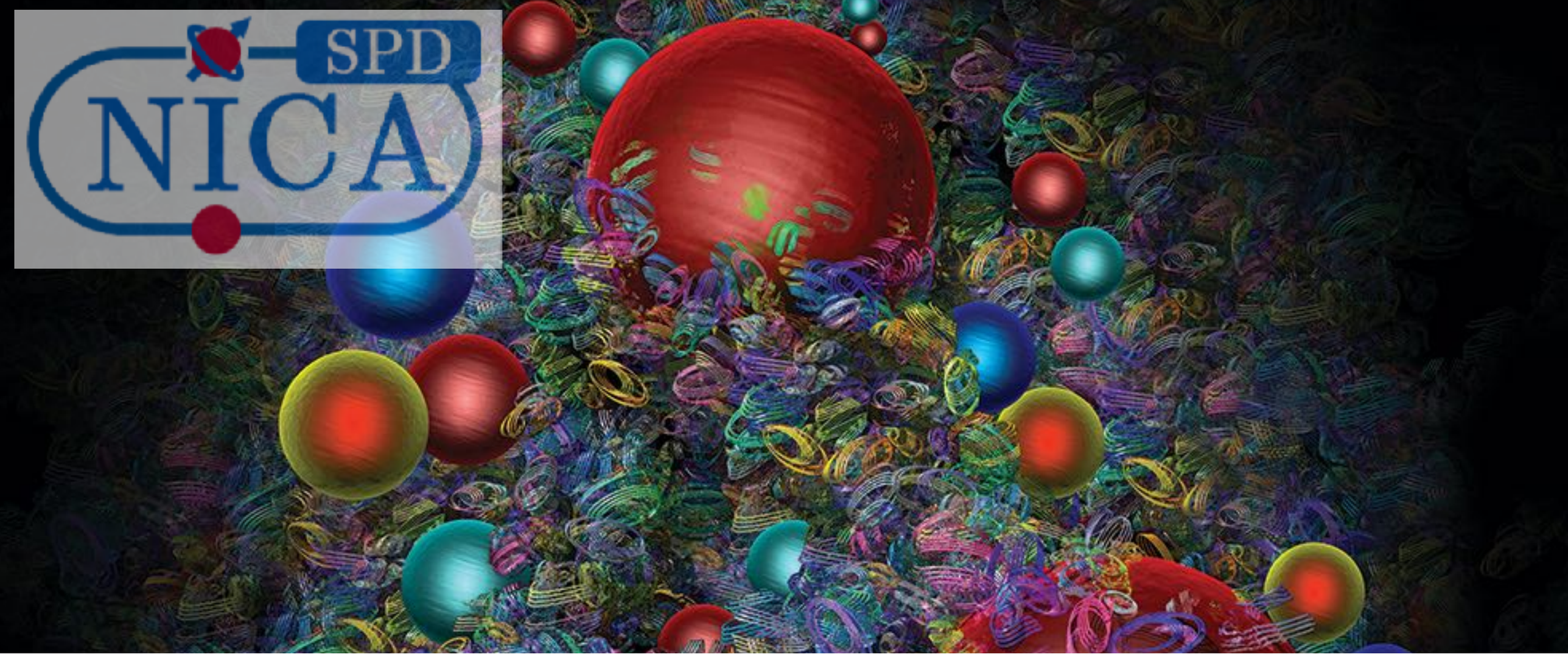


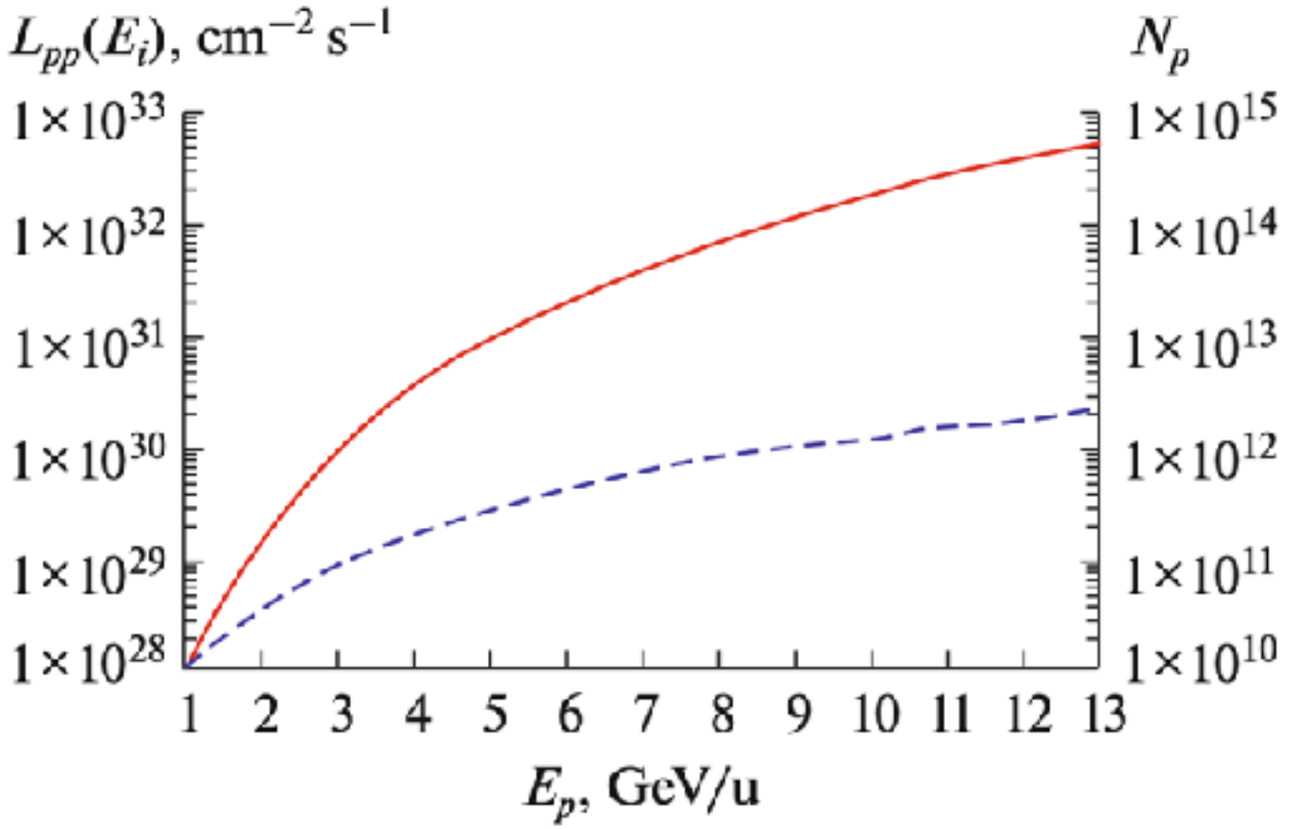
Conceptual Design Report of the SPD

A. Guskov on behalf of the SPD proto-collaboration

THE NUCLOTRON-BASED ION COLLIDER FACILITY (NICA) PROJECT AT JINR

SPD – EXPERIMENTAL CONDITIONS

circumference - 503 m,
number of collision points (IP) - 2,
beta function β_{min} in the IP - 0.35 m,
number of protons per bunch - ~$1 \cdot 10^{12}$,
number of bunches - 22,
RMS bunch length - 0.5 m,
incoherent tune shift, $\Delta_{Lasslett}$ - 0.027,
beam-beam parameter, ξ - 0.067,
beam emittance ε_{nrm} (normalized)
at 12.5 GeV, π mm mrad - 0.15.
|P|>0.6



Beam energies:
$p\uparrow p\uparrow(\sqrt{s_{pp}}) = 12 \div \geq 27$ GeV ($5 \div \geq 12.6$ GeV of proton kinetic energy),
$d\uparrow d\uparrow(\sqrt{s_{NN}}) = 4 \div \geq 13.8$ GeV ($2 \div \geq 5.9$ GeV/u of ion kinetic energy).

Unique possibility!

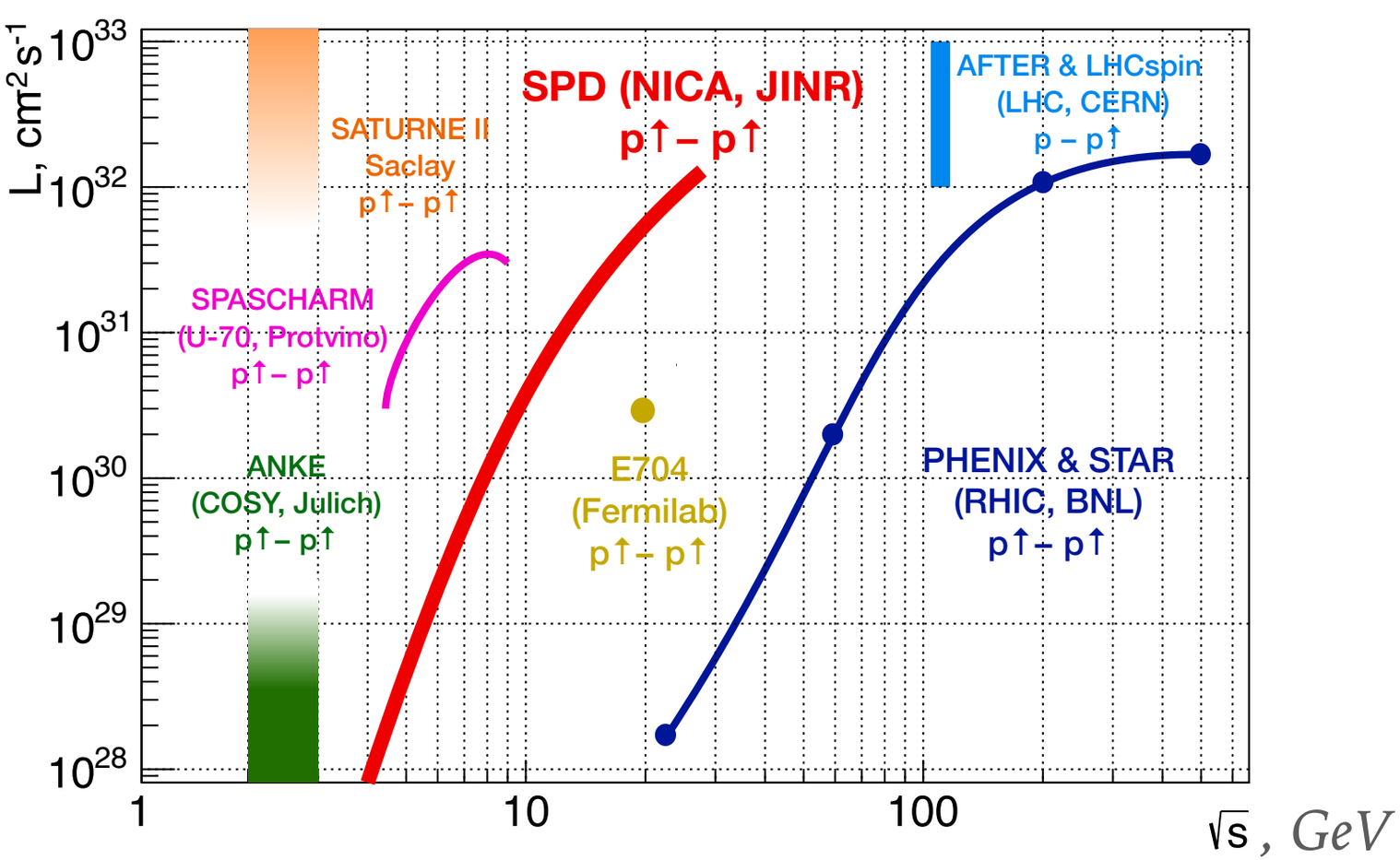
also $p\uparrow d\uparrow$

All combinations of collisions are possible -

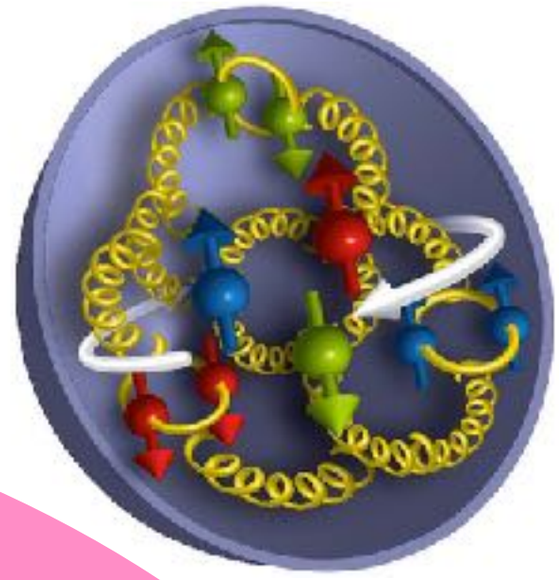
UU, LL, TT, UL, UT, LT

SPD – VS OTHERS

Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	LHCspin
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^{\uparrow}$-$p^{\uparrow}$ $d^{\uparrow}$-$d^{\uparrow}$ $p^{\uparrow}$-d, p-$d^{\uparrow}$	$p^{\uparrow}$-$p^{\uparrow}$	$e^{\uparrow}$-$p^{\uparrow}$, $d^{\uparrow}$, $^3He^{\uparrow}$	p-$p^{\uparrow}$,$d^{\uparrow}$	p-$p^{\uparrow}$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	≤27 (p-p) ≤13.5 (d-d) ≤19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	~1 (p-p) ~0.1 (d-d)	2	1000	up to ~10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025



CONCEPT OF THE SPD PHYSICS PROGRAM



SPD - a universal facility for comprehensive study of gluon content in proton and deuteron at large x

Charmonia

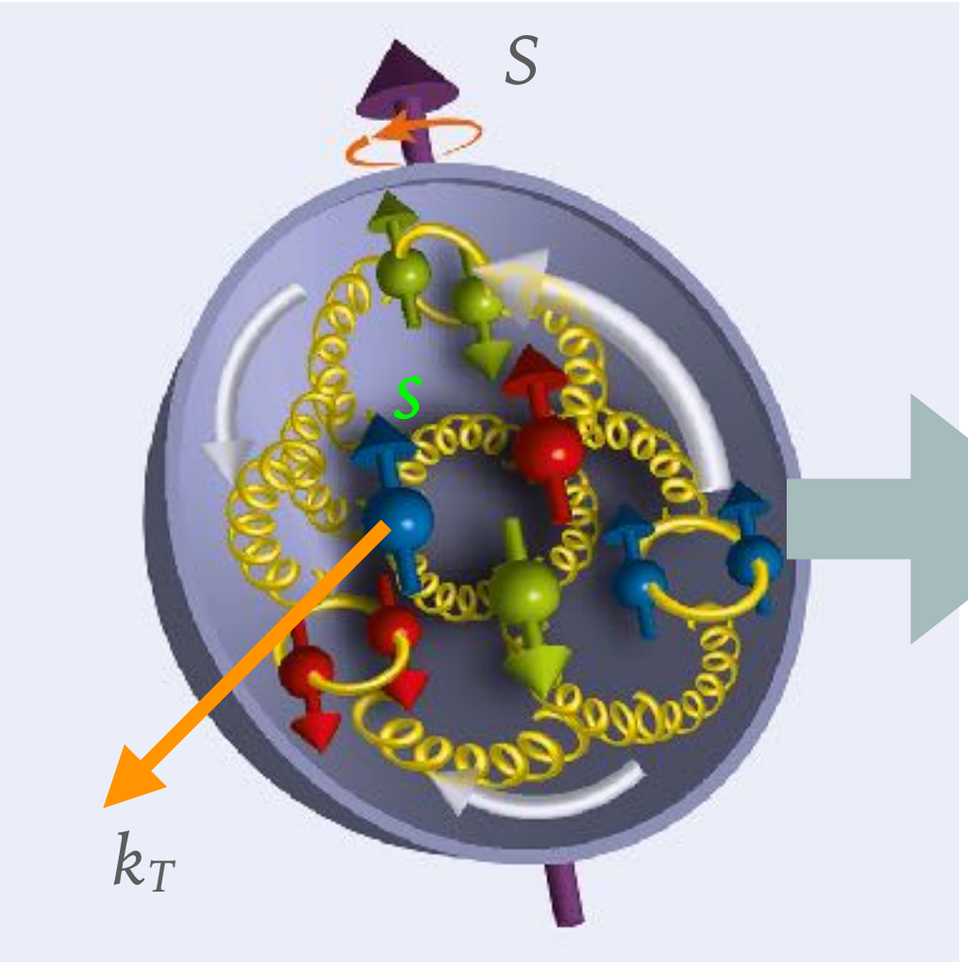
Prompt photons

Open charm

Other spin-related phenomena

Other physics

SPIN STRUCTURE OF NUCLEON



QUARKS	*unpolarized*	*chiral*	*transverse*
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_{1T}, $h_{1T}^{\perp}$

GLUONS	*unpolarized*	*circular*	*linear*
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	h_{1T}^g, $h_{1T}^{\perp g}$

