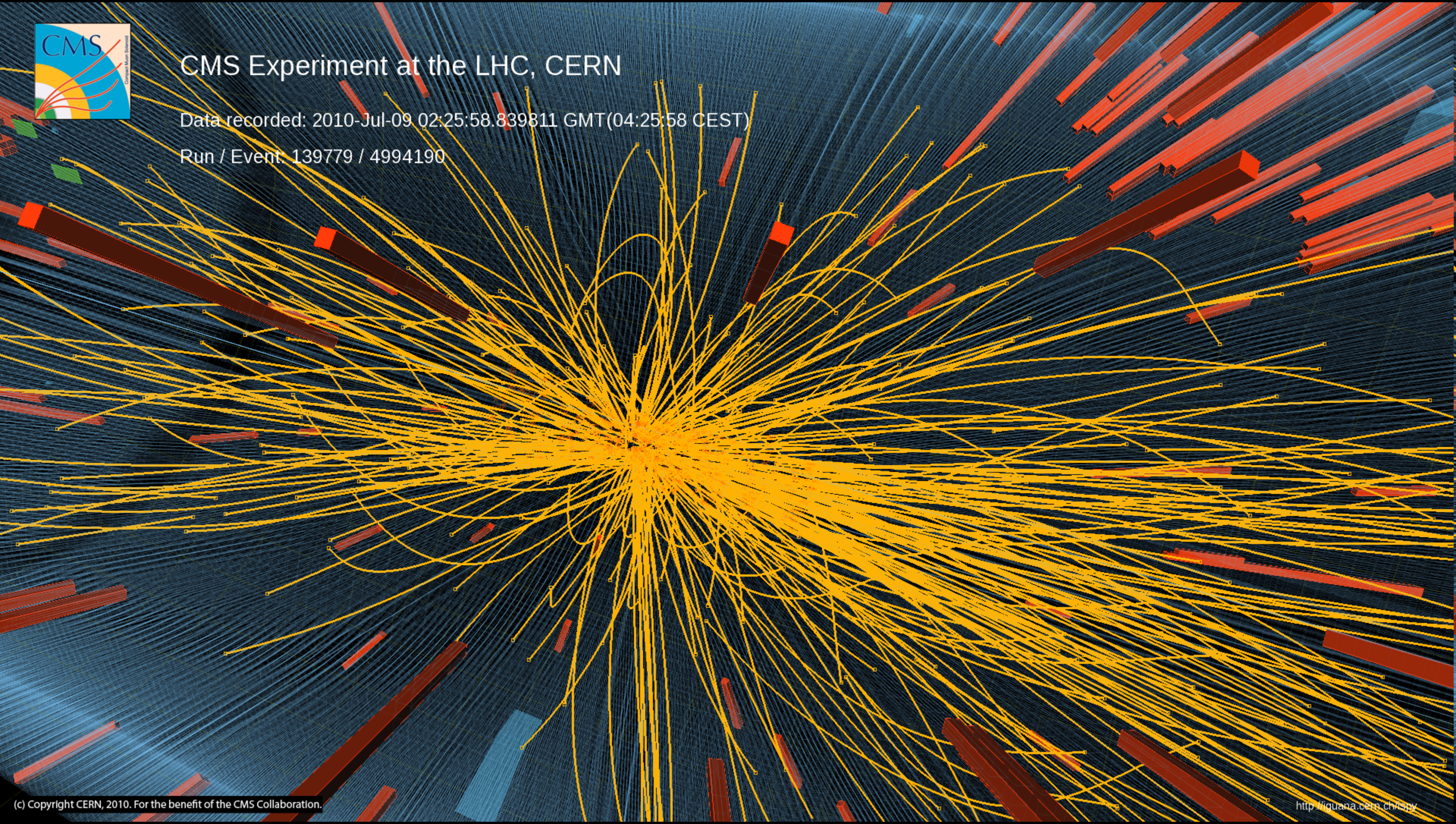
First CMS Results

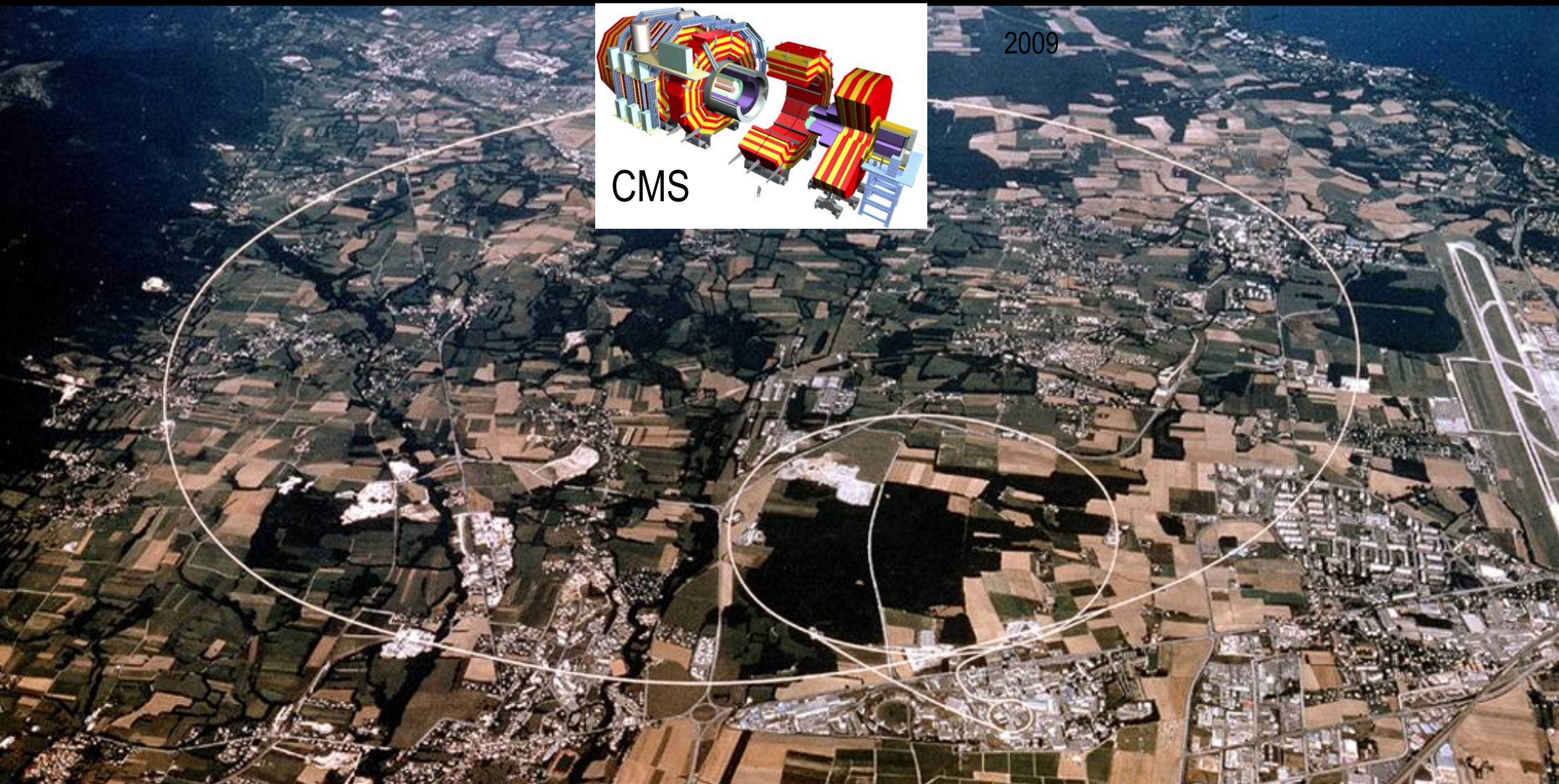


Workshop on Hadron-Hadron & Cosmic-Ray Interactions at multi-TeV Energies

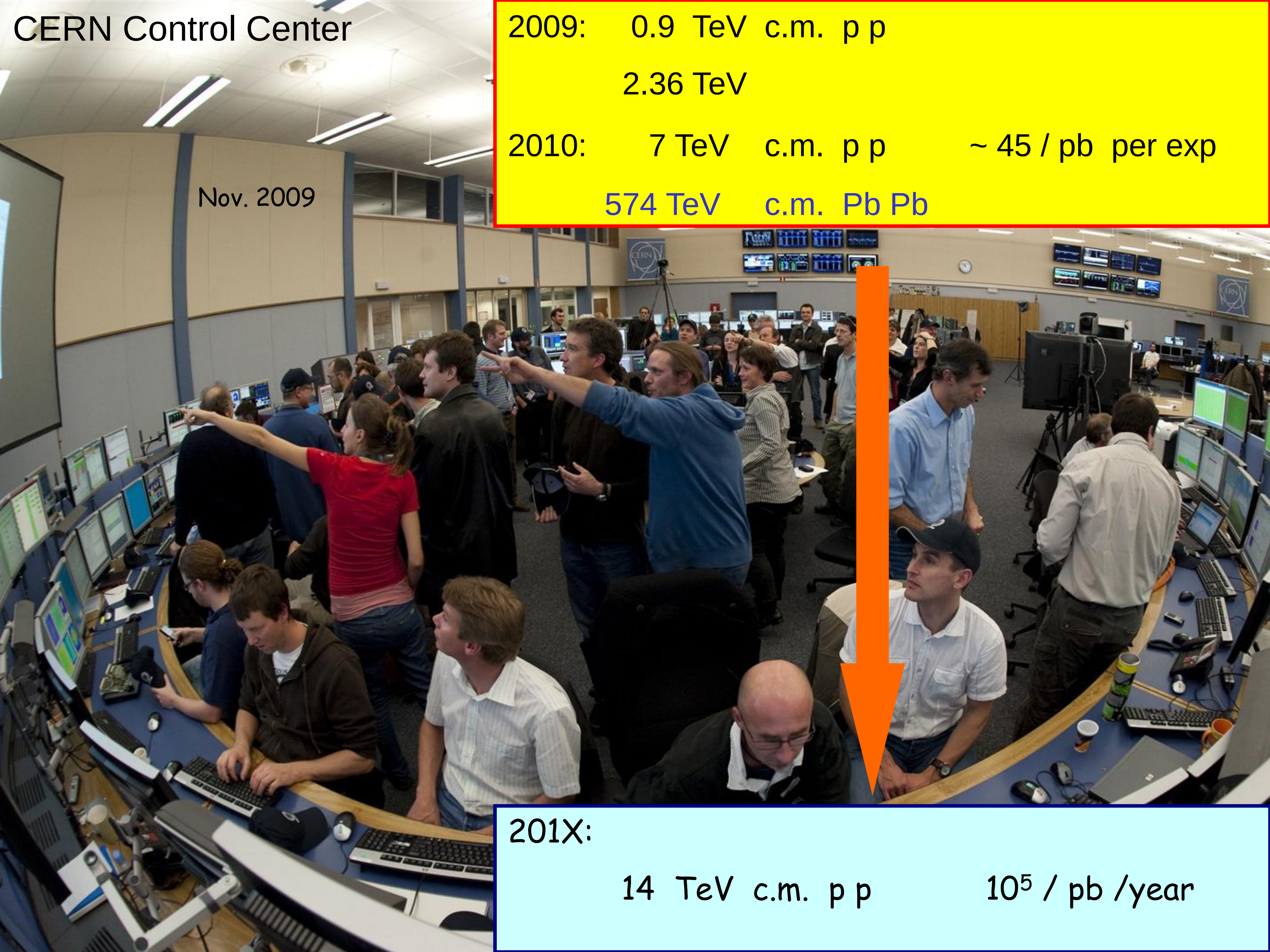
ECT* - Trento, Nov 29th - Dec 3rd, 2010

Thomas Hebbeker, RWTH Aachen University

- LHC and CMS
- Rediscovery of the Standard Model particles
- Highlights from 7 TeV pp run
- Hadron physics results



CERN Control Center



2009: 0.9 TeV c.m. p p

2.36 TeV

2010: 7 TeV c.m. p p ~ 45 / pb per exp

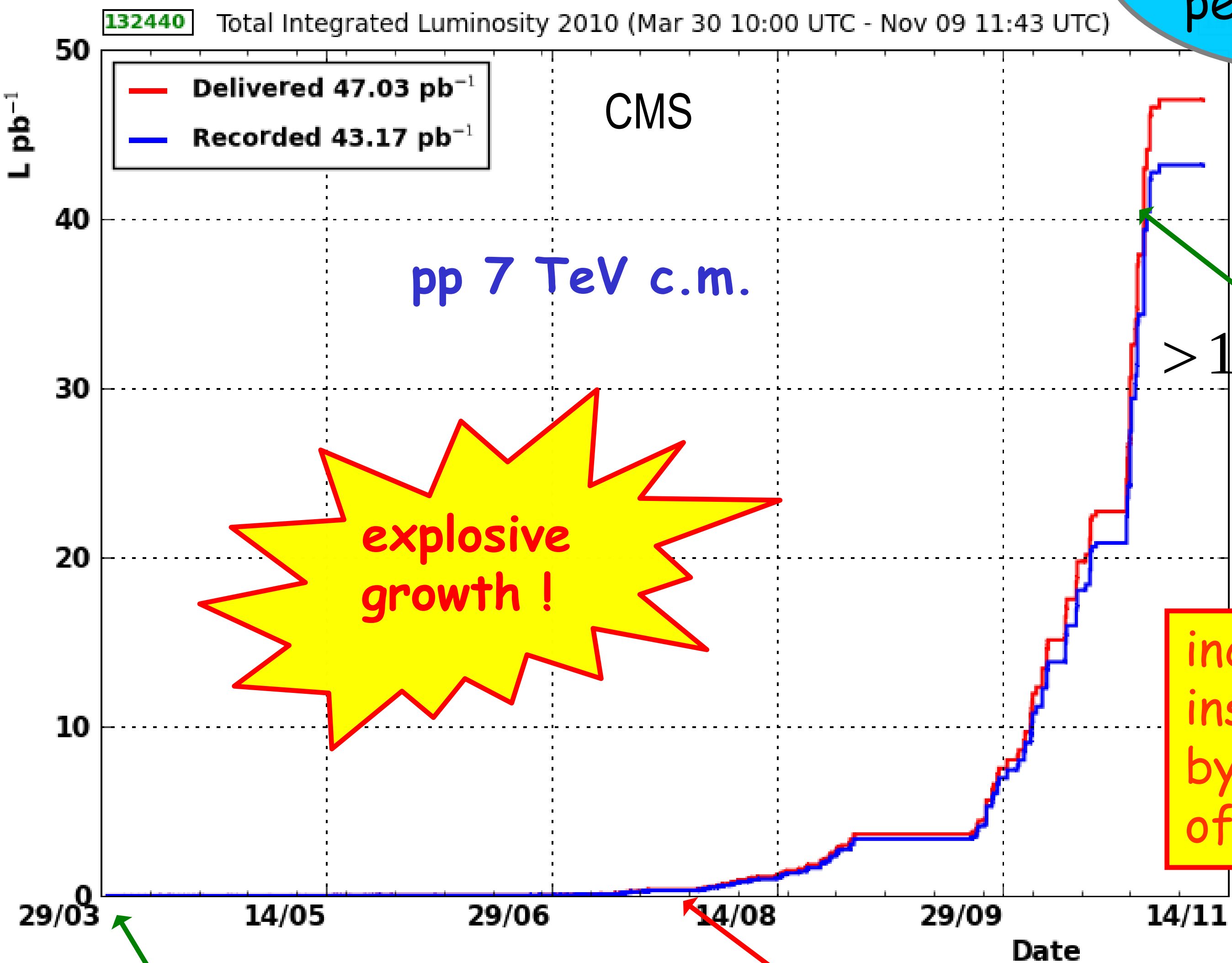
574 TeV c.m. Pb Pb

201X:

14 TeV c.m. p p 10^5 / pb /year

LHC luminosity

typically 2 interactions per crossing



43/pb

$> 10^{32} / cm^2 / s$

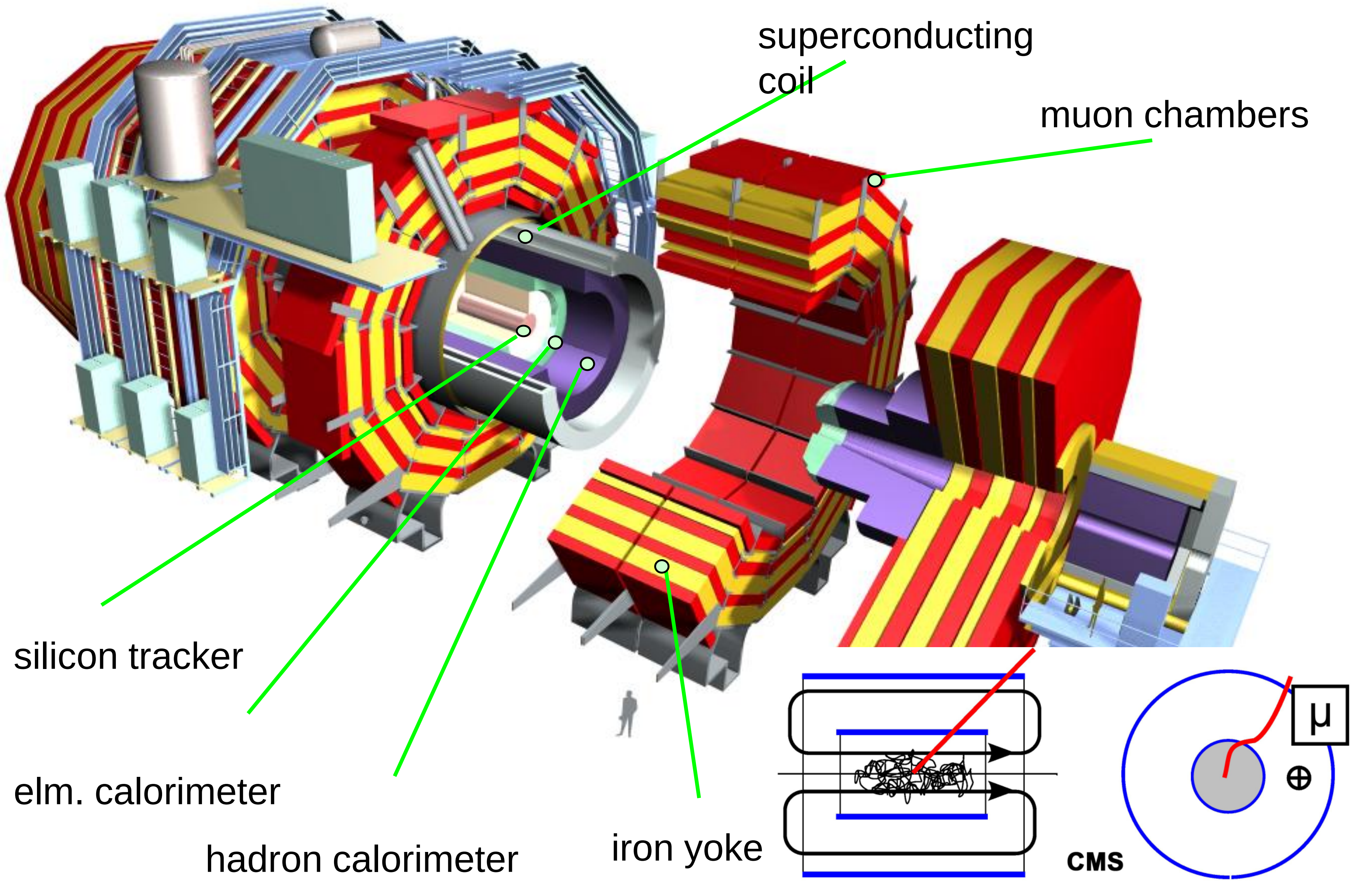
increase of instant. lumi by 5 orders of magnitude!

$10^{27} / cm^2 / s$

ICHEP conference 2010 (0.3/pb)

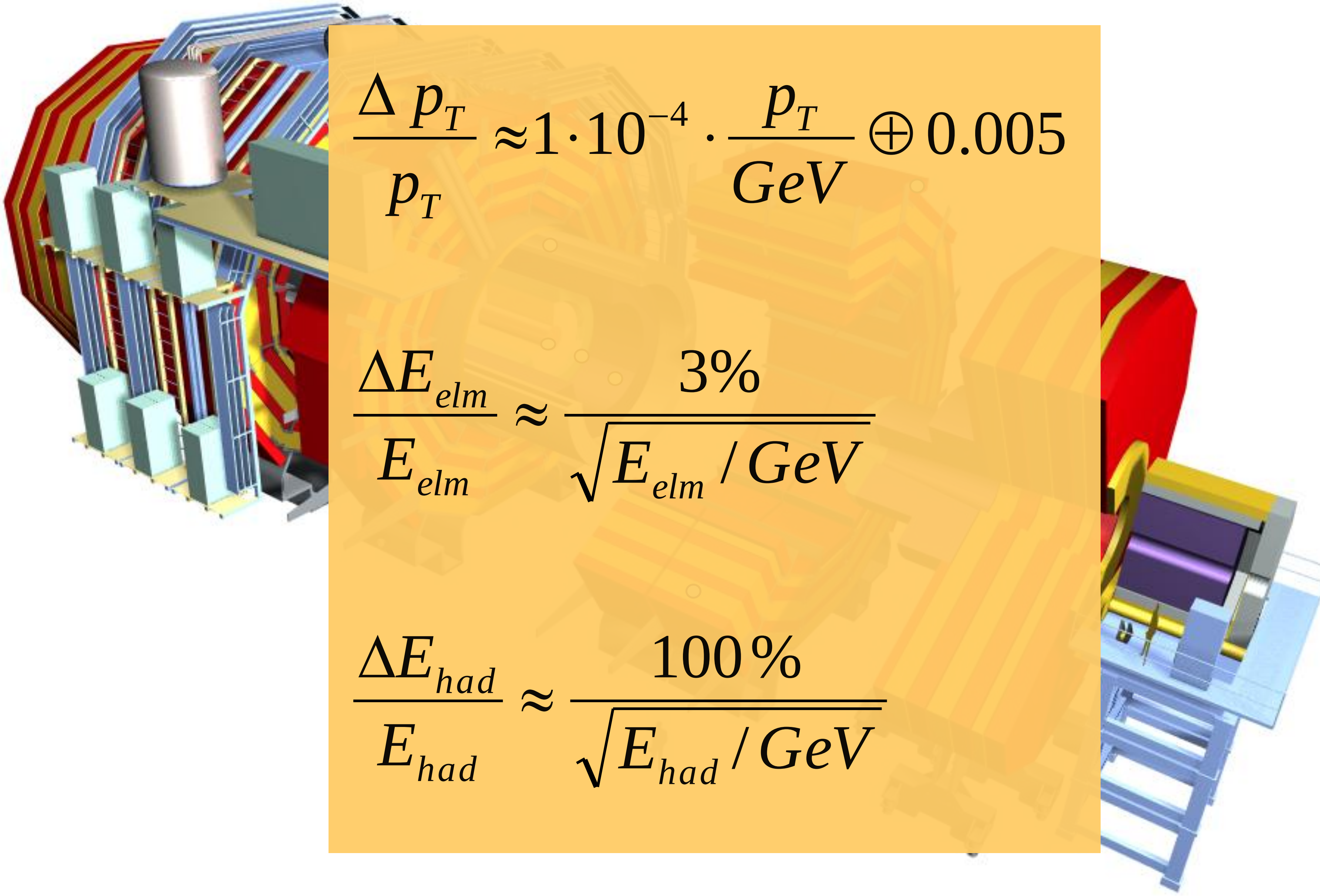
CMS = Compact Muon Solenoid

T.Hebbeker



T.Hebbeker

CMS = Compact Muon Solenoid



$$\frac{\Delta p_T}{p_T} \approx 1 \cdot 10^{-4} \cdot \frac{p_T}{GeV} \oplus 0.005$$

$$\frac{\Delta E_{elm}}{E_{elm}} \approx \frac{3\%}{\sqrt{E_{elm}/GeV}}$$

$$\frac{\Delta E_{had}}{E_{had}} \approx \frac{100\%}{\sqrt{E_{had}/GeV}}$$

- LHC and CMS
- Rediscovery of the Standard Model particles
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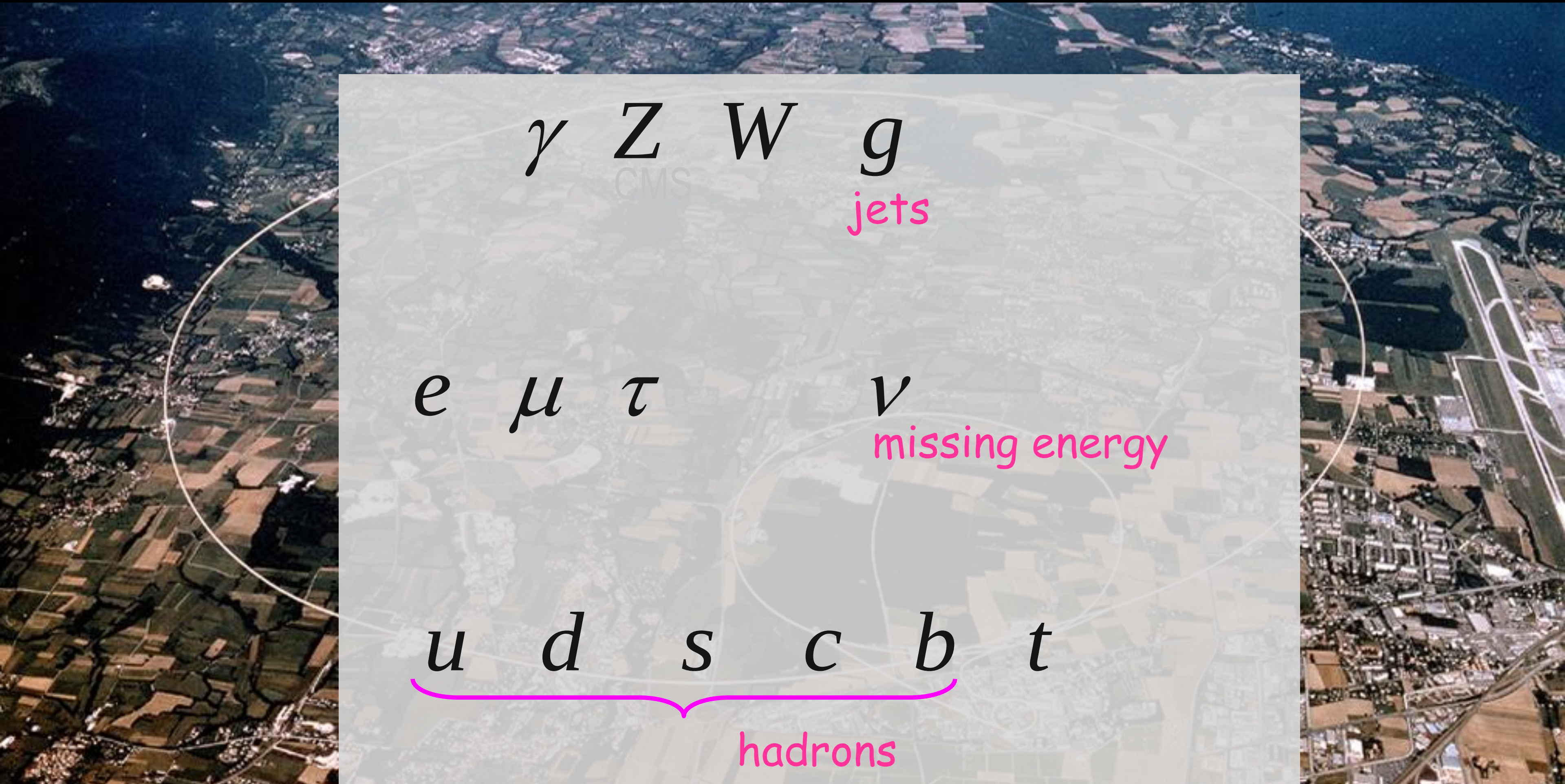
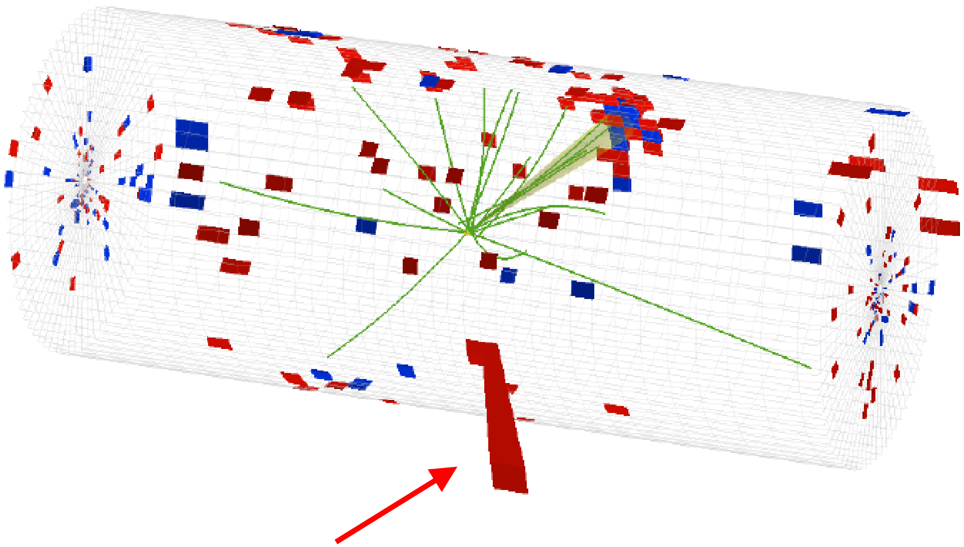
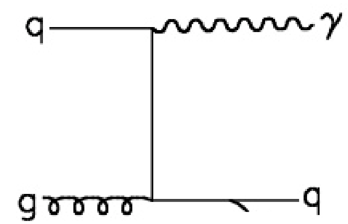
- Hadron physics results



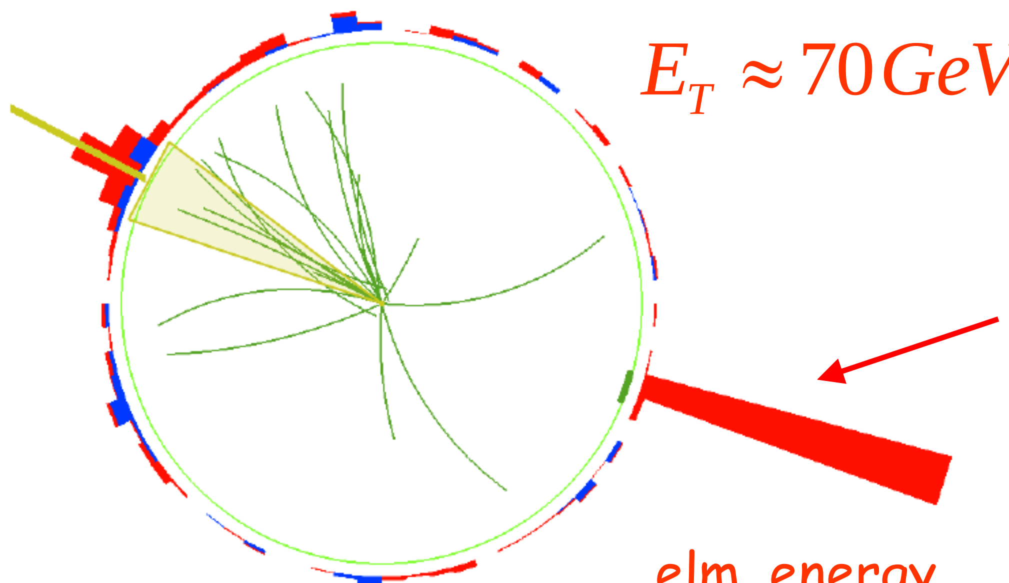
CMS Experiment at LHC, CERN
Data recorded: Thu Jul 1 09:08:48 2010 CEST
Run/Event: 139103 / 222480885

Photons





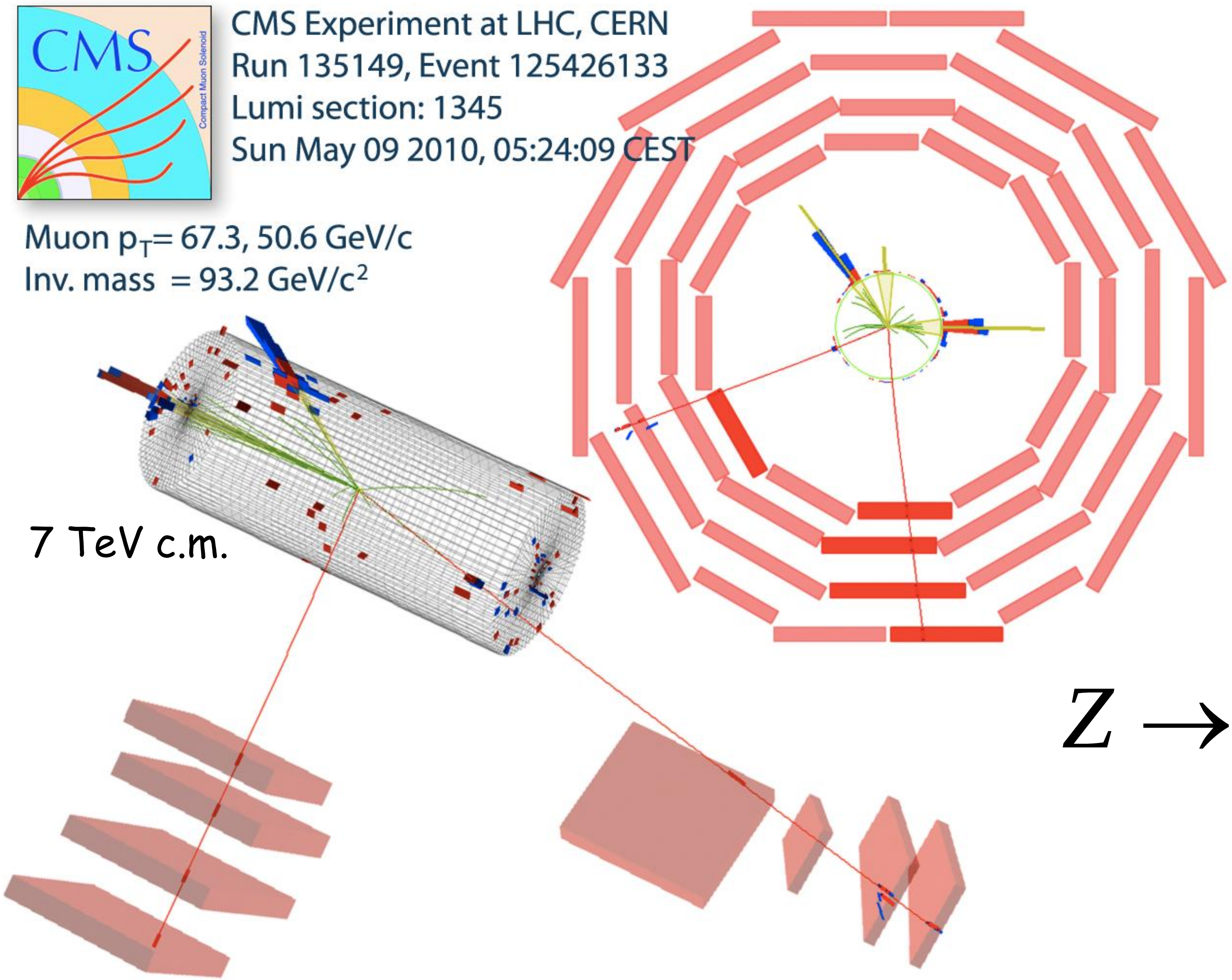
7 TeV c.m.



