Study of double J/ψ production mechanisms at COMPASS

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On behalf of the COMPASS collaboration

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COMPASS

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JINR

Physics motivation

- Study of double J/ψ production mechanisms:
  — single parton scattering (SPS)
  — multiparton interactions
  — intrinsic charm of hadron (IC)

- Search for heavy-quark states decaying to two J/ψ

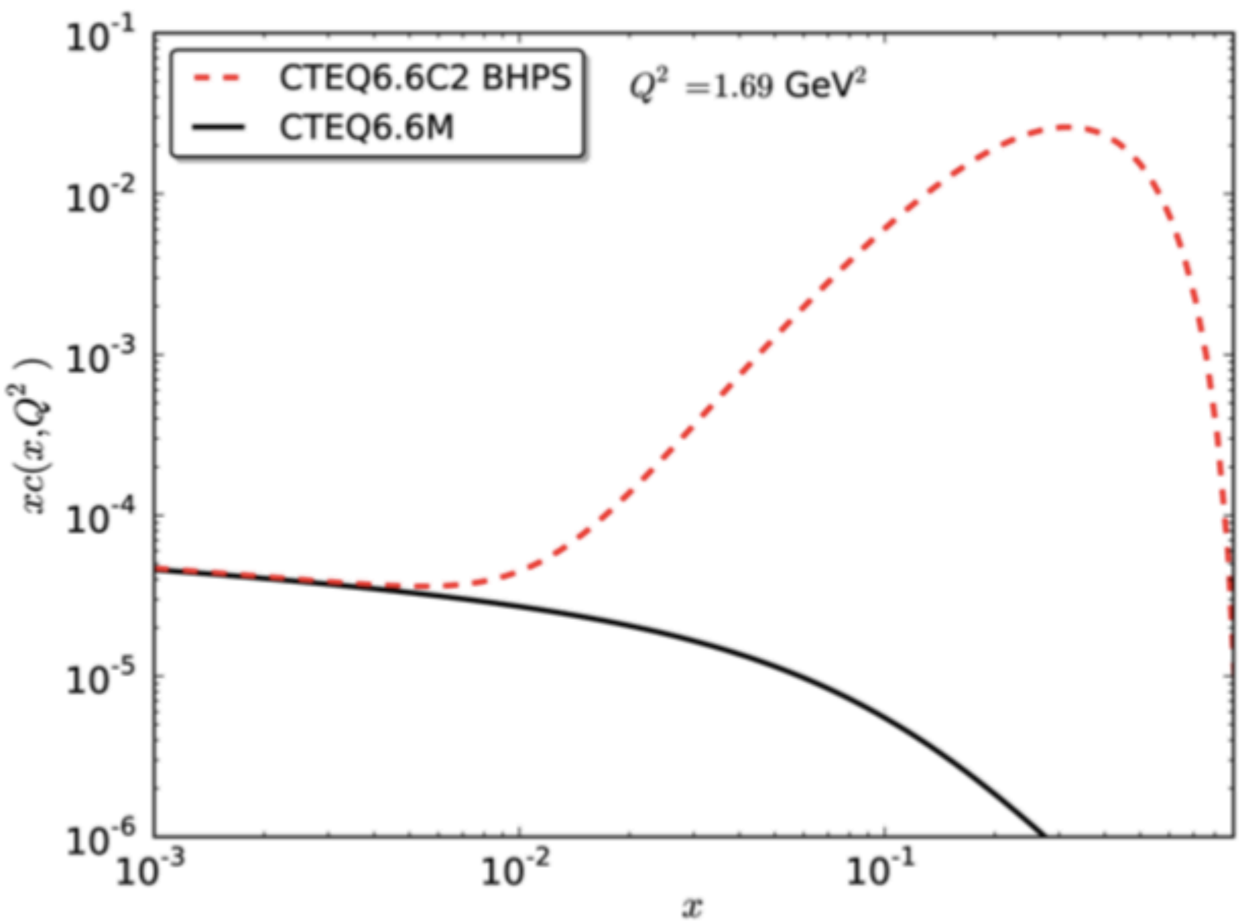
Intrinsic charm of hadron

BHPS model: **S.J. Brodsky, Phys. Lett. B 93, 451 (1980)**

- The existence of non-perturbative (intrinsic) Fock component in a hadron with c-quarks is postulated:

$$|p\rangle = a_0|uud\rangle + a_1|uudg\rangle + \underline{a_2|uudc\bar{c}\rangle} + \ldots$$

- In perturbative QCD the extrinsic charm component in hadrons arises from gluon splitting.
- Intrinsic charm contribution is generated non-perturbatively via $gg \to Q\bar{Q}$;

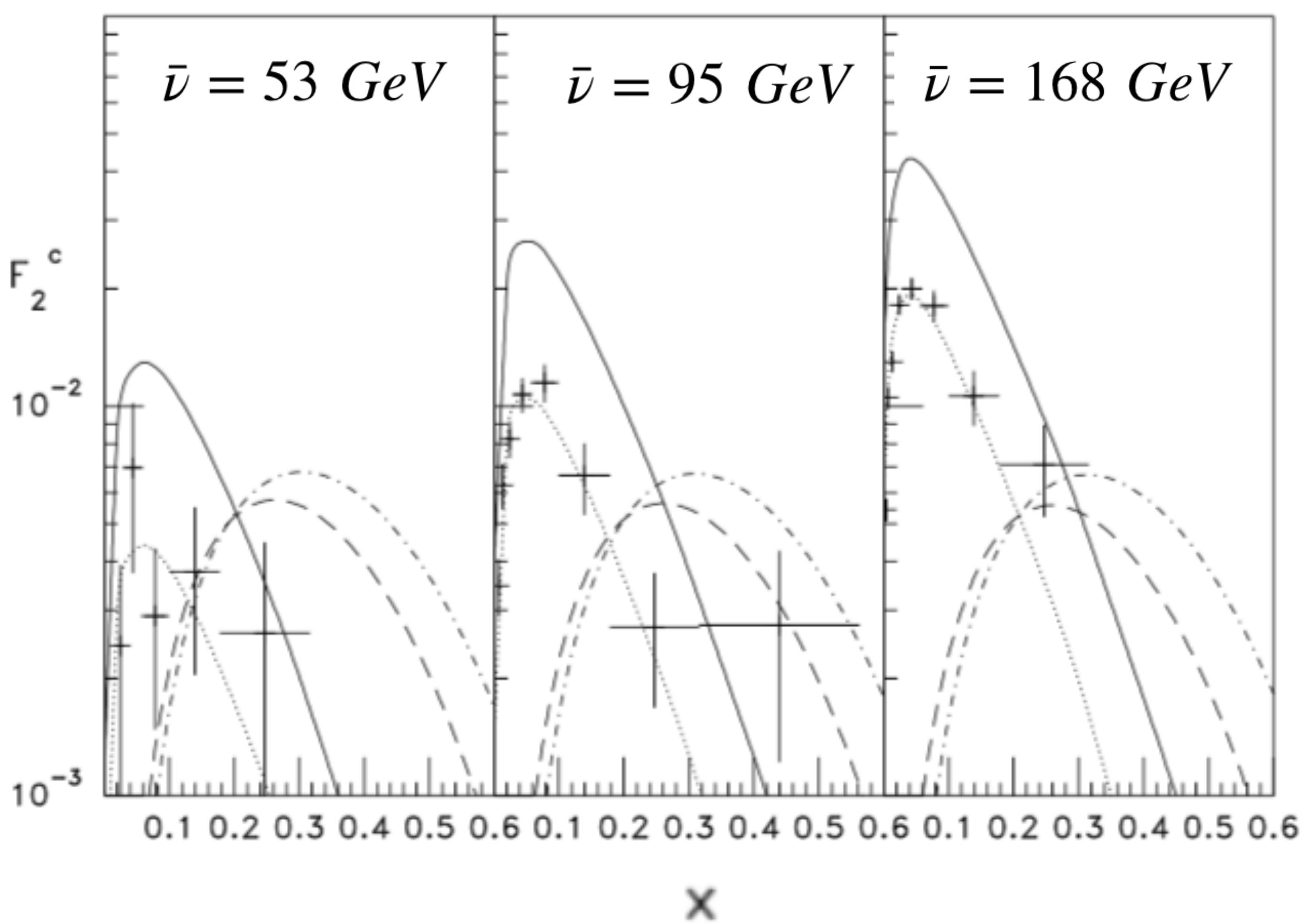


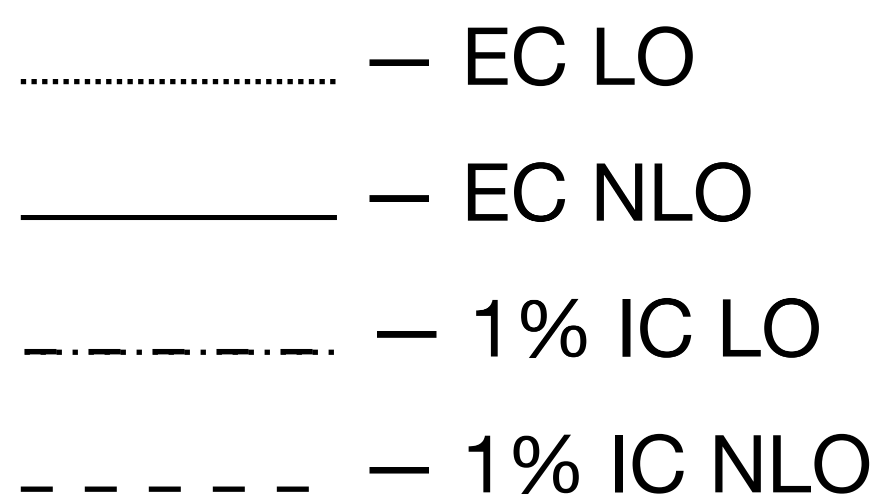
V.A. Bednyakov, G.I. Lykasov Phys. Lett. B, 728, 602 (2014)

Intrinsic charm of baryons

- **EMC experiment:** an evidence for an intrinsic charm component in the proton was found from the comparison of EMC data for $F_2(x, Q^2, m_c^2)$ with NLO predictions at large x.

B. W. Harris, J. Smith, R.Vogt
Nucl.Phys.B 461 (1996) 181-196



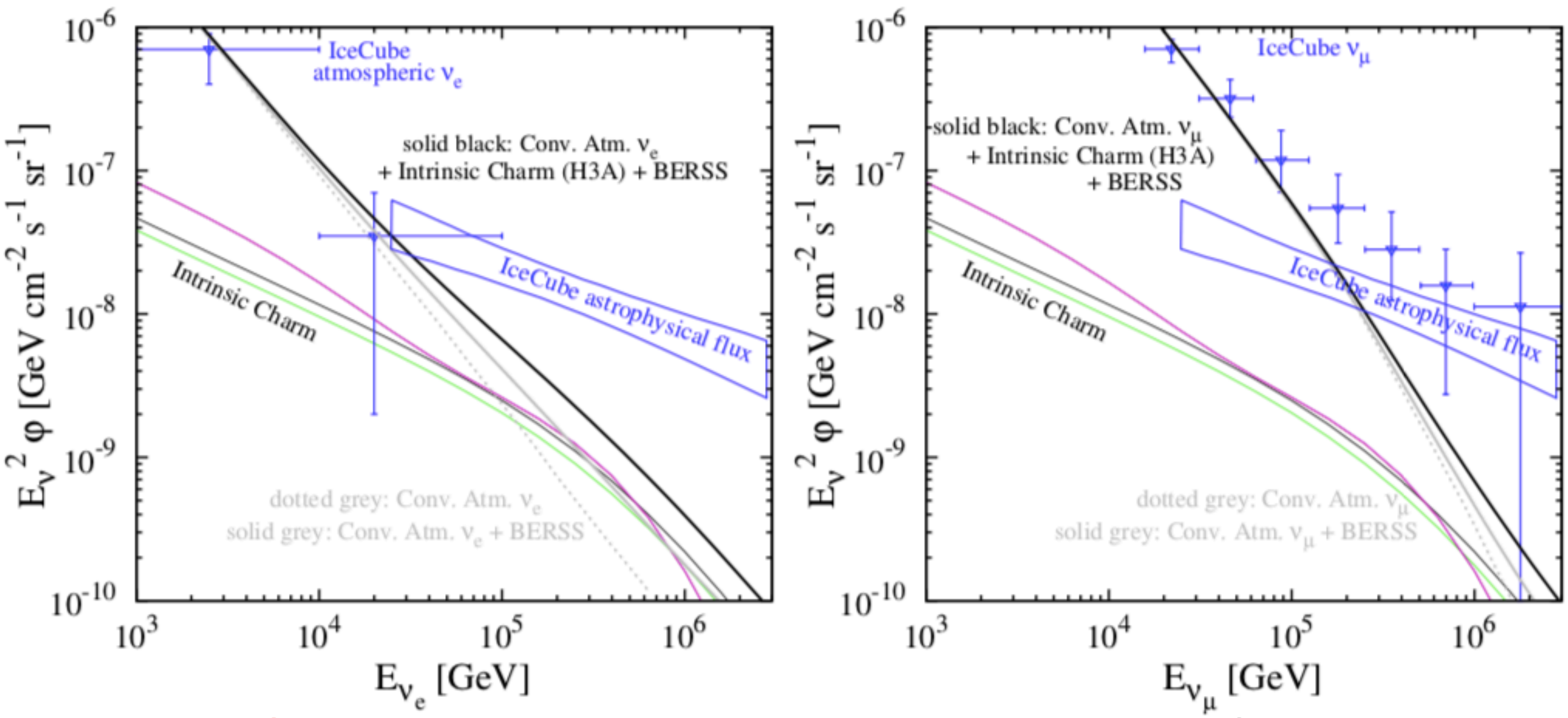


- **SELEX experiment:** inconsistency of the Ξ_c^+, Ξ_{cc}^{++} and Λ_c^+ production rates with QCD predictions.
  Can be explained within the IC hypothesis (intrinsic charm in the wave function of Ξ_{cc}^{++}).

