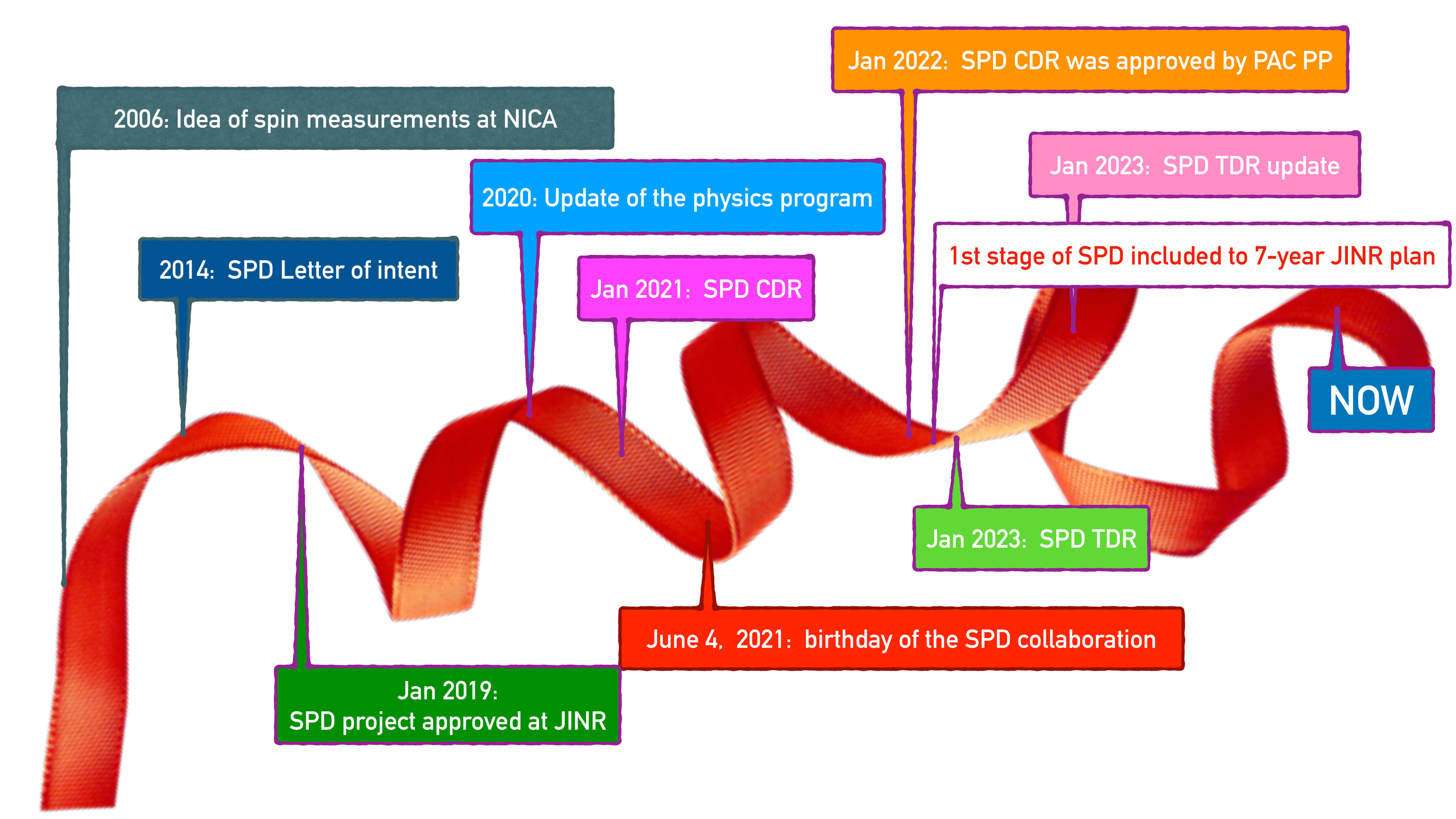
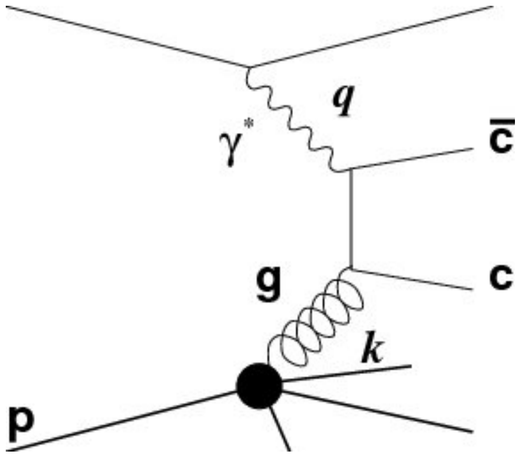
From physics to the SPD setup

A. Guskov

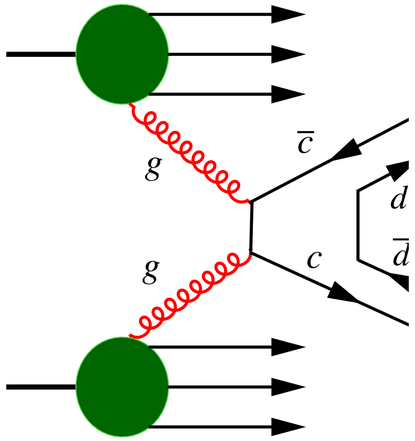

2006: Idea of spin measurements at NICA
2014: SPD Letter of intent
2020: Update of the physics program
Jan 2021: SPD CDR
Jan 2022: SPD CDR was approved by PAC PP
Jan 2023: SPD TDR update
1st stage of SPD included to 7-year JINR plan
NOW
Jan 2023: SPD TDR
June 4, 2021: birthday of the SPD collaboration
Jan 2019:
SPD project approved at JINR

Physic case



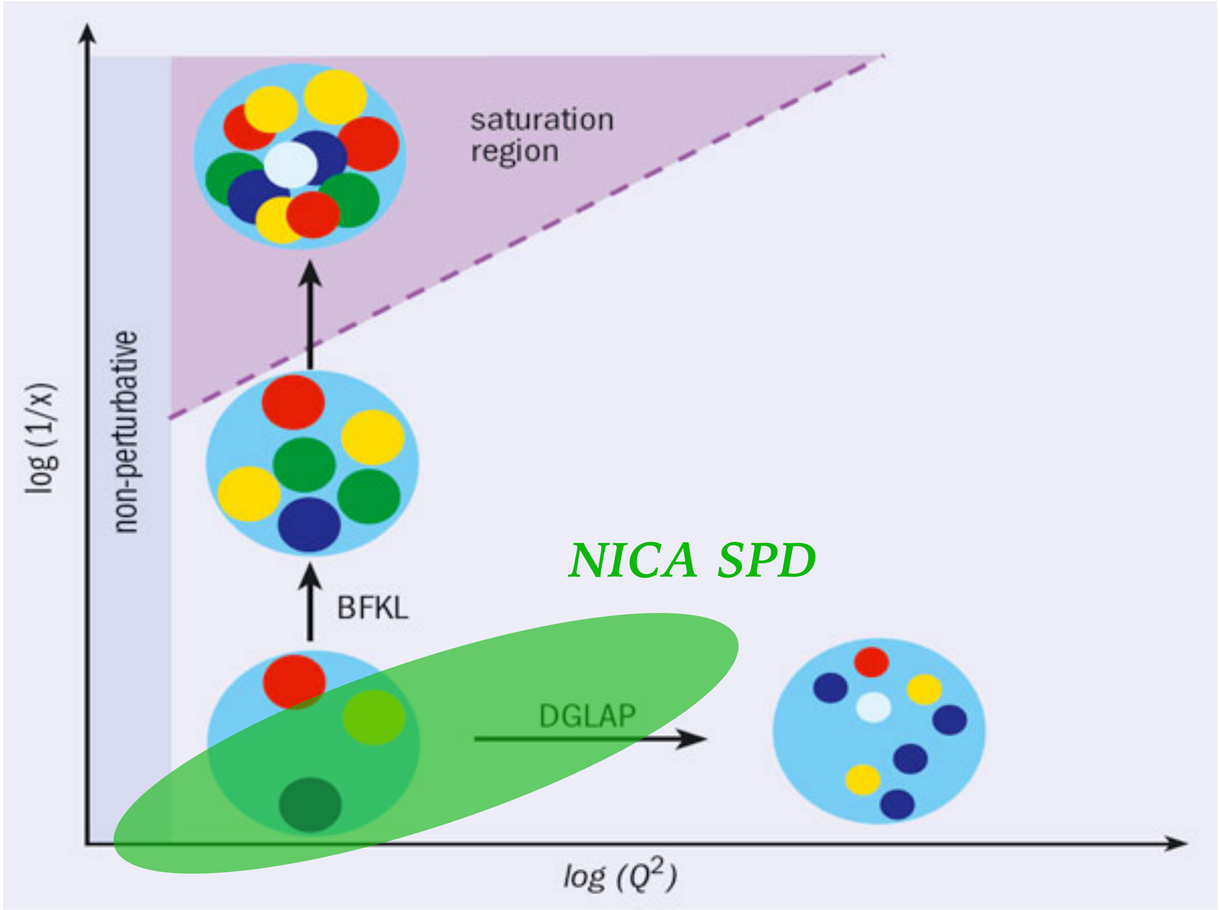
SIDIS

$$\sigma \sim \alpha^2 \alpha_s$$



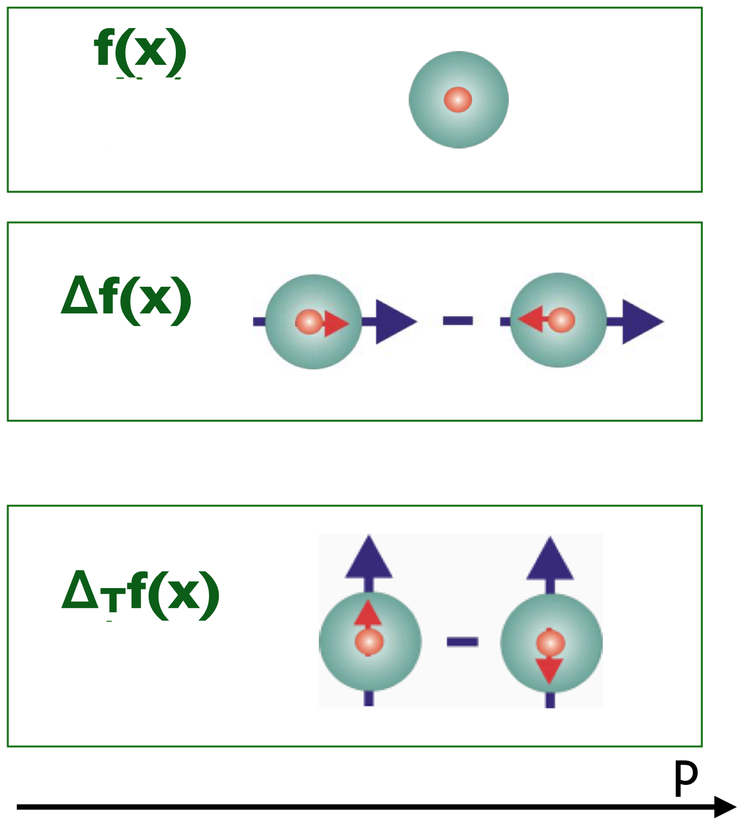
Hadroproduction

$$\sigma \sim \alpha_s^2$$



We cannot compete with SIDIS experiments in the study of the quark content of the nucleon

Spin balance



Unpolarized PDF

Helicity

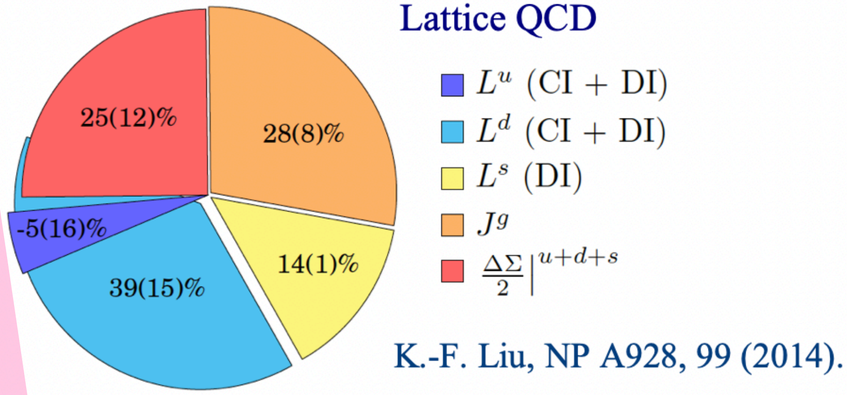
Transversity

$$J = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

~30%

~10-20%

? ?