$E_T \approx 70\,GeV$

elm. energy

Z bosons



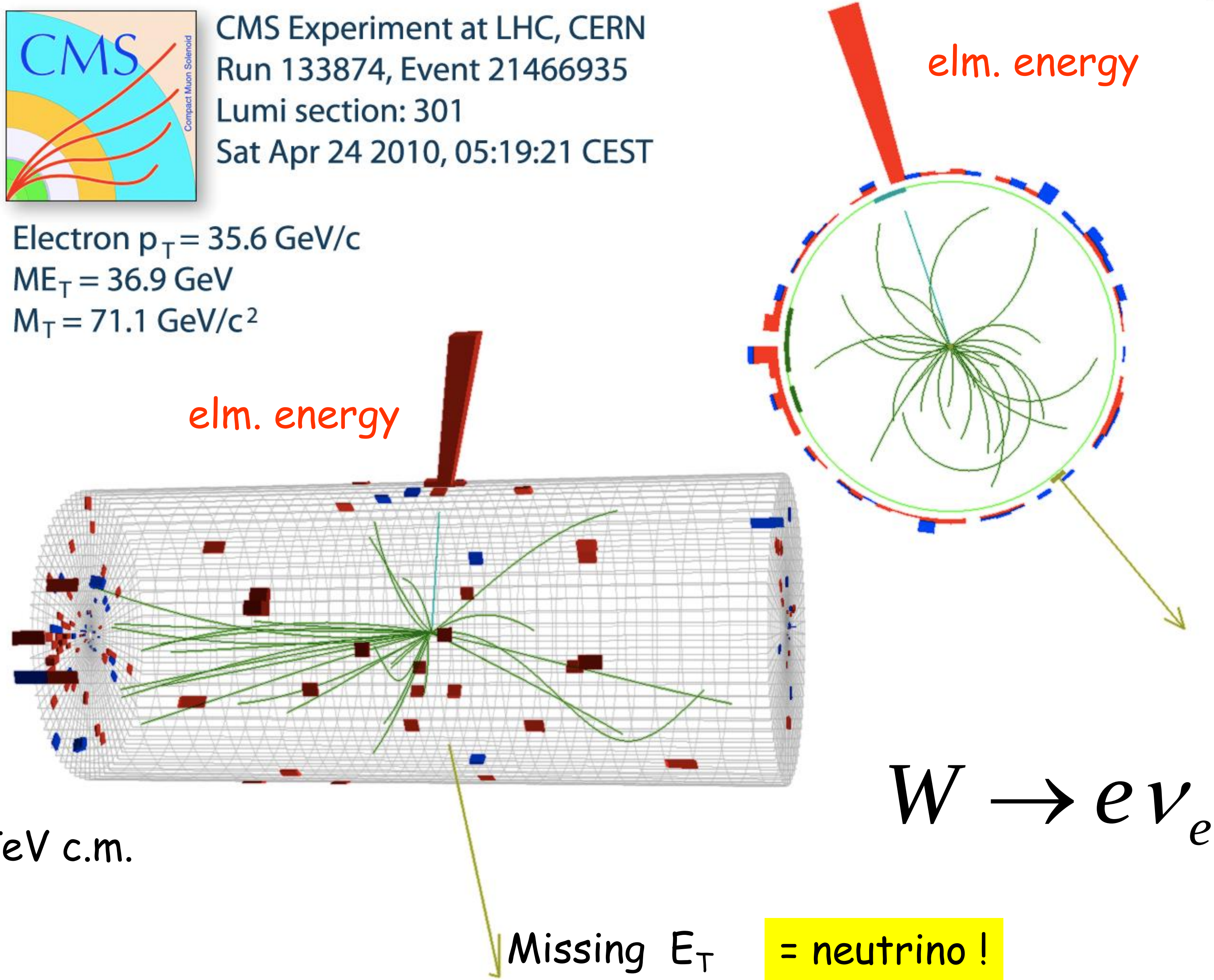
7 TeV c.m.

$Z \to \mu\mu$

W bosons

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2

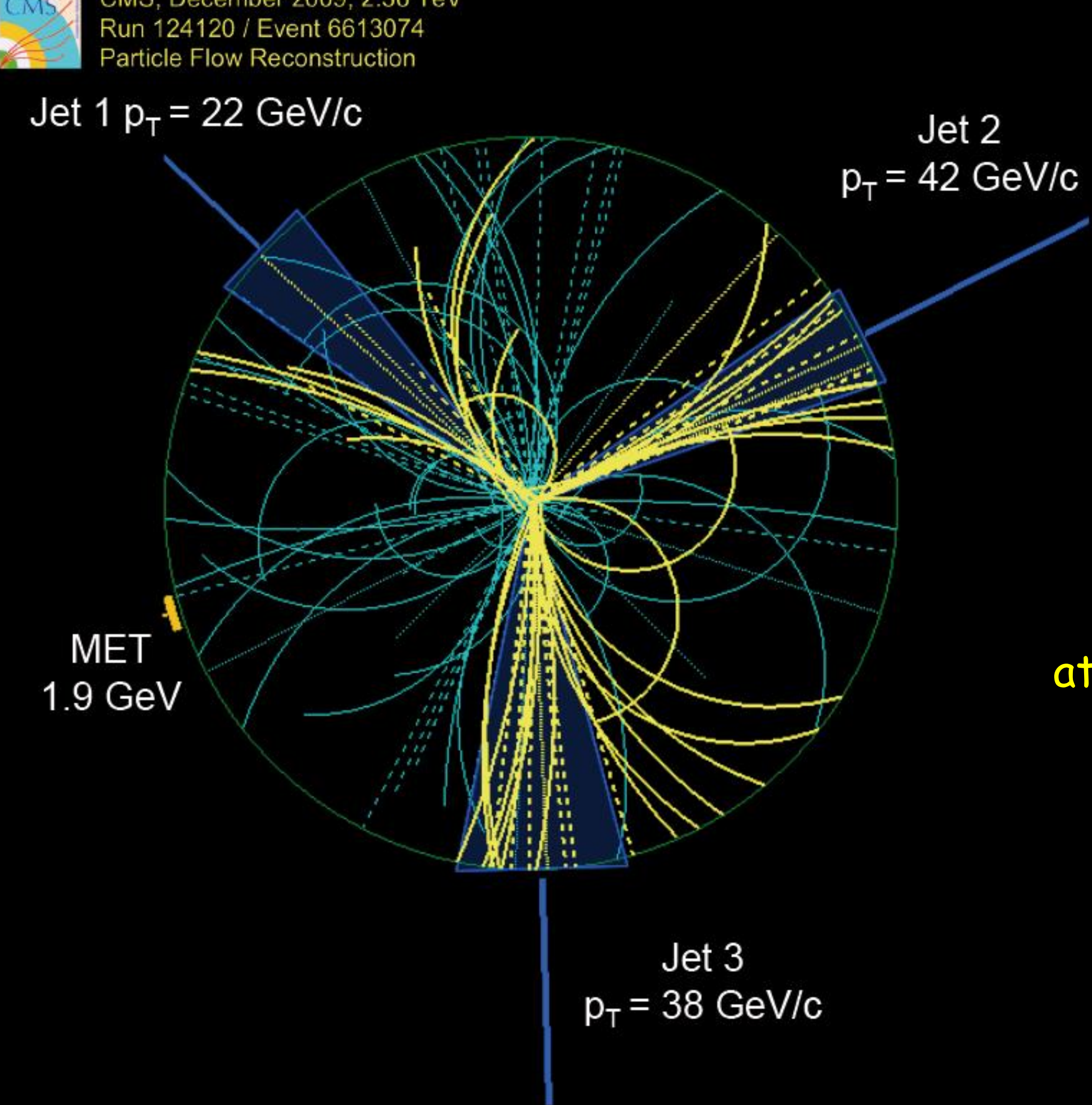


7 TeV c.m.

$$W \rightarrow e\,\nu_e$$

= neutrino !

Gluons

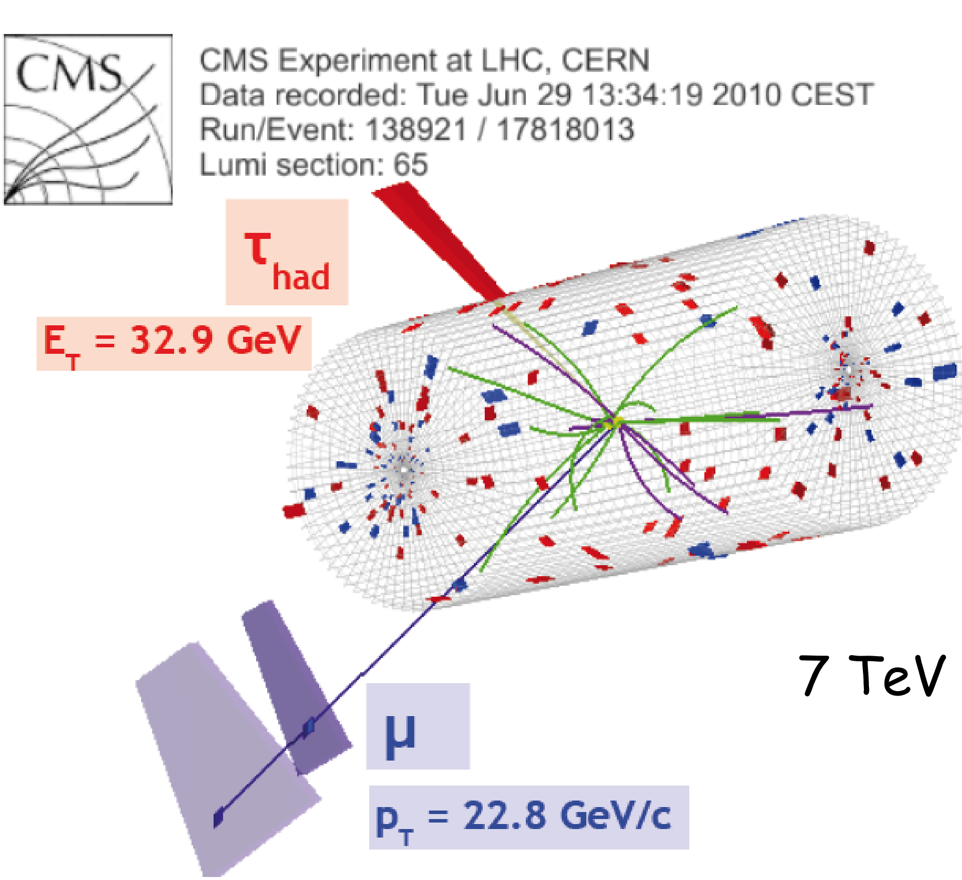


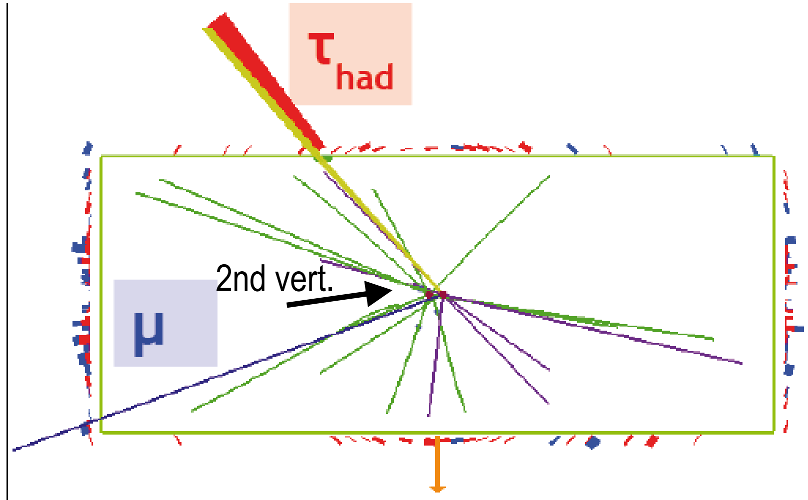
2.36 TeV c.m.

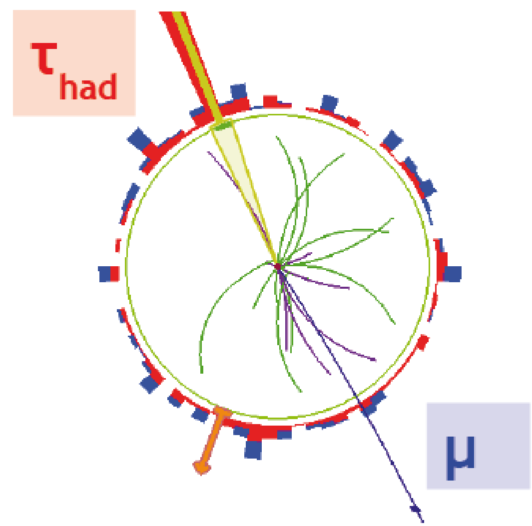
at least one jet is a

gluon jet

Tau leptons







7 TeV c.m.

$$Z \rightarrow \tau + \tau$$

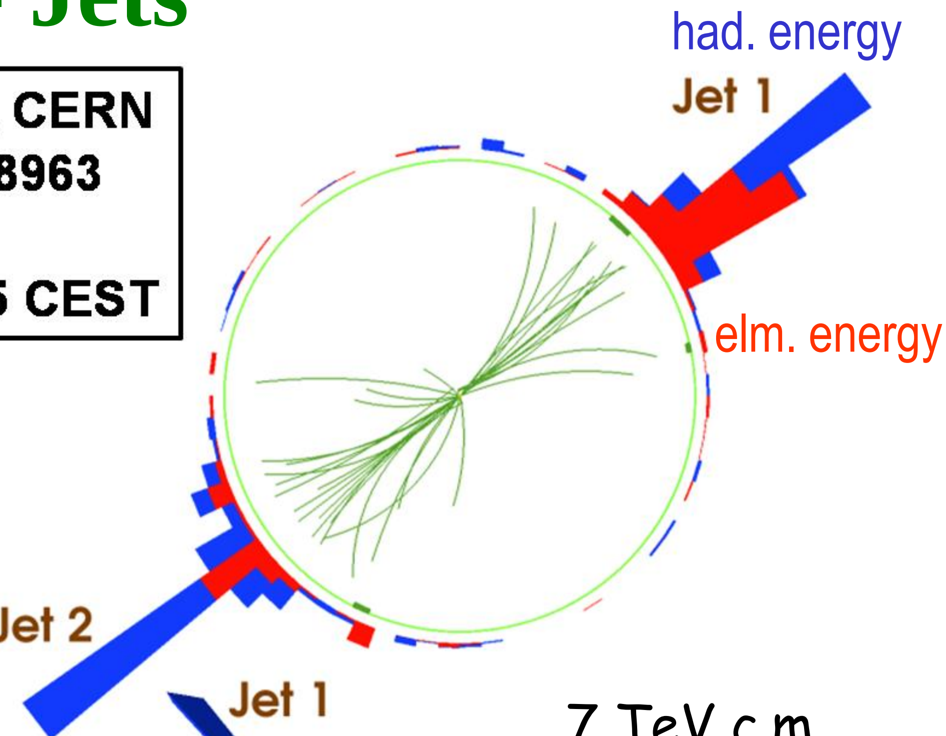
$$\rightarrow \underline{\mu\ \nu\ \nu} + \underline{hadrons\ \ \nu}$$

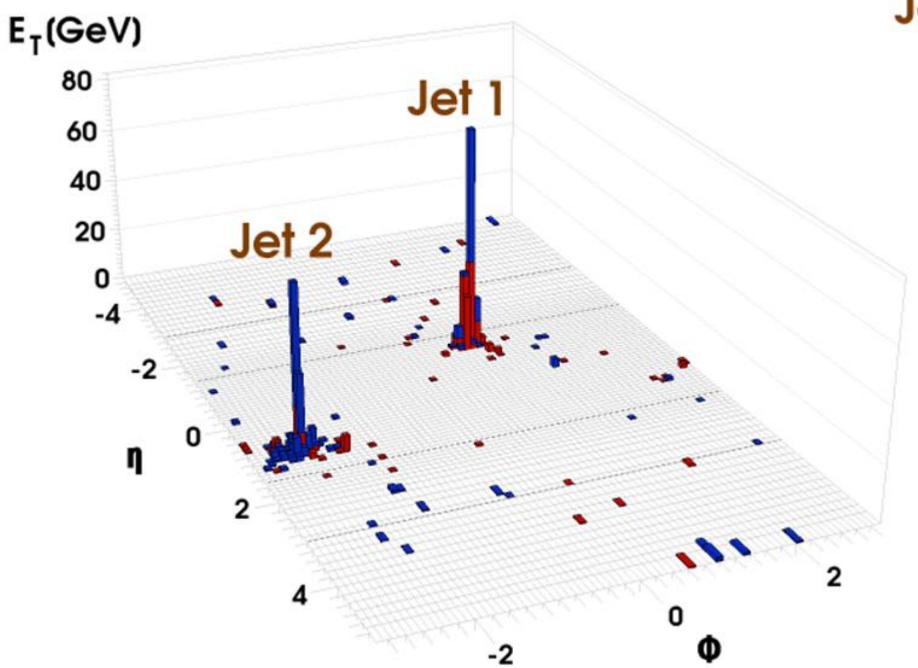
+ neutrinos !

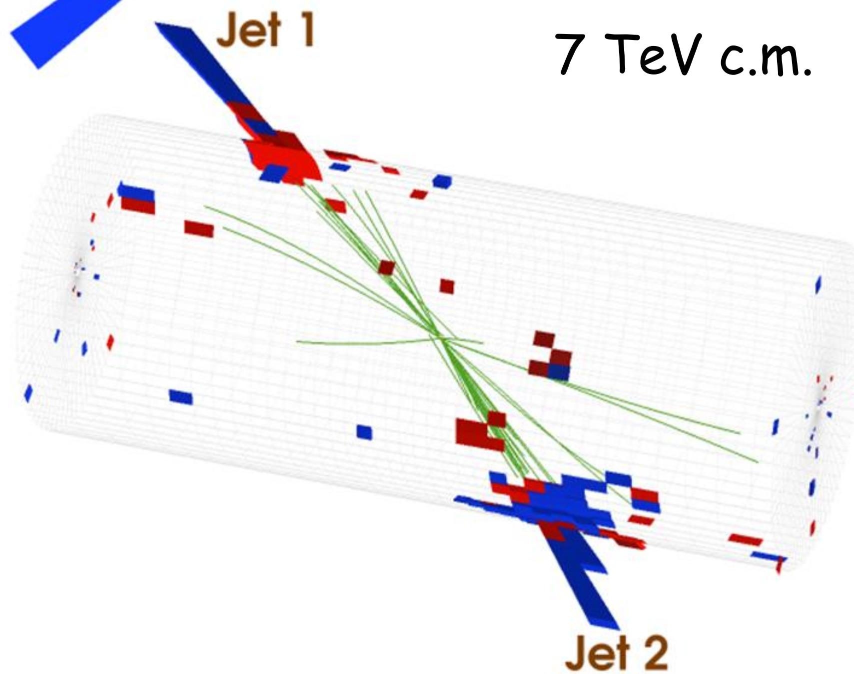
Quarks - Jets

CMS Experiment at LHC, CERN
Run 133450 Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST

Jet1 p_T : 253 GeV
Jet2 p_T : 244 GeV
Dijet Mass : 764 GeV



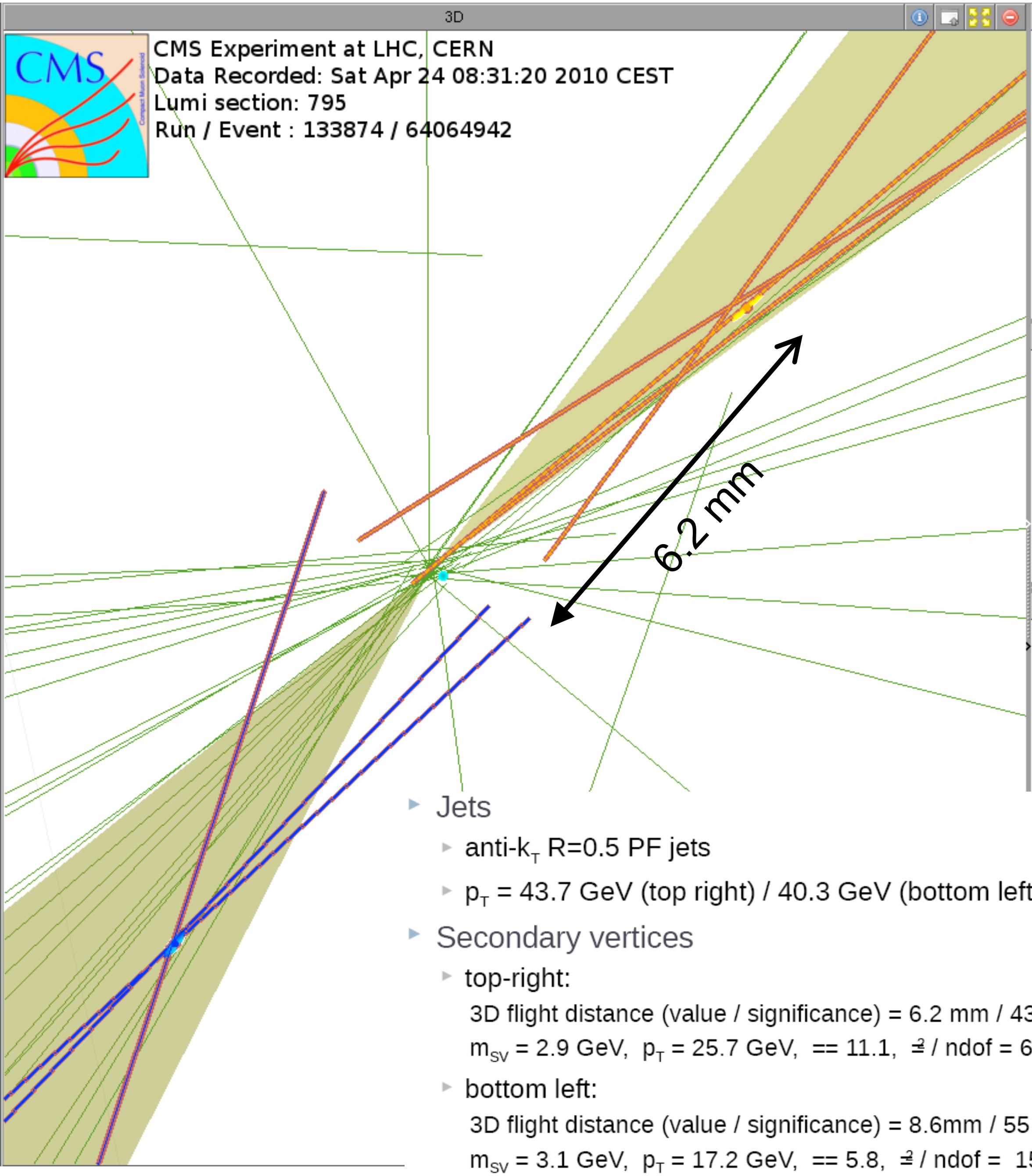


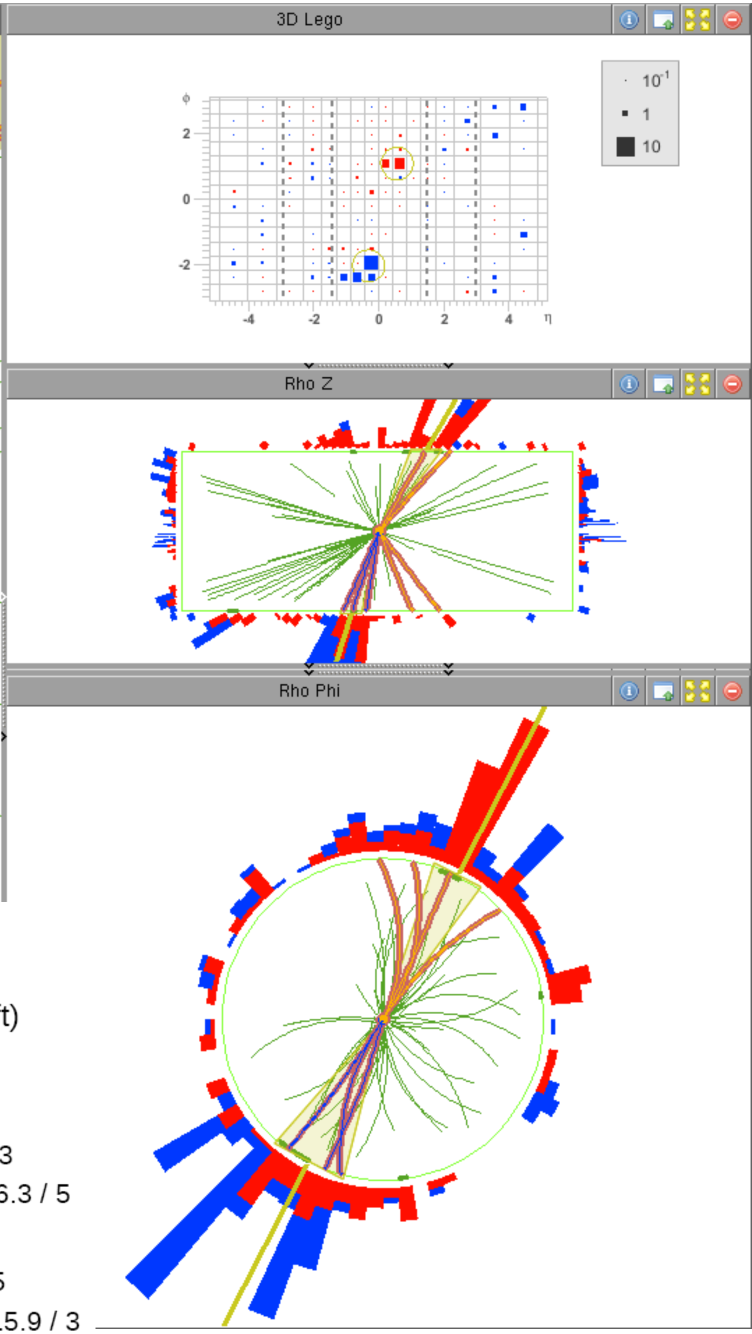


7 TeV c.m.

Bottom Quarks

T.Hebbeker

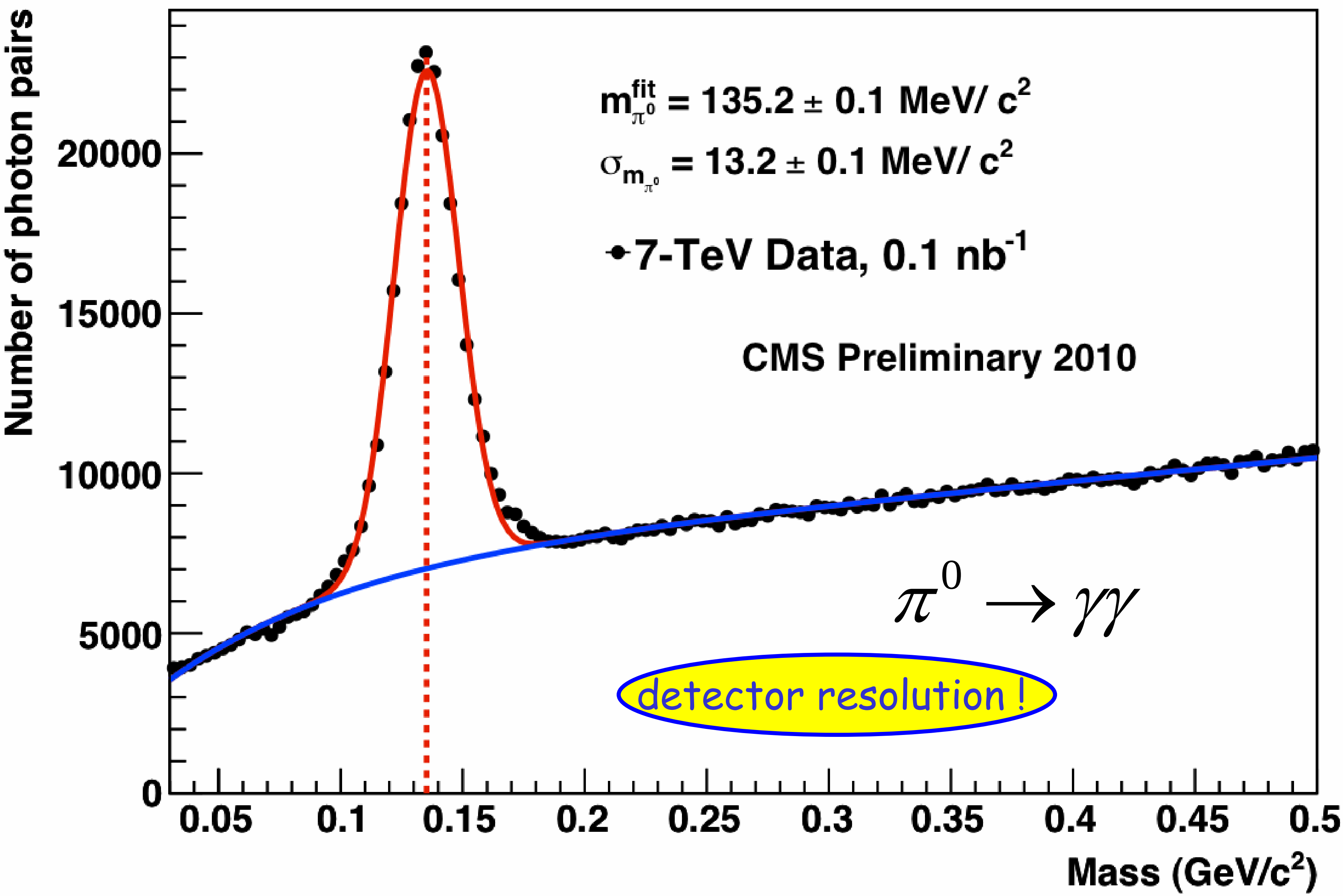




- Jets
  - anti-k$_T$ R=0.5 PF jets
  - p$_T$ = 43.7 GeV (top right) / 40.3 GeV (bottom left)
- Secondary vertices
  - top-right:
    3D flight distance (value / significance) = 6.2 mm / 43
    m$_{SV}$ = 2.9 GeV, p$_T$ = 25.7 GeV, == 11.1, =^{2} / ndof = 6.3 / 5
  - bottom left:
    3D flight distance (value / significance) = 8.6mm / 55
    m$_{SV}$ = 3.1 GeV, p$_T$ = 17.2 GeV, == 5.8, =^{2} / ndof = 15.9 / 3

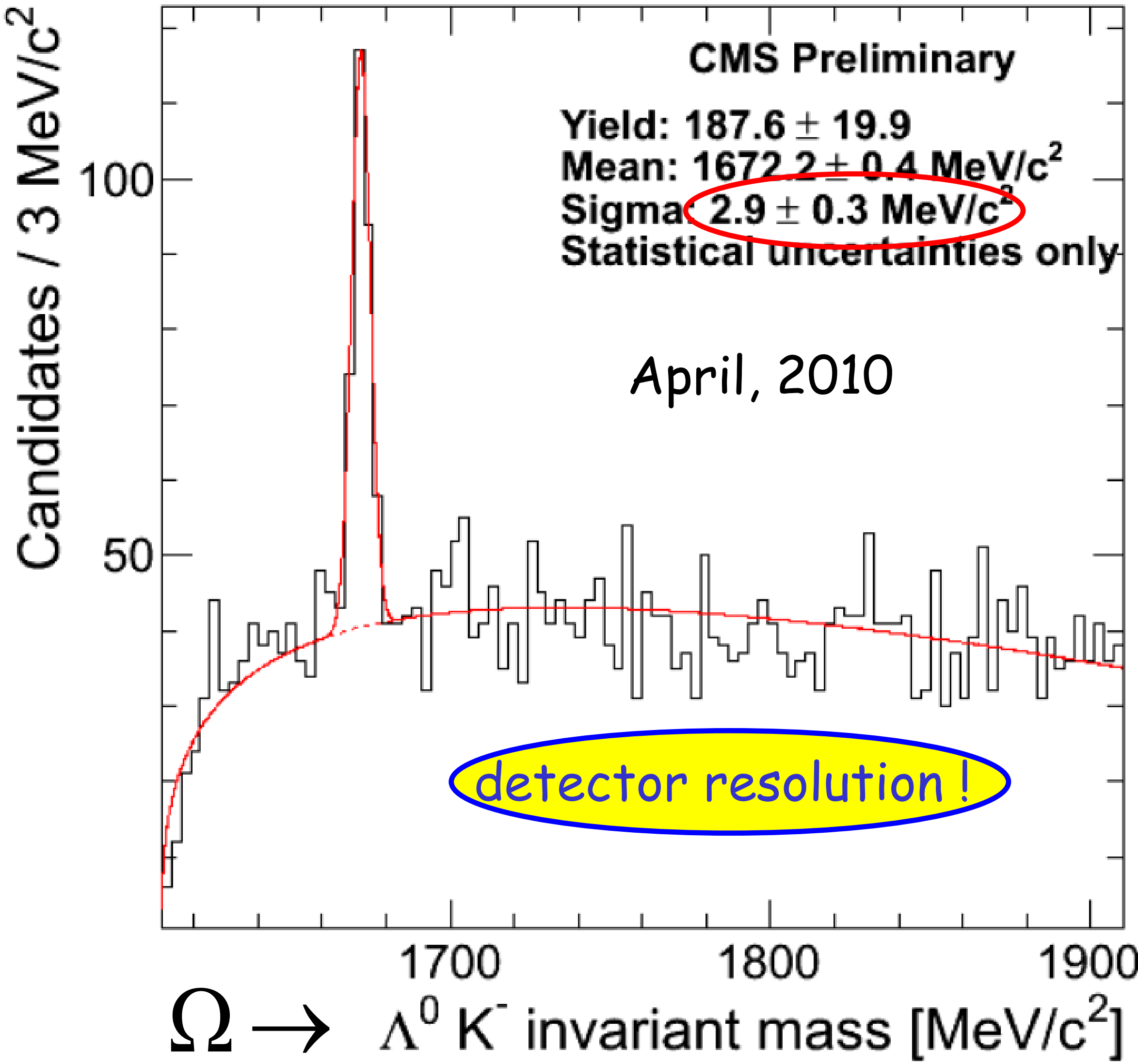
Mesons, e.g. π^0

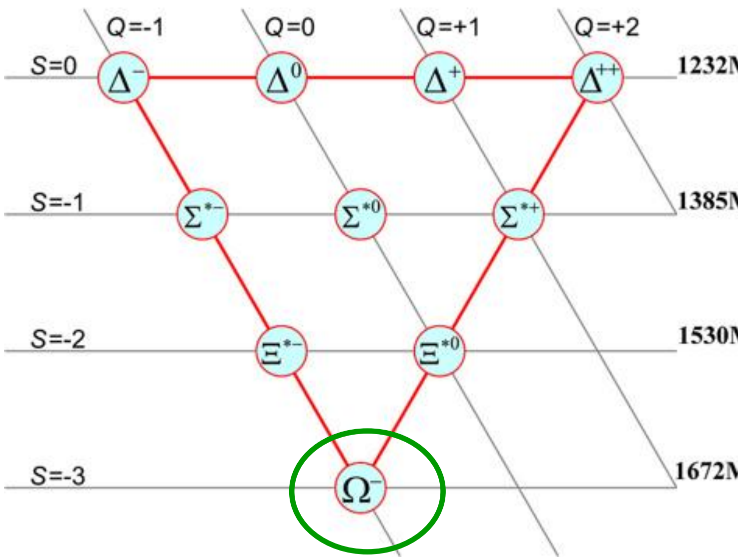
light quarks (u,d) !



