

# *The CMS Experiment:*

## *Status, Performance and Selected Results*

Manfred Jeitler

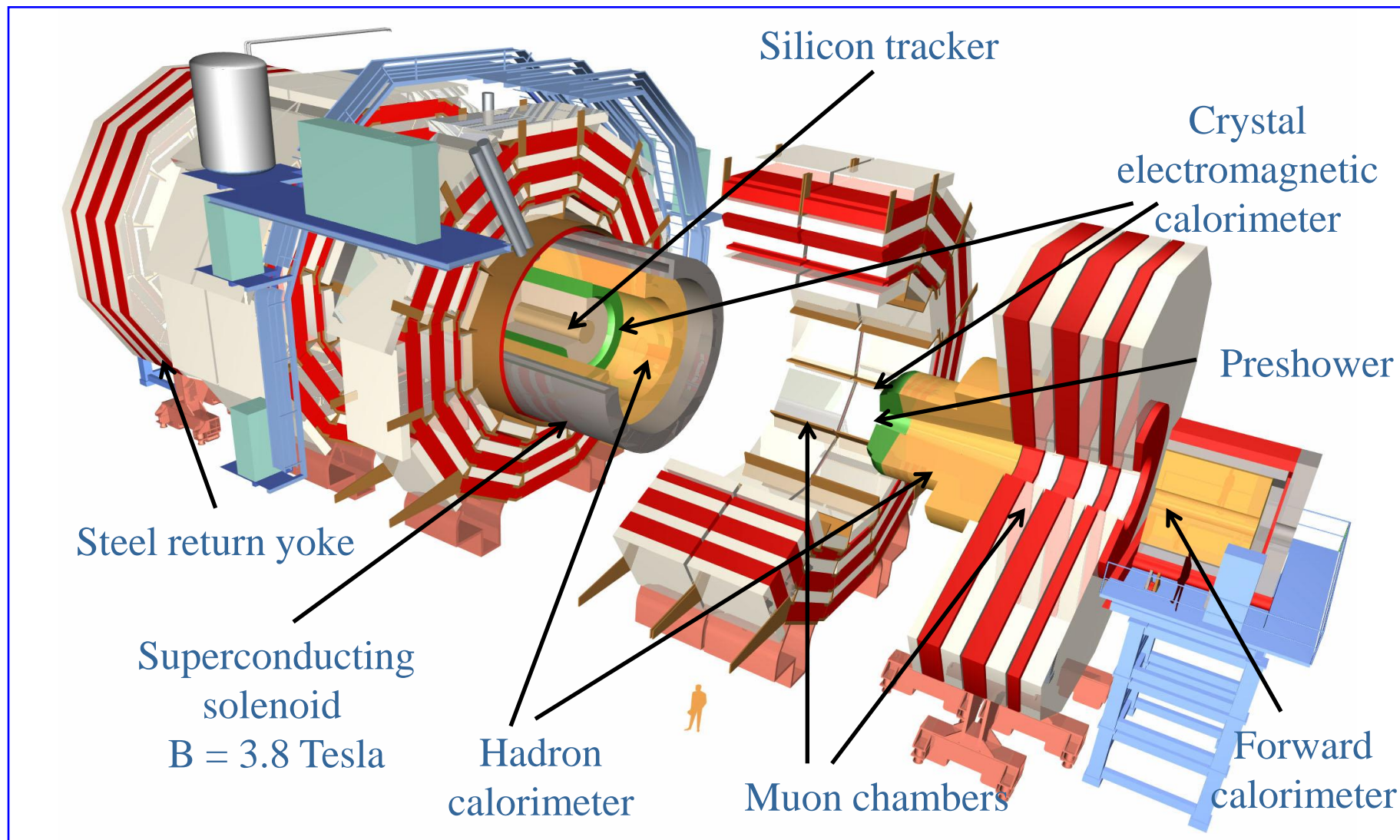
Institute of High Energy Physics of the  
Austrian Academy of Sciences

*for the  
CMS collaboration*





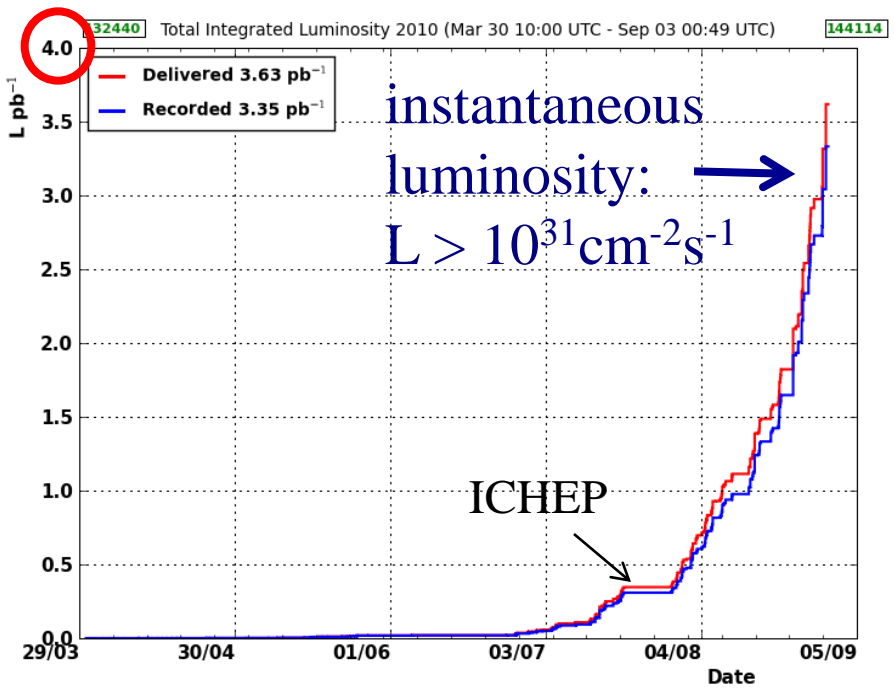
# Compact Muon Solenoid



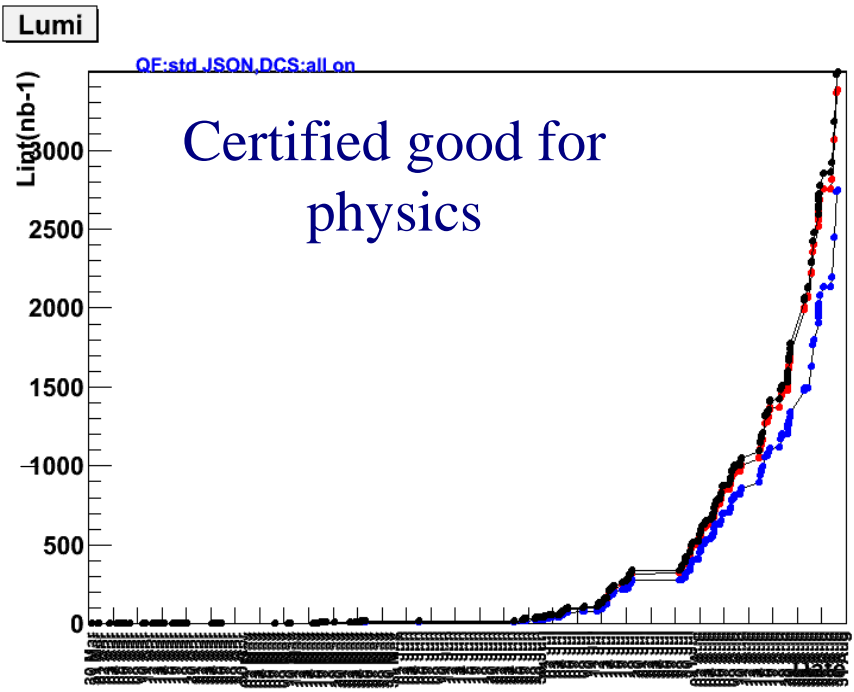


# Statistics accumulated

(before bunch trains were introduced, up to September 2010)



$$\frac{\text{Recorded}}{\text{Delivered}} = 92\%$$



$$\frac{\text{Certified}}{\text{Recorded}} = 88\%$$

(declared perfect by all systems)

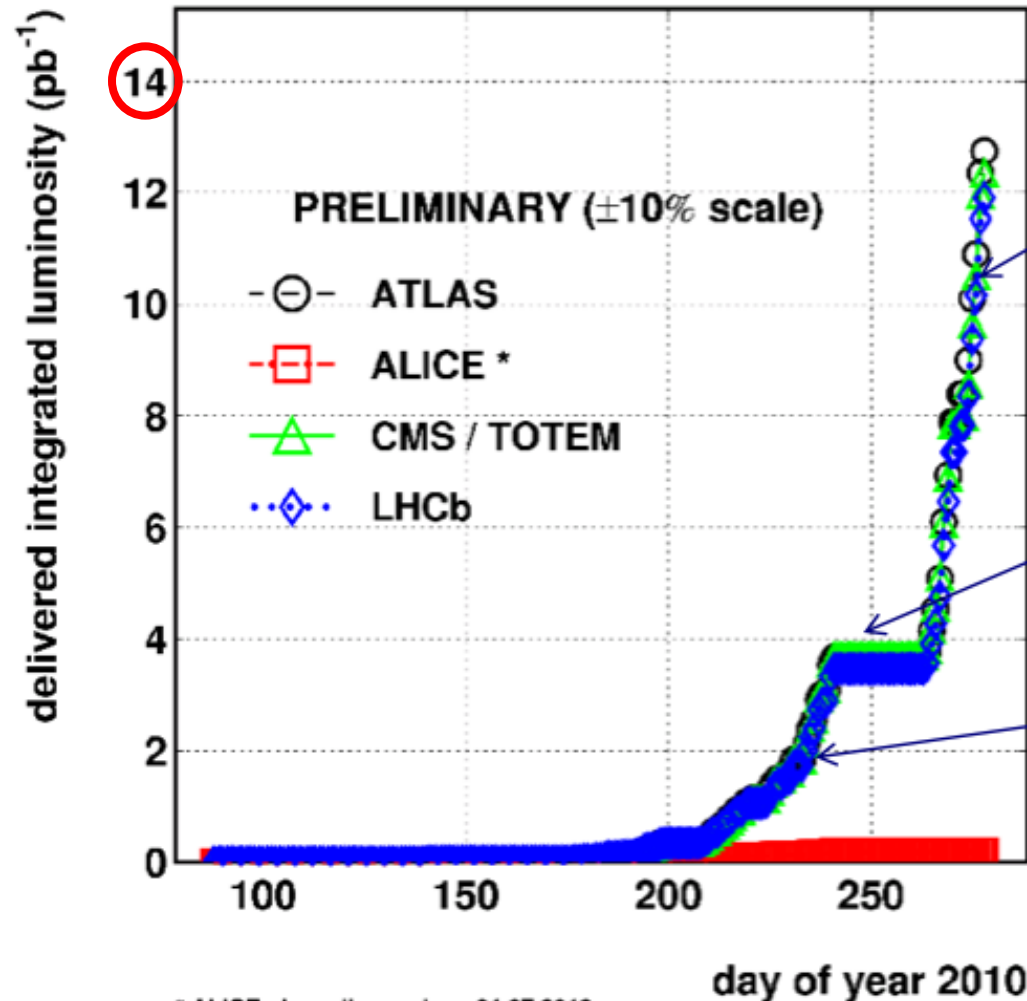


# Total luminosity delivered by LHC

(up to 7 October 2010)

2010/10/07 10.36

## LHC 2010 RUN (3.5 TeV/beam)



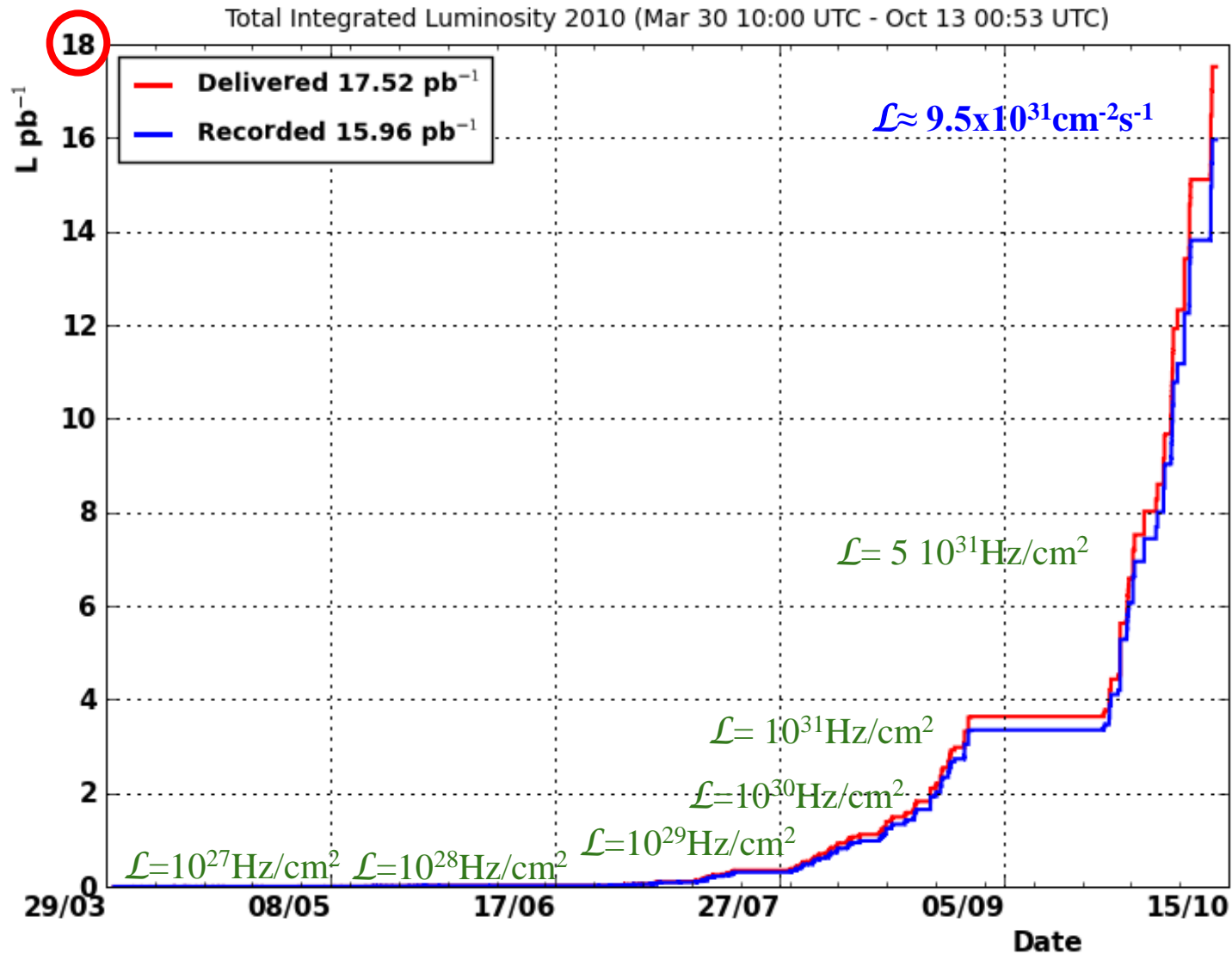
September:  
**2 Weeks (!) of Bunch Trains**

Development of **Bunch Trains**

August: Stable running with about 1  $\mu\text{s}$  bunch spacing

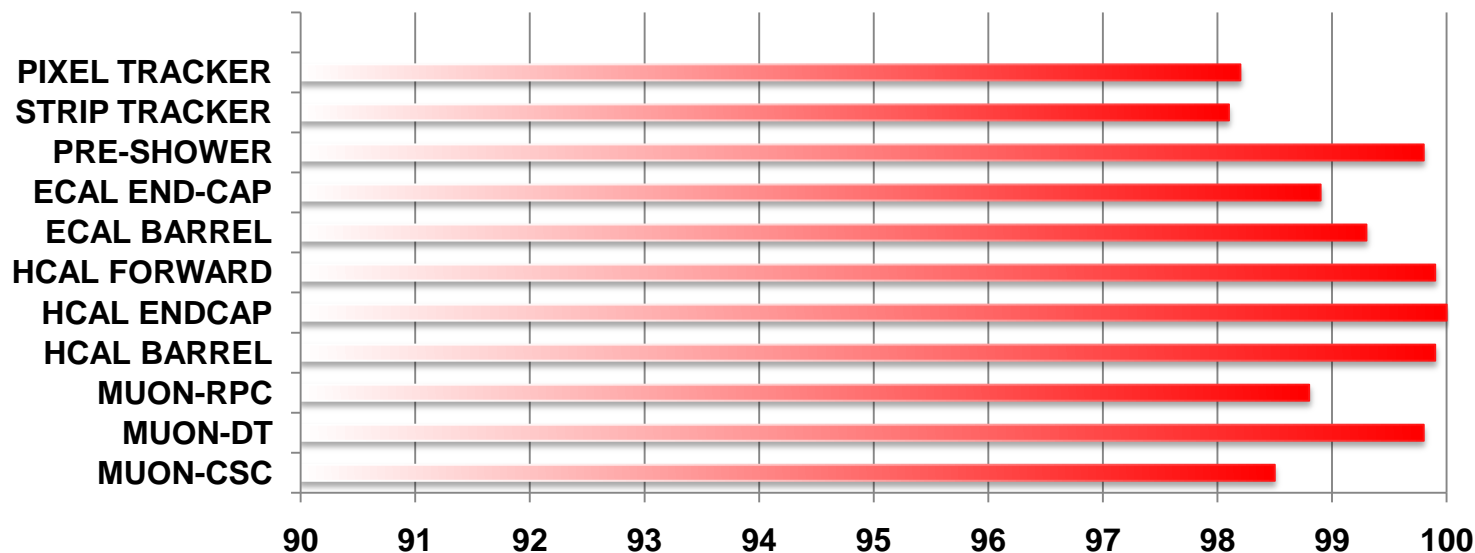
\* ALICE : low pile-up since 01.07.2010

# Statistics doubled in little over a week!



# ... and how CMS is taking this luminosity

- 93% luminosity livetime
- Level-1 trigger rate 45-70 kHz
- High Level Trigger (data logging rate) 350-600 Hz



	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

# PROTON PHYSICS: INJECTION PHYSICS BEAM

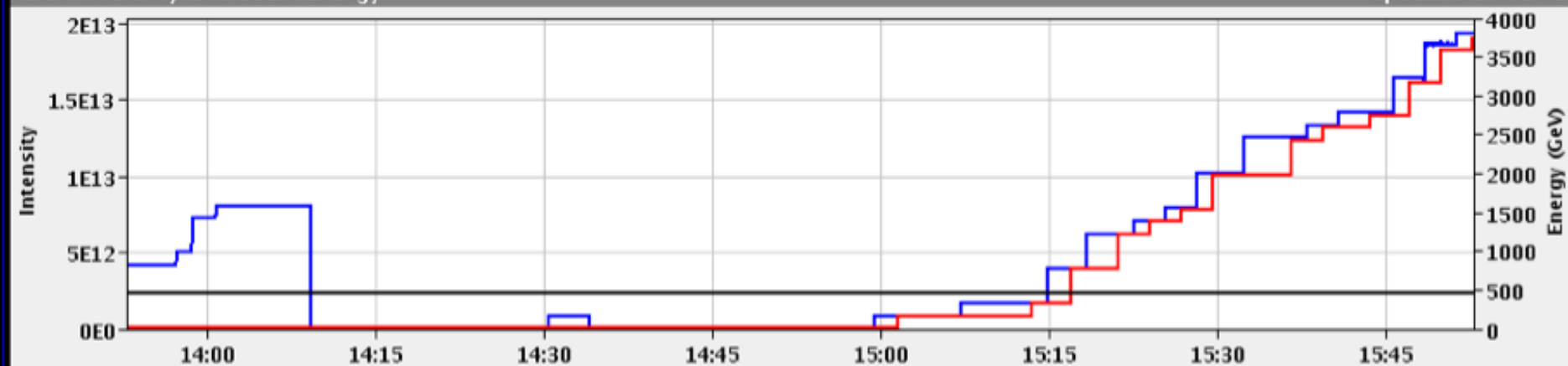
**BCT TI2:** 0.00e+00    **I(B1):** 2.32e+13    **BCT TI8:** 6.60e+11    **I(B2):** 2.14e+13

**TED TI2 position:** **BEAM**    **TDI P2 gaps/mm**    up: 9.94    down: 7.99

**TED TI8 position:** **BEAM**    **TDI P8 gaps/mm**    up: 8.68    down: 8.65

FBCT Intensity and Beam Energy

Updated: 15:52:42



**Comments 10-10-2010 14:34:11 :**

will try and inject for physics  
(while TL experts are still here)

now: TL / injection studies  
then: back to physics (248 bu/ring)

**BIS status and SMP flags**

	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false



# PROTON PHYSICS: RAMP

Energy:

2786 GeV

I(B1):

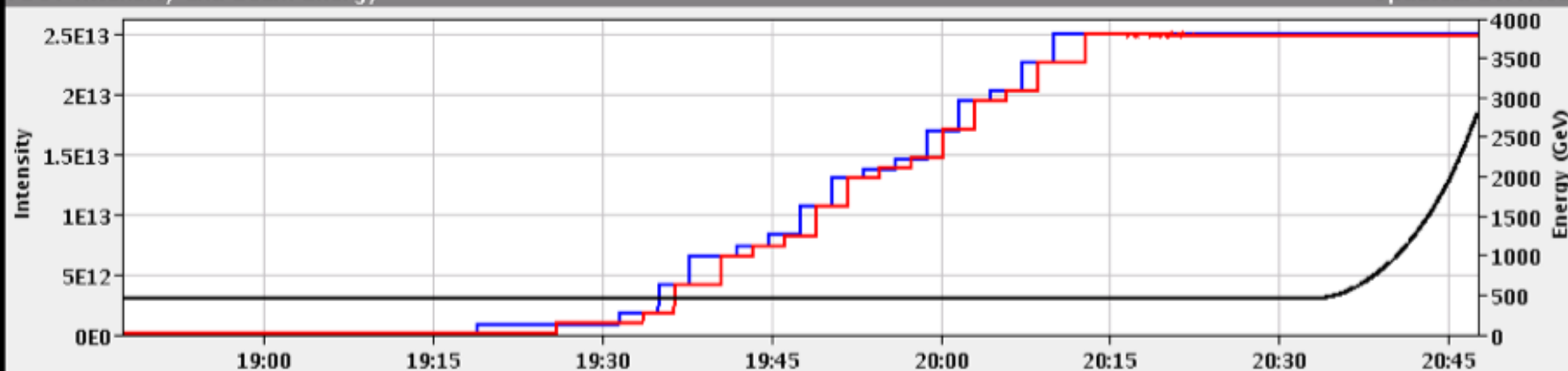
2.70e+13

I(B2):