Momentum of proton

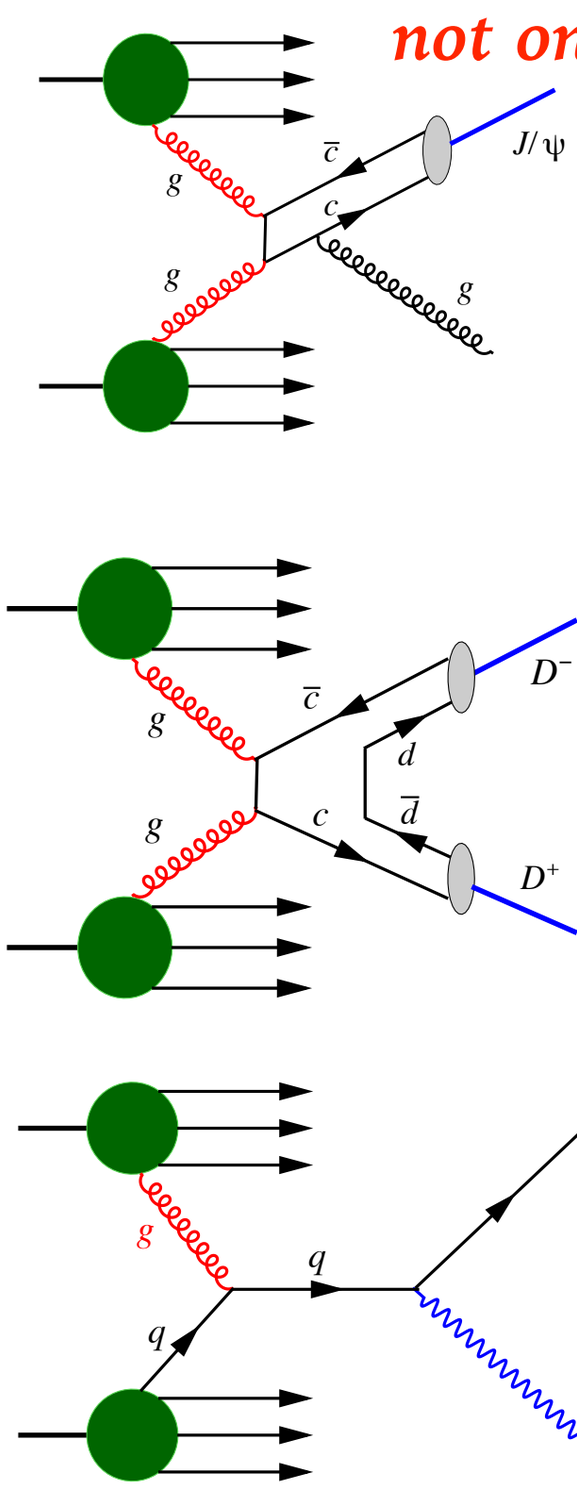
Spin of proton

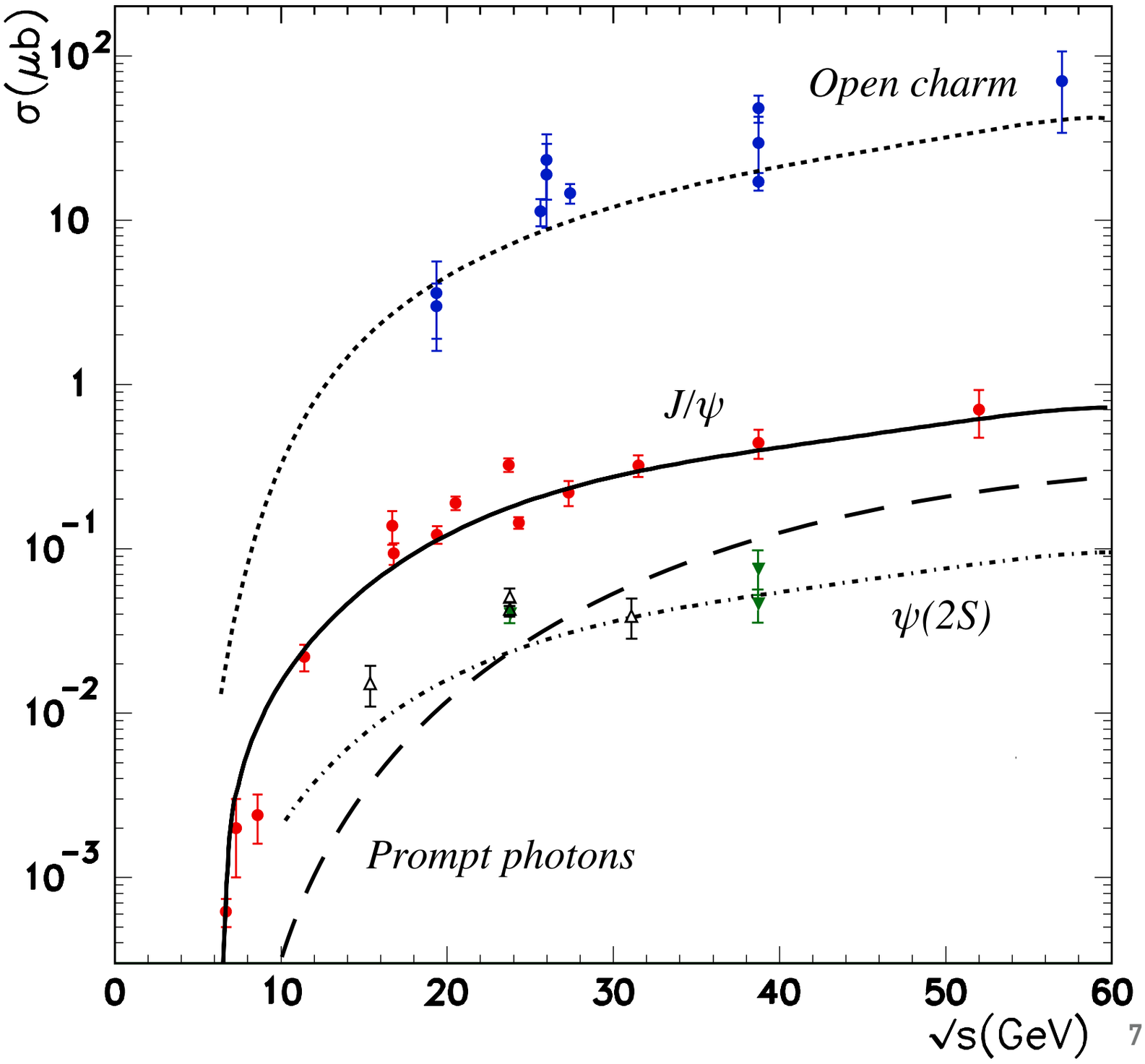
Spin of parton

Transverse momentum of parton

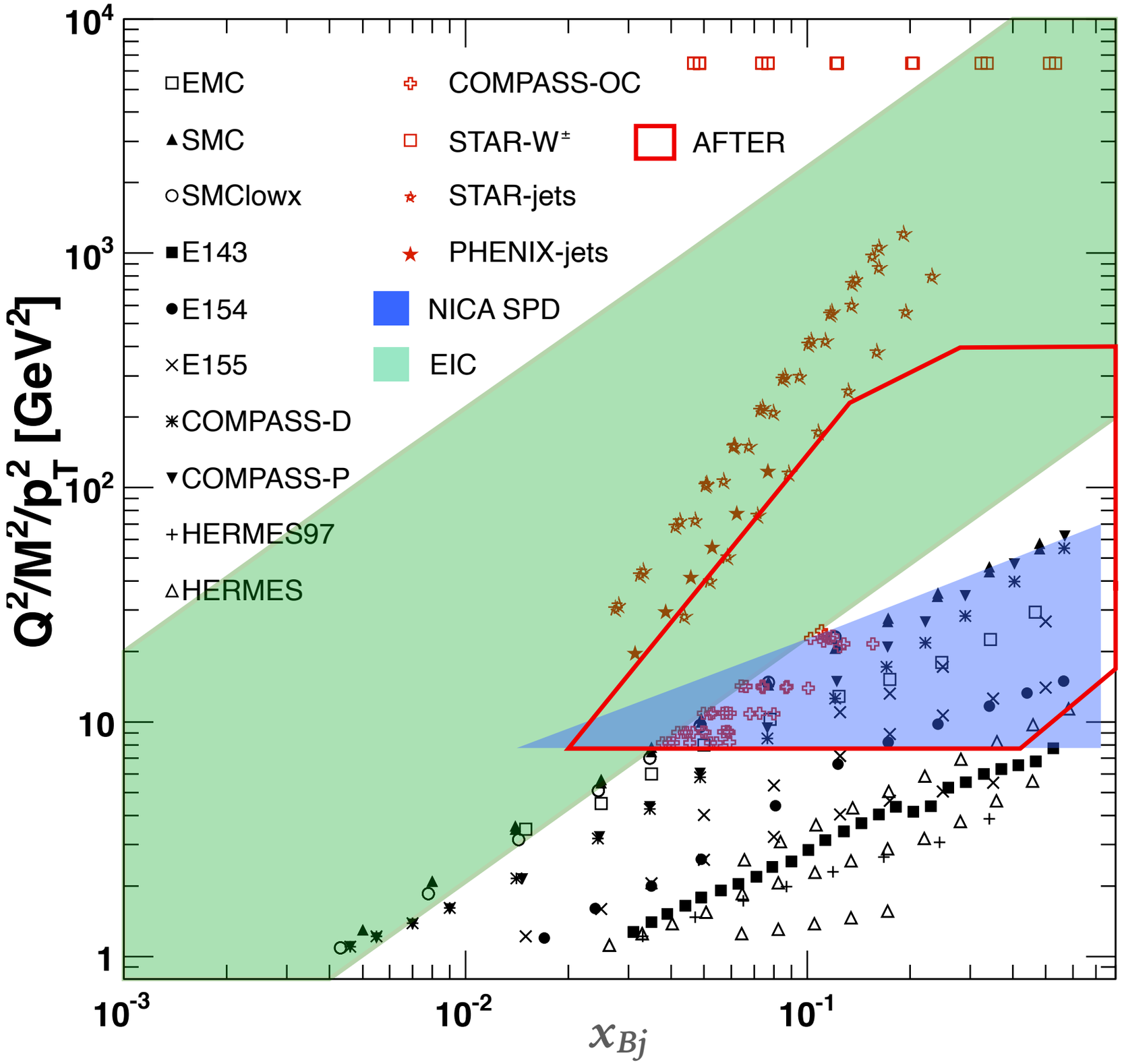
GLUON PROBES AT SPD

not only J/ψ!





MAIN PLAYERS IN POLARIZED GLUON PHYSICS



SPD can cover this range for polarised gluon studies in p↑-p↑ interactions!

open charm

charmonia

high-p_T prompt photons

PARTONIC STRUCTURE OF PROTON AND DEUTERON

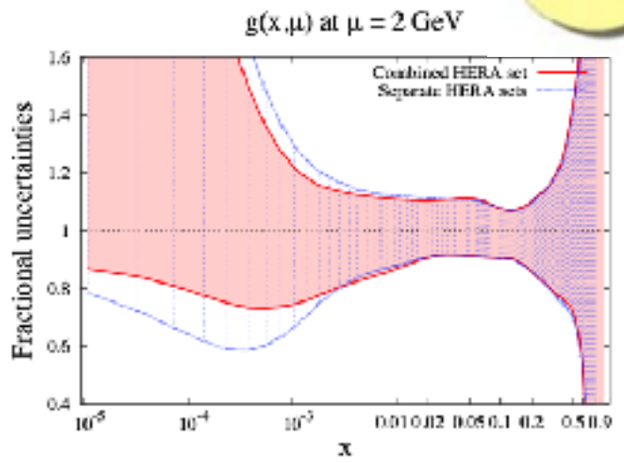
$\sigma(x_F,p_T)$ $A_{LL}(x_F,p_T)$

$A_{TT}(x_F,p_T)$ $A_N(x_F,p_T)$

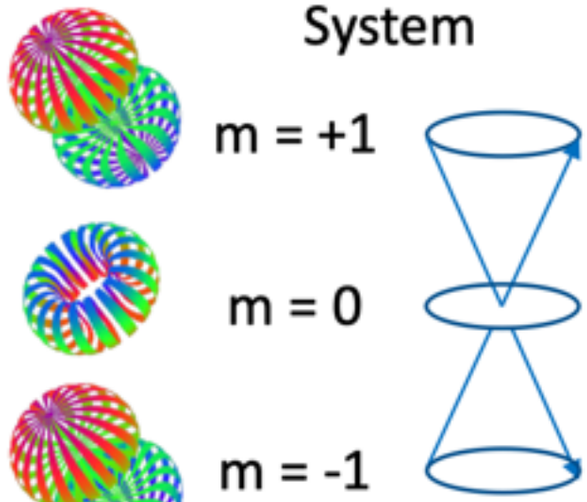
Spin crisis:

Gluon helicity

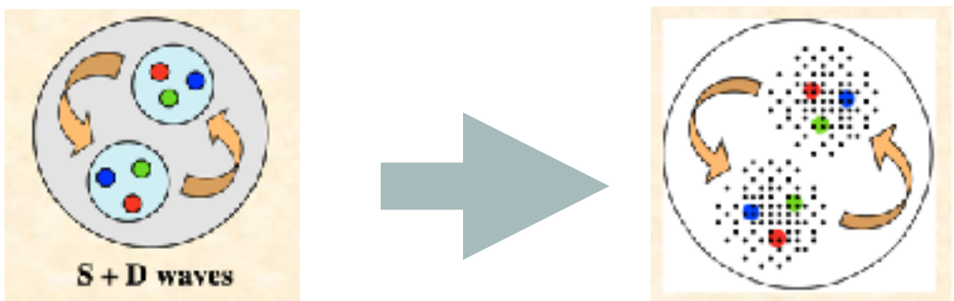
Unpolarized gluons in proton and deuteron at high x:



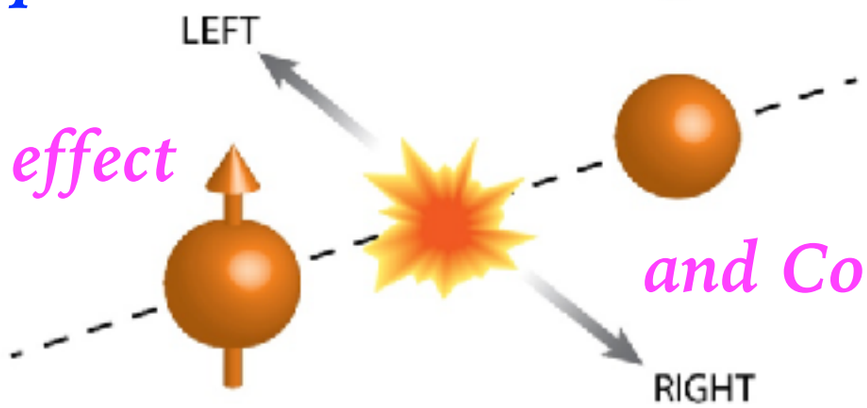
Tensor structure of deuteron:



Nonbaryonic content of deuteron:



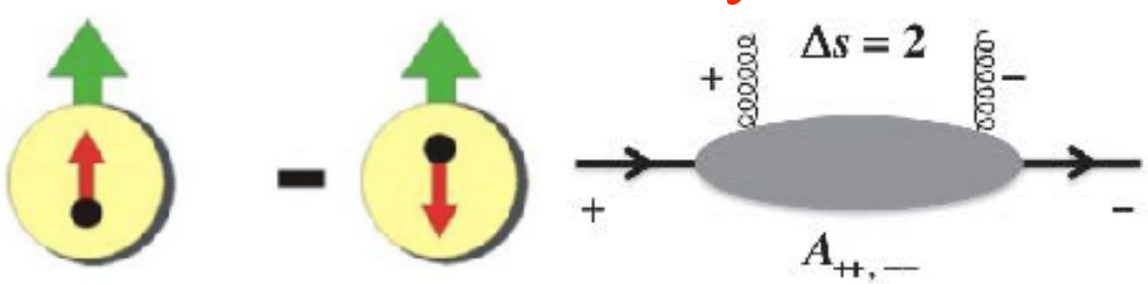
Gluon and quark TMD PDFs:



Sivers effect

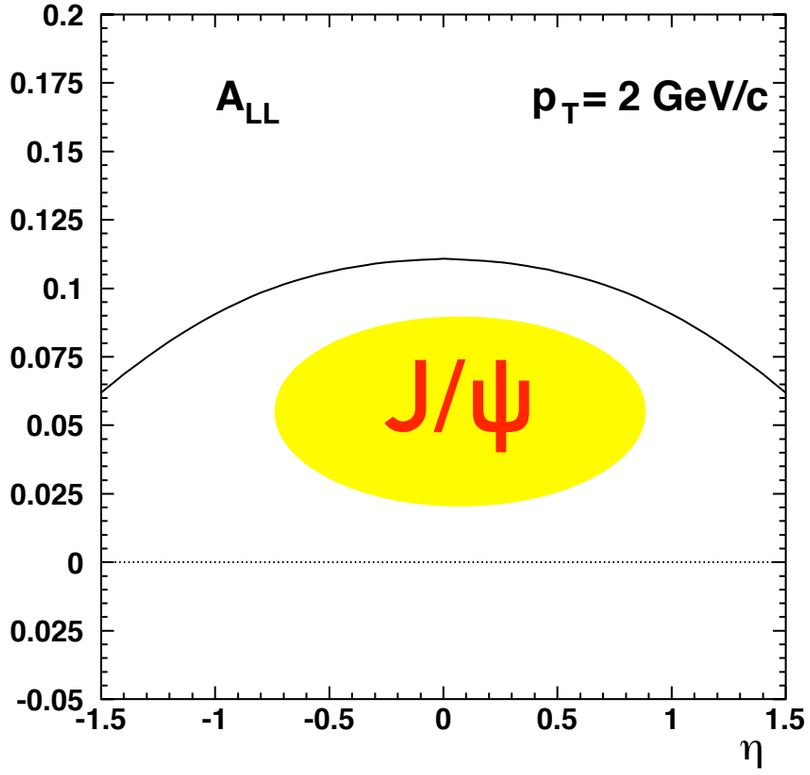
and Collins effect

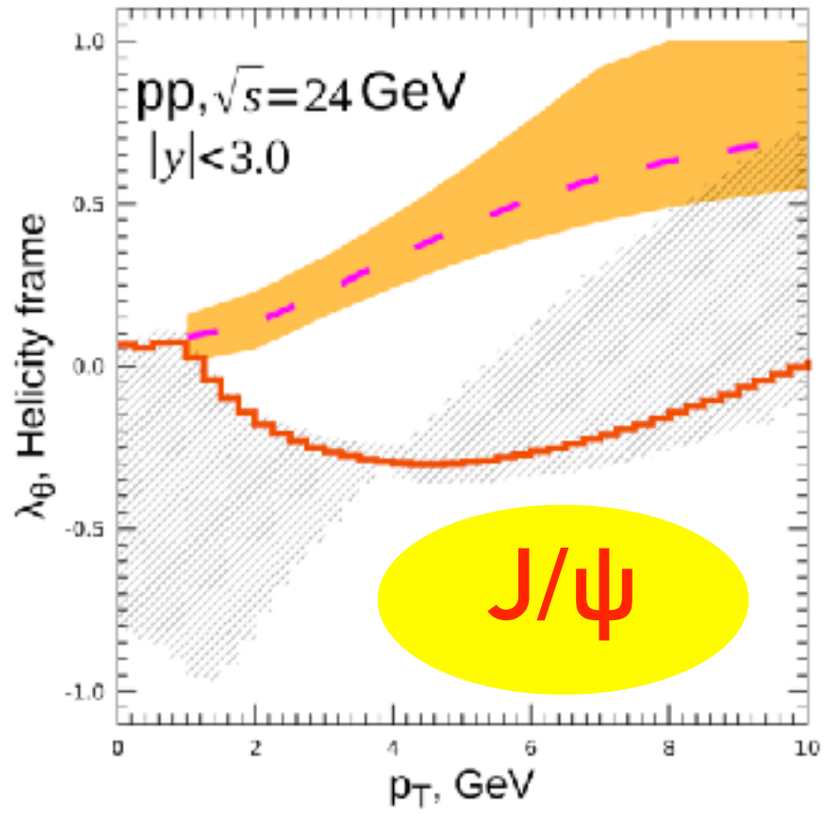
Gluon transversity

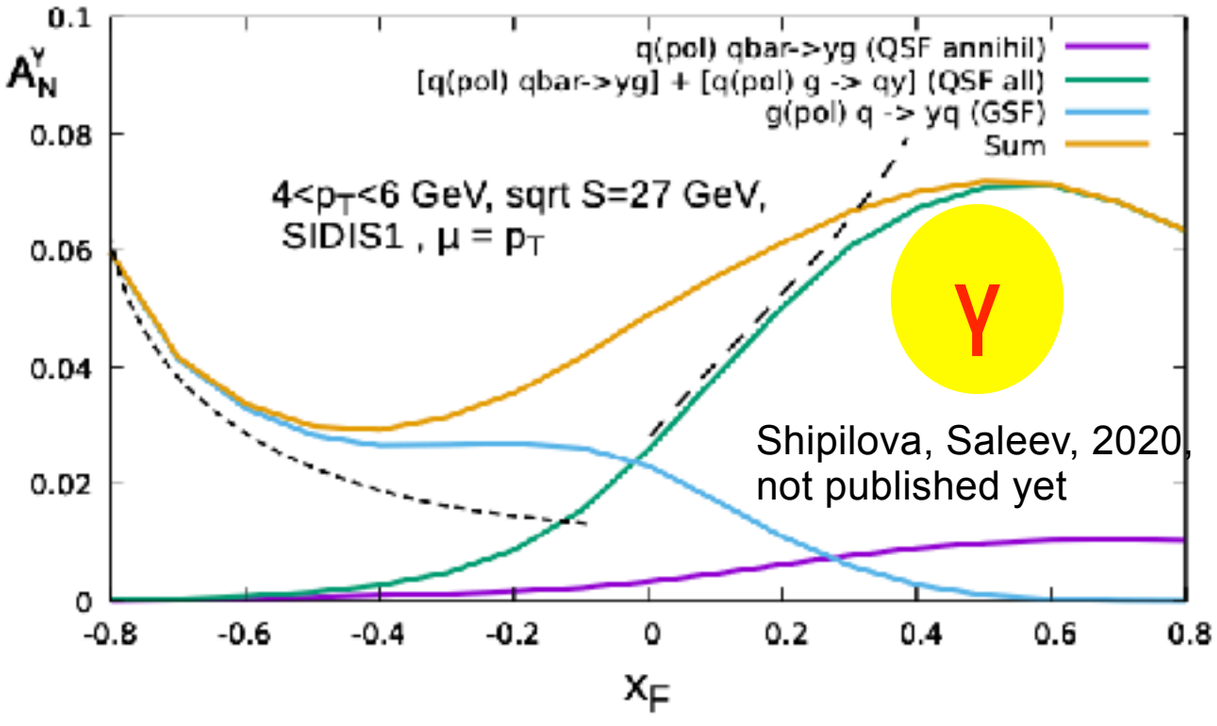


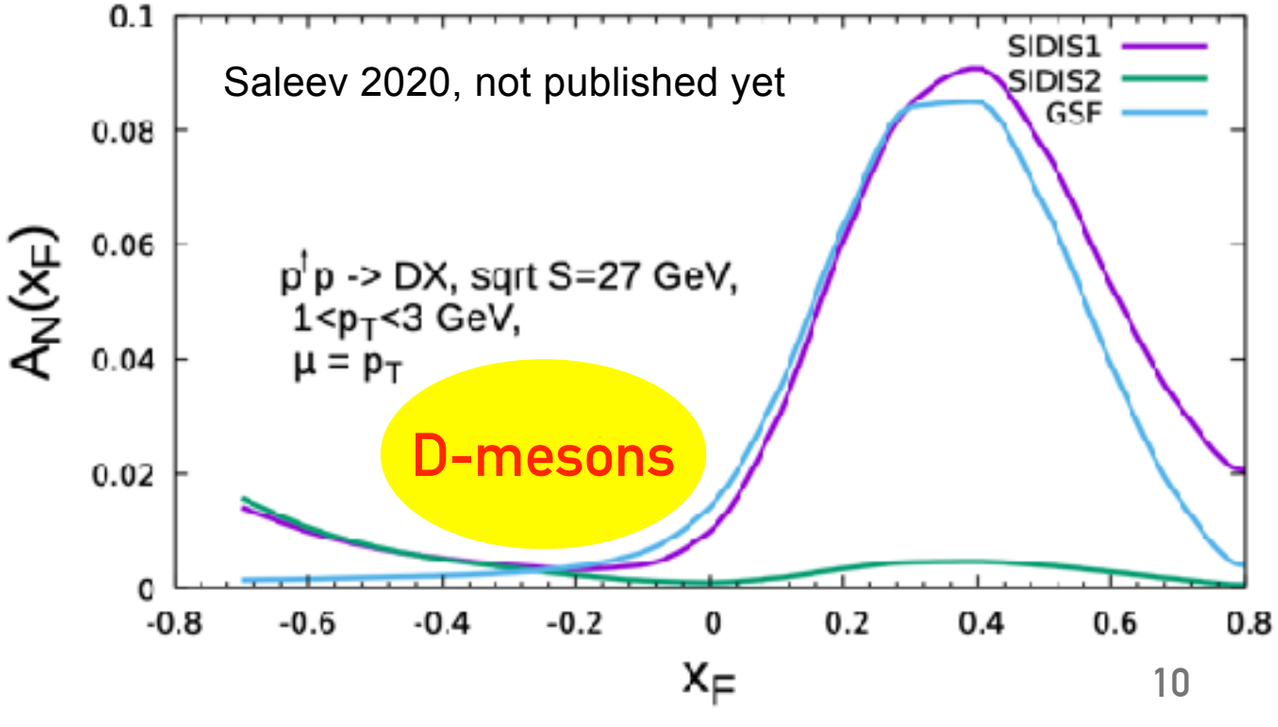
– *spin-dependent fragmentation functions*