Baryons, e.g. Omega = Ω

strange quarks!



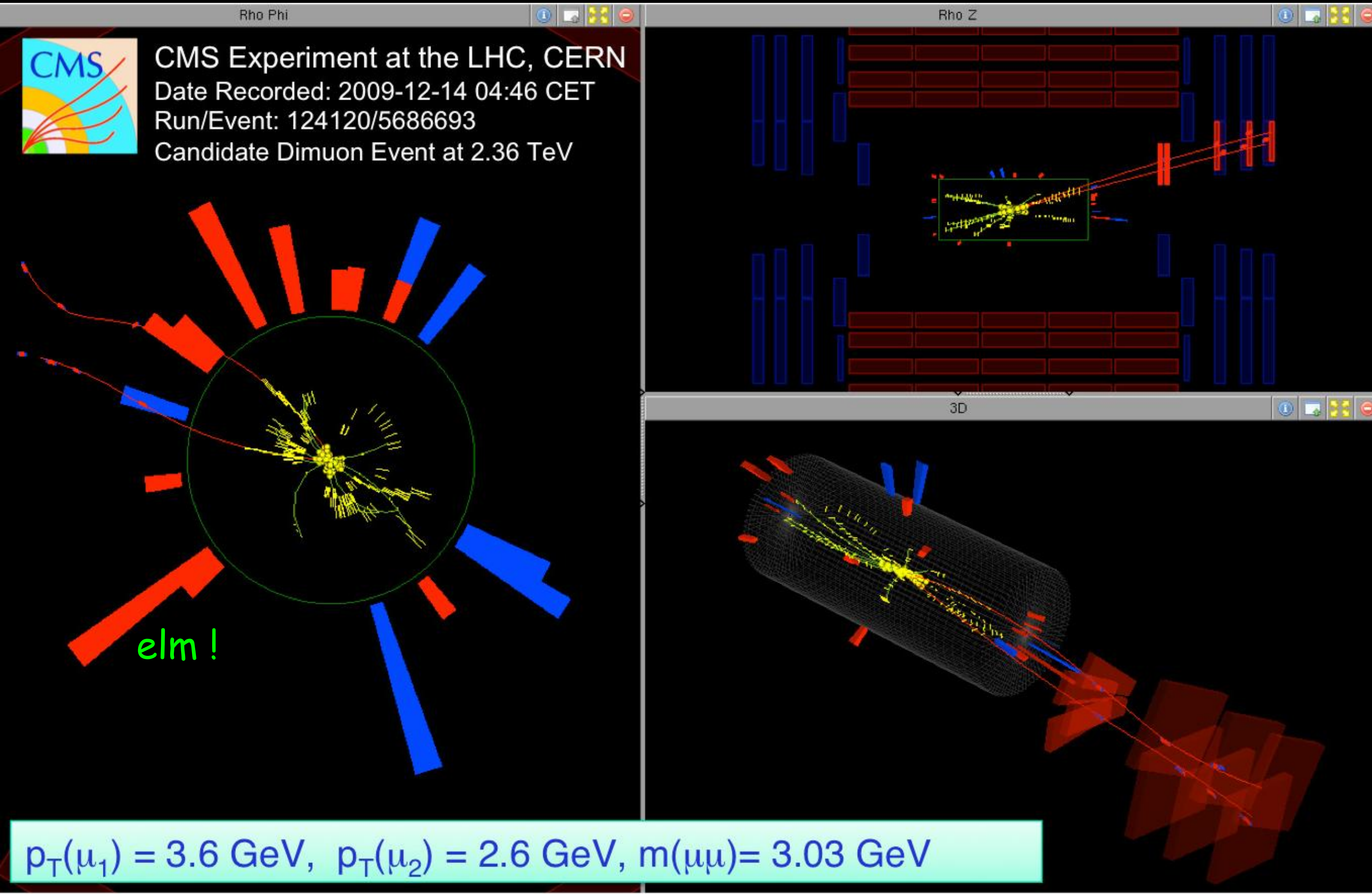


$\Omega \rightarrow \Lambda^0 K^-$

$$\Lambda \rightarrow p\pi^-$$

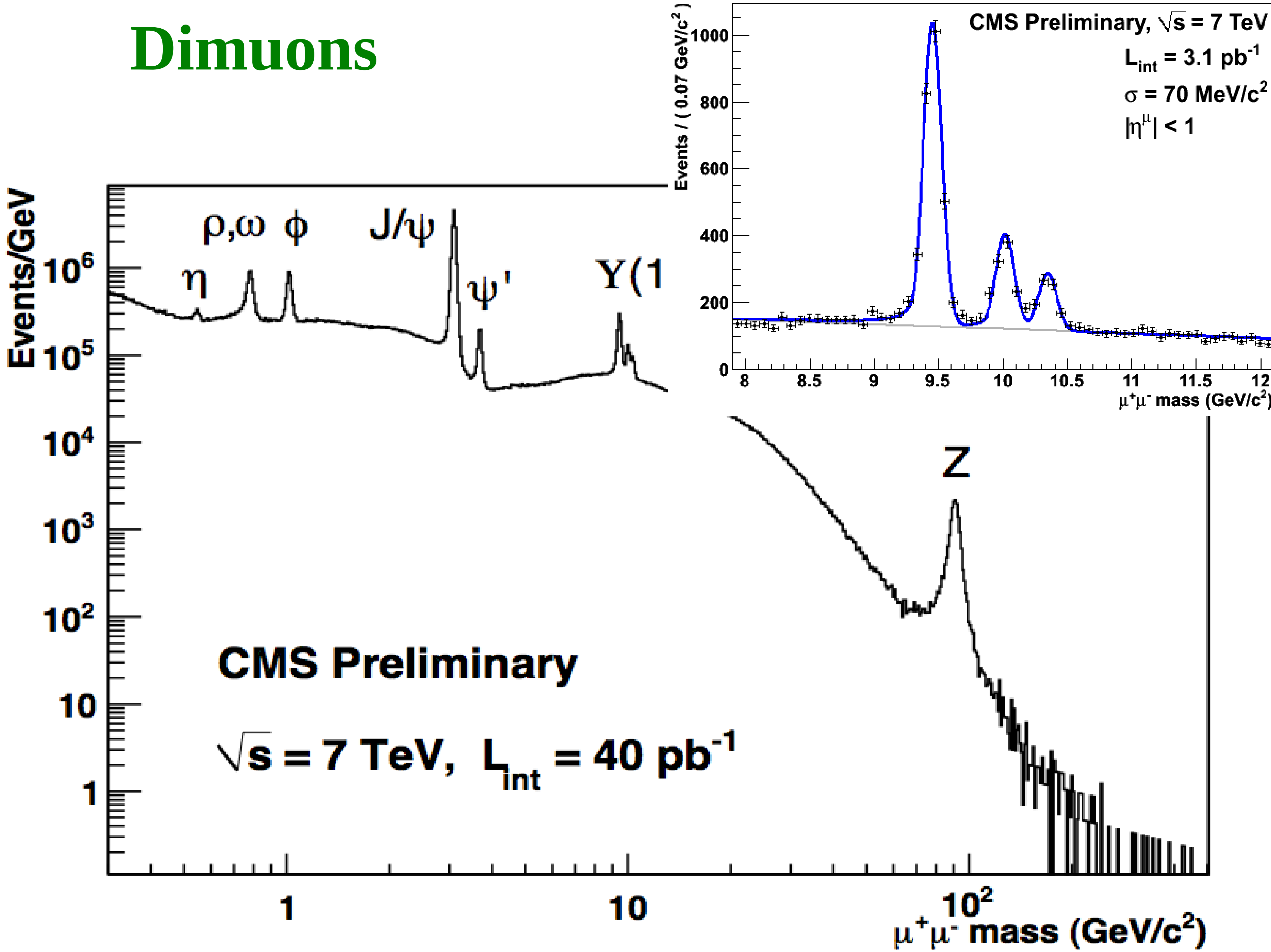
Dimuon event (J/ψ candidate)

charm quarks!



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

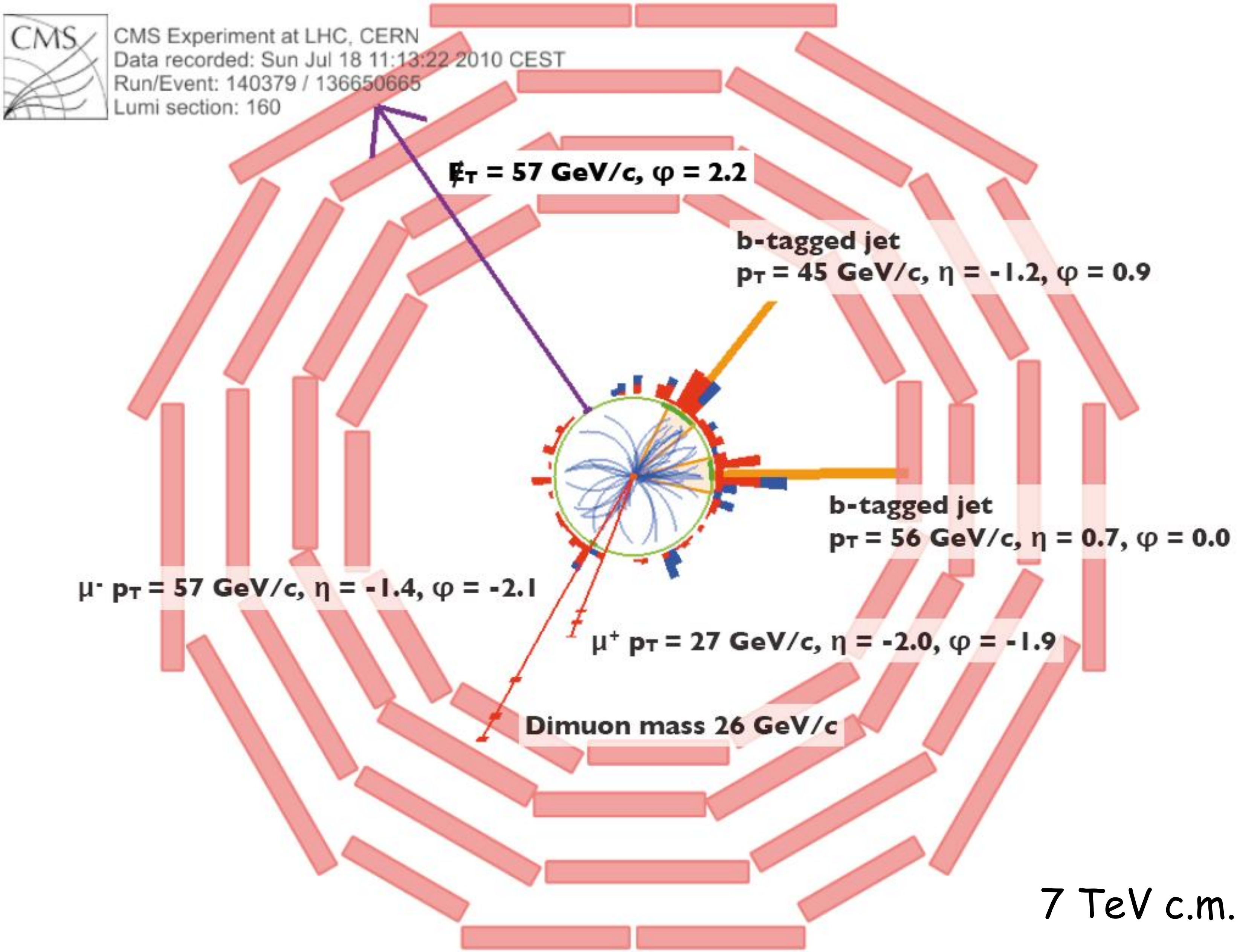
Dimuons



Events/GeV
η
ρ,ω
φ
J/ψ
ψ'
Υ(1
Z
CMS Preliminary
√s = 7 TeV, L_int = 40 pb^-1
1
10
10^2
μ+μ- mass (GeV/c²)
CMS Preliminary, √s = 7 TeV
L_int = 3.1 pb^-1
σ = 70 MeV/c²
|η^μ| < 1
Events / (0.07 GeV/c²)
μ+μ- mass (GeV/c²)

Top quarks

$$t\bar{t} \rightarrow bW\,bW \rightarrow b\mu\nu\,b\mu\nu$$



7 TeV c.m.

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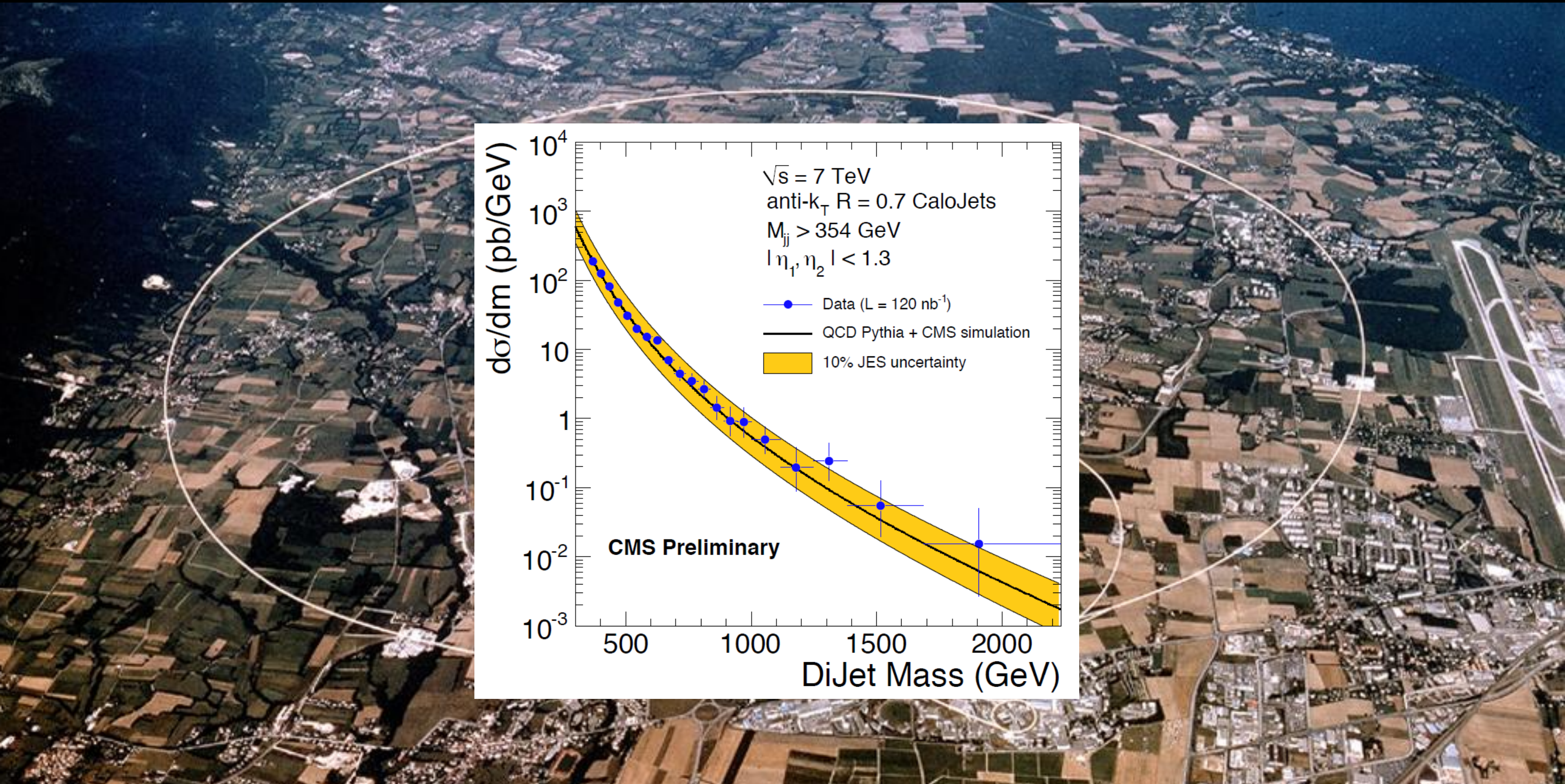
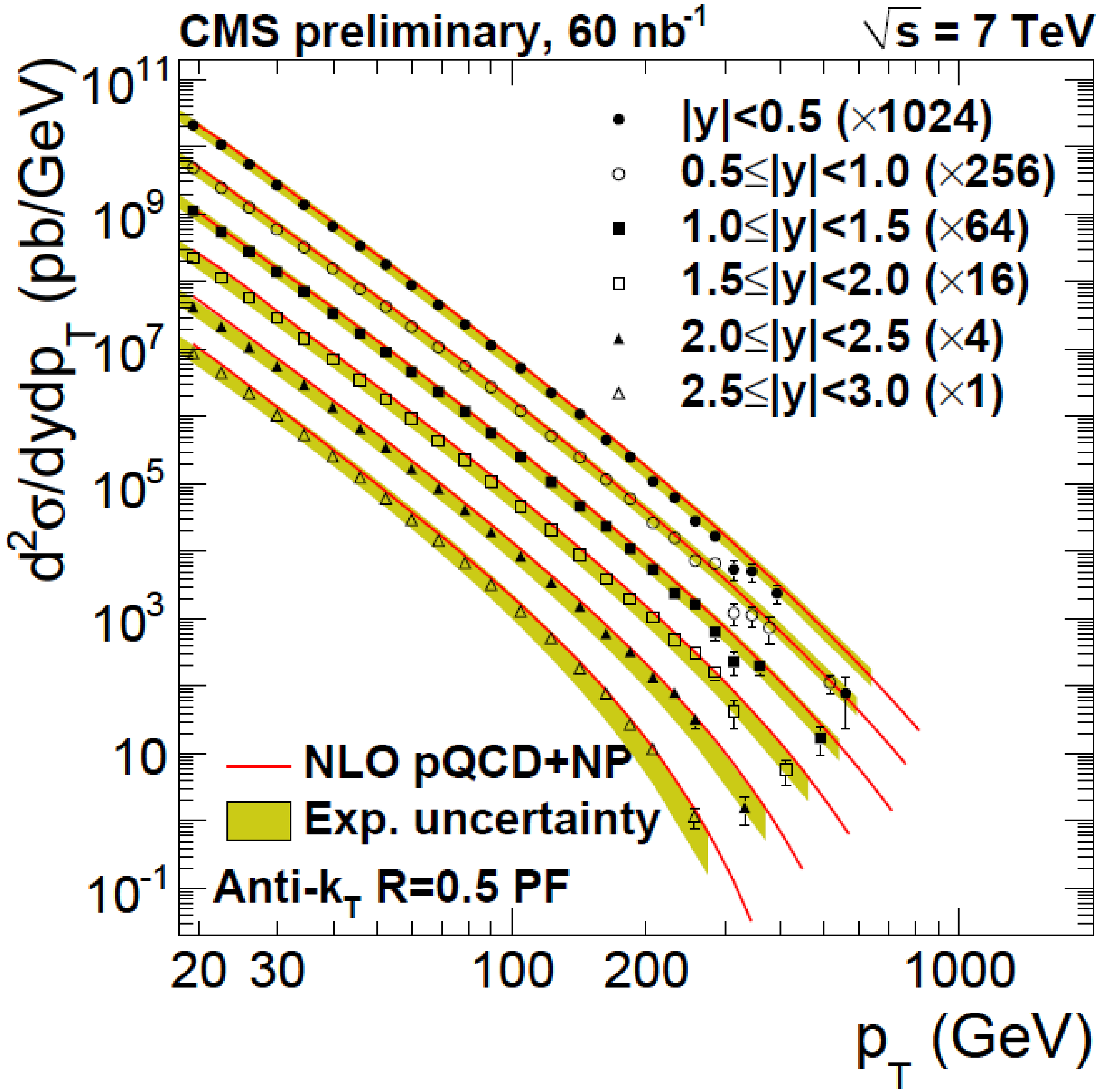


Inclusive jet production

6 orders of magnitudes



NP = Non Perturbative
= mean(Herwig, Pythia)

Agreement with QCD prediction over several orders of magnitude

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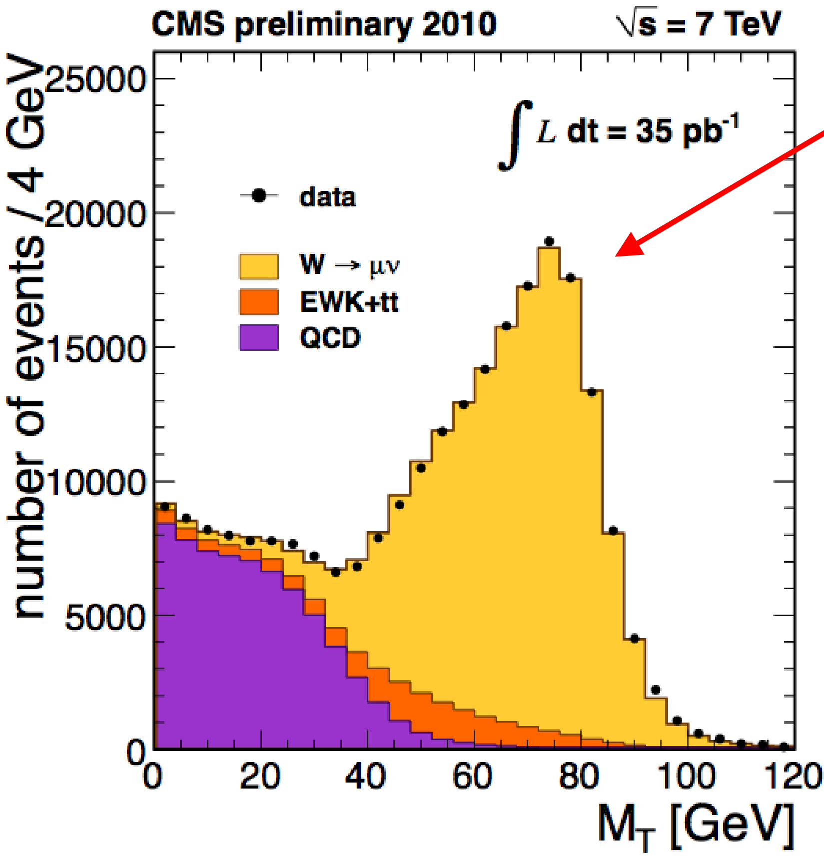
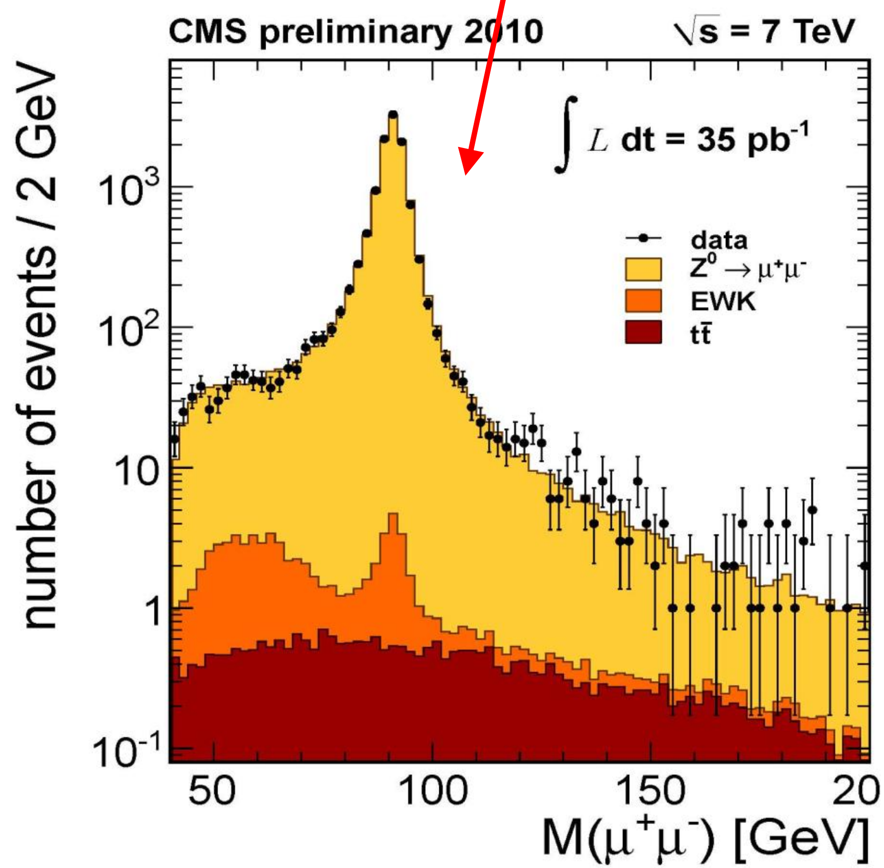
W and Z production

W mass confirmed

~ 100‘000 events!



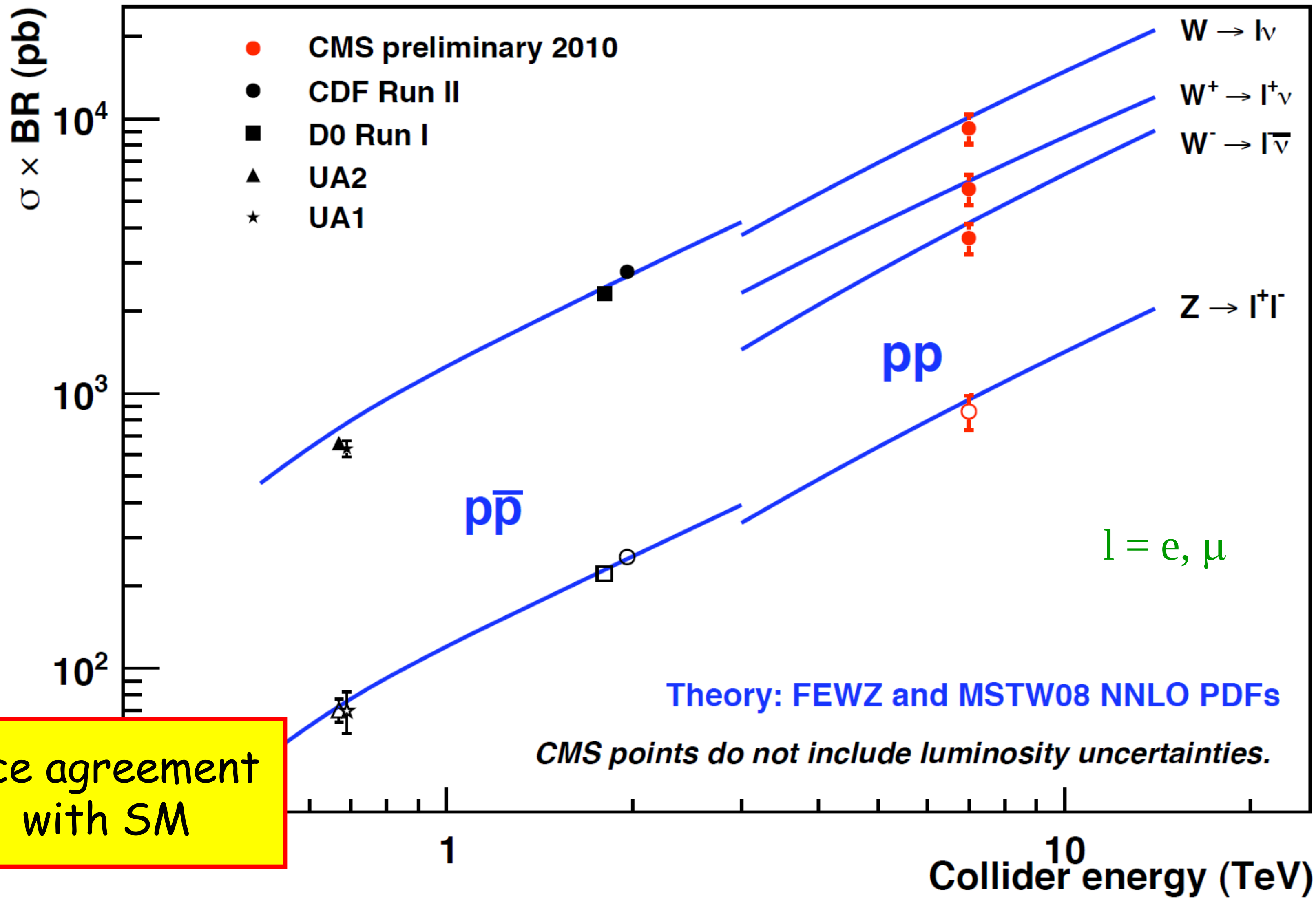
Z mass confirmed



Perfect agreement with SM

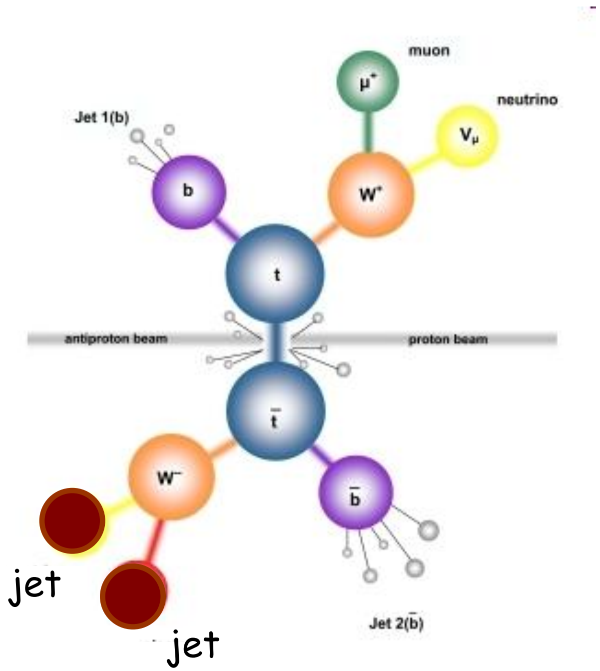
W and Z cross sections

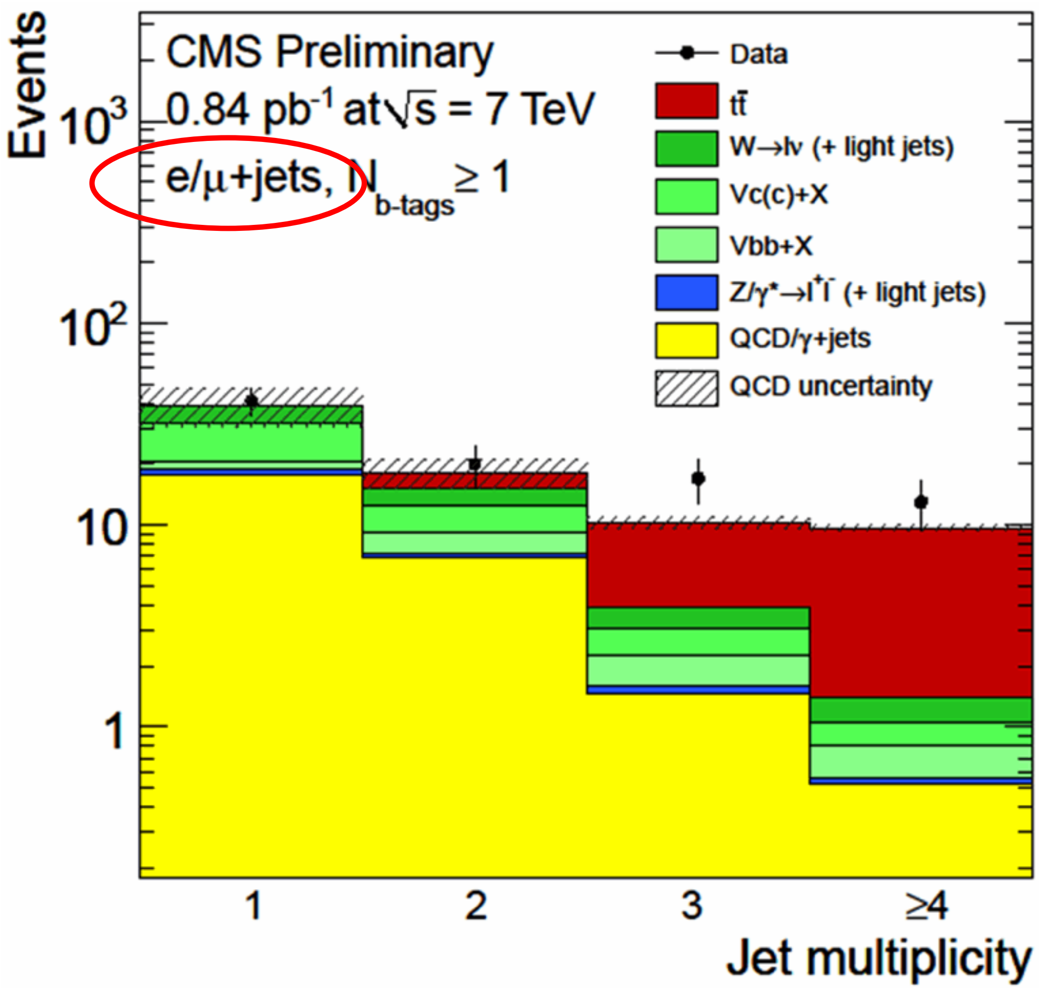
Note: in pp less W,Z bosons than in $p\bar{p}$



Nice agreement with SM

Top production





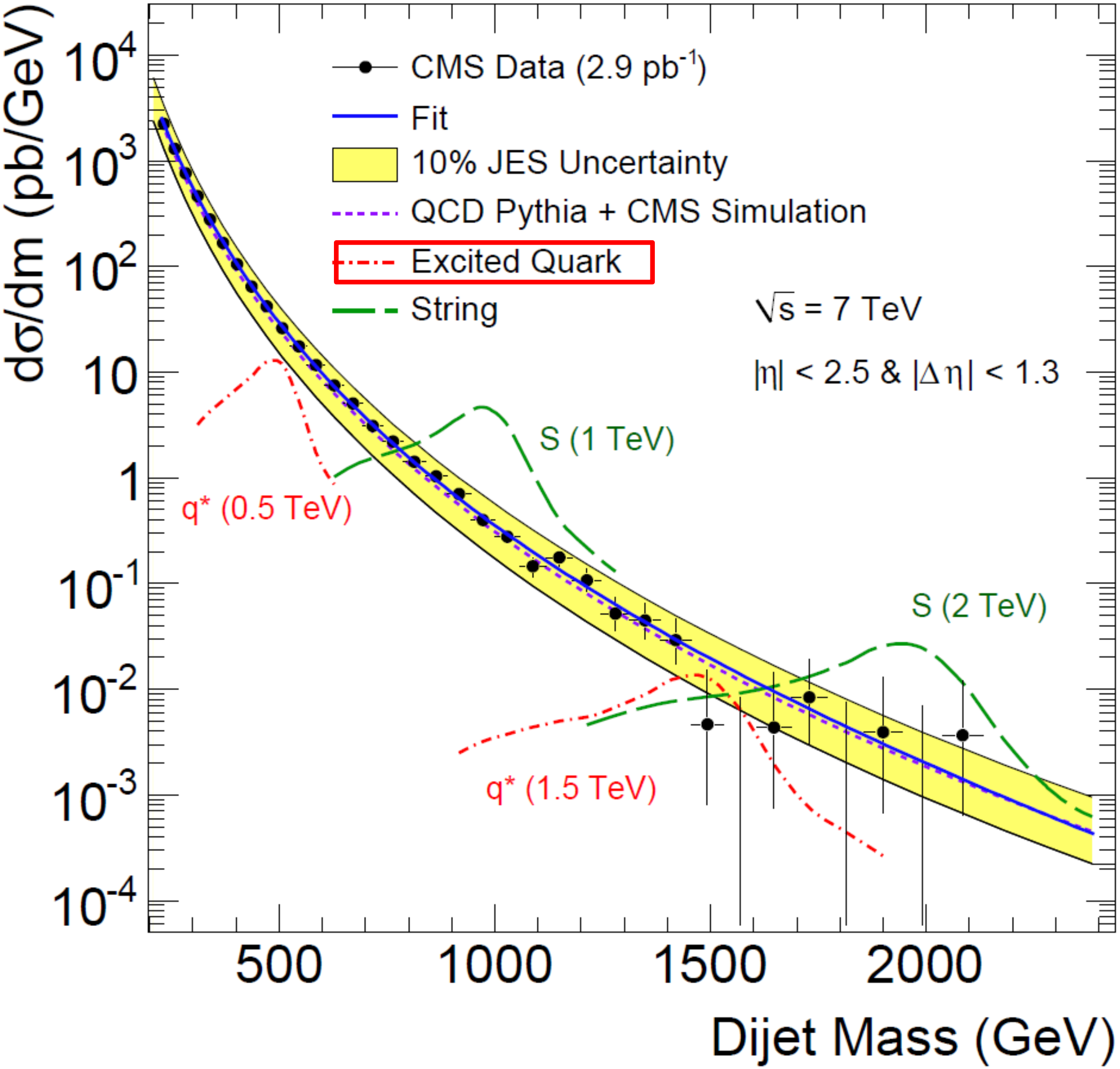
From dilepton events:

$$\sigma(pp \to t\bar{t}) = 194 \pm 72(\text{stat.}) \pm 24(\text{syst.}) \pm 21(\text{lumi.})\ \text{pb}$$

Tevatron: 7 pb !

