Identified particle production at CMS

February 7, 2011

Kevin Stenson
University of Colorado

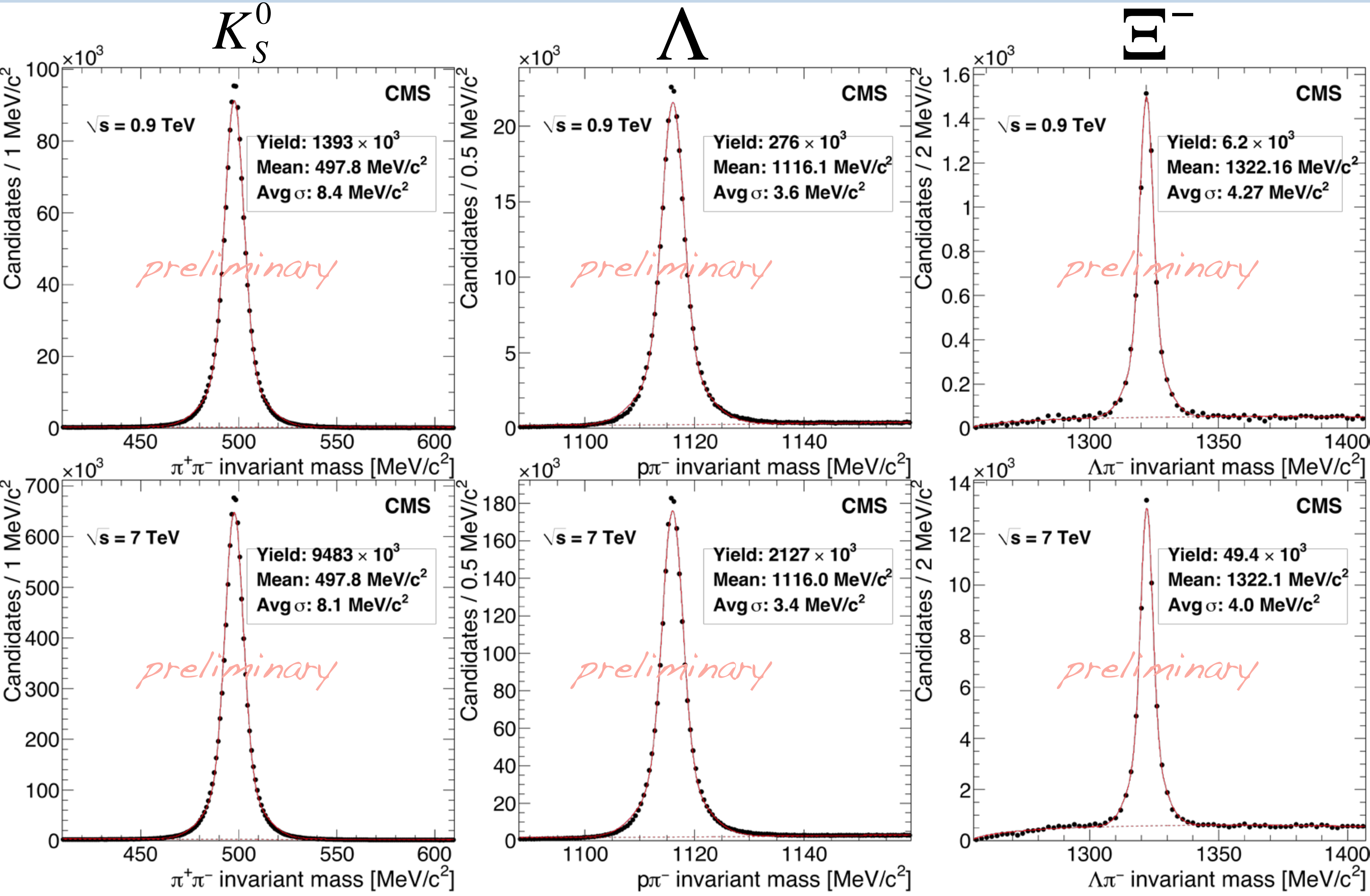
Outline

- Results (still preliminary) from strangeness production analysis (based on updated ICHEP analysis)
  - Distributions of K_S, Λ, and Ξ^- versus rapidity and transverse momentum normalized to NSD events
  - Production ratios $N(\Lambda)/N(K_S)$ and $N(\Xi^-)/N(\Lambda)$
  - Average p_T and fits to p_T distribution
- Plan for future work on strange particle production
  - Normalize to events defined by event observables
  - Addition of Ω^-
  - Baryon asymmetries
  - Determine effect of event multiplicity
- Plan for work on identification of charged hadrons using dE/dx measurements.

Strange particle reconstruction

- Data are from March−May, 2010 including 9 million events at 0.9 TeV and 35 million events at 7 TeV.
- Online selection required activity at one end of the detector (Beam Scintillation Counter at $3.23 < |\eta| < 4.65$) in coincidence with colliding beams (from Beam Pickup Detectors)
- Offline selection required >3 GeV of energy in both forward calorimeters (HF) covering $2.9 < |\eta| < 5.2$ and a primary vertex.
- Select V^0 candidates by combining two oppositely charged into a vertex which is separated from the primary.
- Select Ξ^- candidates by combining Λ candidate with track of correct sign into a vertex which is separated from the primary
- Particles produced at the primary must point back to primary and daughter tracks must miss the primary.
- Misidentification of K_S as Λ (and vice versa) removed with explicit mass cuts.
- All results combine charge-conjugate states

