



Measurement of the UE activity in pp collisions with the CMS detector

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On behalf of CMS collaboration

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Speaker supported by the “Mobility Plus” program of
Ministry of Science and Higher Education,
Republic of Poland



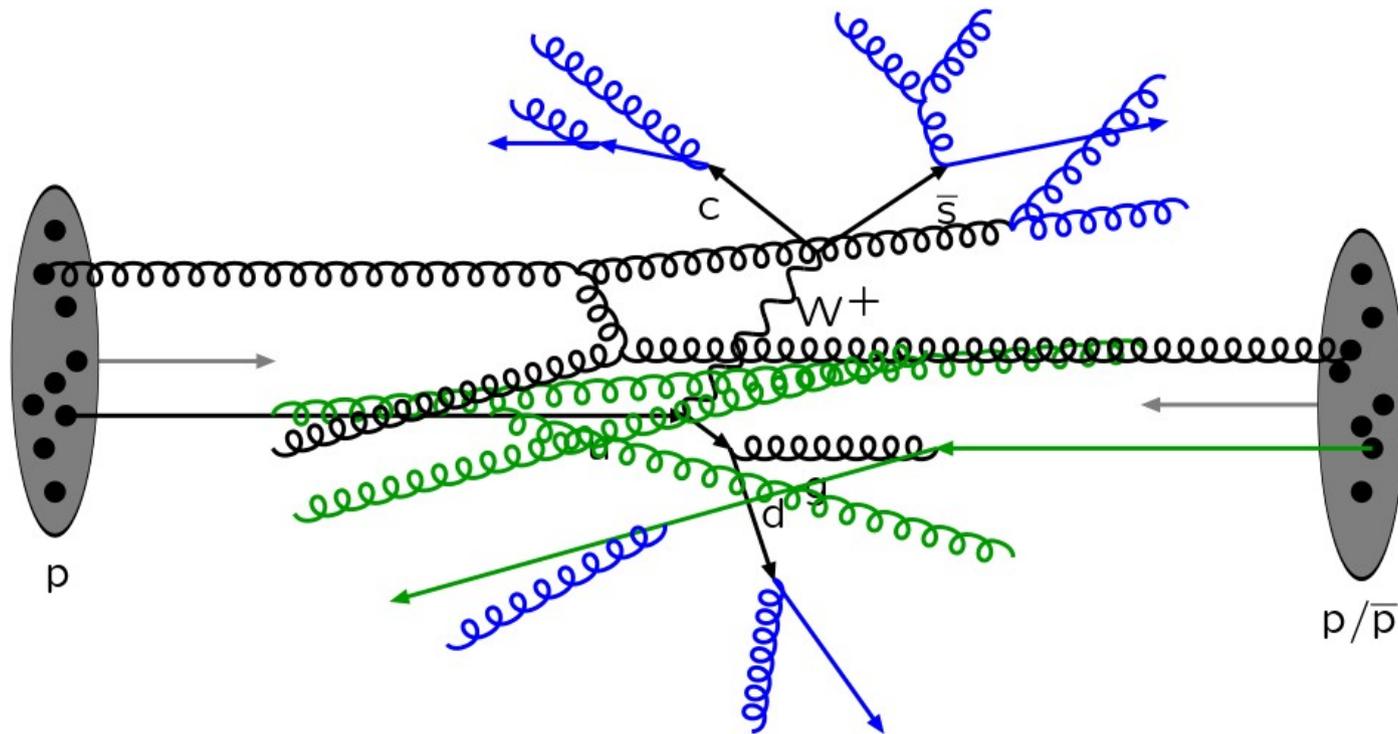
In this talk



- **General UE properties:**
 - “Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV”, CMS PAS FSQ-12-020
- **A look in greater detail – UE composition:**
 - “Measurement of Strange Particle Production in Underlying Events in proton-proton collisions at $\sqrt{s} = 7$ TeV”, Phys.Rev. D88 (2013) 052001
- **UE vs particle multiplicity:**
 - “Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV”, Eur.Phys.J. C73 (2013) 2674
- **UE in ttbar events**
 - “Study of the underlying event, b-quark fragmentation and hadronization properties in ttbar events”, CMS PAS TOP-13-007



Underlying event - definition



Picture from T. Sjostrand,
Monte Carlo generators for the
LHC

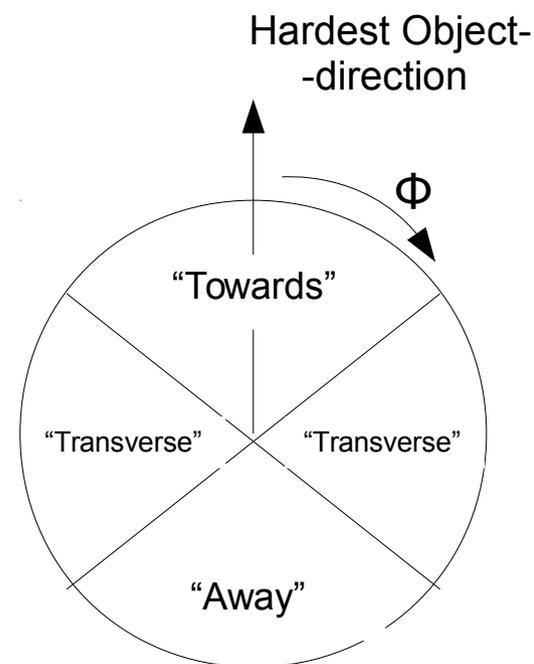
- Underlying Event – all besides products of hard interaction:
 - Picture above – W boson production and decay accompanied by Initial State Radiation (ISR), Final State Radiation (FSR), Multiple Parton Interactions (MPI) and Beam Remnants (BR)



UE analyses – typical strategy



- Find the hardest object in event
 - Defines scale and direction
 - Accompanied by a “balancing” object going back-to-back ($\Delta\phi \approx \pi$)
- Define three regions depending on $\Delta\phi$ wrt the reference object
- Transverse region most interesting
 - Toward & away regions contaminated with hard interaction
 - Measure $\langle p_T \rangle$, $\langle N \rangle$, $\langle \text{other} \rangle$ as a function of scale (defined by reference object)





“Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV”, CMS PAS FSQ-12-020



- Analysis performed for $\sqrt{s}=7$ and 0.9 TeV
- Use all charged particles (tracks) with $p_T > 0.5$ GeV and $|\eta| < 0.8$
- Reference object – leading track in event
- Test variables – average Σp_T and N_{ch} in the transverse region
- Distributions corrected for reconstruction inefficiencies
- Comparison to herwig++ (default tune), pythia6 (Z1, D6T) and pythia8 (tune1)



“Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV”, CMS PAS FSQ-12-020

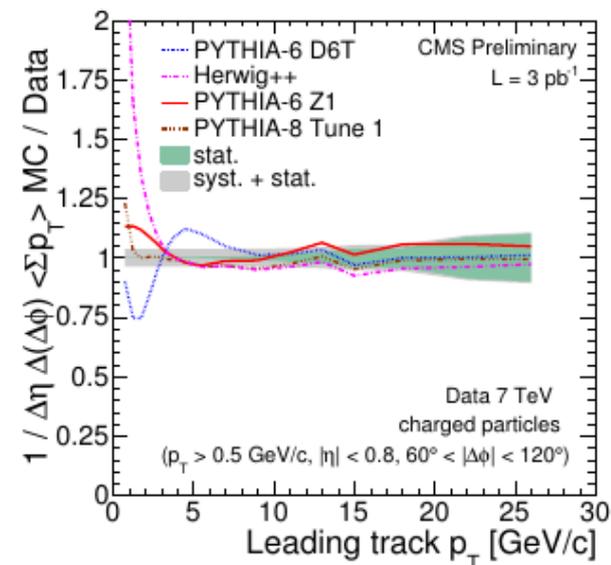
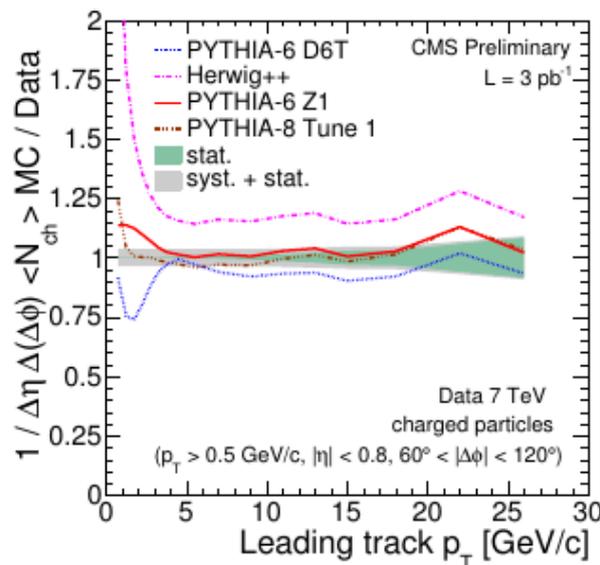
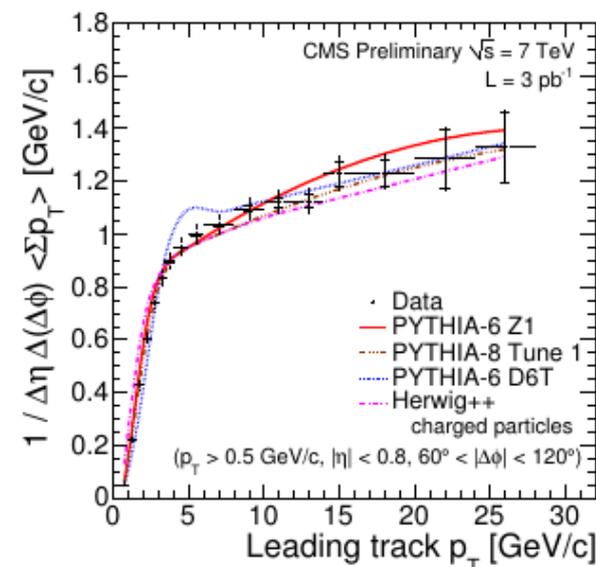
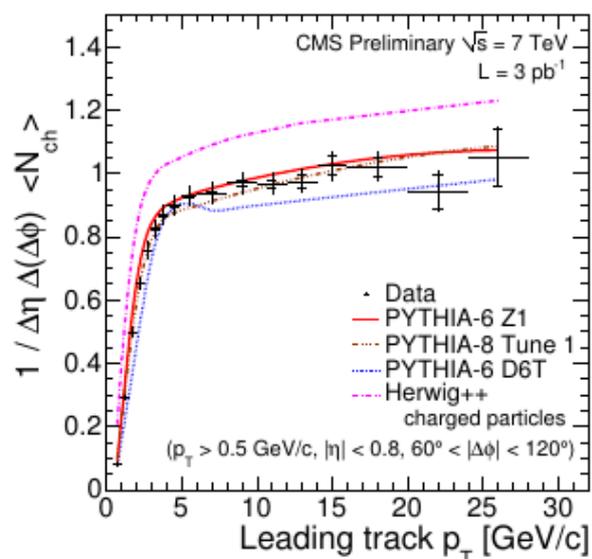


- Measured distributions of average Σp_T and N_{ch} versus lead track p_T for $\sqrt{s}=7$ TeV

- Please note, that this tunes are not the latest...

