Multiple Parton Interactions in ALICE

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on behalf of the ALICE Collaboration

CERN LHC Seminar
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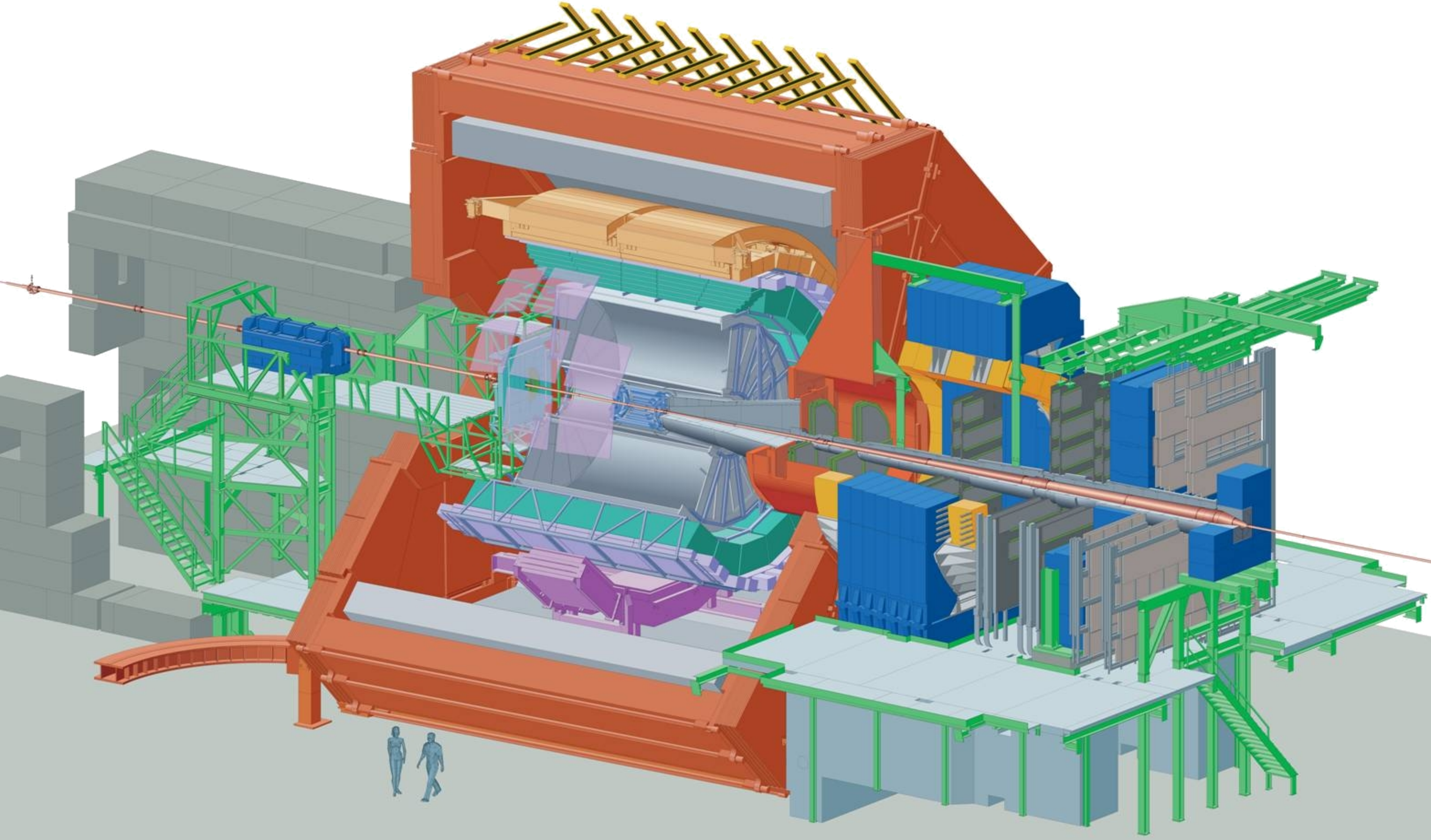
A Large Ion Collider Experiment

- ALICE has been optimized for heavy-ion (Pb-Pb) collisions, but it also studies proton-proton (pp) collisions
  - Several signals in heavy-ion collisions are measured relative to pp
  - ALICE also has a rich pp program
- ALICE special features for pp minimum bias physics
  - Low momentum sensitivity due to low material budget and low magnetic field
  - Excellent primary and secondary vertex resolution
  - Excellent particle identification (PID) capability
- ALICE can give important input to pp studies
  - Rare signals need good description of soft underlying event
  - Tuning of MC generators in low-p_T region
  - Study of high-multiplicity collisions

A Large Ion Collider Experiment



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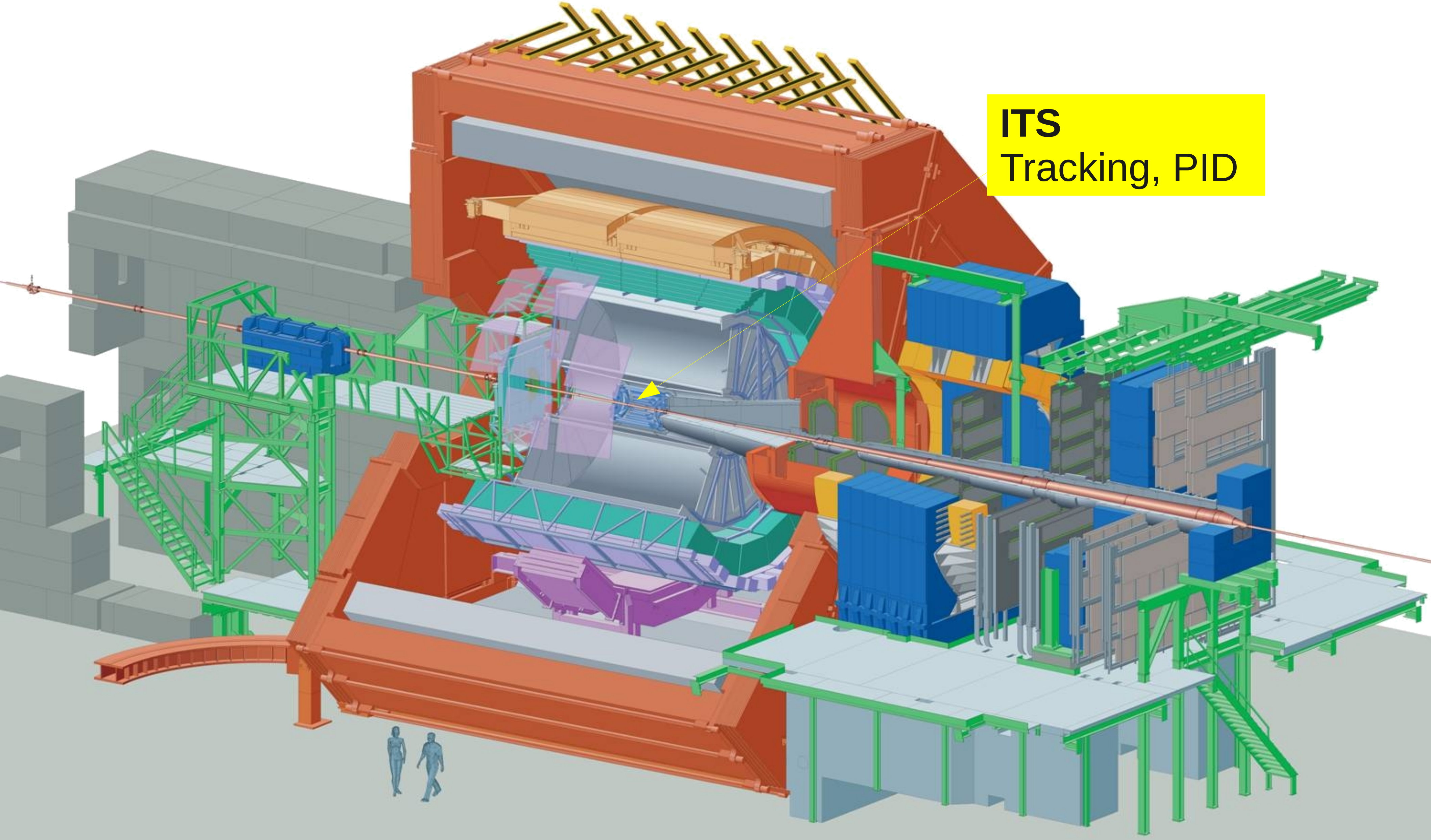

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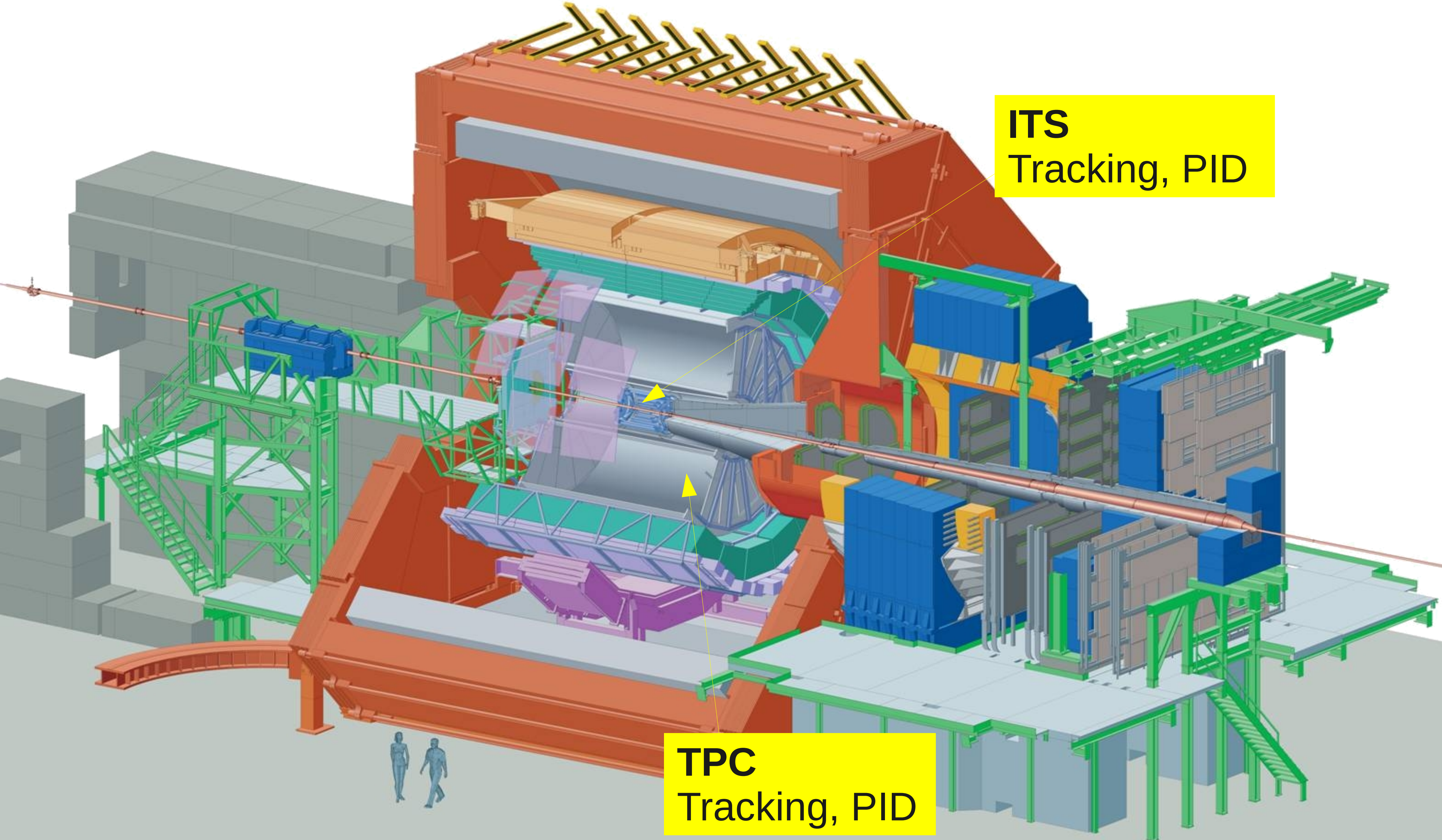

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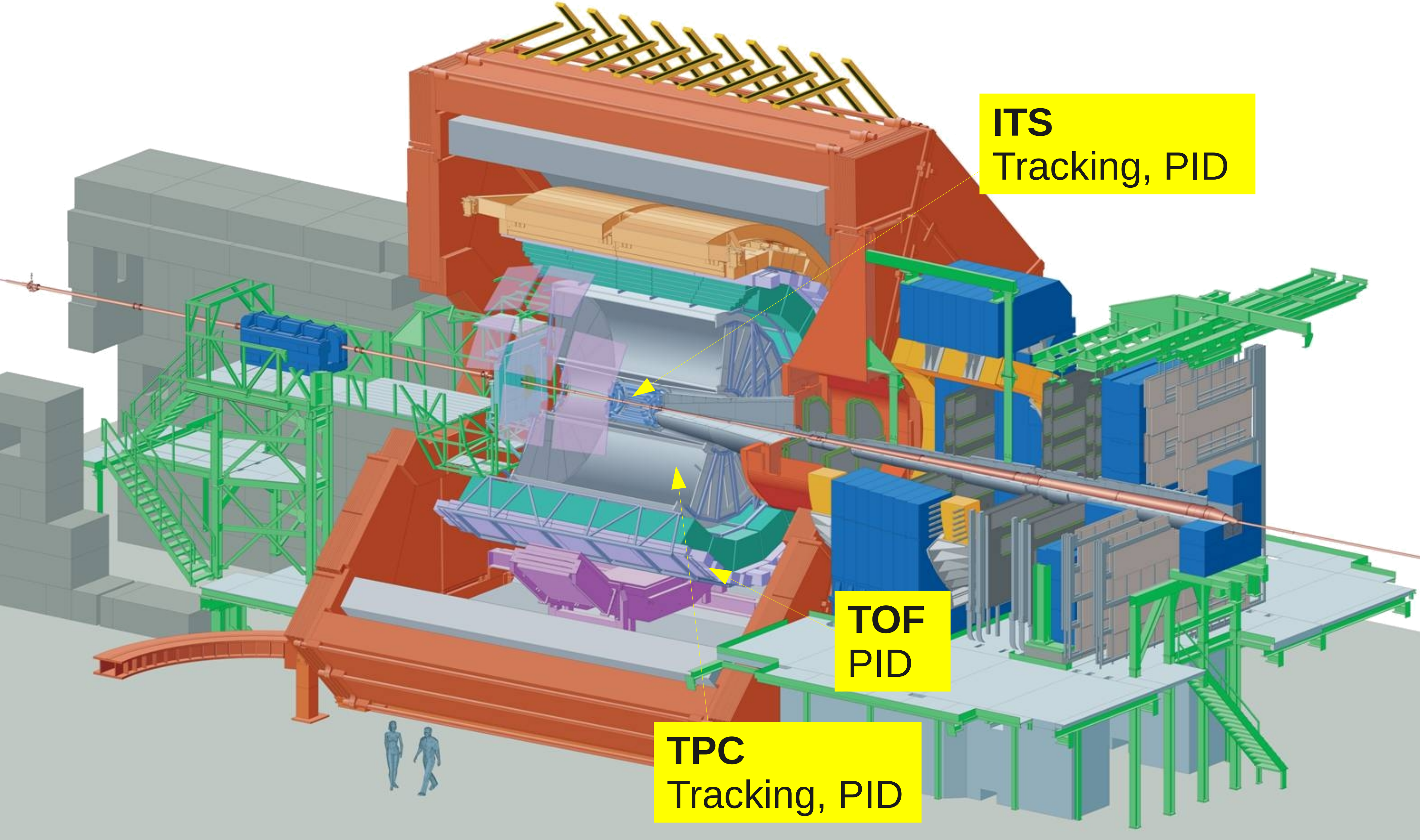

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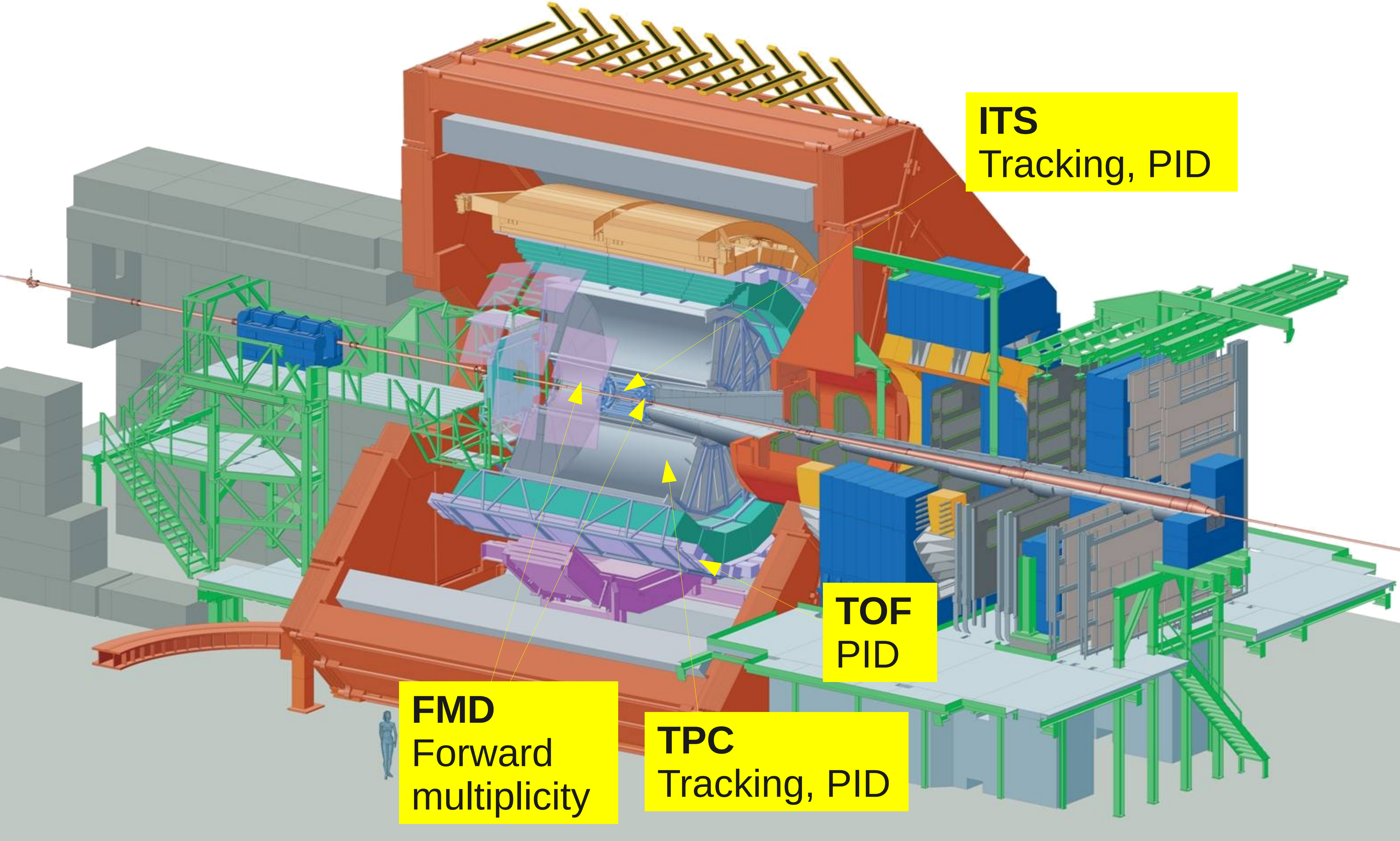

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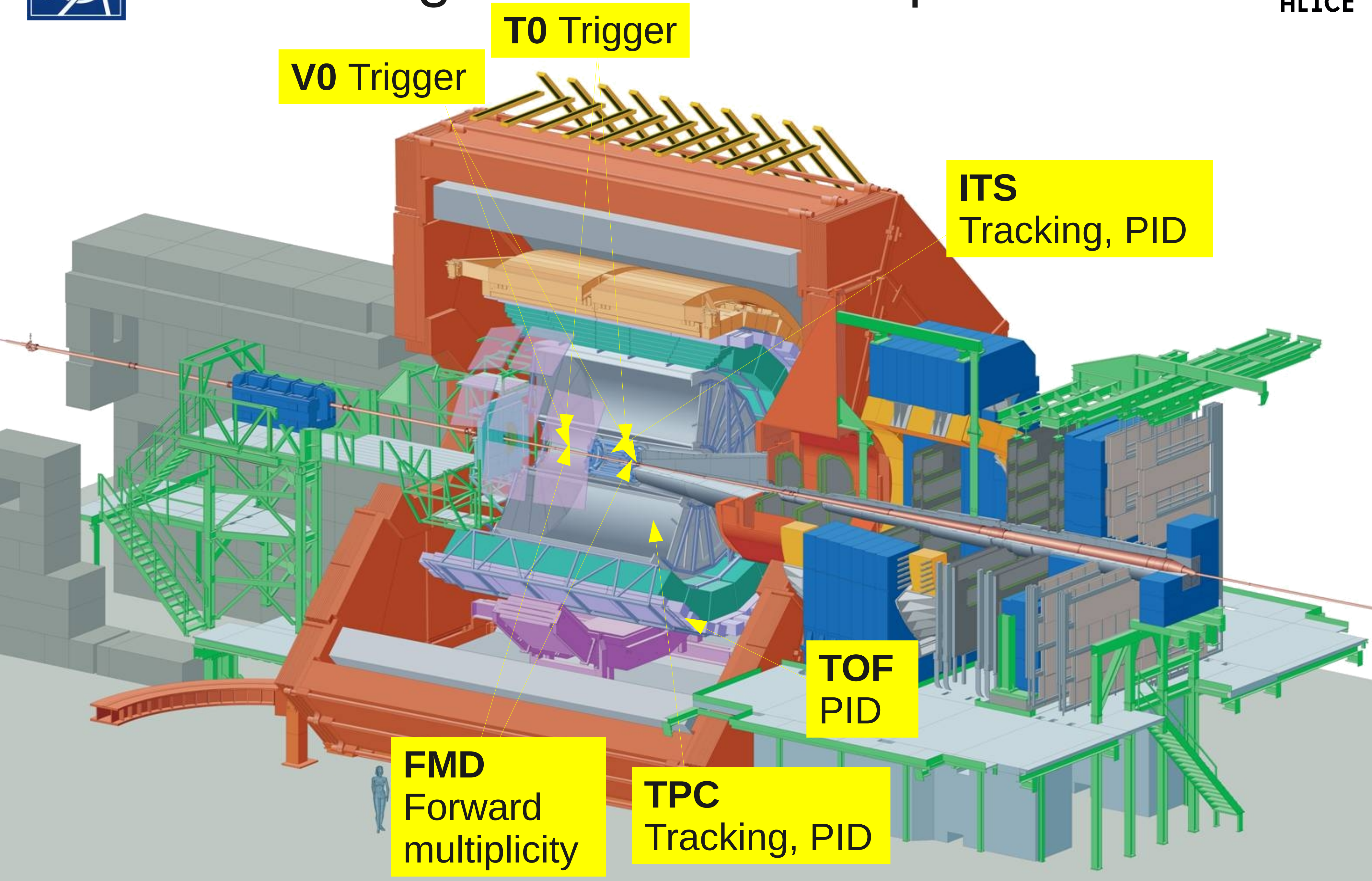

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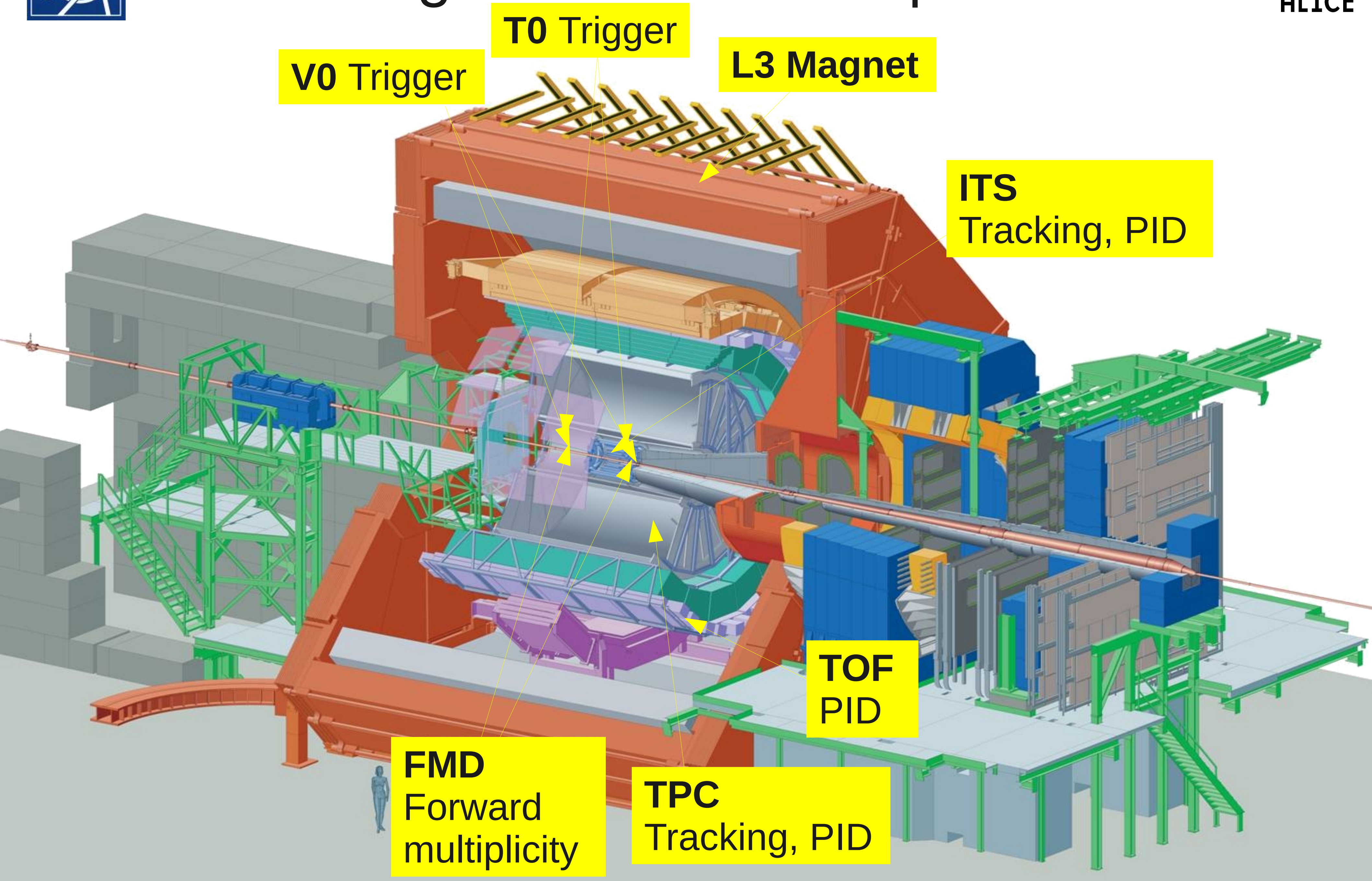

