Title: The Standard Model â€“ Theory: Events and processes @ the LHC

Date: Jul 07, 2015 02:30 PM

URL: http://pirsa.org/15070019

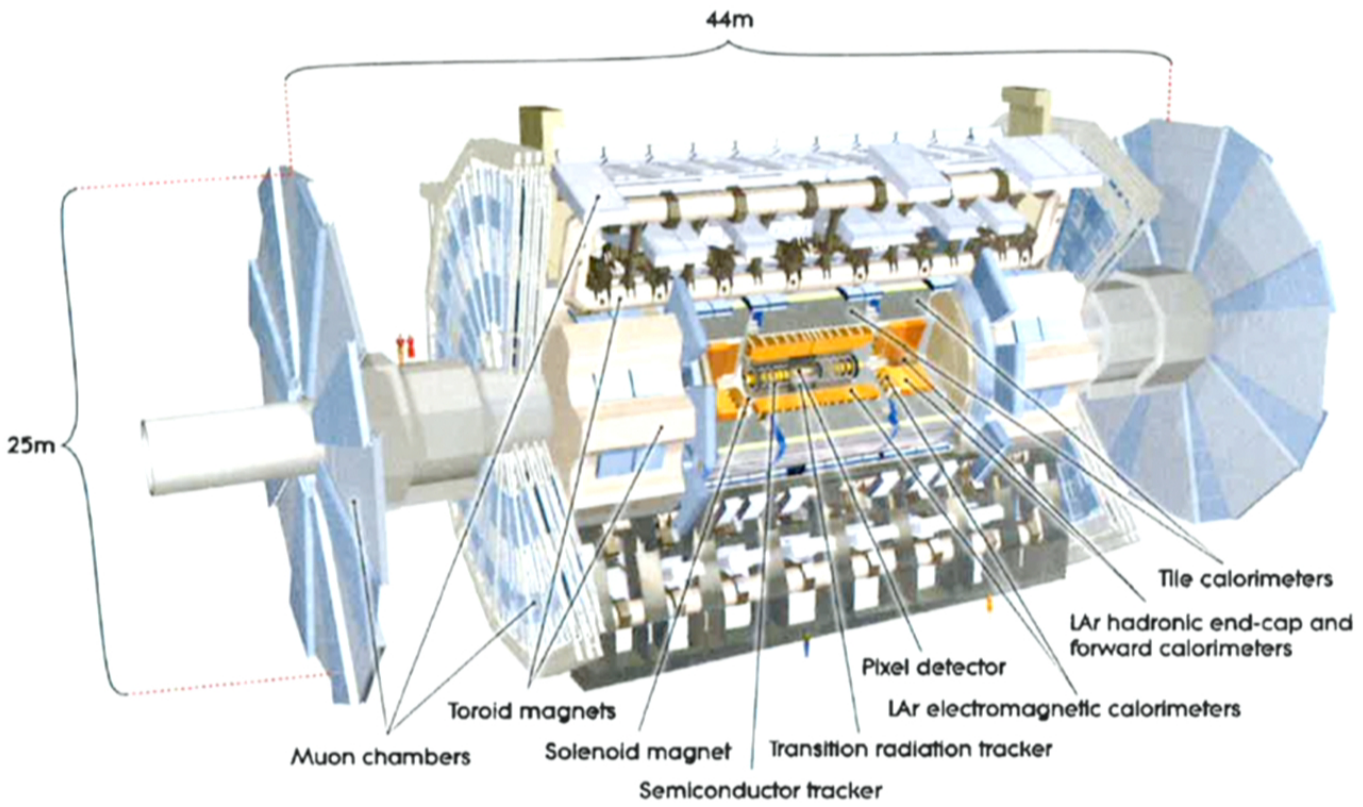
Abstract:

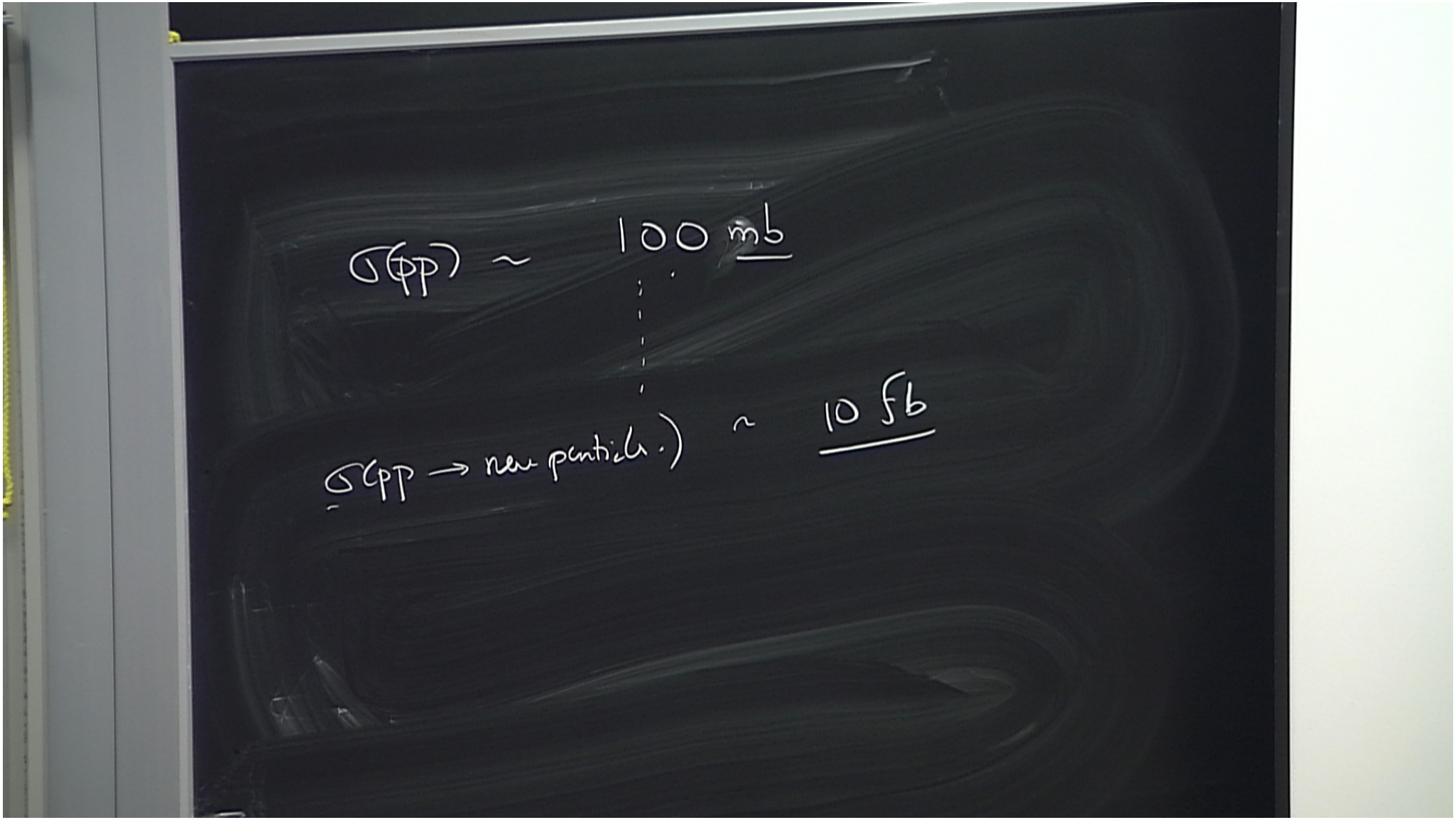
Collider Physics

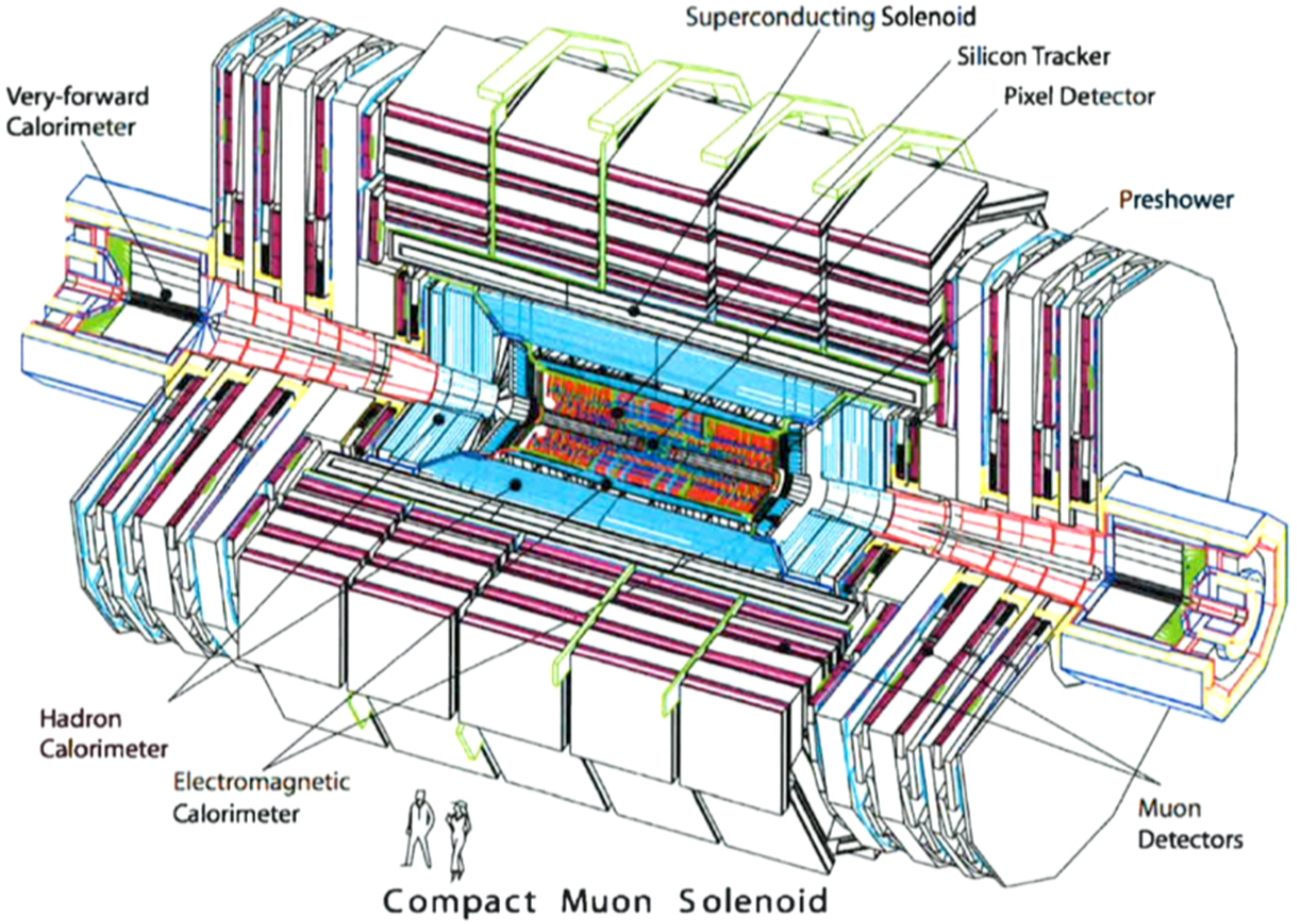
figures for lecture 4

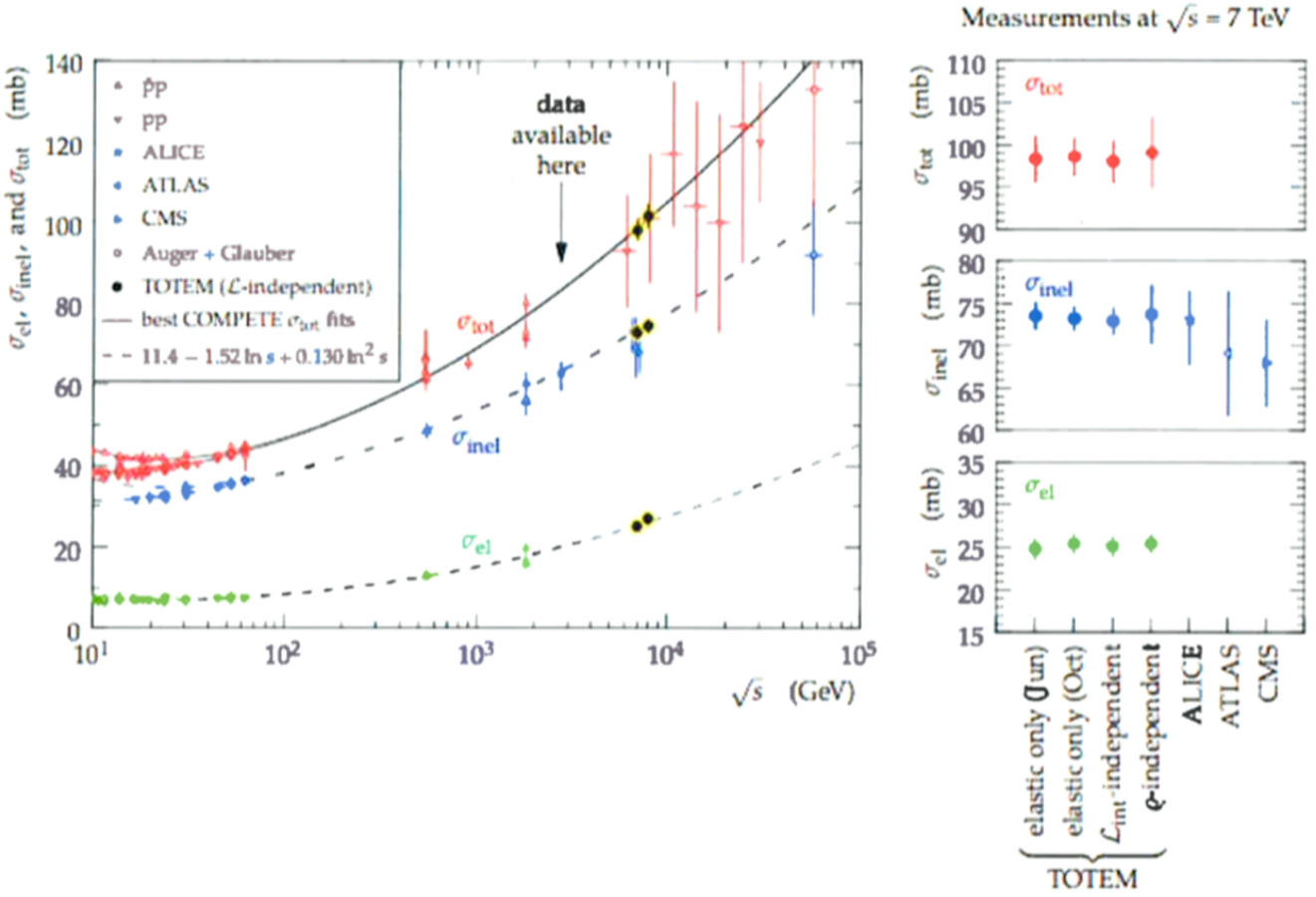
Properties of LHC Events

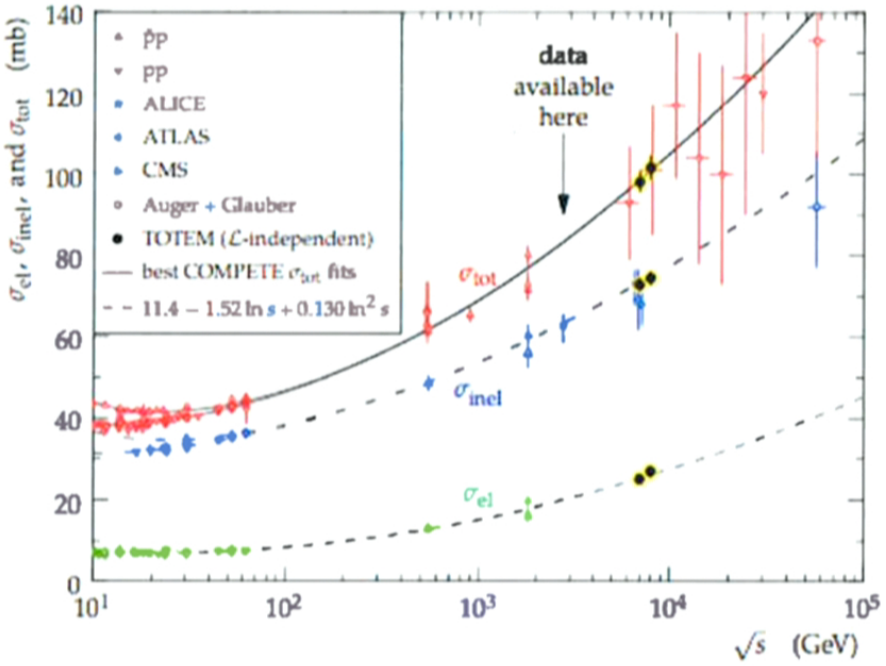
Michael Peskin
TRISEP School 2015

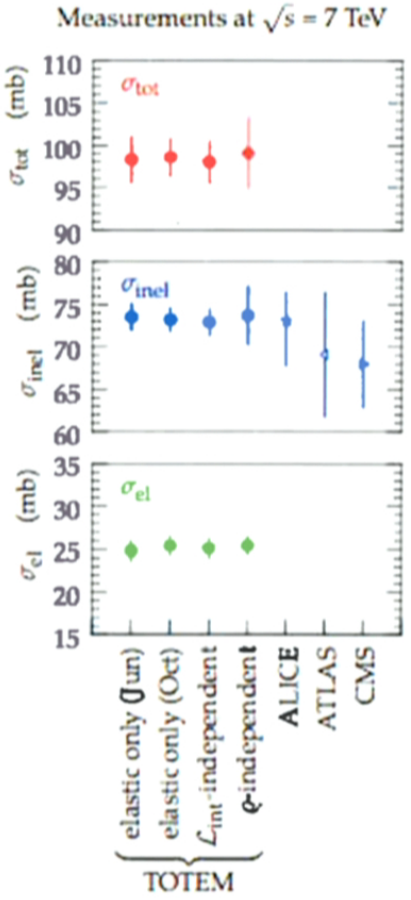

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

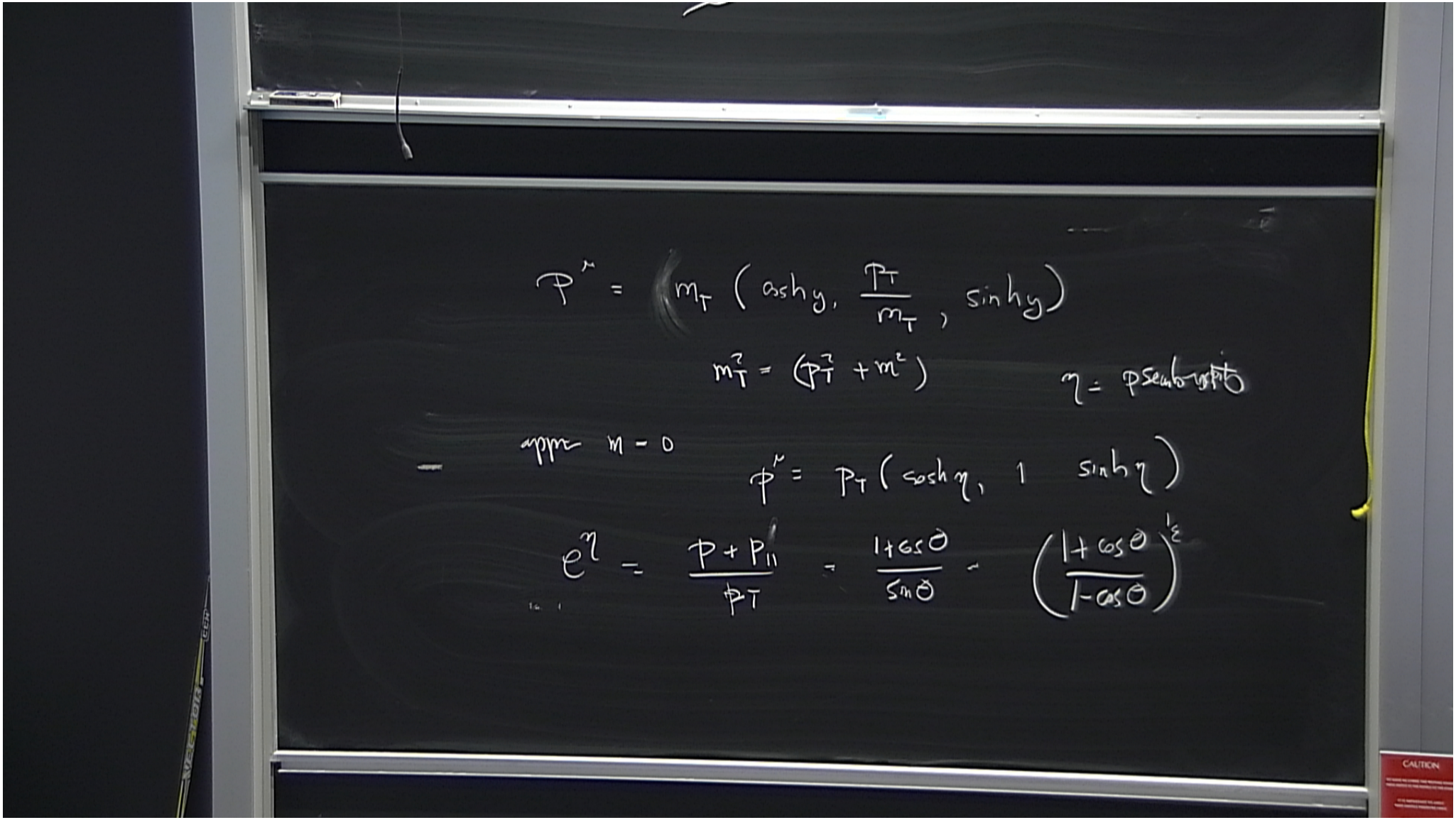

σ(pp) ~ 100 mb
σ(pp → new particle) ~ 10 fb

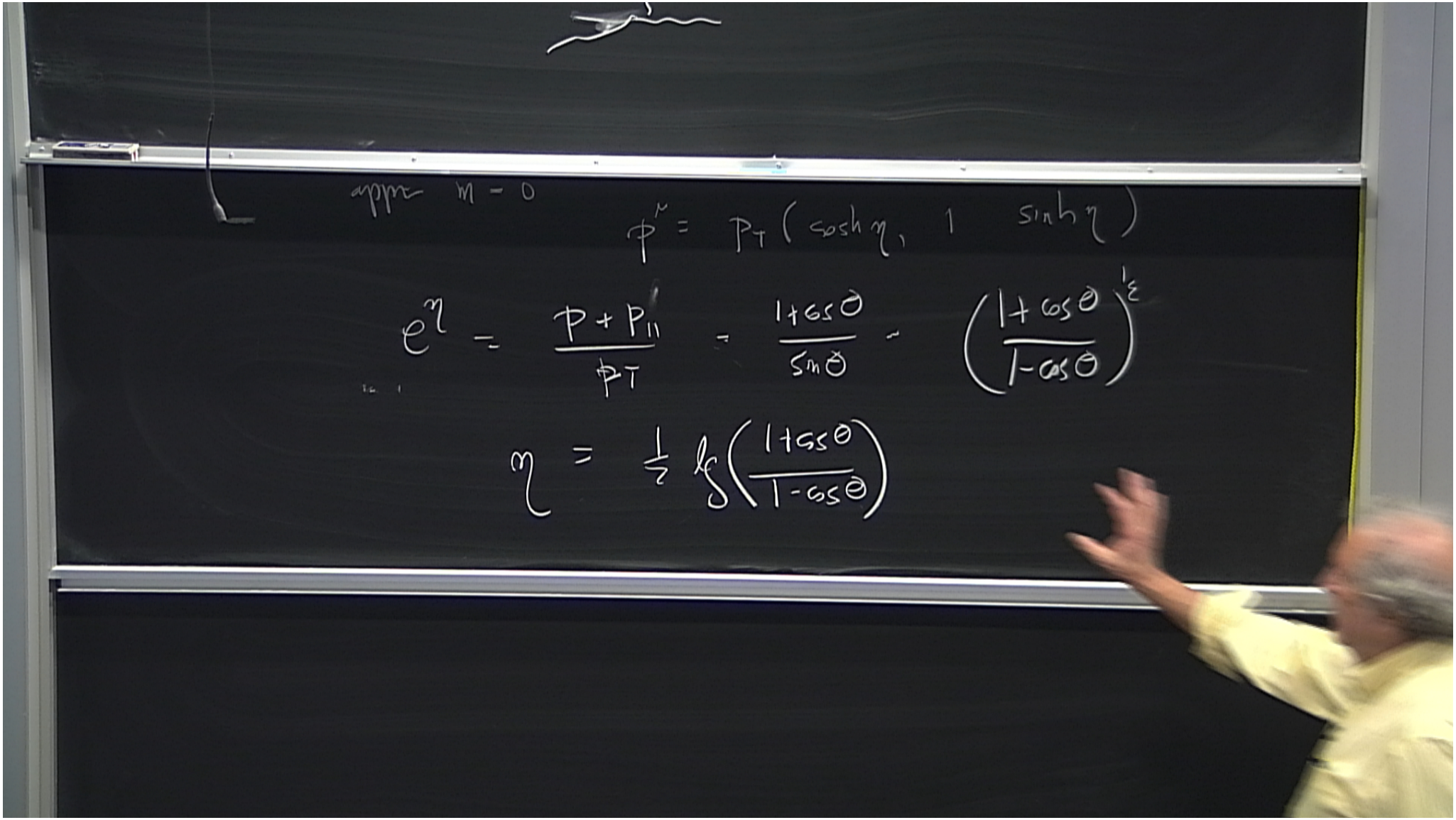

Superconducting Solenoid
Silicon Tracker
Pixel Detector
Very-forward
Calorimeter
Preshower
Hadron
Calorimeter
Electromagnetic
Calorimeter
Muon
Detectors
Compact Muon Solenoid