2.61e+13

FBCT Intensity and Beam Energy

Updated: 20:47:32



Comments 10-10-2010 19:40:36 :

injecting

Next: Fill for physics (248 bu/ring)

BIS status and SMP flags

B1

B2

Link Status of Beam Permits

true

true

Global Beam Permit

true

true

Setup Beam

false

false

Beam Presence

true

true

Moveable Devices Allowed In

false

false

Stable Beams

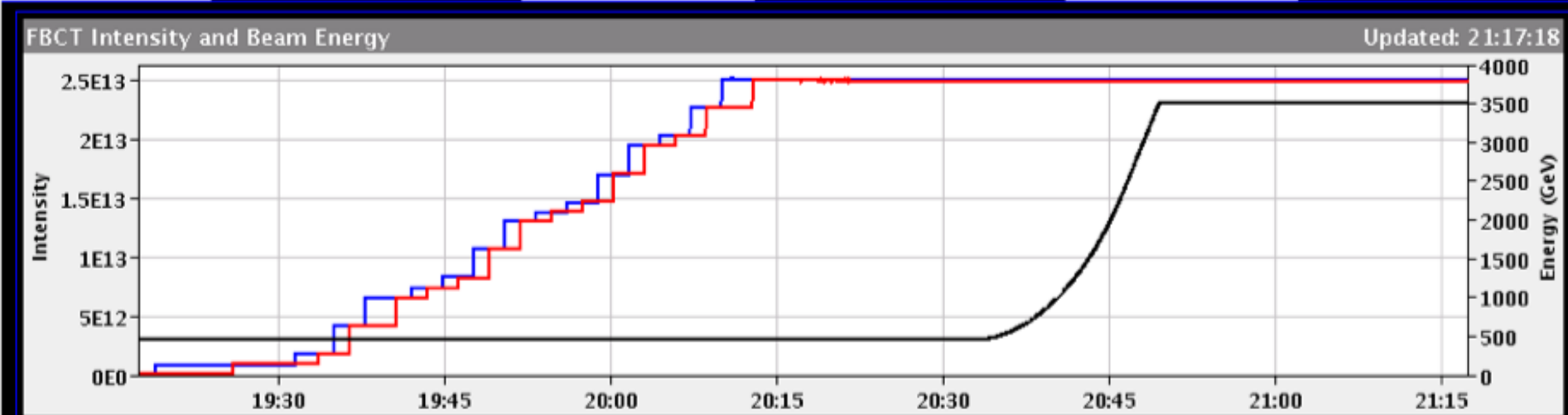
false

false



# PROTON PHYSICS: SQUEEZE

Energy: 3500 GeV I(B1): 2.70e+13 I(B2): 2.61e+13



Comments 10-10-2010 21:06:09 :

squeezing

BIS status and SMP flags

B1

B2

Link Status of Beam Permits

true true

Global Beam Permit

true true

Setup Beam

false false

Beam Presence

true true

Moveable Devices Allowed In

false false

Stable Beams

false false

Next: This fill for physics(248 bu/ring)

# PROTON PHYSICS: STABLE BEAMS

Energy:

3500 GeV

I(B1):

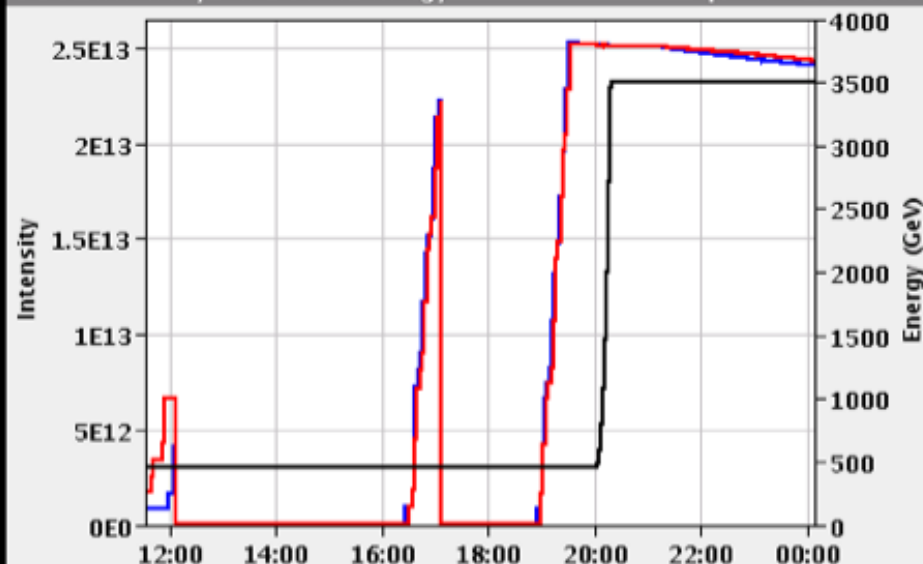
2.59e+13

I(B2):

2.57e+13

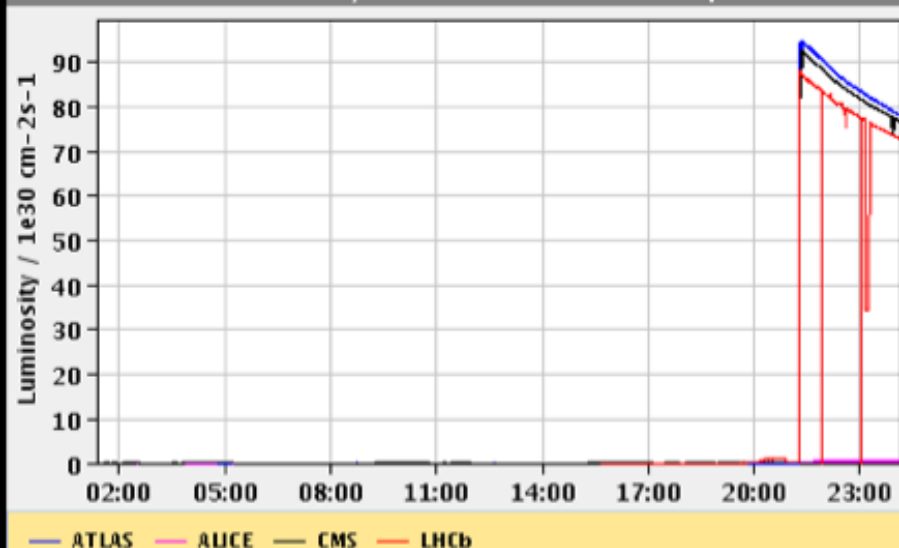
FBCT Intensity and Beam Energy

Updated: 00:07:36



Instantaneous Luminosity

Updated: 00:07:37



Comments 11-10-2010 23:52:23 :

\*\*\* Stable Beams \*\*\*

Doing a mini lumi scan for CMS

fill: 248b\_233\_16\_233\_3x8bpi15inj

(beam dump planned for 7:30 tomorrow)

BIS status and SMP flags

B1

B2

Link Status of Beam Permits

true true

Global Beam Permit

true true

Setup Beam

false false

Beam Presence

true true

Moveable Devices Allowed In

true true

Stable Beams

true true

LHC Operation in CCC : 77600, 70480

PM Status B1

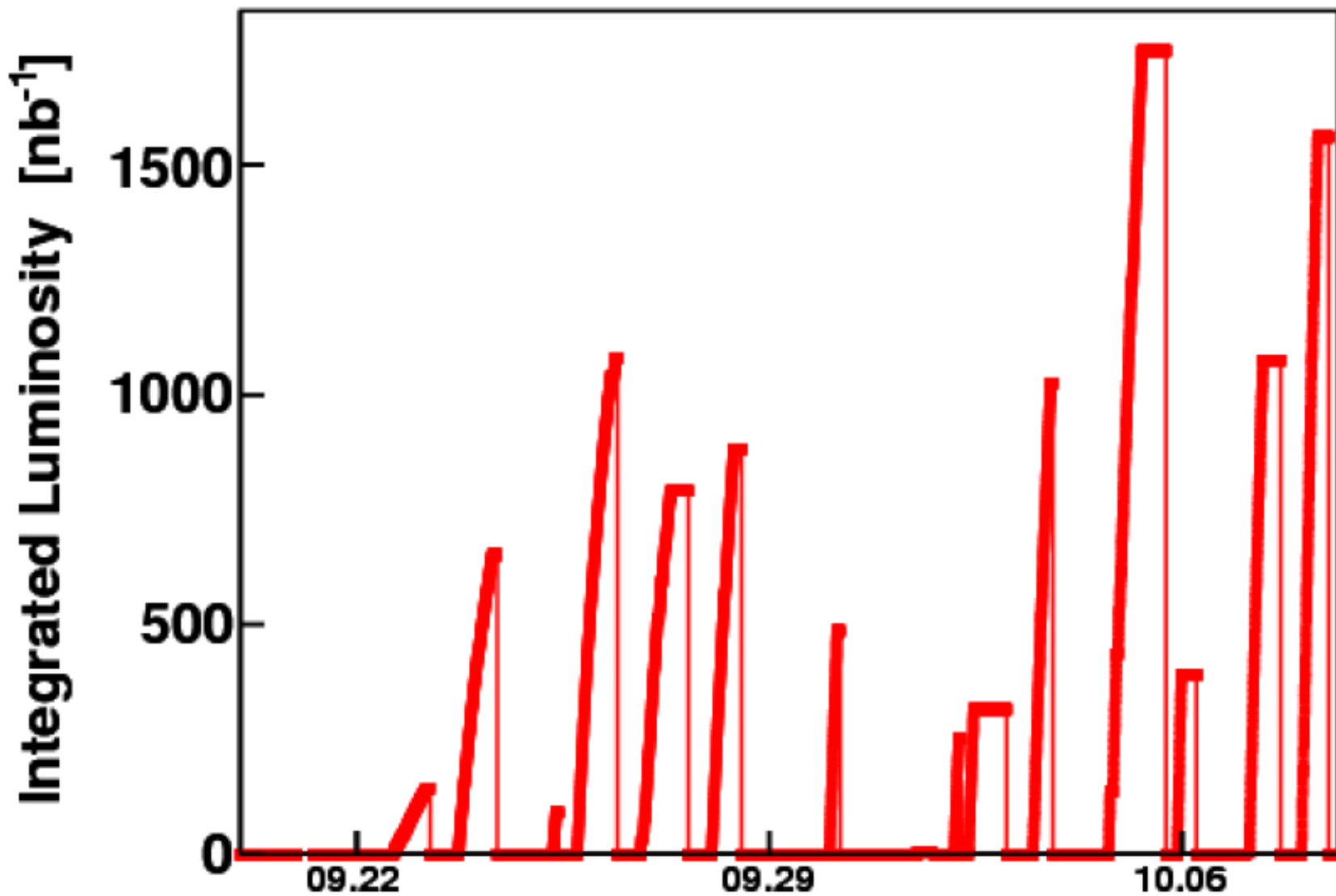
ENABLED

PM Status B2

ENABLED

# *Luminosity per LHC fill*

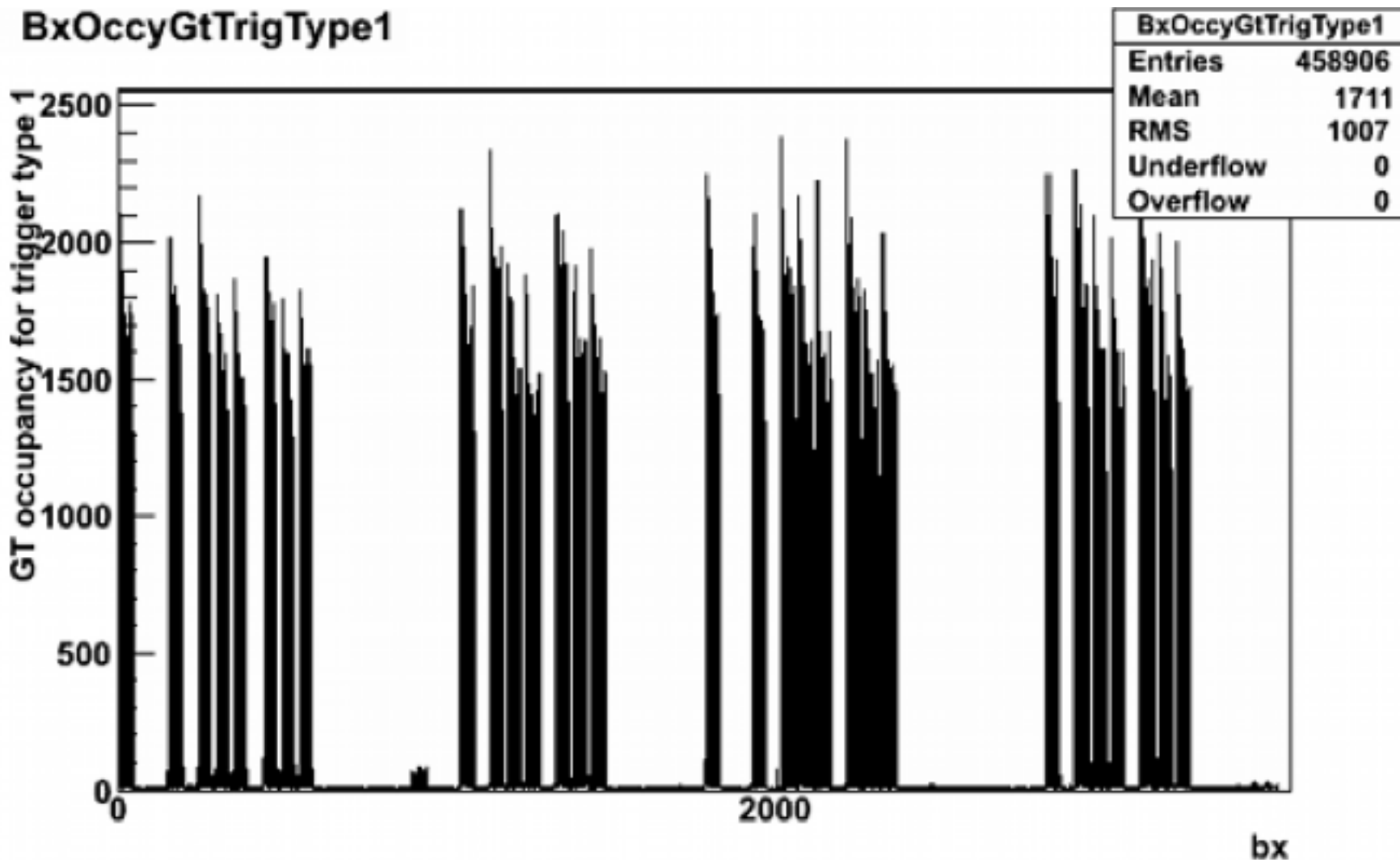
*(September / October 2010)*





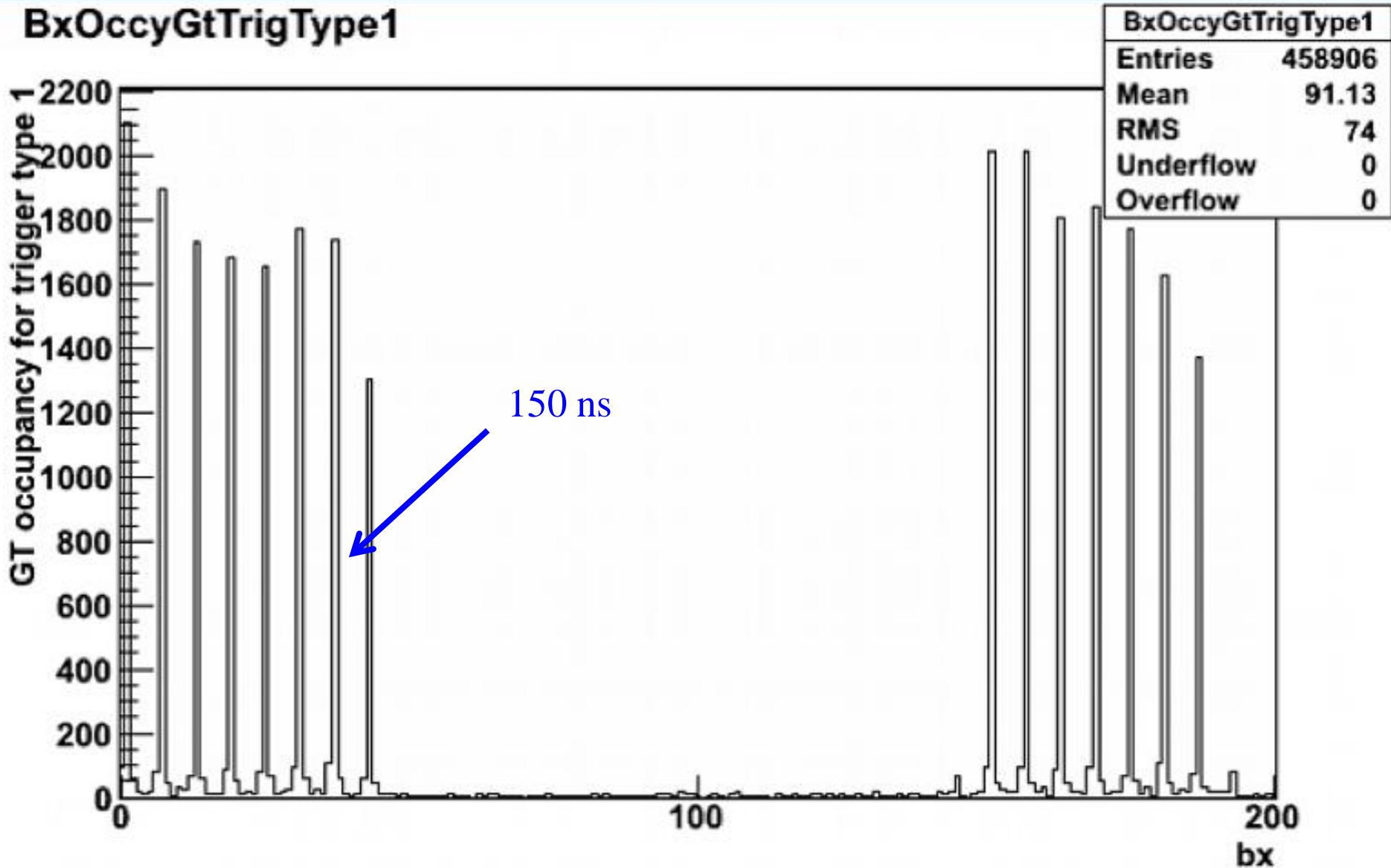
# 233 bunches colliding in CMS

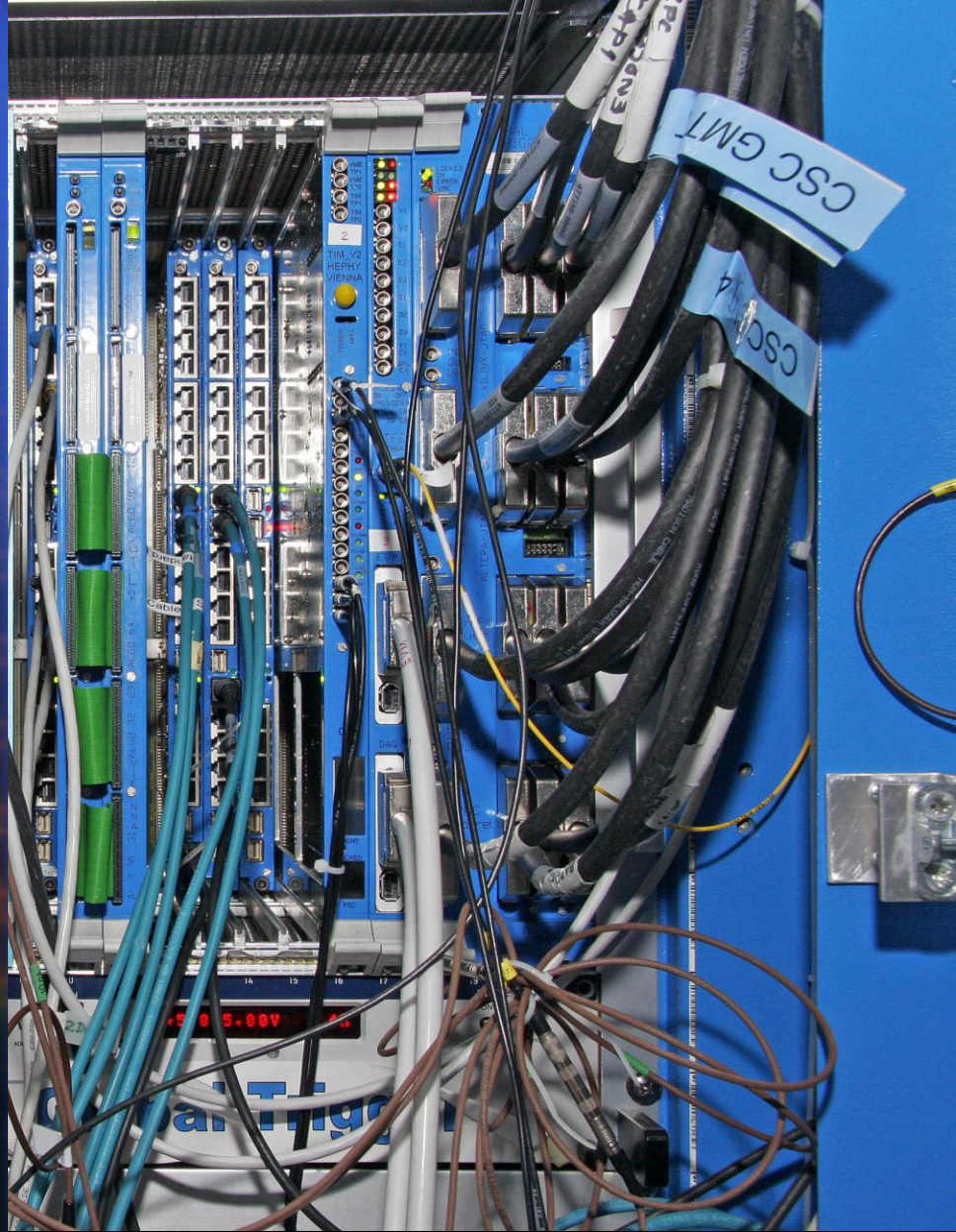
October 8, 2010





# *bunches still widely spaced*





*Level-1 Trigger*



Trigger Supervisor

- Commands
  - 0 General
  - 1 Run
  - 3 TCS PTC
  - 4 GTFE
  - 5 Test
  - Default
- Operations
  - Create
  - Destroy
  - Control
- Control Panels
  - 1 GT Partitioning
  - 2 GT Configuration
  - 3 GT Trigger Monitor**
  - 4 GT Run Settings
  - 5 GT Configuration Editor
  - 6 GT Hardware Monitor
  - 7 Default Configuration Editor
- Monitoring & Alarms
  - Hotspot
  - urn:xdaq-flashlist:gmt\_cell\_mon
  - urn:xdaq-flashlist:gmt\_cell\_scalers\_2
  - urn:xdaq-flashlist:gmt\_cell\_scalers\_3
  - urn:xdaq-flashlist:gmt\_cell\_status
  - urn:xdaq-flashlist:gt\_cell\_general
  - urn:xdaq-flashlist:gt\_cell\_hardwares
  - urn:xdaq-flashlist:gt\_cell\_lumiseg
  - urn:xdaq-flashlist:gt\_cell\_trigger\_tat
  - urn:xdaq-flashlist:gt\_cell\_ttcpartition
  - urn:xdaq-flashlist:l1ts\_cell
- Peers
  - DB
  - MON