- Good agreement for both pythia versions in $p_T^{lead} > 5$ GeV region

- Bad agreement for herwig++ - default (=old) UE tune used

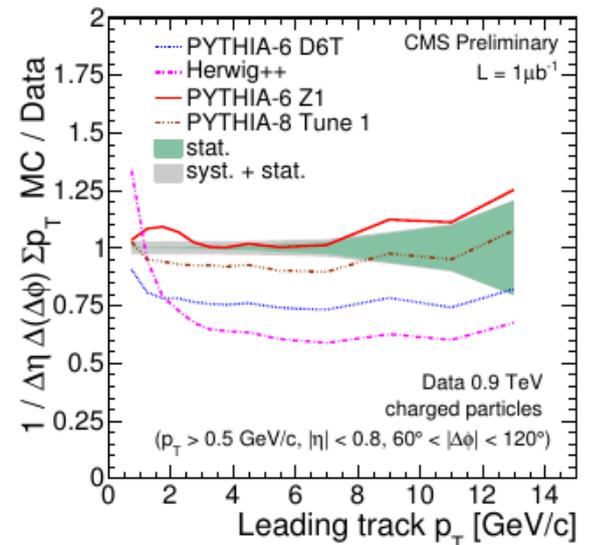
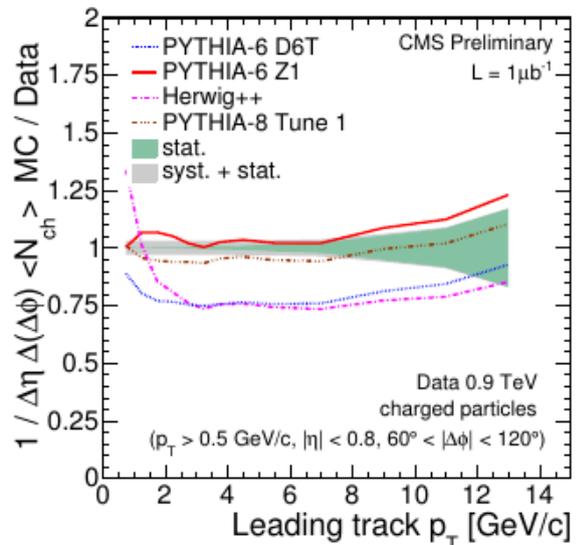
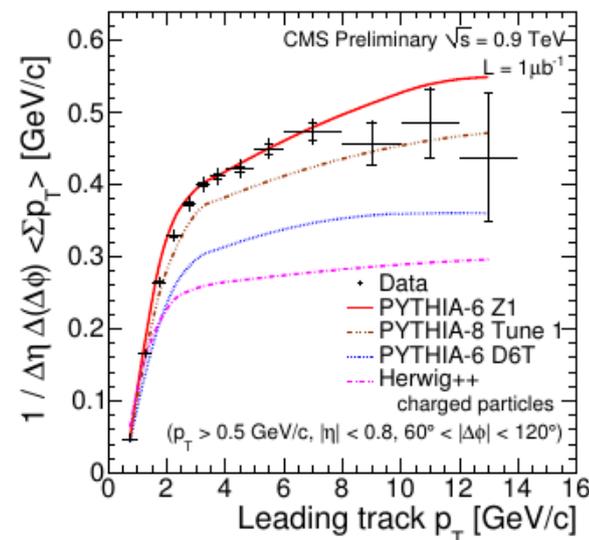
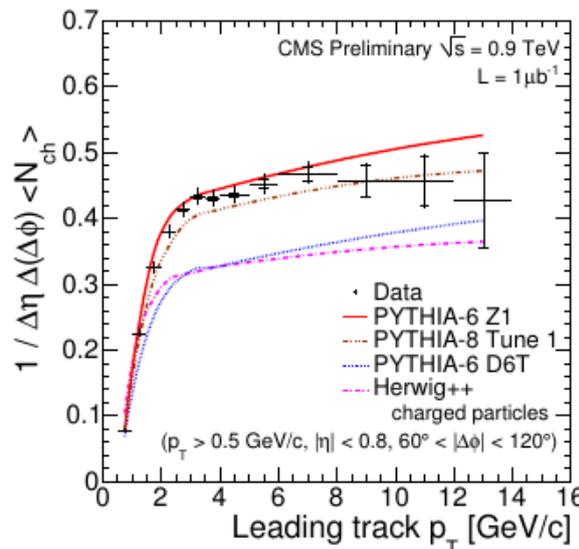




“Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV”, CMS PAS FSQ-12-020

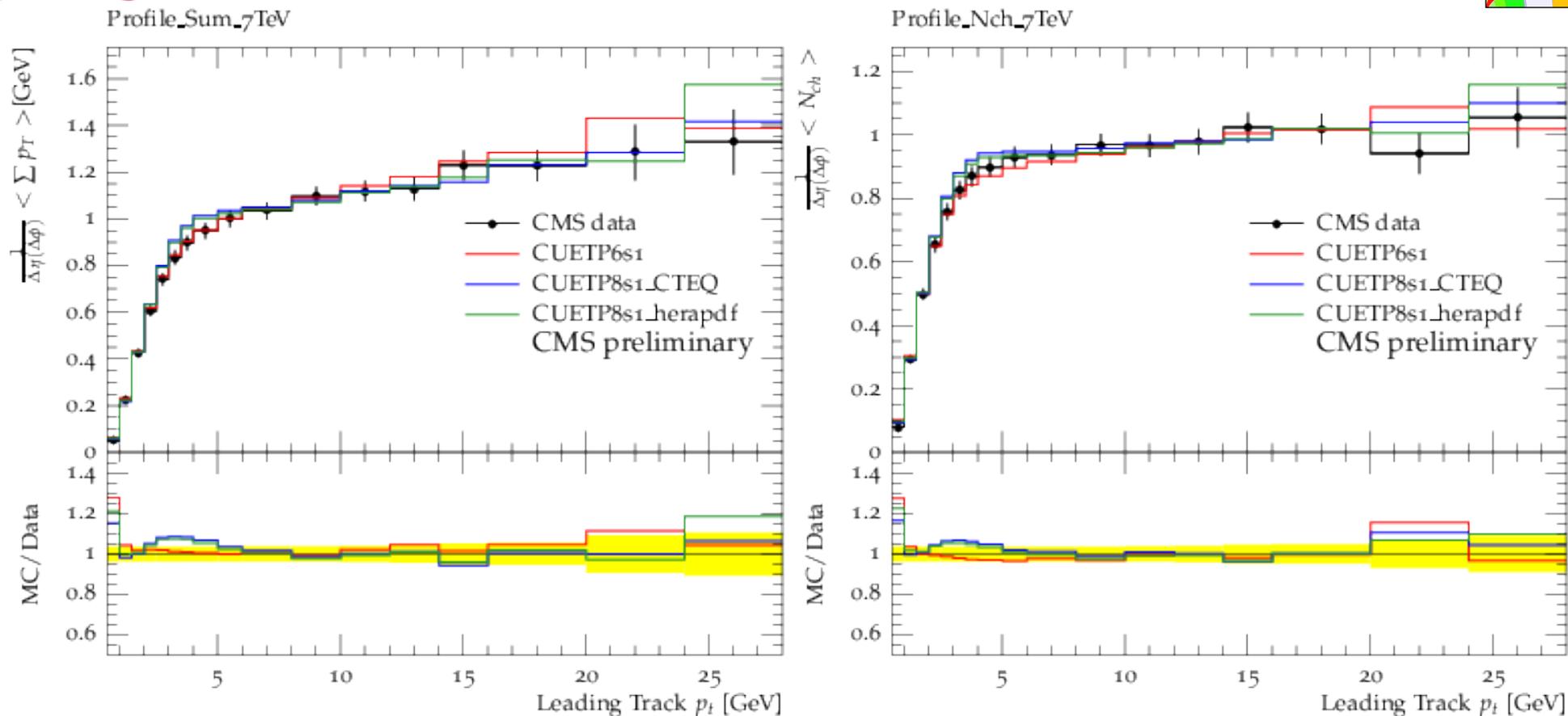


- Measured distributions of average Σp_T and N_{ch} versus lead track p_T for $\sqrt{s}=0.9$ TeV
- Please note, that this tunes are not the latest.
- Important results for UE tuning
 - **See (next) talk by Paolo Gunnelini**





New tunes using “Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV” data



- Recent UE tuning effort in CMS in preparation for 2015 run
 - **CMS Underlying Event Tune** – family of pythia6 and pythia8 tunes
 - Different PDF sets used
 - Results from last slides used as one of the inputs of tuning procedure
- See talk by Paolo for more results with new tunes

