

Compact Muon Solenoid @ Large Hadron Collider

Krzysztof Doroba

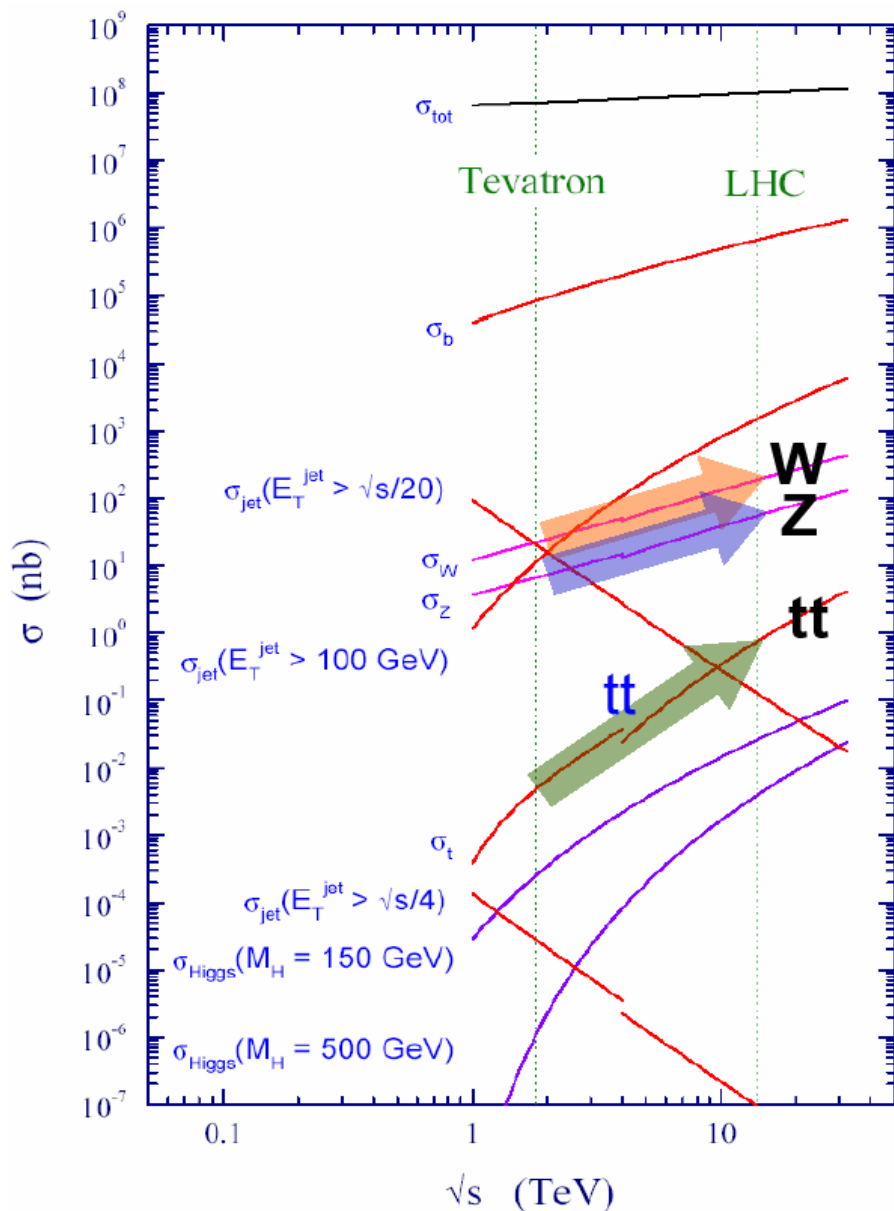
18.11.2010 -Seminarium ZFJA i ZSJ

Plan:

- geneza i start LHC
- eksperyment CMS
 - detektor
 - wkład grupy warszawskiej
- pierwsze wyniki fizyczne - krótki przegląd
 - rozkłady krotności i pędu poprzecznego
 - ridge effect
 - ...
- czego i kiedy możemy oczekiwać
- ciężkie jony - zderzenia PbPb

Large Hadron Collider Workshop

Akwizgran 4-9 Października 1990

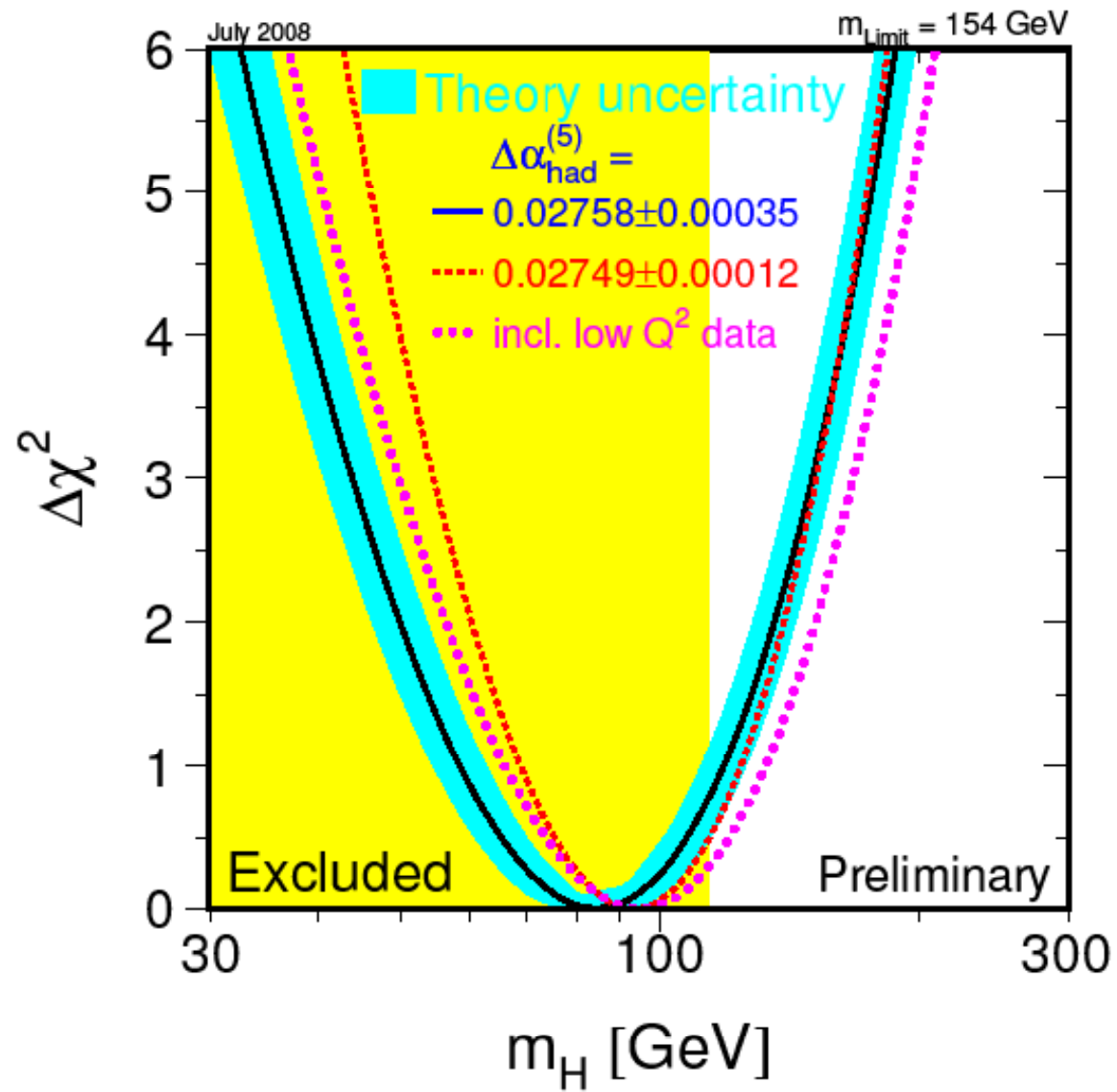


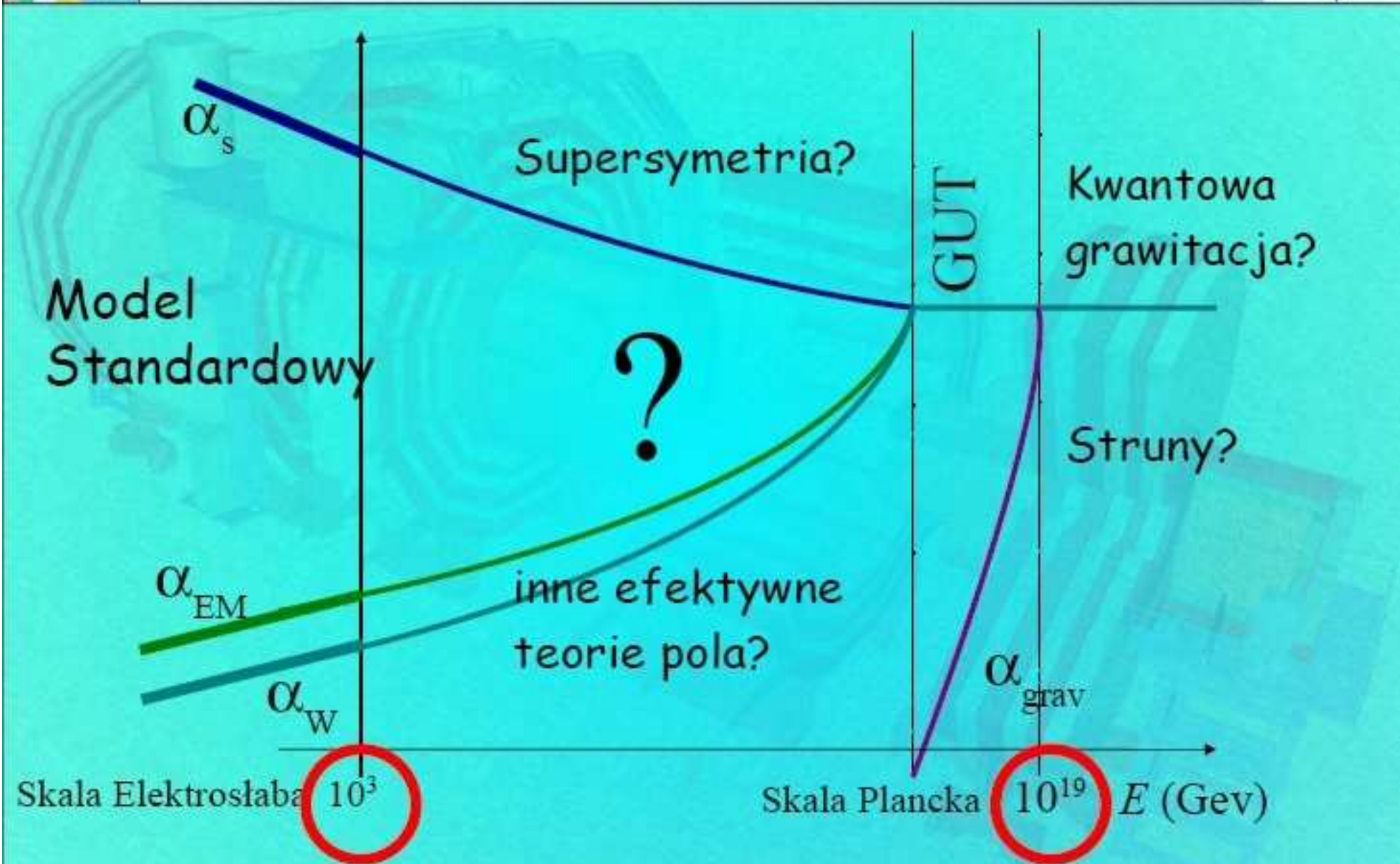
Potrzebna maszyna hadronowa o dużej
światłości ($10^{34} \text{ sek}^{-1} \text{ cm}^{-2}$) i energii rzędu
kilkunastu TeV.

1994 – decyzja budowy
LHC w CERN - ie:

Zderzacz pp, $L=10^{34} \text{ cm}^{-2} \text{ sek}^{-1}$

$$\sqrt{s} = 14 \text{ TeV}$$





Dane techniczne LHC

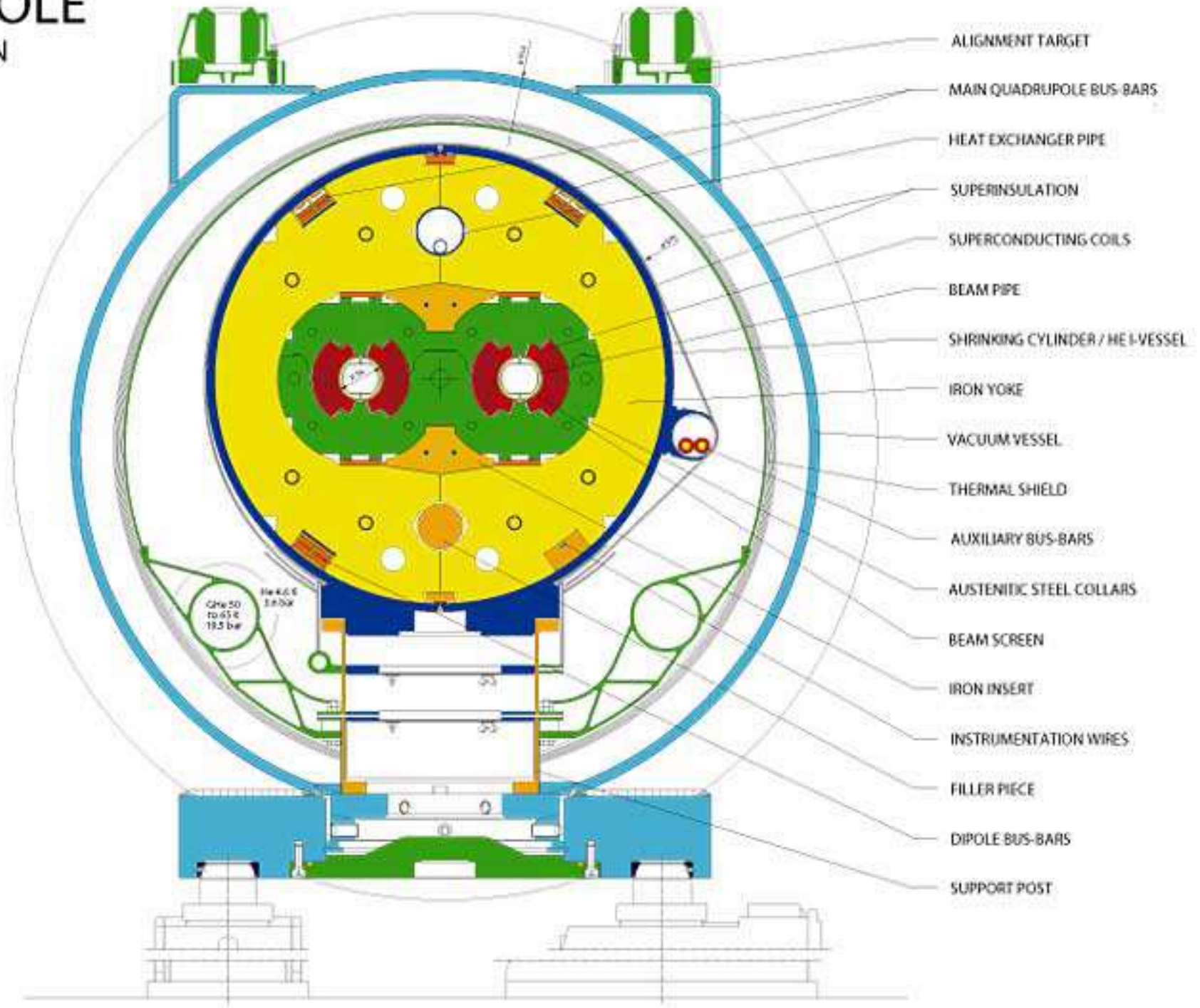
Quantity	number
Circumference	26 659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9300
Number of dipoles	1232
Number of quadrupoles	858
Number of RF cavities	8 per beam
Nominal energy, protons	7 TeV
Nominal energy, ions	2.76 TeV/u (*)
Peak magnetic dipole field	8.33 T
Min. distance between bunches	~7 m
Design luminosity	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
No. of bunches per proton beam	2808
No. of protons per bunch (at start)	1.1×10^{11}
Number of turns per second	11 245
Number of collisions per second	600 million

(*) Energy per nucleon

magnes dipolowy LHC w plenerze



LHC DIPOLE CROSS SECTION



LHC, Large Hadron Collider - Wielki Zderzacz Hadronów





QQBI.27R3



BEAM SETUP: FLAT TOP

Energy:

3500 GeV

I(B1):

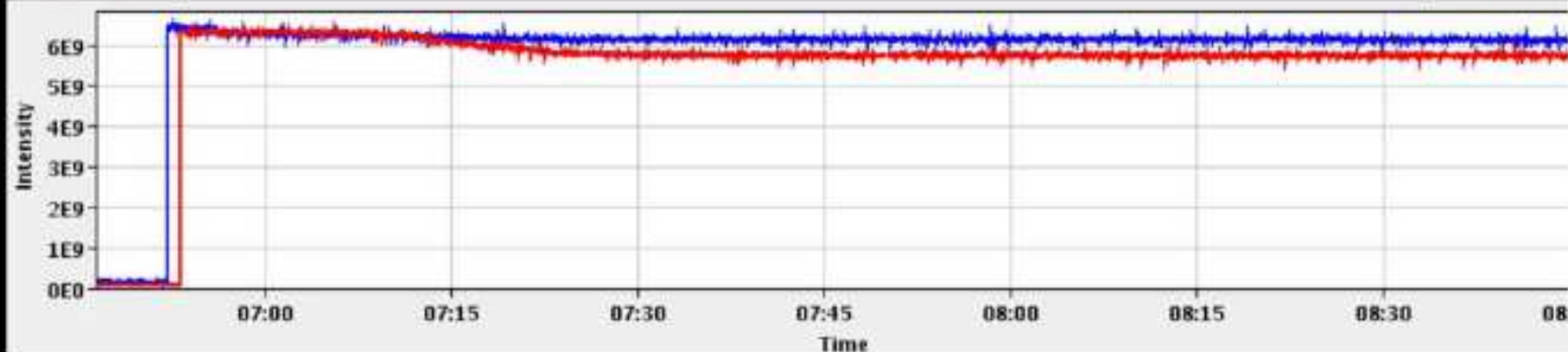
8.09e+09

I(B2):

4.20e+09

FBCT Intensity

Updated: 08:46



Comments 25-03-2010 08:23:03 :

Ramp finished

Optics measurements starting ...