Agreement with SM

Dijet resonance search - excited quarks



compositeness:

$$q^* \to q\, g \to 2\, jets$$

compositeness scale

$$\Lambda = m(q^*)$$

excited quarks excluded up to a mass of

1.58 TeV (95%)

World record !

Tevatron limit: 870 GeV

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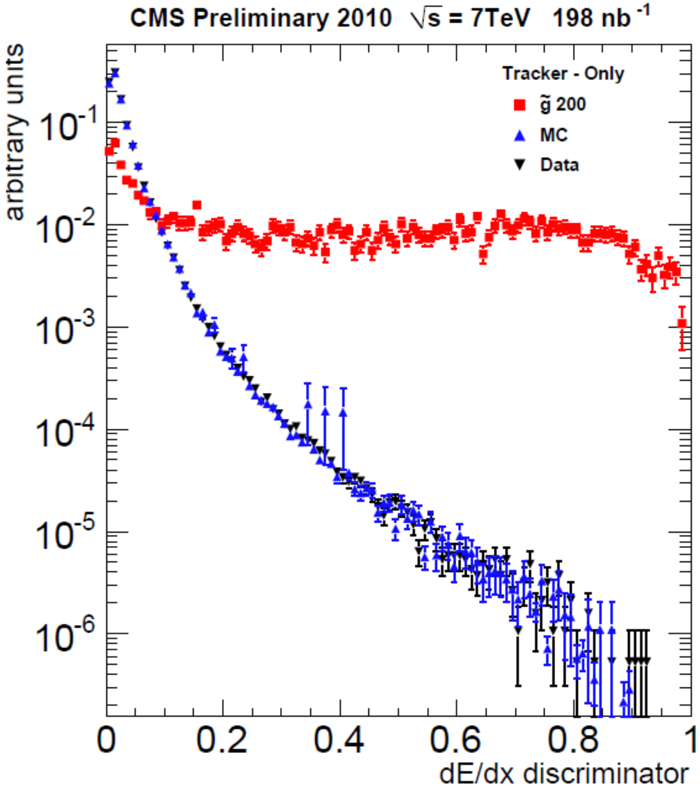
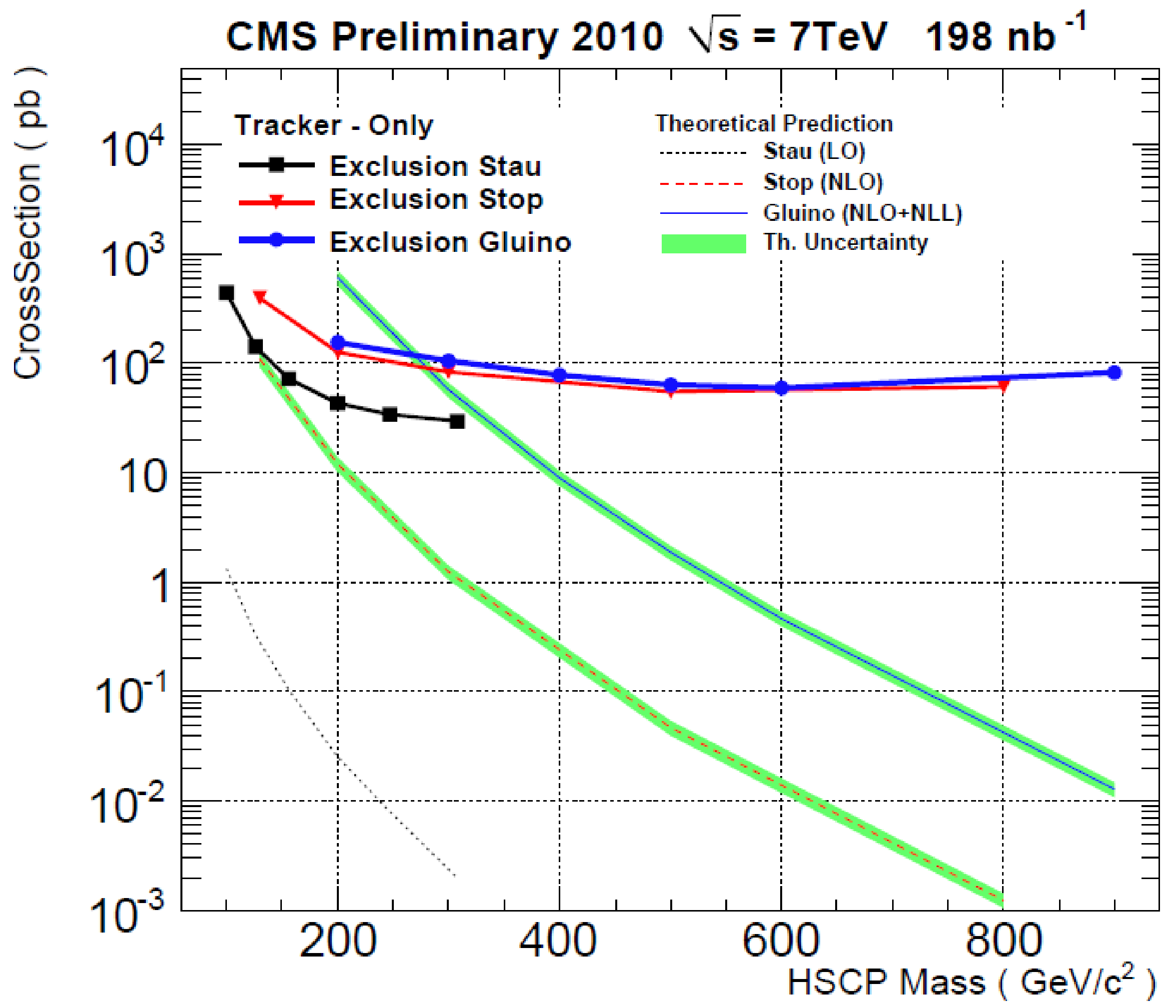
Do we see Heavy Stable Charged Particles (HSCP) ?





stable gluinos (R-hadrons) must be heavier than

284 GeV (95%)

Tevatron limit: 3XX GeV

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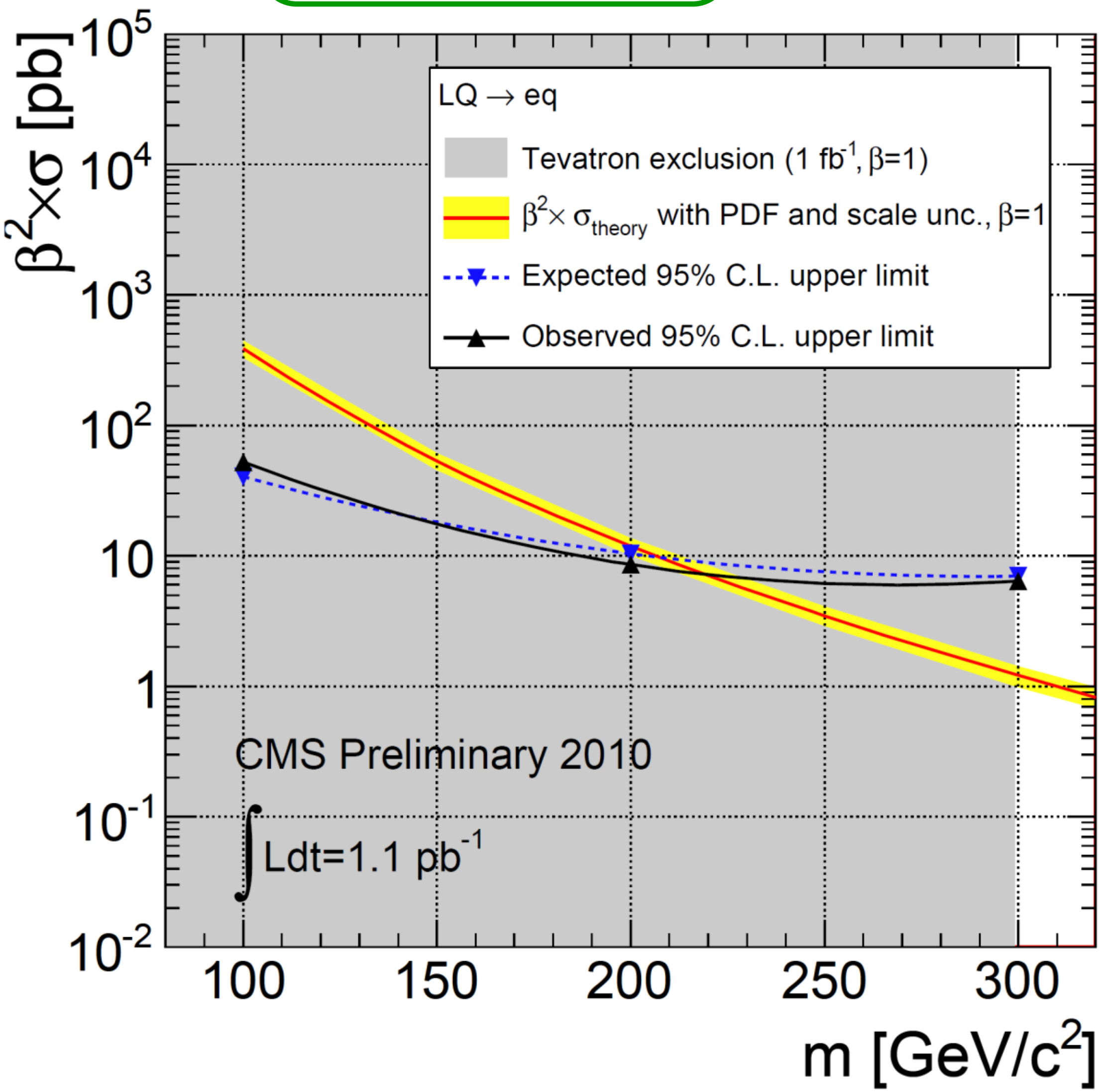
And what about leptoquarks ?

Leptoquark LQ
= composite object
= l + q

$$pp \rightarrow LQ\overline{LQ} \rightarrow eqeq$$

$BR = \beta$



Scalar first generation leptoquarks excluded up to

m_{LQ} = 220 GeV (95%)

for β = 1

Tevatron limit: 300 GeV

- LHC and CMS
- Rediscovery of the Standard Model particles
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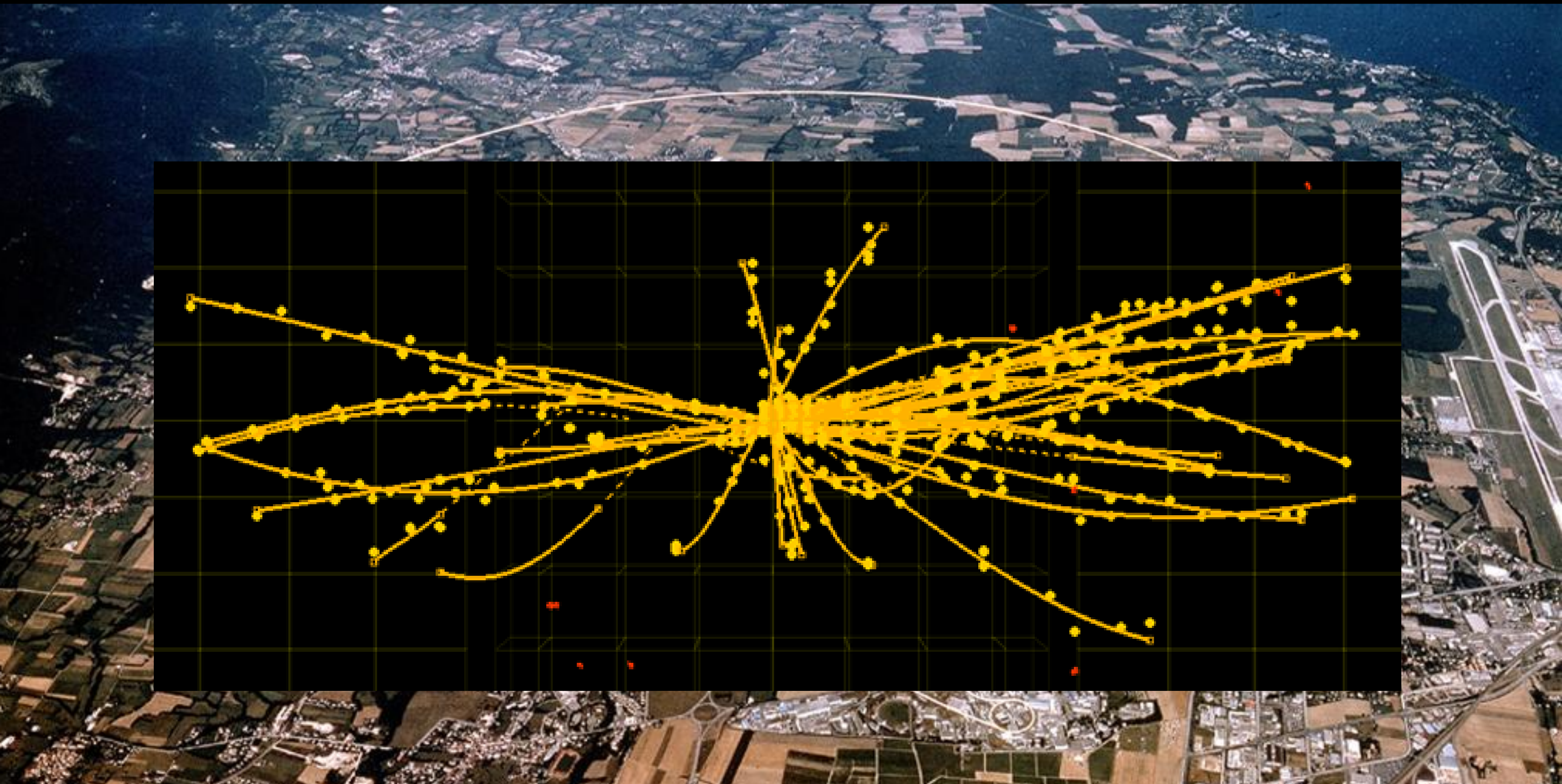
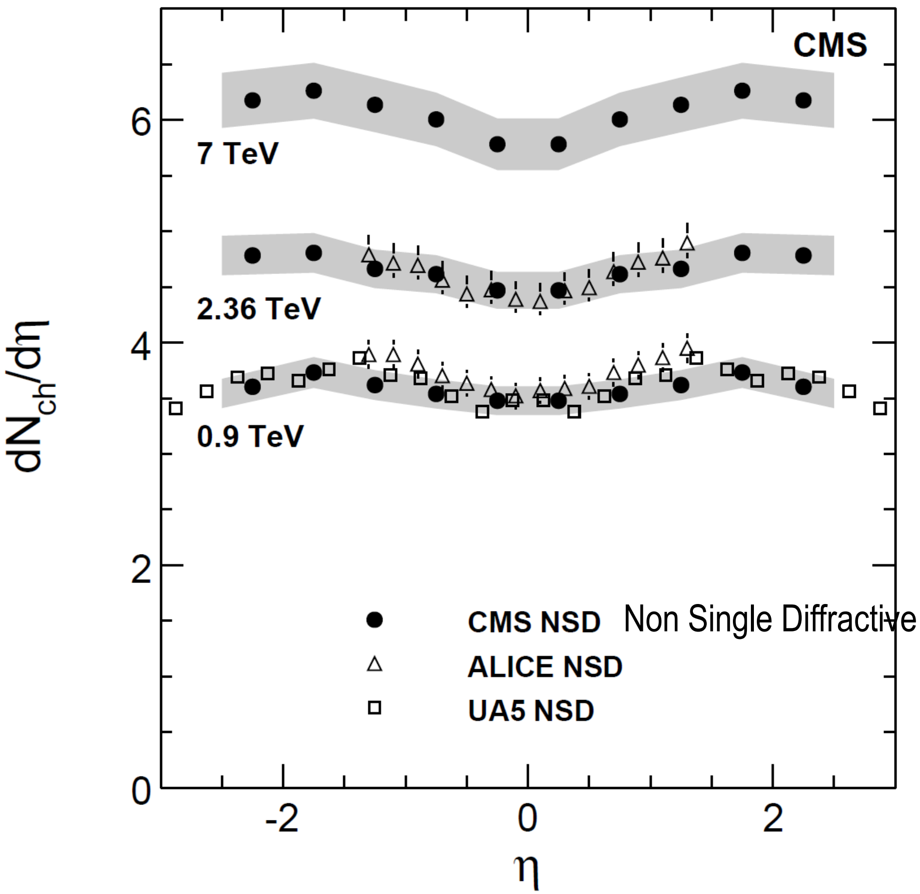
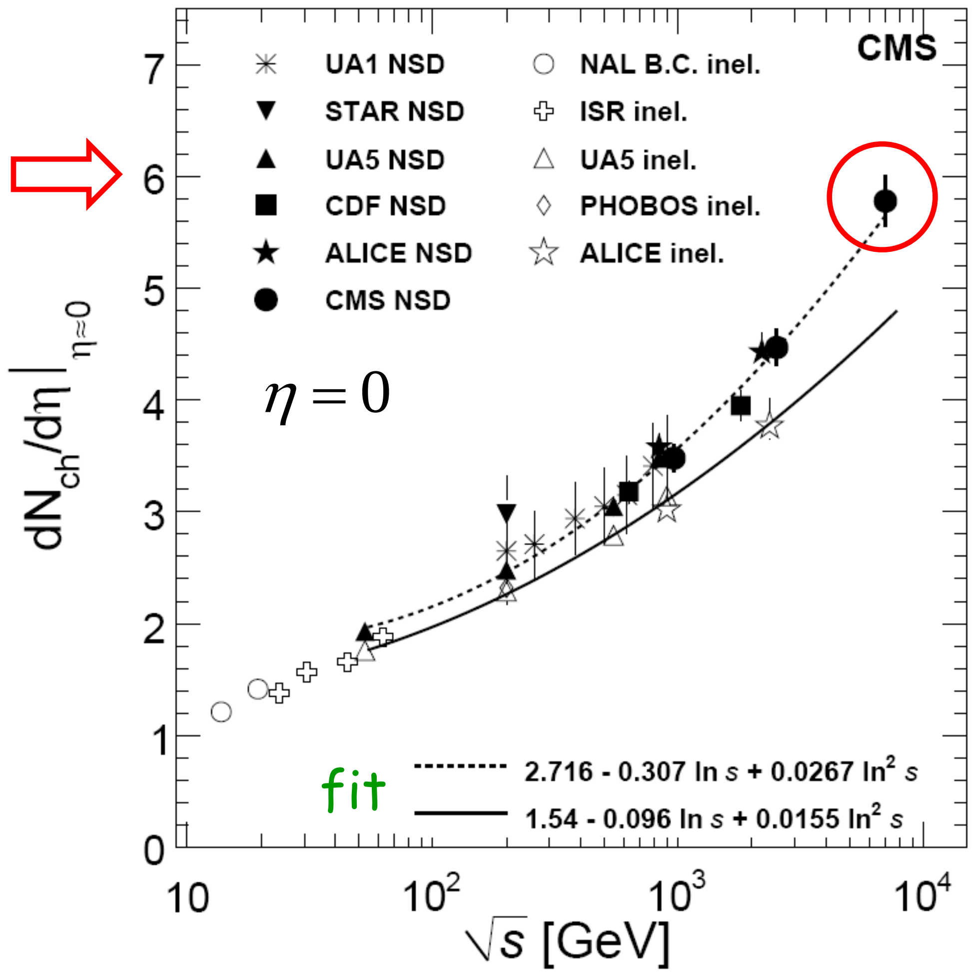


Hadron production

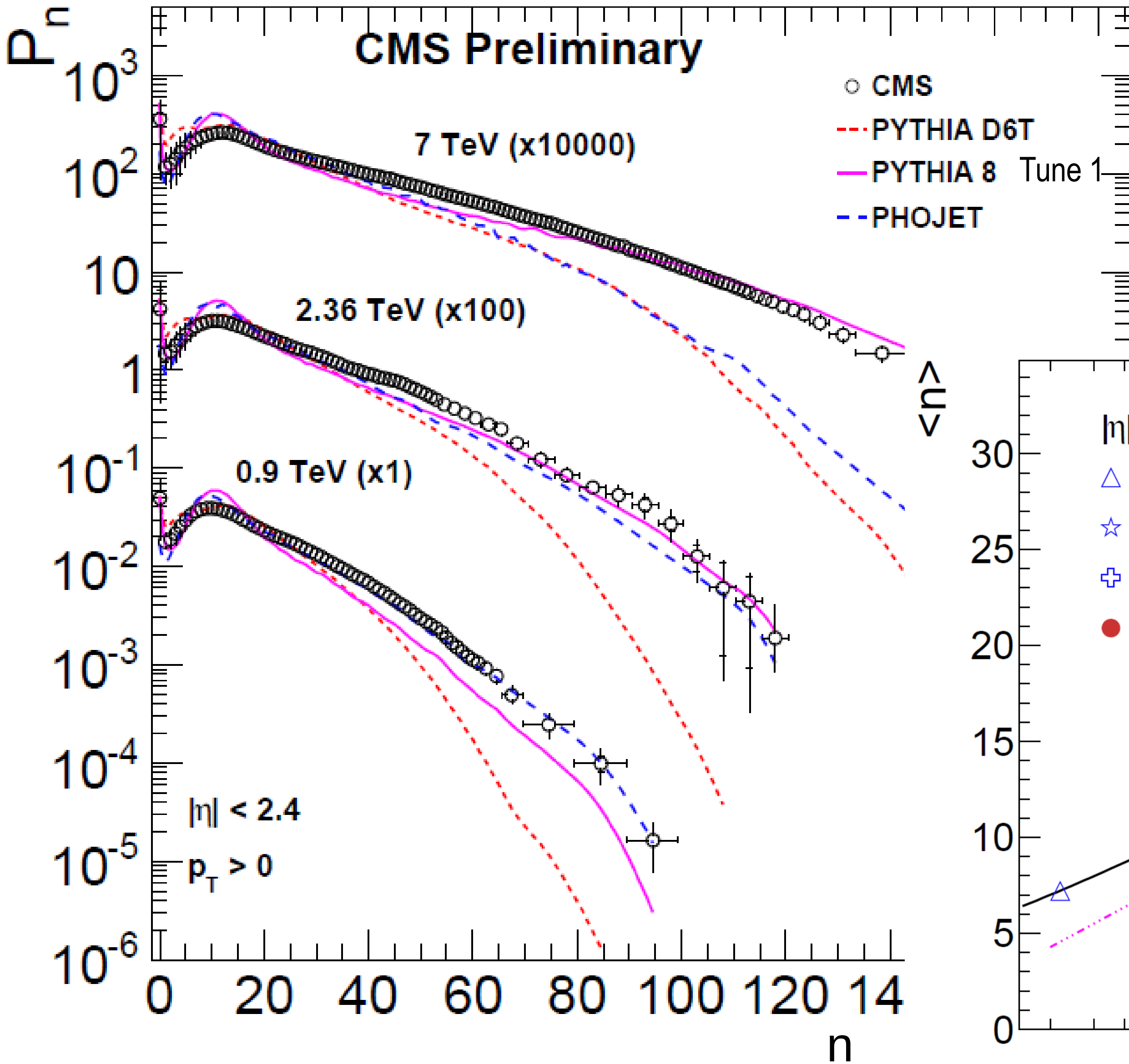
T.Hebbeker



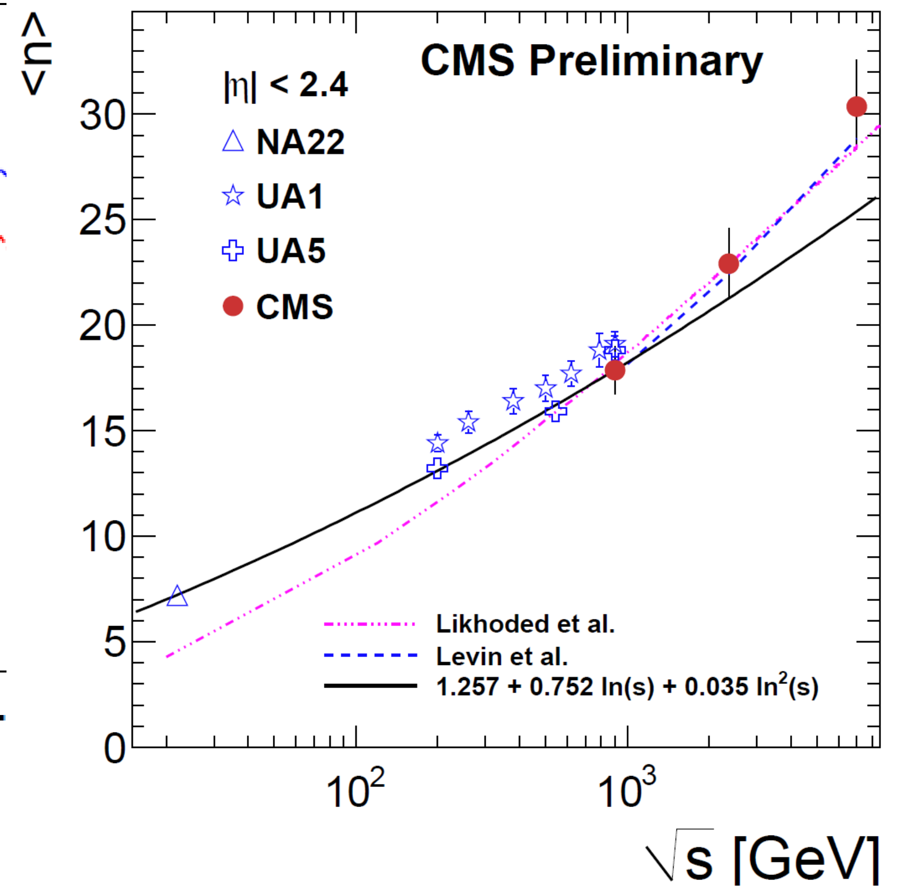


Increase with energy stronger than anticipated !

Charged Particle Multiplicity Distribution

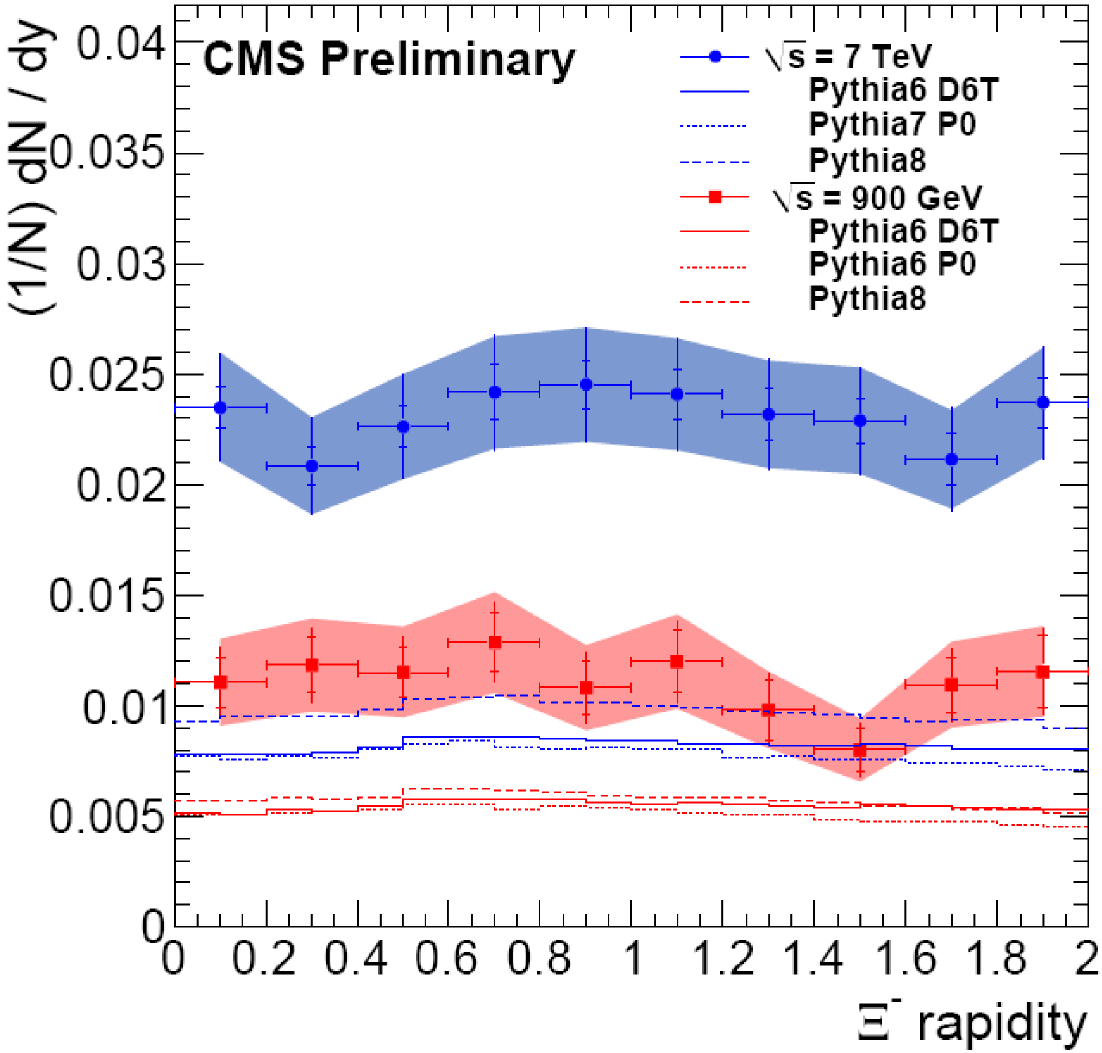


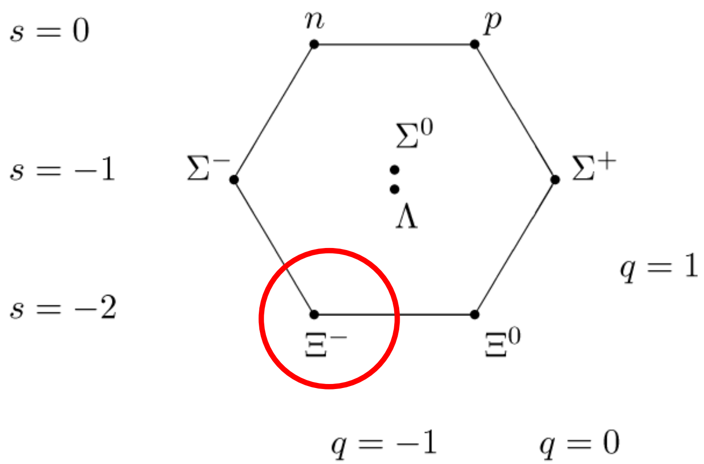
High sensitivity to model parameters!



