Proton-proton cross-sections and multiplicities with ALICE at LHC

Jean-Pierre Revol
CERN

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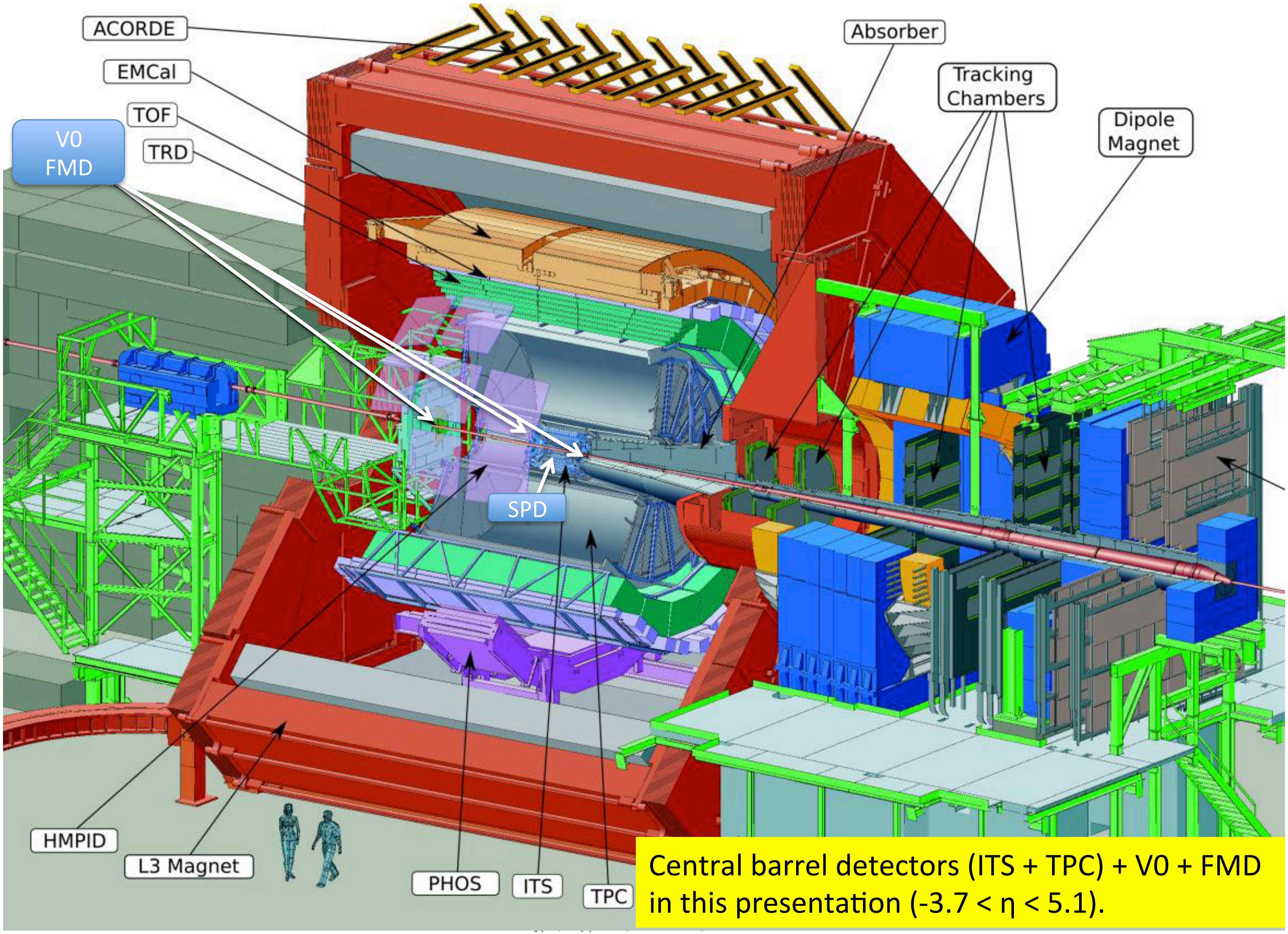
Introduction

- **In order to measure precisely collision properties** (cross sections, multiplicity distributions, particle contents, topologies, etc.) **and confront them with theories**, it is necessary to know as precisely as possible the detector response to particles emitted in the collisions.
- In turn, to determine more precisely the detector response, a better knowledge of collision properties is needed. It is **an iterative process**.
- pp collisions at LHC are probably among the best scrutinized collisions ever (7 detectors, many more physicists …)
- **Measuring properties of pp collisions is an important part of the ALICE scientific program.** Diffraction is a significant part of this programme.

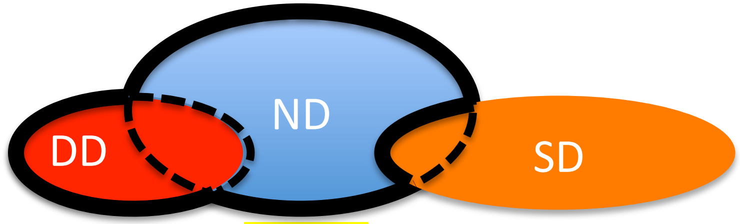


Central barrel detectors (ITS + TPC) + V0 + FMD
in this presentation (-3.7 < η < 5.1).

A practical experimental issue

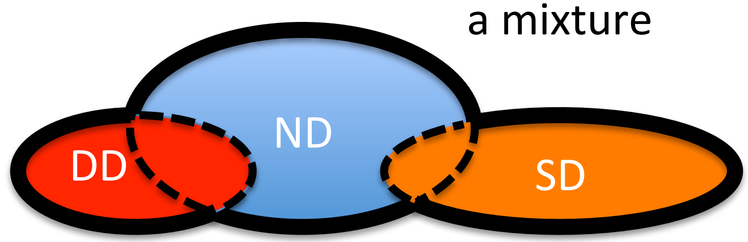
- Non-Single Diffractive (**NSD**) and Inelastic (**INEL**) event classes are traditionally used to compare data between experiments. Diffraction corrections are the largest contribution to the systematic uncertainty.

Uncertainty	$dN_{ch}/d\eta$ analysis		$P(N_{ch})$ analysis	
	0.9 TeV	2.36 TeV	0.9 TeV	2.36 TeV
Tracklet selection cuts	negl.	negl.	negl.	negl.
Material budget	negl.	negl.	negl.	negl.
Misalignment	negl.	negl.	negl.	negl.
Particle composition	0.5–1.0 %	0.5–1.0 %	included in detector efficiency	
Transverse-momentum spectrum	0.5 %	0.5 %	included in detector efficiency	
Contribution of diffraction (INEL)	0.7 %	2.6 %	3–0 % (0–5)	5–0 % (0–5)
Contribution of diffraction (NSD)	2.8 %	2.1 %	24–0 % (0–10)	12–0 % (0–10)
Event-generator dependence (INEL)	+1.7 %	+5.9 %	8–0 % (0–5)	25–0 % (0–10)
Event-generator dependence (NSD)	−0.5 %	+2.6 %	3–5–1 % (0–10–40)	32–8–2 % (0–10–40)
Detector efficiency	1.5 %	1.5 %	2–4–15 % (0–20–40)	3–0–9 % (0–8–40)
SPD triggering efficiency	negl.	negl.	negl.	negl.
VZERO triggering efficiency (INEL)	negl.	n/a	negl.	n/a
VZERO triggering efficiency (NSD)	0.5 %	n/a	1 %	n/a
Background events	negl.	negl.	negl.	negl.
Total (INEL)	$^{+2.5}_{-1.8}$ %	$^{+6.7}_{-3.1}$ %	9–4–15 % (0–20–40)	25–0–9 % (0–10–40)
Total (NSD)	$^{+3.3}_{-3.3}$ %	$^{+3.7}_{-2.7}$ %	24–5–15 % (0–10–40)	32–8–9 % (0–10–40)

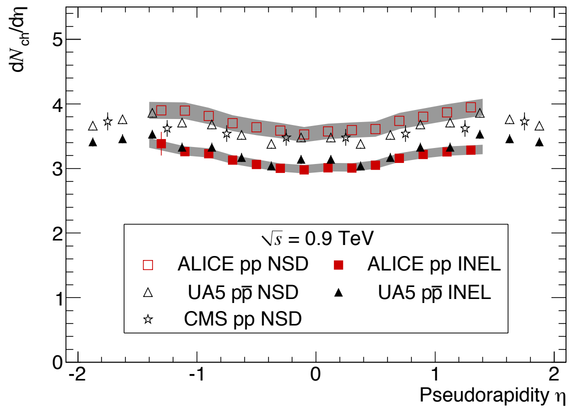


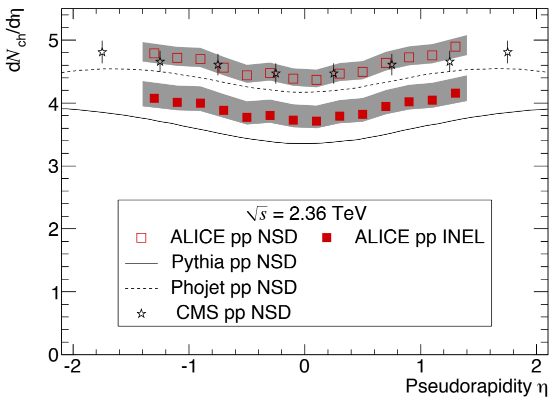
NSD

Triggers select a mixture



INEL (bigger correction)





How can one do better?

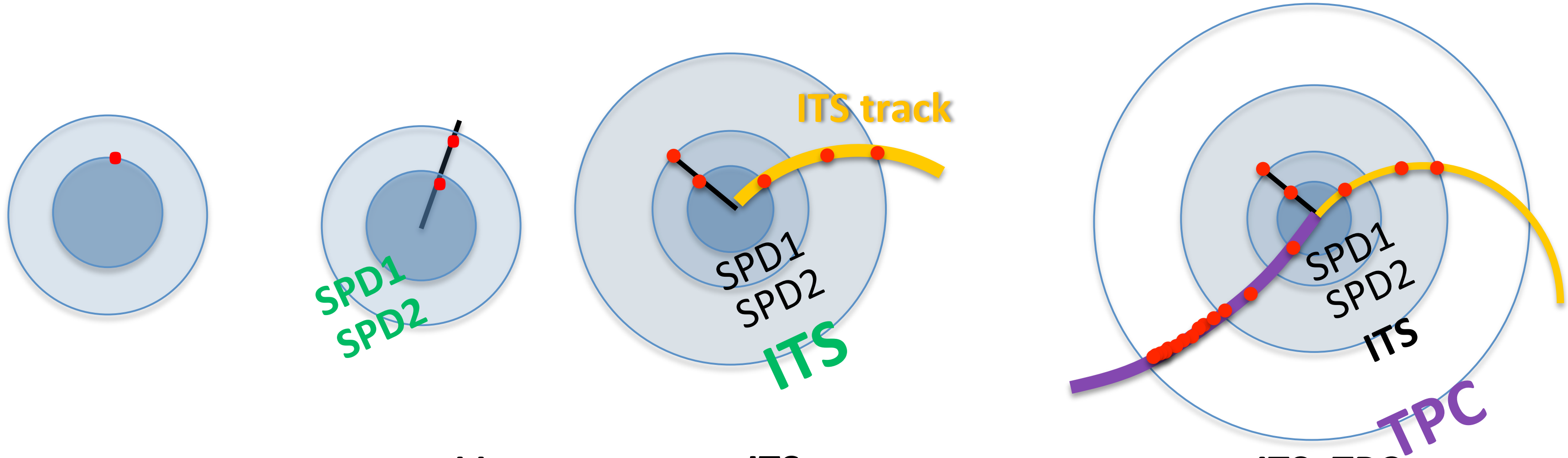
– measure SD and DD processes

– improve knowledge of detector response

– improve the precision of algorithms

Improving multiplicity algorithms

- 4 different ways of measuring multiplicity in the ALICE **“central” pseudorapidity region** ($|\eta| < 1.8$)