...Collimator studies in late morning

BIS status and SMP flags

B1

B2

Link Status of Beam Permits

false

false

Global Beam Permit

true

true

Setup Beam

true

true

Beam Presence

true

true

Moveable Devices Allowed In

false

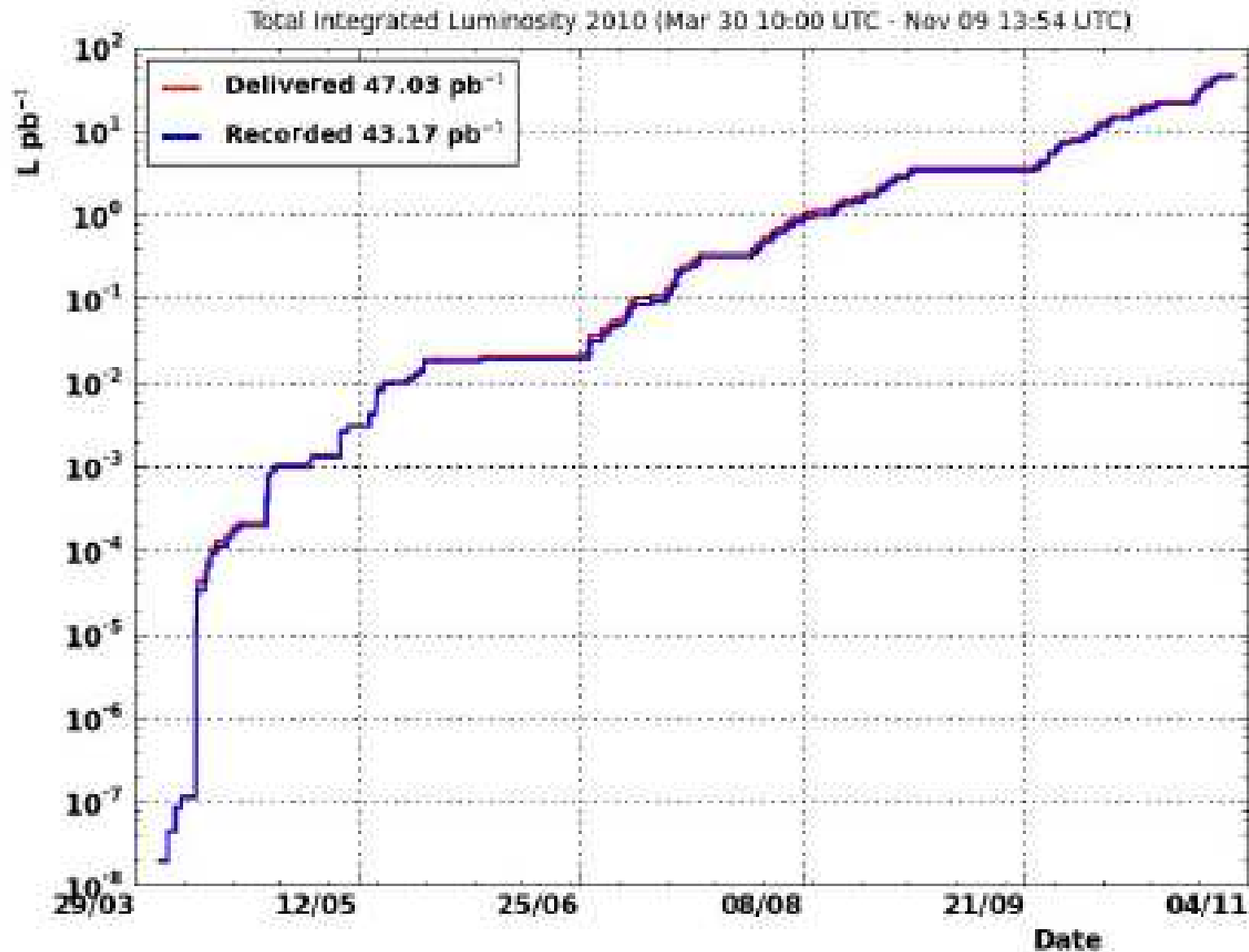
false

Stable Beams

false

false

Scatkowana swietlnosc dla pp w 2010



Podsumowanie pierwszych siedmiu miesięcy zbierania danych pp @ 7 TeV

- ❖ Maksymalne 368 paczek (docelowo 2808)
- ❖ Minimalny odstęp między paczkami 150 ns (50) (50 ns tylko dla 36 bunch/train)
- ❖ ppb (protons per bunch) $\sim 10^{10}-10^{11}$

Maksymalna świetlność = $204.78 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$
Zapisana świetlność = 43.17 pb^{-1} (CMS)

8.11.2010 ruszyły zderzenia PbPb !

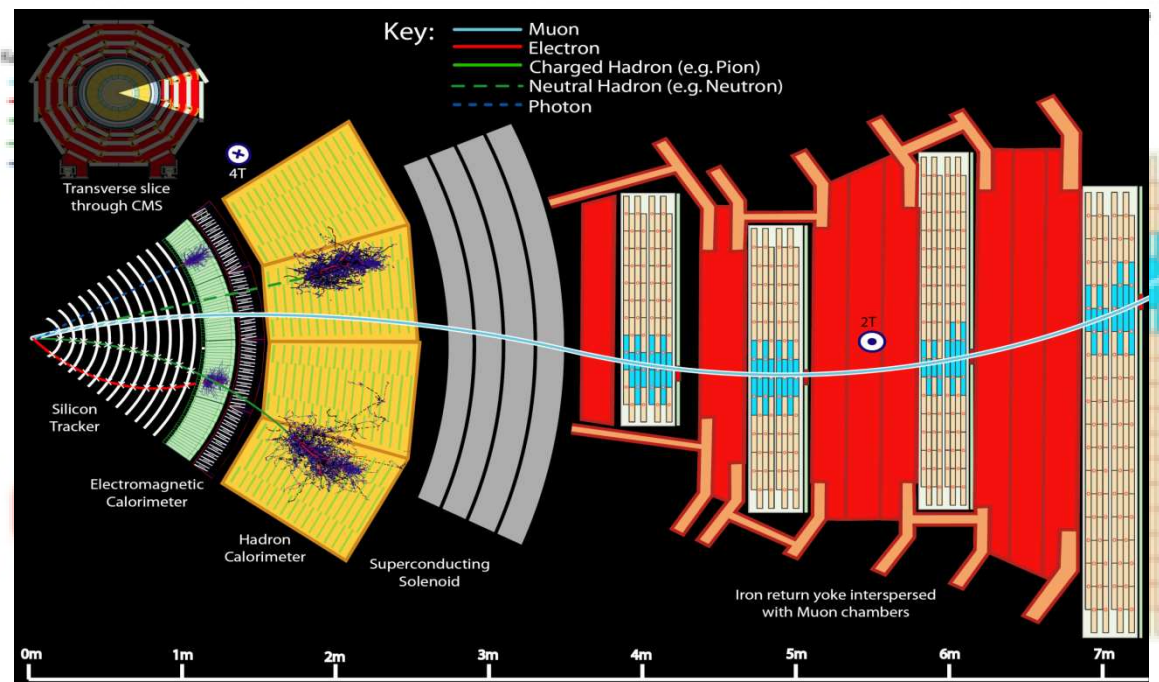
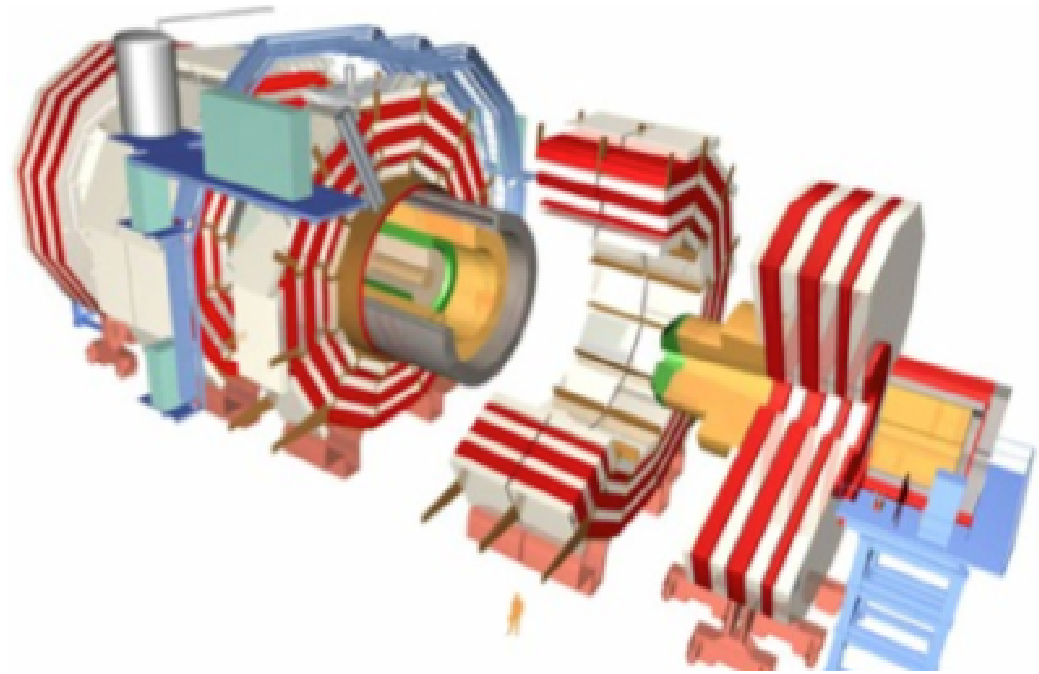
Sukces LHC !!!

Eksperymenty przy LHC:

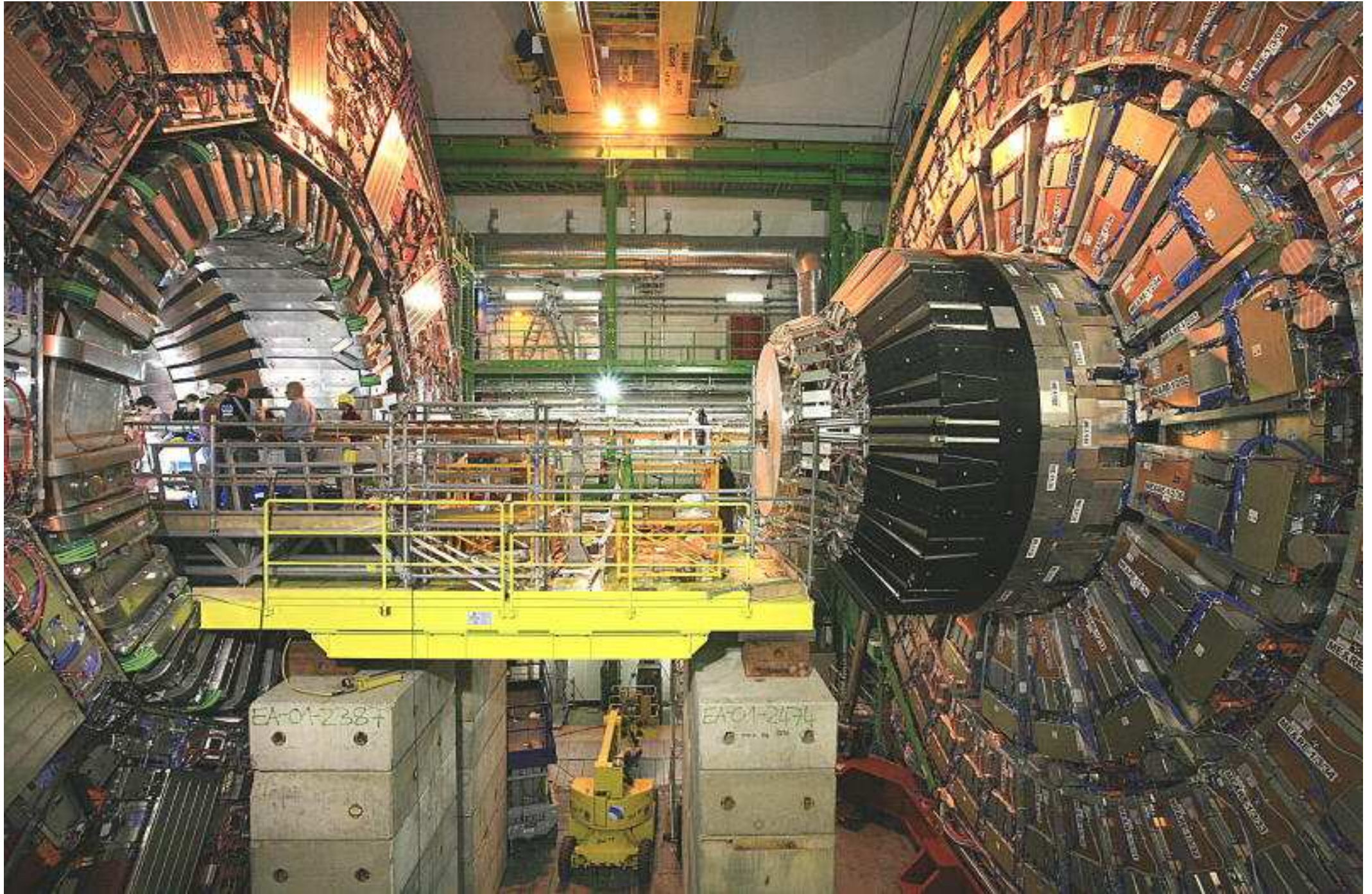
- ❖ **ATLAS i CMS** - detektory ogólnego przeznaczenia
- ❖ **ALICE** - specjalizacja: ciężkie jony
- ❖ **LHCb** - spektrometr jednoramienny (łamanie CP)
- ❖ **TOTEM, LHCf** - amplitudy do przodu

CMS detector

- Tracking, ECAL and HCAL all embedded inside 3.8 T solenoid magnet
- Muon chambers outside magnet, interleaved with iron return yoke
- Precise silicon pixel and silicon strip tracking system at $|\eta| < 2.4$
- Fine-grained (Moliere radius ~ 2 cm) lead tungstate crystal ECAL at $|\eta| < 3.0$
- Barrel+end cap HCAL coverage up to $|\eta| < 3$, hadronic forward up to $|\eta| < 5$