Focus on DAQ Partition(s):

 PTC 0

 PTC 1

 PTC 2

 PTC 3

 PTC 4

Trigger Input:

 Algorithm Bits

 Technical Bits

 Compact

Display what:

 Rates

RunNr	LumSegNr (LS)						Rate (Hz)		Triggers	
<b>147754</b>	<b>24 (9 % complete)</b>						<b>54687.04</b>		<b>28784160</b>	
Algo	Rate (Hz)	Algo	Rate (Hz)	Algo	Rate (Hz)	Algo	Rate (Hz)	Algo	Rate	
15	720.62	33	247.23	50	4501.38	62	217.33	74	4462.00	
16	3364.12	40	2300.82	51	2778.84	63	3193.94	76	4859.00	
17	4682.20	41	11007.10	52	1491.57	65	2429.00	83	3.00	
18	1338.07	42	6432.06	55	13042.67	66	611.19	84	3.00	
19	610.03	43	4299.32	56	7192.88	68	158.34	85	5.80	
20	358.04	44	2640.37	57	5280.22	69	1437.08	87	94.00	
21	240.02	46	2371.34	58	2158.56	70	290.26	88	2096.00	
30	1829.70	47	2325.53	59	1001.27	71	19.78	96	181.00	
31	2469.97	48	11342.66	60	544.65	72	560.31	97	490.00	
32	753.14	49	6695.29	61	342.89	73	1024.56	98	2503.00	
Trigger Counters: Rates (Hz)		LS 23	LS 22	LS 21	LS 20	LS 19	LS 18	LS 17	LS 16	LS 15
TriggersPhysicsGeneratedFDL		55873.11	56169.33	55962.42	55895.63	56125.96	56085.03	56069.37	56135.14	56338.00
TriggersPhysicsLost		1760.50	1994.04	1732.49	1734.29	1855.99	1848.14	1762.56	1809.58	1991.00
TriggersPhysicsLostBeamActive		697.41	716.93	716.07	693.60	704.49	702.56	723.71	731.52	727.20
TriggersPhysicsLostBeamInactive		3971.79	4213.78	3935.15	3960.12	4082.51	4077.88	3962.26	4018.93	4210.00
L1AsPhysics		54112.61	54175.28	54229.94	54161.34	54269.96	54236.88	54306.81	54325.56	54346.00
L1AsRandom		598.87	604.15	594.67	599.77	592.05	600.20	601.66	599.60	589.90
L1AsTest		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L1AsCalibration		98.58	98.75	98.63	98.93	98.97	98.80	98.84	98.80	98.50
Deadtime Counters: Ratios (%)		LS 23	LS 22	LS 21	LS 20	LS 19	LS 18	LS 17	LS 16	LS 15
Deadtime		2.226	2.249	2.241	2.222	2.228	2.224	2.276	2.268	2.260
DeadtimeBeamActive		1.239	1.261	1.253	1.236	1.241	1.237	1.289	1.283	1.270
DeadtimeBeamActiveTriggerRules		0.352	0.350	0.351	0.351	0.354	0.351	0.353	0.354	0.350
DeadtimeBeamActiveCalibration		0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
DeadtimeBeamActivePrivateOrbit		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DeadtimeBeamActivePartitionController		0.853	0.877	0.869	0.852	0.853	0.852	0.903	0.896	0.890
DeadtimeBeamActiveTimeSlot		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000



11/10/10  
Mon 22:44:12

PROTON PHYSICS  
STABLE BEAMS

DAQ state  
Running

Run Number  
147754

Lv1 rate  
53.573 kHz

Ev. <Size> kB  
379.0 [179.6]

DeadTime(AB)  
1.195 %

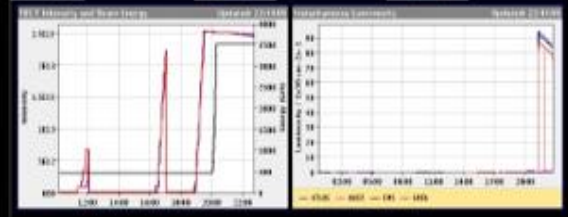
Acc. Hz (%)  
53788.9 (100.0%)

HLT <CPU>  
63.61 %

LHC Page1 FILE 1408 E: 3500 GeV 11-10-2010 22:44:06

PROTON PHYSICS: STABLE BEAMS

Energy: 3500 GeV I(B1): 2.63e+13 I(B2): 2.61e+13



Comments 11-10-2010 22:30:23:  
BIS status and SRP flags  
LHC Status of Beam Permits  
Global Beam Permits  
Setup Beam  
Beam Presence  
Allowable Devices Allowed In Stable Beams  
LHC Operation in CCC : 77600, 70480  
PH Status B1: 0x00000000 PH Status B2: 0x00000000

Data to Surface

Sub-System	State	FRL	FED	IN
TRG	Running	3	3	3
CSC	Running	9	9	9
DAQ	Running	0	0	0
DQM	Running	0	0	0
DT	Running	11	11	11
ECAL	Running	54	54	54
ES	Running	40	40	39
HCAL	Running	32	32	32
PIXEL	Running	40	40	40
RPC	Running	3	3	3
SCAL	Running	1	1	1
TRACKER	Running	250	438	437
CASTOR	Running	3	3	3
		0	0	0

SM streams

Stream	No.Events	Rate (Hz)	BnW (MB/s)
NanoDST	8.155E+6	5350.48	12.58
ALCAP0	2.900E+6	1896.70	6.91
A	836.550E+3	552.89	97.11
RPCMON	800.332E+3	532.79	2.72
ALCAPHISYM	431.704E+3	286.51	1.01
Calibration	148.599E+3	99.63	10.44
EcalCalibrati	148.598E+3	99.60	2.71
Express	83.872E+3	57.57	9.45
HLTMON	21.135E+3	14.41	4.12
OnlineErrors	10.470E+3	6.76	1.45
Error	1.000E+0	0.00	0.00
FaultyEvents	0.000E+0	0.00	0.00

Data Flow

#LS 67  
LHC RAMPING OFF  
Tracker HV ON  
Pixel HV ON  
Physics DECLARED  
iRandom ON  
Physics ON  
CalibCyc ON  
2 siinkCRC  
55 FEDCRC

#Lv1(GT) 83393662  
Lv1 Rate 53.791 kHz

Pending Lv1 112572  
#Frag. in RU  
Max 473  
Min 305

BnW (MB/s) 1.98E+4  
EvSize (kB) 379.3

Events in BU 56  
<Ev.> 0.1  
Pending Req. 12270  
<#P> 18.3  
#Running 4704  
100.00%

FBI occ. % Max 3 Min 0  
FBO occ. % Max 5 Min 0  
4 CRC Err  
4 Data Err  
Rceiv.-Disc. 3892  
95286 P.M-m  
95288 A.M-m  
<PU> 63.6  
100  
0  
Disks usage 0..100%  
EventRate Hz 8925  
Stored 13822520  
Free space TB 112.2  
Time to fill disk 2 of srv-c2c07-15 > day  
TIER0\_TRANSFER ON

Beam setup & DCS states history LHC mode: PROTON PHYSICS, STABLE BEAMS Run# 147754 history time window (2.0 H)



UTC time 11/10/10 20:44:13 Local time: Geneva 22:44, Los Angeles 13:44, Chicago 15:44, Moscow 00:44, Beijing 05:44



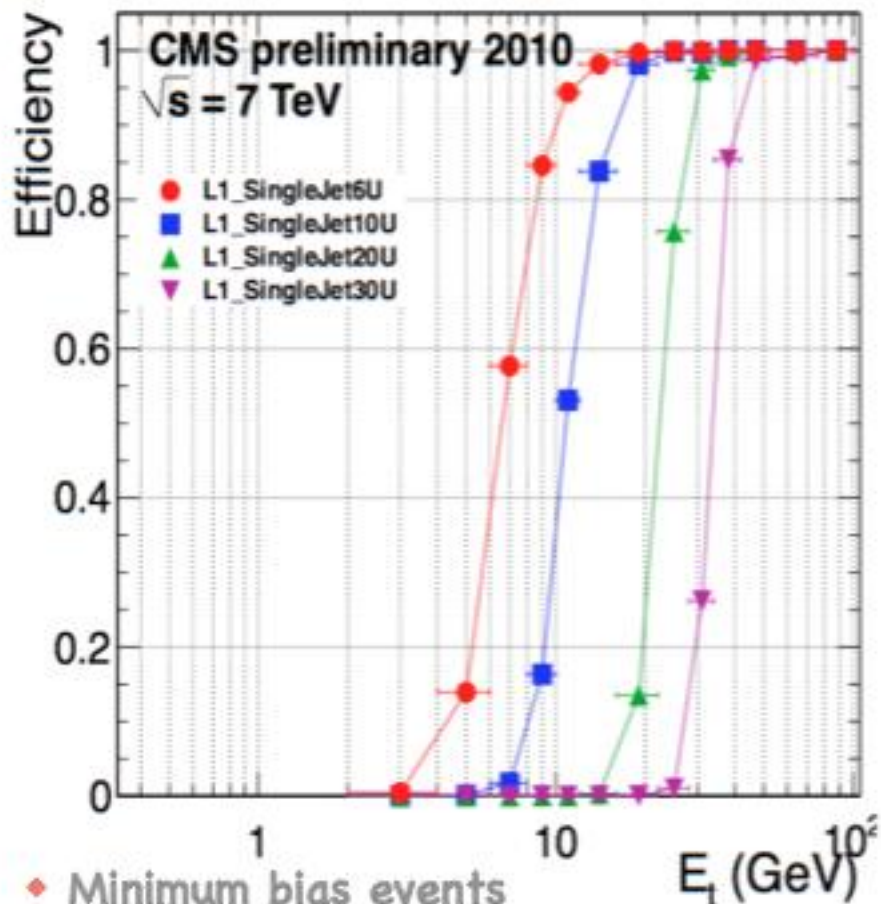
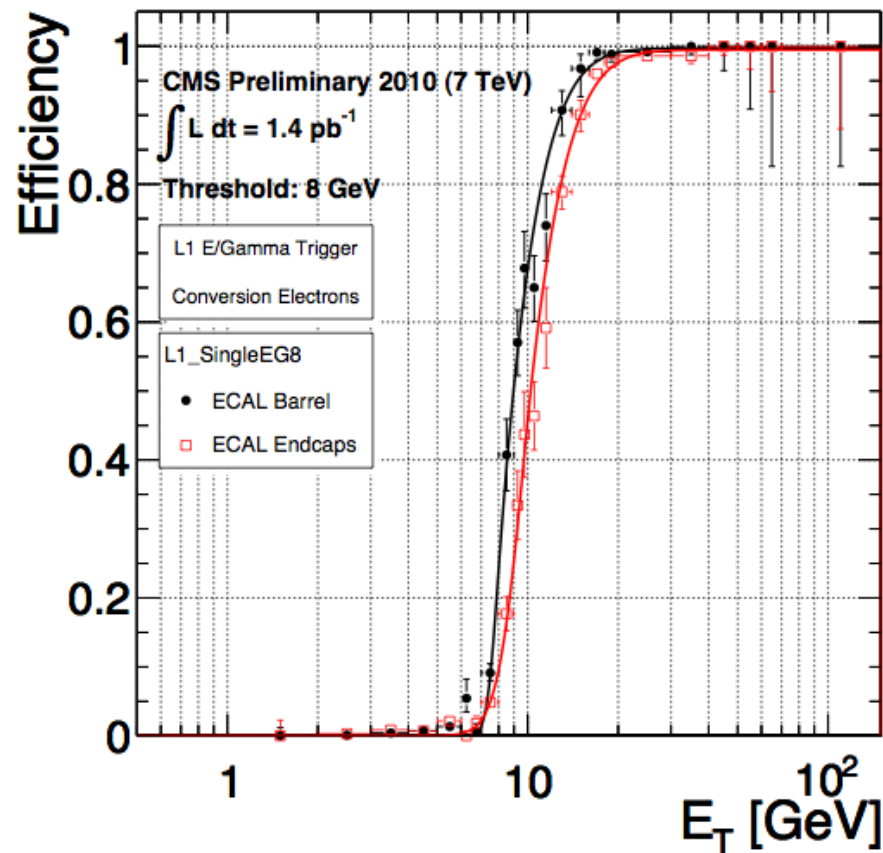


# Level-1 trigger efficiency

*jets* →

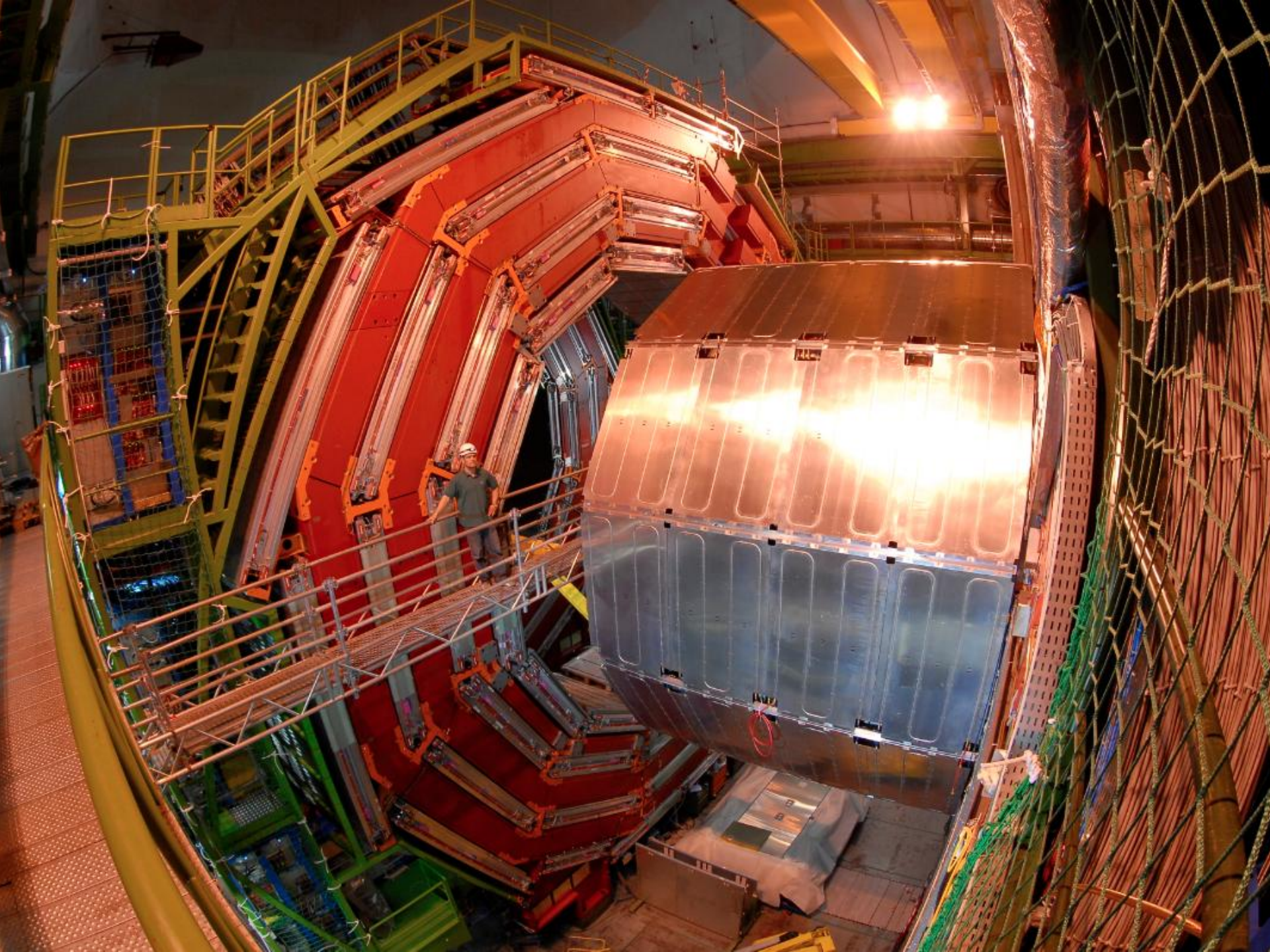
*electrons*

Efficiency : leading offline jet matches a L1-jet within cone of  $\Delta R < 0.5$



- ◆ Minimum bias events
- ◆ Offline jet cuts (loose jet Id,  $E_T > 10 \text{ GeV}$ ,  $|\eta| < 2.6$ )



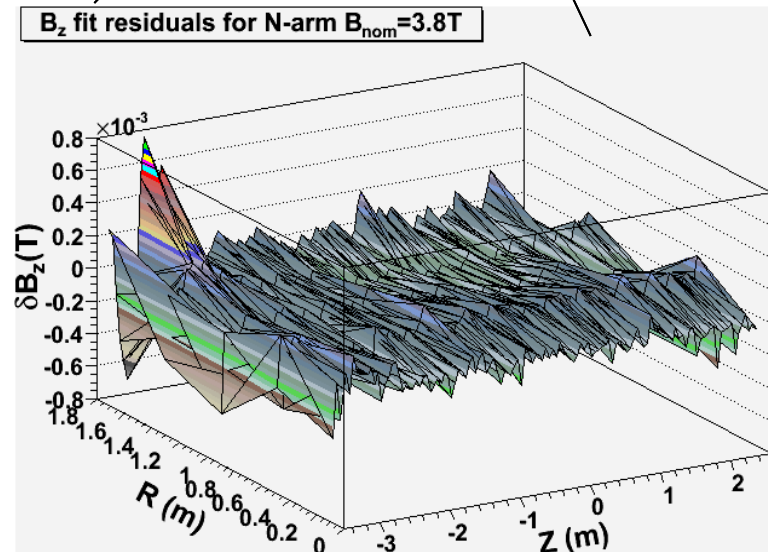
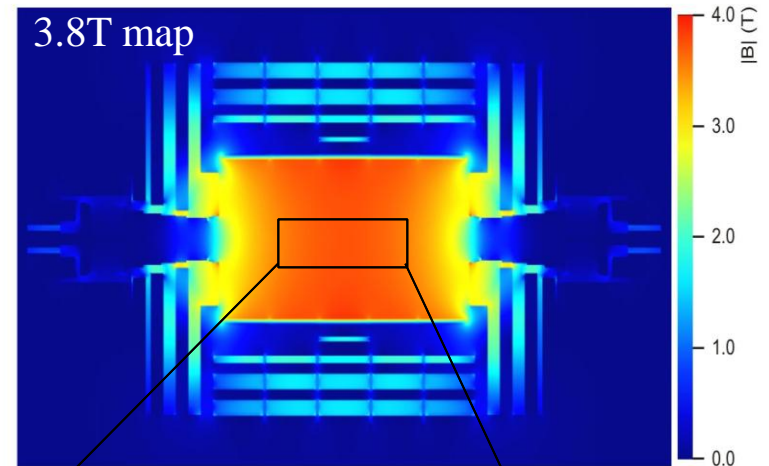




# Momentum Scale

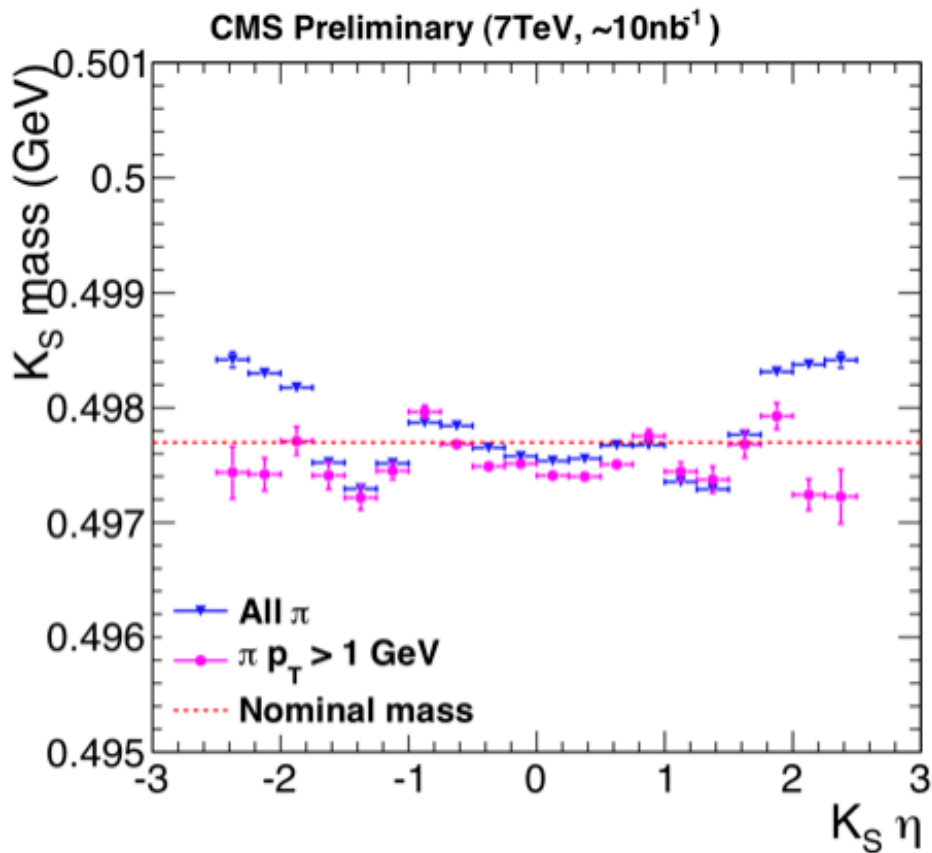
- Measured by Field Mapper (at 2, 3, 3.5, 3.8, 4 T) in 2006

