BSM Searches at HL LHC

Yuri Gershtein

Trouble with cheering for HL LHC

"We need a leader who is not afraid to dream incremental dreams."

Not necessarily more of the same

- New detectors with new possibilities
  - some may be too expensive and technically challenging, but not more so then 16T magnets and O($10bn) costs
- The new detector physics requirements are formulated and design design choices are done by a much smaller fraction of the community then for original LHC detectors
  - experimentalists are busy with Run 1 and preparations for Run 2
  - theorists are excited about FCC

BSM at Hadron Colliders

- Old nightmare: have we missed anything?
  - record ~500 out of 40,000,000 crossings per second
  - there is a deeply ingrained assumption that the BSM comes with isolated leptons, jets and MET
- If there is a discovery in Run 2, the HL LHC strategy is easy
  - if not – what could be changed for HL run?
  - even if we stay the course for 1/ab, should we stay it for 3/ab or change strategy? What kind of detector would we need then?

Hidden (Dark) Sectors

Strassler, Zurek (2006)
Extra U(1)xSU(n_v) - hidden sector with Z' portal

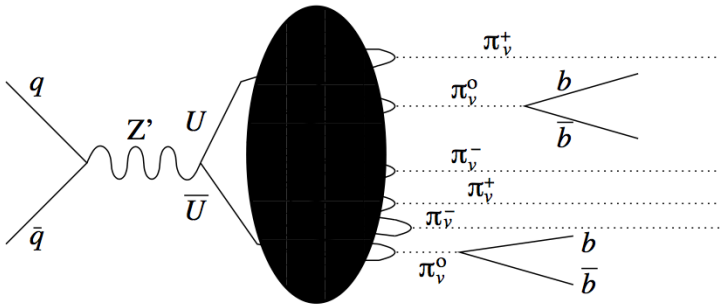
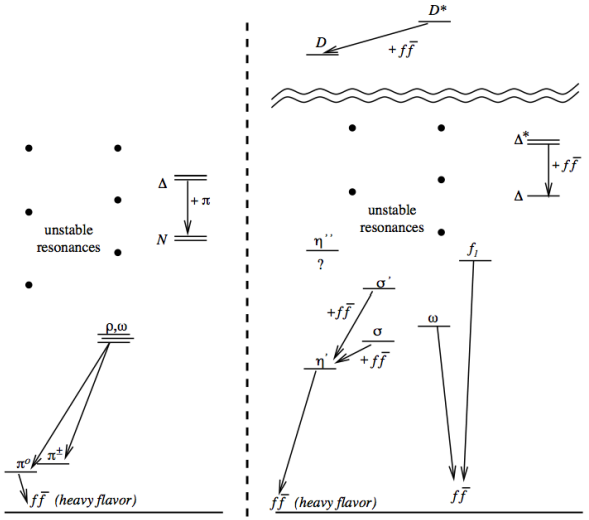


FIG. 3: A possible event in the two-light-flavor regime; note $\pi_v^{\pm}$ is electrically neutral and invisible.



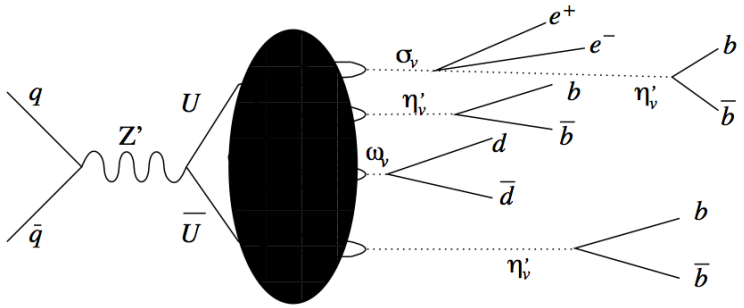


FIG. 4: A possible event in the one-light-flavor regime.

Looks like a strange dijet event

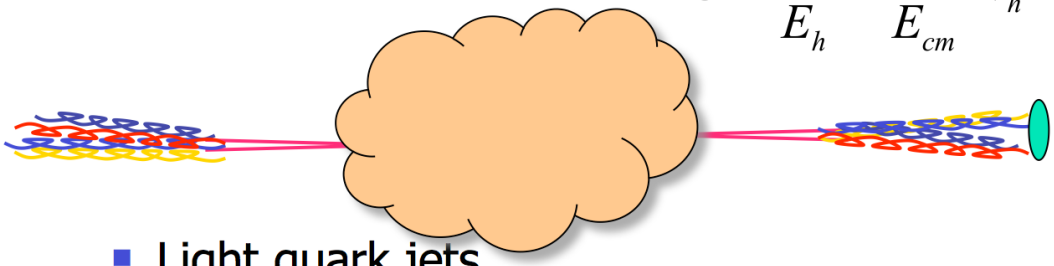
- *may have a lot of particles staying in the dark sector (MET) - Z' may be heavy, but visible ST can be small!!*
- *may have some long-lived particles inside the jets*
- *more massive particles - shorter lifetime, but that results in different event shape*
- *generically ~prompt when M>20-30 GeV*

Hidden Valleys without LLP

Zurek (2006)

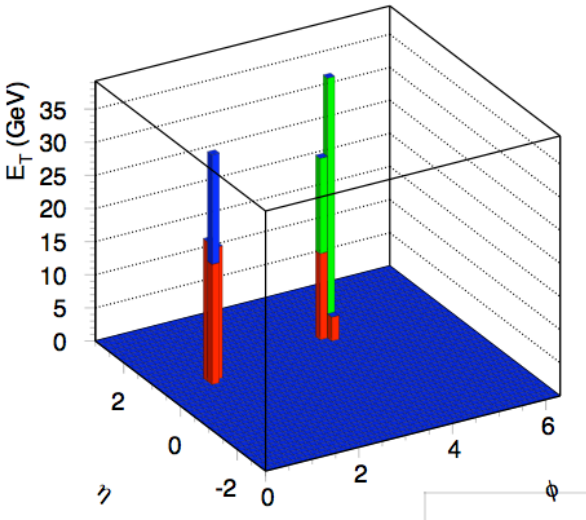
- Shape of event set by v-hadron mass

$$\theta \sim \frac{p_\perp}{E_h} \sim \frac{p_\perp}{E_{cm}} N_h$$

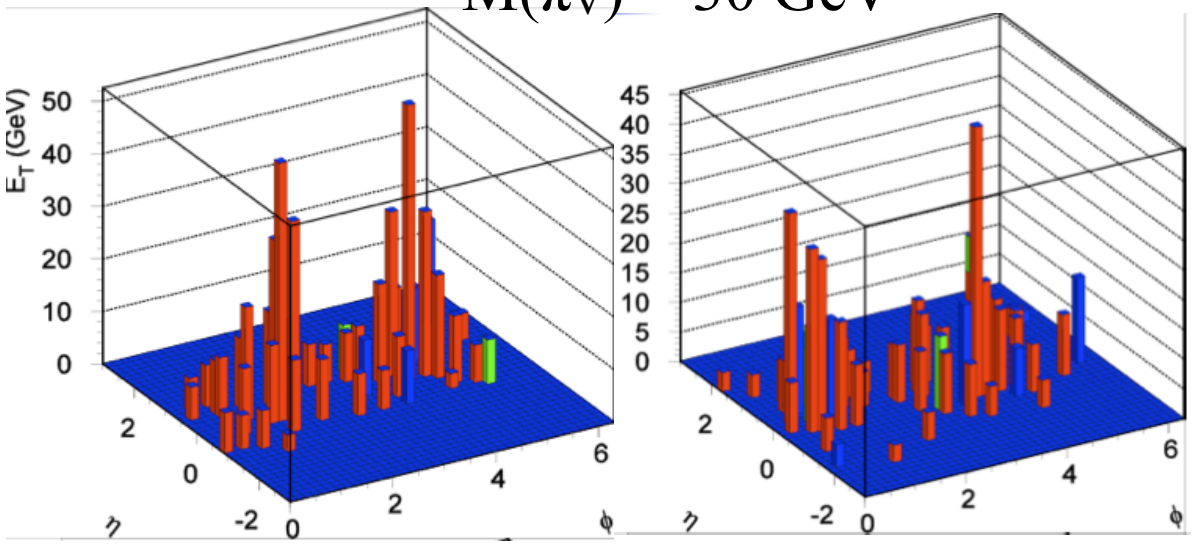


- Light quark jets
- vs. Hidden valley jets--larger opening angles due to higher mass v-hadrons

