Perspective of ATLAS & CMS low-pT physics

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About this call

- I used to work on Flavor physics, but not since I left BaBar in 2007
- So, don't expect a review of recent Flavor results by ATLAS and CMS
- My contribution is more an ongoing effort, on what you will see around the end
- Thanks to those who are working on flavor @ATLAS and @CMS, who provided me with inputs and helped me preparing this talk
  - S. Malvezzi and M. Margoni from CMS
  - U. De Sanctis and J. Walder from ATLAS

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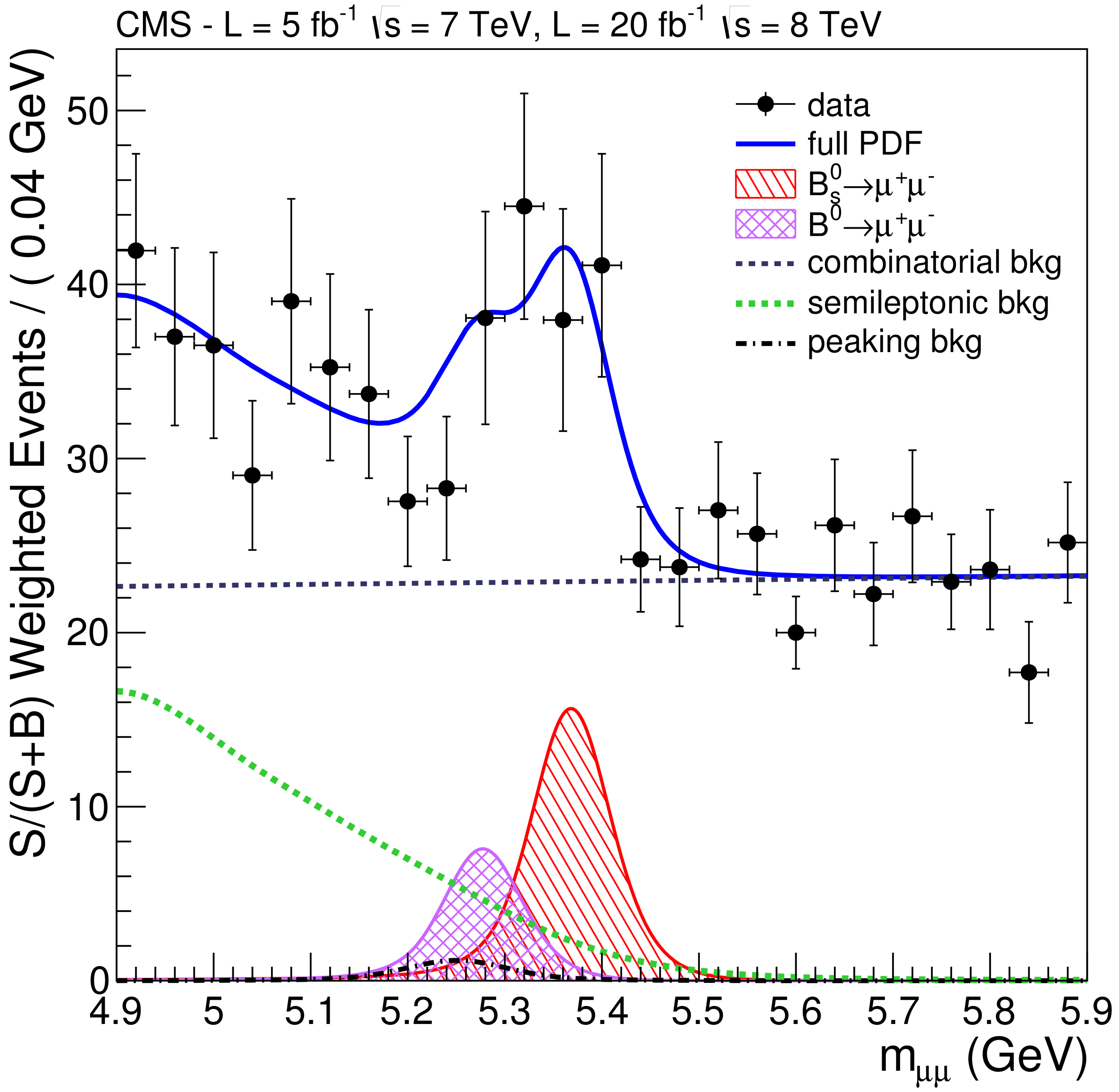
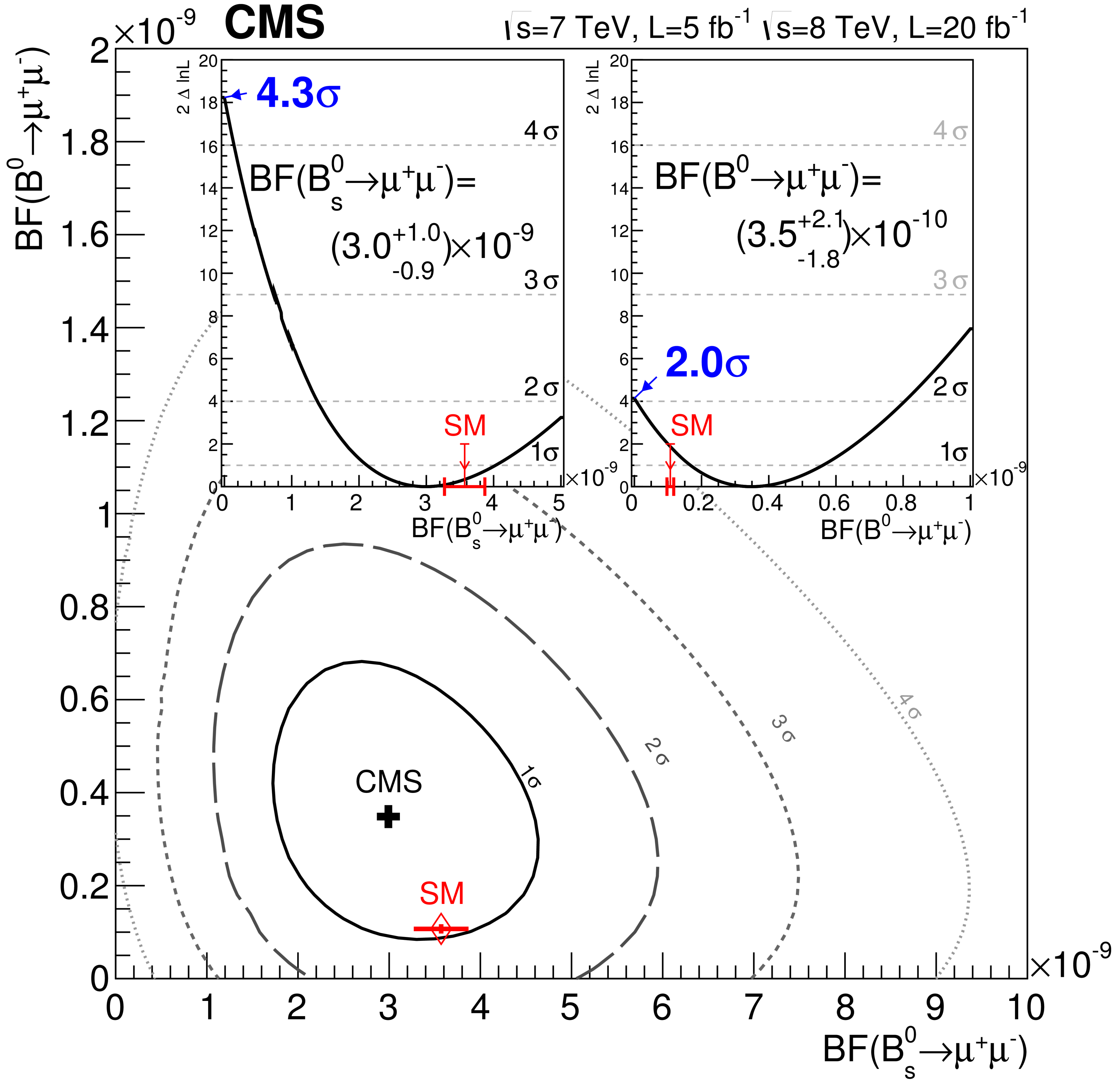
What was done so far

