Study of Upsilon production as a function of charged-particle multiplicity in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the CERN ALICE experiment

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Outline

- **Study of proton-proton collisions at high energy**
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    - Proton structure at high energy
    - Proton-proton collisions
    - Quarkonium production
    - Quarkonia and multi-parton interactions

- **Quarkonium and open heavy flavour production as a function of charged-particle multiplicity**
    - Experimental context
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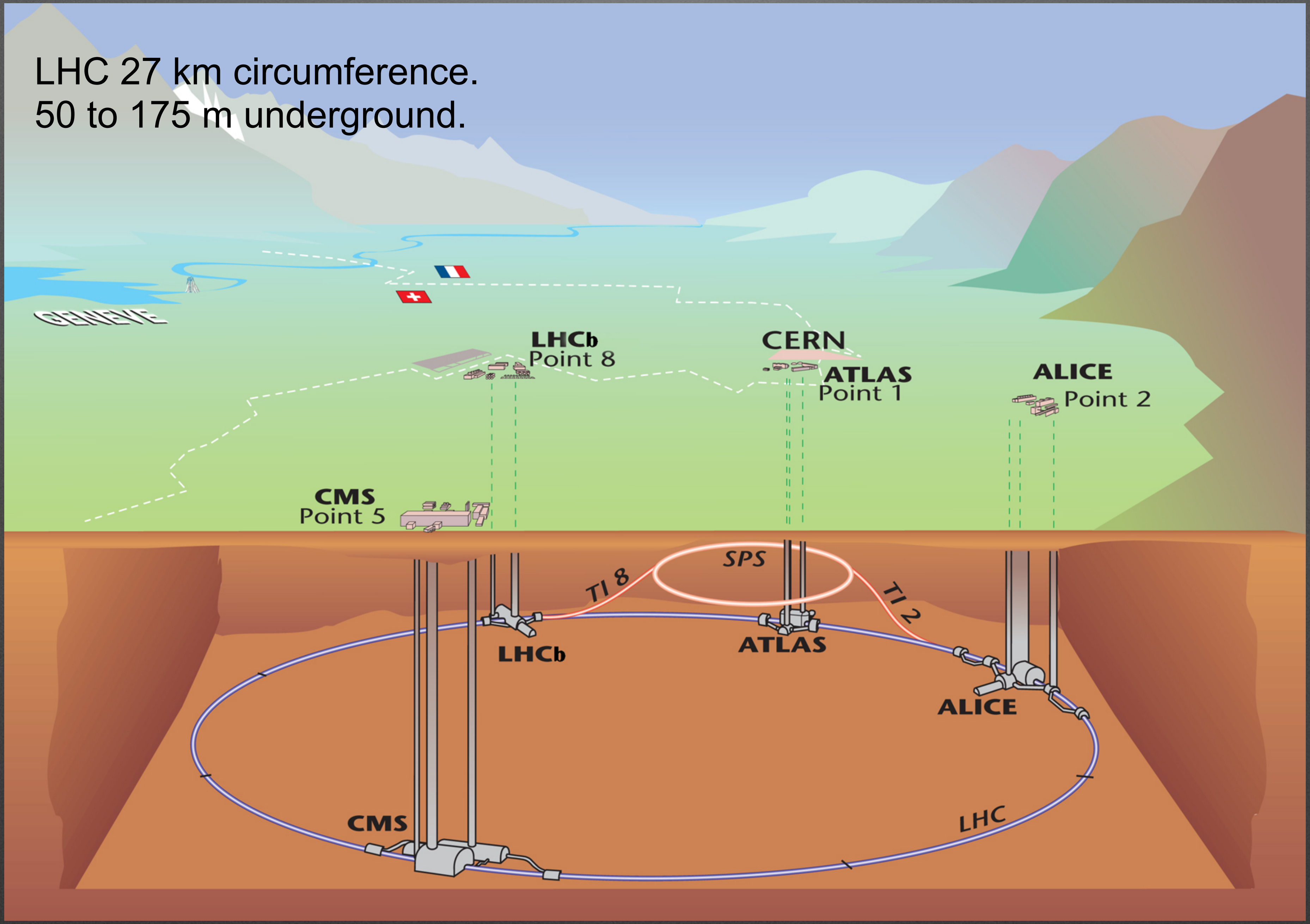
    - With CMS experiment (Υ)

- **Upsilon as a function of charged-particle multiplicity**
    - ALICE experiment
    - Multiplicity estimation
    - Upsilon signal extraction