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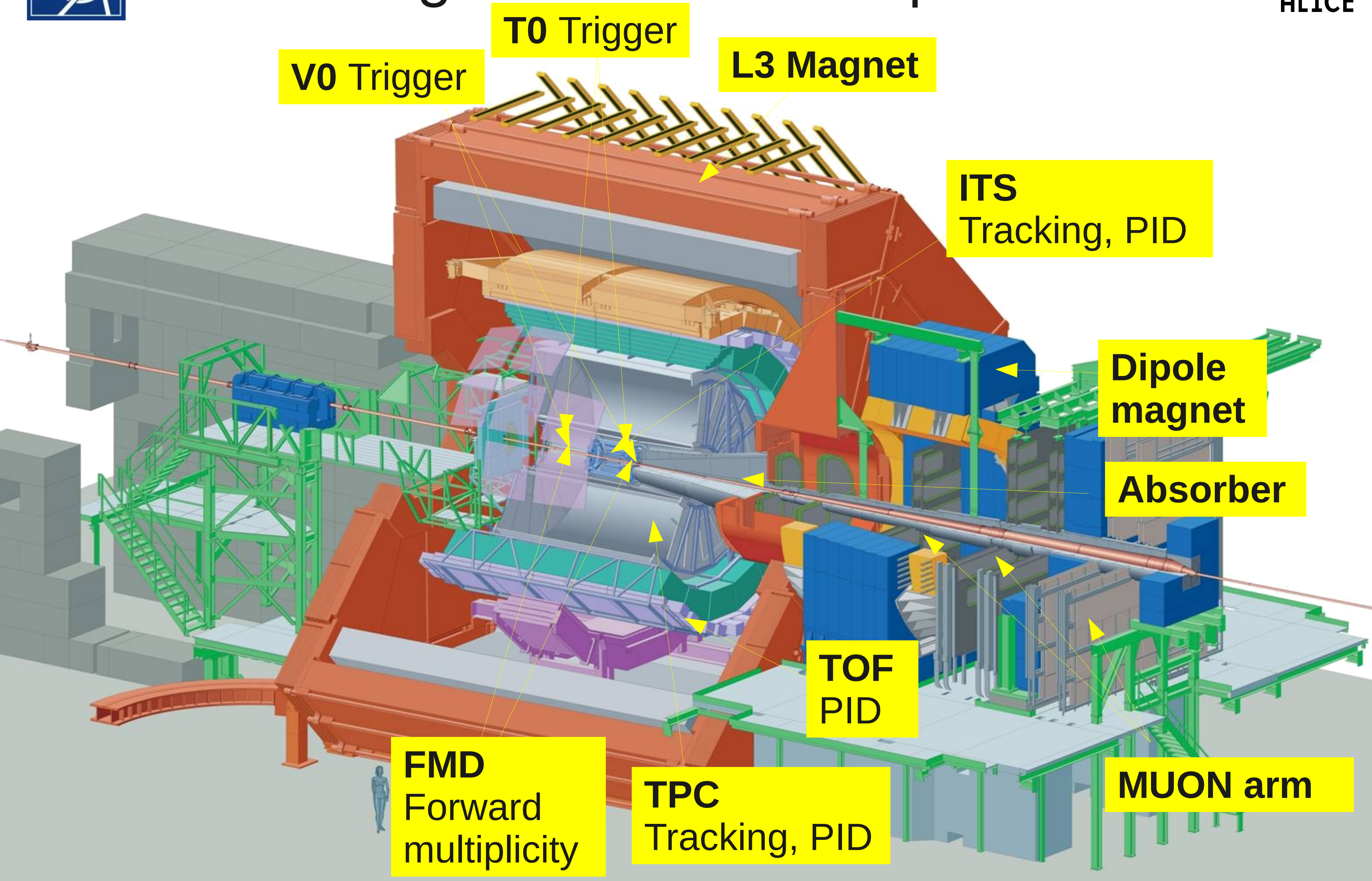

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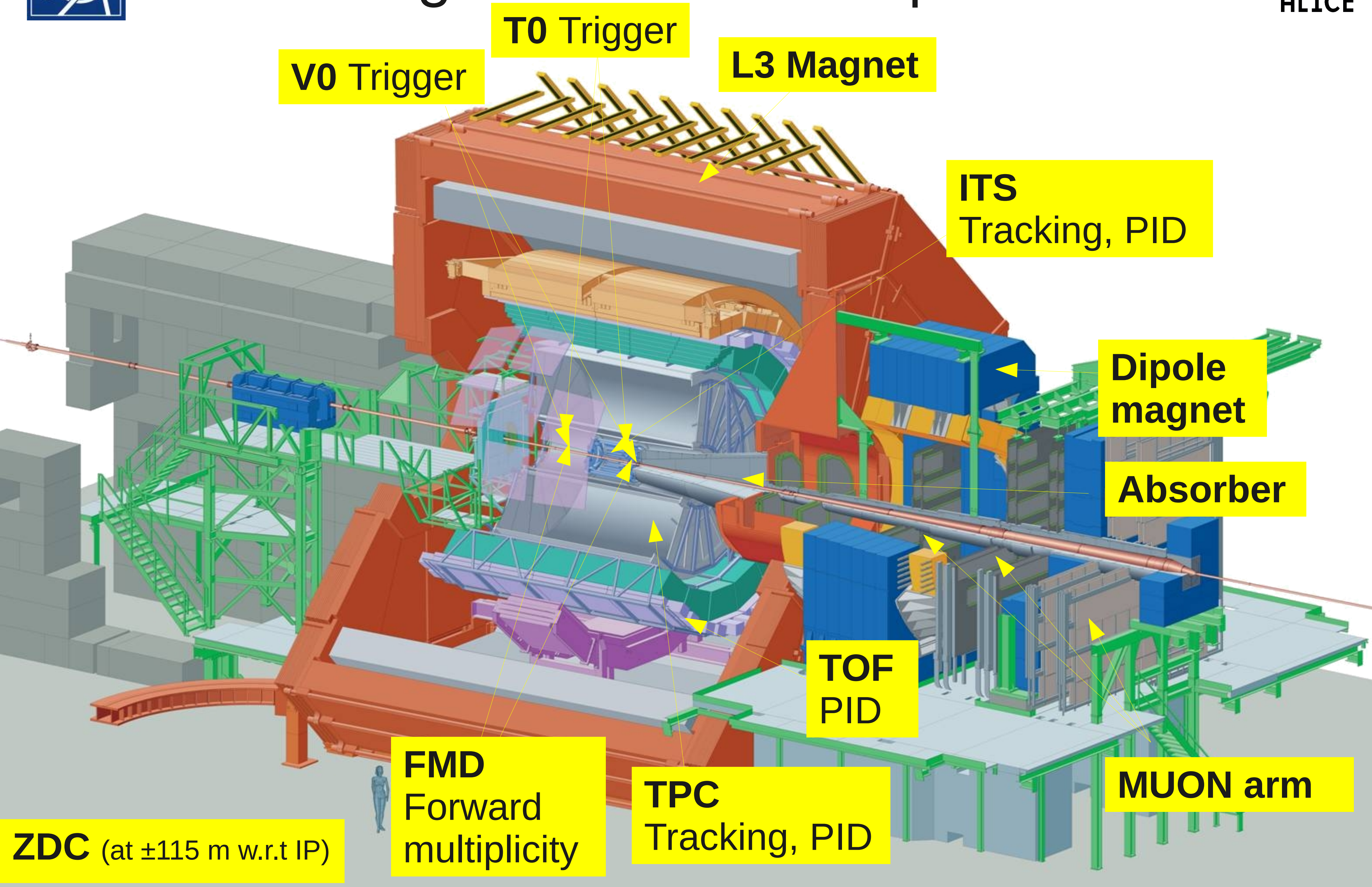

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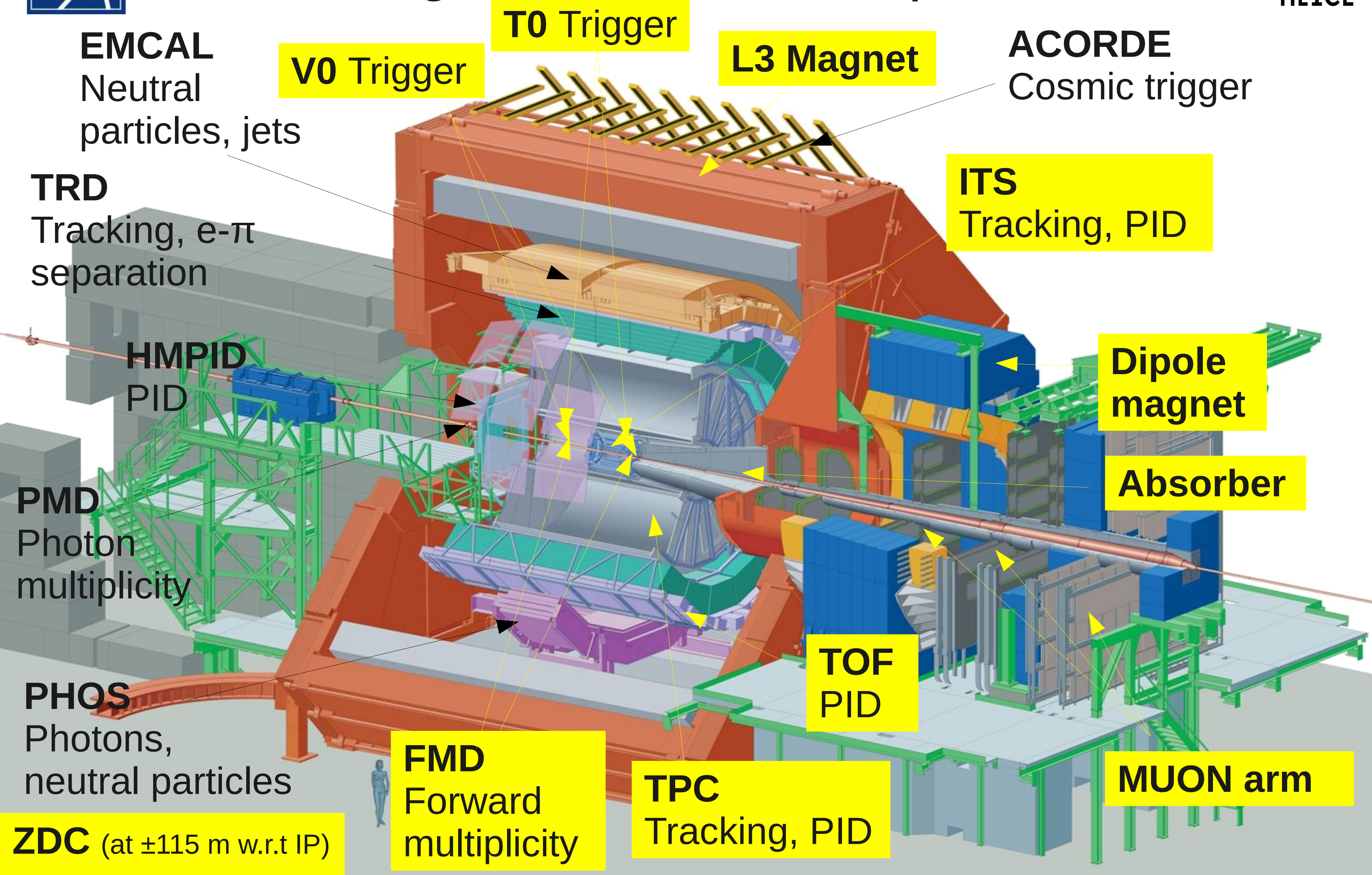
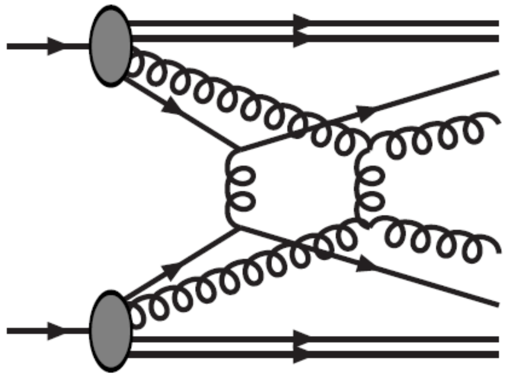


Motivation

- High-energy proton-proton collisions can be interpreted as collisions of two “bunches of partons”
- Multiple distinct pairs of partons can collide with each other

→ Multiple parton interactions (MPI)



JHEP **0403**, 053 (2004)

- At LHC energies, the cross section for parton-parton scattering exceeds the proton-proton inelastic cross section
  → many parton scatterings per event

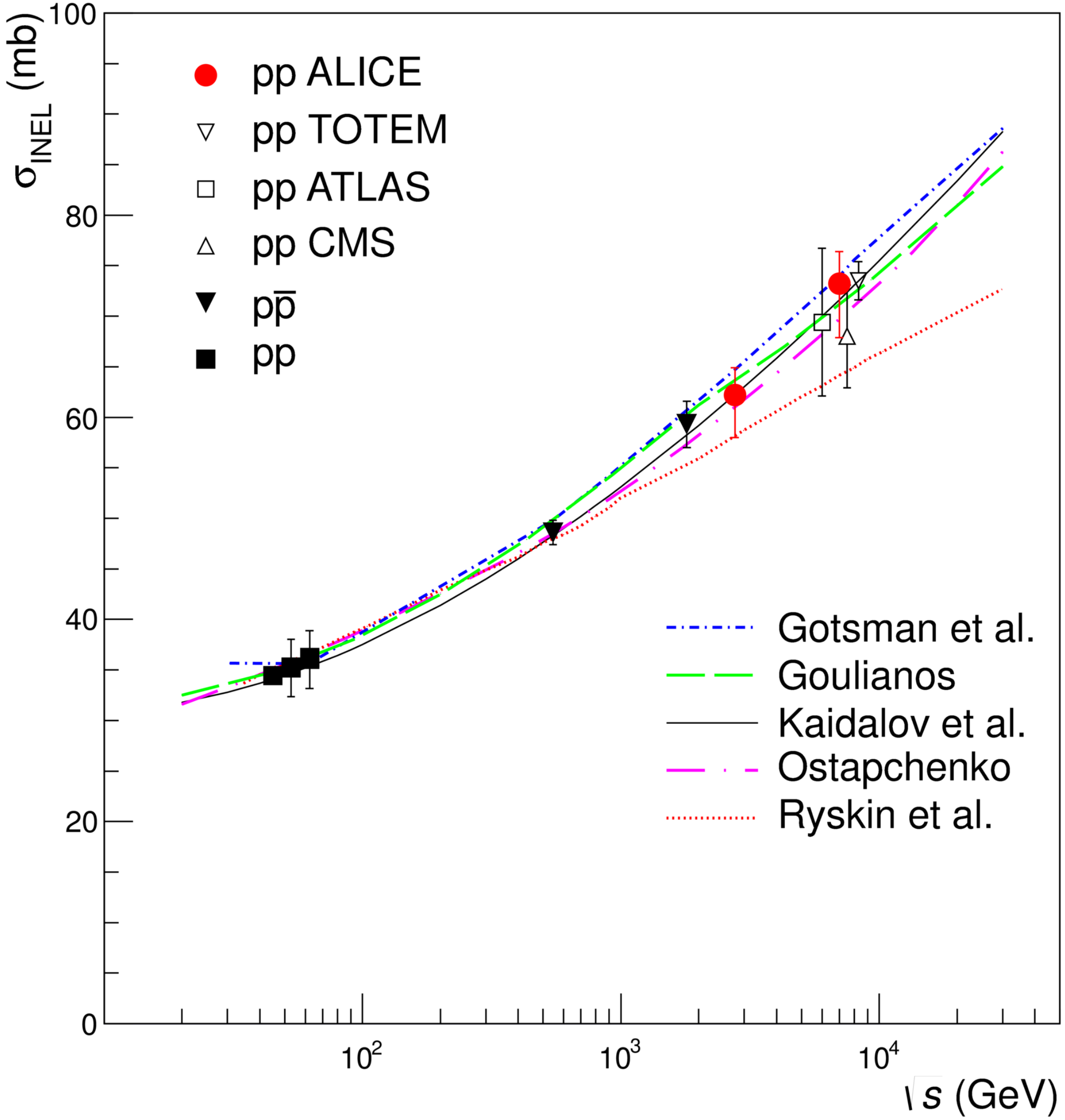
$$\langle N_{\mathrm{MPI}}(p_{\mathrm{T,\,min}})\rangle = \frac{\sigma_{\mathrm{interaction}}(p_{\mathrm{T,\,min}})}{\sigma_{\mathrm{non\text{-}diffractive}}}$$

Outline of the Presentation

Experimental observables related to multiple parton interactions measured by ALICE

1) Inelastic proton-proton cross section
2) Charged particle multiplicity distribution
3) Underlying event
4) Correlation between soft particle production and
   a) Heavy flavor production (J/ψ-mesons, D-mesons)
   b) Event shapes
   c) Low p_T-jets

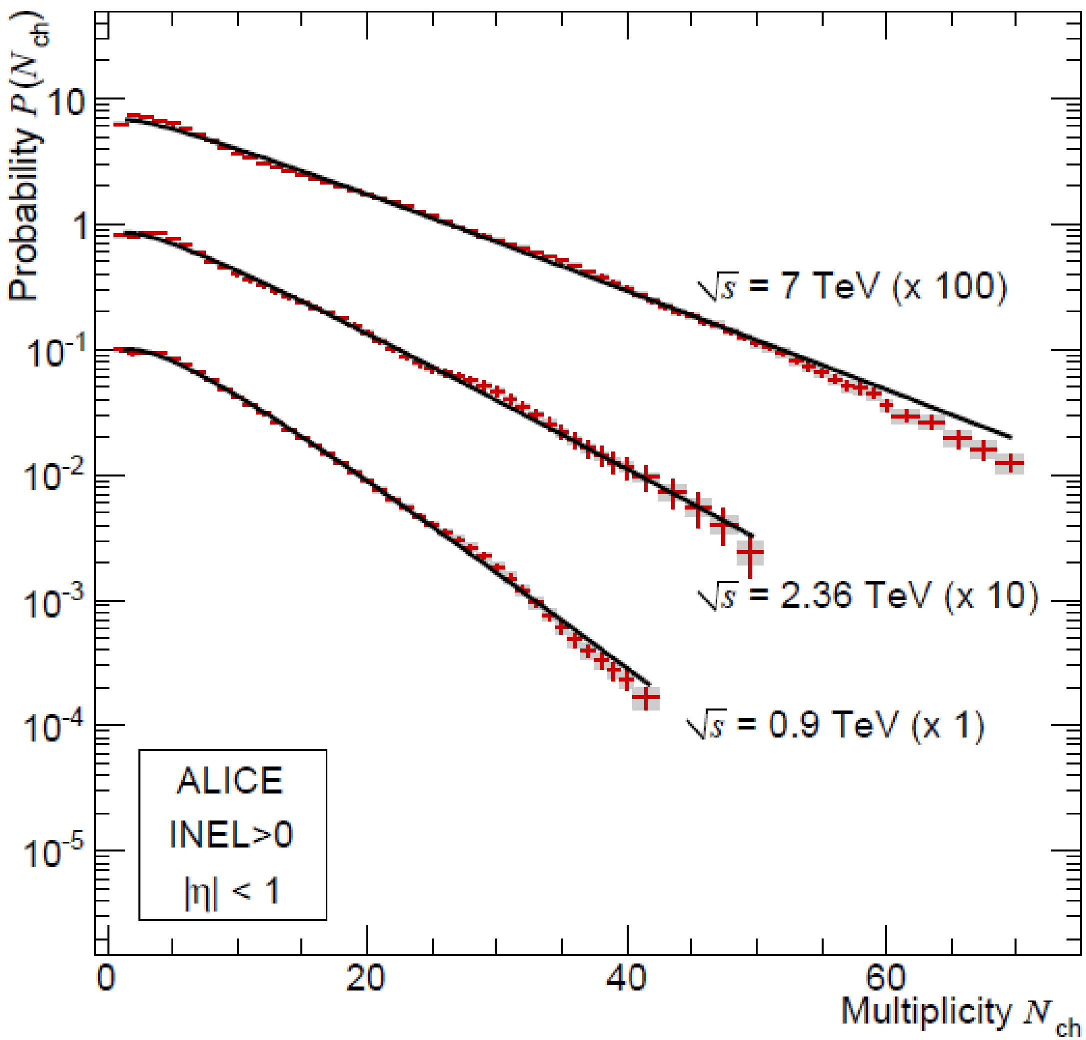
Inelastic Proton-Proton Cross Section



J. Phys. G **38**, 124044 (2011)

- For center-of-mass energies above $\sqrt{s}$ = 100 GeV, the hadronic cross section increases
- Origin of this increase is not yet fully understood
- Can be interpreted as due to the increase of partonic fluctuations

Charged Particle Multiplicity Distribution



Eur. Phys. J. C **68**, 345 (2010)

- Charged particle multiplicity distributions in comparison to negative binomial distribution (NBD) fits
- NBD → clan model
- NBD is a compound Poissonian distribution
- Physical interpretation of NBD
  - mean of Poissonian = number of particle sources (clans)
  - Associated particles per clan distributed according to log-series
- Can be validated by particle correlation studies

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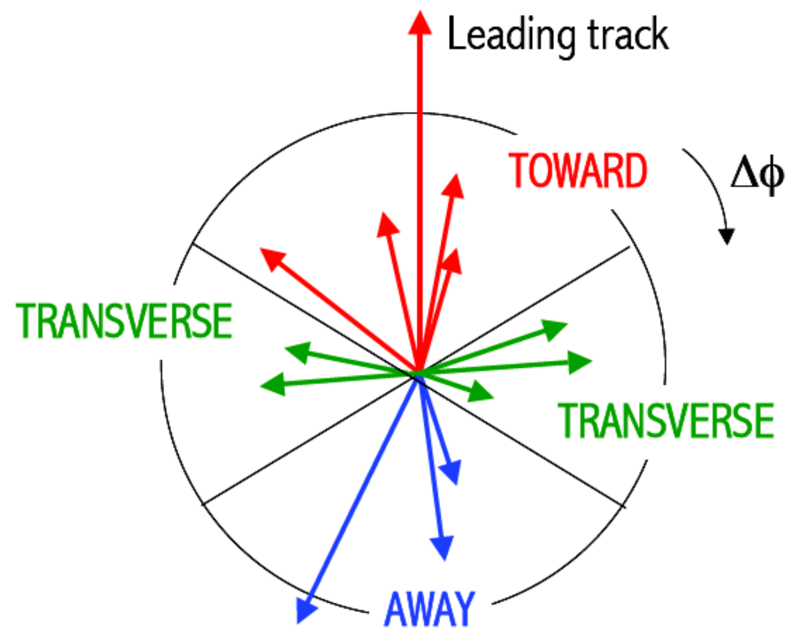
Underlying Event (UE)

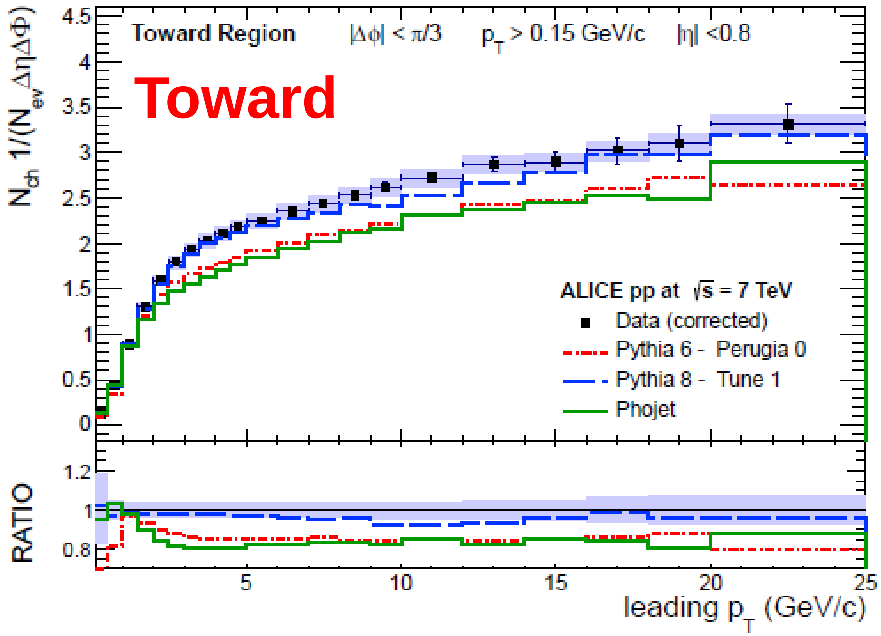
- UE is the sum of all processes that build up the final hadronic state in a collision excluding the hardest partonic interaction
  - Fragmentation of beam remnants
  - ISR and FSR
  - Multiple parton interactions
- Experimental approximation of the hardest partonic interaction
  - Leading jet or leading track in detector acceptance