- *Flavor physics is part of ATLAS and CMS physics programs since day-0*
  - *Plans ahead of data taking to explore B(s) oscillations in all-tracks final states*
  - *Dedicated trigger for $B_{(s)} \rightarrow \mu\mu$ decays*
  - *$B \rightarrow K^* \ell\ell$ angular analysis*
  - *Plus many other topics (b production, spectroscopy, etc)*
- *About 15% of the bandwidth is allocated to B Physics*
- *Dedicated L1 soft-muon triggers to keep sensitivity with increased luminosity*

$B_s \rightarrow \mu\mu$ status & perspectives

- General purpose experiments can be competitive on favourable final states
  - Dimuon is the quintessence of low-pT experimental cleaners @LHC
- More statistics will allow to improve these results
- New trigger functionalities (e.g., tracking @L1) will allow to deal with 200 PU





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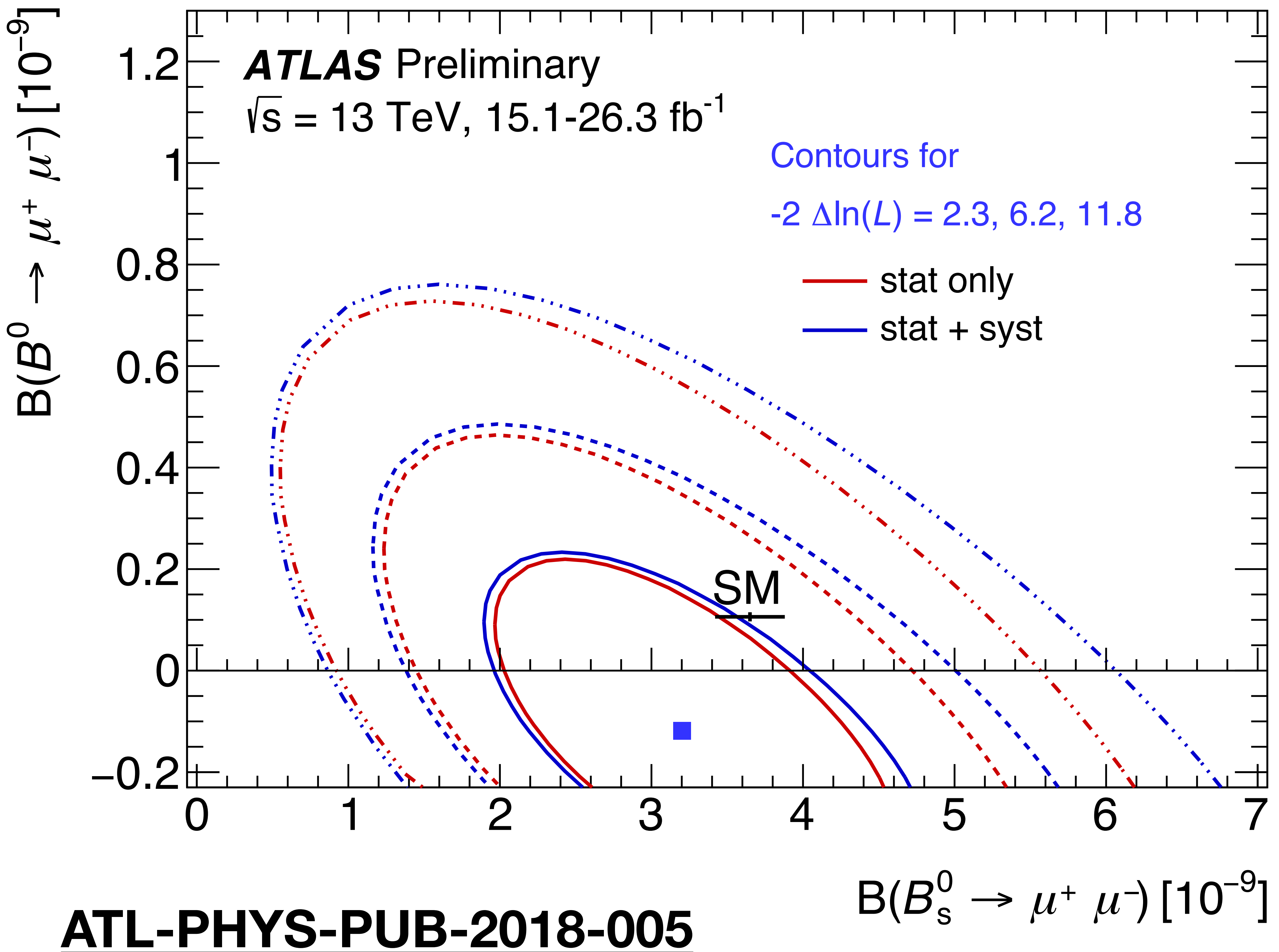