Detektor CMS podczas montażu



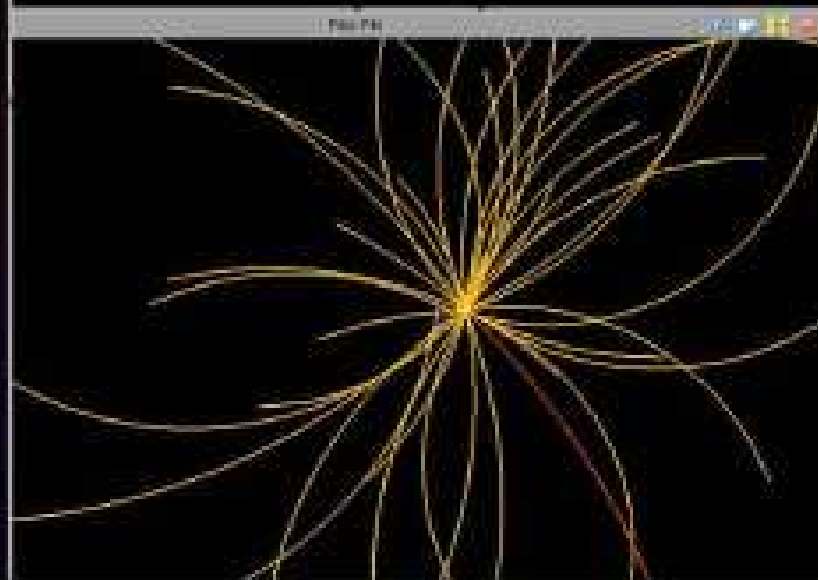
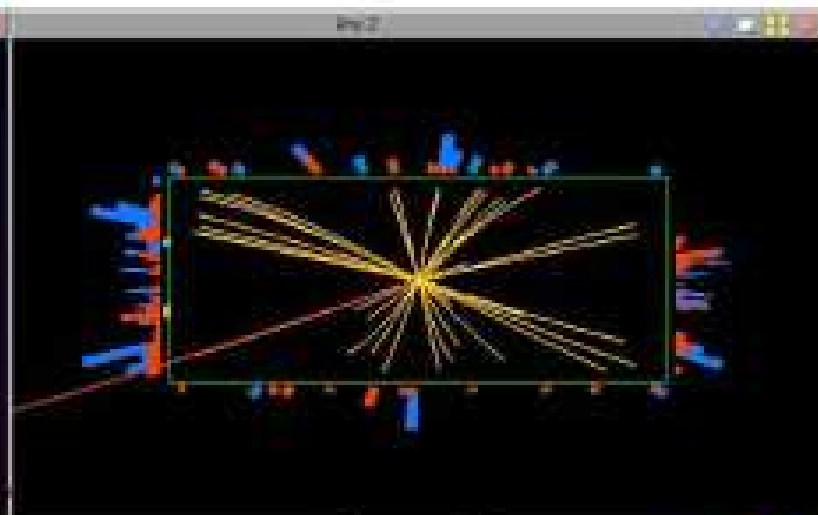
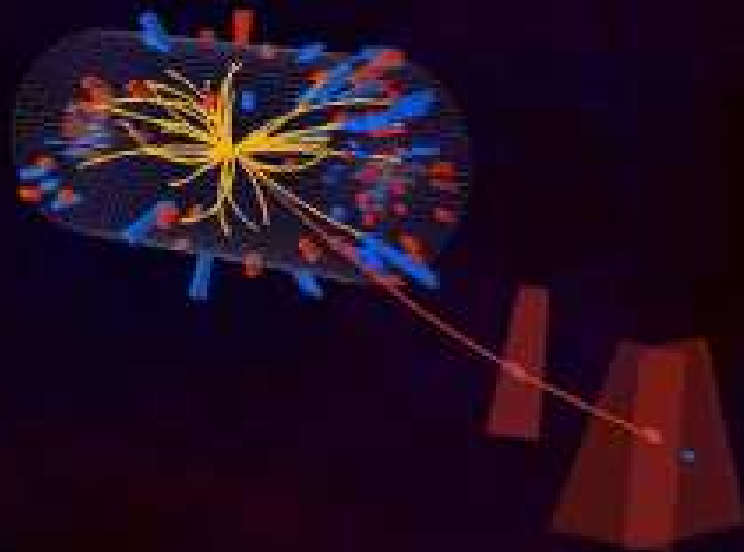
CMS w oczekiwaniu na wiązkę (Pb)

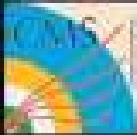
cmseye07 2010-11-12 16:31:49





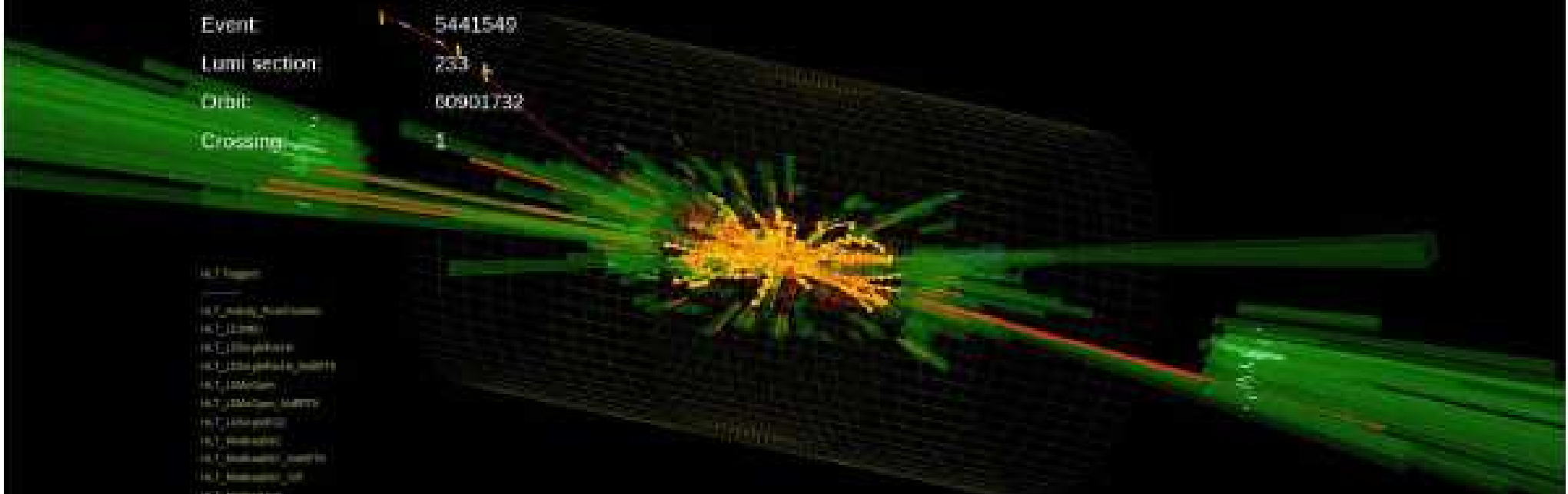
CMS Experiment at LHC, CERN
Data recorded: Tue Mar 30 13:00:53 2010 CEST
Run/Event: 132440 / 2872297
Lumi section: 129
Orbit/Crossing: 33733051 / 1





CMS Experiment at the LHC, CERN

Data recorded: 2010-Mar-30 11:41:09.816679 GMT(13:41:09 CEST)
 Run: 132440
 Event: 5441549
 Lumi section: 233
 Orbit: 60901732
 Crossing: 1

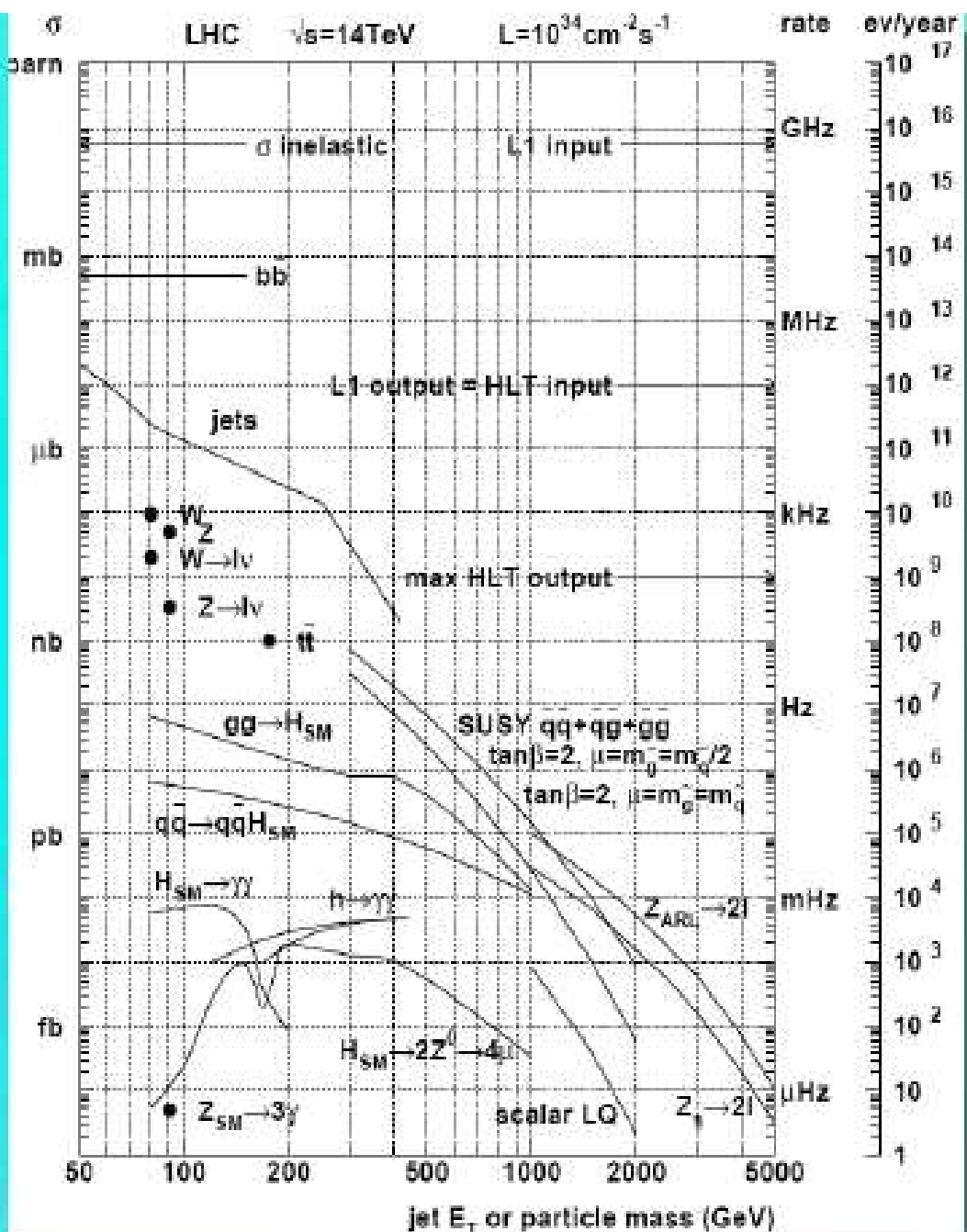


- HLTTrigger
- HLT_Calib_RL
- HLT_D2
- HLT_D2BPT
- HLT_D2BPT_1
- HLT_D2BPT_2
- HLT_D2BPT_3
- HLT_D2BPT_4
- HLT_D2BPT_5
- HLT_D2BPT_6
- HLT_D2BPT_7
- HLT_D2BPT_8
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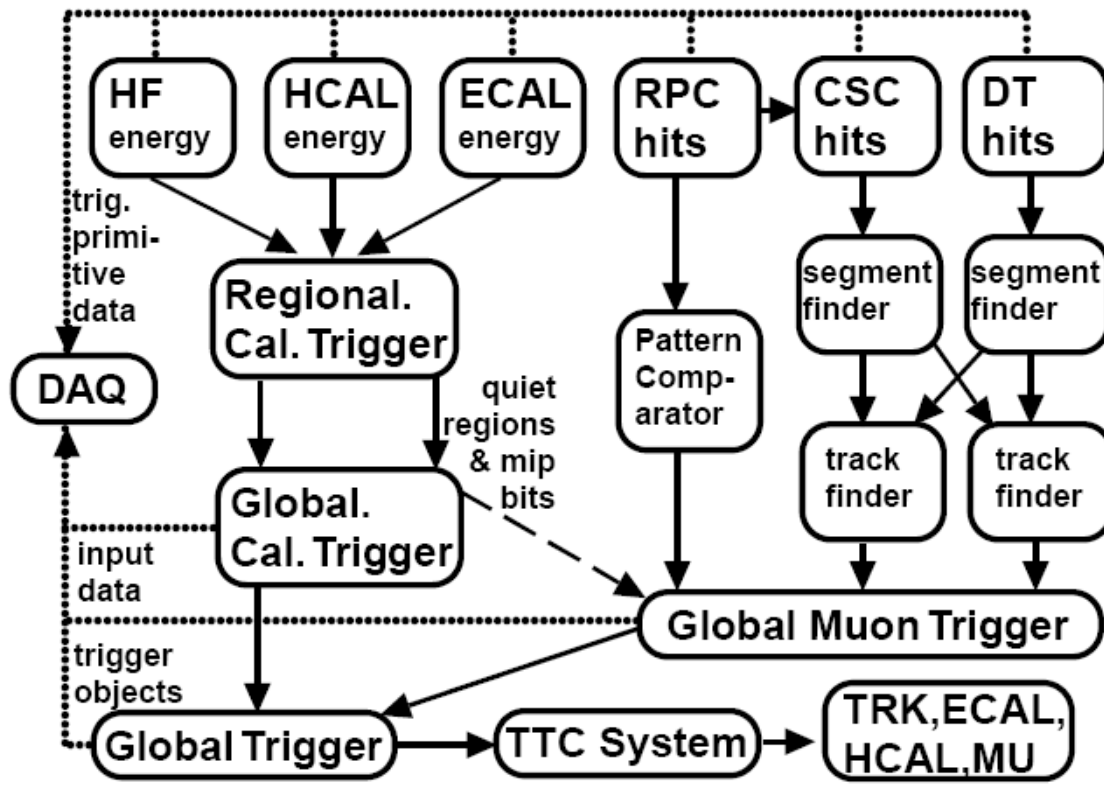
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HLT_D2BPT_2	0.00	0.00
HLT_D2BPT_3	0.00	0.00
HLT_D2BPT_4	0.00	0.00
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HLT_D2BPT_13	0.00	0.00
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HLT_D2BPT_20	0.00	0.00
HLT_D2BPT_21	0.00	0.00
HLT_D2BPT_22	0.00	0.00
HLT_D2BPT_23	0.00	0.00
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HLT_D2BPT_99	0.00	0.00
HLT_D2BPT_100	0.00	0.00

Układ wyzwalający detektora CMS

- Dwustopniowy tryger:
 - Poziom 1 (L1) - hardware detektora
 - Wyższe poziomy (HLT) - programowalny, farma komputerów PC
- Redukcja z poziomu 40 MHz (zderzenia) do ~100 Hz (100 MB/s zapis na taśmę)

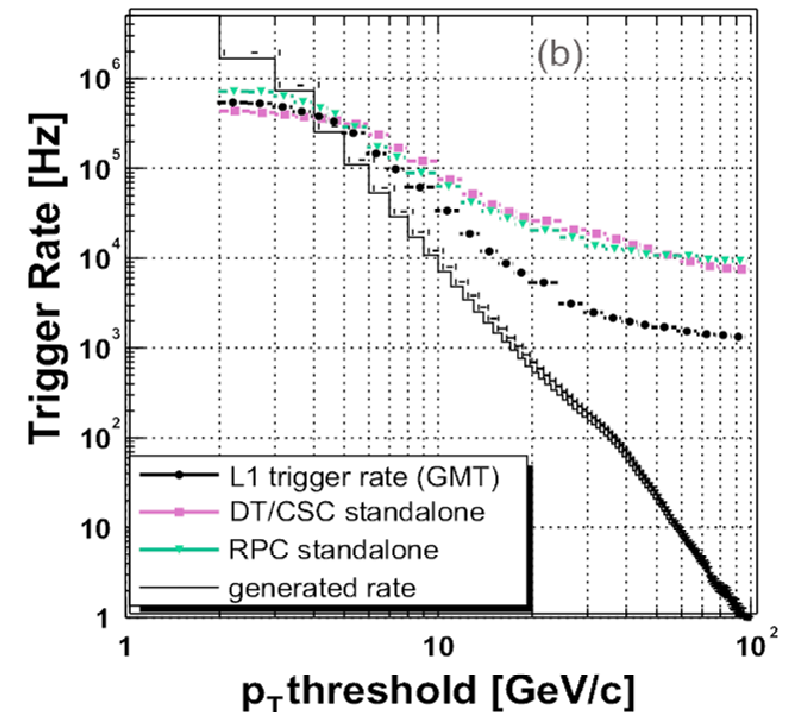


Overview of Level 1 Trigger



Trigger subsystems search for trigger objects, rank them and sort

Applies thresholds, depending on trigger objects localization and coincidence



Grupa Warszawska (UW, IPJ, PW)
zaprojektowała, zbudowała i uruchomiła

Trigger Mionowy oparty o komory RPC (RPC Trigger)

Resistive Plate Chambers (~2000 komór-Włosi) umieszczone są jarzmie magnesu, w silnym polu B, obok komór DT (b) lub CSC (endcap)

RPC Trigger (PAttern Comparator Trigger)

- zbiera informacje z pasków komór RPC
- porównuje krzywiznę toru mionu z przygotowanymi wzorcami (patterns).
- wybiera 4 najszybsze miony o $p_T > p_{Tcut}$ i wysyła te informacje do Globalnego Triggera Mionowego
- zapewnia odczyt komór RPC

