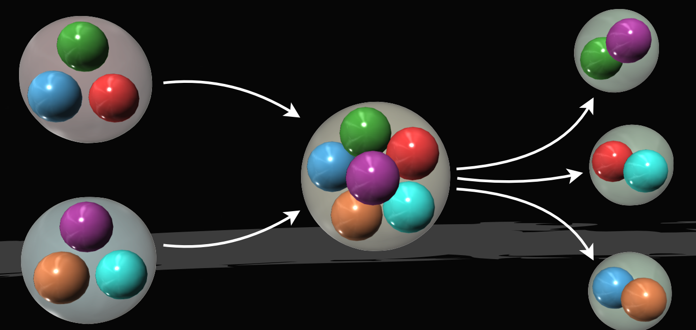
Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

CERN

2014

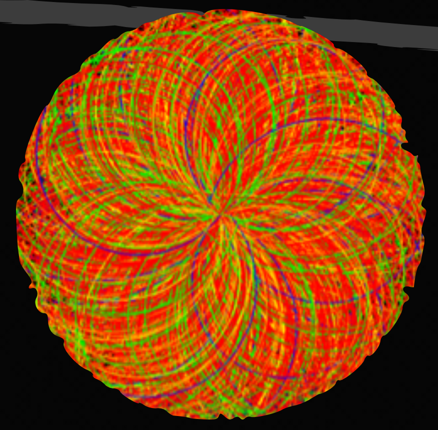


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



ALICE

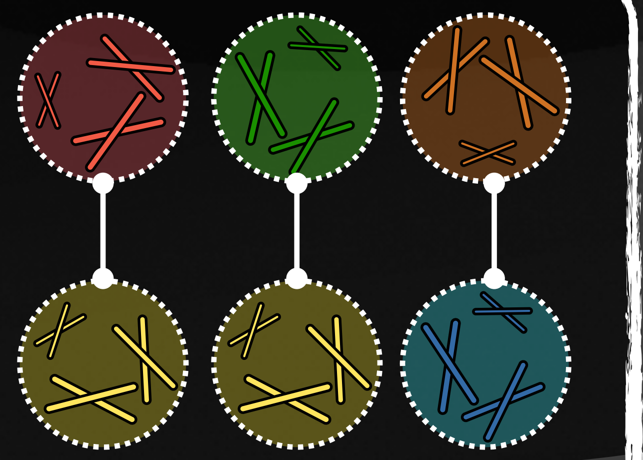
2017

CMS

2018

CERN Fellow

LbL + ALPs



CERN Fellow

HGCal clustering

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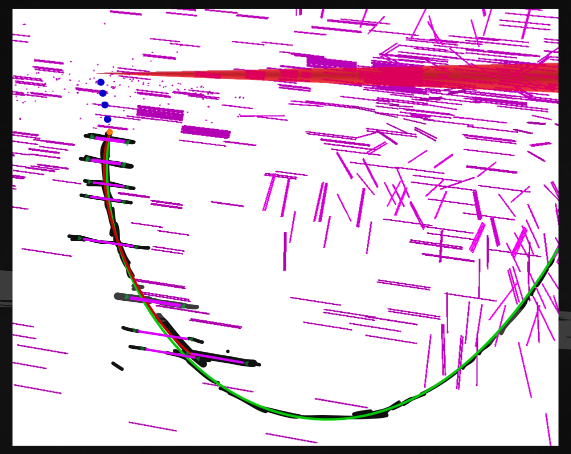
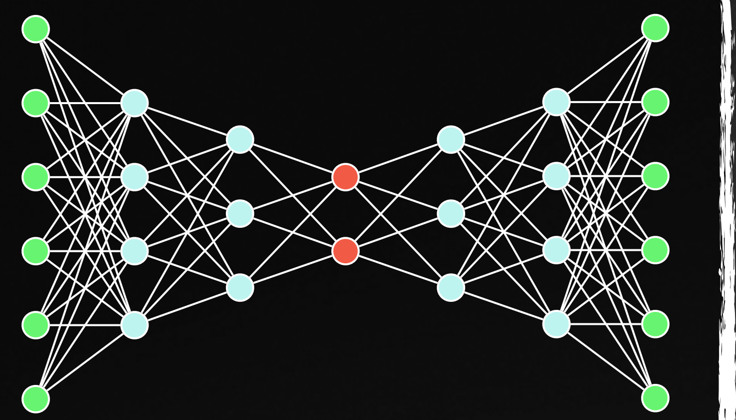
Disappearing tracks



2020



ETH PostDoc

Semivisible Jets

Jeremi Niedziela

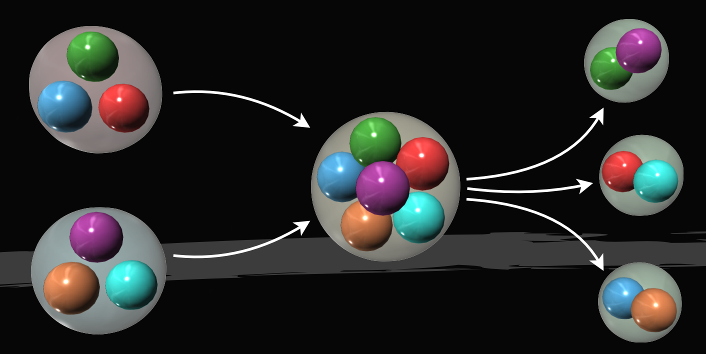
Jeremi Niedziela

Kielce, Poland

Warsaw, Poland

CERN

2014

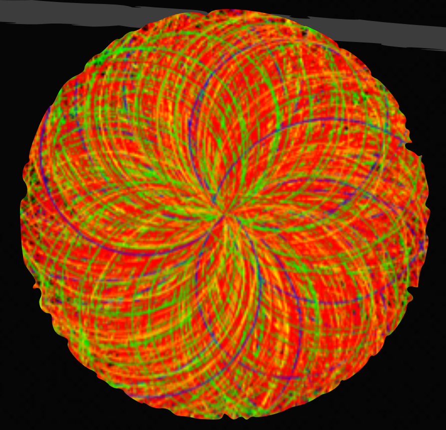


PhD

Baryon—antibaryon interactions

In the meantime

Visualization & Outreach



ALICE

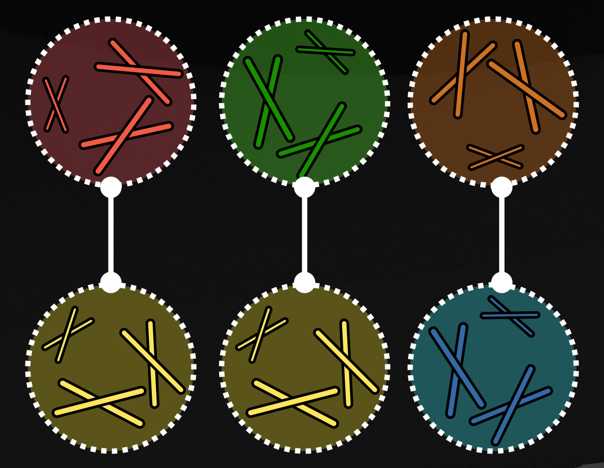
2017

CMS

2018

CERN Fellow

LbL + ALPs

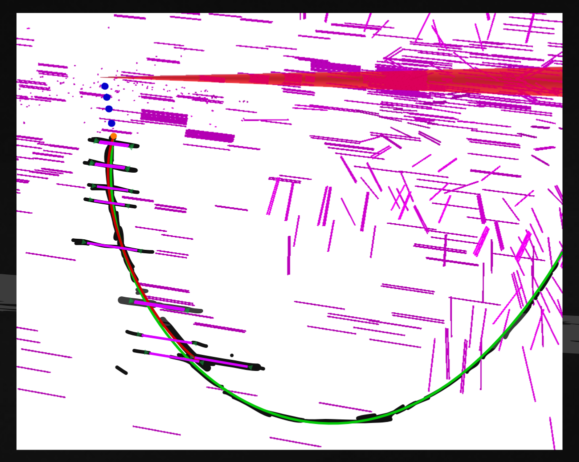


CERN Fellow

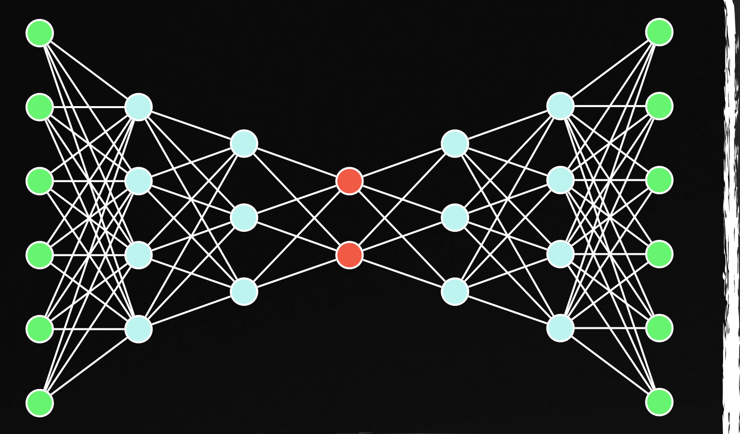
HGCal clustering

CERN Fellow

Disappearing tracks



2020



ETH PostDoc

Semivisible Jets

2022

CERN

2023

DESY.

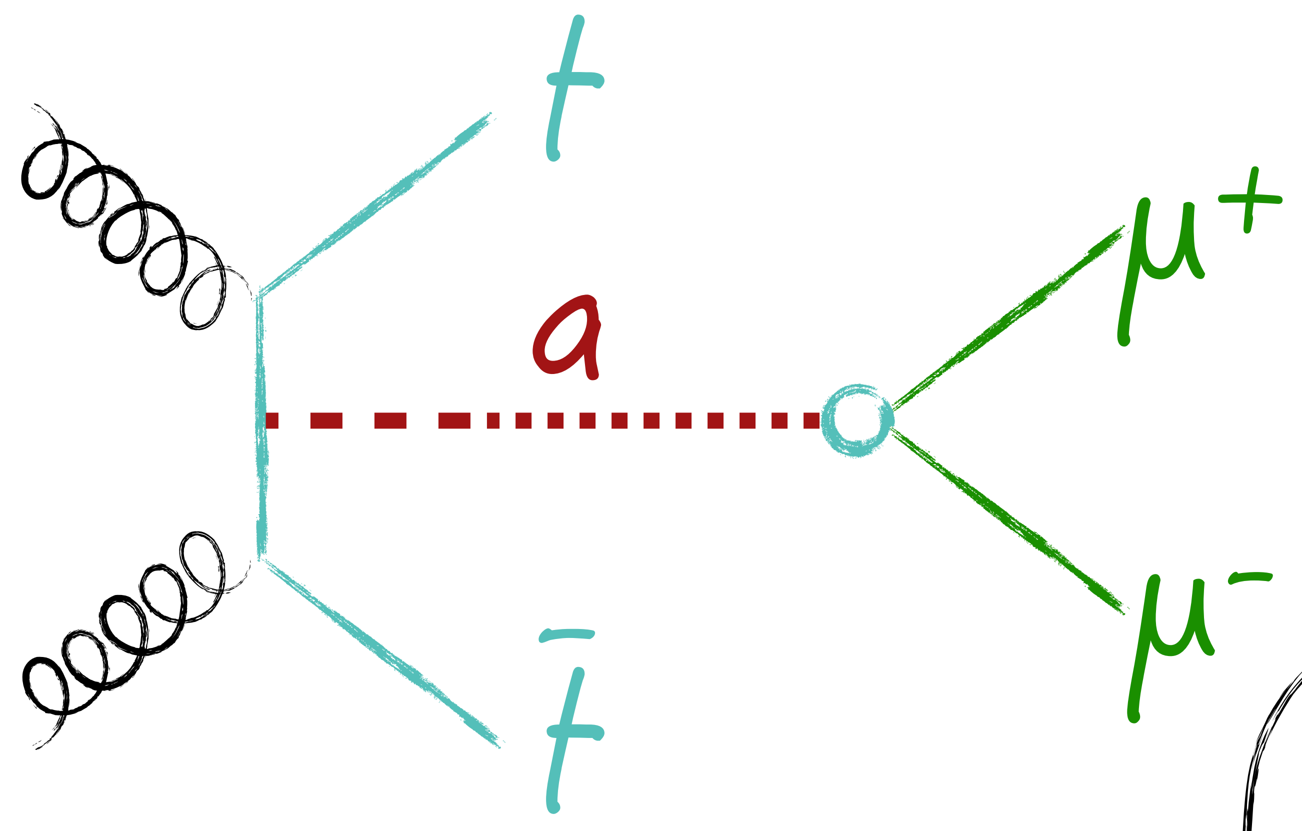
DESY Fellow

HGCal Calibration

??

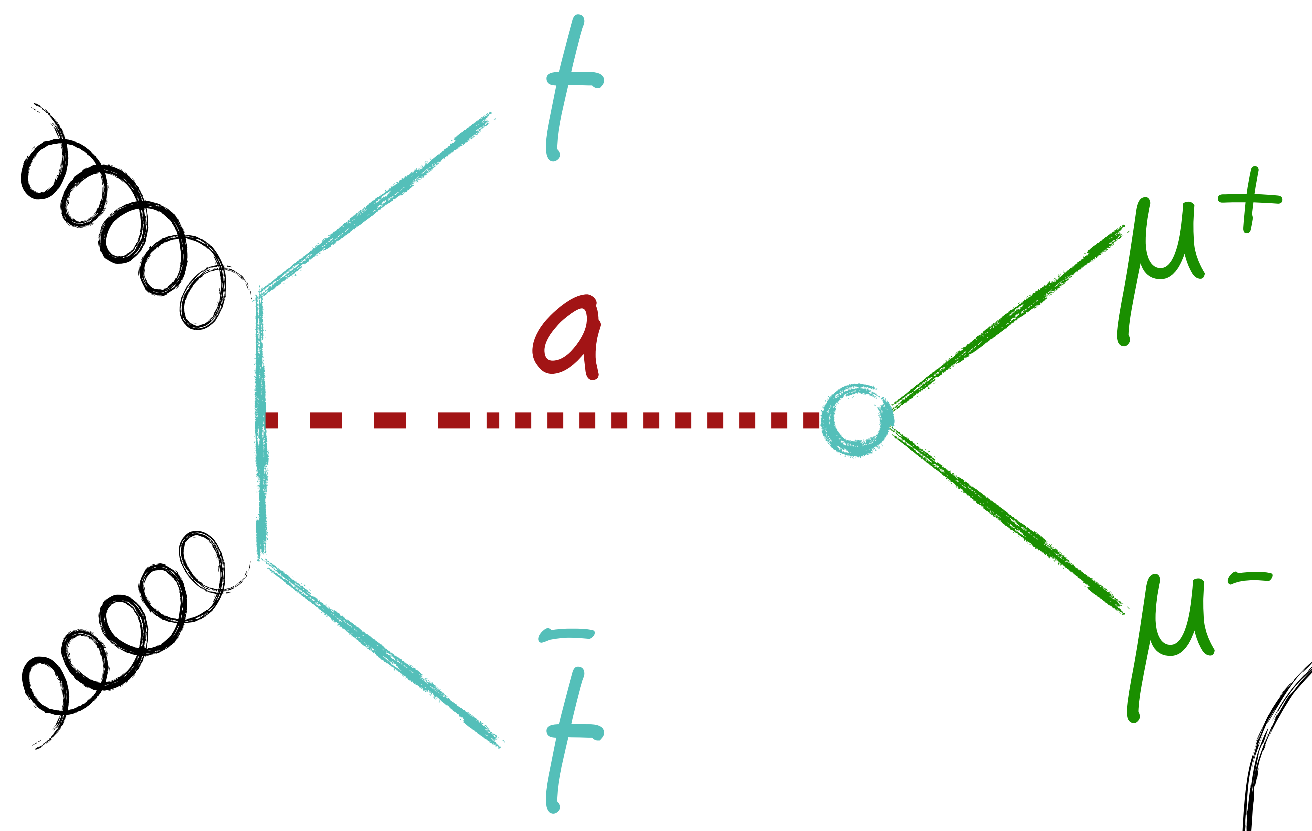

Jeremi Niedziela
Kielce, Poland
Warsaw, Poland
2014
CERN
PhD
Baryon—antibaryon
interactions
In the meantime
Visualization & Outreach
ALICE
2017
CMS
2018
CERN Fellow
LbL + ALPs
CERN Fellow
HGCal clustering
CERN Fellow
Disappearing tracks
2020
ETH PostDoc
Semivisible Jets
2022
CERN
2023
DESY.
DESY Fellow
HGCal Calibration
??
t
a
μ^+
μ^-
$\bar{t}$
DESY Fellow
$t\bar{t}$+ALPs

Current work: $t\bar{t}$+ALPs



- ALPs: new pseudo-scalars:
  → Yukawa-like couplings,
  → preferred interactions with **top quarks**,

Current work: $t\bar{t}$+ALPs



- ALPs: new pseudo-scalars:
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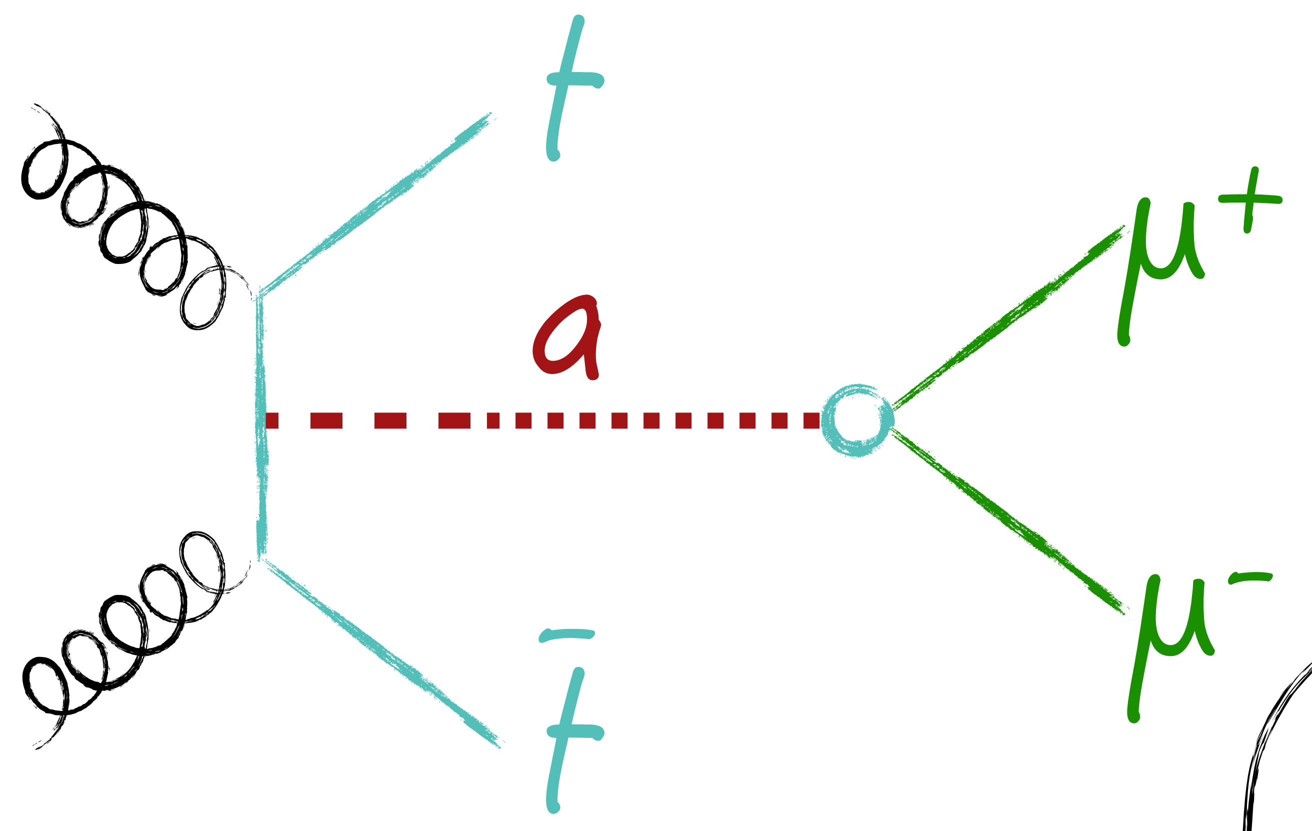

- ALPs: new pseudo-scalars:
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- **triggering on $t\bar{t}$ → lower ALP masses**,
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  → **long lived**,
  → easier background rejection,

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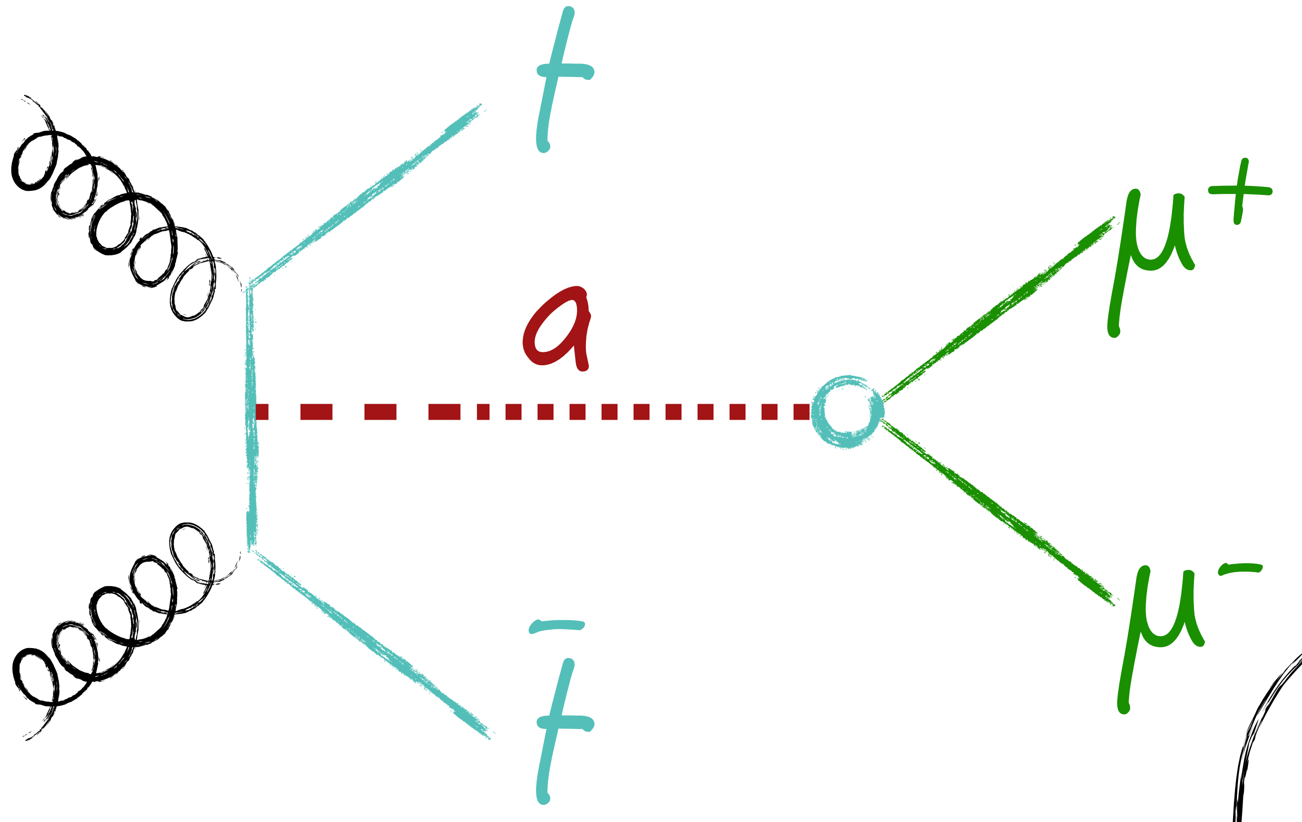
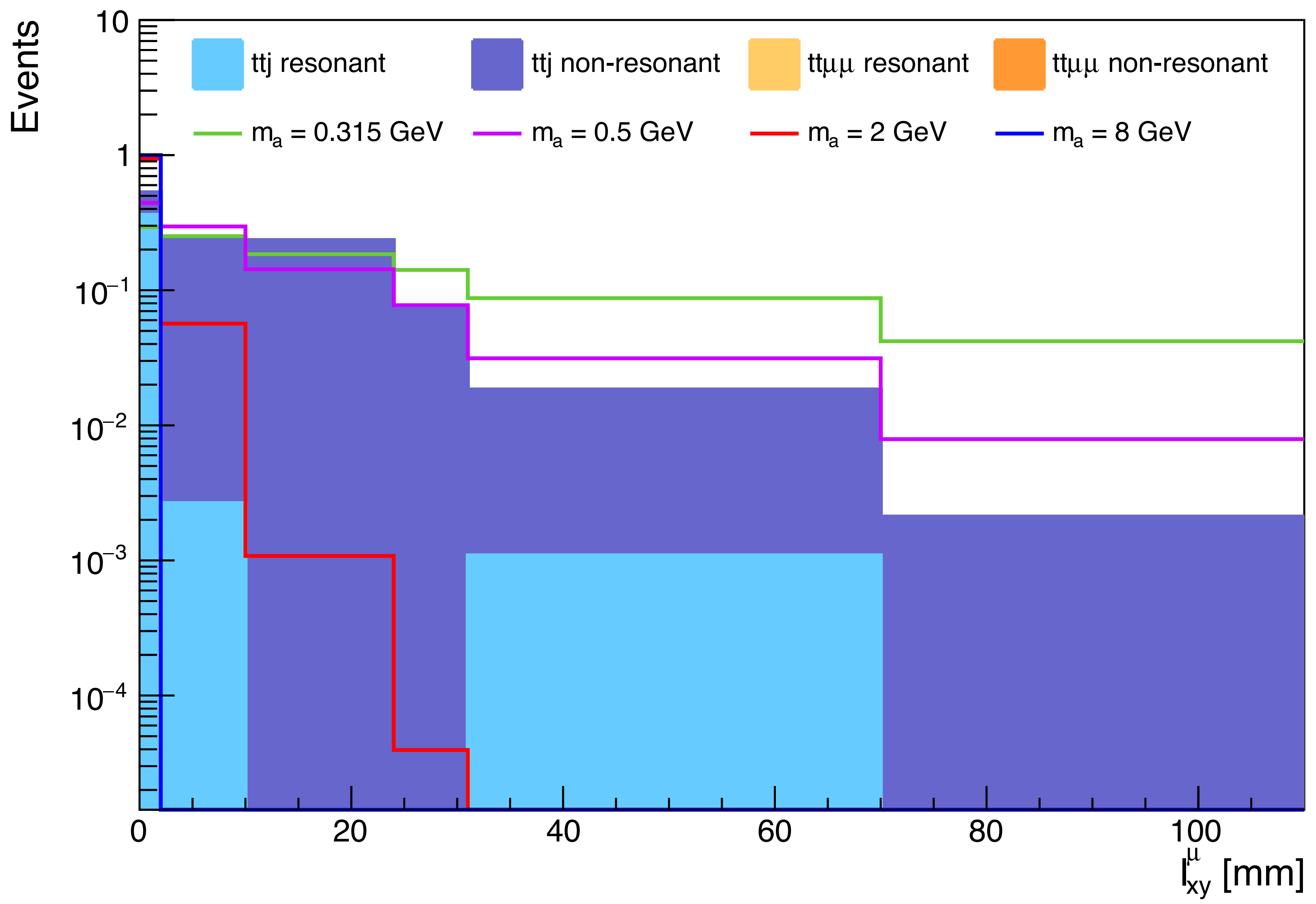


enhance signal



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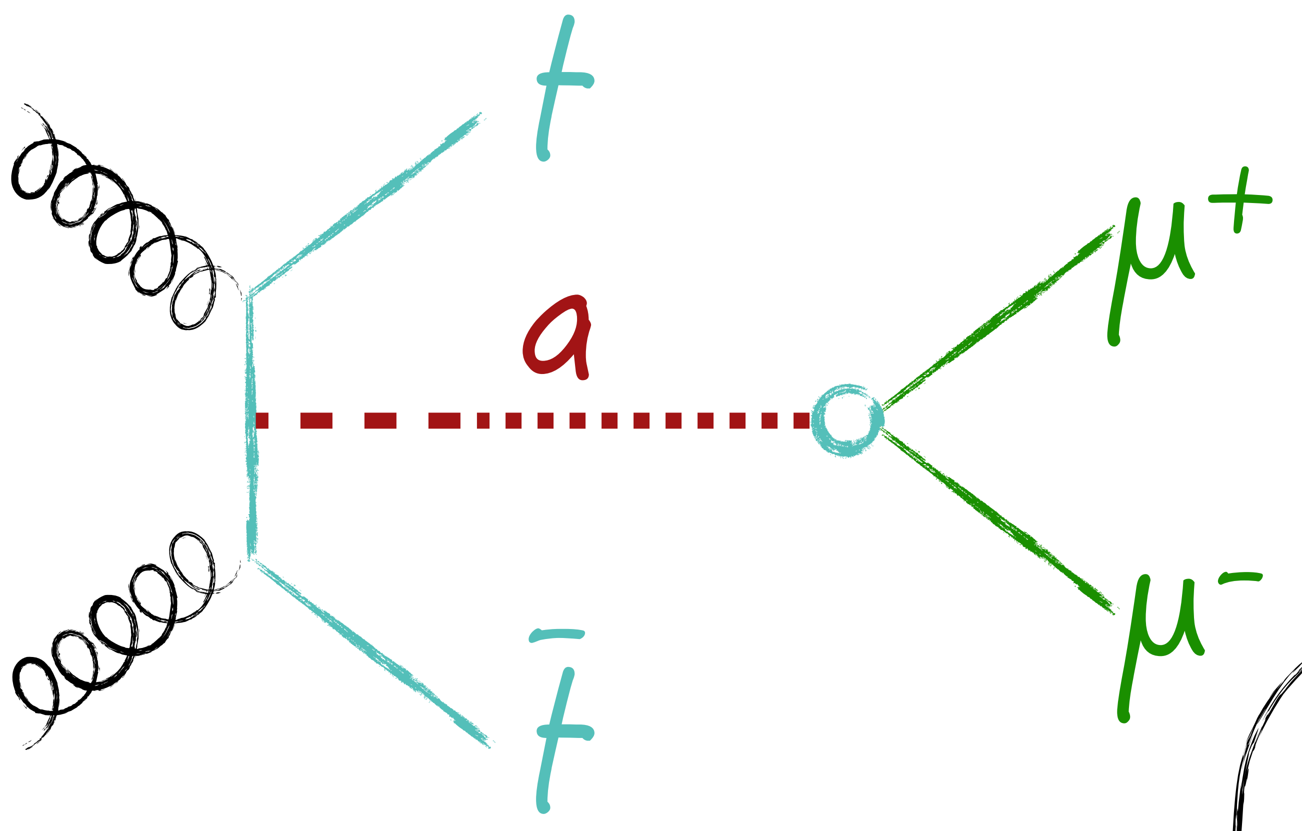
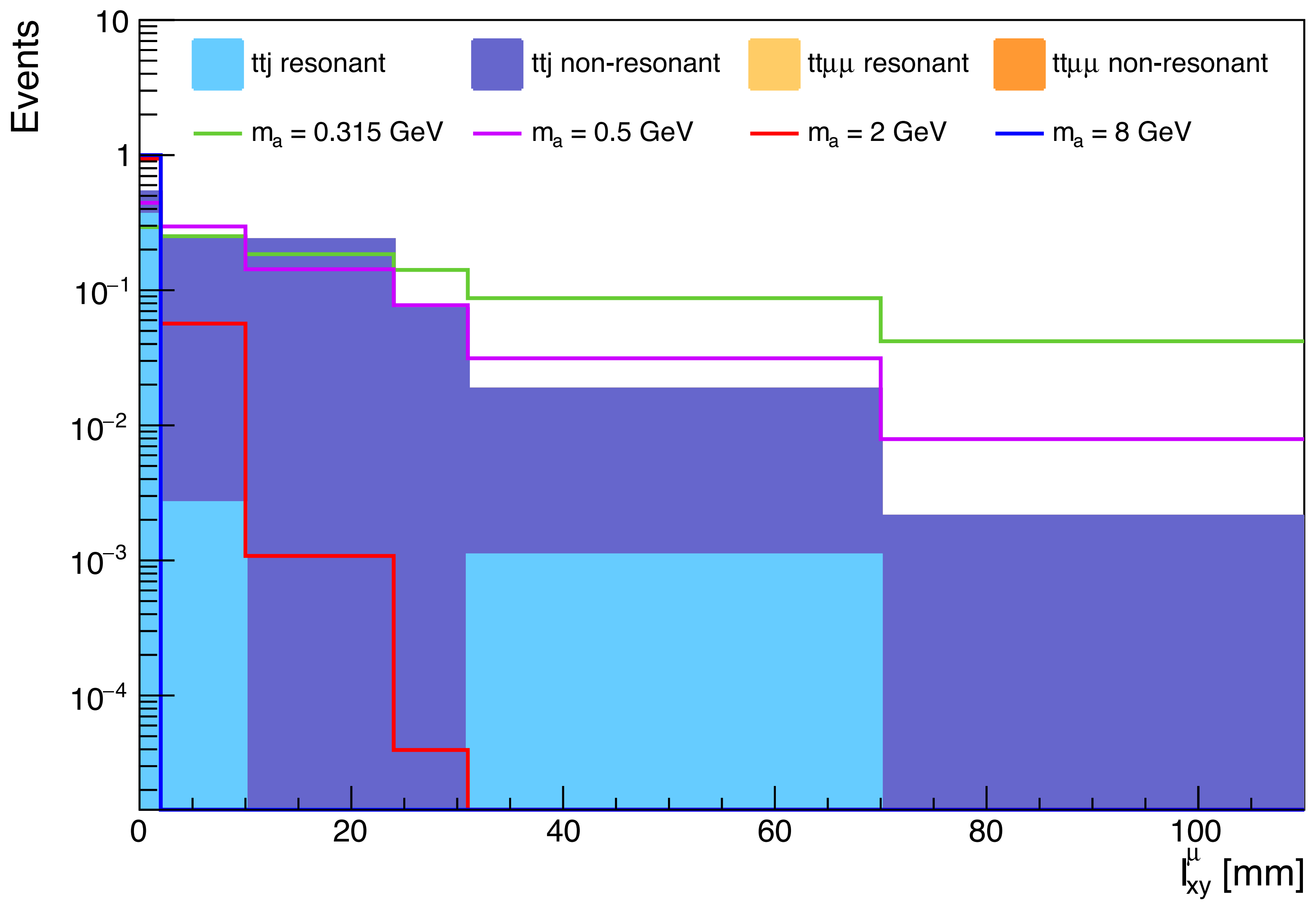


enhance signal



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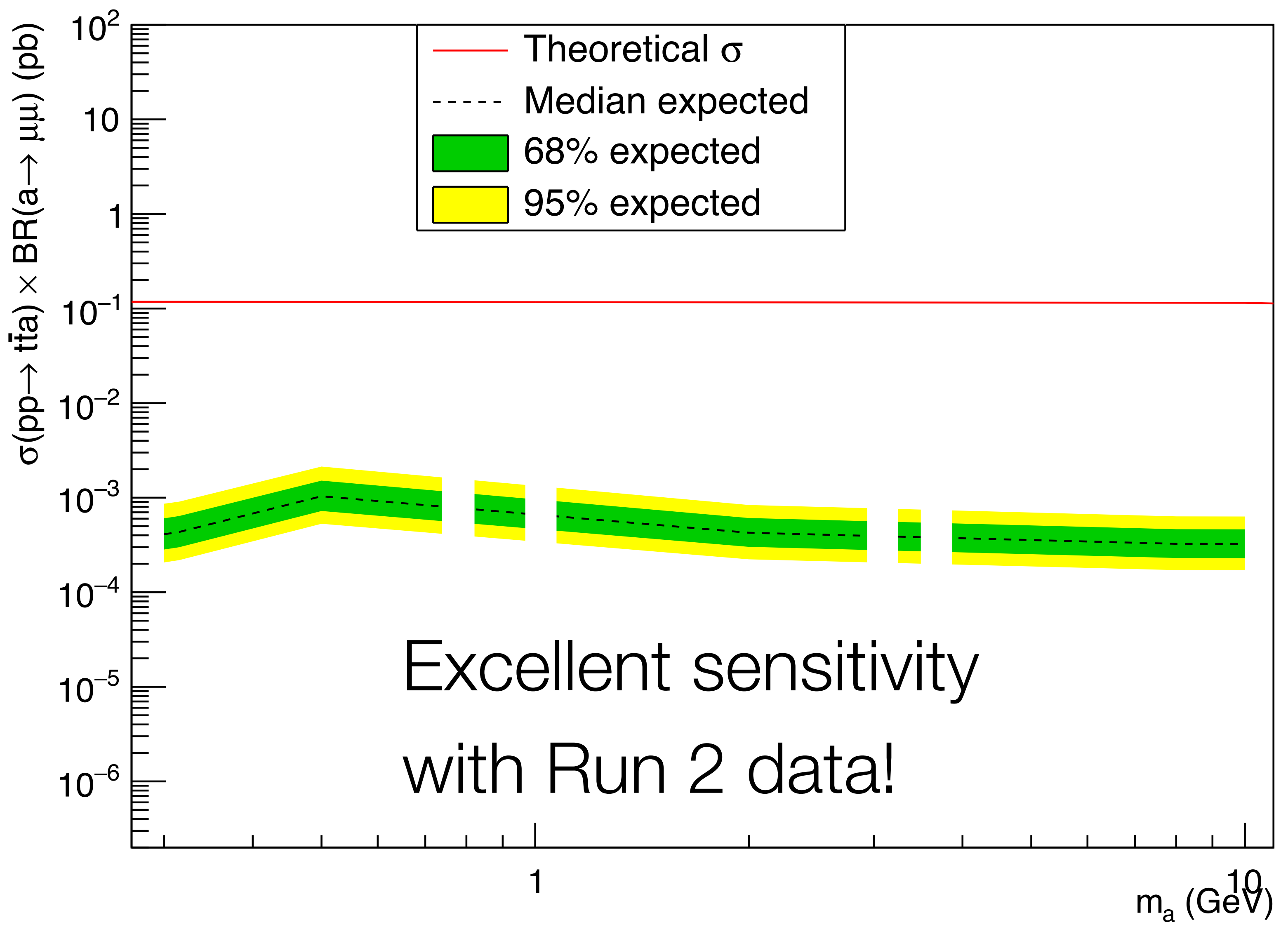
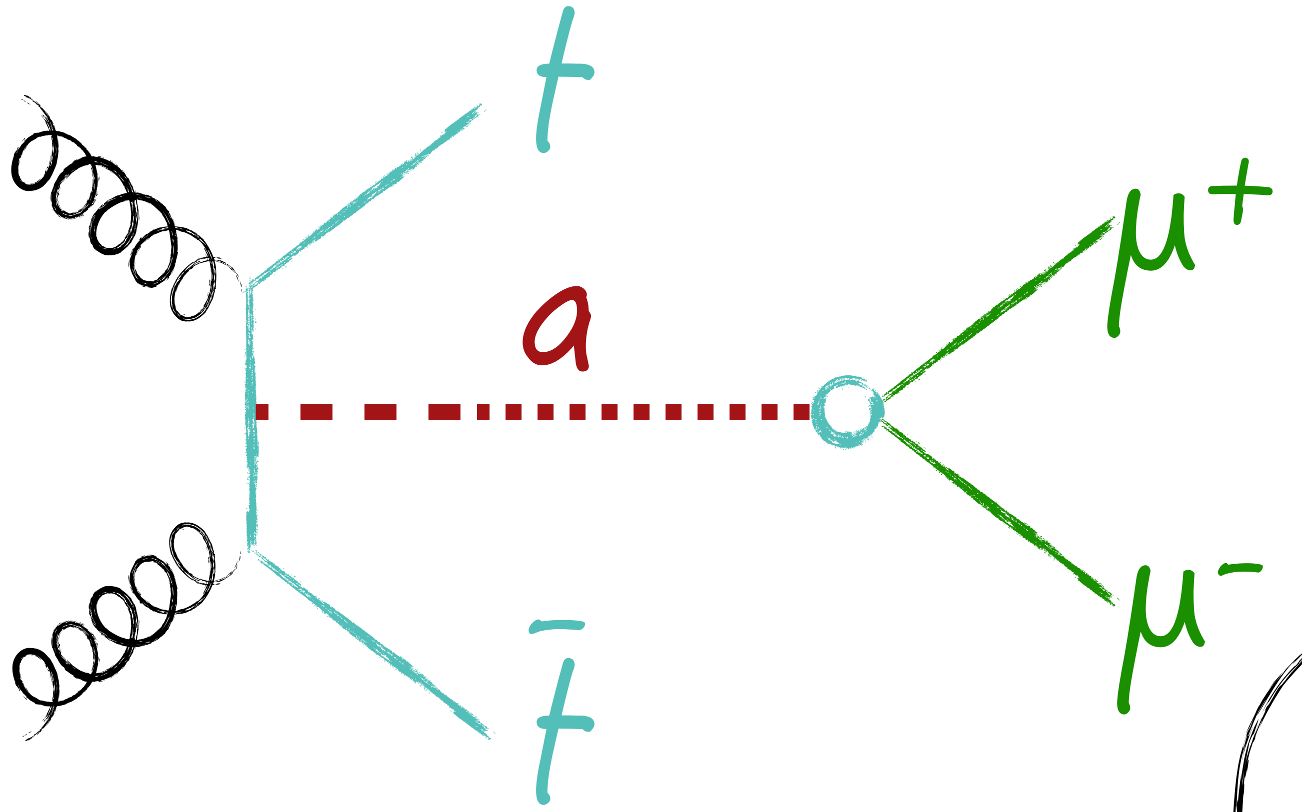
  → easier background rejection,
- pheno study → promising results,

derive limits

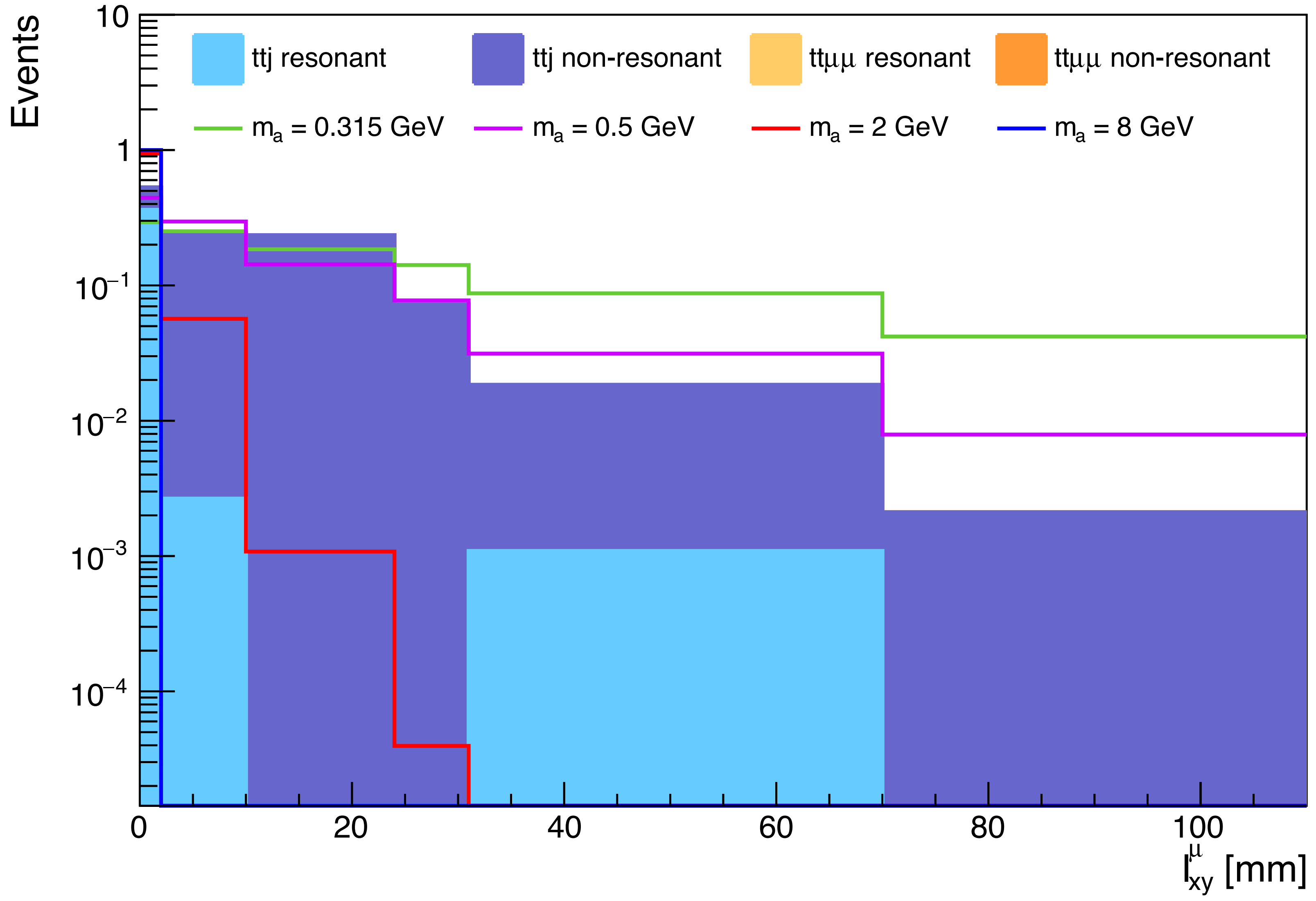


Excellent sensitivity with Run 2 data!

