New Results from Searches for New Physics at CMS

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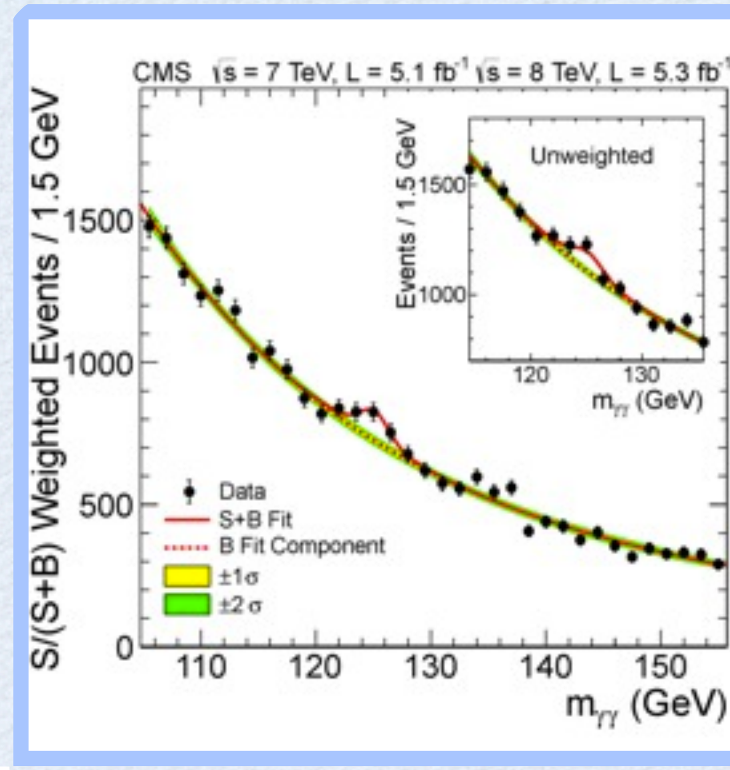
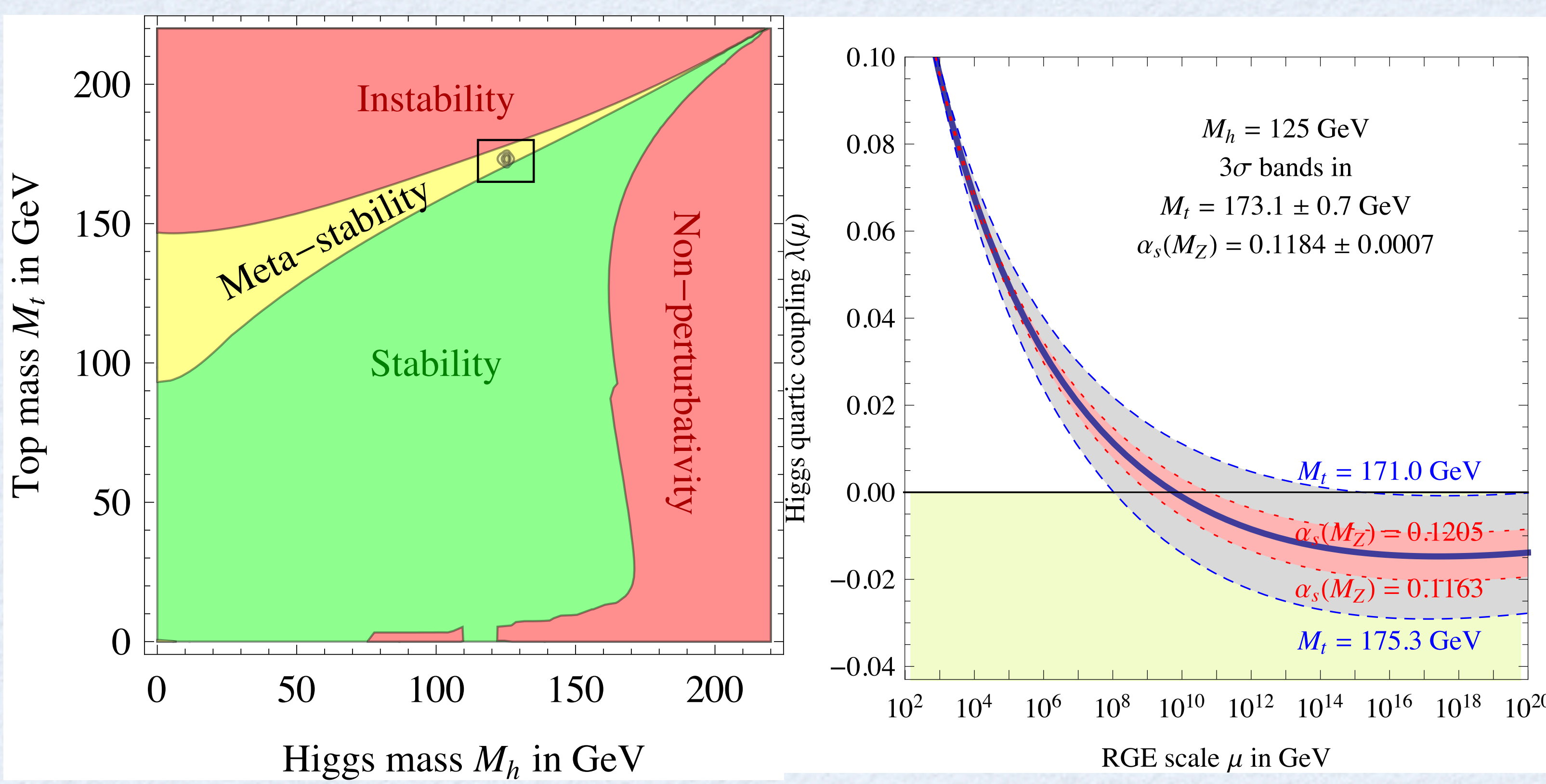
The Newcomer

- A Higgs-like boson was found, close to the lower bound of the Higgs allowed mass range
- Not too heavy (eg for SUSY), but not that light
- Quite a special value. Do we live in a metastable vacuum? Is the quartic coupling zero @Plank scale?





- If this is the end of the story, there is no happy ending... And we don't like that ...

Degrassi et al. arXiv:1205.6497

Go Natural?

the Higgs couplings (signal strength & BRs) could deviate from SM

If New Physics has something to do with making the Higgs light, we expect it @ TeV scale

- **Natural SUSY**

  light stop & sbottom, direct or via gluino decays

- **Extra dimensions (ADD, RS++)**

  high-mass KK partners (eg RS graviton to VV, $\ell\ell$, top pairs, etc)

- **Compositeness**

  exotic top partners lighter than 1 TeV

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OR LIVING UNNATURAL?

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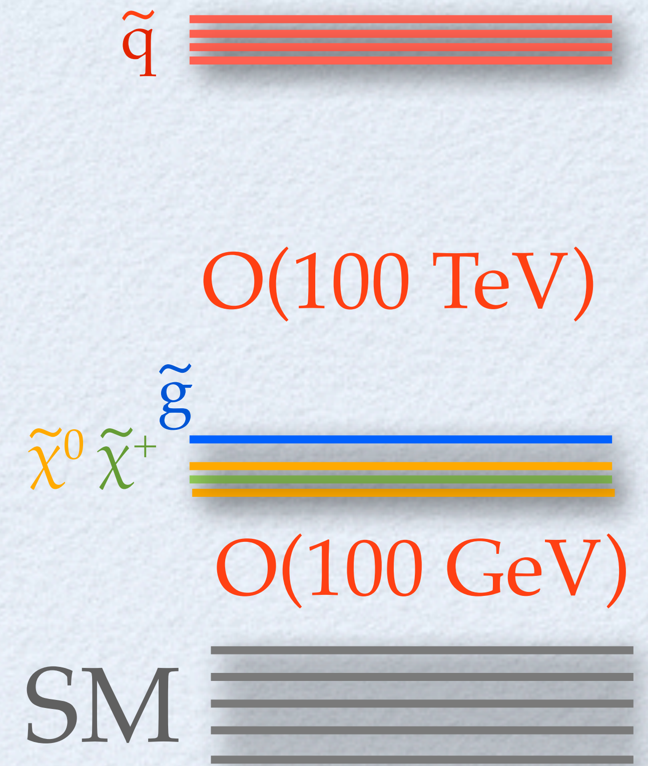
If New Physics has nothing to do with making the Higgs light, we still expect it to give a DM candidate, and possibly unification



- **Split SUSY**

  long-living particles, stopping gluinos, displaced vertices

- **Standard Model**

  We will keep setting limits on new physics for a while

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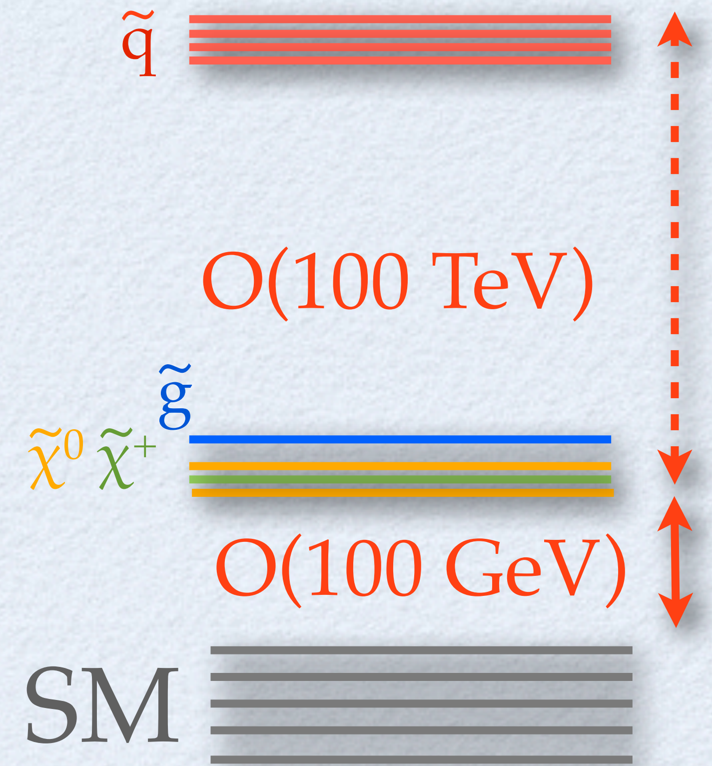

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Natural SUSY Search: multi(b)jet+MET

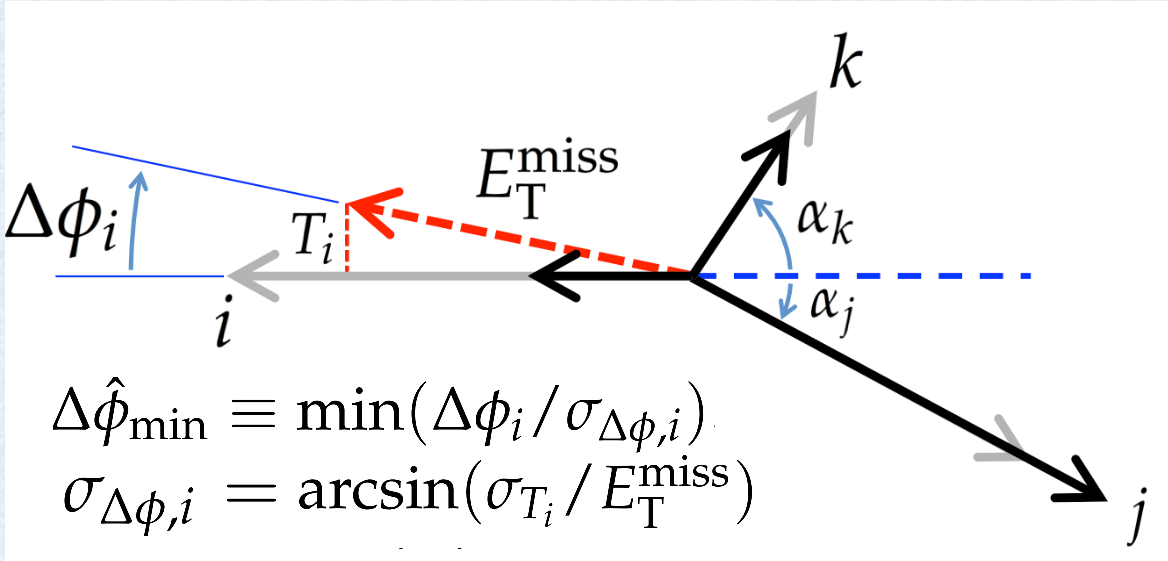
19 fb-1

MULTI(B)JET+MET SUS-12-024

- Hadronic search for SUSY in multijet+MET events with btags

Event Selection

≥ 3 jets with pT > 50 GeV and |η| < 2.4, ≥1 bjet,
≥2 jets with pT>70GeV
Muon & Electron veto (pT > 10 GeV)
Isolated track veto (pT > 15 GeV)
$\Delta\hat{\phi}_{min}$ > 4.0 (sideband used for QCD)



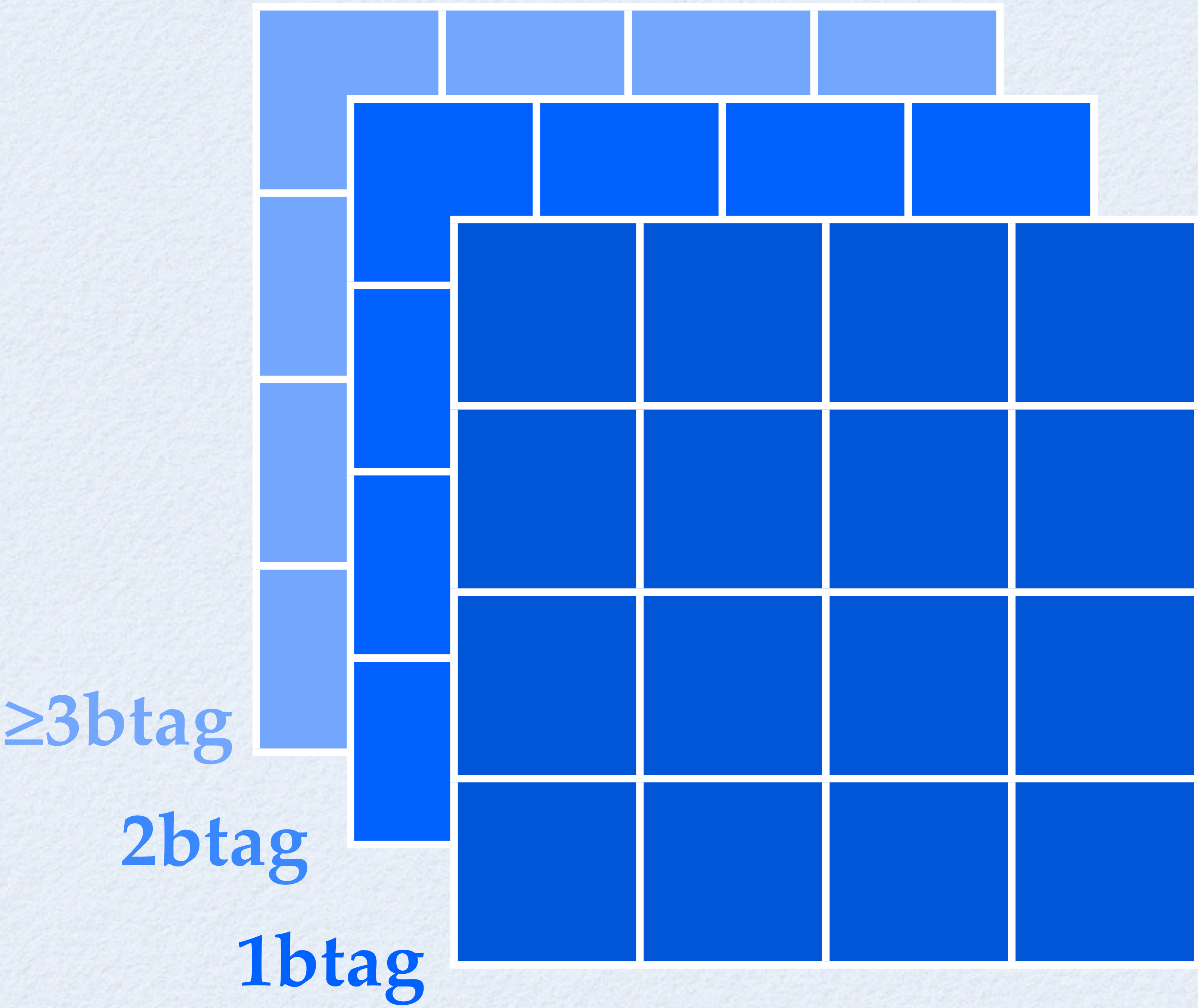
- HT vs MET vs btag multiplicity 3D space binned

- Control samples used to predict backgrounds with data + MC scale factors

$$MET = \sum \vec{E_T}$$
$$HT = \sum |p_T^{jet}|$$

$19\ fb^{-1}$

MULTI(B)JET+MET **SUS-12-024**



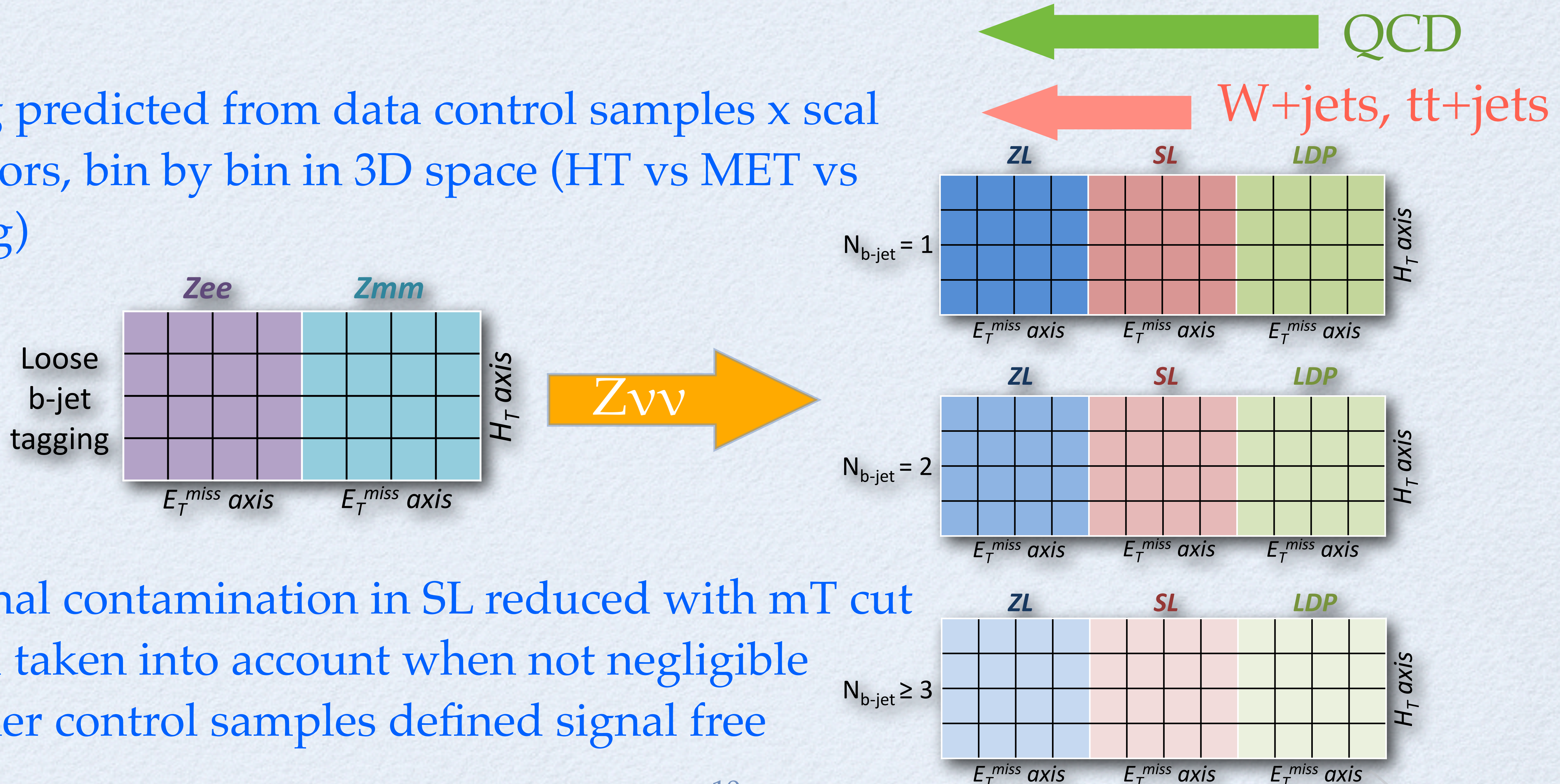
Kinematic plane binned in 4x4 regions in slices of btag multiplicity

Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

19 fb^{-1} MULTI(B)JET+MET SUS-12-024

ZL = Zero Lepton; signal sample	***SL*** = Single Lepton; top & W+jets control sample	***LDP*** = low $\Delta\hat{\phi}_{min}$; QCD control sample	***Zee*** = $Z \to e^+e^-$; Z to $\nu\bar{\nu}$ control sample	***Zmm*** = $Z \to \mu^+\mu^-$; Z to $\nu\bar{\nu}$ control sample

Bkg predicted from data control samples x scal factors, bin by bin in 3D space (HT vs MET vs btag)



Signal contamination in SL reduced with mT cut and taken into account when not negligible

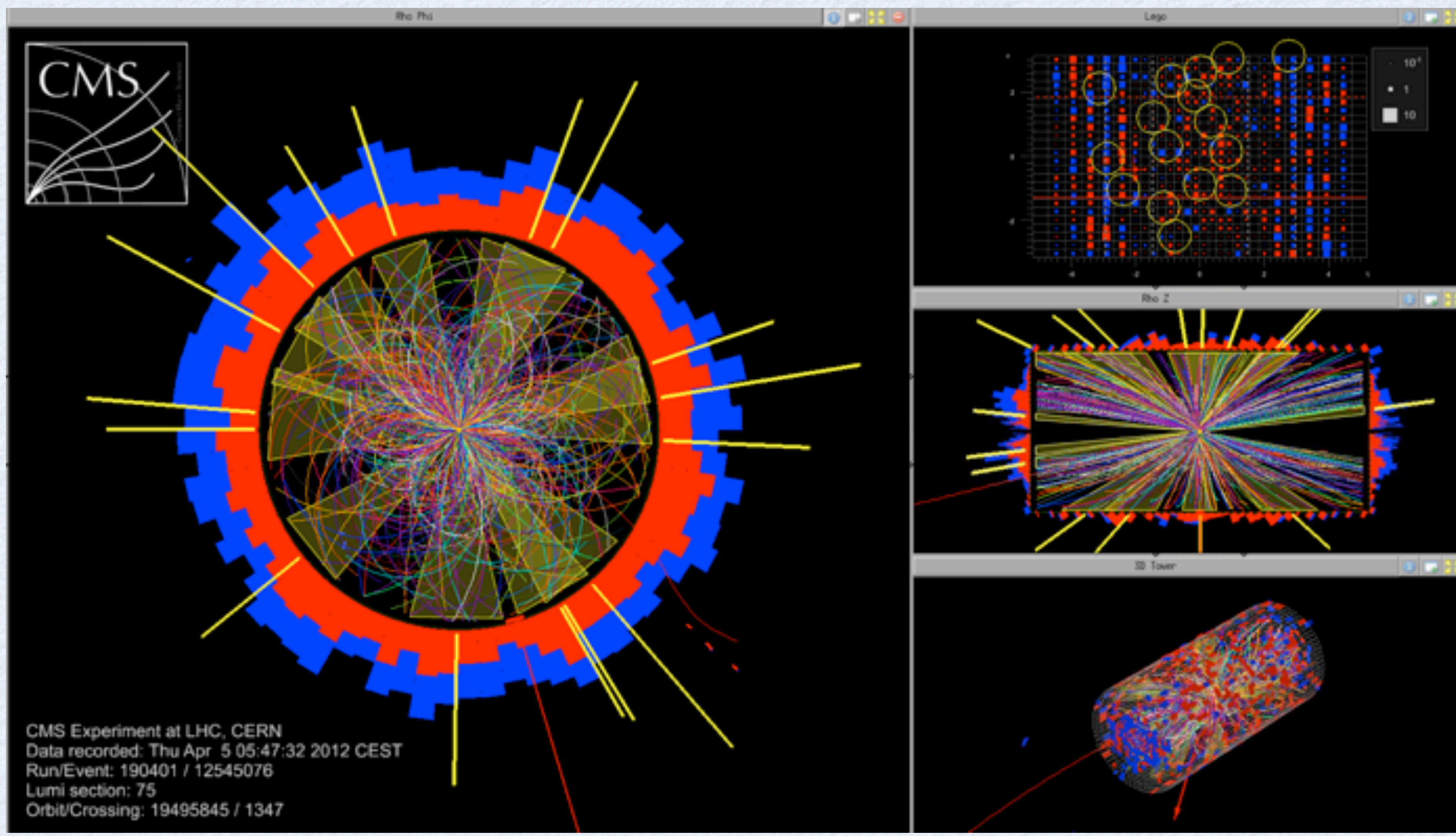
Other control samples defined signal free