- **Conclusions**

Study of proton-proton collisions at high energy

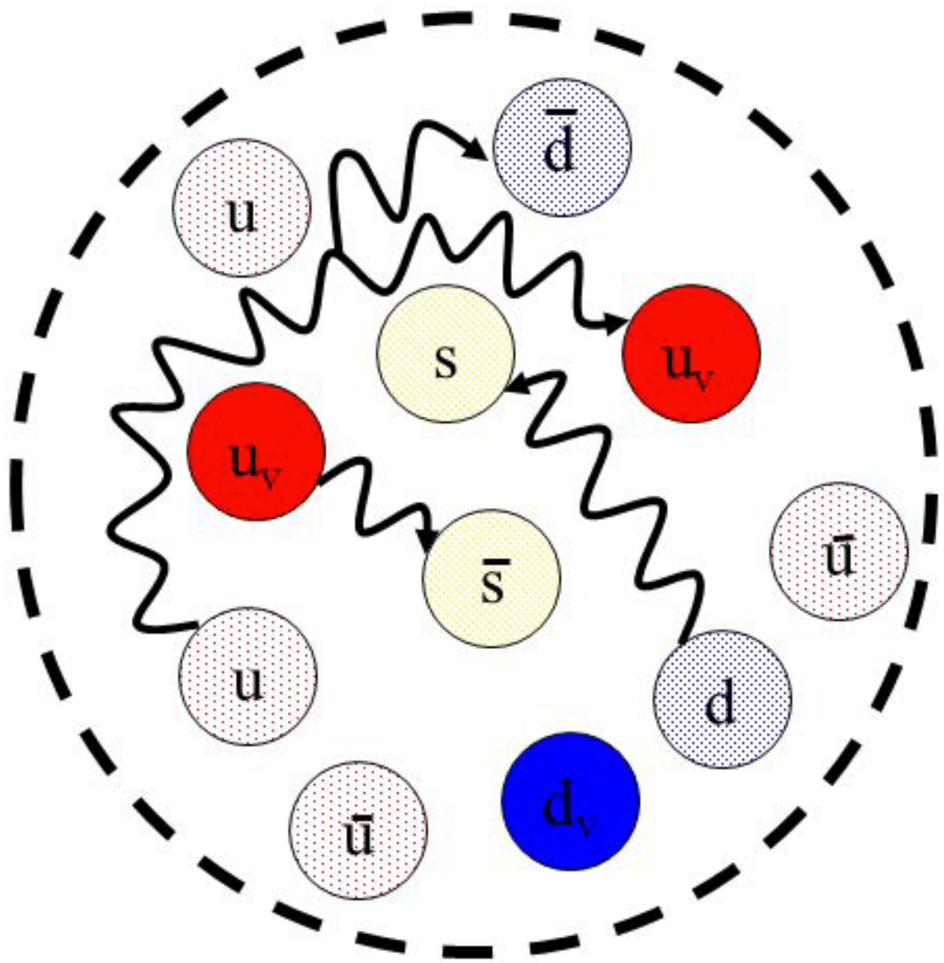
Large Hadron Collider (LHC)

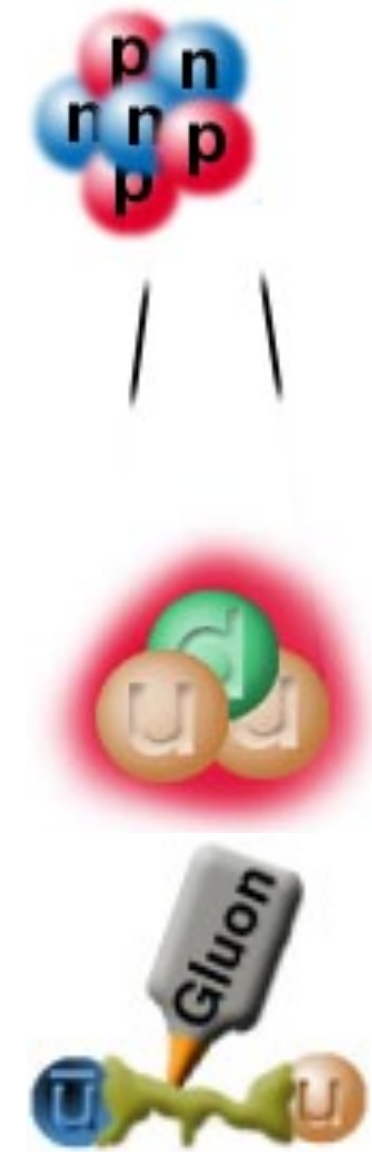


- **Search for new physics and precise Standard Model measurements**
  (Higgs was discovered in 2012)
  - **ATLAS (A Toroidal LHC Apparatus)**
  - **CMS (Compact Muon Solenoid)**
- **Study strongly-interacting particles and Quark-Gluon Plasma**
  - **ALICE (A Large Ion Collider Experiment)**
- **Investigate matter/antimatter asymmetry**
  - **LHCb (Large Hadron Collider beauty)**

Proton structure at high energy

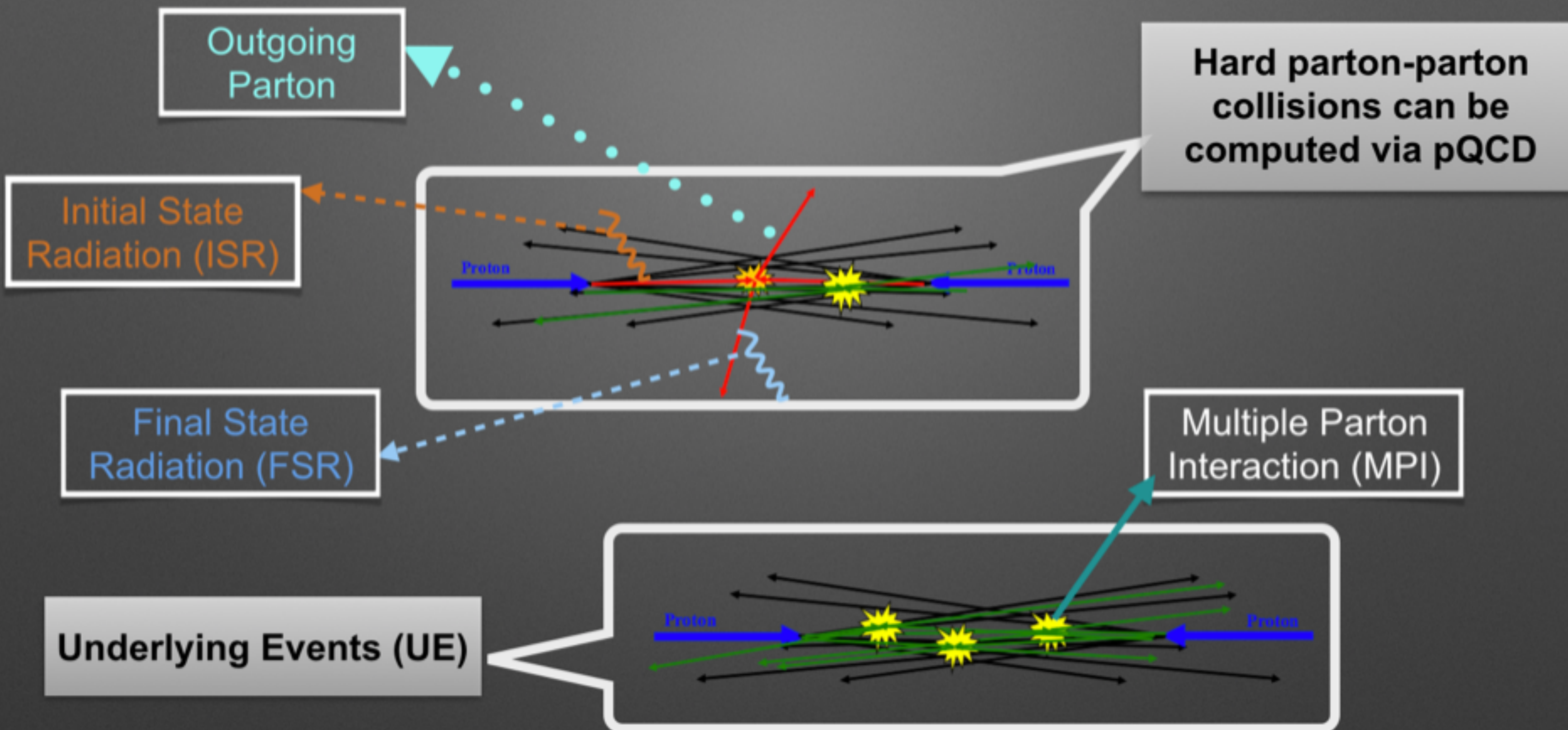
- Proton contains 3 valence quarks uud.
- Also contains sea of virtual quark and antiquark pairs.
- All these held together by gluons.
- Each quark/gluon carries a fraction of the proton's momentum.