Strange particle yields

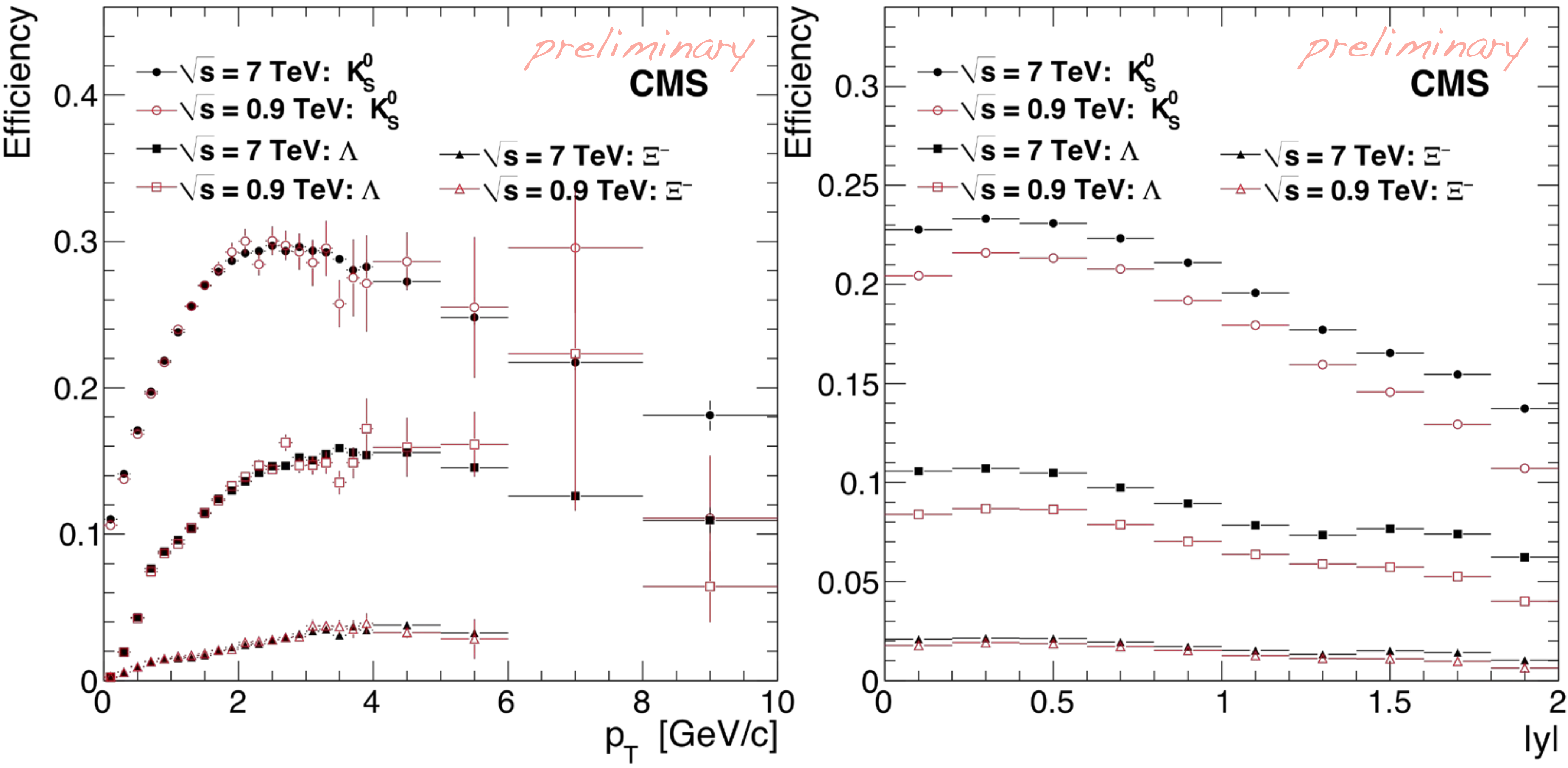


Efficiency determination

- Define efficiency as reconstructed particles from all events divided by generated particles from NSD events.
- Use either truth matching or fit to signal to determine the number of reconstructed particles.
- V^0 efficiency is measured in 2D bins of p_T and $|y|$. Thus, discrepancies between production in MC and data do not affect efficiency.
- Ξ^- efficiency is measured in 1D bins of p_T and $|y|$.
  - Each MC Ξ^- is weighted by $|y|$ (p_T) to match the data when measuring p_T ($|y|$) efficiency. This reduces effect of mismatch in production between MC and data.
- Define efficiency as all reconstructed particles divided by generated prompt particles. Also weight MC to increase production of non-prompt Λ's to better match data.

Efficiency vs. p_T and |y|

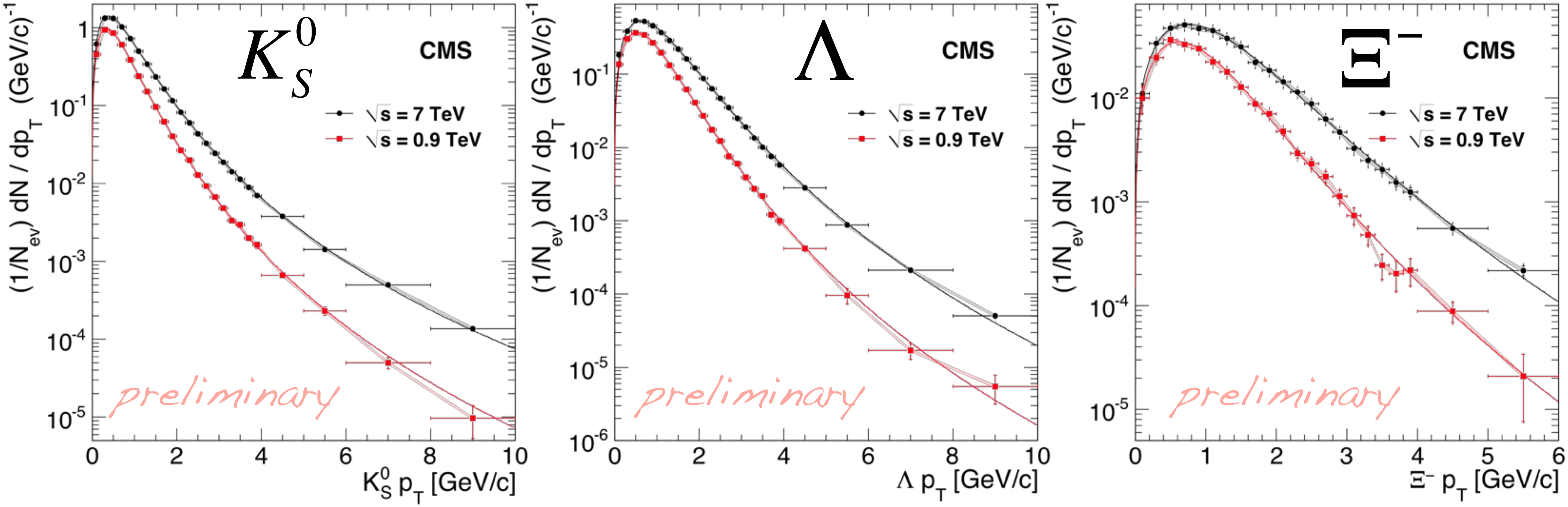
- Efficiency includes acceptance, trigger + event selection efficiency, reconstruction and selection criteria efficiency, and branching fractions.



Calculating number of NSD events

- Efficiencies are used to correct the data to NSD events
  - Efficiency = (# of reconstructed) / (# of generated in NSD events only).
  - Applying this efficiency effectively removes contribution from SD events. Also done in trigger eff calculation.
- Trigger efficiency is calculated two ways
  - Apply track weighting to MC and measure efficiency
  - Measure trigger efficiency versus tracks, apply inverse as weight to data, and count number of weighted data events. Trigger eff = 0 for less than 2 tracks so get fraction of events with tracks < 2 from MC and scale.
- Use 1st method (difference taken as systematic)
- Corrected yields are divided by this number.
- Difference between number of selected events and calculated number of NSD events is 9% at 0.9 TeV and 6% at 7 TeV.

p_T distributions per NSD event



Fit parameters from Tsallis function: $\frac{1}{N}\frac{dN}{dp_T} \propto p_T\left[1+\frac{\sqrt{p_T^2+m^2}-m}{nT}\right]^{-n}$

T parameter like $\exp(-p_T/T)$ (applies at low p_T) and n is inverse power-law parameter (applies at high p_T).

Obtain average p_T from dN/dp_T distribution using bin center from Tsallis function and Tsallis function to account for high p_T.

Analysis of p_T spectra

	$\sqrt{s}$ = 0.9 TeV		$\sqrt{s}$ = 7 TeV	
Particle	T (MeV)	n	T (MeV)	n
K_S	187 ± 1± 4	7.79 ± 0.07 ± 0.26	220 ± 1 ± 3	6.87 ± 0.02 ± 0.09
Λ	216 ± 2 ± 12	9.3 ± 0.2 ± 1.1	292 ± 1 ± 15	9.2 ± 0.1 ± 0.6
Ξ^-	250 ± 8 ± 48	10.1 ± 0.9 ± 4.7	353 ± 6 ± 71	10.6 ± 0.6 ± 4.7

T increases with particle mass and $\sqrt{s}$ (broader at low p_T). n is higher for baryons (falls off faster at high p_T) and for K_S is lower at 7 TeV.

