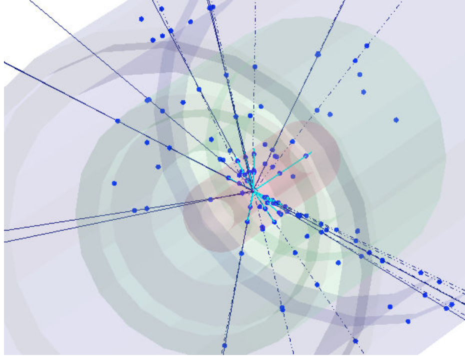

Early Minimum-Bias Physics in ALICE – Status and Plans

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for the ALICE collaboration

Minimum Bias @ Early LHC Meeting
1. - 2. March 2010, CERN

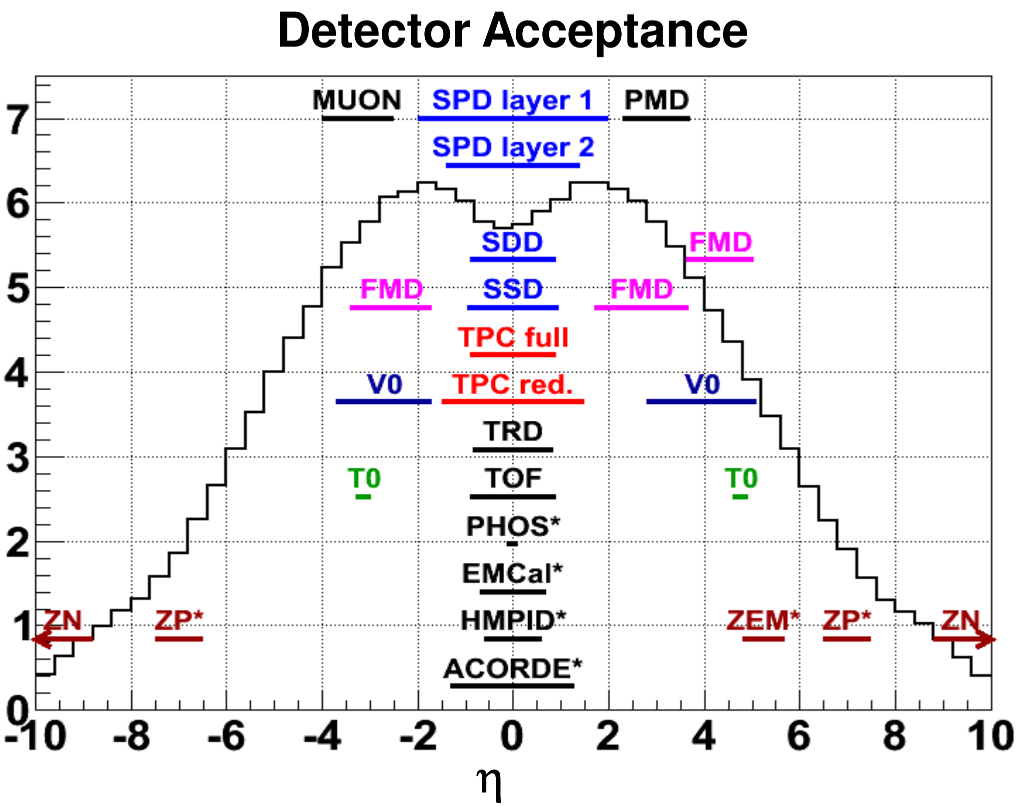
Content

- ALICE's trigger for MB physics
- Event classes
- 0 bin and background
- Diffractive treatment
- Some MB results
- Plans

This talk uses
Pythia 6.4.14 with tune D6T
Phojet 1.12 with Pythia 6.2.14
unless otherwise indicated

ALICE – Trigger and Acceptance

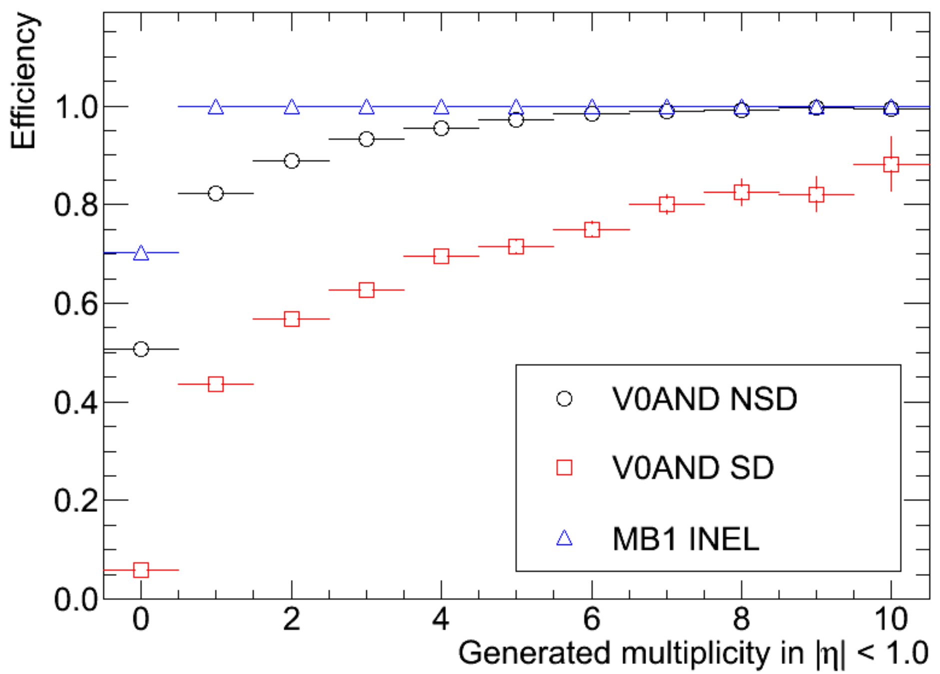
- MB Triggers
  - SPD
    $|\eta| < 2.0$ (1.4)
  - V0
    $2.8 < \eta < 5.1$
    $-1.7 < \eta < -3.7$
- MB Tracking
  - SPD
    $|\eta| < 1.4$
    $p_T > 50$ MeV/c
  - TPC
    $|\eta| < 0.9$
    $p_T > 150$ MeV/c



Trigger for MB Physics

- ALICE measures MB properties for all inelastic (INEL) and non single-diffractive (NSD) events
  - "MB1" trigger for INEL: central pixel hit (SPD) or forward scintillator (V0)
    - One particle in 8 η units
    - (Trigger-)sensitive to 96-98% of the inelastic x-section
  - "V0AND" trigger for NSD: both forward scintillators
- Possible ND trigger V0AND + several hits centrally
  - 90% ND and 20% SD/DD

900 GeV		ND	SD	DD
Pythia	MB1	100	77	92
	V0AND	98	29	49
Phojet	MB1	100	86	98
	V0AND	98	34	66

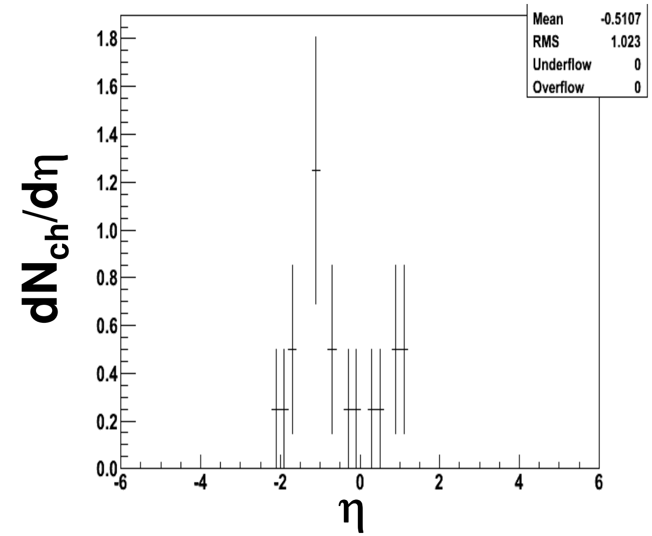


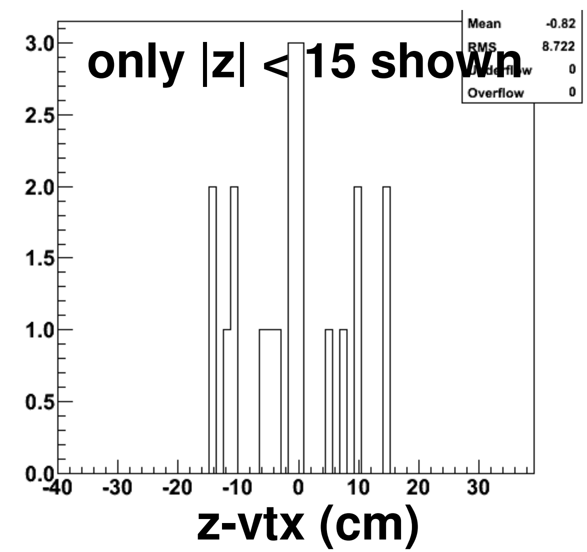
“0 bin” Treatment

- Significant amount of triggered events have no reconstructed vertex, no track in acceptance
- Use the number of triggered events as input for the normalization (“0 bin = measured 0”)
- Correct with trigger efficiency for this bin
  - MC dependence
- Assess background from control triggers
  - Single bunch passing, no bunch passing
  - Background with activity very small