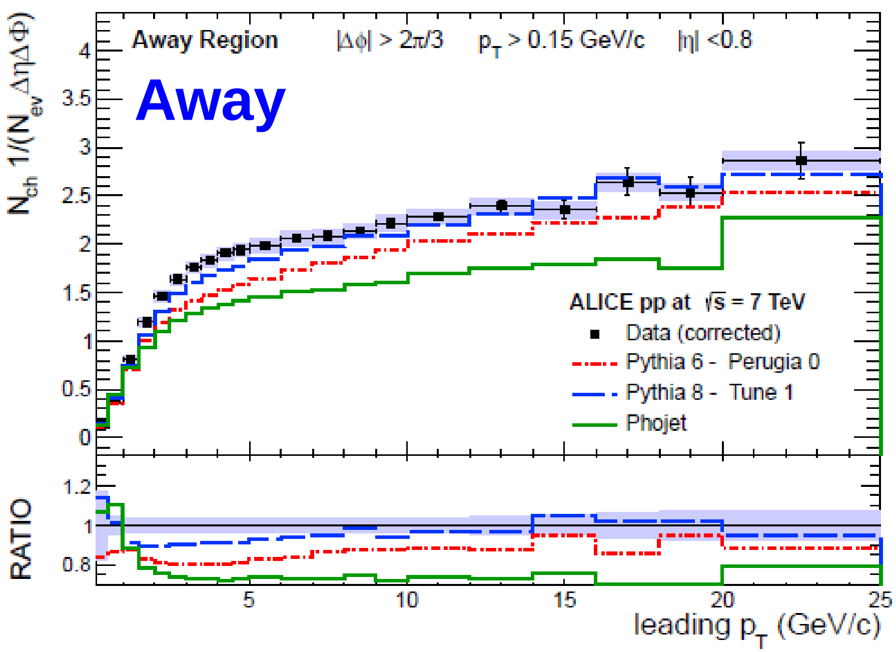


JHEP **1207**, 116 (2012)

- Analysis of particle production w.r.t. the leading particle
  - **Toward**: $|\Delta\Phi| < 1/3\pi$
  - **Away**: $|\Delta\Phi| > 2/3\pi$
  - **Transverse**: $1/3\pi < |\Delta\Phi| < 2/3\pi$

UE: Charged Particle Density

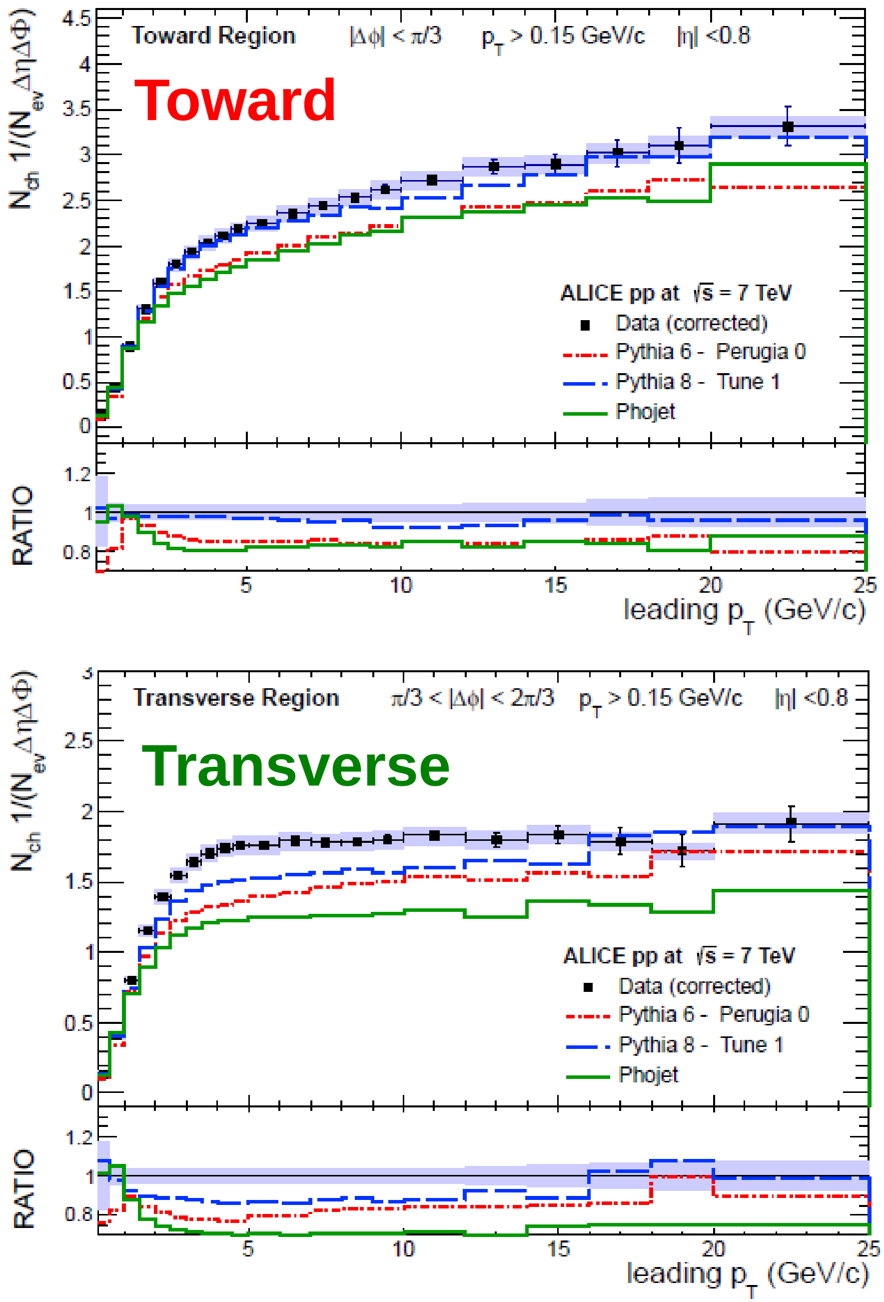




JHEP **1207**, 116 (2012)

- Charged particle density versus p_T of leading particle in detector acceptance of $|\eta| < 0.8$
- **Toward** and **Away** region
  - Fragmentation products of the two back-to-back outgoing partons
  - Increases with p_T of leading particle

UE: Charged Particle Density



JHEP **1207**, 116 (2012)

Transverse region

- Sensitive to underlying event
- Rise up to $p_{T,leading}$ = 5 GeV/c
  - $p_{T,leading}$ increases if N_{ch} increases
- Plateau from $p_{T,leading}$ > 5 GeV/c
  - Hard and soft decouples
  - High $p_{T,leading}$ also at low N_{ch} → jets
- Height of plateau sensitive to multiple parton interactions
  - Independent uncorrelated scatterings

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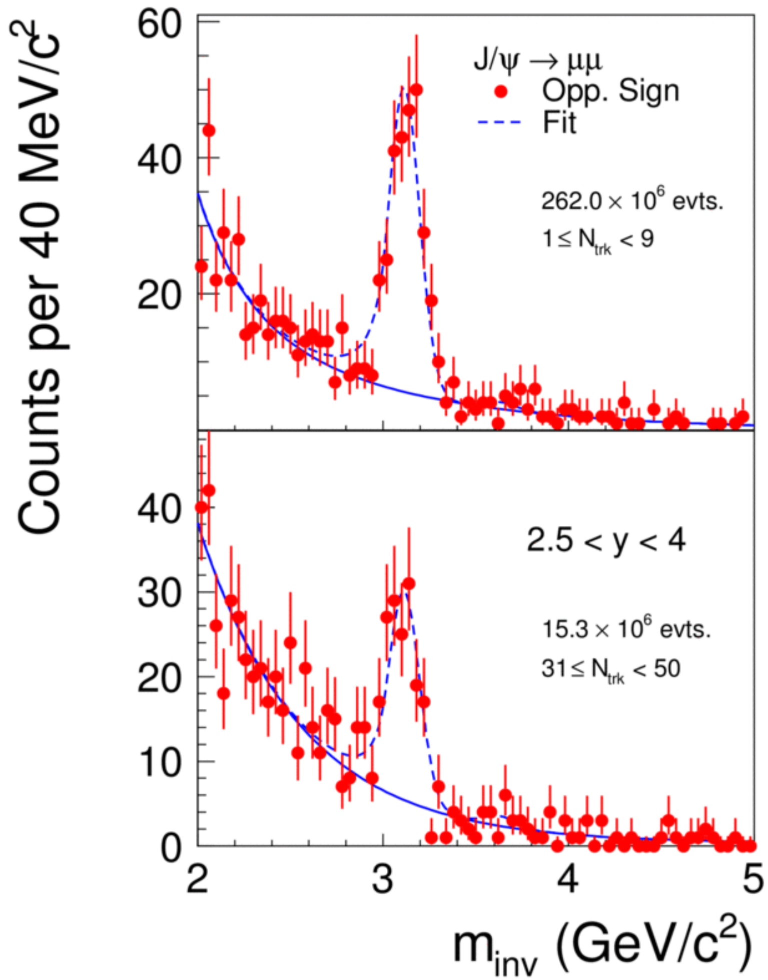
J/ψ and D-Meson Yields

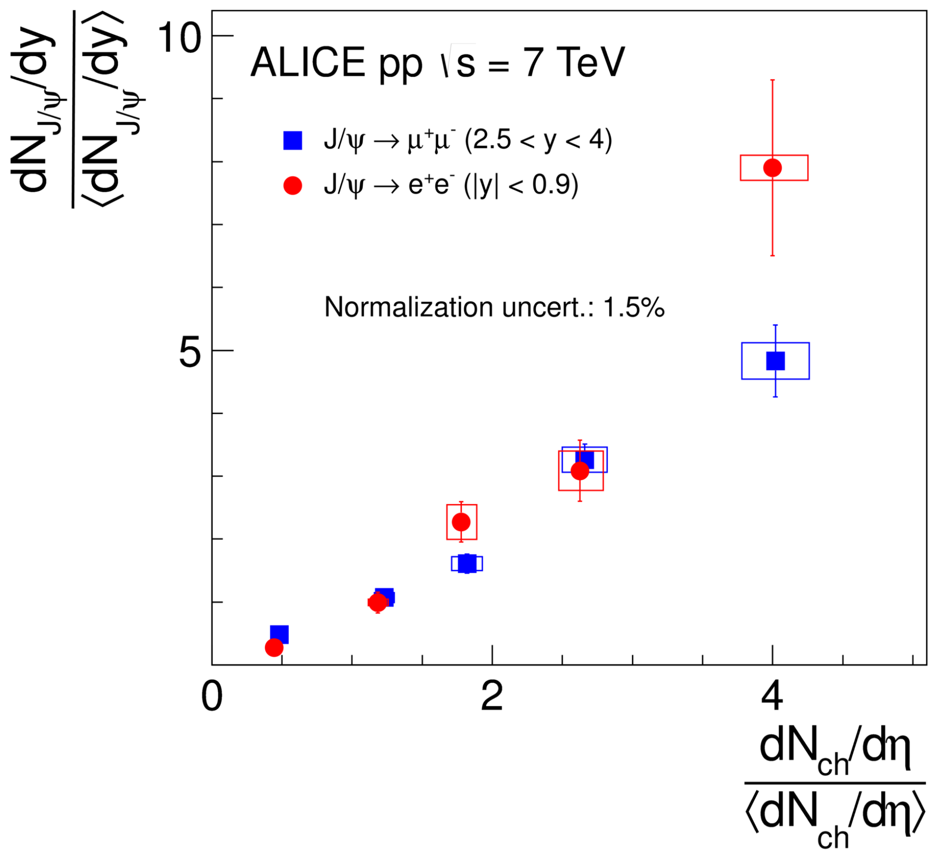
- Measurement of J/ψ yield with p_T>0 GeV/c from
  - $J/\psi \rightarrow e^+e^-$ in $|y| < 0.9$
  - $J/\psi \rightarrow \mu^+\mu^-$ in $2.5 < y < 4$
- Measurement of D-meson yield in $|y| < 0.5$ from
  - $D^0 \rightarrow K\pi$
  - $D^+ \rightarrow K\pi\pi$
  - $D^{*+} \rightarrow D^0\pi$
- Measurement as function of the charged particle density dN_{ch}/dy

- Example: J/ψ reconstruction from $\mu^+\mu^-$



Phys. Lett. B **712**, 165 (2012)

J/ψ Yield versus dN_{ch}/dy



- Approximately linear increase of J/ψ yield (p_T>0 GeV/c) with charged particle density
- Highest charged particle density bin corresponds to 4 times the minimum bias (MB) density
- Enhancement of J/ψ yield relative to averaged yield in MB events for both rapidity ranges
  - Factor of 8 for $|y| < 0.9$
  - Factor of 5 for $2.5 < y < 4$

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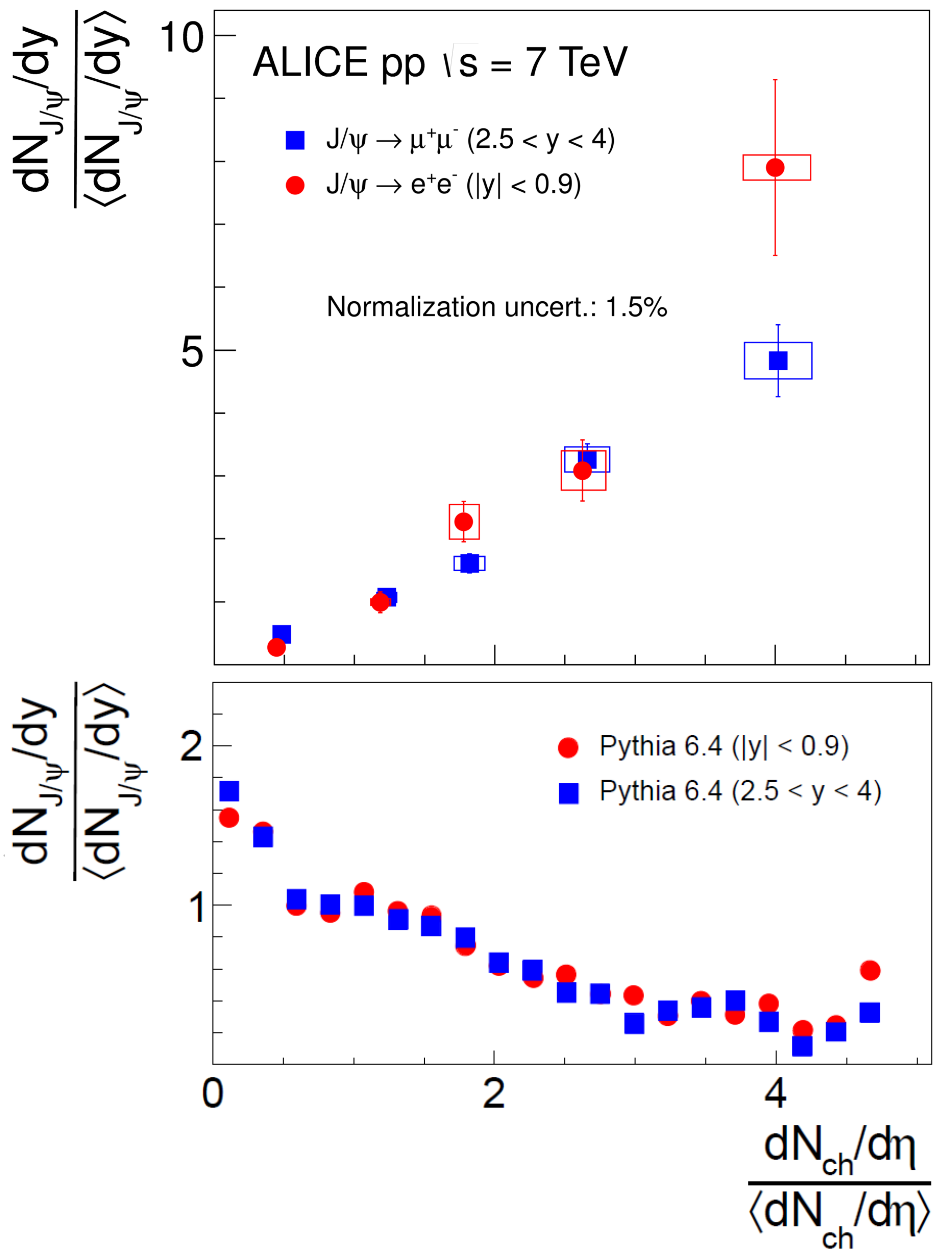

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- Correlation is not reproduced by Pythia6.4 Perugia-2011

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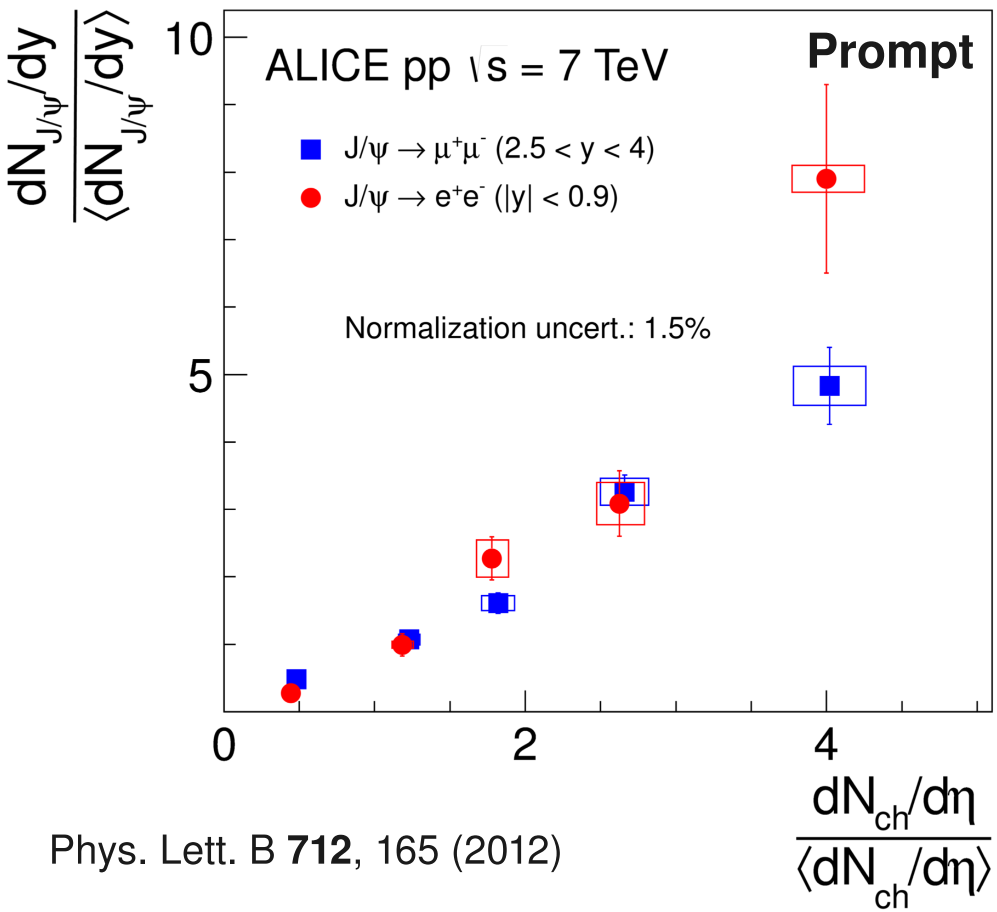
J/ψ Yield versus dN_{ch}/dy



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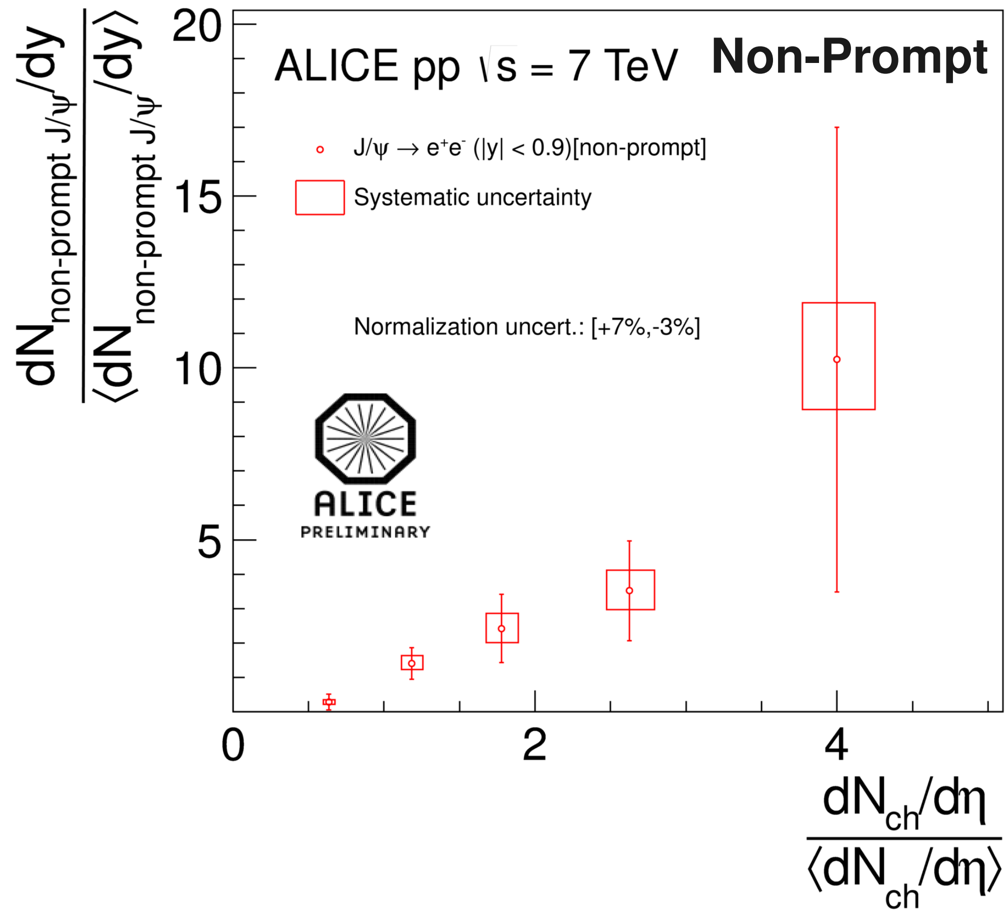
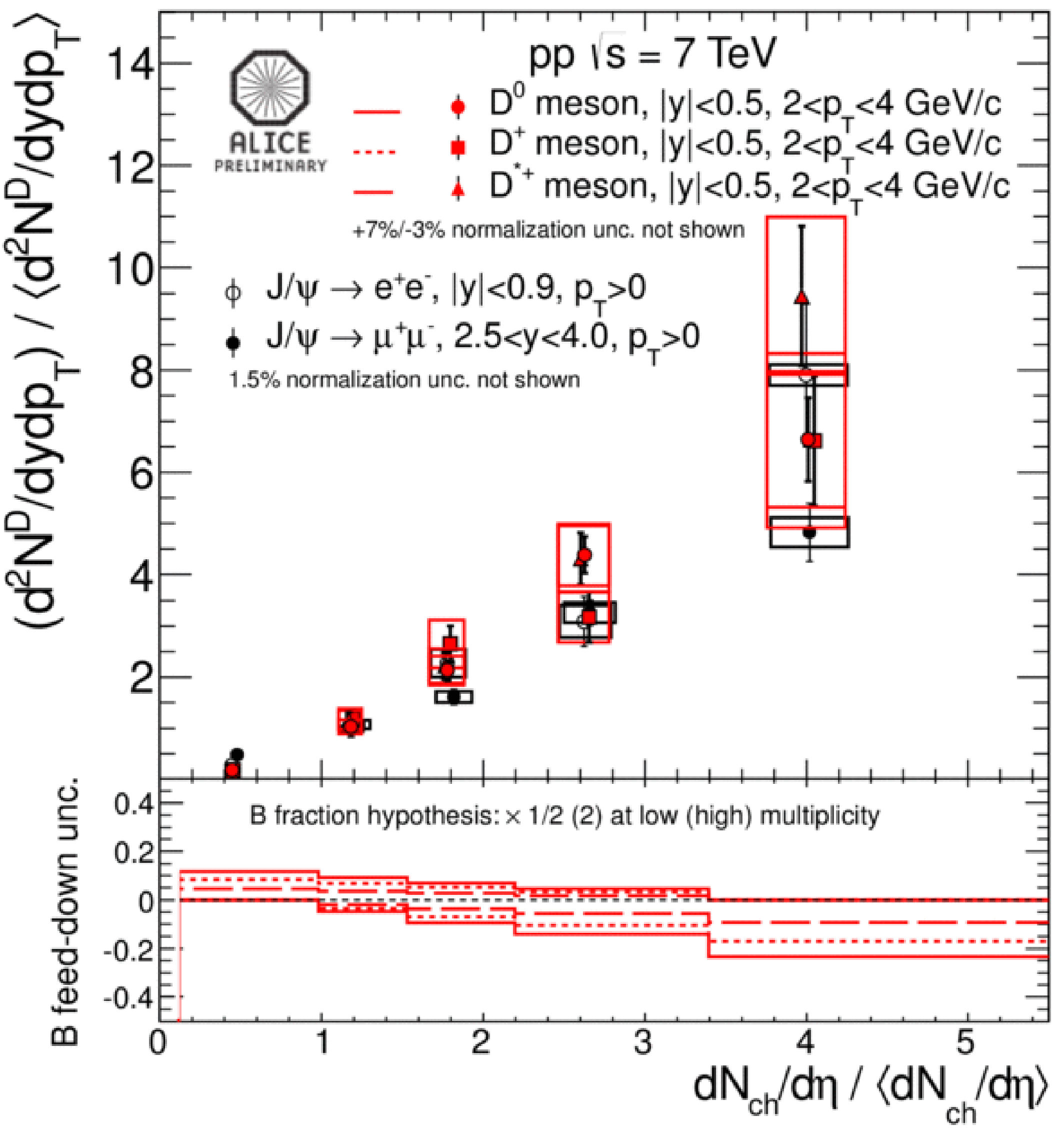


- Linear dependence between J/ψ yield with charged particle density also for non-prompt J/ψ ($|y| < 0.9$, $p_T > 0$ GeV/c)
- Non-prompt J/ψ are measurement for b-hadron yield

D-Meson Yield versus dN_{ch}/dy



- Approximately linear increase also for prompt *D*-meson yield as function of charged particle density similar to *J/ψ*
- Linear dependence given for several bins in transverse momentum, e.g.
  - From $1 < p_T < 2$ GeV/c up to $8 < p_T < 12$ GeV/c
- Consistent results for D^0, D^+, D^{*+}
- Behavior reproduced by Pythia8.157, SoftQCD tune