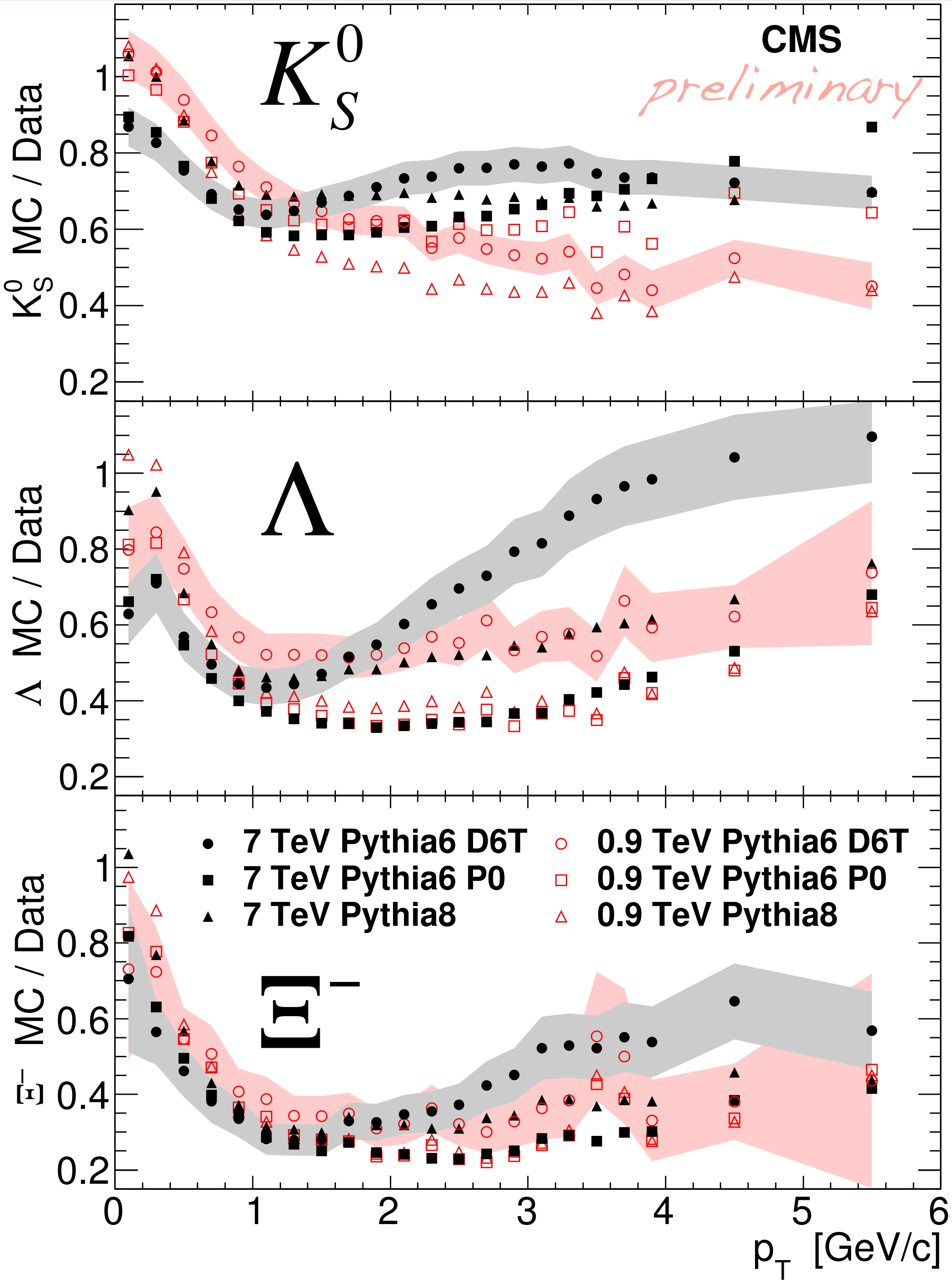
Average p_T (in MeV/c)

	$\sqrt{s}$ = 0.9 TeV		$\sqrt{s}$ = 7 TeV	
Particle	Data	MC (D6T)	Data	MC (D6T)
K_S	654 ± 1 ± 8	580	790 ± 1 ± 9	757
Λ	837 ± 6 ± 44	750	1035 ± 1 ± 68	1071
Ξ^-	971 ± 14 ± 43	831	1231 ± 9 ± 72	1243

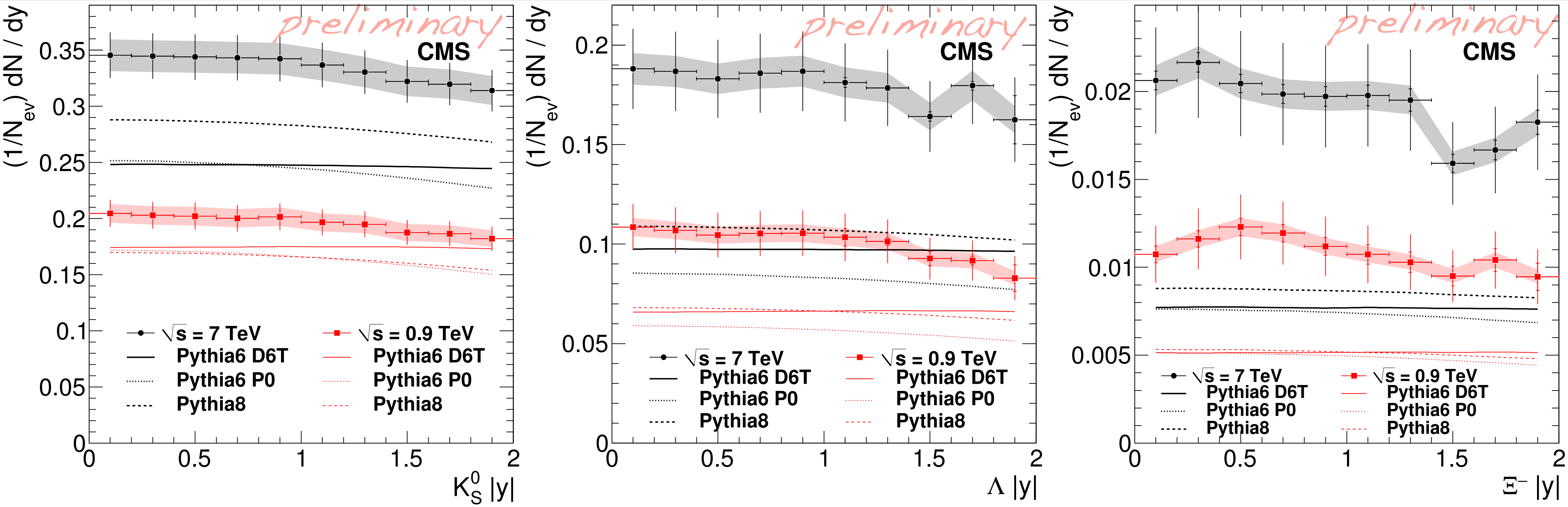
Average p_T increases with particle mass and center-of-mass energy.

p_T distributions compared to PYTHIA

- MC / Data for three particles and three PYTHIA samples.
- To reduce clutter, uncertainties only shown for one ratio (at each energy)
- PYTHIA samples show wide variation by version and tune.
- All PYTHIA results are broader than data.