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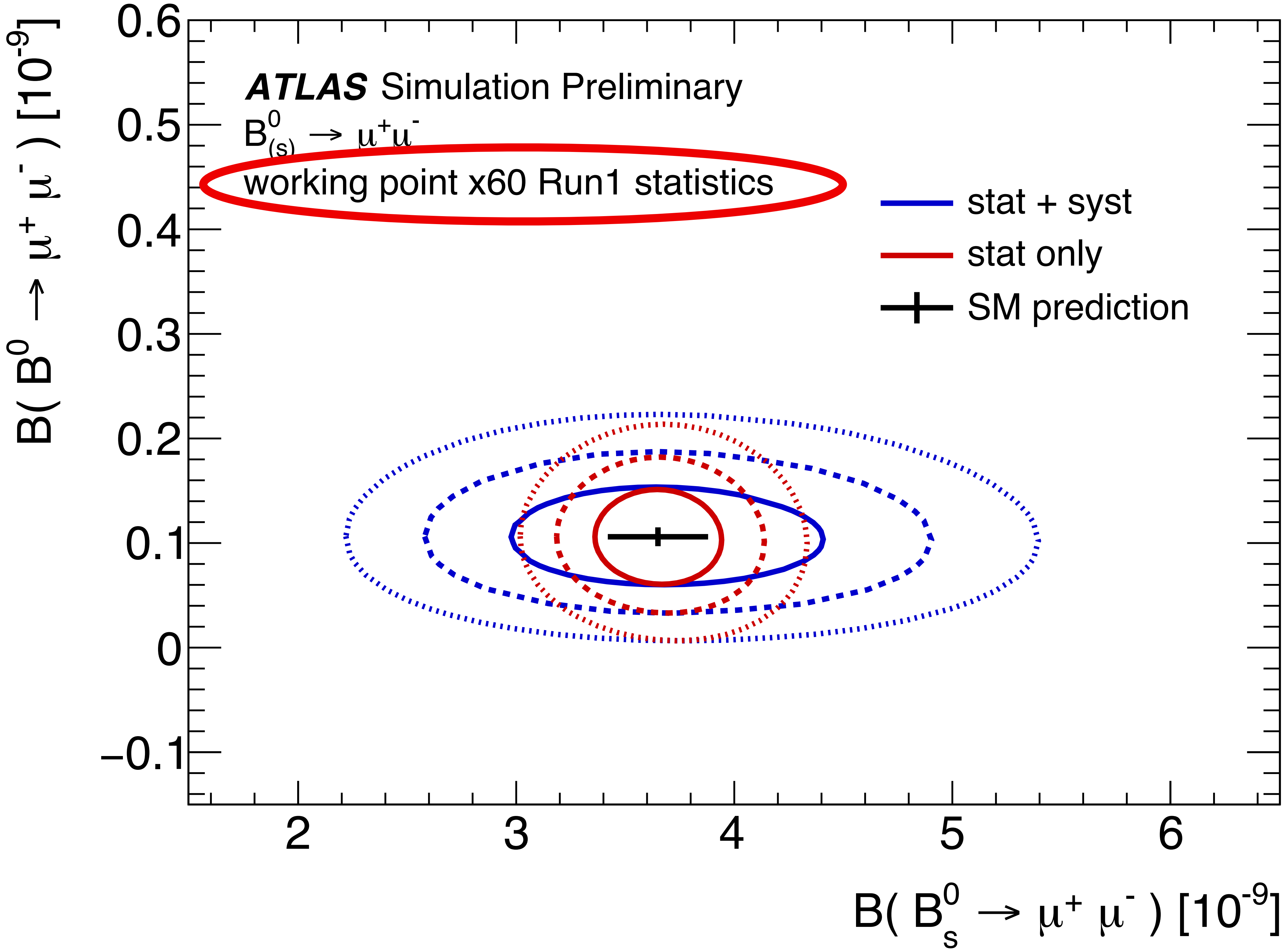

Going beyond

Why can't ATLAS & CMS do as much as LHCb?

- *Detector limitation: experiments designed to do something else, namely cover 10-1000 GeV range. Going below 10 GeV (e.g., with electrons and muons) requires effort*
  - *This is where the problem is today and the work has to go*
- *Limited trigger bandwidth (general purpose vs. dedicated experiments)*
  - *New ideas are opening new opportunities. Not the biggest problem today. More about this later*
- *Needed customisation (reconstruction, trigger, etc.) vs working force (<50 people)*
  - *Clearly, growing interest in flavor (thanks to LHCb anomalies) is helping here. Still, there is much to do in view of HL-LHC*

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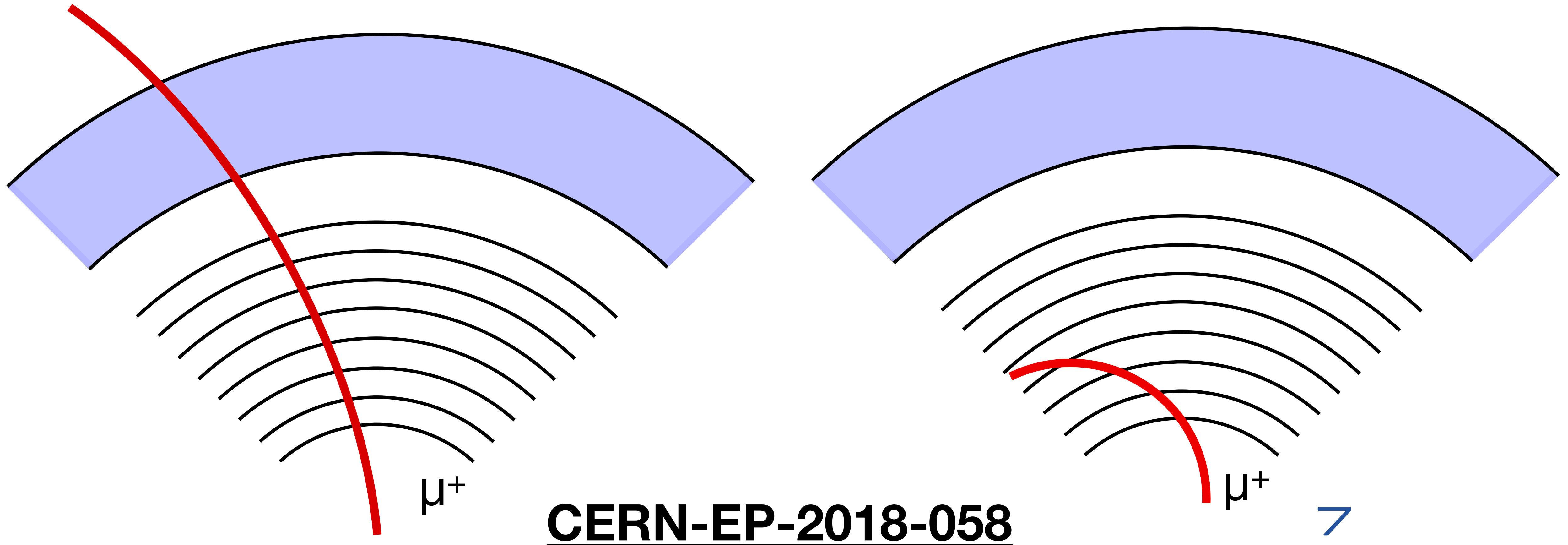
Muon Reconstruction

- Muons are most friendly low-pT objects (good resolution + cleanness)
  - Dedicated L1 triggers in place for low-pT dimuon systems (not easy with electrons)
  - Established sensitivity to low-mass resonances, etc.
- Muons are the essential handle for Flavor physics in ATLAS & CMS