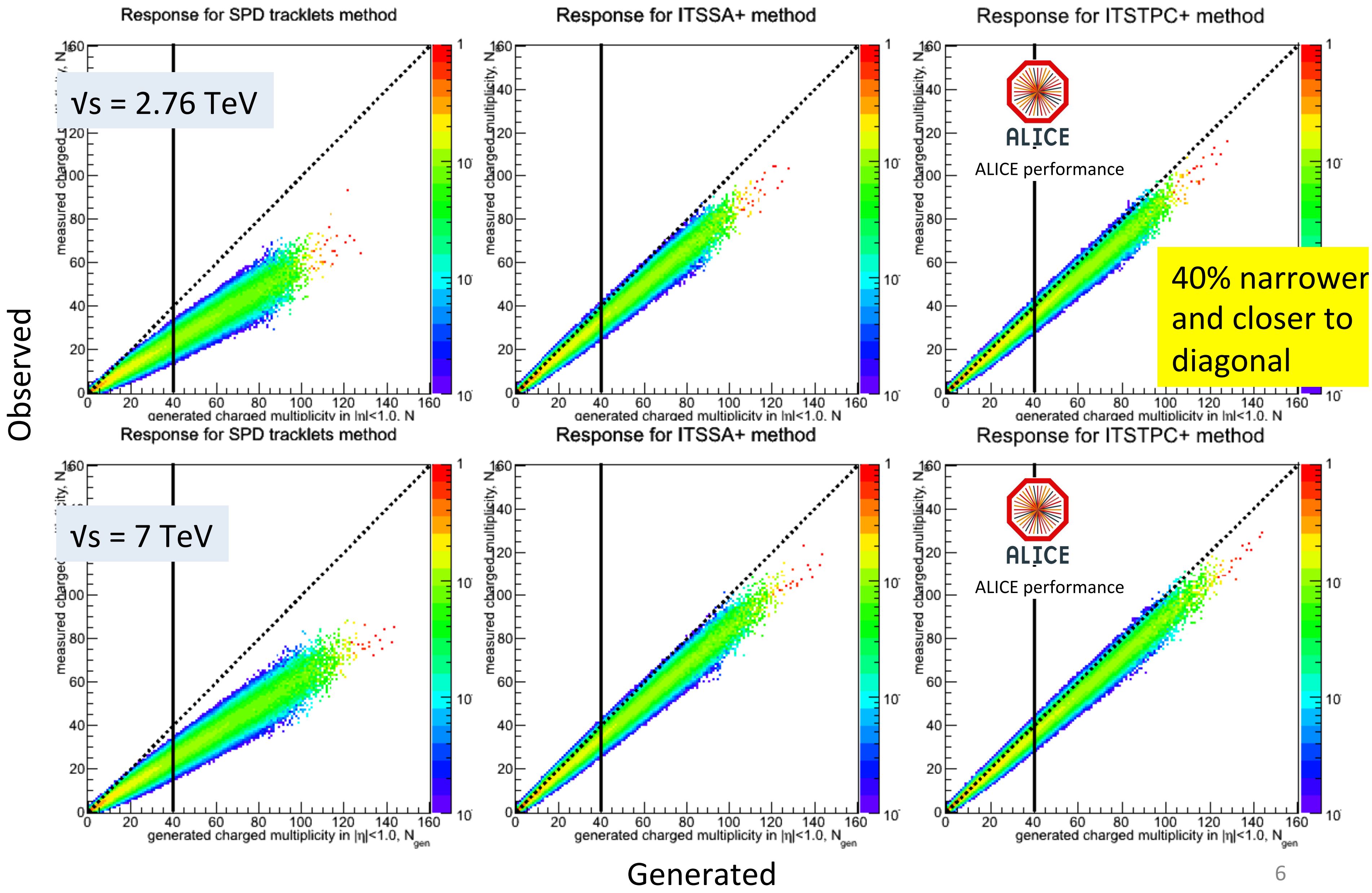


SPD layer	SPD tracklets	ITS + complements	ITS+TPC + complements
Technical tests	Historical		

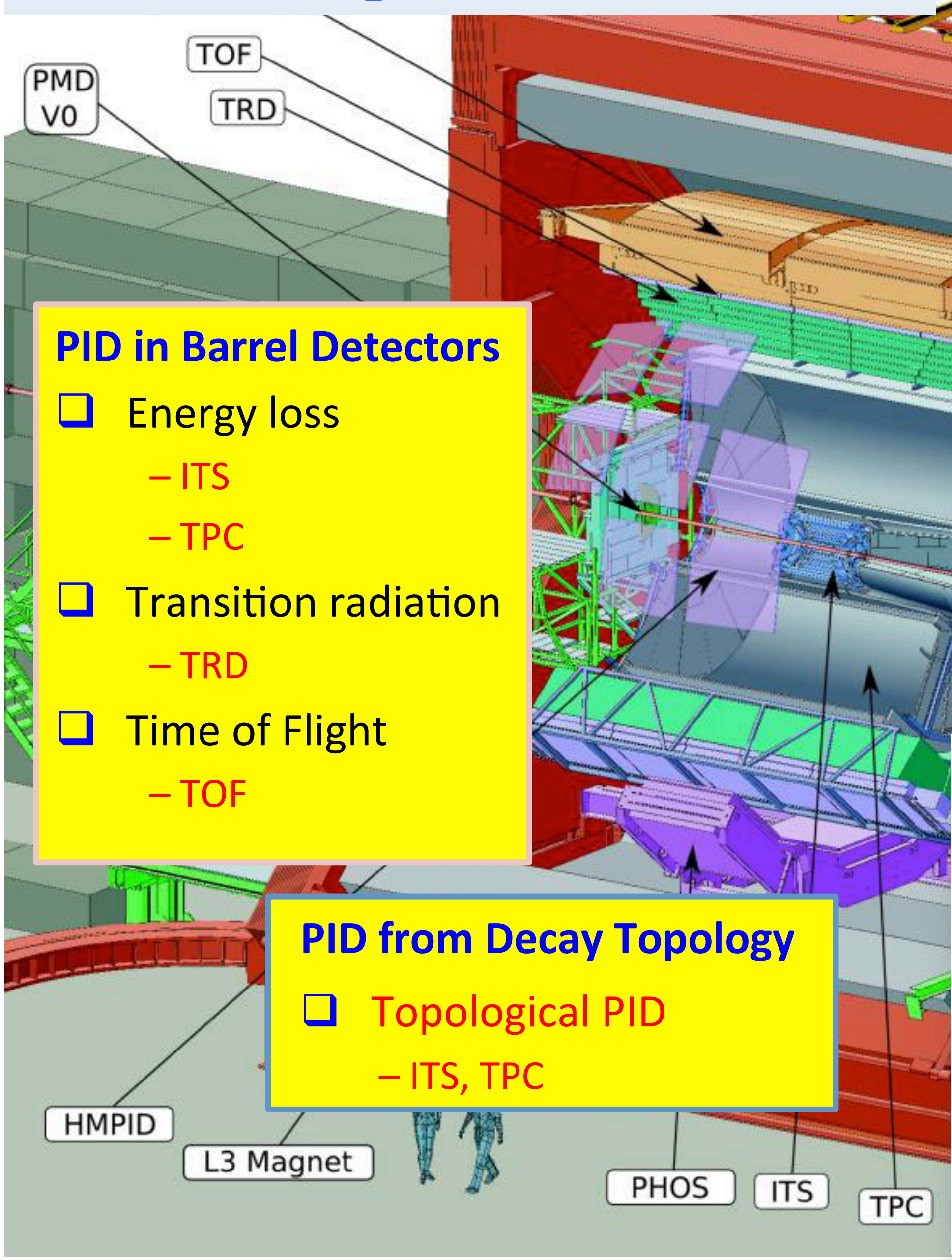
Used in ALICE multiplicity analysis (SPD tracklets → ITS+TPC + complements)

Use the complementarity of ALICE detectors in the central barrel

Response matrix improvement



Making use of PID



PID in Barrel Detectors

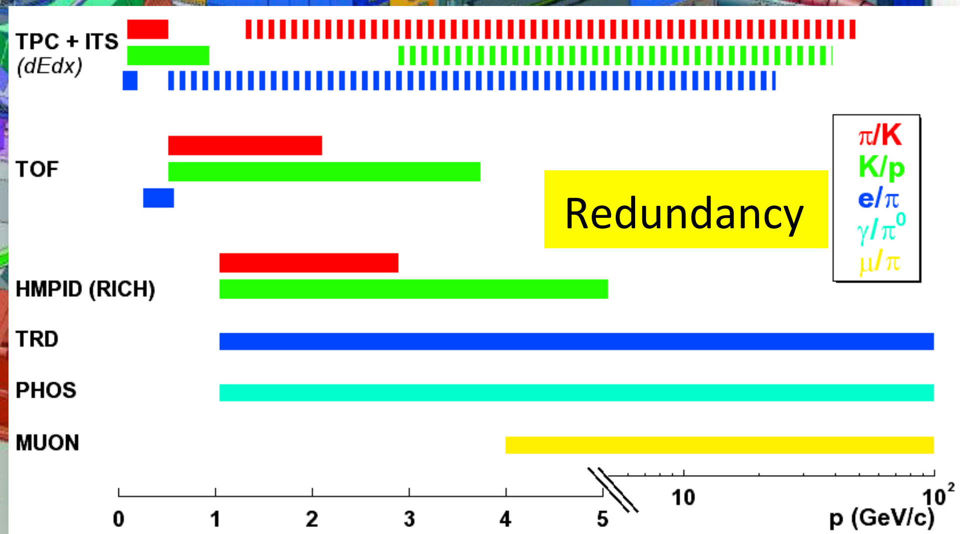
- Energy loss
  - ITS
  - TPC
- Transition radiation
  - TRD
- Time of Flight
  - TOF

PID from Decay Topology

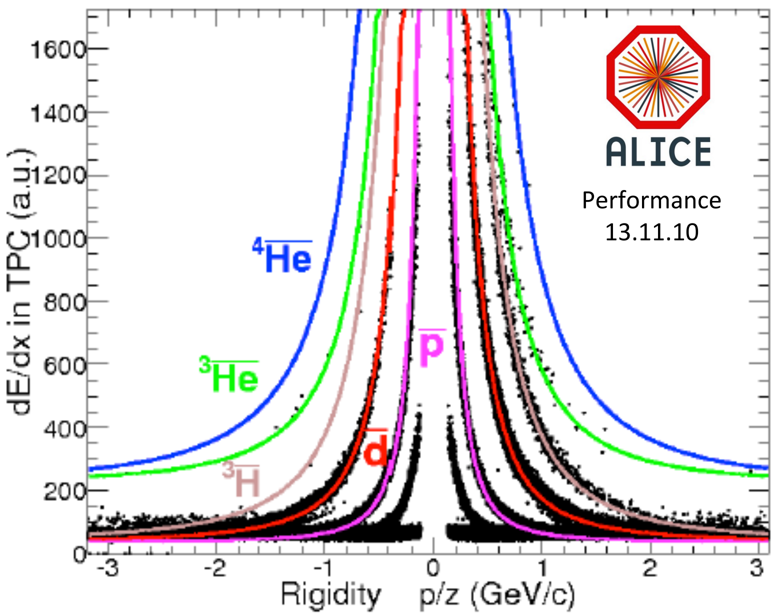
- Topological PID
  - ITS, TPC

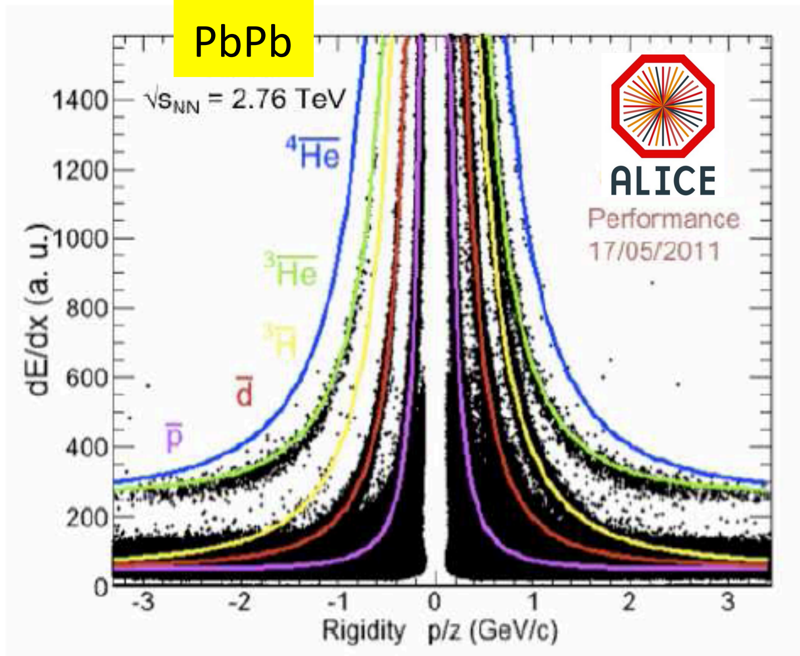
PID in Single-arm Detectors

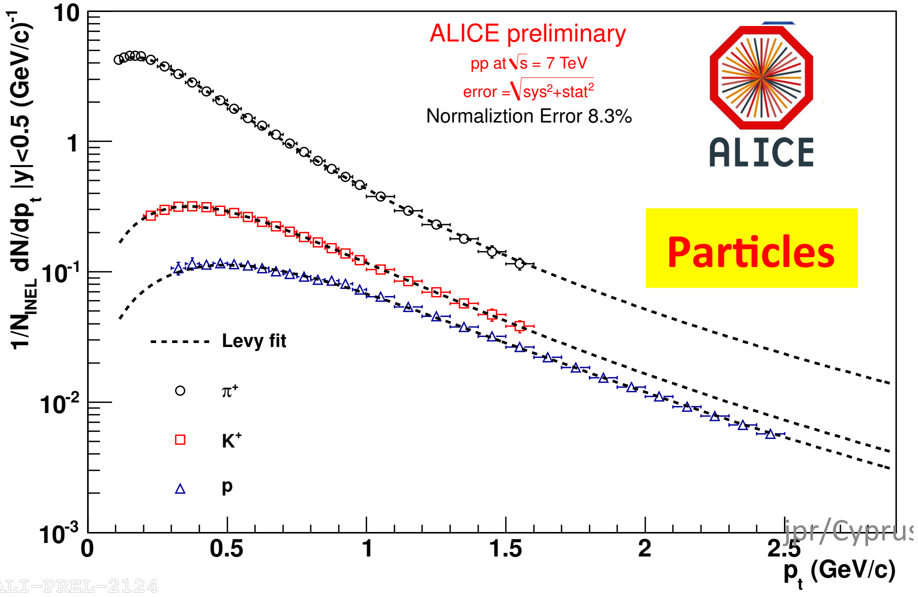
- Calorimetry
  - PHOS
  - EMCAL
- Muon Spectrometry
  - MUON
- Cherenkov Radiation
  - HMPID
- Preshower
  - PMD

