Search for emerging jets in the ATLAS detector

LNF Spring School, Young Researchers' Workshop

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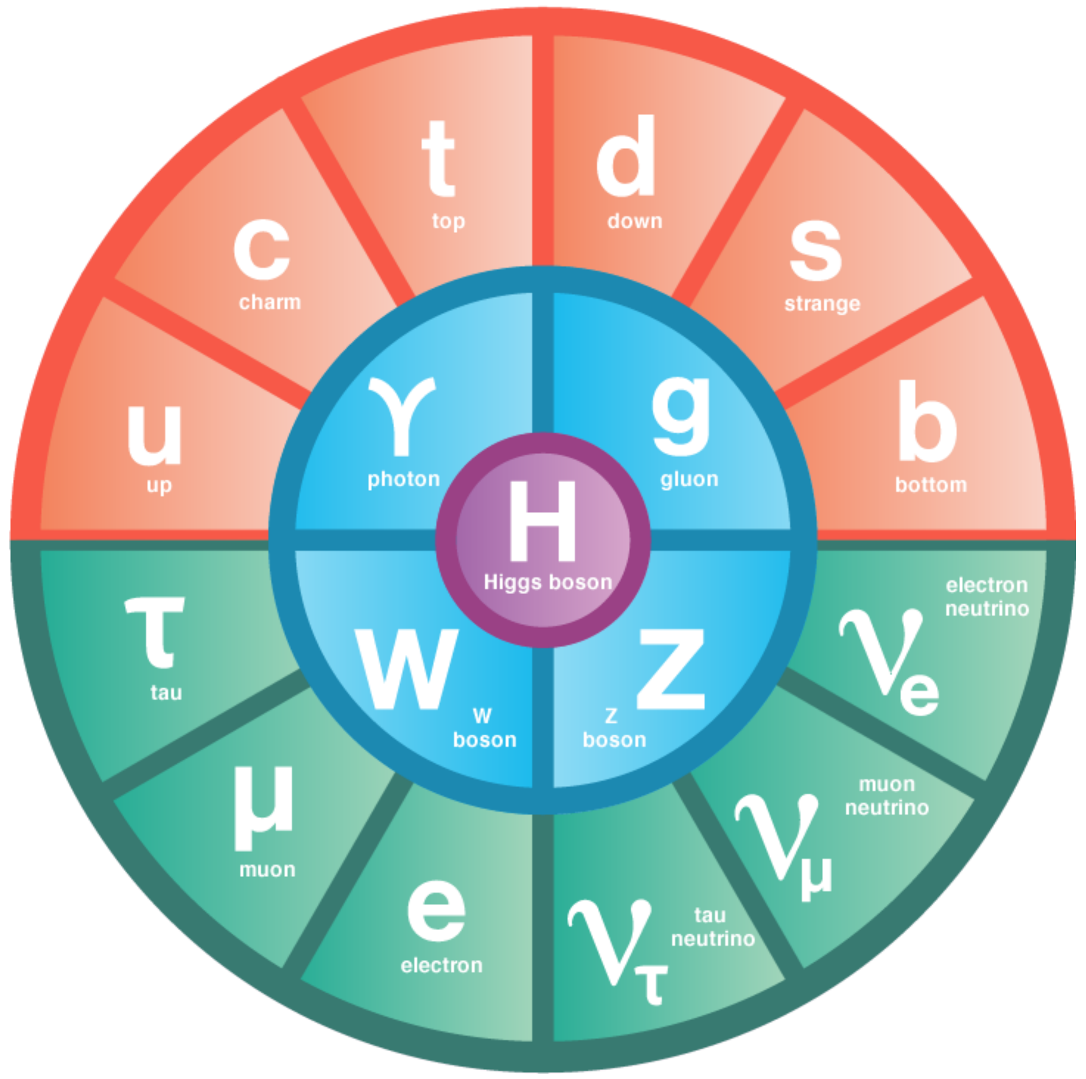
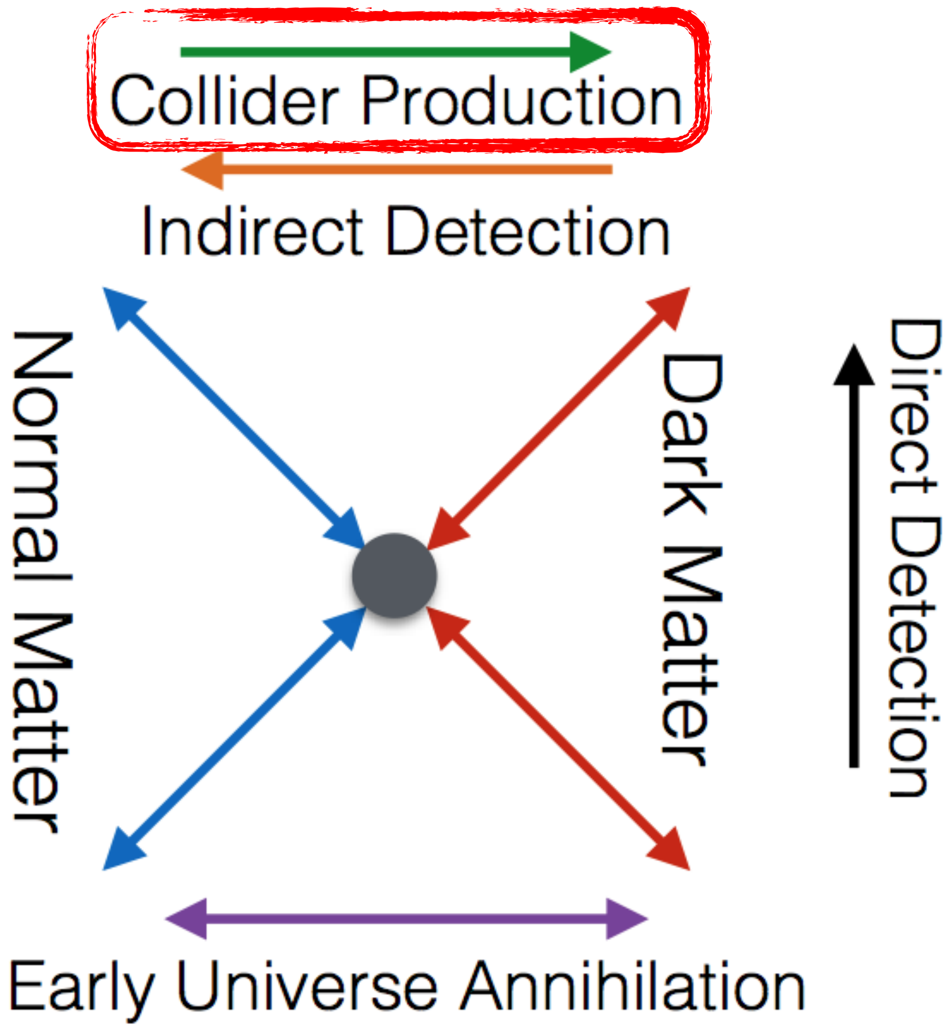
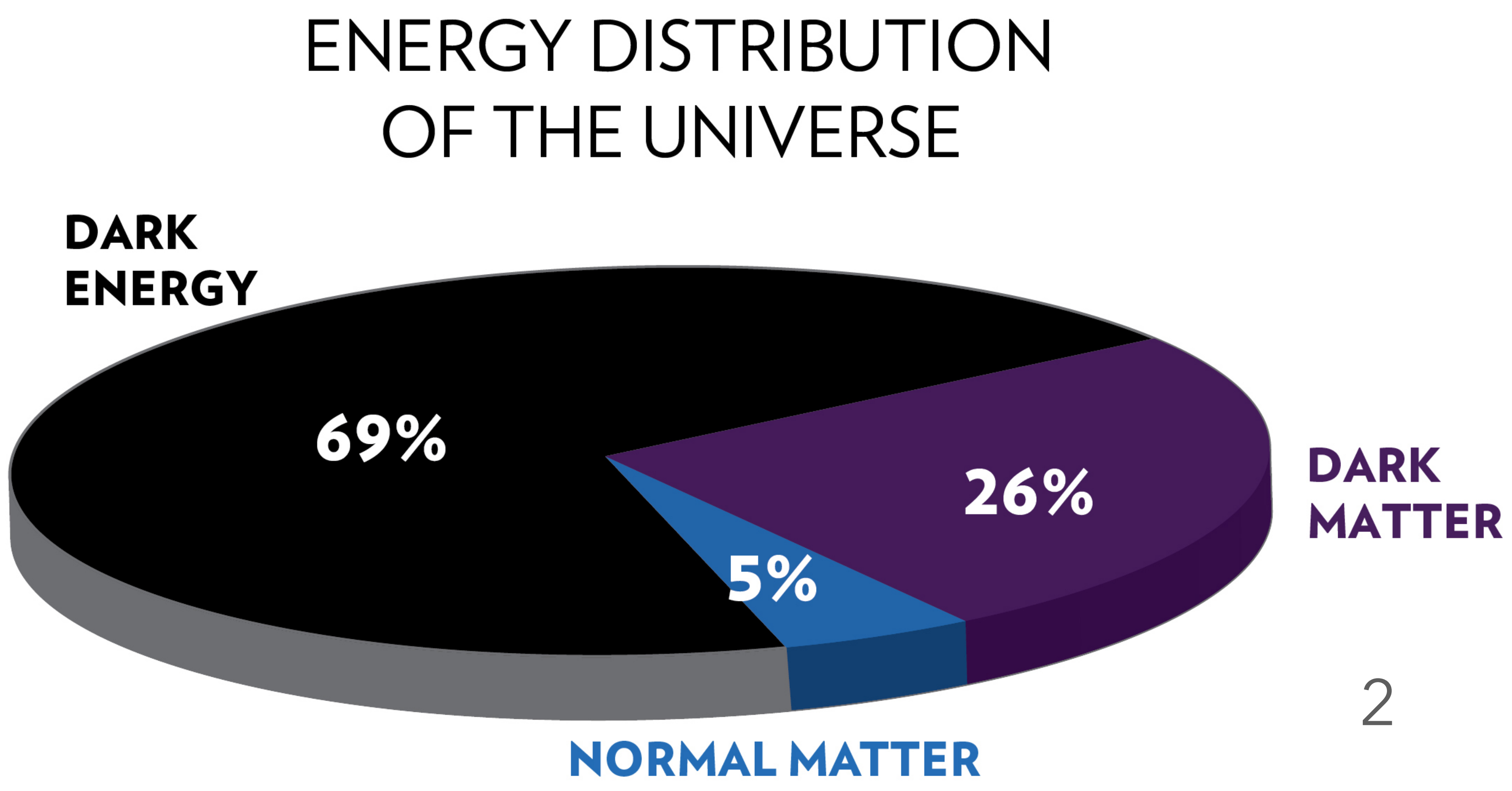
Context