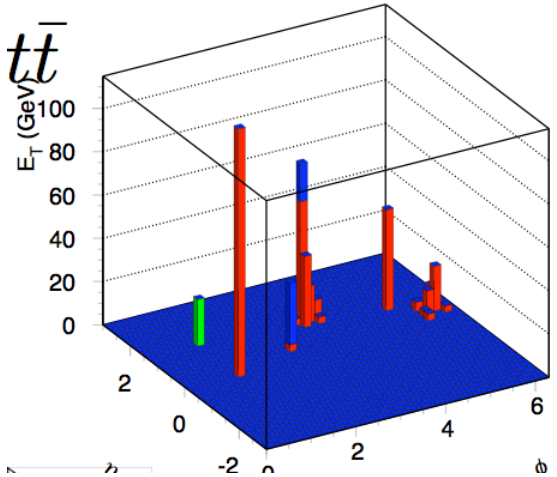
$b\bar{b}$



$M(\pi_V) = 30$ GeV



$t\bar{t}$

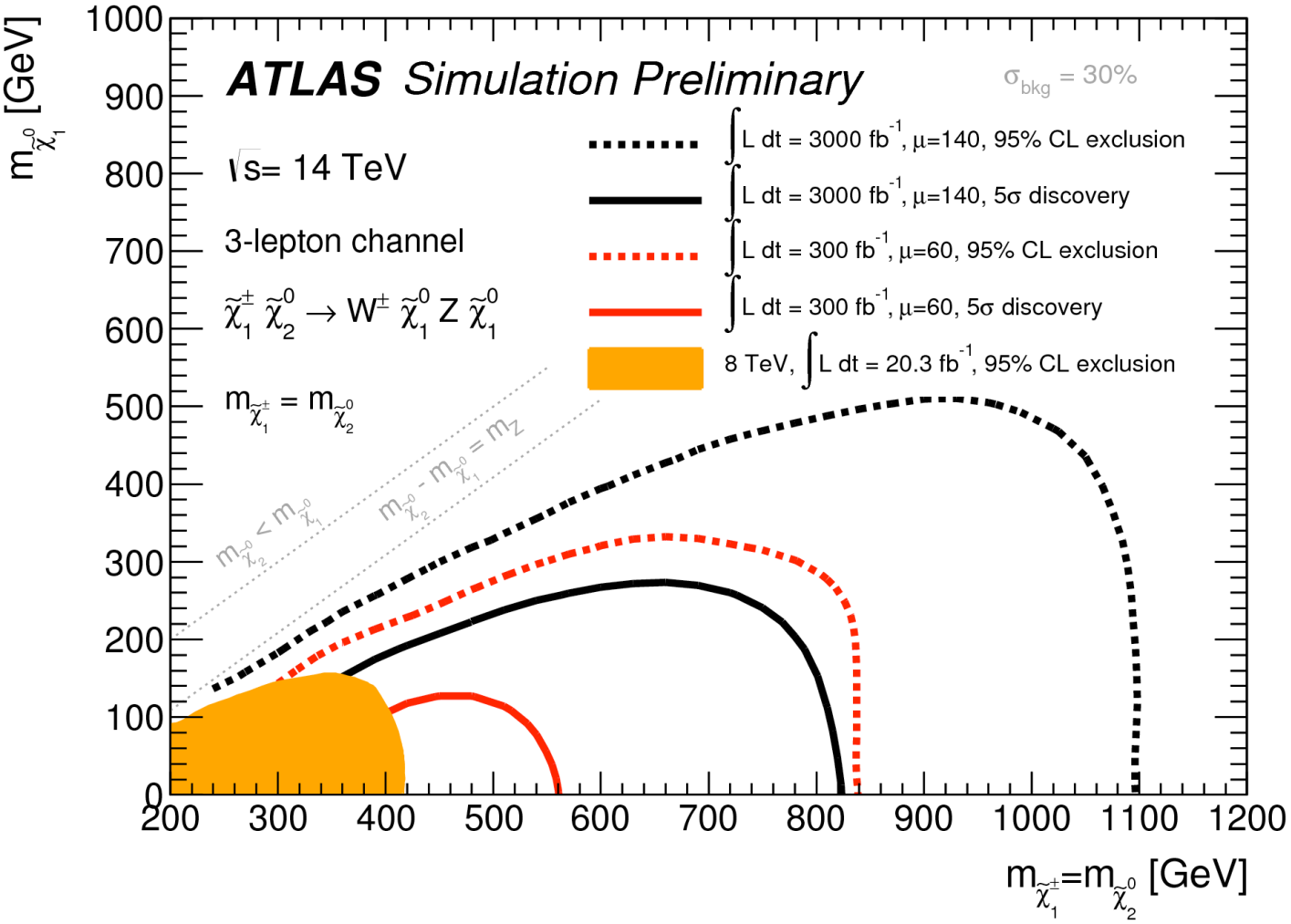


Outline

- a bit on the physics program
- New detectors
- Trigger
- Backgrounds

Long Hard Slog

- Works best for light particles with small cross sections
- I.e: SUSY EWKinons:



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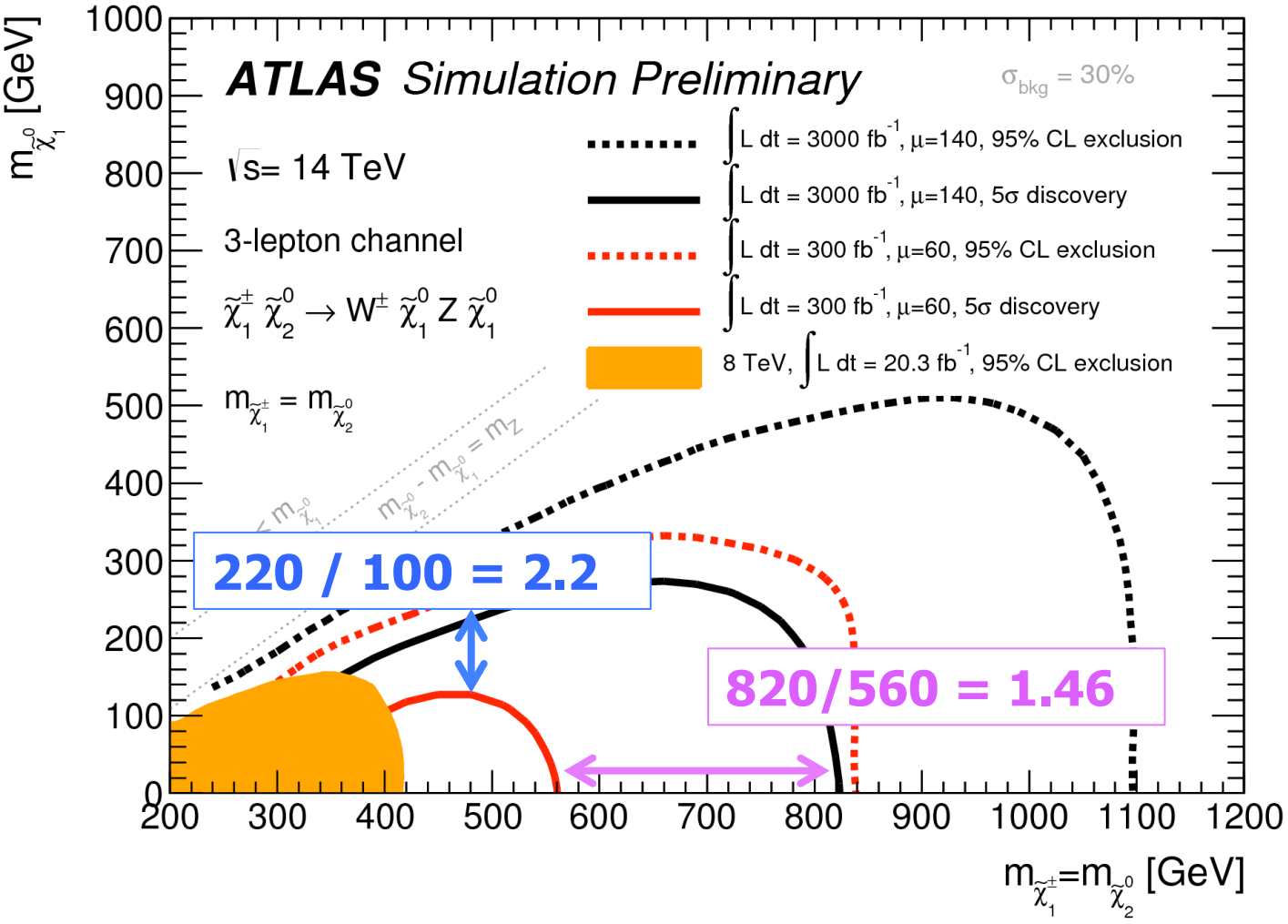
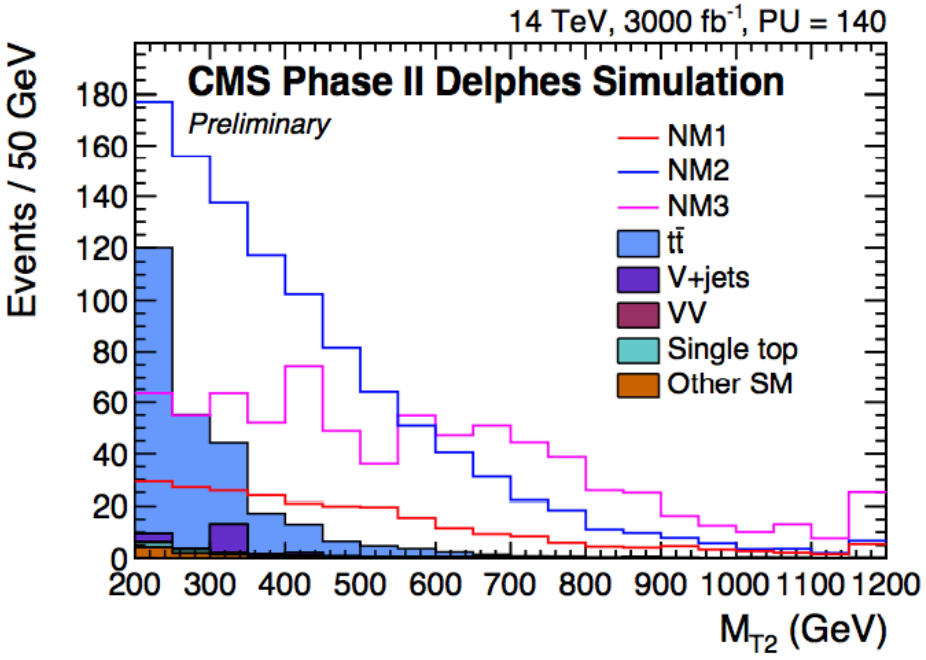
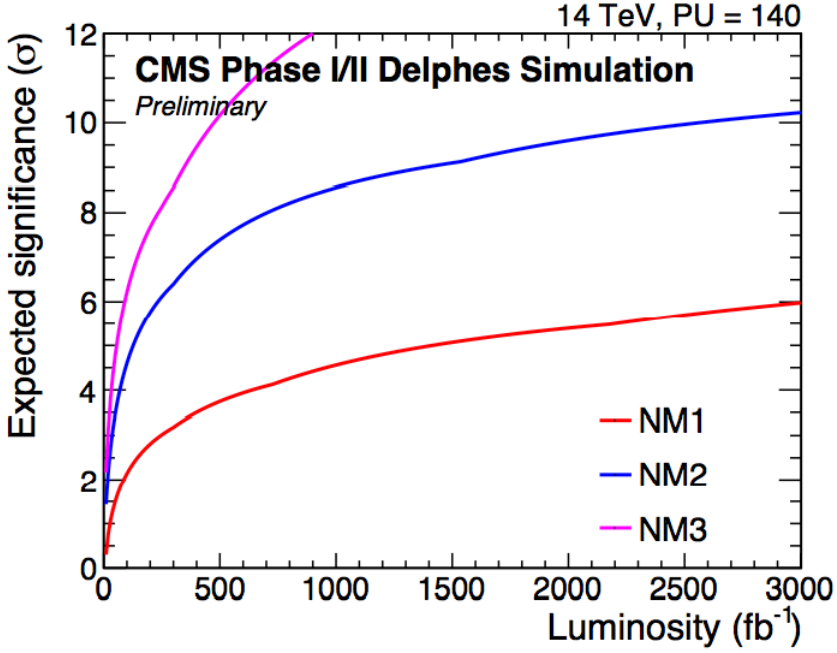


Long Hard Slog

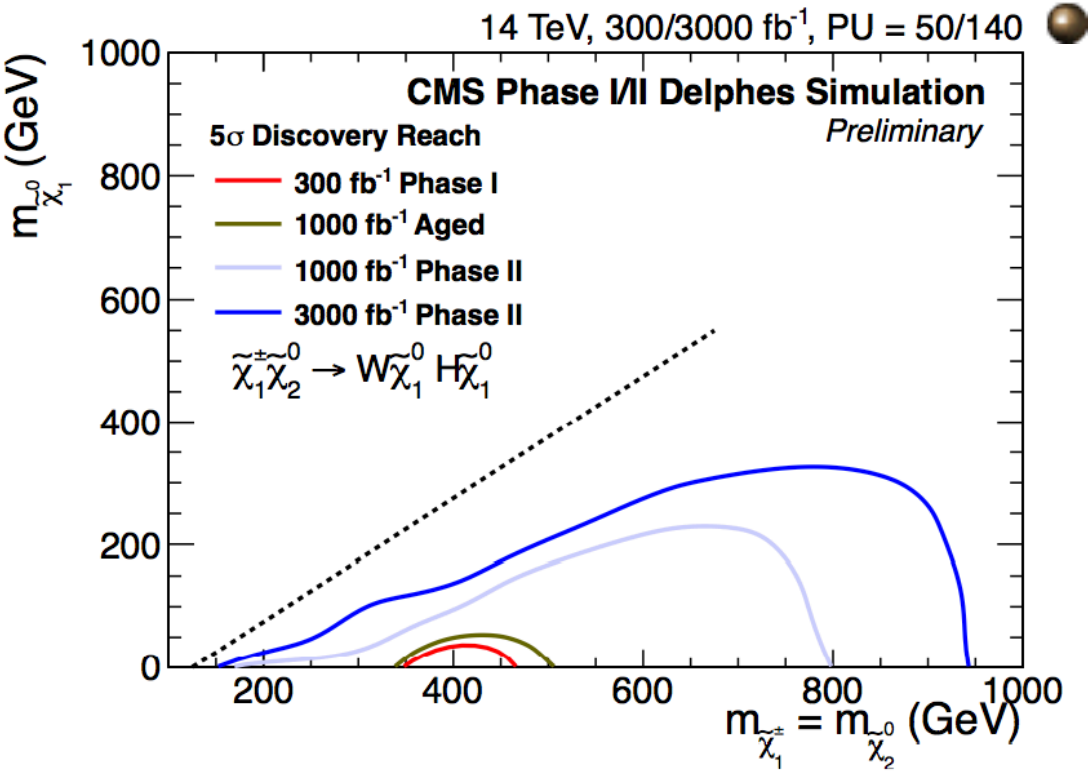
- Three example models
  - Gluino at ~1.7 TeV, stops and sbottoms at 1.1 TeV
  - different gaugino sectors
- M_{T2} search for Natural SUSY
  - Lepton veto
  - $N_j >= 8$, $H_T > 2$TeV, $N_b > 3$