At high energies the proton is much more complex than just uud because of the sea of quarks/anti-quarks and gluons.

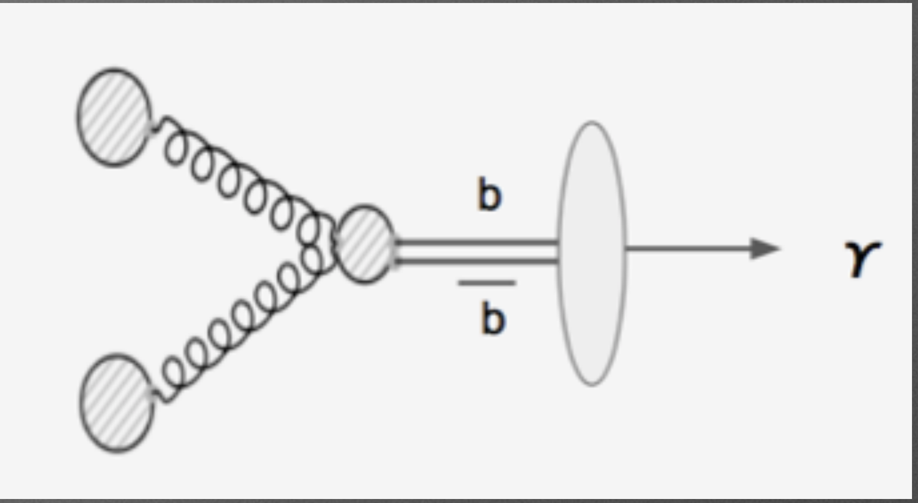
Proton-proton (pp) collisions



proton-proton collision → hard Scattering + underlying event
underlying event → all other interactions including MPI

Quarkonium Production

- Quarkonium production is a hard process.
- **Charmonia**: bound state $c\bar{c}$ pair (J/Ψ, Ψ')
- **Bottomonia** : bound state $b\bar{b}$ pair (Υ(1S) ,Υ(2S) ,Υ(3S))

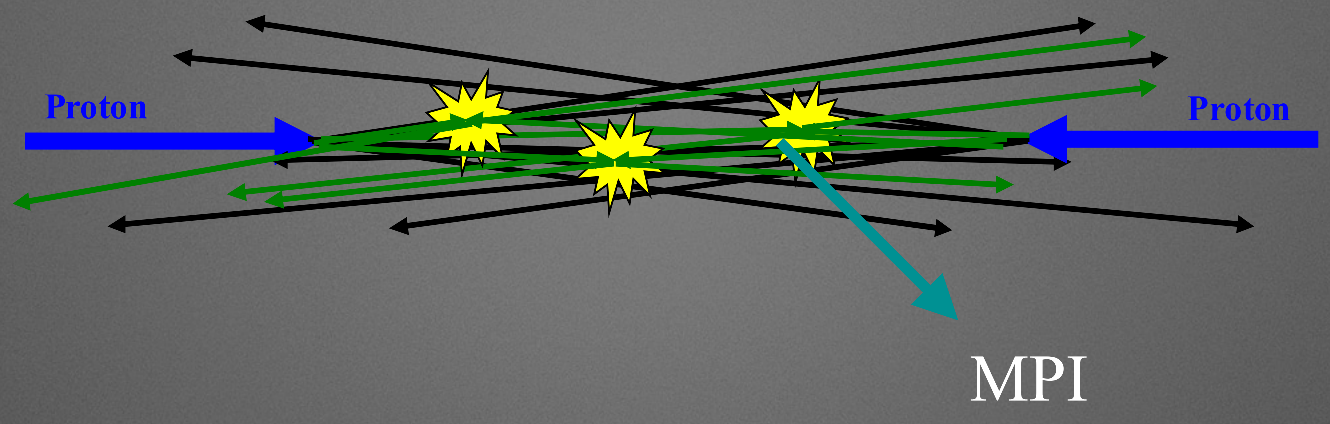


Main theoretical approaches which are used to describe the hadronic production of quarkonia:

- **Color Singlet Model (CSM)** 10.1103/PhysRevLett.98.252002
  - perturbative QCD is used to describe $q\bar{q}$.
  - Initial quark-antiquark and final quarkonium state are in colour singlet state.