NMR probes inside solenoid confirm agreement



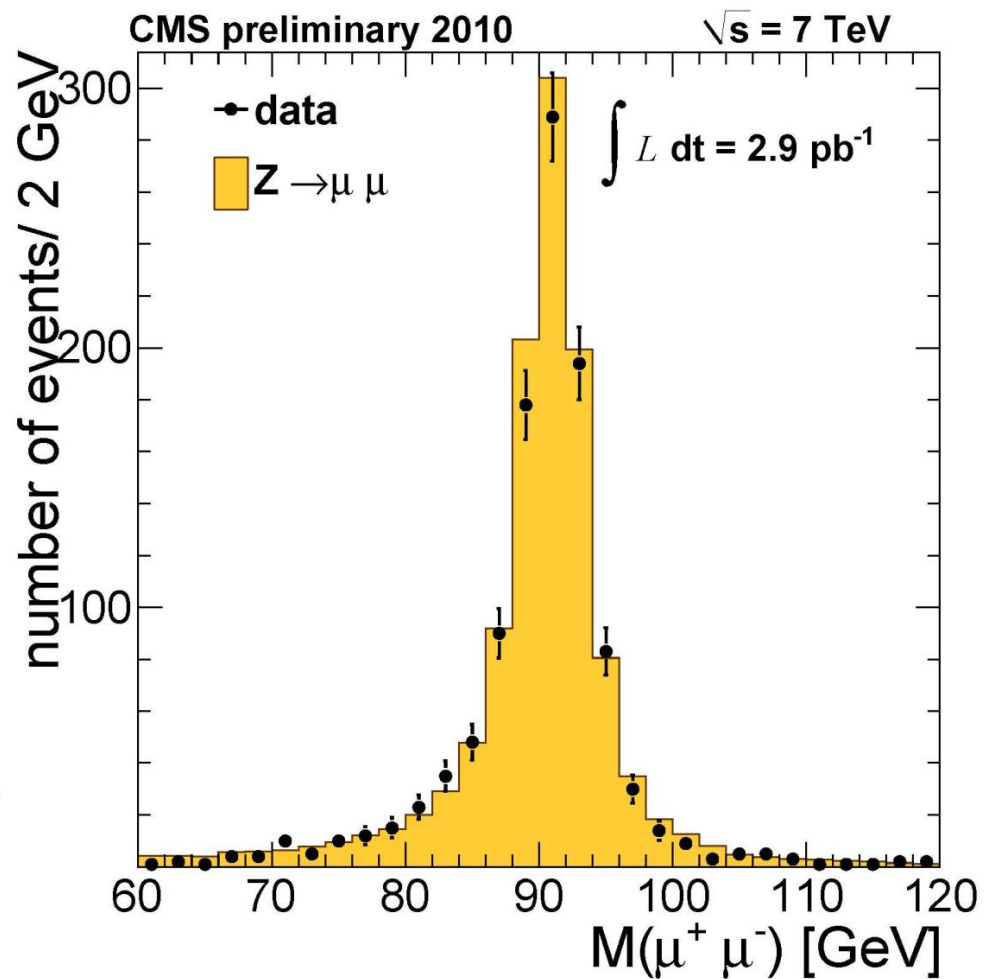
# Momentum Scale

*in the  $K_S$  energy range ...*

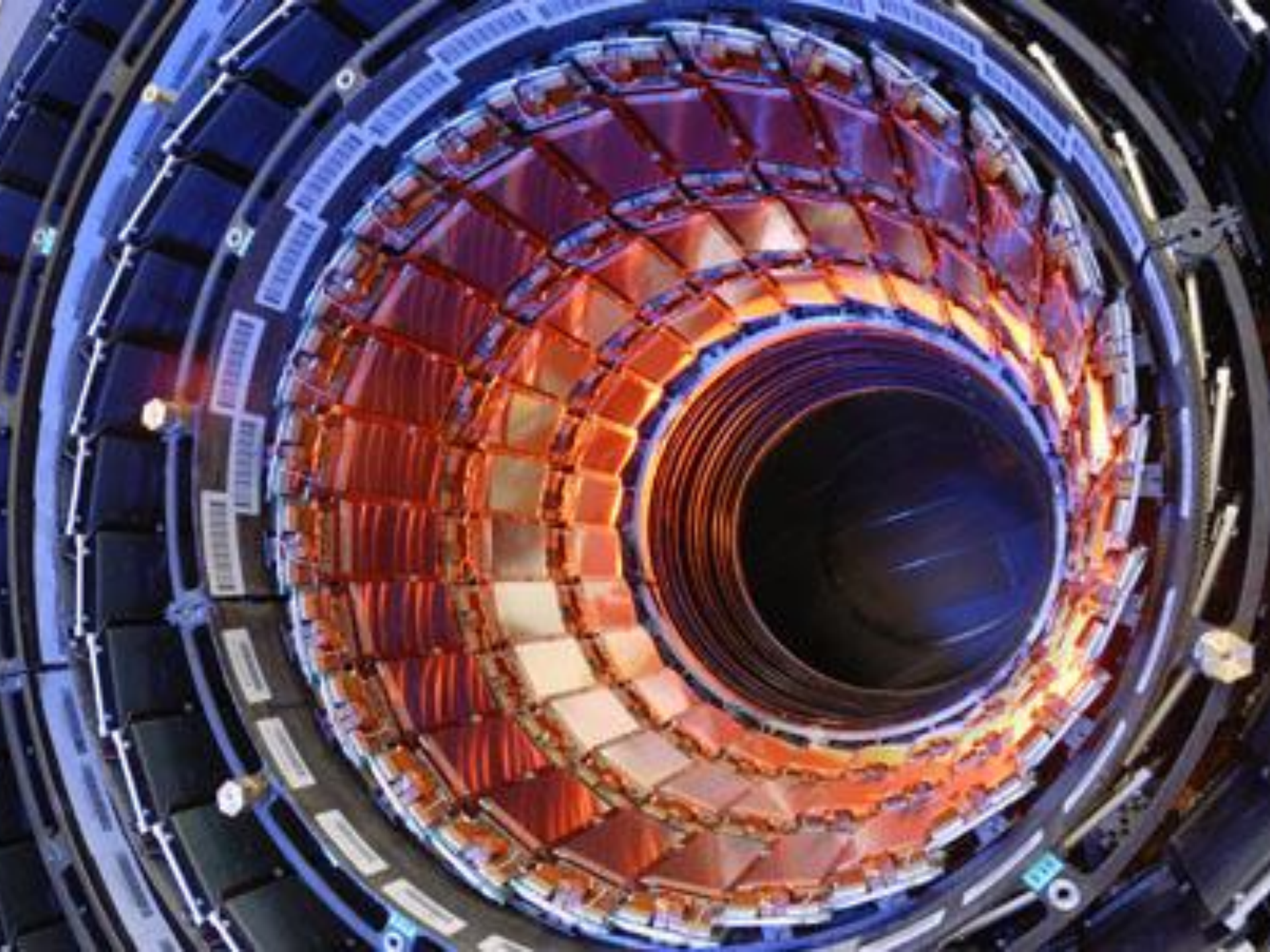


Using tracks with  $P_t > 1\text{GeV}$  gives agreement at the 0.6 per mille level.

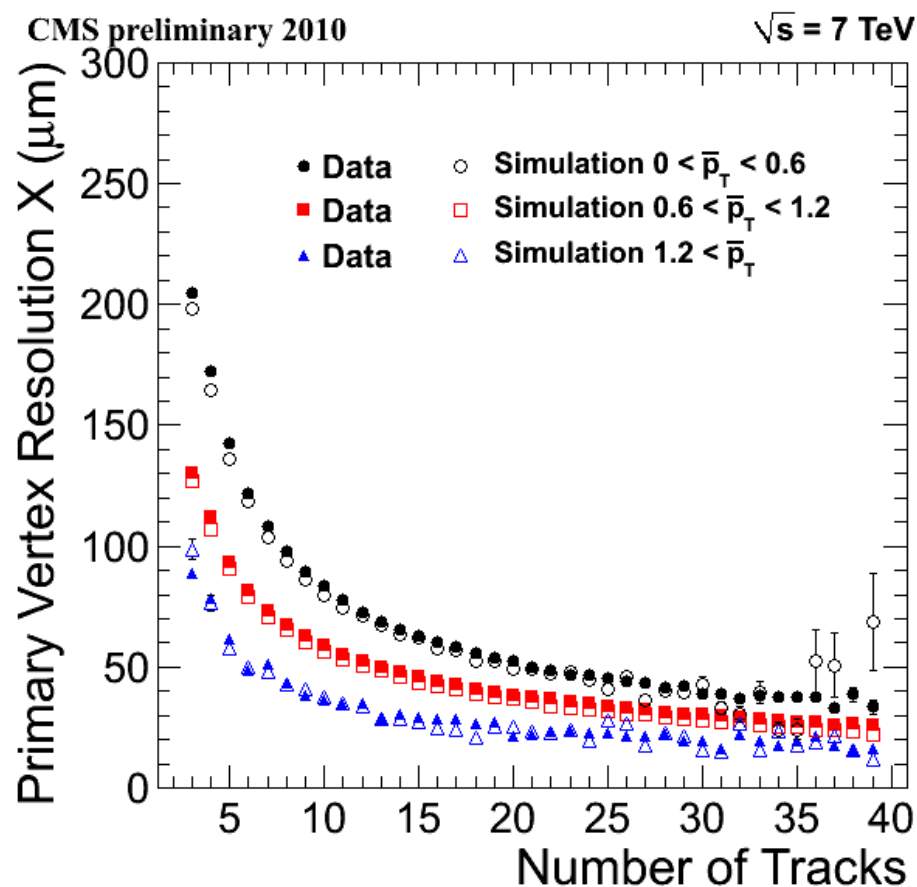
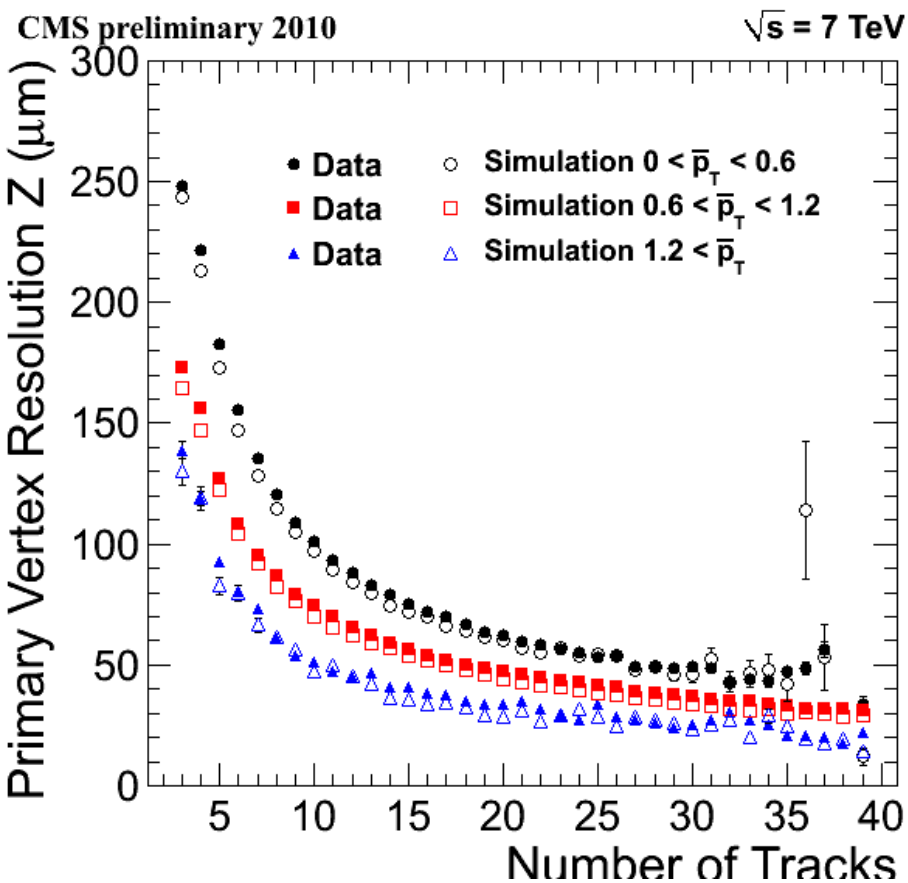
*... and in the Z energy range*