Need for New Detector

lepton + bb + MET



- Degradation from
  - b-tagging x 0.67
  - trigger:
    - e: pT> 40 GeV -> 50 GeV
    - μ: $|\eta|$<2.4 -> 1.1
  - Lepton identification x 0.84
  - some degradation from reduced MET resolution due to calorimeter radiation damage

Rare / exotic Higgs decays

- That's what the integrated lumi is good for!
- conventional wisdom:
  - can get a large "unbiased" Higgs sample from triggering on
    - $W \rightarrow l\nu$
    - forward jets from VBF
  - same VBF jets can greatly reduce the SM backgrounds

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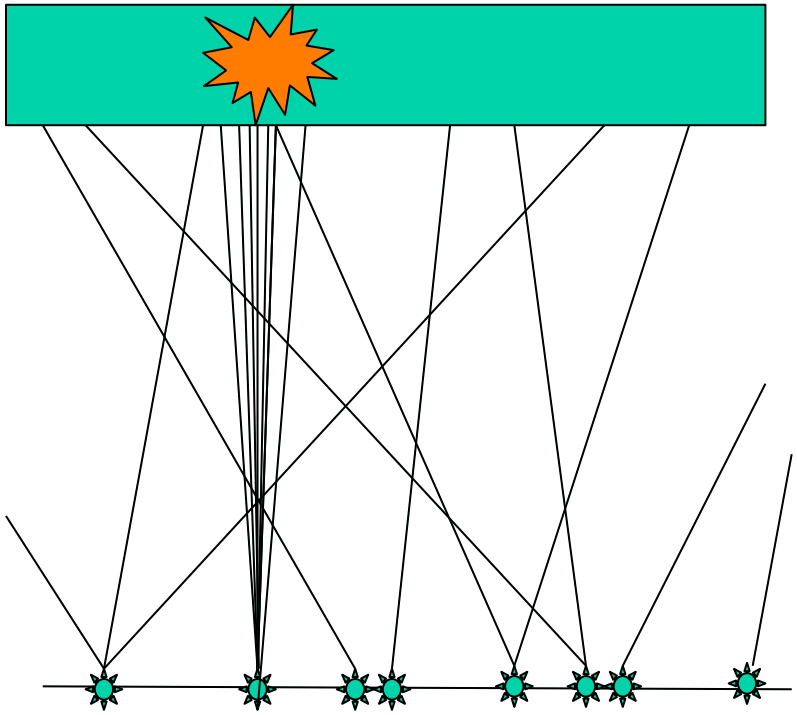
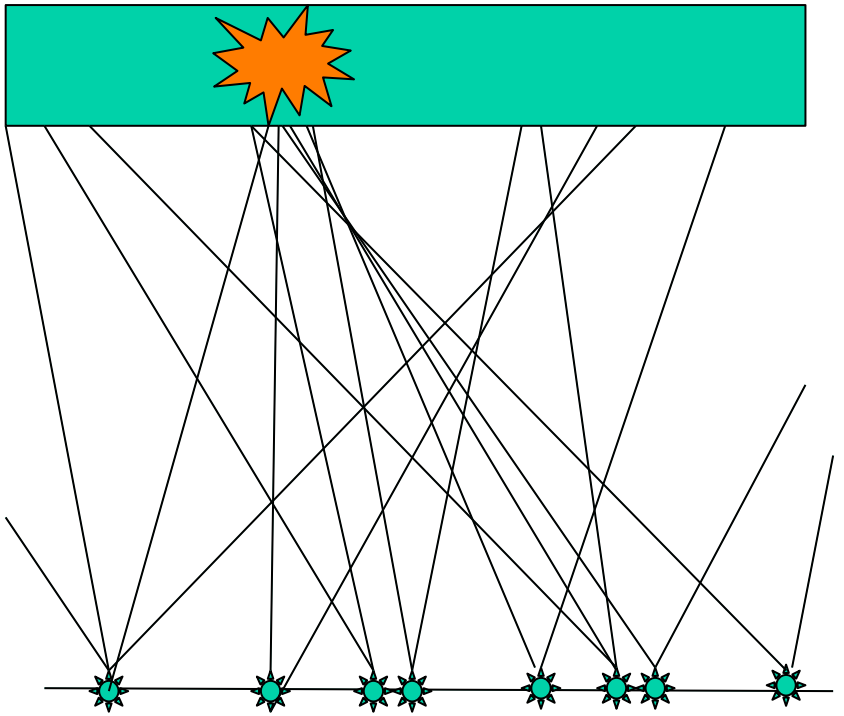
- VBF jet $\Delta\eta$ is larger then span of the tracker

Surviving 140 events pileup

- Tracker is essential for jet identification



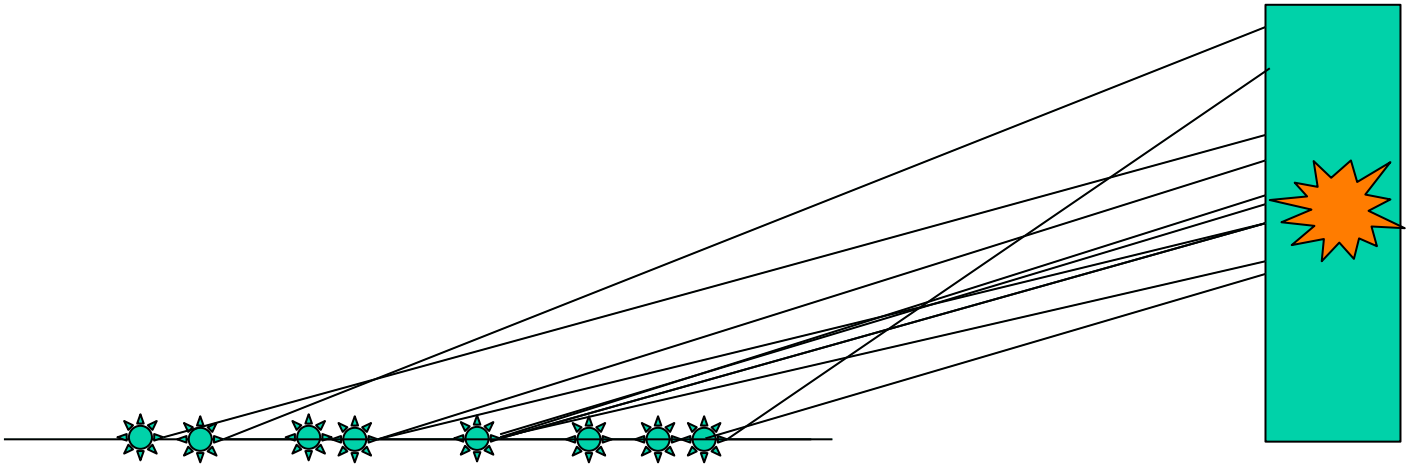


Tracking

- Both ATLAS and CMS need new trackers (old ones start failing shortly after several hundred fb^{-1})
- An opportunity to make better ones:
  - lower mass
  - better resolution
  - better pattern recognition
  - a trigger-friendly device
  - better coverage (up to $\eta \sim 4$)

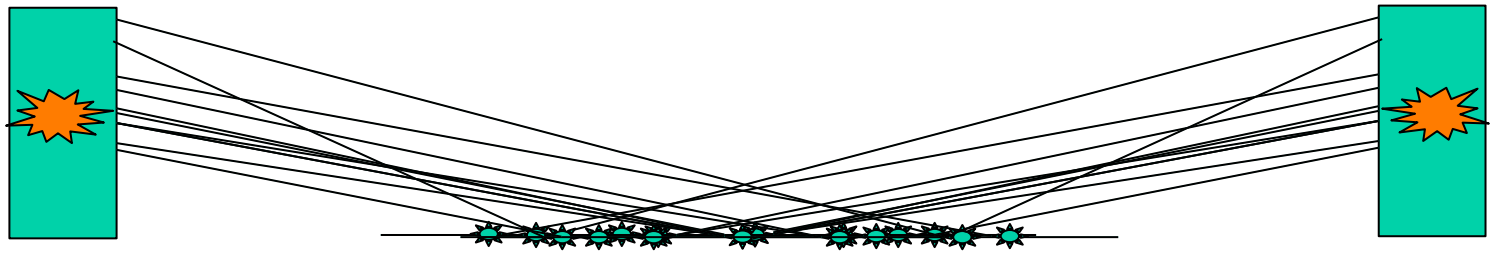
Tracker extension to $\eta \sim 4$

- $\eta = 4$ is $\theta = 0.037$
- typical distance between PU vertices at that angle is $\sim 40\mu$
- removal of fake jets is still a challenge



