https://us.whitewall.com/mag/cern-between-science-and-art-an-interview-with-michael-hoch

Data scouting & parking in CMS

Swagata Mukherjee

On behalf of the CMS Collaboration

Heavy Ions and Hidden Sectors
CP3-UCLouvain
December 4-5, 2018

Physics Institute III A

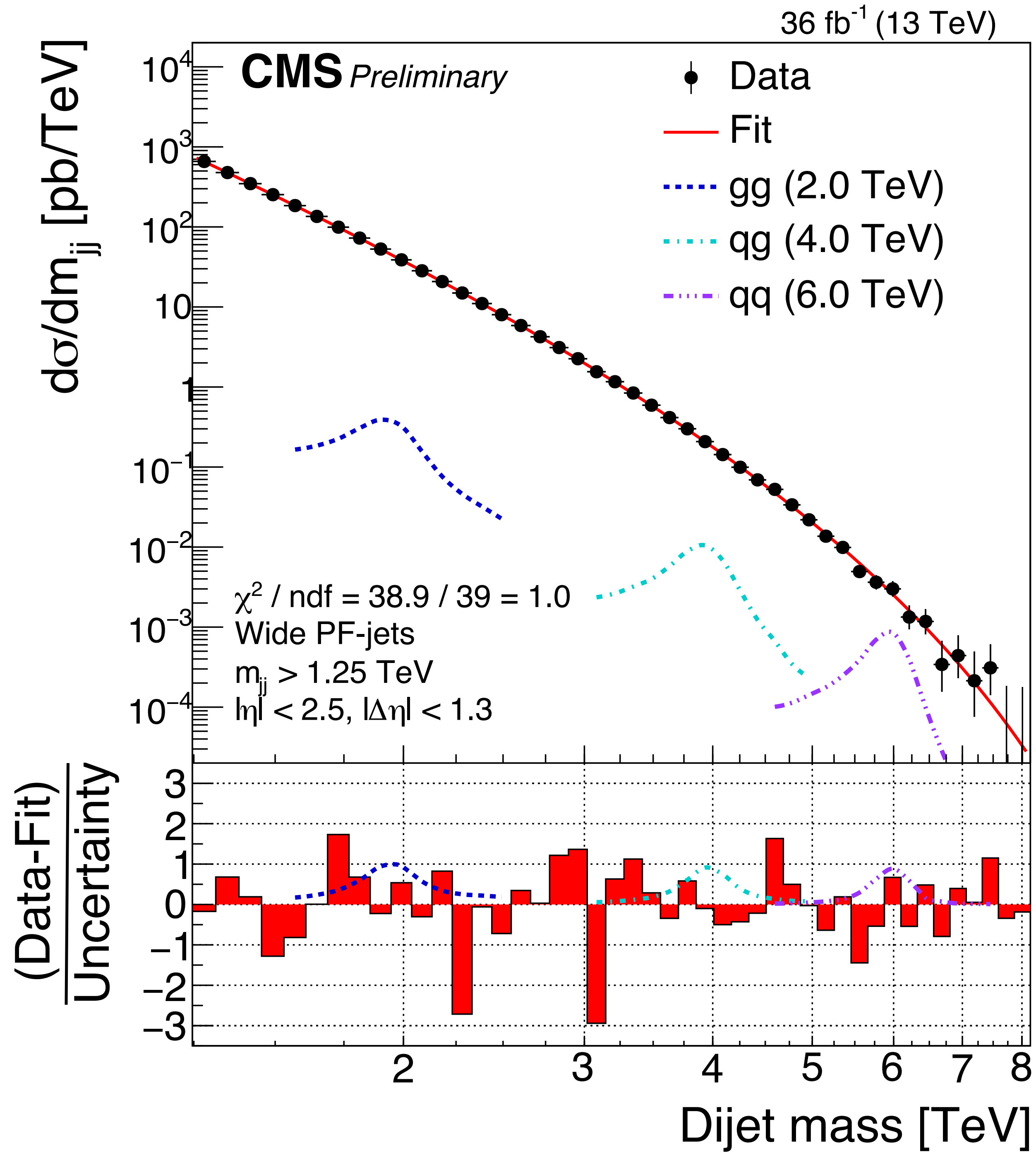
RWTH AACHEN UNIVERSITY

SPONSORED BY THE
Federal Ministry of Education and Research

CMS
Compact Muon Solenoid

Where is new physics hiding?

- Run II just ended
- No clear sign of new physics until now
- Many searches can't probe low / intermediate masses because of trigger threshold
- One good example is di-jet resonance search
- Search starts from ~1.2 TeV (using nominal triggers)



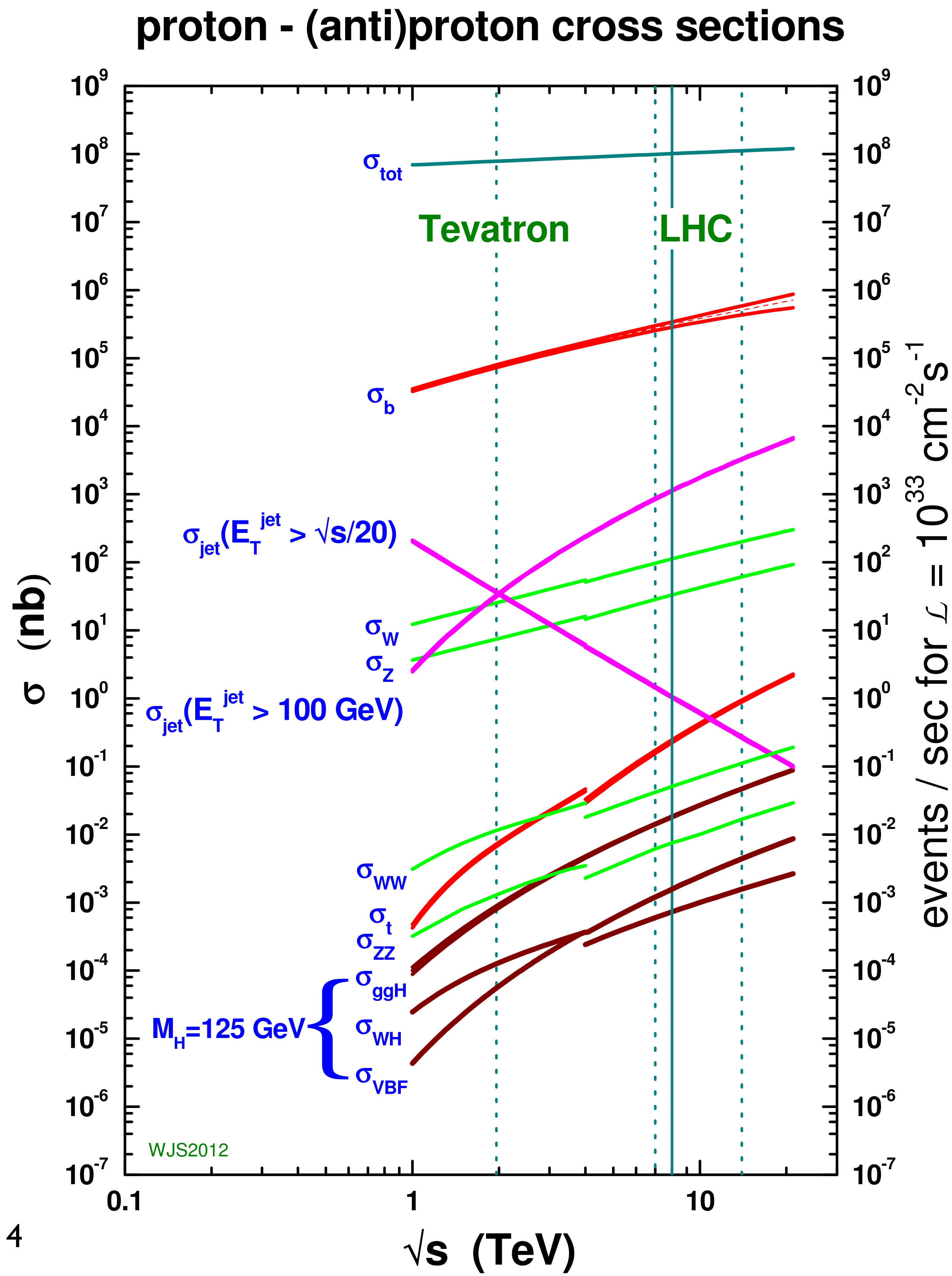
Why trigger threshold is an issue in LHC ?

Why trigger threshold is an issue in LHC ?

- At instantaneous luminosity of 1.2×10^{34} $cm^{-2}s^{-1}$, LHC produces ~1 billion p-p collisions per second
- To save all these collision events, CMS would need to read, process, transfer, and store, tens of TB per second

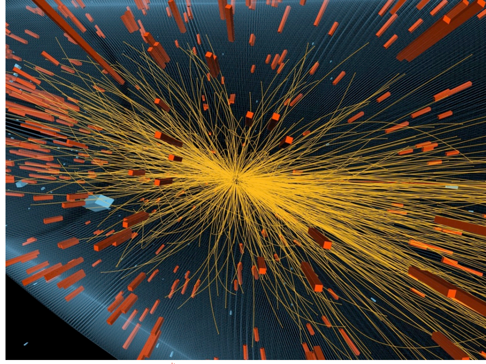
Why trigger threshold is an issue in LHC ?

- Do we even need such large amount of data ?
- Interesting processes are much rarer than the p-p scattering !
- Filter out un-interesting events
    - TRIGGER !
- End up selecting events with high-pT objects
- Limited sensitivity to low-mass searches



Is it possible to lower trigger threshold?

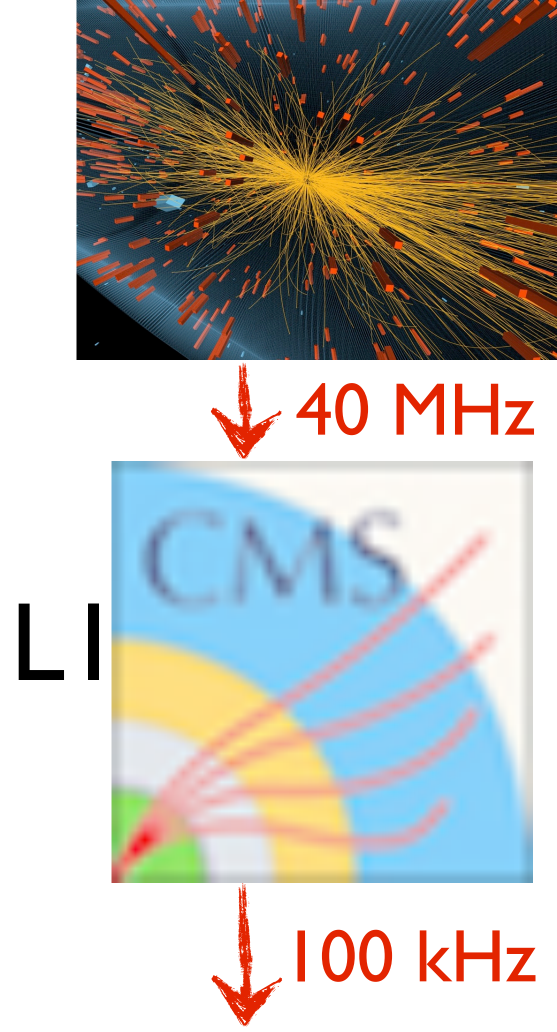
A detour to CMS trigger system



↓ 40 MHz

- LHC collide proton bunches each 25 ns, with rate up to 40 MHz
- CMS experiment uses a **two-level trigger system** to reduce the data volume

A detour to CMS trigger system

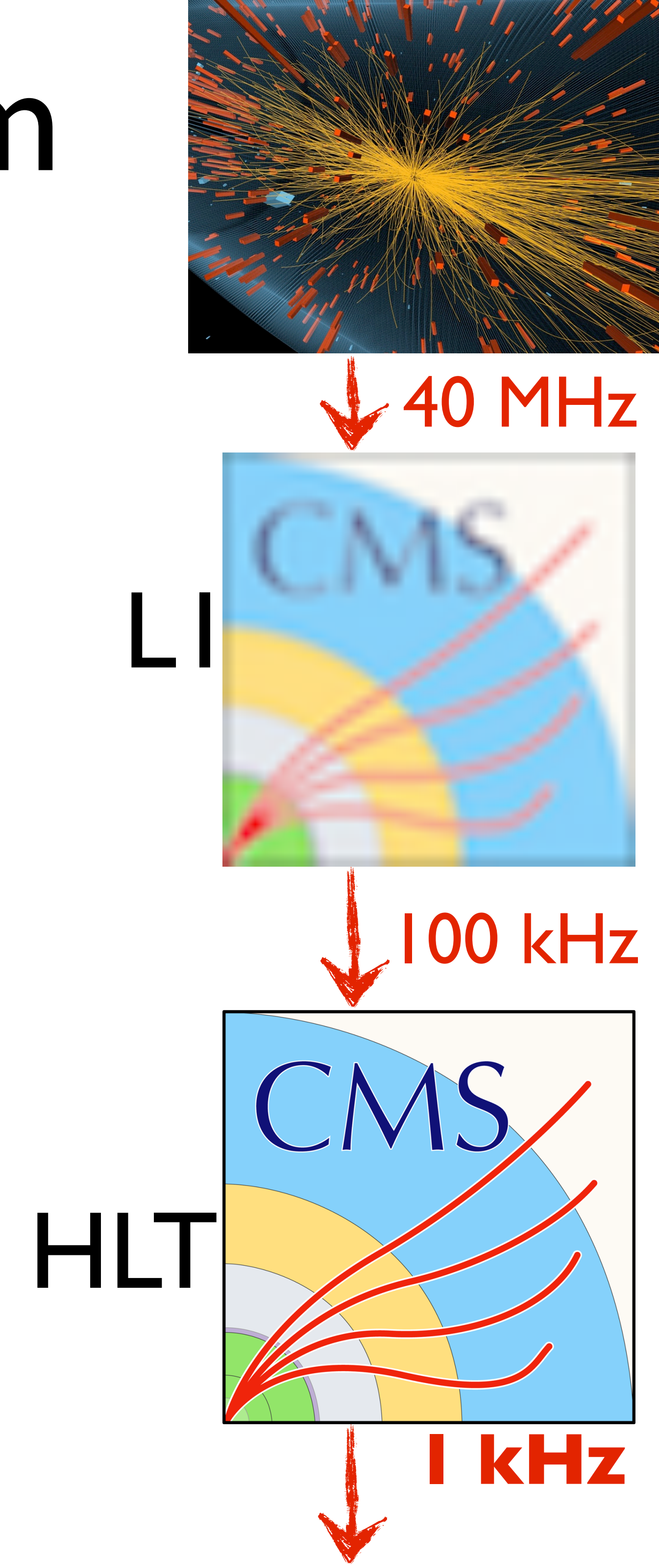


- Level 1 (L1) Trigger
  - hardware-based, fast read-out of detector with coarse granularity
  - 40 MHz → L1 → 100 kHz
  - Only simplified event information available (no tracker information)

