Search for standard and exotic supersymmetry signatures at CMS

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on behalf of the CMS Collaboration

outline

- CMS detector is fully operational
- CMS 2008/2009: millions of cosmics data
- CMS fall 2009: LHC is back
- What we have seen in the first collisions?
- What we expect for 2010?
- Search for standard SUSY examples – data driven approach
- Search for exotic SUSY examples – beyond detector design
- Conclusions

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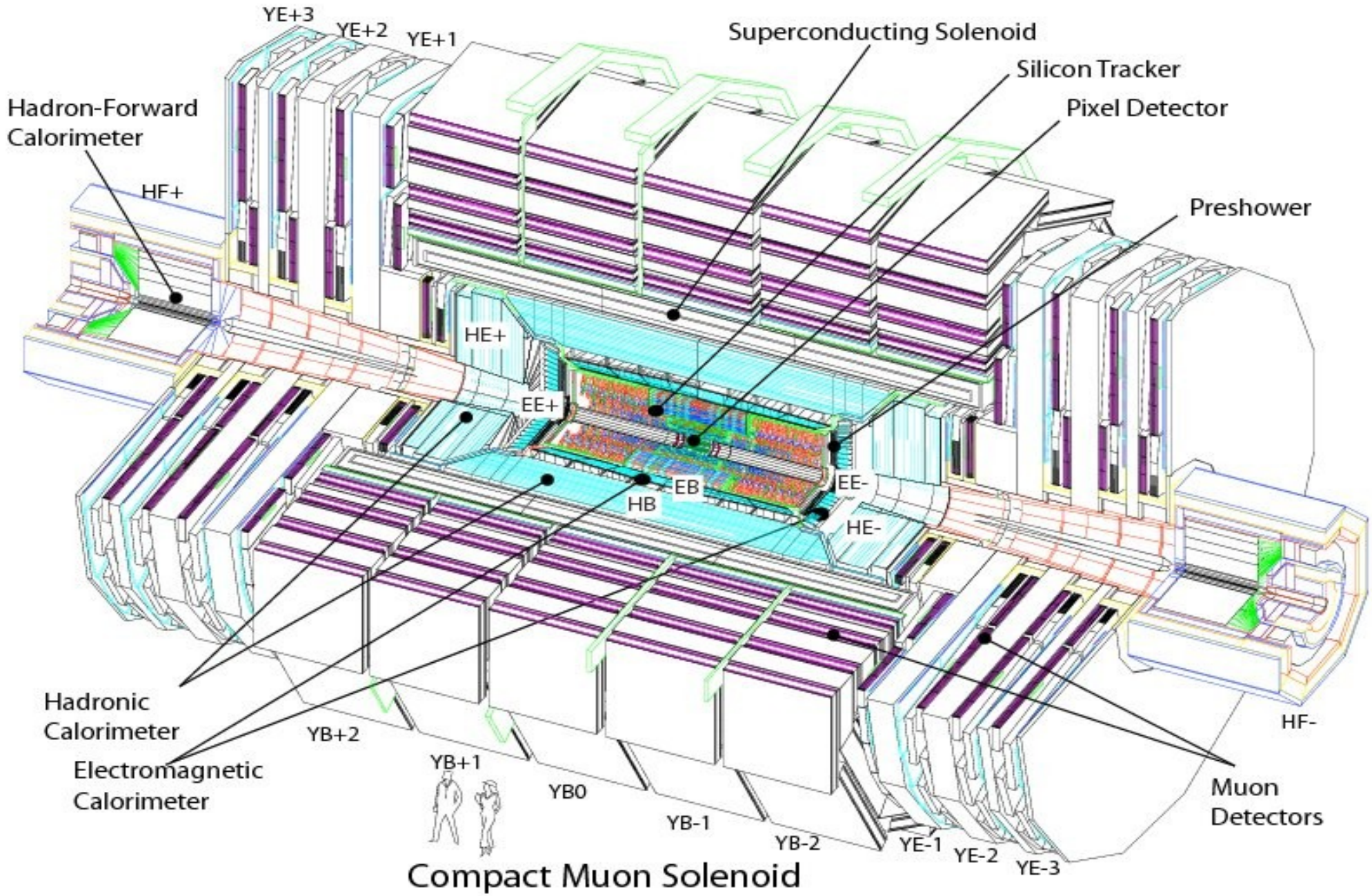
CMS detector



Cosmics data: Oct'08, Sep'09 with 3.8T

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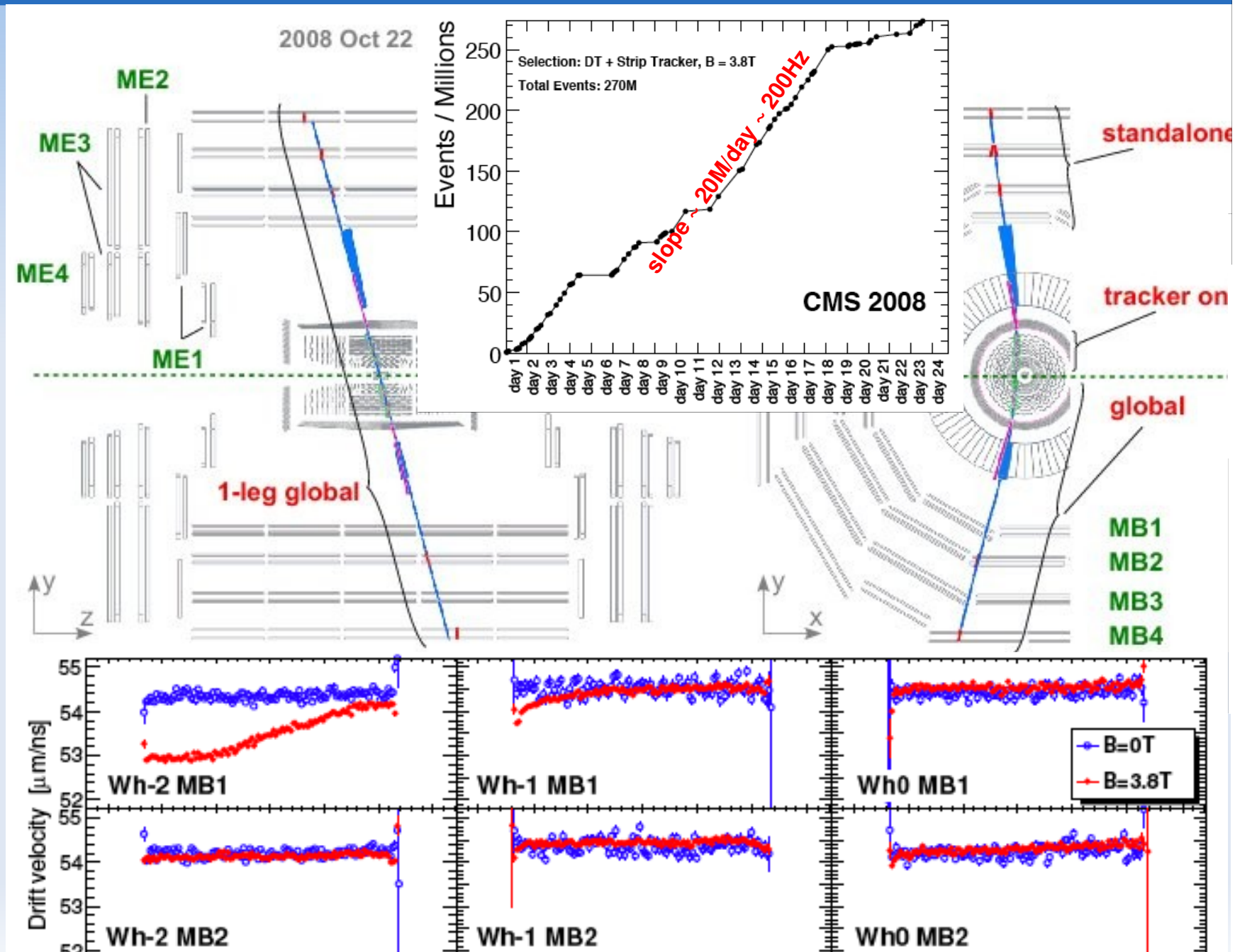
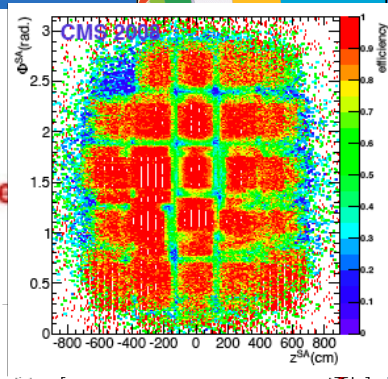
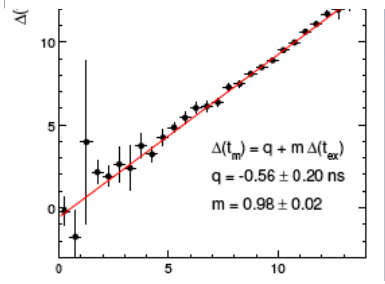
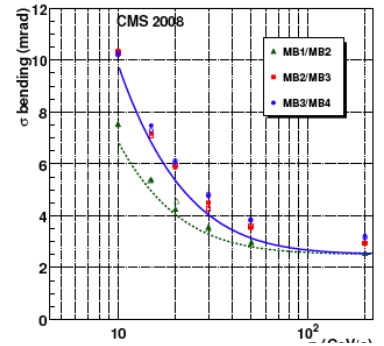
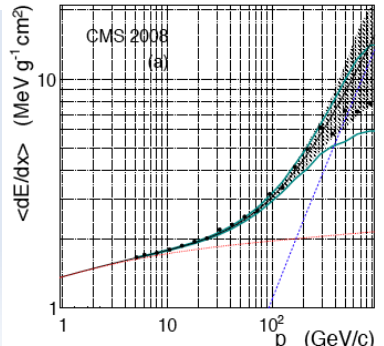
23 papers submitted to JINST











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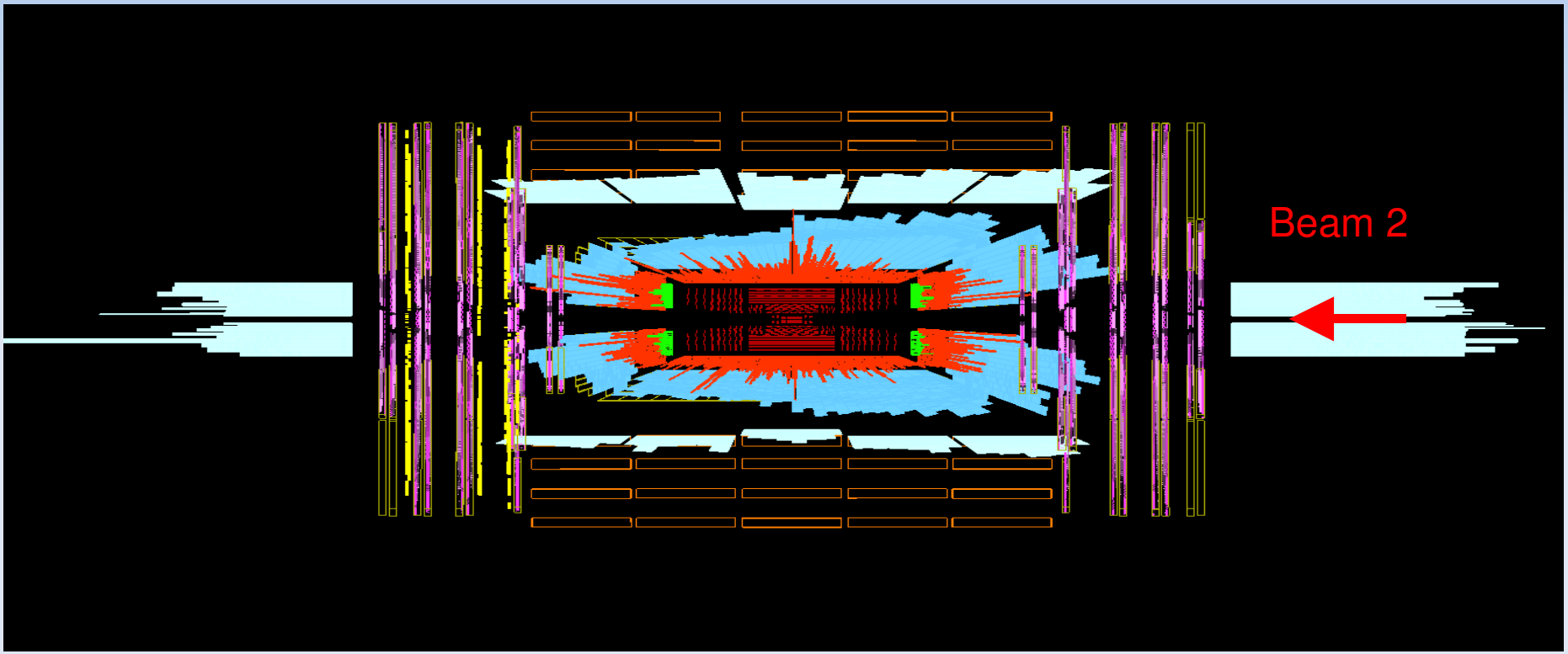
Beam splashes

Saturday 7 November 2009



ECAL energy deposits in red, Preshower in green, HCAL energy deposits in blue (and light blue), RPC muon hits are in yellow, and CSC muon hits are in magenta.

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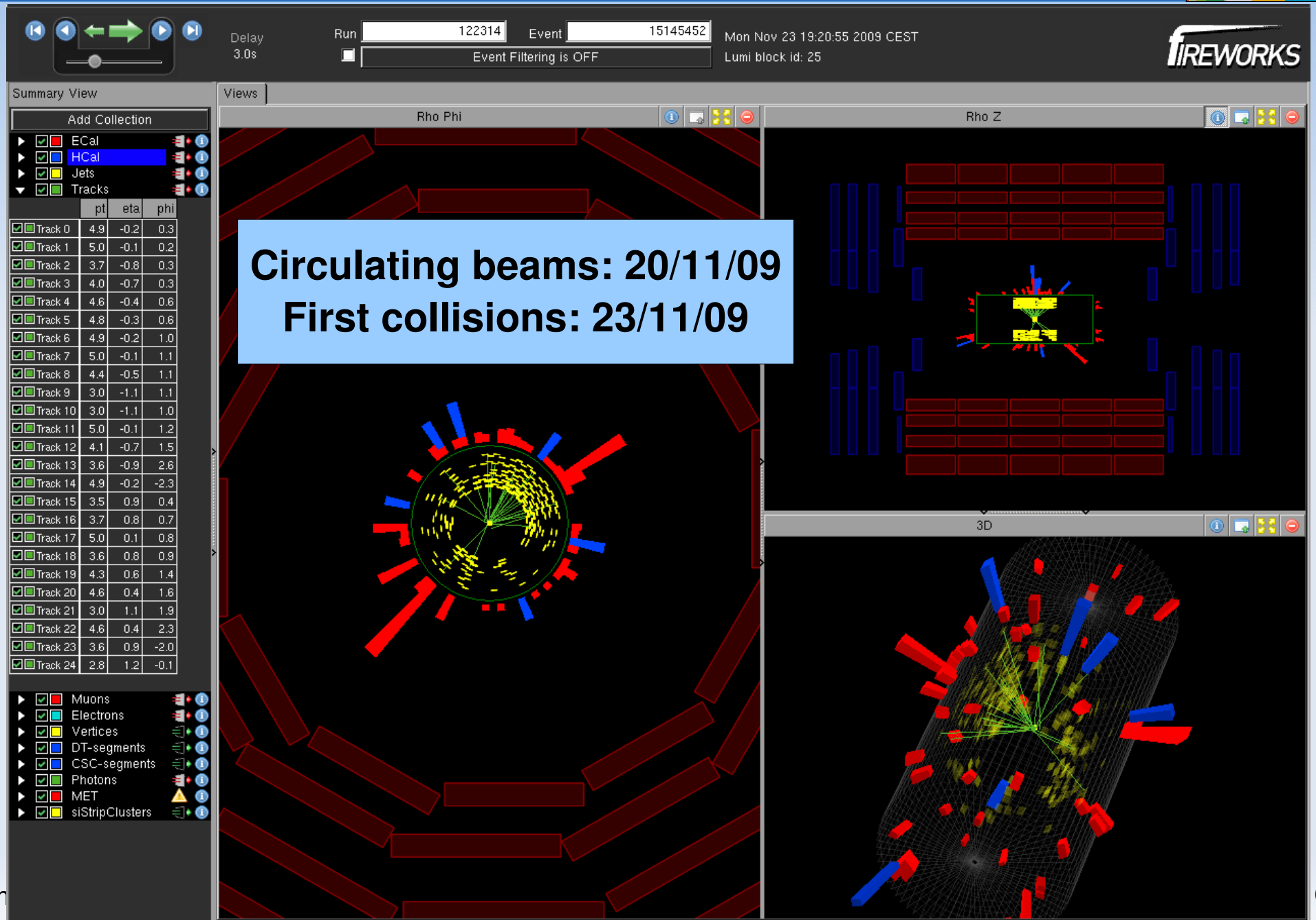
First collisions!