Picosecond Timing

- Complementary to tracking – works best at small angles



$$t_F = t_{vtx} + (Z_{HF} - Z_{vtx})/c$$
$$t_B = t_{vtx} + (Z_{HF} + Z_{vtx})/c$$

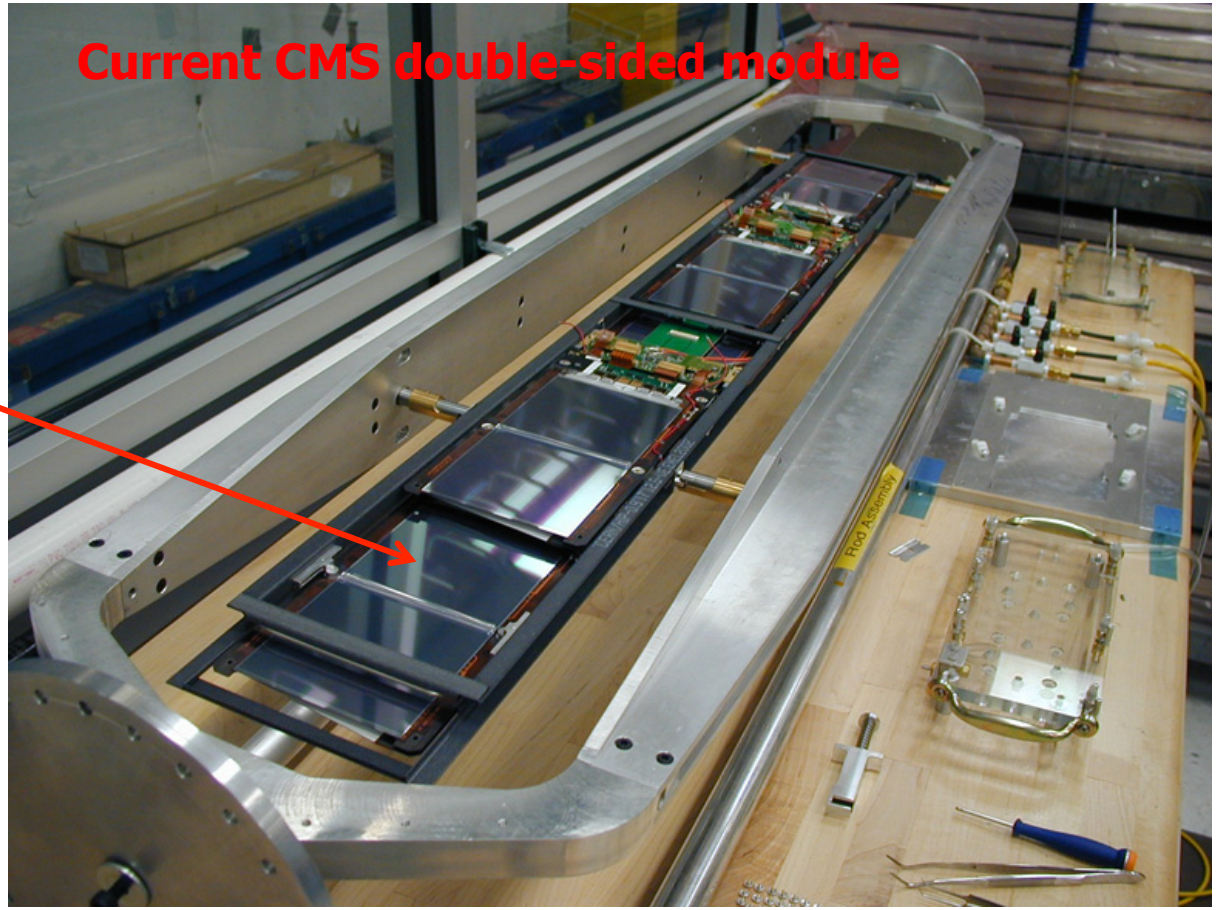
$$t_{vtx} = \frac{1}{2}(t_F + t_B) - Z_{HF}/c$$
$$Z_{vtx} = \frac{1}{2}c(t_B - t_F)$$

- $\sigma(t_{vtx}) \sim \sigma(Z_{vtx}/c) \sim 300$ ps
- Need resolution of 10 ps or better
- Has to be a separate large area device
  - Expensive and technically challenging
  - Option is considered for ATLAS, not seriously considered at CMS

Track Trigger

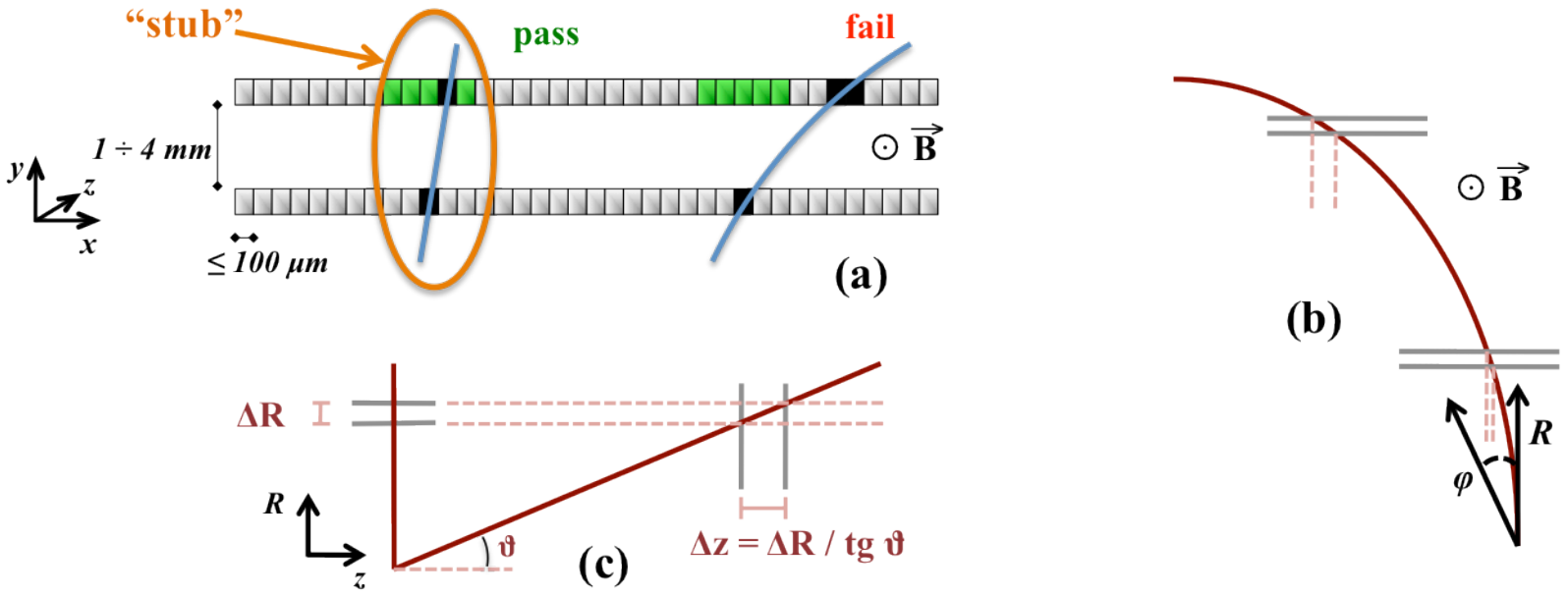
- Challenge is to read out all the hits – enormous amount of information, can not be done at required latencies