A detour to CMS trigger system

- High Level Trigger (HLT)
  - Software-based, full readout of detector with full granularity
  - 100 kHz→HLT→ 1 kHz

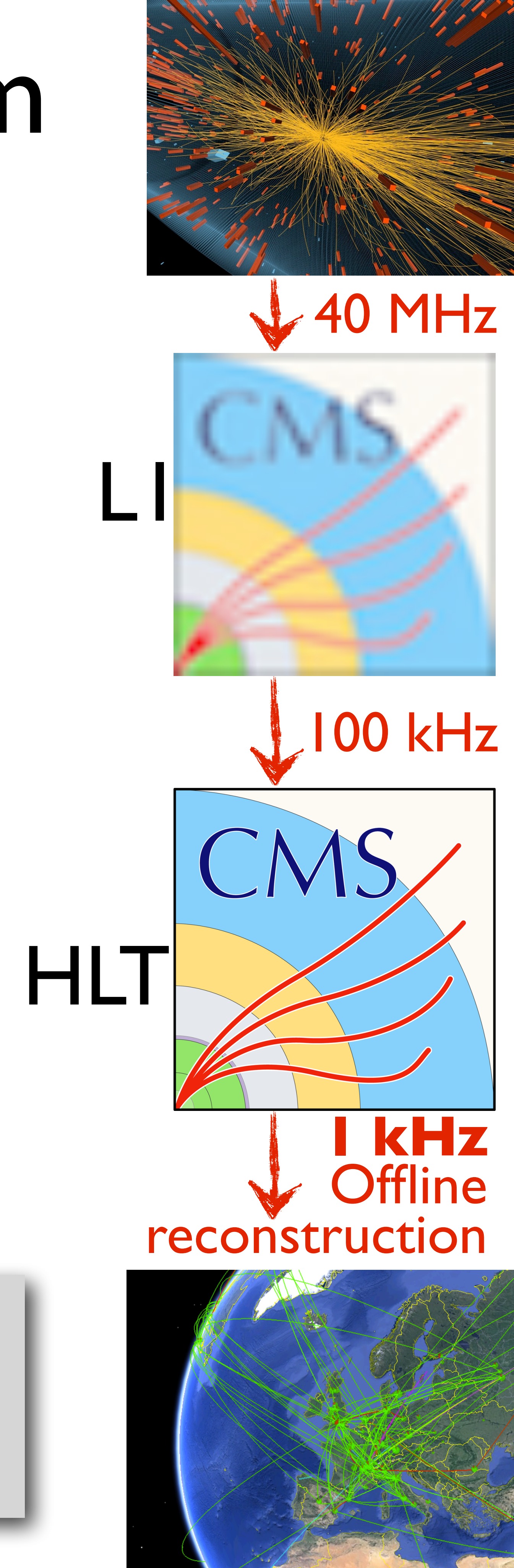
Next few slides are about how to **increase** this number



A detour to CMS trigger system

- Events accepted by HLT are transferred to Tier-0, reconstructed offline and stored world-wide.
  - **Performance of HLT quite close to the offline reconstruction**
  - Similar algorithms and calibrations, optimized for speed

Events that are not selected by trigger system are lost, **forever**!



The actual limitation...

We are limited by

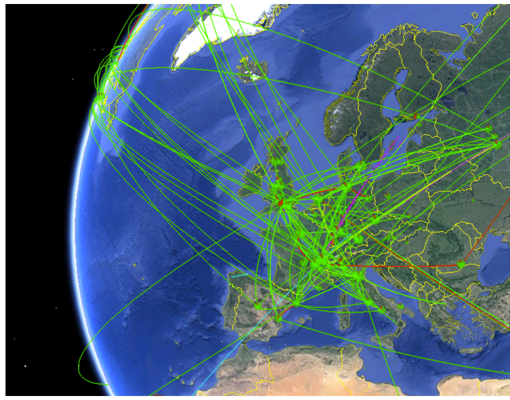
Trigger Bandwidth = Event Rate × Event Size

~1 kHz × ~1 MB

≈1 GB/sec

HLT

1 kHz
Offline reconstruction



A way out...

Trigger Bandwidth = Event Rate × Event Size

~1 kHz × ~1 MB

If we want to **increase** rate (i.e. decrease threshold)

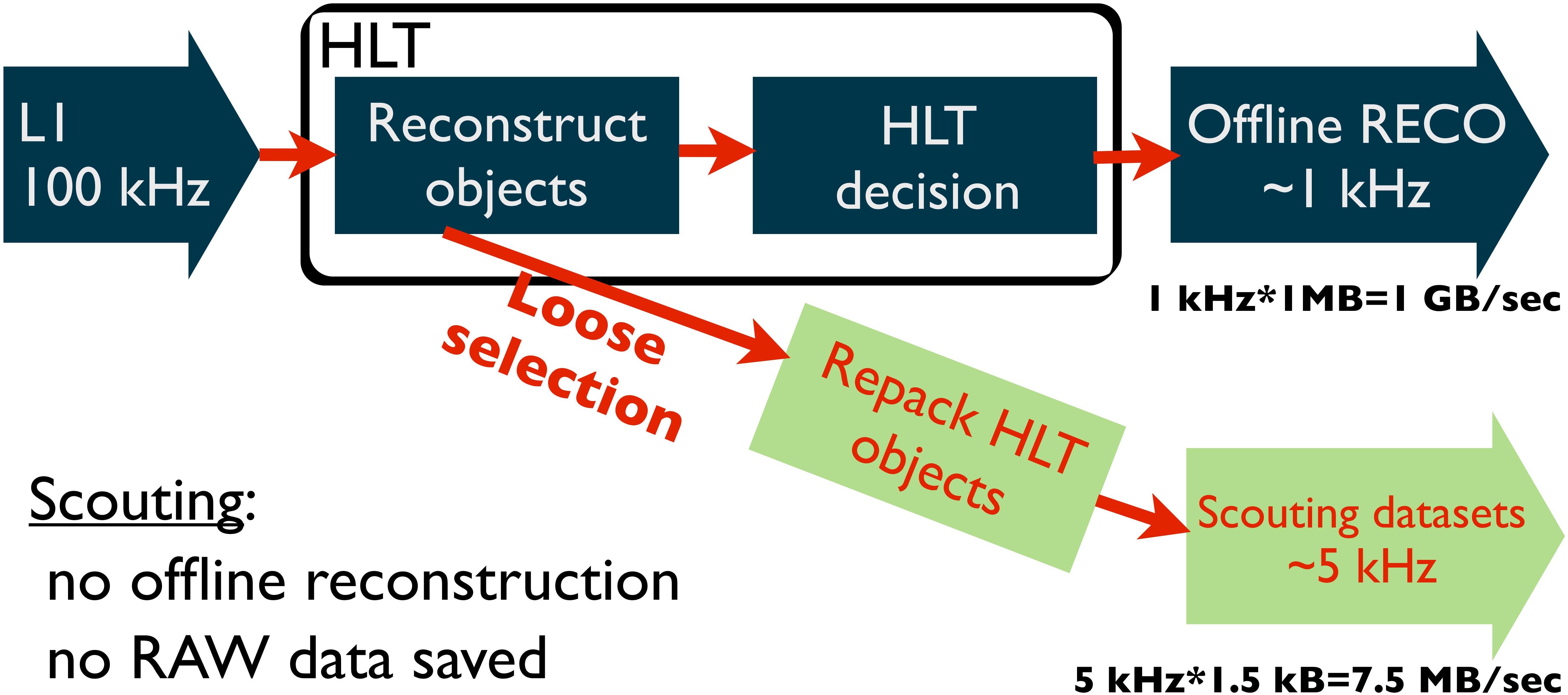
We need to **decrease** event size

This is the idea of data scouting

Advantage
(I)Save low pT objects (II)Probe low mass regions

https://cds.cern.ch/record/1480607/files/DP2012_022.pdf

Data Scouting: technicalities in a nutshell



<u>Scouting</u>:

no offline reconstruction

no RAW data saved

Scouting being used in CMS since 2011

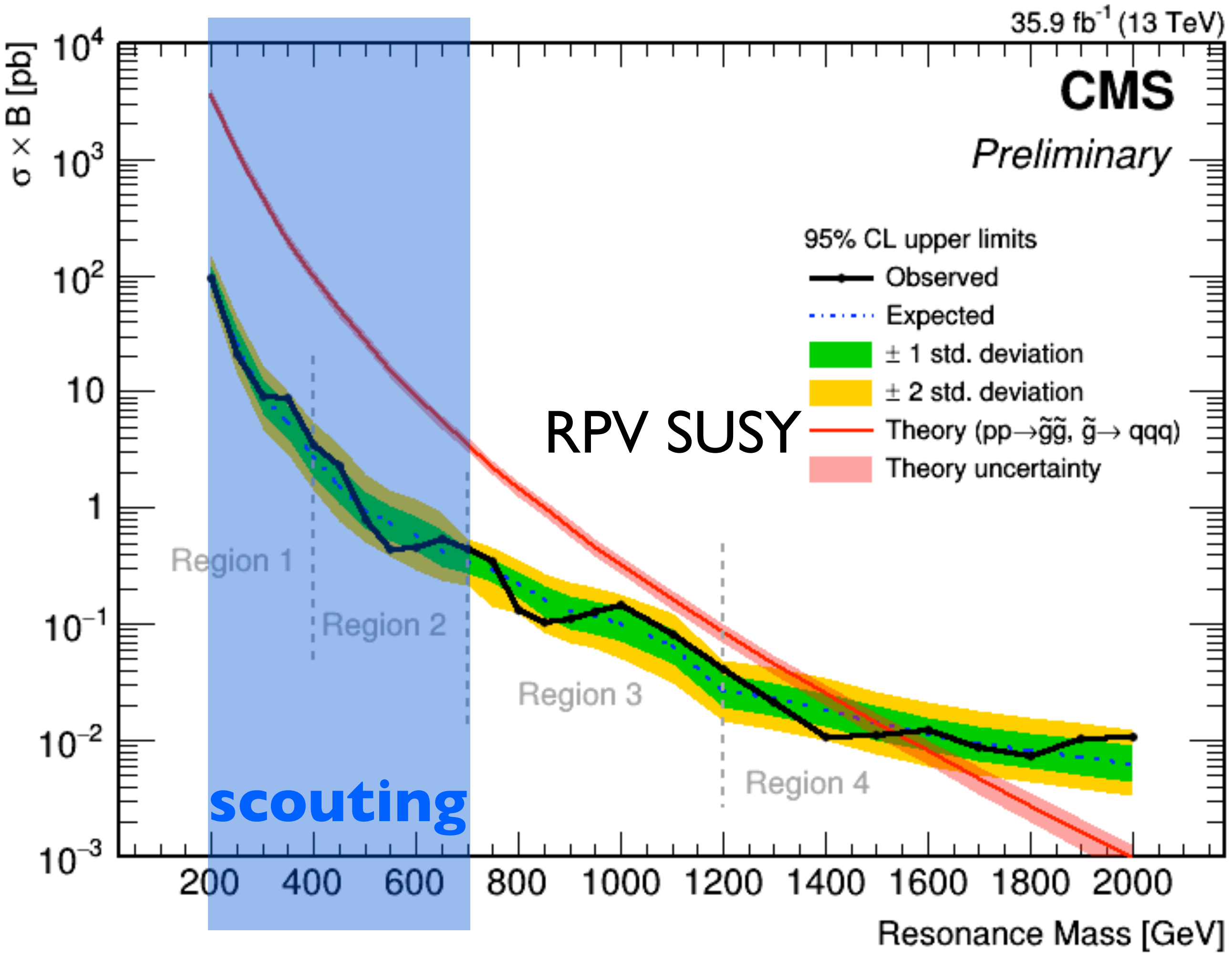
Di-jet resonance search: first successful application of scouting