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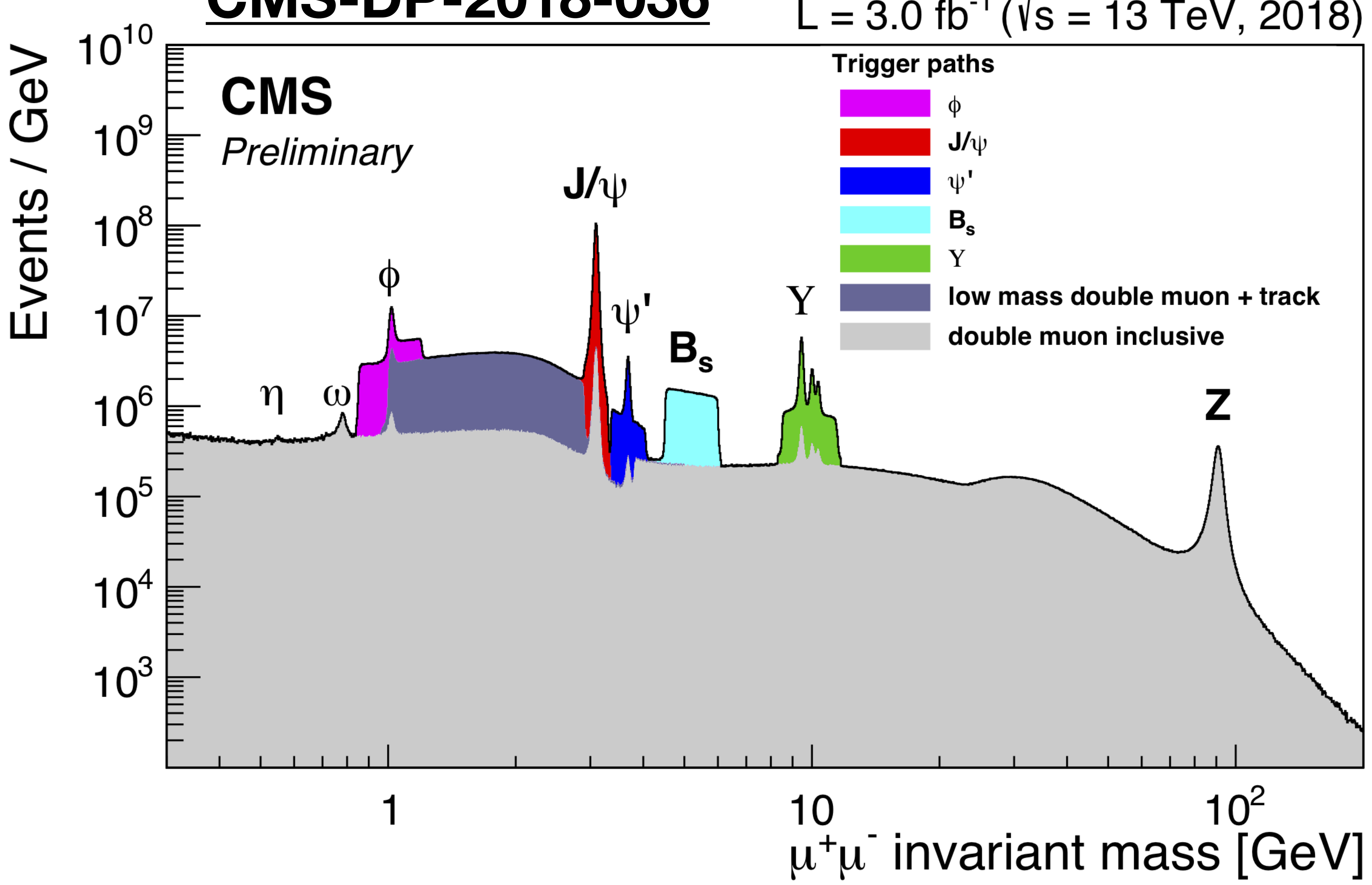