THE ENVIRONMENT CHALLENGE

Hadronic analyses in hadronic environment are challenging

No signal selection (e.g. photon, leptons) comes at rescue

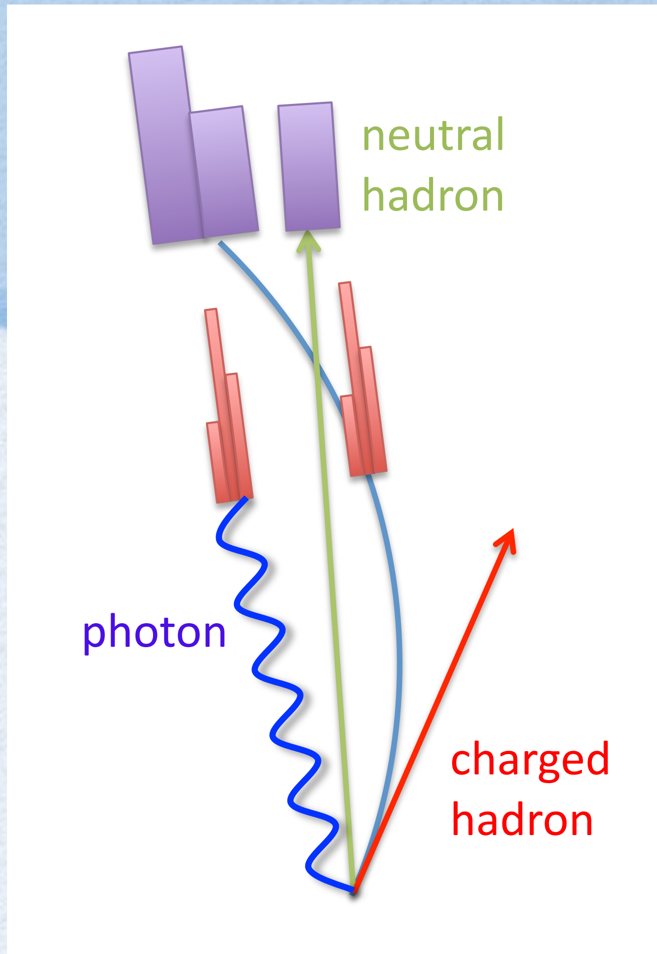
Any possible detector effect is a potential signal (e.g. calorimeter spikes look like jet&MET to first sight)



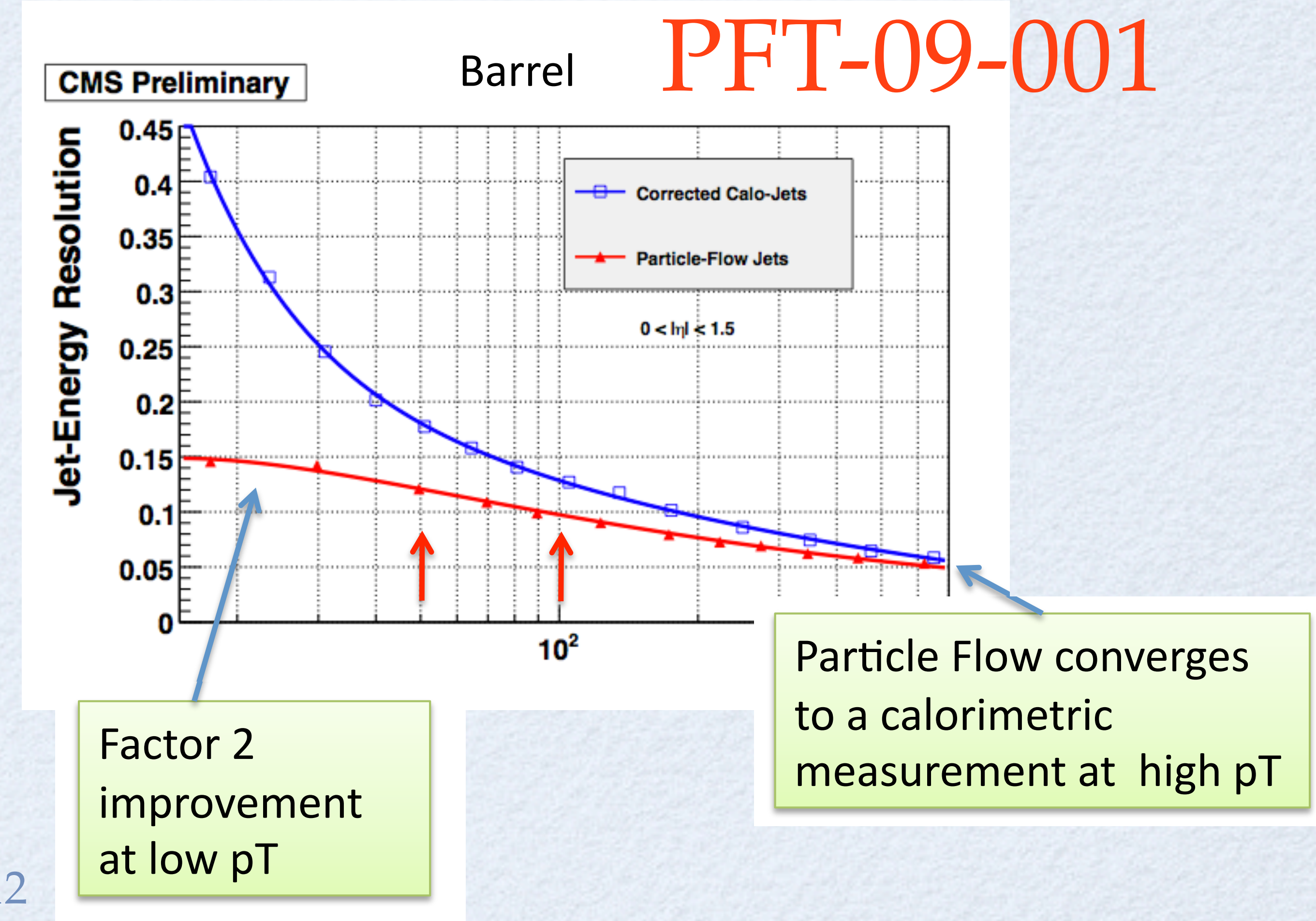
And the high PU environment does not help

Particle Flow

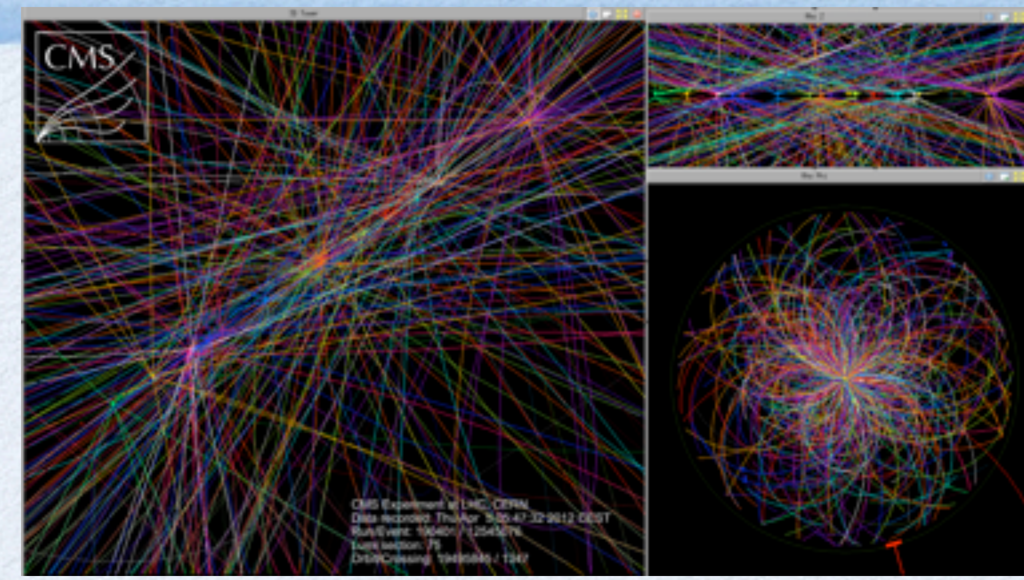
- Combine the information from all detectors to reconstruct single particles
- Provides lists of particles (e,m,g, charged and neutral hadrons)
- Improves HCAL resolution with tracker
- Replace the HCAL granularity with tracker granularity (important for jet substructure)



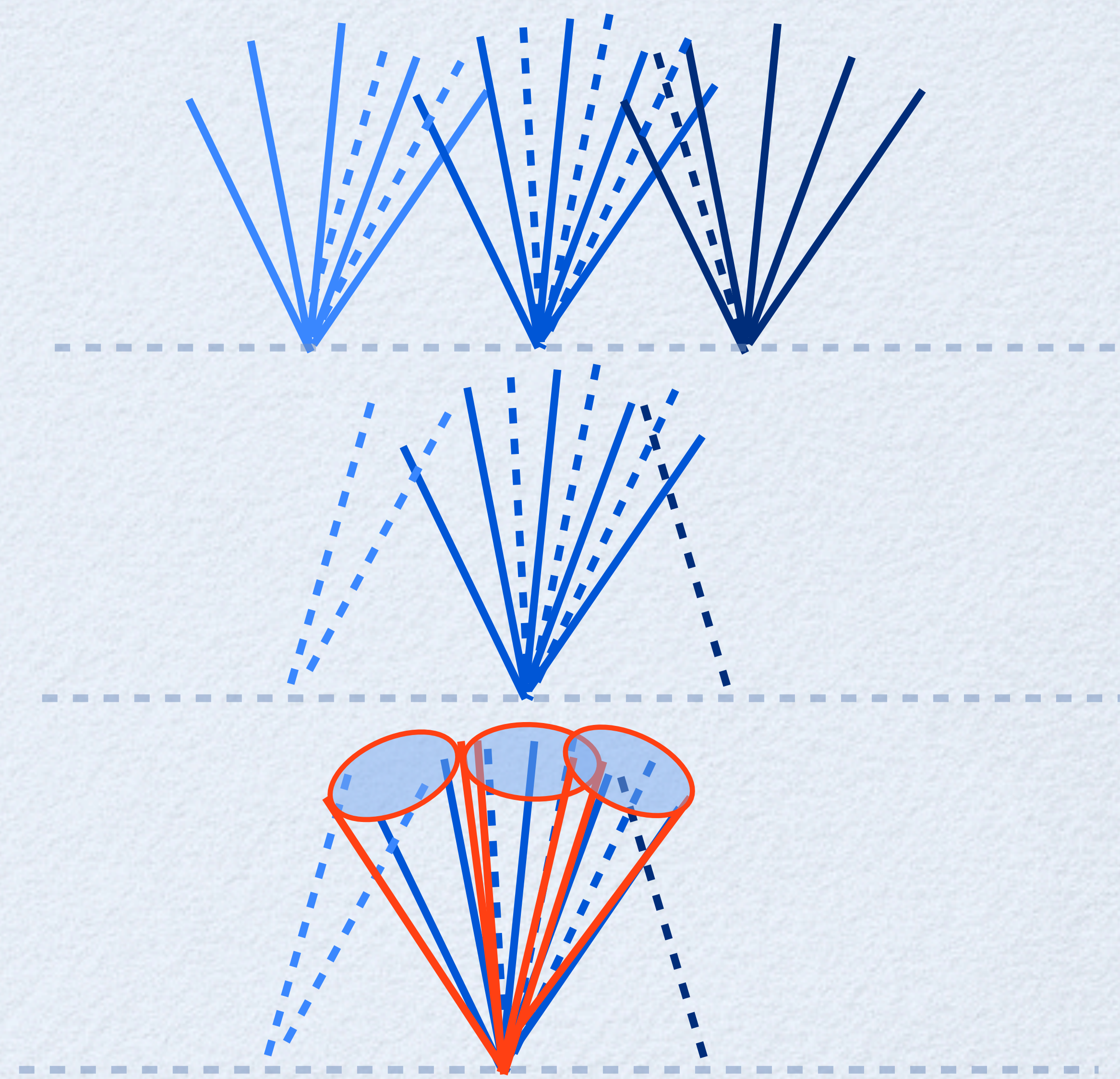
PFT-09-001



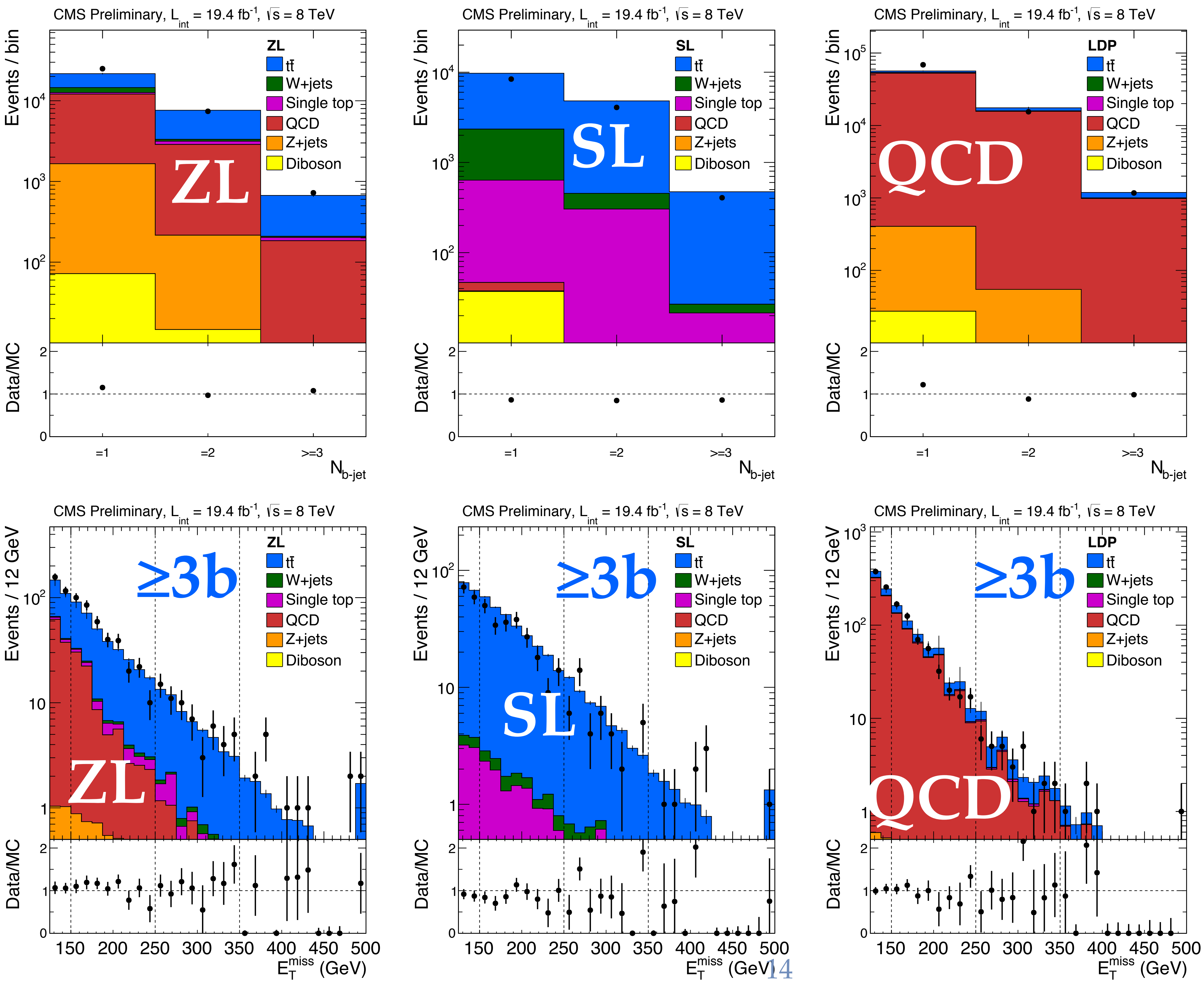
PU correction with PF



- We have a wonderful tracker and a 4T magnetic field
- Jets are clustered from PF candidates (e,μ,γ,charged and neutral hadrons)
- Only the charged particles from the primary vertex are clustered. This removes the PU contribution from charged particles
- The neutral contribution is subtracted in average, using FASTJET



19 fb-1 MULTI(B)JET+MET SUS-12-024



Observed distributions agree with MC prediction

Prediction not used in the analysis (illustration only)

19 fb^{-1}

MULTI(B)JET+MET SUS-12-024

bin-by-bin scale factor (constrained to MC with sys error)

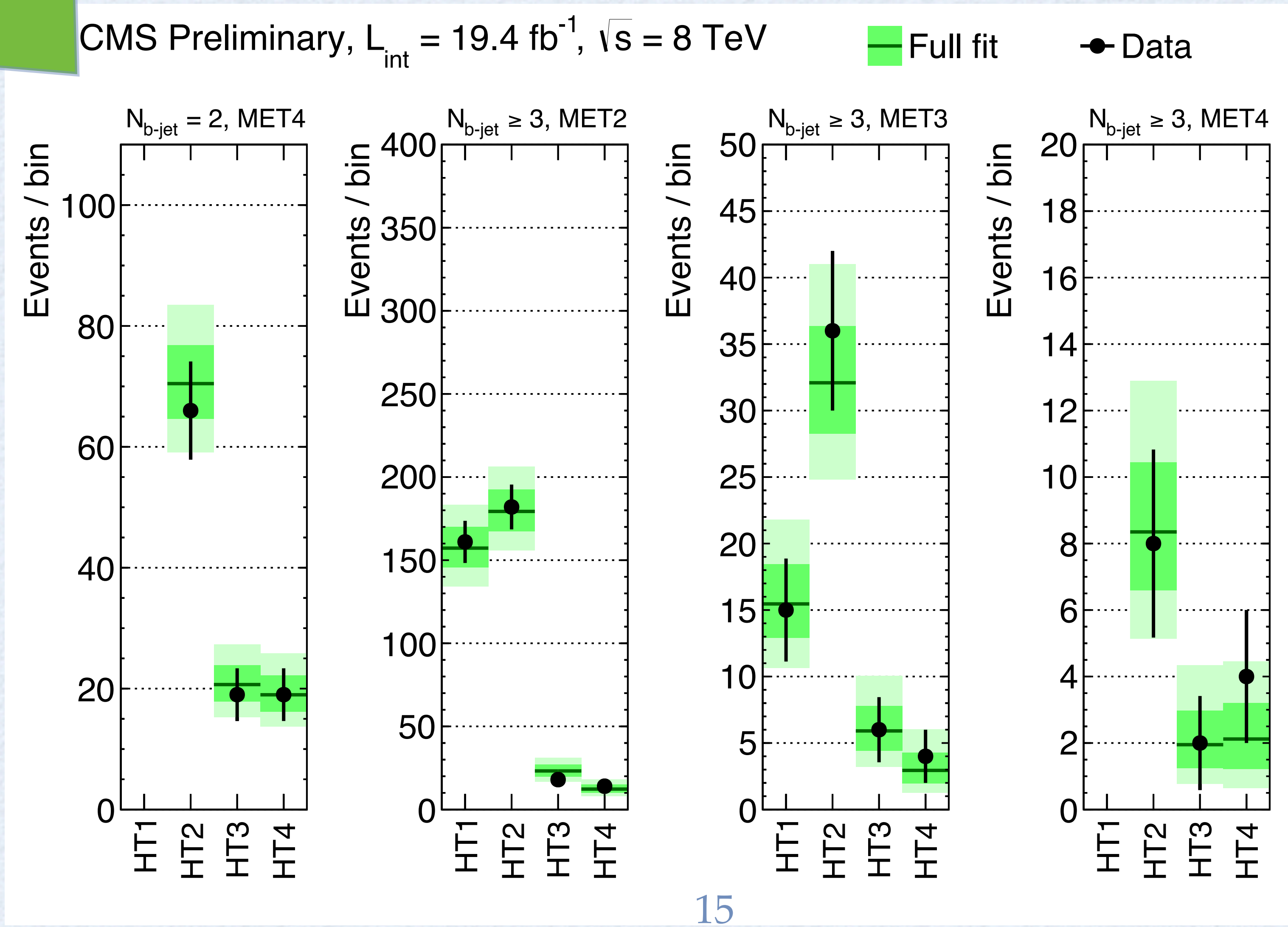
expected background in bin ijk

observed yield in control sample

$$\mu^{ttWj}_{ZL;i,j,k} = S^{ttWj}_{i,j,k} \cdot R^{ttWj}_{ZL/SL} \cdot \mu^{ttWj}_{SL;i,j,k},$$

overall normalization (unconstrained nuisance)