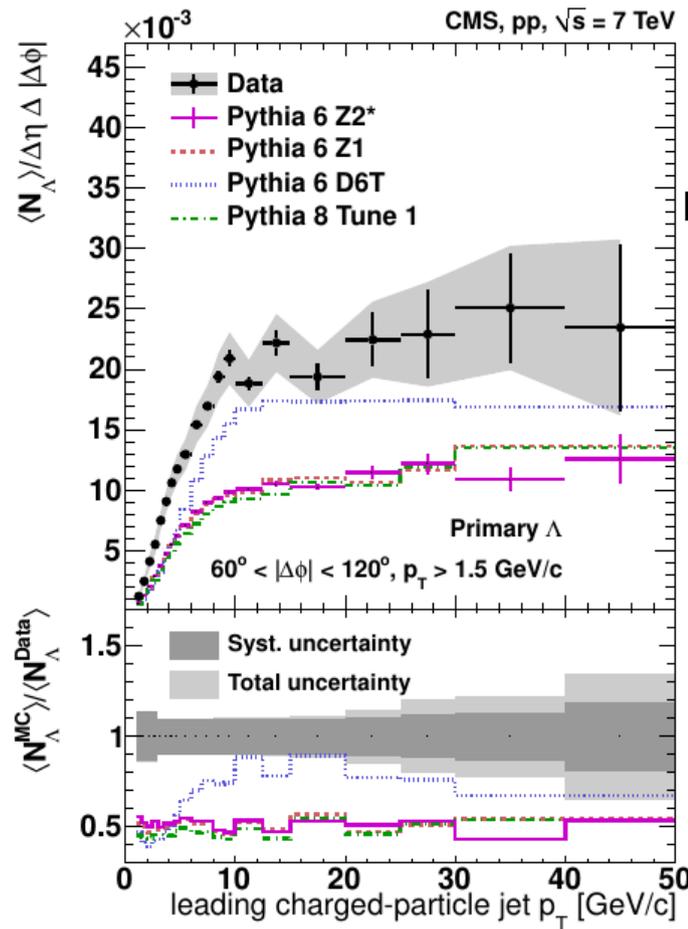
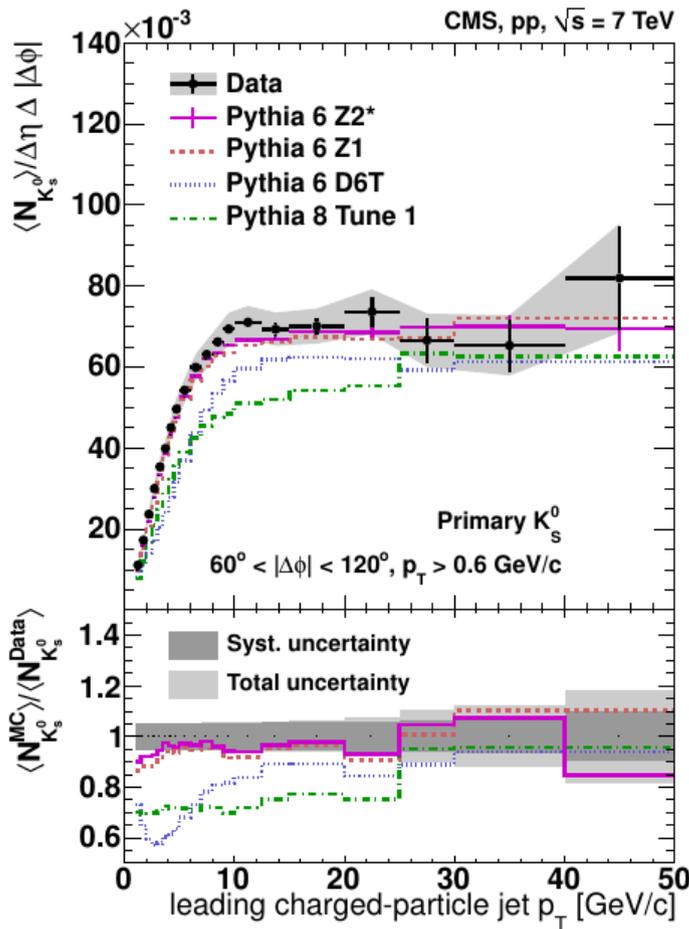
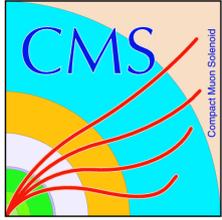


- Measurement of K_s^0 and Λ production in the transverse region
- Similar analysis strategy - $\langle N \rangle$, $\langle p_T \rangle$ of strange particles measured in the transverse region as a function of leading track-jet p_T
- Pythia6 (tunes Z1, Z2, D6T) and Pythia8 (tune 4C) compared to $\sqrt{s} = 7$ TeV data



“Measurement of Strange Particle Production in Underlying Events in proton-proton collisions at $\sqrt{s} = 7$ TeV”