Background @ 900 GeV

- Relative to accepted events in bunch crossing trigger
  - About 2.1% each in single bunch triggers
  - About 1.2% in “empty” trigger (= noise)
  - 0.02% have a vertex and tracks
  - The remaining go into the 0 bin, which can be subtracted with the control triggers
  - Bunch intensities taken into account
- Background with activity is negligible





ALICE run 104967,90,92

Diffractive Treatment
Single Diffraction

- Use MC generator for corrections per process type (SD, DD, ND)
- Combine using measured weights
- Replay measurement conditions
  - $M^2/s < 0.05$ for UA5 measurement
  - Weight SD such that replayed fraction matches measurement
  - Experiments have corrected for non-SD contribution in their measurements

SD, 900 GeV	Pythia	Phojet
MC fraction	22.3%	19.1%
Replay	18.9%	15.2%
Measurement	(15.3 ± 2.3)%	

*UA5: Z. Phys. C33, 175, (1986) derived from ratio of SD/NSD

Diffractive Treatment
Double Diffraction

- Does DD matter?
  - Yes, unless your trigger is 100% efficient for DD
- UA5
  - Uses central gap of $|\eta| < 1 .. 3$
  - UA5 somehow corrects for their efficiency to find certain gap sizes
  - Hadron-level definition for DD not evident from the paper
- CDF
  - Measures with a gap of 3 η-units (including $\eta = 0$)

DD, 900 GeV	Pythia	Phojet
MC	12.3%	6.4%
Measurement	(8 ± 5)%	

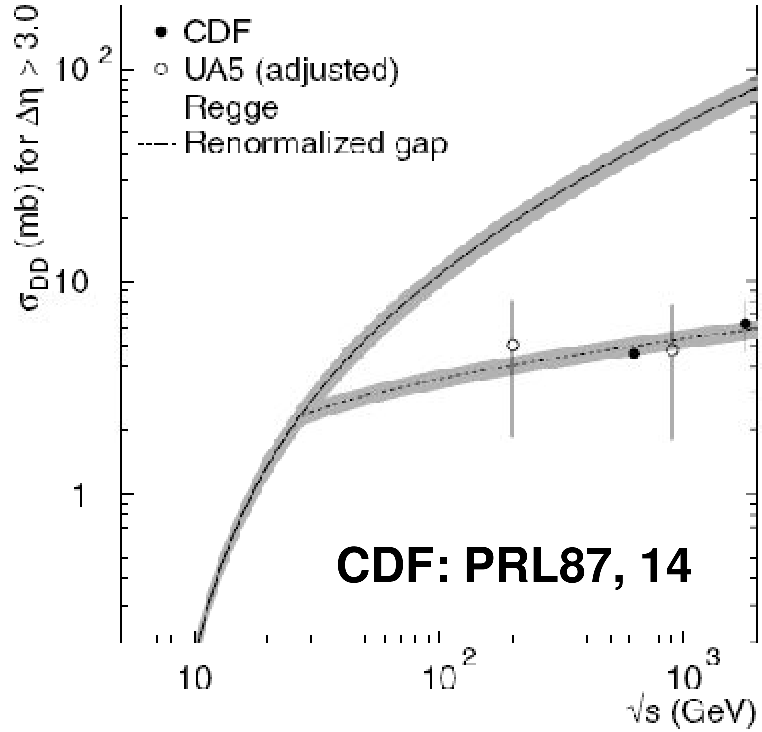
DD, 1.8 TeV	Pythia	Phojet
MC	12.6%	5.8%
Replay $\Delta\eta^0 > 3$	6.6%	2.2%
Measurement	(7.5 ± 2.2)%	

UA5: Z. Phys. C33, 175, (1986)

CDF: PRL87, 14

Diffractive Treatment - DD (2)

- CDF scales their and UA5 result to floating gap of 3 η-units ("Δη > 3")
- Consistent measurements
- Replay works for Pythia, but not for Phojet
- Treatment of DD remains ambiguous



		Pythia	Phojet
900 GeV	MC	12.3%	6.4%
	Replay Δη > 3	10.6%	3.6%
	UA5 scaled	(9.5 ± 6)%	
1.8 TeV	MC	12.6%	5.8%
	Replay Δη > 3	10.3%	3.5%
	CDF scaled	(10.7 ± 3.1)%	

Diffractive Treatment at Larger √s

- 2.36 TeV
  - Measurements at 1.8 TeV
    - For SD: E710, Phys. Lett. B301, 313 (1993)
      - Other cut on SD: $2 < M^2 < 0.05s$
    - For DD: CDF: PRL87, 14
  - Ratios SD/INEL, DD/INEL fairly constant as function of √s
    - No extrapolation needed from 1.8 TeV and 2.36 TeV
- 7 TeV?
  - Topic for discussion at this workshop

Towards a Hadron-Level Definition for SD

- ALICE plans to use a hadron-level definition for SD (for the correction to NSD)
  - Study difference between MC flags and hadron-level definition
- Use the UA5 definition
  - $M^2/s < 0.05$
- First observations
  - The SD bin gets other contributions
    - Small contribution from DD, ND
    - Central diffraction flows to 90% into SD (Phojet)

Systematic Uncertainties

- Use uncertainty on measurement to estimate systematic uncertainty due to unknown relative fraction
  - E.g. for SD at 900 GeV*: (15.3 ± 2.3)%
  - Large errors on DD, dominate
- For ALICE
  - Effect on INEL sample, MB1 triggered data < 1%
  - Effect on NSD sample, V0AND triggered data 2-3%
- Use Pythia / Phojet to assess different kinematics

*** Z. Phys. C33, 175, (1986)**

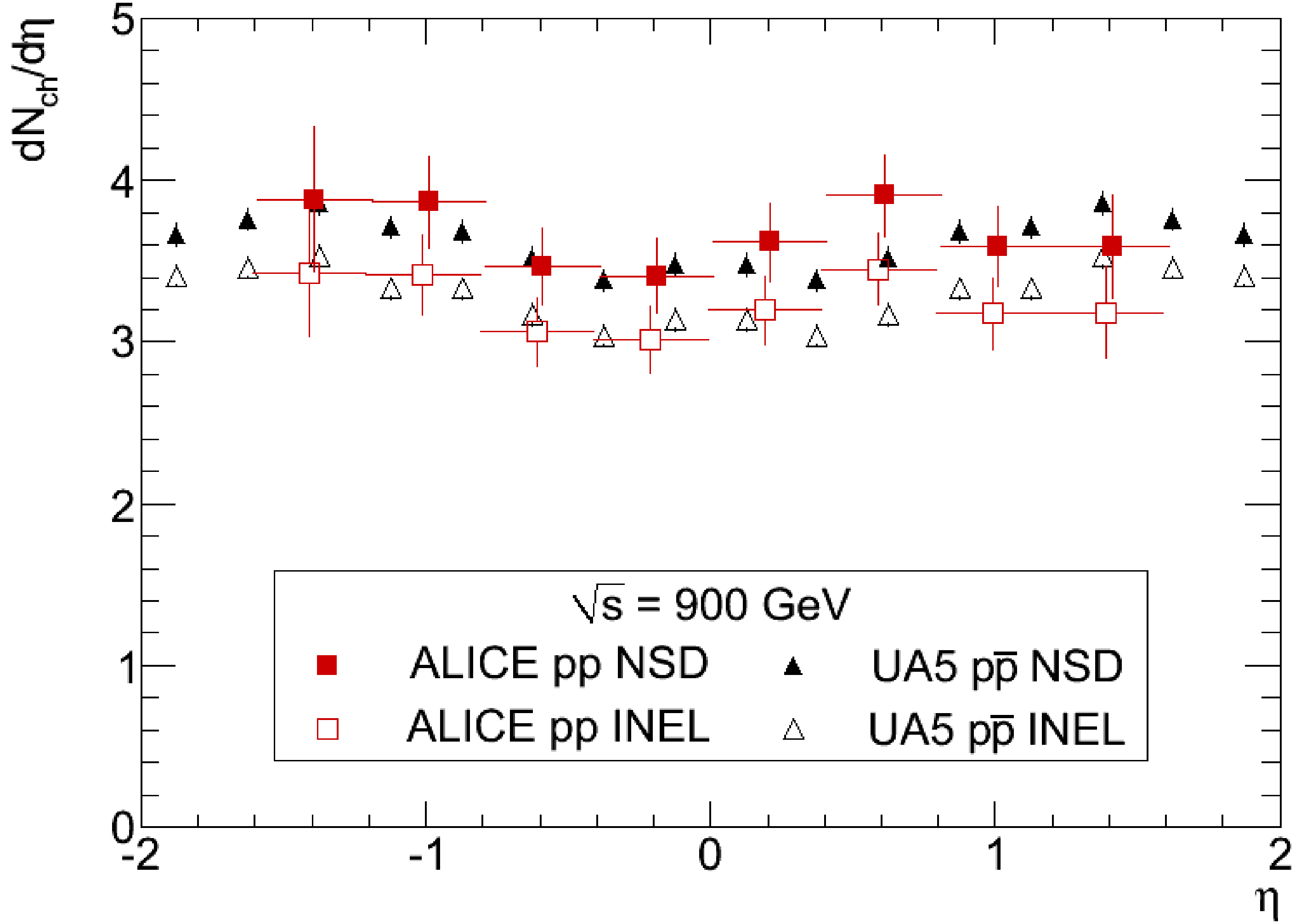
Other Remarks

- Normalization to 1 track
  - Normalization to one *measured* track trivial
  - However, to compare with other experiments
    - Correct for tracking inefficiency, dead areas etc.
    - Some MC dependence comes in due to the multiplicity distribution
  - Alternative
    - Correct to events triggered in the same phase space region
      - Possible for ALICE SPD trigger because it is part of the online trigger
      - Other experiments?