Circulating beams: 20/11/09
First collisions: 23/11/09

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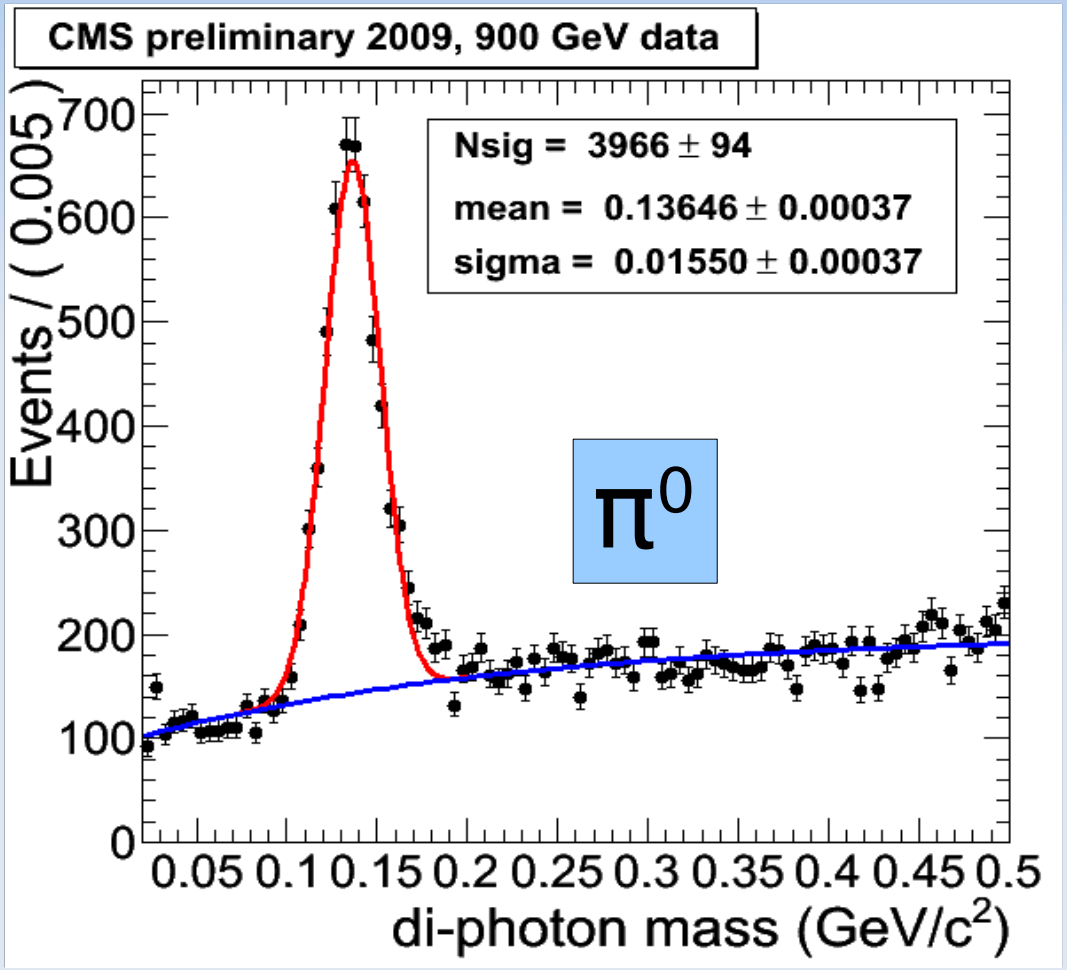
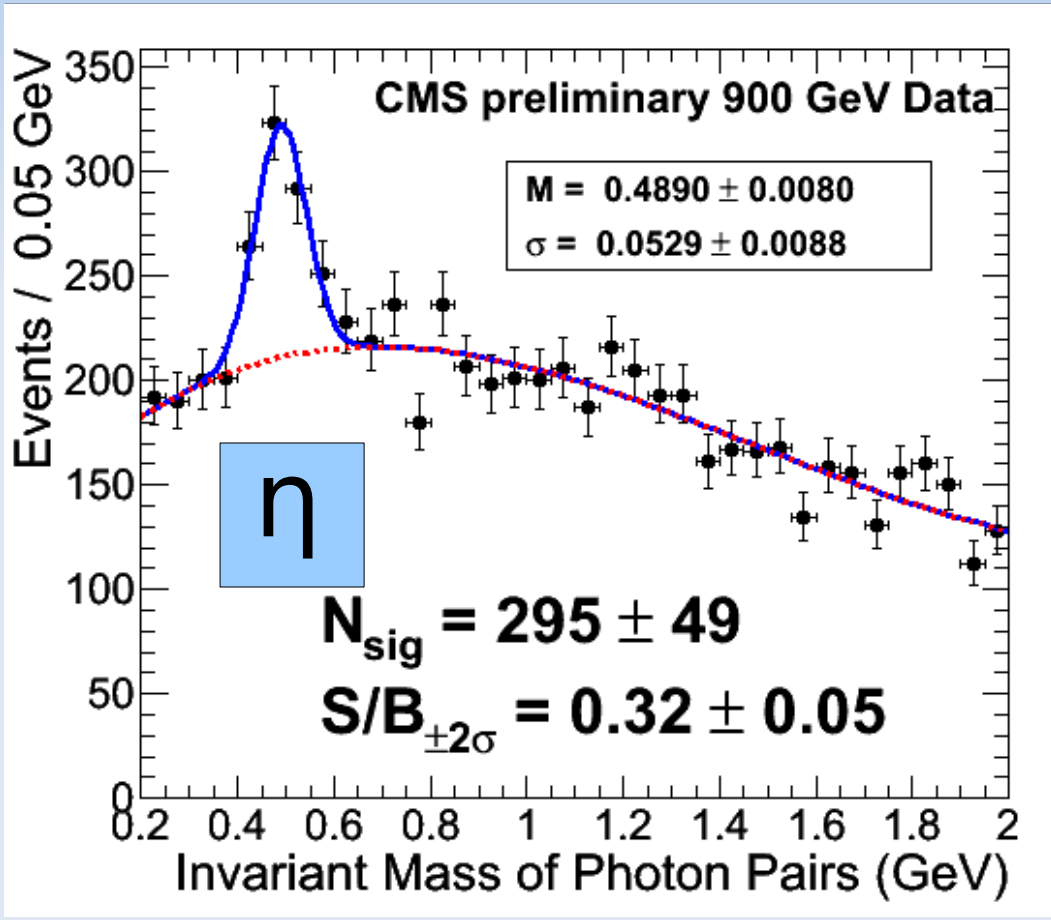
First results from ECAL





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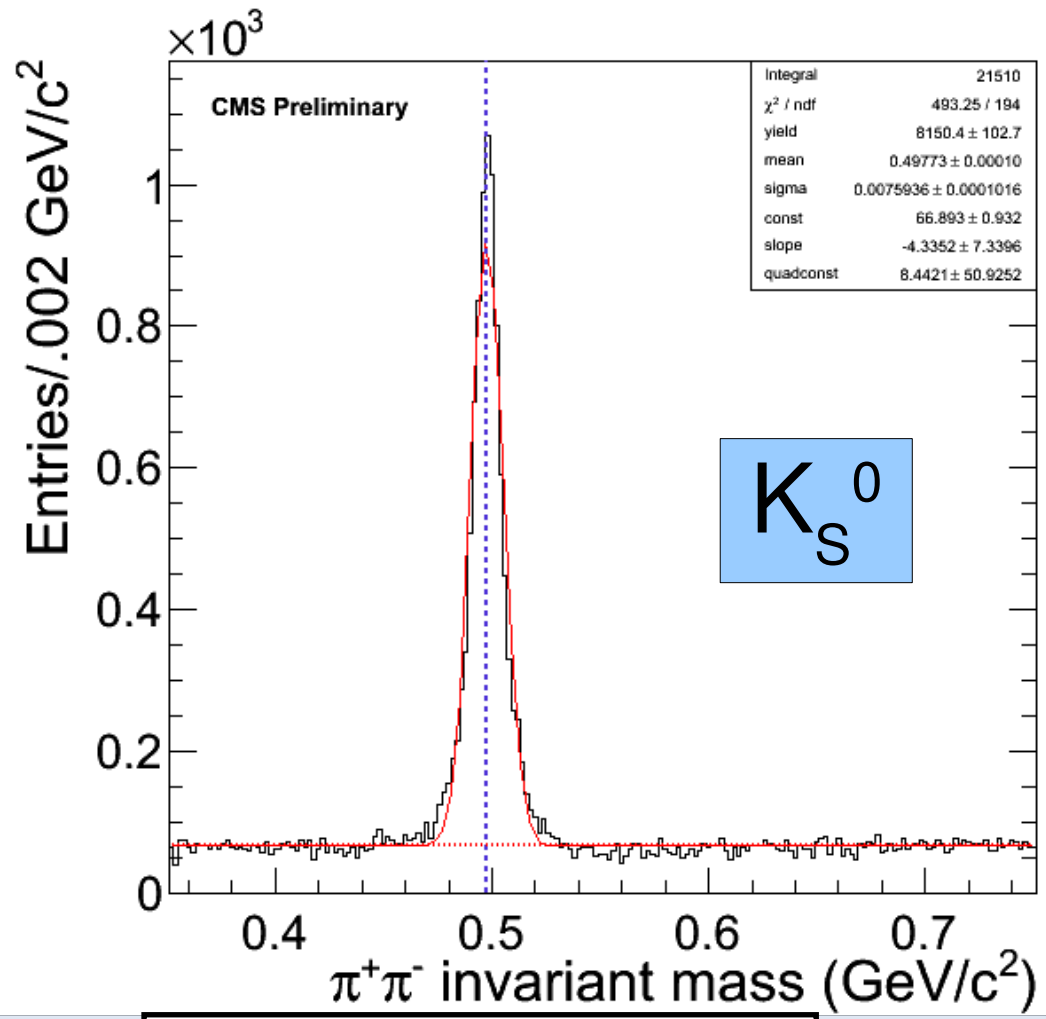
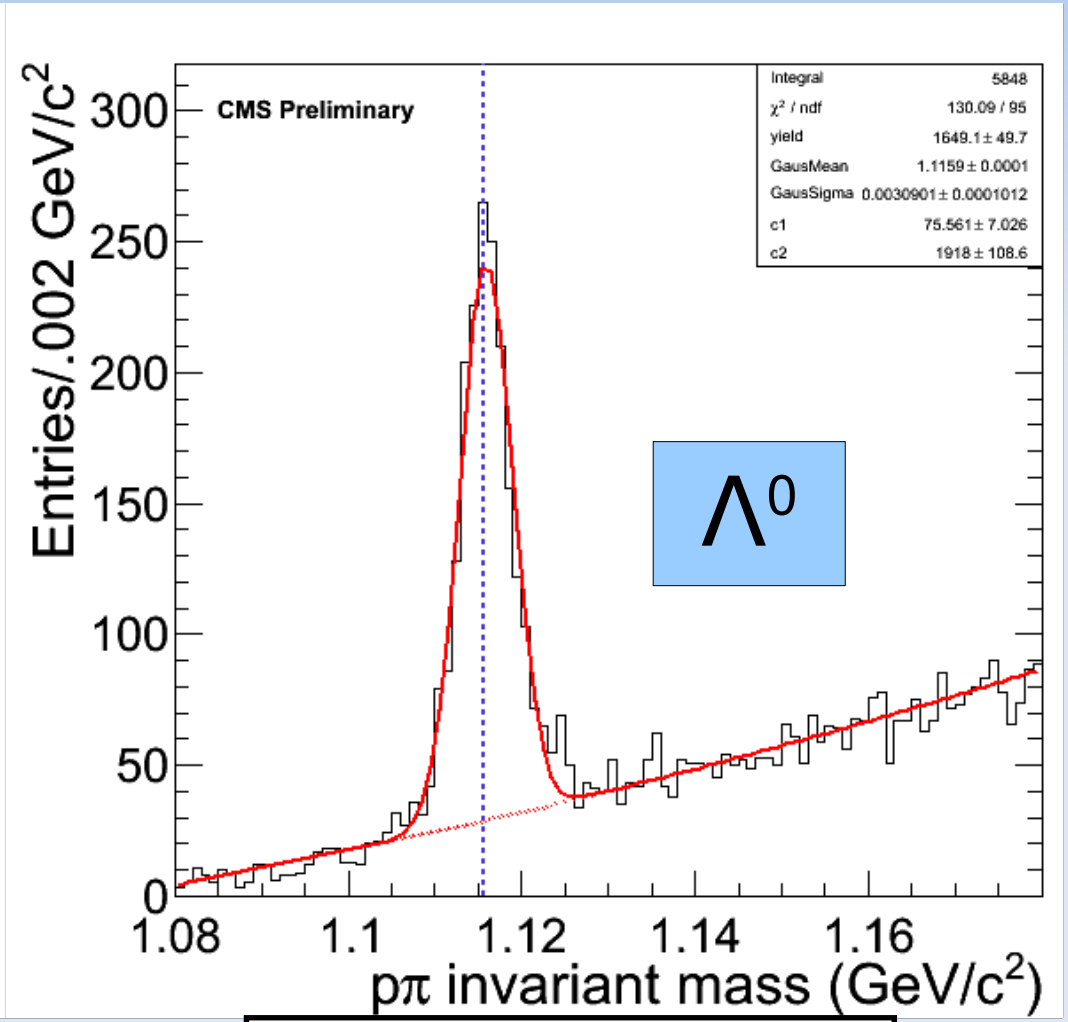
6/12/09: stable beams

Results were shown next day!



M=497.7 MeV/c2, σ=7.6 MeV/c2



M=1.116 GeV/c2, σ=3.1 MeV/c2

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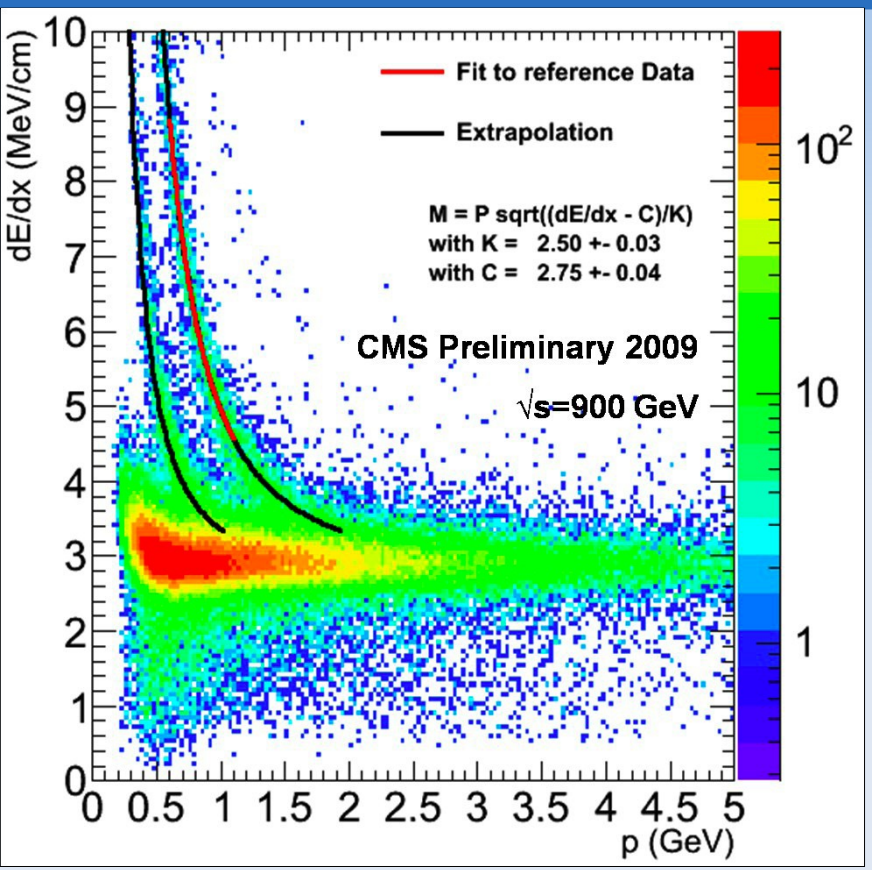
dE/dx in slicon tracker particle identification