Phys.Rev. D88
(2013) 052001



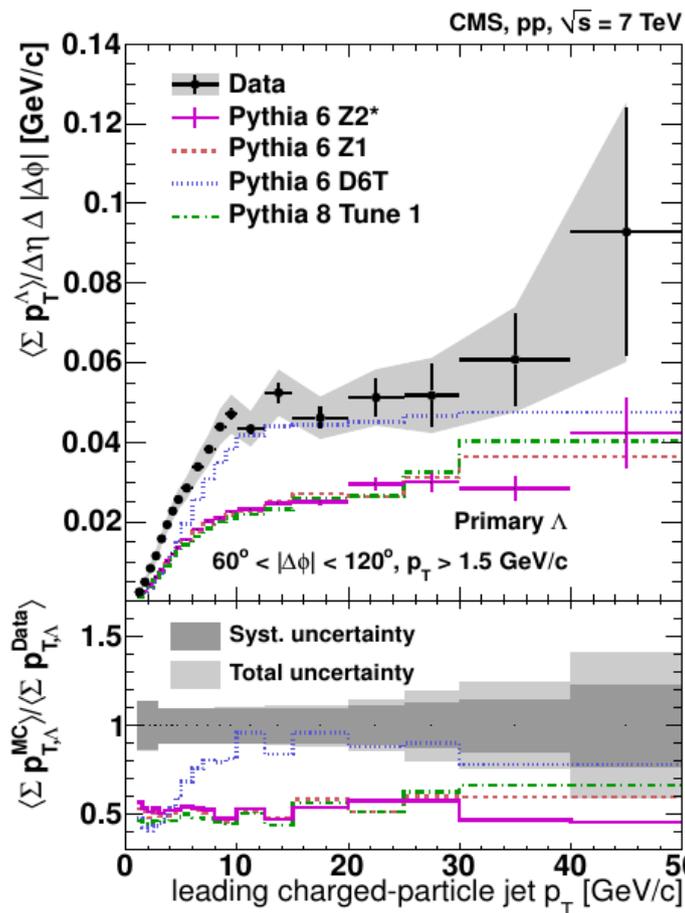
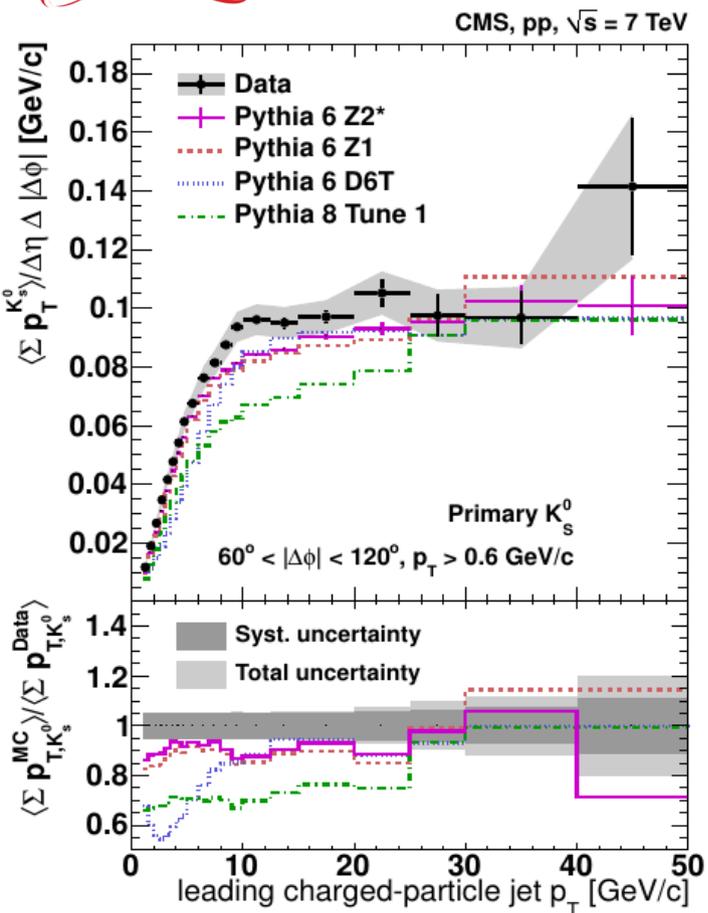
Note - promising attempts to model this behavior by Lund group with DIPSY generator - see presentation from MPI @ LHC 2013 workshop

- Average multiplicity of strange particles (K_s^0 and Λ) as a function of lead track-jet p_T
- Underestimated by all of the tunes (both pythia6 and 8), pythia6 D6T closest to reality
 - Bigger tension for Λ than for K_s^0



“Measurement of Strange Particle Production in Underlying Events in proton-proton collisions at $\sqrt{s} = 7$ TeV”

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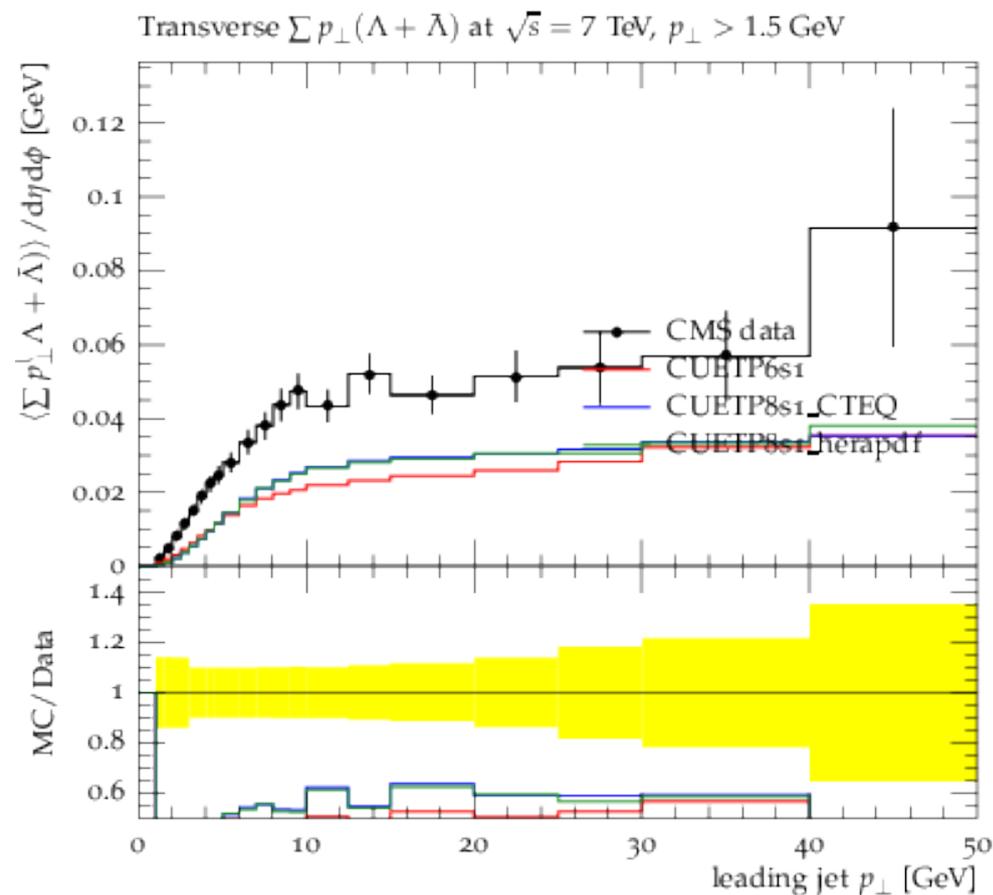
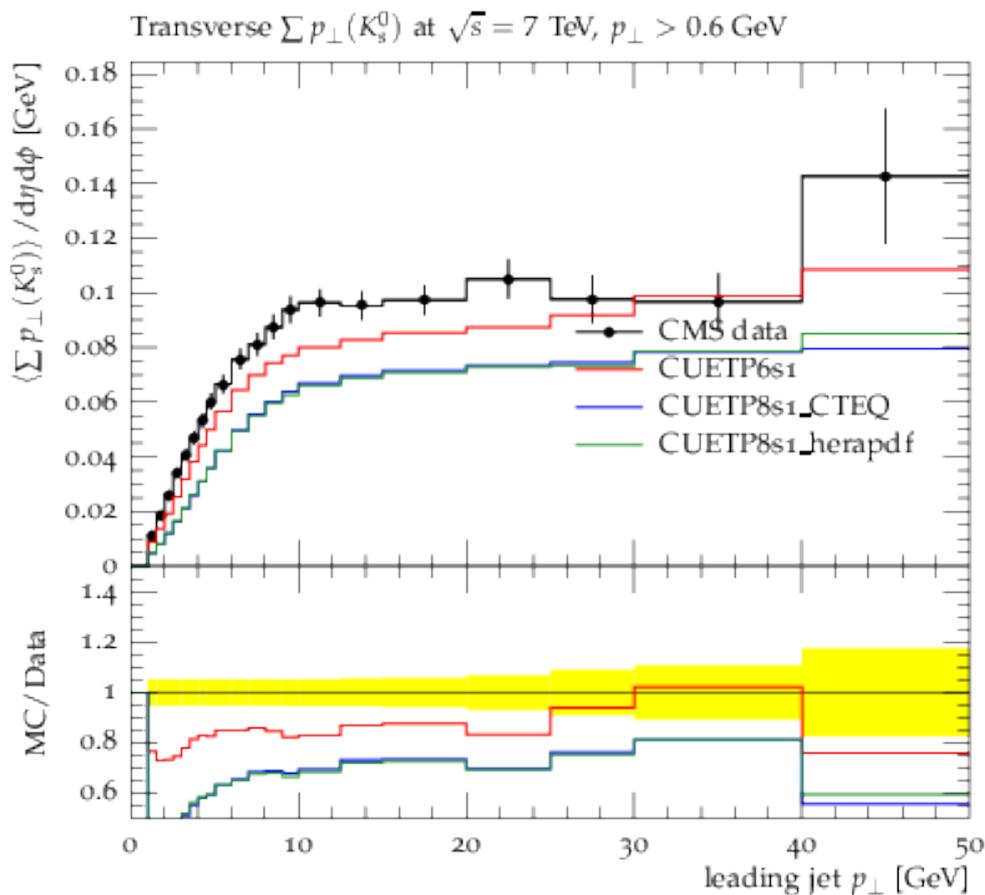