Rapidity distributions per NSD event

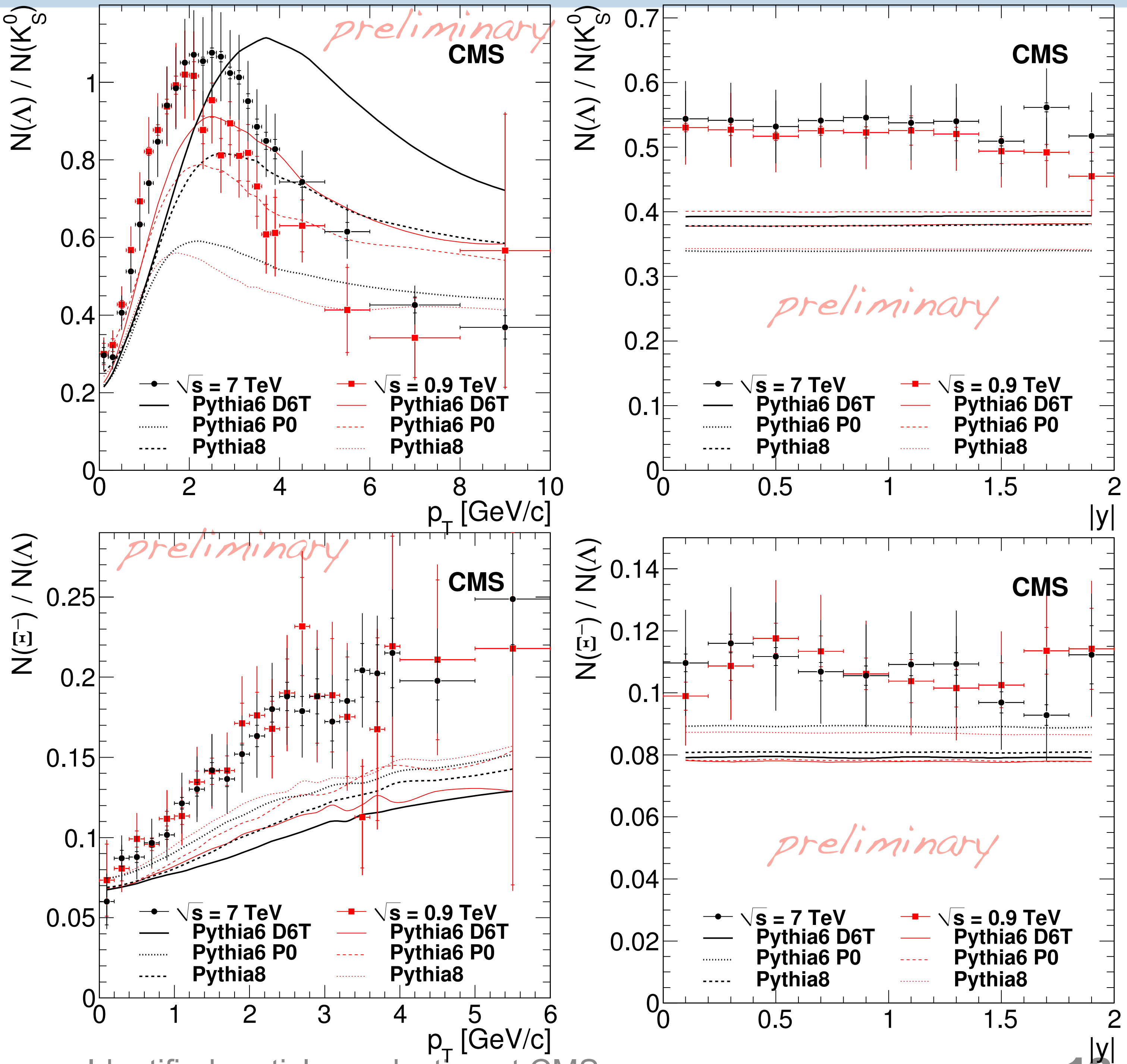


First two columns show increase in production going from .9 to 7 TeV. Data has larger increase than PYTHIA. Second two columns show MC/Data at .9 & 7 TeV. The underproduction in PYTHIA gets worse at higher energy.

Particle	dN/dy@y≈0(7 TeV) / dN/dy@y≈0(.9 TeV)		dN/dy@y=0(MC)/dN/dy@y=0(data)	
	Data	PYTHIA	0.9 TeV	7 TeV
K_S	1.69±0.01±0.06	1.42	0.852±0.005±0.061	0.719±0.001±0.052
Λ	1.73±0.02±0.08	1.47	0.609±0.007±0.070	0.518±0.002±0.060
Ξ	1.92±0.10±0.11	1.51	0.475±0.021±0.071	0.374±0.021±0.071

Production ratios

- $N(\Lambda)/N(K_S)$ (top) & $N(\Xi^-)/N(\Lambda)$ (bottom)
- Most normalization systematics cancel.
- Interesting: no change with $\sqrt{s}$
- PYTHIA shows significant variations in $N(\Lambda)/N(K_S)$ vs p_T with tune/ version.



Summary of strangeness production results

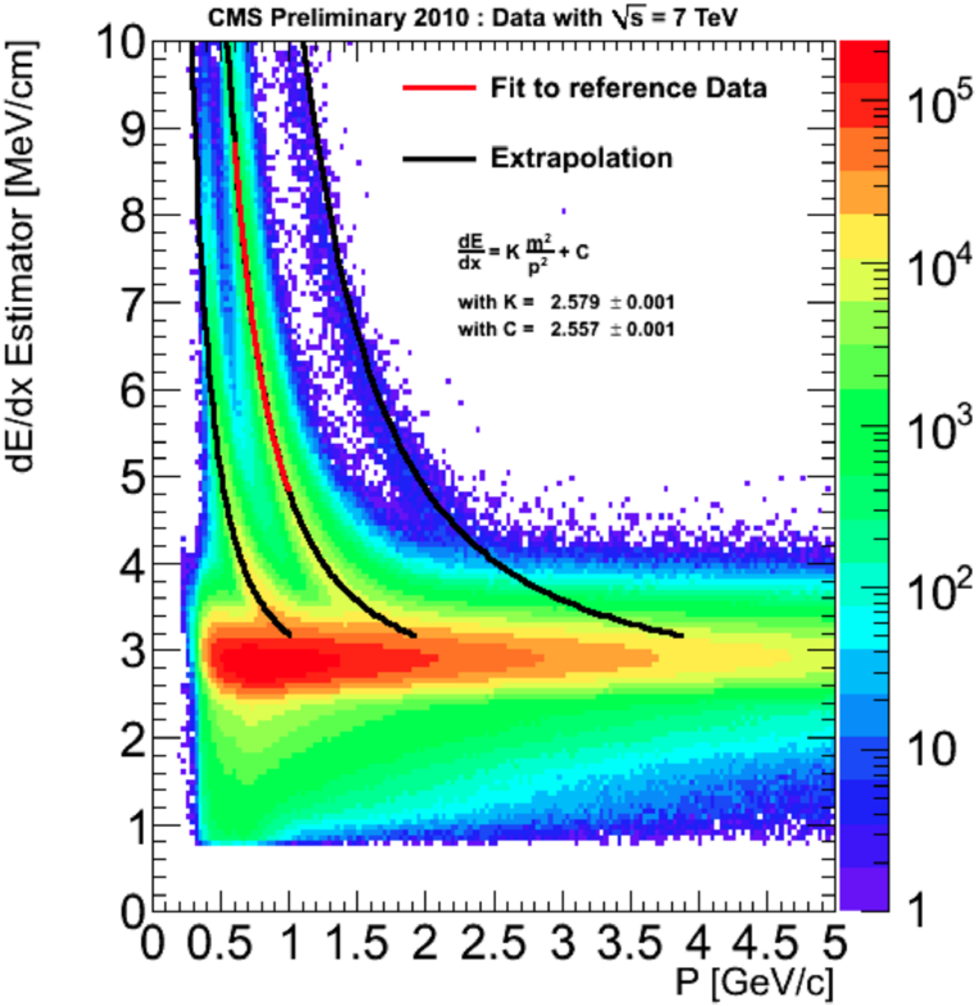
- Measurements of strangeness production at $\sqrt{s}$ = 0.9, 7 TeV.
- p_T distributions show average p_T increases with particle mass and center-of-mass energy and that K_S has longer tail than Λ and Ξ^-. PYTHIA has broader p_T distribution which is sensitive to version/tune.
- Increase in K_S, Λ, Ξ^- production from 0.9 to 7 TeV (1.69, 1.73, 1.92) is similar to results from charged particles (1.67) and different from PYTHIA (1.42, 1.47, 1.51).
- PYTHIA deficit of K_S particles, 15% (28%) at 0.9 (7) TeV, is consistent with charged particles. However, deficit of Λ and Ξ^- is worse. Most extreme case: at 7 TeV, only 37% as many Ξ^- are produced in PYTHIA compared to data.
- Production ratios, $N(\Lambda)/N(K_S)$ and $N(\Xi^-)/N(\Lambda)$ show no rapidity dependence and no dependence on center-of-mass energy. PYTHIA p_T distributions sensitive to tune/version.