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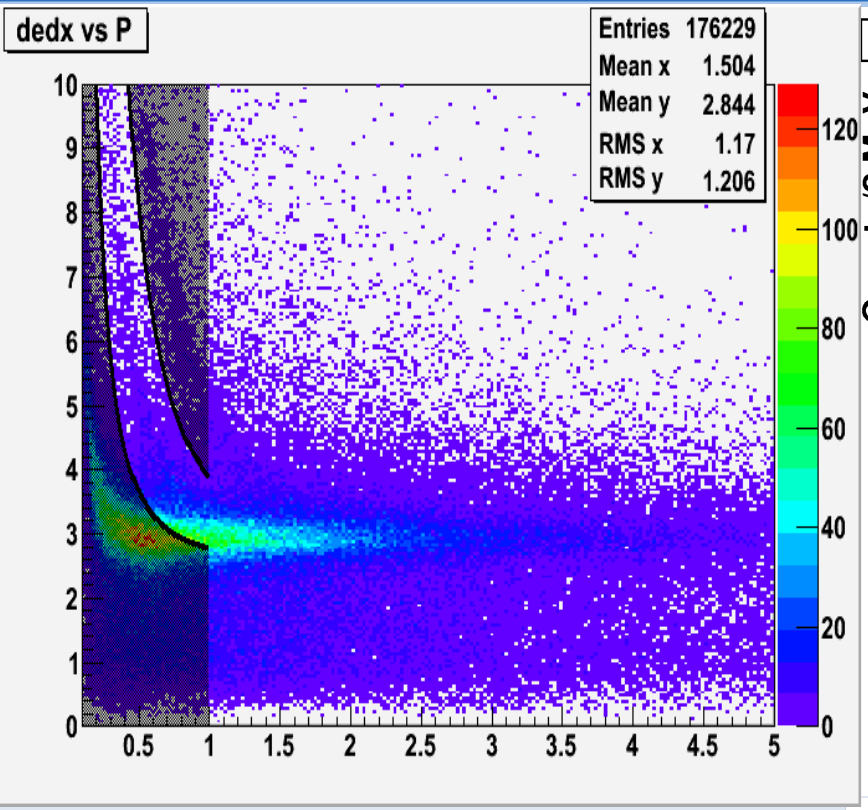
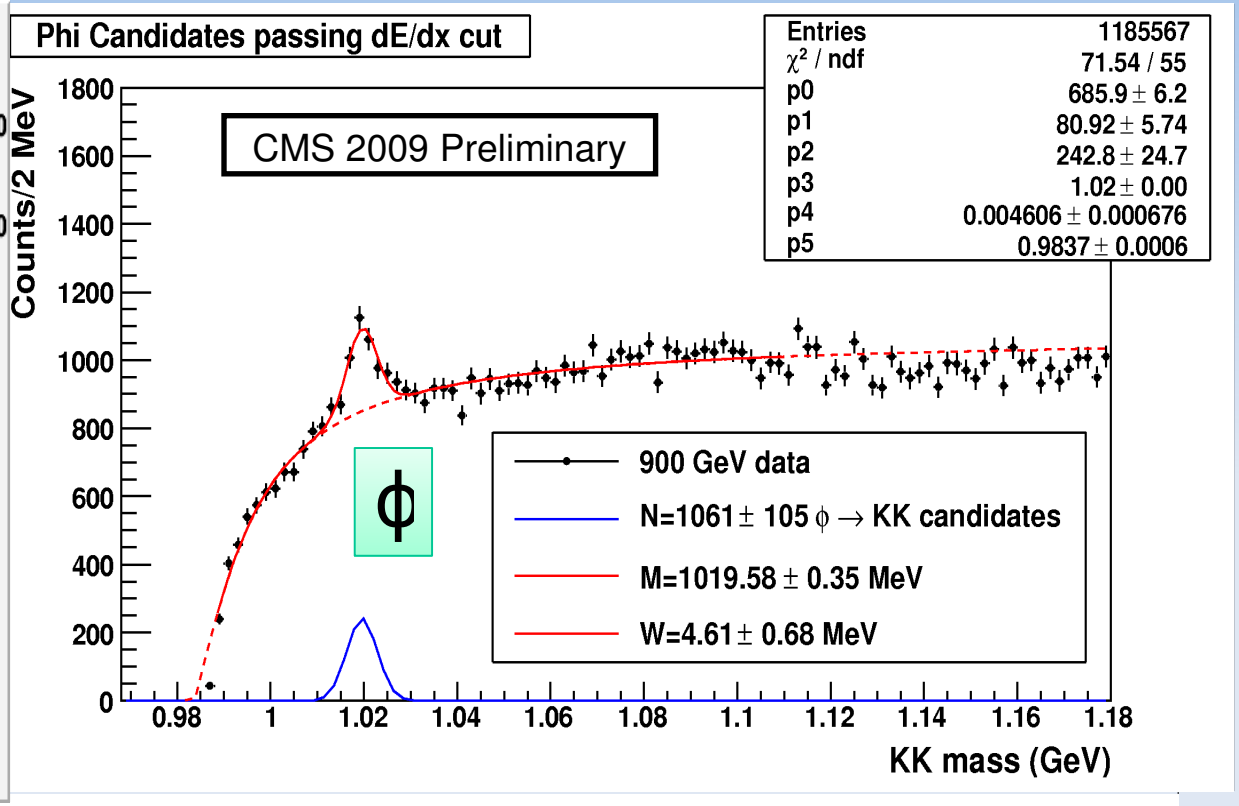
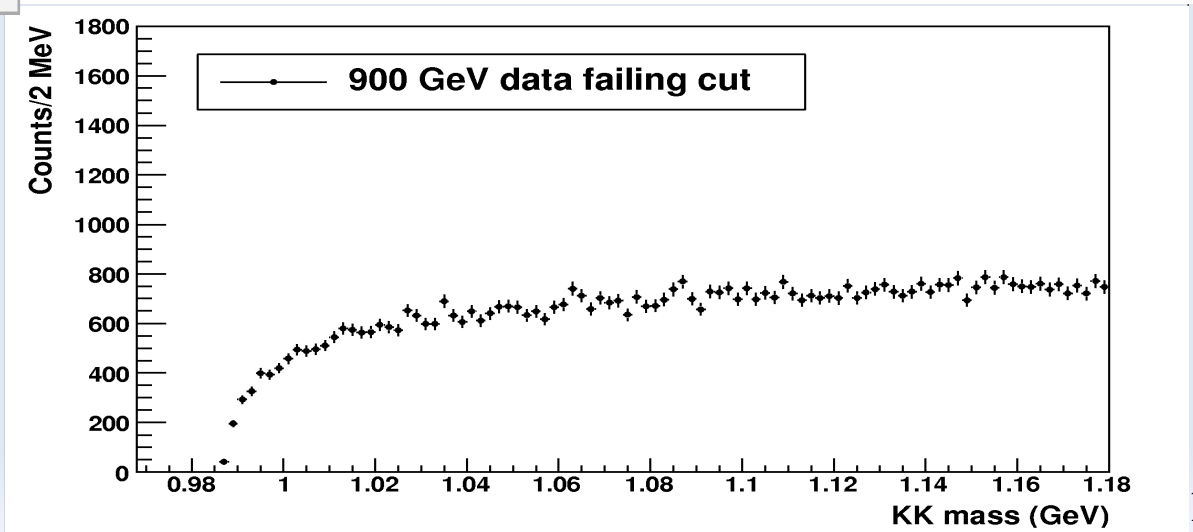
dE/dx in slicon tracker particle identification







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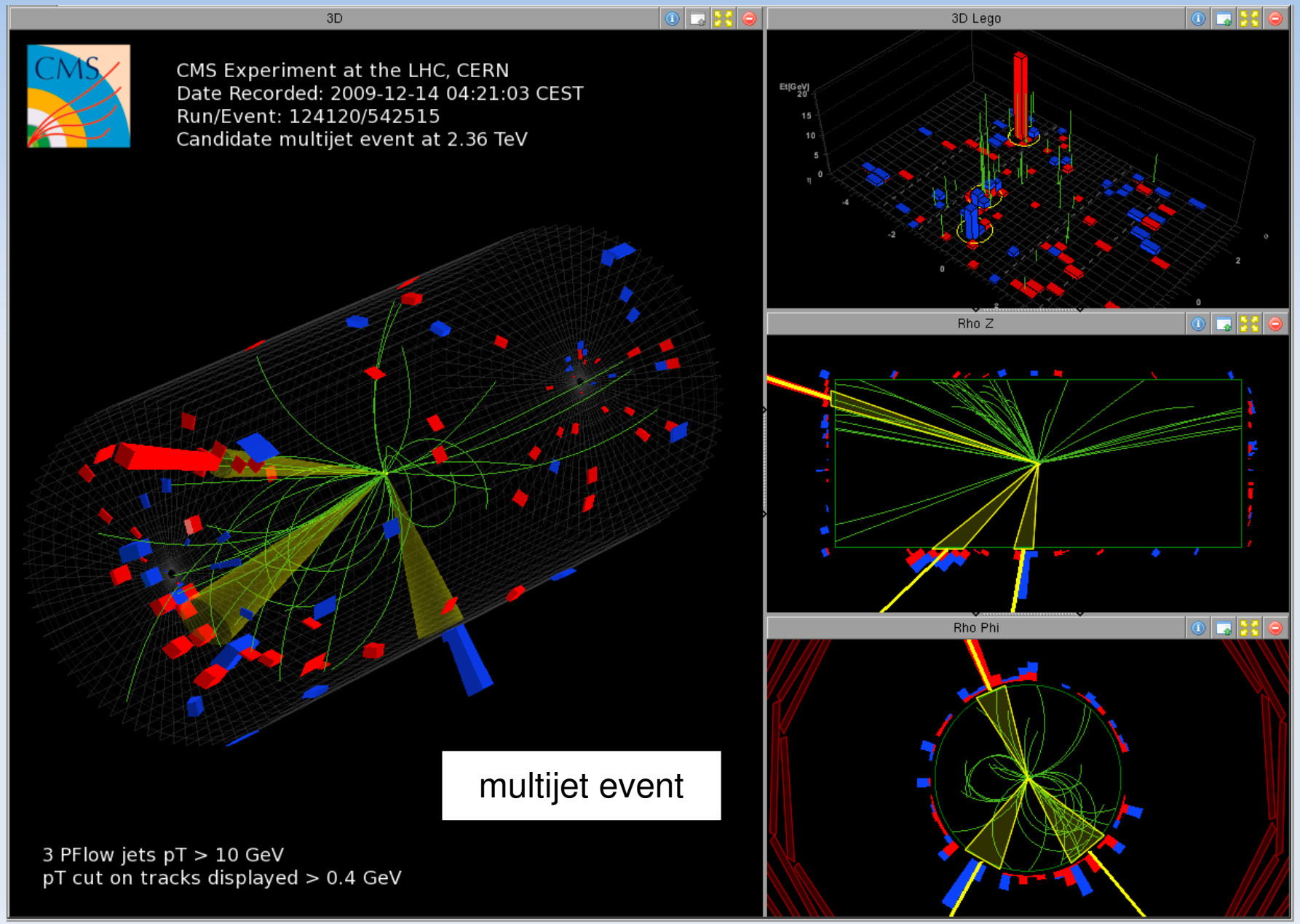
14 December 2009: 2.36 TeV



multijet event

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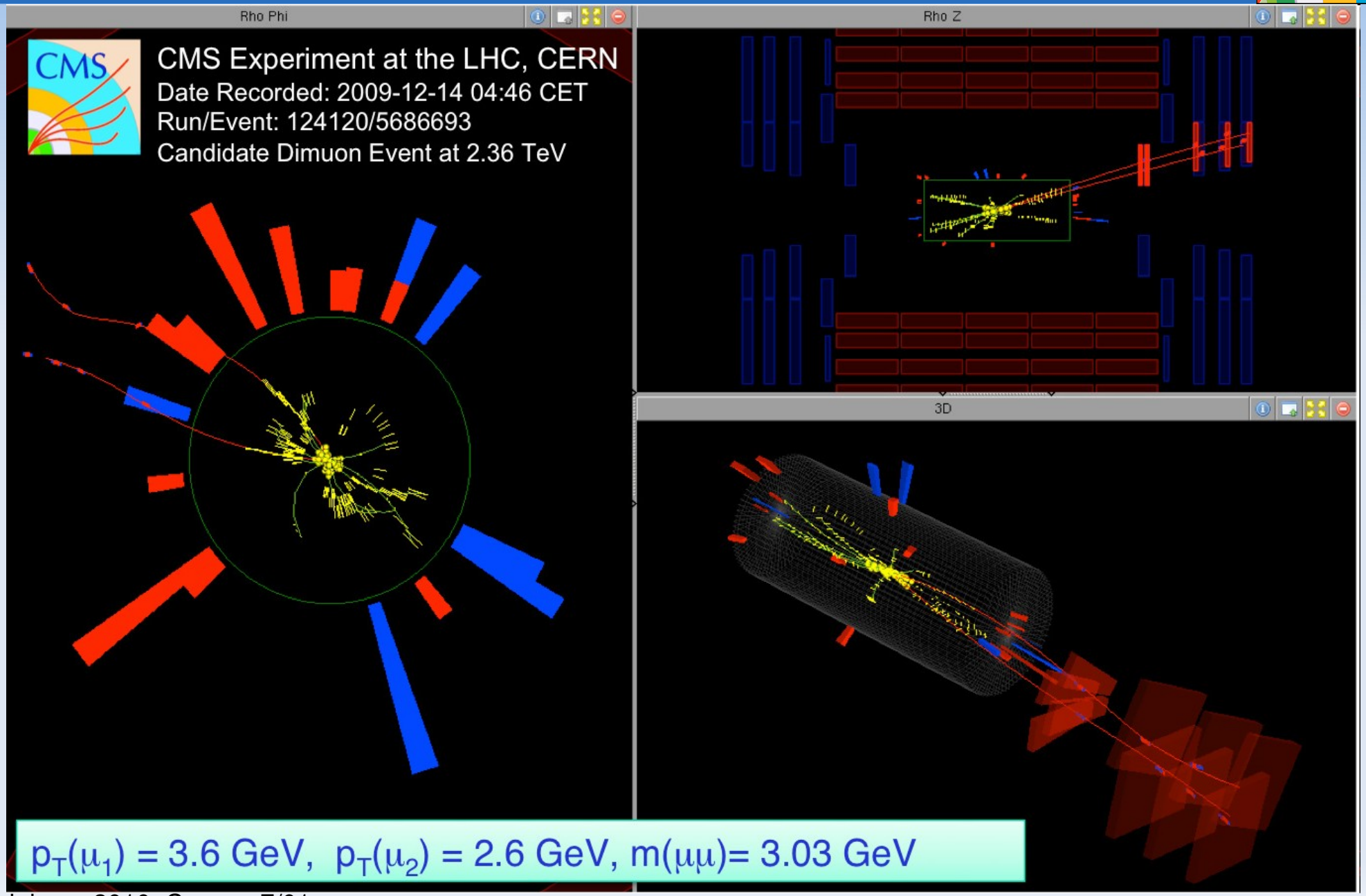
Interesting dimuon candidate



$p_T(\mu_1) = 3.6$ GeV, $p_T(\mu_2) = 2.6$ GeV, $m(\mu\mu) = 3.03$ GeV

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LHC 2009/2010

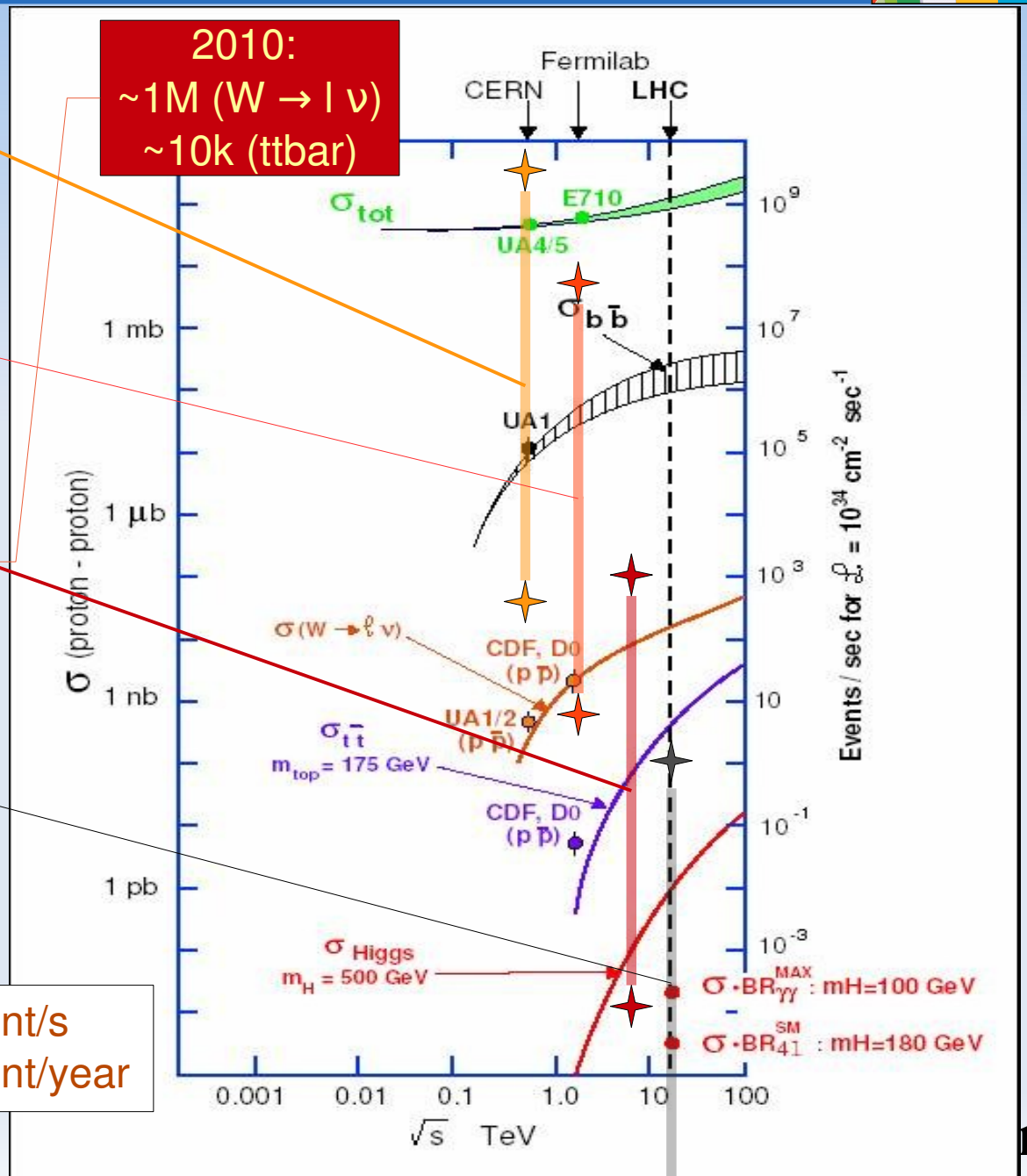
23/11/09: rate ~0.1Hz
luminosity: few $10^{24}cm^{-2}s^{-1}$
after 10^7s: ~100/ub

December 09: rate ~10Hz
luminosity: few $10^{26}cm^{-2}s^{-1}$
after 10^7s: ~1/nb

2010: rate ~10kHz (?)
luminosity: ~$10^{31}cm^{-2}s^{-1}$ (?)
after 10^7s: ~100/pb (?)