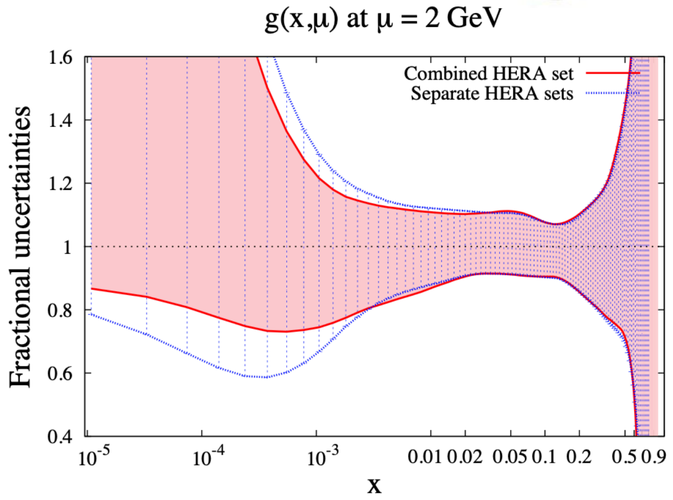


K.-F. Liu, NP A928, 99 (2014).

To access angular momenta info about 3D structure is needed!

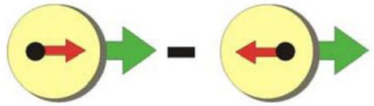
Physics case: gluons in proton

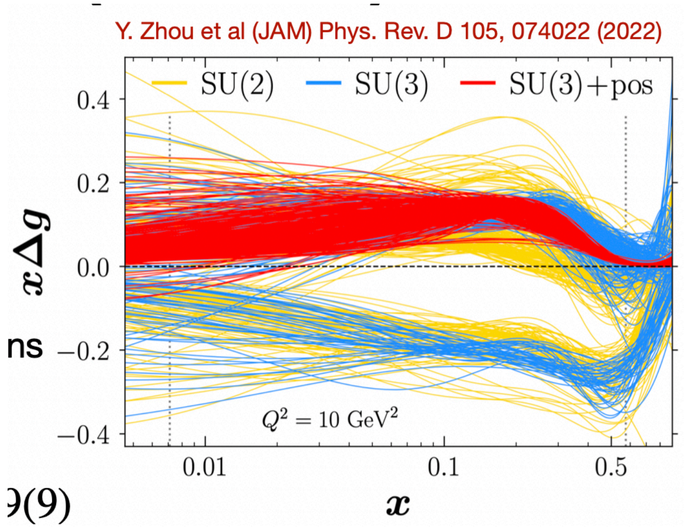
Unpolarized gluons in proton and deuteron at high x:



$\sigma(x_F, p_T)$

Gluon helicity

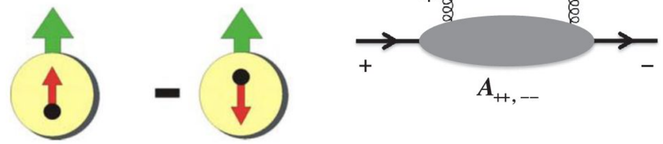




$A_{LL}(x_F, p_T)$

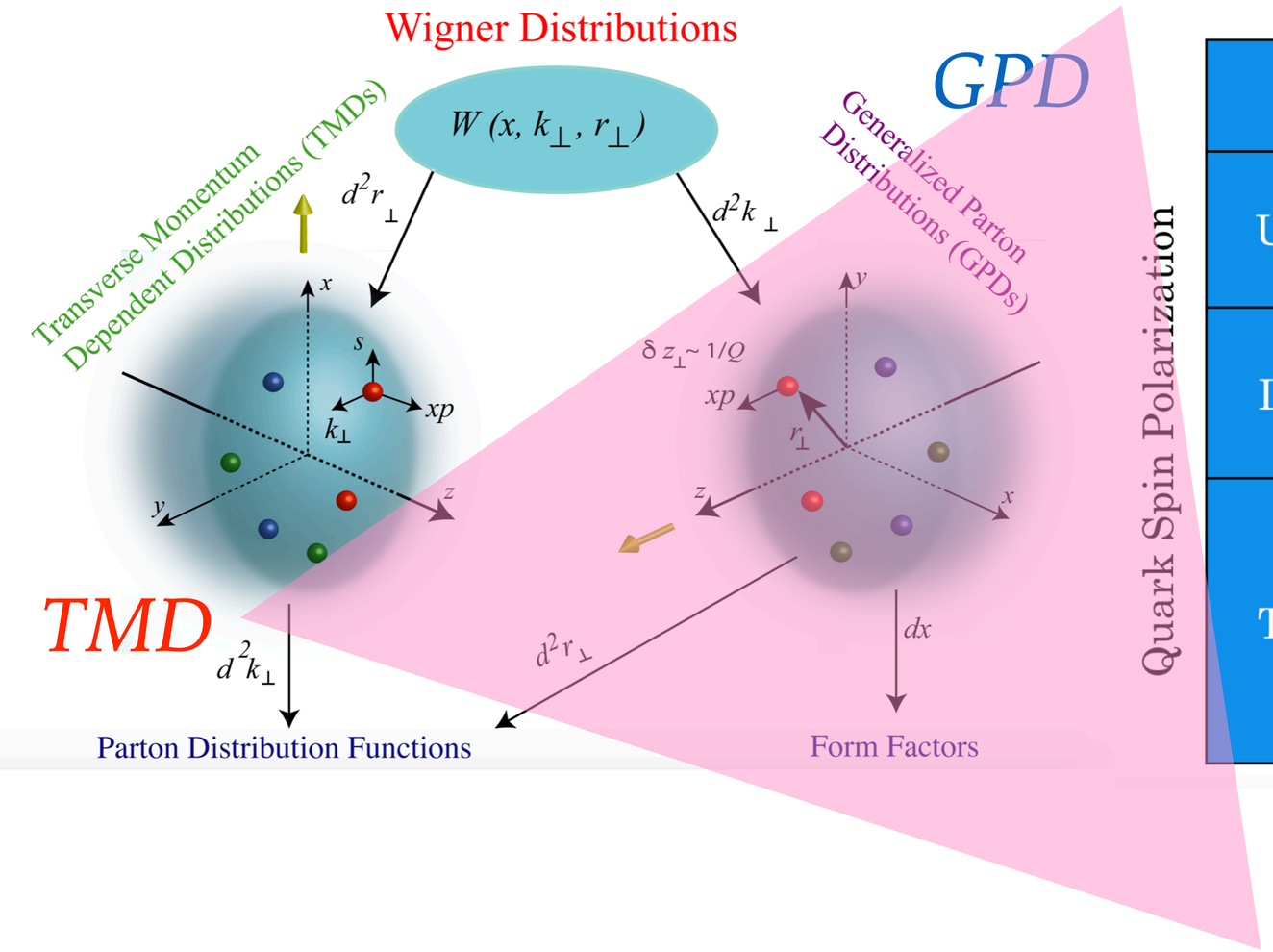
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \sim \Delta G$$

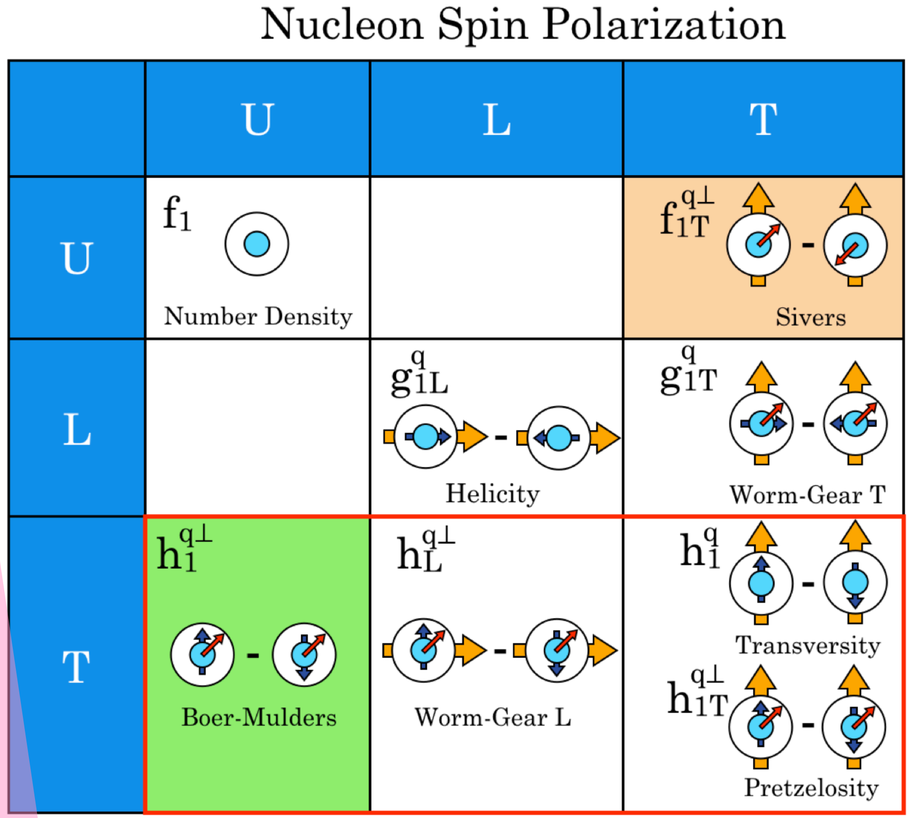
Gluon transversity

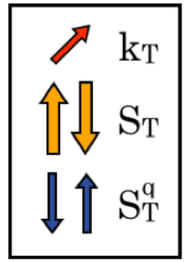


Impossible for proton!

3D tomography of proton







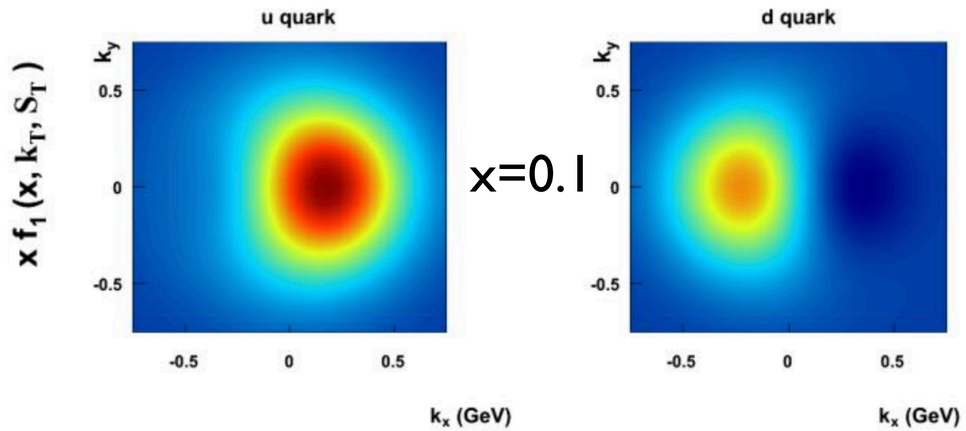
5 additional (TMD) functions describing the correlation between the nucleon spin, parton spin, and parton transverse momentum.

Gluon TMDs are mostly unknown!

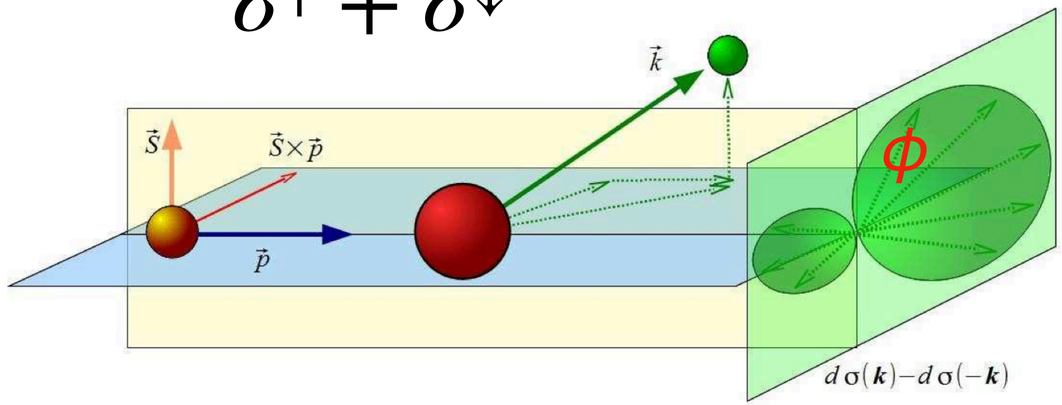
Azimuthal asymmetryes in inclusive production

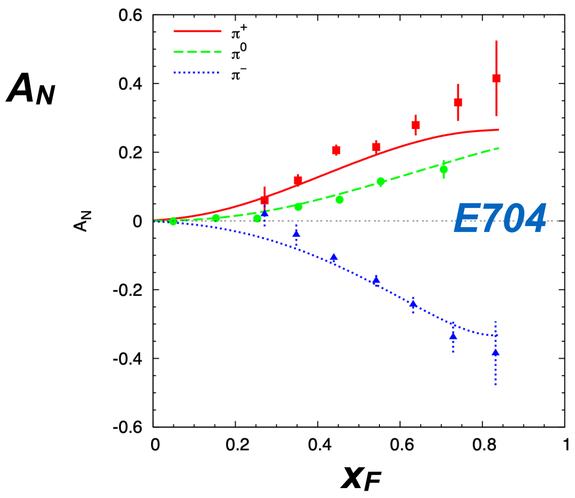
Sivers function (as an example)

Probabilities to meet in a transversely polarized proton a parton moving to the left and to the right with respect to the $(\vec{S}, \vec{p})$ plane are different!