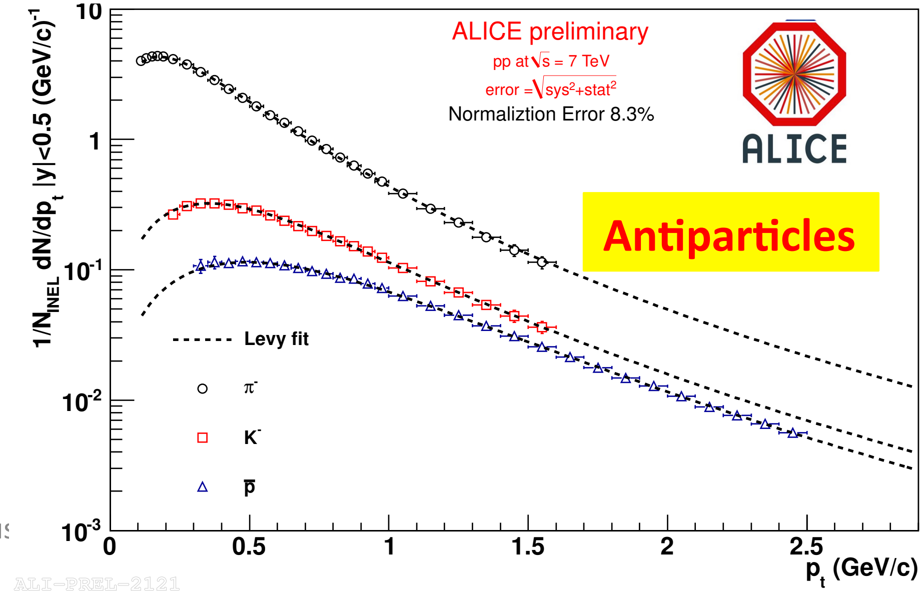


Identified particle spectra







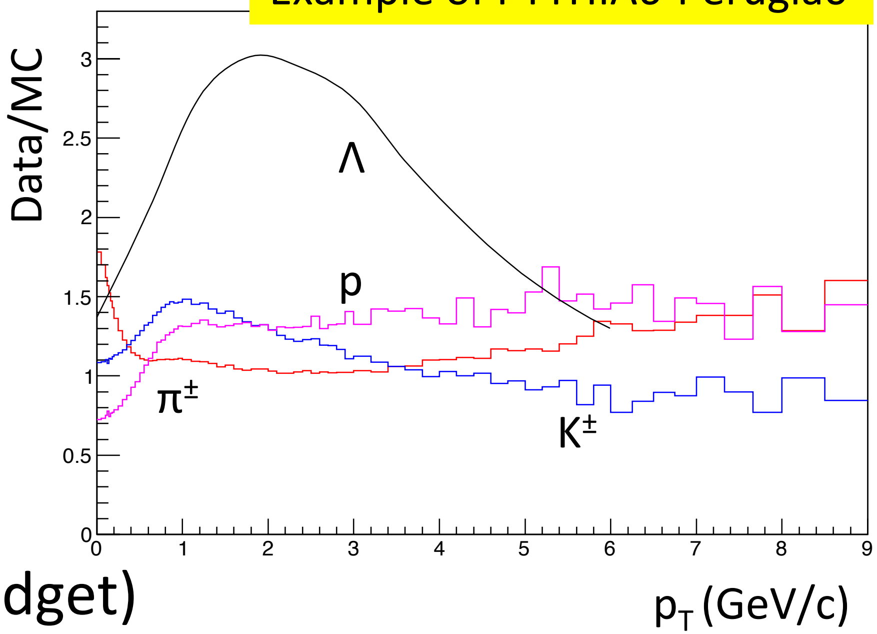


Tuning MC

- **Many more aspects of collisions are measured**, many other particle productions (see for instance Angela Badala's talk for low-mass vector mesons), event topologies, etc., **which are not reproduced by current models**.

  Simulation = detector simulation
  + alignment + transport (material budget)
  + calibration

Example of PYTHIA6-Perugia0

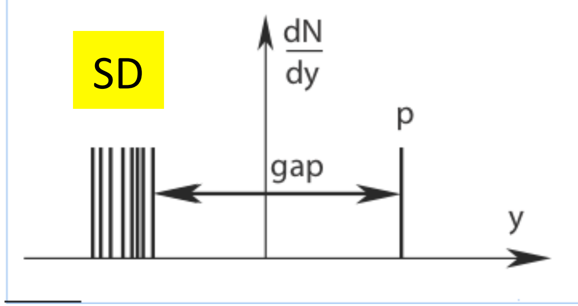


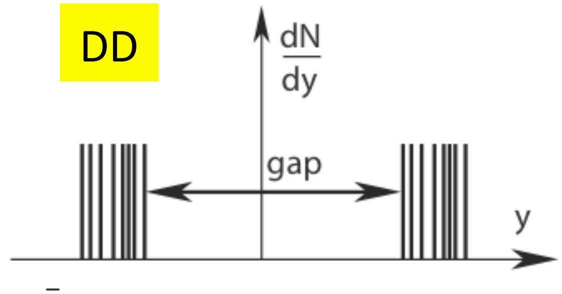
- However, to obtain an accurate detector response to pp collisions requires also adjusting MC simulations to all measured properties, including the different processes involved in non-elastic pp collisions:
  - Non-diffractive collisions
  - **Single-Diffractive** collisions
  - **Double-Diffractive** collisions

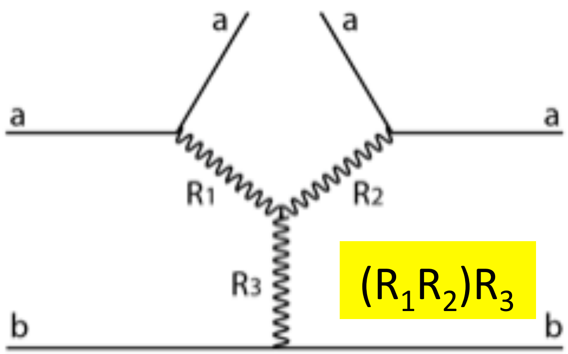
Simulation of Single Diffraction

- Experimental definition of diffraction: **a process with large rapidity gaps**, either Reggeon or Pomeron exchange (separation between them is model dependent, we leave it to theorists) **– SD: $M_X \leq 200$ GeV; DD: $\Delta\eta > 3$**
- Main source of systematics in diffraction studies is from the uncertainty on the diffracted mass (M_X) distribution (detector acceptance) and on the relative rate of the process, not known at a new energy
- In Regge pole approximation, the SD cross-section ($d\sigma/dM_X$) is dominated by triple-Reggeon diagram (R can be a Pomeron or secondary Reggeon)
  - (PP)P term proportional to $1/(M_X)^{1+2\Delta}$
  - (PP)R term proportional to $1/(M_X)^{2+4\Delta}$
  - PYTHIA6 and PHOJET: ~ $1/M_X$, (PP)P term with $\Delta=0$)
  - **UA4 and CDF → M_X dist. steeper than $1/M_X$**
  - Current models also have M_X dist. steeper than $1/M_X$
  - PYTHIA8 (BG): $M_X \sim 1/M_X$ or $1/(M_X)^{1+2\Delta}$
  - Today there are much more advanced models, we chose **Kaidalov/Poghosyan**[1] as a guide, we could have chosen the KMR or GLM models).

$\Delta = \alpha_P - 1 \sim 0.085$





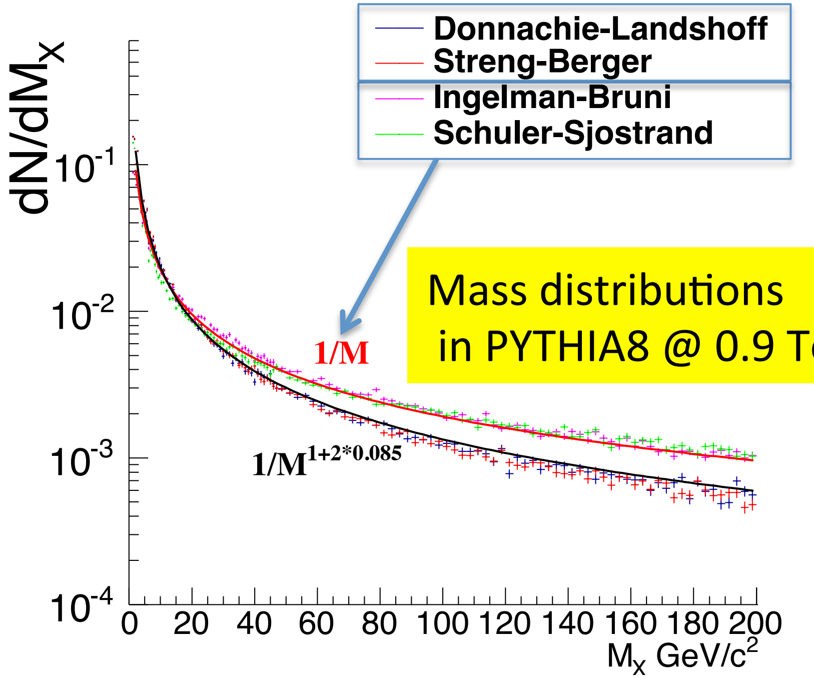


[1] **A.B. Kaidalov and M.G. Poghosyan, ArXiv:0909.5156 [hep-ph], Eur. Phys. J. C67 (2010) 397**

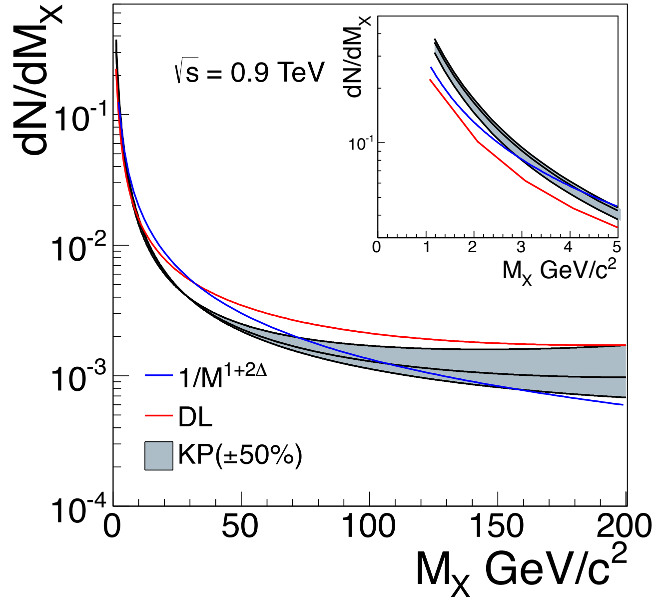
arXiv:1109.3697v1 [hep-ph] for cross-section predictions (σ_{tot} = 96.4 mb@ 7TeV)

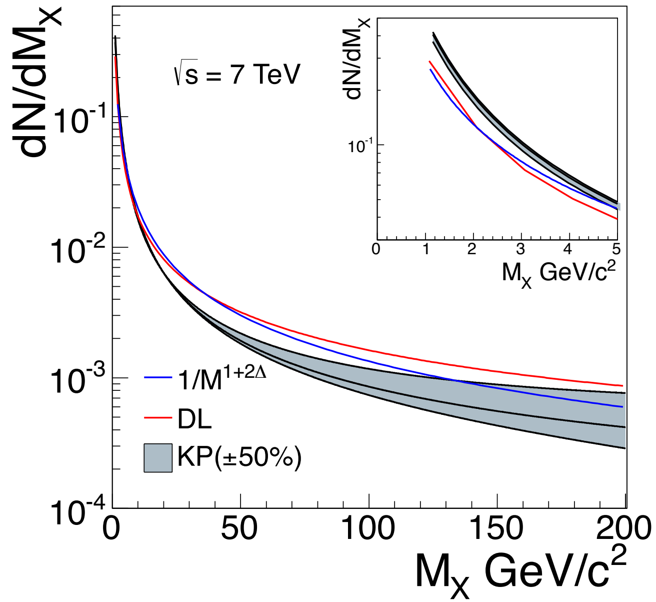
Modeling SD mass distributions

How do we account for diffracted masses (M_X) outside the detector acceptance?