201?: rate ~40MHz
luminosity: ~$10^{34}cm^{-2}s^{-1}$
after 10^7s: ~100/fb

2010:
~1M (W → l ν)
~10k (ttbar)



Upper star: x-sec: rate= event/s
Lower star: x-sec: rate= event/year

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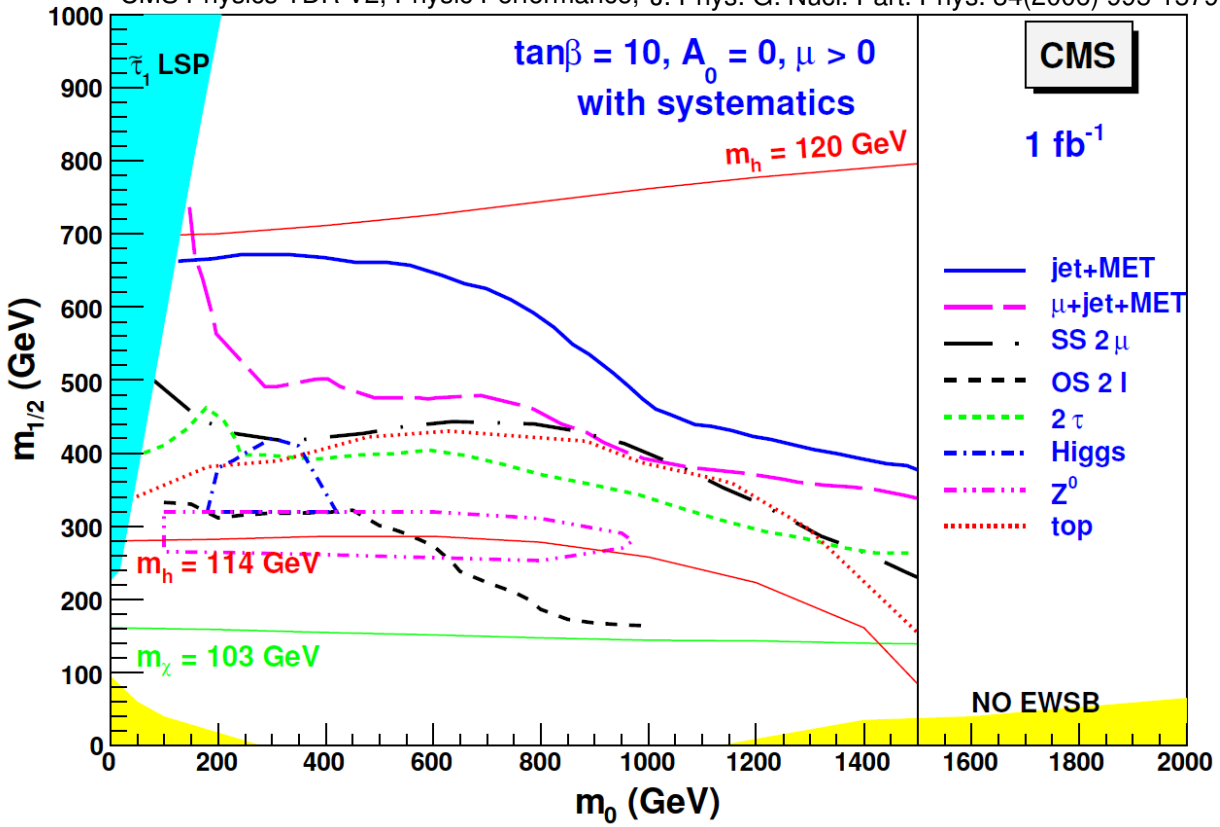
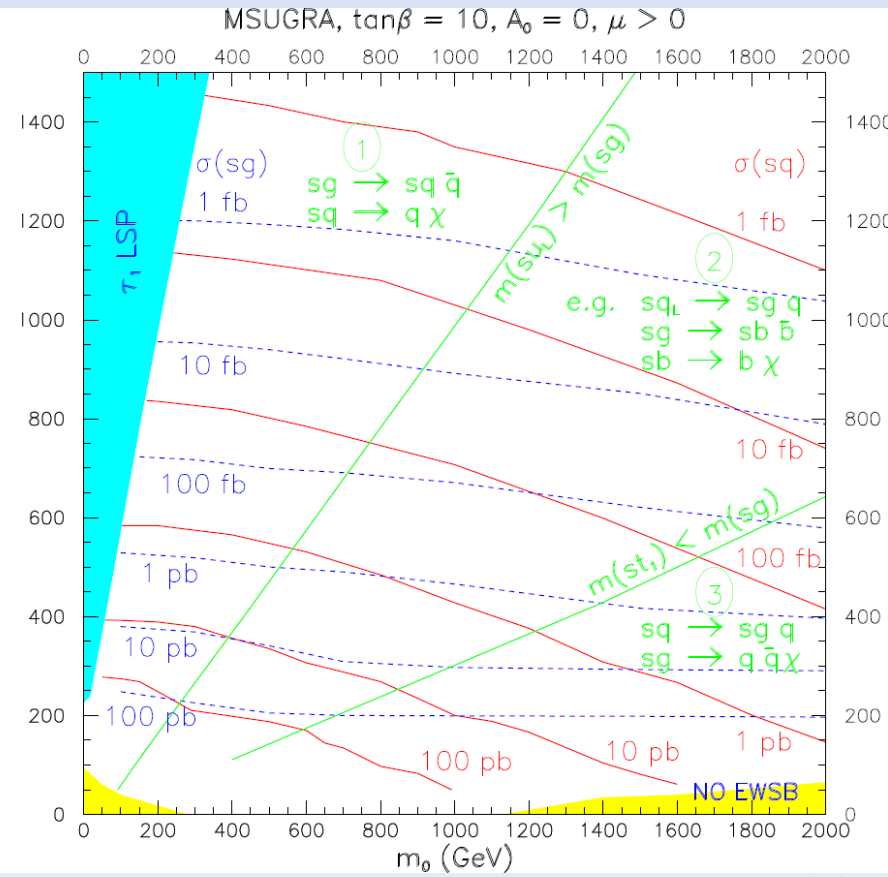
Search for Supersymmetry

CMS PTDR2 2006 (rev. 2007) -->

Physic performance of the CMS detector was described in detail in the Physics TDR Vol. 2 in 2006. The observability of SUSY was studied using mSUGRA benchmark points with detailed simulation and extrapolated to $m_{1/2}$, m_0 plane for representative values of other mSUGRA parameters. Study was done for 14TeV and at least 1/fb integrated luminosity. Here I recall only one plot showing reach in different inclusive channels. On the right x-section for production of gluinos (sg) and squarks (sq) could be readout. One should remember, however, that in 2010 we expect only O(100/pb) and that for 7TeV the x-sections are about 10 times smaller.

CMS Physics TDR V2, Physic Performance, J. Phys. G: Nucl. Part. Phys. 34(2006) 995-1579





S1. Search strategy for exclusive multi-jet events from supersymmetry (1)

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The post Physics TDR results are published as CMS Physics Analysis Summary notes.
I will present three recent examples as far as search for standard SUSY is concerned.

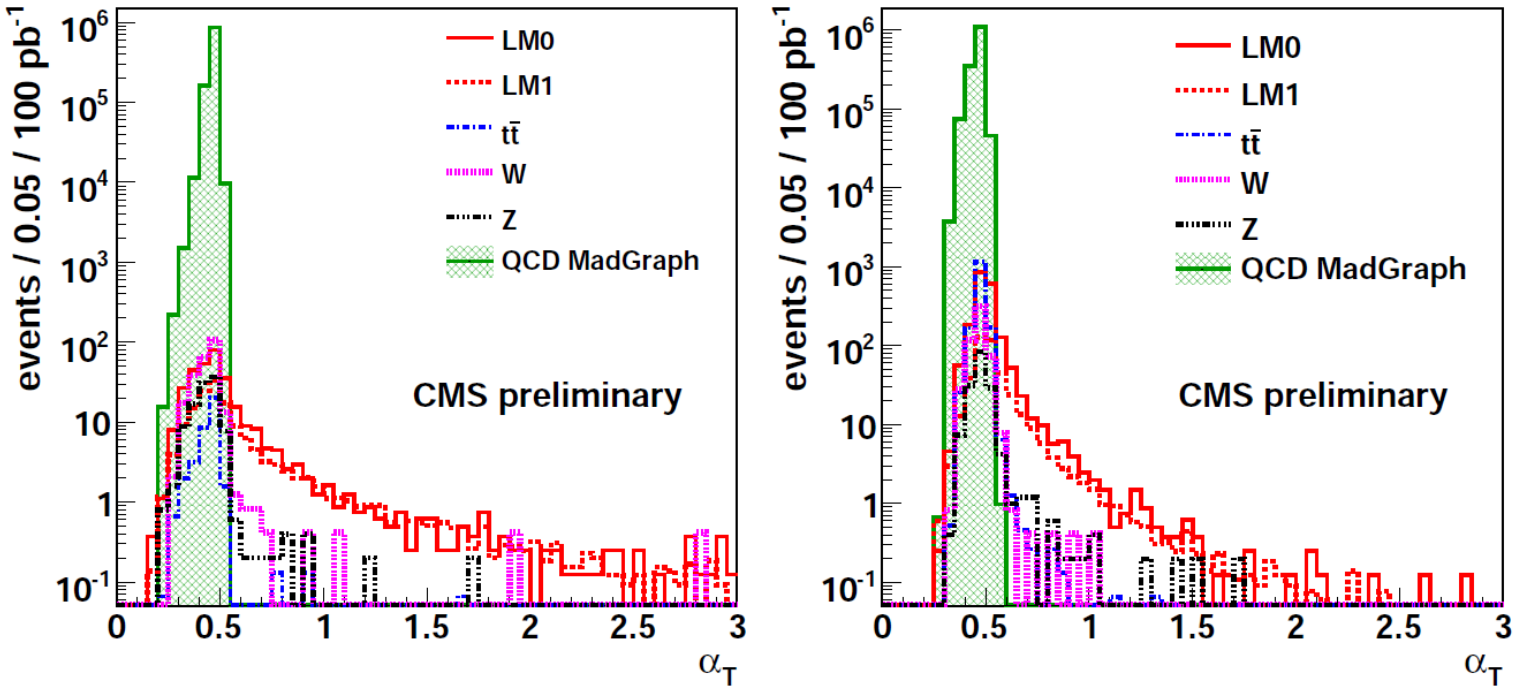
CMS PAS SUS-09-001

Robust analysis technique suited to early data based on α_T variable (first introduced in: CMS PAS SUS-08-005)

$\alpha_T = E_T^{j2}/M_T$, where
$M_T = \mathrm{sqrt}\{ H_T^2 - (H_T^{miss})^2 \}$
and H_T is scalar, whereas
$-H_t^{miss}$ is vector sum of transverse jet energies.

Multi-jet systems are reduced to two pseudo-jets, by combining jets in a way to minimize the difference between scalar sums of transverse energy of jets forming each pseudo-jet.

For ideally measured event without missing energy $\alpha_T = 0.5$



α_T distribution for di-jet (left) and multi-jet (right) events (10TeV)
Preselection is described in the note

The variable α_T is designed to discern true missing energy from artifacts due to mismeasured jest energies.
It selects out QCD background very efficiently.

The most important is, however, to be able to control this selectivity with real data.

S1. Search strategy for exclusive multi-jet events from supersymmetry (2)

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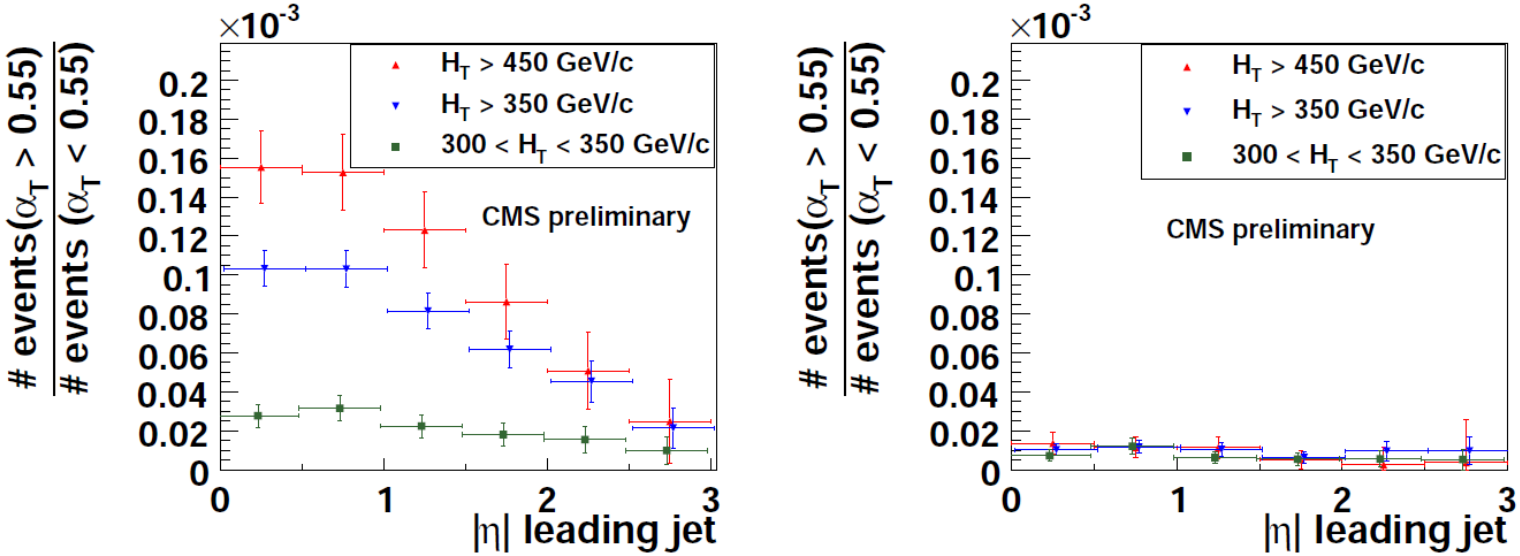
Signal events are more central than SM backg., in particular QCD.

The ratio is flat for background (right plot), whereas it grows with Decreasing |eta| in a presence of the signal (left plot).

The level of QCD backg, can be controlled using the last |eta| bin.



Dependence of the ratio #(α_T>0.55)/#(α_T<0.55) on eta of the leading jet for SUSY(LM0)+SM (left) and SM only (right). Errors correspond to 100/pb.

Z+jets backg. (with Z to neutrinos decay) could be estimated using gamma+jets and W+jets as it was shown in *Data-Driven Estimation of the Invisible Z Background to the SUSY MET Plus Jets Search* (CMS PAS SUS-08-002).

In addition, highly boosted **Ws form W+jets and ttbar** events survive selection, when W decays to tau and its neutrino. This contribution could be evaluated by selecting W to muon and neutrino decays and replacing reconstructed muon by simulated hadronic tau decay (details: CMS PAS HIG-08-001).

Kinematic variables instead of absolute MET. Several data control distribution (not covered here, see the note).