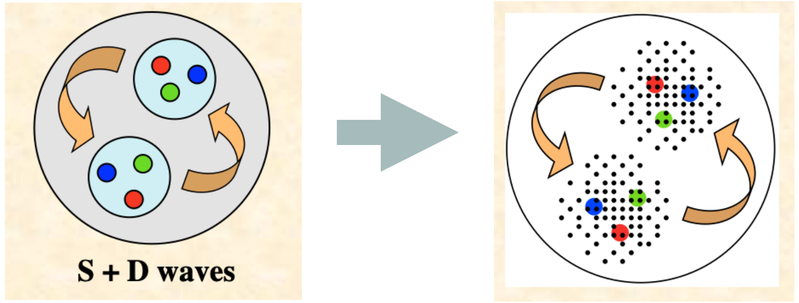
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim f_{Sivers}\ cos\ \phi$$





The Sievers effect is usually observed together with the Collins effect, an asymmetry arising from the fragmentation of the final state.

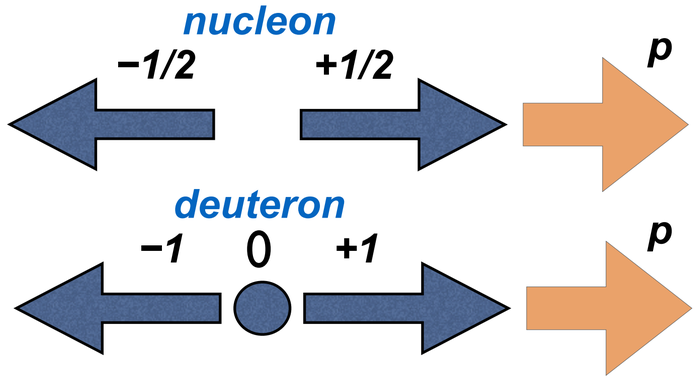
Deuterons



$$|6q\rangle = c_1|NN\rangle + c_2|\Delta\Delta\rangle + \boxed{c_3|CC\rangle}$$

hidden color

Tensor structure of deuteron



Vector polarization

$$\frac{N_{1/2} - N_{-1/2}}{N_{1/2} + N_{-1/2}}$$

Tensor polarization

$$\frac{2N_0 - (N_{-1} + N_1)}{2N_0 + N_{1/2} + N_{-1/2}}$$

Unpolarized gluons

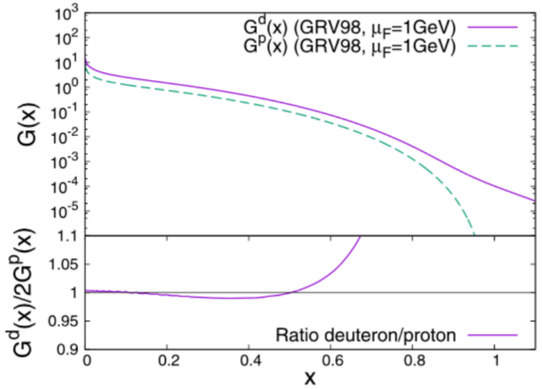
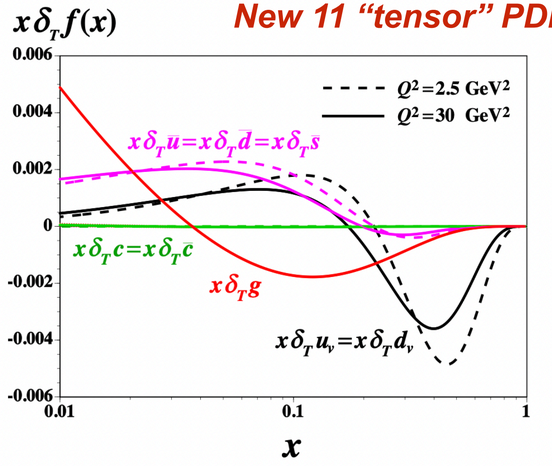
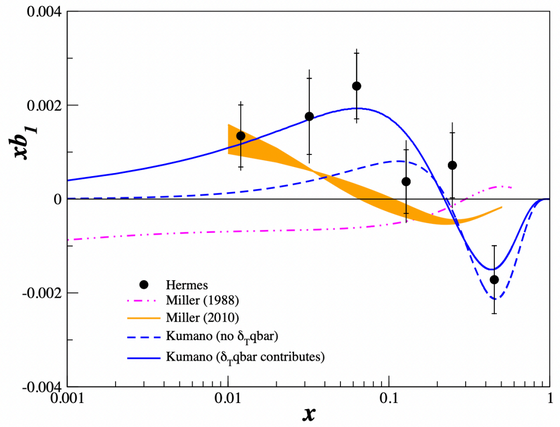


Fig. 6. Gluon PDF in the deuteron and in the nucleon.

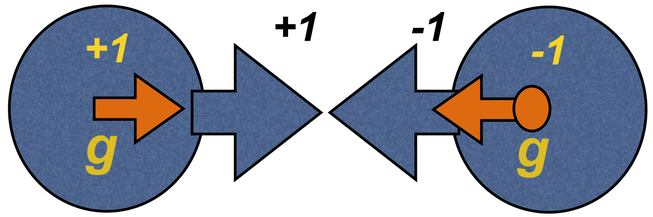
New 11 "tensor" PDFs, mostly unknown





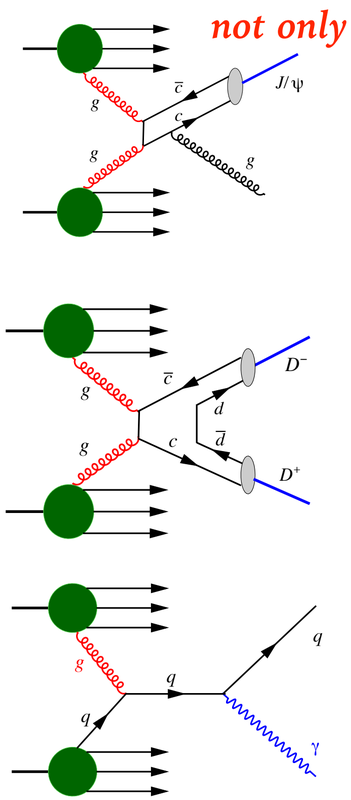
New possibilities for gluons:

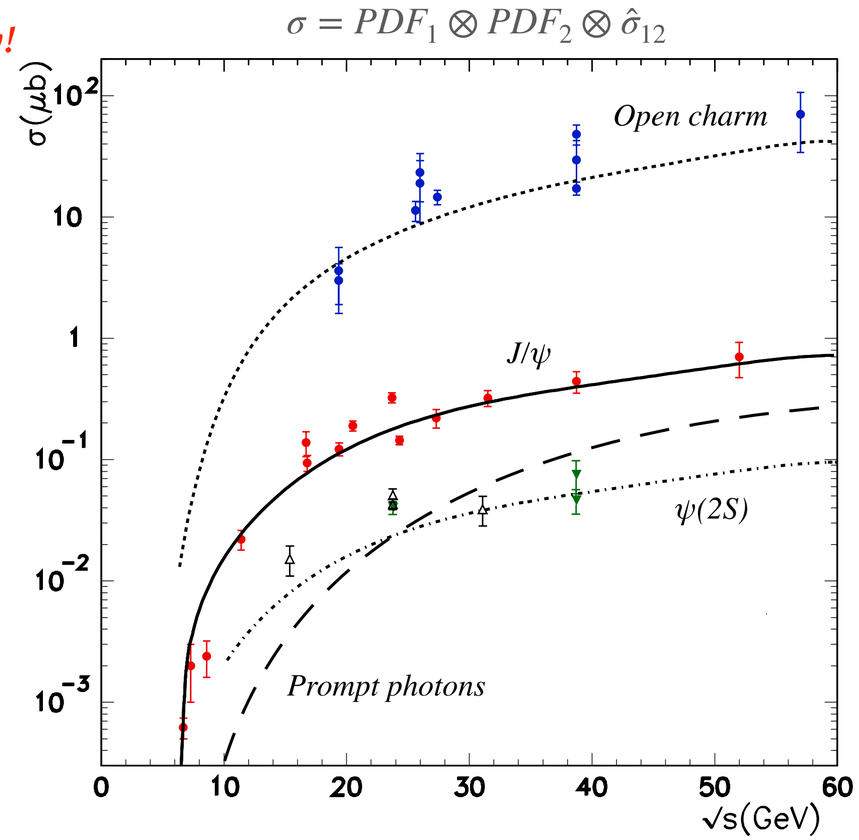
Gluon transversity



A_{TT}, tensor asymmetries

Cross sections and rates





Probe	$\sigma_{27\,\mathrm{GeV}}$, nb (×BF)	$\sigma_{13.5\,\mathrm{GeV}}$, nb (×BF)	$N_{27\,\mathrm{GeV}}$, 10^6	$N_{13.5\,\mathrm{GeV}}$ 10^6
Prompt-γ ($p_T > 3$ GeV/c)	35	2	35	0.2
J/ψ	200	60		
$\to \mu^+\mu^-$	12	3.6	12	0.36
$\psi(2S)$	25	5		
$\to J/\psi\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$	0.5	0.1	0.5	0.01
$\to \mu^+\mu^-$	0.2	0.04	0.2	0.004
$\chi_{c1} + \chi_{c2}$	200			
$\to \gamma J/\psi \to \gamma\mu^+\mu^-$	2.4		2.4	
η_c	400			
$\to p\bar{p}$	0.6		0.6	
Open charm: $D\overline{D}$ pairs	14000	1300		
Single D-mesons				
$D^+ \to K^-2\pi^+$ ($D^- \to K^+2\pi^-$)	520	48	520	4.8
$D^0 \to K^-\pi^+$ ($\overline{D}^0 \to K^+\pi^-$)	360	33	360	3.3

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Progress in Particle and Nuclear Physics xxx (xxxx) xxx

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Progress in Particle and Nuclear Physics

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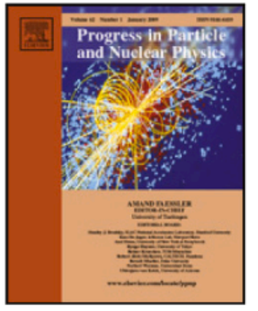

Review

On the physics potential to study the gluon content of proton and deuteron at NICA SPD