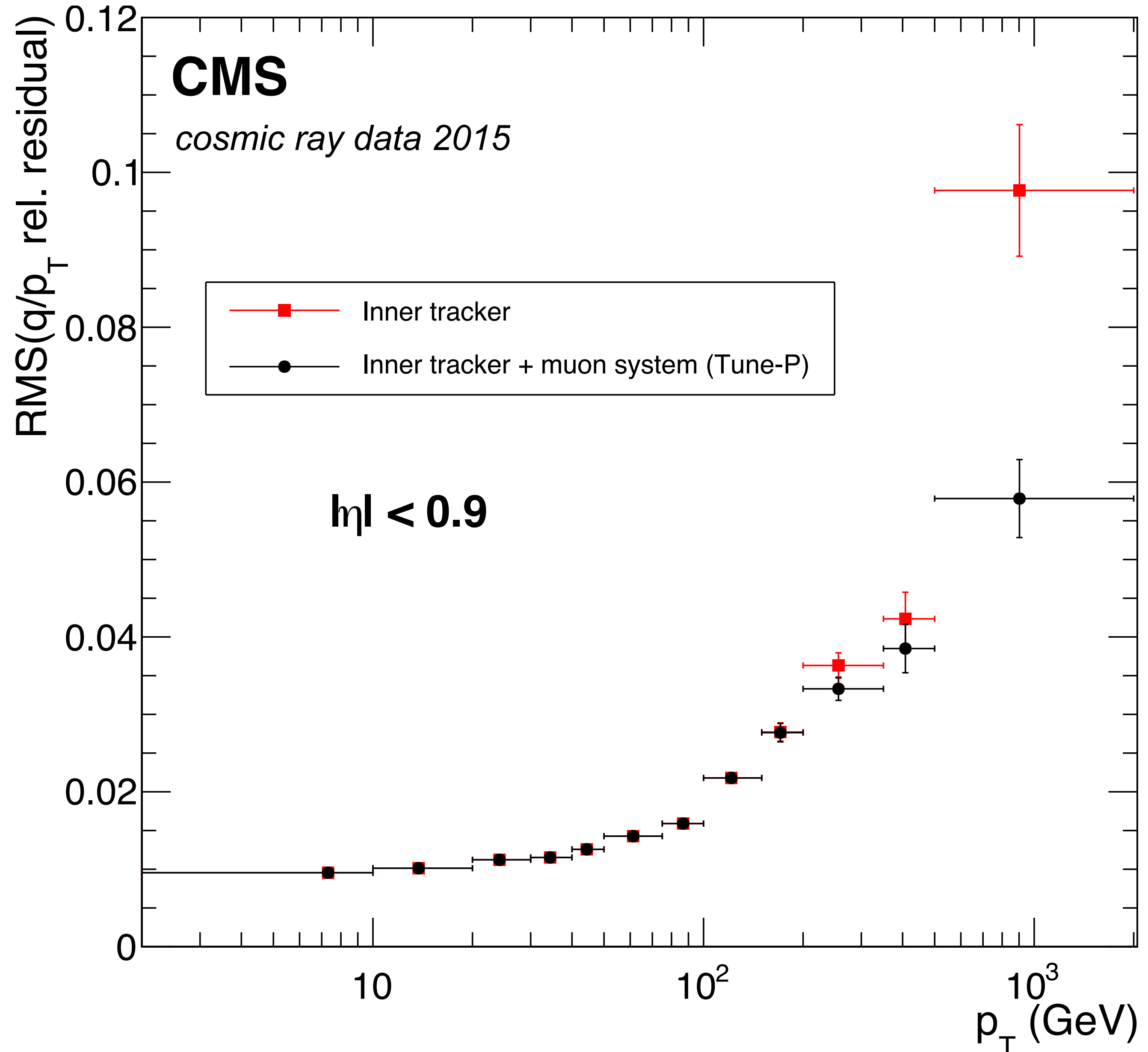
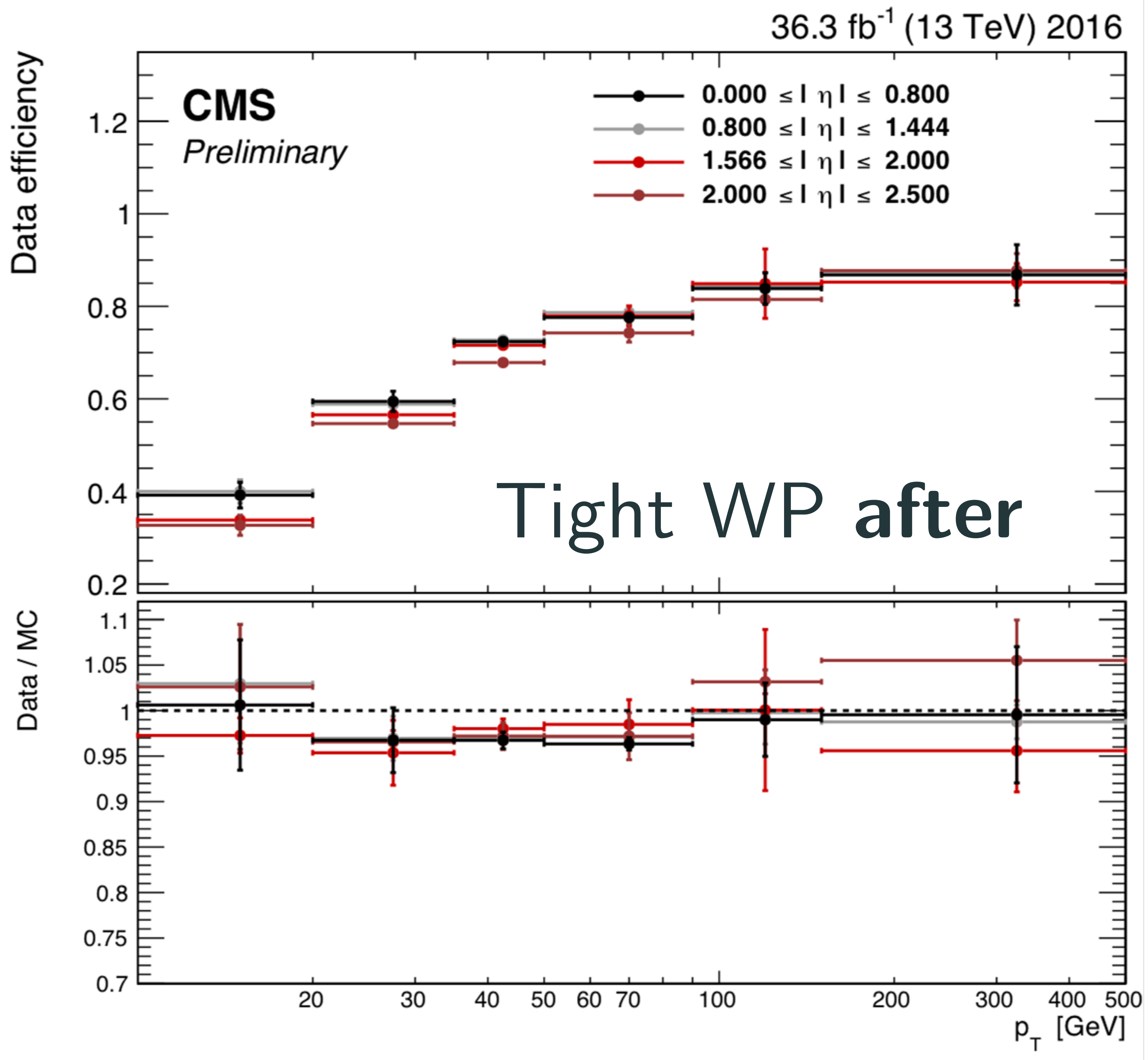
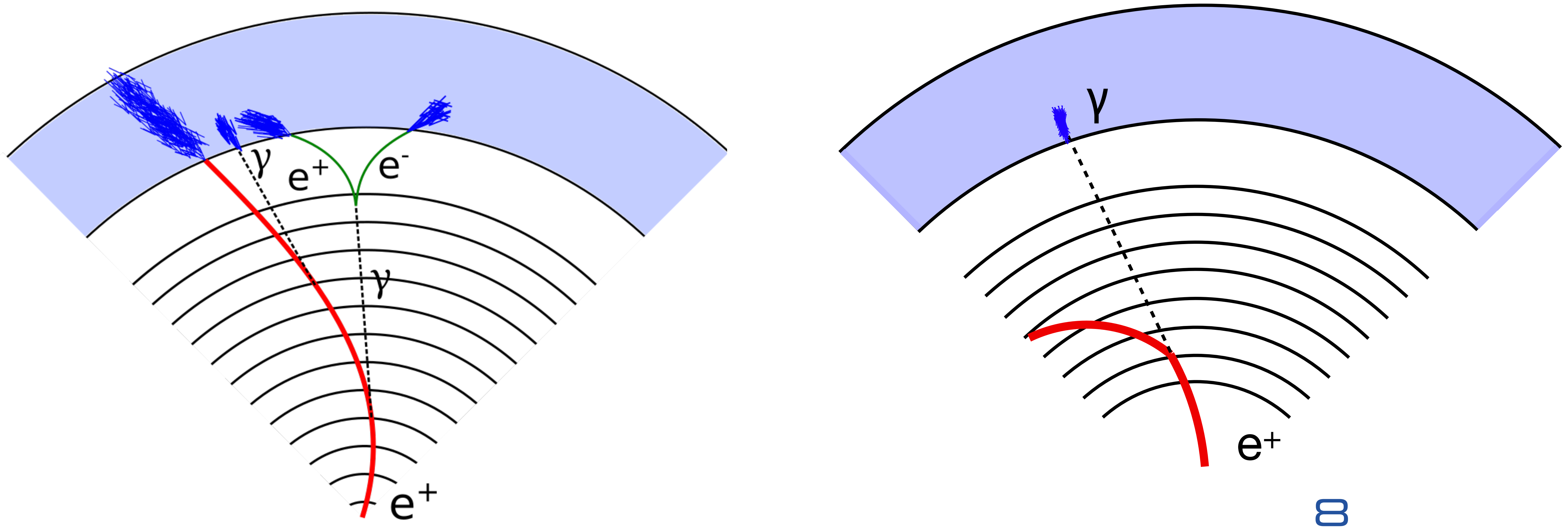