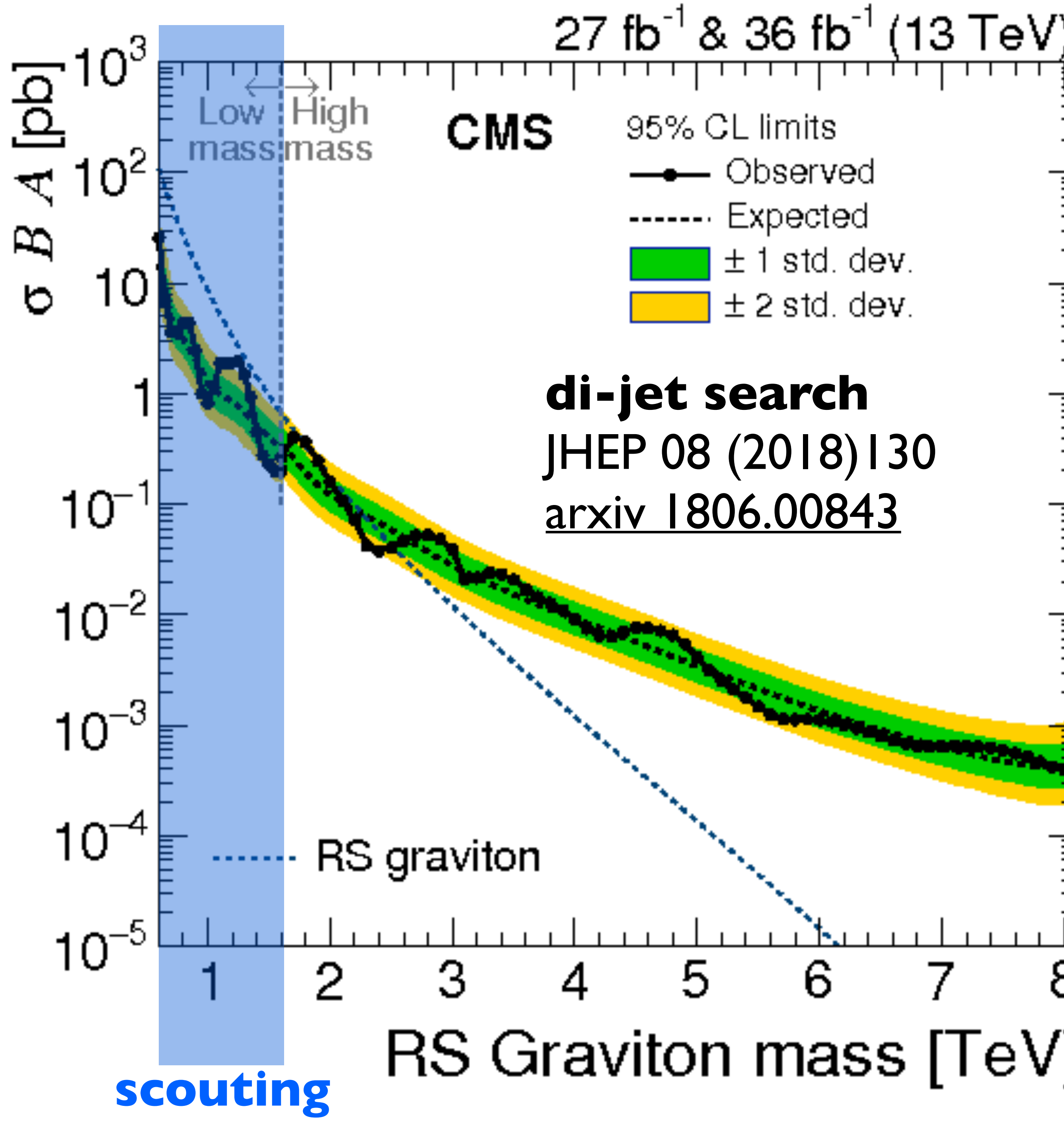
What do we gain? From HEAVY to LIGHT

200<Mjjj<700 GeV accessible by H_T PF scouting

600<Mjj<1600 GeV accessible by H_T calo scouting

tri-jet search
CMS-PAS-EXO-17-030

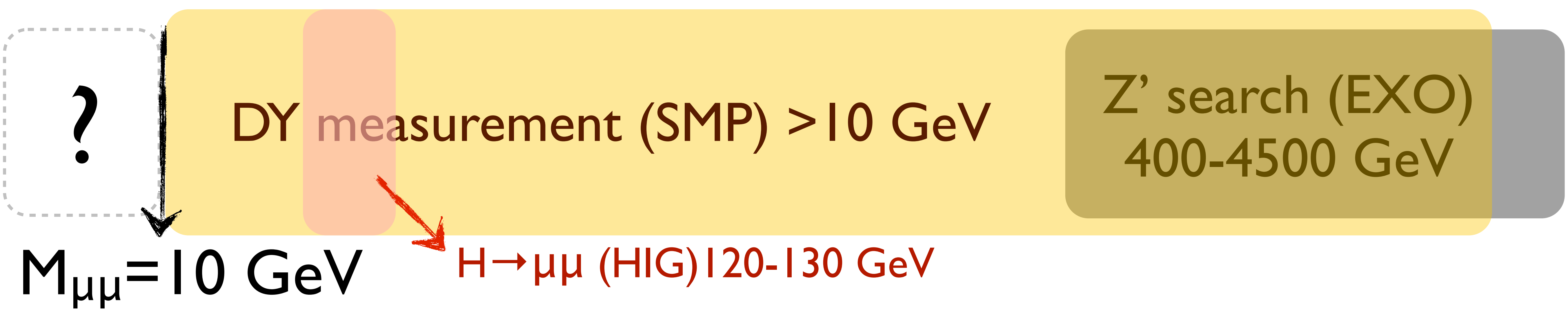




Jet substructure with PF scouting ?
If yes, more searches will be possible.

Going beyond jets: *di-muon scouting*

- Until now, searches involving jets are the only (publicly available) analyses in CMS, using scouting data.
- However, efforts made for di-muon scouting in Run II.
- With nominal triggers, CMS covers ~10 GeV-4.5 TeV di-muon masses.
- Masses below 10 GeV not probed, no suitable trigger available.
  - B-physics group has triggers focussing on low mass resonances, not useful for searches over full mass spectrum.

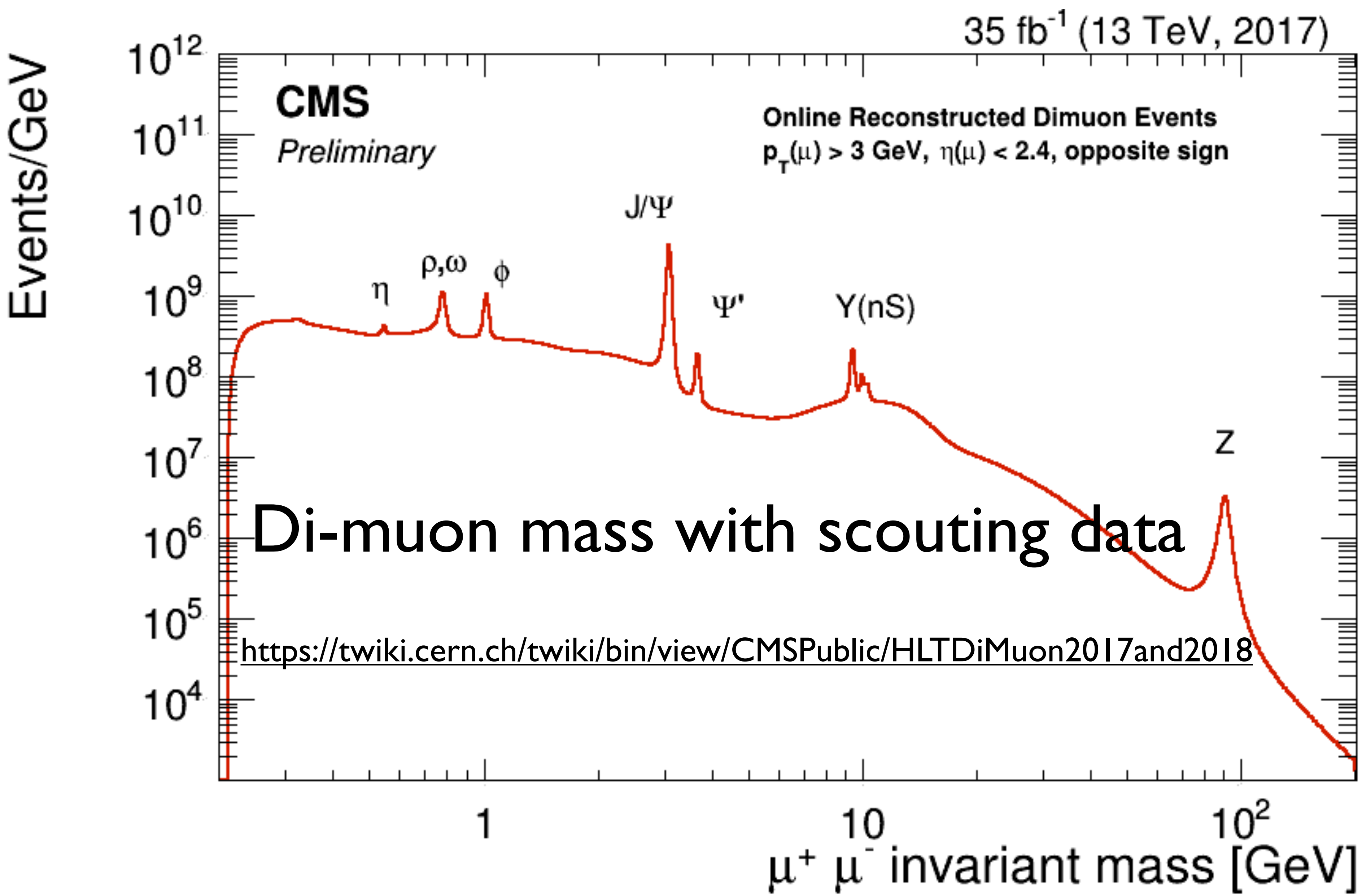


Di-muon scouting trigger

Dedicated di-muon scouting trigger designed for **prompt** and **displaced** di-muon search.

Loose HLT requirement:

- At least 2 muons with p_T>3 (1) GeV in 2017 (2018). **No mass cut**.
- Di-muon vertex can be displaced, upto ~10 cm, w.r.t primary vertex.



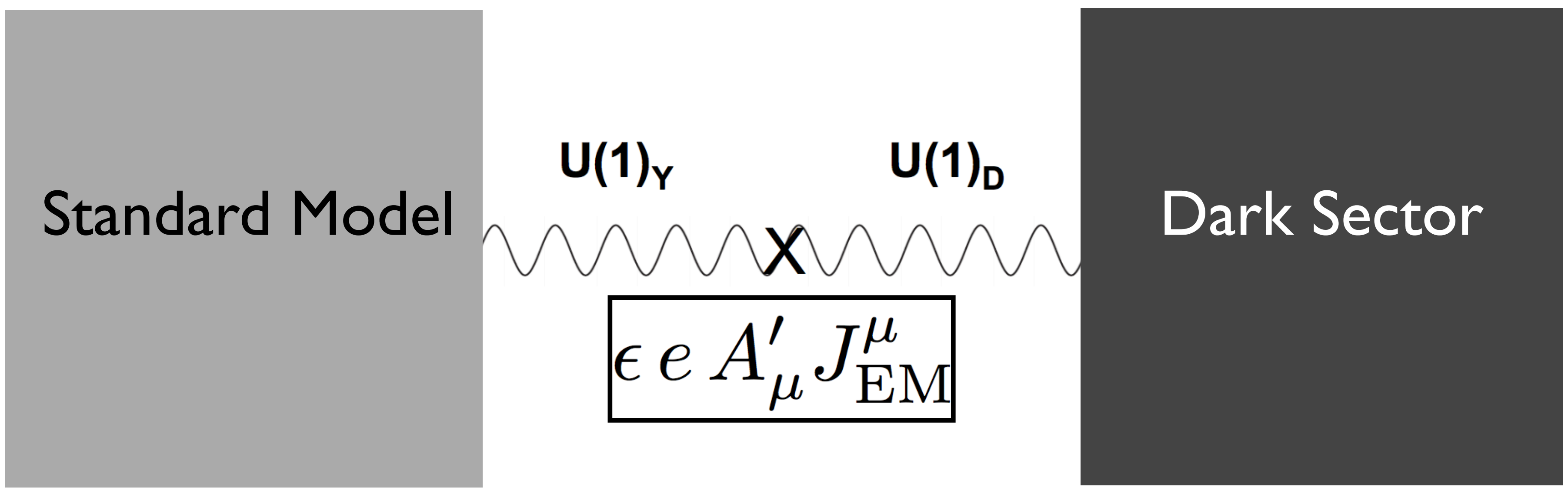
Di-muon mass with scouting data

https://twiki.cern.ch/twiki/bin/view/CMSPublic/HLTDiMuon2017and2018

Di-muon scouting

Theoretical motivation: Search for dark photons (A' or Z_d) in dimuon channel. For small mixing (ϵ), Z_d can be long-lived → displaced muon-pair

cross section is suppressed by ϵ^2



Scouting data can be used to test other models also

- BABAR / LHCb already put some constrains in $M(Z_d)$-ϵ plane
- Energy frontier capabilities are unique and complementary to those at Intensity frontiers
- CMS dark-photon search in di-muon channel: work-in-progress
- Aiming for 2019 winter/spring conference

A drawback of Scouting & The Idea of Parking

- Full event information not available in scouting
  - Difficult to fully characterize a potential signal (if seen)
- Way out: Parking of the full RAW data
  - NO offline reconstruction immediately
  - Reconstruct only in case of a discovery in the scouting data

2016 (2017): Full (partial) scouting data was parked

Data parking not necessarily only for scouting trigger.
In 2018, CMS is investing resource in B-physics parking.