Prog.Part.Nucl.Phys. 119 (2021) 103858

arXiv:2011.15005

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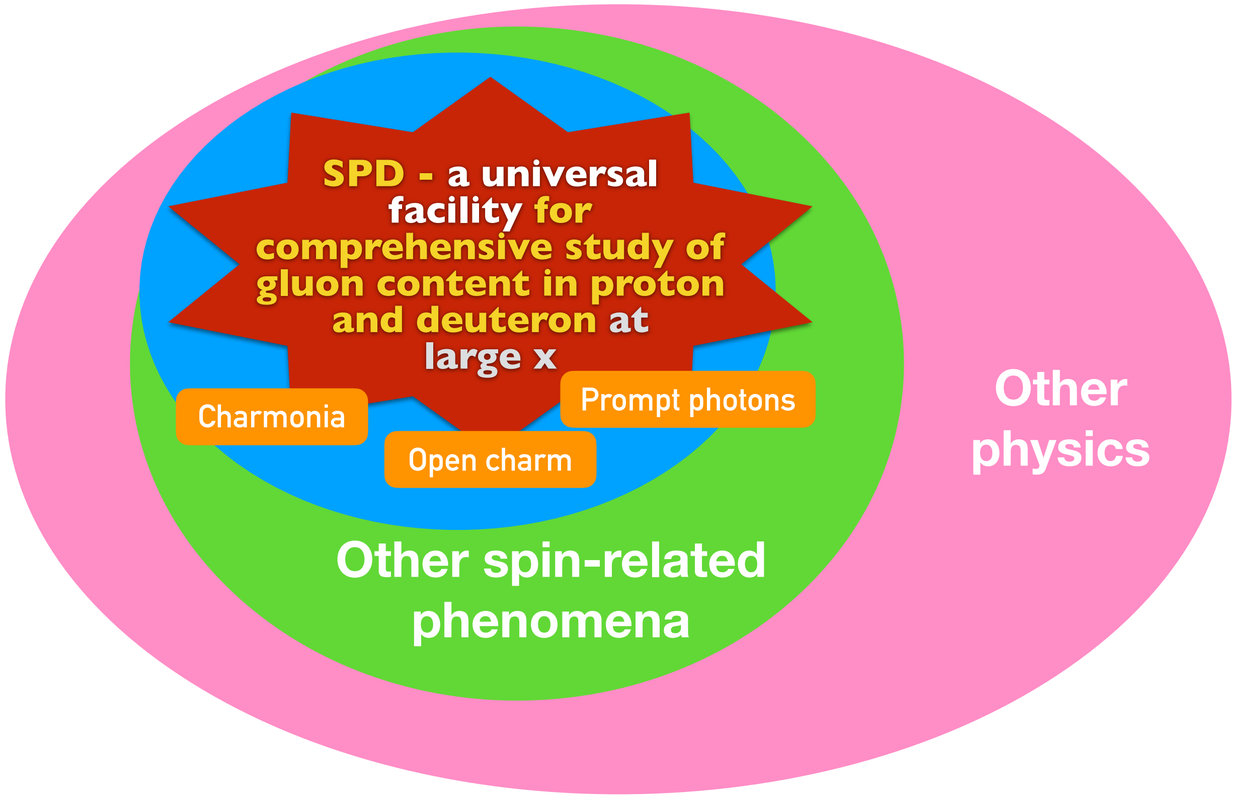
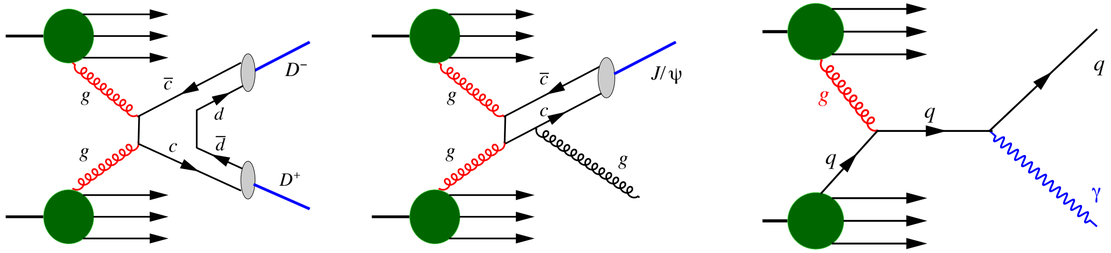
[h] *INFN Sezione di Cagliari, I-09042 Monserrato, Italy*

SPD physics program



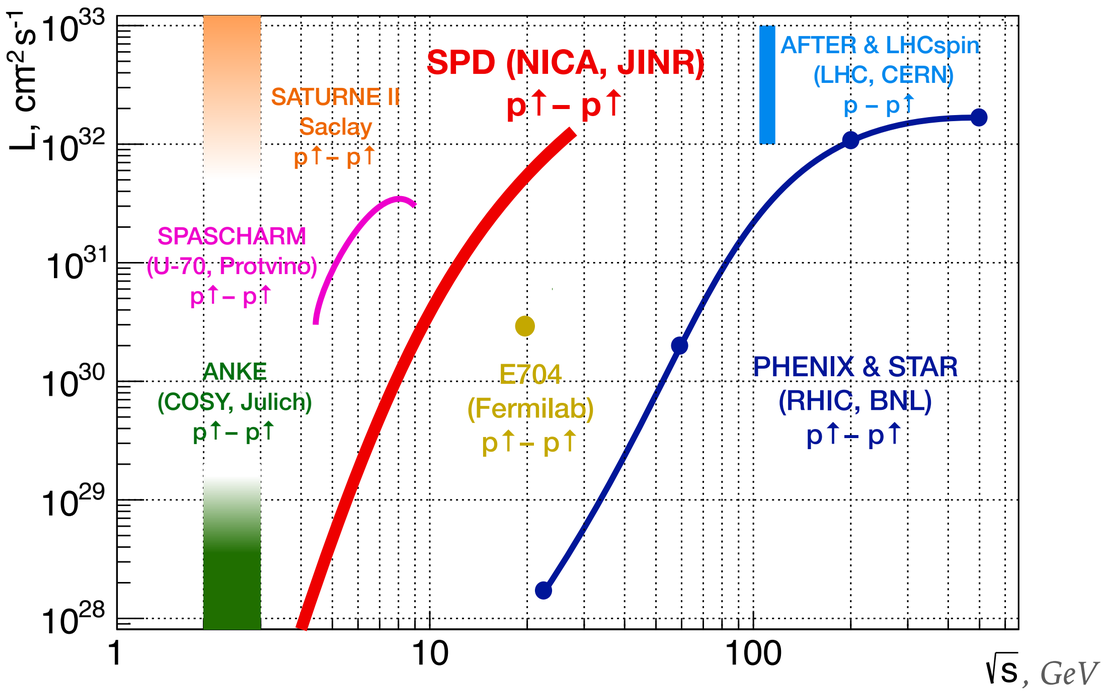


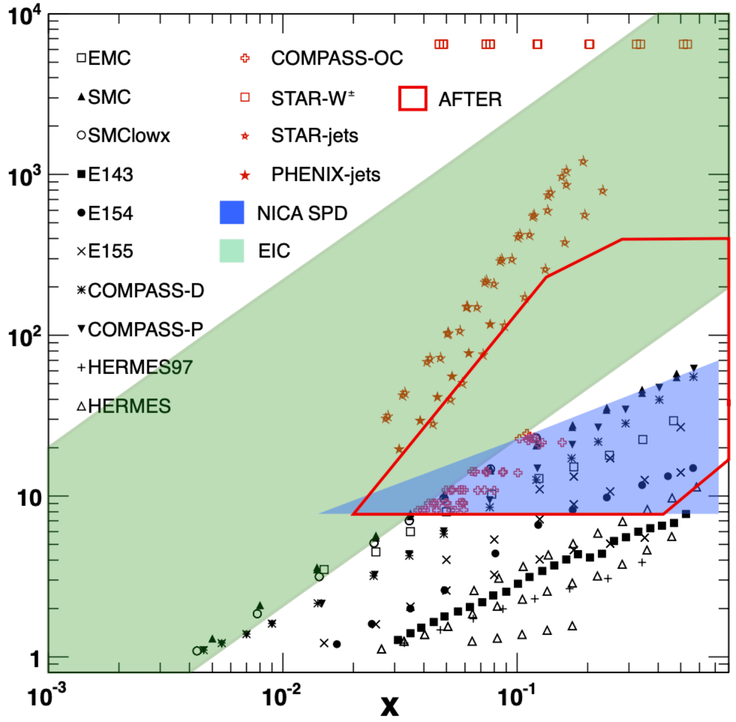
We optimize our setup for gluon studies via these 3 processes **BUT…**

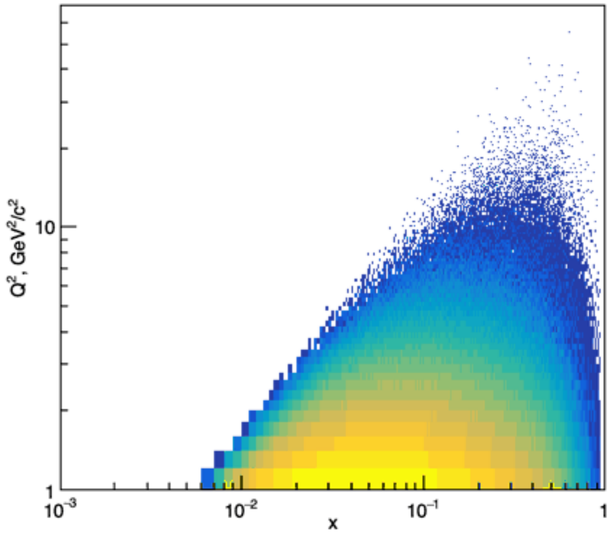
Our setup is planned to be universal enough to study other spin-dependent phenomena as well like:

quark TMDs, GPDs, spin-dependent central production, polarization of hyperons, elastic scattering, etc.

SPD vs. others







$Q^2 = 1\ GeV^2/c^2, < x > = 0.16$

$Q^2 = 10\ GeV^2/c^2, < x > = 0.3$

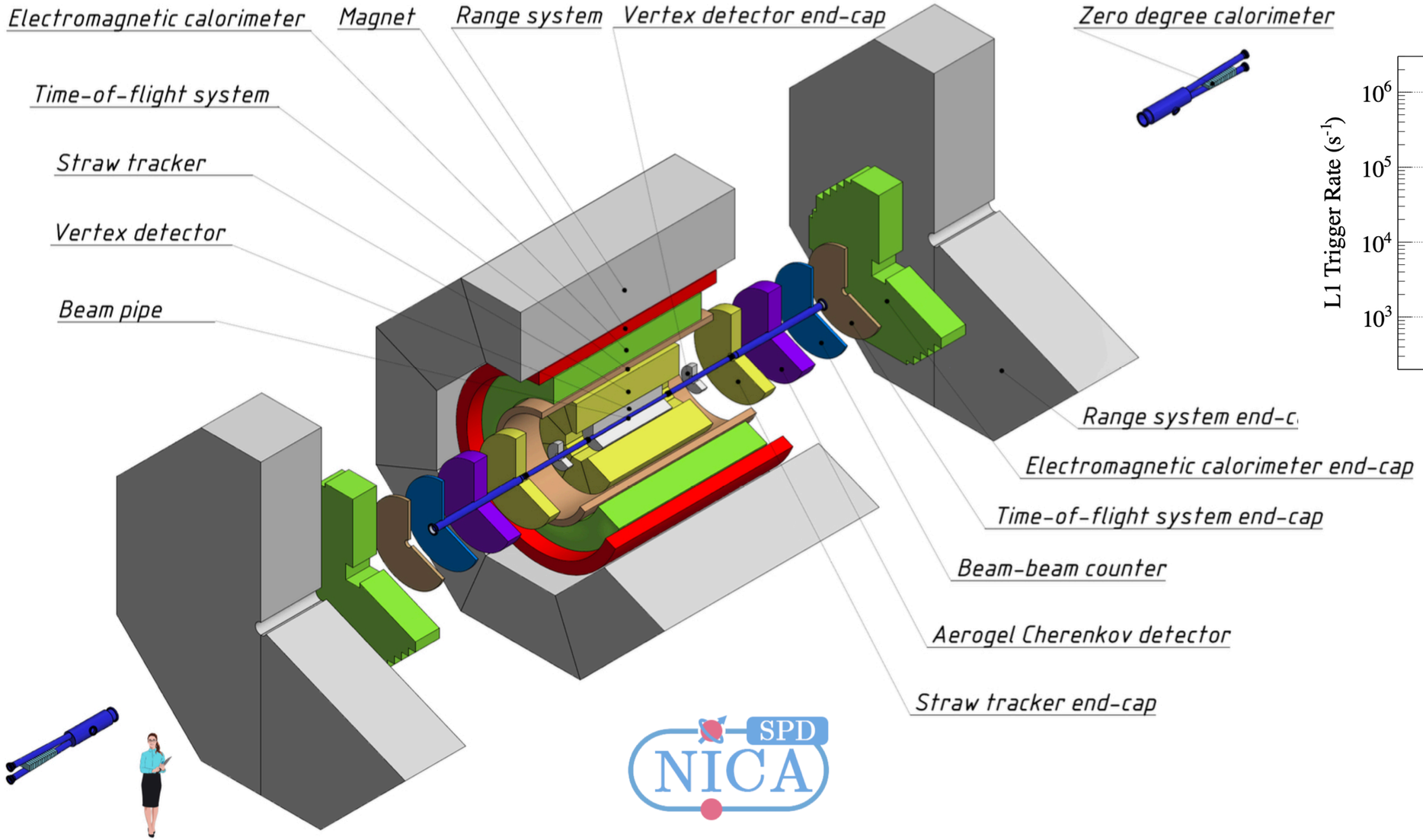
In the $d^\uparrow d^\uparrow$ mode
NICA is unique

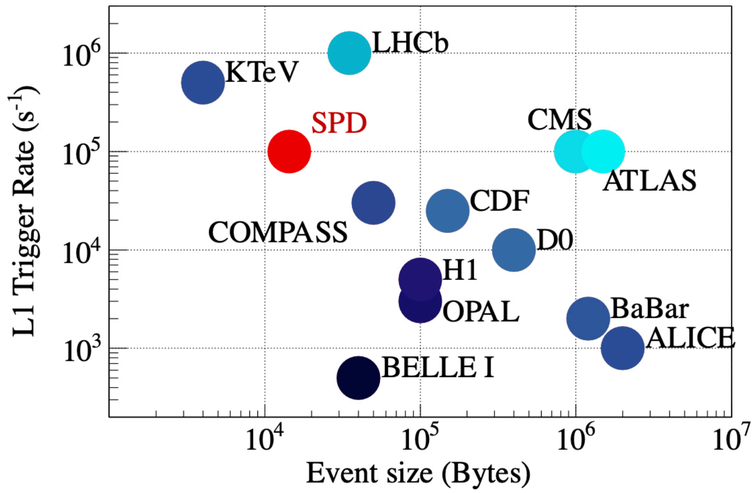
Requirements to the setup

- Muon system for charmonia
- ECAL for photons
- precision vertex detector for D-meson secondary vertex
- PID
- local polarimetry
- luminosity monitor
- unbiased trigger system as well as possible