Search for physics beyond Standard Model at the LHC

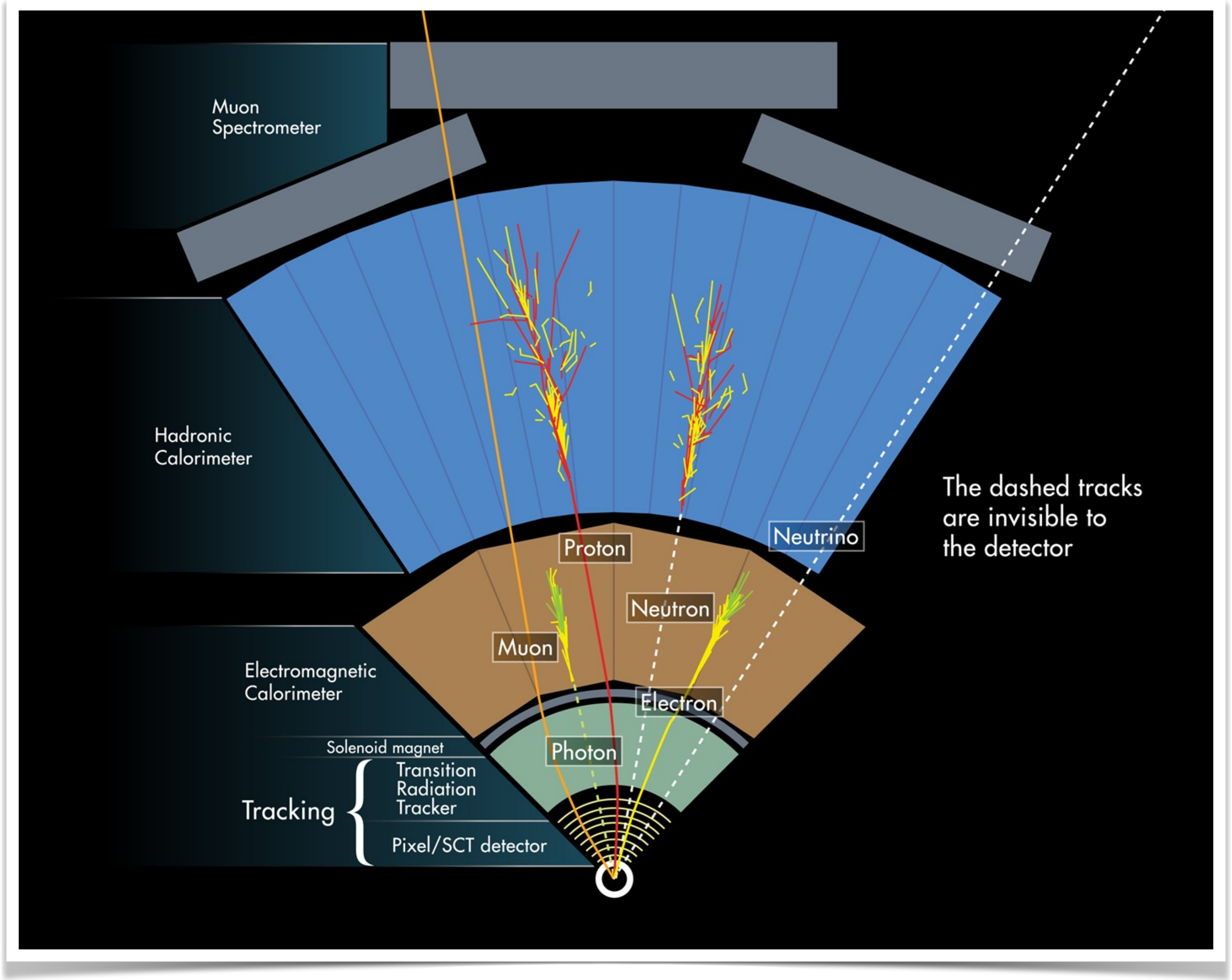
- Standard Model (SM) : only 5% of the energy-mass in the Universe
- **Dark Matter** :
  - manifestation through gravitational effects (galaxy rotation curves, gravitational lensing ...), but unknown nature
  - hypothesis : could be new massive particles weakly interacting with SM ones
- Large Hadron Collider : p-p collisions at 13.6 TeV total energy
  - possible production of dark matter particles through very rare process

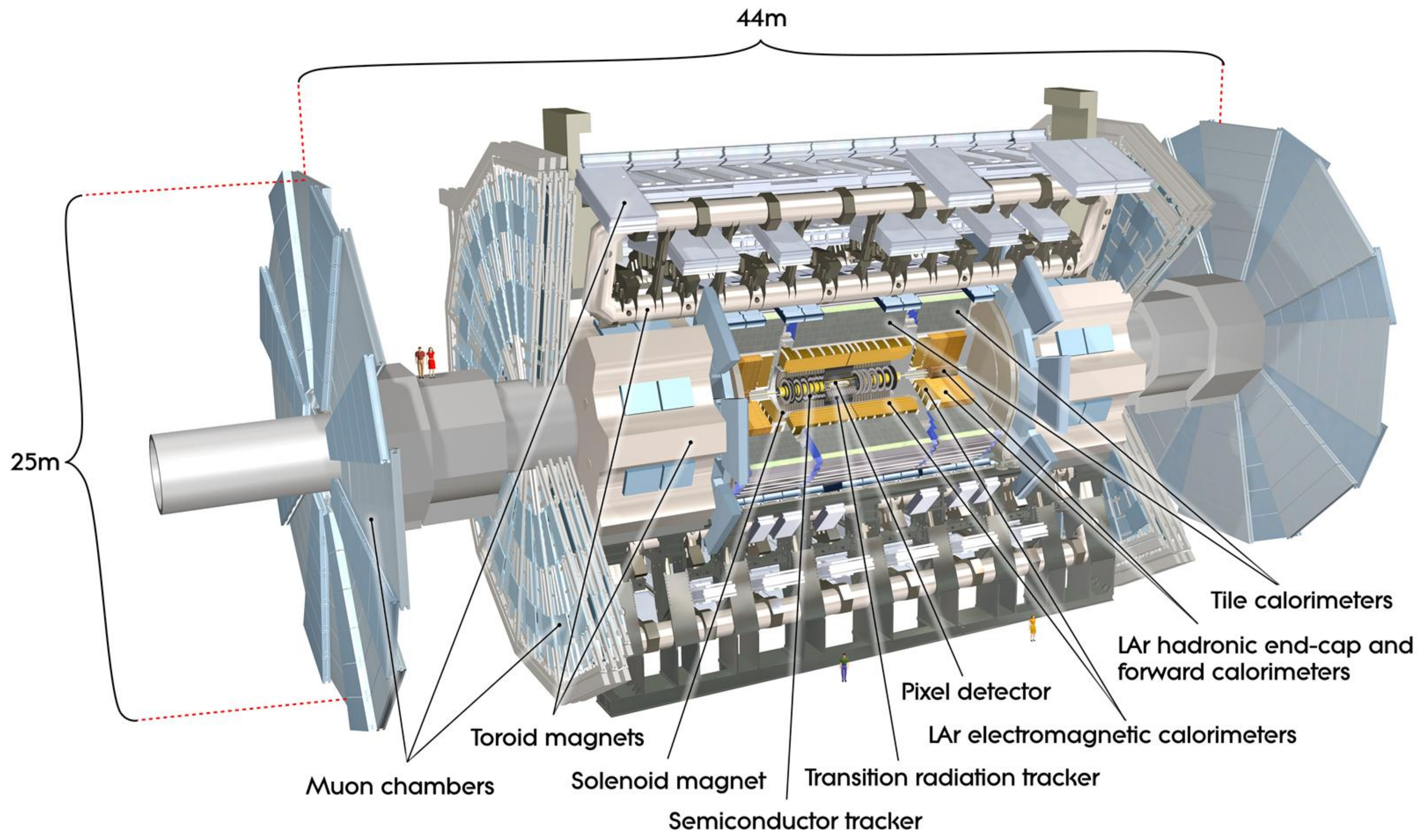




ATLAS detector

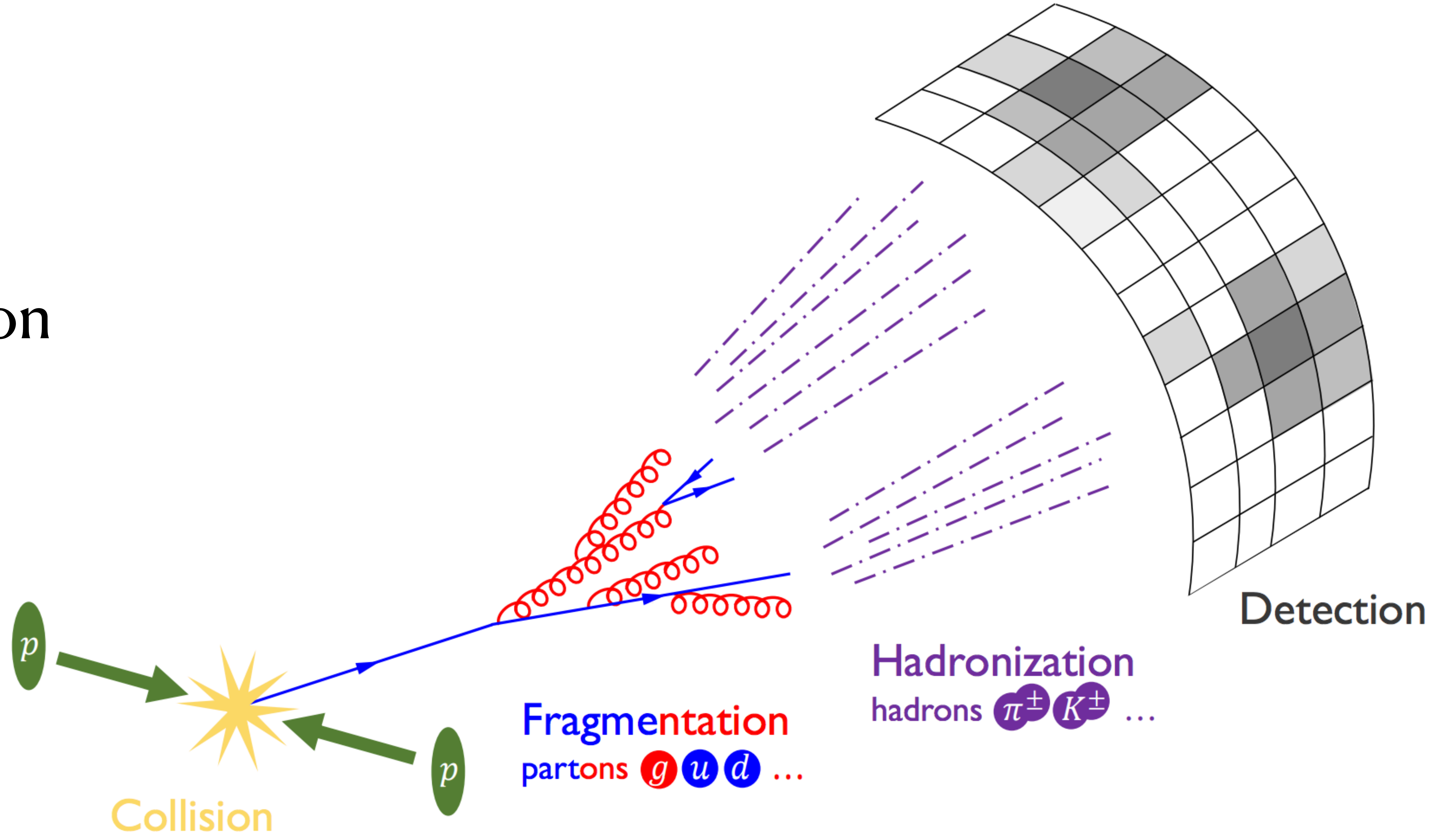
- General purpose detector : SM, search for new physics
- Structure in layers :
  - **inner detector** : *track* (trajectory and momentum of a charged particle curved by magnet system)
  - **calorimeters** : *cluster* (particle energy deposition except for μ and ν)
  - **muon spectrometer** : muon trajectory and momentum