- **Non-Relativistic QCD Model (NRQCD)** 10.1103/PhysRevD.51.1125
  - Color singlet and octet state.
  - Color neutralisation of the color octet state is treated as a non-perturbative process.
  - The production cross section of a quarkonium state can be defined as a sum of terms taking into account a short distance partonic cross section and a long distance matrix element.

Quarkonia and MPI



- Probability to produce particle from hard interaction increases with higher multiplicity (number of charged-particles).
- The number of charged-particles is proportional to hard interaction and also to the MPI.
- To look at the quarkonium yields related to the associated multiplicity can help to learn more about interplay between hard and underlying events which was first proposed in 2010. 10.1016/j.nuclphysbps.2011.03.082

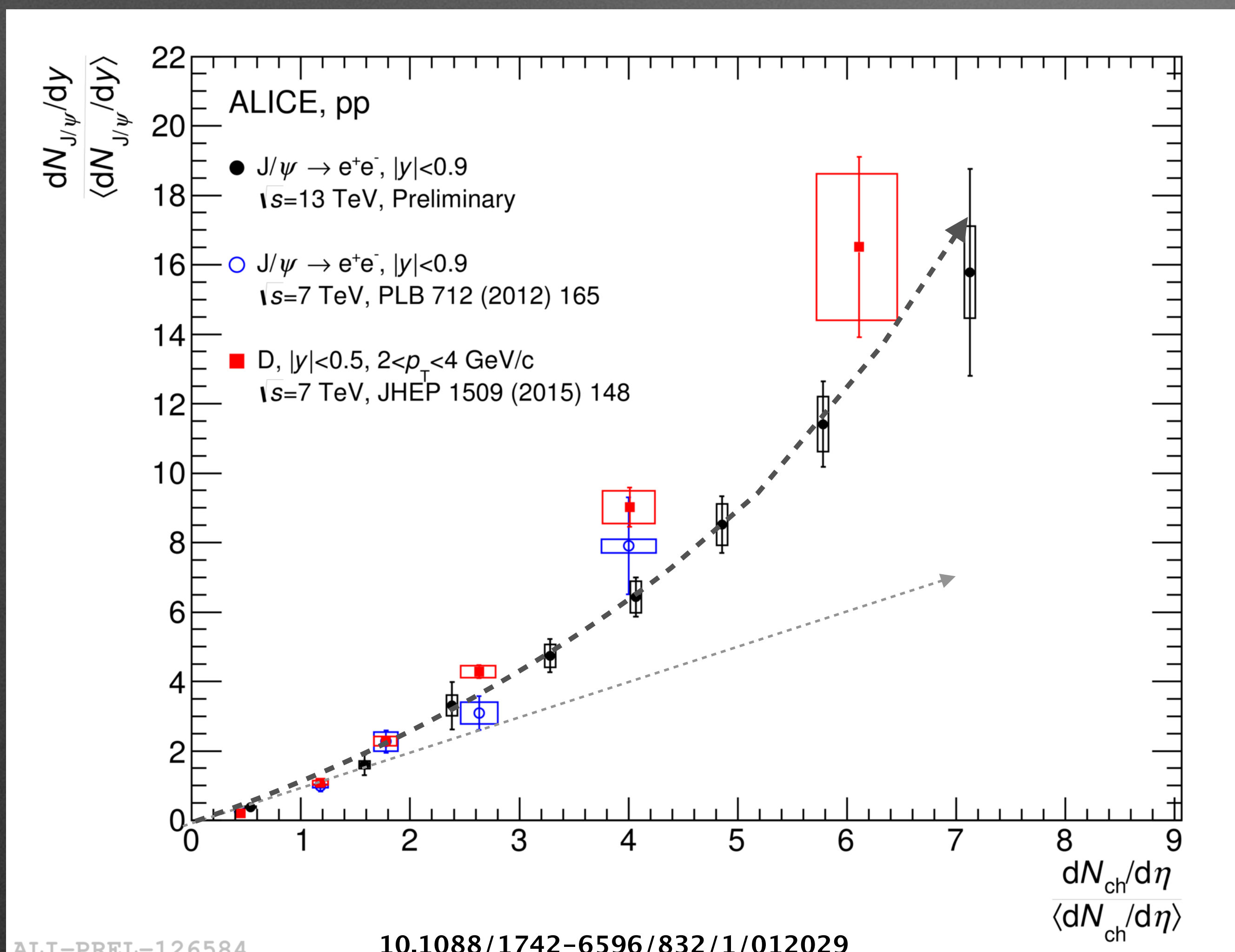
Quarkonia and open heavy flavours as a function of multiplicity with different experiments

STATE	SYSTEM	RAPIDITY RANGE	ENERGY	EXPERIMENT	REF
J/Ψ	pp	$\|y\| < 1$	500 GeV	STAR*	Nuclear Physics A 956 (2016) 721–724
J/Ψ	pp	$\|y\| < 0.9$, $2.5<y<4.0$	7 TeV	ALICE	Phys.Lett. B712 (2012) 165-175
J/Ψ	pp	$\|y\| < 0.9$	13 TeV	ALICE	10.1088/1742-6596/832/1/012029
J/Ψ	p-Pb	$2.5<y<4.0$	5.02 TeV	ALICE	Accepted by PLB CERN-EP-2017-056
Non prompt J/Ψ	pp	$\|y\| < 0.9$	7 TeV	ALICE	10.1007/JHEP09(2015)148
D^0, D^+, D^{*+}	pp	$\|y\| < 0.5$	7 TeV	ALICE	10.1007/JHEP09(2015)148
D^0, D^+, D^{*+}	p-Pb	$\|y\| < 0.5$	5.02 TeV	ALICE	10.1007/JHEP08(2016)078
Υ(1S), Υ(2S), Υ(3S)	pp	$\|y\| < 1.93$	2.76 TeV	CMS	10.1007/JHEP04(2014)103
Υ(1S), Υ(2S), Υ(3S)	p-Pb	$\|y\| < 1.93$	5.02 TeV	CMS	10.1007/JHEP04(2014)103
Υ(1S), Υ(2S), Υ(3S)	Pb-Pb	$\|y\| < 1.93$	2.76 TeV	CMS	10.1103/PhysRevLett.109.222301

*Solenoidal Tracker At RHIC; RHIC is the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory.