- Charged primary hadrons vs. charged primary particles
  - ALICE: charged primary particles, excluding weak decays from strange particles
  - CMS: charged primary hadrons
  - Charged leptons about 1.5% of charged primaries at 900 GeV, $|\eta| < 1$ (Pythia)
    - Includes e^+e^- from π^0 etc.

Results…

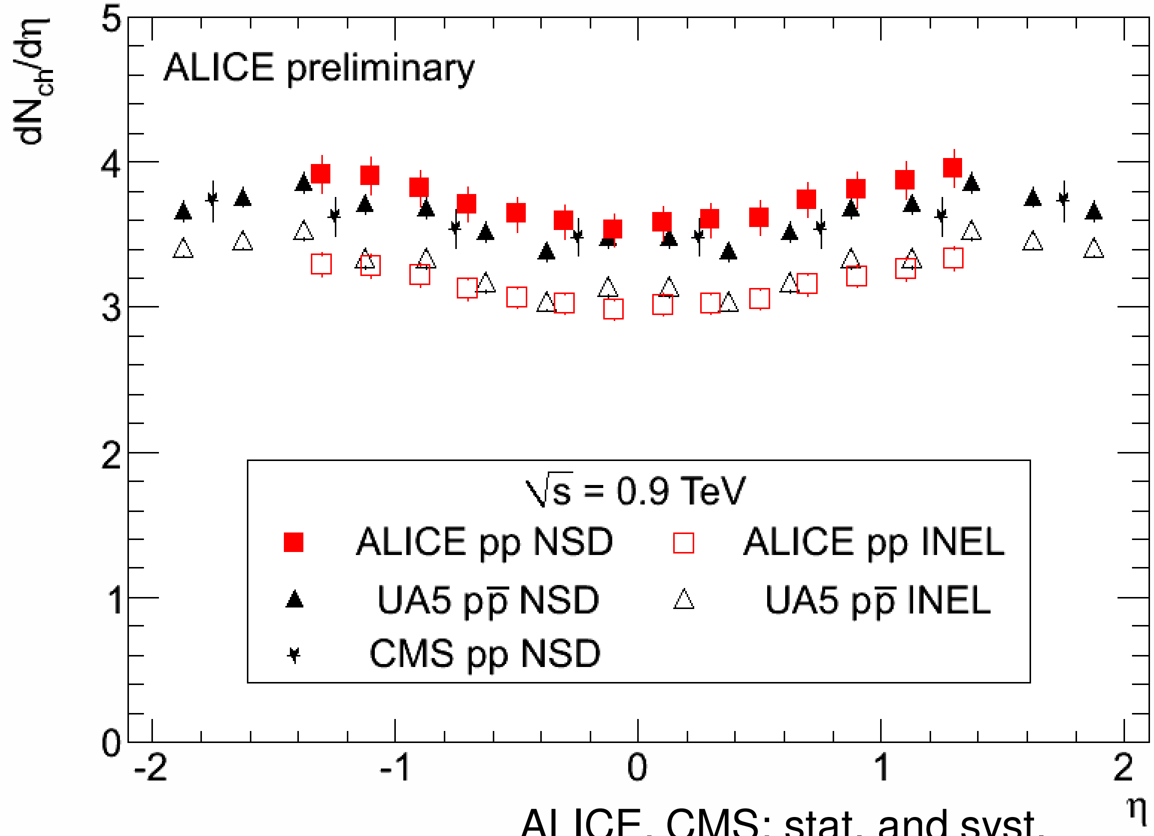
$dN_{ch}/d\eta$ @ 900 GeV



European Physical Journal C: Volume 65, Issue 1 (2010), Page 111

$dN_{ch}/d\eta$

- 900 GeV
- High-statistics measurement (90k events)
- Different triggers for NSD and INEL

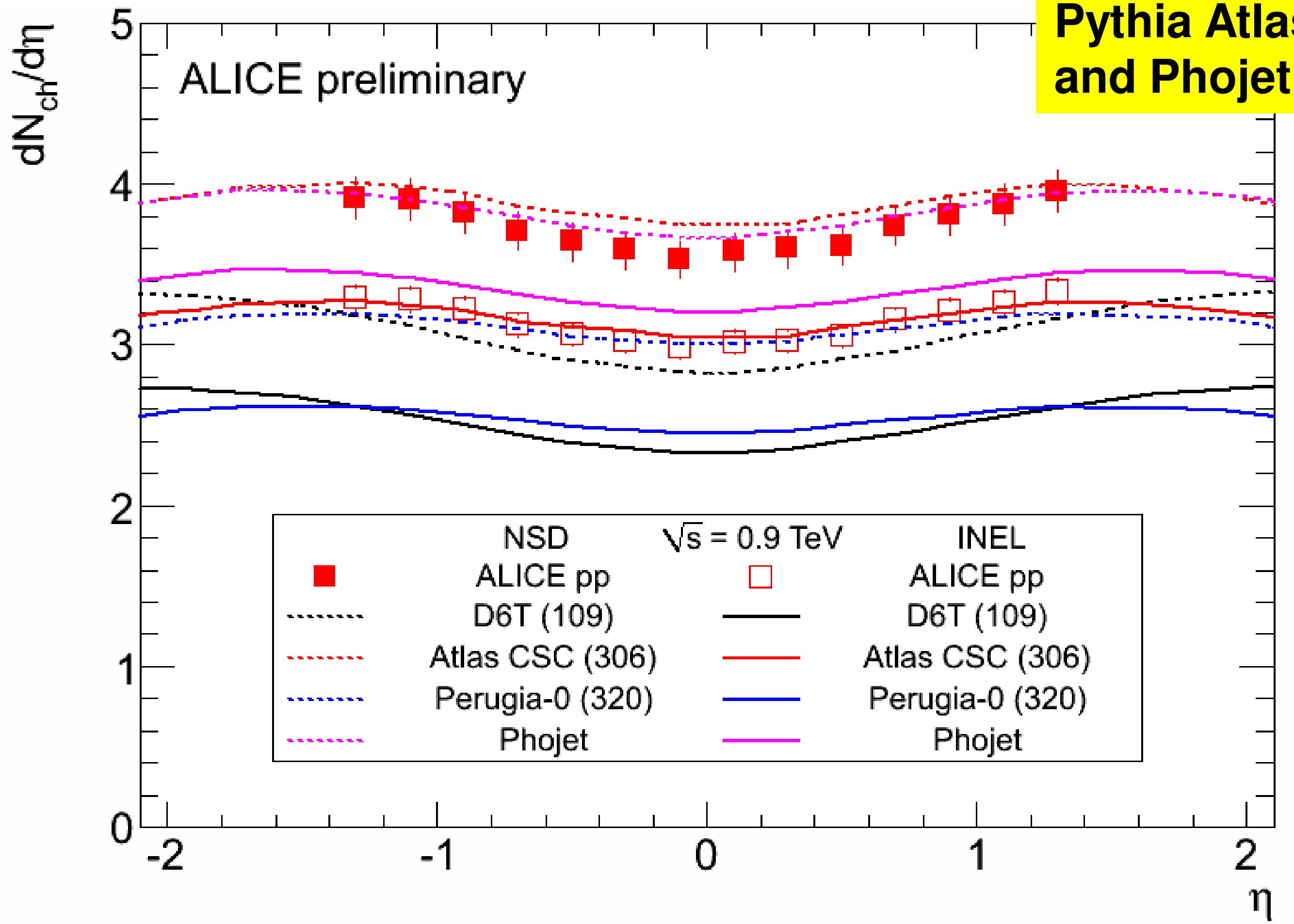


ALICE, CMS: stat. and syst. uncertainty added in squares

	INEL	NSD
ALICE preliminary	**3.02 ± 0.01 ± 0.07**	**3.58 ± 0.01 ± 0.11**
ALICE published	**3.10 ± 0.13 ± 0.22**	**3.51 ± 0.15 ± 0.25**
UA5 Z. Phys. C33 1 (1986)	**3.09 ± 0.05 ± ?**	**3.43 ± 0.05 ± ?**
CMS JHEP 02 (2010) 041		**3.48 ± 0.02 ± 0.13**