Current work: $t\bar{t}$+ALPs

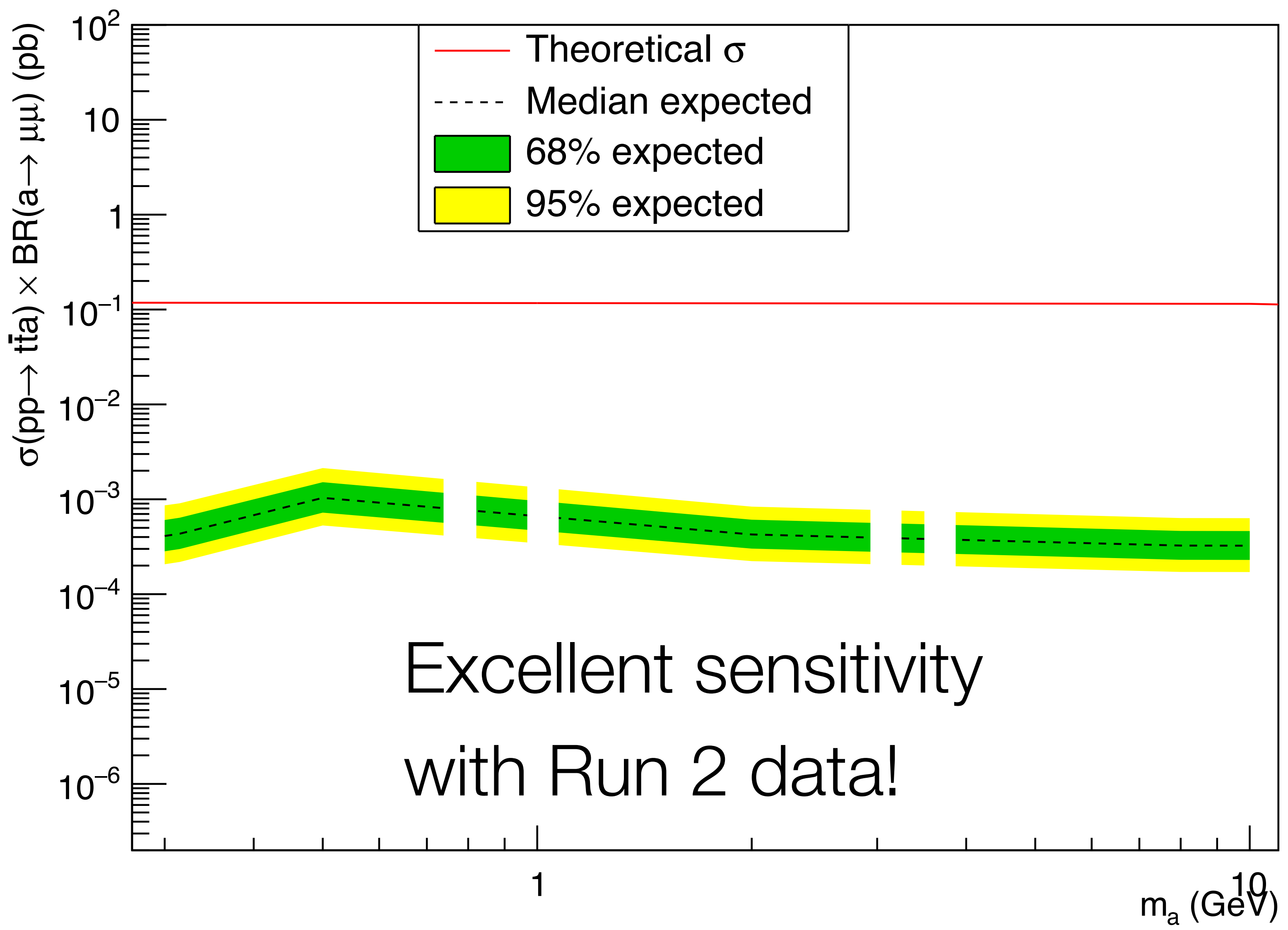


enhance signal



derive limits

- ALPs: new pseudo-scalars:
  → Yukawa-like couplings,
  → preferred interactions with **top quarks**,
- **triggering on $t\bar{t}$ → lower ALP masses,**
- decays loop-induced:
  → **long lived,**
  → easier background rejection,
- pheno study → promising results,
- time to **implement in CMS** and look at the data!



check what sits in CMS data

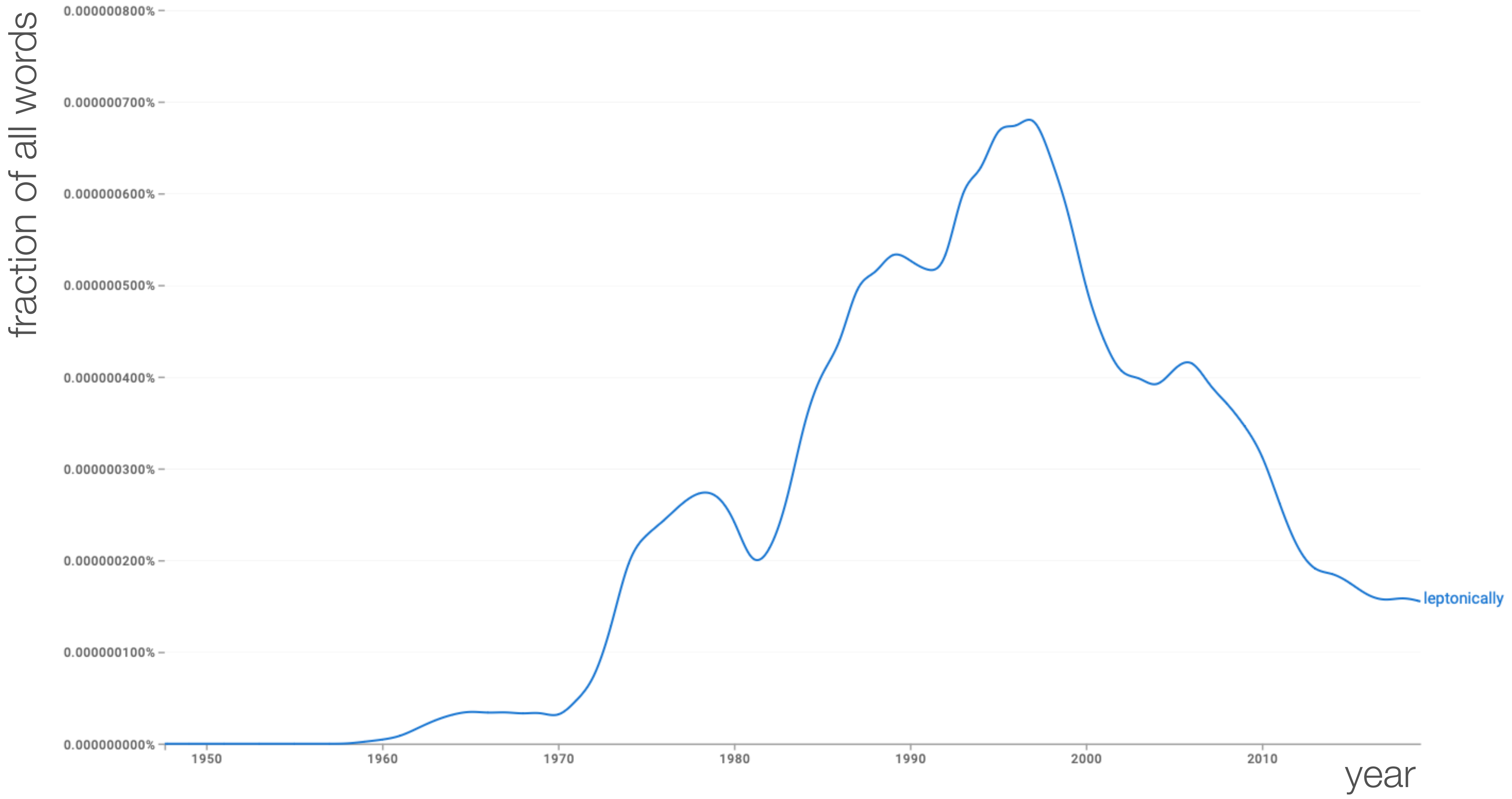
My (not) favorite plot

My (not) favorite plot

Is **“leptonically”** a word?

My (not) favorite plot

Is **“leptonically”** a word?



My (not) favorite plot

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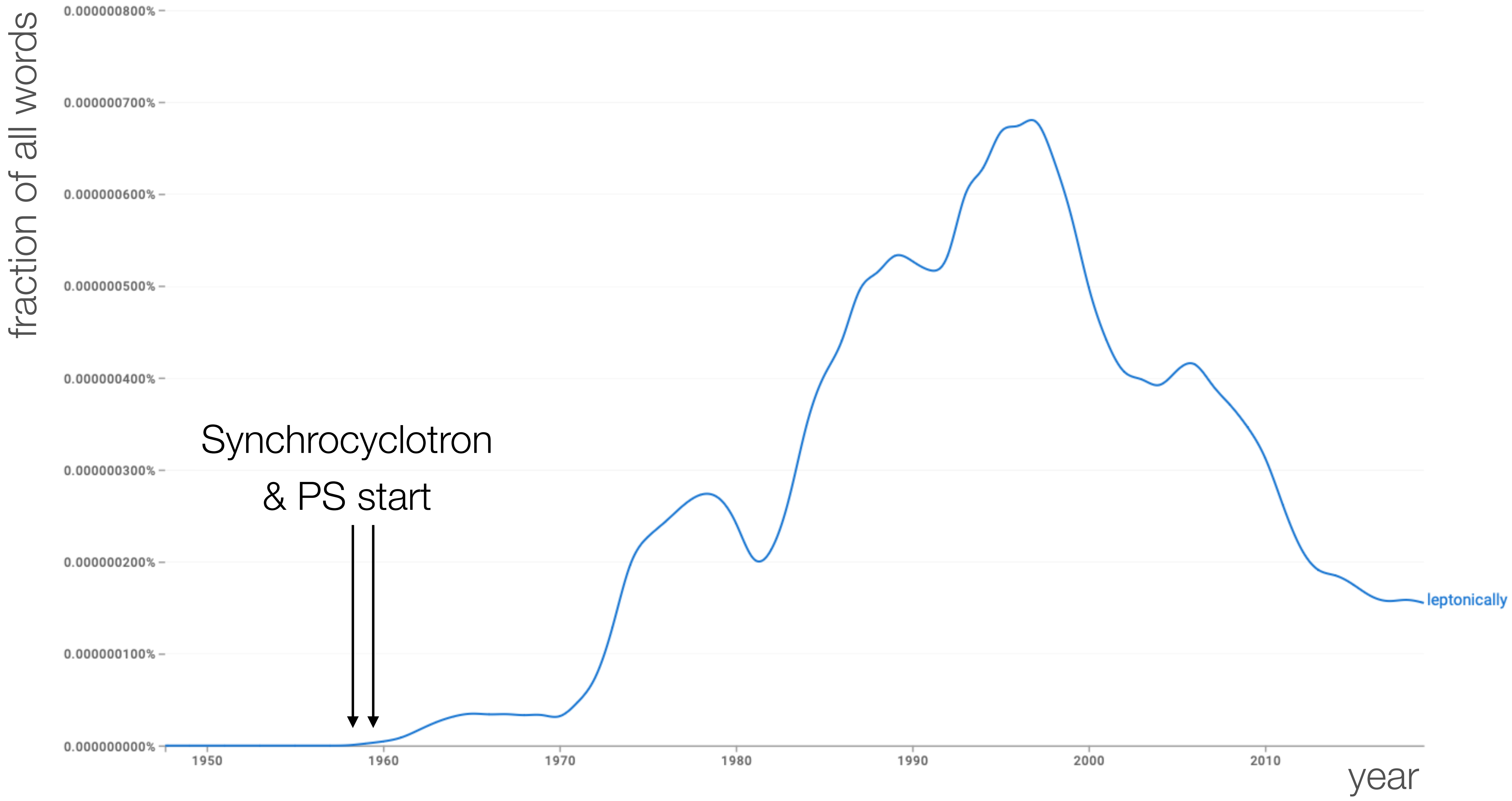

My (not) favorite plot

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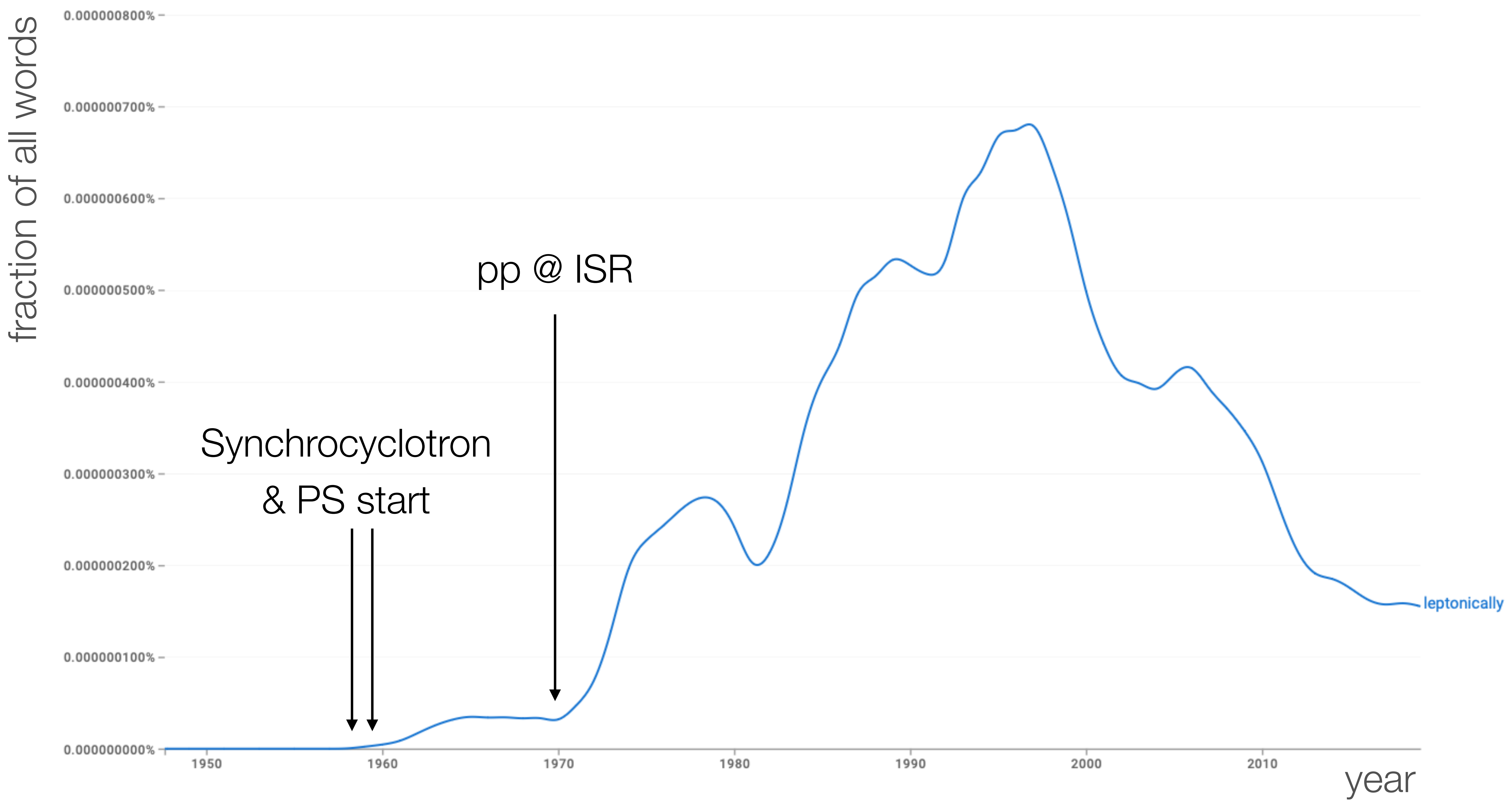

My (not) favorite plot

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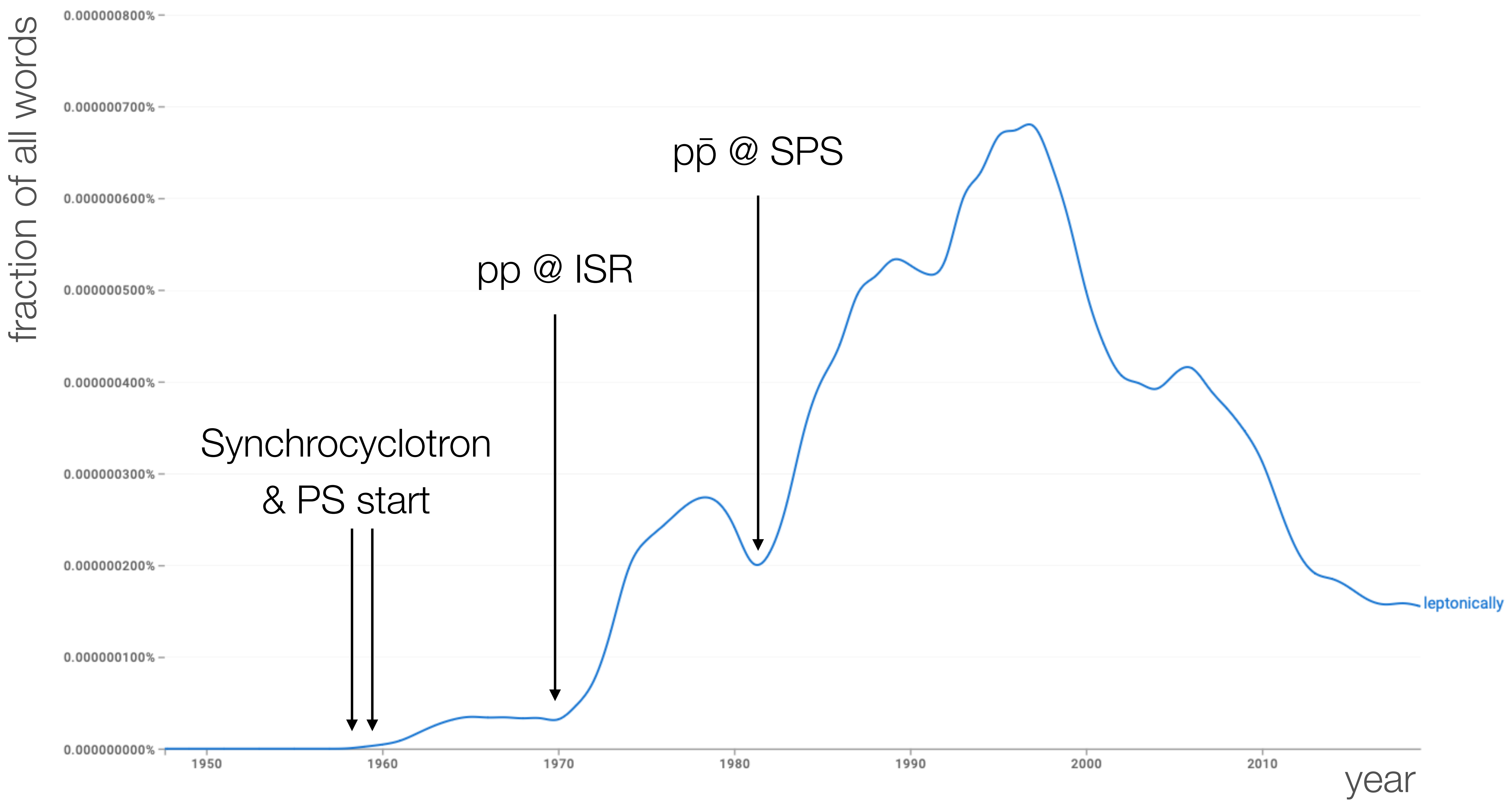
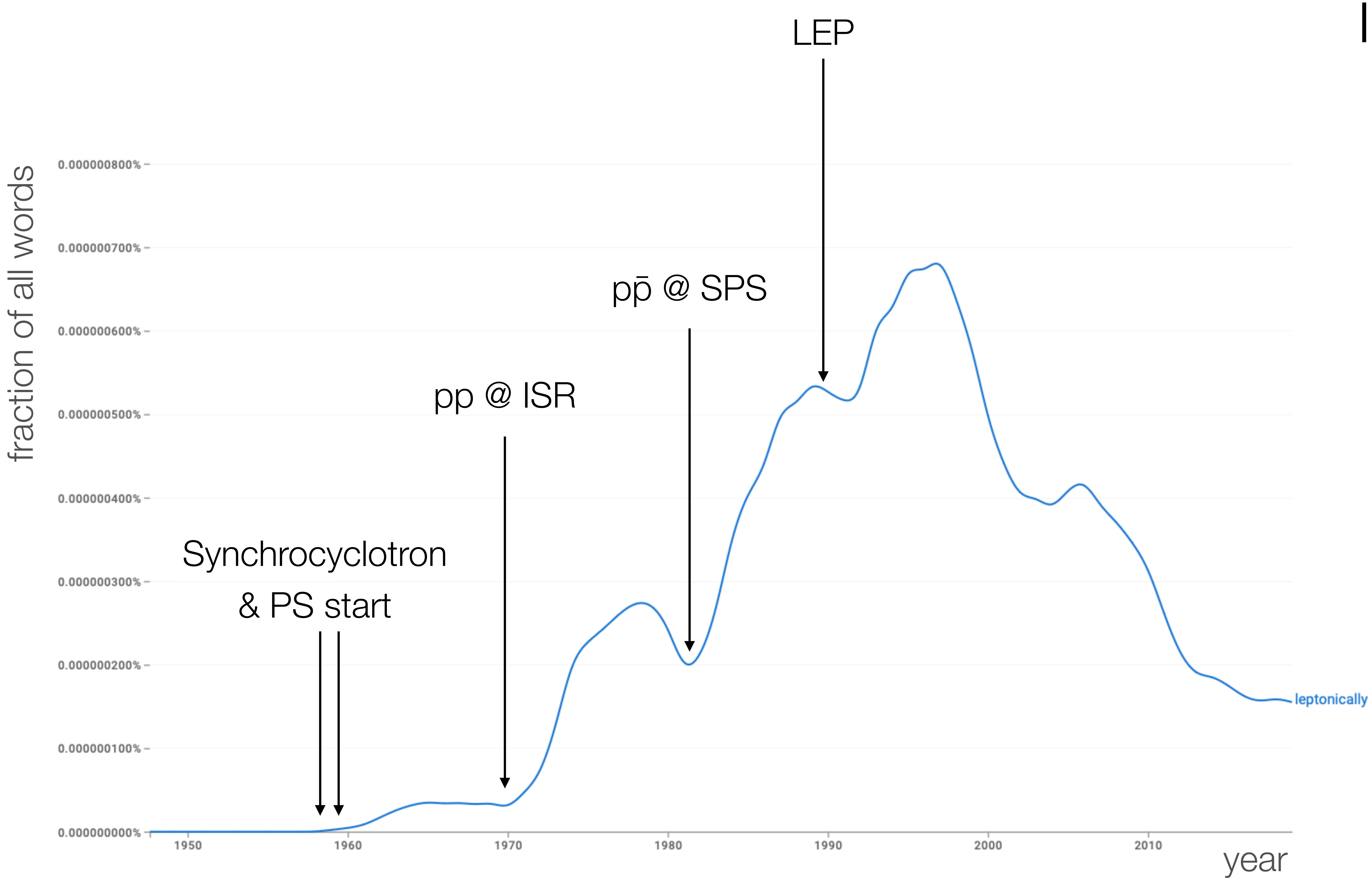


My (not) favorite plot



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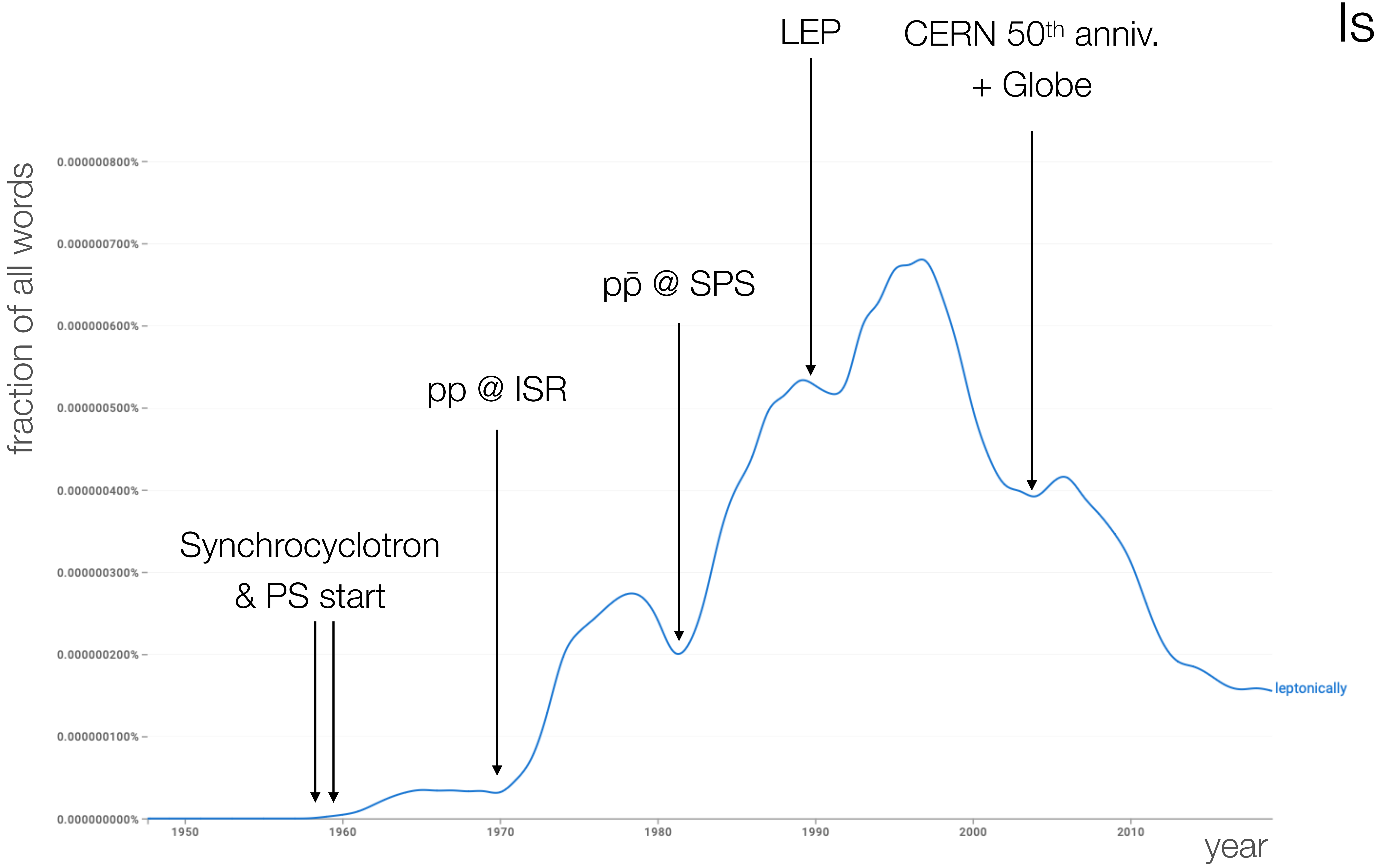
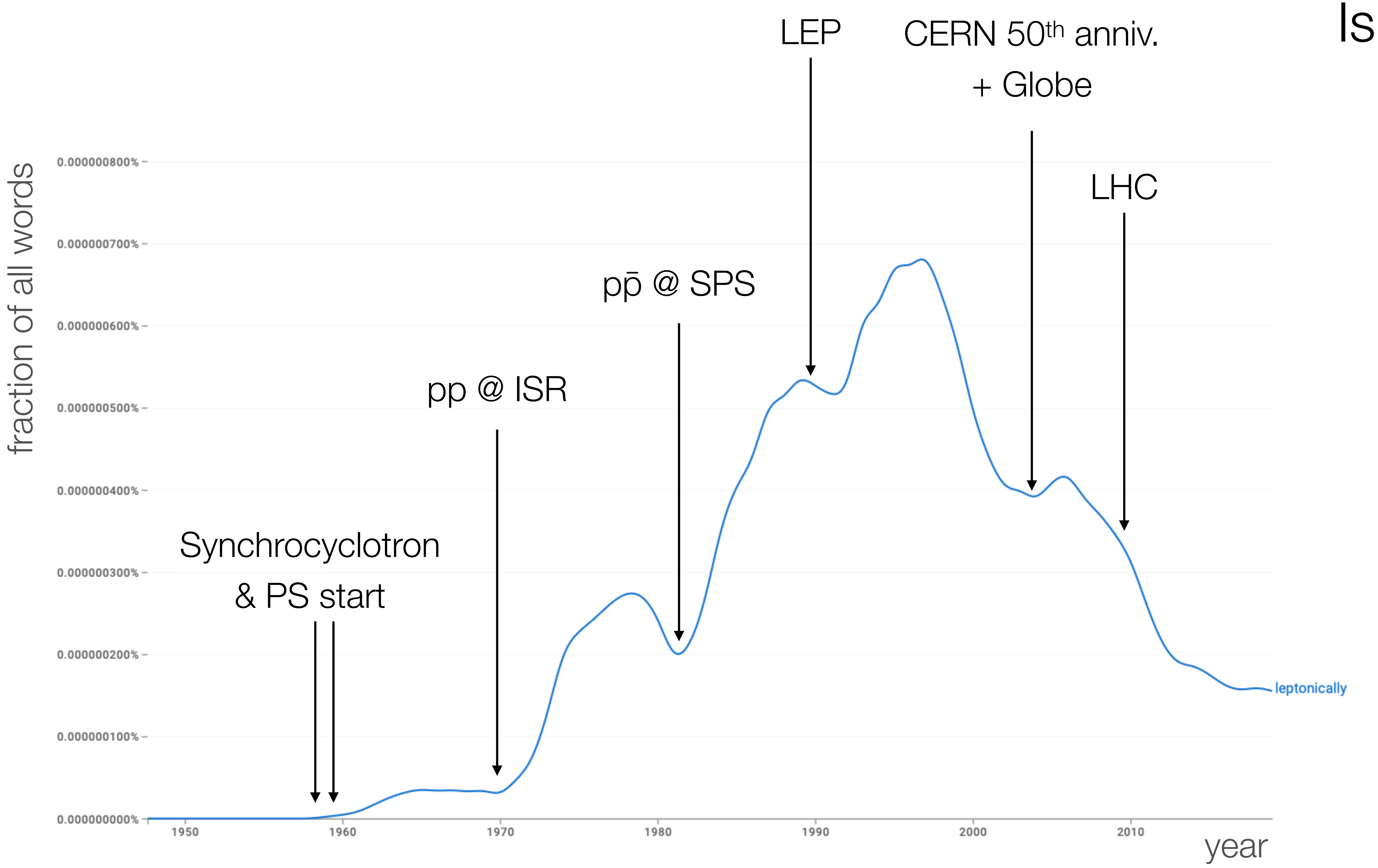
My (not) favorite plot



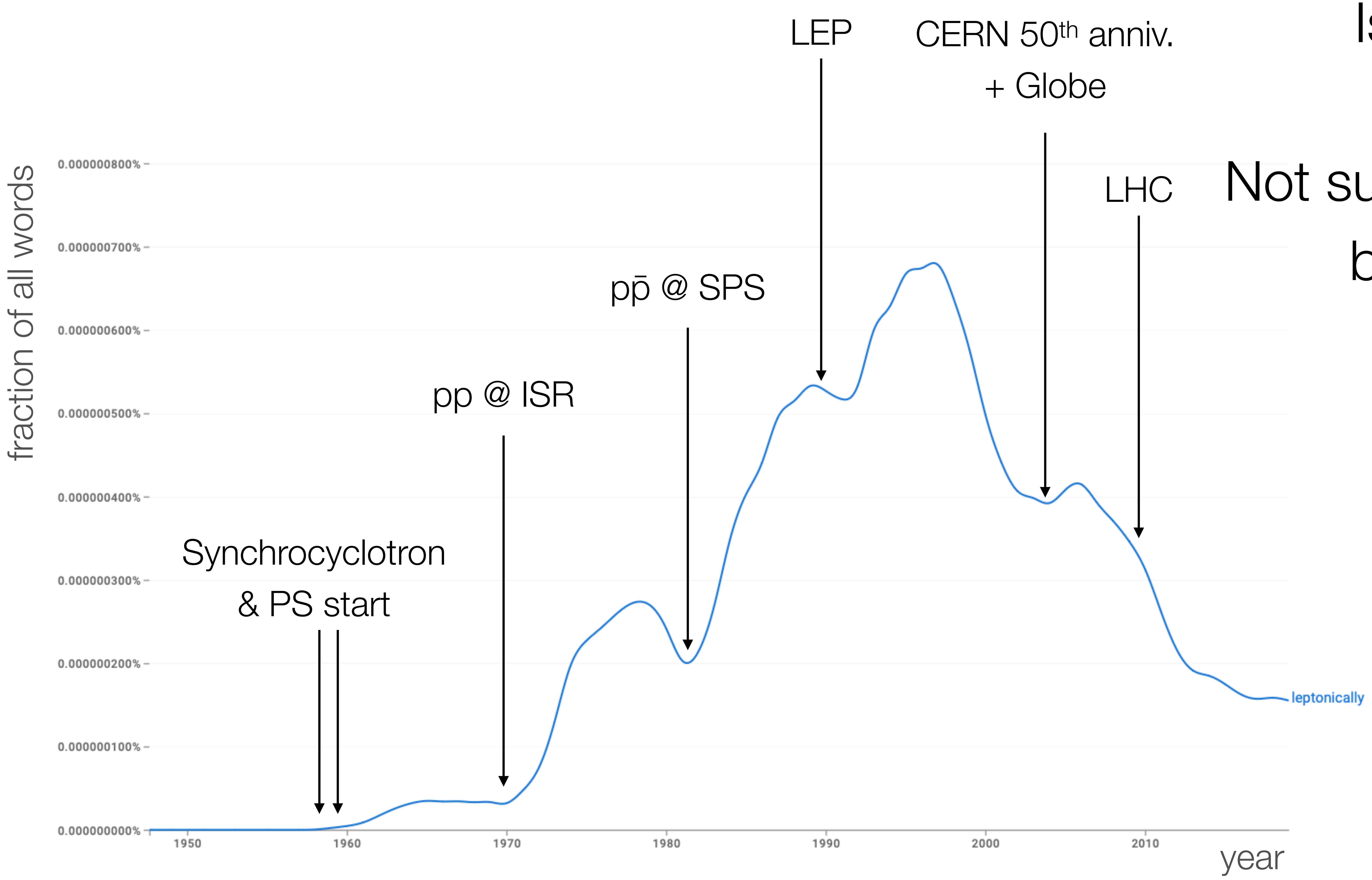
Is “**leptonically**” a word?

My (not) favorite plot



Is **"leptonically"** a word?

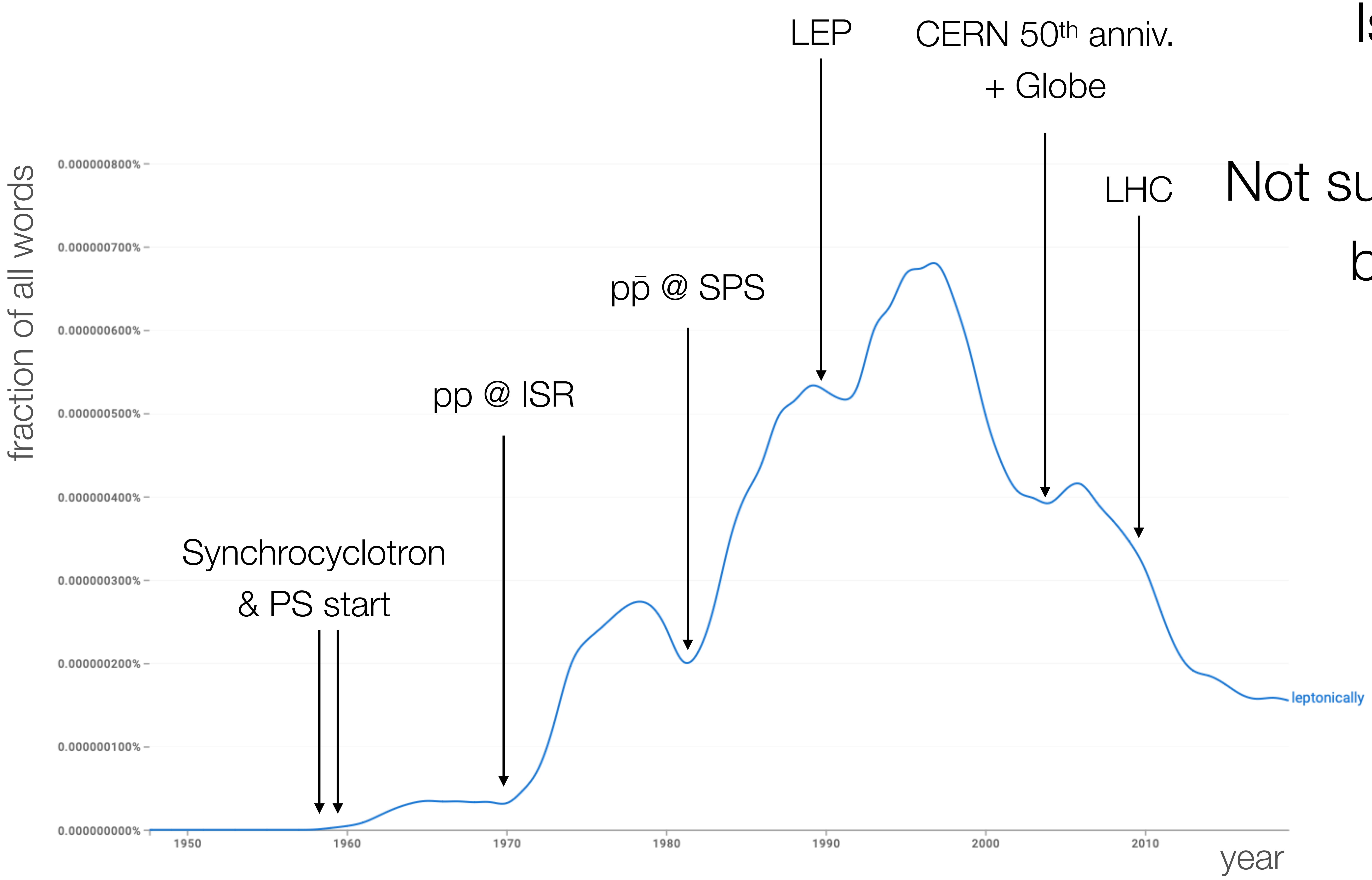
My (not) favorite plot



Is “**leptonically**” a word?

Not sure which collider to build next but we **better hurry up…**

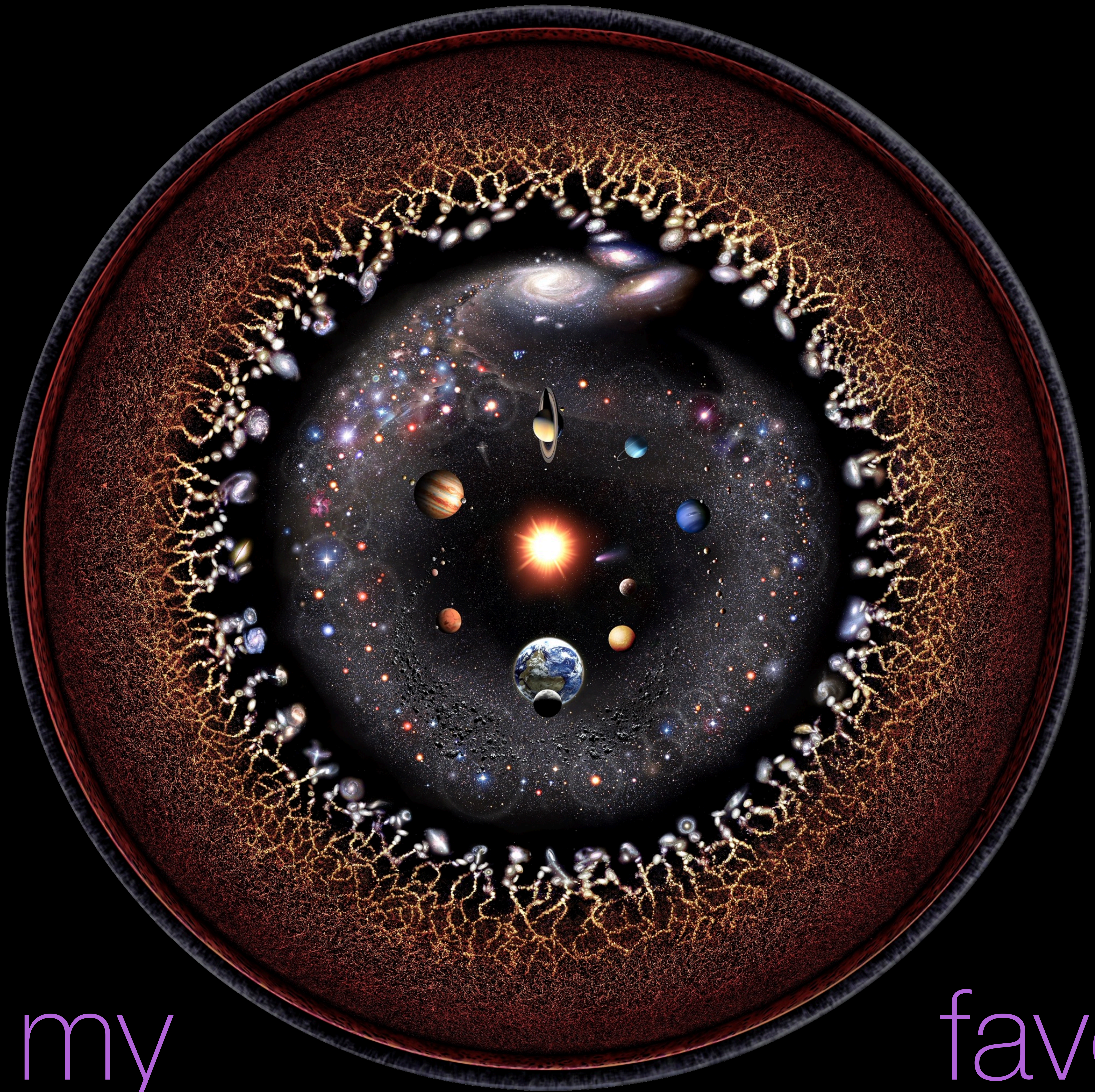
My (not) favorite plot



Is “**leptonically**” a word?