S.Koshkarev, V.Anikeev, Phys.Lett.B765,171 (2017)

Intrinsic charm of baryons

- **IceCube experiment:** IC in the wave function of the projectile proton can significantly contribute to the prompt neutrino flux (can be enhanced by a factor of two at neutrino energies about 10^6 GeV).



R. Laha, S.J. Brodsky
Phys.Rev.D 96, 123002 (2017)

- **ATLAS experiment:** an upper limit on IC probability in proton obtained using $\gamma + c$-jet data: $w_{c\bar{c}} < 1.93\%$ (68% CL). In agreement with theoretical predictions.

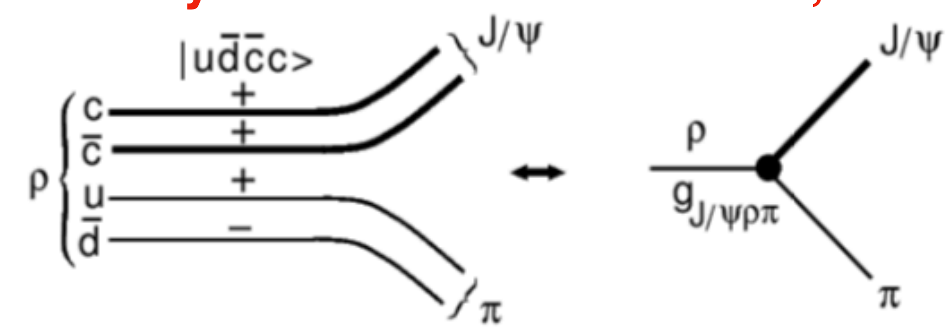
V.A. Bednyakov, S.J. Brodsky et al.
EPJC volume 79, 92 (2019)

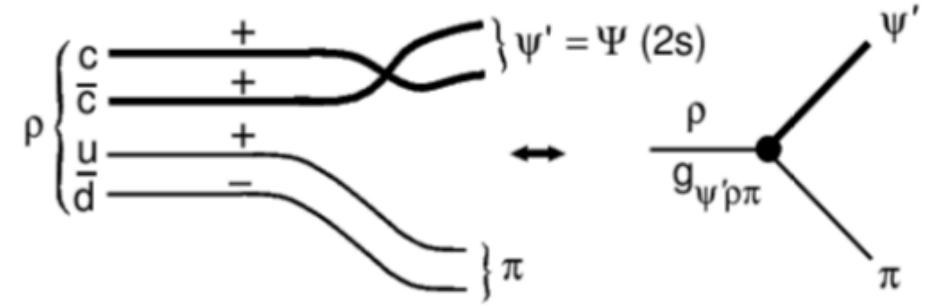
Intrinsic charm of mesons

The presence of the $|u\bar{d}c\bar{c}\rangle$ Fock state in the ρ:

- $J/\psi \to \rho\pi$ decay allowed (due of overlap with J/ψ and pion wave functions of the ρ);
- $\psi' \to \rho\pi$ decay is suppressed (radial wave function of the ψ' has one node and it is orthogonal to the $c\bar{c}$ in the $|u\bar{d}c\bar{c}\rangle$ state of the ρ).

S.J.Brodsky, M. Karliner
Phys.Rev.Lett.78:4682-4685,1997





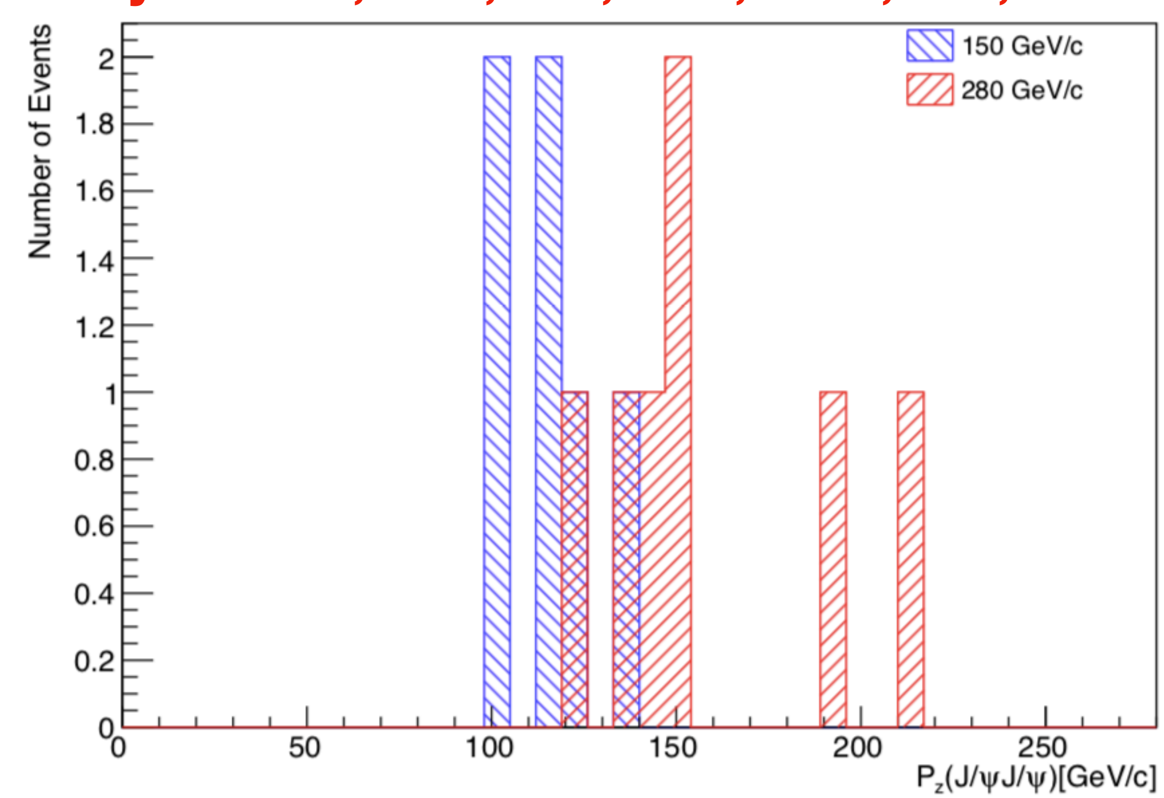
The NA3 double J/ψ results:

- π^- (150, 280 GeV) and p (400 GeV) beams;
- N.B. kinematic distributions are not corrected for the acceptance;
- interpreted using double IC hypothesis ($|d\bar{u}c\bar{c}c\bar{c}\rangle$ Fock component of pion materialization).

R Vogt, S.J. Brodsky
Phys.Lett.B349:569-575,1995

J.Badier et al (NA3)

Phys Lett B,v114,No6,1982, v158,No1, 1985



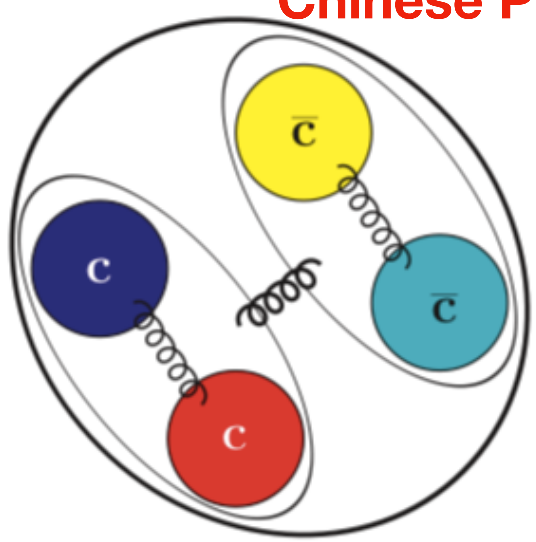
T_{4c}-tetraquarks

$N^{2S+1}\ell_J$	M_{T4c}	J^{PC}
Diquark		
1^3S_1	3133.4	1^+
Tetraquark		
1^1S_0	5969.4	0^{++}
1^3S_1	6020.9	1^{+-}
1^5S_2	6115.4	2^{++}
1^1P_1	6577.1	1^{--}
1^3P_0	6480.4	0^{-+}
1^3P_1	6577.4	1^{-+}
1^3P_2	6609.9	2^{-+}
1^5P_1	6495.4	1^{--}
1^5P_2	6600.2	2^{--}
1^5P_3	6641.2	3^{--}
2^1S_0	6663.3	0^{++}
2^3S_1	6674.5	1^{+-}
2^5S_2	6698.1	2^{++}
2^1P_1	6944.1	1^{--}
2^3P_0	6866.5	0^{-+}
2^3P_1	6943.9	1^{-+}
2^3P_2	6970.4	2^{-+}
2^5P_1	6875.6	1^{--}
2^5P_2	6962.1	2^{--}
2^5P_3	6996.7	3^{--}

Y. Iwasaki, Prog. Theor. Phys. V.54, p492 (1975)

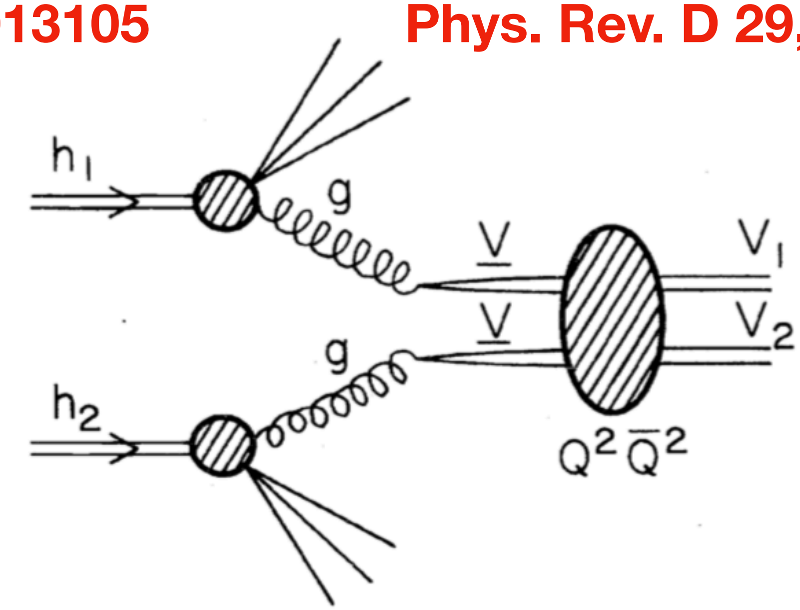
- first time T_{4c} states were predicted in 1975;
- many theoretical models ($[cc][\bar{c}\bar{c}]$ model, Drell-Yan type mechanism, etc) exist;
- $M_{T_{4c}} \approx$ 6 – 7 GeV/c^2;
- no experimental observations of T_{4c} till 2020;

V.R.Debastiani, F.S.Navarra
Chinese Phys. C 43 013105



$[cc][\bar{c}\bar{c}]$ **model**

Bing-An Li, Keh-Fei Liu
Phys. Rev. D 29, Vol 3, 1984



Drell-Yan type mechanism

LHCb double J/ψ results

arXiv:2006.16957 [hep-ex]

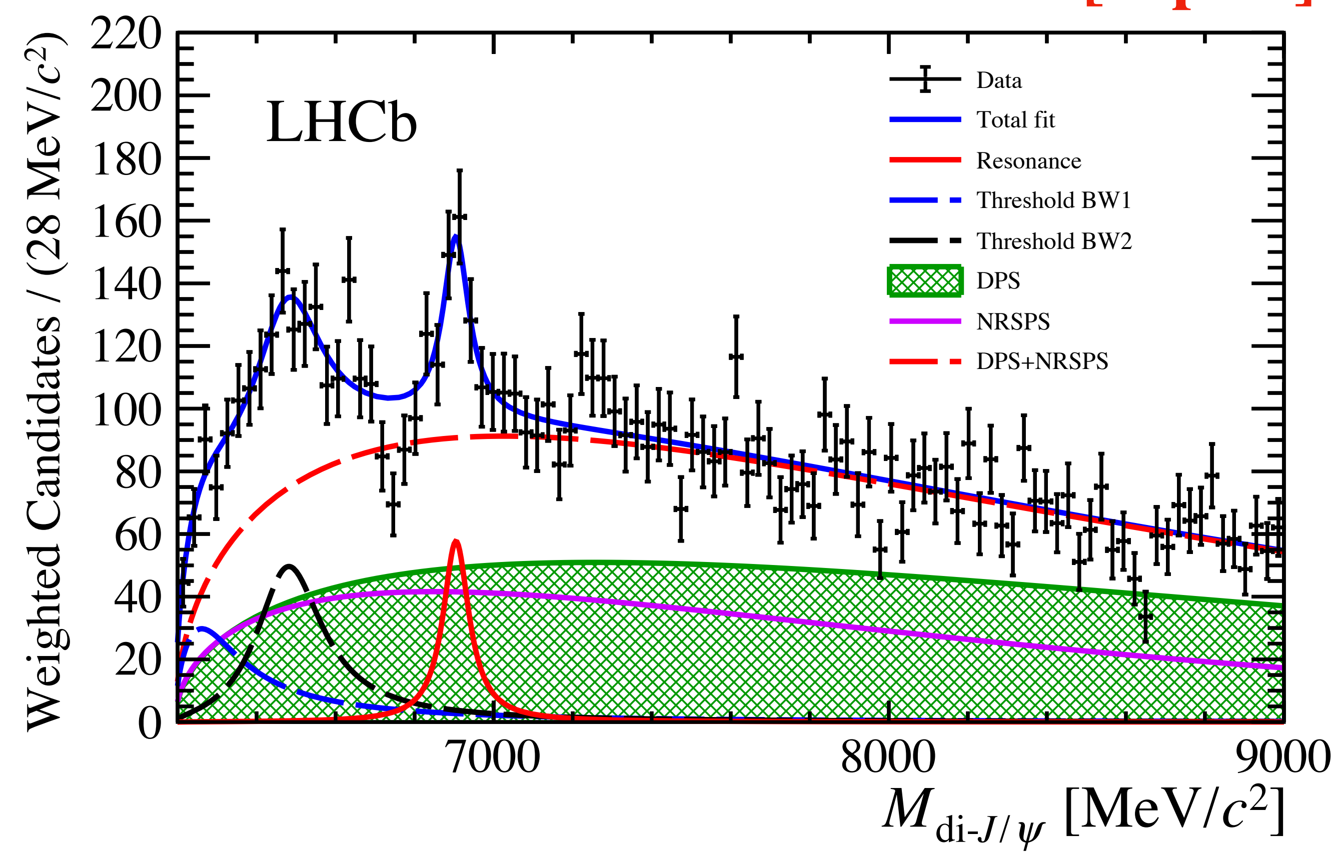
The LHCb reported the narrow X(6900) structure in the double J/ψ mass spectrum using proton-proton collision data at $\sqrt{s} = 7,\ 8$ and 13 TeV.