Inclusive J/ψ production as a function of charged-particle density at mid-rapidity in pp collisions at √s = 13 TeV

- X-label: relative multiplicity
- Y-label: relative quarkonium yield



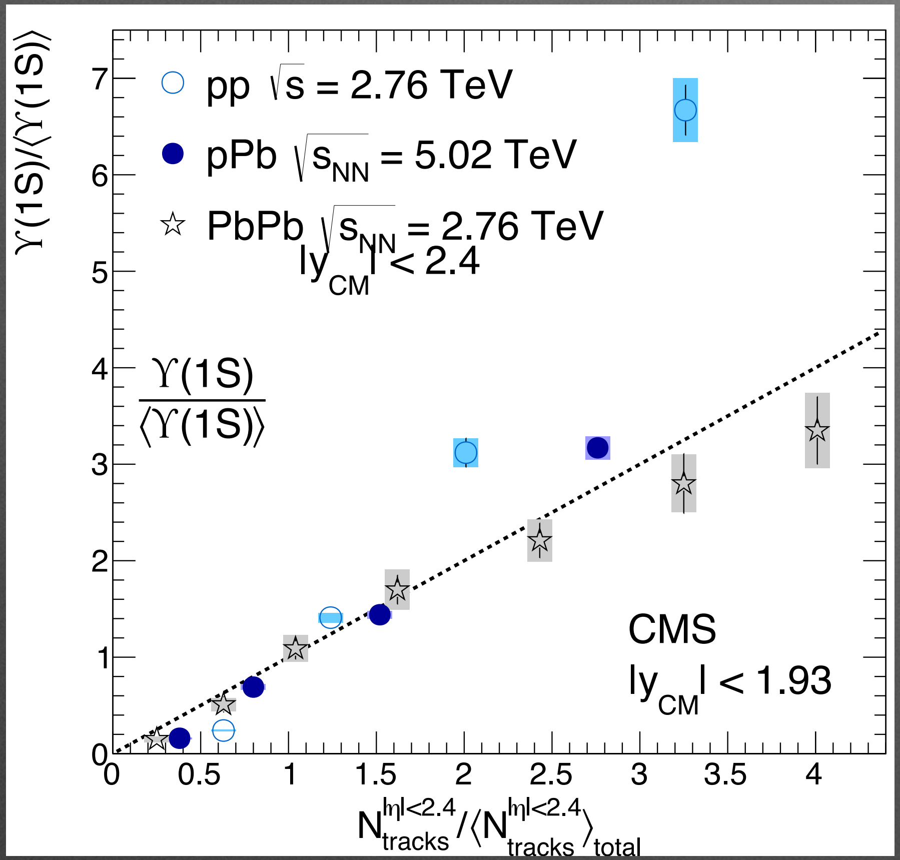
Self-normalized J/ψ yield as function of self-normalized multiplicity for J/ψ (black points) at 13 TeV together with results from D-meson (red points) and J/ψ (blue points) at 7 TeV.

- At low multiplicity the increase can be explained by initial-state radiation, final-state radiation, jet fragmentation.
- MPI contribution could explain a linear increase.
- To explain the deviation from linearity, other mechanisms are necessary such as a reduction of the charged-particle multiplicity with the percolation model[1] or collectivity with the EPOS event generator[2].

1. Phys. Rept. 350 (2001) 93–289, arXiv:0007198
2. Phys.Rev. C89 (2014) 064903, arXiv:1312.1233

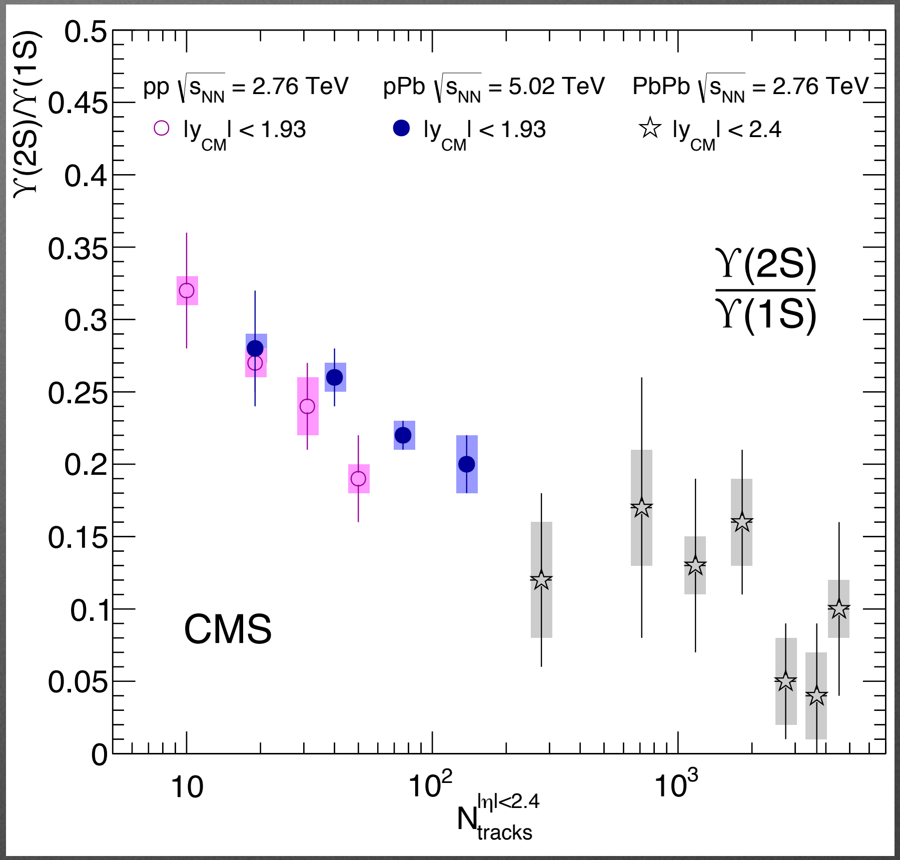
Event activity dependence of Υ(nS) production in $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb and $\sqrt{s}$ = 2.76 TeV pp collisions with CMS experiment