Mass distributions
in PYTHIA8 @ 0.9 TeV



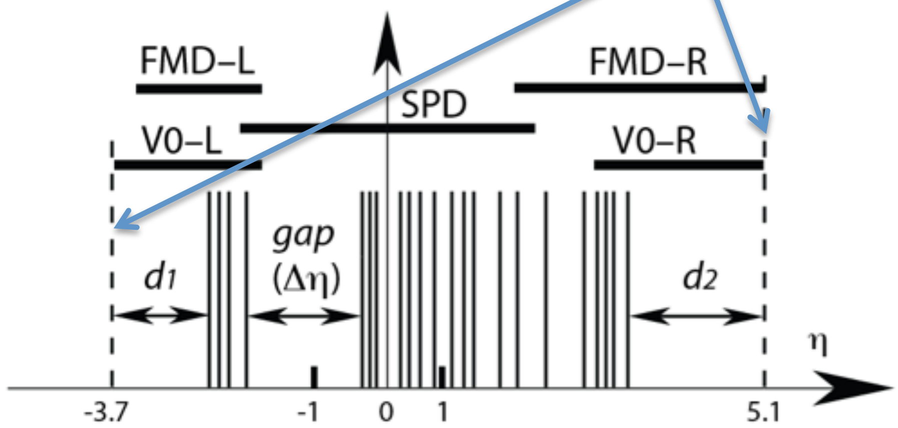


The systematic uncertainty estimated by ALICE was obtained from the Kaidalov-Poghosyan (KP) model with a ± 50% variation (grey area) and the Donnachie-Landshoff model, resulting into an asymmetric systematic error

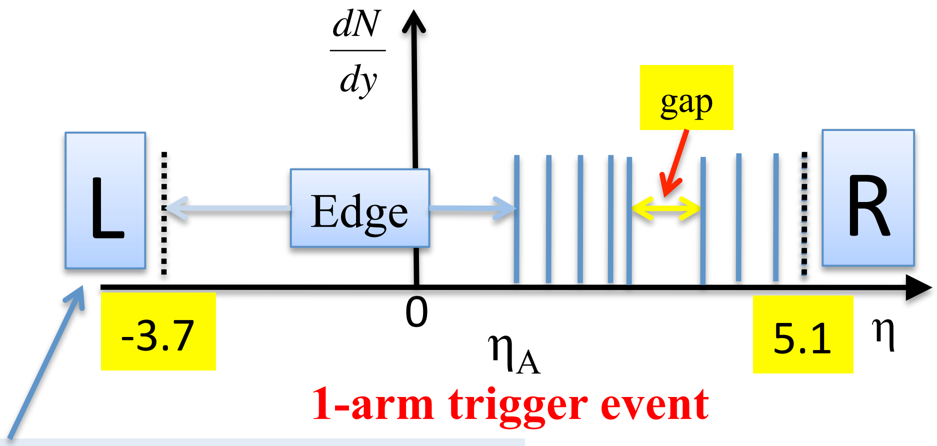
Measuring SD & DD in ALICE

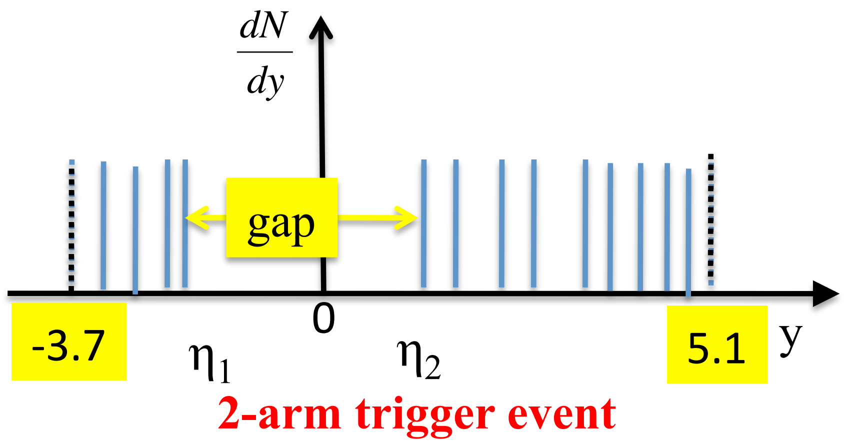
Edges of detector acceptance

- Within the SPD acceptance (|η| < 2) + V0 (-3.7 < η < -1.7 and 2.8 < η < 5.1) + FMD (-3.4 < η < -1.7 and 1.7 < η < 5.1) (**8.8 units of pseudorapidity**) **study pseudorapidity distributions of "gaps"** on an event per event basis
- **ALICE gaps ≠ ATLAS & CMS gaps**



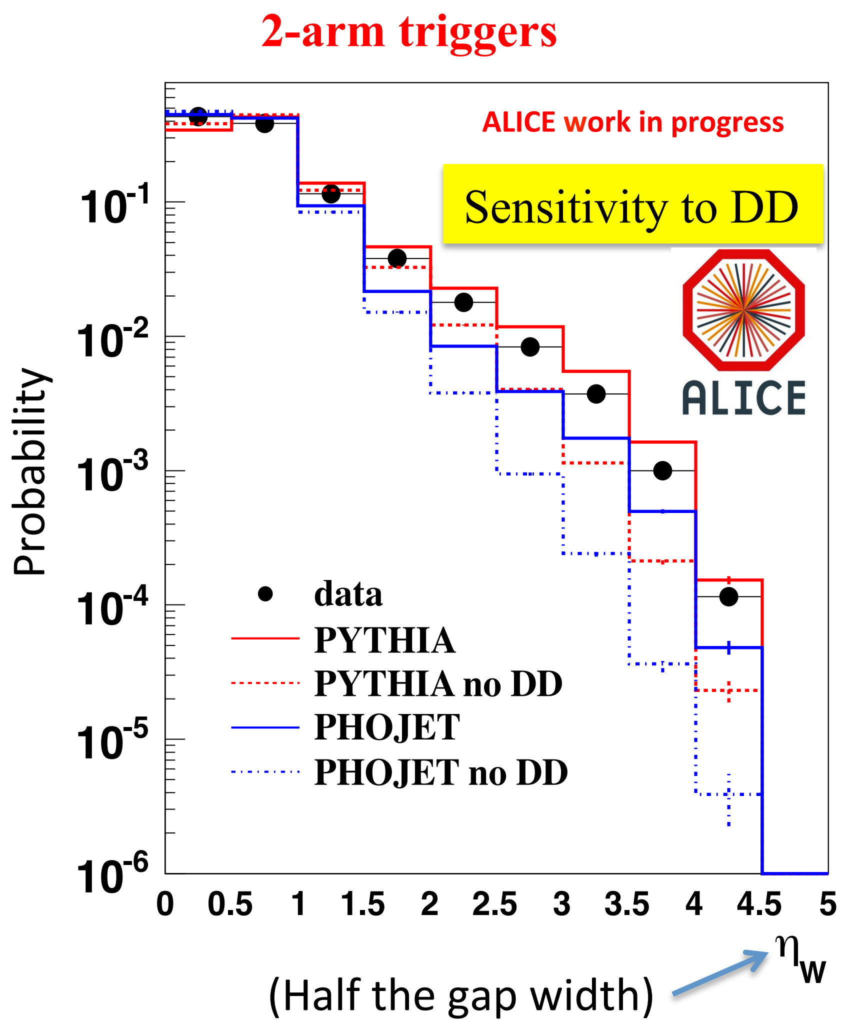
Classification of events into 1-arm or 2-arm offline "triggers"

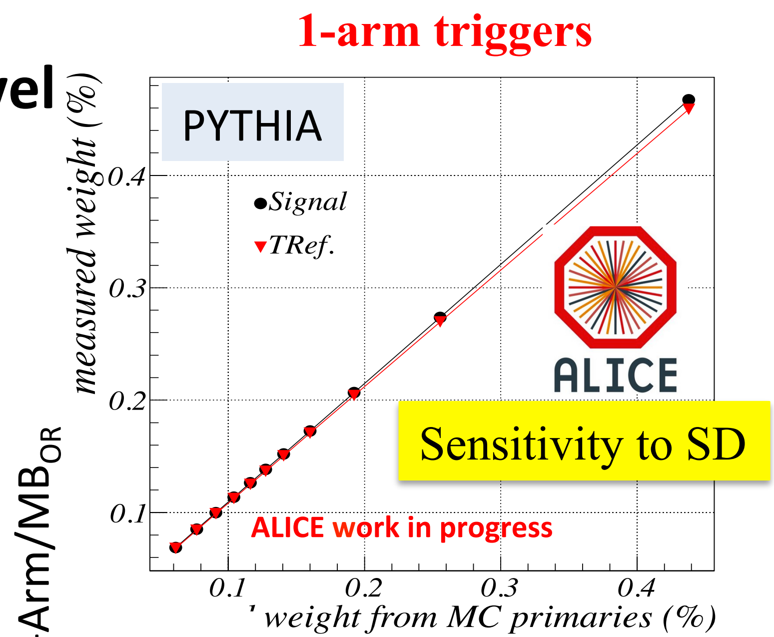


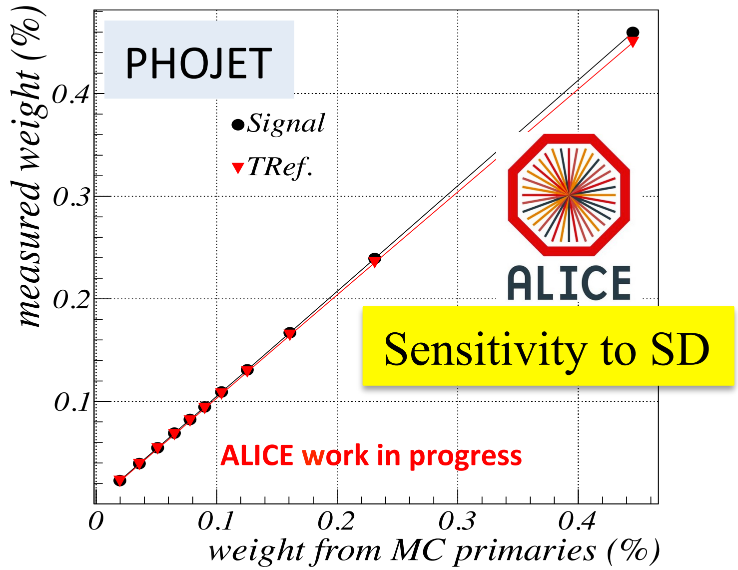


ALICE sensitivity to SD and DD

Varying SD and DD rates at generator level





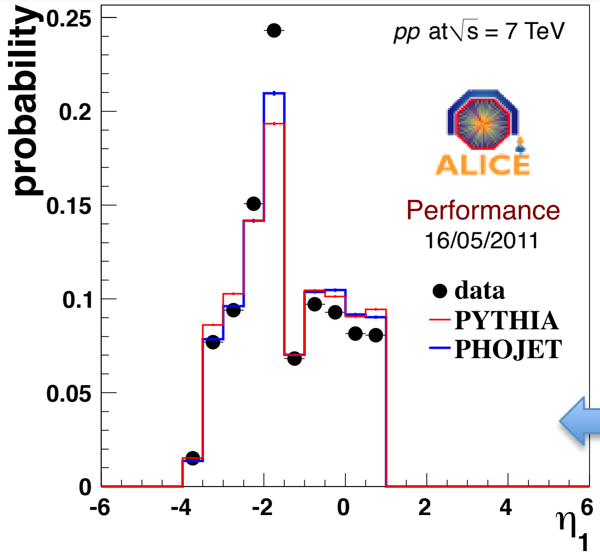


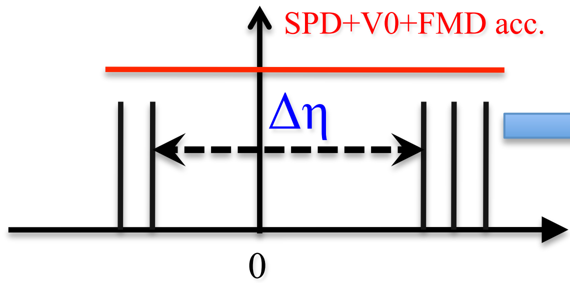
Gap width distribution and relative rates of One-Arm triggers are sensitive to SD and DD

Uncorrected data vs Simulation (7 TeV)