Not sure which collider to build next but we **better hurry up**…

…or **a word will die!**

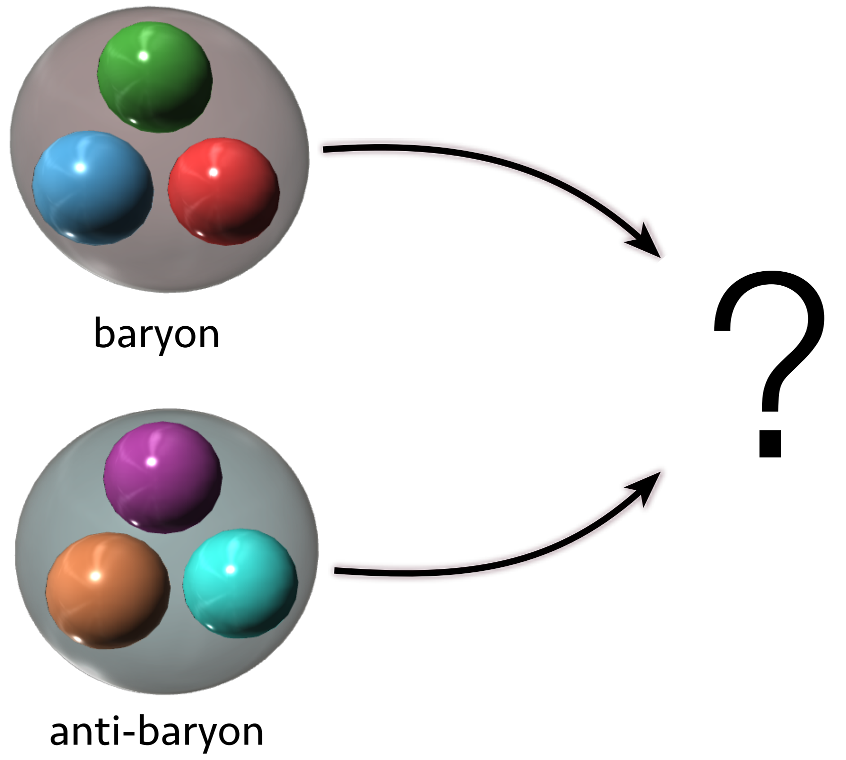


(maybe) my favorite plot

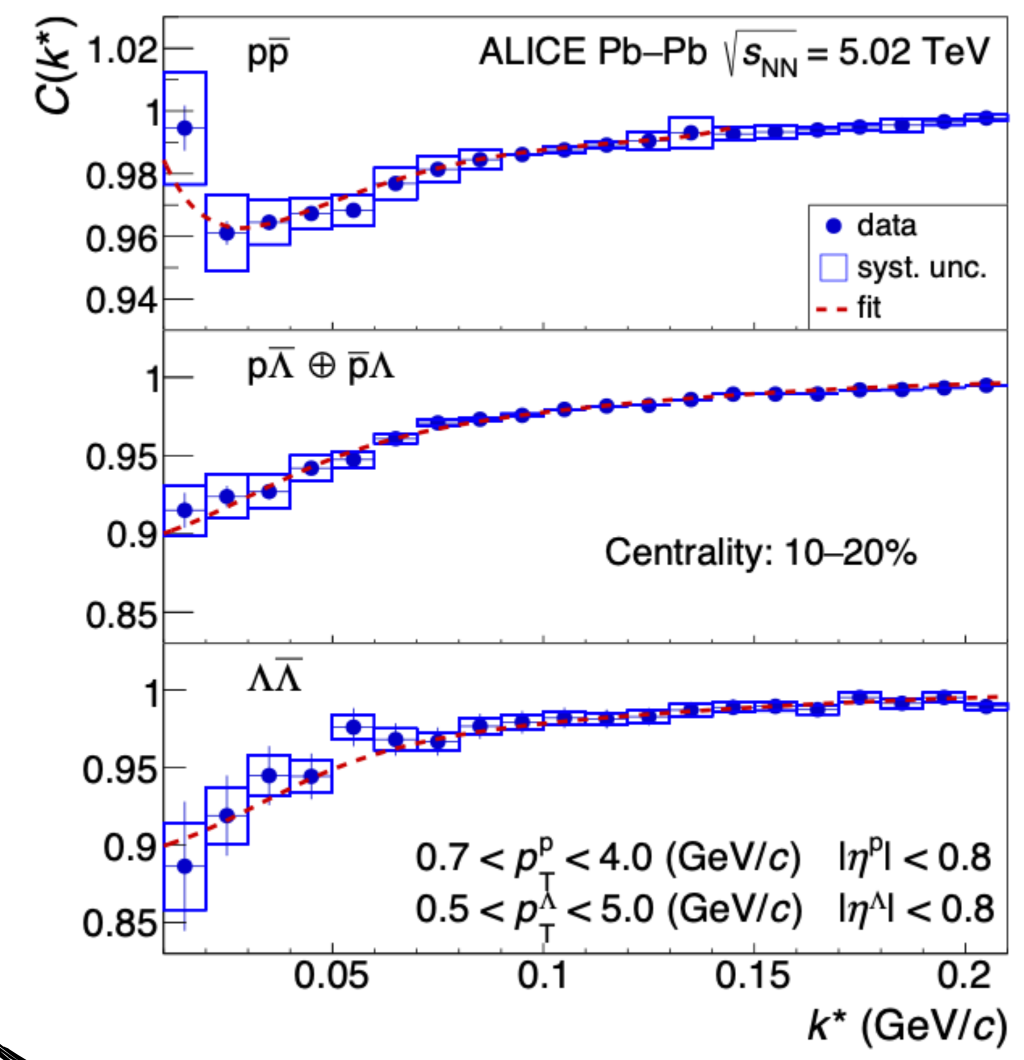
Backup

Baryon-antibaryon interactions

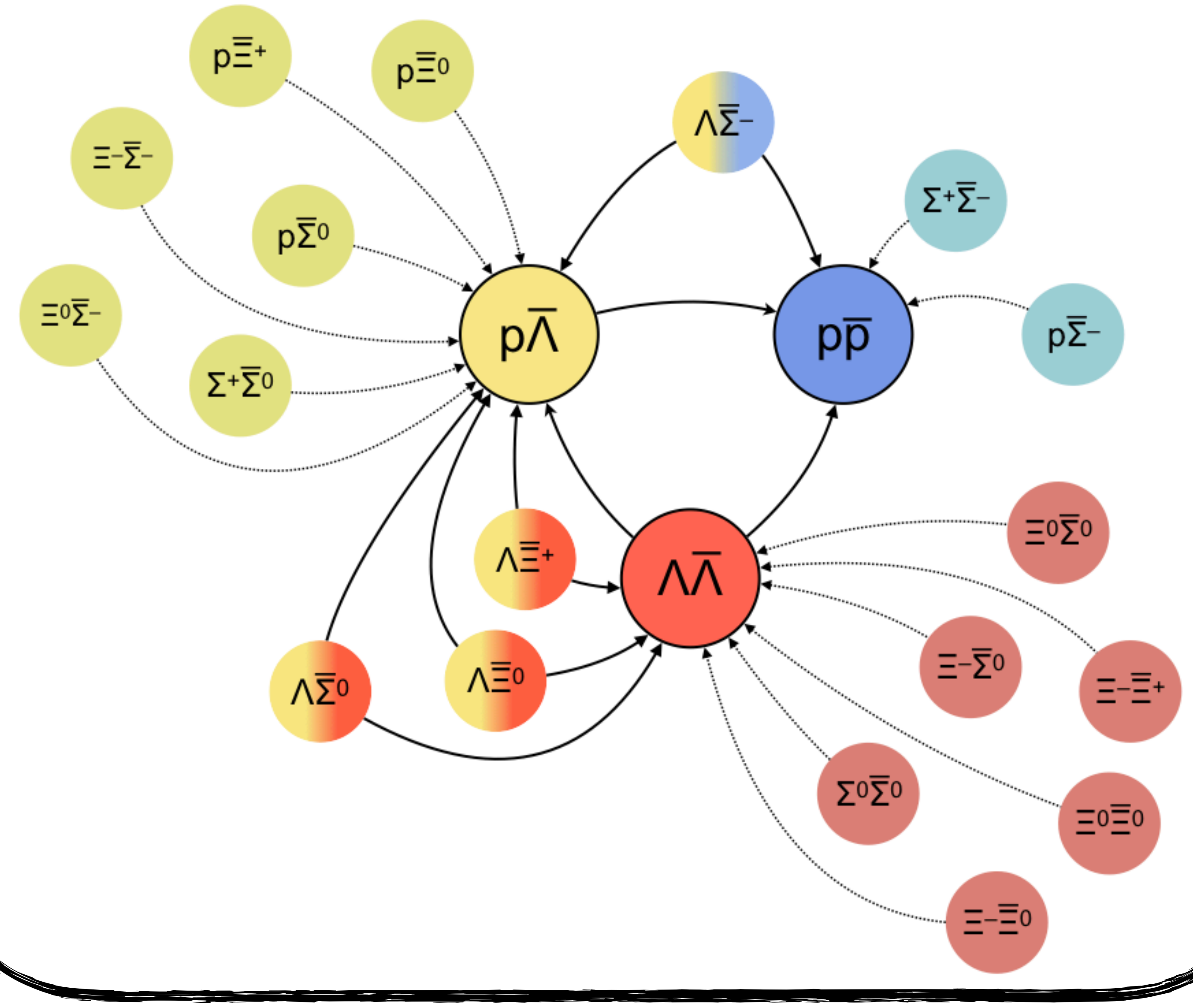
What happens when a strange baryon meets an antibaryon?



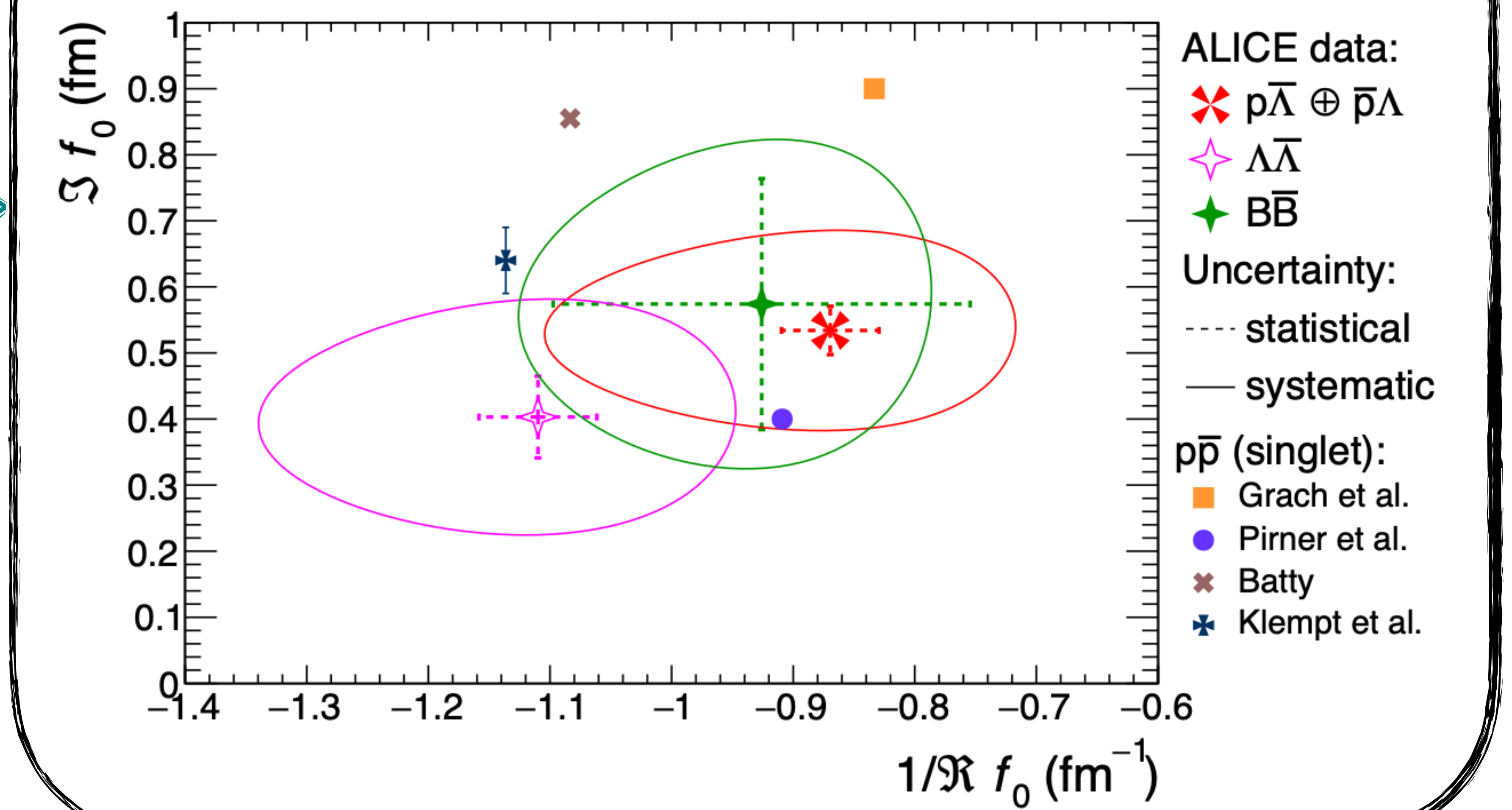
measured 36 $B\bar{B}$ **correlation functions**



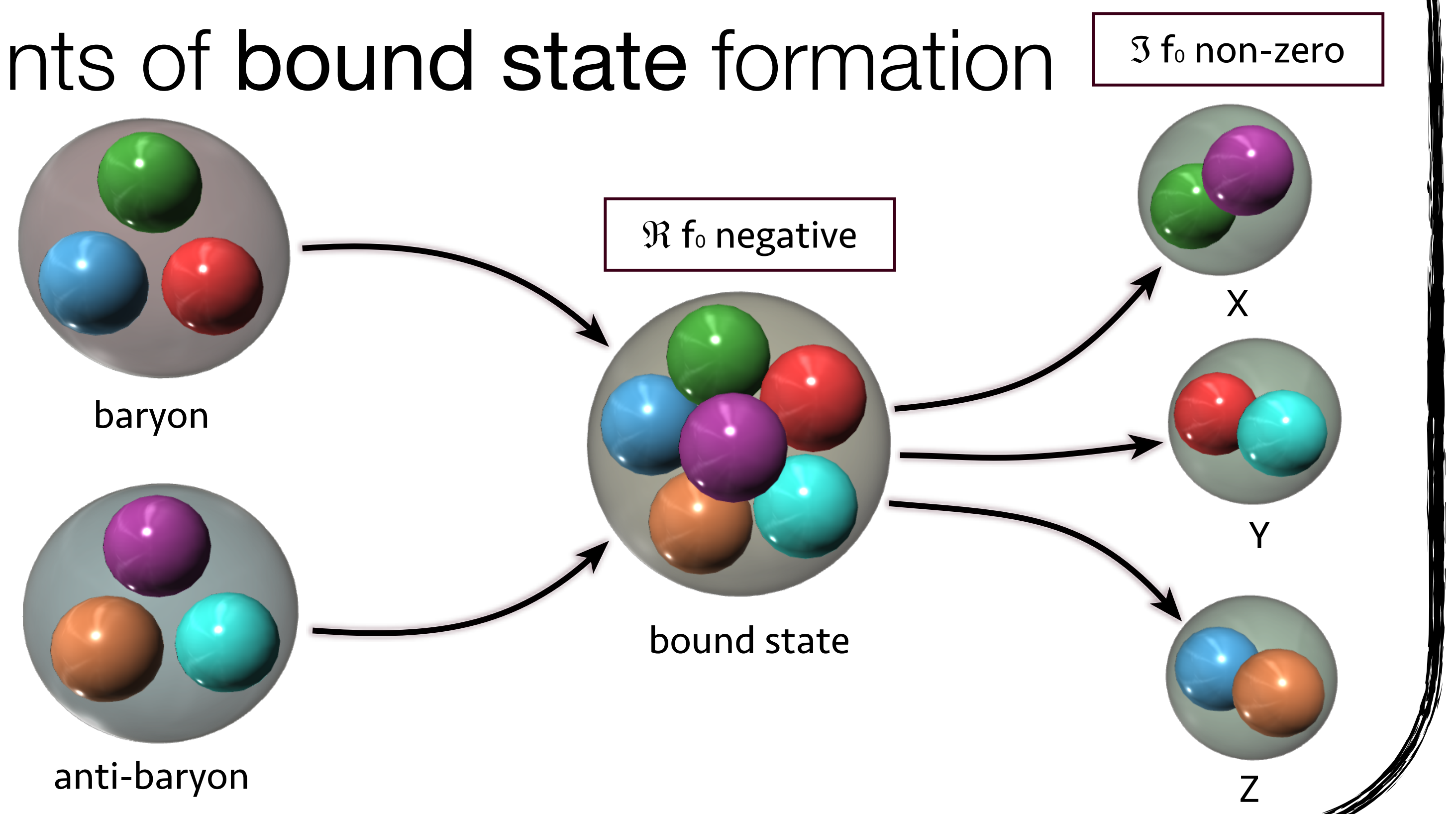
simultaneous fit **exploiting links** between different pairs



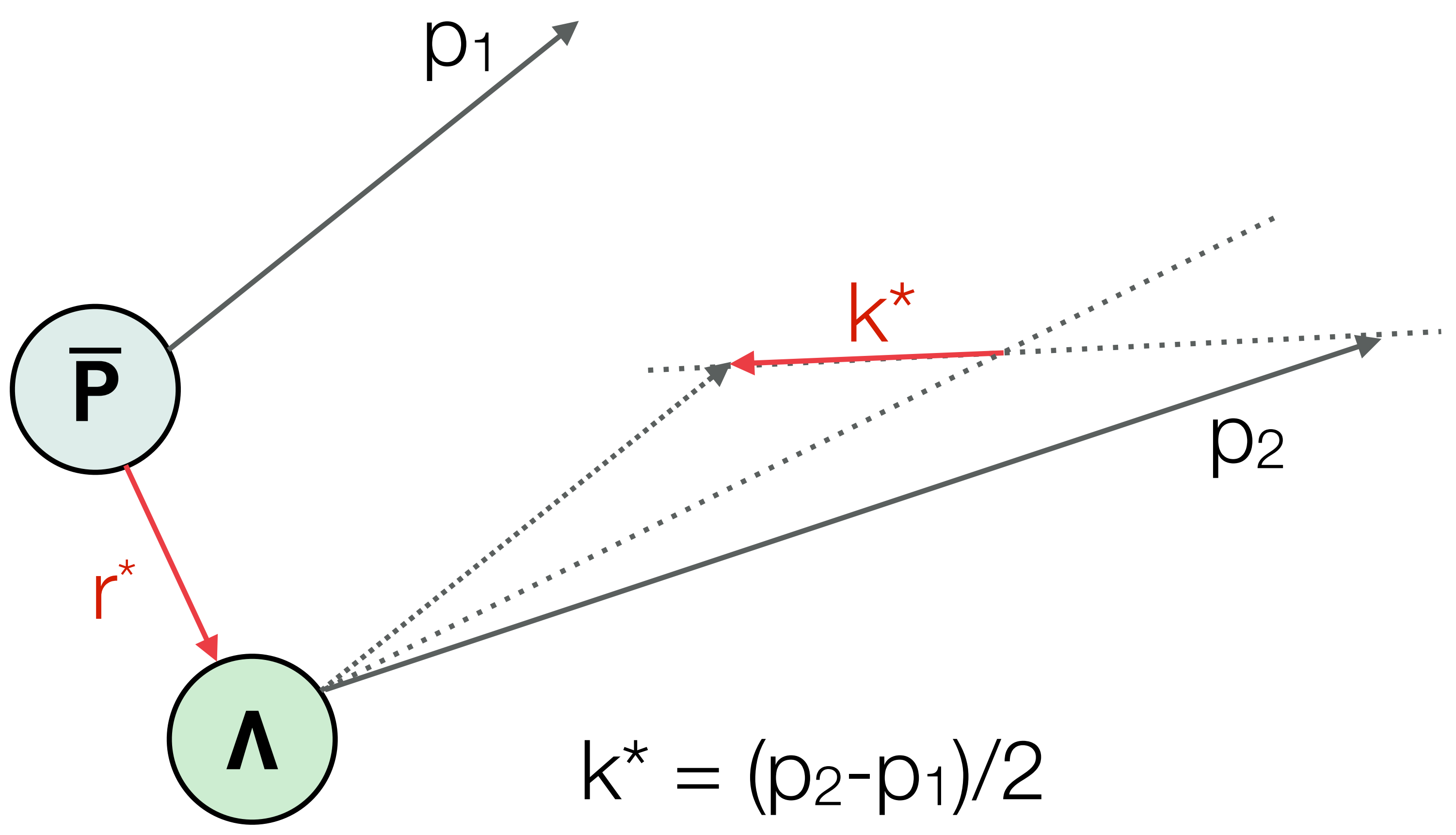
extraction of **interaction parameters**



- strong **annihilation** channel
- hints of **bound state** formation



BARYON-ANTIBARYON INTERACTIONS

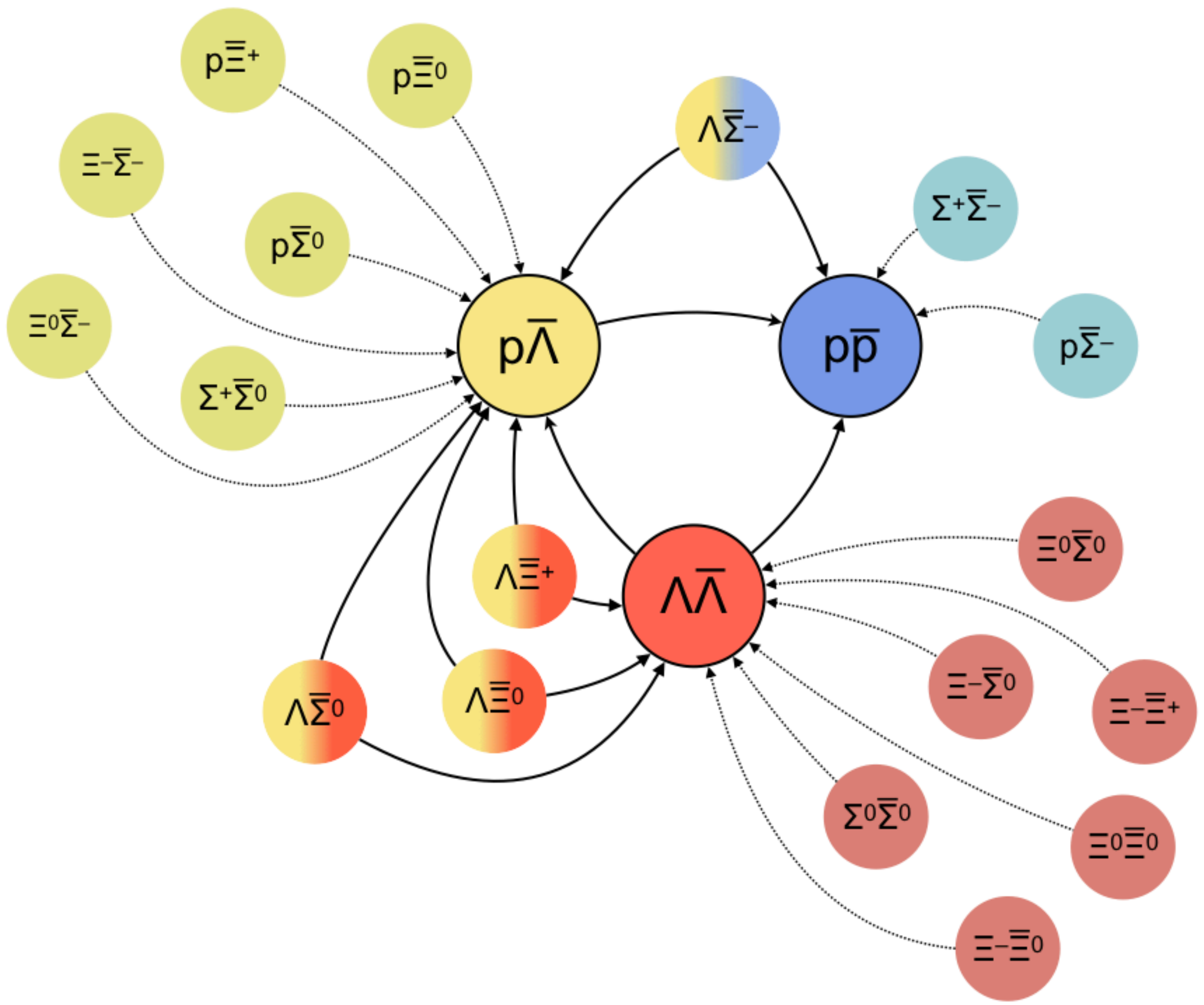


Source emission function
(size and shape of the source)

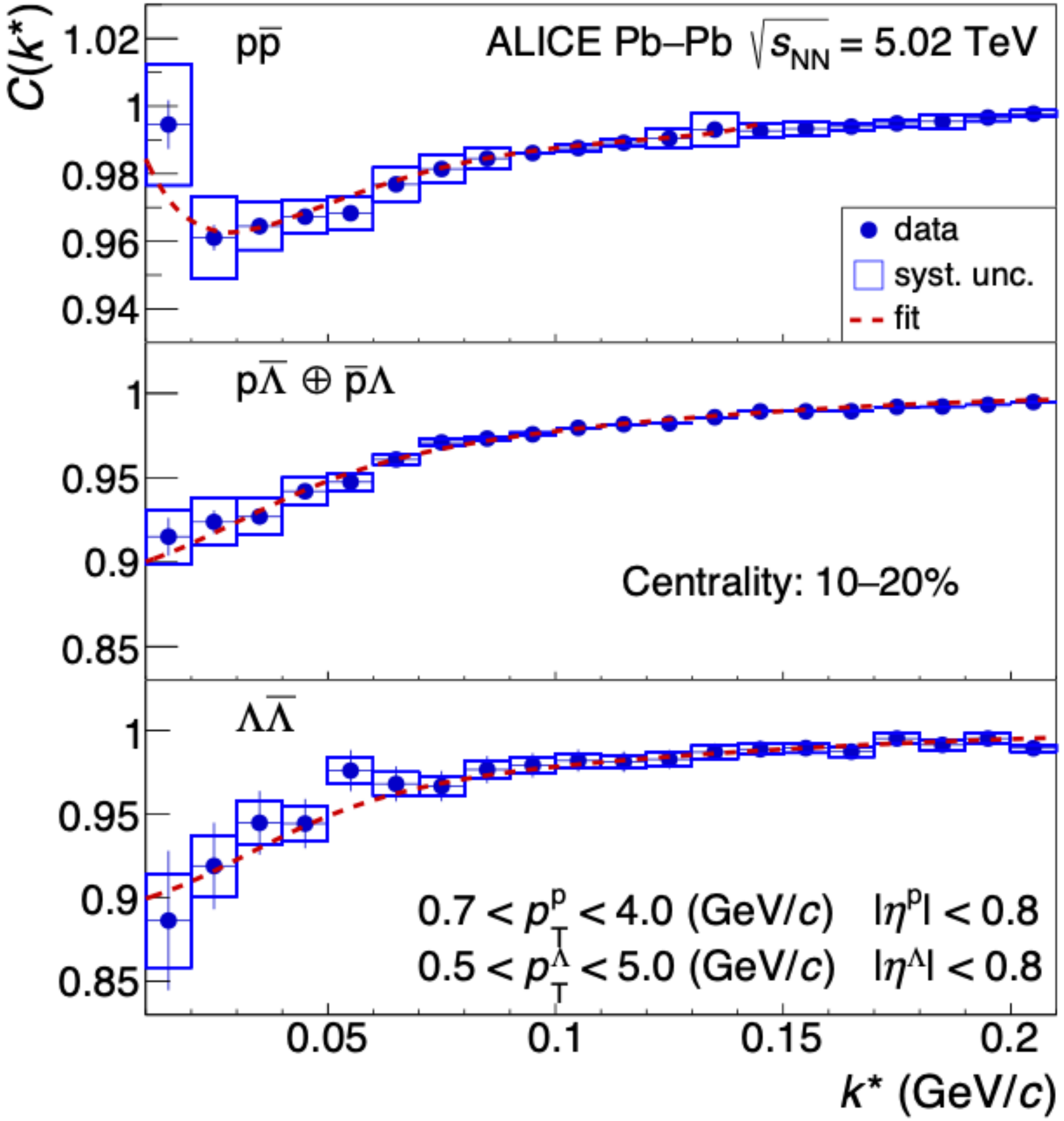
$$C(k^*) = \int S(\mathbf{r}) \left| \Psi(k^*, \mathbf{r}) \right|^2 d^4\mathbf{r}$$

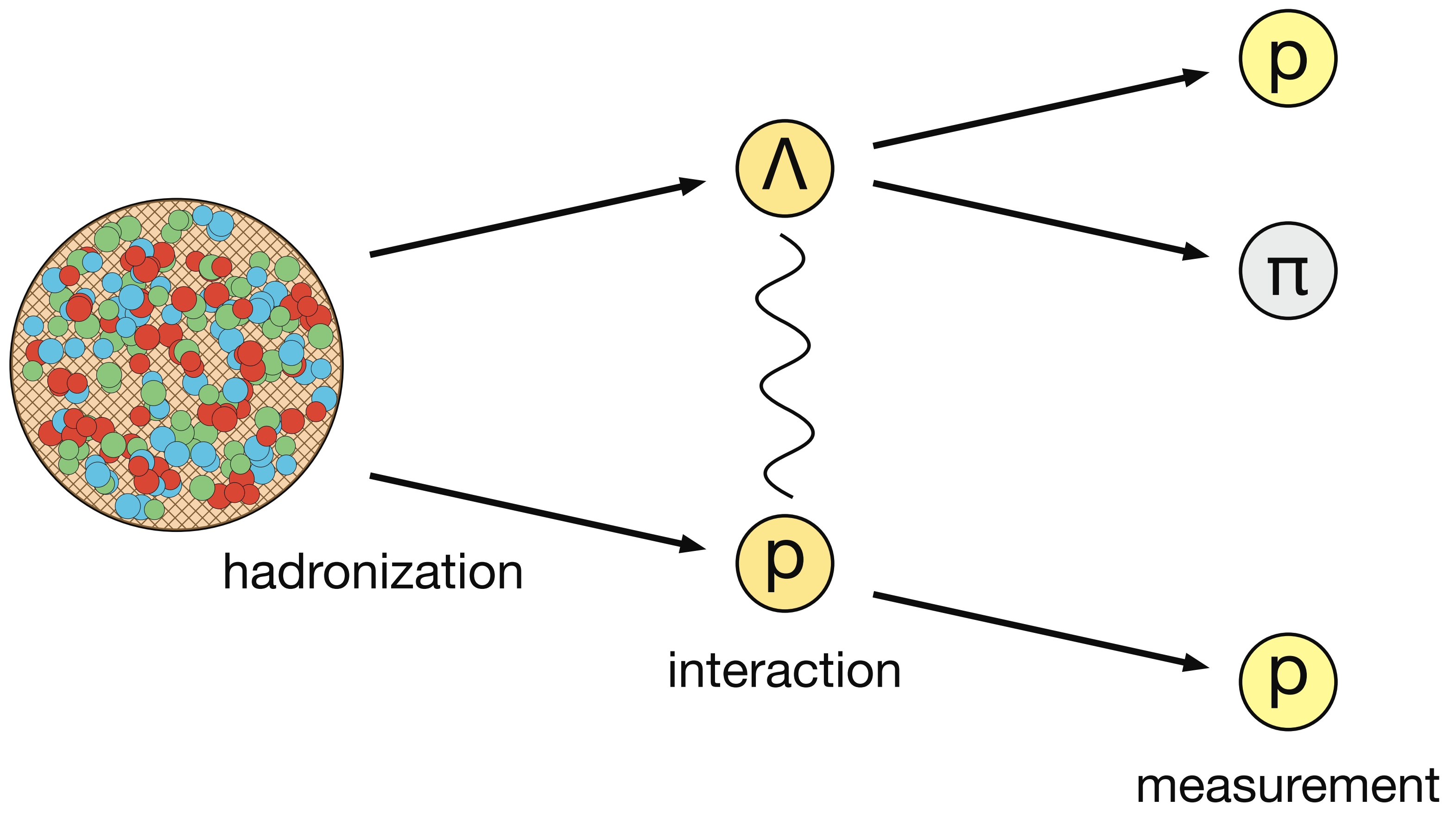
Correlation function
(can be measured)

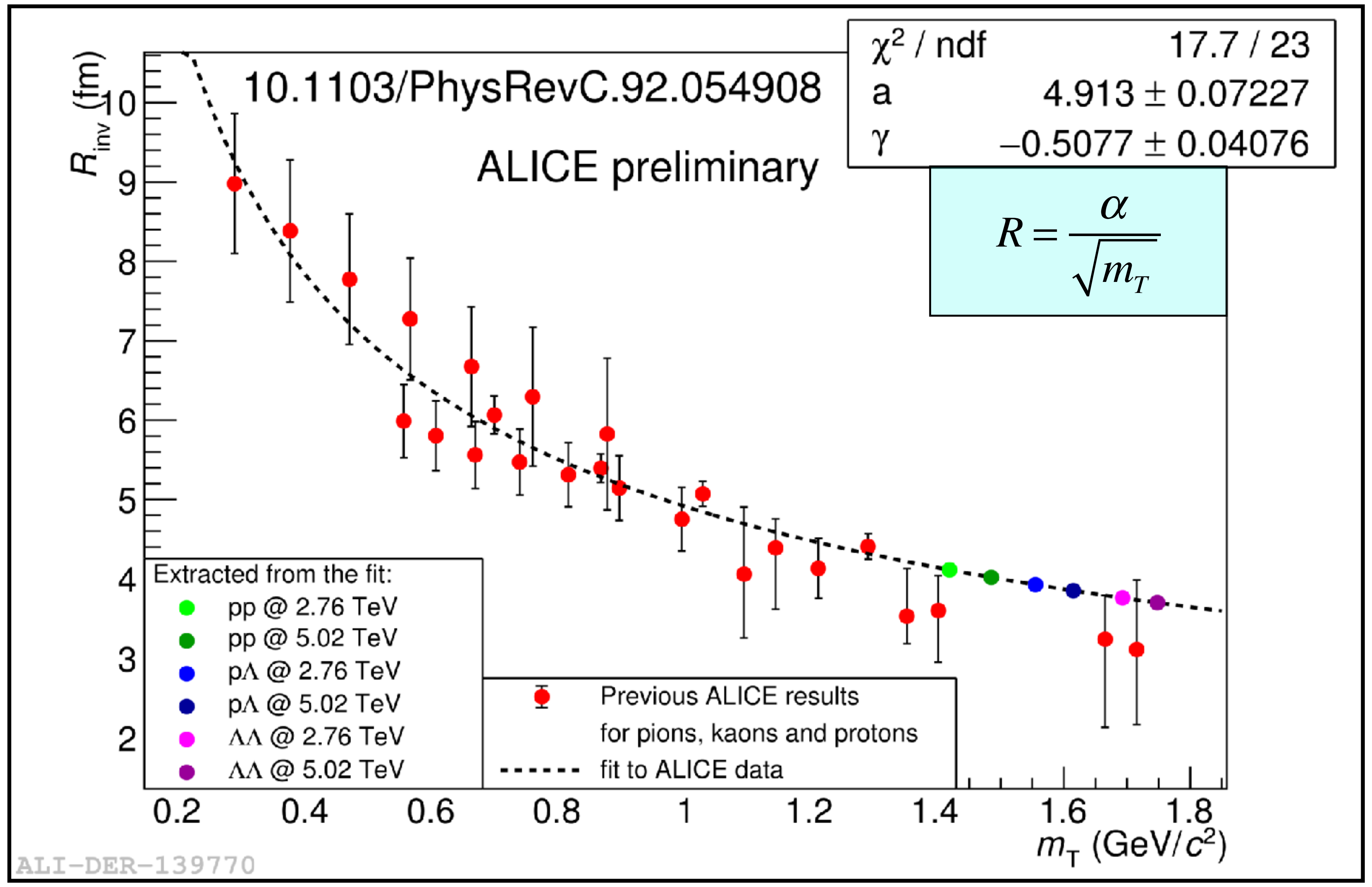
Pair wave function
(describes interaction)



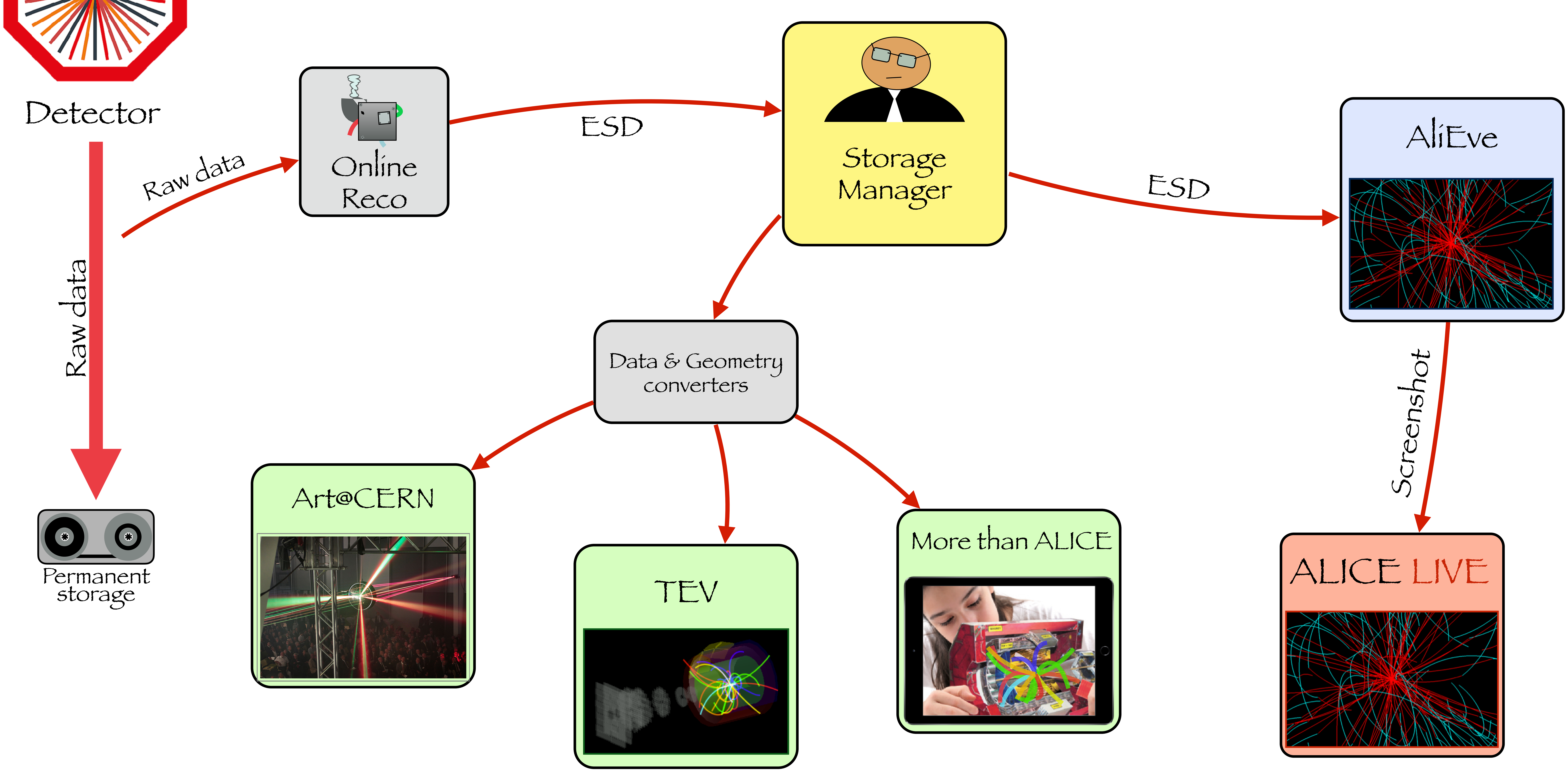
Measurement







EVENT VISUALIZATION




ALICE
Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV

CERNpress @CERNpress · Nov 25
[Press Release] The #LHC collides ions at new record energy: cern.ch/go/6F7K
ALICE Experiment, ATLAS Experiment, LHCb Experiment and CMS Experiment CERN
83
82
search
dating
more
International
theguardian
ball
opinion
culture
business
lifestyle
fashion
environment
tech
travel
browse all sections
CERN makes hotter quark-gluon soup
Every year, as Christmas approaches and the bankers of Geneva sit around their fondues yodelling festive tunes and melting cheese with holes in it, the Large Hadron Collider switches from protons to lead. But this year is a bit special
Most popular
Champions League last-16 draw - as it happened
Europa League knockout-stage draw -as it happened
Australian newspaper cartoon depicting Indians eating solar panels attacked as racist
дронный Коллайдер
изучению кварк-
лазмы
27 listopada 2015, 07:57 | Astronomia/fizyk
ALICE
rd high
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PX) Dec 03, 2015
powerful accelerator, the 27
dron Collider (LHC)
N in Geneva established
n lead nuclei, this morning,
rgies ever.
n colliding protons at record
the summer, but now the
ne to collide large nuclei
, consist of 208 neutrons
experiments aim at
LIVE
ENCIA
Nuevo récord de energía en el LHC
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Mots-clés | QCD, cern, big bang, cosmologie
Le LHC explore le quagma du Big
Chaque année, durant un mois, lors des saiso
font entrer en collision des ions lourds pour
gluons, le quagma. Ils viennent de battre ur
énergies mises en jeu. De quoi mieux compren
Le 28/11/2015 à 09:35 - Laurent Sacco, Futura-Sciences
3 commentaires
RÉAGIR
Une vue du feux d'artifice de particules secondaires produites par les collisions d'ions de plomb dans le détecteur Alice du LHC au Cern le 25 novembre 2015. © Federico Ronchetti, Cern
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SCIENTIFIC METHOD / SCIENCE & EXPLORATIO
CERN starts first lead collisions in upgraded Large Hadron Collider
Resulting collisions have over a Peta-electronVolt of energy.
by John Timmer - Nov 25, 2015 10:40pm CET
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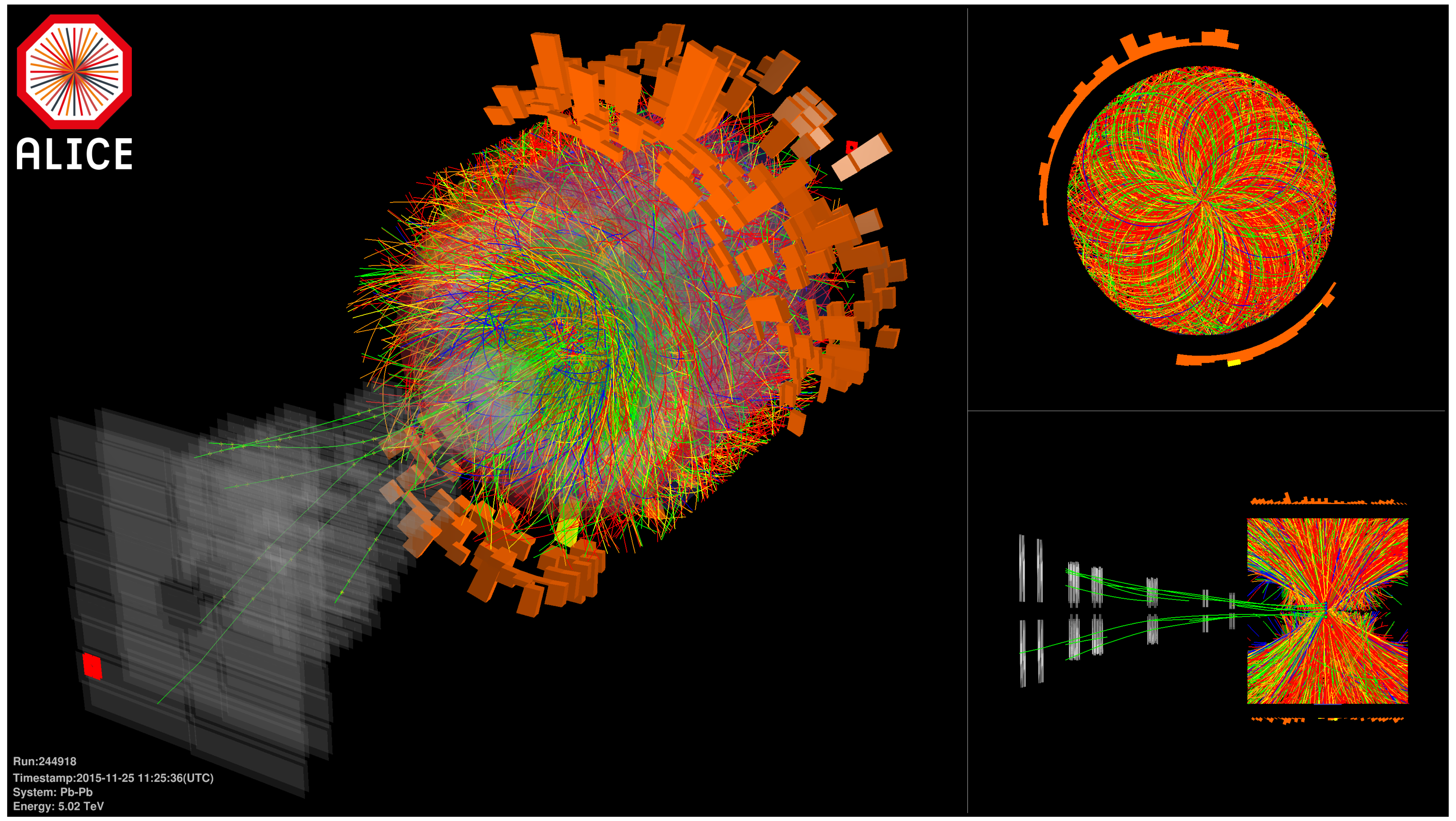
Nauka / Kolejne osiągnięcie Zderzacza – przekroczył właśnie granicę 1PeV
Kolejne osiągnięcie Zderzacza – przekroczył w granicę 1PeV
utor: Adam Kudelski, Opublikowano: 29 listopada 2015
una de las varias existentes en la cósmica "sopa primordial" que aportara información sobre quarks y gluones.
ALICE es uno de los principales componentes del LHC, y estará involucrada directamente en esta nueva fase de colisiones de iones de plomo. Este experimento fue diseñado específicamente con este propósito y durante la parada técnica mejoró aún más.