10.1007/JHEP04(2014)103



In pp collisions the increase is similar to the one observed in ALICE

10.1007/JHEP04(2014)103



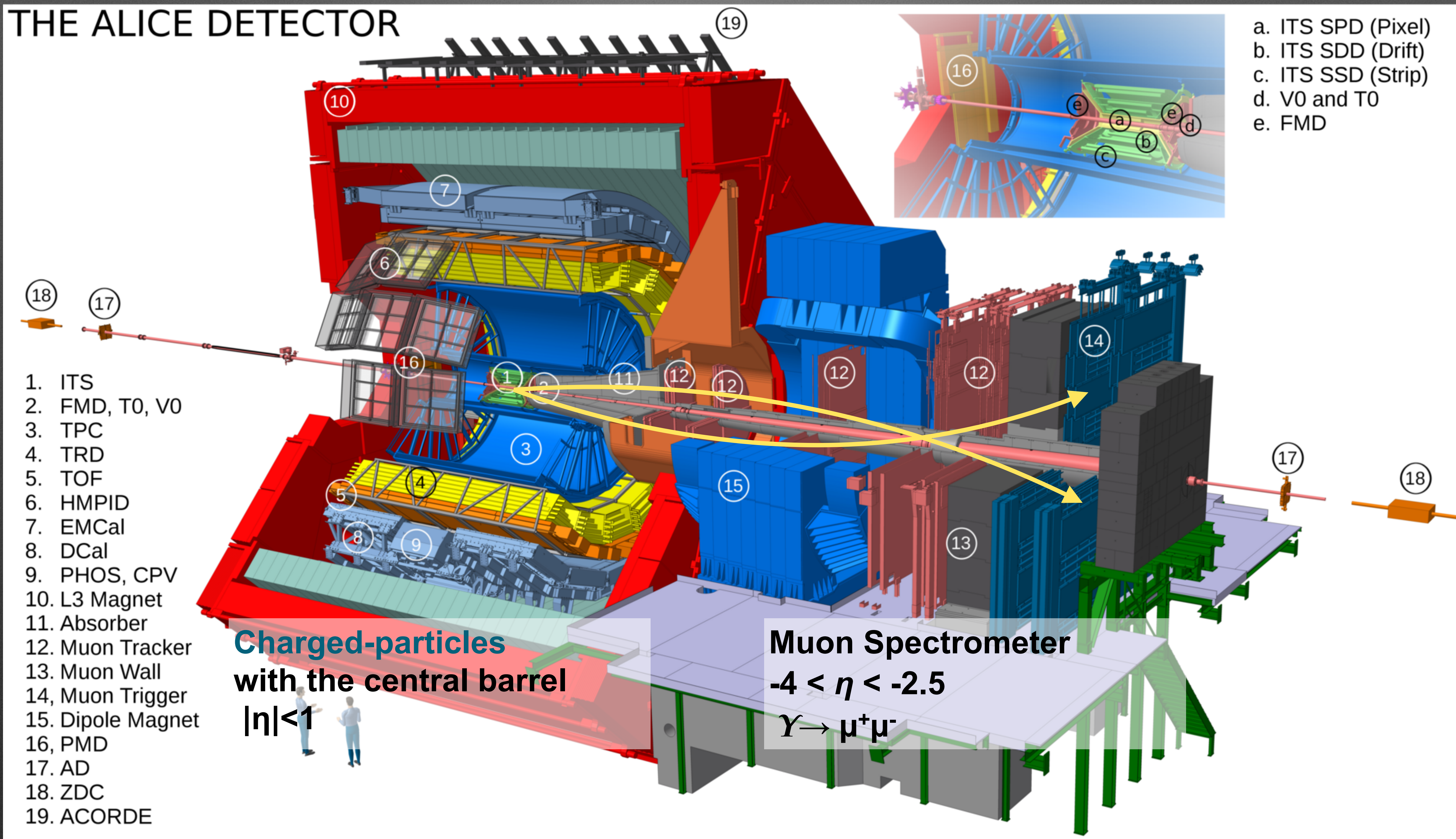
Υ_{2S} is suppressed compared to Υ_{1S} as a function of multiplicity

- The suppression of heavier state is still not understood (initial-state vs. final-state effects?)
- Comparison between J/Ψ and Υ can bring some light.

The study of upsilon as a function of multiplicity with ALICE in different energy and rapidity range can help to understand these phenomena.