EXPECTATIONS FOR SPD ENERGIES









MORE DETAILS ABOUT GLUON PHYSICS AT SPD:

arXiv:2011.15005

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

A. Arbuzov[a], A. Bacchetta[b,c], M. Butenschoen[d], F.G. Celiberto[b,c], U. D'Alesio[e,f], M. Deka[a], I. Denisenko[a], M. G. Echevarria[g], A. Efremov[a], N.Ya. Ivanov[a,h], A. Guskov[a,i], A. Karpishkov[j,a], Ya. Klopot[a,k], B. A. Kniehl[d], A. Kotzinian[h,m], S. Kumano[n], J.P. Lansberg[o], Keh-Fei Liu[p], F. Murgia[f], M. Nefedov[j], B. Parsamyan[a,l,m], C. Pisano[e,f], M. Radici[c], A. Rymbekova[a], V. Saleev[j,a], A. Shipilova[j,a], Qin-Tao Song[q], O. Teryaev[a]

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Submitted to Progress in Particle and Nuclear Physics Journal

PHYSICS OF THE FIRST STAGE OF SPD RUNNING

- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Open charm and charmonia near threshold
- Auxiliary measurements for astrophysics
- …

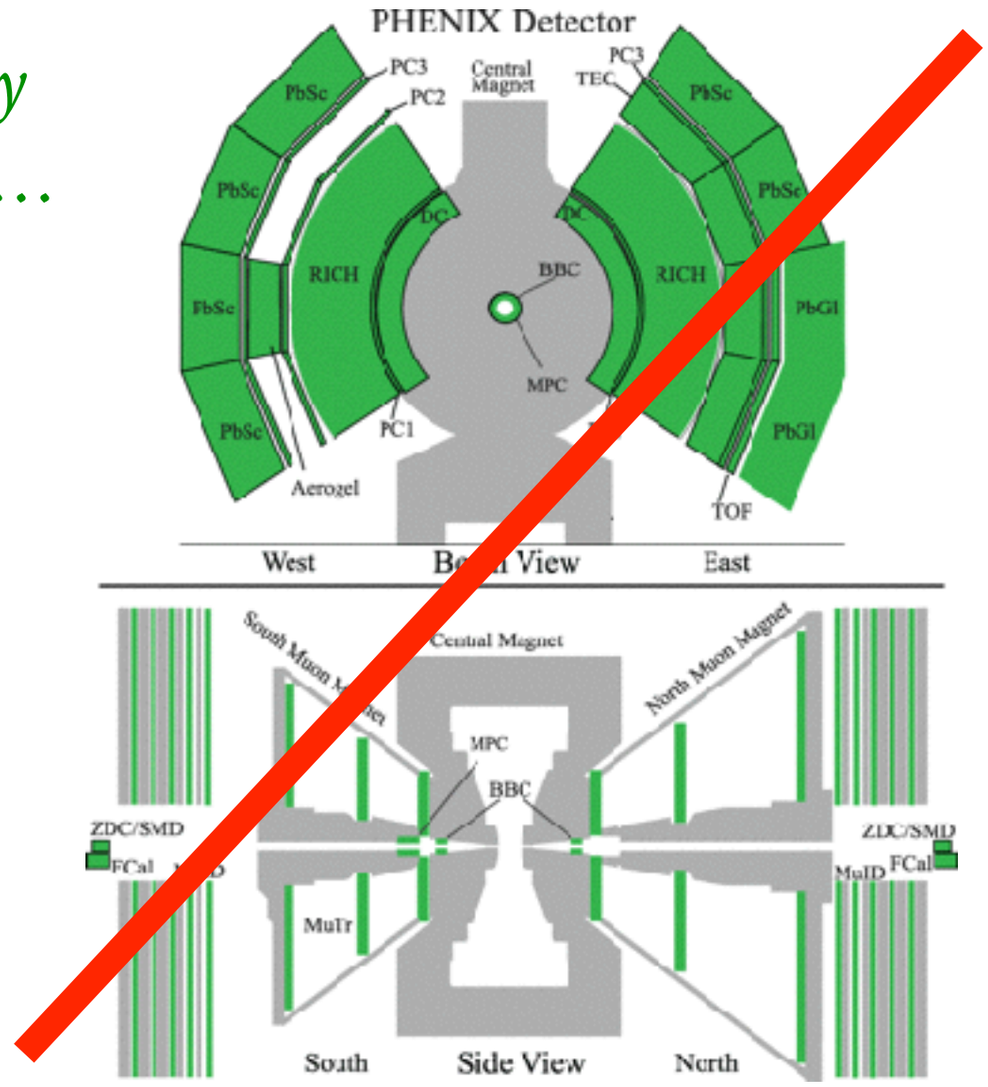
SPD SETUP: GENERAL CONDITIONS

Detector mass must be kept below 1500 ton together with lodgement and moving system + *No effective muon ID with muon system with* $<4\ \lambda_I$ = *Strong limitation to geometrical size of the setup*

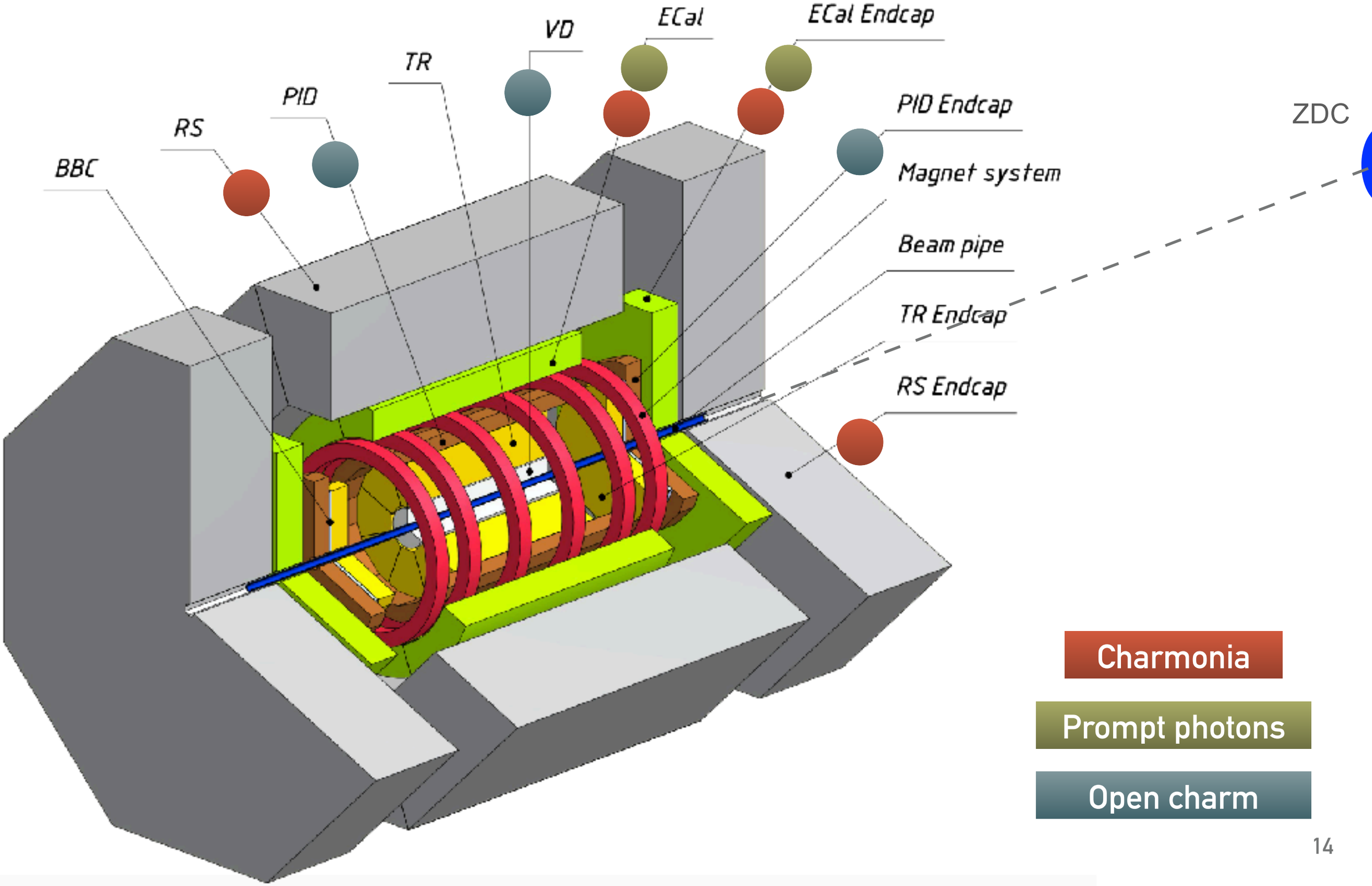
Tiny cross-sections of signal processes + *No sizable boost for produced signal heavy particles like J/ψ, D …*

= *~4π geometry for all subsystems*

Interaction rate up to 4 MHz at 27 GeV



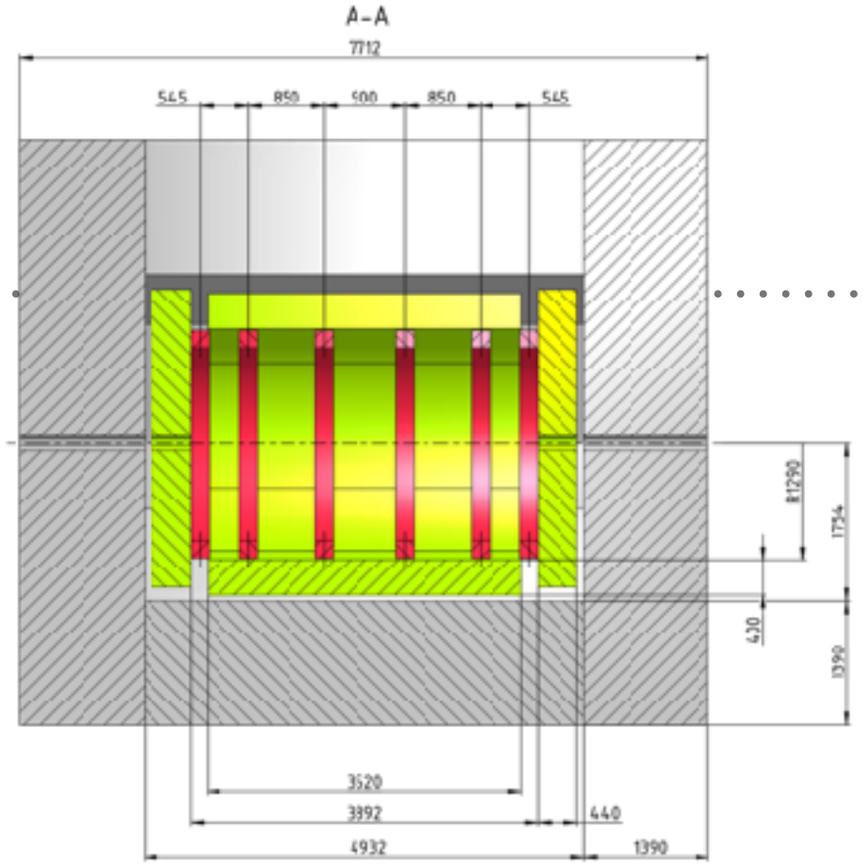
DETECTOR: GENERAL OVERVIEW

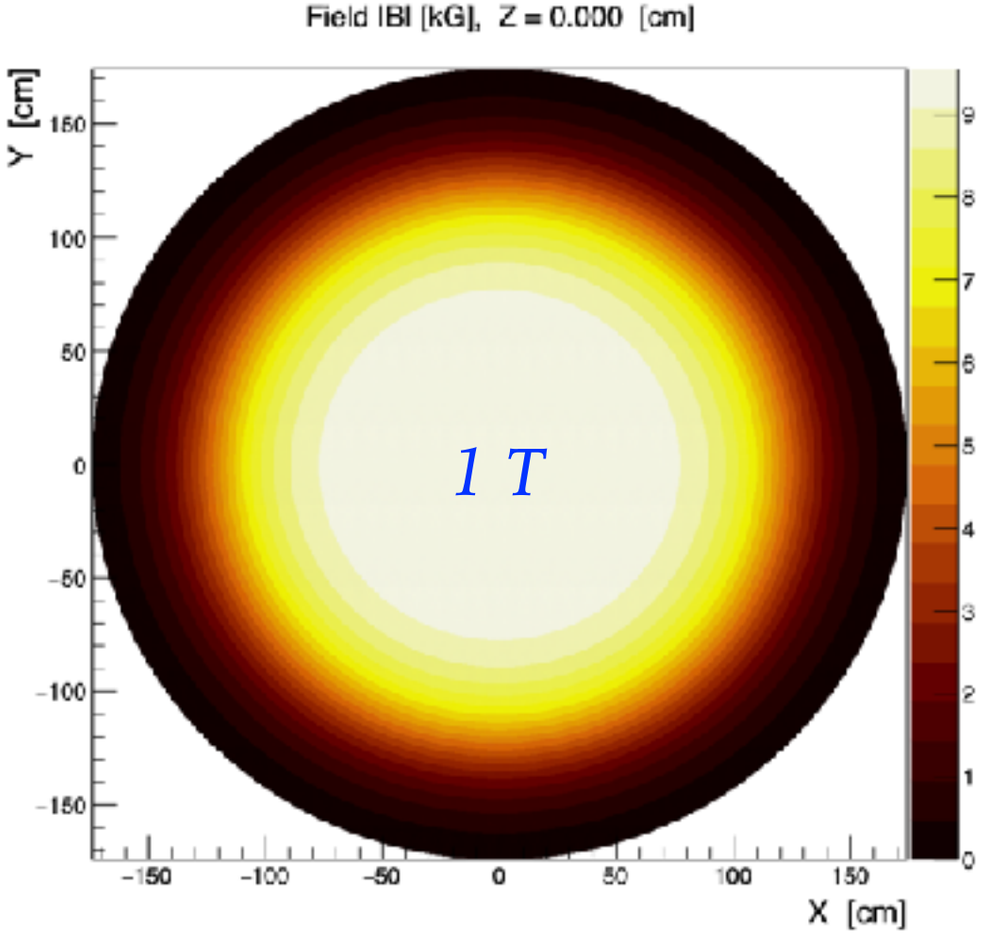


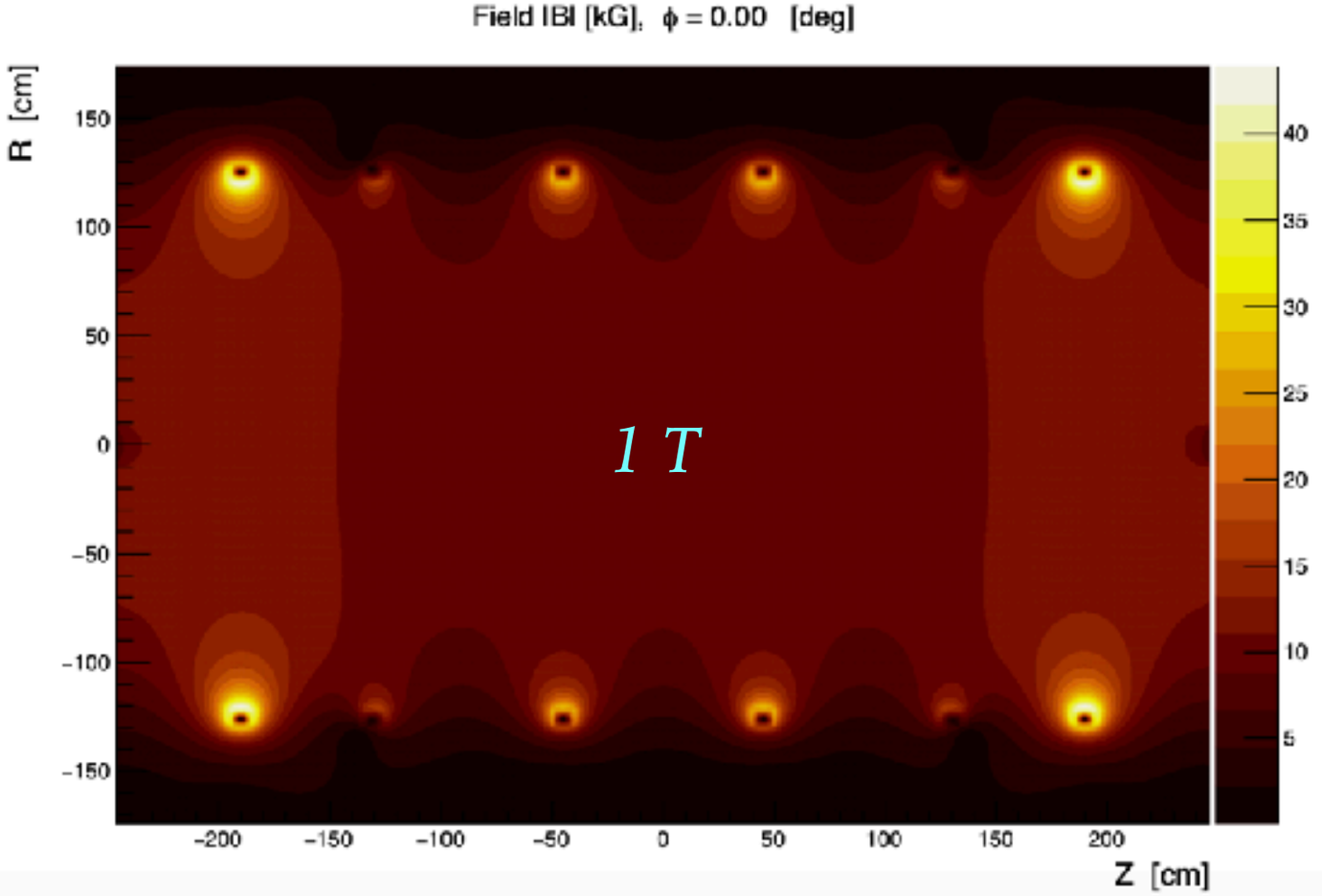
MAGNETIC SYSTEM

6 solenoidal coils inside the ECAL:

- *compact*
- *1 T at the beam axis*
- *Z-optimization*



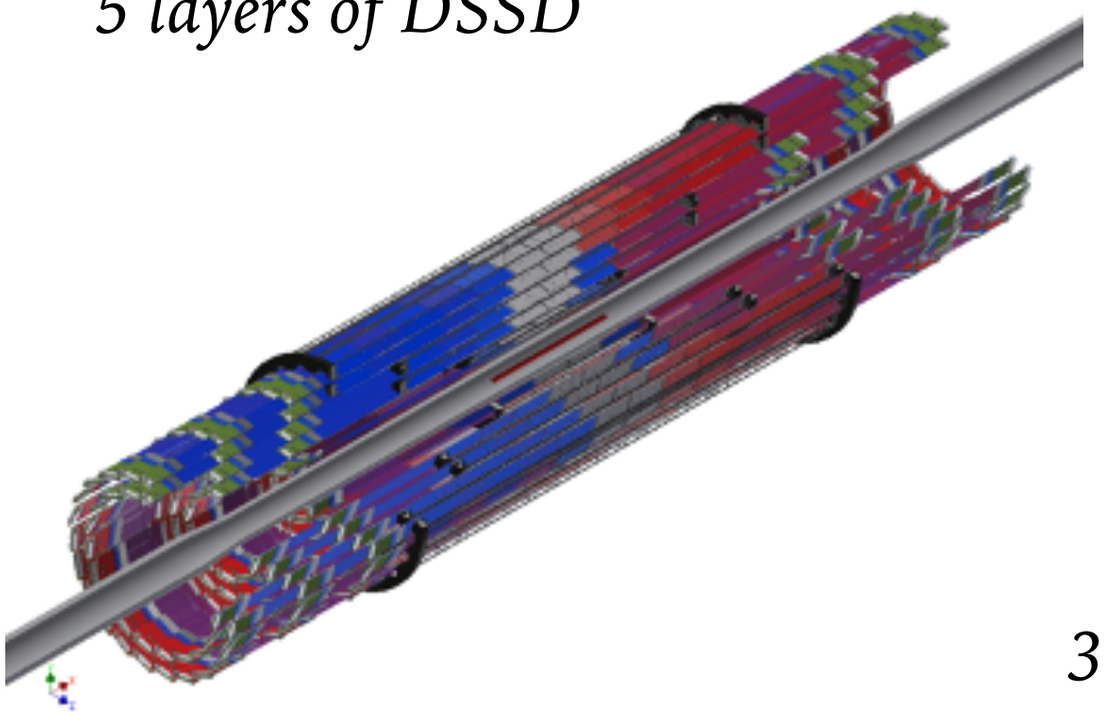


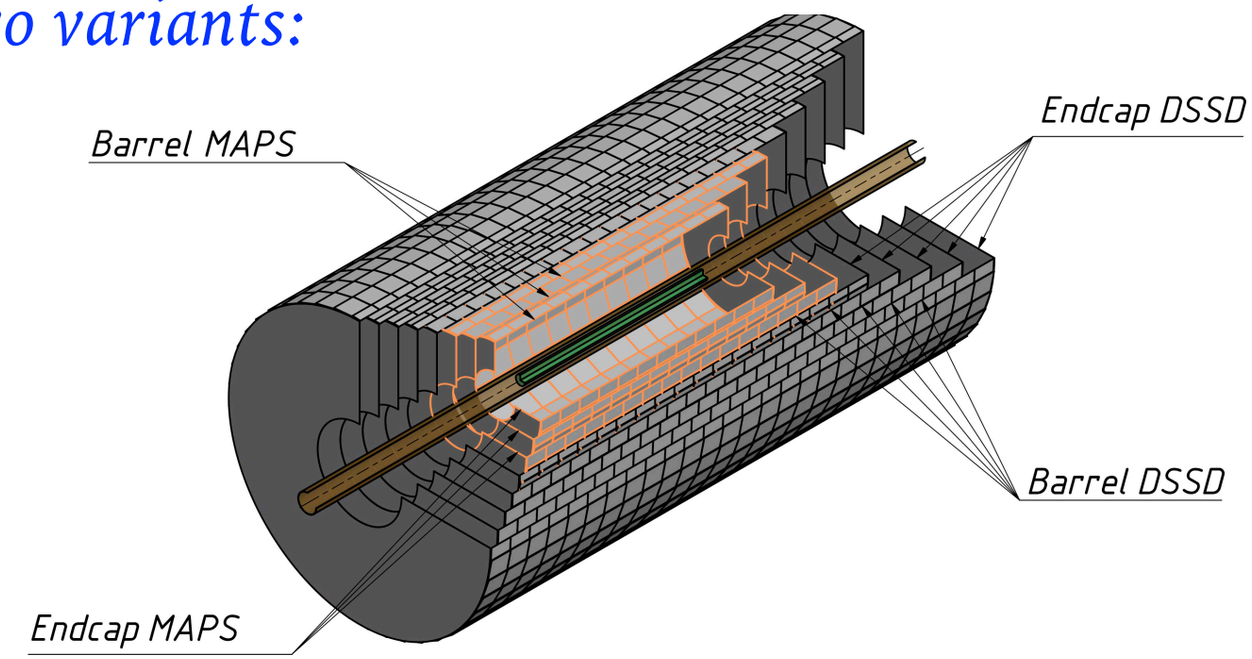


VERTEX DETECTOR

Two variants:

5 layers of DSSD





3 internal layers in barrel replaced by MAPS

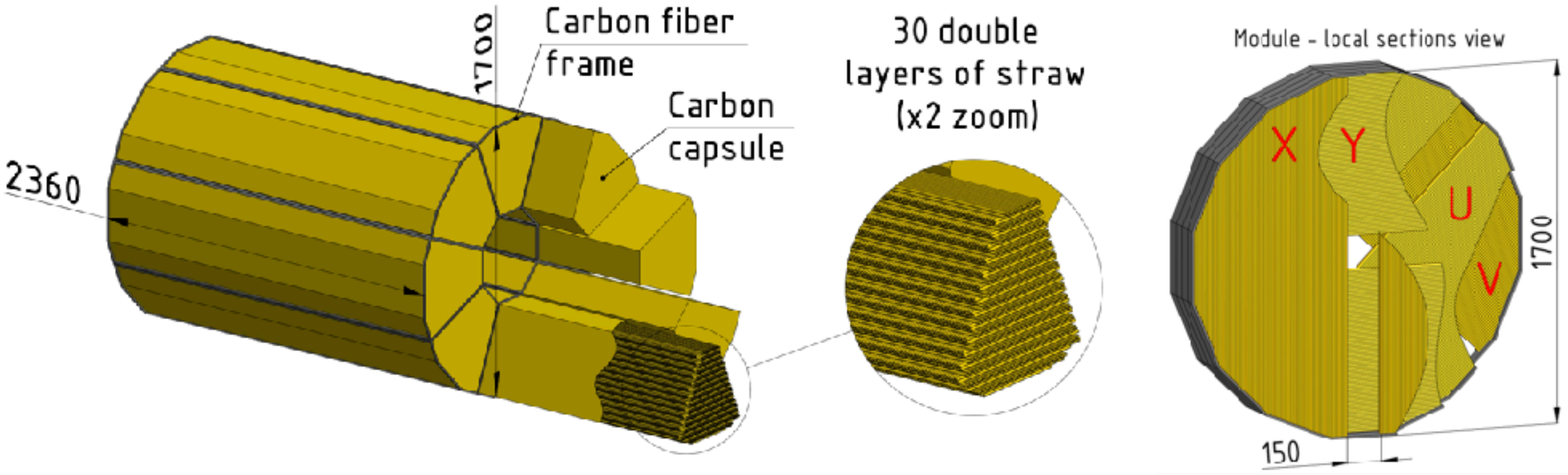
Goals:

- *Reconstruction of secondary vertices for D-mesons decay*
- *Participation in track reconstruction and momentum measurement*

Requirements:

- *Spatial resolution <100 μm*
- *Low material budget*
- *Has to be installed as close as possible to the IP*

STRAW TRACKER



Goals:

- *Track reconstruction and momentum measurement*
- *Participation in PID via dE/dx measurement*

Requirements:

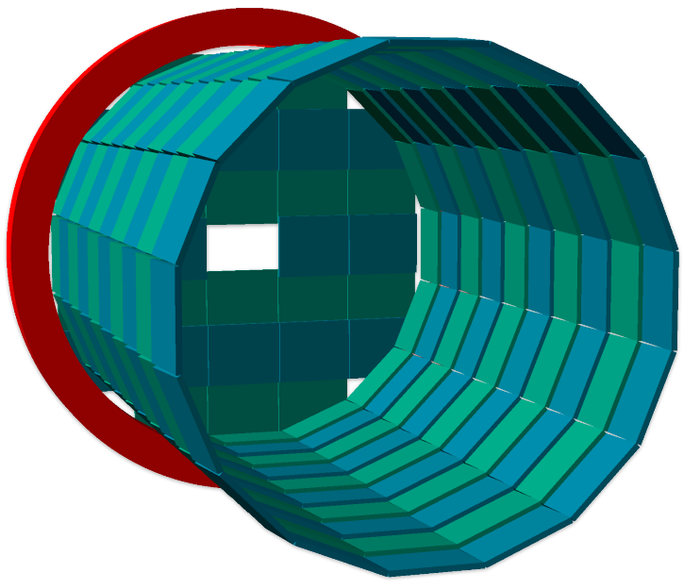
- *Spatial resolution ~150 μm*
- *Low material budget*
- *Operation in magnetic field of about 1 T*

some R&D is still needed

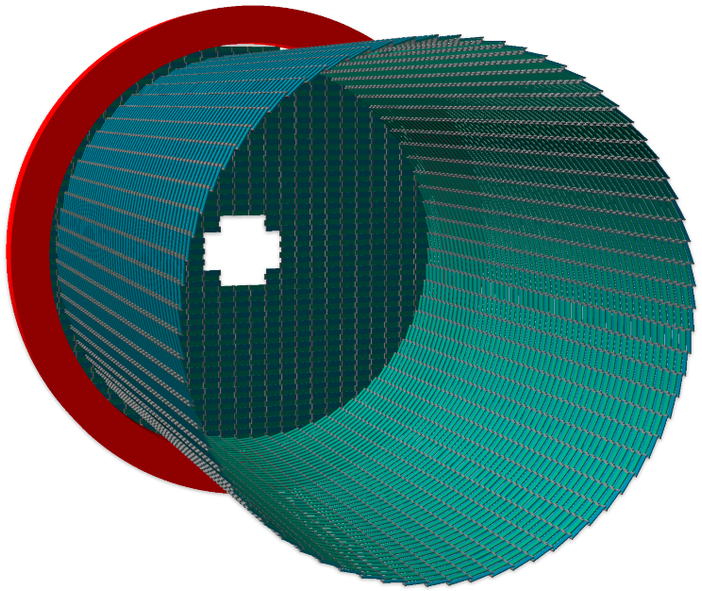
PARTICLE IDENTIFICATION SYSTEM

TOF system

mRPC-based



Scintillator-based



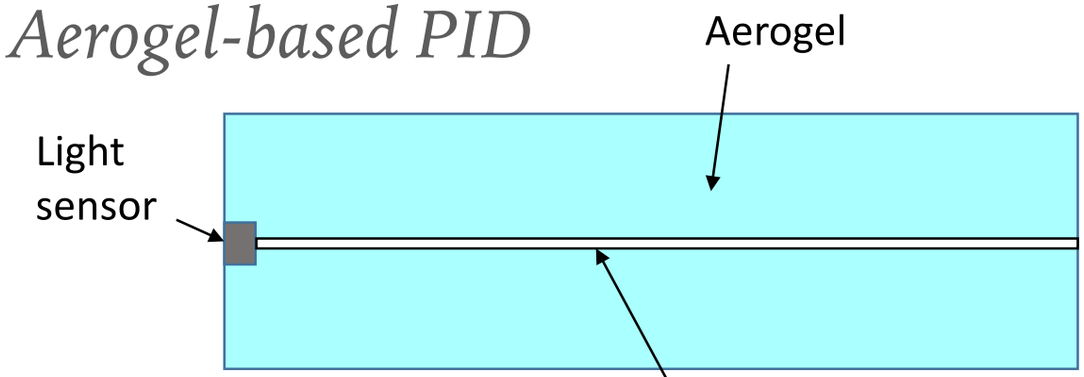
Goals:

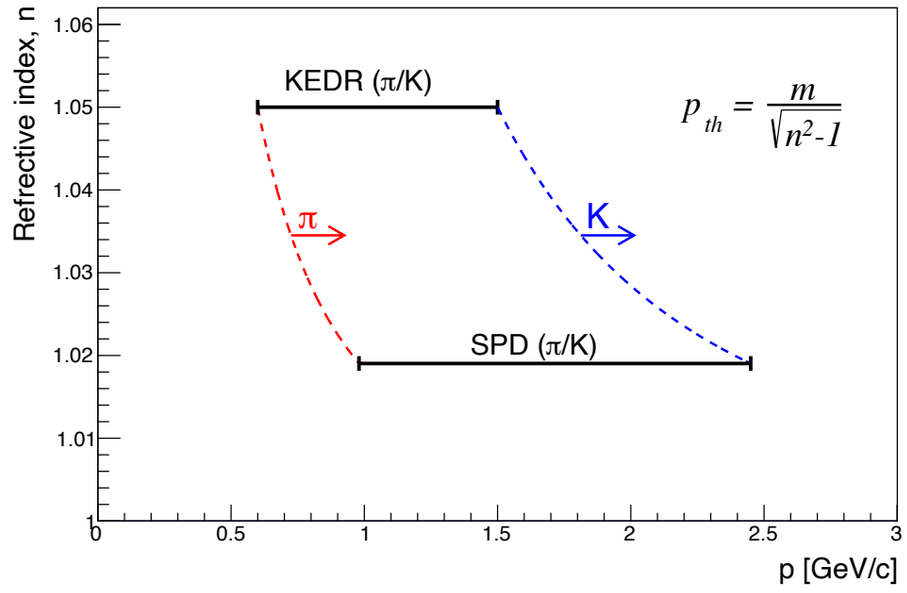
- *π/K separation up to ~1.5 GeV*
- *K/p separation*
- *t_0 determination*

Requirements:

- *Time resolution ~60-70 ps*

Aerogel-based PID





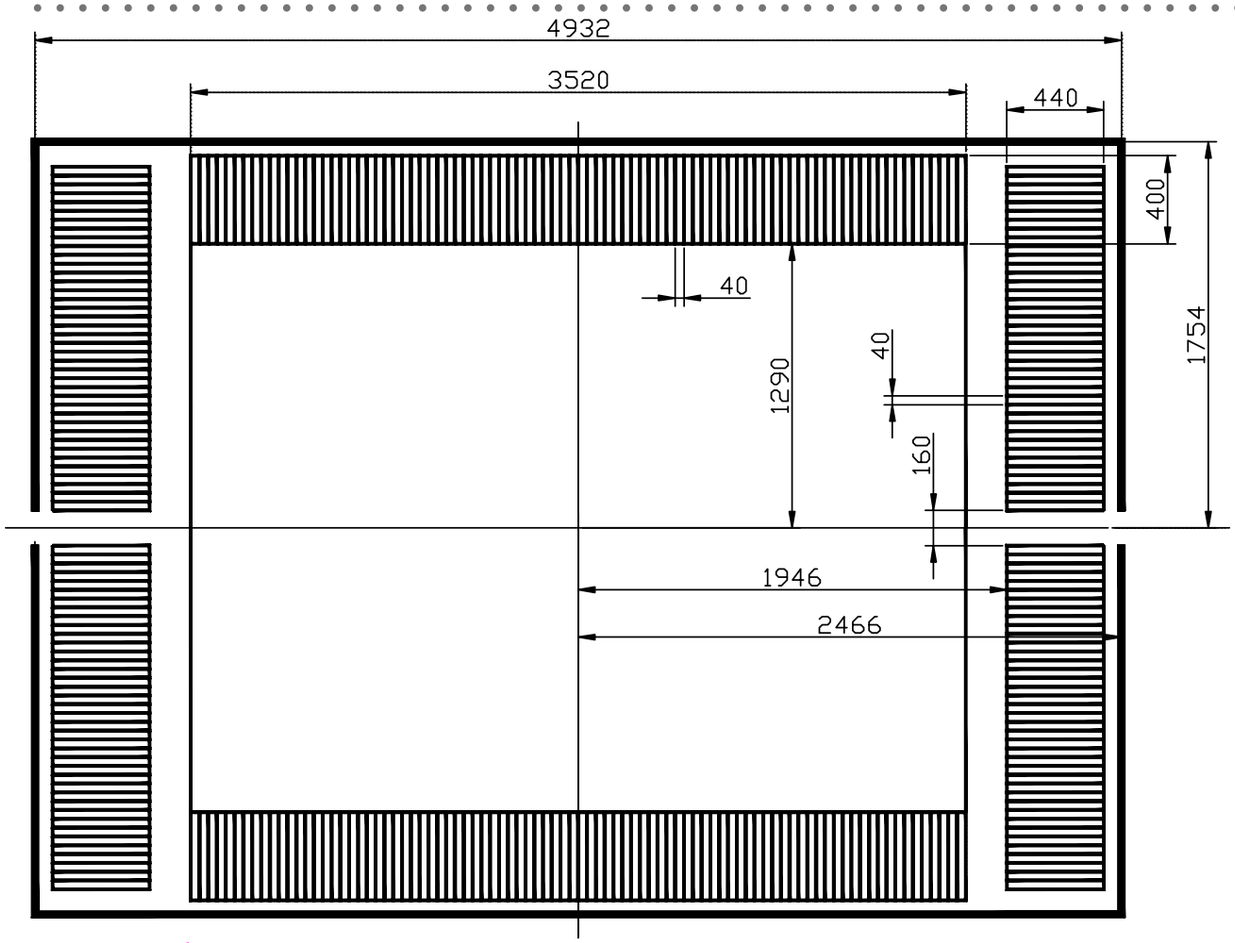
Goals:

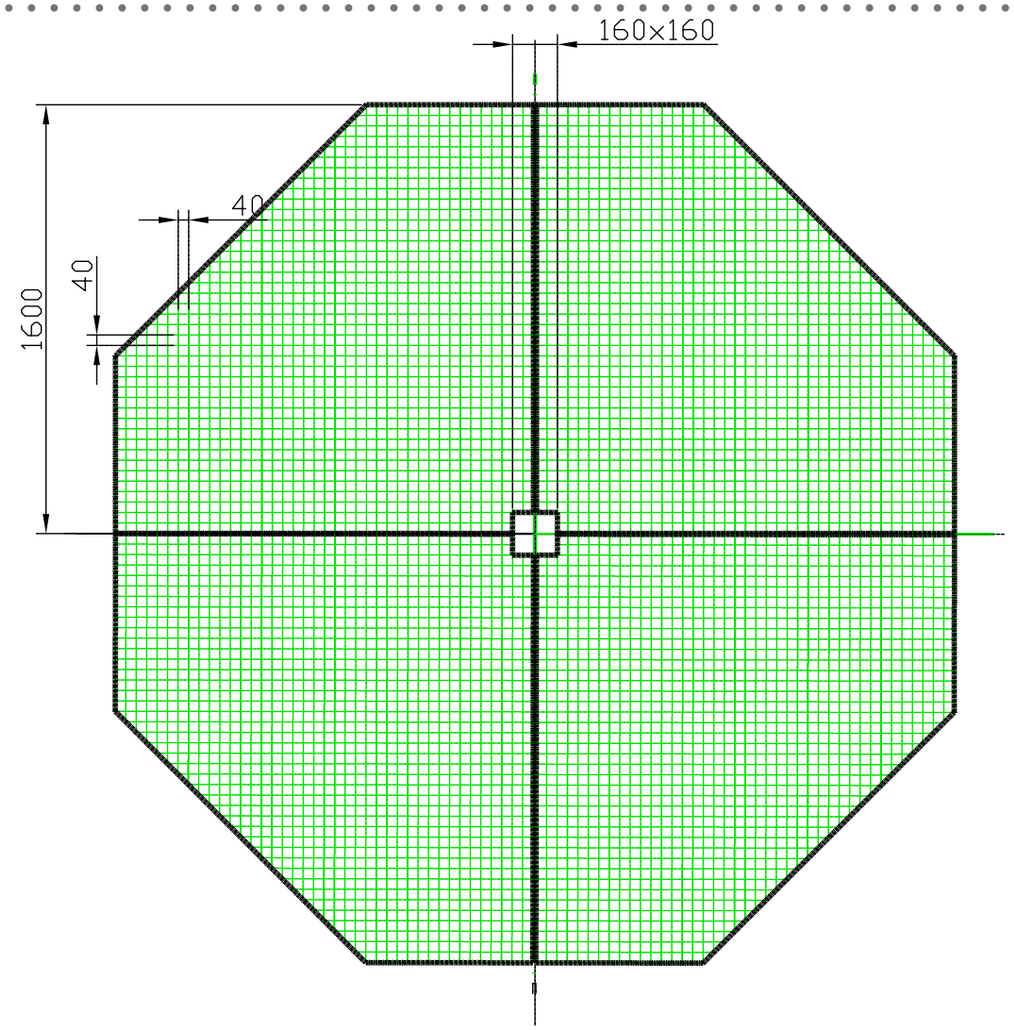
- *π/K separation up to 2.5 GeV range*

Requirements:

- *We should have enough light!*

ELECTROMAGNETIC CALORIMETER





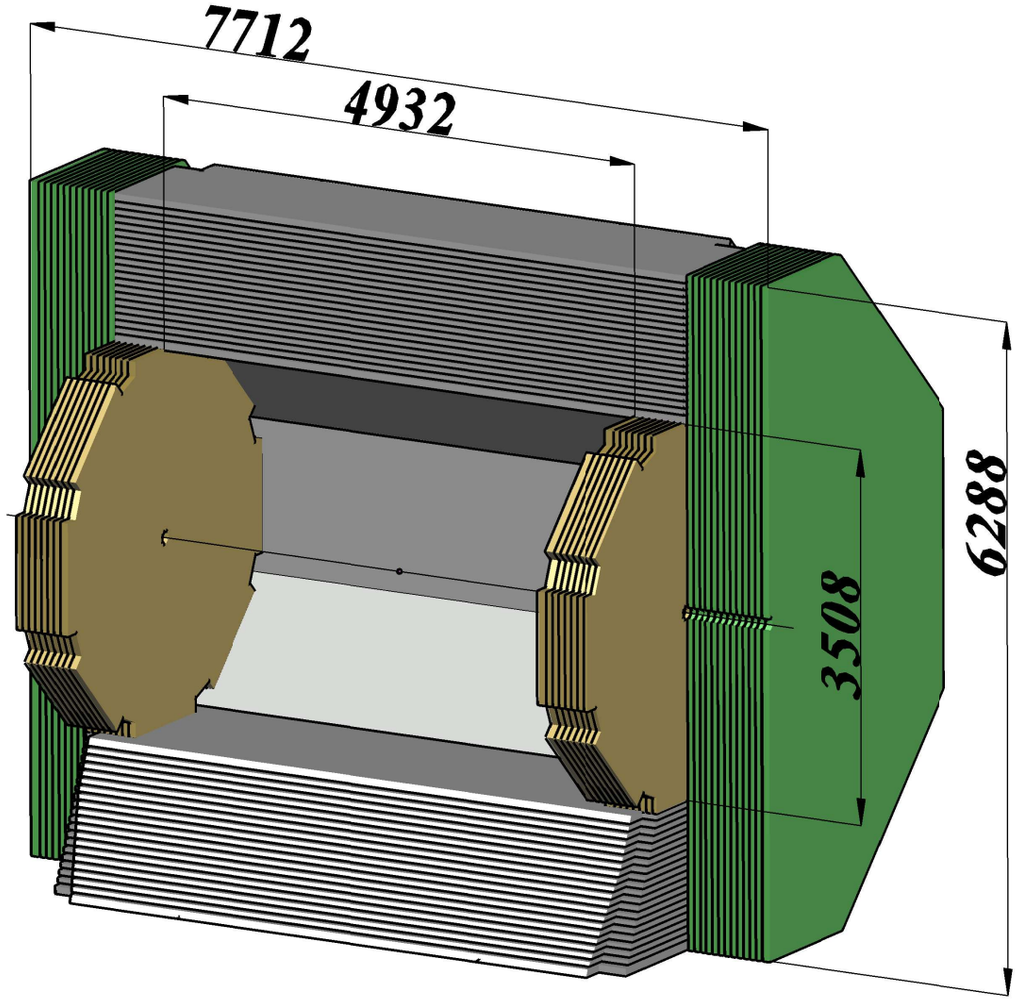
Goals:

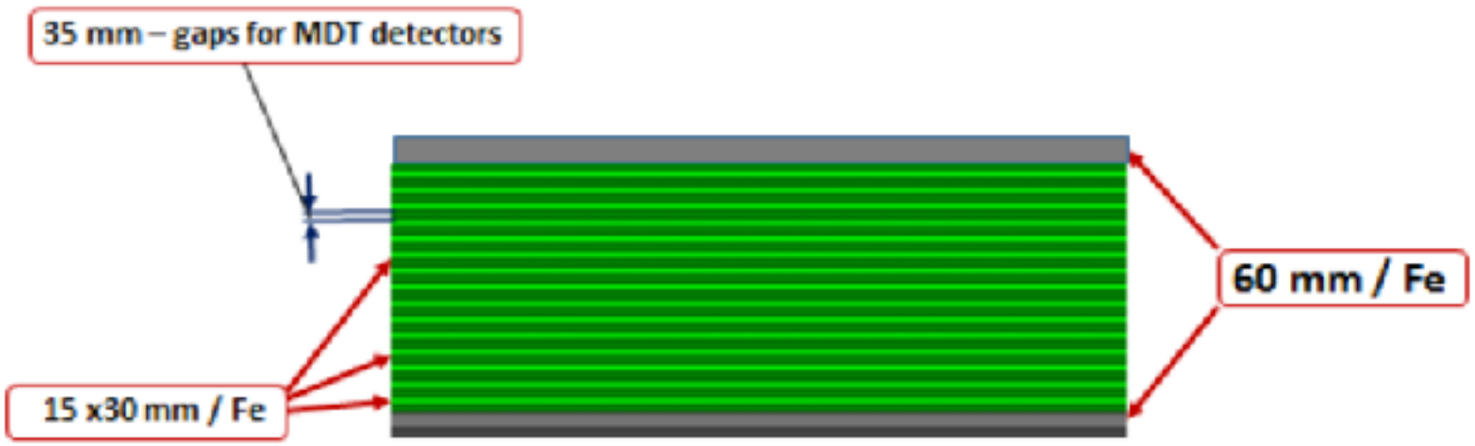
- *Detection of prompt photons, photons from π^0, η and χ_c decays*
- *Identification of electrons and positrons, participation in muon identification*

Requirements:

- *Granularity ~4 cm*
- *Low energy threshold (~50 MeV)*
- *Energy resolution* $\sim 5\,\%/\sqrt{E}$

RANGE (MUON) SYSTEM





Event examples at 5 GeV/c

Goals:

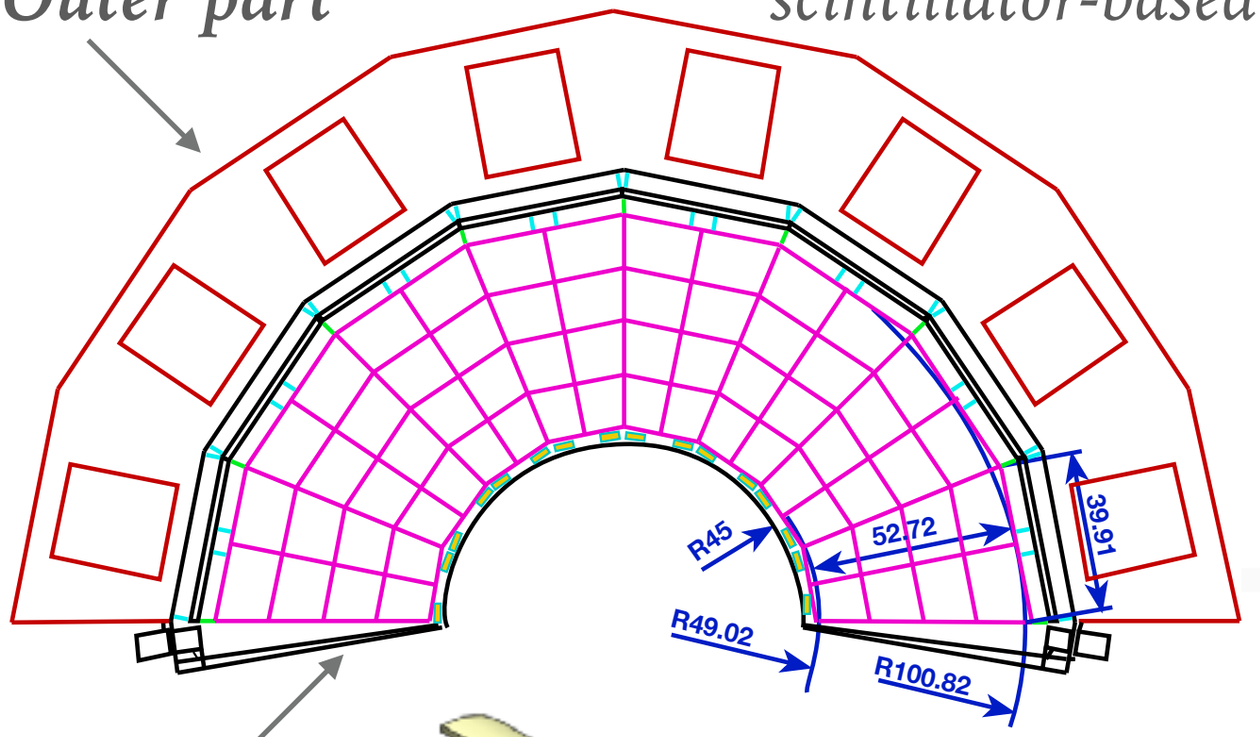
- *Muon identification*
- *Rough hadron calorimetry*

Requirements:

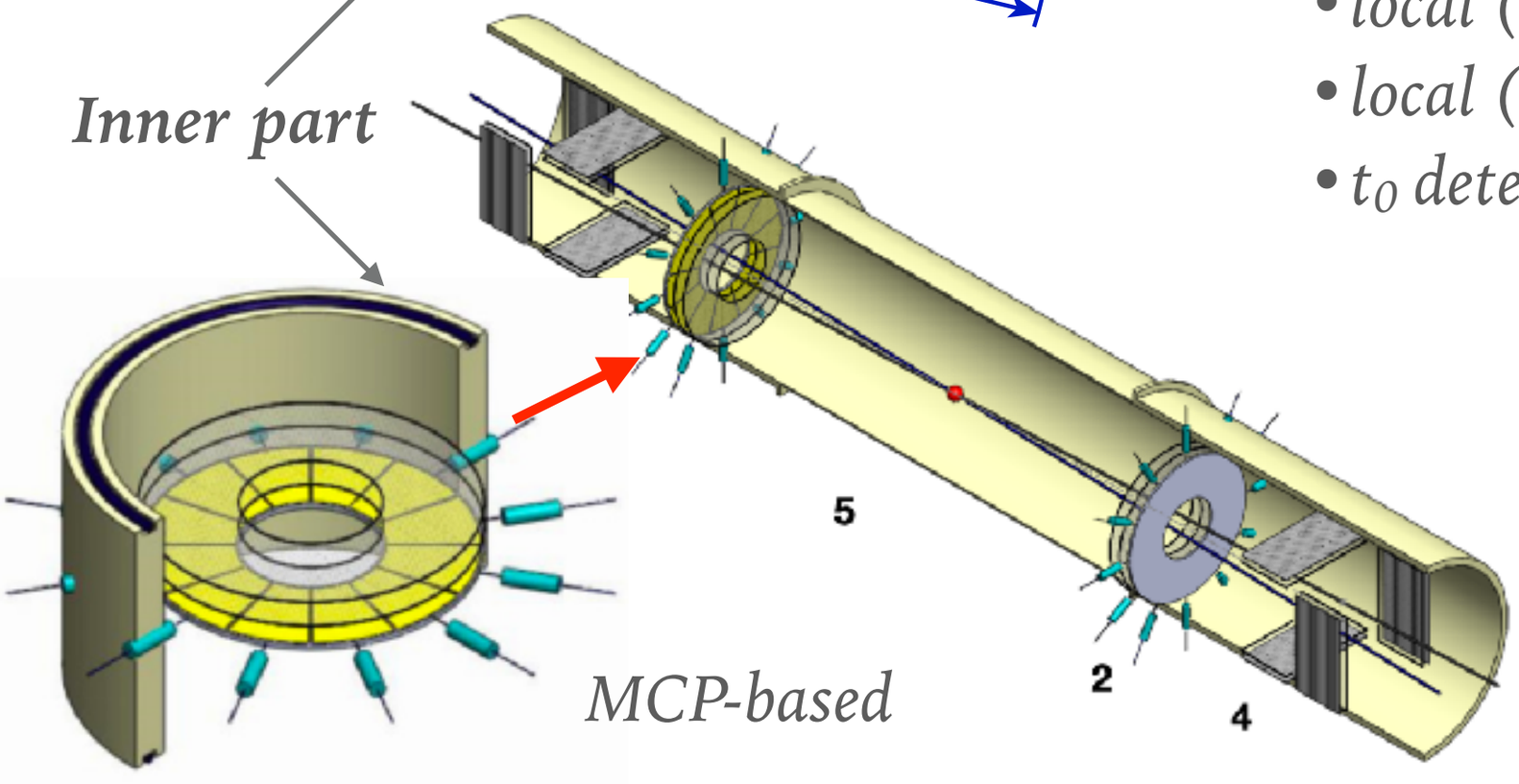
- *should have at least* $4\lambda_I$

BEAM–BEAM COUNTERS

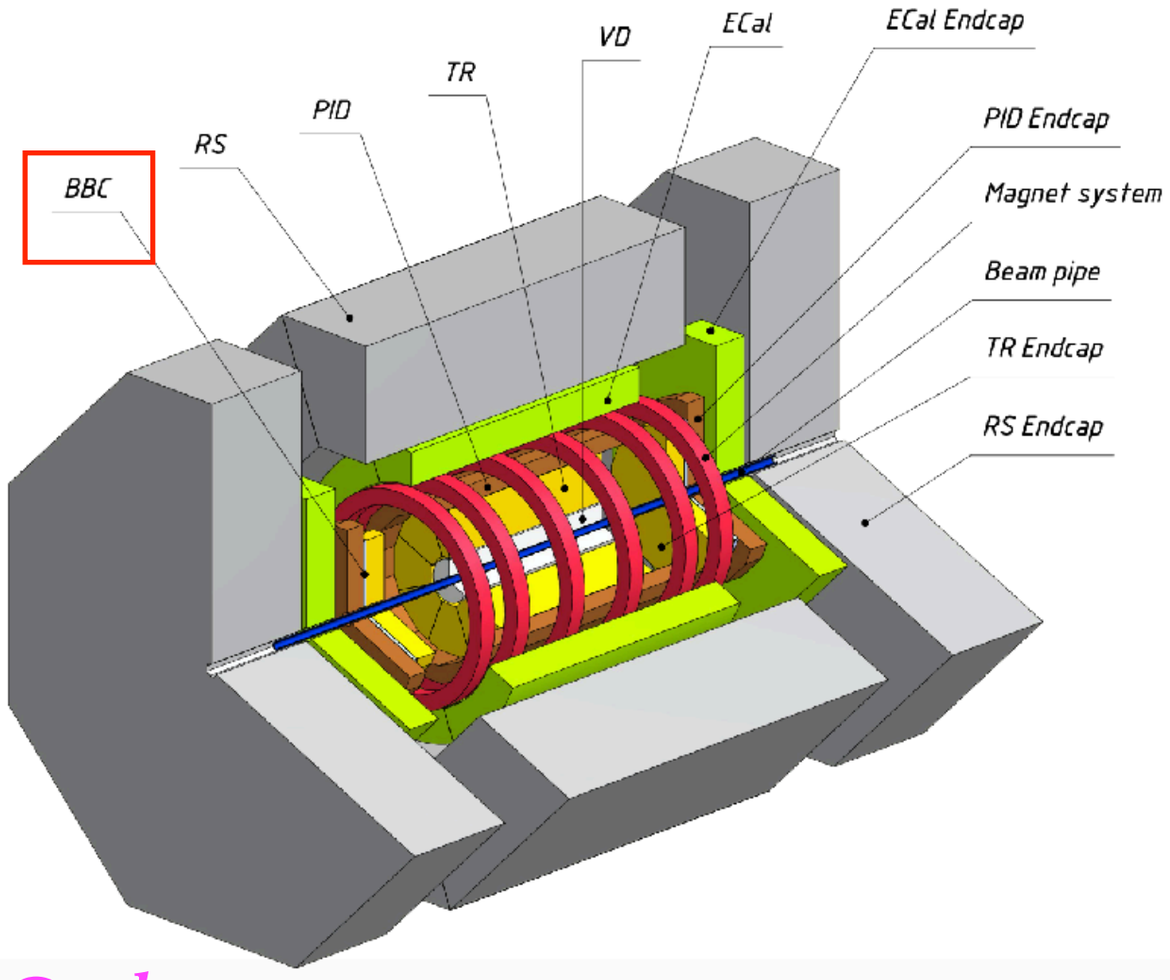
Outer part — *scintillator-based*



Inner part



MCP-based



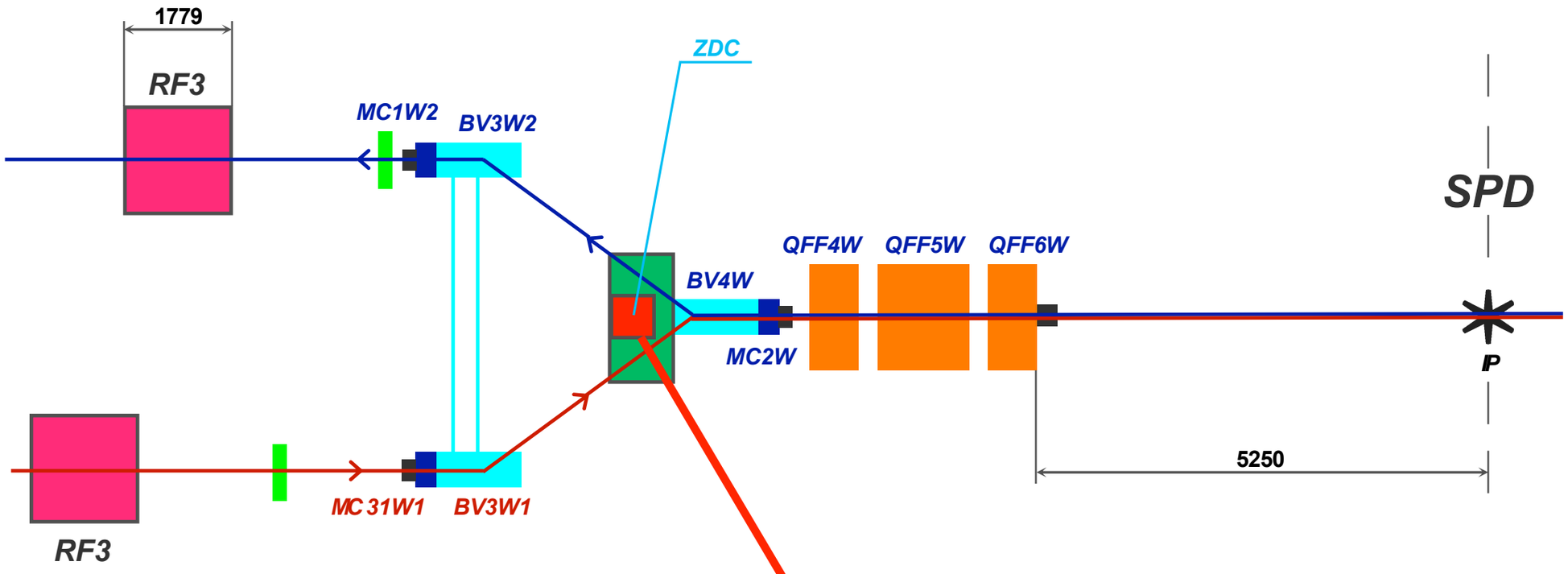
Goals:

- *local (online) polarimetry*
- *local (online) luminosity monitor*
- *t_0 determination*

Requirements:

- *Operation inside the beam pipe (inner part)*
- *Time resolution ~1 ns (inner) and ~400 ps (outer part)*

ZERO-DEGREE CALORIMETERS

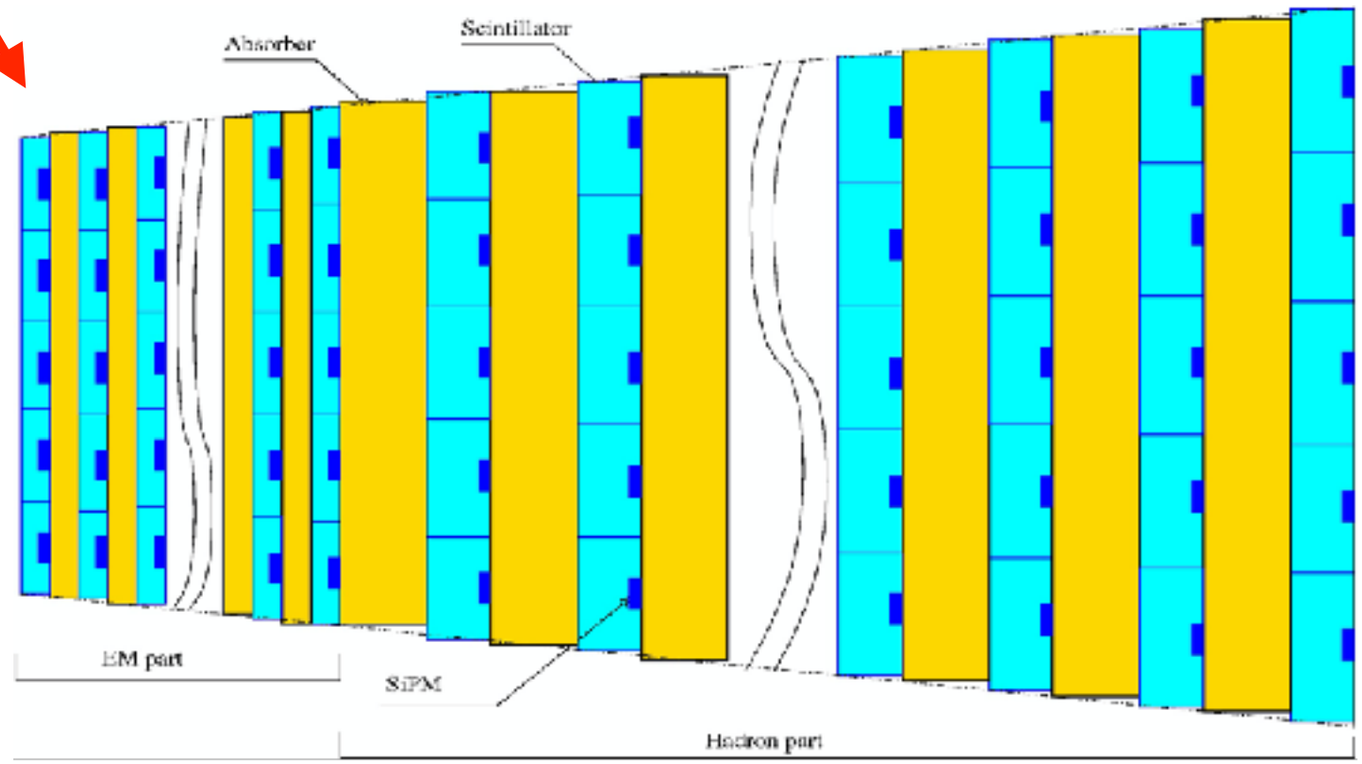


Goals:

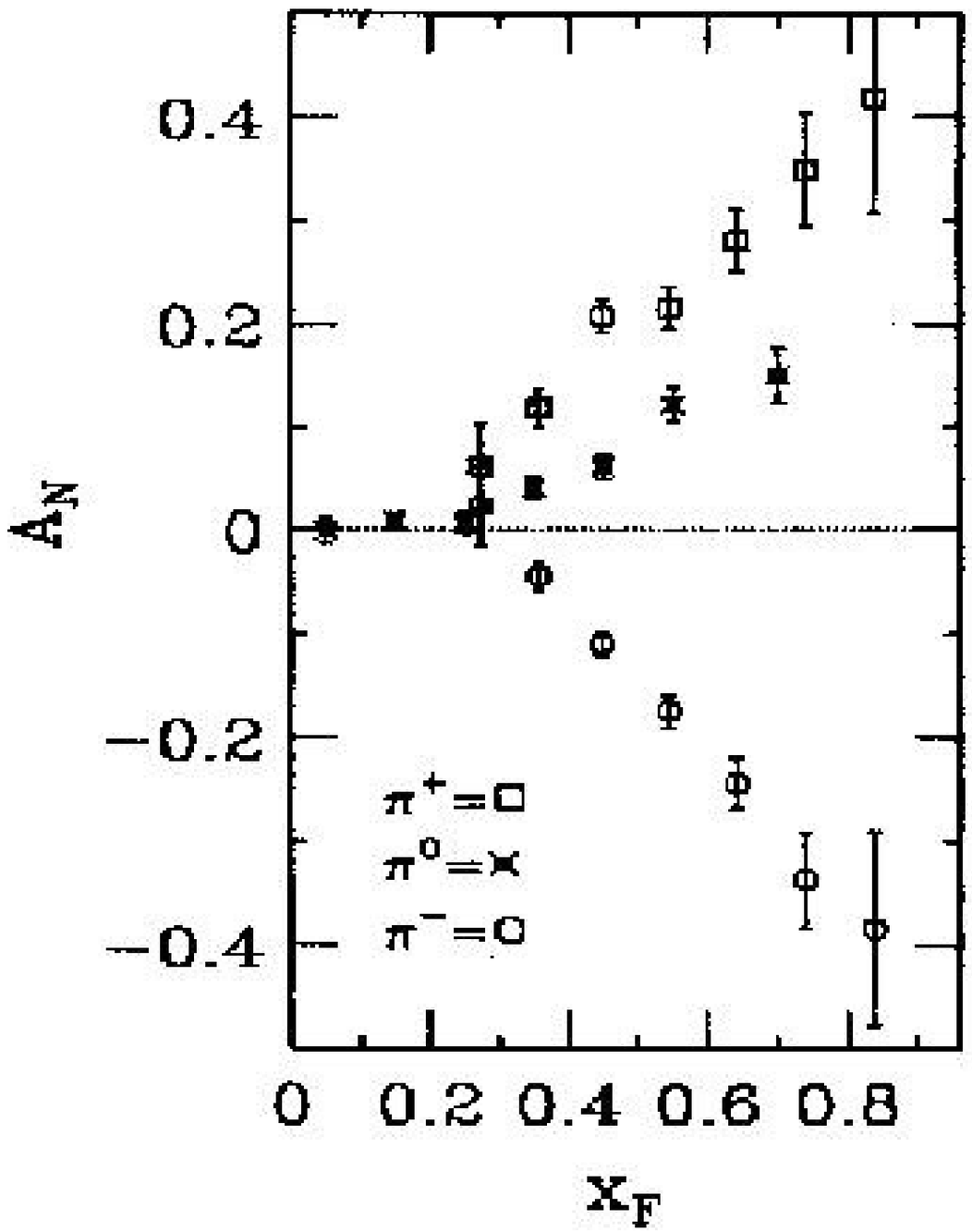
- *Luminosity monitor*
- *n/γ detection*