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Event Shape Analysis: Sphericity

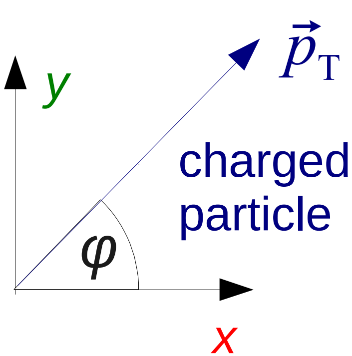
- Transverse sphericity S_T is defined in terms of the eigenvalues λ_1 and λ_2 of the linearized transverse momentum matrix $S^L_{x,y}$

$$S^{L}_{x,y}=\frac{1}{\sum_i p_{T,i}}\sum_i \frac{1}{p_{T,i}}\begin{pmatrix} p^2_{x,i} & p_{x,i}\,p_{y,i} \\ p_{x,i}\,p_{y,i} & p^2_{y,i}\end{pmatrix} \rightarrow S_T=\frac{2\lambda_2}{\lambda_1+\lambda_2}$$

- S_T is infrared safe and co-linear safe

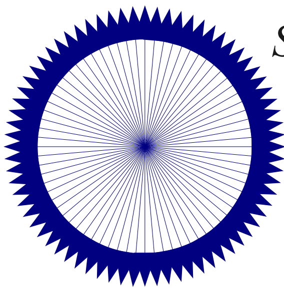
- Characterize transverse event shape in proton-proton collisions with S_T

- Examples:



$S_T=0$

Pencil like



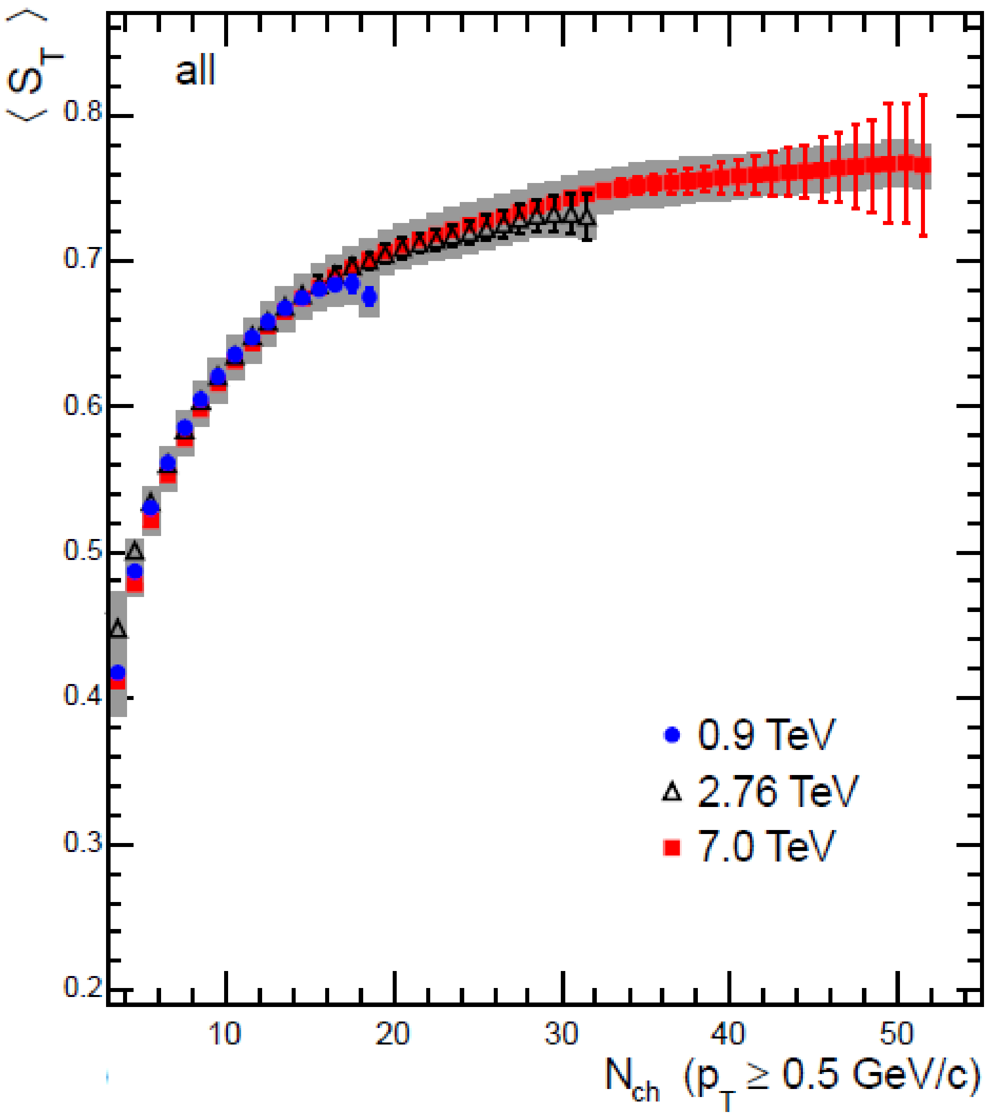
$S_T \lesssim 1$

Quite isotropic

$S_T \rightarrow 1$

in the isotropic limit

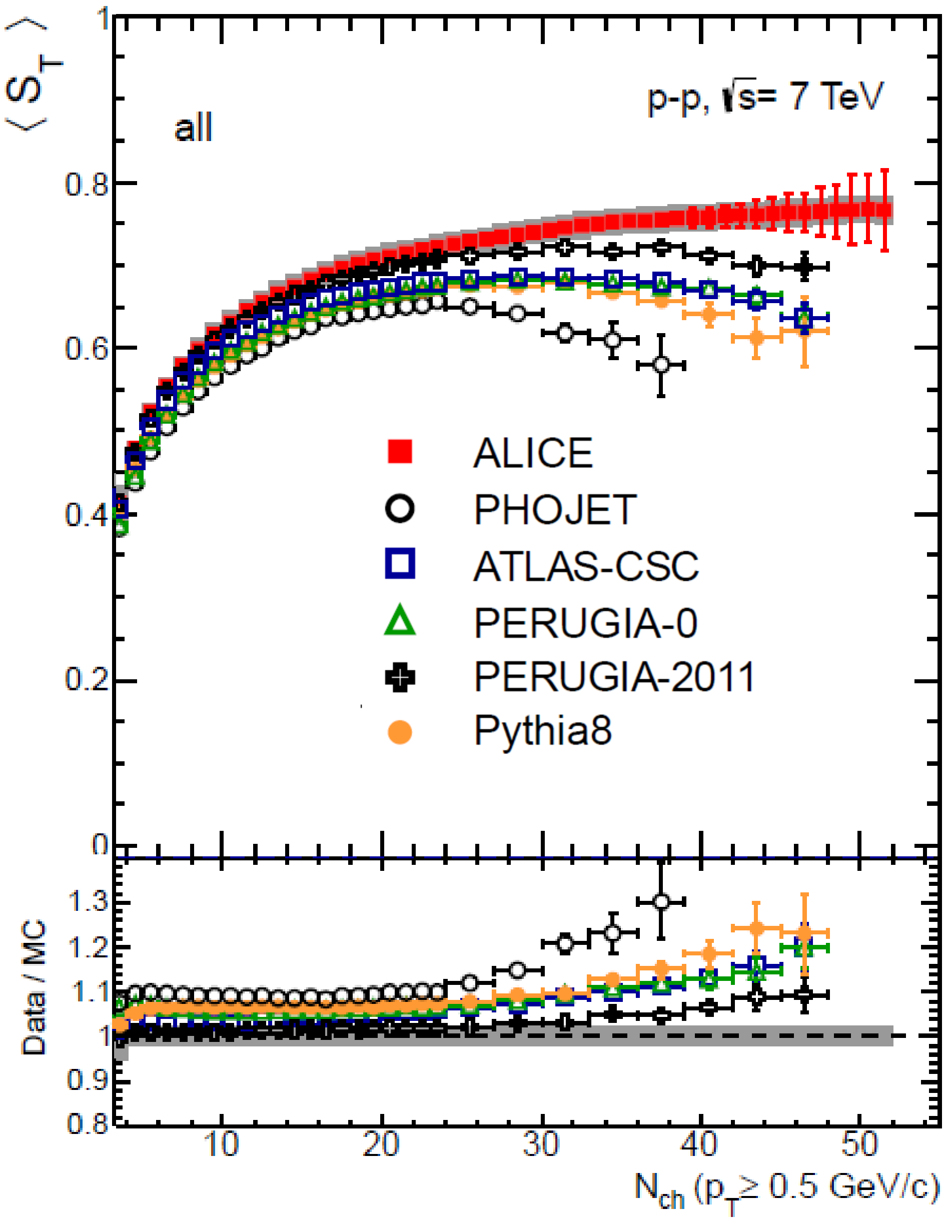
Mean Transverse Sphericity



Eur. Phys. J. C **72**, 2124 (2012)

- Transverse sphericity grows as function of the charged particle multiplicity
- Possible interpretation:
  - High multiplicity events comprise particles from several independent sources of particle production $\rightarrow$ particle production independent in the azimuthal angle φ
- For same N_{ch}, almost no center-of-mass energy dependence

Mean Transverse Sphericity



- Data prefers model with softer fragmentation than in pre-LHC tunes
  - Best agreement for Pythia6.4 Perugia-2011
  - Larger underlying event and slightly softer fragmentation than in pre-LHC tunes

Eur. Phys. J. C **72**, 2124 (2012)

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Multiple Parton Interactions and Jets

- One parton-parton interaction can produce one di-jet
- Multi-jet events with pair-wise p_T-balanced jets can be produced in multi parton interactions

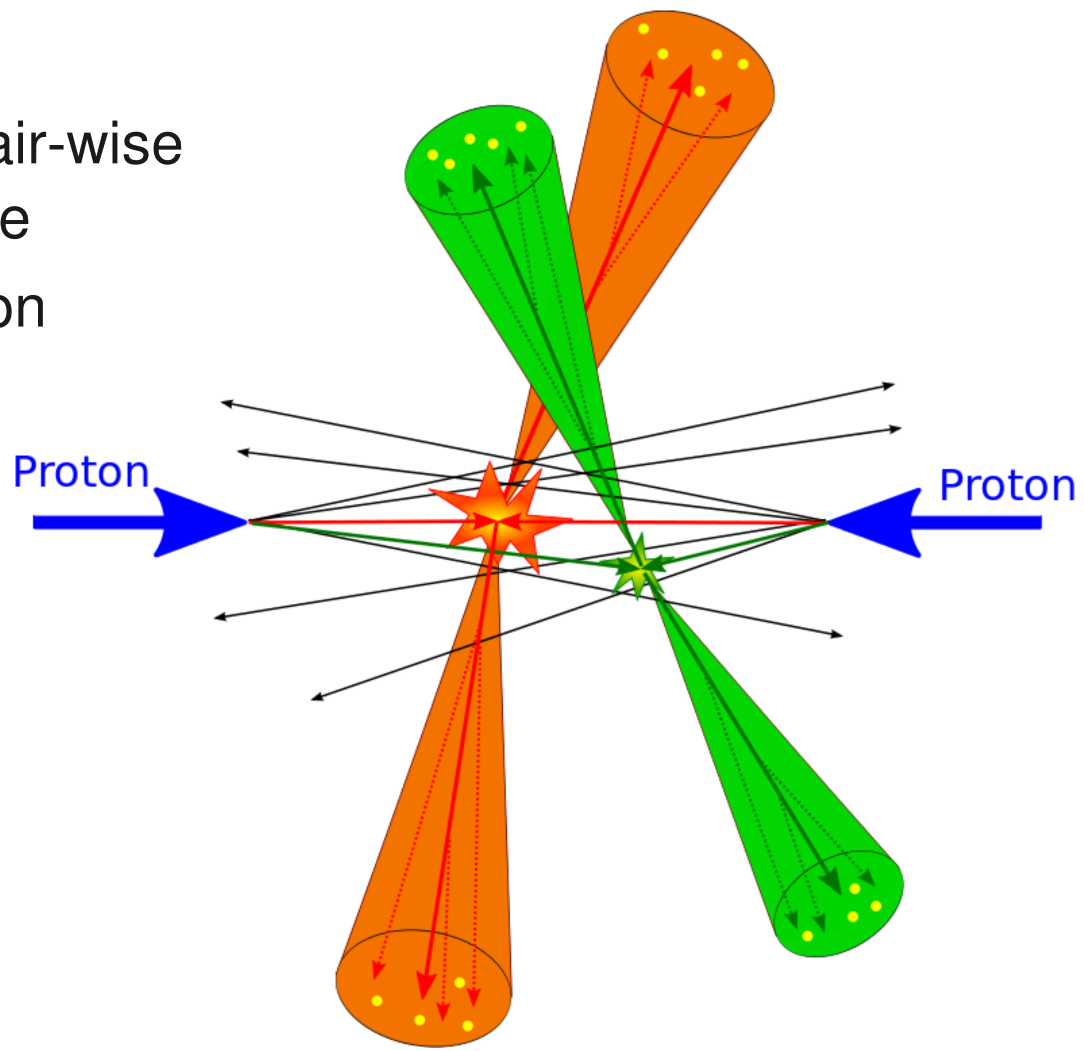
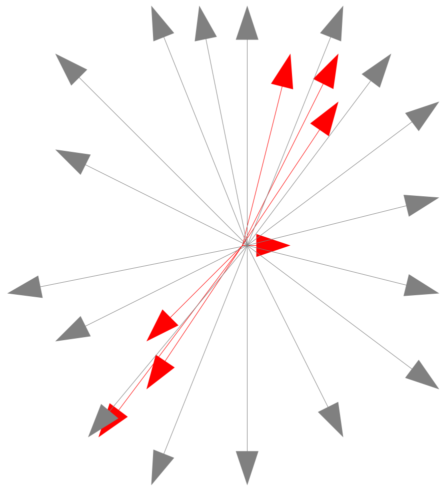


Figure: inspired by R. Field

Jet Measurement at High N_{ch}

- Low-energy jets at high N_{ch}
  - Reconstructed jet energy can be biased significantly in events with high charged particle multiplicity



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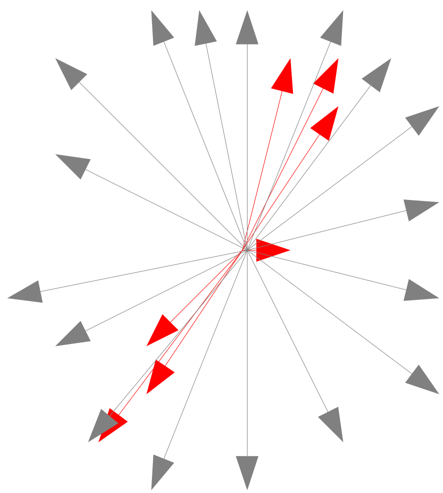
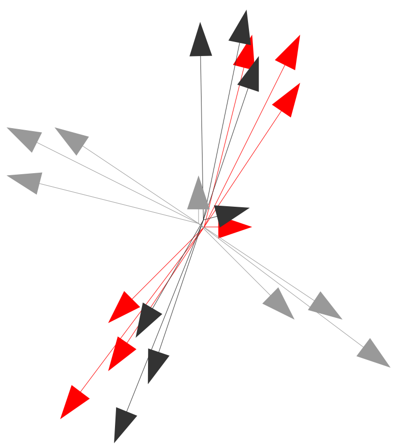
  - Jets might overlap





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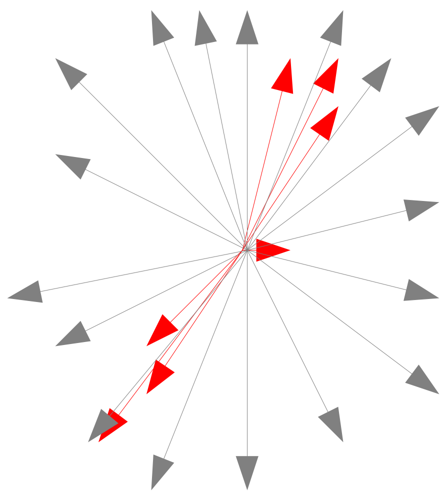
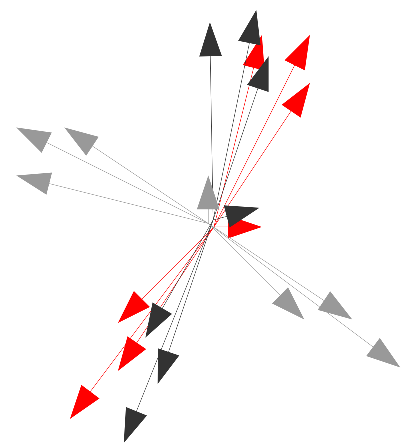
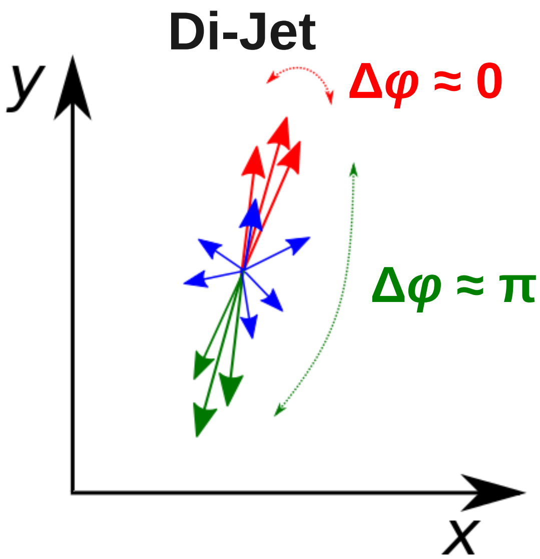




- Event-by-event jet reconstruction in these cases not possible
- Solution: Statistical analysis (= correlation averaged over many events) of the jet properties

Two-Particle Angular Correlations



- Measure distances between particle pairs of trigger particles ($p_T > p_{T,\,trig}$ with $p_{T,\,trig} >> \Lambda_{QCD}$) and associated particles ($p_T > p_{T,\,assoc}$)
- Distance in terms of azimuthal angle φ

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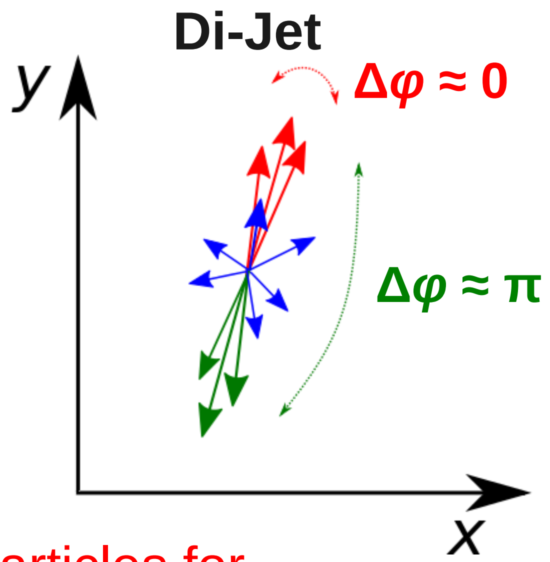

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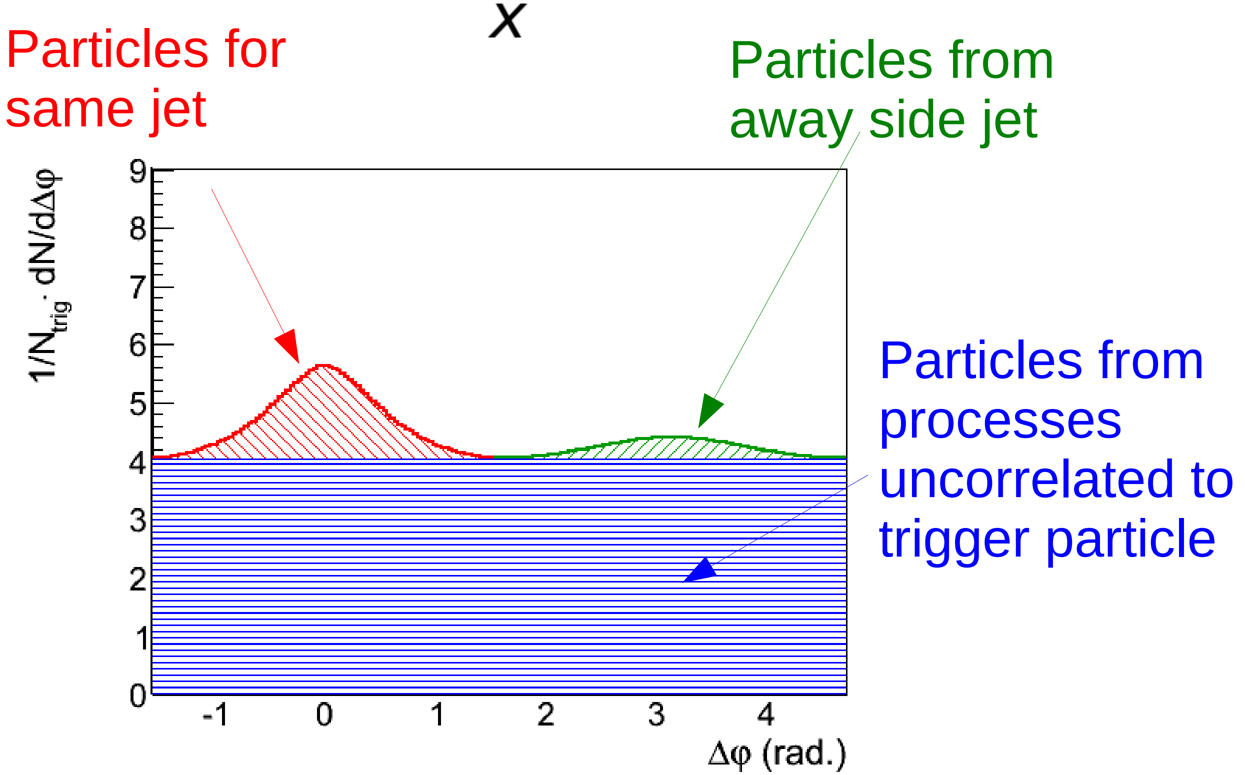

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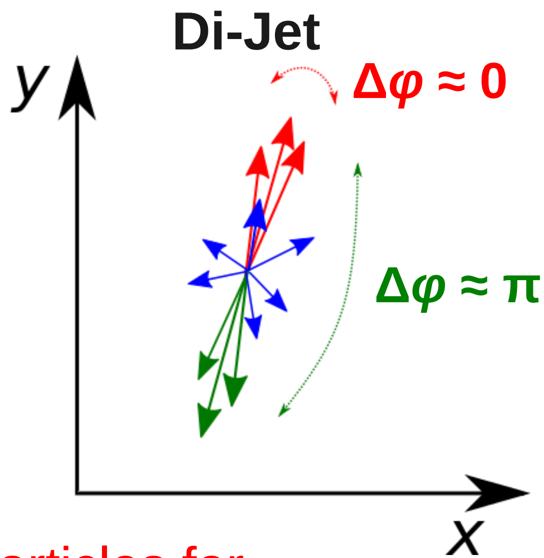

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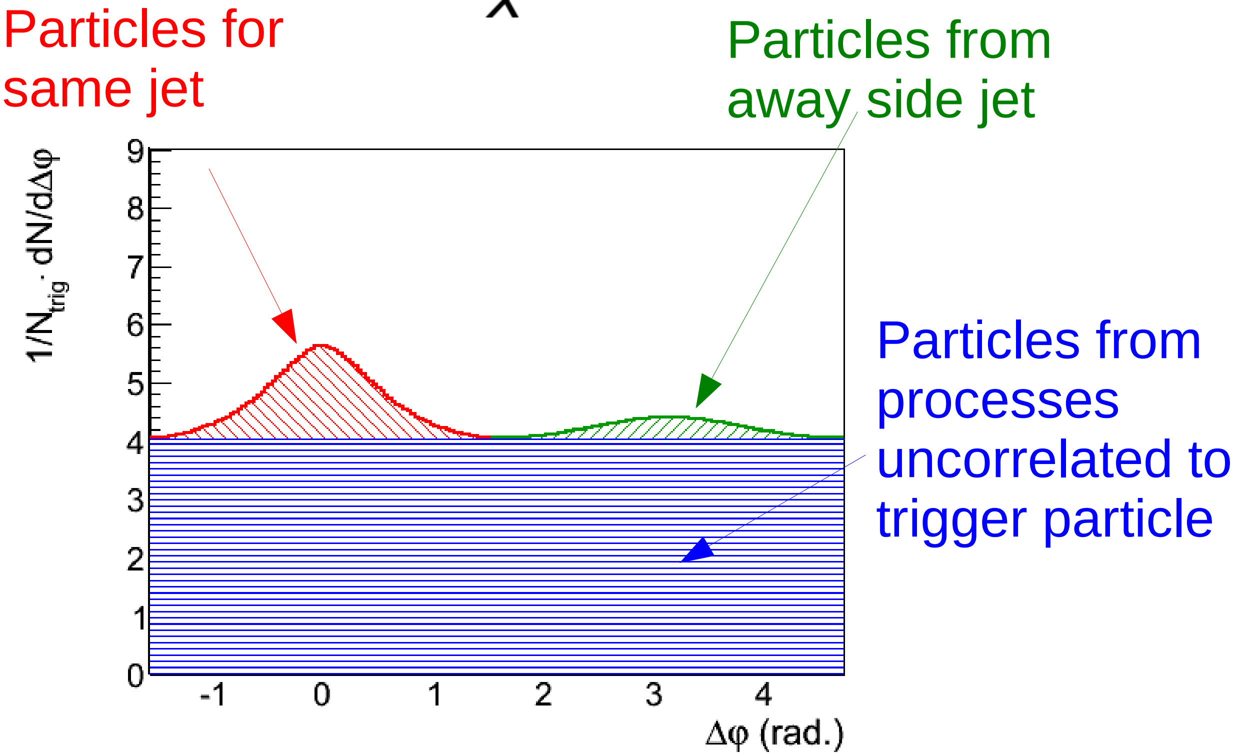
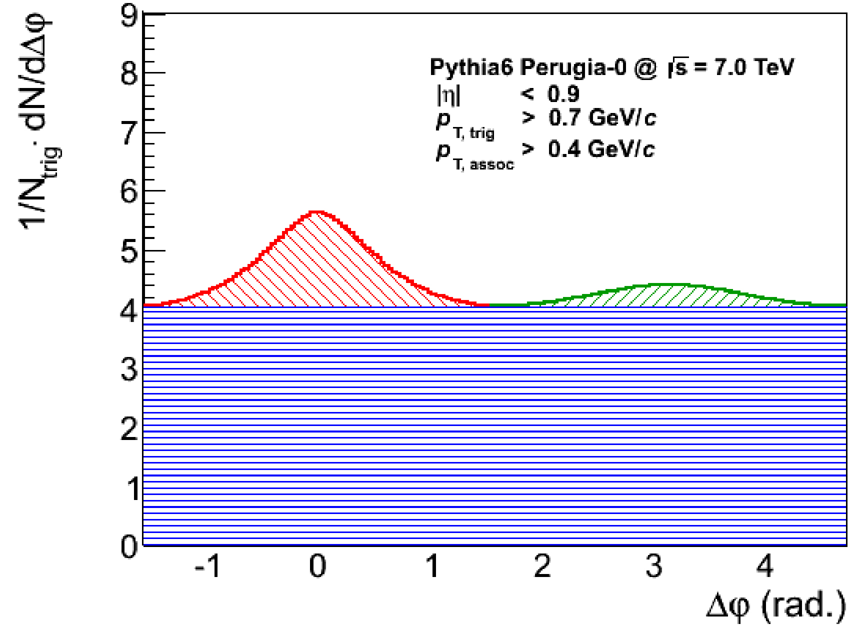