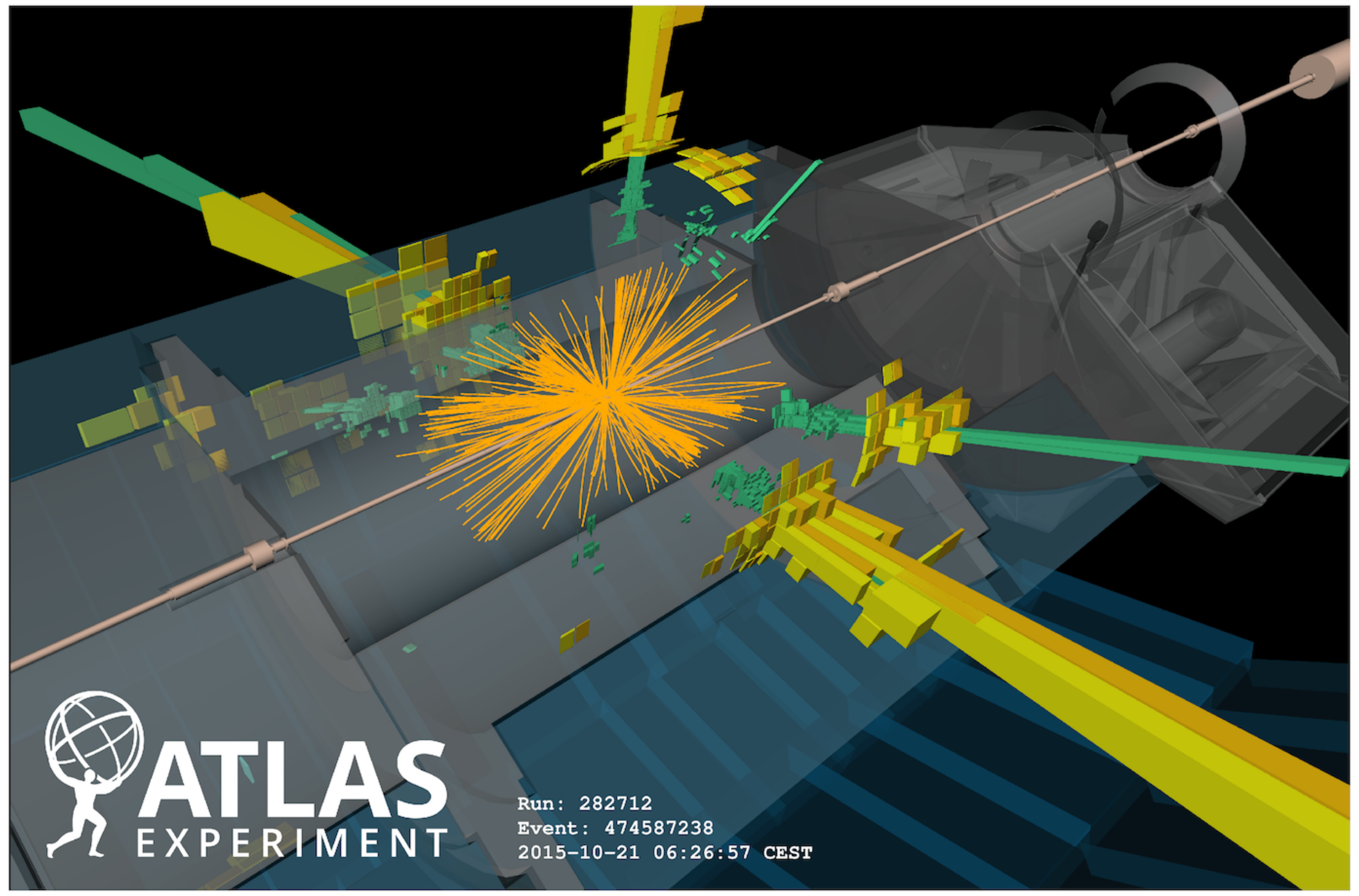


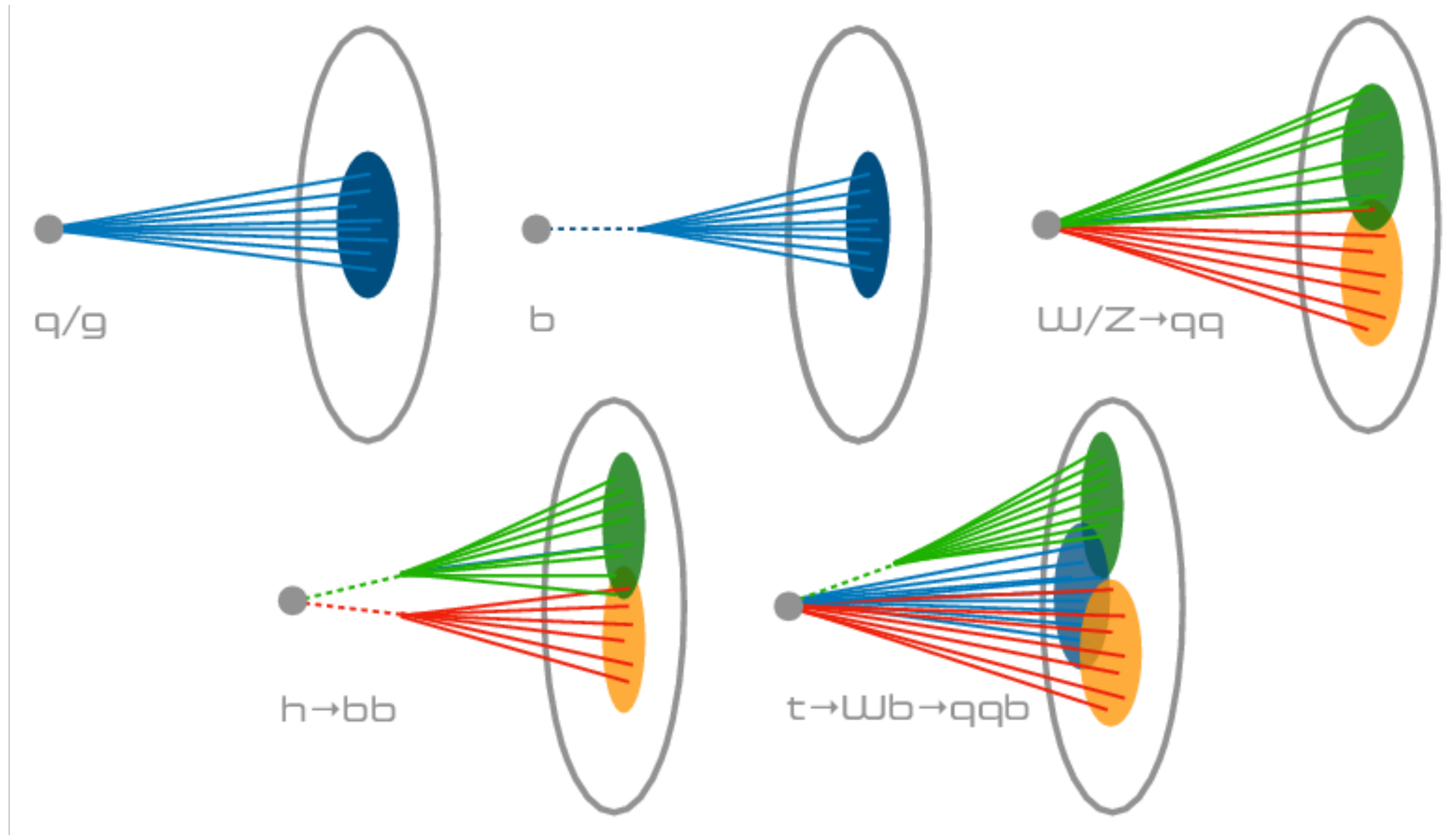
- 40.10^6 beam crossings /s : **trigger system**, 1000 events /s stored for analysis
  - must be very well configured
- Offline event reconstruction : signals turn into physical object (jets, leptons, photons ...)

Hadronic jets



- **QCD processes** :
  - pp collision, emission of high energy parton
  - parton shower : collinear partons emitted
  - hadronization : gathering of partons to form hadrons
- Jet : cone of produced hadrons
  - highly common object at the LHC
- Different jet topologies (q/g, top ...)





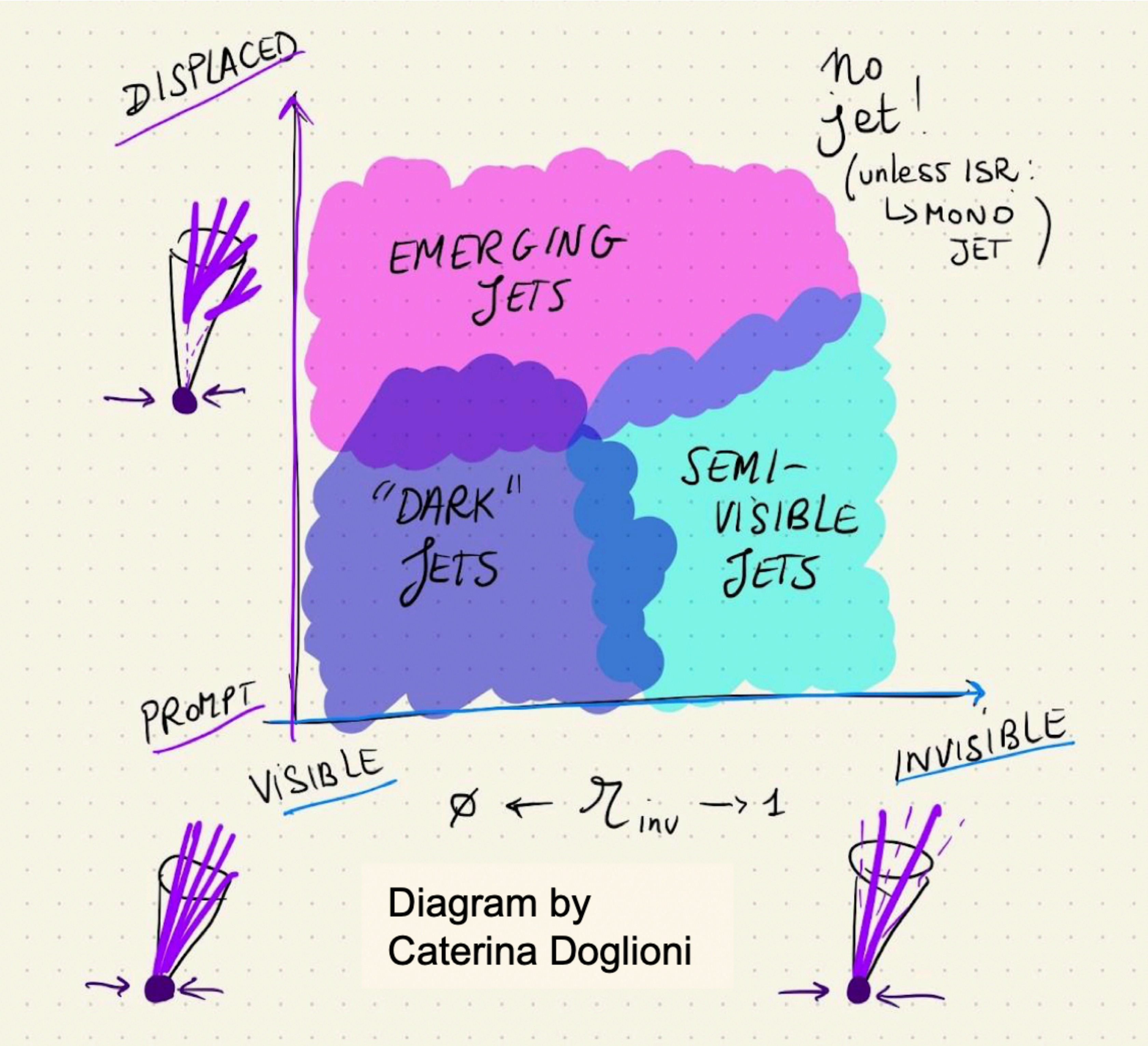
- In ATLAS, different ways to reconstruct jet constituents using tracks and clusters
- Jet algorithms regroup constituents