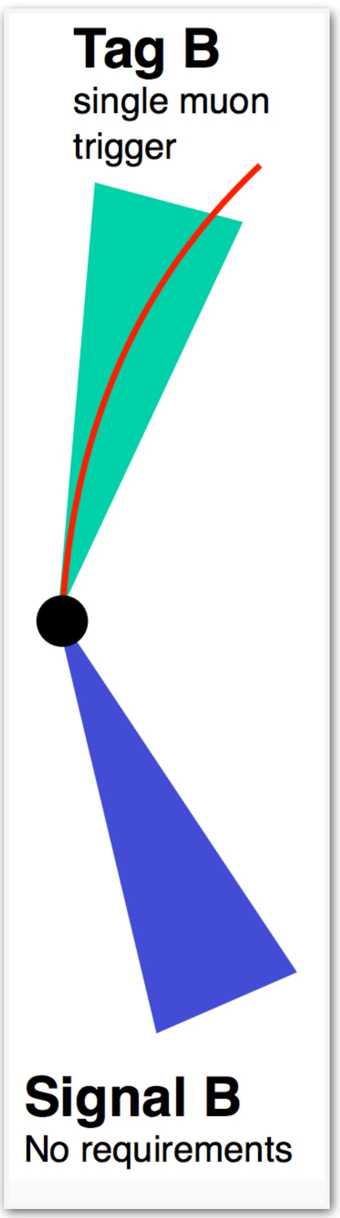
B Parking in CMS

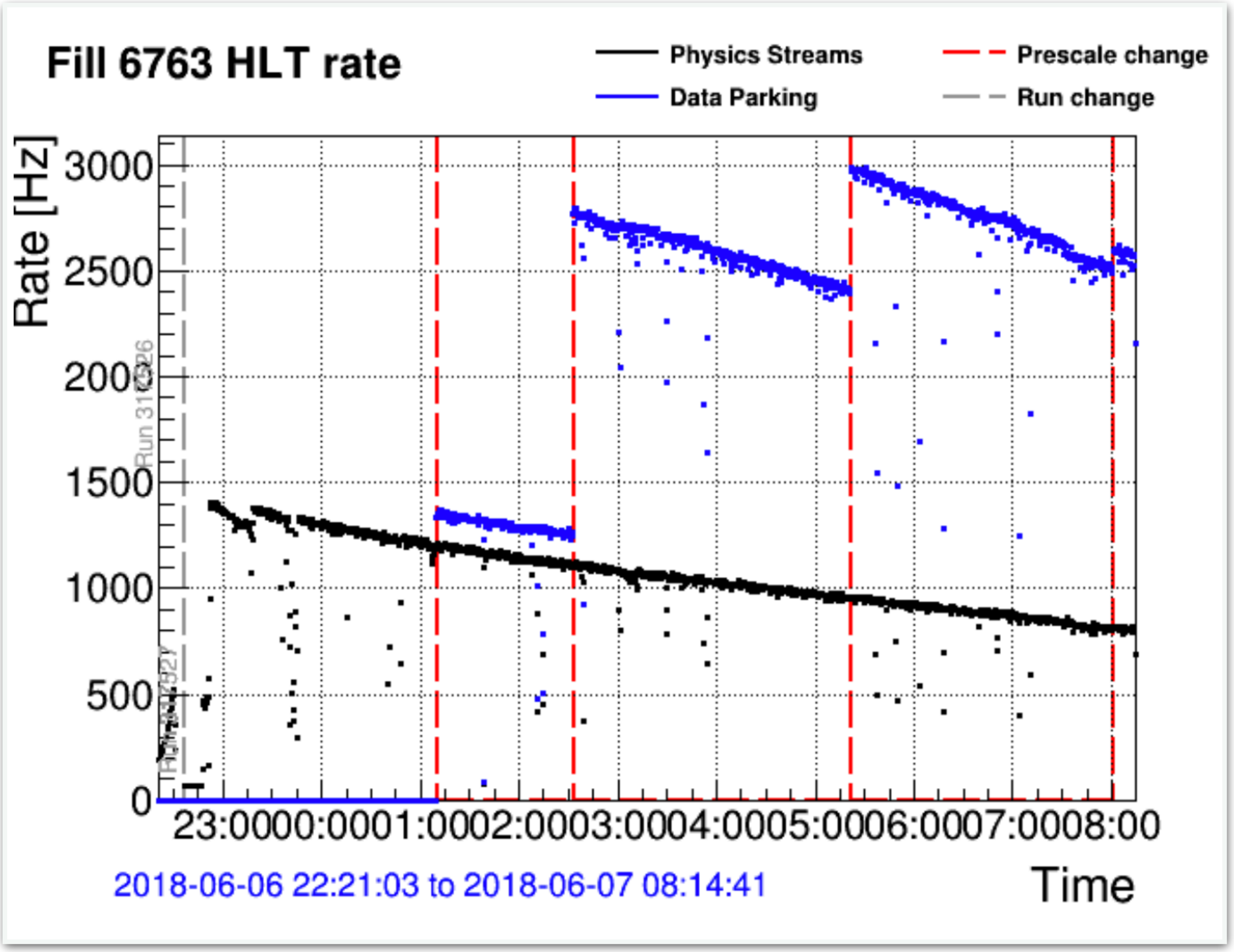
See also the nice talk by Jessica Prisciandaro on Tuesday

Motivation: Study B anomalies. Can also be used also for other searches

Goal: Collect large (~10^{10} events) unbiased sample of B

Idea: Triggering on muon from B (tag), to collect unbiased B on the other side (probe)





Single copy,
2 kHz to DAQ

Plot source: J. Duarte's talk in https://indico.fnal.gov/event/17519/

B Parking in CMS *usage in different searches*

Motivation: Study B anomalies. Can also be used for other searches

↓

Which models could be sensitive?

- Sub-GeV hidden sector models
  - $B^0 \rightarrow SS$ and $S \rightarrow \ell\ell$ (S: generic neutral state in hidden sector, can be LL)
  - Multi-lepton Signatures of a Hidden Sector in Rare B Decays, B. Batell, M.Pospelov, and A. Ritz, PRD, arxiv0911.4938
- Models featuring new $U(1)_d$ symmetry
  - Use $B \rightarrow K\ell^+\ell^-$ to place tight constraints on the size of Z-Z_d mixing. (Z_d: dark photon, can be LL)
  - "Dark" Z implications for Parity Violation, Rare Meson Decays, and Higgs Physics, H. Davoudiasl, H. Lee, and W. Marciano, PRD, arxiv1203.2947

These are just two example papers, other models/scenarios may exist...

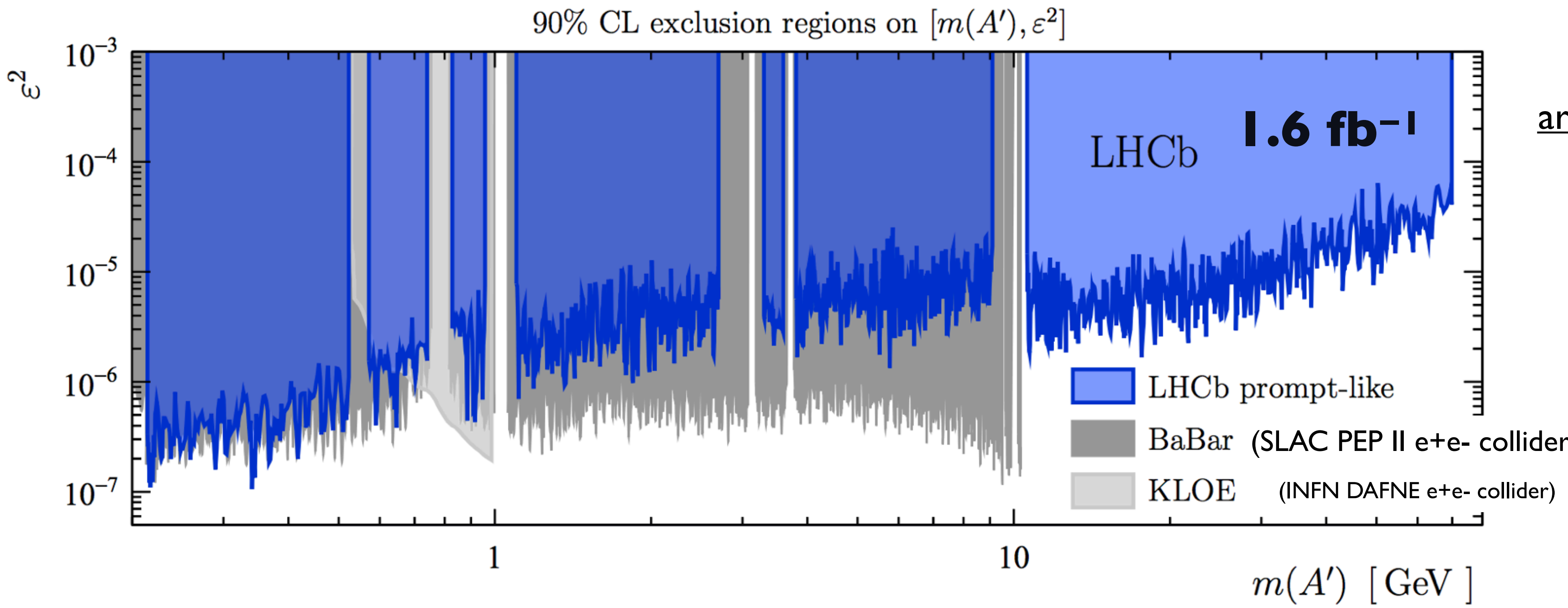
Summary

- Reach so-far-unexplored territory with the help of scouting & parking.
- Successful 'prompt' searches using scouting technique motivate more challenging attempts (eg. displaced dimuon search).
- Possibilities to expand scouting beyond jet and muon in Run III
- Leave no stone unturned. Do the best that can be done with CMS.

More searches to come.

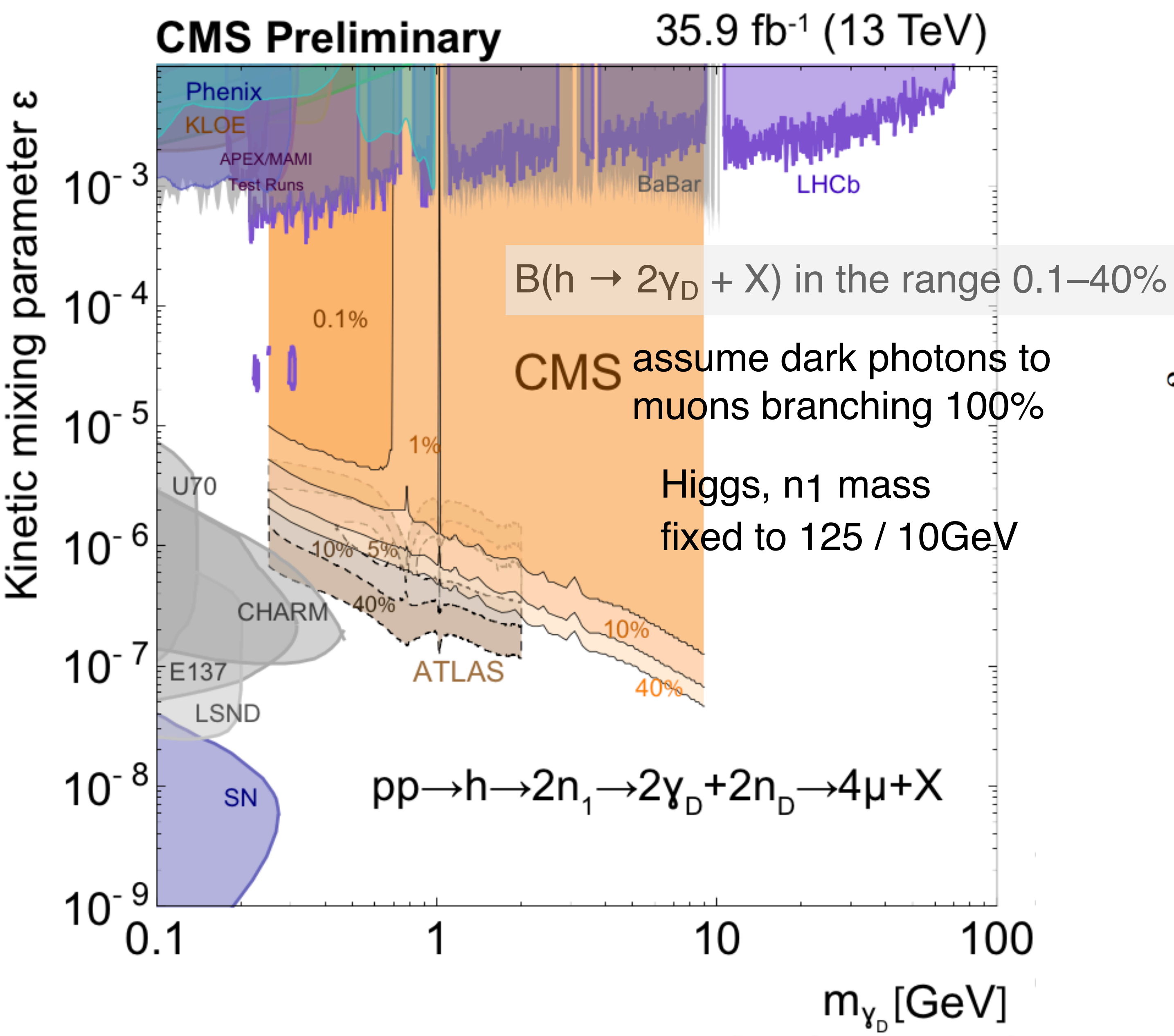
Stay tuned !