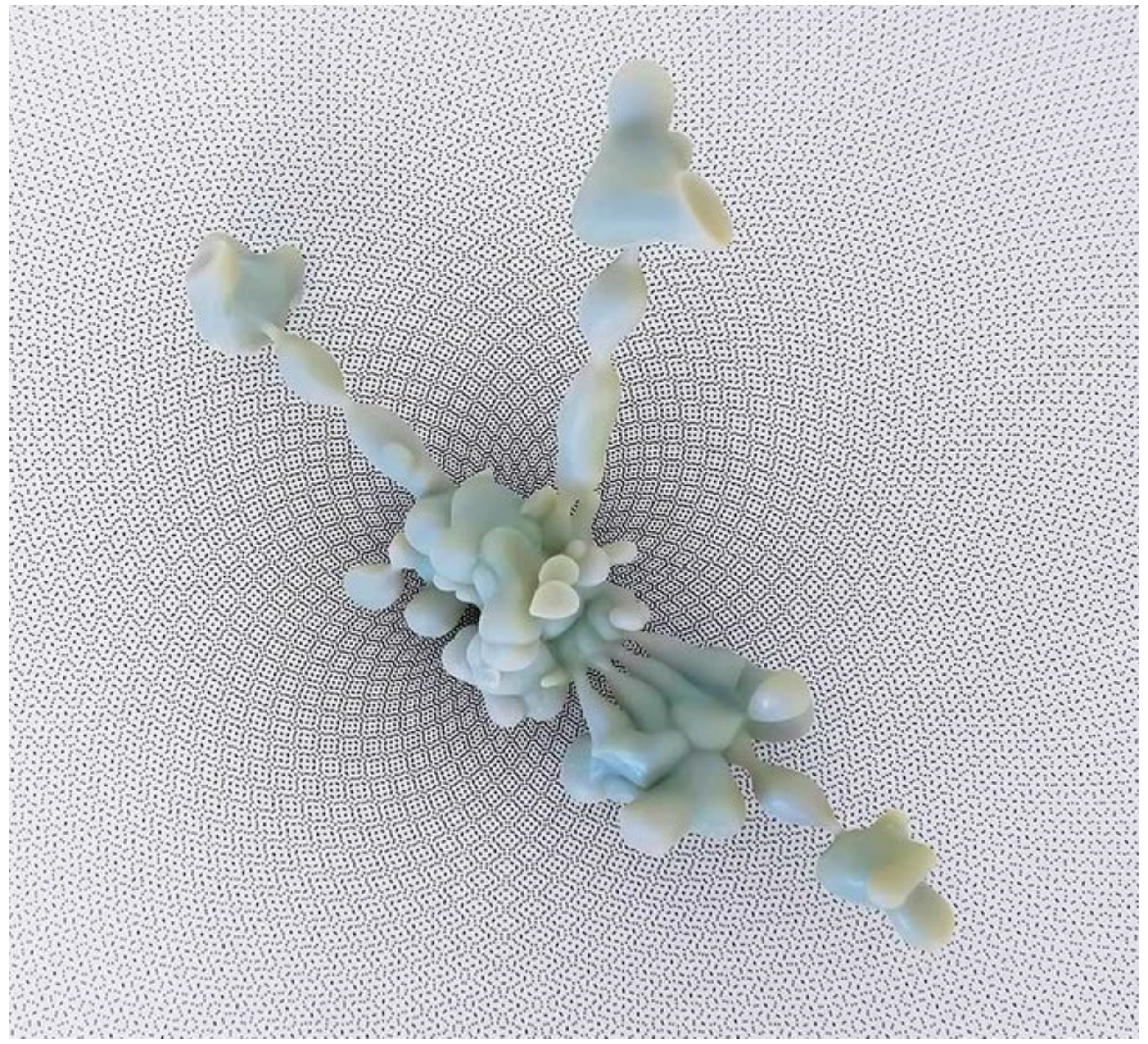
ALICE Visualization



Astronarium

Little Bang Theory

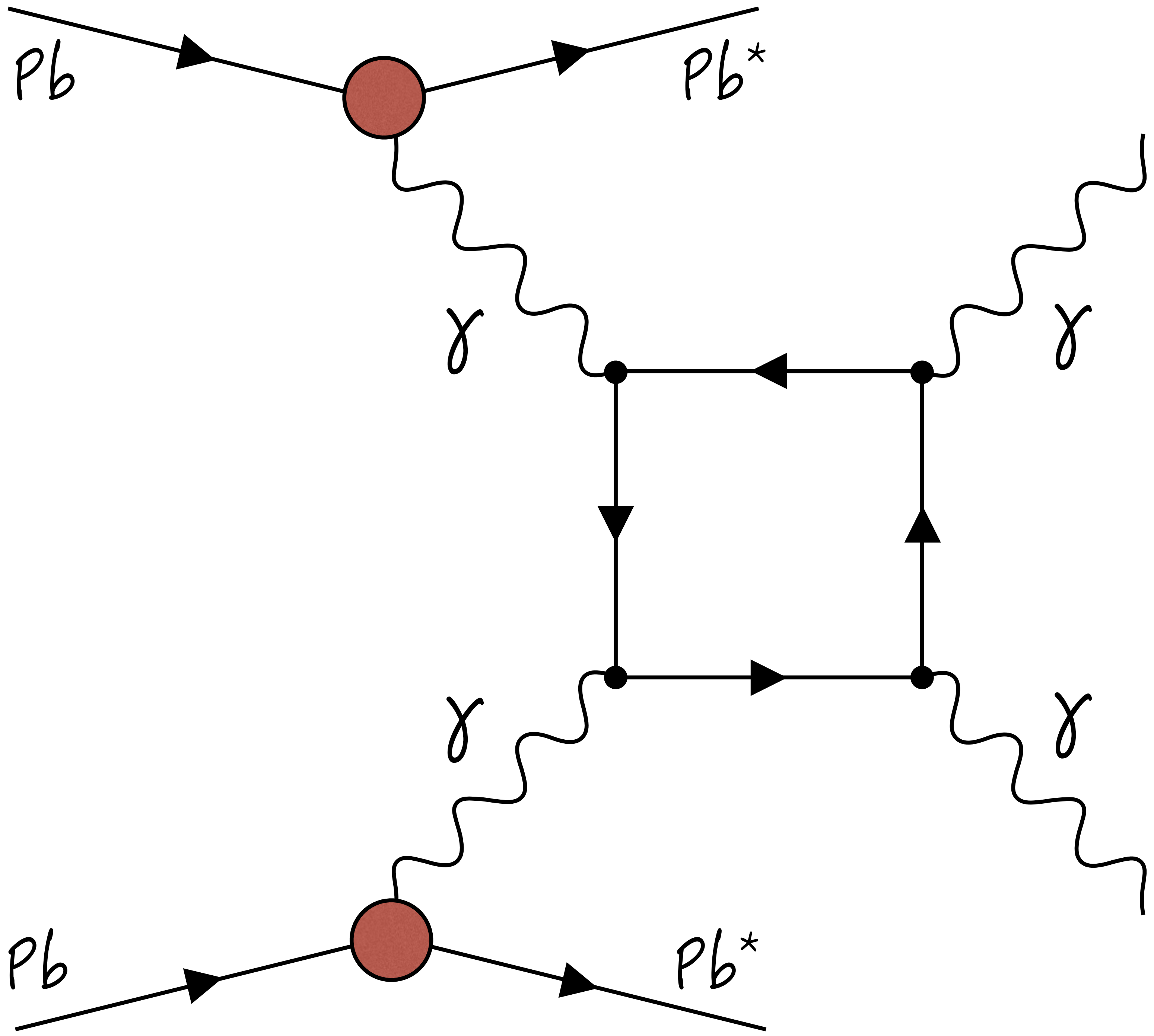
Quantum Nuggets



Touching the invisible

CERNLand games

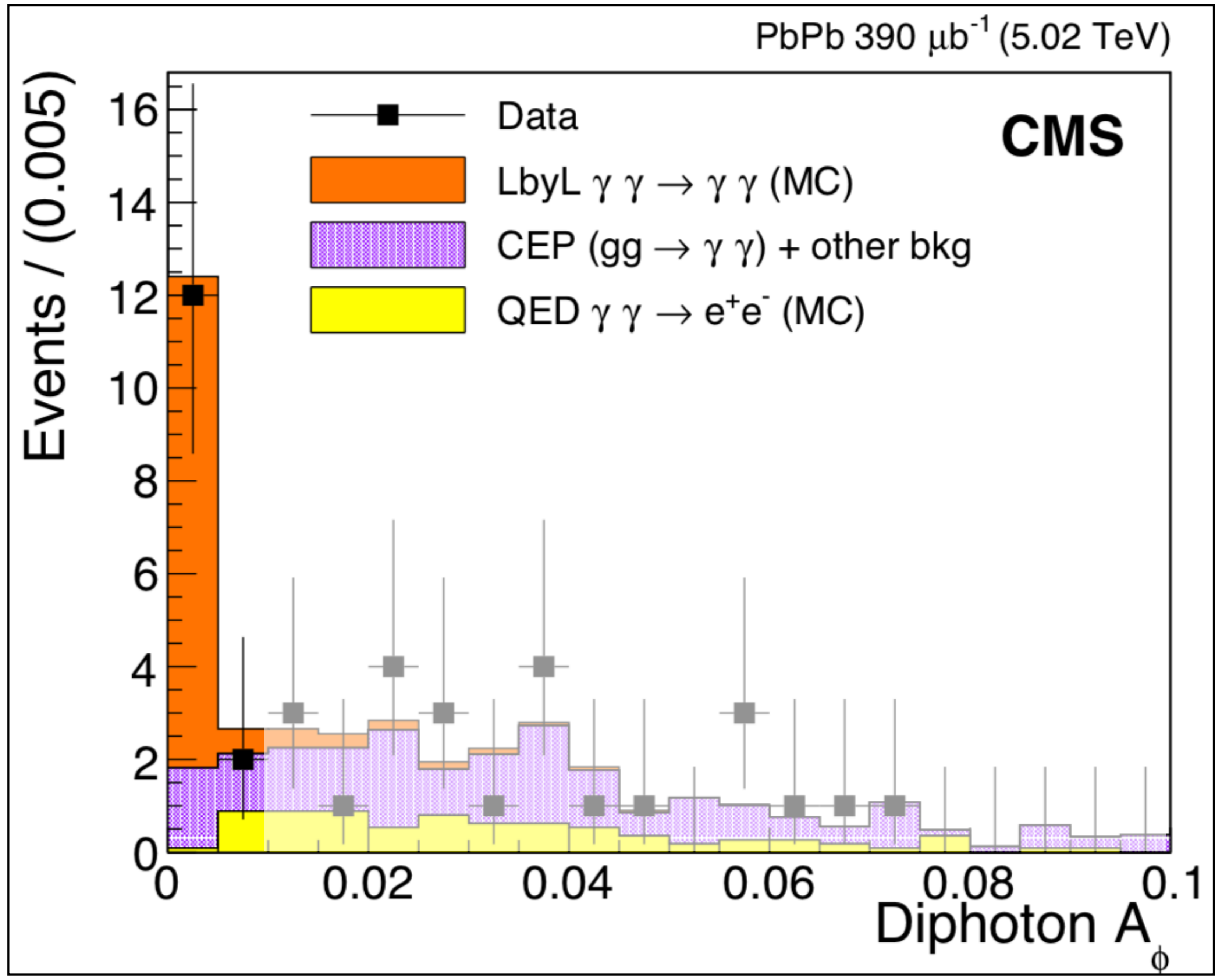
Light-by-light Scattering

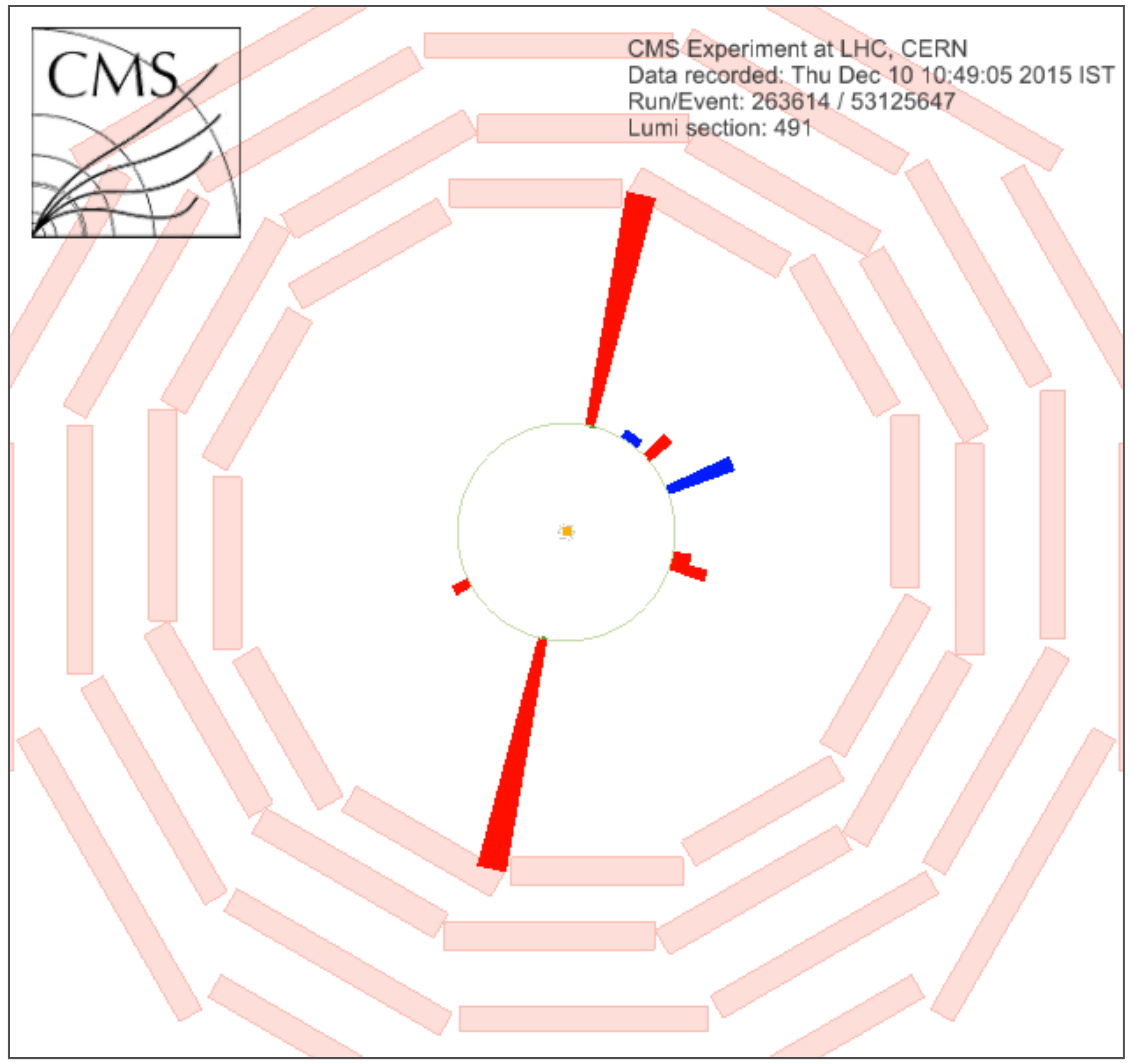


In principle - yes: through a box of charged (B)SM particles.

Best place to look for this process:
ultra-peripheral heavy-ion collisions

First **evidence**: 2015 data (CMS & ATLAS)
>5σ **observation** from ALTAS with 2018 data.



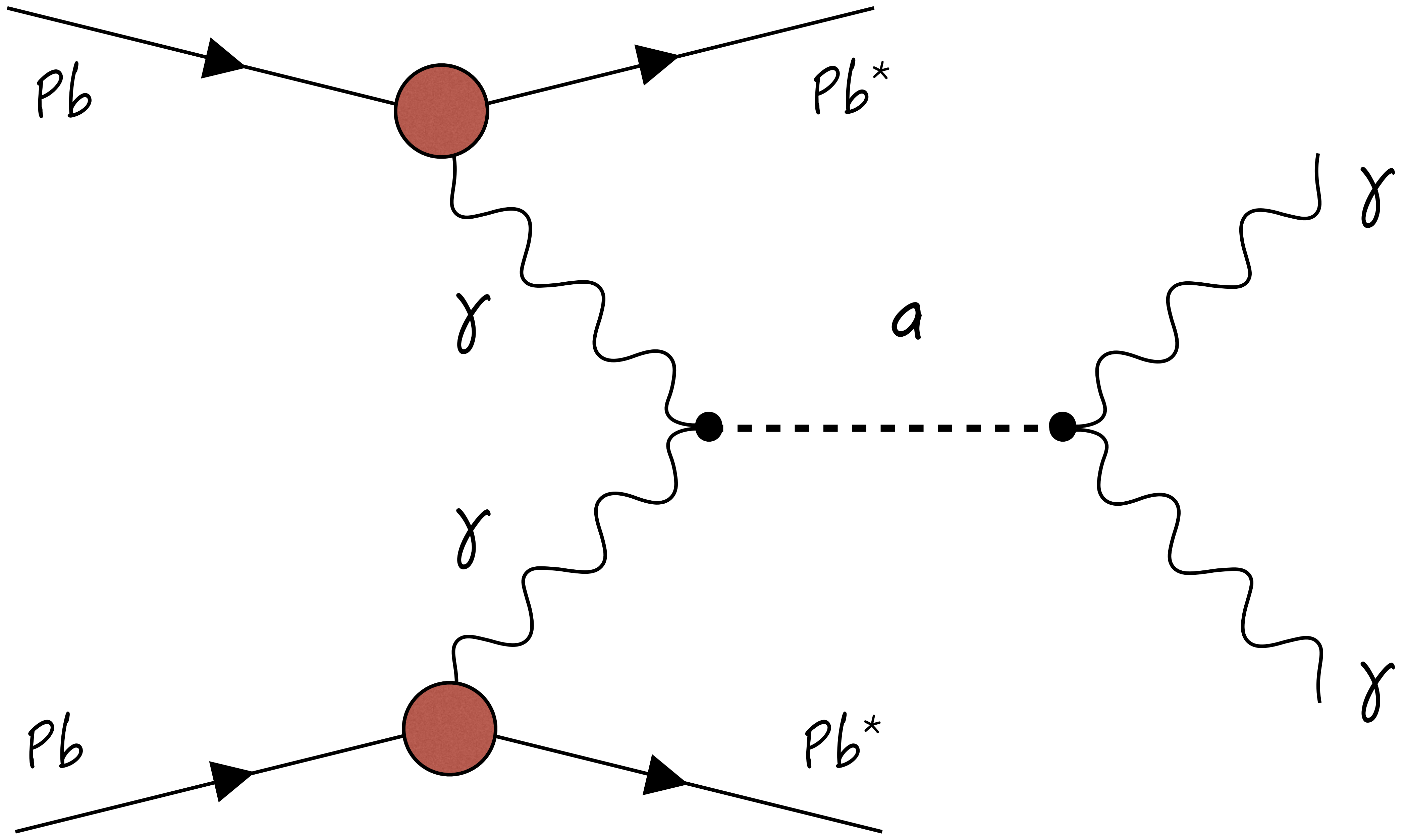


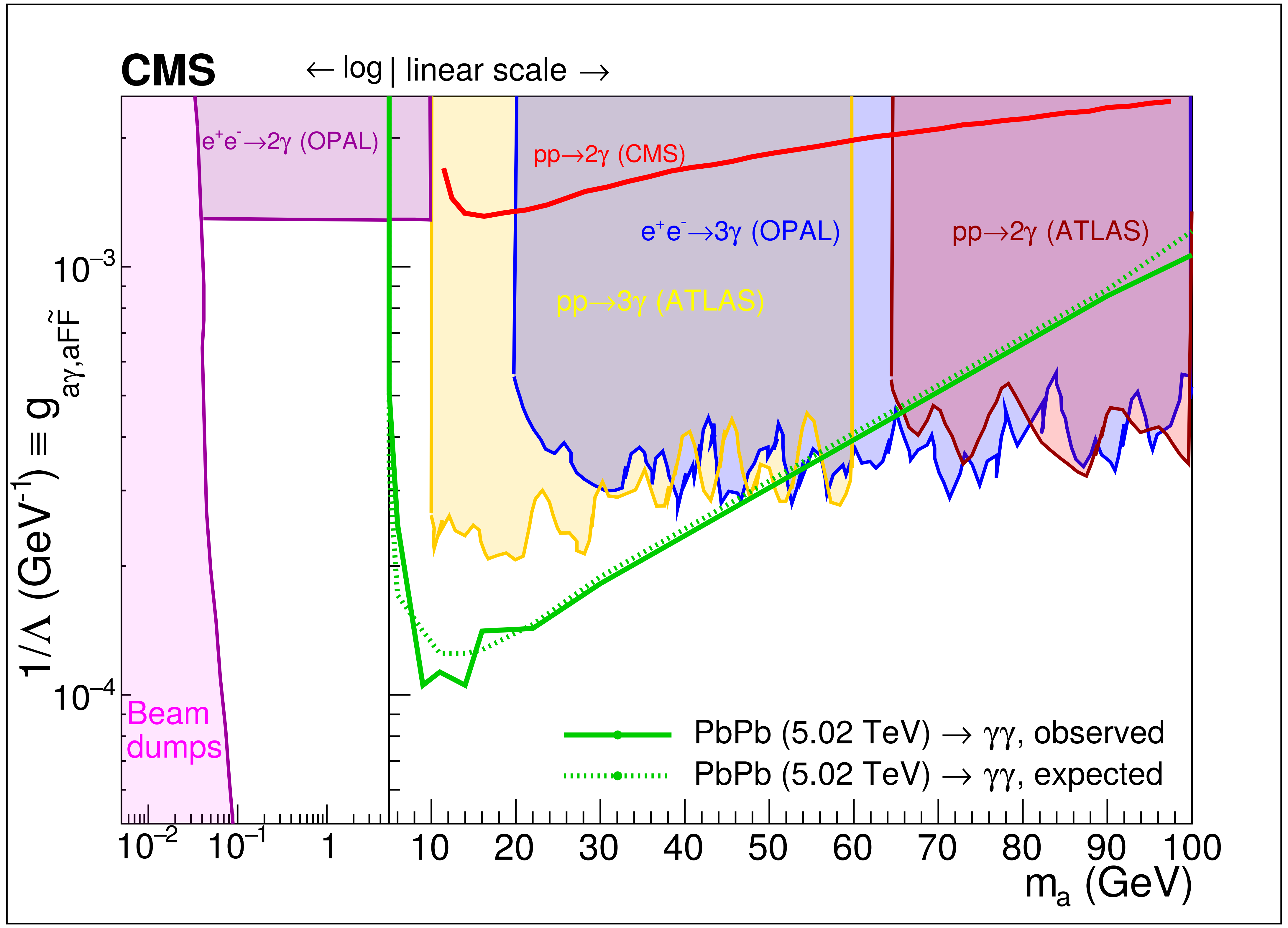
ALPs in UPC HI

Great way to probe **Axion-Like Particles** (ALPs) coupling to photons.

Direct light-by-light scattering through ALPs.

Just **14 observed events** (expected 11 signal + 4 background)
→ **most stringent limits** at that time in 5-50 GeV range.

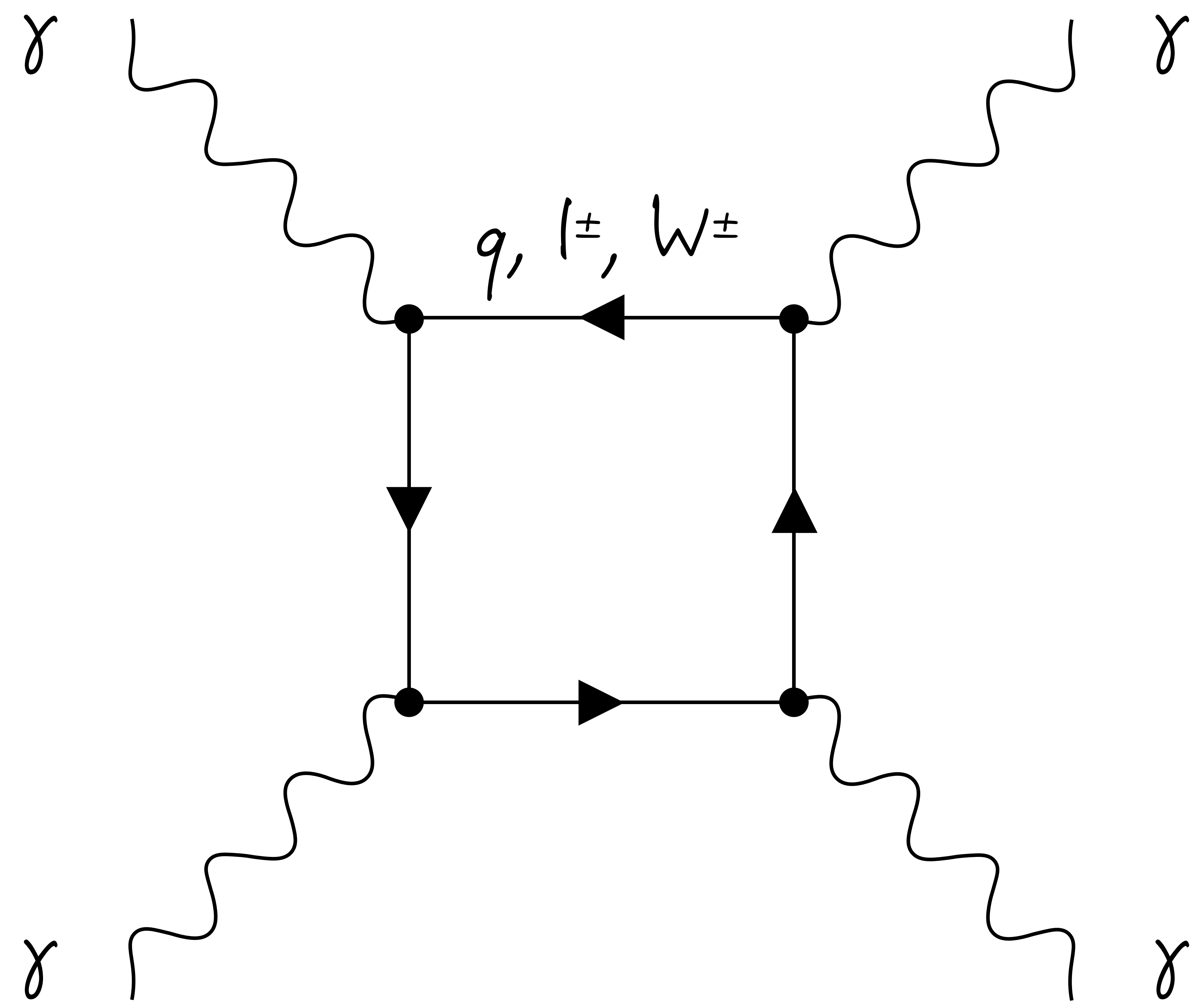




LIGHT-BY-LIGHT SCATTERING

Elastic photon-photon scattering

- **fundamental** quantum-mechanical process. Yet, it has remained **unobserved** until last year…
- the difficulty to observe this process comes from a **very low cross-section**,
- the loop could also contain **new charged particles** (SUSY) or new spin-even resonances (**axions, monopoles**).



Proposed experiments

- the only similar process experimentally confirmed: Delbrück scattering (γ deflection in the nucleus field),
- Compton backscattered photons agains laser photons,
- photon-photon collisions from microwave waveguides, cavities of high-power lasers,
- photon colliders: scattering laser-light off two e± beams,
- ultra-peripheral (electromagnetic) interactions of proton/lead **beams at the LHC**.

CMS DETECTOR

- Photons from light-by-light scattering measurable in CMS over |η|<2.5, exclusivity condition over |η|<5.2,
- final state - just two tower in the ECAL, no activity in the tracker, hadron calorimeters, muon detectors.

Electromagnetic Calorimeter

Barrel EB (|η| < 1.479)

End-cap EE (1.479 < |η| < 3.0)

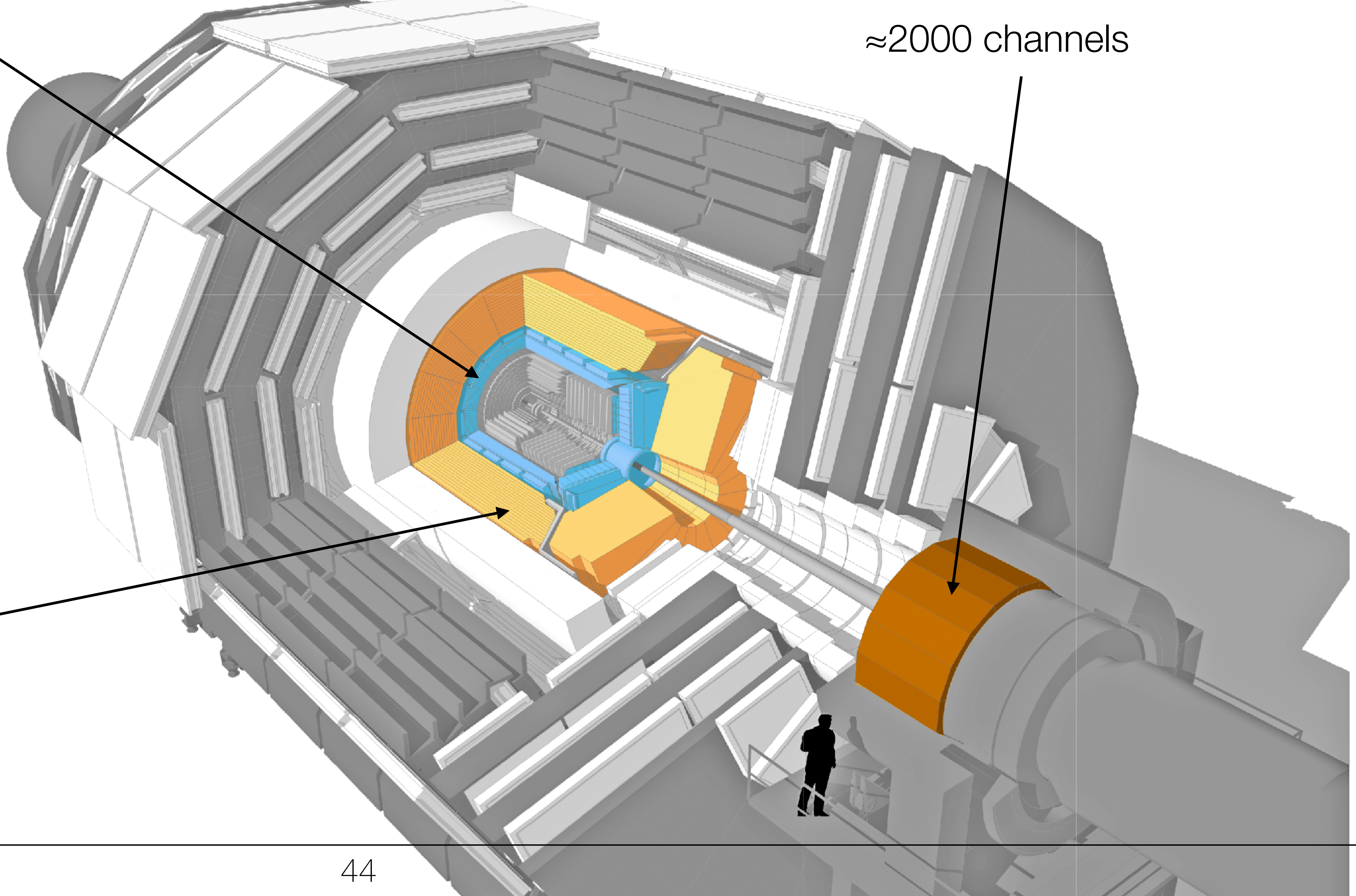
≈76 000 scintillating PbWO4 crystals

Hadron Forward Calorimeter

HF (2.9 |η| < 5.2)

Steel + Quartz fibers

≈2000 channels



Hadron Calorimeter

Barrel HB (|η| < 1.3)

End-cap HE (1.3 < |η| < 3.0)

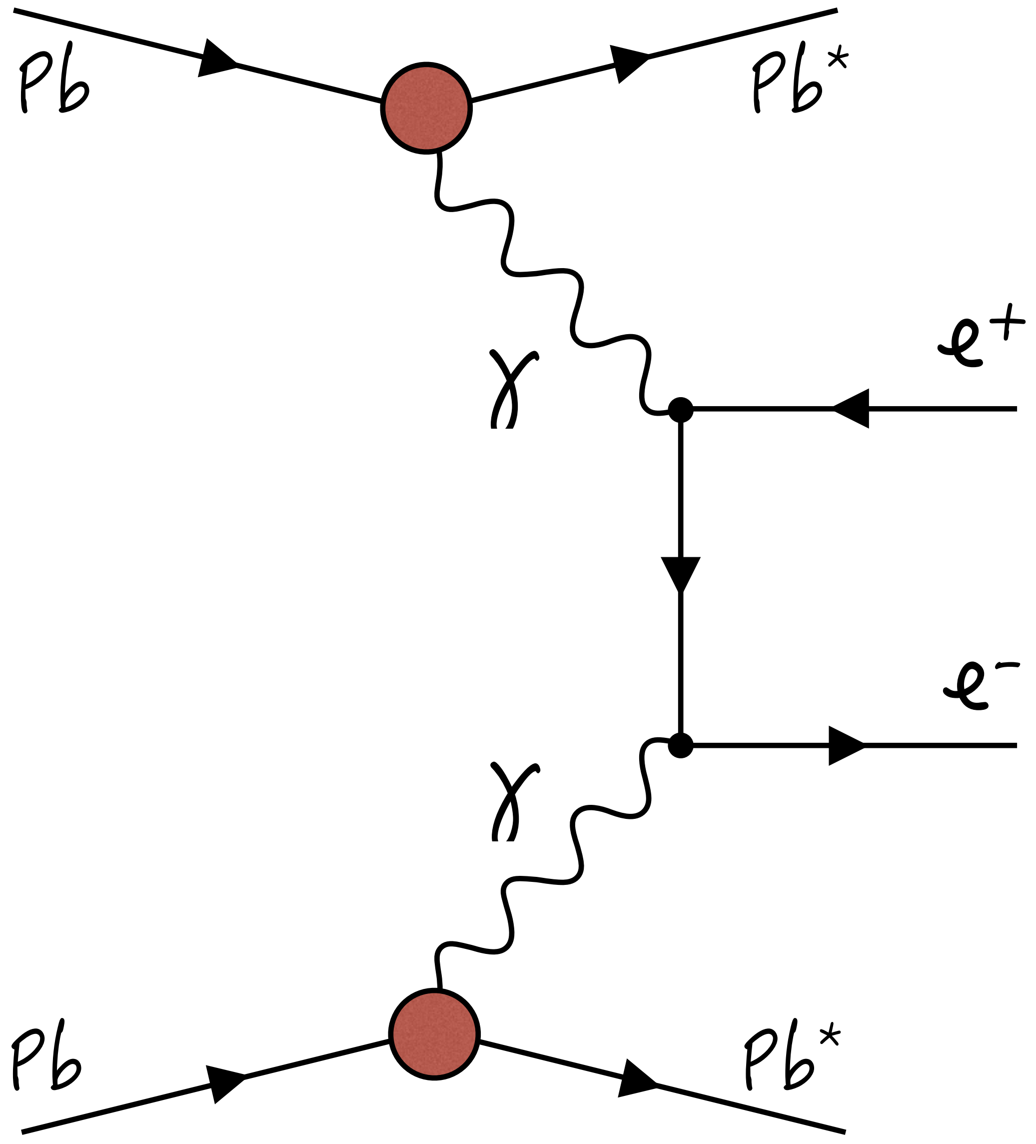
Brass + Plastic scintillator

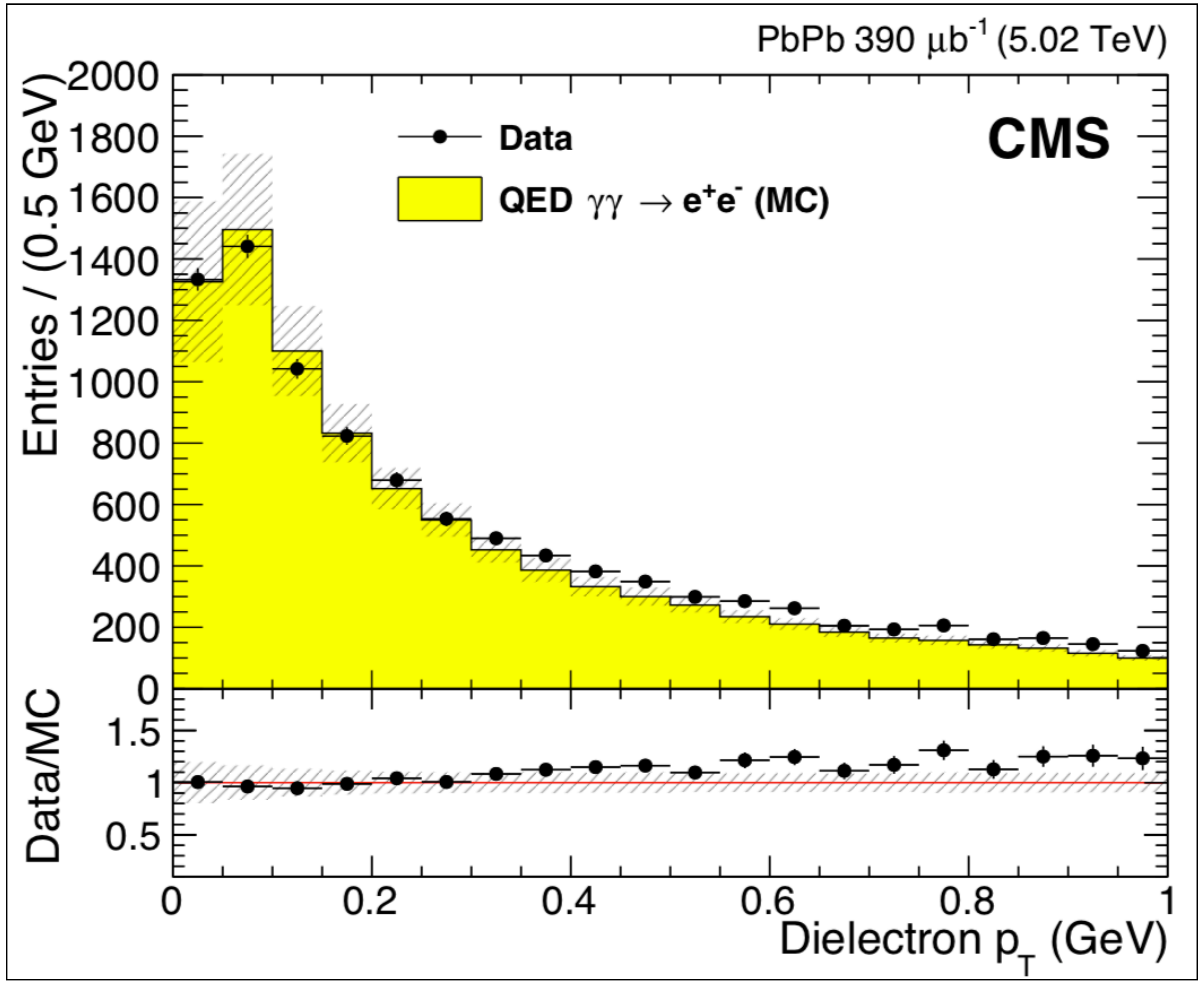
≈7000 channels

Background analysis

QED e+e- background

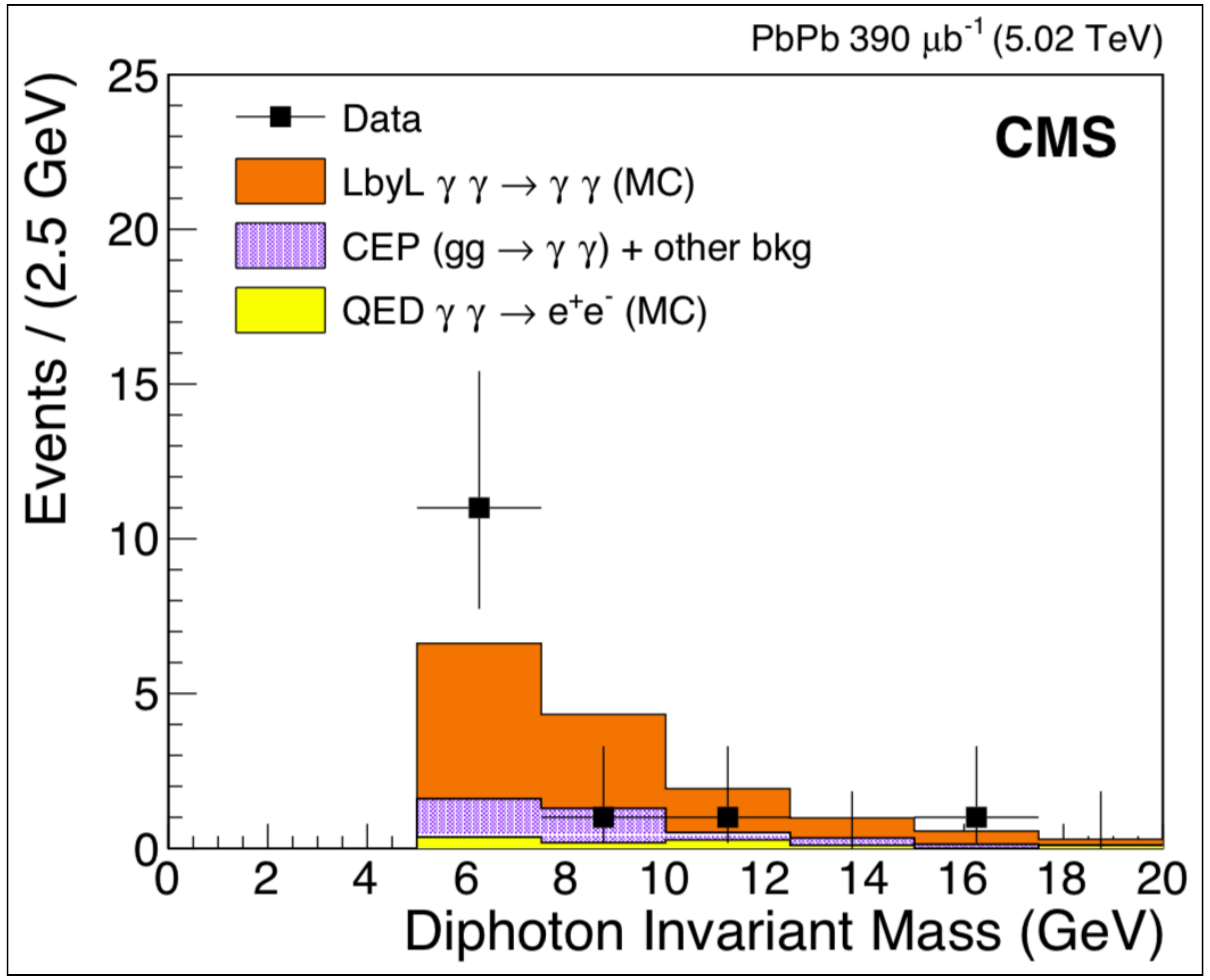
- the same analysis repeated, now requiring exclusive **e+e- pair instead of γγ**,
- **kinematic distributions** reproduced well by the Starlight MC generator (except increasing acoplanarity tail from γγ → e+e-(γ)),
- **confirms quality** of:
  - electron/photon reconstruction,
  - event selection criteria,
  - MC predictions for PbPb UPCs,
- estimated e+e- background after cuts: **1.0 ± 0.3 events**.