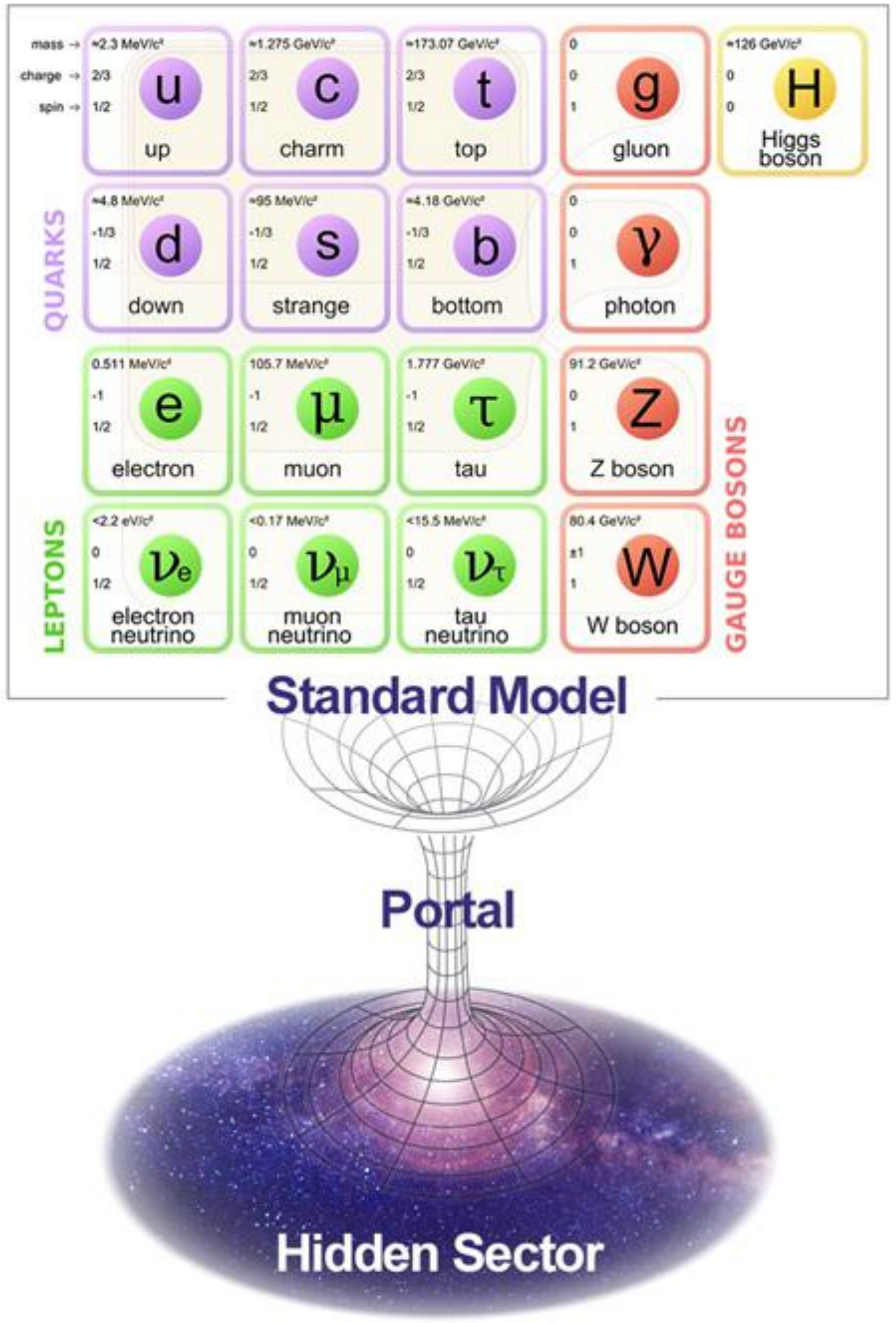
Hidden sector

- Extension SM : **QCD-like hidden dark sector**
  - dark quarks q_d
  - dark gluons g_d

$$\mathcal{L}_d = \bar{q}'_i (i \not{D} - m_{q'_i}) q'_i - \frac{1}{4} G'^{\mu\nu} G'_{\mu\nu}$$

- Parton shower and hadronization in dark sector → jet of dark hadrons
- Stable particle : DM candidates
- **Portal SM - hidden sector**, new interaction :
  - q_d production in pp collisions
  - dark hadrons decay to SM quarks, forming jets : dark, semi-visible or **emerging**