Physics goal	SVD	ST+ MCT	TOF+ FARICH	ECal	RS	BBC	ZDC
Study of polarized gluon content in proton and deuteron with:							
– charmonia	+	++	+	++	++		
– open charm	++	++	++	+	+		
– prompt photons		+		++			
Elastic *p-p* and *d-d* scattering		++	+			++	+
Single-spin physics		++	++			++	+
Vector light and charmed meson production		++	++		++		
Scaling behavior of exclusive reactions with lightest nuclei and spin observables		++	+			++	++
Multiquark correlations and exotic hadron state production		++	++				
Exclusive processes in *d-d* collisions		++	+			++	++
Search for deconfinement in *p-p* and *d-d* central collisions		++	++				
Search for dibaryons		++	+			+	
Search for lightest neutral hypernuclei with strangeness -1 and -2		++	++				
Problems of soft *p-p* interactions		++	++				
Measuring antiproton production cross-section for dark matter search		++	++				+
Hadron formation effects in heavy ion collisions		++	++				
Polarization of hyperons		++	+				

SPD setup





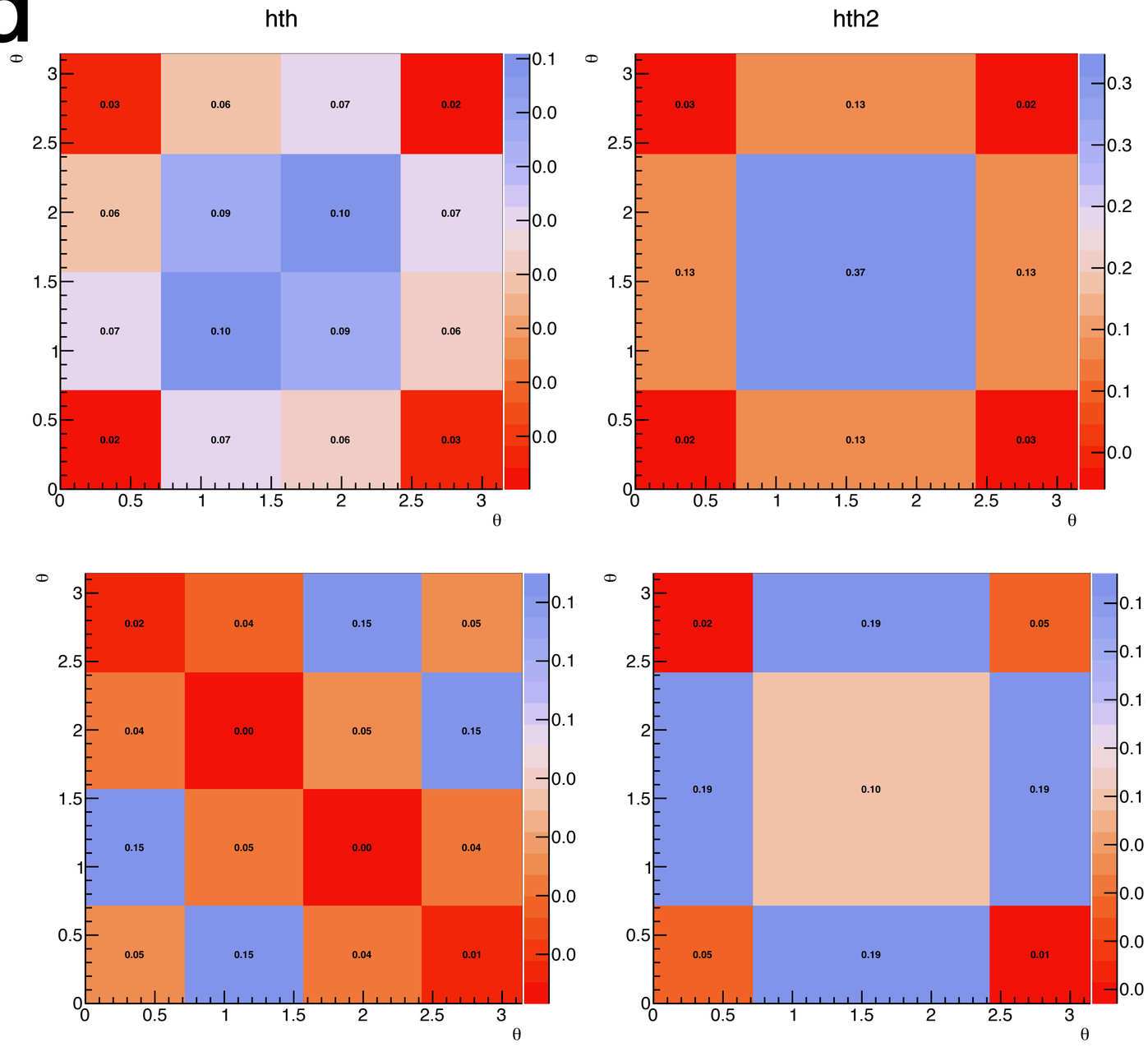
Free-running DAQ

RS geometry and charmonia

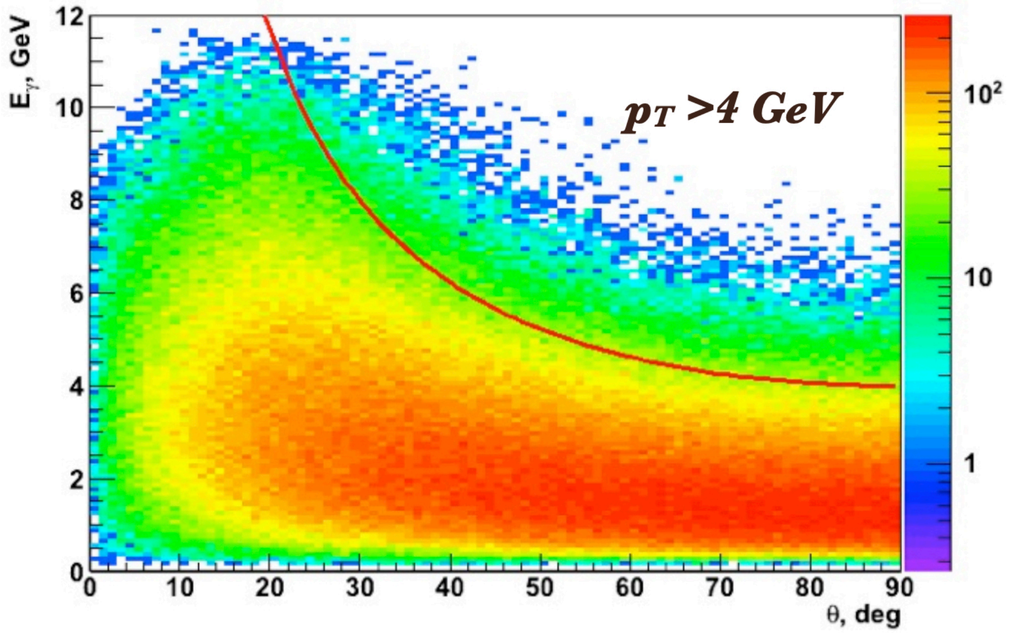
No RS endcaps: lost of 63% J/ψ (90% for $|x_F|>0.2$)

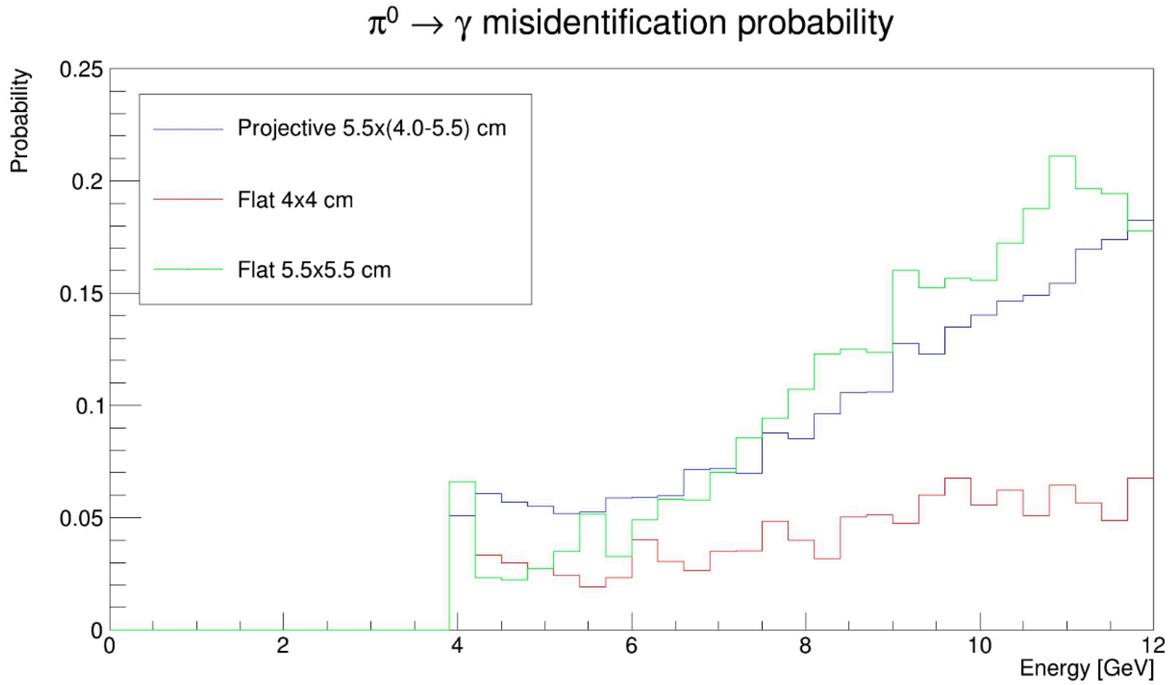
No RS barrel: lost of 90% J/ψ (86% for $|x_F|>0.2$)

Half of RS in Z: lost of 74% J/ψ (91% for $|x_F|>0.2$)



ECAL geometry and photons

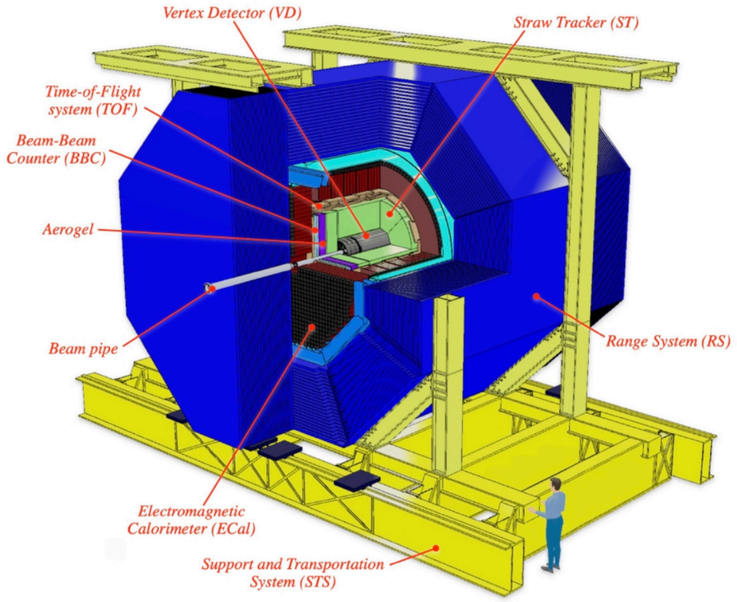


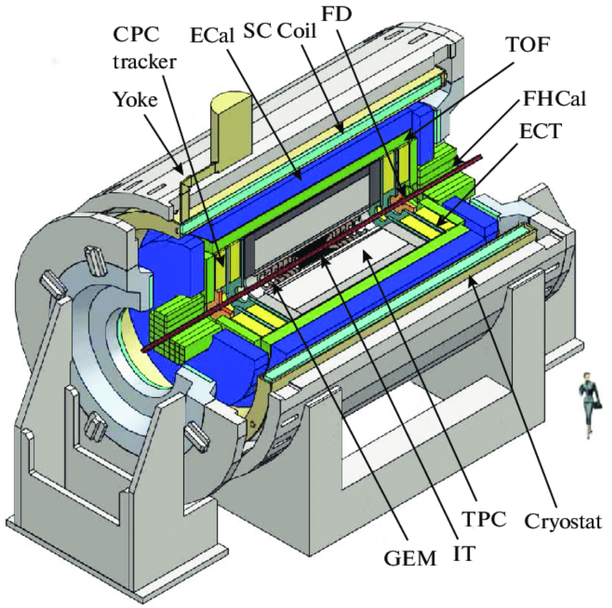


No projective geometry:

- interaction region is too long
- a small gain in …
- **Much more expensive and complex!**

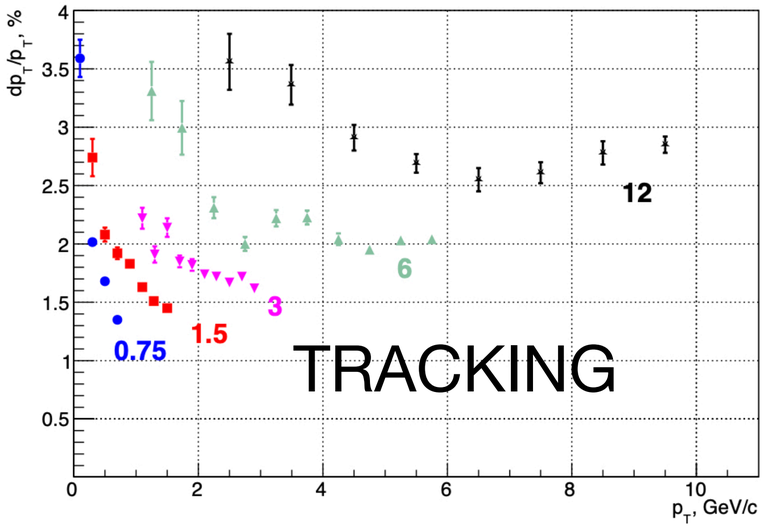
SPD vs. MPD

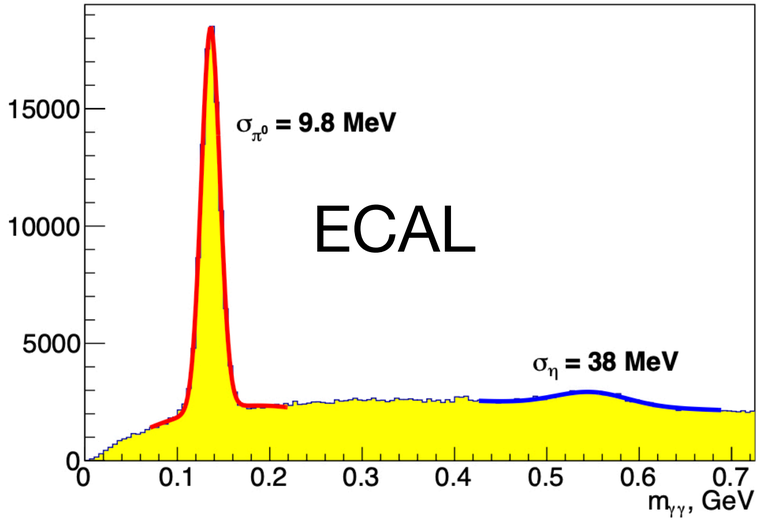


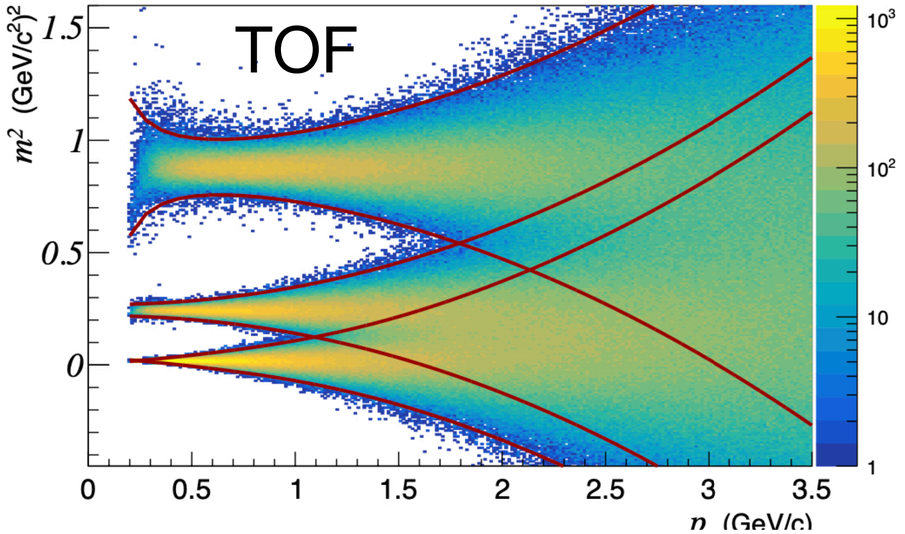


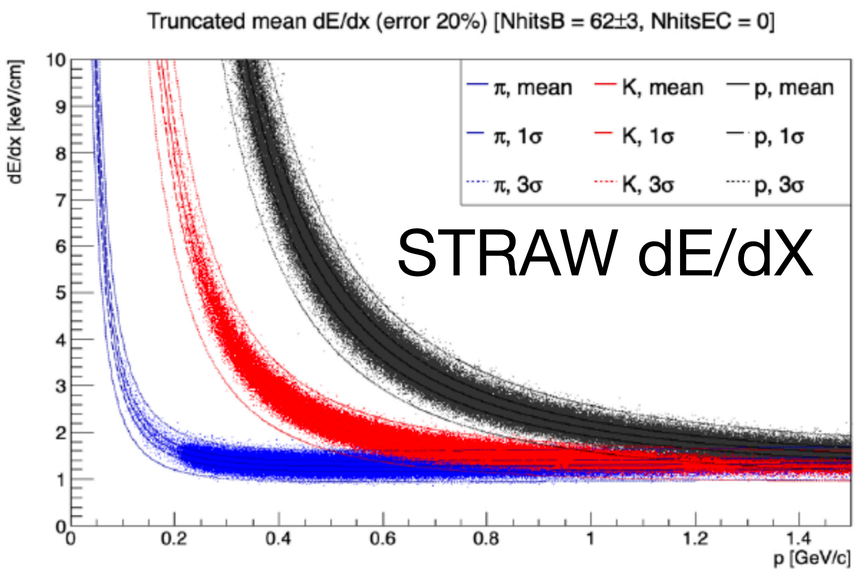
	SPD	MPD
Luminosity, cm^{-2} s^{-1}	10^{32} (p-p), 10^{31} (d-d),	10^{27} (Au-Au)
Maximal track multiplicity	~30	>100
Muon ID	Range system	no
Magnetic field in IP, T	1	0.5
π/K separation range, GeV/c	up to 8 GeV/c (FARICH), ~1.5 (TOF)	~1.5 (TOF)
Local polarimetry	BBC. ECal (barrel), ZDC	no
Maximal DAQ rate, kHz	3000	7