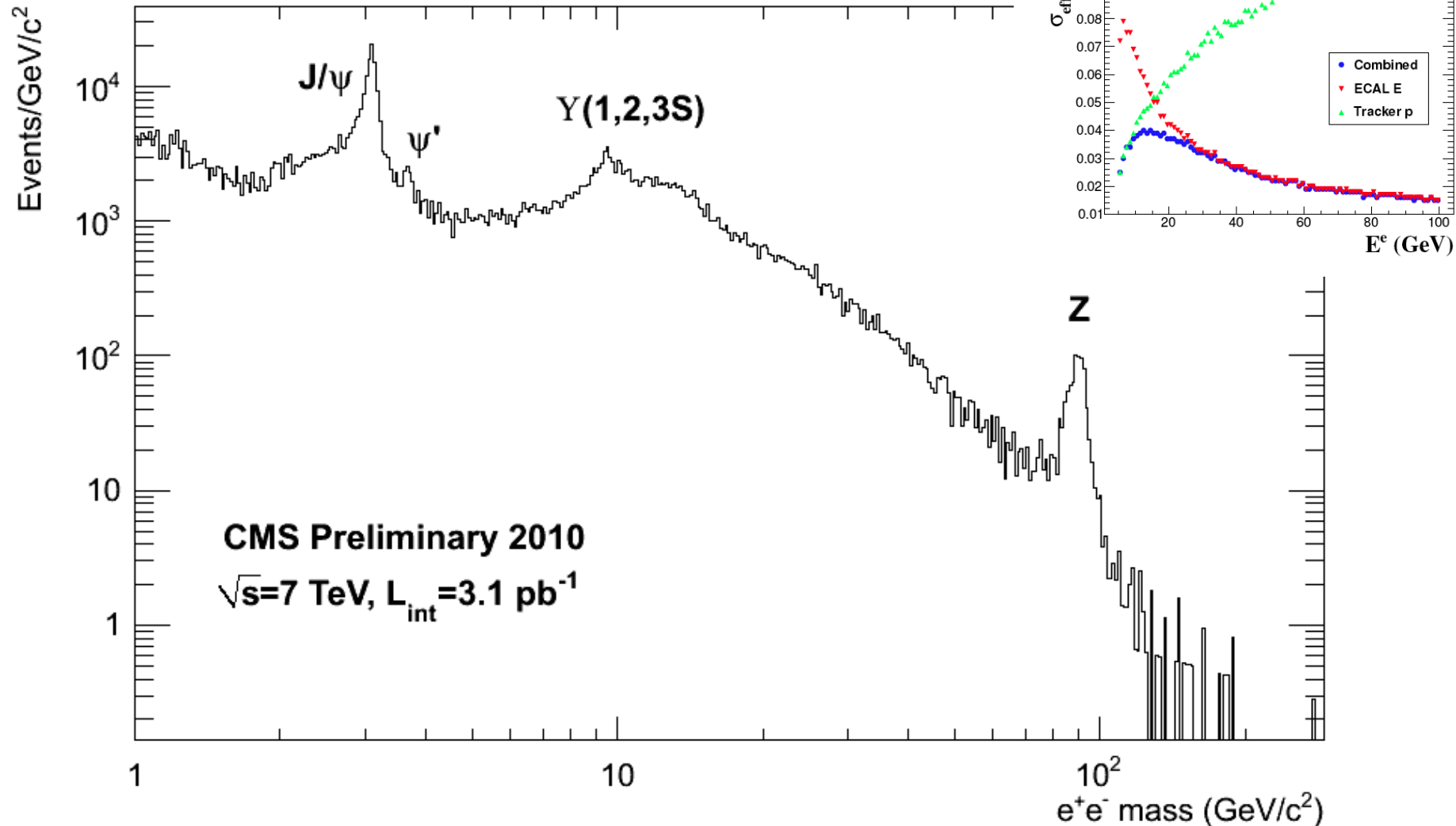




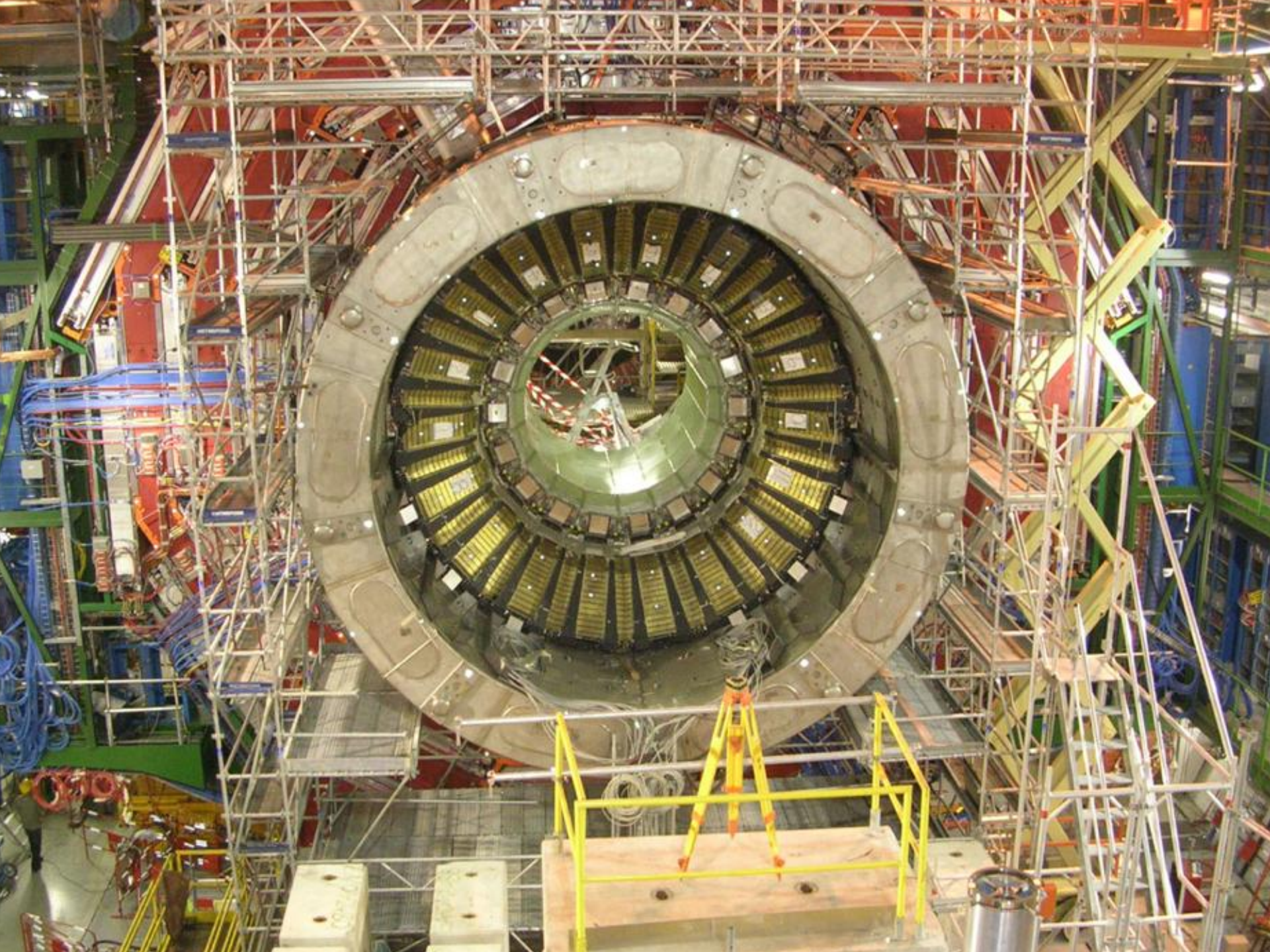
# Vertex resolution



# $e^+e^-$ spectrum









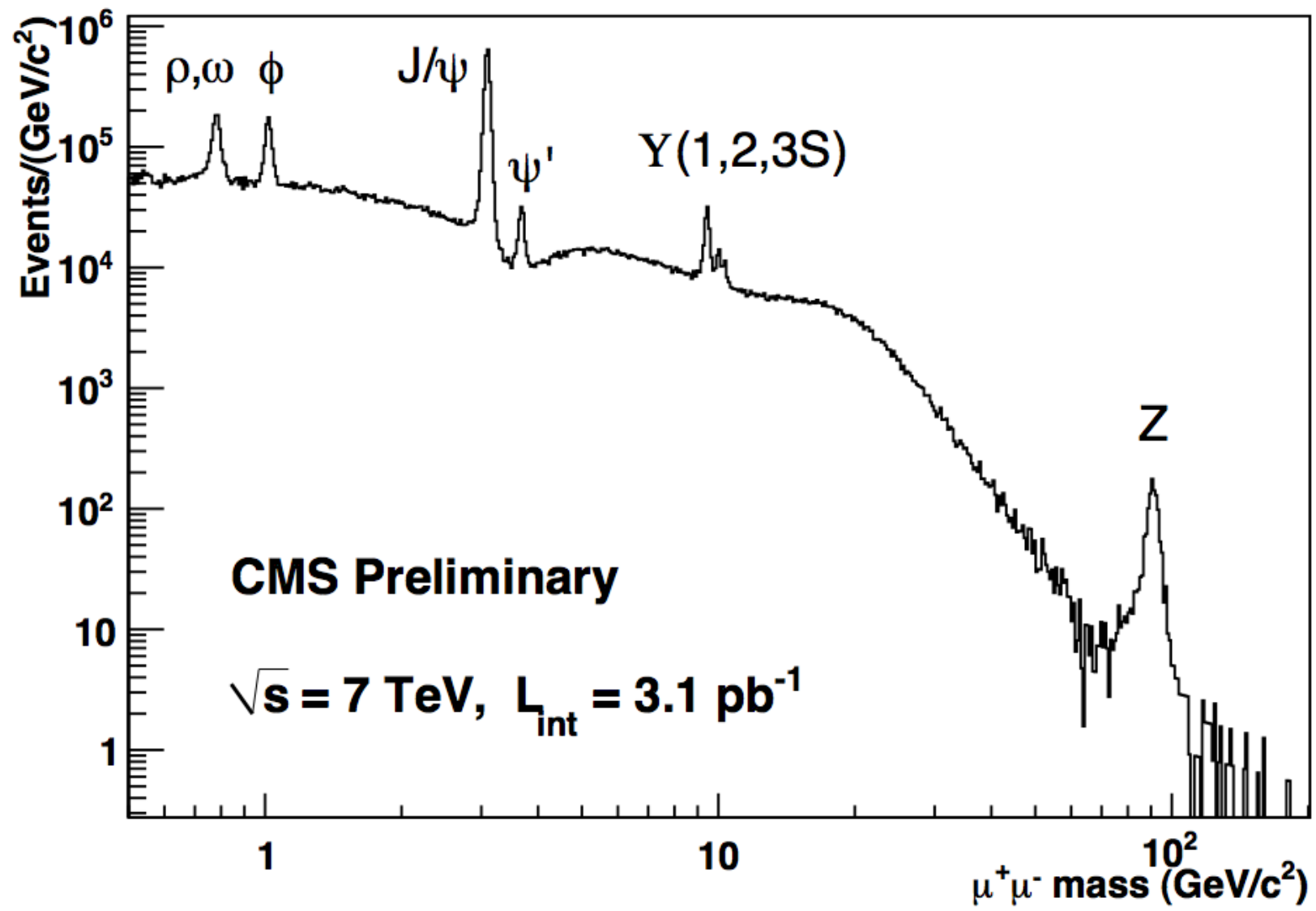
*brass from Russian  
artillery shells*



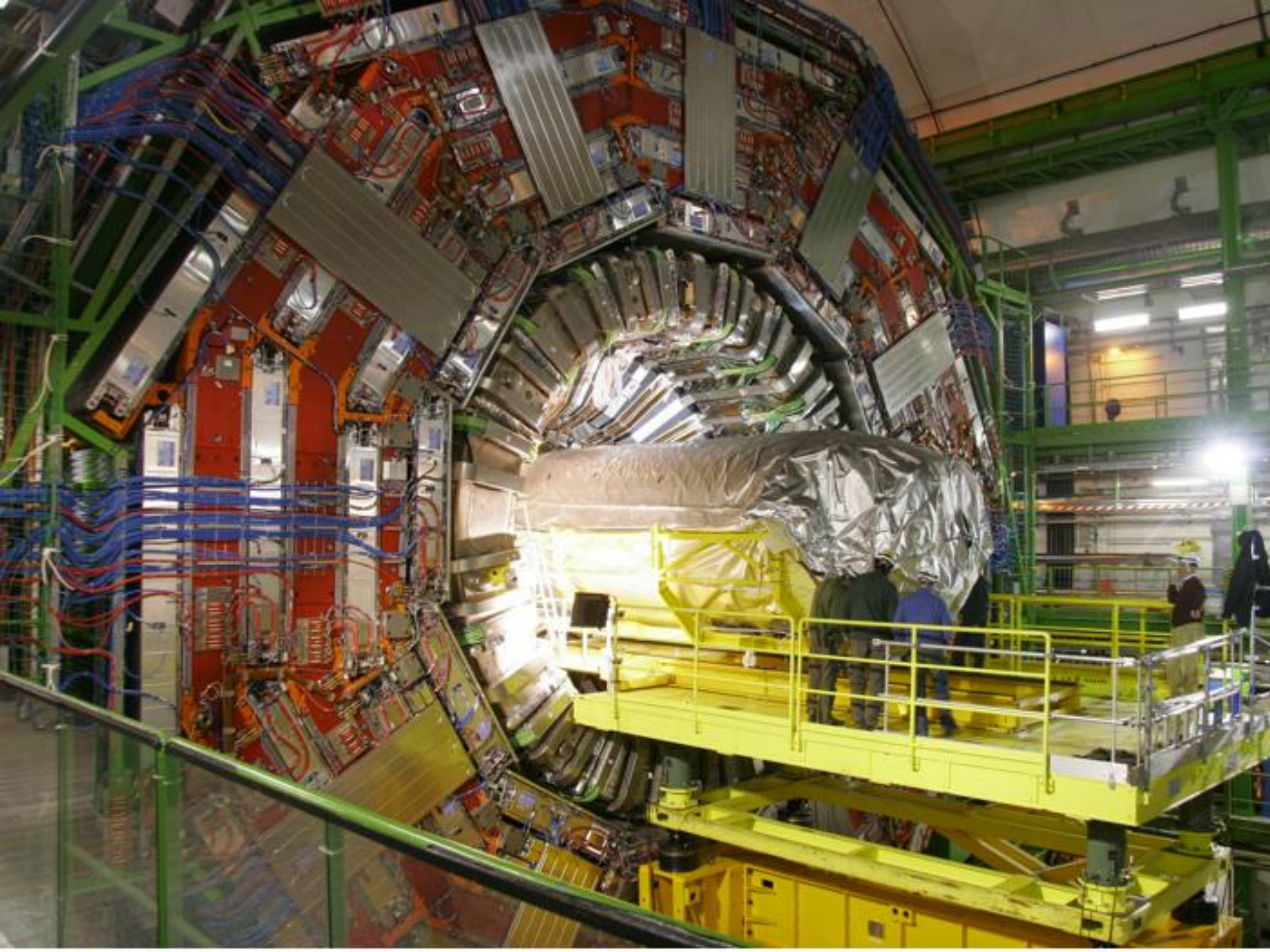
*transformed into plates for the CMS  
hadron calorimeter*



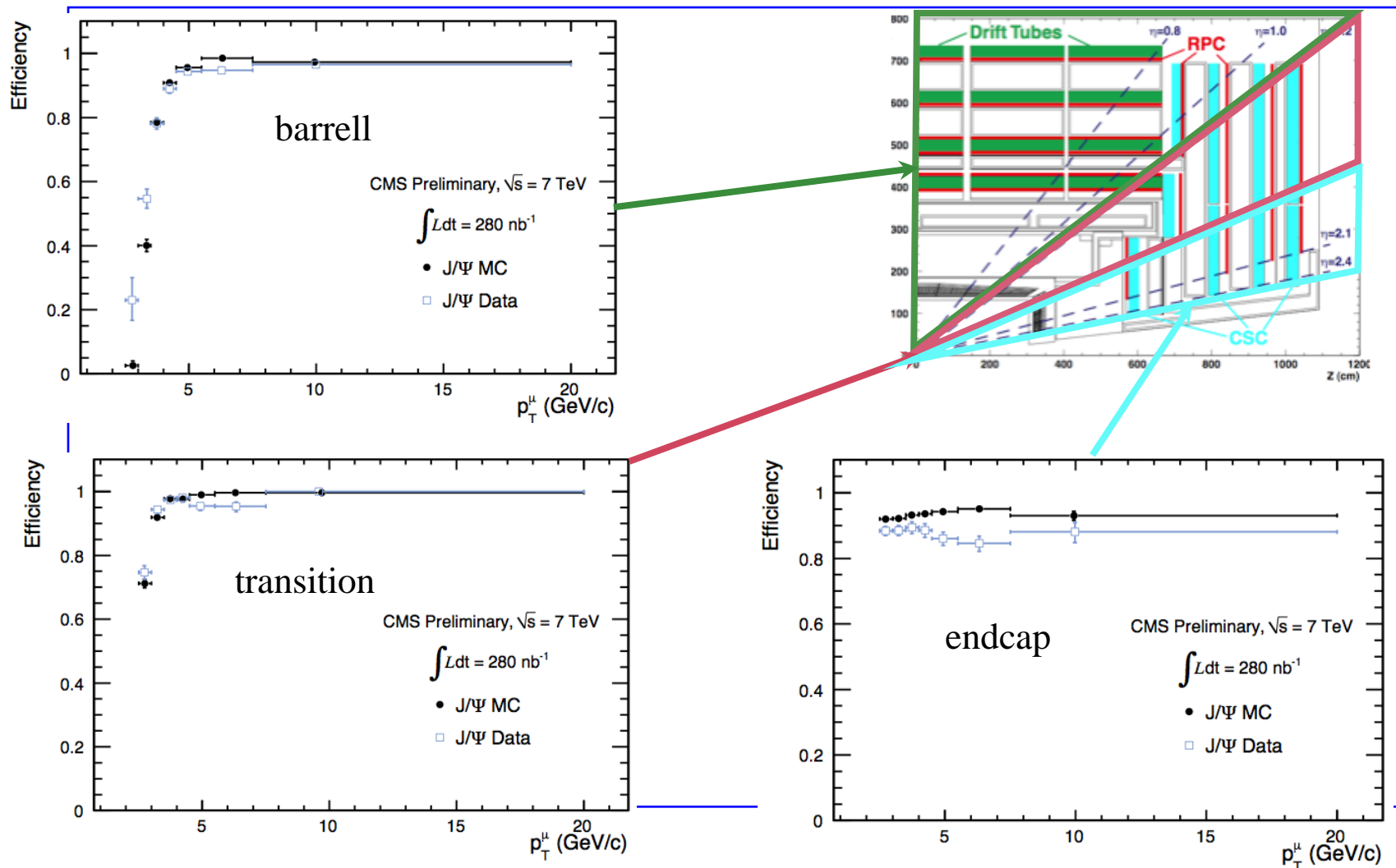
# $\mu^+\mu^-$ spectrum





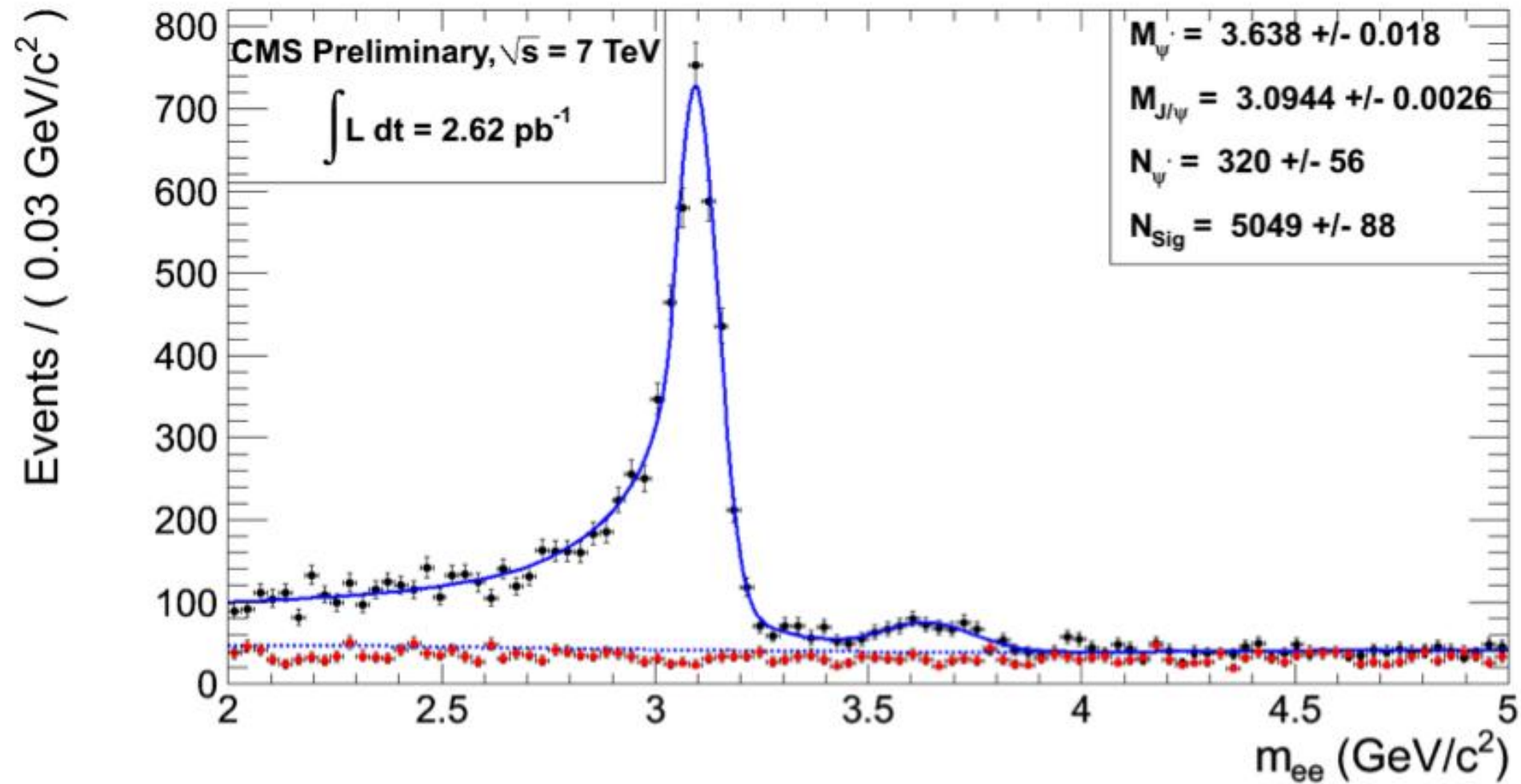


# Muon trigger



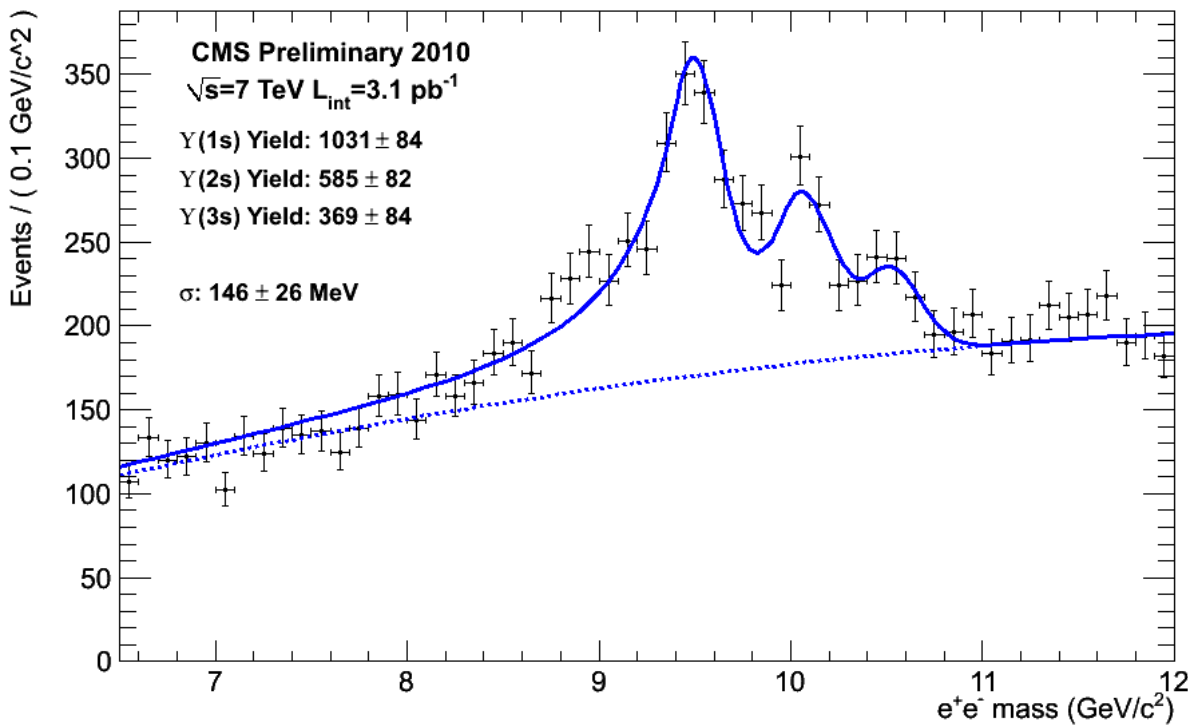


# zooming in: $J/\psi \rightarrow e^+e^-$





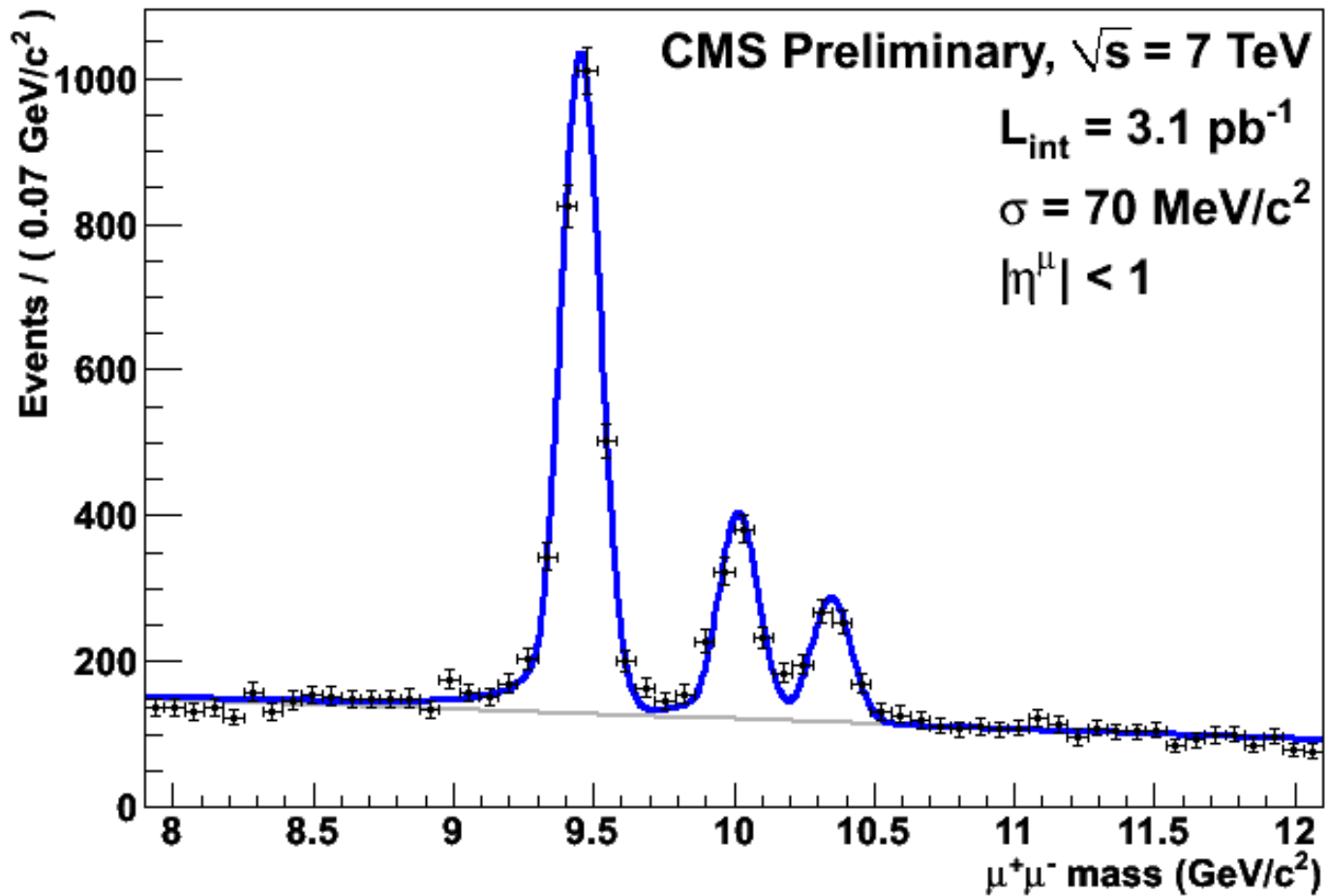
# zooming in: $Upsilon \rightarrow e^+e^-$



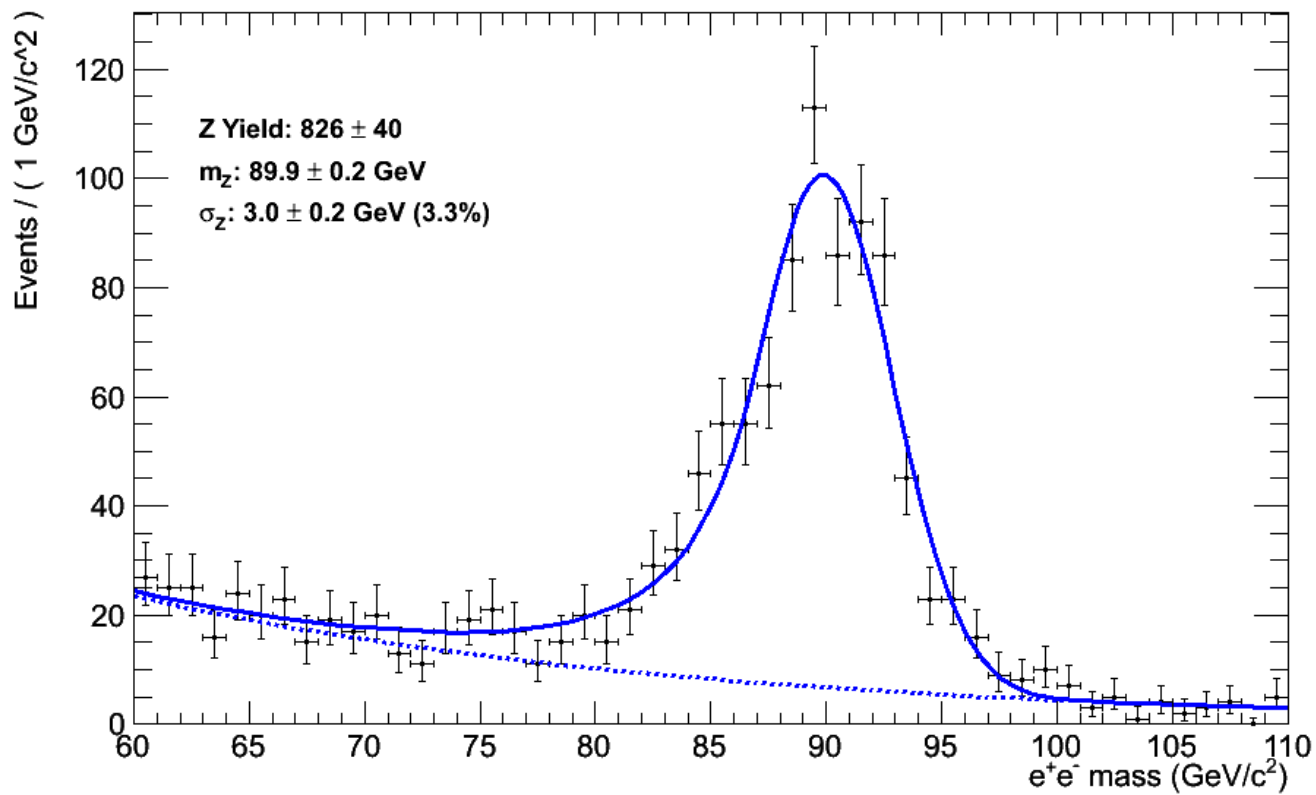
Same fit technique used as for the psi region