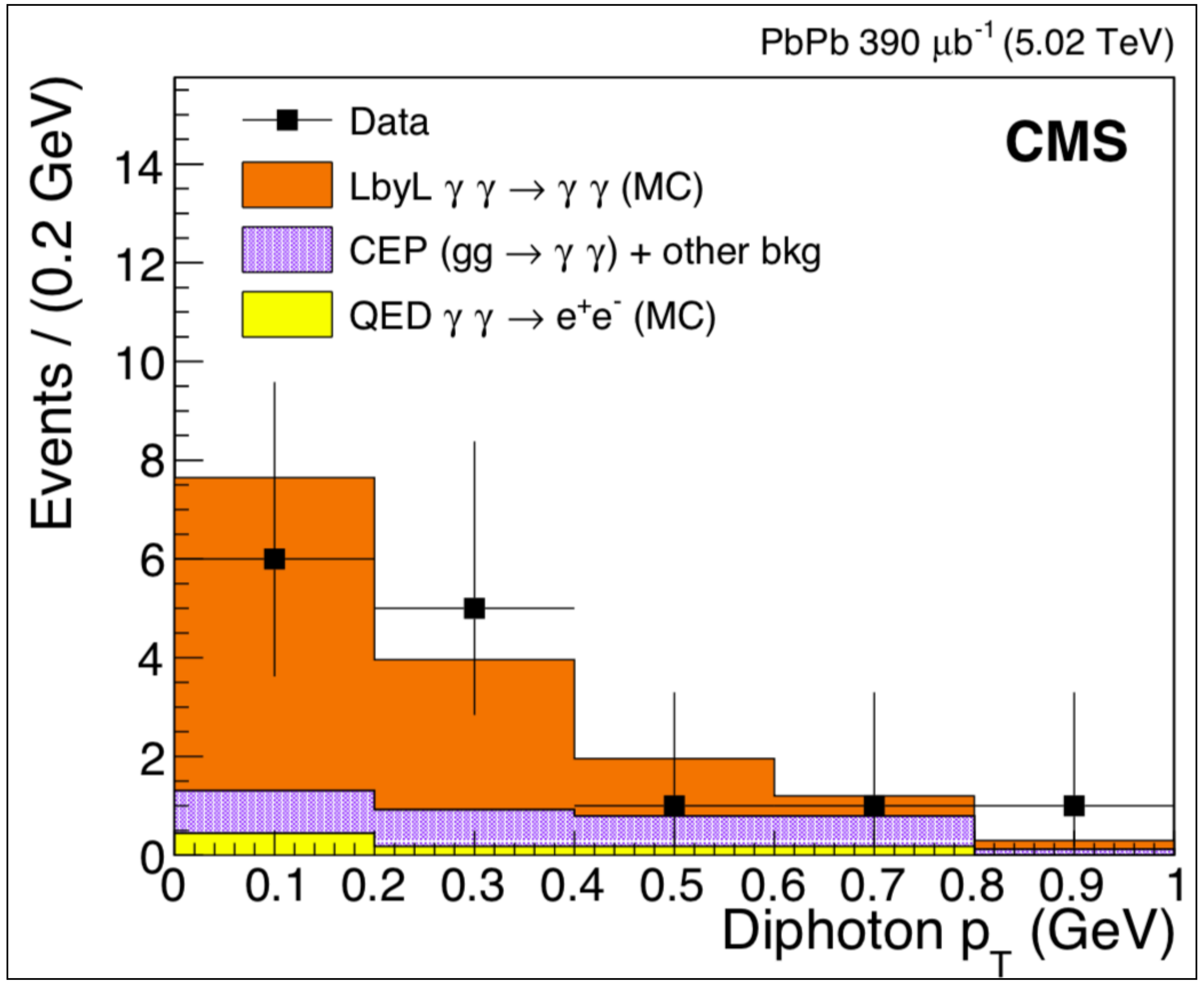




Kinematic distributions

Measured distributions reproduced well by the sum of LbL signal and QED + CEP backgrounds:

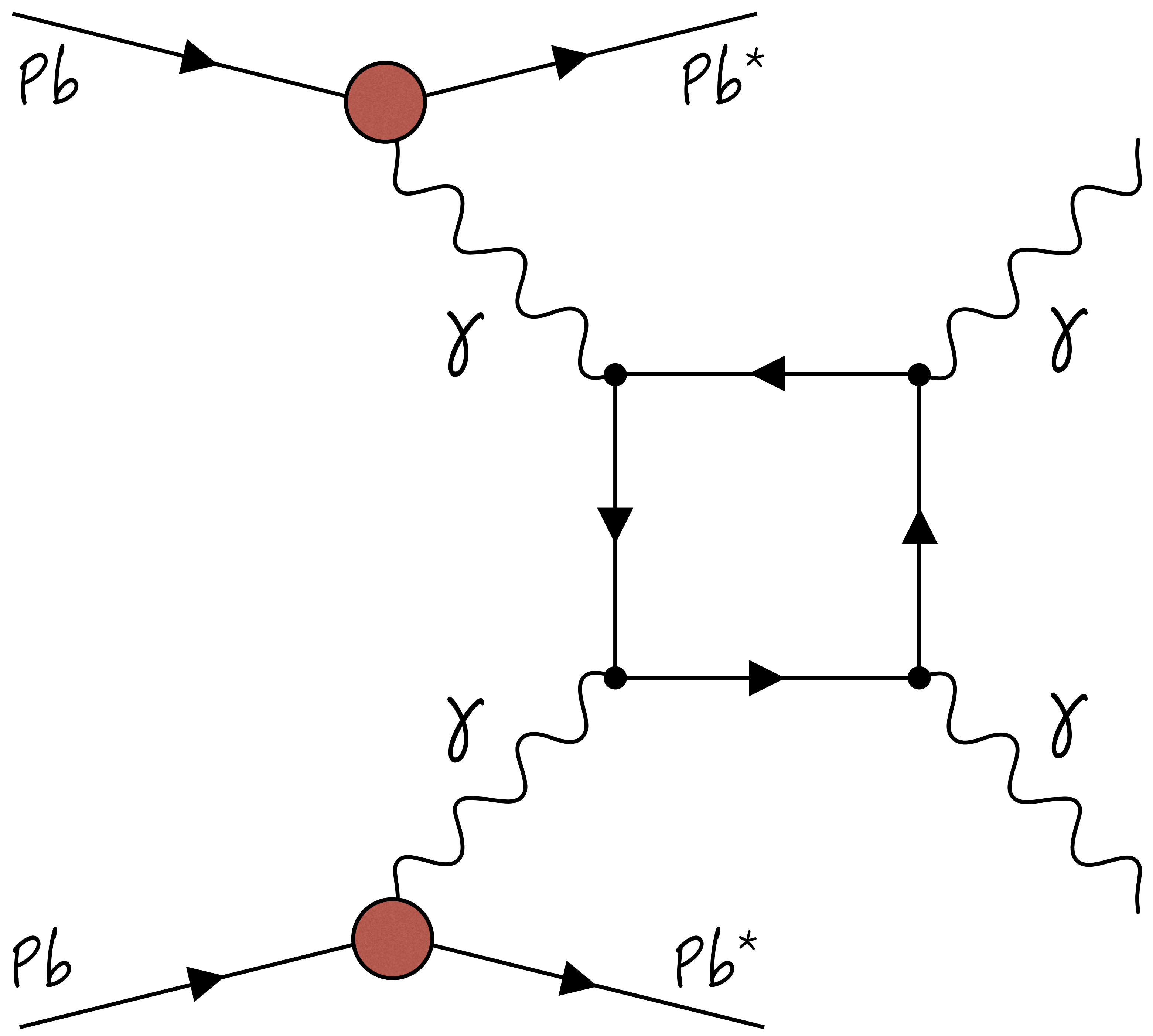




LIGHT-BY-LIGHT IN UPCs

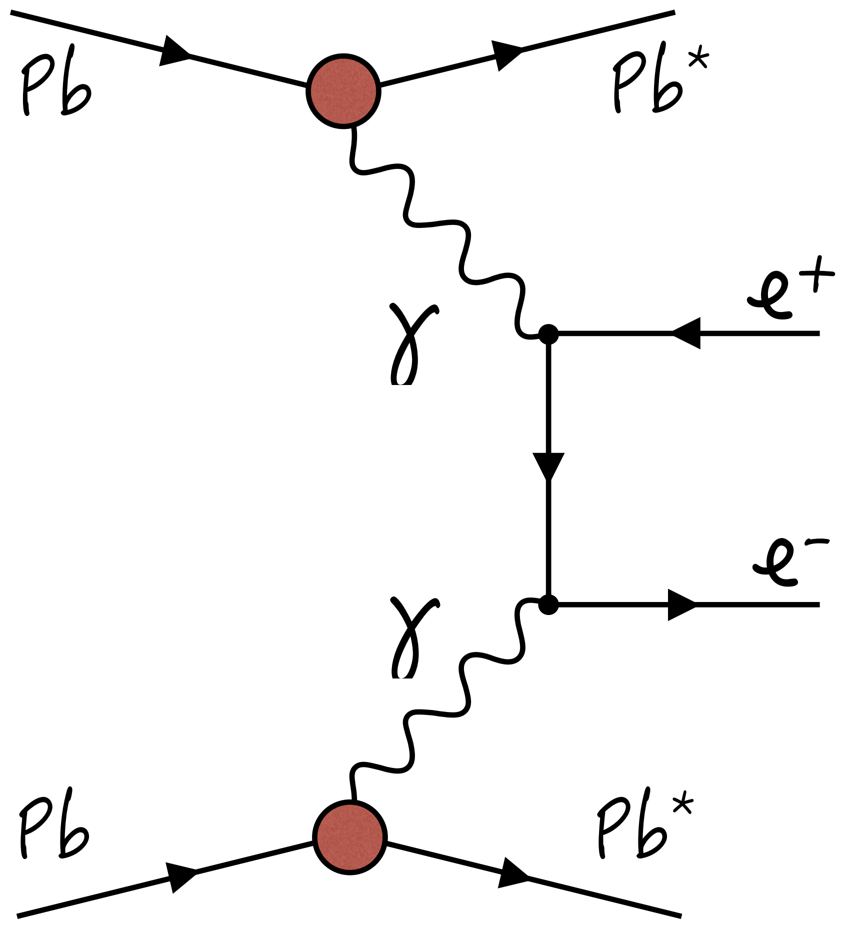
Ultraperipheral Heavy-Ion collisions

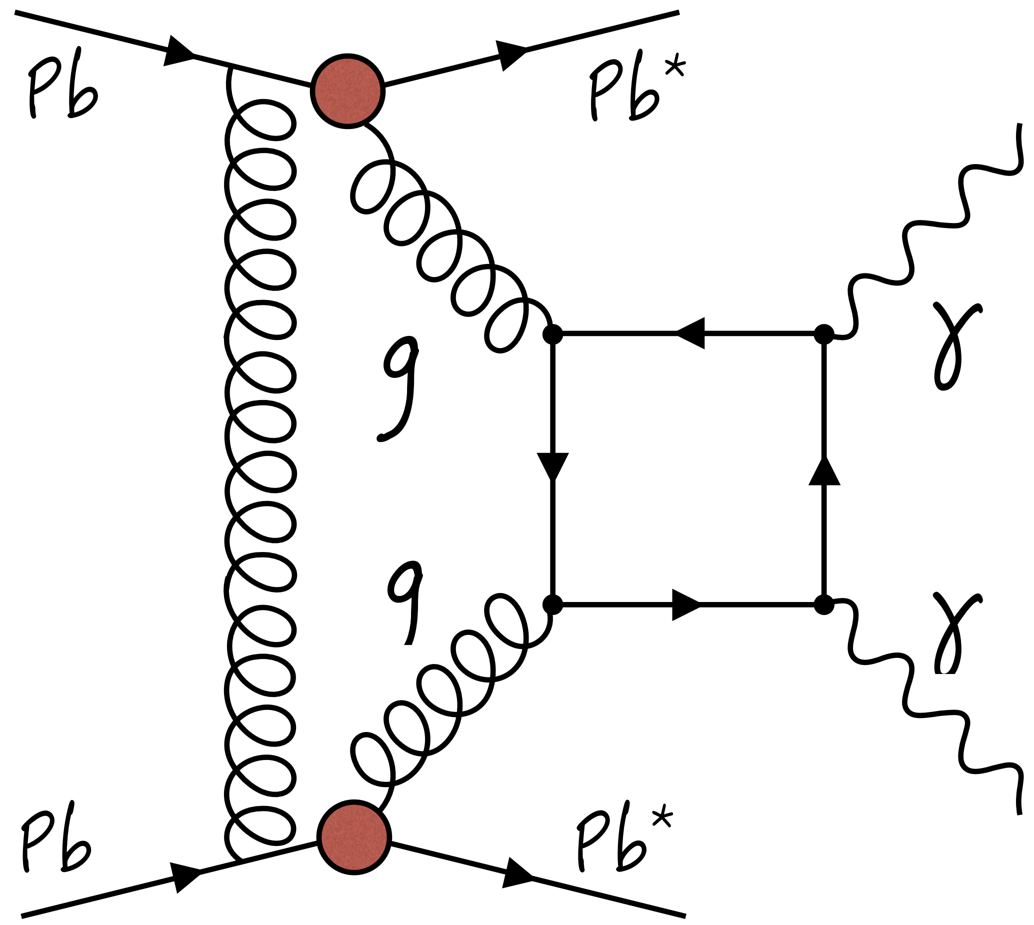
- passing heavy ions generate **huge EM fields** (10^{14} T),
- cross-section is **amplified** by Z^4, for PbPb (Z=82) $\sigma_{\gamma\gamma\rightarrow\gamma\gamma}$ is $5{\cdot}10^7$ higher than for p-p or e^+e^-,
- maximum γ energies at LHC 80 GeV (Pb), 2.5 TeV (p),
- $W^{\pm}$ contributions only relevant for $m_{\gamma\gamma} > 2{\cdot}m_W$, hadronic loops only for $m_{\gamma\gamma} \lesssim 2$ GeV,



Main backgrounds:

- Exclusive QED e^+e^-,
- Central Exclusive Production (CEP).

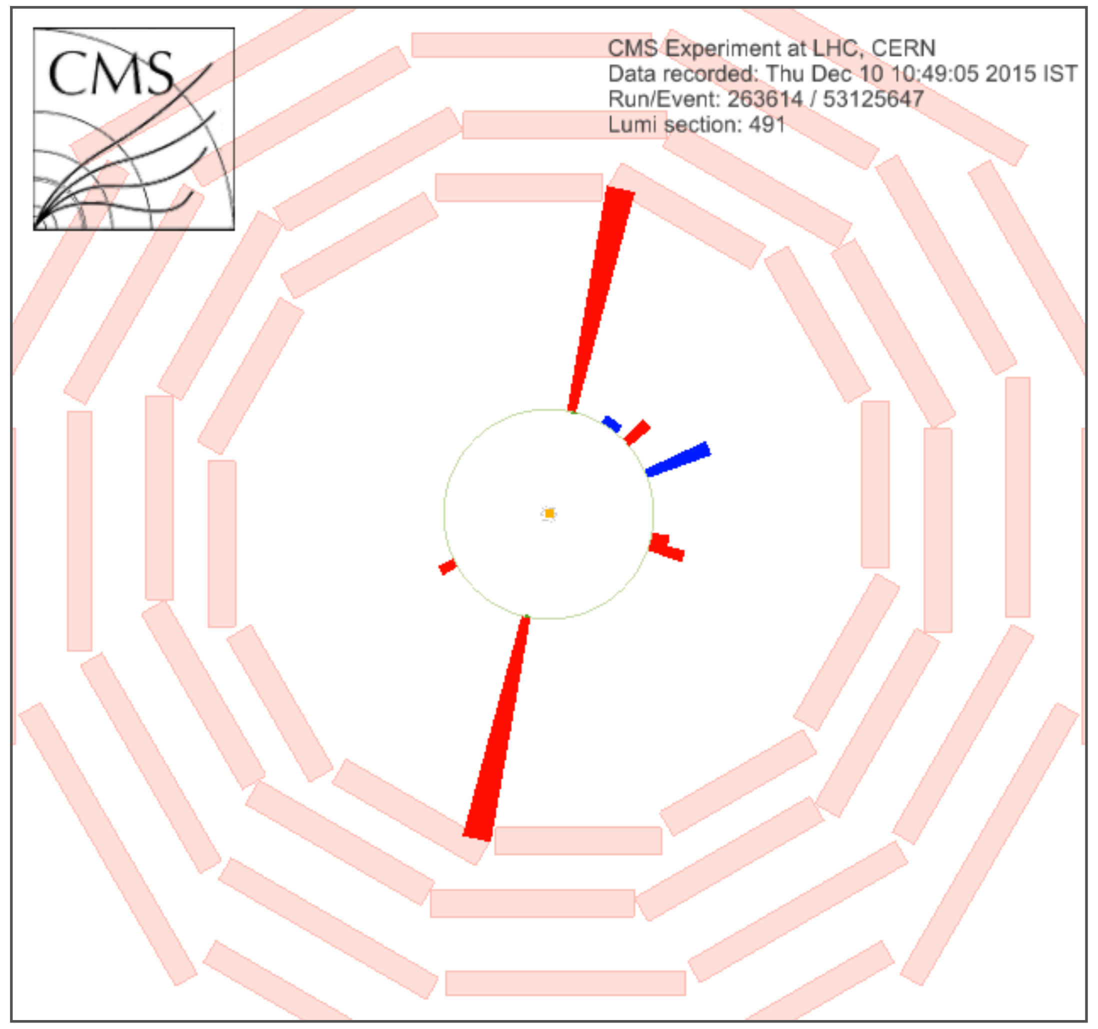




DATA SELECTION

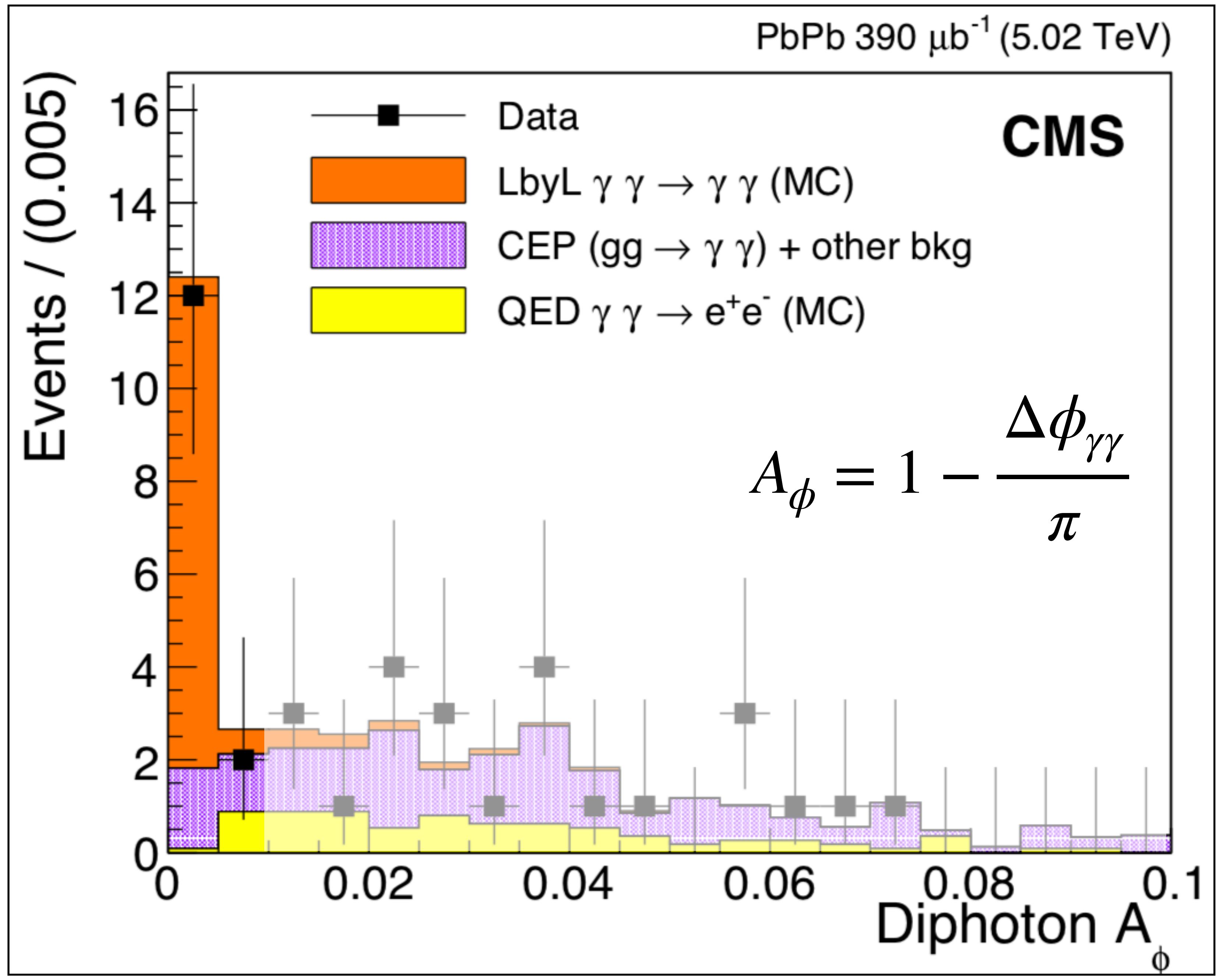
Data sample

- PbPb @ 5.02 TeV (2015: L_{int} = 390 μb^{-1}),
- trigger: ≥2 E/γ in ECal with E_T > 2 GeV each, ≥1 Hadron Forward (HF) empty.
- standard CMS high-E_T e/γ reco (E_T > 10 GeV) retuned for this analysis,



Exclusivity requirements

- reject events with any towers (above noice threshold) in calorimeters other than the photon candidates,
- reject events with any charged particle with p_T > 0.1 GeV,
- diphoton $p_{\gamma\gamma}$ < 1 GeV to reduce all non-exclusive photon backgrounds.

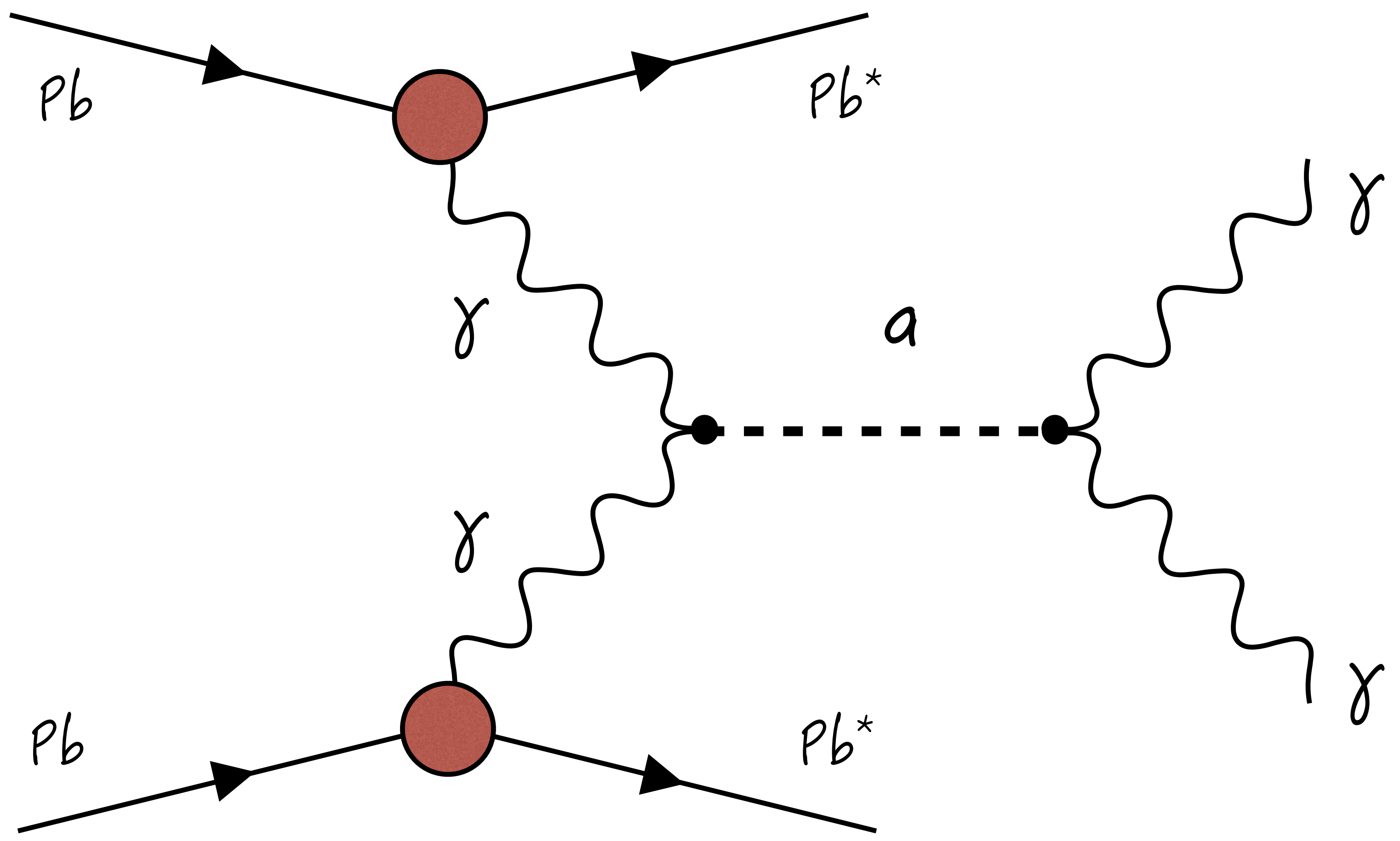


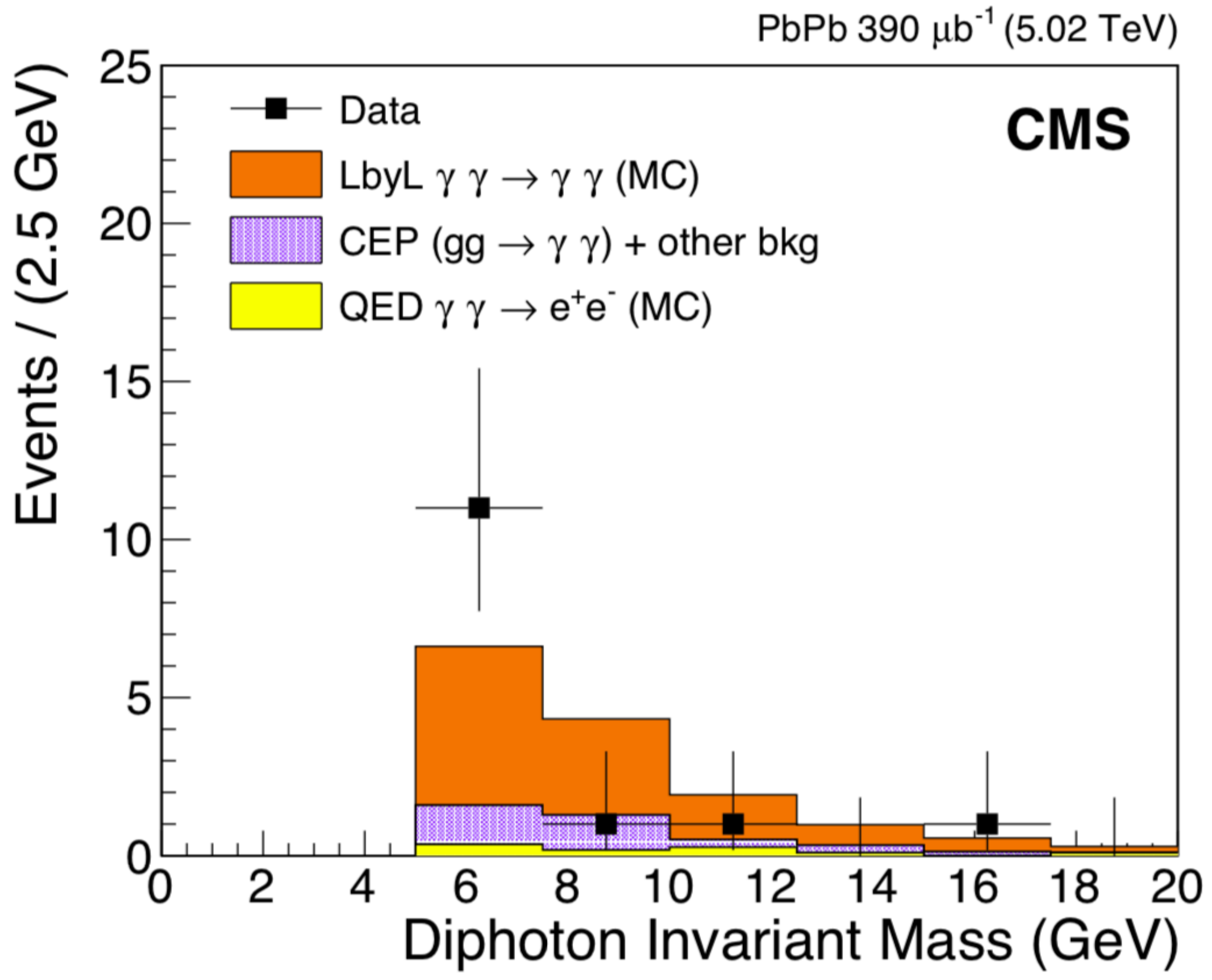
Results

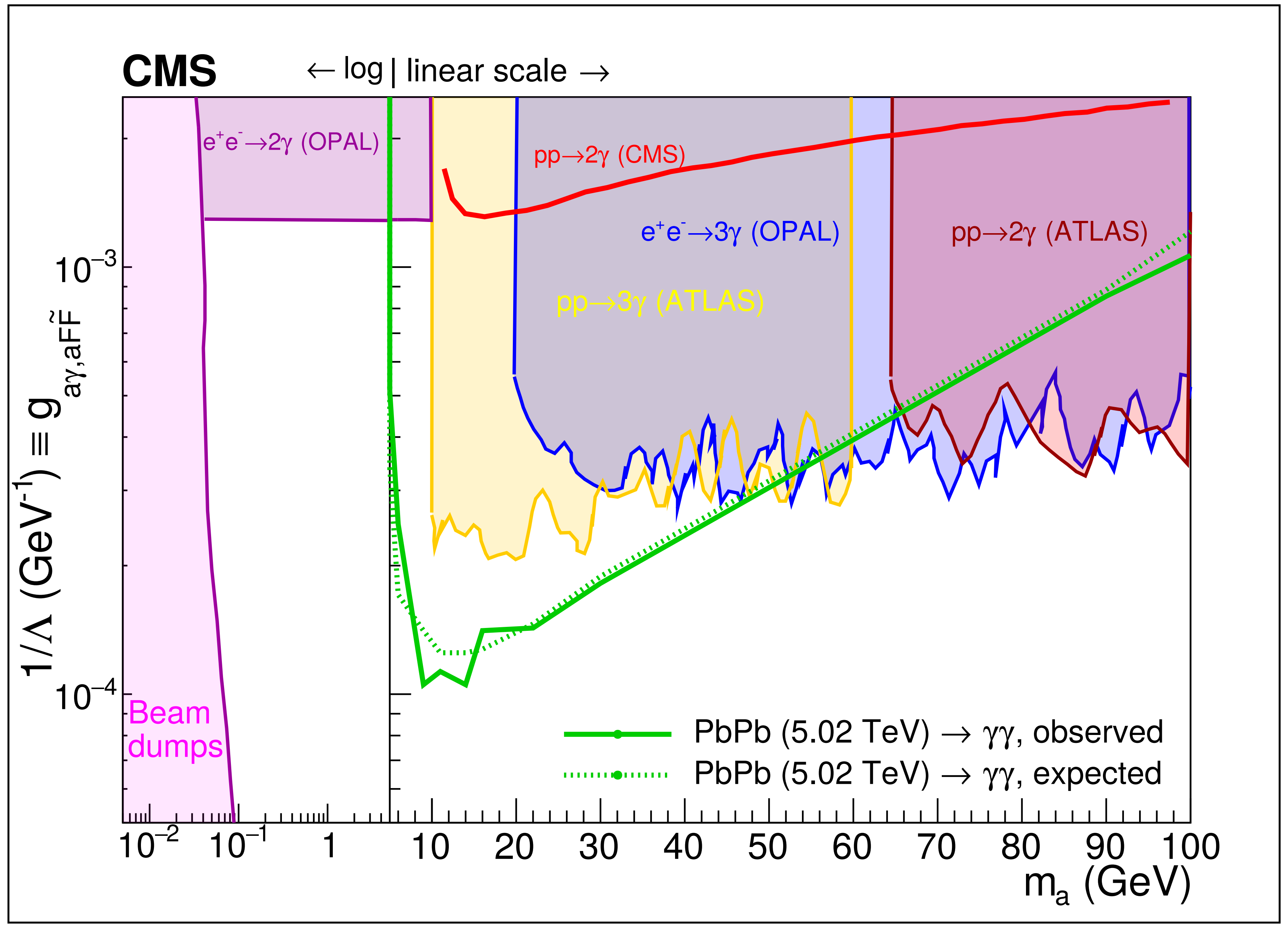
- observed **14 events** in the signal region,
- expected: 11.1 ± 1.1 (th) signal and 4.0 ± 1.2 (stat) background events,
- **significance** observed: 4.1σ (expected: 4.4σ)
- fiducial cross section measured: 120 ± 46 (stat) ± 28 (syst) ± 4 (th) nb (expected: 138 ± 14 nb).

Axion-Like Particles

- Exclusive $\gamma\gamma \rightarrow \gamma\gamma$ is also sensitive to physics signals beyond the SM such as axions,
- Axion-Like Particles (ALPs): more general class of elementary pseudo-scalar particles, where mass-coupling relation is not fixed,
- no significant ALP excess observed in data above LbL+backgrounds continuum,
- limits in cross-section → limits in $g_{a\gamma}$ vs. m_a plane ($g_{a\gamma} = 1/\Lambda$),
- new limits on axion-like particles over m_a = 5-50 GeV.



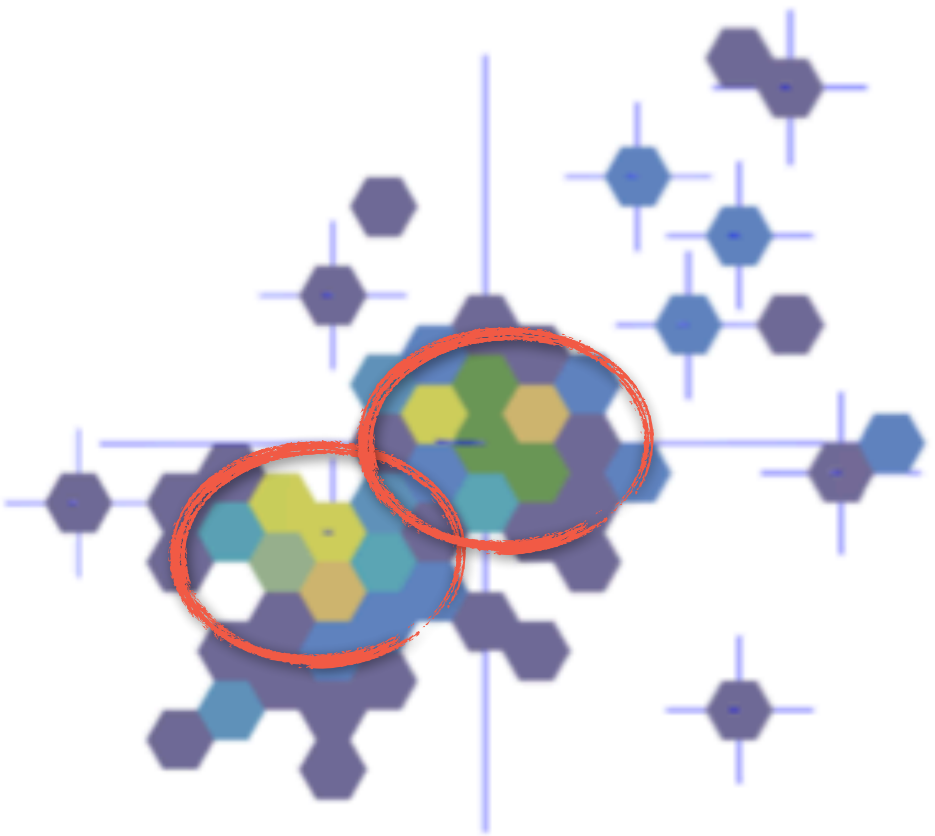


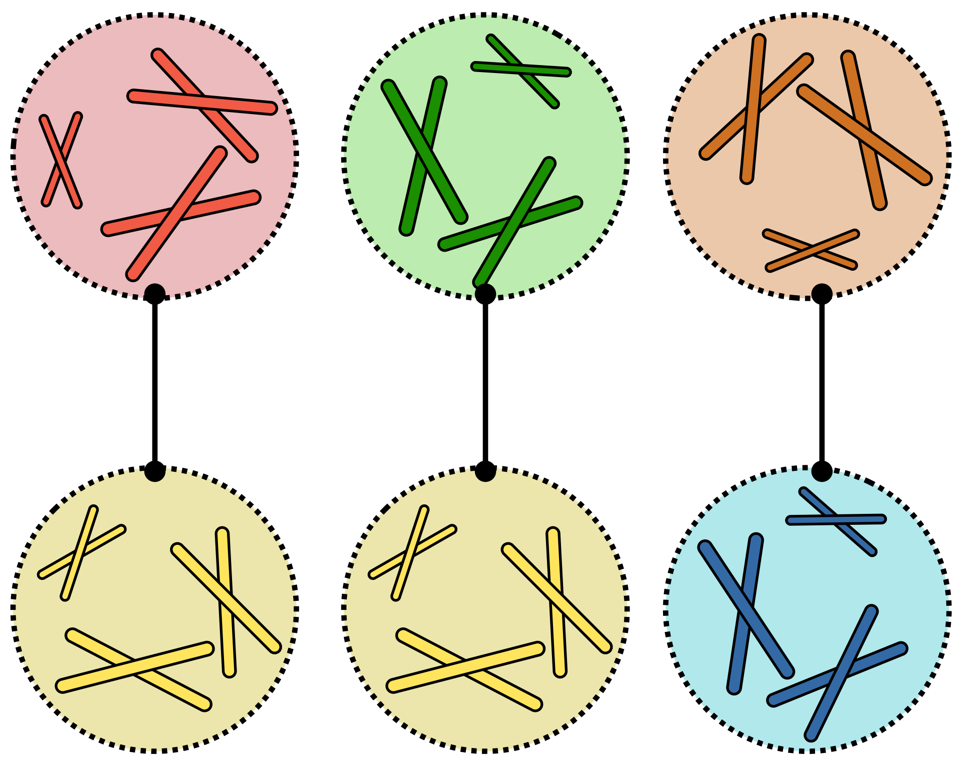


PLB: inspirehep.net/record/1697838
Proceedings: inspirehep.net/record/1731403
New Physics in HI: inspirehep.net/record/1709994
Ongoing analysis: CMS AN-18-254

HGCal cells clustering

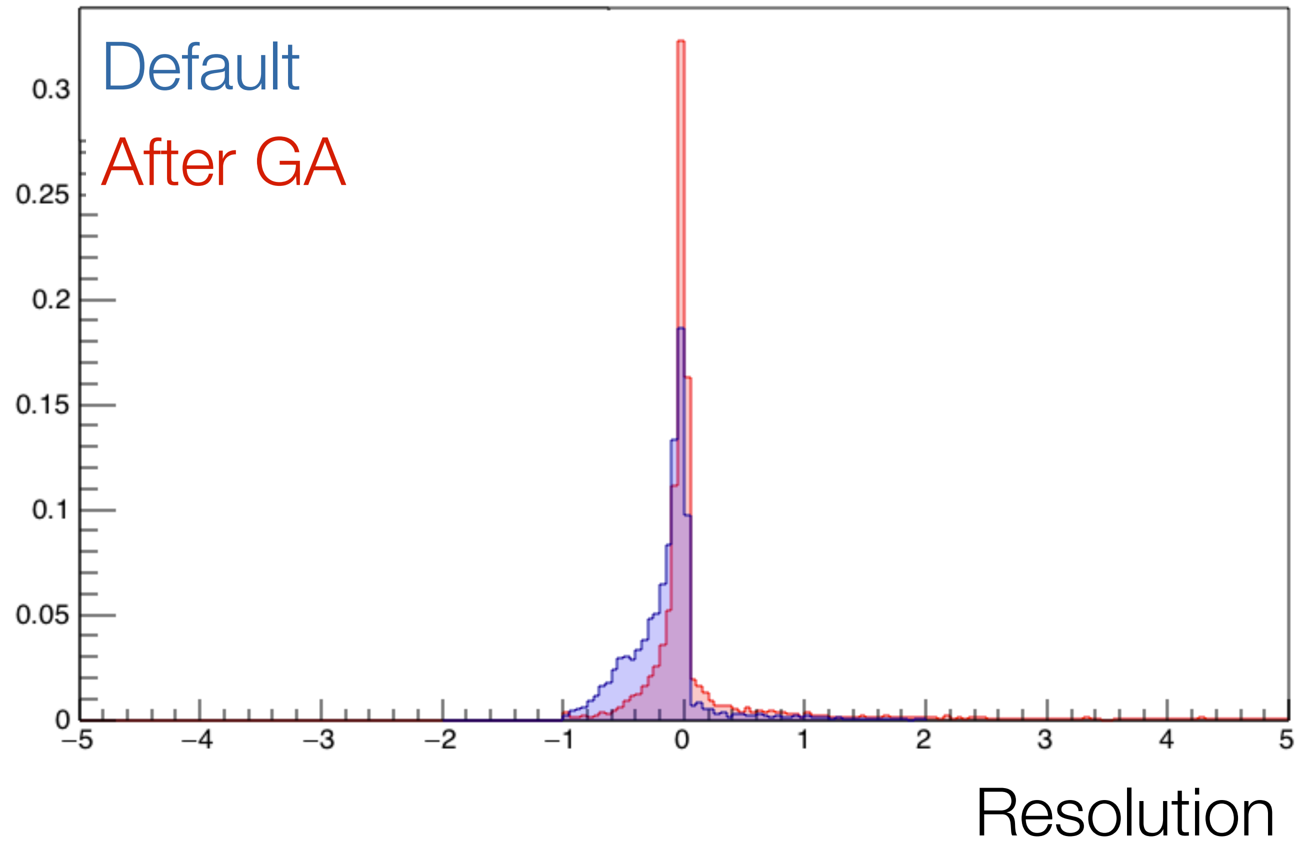
clustering of small hexagonal cells challenging

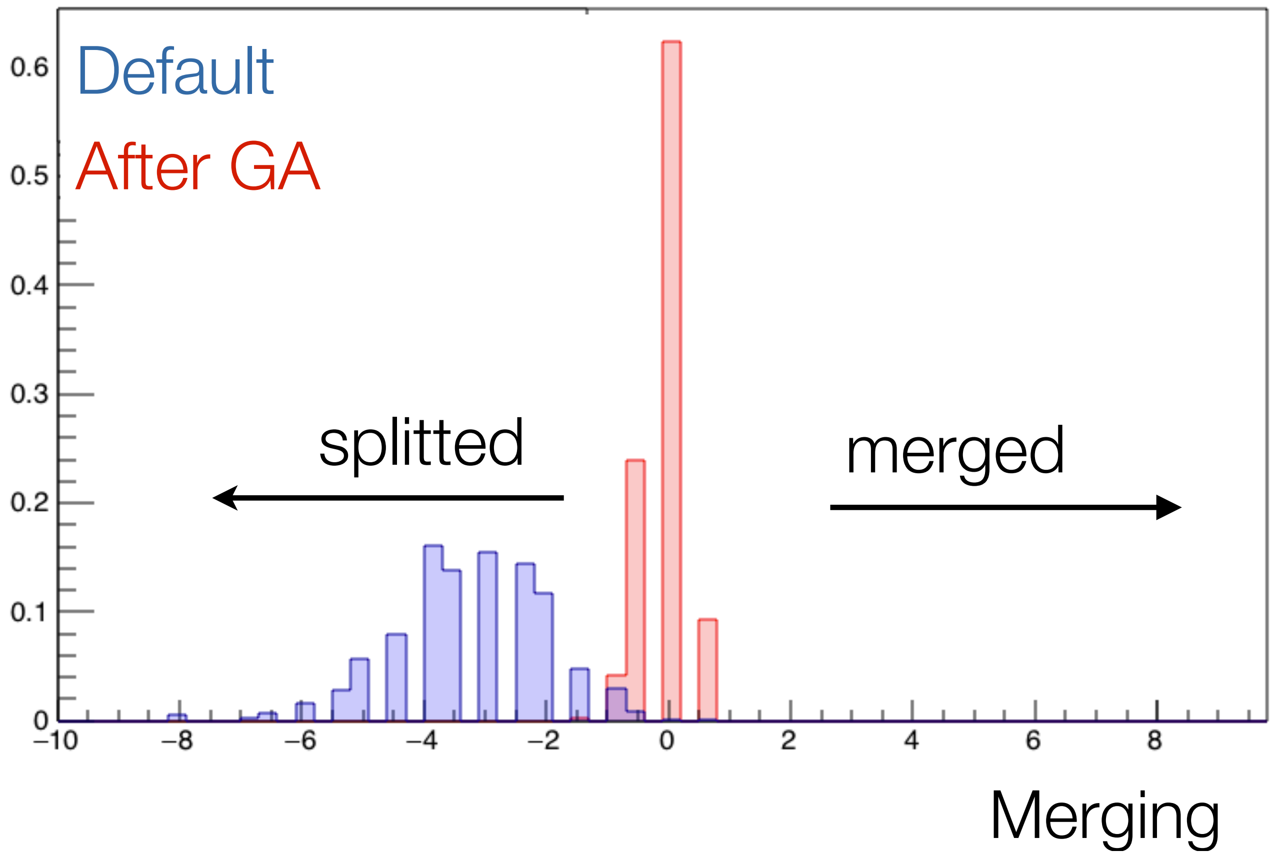




implemented a **genetic algorithm**

Improved **resolution** & cluster **splitting/merging**

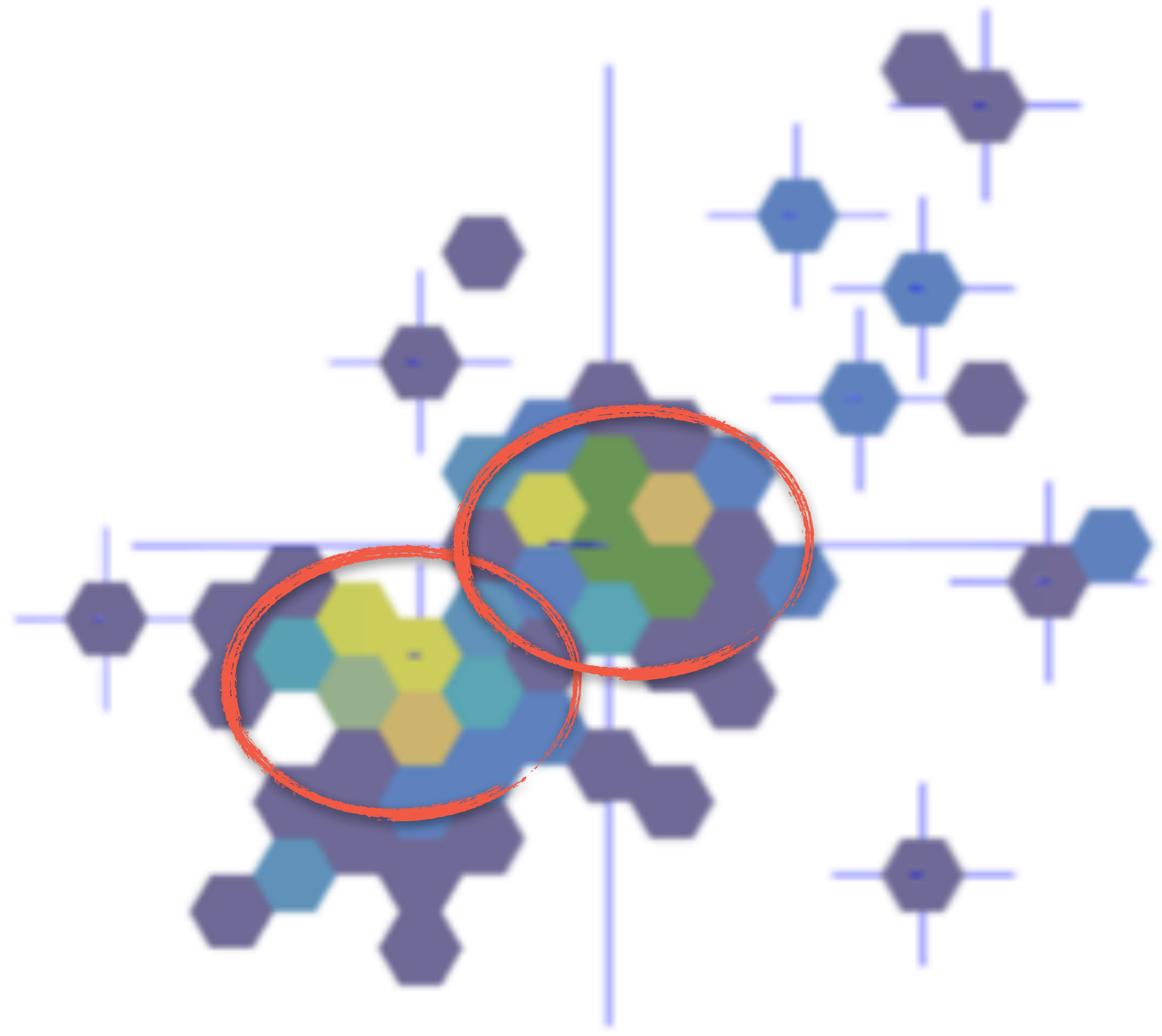


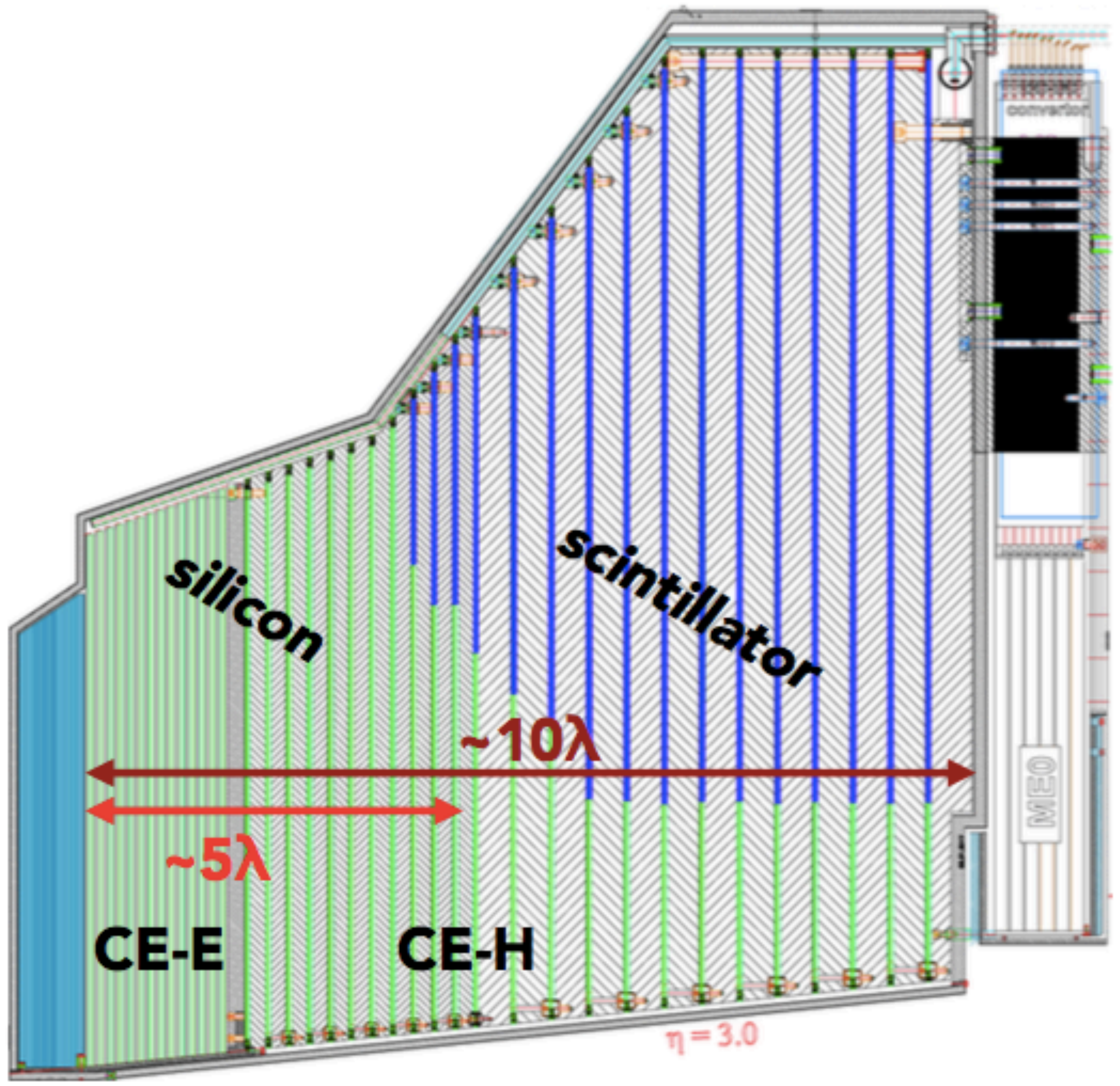


HGCAL 2D CLUSTERING

New calorimeter end-caps in Phase-2

- hexagonal silicon cells + plastic scintillator, ≈**50 layers**,
- for the first time we'll have a **tracking calorimeter**!
- reconstruction more **challenging** than in regular calorimeter,





Layer clustering

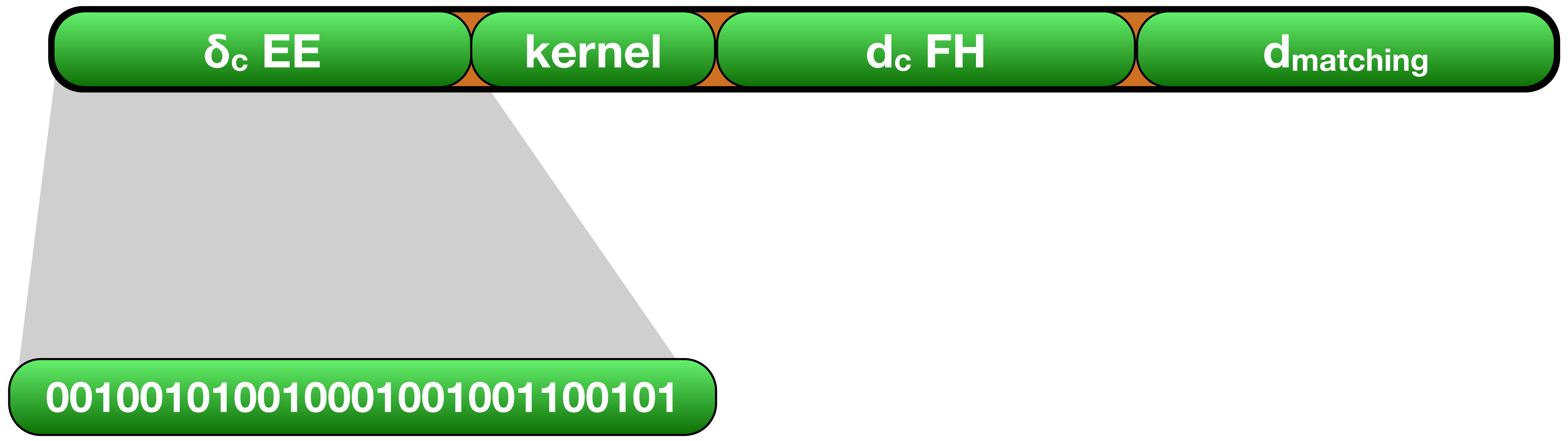
- layer-by-layer clustering is a first step or the "**classical**" reconstruction.
- clustering algorithm exists and has O(10) **free parameters**,
- problem: find the best values of parameters to reconstruct cluster energy as close as possible to the true one.