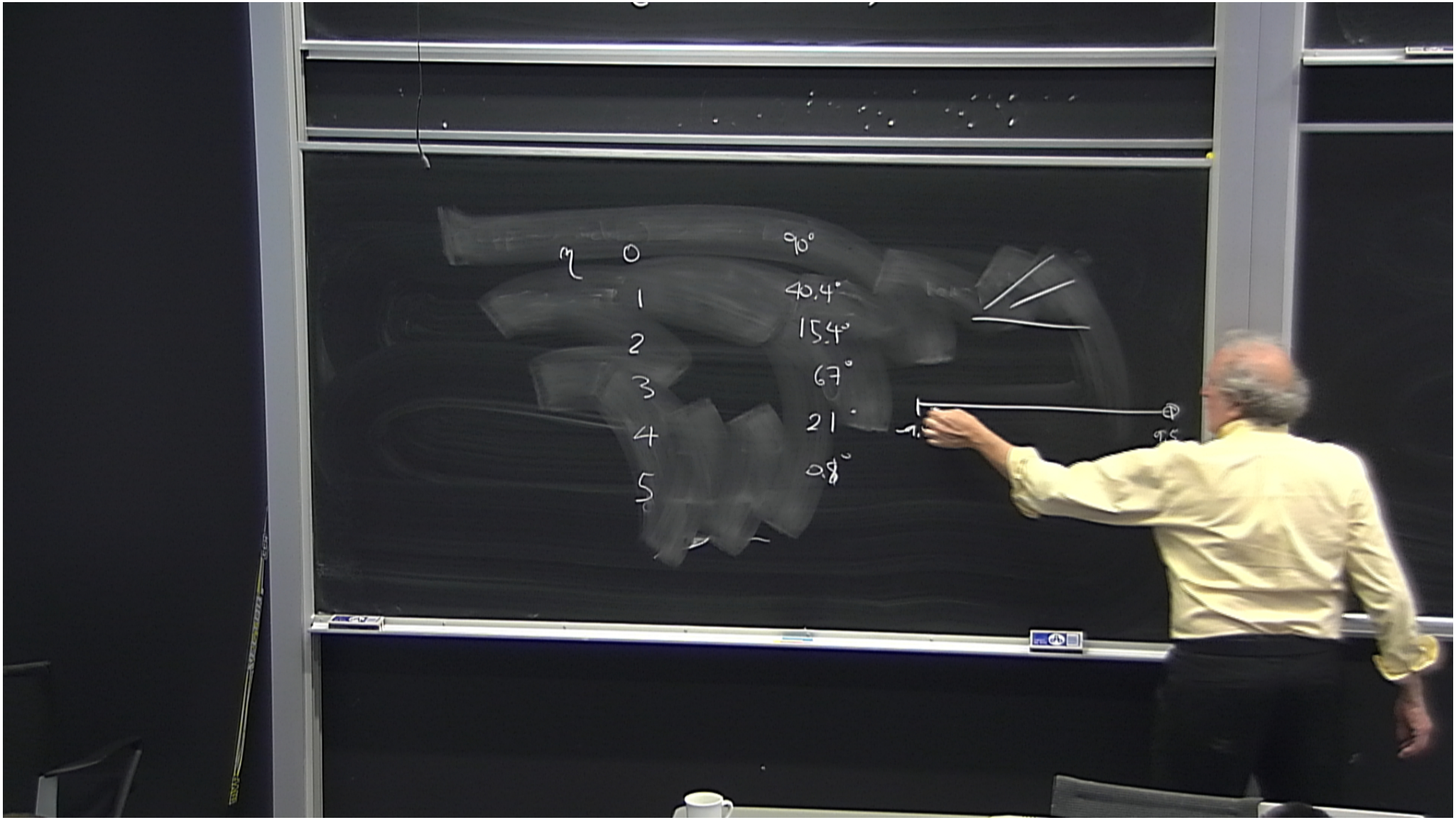

$\bar{p}p$
pp
ALICE
ATLAS
CMS
Auger + Glauber
TOTEM ($\mathcal{L}$-independent)
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
data available here
σ_{tot}
σ_{inel}
σ_{el}
σ_{el}, σ_{inel}, and σ_{tot} (mb)
$\sqrt{s}$ (GeV)
Measurements at $\sqrt{s}$ = 7 TeV
elastic only (Jun)
elastic only (Oct)
$\mathcal{L}_{int}$-independent
ρ-independent
TOTEM
ALICE
ATLAS
CMS

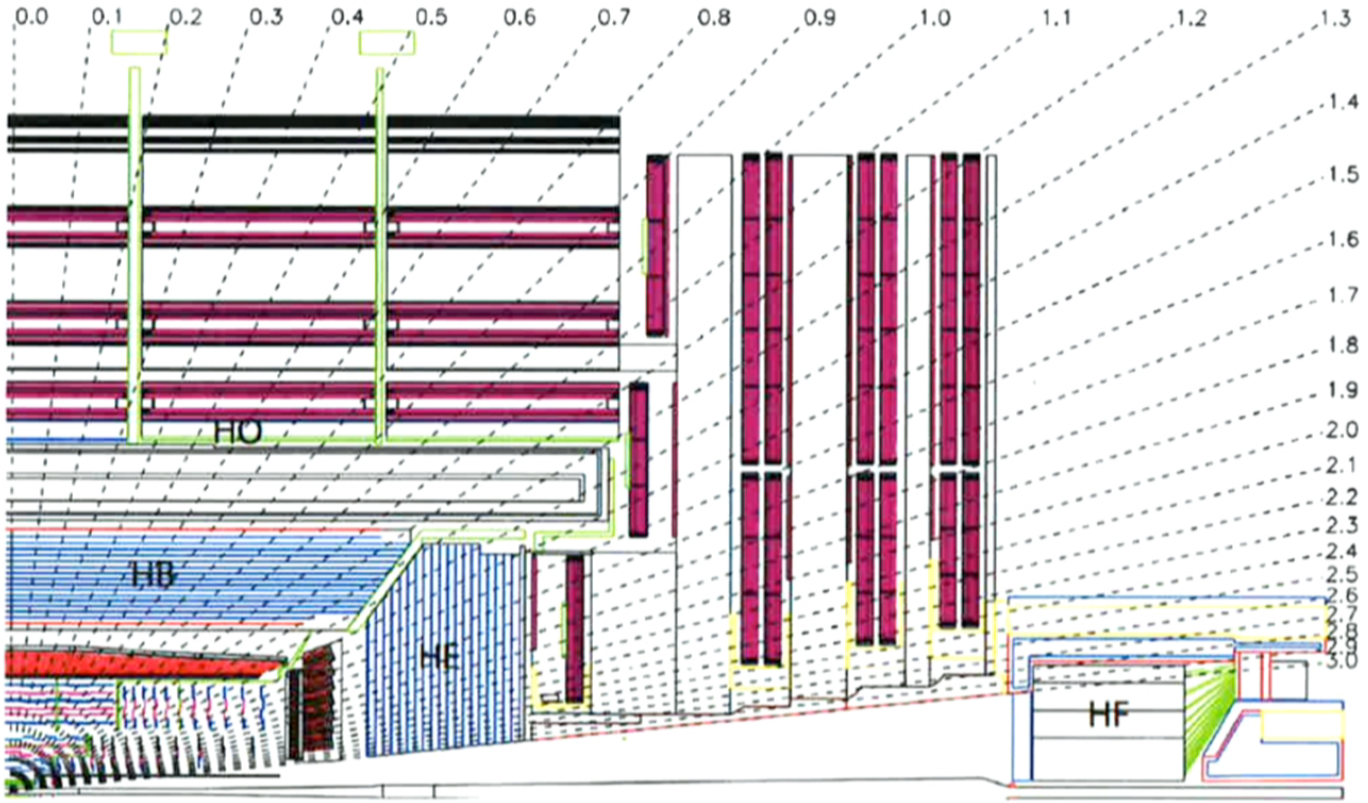

$\bar{p}p$
pp
ALICE
ATLAS
CMS
Auger + Glauber
TOTEM ($\mathcal{L}$-independent)
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
data available here
σ_{tot}
σ_{inel}
σ_{el}
σ_{el}, σ_{inel}, and σ_{tot} (mb)
$\sqrt{s}$ (GeV)

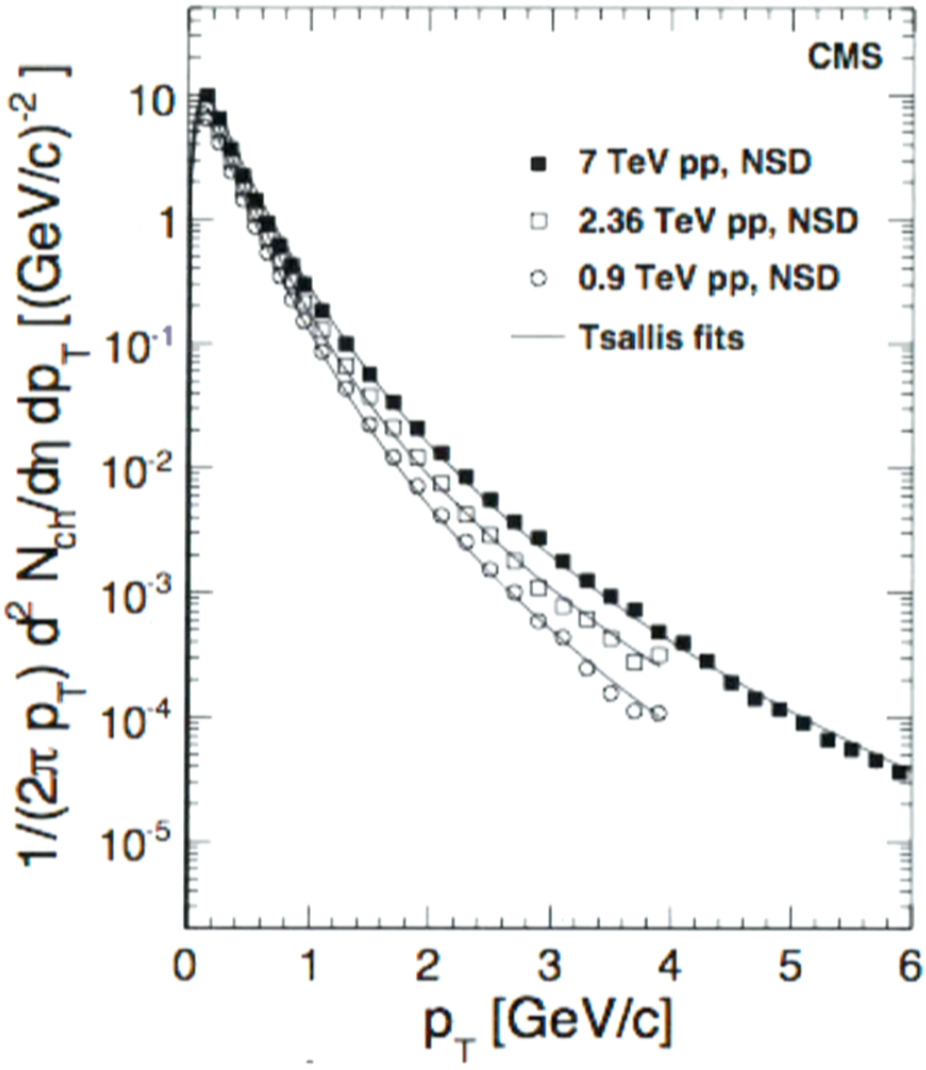

Measurements at $\sqrt{s}$ = 7 TeV
σ_{tot} (mb)
σ_{inel} (mb)
σ_{el} (mb)
elastic only (Jun)
elastic only (Oct)
$\mathcal{L}_{int}$-independent
ρ-independent
TOTEM
ALICE
ATLAS
CMS

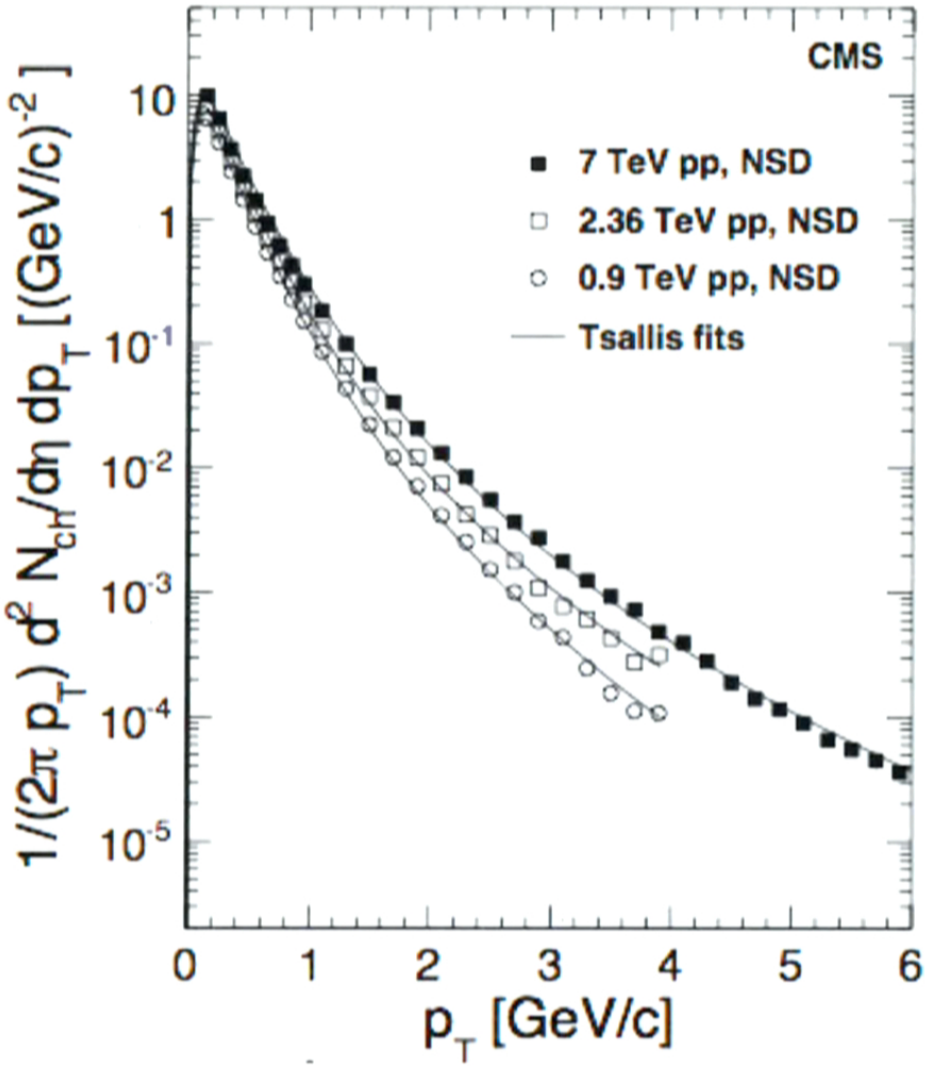

$p^\mu = m_T(\cosh y, \frac{p_T}{m_T}, \sinh y)$
$m_T^2 = (p_T^2 + m^2)$
η = pseudo-rapidity
upper $m = 0$
$p^\mu = p_T(\cosh\eta, 1, \sinh\eta)$
$e^\eta = \frac{p + p_\parallel}{p_T} = \frac{1+\cos\theta}{\sin\theta} = \left(\frac{1+\cos\theta}{1-\cos\theta}\right)^{\frac{1}{2}}$

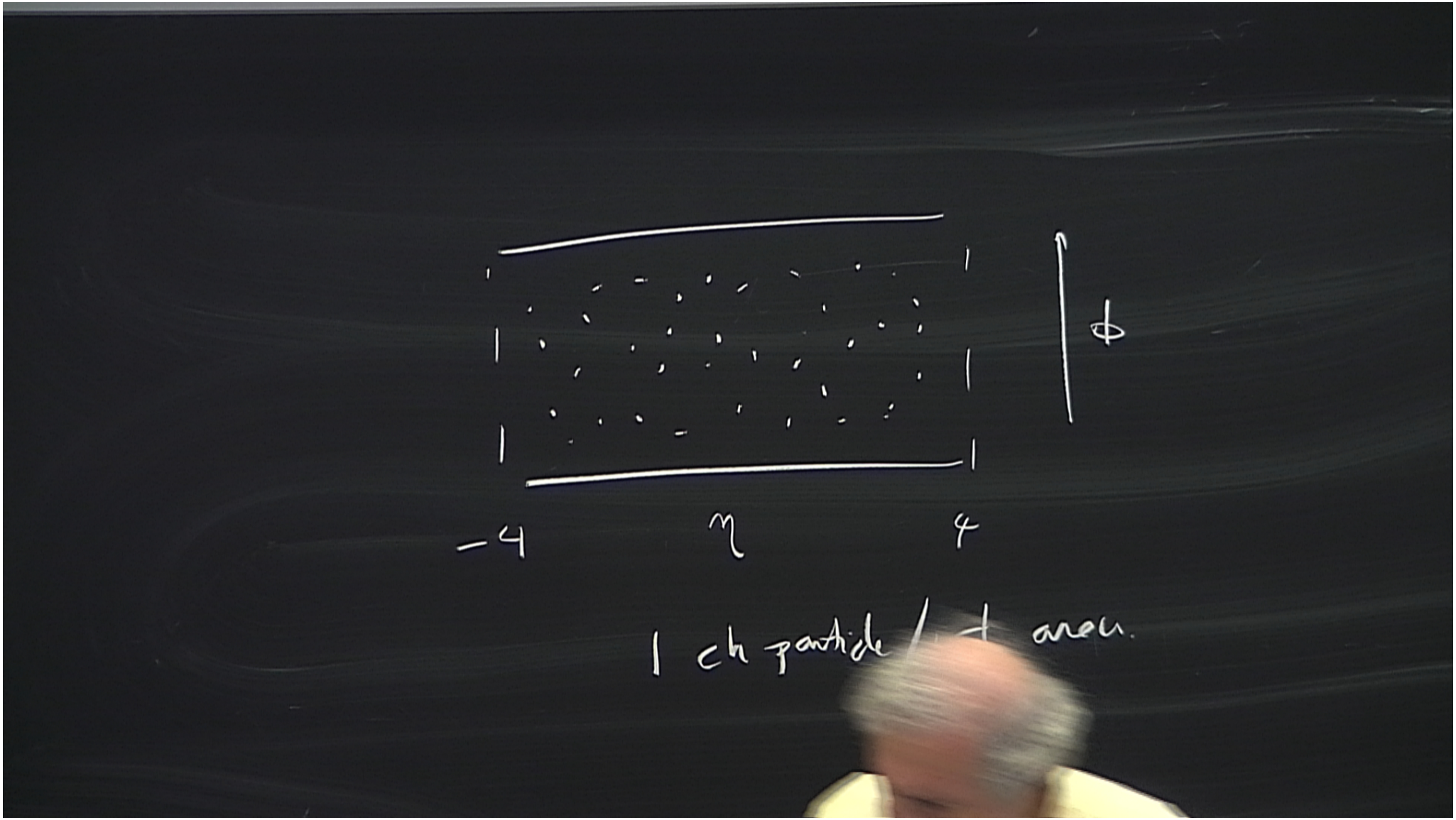

appr. m = 0
$p^\mu = p_T(\cosh\eta, 1, \sinh\eta)$
$e^\eta = \frac{p + p_\parallel}{p_T} = \frac{1+\cos\theta}{\sin\theta} = \left(\frac{1+\cos\theta}{1-\cos\theta}\right)^{\frac{1}{2}}$
$\eta = \frac{1}{2}\ln\left(\frac{1+\cos\theta}{1-\cos\theta}\right)$