Comparison to MC

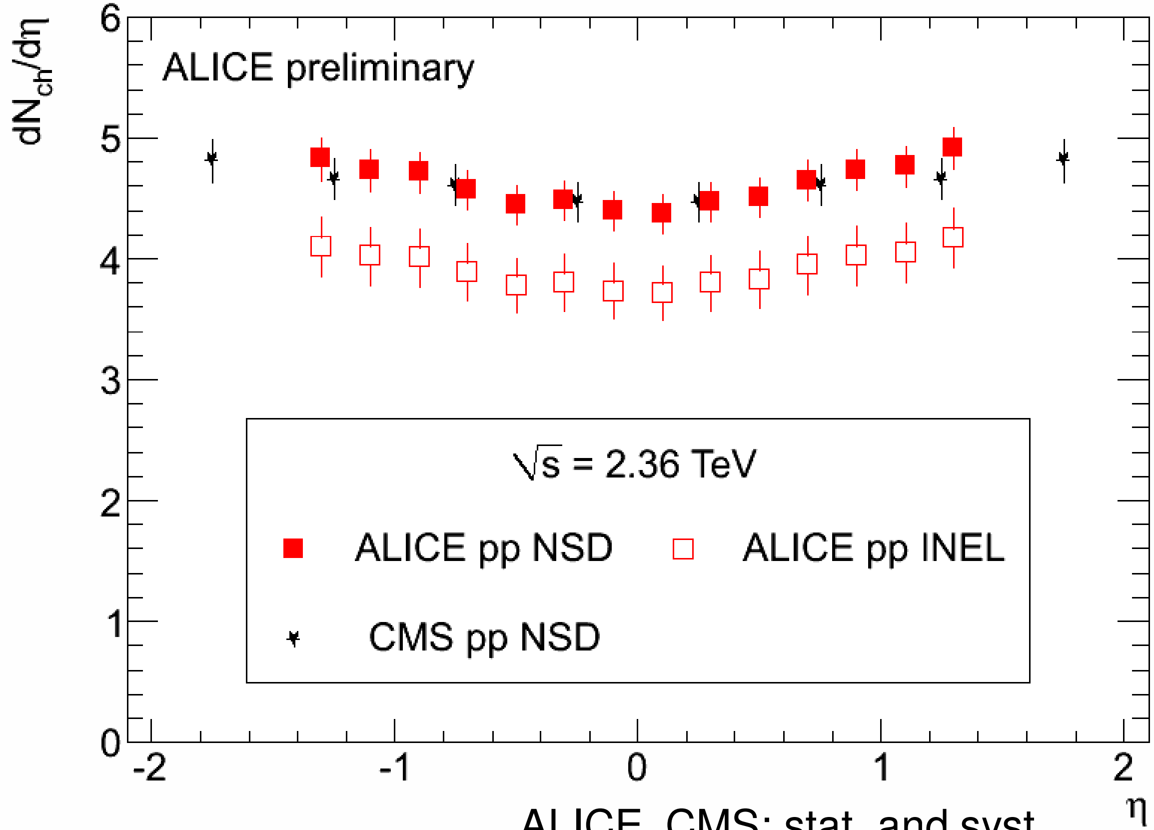
Pythia Atlas CSC and Phojet match best



D6T/Atlas: Pythia 6.4.14 - Perugia-0: Pythia 6.4.21 - Phojet 1.12 with Pythia 6.2.14

$dN_{ch}/d\eta$

- 2.36 TeV
- 41k events
- Same trigger for INEL/NSD
- 0 bin correction from MC
  - Larger syst. uncertainty

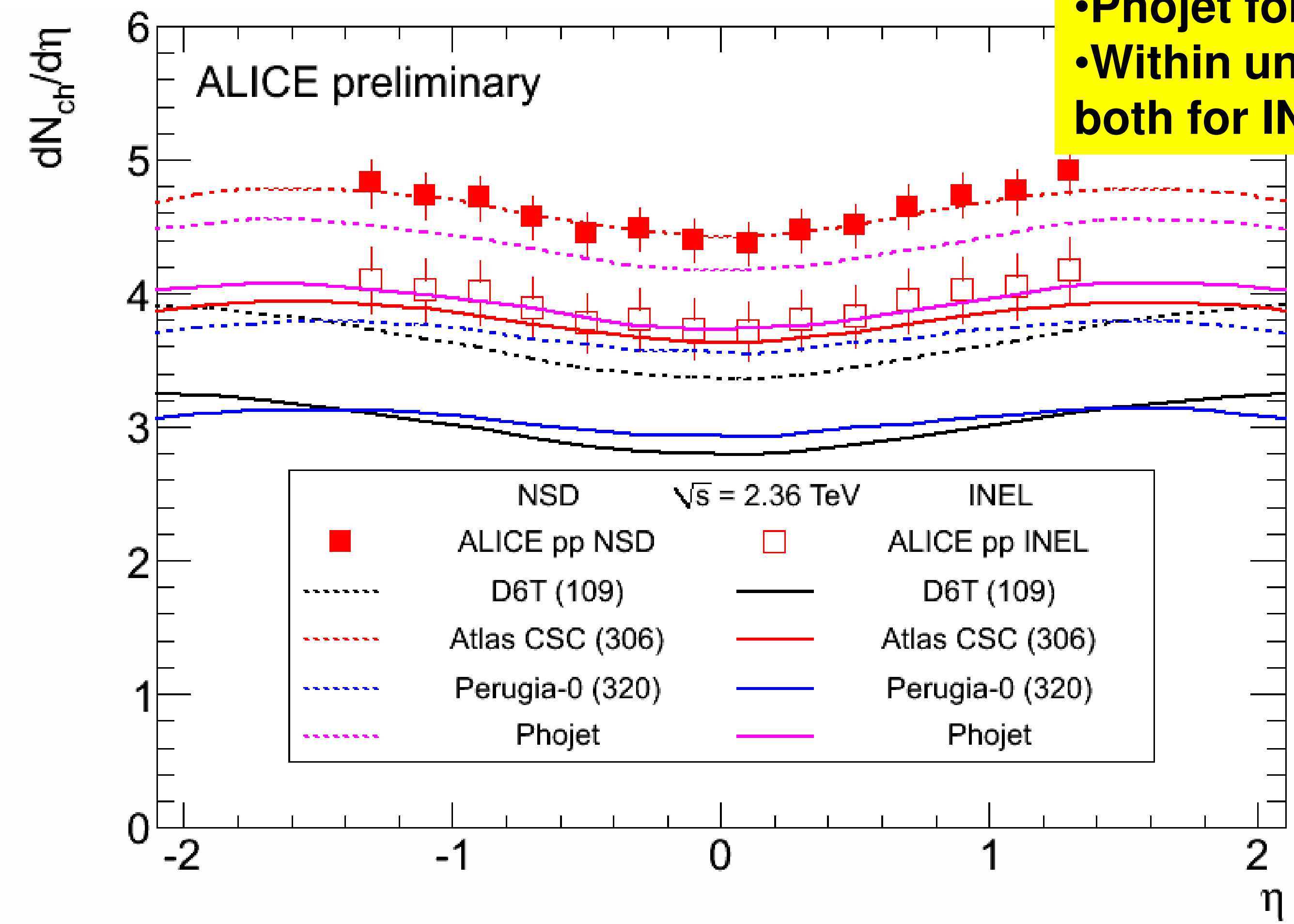


ALICE, CMS: stat. and syst. uncertainty added in squares

	INEL	NSD
ALICE preliminary	**3.77 ± 0.01 ± 0.23**	**4.44 ± 0.01 ± 0.16**
CMS JHEP 02 (2010) 041		**4.47 ± 0.04 ± 0.16**

Comparison to MC

- **Pythia Atlas CSC for NSD**
- **Phojet for INEL**
- **Within uncertainties both for INEL/NSD**



D6T/Atlas: Pythia 6.4.14 - Perugia-0: Pythia 6.4.21 - Phojet 1.12 with Pythia 6.2.14

Increase from 0.9 to 2.36 TeV

- $dN_{ch}/d\eta$ in $|\eta| < 0.5$

Larger increase of multiplicity at mid-rapidity as in MC generators

in %	**INEL**	**NSD**
ALICE preliminary*	**24.8 ± 0.5 ± 7.6**	**24.0 ± 0.5 ± 4.5**
CMS JHEP 02 (2010) 041		**28.4 ± 1.4 ± 2.6**
Pythia D6T (109)	**19.7**	**18.7**
Pythia ATLAS CSC (306)	**19.2**	**18.3**
Pythia Perugia-0 (320)	**19.6**	**18.5**
Phojet	**17.5**	**14.5**