Note - promising attempts to model this behavior by Lund group with DIPSY generator - see presentation from MPI @ LHC 2013 workshop

- Average transverse momentum of strange particles (K_s^0 and Λ) as a function of lead track-jet p_T
- Similarly – discrepancies visible for all of the tunes (both pythia6 and 8), pythia6 D6T closest to reality
 - Bigger tension for Λ than for K_s^0



CUET tunes vs “Measurement of Strange Particle Production in Underlying Events in proton-proton collisions at $\sqrt{s} = 7$ TeV”

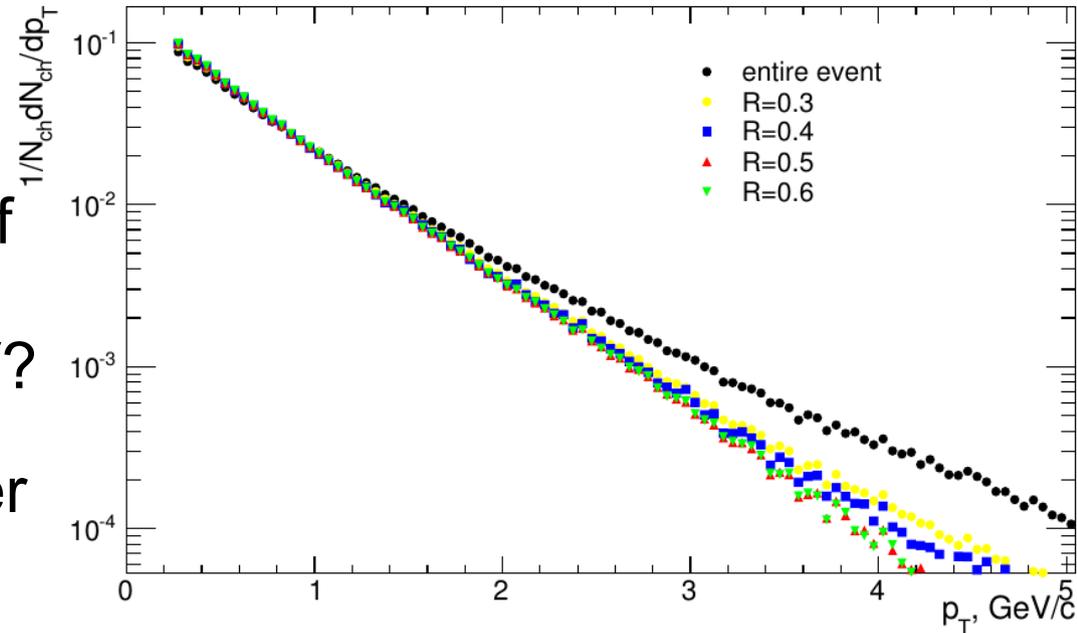


- Similar tensions visible in strange particles production for new CUET tunes



- Different analysis strategy:

- UE/intrajet (=hard interaction component) decomposition of the event– does given track belong to a jet with $p_T > 5$ GeV?
- Optimized distance parameter of the jet finding algorithm
 - Better UE/intrajet separation



- Analysis performed for different particle multiplicities
 - Probes event centrality (similarly as in analyses with pb-pb data)
- **No towards/transverse/away region used in analysis**



“Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV”,
Eur.Phys.J. C73 (2013) 2674