16 most sensitive bins shown

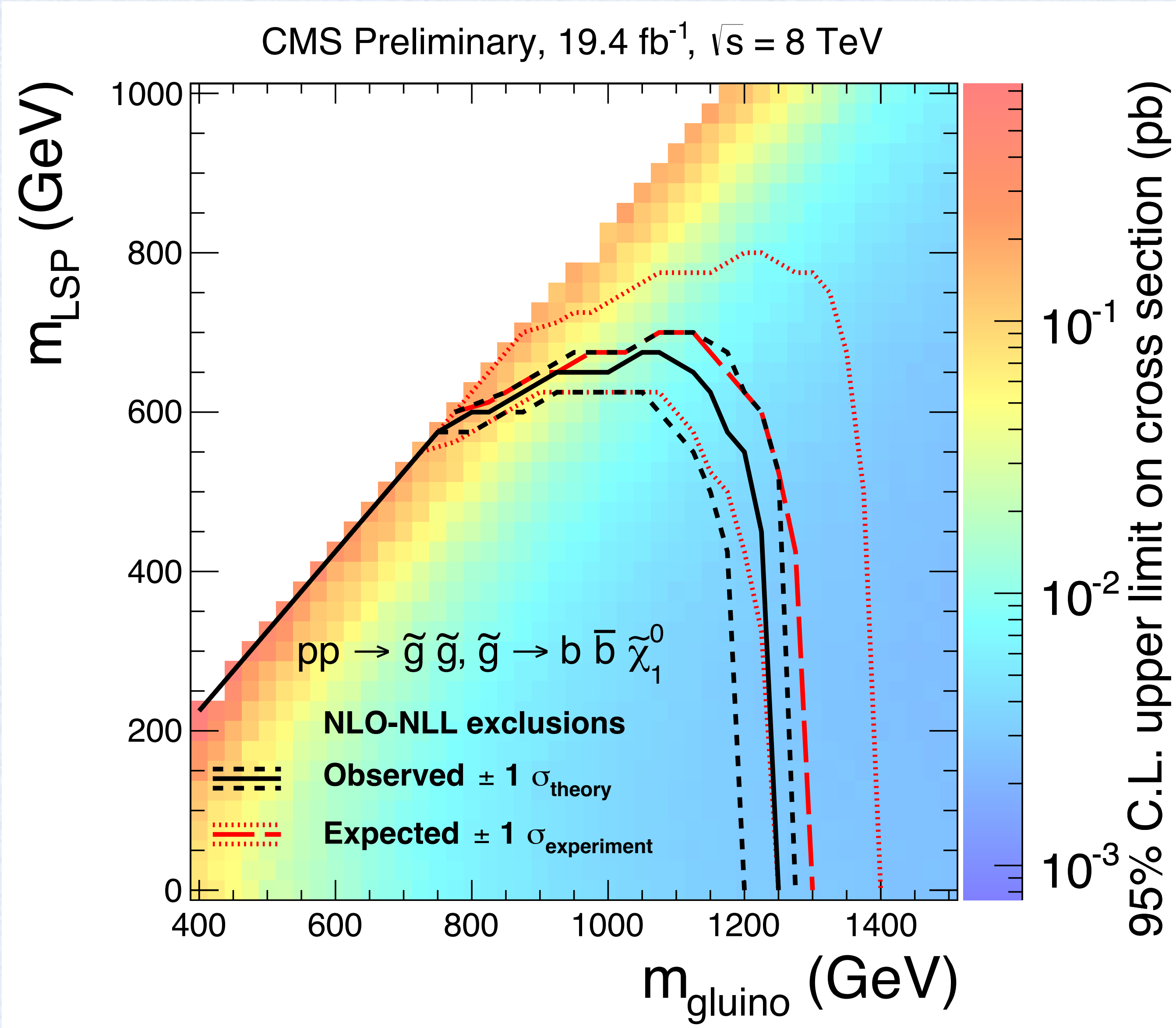


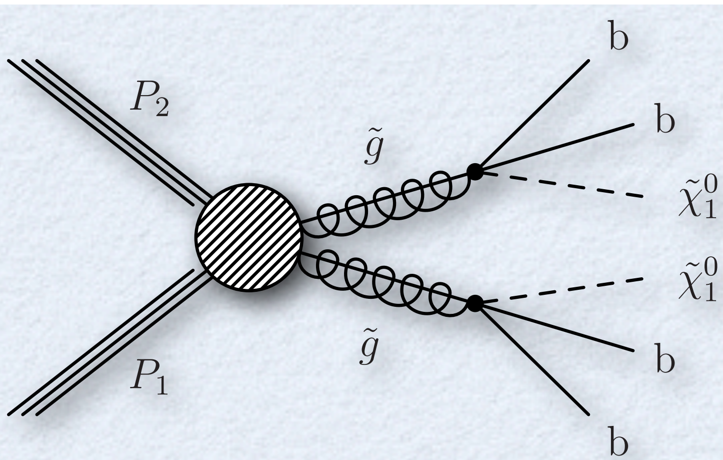
Data agree with prediction

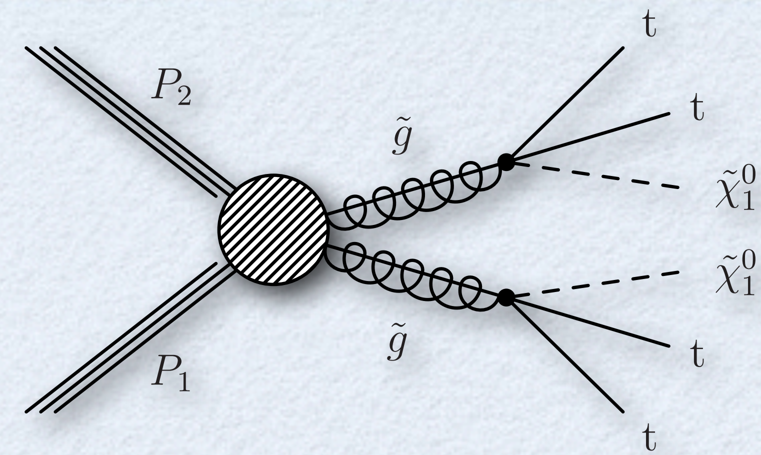
No evidence for excess

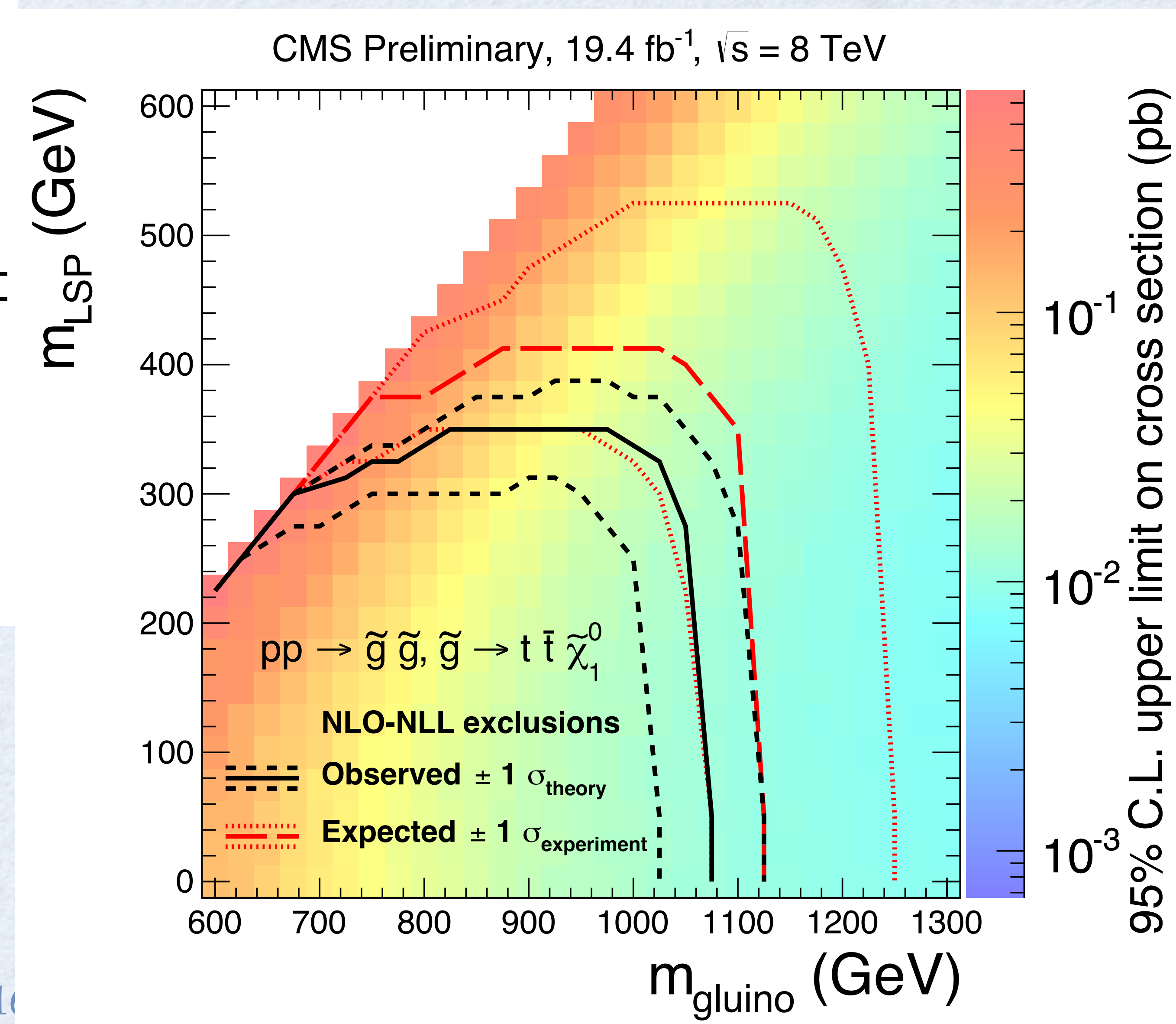
19 fb^{-1}

MULTI(B)JET+MET SUS-12-024





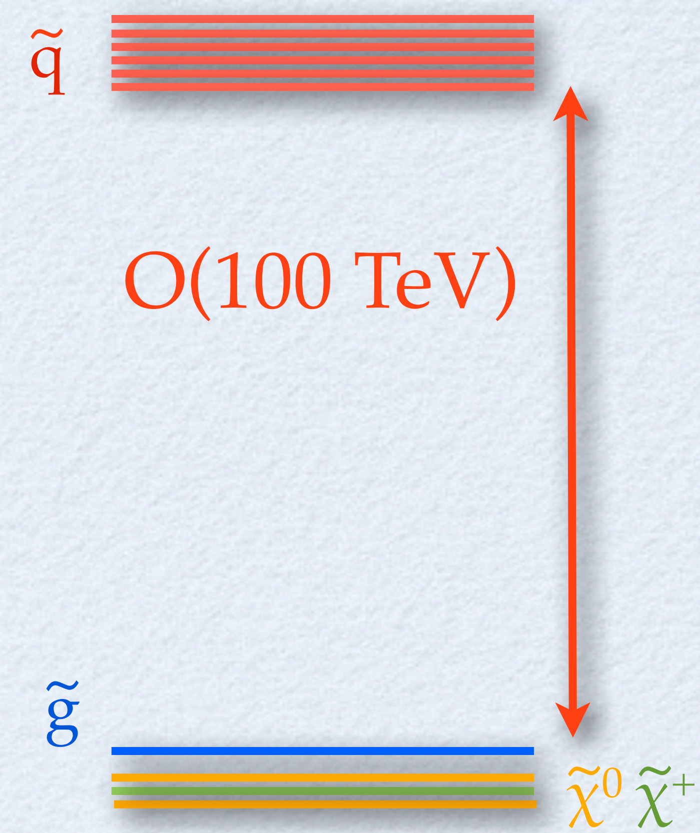


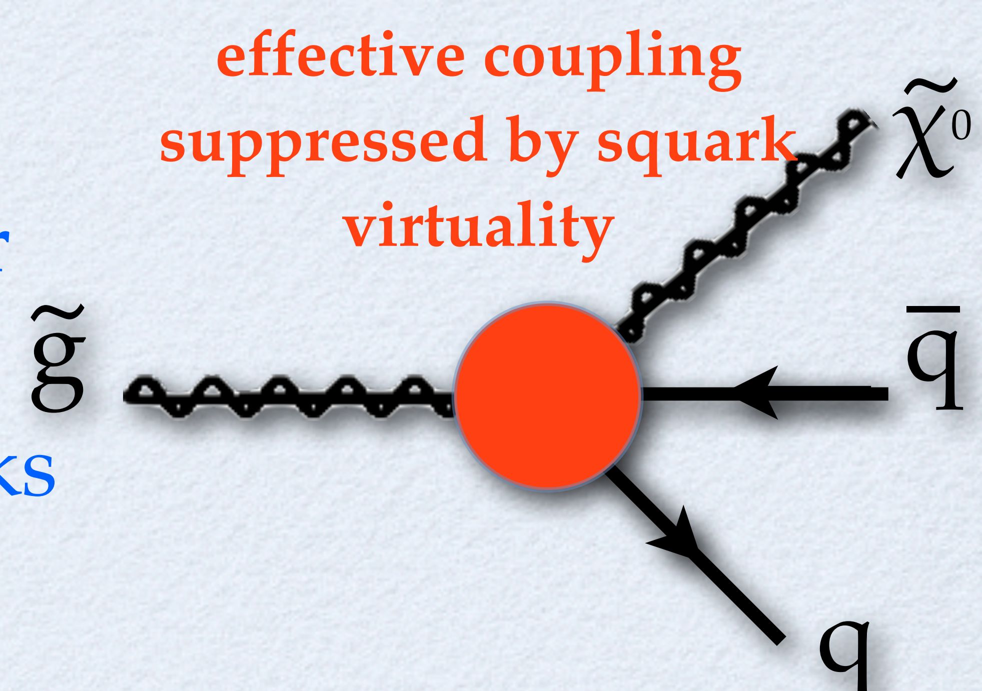


Unnatural SUSY search: Heavy Stable Charged Particles

Split SUSY & HSCP

- Split SUSY predicts a large mass gap between fermion (light) and scalar (heavy) sparticles
- The gluino travels through the detector as a Rhadron (hadronizig or interacting with the mateial), with or without electric charge
- We expect a slow particles traveling across the detector
- Could start charged and become neutral (or vice versa) or stay charged all the way through (depending on what the gluon picks when hadronizing)





HSCP in CMS

- **Tracker only**

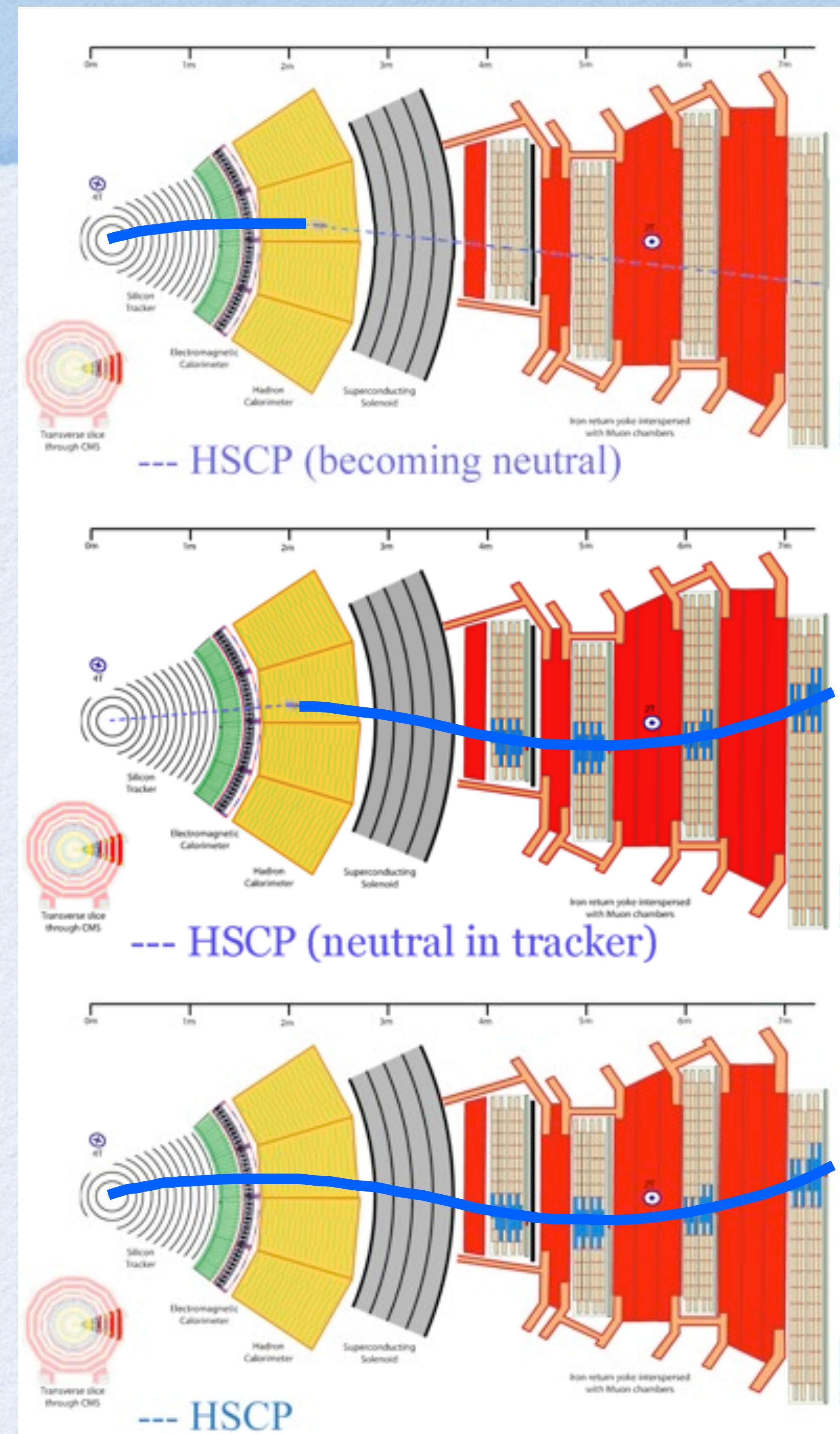
  Sensitive to any HSCP produced prompt (irrespective of what happens after)
  Uses dE/dX in tracker to separate signal from BKG

- **Muon Only**

  Sensitive to any HSCP crossing muon detector (irrespective of what happens before)
  Uses TOF to separate signal from BKG

- **Tracker + TOF**

  uses both (for HSCP crossing the detector)



dE/dX in the tracker

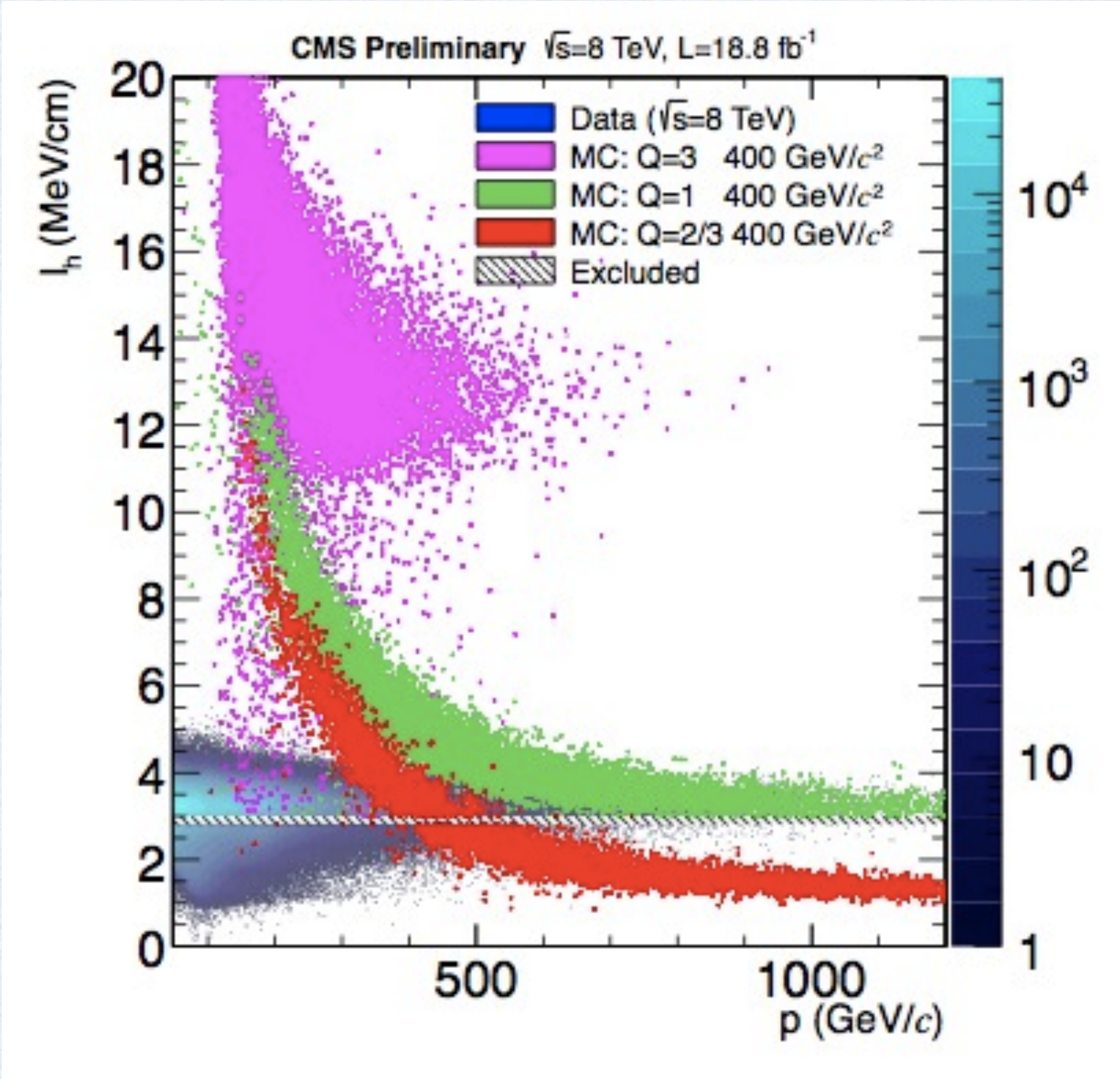
- Measure the charge released in the tracker
- Compute ionization, which gives a measurement of p/m through charge-dependent empirical coefficients

charge/unit path (fixed k=2)

$$I_h = \left(\frac{1}{N}\sum_i c_i^k\right)^{1/k} = K\frac{m^2}{p^2} + C$$

empirical coefficients

Ih vs pT distributions provides S vs B discrimination



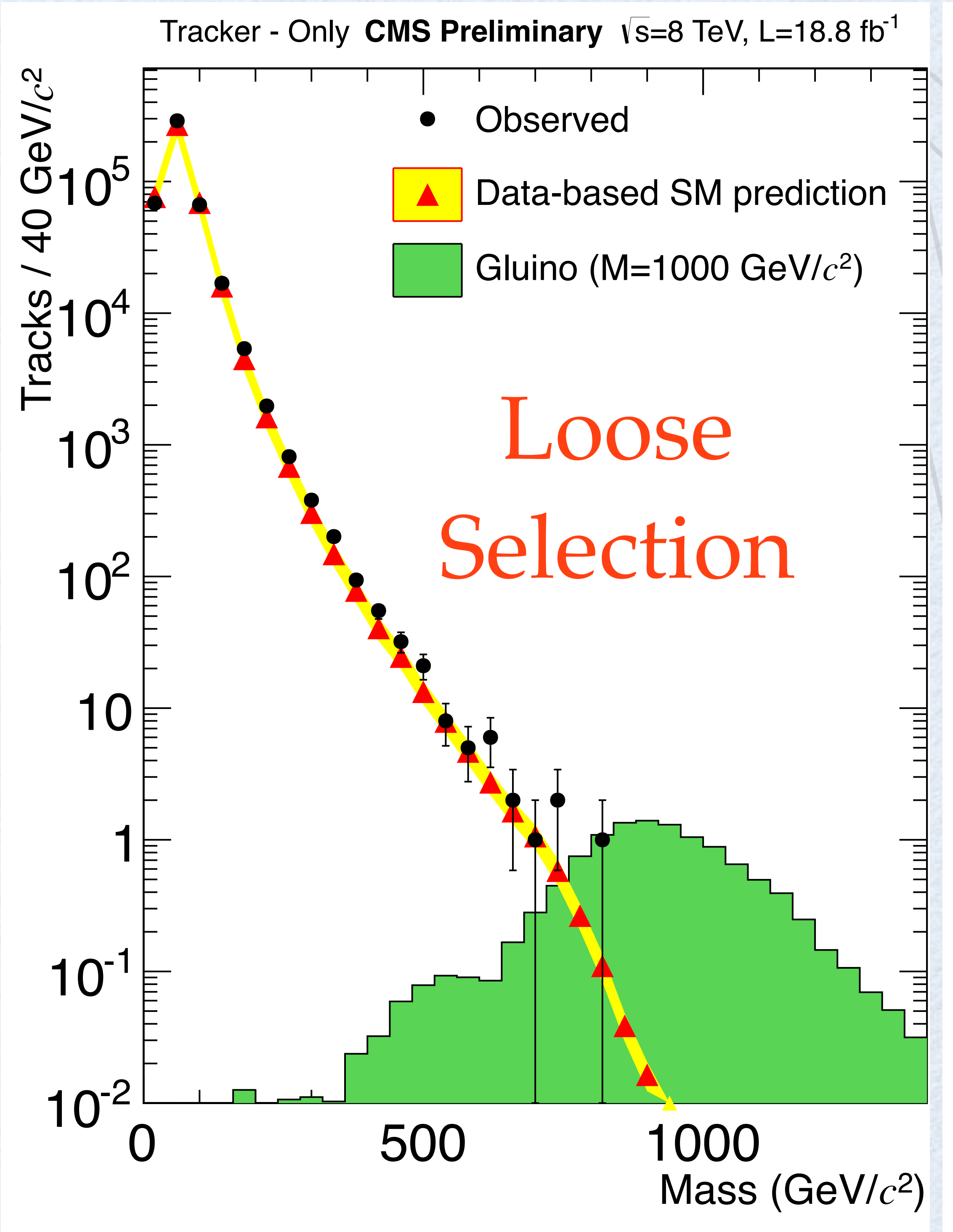
dE/dX in the Tracker

- Additional discrimination from p-value of MIP-ionization pdf (for data-driven BKG determination)

probability MIP to produce <= observed ionization

$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right)$$

- Measurement of mass from the knowledge of $I_h(p)$ [measured on data sideband]