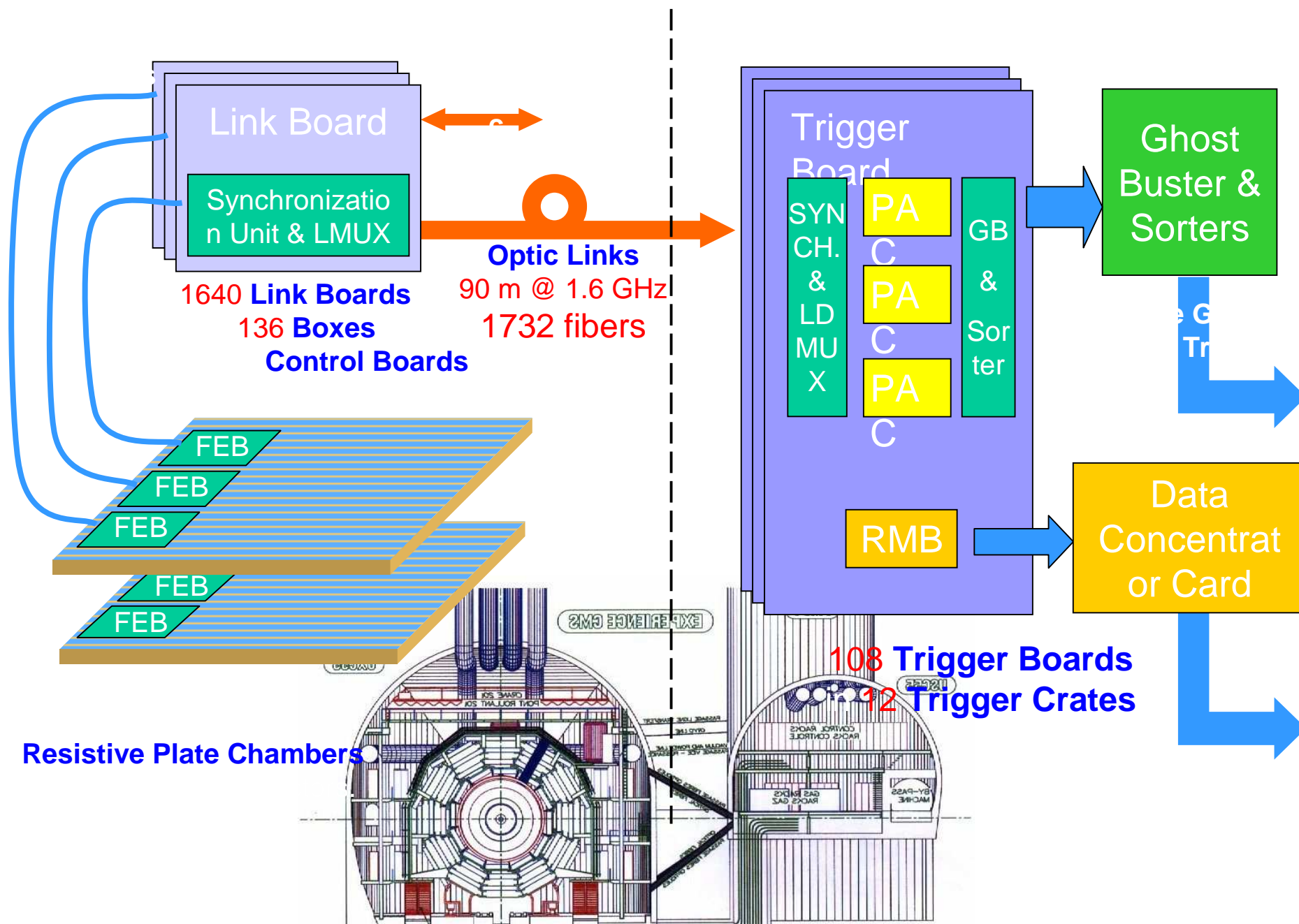
Technologia: ASIC → FPGA

Autorstwo: J. Królikowski, M. Kudła, G. Wrochna, M. Konecki, K. Poźniak, W. Zabołotny, ...

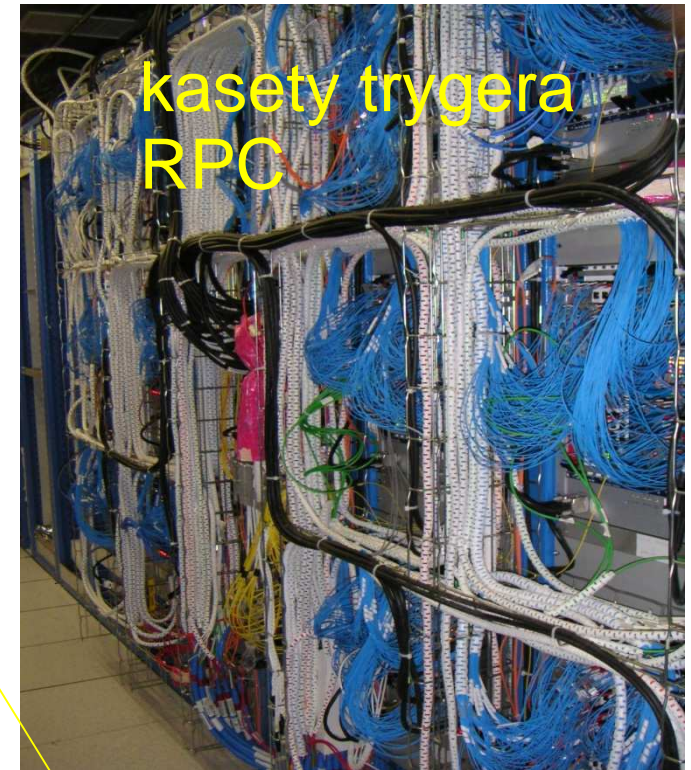
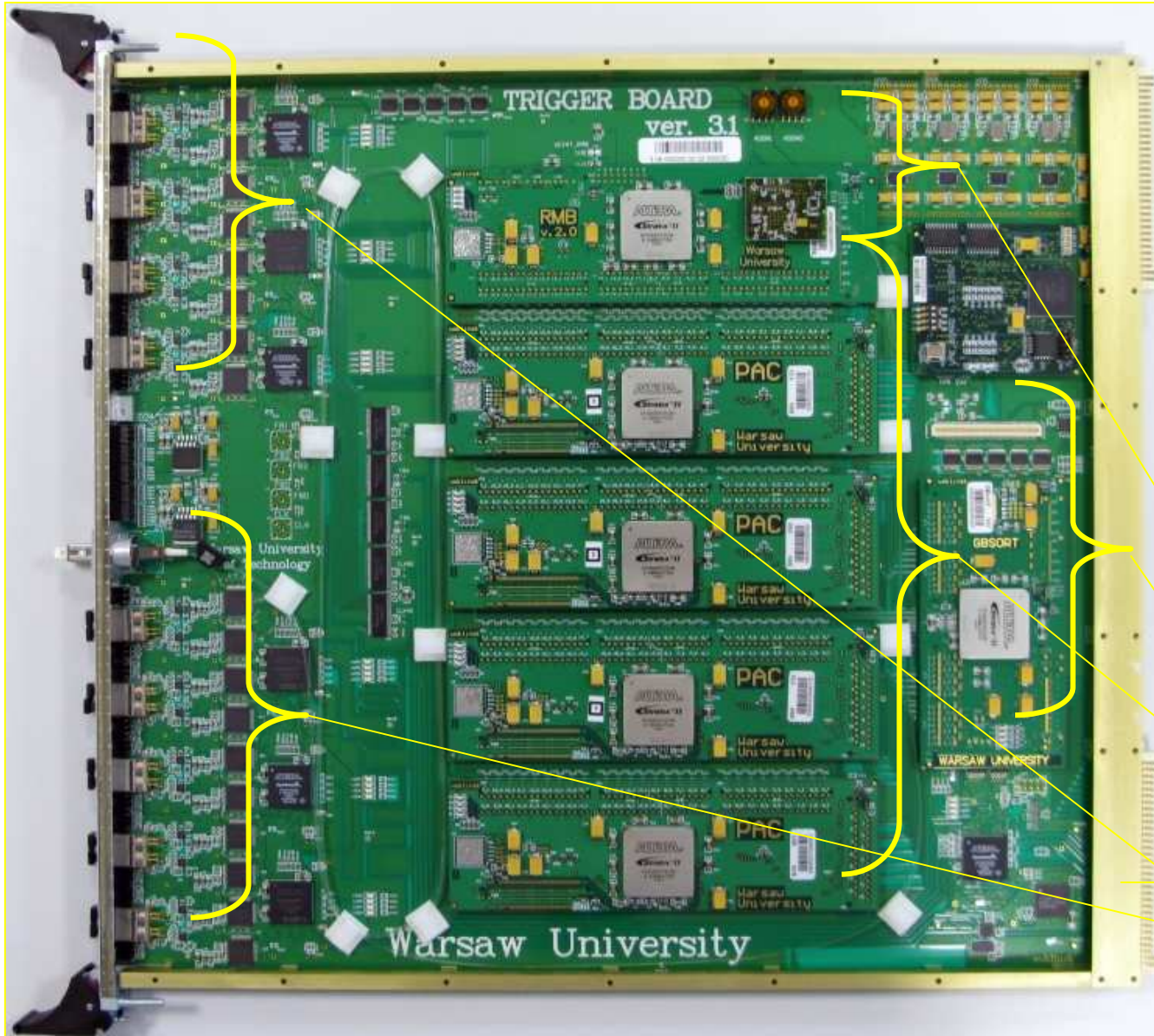
Plus pozostali członkowie warszawskiej grupy CMS:

K. Kierzkowski, W. Okliński, M. Cwiok, M. Górski, W. Dominik, P. Zalewski, M. Bluj, A. Kalinowski, M. Szleper, M. Kazana, P. Traczyk, K. Nawrocki, R. Gokieli, L. Białkowska, K. Doroba, T. Fruboes (doktorant), studenci (5)

RPC PAC Muon Trigger overview



Serce systemu: Trigger Board

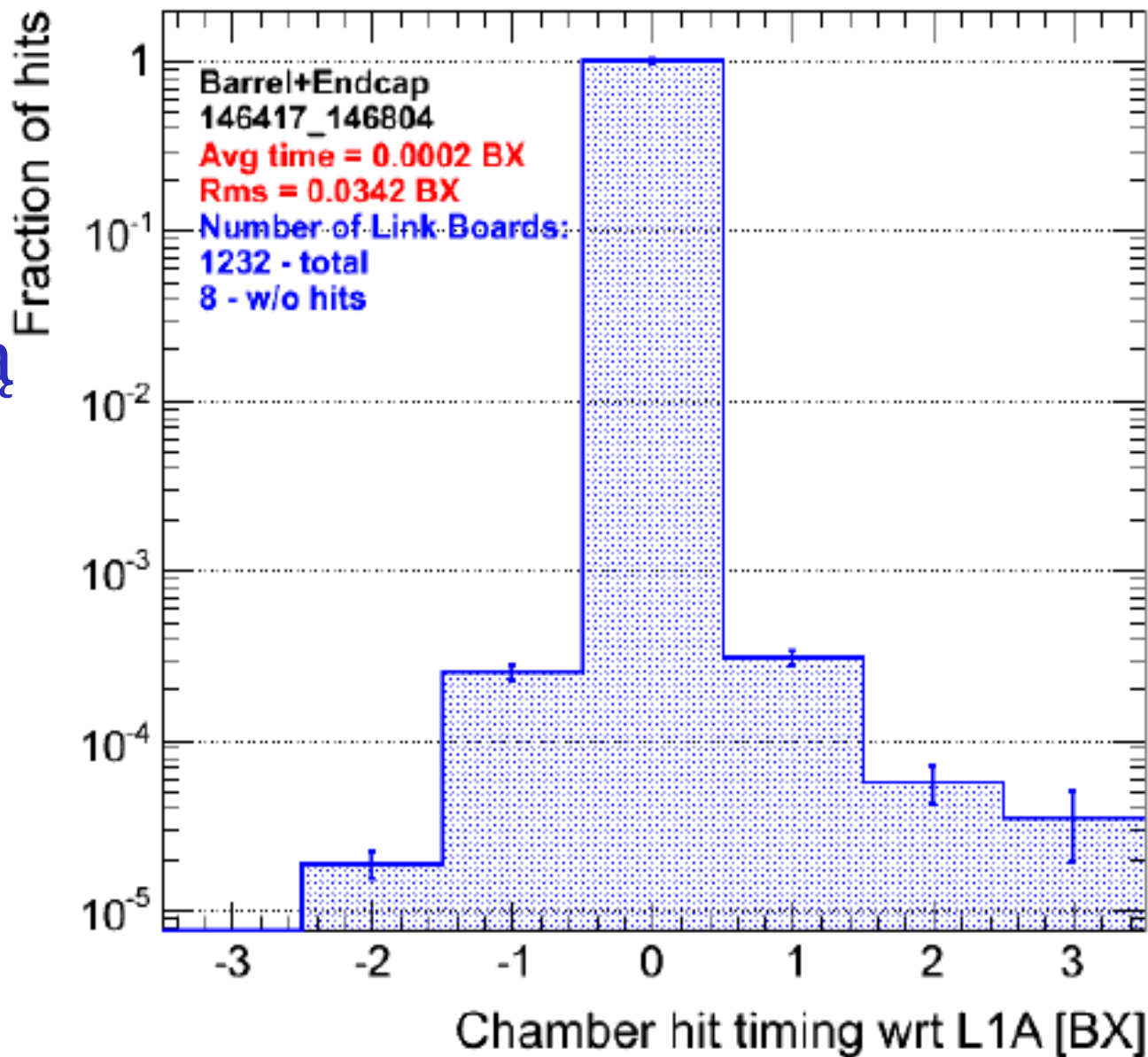


- RMB
- GB
- PAC (tryger)
- wyjście danych
- wejście danych

DANE DOŚWIADCZALNE 2010: Synchronizacja sygnałów na płycie triggera TB

CMS Preliminary $\sqrt{s} = 7\text{TeV}$

Równoległe sygnały z komór są serializowane przez LB, przesyłane ~ 90 m do TB gdzie są zrównoleglane.



Efektywność triggera RPC

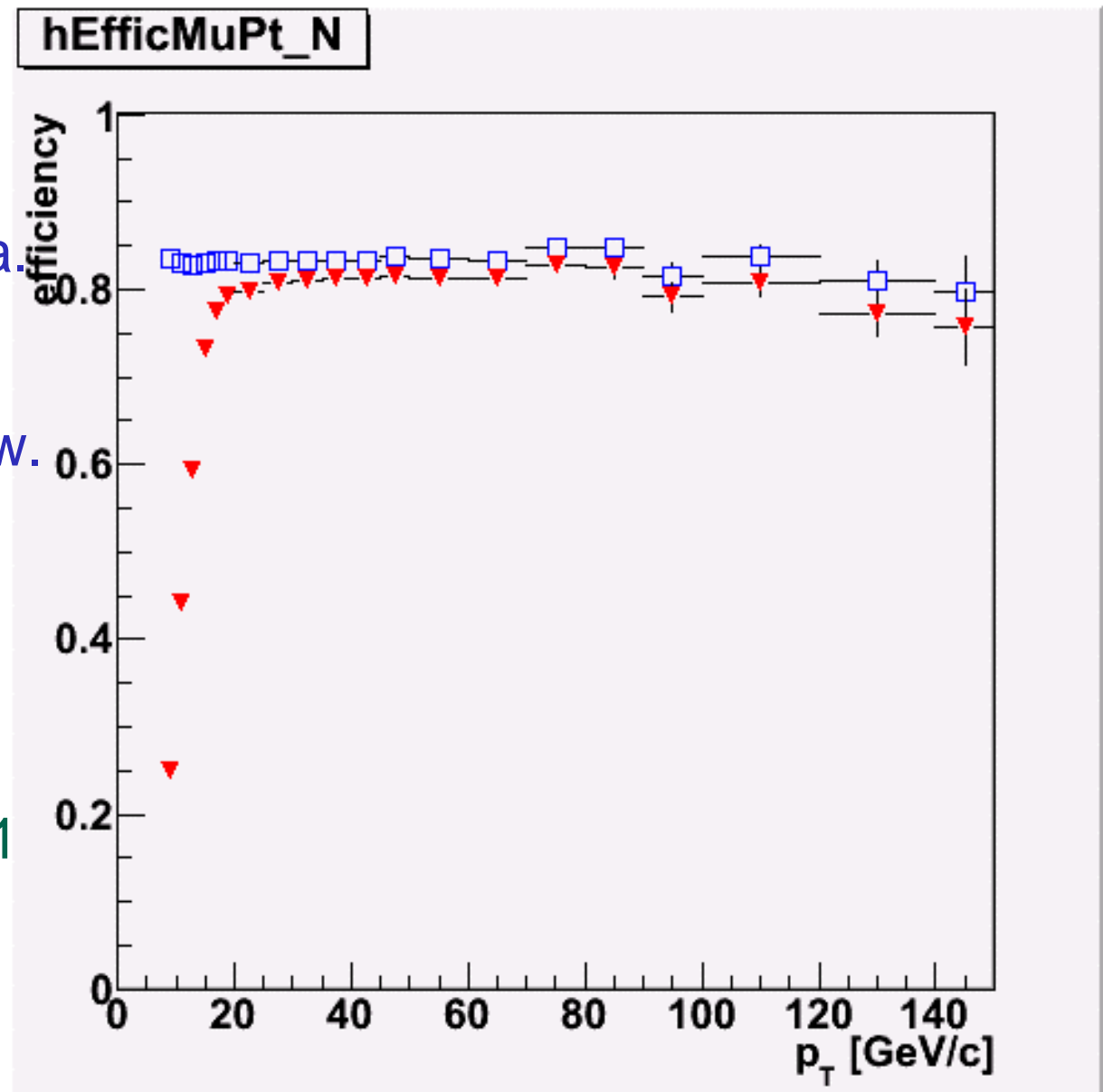
$$\text{Eff} = L/M$$

M – liczba mionów z wierzchołka oddziaływania.

L – liczba mionów, którym odpowiada któryś z patternów.

L – liczba mionów, którym odpowiadają patterny o $p_T > 15 \text{ GeV}$

$$L_{\text{int}} = 12 \text{ pb}^{-1}$$



Fizyczna analiza danych @50pb⁻¹

(Rediscovering the Standard Model)

Analiza danych w licznych zespołach tematycznych oddzielnie wewnątrz każdego eksperymentu.
Dyskusja wyników w trakcie zebrań i poprzez łącza internetowe.