Model I - X(6900) resonance (without interference):

$$m[X(6900)] = 6905 \pm 11 \pm 7\ \text{MeV}/c^2$$

$$\Gamma[X(6900)] = 80 \pm 19 \pm 33\ \text{MeV}$$

5.1 σ

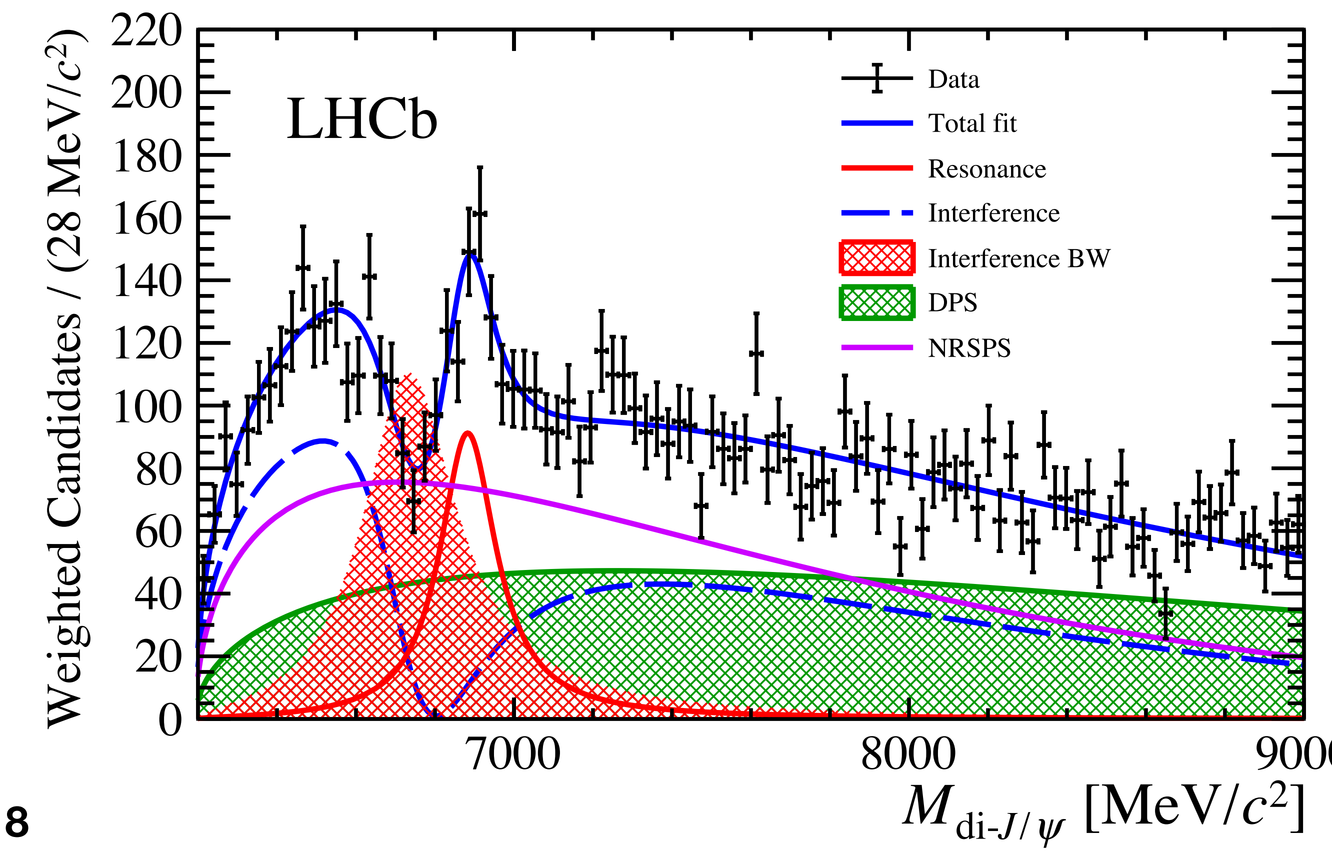


Model II - X(6900) + interference between broad structure (6.2-6.8) and SPS:

$$m[X(6900)] = 6886 \pm 11 \pm 11\ \text{MeV}/c^2$$

$$\Gamma[X(6900)] = 168 \pm 33 \pm 69\ \text{MeV}$$

6.4 σ



COMPASS experiment at CERN

COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

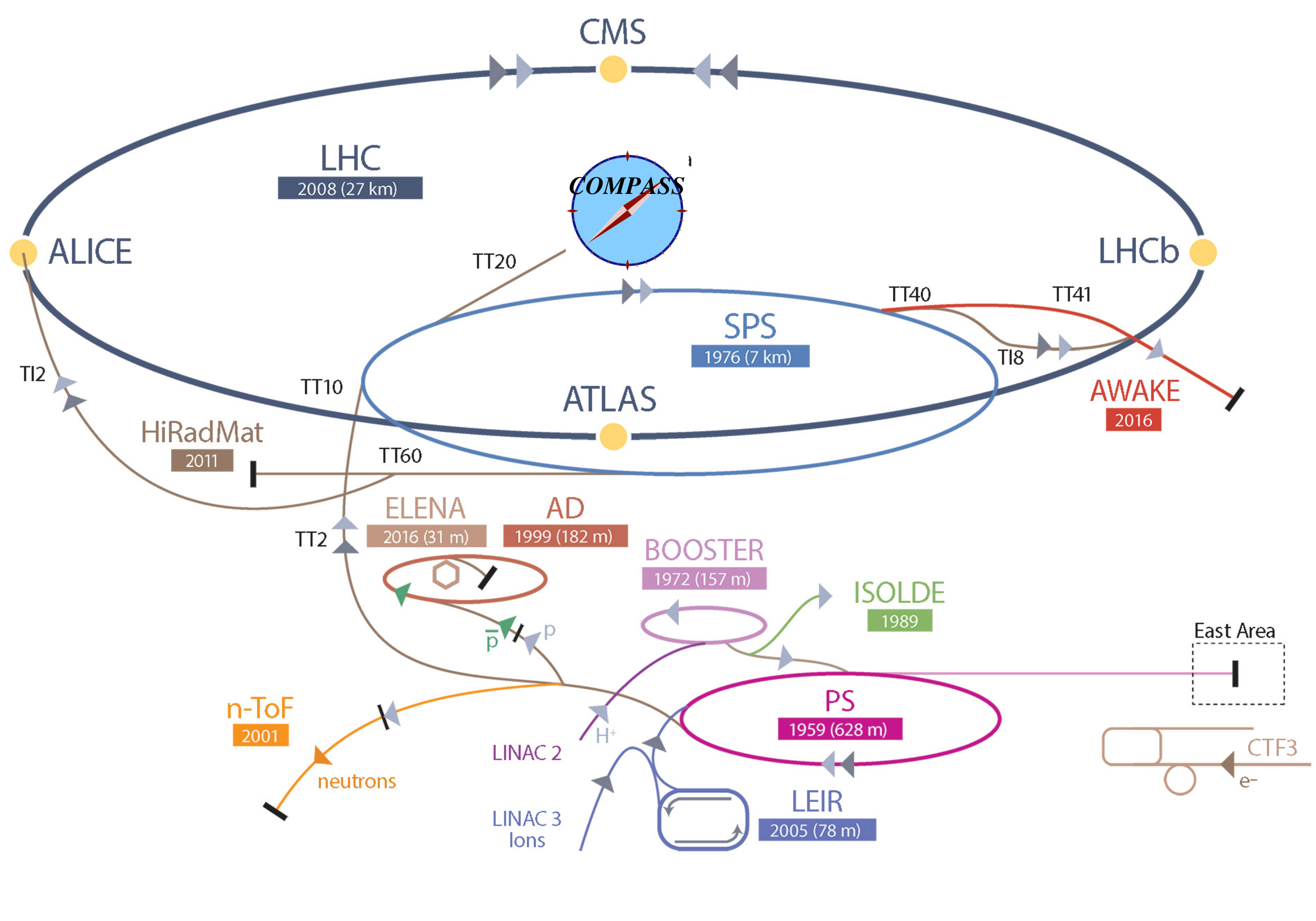
Phase 1:

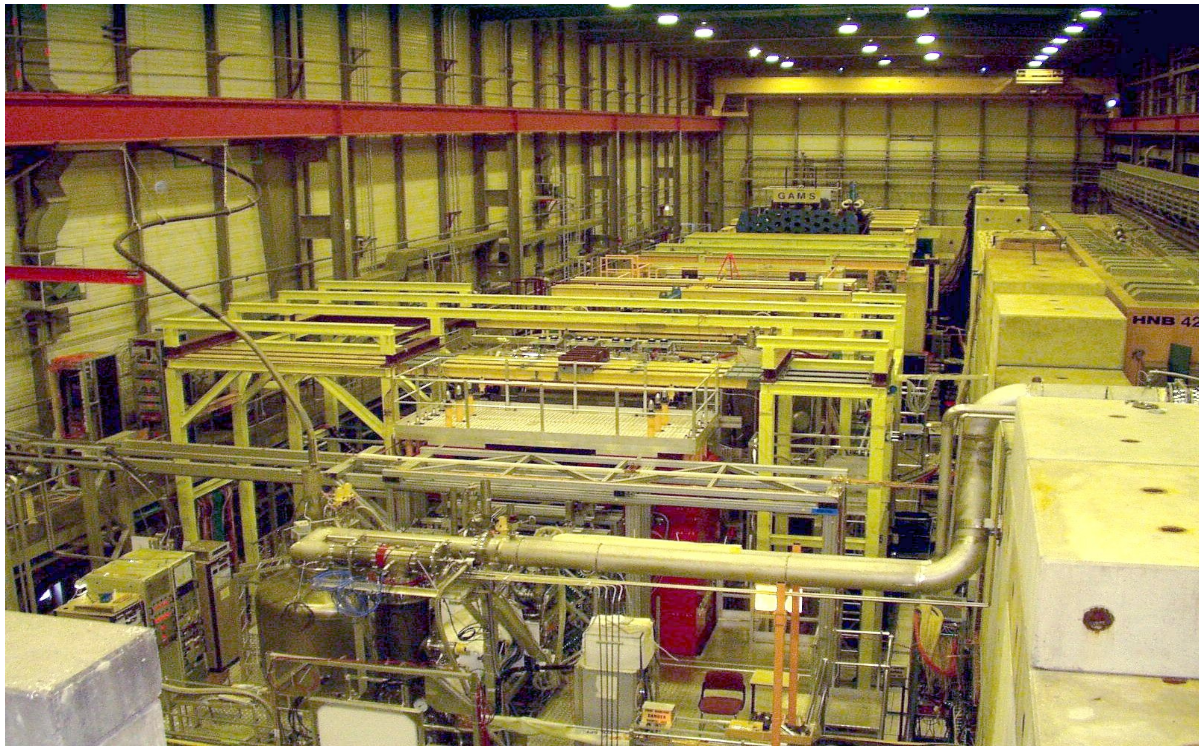
- Nucleon Spin Structure (2002-2011)
- Hadron Spectroscopy (2008-2009)

Phase 2:

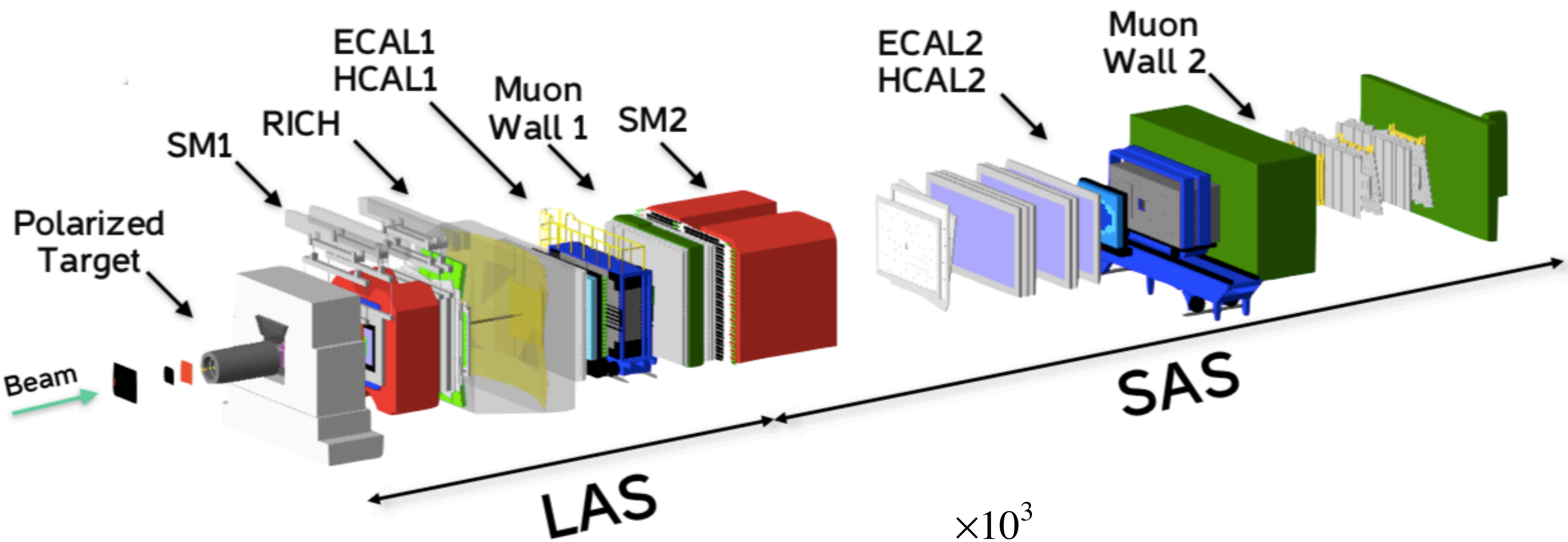
- Primakoff (2012)
- DVCS, SIDIS (2012, 2016, 2017)
- Drell-Yan (2015, 2018)

CERN's Accelerator Complex



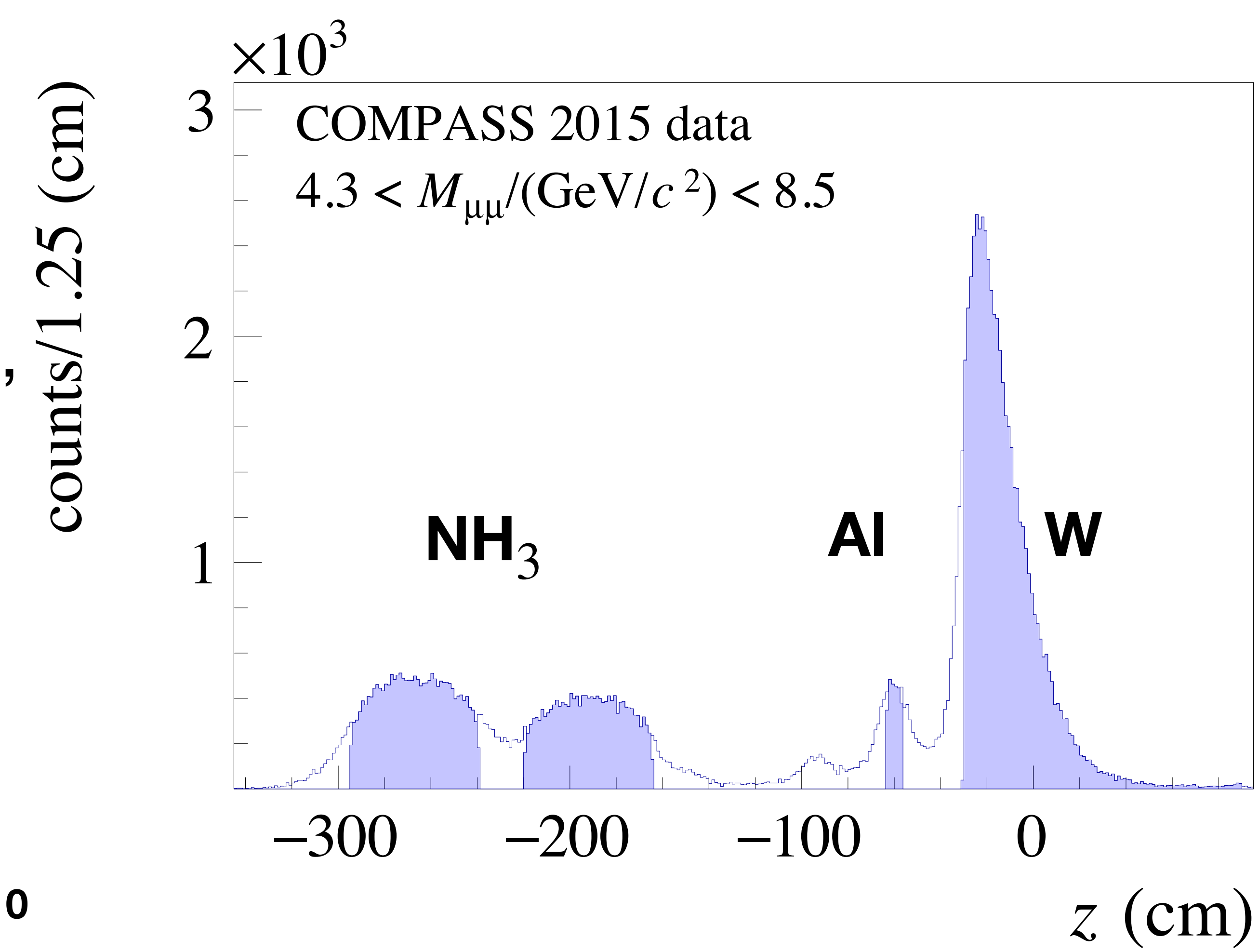


COMPASS Drell-Yan setup



Unique hadron beam in DY runs :

- hadron beam composition: 96.80% π^-, 2.40% $\bar{K}$, 0.80% $\bar{p}$;
- beam momentum : **190 ± 3 GeV/c;**
- intensity: up to **7x10^7 hadrons / sec;**



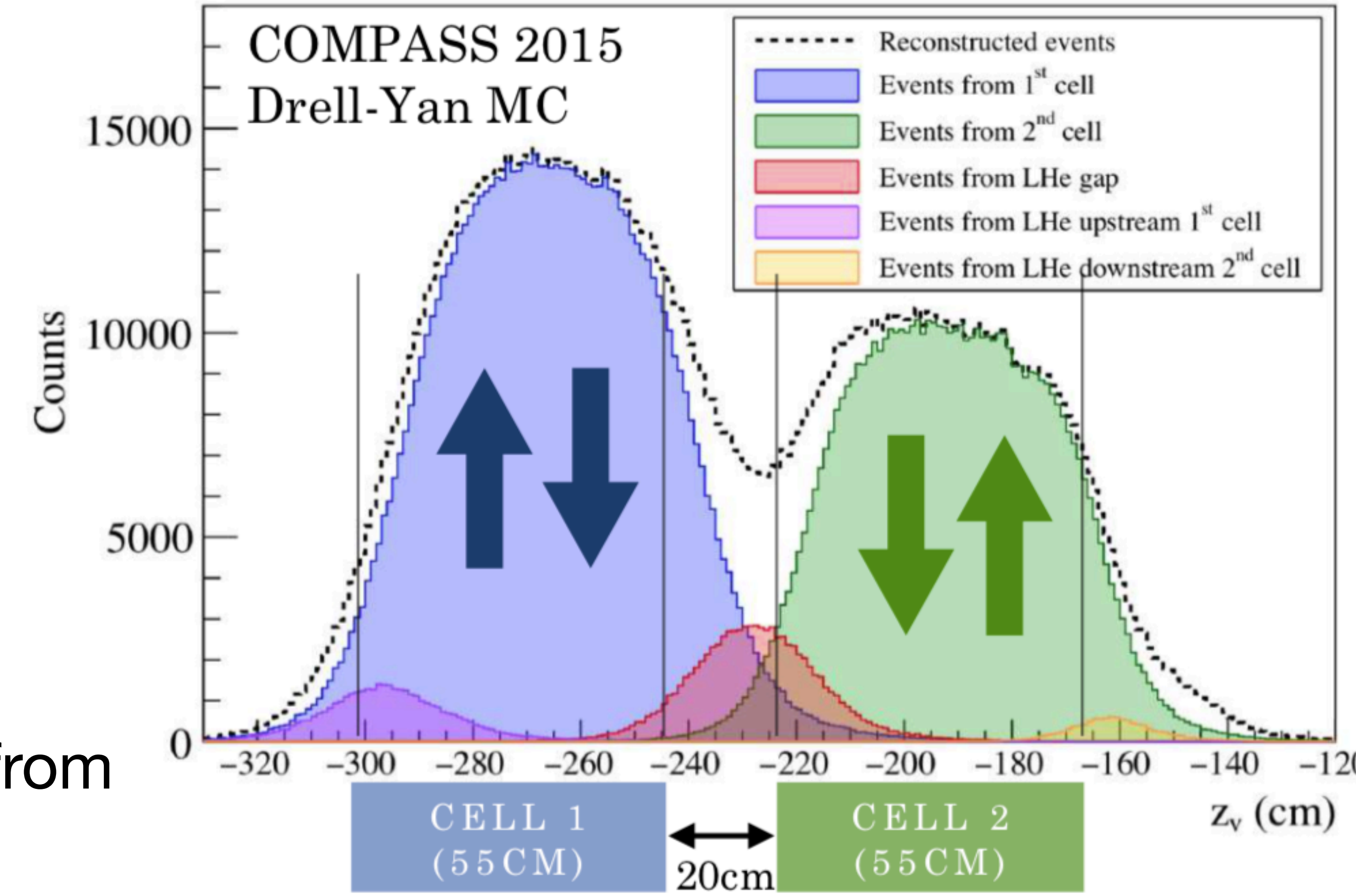
COMPASS Drell-Yan setup

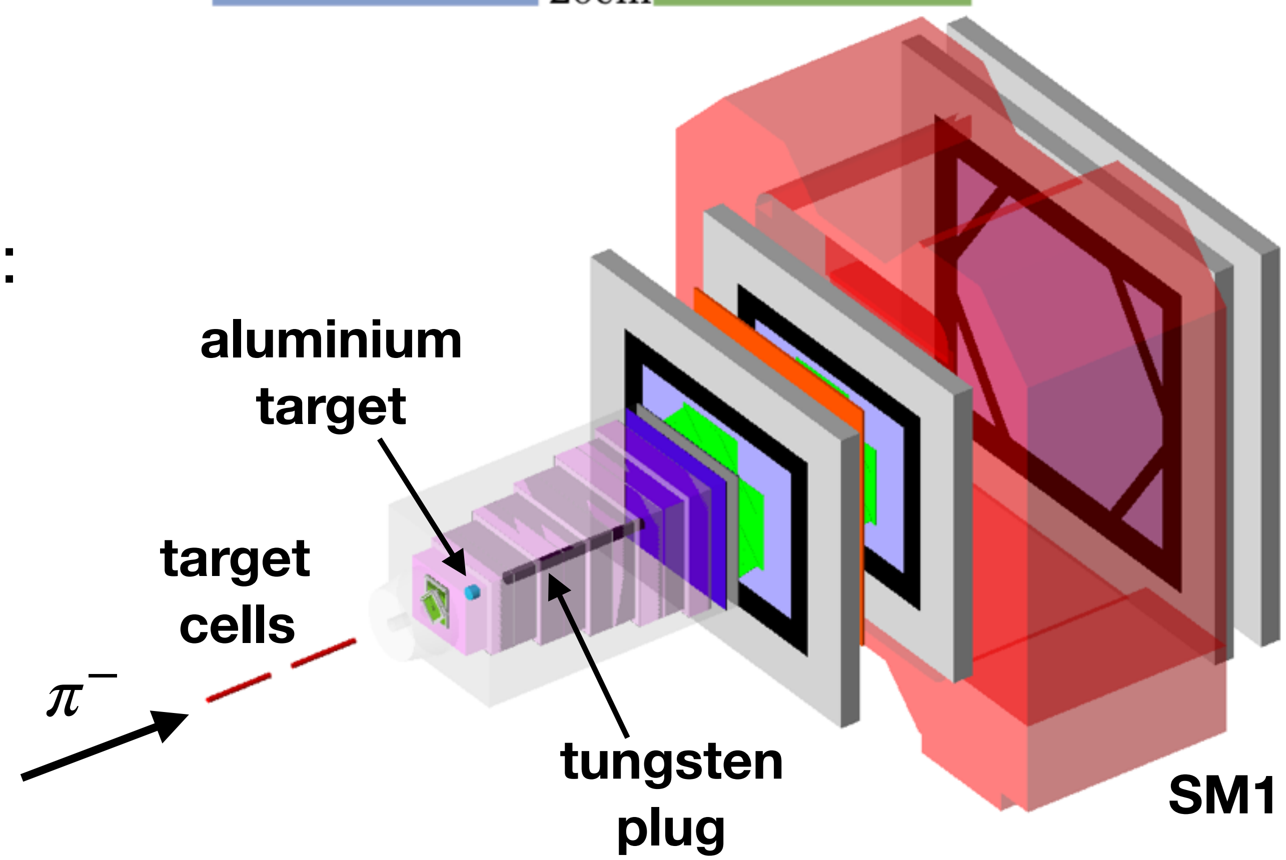
Polarized target:

- two 55 cm long cells filled with NH_3 immersed in LHe used in particular in polarized DY studies.