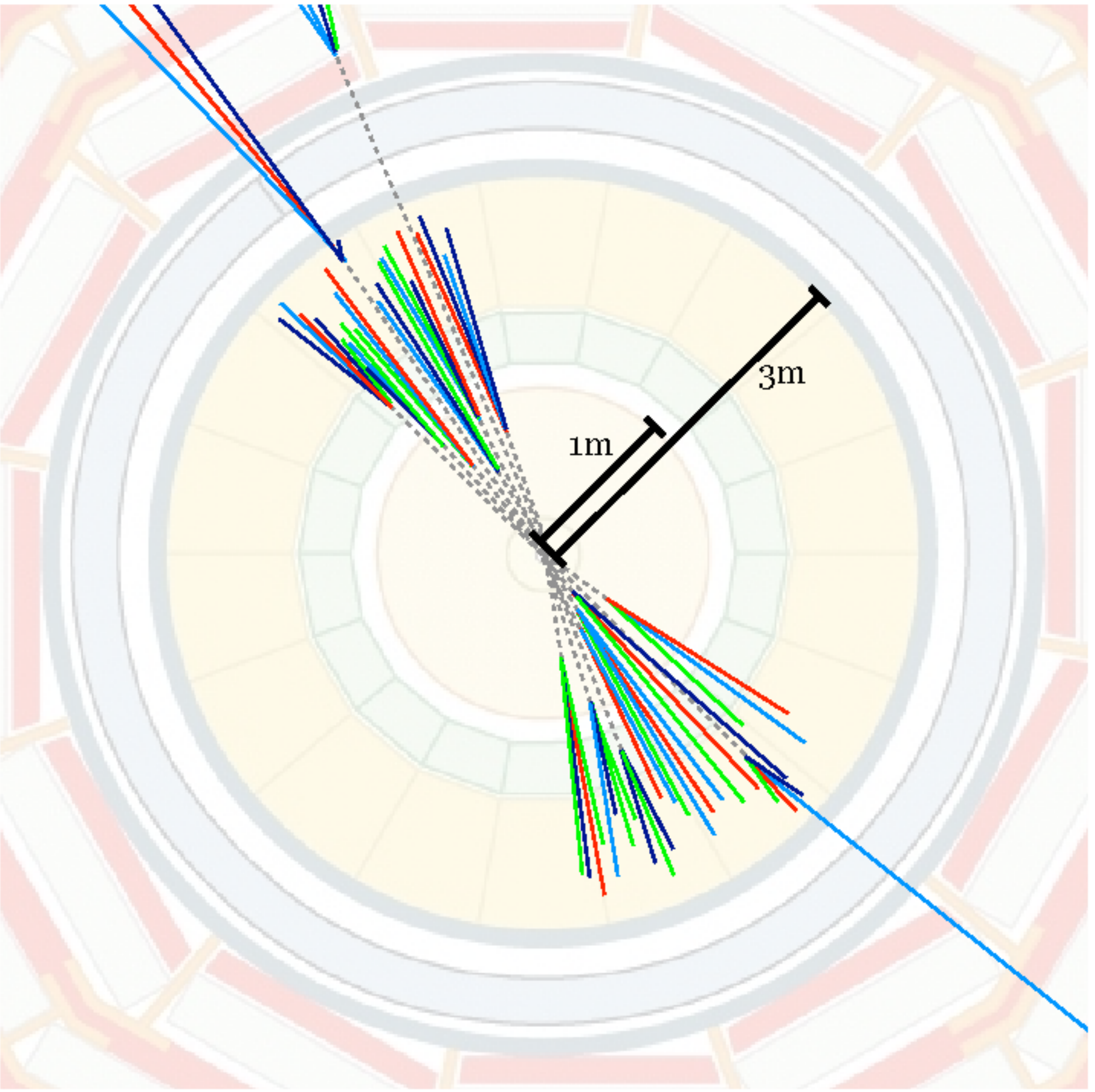


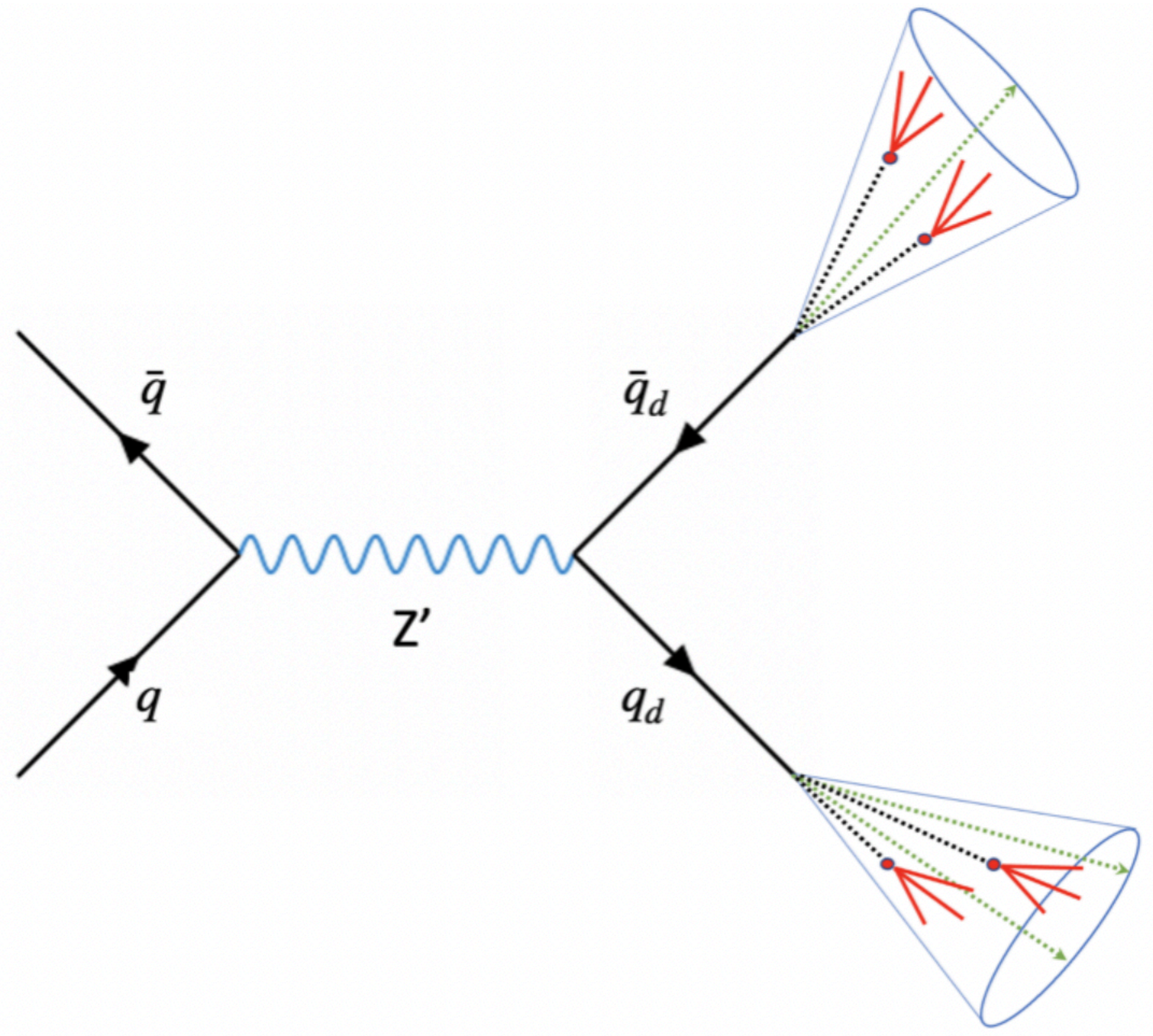
Emerging jets

- Model considered :
  - q_d production via **new Z' mediator** (s-channel)

$$\mathcal{L}_{\text{med}} = -\frac{1}{4}Z'^{\mu\nu}Z'_{\mu\nu} - \frac{1}{2}M^2_{Z'}Z'^{\mu}Z'_{\mu} + Z'_{\mu}(\bar{q}'_i\gamma^{\mu}q'_i + \bar{q}_j\gamma^{\mu}q_j)$$

- Formation of jet containing unstable ρ_d and π_d :
  - ρ_d decays to π_d
  - π_d decays to SM quarks with $c\tau_{\pi_d} \sim$ mm

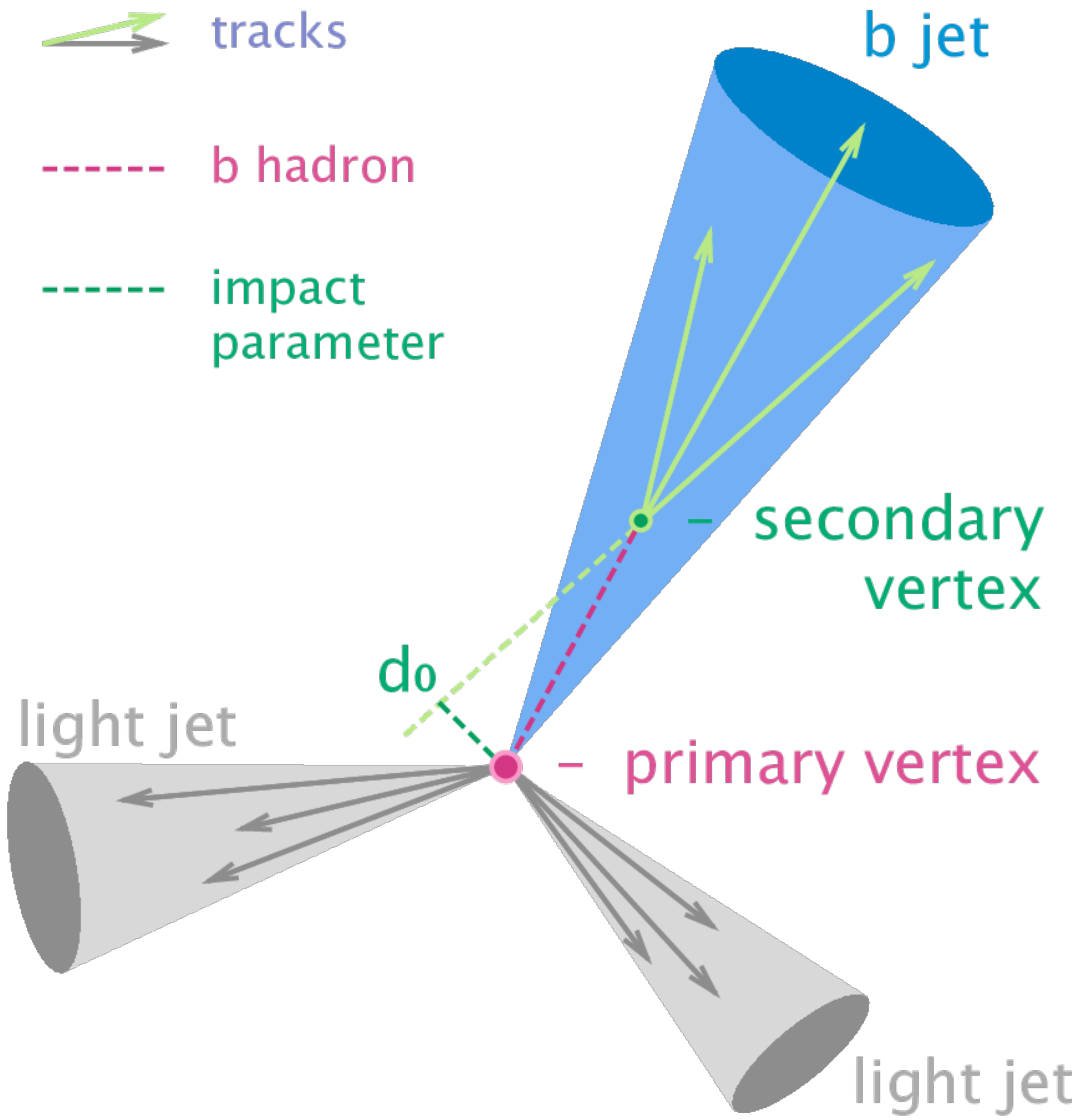


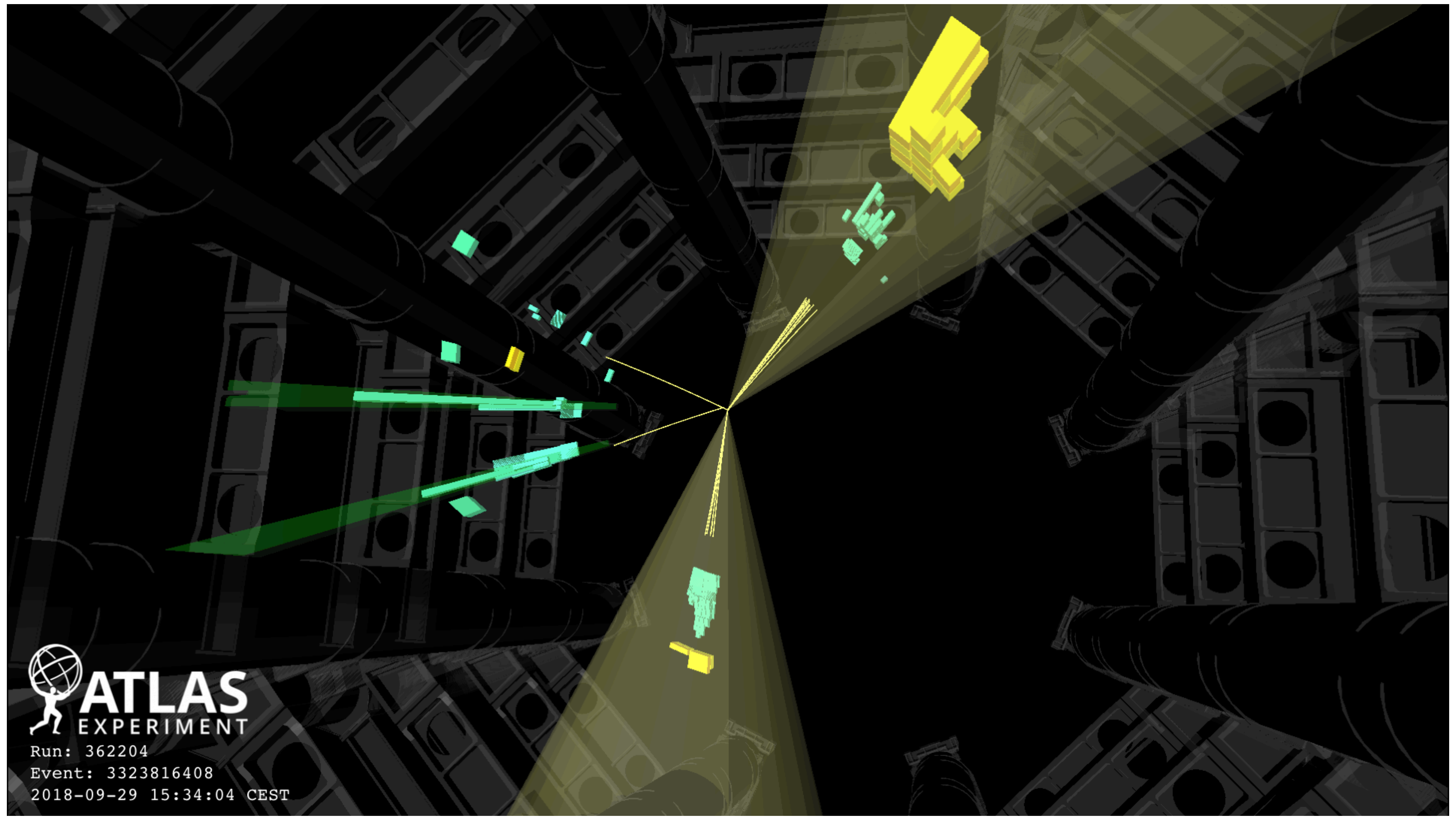


- **Double hadronization** (in both hidden and visible sectors)
- Signal appearance at some distance from the interaction point : emerging jet (EJ)
- Unexplored jet topology

Emerging jets analysis

- Final state :
  2 energetic jets, **displaced tracks** and **secondary vertices**
- Main background : di-jet events from QCD processes
  - can reproduce EJ signature : neutral B mesons, photons (pair production)