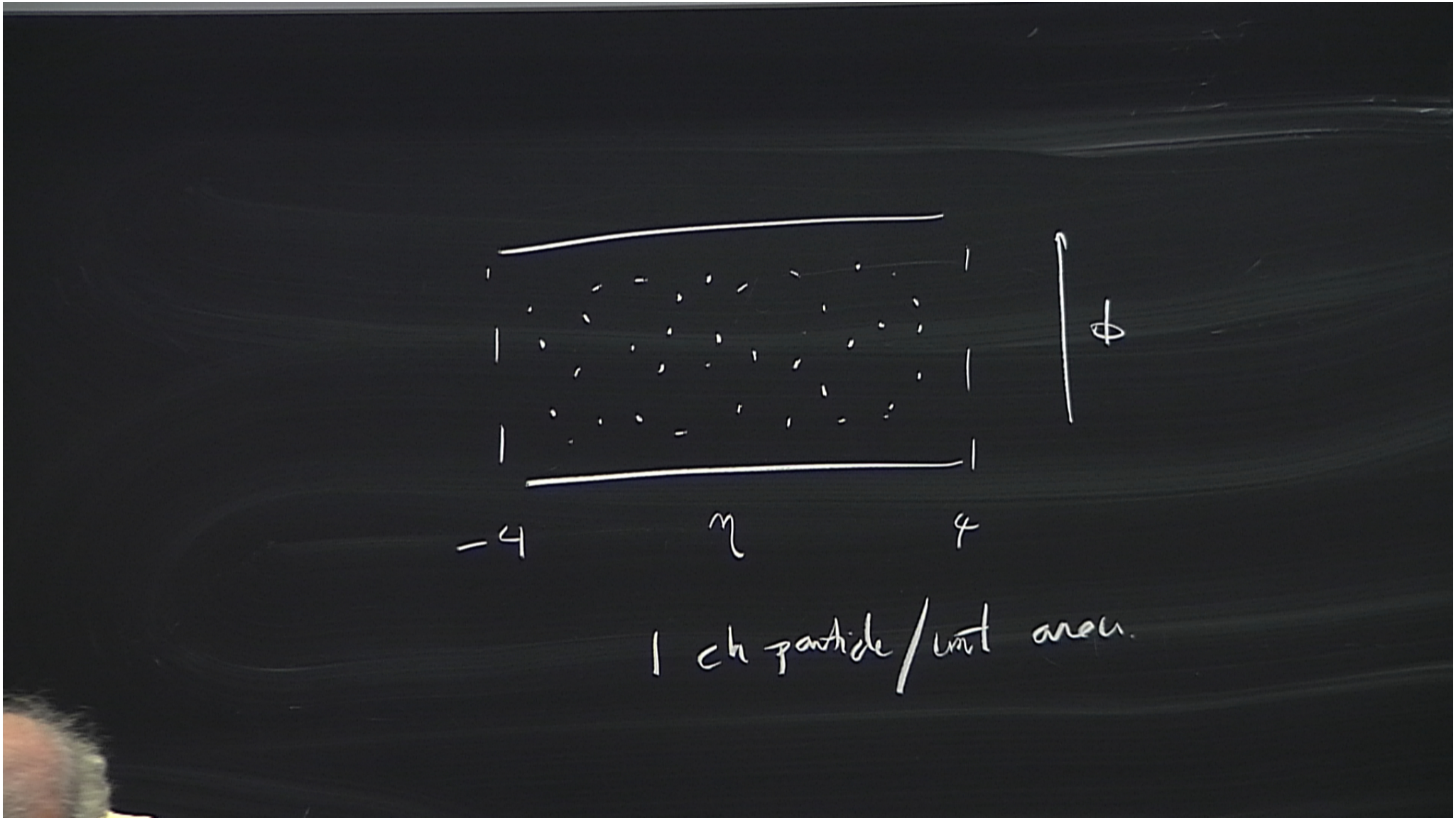

m
0
1
2
3
4
5
90°
40.4°
15.4°
6.7°
2.1°
0.8°

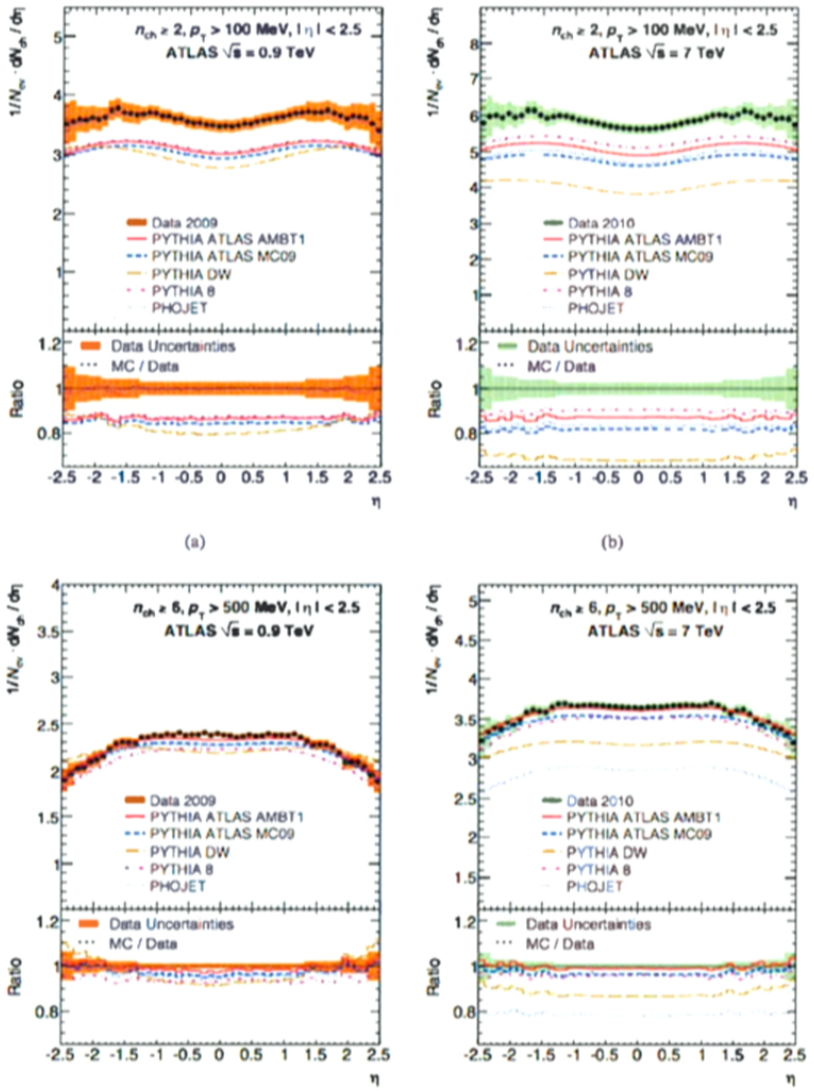

0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
HO
HB
HE
HF

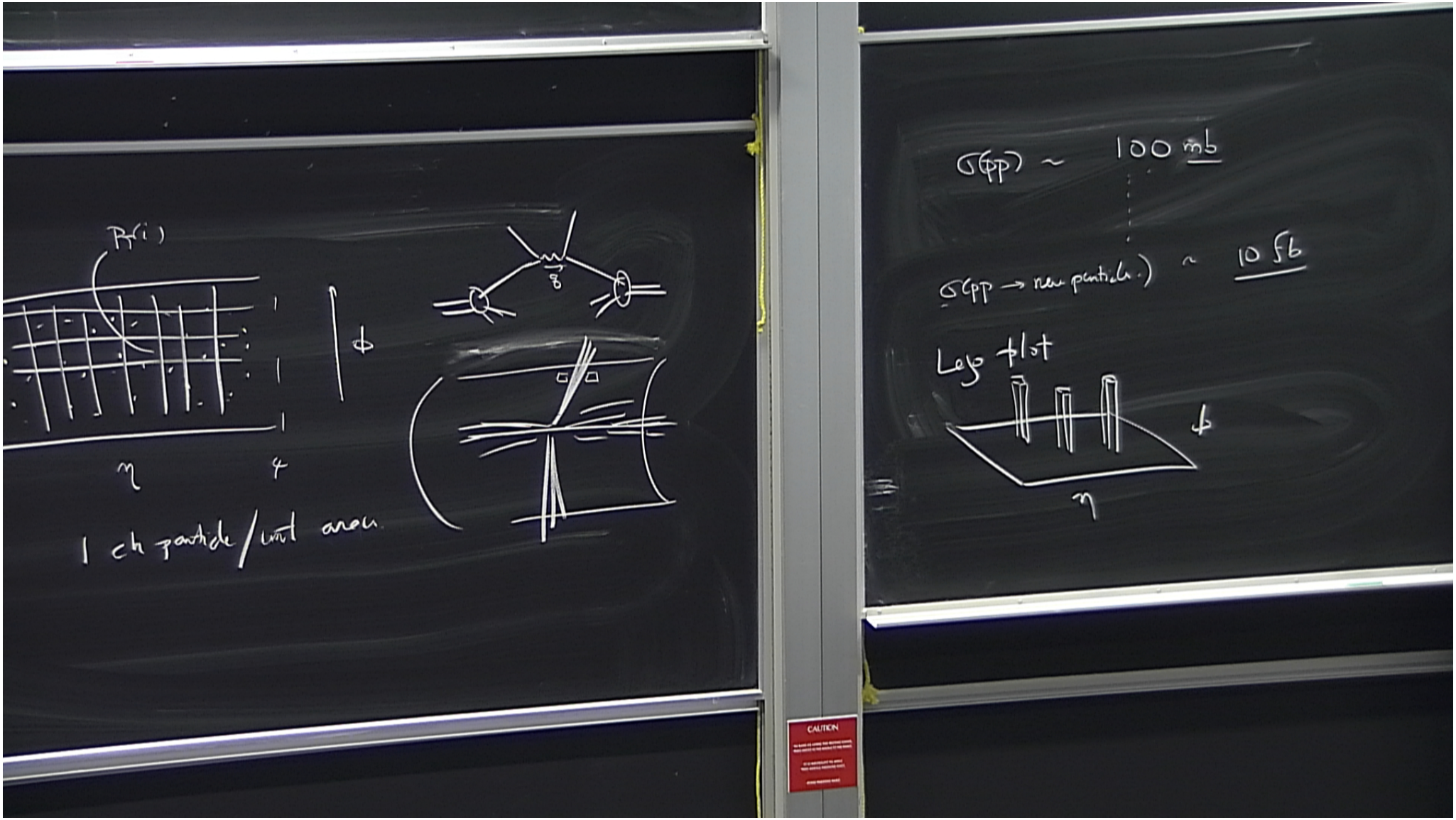

CMS
7 TeV pp, NSD
2.36 TeV pp, NSD
0.9 TeV pp, NSD
Tsallis fits
1/(2π p_T) d² N_ch/dη dp_T [(GeV/c)^-2]
p_T [GeV/c]
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
0
1
2
3
4
5
6

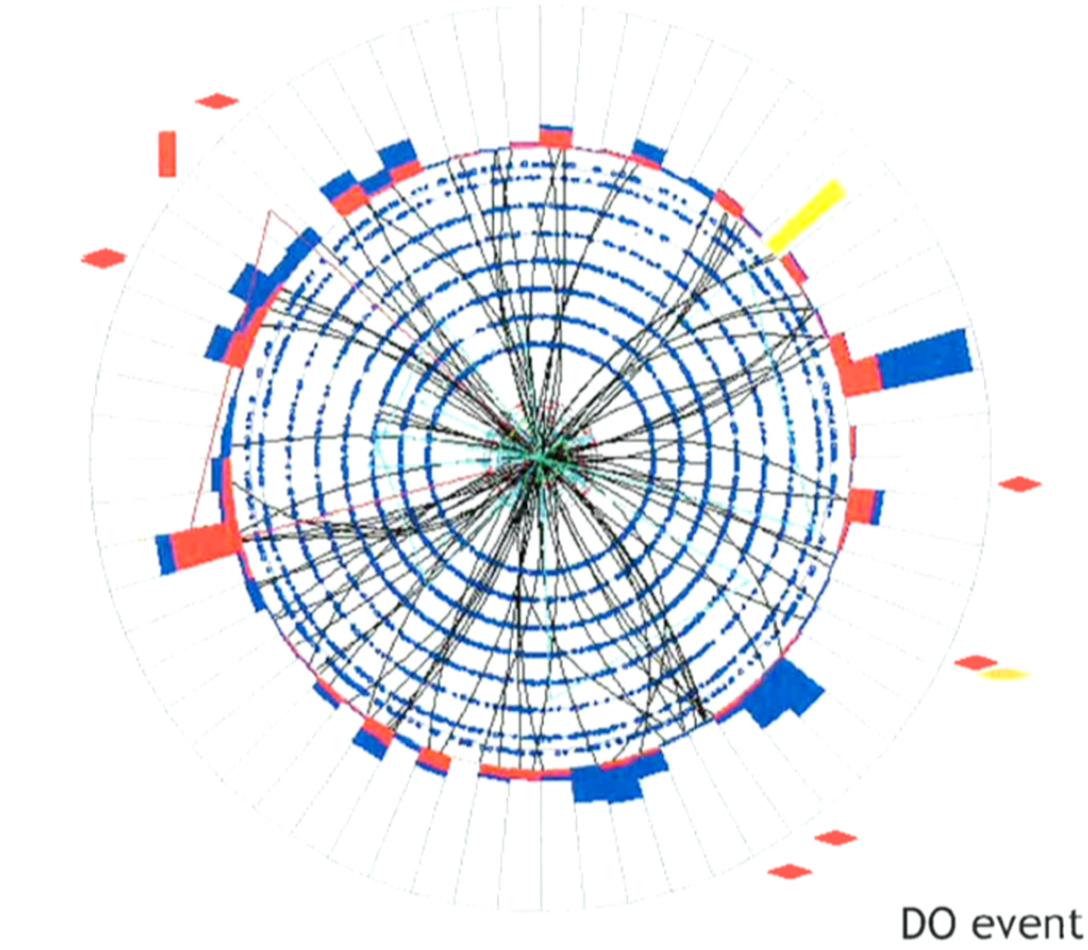

CMS
7 TeV pp, NSD
2.36 TeV pp, NSD
0.9 TeV pp, NSD
Tsallis fits
$1/(2\pi p_T)\, d^2 N_{ch}/d\eta\, dp_T\ [(GeV/c)^{-2}]$
p_T [GeV/c]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
1
2
3
4
5
6


φ
-4
η
4
1 ch particle / Δ area.

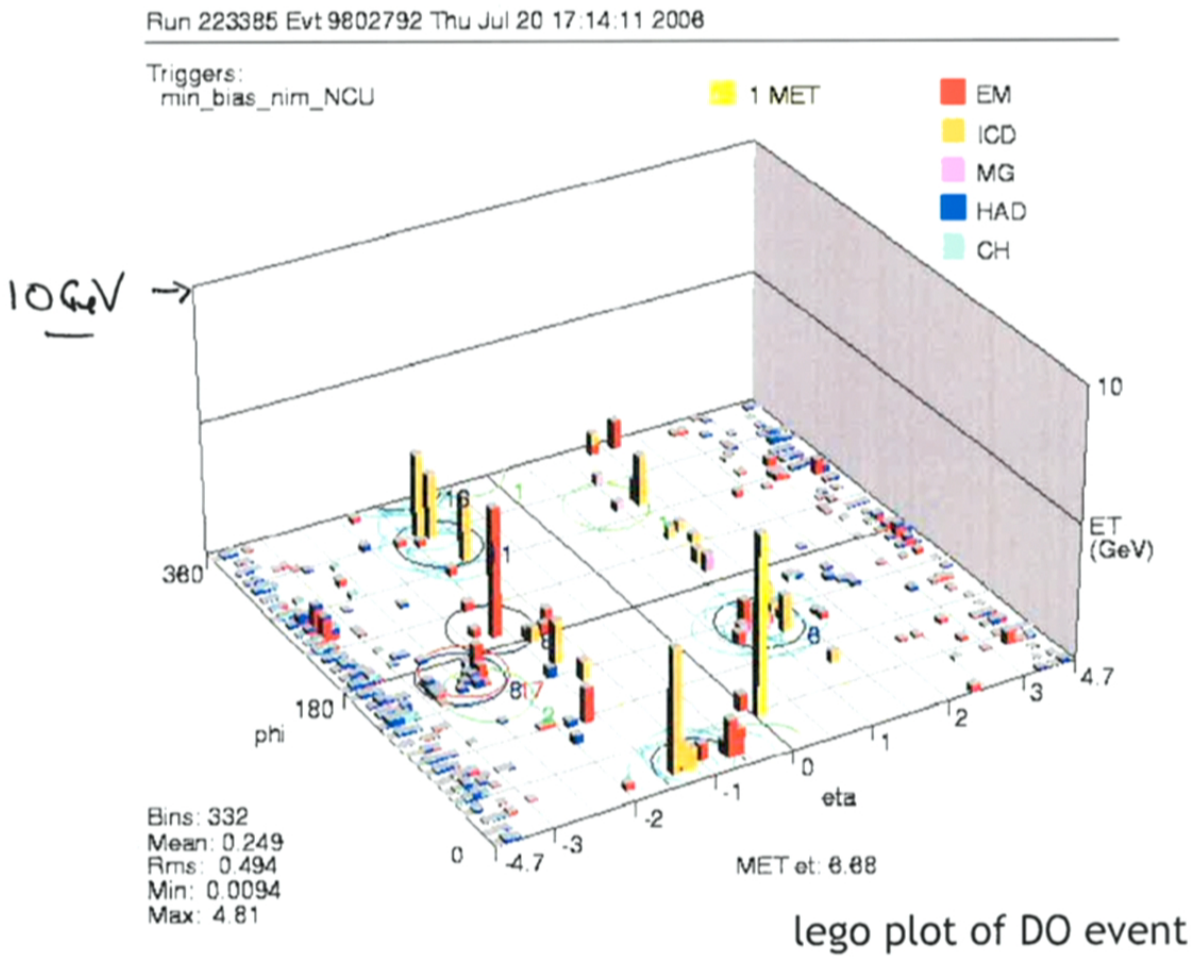

ϕ
-4
η
4
1 ch particle / unit area.


$n_{ch} \geq 2$, $p_T > 100$ MeV, $|\eta| < 2.5$
ATLAS $\sqrt{s} = 0.9$ TeV
$1/N_{ev} \cdot dN_{ch}/d\eta$
Data 2009
PYTHIA ATLAS AMBT1
PYTHIA ATLAS MC09
PYTHIA DW
PYTHIA 8
PHOJET
Data Uncertainties
MC / Data
Ratio
η
(a)
$n_{ch} \geq 2$, $p_T > 100$ MeV, $|\eta| < 2.5$
ATLAS $\sqrt{s} = 7$ TeV
Data 2010
PYTHIA ATLAS AMBT1
PYTHIA ATLAS MC09
PYTHIA DW
PYTHIA 8
PHOJET
Data Uncertainties
MC / Data
Ratio
η
(b)
$n_{ch} \geq 6$, $p_T > 500$ MeV, $|\eta| < 2.5$
ATLAS $\sqrt{s} = 0.9$ TeV
Data 2009
PYTHIA ATLAS AMBT1
PYTHIA ATLAS MC09
PYTHIA DW
PYTHIA 8
PHOJET
Data Uncertainties
MC / Data
Ratio
η
$n_{ch} \geq 6$, $p_T > 500$ MeV, $|\eta| < 2.5$
ATLAS $\sqrt{s} = 7$ TeV
Data 2010
PYTHIA ATLAS AMBT1
PYTHIA ATLAS MC09
PYTHIA DW
PYTHIA 8
PHOJET
Data Uncertainties
MC / Data
Ratio
η

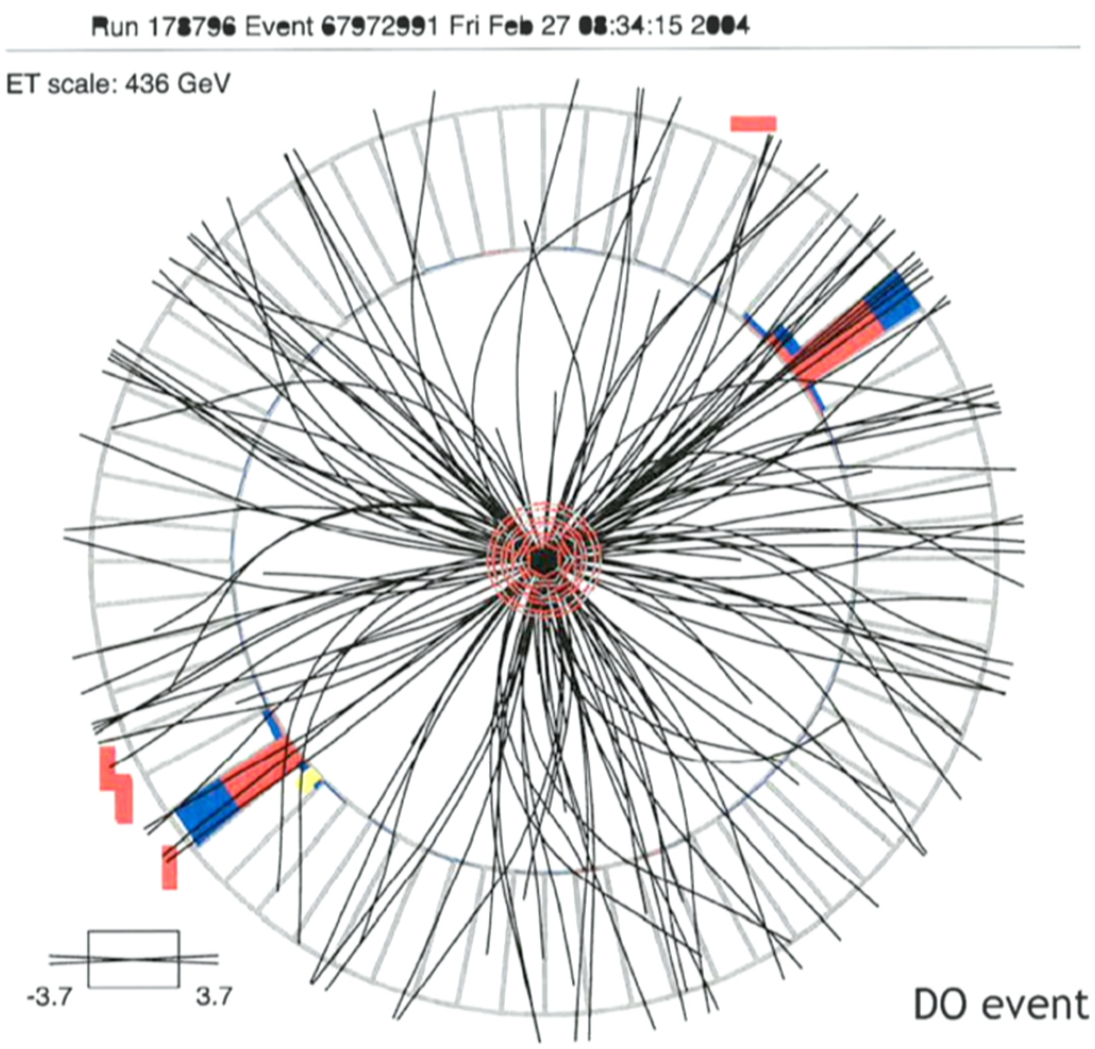

R(i)
η
φ
1 ch particle / unit area
σ(pp) ~ 100 mb
σ(pp → new particle) ~ 10 fb
Log plot
φ
η