Two strip sensors at a small angle allow for precise measurement of the azimuth and a fairly good measurement of z



Track Trigger

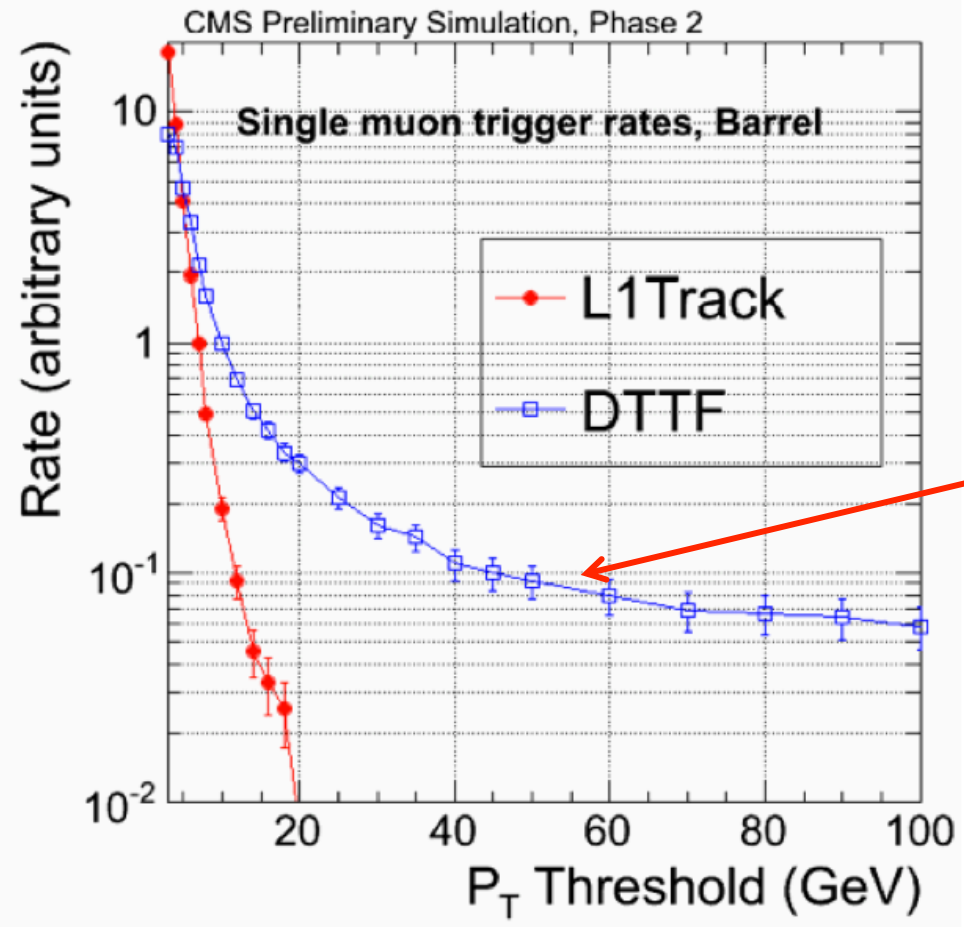
- Solution: have the two sensor both run strips along the beam
  - Make strips shorter (as short as a couple of mm -> macro pixels) to deal with occupancy and provide a Z measurement
  - The pair of hits measures pT of the track that left them
  - The electronics that measures that pT can live on the module – a factor of order 100 in the occupancy, sufficient to make readout of the high pT hits possible



Similar approach in ATAS and CMS, differences due to general trigger architecture

Need for L1 Track Trigger

- have to have it for muons



Flattening of the rate due to poor momentum resolution

Example Menu (ATLAS)

Elliot Lipeles

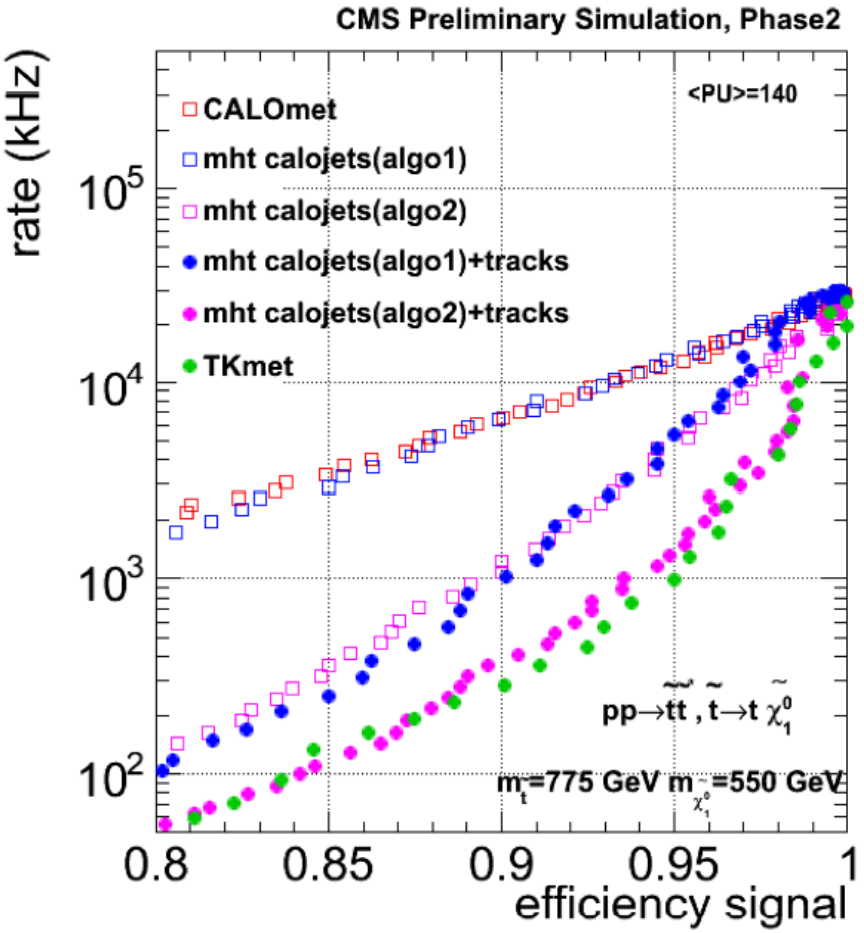
Penn
University of Pennsylvania

Resulting Rates

Object(s)	Trigger	Estimated Rate	
		no L1Track	with L1Track
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz*
μ	MU20	$>$ 40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	
$\gamma\gamma$	2EM10	as above	
$e\mu$	EM10_MU6	30 kHz	small
$\mu\mu$	2MU10	4 kHz	
$\tau\tau$	2TAU15I	40 kHz	
Other	JET + MET	$\sim$ 100 kHz	$\sim$ 100 kHz
Total		$\sim$ 500 kHz	$\sim$ 200 kHz

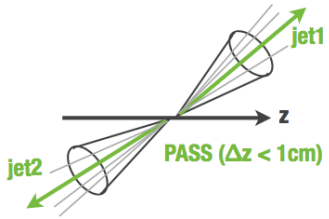
L1 Track Trigger can do more

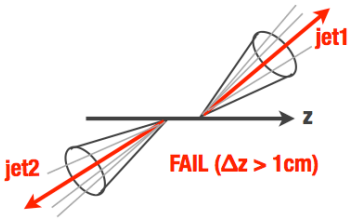
- Construct TkMET – missing ET using just L1 tracks
  - **works better then L1 Calo MET!**



Compare:

- Calorimeter only
- Calorimeter with PV confirmation using L1Tracks





- TkMET

What is actually needed?

- The menu of what is possible to build is large
  - low E_T thresholds for leptons
  - isolation for leptons / photons
  - b-tagging
  - track-based PU corrections at L1
  - event variables (TkMET, etc)
- On the other hand, input rates into HLT are large, and you can do all these thing better at the HLT
  - Why make the single e trigger be efficient at 15 GeV if the HLT will cut at 40?
- Some of the options are fairly cheap, some are very expensive
  - what would we need?