Requirements:

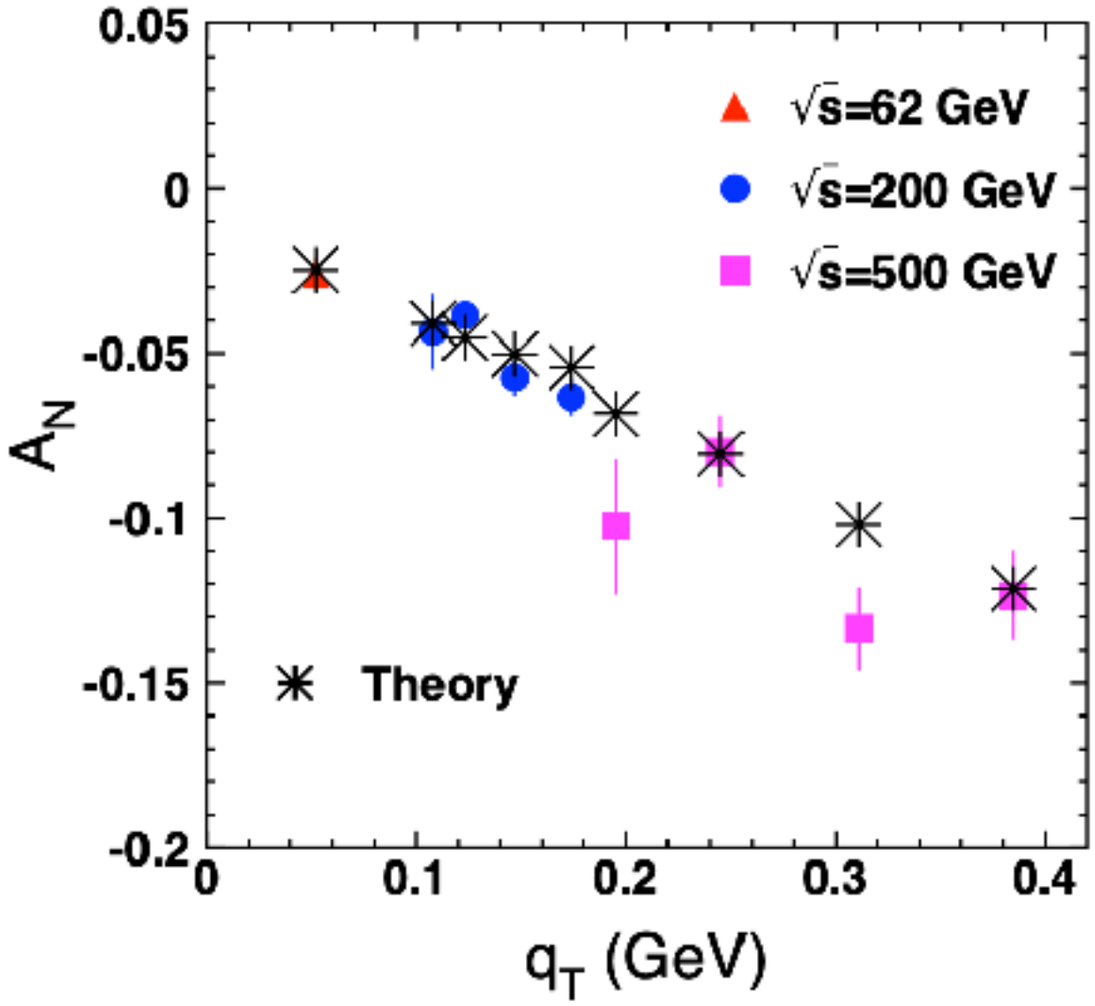
- *$13X_0$ for EM-part and $2.9\lambda_I$ for hadron part*
- *Energy resolution $50\,\%/\sqrt{E} \oplus 30\,\%$ for hadrons and $20\,\%/\sqrt{E} \oplus 9\,\%$ for γ*
- *Time resolution ~150 ps*



LOCAL ONLINE POLARIMETRY

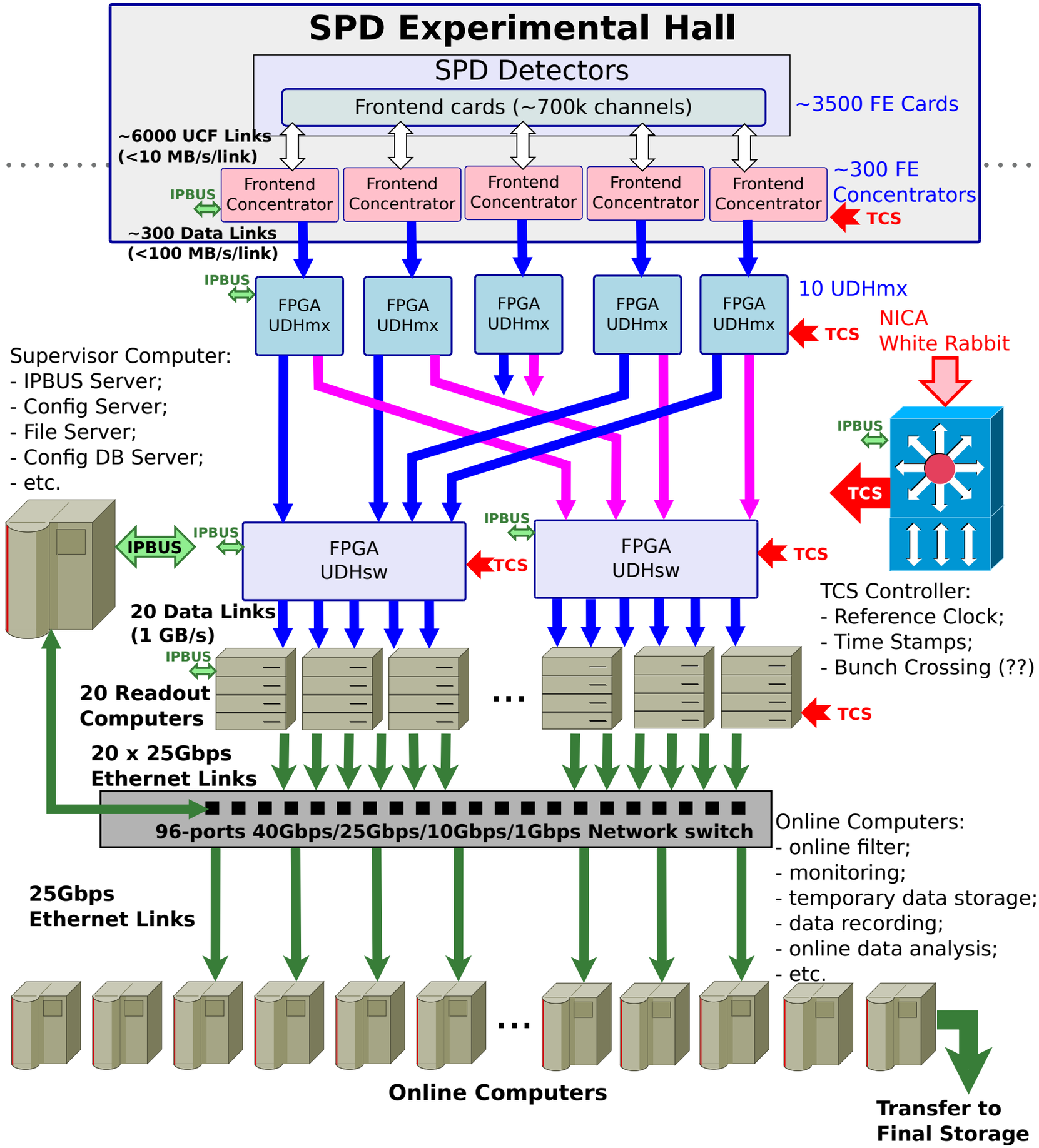


- *Charged particles in BBC*
- *π^0 in the end-cap part of ECAL*
- *Neutrons in ZDC*

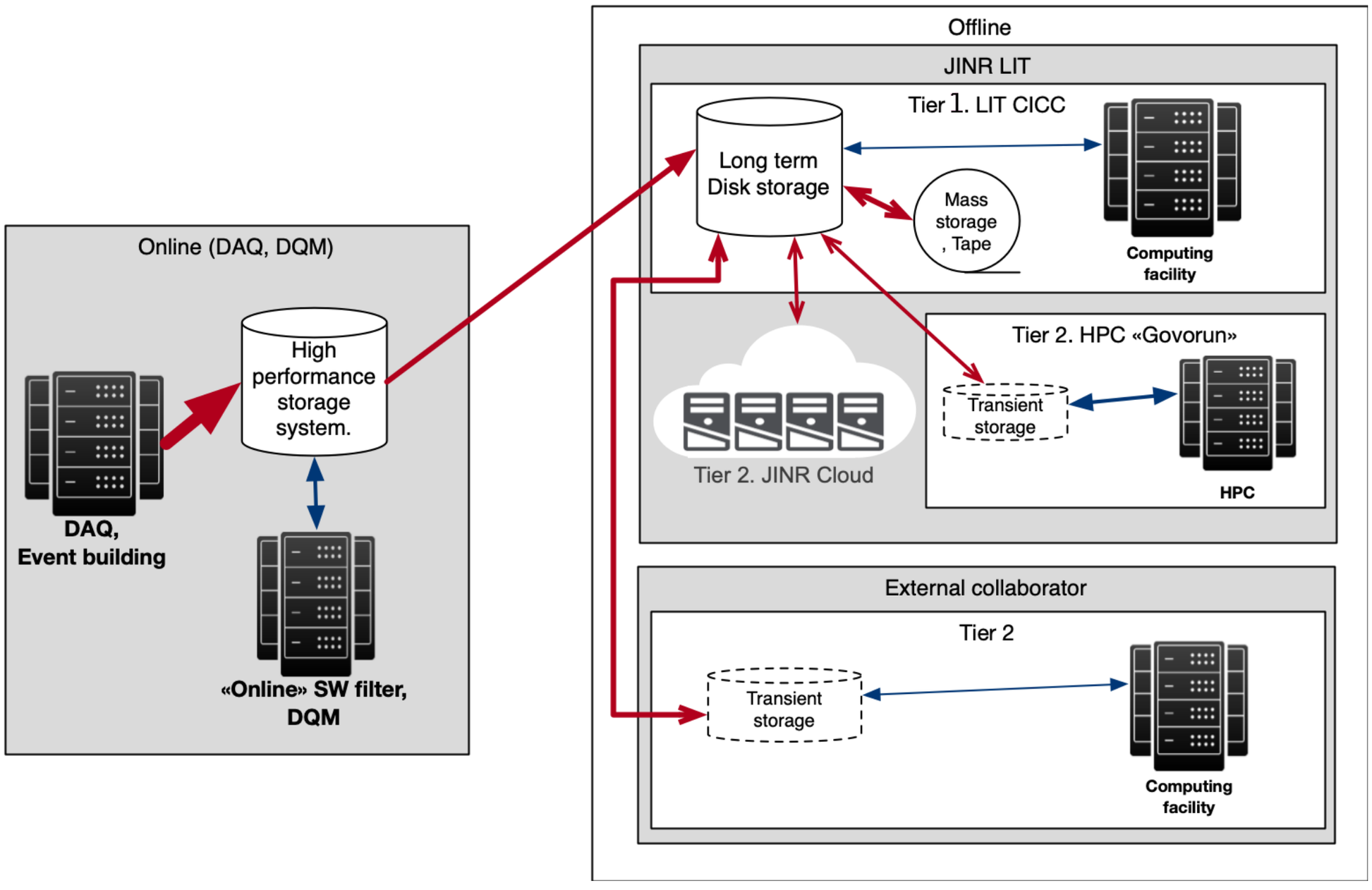


DAQ

No hardware triggers to avoid possible bias!

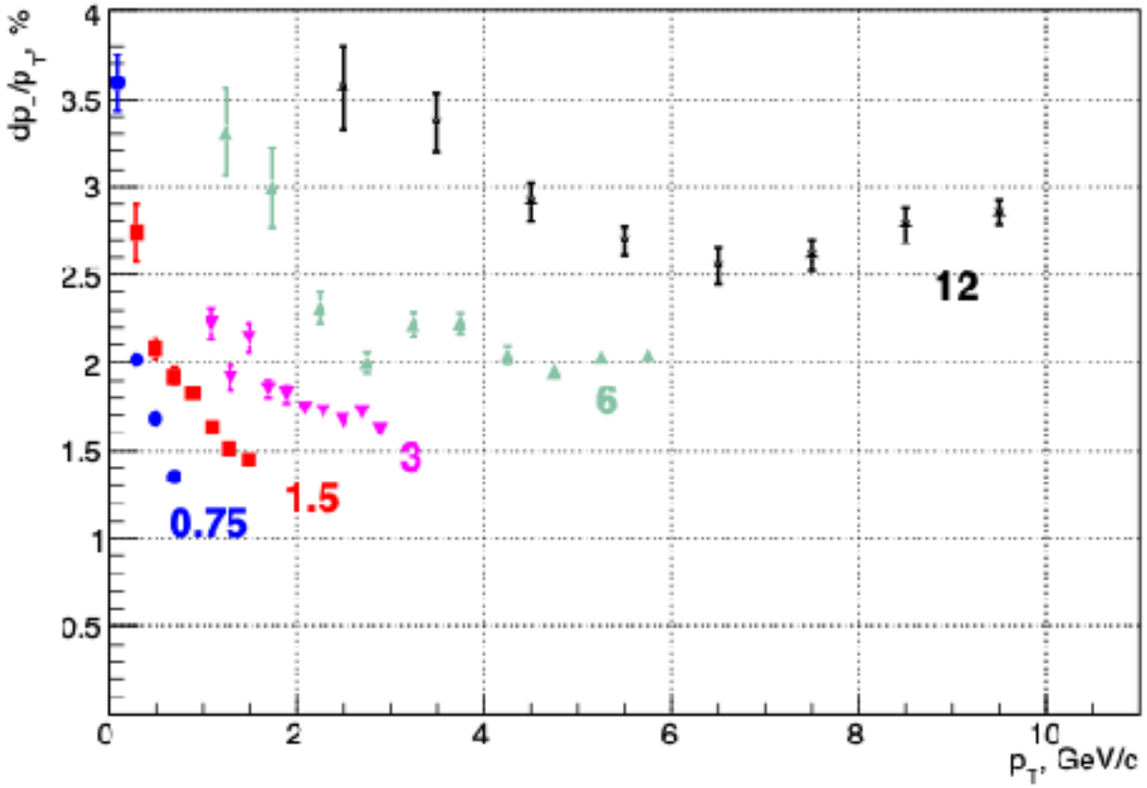


COMPUTING

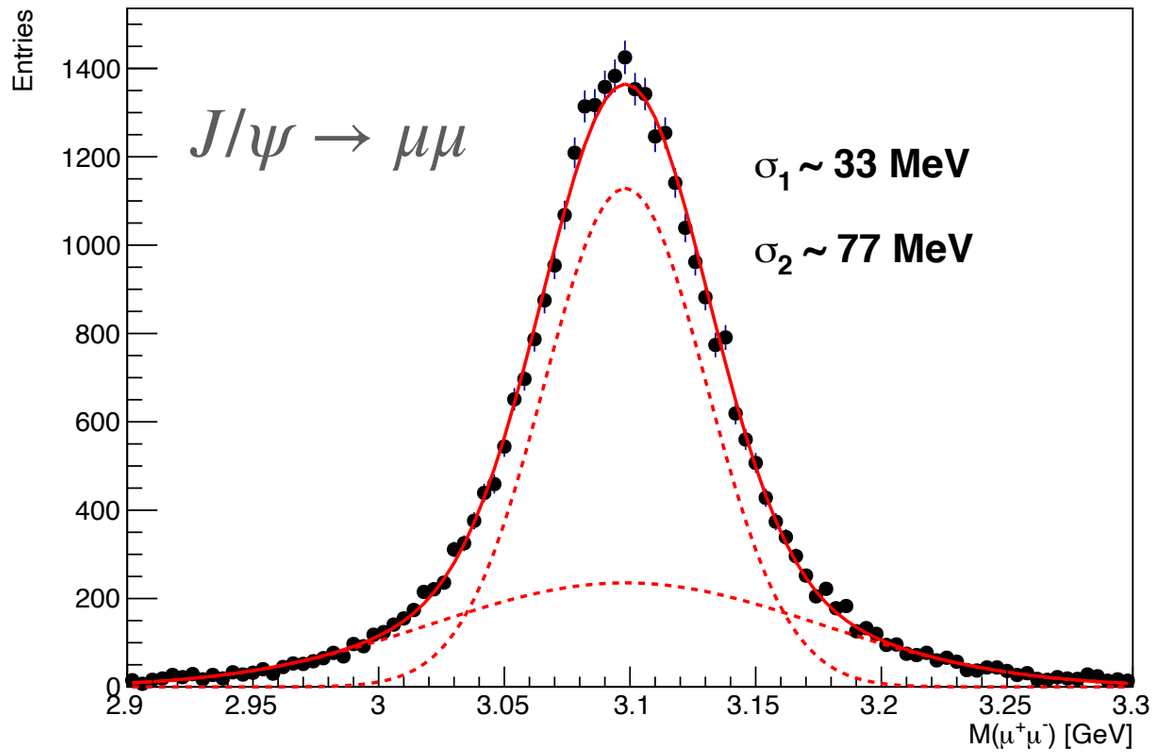


	CPU [cores]	Disk [PB]	Tape [PB]
Online filter	6000	2	none
Offline computing	30000	5	9 per year

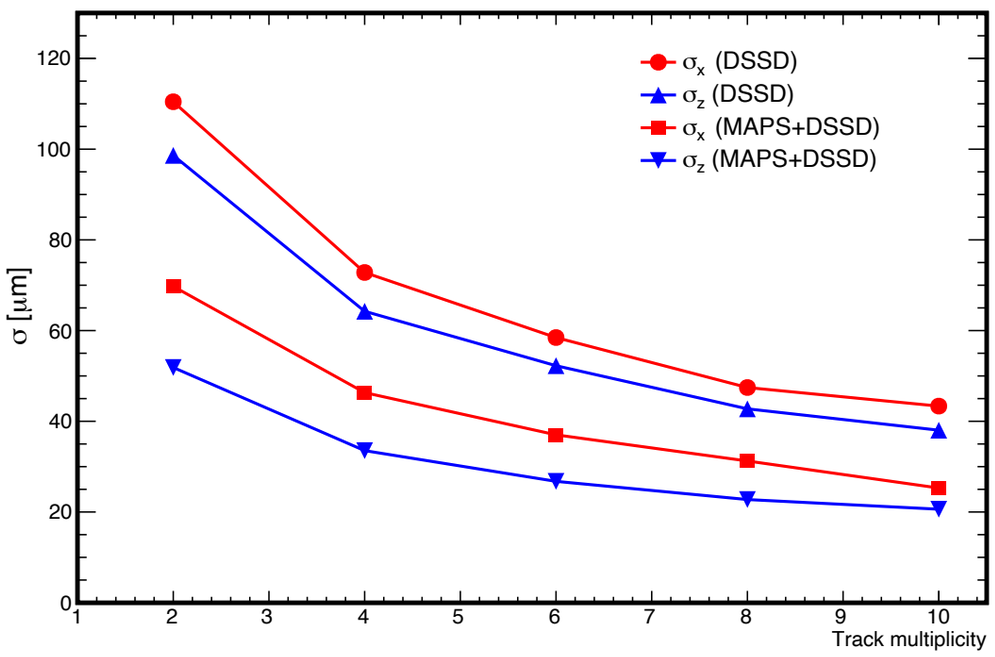
PHYSICS PERFORMANCE: TRACKING AND VERTEXING