Electron Reconstruction

- *Electron reconstruction at ATLAS & CMS is about matching a track to >= 1 ECAL deposit*
- *At low pT, the track might not even make it to ECAL*
- *At low pT, ECAL deposits are very low-energetic: difficult to disentangle them from noise, pileup, etc*

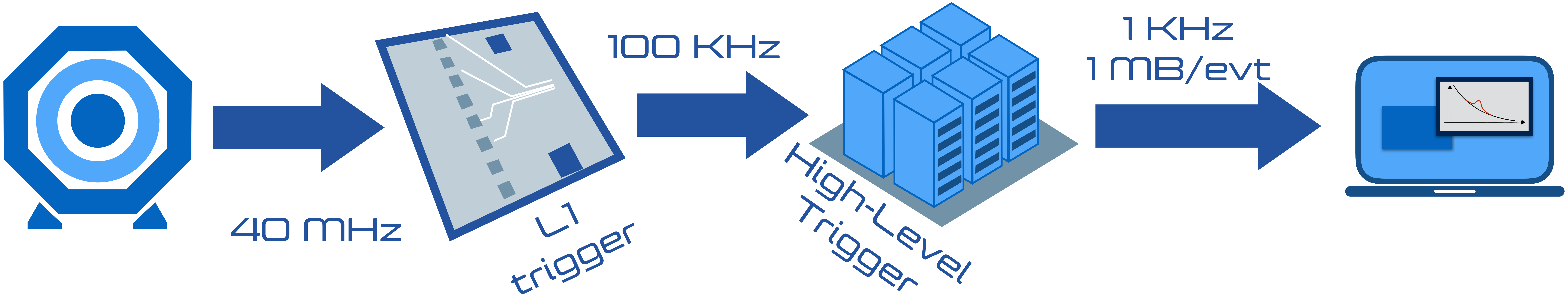




More info at this link

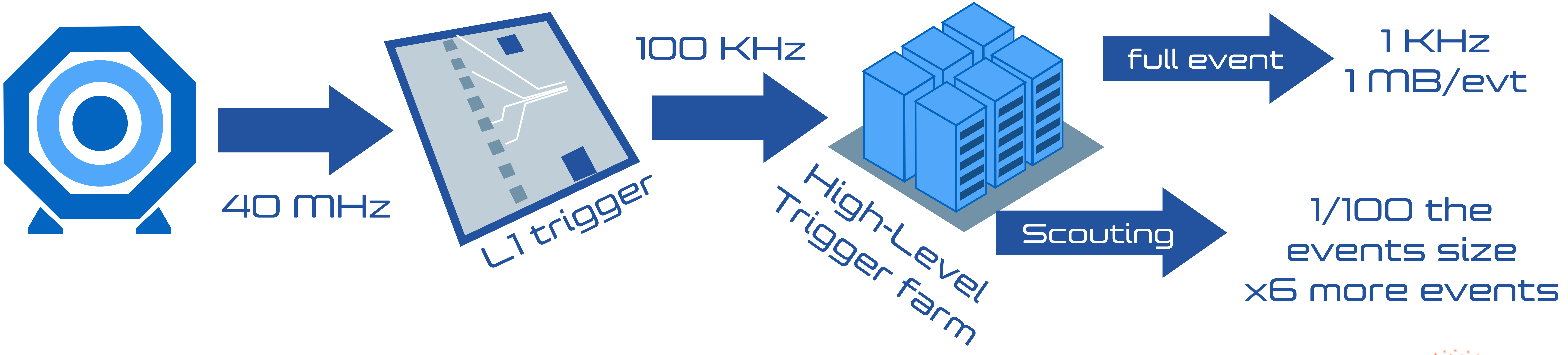
The trigger bottleneck

- *The first limitation for extensive B-physics program is collecting the events*
  - *CMS & ATLAS store 1000 evt/sec. About 15% are dedicated to B physics*
- *One cannot increase this fraction (i.e., sacrificing Higgs, EW, QCD, and BSM high-pT physics)*



“New ideas”: Scouting

- Since 2010, CMS is taking special “scouting” streams:
  - Run reconstruction in trigger farm (muons, jets, …)
  - Write object features (e.g., four momenta) rather than the full event
  - Few KB traded for 1 MB: can write thousands more
- Same paradigm now by ATLAS (TLA), LHCb (TurboStream + upgrade) and ALICE



"New ideas": parking

- *Limitation to write 1000 evt/sec is not the trigger itself*
- *The problem is computing resources downstream*
  - *Disk & CPU power*
- *In 2012, both ATLAS&CMS took more data, counting on shutdown computing pledges & opportunistic computing resources to process them*

- Extra **300-350 Hz of "parked" data** are collected to **extend the physics program:** standard model measurements and searches for new physics
- The triggers defining the parked datasets are either a looser version of the core physics triggers (for instance with reduced p_T thresholds on the reconstructed objects) or brand-new triggers with small overlap with the rest
- These data are temporarily "parked", waiting to be reconstructed towards the end of the 2012-13 data taking (or earlier, if computing resources are available)
- This provides a complementary set of collision events to perform new physics analyses or improve the existing ones (thanks to the increased acceptance) during the 2013-14 LHC shutdown

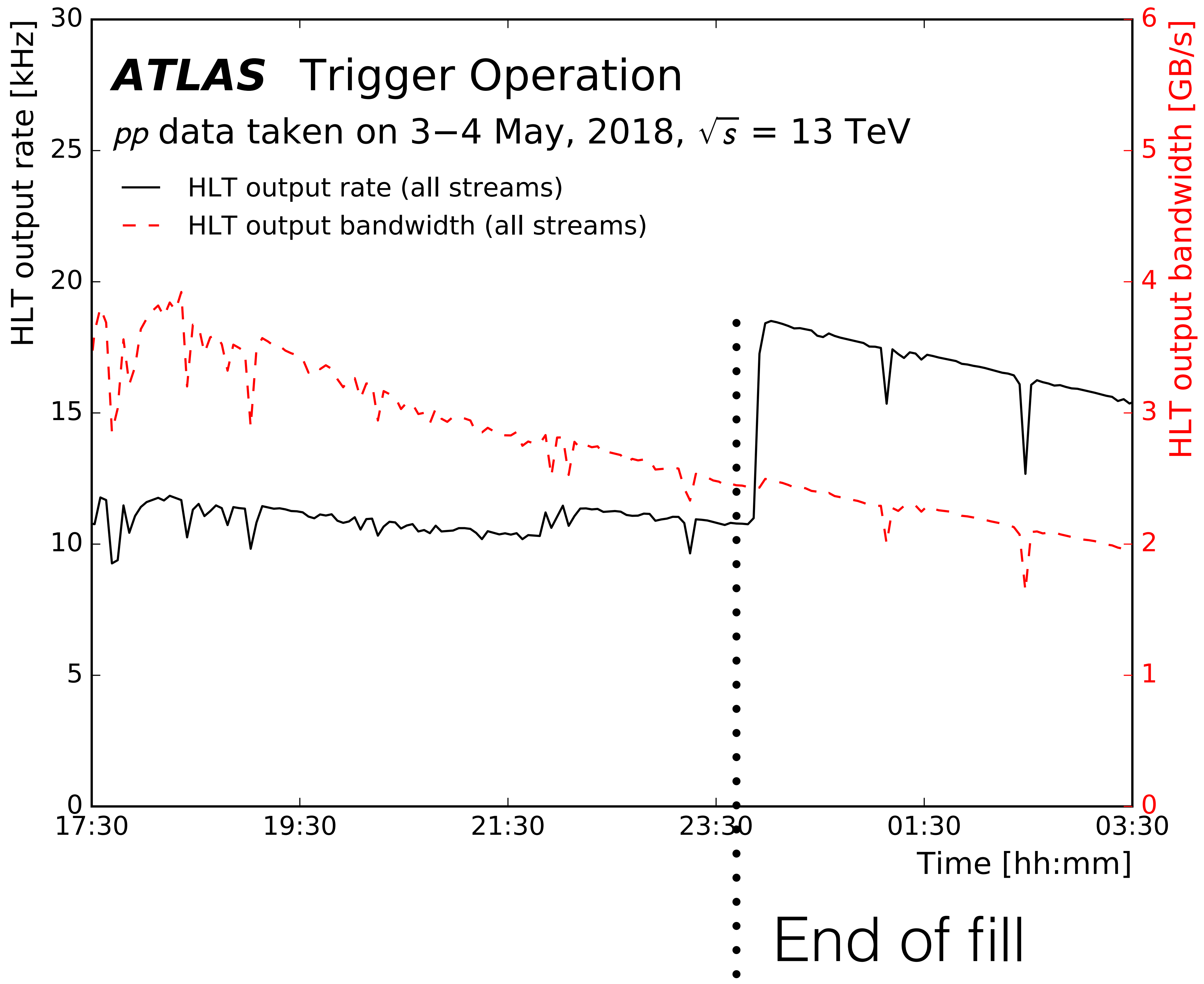
Trigger Selection for Data Parking	Main Physics Motivation	Average Rate (Hz) over typical LHC fill	Tighter / complementary version in the "core" trigger menu
M_{jj}>650 GeV , $\|\Delta\eta_{jj}\|$>3.5	Generic final state produced via Vector Boson Fusion (VBF)	130	QuadJet75_55_38_20: 1 b-jet + 2 "VBF" jets
At least 4 jets with p_T>50 GeV (QuadJet50)	Pair production of stops → top (hadronic decay) + neutralino in models with small mass splitting between stop and neutralino	75	QuadJet60 + DiJet20 OR QuadJet70
R^2*M_R>45 GeV + R^2>0.09	Extend SUSY hadronic searches with "razor" variables (M_R,R^2): compressed mass spectra and light stop searches	20	R^2*M_R>55 GeV + R^2>0.09 + M_R>150 GeV
H_T>200 GeV , α_T>0.57	Extend SUSY hadronic searches with α_T variable	10	H_T>250 GeV , α_T>0.55 H_T>250 GeV , α_T>0.57 H_T>300 GeV , α_T>0.53 H_T>350 GeV , α_T>0.52 H_T>400 GeV , α_T>0.51
Dimuon: $p_T(\mu_1)$ > 13 GeV , $p_T(\mu_2)$ > 8 GeV	PDF constrains using Drell-Yan events at low $M_{\mu\mu}$	10	$p_T(\mu_1)$ > 17 GeV $p_T(\mu_2)$ > 8 GeV
DiTau: $p_T(\tau_{1,2})$ > 35 GeV, $\|\eta(\tau_{1,2})\|$<2.1, isolation, $N_{trk}(\Delta R<0.15)$<5	Include 3-prong tau decays. h→ττ measurements: i.e. spin, parity, CP measurement	25	1-prong decay (N_{trk}<3) OR "same" but $p_T(\tau_{1,2})$>30 GeV + 1 jet p_T>30 GeV