- Wyniki Współpracy CMS ogłoszone w/na
- publikacje o krotkościach i p_T
 - ICHEP 2010 Paryż
 - publikacje o korelacjach w pp



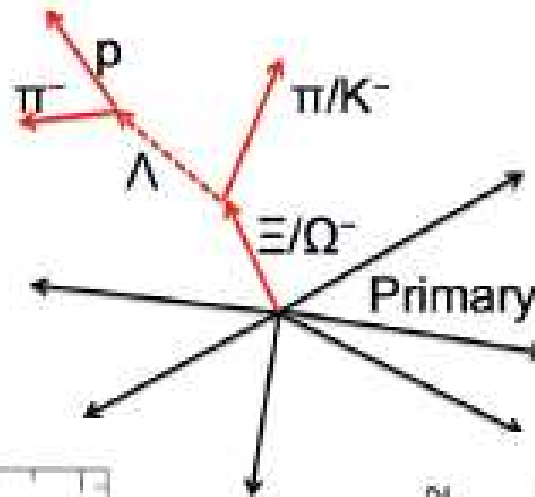
Resonances



ΛK^- or anti- ΛK^+

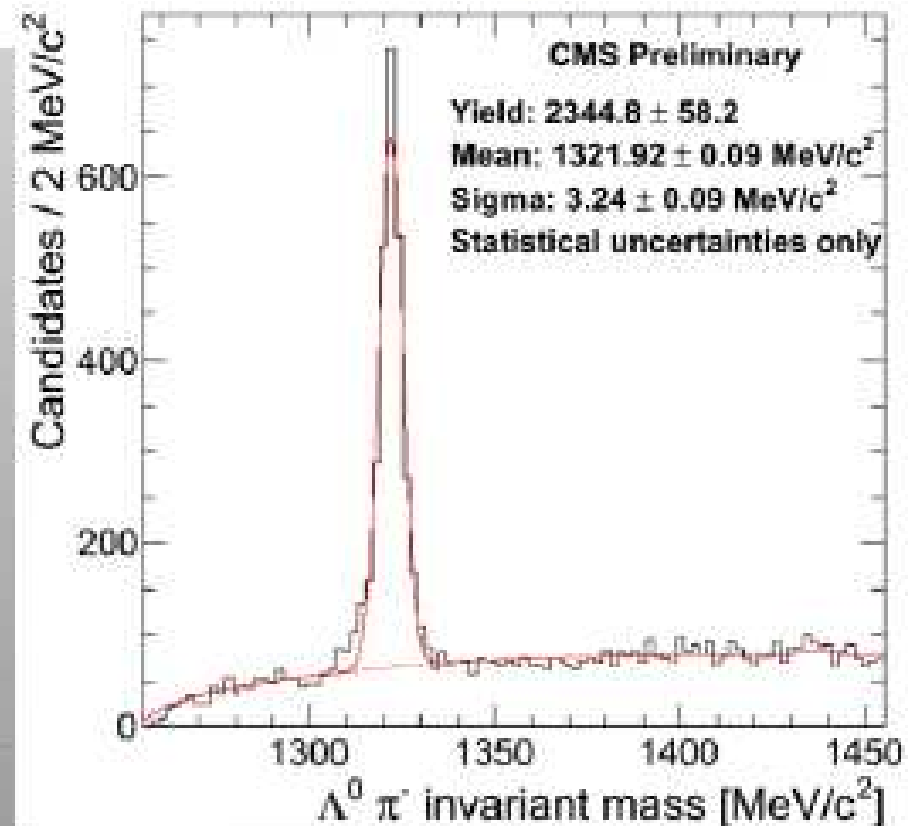
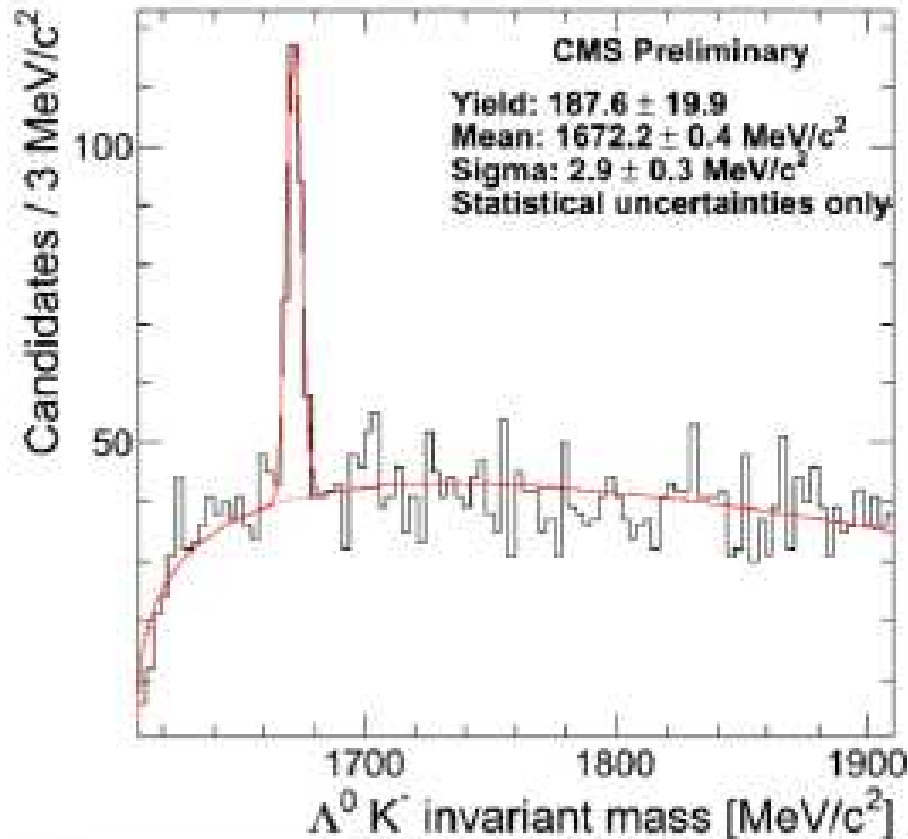
Invariant mass

- combinations fit to a common vertex

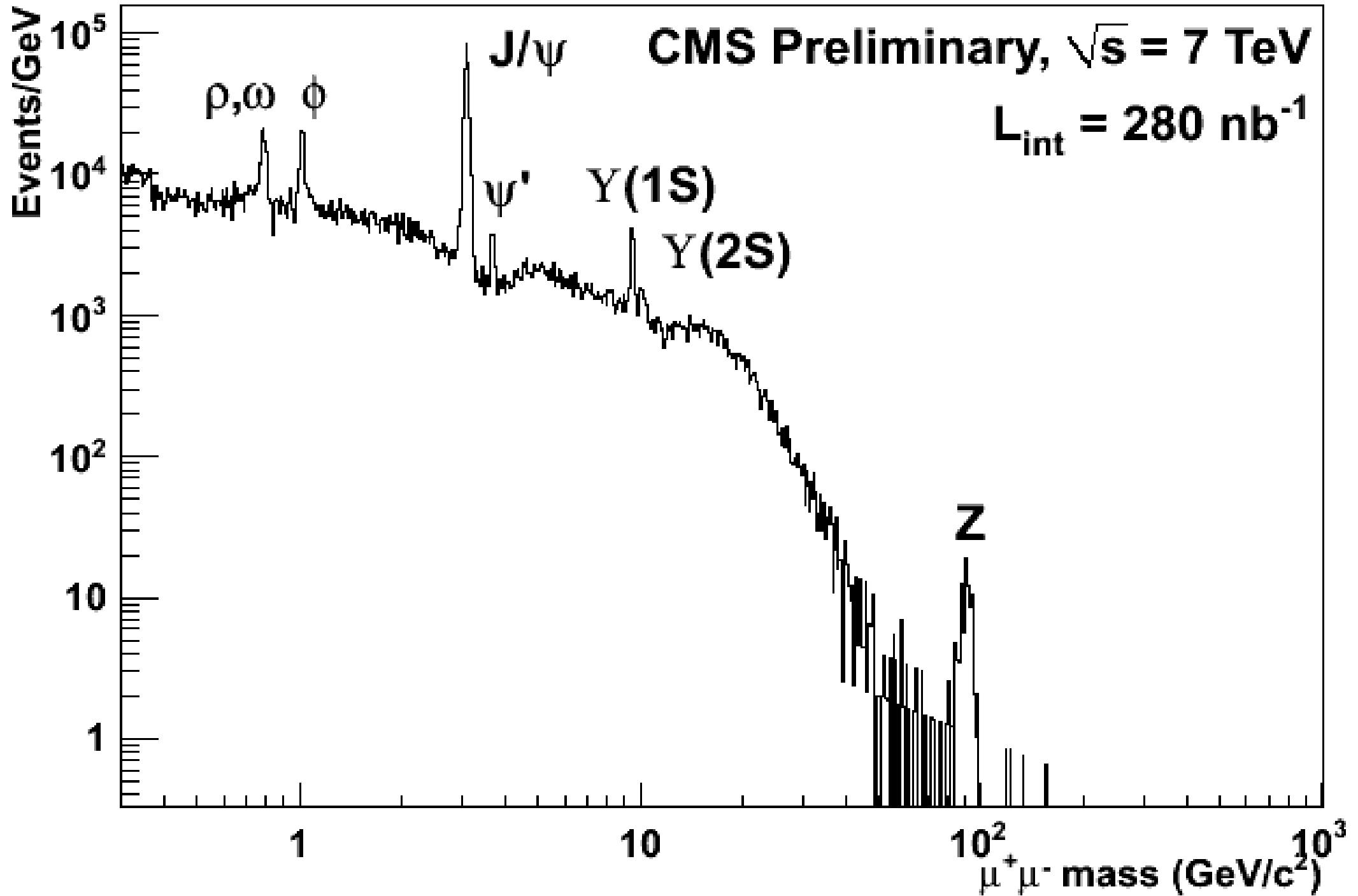


$\Lambda \pi$ Invariant mass

- tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)



Here is the Compact **Muon** Solenoid



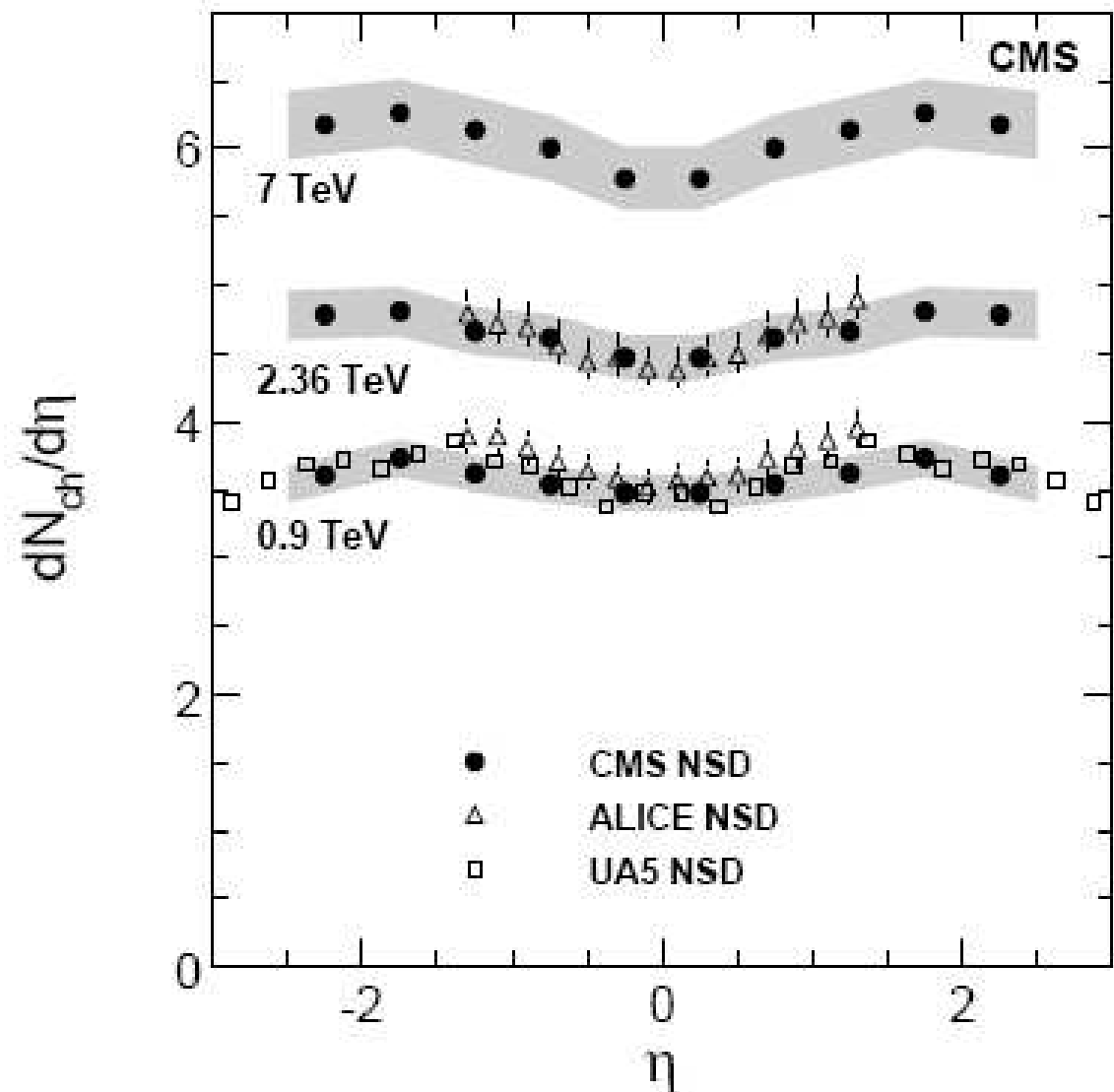
Rozkłady pseudorapidity i pędu poprzecznego

Phys.Rev.Lett 105:022002,2010

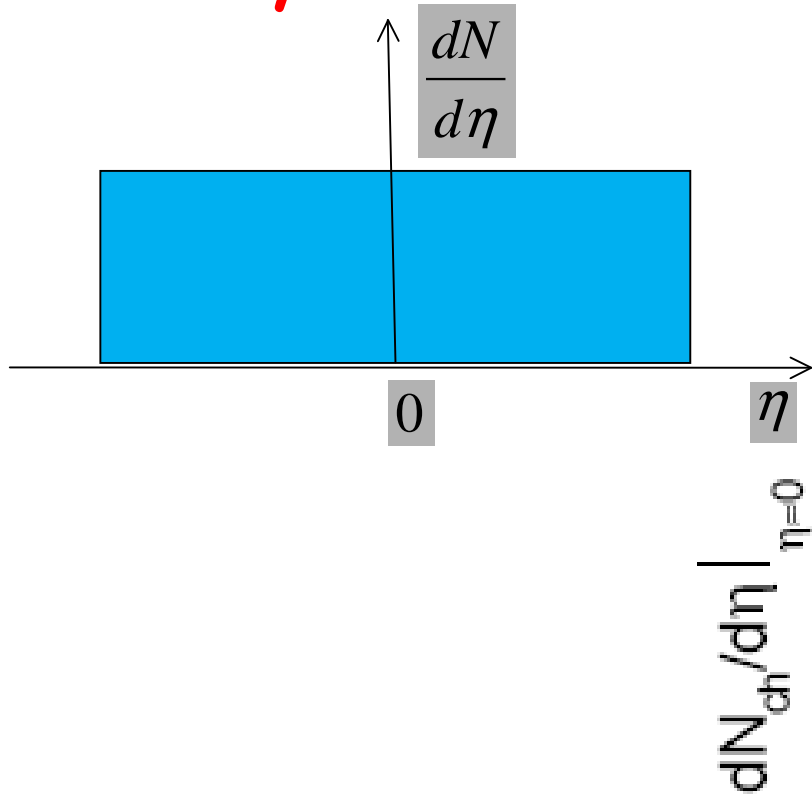
Non
Single
Diffractive events.