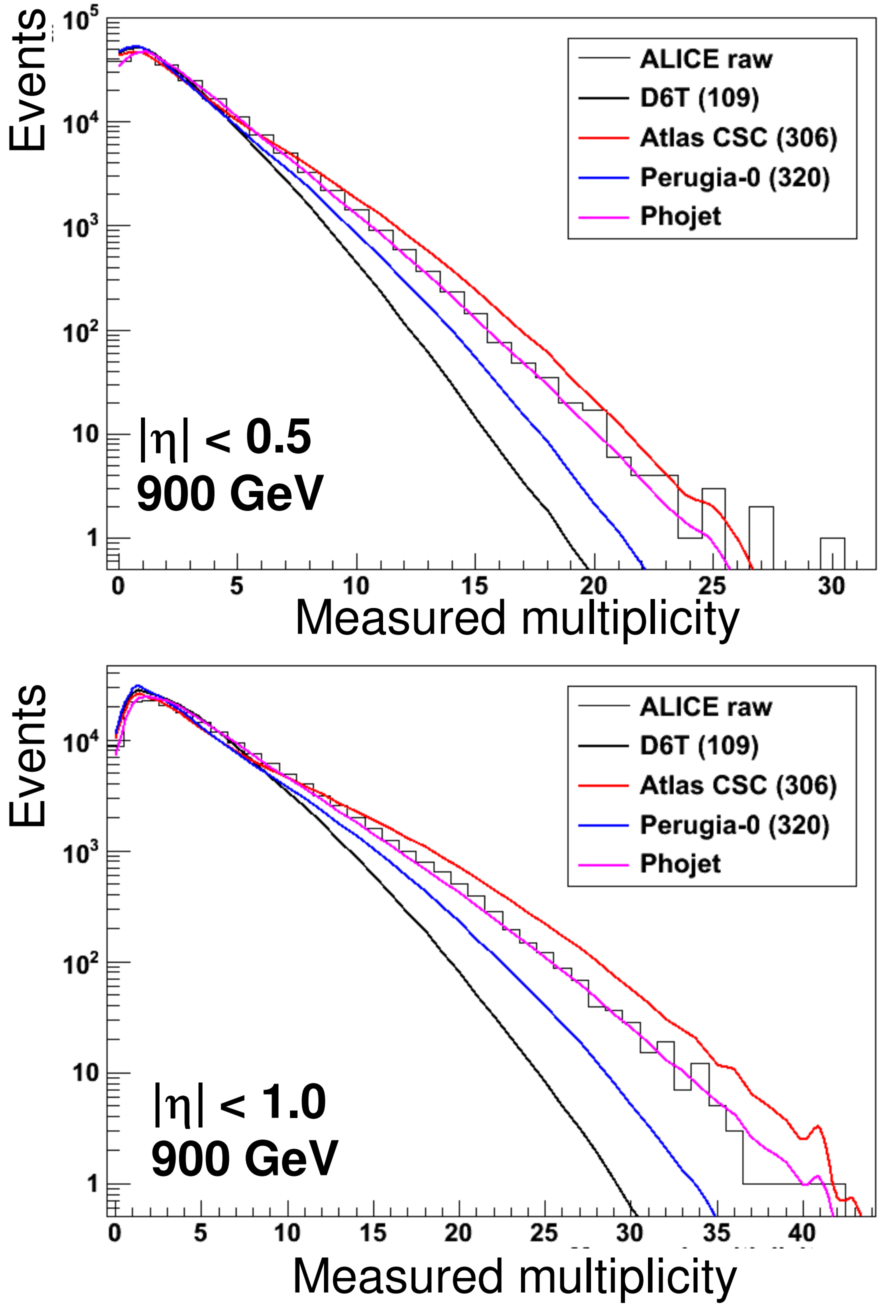
Stat. uncertainty on MC values < 0.1%

* systematic uncertainty overestimated (correlations not taken into account, yet)

Multiplicity Distributions

- 900 GeV
- Work in progress
- RAW spectra
- MCs propagated through detector response

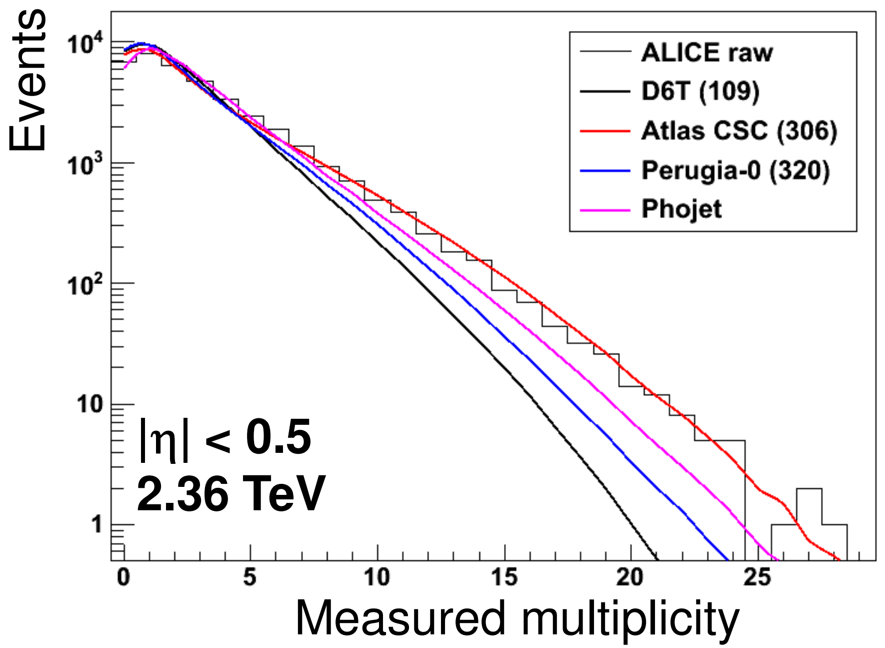
Phojet remarkably close to data

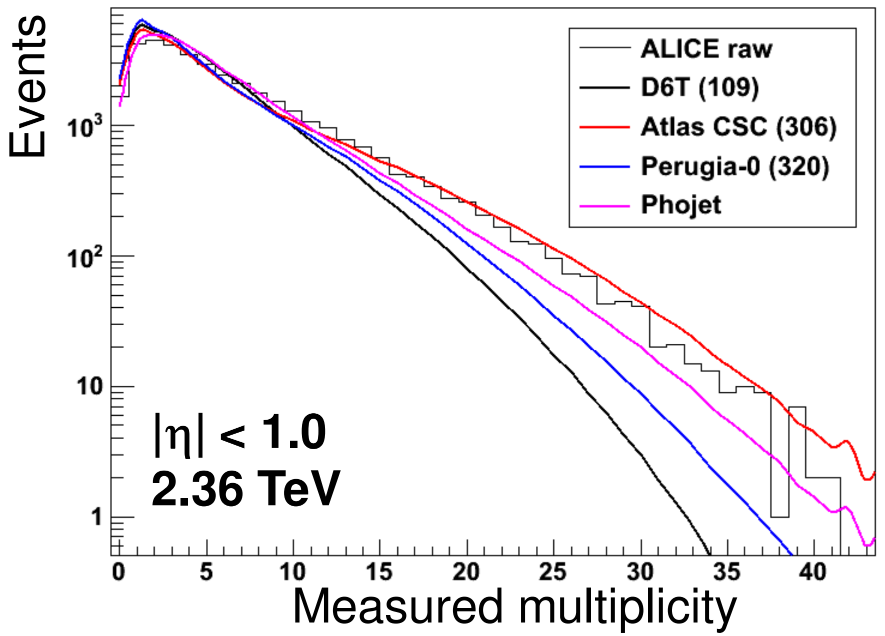


Multiplicity Distributions

- 2.36 TeV
- Work in progress
- RAW spectra
- MCs propagated through detector response

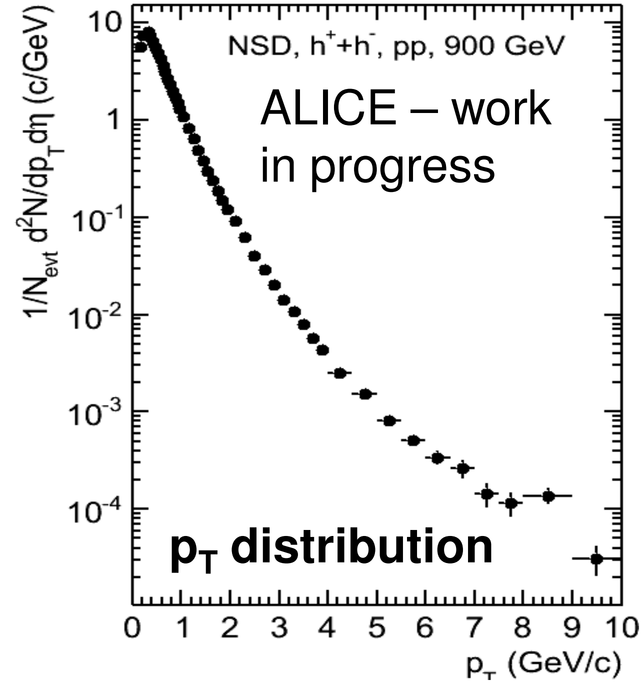
Tail grows faster than expected

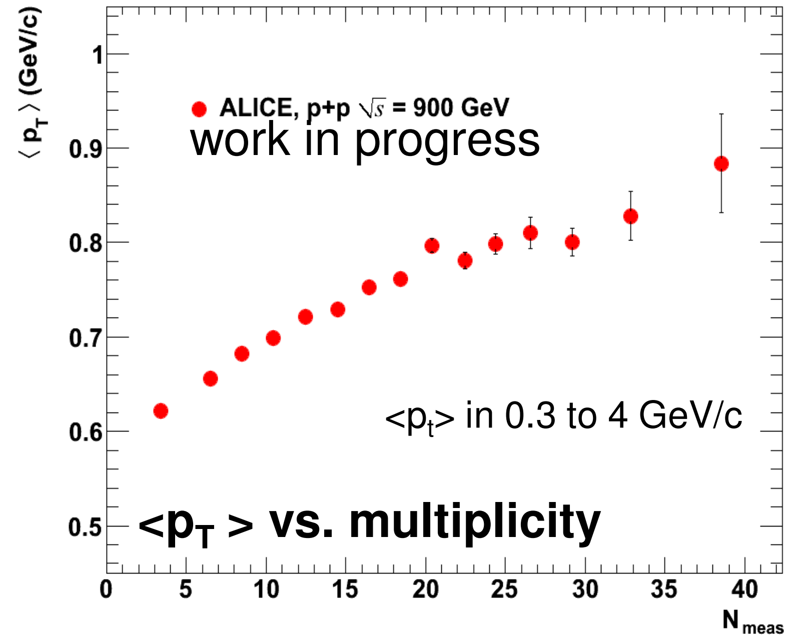




Other Ongoing Analysis Effort

- Charged particle pseudorapidity density + multiplicity distribution (0.9 + 2.36 TeV)
- Charged particle p_T
- Identified particles p_T (π, K, p)
- Strangeness production (K^0, Λ, Ξ, Φ)
- Baryon-antibaryon asymmetry
- Bose-Einstein correlations
- π^0 spectra
- Event structure
- Azimuthal correlations
- η-φ correlations