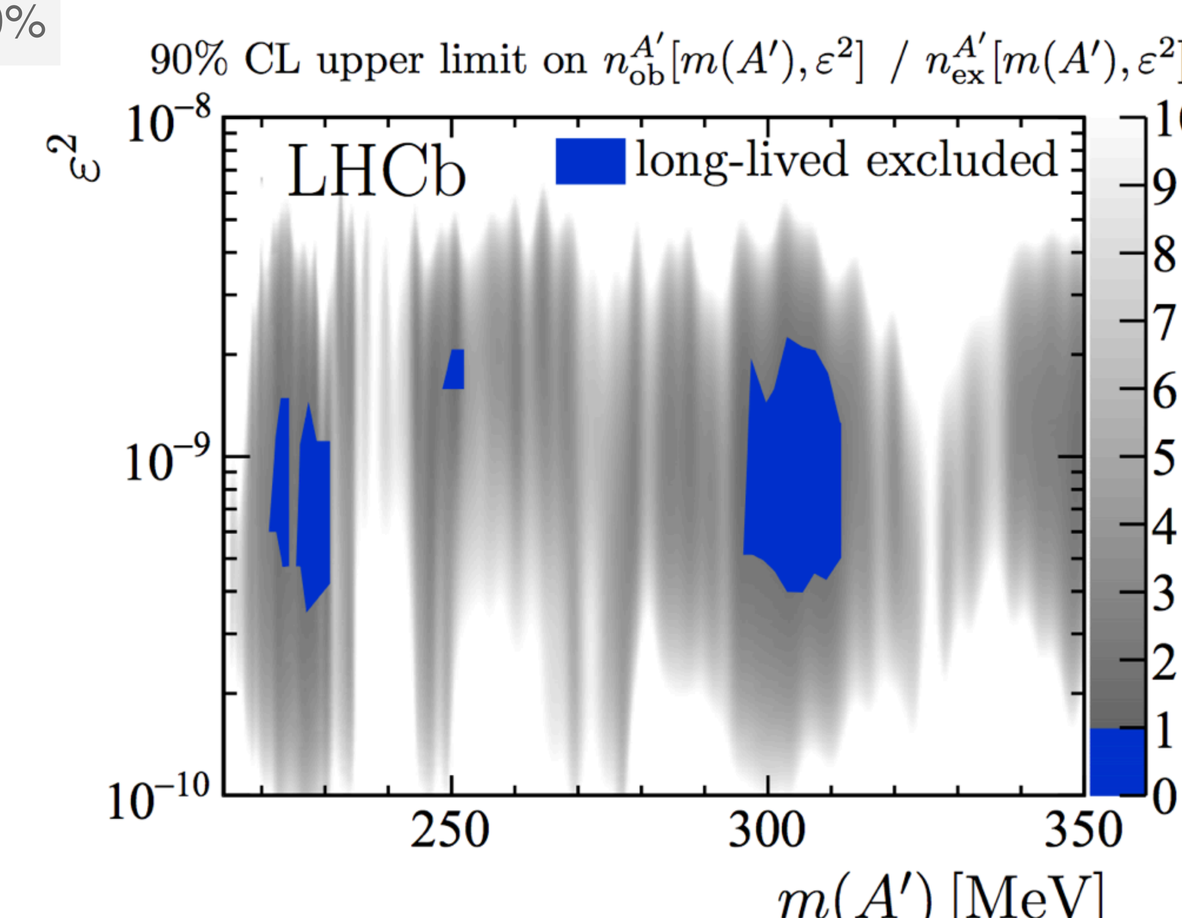
Extra Slides



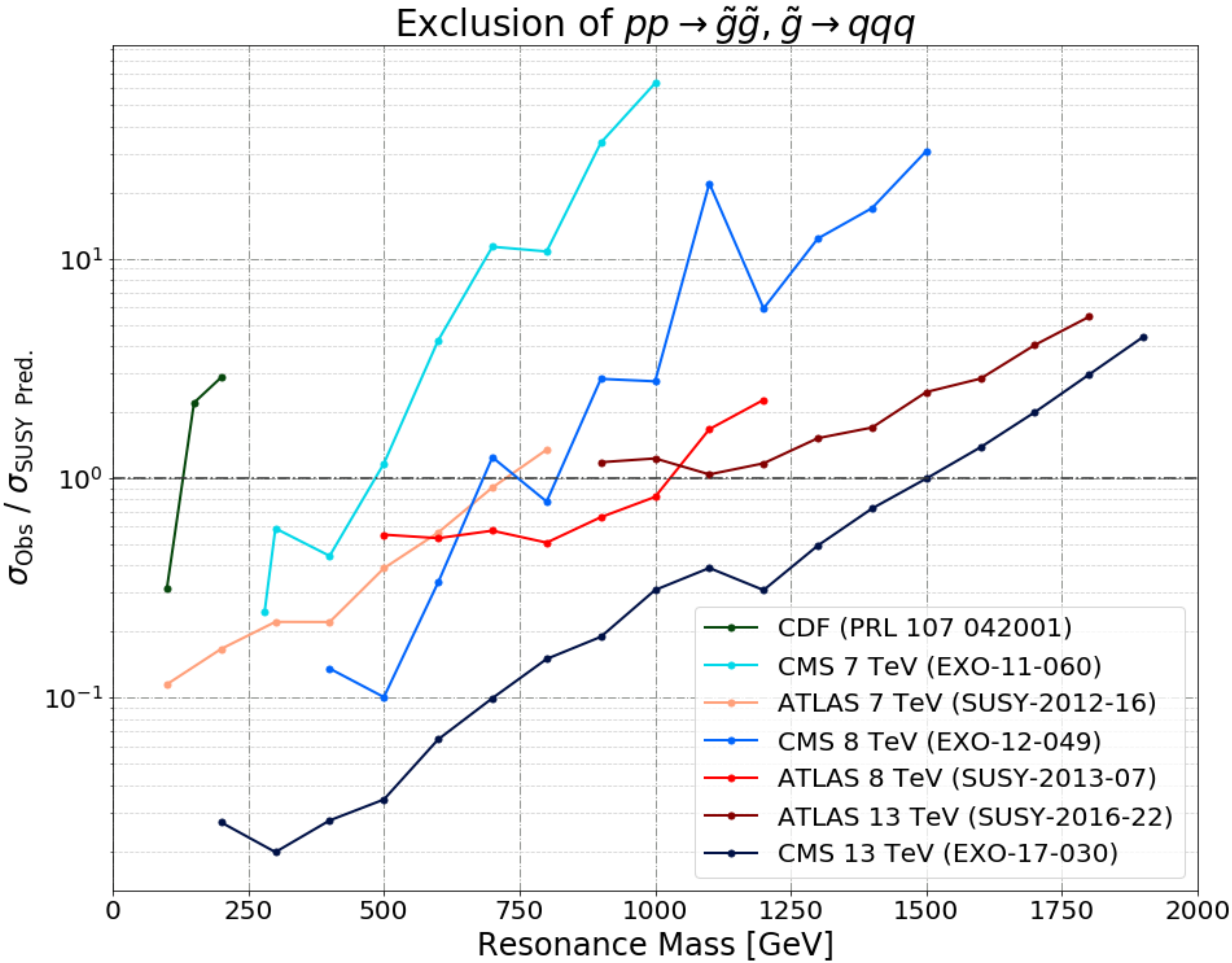
LHCb collaboration
arxiv1710.02867 (Oct 2017)

BABAR search:
A'→μμ, ee using
514 fb^{-1} of data



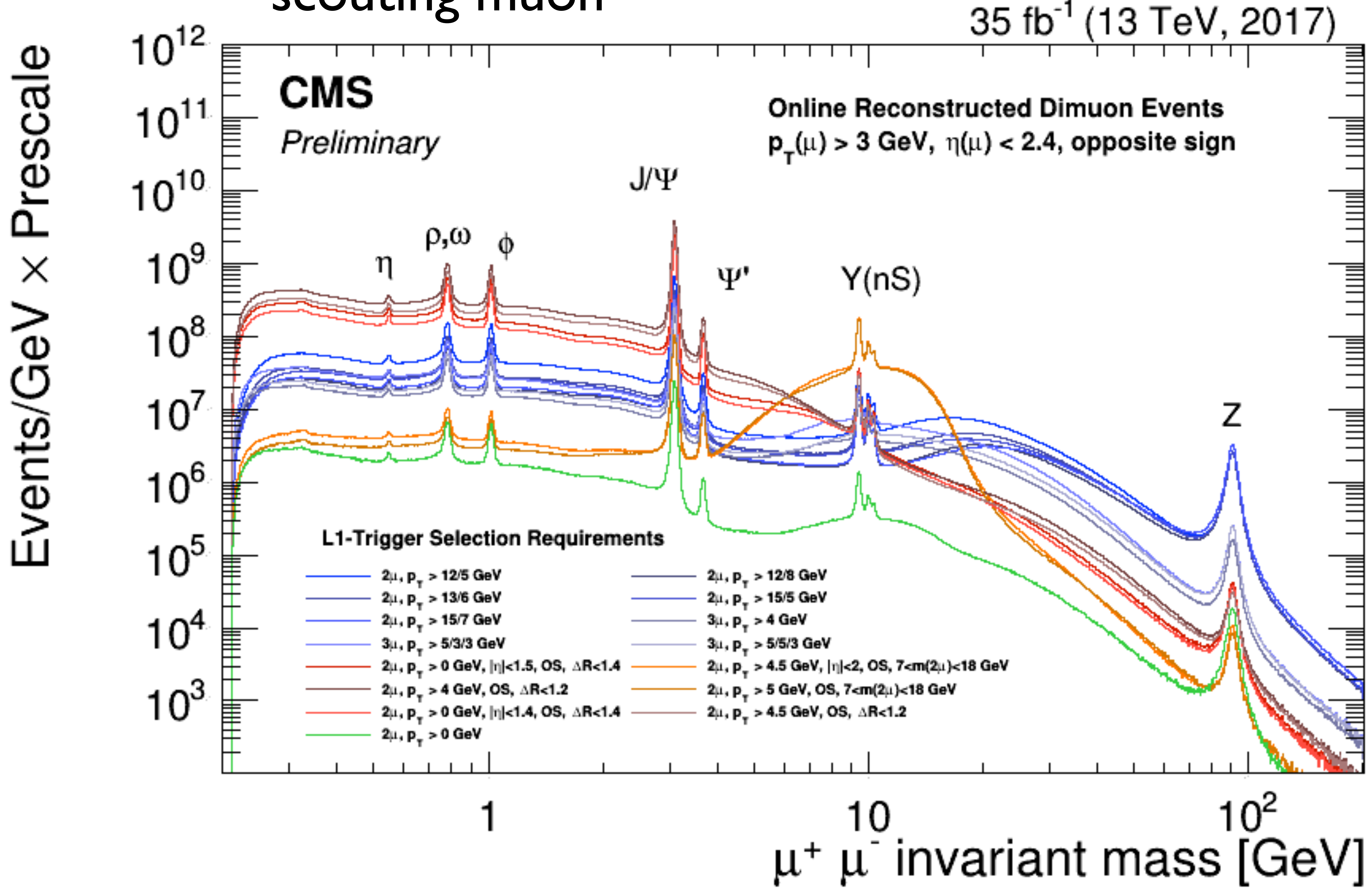


CMS PF scouting

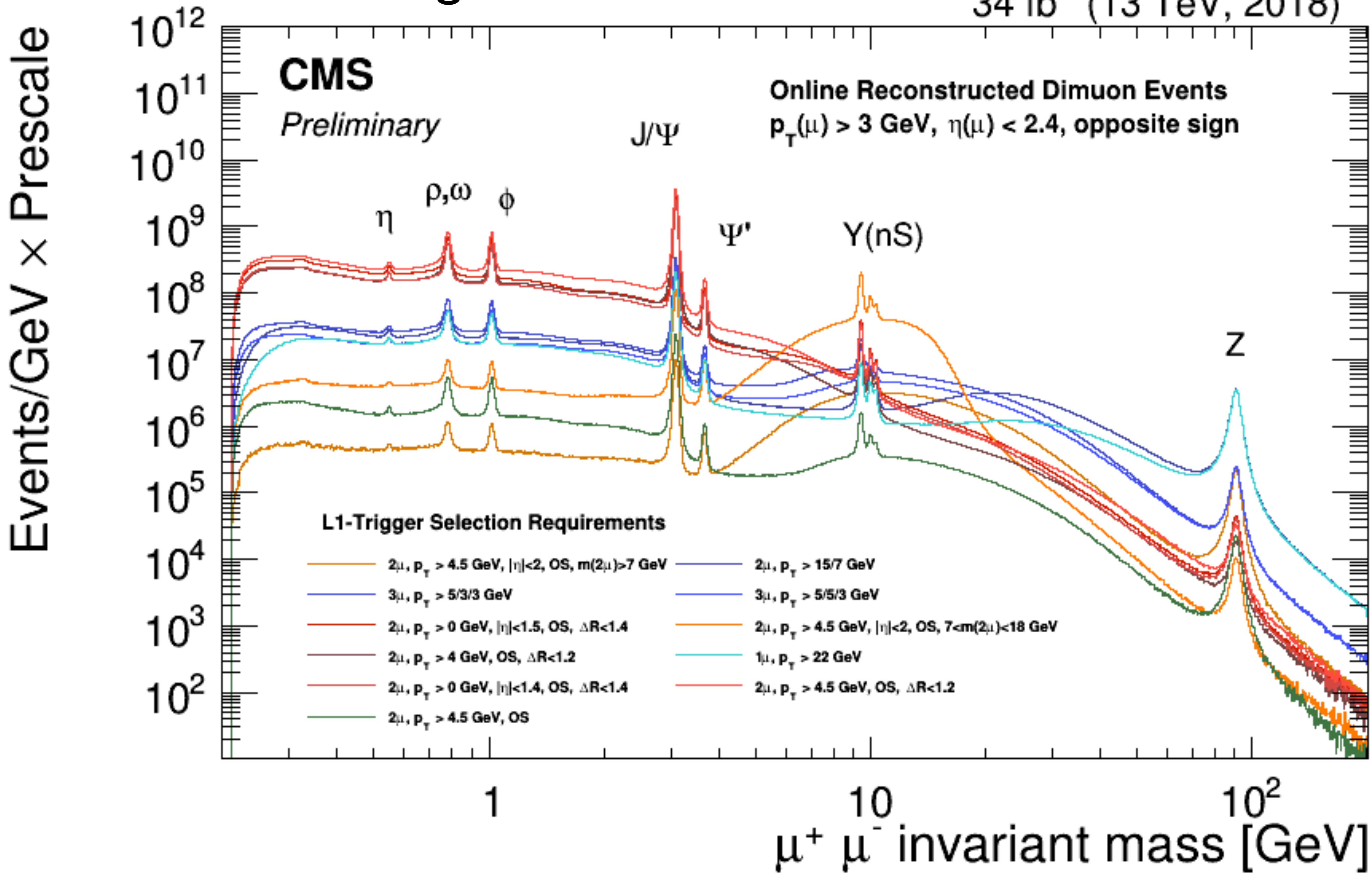


Parameter	Nominal LHC (design report)	HL-LHC 25ns (standard)	HL-LHC 25ns (BCMS)	HL-LHC 50ns
Beam energy in collision [TeV]	7	7	7	7
N_b	1.15E+11	2.2E+11	2.2E+11	3.5E+11
n_b	2808	2748	2604	1404
Number of collisions in IP1 and IP5	2808	2736 [1]	2592	1404
N_{tot}	3.2E+14	6.0E+14	5.7E+14	4.9E+14
beam current [A]	0.58	1.09	1.03	0.89
x-ing angle [μrad]	285	590	590	590
beam separation [σ]	9.4	12.5	12.5	11.4
β^* [m]	0.55	0.15	0.15	0.15
ε_n [μm]	3.75	2.50	2.50	3
ε_L [eVs]	2.50	2.50	2.50	2.50
r.m.s. energy spread	1.13E-04	1.13E-04	1.13E-04	1.13E-04
r.m.s. bunch length [m]	7.55E-02	7.55E-02	7.55E-02	7.55E-02
IBS horizontal [h]	80 -> 106	18.5	18.5	17.2
IBS longitudinal [h]	61 -> 60	20.4	20.4	16.1
Piwinski parameter	0.65	3.14	3.14	2.87
Geometric loss factor R0 without crab-cavity	0.836	0.305	0.305	0.331
Geometric loss factor R1 with crab-cavity	(0.981)	0.829	0.829	0.838
beam-beam / IP without Crab Cavity	3.1E-03	3.3E-03	3.3E-03	4.7E-03
beam-beam / IP with Crab cavity	3.8E-03	1.1E-02	1.1E-02	1.4E-02
Peak Luminosity without crab-cavity [$cm^{-2} s^{-1}$]	1.00E+34	7.18E+34	6.80E+34	8.44E+34
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2} s^{-1}$]	(1.18E+34)	19.54E+34	18.52E+34	21.38E+34
Events / crossing without levelling and without crab-cavity	27	198	198	454
Leveled Luminosity [$cm^{-2} s^{-1}$]	-	5.00E+34 [5]	5.00E+34	2.50E+34
Events / crossing (with leveling and crab-cavities for HL-LHC)	27	138	146	135
Peak line density of pile up event [event/mm] (max over stable beams)	0.21	1.25	1.31	1.20
Leveling time [h] (assuming no emittance growth)	-	8.3	7.6	18.0
Number of collisions in IP2/IP8	2808	2452/2524 [7]	2288/2396	0[4]/1404
N_b at SPS extraction [2]	1.20E+11	2.30E+11	2.30E+11	3.68E+11
n_b / injection	288	288	288	144
N_{tot} / injection	3.46E+13	6.62E+13	6.62E+13	5.30E+13
ε_n at SPS extraction [μm] [3]	3.40	2.00	< 2.00 [6]	2.30