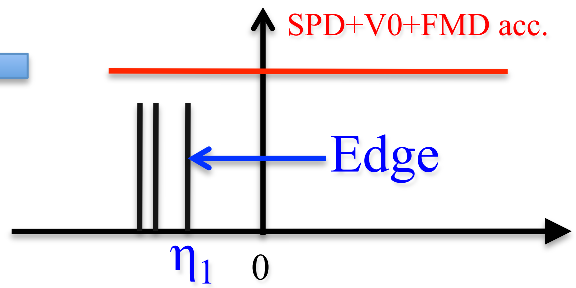
SPD+V0+FMD

edge of left-side 1-arm trigger event

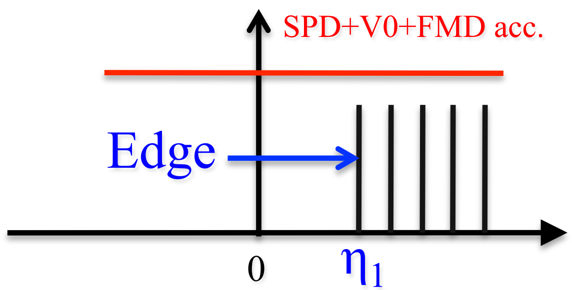




2-arm trigger event

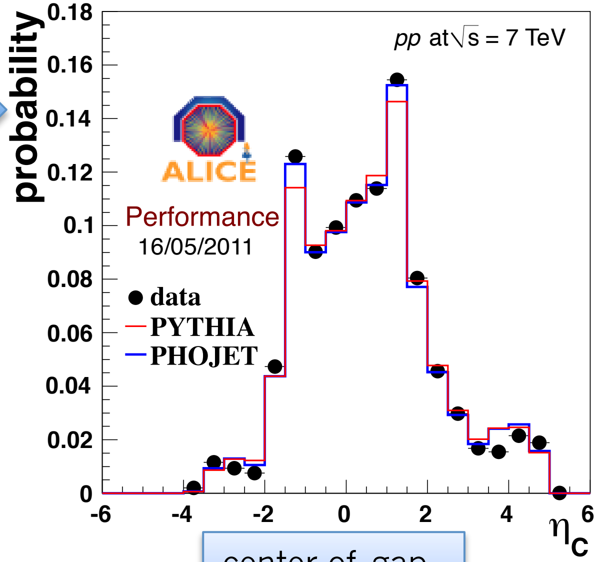


L-side 1-arm trigger event



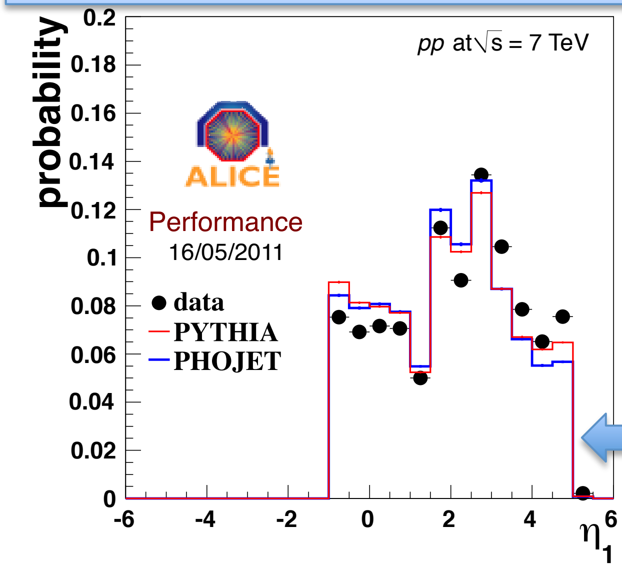
R-side 1-arm trigger event

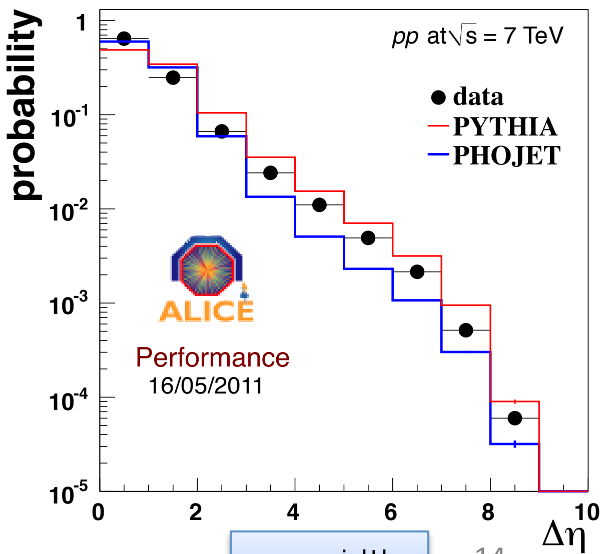
2-arm triggers



center of gap

edge of right-side 1-arm trigger event



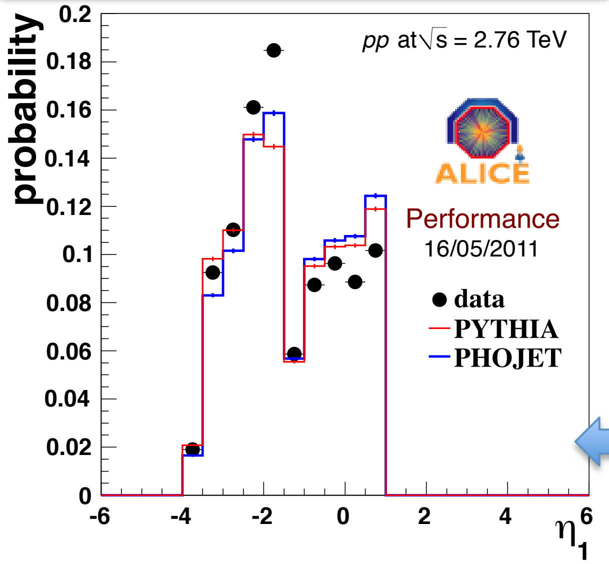


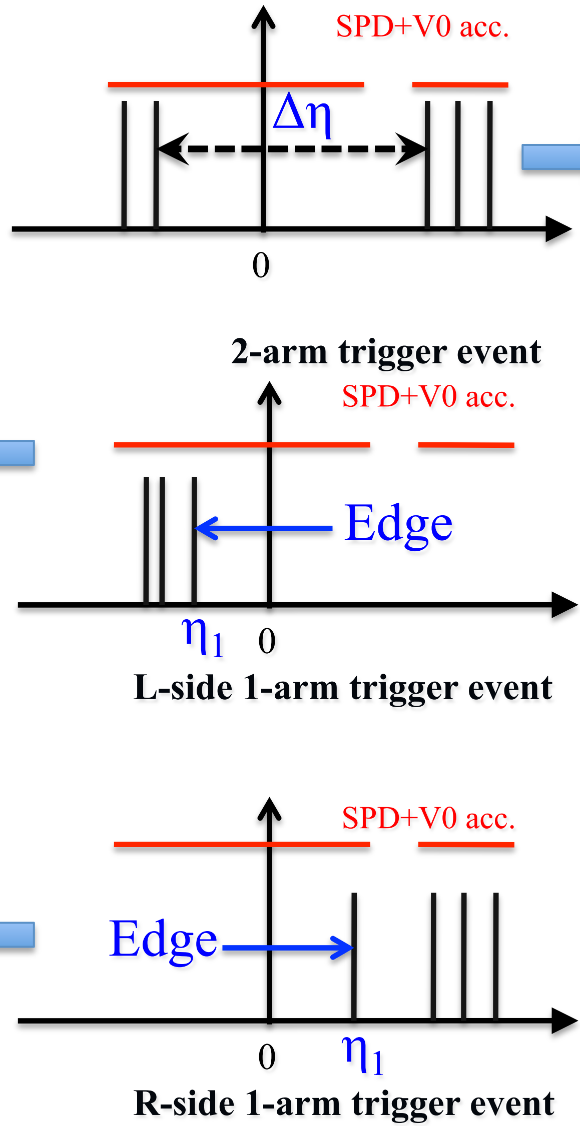
gap width

Uncorrected data vs Simulation (2.76 TeV)

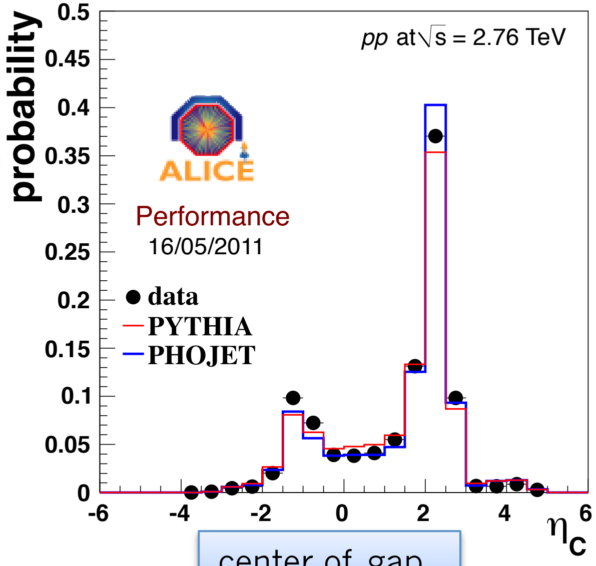
SPD+V0

edge of left-side 1-arm trigger event



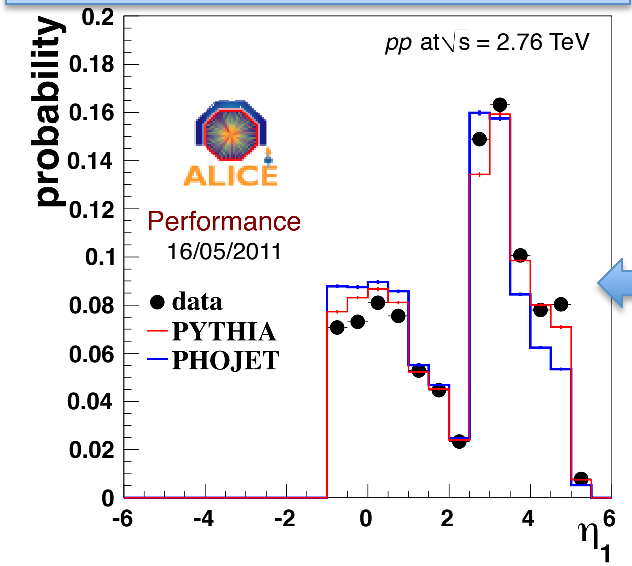


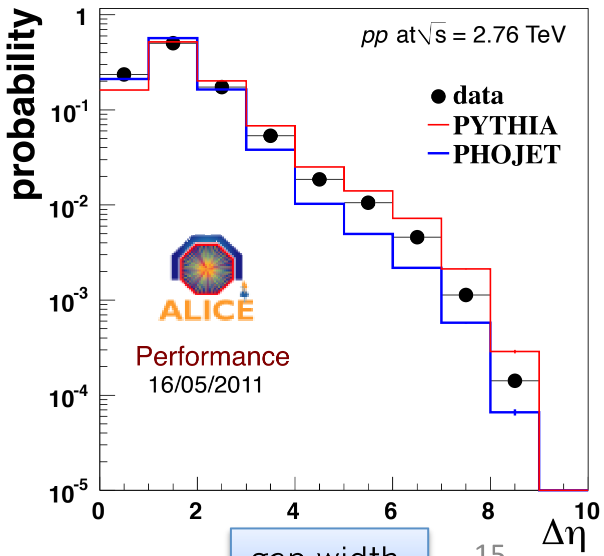
2-arm triggers



center of gap

edge of right-side 1-arm trigger event



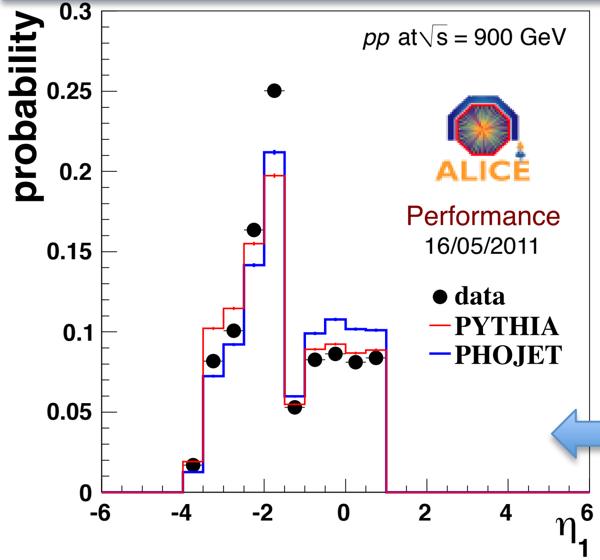


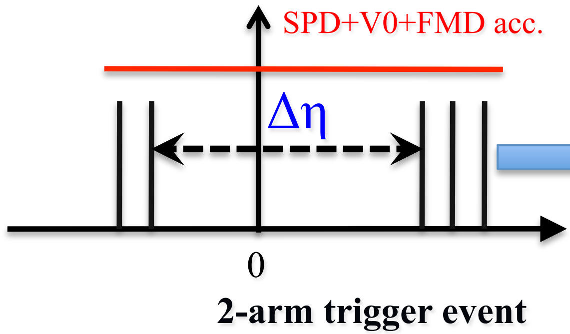
gap width

Uncorrected data vs Simulation (0.9 TeV)