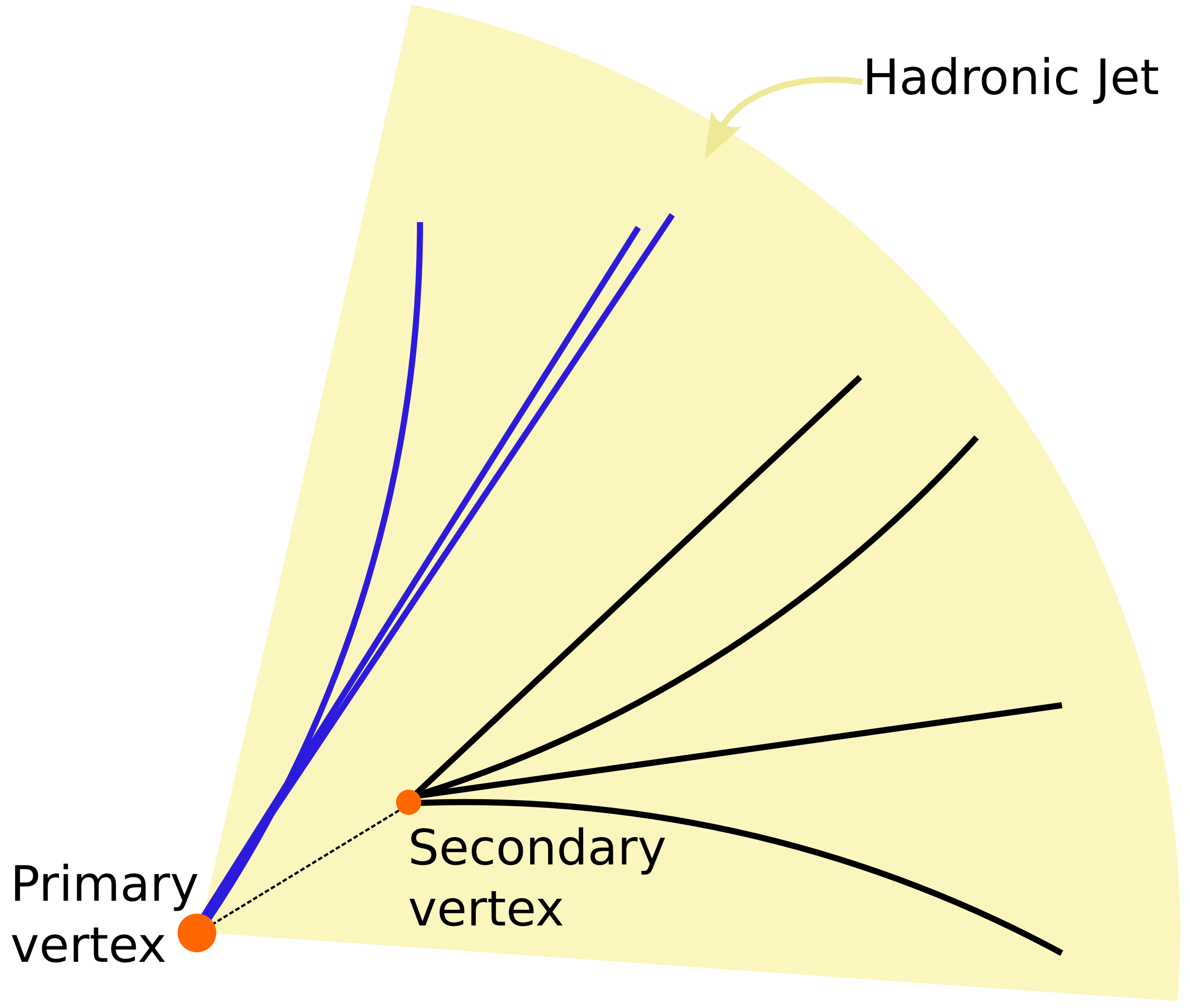


ATLAS event with 2 pair-producing photons (green cones)

- « Cut-and-count analysis » :
  - events selection optimisation (based on simulated events), signal region (SR) definition
  - SM contribution estimation in SR
  - events count in SR, comparison to SM expectation
  - statistical interpretation, constraint on model parameters (if no excess)

ATLAS Trigger and EJ model

- **High p_T jet trigger** : jet with $p_T > 460$ GeV
- **Emerging jet trigger** : jet with $p_T > 200$ GeV, $PTF^{jet} < 0.08$ (Prompt Track p_T Fraction)

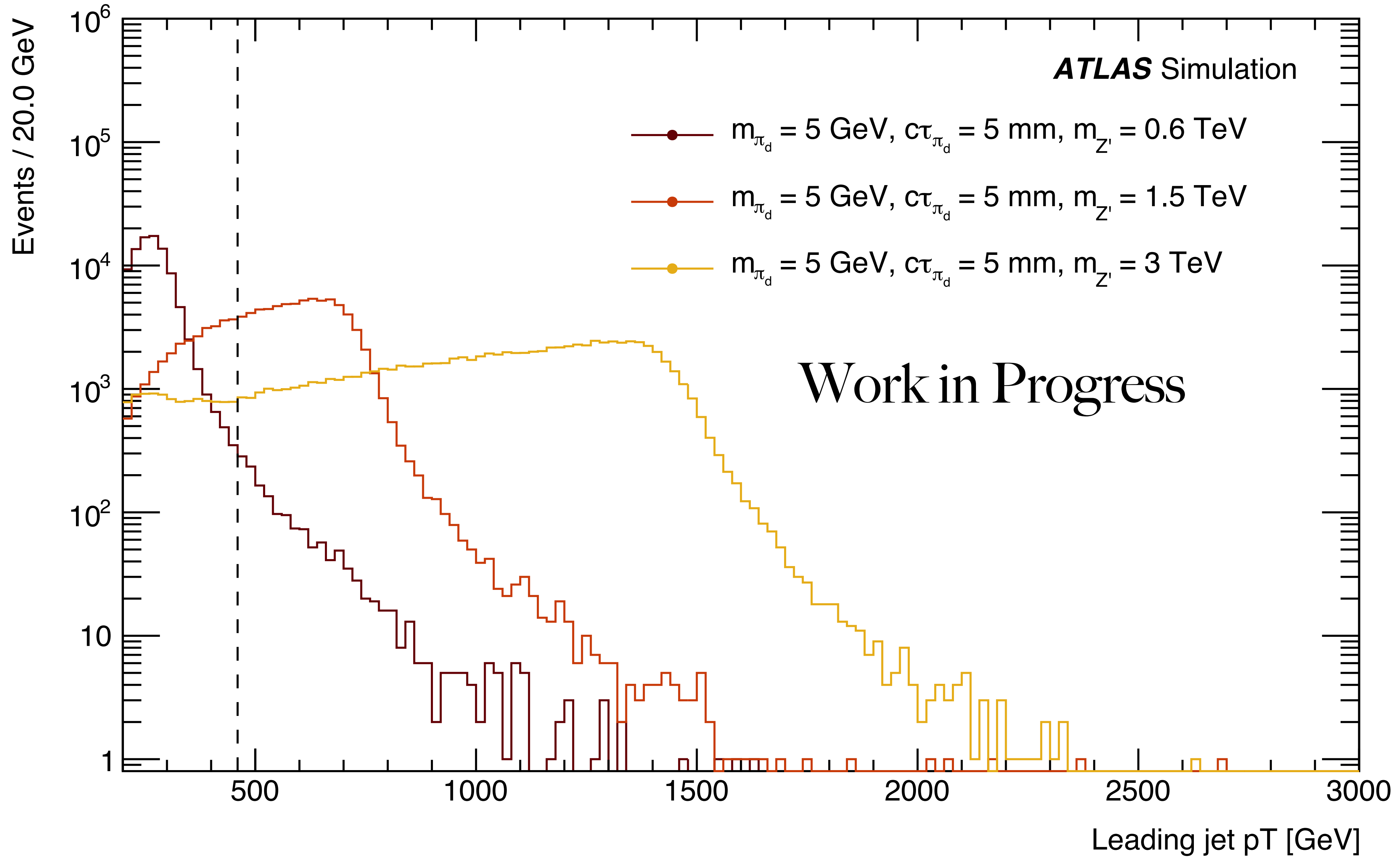


$$\text{PTF} = \frac{p_{T,\text{ prompt}}}{p_{T,\text{ total}}}$$

- Signal events MC simulation : 3 free parameters

m_{π_d} (GeV)	5	10	20
$c\tau_{\pi_d}$ (mm)	5, 50		
$m_{Z'}$ (GeV)	600, 1500, 3000		

High p_T jet trigger can't be used to search for $m_{Z'} = 600$ GeV signal



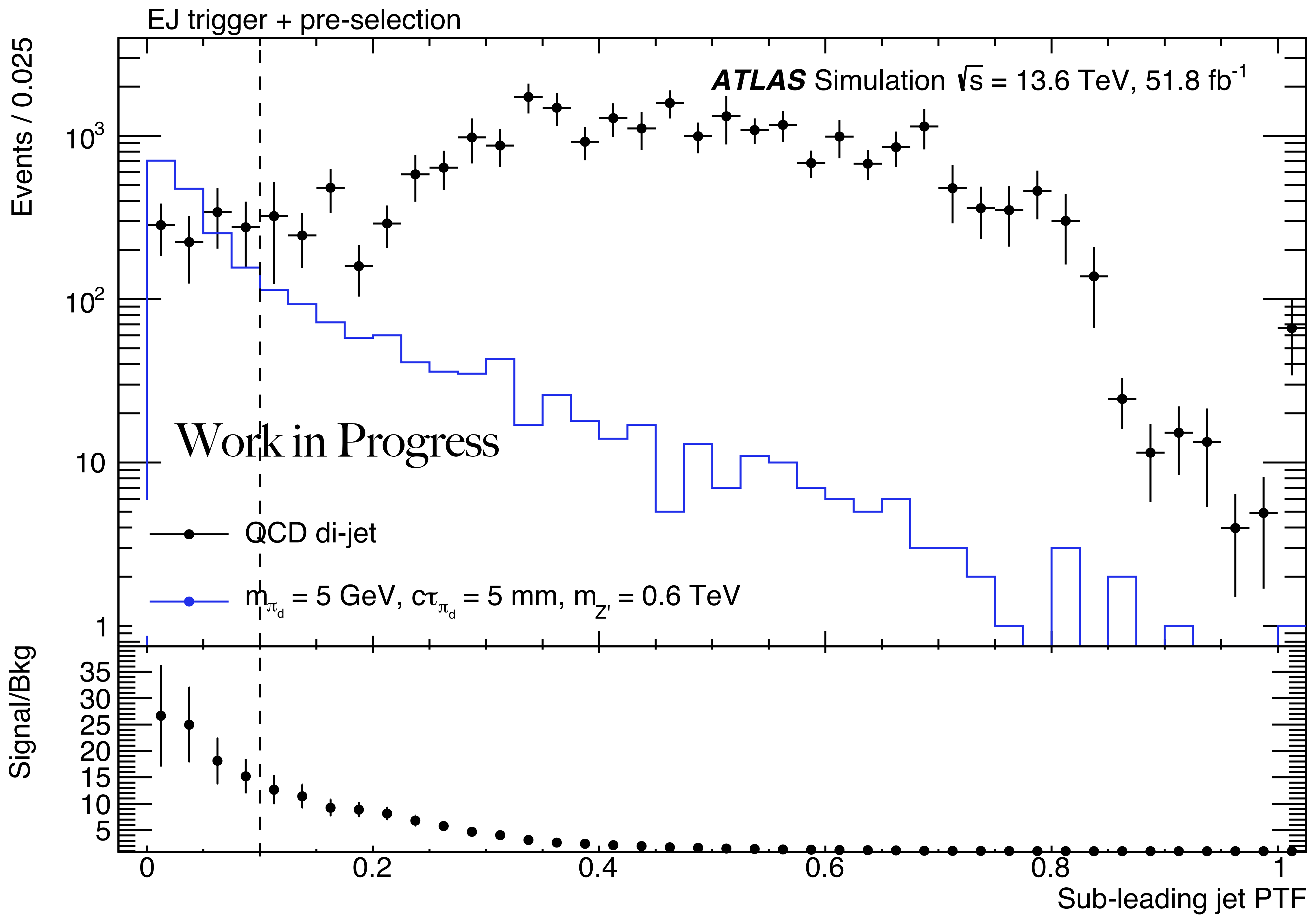
- Strategy : **2 separate event selections**
  - one using the high p_T jet trigger
  - the other using the emerging jet trigger, sensibility to low $m_{Z'}$ signal