scouting muon



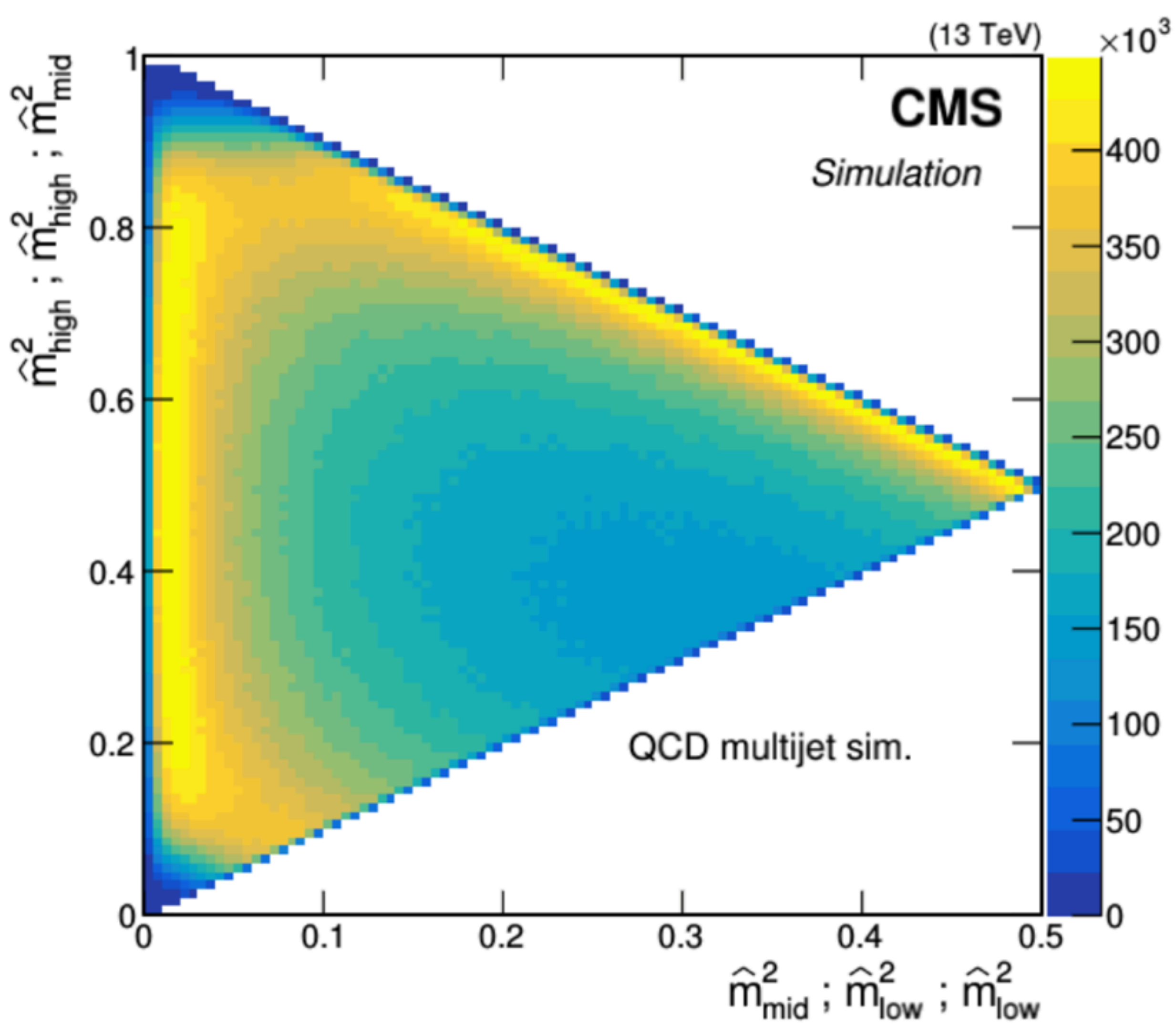
scouting muon

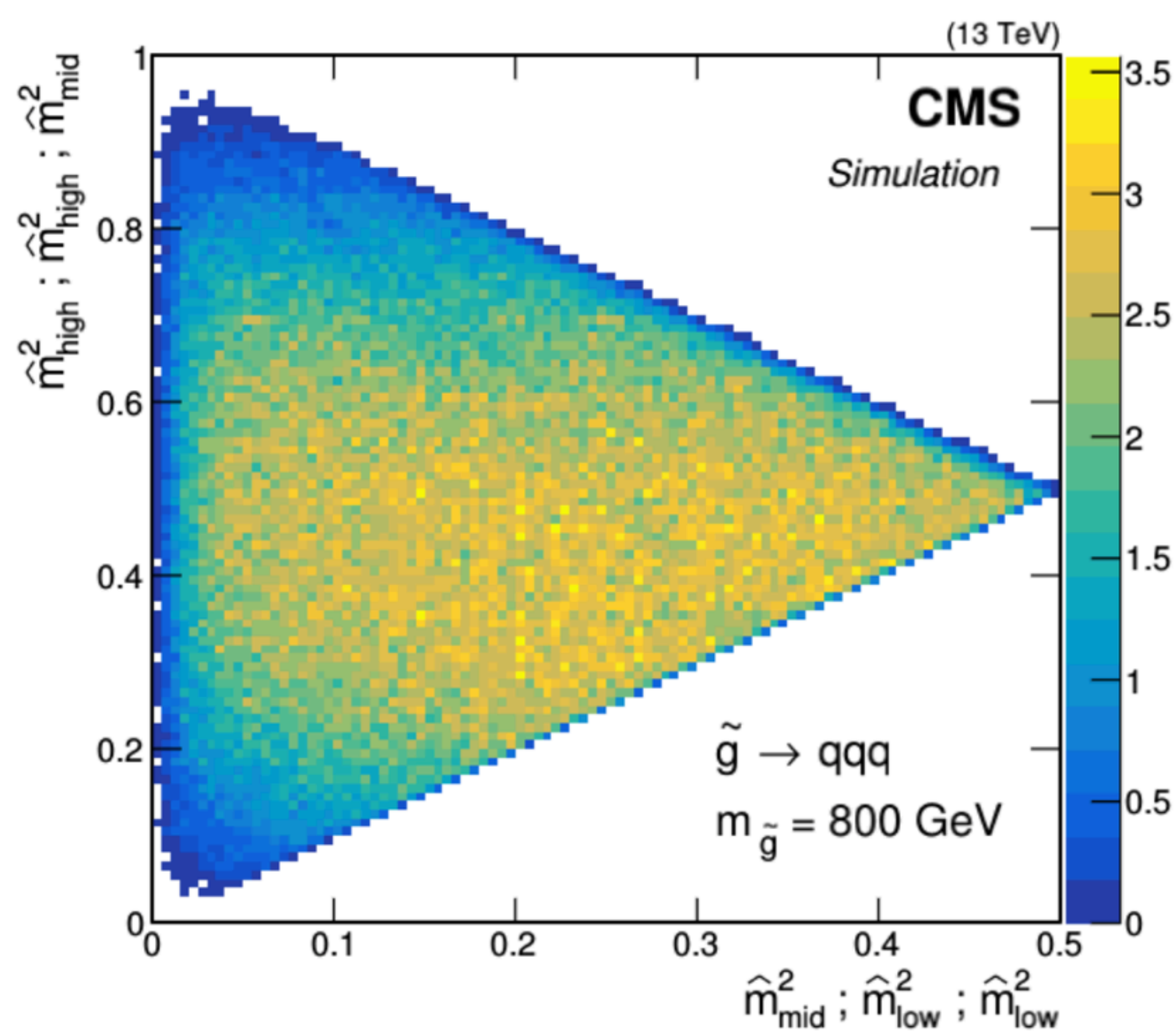


Tri-jet search

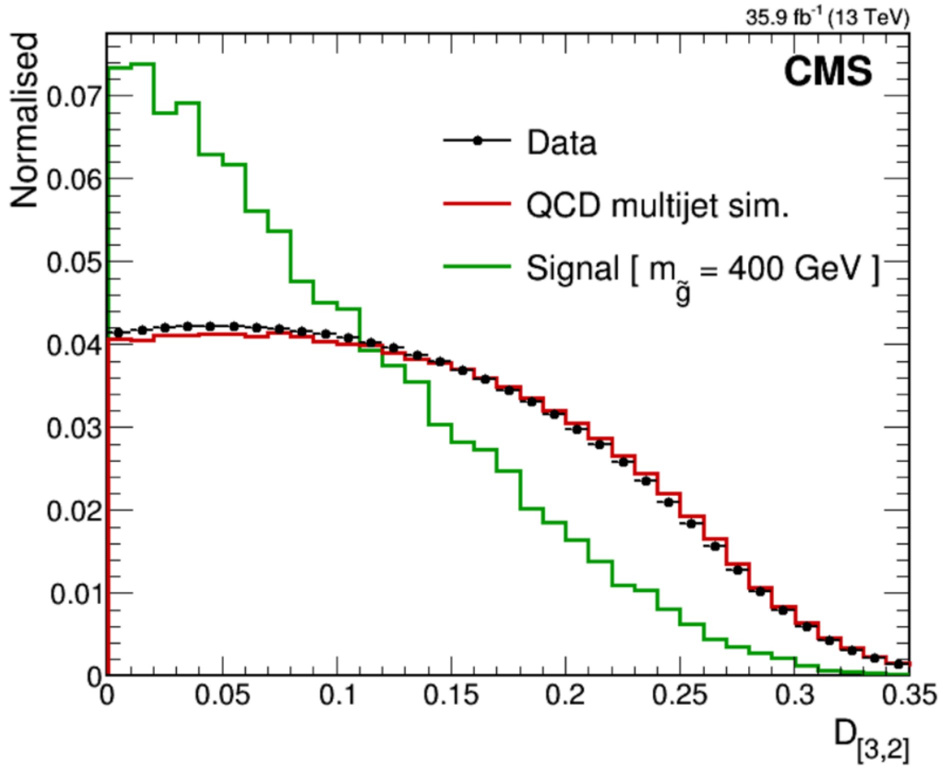
gluinos decay to quarks (udd RPV coupling): 100% branching fraction
all superpartners except the gluino are decoupled, set squark masses to high values.
natural width of gluino resonance << resolution of detector
Require at least six reconstructed jets.
Dalitz variables

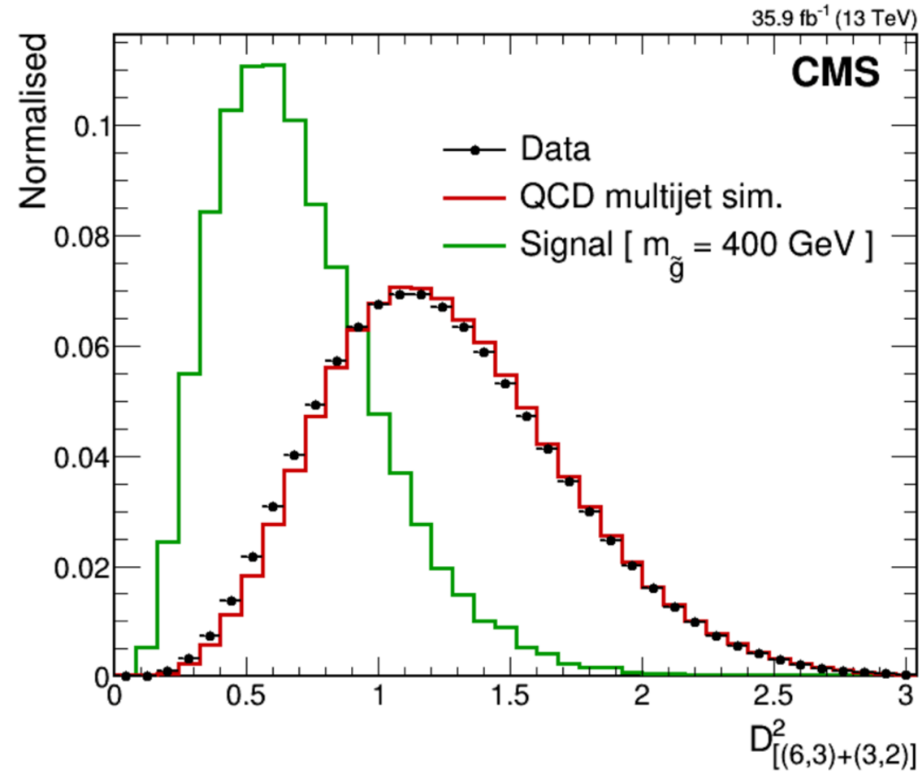
$$\hat{m}(3,2)^2_{ij} = \frac{m^2_{ij}}{m^2_{ijk} + m^2_i + m^2_j + m^2_k} \quad (\text{where } i,j,k \in \{1,2,3\}).$$