L1 Trigger

- One can view L1 as a device that just needs to fish out one interesting event in few hundreds
  - and let HLT do the rest of the work
  - need to realize the HLT limitations, especially at high PU – tracking takes a long time even for prompt tracks

- displaced jets at L1?
- very soft lepton multiplicity?
- substructure / event shapes at L1?
- …

Backgrounds

Backgrounds

4 body production

- σ x Br (WWW) $\rightarrow$3l ~ 1fb N=3000
- σ x Br (ttWW) $\rightarrow$ (3+)l ~0.05 fb N=150
- σ x Br (WWWW) ~ (3+)l ~0.01 fb N=30

Double parton scattering

- σ x Br (WW) $\rightarrow$2l (same sign) 0.4 fb N=1200

How reliable are these numbers?

How many processes like that exist?

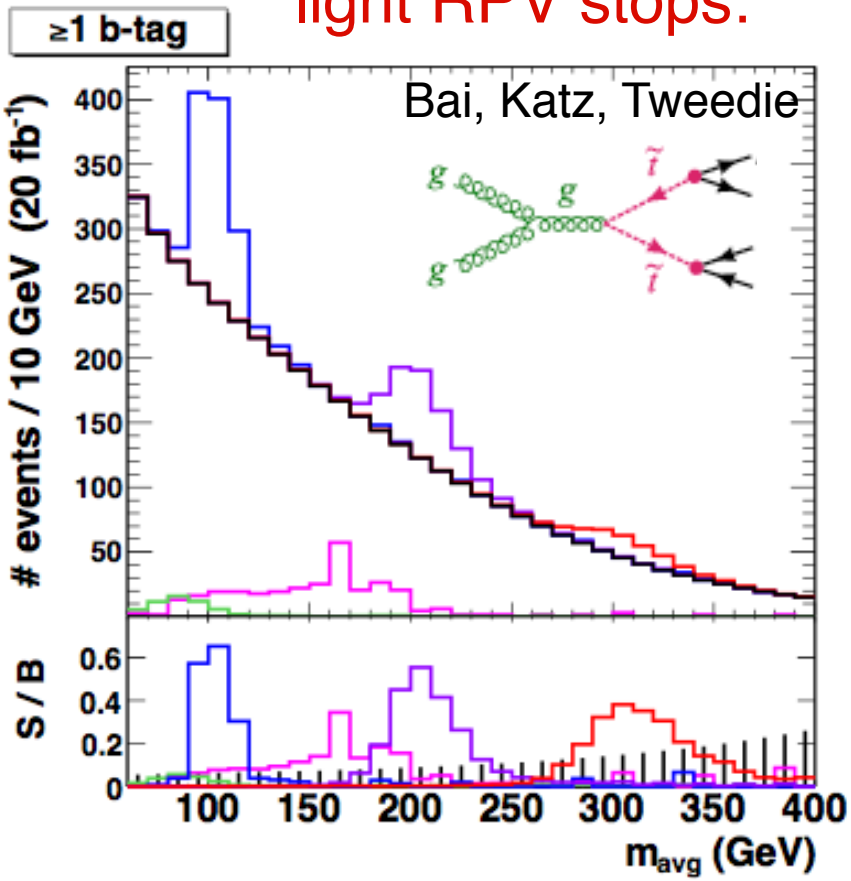
Details of top kinematics

- Recall the time when t-tbar asymmetry meant new physics?

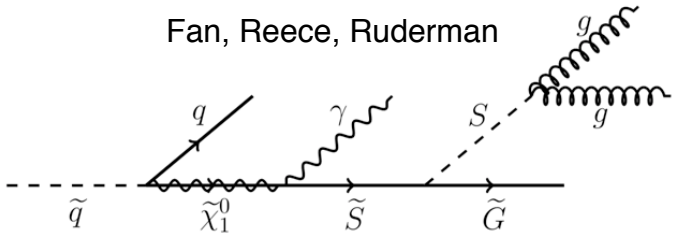
Details of jet fragmentation

Boosting non-SM particles?

light RPV stops:



Stealth SUSY:

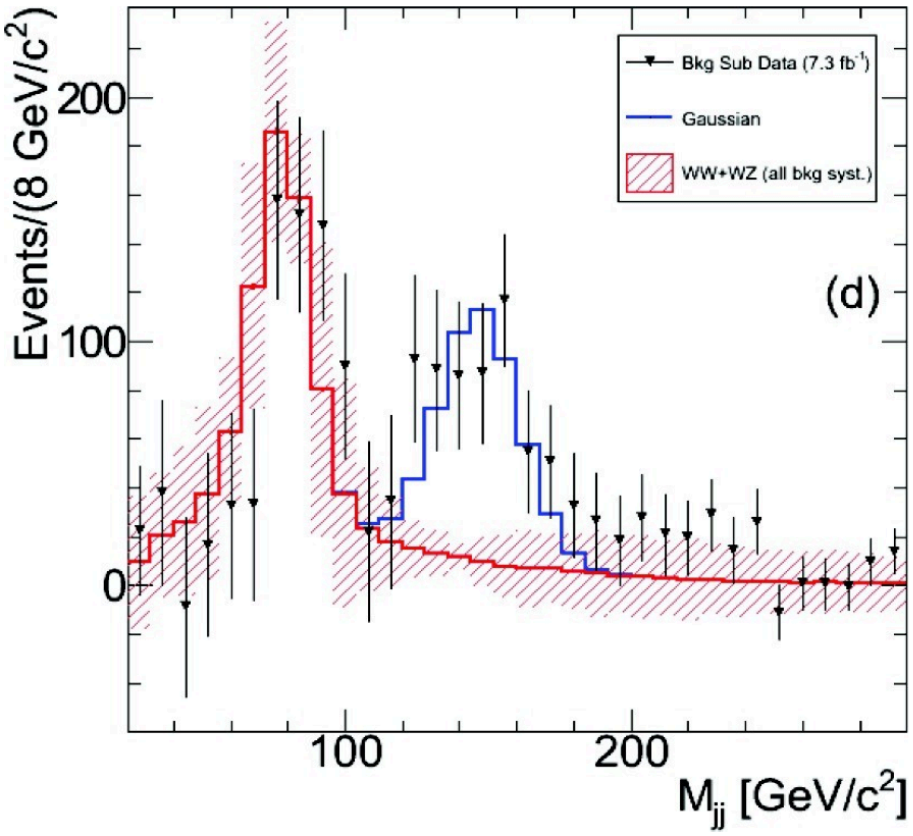


as M_{squark} limits are pushed much higher then M_S

- di-**gluon** resonances
- Sγ pseudo-resonances

- Are we ready to believe we discovered a new particle if we see a bump in a fat jet mass at 110 GeV? Or we would think that PU cleaning and kinematical cuts we make move QCD/Z/W/h/t around?

Boosting non-SM particles?



Real bump - but not new physics...