→ **Robust search with early physics data.**

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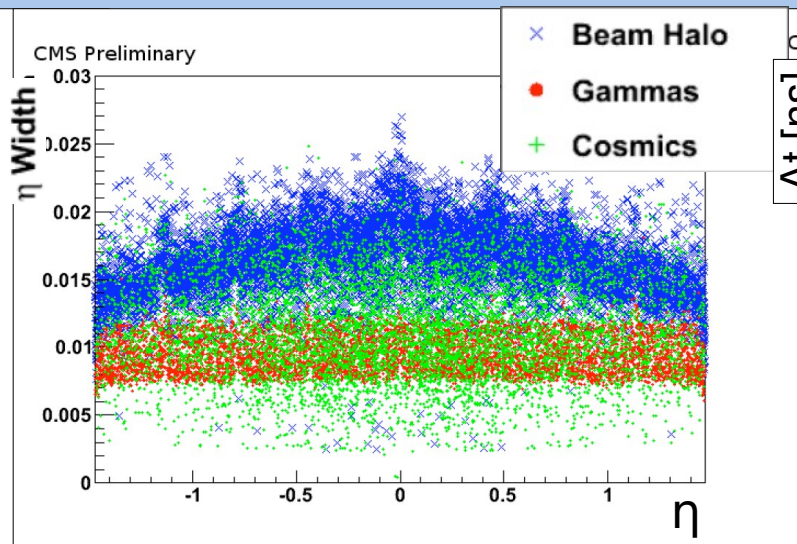
S2. Data-driven Background Estimates for SUSY Di-Photon Searches (1)

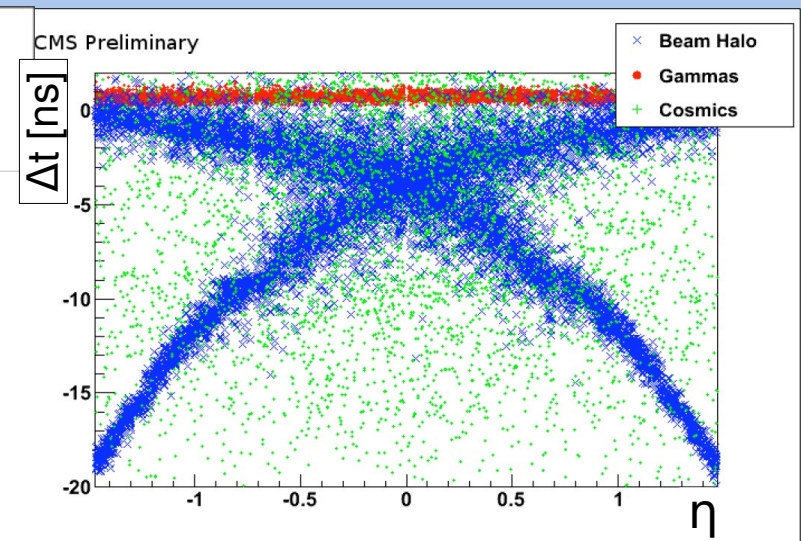
CMS PAS SUS-09-004

Pair of high E_T photons with large MET could signal new physics (GMSB) and has low genuine background.

Instrumental background has 3 main components:

- QCD: jet misidentification & MET mismeasurements,
- EW: electron misident. in events with genuine MET,
- non-beam background →





Non-beam background is mainly due to e-m cascades due to cosmic and beam halo muons. To control these backgrounds eta width of the ECAL cluster (left plot) and ECAL timing (right plot) could be used.

Selected ECAL clusters (E_T>30GeV, isolation, eta cluster width < 0.013) are classified as electrons if they have pixel seed and photons otherwise.

The efficiency of pixel match is estimated using ee sample to describe Z → ee peak and eγ sample to measure Z signal with one misidentified electron. The result is: $1-f_{e\to\gamma}$ =(97,5±1.5)%, where $f_{e\to\gamma}$ is electron misidentification probability (not pixel matched electron is, by definition, regarded as photon). This probability will be reevaluated with real data.
It is used to estimate EW and QCD backgrounds (see next slide).

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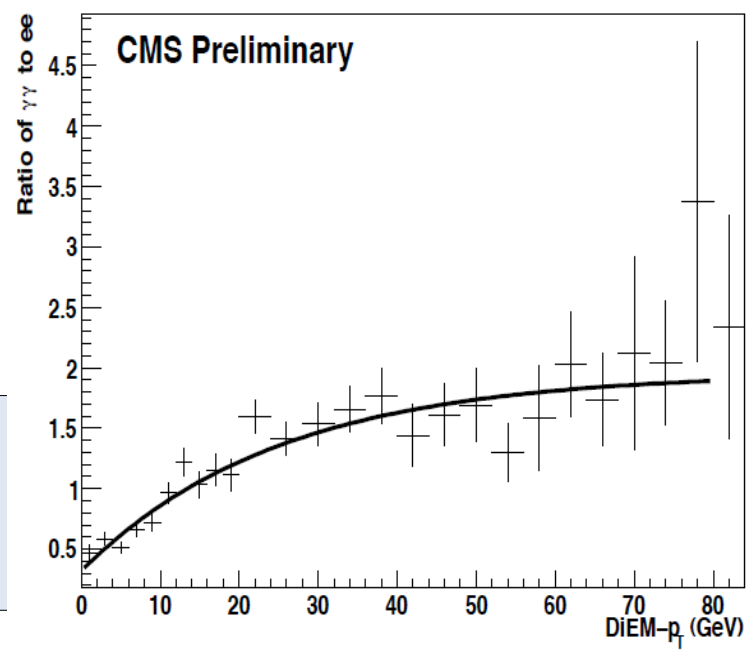
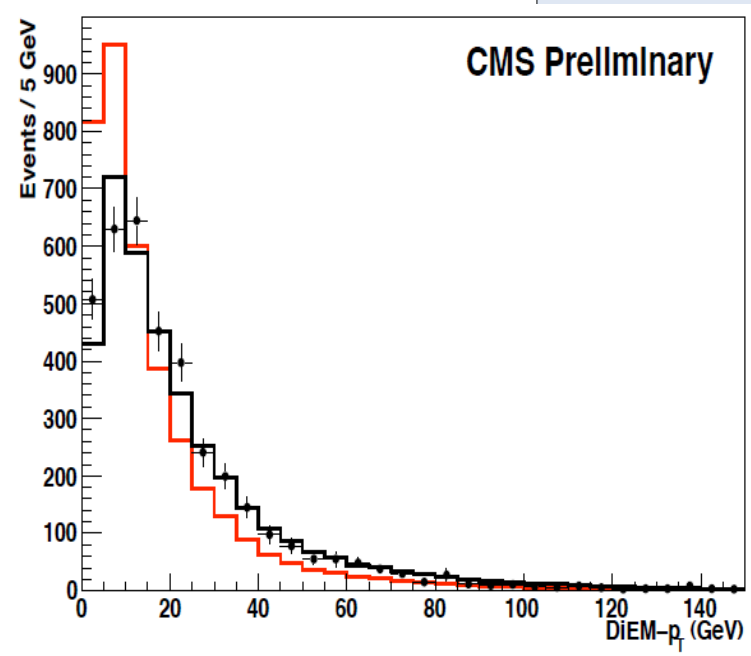
S2. Data-driven Background Estimates for SUSY Di-Photon Searches (2)

Determination of MET Distribution from Data

First MET of EW background is determined multiplaying MET of eγ sample by $f_{e\to\gamma}/(1-f_{e\to\gamma})$.

Than QCD background is modeled using reweighted Z → ee sample (see plots below).
Weighted distribution is normalized to γγ distribution for low MET (<20GeV).
The key assumption is that we could separate event into di-EM system, which is measured well, and recoil and other hadronic activity. This assumption cannot be derived from the first principles but it was proved to hold using MC, and it could be verified using real multi-jet events with two jets dominated by neutral pions.





Left: Ratio of # di-EM: (γγ) / (Z → ee) events versus di-EM p_T.
Right: Di-EM p_T distributions: γγ (points), Z → ee (histos) before and after reweighting.

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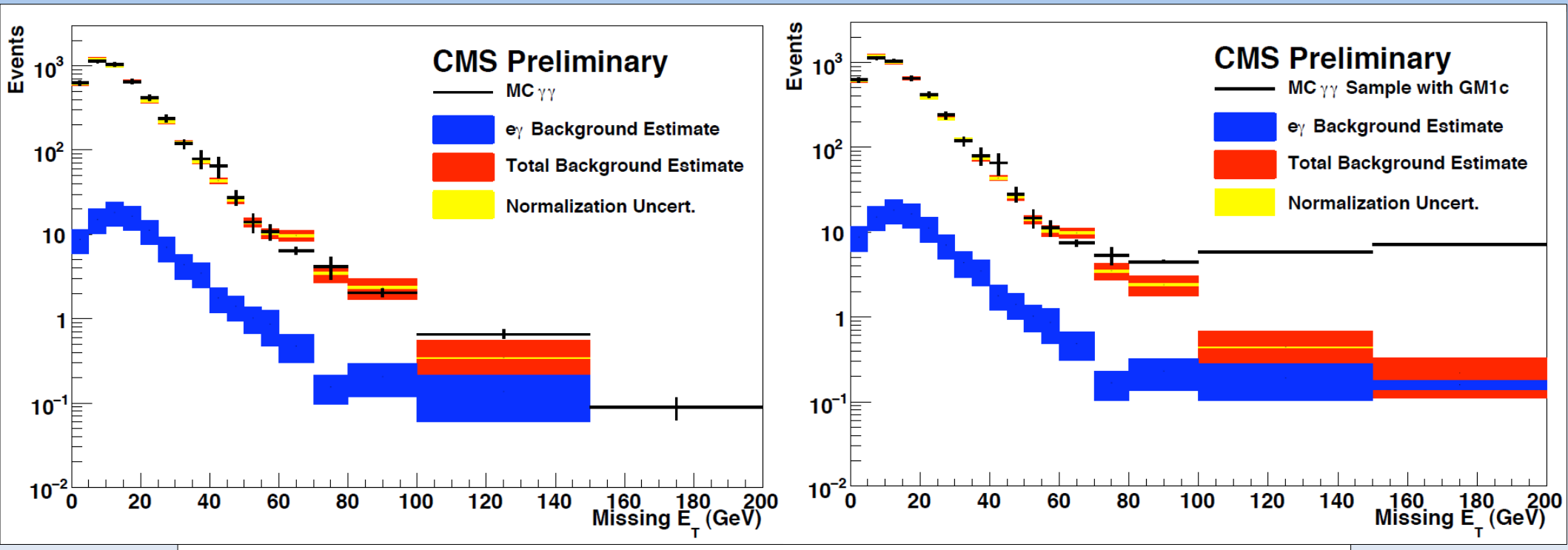
S2. Data-driven Background Estimates for SUSY Di-Photon Searches (3)



Background closure test using Z → ee events to describe the QCD background.
Left: without SUSY signal. Right: with GM1c SUSY.
The number of events correspond to 100/pb at 10 TeV.

Described techniques would allow to infer the existence of new physics in di-photon events with large missing transverse energy in early data.

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S3. Discovery potential and measurement of a dilepton edge in SUSY at 10 TeV (1)

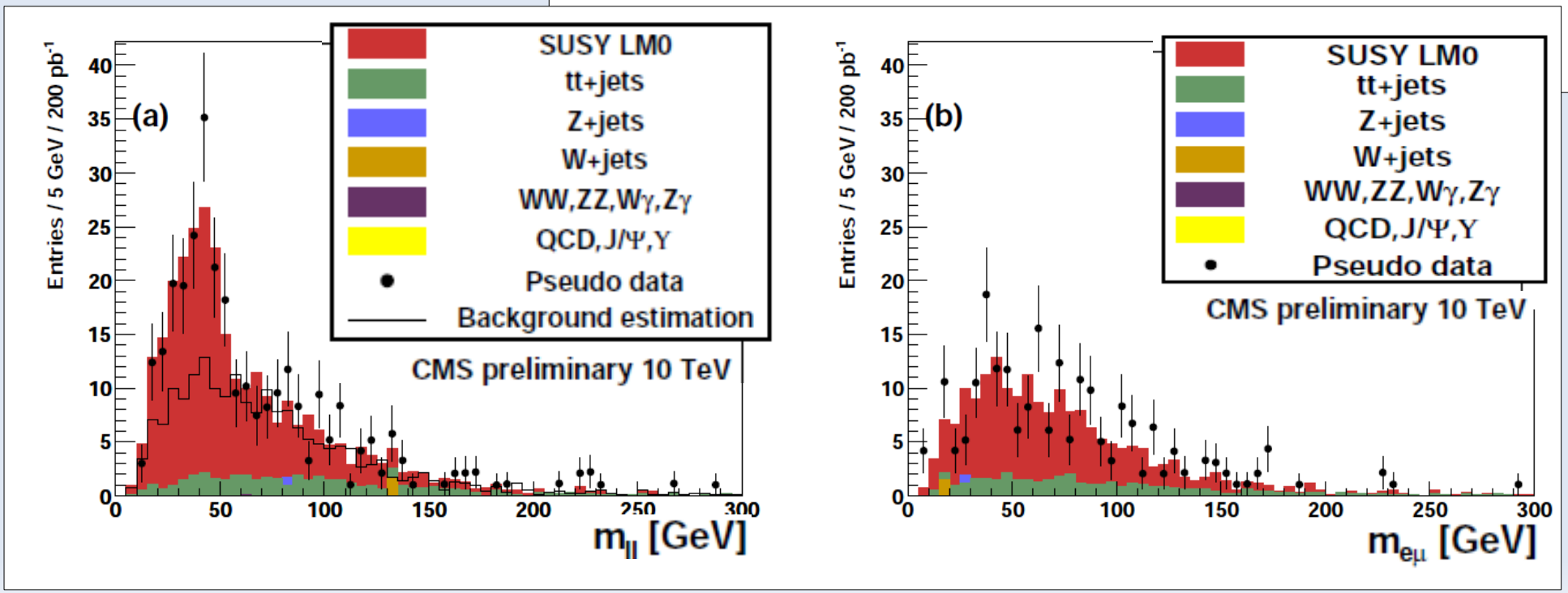
CMS PAS SUS-09-002

Decays of neutralino 2 to LSP neutralino 1 and SFOS lepton pair is one of the most studied mSUGRA signatures.

In this note signal visibility for sqrt(s)=10 TeV is studied in detail.

Selection: 2 OS isolated leptons, p_T^{l1}>16GeV, p_T^{j1}>100GeV, p_T^{j2},p_T^{j3}>50GeV, MET>100GeV

Left: SFOS lepton pair distribution after all cuts; the black solid line represents the extrapolation form OFOS shown in the right plot. The black points represent pseudo data corresponding to 200/pb. SM background is small. SUSY is the main background!



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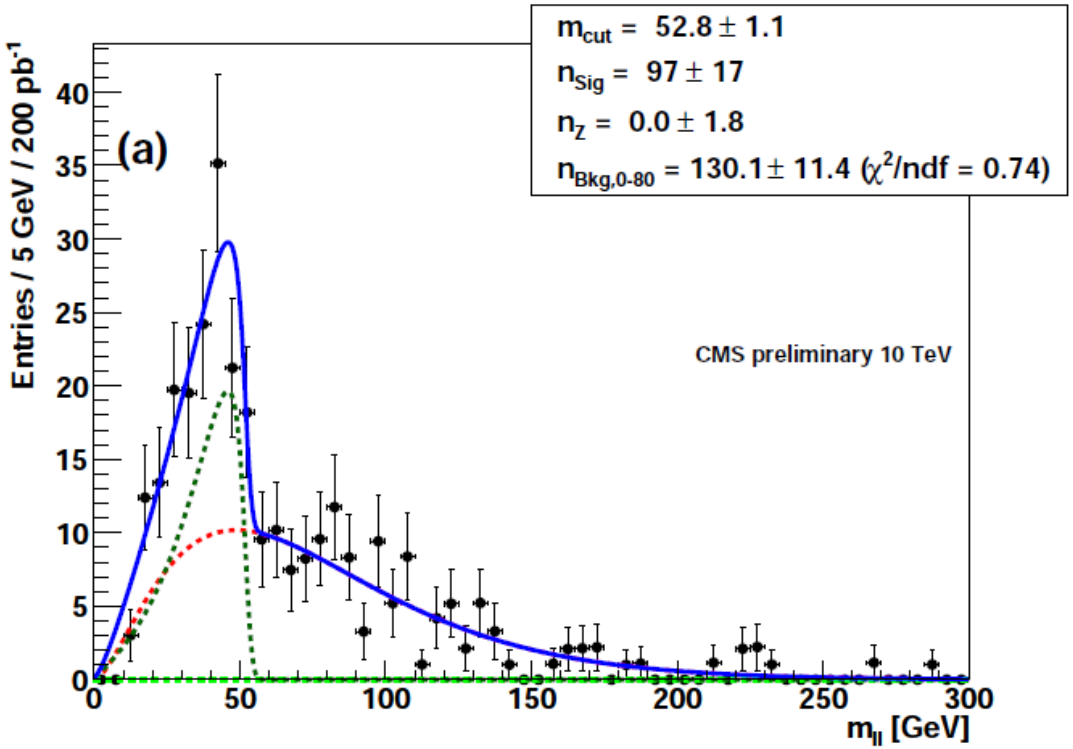
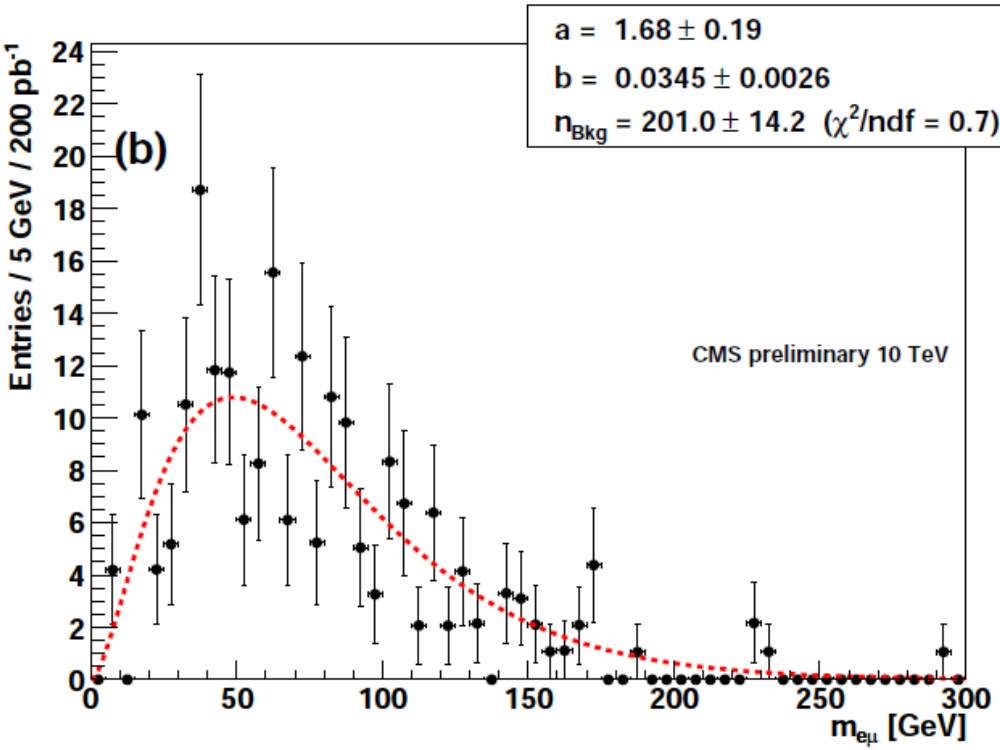
S3. Discovery potential and measurement of a dilepton edge in SUSY at 10 TeV (2)





The combined fit (common back. shape) of SFOS (left) and OFOS (right) lepton pairs at LM0 for 200/pb. Signal (green dashed on left plot) is fitted with three body or two body decay hypothesis depending on the goodness of the fit (chi2), Z peak is also fitted (it is absent at LM0).
Resolution and efficiencies are determined using Z decays.