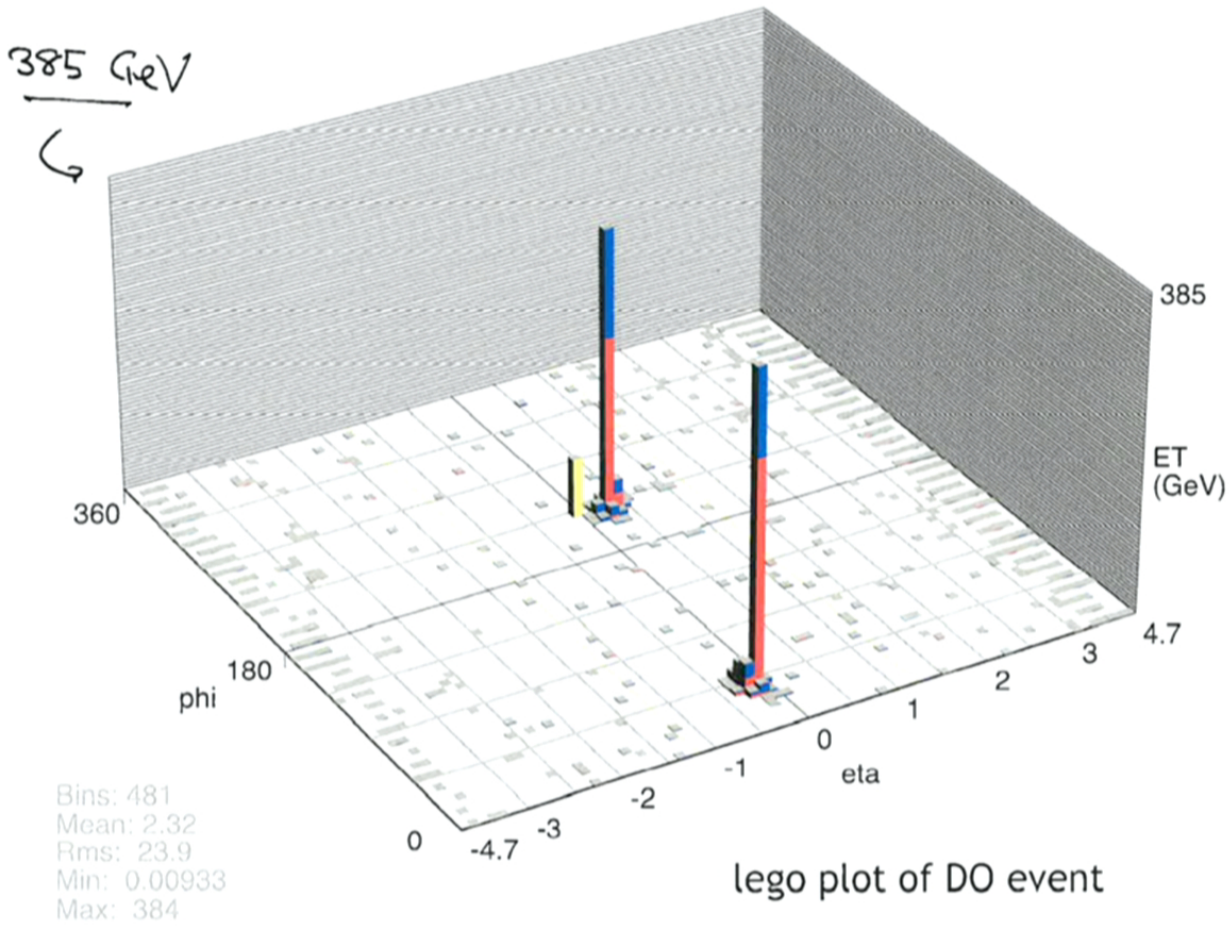


DO event

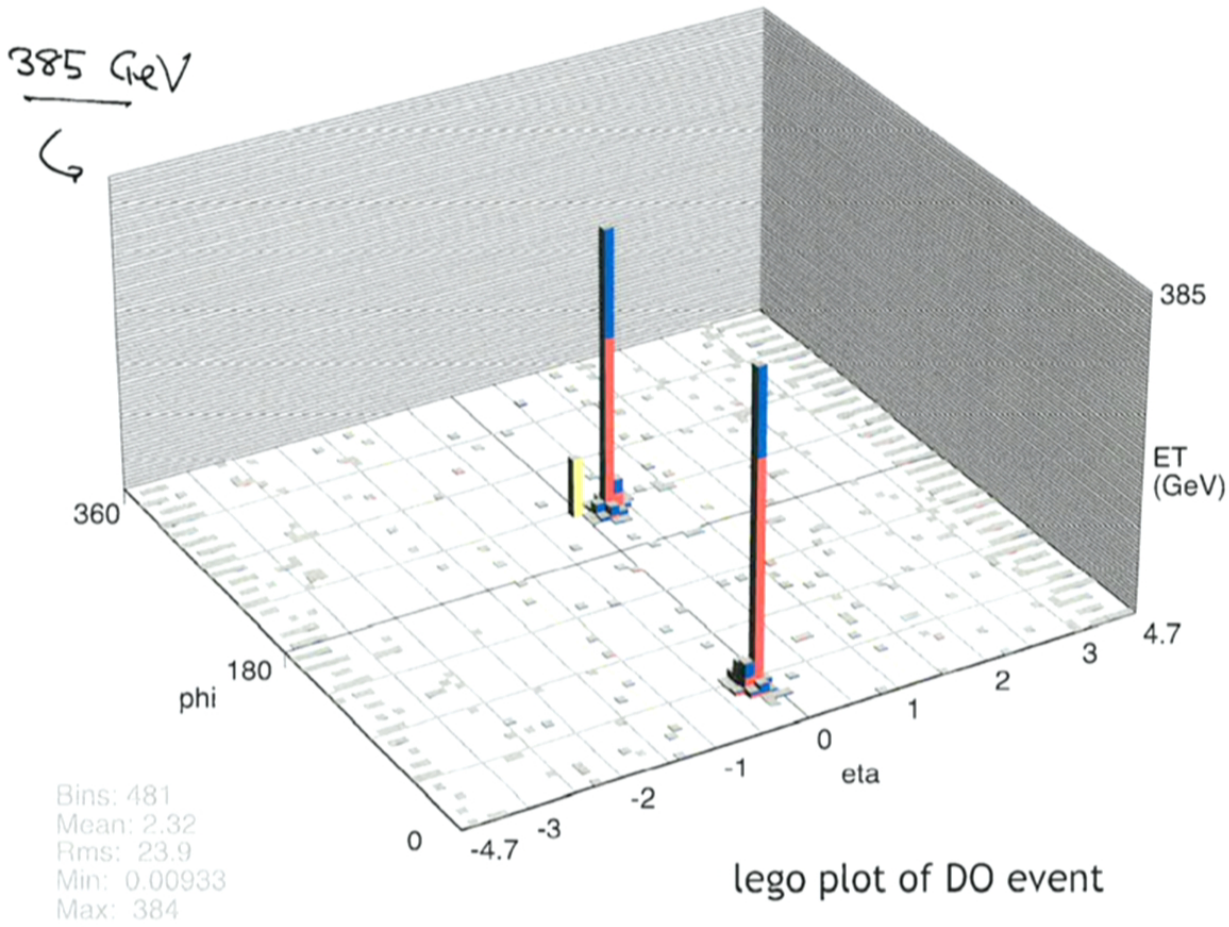


lego plot of DO event

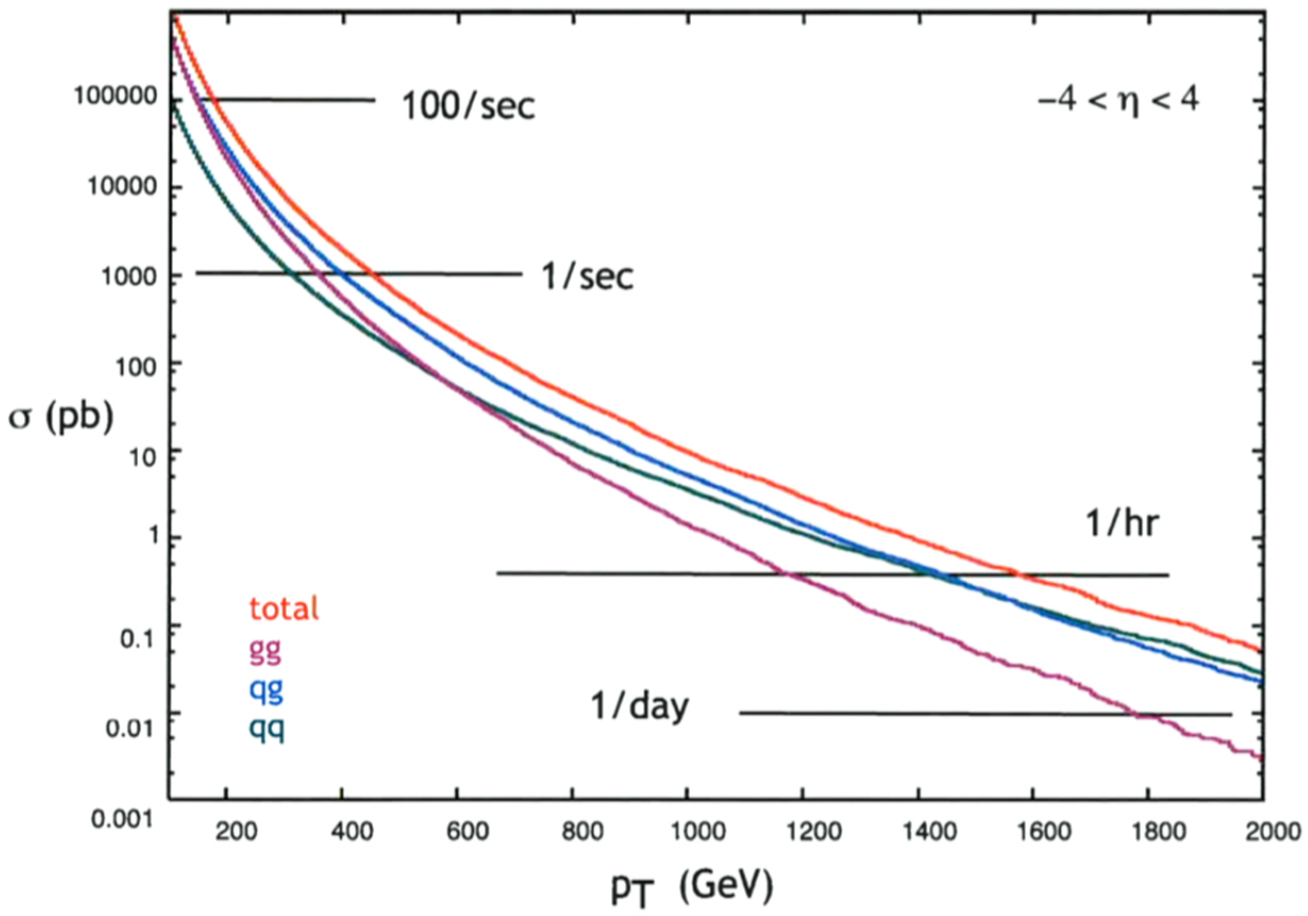

Run 178796 Event 67972991 Fri Feb 27 08:34:15 2004
ET scale: 436 GeV
-3.7
3.7
DO event

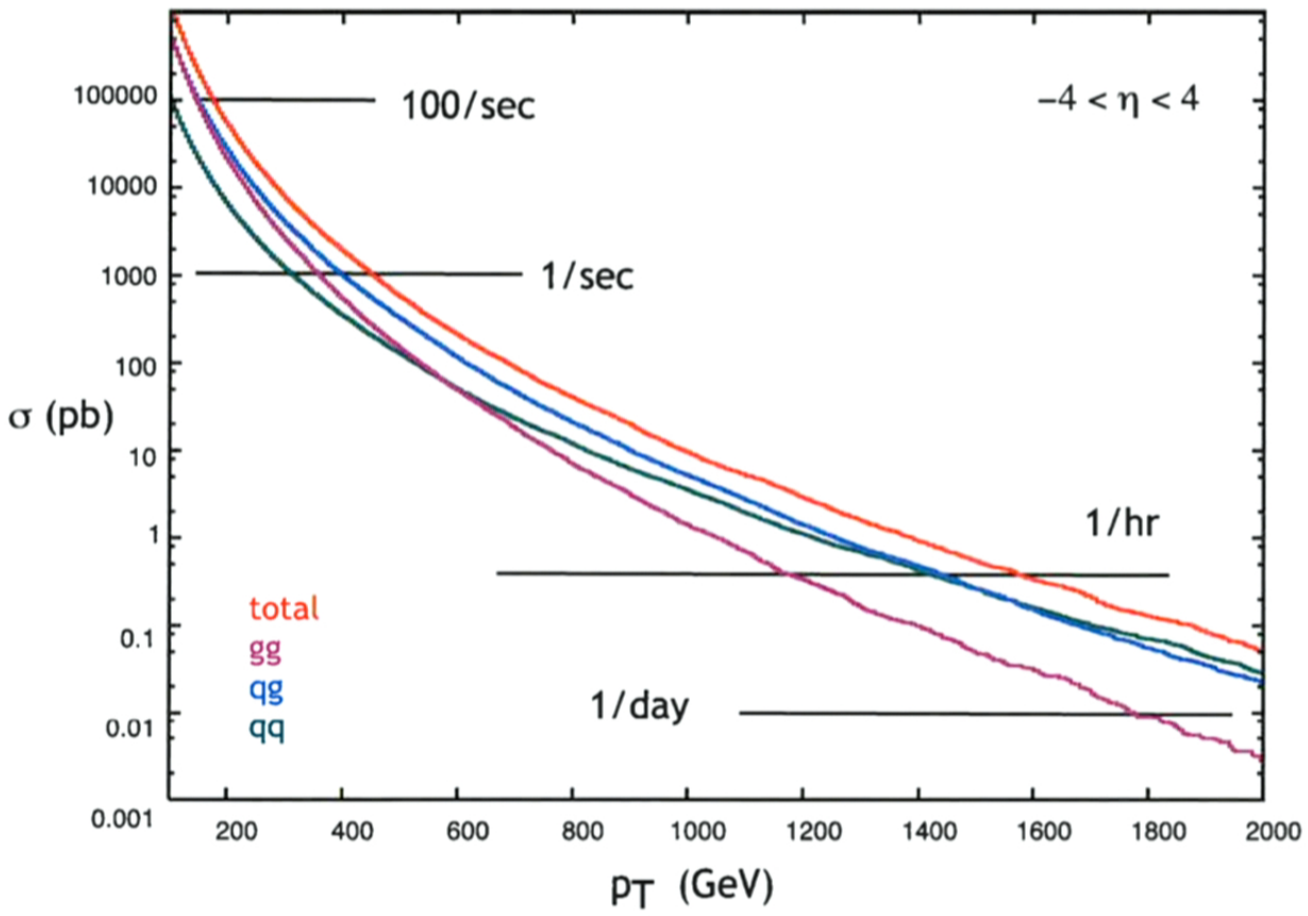


lego plot of DO event



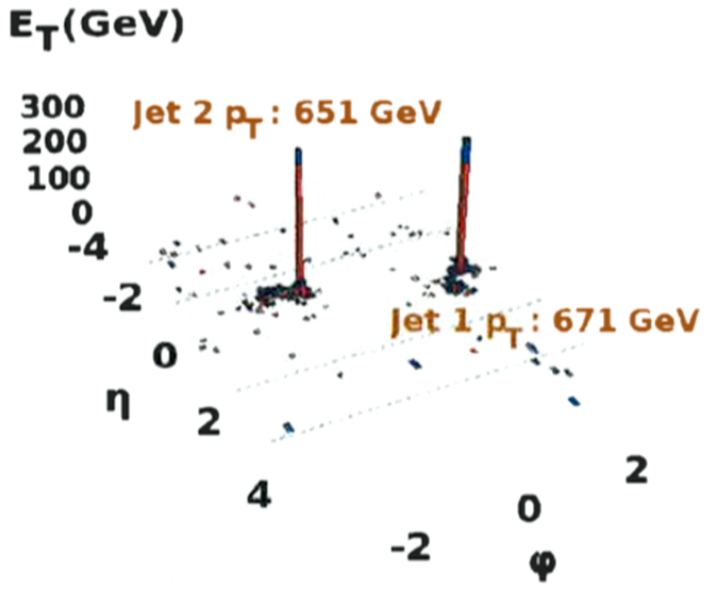
lego plot of DO event

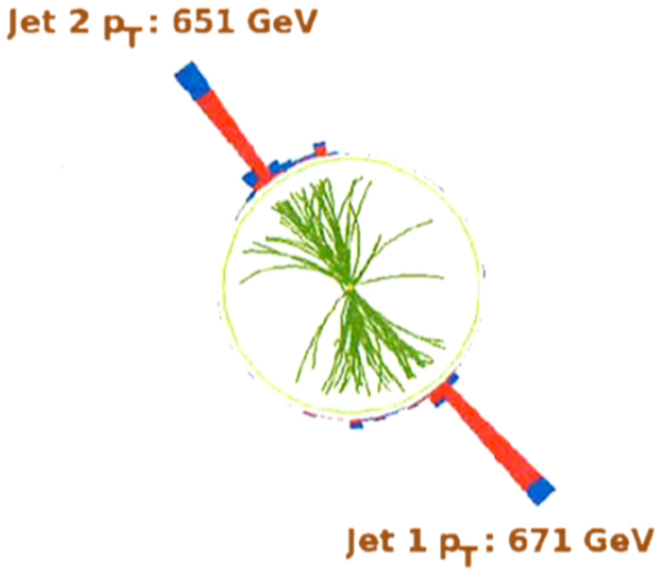

100/sec
−4 < η < 4
1/sec
1/hr
1/day
total
gg
qg
qq
σ (pb)
100000
10000
1000
100
10
1
0.1
0.01
0.001
200
400
600
800
1000
1200
1400
1600
1800
2000
pT (GeV)

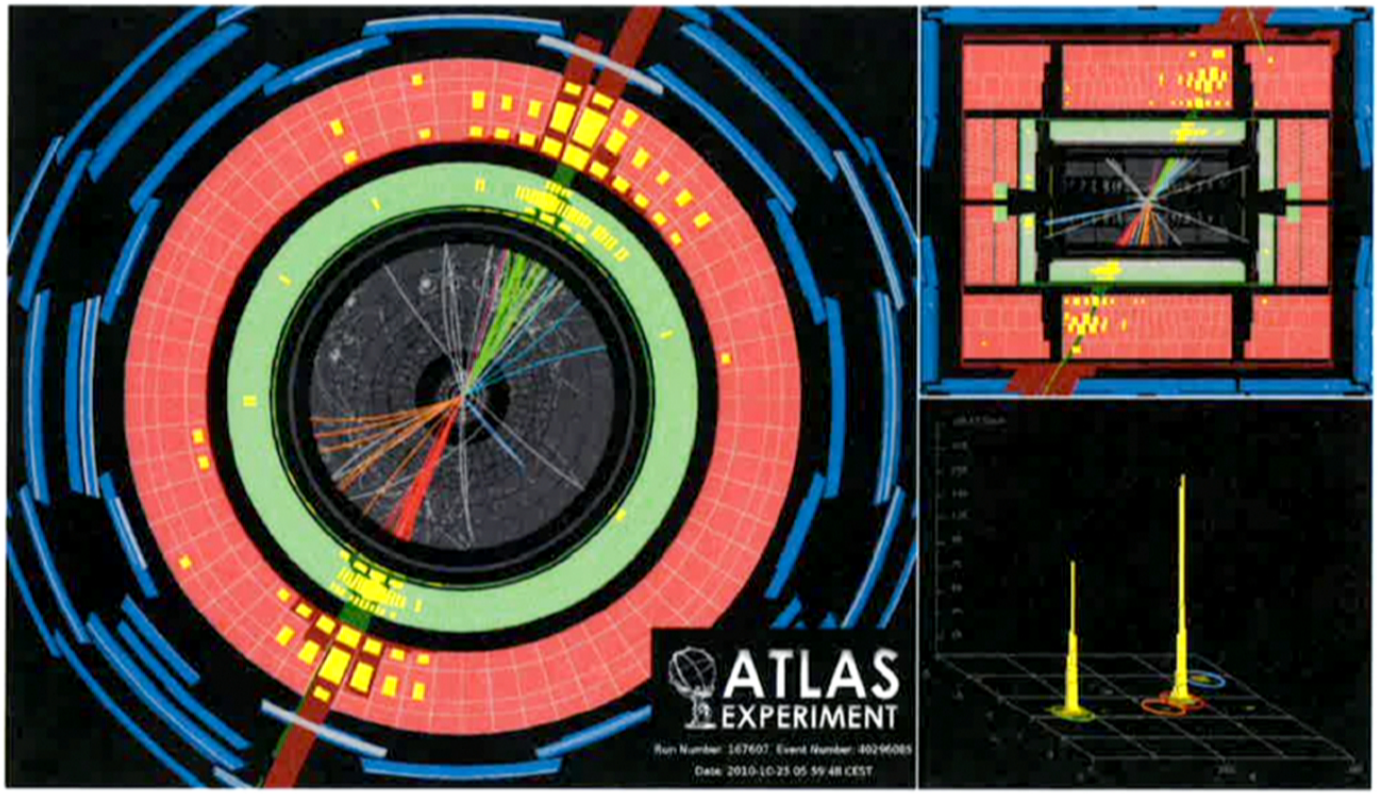

100/sec
−4 < η < 4
1/sec
1/hr
1/day
total
gg
qg
qq
σ (pb)
100000
10000
1000
100
10
1
0.1
0.01
0.001
200
400
600
800
1000
1200
1400
1600
1800
2000
pT (GeV)