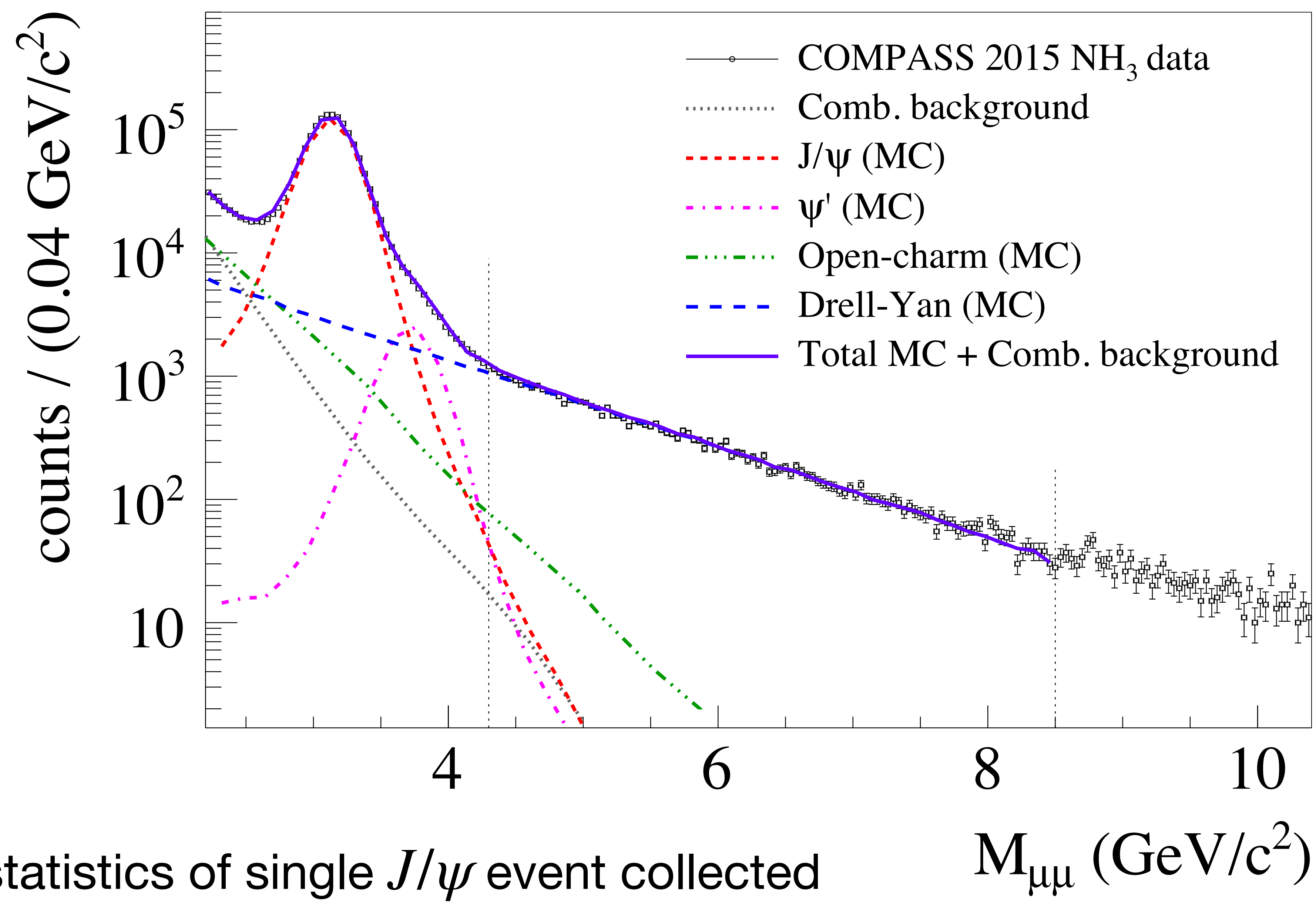
Nuclear targets (Al and W):

- used to remove hadrons originating from target interactions or beam;
- used as an additional nuclear targets:
  — aluminum (A ~ 27): 7cm length;
  — tungsten (beam plug, 120 cm, A ~ 184): first 10 cm used for the physics analyses.



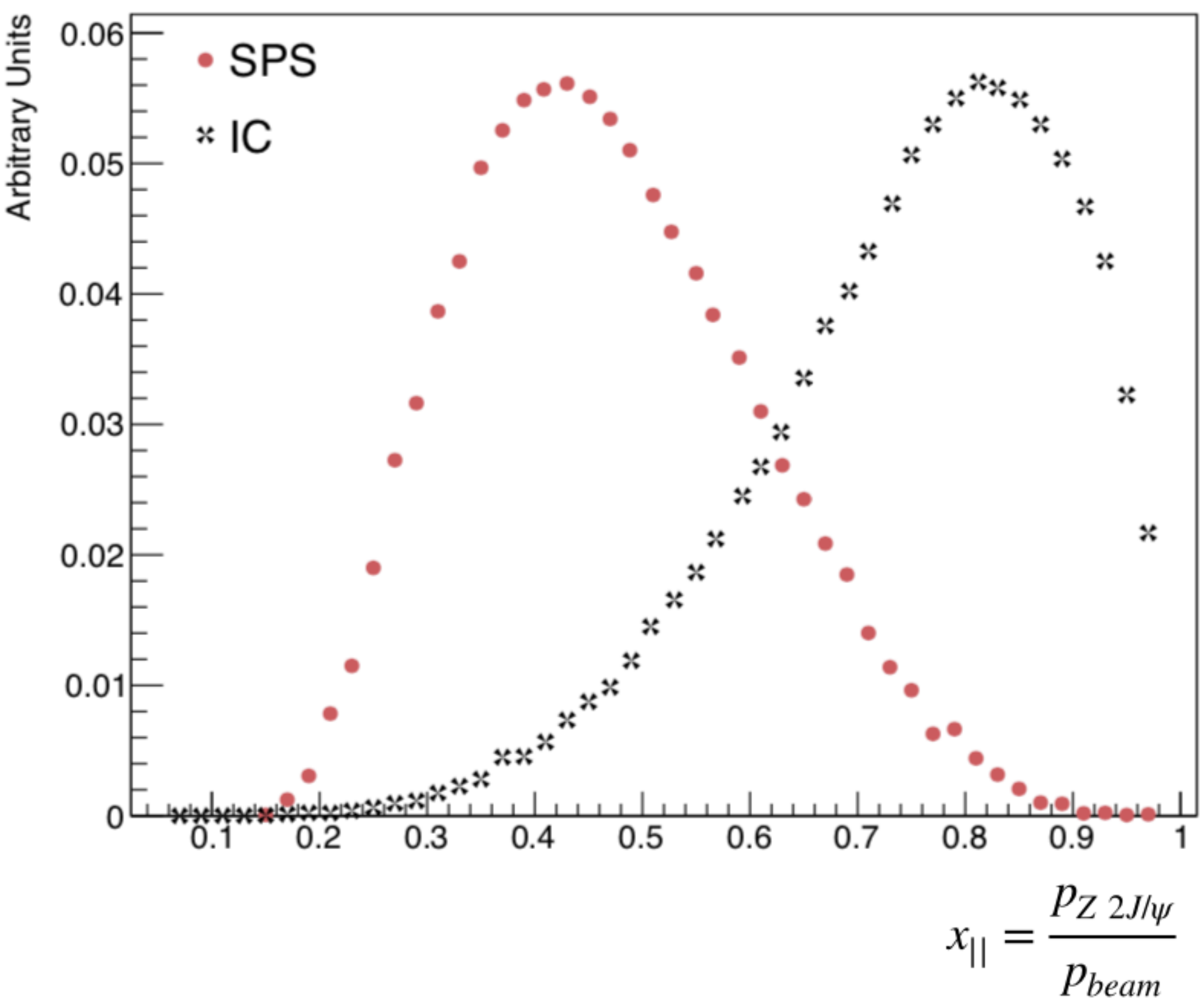


DY and J/ψ studies at COMPASS



- Large statistics of single J/ψ event collected
- Mass resolution: $\sigma_{J/\psi}$ = 0.181 GeV/c^2
- A shoulder from $\psi(2S)$ is visible

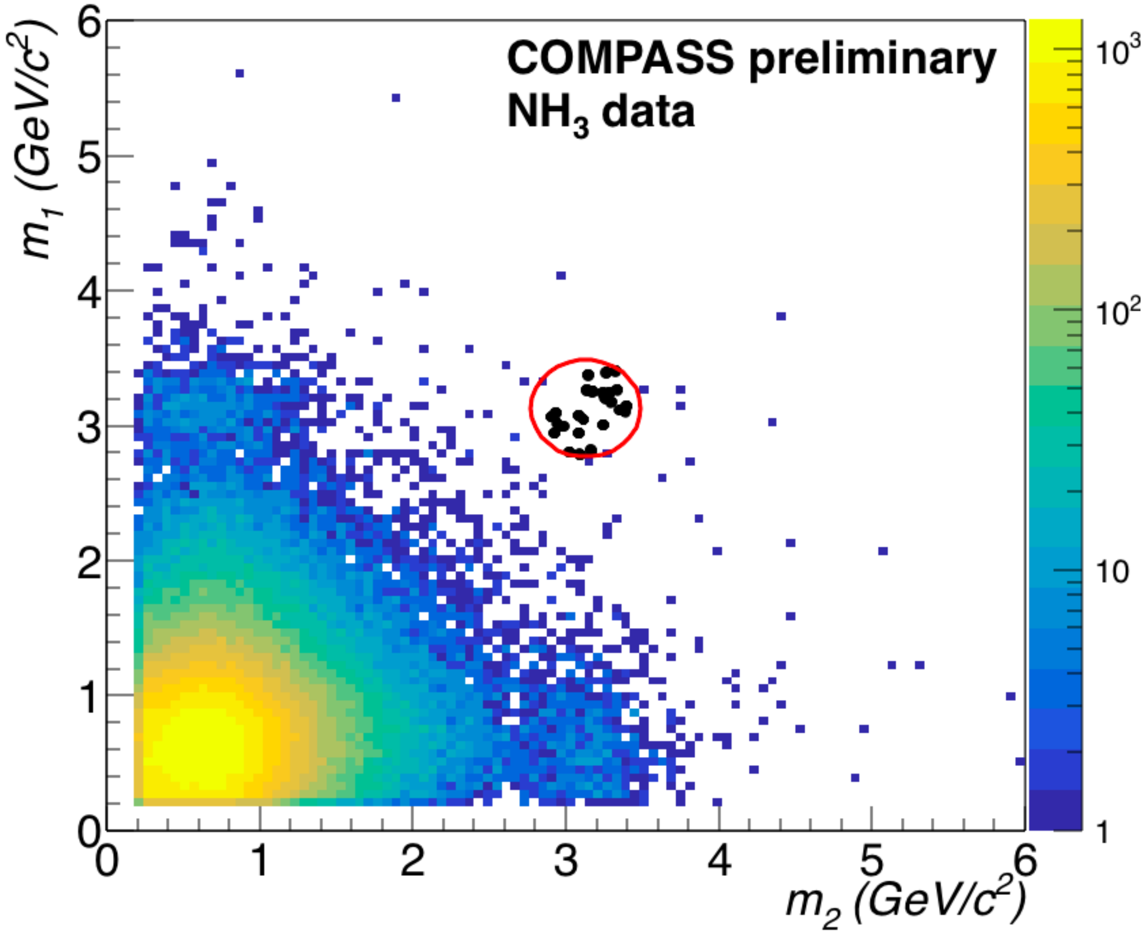
Double J/ψ studies at COMPASS



- The distribution of longitudinal momentum fraction of J/ψ pair in the lab frame is studied. Can be used to determine the relative weights of double J/ψ production mechanisms (IC, single parton scattering).

- Invariant mass distribution of double J/ψ events could be used for the search for T_{4c} states.