Future plans for strangeness production

- Add the Ω^-
- Measure baryon−antibaryon asymmetries
- Normalize to easily identifiable event characteristic rather than NSD events
- Measure effect of track multiplicity
- Perhaps measure baryon polarization
- Another group is working on K* and Σ* production.

Production of identified π/K/p particles

- CMS can use dE/dx to separate charged particles at low momentum. Results at right from strips only.
- Work is ongoing to integrate pixel information as well.
- Comprehensive calibration and validation program.
- Will be used to produce physics measurements of:



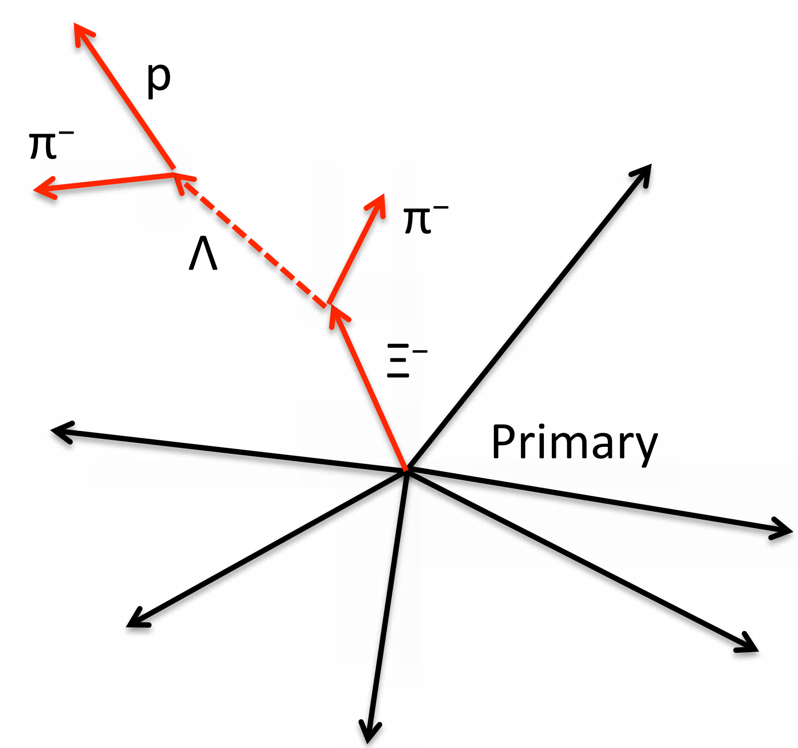
  - p_T distributions of π, K, p (particle and antiparticle separately)
  - Ratios of particles versus p_T
  - Effect of particle multiplicity including $\langle p_T \rangle$ vs. track multiplicity

Backup

V^0 reconstruction

- Fit pair of oppositely charged tracks to common vertex
- Track requirements
  - From collection of generalTracks + minimum bias tracks.
  - χ^2/dof < 5
  - Miss primary vertex by >3σ (3D)
- Vertex requirements
  - χ^2/dof < 7
  - Position >5σ from primary (3D)
  - No track hits >4σ inside vertex
- Require V^0 point to primary within 3σ (3D)
- Reject if consistent within 2.5σ of other V^0 mass hypothesis
- Low p_T Λ's (p_T<0.6 GeV/c) require additional cuts to remove background:
  - Daughter tracks miss primary vertex by >(7-2|y|)σ (instead of 3σ) where y is the Λ rapidity
  - 3D vertex separation from primary >10σ (instead of 5σ)
  - 2D vertex separation from beamspot >5σ (instead of no cut)