TIME OF FLIGHT

- Use arrival time in the muon chambers to measure the TOF

- For a single hit determines β^{-1}

$$\beta^{-1} = 1 + \frac{c\delta_t}{L}$$

- For a track, weighted average of the single hits

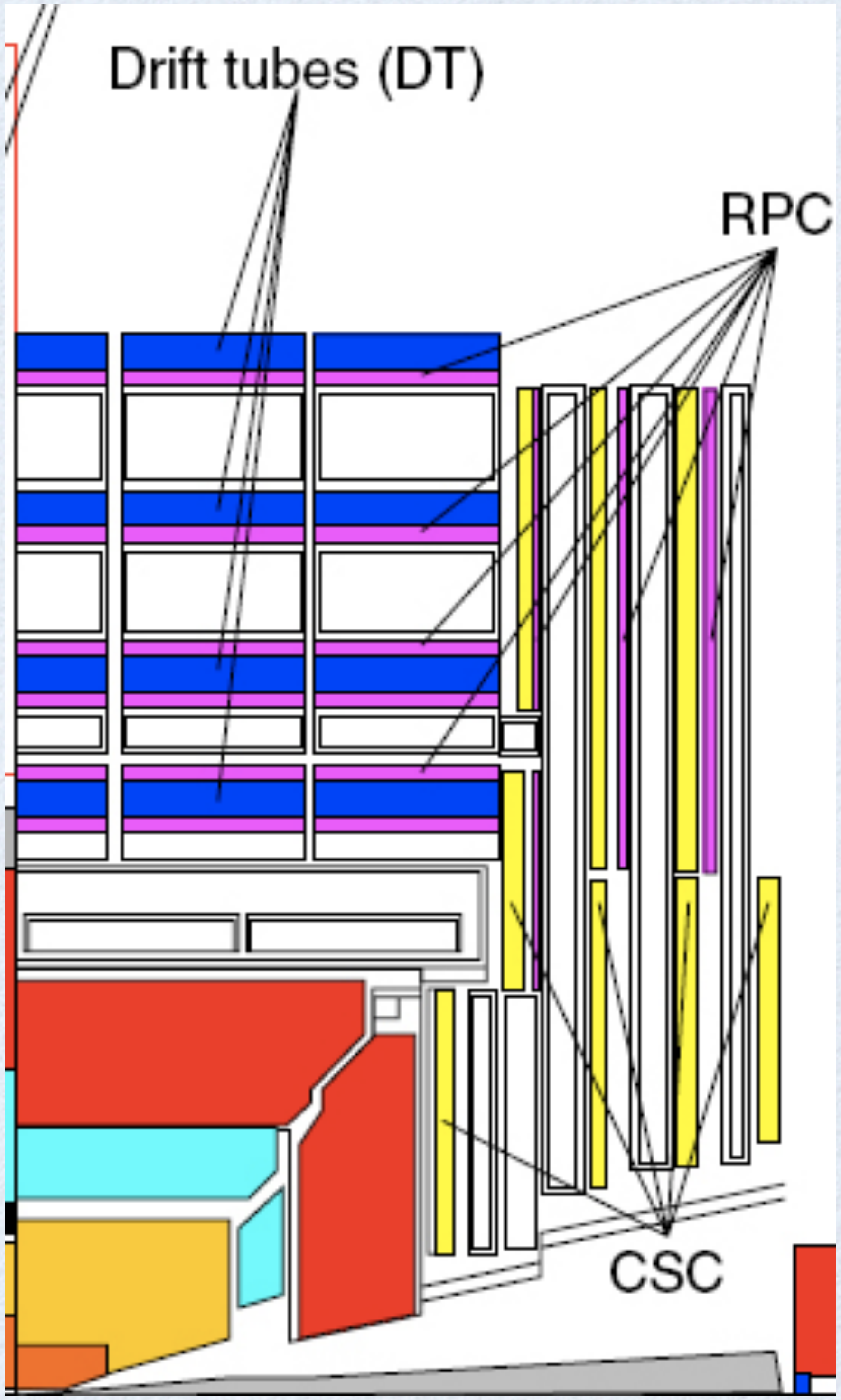
$$w_i = \frac{(n-2)}{n}\frac{L_i^2}{\sigma_{DT}^2}$$

DTs ($\sigma \sim 3$ ns)

$$w_i = \frac{L_i^2}{\sigma_i^2}$$

CSCs ($\sigma \sim 7$ ns for cathode, 9 ns for anode)

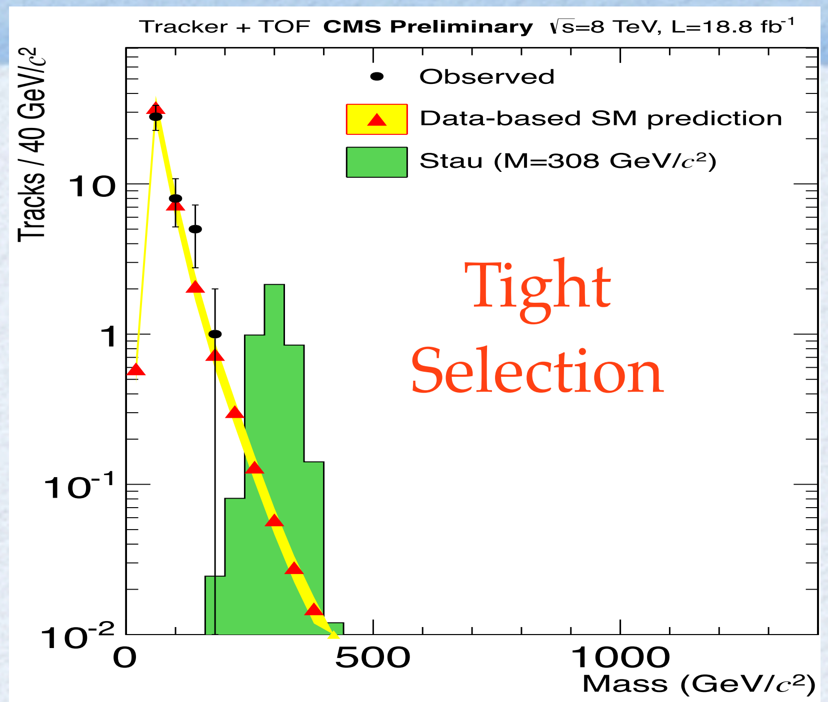
For both $\sigma(\beta^{-1}) \sim 0.07$



7Tev +8TeV

Heavy Stable Charged Particles

EXO-12-026

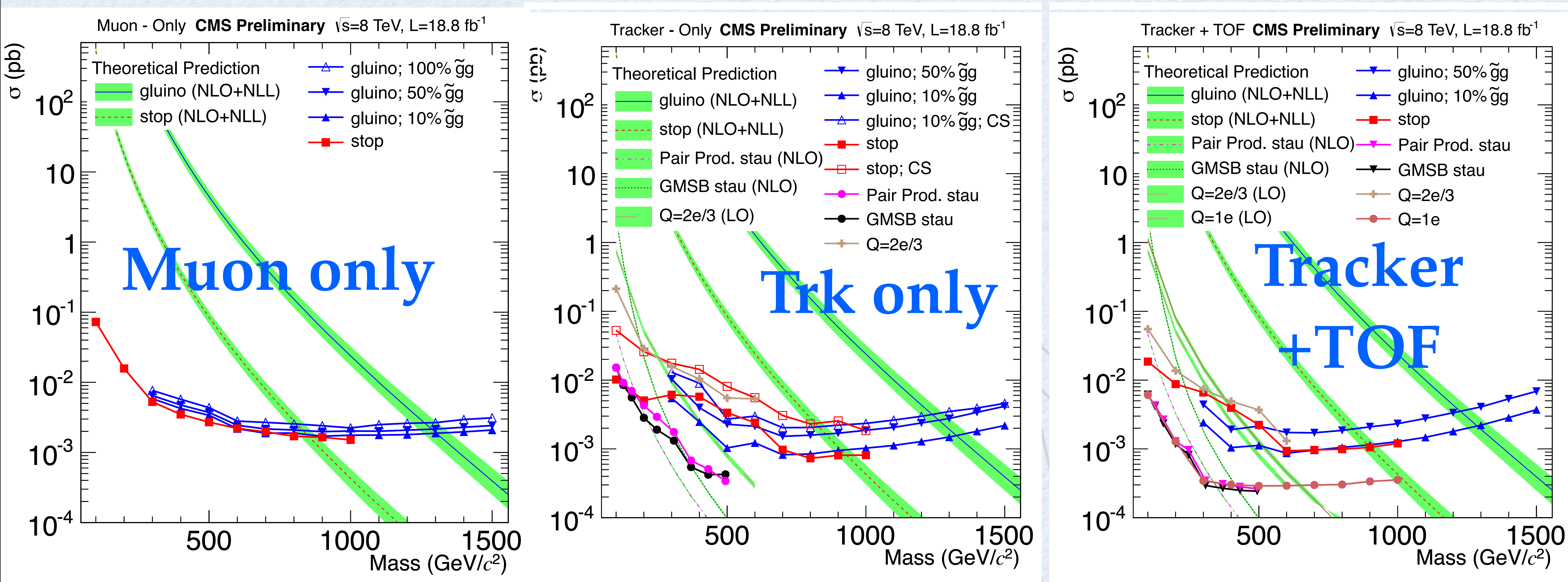


- Use ionization and TOF to predict bkg tail at large m with data
- Data driven ABCD method based on pairs of uncorrelated variables

	Selection criteria				Numbers of events $\sqrt{s}=7$ TeV		$\sqrt{s}=8$ TeV	
	p_T (GeV/c)	$I_{as}^{(\prime)}$	$1/\beta$	Mass (GeV/c^2)	Pred.	Obs.	Pred.	Obs.
tracker-only	> 70	> 0.4	-	> 0	7.1 ± 1.5	8	32.5 ± 6.5	41
				> 100	6.0 ± 1.3	7	26.0 ± 5.2	29
				> 200	0.65 ± 0.14	0	3.1 ± 0.6	3
				> 300	0.11 ± 0.02	0	0.55 ± 0.11	1
				> 400	0.030 ± 0.006	0	0.15 ± 0.03	0
tracker+TOF	> 70	> 0.125	> 1.225	> 0	8.5 ± 1.7	7	43.5 ± 8.7	42
				> 100	1.0 ± 0.2	3	5.6 ± 1.1	7
				> 200	0.11 ± 0.02	1	0.56 ± 0.11	0
				> 300	0.020 ± 0.004	0	0.090 ± 0.02	0
muon-only	> 230	-	> 1.40	-	—	—	5.6 ± 2.9	3
$\|Q\| > 1e$	-	> 0.500	> 1.200	-	0.15 ± 0.04	0	0.52 ± 0.11	1
$\|Q\| < 1e$	> 125	> 0.275	-	-	0.12 ± 0.07	0	0.99 ± 0.24	0

Heavy Stable Charged Particles

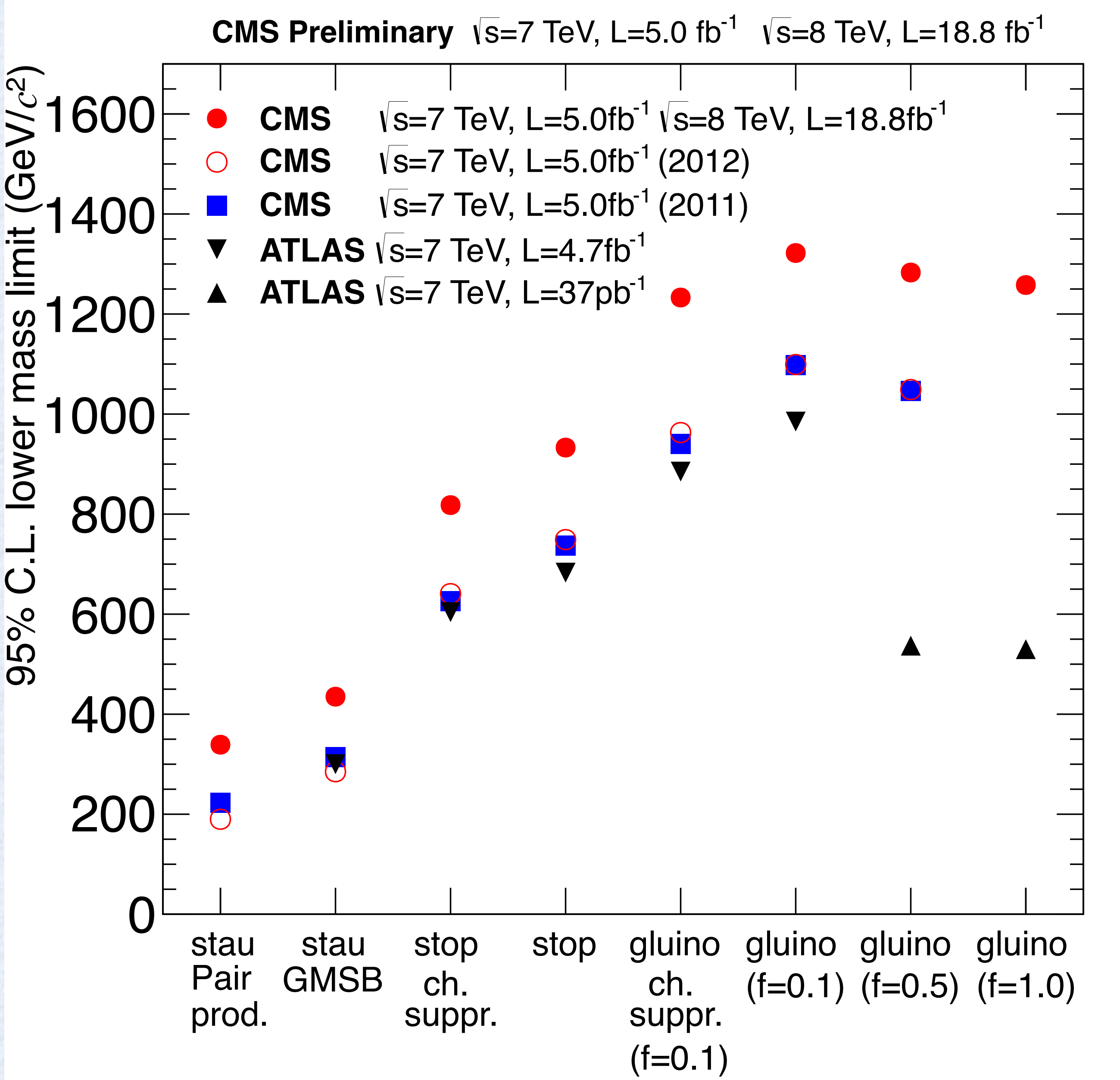
EXO-12-026

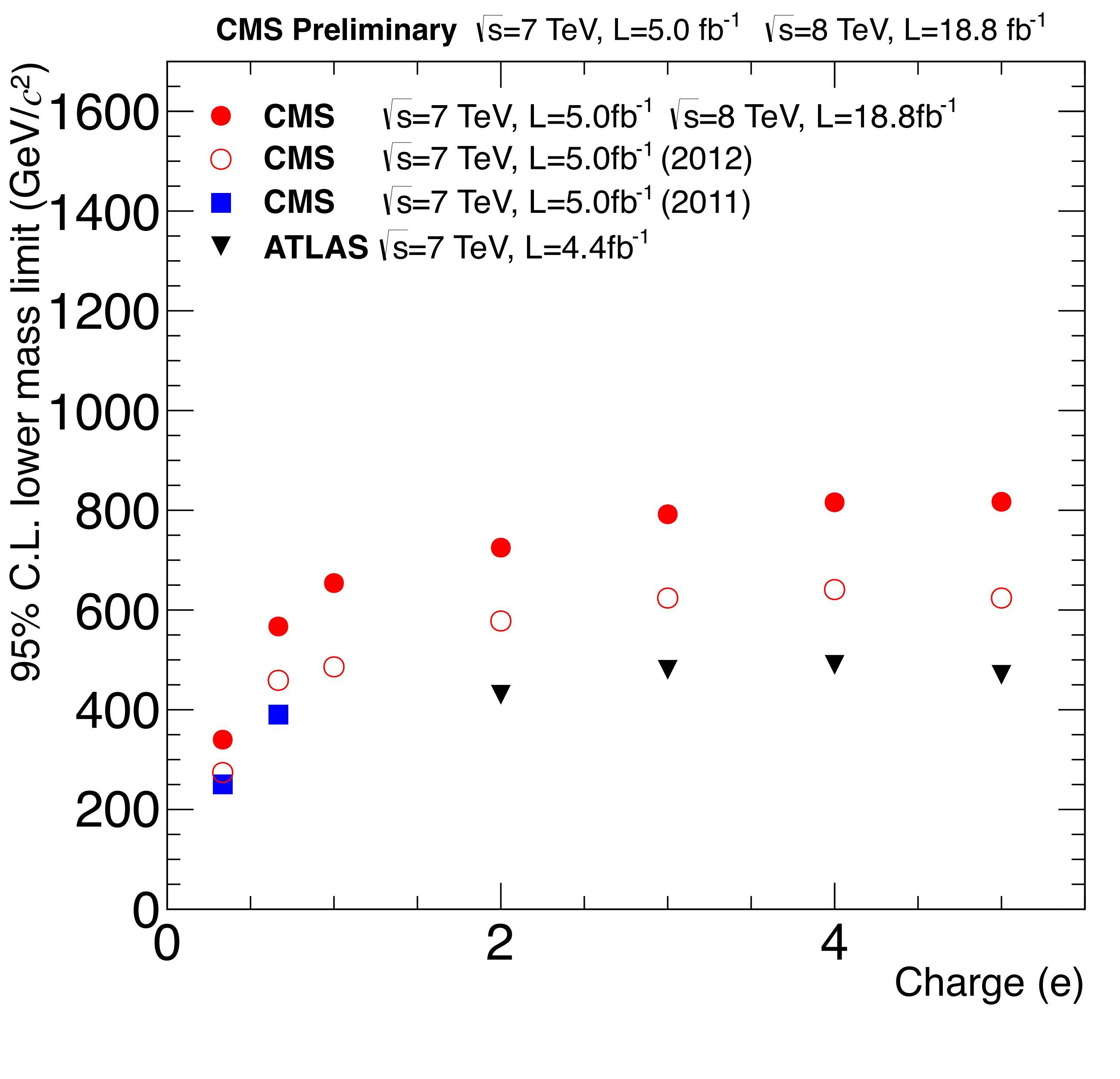


Limits obtained with 8TeV data

Heavy Stable Charged Particles

EXO-12-026





Final limit obtained combining 7TeV and 8TeV data

New Resonances

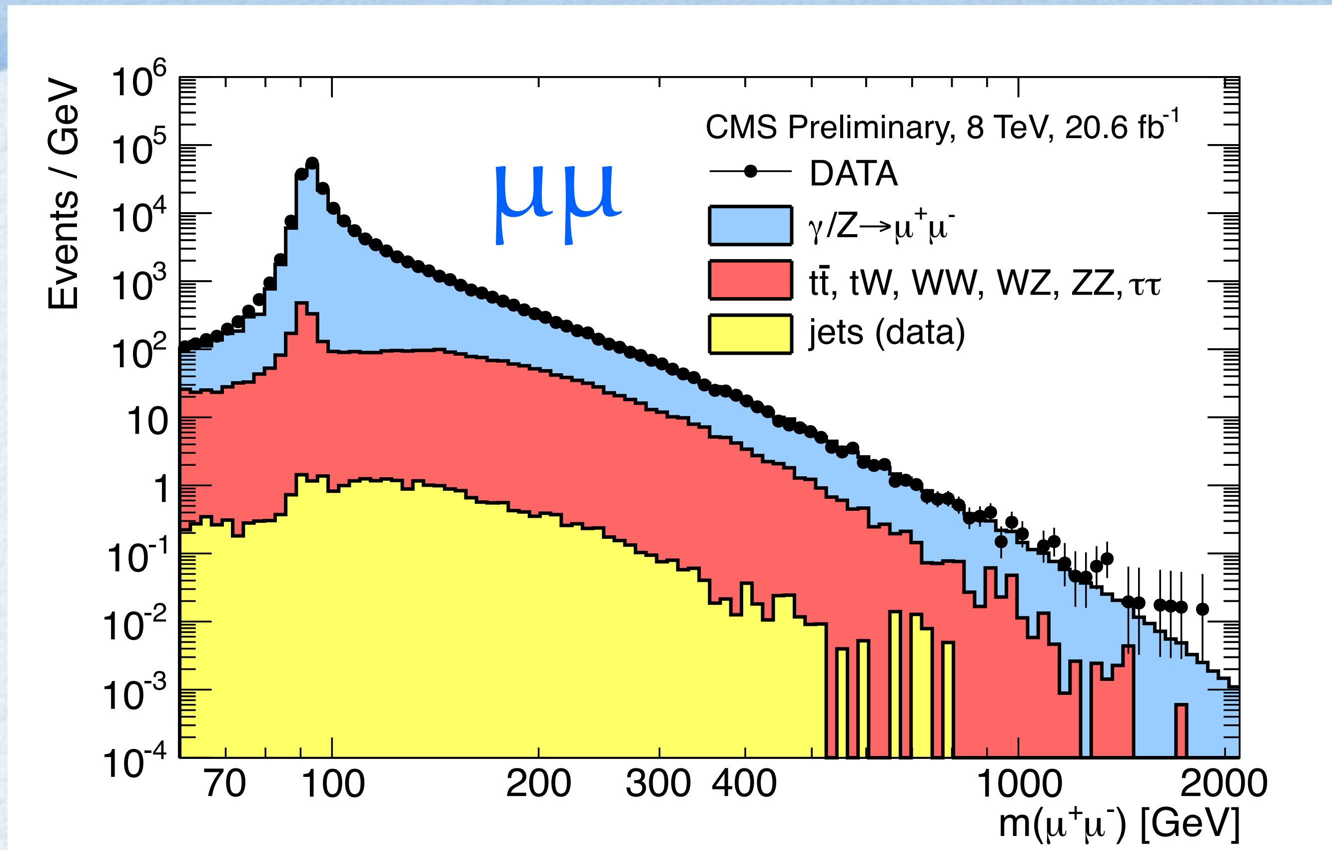
21 fb^{-1}

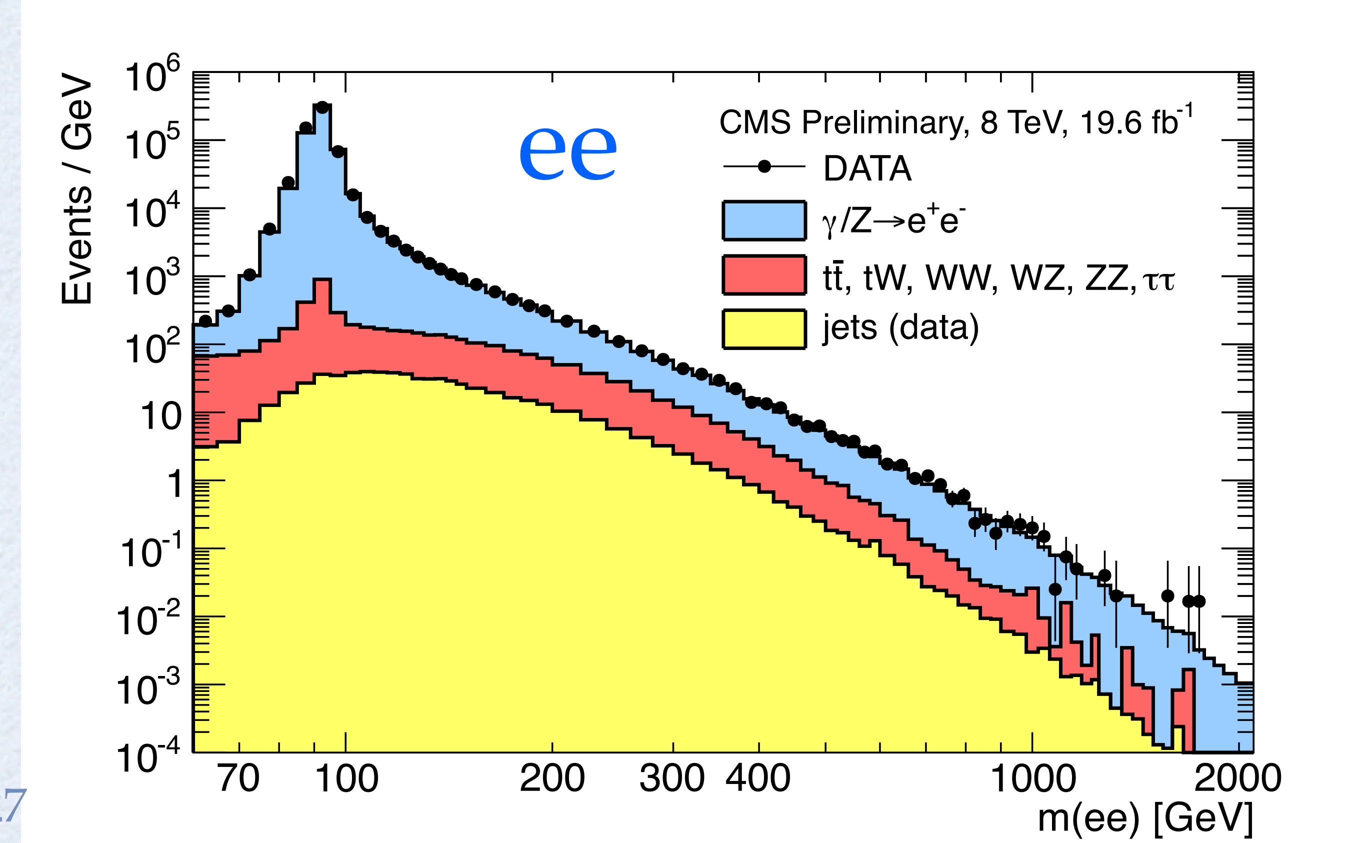
Dilepton Searches EXO-12-061

- Pair of high-pT isolated leptons with same flavor (e,μ)