Trigger Selection for Data Parking	Main Physics Motivation	Average Rate (Hz) over typical LHC fill	Tighter / complementary version in the "core" trigger menu
$\mu^+\mu^-$: $p_T(\mu\mu)$>5 GeV, $\|y(\mu\mu)$<2.5$\|$, ΔR<2 , $m_{\mu\mu}\approx m_{\Psi'}$→[3.35,4.05] GeV	Quarkonium physics (polarization, χ_c, χ_b, exotic states, etc..)	5	Dimuon triggers $p_T(\mu_{1/2})$ > 17/8 GeV (high p_T Ψ')
$\mu^+\mu^-$: $p_T(\mu\mu)$>8 GeV, $\|y(\mu\mu)$<2.5$\|$, ΔR<2 , $m_{\mu\mu}\approx m_{J/\Psi}$ →[2.8,3.35] GeV	As above	35	Dimuon triggers (high p_T J/Ψ) or displaced triggers for J/Ψ from B decays
$\mu^+\mu^-$: $p_T(\mu\mu)$>5 GeV, $\|y(\mu\mu)$<2.5$\|$, ΔR<2 , $m_{\mu\mu}\approx m_{\Upsilon}$ →[8.5,11.5] GeV	As above	10	$p_T(\mu^+\mu^-)$>7 GeV
$\mu^+\mu^-$: $p_T(\mu)$>3.5 GeV, $\|\eta(\mu)$<2.2$\|$, $p_T(\mu\mu)$>6.9 GeV, displaced vertex wrt beam, $m_{\mu\mu}$ = [1.0,4.8] GeV	Rare B decays with low mass dimuons (displaced)	20	$p_T(\mu)$>4 GeV $m_{\mu\mu}\approx m_{J/\Psi}$ →[2.9,3.3] GeV
1 jet + 1 muon: p_T(jet)>20 (60) GeV, $p_T(\mu)$>4 GeV, $\Delta R(\mu$,jet)<0.4 *Prescale = 300 (30)*	Select unbiased sample of signal (hadronic decays of D's, B's) using the recoil of a triggered b-jet	10 (5)	2 jets + 1 muon: p_T(jet)>20,40,70 GeV $p_T(\mu)$>5 GeV, $\Delta R(\mu$,jet)<0.4 , larger prescale

CMS-DP-2012/022

ATLAS data taking in 2018

- After few hours of collisions, L1 rate and HLT processing slots free up thanks to luminosity exponential decay
- High-rate and CPU-intensive triggers can be enabled within the data storage output limitation
- Strategy is used for the Trigger-level Analysis (ATL-DAQ-PUB-2017-003)
  - tiny event size with only information on HLT jets, collected by low-pt single jet trigger at an HLT rate up to 13 kHz when luminosity is below 1.0×10^{34}
  - total HLT output bandwidth is only marginally increased by these additional events
- End-of-fill strategy used for triggers for B-physics signals (high processing power needed)