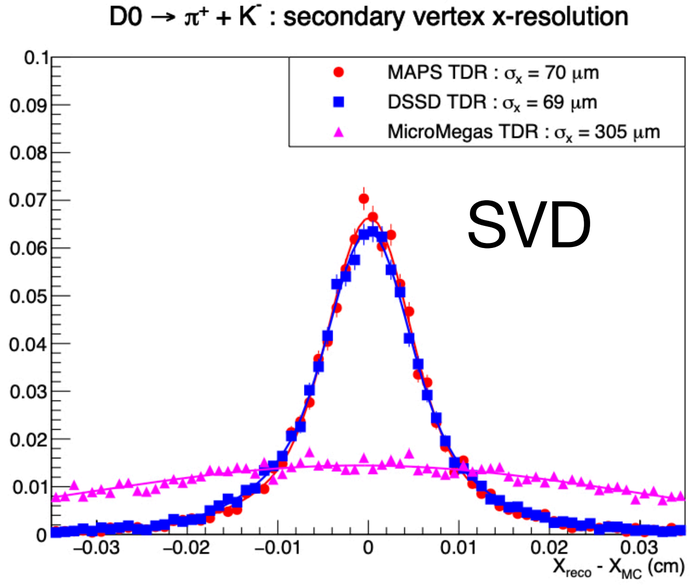
Expected performance

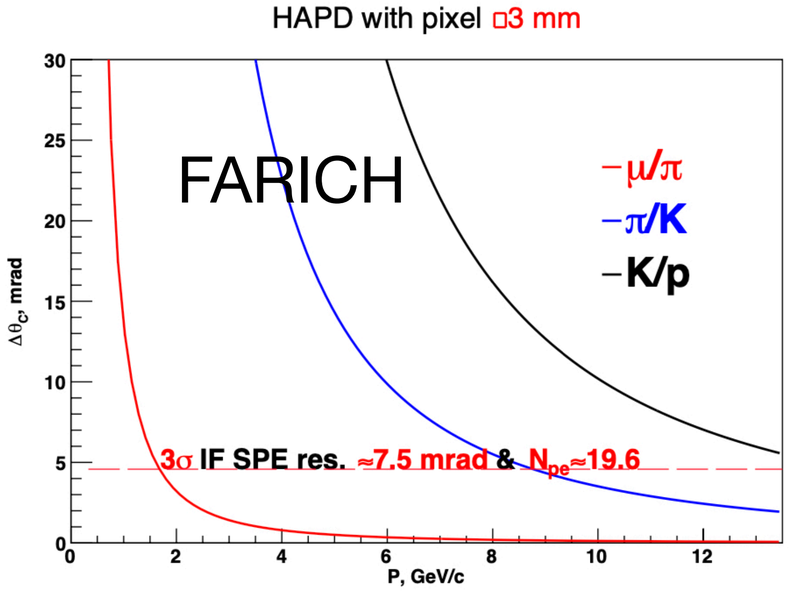




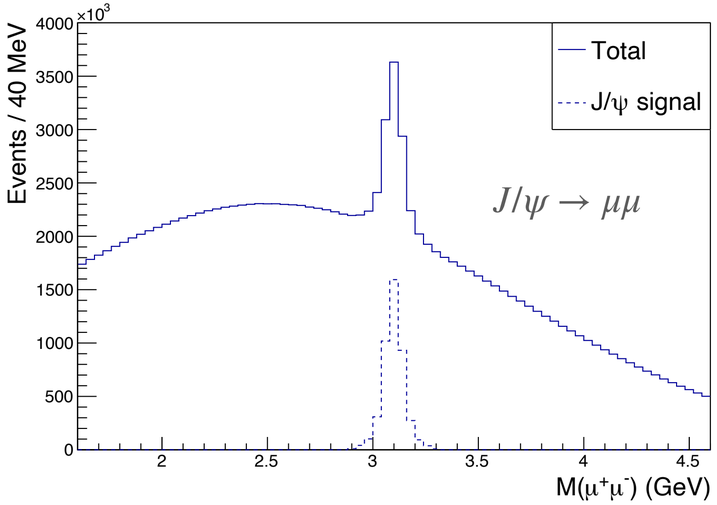


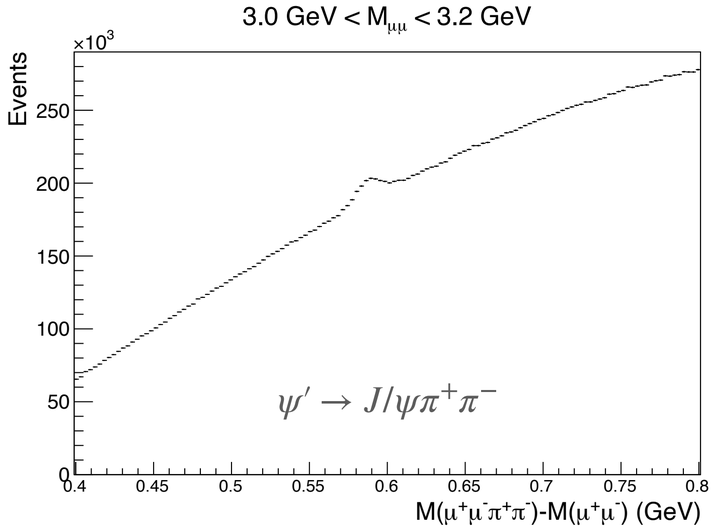


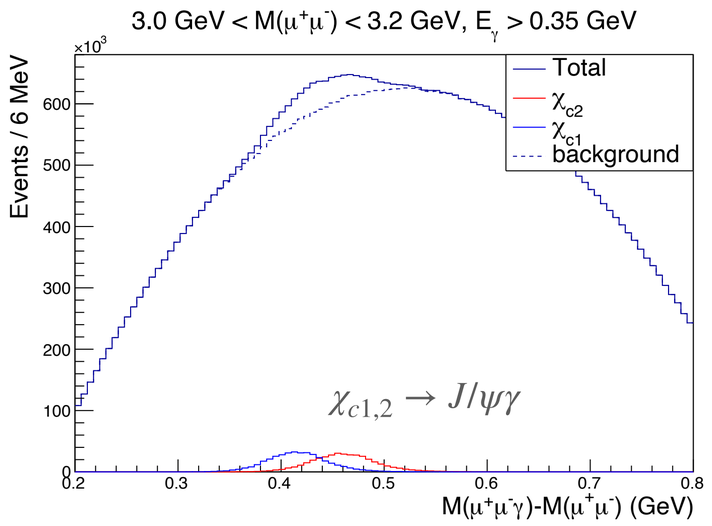


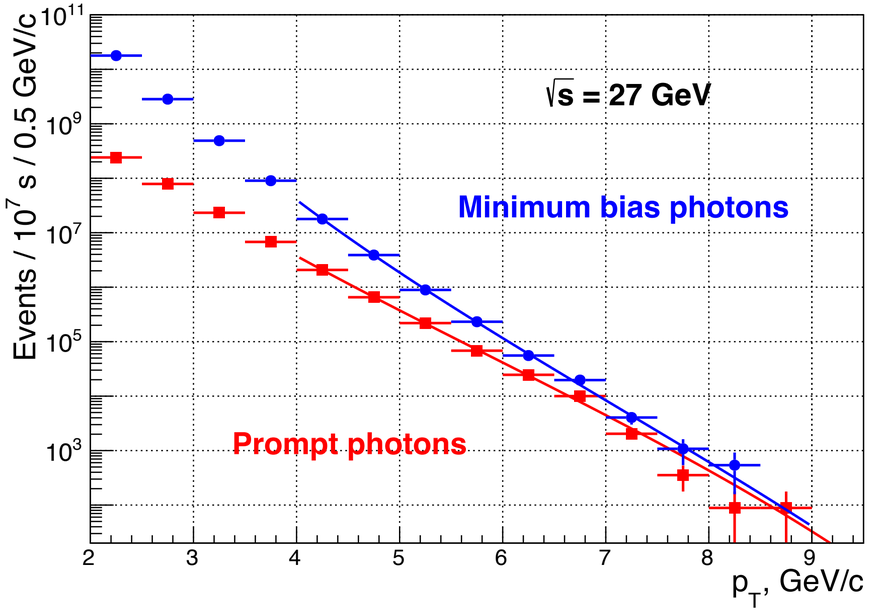


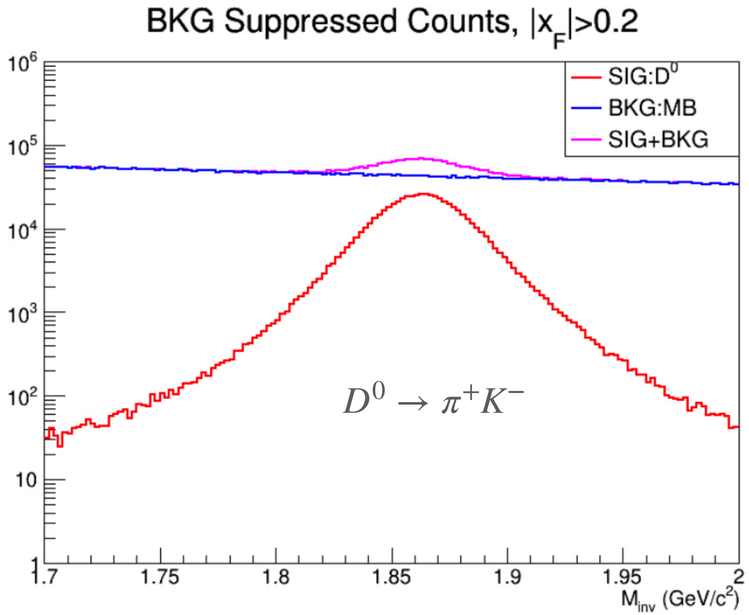
Expected performance: S/B



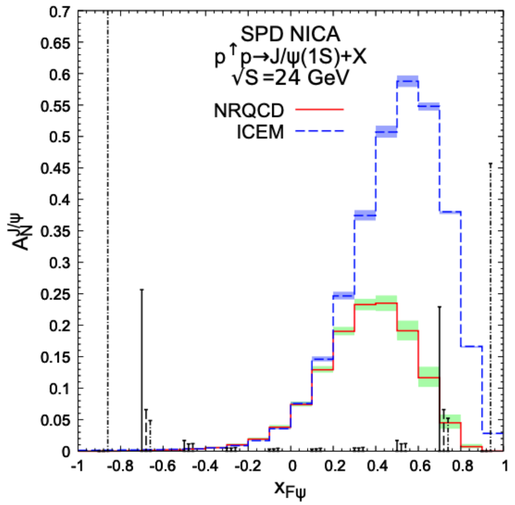




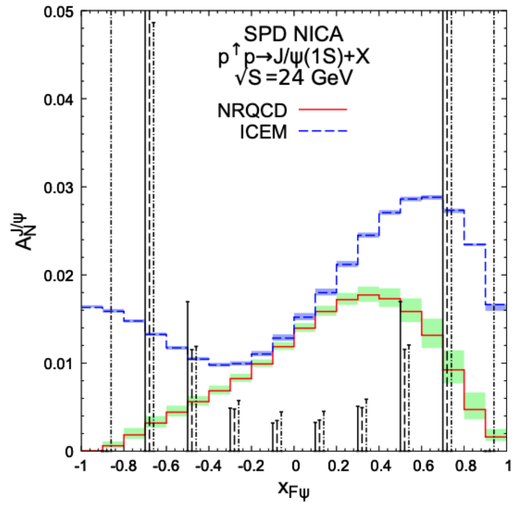


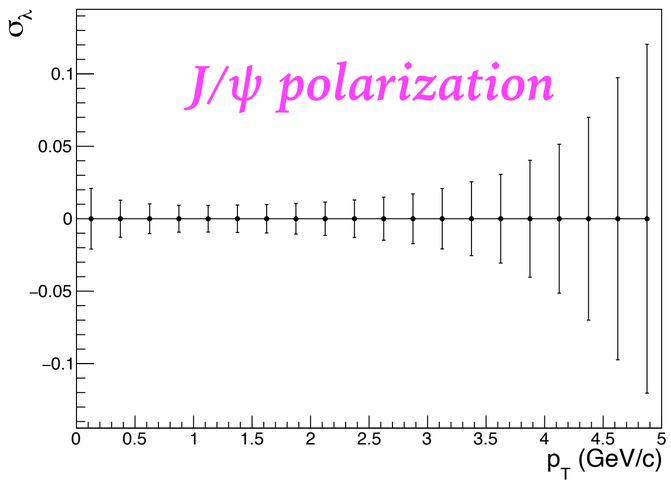


Expected performance: physics



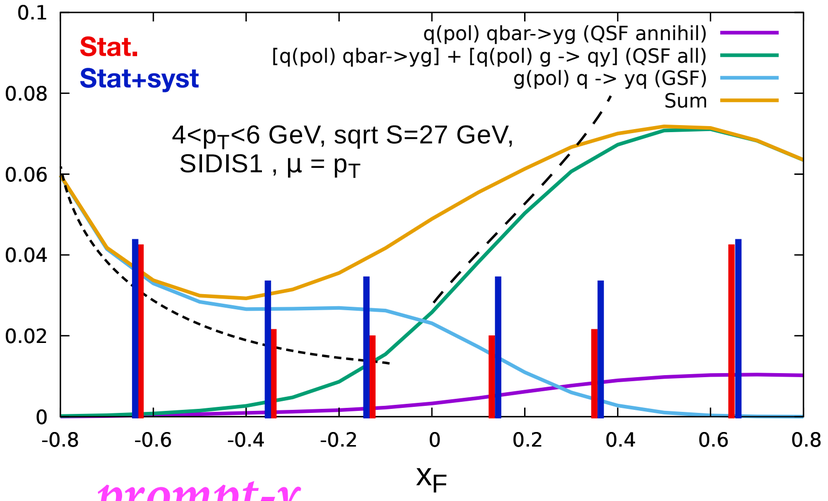
J/ψ



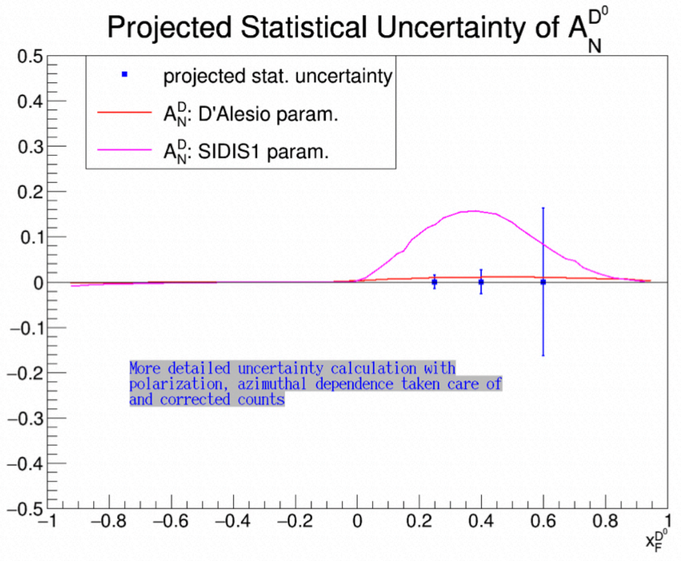


J/ψ polarization

Different inputs for gluon Sivers function

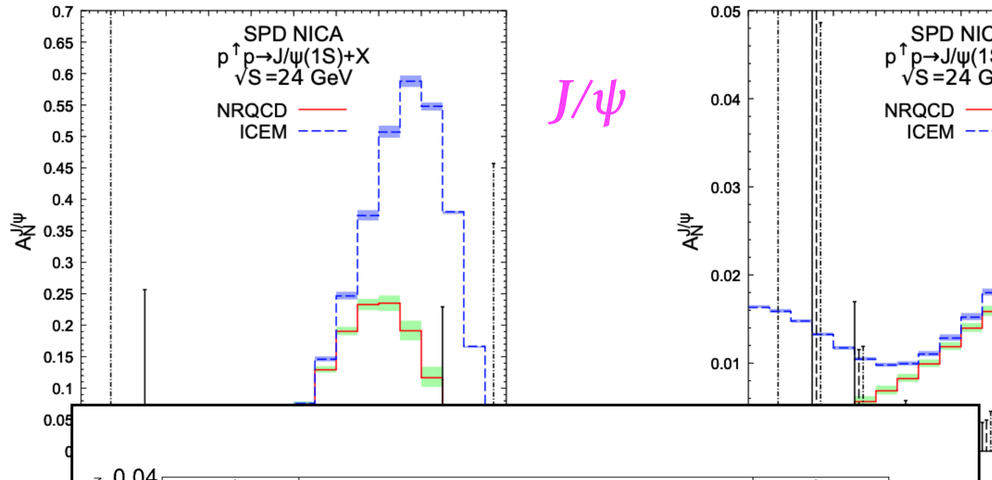


prompt-γ

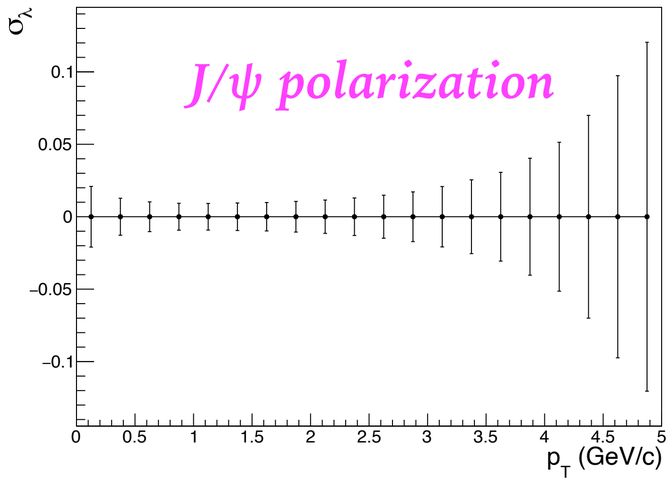


D^0

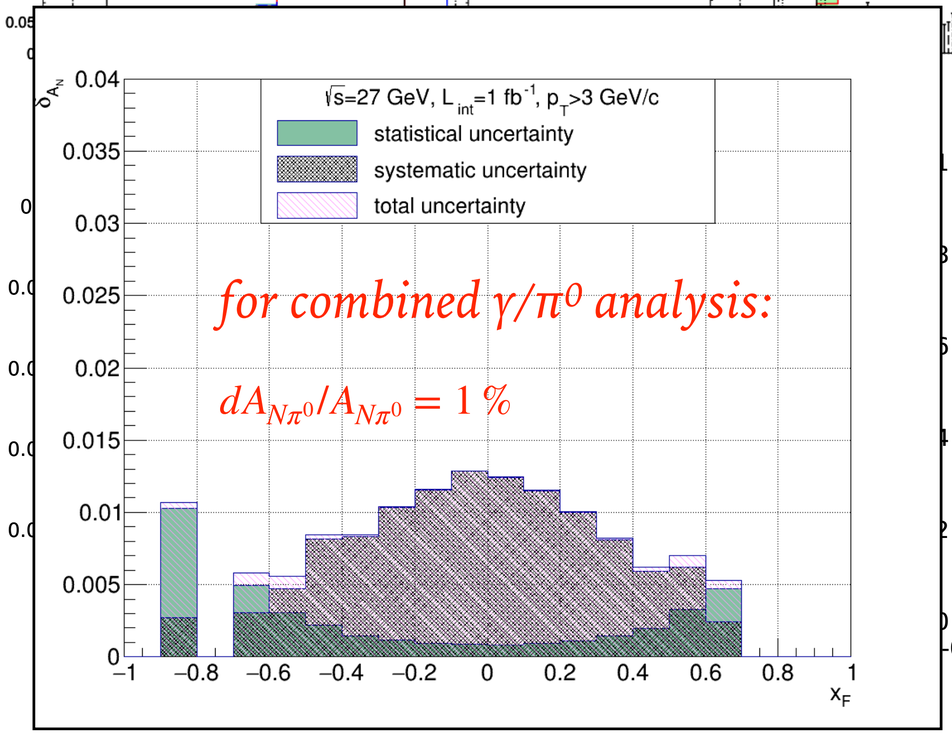
Expected performance: physics



J/ψ

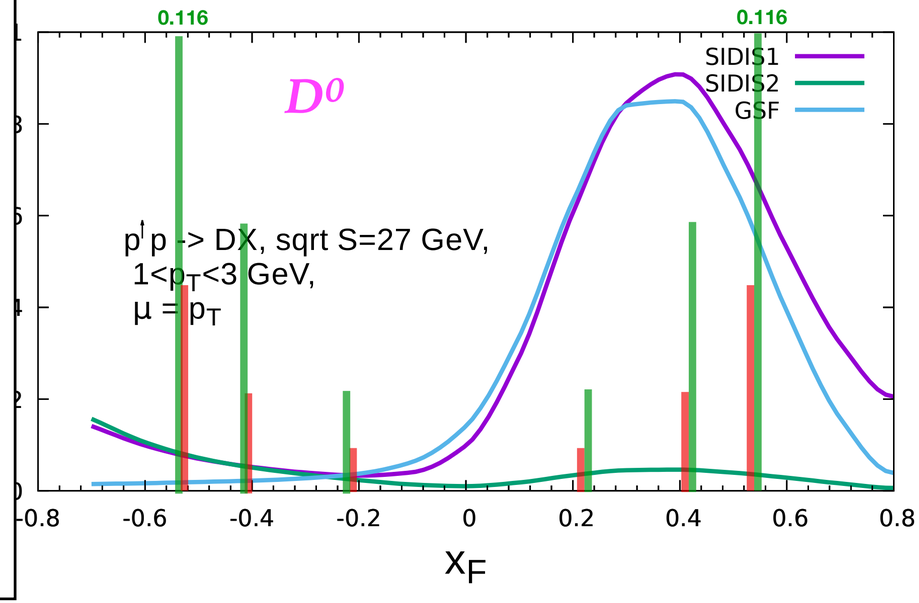


J/ψ polarization



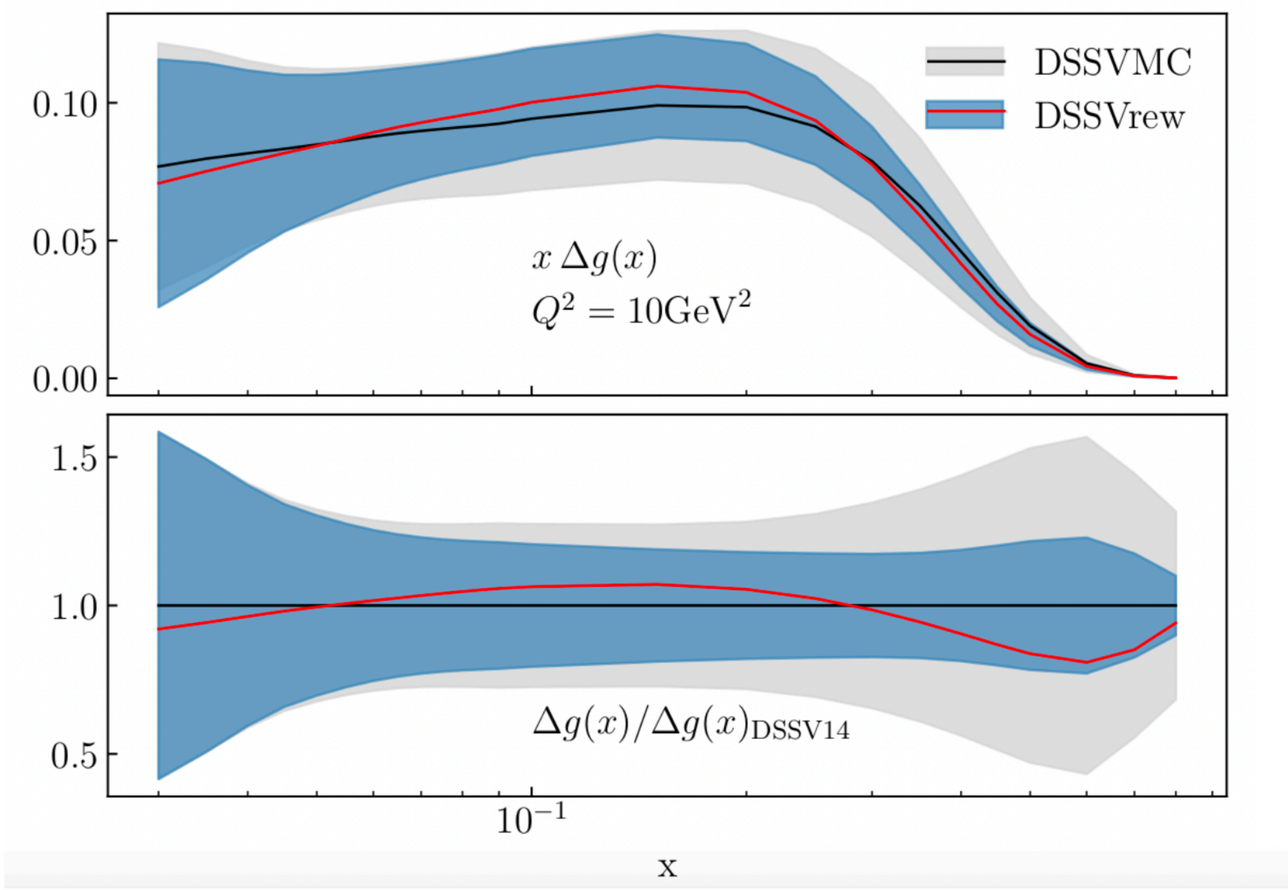