- Selection tuned to maximize significance. S vs B discrimination from $m_{\ell\ell}$ shape

- Bkg shape taken from MC and normalized to data in the mass sideband [60,120] GeV





HIGH-PT LEPTONS

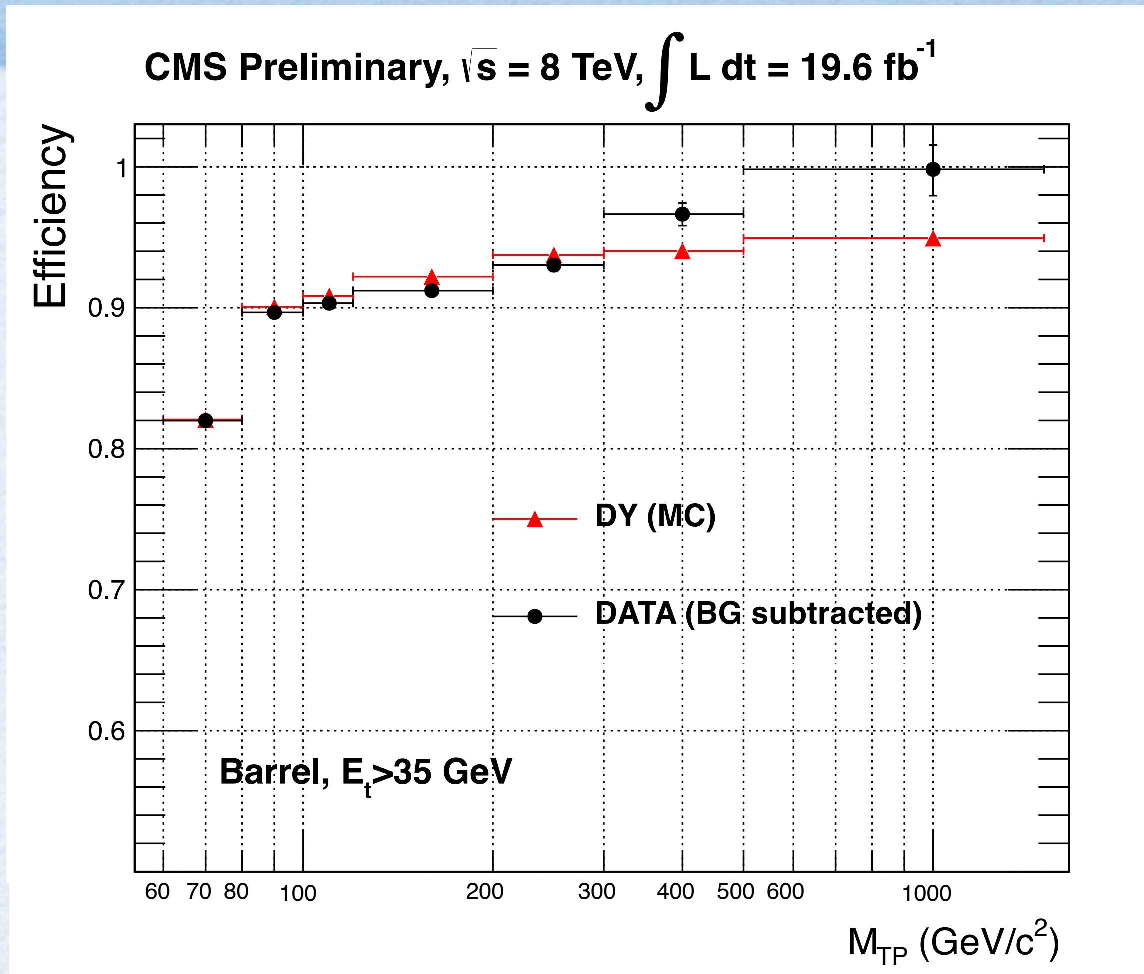
Leptons at high pT are different than standard leptons

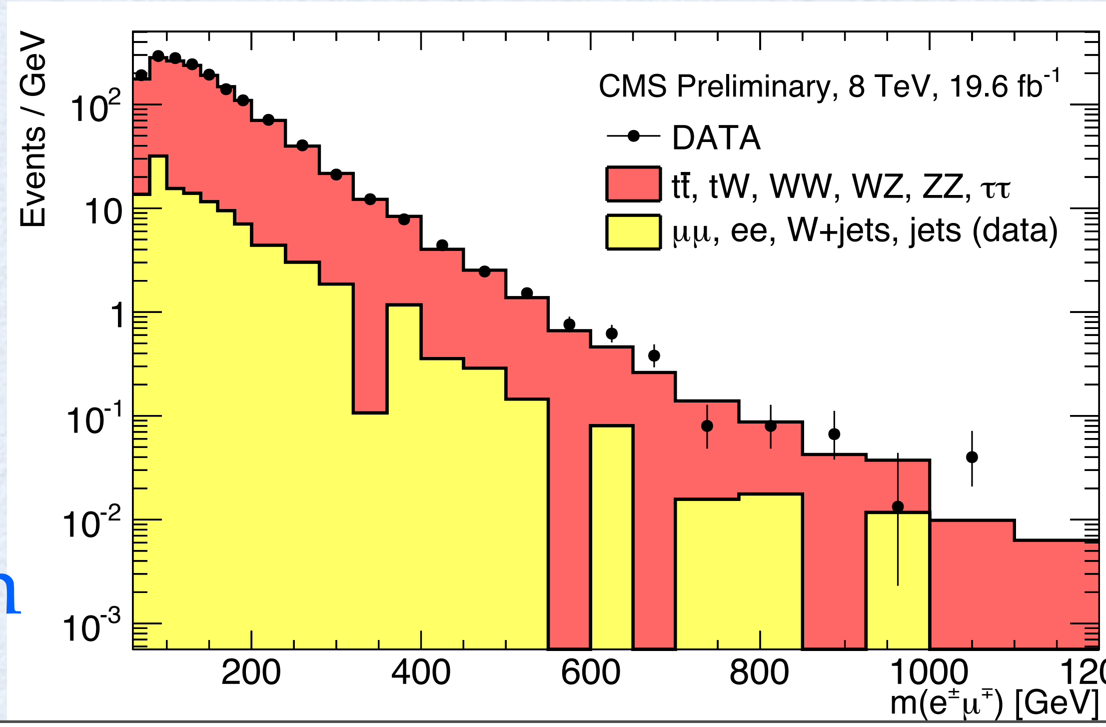
pT resolution worse (better) for muons (electrons)

Energy deposits in the hadronic calorimeter could spoil isolation

Reconstruction and identification tuned differently

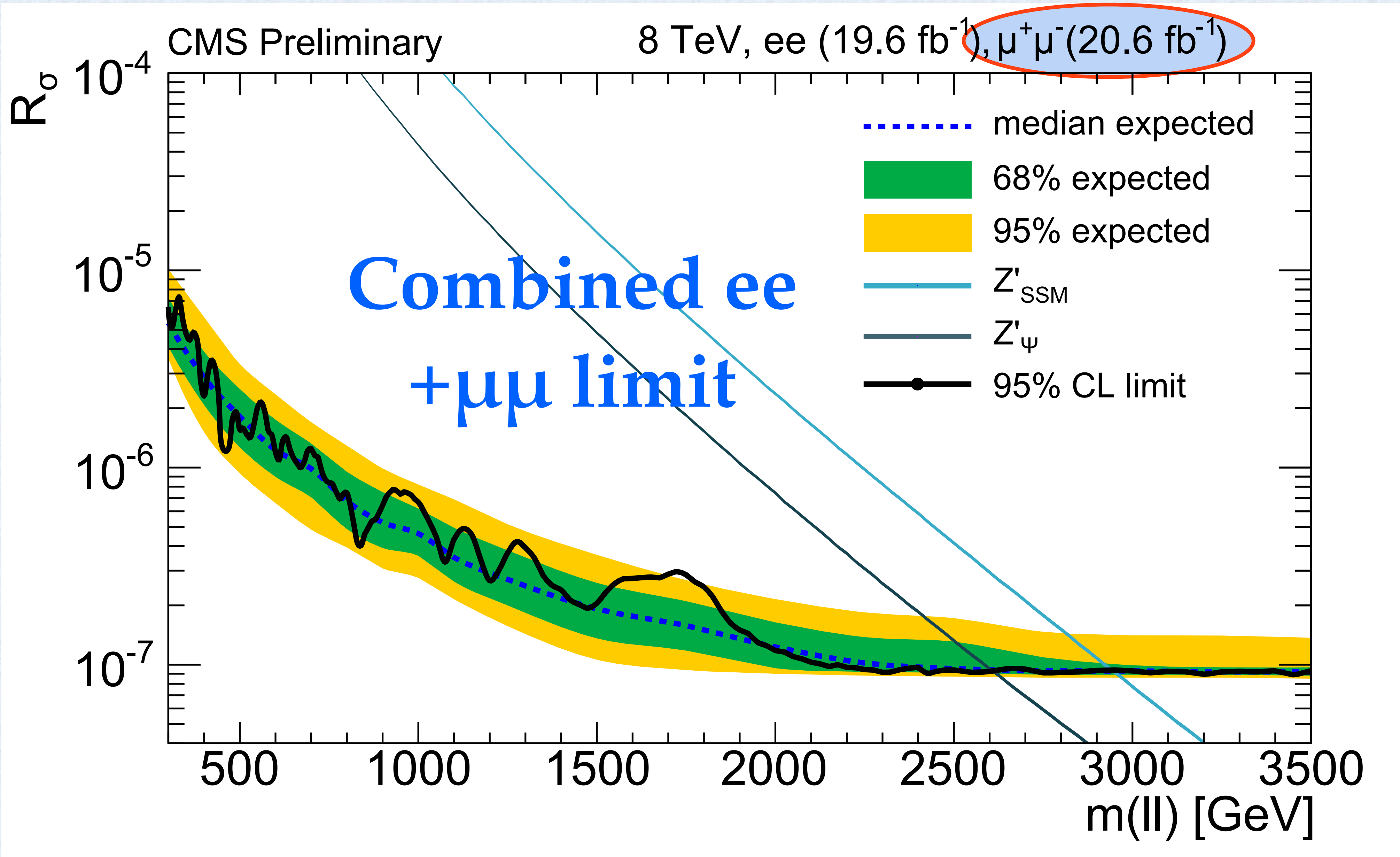
The effects are well model by the MC, as confirmed studying the em mass spectrum





21 fb^{-1} Dilepton Searches EXO-12-061

$mZ'_{SSM} > 2960$ GeV $mZ'_{\Psi} > 2600$ GeV

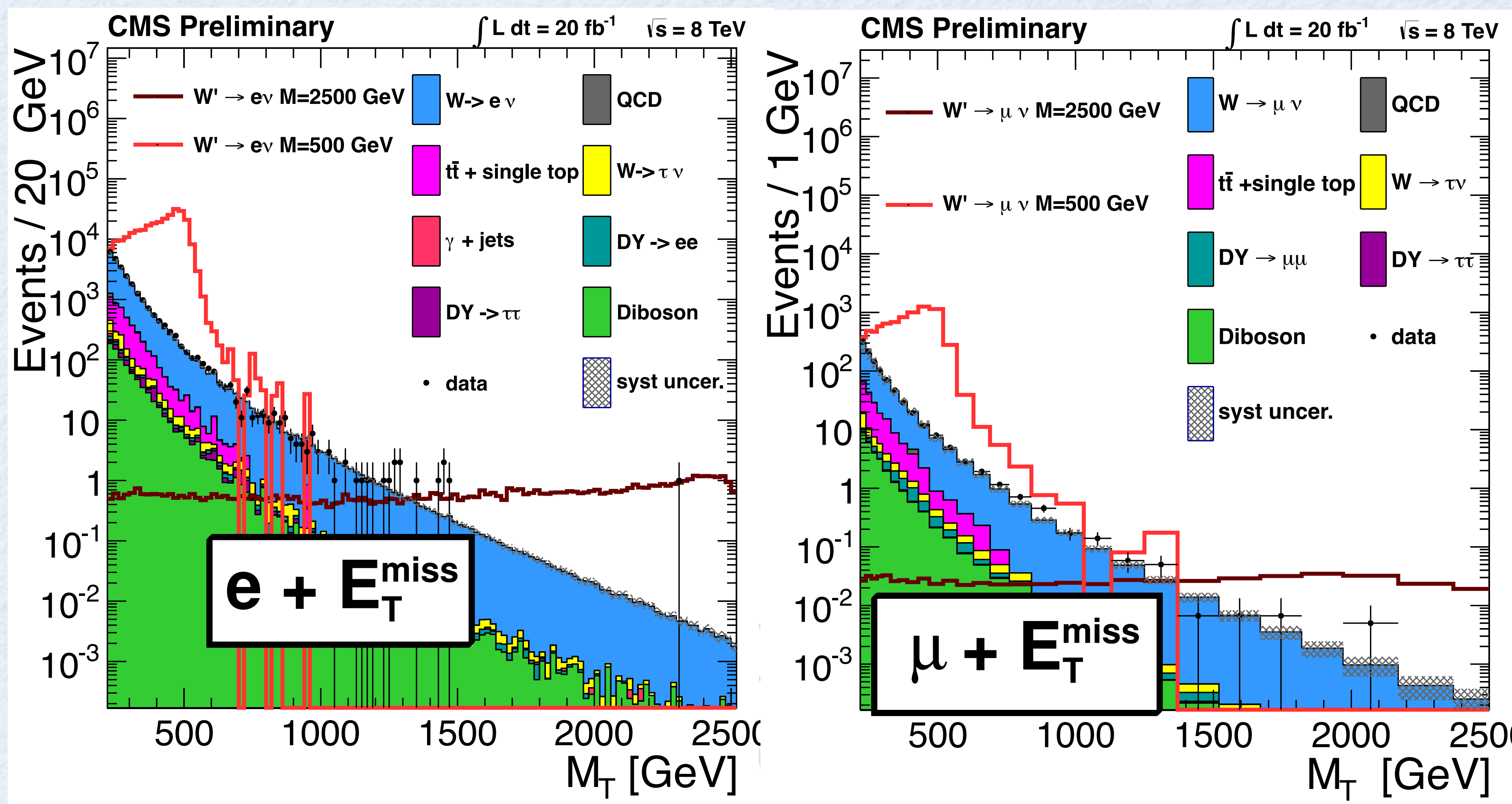


20 fb^{-1}

$W' \rightarrow \ell\nu$ SEARCHES EXO-12-060

- one muon (electron) with $p_T > 45$ GeV ($E_T > 100$ GeV)
- Muon track-based isolation <15% for $\Delta R < 0.3$ and $\Delta p_T / p_T < 0.3$
- Electron from isolated ECAL deposits matched to track. E_T from ECAL
- Fit MT distribution with empirical function to predict bkg on the tail

$$f(M_T) = \frac{a}{(M_T^3 + bM_T + c)^d}$$

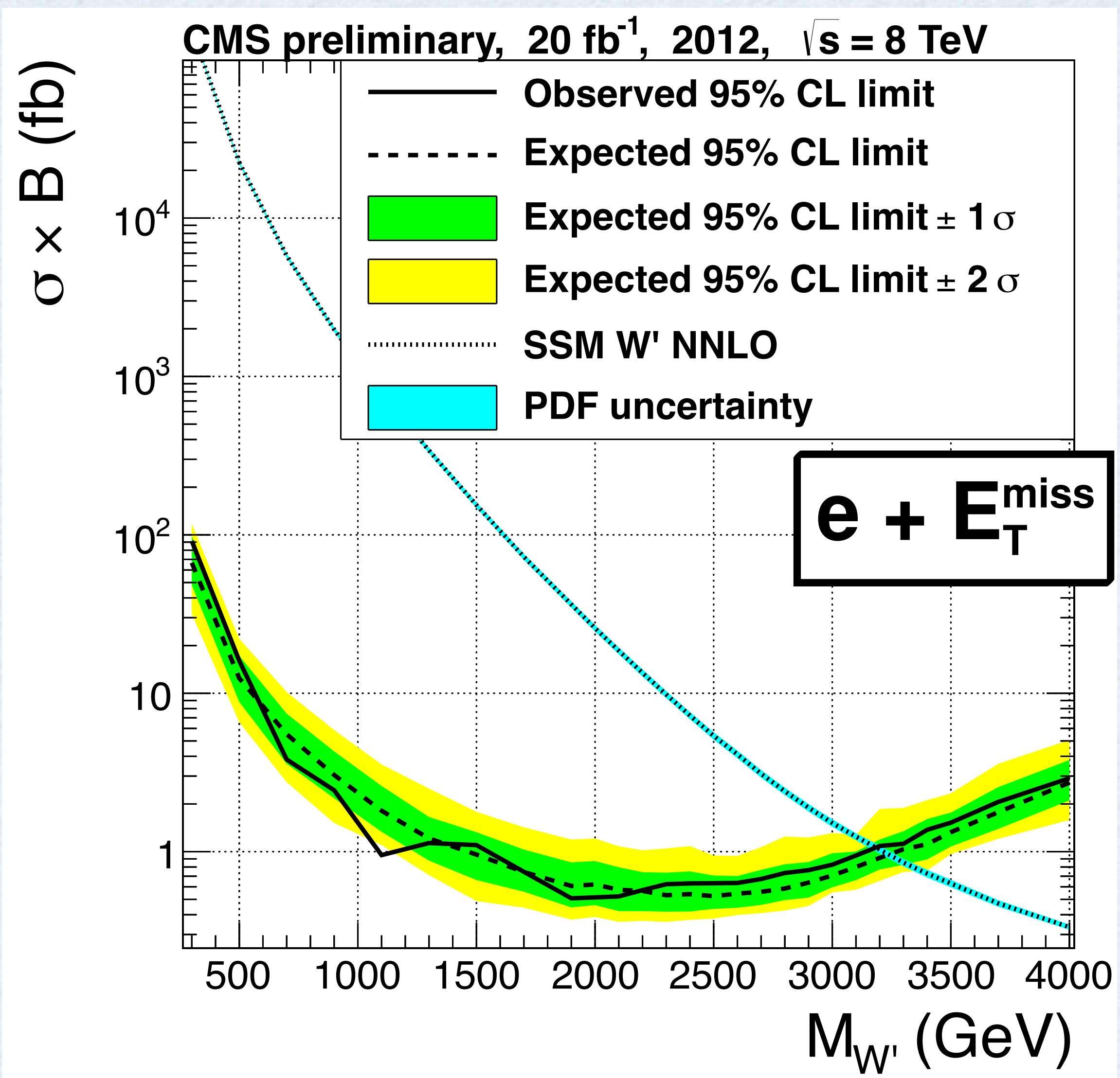


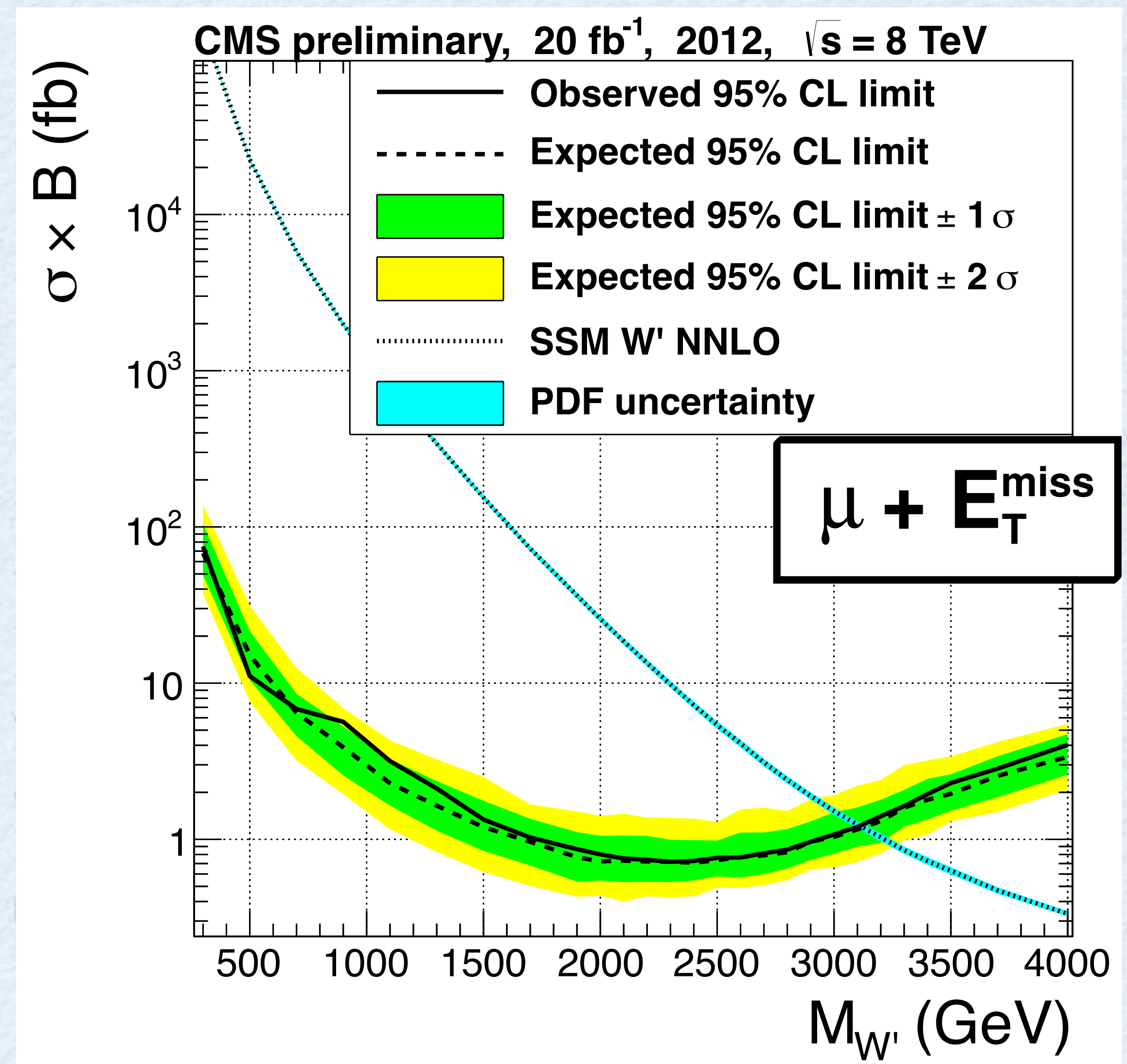
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

20 fb^{-1}

$W' \to \ell\nu$ searches EXO-12-060

$mW'_{SSM} > 3350$ GeV





	$M_T > 1.0$ TeV	$M_T > 1.5$ TeV	$M_T > 2.0$ TeV
Electron channel			
Data	22	1	1
SM background	$26^{+2.6}_{-2.4}$	$1.99^{+0.27}_{-0.24}$	$0.218^{+0.037}_{-0.032}$
W', $M_{W'} = 2.5$ TeV	$51^{+1.2}_{-1.2}$	$39^{+0.96}_{-0.94}$	$24^{+0.74}_{-0.72}$
W', $M_{W'} = 3$ TeV	$10^{+0.25}_{-0.25}$	$8.03^{+0.2}_{-0.2}$	$5.91^{+0.17}_{-0.16}$