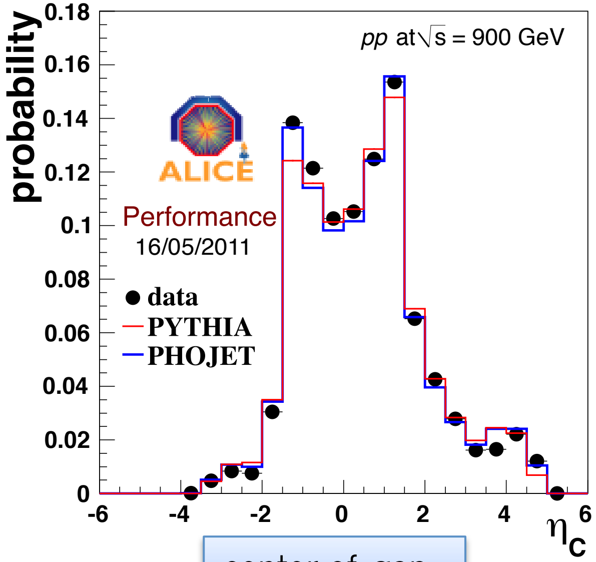
SPD+V0+FMD

edge of left-side 1-arm trigger event

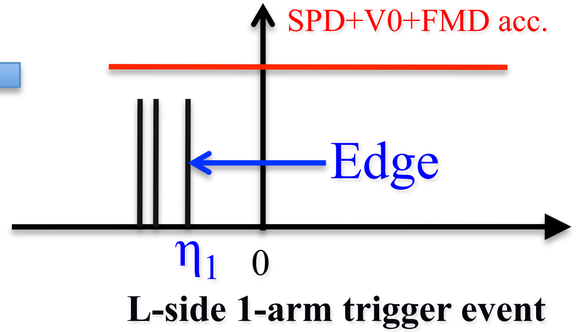




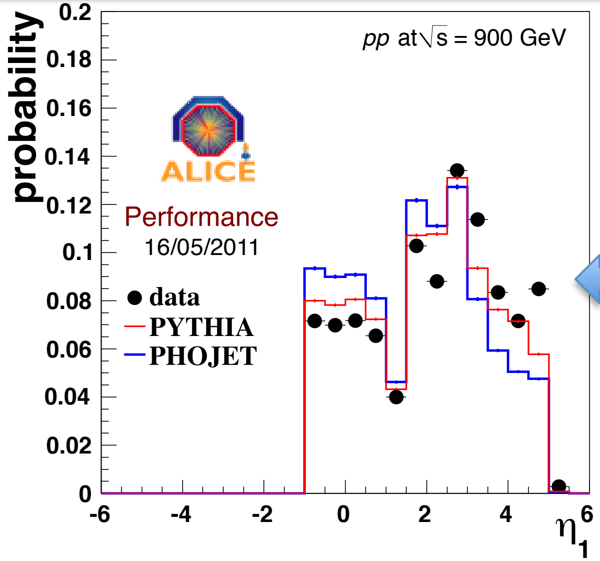
2-arm triggers

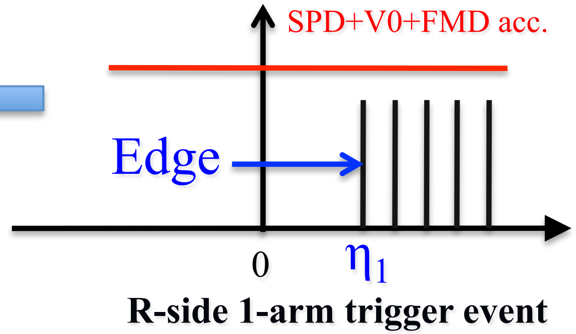


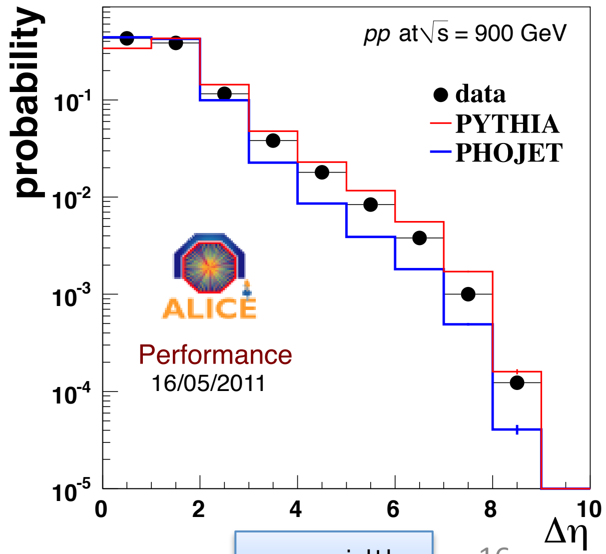
center of gap



edge of right-side 1-arm trigger event

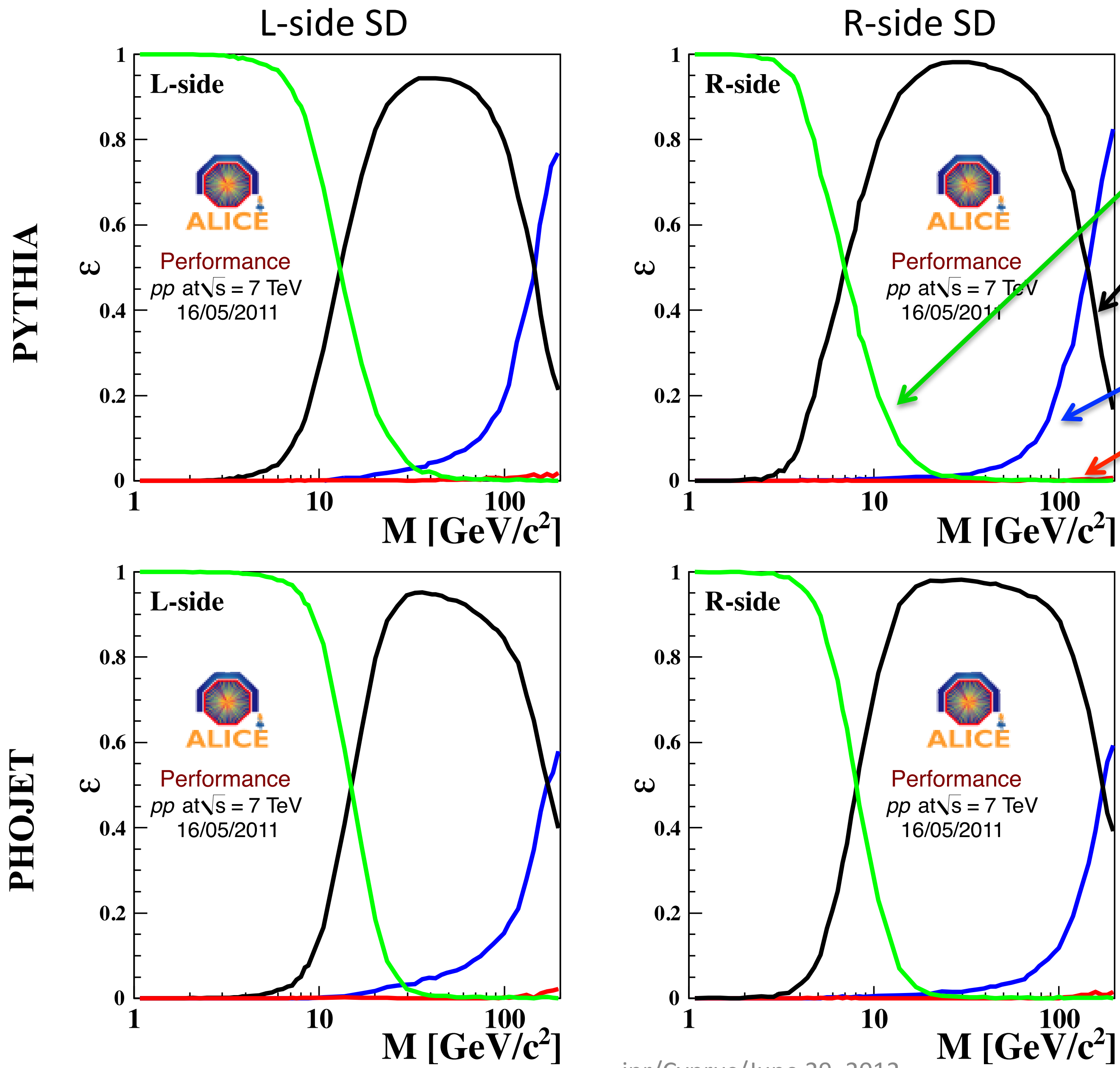






gap width

Efficiency/Inefficiency vs mass for Single Diffraction (7 TeV)



no trigger (inefficiency)

1-arm trigger

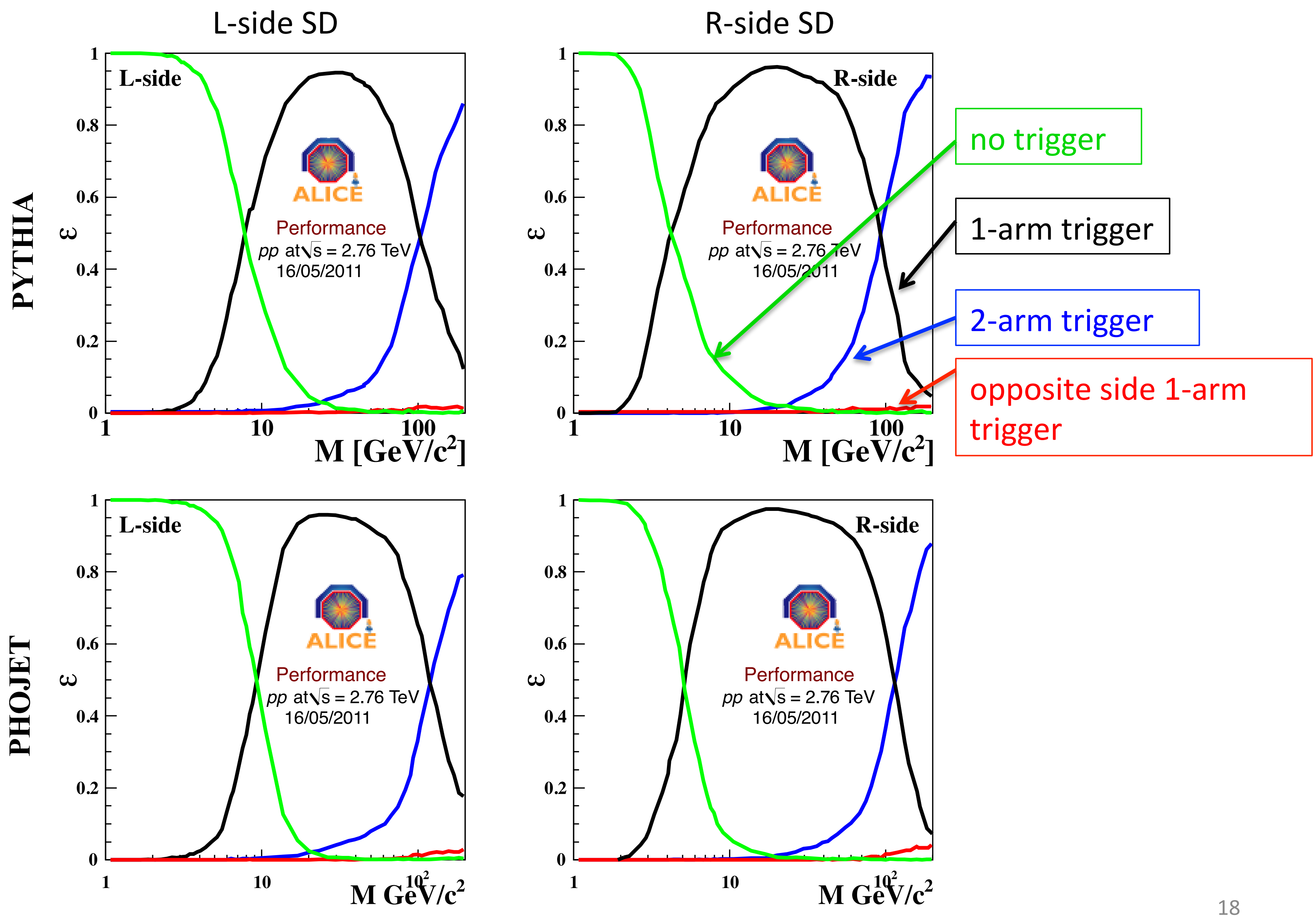
2-arm trigger

opposite side 1-arm trigger

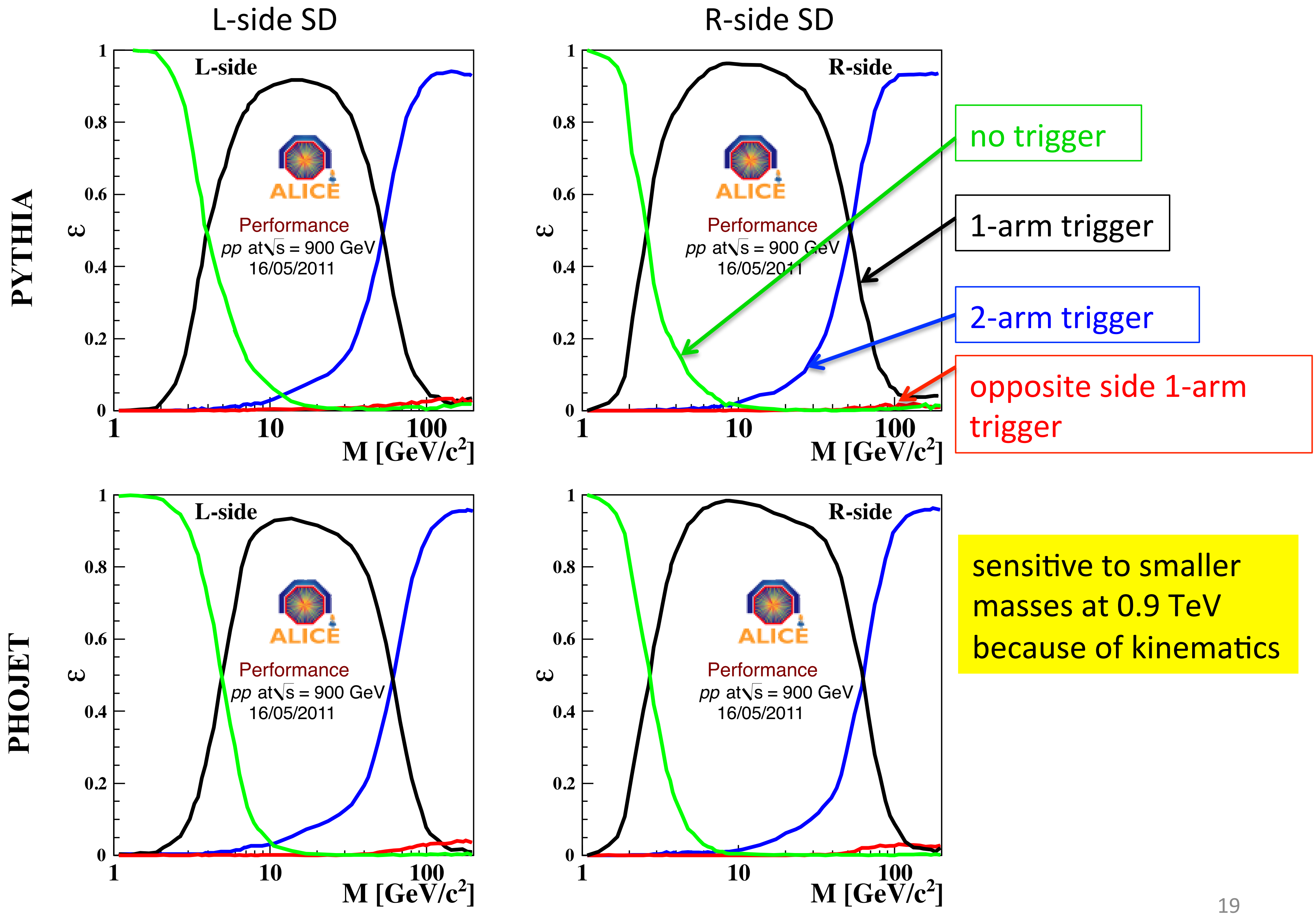
R-side sensitive to smaller masses because of asymmetric detector acceptance

Efficiencies used in the analysis: mean between “tuned” PYTHIA and “tuned” PHOJET

Efficiency/Inefficiency vs mass for Single Diffraction (2.76 TeV)