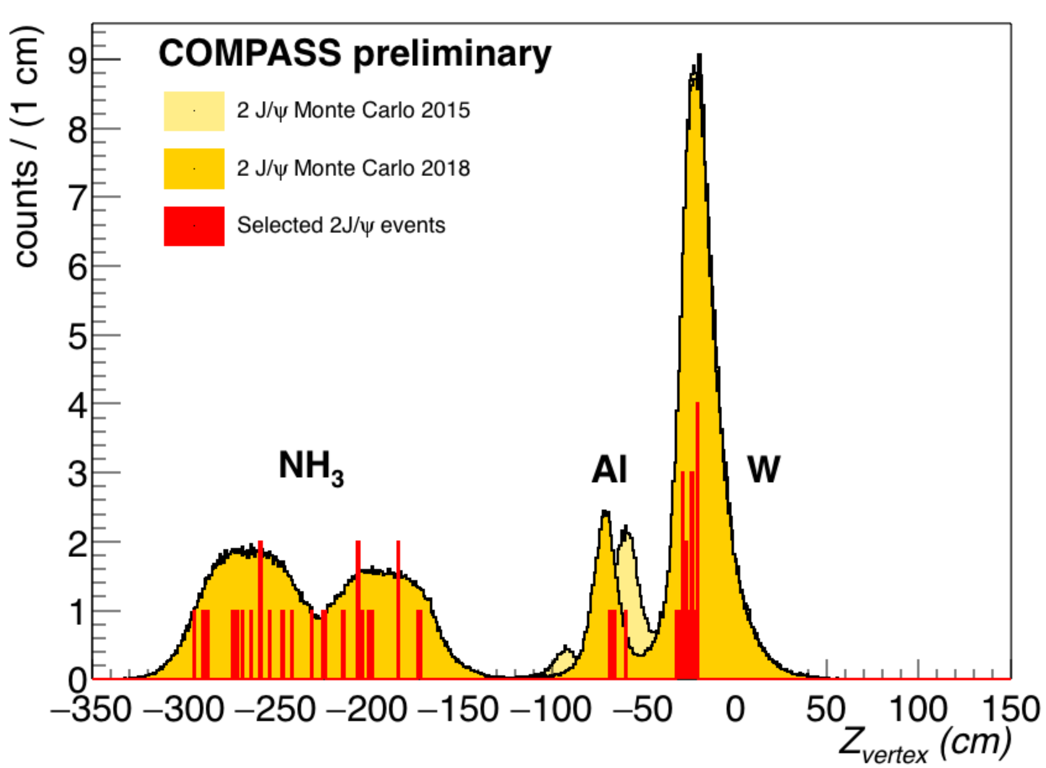
Double J/ψ data at COMPASS



2015: ~4 months of data taking;
2018: ~5 months of data taking;

NH_3 target: 25 events

- used for the analysis



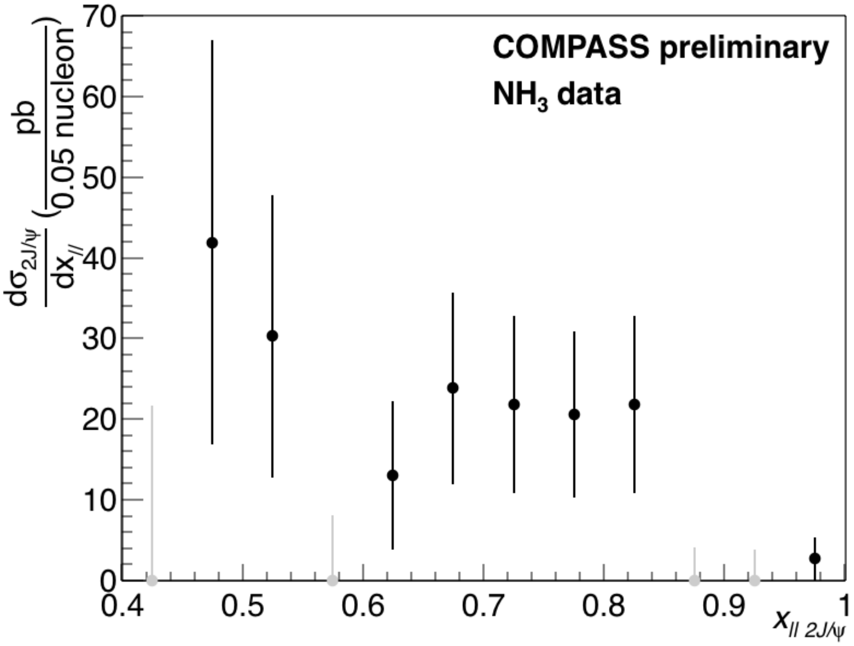
Al target: 4 events

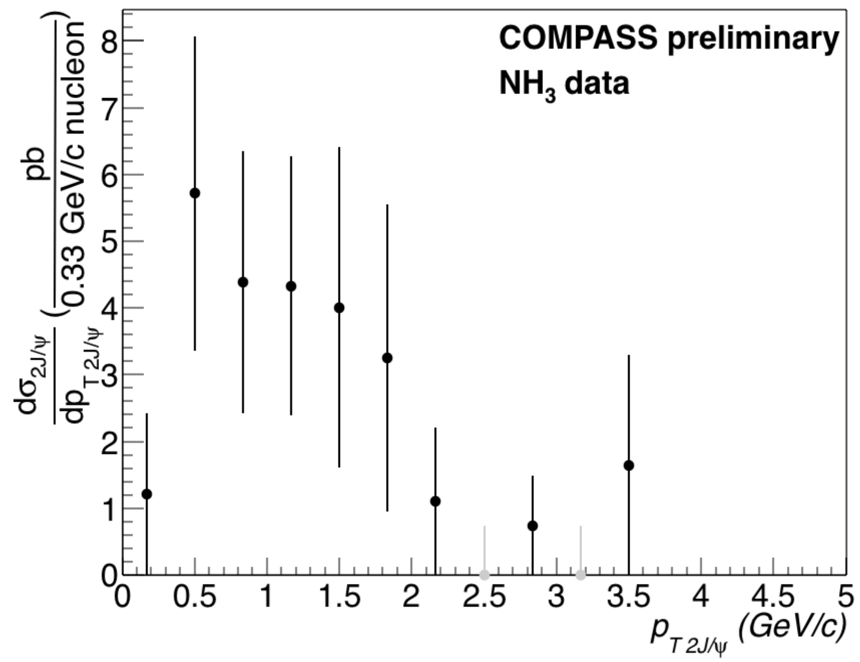
W target: 21 events

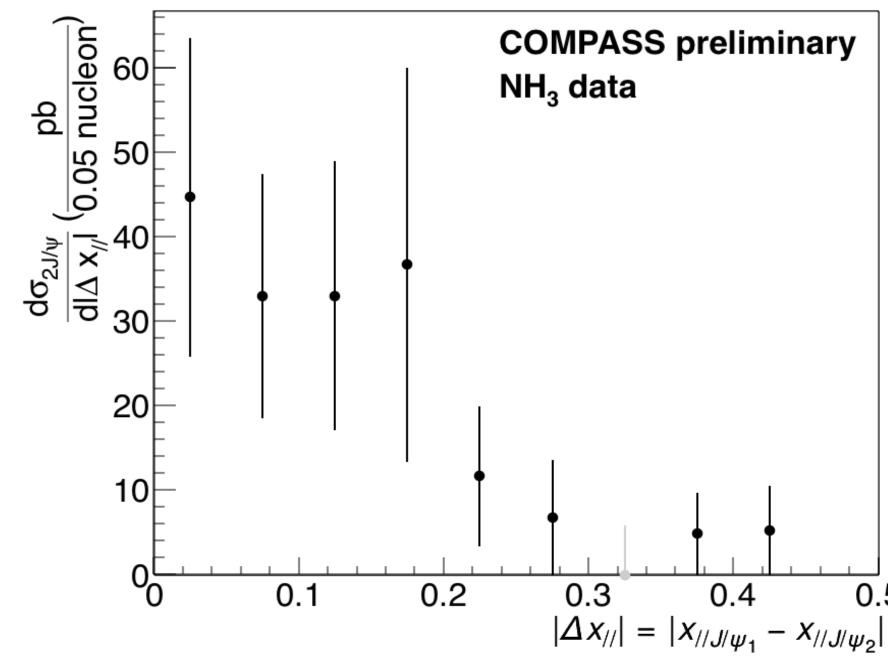
- large background contamination
- used only for cross-section estimation.

Differential cross-sections

COMPASS results:





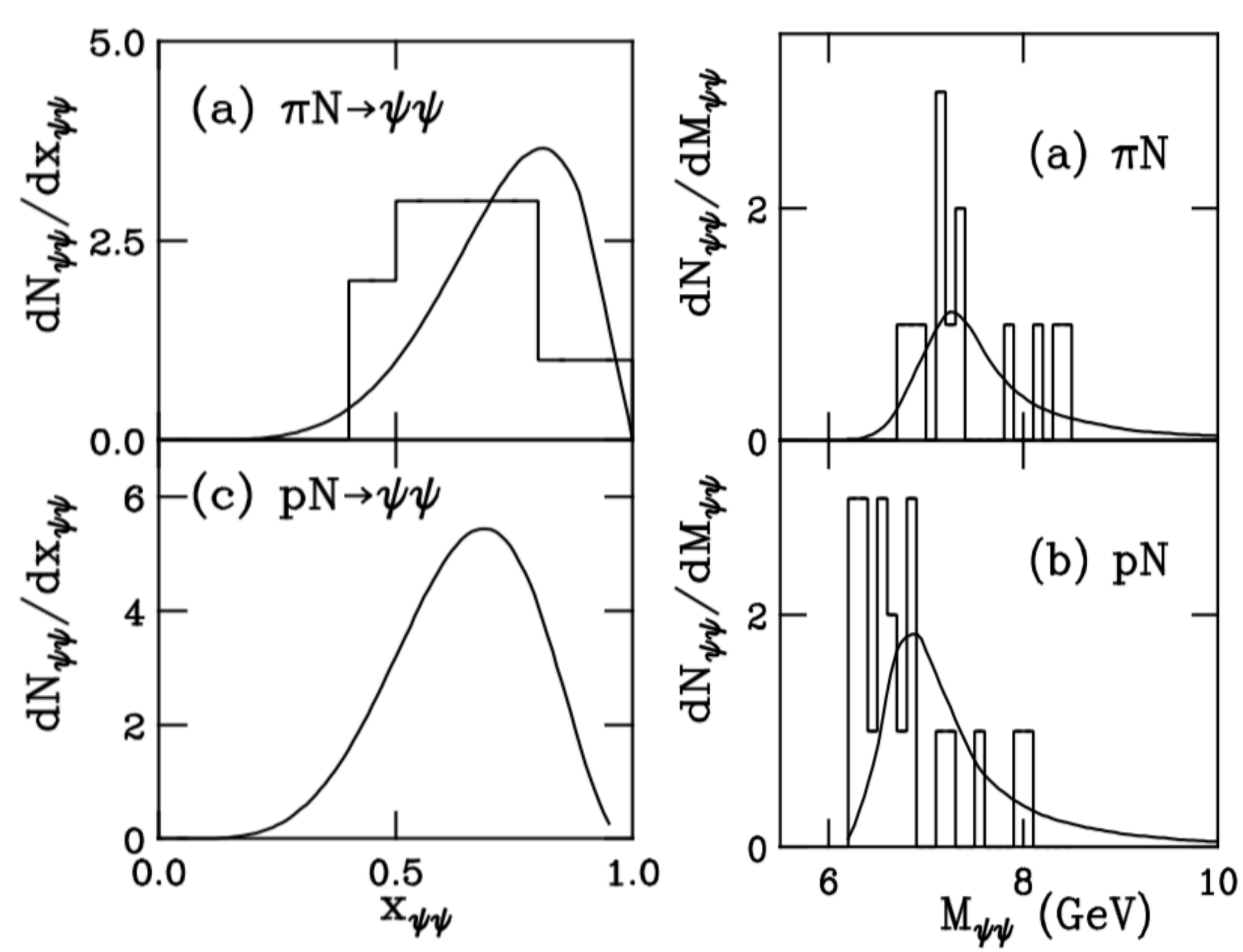


The NA3 results:

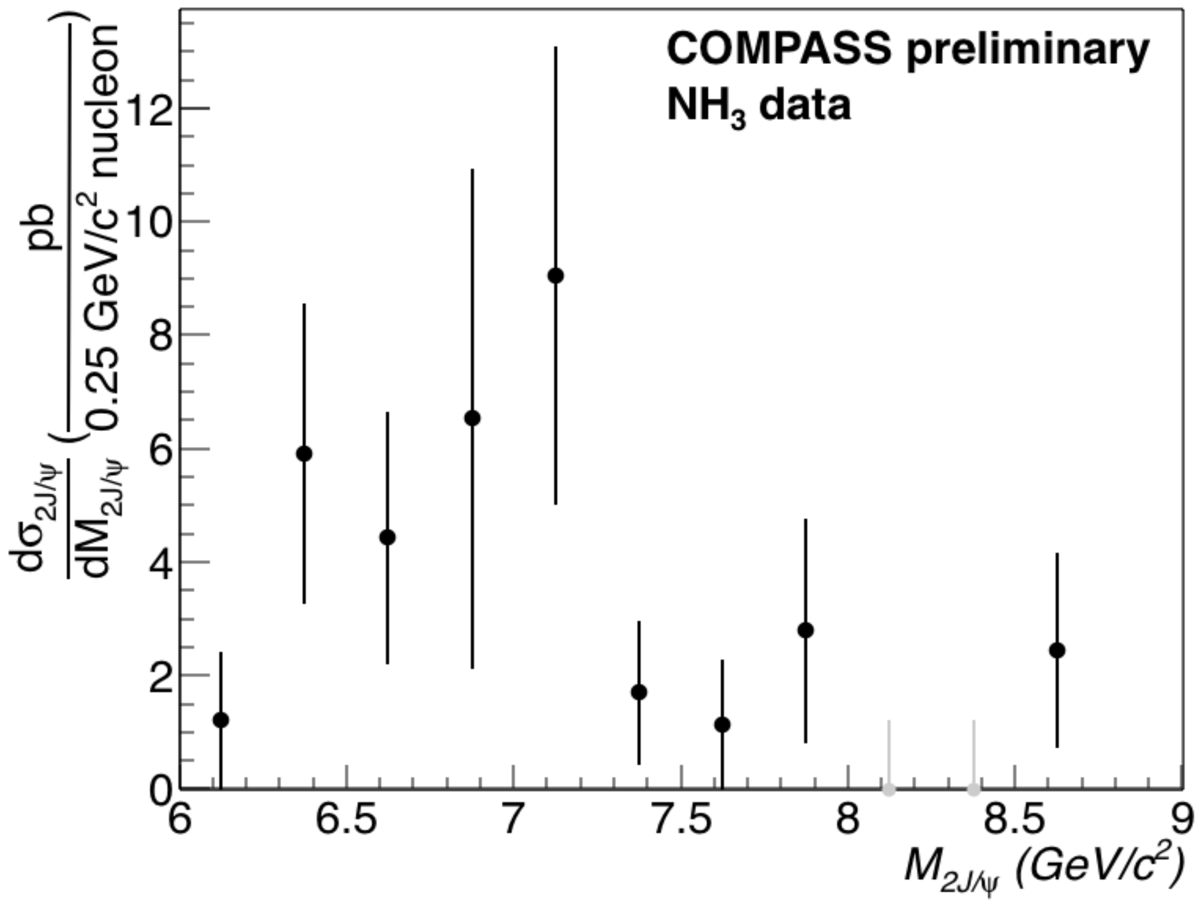
- Results were interpreted using double IC of pion hypothesis.