- Further possible contributions can be neglected when choosing $p_{T,trig}^{max} > 0.7$ GeV/c
  - Particle decay
  - Photon conversion
  - Hanbury Brown and Twiss effect (HBT)

Yield Extraction of Azimuthal Correlation

- Azimuthal correlation can be divided into three contributions: background and two peaks



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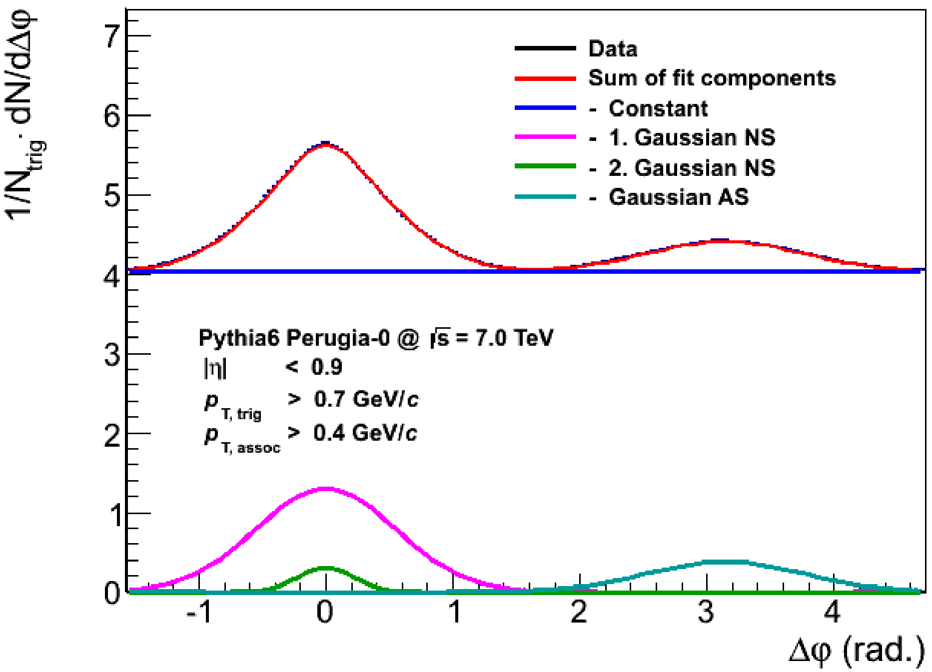
- Fit function: Combination of constant and Gaussian functions

$$f(\Delta\varphi) = C + A_1 e^{\frac{-\Delta\varphi^2}{2\sigma_1^2}} + A_2 e^{\frac{-\Delta\varphi^2}{2\sigma_2^2}} + A_3 e^{\frac{-(\Delta\varphi-\pi)^2}{2\sigma_3^2}}$$



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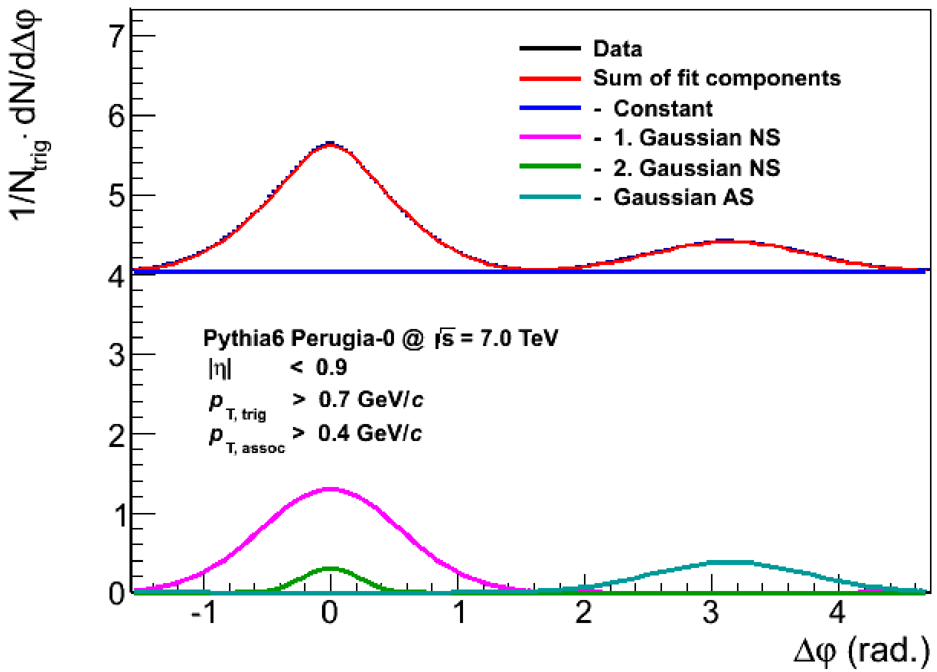

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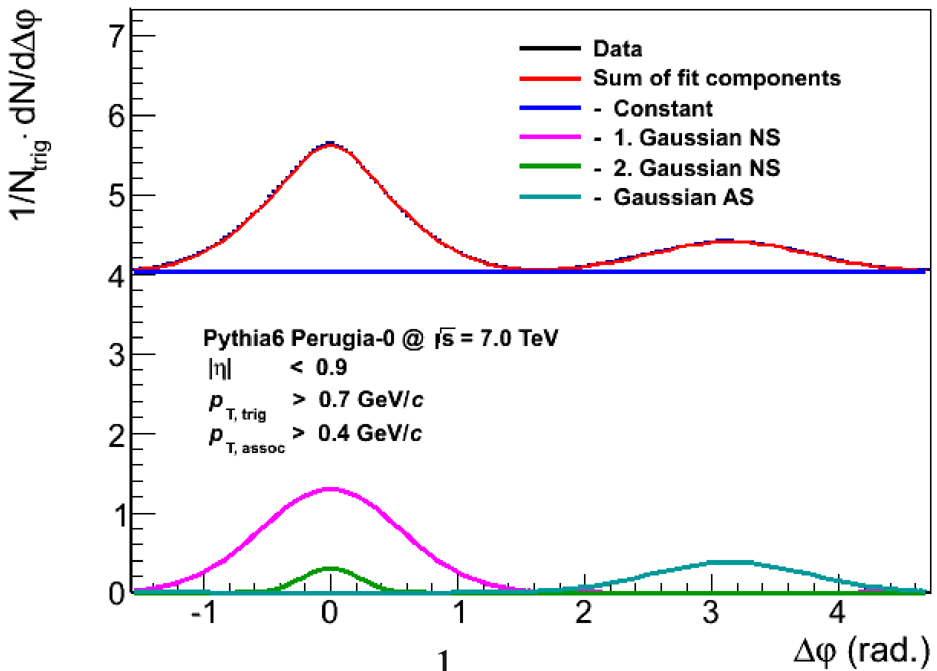


$$\langle N_{\text{isotrop}} \rangle = \frac{1}{N_{\text{trigger}}} \cdot C$$

$$\langle N_{\text{assoc, near side}} \rangle = \frac{1}{N_{\text{trigger}}} \sqrt{2\pi} (A_1 \sigma_1 + A_2 \sigma_2)$$

$$\langle N_{\text{assoc, away side}} \rangle = \frac{1}{N_{\text{trigger}}} \sqrt{2\pi} (A_3 \sigma_3)$$

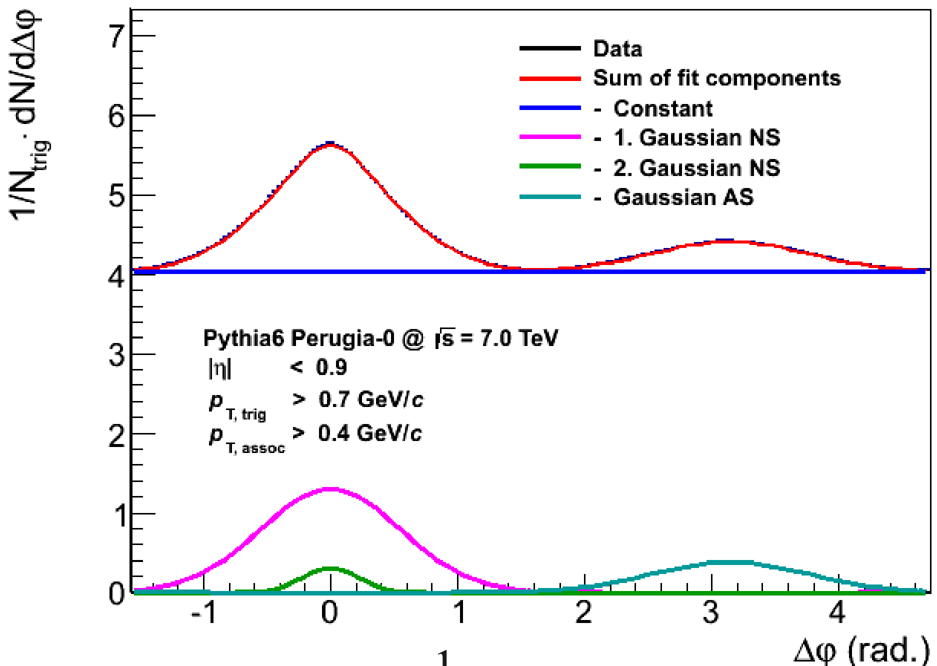
$$\langle N_{\text{trigger}} \rangle = \frac{N_{\text{trigger}}}{N_{\text{event}}}$$

Yield Extraction of Azimuthal Correlation

- Azimuthal correlation can be divided into three contributions: background and two peaks
- Fit function: Combination of constant and Gaussian functions

$$f(\Delta\varphi) = C + A_1 e^{\frac{-\Delta\varphi^2}{2\sigma_1^2}} + A_2 e^{\frac{-\Delta\varphi^2}{2\sigma_2^2}} + A_3 e^{\frac{-(\Delta\varphi-\pi)^2}{2\sigma_3^2}}$$

- Data and fit are in excellent agreement, fit is stable
- Compute number of sources of particle production → possibility to access information about MPI



$$\langle N_{\text{isotrop}} \rangle = \frac{1}{N_{\text{trigger}}} \cdot C$$

$$\langle N_{\text{assoc, near side}} \rangle = \frac{1}{N_{\text{trigger}}} \sqrt{2\pi} (A_1\sigma_1 + A_2\sigma_2)$$

$$\langle N_{\text{assoc, away side}} \rangle = \frac{1}{N_{\text{trigger}}} \sqrt{2\pi} (A_3\sigma_3)$$

$$\langle N_{\text{trigger}} \rangle = \frac{N_{\text{trigger}}}{N_{\text{event}}}$$

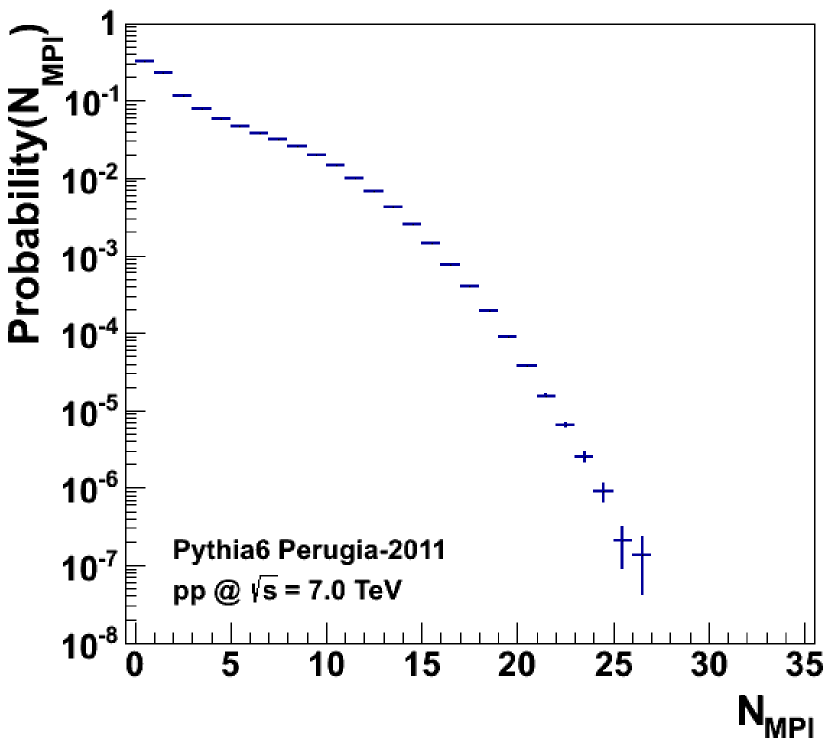
$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}} (p_T > p_{T,\text{trig}}) \rangle}$$

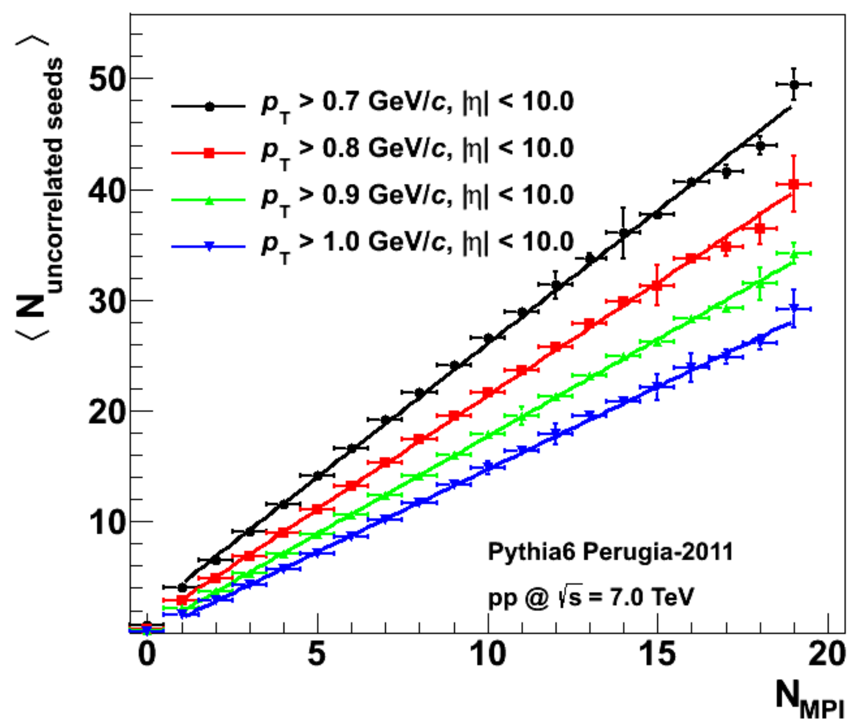
Number of Multiple Parton Interactions

- Pythia has a phenomenological model of multiple parton interactions (MPI)

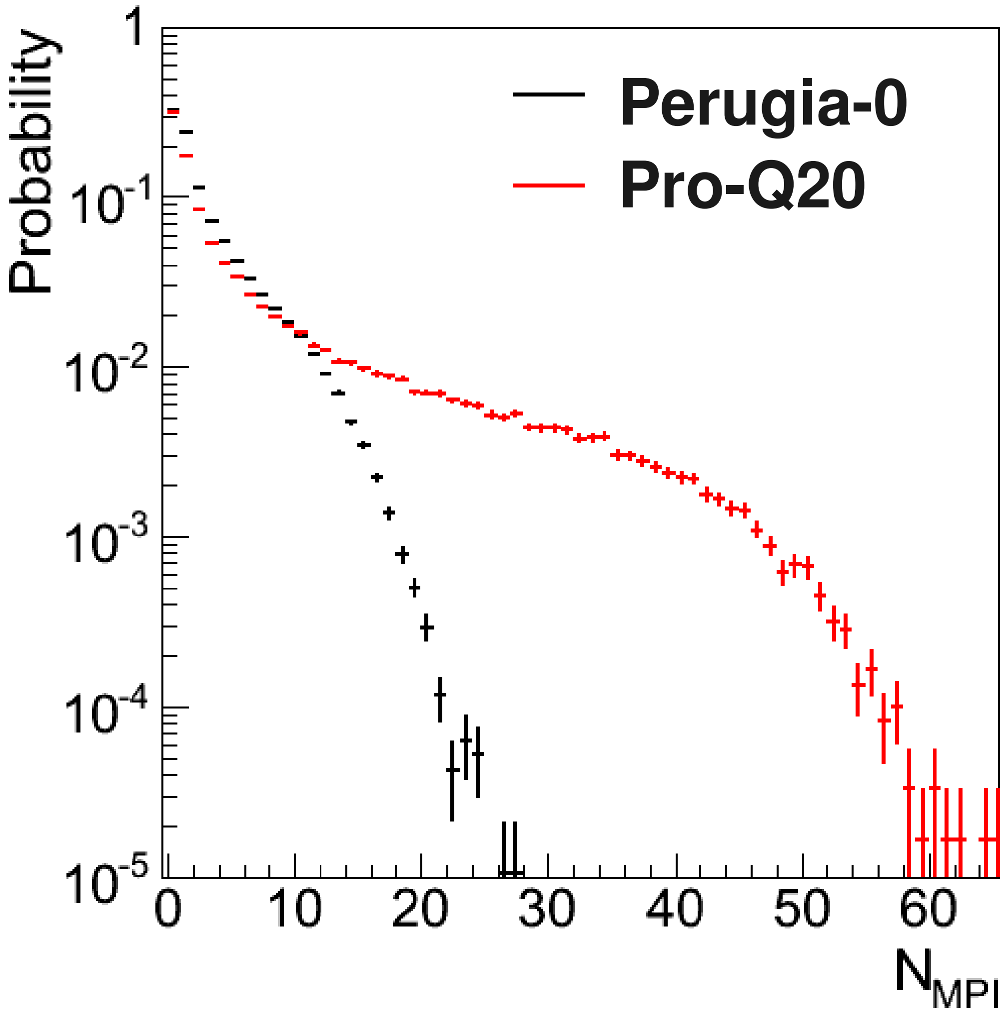
$$\langle N_{\mathrm{MPI}}(p_{\mathrm{T,\,min}})\rangle = \frac{\sigma_{\mathrm{interaction}}(p_{\mathrm{T,\,min}})}{\sigma_{\mathrm{non\text{-}diffractive}}}$$

- Within the Pythia model, N_{MPI} is proportional to the number of uncorrelated seeds $N_{\mathrm{uncorrelated\ seeds}}$
- Possibility to access N_{MPI} using presented analysis method





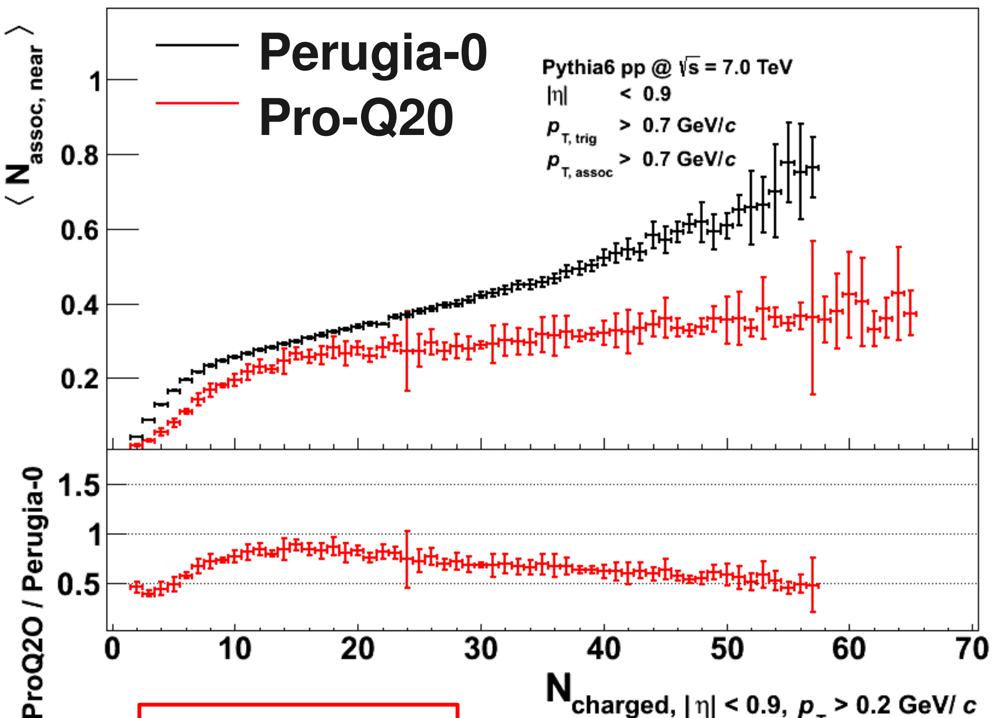
MPI in Pythia6



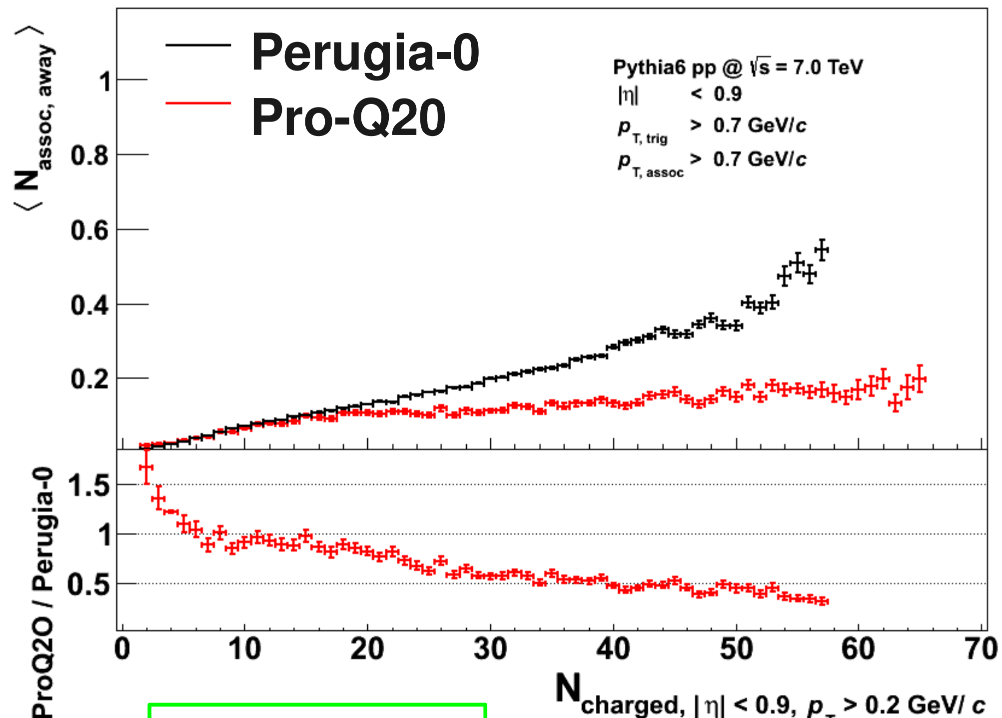
$N_{MPI} = MSTI(31)_{Pythia}$

- The Pythia tunes **Perugia-0** and **Pro-Q20** use very different number of MPI while giving similar charged particle multiplicity distributions
  - **Perugia-0** has comparably low number of MPI
  - **Pro-Q20** has higher number of MPI
- Is this visible in the correlation analysis?