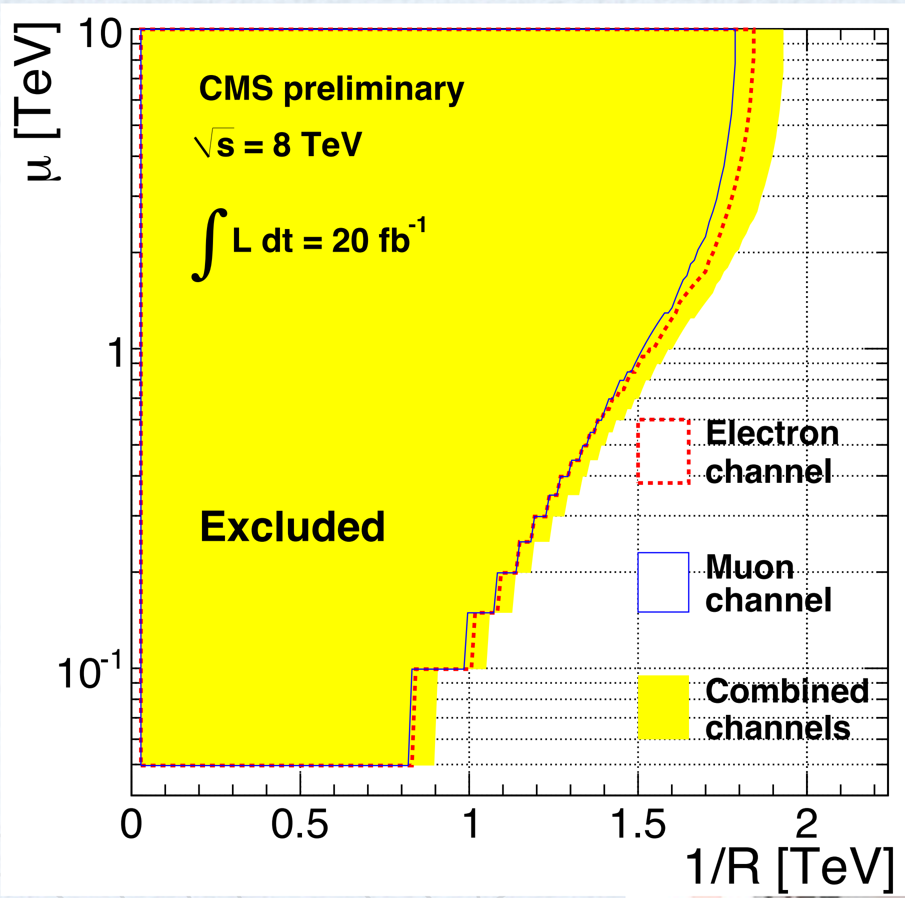
	$M_T > 1.0$ TeV	$M_T > 1.5$ TeV	$M_T > 2.0$ TeV
Muon channel			
Data	33	3	1
SM background	$26^{+4}_{-3.5}$	$2.27^{+0.62}_{-0.49}$	$0.33^{+0.15}_{-0.1}$
W', $M_{W'} = 2.5$ TeV	$47^{+5.4}_{-4.8}$	$35^{+4.9}_{-4.3}$	$20^{+4.8}_{-3.8}$
W', $M_{W'} = 3$ TeV	$9.9^{+1.5}_{-1.3}$	$7.4^{+1.3}_{-1.1}$	$5.15^{+1.2}_{-0.99}$

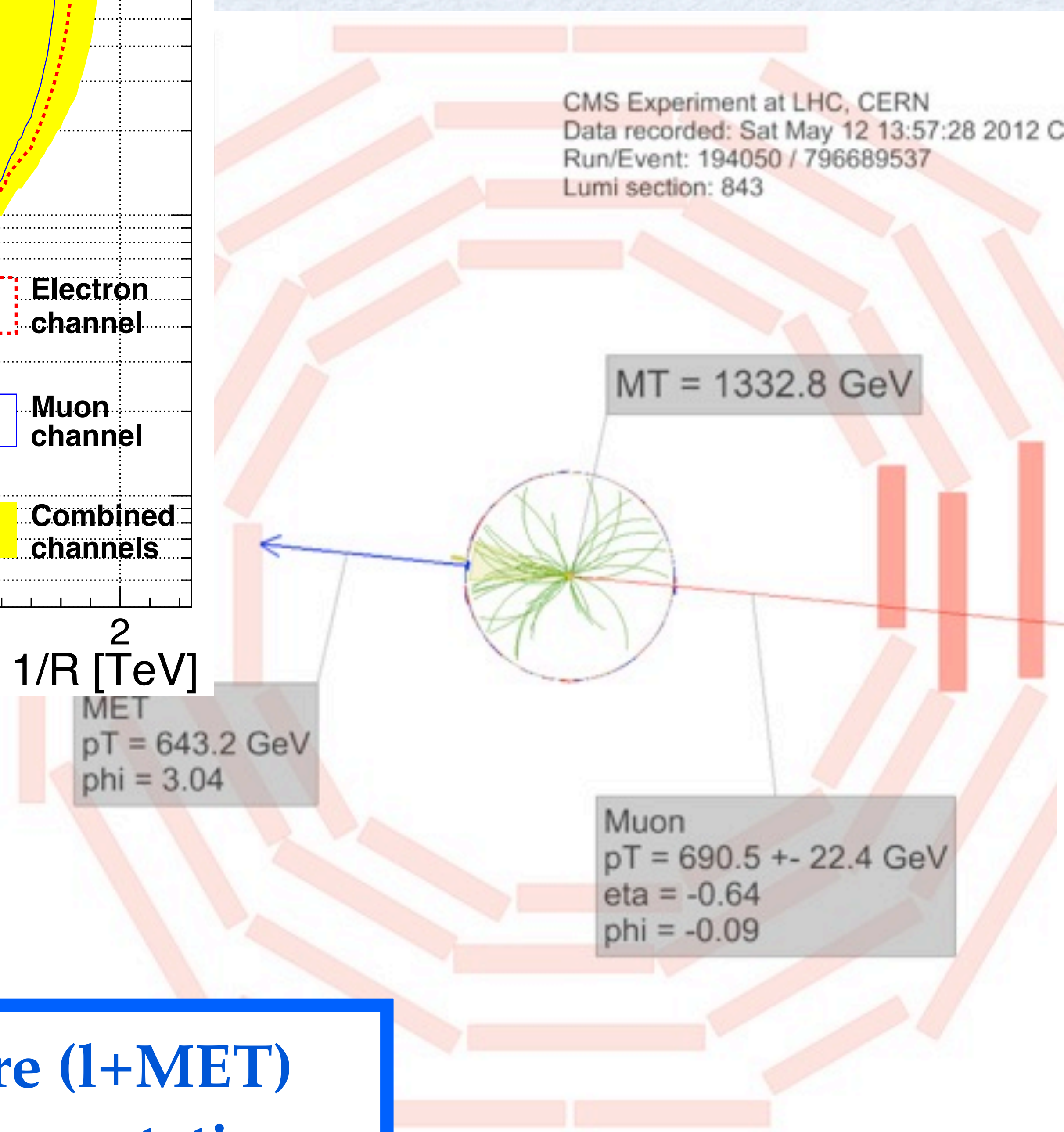
Further ℓ+MET interpretations

20 fb^{-1}

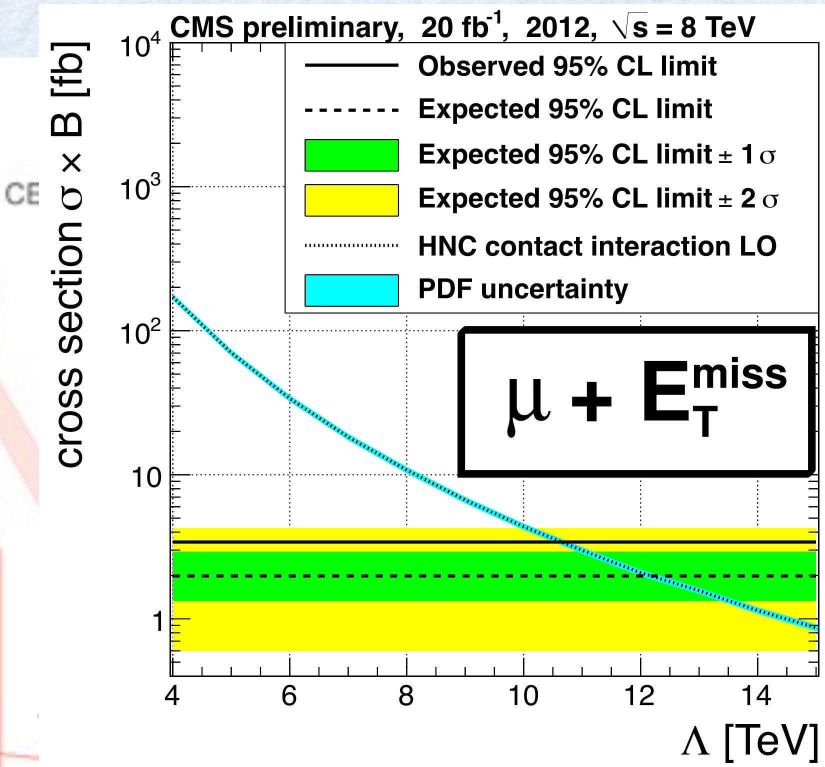
EXO-12-060

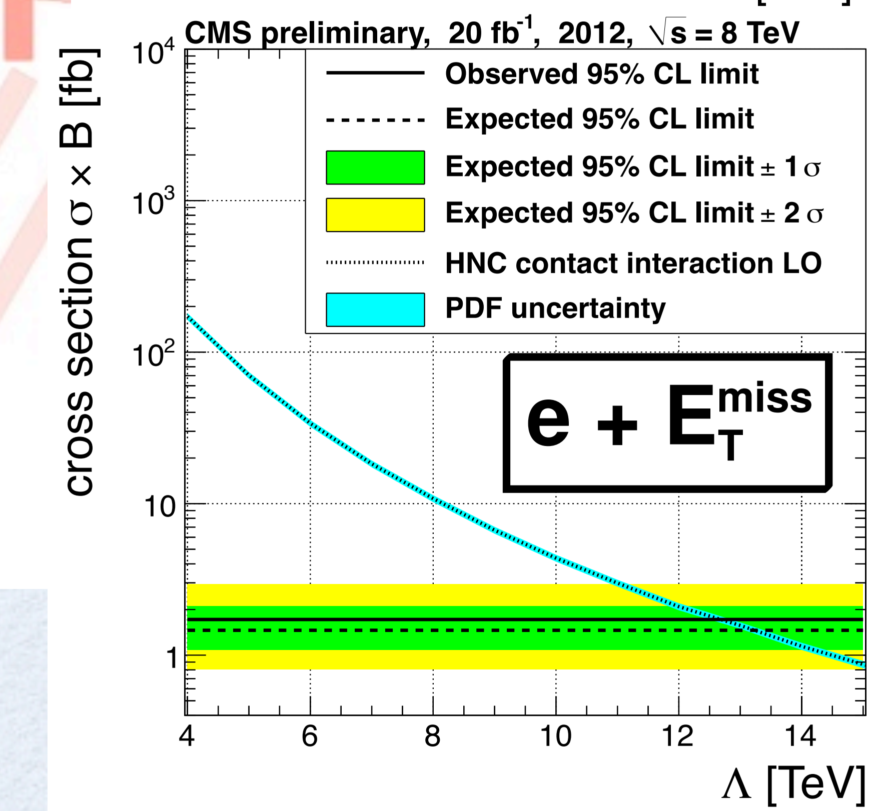
UED





CONTACT INTERACTIONS





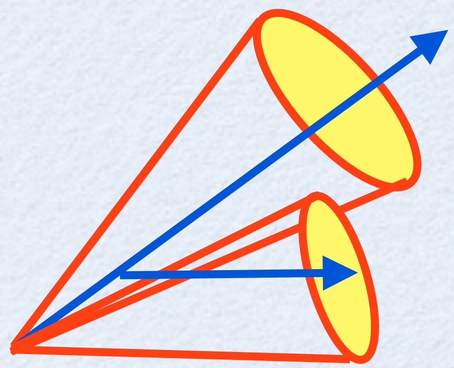
Generic signature (l+MET) allows many interpretations

20 fb^{-1}

Dijet Search

EXO-12-059

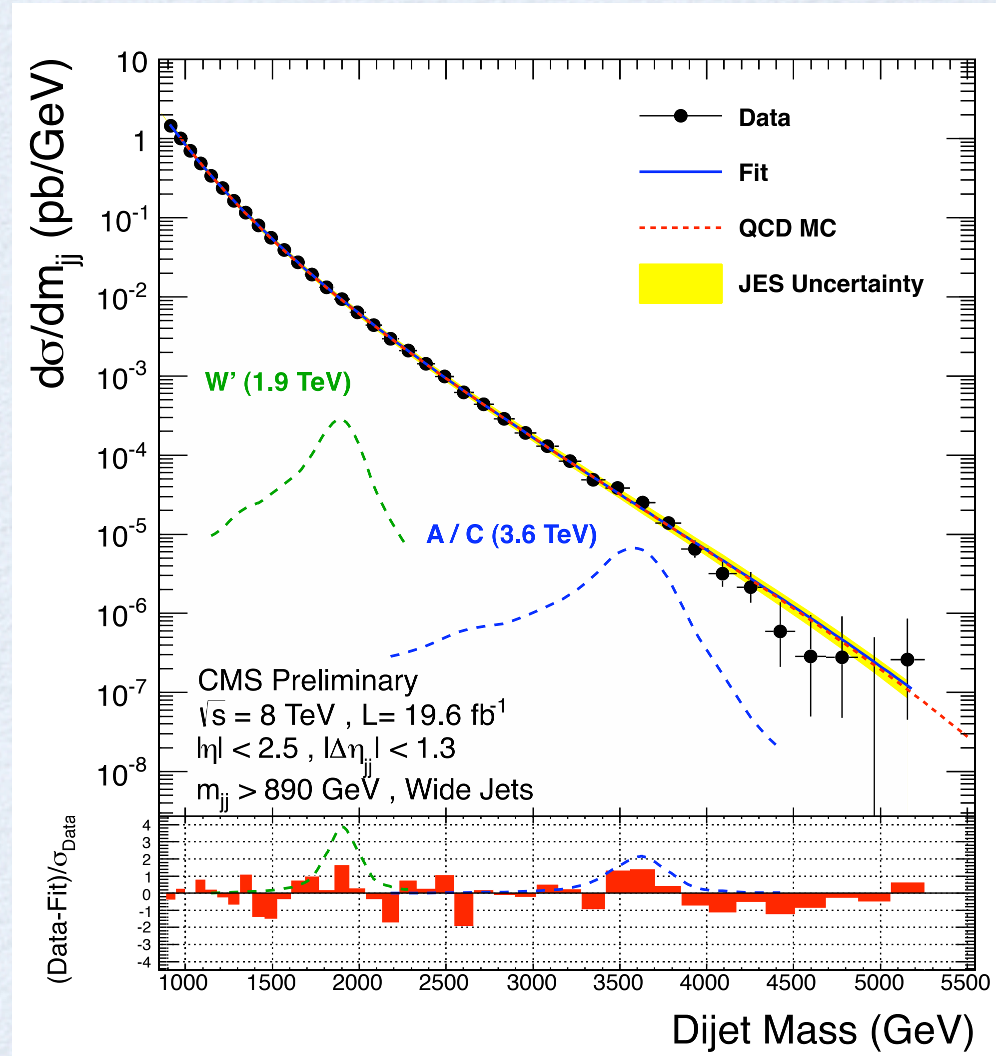
- Build two **wide jets** of ΔR=1.1 around the two highest-pT jets



- AntiKt jets R=0.5 with pT>40 GeV
- Look for secondary jets with ΔR<1.1 around the two leading jets

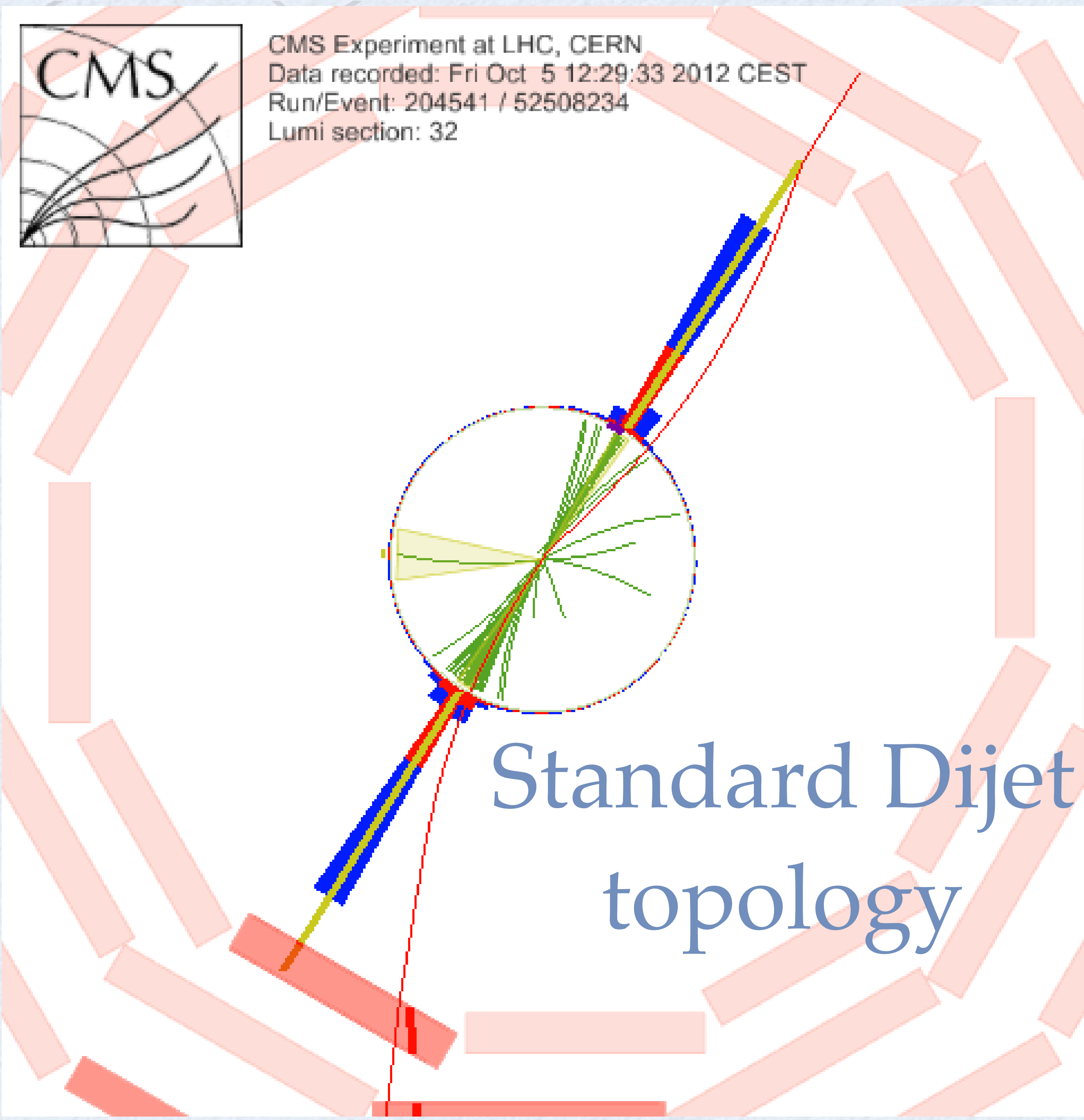
- Widejet selection $|\eta_{wj}|$<2.5, $|\Delta\eta_{wj}|$<1.3

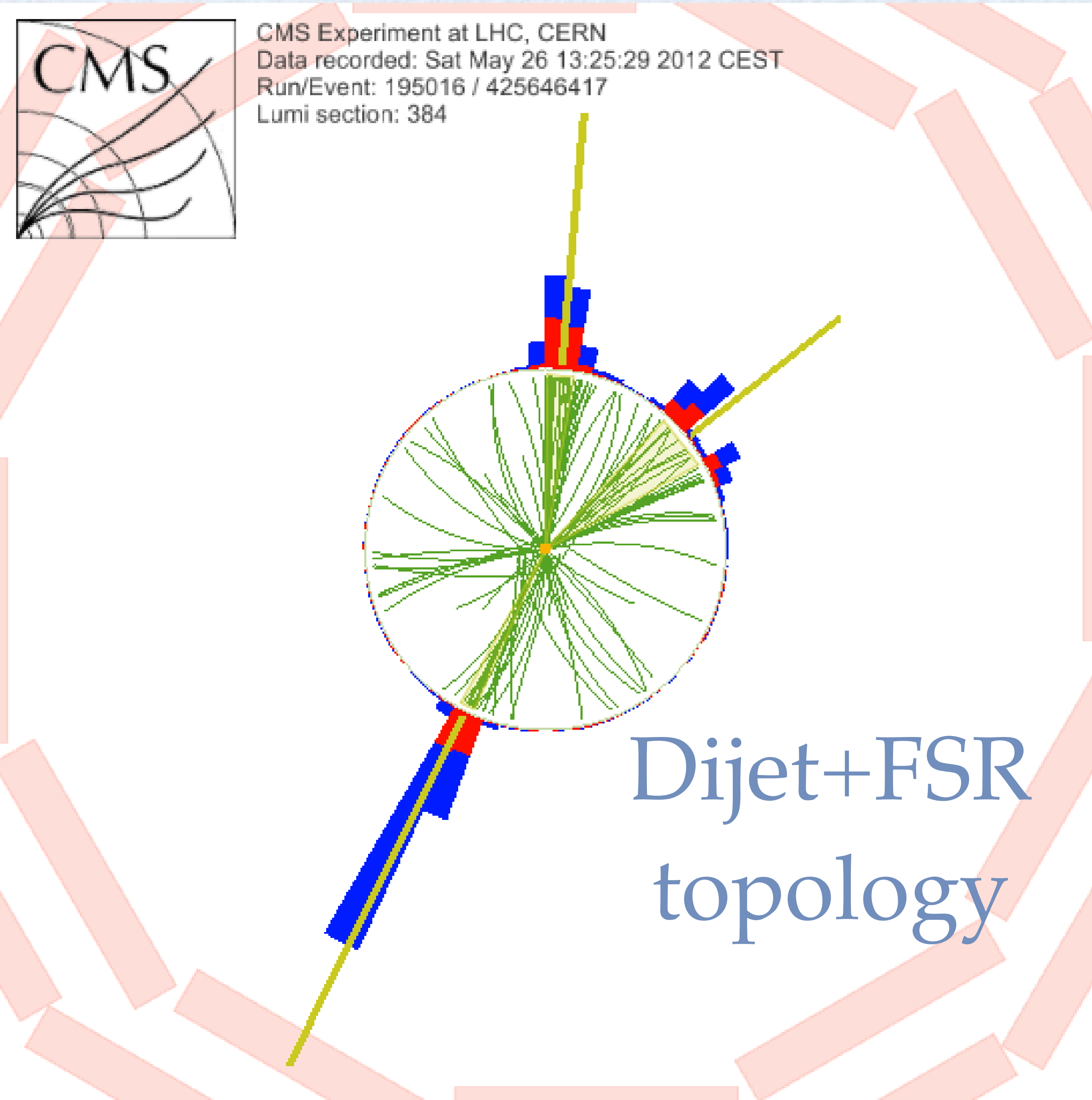
- Study the di-widejet mass spectrum: look for a bump on the falling QCD distribution