Inclusive Strange Particle Production

Example: Ξ^-





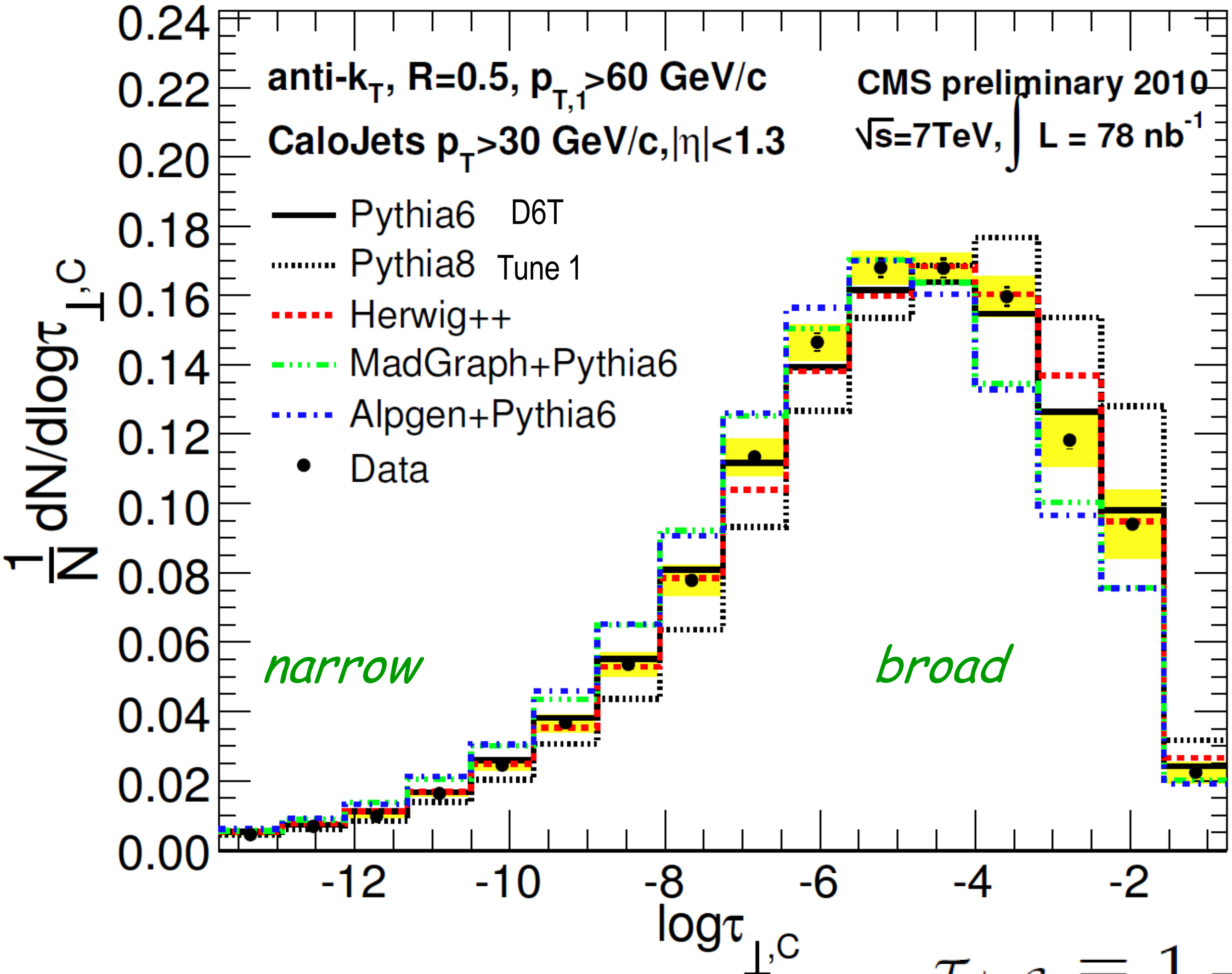
Yield increases strongly with energy

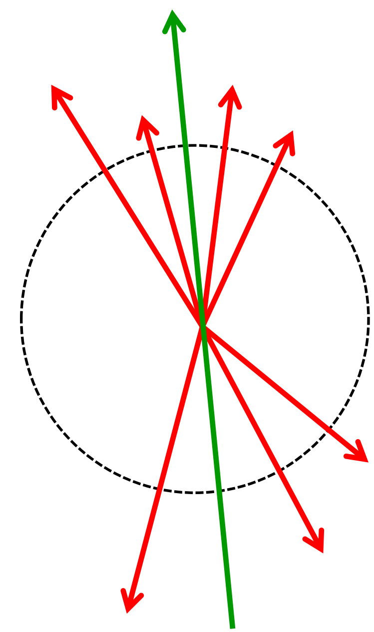
not predicted by current Monte Carlo `tunes`

Hadronic Event Shapes

central transverse thrust
$|\eta| < 1.3$

$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

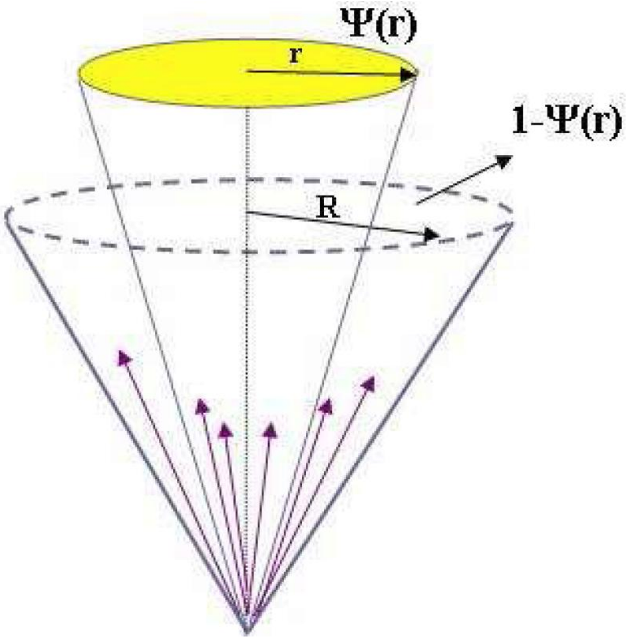




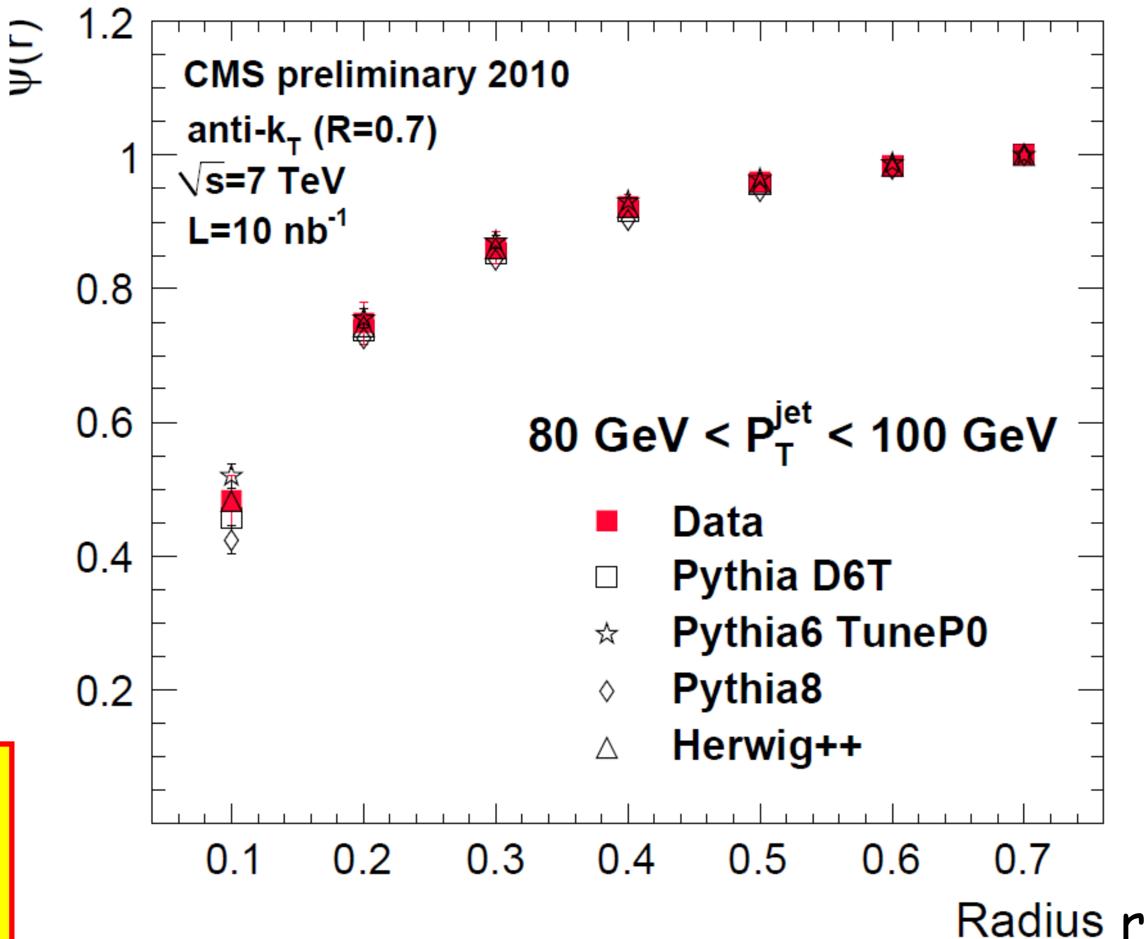
First measurement of event shape variables at LHC

$$\tau_{\perp,\mathcal{C}} \equiv 1 - T_{\perp,\mathcal{C}}$$

Jet Structure



integrated jet shape



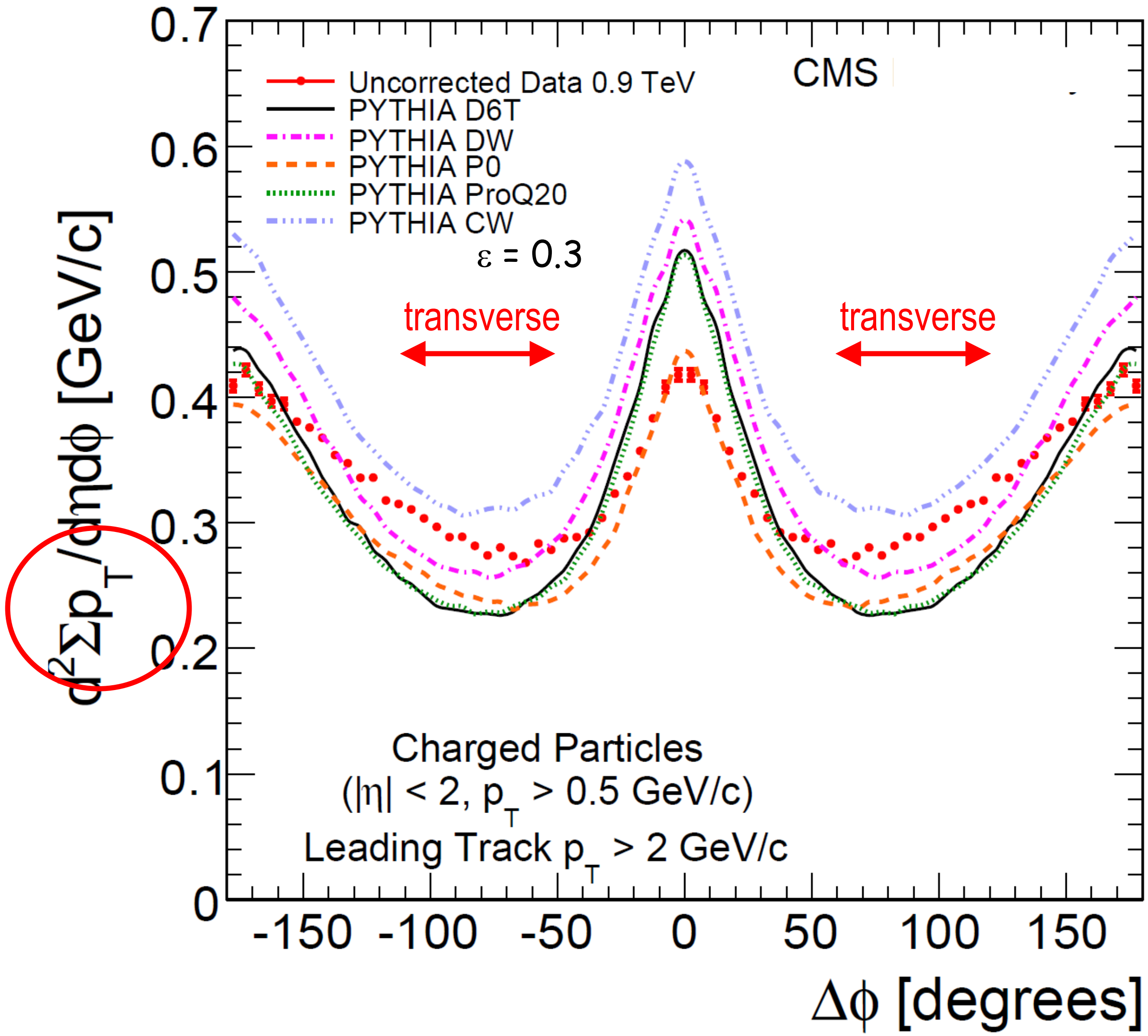
Transverse jet shape: model predictions ok

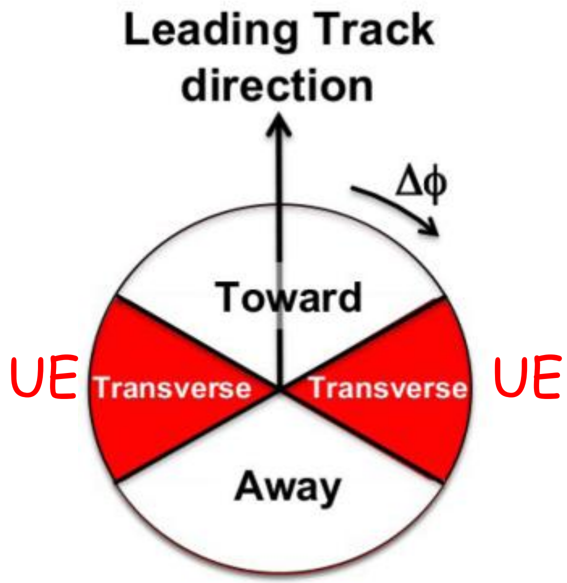
Underlying event activity

Underlying event = UE:

multiple parton interactions + beam beam remnants

[excluding hard process and related initial and final state radiation]

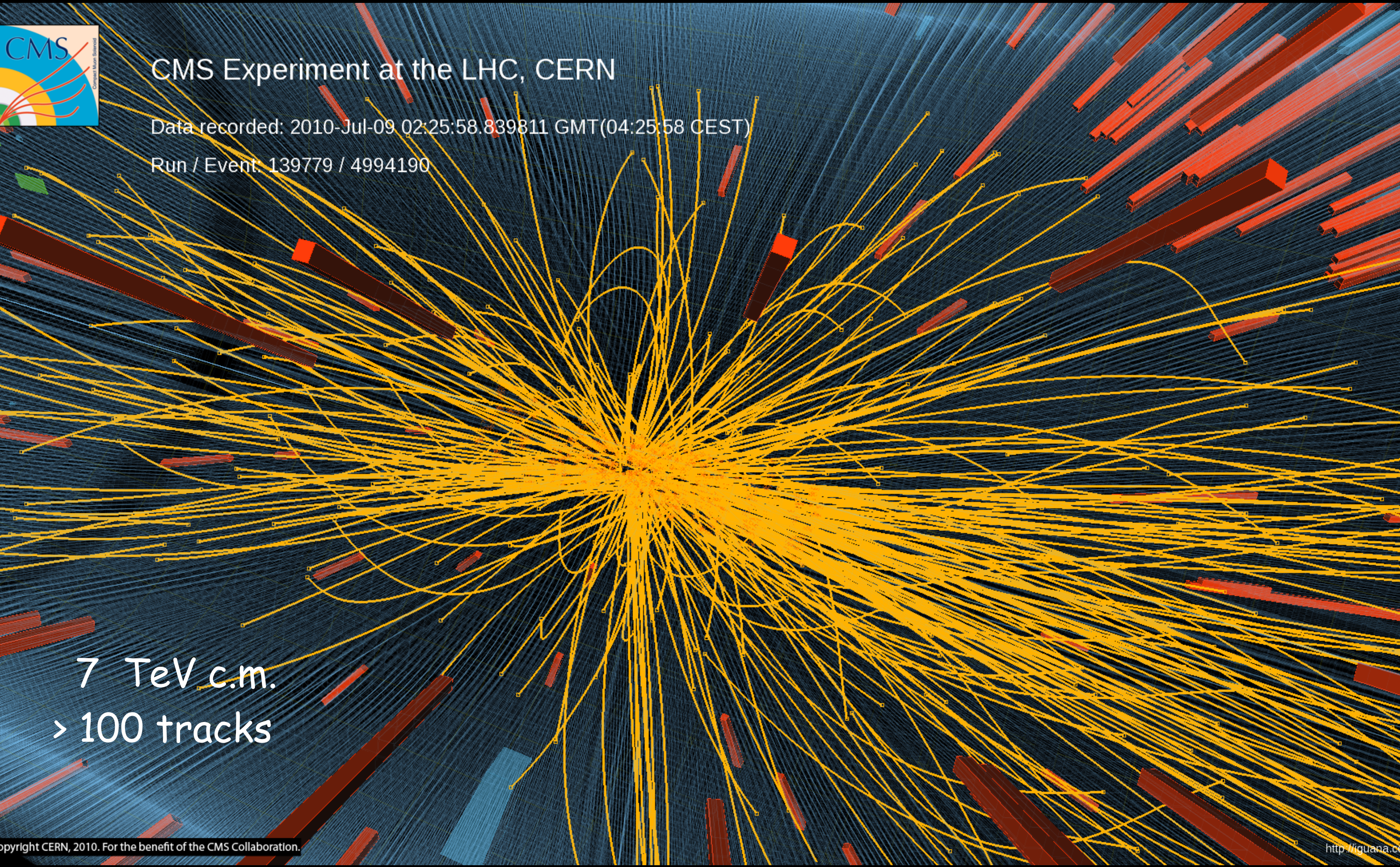




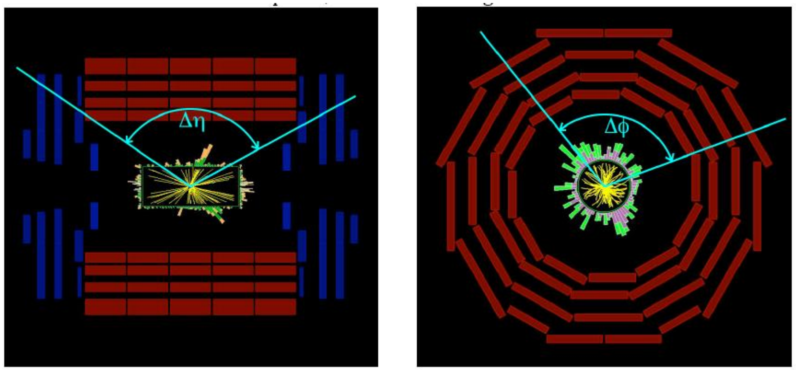
Models tend to underestimate UE

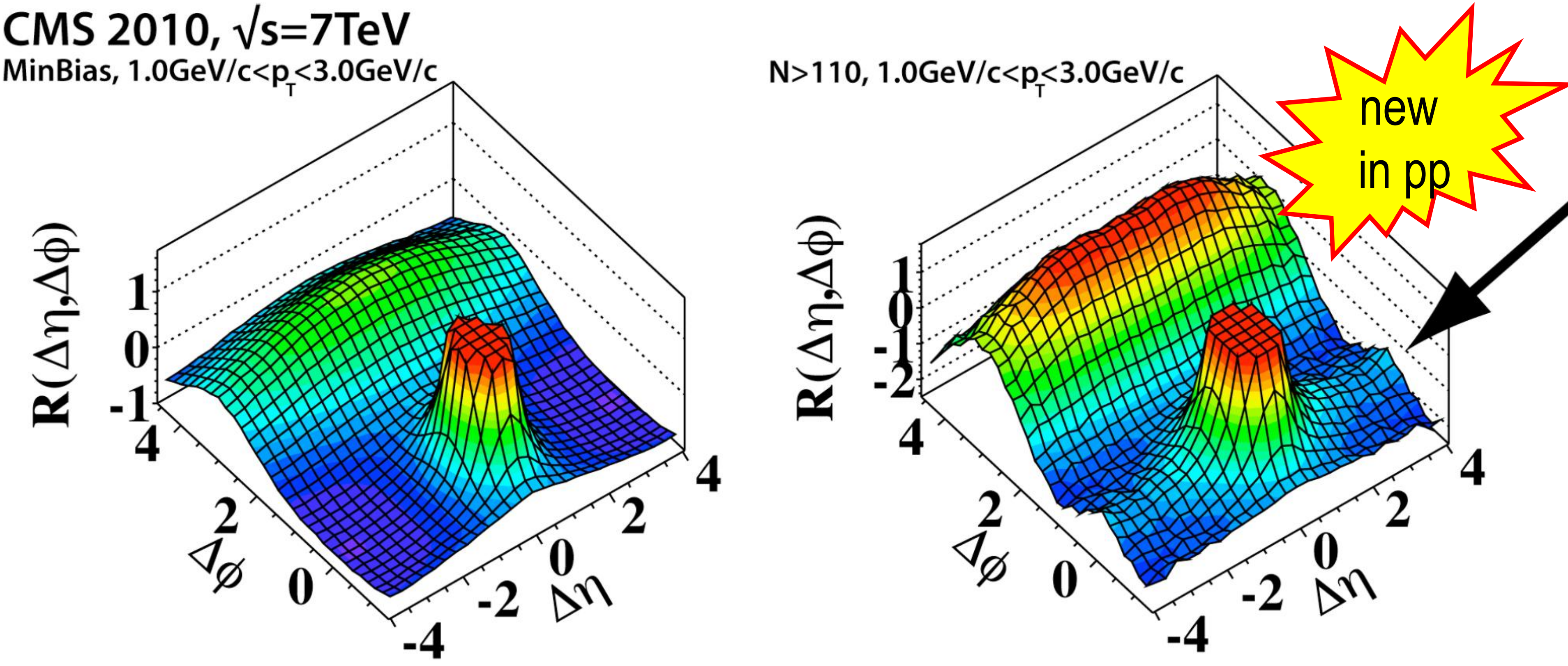
Multi hadron production

dedicated trigger !

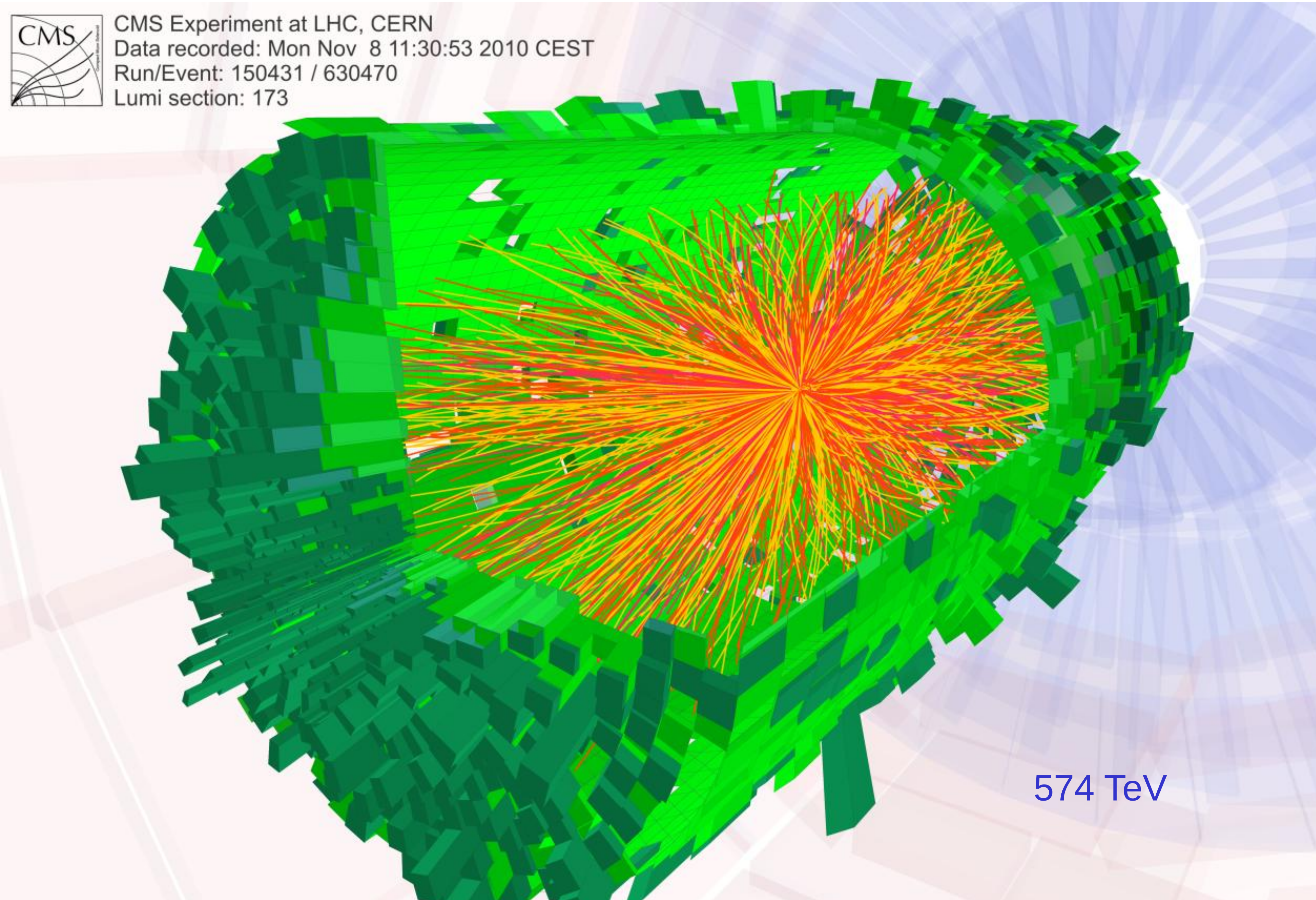


Particle correlations in multi hadron events

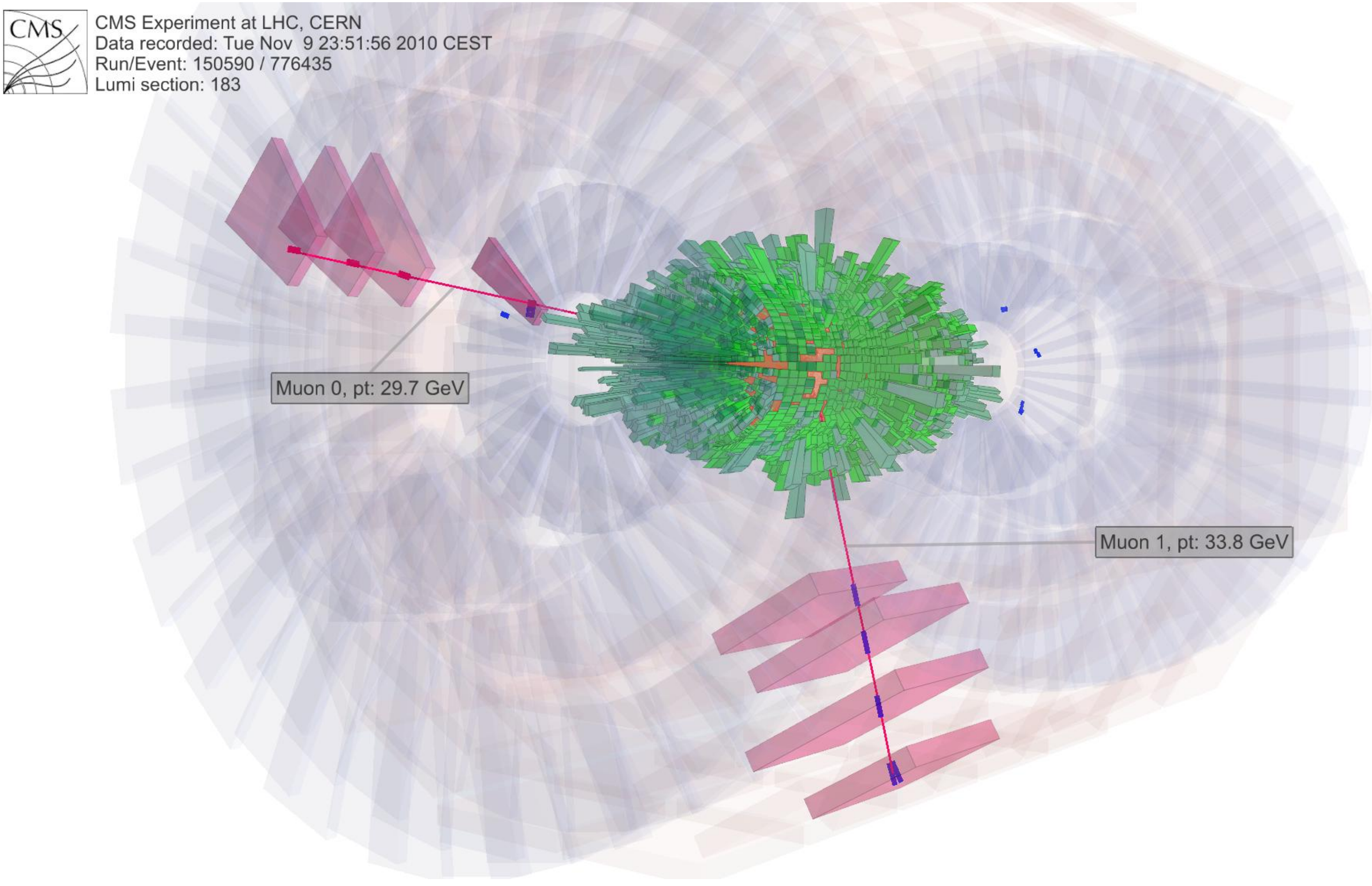




Lead-Lead collision

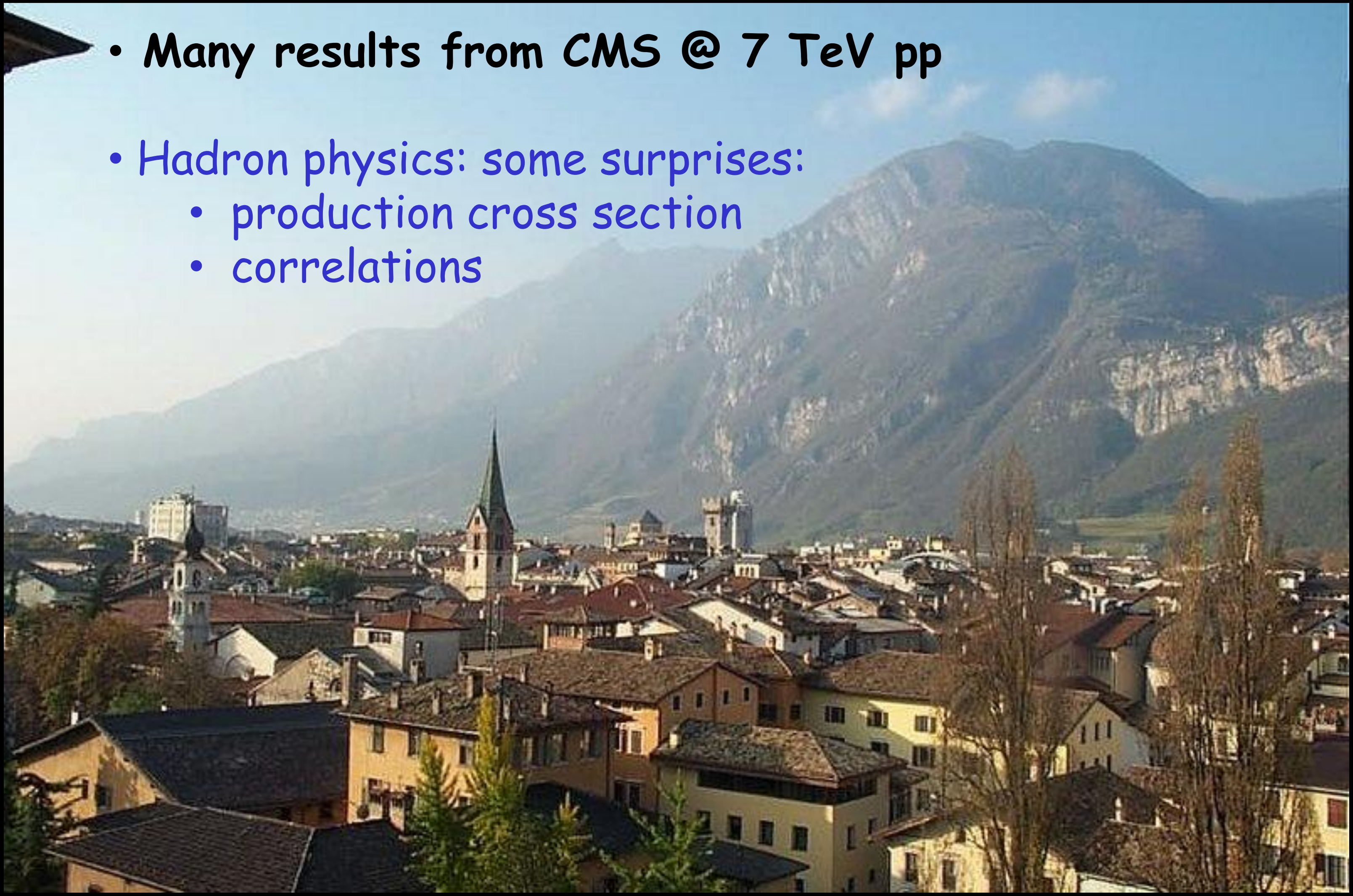


First observation of Z's in heavy ion collisions



Summary

- **Many results from CMS @ 7 TeV pp**
- Hadron physics: some surprises:
  - production cross section
  - correlations