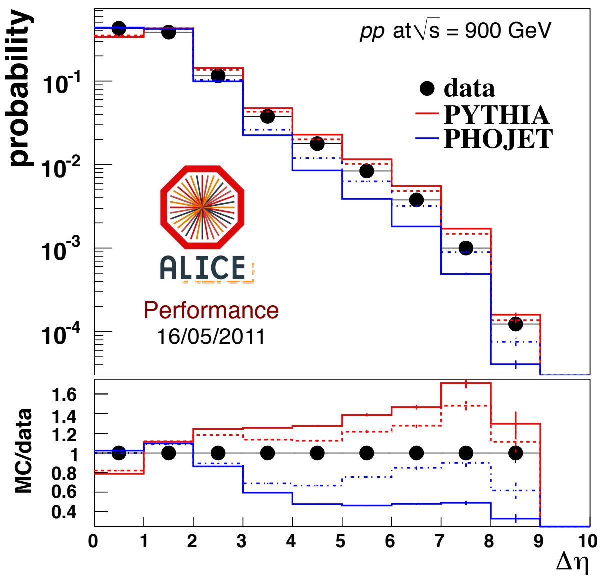
Efficiency/Inefficiency vs mass for Single Diffraction (0.9 TeV)



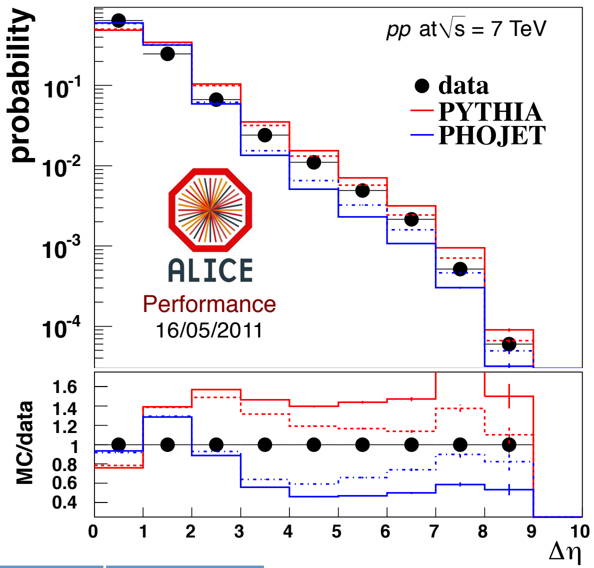
sensitive to smaller masses at 0.9 TeV because of kinematics

Modeling diffraction in MC

- We use the measured width distribution in two-arm triggers to constrain the contribution of double-diffraction (from above with PYTHIA from below with PHOJET), adjusting DD, while at the same time adjusting the SD fraction to keep the simulated One-Arm to Two-Arm trigger ratio equal to the measured one



Full line histograms are default PYTHIA and PHOJET
Dotted lines "tuned" versions



DD fractions

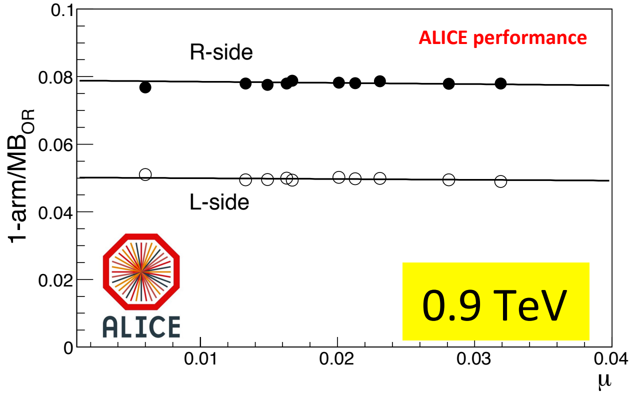
√s (TeV)	Tuned PYTHIA	Tuned PHOJET	PYTHIA	PHOJET
0.9	0.10	0.11	0.12	0.06
7	0.09	0.07	0.13	0.05

At both energies the new DD fractions approach a common value

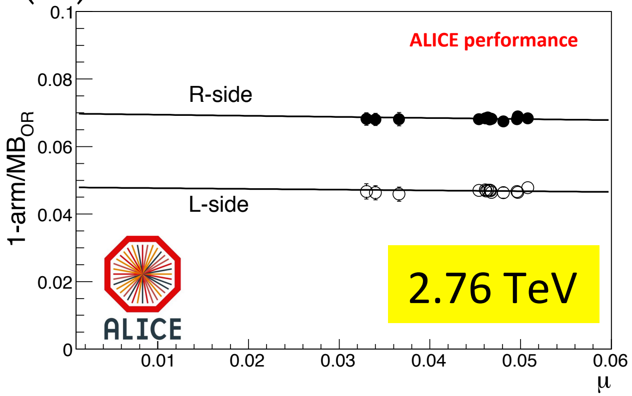
Measurement of σ_{SD} / σ_{INEL}

Raw trigger ratios fitted with $A(\mu) = (e^{A_0 \mu} - 1)/(e^{\mu} - 1)$

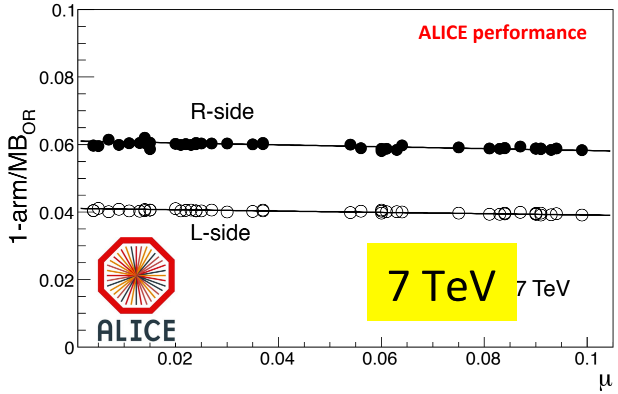
μ = collisions per trigger



R-side/2-arm = 0.0906 ± 0.0003
L-side/2-arm = 0.0576 ± 0.0002



R-side/2-arm = 0.0791 ± 0.0004
L-side/2-arm = 0.0543 ± 0.0004



R-side/2-arm = 0.0680 ± 0.00005
L-side/2-arm = 0.0458 ± 0.00004

Relative rates of Single Diffraction obtained from above trigger ratios corrected for efficiencies

$$\frac{\sigma_{SD}^{left}}{\sigma_{Inel}} = 0.103 \pm 0.015 \qquad \frac{\sigma_{SD}^{left}}{\sigma_{Inel}} = 0.085 \pm 0.03 \qquad \frac{\sigma_{SD}^{left}}{\sigma_{Inel}} = 0.101 \begin{smallmatrix} + & 0.02 \\ - & 0.04 \end{smallmatrix}$$

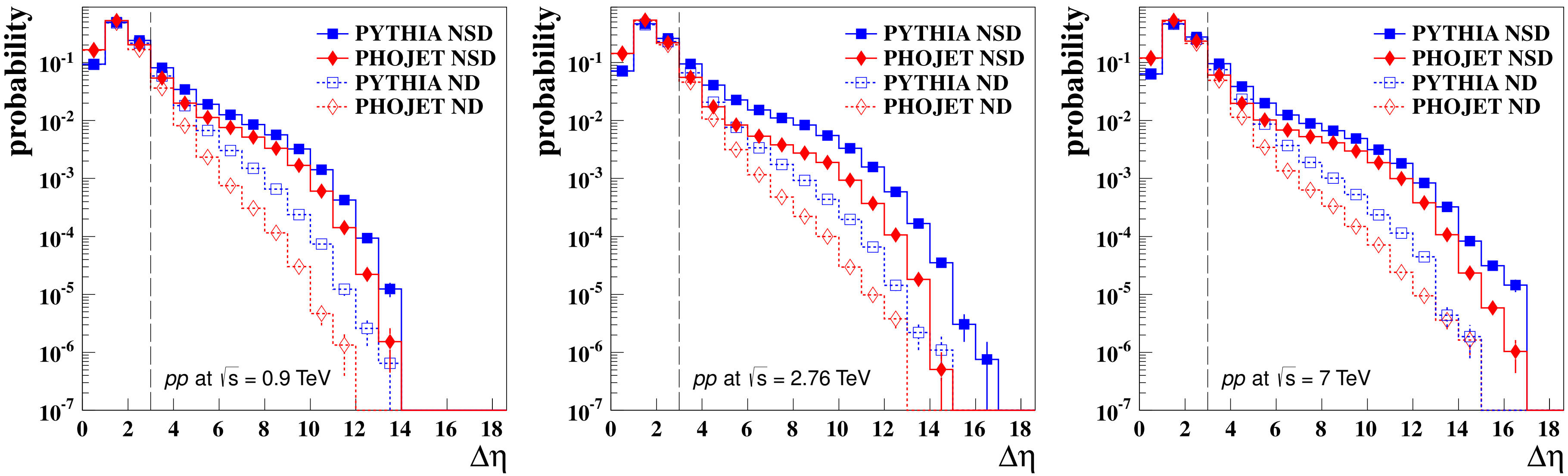
$$\frac{\sigma_{SD}^{right}}{\sigma_{Inel}} = 0.111 \pm 0.015 \qquad \frac{\sigma_{SD}^{right}}{\sigma_{Inel}} = 0.112 \begin{smallmatrix} + & 0.04 \\ - & 0.05 \end{smallmatrix} \qquad \frac{\sigma_{SD}^{right}}{\sigma_{Inel}} = 0.102 \begin{smallmatrix} + & 0.02 \\ - & 0.03 \end{smallmatrix}$$

Despite different acceptances of the two ALICE sides, results are symmetrical as expected from the symmetry of the physics process.

$$\frac{\sigma_{SD}}{\sigma_{Inel}} = 0.214 \pm 0.030 \qquad \frac{\sigma_{SD}}{\sigma_{Inel}} = 0.197 \begin{smallmatrix} + & 0.07 \\ - & 0.08 \end{smallmatrix} \qquad \frac{\sigma_{SD}}{\sigma_{Inel}} = 0.202 \begin{smallmatrix} + & 0.04 \\ - & 0.07 \end{smallmatrix}$$

SD defined for M_X < 200 GeV/c^2 for all energies (separation between SD and ND)

Measurement of $\sigma_{DD} / \sigma_{INEL}$



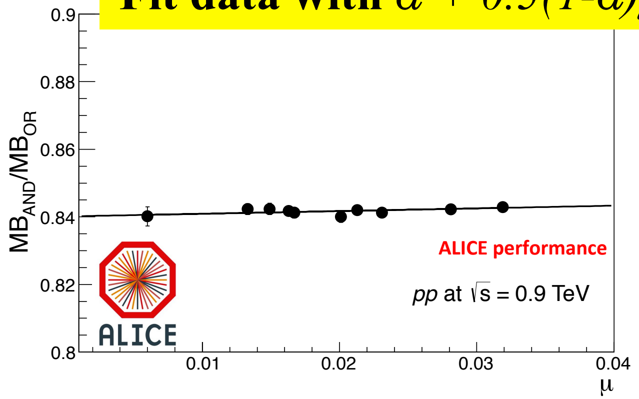
DD defined as all events with a gap Δη > 3*

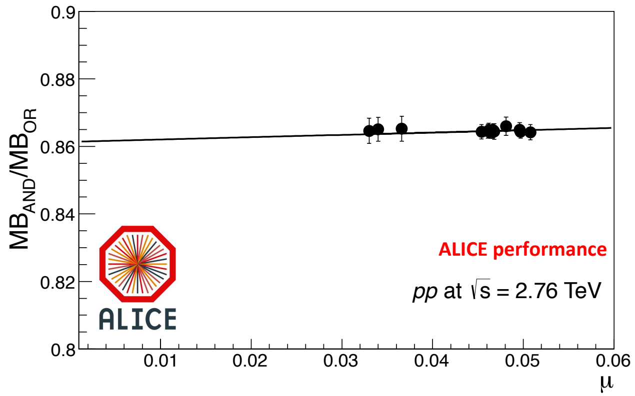
900 GeV	2.76 TeV	7 TeV
$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.108 \pm 0.03$	$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.124^{+0.054}_{-0.052}$	$\frac{\sigma_{DD}}{\sigma_{Inel}} = 0.124^{+0.045}_{-0.040}$

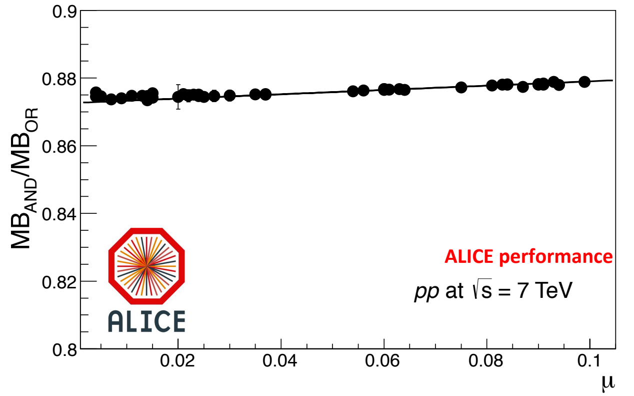
*In measurements by UA5 and CDF the contribution from secondary Reggeon is subtracted (large correction which is model dependent), which complicates comparison