Pythia6: Near/Away Side Pair Yield

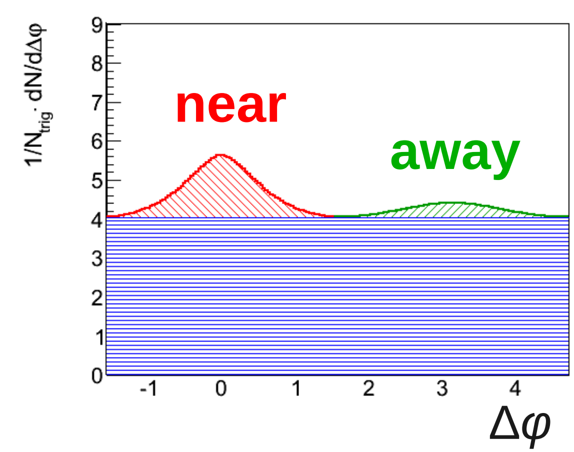


Near side

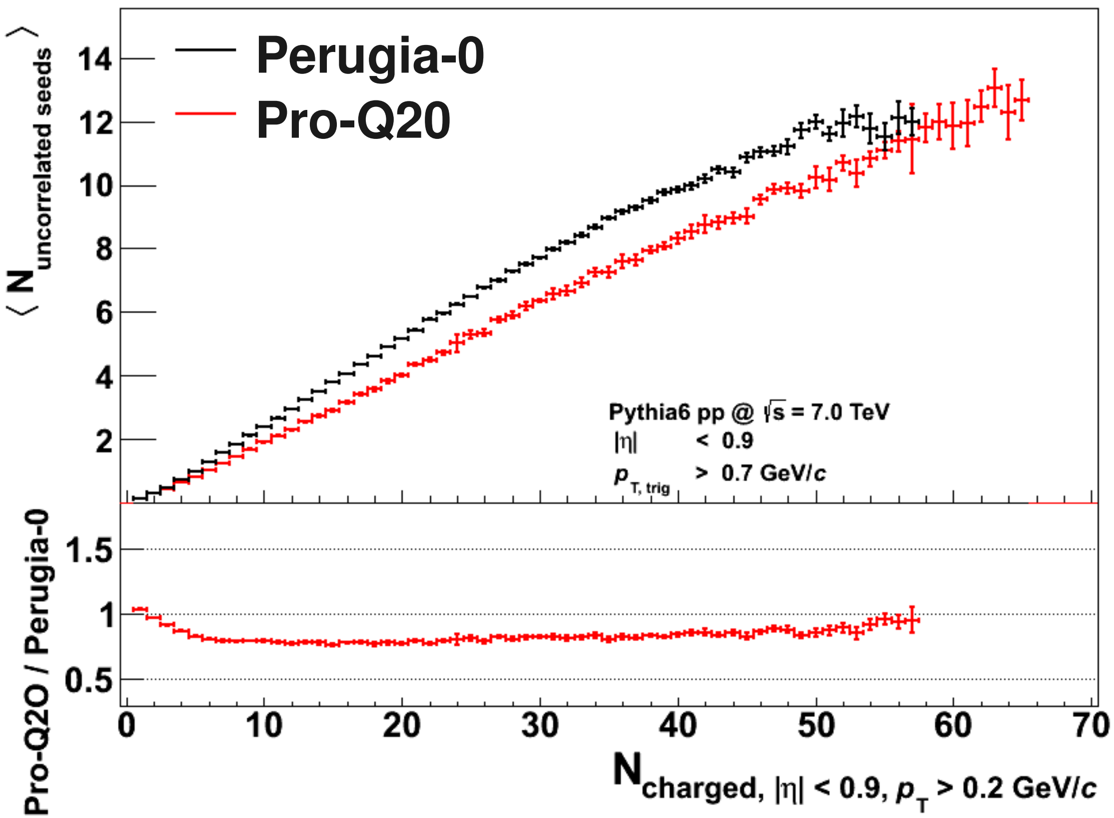


Away side

- High N_{ch} can only be reached in **Perugia-0** by increasing near and away side yield
  → fragmentation bias towards high N_{ch}
- Near and away side yield stays almost constant in **Pro-Q20** as function of N_{ch}



Pythia6: Number of Uncorrelated Seeds

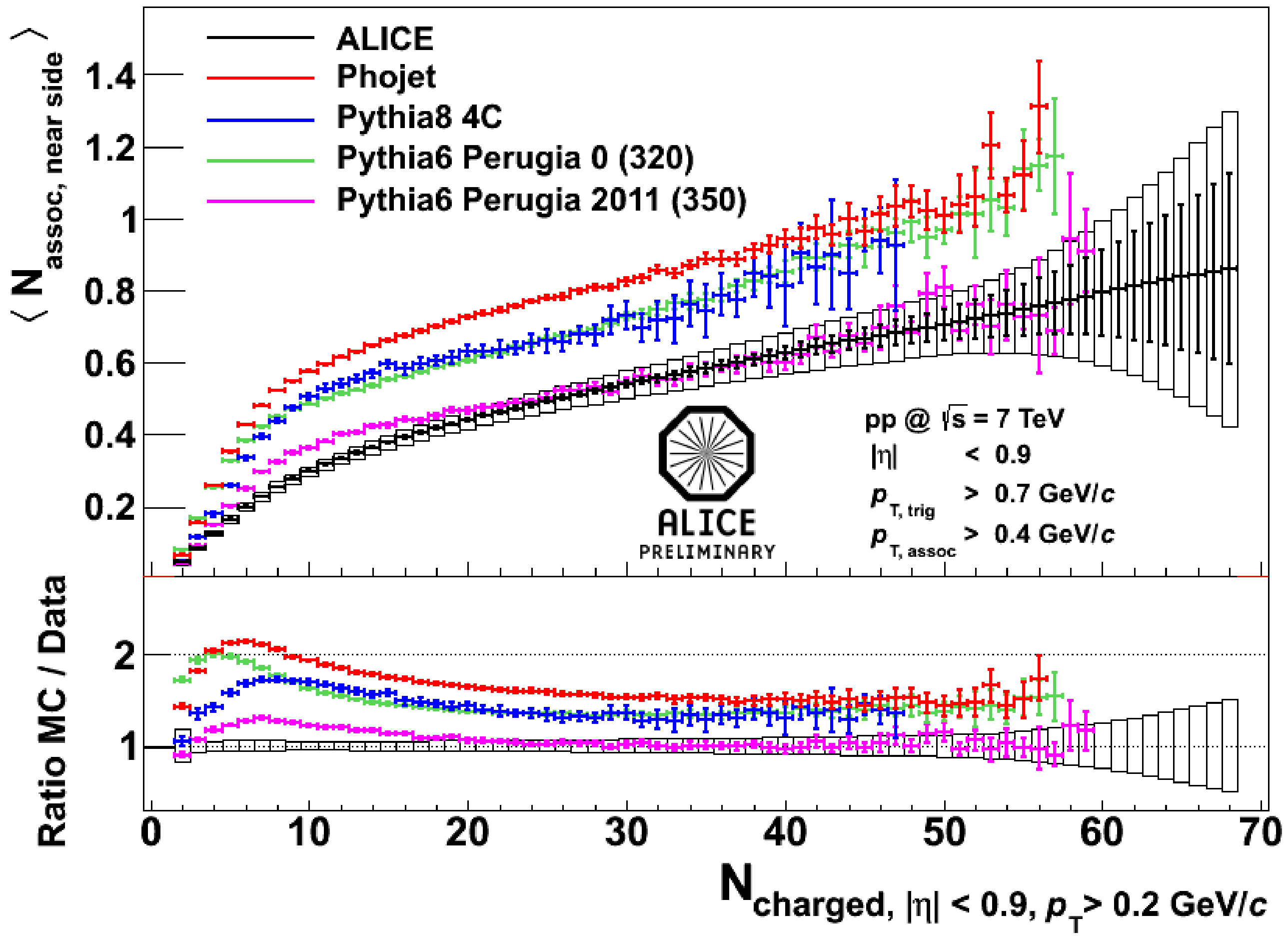


$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}}(p_T > p_{T,\text{trig}}) \rangle}$$

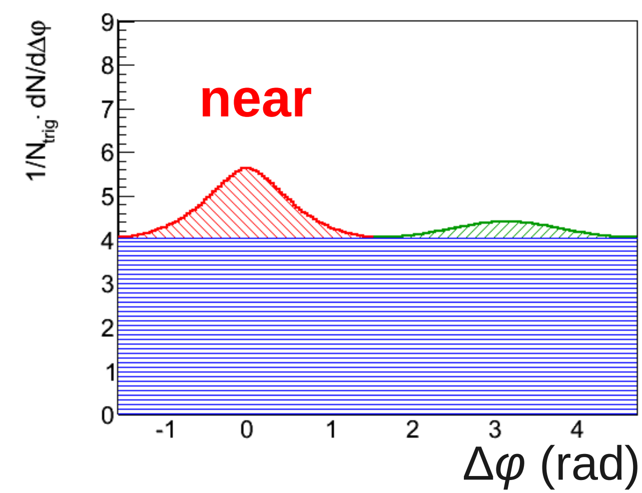
- Number of uncorrelated seeds scales linearly with the number of multiple parton interactions in Pythia6
- Number of uncorrelated seeds in **Perugia-0** reaches limit at highest charged particle multiplicities
- Uncorrelated seeds in **Pro-Q20** continues rising at same multiplicities

Results

Per-Trigger Near Side Pair Yield

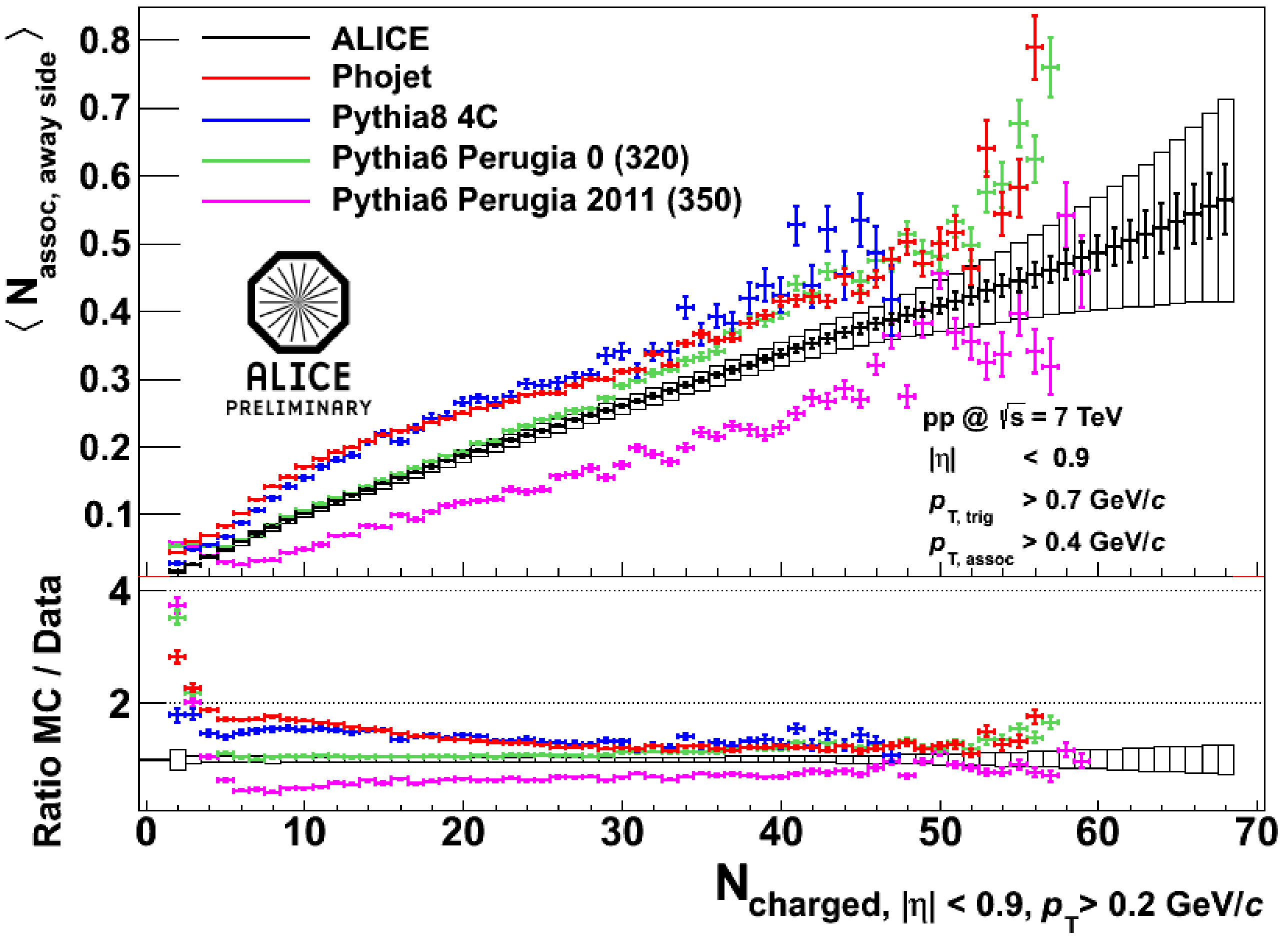


- Particle production in near side peak is dominated by jet fragmentation



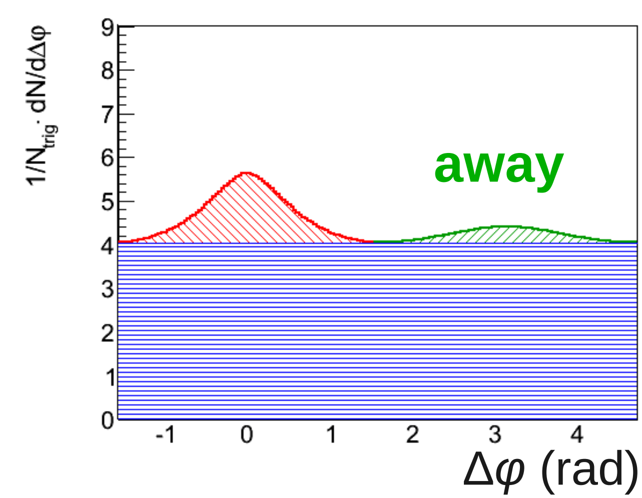
- Per-trigger near side pair yield grows with N_{ch}
- Near side is overestimated by Phojet, Pythia8, and Pythia6 Perugia-0 by up to 100%, Pythia6 Perugia-2011 gives best agreement with only small deviations

Per-Trigger Away Side Pair Yield

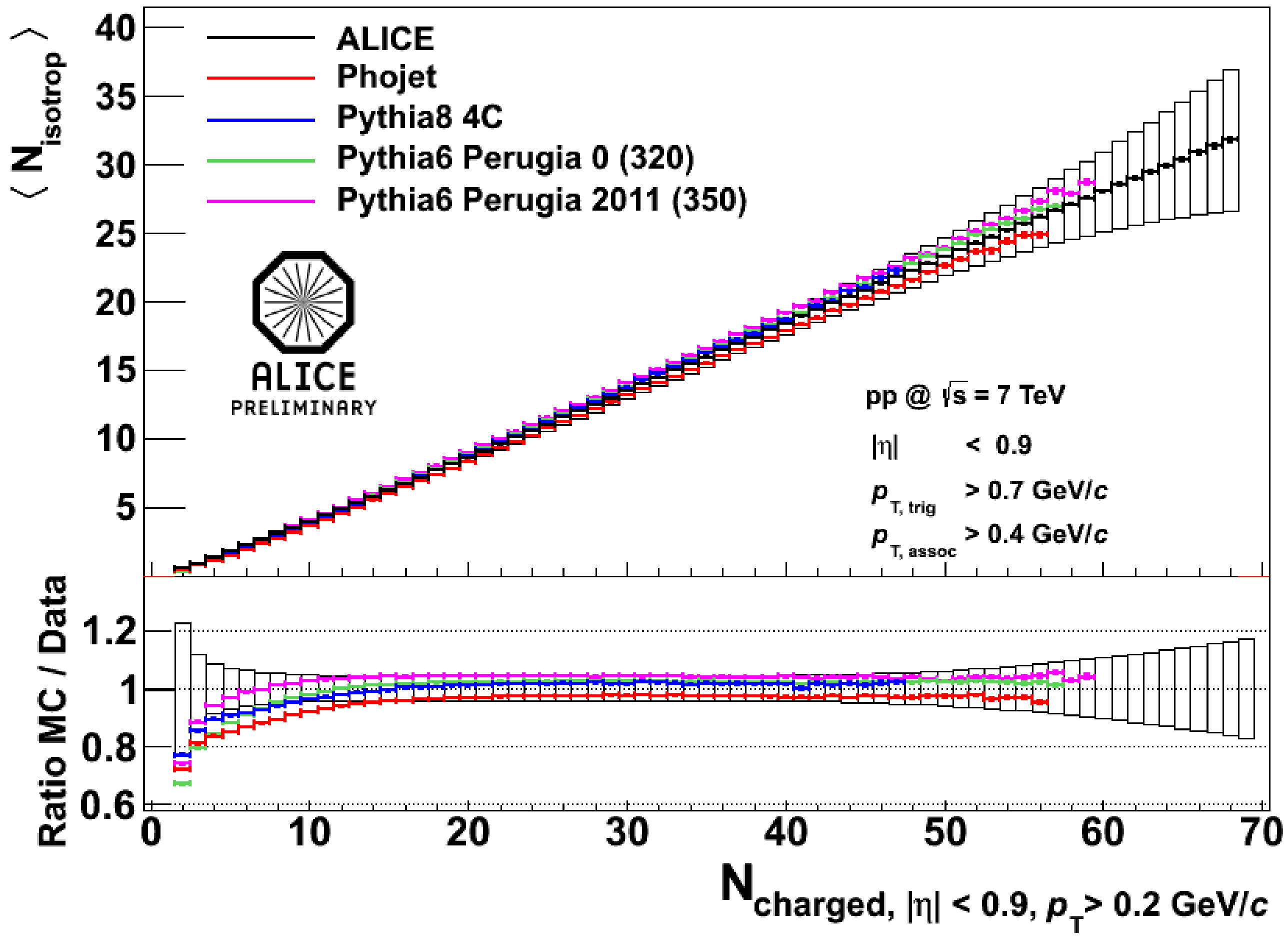


- Particles in away side peak are produced in recoiling jets

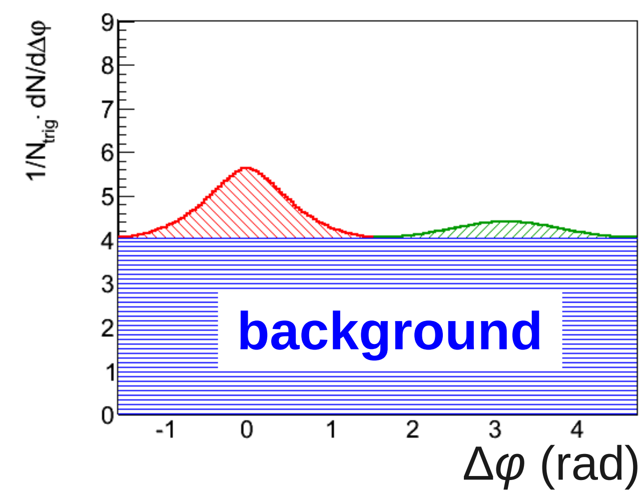
- Per-trigger away side pair yield grows with N_{ch}
- Pythia6-Perugia-0 gives best agreement with ALICE results



Pair Yield in Combinatorial Background

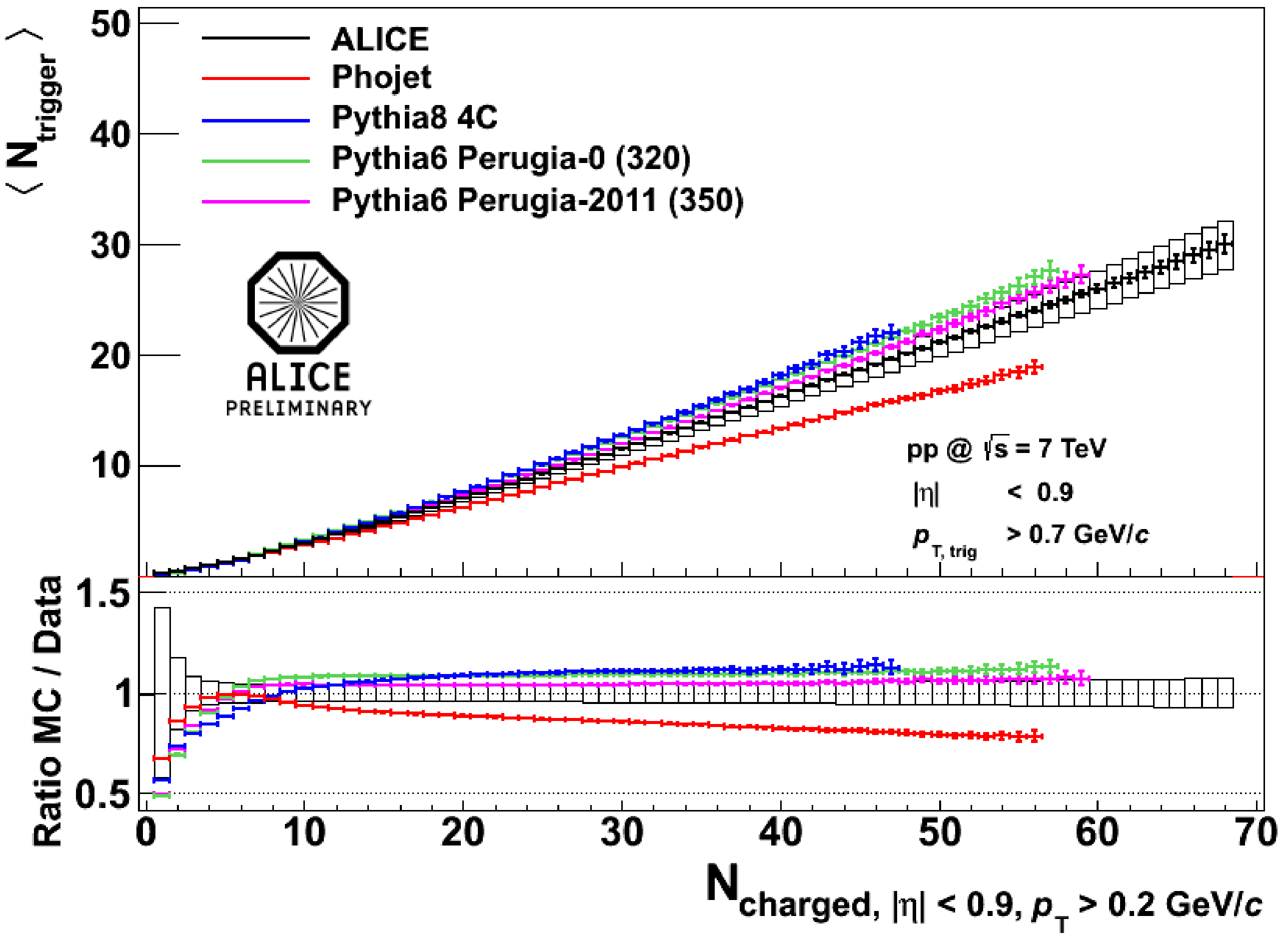


- Particles from processes which are uncorrelated to production process of trigger particle



- Pair yield in uncorrelated background is well reproduced by all models within the systematic uncertainties

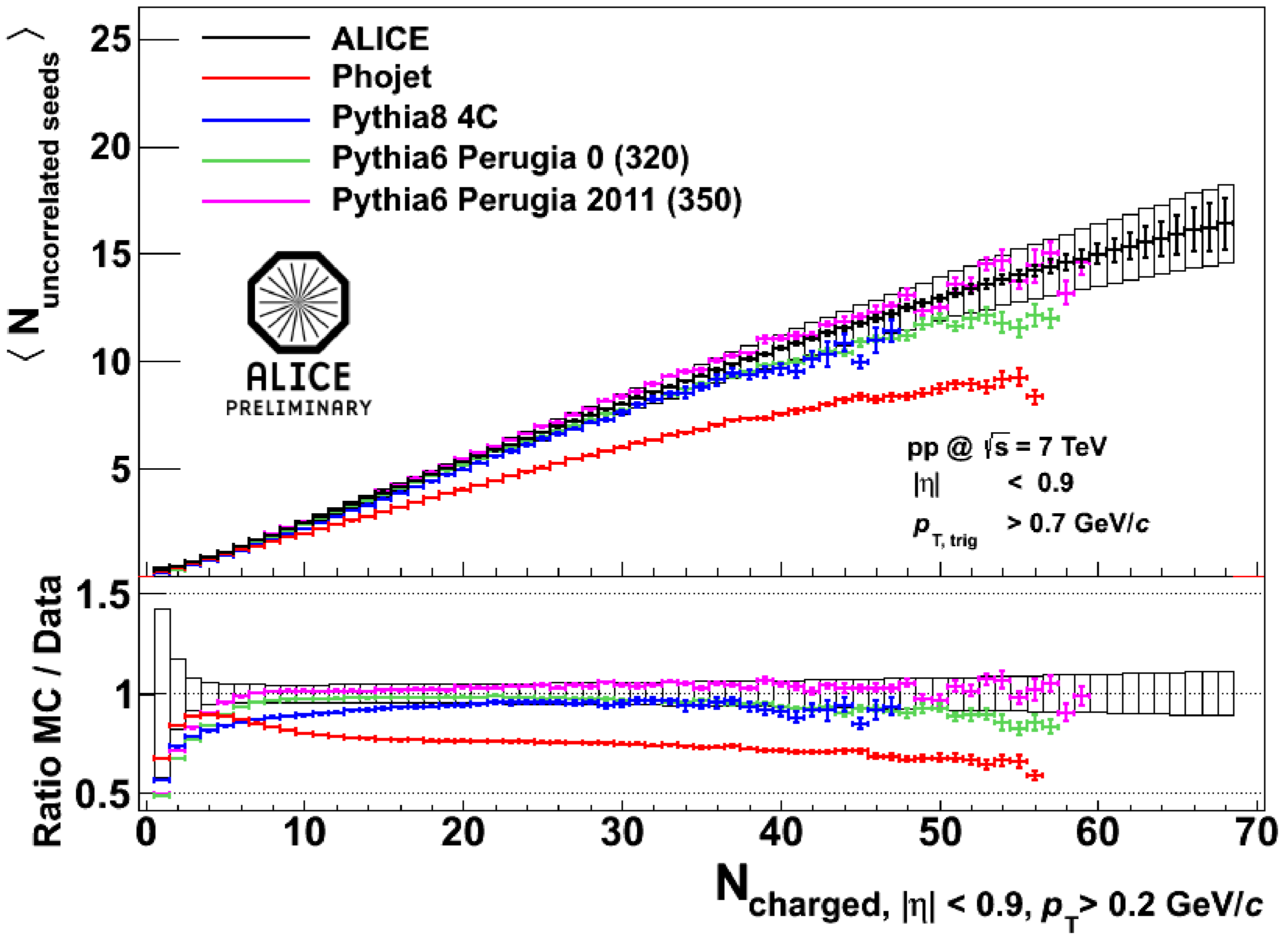
Average Number of Trigger Particles



- Average number of trigger particle contains information about MPI and fragmentation
- $N_{trigger}$ grows slightly faster than linear, growth of mean-p_T with N_{ch}

- All Pythia tunes slightly overestimate the ALICE results
- Phojet underestimated the ALICE results