Optimizing clustering parameters

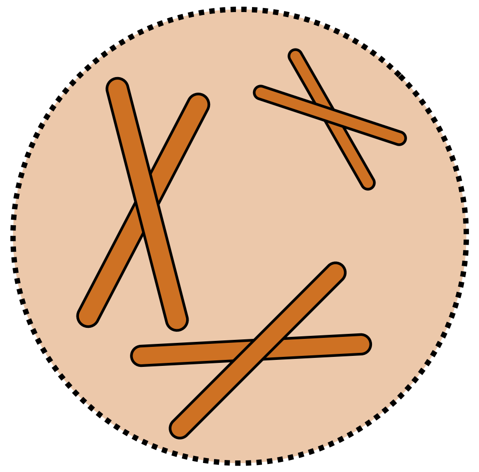
Genetic algorithms (GA)

- GA is similar to how the evolution works. Optimization problem is stated in the language of natural selection,
- the basic unit is the **chromosome**, which encodes part of a single solution (good or bad) to the problem,
- one single solution, containing all parameters, is called a creature and contains a few chromosomes.

Chromosome



Creature

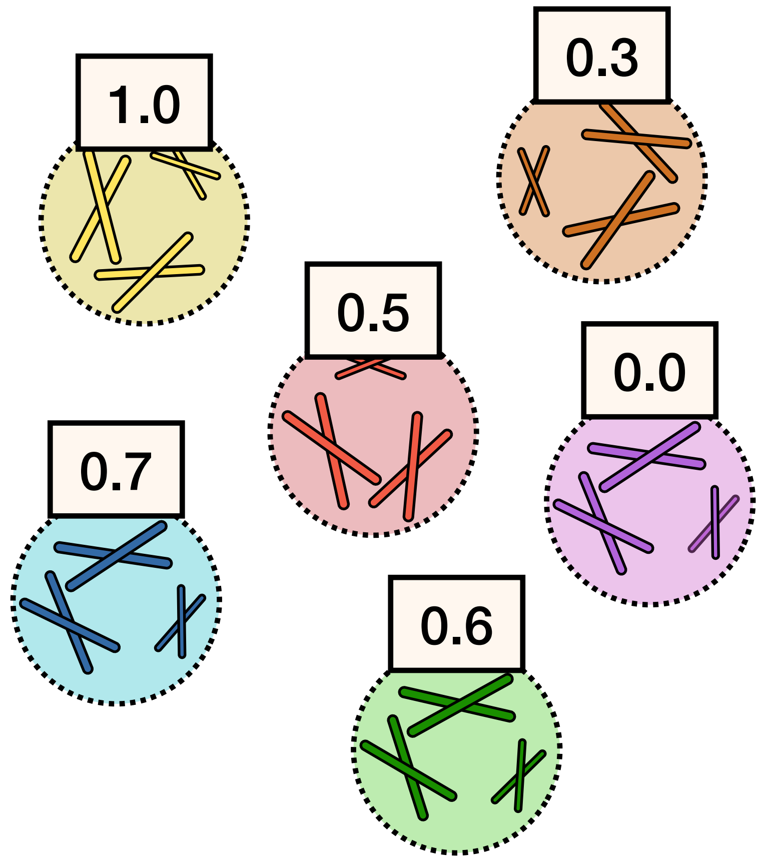


GENETIC ALGORITHMS

Step one

randomly draw an initial population

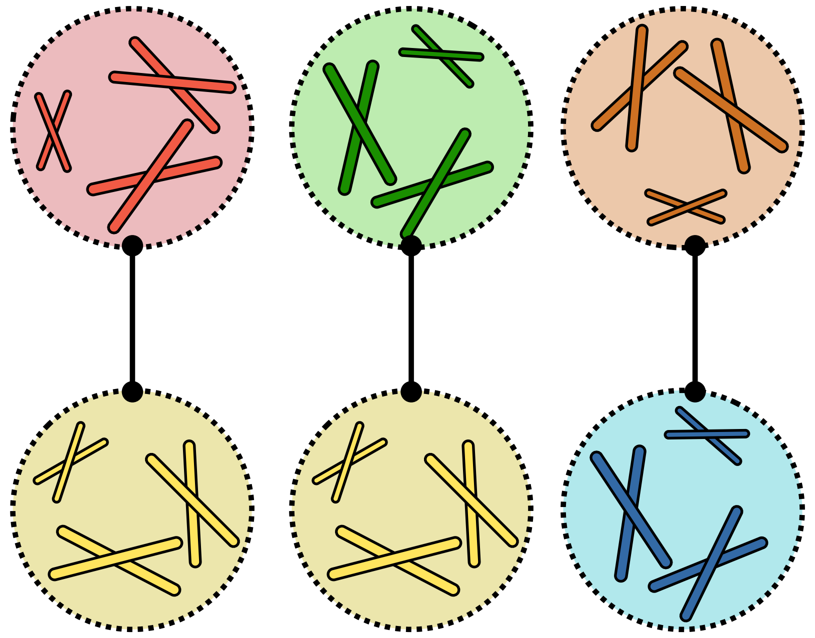
- create N_c random creatures,
- some solutions will be completely wrong,
- some of them, just by chance, will be a bit better.



Step two

test all creatures (check their fitness)

- calculate score using the some formula,
- normalize the score and assign to creatures.



Step three

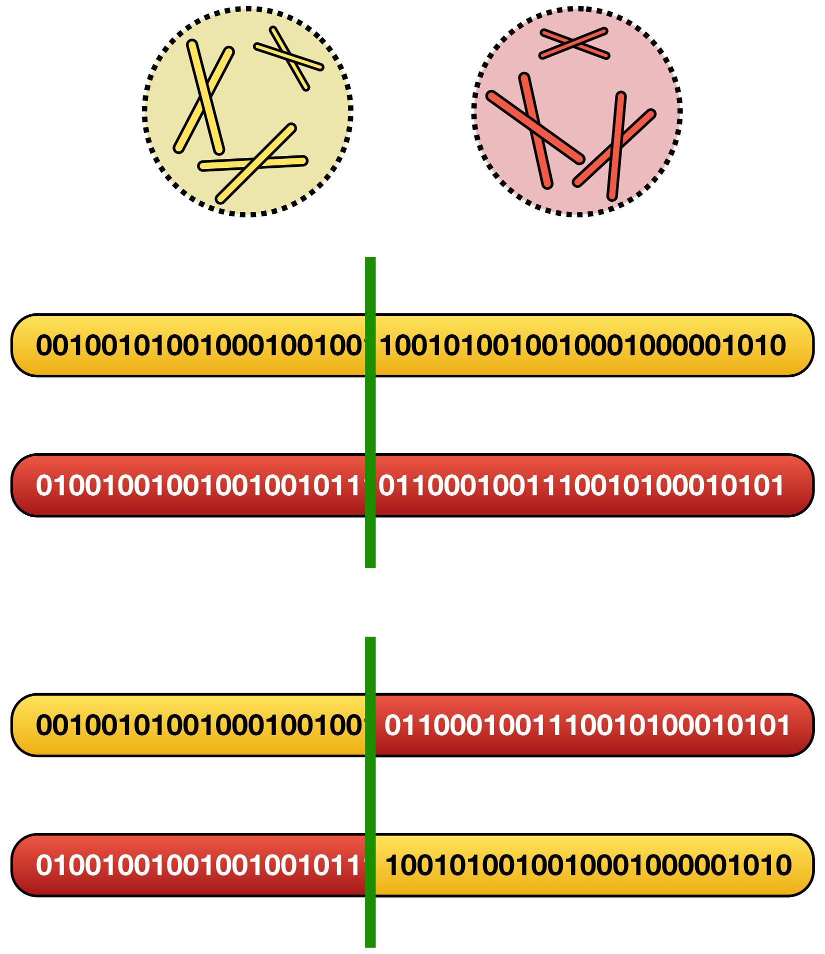
selection

- select $N_c/2$ pairs of creatures, according to their fitness,
- creatures with high score will be selected many times,
- those with low score may never get selected (they will die…).

Step four

crossover

- cross chromosomes in each selected pair,
- there are many ways of doing that (single point, many points, uniform…).



Step five

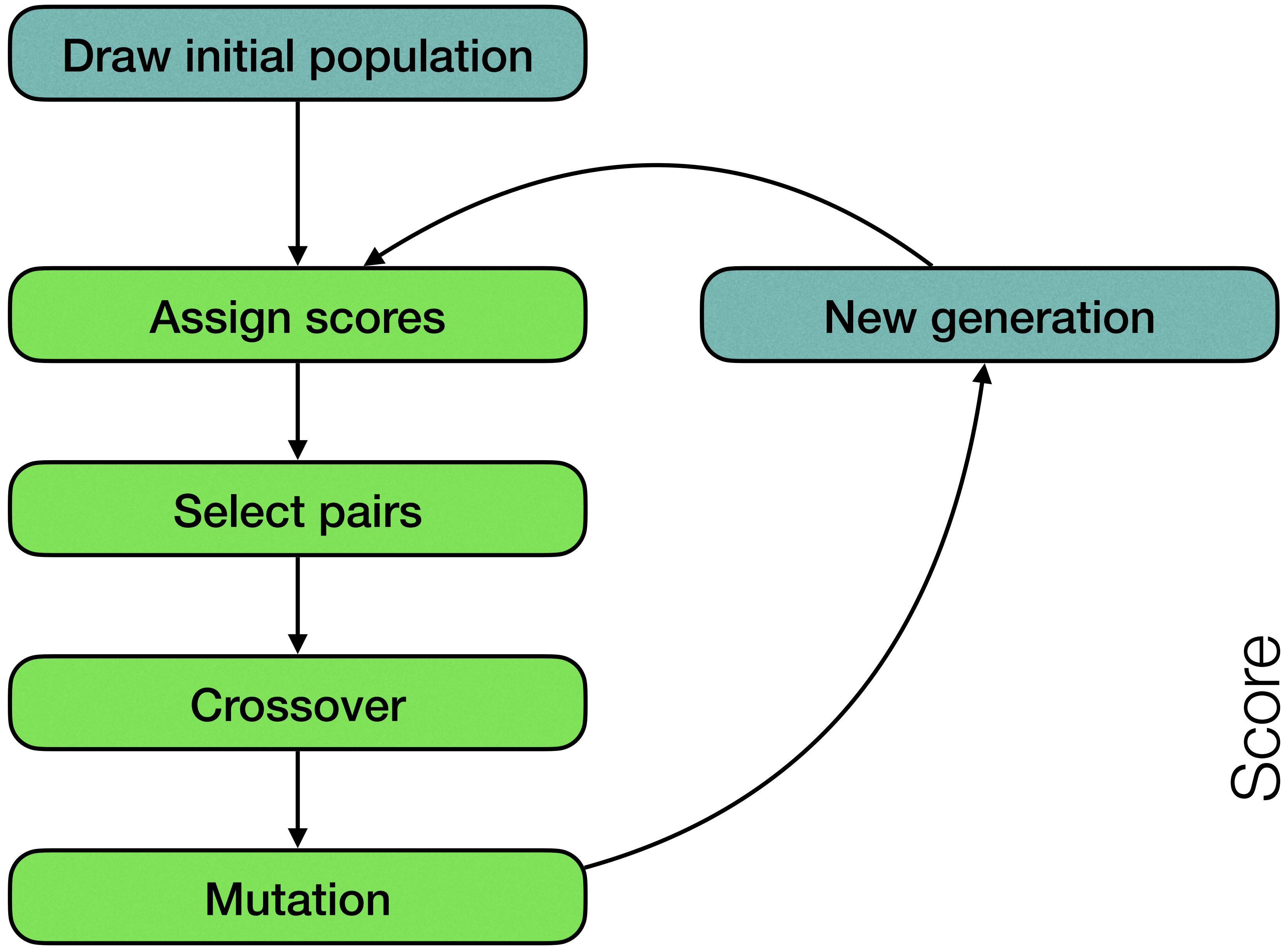
mutation

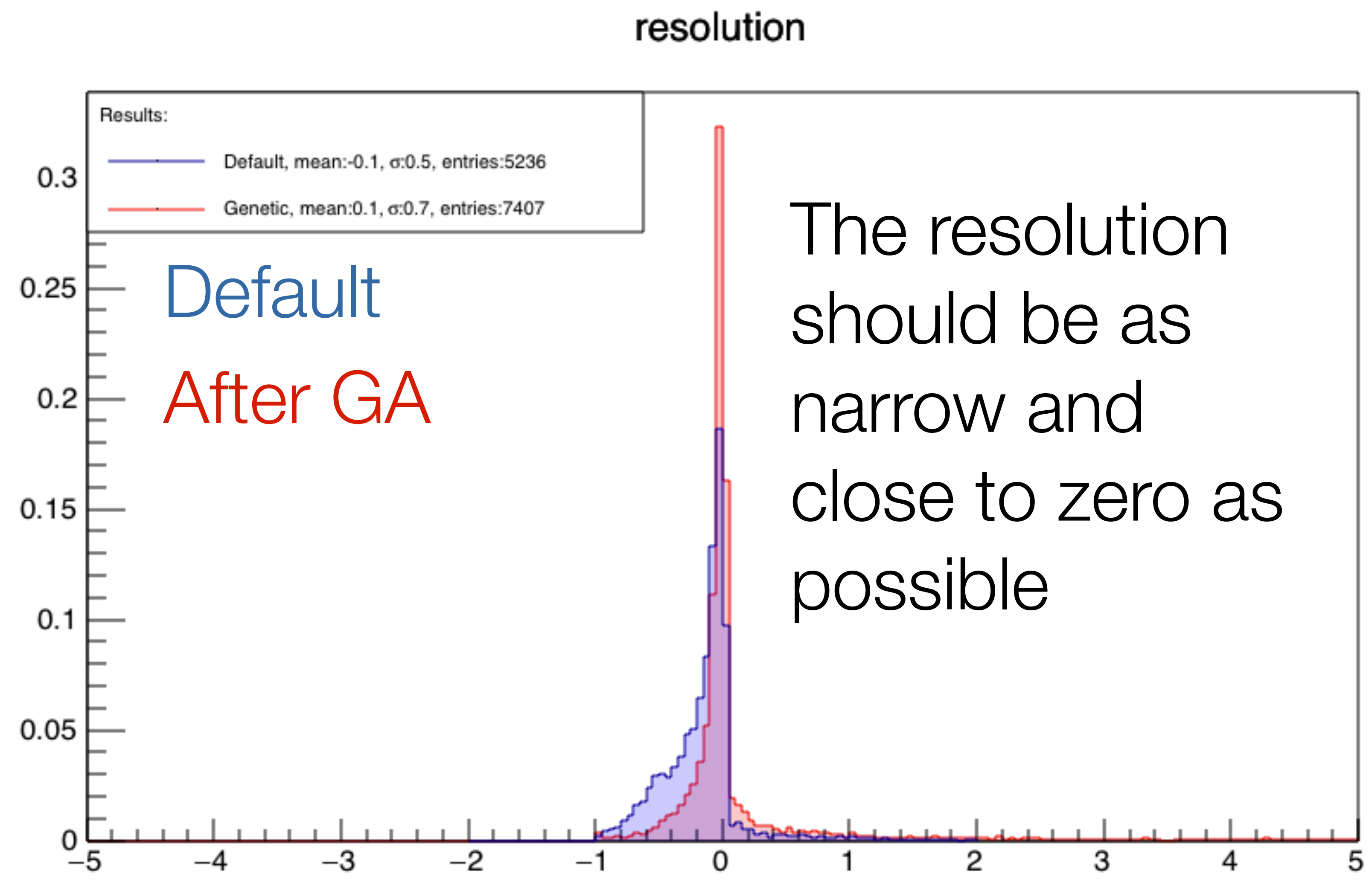
- randomly flip bits in child chromosome (with a very small probability).

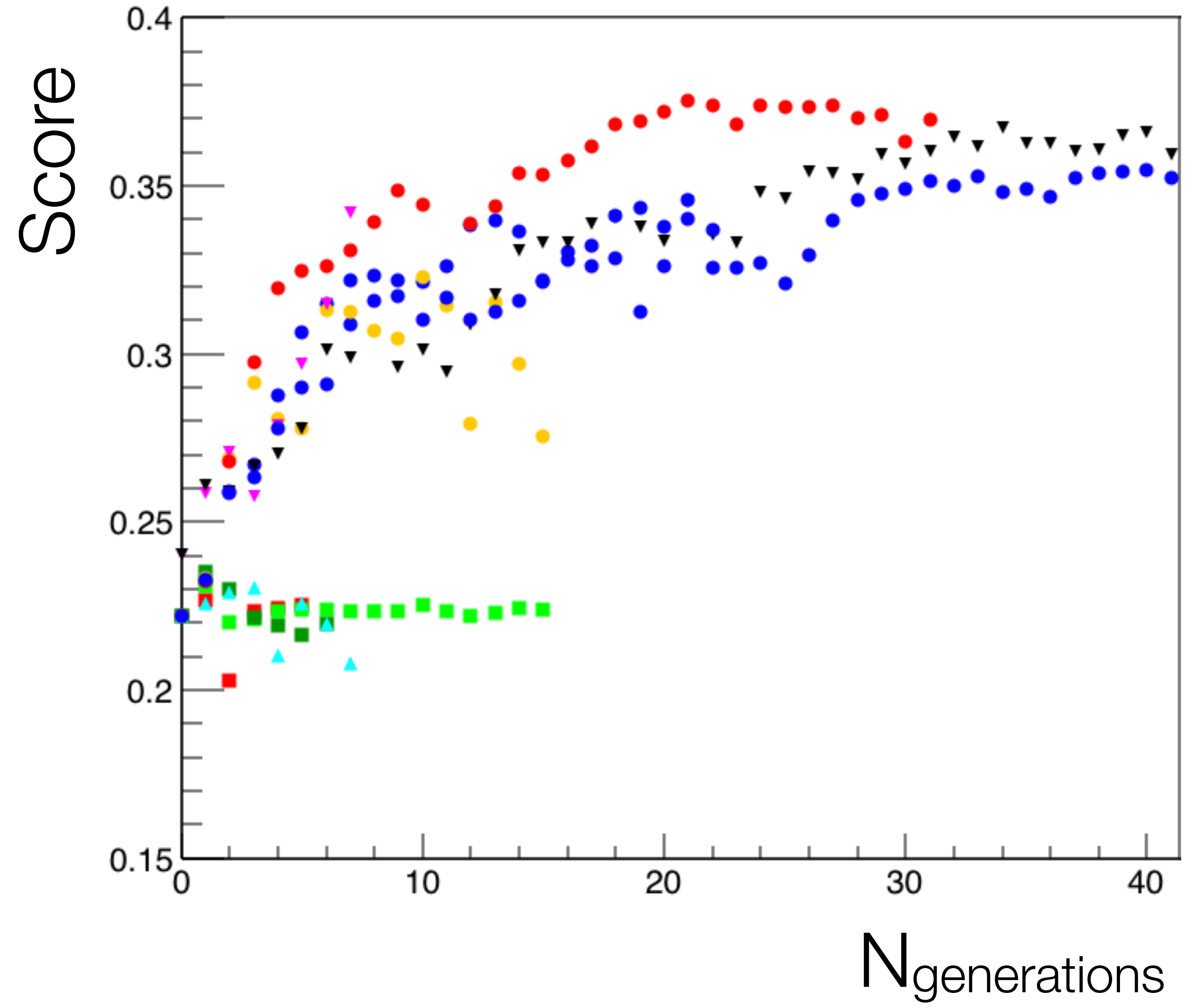
At this point, we have a new population (2nd generation), that should in general be a bit better adapted.

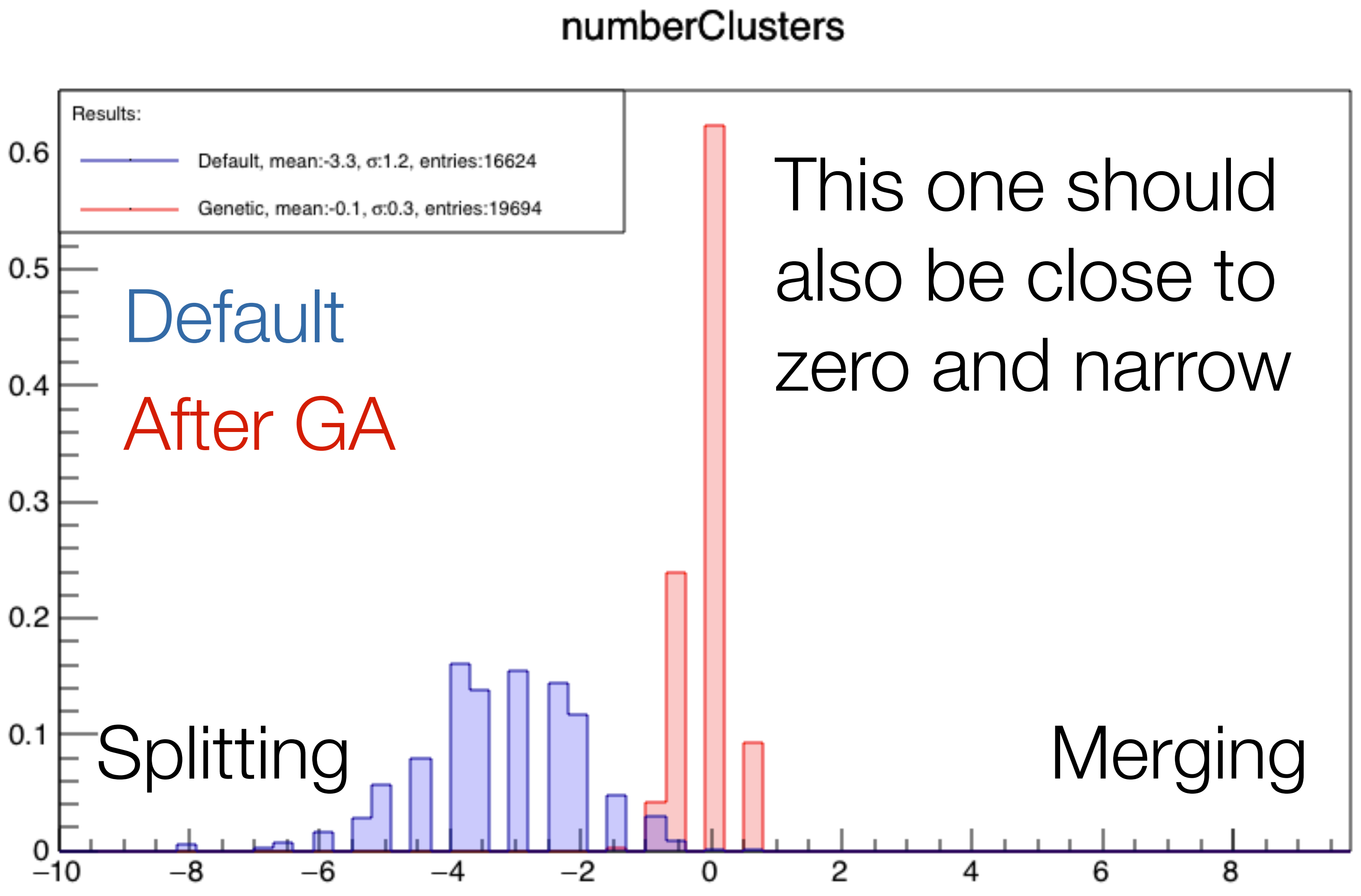
HGCAL OPTIMIZATION - RESULTS

We repeat this process until our solutions don't get much better with each iteration



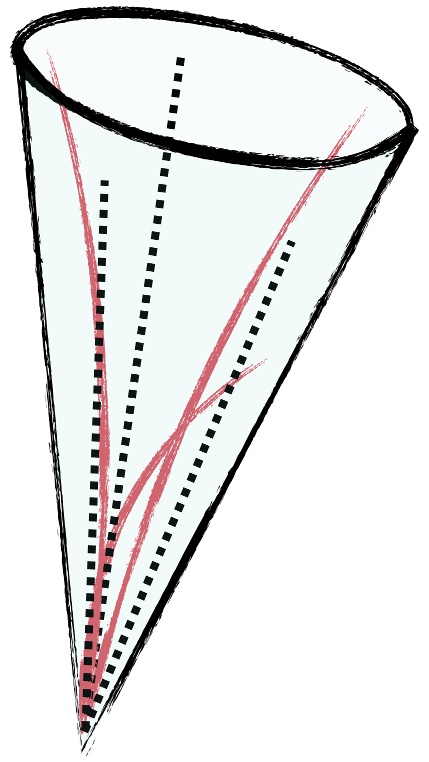


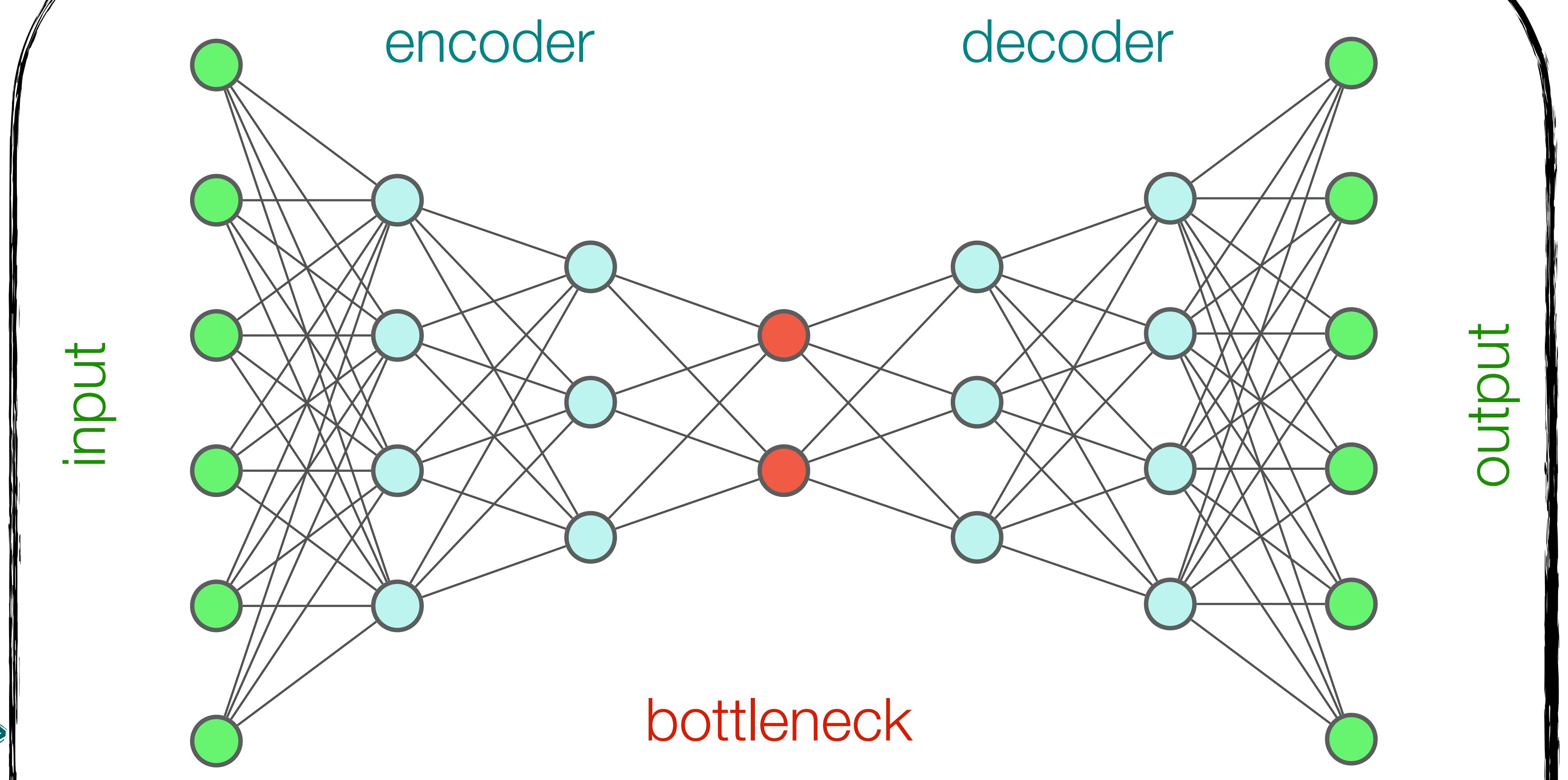




Semivisible jets

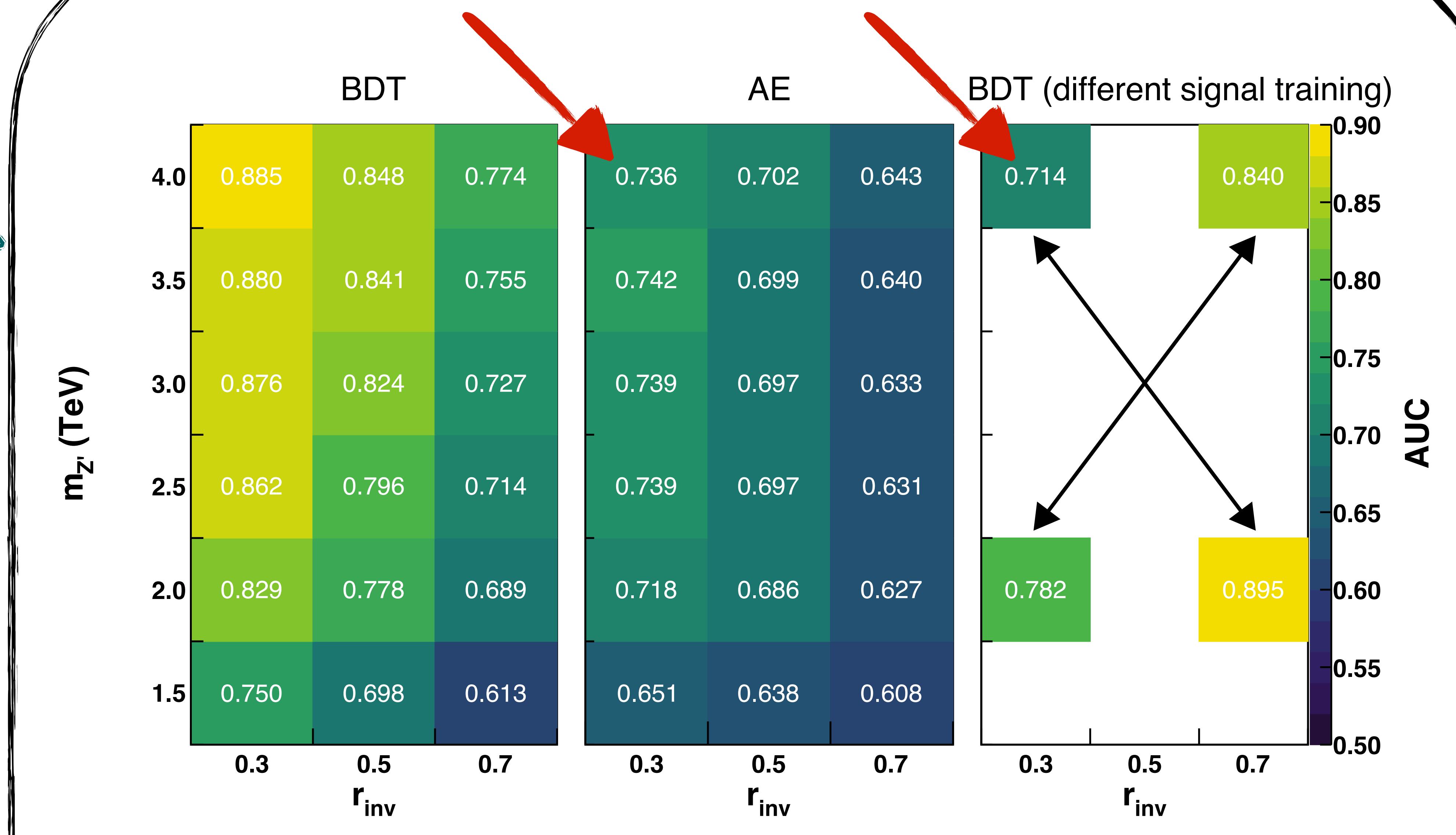
Challenging signature: **jets** containing both **SM and DM particles**





(variational)(graph)**autoencoders**

highly **model independent**

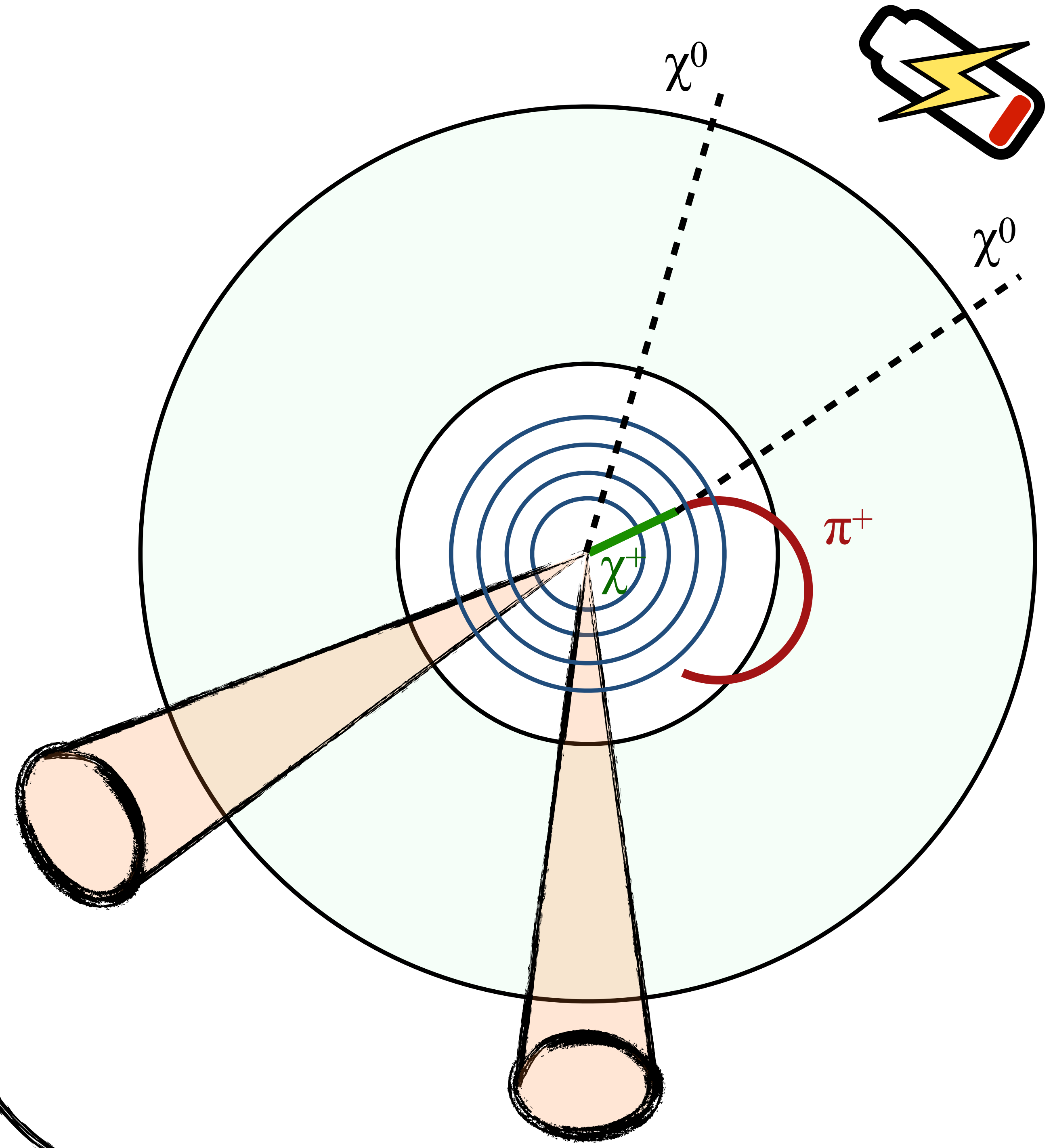


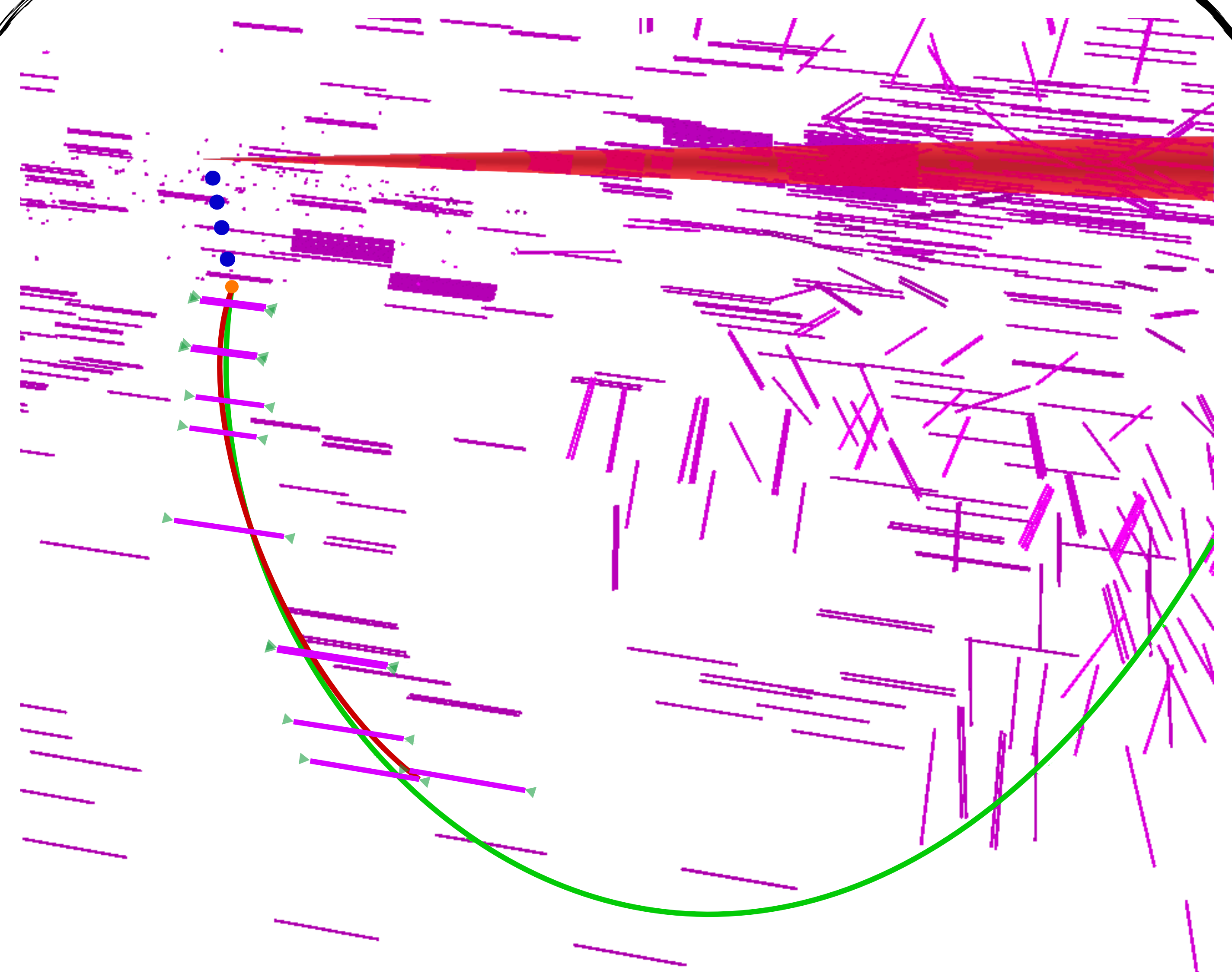
Good performance of **unsupervised learning.**

Sometimes **better than a classifier!**

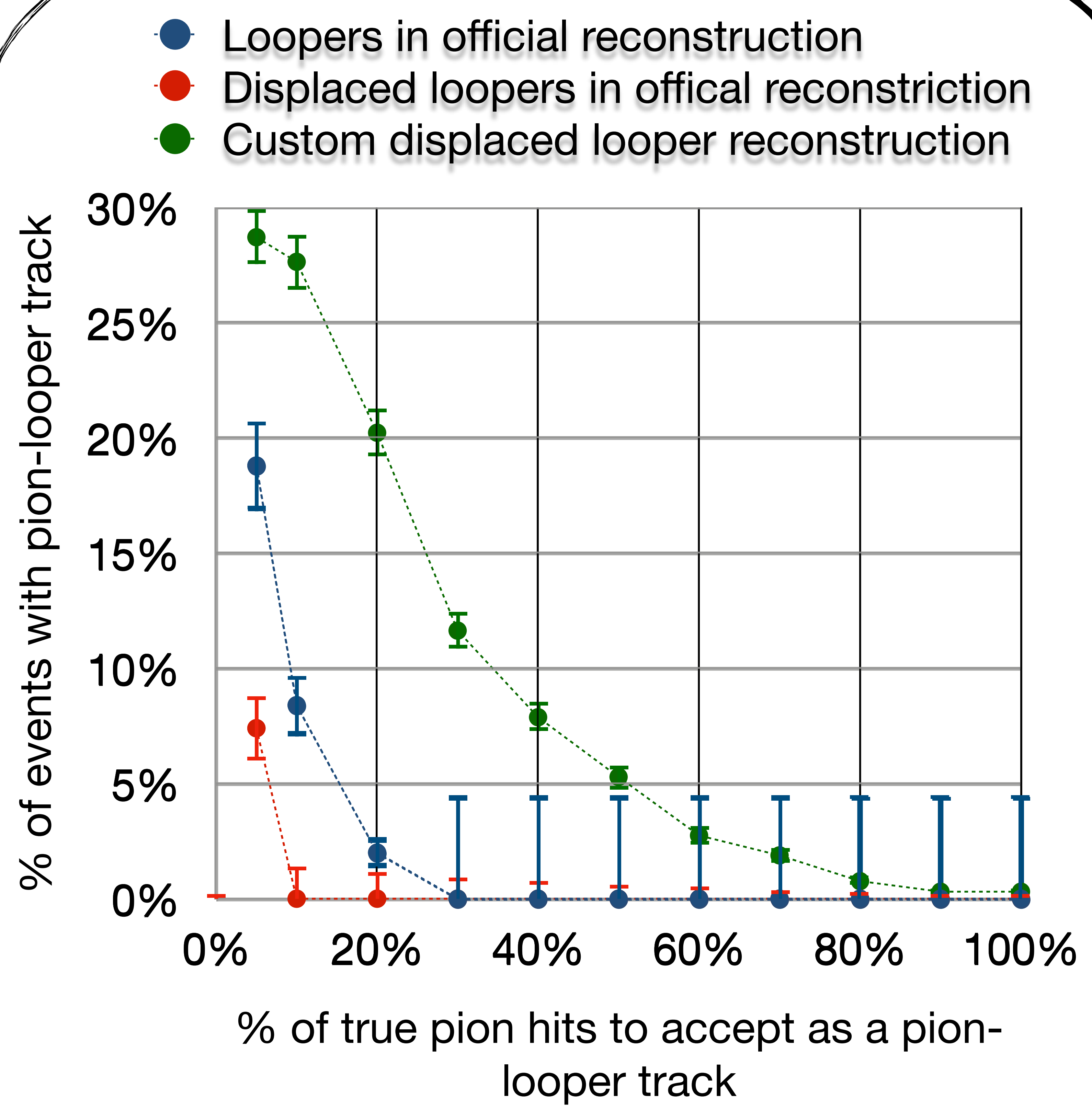
Disappearing Tracks

Boss, why can't we **reconstruct this soft pion?**





Boss: **give it a go!**



Works better than default reconstruction!