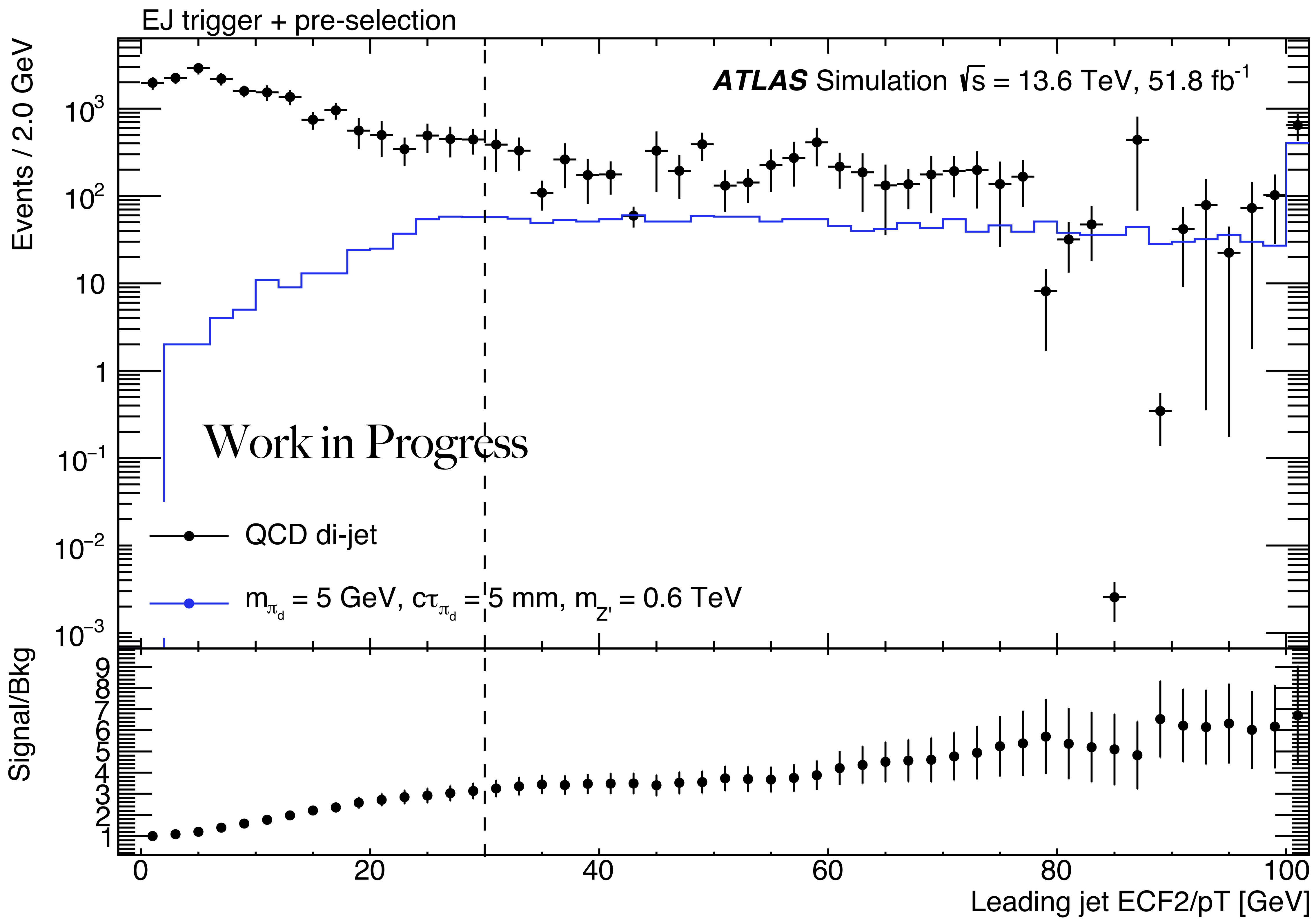
Event selection based on EJ trigger

- Discriminating jet variables :
  - **track variable** : *PTF*
  - **substructure** : $ECF2 = \sum_{i,j \in j} p_{T_i}\, p_{T_j}\, \Delta R_{ij}$

  (quantify energy distribution within the jet)

- SR defined by $ECF2_{lead.\ jet}$ and $PTF_{sub-lead.\ jet}$ cuts
  - **decorrelated** variables
  - **complementary effects** on background elimination
- What cut values ? : gain on signal/background ratio





Background estimation

- 4 regions in a $(PTF_{sub-lead.\ jet}, ECF2/p_{T\ lead.\ jet})$ plane delimited by cut values
- **Data-driven** background estimation in A (SR):

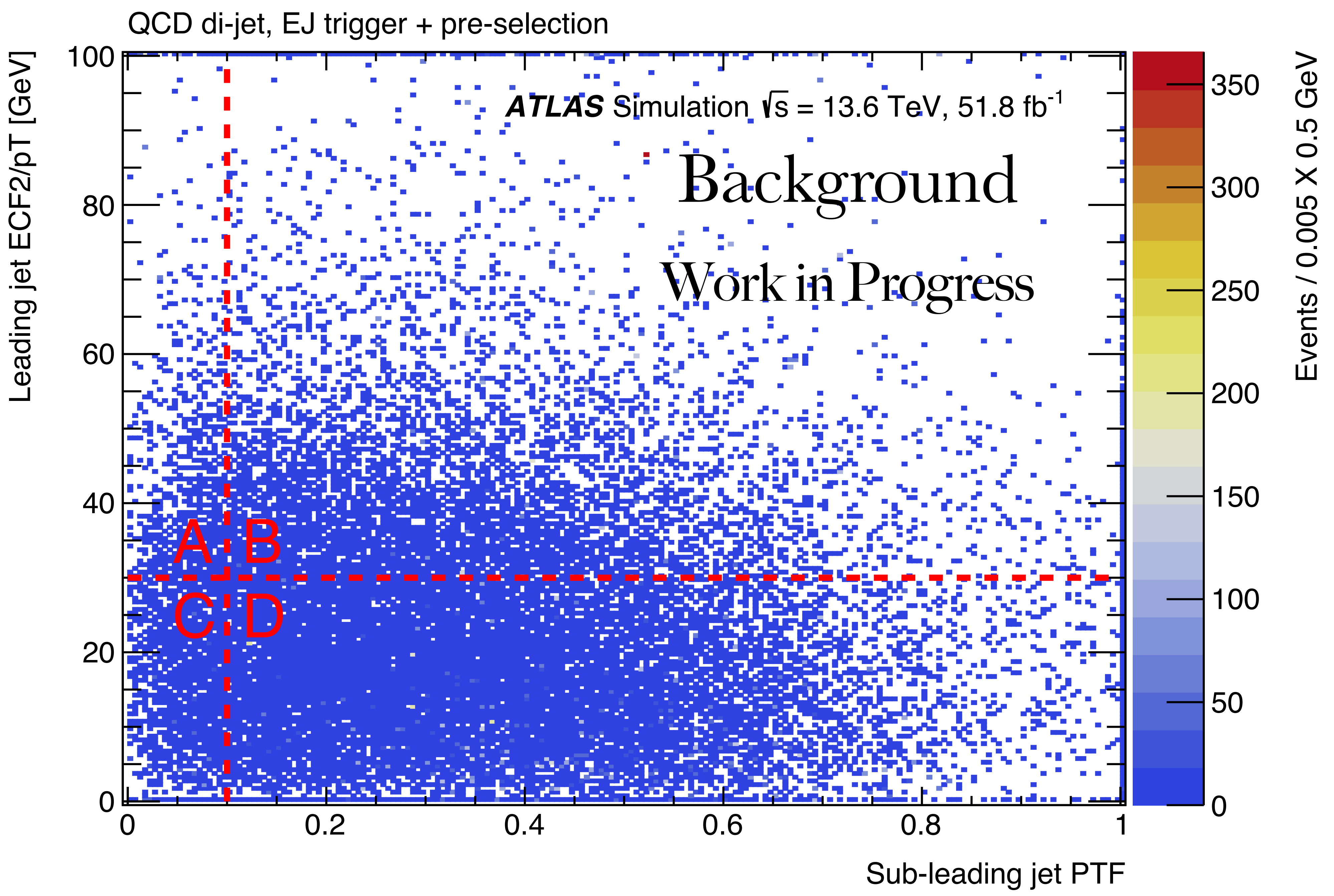
$$N_A^{bkg} = \frac{N_C^{bkg}}{N_D^{bkg}} \times N_B^{bkg} \approx \frac{N_C}{N_D} \times N_B$$