The edge estimate: 3-body: (52.8±1.1)GeV (chi2/ndf=0.74); 2-body: (50.0±1.8)GeV (chi2/ndf=0.79)
Theoretical endpoint: 52.7 GeV

Int. lumi. for 5σ significance (including systematics): LM0: 200/pb; LM1: 250/pb; LM9: 350/pb

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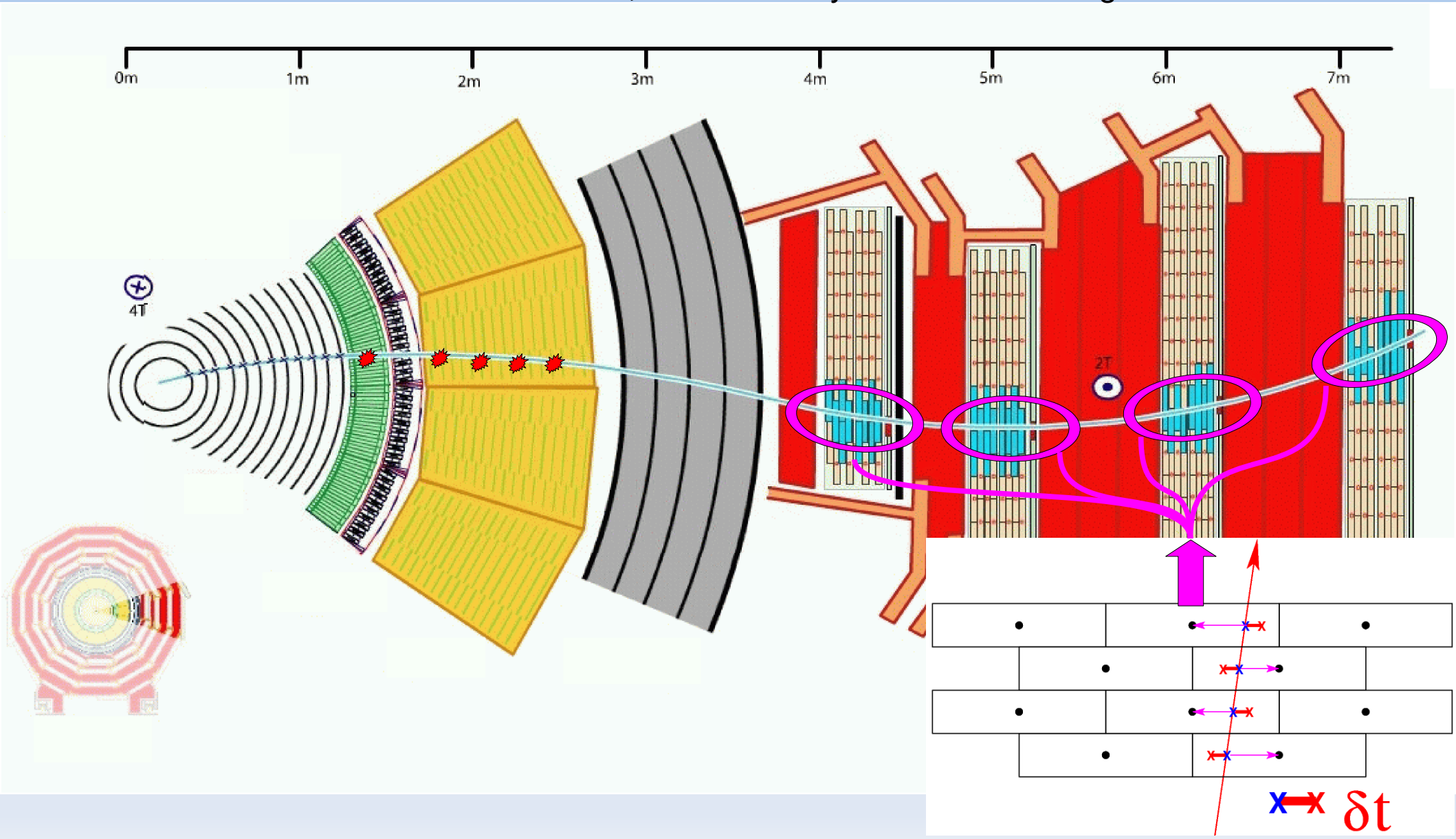
E1. HSCP search (1)

Exotica, or search beyond detector design.



E1. HSCP search (1)

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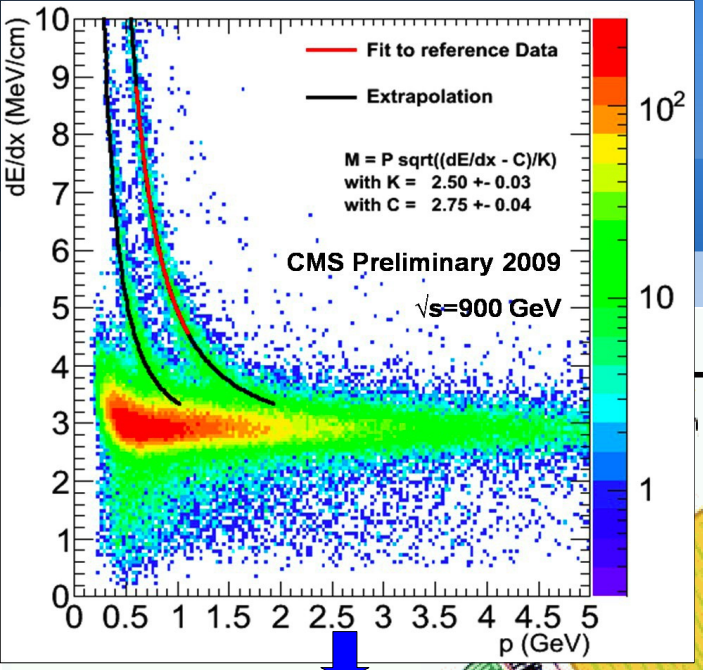
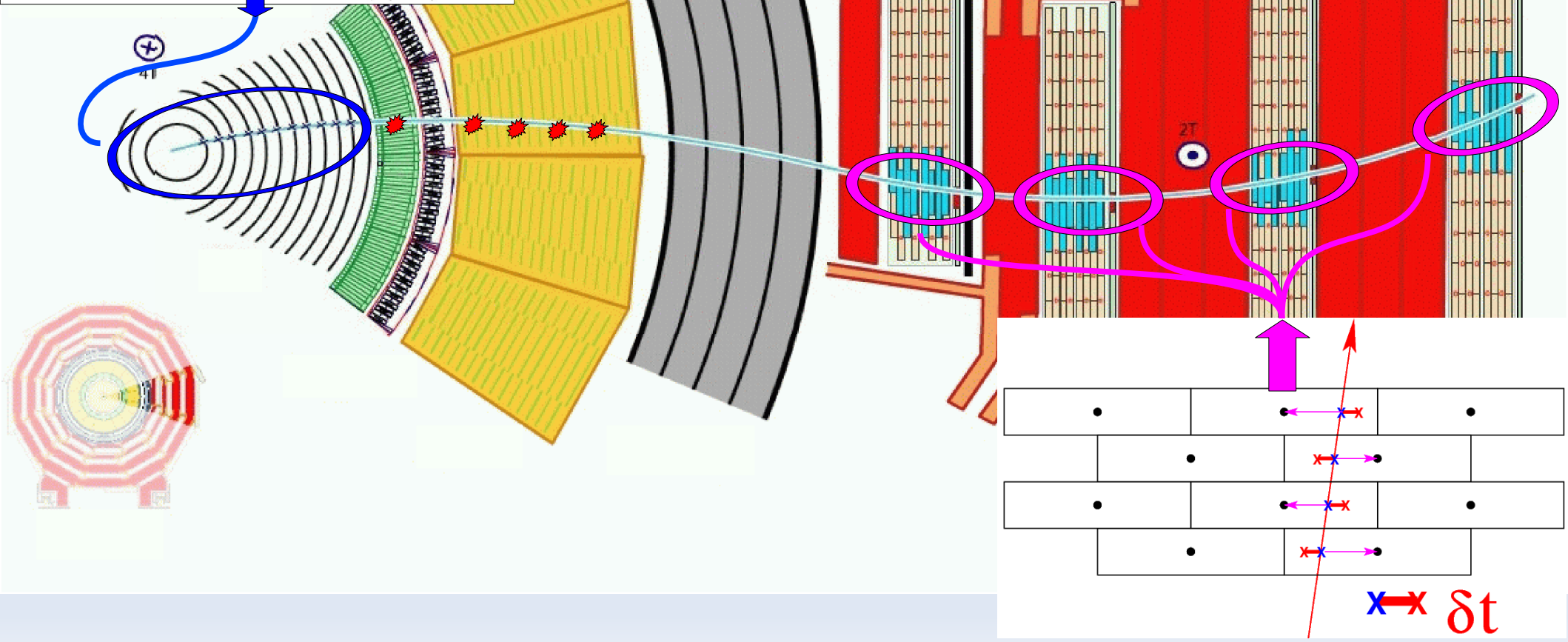
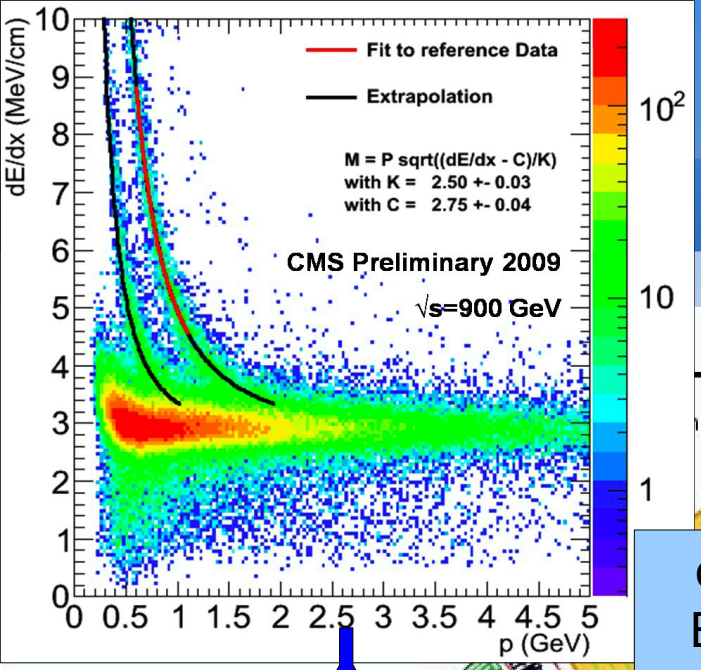


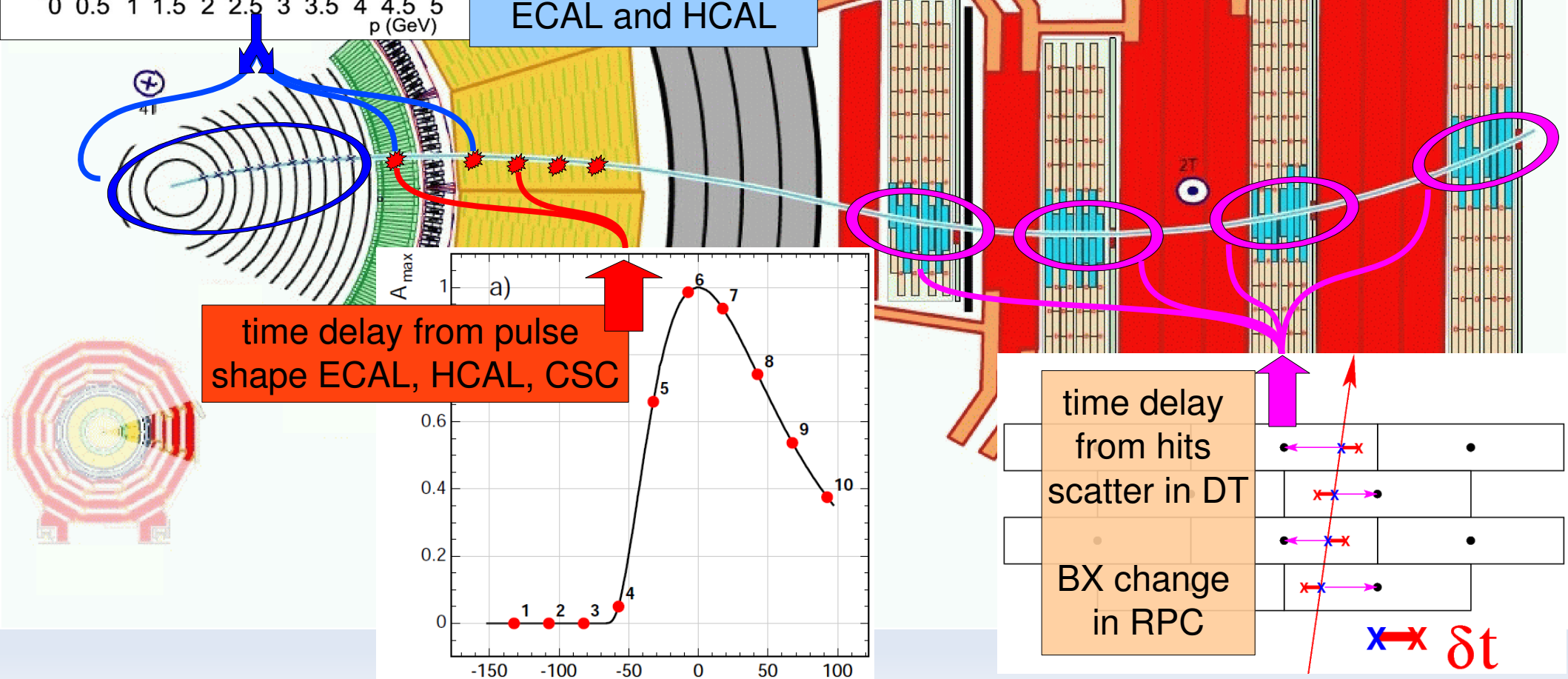


E1. HSCP search (1)

Exotica, or search beyond detector design.



dE/dx in tracker ECAL and HCAL



time delay from pulse shape ECAL, HCAL, CSC

time delay from hits scatter in DT

BX change in RPC

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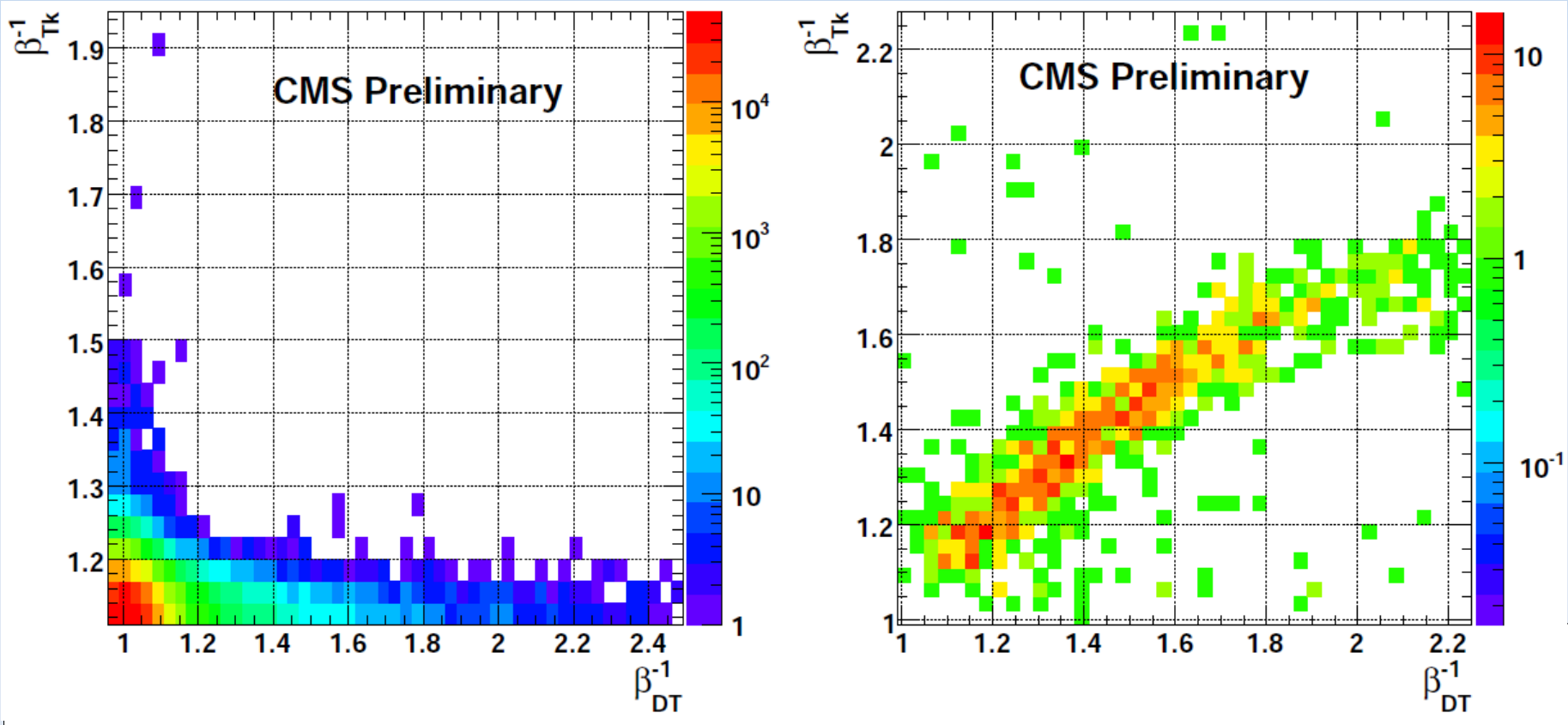
E1. HSCP search (2)

Search for Heavy Stable Charged particles with 100/pb and 1/fb

CMS PAS EXO-08-003



Invers beta estimate via dE/dx in the tracker versus estimate via TOF in the DT muon system for 1/fb. Left: background. Right: signal: stop 500GeV.