Not good enough to improve the analysis…

SHORT DISAPPEARING TRACKS

We are interested in theoretical models which give a signature of a **short disappearing track**, such as SUSY with small mass splitting.

SUSY wino scenario

(max LSP mass ≈ 3 TeV, Δm ≈ 166 MeV)

$$\tilde{H}_{u,d} \to \tilde{\chi}^0_{3,4}/\tilde{\chi}^\pm_2$$
$$\tilde{B} \to \tilde{\chi}^0_2$$
$$\tilde{W} \to \tilde{\chi}^0_1/\tilde{\chi}^\pm_1$$

SUSY higgsino scenario

(max LSP mass ≈ 1.1 TeV, Δm ≈ 355 MeV)

$$\tilde{W} \to \tilde{\chi}^0_4/\tilde{\chi}^\pm_2$$
$$\tilde{B} \to \tilde{\chi}^0_3$$
$$\tilde{H}_{u,d} \to \tilde{\chi}^0_{1,2}/\tilde{\chi}^\pm_1$$

Generic minimal DM model

(e.g. arxiv:0512090)

SU(2) n-plet, n=2,3,5,7

n=2: higgsino scenario

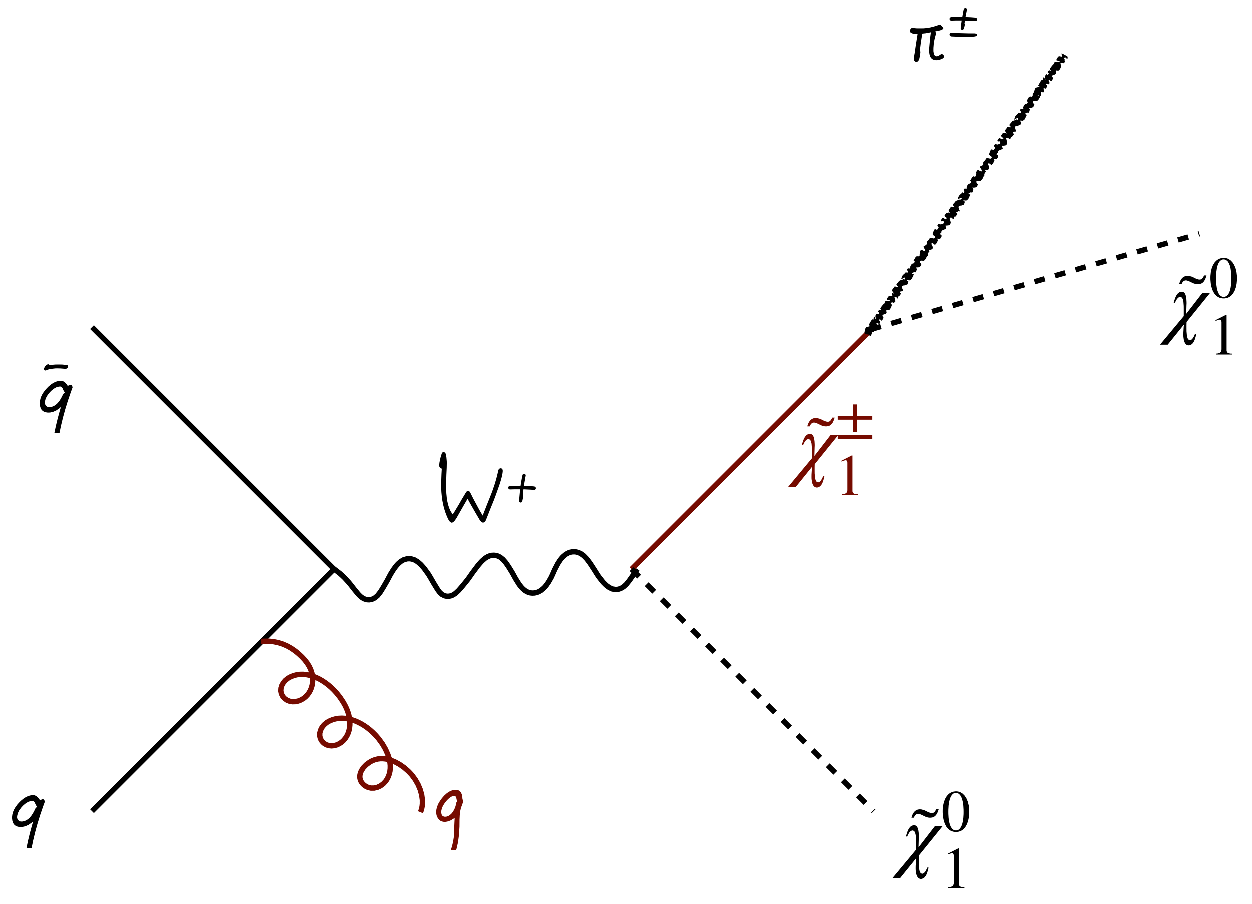
n=3: wino scenario

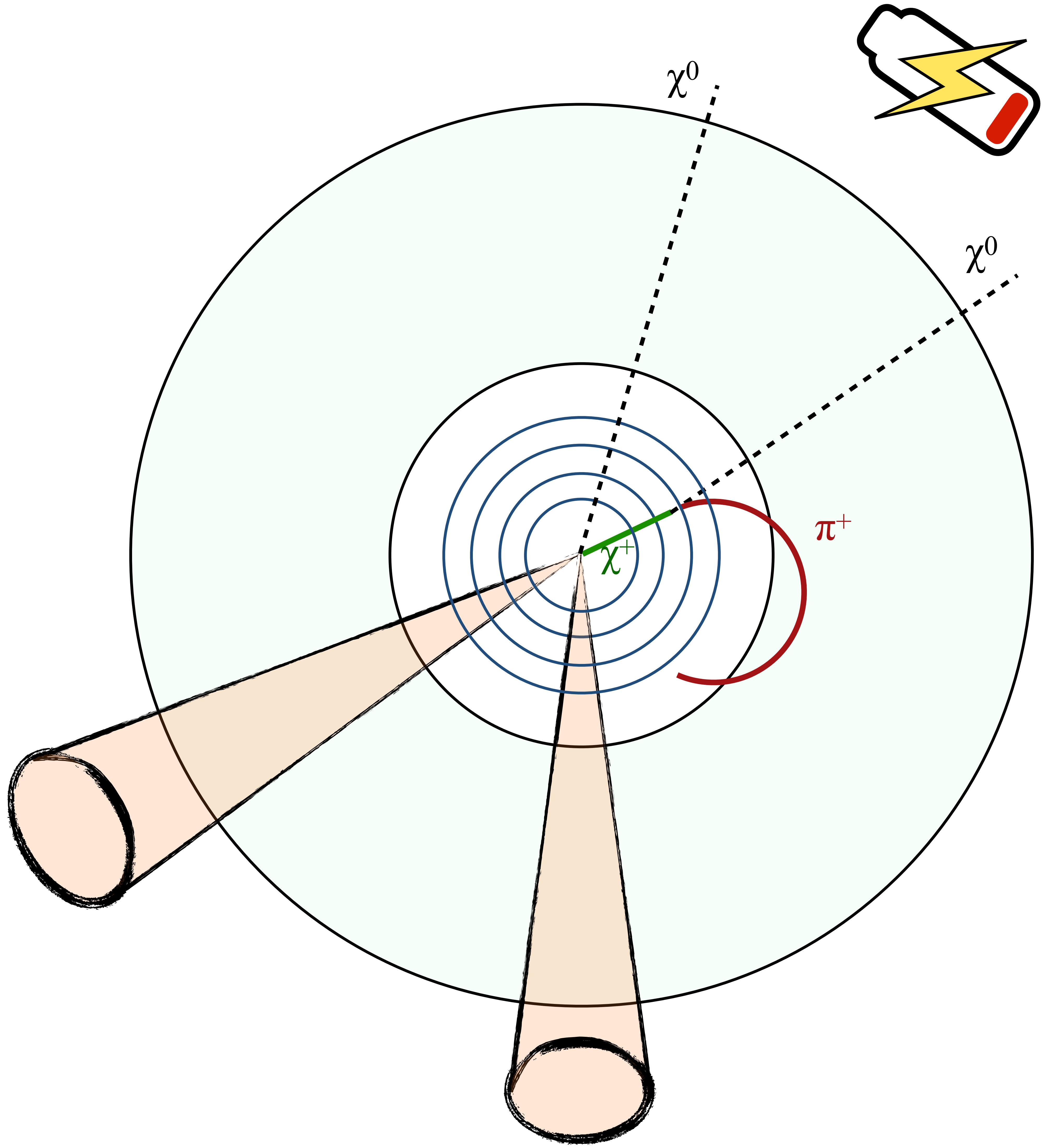
n=5 also interesting

EXPECTED SIGNATURE

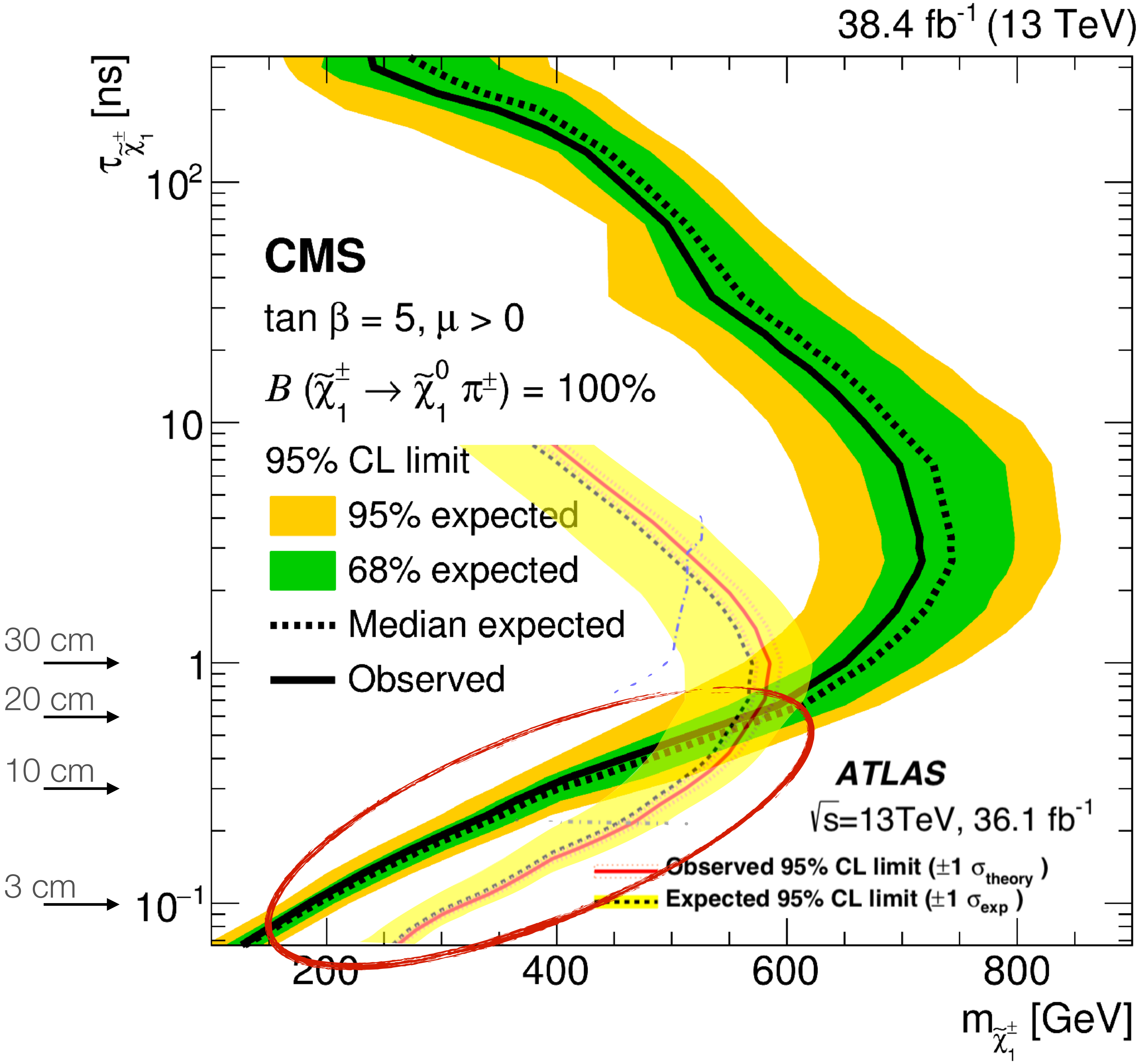
Signature

- a **short, isolated track**:
  - "disappearing" after passing <10 layers of the tracker,
  - with relatively **large energy deposit** in the silicon detectors,
- high **MET** (missing transverse energy) in the track's direction,
- one or more **jets** (against which the chargino recoils),
- a very **soft pion** coming from the chargino decay vertex (≈200 MeV).





CURRENT STATE OF THE ART



CMS: EXO-16-044 | ATLAS: 1712.02118

Current disappearing track analyses

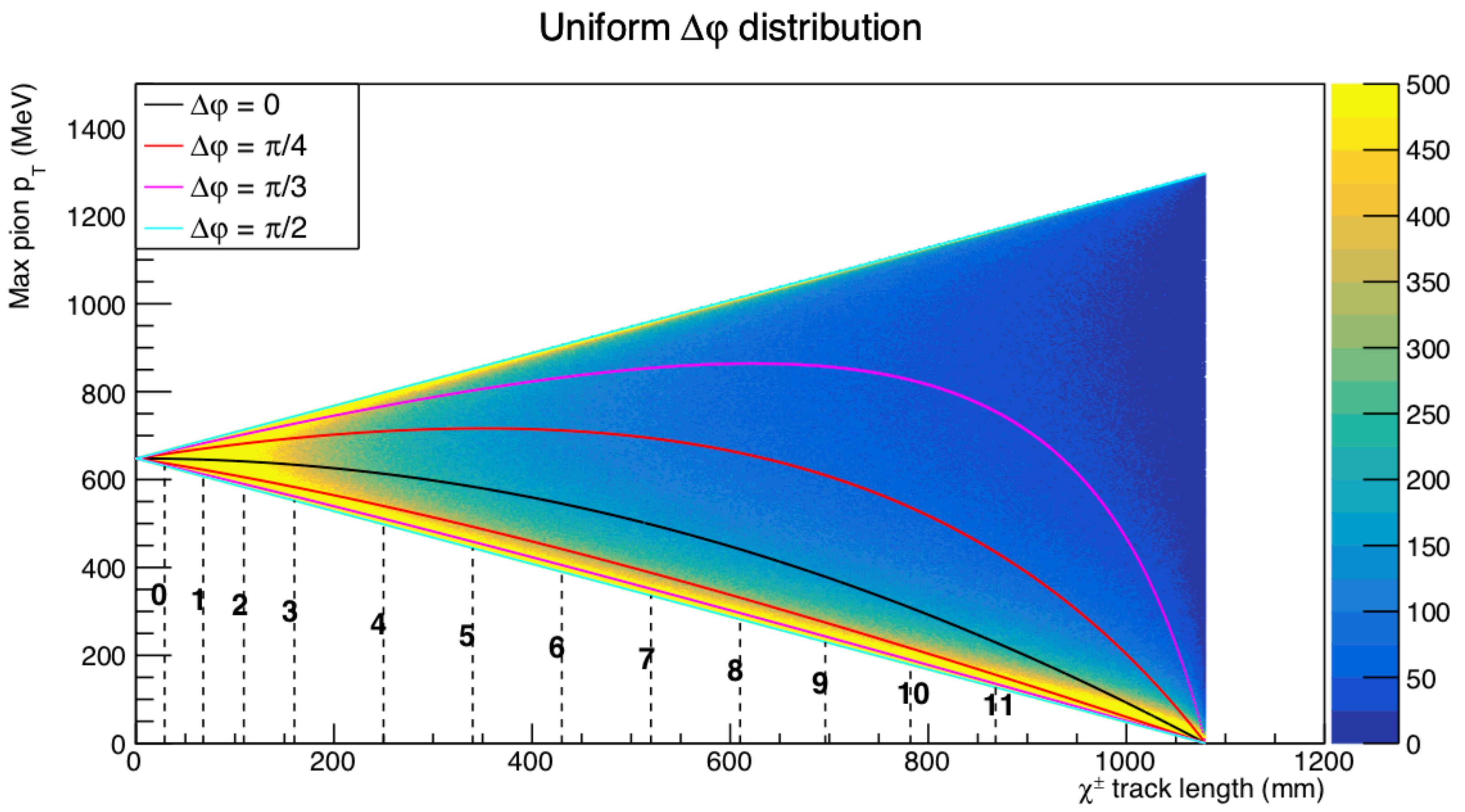
- **CMS result** (EXO-16-044) requires ≥ 7 hits in the tracker,
- **ATLAS result** (1712.02188) went down to 4 layers (thanks to the IBL),
- **EXO-19-010** (in CWR) with full Run 2 data, 4 layers.

This analysis

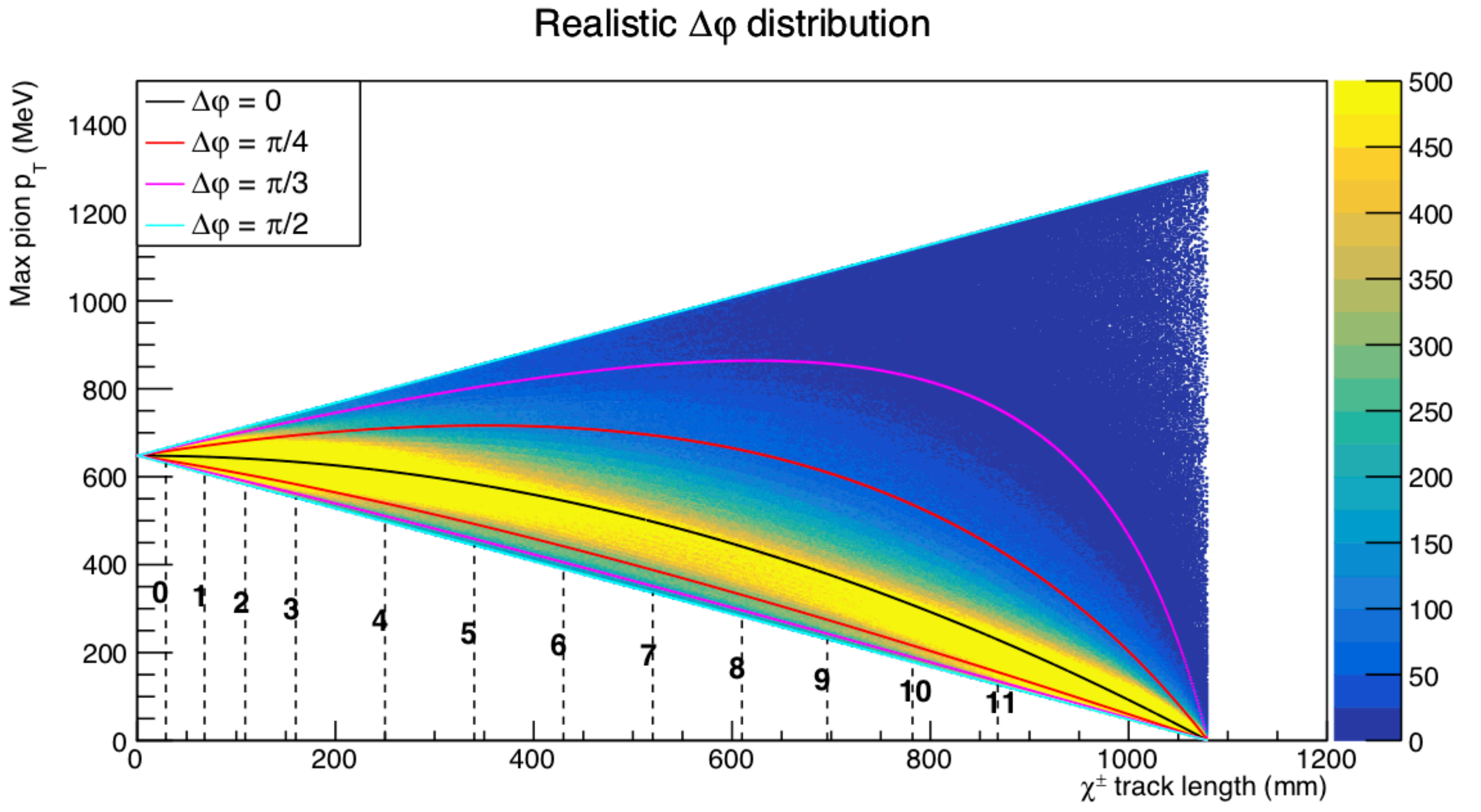
- focus on lifetimes below 1 ns (cτ < 30 cm),
- reduce the N_{hits} requirement, even below 4 hits,
- include **two-track** scenario,
- use the **dE/dx** in pixel and strips,
- exploit the **helix trajectory** of the pion.

Looper probability

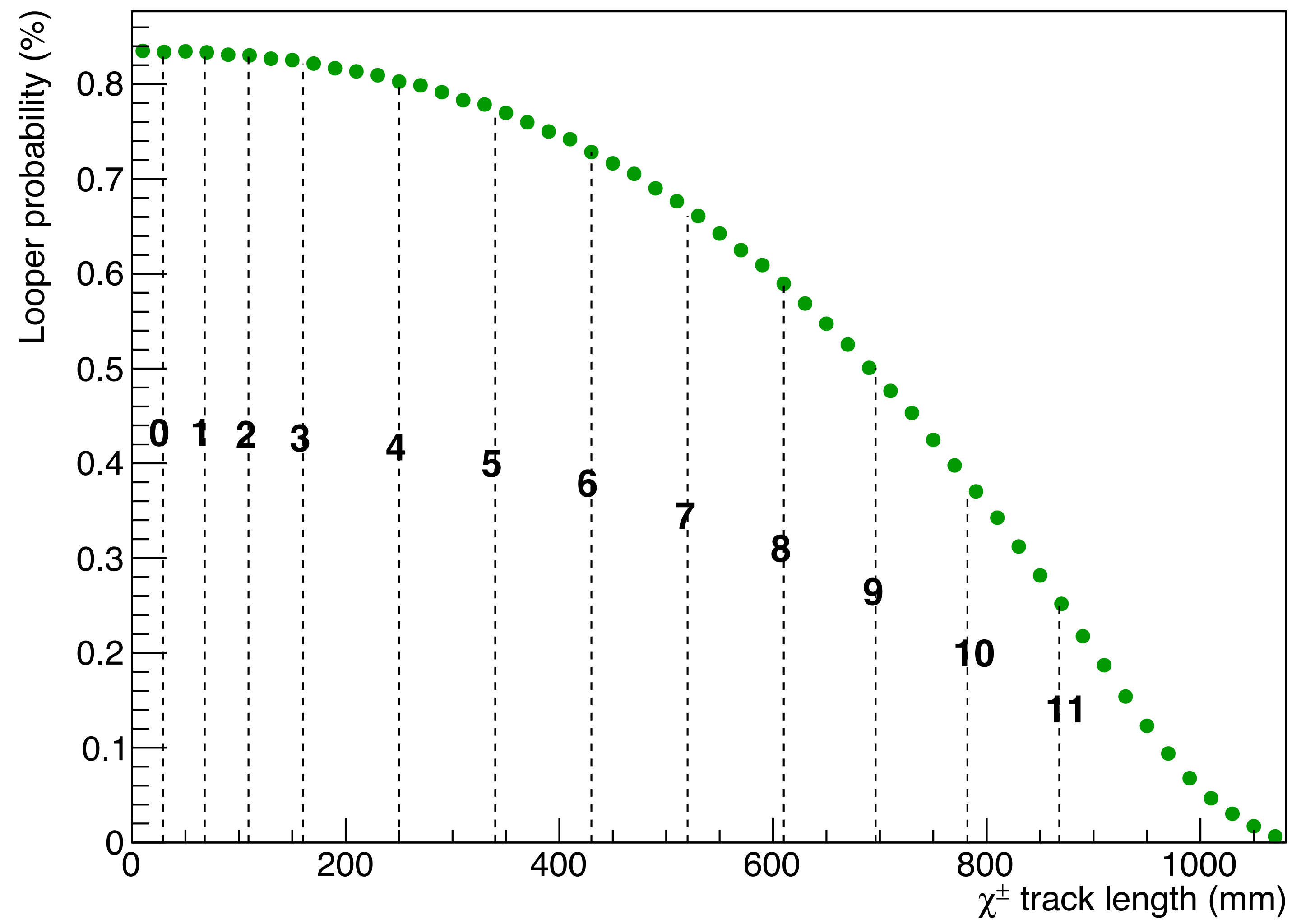
How low the momentum has to be, depending on where did the chargino decay and what was the Δϕ(χ, π), to get a looper?



Δϕ(χ, π) distribution



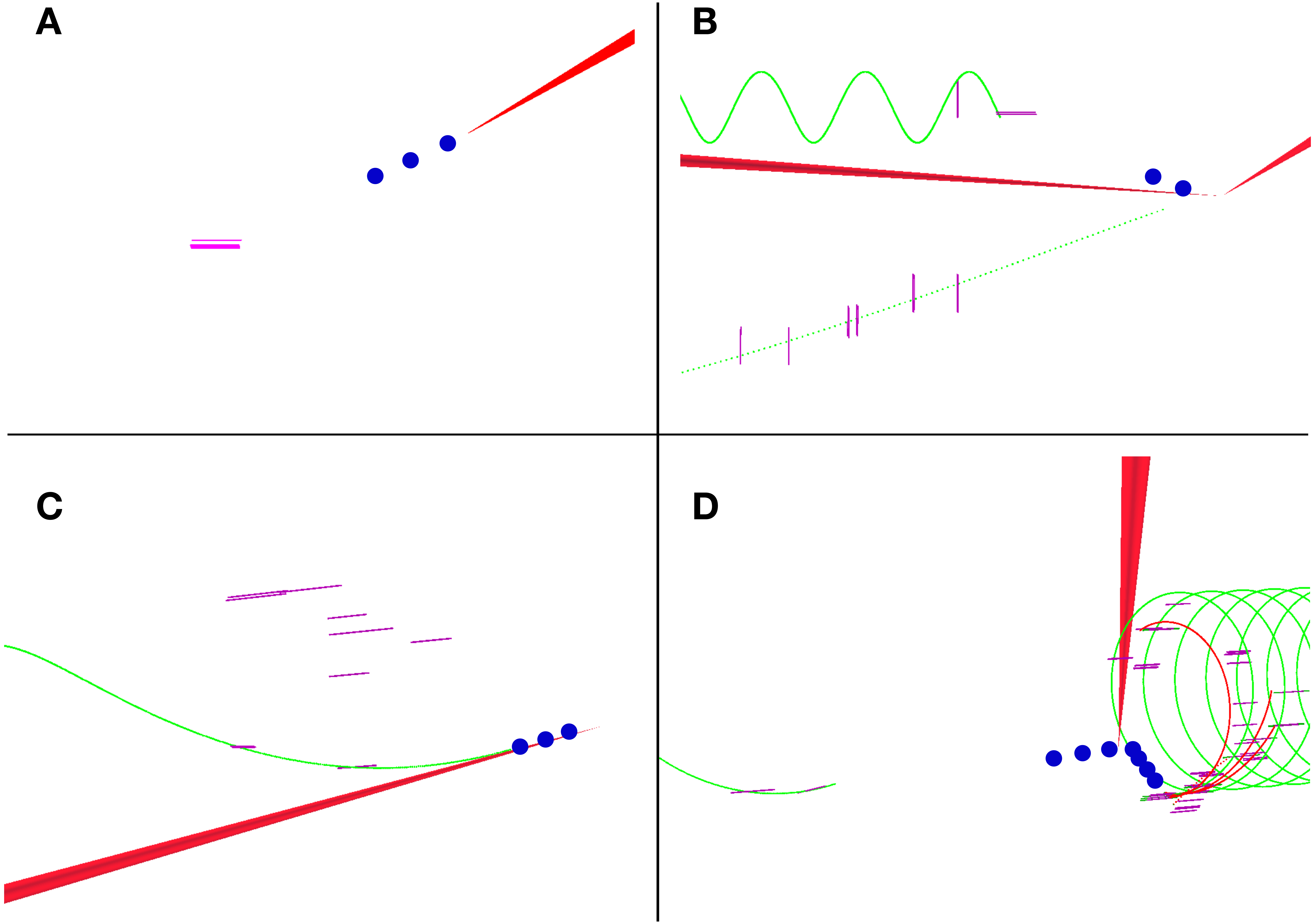
Pion p_T distribution



χ track length distribution (10 cm)

70%

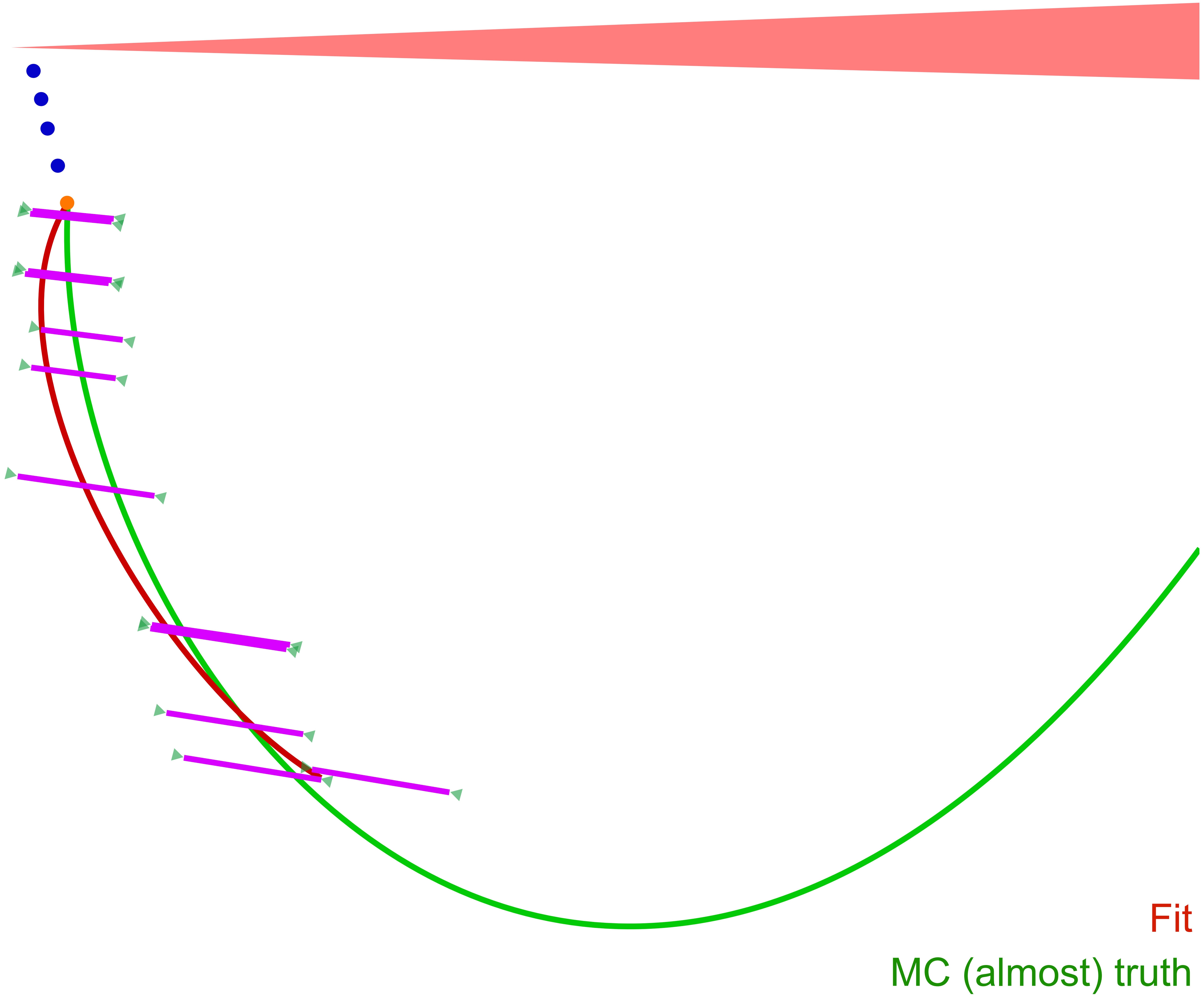
Impossible/Challenging cases



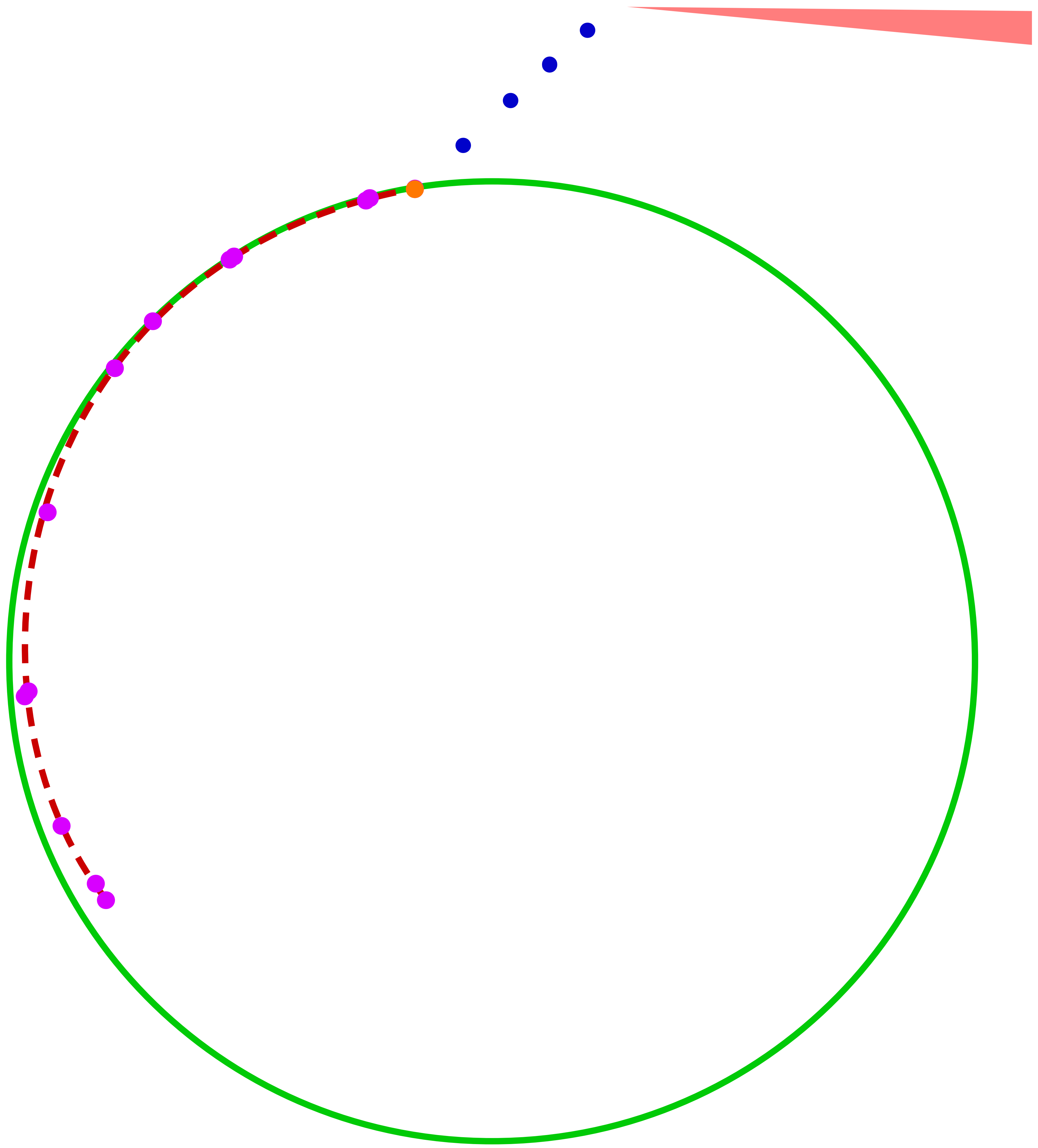
Sometimes, configuration of hits is such that it becomes practically **impossible** to reconstruct any track:

A. no hits,
B. chargino not reconstructed,
C. hits heavily scattered,
D. very low p_z (multiple solutions).

RESULTS

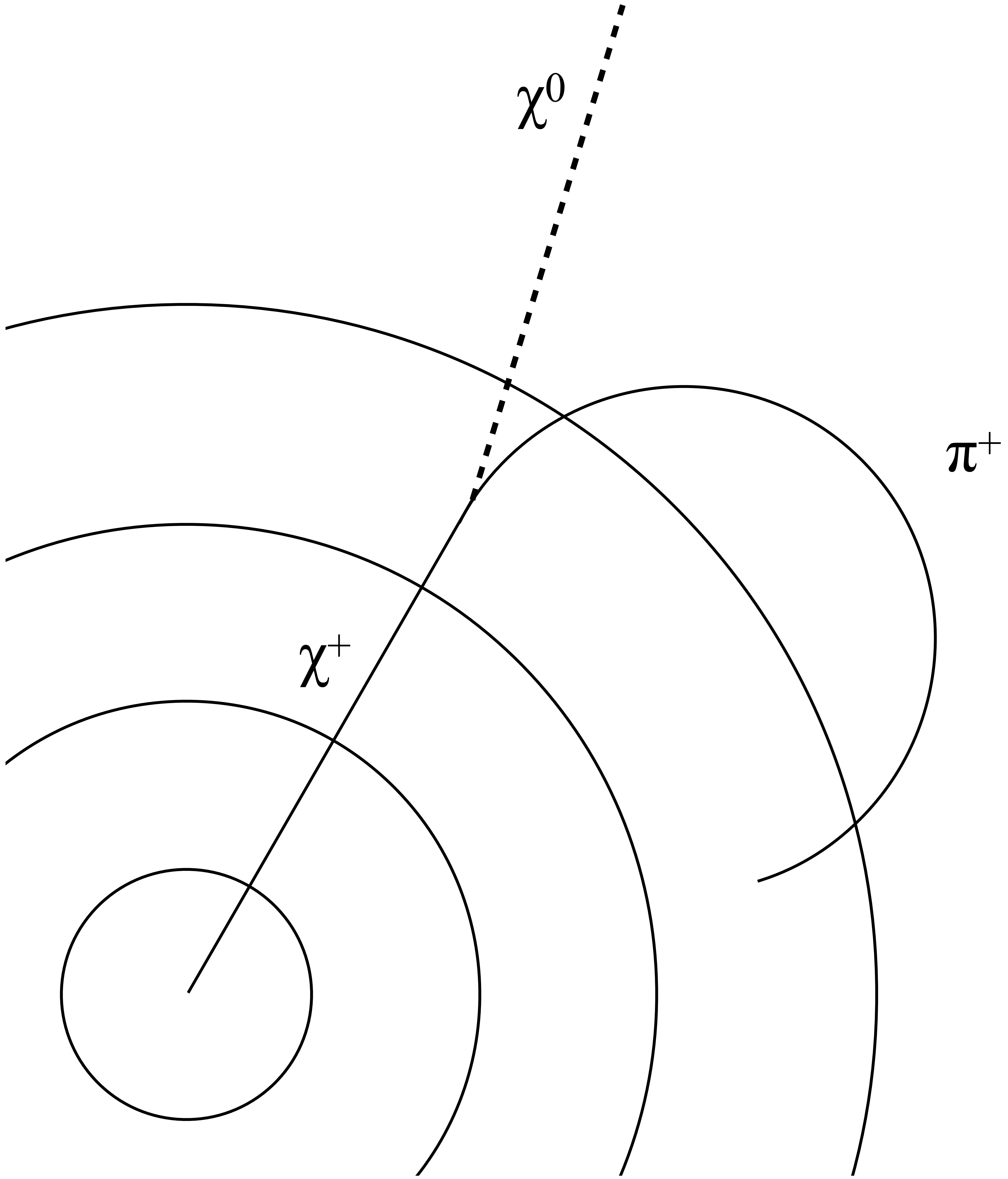


Then, one can start with an **easy case**, with only pion clusters.



LOOPER TAGGING

Reconstruction of the soft pion coming from the chargino decay vertex would be very **challenging**, but could be worth it!



Challenges

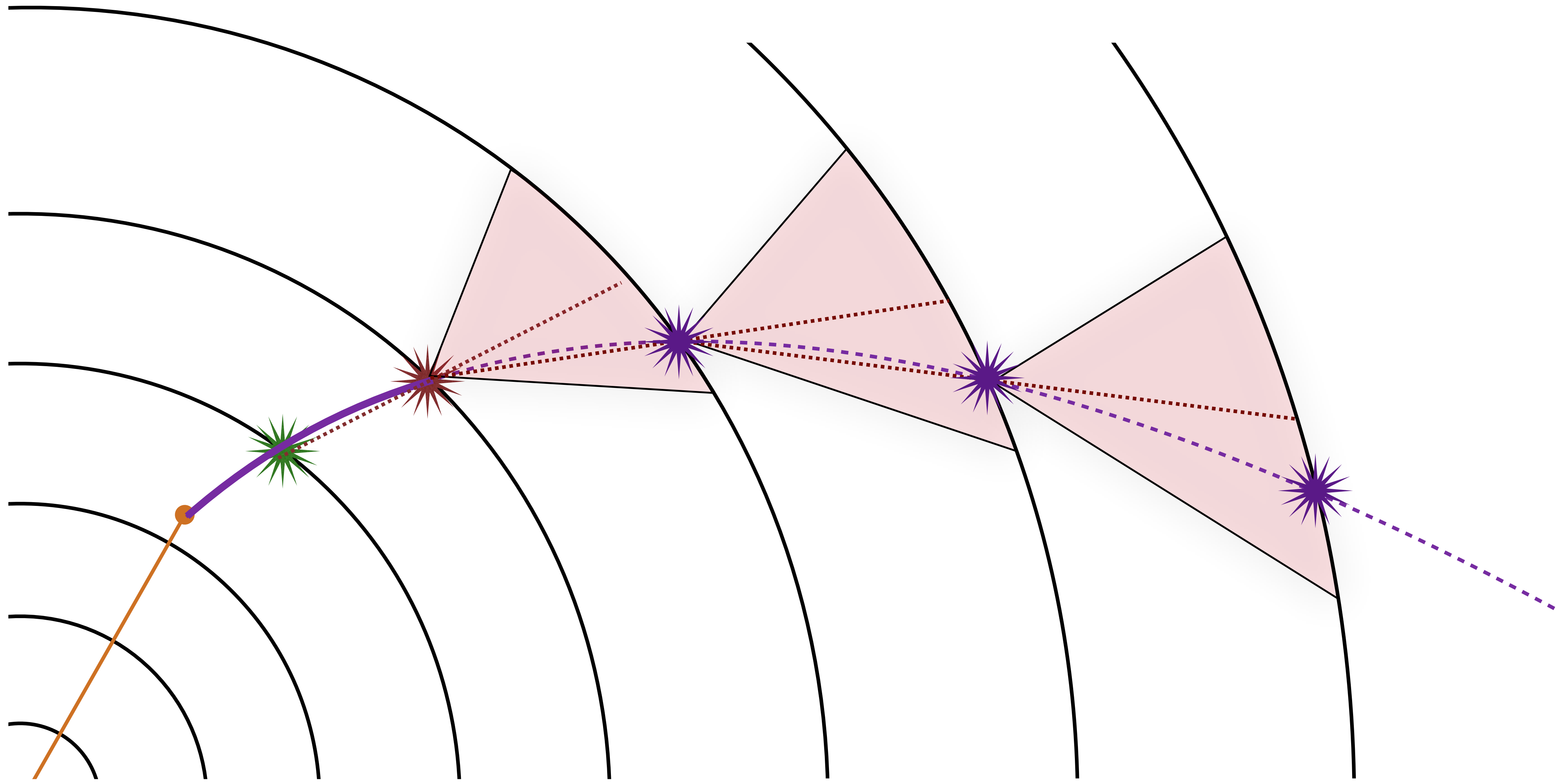
- **multiple scattering** (not well determined hit location in next layer),
- soft pion can **stop quickly** in the material,
- large momentum loss - heavily **shrinking helix**,
- **tracker-only**, no matching with calorimeters,
- high number of **background** ("noise") hits,
- **chargino mis-reconstruction** (N_{layers}, charge).