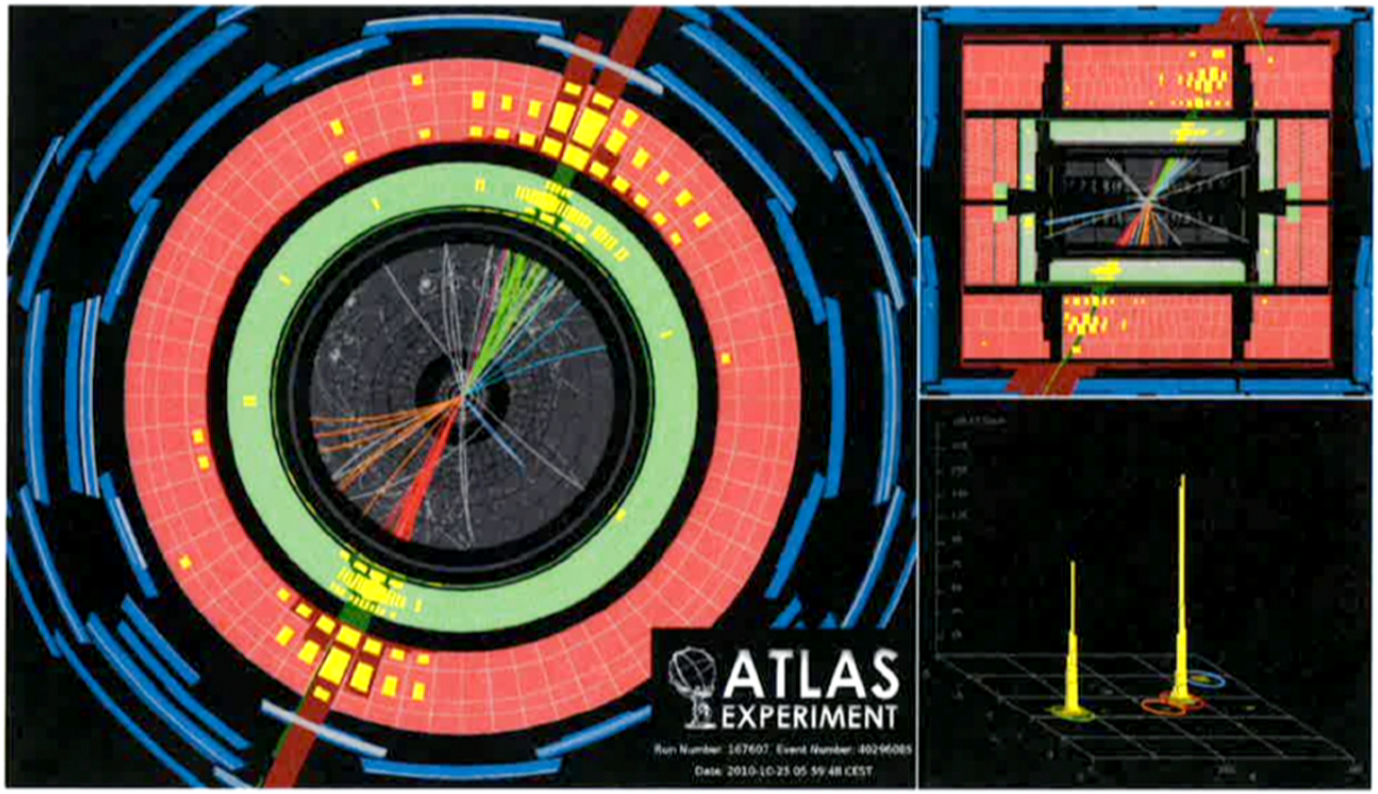

Run : 142038
Event : 240422134
Dijet Mass : 1451 GeV

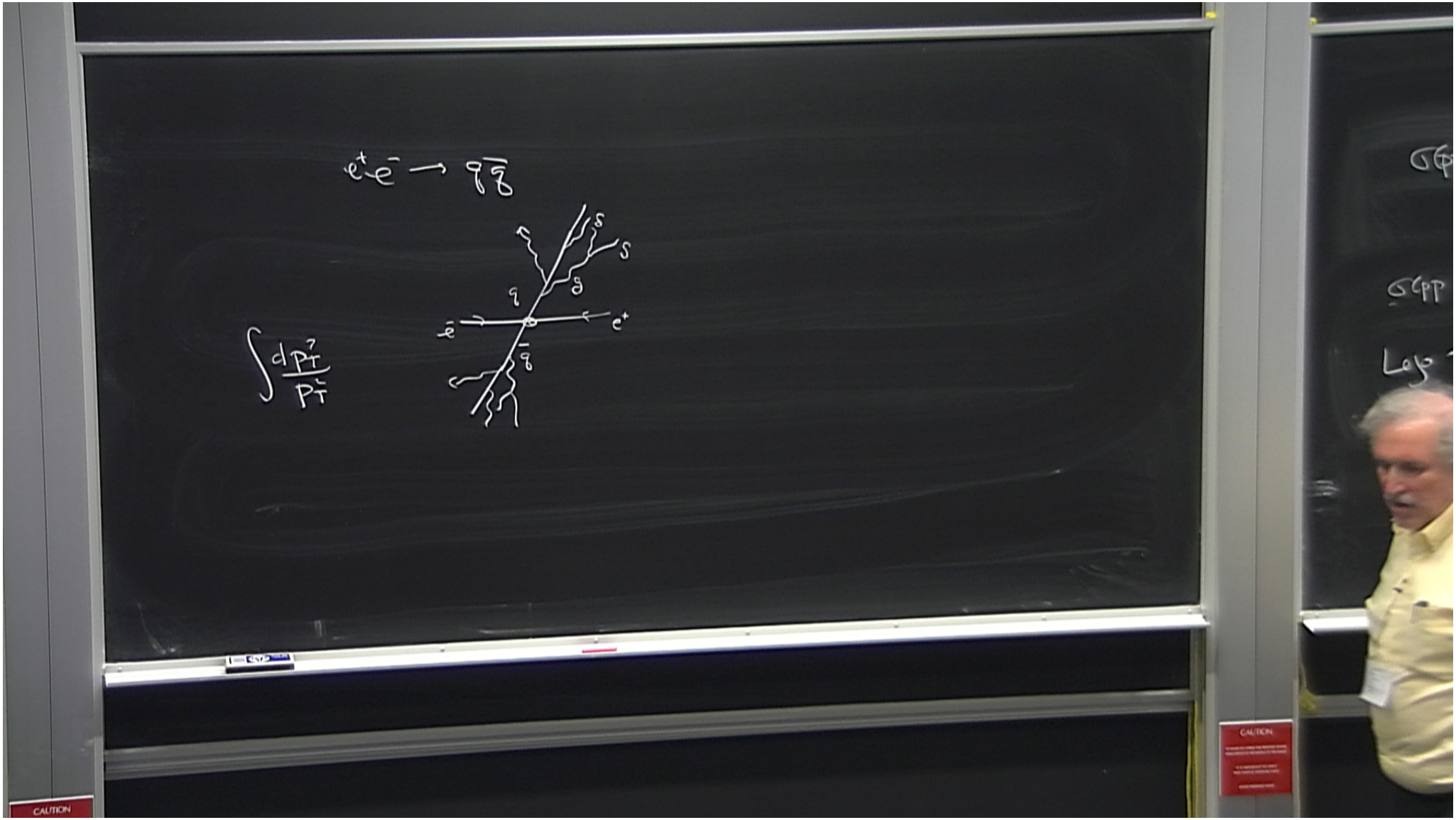

Run : 142038
Event : 240422134
Dijet Mass : 1451 GeV

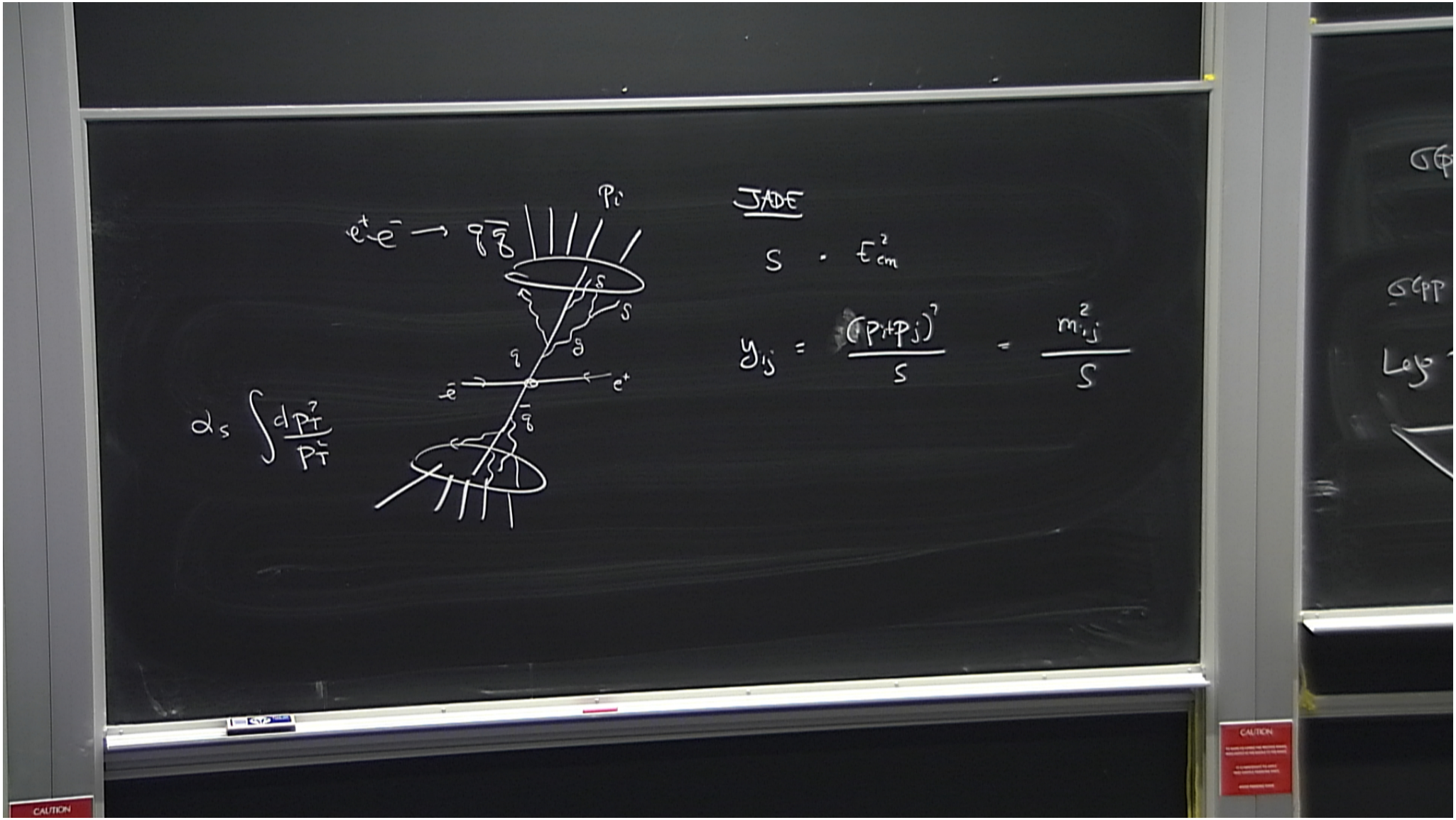

E_T(GeV)
300
200
100
0
Jet 2 p_T : 651 GeV
Jet 1 p_T : 671 GeV
-4
-2
0
η
2
4
-2
0
2
φ

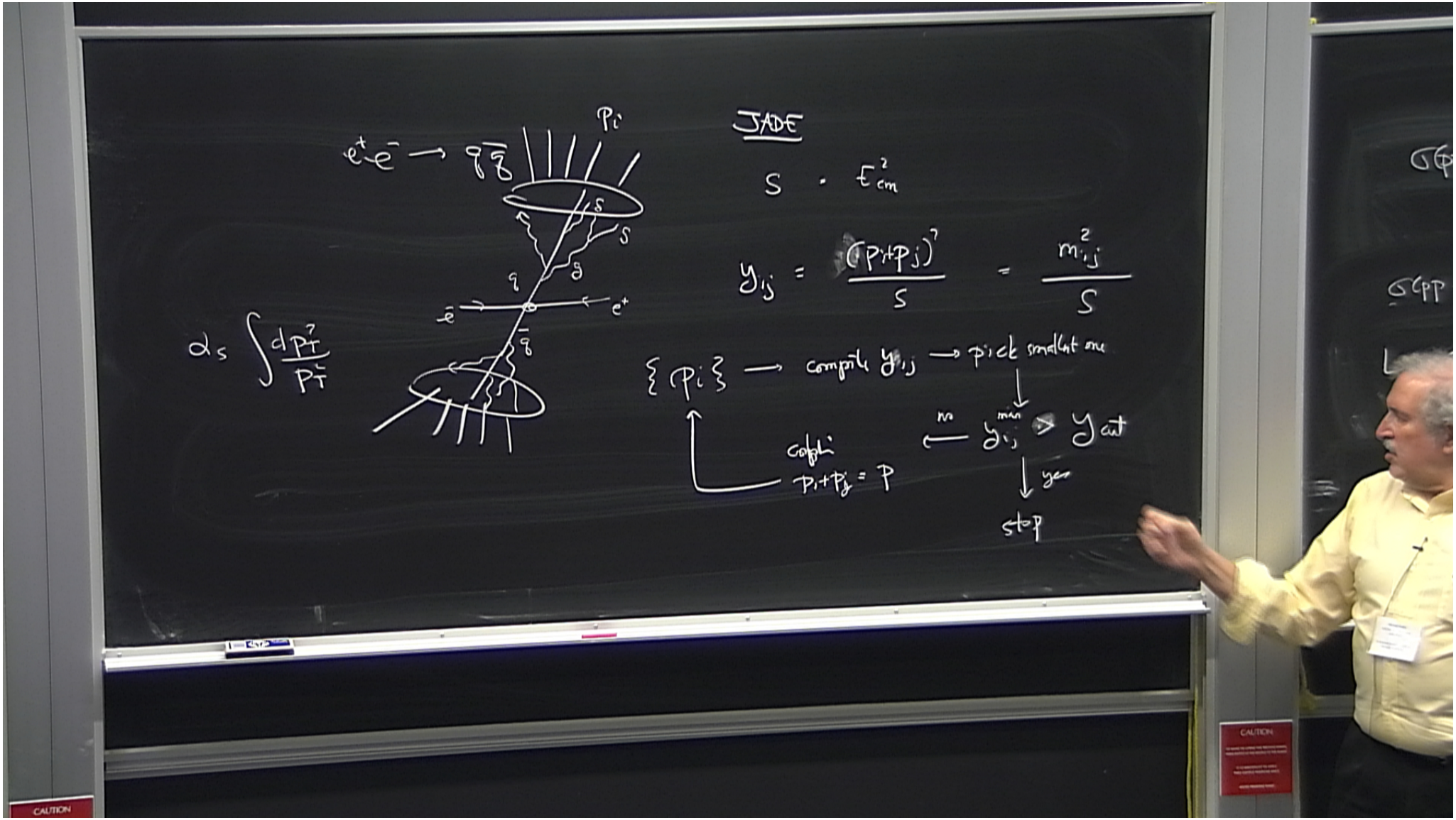

Jet 2 p_T : 651 GeV
Jet 1 p_T : 671 GeV

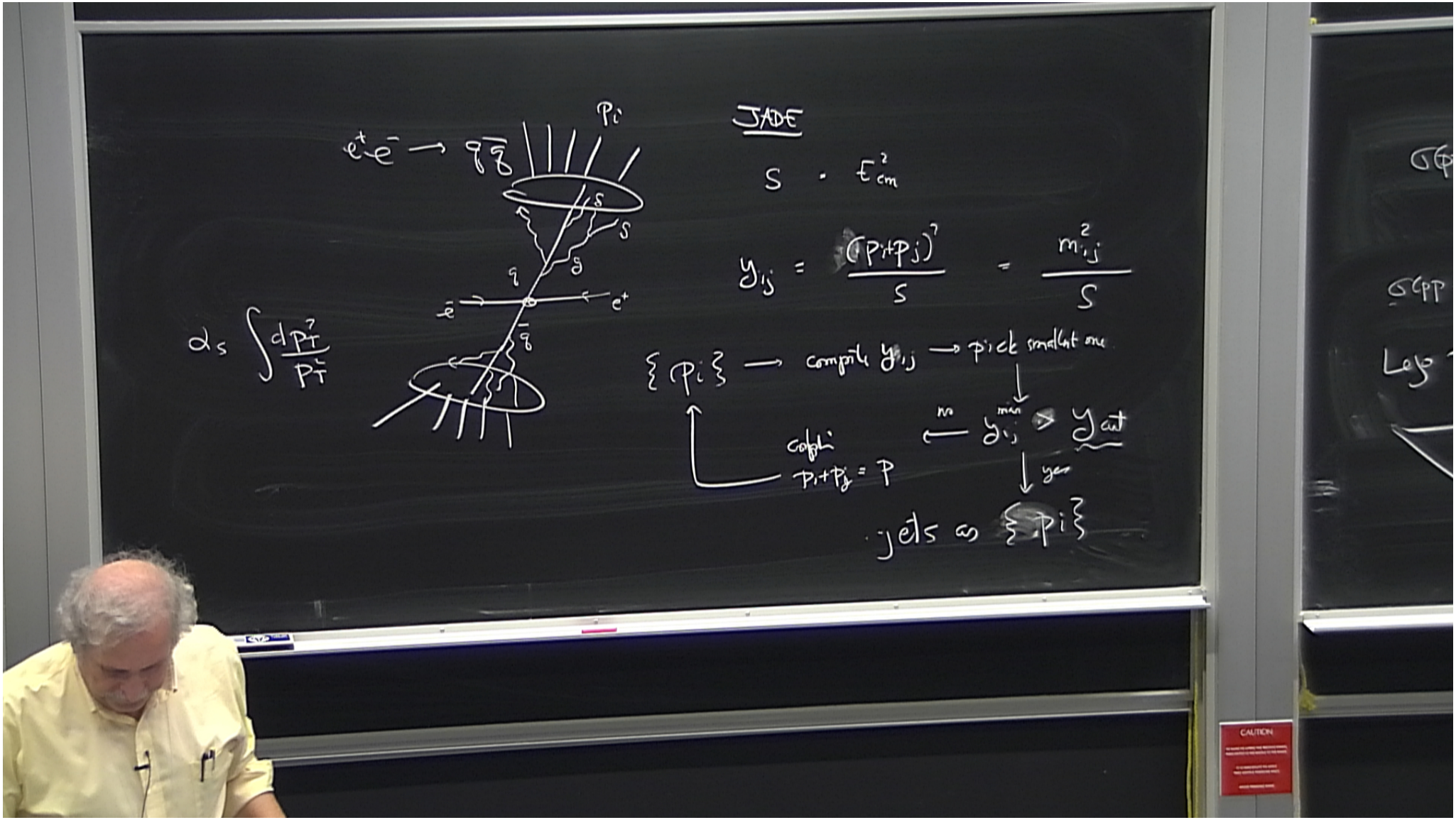

ATLAS
EXPERIMENT
Run Number: 167607, Event Number: 40296085
Date: 2010-10-25 05:59:48 CEST

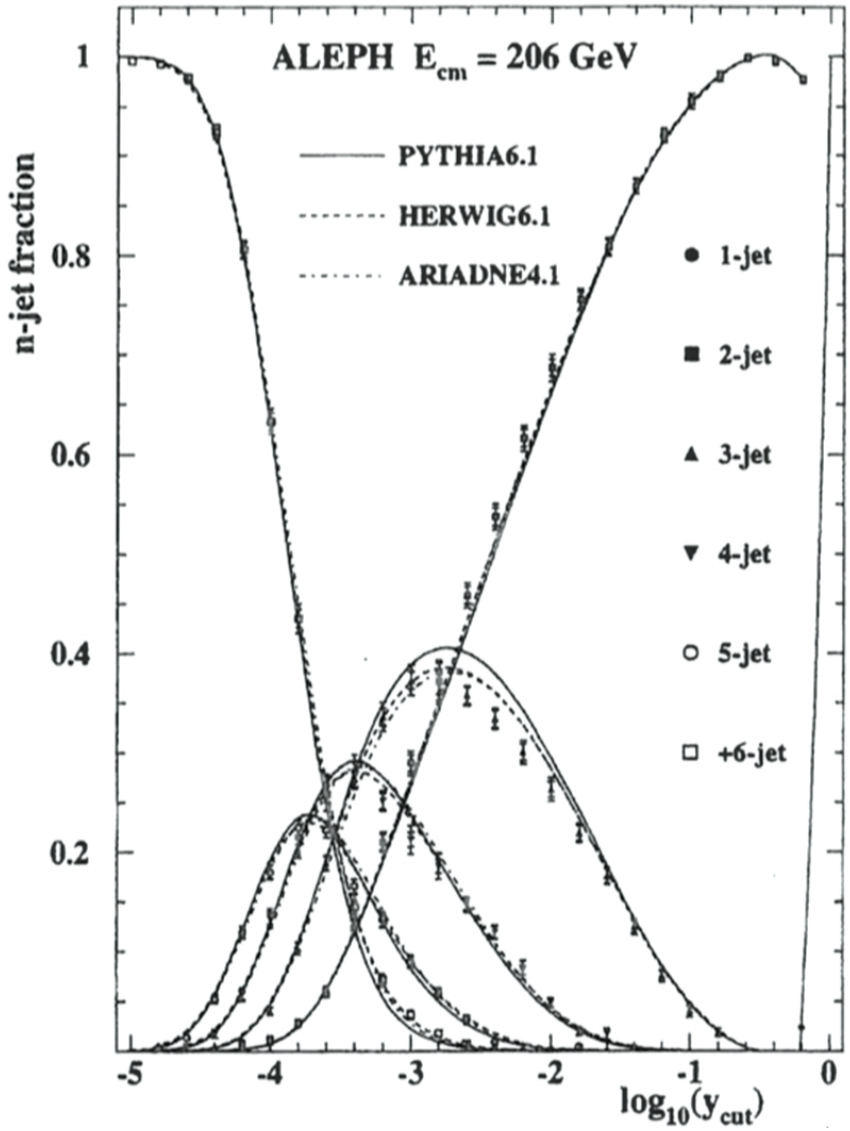

ATLAS
EXPERIMENT
Run Number: 167607, Event Number: 40296085
Date: 2010-10-25 05:59:48 CEST