- No significant excess seen

Dijet search EXO-12-059



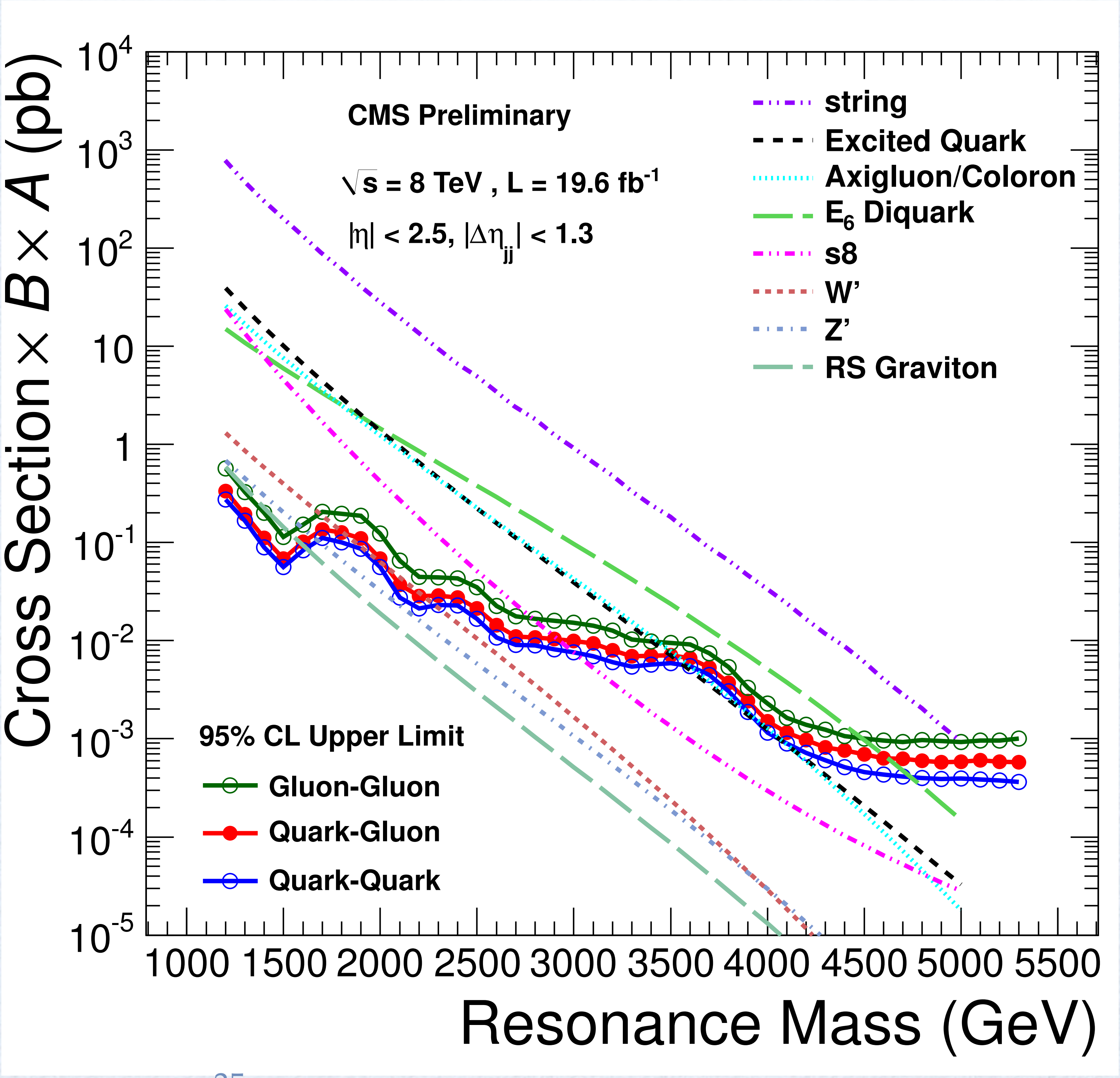


20 fb^{-1}

Dijet Search

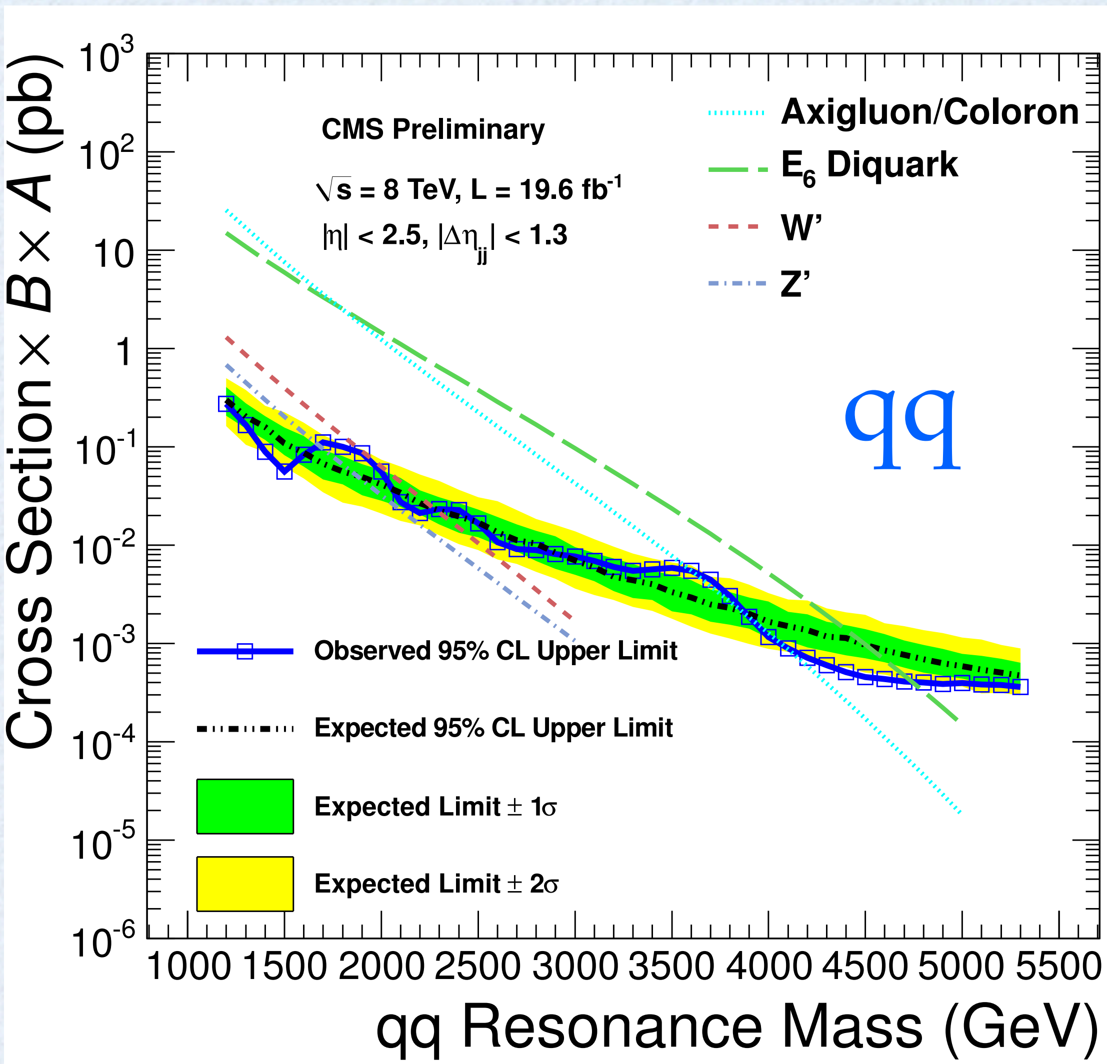
EXO-12-059

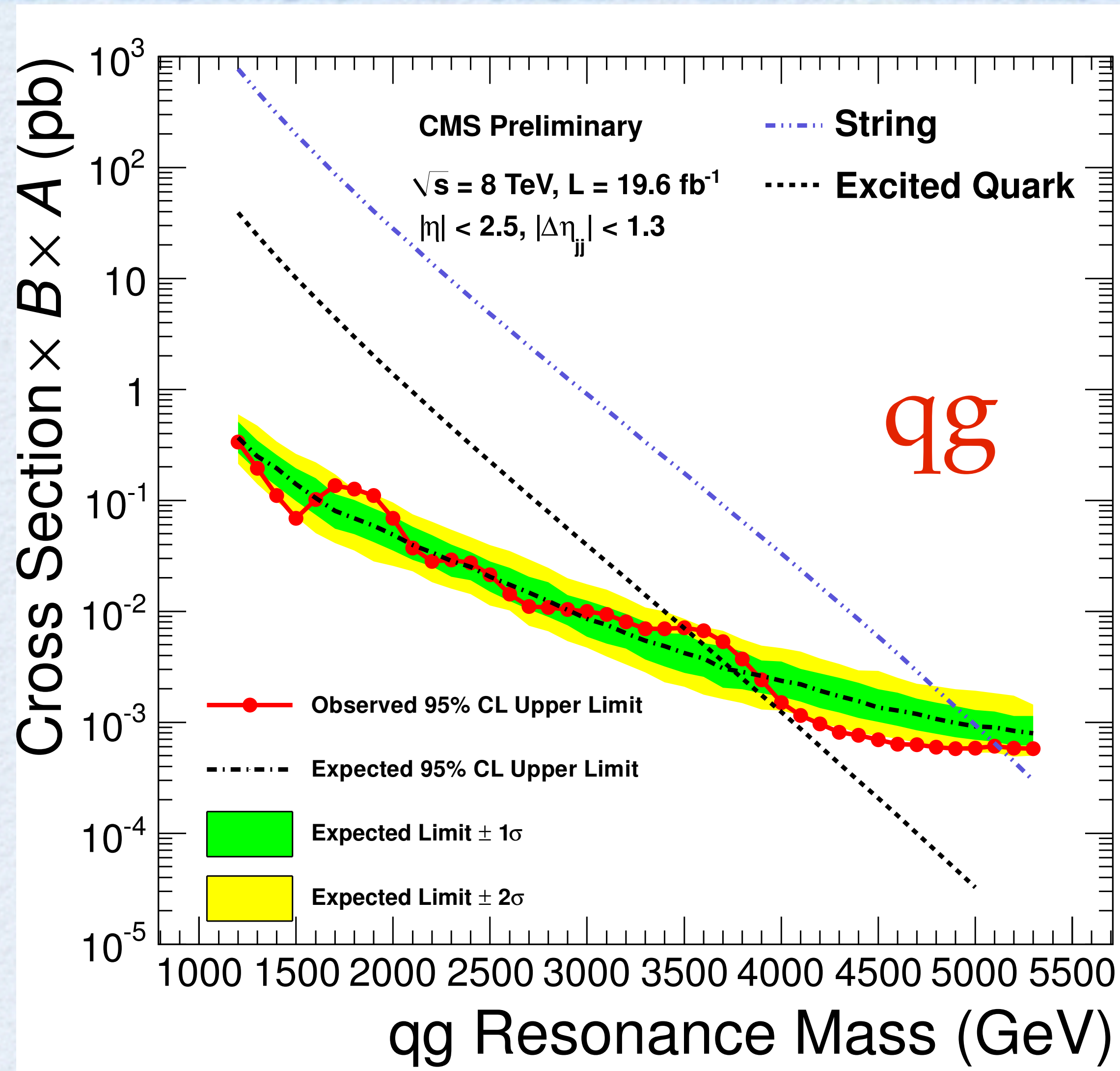
- Model-independent xsec limit on generic qq, qg, and gg final states
- Limit compared to specific models to derive mass lower limits



20 fb^{-1}

Dijet Search EXO-12-059



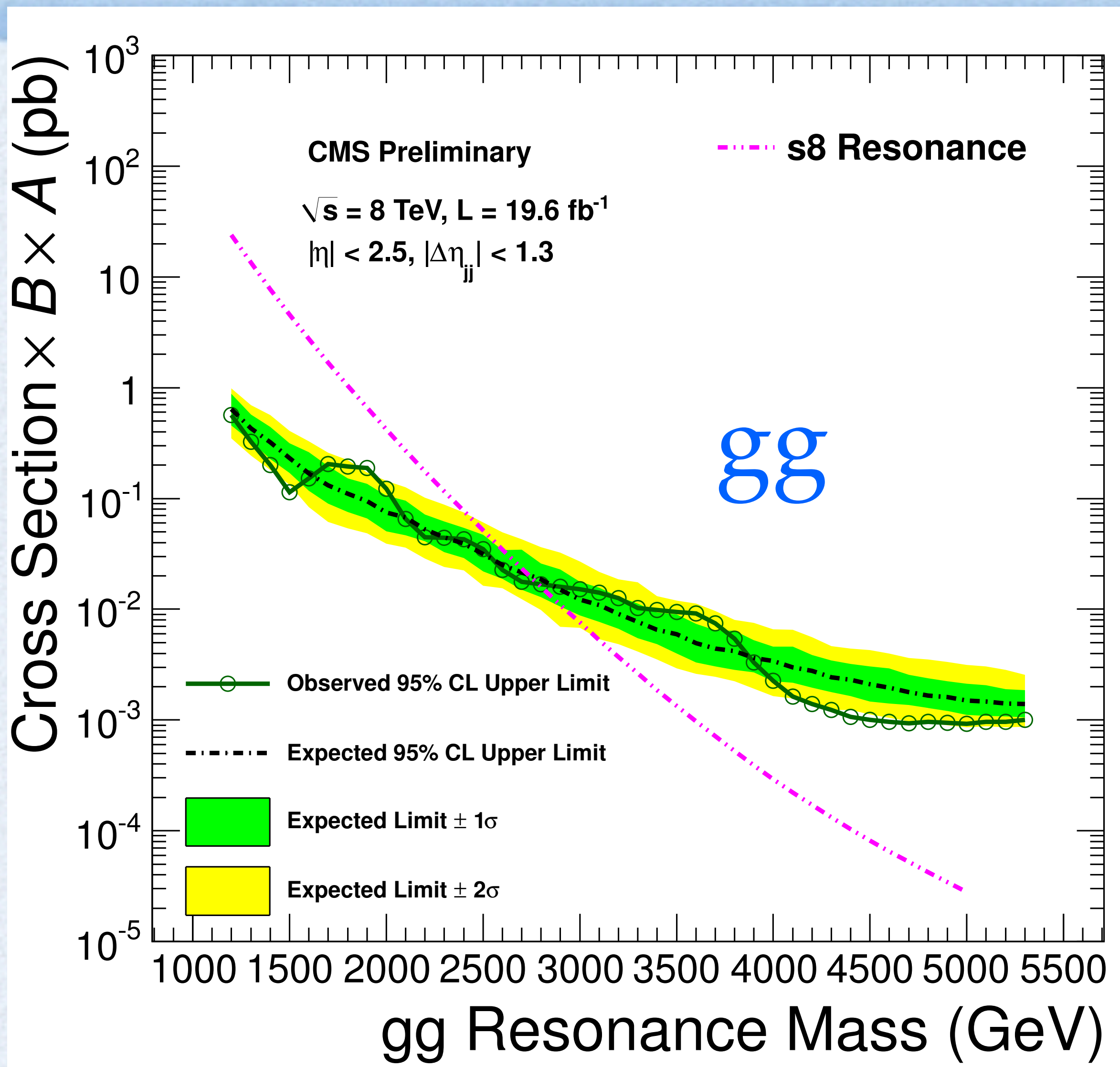


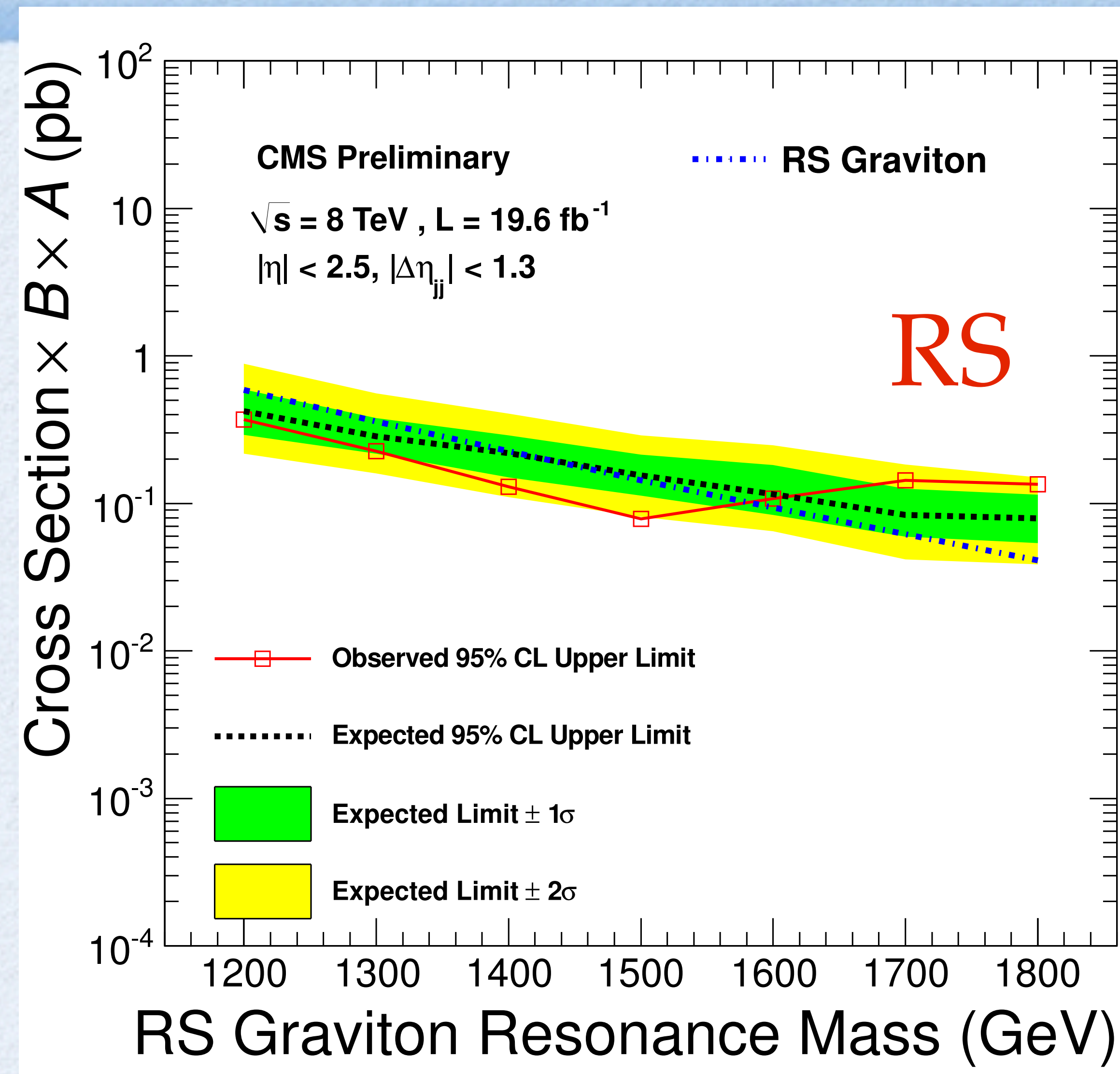
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]

Dijet Search

20 fb^{-1}

EXO-12-059





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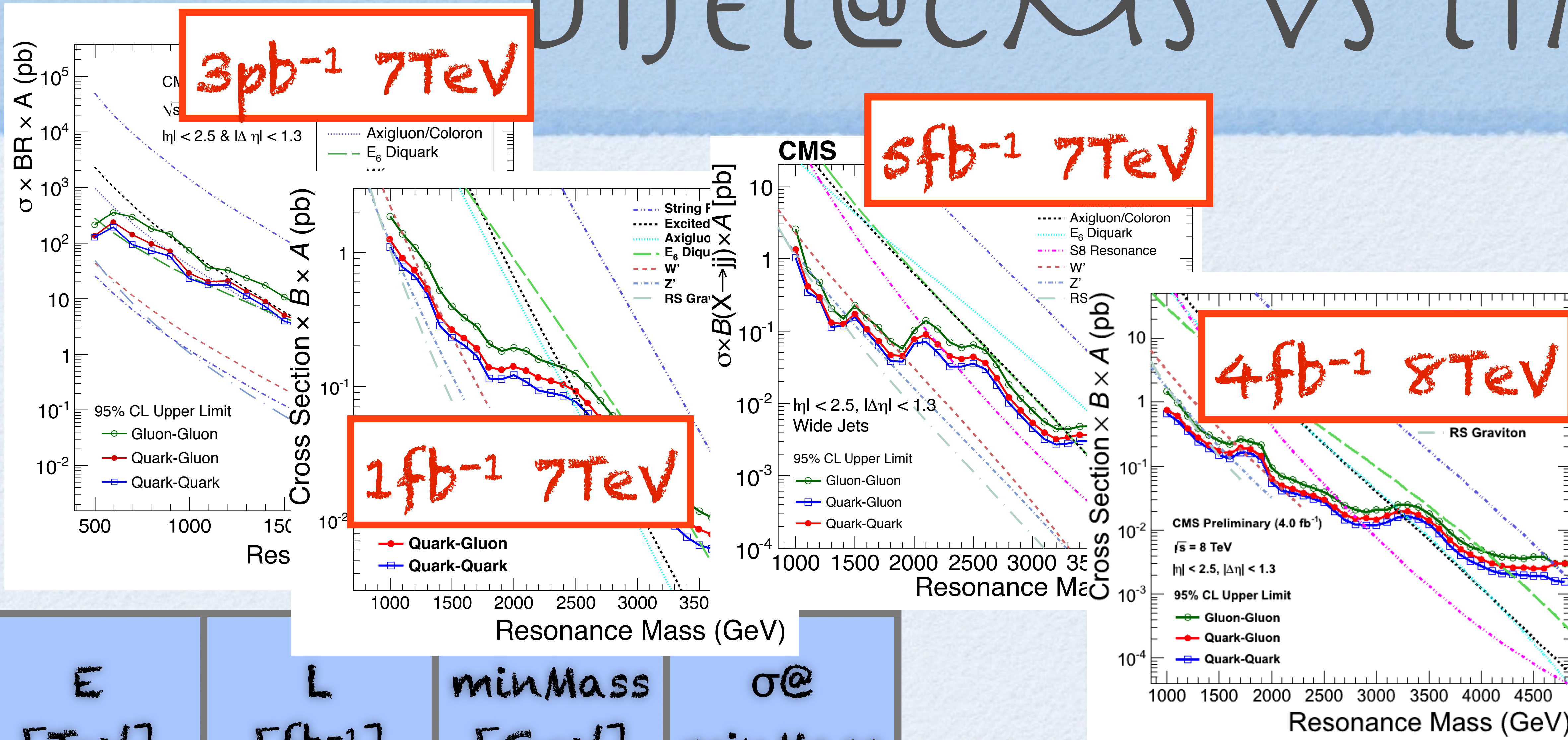
Dijet@CMS vs time

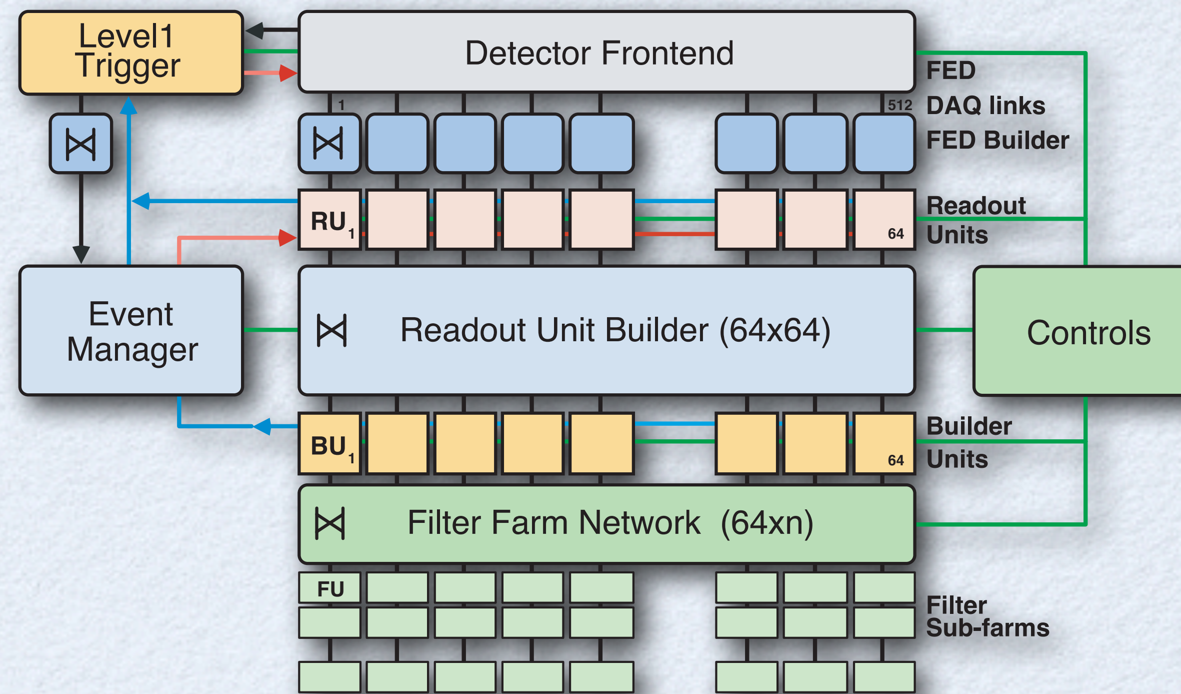


E [TeV]	L [fb^{-1}]	minMass [GeV]	σ@ minMass
7	0.003	400	~ 200 pb
7	1	900	~ 1 pb
7	5	1000	~ 1 pb
8	3	1000	~ 0.6 pb