Checking trigger efficiencies

Fit data with $a + 0.5(1\text{-}a)\mu$







Measurements

a = 0.8401 ± 0.0004

a = 0.8613 ± 0.0006

a = 0.87266 ± 0.00007

Simulation

$$MB_{AND} = 0.763 \; {}^{+0.02}_{-0.003}$$

$$MB_{OR} = 0.91 \; {}^{+0.03}_{-0.01}$$

$$\frac{MB_{AND}}{MB_{OR}} = 0.839 \; {}^{+0.006}_{-0.008}$$

$$MB_{AND} = 0.76 \; {}^{+0.05}_{-0.03}$$

$$MB_{OR} = 0.88 \; {}^{+0.06}_{-0.03}$$

$$\frac{MB_{AND}}{MB_{OR}} = 0.863 \; {}^{+0.02}_{-0.03}$$

$$MB_{AND} = 0.74 \; {}^{+0.05}_{-0.02}$$

$$MB_{OR} = 0.85 \; {}^{+0.06}_{-0.03}$$

$$\frac{MB_{AND}}{MB_{OR}} = 0.871 \; \pm 0.007$$

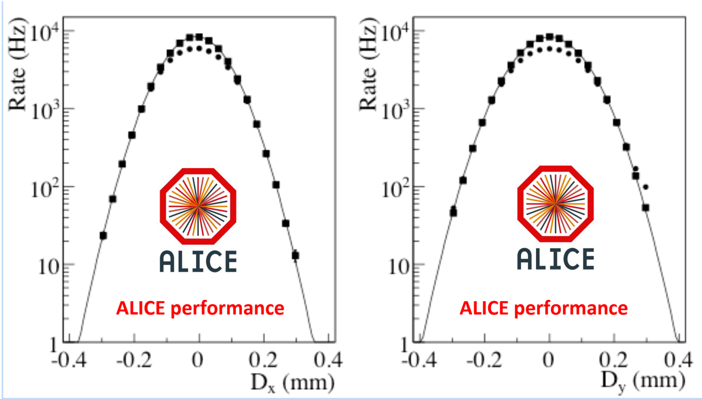
Measurement of σ_{INEL}

- Rate of MB_{AND} (coincidence between V0-L and V0-R) measured in a van der Meer scan

$$\frac{dN(MB_{AND})}{dt} = A \times \sigma_{INEL} \times L$$

$$A \times \sigma_{INEL} = 54.34 \pm 1.9 mb$$

- A = MB_{AND} efficiency obtained as described previously

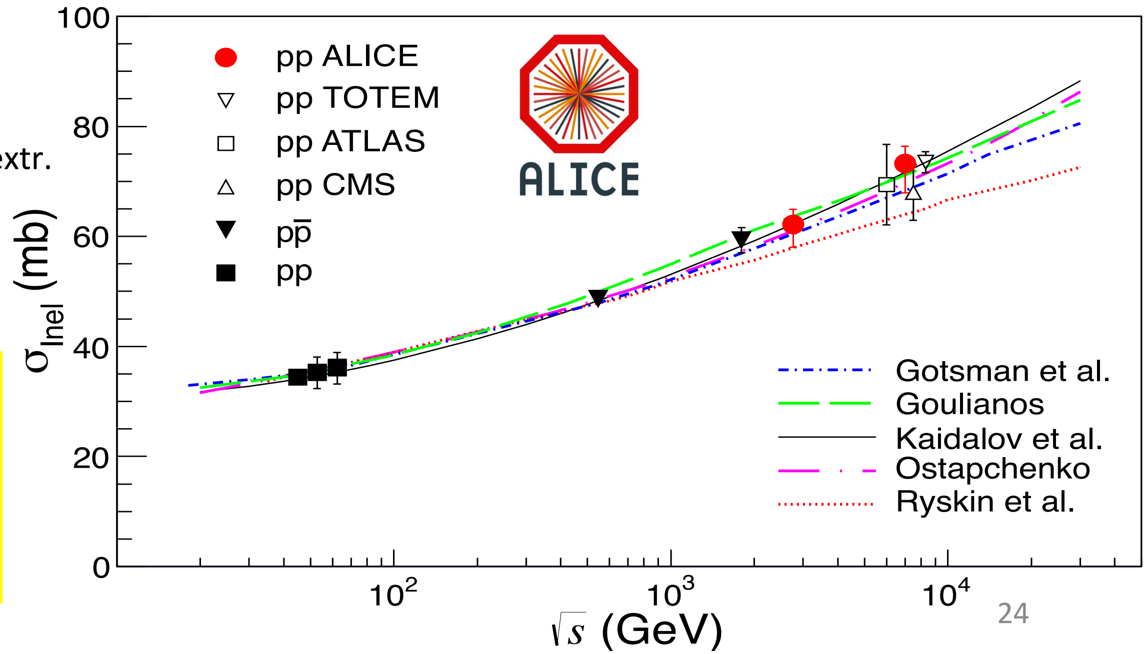


ALICE $\sigma_{INEL}(7TeV) = 73.2^{+2}_{-4.6}(\text{mod.}) \pm 2.6(lumi.)mb$

ATLAS : $69.4 \pm 2.4^{exp.} \pm 6.9^{extr.}$

CMS : $68.0 \pm 2.0^{syst.} \pm 2.4^{lumi} \pm 4^{extr.}$

TOTEM: $73.5 \pm 0.6^{stat.}\ {}^{+1.8}_{-1.3}\ ^{syst.}$

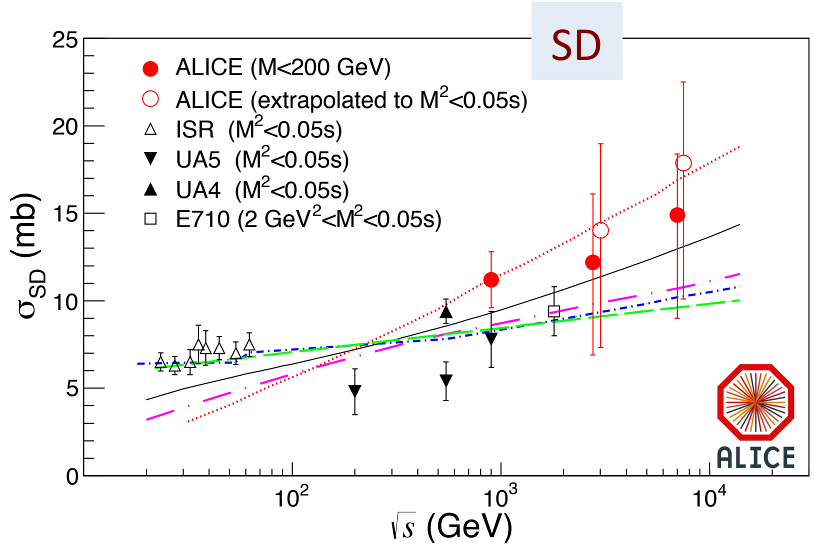


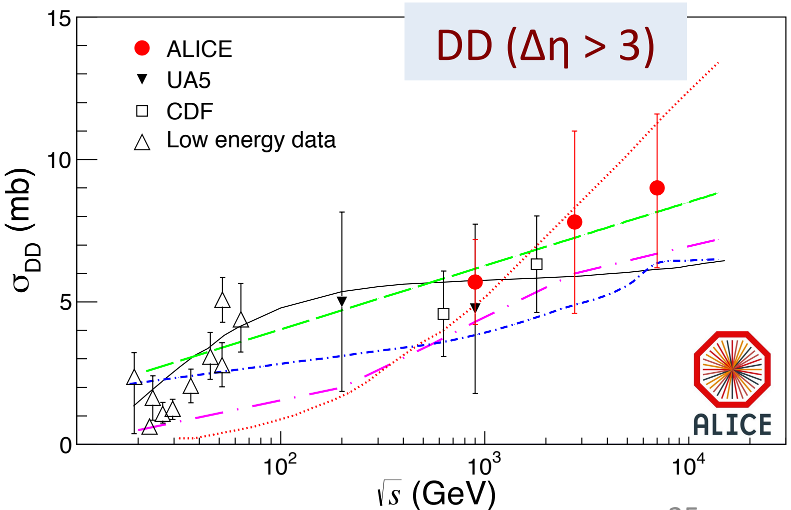
Using PYTHIA8 (DL?) instead of our tuned MC we obtain:
σ_{INEL} = 68.5 ± 2.5 mb, very close to CMS and ATLAS numbers

Diffractive cross sections

- Combining the inelastic cross-sections with the relative rates of processes we obtain the SD and DD cross-sections
- Note that for 0.9 TeV where we did not perform a vdM scan, we used σ_{INEL} = 52.5 ± 2 mb from UA5

– ALICE result at 900 GeV are consistent with UA5





Conclusion

- **Diffraction is a challenging phenomenon**, especially for ALICE, which was not optimized to measure diffraction. However, the knowledge of diffraction is important to model pp collisions at a new energy, and for this reason a gap analysis was performed.

- ALICE measured inelastic, SD and DD cross sections at 3 energies

√s (TeV)	σ_{vdM} (mb)	σ_{Inel} (mb)	σ_{SD}(**M < 200 GeV**)	σ_{DD}(**Δη>3**)	**SD/Inel**
0.9		52.5 ± 2	11.2 ± 1.6	5.7 ± 1.5	0.213
2.76	47.7 ± 0.9	$62.8^{+2.4}_{-4.0} \pm 1.2$	$12.2^{+3.9}_{-5.3} \pm 0.2$	$7.8 \pm 3.2 \pm 0.2$	0.194
7	54.34 ± 1.9	$73.2^{+2.0}_{-4.6} \pm 2.6$	$14.9^{+3.4}_{-5.9} \pm 0.5$	$9.0 \pm 2.6 \pm 0.3$	0.203

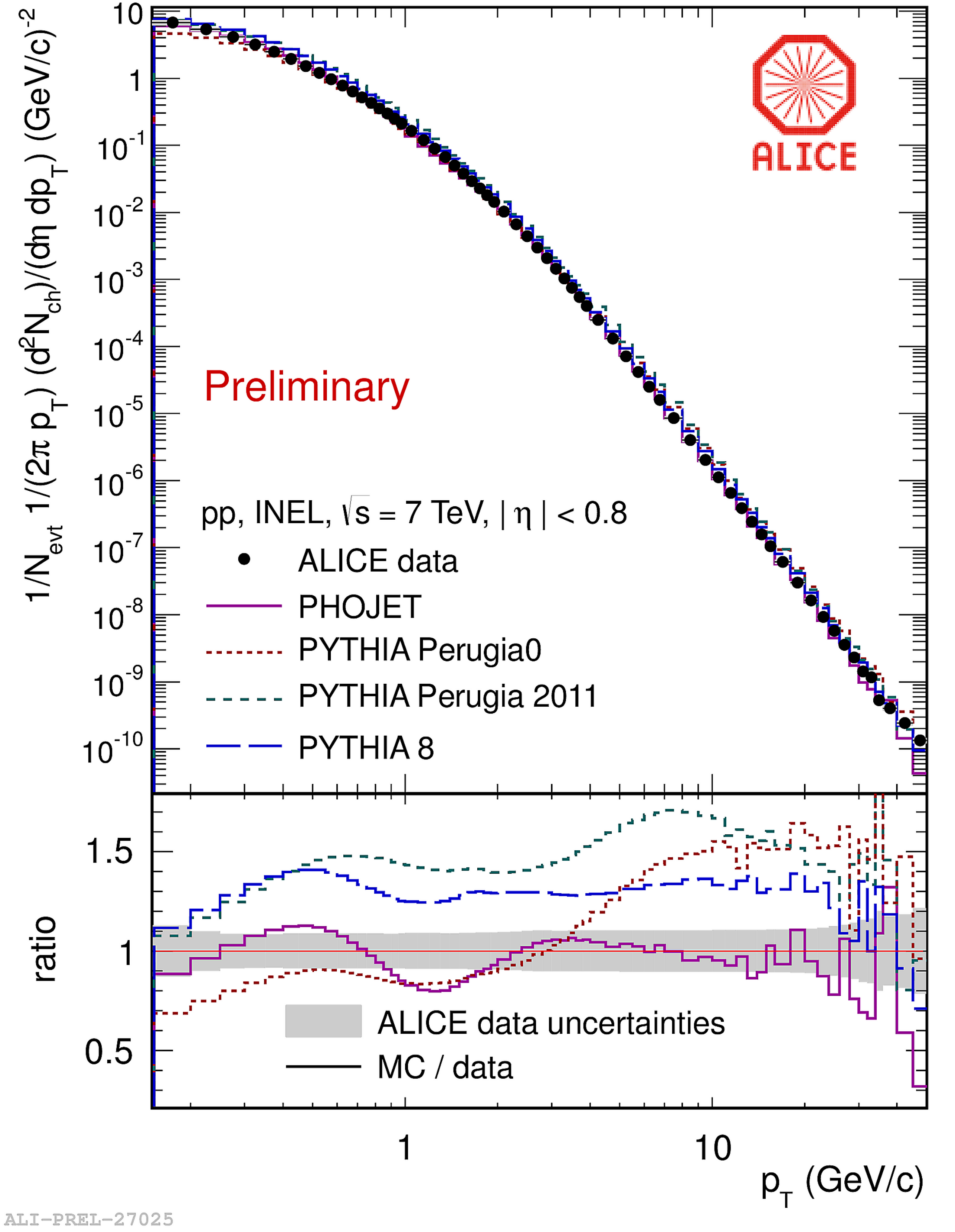
- Results on diffraction are consistent with UA5 at √s = 0.9 TeV
- Results on the inelastic cross section at 7 TeV are consistent with ATLAS, CMS and TOTEM at √s = 7 TeV
- Within our accuracy, we do not observe variations of relative rates of SD and DD with energy $\sigma_{\mathrm{SD}}/\sigma_{\mathrm{Inel}} \approx 0.2$).

ALICE publication to be submitted to EPJC

Reserve slides

checks

- ALICE diffraction SD and DD data agree with UA5 at 900 GeV (not a trivial check)
- Two sides of detector sensitive to different $\xi = M^2/s$ values, give equal results for SD as they should
- When changing $M_X < 200$ GeV to $M_X < 100$ GeV or $M_X < 50$ GeV, data follow nicely the model
- Tuned PYTHIA and PHOJET reproduce extremely well measured trigger efficiencies at 3 energies



– p_T comparison between models and data not too bad given that it has to cover 10 orders of magnitudes
– important (together with particle mix), when converting rapidity from MC to pseudorapidity (η)