$M(Y1s) = 9484 \pm 22(\text{stat}) \text{ MeV}/c^2$   
 $M(Y2s) = 10044 \pm 31(\text{stat}) \text{ MeV}/c^2$   
 $M(Y3s) = 10500 \pm 50(\text{stat}) \text{ MeV}/c^2$

# $Upsilon \rightarrow \mu^+ \mu^-$

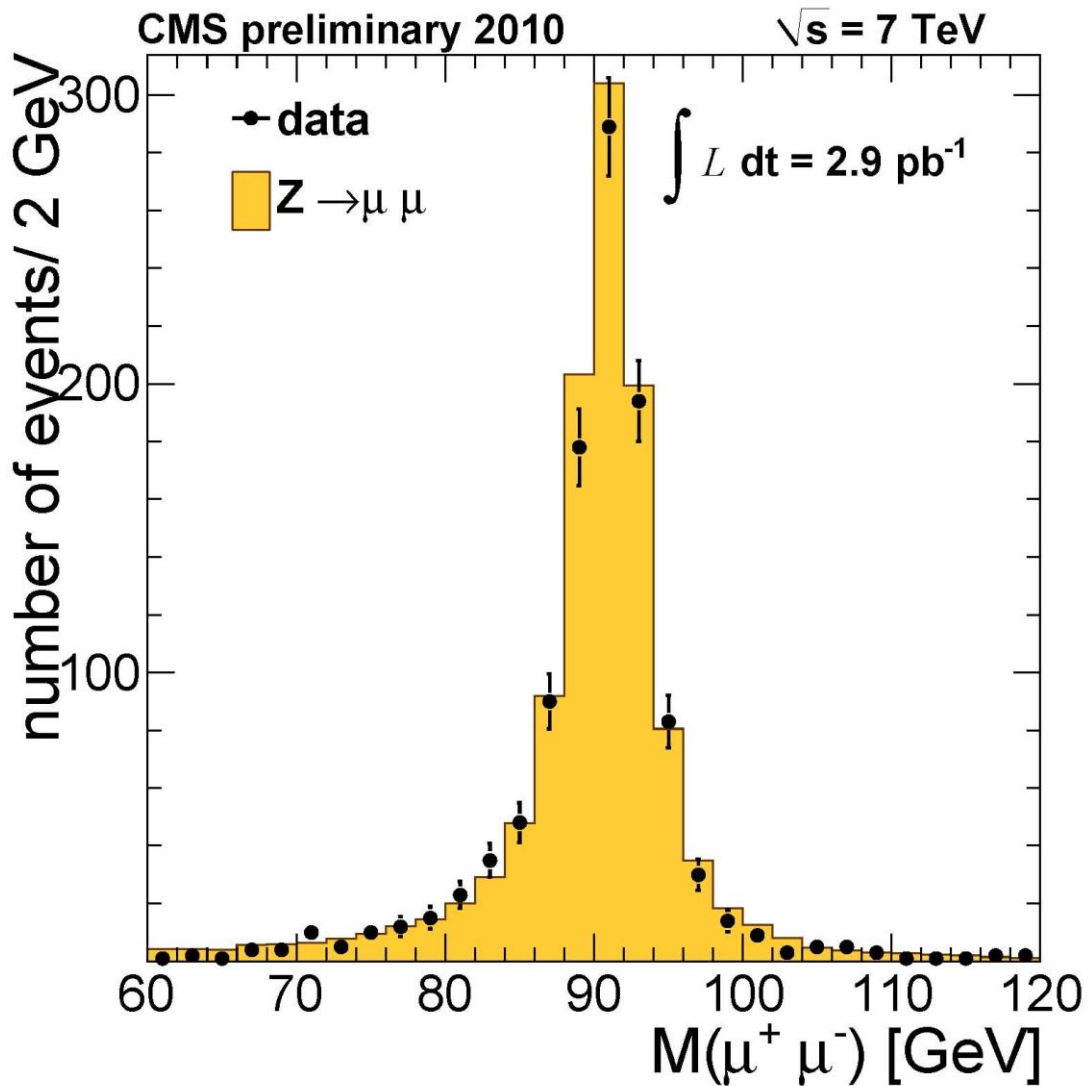


$$Z^0 \rightarrow e^+e^-$$





$$Z^0 \rightarrow \mu^+ \mu^-$$

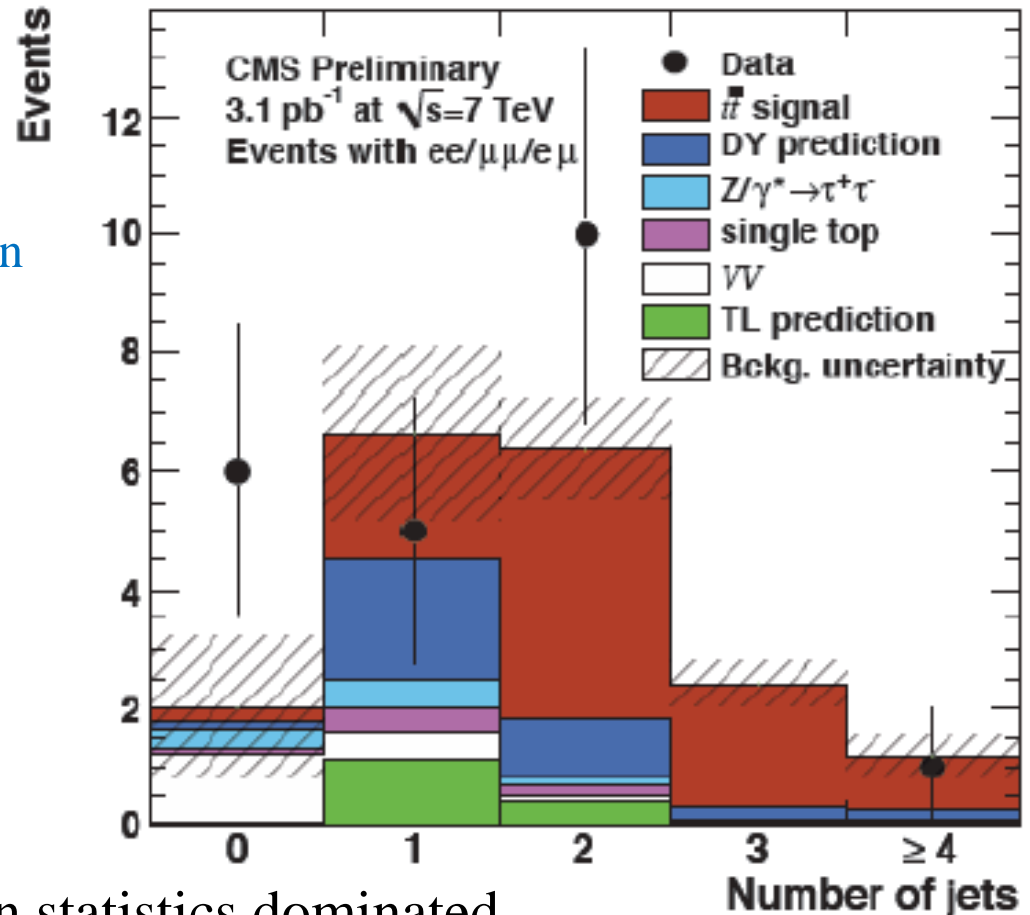


# Top Quark Physics at CMS

- First measurement of the top pair production cross section in dilepton channels

- $t\bar{t}$ , single top, Drell-Yan- $\rightarrow\tau\tau$  and double boson estimate from simulation

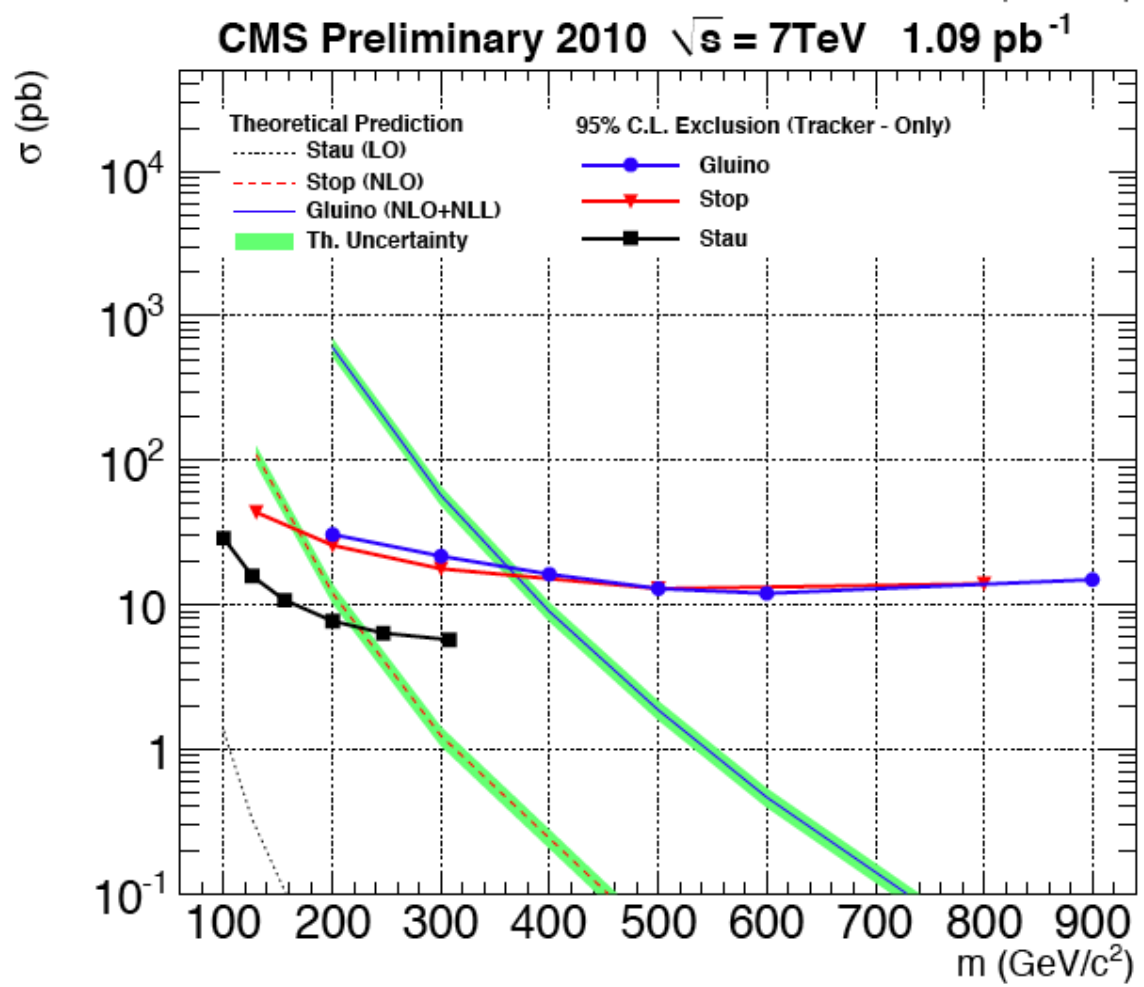
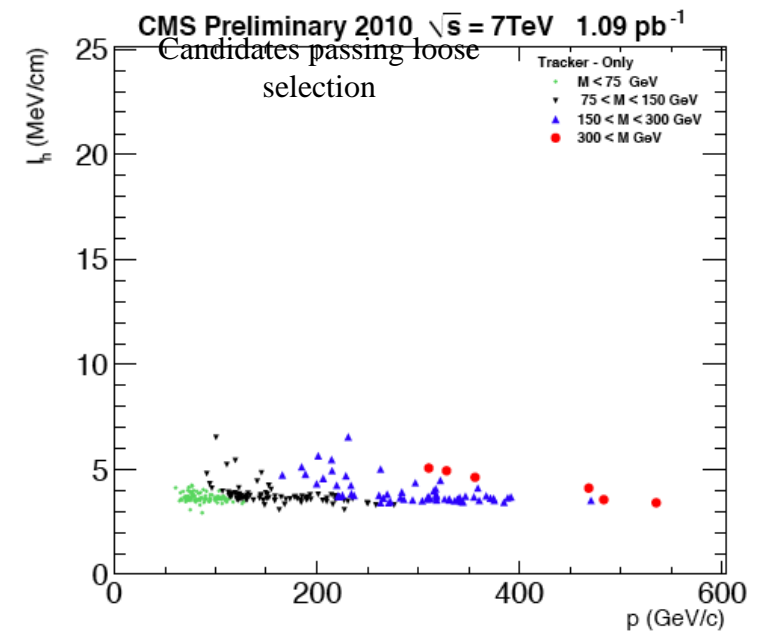
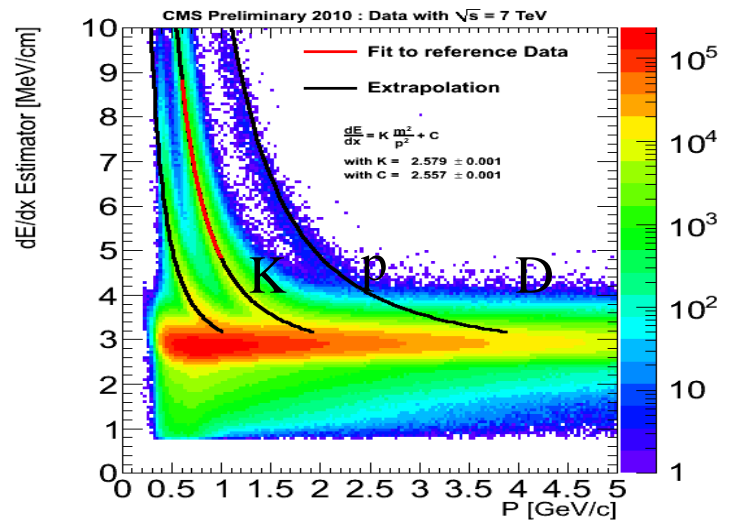
- Drell-Yan- $\rightarrow ee, \mu\mu$  and events with fake leptons estimated via data-driven techniques



- Uncertainty on cross section statistics dominated



# “HSPC” = “Heavy Stable Charged Particles”

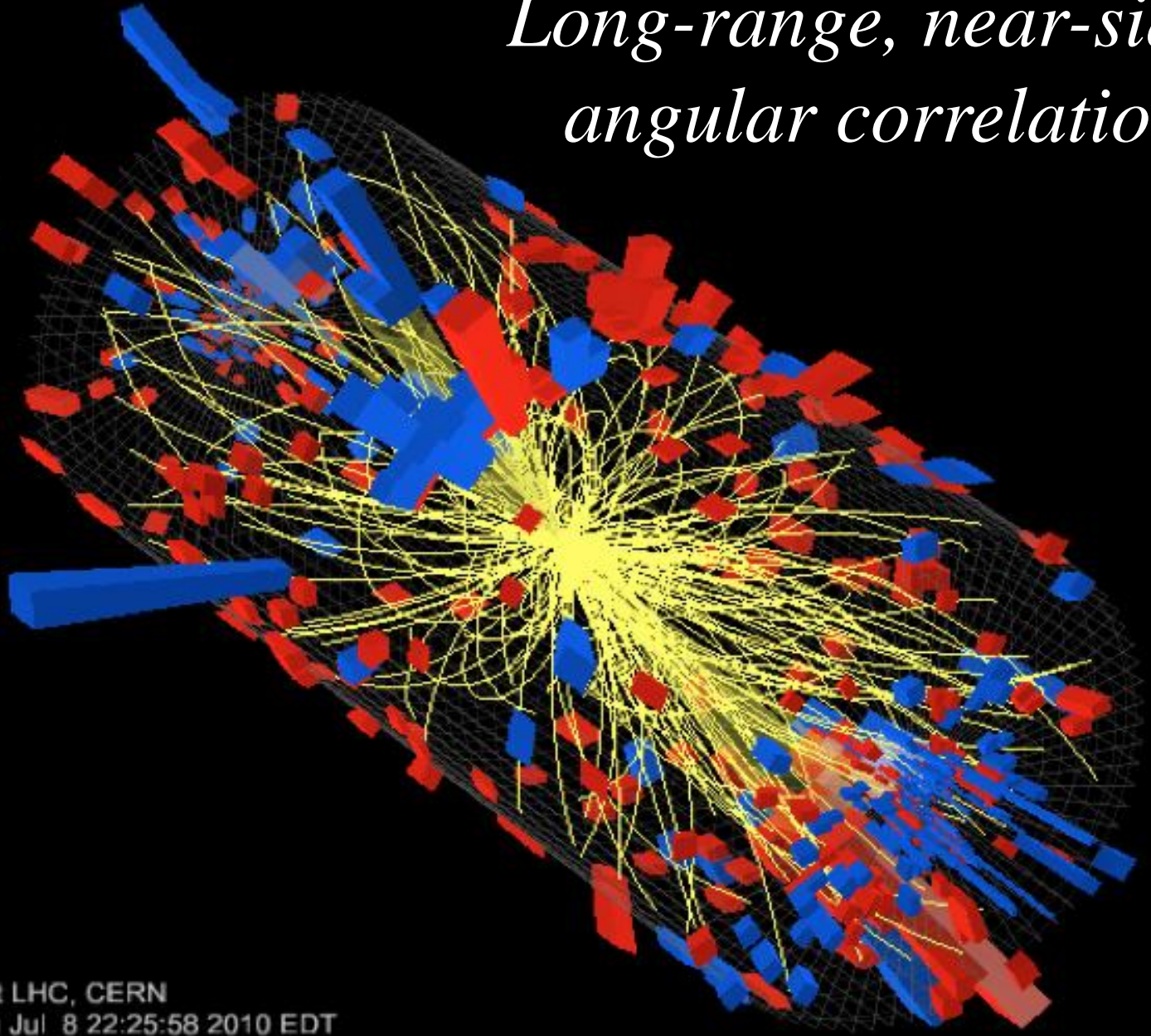


Tight Selection:  $0.088 \pm 0.021$  expected,  
0 observed





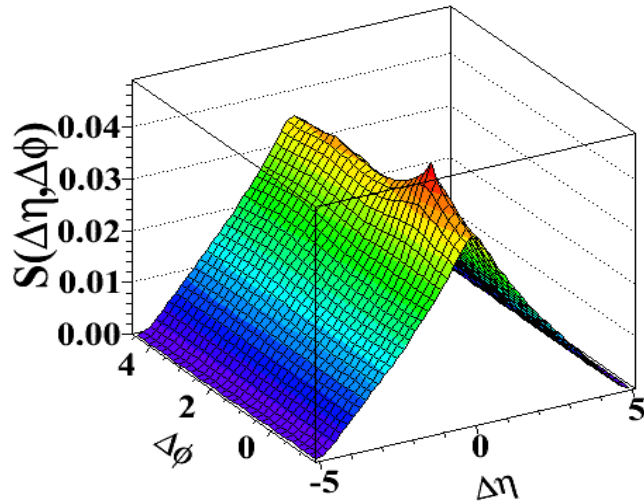
# *Long-range, near-side angular correlations*



CMS Experiment at LHC, CERN  
Data recorded: Thu Jul 8 22:25:58 2010 EDT  
Run/Event: 139779 / 4994190  
Lumi section: 5  
Orbit/Crossing: 1302609 / 401

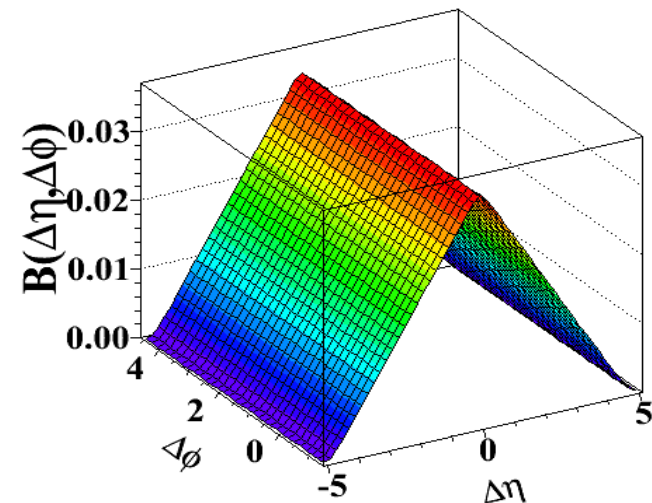
# Correlation Function Definition

Signal distribution:



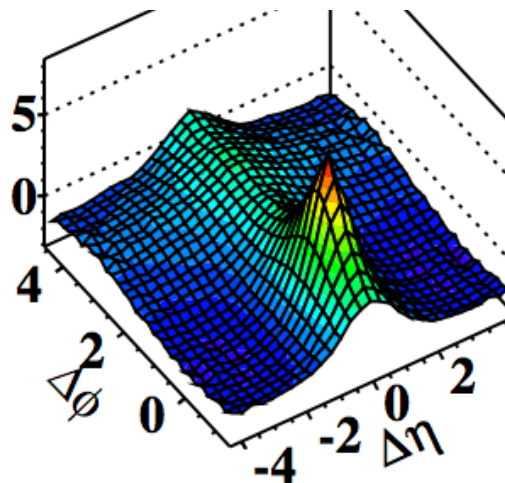
Same event pairs

Background distribution:

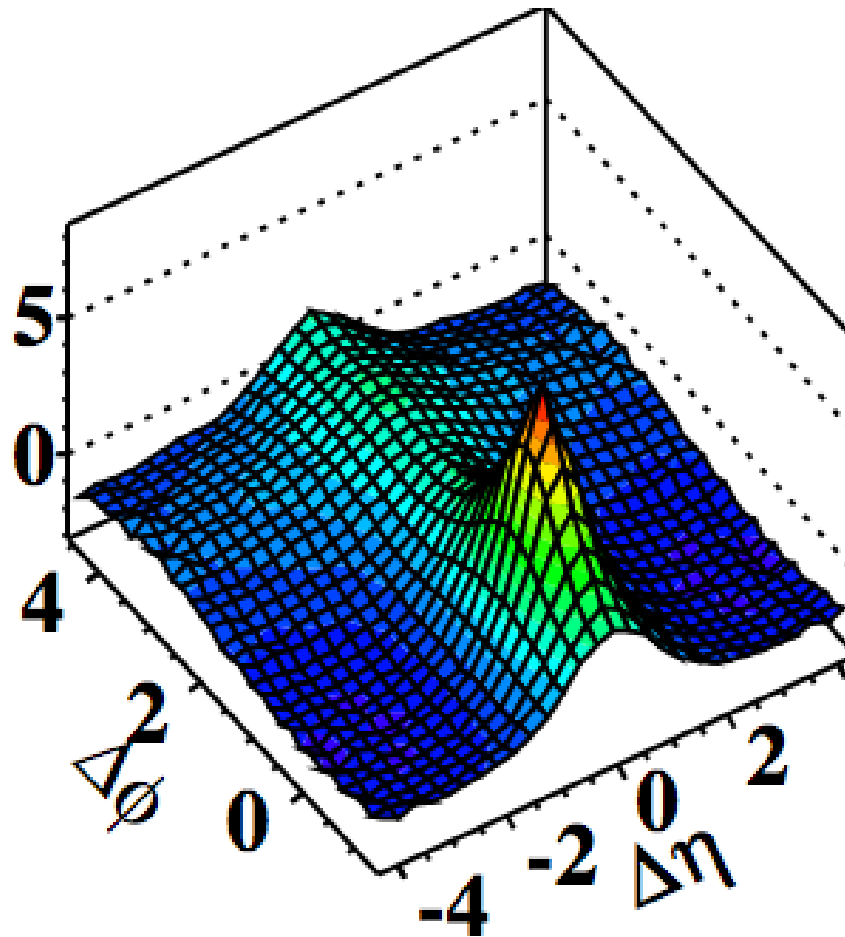


Mixed event pairs

Ratio Signal/Background

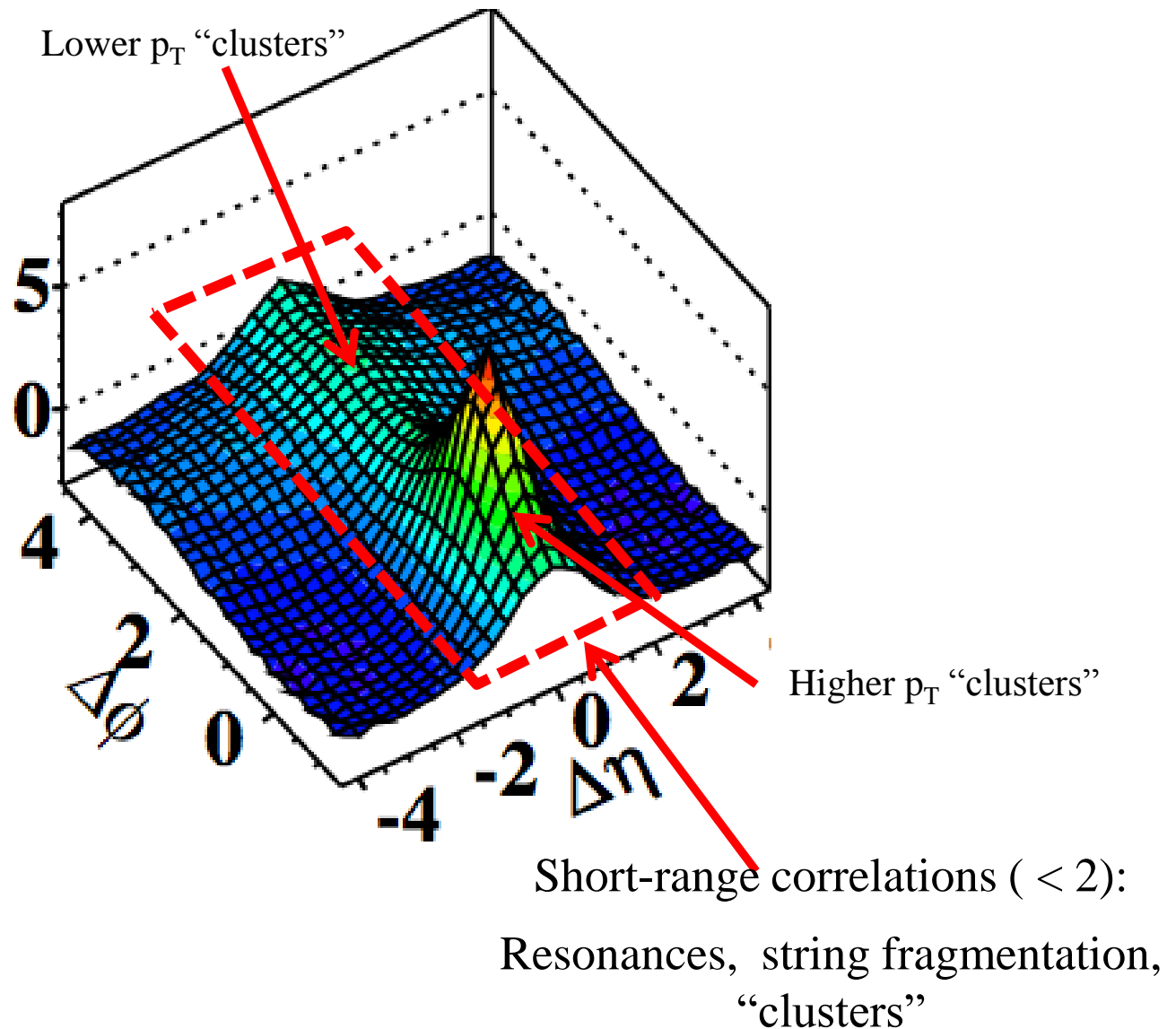


# Angular Correlation Functions





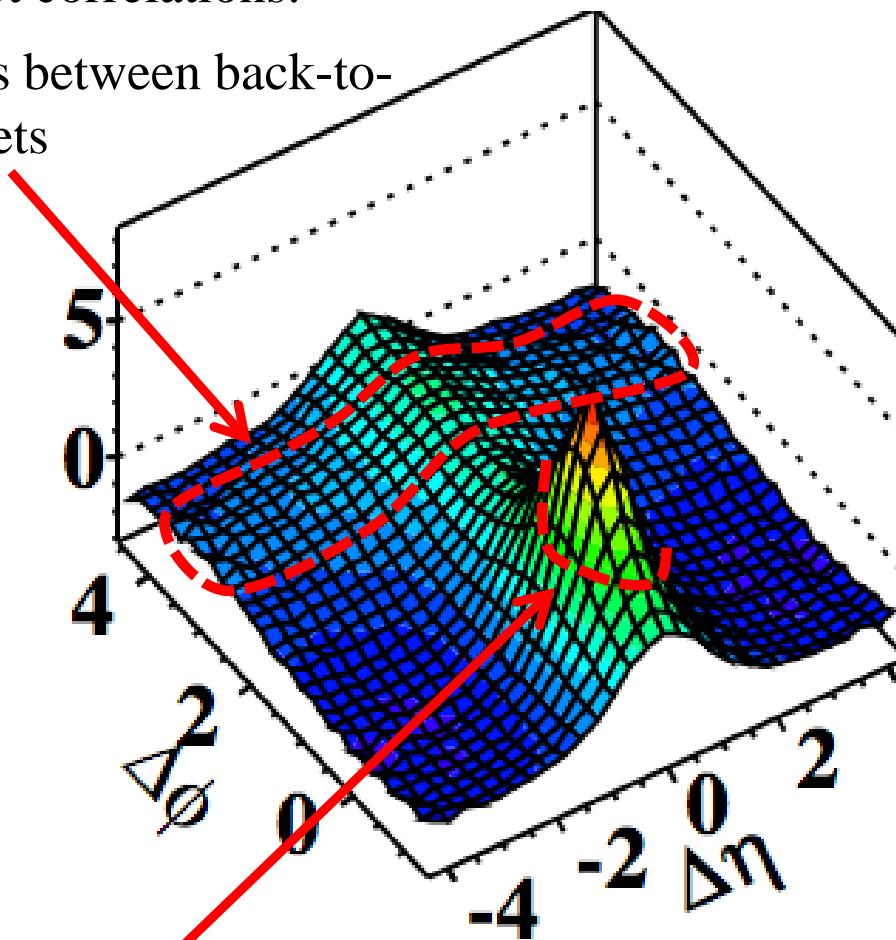
# Angular Correlation Functions



# Angular Correlation Functions

“Away-side”  $\sim \pi$  jet correlations:

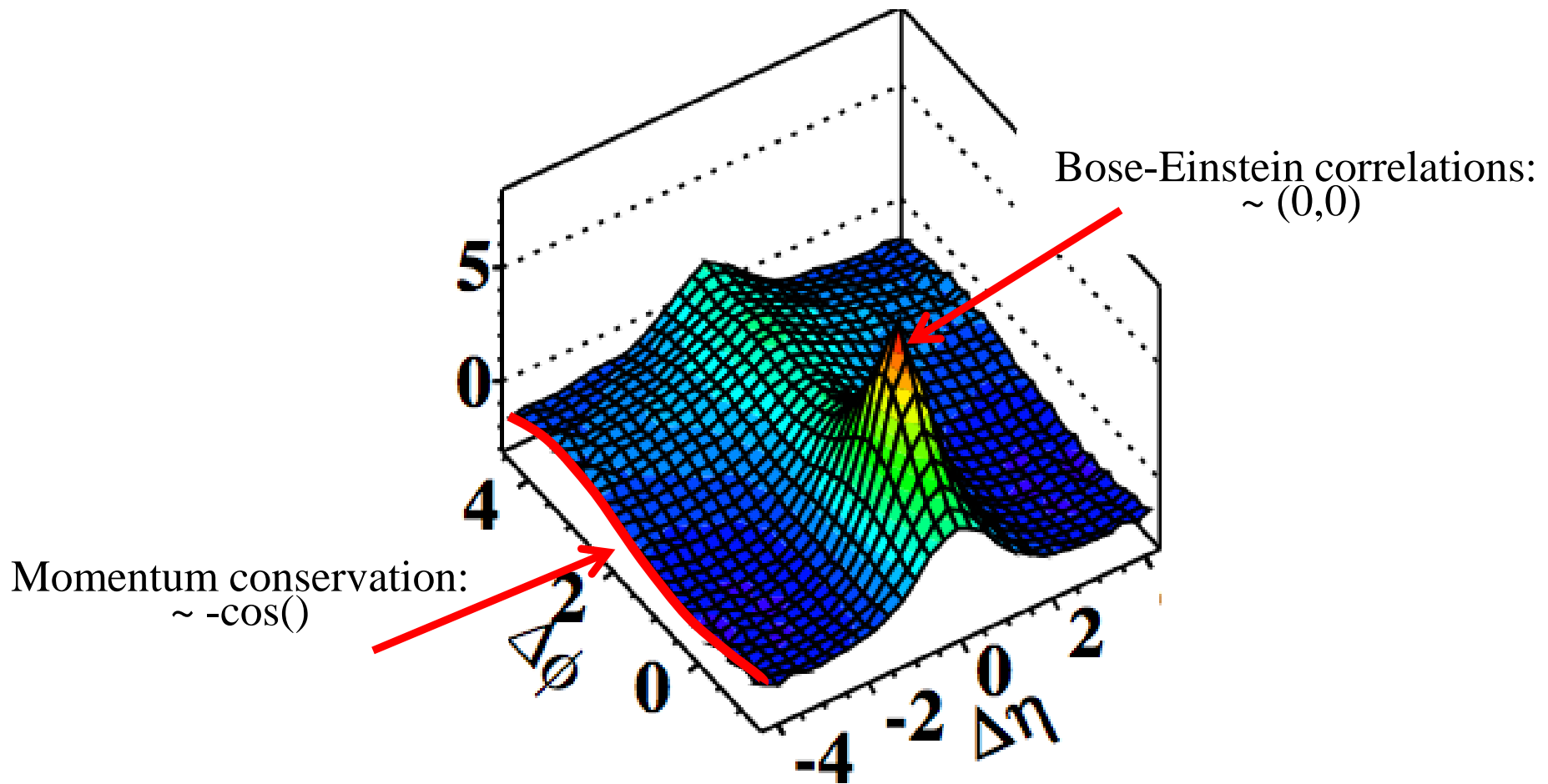
Correlation of particles between back-to-back jets



“Near-side”  $\sim 0$  jet peak:

Correlation of particles within a single jet

# Angular Correlation Functions



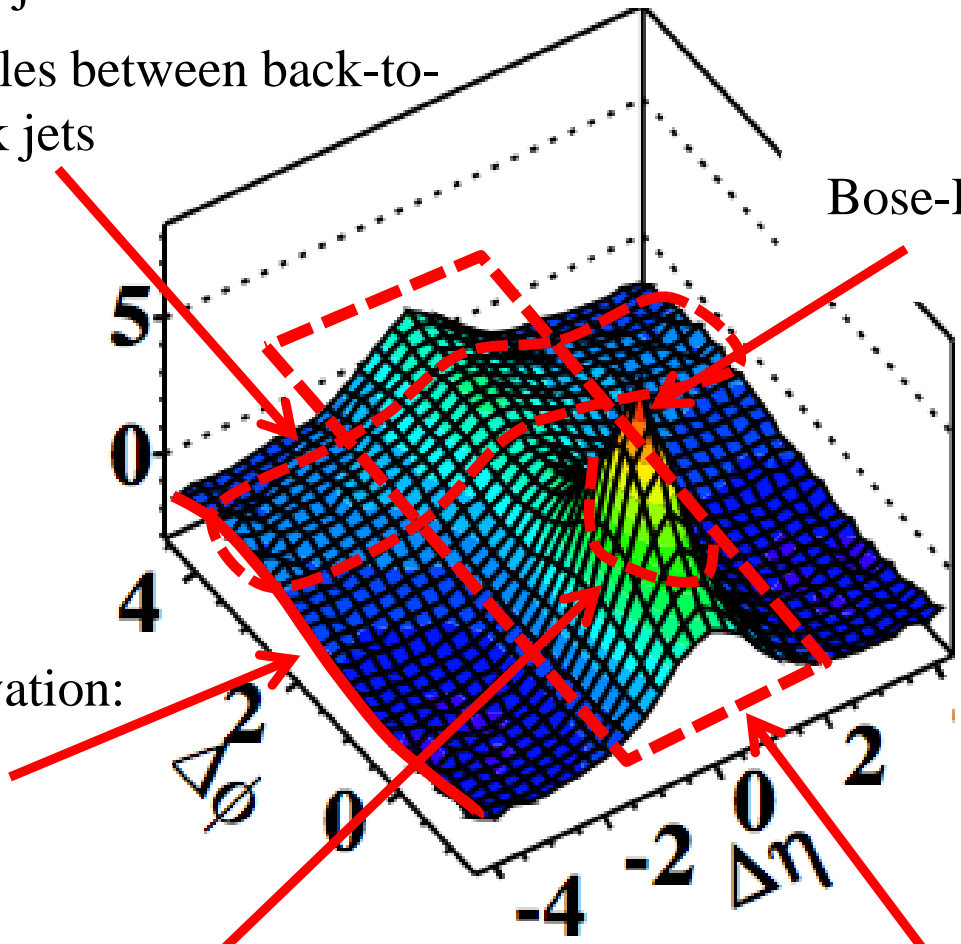


# Angular Correlation Functions

“Away-side”  $\sim$  ) jet correlations:

Correlation of particles between back-to-back jets

Bose-Einstein correlations:  $\sim (0,0)$



Momentum conservation:  $\sim -\cos()$

“Near-side”  $\sim 0$ ) jet peak:

Correlation of particles within a single jet

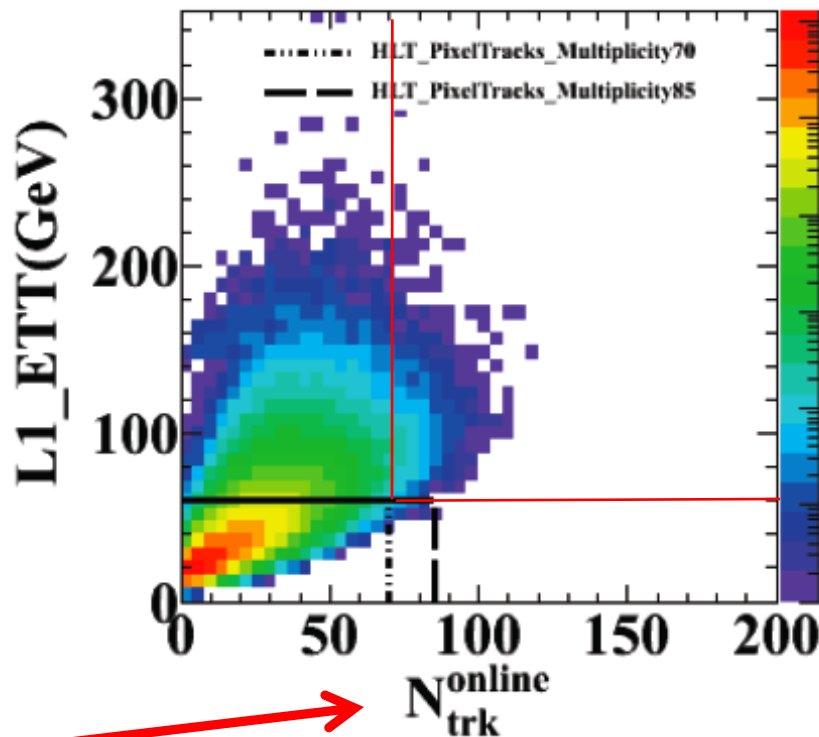
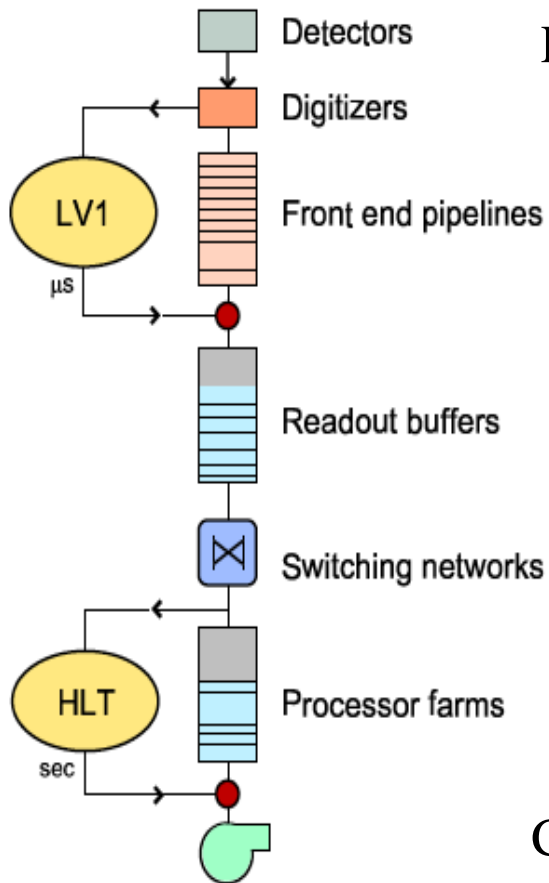
Short-range correlations ( $< 2$ ):

Resonances, string fragmentation, “clusters”

# High Multiplicity Events

*dedicated trigger used to select high multiplicities*

Level-1:  
Require  $E_T > 60$  GeV  
in calorimeters

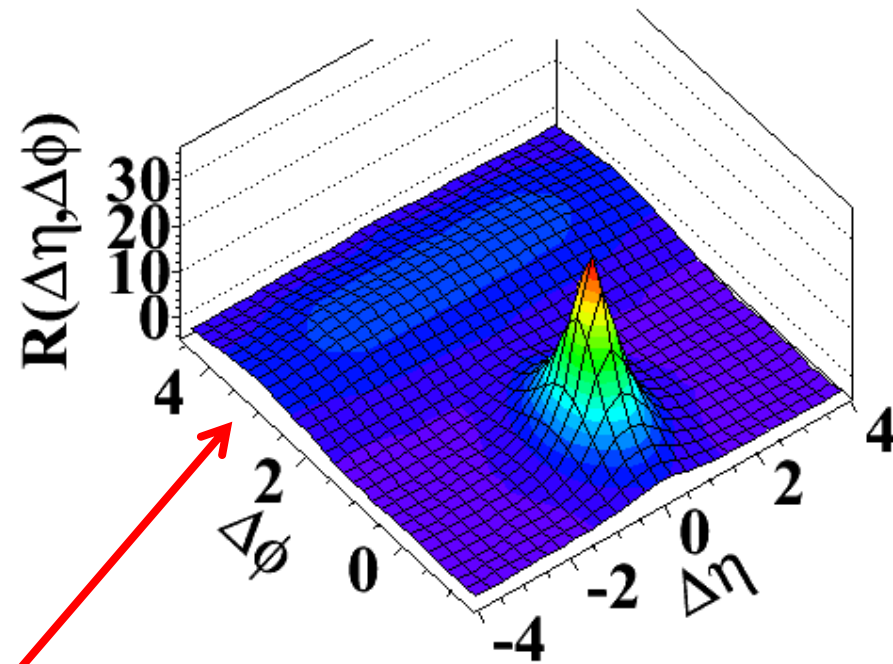
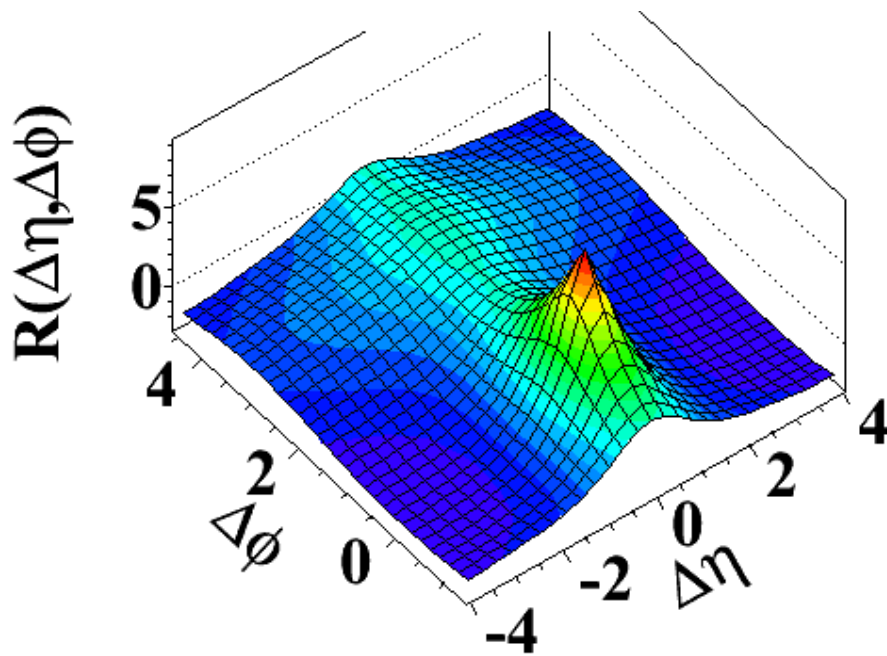