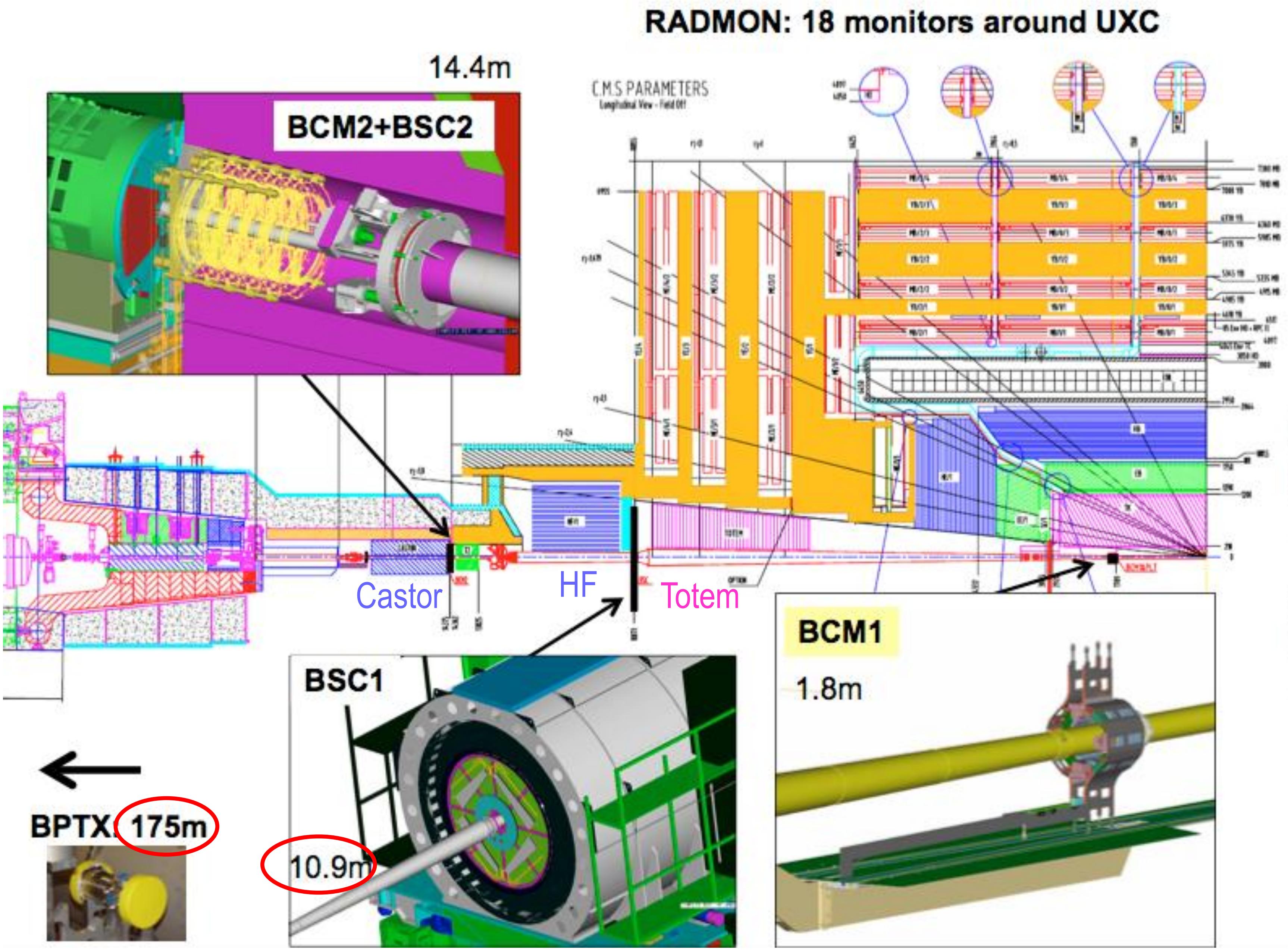


Wikipedia

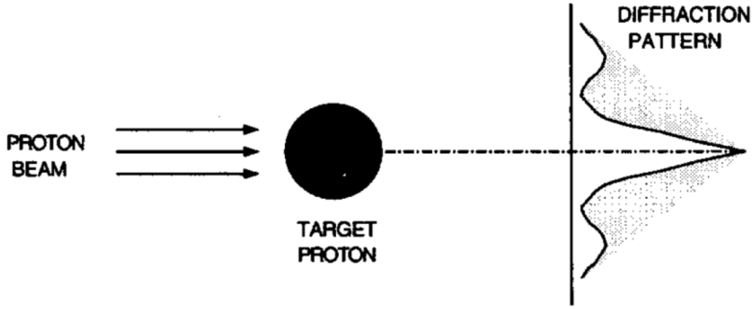
Trento

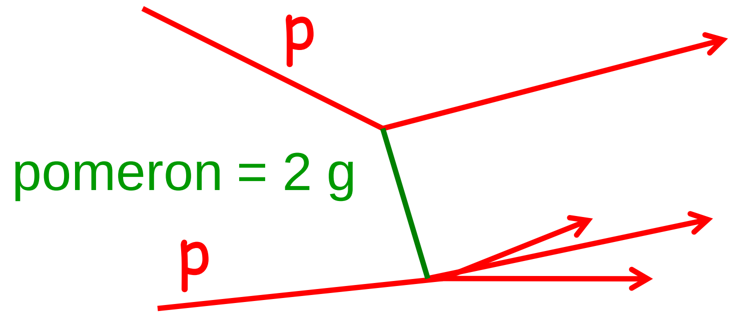
Appendices

CMS forward detectors



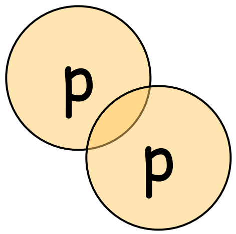
Inelastic processes - typology

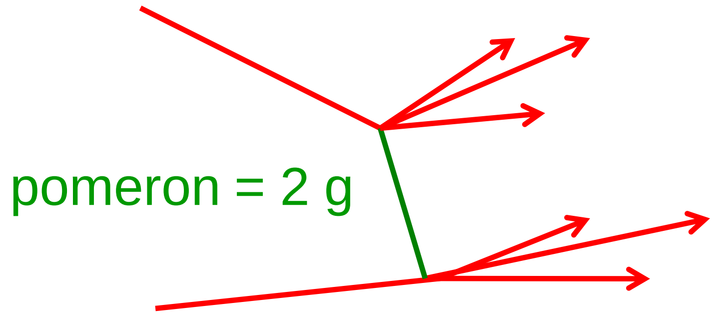




single diffractive

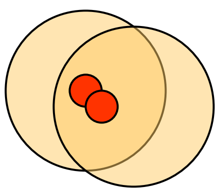
diffractive

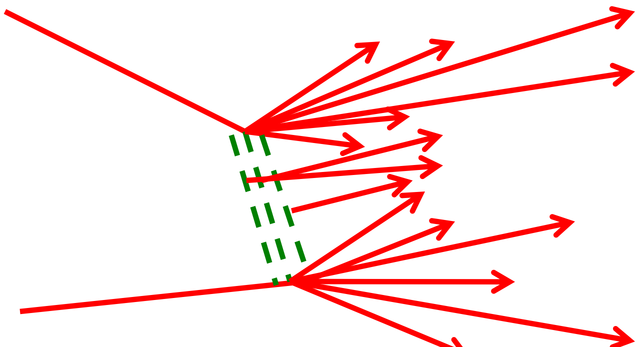




double diffractive

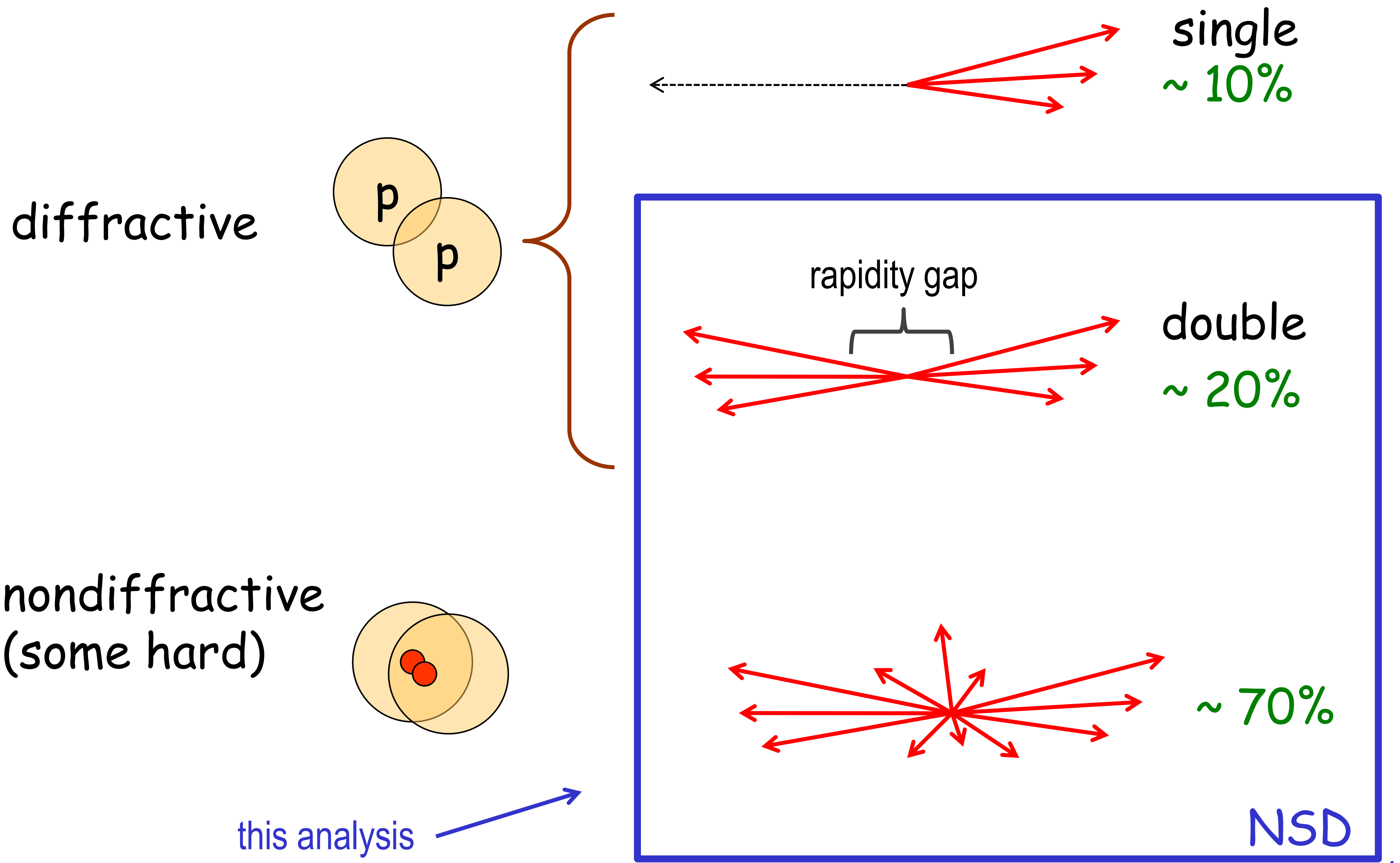
nondiffractive (some hard)



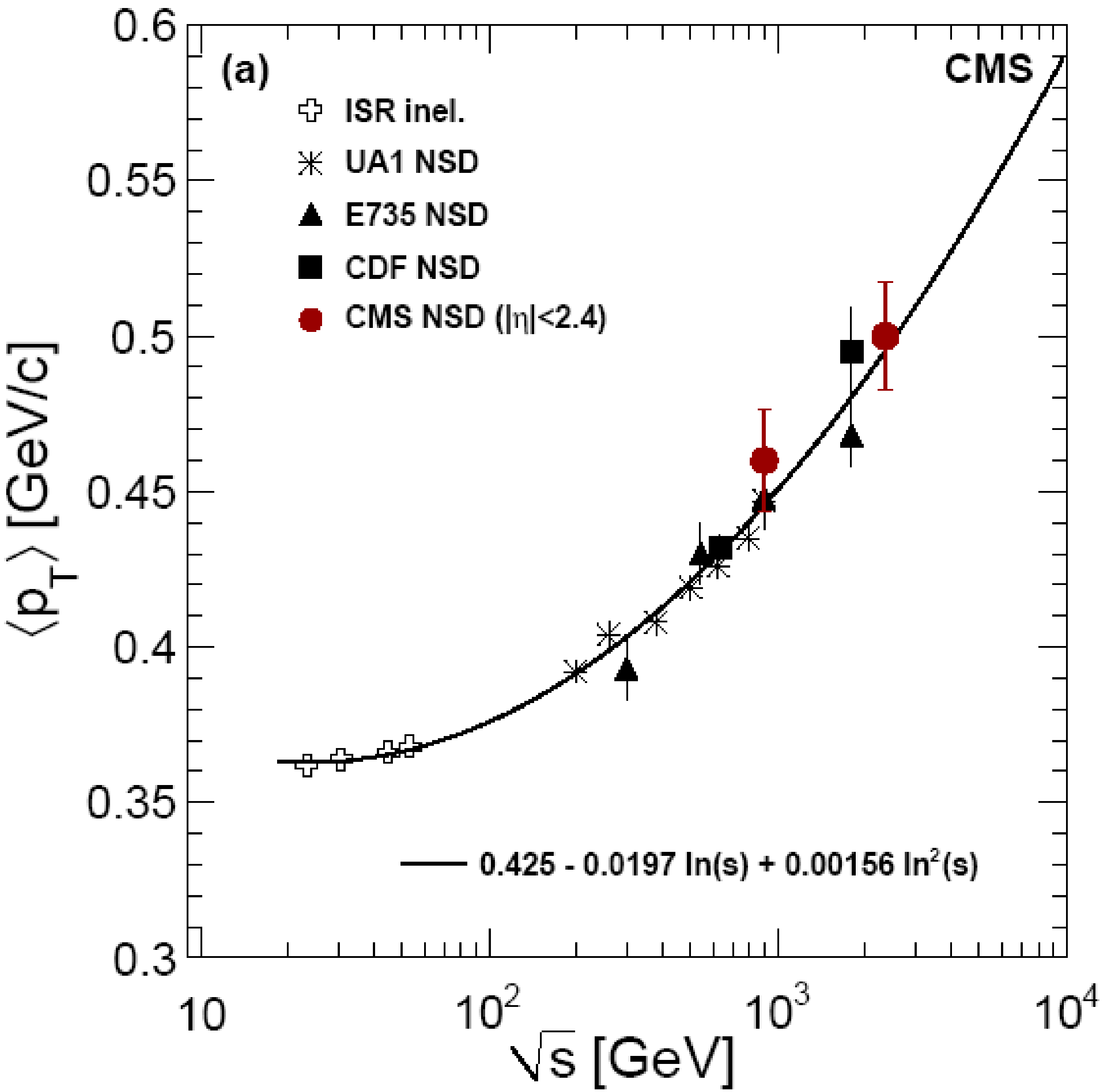


deep inelastic

Inelastic processes - typology



CMS results

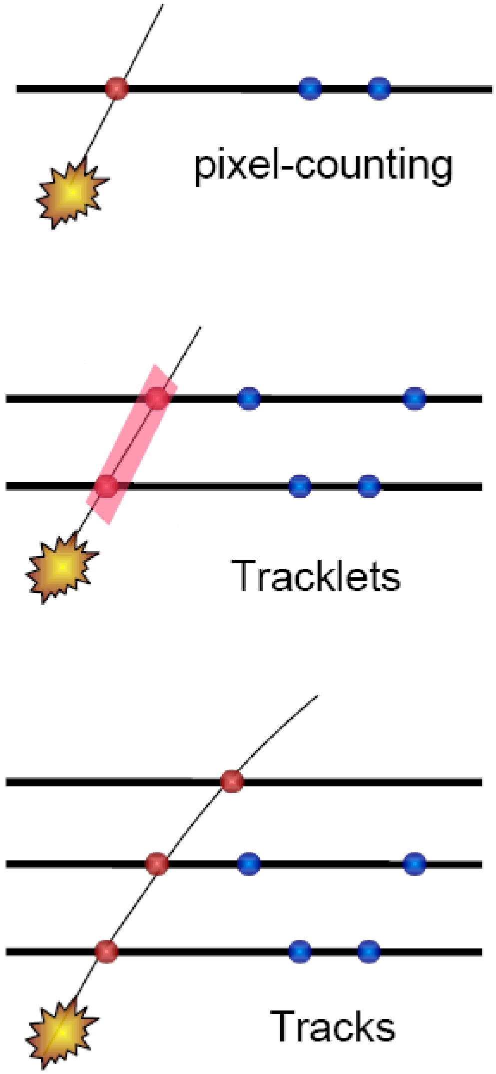


increase!

empirical formula

Charged particle tracking in CMS

θ measurement



$p_T > 30\,MeV$

$p_T > 50\,MeV$

$p_T > 100\,MeV$

NO momentum measurement

Bose-Einstein Correlations in particle collisions

two <u>identical bosons</u> 1,2 from the same source; p = four momentum:

$$R = \frac{P(p_1, p_2)}{P(p_1)\, P(p_2)}$$

$$R = \frac{dN/dQ}{dN/dQ_{ref}} \qquad Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{m_{inv}^2 - 4m_\pi^2}$$

BE off

model ansatz:

$$R(Q) = C\,[1 + \lambda\, e^{-(Qr)^2}]$$

- $(1 + \delta Q)$ phenomenological correction
- 'Gamow factor' correcting for coulomb repulsion of charged particles

physics:

a) QM: interesting (see below)

b) QCD: difficult

CMS BE analysis (0.9 and 2.36 GeV)

general difficulty: what to expect for R(Q) if there is NO BE effect

BE on → BE off →

$$R = \frac{dN/dQ}{dN/dQ_{ref}}$$

need reference sample!

<u>possibilities:</u>

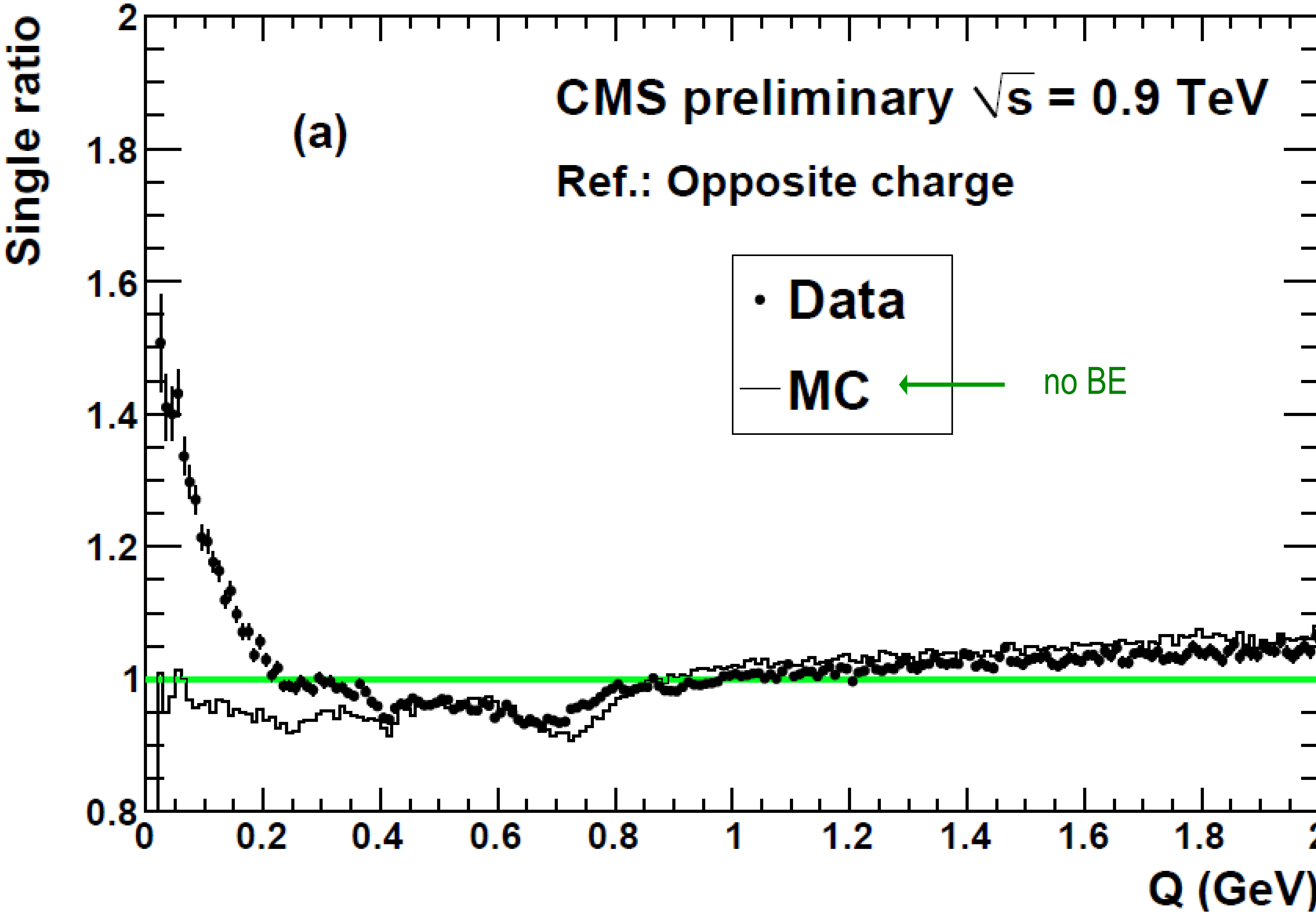
- opposite charge pairs [beware of resonances !]
- opposite hemisphere pairs (invert momentum)
- rotated particles (mirror momentum component x and y)
- mixing particles from different events (several ways of mixing)
- **(Monte Carlo)**

$$\mathcal{R} = R/R_{\mathrm{MC}} = \left(\frac{\mathrm{d}N/\mathrm{d}Q}{\mathrm{d}N/\mathrm{d}Q_{\mathrm{ref}}}\right) / \left(\frac{\mathrm{d}N/\mathrm{d}Q_{\mathrm{MC}}}{\mathrm{d}N/\mathrm{d}Q_{\mathrm{MC,ref}}}\right)$$

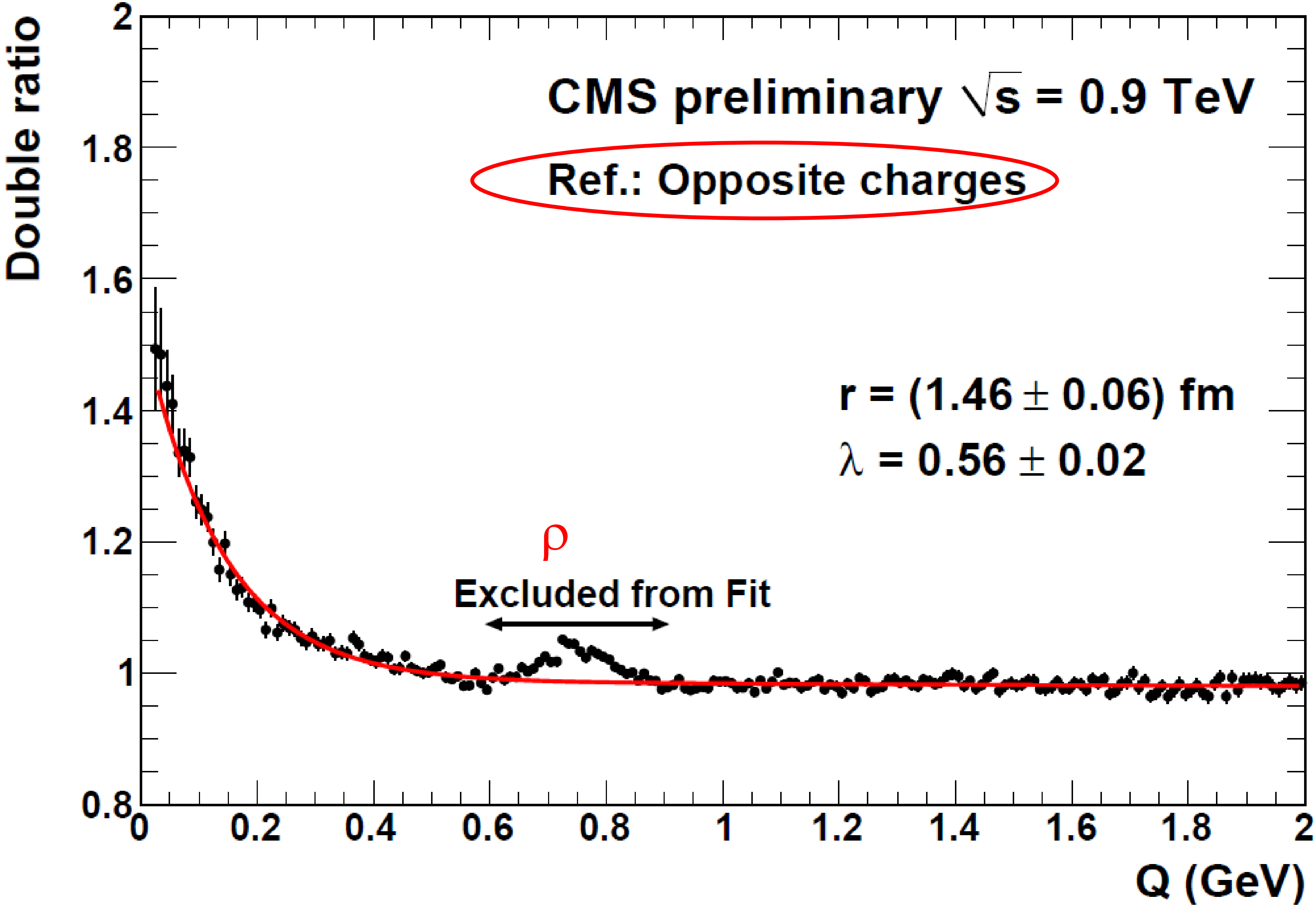
← no BE

double ratio

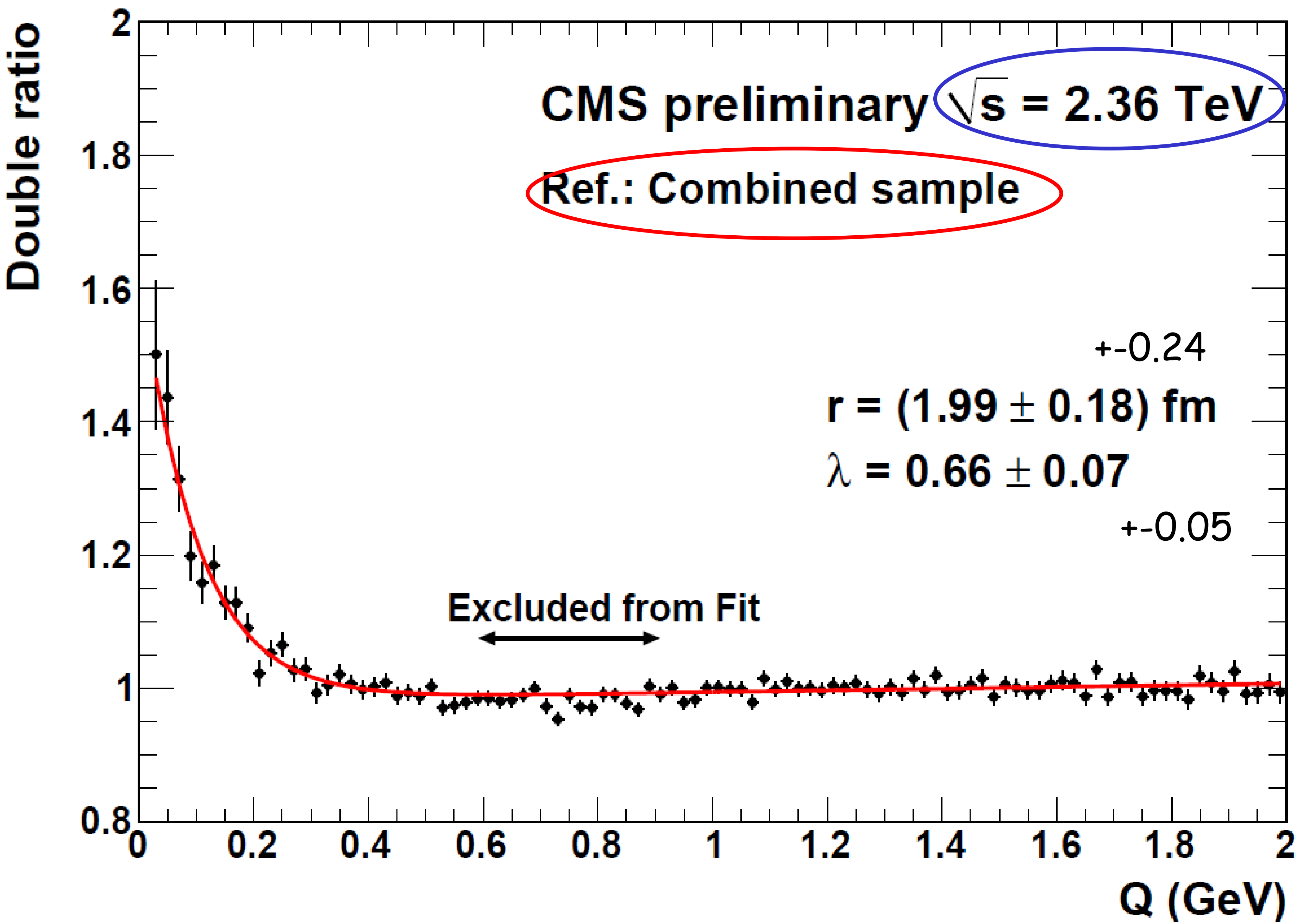
R


Single ratio
2
1.8
1.6
1.4
1.2
1
0.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Q (GeV)
(a)
CMS preliminary √s = 0.9 TeV
Ref.: Opposite charge
Data
MC
no BE

T.Hebbeker



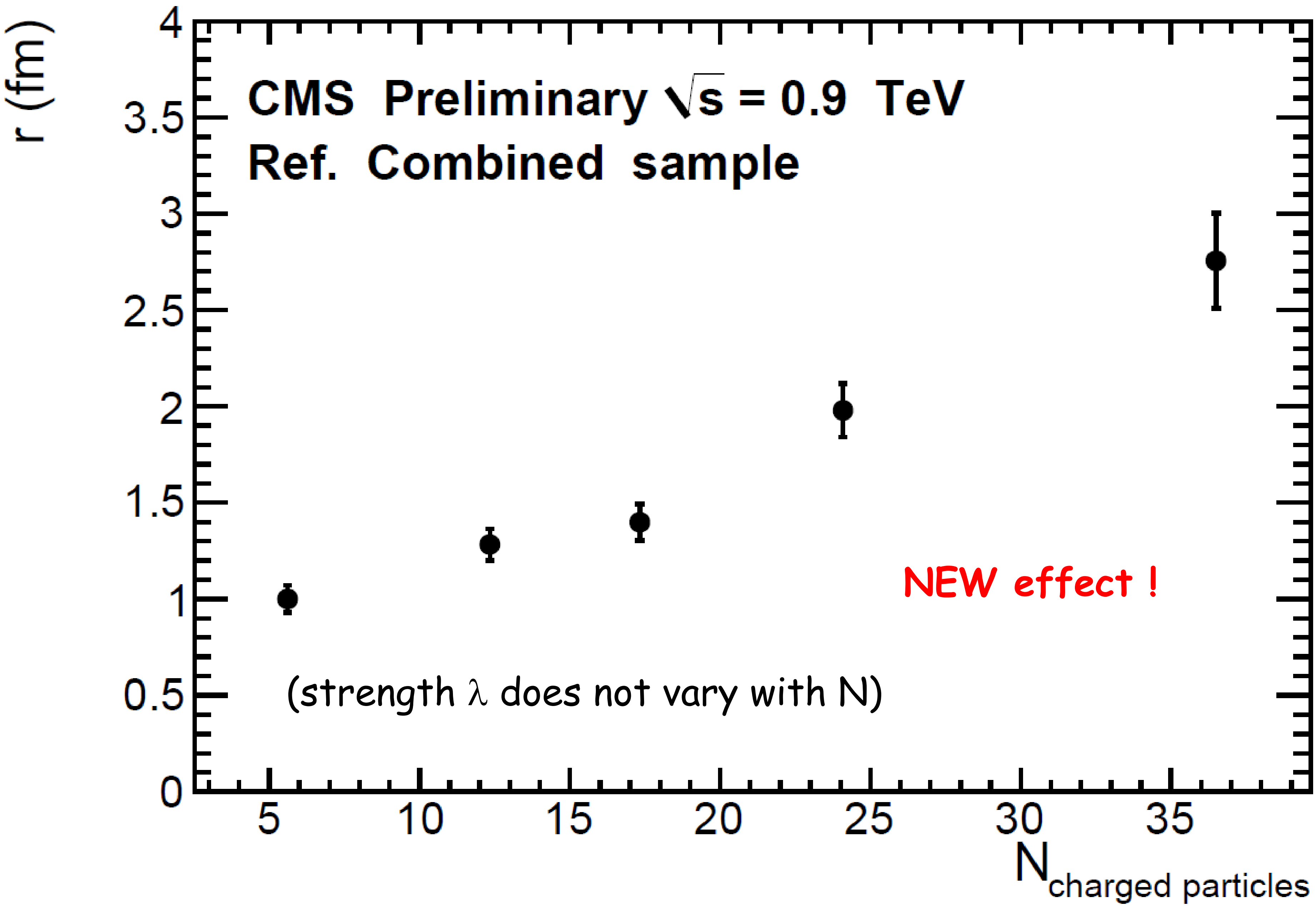
CMS preliminary √s = 0.9 TeV
Ref.: Opposite charges
r = (1.46 ± 0.06) fm
λ = 0.56 ± 0.02
ρ
Excluded from Fit
Double ratio
Q (GeV)
2
1.8
1.6
1.4
1.2
1
0.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



CMS preliminary √s = 2.36 TeV
Ref.: Combined sample
+-0.24
r = (1.99 ± 0.18) fm
λ = 0.66 ± 0.07
+-0.05
Excluded from Fit
Double ratio
Q (GeV)
2
1.8
1.6
1.4
1.2
1
0.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Dependence on particle multiplicity in event

T.Hebbeker

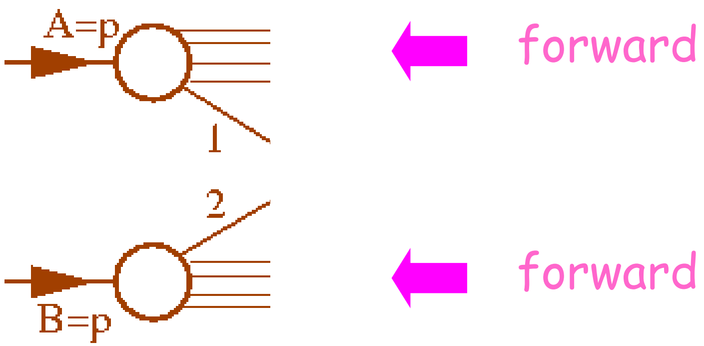


„Dirty“ environment

- **beam remnants**

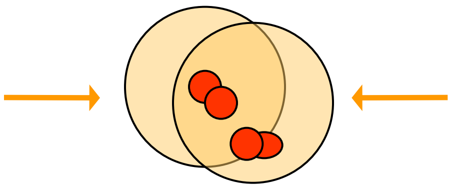
  from hadronization

  of ‘other’ partons



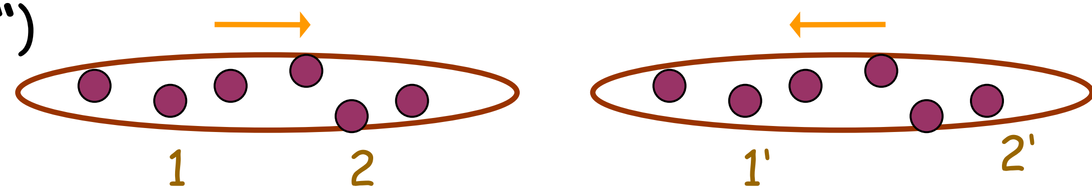
- **multiple parton interactions**

  some percent



- **multiple p p int. („pile up“)**

  so far rare !



- **„detector pile up“**
  - drift time > bunch distance
  - thermalized neutrons

Terminology: often unclear

• **Zero Bias event:**
random trigger not looking at the detector: detector noise+collisions

• **Minimum Bias event** (try to minimize trigger bias!):
triggered as inelastic pp interaction(s) [diffractive or hard scattering]

$$\sigma \sim 80mb = 80\% \, \sigma_{tot}$$

trigger

Note: PAS **avoids** these terms (minimum bias etc) !