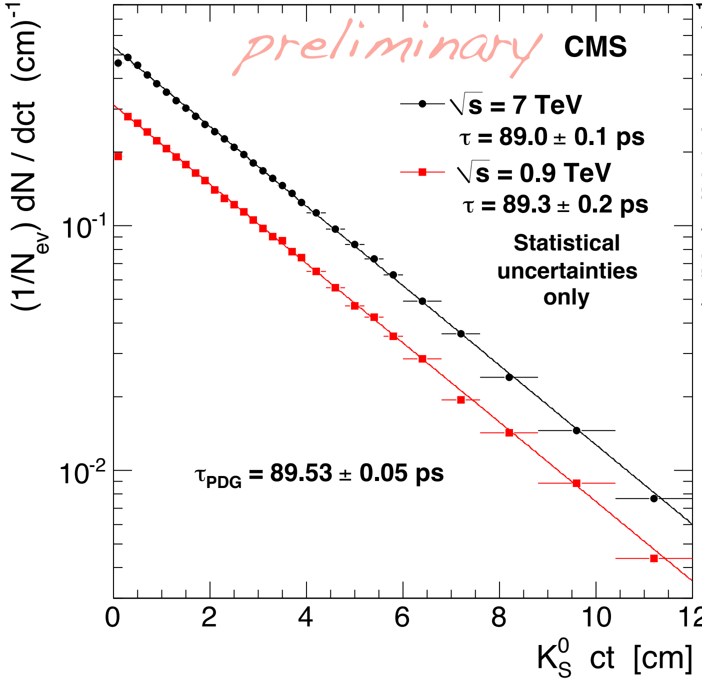
Ξ^- reconstruction

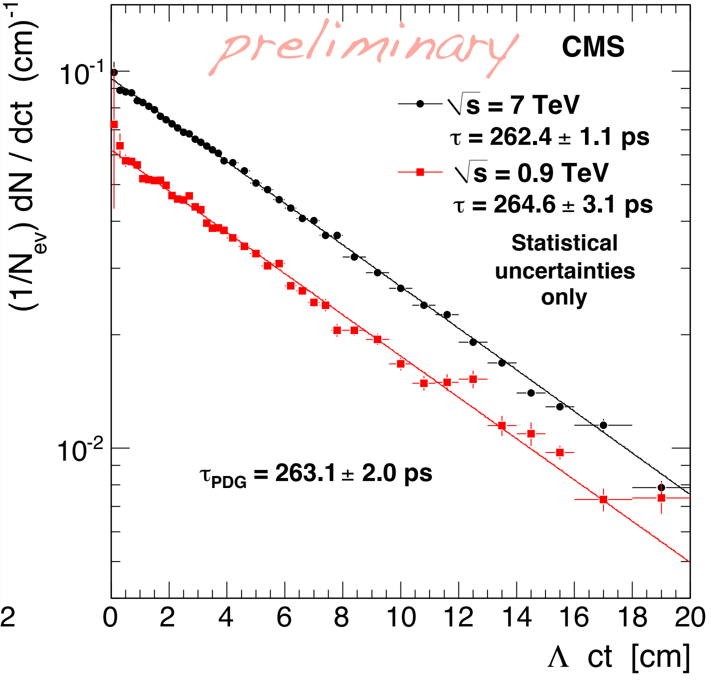


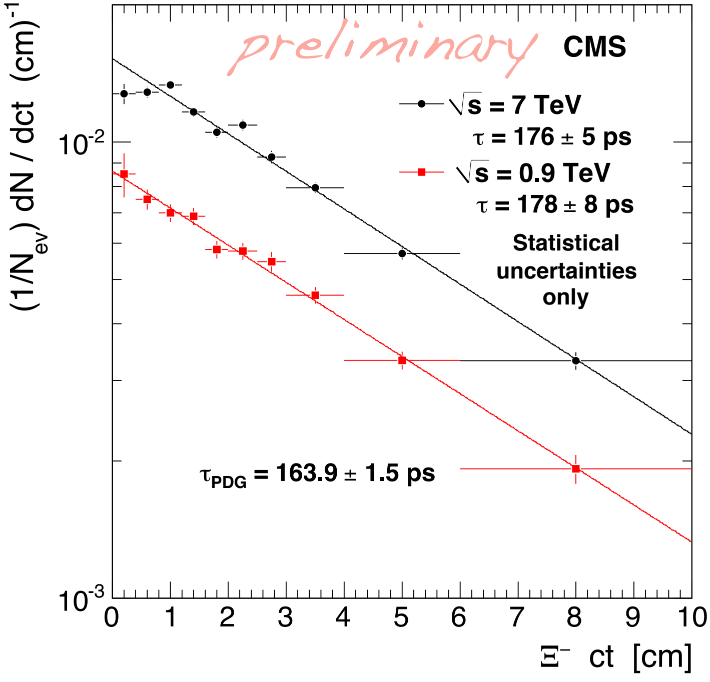
- Fit Λ and correctly-signed track to common vertex
- Proton (pion) from Λ must miss primary in 3D by $> 2\sigma$ (3σ)
- Λ vertex $> 10\sigma$ from primary (3D)
- Pion from Ξ^- must miss primary in 3D by $> 4\sigma$
- Ξ^- vertex fit probability > 5%
- Require Ξ^- point to primary within 3σ (3D)
- Ξ^- vertex separated from primary by $> 2\sigma$ (3D)
- Invariant mass of Λ daughters reconstructed as $\pi^+\pi^-$ must be > 20 MeV/c^2 from K_S mass.

Lifetimes

- To verify the MC simulation, lifetimes were measured using the same reconstruction and efficiency correction procedure.
- After correction, lifetimes are approximately exponential.
- The first bin has low efficiency and statistics due to the vertex separation requirements which can lead to deviations. An actual lifetime measurement would use the reduced proper lifetime, starting the clock after the cut.
- Nevertheless, reasonable agreement is found with the PDG.







Uncorrelated systematic uncertainties

Uncertainties which are not necessarily correlated bin-to-bin

- Effect of MC production evaluated using D6T, P0, PYTHIA8
- Comparison of kinematic weighting and 2D binning
- Effect of non-prompt Λ: varied amount in MC by 50%
- MC fidelity evaluated by varying cuts
- Understand MC efficiency from lifetime (use difference between measured and PDG except 2% for K_S & Λ since difference <1%)
- Fit mass with signal shape from MC.
- Check of alignment using MC rather than START conditions.
- Check effect of beam spot using MC with bad beamspot.
- Check effect of uncertain detector material by measuring efficiency with maximum reasonable interaction cross section.
- Check effect of bad antiproton cross section in GEANT4 by looking at Λ, Λbar asymmetry and efficiencies.

Correlated systematic uncertainties

Uncertainties on normalization:

- Use difference between two calculations of trigger efficiency.
- Account for unknown SD amount by measuring trigger efficiency varying SD contribution by ±50%.
- Account for modeling uncertainty using different MC: PYTHIA6 D6T, PYTHIA6 P0, PYTHIA8.
- Vary track weighting using two alternative requirements when measuring track multiplicity:
  - Require primary vertex (and use the 2-track weight for the events with tracks ≤ 2).
  - Require primary vertex (as above) but no HF requirement.
- Branching ratio uncertainties from PDG.

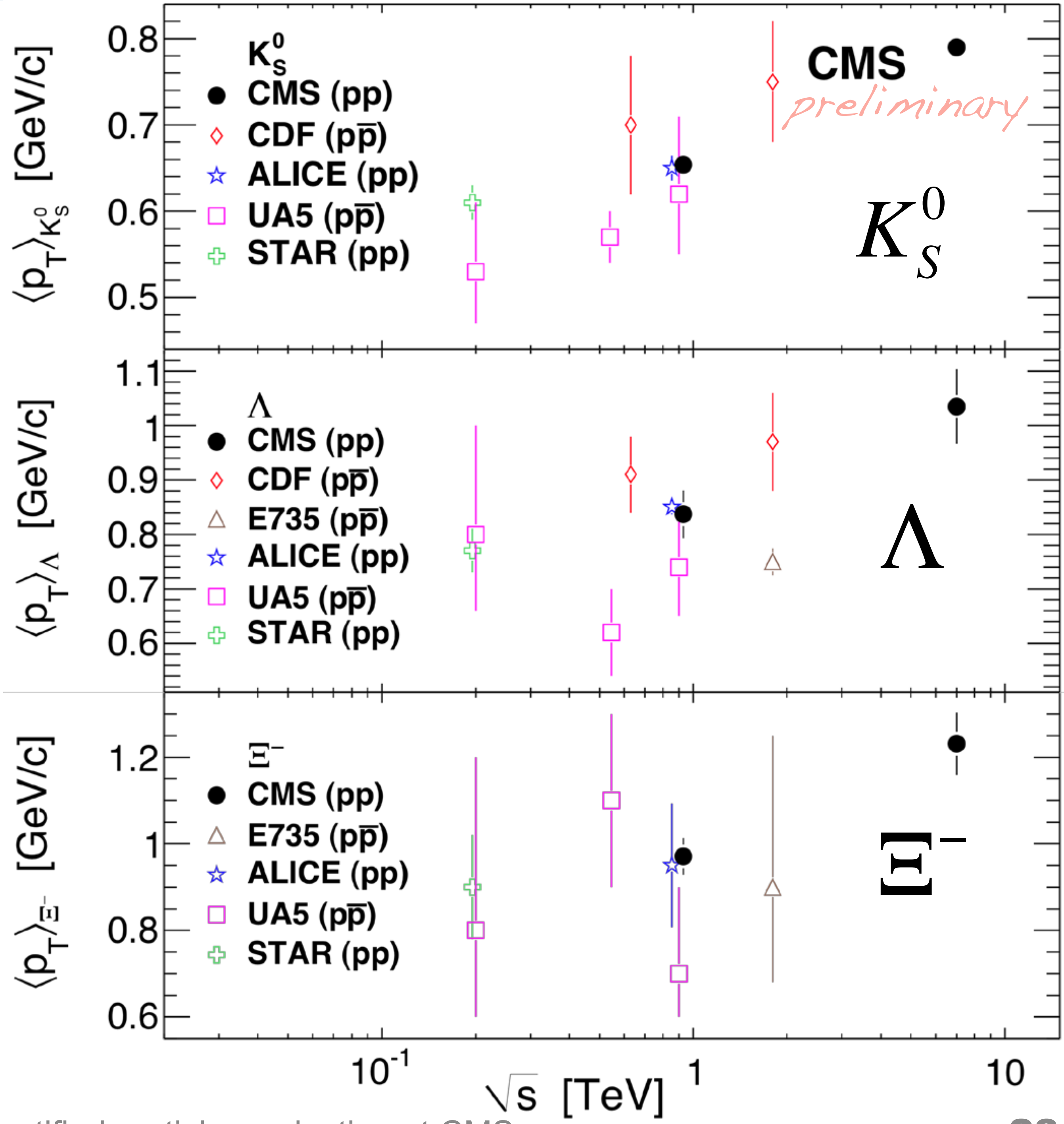
Systematic uncertainties

0.9 and 7 TeV results are consistent. We use the higher statistics 7 TeV values.