Lower bound marginally affected by the increase in luminosity (and rate)
Thanks to the use of dedicated triggers running the analysis selection online

FLEXIBILITY @HLT

- Hardware L1 trigger interfaced to the detector (standard)
- No L2/L3 trigger. Instead, software-based trigger running on PC farm
- Running online a faster version of the offline reconstruction
- In principle (and in practice) one could run the analysis selection online
- This is what we do to keep the analyses as efficient as possible

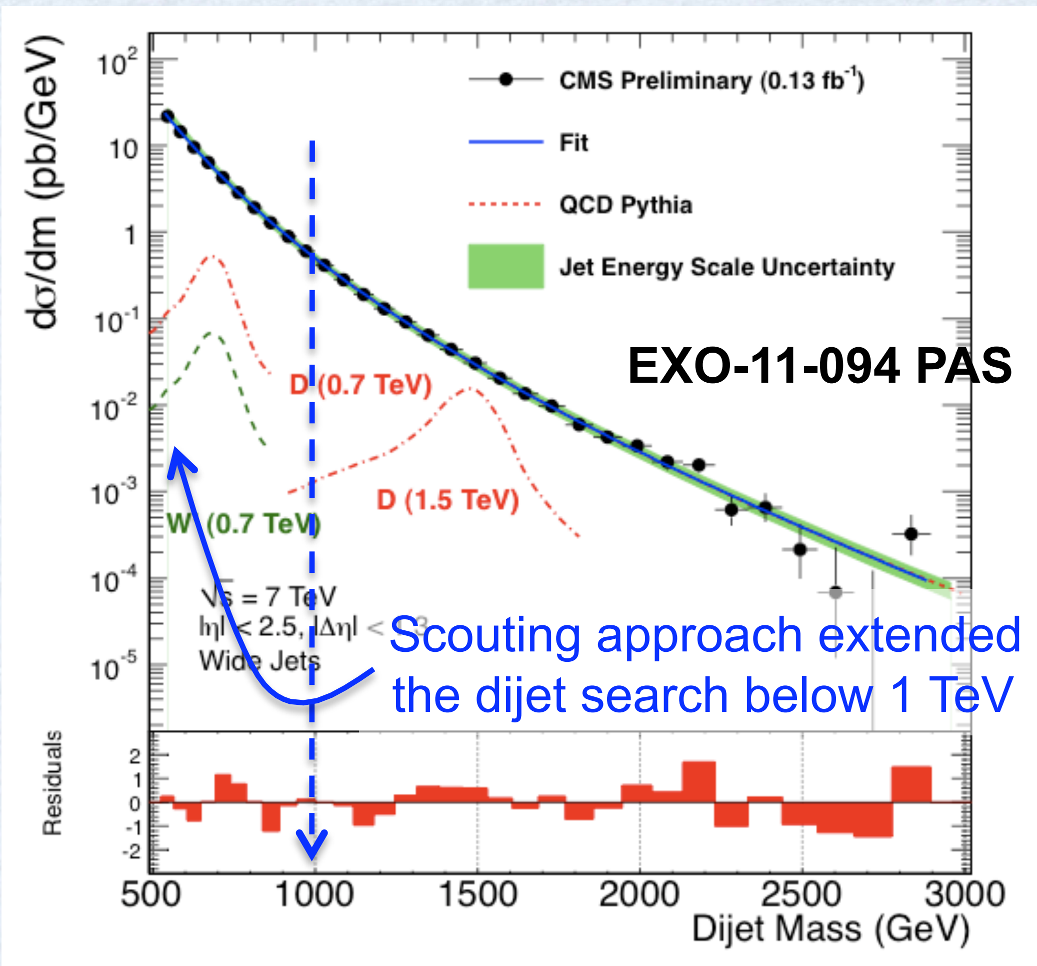


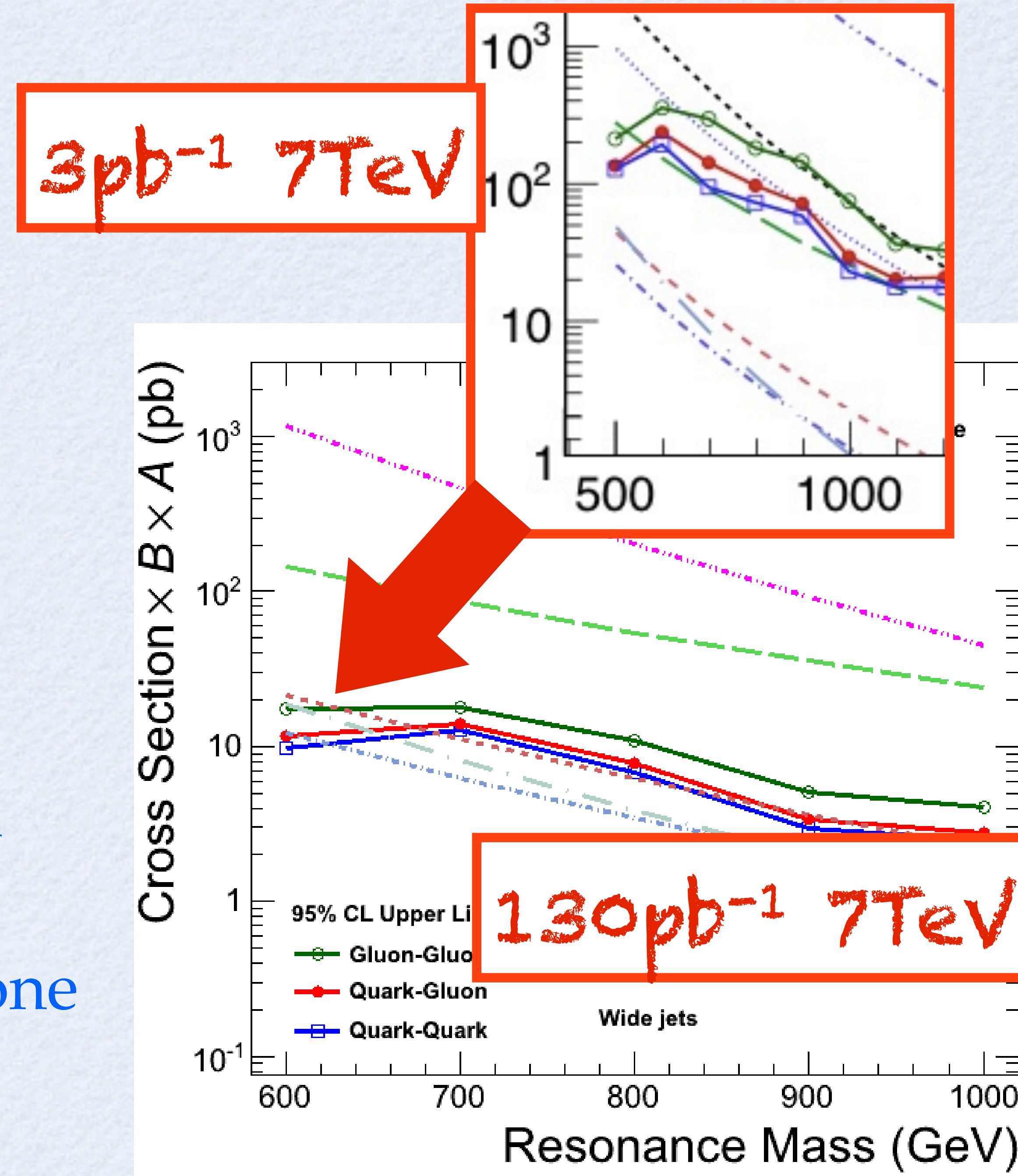
~ 350 Hz of physics taken and reconstructed
~ 600 taken and parked for next year (not enough CPU @T0)

Tuesday, February 26, 13

Flexibility @HLT

Trigger rate ~ kHz for one trigger writing a reduced event content (HLT jet list)





Run for 16h at the end of 2011 run (7TeV)

Collected ~4 times the statistics we had in 2010 (35 pb^{-1}) with equivalent trigger

Improved the limit published in 2010 by one order of magnitude

Similar results @8TeV by Summer

NP Searches in the Higgs Era

- We started the run searching for anything The LHC is a discovery machine, and CMS a multipurpose experiment
- We found something, and we have a better view on the “right” questions natural NP vs unnatural scenarios becoming quantitative
- The run is over, but there is still a lot to learn from these data new searches for specific scenarios, suggested by the Higgs discovery
- The first LHC run was a successful warmup no matter what the new searches will tell us
- But let’s all keep in mind that this is a ~14 TeV machine and the best might still have to come

BACKUP

7Tev +8TeV

HSCP

EXO-12-026

	Selection criteria				Numbers of events			
					$\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
	p_T (GeV/c)	$I_{as}^{(\prime)}$	$1/\beta$	Mass (GeV/c^2)	Pred.	Obs.	Pred.	Obs.
tracker-only	> 70	> 0.4	-	> 0	7.1 ± 1.5	8	32.5 ± 6.5	41
				> 100	6.0 ± 1.3	7	26.0 ± 5.2	29
				> 200	0.65 ± 0.14	0	3.1 ± 0.6	3
				> 300	0.11 ± 0.02	0	0.55 ± 0.11	1
				> 400	0.030 ± 0.006	0	0.15 ± 0.03	0
tracker+TOF	> 70	> 0.125	> 1.225	> 0	8.5 ± 1.7	7	43.5 ± 8.7	42
				> 100	1.0 ± 0.2	3	5.6 ± 1.1	7
				> 200	0.11 ± 0.02	1	0.56 ± 0.11	0
				> 300	0.020 ± 0.004	0	0.090 ± 0.02	0
muon-only	> 230	-	> 1.40	-	—	—	5.6 ± 2.9	3
$\|Q\| > 1e$	-	> 0.500	> 1.200	-	0.15 ± 0.04	0	0.52 ± 0.11	1
$\|Q\| < 1e$	> 125	> 0.275	-	-	0.12 ± 0.07	0	0.99 ± 0.24	0

	$\|Q\| < 1e$	tracker-only	tracker+TOF	$\|Q\| > 1e$	muon-only
Signal acceptance	$< 31\%$	$< 32\%$	$< 31\%$	$< 29\%$	$< 13\%$
Expected collision background	20%	20%	20%	20%	20%
Expected cosmic background	50%	-	-	-	80%
Integrated luminosity	2.2%(4.4%) for $\sqrt{s} = 7(8)$ TeV				

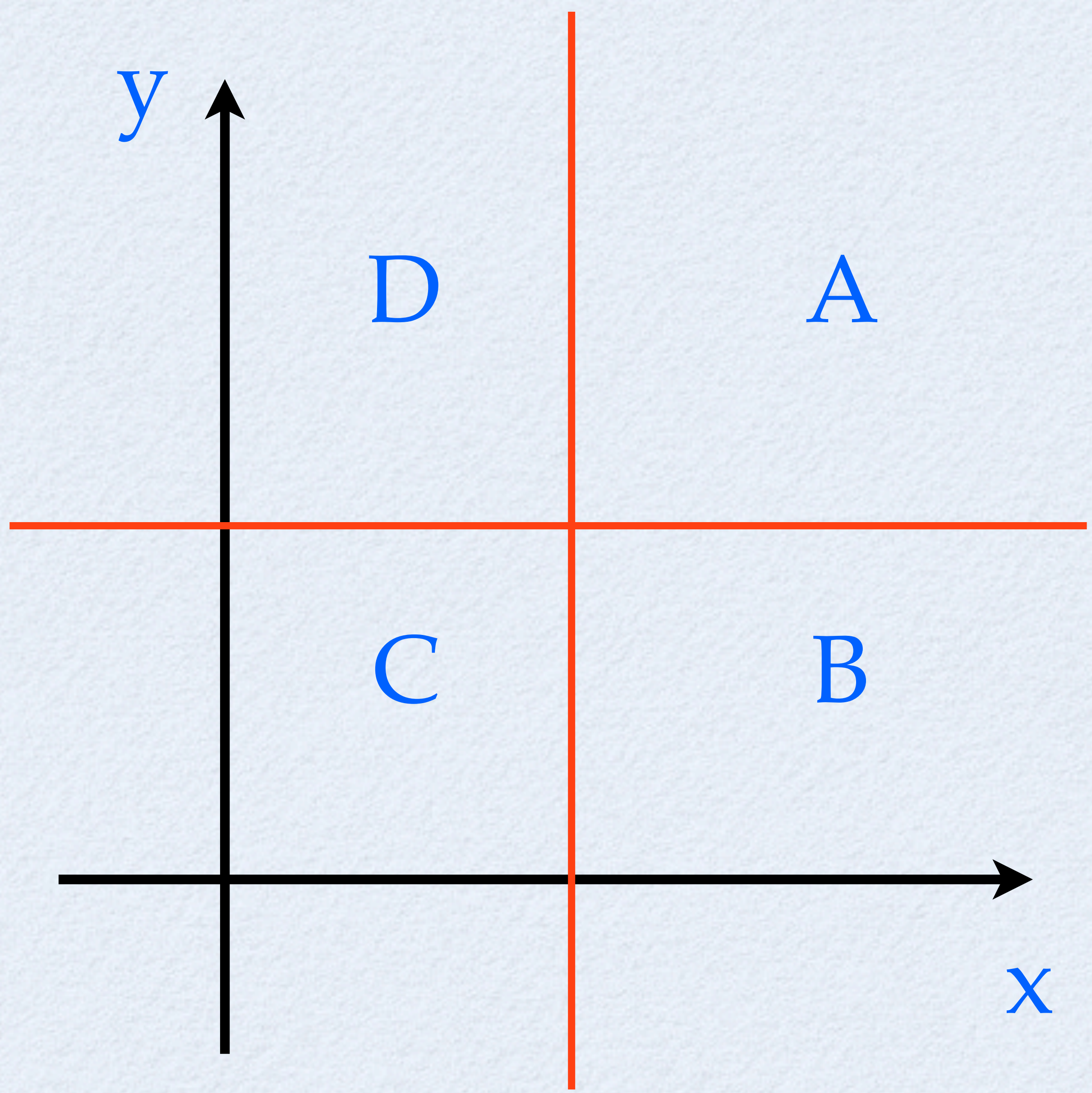
7Tev +8TeV

HSCP

EXO-12-026

Mass (GeV/c^2)	M cut (GeV/c^2)	σ (pb) ($\sqrt{s}=7$ TeV) Exp.	Obs.	Eff.	σ (pb) ($\sqrt{s}=8$ TeV) Exp.	Obs.	Eff.	σ/σ_{th} (7+8 TeV) Exp.	Obs.
Gluino ($f=0.1$) particles with the tracker-only analysis									
300	>100	0.0046	0.0063	0.17	0.0055	0.0055	0.15	3.7×10^{-5}	4.6×10^{-5}
700	>370	0.0028	0.003	0.21	7.7×10^{-4}	8.2×10^{-4}	0.19	0.0016	0.0017
1100	>540	0.0039	0.0039	0.15	0.0011	0.0011	0.14	0.098	0.1
1500	>530	0.0088	0.0081	0.07	0.0021	0.0022	0.07	5	5.4
Gluino ch. suppr. ($f=0.1$) particles with the tracker-only analysis									
300	>130	0.035	0.036	0.02	0.013	0.013	0.05	1.1×10^{-4}	1.2×10^{-4}
700	>340	0.012	0.013	0.05	0.0021	0.002	0.08	0.0044	0.0044
1100	>410	0.018	0.018	0.03	0.0025	0.0026	0.06	0.24	0.24
1500	>340	0.034	0.035	0.02	0.0045	0.0046	0.04	11	11
Gluino ($f=0.5$) particles with the muon-only analysis									
300	-	-	-	-	0.006	0.0065	0.06	5.8×10^{-5}	6.3×10^{-5}
700	-	-	-	-	0.0026	0.0022	0.12	0.0062	0.0051
1100	-	-	-	-	0.0024	0.002	0.13	0.24	0.2
1500	-	-	-	-	0.003	0.0024	0.11	7.5	6.2
Gluino ($f=1.0$) particles with the muon-only analysis									
300	-	-	-	-	0.0066	0.0077	0.05	6.4×10^{-5}	7.4×10^{-5}
700	-	-	-	-	0.0032	0.0027	0.10	0.0075	0.0063
1100	-	-	-	-	0.003	0.0025	0.11	0.3	0.25
1500	-	-	-	-	0.0037	0.0031	0.09	9.5	7.9

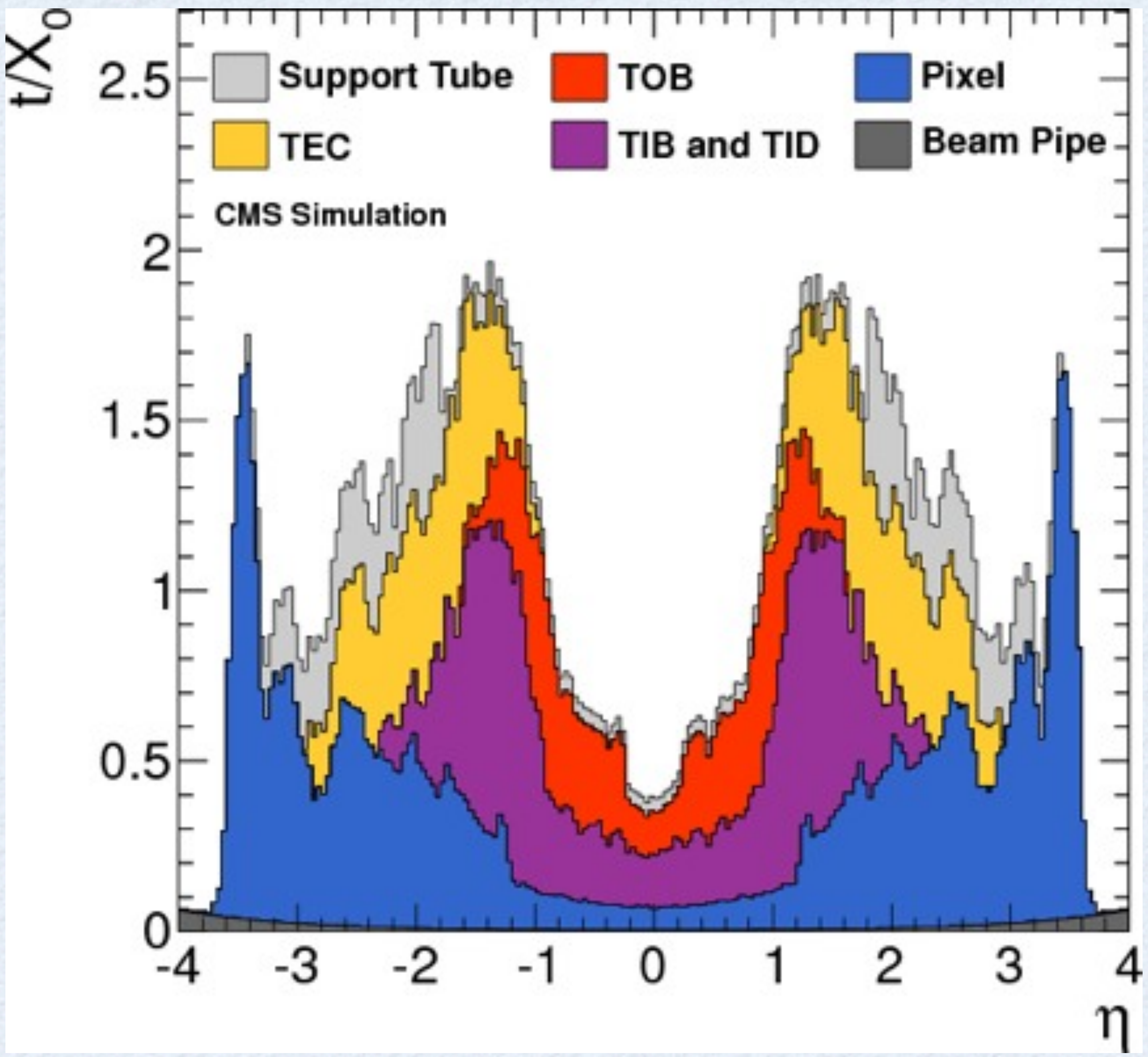
ABCD Method

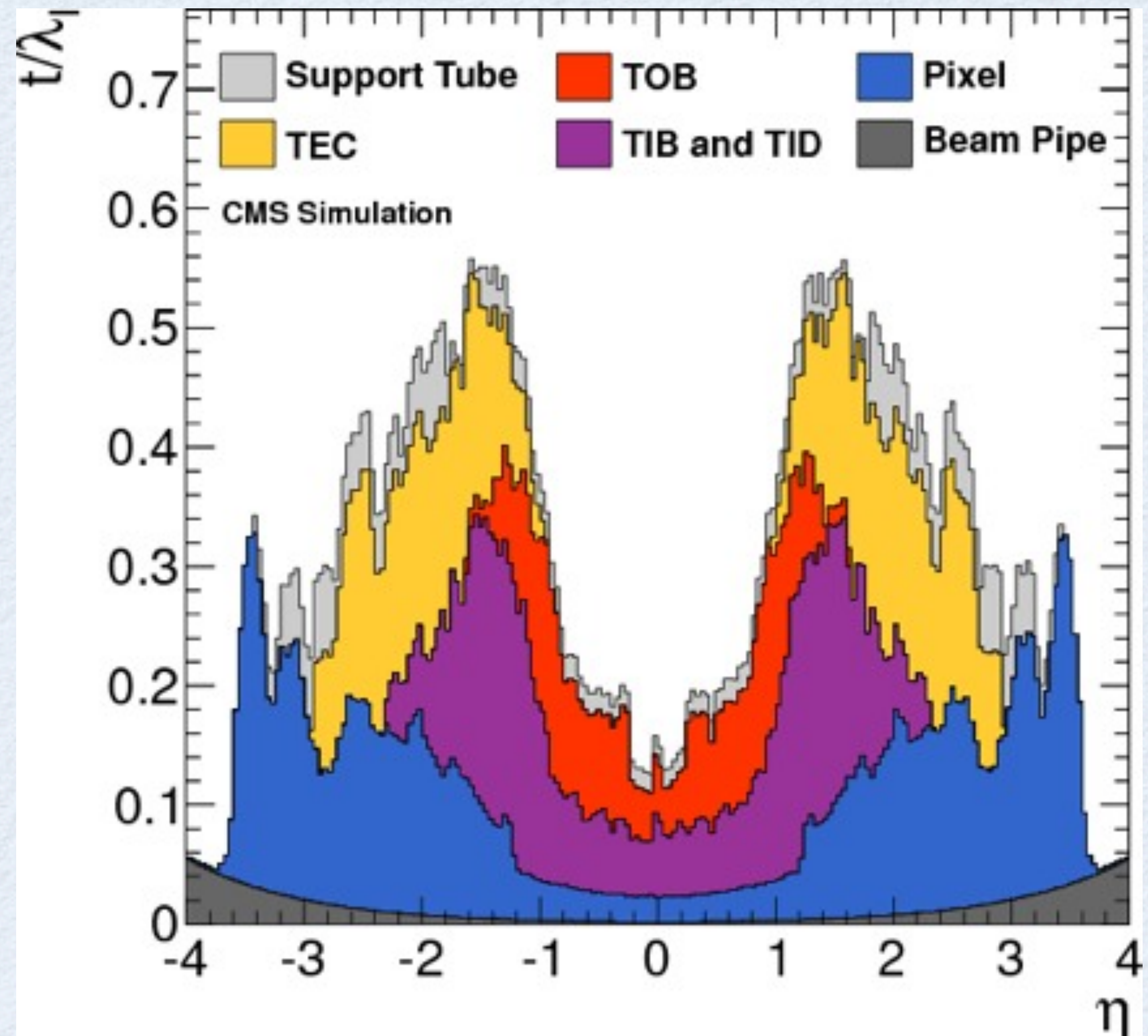


x and y uncorrelated
the observed yield in B,C, and D gives an estimate of A

$N_A = N_B \times N_D / N_C$

Material Budget





HCAL: At eta=0 there is less than 6 interaction lengths of HCAL.
ECAL provides an additional interaction length
ECAL ~25 radiation length (23 cm crystals, 0.9 cm rad length)