Study of Upsilon production as a function of charged-particle multiplicity at forward rapidity in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the CERN ALICE experiment

ALICE Detector



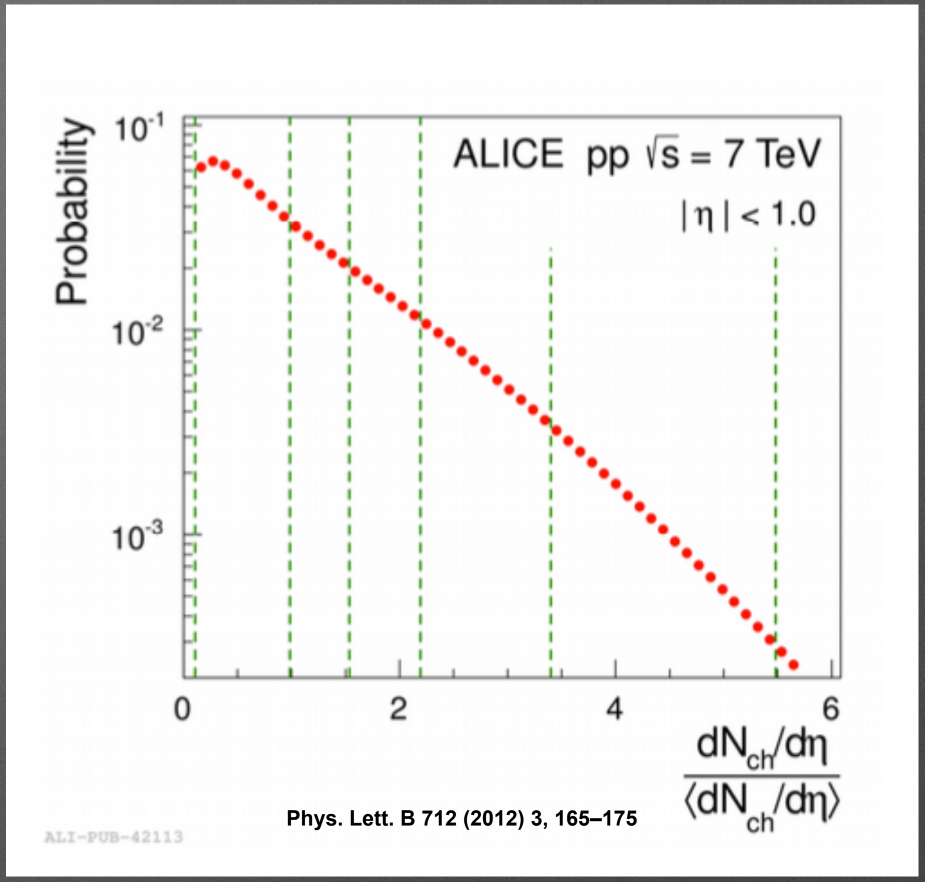
Upsilon as a function of multiplicity

✦ Multiplicity estimation

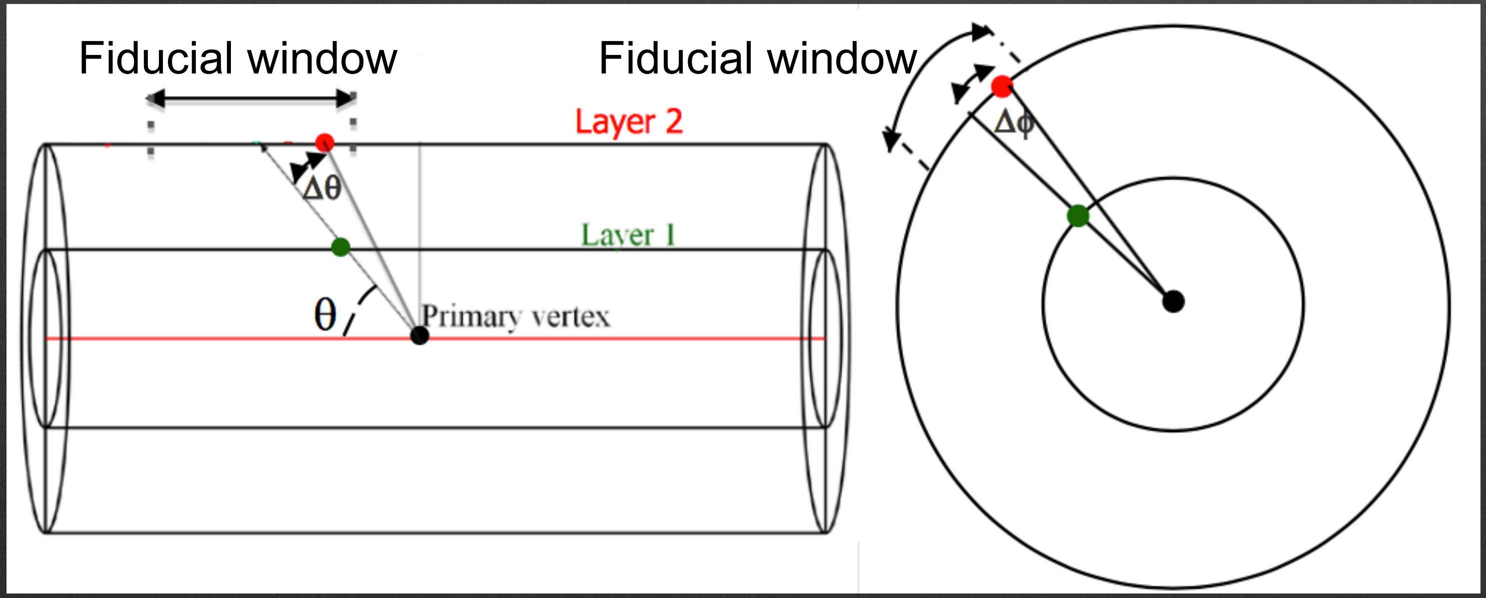
$$\frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle} \propto \frac{N_{\text{tracklets}}}{\langle N_{\text{tracklets}} \rangle}$$