(SD,DD,ND)

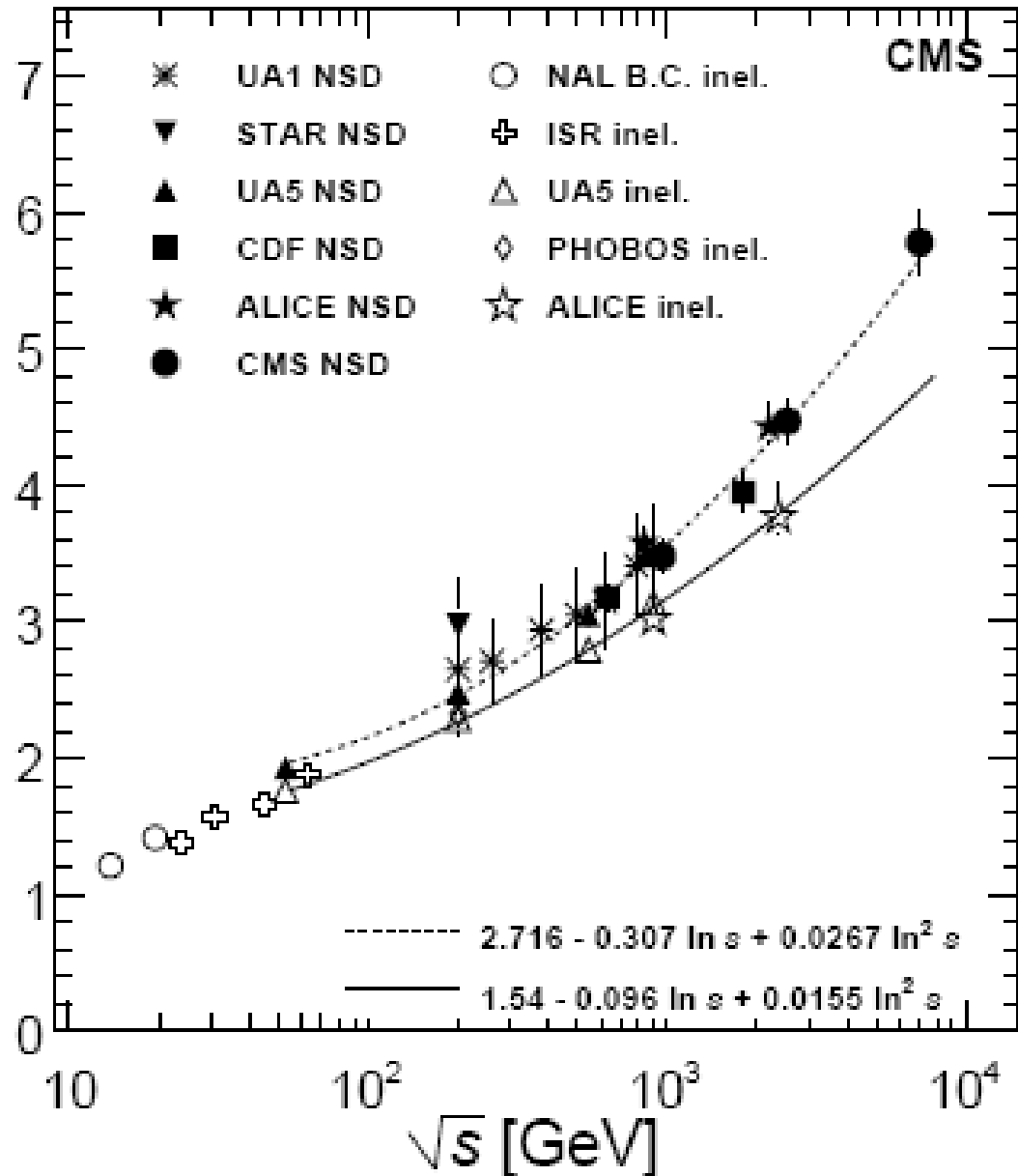
$$\eta = -\ln(\operatorname{tg}(\Theta/2))$$



Wysokość rozkładu w pseudorapidity

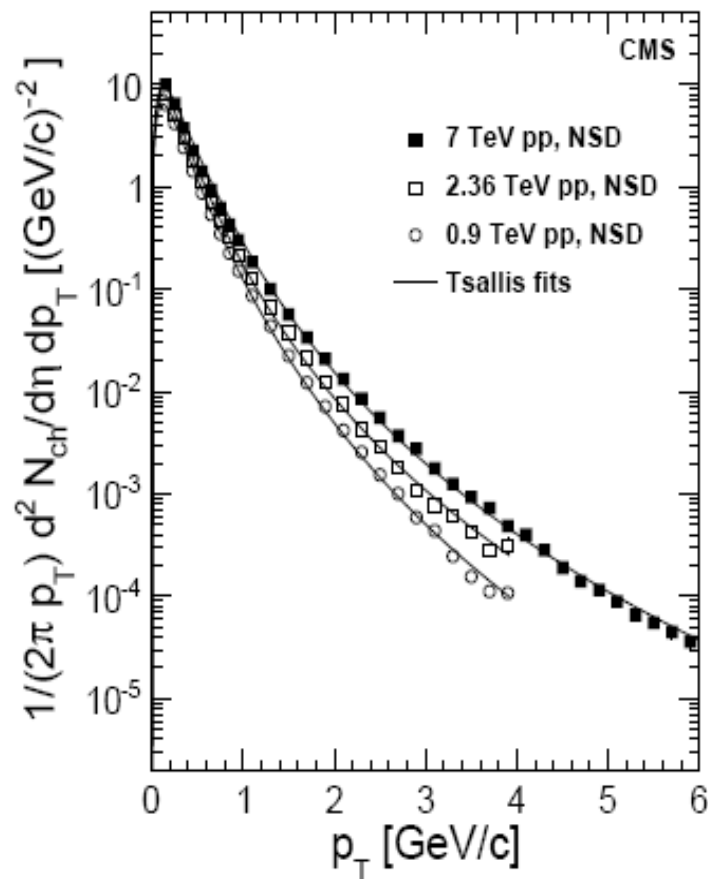


Oczekiwano (Pythia)
łagodniejszego
wzrostu plateau

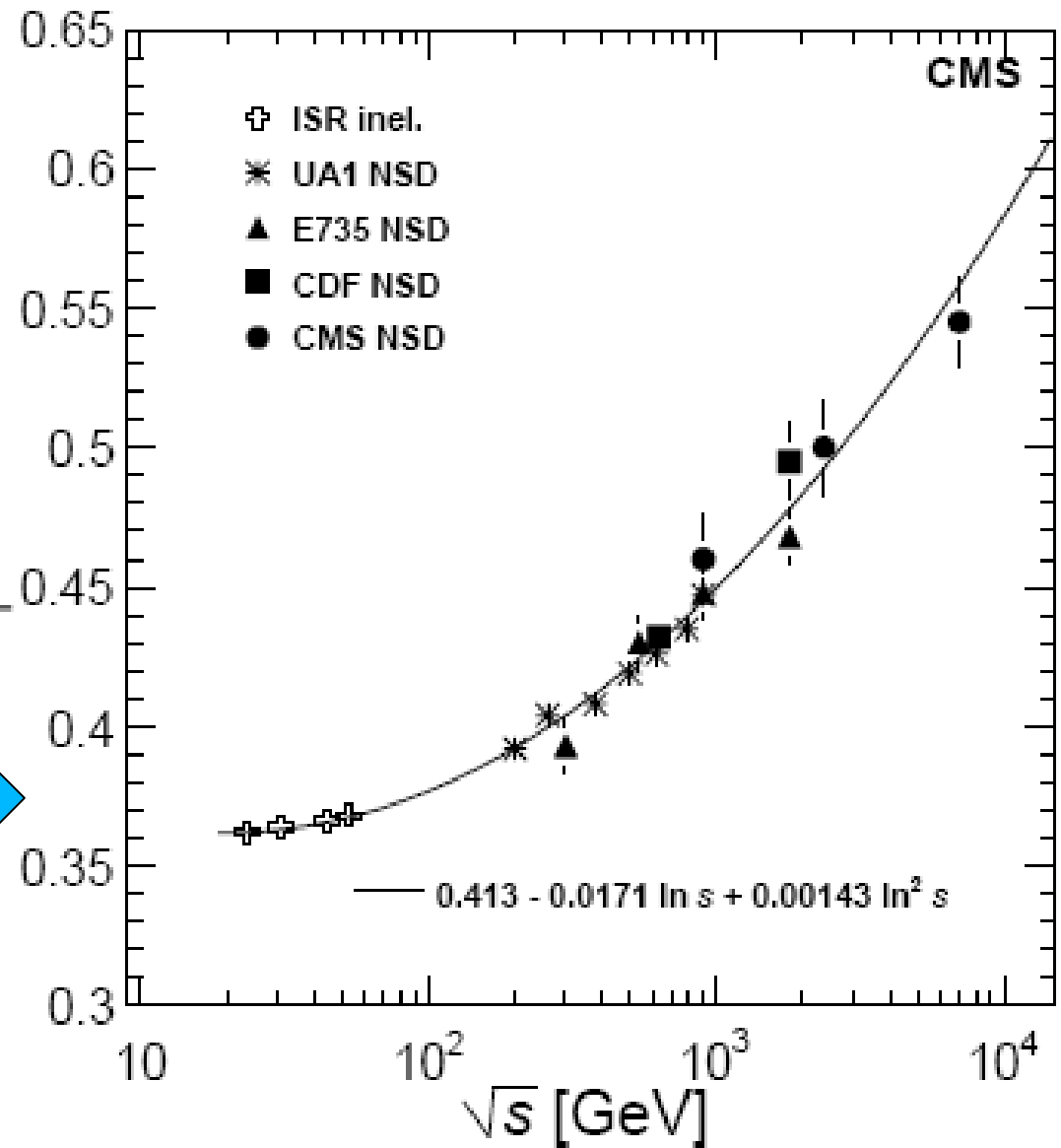


Średni pęd poprzeczny:

Rozkłady p_T



$\langle p_T \rangle$ [GeV/c]



Korelacje dwucząstkowe:

Korelacje Bose-Einstaina dla $\pi\pi$ - rozmiar źródła

Dane pp 0.9 TeV

Phys.Rev.Lett.105:032001,2010.

Table 2: Results of the fits to the double ratio $\mathcal{R}^{\text{comb}}$ for the combined reference samples, using the parameterization of Eq. (2) with the exponential form, as a function of the charged-particle multiplicity in the event, for 0.9 TeV data. Errors are statistical only, except for λ and r where statistical (first error) and systematic uncertainties (second error) are given.

Mult. range	p val. (%)	C	λ	r (fm)	δ (10^{-3} GeV $^{-1}$)
2–9	97	0.90 ± 0.01	$0.89 \pm 0.05 \pm 0.20$	$1.00 \pm 0.07 \pm 0.05$	72 ± 12
10–14	38	0.97 ± 0.01	$0.64 \pm 0.04 \pm 0.09$	$1.28 \pm 0.08 \pm 0.09$	18 ± 5
15–19	27	0.96 ± 0.01	$0.60 \pm 0.04 \pm 0.10$	$1.40 \pm 0.10 \pm 0.05$	28 ± 5
20–29	24	0.99 ± 0.01	$0.59 \pm 0.05 \pm 0.17$	$1.98 \pm 0.14 \pm 0.45$	13 ± 3
30–79	28	1.00 ± 0.01	$0.69 \pm 0.09 \pm 0.17$	$2.76 \pm 0.25 \pm 0.44$	10 ± 3

Observation of Long Range, Near Side Angular Correlations in Proton-Proton Collisions at the LHC

JHEP 1009:091,2010.

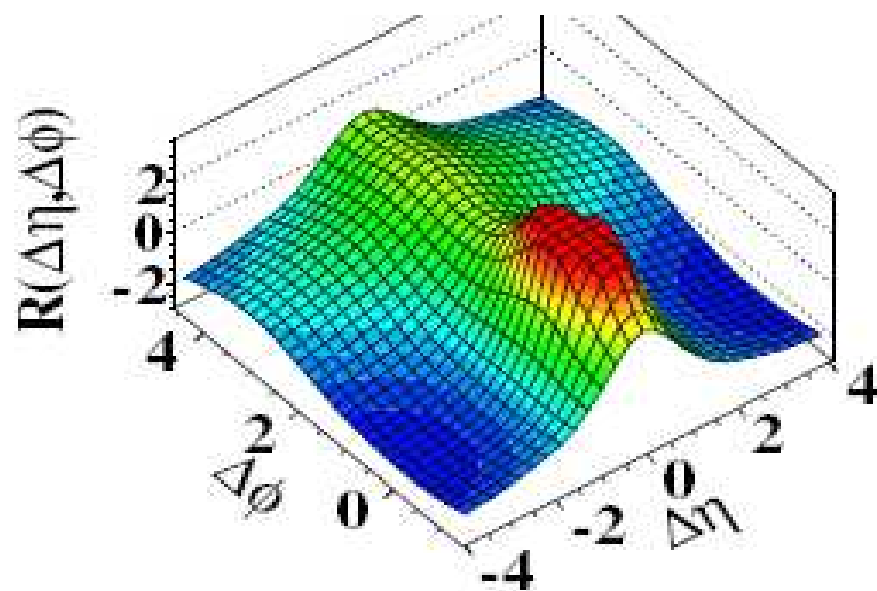
$$\Delta\eta = \eta_1 - \eta_2; \quad \Delta\phi = \phi_1 - \phi_2;$$

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

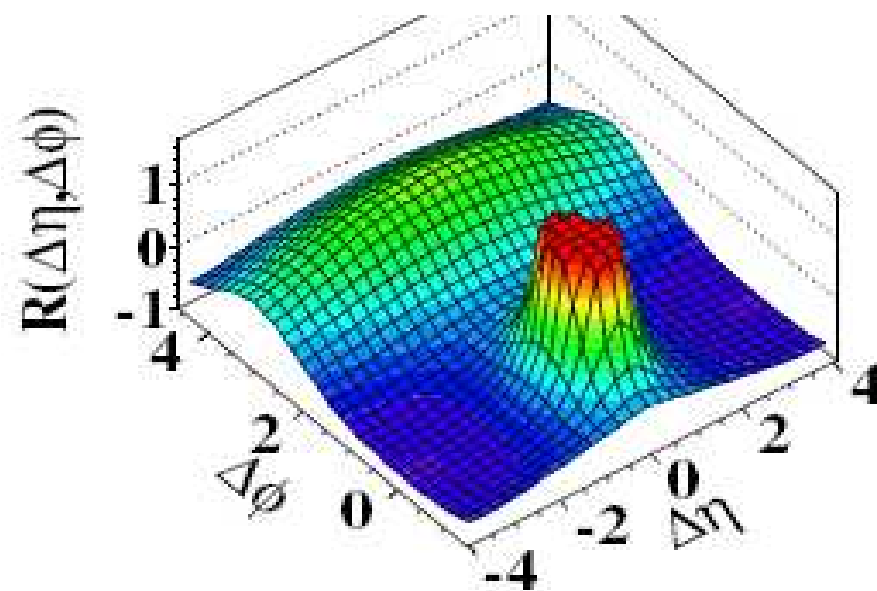
$$B_N(\Delta\eta, \Delta\phi) = \frac{1}{N(N-1)} \frac{d^2 N^{mixed}}{d\Delta\eta d\Delta\phi}$$

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

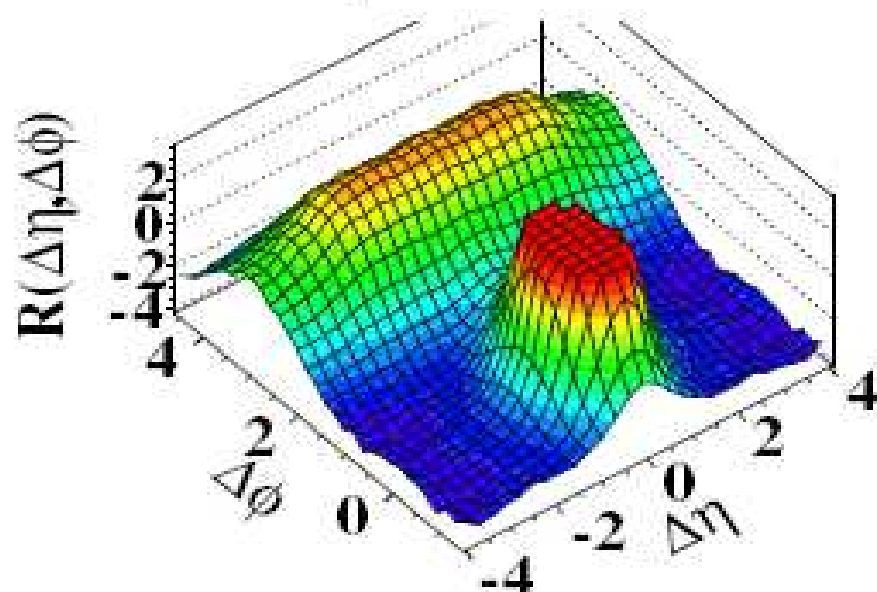
(a) CMS MinBias, $p_T > 0.1 \text{ GeV}/c$



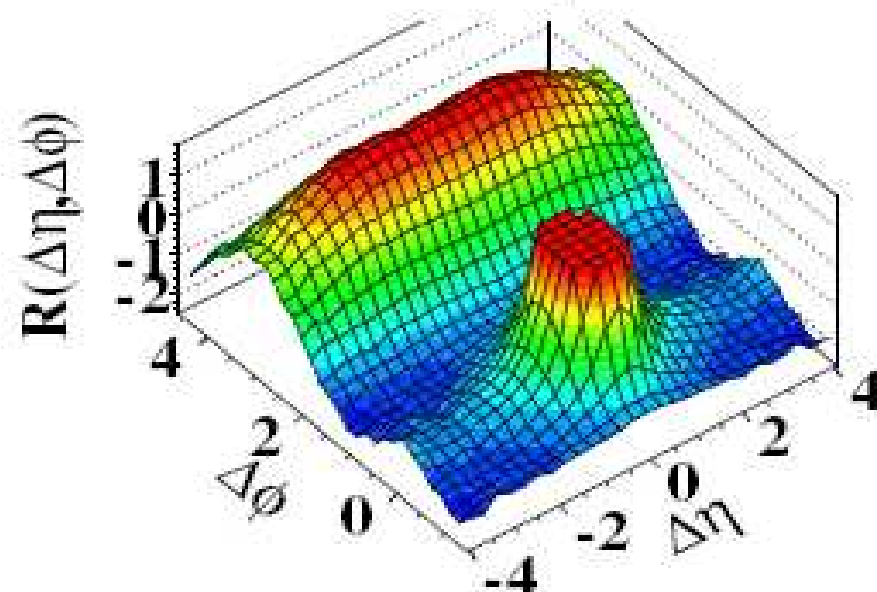
(b) CMS MinBias, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