	Source	**K_S (%)**	**Λ (%)**	**Ξ^- (%)**
	Kinematic weight vs. 2D binning	1.0	1.0	1.0
	Non-prompt Λ	-	3.0	-
uncorrelated	MC tune	2.0	3.0	4.0
	Reconstruction cuts	4.0	5.0	5.0
	Detached particle reconstruction	2.0	2.0	7.6
	Mass fits	0.5	2.0	2.0
	Matching vs fitting	2.0	3.0	3.0
	Misalignment	1.0	1.0	1.0
	Beamspot	1.0	1.5	2.0
	Detector material	2.0	5.0	8.0
	GEANT 4 cross sections	0.0	5.0	5.0
normalization	Trigger calculation	1.8	1.8	1.8
	Diffractive modeling	1.5	1.5	1.5
	SD fraction	2.8	2.8	2.8
	Track weighting	2.0	2.0	2.0
	Branching ratios	0.1	0.8	0.8
	Overall sum	7.2	11.5	15.0

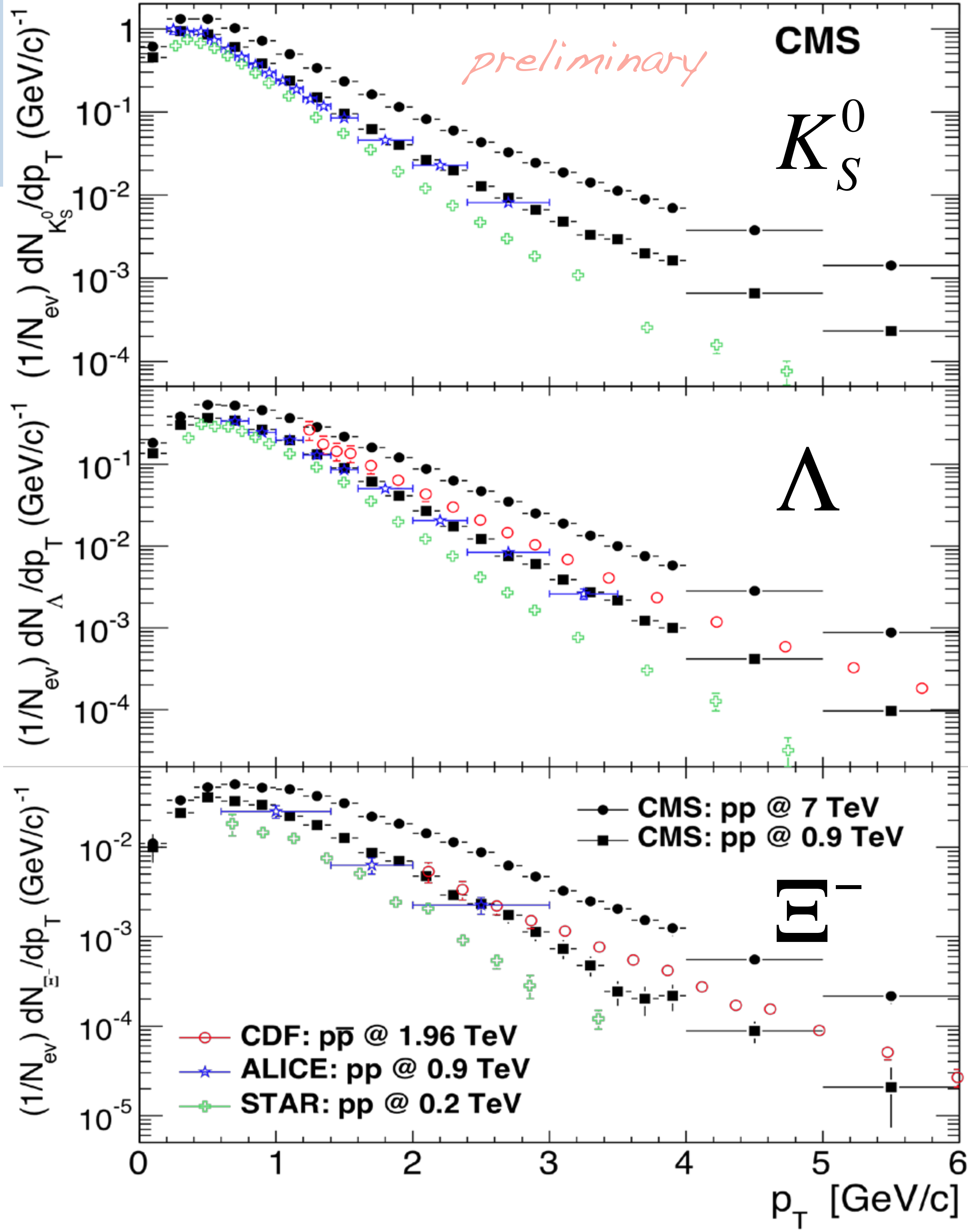
Average p_T vs $\sqrt{s}$

Plot of average p_T versus center-of-mass energy for strange particles.