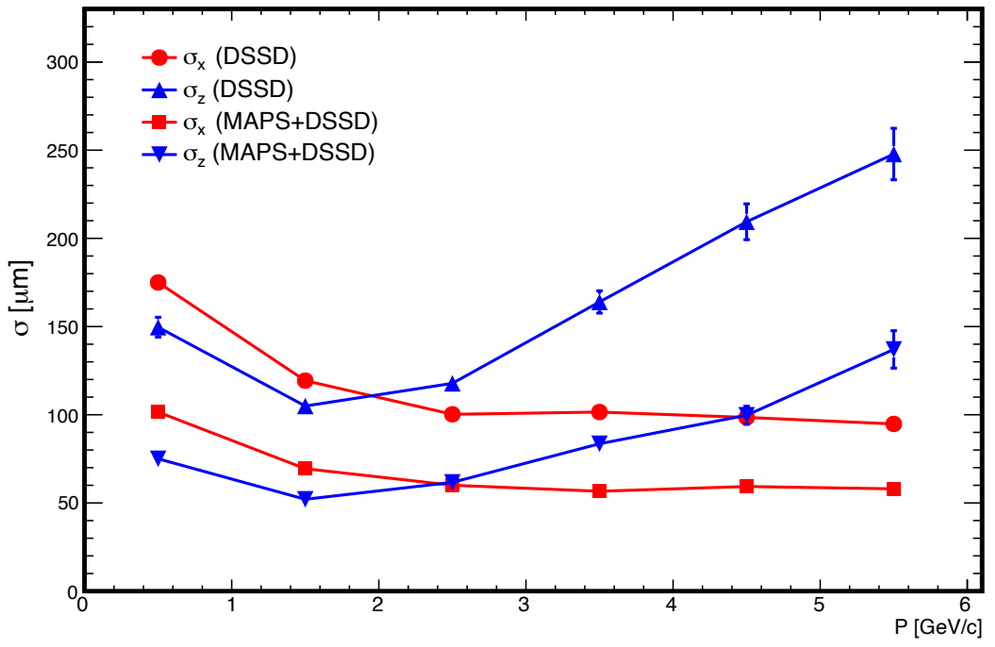
Dimuon mass spectrum fitted with the double Gaussian shape



Spatial resolution for primary vertices

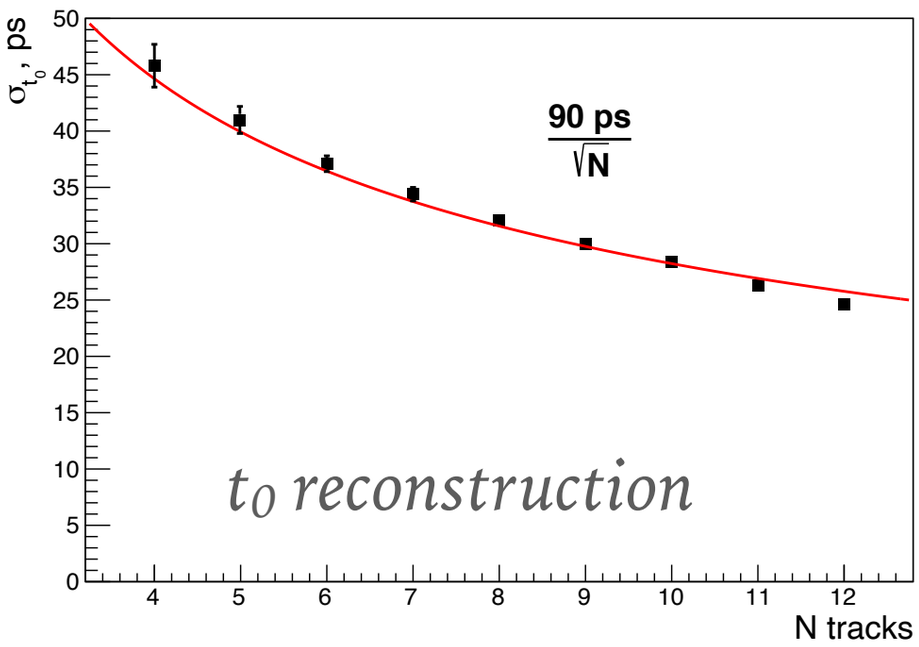


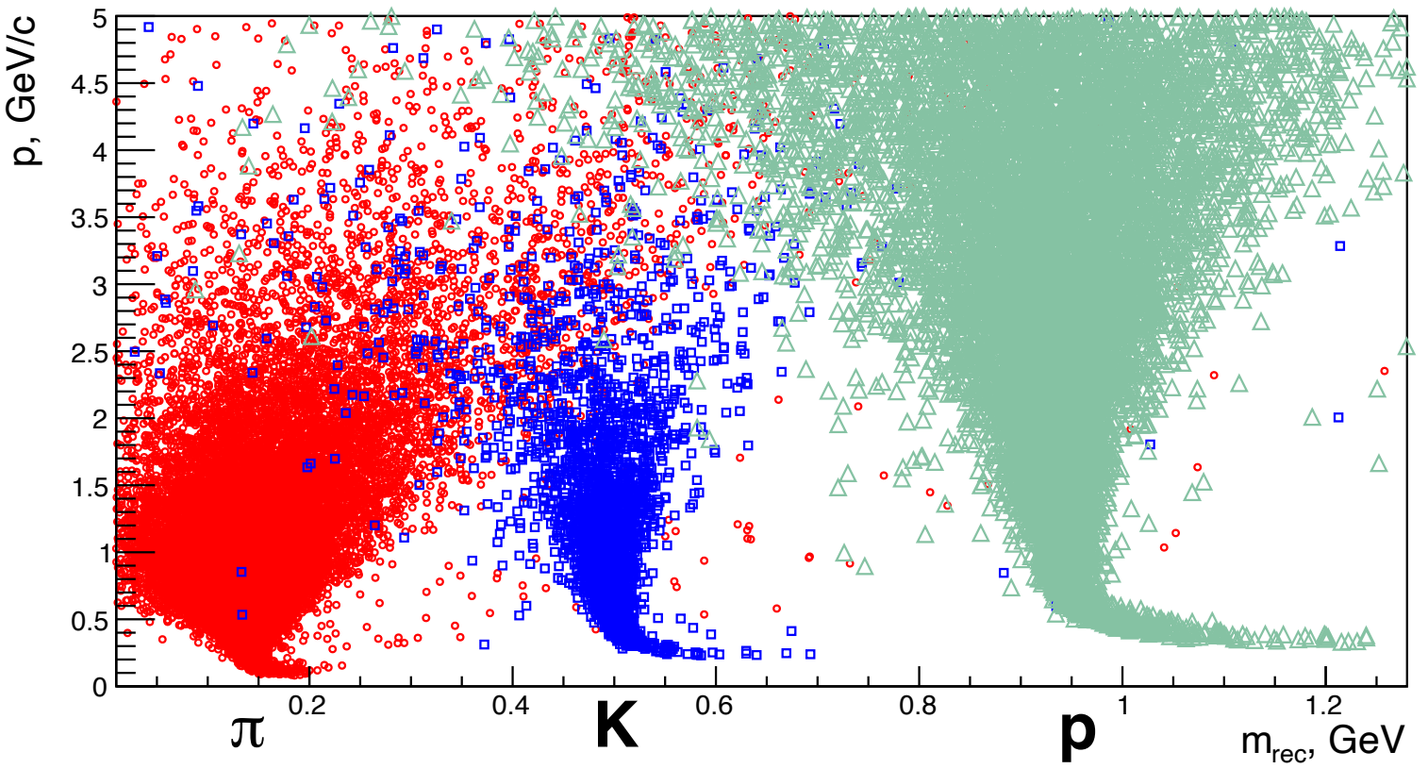
Spatial resolution for secondary D^0 decay vertices

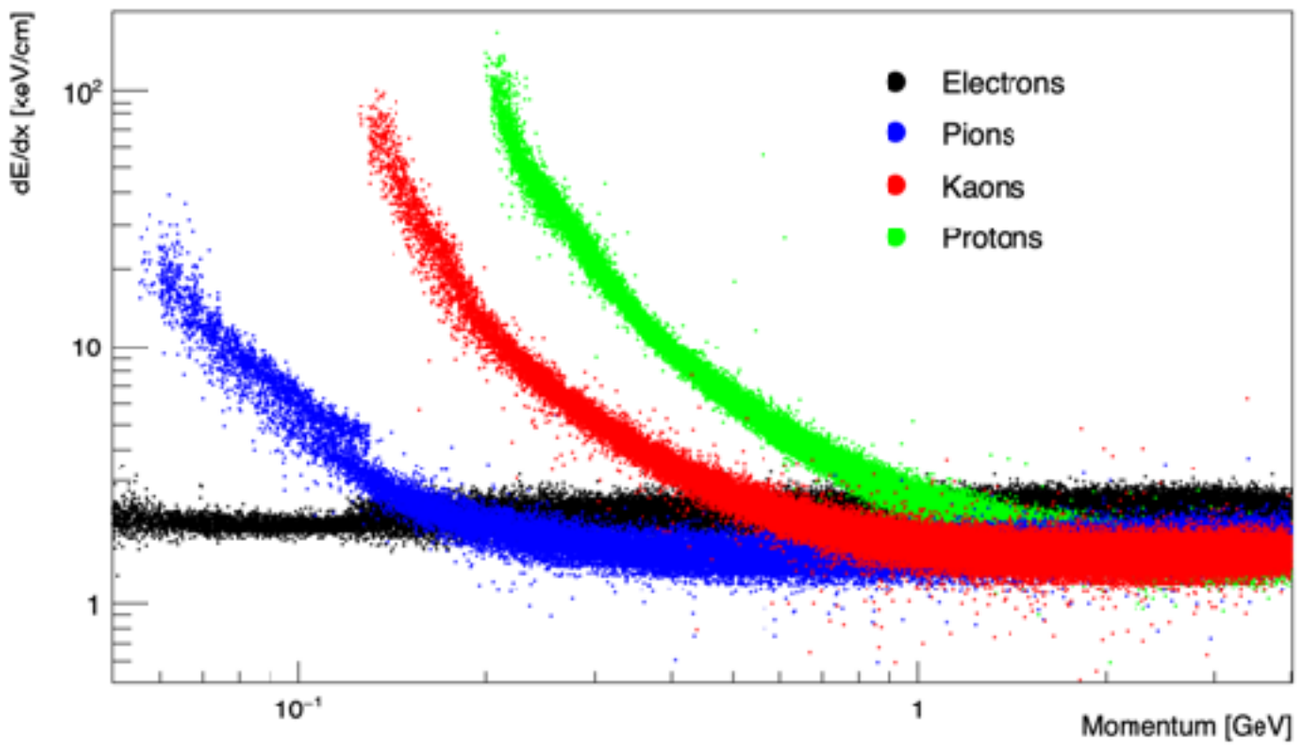


PHYSICS PERFORMANCE: PID

TOF (σ_T=70 ps)

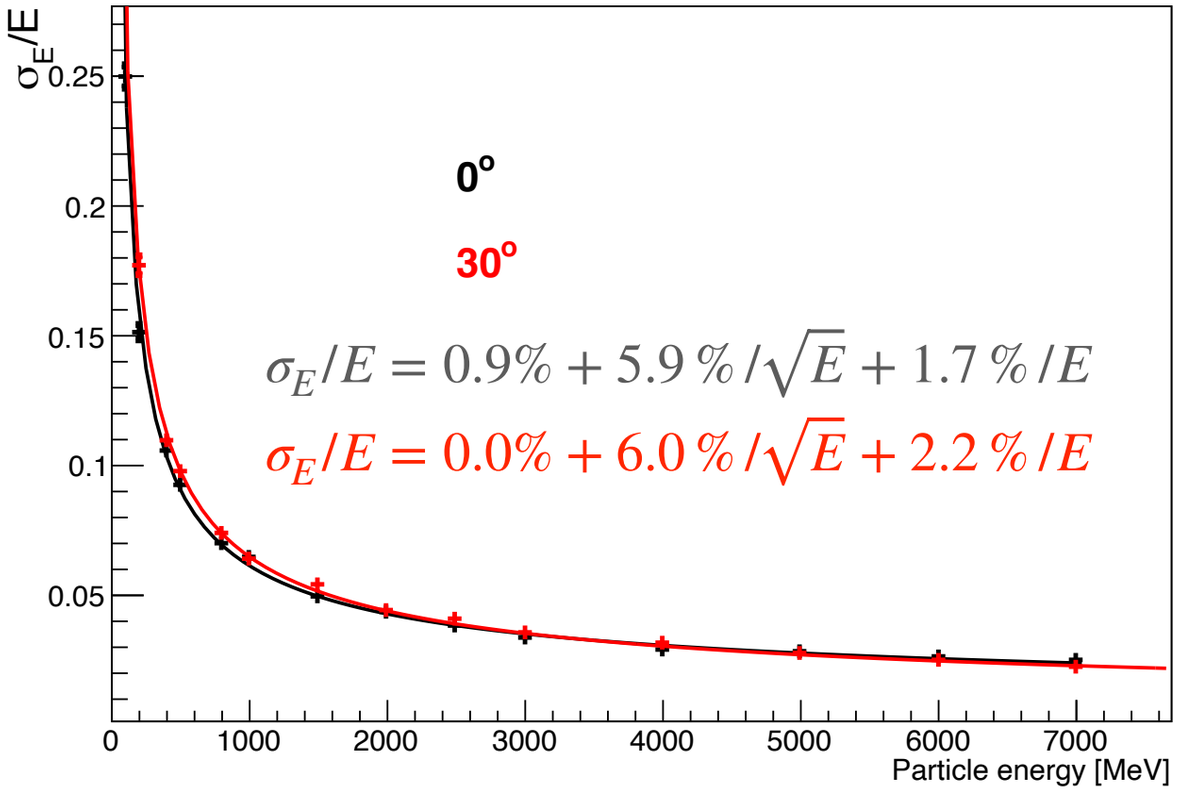


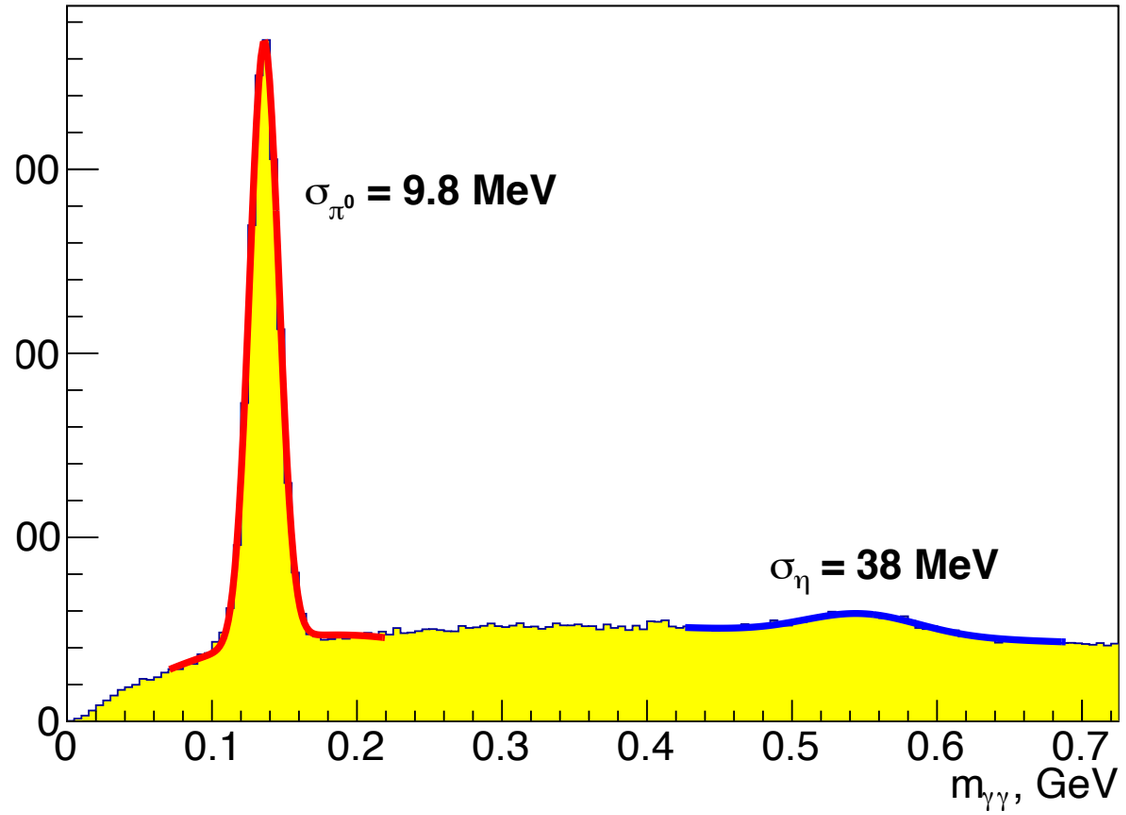


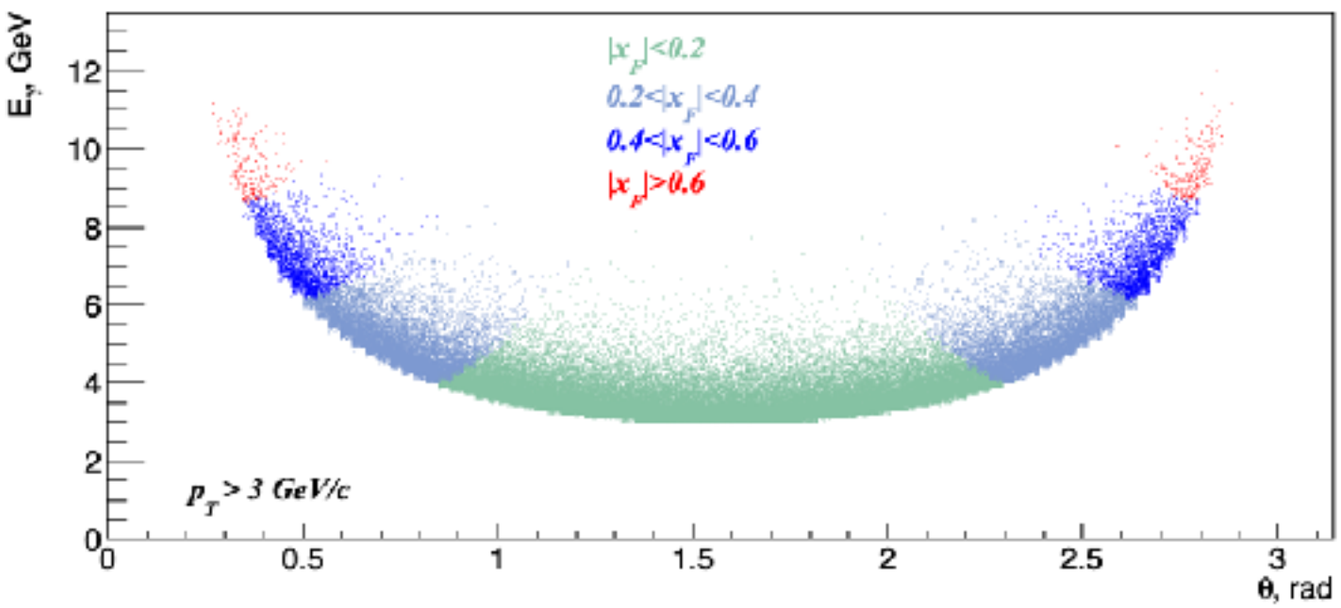


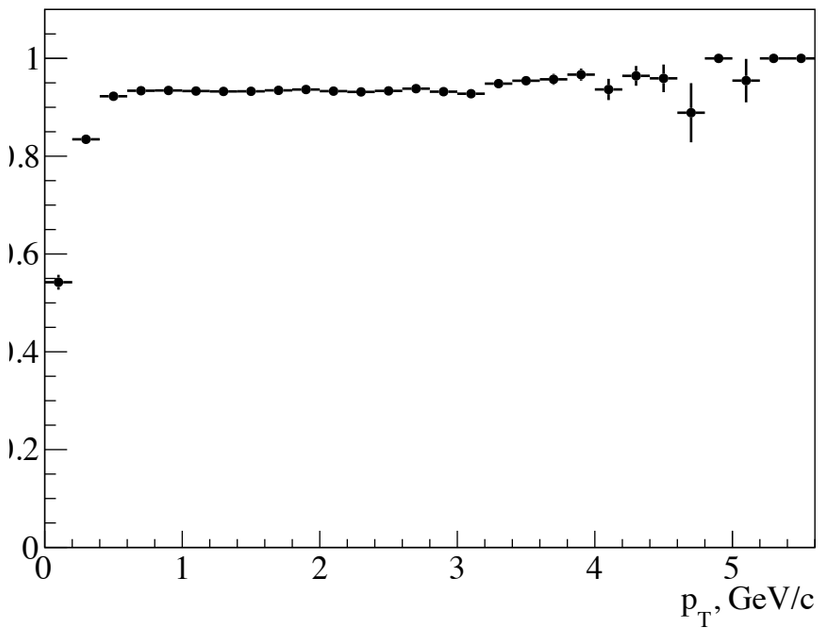
dE/dx in Straw Tracker (truncated average method)