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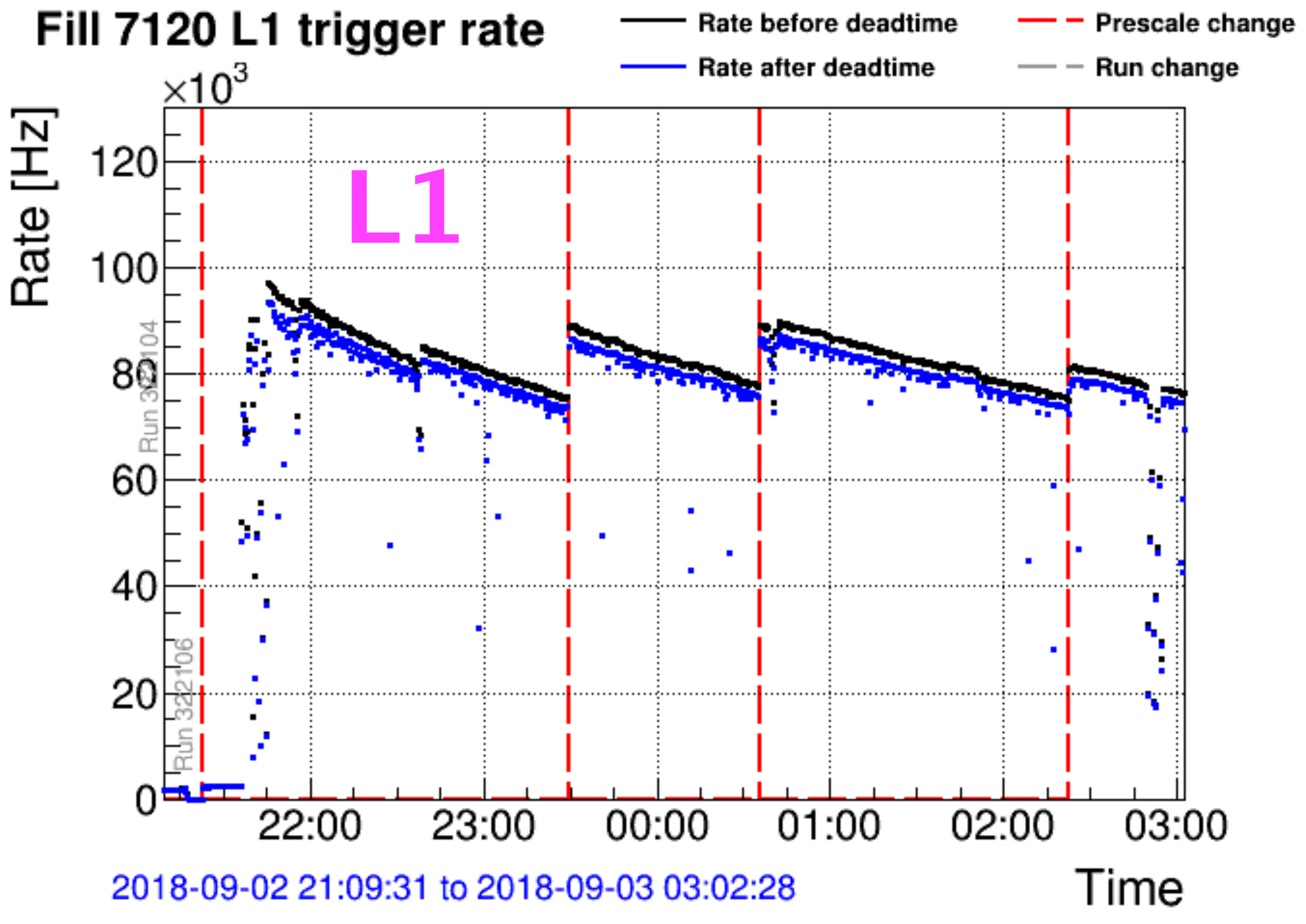
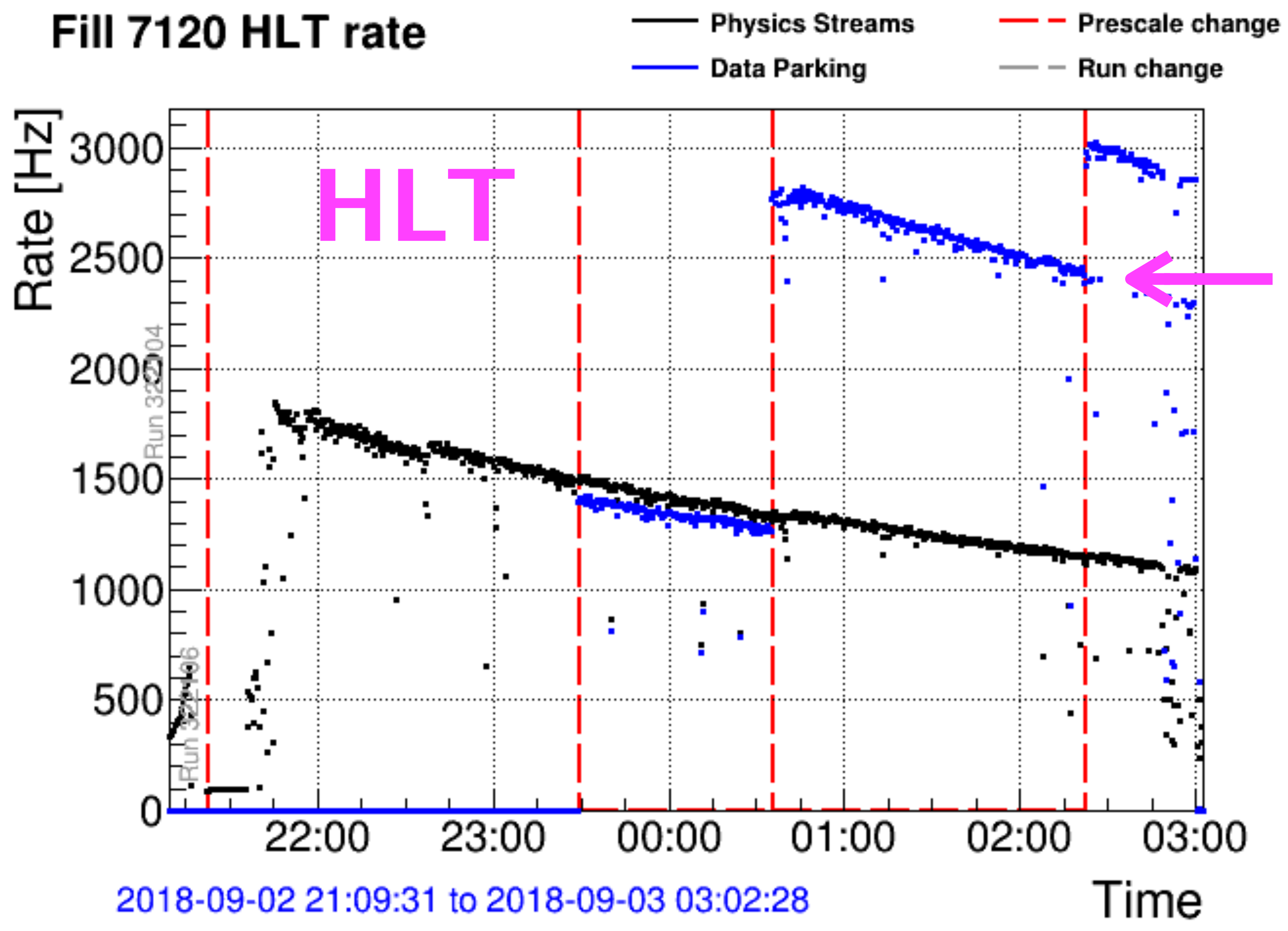
CMS data taking in 2018

- Smooth running – only minor updates to trigger have been implemented.
- **L1 trigger** rate reaching **95 kHz** at 2×10^{34} cm^{-2} s^{-1}
  - We been able to lower L1 thresholds for single Egamma, MET, di-tau to improve HLT turn-on curves.
- **HLT** rate reaching **1.8 kHz** at 2×10^{34} cm^{-2} s^{-1} – averaging 1.1 kHz over 12h fill
- We are **"parking" an unbiased sample of B mesons** for future analysis
  - rates reach 5 kHz, so far we have recorded over 9B events.





data parking

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Conclusions

- B physics is a relevant part of CMS and ATLAS physics program, but it's not all of it
  - Limited resources, small number of people involved, detectors mostly designed to do something else
- LHCb anomalies are raising interest and new ideas are emerging
  - Take more data (online processing + delayed reconstruction)
  - And figure out what to do with them