R Vogt, S.J. Brodsky
Phys.Lett.B349:569-575,1995

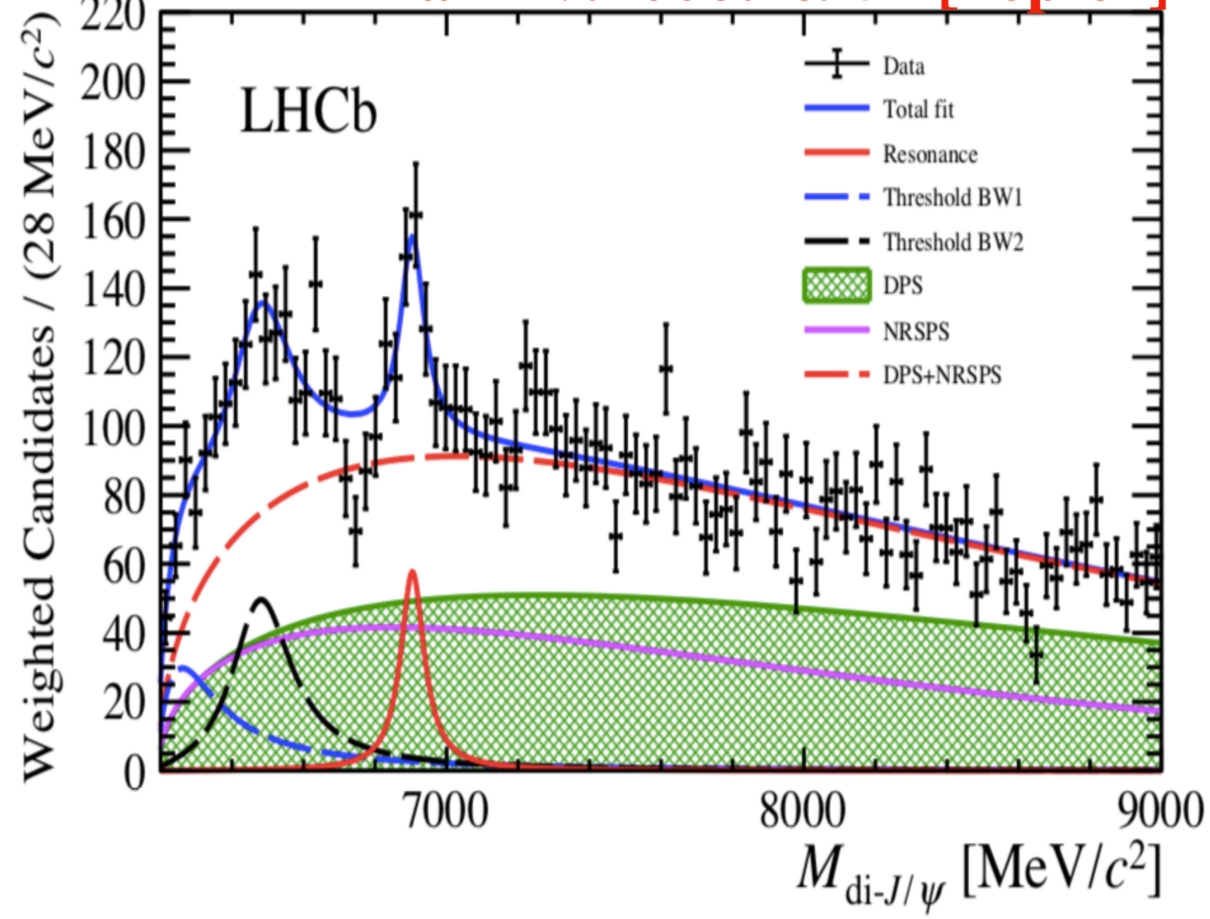
- N.B. Double J/ψ kinematic distributions were published without acceptance correction.



Double J/ψ mass spectrum



arXiv:2006.16957 [hep-ex]



The COMPASS double J/ψ mass spectrum does not contain any evident signal from T_{4c} states.

Double J/ψ production mechanisms

SPS curve:

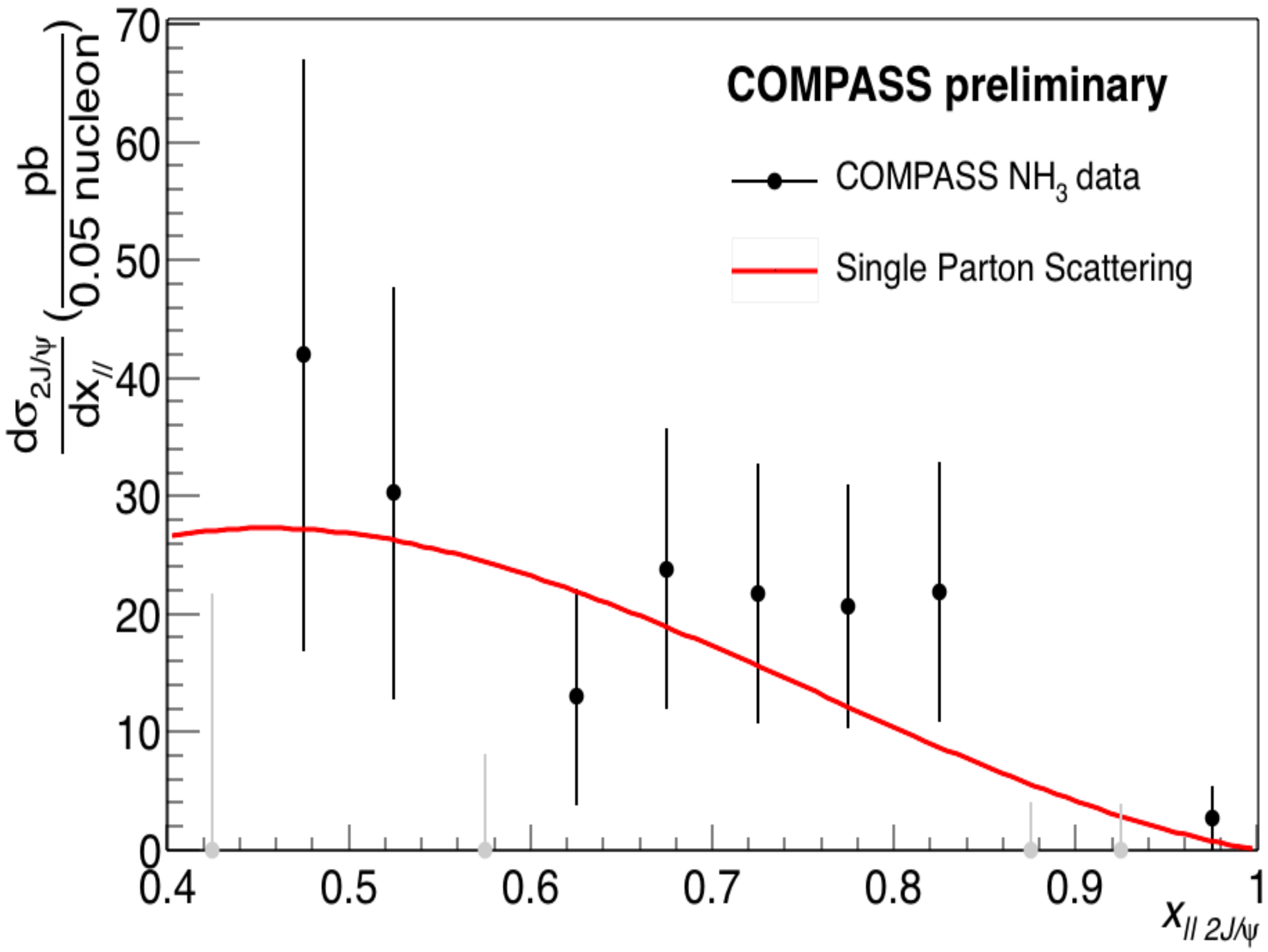
- HELAC-Onia generator: **arXiv:1507.03435 [hep-ph]**;
- Color Singlet J/ψ production model.

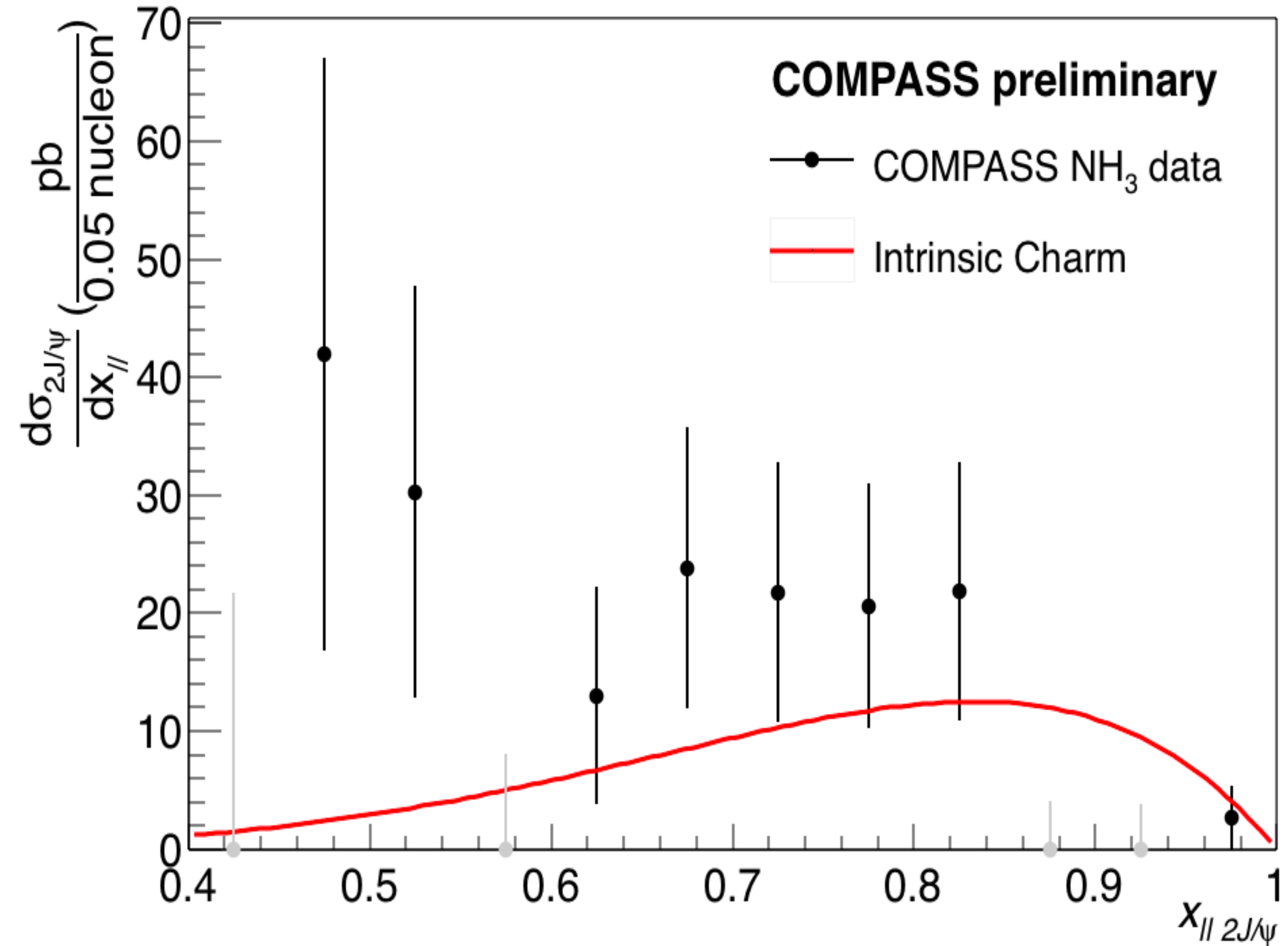
IC curve:

- predictions for COMPASS from **Phys.Part.Nucl.Lett. Vol17, No6 (2020)**.