(c) CMS $N \geq 110$, $p_T > 0.1 \text{ GeV}/c$



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

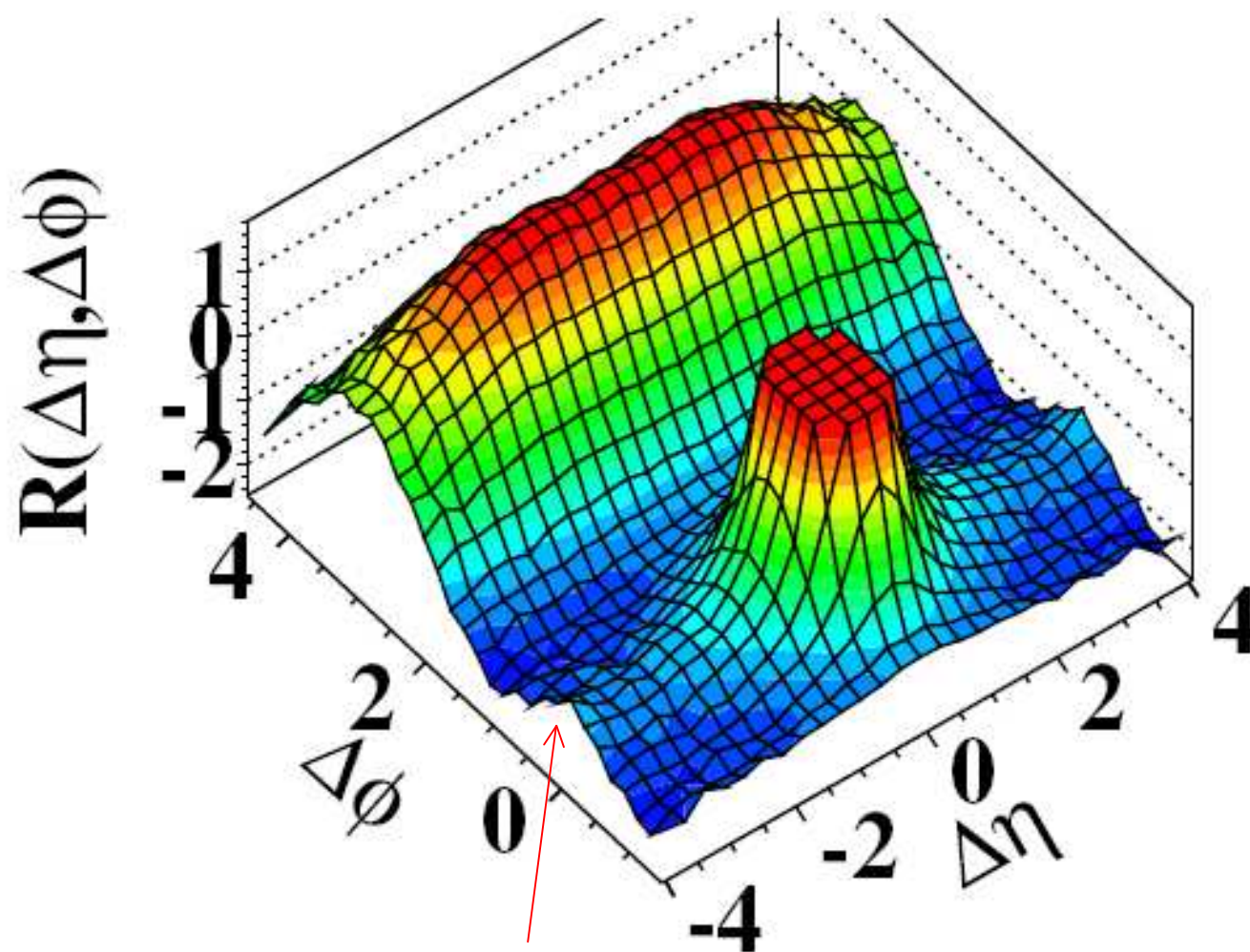


Specjalny trigger:

Level 1: MB oraz $ECAL+HCAL+HF > 60 \text{ GeV}$

HLT: $N_{\text{trk}} > 70$

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



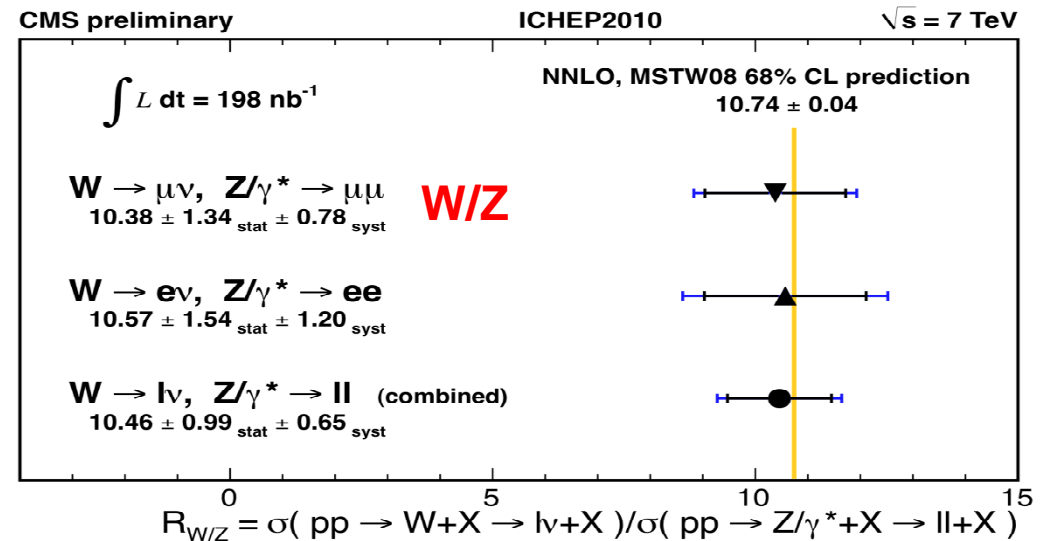
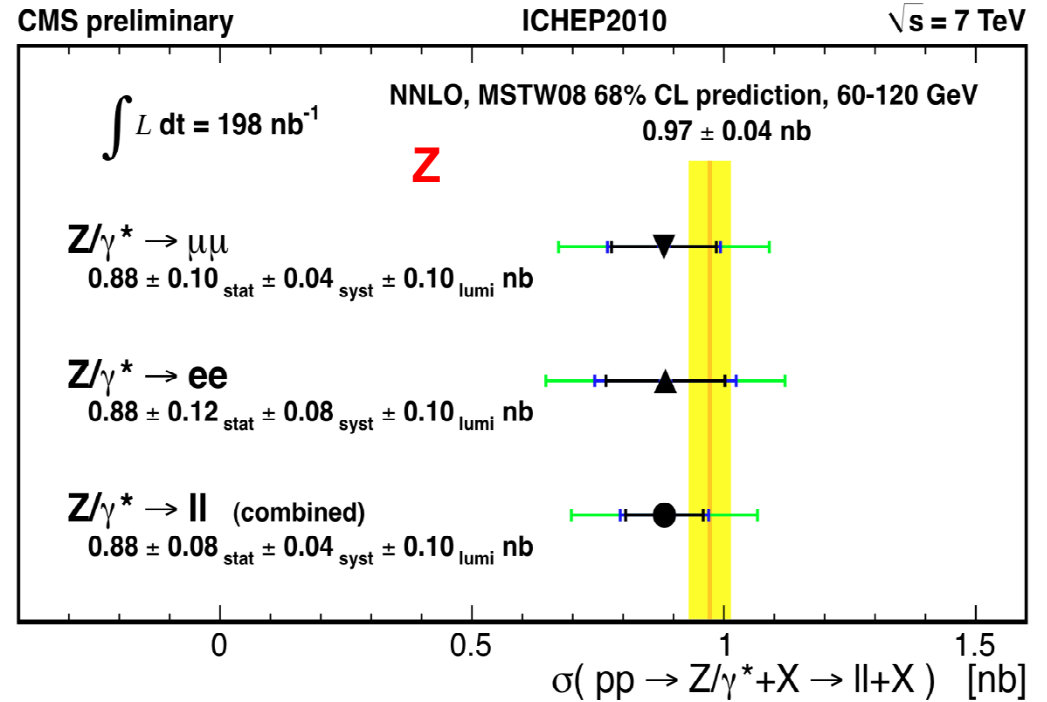
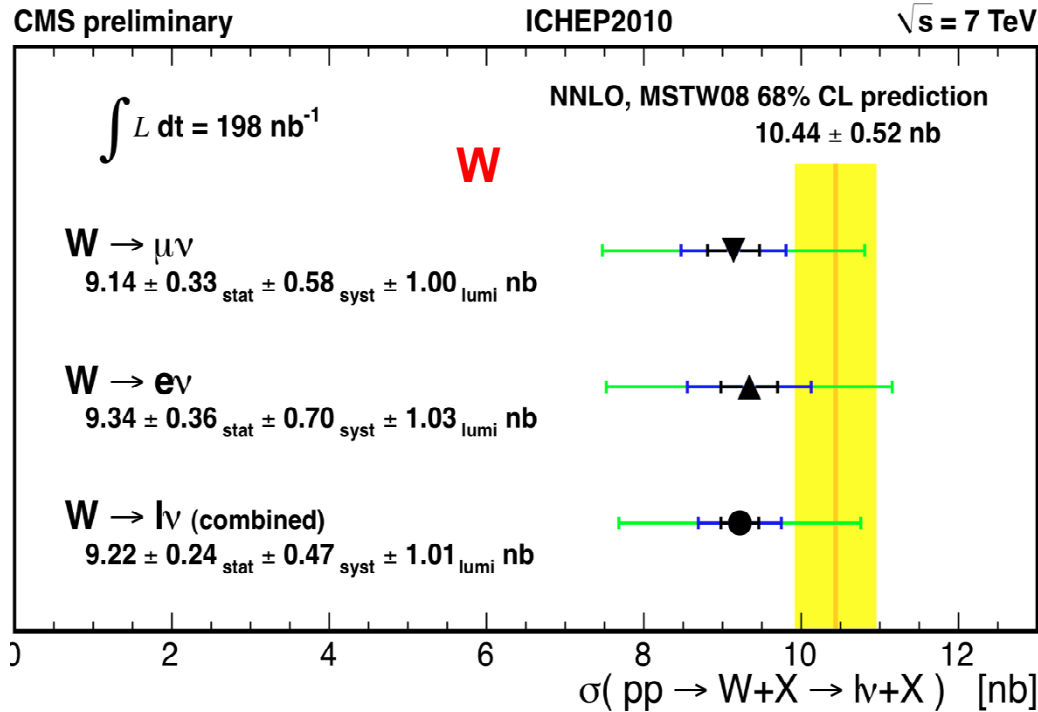
Inne opublikowane prace:

- First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at $\sqrt{s} = 7$ TeV.
- Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at $\sqrt{s} = 7$ TeV.
- Search for Dijet Resonances in 7 TeV pp Collisions at CMS.
-
-

W przygotowaniu:

- Charged particle multiplicities in pp interactions at $\sqrt{s} = 0.9, 2.36, 7$ TeV.
- Search for stopped gluinos in pp collisions at $\sqrt{s} = 7$ TeV.
- Meas. Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7$ TeV.

Results



Notice: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.

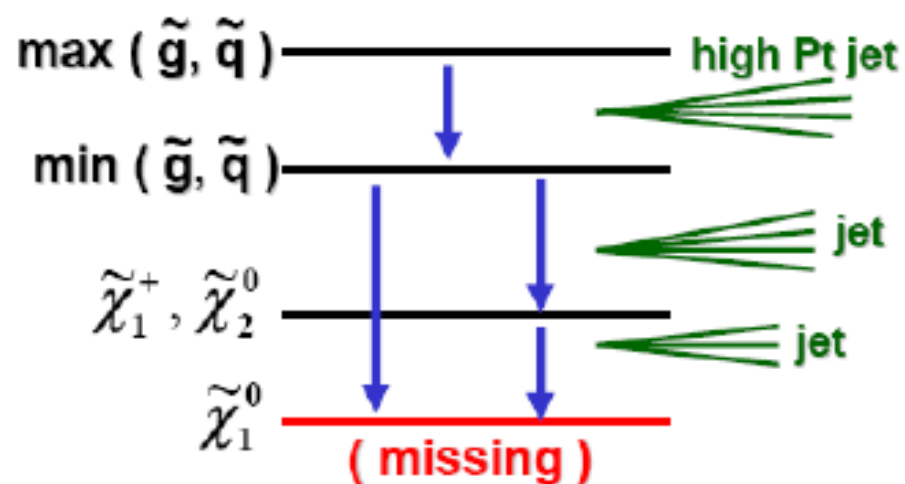
...ważne są dni, których jeszcze nie znamy....

Nowa Fizyka

- SUSY: mSUGRA, nMSSM, GMSB, AMSB \Leftrightarrow
- MSSM Higgs .vs. MS Higgs
- Wyższe Wymiary: RS, ADD, UED
- Extra Gauge Bosons: Z' , W'
- Quirks - makroskopowe struny
- Fizyka z Hidden Valley
- Antycząstki
- Czarne dziury
- (...) nowe idee
- MET+dżety
- n leptons (+dżety+MET)
- Di-leptons
- Długożyciowe cząstki
- Niecelujące cząstki
- Podwójnie naładowane
- Zmieniające ładunek
- (...) inne "funny" sygnatury

(Wg Małgorzaty Kazany)

Produkcja przypadków SUSY w LHC:



ZŁOTY KANAŁ

Podstawowe cięcia dla SUSY:

$MET > 200 \text{ GeV}$

Jet No ($p_T > 30 \text{ GeV}, |\eta| < 3$) ≥ 3

1st jet $|\eta| < 1.7$

CMS

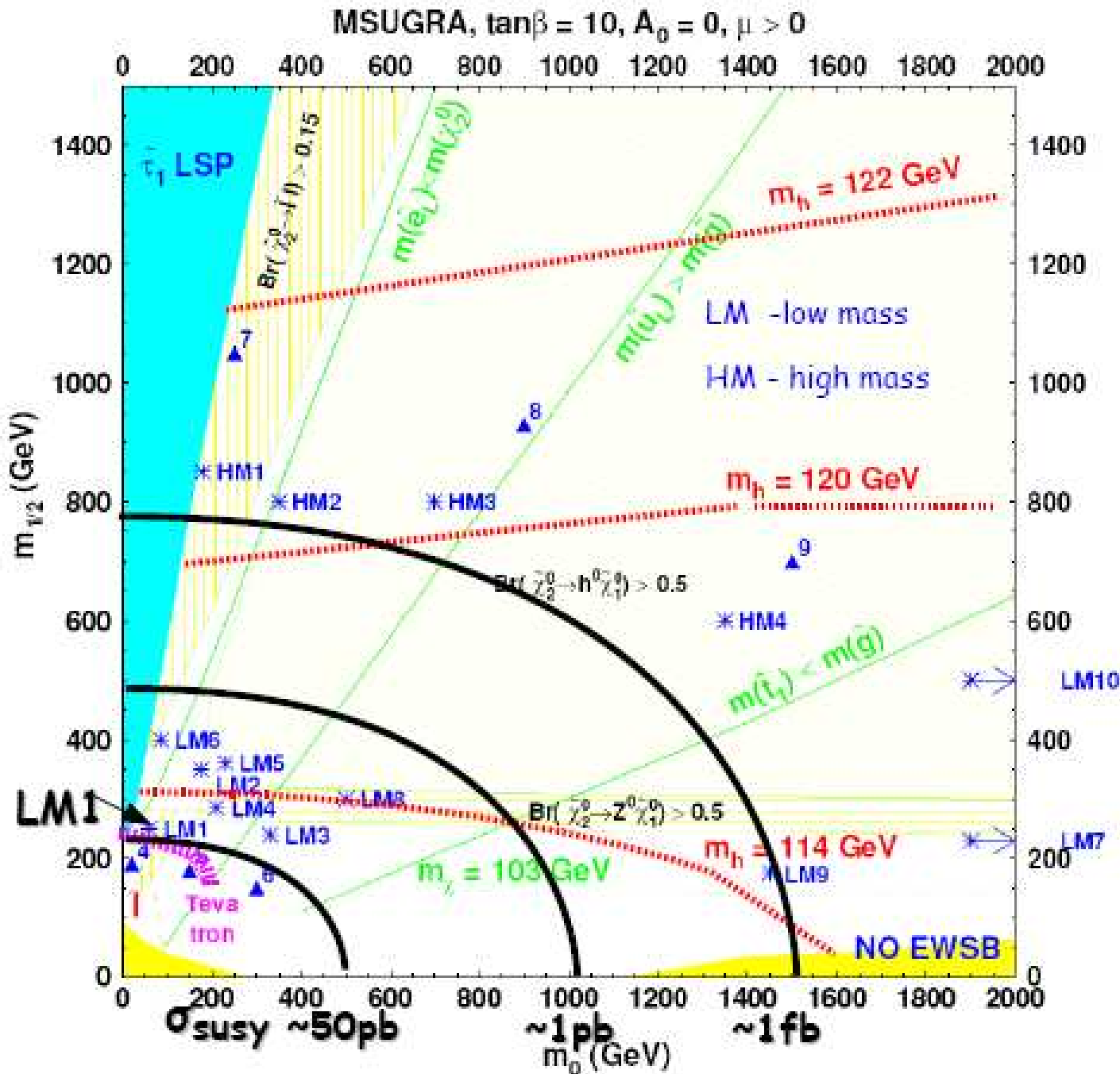
SYGNATURA:

duży MET + multi-dżety

PODSTAWOWE TŁO:

QCD, $t\bar{t}$ /W/Z-QCD produkcja stowarzyszona z dżetami

Przestrzeń mSUGRA



$[m_0, m_{1/2}, A_0, \tan\beta, \text{sign}\mu]$
LM1 [60, 250, 0, 10, +1]

$\sigma = 49\text{pb}$

$m(\tilde{g}) \geq m(\tilde{q})$

$\tilde{g} \rightarrow \tilde{q}_{L,R} + q$

$\tilde{q}_R \rightarrow q\tilde{\chi}_1^0, (100\%)$

$\tilde{q}_L \rightarrow q + \tilde{\chi}_2^0, (30\%)$

$\tilde{q}_L \rightarrow q + \tilde{\chi}_1^+, (70\%)$

$\tilde{\chi}_2^0 \rightarrow \bar{\ell}_R \ell, (11.2\%)$

$\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau, (46\%)$

$\tilde{\chi}_1^+ \rightarrow \tilde{\nu}_L \ell, (36\%)$

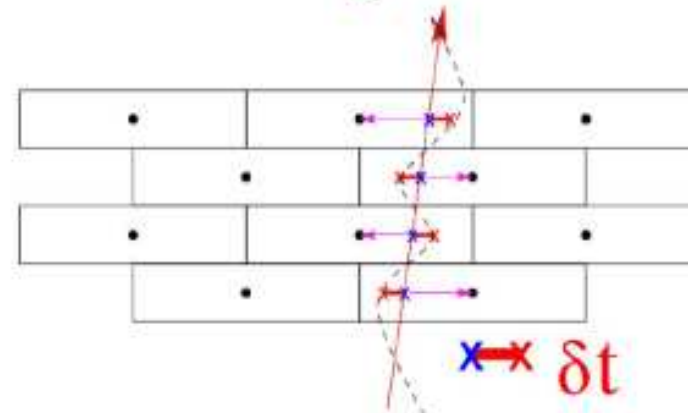
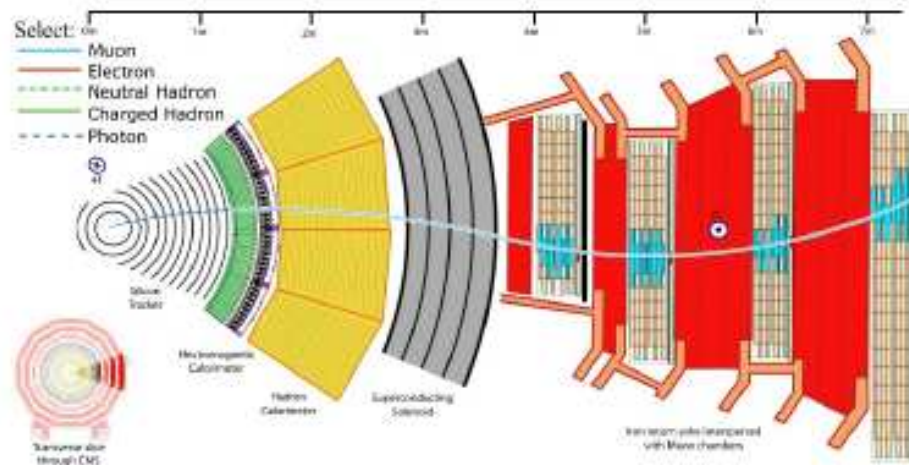
Heavy Stable Charged Particle - HSCP



CMS TOF measurement



Use of the **Drift Tubes** of the Muon System for the **time of flight** measurement

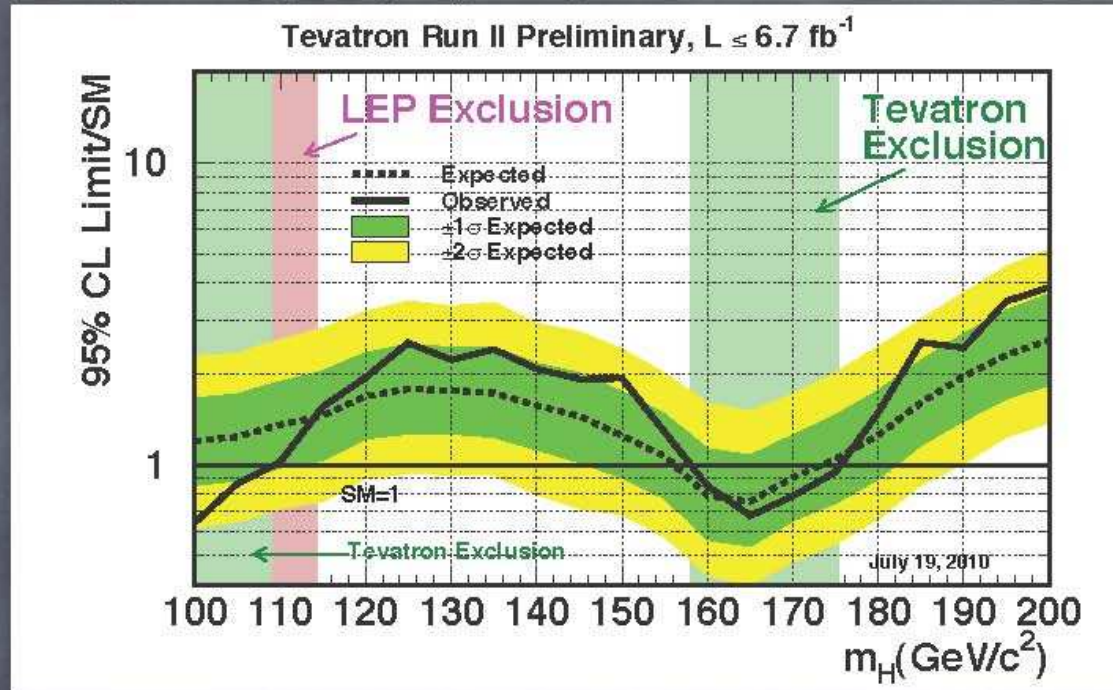


$$\frac{1}{\beta} = 1 + \frac{\delta_x}{L} \frac{c}{v_{\text{drift}}}$$

- DT are synchronized for the **c-speed ($\beta=1$) particle** produced in the interaction point to have an aligned pattern of hits
- A **slow $\beta < 1$ particle** produce a zigzag pattern with offsets which are a measure of its delay

Approaching the moment of truth

Conclusions



- ④ Higgs has no place to hide !
 - ▶ Squeezing allowed mass from both sides
 - 95% CL Exclusion $158 < m_H < 175 \text{ GeV}$ (about expected)
 - Limit $1.5 \cdot \text{SM}$ @ 115 GeV
- ④ BSM searches : consistent with SM
 - ▶ 2 sigma is largest discrepancy in CDF MSSM $H \rightarrow bb$ (so far)

W zależności od jego masy, bozon Higgsa poszukiwany będzie w różnych kanałach

$H \rightarrow \gamma\gamma$	$m_H \approx 115 - 150 \text{ GeV}$
$H \rightarrow \tau\tau$	115 - 145
$H \rightarrow bb$	115 - 125
$H \rightarrow WW \rightarrow l\nu jj$	130 - 200
$H \rightarrow WW \rightarrow 2l2\nu + 0/1j$	120 - 600
$H \rightarrow ZZ \rightarrow 4l$	120 - 600
$H \rightarrow ZZ \rightarrow 2l2\nu$	200 - 600
$H \rightarrow ZZ \rightarrow 2l2b$	300 - 600

Oczekiwania dla 7 TeV, 1fb⁻¹

Wykluczenie Higgsa w Modelu Standardowym
(jeśli SM Higgs nie istnieje)

CMS : $m_H = 135-450 \text{ GeV}$

"ATLAS+CMS" (2 x CMS): $m_H = 120-525 \text{ GeV}$

Jeśli zaś SM Higgs istnieje

Odkrycie Higgsa w Modelu Standardowym

"ATLAS+CMS" (2 x CMS) projected 3 σ
sensitivity: $m_H = 135-475 \text{ GeV}$

Analizy prowadzone w Warszawie:

- Poszukiwanie cząstek supersymetrycznych (HSCP,...)
- Poszukiwanie bozonu Higgsa: $H \rightarrow \tau\tau$
(od $Z \rightarrow \mu\mu$, do $Z \rightarrow \tau\tau$ i dalej do $H \rightarrow \tau\tau$)
- Wyznaczanie masy bozonu W (Test EW)
- Rozpraszanie WW (...gdyby nie znaleziono bozonu Higgsa (!?))
- ...

LHC Page1

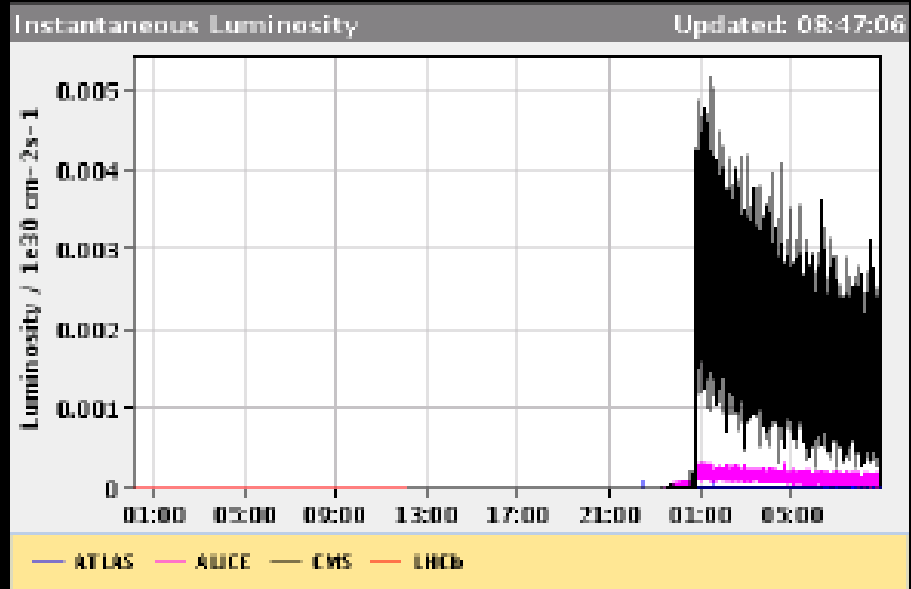
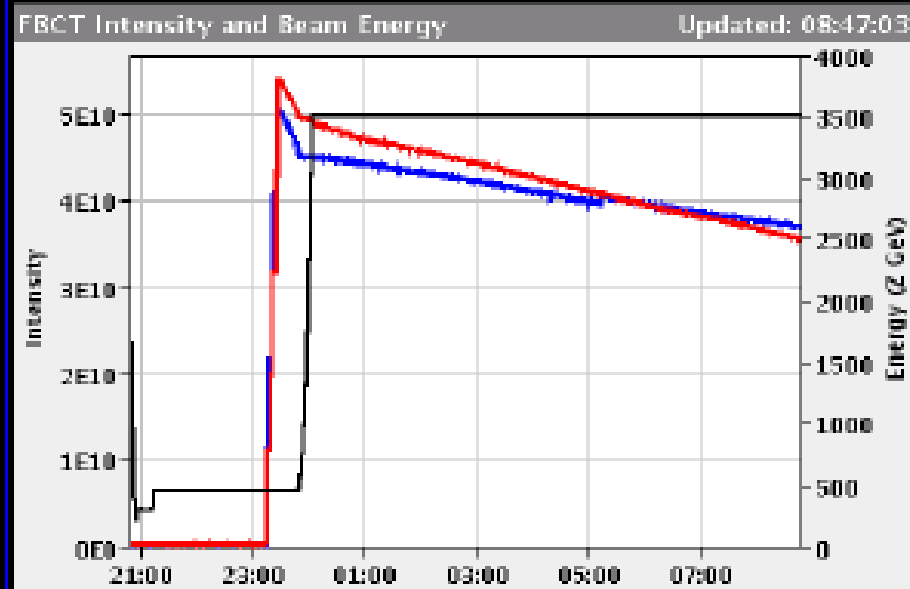
Fill: 1483

E: 3500 Z GeV

09-11-2010 08:50:44

ION PHYSICS: STABLE BEAMS

Energy: **3500 Z GeV** I(B1): **3.85e+10** I(B2): **3.57e+10**



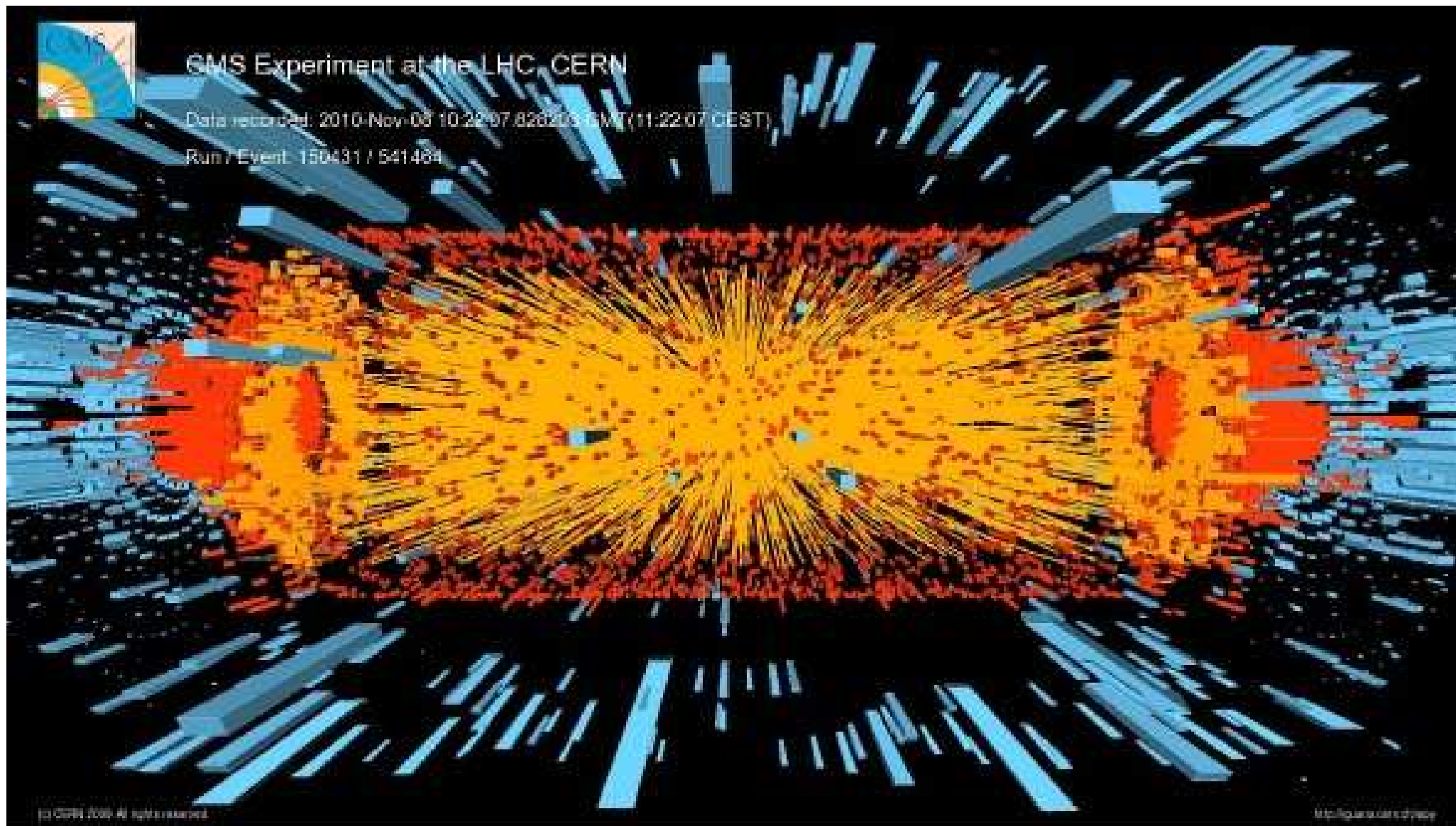
Comments 09-11-2010 01:01:51 :

*** STABLE BEAMS ***

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

Zderzenie PbPb @ 7 TeV*Z

8 Listopad 2010



Plany (jeszcze nie zatwierdzone)*

- W latach 2011 i 2012 LHC będzie działać @ $\sqrt{s}=8$ TeV
- celem będzie zebranie minimum $5 \text{ fb}^{-1}/\text{exp.}$
- ambitnym celem będzie zebranie $10 \text{ fb}^{-1}/\text{exp.}$

*Decyzja po spotkaniu w Chamonix
-styczeń 2011

Dziękuję !!!