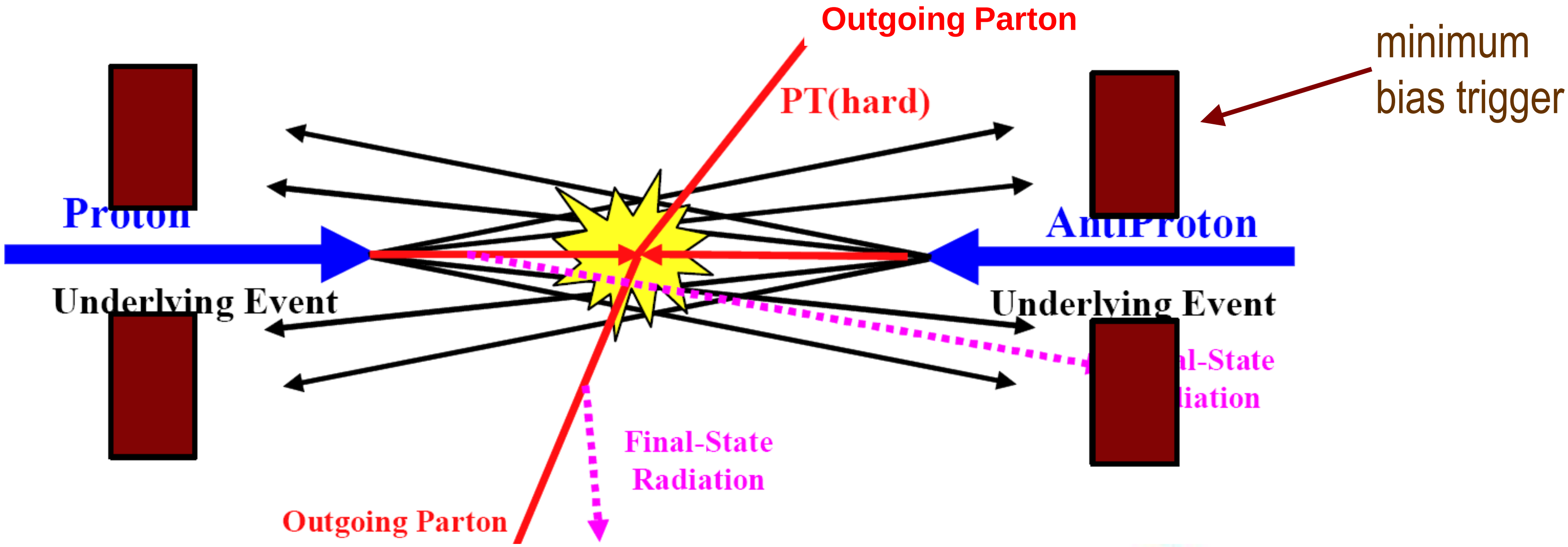
• **Underlying event (UE)**:
multiple parton interactions (MPI) + beam beam remnants (BBR)
[excluding hard process and related initial and final state radiation]

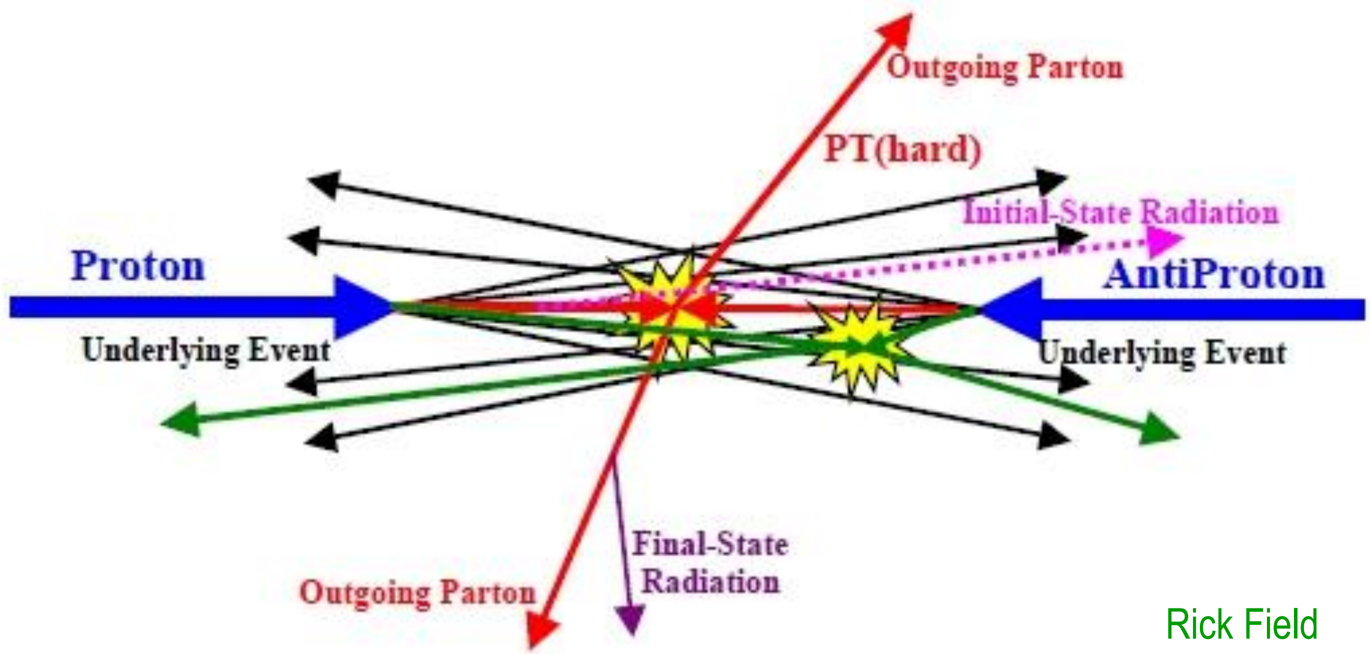
• **multiple interactions (sometimes "pile up")**
adding up several pp interactions (with all that is in there)

• **detector pile up:**
in-time (same crossing) and out-of-time (different crossings)

physics

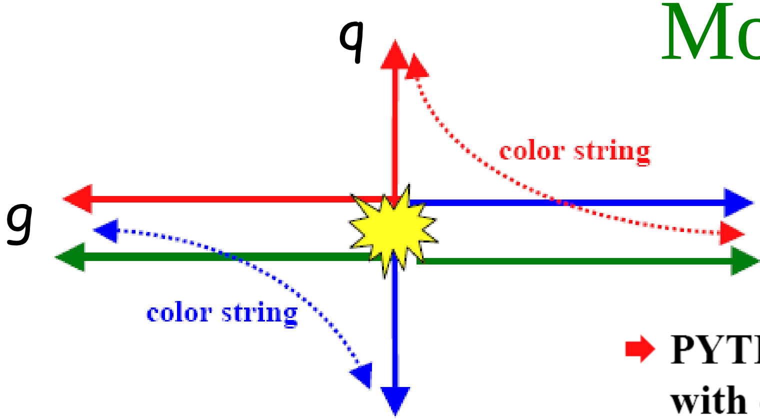
Underlying event





Rick Field

Modeling ?



not ab initio, non perturbative !

- PYTHIA models the "soft" component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (MPI) in which one interaction is hard and the other is "semi-hard".

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the "nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed [illegible] g fraction consists of
PARP(89)	1 TeV	D[illegible]ines the reference energy E_0.
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

Affects the amount of initial-state radiation!

ε parameter, see below

Rick Field

Model “tunes” – ε parameter

PYTHIA D6T	$\varepsilon = 0.16$
PYTHIA DW	0.25
PYTHIA P0	0.25
PYTHIA ProQ20	0.25
PYTHIA CW	0.30

“strong energy dependence”
(here: “down” from CDF to CMS!)

non perturbative cutoff for cross sections:

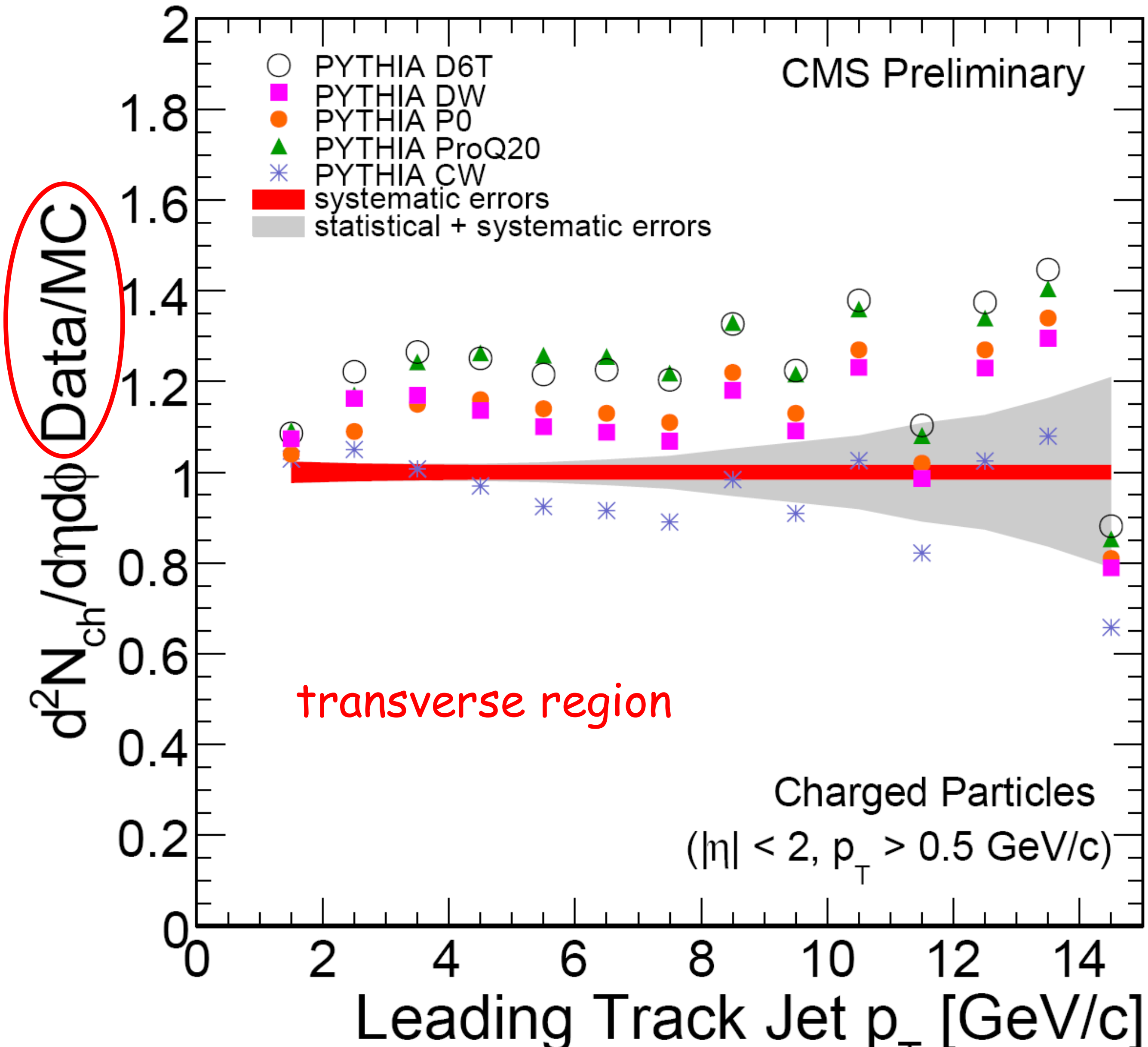
$$\frac{1}{\hat{p}_T^4} \Rightarrow \frac{1}{(\hat{p}_T^2 + p_{T_o}^2)^2}$$

ε

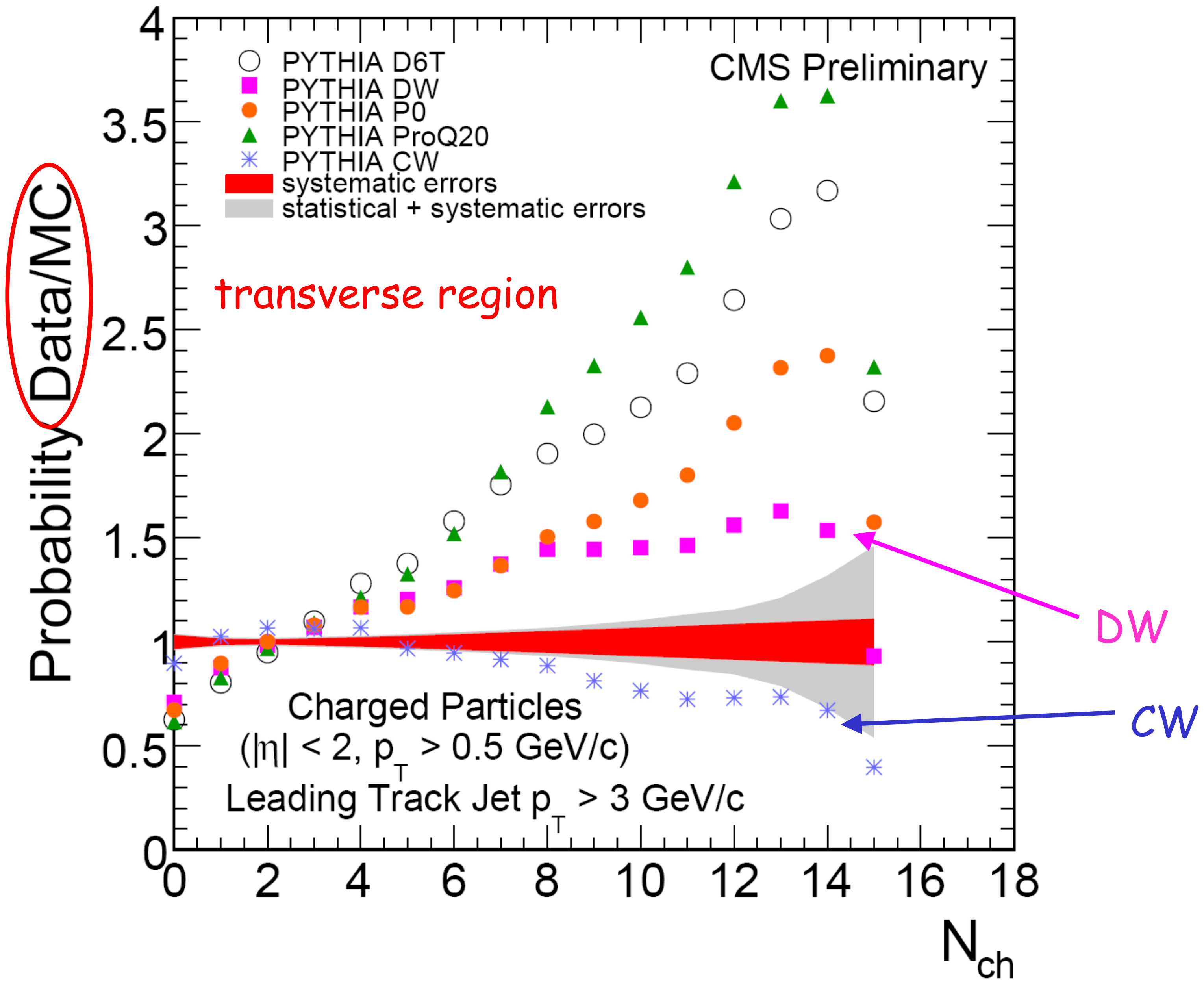
$$p_{T_0}(\sqrt{s}) = p_{T_0}(\sqrt{s_0}) \cdot \left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{\varepsilon}$$

$2.0 GeV (1.8 TeV)$

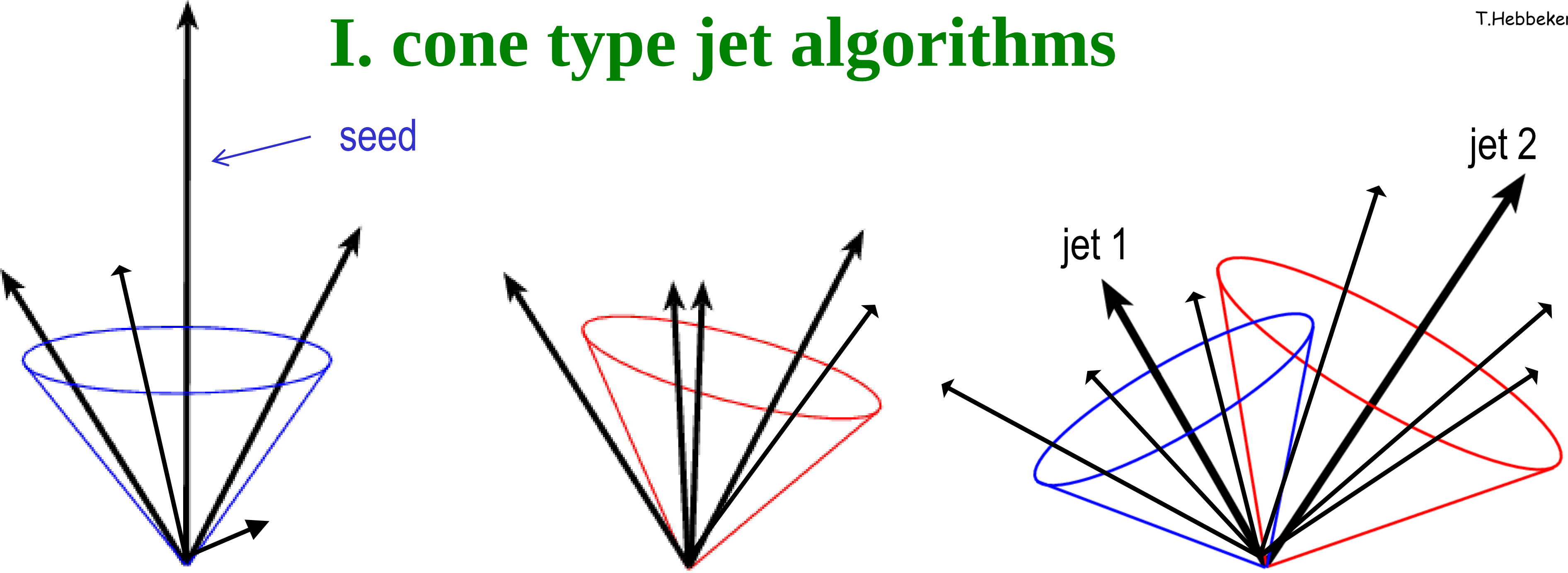
Model comparisons



Model comparisons



I. cone type jet algorithms



Cone defined in η, φ projection, radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$ (typ = 0.5)

Isolated low energy particles are ignored

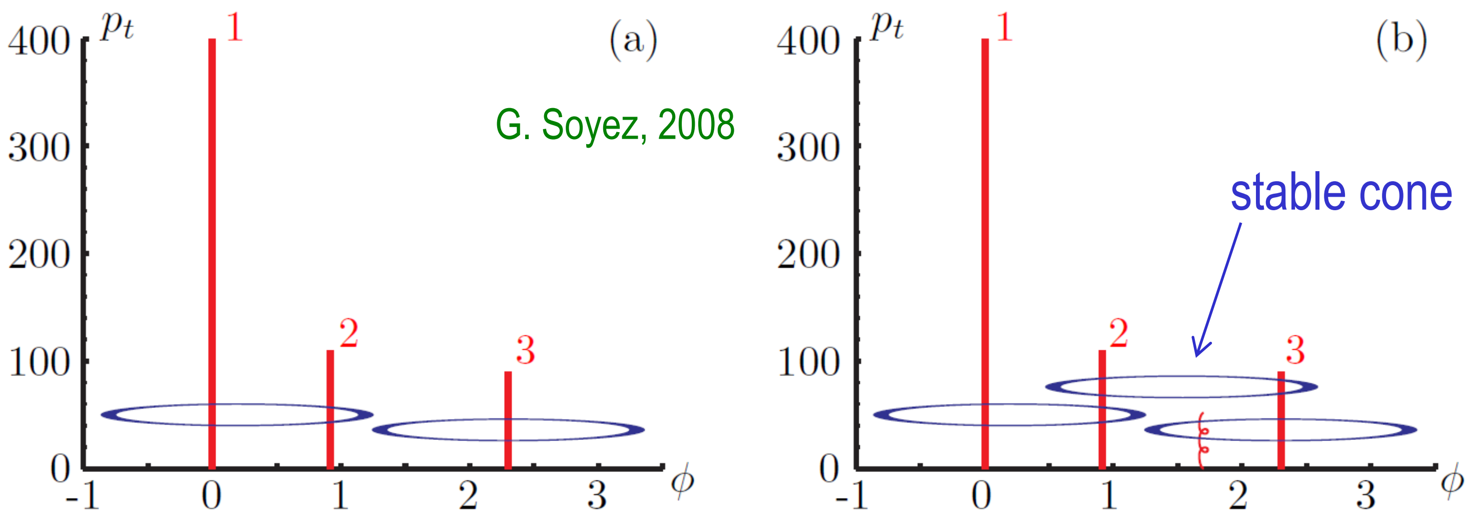
Sum of 4-momenta of objects inside cone = jet 4-momentum

potential problems: seed dependence, overlapping jets, infrared sensitivity ...

several variations exist

SISCone algorithm

Example for cone algorithm that is **NOT** infrared safe:



midpoint algorithm

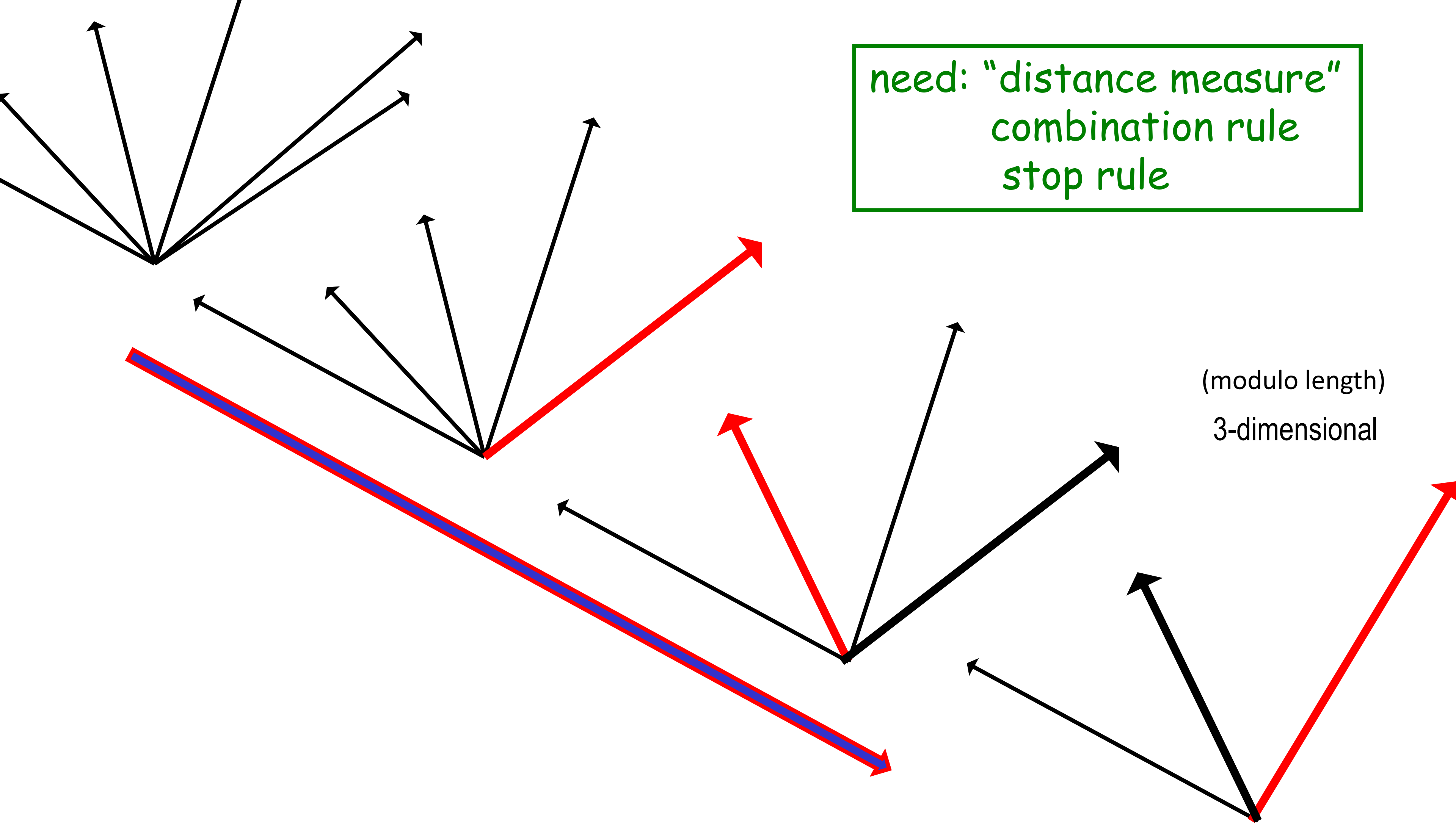
SISCone = Seedless Infrared Safe Cone:

- uses all combinations of particles to find find all ‚stable cones'
- clever implementation :
  avoid excessice number of combinations to be tested
- **infrared and collinear stable**

P. Salam et al, 2007

II. sequential jet algorithms

need: “distance measure”
combination rule
stop rule



disadvantage: computing time grows strongly with number of particles

several variations exist: eg kT, Cambridge/Aachen

infrared and collinear stable

kT jets

$(kT = k_t = p_T = \ldots)$

i) list of hadrons = clusters

ii) each cluster:

$$d_{iB} = p_{T,i}^2$$

each pair of clusters:

$$d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) \cdot \Delta_{ij}^2$$

$$\Delta_{ij}^2 = (\Delta\eta_{ij})^2 + (\Delta\varphi_{ij})^2$$

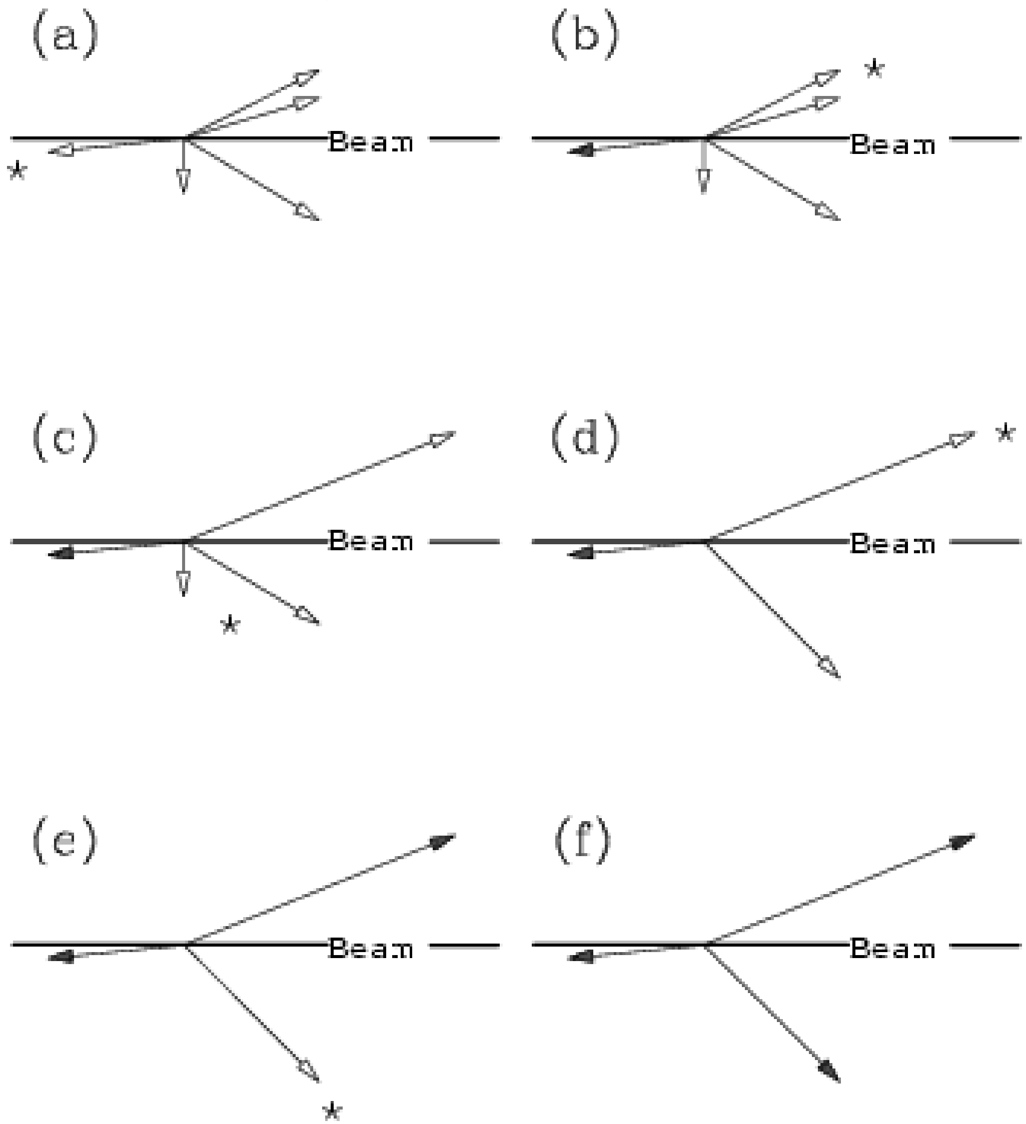
iii) minimum of d_{ij} , d_{iB}

→ combine or remove from list

iv) iterate: goto ii)

till list empty

Example:



S. Catani et al, S.D. Ellis et al, 1993

anti-kT algorithm

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2}$$

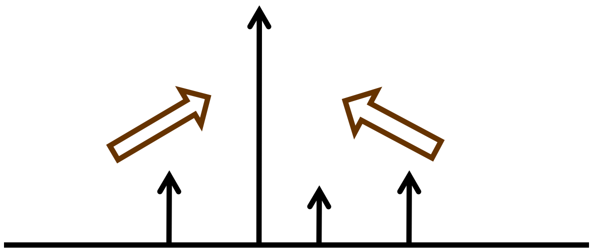
$$d_{iB} = k_{ti}^{2p} \, ,$$

parameter
CMS: R = 0.5

```
kT:                   p = +1
Cambridge/Aachen:     p =  0
Anti-kT:              p = -1
```

first combines soft particles with nearby hard particle

All infrared and collinear safe

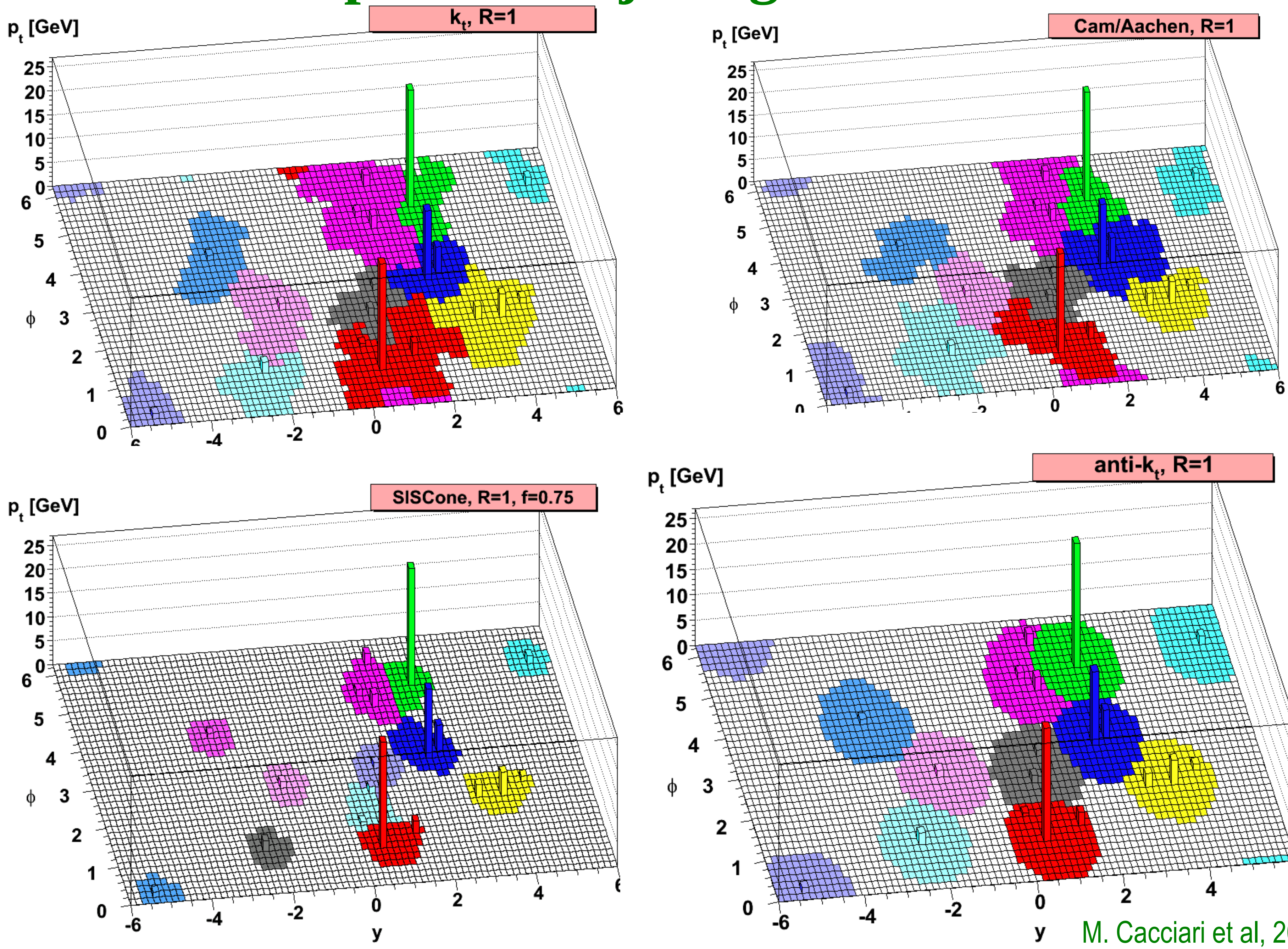


cone algorithm like behavior !
Combines the best properties of the two „jet worlds“ !