Positives

- approximate decay **vertex location** (along chargino's track),
- distributions of (from MC):
  - initial and final helix **radius**,
  - initial **momentum**,
  - **next-hit** location,
- **charge** of the pion (from chargino's charge).

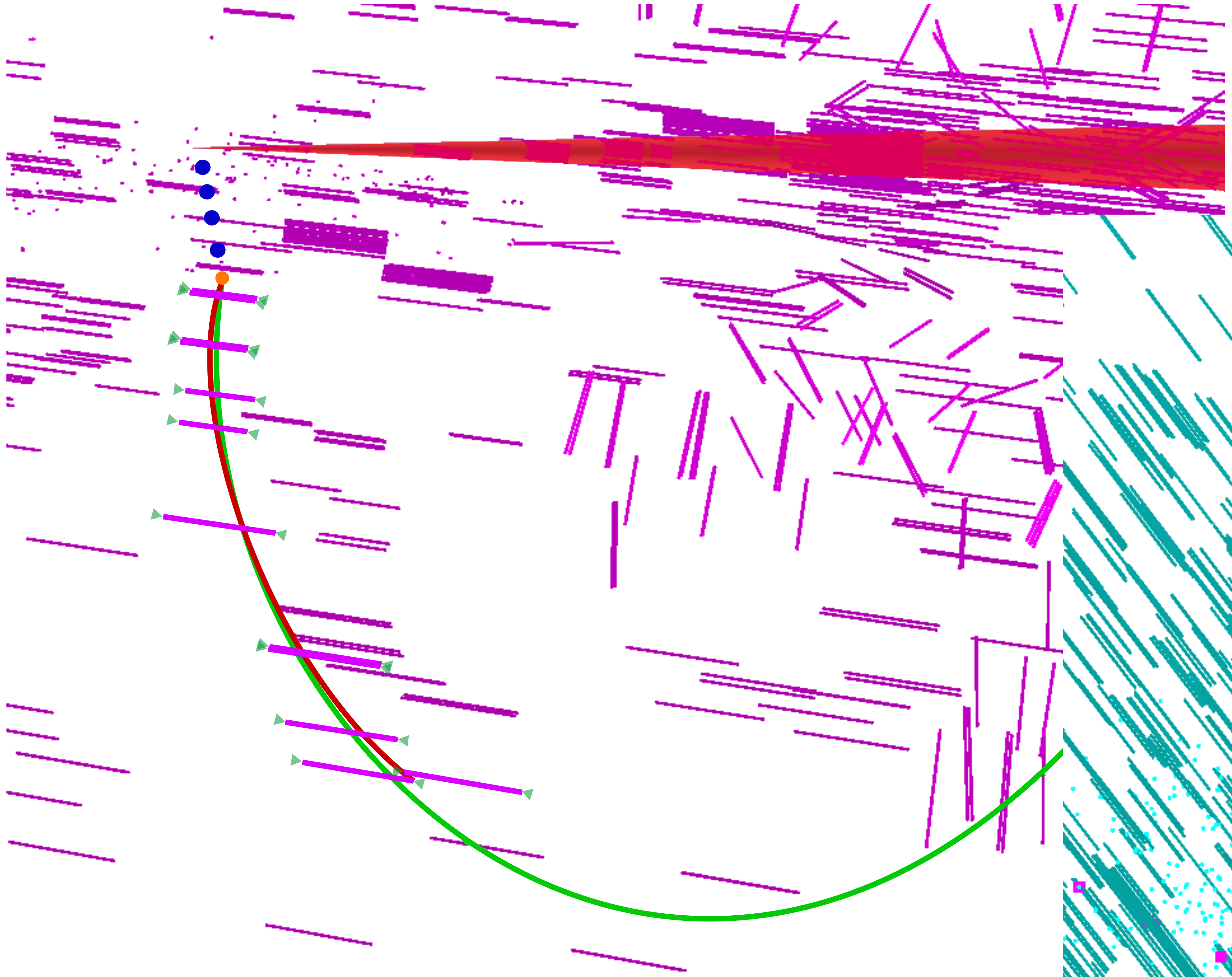
DEDICATED RECONSTRUCTION

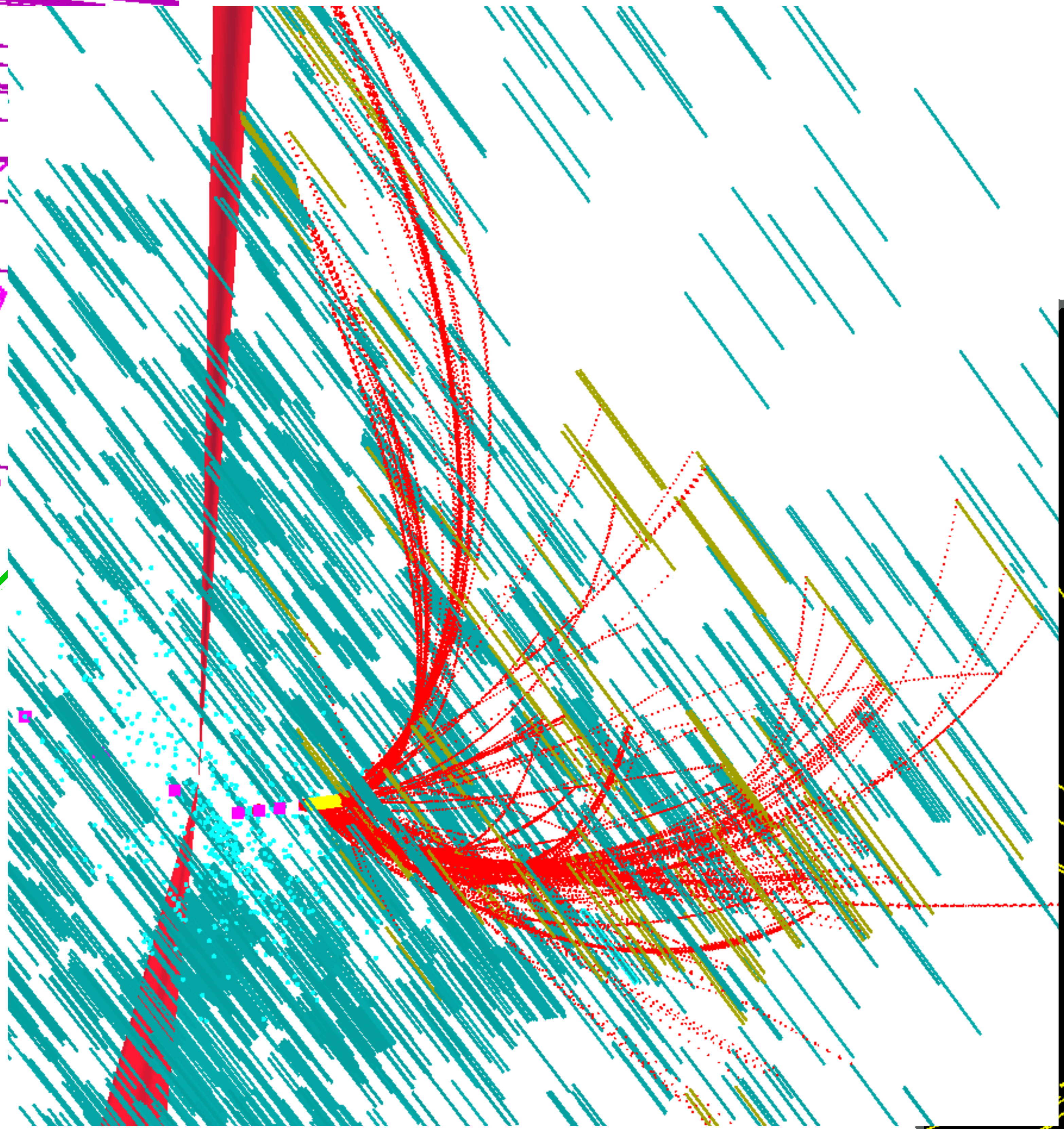
- a **dedicated algorithm** was developed,
- written in a way allowing for high level of **customization** using a large number of parameters, optimized based on:
  - tracker **geometry** and event topology,
  - **MC distributions**,
  - iteratively reconstructing events and **maximizing significance boost**,
  - with a genetic algorithm.

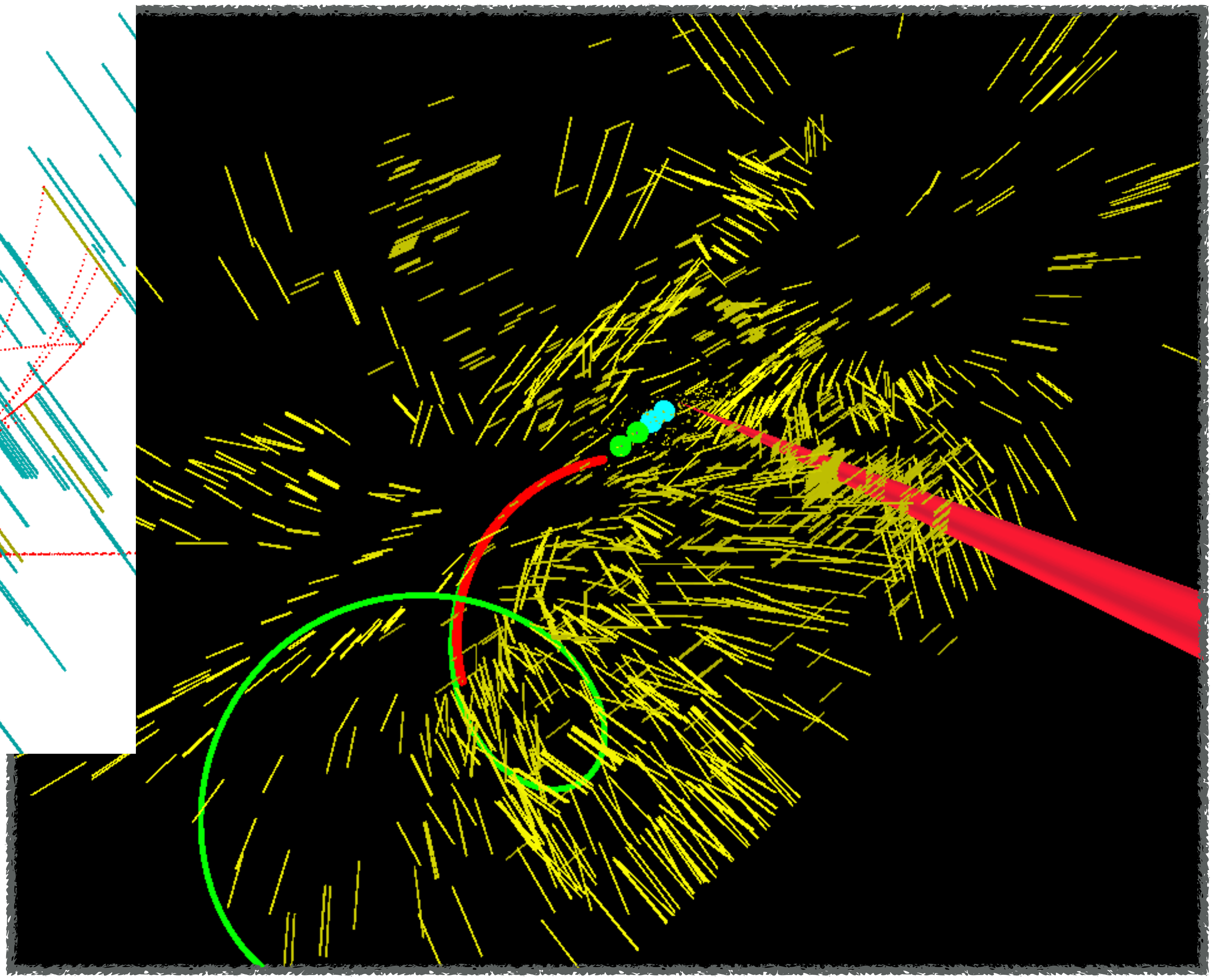


- introducing special features for low-momentum, displaced track reconstruction:
  - **secondary vertex** along a track, rather than in a box,
  - **asymmetric** (tilting) next hit search windows,
  - **charge** can be deduced from chargino's track
  - next hit can be located in the next or previous layer (**turning back**),
  - …

LOOPER RECONSTRUCTION - RESULTS







MC (almost) truth

Fitted track

$t\bar{t}$+ALPs

ALP searches at the LHC

- huge **mass range:** 0.2 to 1600 GeV,
- various final states and production mechanisms, probing **various ALP couplings,**
- but no searches so far aiming at ALP-top coupling!

This study

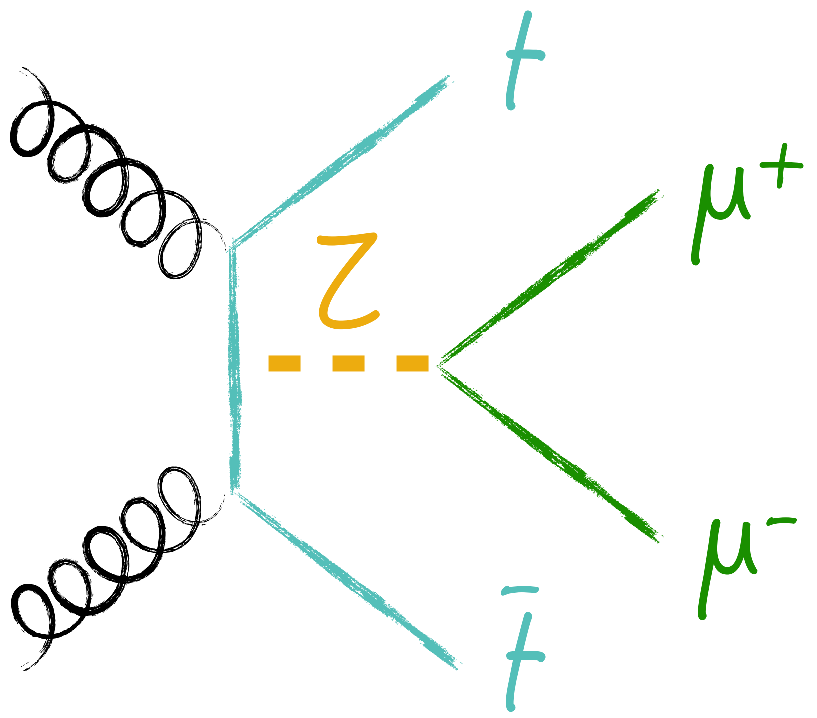
- directly probing previously unexplored **top-ALP coupling** → well **theoretically motivated,**
- interesting, **uncovered signature** ($t\bar{t}$ + displaced dimuon), with improved sensitivity thanks to **$t\bar{t}$ requirement.**

$t\bar{t}$+ALPs

Considering **two sources of backgrounds**

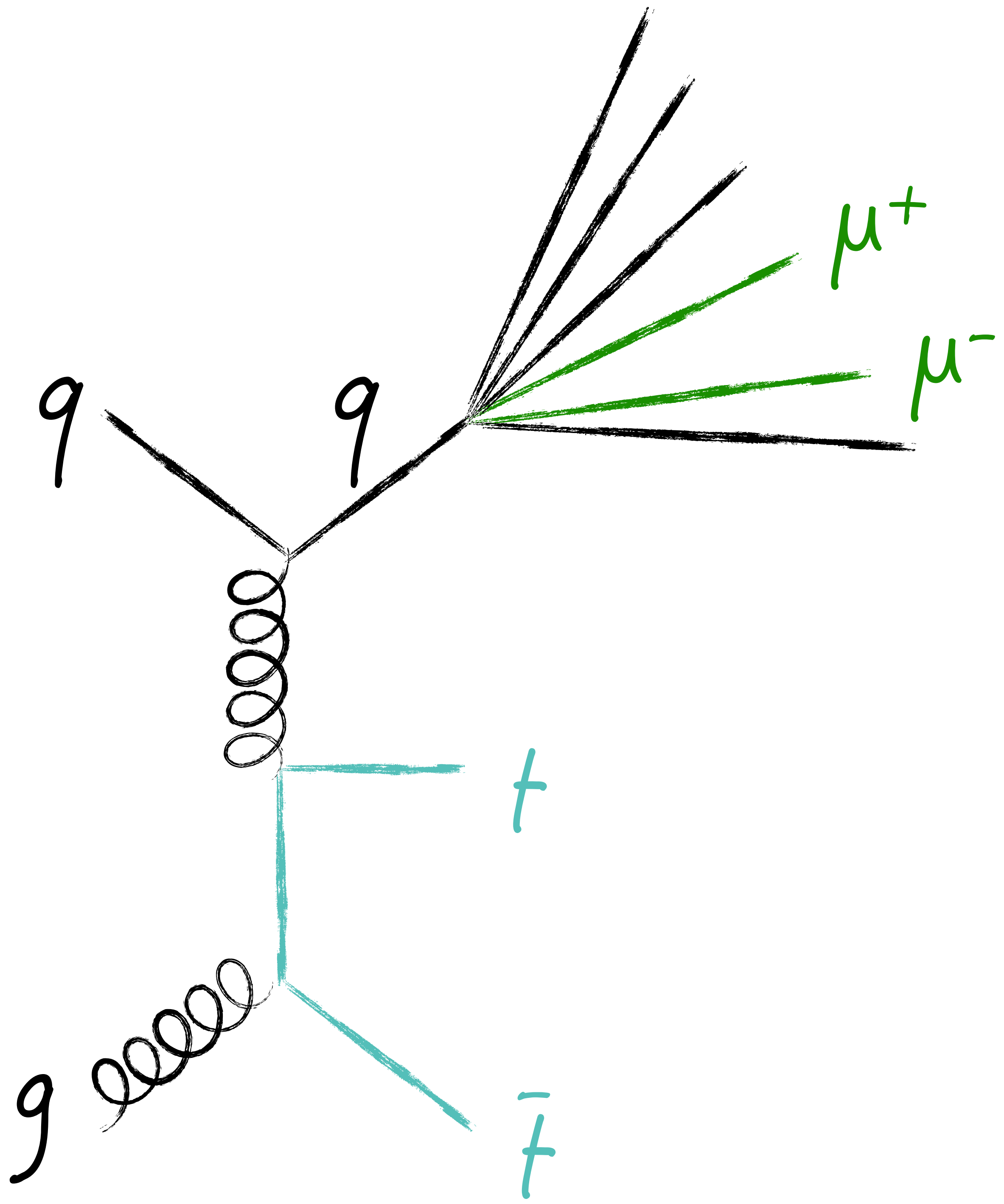
$t\bar{t}\mu\bar{\mu}$

Z boson produced in association with $t\bar{t}$ pair and **decaying to $\mu^+\mu^-$**



$t\bar{t}$+jet

particles in the jet **decay to muon(s)**

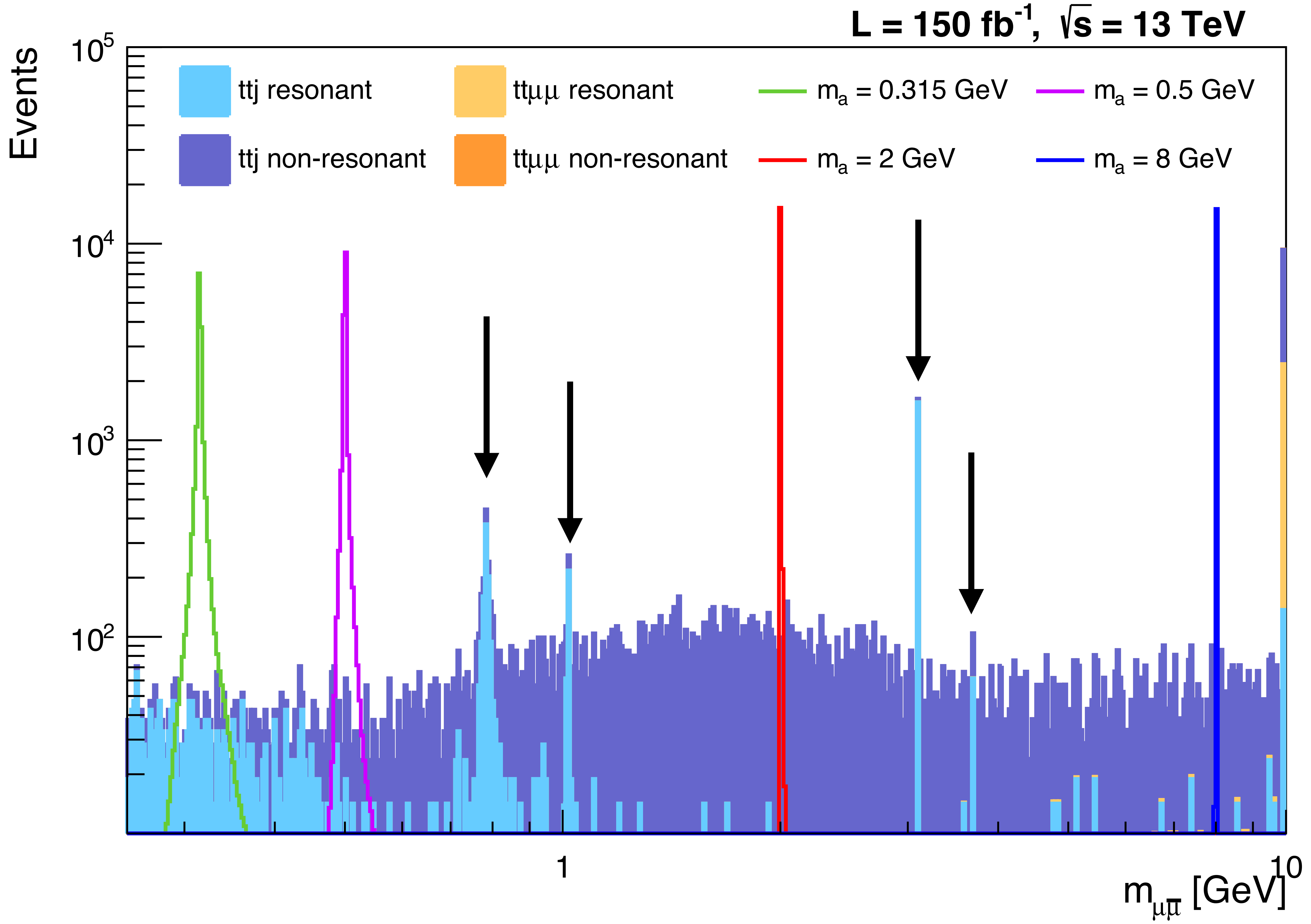


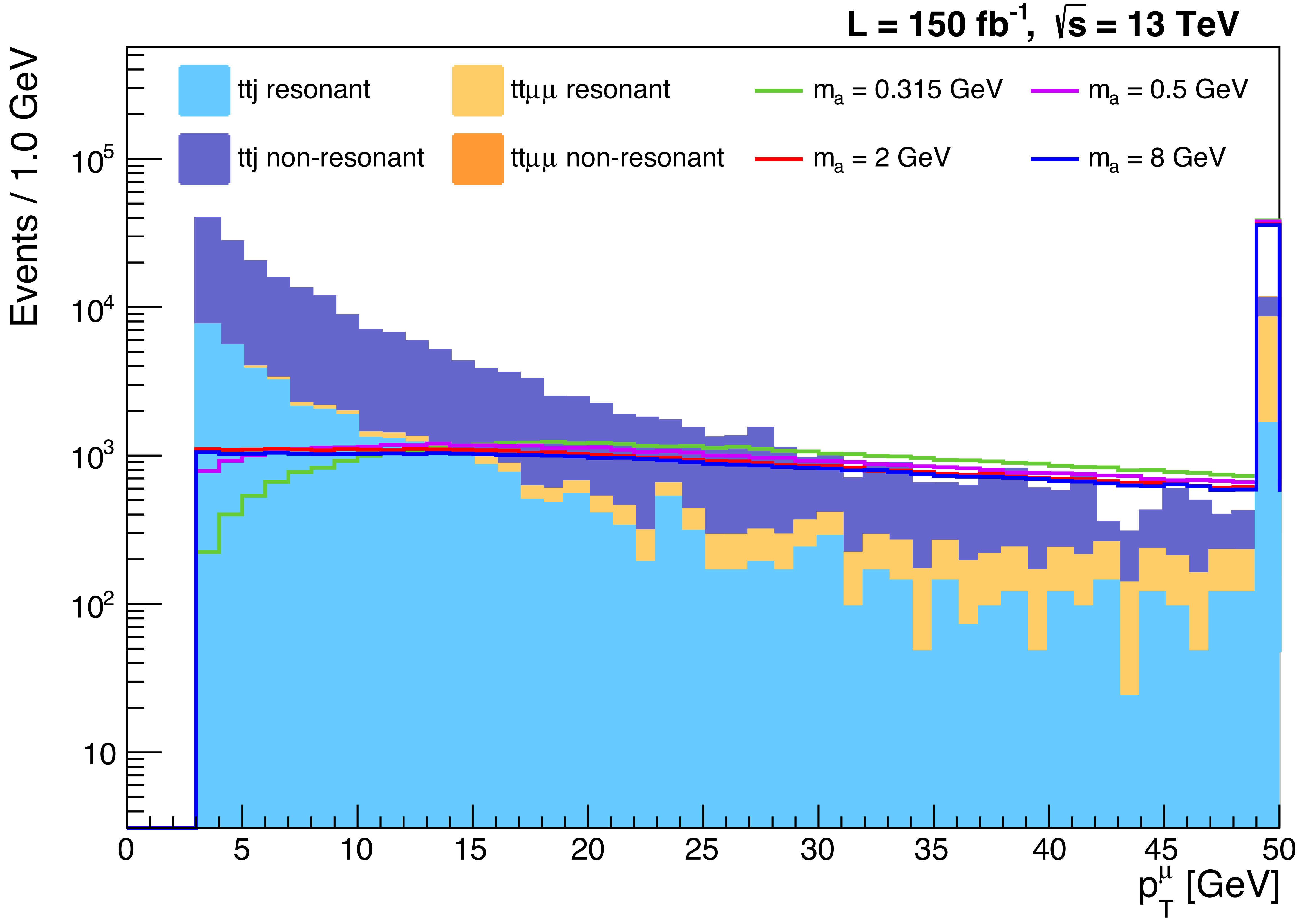
$t\bar{t}$+ALPs

Suppressing known resonances

Muons coming from decays of known resonances suppressed by **explicit $m_{\mu\mu}$ cuts**:

- considering ρ, ω, ϕ, J/Ψ, Ψ(2S) mesons,
- cutting at $m_R \pm 5\% \cdot m_R$.





Exploiting p_T spectrum

Signal muon transverse momentum (p_T) tends to be **much harder** than for the backgrounds

→ applying **p_T^μ > 10 GeV** selection.

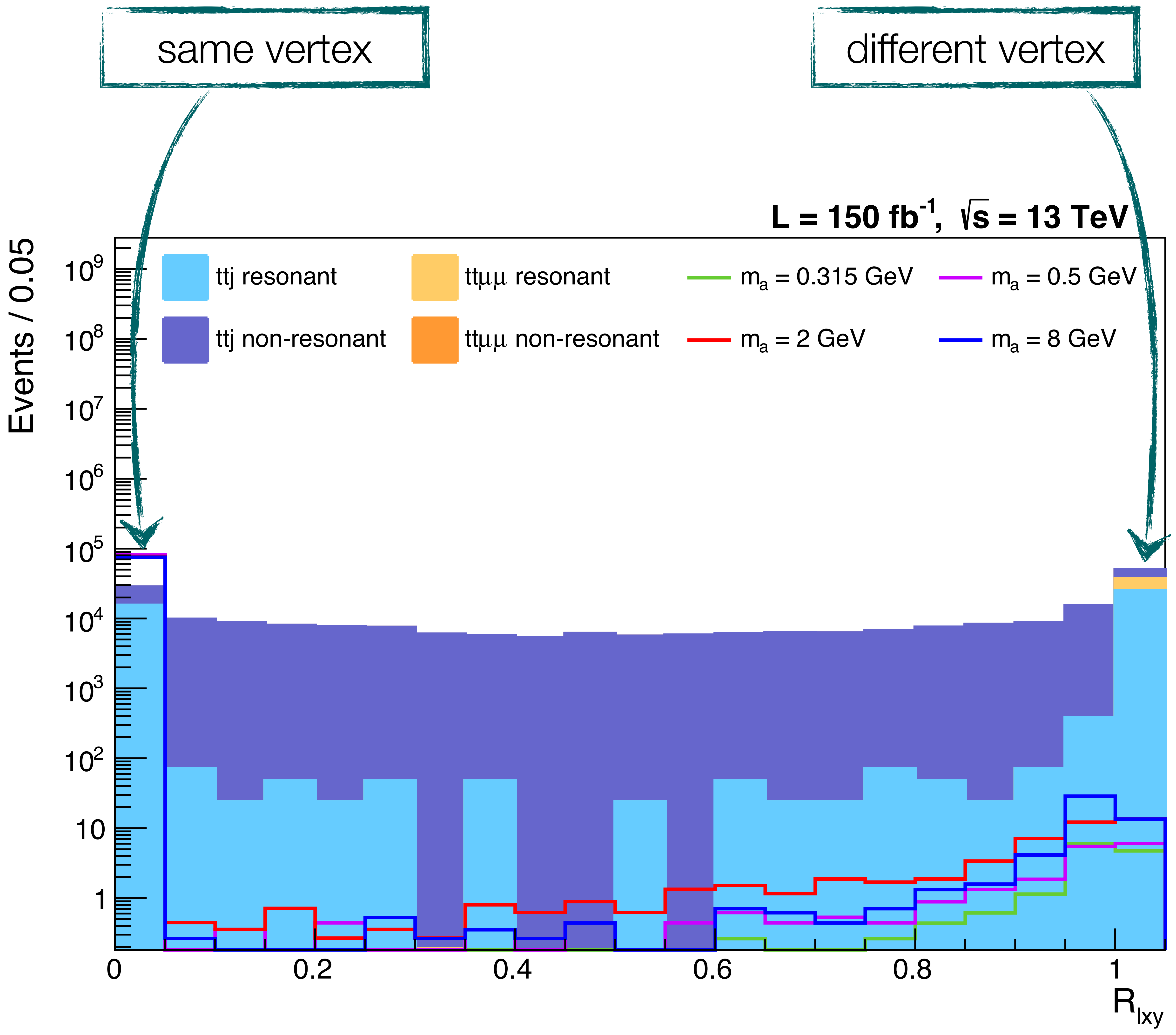
$t\bar{t}$+ALPs

Picking muons from the same vertex

- we're using the following variable:

$$R_{l_{xy}} = \sqrt{\frac{(x^{\mu} - x^{\bar{\mu}})^2 + (y^{\mu} - y^{\bar{\mu}})^2}{(|x^{\mu}| + |x^{\bar{\mu}}|)^2 + (|y^{\mu}| + |y^{\bar{\mu}}|)^2}}$$

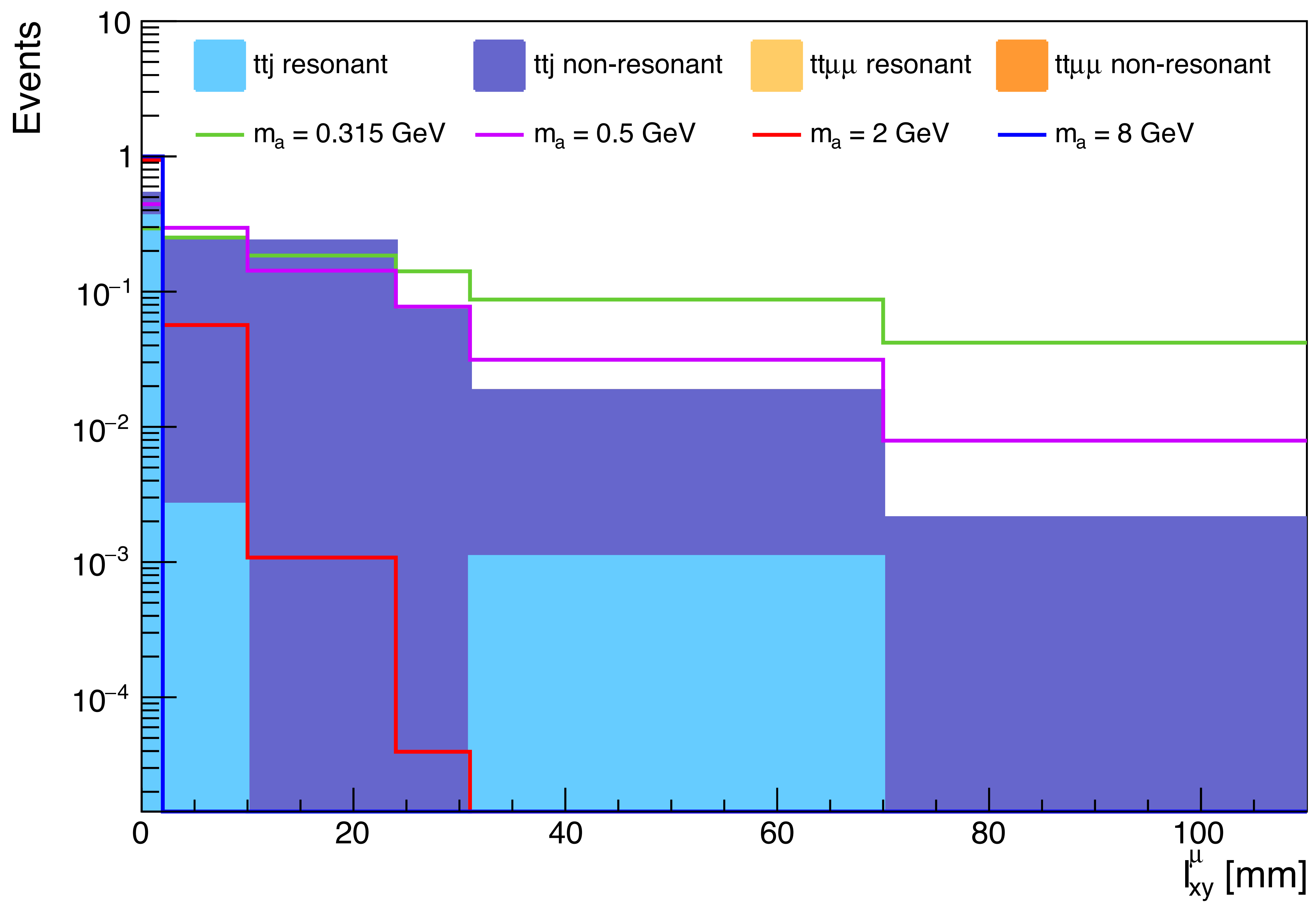
  - sensitive to the **difference in muons' origins** (x, y),
  - largely independent from **detector resolution**,
- selection:
  - pick the pair with the **smallest R_{lxy}**,
  - keep events with **$R_{lxy} < 0.05$**
    (conservative estimate, should be able to do better than that).



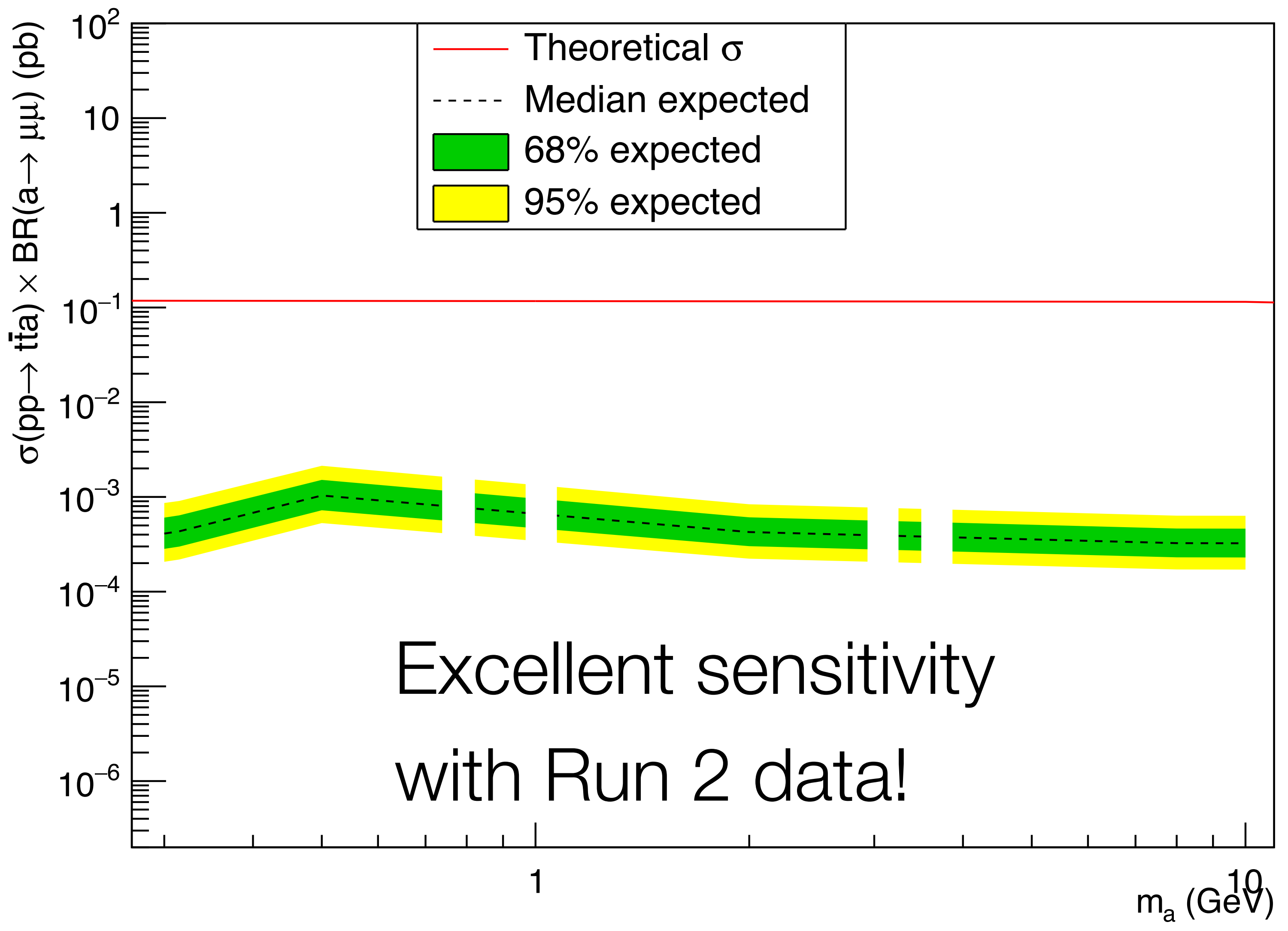
$t\bar{t}$+ALPs

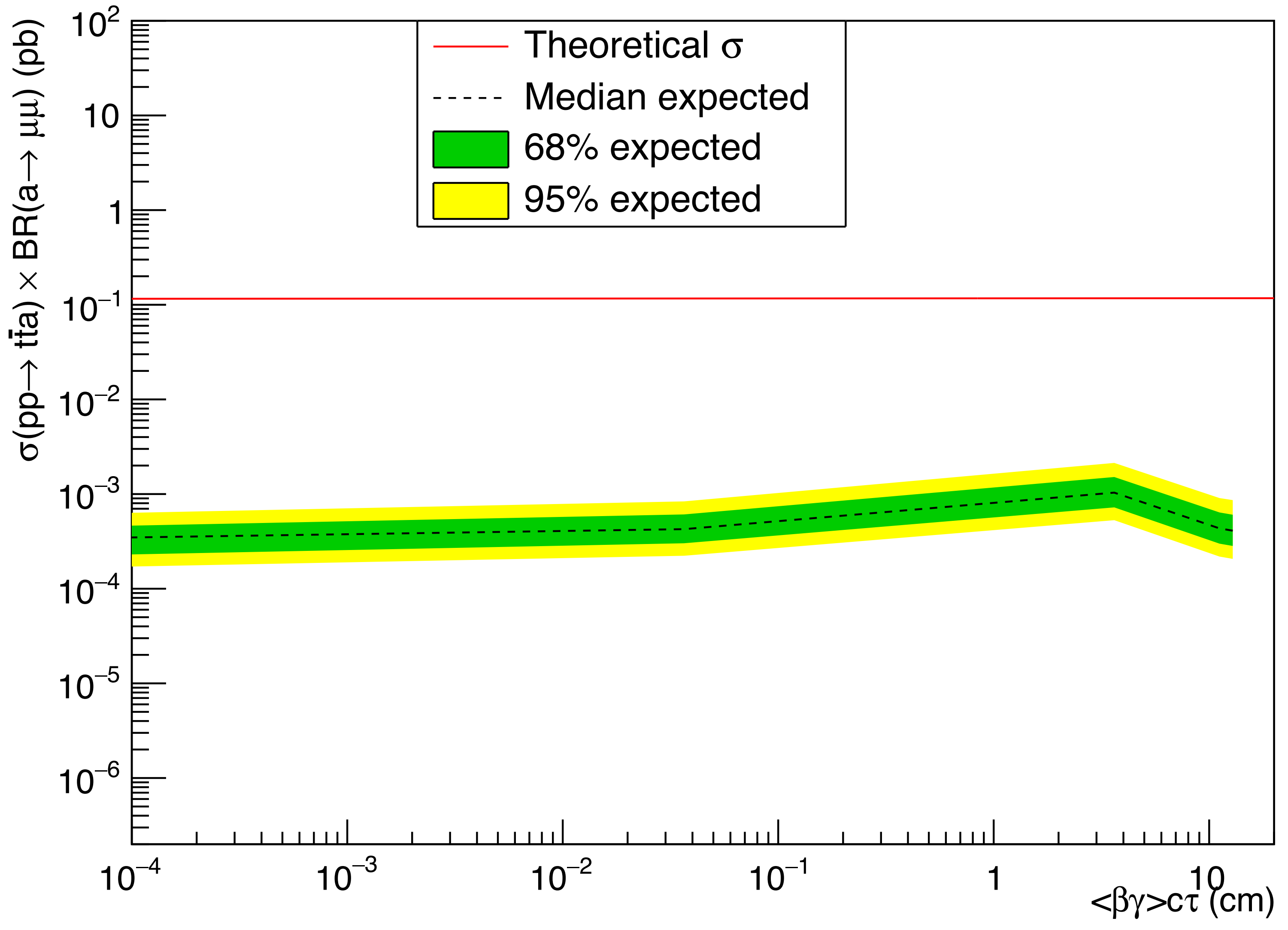
Events categorization in transverse displacement

- bin surviving events in **secondary vertex displacement l_{xy}**
  → further increase sensitivity to **displaced signatures**,
- bins based on an **existing CMS analysis** (EXO-20-014, 2112.13769), driven by beam pipe and tracker layers location.



derive limits





Selections summary

Preliminary

Preselection

ALPs:

- $p_T^a > 20$ GeV,

Jets:

- $p_T^j > 20$ GeV,
- $|\eta_j| < 3.0$,

Muons:

- $p_T^\mu > 5$ GeV,
- $|\eta_\mu| < 2.5$,
- **veto** muons coming **from top decays**,
- at least one pair of **opposite-sign** muons in event.

Further background suppression

- **known resonances**: explicit mass cuts,
- exploit **p_T spectrum**: $p_T^\mu > 10$ GeV,
- muons coming from the same **vertex**: $R_{lxy} < 0.05$.

Selections summary

- **signal efficiency** close to 100%,
- **p_T and R_{lxy}** nicely suppresses $t\bar{t}j$ background,
- **mass and R_{lxy}** requirements kill $t\bar{t}\mu\bar{\mu}$ background.

Expected number of events for 150 fb^{-1}

	signals (c_{tt} = 1.0)												backgrounds					
selection	0.3 GeV			0.5 GeV			2 GeV			8 GeV			$t\bar{t}j$			$t\bar{t}\mu\bar{\mu}$		
Preselection	16480		± 18	15505		± 17	15066		± 16	14966		± 16	41308		± 442	2565		± 1
$p_T^\mu > 10$ GeV	14770	± 16	**90%**	12425	± 15	**80%**	12179	± 15	**81%**	12128	± 15	**81%**	6048	± 169	**15%**	2328	± 1	**91%**
Dimuon mass selection	14770	± 16	**100%**	12424	± 15	**100%**	12178	± 15	**100%**	12127	± 15	**100%**	5135	± 156	**85%**	575	± 0	**25%**
$R_{lxy} < 0.05$	14769	± 16	**100%**	12422	± 15	**100%**	12176	± 15	**100%**	12125	± 15	**100%**	558	± 51	**11%**	0	± 0	**0%**

ALPs MODEL — TOP SCENARIO

Top scenario of the ALP model

- a new (pseudo-)scalar is expected to have **Yukawa-like couplings** to SM fermions,
- if that is the case, it would couple **predominantly to top quark** (light quark coupling suppressed by small masses),
- for simplicity, we assume **only top couplings**,
- overall, just **2 free parameters** in the model:
  - m_a - ALP **mass**,
  - c_{tt} - top-ALP **coupling**,
- ALP decays:
  - **loop induced** (decay width determined by c_{tt}),
  - ALPs likely to be **long lived**,
  - for $2 \cdot m_\mu < m_a < 3 \cdot m_\pi$ predominantly to **muons.**