Tri-jet search

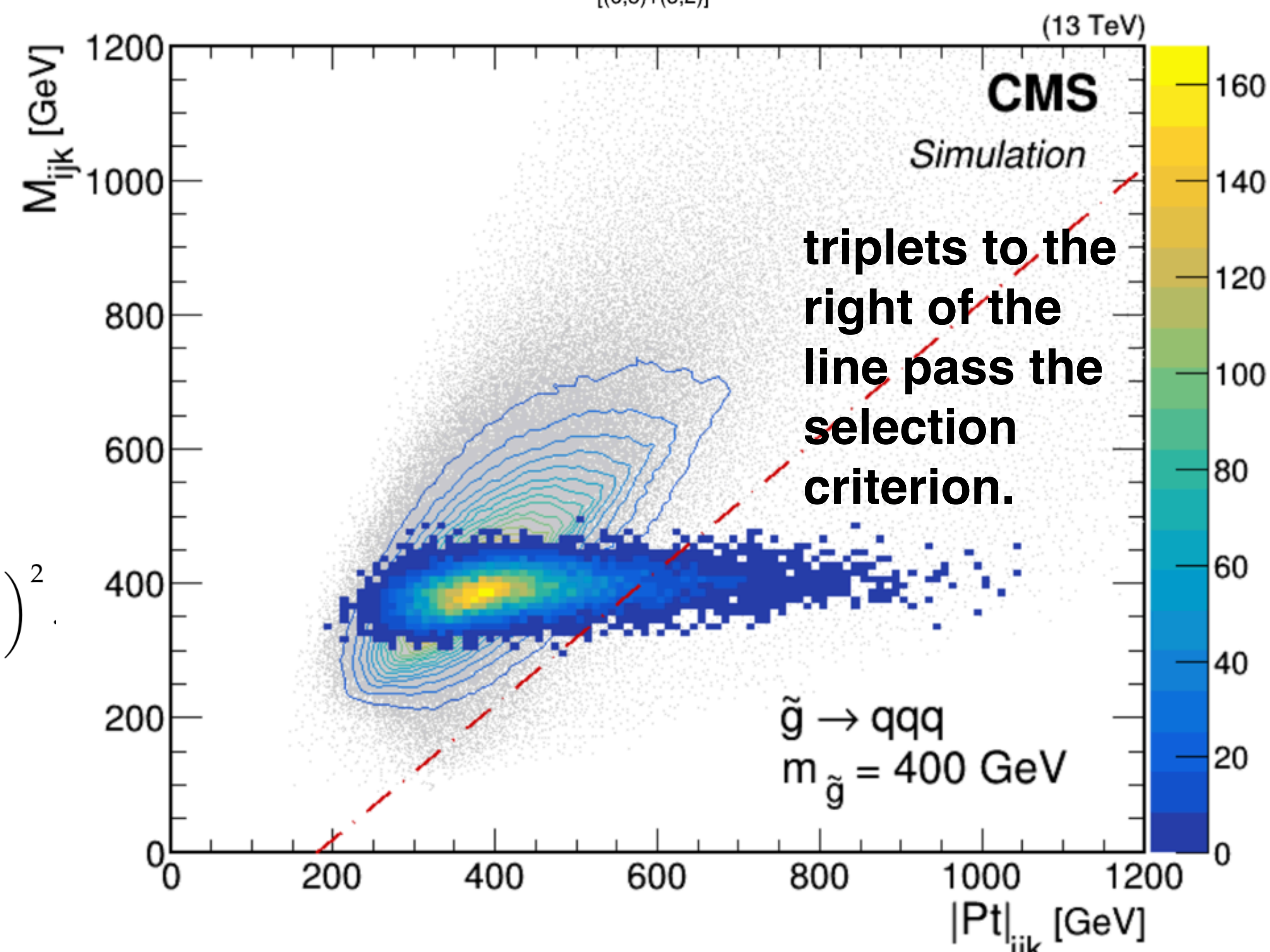




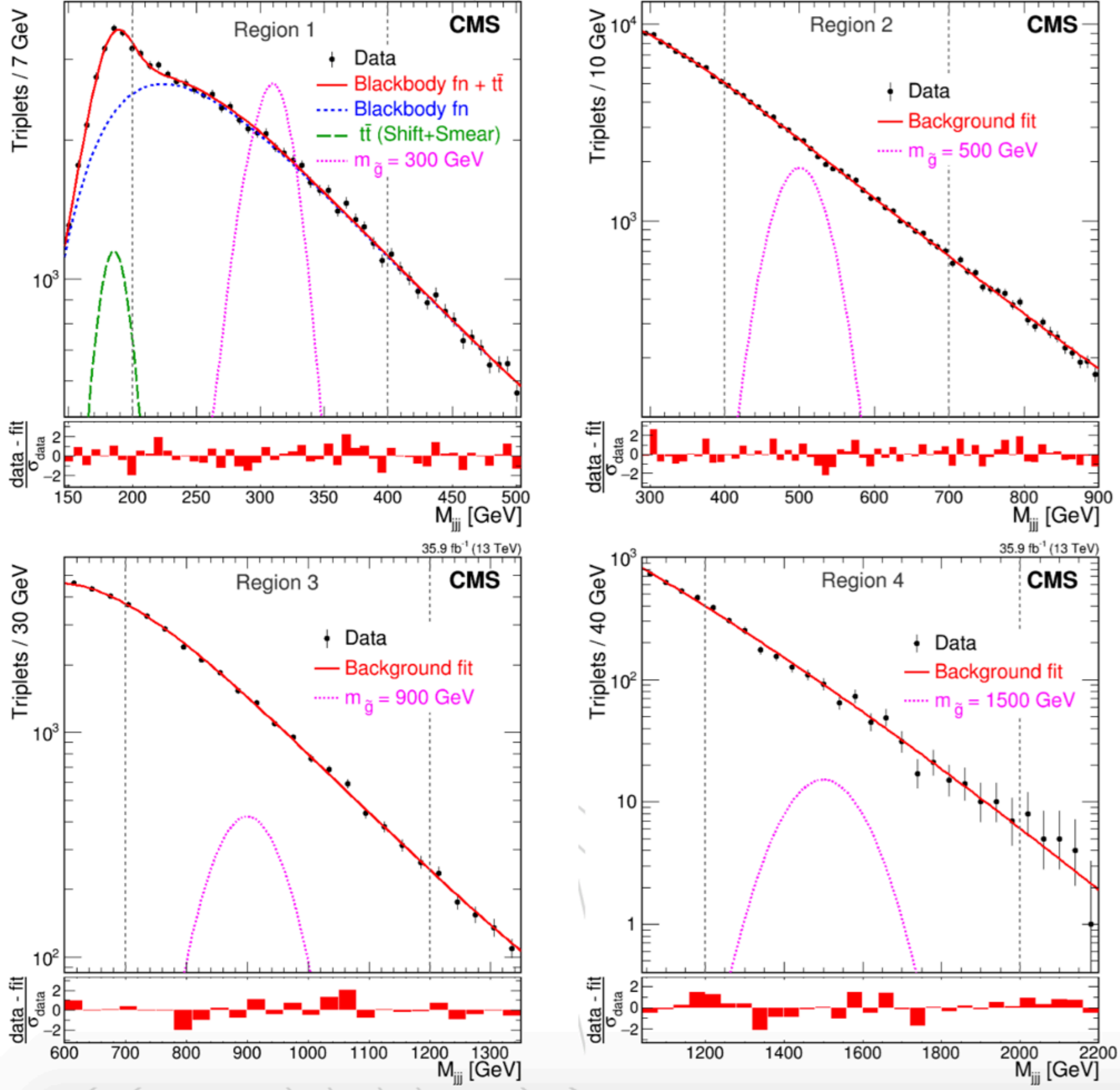
$$D^2_{[3,2]} = \sum_{i>j} \left(\hat{m}_{ij} - \frac{1}{\sqrt{3}} \right)^2 .$$

$$\hat{m}(6,3)^2_{ijk} = \frac{m^2_{ijk}}{4\; m^2_{ijklmn} + 6\; \sum_i m^2_i}$$

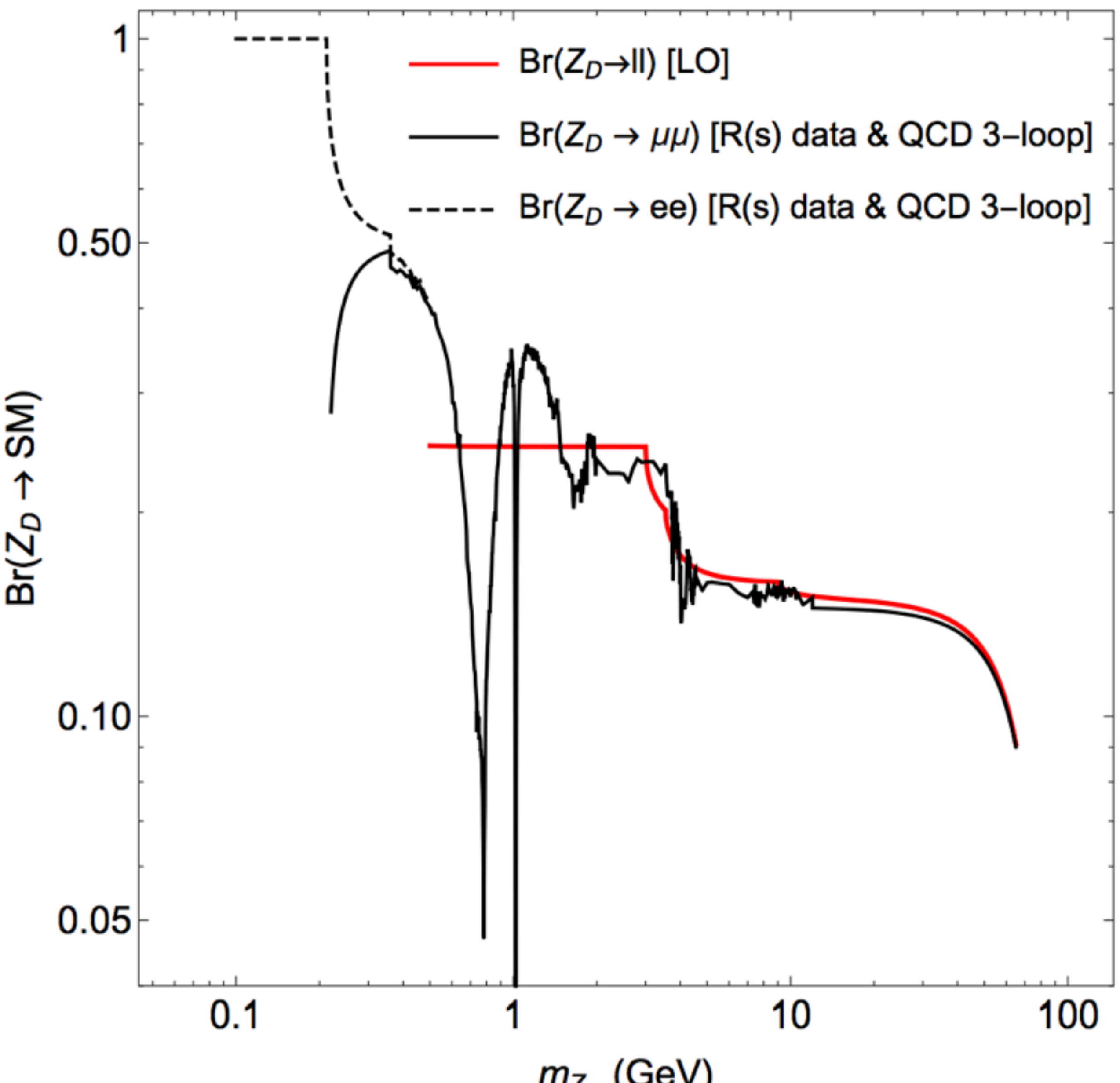
$$D^2_{[(6,3)+(3,2)]} = \sum_{i<j<k} \left(\sqrt{\hat{m}(6,3)^2_{ijk} + D^2_{[3,2],ijk}} - \frac{1}{\sqrt{20}} \right)^2 .$$