for combined γ/π⁰ analysis:

$dA_{N\pi^0}/A_{N\pi^0} = 1\ \%$

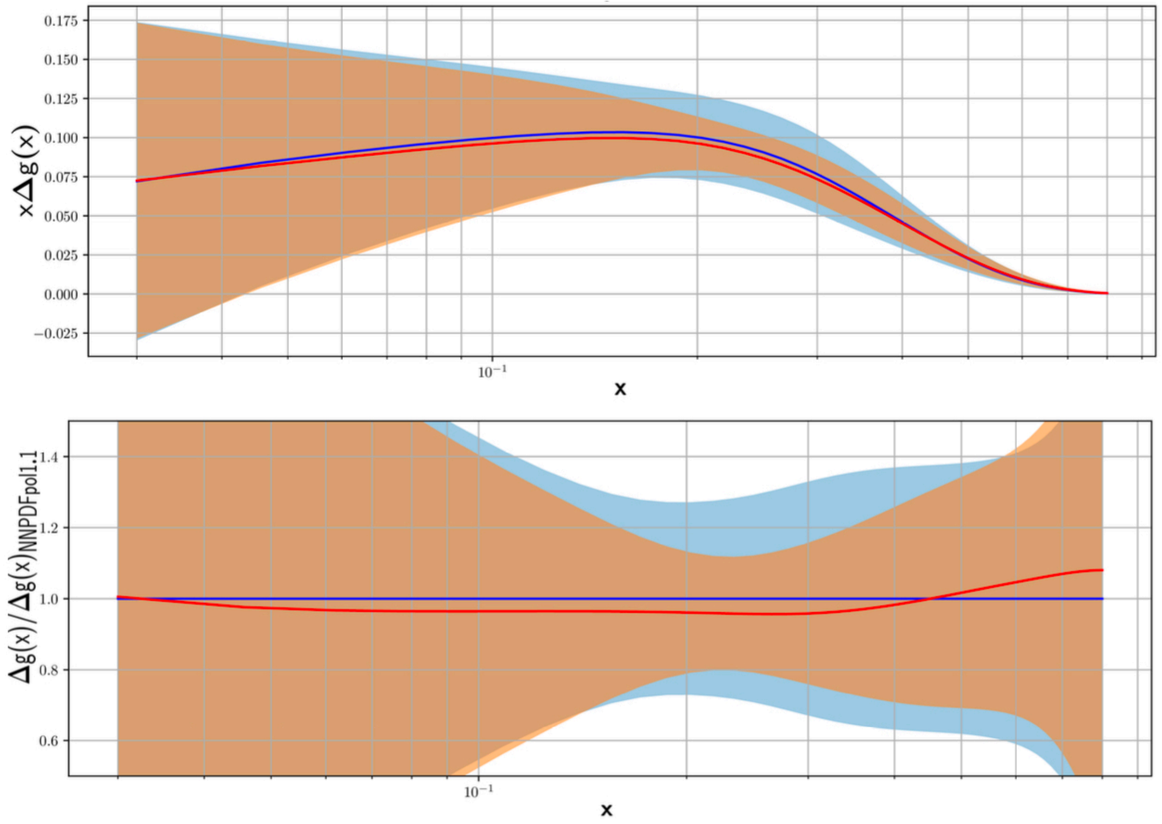


D⁰

Expected impact

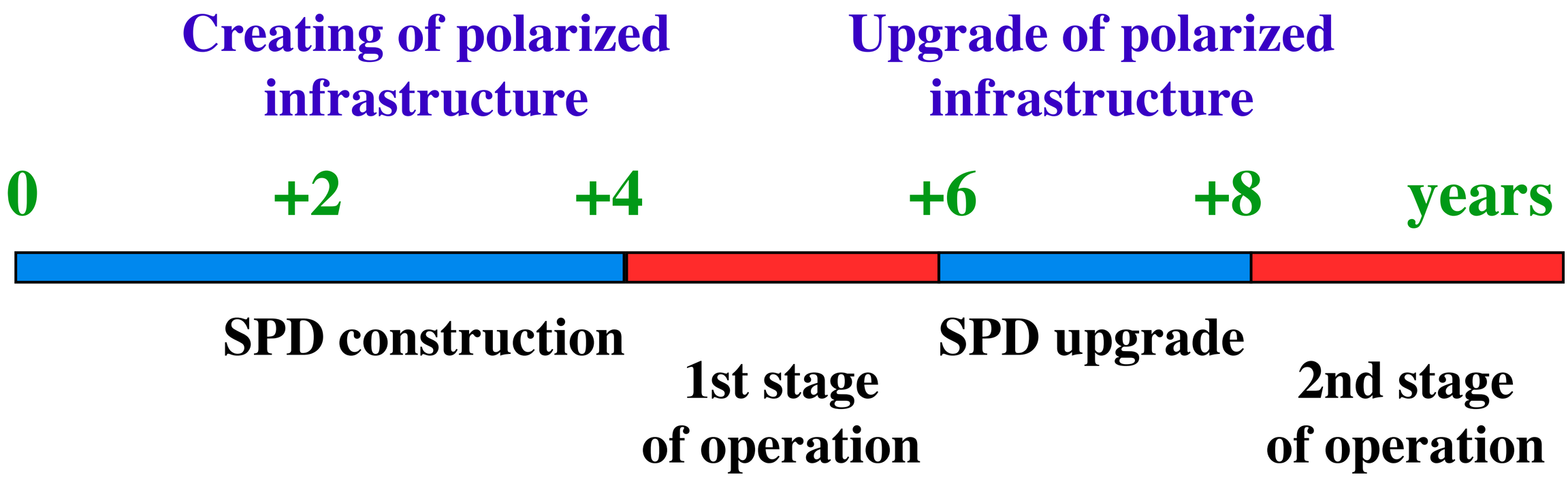


A_{LL} *for prompt photons*



A_{LL} *for* J/ψ

Implementation phases



Summary

- The Spin Physics Detector at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized gluon content of proton and deuteron; in polarized high-luminosity p-p and d-d collisions. Complementary probes such as charmonia (J/ψ and higher states), open charm and prompt photons will be used for that. Other polarized and unpolarized physics will be addressed in parallel.
- The SPD project has successfully passed developing of the physical program and the setup concept development phase. It is currently in the transition from working out technical solutions to building the first stage of the detector.
- **We look forward to a long-term and fruitful interaction with the international SPD Detector Advisory Committee**