M. Cacciari et al, 2008

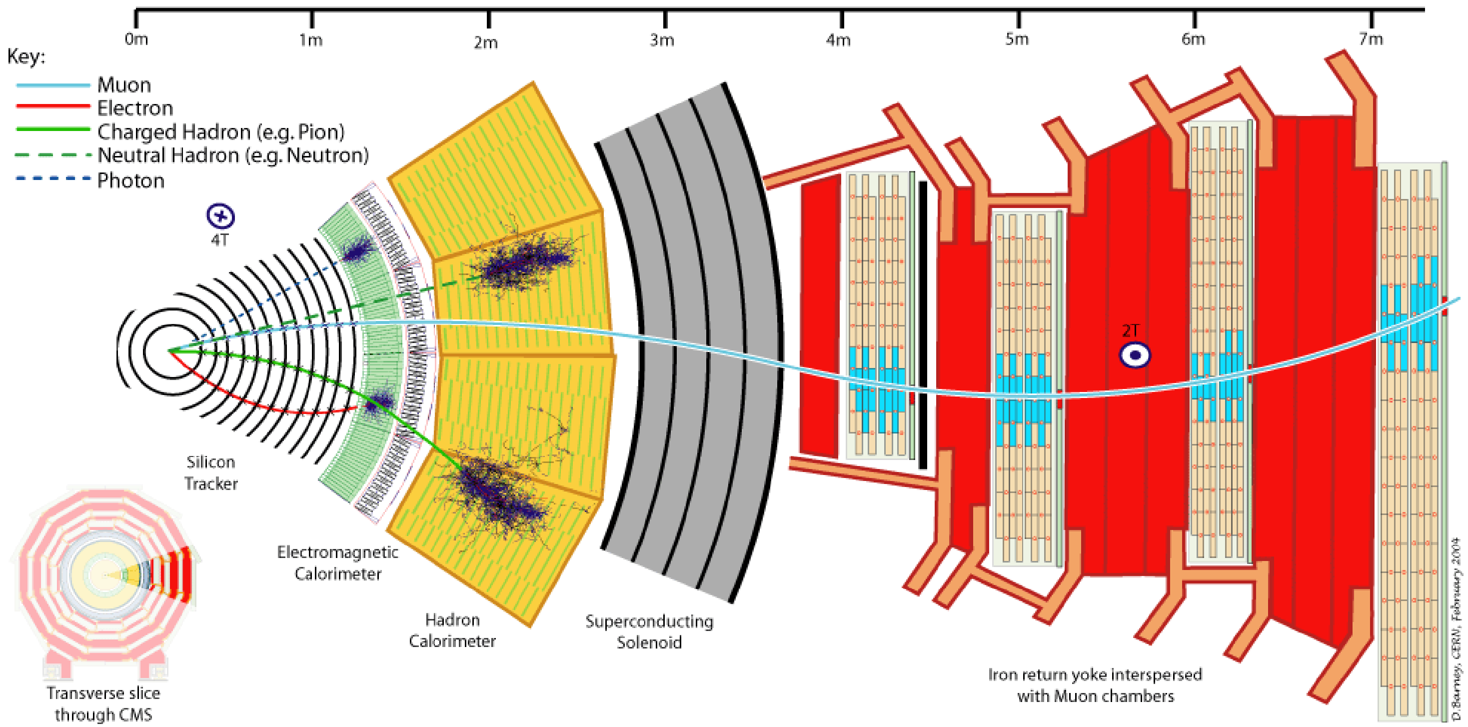
Comparison of jet algorithms

T.Hebbeker



M. Cacciari et al, 2009

Jet (re)construction in CMS



Jet algorithm:
anti-kT, R=0.5

- Calorimeter jets (CaloJets)
- Jet-Plus Tracks (JPT)
- Particle Flow (PF)

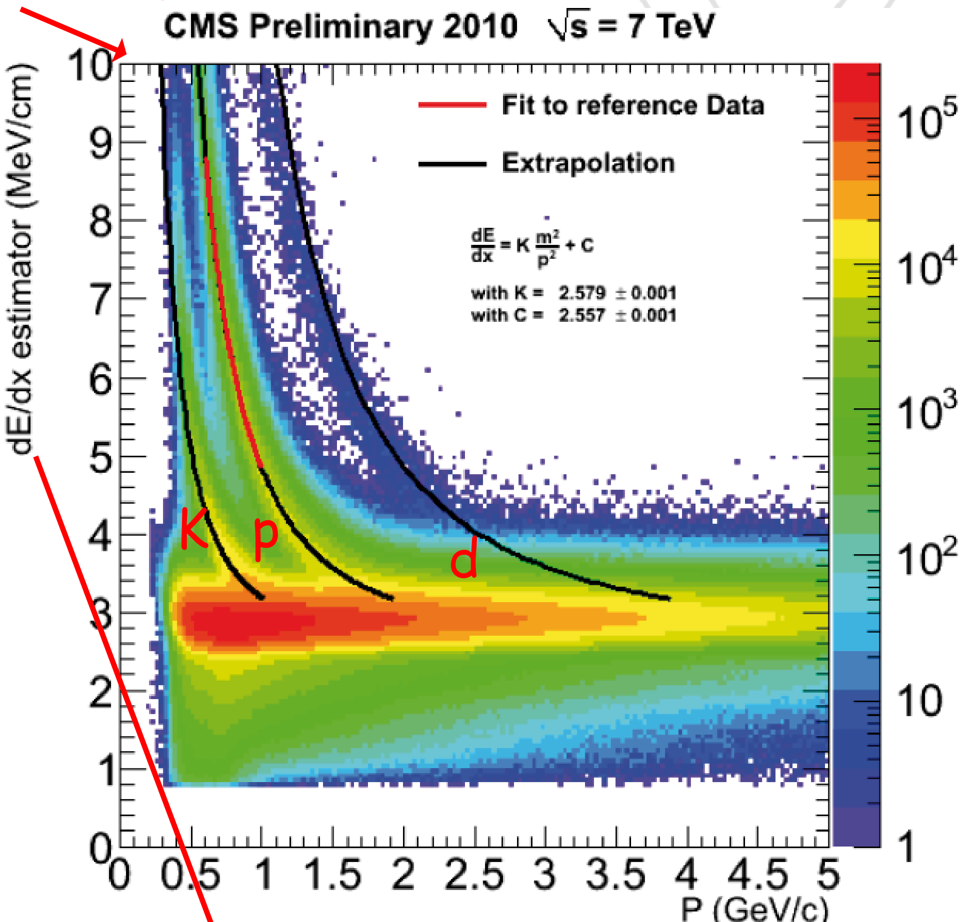
compare → dijets, incl. jets

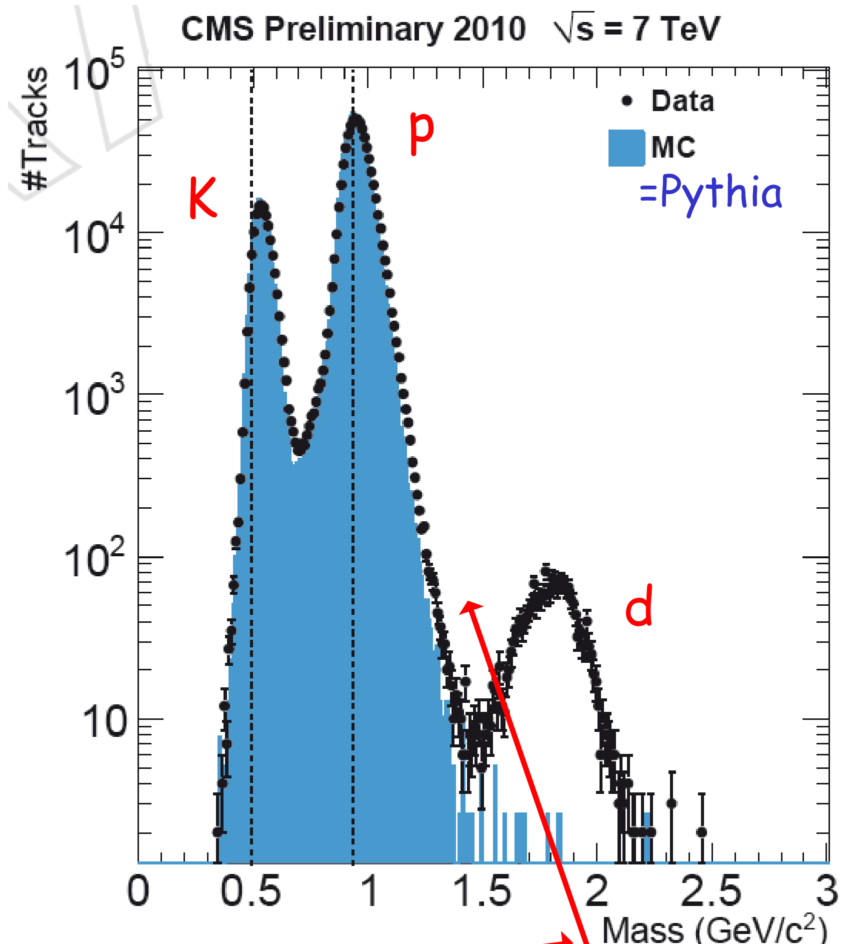
T.Hebbeker

Ionization measured in silicon tracker (ADC)

- known particles -

ADC range





$$I_h = K\frac{m^2}{p^2} + C$$

(most probable value, not mean)

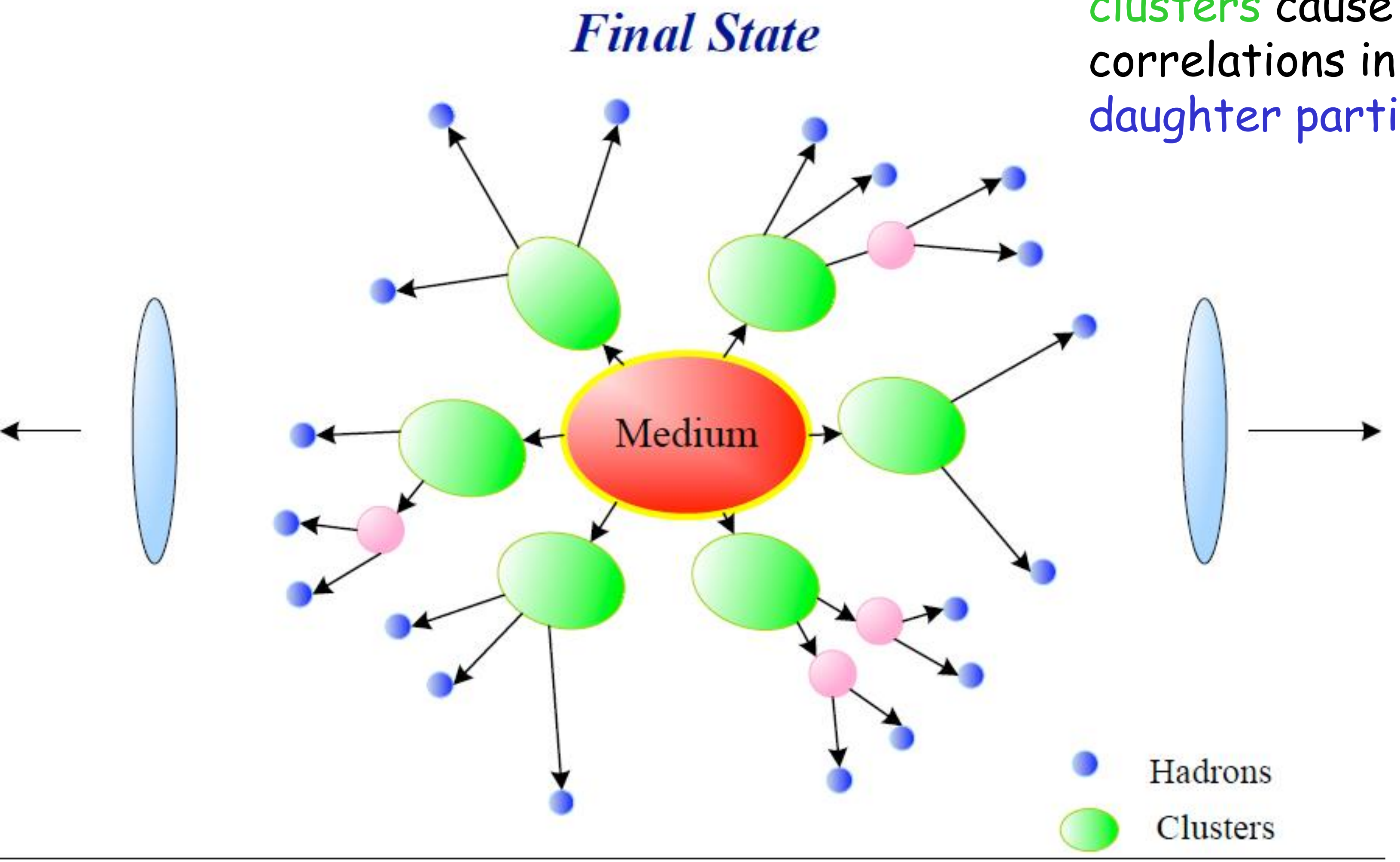
$$\left(I \sim \frac{dE}{dx} \sim \frac{1}{\beta^2} \sim \frac{E^2}{p^2} \sim \frac{m^2 + p^2}{p^2} \right)$$

At least 5 silicon strip hits

Ionization > 5 MeV/cm

Momentum < 2 GeV

Correlations: Independent Cluster Model

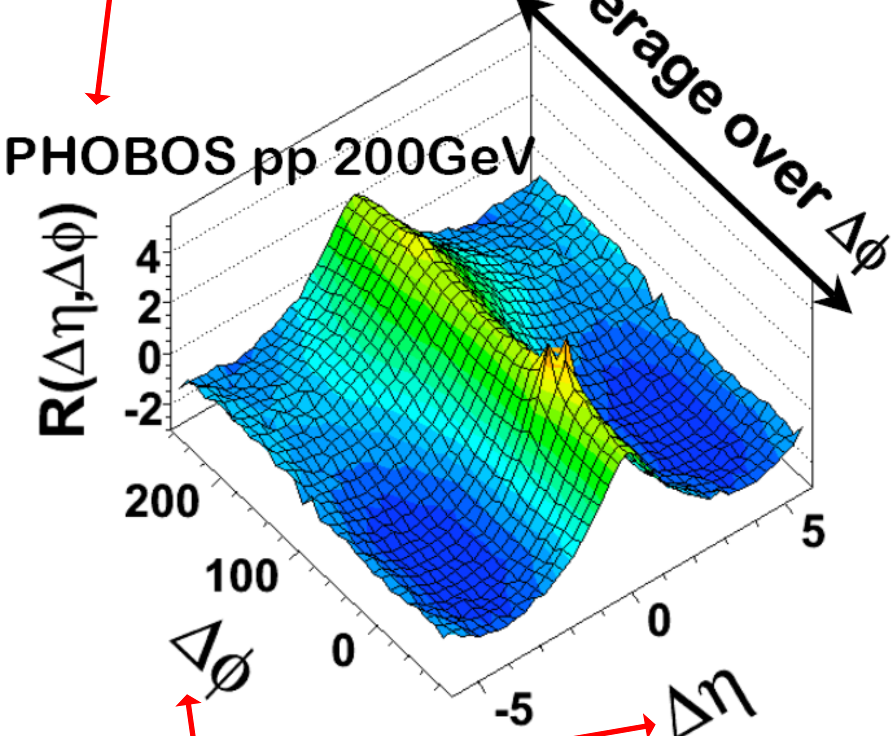


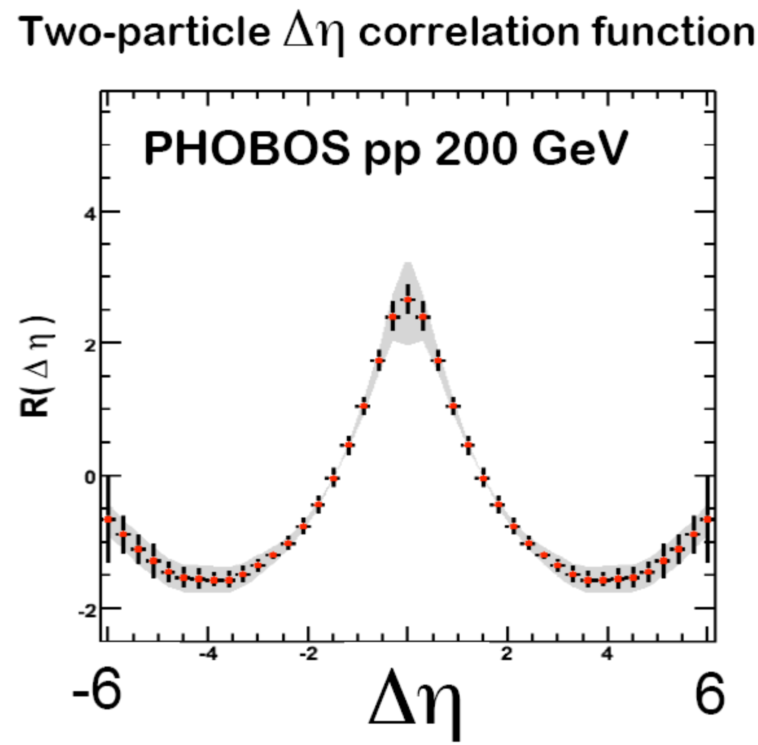
clusters cause correlations in between daughter particles

„Clusters could be resonances, jets, strings or any other kind of short-range correlations.“ (Wie Li)

Method: 2D correlation

RHIC



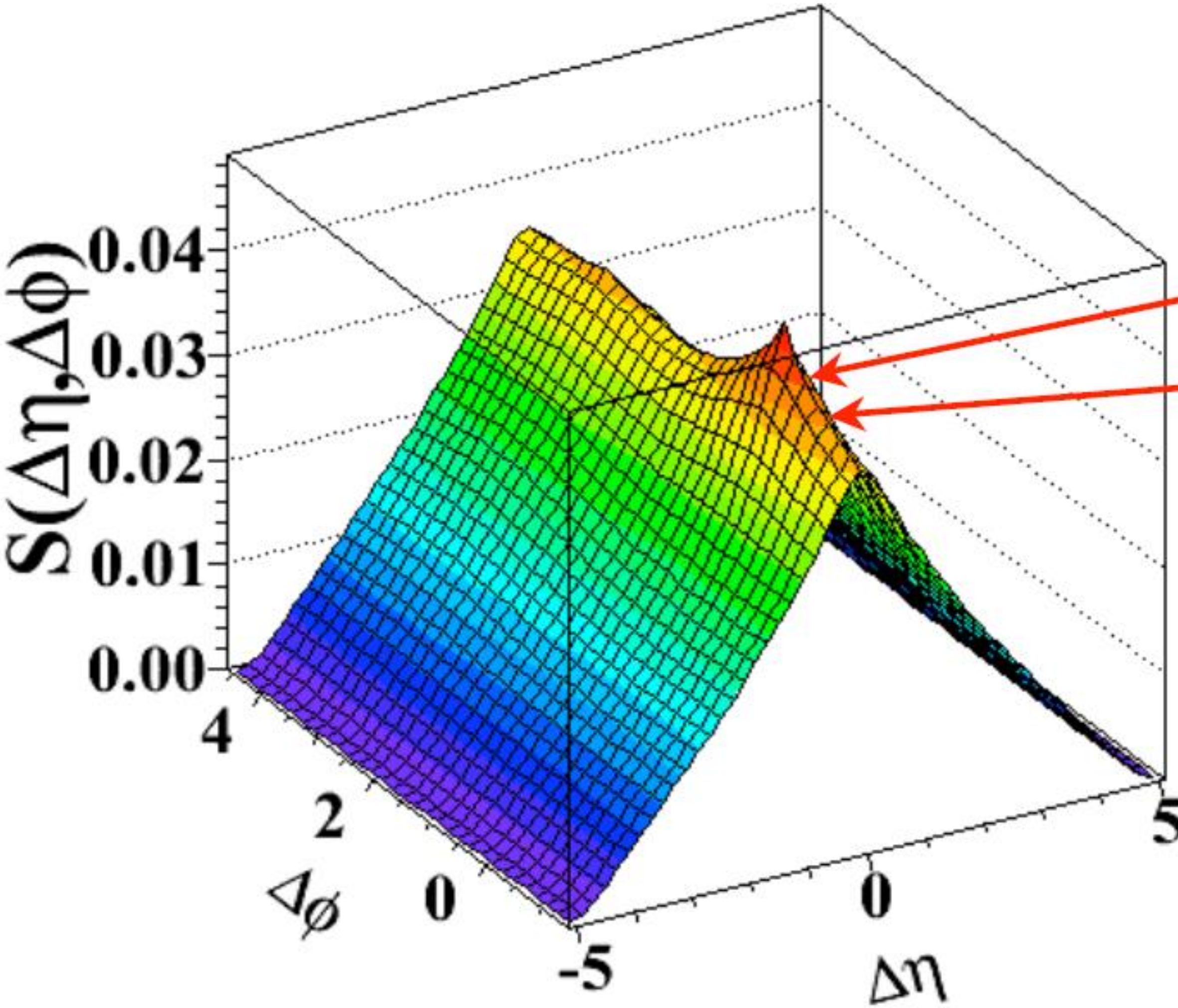


DELTA !

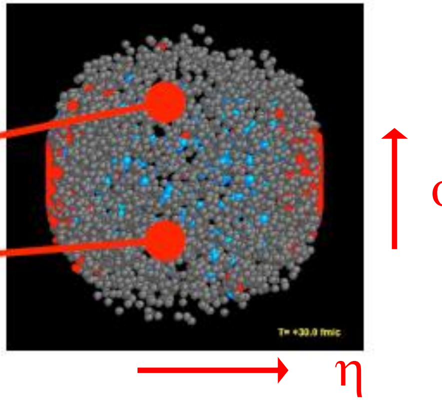
$$R(\Delta\eta, \Delta\phi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)} - 1\right)\right\rangle_N$$

multiplicity

Measurement of Signal Correlation



Event 1

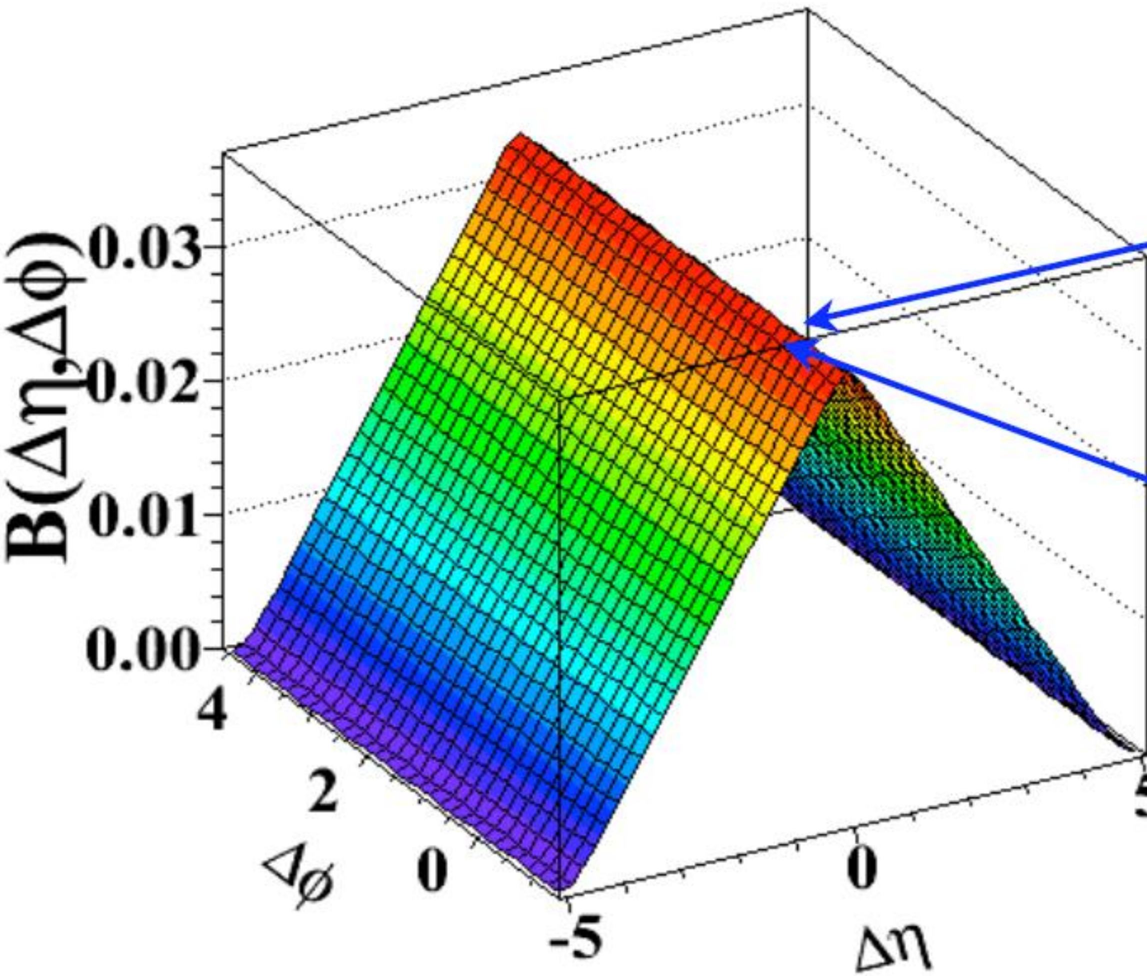


$$\Delta\eta = \eta_1 - \eta_2,$$
$$\Delta\varphi = \varphi_1 - \varphi_2$$

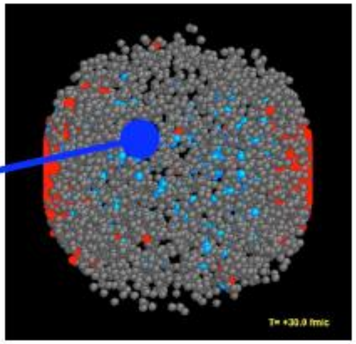
N: total multiplicity

N fixed: $$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$ (unit integral)

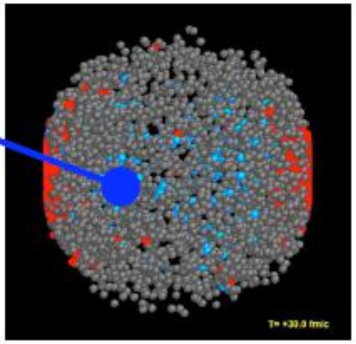
Measurement of Background Correlation



Event 1



Event 2



$\Delta\eta = \eta_1 - \eta_2,$

$\Delta\varphi = \varphi_1 - \varphi_2$

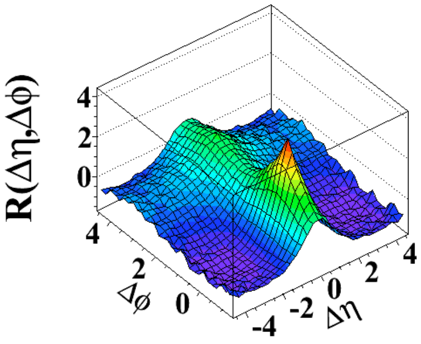
N: total multiplicity

N fixed: $B_N(\Delta\eta,\Delta\varphi) = \dfrac{1}{N^2}\dfrac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$ (unit integral)

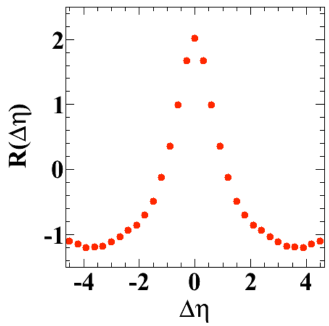
2D correlation and projection

T.Hebbeker

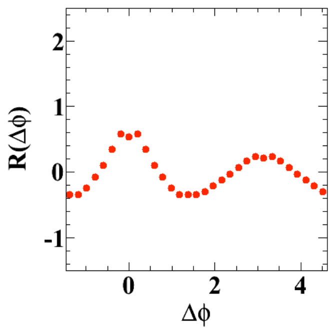
$$R(\Delta\eta,\Delta\phi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_N$$



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



(



)

T.Hebbeker

1D correlation and interpretation

Pythia comparison ?

Cluster parameterization:

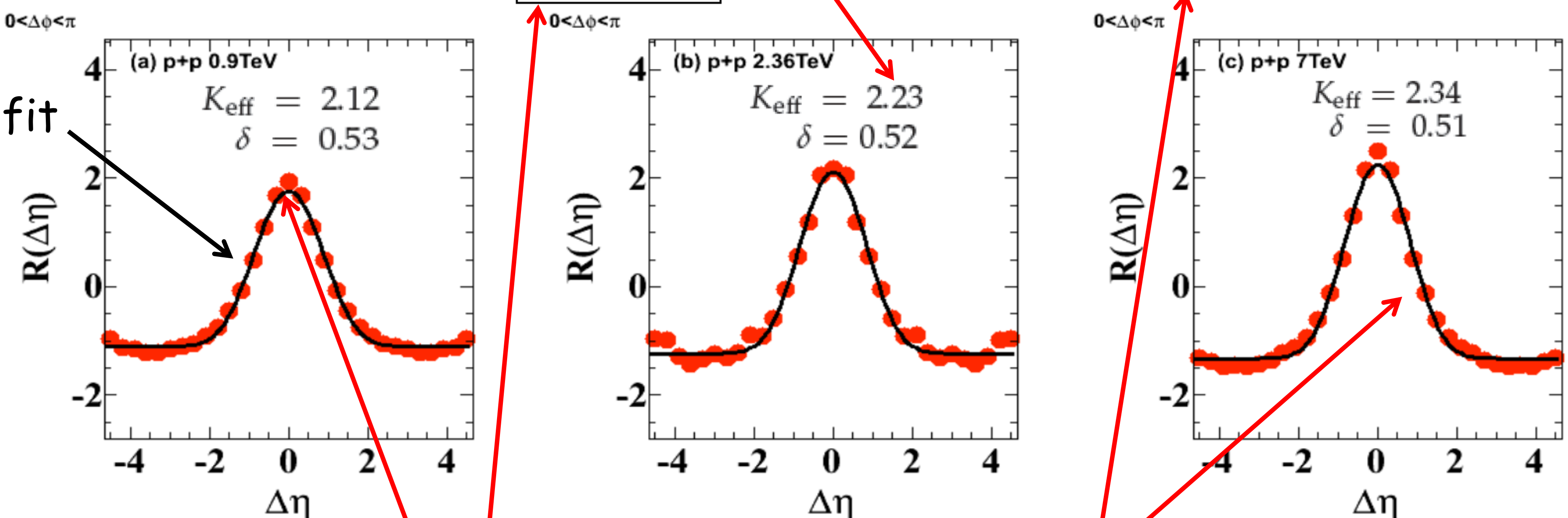
K. Eggert et al.,
Nucl. Phys. B 86:201, 1975

$$R(\Delta\eta) = (K_{eff} - 1)\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right] \qquad \Gamma(\Delta\eta) \propto \exp\left(-\frac{(\Delta\eta)^2}{4\delta^2}\right)$$

Effective Cluster Size

more than expected
from resonance decays

Cluster Width



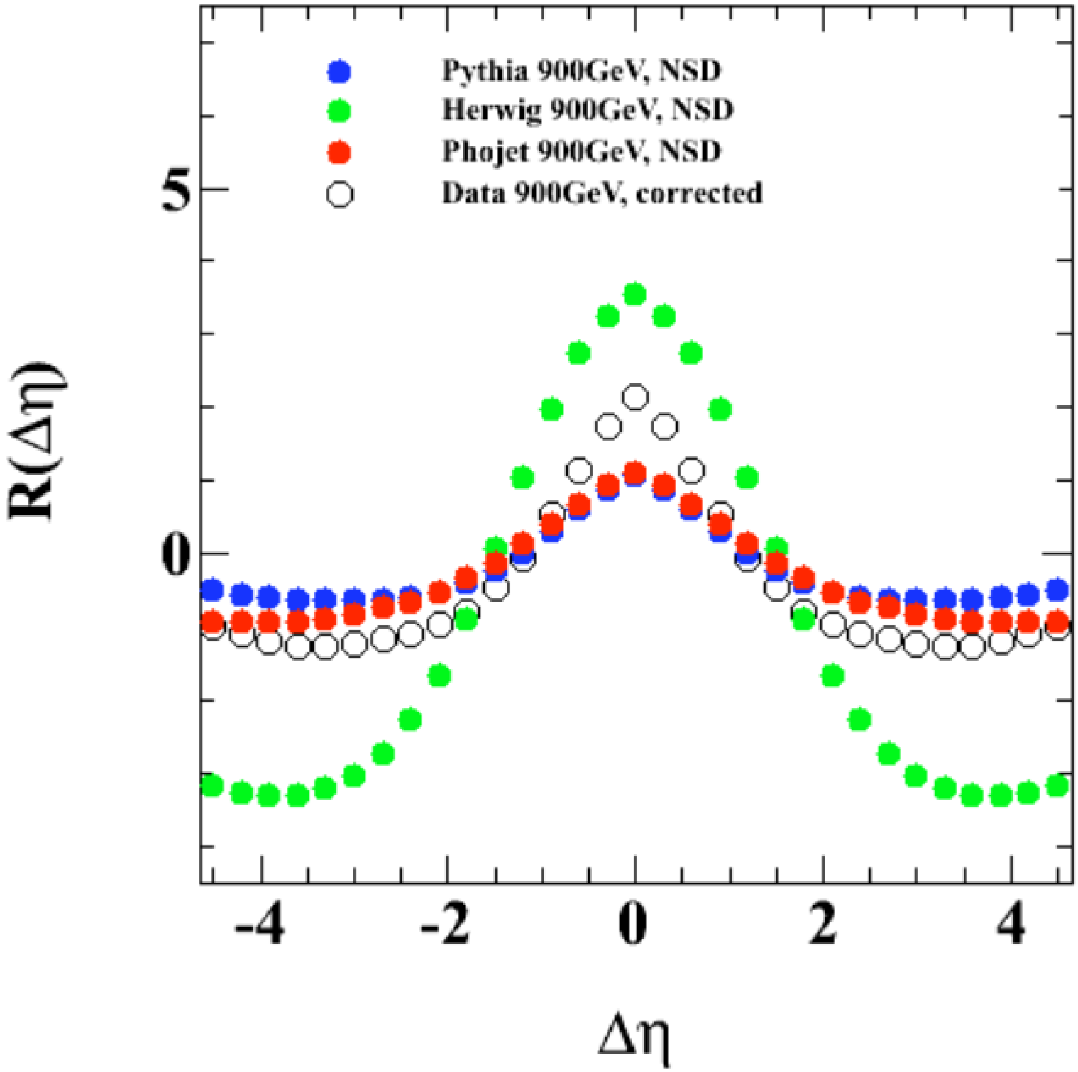
width

height

= spread of daughter particles in η

= number of particles in cluster

1D-comparison with MC



„HERWIG is not designed to reproduce this aspect of the data``

New PYTHIA 6.2 Tunes

Use LO α_s with Λ = 192 MeV!

NLO Structure Function!

K-factor (T. Sjostrand)

UE Parameters

Tune A energy dependence!

ISR Parameter

Intrinsic KT

Parameter	Tune DW	Tune D6	Tune QW	Tune QK
PDF	CTEQ5L	CTEQ6L	CTEQ6.1	CTEQ6.1
MSTP(2)	1	1	1	1
MSTP(33)	0	0	0	1
PARP(31)	1.0	1.0	1.0	1.8
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	1.9 GeV	1.8 GeV	1.1 GeV	1.9 GeV
PARP(83)	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.4
PARP(85)	1.0	1.0	1.0	1.0
PARP(86)	1.0	1.0	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2	0.2
PARP(67)	2.5	2.5	2.5	2.5
MSTP(91)	1	1	1	1
PARP(91)	2.1	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0	15.0

New PYTHIA 6.2 Tunes

Use LO a_s with L = 192 MeV!

NLO Structure Function!

Parameter	Tune DWT	ATLAS	Tune D6T	Tune QWT	Tune QKT
PDF	CTEQ5L	CTEQ5L	CTEQ6L	CTEQ6.1	CTEQ6.1
MSTP(2)	1	1	1	1	1
MSTP(33)	0	0	1	1	1
PARP(31)	1.0	1.0	1.0	1.0	1.8
MSTP(81)	1	1	1	1	1
MSTP(82)	4	4	4	4	4
PARP(82)	1.9409 GeV	1.8 GeV	1.8387 GeV	1.1237 GeV	1.9409 GeV
PARP(83)	0.5	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.5	0.4	0.4	0.4
PARP(85)	1.0	0.33	1.0	1.0	1.0
PARP(86)	1.0	0.66	1.0	1.0	1.0
PARP(89)	1.96 TeV	1.0 TeV	1.96 TeV	1.96 TeV	1.96 TeV
PARP(90)	0.16	0.16	0.16	0.16	0.16
PARP(62)	1.25	1.0	1.25	1.25	1.25
PARP(64)	0.2	1.0	0.2	0.2	0.2
PARP(67)	2.5	1.0	2.5	2.5	2.5
MSTP(91)	1	1	1	1	1
PARP(91)	2.1	1.0	2.1	2.1	2.1
PARP(93)	15.0	5.0	15.0	15.0	15.0

K-factor (T. Sjostrand)

UE Parameters

ATLAS energy dependence!

ISR Parameter

Intrinsic KT

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MC Tunes

Table 2.1. Parameters for several PYTHIA 6.2 tunes. Tune A is the CDF Run 1 "underlying event" tune. Tune AW and DW are CDF Run 2 tunes which fit the existing Run 2 "underlying event" data and fit the Run 1 Z-boson p_T distribution. The ATLAS Tune is the tune used in the ATLAS TRD. Tune DWT use the ATLAS energy dependence for the MPI, PARP(90). The first 9 parameters tune the multiple parton interactions. PARP(62), PARP(64), and PARP(67) tune the initial-state radiation and the last three parameters set the intrinsic k_T of the partons within the incoming proton and antiproton.

Parameter	Tune A	Tune AW	Tune DW	Tune DWT	ATLAS
PDF	CTEQ5L	CTEQ5L	CTEQ5L	CTEQ5L	CTEQ5L
MSTP(81)	1	1	1	1	1
MSTP(82)	4	4	4	4	4
PARP(82)	2.0	2.0	1.9	1.9409	1.8
PARP(83)	0.5	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.4	0.5
PARP(85)	0.9	0.9	1.0	1.0	0.33
PARP(86)	0.95	0.95	1.0	1.0	0.66
PARP(89)	1800	1800	1800	1960	1000
PARP(90)	0.25	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	0.2	1.0
PARP(67)	4.0	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1	1
PARP(91)	1.0	2.1	2.1	2.1	1.0
PARP(93)	5.0	15.0	15.0	15.0	5.0

Rick Field, CDF

MC Tunes

- 100: **A**: Rick Field's Tune A to Tevatron Underlying-Event Data. Uses the "old" UE and shower models, with a double-gaussian matter profile, 1 GeV of primordial kT, and near-maximal color correlations. [Oct 2002]
- 103: **DW**: Rick Field's Tune DW to Tevatron Underlying-Event and Drell-Yan Data. Similar to Tune A, but has 2 GeV of primordial kT and uses a very small renormalizatio scale for initial-state radiation (i.e., more ISR radiation). It also has completely maximal color correlations. [Apr 2006]
- 104: **DWT**: Variant of DW using the Pythia 6.2 default collider energy scaling (has worse agreement with Tevatron energy scaling quantities than DW). [Apr 2006]
- 106: **ATLAS-DC2** ("Rome"): first ATLAS tune of the Q2-ordered showers and old UE framework. Does not give very good agreement with Tevatron min-bias quantities.
- 107: **A-CR**: variant of Tune A using the Pythia 6.2 default color connections but with the new "color annealing" color reconnection model applied as an afterburner. Is intended as an example of strong color reconnections. [Mar 2007]
- 108: **D6**: Rick Field's Tune D6 to Tevatron data, using CTEQ6L1 PDFs.

Peter Skands