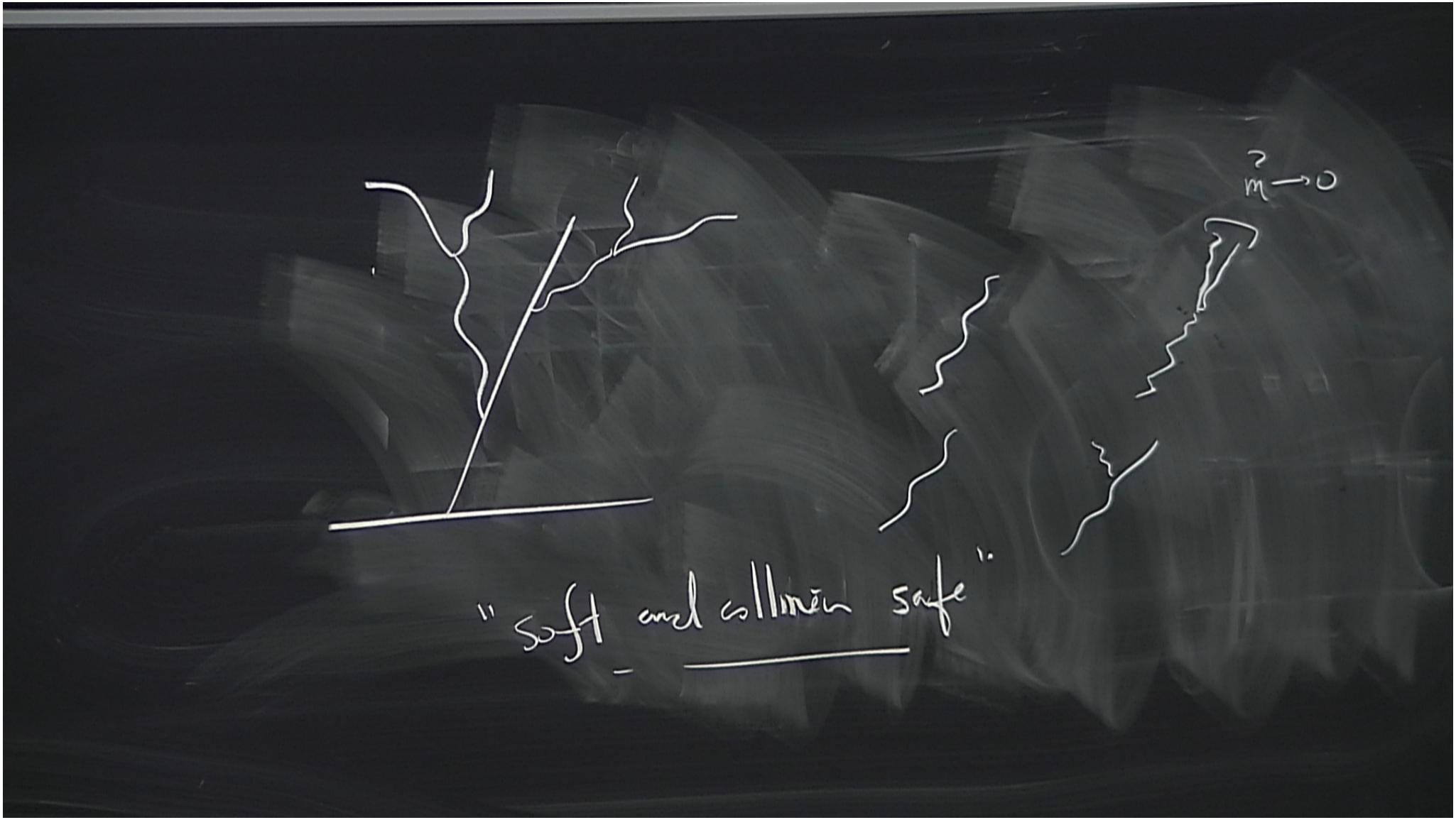

$e^+e^- \to q\bar{q}$
$\int \frac{dp_T^2}{p_T^2}$
g
g
g
q
$\bar{q}$
e^-
e^+

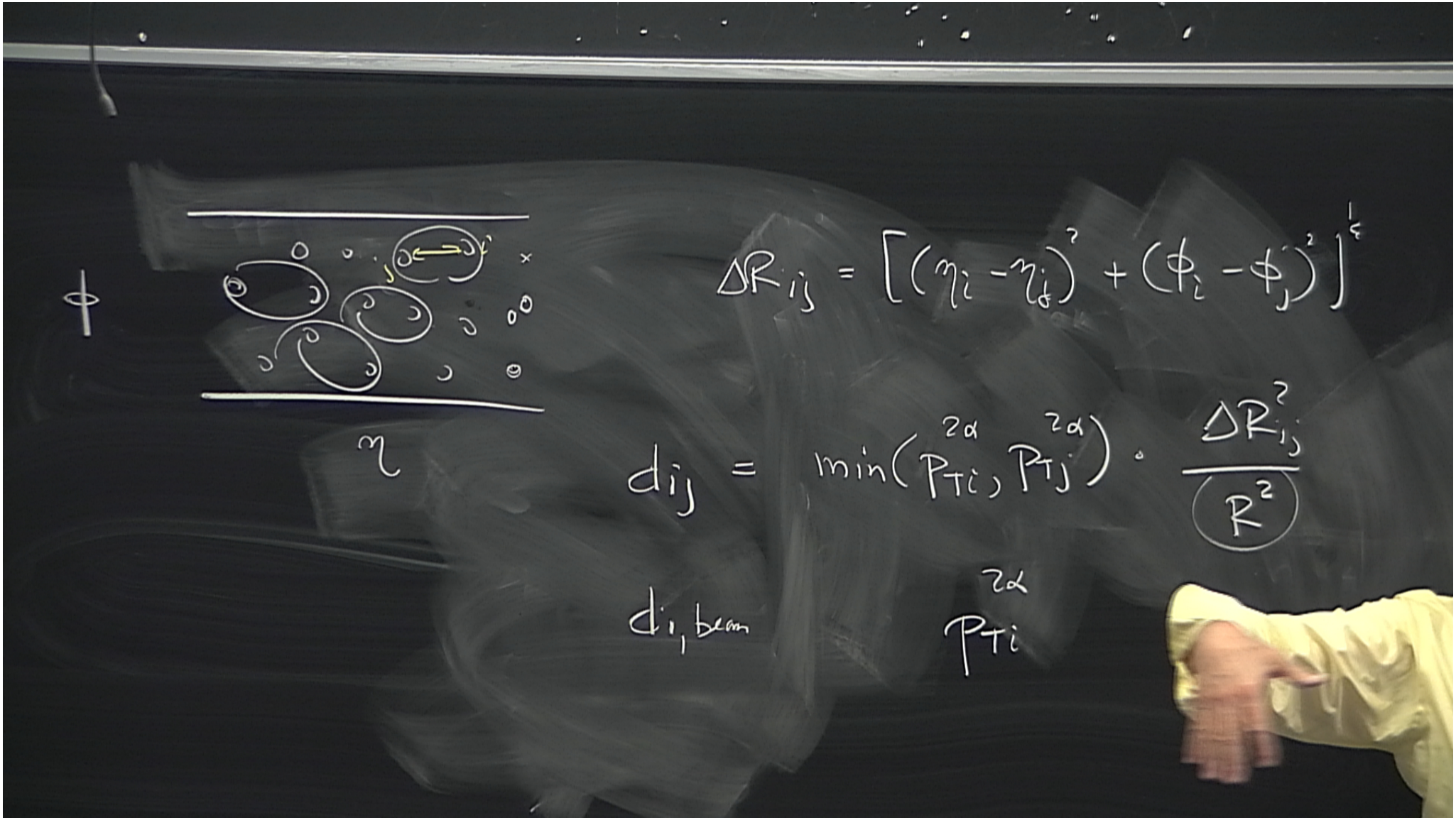

$e^+e^- \to q\bar{q}$
p_i
s
s
q
g
e
e^+
$\bar{q}$
$\alpha_s \int \frac{dp_T^2}{p_T^2}$
JADE
$s = E_{cm}^2$
$y_{ij} = \frac{(p_i+p_j)^2}{s} = \frac{m_{ij}^2}{s}$

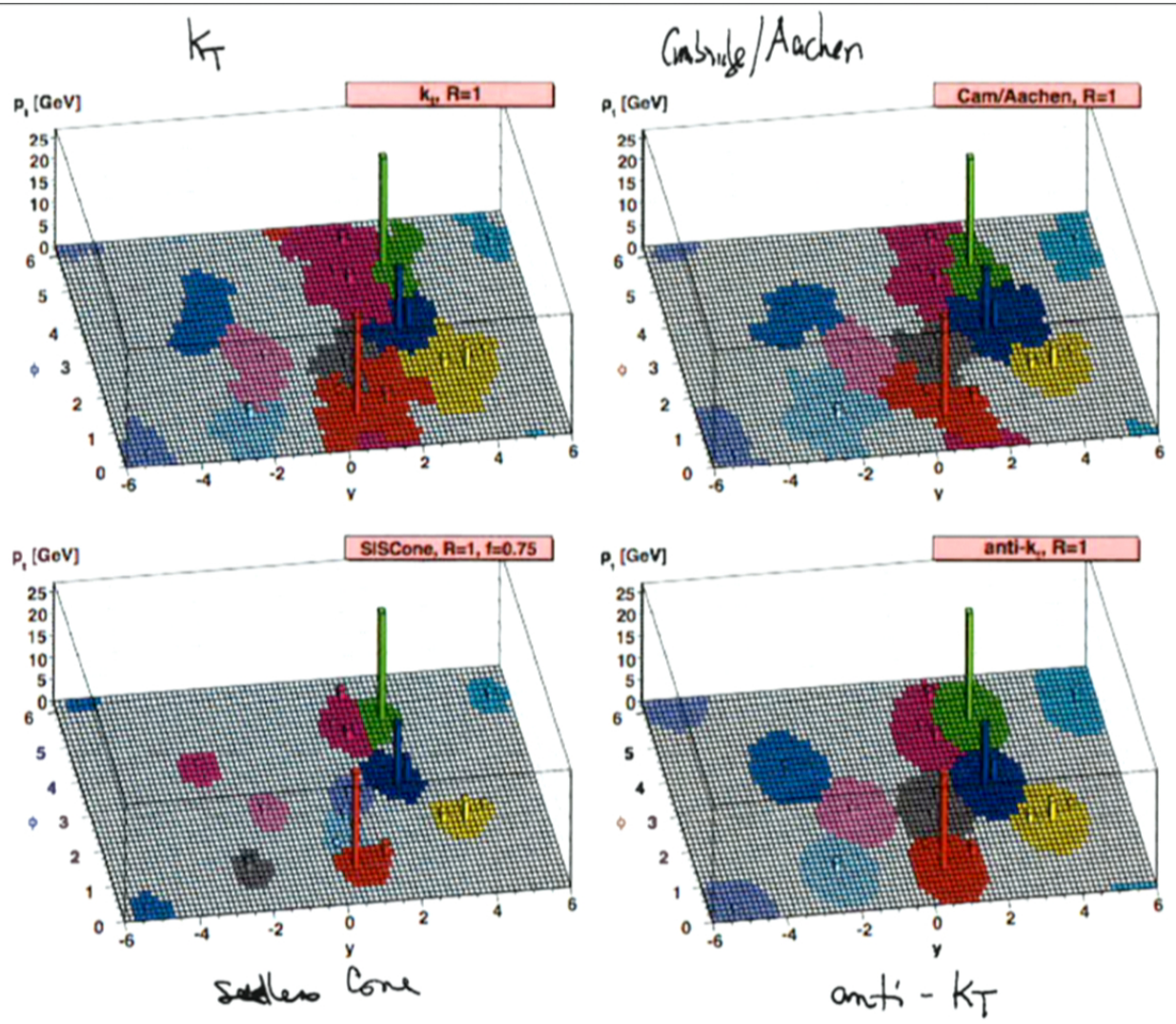

$e^+e^- \to q\bar{q}$
p_i
q
g
$\bar{q}$
e^-
e^+
JADE
$s = E^2_{cm}$
$y_{ij} = \frac{(p_i+p_j)^2}{s} = \frac{m^2_{ij}}{s}$
$\alpha_s \int \frac{dp_T^2}{p_T^2}$
$\{p_i\} \to$ compute $y_{ij} \to$ pick smallest one
$y^{min}_{ij} > y_{cut}$
no
yes
stop
combine
$p_i + p_j = p$


$e^+e^- \to q\bar{q}$
p_i
q
$\bar{q}$
e^-
e^+
$\alpha_s \int \frac{dp_T^2}{p_T^2}$
JADE
$s = E_{cm}^2$
$y_{ij} = \frac{(p_i+p_j)^2}{s} = \frac{m_{ij}^2}{s}$
$\{p_i\} \to$ compute $y_{ij} \to$ pick smallest one
$\leftarrow y_{ij}^{min} > y_{cut}$
yes
combine $p_i + p_j = p$
jets $\Leftrightarrow \{p_i\}$

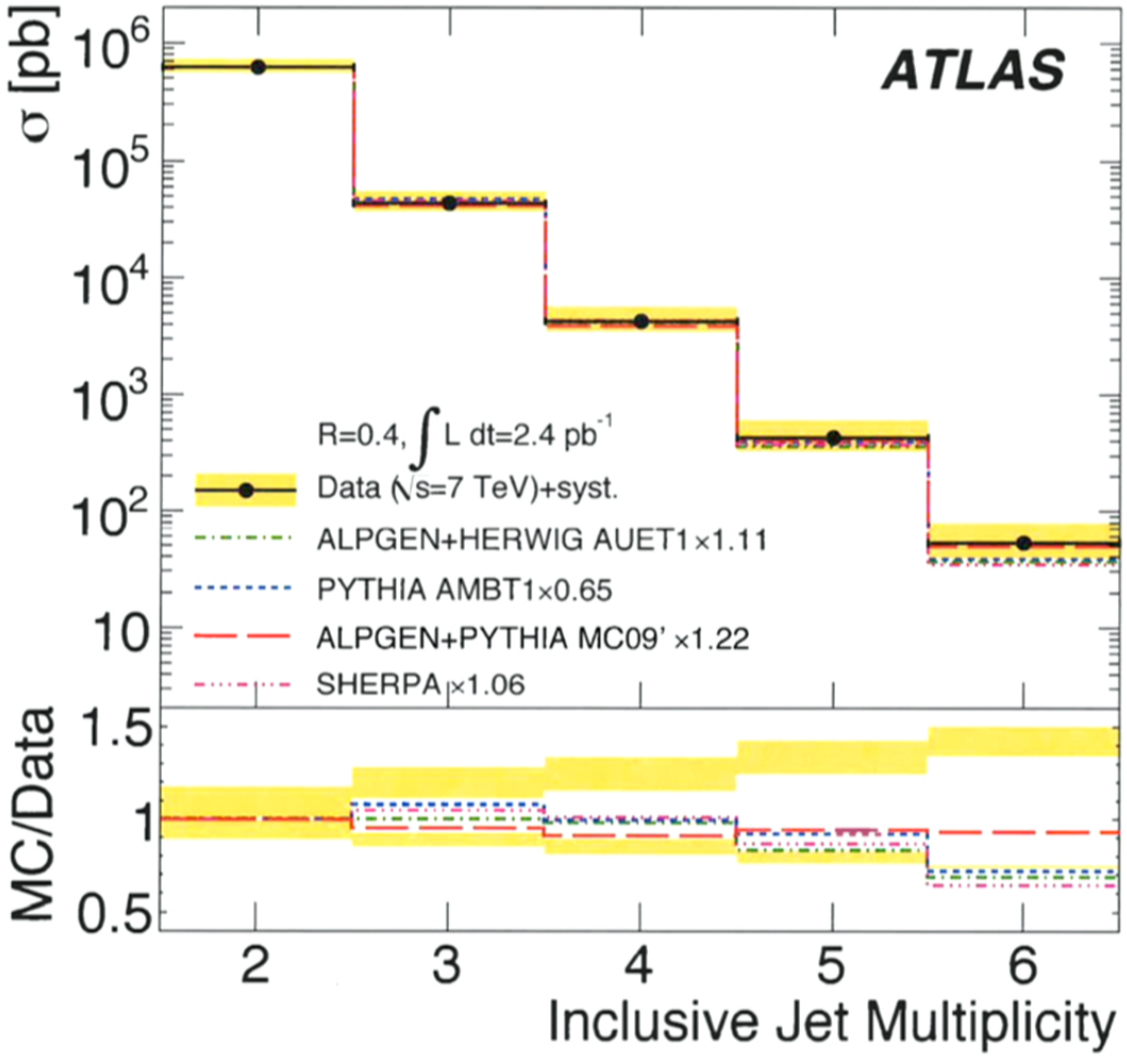

ALEPH E_{cm} = 206 GeV
PYTHIA6.1
HERWIG6.1
ARIADNE4.1
1-jet
2-jet
3-jet
4-jet
5-jet
+6-jet
n-jet fraction
1
0.8
0.6
0.4
0.2
-5
-4
-3
-2
-1
0
$\log_{10}(y_{cut})$

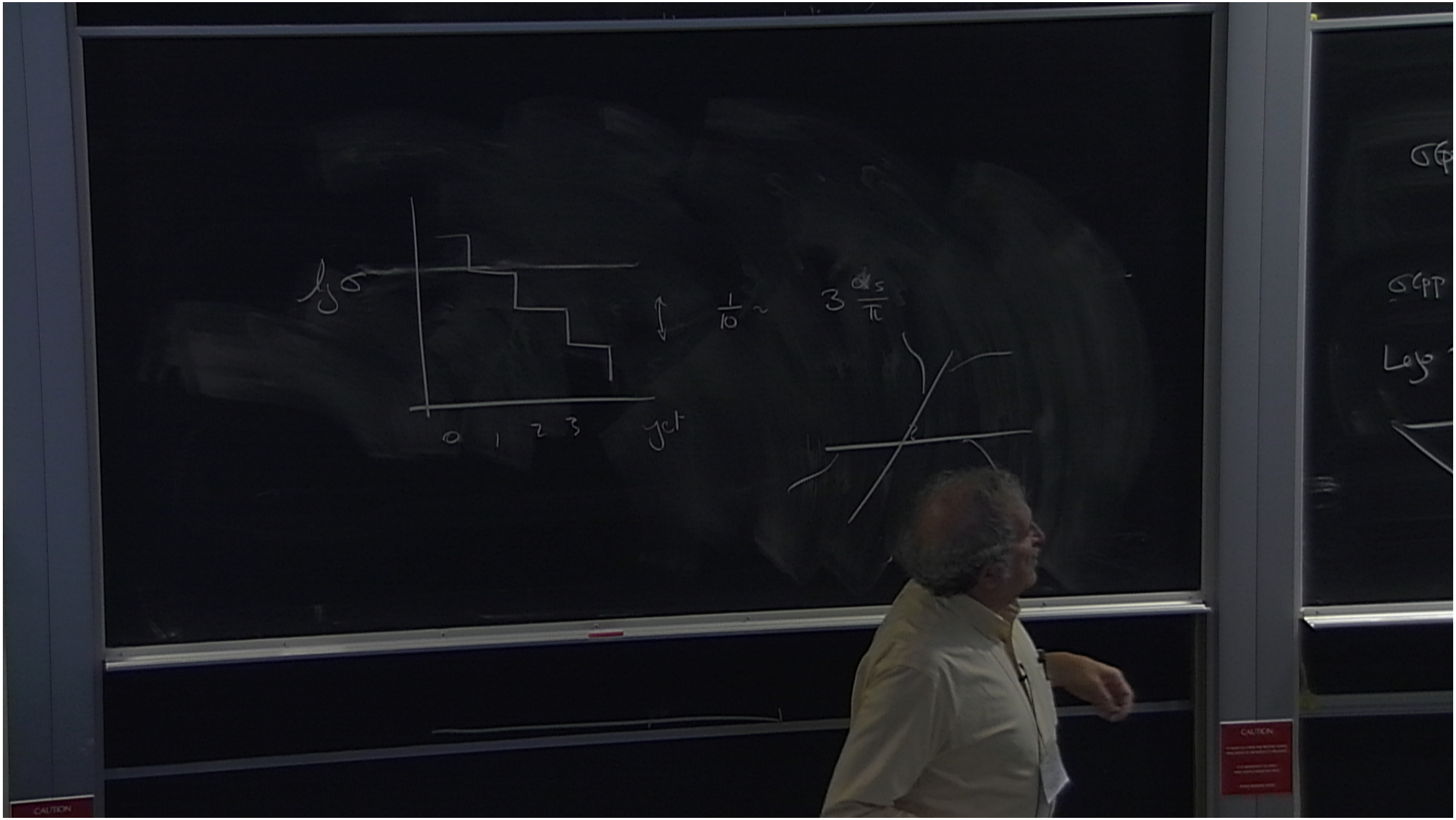

"soft and collinear safe"

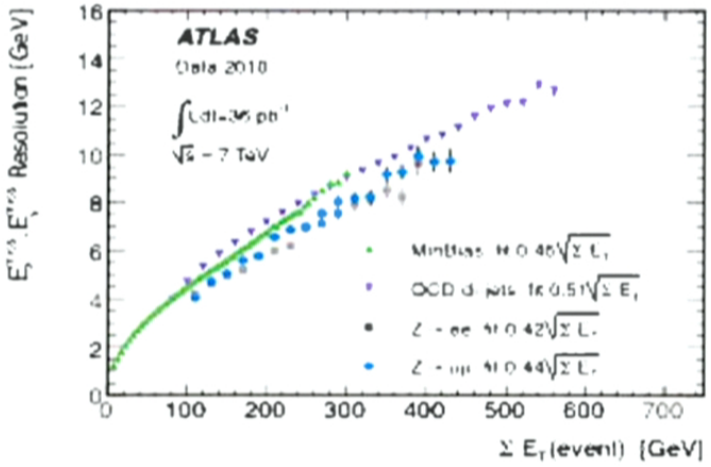

ϕ
η
$\Delta R_{ij} = \left[(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2 \right]^{\frac{1}{2}}$
$d_{ij} = \min(p_{Ti}^{2\alpha}, p_{Tj}^{2\alpha}) \cdot \frac{\Delta R_{ij}^2}{R^2}$
$d_{i,\text{beam}} \quad p_{Ti}^{2\alpha}$

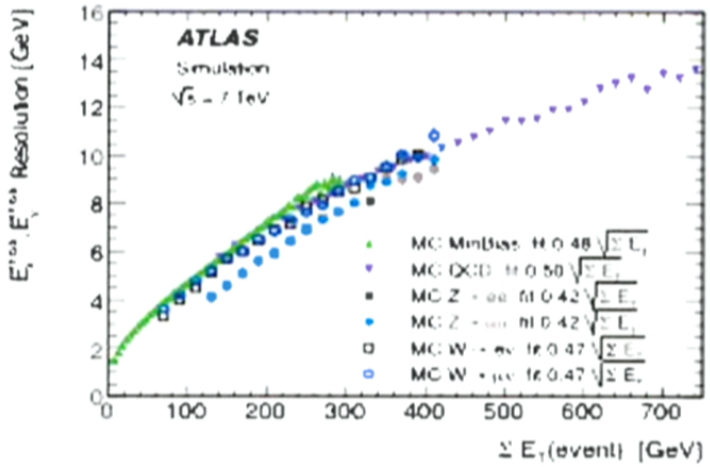


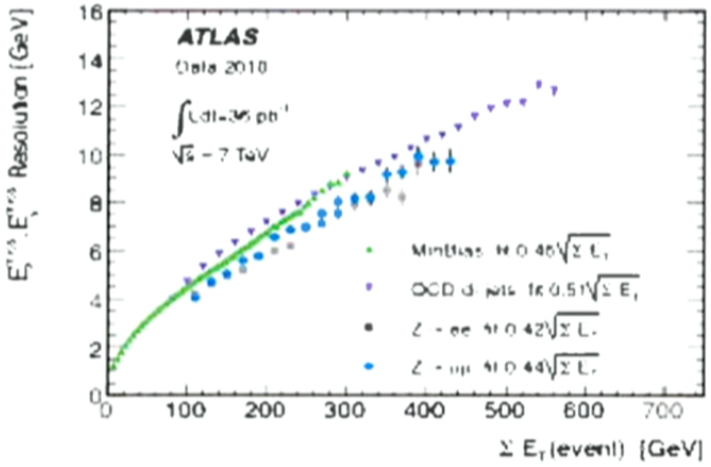
Salam arXiv:0906.1833

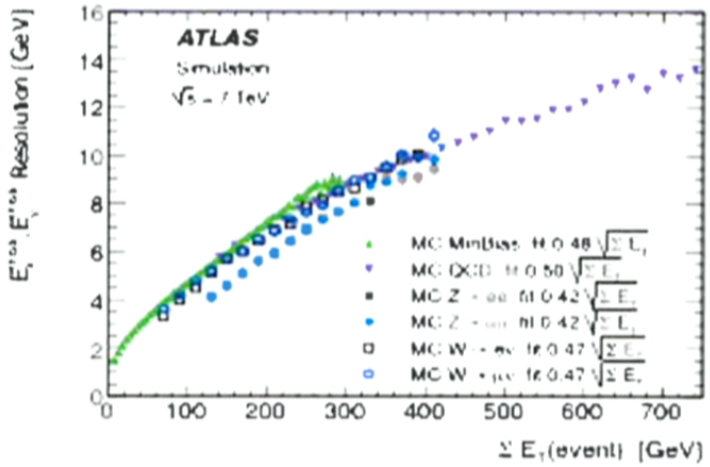

ATLAS
σ [pb]
10^6
10^5
10^4
10^3
10^2
10
R=0.4, $\int$ L dt=2.4 pb^{-1}
Data ($\sqrt{s}$=7 TeV)+syst.
ALPGEN+HERWIG AUET1 ×1.11
PYTHIA AMBT1×0.65
ALPGEN+PYTHIA MC09' ×1.22
SHERPA ×1.06
MC/Data
1.5
1
0.5
2
3
4
5
6
Inclusive Jet Multiplicity