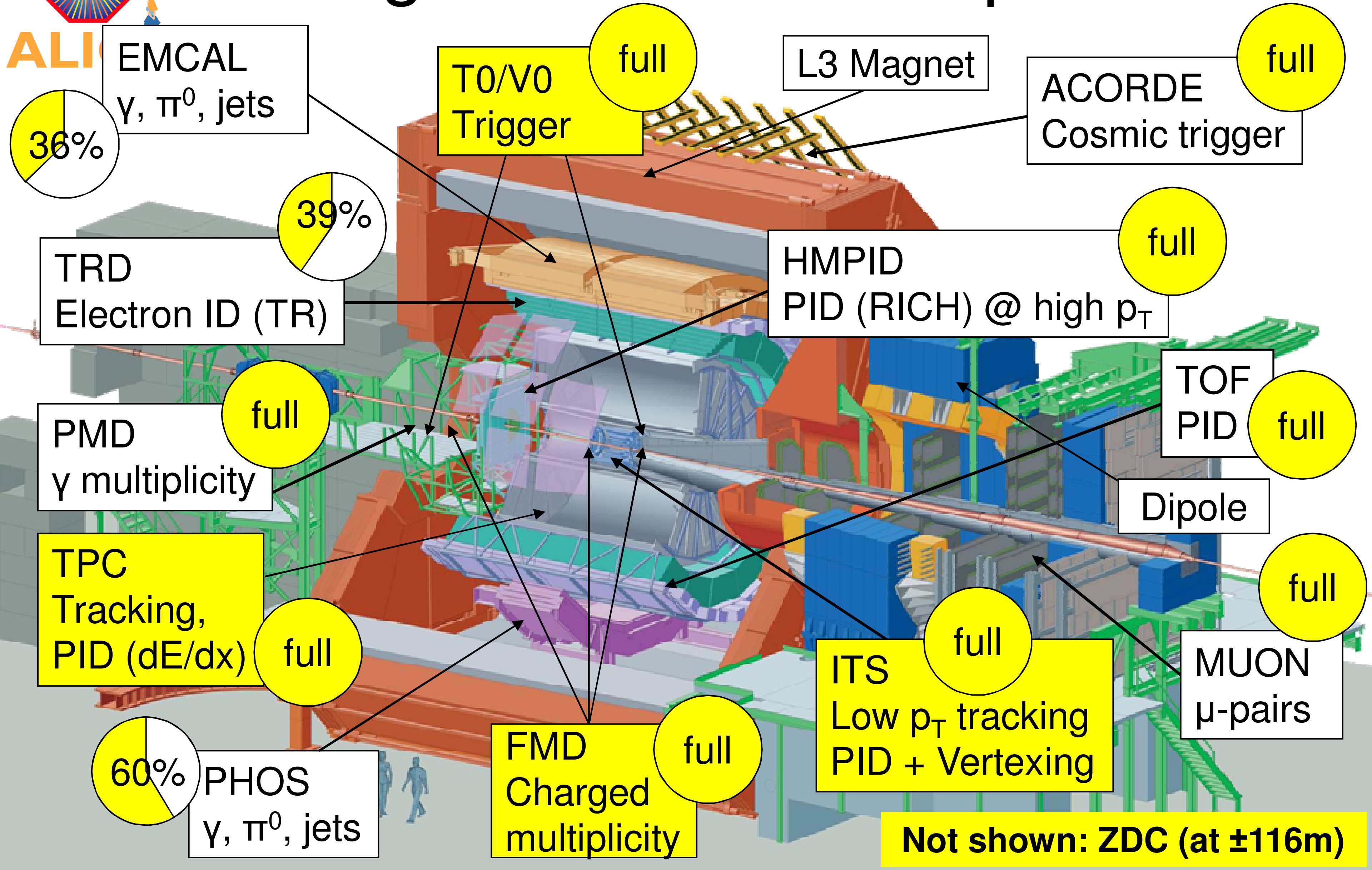
Summary

- Data from LHC at 0.9 and 2.36 TeV leads to a rich set of analyses and MB results
- First MB results presented
  - Treatment of diffraction is time-consuming and partly ambiguous
  - We can challenge the MCs already at 2.36 TeV
  - Other comparison plots for this WG to be produced when analyses are in final stage

Credits for help with preparing this talk: Sparsh Navin, Martin Poghosyan, Andreas Morsch, Michele Floris

Backup

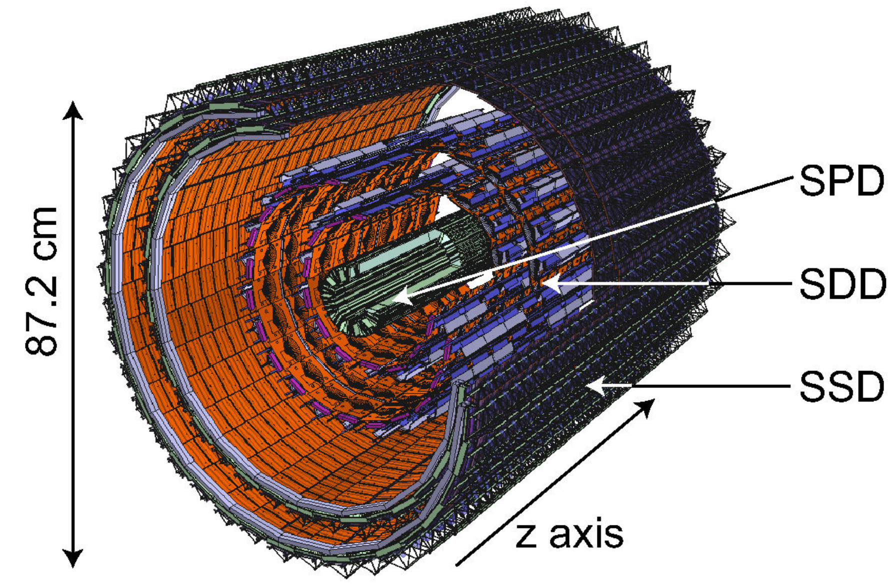
A Large Ion Collider Experiment

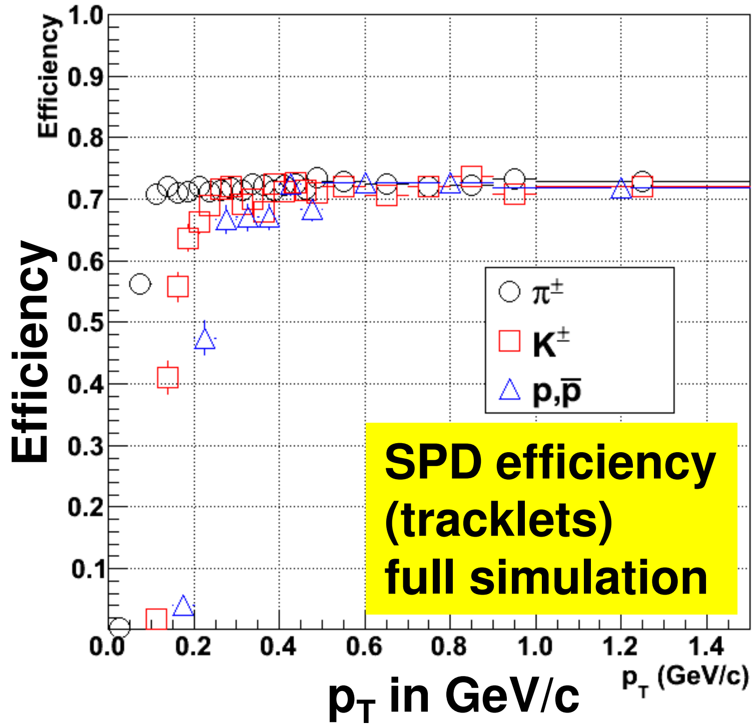


Not shown: ZDC (at ±116m)

Silicon Pixel Detector (SPD)