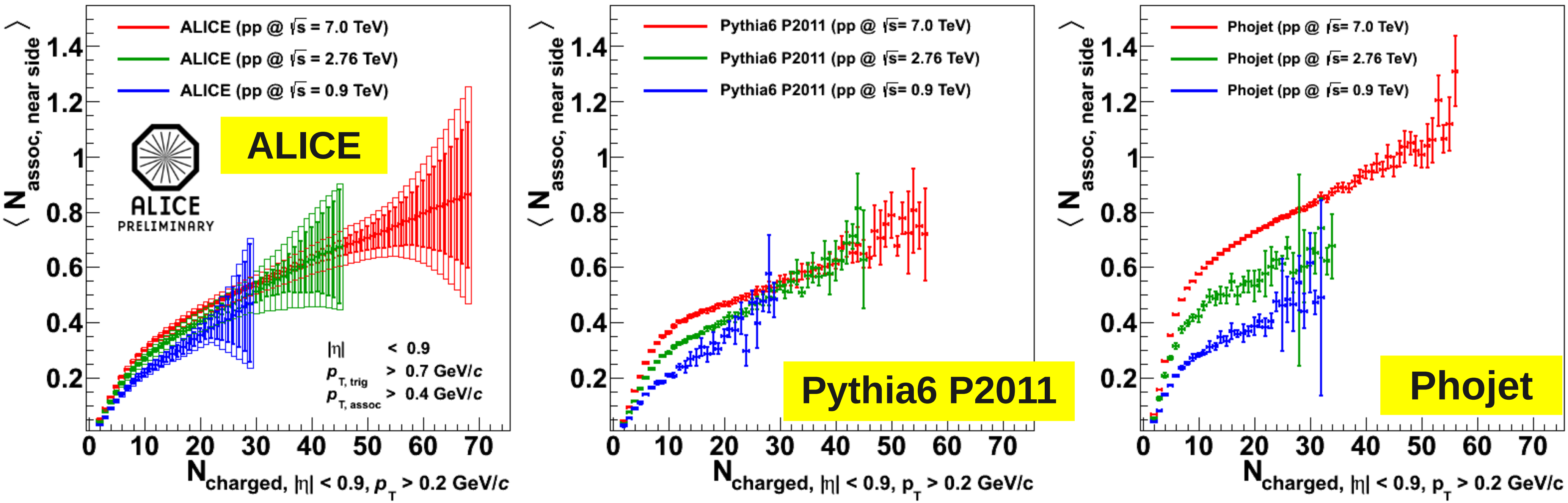
Number of Uncorrelated Seeds



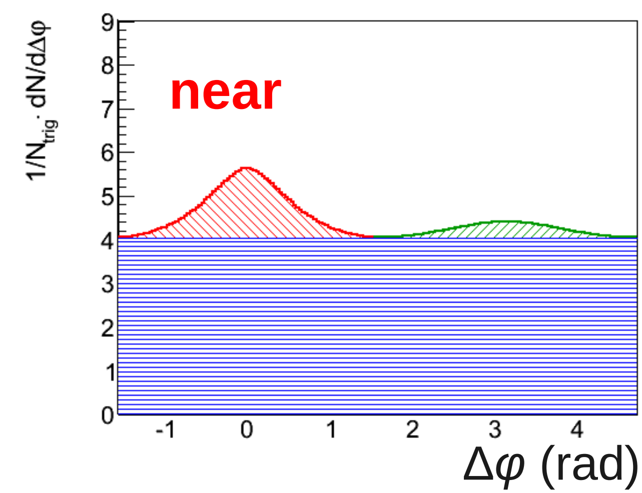
- The number of uncorrelated seeds contains information about MPI: In Pythia N_{MPI} and $N_{uncorrelated\ seeds}$ are proportional
- All Pythia tunes reproduced the ALICE results fairly well
- Phojet underestimates the ALICE results

$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}}(p_T > p_{T,\text{trig}}) \rangle}$$

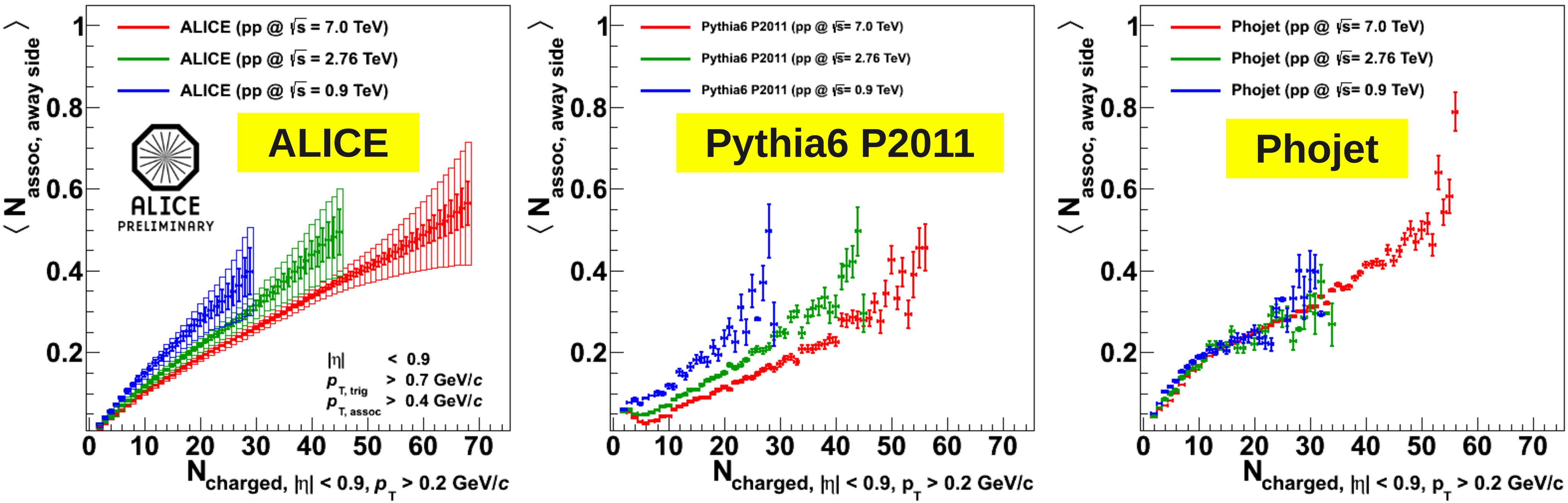
Per-Trigger Near Side Pair Yield



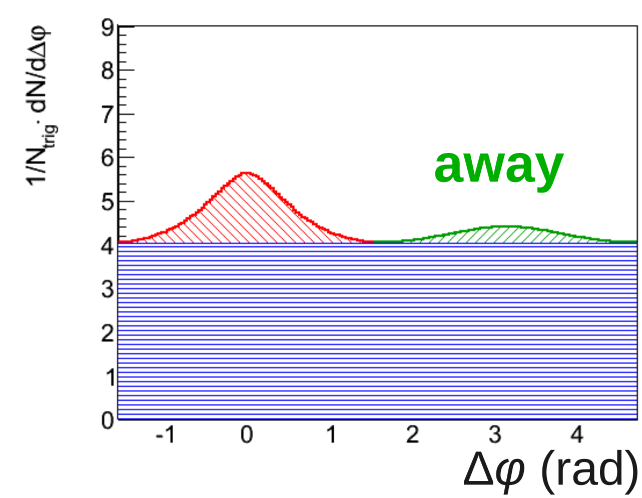
- Center-of-mass energy $\sqrt{s}$ = **0.9**, **2.76**, **7.0** TeV
- Near side pair yield at same multiplicity bin grows with increasing center-of-mass energy
- Splitting between slopes for different $\sqrt{s}$ is largest for Phojet



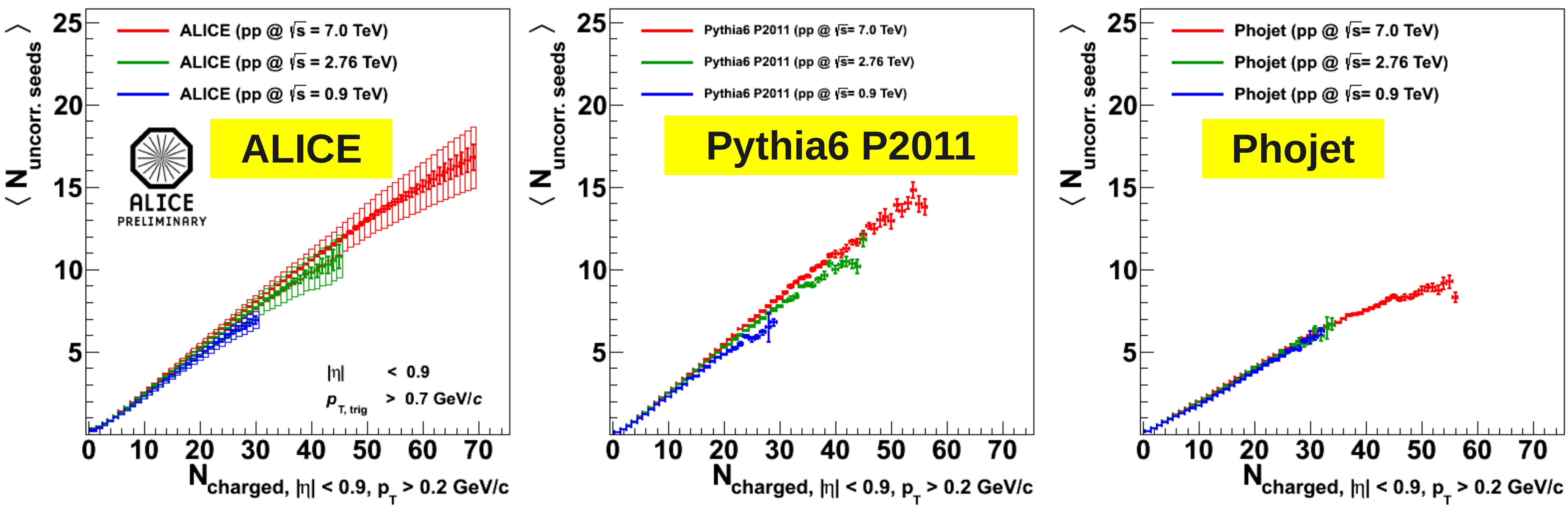
Per-Trigger Away Side Pair Yield



- Away side yield at same multiplicity bin shrinks with increasing √s
- Pythia6 Perugia-2011 underestimates ALICE data
- Phojet shows almost no √s dependence



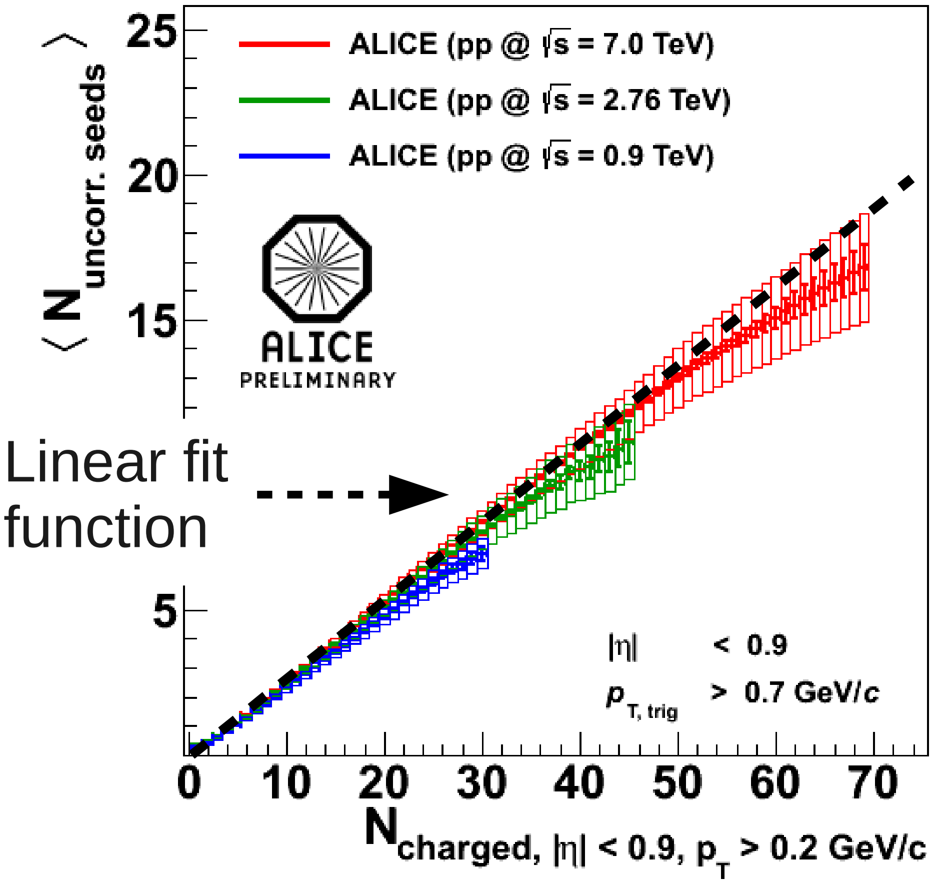
Average Number of Uncorrelated Seeds

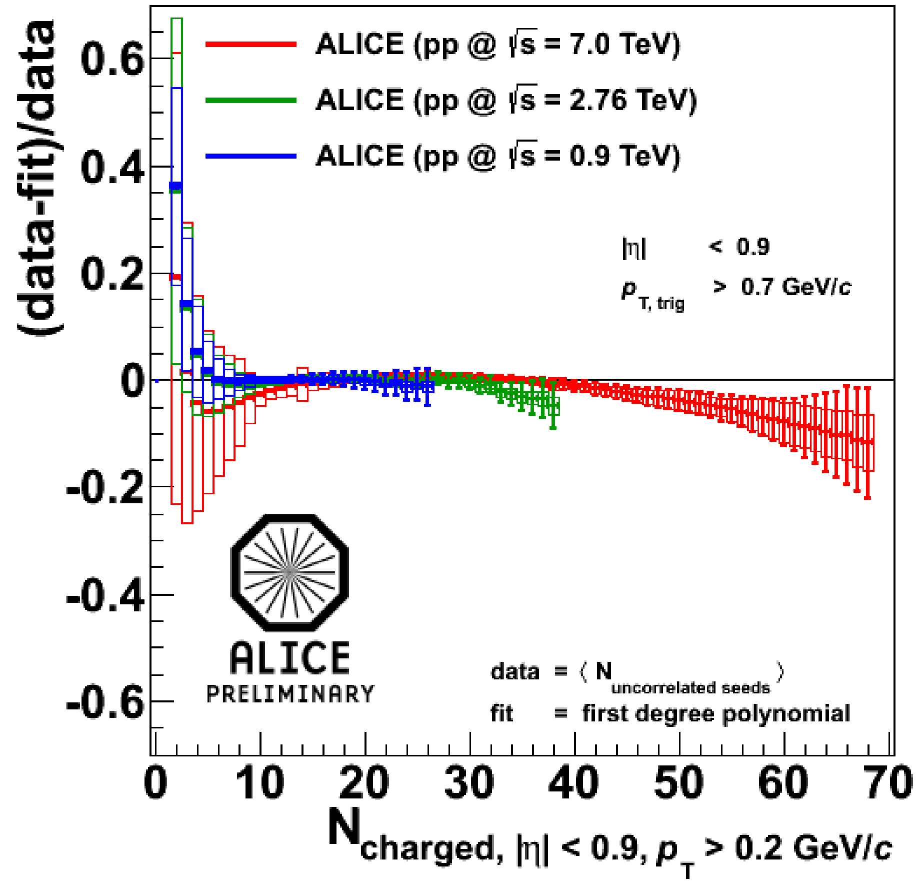


$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near + away}}(p_T > p_{T,\text{trig}}) \rangle}$$

- Only small √s dependence
- In low and intermediate multiplicity region: $N_{\text{uncorrelated seeds}}$ grows linearly with N_{ch}
- At high multiplicities, the number of $N_{\text{uncorrelated seeds}}$ stagnates → Multiplicity increases only by selecting events with highly populated jets, limit in N_{MPI}

$\langle N_{\text{uncorrelated seeds}} \rangle$ and Linear Fit





- Compare distribution with linear fit in intermediate N_{ch} range
- At high multiplicities, hint of deviation from linear dependence – this would indicate a limit in MPI

Summary: MPI in ALICE

- Study of observables which can give insight into the physics of multiple parton interactions
  - Inelastic proton-proton cross section
  - Charged particle multiplicity distribution
  - Underlying event
  - Correlation between soft particle production and
    - J/ψ and D-meson yield
    - Transverse sphericity
    - Jets: Per-trigger pair-yields

Summary Jet Analysis

- Study of the per-trigger pair yield at the near side and the away side as well as the number of uncorrelated seeds using a two-particle correlation analysis
- Pythia studies show that the analysis approach can probe number of multi parton interactions (MPI)
  - Information about jet fragmentation and MPI
- At high multiplicities, the number of uncorrelated seeds shows a hint of a deviation from a linear dependence with multiplicity – this would indicate a limit in MPI
- Pythia Perugia-2011 gives best description of ALICE results
- Phojet, Pythia6-Perugia-0, and Pythia8 show large discrepancies to ALICE results

Backup

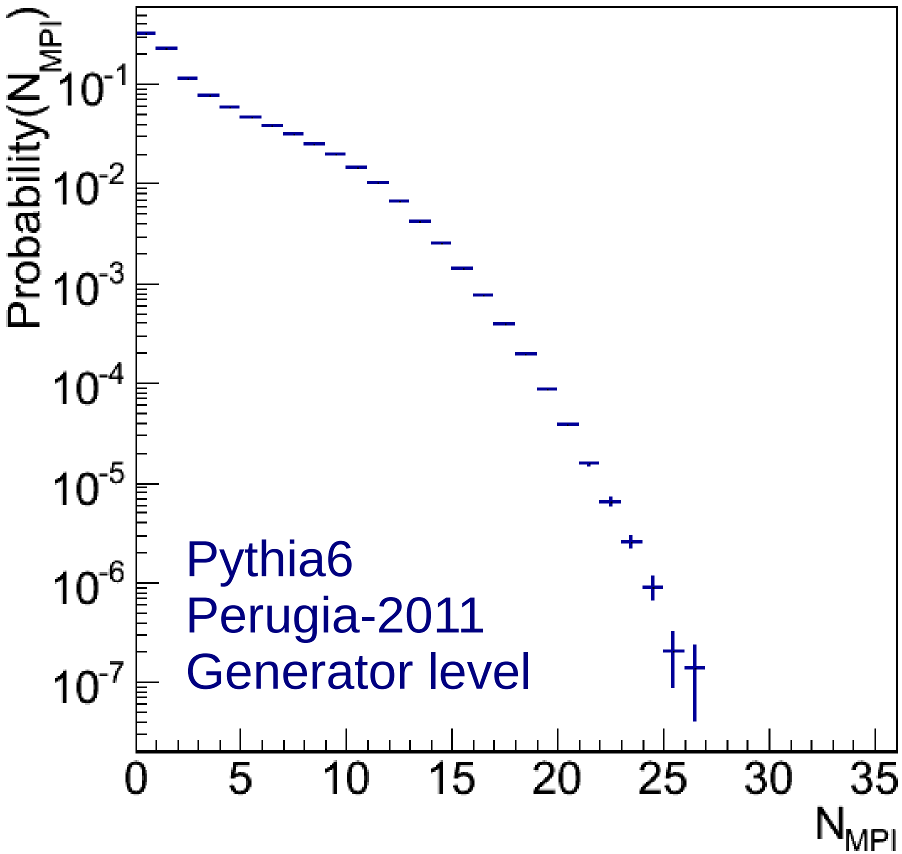
Assumption: $N_{\text{uncorrelated seeds}} \rightarrow N_{\text{MPI}}$

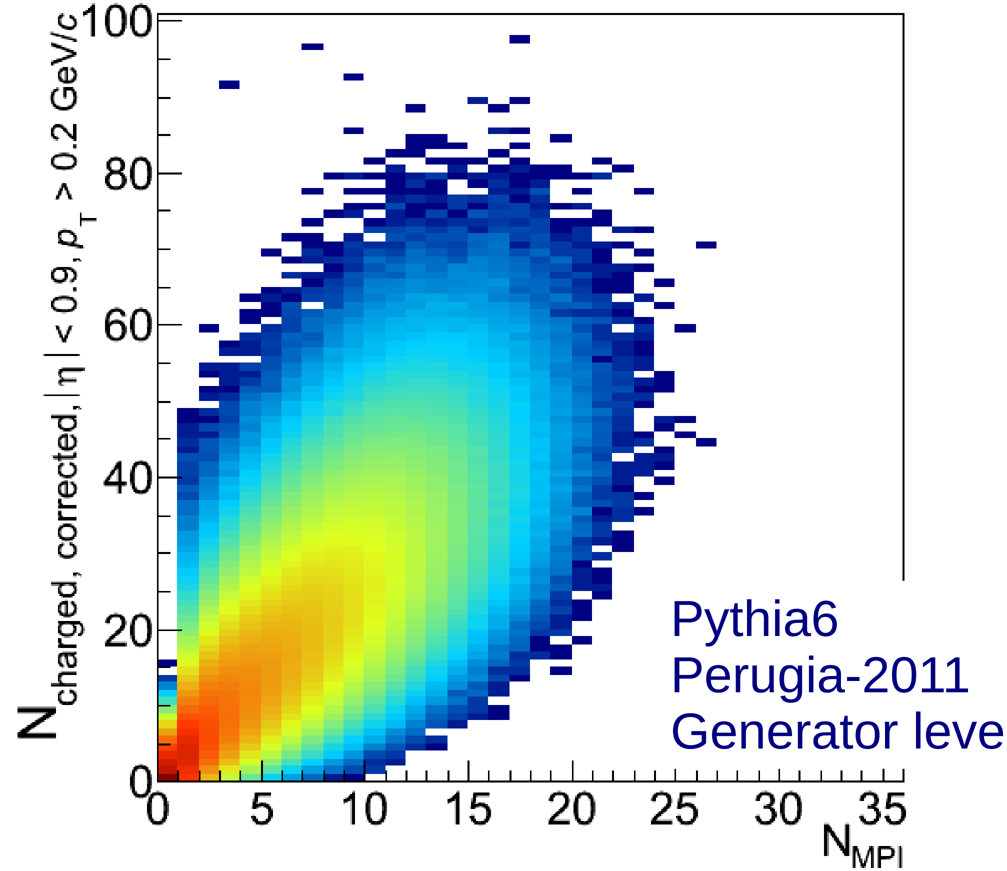
- We measure $N_{\text{uncorrelated seeds}}$

$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near}\,,\, p_{\text{T}} > p_{\text{T,trig}}} + N_{\text{assoc, away}\,,\, p_{\text{T}} > p_{\text{T,trig}}} \rangle}$$

- We assume that $N_{\text{uncorrelated seeds}}$ scales with the number of multiple parton interactions
- Can we demonstrate a direct dependence in Pythia simulations
  - Perform two-particle correlation analysis of Pythia6 simulations as function of N_{MPI} = number of multiple parton interactions
  - N_{MPI} (Pythia definition) = number of hard or semi-hard scatterings that occurred in the current event in the multiple interaction scenario; is 0 for a low-p_{T} event

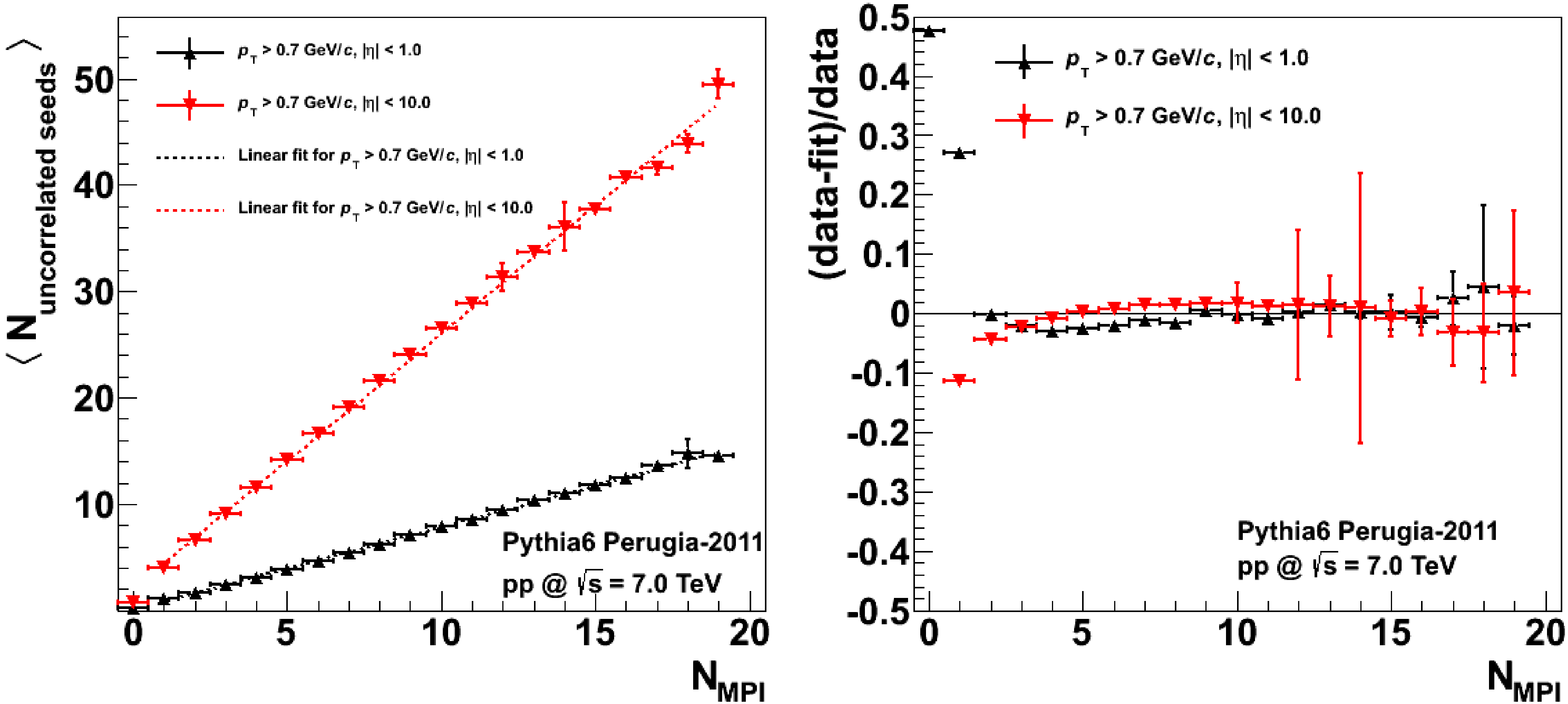
MPI in Pythia6 Perugia2011





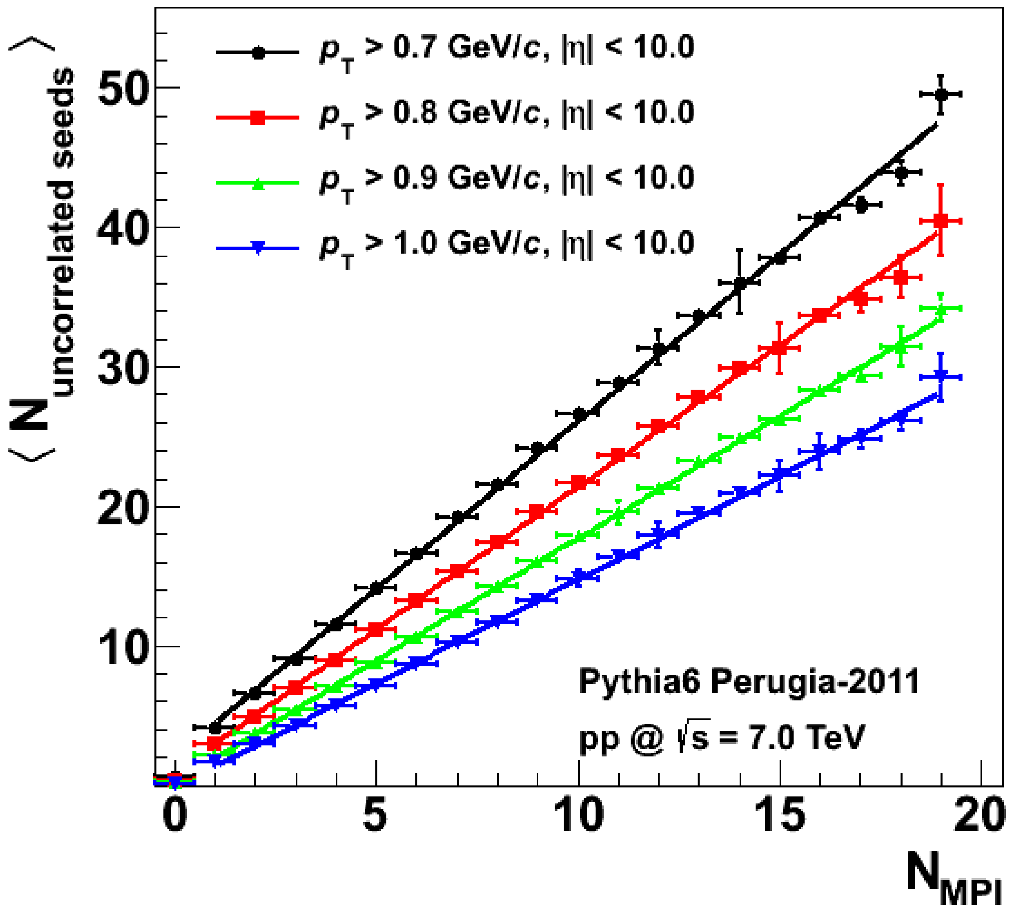
- Spectrum of multiple parton interactions in Pythia6 Perugia-2011
- Correlation of measured multiplicity to number of multiple parton interactions