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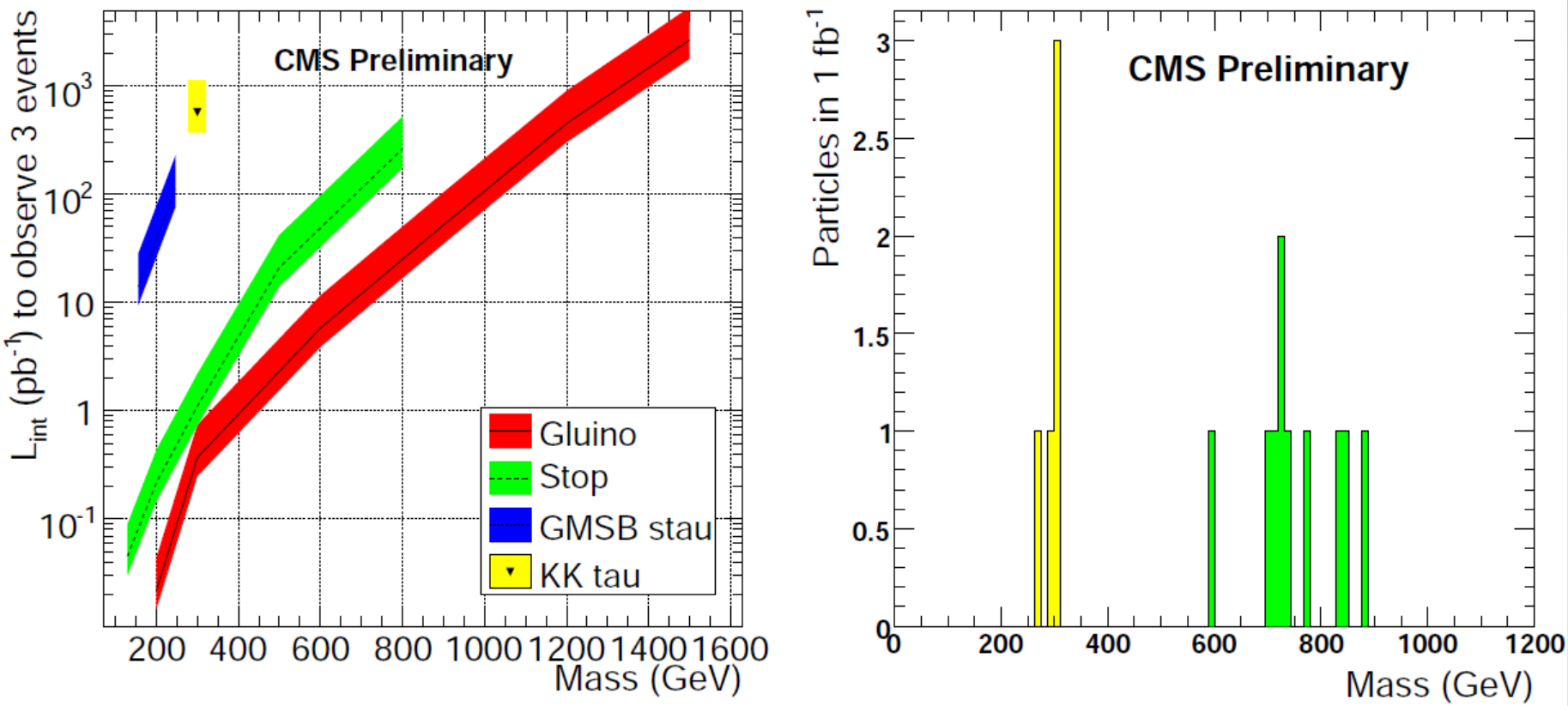
E1. HSCP search (3)



The left plot shows the integrated luminosity needed to select 3 events, for four types of signal models (see the legend) as a function of HSCP mass.

The right plot shows the reconstructed mass distribution for two lowest x-section samples (300 GeV KK tau: 20fb; and 800 GeV stop: 80fb) for 1/fb.

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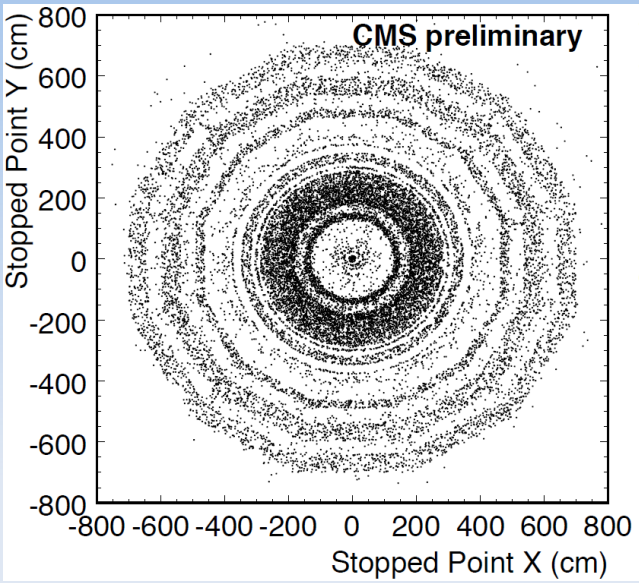
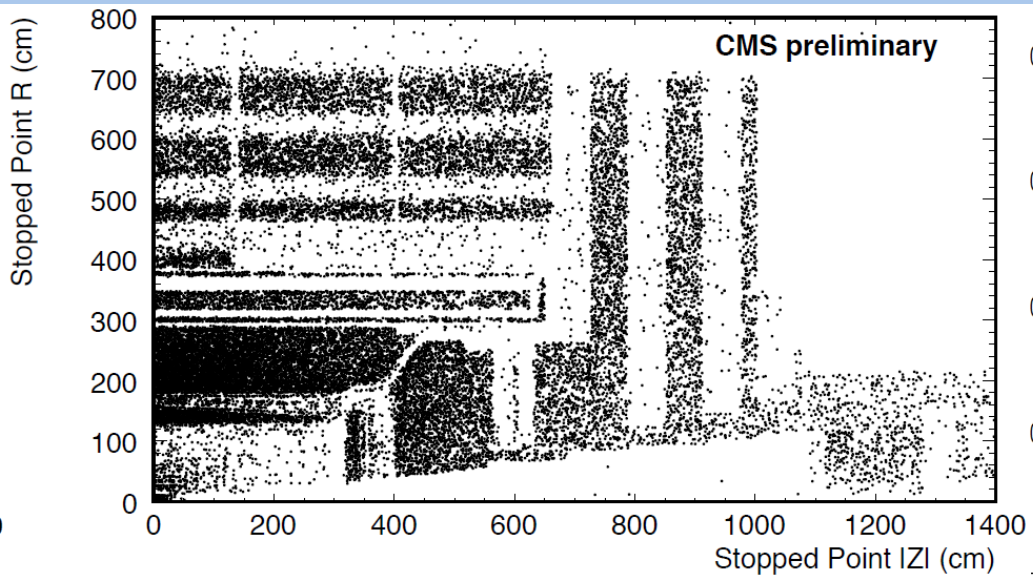
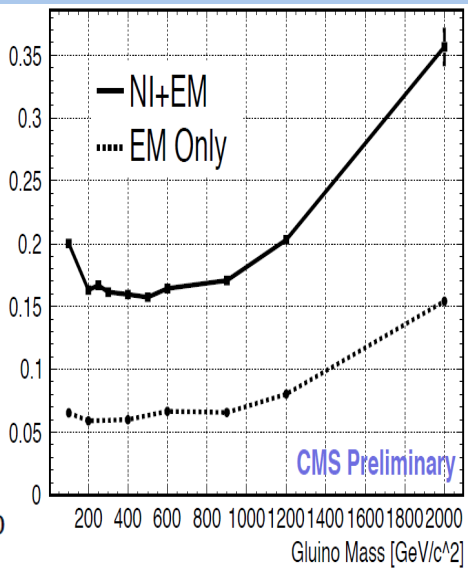
E2. Search for Stopped Gluinos during Beam-off Periods (1)





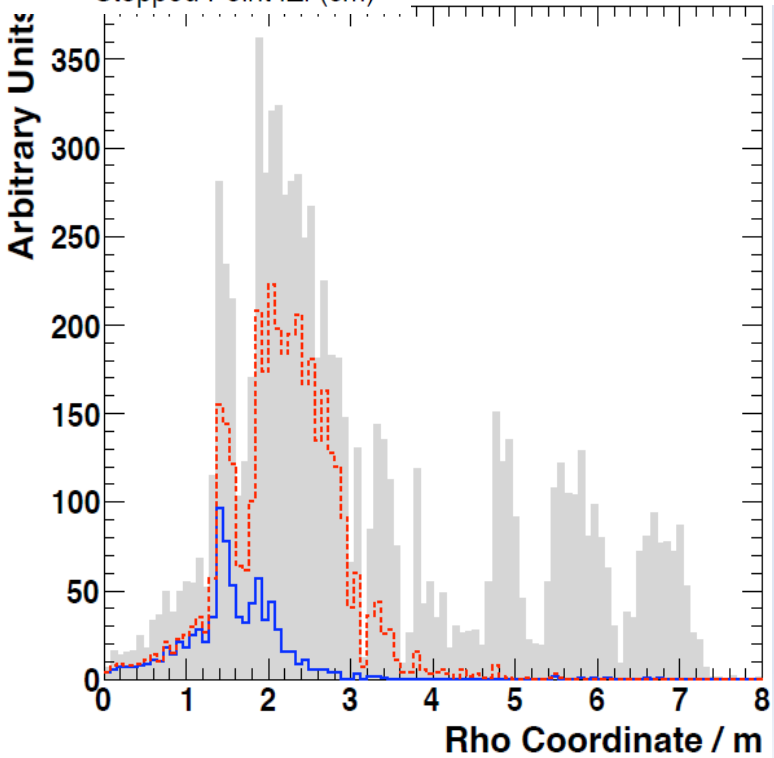


CMS PAS EXO-09-001

The less energetic HSCP will stop in the detector, and decay asynchronously. The stopping power is the greatest for R-hadron (upper right plot). More of R-hadron stopping in the CMS will stop in the calorimeters, mainly HCAL.

In the plot in the bottom right corner shadowed histogram shows rho coordinate at stopping point , whereas red dashed histogram corresponds to gluinos decays giving more than 5 GeV deposit in the calorimeters.

Such deposit could be used for trigger during beam-off periods.



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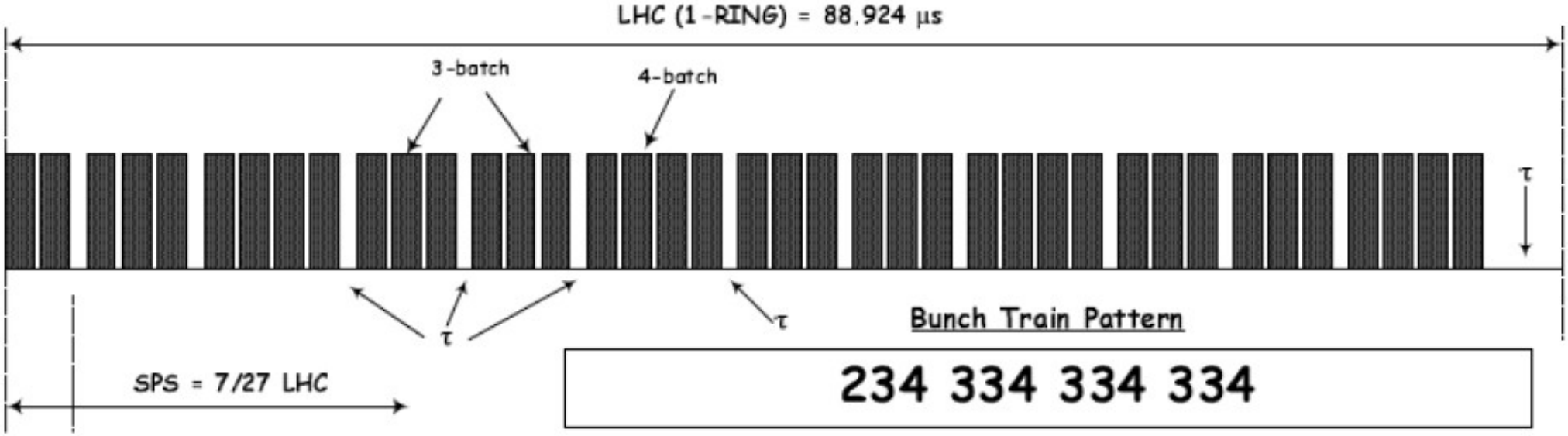
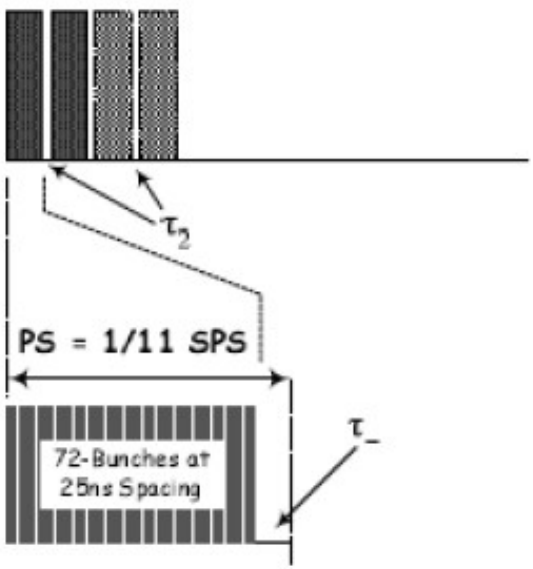
E2. Search for Stopped Gluinos during Beam-off Periods (2)





Bunch Train Pattern

234 334 334 334

Filling Scheme

3564 =
2x (72b + 8e) + 30e + 3x(72b + 8e) + 30e + 4x (72b + 8e) + 31e +
3x { 2x [3x (72b + 8e) + 30e] + 4x (72b + 8e) + 31e } + 80e

Beam Gaps

τ_1 = 12 bunch gap in the PS (72 bunches on h=84)
τ_2 = 8 missing bunches (SPS Injection Kicker Rise time = 225ns).
τ_3 = 38 missing bunches (LHC Injection Kicker Rise Time = 0.975μs)
τ_4 = 39 missing bunches (" 1.0μs)
τ_5 = 119 missing bunches (LHC Beam Dump Kicker Rise Time = 3μs)