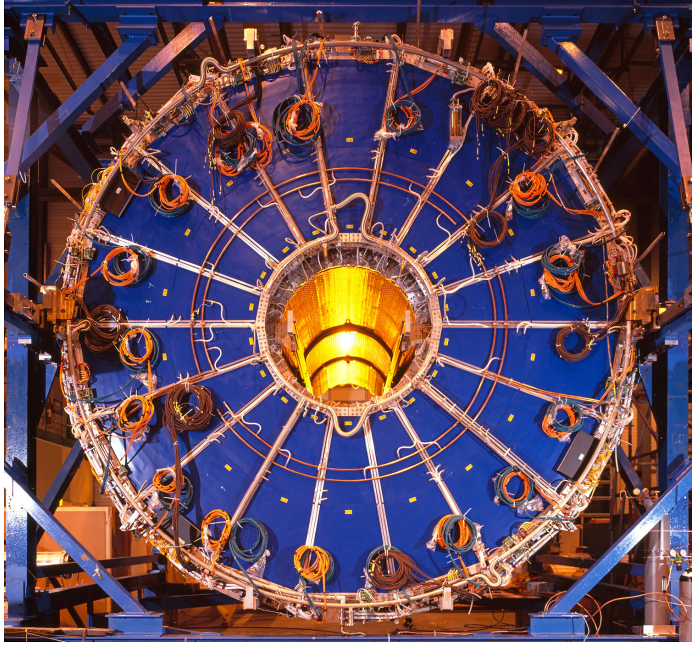
- Two innermost layers of the Inner Tracking System (ITS)
- Radii of 3.9/7.6 cm ($|\eta| < 2.0/1.4$)
- 9.8 M channels
- MB trigger (Fast OR) + High-multiplicity trigger
- Tracklet: 2 points + vertex
- Very efficient down to p_T ~ 30 MeV/c
- Nominal efficiency 99%
  - but ~ 12 % need hardware fixes

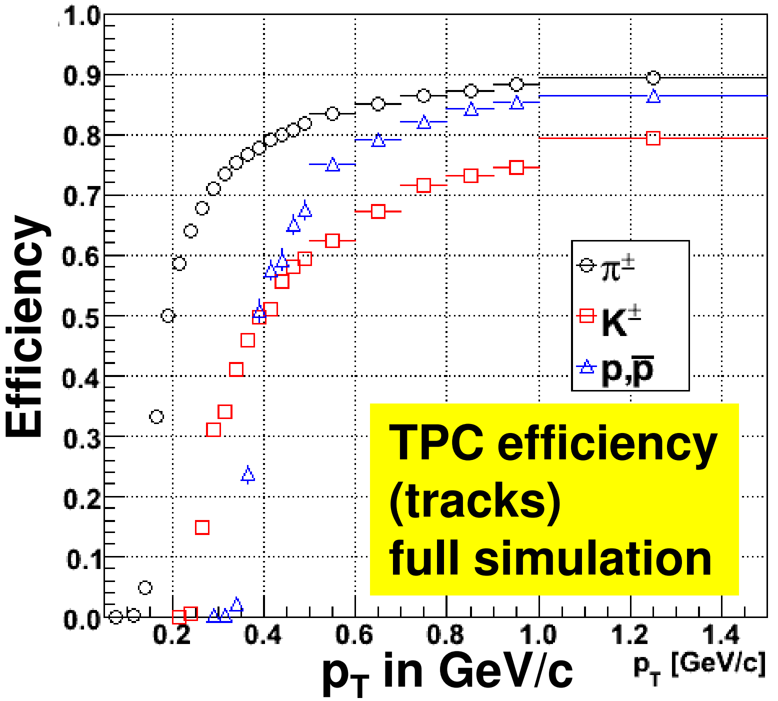




Time Projection Chamber (TPC)

- Largest TPC in the world (90 m³)
- 0.85 m < r < 2.5 m
- $|\eta| < 0.9$ (1.5)
- 560 K channels, up to 160 clusters per track
- Tracking & PID
- Laser system for calibration and alignment

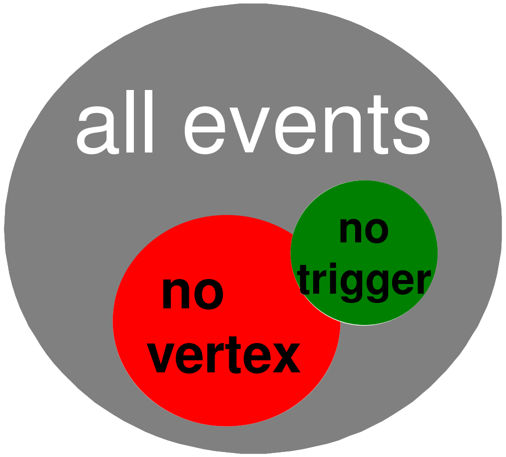




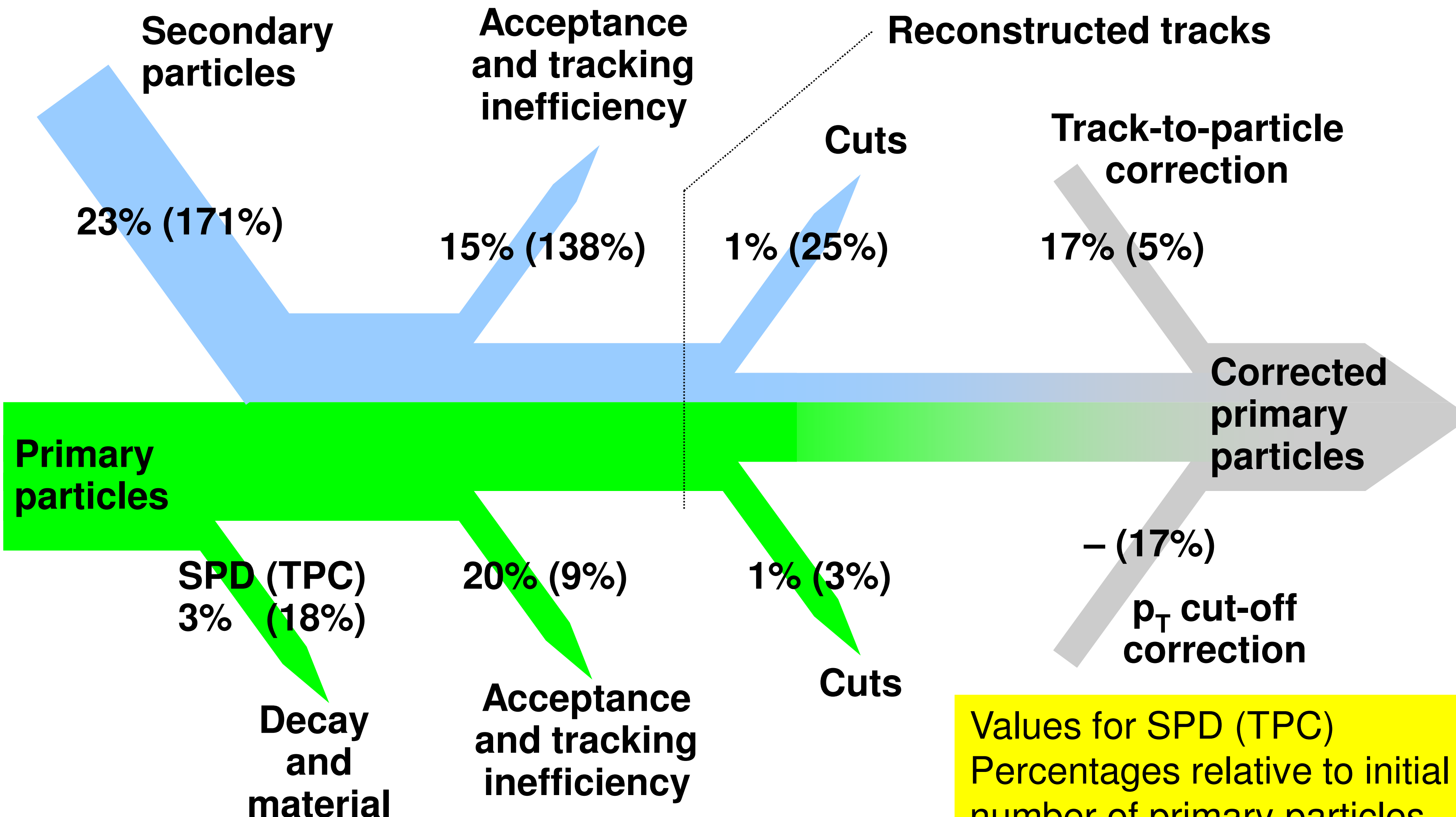
$dN_{ch}/d\eta$ Measurement

- Basically $\frac{dN_{ch}}{d\eta} = \frac{\text{Tracks}}{\text{Events}}$ if the detector was perfect
- But… there is
  - Detector acceptance, tracking efficiency
  - Decay, energy loss, stopping
  - Vertex reconstruction efficiency/bias, trigger efficiency/bias
  - Low momentum cut-off
- Three corrections needed
  - Track-to-particle correction
    - p_T cut-off (only TPC)
  - Vertex reconstruction correction
  - Trigger bias correction

Primary Particles = charged particles produced in the collision and their decay products excluding weak decays from strange particles