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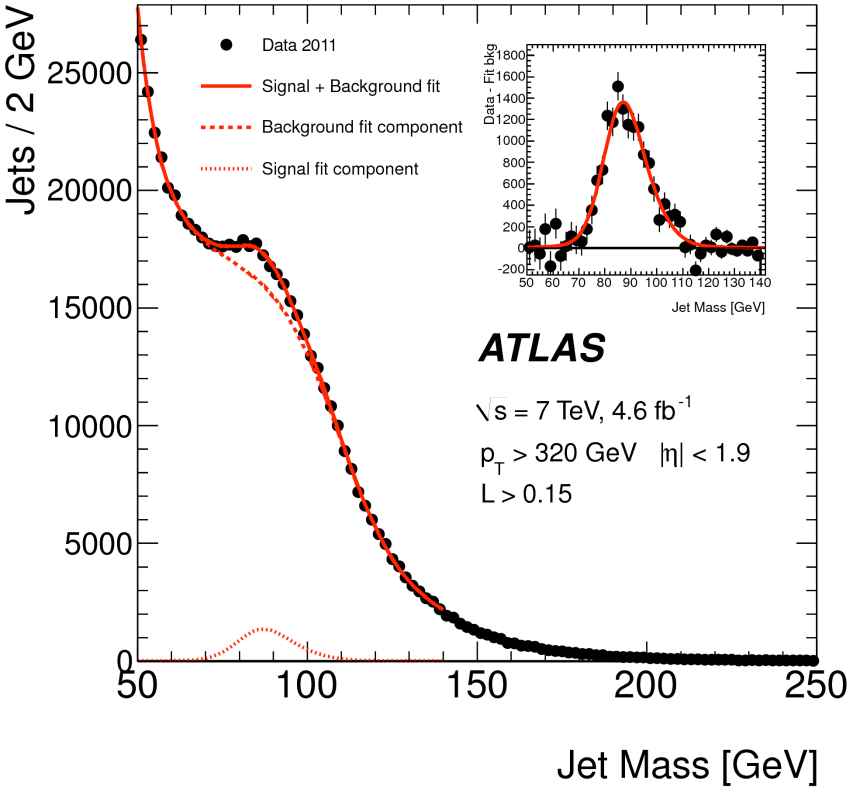
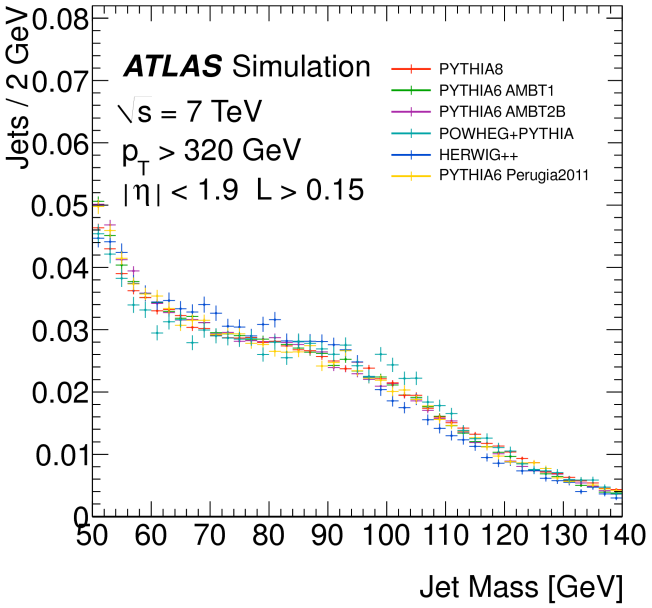
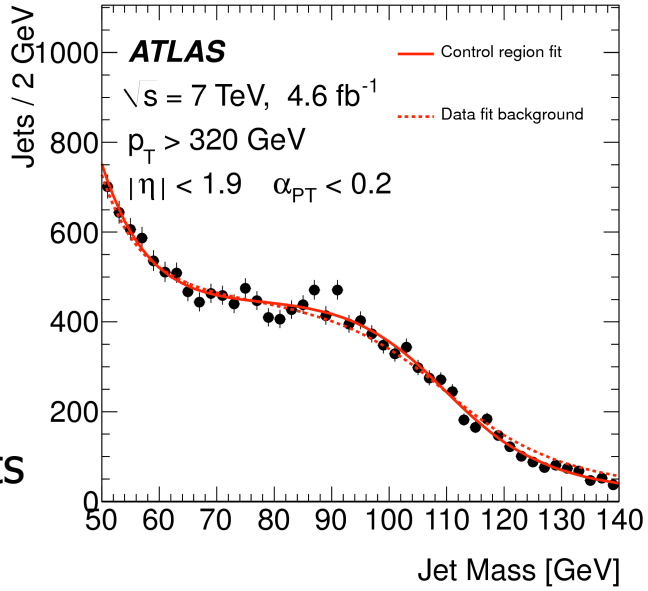
Enough to "discover" W?



Different MC agree on the background shape



Control samples do not have enough stats



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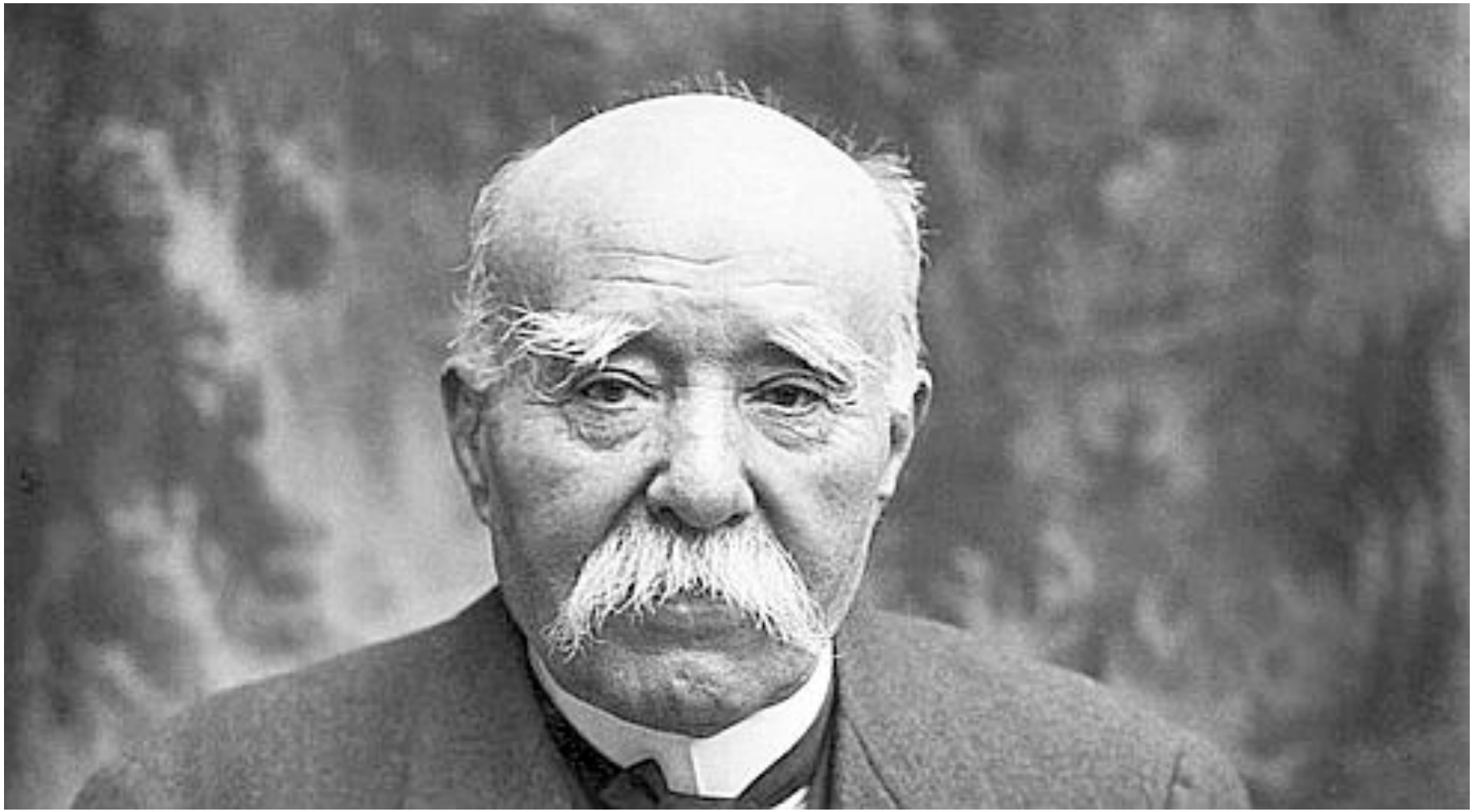
- LHC will run through 2030'es
  - new capabilities: L1 tracking, ps timing
  - some modifications to detectors are still possible
  - march to N/ab or switch to new strategy after 1/ab? What **is** that strategy? What detector and trigger modifications are needed to implement it?



"War is too important a matter to be left to the military"

Georges Clemenceau