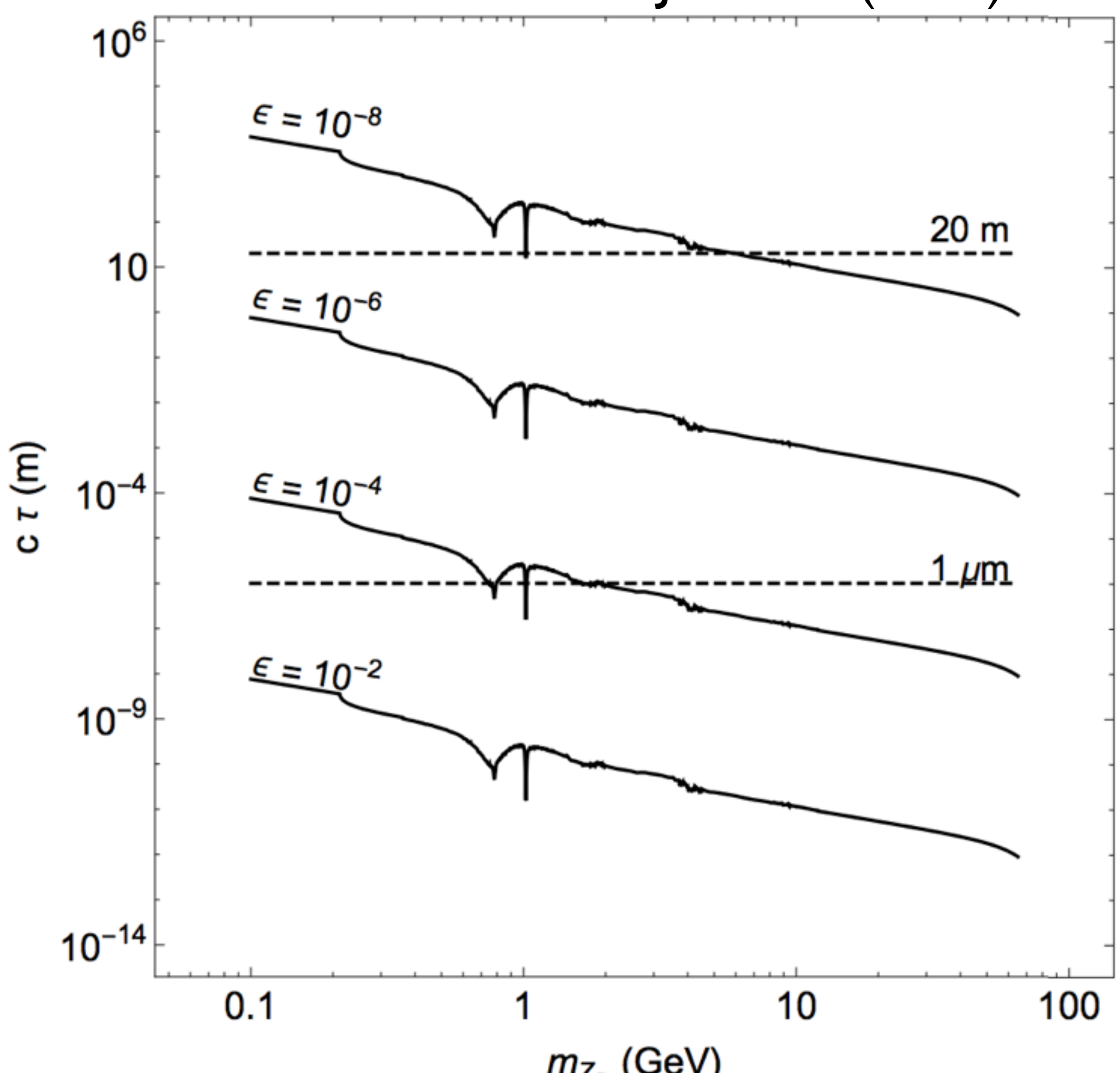


Tri-jet search



JHEP 02 (2015) 157





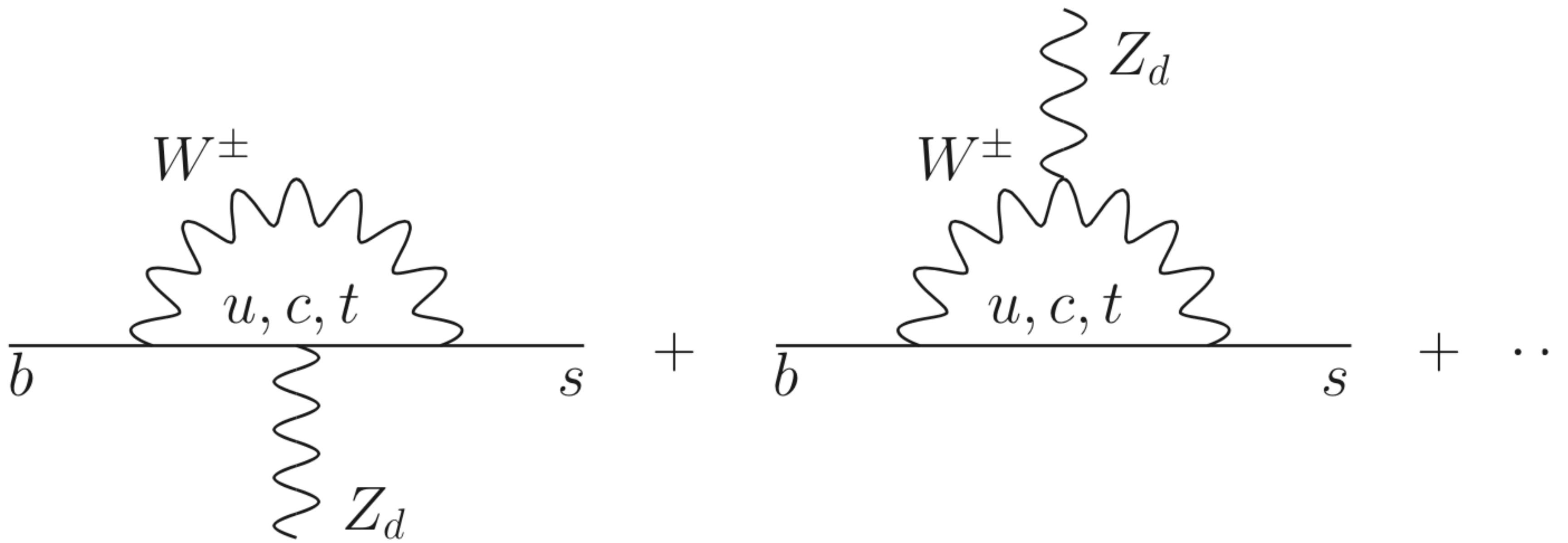
Sub-GeV hidden sector models

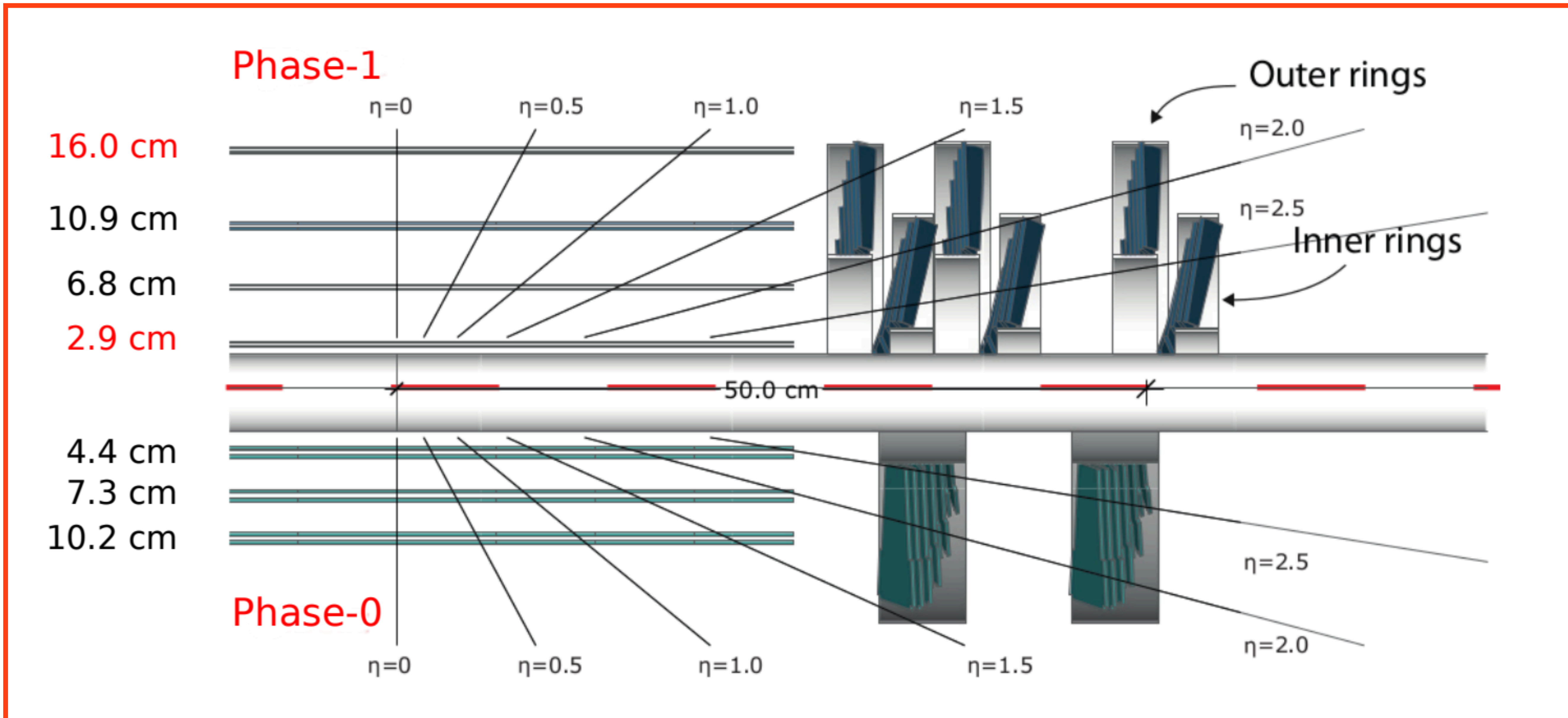
- $B^0 \to SS$ and $S \to \ell\ell$ (S: generic neutral state in hidden sector, can be LL)
- Multi-lepton Signatures of a Hidden Sector in Rare B Decays, B. Batell, M.Pospelov, and A. Ritz, PRD, arxiv0911.4938

Check sensitivity of rare flavour-changing decays from the generic standpoint of 'portal' operators. Analyze feasibility of searching for light states coupled to SM via these portals in Bmeson decays.

$H^\dagger H(AS + \lambda S^2)$	Higgs portal (dim $= 3, 4$),
$\kappa F^Y_{\mu\nu} F'_{\mu\nu}$	Vector portal (dim $= 4$),
$Y_N \bar{L} H N$	Neutrino portal (dim $= 4$),
$f_a^{-1} \bar{\psi}\gamma_\mu\gamma_5\psi\partial_\mu a$	Axion portal (dim $= 5$).

- Models featuring new $U(1)_d$ symmetry
  - Use $B\to K\ell^+\ell^-$ to place tight constraints on the size of Z-Z_d mixing. (Z_d: dark photon, can be LL)
  - "Dark" Z implications for Parity Violation, Rare Meson Decays, and Higgs Physics, H. Davoudiasl, H. Lee, and W. Marciano, PRD, arxiv1203.2947





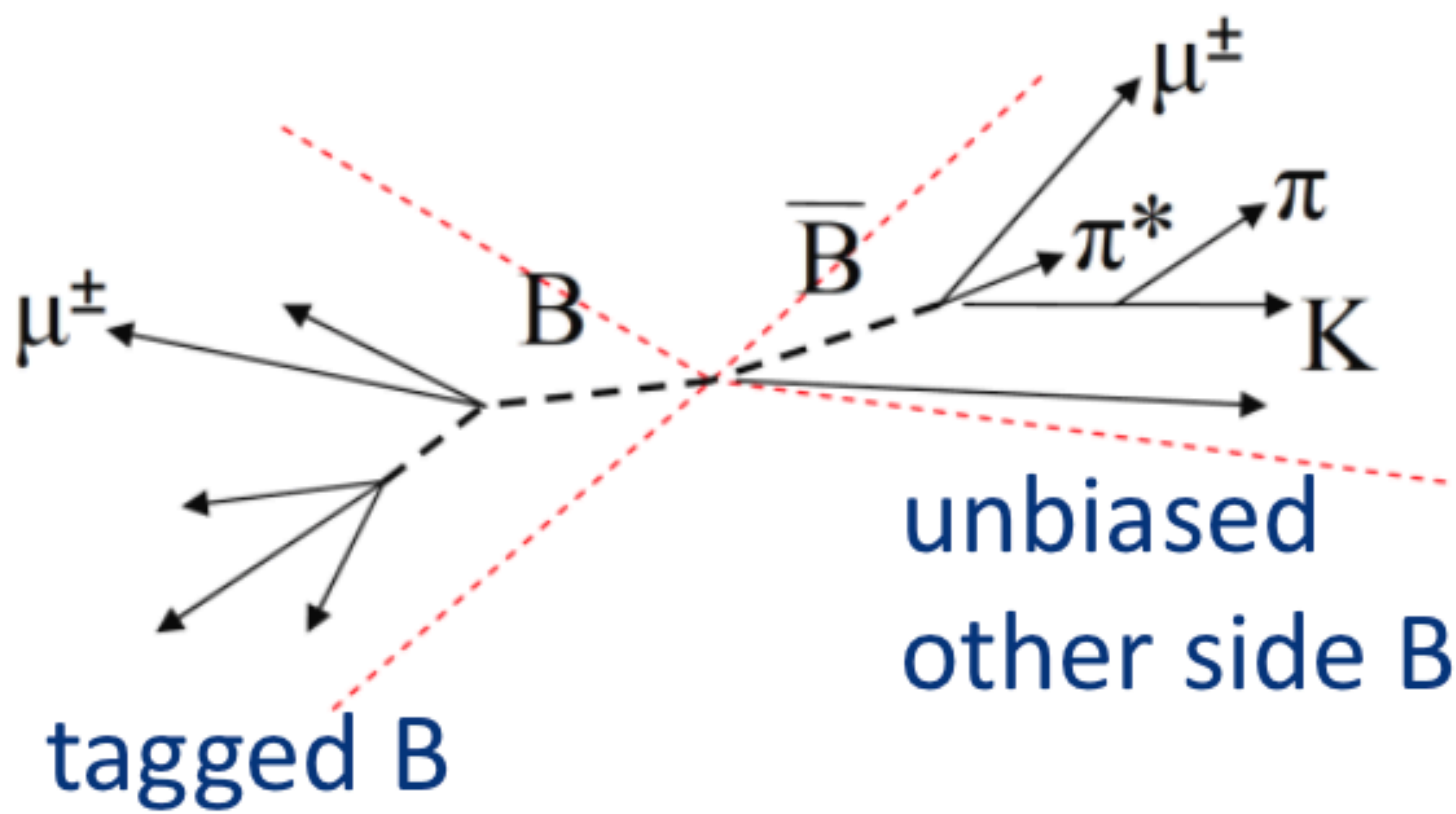
Phase-1
Outer rings
η=0
η=0.5
η=1.0
η=1.5
η=2.0
16.0 cm
10.9 cm
η=2.5
Inner rings
6.8 cm
2.9 cm
50.0 cm
4.4 cm
7.3 cm
10.2 cm
η=2.5
Phase-0
η=2.0
η=0
η=0.5
η=1.0
η=1.5

B Parking in CMS

Motivation: Study B anomalies. Can also be used also for other searches

Goal: Collect large (~10^{10} events) unbiased sample of B

Idea: Triggering on muon from B (tag), to collect unbiased B on the other side (probe)



Single copy, 2 kHz to DAQ