PHYSICS PERFORMANCE: CALORIMETRY

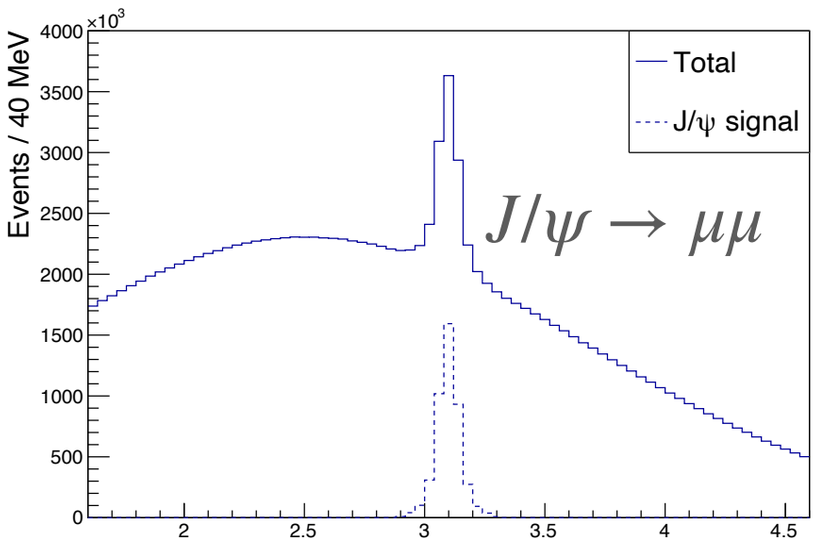


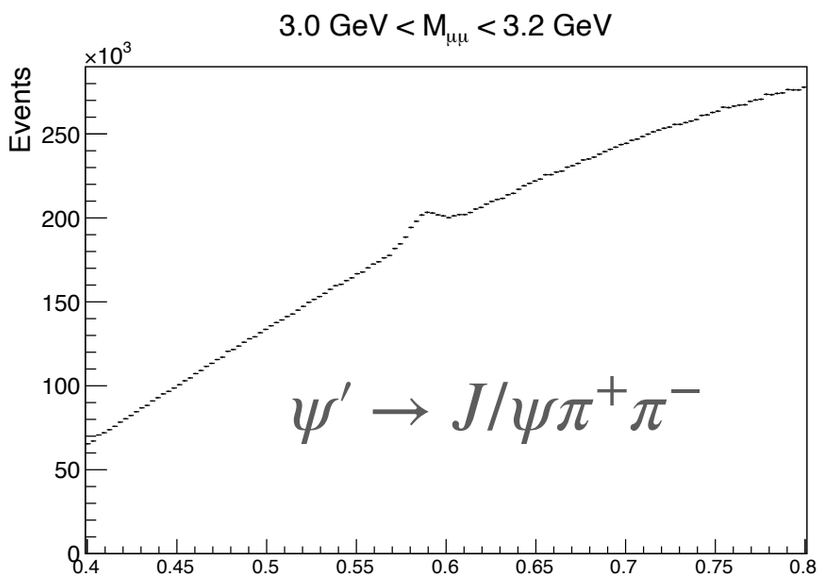


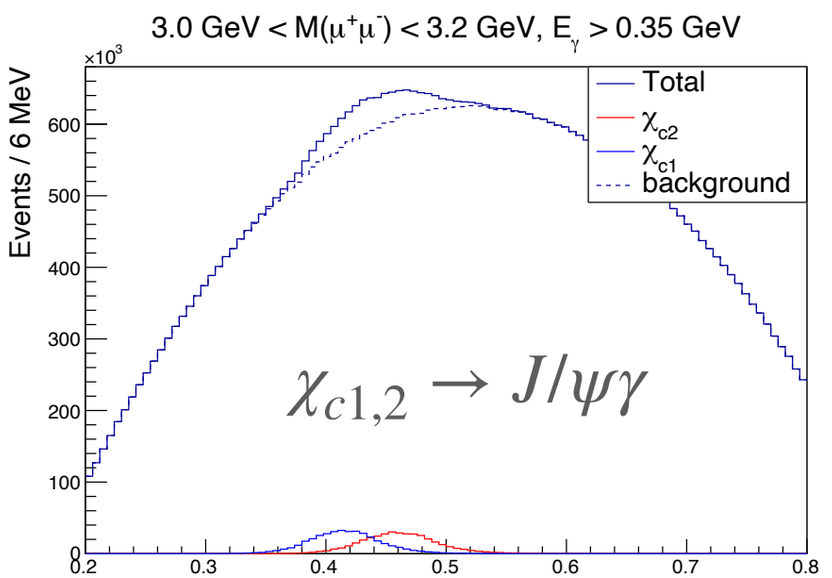


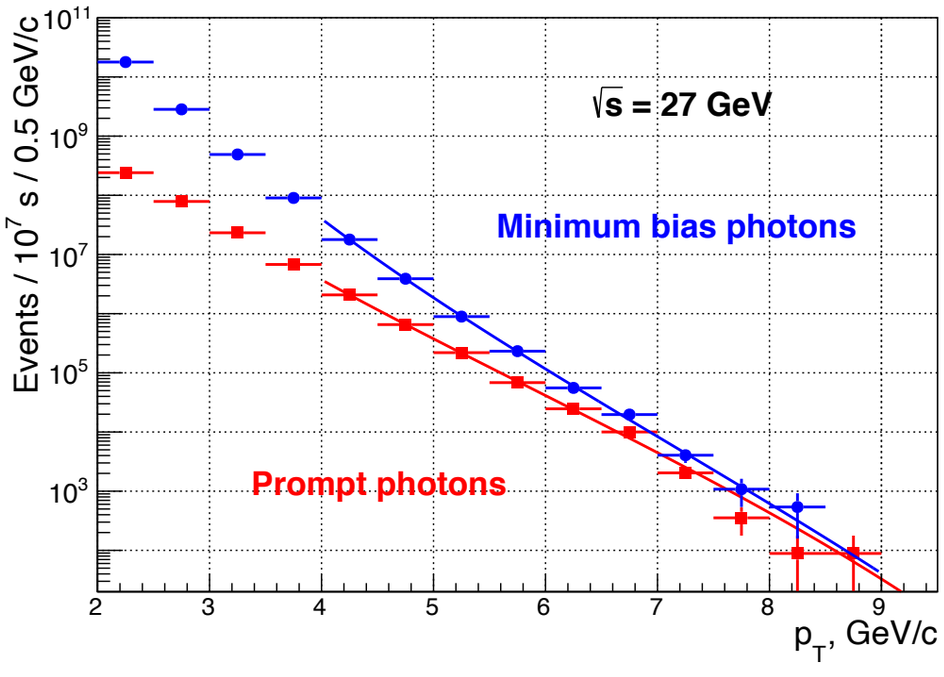


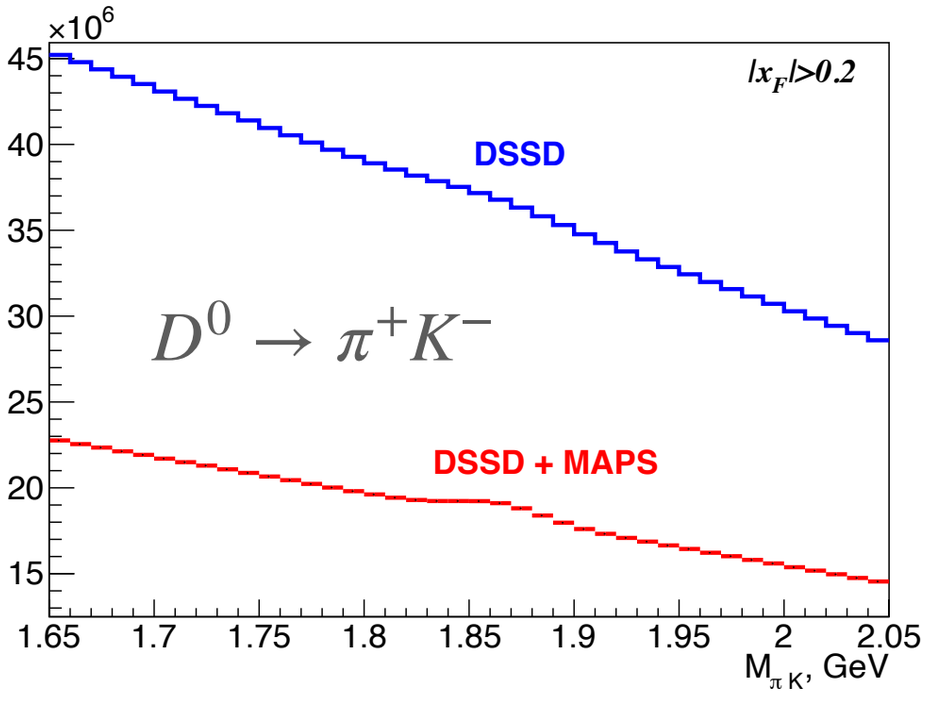
PHYSICS PERFORMANCE: GLUON PROBES



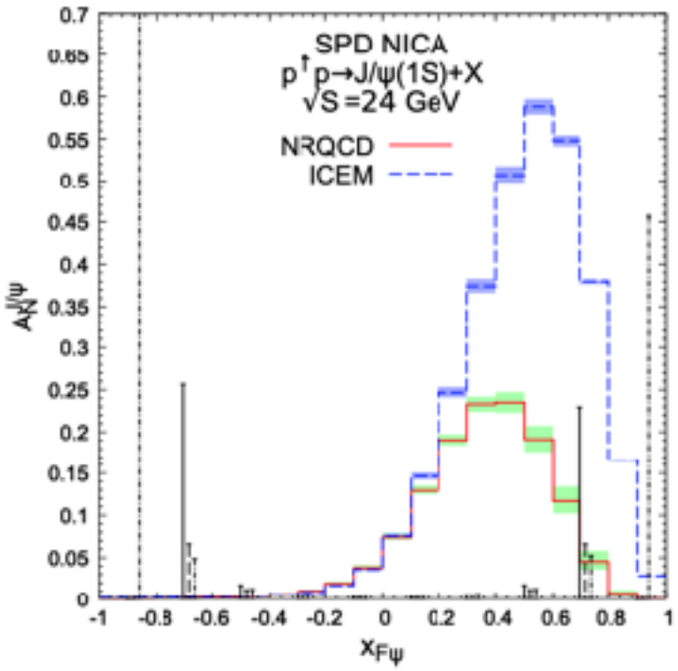




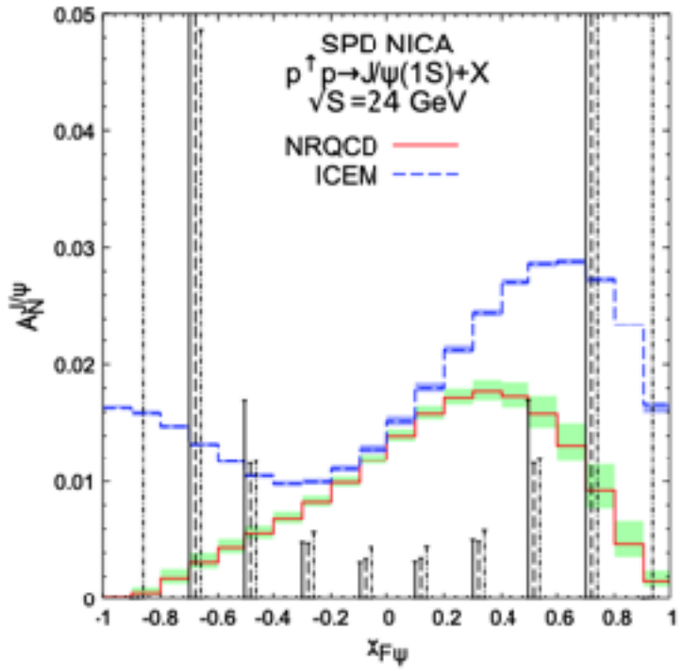


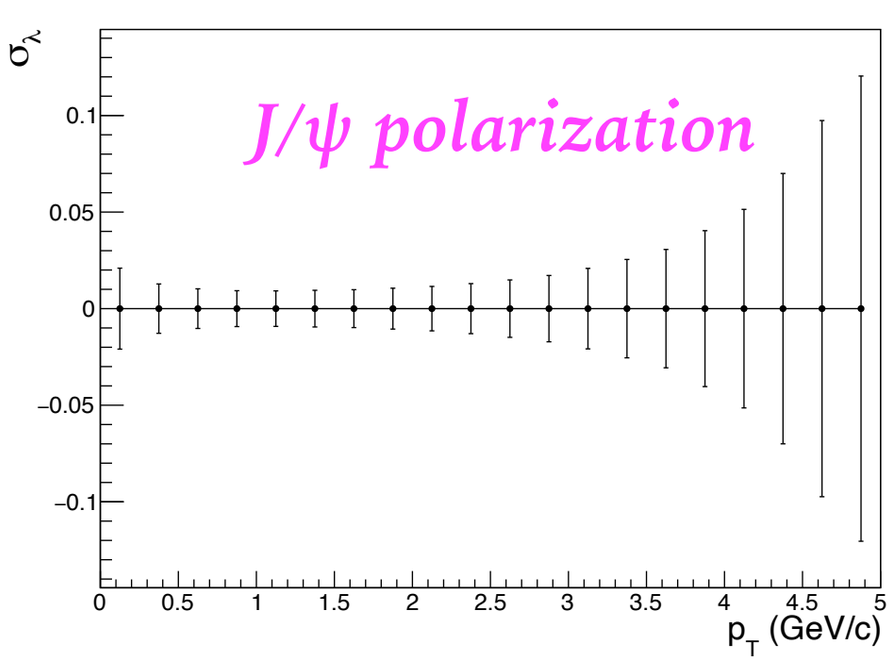


PHYSICS PERFORMANCE: ACCURACIES

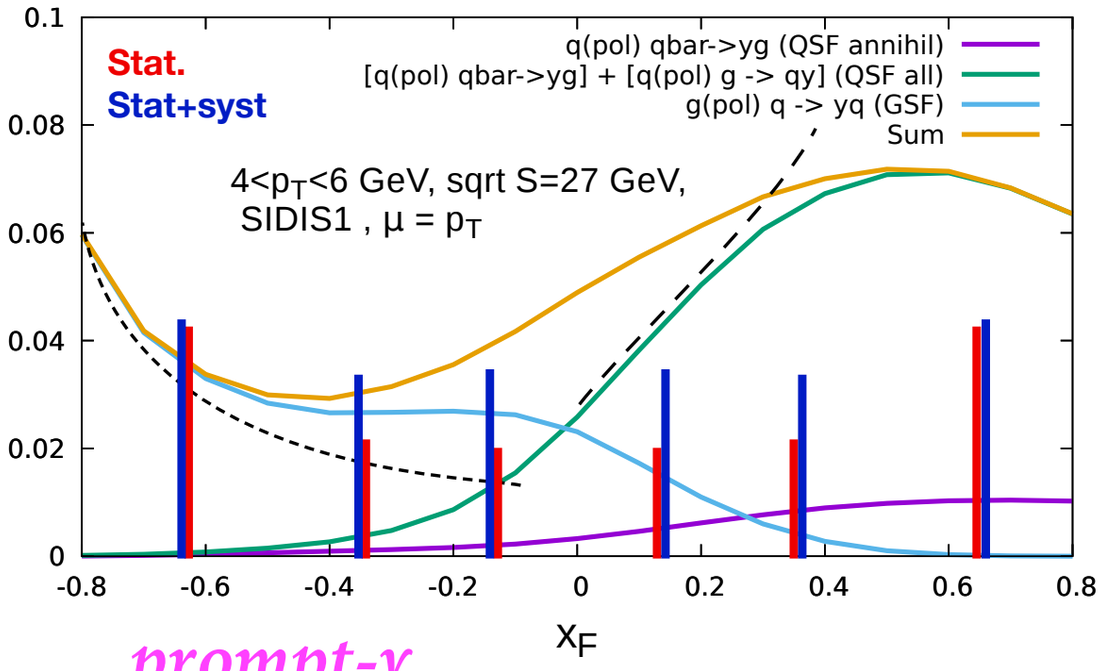


J/ψ

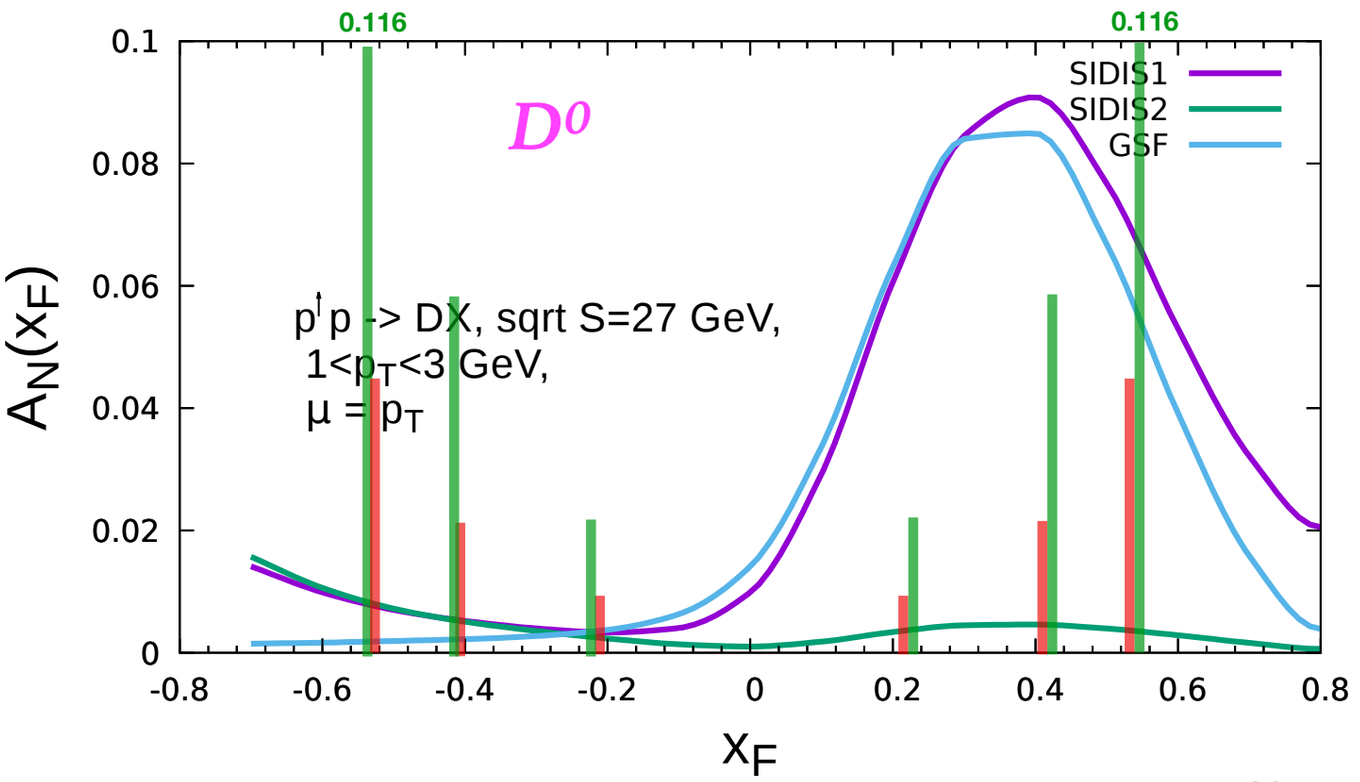




J/ψ polarization



prompt-γ



TENTATIVE RUNNING PLAN

Physics goal	Required time	Experimental conditions
First stage		
Spin effects in p-p scattering dibaryon resonanses	0.3 year	$p_{L,T}$-$p_{L,T}$, $\sqrt{s}$ <7.5 GeV
Spin effects in p-d scattering, non-nucleonic structure of deuteron, $\bar{p}$ yield	0.3 year	d_{tensor}-p, $\sqrt{s}$ <7.5 GeV
Spin effects in d-d scattering hypernuclei	0.3 year	d_{tensor}-d_{tensor}, $\sqrt{s}$ <7.5 GeV
Hyperon polarization, SRC, ... multiquarks	together with MPD	ions up to Ca
Second stage		
Gluon TMDs, SSA for light hadrons	1 year	p_T-p_T, $\sqrt{s}$ =27 GeV
TMD-factorization test, SSA, charm production near threshold, onset of deconfinment, $\bar{p}$ yield	1 year	p_T-p_T, 7 GeV< $\sqrt{s}$ <27 GeV (scan)
Gluon helicity, ...	1 year	p_L-p_L, $\sqrt{s}$ =27 GeV
Gluon transversity, non-nucleonic structure of deuteron, "Tensor porlarized" PDFs	1 year	d_{tensor}-d_{tensor}, $\sqrt{s_{NN}} = 13.5$ GeV or/and? d_{tensor}-p_T, $\sqrt{s_{NN}} = 19$ GeV

≥ 5 years of data taking

COST ESTIMATION

	Subsystem	Option	Cost, M$
SPD setup	Vertex detector: – DSSD – DSSD+MAPS	 VD1 VD2	 9.4+6.5 (FE) 9.4+7.0 (FE)
	Straw tracker		2.4
	PID system: – RPC-based TOF – Scintillator-based TOF – Aerogel PID system	 PID1 PID2 PID3	 5 4 5
	Electromagnetic calorimeter		21.1
	Range system		14.2
	ZDC		2
	BBC		0.4
	Magnetic system		10
	Beam pipe		2
General infrastructure			5
Slow control system			0.8
Data acquisition system			1.6
Computing			10
TOTAL COST	VD2+PID2+PID3		94.9

+4.5 per year

SUMMARY

- We plan 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** (up to 10^{32} $cm^{-2}s^{-1}$) and **d-d** collisions at $\sqrt{s} \leq 27\ GeV$. The wide physics program is also prepared for the first period of running with reduced energy and luminosity.
- Complementing main probes such as **charmonia** (J/ψ and higher states), **open charm** and **prompt photons** will be used for that.
- The physics program dictates the layout of the setup: we propose the SPD as a universal 4π detector equipped with the silicon vertex detector, straw tracker, PID system based on TOF and/or aerogel Cherenkov detector, electromagnetic calorimeter, muon (range) system, two beam-beam counters and two zero degree calorimeters.
- The performed Monte Carlo study shows that the proposed detector meets the requirements of the physics program.
- The proposed physics program covers at least 5 years of data taking.
- Preliminary estimation for cost of the SPD setup is 95 M$.
- The first version of the Conceptual Design Report is almost ready and will be presented in January 2021 at the winter session of the PAC.