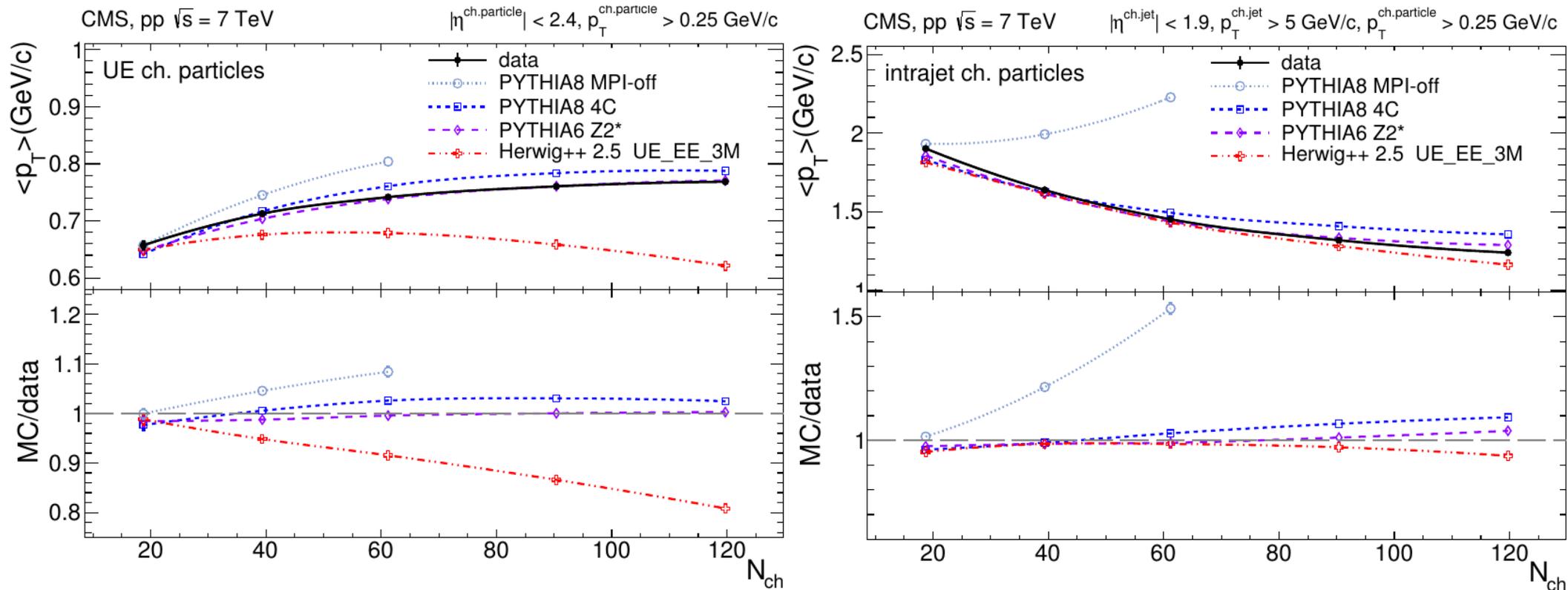


- Data and models:

- 2010 low PU data, 3.18 pb^{-1} (LHC run 2010A)
- Tested models:
 - Pythia 6 Z2*
 - Pythia 8 4C
 - Herwig++ 2.5 (UE_EE_3M)
 - Pythia 8 MPI-off



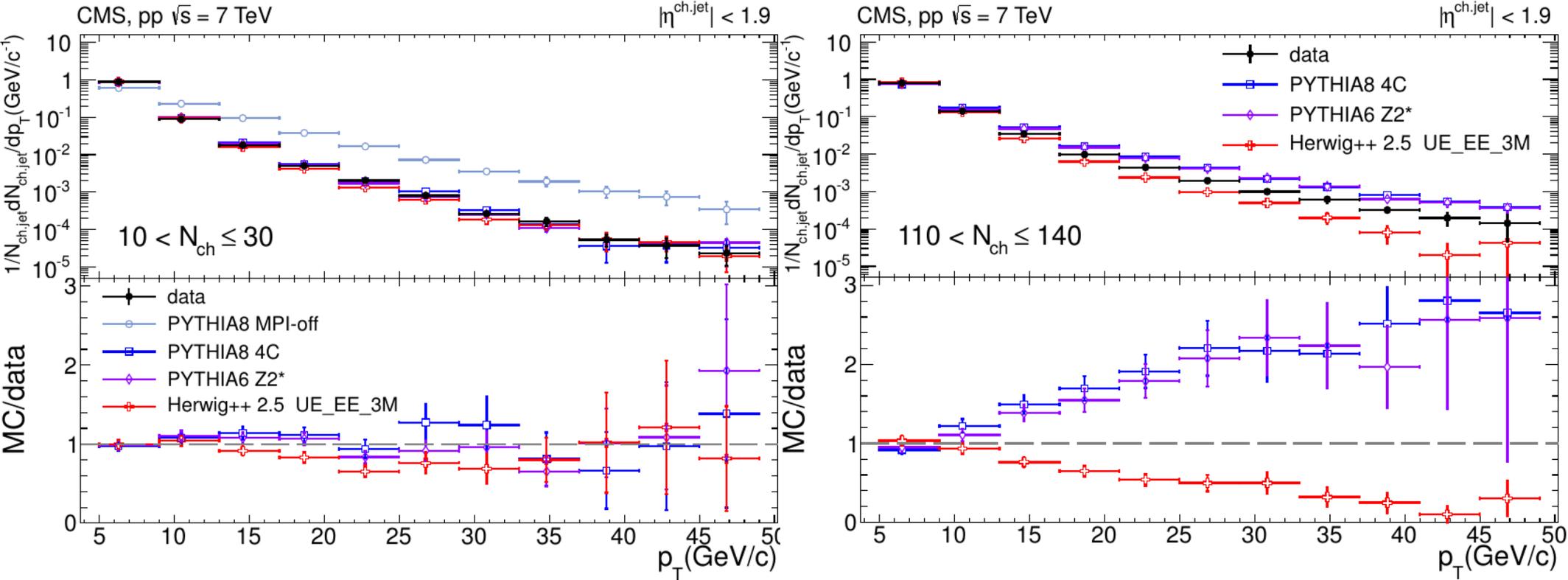
“Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV”,
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- Average track p_T in different multiplicity domains for UE and intrajet
- Pythia 6 Z2* gives best description of avg p_T for UE and intrajet tracks
- Big tension visible for herwig++
- Dependence completely missed by pythia8 MPI-off



“Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV”,
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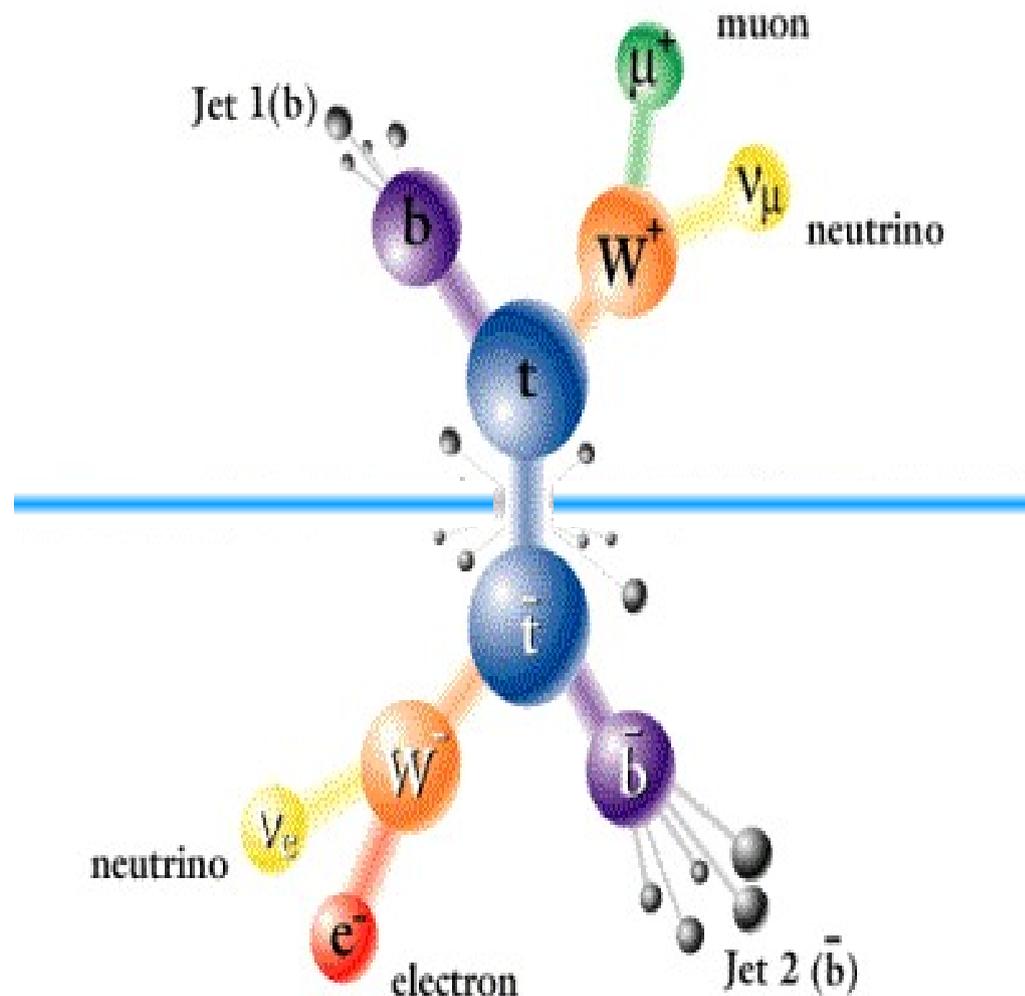
- Jet momentum distribution for lowest and highest multiplicity domains:
 - Low multiplicity - good agreement for pythia Z2* and 4C, herwig++ predicts slightly softer jets. Dependence completely missed by MPI-off tune
 - High multiplicity – herwig++ predicts softer jets, pythia overestimates rate of hard ($p_T > 30\text{GeV}$) more than 2x