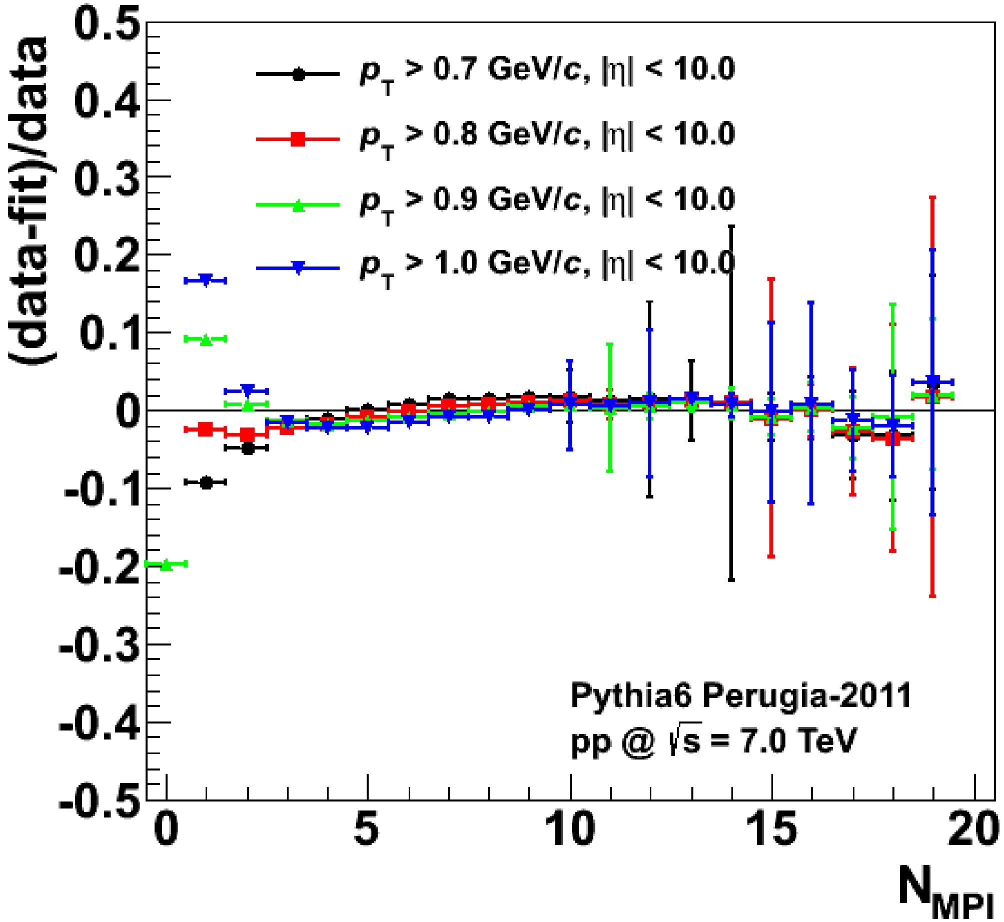
$N_{uncorrelated\ seeds} \sim N_{MPI}$



- Agreement with linear fit is better when accepting tracks at full η acceptance and not only the tracks in the ALICE acceptance

$N_{\text{uncorrelated seeds}} \sim N_{MPI}$





- Linear dependence is given for several p_T thresholds

Estimation of Combinatorics in Auto Correlations

For an a priori unknown multiplicity distribution $P(n)$ of the mini-jet, we measure

$$\frac{\langle n(n-1)\rangle}{2\langle n\rangle}=\frac{1}{2}\left(\frac{\langle n^2\rangle}{\langle n\rangle}-1\right)$$

For steadily falling P(n) and small <n> this is in good approximation:

$$\frac{1}{2}\left(\frac{\langle n^2\rangle}{\langle n\rangle}-1\right) \quad \rightarrow \quad \frac{\langle n\rangle}{1-P(0)}-1$$

(= <n> with trigger condition - 1)

Which is the mean number of associated particles.

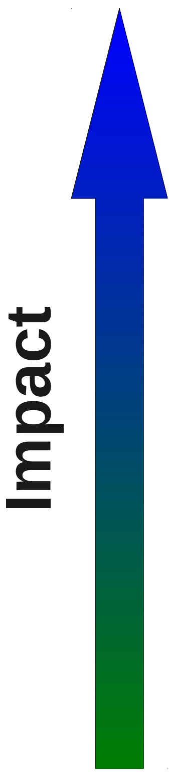
Example 1 (geom. row):	Example 2 (Poisson):	Example 3 (Log Series):
$P(n)=(1-q)q^n$ $\langle n\rangle=\frac{q}{1-q}$ $\langle n^2\rangle=2\langle n\rangle^2$ $\frac{1}{2}\left(\frac{\langle n^2\rangle}{\langle n\rangle}-1\right)=\langle n\rangle$ $\frac{\langle n\rangle}{1-P(0)}-1=\langle n\rangle$ Relation is exact !	$P(n)=\frac{\mu^n e^{-\mu}}{n!}$ $\langle n\rangle=\mu$ $\langle n^2\rangle=\mu^2+\mu$ $\frac{1}{2}\left(\frac{\langle n^2\rangle}{\langle n\rangle}-1\right)=\frac{\mu}{2}$ $\frac{\langle n\rangle}{1-P(0)}-1=\frac{\mu}{1-e^{-\mu}}-1=\frac{\mu}{2}+\frac{\mu^2}{12}+\ldots$	$P(n)=\frac{-1}{\ln(1-p)}\frac{p^n}{n}$ $\langle n\rangle=\frac{-1}{\ln(1-p)}\frac{p}{(1-p)}$ $\langle n^2\rangle=\frac{\langle n\rangle}{(1-p)}$ $\frac{1}{2}\left(\frac{\langle n^2\rangle}{\langle n\rangle}-1\right)=\frac{p}{2(1-p)}$ $\frac{\langle n\rangle}{1-P(0)}-1=\frac{p}{2(1-p)}+\frac{p^2}{12(1-p)}+p^3\ldots$

Expect P(n) to be steadily falling, choose $p_{T,trig}$ such that <n> is low

Analysis Details

- Data (including ITS and TPC)
  - pp @ $\sqrt{s}$ = 0.9 TeV:
    - 7 million events
  - pp @ $\sqrt{s}$ = 2.76 TeV:
    - 27 million events
  - pp @ $\sqrt{s}$ = 7.0 TeV:
    - 204 million events
- Event cuts
  - Minimum bias trigger: hit in V0 or SPD
  - One distinct reconstructed vertex within $|z_{\text{vertex}}| < 10$ cm of good quality
  - At least one track in ITS-TPC acceptance ($p_T > 0.2$ GeV/c, $|\eta| < 0.9$)
- Track cuts
  - Full refit procedure during the tracking in ITS and TPC
  - At least 1 hit per track in one of the first 3 ITS layers (first 3 out of 6)
  - At least 70 clusters per track in the TPC drift volume (out of 159)
  - χ^2/TPC cluster < 4
  - Reject tracks with kink topology
  - p_T-dependent DCA_{xy} cut corresponding to 7σ of track distribution ($DCA_{xy,\text{max}}$ = 0.3 cm)
  - $DCA_z < 2$ cm

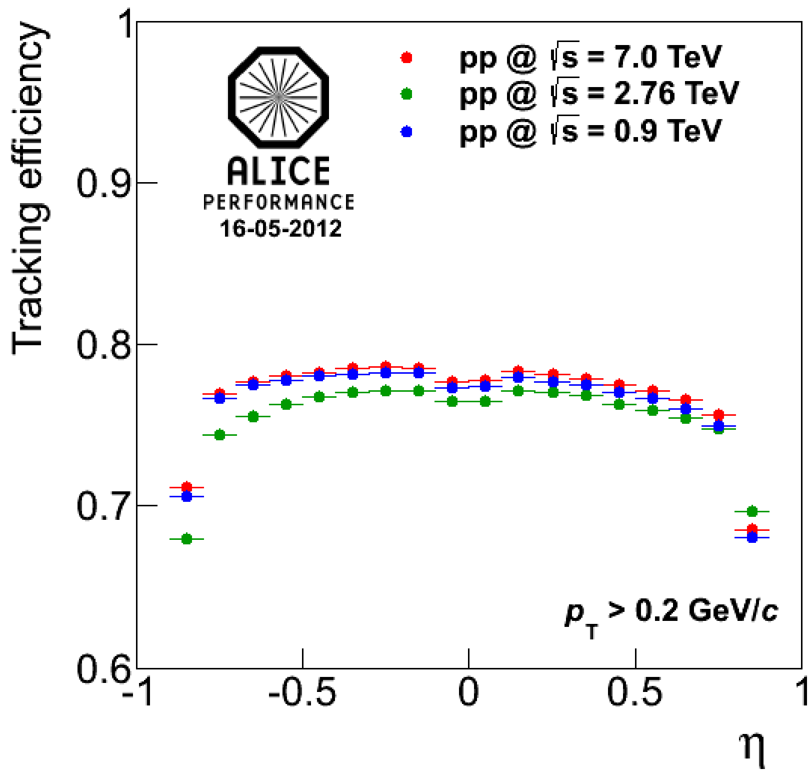
Corrections and Systematic Uncertainties

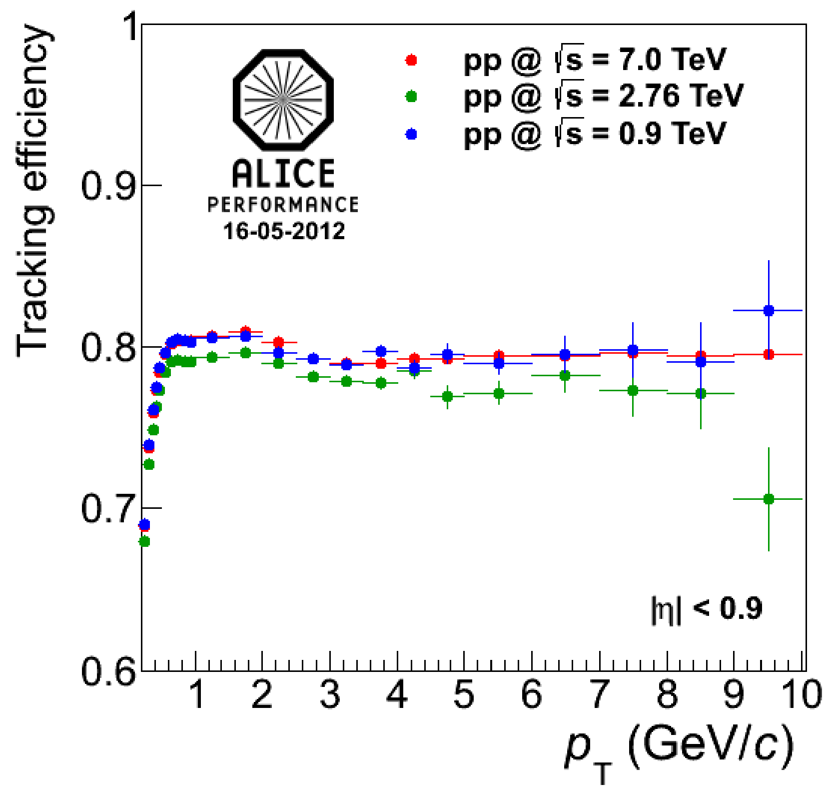


- Correction chain
  - Reconstruction efficiency
  - Contamination with tracks from secondary particles
  - Two-track and detector effects
  - Multiplicity correction
  - Contamination from strange particles
  - Vertex reconstruction efficiency
  - Trigger efficiency

- Sources of systematic uncertainties
  - Uncertainty of ITS-TPC efficiency
  - Particle composition in MC
  - Track cut dependence
  - Correction procedure
  - Event generator dependence
  - Transport MC dependence
  - Signal extraction
  - Vertex quality cut dependence
  - Pileup events
  - Influence of resonances
  - Material budget
  - Strangeness correction

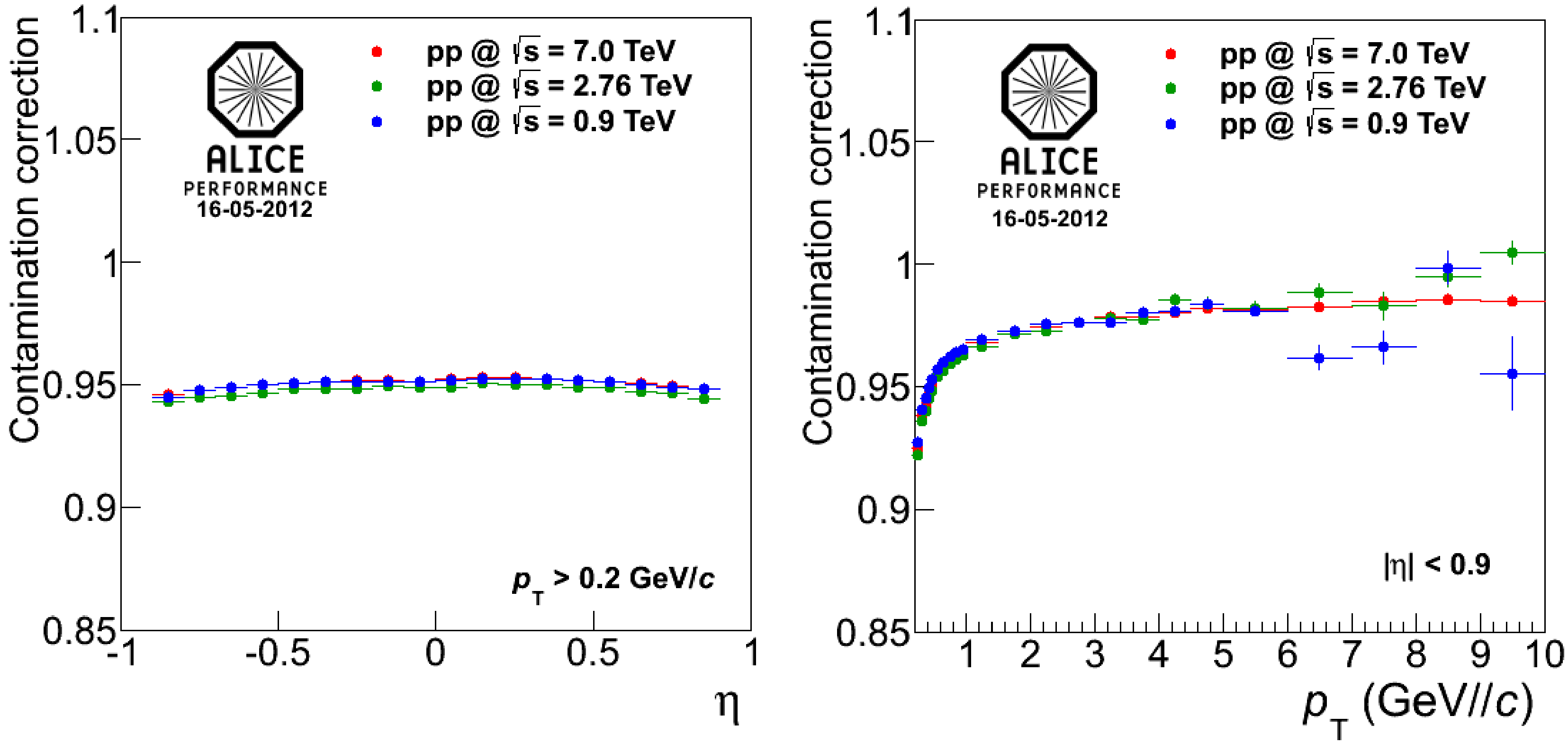
Correction: Reconstruction Efficiency





- *Reconstruction efficiency*: Ratio of the number reconstructed and accepted particles tracks of primary particles to number of primary particles
- 78% of all primary particles (at p_T > 0.2 GeV/c, $|\eta|$ < 0.9) are found in the reconstruction → Loss of 22%

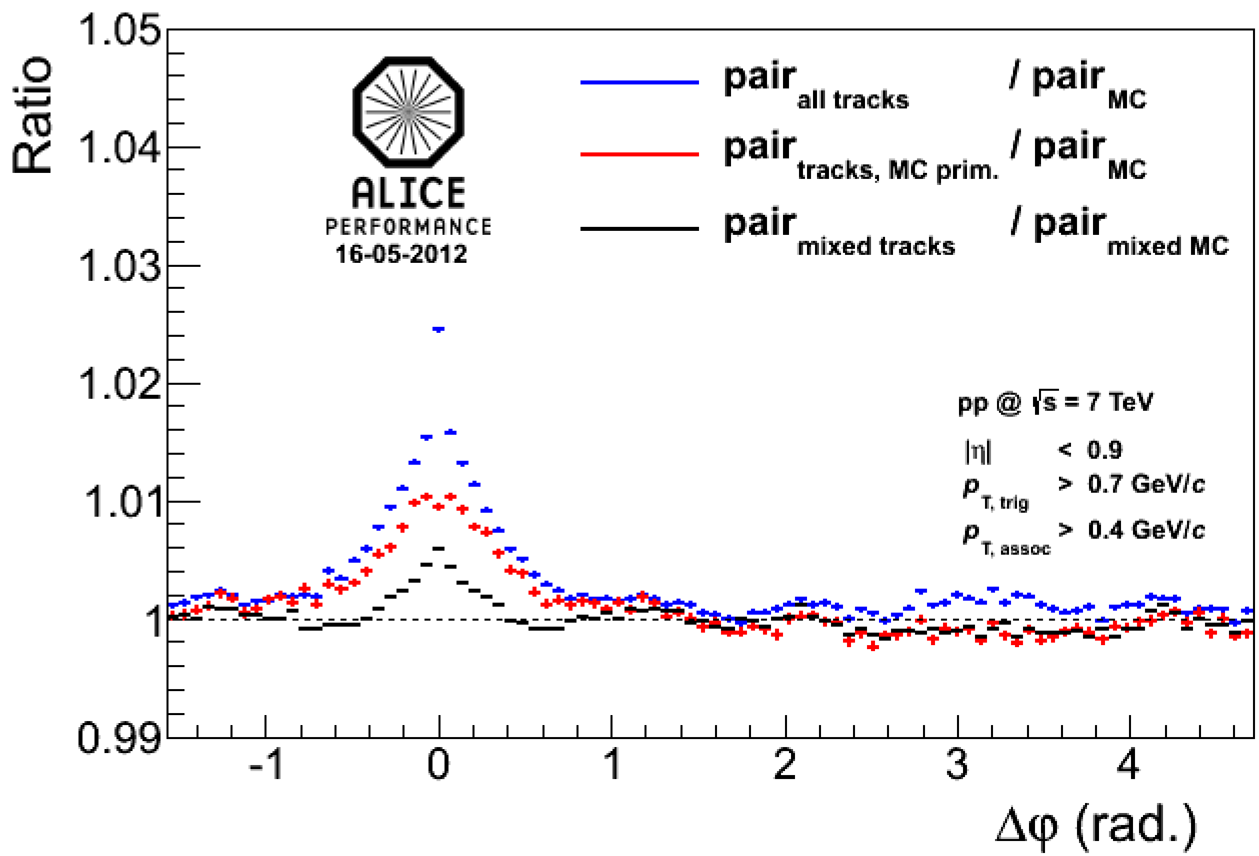
Correction: Contamination



- *Contamination*: Ratio of number of all reconstructed tracks to number of reconstructed tracks of primary particles →
  Contamination from decay produces of strange particles, photon conversion, hadronic interaction with the detector material

- Contamination of 6% (at p_T > 0.2 GeV/c, $|\eta|$ < 0.9)

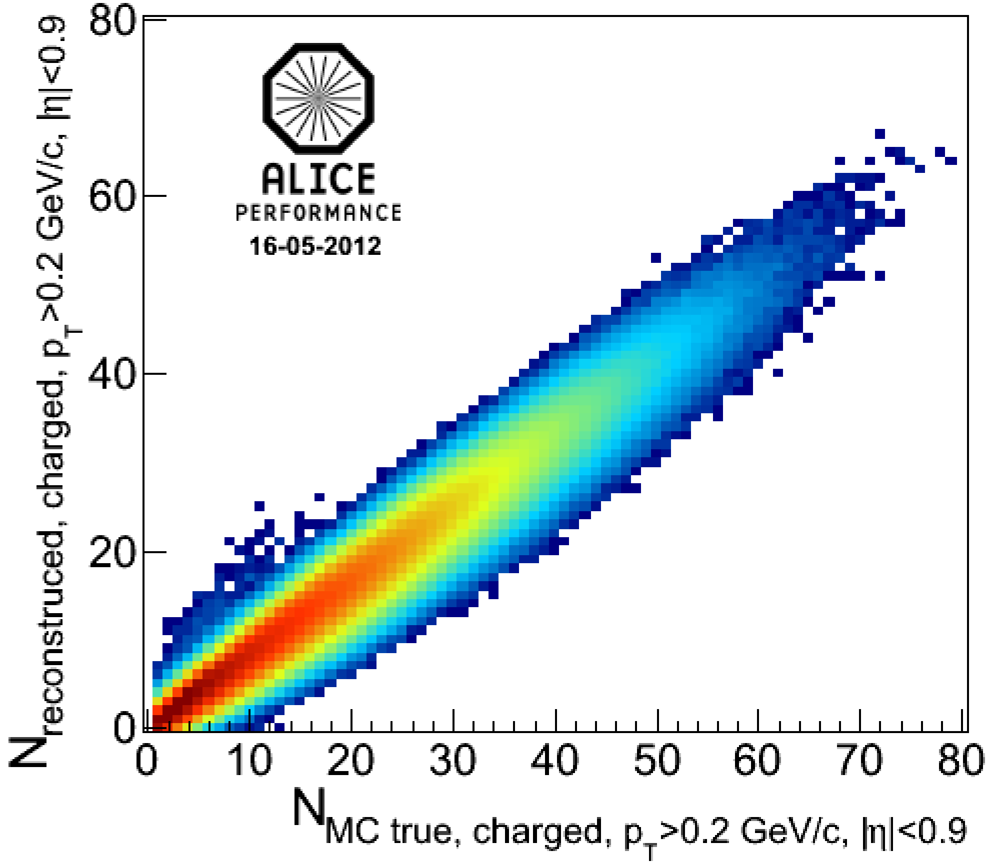
Correction: Two Track and Detector Effects



- A fraction of the near side peak after single track correction is due to detector effects (black) → limited flatness in φ distribution give rise to structures in Δφ
- Remaining peak comes from split tracks, resonances, gamma conversion
- Correction on total yield is very small

Multiplicity Correction

- Multiplicity correction via normalized and extended correlation matrix
- Normalization:
  - $$\sum_{N_{\text{rec}}} R(N_{\text{mc}}, N_{\text{rec}}) = 1$$
- Extension:
  - Fit slice of correlation matrix with Gaussian function and extract sigma and mean
  - Used extrapolated sigma and mean for extended correlation matrix



- Correction:

$$\text{Observable}(N_{\text{mc}}) = \sum_{N_{rec}} \text{Observable}(N_{\text{rec}}) \cdot R_{1,\text{extended}}(N_{\text{mc}}, N_{\text{rec}})$$

Cross Section

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