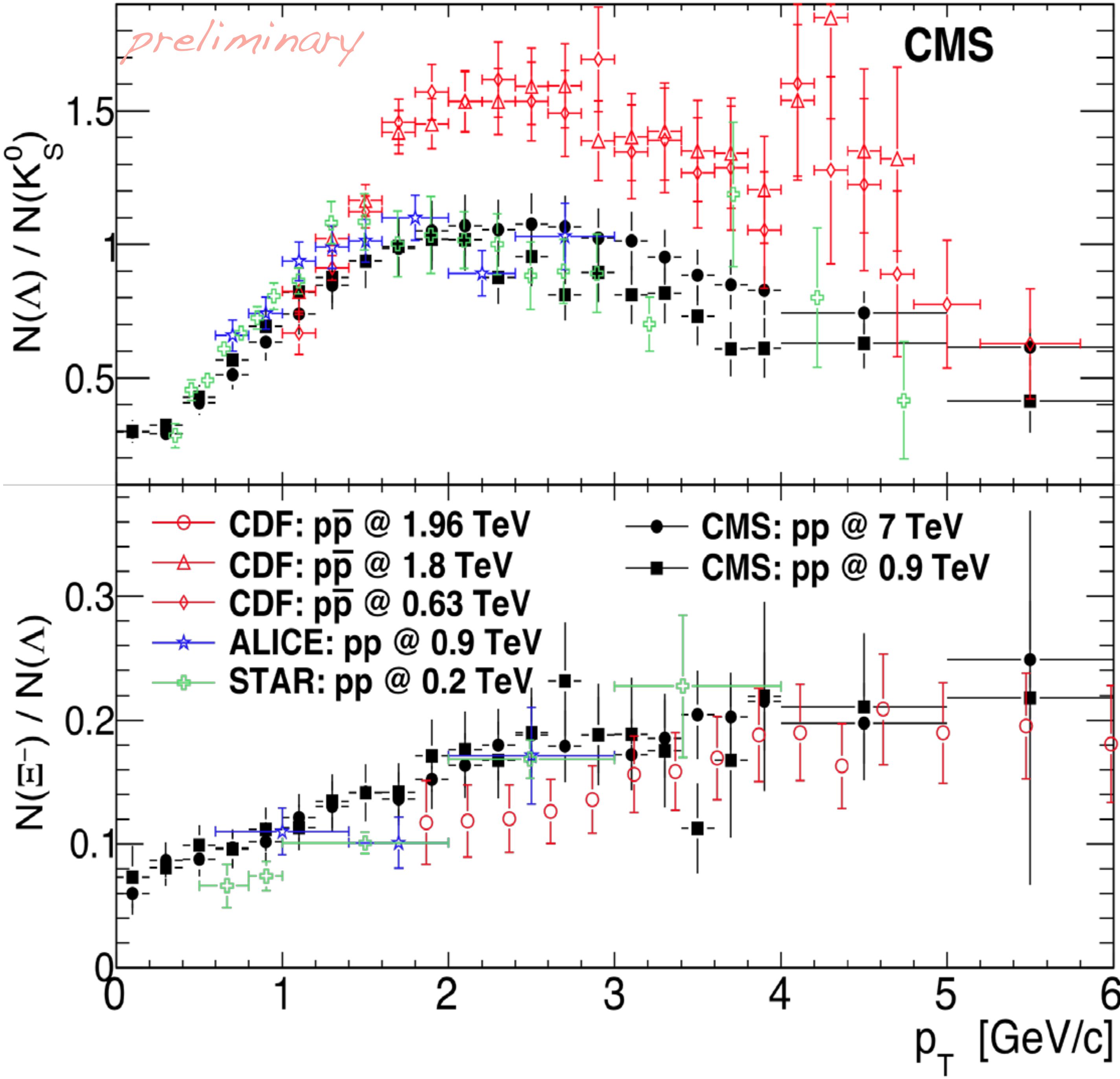
Comparing p_T distributions

- Comparing the CMS p_T distributions to those from CDF, ALICE, and STAR
- ALICE is per inelastic event, CDF have been converted to per NSD event, and CMS and STAR are per NSD event.
- Behavior is as expected.



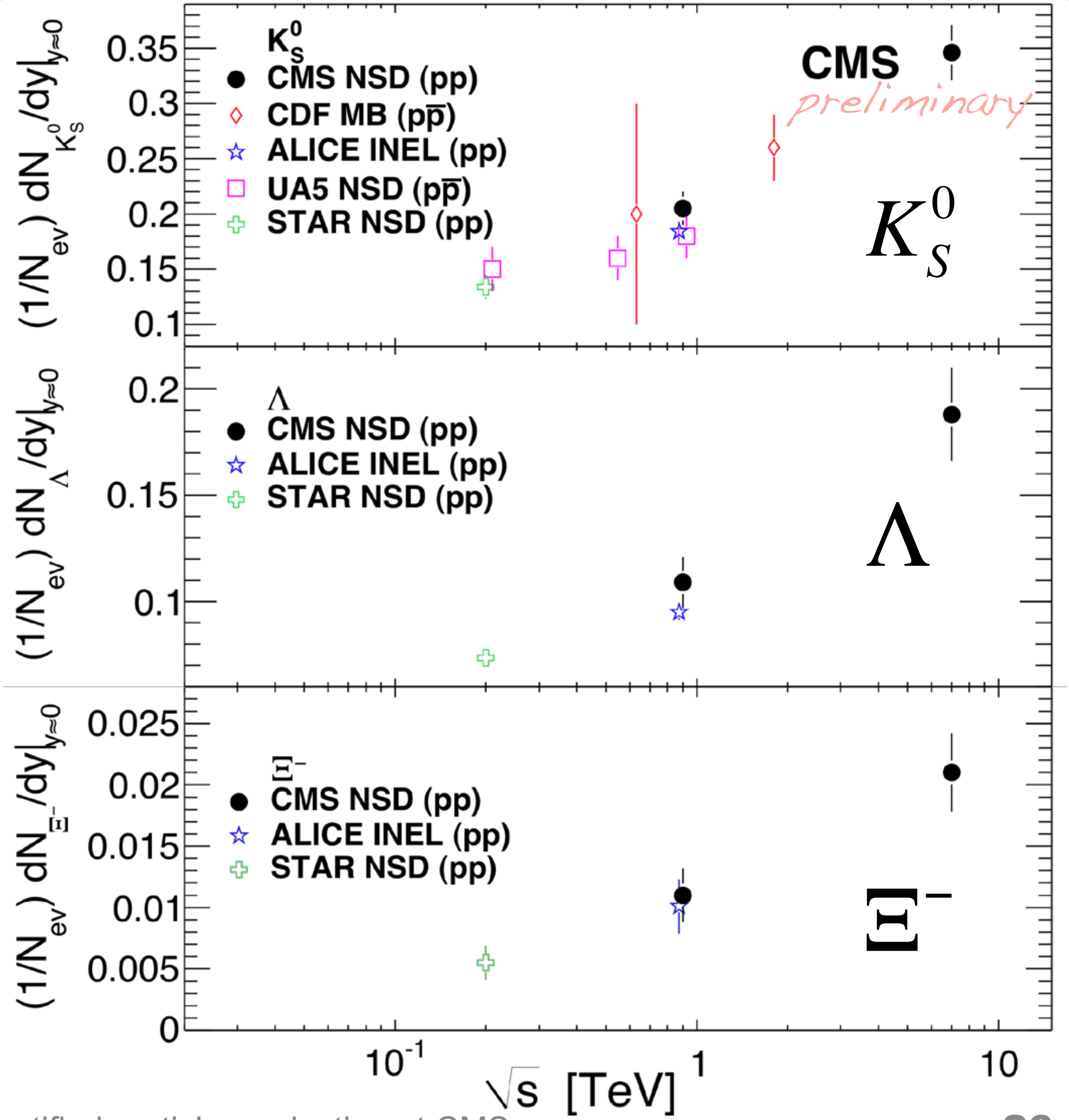
Production ratios

- $N(\Lambda)/N(K_S)$ (top) & $N(\Xi^-)/N(\Lambda)$ (bottom)
- Most normalization systematics cancel.
- Interesting: there is no change with √s
- CMS results agree well with ALICE and STAR, not so much with CDF.



Average dN/dy vs √s

Plot of dN/dy at y≈0 versus center-of-mass energy for strange particles.



Production rates

dN/dy@y=0 is the |y|<0.2 bin. Total # is the integral over p_T for |y|<2. Both are normalized to NSD events.

Particle	√s = 0.9 TeV		√s = 7 TeV	
	dN/dy@y≈0	N (|y|<2.0)	dN/dy@y≈0	N (|y|<2.0)
K_S	0.205±0.001±0.015	0.784±0.002±0.056	0.346±0.001±0.025	1.337±0.001±0.096
Λ	0.108±0.001±0.012	0.404±0.004±0.046	0.188±0.001±0.022	0.716±0.004±0.082
Ξ	0.011±0.001±0.002	0.043±0.001±0.007	0.021±0.001±0.003	0.080±0.001±0.012