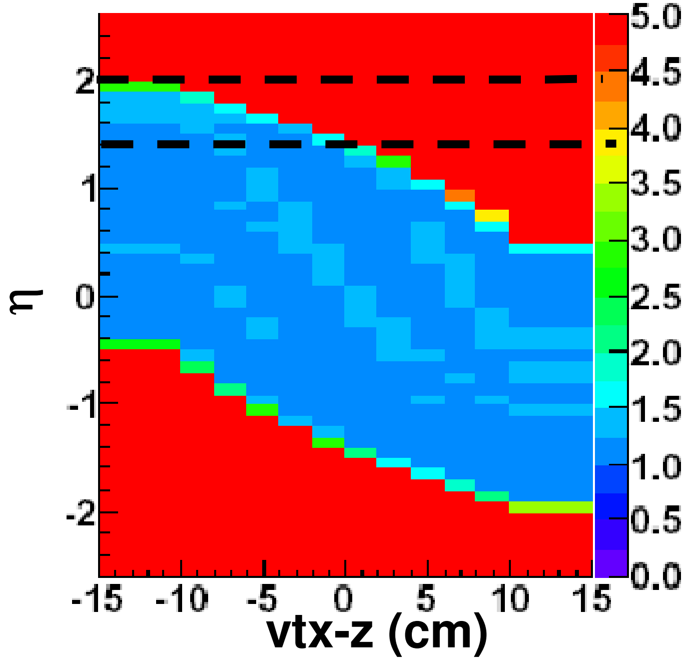
Correction on Track Level

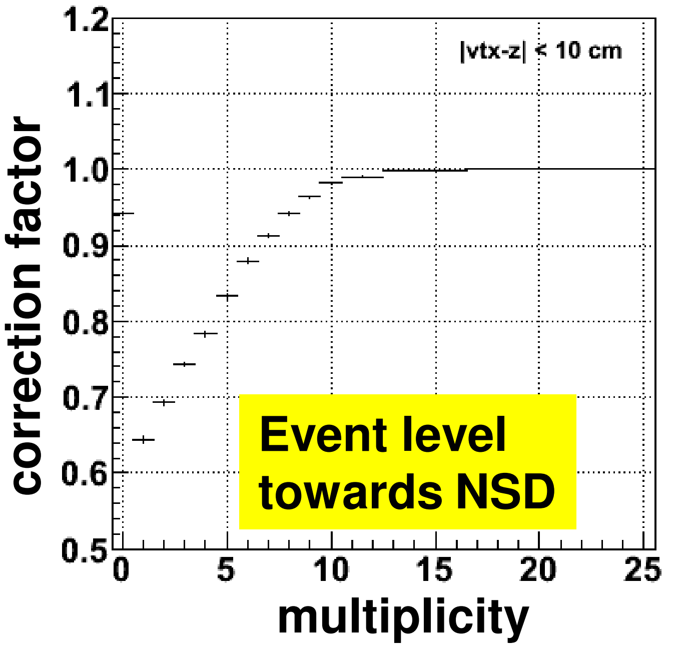


Values for SPD (TPC)
Percentages relative to initial number of primary particles

Corrections

- Track-to-particle correction
  - Acceptance of the SPD clearly visible
  - Average factor ~ 1.3 (central region)
  - Function of η, z-position of event vertex (vtx-z)
- Trigger-bias correction
  - Corrects towards
    - Inelastic events
    - NSD events
  - Event and track level
  - Function of multiplicity, vtx-z

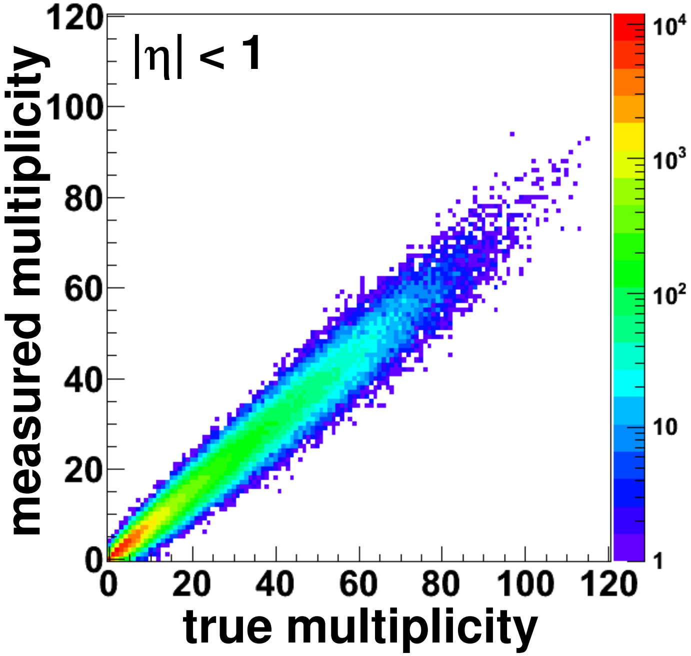




Multiplicity Measurement

$$P(N_{ch}) = \frac{\text{Events with multiplicity } N_{ch}}{\text{All events}}$$

- Efficiency, acceptance
  - Resolution vs. bin size → bin flow
  - Correction by unfolding
- Detector response $M = RT$
  - Probability that a collision with the true multiplicity ***t*** is measured as an event with the multiplicity ***m***
- Vertex reconstruction, trigger bias correction
  - Like for $dN_{ch}/d\eta$, but in unfolded variables (true multiplicity) because it is applied after unfolding

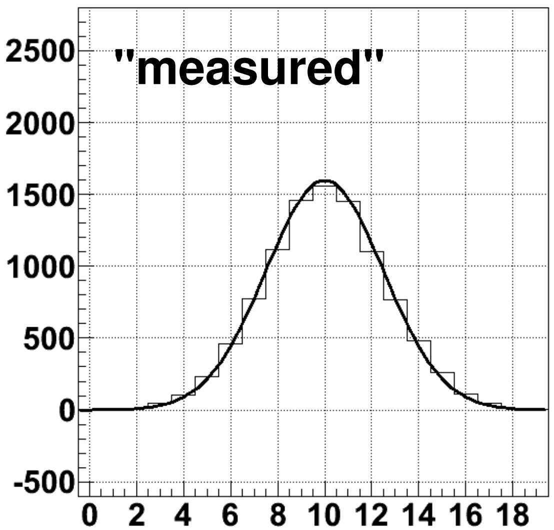


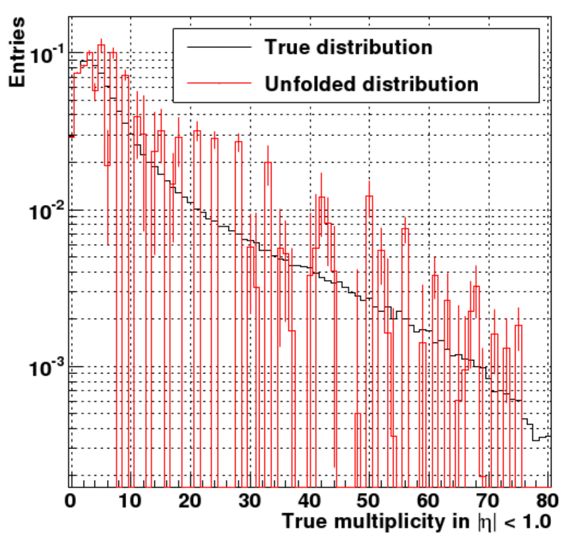
Challenges with Unfolding

- Example with a simple quadratic response matrix R
- True distribution (Gaussian is assumed) converted to measured distribution using R
- 10,000 measurements generated
- R is inverted and used to infer the 'true' distribution
  → large statistical fluctuations

$$\begin{pmatrix} 0.75 & 0.25 & 0 & \cdots \\ 0.25 & 0.50 & 0.25 & \\ 0 & 0.25 & 0.50 & \\ \vdots & & & \ddots \end{pmatrix}$$

$$T = R^{-1} M$$





Unfolding using χ^2-Minimization

$$\chi^2(U) = \sum_m \left(\frac{M_m - \sum_t R_{mt} U_t}{e_m} \right)^2 + \beta R(U)$$

- One free parameters per bin for unfolded spectrum U_t
- Regularization
  - Prefer constant
  - Least curvature
  - Reduced cross-entropy (MRX) (optional: a-priori distribution ε) (Nucl.Instrum.Meth. A340:400-412,1994)

Regularizations

$$R(U) = \sum_t (a_t)^2$$

$$a_t = \frac{U'_t}{\sqrt{U_t}} = \frac{U_t - U_{t\text{-}1}}{\sqrt{U_t}}$$

$$a_t = \frac{U''_t}{\sqrt{U_t}} = \frac{U_{t-1} + 2U_t - U_{t+1}}{\sqrt{U_t}}$$

$$R(\hat{U} = U/\sum_t U_t) = \sum_t \hat{U}_t \ln \frac{\hat{U}_t}{\varepsilon_t}$$

Unfolding using Bayesian Method

Bayesian method (based on Bayes' theorem)

(e.g. Nucl.Instrum.Meth.A362:487-498,1995)

$$\tilde{R}_{tm} = \frac{R_{mt} P_t}{\sum_{t'} R_{mt'} P_{t'}}$$

$$U_t = \sum_m \tilde{R}_{tm} M_m$$

$$\hat{U}_t = (1-\alpha) U_t + \frac{\alpha}{3}(U_{t-1} + U_t + U_{t+1}) \quad \text{(optional)}$$

R_{mt}	**Response matrix**
$\tilde{R}_{tm}$	**Smearing matrix**
P_t	**Prior distribution (guess)**
M_m	**Measured distribution**
U_t	**Unfolded distribution**
α	**Weight parameter**

Limited number of iterations provides implicit regularization (V. Blobel, hep-ex/0208022)

Iterative method:

1. **Choose prior distribution P_t**
2. **Calculate $\tilde{R}_{tm}, U_t, \hat{U}_t$**
3. **Replace P_t by $\hat{U}_t$; go to 2.**