High-Level trigger:  
Count number of tracks with  $p_T > 0.4$  GeV/c,  $|\eta| < 2$ , within  
 $dz < 0.12\text{cm}$  of a **single** vertex with  $z < 10\text{cm}$

*no cut on  $p_T$*

minimum bias

high multiplicity ( $N > 110$ )



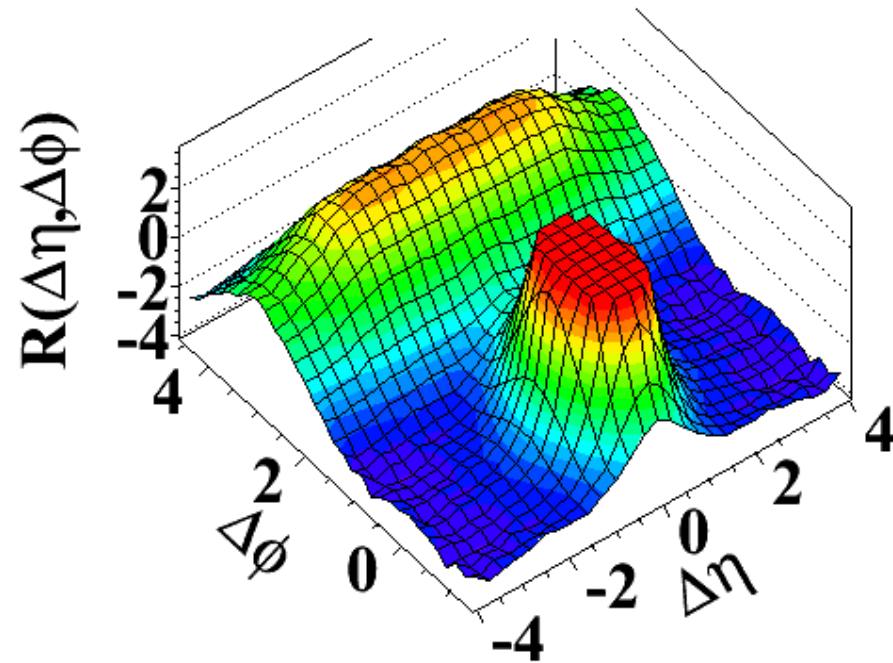
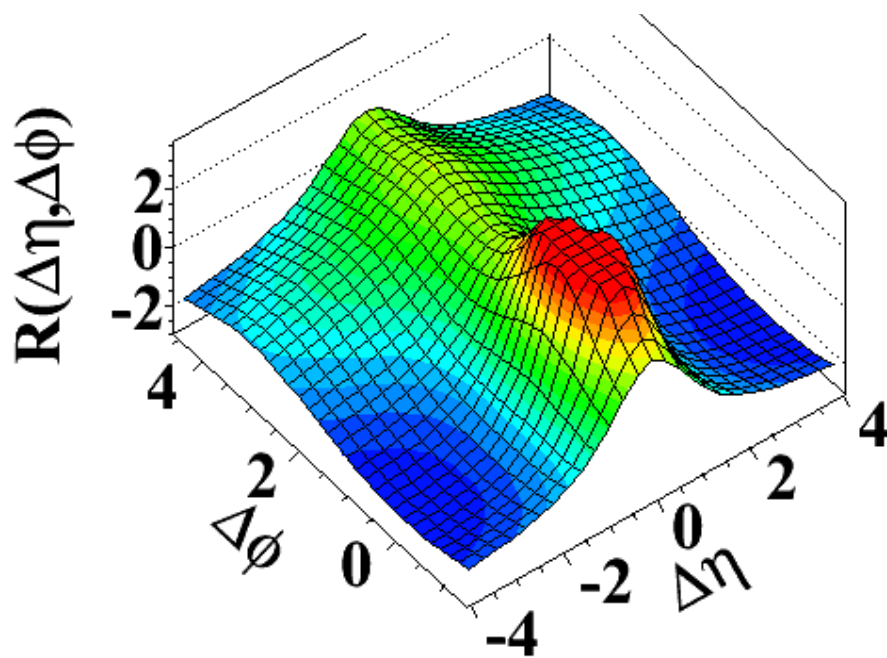
Jet peak/away-side correlations enhanced in high multiplicity events



*no cut on  $p_T$*

minimum bias

high multiplicity ( $N > 110$ )



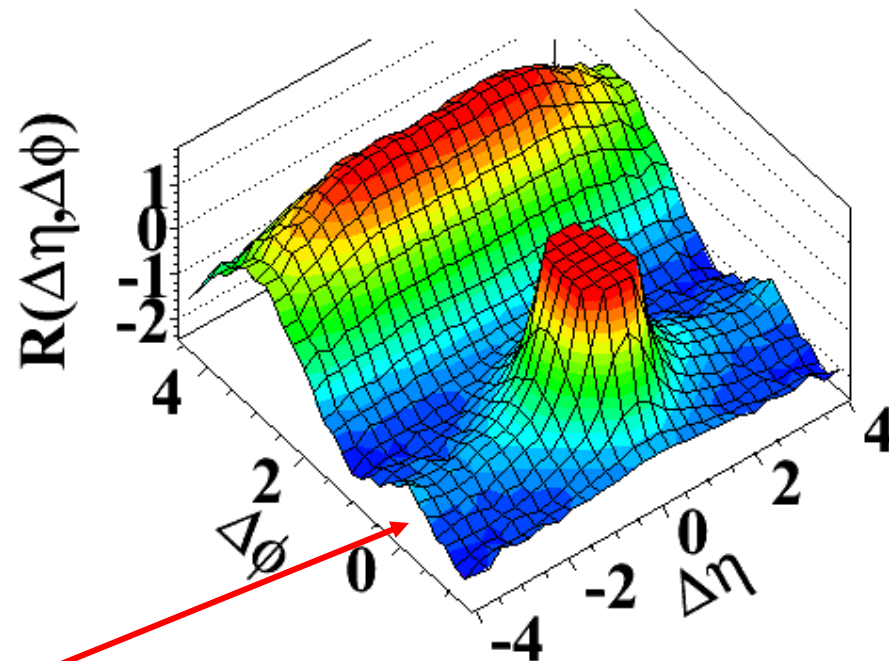
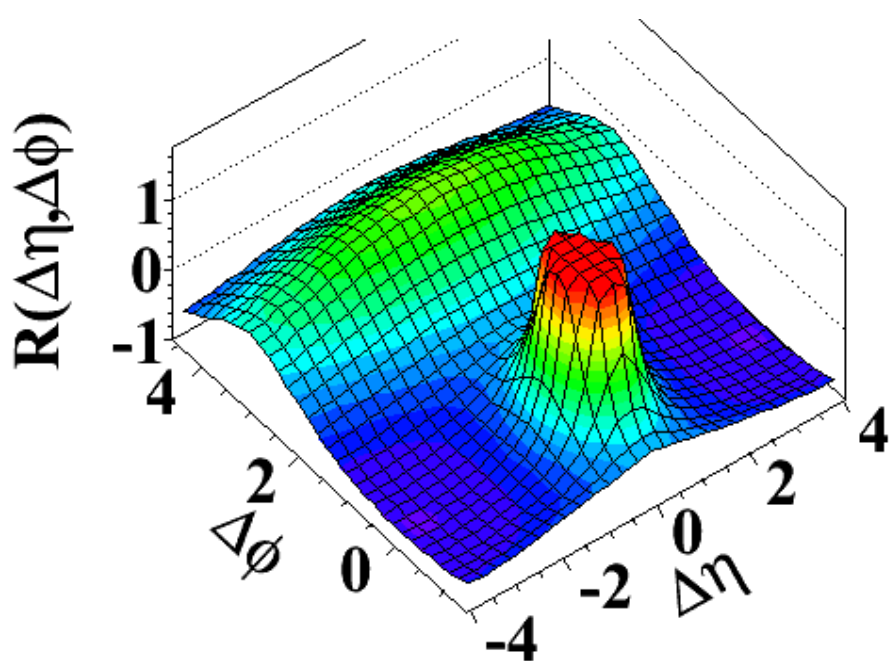
Cut off peak at (0,0):

Shows structure of away-side ridge (back-to-back jets)  
Small change for large  $\Delta\eta$  around  $\sim 0$  ?

# Intermediate $p_T$ : 1-3 GeV/c

minimum bias

high multiplicity ( $N > 110$ )



*structure at large around  $\sim 0$  : "the ridge"*

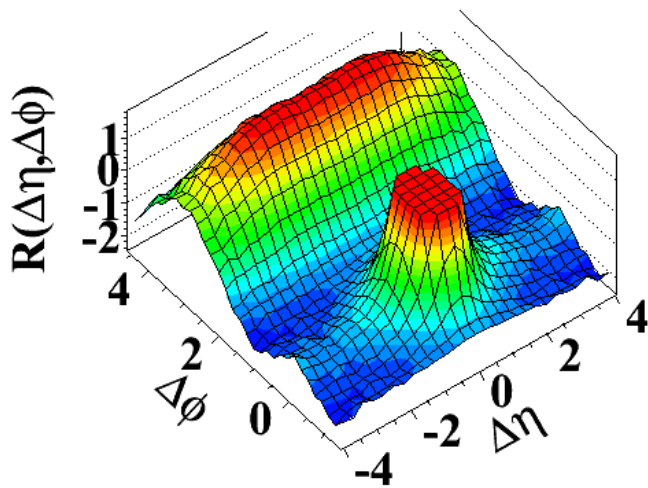
# *The Ridge as seen from CMS*

- *long-range, near-side correlations in high multiplicity events*
  - *signal grows with event multiplicity*
  - *biggest effect for  $1 < p_T < 3 \text{ GeV}/c$*
- *resembles effects seen in heavy-ion collisions at high energies*
- *careful work is needed to establish physical origin*



*some papers discussing or interpreting this observation of the “ridge” by CMS:*

(d)  $N > 110, 1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



<http://arxiv.org/abs/1009.5643>

<http://arxiv.org/abs/1010.0405>

<http://arxiv.org/abs/1010.0964>

<http://arxiv.org/abs/1010.0918>

<http://arxiv.org/abs/1009.5295>

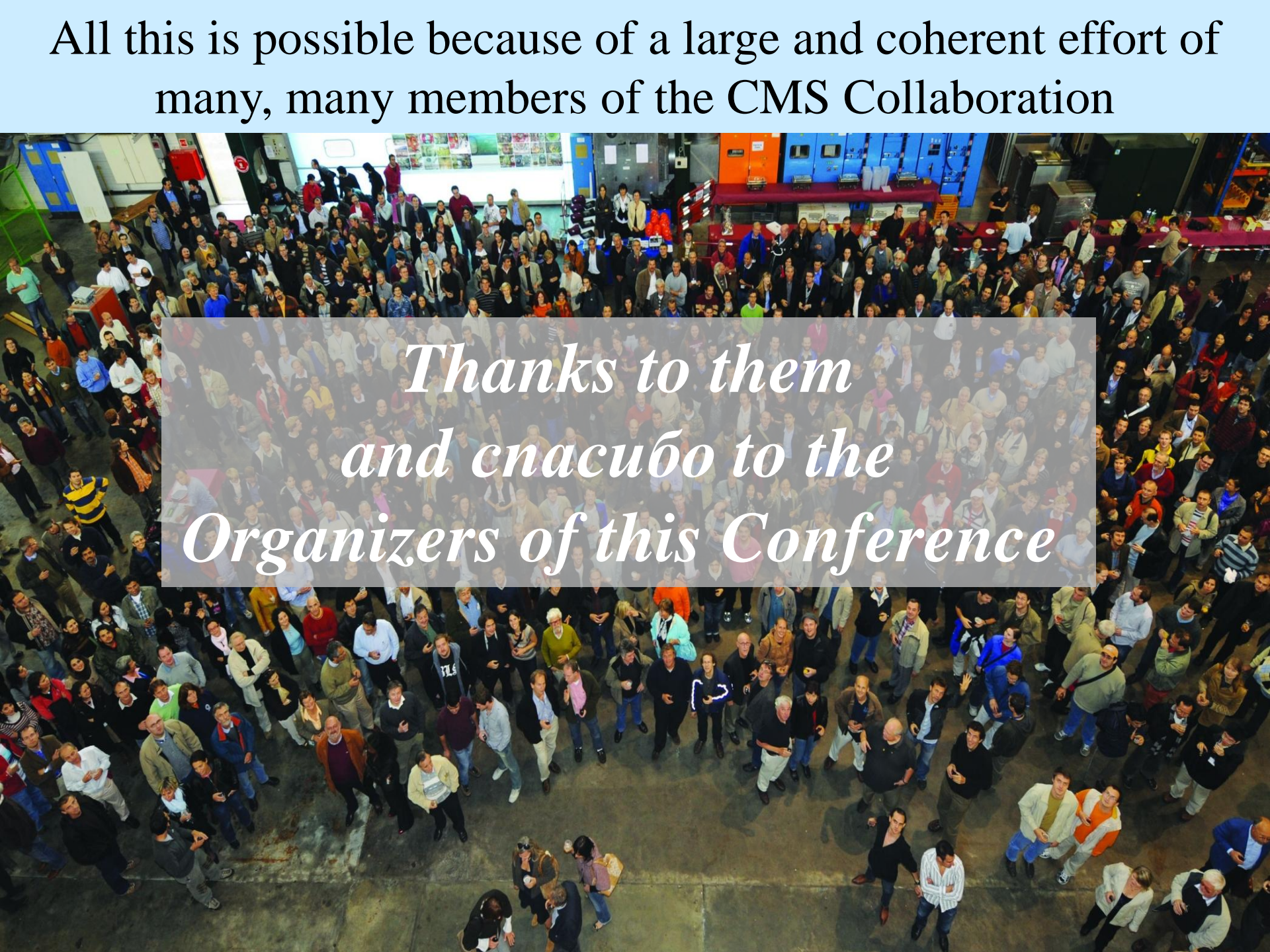
<http://arxiv.org/abs/1009.5229>

# Conclusions

- LHC rapidly picking up speed
- CMS making good use of the delivered luminosity
- yielding lots of new physics results
  - see also the other presentations at this Conference
- next year we may already get first answers to some long-standing questions in physics
  - Higgs? Susy?
- fascinating New Physics may be just around the corner



All this is possible because of a large and coherent effort of many, many members of the CMS Collaboration

A high-angle, wide shot of a large, diverse crowd of people gathered in a large, open hall, likely for a conference. The people are densely packed, filling most of the frame. In the background, there are blue and orange structures, possibly part of the conference infrastructure or exhibition area. The lighting is bright and even.

*Thanks to them  
and enacuño to the  
Organizers of this Conference*

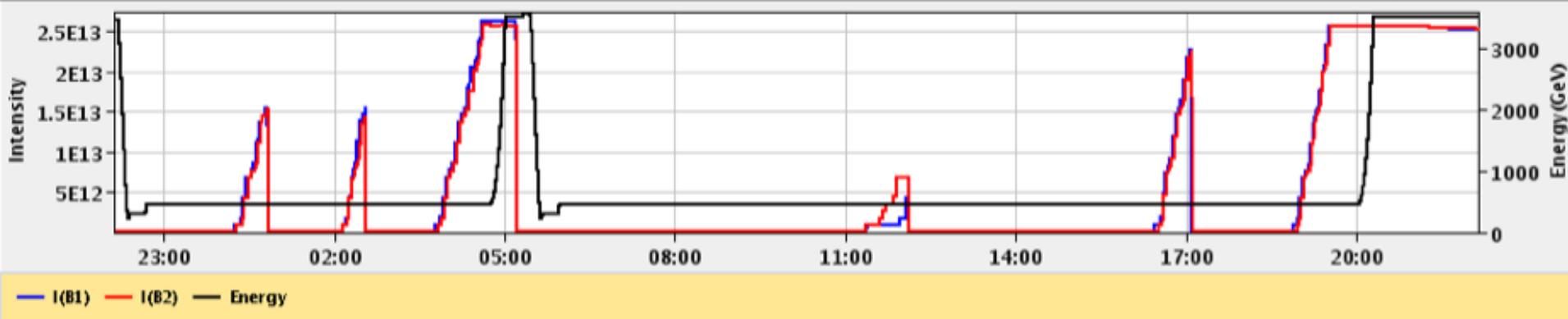


# *BACKUP*

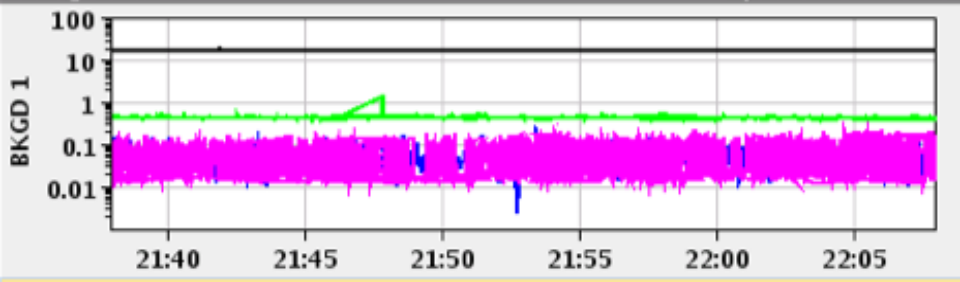
Experiment Status	ATLAS PHYSICS	ALICE STANDBY	CMS PHYSICS	LHCb NOT_R..
Instantaneous Lumi (ub.s) <sup>-1</sup>	89.161	0.434	87.123	82.325
BRAN Luminosity (ub.s) <sup>-1</sup>	64.561	0.675	79.148	74.328
Fill Luminosity (nb) <sup>-1</sup>	259.0	--	247.0	238.6
BKGD 1	0.039	0.015	16.873	0.432
BKGD 2	259.000	1.575	0.002	1.370
BKGD 3	34.000	0.005	2.344	0.370

LHCb VELO Position **IN** Gap: 0.0 mm **STABLE BEAMS** TOTEM: **STANDBY**

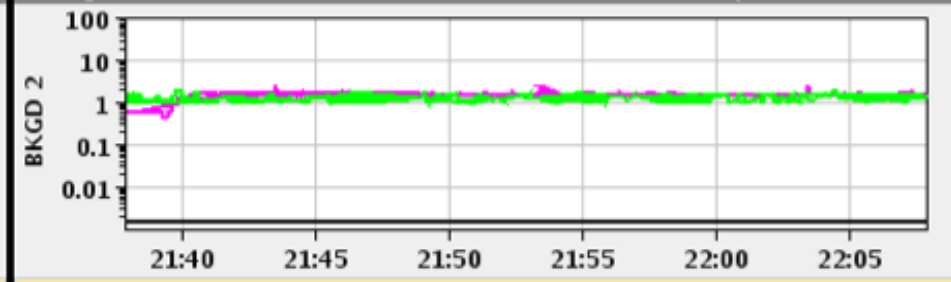
Performance over the last 24 Hrs Updated: 21:56:25



Background 1 Updated: 21:56:32



Background 2 Updated: 21:56:32

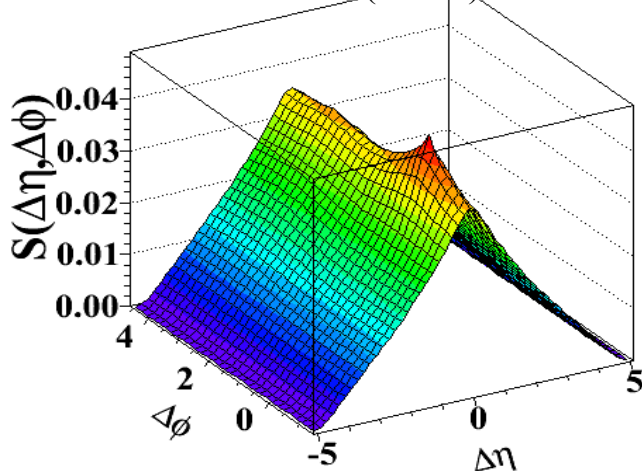




# Correlation Function Definition

Signal distribution:

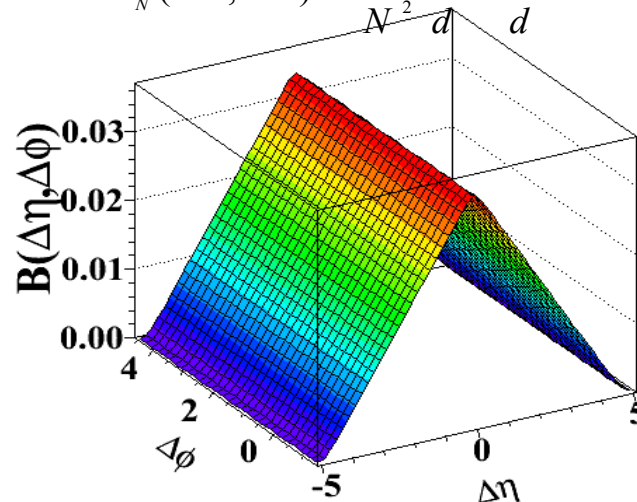
$$S_N(\Delta\eta, \Delta\phi) = \frac{1}{N(N-1)} \frac{d^2 N^{signal}}{d\Delta\eta d\Delta\phi}$$



Same event pairs

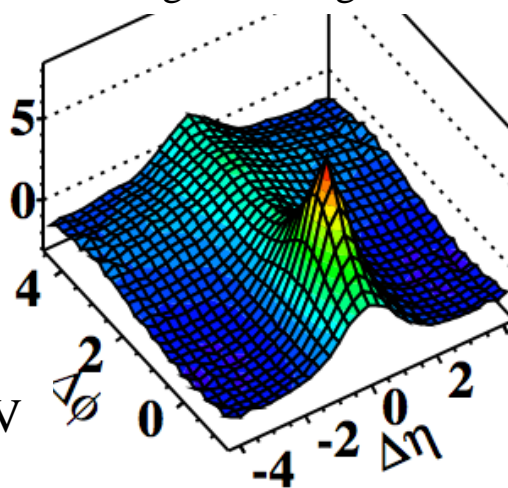
Background distribution:

$$B_N(\Delta\eta, \Delta\phi) = \frac{1}{N^2} \frac{d^2 N^{bkg}}{d\Delta\eta d\Delta\phi}$$



Mixed event pairs

Ratio Signal/Background



CMS pp 7TeV

$$R(\Delta\eta, \Delta\phi) = \left\langle (N-1) \frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)} - 1 \right\rangle_N$$

$p_T$ -inclusive two-particle  
angular correlations in  
min bias collisions