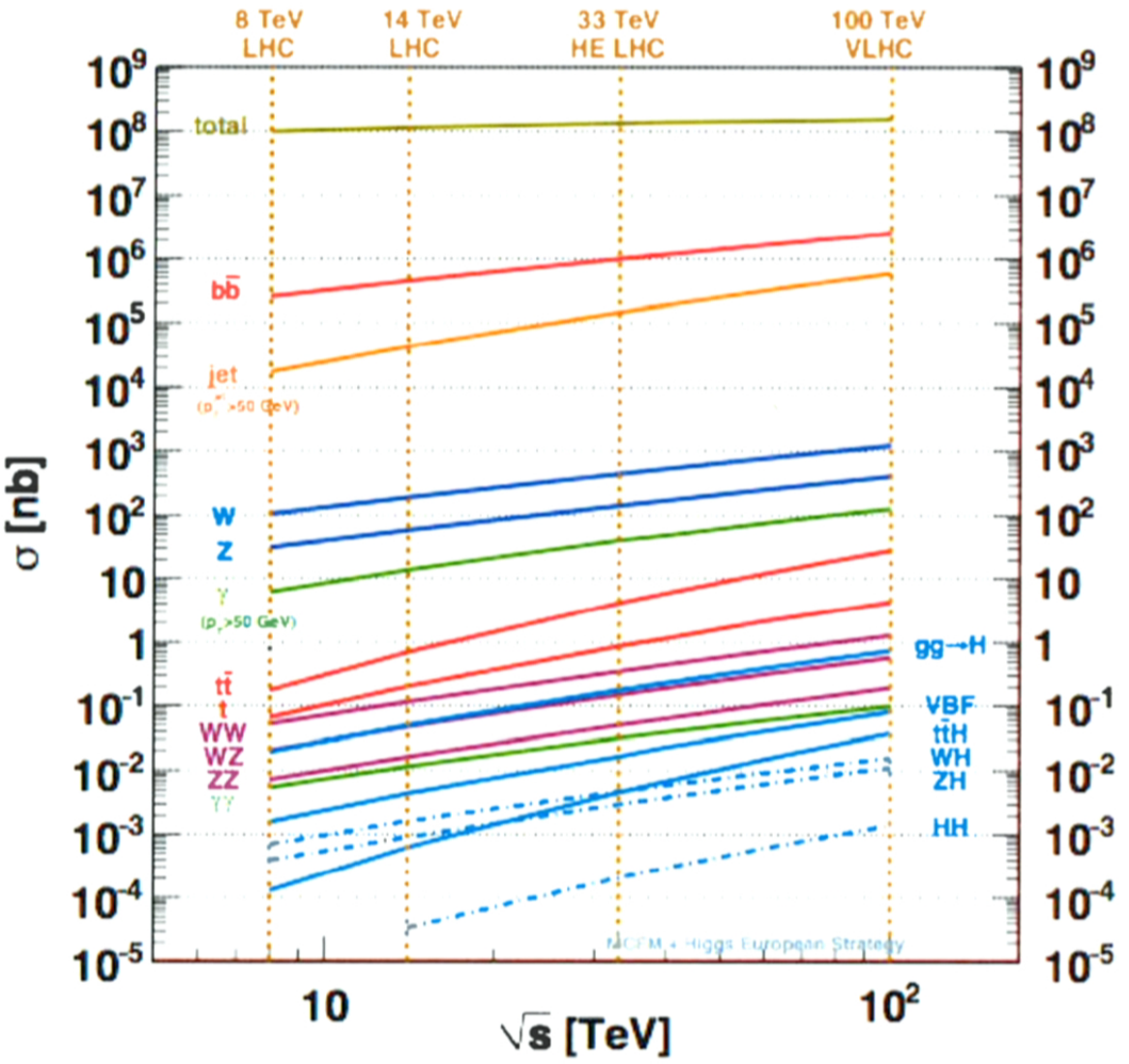

0 1 2 3
jet
$\frac{1}{10} \sim 3\frac{\alpha_s}{\pi}$

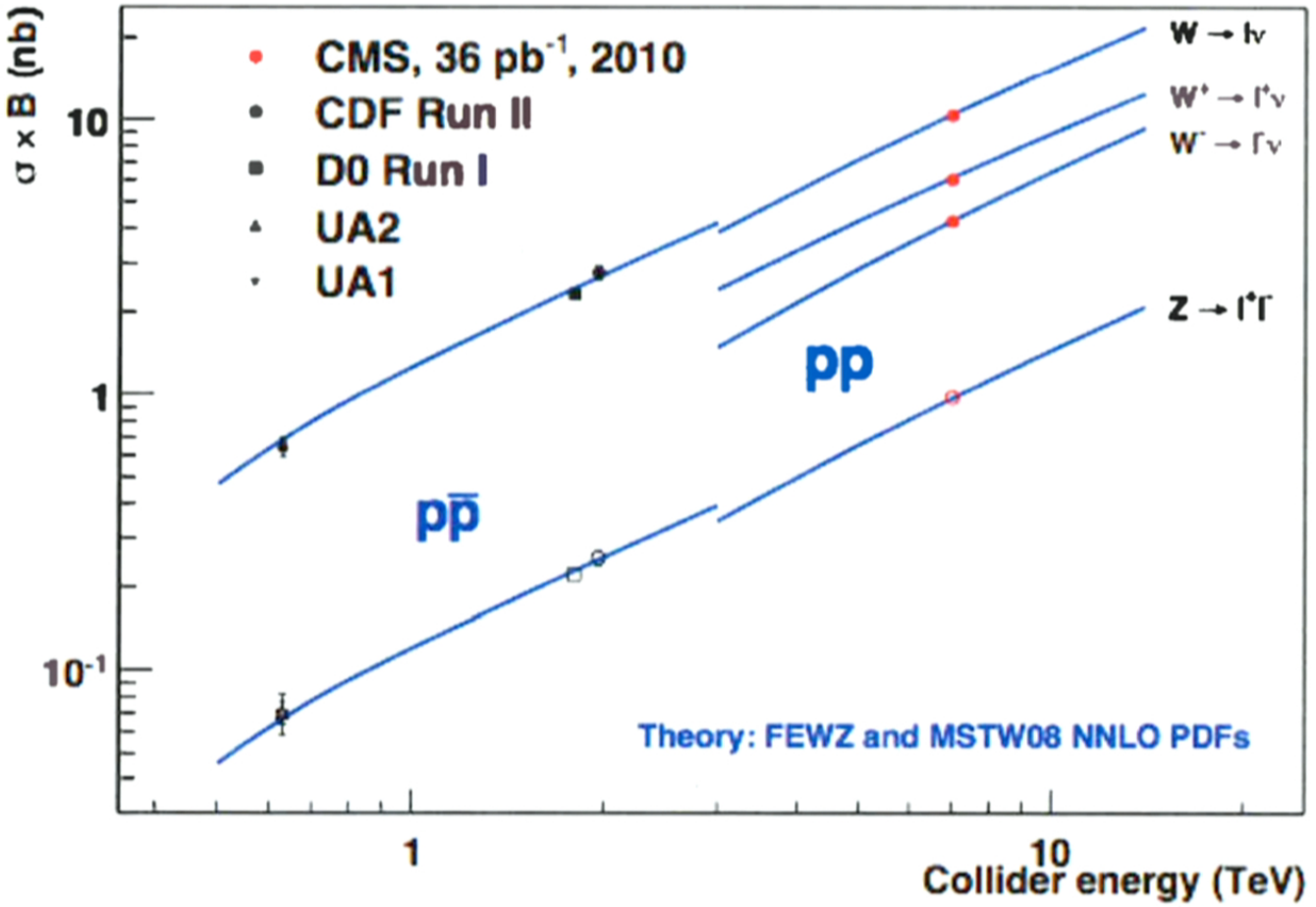

ATLAS
Data 2010
√s = 7 TeV
Σ E_T(event) [GeV]

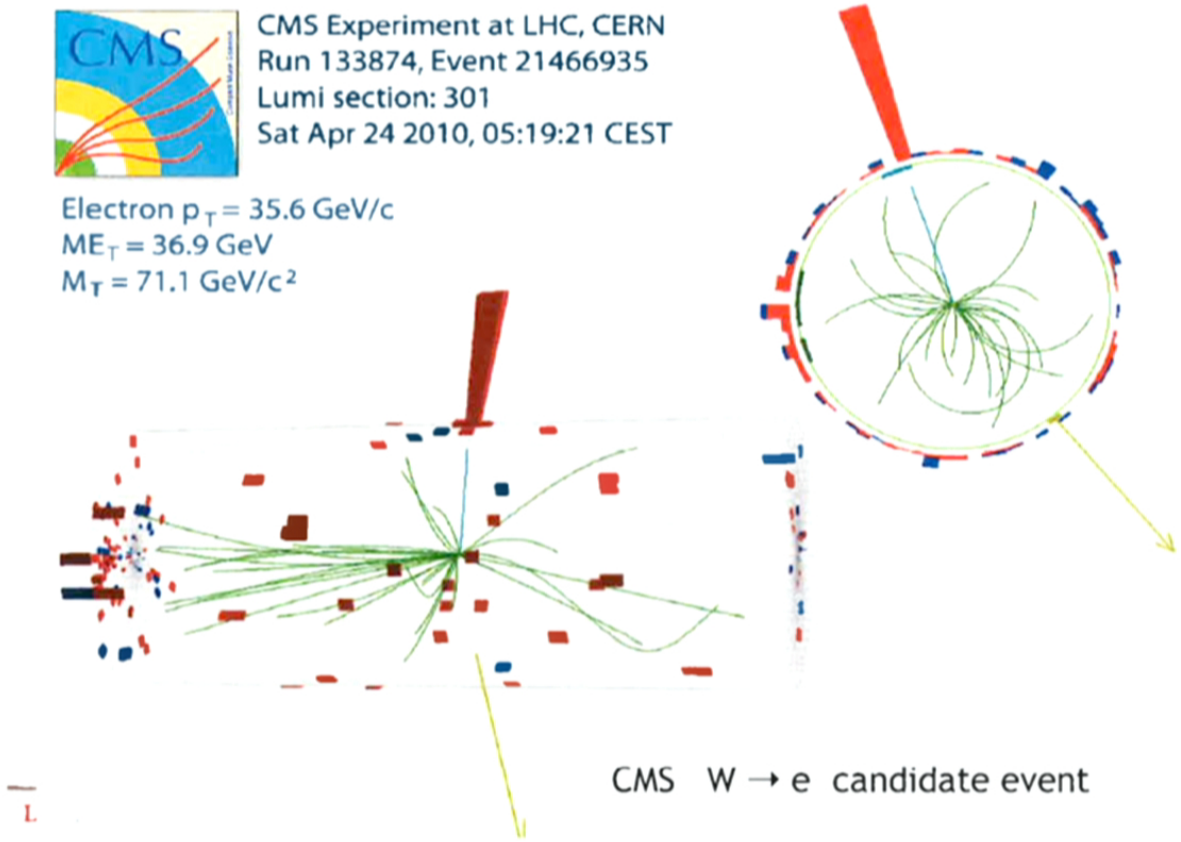

ATLAS
Simulation
√s = 7 TeV
Σ E_T(event) [GeV]

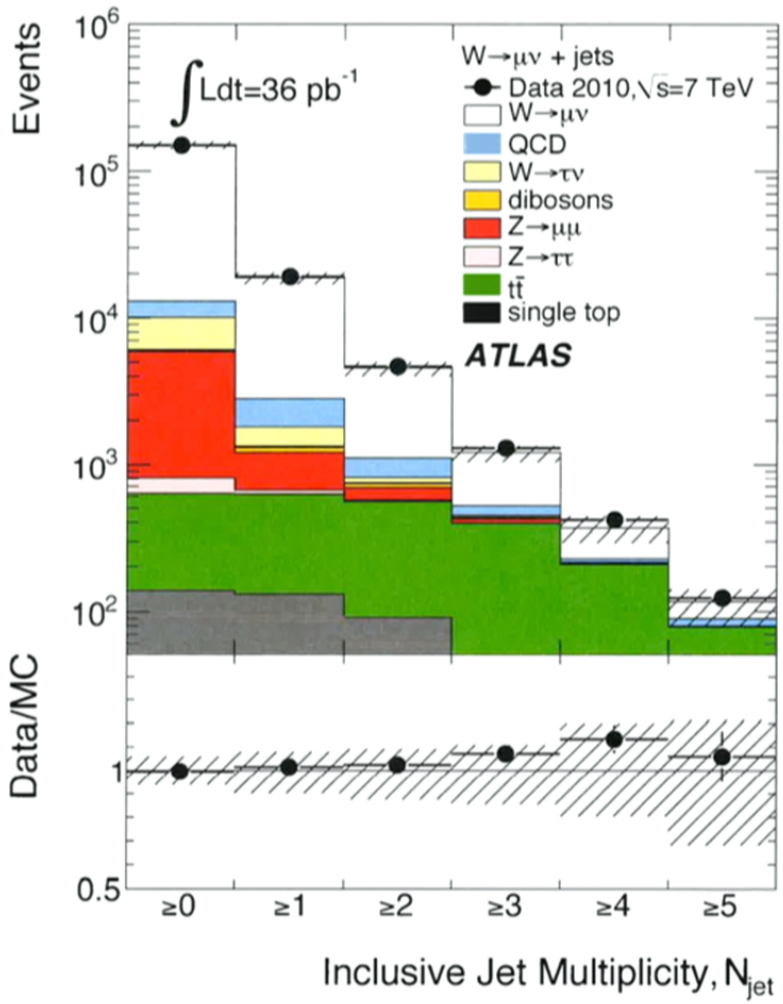

ATLAS
Data 2010
√s = 7 TeV
Σ E_T(event) [GeV]

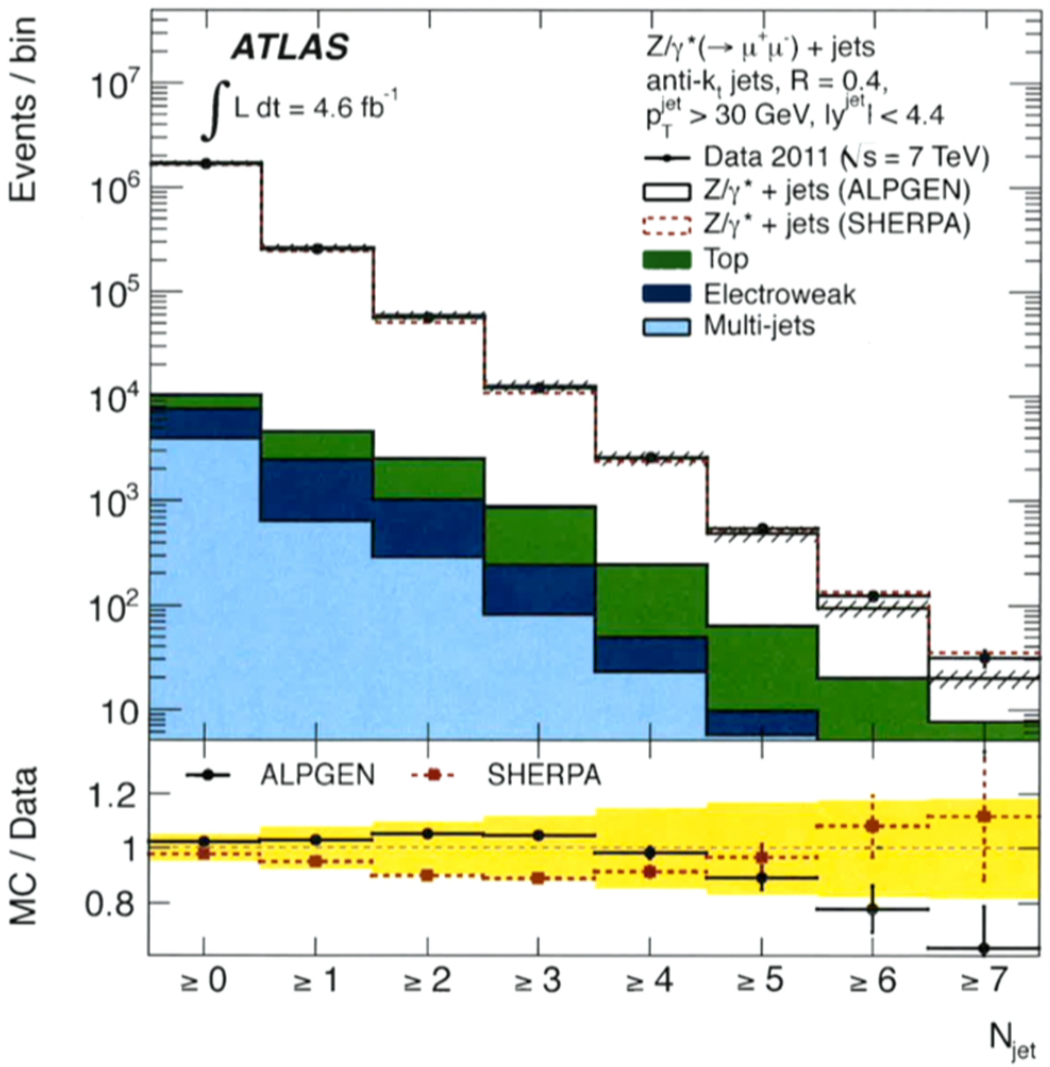

ATLAS
Simulation
√s = 7 TeV
Σ E_T(event) [GeV]

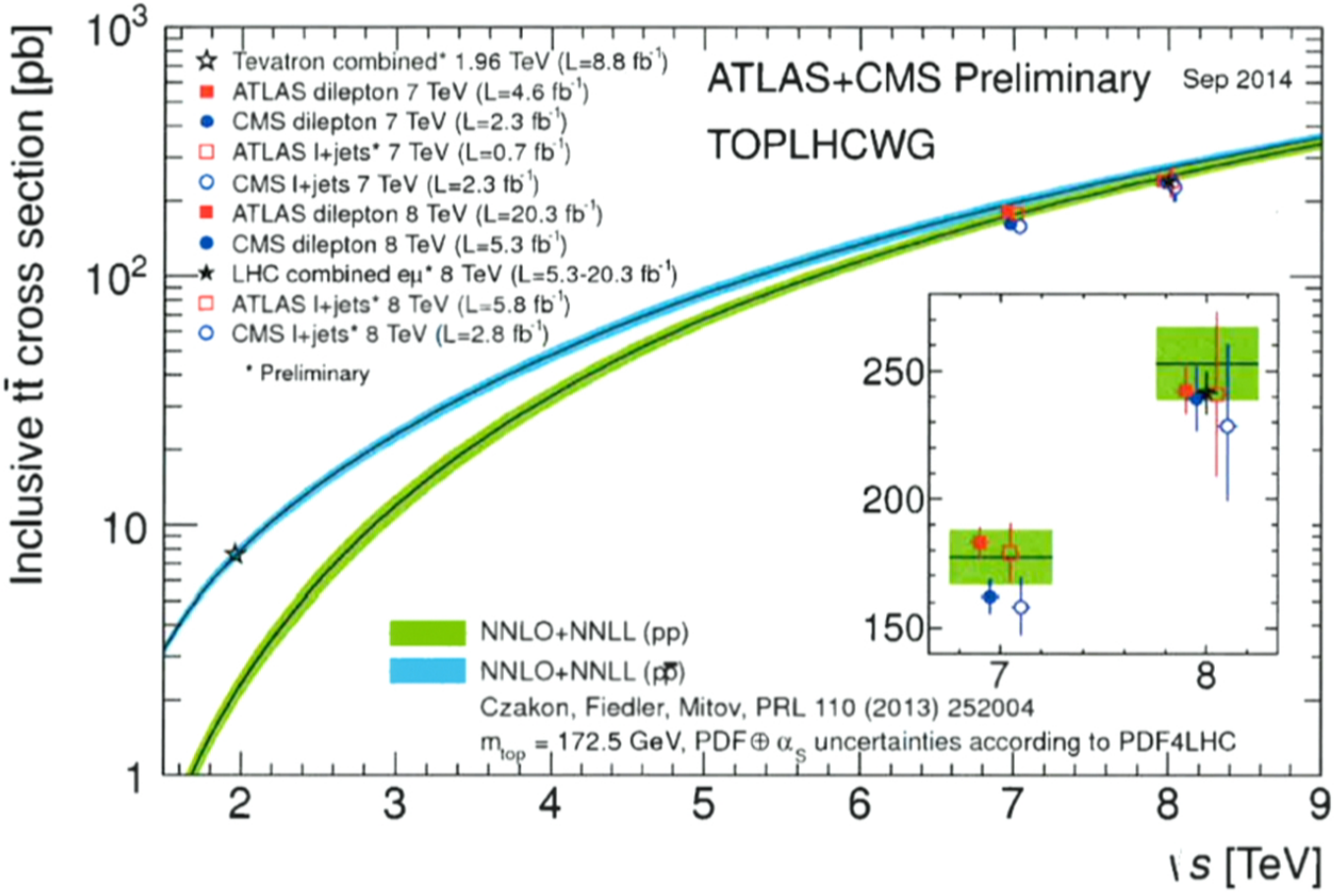

8 TeV LHC
14 TeV LHC
33 TeV HE LHC
100 TeV VLHC
total
bb̄
jet
W
Z
γ
tt̄
t
WW
WZ
ZZ
γγ
gg→H
VBF
ttH
WH
ZH
HH
σ [nb]
√s [TeV]
10
10²

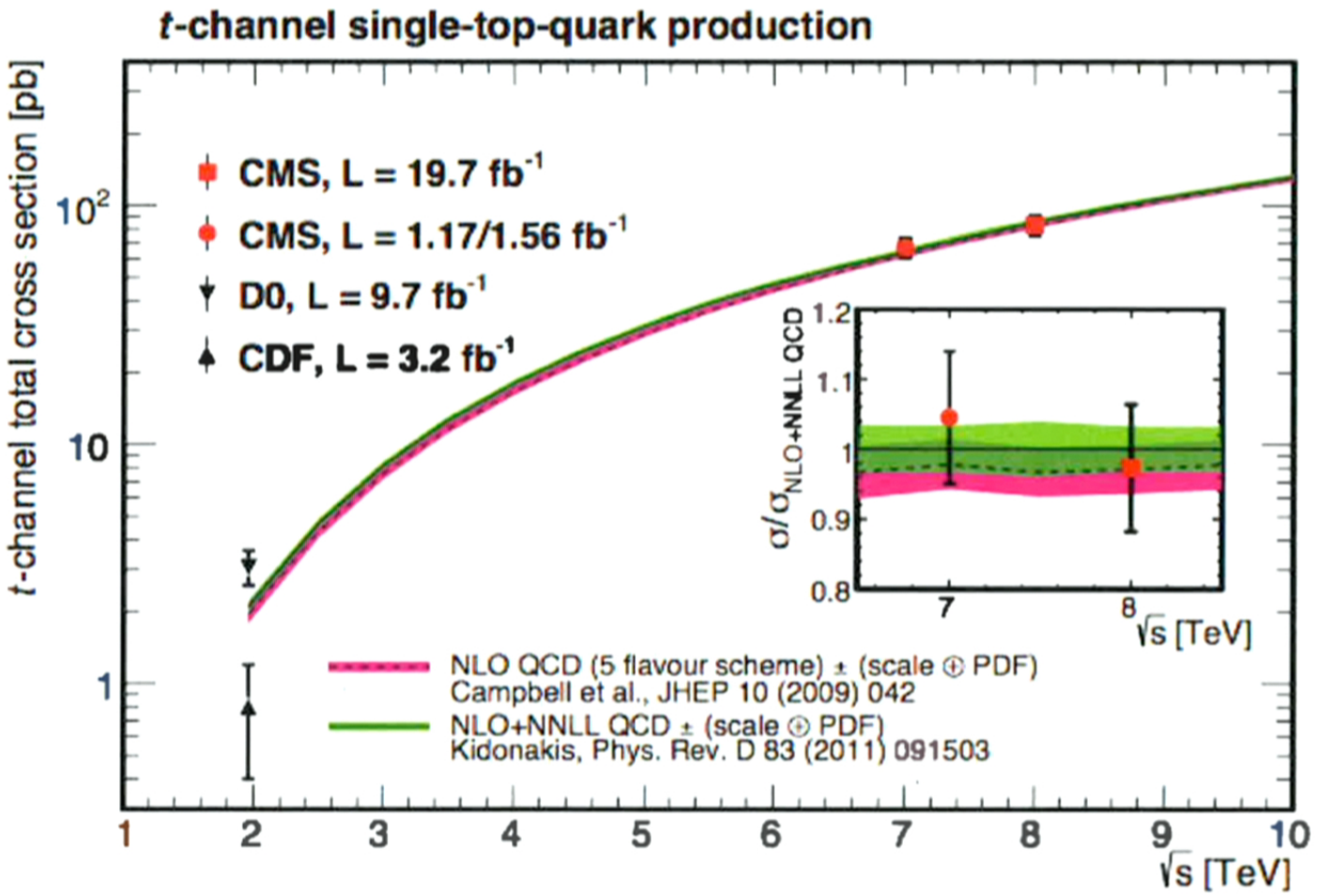

σ x B (nb)
10
1
10⁻¹
CMS, 36 pb⁻¹, 2010
CDF Run II
D0 Run I
UA2
UA1
W → lν
W⁺ → l⁺ν
W⁻ → l⁻ν
Z → l⁺l⁻
pp
pp̄
Theory: FEWZ and MSTW08 NNLO PDFs
1
10
Collider energy (TeV)