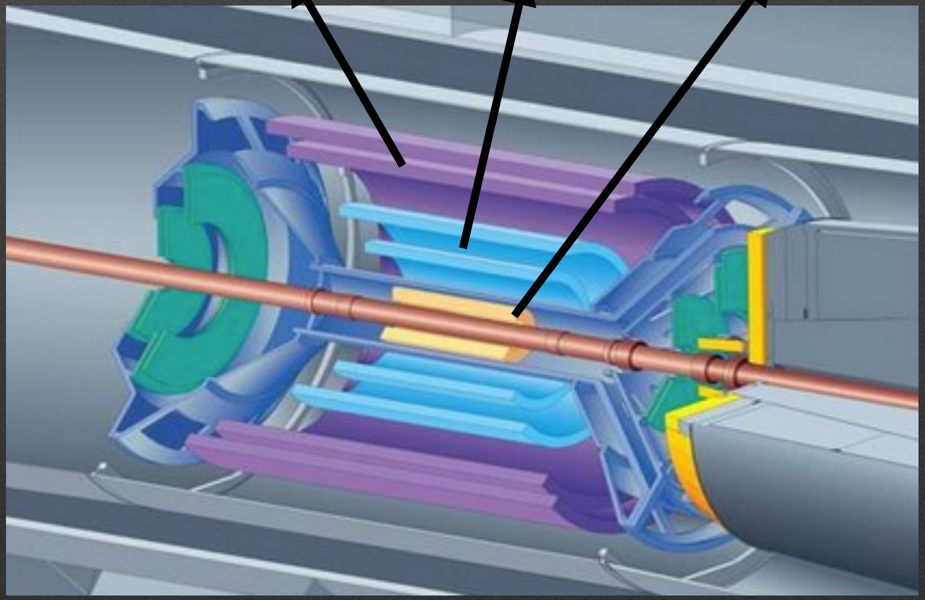
- X-Label : Charged-particles or multiplicity estimation are based on tracklets ($N_{\text{tracklets}}$).

- Tracklets - Segment of the track from Silicon Pixel Detector (SPD). SPD is the 2 innermost layers of ITS.
- Tracklet Reconstruction - pair of hits in 2 layers, aligned with the primary vertex, within a fiducial window (θ,ϕ).



J/Ψ analysis in pp collisions at √s=7 TeV





Inner Tracking System (ITS)

Upsilon as a function of multiplicity

✦ Data sample and event selection in muonic channel:

- LHC 2015 data sample
- Tracklets have been selected within the detector acceptance ($|\eta|<1$).

✦ Multiplicity estimation

Mean number of tracklets vs. Z_{vertex}

work in progress

- If the detector was perfect in the acceptance $|\eta|<1$; the number of mean tracklets should be same within the $|Vz|<10$.
- Z_{vertex} : interaction position towards the z axis along the beam pipe.

Data Driven Method

$$N^{corr}_{tracklets}(Z_v) = N_{tracklets}(Z_v) + \Delta N_{rand}$$

$$\Delta N = N_{tracklets}(Z_v)\,\frac{\langle N_{tracklets}(Z_{v,0})\rangle - \langle N_{tracklets}(Z_v)\rangle}{\langle N_{tracklets}(Z_v)\rangle}$$

- $<N_{tracklets}(Z_v)>$ is the mean number of tracklets at a given Z vertex
- $<N_{tracklets}(Z_{v,0})>$ is the reference value to be corrected, it can be taken as the minimum or the maximum.

We use the data driven method to correct from SPD inefficiency .

Upsilon as a function of multiplicity

✦ Multiplicity estimation

Mean number of tracklets vs. Z_{vertex}

work in progress

After correction the distribution becomes flat.

- Here the maximum value of the uncorrected (blue) histogram is reference input for the data driven method to get the corrected (red) histogram.
- The correction is applied event by event on the number of tracklets.

Tracklet distribution in events

work in progress

After correction the distribution is shifted to higher multiplicity.

- **Objectives of tracklet distribution:**
  - Definition of multiplicity classes according to the black lines.
  - Estimation of charged-particles.

Upsilon as a function of multiplicity

✦ Signal extraction in multiplicity classes

1. The corrected tracklet distribution has been used to define multiplicity classes/ bins.

2. The Upsilon signal is extracted in each multiplicity class.

3. The signal extraction is performed according to a fit of the dimuon invariant mass spectrum using the following fit functions:
   - 3 Double Cristal Ball for the signal (one for each state)
   - background (two exponential in the following example)

work in progress

Next Step: estimation of the relative upsilon yield

Upsilon production rate as a function of multiplicity in pp collision at $\sqrt{s}$ = 13 TeV with ALICE experiment

✓Data sample, event and track selection in muonic channel
- ✓2015
- ✓2016
- ✓2017

✓Multiplicity measurement
- ✓Determine the correction factor for the SPD tracklets
- ✓Charged-particle estimation from tracklets
- ✓Define the multiplicity classes
- ✓Pile-up study (Pile-up is a superimposition of multiple pp collisions)

✓Upsilon yields in multiplicity bins
- ✓Produce dimuon invariant mass plot in multiplicity classes
- ✓Fit the mass plot to extract the upsilon yields

✓Upsilon production as a function of charged-particle multiplicity

✓Estimation of systematic and statistical uncertainties

Conclusions

- LHC gives a great opportunity for studying the interaction between elementary particles.
- Study of quarkonium production as a function of multiplicity is an interesting way to understand the interplay between hard production and underlying event of the proton-proton collision.
- Some studies are already done on quarkonium at different energies and for different systems.
- Study of upsilon as a function of multiplicity at 13 TeV will bring more light on the understanding of initial-state of proton-proton collisions. It will be very interesting to compare with J/Ψ and non prompt J/Ψ at the same energy and rapidity.
- Upsilon as a function of multiplicity: tracklet correction, multiplicity classes and mass-fits are initiated. Next step: use 2016 data (5 times for statistics), pile-up studies, efficiency calculation and estimation of systematic uncertainties.

Thank You