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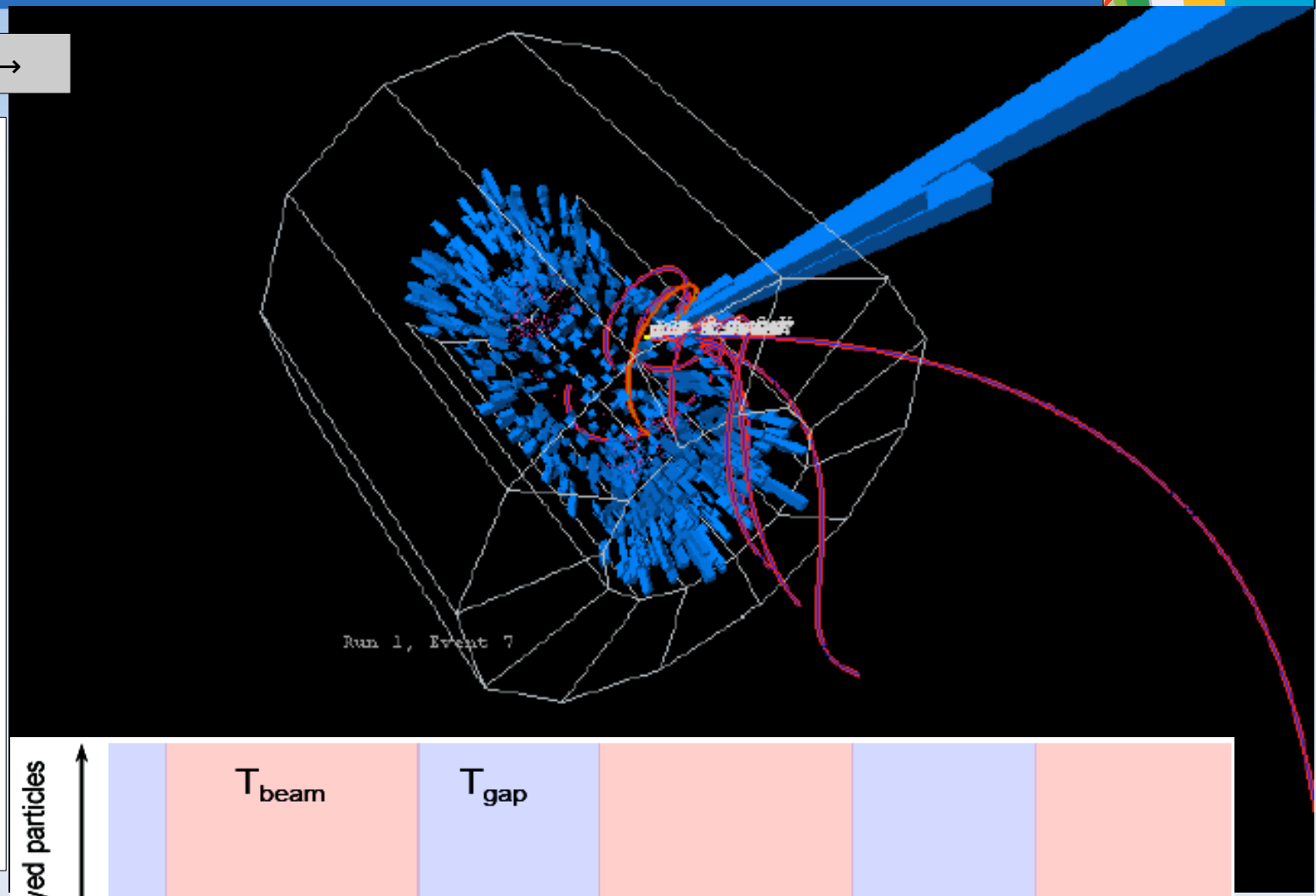
E2. Search for Stopped Gluinos during Beam-off Periods (3)

Visualisation of a gluino decay →

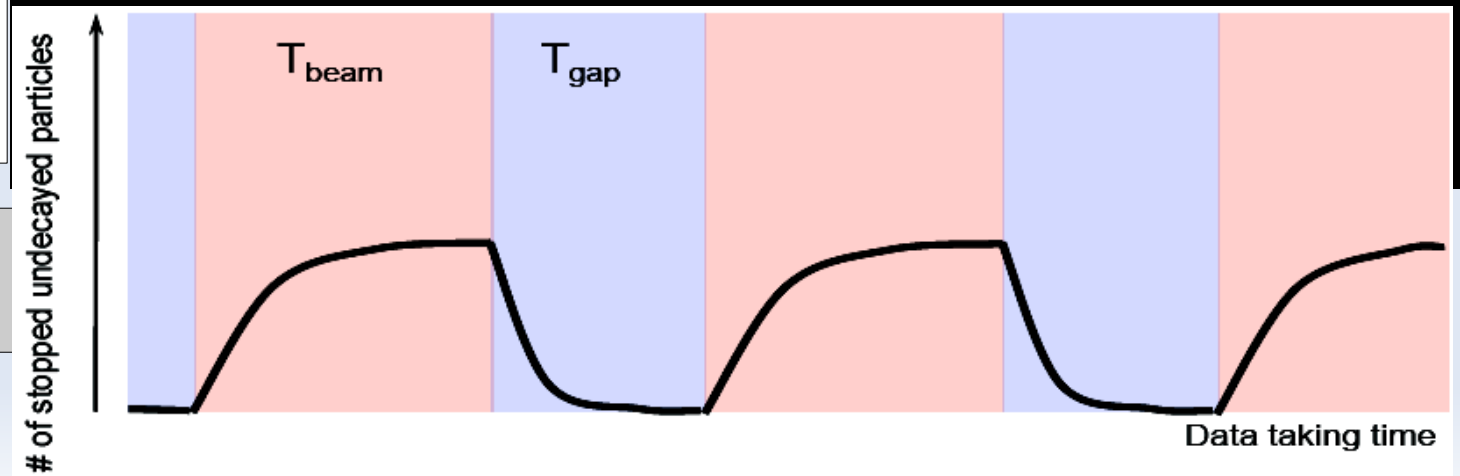
L1 trigger is the logical AND of (i) the lowest threshold (10 GeV) normal jet trigger with (ii) the no beam condition. During cosmic runs the rate was 200Hz.

To reduce this rate further, at the HLT level, noisy HCAL channels are filtered out and jets are reconstructed and 20 GeV threshold applied to the leading jet energy. Cosmic veto is applied off-line.

The rate was measured to be less than 10Hz, and relative efficiency is expected to be around 30%.



Sketch showing time evolution of a number of stopped undecayed gluinos →



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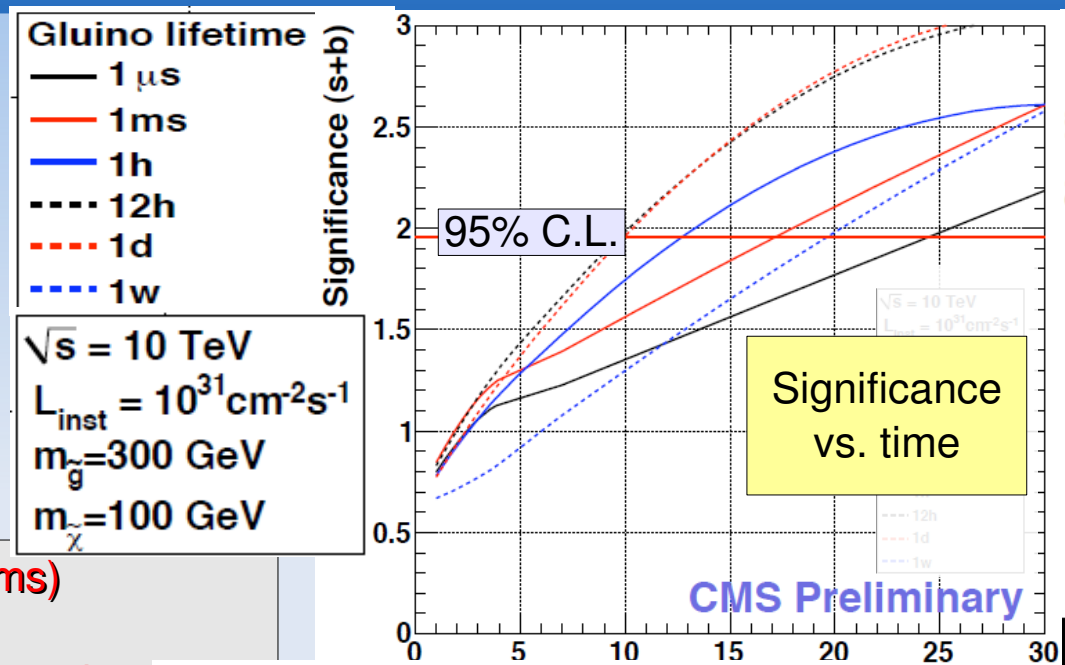
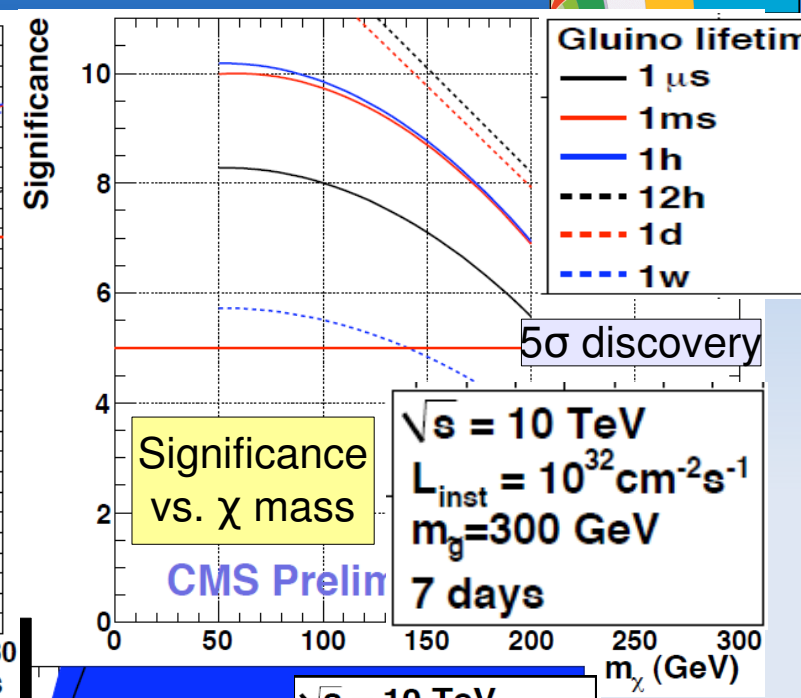
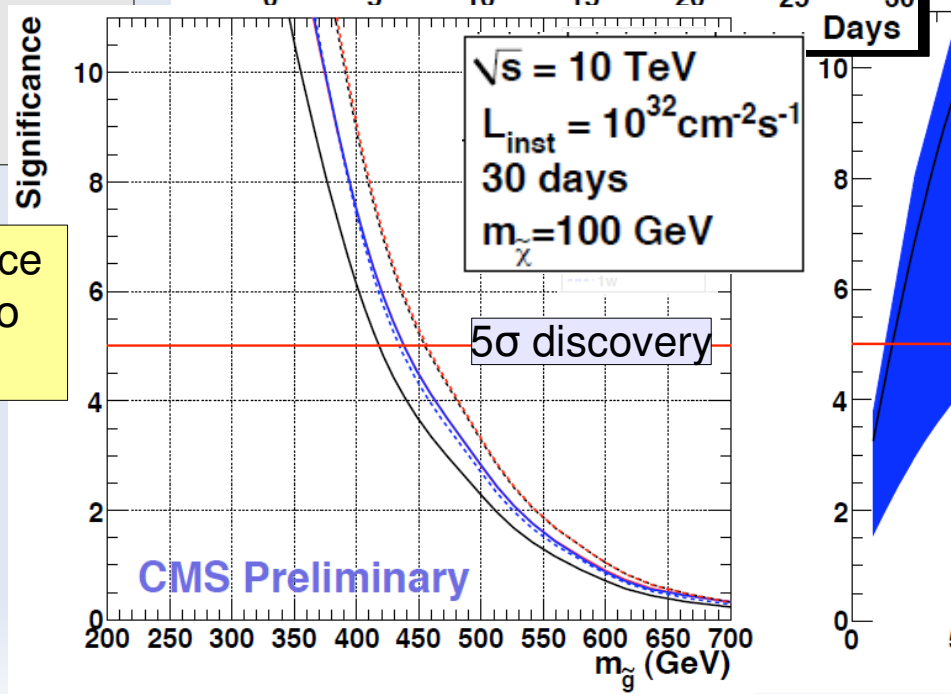
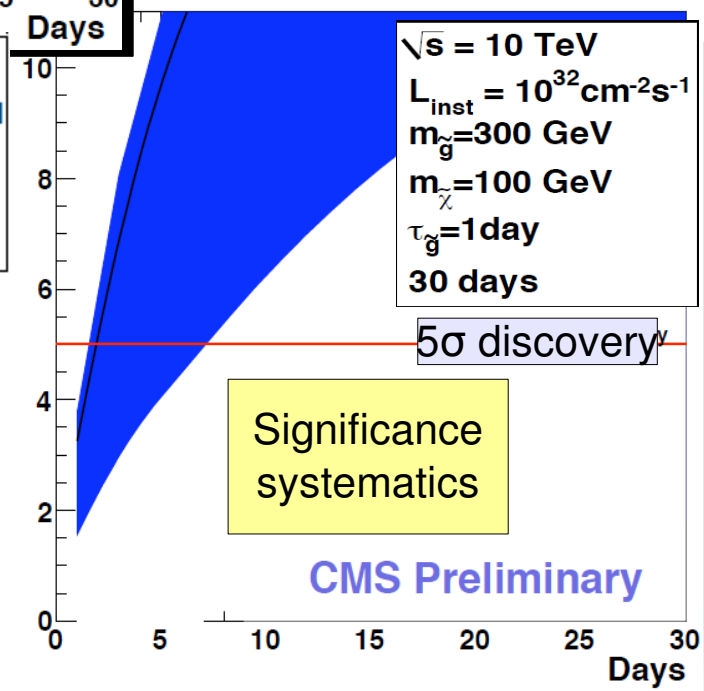
E2. Search for Stopped Gluinos during Beam-off Periods (4)





The red (1ms) curves are representative of a range from 10us to 100s.





Conclusions

CMS is waiting for 2010 collisions
More than 99% of subdetector electronic channels are operational.
Data can be analyzed rapidly, all analysis chains are working well.
Detector is initially aligned and time callibrated. This situation will further improve with data.

With only few tens of inverse picobarns of data at 3.5 TeV, CMS will be sensitive to new phenomena. One of the intriguing possibilities is existence of supersymmetry.

On top of well defined strategies we have developed several methods to be applied on first collisions data at high energy. These methods will allow us to infer background levels from data and discover new physics if its x-section is above pb level.

We have also program to look at signatures not taken into account during CMS design. It is interesting to note, that such phenomena could be seen before standard one, if appropriate version of physics beyond standard model is realized in nature.

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Backup slide: SUSY points

Benchmark	m0	m1/2	A0	tanb	sgn(mu)
LM0	200	160	-400	10	1
LM1	60	250	0	10	+
LM2	185	350	0	35	+
LM2mhf360	185	360	0	35	+
LM3	330	240	0	20	+
LM4	210	285	0	10	+
LM5	230	360	0	10	+
LM6	85	400	0	10	+
LM7	3000	230	0	10	+
LM8	500	300	-300	10	+
LM9	1450	175	0	50	+
LM9p	1450	230	0	10	+

Sample	m_0 (GeV/c^2)	$m_{1/2}$ (GeV/c^2)	A_0	$\tan\beta$	sign(μ)	σ LO (pb)	lightest $\tilde{q}$ (GeV/c^2)	χ_1^0 (GeV/c^2)
LM0	200	160	-400	10	+	110	207	60
LM1	60	250	0	10	+	16.1	410	97
LM2	185	350	0	35	+	2.4	582	141
LM3	330	240	0	20	+	11.8	446	94
LM4	210	285	0	10	+	6.7	483	112
LM5	230	360	0	10	+	1.9	603	145

Benchmark	m0	m1/2	A0	tanb	sgn(mu)
HM1	180	850	0	10	+
HM2	350	800	0	35	+
HM3	700	800	0	10	+
HM4	1350	600	0	10	+

Benchmark	Lambda	M_mess	N5	C_Grav	tanb	sgn(mu)
GM1b	80	160	1	1	15	+
GM1c	100	200	1	1	15	+
GM1d	120	240	1	1	15	+
GM1e	140	280	1	1	15	+
GM1f	160	320	1	1	15	+
GM1g	180	360	1	1	15	+

Data Sample	Cross section (pb)
$\tilde{\tau}_1$ (156 GeV)	1.19
$\tilde{\tau}_1$ (247 GeV)	0.097
KK tau (300 GeV)	0.020
$\tilde{g}$ (200 GeV)	2.2×10^3
$\tilde{g}$ (300 GeV)	100
$\tilde{g}$ (600 GeV)	5.00
$\tilde{g}$ (900 GeV)	0.46
$\tilde{g}$ (1200 GeV)	61×10^{-3}
$\tilde{g}$ (1500 GeV)	10×10^{-3}
$\tilde{t}_1$ (130 GeV)	1.11×10^3
$\tilde{t}_1$ (200 GeV)	1.77×10^2
$\tilde{t}_1$ (300 GeV)	27.4
$\tilde{t}_1$ (500 GeV)	1.27
$\tilde{t}_1$ (800 GeV)	7.81×10^{-2}

← HSCP