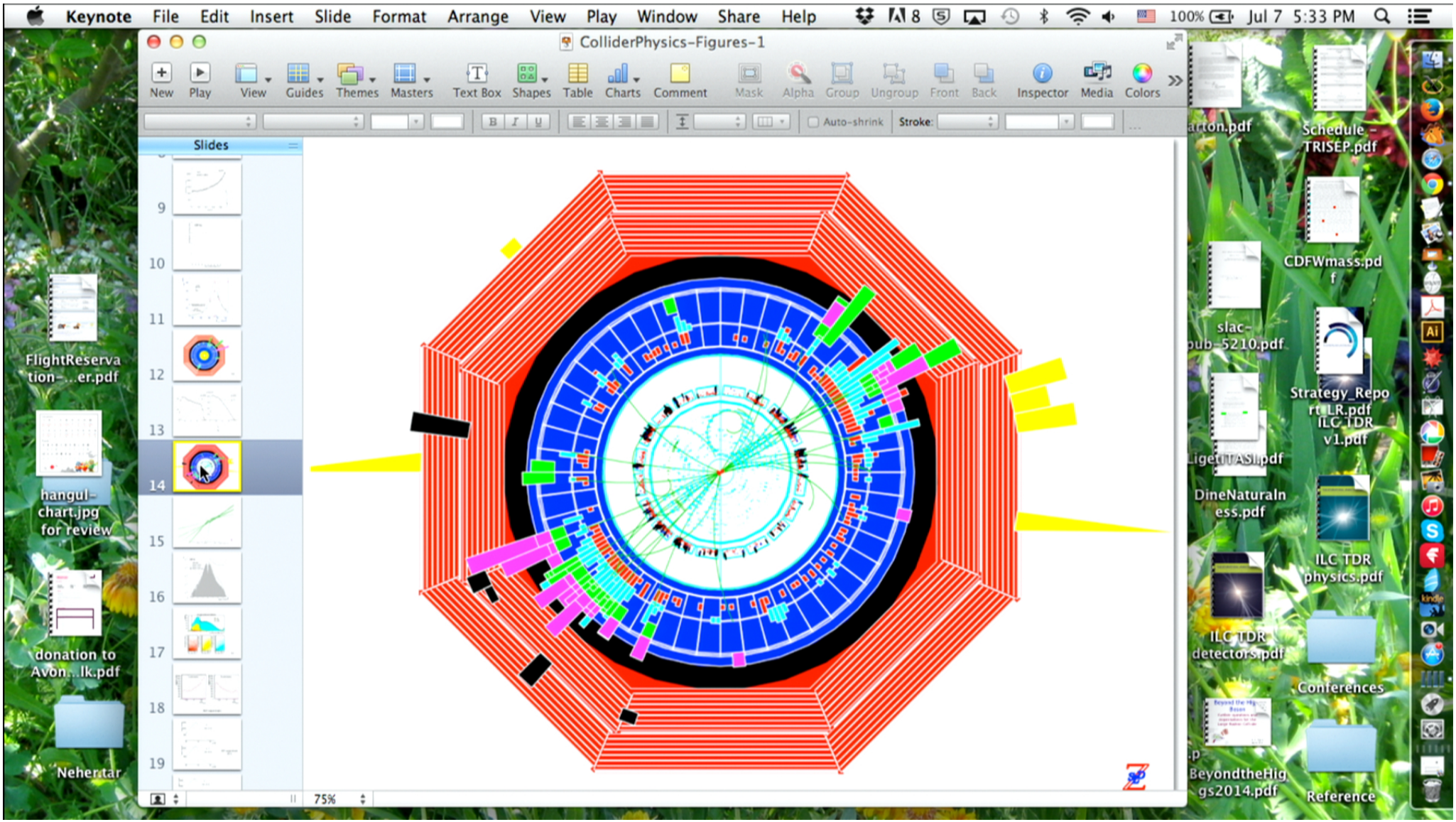

CMS
CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST
Electron p_T = 35.6 GeV/c
ME_T = 36.9 GeV
M_T = 71.1 GeV/c^2
CMS W → e candidate event

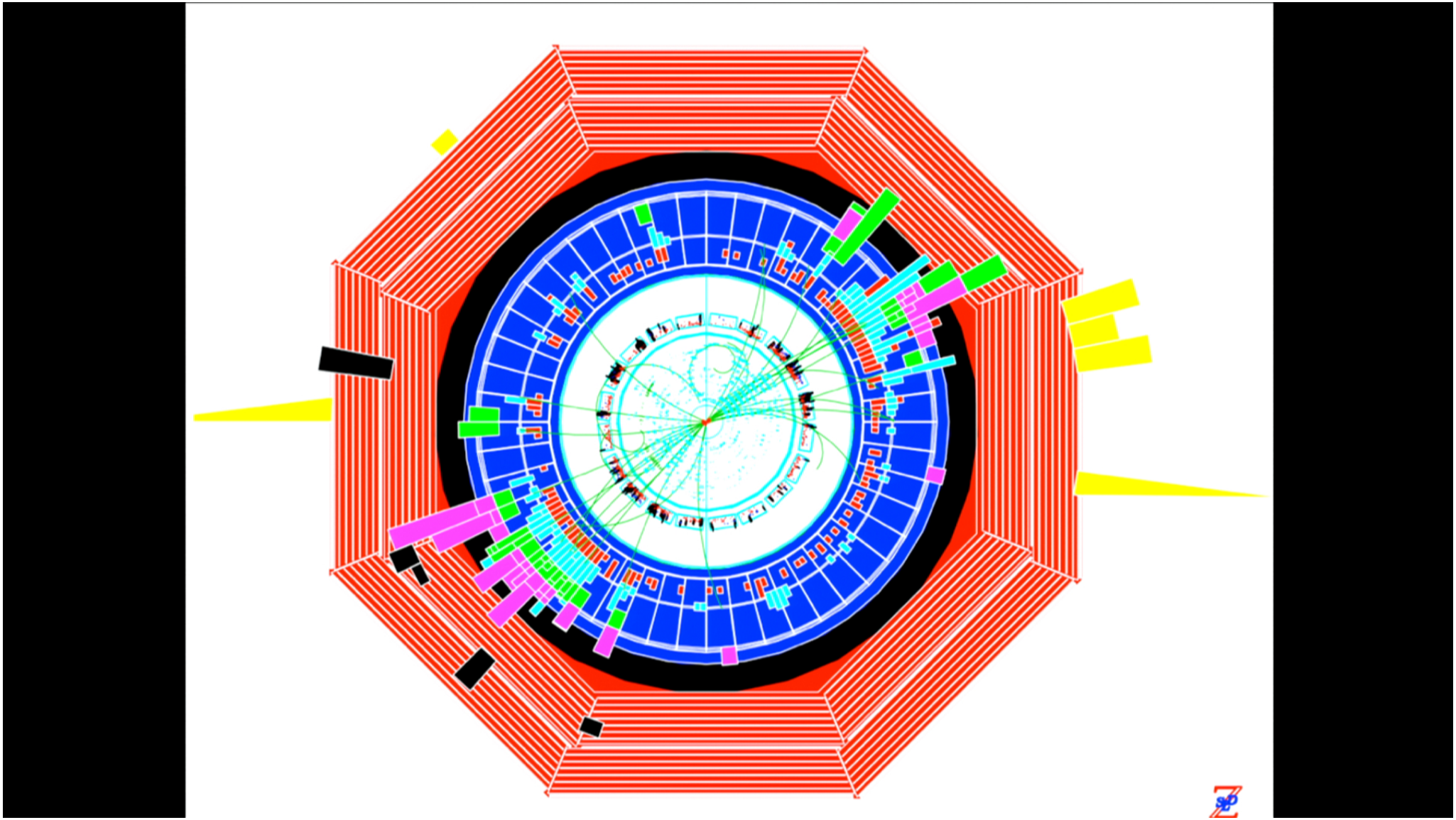

Events
Data/MC
10^6
10^5
10^4
10^3
10^2
1
0.5
$\int$Ldt=36 pb^{-1}
W→μν + jets
Data 2010,√s=7 TeV
W→μν
QCD
W→τν
dibosons
Z→μμ
Z→ττ
tt̄
single top
ATLAS
≥0
≥1
≥2
≥3
≥4
≥5
Inclusive Jet Multiplicity, N_{jet}

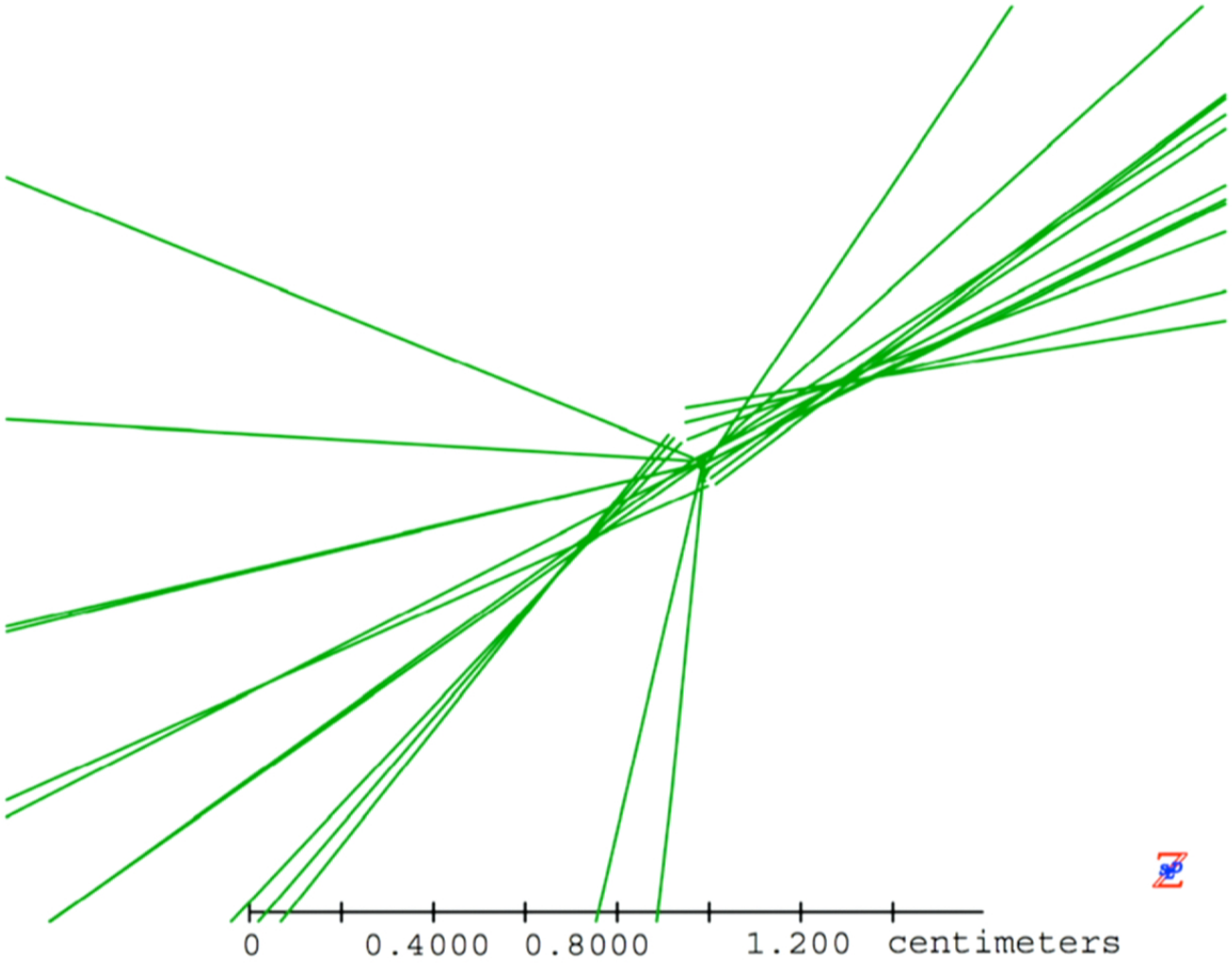

ATLAS
∫ L dt = 4.6 fb-1
Z/γ*(→ μ+μ-) + jets
anti-kt jets, R = 0.4,
pTjet > 30 GeV, |yjet| < 4.4
Data 2011 (√s = 7 TeV)
Z/γ* + jets (ALPGEN)
Z/γ* + jets (SHERPA)
Top
Electroweak
Multi-jets
Events / bin
ALPGEN
SHERPA
MC / Data
≥ 0
≥ 1
≥ 2
≥ 3
≥ 4
≥ 5
≥ 6
≥ 7
Njet

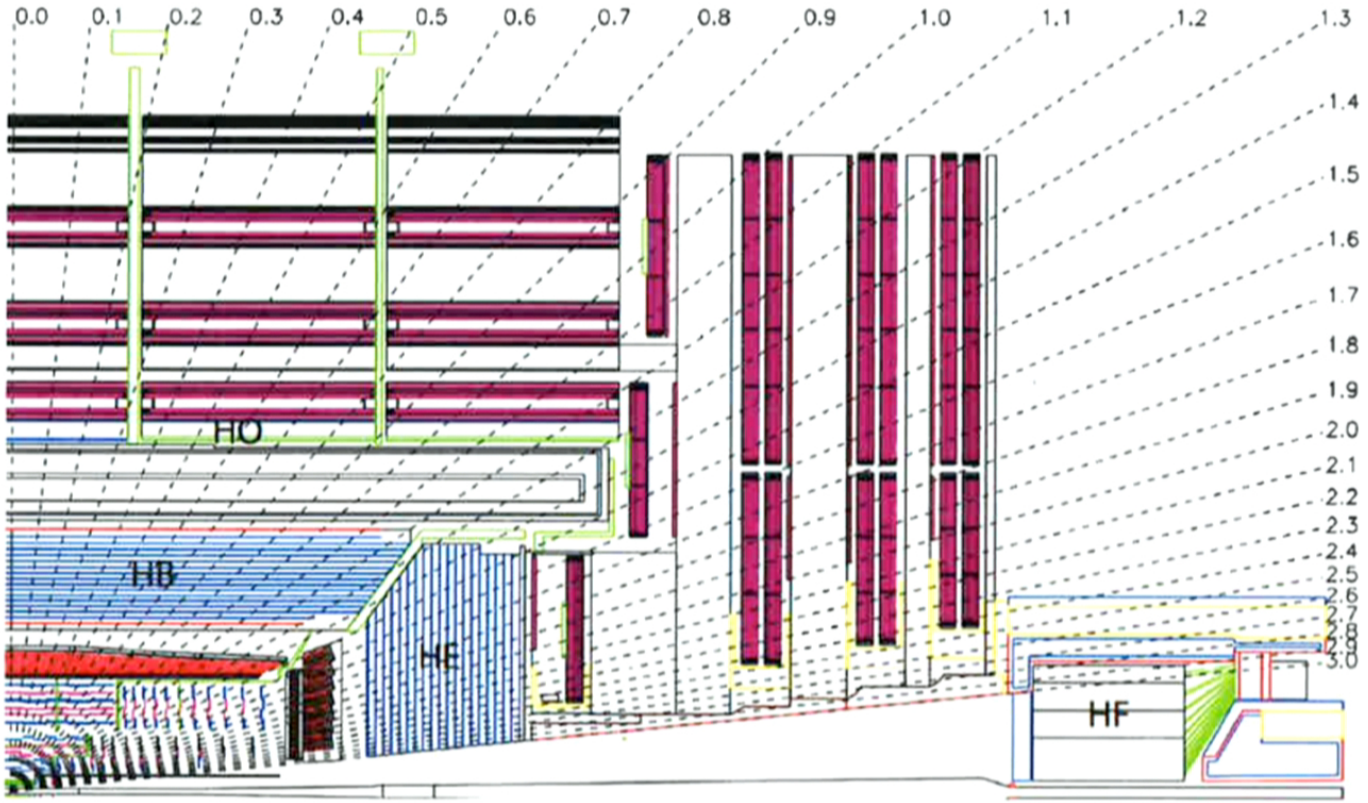

ATLAS+CMS Preliminary Sep 2014
TOPLHCWG
Tevatron combined* 1.96 TeV (L=8.8 fb-1)
ATLAS dilepton 7 TeV (L=4.6 fb-1)
CMS dilepton 7 TeV (L=2.3 fb-1)
ATLAS l+jets* 7 TeV (L=0.7 fb-1)
CMS l+jets 7 TeV (L=2.3 fb-1)
ATLAS dilepton 8 TeV (L=20.3 fb-1)
CMS dilepton 8 TeV (L=5.3 fb-1)
LHC combined eμ* 8 TeV (L=5.3-20.3 fb-1)
ATLAS l+jets* 8 TeV (L=5.8 fb-1)
CMS l+jets* 8 TeV (L=2.8 fb-1)
* Preliminary
NNLO+NNLL (pp)
NNLO+NNLL (pp̄)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
m_top = 172.5 GeV, PDF ⊕ α_S uncertainties according to PDF4LHC
Inclusive tt̄ cross section [pb]
√s [TeV]

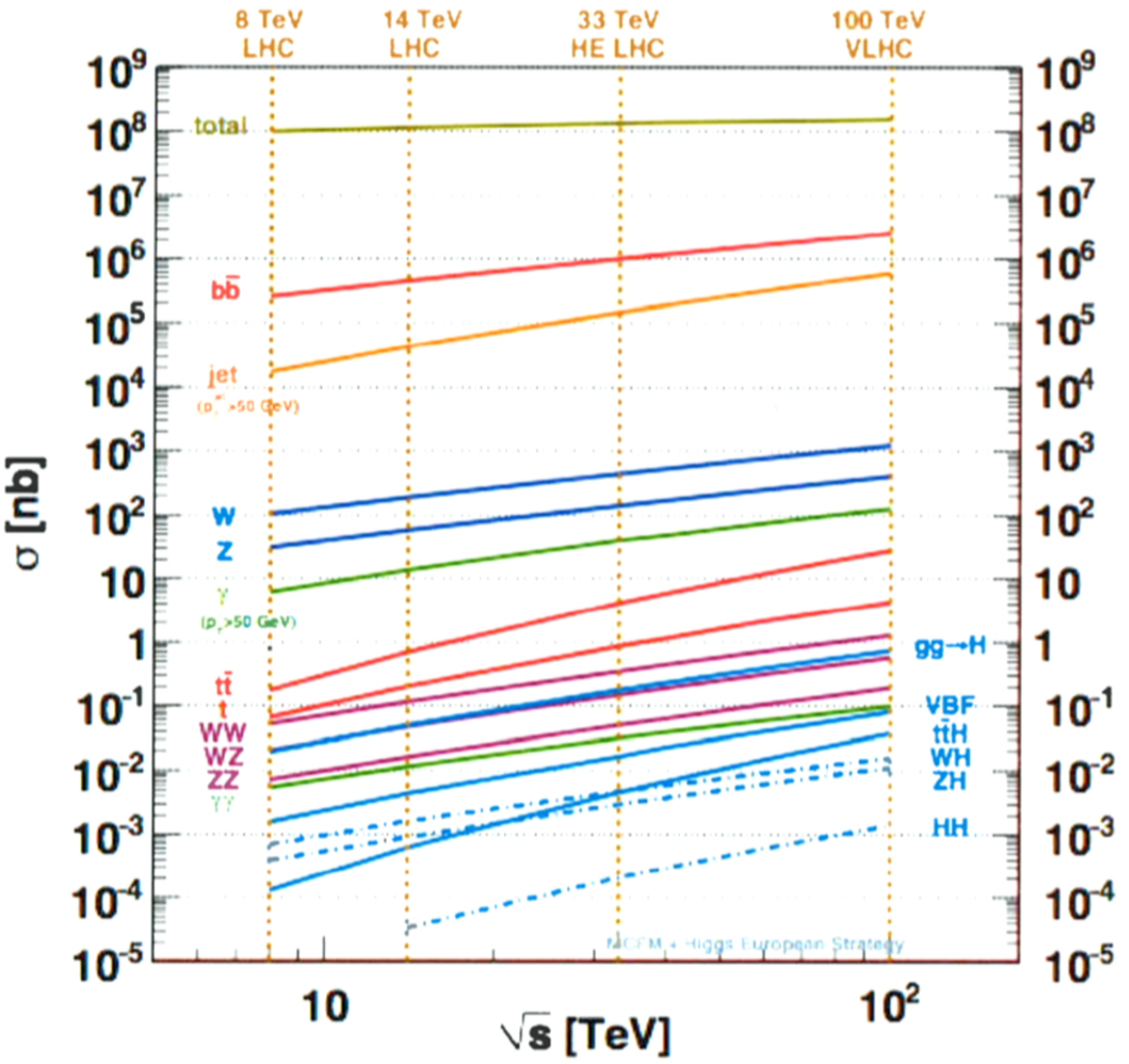

t-channel single-top-quark production
t-channel total cross section [pb]
CMS, L = 19.7 fb-1
CMS, L = 1.17/1.56 fb-1
D0, L = 9.7 fb-1
CDF, L = 3.2 fb-1
σ/σNLO+NNLL QCD
√s [TeV]
NLO QCD (5 flavour scheme) ± (scale ⊕ PDF)
Campbell et al., JHEP 10 (2009) 042
NLO+NNLL QCD ± (scale ⊕ PDF)
Kidonakis, Phys. Rev. D 83 (2011) 091503
√s [TeV]


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donation to Avon...lk.pdf
Nehertar
Schedule - TRISEP.pdf
CDFWmass.pdf
slac-...ub-5210.pdf
Strategy_Report_LR.pdf
ILC_TDR v1.pdf
DineNaturalness.pdf
ILC TDR physics.pdf
ILC_TDR detectors.pdf
Conferences
Reference




0
0.4000
0.8000
1.200
centimeters


0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
HO
HB
HE
HF


8 TeV LHC
14 TeV LHC
33 TeV HE LHC
100 TeV VLHC
total
bb̄
jet
(p_T^jet>50 GeV)
W
Z
γ
(p_T>50 GeV)
tt̄
t
WW
WZ
ZZ
γγ
gg→H
VBF
ttH
WH
ZH
HH
σ [nb]
√s [TeV]
10
10^2
HiggsEuropeanStrategy