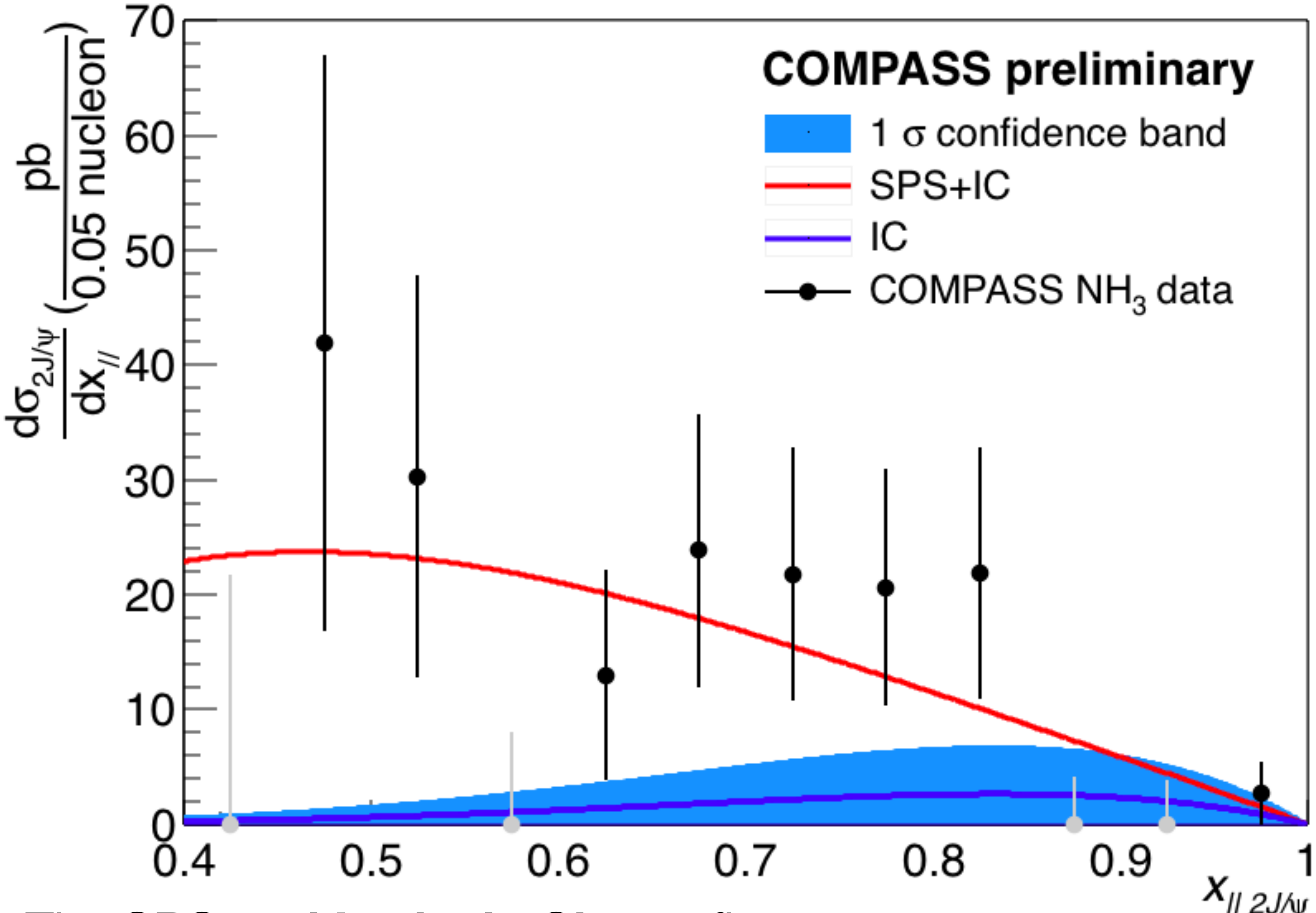
SPS and **IC** fits:

- the SPS hypothesis describes the COMPASS data better than IC hypothesis.

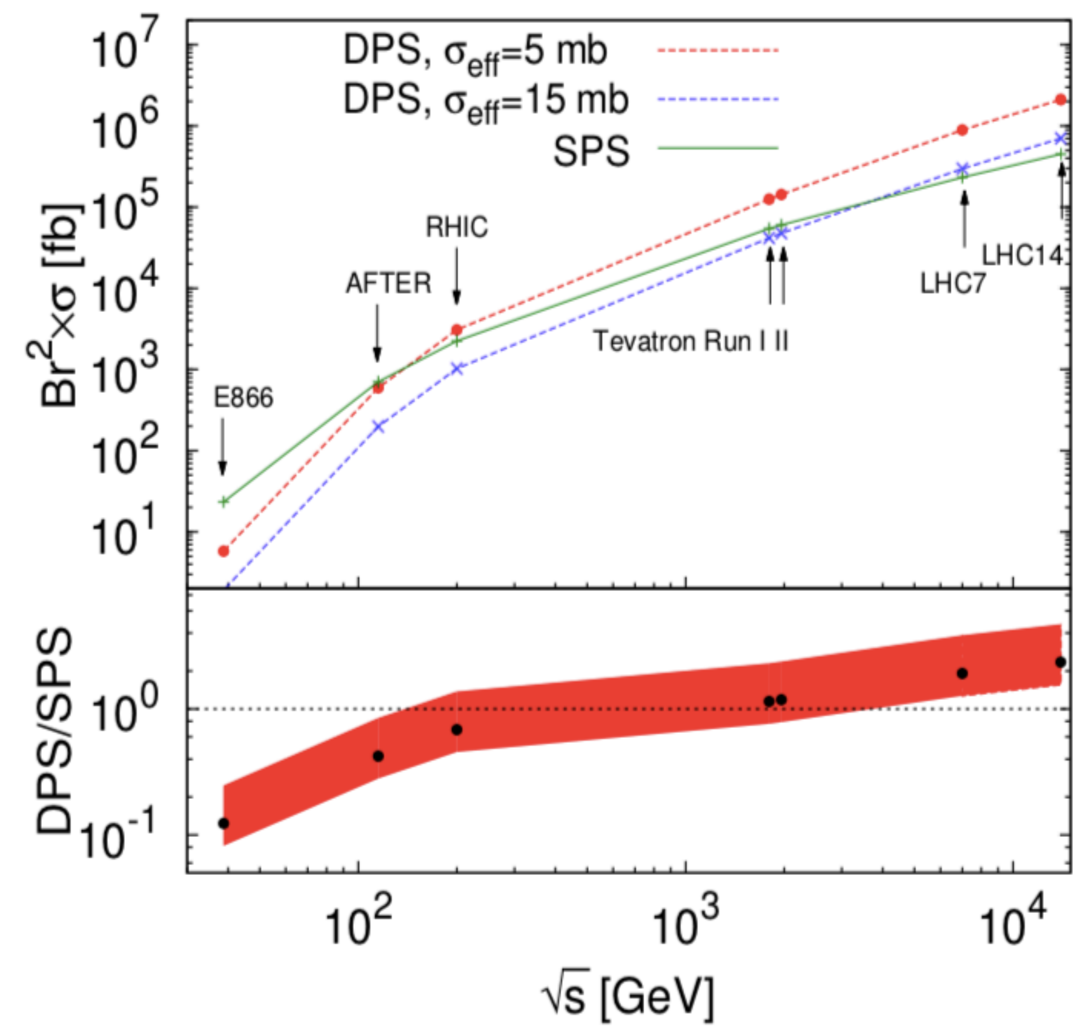




Double J/ψ production mechanisms



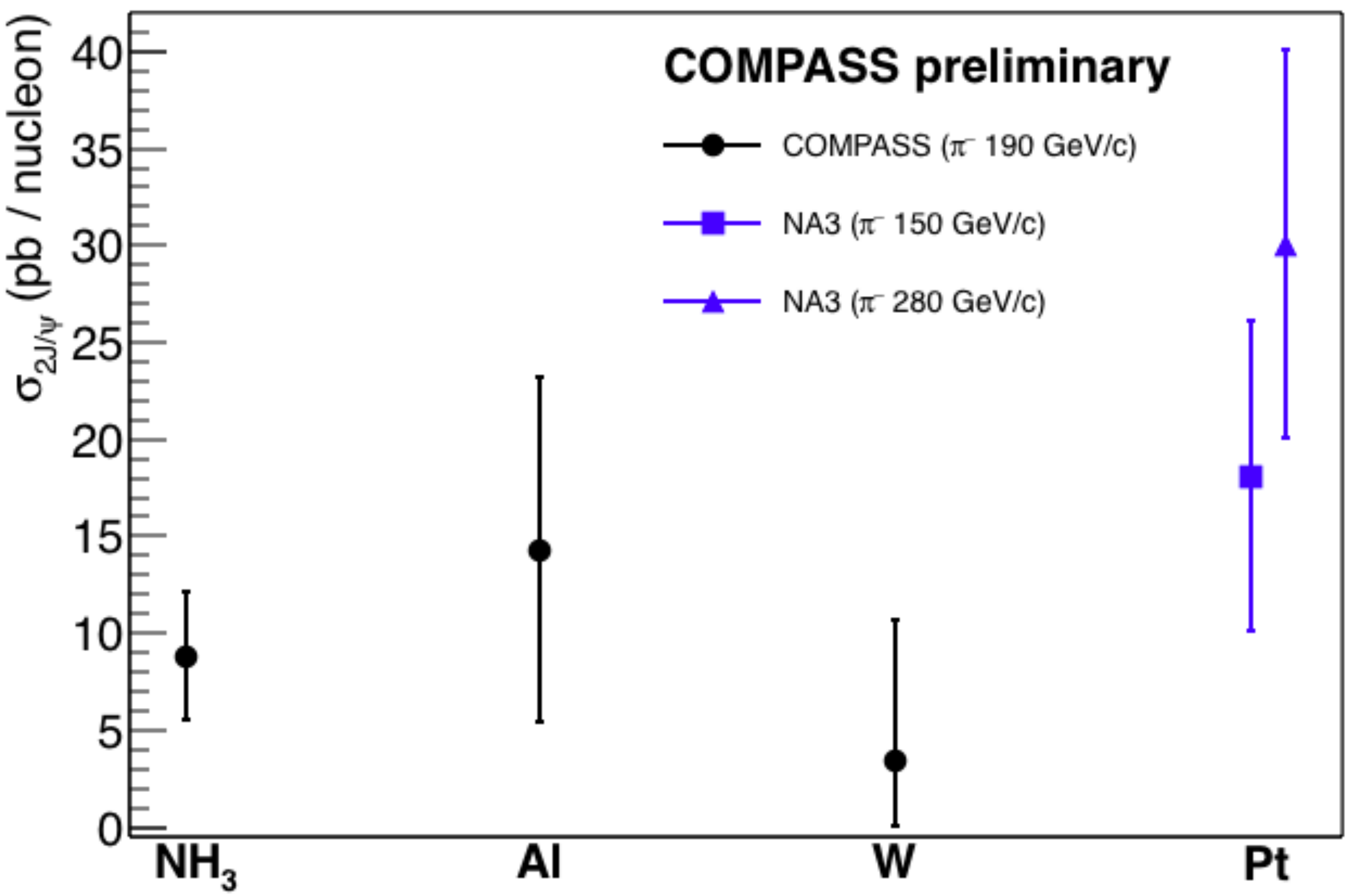
J.-P. Lansberg, H.-S. Shao
Nucl. Phys. B 900 (2015) 273



The **SPS and Intrinsic Charm** fit:

- relative weights of mechanisms were estimated from the fit;
- the double parton scattering (DPS) is not considered in the fit;
- the DPS contribution at $\sqrt{s} = 18.9$ GeV is less than 8% (**arXiv:1909.06195 [hep-ph]**);
- the data are consistent with pure SPS hypothesis.

Double J/ψ cross-section measurement



$$\left.\frac{\sigma_{2J/\psi}}{\sigma_{J/\psi}}\right|_{x_F>0} = (1.1 \pm 0.3_{stat} \pm 0.2_{syst}) \cdot 10^{-4} (NH3)$$

$$\left.\sigma^{NH3}_{2J/\psi}\right|_{x_F>0} = 8.8 \pm 2.2_{stat} \pm 2.4_{syst} \ \frac{pb}{nucleon}$$

$$\left.\sigma^{W}_{2J/\psi}\right|_{x_F>0} = 3.4 \pm 4.3_{stat} \pm 5.8_{syst} \ \frac{pb}{nucleon}$$

$$\left.\sigma^{Al}_{2J/\psi}\right|_{x_F>0} = 14.3 \pm 7.7_{stat} \pm 4.5_{syst} \ \frac{pb}{nucleon}$$

Main sources of systematics:

- uncertainty of $\sigma_{J/\psi}$
- background estimation
- acceptance of double J/ψ
- acceptance of single J/ψ
- uncertainty of the number of single J/ψ

COMPASS results do not contradict to NA3 values.

No A-dependence of $\sigma_{2J/\psi}$ was found.

The measured by the NA3 $\sigma_{J/\psi} = 4.9 \pm 0.77 \frac{nb}{nucleon}$ was used for the estimation of $\sigma_{2J/\psi}$.

Summary

1. Double J/ψ hadroproduction is a tool:
   - to study the intrinsic charm component of hadrons
   - to search for bound T_{4c} states.
2. The COMPASS collaboration:
   - has searched for double J/ψ events produced in NH_3, Al and W targets
   - has estimated double J/ψ production cross-section.
3. The COMPASS data are consistent with SPS production mechanism.
4. No evidence of presence of T_{4c} states in the double J/ψ mass spectrum.

Thank you for attention!

Backup