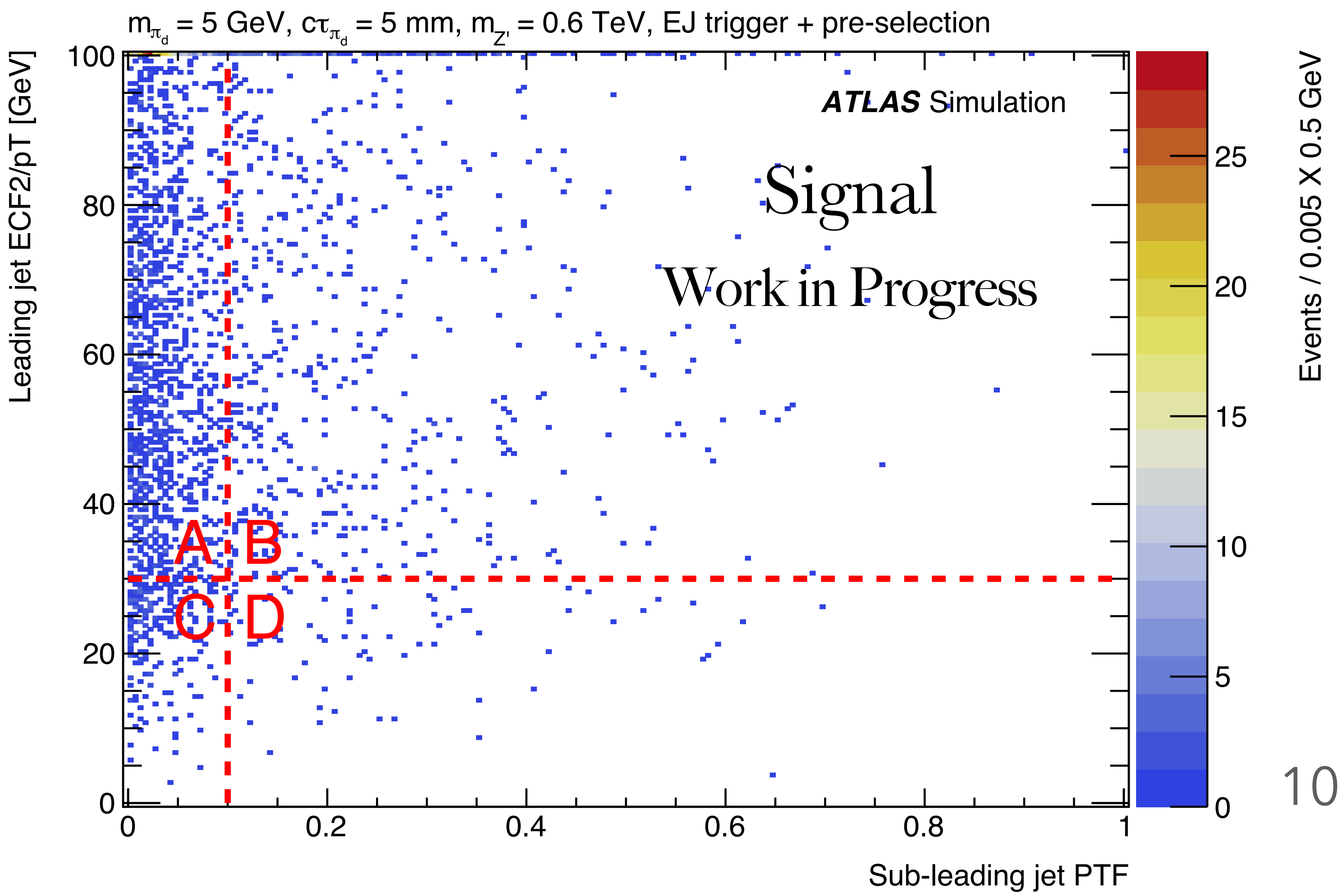
- decorrelated variables for background events
- negligible signal presence in B, C and D (likelihood-fit can take it into account)

- First check on simulated background events :

QCD di-jet	N_{events} ± MC stat. uncertainty
A	305 ± 141
B	6324 ± 730
C	818 ± 182
D	17462 ± 1003

$n_A^{bkg} = (n_B^{bkg} \times n_C^{bkg})/n_D^{bkg} = 296 \pm 76$ (MC stat.)

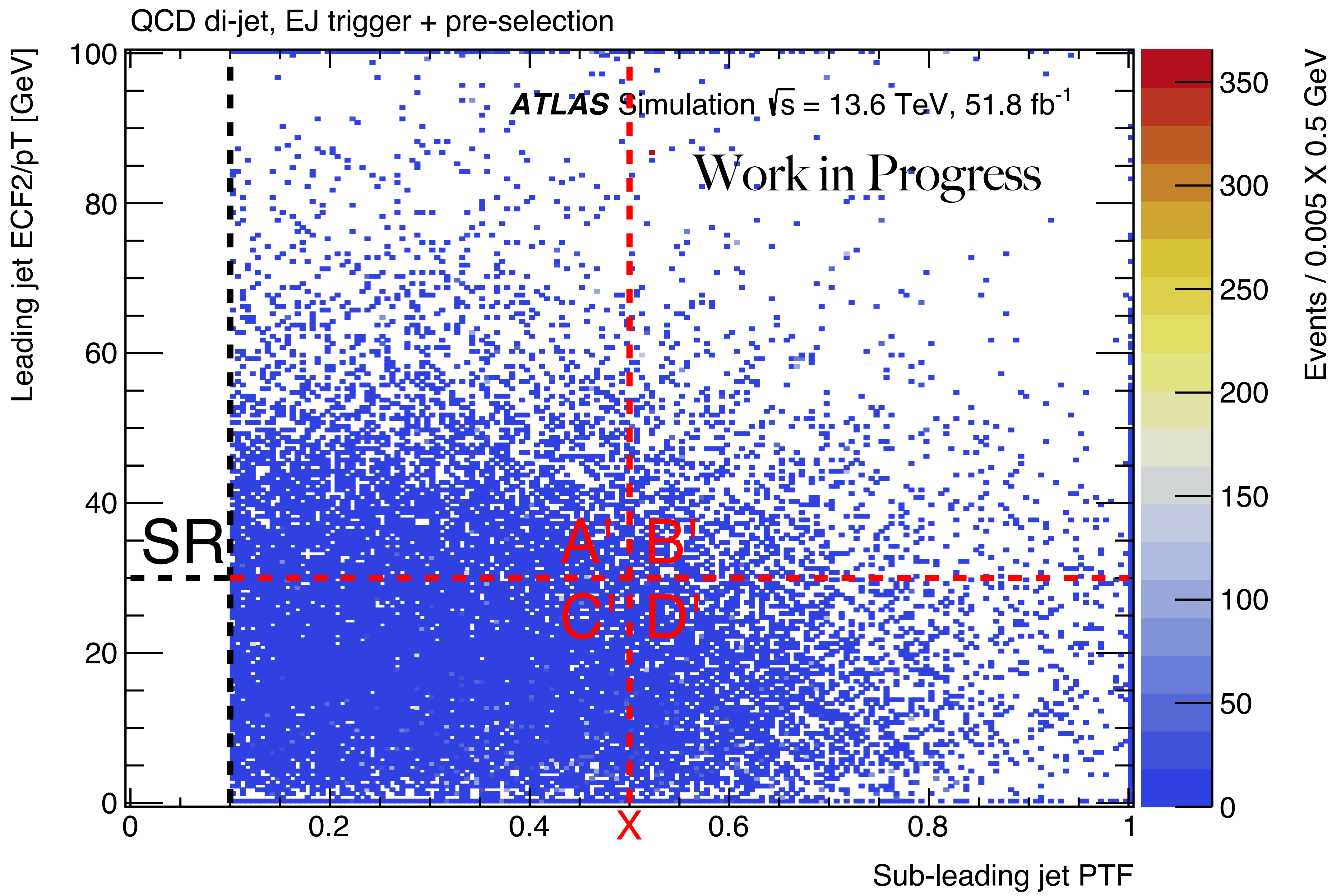




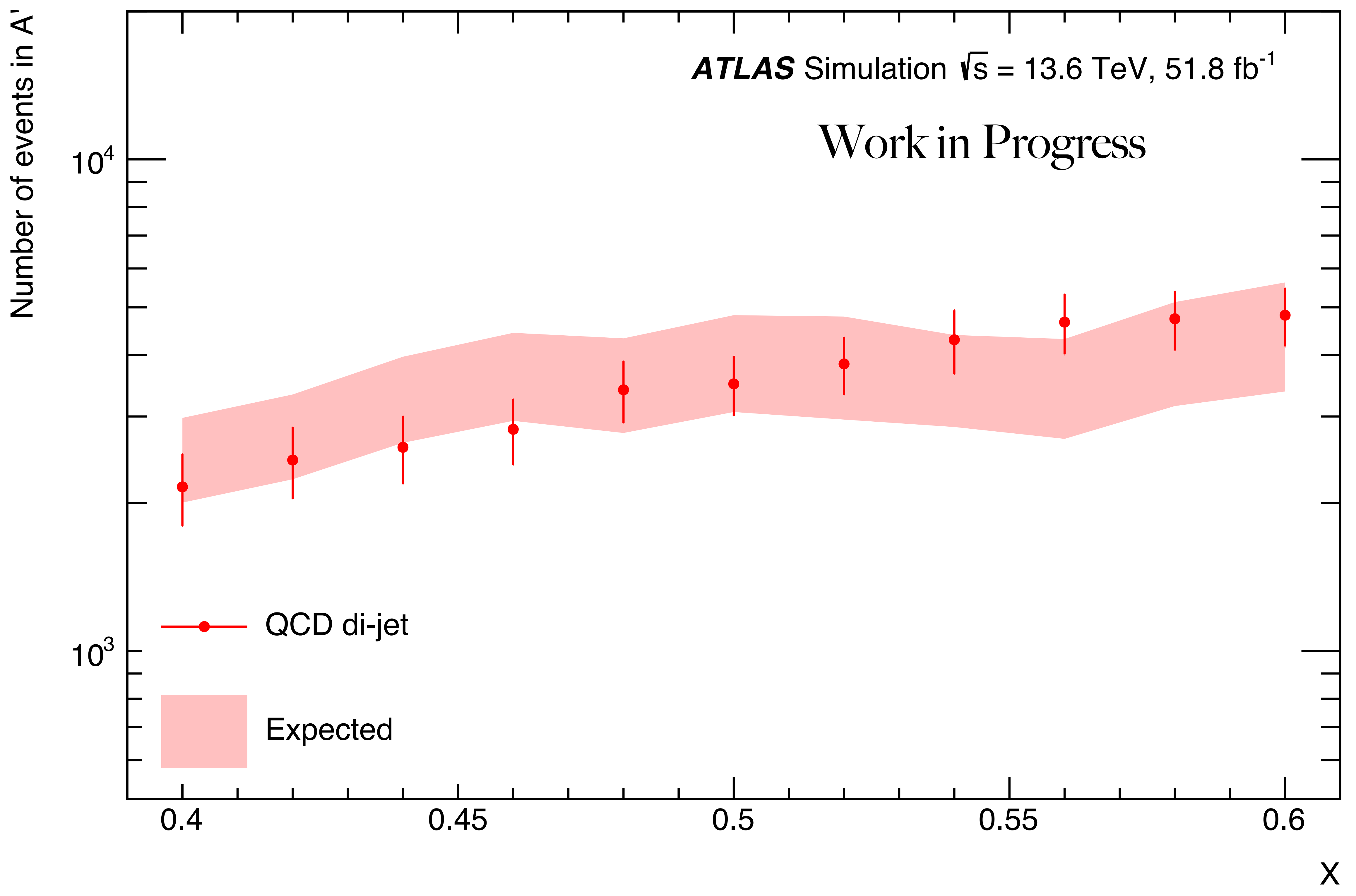
ABCD method in validation regions

- 4 new regions with X varying :

	$0.1 < PTF_{sub-lead.\ jet} < X$	$PTF_{sub-lead.\ jet} \geq X$
$ECF2/p_{T_{lead.\ jet}} \geq 30$ GeV	A’	B’
$ECF2/p_{T_{lead.\ jet}} < 30$ GeV	C’	D’



$$n_{A'}^{exp} = (n_{B'}^{bkg} \times n_{C'}^{bkg})/n_{D'}^{bkg} \pm \text{(MC stat.)}$$



Conclusions - Prospects

- Search for BSM physics with the ATLAS detector : long lived particles producing a unusual di-jet topology

- Optimisation still need to be improved : additional selections on vertices, on track variables ; different approach for the ABCD plane to be tested
- Validation of the background estimation in data, in a region far away from the SR (to avoid possible signal contamination)

Thanks for your attention