“Study of the underlying event, b-quark fragmentation and hadronization properties in $t\bar{t}$ events”, CMS PAS TOP-13-007

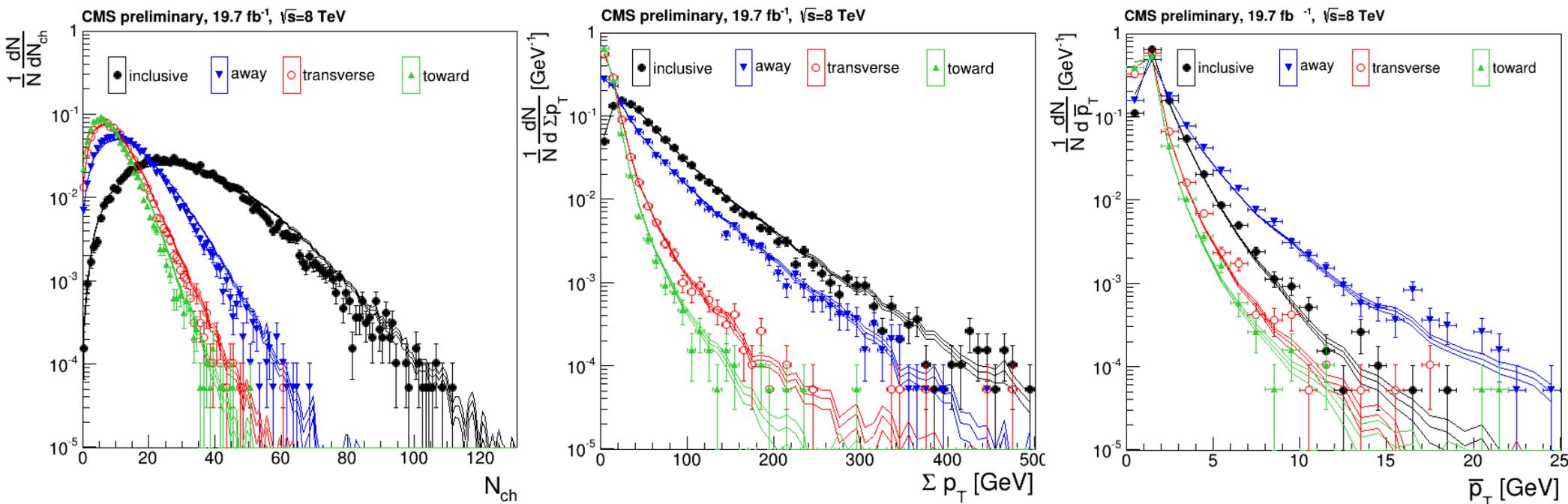


- Back to “usual” UE analysis strategy - reconstruct $t\bar{t}$ pair by summing momenta of its decay products (+MET) – gives scale and direction
 - Measure UE activity using all charged tracks ($p_T > 0.5$ GeV) that were not coming from $t\bar{t}$ decay
- Required topology – lepton pair ($\mu\mu$, ee or $e\mu$) accompanied by two b-tagged jets
- Analysis using 19.7 fb^{-1} @ 8 TeV
 - PU tracks discarded using vertex info
- Non-negligible background contamination
- **Data compared to madgraph+pythia6 Z2* tune**





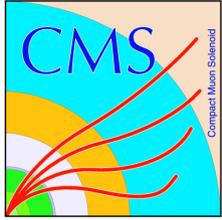
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- Number of charged particles (left), total p_T flux (center), mean p_T carried by charged particles (right) in toward/away/transverse region
- Fair agreement with madgraph+pythia6 Z2*
- Higher multiplicities (at $N_{\text{ch}} \approx 30 \sim 40$) for the away region predicted in MC



Summary



- **General UE properties** - “Measurement of the underlying event activity in pp collisions at the LHC using leading tracks at $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV”
 - Good description with different tunes
- **A look in greater detail on UE composition** – “Measurement of Strange Particle Production in Underlying Events in proton-proton collisions at $\sqrt{s} = 7$ TeV”
 - Tensions visible for all tunes in strangeness production rates
- **UE vs particle multiplicity** - “Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV” ,
 - MPI is an important part of UE modeling
 - For high multiplicity domains jet rate overestimated by pythia, underestimated by herwig++
- **UE in ttbar events** - “Study of the underlying event, b-quark fragmentation and hadronization properties in ttbar events” ,
 - Fair UE description by Pythia6 Z2* tune



Backup



“Study of the properties of hard and soft particle production as a function of particle multiplicity in p-p collisions at $\sqrt{s} = 7$ TeV”,
CMS PAS FSQ-12-022



- Event decomposition (UE/intrajet) based on jet finding:
 - Track selection:
 $p_T > 0.25$ GeV, $|\eta| < 2.4$
 - Jet finding performed by anti- k_T algorithm on selected tracks
 - Neutral particles not included (lower systematics)
 - Intrajet particles (“hard” event component) – all particles that were clustered into jets above 5 GeV
 - UE – remaining tracks

